STATE OF NEW MEXICO
WATER QUALITY CONTROL COMMISSION

IN THE MATTER OF:

PETITION FOR REGULATORY CHANGE TO
ADOPT AMENDMENTS TO 20.6.4 NMAC –
Standards For Interstate and Intrastate Surface Waters **WQCC 25-75 (R)**

DIRECT TECHNICAL TESTIMONY OF MICHAEL BACA

I. INTRODUCTION

My name is Michael Baca, and I am the Water Quality Standards Coordinator for the New Mexico Environment Department (NMED or Department) Surface Water Quality Bureau (SWQB). I am presenting this written testimony (**NMED Exhibit 1**) on behalf of the Petitioner, NMED, concerning the proposal to amend the State of New Mexico's *Standards for Interstate and Intrastate Surface Waters* (Standards or WQS), codified at Title 20, Chapter 6, Part 4 of the New Mexico Administrative Code (20.6.4 NMAC). Section 303(c)(1) of the federal Clean Water Act (CWA) requires states to hold a public hearing at least every three years to review and amend, as appropriate, a state's WQS, commonly referred to as a Triennial Review.

The SWQB has five primary objectives for the 2026 Triennial Review:

1) adopt WQS for the protection of surface waters of the state, including wetlands;
2) amend or add definitions for terms used in the Standards or to implement the Standards;
3) make the Standards clearer, informative, consistent, and accessible;
4) address segment-specific issues; and
5) update criteria applicable to existing, designated, or attainable uses (20.6.4.900 NMAC) to reflect new information and technical capabilities.

My testimony provides an overview of water quality standards; an outline of the regulatory requirements for adopting standards; information regarding this Triennial Review, background from prior Triennial Reviews; a summary of the proposed amendments for this Triennial Review; and stakeholder engagement activities, including public notice. Additionally, my testimony provides the basis and supporting evidence for amendments proposed in 20.6.4 New Mexico

Administrative Code (NMAC) associated with definitions (Section 7), administrative rulemaking procedures and costs (Section 10), amendments to WQS (Section 10 and 15), temporary standards (Section 7, 10, and 318), and NMAC structure, style, or grammar in conformance with 1.24.10 NMAC.

II. QUALIFICATIONS AND EXPERIENCE

I hold a Bachelor of Arts in Chemistry from Carleton College, and I am currently employed as the Surface Water Quality Bureau (SWQB) Monitoring, Assessment, and Standards Section (MASS) Standards and Outreach Team Supervisor, and serve as the Water Quality Standards Coordinator for the SWQB. In this position, I lead and assist MASS staff with the development, review, revision, and maintenance of surface water quality standards; supervise SWQB's Quality Assurance Officer; and provide direction to staff working on special initiatives related to harmful algal blooms and volunteer data collection.

I began working for the Department in February of 2005 as an Environmental Scientist and Specialist – Operational in the Environmental Health Bureau in the Gallup Field Office. In this position I provided training, issued permits, conducted compliance inspections and completed enforcement actions for the Food Safety, Onsite Wastewater, and Public Pool and Spa Safety Programs. I was promoted to Environmental Scientist and Specialist – Advanced in July of 2006 to serve as the Pool Specialist in northwestern New Mexico. I continued my duties in the food and onsite wastewater programs while taking on additional responsibilities as the subject matter expert and certified trainer for the pool program. In this role, I ensured consistent administration, implementation, and enforcement of the program across the district and provided internal and external training, technical guidance, and policy development at a state level.

I started working for the NMED Air Quality Bureau in July of 2008 as an Environmental

Analyst – Advanced in their Policy and Planning Section's Control Strategies Team in Las Cruces. In this position, I served as the border liaison and worked on climate, particulate matter and ozone pollution issues. I worked with stakeholders in formal and informal settings on cross jurisdictional air quality and climate concerns in the tri-state, bi-national Paso del Norte Airshed near Sunland Park, New Mexico, El Paso, Texas and Ciudad Juárez, Mexico. I developed ozone and particulate matter air quality management plans and participated in special studies regarding emissions inventories, monitoring, and photochemical modeling. I developed New Mexico's recommendation for an ozone nonattainment area in and around Sunland Park in southern Doña Ana County, as well as portions of that area's nonattainment State Implementation Plan (SIP) under the federal Clean Air Act.

From December of 2018 to September 2023, I served as the Control Strategies manager in Santa Fe, with a staff of six that develop air quality rules and the New Mexico SIP; track and comment on federal air quality and climate rules, guidance, and regulatory actions; manage and participate in air quality studies; lead and participate in regional and local climate change and air quality improvement groups and committees; implement air quality management plans and grant programs; and facilitate stakeholder engagement, outreach and education events. My team also managed the Diesel Emissions Reduction Act and the Volkswagen Environmental Mitigation Trust settlement, awarding nearly $20 million dollars to replace heavily polluting diesel vehicles and equipment with cleaner burning alternative fueled models, including electric vehicles and charging stations.

I have led and been a part of several rulemaking efforts for NMED before the Environmental Improvement Board, including the Ozone Precursor Rule (20.2.50 NMAC),

Energy Transition Act Rule (20.2.101 NMAC), Regional Haze (draft 20.2.68 NMAC), Fugitive Dust (20.2.23 NMAC) and Permitting Rules for Nonattainment Areas (20.2.79 NMAC), covering emission sources in the Oil and Gas, Electric Power, and Construction Sectors. Additionally, I have led and participated in rulemaking efforts before the Water Quality Control Commission regarding the designation of Outstanding National Resource Waters (20.6.4.9 NMAC), Copper Site Specific Criteria for the Pajarito Plateau (20.6.4.900 NMAC), Sandia Canyon Use Attainability Analysis (20.6.4.126 NMAC and 20.6.4.141 NMAC), and the reclassification of Tijeras Arroyo as an ephemeral stream (20.6.4.97 NMAC). An accurate and up-to-date copy of my resume is included as **NMED Exhibit 2**.

III. WATER QUALITY STANDARDS

Under the New Mexico Water Quality Act (WQA), the Water Quality Control Commission (WQCC or Commission) is responsible for adopting WQS. NMSA 1978, § 74-6-4(D). The standards must at a minimum protect public health or welfare, enhance the quality of water and serve the purposes of the WQA. *Id.* The federal CWA regulations provide similar direction: "States adopt water quality standards to protect public health or welfare, enhance the quality of water and serve the purposes" of the CWA. 40 C.F.R. § 131.2. Section 101(a)(2) of the CWA requires that, wherever attainable, water quality shall provide "for the protection and propagation of fish, shellfish and wildlife and for recreation in and on the water." 33 U.S.C. § 1251(a). In accordance with 40 C.F.R. § 131.10(a), each State must specify appropriate water uses to be achieved and protected. Additionally, adoption of WQS must ensure the attainment and maintenance of WQS for downstream waters. 40 C.F.R. § 131.10(b). The water quality standards requirements as outlined in the WQA, 40 C.F.R. § 131, and the CWA have been codified in New Mexico regulations under 20.6.4 NMAC. Throughout the Department's testimony, we use the terms WQS

and 20.6.4 NMAC interchangeably.

A water quality standard "defines the goals for a water body, or portion thereof, by designating the use or uses to be made of the water and by setting criteria necessary to protect the uses." 40 C.F.R. § 131.2. The designated uses in New Mexico's Surface Water Quality Standards, set forth in 20.6.4.900 NMAC, are:

- fish culture
- public water supply
- industrial water supply
- domestic water supply
- irrigation and irrigation storage
- primary and secondary contact
- livestock watering
- wildlife habitat, and
- aquatic life (seven subcategories)

The Standards also establish water quality criteria that protect the designated uses of a water body. Criteria also serve as the primary regulatory basis for Total Maximum Daily Load (TMDL) calculations and National Pollutant Discharge Elimination System (NPDES) permit limits. These criteria can be general narrative criteria that apply to all waters or categories of waters, or numeric criteria that apply to a specific designated use or water quality segment. An example of a narrative criterion is that for plant nutrients, which states, "Plant nutrients from other than natural causes shall not be present in concentrations that will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the state." 20.6.4.13(E) NMAC. Examples of numeric criteria include maximum, 4T3 temperature[1], or 6T3 temperature[2] criteria

[1] "4T3 temperature" means the temperature not to be exceeded for four or more consecutive hours in a 24-hour period on more than three consecutive days. 20.6.4.7(A)(2) NMAC.
[2] "6T3 temperature" means the temperature not to be exceeded for six or more consecutive hours in a 24-hour period on more than three consecutive days. 20.6.4.7(A)(3) NMAC.

applicable to various existing, designated, or attainable uses, found in 20.6.4.900(H) NMAC.

According to CWA regulations at 40 C.F.R. §131.12, water quality standards must also contain an antidegradation policy. New Mexico's antidegradation policy is codified at 20.6.4.8 NMAC. The Commission has also adopted implementation measures specific to antidegradation through its approval of the State of New Mexico Water Quality Management Plan and Continuing Planning Process (WQMP/CPP), specifically Appendix A: Antidegradation Policy Implementation Procedure (**NMED Exhibit 3**). Such measures are also subject to EPA review and action consistent with Section 303(c) of the CWA and with 40 C.F.R. § 131.12(a), which require states to identify methods for implementing their statewide antidegradation policy, and 40 C.F.R. § 130.5(b)(6), which requires that the state describe the process for establishing and assuring adequate implementation of new or revised standards in its WQMP/CPP. EPA approved New Mexico's current antidegradation policy and implementation procedures on October 23, 2020.

In addition to setting water quality goals, 40 C.F.R. § 131.2 specifies that WQS also serve "as the regulatory basis for the establishment of water quality-based treatment controls and strategies beyond technology-based levels of treatment required by Sections 301(b) and 306 of the [Clean Water] Act." Discharges from point sources or nonpoint sources are to be managed in such a manner that designated uses are protected. Point source discharges are currently regulated under NPDES permits, issued by EPA under Section 402 of the CWA, and the discharge of dredged or fill material requires a permit issued by the U.S. Army Corps of Engineers under Section 404 of the CWA. In both cases, pursuant to Section 401 of the CWA, NMED must certify that the permitted activities will be conducted in a manner that will comply with applicable NM WQS. 20.6.2.2001 and 20.6.2.2002 NMAC. NMED also implements a Nonpoint Source Management

Program that identifies non-regulatory strategies for controlling nonpoint sources of pollution to achieve the Standards. Finally, NMED is authorized to enforce the WQA against a person that violated or is violating the Standards and may issue compliance orders, bring legal actions in court, and assess civil penalties. NMSA 1978, § 74-6-10.

IV. REGULATORY AUTHORITY FOR ADOPTION OF STANDARDS

In accordance with the WQA, "The Commission is the state water pollution control agency for this state for all purposes of the federal [Clean Water] [A]ct…" NMSA 1978, § 74-6-3(E). Furthermore, the Commission must "adopt water quality standards for surface and ground waters of the state based on credible scientific data and other evidence appropriate under the WQA." NMSA 1978, § 74-6-4(D).

As provided in NMSA 1978, § 74-6-4(G), the Commission "…shall assign responsibility for administering its regulations to constituent agencies to assure adequate coverage and prevent duplication of effort. To this end, the Commission may make such classification of waters and sources of water contaminants as will facilitate the assignment of administrative responsibilities to constituent agencies." Since the administrative authority for upholding the requirements under the federal CWA in the State of New Mexico is delegated to the WQCC, and the Commission has no technical staff of its own, many of the tasks associated with reviewing and proposing amendments to the State's water quality standards are delegated to the Department (**NMED Exhibit 4**). As such, the Department serves as the Petitioner for the Triennial Review.

V. 2026 TRIENNIAL REVIEW

In accordance with Section 303(c)(1) of the CWA, the State is required to hold a public hearing from time to time, but at least every three years, to review and, as appropriate, modify and adopt water quality standards. 33 U.S.C. § 1313. New or revised Standards adopted by the

Commission must be submitted by the State to the EPA for approval in accordance with Section 303(c)(2) of the CWA. In addition, the State must submit the methods used and analyses conducted to support the water quality standard revisions and general information that aids EPA in determining the adequacy of the scientific basis of the amendments that do not include the uses specified in Section 101(a)(2) of the CWA, commonly referred to as the fishable/swimmable uses. *See* 33 U.S.C. § 1251. Lastly, the state must submit information on general policies applicable to the State's standards, which may affect their application and implementation. 40 C.F.R. § 131.6.

State and federal rulemaking regulations require an adequate opportunity for public participation at the hearing, including opportunities to provide public comment, views, or arguments to the Commission. Following the hearing, the Commission will deliberate, considering public comments and technical testimony provided in the record proper before making a decision to adopt proposed amendments or new WQS. A rule cannot become effective until after the Commission has issued its Statement of Reasons, and the rule is filed and published with the State Records Center and Archives (SRCA). The State Rules Act states that a rule adopted by the Commission becomes effective after publication in the *New Mexico Register*. NMSA 1978, § 14-4-5. However, the WQA adds that "[n]o regulation or water quality standard or amendment or repeal thereof adopted by the [C]ommission shall become effective until thirty days after its filing…" with the SRCA. NMSA 1978, § 74-6-6(E). Once the new rule or proposed amendments are adopted and effective for State purposes, the Department will submit a rulemaking record to EPA to review the findings of the Triennial Review. Pursuant to 40 C.F.R. § 131.6, the State is required to submit a Certification by the State Attorney General that the water quality standards were adopted pursuant to applicable State laws.

Since 2010, NMED considers the "public hearing" requirement, as termed in 40 C.F.R. § 131.20, as being met through the Commission's public rulemaking process, which is initiated upon the filing of a petition and request for hearing with the Commission and completed upon EPA's approval. For this Triennial Review, the Department satisfied the three-year review requirements by initiating stakeholder outreach in August 2025 and by holding a 60-day public comment period and a public meeting, and by filing a rulemaking petition with the WQCC on November 26, 2025. This petition was timely filed as EPA last approved New Mexico's Triennial Review on January 20, 2023.

The Department filed a Statement of Reasons and the Proposed Amendments to 20.6.4 NMAC, *Standards for Interstate and Intrastate Surface Waters*, in support of the petition. The Commission heard the Department's request for hearing on the petition at a regularly scheduled Commission meeting on December 9, 2025, and granted a public hearing. After further consideration of public and internal comments, the Department submitted an amended petition on June 2, 2026. It is the purpose of this Triennial Review hearing to fulfill the requirements of the federal CWA as well as the WQA and other applicable federal and state regulations.

It should be noted that the State does not limit proposed amendments to the Standards to only the Triennial Review hearing. Rather, in accordance with 20.6.4.9 NMAC, 20.6.4.10 NMAC, and 20.6.4.15 NMAC, there are mechanisms by which the Commission may grant hearings to any person for designating waters as Outstanding National Resource Waters; amending designated uses; adopting temporary standards; or adopting site-specific water quality criteria, as needed outside of the Triennial Review process. In fact, since EPA approved the 2020 Triennial Review, the Standards have been amended six times.

VI. PREVIOUS TRIENNIAL REVIEWS AND SCOPE OF CURRENT PROCEEDING

Although the State, or other petitioners, may bring amendments before the Commission at any time, most amendments not directly related to uses for specific waterbodies are only proposed during the Triennial Review process. The State has undergone numerous Standards amendments to what is now codified as 20.6.4 NMAC, including those adopted in 1968, 1969, 1970, 1971, 1973, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1985, 1987, 1988, 1991, 1995, 2000, 2002, 2005, 2006, 2007, 2010, 2011, 2012, 2017, 2018, 2019, 2020, 2022, 2025 and most recently in February of 2026. Although rare, there have been cases where there have been multiple amendments adopted and made effective for State purposes within a single calendar year. For instance, in 2025, the WQCC adopted amendments related to Outstanding National Resource Waters in 20.6.4.9 NMAC (WQCC 24-46), site-specific criteria on the Pajarito Plateau (WQCC 24-31), and classified waters under 20.6.4.126 and .141 NMAC (WQCC 24-65).

Those amendments adopted prior to the statutory amendments to the CWA in 1972 and prior to the creation of the EPA were not subject to EPA approval. The Department affirms that it completed amendments made in 1985, 1991, 1995, 2000, 2005, 2010, 2017 and most recently in 2022 as formal Triennial Reviews. As can be noted by the dates, Triennial Reviews are not always adopted every three years as the name indicates. The additional time between Triennial Reviews is predominately due to the lengthy administrative process, which must provide adequate opportunity for public engagement, the Commission's deliberations and adoption of proposed rules, and approval by EPA.

The hearing for the last Triennial Review was initiated in 2020; however, amendments were not adopted by the Commission and made effective for State implementation until April 23, 2022. In accordance with 40 C.F.R. § 131.20, the Department submitted the revised standards for

review and approval by EPA on May 2, 2022 (**NMED Exhibit 5**). EPA issued a technical support document on January 19, 2023, approving a majority of the amended WQS (**NMED Exhibit 6**). However, EPA withheld approval of criteria for acrolein, ammonia, cadmium, carbaryl, chloride, chloropyrifos, demeton, guthion, iron, malathion, methoxychlor, mirex, parathion, and tributyltin. Adoption of these criteria are subject to the consultation requirements of the federal Endangered Species Act. EPA completed consultation with the U.S. Fish and Wildlife Service (USFWS) for acrolein, cadmium, carbaryl, demeton, guthion, methoxychlor, mirex, parathion, and tributyltin and approved those criteria on April 27, 2023 (**NMED Exhibit 7**). Due to an initial difference of professional opinion, EPA conducted a formal consultation with USFWS for ammonia, chloride, and iron. EPA approved of those criteria on June 13, 2024 (**NMED Exhibit 8**). EPA continues consultation with USFWS on a national level regarding pesticides, including chlorpyrifos and malathion criteria, but has not provided NMED with additional information regarding their approval status.

As part of this Triennial Review, SWQB proposes several types of amendments to the Standards. SWQB considered all Triennial Review requirements detailed in 40 C.F.R. § 131.20 and proposed updates to the Standards accordingly. The proposed amendments include new and revised definitions, clarification of third-party rulemaking procedures and costs, revisions to segment descriptions, WQS for wetlands, clarification of implementation language, updated references, as well as, new or revised designated uses, criteria, and antidegradation requirements. The Department has also proposed non-substantive amendments to correct cross references or conform to NMAC formatting, grammar, or style.

These changes were the result of a public participation process and stakeholder engagement

opportunities, including an informal 60-day public comment period. In addition, proposed amendments resulted from internal comments, implementation challenges, and the CWA § 303(d)/§ 305(b) Integrated Report.

VII. RULEMAKING PROCEDURES, PUBLIC NOTICE, AND STAKEHOLDER ENGAGEMENT

The Triennial Review is a rulemaking process governed by several federal and state laws. The New Mexico Legislature delegated authority to the Commission to "adopt water quality standards for surface and ground waters of the state based on credible scientific data and other evidence appropriate under the Water Quality Act." NMSA 1978, § 74-6-4(D). Amendments to the Standards must comply with NMSA 1978, § 74-6-6 and 20.1.6 NMAC, which set forth procedural requirements for rulemaking proceedings before the Commission.

In accordance with NMSA 1978, § 74-6-6, no amendment to a water quality standard may be adopted or amended until after a public hearing. In addition, and in accordance with 40 C.F.R. § 131.20, EPA requires states to have a "public hearing for the purpose of reviewing applicable water quality standards adopted pursuant to 40 C.F.R. §§ 131.10 through 131.15". EPA requires that these hearings are held according to State law and EPA's public participation regulation found in 40 C.F.R. Part 25.

Rulemaking before the Commission begins when a person files a written petition and statement of reasons to adopt, amend, or repeal a regulation, in accordance with 20.1.6.200 NMAC. The petitions must specify the statutory authority for the Commission to adopt proposed rules, estimate the amount of time to conduct the hearing, and include a copy of the entire rule with line numbers and proposed changes in redline fashion (20.1.6.200(B) NMAC). The Commission may grant a rulemaking hearing, in accordance with 20.1.6.200(C) NMAC and

specify the procedures for conducting the hearing as outlined in 20.1.6.200(D) NMAC, including provisions for public notice and public participation.

EPA's regulations under 40 C.F.R. § 25.5 set out a state's responsibilities to notify the public of hearings associated with the federal CWA, including hearings for Triennial Reviews of State WQS. In part, EPA requires that a notice of the hearing be "well-publicized" and mailed to interested and affected parties at least 45 days prior to the hearing date. The WQCC's rulemaking rules at 20.1.6.201 NMAC require publication of the public notice at least 60 days prior to the hearing.

A. PUBLIC AND STAKEHOLDER OUTREACH

In accordance with 40 C.F.R. § 25.3 states are required to provide for, encourage, and assist the participation of the public for activities being carried out under the CWA, such as a rulemaking. Public participation includes providing access to the decision-making process, seeking input from and conducting dialogue with the public, assimilating public viewpoints and preferences, and demonstrating that those viewpoints and preferences are considered. Public agencies should encourage full presentation of issues at an early stage so that they can be resolved, and timely decisions can be made. The Department ensures adherence to the requirements in 40 C.F.R. § 25.3 through the application of public outreach actions prescribed in the State's approved WQMP/CPP (**NMED Exhibit 3**).

The Department provided an early public comment period for a Public Review Draft (PRD) of amendments prior to petitioning the Commission for a hearing (**NMED Exhibit 9**). As part of the Department's efforts to provide the public opportunity for meaningful engagement, notification was distributed via several outlets, including posting the notification on the Bureau's main

webpage, the Water Quality Standards webpage, and the 2026 Triennial Review webpage. The Department provided notification in both English and Spanish through the SWQB's listserv email to 1,920 individuals subscribed to the Bureau's distribution list (**NMED Exhibit 10**).

The public comment period was open from August 15, 2025, through October 15, 2025. The Department conducted a virtual public meeting as a part of the public outreach efforts to familiarize the public with the Triennial Review and how to participate in the process. The meeting was held on September 10, 2025, from 5:30 – 7:00 pm with approximately 20 people in attendance (**NMED Exhibit 11**). In addition, the Department posted a recording of the meeting on the Bureau's 2026 Triennial Review webpage at https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. The Department received comments from EPA Region 6 (**NMED Exhibit 12**); Triad National Security (management and operating contractor for Los Alamos National Laboratory); New Mexico Mining Association; San Juan Water Commission; Western Resource Advocates; one private citizen, and a collaborative submission from Amigos Bravos, American Rivers Action Fund, Breath of My Heart Birthplace, Communities for Clean Water, Concerned Citizens for Nuclear Safety, Gila Resources Information Project, Green Latinos, New Mexico Acequia Association, New Mexico Interfaith Power and Light, New Mexico Wild, Partnership for Earth Spirituality, Rio Grande Chapter of the Sierra Club, Trout Unlimited, and Western Environmental Law Center (**NMED Exhibit 13**). The Department posted the comments, as submitted, on the Department's Triennial Review webpage. These comments, in addition to those from EPA and SWQB staff, helped inform the proposed amendments to 20.6.4 NMAC as submitted in the Department's petition on November 26, 2025, and in the amended petition on June 2, 2026.

The SWQB has not received any additional contact or comments regarding this matter. However, written public comment for the hearing is being accepted through the close of the hearing via the Department's Public Comment Portal and by the Commission Administrator through their email account. All public comments are posted on the portal as they are received to allow for WQCC and public review. Additionally, oral public comment opportunities will be provided each day of the hearing, both in-person and virtually.

B. PUBLIC NOTICE

Notice of rulemaking hearings must be provided to the public in accordance with the State Rules Act (NMSA 1978, § 14-4-1) and 20.1.6.201(A) NMAC. The public notice must include publication in a newspaper of general circulation, the *New Mexico Register*, and other means necessary as determined by the Commission. 20.1.6.201(B) NMAC. The public notice of rulemaking must include: the subject, a summary, and the purpose of the proposed rule, the legal authority for the rule and its adoption, the technical basis for the proposed rule and how to find technical information, governing laws of procedure, and information on how to present information and participate in the hearing, examine documents, and download information. 20.1.6.201(C)(1)-(7) NMAC. The public notice may also state the Commission's intent to make a decision at the conclusion of the hearing, as applicable. 20.1.6.201(C)(8) NMAC. In addition to publication of notice, the Commission must "provide [notice] to the public," as defined at 20.1.6.7(P) NMAC, by distributing rulemaking information by:

- posting it on the Commission's website,
- posting it on the New Mexico Sunshine Portal,
- making it available at [NMED's] district, field, and regional offices,
- sending it by email to persons who have made a written request for notice of announcements addressing the subject of the rulemaking proceeding and who have provided an email address to the Commission Administrator,

- sending it by email to persons who have participated in the rulemaking and who have provided an email address to the Commission Administrator,
- sending written notice that includes, at a minimum, an internet and street address where the information may be found to persons who provide a postal address; and
- providing it to the New Mexico Legislative Council [Service] for distribution to appropriate interim and standing legislative committees.

The public notice for the hearing was published by the Department in the *Albuquerque Journal*, *Santa Fe New Mexican*, *Silver City Daily Press* and the *New Mexico* Register on June 23, 2026, in the Tri-City Record on June 24, 2026, and in the Las Cruces Sun News and *Roswell Daily Record* on June 25, 2026 (**NMED Exhibit 14**). The Department assisted the Commission Administrator with completing notification requirements and provided rulemaking information to the public, as described in 20.1.6.7(P) NMAC. The Department posted public notice and the proposed rules to the SWQB's 2026 Triennial Review website, the WQCC's Docketed Matters webpage, NMED's public notice webpage, and the New Mexico Sunshine Portal. The Department also posted notice of the hearing and the proposed rules at its District and Field Offices around the state. Public notice was also provided through emails to the Legislative Council Service, persons and organizations that participated in the rulemaking through early public comment, the WQCC's listserv distribution list, and the SWQB's listserv distribution list, which reached 3,190 subscribers. The Department completed "provide to the public" notice requirements on or before June 25, 2026 (**NMED Exhibit 15**).

C. NOTICE TO NEW MEXICO'S NATIONS, TRIBES, AND PUEBLOS

The State recognizes the importance of communication and collaboration with its Nations, Tribes, and Pueblos to ensure water quality across boundaries. The State has memorialized this sentiment through the State-Tribal Collaboration Act, NMSA 1978, § 11-18-3, Executive Order 2005-004, and the Department's Tribal Communication and Collaboration Policy. In an effort to

ensure the opportunity for adequate communication and collaboration with tribal nations, the Department provided initial notice of the Triennial Review, public comment period, and opportunities for engagement to representatives of the governments of New Mexico's Nations, Tribes, and Pueblos on August 15, 2025 (**NMED Exhibit 16**), including a copy of the PRD (**NMED Exhibit 9)**.

In addition to the initial notification, the Department provided notice of the public hearing with a copy of the proposed amendments to representatives of the governments of New Mexico's Nations, Tribes, and Pueblos on June 23, 2026. The notification included information on how to participate in the hearing and engage with NMED, should they choose to do so. The Department notified the following Nations, Pueblos, and Tribes: the Navajo Nation; the Pueblos of Acoma, Cochiti, Isleta, Jemez, Kewa, Laguna, Nambe, Ohkay Owingeh, Picuris, Pojoaque, San Felipe, San Ildefonso, Sandia, Santa Ana, Santa Clara, Taos, Tesuque, Ysleta del Sur, Zia, and Zuni, as well as, the Eight Northern Indian Pueblos Council; and the Fort Sill Apache Tribe, Jicarilla Apache Tribe, Mescalero Apache Nation, and Ute Mountain Ute Tribe (**NMED Exhibit 16**).

D. NOTICE TO THE SMALL BUSINESS REGULATORY ADVISORY COUNCIL

Finally, in accordance with the Small Business Regulatory Relief Act (NMSA 1978, § 14-4A-4), the Department provided notification of the proposed amendments to the Small Business Regulatory Advisory Council on July 7, 2026 (**NMED Exhibit 17**).

VIII. PROPOSED AMENDMENTS TO WATER QUALITY STANDARDS

A. 20.6.4.7 NMAC - DEFINITIONS

i. 20.6.4.7(A)(1) NMAC, definition of "4Q3"

The Department proposes to amend the definition for "4Q3" to include the term "hydrologically based" as EPA requested in its January 2023 Action Letter for the 2020 Triennial

Review (**NMED Exhibit 6)**. With the exception of human health-organism only criteria, the "4Q3" is the critical low flow value used to develop NPDES permit requirements to meet the other criteria in 20.6.4.97 through 20.6.4.900 NMAC. Although "4Q3" is referenced in the Standards only in relation to NPDES permits, other applications such as TMDL calculations and water quality modeling use the "4Q3" as a low-flow statistic. The proposed change clarifies that the definition is hydrologically based and does not alter the meaning nor will this proposed modification affect implementation of the WQS.

ii. 20.6.4.7(A)(4) NMAC, abbreviations used for units and subparagraph lettering

The Department proposes new abbreviations to reflect the biological sampling methods associated with newly proposed criteria for Selenium, Perfluorooctane Sulfonate (PFOS) and Perfluorooctanoic Acid (PFOA). The new abbreviations are proposed for adoption at 20.6.4.7(A)(4)(c), (d), (e), (f) and (o) NMAC and cover fish tissue and invertebrate sampling methods, including "dw" for dry weight, "iwbt" for invertebrate whole body tissue, "fmt" for fish muscle tissue, "fwbt" for fish whole body tissue, and "ww" for wet weight. These abbreviations are included in 20.6.4.7(A)(4) in alphabetical order, necessitating the renumbering of the existing subparagraphs from 20.6.4.7(A)(4)(e)-(j) NMAC to 20.6.4.7(A)(4)(g)-(n) NMAC, respectively.

iii. 20.6.4.7(A)(7) NMAC, New definition for "administrative rulemaking costs"

The Department proposes to add a new definition at 20.6.4.7(A)(7) NMAC for administrative rulemaking costs. Within that proposed definition, the Department excluded costs and activities that are not under the control of, or paid for, by a third party. Some of these costs and activities include posting notice and rulemaking information on the Commission's website, posting on the New Mexico Sunshine Portal, publishing in the *New Mexico Register*, paying for a

venue for the rulemaking hearing, paying for a hearing officer, or filing adopted rules with SRCA. The Department is excluding these costs for third-party petitioners and agreeing to provide these services and funding on an ongoing basis.

Additional costs that may be incurred during a rulemaking process include a court reporter, transcripts, translations, interpretations, public engagement, and publishing public notice in newspapers. This is not an exhaustive list of administrative costs that a petitioner would be responsible for. Furthermore, this does not include the technical or legal costs that a petitioner may be charged to develop and present a rulemaking petition before the Commission.

iv. 20.6.4.7(A)(8) and (9) NMAC, paragraph numbering

The Department proposes to amend the current 20.6.4.7(A)(7) and (8) NMAC to 20.6.4.7(A)(8) and (9) NMAC, for "Aquatic life" and "Attainable use," respectively. The renumbering would be necessary if the Commission adopts the proposed definition in 20.6.4.7(A)(7) NMAC.

v. 20.6.4.7(C)(9) NMAC, definition of "Criteria"

The Department proposes to change the term "water" to "waterbody" to focus the term on surface waters specifically and recognize that criteria support the chemical, biological, or physical characteristics that define a designated use for a waterbody (e.g., river, stream, lake, etc.).

vi. 20.6.4.7(E)(3) NMAC, definition of "Ephemeral"; 20.6.4.7(I)(2) NMAC, definition of "Intermittent"; 20.6.4.7(P)(2) NMAC, definition of "Perennial": consistent terminology - "water body" to "waterbody"

The Department proposes to make non-substantive amendments to change the term "water body" to "waterbody"—by deleting the space between two words and creating a single word—in several definitions to provide consistency throughout the WQS. Throughout the standards, these two terms are used interchangeably. The Department's research indicated that the use of the terms

was a matter of preference and not restricted by regulatory definition or common usage. The proposed change does not alter the meaning of the term nor will it affect implementation of the WQS.

vii. 20.6.4.7(P)(7) NMAC, definition of "Public water supply"

The Department proposes to amend the definition of "public water supply" to accurately reflect the Drinking Water rules at 20.7.10 NMAC and 40 C.F.R. § 141. The Department proposes to amend language because "public water system" is not defined in 20.7.10 NMAC, as indicated. Instead, the rules rely on the definition provided in 40 C.F.R. § 141, through incorporation by reference. The Department is also proposing to clarify that the term specifically applies to public water systems that use surface water as a source.

The Department proposes to amend "may need to" to "shall" to indicate these waters are subject to drinking water regulations before public consumption. When surface waters are used as a source supply for a public water system, they are subject to the treatment requirements of 40 C.F.R. § 141.70, also known as Subpart H – Filtration and Disinfection. Further, the Department indicates that those systems should be complying with applicable drinking water standards in order to supply water to customers. The purpose of this statement is to indicate to the public that surface waters, even those with the public water supply use are not safe to drink without some form of treatment. Public water supply criteria remain limited to the general criteria in 20.6.4.13 NMAC and the numeric criteria for bacterial quality, pH, and temperature. 20.6.4.900(A) NMAC. In no way does this create new obligations or requirements for public water systems.

viii. 20.6.4.7(T)(2) NMAC, New definition of "Temporary standard"

The Department proposes to relocate the definition of "temporary standard" to 20.6.4.7(T)(2) NMAC to provide a consistent location for definitions, in accordance with

1.24.10.8(F) NMAC. Additionally, the Department is proposing to add "or water quality variance as defined by 40 CFR § 131.3(o)" at the suggestion of EPA to maintain equivalency between the federal and state terms.

ix. 20.6.4.7(T)(3) – (5) NMAC, paragraph numbering

The Department proposes to amend the paragraph numbering to reflect the proposed amendment to include temporary standard in the definitions. If that proposed amendment is adopted, the subsequent paragraphs would need to be renumbered from 20.6.4.7(T)(2)-(4) NMAC to 20.6.4.7(T)(3)-(5) NMAC for "Toxic pollutant," "Tributary," and "Turbidity," respectively.

x. 20.6.4.7(W)(4) NMAC, definition of "Wetlands"

The Department proposes to amend the definition of "wetlands" for clarity. Wetlands provide a variety of important functions, and vary regionally and locally due to their soils, topography, climate, hydrology, water chemistry, vegetation, and other factors. New Mexico surface water quality programs conduct waterbody and habitat condition assessments, evaluate antidegradation provisions, develop appropriate mitigation ratios, and develop effluent limitations and permit conditions for surface water discharges, including point source and dredge and fill discharges.

The SWQB Wetlands Program has been mapping wetlands using the Cowardin Classification, which only requires one parameter, hydrology, soil, or vegetation to classify a system as a wetland. To align the "wetlands" definition with that work, the Department proposes to remove "sufficient to" and "and under normal circumstances do support, a prevalence of" and replaced them with "that typically" support vegetation. "Prevalence of vegetation" may not be typical for some wetlands such as playa lakes where vegetation may only be present along the annulus/fringe seasonally during wet conditions.

The Department also proposes to clarify that constructed wetlands for wastewater treatment are excluded from this definition, unless they impound a surface water of the state.

B. 20.6.4.10 NMAC - REVIEW OF STANDARDS; NEED FOR ADDITIONAL STUDIES

The Department proposes to amend the language pertaining to reviewing and amending standards (20.6.4.10 NMAC) to clarify when and how a designated use or criterion may be amended for a surface water of the State. Based on recent experience with third-party rulemakings, the Department is proposing to clarify expectations and roles of the petitioner, the Department, and the Commission Administrator to hold a hearing. As previously mentioned, the WQS were amended six times since EPA's last approval of the Triennial Review. For three of these rulemakings (see WQCC 24-31, WQCC 24-64, and WQCC 25-28) third parties (i.e., parties other than the Department) petitioned the Commission to initiate the rulemaking process. The proposed amendments to this section are the result of those hearing processes and experiences, and public comment received on the PRD in October of 2025.

i. 20.6.4.10(F) NMAC, New Subsection for rulemaking and associated costs

The Department proposes a new Subsection F at 20.6.4.10 NMAC, to clarify that any person may petition the Commission for a rulemaking and provide examples of the types of new or amended WQS a petitioner might seek. Additionally, the Department proposes to clarify that the petitioner would be responsible for any "Administrative Rulemaking Costs" as proposed within the definitions in 20.6.4.7(A)(7) NMAC.

In addition to the Department's recent experiences with third party rulemakings, early public comment received on the PRD shaped the proposed amendment and highlighted the need to clarify costs associated with rulemaking and the expected financial responsibility of the

petitioner. LANL, Amigos Bravos (and other NGOs), and the San Juan Water Commission (SJWC) provided comment on the PRD in partial or full opposition of the draft amendment.

LANL suggested that petitioners may be responsible for other parties' legal or technical experts. Although the basis for change in the PRD included a non-exhaustive list of costs, including "technical experts, scientific reports, and additional stakeholder outreach" the proposed language in the PRD did not reflect responsibility for third party contracting. LANL further suggested that the administrative costs of rulemaking would be a deterrent from initiating the rulemaking process and felt that they should only be responsible for the costs borne from presenting their case as the petitioner, but not be responsible for the costs due to the participation of outside parties, including their court reporting services. Additionally, LANL suggested, and the Department agreed, that the rules should define the costs a petitioner may bear and limit those to costs under the petitioner's control. See Section VIII.A.iii above for the Department's proposed language for "administrative rulemaking costs" at 20.6.4.7(A)(7) NMAC.

The Department feels that the largest and most prohibitive costs to rulemaking are those for legal and technical expertise, not the administrative costs. Additionally, the proposed amendment does not limit the Department from agreeing to initiate a rulemaking process or include such amendments during the next Triennial Review. Furthermore, it's the petitioner's responsibility to convince the WQCC to adopt their proposal and facilitate the public involvement that should lead up to such a decision. The Department does not agree that third party petitions and rulemakings, outside of the Triennial Review, are the "costs of having, administering, and improving" the surface water quality standards as suggested by LANL.

The San Juan Water Commission fully opposed the new language and argued that

"hearings are a statutory function of the WQCC" and it is the WQCC's fiscal responsibility to ensure adequate funding to hold hearings. Although Section 74-6-6 of the Water Quality Act requires a public hearing before a regulation or water quality standard is adopted, the Commission is not obligated to grant hearings. Additionally, the Department could oppose rulemaking petitions solely on the grounds of lack of budget, potentially further restricting the rulemaking process for third party petitioners. The Commission currently does not have an annual budget of its own to pay the "administrative rulemaking costs" and relies on the Department, and, more specifically, each Bureau to pay these costs. NMED's Bureaus are generally aware of rulemakings that they intend to initiate each fiscal year and can request funds to cover administrative costs in their annual budgets. This is especially true when considering and planning for complex and lengthy hearings that may incur more expensive administrative costs, such as those associated with a court reporter, transcript production, or simultaneous interpretation. Historically, NMED covered all costs of a rulemaking hearing when it was the petitioner. The Department did not cover these costs for third party petitioners, unless discussed and agreed upon before a third party petitioned the WQCC.

Furthermore, requiring that all hearings be paid for by the WQCC or the Department will increase a rulemaking's timeline by one to two years to accommodate a new budget cycle. Budgets for new fiscal years (FY), starting on July 1, are requested in September of the previous FY. For rulemakings that would be petitioned in October of a given year, they would have to wait eleven months to be included in a budget request, and an additional ten months before funding would be available to start the rulemaking hearing process.

To illustrate the potential length of time required for this, I'll discuss a timeline for a third party rulemaking with a hypothetical petition date of October 2025, which would not be included

in NMED's budget request until September 2026. If the budget request is approved, the funding would be available on July 1, 2027. The Department would then be able to start procurement for the hearing process that would typically be held 90 days later, or September of 2027. This would be nearly two years after the petition, *if the budget request was approved*.

The proposed amendment is not a new concept as existing regulatory language in 20.6.4.15 NMAC already requires petitioners to be responsible for administrative costs for Use Attainability Analyses (UAAs). The Department proposes expanding this concept to the other types of rulemaking for 20.6.4 NMAC. The WQS allow for amendments that are based on sound science and include robust public involvement. A petitioner may initiate a rulemaking at any time, but they should be aware that the process is dynamic, and at times controversial, which requires constant communication with stakeholders and adaptable planning. For the public, the largest costs and obstacles for rulemaking are the technical and legal work required to prepare petitions and present technical testimony at a hearing. Legal and technical fees will far exceed the administrative costs of rulemaking discussed here.

Historically, NMED works with the public to identify standards amendments and will take on rulemakings that benefit the public and environment of New Mexico. The Triennial Review serves as one avenue which the public can make their interests known and begin discussions with the Department. Outside of the Triennial Review, a recent example of NMED taking on a rulemaking due to public interest was the 2024 ONRW special designations (WQCC 24-46).

The Department will continue to work with third parties to ensure the WQS are protective of the designated uses. Additionally, the Department will continue to engage with interested parties to evaluate the need for new or amended WQS outside of the Triennial Review, including those

where the Department would be the petitioner, or agree to be partially or fully responsible for the "administrative rulemaking costs" for a hearing. These proposed amendments are provided to clarify the process and are in no way intended to limit the public from initiating or participating in the rulemaking process.

ii. 20.6.4.10(G)(3) – (6) NMAC, New paragraphs related to Site Specific Criteria

The Department proposes new paragraphs in the proposed Subsection G to align the rulemaking process for site-specific criteria and conducting a UAA. The Department proposes to include work plan requirements for entities outside of the Department for deriving site-specific criteria. A work plan will improve communication between outside agencies, the regulated community, stakeholders, and the Department. The work plan should clearly outline expectations and responsibilities for the third party and the Department when deriving criteria. Additionally, work plans are already required for conducting a UAA by an entity other than NMED and this will bring more uniformity to the process for new or amended WQS.

iii. 20.6.4.10(H)(12) NMAC, definition of "Temporary standard"

The Department proposes to move the definition of "temporary standard" where it is currently located in 20.6.4.10(H)(12) NMAC and place it within the definitions at 20.6.4.7 NMAC as outlined above in my testimony in Section VIII.A.x.

iv. 20.6.4.10 (C), (G) – (I) NMAC, Amended language, subsections' lettering, paragraph numbering, and cross references to maintain consistency.

The Department proposes to update the cross references in the current 20.6.4.10(C) and (H) NMAC to align with the newly proposed Subsection F. If the newly proposed subsection is adopted, the current Subsections F, G, and H would have to be re-lettered to Subsections G (Site-Specific Criteria), H (Natural Background), and I (Temporary Standards), necessitating the need

to update the cross references.

In addition, throughout this section, the Department proposes to amend the terms "water body" to "waterbody" to provide a consistent term throughout the WQS as previously discussed.

C. 20.6.4.11 NMAC – APPLICABILITY OF WATER QUALITY STANDARDS

i. 20.6.4.11(E)(2) NMAC, cross reference

The Department proposes to update the cross references in the current 20.6.4.11(E)(2) NMAC from Subsection "K" to "L" to align with the numerical criteria values provided therein and provide clarity to staff implementing the regulations.

ii. 20.6.4.11(G) NMAC, New clarifying language

The Department proposes to include the new language "for persistent toxic pollutants, unless" to remain consistent with 20.6.4.900(H)(7) NMAC and the criteria language for Limited Aquatic Life.

D. 20.6.4.15 NMAC – USE ATTAINABILITY ANALYSIS

i. 20.6.4.15(B) NMAC, New and updated references, amended paragraph numbering

The Department proposes to amend Subsection B of 20.6.4.15 NMAC to reflect the most current methods for developing a UAA including a new reference at 20.6.4.15(B)(1) NMAC to EPA's Water Quality Standards Handbook that provides current guidance and case studies for developing and implementing WQS. If adopted by the Commission, the subsequent paragraphs would need to be renumbered from 20.6.4.15(B)(1)-(3) NMAC to 20.6.4.15(B)(2)-(4) NMAC. This is an online resource updated by EPA periodically and currently available at https://www.epa.gov/wqs-tech/water-quality-standards-handbook.

The Department further proposes to include updated economic guidance intended to be

used in conjunction with the existing reference at 20.6.4.15(B)(3) for economic guidance (**NMED Exhibit 18**). These resources provide a framework for WQS decisions with economic considerations, like UAAs and temporary standards.

ii. 20.6.4.15(D)(2) and (3) NMAC, consistency and clarity

Throughout this section, the Department proposes to change the terms "water body" to "waterbody" to provide a consistent term throughout the WQS, as previously discussed.

The Department proposes to amend language at 20.6.4.15(D)(2)(g) NMAC to clarify that EPA will not provide approval of a UAA until duly adopted by the WQCC and submitted to them under Section 303(c)(2) of the CWA.

The Department proposes to include a new Paragraph 3 at 20.6.4.15(D) NMAC to correct an oversight in NMAC formatting. This paragraph should have been previously identified as separate from Paragraph (2) and included as proposed. Additionally, the Department proposes to include "designated use" to clarify what amendment would result from conducting and adopting a UAA.

iii. 20.6.4.15(E) NMAC, third party UAAs

The Department proposes to amend language within Subsection E to remove the term "proponent" from the WQS. This term is undefined in the WQS and is not commonly used in New Mexico Statute or rulemaking rules, becoming a potential source of confusion. The Department proposes further edits to clarify actions and language.

As previously discussed in Sections VIII.A.iii and VIII.B.i of my testimony, the Department proposes to consolidate the financial responsibility requirements for the administrative rulemaking process in 20.6.4.10(F) NMAC and provide a definition of "administrative rulemaking costs" at 20.6.4.7(A)(7) NMAC. Further, the Department proposes to remove the reference to costs

of developing a UAA and the subsequent costs associated with the administrative rulemaking process within the existing Paragraph 5 of 20.6.4.15(E) NMAC.

E. 20.6.4.318 NMAC – CANADIAN RIVER BASIN

The Temporary Standard for Doggett Creek that was approved by the WQCC and EPA in 2020 became effective for federal CWA purposes on July 24, 2020. In accordance with the Temporary Standard at 20.6.4.318(C)(10) NMAC, the Department reviewed socioeconomic factors in Raton, NM, trends in highest attainable condition (HAC), and progress made toward implementation of pollutant control technologies. Socioeconomic conditions and HAC remain unchanged from the initial evaluation. Progress has been made by the City of Raton and nutrient concentrations are decreasing in discharge to Doggett Creek but are not at the levels required by the temporary standard. The City of Raton has made progress toward improvement including pilot testing coagulation for phosphorous removal, performing a zero-discharge feasibility study, and submitting funding applications for facility upgrades.

The Department presented the temporary standard reevaluation to the WQCC on May 13, 2025, and recommended that the temporary standard remain as written and approved in 20.6.4.318 NMAC. The WQCC deliberated after the presentation and voted to approve "no changes" to the temporary standard other than to update the "Proposed Actions and Implementation Schedule" within the city's NPDES permit.

Public comment and participation on the Temporary Standard was solicited through the public notice and comment period for the draft renewal of NPDES permit no. NM0020273, which occurred in November of 2025. The NPDES permit was reissued with an effective date of March 1, 2026.

i. 20.6.4.318(C) NMAC, effective date language and cross reference

The Department proposes to amend language within the temporary standard to reflect the EPA approval/effective date of July 24, 2020. This will provide a baseline date to track the reevaluation interval as well as invite public comment on the Section in accordance with 20.6.4.318(C)(10) NMAC.

The Department also proposes to update the cross reference in 20.6.4.318(C)(10) NMAC to reflect proposed changes to 20.6.4.10 NMAC to renumber Subsection H to Subsection I.

IX. CONCLUSION

The Department recommends that the Commission adopt the proposed amendments to the Standards, filed with the Department's First Amended Petition (**NMED Exhibit 27**) and based upon the testimony of the SWQB's witnesses. This concludes my direct testimony.

MICHAEL G. BACA

EDUCATION - September 1999-June 2004, Carleton College, Northfield, MN, B.A. in Chemistry

PROFESSIONAL EXPERIENCE – February 2005-Present, New Mexico Environment Department

October 2023 – Present, Surface Water Quality Bureau, Water Resources Manager I

Serve as the Water Quality Standards Coordinator and the supervisor for the Standards and Outreach Team. Oversee, lead, and assist in the development, revision, and implementation of New Mexico's surface water quality standards, including rulemakings and special projects. Provide technical testimony and exhibits for proposed water quality management plans and standards amendments presented before the Water Quality Control Commission, including third-party rulemakings, the Triennial Review and the Water Quality Management Plan and Continuing Planning Process. Organize public stakeholder engagement opportunities regarding proposed changes to standards to provide feedback and discussion with the public, regulated community, interests groups, nonprofit organizations, academia and state, local and federal government agencies and elected officials. Build effective partnerships with the public, government agencies, stakeholders, and regulated entities through effective communication and collaborations. Direct the day-to-day operations of the team: manage, assign and prioritize tasks and projects in accordance with grant objectives and budgets, oversee professional growth development, provide team leadership, interpret technical and policy guidance, and administer personnel related actions such as evaluations, discipline, and hiring.

December 2018-September 2023, Air Quality Bureau, Staff Manager

Manage the daily operations of the Control Strategies Section including a staff six to implement and enforce the federal Clean Air Act in New Mexico through the development and revision of the State Implementation Plan and other air quality management plans and rules for the state, including Climate Change. Assign and prioritize completion of tasks and projects to achieve the vision and mission of the Department and the Bureau's performance measures. Provide technical and policy guidance through the development of work products and administration of existing programs, policies, rules, regulations, and resources. Oversee, lead and assist with rulemaking and special projects including the adoption of rules and management plans by presenting testimony and exhibits before the Environmental Improvement Board. Manage air quality programs and projects to award contracts and grants, ensure timely submission of deliverables and technical reports, and review financial expenditures to meet contractual obligations and compliance with state procurement rules. Organize and develop public stakeholder engagement strategies to provide meaningful engagement opportunities and collaborations with the public, regulated community, interests groups, nonprofit organizations, academia and state, local and federal government agencies and elected officials. Complete timely HR actions to include training, employee evaluations, discipline, hiring and other personnel actions.

July 2008-December 2018, Air Quality Bureau, Environmental Analyst

Represent the Department as the air quality liaison with binational border air quality agencies and stakeholders, participating in the Joint Advisory Committee and the US Environmental Protection Agency (USEPA) border programs. Develop and prepare technical testimony and exhibits for public hearings in front of the Environmental Improvement Board to present and defend air quality and climate change plans and rules for adoption in New Mexico, including state implementation plans required by the USEPA. Analyze ambient air quality monitoring data and prepare technical documents for submission to the USEPA for high wind blowing dust events that cause air pollution episodes. Conduct public education and outreach meetings and develop educational material regarding air quality, rule requirements, and rule

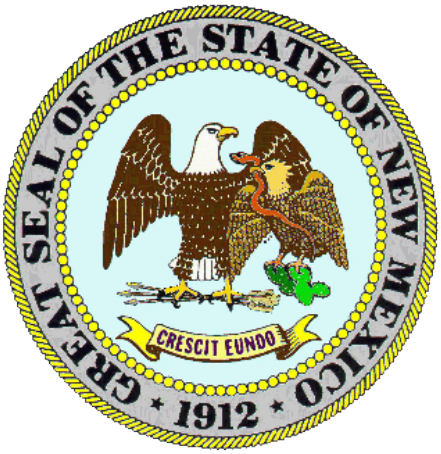
development. Review and comment on permits, Environmental Impact Statements, and Environmental Assessments for compliance with federal and state rules and standards. Manage air quality research projects and contracts in the border area to ensure timely submission of deliverables.

February 2005 -July 2008, Field Operations Division, Environmental Scientist and Specialist

Oversee public swimming pool program at a district level to ensure consistent permitting, inspection, and enforcement actions across six counties in northwest New Mexico. Review engineering plans and approve permits for construction of swimming pool and bath facilities. Conduct training for swimming pool department staff and operators. Permit and inspect restaurants and food processors, swimming pool facilities, and liquid waste disposal system installations and initiate enforcement actions for compliance with applicable regulations. Conduct public education and outreach to help the regulated community comply with environmental management principles, administrative requirements, and state regulations.

STATE OF NEW MEXICO

STATEWIDE WATER QUALITY MANAGEMENT PLAN
AND
CONTINUING PLANNING PROCESS



NEW MEXICO
WATER QUALITY CONTROL COMMISSION

P.O. Box 5469
Santa Fe, New Mexico 87502

https://www.env.nm.gov/surface-water-quality/wqmp-cpp/
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WQCC Approval Date: September 21, 2020
EPA Approval Date: October 23, 2020

Copies of this document and the incorporated documents are available through the State library, the New Mexico Environment Department Surface Water Quality Bureau, Harold Runnels Building, 1190 St. Francis Drive, Santa Fe, NM 87502 in Santa Fe, or online at https://www.env.nm.gov/surface-water-quality/.

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Appendix C: Hydrology Protocol for the Determination of Uses Supported by Ephemeral, Intermittent and Perennial Waters

NMED Exhibit 3

LIST OF ACRONYMS AND ABBREVIATIONS

BPJ	Best Professional Judgment
BLM	Bureau of Land Management
BMPs	Best Management Practices
BOR	United States Bureau of Reclamation
CFR	Code of Federal Regulations
CPB	Construction Programs Bureau of NMED
CPP	Continuing Planning Process
CWA	Clean Water Act (33 U.S.C. 1251 et seq.)
CWSRF	Clean Water State Revolving Fund
DMA	Designated Management Agency
EMNRD	Energy, Minerals and Natural Resources Department
EPA	United States Environmental Protection Agency
GWQB	Ground Water Quality Bureau of NMED
LA	Load Allocation
MOS	Margin of Safety
NM	New Mexico
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
NMIP	Procedures for Implementing NPDES Permits in New Mexico
NMSA	New Mexico Statutes Annotated
NPDES	National Pollutant Discharge Elimination System
NPS	United States National Park Service
NPSMP	Nonpoint Source Management Program
OCD	Oil Conservation Division of EMNRD
ONRW	Outstanding National Resource Water
PIP	Public Involvement Plan
POTWs	Publicly Owned Treatment Works
QAPP	Quality Assurance Project Plan
RIP	Rural Infrastructure Revolving Loan Program
SDWA	Safe Drinking Water Act
SOP	Standard Operating Procedure
SWQB	Surface Water Quality Bureau of NMED
TAS	Treatment in a Similar Manner
TBEL	Technology Based Effluent Limit
TMDL	Total Maximum Daily Load
UAA	Use Attainability Analysis
UIC	Underground Injection Control
USACE	United States Army Corps of Engineers
USC	United States Code
USDA	United States Department of Agriculture
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service

NMED Exhibit 3

USGS	United States Geological Survey
WLA	Waste Load Allocation
WQA	New Mexico Water Quality Act (Chapter 74, Article 6 NMSA 1978)
WQBEL	Water Quality Based Effluent Limit
WQCC	New Mexico Water Quality Control Commission
WQMP	Water Quality Management Plan
WQS	Water Quality Standards

NMED Exhibit 3

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I. INTRODUCTION

A. Purpose

New Mexico's Statewide Water Quality Management Plan and Continuing Planning Process (WQMP/CPP) provides a concise summary of the water quality management system in New Mexico (NM) and the roles of the major participants in that system, as required by Sections 208 and 303 of the federal Clean Water Act (CWA) and New Mexico Statutes Annotated (NMSA) 1978, Section 74-6-4(B) of the New Mexico Water Quality Act (WQA).

In accordance with Section 303(e) of the CWA and 40 CFR 130.5, states are required to have a CPP which describes the processes used to manage the state's water quality programs. The state may determine the format of its CPP as long as it meets the minimum requirements, as described in Section 303(e)(3)(A)-(H) of the CWA and 40 CFR 130.5, but it may also include other processes at its discretion.

In accordance with 40 CFR 130.6(b), the WQMP is used to direct implementation and draw upon the water quality assessments to identify priority point and nonpoint water quality problems, consider alternative solutions and recommend control measures, including the financial and institutional measures necessary for implementing recommended solutions. The WQMP/CPP addresses nine (9) elements to implement water quality management planning, in accordance with 40 CFR 130.6(c) and as described under Section 205(j) of the CWA; areawide Waste Treatment Management under Section 208 of the CWA; and Water Quality Standards (WQS) and implementation plans as described under Section 303 of the CWA.

The Statewide WQMP/CPP is used to direct implementation of New Mexico's water quality programs. The WQMP/CPP is intended to provide a consistent approach to preserve, protect, and improve water quality by ensuring that WQS are established to protect designated uses, the quality of water in the environment is periodically assessed, and point and nonpoint pollution sources that may adversely impact water quality are identified, prioritized, and controlled.

B. Significant Challenges to Water Quality Management in New Mexico

There are many challenges in meeting the objectives of the CWA and the WQA. This section highlights some of the more significant surface water quality issues in New Mexico.

Climate Change

The impact of climate change on the state's water resources should be acknowledged because the science shows that these changes will lead to further problems and uncertainties. Droughts are predicted to increase in both frequency and severity in many regions of the world, including the southwestern U.S., due to climate change. In general, droughts and the immediate recovery period have substantial water quality effects on the waterbody and its watershed. For example, decreases in stream flow typically increase pollutant concentrations due to evaporation and less dilution. Other water quality impacts associated with climate change and drought include higher water temperatures, enhanced algal production, toxic algal blooms, and lower dissolved oxygen

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levels, all of which are stressors to aquatic life. As temperature and precipitation patterns undergo extreme cycles, more frequent and more powerful storms will increase pollutant runoff from the watershed, physically modify and erode riparian habitat, and disrupt biological communities that depend on these habitats. In addition, shifting temperature and precipitation patterns affect vegetation composition and density and increase the propensity for wildfire in non-fire adapted ecosystems.

As waters become stressed by climate change, drought, wildfires, overuse, and groundwater mining, many perennial and intermittent streams and springs will fade. Currently, many perennial "rivers" and "tributaries" in New Mexico contain non-perennial sections. As a result of climate change, these "perennial" waters will likely diminish and the need for clean water will strain these systems even further.

To address some of these concerns, in 2019 Governor Lujan Grisham signed executive order 2019-003 on Addressing Climate Change and Energy Waste Prevention. EO 2019-003 directs all State agencies to evaluate the impacts of climate change on their programs and operations and integrate climate change mitigation and adaptation practices into their programs and operations. The WQMP/CPP ties in directly with various initiatives for resource management in the State of New Mexico, including EO 2019-003. The long-term water quality monitoring programs under the State's Water Quality Management Plan are designed to identify trends in water quality and evaluate project effectiveness. In addition, watershed restoration projects enhance the natural environment and improve watershed resilience to climate change.

Stormwater and MS4s

Controlling stormwater runoff and its impact is a serious issue facing communities across New Mexico. Urban and highway stormwater runoff is rainfall or snowmelt that runs off the ground or impervious surfaces such as buildings, roads, and parking lots, and drains into natural or man-made drainage systems. In most cases, it drains directly into streams, river, lakes, or wetlands without receiving any treatment to remove pollutants. Because of this, stormwater is a leading cause of water pollution.

Changes in land use have a major effect on both the quantity and quality of stormwater runoff. Urbanization, if not properly planned and managed, can dramatically alter the natural hydrology of an area because it increases impervious cover, decreases the amount of rainwater that can naturally infiltrate into the soil, and consequently increases the volume and rate of stormwater runoff. Stormwater runoff also typically contains elevated concentrations of a variety of constituents that exceed water quality standards (e.g., copper, lead, and zinc; polyaromatic hydrocarbons (PAHs) and pesticides; oil and grease; nutrients (nitrogen and phosphorus); sediment; and *E. coli* bacteria). Untreated stormwater entering our waterways can kill aquatic life and result in the contamination of fish tissue and drinking water supplies; prohibit or limit swimming, fishing or boating; present dangers to public health and safety; and increase the frequency and magnitude of flooding.

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Polluted stormwater runoff also is commonly transported through municipal separate storm sewer systems (MS4s) in urbanized areas to local waterbodies. To prevent harmful pollutants from being washed or dumped into MS4s, certain operators are required to obtain National Pollutant Discharge Elimination System (NPDES) permits and develop stormwater management programs (SWMPs). The SWMP describes the stormwater control practices that will be implemented consistent with permit requirements to minimize the discharge of pollutants from the urbanized area. Furthermore, effective water quality protection requires the "treatment" of stormwater through the use of various preventive and control measures (e.g., best management practices, low impact development, structural controls) to reduce the impact of impervious surfaces and minimize increases in stormwater runoff.

The U.S. Environmental Protection Agency's (EPA) "Procedures for Implementing NPDES Permits in New Mexico – NMIP" establishes procedures to effectively incorporate state water quality standards and total maximum daily loads (TMDLs) into NPDES permits. EPA Region 6 is the NPDES permitting authority in New Mexico. As such, EPA R6 uses the NMIP to explain NPDES permitting decisions in New Mexico. The EPA developed the NMIP in coordination with the NMED Surface Water Quality Bureau. Specific measures to ensure permitting effectiveness and appropriate implementation of New Mexico's water quality standards and TMDLs are contained in the NMIP.

Navigable Waters Protection Rule and "Waters of the U.S."

In 2019, the EPA and the Department of the Army proposed the Navigable Waters Protection Rule to define "waters of the U.S." and delineate which waters are protected under the federal CWA. The rule was finalized in April 2020 and went into effect on June 22, 2020. The new rule interprets the term "waters of the U.S." to encompass the following four categories of waters:

1. Territorial seas and traditional navigable waters;
2. Perennial and intermittent tributaries to territorial seas and navigable waters;
3. Certain lakes, ponds and impoundments of jurisdictional waters; and
4. Wetlands adjacent to other jurisdictional waters.

The new rule identifies 12 categories that are not "waters of the U.S." and therefore, not federally regulated or protected under the CWA, including ephemeral features that flow only in response to rainfall, groundwater, wetlands that do not abut a jurisdictional water, many farm and roadside ditches, certain artificial lakes and ponds, and waste treatment systems.

Under the new rule, at least 89 percent of the state's rivers and streams and approximately 40 percent of the state's wetlands lose federal regulation and protection from pollution. New Mexico is one of three states in the U.S., and the only state in the West, that does not have authority (aka "delegation") from the EPA to administer and implement the NPDES program under Section 402 of the CWA. The NPDES program regulates facilities that discharge pollutants into "waters of the U.S." and includes permit issuance, compliance, and enforcement activities.

This federal rollback of environmental protections for streams and wetlands will put more burden on the State's water quality management agencies, especially the New Mexico Environment

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Department (NMED), to ensure continued protection of surface waters of the state and adequate resources to maintain and improve water quality. Without a state permitting program to authorize discharges to surface waters of the state including waters of the U.S., NMED is unable to fill the regulatory gap created by the new rule.

Currently, NMED is actively investigating available options. This includes conducting a NPDES gap analysis that (1) evaluates statutory, regulatory, and programmatic gaps associated with potential pursuit of NPDES program authorization for the State of New Mexico and (2) identifies actions necessary to eliminate the gap and assume authority over the program.

Watershed Management and Water Quality

Interagency collaboration has always played a significant role in managing watersheds on public lands within New Mexico. There are many federal and state agencies with varying missions and priorities for utilizing and protecting New Mexico's natural resources. In part, these activities include habitat restoration, water quality management, water rights management, mining, grazing, silviculture, conservation management, wildlife management, outdoor recreation, hunting, and fishing. As discussed in further detail under subsection F of this Section, this Water Quality Management Plan identifies some of those entities the State engages with to ensure continued water quality protection for the State of New Mexico.

C. Cross-walk of Sections in the WQMP/CPP and the Federal Requirements

The nine (9) federal requirements of a WQMP are found in 40 CFR 130.6(c), and the nine (9) federal requirements of a CPP are found in 40 CFR 130.5(b). Table I-1 shows how this document is organized to incorporate requirements of both the WQMP and the CPP. Any reference to the State's WQMP or CPP in statutes, regulations, standards or other documents refers to this document.

Table I-1: Federal Requirements for WQMP and CPP

WQMP/CPP Section	40 CFR 130.6 WQMP Requirements	40 CFR 130.5 CPP Requirements
I. Introduction	Not required by 40 CFR 130.6	**40 CFR 130.5(b)(4)** *The process for updating and maintaining WQMPs, including schedules for revision;* **40 CFR 130.5(b)(5)** *The process for assuring adequate authority for intergovernmental cooperation in the implementation of the State's WQMP.*
II. Water Quality Standards	Not required by 40 CFR 130.6	**40 CFR 130.5 (b)(6)** *The process for establishing and assuring adequate implementation of new or revised water quality standards.*
III. Assessment, Monitoring and Reporting	Not required by 40 CFR 130.6	Not required under 40 CFR 130.5

WQMP/CPP Section	40 CFR 130.6 WQMP Requirements	40 CFR 130.5 CPP Requirements
IV. Total Maximum Daily Loads (TMDLs)	**40 CFR 130.6 (c)(1)** *A list of approved TMDLs.*	**40 CFR 130.5(b)(3)** *The process for developing TMDLs and individual water quality-based effluent limitations for pollutants.*
V. Effluent Limitations	**40 CFR 130.6 (c)(2)** *Effluent limitations including water quality-based effluent limitations and schedules of compliance.*	**40 CFR 130.5 (b)(1)** *The process for developing effluent limitations and schedules of compliance;* **40 CFR 130.5(b)(9)** *The process for determining the priority of permit issuance.*
VI. Municipal and Industrial Waste Treatment	**40 CFR 130.6 (c)(3)** *Identification of anticipated municipal and industrial waste treatment works; programs to provide necessary financial arrangements for such works; establishment of construction priorities and schedules for initiation and completion of such treatment works including an identification of open space and recreation opportunities from improved water quality.*	**40 CFR 130.5(b)(7)** *The process for assuring adequate controls over the disposition of all residual waste from any water treatment processing;* **40 CFR 130.5(b)(8)** *The process for developing an inventory and ranking, in order of priority of needs for construction of waste treatment works.*
VII. Nonpoint Source Management and Control	**40 CFR 130.6 (c)(4)** *The regulatory and non-regulatory programs, activities, and Best Management Practices (BMPs) to control nonpoint source pollution where necessary to protect or achieve approved water uses.*	Not required by 40 CFR 130.5
VIII. Management Agencies	**40 CFR 130.6 (c)(5)** *Identification of agencies necessary to carry out the WQMP and provision for adequate authority for intergovernmental cooperation.*	Not required by 40 CFR 130.5
IX. Implementation Measures	**40 CFR 130.6(c)(6)** *Identification of implementation measures necessary to carry out the WQMP.*	Not required by 40 CFR 130.5
X. Dredge and Fill Program	**40 CFR 130.6(c)(7)** *Identification and development of programs for the control of dredge and fill material.*	Not required by 40 CFR 130.5.
XI. Basin Plans	**40 CFR 130.6(c)(8)** *Identification of any relationship to applicable basin plans developed under Section 209 of the CWA.*	**40 CFR 130.5(b)(2)** *The process for incorporating elements of any applicable areawide waste treatment plans under Section 208, and applicable basin plans under Section 209 of the CWA.*
XII. Groundwater	**40 CFR 130.6(c)(9)** *Identification and development of programs for control of ground-water pollution.*	Not required by 40 CFR 130.5

WQMP/CPP Section	40 CFR 130.6 WQMP Requirements	40 CFR 130.5 CPP Requirements
XIII. Determination of Compliance with WQS – Human Health Criteria	Not required by 40 CFR 130.6 (required by 20.6.4 NMAC)	Not required by 40 CFR 130.5
XIV. Public Participation	Not required by 40 CFR 130.6	**40 CFR 130.5(b)(4)** *The process for updating and maintaining the WQMP.*

D. History and updates to the WQMP/CPP

The New Mexico Water Quality Control Commission (WQCC) first adopted the WQMP and the CPP in 1979, under the statutory authority of Section 74-6-4(B) of the WQA. Prior to 2011, the WQMP and the CPP were maintained independently of each other. Beginning in 2011, the New Mexico Environment Department's (NMED's) Surface Water Quality Bureau (SWQB) consolidated the WQMP and CPP into one document.

The chronological summary of the subsequent updates are as follows:

- March 1976 CPP initially adopted
- October 1978 WQMP initially adopted
- May 1979 WQMP
  - Initially adopted Work Elements 2.5 (Trout Hatcheries), 4.3 (Sediment Study) 8.0 (Industrial Waste Treatment System Needs: Toxic Substance Study) and 9.5 (Development of Statewide Groundwater Monitoring System)
- October 1979 WQMP
  - Updated Work Element 3 (Population Projections)
- October 1980 WQMP
  - Initially adopted Work Element 13 (Designation of Management Agencies)
  - Updated Work Element 3 (Population Projections)
- May 1982 WQMP
  - Updated Work Element 6 (Point Source Load Allocations)
- September 1983 WQMP
  - Updated Work Element 4.1 (Irrigated Agriculture)
- August 1984 WQMP
  - Initially adopted Work Element 14 (Implementation Schedules)
  - Updated Work Elements 4.1 (Irrigated Agriculture), 4.2 (Silviculture), 4.3 (Sediment Study), 13 (Designation of Management Agencies)
- October 1985 WQMP
  - Updated Work Elements 6 (Point Source Load Allocations) and 13 (Designation of Management Agencies)
- April 1986 WQMP
  - Updated Work Element 3 (Population Projections)
- September 1988 WQMP

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    - Updated Work Element 13 (Designation of Management Agencies)
- September 1989 WQMP
    - Updated Work Element 6 (Point Source Load Allocations)
- July 1998 CPP
- December 2002 WQMP
    - Approved December 17, 2002
    - Restructured for comprehensiveness, accessibility, and usability
    - Reorganized to track current federal requirements
    - Removed outdated or non-applicable elements
    - Consolidated partial updates
- May 2003 WQMP
    - Updated Introduction to provide background on how water quality is managed and Work Element 11 (Public Participation Program) (now Section XIV) to include outreach protocols and strategies
- December 2004 CPP
    - Initially adopted Antidegradation Policy Implementation Procedure
- November 2010 WQMP
    - Updated the Antidegradation Policy Implementation Procedure (Appendix A)
- May 2011 WQMP/CPP
    - Consolidated WQMP and CPP
    - Initially adopted the following new elements:
        - Developed Wetlands Program
        - Adopted Underground Injection Control (UIC) regulations
        - Created Water Cabinet for Water and Wastewater Infrastructure
        - Added Hydrology Protocol for determining water body type (ephemeral, intermittent, perennial)
    - Updated and revised:
        - References and citations
        - Program descriptions
        - WQS amendments
        - Completion of the TMDL settlement agreement requirements
        - Process for establishing TMDLs
        - Nonpoint Source Management Program
        - Provided a format that supported opportunity for future growth of the WQMP

The primary goals of this 2020 update include the following:

- Incorporate changes and new developments that have occurred since the last revision in 2011;
- Update the antidegradation policy implementation procedure (Appendix A);
- Incorporate the Wetland Program (Previously Section XV) into regulatory mandated portions of the WQMP/CPP primarily under the Nonpoint Source Management and Control (Section VII); and
- Update program descriptions and citations to referenced documents.

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E. The process for updating and maintaining the WQMP/CPP including schedules for revision

[As required by 40 CFR 130.5(b)(4) for CPP]

To ensure that the WQMP/CPP continues to provide an effective framework for water quality management, updates may be developed for reasons such as: changes in population, economic development, changing water quality conditions, results of implementation activities, new and revised effluent limitations, and new requirements, including new laws, regulations, and standards.

The WQMP/CPP is periodically reviewed and revised in accordance with 40 CFR 130.5 and 40 CFR 130.6(e) to ensure the processes are current and adequately reflect the State's water quality management system. Any updates and revisions to the WQMP/CPP must be approved by the WQCC and the United States Environmental Protection Agency (EPA).

Following an identification for the need to update the WQMP/CPP, NMED proceeds with outreach efforts to Tribal counterparts in accordance with NMED's 2009 Tribal Collaboration and Communication Policy. Identification of potential stakeholders is also conducted to engage individuals or entities that may be impacted by the actions under the WQMP/CPP. Following outreach to Tribes and Stakeholders, the public notice process is driven primarily by various Federal and State regulations as well as NMED policies as outlined in Section XIV of this WQMP/CPP. After public comments are received, NMED reviews and incorporates necessary revisions, as applicable. NMED then presents the proposed revisions to the WQCC for consideration and approval. NMED may submit a proposed update to EPA for technical review before presentation to the WQCC. The WQCC considers the proposed update at one of its public meetings. At the WQCC meeting, the WQCC allows all interested persons reasonable opportunity to provide comment before deciding whether to approve the update.

After adopting an update, the WQMP/CPP is sent to the Governor or designee by the Department on behalf of the WQCC for review and certification that the update is consistent with all other parts of the plan. The WQCC sends the approved WQMP/CPP, along with the Governor's certification, to EPA Region 6 for approval. Once approved by EPA Region 6, the approved WQMP/CPP is maintained within NMED and filed as a State publication with the New Mexico State Library.

Updates to the appendices of the WQMP/CPP, including the Antidegradation Policy Implementation Procedure and the Hydrology Protocol for the Determination of Uses Supported by Ephemeral, Intermittent and Perennial Waters (Appendix A and C, respectively), are done in accordance with the process to update the WQMP/CPP. Updates to the TMDL List (Appendix B) are made once a TMDL has been adopted or removed in accordance with the process described in Section IV of this WQMP/CPP.

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Several documents that relate to components of this WQMP/CPP are incorporated by reference. Documents incorporated by reference may be revised and updated independently, but in accordance with the WQMP/CPP. The context of each reference should be used to determine if a specific version or the most current version of the document is being referenced. The regulations and documents incorporated by reference into the WQMP/CPP include the following:

Ground and Surface Water Protection regulations *(20.6.2 NMAC)*

New Mexico Nonpoint Source Management Plan

Standards for Interstate and Intrastate Surface Waters regulations *(20.6.4 NMAC)*

State of New Mexico Integrated Clean Water Act §303(d)/§305(b) Integrated Report

Surface Water Quality Bureau Quality Management Plan (QMP)

Surface Water Quality Bureau Quality Assurance Project Plan for Water Quality Management Programs (QAPP)

F. Process for assuring adequate authority for intergovernmental cooperation in the implementation of the State's Water Quality Management Program

[As required by 40 CFR 130.5(b)(5) for CPP]

The creation of the WQCC as the control agency for all purposes of the WQA and, in turn, the federal CWA, are established under NMSA 1978, Section 74-6-3 of the WQA. The duties and powers of the WQCC under Section 74-6-4 of the WQA assure adequate authority for intergovernmental cooperation in the implementation of the WQMP/CPP.

Intergovernmental cooperation in the implementation of the WQMP/CPP programs is provided by four factors:

Factor 1: The composition of the WQCC.

The WQCC is the water pollution control agency for New Mexico. It is responsible for developing specific water quality policy in NM, in a manner that implements the broader policies set forth by the NM Legislature in the WQA. In accordance with Section 74-6-3 of the WQA, the WQCC is comprised of fourteen (14) members; nine (9) of which are representatives of State agencies involved in some aspect of water quality management; one (1) member is a representative of county or municipal government; and the other four (4) members are representatives of the public that are appointed by the Governor. Thus, the WQCC itself serves as a forum for exchange of information, coordination, and cooperation. The fourteen members of the WQCC include:

- Secretary of the Environment Department*
- Secretary of the Department of Health*
- Director of the Department of Game and Fish*

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- State Engineer*
- Chair of the Oil Conservation Commission*
- Director of the State Park and Recreation Division of the Energy, Minerals and Natural Resources Department (EMNRD)*
- Director of the New Mexico Department of Agriculture*
- Chair of the Soil and Water Conservation Commission or a Soil and Water Conservation District Supervisor designated by him/her
- Director of the Bureau of Geology and Mineral Resources at the New Mexico Institute of Mining and Technology*
- Representative of County or Municipal Government
- Four representatives of the public to be appointed by the governor for terms of four years

*indicates that a Commissioner can appoint a designee.

The WQCC is the entity with authority to approve the WQMP/CPP, adopt WQS to protect waters of the State, as well as various regulations aimed at achieving compliance with those standards. In addition to its formal rulemaking role, the WQCC serves as a forum to facilitate and advance a statewide policy dialogue on a variety of important water quality topics. In accordance with NMSA 1978, Section 74-6-4(F), the WQCC shall also hear and decide disputes between constituent agencies as to jurisdiction concerning any matters within the purpose of the WQA. Additional duties and powers of the WQCC are defined in the WQA at NMSA 1978, Section 74-6-4.

Factor 2: The delegation of responsibilities to constituent agencies by the WQCC.

Under Section 74-6-4(F) of the WQA the WQCC has the authority to delegate responsibility for administering its regulations to constituent agencies to assure adequate coverage and prevent duplication of effort. The WQCC reviews, adopts, and records such delegations at its regular open meetings. As the WQCC has no staff of its own, responsibilities for administering its regulations are assigned among eight (8) constituent agencies identified in the WQA at NMSA 1978, Section 74-6-2(K). Those agencies, along with any applicable responsibilities pertaining to this WQMP/CPP, are as follows:

New Mexico Environment Department (NMED)

The Secretary of NMED is delegated as a member of the WQCC. Under the WQCC's delegation of Responsibilities to Environmental Improvement Division (now NMED) and Oil Conservation Division (OCD) dated July 21, 1989, NMED is the primary constituent agency responsible for administering and enforcing all programs implemented by the state under the CWA. Such actions include implementing the WQMP/CPP, as well as administering regulations adopted by the WQCC for discharges to surface and ground water. NMED is the principal source of technical expertise available to the WQCC in its rulemaking and other policy-setting activities. The WQCC, in accordance with NMSA 1978, Section 74-6-3(F), is administratively attached to NMED.

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On July 21, 1989, through the Water Quality Control Commission's "Delegation of responsibilities to Environmental Improvement Division and Oil Conservation Division "the WQCC delegated NMED as the constituent agency to administer the following duties:

- Maintain, restore and improve the quality of the State's waters;
- Regulate discharges for compliance with regulations and standards;
- Develop water quality classifications and standards;
- Perform site application and design and specification reviews of new or expanding domestic wastewater treatment facilities;
- Undertake monitoring and enforcement of the statutes and permits;
- Coordinate water quality management planning;
- Manage state and federal construction grant and loan assistance programs which provide financial support to municipalities for construction or improvement of wastewater treatment facilities;
- Manage the groundwater quality protection program with the goal of protecting the public health and beneficial ground water uses; and
- Provide technical assistance to local governments regarding water and wastewater treatment.

Section 74-6-4(F) of the WQA also specifically assigns the following duties to NMED:

- Provide technical services, including certification of permits pursuant to the federal CWA, and
- Maintain a repository of the scientific data required by the WQA.

The following describes specific NMED bureaus and their responsibilities relating to the implementation of the WQMP/CPP. For additional information visit: https://www.env.nm.gov/.

Construction Programs Bureau (CPB): The CPB is involved in implementing portions of the WQMP/CPP as they pertain to prioritizing water, wastewater, and solid waste planning, design, and construction funding through the administration of the following programs: New Mexico Clean Water State Revolving Fund (CWSRF), also known as the Wastewater Facility Construction Loan Fund; Rural Infrastructure Program (RIP); and Capital Outlay Special Appropriations Program (SAP). As part of these programs, the CPB:

- Administers low interest loan and grant programs for water, wastewater and other environmental infrastructure projects that protect surface and groundwater;
- Manages the timely construction and administrative completion of publicly funded water, wastewater, and solid waste projects; and
- Ensures that projects are environmentally sound, of high quality, and free of waste, fraud, and abuse.

Ground Water Quality Bureau (GWQB): The GWQB protects the quality of NM's groundwater resources in accordance with the WQMP/CPP and as mandated by the WQA, the federal Safe

Drinking Water Act (SDWA), Ground and Surface Water Protection Regulations (20.6.2 NMAC), Ground Water Protection-Supplemental Permitting Requirements for Dairy Facilities (20.6.6 NMAC), and Ground Water Protection-Supplemental Permitting for Copper Mine Facilities (20.6.7 NMAC). The GWQB:

- Develops standards and regulations pertaining to groundwater quality;
- Issues groundwater pollution prevention discharge permits;
- Implements the Department's responsibilities under the New Mexico Mining Act to ensure that environmental issues are addressed, and standards are met;
- Implements NM's underground injection control (UIC) programs;
- Oversees groundwater investigation and remediation activities; and
- Identifies, investigates and remediates contaminated sites that pose significant risks to human health and the environment through implementation of the Bureau's Voluntary Remediation Program, Brownfields Program, and the federal Superfund program.

GWQB also strives to increase industry and public understanding and awareness of the importance of safe groundwater supplies in sustaining the quality of life in New Mexico for this and future generations, and the importance of protecting groundwater quality through pollution prevention initiatives.

Surface Water Quality Bureau (SWQB): The SWQB protects and improves NM's surface water quality by controlling pollution from both discrete point sources and dispersed nonpoint sources. The SWQB maintains and revises the WQMP/CPP and is the primary bureau within NMED that is responsible for implementing the majority of the sections under the WQMP/CPP. Operating under the CWA, the SDWA, the WQA, the Standards for Interstate and Intrastate Surface Waters (20.6.4 NMAC), and Ground and Surface Water Protection regulations (20.6.2 NMAC) the SWQB:

- Administers the Nonpoint Source (NPS) Program through the federally funded Program under Section 319 of the CWA and the state-funded River Stewardship Program;
- Administers the Wetlands Program;
- Certifies federal permits issued under Section 402 of the CWA pertaining to National Pollutant Discharge Elimination System (NPDES) and Section 404 of the CWA pertaining to Dredge and Fill;
- Assists the WQCC in developing surface WQS and regulations for the State;
- Conducts monitoring and assessment activities to report on water quality status and identify impairments of NM's surface waters; and
- Develops water quality planning documents identifying pollutant load reductions necessary to attain WQS.

Other NMED Bureaus and Programs: Other Bureaus and Programs also contribute to water quality protection and may work indirectly under the WQMP/CPP from time to time. Some of which are listed as follows:

- Utility Operator Certification Program ensures adequate training and certification for drinking water and wastewater operators.
- The Liquid Waste Program regulates individual on-site liquid waste systems to protect public health and to prevent contamination of ground and surface water.
- The Petroleum Storage Tank Bureau reduces, mitigates and eliminates the threats to the environment posed by petroleum products or released from underground and above ground storage tank systems.
- The Solid Waste Bureau assures that solid waste is managed in such a way as to minimize impact on the environment and public health.
- The Drinking Water Bureau assists communities in protecting the sources of their drinking water supplies from contamination.
- The Hazardous Waste Bureau regulates hazardous waste treatment, storage and disposal facilities, oversees cleanup of contaminated sites, and implements Federal Facility Compliance Orders at Los Alamos and Sandia National Laboratories.

Office of the State Engineer and Interstate Stream Commission

The State Engineer is delegated as a member of the WQCC. No other applicable responsibilities pertaining to this WQMP/CPP have been identified.

New Mexico Department of Game and Fish

The Director of the New Mexico Department of Game and Fish is delegated as a member of the WQCC. The Department of Game and Fish has also been delegated authority through the WQCC to enforce the regulation for disposal of refuse in a watercourse. No other applicable responsibilities pertaining to this WQMP/CPP have been identified.

New Mexico Oil Conservation Commission

The chair of the New Mexico Oil Conservation Commission is delegated as a member of the WQCC. In accordance with NMSA 1978, Section 70-2-4, the chair of the Oil Conservation Commission is elected from one of the three Commission members; a designee of the commissioner of public lands, a designee of the secretary of New Mexico's Energy, Minerals and Natural Resources Department (EMNRD), and the Director of the Oil Conservation Division (OCD).

In accordance with NMSA 1978, Section 70-2-6, the Oil Conservation Commission has concurrent jurisdiction and authority with the Oil Conservation Division (OCD). The WQCC's delegation of Responsibilities to Environmental Improvement Division (now NMED) and Oil Conservation Division (OCD), dated July 21, 1989, outlines the division of responsibilities between the agencies for administering WQCC regulations to protect water quality and abate water pollution (*see generally* 20.6.2 NMAC). The OCD administers these regulations as they pertain to "discharges from facilities for the production, refinement, pipeline transmission of oil and gas or products thereof, the oil field service industry as related to oil and gas production activities, oil field brine production wells, geothermal installations and carbon dioxide facilities" (*see* Subsection A(1) of 20.6.2.1201 NMAC).

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The disposition by use of produced water not for drilling, completion, producing, secondary recovery, pressure maintenance or plugging of wells pursuant to 19.15.34 NMAC requires prior approval from the OCD (see Subsection A *of* 19.15.34.8 NMAC), and also requires the submission of a Notice of Intent to NMED and/or EPA if the use includes a potential discharge to ground or surface waters (*see* 20.6.2.1201 NMAC and Section 402 of the CWA, respectively). Discharges from other types of facilities that could affect groundwater quality are regulated by NMED's Ground Water Quality Bureau. No other applicable responsibilities pertaining to this WQMP/CPP have been identified.

New Mexico State Parks Division of the Energy, Minerals and Natural Resources Department

The Director of the New Mexico State Parks Division of the Energy, Minerals and Natural Resources Department is delegated as a member of the WQCC. The State Parks Division of the EMNRD has been delegated authority to enforce the WQCC regulation for disposal of refuse in a watercourse. No other applicable responsibilities pertaining to this WQMP/CPP have been identified.

New Mexico Department of Agriculture

The Director of the New Mexico Department of Agriculture is delegated as a member of the WQCC. No other applicable responsibilities pertaining to this WQMP/CPP have been identified.

New Mexico Soil and Water Conservation Commission

The Chair of the New Mexico Soil and Water Conservation Commission is delegated as a member of the WQCC. No other applicable responsibilities pertaining to this WQMP/CPP have been identified.

New Mexico Bureau of Geology and Mineral Resources at the New Mexico Institute of Mining and Technology

The Director of the Bureau of Geology and Mineral Resources at the NM Institute of Mining and Technology is delegated as a member of the WQCC. No other applicable responsibilities pertaining to this WQMP/CPP have been identified.

Factor 3: The authority of the WQCC to enter into or authorize its constituent agencies to enter into agreements with federal or state agencies for purposes consistent with the WQA.

Under the WQA at NMSA 1978, Section 74-6-4(G), the WQCC has the authority to enter into, or authorize constituent agencies to enter into, agreements with the federal government or other state governments. This provides the WQCC with a means of formally coordinating with agencies outside of the WQCC and allows the WQCC to use the expertise of those agencies in fulfilling its responsibilities.

Factor 4: The designation of management agencies to carry out specific responsibilities under the WQMP/CPP.

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The WQCC designates management agencies to carry out specific responsibilities. Designated Management Agencies (DMAs) are generally municipal or public entities that must satisfy the requirements of 40 CFR 130.6(c)(5), including demonstration that the agencies have the legal, institutional, managerial, and financial capability, as well as programmatic capacity, to carry out the designated responsibilities. The designation must be formally accepted by the management agency and adopted by the WQCC before it is certified by the Governor.

Pursuant to Section 208 of the CWA, the governor of a state must identify areas of the state which, as a result of urban or industrial concentration or other significant factors, have substantial water quality problems. The governor may designate regional planning agencies for these areas, after consultation with local governmental officials having jurisdiction over the area, to conduct the planning required by Section 208. As specified at 40 CFR 130.12(b), Section 201 of the CWA funding can only be awarded to DMAs that are in conformance with the statewide WQMP/CPP. A list of approved DMAs can be found in Section VIII of this WQMP/CPP.

G. Other Entities participating in water quality management

A multi-agency approach is implemented to carry out the directives of the CWA, the State's WQA and the mission of NMED. Numerous entities at the local, state and federal level participate in water quality management. The following describes the entities and their identified roles and responsibilities as they pertain to water quality management and planning in New Mexico.

Other State Agencies

Several other state agencies conduct activities that impact water quality and are considered in the coordination and implementation of this WQMP/CPP as appropriate. These include, but are not limited to:

- Department of Transportation
- Department of Health
- State Forestry Division
- State Land Office
- Energy, Minerals and Natural Resources Department (specifically, Mining and Minerals Division)

Other Watershed-Based Water Quality Authorities/Associations/Forums

Increasing interest in a watershed-based approach to water quality management has led to the development of a number of local and regional initiatives in NM. These initiatives reflect a great diversity of organizational models and functional roles. The various initiatives focus on a number of different priorities such as: implementation of site-specific control regulations adopted by the WQCC, information sharing (outreach and education), or implementation of remediation and restoration projects. The number and nature of these local and regional watershed initiatives in New Mexico is evolving rapidly. No effort is made in this WQMP/CPP to comprehensively catalogue or describe such initiatives.

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U.S. Environmental Protection Agency (EPA)

In addition to providing a significant amount of programmatic funding through CWA grant programs, EPA has several roles with respect to NM's water quality control programs:

- WQS In accordance with Section 303(c)(3) of the CWA, EPA is required to review state water quality standards and either approve WQS as being compliant with the federal act, or to disapprove and promulgate classifications and standards for NM.

- TMDLs - EPA reviews and approves the State's CWA §303(d) List of Impaired Waters. States are required to develop TMDLs for impaired waterbodies (Per Section 303(d) of the CWA, 33 U.S.C. §1313). TMDLs that are first adopted by the WQCC are then reviewed and approved by EPA under the CWA.

- Discharge Permits - EPA issues NPDES discharge permits in New Mexico which are certified by SWQB under Section 401 of the CWA.

- EPA is responsible for approving Section 208 of the CWA plans (regional WQMPs) submitted by states, as well as state CPPs prepared in accordance with Section 303(e) of the CWA.

- Guidance - In addition to adopting regulations establishing water quality program requirements that must be met by states, EPA frequently issues guidance documents or policy statements on a variety of water quality topics.

Other Federal Agencies

Several other federal agencies involved in water quality management in NM, including the U.S. Forest Service (USFS), U.S. Bureau of Land Management (BLM), and National Park Service (NPS), consider water quality protection in their management programs. The U.S. Army Corps of Engineers (USACE) administers the permit program under Section 404 of the CWA, which regulates the discharge of dredged and fill material that may adversely impact waters of the United States, including wetlands. The U.S. Bureau of Reclamation (BOR) has increasingly included environmental protection considerations into its management of federal water projects. The U.S. Department of Agriculture (USDA) administers an Environmental Quality Incentive Program under the federal Farm Bill. The U.S. Fish and Wildlife Service (USFWS) consults with other federal agencies under Section 7 of the Endangered Species Act regarding activities that may adversely impact threatened or endangered species. EPA consults with USFWS to evaluate potential impacts from water quality program activities on threatened and endangered species. The U.S. Geological Survey (USGS) undertakes a variety of studies regarding water quality, including the National Water Quality Assessment program.

Tribes

Although the State's water quality regulations are not applicable to tribal waters within the exterior boundaries of a tribe or those lands to which the Tribe has incorporated into federal

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trust; many waters cross boundaries and jurisdictional protections, and as such there is a shared interest in the protection of water quality between the Tribes and the State of New Mexico. The State recognizes the importance of communication and collaboration with Tribes to ensure water quality across boundaries.

The State has memorialized this sentiment through Executive Order 2005-004, The State-Tribal Collaboration Act, NMSA 1978, Section 11-18-1, and subsequently NMED's *Tribal Consultation and Collaboration Policy* (NMED Office of the Secretary 2020). It is through the *Tribal Consultation and Collaboration Policy* that NMED engages Tribes during any action(s) that may impact the natural, cultural and environmental resources of a Tribe. Tribes are recognized as sovereign entities. Therefore, the State interacts accordingly with them in a government-to-government capacity. These actions with Tribes are independent of stakeholder and public outreach efforts.

The 23 federally recognized Tribes throughout the State of New Mexico include:

- *Acoma Pueblo
- Pueblo de Cochiti
- *Pueblo of Isleta
- Jemez Pueblo
- *Laguna Pueblo
- *Nambe Pueblo
- *Ohkay Owingeh
- *Picuris Pueblo
- *Pojoaque Pueblo
- *Pueblo of Sandia
- Pueblo of San Felipe
- Pueblo de San Ildefonso
- *Pueblo of Santa Ana
- *Santa Clara Pueblo
- Santo Domingo Pueblo
- *Taos Pueblo
- *Pueblo of Tesuque
- Pueblo of Zia
- Zuni Pueblo
- Mescalero Apache
- Jicarilla Apache
- Fort Sill Apache
- *Navajo Nation

*Indicates that as of the approval date of this WQMP/CPP, tribe was identified by EPA to have Treatment in a Similar Manner as a State ("TAS") under Section 303(c) of the CWA allowing them to develop their own water quality standards for waters within the exterior boundaries of their Tribe. Please note this is a designation through the EPA and is independent of the State of New Mexico and the status, as listed here, may change at any time. For current status of TAS and WQS for tribes refer to EPA's website (https://www.epa.gov/wqs-tech/epa-actions-tribal-water-quality-standards-and-contacts).

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In addition, the State also recognizes the Ysleta del Sur Pueblo near El Paso, Texas which also has critical interest in the protection of water quality along the Rio Grande as it enters Texas from New Mexico. The State also recognizes the Southern Ute Indian Tribe of the Southern Ute Reservation and Ute Mountain Ute Tribe in Colorado along the New Mexico Colorado border.

Stakeholders and the General Public

Stakeholder and public participation are an integral part of water quality management in NM. All regulatory actions of the WQCC and NMED are required to follow appropriate public comment, notice, and hearing requirements. In addition, with respect to policy-related and non-regulatory activities of the WQCC and NMED, an opportunity for public input is often provided through informational public meetings.

II. SURFACE WATER QUALITY STANDARDS

A. Extent of Authority

New Mexico's Standards for Interstate and Intrastate Surface Waters (20.6.4 NMAC) establish surface WQS that consist of designated uses for surface waters of the State, the water quality criteria necessary to protect the designated uses, and an Antidegradation Policy. These standards are not applicable to tribal waters within the exterior boundaries of a tribe or those lands to which the tribe has incorporated into federal trust. Section 518 of the CWA authorizes EPA to treat eligible Indian tribes with reservations in a similar manner to states (TAS) for administering each of the principal CWA regulatory programs. Therefore, protection of these waters is administered under the individual tribe's WQS as approved by EPA or by EPA for those tribes that have not received TAS under Section 518(e) of the CWA. The State of New Mexico does not have jurisdiction to adopt or impose WQS for tribal waters within NM's borders.

B. Objective

The Standards for Interstate and Intrastate Surface Waters state the following objective:

> *The State of New Mexico is required under the New Mexico Water Quality Act … and the federal Clean Water Act … to adopt water quality standards that protect the public health or welfare, enhance the quality of water, and are consistent with and serve the purposes of the New Mexico Water Quality Act and the federal Clean Water Act. It is the objective of the federal Clean Water Act to restore and maintain the chemical, physical, and biological integrity of the nation's waters, including those in New Mexico. This part is consistent with Section 101(a)(2) of the federal Clean Water Act, which declares that it is the national goal that wherever attainable, an interim goal of water quality that provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983. Agricultural, municipal, domestic and industrial water supply are other essential uses of New Mexico's surface water; however, water contaminants resulting from these activities will not be permitted to lower the quality of surface waters of the state below that required for protection and propagation of fish, shellfish and wildlife and recreation in and on the water, where practicable.* (20.6.4.6(B) NMAC).

C. Components of New Mexico's Surface Water Quality Standards

The federal WQS regulation (40 CFR 131) establishes the requirements for states and tribes to review, revise and adopt WQS. It also establishes the procedures for EPA to review, approve, disapprove and promulgate WQS pursuant to Section 303 (c) of the CWA. As such, WQS are designed to protect the public health or welfare, enhance the quality of water and serve the purposes of the Act. New Mexico's WQS (20.6.4 NMAC), as required under the CWA, define water quality goals by designating uses for surface waters of the State, setting criteria to protect those uses, and establishing an Antidegradation Policy and implementation plan to preserve water quality. Each of these components is described in more detail below.

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Designated Uses

In accordance with 40 CFR 131.10, the State is required to specify goals and expectations for how each water body is used. The system for designating these uses is through development of surface WQS. Numeric criteria are adopted to protect each designated use. It is through the designation of a use for a specific waterbody that water quality protections are implemented.

Designated uses include fish culture, public water supply, industrial water supply, domestic water supply, irrigation and irrigation storage, primary contact, secondary contact, livestock watering, wildlife habitat, and several aquatic life subcategories. The full list of designated uses is specified in 20.6.4.900 NMAC.

Within each river basin, waters are divided into individual "segments" for classification and standard-setting purposes (20.6.4.101 through 20.6.4.899 NMAC). Most of the state's perennial water segments and many non-perennial segments have designated uses listed under 20.6.4.101 to 899 NMAC. All other "non-classified" waters are assigned default designated uses under 20.6.4.98 to 99 NMAC; however, some waters that have been characterized through a use attainability analysis have designated uses specified under 20.6.4.97 NMAC.

Water Quality Criteria

Water quality criteria are established to sustain and protect designated uses of surface waters of the State. States typically adopt both narrative criteria (e.g., general criteria that describe the desired condition of a surface water) and numeric criteria (e.g., maximum allowable pollutant concentration in a surface water).

The State of New Mexico has adopted narrative, or general, criteria under 20.6.4.13 NMAC. General criteria apply to all surface waters of the state and declare that:

> *"…surface waters of the State shall be free of any water contaminant in such quantity and of such duration as may, with reasonable probability, injure human health, animal or plant life or property, or unreasonably interfere with the public welfare or the use of property."*

As identified under Subsections A to M of 20.6.4.13 NMAC, New Mexico's general criteria include: bottom deposits and suspended or settleable solids; floating solids, oil and grease; color; organoleptic quality (odor and taste of fish and water); plant nutrients; toxic pollutants; radioactivity; pathogens; temperature; turbidity; total dissolved solids (TDS); dissolved gases; and biological integrity.

Numeric criteria are specific quantitative limits for pollutants established to protect specific designated uses and specific WQS segments. Use-specific numeric criteria are provided in 20.6.4.900 NMAC and apply to all waters with the applicable designated uses, unless otherwise specified in 20.6.4.101 through 20.6.4.899 NMAC as segment-specific criteria. The WQS also include numeric "human health-organism only" criteria established to protect human health when aquatic organisms are consumed from waters containing pollutants.

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Antidegradation Policy

New Mexico's Antidegradation Policy, which is based on requirements in 40 CFR 131.12, describes how waters are to be protected from degradation (Subsection A of 20.6.4.8 NMAC). At a minimum, the policy protects existing instream uses. Water quality that exceeds the levels necessary to support the propagation of fish, shellfish, and wildlife, and recreation in and on the water is to be maintained unless the WQCC finds that allowing lower water quality is necessary to accommodate important economic and social development. Waters designated as Outstanding National Resource Waters (ONRWs) are to receive the highest level of antidegradation protection. Designated ONRWs are listed in 20.6.4.9 NMAC.

D. Process for Establishing and Updating Water Quality Standards

[As required by 40 CFR 130.5(b)(6) for CPP]

General Process for Establishing or Revising Water Quality Standards

Under the State's WQA, NMSA 1978, Section 74-6-2(H), the duties and powers of the WQCC include adoption of standards for surface and groundwaters of the state. Anyone may propose new or revised standards to the WQCC at any time in accordance with the rulemaking procedures for the WQCC (20.1.6 NMAC) and the State's WQS (20.6.4 NMAC). These regulations specify requirements for pre-hearing procedures and petitions for regulatory changes, hearing notices, hearing participation, post-hearing actions and appeals. It is recognized that notification and engagement of the public prior to petition is vital to the rule-making process and, therefore, additional requirements have been identified under this WQMP/CPP to encourage participation, allow effective presentation of evidence and points of view, allow participants an opportunity to submit information, and assure that hearings are conducted in a fair and equitable manner. For all proposed changes to the State's WQS, the WQCC bases its decision on evidence presented at the public hearing.

The process to adopt new or amended surface WQS conforms to requirements under numerous federal and state acts including, but not limited to, the CWA (33 U.S.C. § 1251 *et seq)*, the Endangered Species Act (16 U.S.C. §1531 *et seq*), the Civil Rights Act (18 U.S.C. § 241 *et seq*), the Americans with Disabilities Act (42 U.S.C. 12101 *et seq*), the Freedom of Information Act 5 U.S.C. § 552, the WQA (NMSA 1978, Section 74-6-4), the New Mexico State Rules Act (NMSA 1978, Section 14-4-1), and the New Mexico Open Meetings Act (NMSA 1978, Section 10-15-1).

New or amended WQS codified under 20.6.4 NMAC, as adopted by the WQCC, are filed with the State Records Center pursuant to the regulatory provisions under the State's WQA (NMSA 1978, Section 74-6-1 *et seq*.) and the State Rules Act (NMSA 1978, Section 14-4-1 *et seq*.), and in accordance with the State's regulations for rules filed under 1.24.1 NMAC. The new or amended standards become effective for state purposes thirty (30) days after filing.

New or revised surface WQS adopted by the WQCC are certified by the State Attorney General as being duly adopted pursuant to state laws and then submitted by the WQCC to the EPA Region

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6 Administrator. In accordance with the CWA Section 303(c)(3), the EPA Administrator must determine, within sixty days of submission, if the new or amended WQS meet the requirements of the CWA. If the Administrator determines that any such revised or new standard is not consistent with the applicable requirements of the CWA, the Administrator shall notify the State and specify the changes to meet such requirements no later than the ninetieth day after the date of submission. If the State does not remedy the deficiencies, EPA will publish proposed regulations and promulgate a standard to supersede the disapproved State standard.

Establishing or Revising Water Quality Standards through the Triennial Review

Section 303(c)(1) of the CWA requires the State to hold public hearings for the purpose of reviewing WQS including standards that do not include the uses specified in section 101(a)(2) of the Clean Water Act and, as appropriate, amend and adopt standards at least once every three years. This review is referred to as a "Triennial Review." The WQCC conducts a Triennial Review of the State's surface WQS as required by Section 303(c)(1) of the CWA and 20.6.4.10 NMAC. NMED is delegated the responsibility for organizing and presenting the Triennial Review at the required intervals. The general process for establishing or revising water quality standards described above are followed for Triennial Review proceedings.

Establishing or Revising a Designated Use through a Use Attainability Analysis

The process for establishing or revising a designated use occurs through the development of a Use Attainability Analysis (UAA). The UAA is a scientific study that assesses the factors affecting the attainment of a designated use. In accordance with 20.6.4.15 NMAC, the UAA is required to be conducted before a designated use specified in Section 101 (a)(2) of the CWA may be removed or changed to a subcategory requiring less stringent criteria. The uses specified in Section 101(a)(2) of the CWA "provides for the protection and propagation of fish, shellfish, and wildlife, and provides for recreation in and on the water." The established designated uses meeting this goal in the State's WQS include the wildlife habitat use, the primary and secondary contact use, and all aquatic life use subcategories except the limited aquatic life use.

In order for a state to designate a use, or remove a use that is not an existing use, the UAA must demonstrate that attainment of the use is not feasible based on one of the factors identified at 40 CFR 131.10(g):

(1) Naturally occurring pollutant concentrations prevent the attainment of the use; or

(2) Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating State water conservation requirements to enable uses to be met; or

(3) Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place; or

(4) Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use; or

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(5) Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses; or

(6) Controls more stringent than those required by sections 301(b) and 306 [technology-based effluent limitations] of the Act would result in substantial and widespread economic and social impact.

A UAA may be conducted by the Department or, in accordance with Subsection D of 20.6.4.15 NMAC, by any person who submits notice to the Department with intent to conduct a UAA. A UAA must rely on a scientifically defensible method and the result, should it support a designated use change under one of the six factors under 40 CFR 131.10(g), must undergo the same administrative review and hearing process as that for the Triennial Review.

Prior to commencement of any investigation, third-parties seeking to conduct a UAA, shall submit a work plan to the Department and EPA for review. Upon approval of the work plan by the Department, the proponent may then conduct the UAA. Upon completion, data, findings and conclusions will be submitted to the Department and either the proponent or the Department may proceed with the administrative review and hearing process for the designated use change. As with the Triennial Review process, the change shall not be considered effective for State purposes until approved by the WQCC and published with an effective date in the New Mexico Register. For CWA purposes, the designated use change shall only be considered effective following EPA review and approval process described above.

For a designated use change that is being proposed based on evidences of the natural, ephemeral, intermittent or low flow conditions as identified under 40 CFR 131.10(g)(2), the *Hydrology Protocol* method under Appendix C of this WQMP/CPP is recommended. The *Hydrology Protocol* was designed as a multi-parameter evaluation to determine the natural hydrologic conditions of a waterbody and the associated designated uses that should be attainable. For studies investigating a possible designated use change due to hydrologic conditions under 40 CFR 131.10(g)(2), consideration must be taken for any supplemental flows attributed to permitted effluent discharges.

Existing uses, defined in the WQS as "a use actually attained in a surface water of the state on or after November 28, 1975, whether or not it is a designated use", may not be removed regardless of the outcome of a UAA unless a use with more stringent criteria is added. (40 CFR 131.10(h) and Subsection A of 20.6.4.15 NMAC).

Establishing or Revising a Designated Use using the *Hydrology Protocol*

There are three primary types of hydrologic conditions defined under the WQS in New Mexico, each of which has established designated uses for protections under Section 101(a)(2) of the CWA. These include listed ephemeral waters (20.6.4.97 NMAC), general intermittent waters (20.6.4.98 NMAC), and general perennial waters (20.6.4.99 NMAC). In addition, the State's WQS also identify many classified waters by their hydrology, e.g., "perennial tributaries to" or "perennial reaches of" (20.6.4.101 to 899 NMAC).

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The *Hydrology Protocol,* attached as Appendix C, is primarily used to provide scientific technical support for a designated use change through a UAA based on natural, ephemeral, intermittent or low flow conditions or water levels that prevent the attainment of the designated use. Since the *Hydrology Protocol* is done in support of a UAA, it can be conducted either by the Department, or by an entity other than the Department. If an entity other than the Department conducts this type of analysis, a UAA workplan for the use of the *Hydrology Protocol* must be submitted to the Department for review and approval in accordance with Subsection D of 20.6.4.15 NMAC before proceeding with the survey.

For waterbodies that are classified under 20.6.4.101 to 899 NMAC, the State asserts protections for these waters under the classified segment. A survey using the *Hydrology Protocol* can be used to confirm or delineate segment-specific hydrological regimes that may or may not lead to a revision to the State's WQS. For example, numerous classified segments in the WQS include only perennial waters, without specifically identifying which reaches are perennial (e.g., "perennial reaches of…", "perennial tributaries to…"). In such cases, the *Hydrology Protocol* can be used to determine whether a waterbody in whole, or a segment of the waterbody is perennial and therefore included in the classified segment, or non-perennial and therefore subject to the designated uses and criteria for general non-perennial waters in 20.6.4.98 NMAC. Such determinations do not require a UAA or a hearing because they do not change the designated uses or criteria but merely allow for the applicable uses to be properly identified. However, if a revision to incorporate the results of the *Hydrology Protocol* survey are needed to further refine, delineate or re-classify a waterbody under 20.6.4.101 to 899 NMAC this must be done through the UAA process.

For waterbodies that are perennial but have not been classified under 20.6.4.101 to 899 NMAC, the State asserts perennial protections for these waters under 20.6.4.99 NMAC. A survey using the *Hydrology Protocol* may be used to verify the hydrological regime for these unclassified perennial waters. A revision to incorporate the results of the *Hydrology Protocol* survey to classify a waterbody under 20.6.4.101 to 899 NMAC is done through the UAA process.

For the waterbodies in the State that are non-perennial but have not undergone an in-depth investigation to determine the hydrologic regime (i.e., intermittent, ephemeral), the State asserts intermittent protections for these waters under 20.6.4.98 NMAC, consistent with the goals in Section 101(a)(2) of the CWA. If the results of the *Hydrology Protocol* survey indicate that the waterbody is in fact intermittent, no further action is required because it is protected, by default, under 20.6.4.98 NMAC for intermittent waters.

For those cases in which the results of the *Hydrology Protocol* survey demonstrate that an unclassified non-perennial waterbody is ephemeral, designated uses that are not existing uses may only be changed if a UAA is conducted according to 40 CFR 131.10(g) and 20.6.4.15 NMAC in order for the State to assert protections for the ephemeral waterbody under 20.6.4.97 NMAC.

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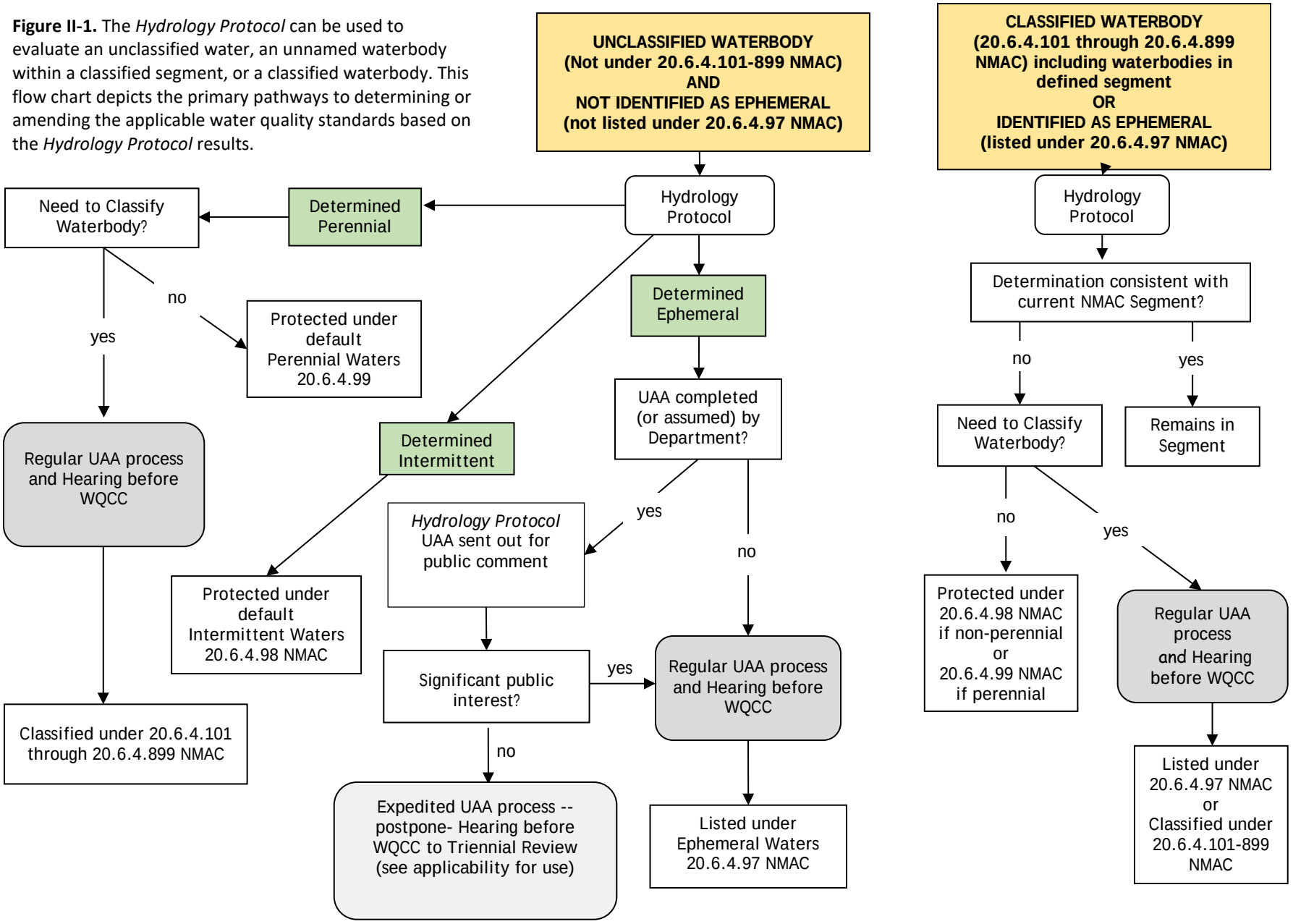
In some cases, an expedited UAA process outlined under Subsection C of 20.6.4.15 NMAC and illustrated in Figures II-1 and II-2 may be pursued. The expedited UAA process is not applicable for entities other than the Department. However, this does not preclude third-parties from developing and executing a workplan for the use of the *Hydrology Protocol* and submitting the UAA to the Department for use in the expedited process. The expedited UAA process facilitates the efficient application of the limited aquatic life and secondary contact uses to ephemeral waters where appropriate. As described under Subsection C of 20.6.4.15 NMAC, it is the Departments' role and responsibility to post the use attainability analysis on its water quality standards website, notify its interested parties of a 30-day public comment period, submit to EPA and if given technical approval, petition and testify regarding the standards changes before the WQCC periodically.

The *Hydrology Protocol* can also be used to support other factors under 40 CFR 131.10(g), such as those attributed to hydrological modifications, and provide additional evidence that "it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use." 40 CFR 131.10(g)(4).

Persons or entities proposing to conduct a UAA using the *Hydrology Protocol* must submit a UAA workplan for the use of the *Hydrology Protocol* to the SWQB for review and approval before proceeding (Subsection D of 20.6.4.15 NMAC). Such an approach will help ensure that the *Hydrology Protocol* and UAA process proceed smoothly, without delay, and that the study will comply with applicable statutes and rules.

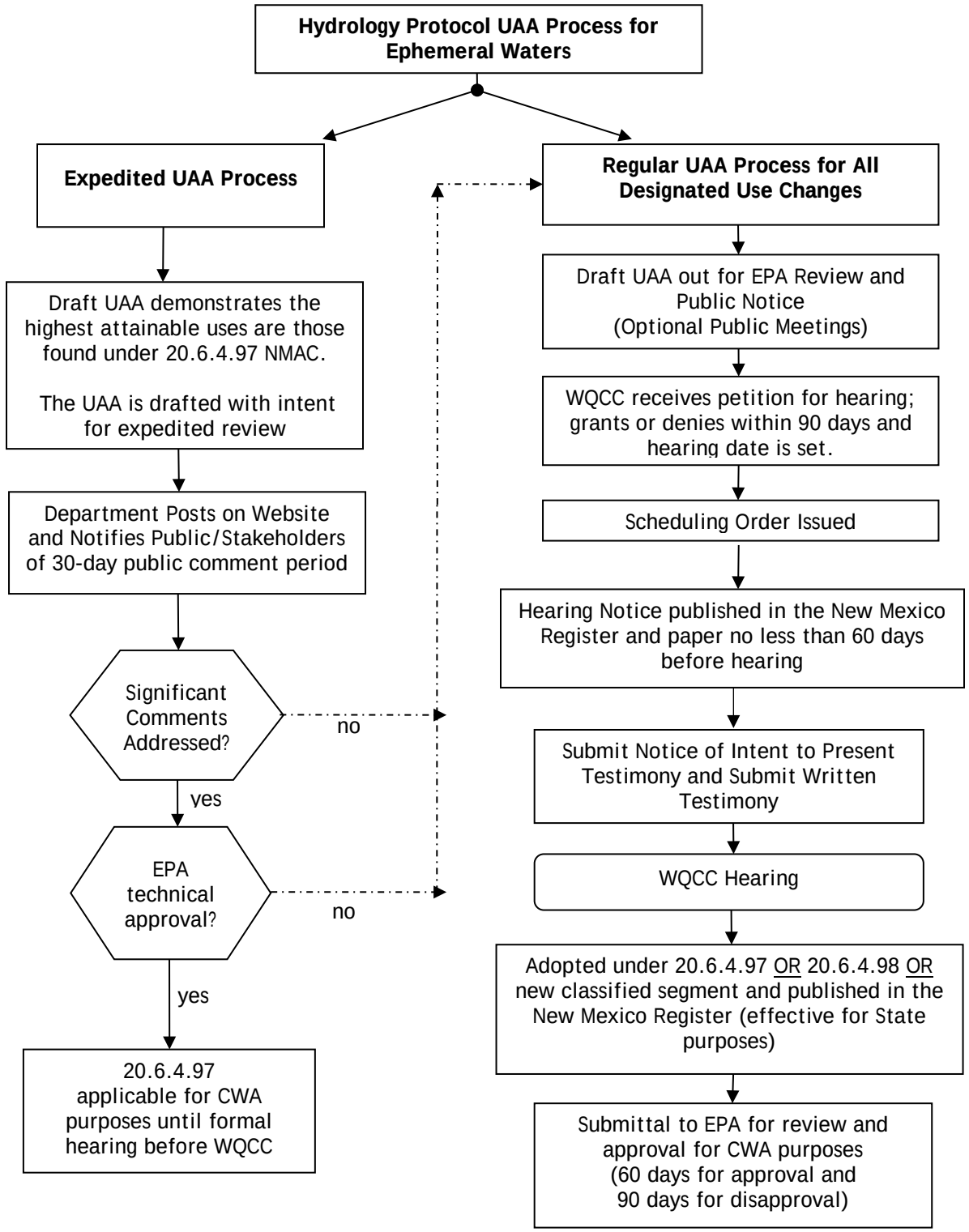
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Figure II-1. The *Hydrology Protocol* can be used to evaluate an unclassified water, an unnamed waterbody within a classified segment, or a classified waterbody. This flow chart depicts the primary pathways to determining or amending the applicable water quality standards based on the *Hydrology Protocol* results.



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Figure II-2. Flow chart compares the expedited UAA process for an ephemeral stream determined through a hydrology protocol with the UAA process.



Establishing or Revising a Site-Specific Standard

In accordance with 20.6.4.10 NMAC, there are circumstances such as species sensitivity; site specific physical, chemical or biological conditions that alter bioaccumulation of a chemical; or natural background concentrations that exceed a particular numeric criterion for an established designated use that warrants inclusion or updating due to site specific conditions. The commission may adopt site-specific numeric criteria based on relevant site-specific conditions pertaining to those conditions listed under 20.6.4.10(D)(1).

Any person may petition the commission to adopt site-specific criteria, giving a thorough explanation of the rational for the proposal that justifies the proposed criteria and relying on scientifically defensible methods that demonstrate the site-specific criteria fully protects the designated use, such as those listed under Subsection D(4) of 20.6.4.10 NMAC. In the same process for establishing or revising designated uses for waterbodies, establishing site-specific standards requires the petitioner (the State or other party) to submit demonstration of the supporting evidence for the standard. The process to petition for a site-specific criteria is a rulemaking under 20.6.4 NMAC and requires adherence to rulemaking processes by the WQCC under 20.1.6 NMAC.

Process for Establishing or Revising a Temporary Standard

When a waterbody has been determined to have the appropriate designated use, but specific limiting conditions prevent the attainment of that use in the short-term, the WQCC may adopt a temporary standard. A temporary standard is a time-limited designated use and criterion for a specific pollutant(s) or water quality parameter(s) that reflects the highest attainable condition during the term of the temporary standard. A temporary standard is a change in a designated use, and therefore, must be adopted by the WQCC and EPA under rule-making procedures, just as with any other water quality standard amendment. A temporary standard may be granted if the petitioner can meet the applicability and demonstration requirements identified under 20.6.4.10(F) NMAC. .

Water Quality Standards for Wetlands

Wetlands in New Mexico are protected as "surface waters of the state." However, wetland-specific designated uses and criteria associated with those uses have not been developed. Wetlands designated and protected as ONRWs are identified in the *Maps and List of Wetlands Within United States Forest Service Wilderness Areas Designated as Outstanding National Resource Waters* (Subsection D(3)(h) of 20.6.4.9 NMAC). Other wetlands not identified as ONRWs and not identified as a classified water in sections 20.6.4.101 through 20.6.4.899 NMAC are protected through the designated uses identified in 20.6.4.98 and 20.6.4.99 NMAC, depending on their hydrology.

SWQB is working toward increasing wetlands protection through monitoring and strengthening WQS that pertain to the State's wetlands resources. To achieve these goals the SWQB is currently:

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- developing a Rapid Assessment Methodology for New Mexico (NMRAM) for a range of environments and wetland types;
- mapping wetland resources in New Mexico; and,
- ranking the condition of existing wetlands.

SWQB will utilize the information gathered from the monitoring effort to propose wetland-specific state WQS to the WQCC. This information and data will also be used to assess the effectiveness of wetland restoration and mitigation activities.

E. Process for Assuring Adequate Implementation of Water Quality Standards

[As required by 40 CFR 130.5(b)(6) for CPP]

NMED, acting under the authority delegated by the WQCC, implements the WQS by establishing and maintaining controls on the discharge of point source and non-point source pollutants to surface waters of the state. This occurs through ongoing monitoring and assessment of water quality to the State's approved WQS (*see* Section III of this WQMP/CPP); evaluation of proposed discharges in accordance with the Implementation Plan described at Subsection B of 20.6.4.8 NMAC and the State's *Antidegradation Policy Implementation Procedure* (Appendix A of this WQMP/CPP); establishment of controls on point source pollutant discharges as described under Section V of this WQMP/CPP; and through Best Management Practices (BMPs) applied to nonpoint sources of pollution, as outlined under the State's Nonpoint Source Management Program (NPSMP) and Section VII of this WQMP/CPP. Violations of the WQS are enforceable through civil and/or criminal actions pursuant to the WQA at NMSA 1978, Section 74-6-10.

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III. SURFACE WATER QUALITY MONITORING, ASSESSMENT & REPORTING

Monitoring, assessment, and reporting are ongoing throughout the state. This WQMP/CPP relies upon these activities to identify priorities and recommend control measures.

A. Monitoring

Monitoring of surface water quality is an important component of the State's Water Quality Management Program and is essential to identify and characterize water quality problems, revise WQS, and develop and evaluate the results of control actions. Additionally, water quality monitoring data can be used for pollutant allocation computer modeling and as evidence for enforcement actions. The goal of the Monitoring Program is to provide information to assess the quality of surface waters and direct water quality management activities. The surface water monitoring strategy implemented by SWQB focuses on collecting chemical, physical, and biological data from rivers, streams, lakes, reservoirs, and other aquatic habitats. The comprehensive strategy is described in the *State of New Mexico Surface Water Quality 10-Year Monitoring and Assessment Strategy* (NMED SWQB 2016 or most current revision). In the last major revision to the *Strategy*, the state incorporated wetlands monitoring and assessment. The monitoring goal of the New Mexico Wetlands Program is to provide the information and data necessary to create a baseline inventory and condition of existing wetlands, facilitate wetland protection, develop WQS for wetlands, assess wetland mitigation activities, and monitor wetland restoration activities for efficacy.

The monitoring strategy establishes methods of identifying and prioritizing water quality data needs, specifies procedures for acquiring and managing water quality data, and describes how these data are used toward three basic monitoring objectives. These objectives include conducting water quality assessments, developing water quality-based controls to minimize pollutants, and evaluating the effectiveness of such controls. From approximately 1998 to present, the SWQB has primarily utilized a rotating basin system approach to water quality monitoring similar to several other states. Using this approach, a select number of watersheds are monitored for two years with an approximate return frequency of eight to ten years depending on available staff, watershed conditions, and financial resources. SWQB will continue to pursue additional funding to increase the frequency of monitoring in New Mexico's surface waters. The rotating basin strategy is supplemented with other data collection efforts and external data sources that meet SWQB's quality assurance and quality control requirements.

The SWQB has established sampling and analytical techniques under 20.6.4.14 NMAC and maintains a Quality Management Plan (QMP), Quality Assurance Project Plans (QAPPs), Field Sampling Plans (FSPs) and Standard Operating Procedures (SOPs) that cover all monitoring activities. The Bureau's QMP and QAPPs must be approved by EPA prior to work being conducted under them. The QAPPs and SOPs are key elements in implementing this WQMP/CPP. SWQB staff conducting activities specified in the QAPP and SOPs must sign acknowledgement pages indicating they are familiar with the processes outlined in the document and will adhere to its procedures.

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B. Assessment

Assessment is the process by which water quality data are analyzed to determine if WQS are being attained. Assessments are based on surface water quality data collected by the SWQB and also by other federal, state, and local agencies and groups, when available. All data used for assessment must meet the Bureau's quality assurance and quality control requirements.

Water quality data are assessed every other year according to the most recent version of the Comprehensive Assessment and Listing Methodology (CALM) and associated appendices, which are reviewed and updated as appropriate. The water quality assessment results are then used as a basis for water quality management decisions, such as:

- Determining whether proposals to make changes to the standards are needed;
- Identifying the need for water quality-based effluent limitations in NPDES permits;
- Conducting an antidegradation review of proposed new or increased permitted discharges as prescribed in the *Antidegradation Policy Implementation Procedure*, found in Appendix A of this WQMP/CPP;
- Developing TMDLs that identify pollutant reduction targets designed to improve water quality and meet standards;
- Developing source water protection plans designed to reduce pollutants and provide safe drinking water quality;
- Determining efficacy of projects for watershed protection and restoration under Section 319 of the CWA; and,
- Certifying federal permits under Section 401 of the CWA.

C. Reporting

The CWA has two primary requirements for reporting water quality in a state: The "303(d) List," and the "305(b) Report." These requirements have been combined into the *State of New Mexico CWA §303(d)/§305(b) Integrated Report* (IR; NMED SWQB 2018, or most recent approved version), which is incorporated into this WQMP/CPP by reference. The IR is designed to satisfy the statutory requirements of Section 303(d), Section 305(b), and Section 314 of the CWA, and must be approved by the WQCC and EPA. The two elements are described below. An explanation of assessment and listing methods, as well as definitions of Integrated Reporting categories, can be found in the current version of the CALM, available at: https://www.env.nm.gov/surface-water-quality/calm/.

303(d) List

Section 303(d) of the CWA requires states to submit to EPA a list of water bodies that do not meet applicable WQS. Waterbodies and segments are included on the 303(d) list of impaired waters, based on an evaluation of biological, chemical and/or physical data that demonstrate nonattainment of applicable numeric or narrative standards resulting in designated use impairment. Once a water body is listed as impaired, several management decisions can be made to improve water quality including development of TMDLs or watershed-based plans (WBPs); proposing changes to the standards; identifying appropriate effluent limits in NPDES permits; and prioritizing where restoration projects should be implemented. If the data indicate that a

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previously impaired stream segment is meeting applicable WQS, the waterbody would be delisted, i.e., removed from the 303(d) list.

305(b) Report

Section 305(b) of the CWA requires states to prepare and submit a report biennially to EPA on the status of water quality within the state. The report provides an assessment of water quality in a state, a summary of water quality management programs, and an estimate of the environmental, social, and economic impacts associated with achieving the objectives of the CWA. EPA uses the information contained in the Section 305(b) Report to update the U.S. Congress on: progress toward meeting the goals of the CWA; the costs and benefits of working towards these goals; program plans and needs in areas such as permits, grants, effluent guidelines, etc.; and mechanisms to implement needed changes.

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IV. TOTAL MAXIMUM DAILY LOADS (TMDLs)

[As required by 40 CFR 130.6(c)(1) for WQMP]

A. Background

Pursuant to Section 303(d) of the CWA, TMDLs or TMDL alternatives must be developed for water quality limited segments (also known as "impaired" waterbodies). Water quality limited segments are those segments where water quality does not meet, or is not expected to meet, applicable WQS. TMDLs are established on a pollutant by pollutant basis for each assessment unit or watershed. A TMDL establishes the amount of a pollutant a waterbody can assimilate without causing a violation of WQS. The target load is generally determined by multiplying the applicable water quality criterion by the critical flow and a pollutant-specific conversion factor.

Per 40 CFR §130.2(i), TMDLs are the sum of the following three components: 1) the individual Waste Load Allocations (WLA) for point sources; 2) the Load Allocations (LA) for nonpoint sources and background conditions; and 3) the Margin of Safety (MOS) to account for uncertainty:

$$TMDL = \Sigma WLA + \Sigma LA + MOS$$

Where Σ= sum

In practical terms, a TMDL is a water quality planning document that establishes specific goals to meet surface WQS. Once the required TMDL calculations are documented, probable sources of pollutants are examined, and a brief outline of a potential implementation plan is described.

B. TMDL Prioritization

From 1997 to 2007, the development of TMDLs was prioritized according to the terms and schedule set forth in a consent decree and settlement agreement negotiated between EPA and Forest Guardians/Southwest Environmental Center. The consent decree TMDLs have been completed, and the consent decree was dismissed in 2009.

Following completion of the settlement agreement schedule, SWQB prioritizes TMDL development based on the results of ongoing monitoring and assessment. SWQB developed the *Prioritization Framework and Long-Term Vision for Water Quality in New Mexico* (NMED SWQB 2015a), and as a result the TMDL program in New Mexico was revised to allow a greater focus on state water quality priorities, encourage TMDL alternatives, and emphasize the value of protecting waterbodies that are not impaired. Additionally, SWQB will develop TMDLs as outlined under the current Section 106 and 604(b) of the CWA work plans. TMDLs may also be developed, reviewed, and updated in response to changed conditions, new data, or revised standards.

C. Process for TMDL Development

[As required by 40 CFR 130.5(b)(3) for CPP]

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TMDLs are incorporated into the WQMP/CPP upon approval by EPA. The process SWQB uses for developing a TMDL is as follows:

- Develop a list of Category 5 assessment units and pollutants from the most recent *State of New Mexico CWA §303(d)/§305(b) Integrated Report* . Identify those Category 5 assessment units that may be candidates for TMDL alternatives, such as a Watershed Based Plan.
- Collate all existing and readily available data necessary to draft TMDLs, including field and laboratory data (chemical, physical and biological) from the assessment process, and critical flow data. In addition, identify point sources covered by individual and general NPDES permits, NPDES permit numbers, and expiration dates.
- Plan a sampling effort to collect any additional data that are needed.
- Draft the TMDL document; solicit and incorporate comments from SWQB, NMED Office of General Counsel, and EPA staff.
- Conduct public participation for the TMDL in accordance with Section XIV of the WQMP/CPP. This includes a public comment period of at least 30 days. SWQB issues a public notice for distribution via email and the SWQB website. The public notice must include:
    - a description of the watershed and parameters for which the TMDL is proposed;
    - a brief explanation of the TMDL;
    - the start and end dates of the public comment period;
    - how and where to submit comments for inclusion in the record;
    - a description of the process for requesting approval of the TMDL before the WQCC;
    - how to obtain a copy of the TMDL document or request additional information;
    - the location, date, time, purpose, and format of any proposed public meeting or other forum for obtaining information;
    - contact information for persons with disabilities to obtain assistance in participating in the public process.
- After the public comment period closes, collate all comments, prepare a response to comments, and make appropriate changes to the draft TMDL based on those comments. The response to comments is added as an appendix to the draft TMDL and provided to those stakeholders who submitted written comments.
- Post the final draft TMDL on NMED website no less than 10 days before the WQCC meeting.
- Present the final draft TMDL at a WQCC meeting and request approval. WQCC comments are incorporated into the TMDL as necessary.
- Following adoption by the WQCC as an amendment to Appendix B of the WQMP/CPP, submit the TMDL to EPA Region 6 for approval. The submittal to EPA shall be certified by the Governor or the Governor's designee (e.g., NMED Secretary) that the WQMP/CPP update is consistent with all other parts of the plan as required by 40 CFR 130.6(e).

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- Post the approved TMDL document, the response to comments, the WQCC approval document, and EPA approval document on SWQB's website, and update the administrative record accordingly.
- Update Appendix B of this WQMP/CPP to include the approved TMDL. (Available at https://www.env.nm.gov/surface-water-quality/wqmp-cpp/)

TMDLs may be revised as necessary, following the process outlined above, based on changes to WQS or other factors influencing the TMDL calculation or distribution between the WLA and LA in the TMDL. TMDLs may be removed from the WQMP with WQCC approval if the waterbody is no longer impaired and meets the requirements for TMDL removal.

D. TMDL Implementation

As TMDLs are developed and approved, they are incorporated into Appendix B-1 of this WQMP/CPP and used as the basis for implementation of water pollution control activities. For point sources, TMDLs are implemented through NPDES permits (see Section V), whereas for nonpoint sources, TMDLs are implemented through the Nonpoint Source Management Program (NPSMP; see Section VII).

Point Sources

The process for incorporating WLAs as individual effluent limitations in NPDES permits is described in Section V.B of this WQMP/CPP.

Nonpoint Sources

The NPSMP seeks voluntary solutions to address nonpoint source water quality problems and provides funding opportunities for implementation projects. The NPSMP, funded through Section 319 of the CWA, prioritizes watershed-based planning and on-the-ground implementation projects where TMDLs have been developed. Priority watersheds for watershed-based planning are defined in the current NPS management plan as 12-digit hydrologic unit codes (HUCs, or watersheds) (see https://www.env.nm.gov/surface-water-quality/nps-plan). The large majority of these priority watersheds are where TMDLs have been developed. Watershed-based plans (WBPs) are, in essence, TMDL implementation plans (US EPA 2013). Completed WBPs are available at https://www.env.nm.gov/surface-water-quality/accepted-wbp/.

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V. EFFLUENT LIMITATIONS

[As required by 40 CFR 130.6(c)(2) for WQMP]

A. Introduction

The primary mechanism for controlling point source discharges to "waters of the United States" (as defined under 40 CFR 122.2) in New Mexico is the NPDES permit program established under Section 402 of the CWA. The State of NM is not currently delegated authority for issuing NPDES permits; therefore, EPA Region 6 is the permitting authority responsible for issuing NPDES permits in New Mexico and specifying the amount and concentration of pollutants (i.e. effluent limitations) that a permittee may discharge to a surface water. The permitting authority is also responsible for the enforcement of effluent limitations stipulated by NPDES permits.

Two types of effluent limitations are developed by EPA for NPDES permits: technology based effluent limitations (TBELs) and water quality-based effluent limitations (WQBELs). TBELs are defined in federal regulations and are applicable across a category of effluent discharge. The applicability of effluent limitations is summarized in Table V-1.

Table V-1. Effluent Limitations for NPDES Permits

Technology Based		Water Quality Based	
Publicly Owned Treatment Works (POTWs) – Secondary Treatment (40 CFR 133)	Industry – Effluent Limitation Guidelines (40 CFR Subchapter N, or Best Professional Judgment (BPJ))	WLA from approved TMDL	If there is no TMDL or WLA, a WQBEL may be developed on a case by case basis to protect water quality
Additional State-adopted control strategies for protection of public health or environment		WQBELs may be expressed as chemical specific limitations (e.g., phosphorus), narrative limitations (e.g., visible sheen, BMPs, etc.), or as whole effluent toxicity requirements (e.g., biomonitoring).	

Federal regulations require that NPDES permits include TBELs and other necessary effluent limitations for toxic pollutants and sewage sludge. EPA is responsible for development and promulgation of TBELs pursuant to Sections 301, 304, 306, 307, and 316 of the CWA. Federally promulgated TBELs for each industry are published by EPA in 40 CFR Chapter I Subchapter N - *Effluent Guidelines and Standards*. If TBELs have not been established by regulation for a particular industry, a permit writer may establish effluent limitations based on "best professional judgment" with the rationale should be documented in the permit's fact sheet (major facilities) or statement of basis (minor facilities).

If TBELs are not adequate to protect applicable WQS, then NPDES permits must contain WQBELs (40 CFR 122.44(d)). WQBELs may be calculated as part of a WLA in a TMDL (see Section IV) and

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incorporated into an NPDES permit; WQBELs may be based on reasonable potential calculations drafted by EPA; or WQBELs may be based on an antidegradation review in accordance with the *Antidegradation Policy Implementation Procedure* in Appendix A of this WQMP/CPP. EPA will evaluate all three scenarios and, in coordination with NMED through the 401 Certification process, choose the most protective effluent limitation.

If a WLA has been developed in a TMDL, the permitting authority is required to incorporate it into the NPDES permit. A TMDL details the assumptions and processes used to develop the WLA. EPA's Technical Support Document (TSD) procedures should be used by the permitting authority to incorporate the WLA into the NPDES permit. However, if no TMDL has been established, the permitting authority reviews effluent discharge data to ensure that NPDES permits are protective of WQS. For all pollutants that have a reasonable potential to cause or contribute to a violation of a water quality standard, the permitting authority performs calculations or modeling to determine effluent limitations for those pollutants. This review is done in accordance with applicable federal regulations and guidance. Specific evaluations for NPDES permits issued in New Mexico are discussed in the EPA Region 6 document *Procedures for Implementing NPDES Permits in New Mexico* (NMIP) developed by EPA in consultation with NMED.

In addition, the WQCC previously adopted additional control strategies for the protection of public health and the environment. This strategy was originally adopted by the WQCC in 1989 in the WQMP's Work Element 6 and retained in the 2002 WQMP update in Work Element 2. In the 2011 update, the previously included fecal coliform limitation of 500 colony forming units (cfu)/100 milliliters (mL) was dropped because the WQS now apply *E. coli* bacterial criteria to all waters. These strategies are as follows:

- NMED will review NPDES permit actions for purposes of state certification in accordance with Section 401 of the CWA, WQA NMSA 1978, 74-6-5(E), and 20.6.2.2001 NMAC. NMED will assure through appropriate review and communication with the permitting authority that permit requirements and effluent limitations are compatible with appropriate state law, protect WQS and implement this WQMP/CPP.

- NMED will use a pH limitation of 6.0-9.0 for state certifications of NPDES permits except when:
    a. more stringent effluent limitations are needed to meet the antidegradation policy and implementation plan of the New Mexico WQS, (20.6.4 NMAC);
    b. the WQCC has adopted a more stringent effluent limitation in a point source WLA.

  In all cases, state-certified effluent limitations for pH shall be stringent enough so that receiving waters meet WQS.

For effluent discharges that are not addressed by an NPDES permit or that are in extended violation of an NPDES permit, Sections 20.6.2.2100 through 2102 NMAC of the *Ground and*

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Surface Water Protection regulations specify additional effluent limitations for the protection of surface water quality.

Compliance schedules for NPDES permits are allowed by 20.6.4.12 NMAC and 40 CFR 122.47. Compliance schedules are established by EPA per the NMIP. Compliance schedules may be included in NPDES permits at the time of renewal or modification and are written to require compliance at the earliest practicable time. Compliance schedules include milestone dates and provisions for submitting progress reports and a final report detailing activities conducted toward meeting compliance schedule provisions. Other uses of compliance schedules by the NPDES permitting authority may also be allowable.

The permitting authority may not issue an NPDES permit that is in conflict with this WQMP/CPP (40 CFR 130.12(a)). Effluent limitations, including WQBELs and compliance schedules where applicable, are contained in NPDES permits, which can be viewed at: https://www.env.nm.gov/surface-water-quality/npdes-permits/.

B. Process for Development and Certification of Effluent Limitations and Schedules of Compliance for NPDES Permits

[As required by 40 CFR 130.5(b)(1) for CPP]

As the current NPDES permitting authority for NM, EPA Region 6 develops effluent limitations and schedules of compliance in accordance with the NMIP, which is based on applicable federal regulations and guidance. NPDES permits may not be issued until the State is provided an opportunity to review and certify the permit. The WQA assigns the responsibility for certifying permits issued under the CWA to NMED (NMSA 1978, Section 74-6-4(F)), and also specifies the conditions under which a certification shall be denied (NMSA 1978, Section 74-6-5(E)). NPDES regulations at 40 CFR § 124.53(e) require that state certification shall include conditions which are necessary to assure compliance with the applicable provisions of CWA and appropriate requirements of state law. For each more stringent condition, NMED must cite WQA or State law references upon which the condition is based. Failure to provide such a citation waives the right to certify (and require) the condition.

Section 20.6.2.2001 NMAC of the *Ground and Surface Water Protection* regulations sets forth procedures for state certification of NPDES permits. The procedures specify public notice requirements, a public comment period, the content and distribution of a certification or denial, timeframes, and appeal requirements. NMED also evaluates outreach needs for the affected community during the process of permit reissuance and evaluates the need for document translation and other access needs during the public comment period. A public involvement plan (PIP) will be developed for each action and a link posted on NMED's website. If an affected party or the public needs additional assistance to participate in the permitting process, they must make the request to the Point Source Regulation Program Manager - contact information is listed at: https://www.env.nm.gov/surface-water-quality/point-source-regulation-section/.

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C. Incorporating TMDL Waste Load Allocations into NPDES Permits

Pursuant to 40 CFR 130.12(a), NPDES permits must be consistent with the WQMP. Each NPDES permit issued must contain requirements necessary to achieve WQS (40 CFR 122.4(d)). Therefore, where a WLA has been assigned through the TMDL process, the WLA must be incorporated into the permit as specific effluent limitations. All WLA (original and revised) are documented in Appendix B-2 of this WQMP/CPP.

If an application for a new or revised permit is received for a discharge into an impaired waterbody with an approved TMDL but with no previously developed WLA, the permit may be issued without revision of the TMDL provided the discharge is at or less than the in-stream TMDL target concentration. In the case of a new permit, the WLA will be calculated using the TMDL target concentration and applicable flow value as specified in EPA's NMIP. In the case of a revised permit for which there is already an existing WLA but there has been a change to the design flow, the TMDL will be revised to include a revised WLA calculated using the TMDL target concentration and the change in design or production flow. In the case of a new or revised stormwater WLA, the jurisdictional area approach will be used to calculate the WLA unless another method is determined to be more appropriate. All new and revised WLA will be tracked in Appendix B-2 of this WQMP/CPP and the associated TMDL will be revised during the next scheduled TMDL development.

D. Process for Determining the Priority of Permit Issuance

[As required by 40 CFR 130.5(b)(9) for CPP]

As the current permitting authority for New Mexico, EPA Region 6 determines the priority of NPDES permit issuance.

E. Process for Deriving WQBELs based on Narrative Standards in NPDES Permits

[As required by 40 CFR 130.5(b)(1) for CPP]

EPA derives numeric permit limitations from effluent limitations guidelines in the federal regulations at 40 CFR 405 through 471, or from numeric WQS at 20.6.4 NMAC. New Mexico also has narrative water quality standards at 20.6.4 NMAC, but because of the difficulty of deriving permit limits from narrative standards, this issue has largely been unaddressed. However, circumstances may arise that require narrative standards to be addressed in NPDES permits due to the issuance of a TMDL or the presence of a 303(d) impairment in the facility's receiving water.

Nutrients

There are no technology-based effluent limits for nutrients in EPA's *Effluent Guidelines and Standards* in the code of federal regulations (40 CFR Ch. 1 Sub. N), which has resulted in much discussion nationwide about the process for incorporating nutrient limits into NPDES permits. SWQB's listing methodology uses thresholds to determine what background levels of nutrients are expected in a healthy, reference stream. Consequently, these thresholds are also used in TMDL development, which has led to stringent effluent limitations in NPDES permits. The WQS

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have provisions for temporary standards, or Use Attainability Analyses, but these tools may not apply in some situations.

When SWQB reviews draft permits in accordance with the 401 Certification process, the approach that will be taken with respect to nutrient effluent limitations is the following:

- When an impairment exists in the waterbody without a TMDL and there are no data, SWQB will first require monitoring of effluent to collect nutrient data.

- When an impairment exists in the waterbody without a TMDL and there are available effluent data, SWQB will analyze the effluent data to determine an effluent limit that will be protective of the receiving waterbody based on the frequency of collection and confidence of the data. This approach is consistent with Tier One protection of SWQB's antidegradation policy, which states that no further degradation of existing water quality is permitted in a surface water where the existing water quality does not meet applicable WQS.

SWQB will evaluate other methods for deriving numeric nutrient limits as necessary.

TDS Salinity

As outlined in the Colorado River Salinity Control Forum, SWQB will adhere to the monitoring frequency outlined in that document for both municipal and industrial facilities.

Other Narrative Standards

As future numeric translators are developed, SWQB will utilize those translators as appropriate to evaluate protective water quality-based effluent limitations in the appropriate NPDES permits.

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VI. MUNICIPAL AND INDUSTRIAL WASTE TREATMENT

[As required by 40 CFR 130.6(c)(3) for WQMP]

A. Clean Watersheds Needs Survey

Every four years EPA conducts the Clean Watersheds Needs Survey and submits a report to Congress in compliance with Section 516 of the CWA. The report is a comprehensive assessment of the capital needs to meet the water quality goals set in the CWA. The states and EPA collect information about publicly owned wastewater collection and treatment facilities; stormwater and combined sewer overflows control facilities; nonpoint source pollution control projects; and decentralized wastewater management.

The State of New Mexico participates in these surveys by collecting information and submitting it to EPA. The current version of the report is available at: http://www.epa.gov/cwns/.

B. Clean Water State Revolving Fund

The CWA, as amended in 1987, authorized EPA to make capitalization grants to the states to establish revolving loan funds with the condition that the states make 20% matching contributions. The Clean Water State Revolving Fund (CWSRF) provides affordable loans for the construction of wastewater treatment facilities and other water quality projects to prevent or abate water pollution. CWSRF monies can also be used for nonpoint source control (see Section VII). Combination loan/grants are available for projects that meet the criteria described in the CWSRF regulations. A portion of the available CWSRF funding may be targeted for projects that support green infrastructure, water or energy efficiency, and environmentally innovative projects.

NMED's CPB administers the loan program under 20.7.5, 20.7.6 and 20.7.7 NMAC and WQA NMSA 1978, Sections 74-6A-1 to 74-6A-15. In the 2018 session of the New Mexico Legislature, the CWSRF authorizing state statute (Wastewater Facility Construction Loan Act, WQA NMSA 1978, Sections 74-6A-1 to 15) was amended to expand the types of eligible projects and borrowers to bring it into alignment with the CWA and the 2014 Water Resources Reform and Development Act. The 2018 statutory change affected 20.7.5.6 NMAC and was therefore amended by the WQCC in August of 2018. The remaining NMAC sections are planned to be administratively amended within a year of approval of this document.

C. Process for Priority Rating of Wastewater Construction Loans Projects and Management of the Priority List

[As Required by 40 CFR 130.5(b)(8) for CPP]

As part of its administration of the CWSRF program, CPB follows a priority rating system compliant with 40 CFR 35.2015. The Priority Rating System Guidance document is available on CPB's website at: https://www.env.nm.gov/construction-programs/clean-water-state-revolving-fund-cwsrf/. The document establishes a systematic, fair and consistent approach for ranking

funding applications. The results of each application cycle are published on the website above as the Integrated Project Priority list and the corresponding Intended Use Plan.

The priority rating process is summarized as follows:

- Determine the time frame for opening the priority list per federal requirements.
- Send out an invitation to eligible entities to apply.
- Receive applications.
- Review the applications for eligibility.
- Inform applicants if they are not eligible for the CWSRF and if they may be eligible for other funding programs.
- Perform a technical review of each application using the Priority Rating System.
- Compile the CWSRF Integrated Projects Priority List.
- Prepare the draft Intended Use Plan that identifies the intended uses of the CWSRF and describe how those uses support the goal of the fund and incorporates the Integrated Projects Priority List.
- Publish the draft Intended Use Plan and associated Integrated Projects Priority List on its website at: https://www.env.nm.gov/construction-programs/clean-water-state-revolving-fund-cwsrf/ for public comment.
- Submit the draft Intended Use Plan to EPA for comment and approval.

CPB reviews the Priority Rating System periodically and proposes any amendments deemed necessary for effective program implementation. Any revisions to the Priority Rating System are presented to WQCC for approval. The amended system must then be approved by EPA.

As part of the funding process, CPB reviews preliminary engineering reports or technical memorandum for projects requesting CWSRF funding. CPB follows USDA Guidance 1780-2 for preliminary engineering reports.

D. Rural Infrastructure Revolving Loan Program

The New Mexico Rural Infrastructure Act (NMSA 1978, Sections 75-5-1 to -6) created the Rural Infrastructure Revolving Loan Program (RIP) in 1988. The purpose of the RIP is to provide financial assistance to local authorities for the construction or modification of water supply facilities. The Rural Infrastructure Act was amended in 2001 to include construction or modification of wastewater facilities and solid waste facilities.

Any incorporated city, town, village, mutual domestic association, or water and sanitation district whose water supply facility serves a population of less than twenty thousand persons or a county that serves a population of less than two hundred thousand may be eligible. These types of projects can be financed through RIP:

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- Eligible water, wastewater and water pollution control projects
- Water pipelines
- New sewer interceptors and collectors
- Infiltration/inflow correction
- Water and sewer system rehabilitation
- Treatment plant improvements
- Nonpoint source projects (e.g., septic tanks)
- Cost of water rights acquisition
- Eligible solid waste facilities including collection, disposal, storage and recycling
- Engineering studies and design
- Project inspection
- Easement and right-of-way
- Project legal costs
- Purchase of equipment

E. Special Appropriations Program

CPB provides oversight for water, wastewater and other environmental infrastructure construction projects funded through the Special Appropriations Program. These are state grants for special projects issued annually when authorized by the New Mexico Legislature during the legislative session and approved by the Governor. Since 1973 NMED has managed over $542 million in Special Legislative Appropriations for construction of community water supplies, wastewater facilities and other environmentally related projects.

F. Process for Controlling Disposition of Residual Waste from Wastewater Treatment Processing

[As required by 40 CFR 130.5(b)(7) for CPP]

Proper biosolids management to prevent ground and surface water pollution is important. State regulations allow several methods for the disposal of municipal sludge:

- The disposal of dry sludge in landfills, or composting and reuse, regulated under 40 CFR 503 and NM's *Solid Waste Management* regulations at 20.9.1 – 20.9.10 NMAC.
- Land application, including the injection of liquid sludge into subsurface soil, regulated under 40 CFR 503, Subpart B and NM's *Ground and Surface Water Protection* regulations under 20.6.2 NMAC.
- Surface disposal within an approved disposal unit, regulated under 40 CFR 503, Subpart C and NM's *Ground and Surface Water Protection* regulations under 20.6.2 NMAC.

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VII. NONPOINT SOURCE MANAGEMENT AND CONTROL

[As required by 40 CFR 130.6(c)(4)]

A. Nonpoint Source Management Program

Nonpoint sources of water pollution are recognized as major contributors to water pollution in New Mexico as well as the nation. Principal sources of surface water nonpoint source pollution in New Mexico include on-site liquid waste disposal, roads, recreation, urban storm water run-off, erosion from rangelands, agricultural activities, construction, silviculture, wildfires, resource extraction and land disposal. Hydromodification may affect attainment of designated uses by diverting water out of stream channels, impounding waters, and channelizing or otherwise disturbing streambeds. Principal known sources of nonpoint source groundwater pollution in rural and suburban areas include household septic tanks, cesspools, hard rock mines, and agricultural activities.

B. Nonpoint Source Management Plan

NM's plan for management of nonpoint source pollution is described in the *New Mexico Nonpoint Source (NPS) Management Plan*. The purpose of the NPS Management Plan is to describe the regulatory and non-regulatory programs, programmatic actions, and best management practices (BMPs) necessary to reduce pollutants from nonpoint sources entering surface water and groundwater. Included in the plan are six objectives that facilitate achievement of program goals. Implementation of the plan will help New Mexico succeed in attainment of surface water quality criteria that will fully protect designated uses as described in the State's WQS, meet the goals of the federal CWA and ensure adequate groundwater quality for municipal, domestic, and agricultural uses.

The NPS Management Plan has established a process to develop programs and activities within watersheds that will facilitate the achievement of surface WQS. Watershed-based planning is emphasized as a means of coordinating watershed restoration efforts, fostering watershed associations, and encouraging partnership among agencies, nongovernmental organizations, and the public. The Plan supports local watershed-based implementation of TMDLs and also coordinates with other land and resource management agencies that have established resource protection programs and activities.

The NPS Management Plan uses a voluntary approach to achieve water quality improvements. Incentives to voluntarily implement projects and restoration efforts include competitive grant funding through Section 319(h) of the CWA and technical support and guidance through SWQB. EPA has provided watershed planning guidance in the *Nonpoint Source Program and Grants Guidelines for States and Territories* (USEPA 2013). Completion of watershed planning per the guidelines is a requirement for Section 319 funds to be used for water quality restoration activities.

In order to fund water quality improvement projects, SWQB issues annual requests for applications for projects to be considered for funding from the federal NPS program grant under

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Section 319(h) of the CWA. The requests identify impaired waters with TMDLs describing the impairments, and a smaller category of impaired waters which do not require TMDL development because the impairments are thought to be caused by insufficient flow rather than excessive pollutant loading (Category 4C waters). Proposed projects must address impairment issues in these waters through planning or implementation.

Low-interest loans through the CWSRF are another potential source of funding for nonpoint source control projects. Both public and private entities as defined in the CWA are eligible for funding for non-point source projects.

SWQB has reviewed, upgraded, and will continue to implement all Section 319(b) management program components. These components include:

- Identification of BMPs appropriate to nonpoint source pollution problems in NM, as well as appropriate application and implementation of these BMPs;
- A schedule of milestones that provides focus, traceable events, and deadlines for program implementation;
- Identification of funding sources and potential partnerships based on available funding programs; and
- Identification of federal financial assistance programs and development projects.

Another important element of the NPS Management Plan is coordination with government agencies. Many of the stream segments which have been or are water quality limited due to nonpoint source pollution pass through public lands. A number of the federal agencies involved have agreed, formally or informally, to ensure that all new and renewed land use authorizations, easements, rights-of-way documents, allotment management plans, term-grazing permits, and other agreements involving permitted activities on properties administered by the federal agency would have enforceable provisions for compliance with WQS. Efforts under these agreements have resulted, and are expected to continue to result, in the implementation of BMPs and mitigation measures at many sites.

C. Wetlands Program

The SWQB Wetlands Program administers wetland restoration and program development grants received from EPA under Section 104(b)(3) of the CWA. The overall goals of the Wetlands Program are to protect and restore NM's wetlands and riparian areas and to increase self-sustaining and naturally functioning wetlands and riparian areas. The Wetlands Program emphasizes the role of wetlands in prevention and reduction of water quality impairments and providing habitat for aquatic life and wildlife.

EPA identified four core components critical to effective, comprehensive wetland programs (EPA 2009). The components are regulatory actions; monitoring and assessment (*see* Section III of this WQMP/CPP); restoration and protection; and WQS (*see* Section II of this WQMP/CPP). A description of these components in NM's Wetlands Program are found in the *Wetlands Program*

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Plan for New Mexico (NMED SWQB 2019). Regulatory actions/controls and restoration and protection are described in further detail below.

Regulatory Controls

The State's regulatory program, which applies to all surface waters of the state including wetlands, is described in Dredge and Fill Program and Effluent Limitations sections of this WQMP/CPP (Section X and V, respectively). Specifically, NPDES permits under Section 402 of the CWA regulate discharges to wetlands, and the Dredge and Fill Program under Section 404 of the CWA regulates other activities affecting wetlands.

Restoration and Protection

SWQB encourages wetland protection on a watershed basis. This approach involves assisting watershed groups throughout the state to develop "Wetland Action Plans" as a component of watershed-based plans. A Wetland Action Plan is a planning document designed specifically to address wetlands and riparian resources within the boundaries of a specific watershed. Participating watershed groups assess wetlands and riparian areas in their watershed and develop proposals to protect, restore, and create wetlands locally. This effort helps watershed groups incorporate wetland issues into their mission and promotes stewardship of wetlands through cooperative approaches involving agencies, local governments, tribes, nonprofit organizations, and the public.

In addition, SWQB promotes wetland restoration as an integral part of watershed restoration and health. A number of restoration projects are occurring statewide and are funded by EPA Region 6 Program Development grants under Section 104(b)(3) of the CWA. Project activities include restoration of wet meadows and waterfowl habitat on the Rio Grande along the central flyway, restoration of Bosque on private land parcels, re-establishment of natural flooding, increasing wetland plant diversity and habitat diversity, removal of exotic vegetation, restoration of springs, planning for open-space and conservation easements to protect wetlands resources including buffer zones, restoring beaver habitat, restoring high mountain fen wetlands, river restoration to address transportation maintenance issues, and conservation of playas and closed basin wetlands. The Wetlands Program maintains the New Mexico Statewide Wetlands Roundtable, consisting of state and federal agency and tribal participation. The wetland restoration and protection program also includes provisions for technical assistance to landowners or organizations carrying out wetland restoration projects, active research regarding effective wetland restoration techniques and methods to measure the success of restoration activities, and training and capacity-building for organizations interested in joining restoration partnerships.

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VIII. MANAGEMENT AGENCIES

[As required by 40 CFR 130.6(c)(5) for WQMP]

A. Designated Management Agencies for Wastewater Management

Under Section 208 of the CWA, WQMPs are to include identification of Designated Management Agencies (DMAs) necessary to implement the WQMP and provisions for adequate authority for intergovernmental cooperation. DMAs must demonstrate legal, institutional, managerial, and financial capability, and specific activities necessary to carry out their responsibilities. Incorporated municipalities, counties, sanitation districts, and water and sanitation districts have the necessary authorities under state law to satisfy the requirements of Section 208(c)(2) of the CWA, which include the authority to:

- carry out appropriate portions of an areawide waste treatment management plan developed under Section 208(b)of the CWA;
- manage effectively waste treatment works and related facilities serving such area in conformance with any plan required by subsection (b) of this section;
- directly or by contract, design and construct new works, and to operate and maintain new and existing works as required by any plan developed pursuant to subsection (b) of this section;
- accept and utilize grants, or other funds from any source, for waste treatment management purposes;
- raise revenues, including the assessment of waste treatment charges;
- incur short- and long-term indebtedness;
- assure in implementation of an areawide waste treatment management plan that each participating community pays its proportionate share of treatment costs;
- refuse to receive any wastes from any municipality or subdivision thereof, which does not comply with any provisions of an approved plan under this section applicable to such area; and
- accept, for treatment, industrial wastes.

State law provides the designated agencies with the necessary authority to design, construct, operate, and maintain wastewater treatment plants and to accept and utilize state and/or federal funds for these purposes. As specified at 40 CFR 130.12(b), Section 201 of the CWA funding can only be awarded to DMAs that are in conformance with the statewide WQMP.

B. Process for Designating Wastewater Management Agencies

The WQCC has the responsibility of designating management agencies which are then certified by the Governor (40 CFR 130.6(e)). DMAs must demonstrate legal, institutional, managerial and financial capability necessary to carry out the entity's responsibilities in accordance with Section 208(c) of the CWA. EPA shall accept such designations unless it is found that the DMAs do not have adequate specified authorities required in Section 208(c)(2) of the CWA (40 CFR 130.9(d)).

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As economic development and growth continue in NM, or as the need arises, additional DMAs for wastewater will be considered. The WQCC will consider new DMAs upon presentation of a petition requesting such designation. The petitioning DMA must demonstrate legal, institutional, managerial, and financial capability necessary to carry out the entity's responsibilities in accordance with Section 208(c) of the CWA. Designation of a management agency will occur only after appropriate public participation and presentation of relevant authorities by the petitioner.

C. Management Agencies for Point Source Management

The Governor certified the designation of ninety-seven (97) wastewater management agencies in 1980. Additional management agencies were certified in September 1983, August 1984, October 1985, April 1999, and May 2001. A total of eighty-four (84) municipalities, two (2) counties, eleven (11) sanitation or water and sanitation districts, four (4) state agencies, and two (2) Native American tribal entities have been designated wastewater management agencies.

Designated wastewater management agencies are listed in Table VIII-1. Each agency that has accepted this designation shall be responsible for wastewater management in its facility planning area and shall, if the agency satisfies applicable federal regulations, be able to receive construction program funding under Section 201 of the CWA.

D. Management Agencies for Nonpoint Source Management

The NPS Management Plan identifies specific federal, state and local agencies with a role in implementing nonpoint source pollution management and control. Unlike with the Wastewater Designated Management Agencies, a nonpoint source management agency can be entered into through interagency agreements, which are developed as needed to outline management responsibilities unique to each agency's area of responsibility and expertise.

For nonpoint source management, agencies or organizations participating through formal agreements under the NPS Management Plan will be considered a management agency for purposes of the WQMP/CPP.

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Table VIII-1. Designated Management Agencies for Wastewater Management.

INCORPORATED MUNICIPALITIES Agency Designated	Accepted	Rejected
Alamogordo	X	
Albuquerque	X	
Artesia	X	
Aztec	X	
Bayard	X	
Belen	X	
Bernalillo	X	
Bloomfield	X	
Capitan	X	
Carlsbad	X	
Carrizozo	X	
Causey	X	
Chama	X	
Cimarron	X	
Clayton	X	
Cloudcroft	X	
Clovis	X	
Columbus	X	
Corona	X	
Cuba	X	
Deming	X	
Des Moines	X	
Dexter	X	
Dora	X	
Eagle Nest	X	
Elida	X	
Encino	X	
Espanola	X	
Estancia	X	
Eunice	X	
Farmington	X	
Floyd	X	
Folsom	X	
Fort Sumner	X	
Gallup	X	
Grady	X	
Grants	X	

INCORPORATED MUNICIPALITIES Agency Designated	Accepted	Rejected
Grenville		X
Hagerman	X	
Hatch	X	
Hobbs	X	
Hope		X
House	X	
Jal	X	
Jemez Springs	X	
Lake Arthur	X	
Las Cruces	X	
Las Vegas	X	
Logan	X	
Lordsburg	X	
Los Alamos County	X	
Los Lunas	X	
Loving	X	
Lovington	X	
Magdalena	X	
Maxwell	X	
Melrose	X	
Moriarty	X	
Mosquero	X	
Mountainair	X	
Pecos	X	
Portales	X	
Questa	X	
Raton	X	
Red River	X	
Reserve	X	
Rio Rancho	X	
Roswell	X	
Roy	X	
Ruidoso	X	
San Jon	X	
San Ysidro	X	
Santa Fe	X	
Santa Rosa	X	

INCORPORATED MUNICIPALITIES	Accepted	Rejected
Agency Designated		
Silver City	X	
Socorro	X	
Springer	X	
Sunland Park	X	
Taos	X	
Tatum	X	
Texico	X	
Truth or Consequences	X	
Tucumcari	X	
Tularosa	X	
Vaughn	X	
Virden		X
Wagon Mound	X	
Willard		X

COUNTIES	Accepted	Rejected
Agency Designated		
Valencia	X	
Dona Ana	X	

SANITATION DISTRICTS / WATER & SANITATION DISTRICTS	Accepted	Rejected
Agency Designated		
Alpine Village Sanitation District	X	
Anthony Sanitation District	X	
Bluewater Water & Sanitation District		X
El Valle de los Ranchos Water & Sanitation District	X	
Lakeshore City Sanitation District	X	

SANITATION DISTRICTS / WATER & SANITATION DISTRICTS	Accepted	Rejected
Agency Designated		
Pena Blanca Water & Sanitation District	X	
Ranchos de Placitas Sanitation District	X	
San Rafael Water & Sanitation District	X	
Thoreau Water & Sanitation District	X	
Twining Water & Sanitation District	X	
Williams Acres Water & Sanitation District	X	
Yah-ta-hey Water & Sanitation District	X	

STATE AGENCIES	Accepted	Rejected
Agency Designated		
Corrections Dept.	X	
Dept. of Finance and Administration	X	
Health and Environment Dept.	X	
Natural Resources Dept.	X	

NATIVE AMERICAN TRIBAL ENTITIES	Accepted	Rejected
Agency Designated		
Navajo Tribal Utility Authority (interim wastewater management agency)	X	
Pueblo of Pojoaque	X	

IX. IMPLEMENTATION MEASURES

[As required by 40 CFR 130.6(c)(6) for WQMP]

A. Overview

This section addresses implementation measures necessary to carry out those programs that are listed in this Statewide WQMP/CPP. Schedules that specify when pollution control programs are expected to be implemented are useful in tracking the progress of control programs incorporated into the WQMP/CPP. Implementation schedules inform management agencies responsible for the programs, and other interested or affected parties, when significant milestones leading to implementation are expected to occur.

Where appropriate or required, individual documents also contain additional implementation procedures specific to a program. For example, Appendix A describes the implementation procedure for the State's Antidegradation Policy. Another example is the NPS Management Plan that identifies implementation and financing of measures for nonpoint source pollution control.

Implementation schedules may also be affected by statutory or Court imposed orders. An example of a statutory schedule is Section 303(c) of the CWA which requires States to review their WQS every three years. An example of a Court imposed schedule is the consent decree and settlement agreement that resulted from *Forest Guardians and Southwest Environmental Center v. Carol Browner, Administrator, U. S. Environmental Protection Agency* (1997) and the resultant MOU between EPA and NMED for the development of TMDLs (see Section IV of this WQMP/CPP).

Measures for financing these programs arise from a variety of sources including federal grants (e.g., Sections 106, 201, and 319 of the CWA), state budgets authorized by the NM Legislature, state revolving funds, local governments, cost sharing with stakeholders (public and private) or other means as appropriate to the task.

B. Planning Strategy for Implementation Measures

Implementation measures will be completed by:

- Using the process descriptions in this WQMP/CPP as a reference guide to program implementation and scheduling.
- Adhering to statutory, regulatory and court sanctioned schedules.
- Using funding sources appropriate to the task.
- Posting on NMED's website anticipated or tentative review schedules. Examples include but are not limited to: Triennial Review of WQS and biennial review of the *State of New Mexico CWA §303(d)/§305(b) Integrated Repor*t.

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X. DREDGE AND FILL PROGRAM

[As required by 40 CFR 130.6(c)(7) for WQMP]

A. Description of the Dredge and Fill Program

The U.S. Army Corps of Engineers (USACE) is responsible for issuing permits for activities involving the discharge of dredged or fill materials to waters of the U.S. pursuant to Section 404 of the CWA. New Mexico is not delegated authority for the issuance or enforcement of Section 404 permits, but NMED does review the permits for purposes of state certification or denial under Section 401 of the CWA.

In addition to the certification of permits, the Dredge and Fill Program includes consultation with applicants and USACE as needed, compliance site inspections, education, and outreach activities.

B. Process for Certification of Dredge and Fill Permits under Section 401 of the CWA

In accordance with Section 401 of the CWA, USACE may not issue permits for the discharge of dredged or fill materials to waters of the U.S. until the State is provided an opportunity to review and certify the permit. The WQA assigns the responsibility for certifying permits issued under the CWA to NMED (NMSA 1978, Section 74-6-4(F)), and also specifies the conditions under which a certification shall be denied (Section 74-6-5(E)).

Section 20.6.2.2002 NMAC of the *Ground and Surface Water Protection* regulations sets forth procedures for the state certification of dredge and fill permits. The procedures specify public notice requirements, a public comment period, the content and distribution of a certification or denial, timeframes, and appeal requirements.

C. Planning Strategy for the Dredge and Fill Program

NMED, through the SWQB, will review the Dredge and Fill Program annually to determine if improvements are required. SWQB will also review and certify, certify with conditions, or deny USACE individual, regional and nationwide permits under Section 404 of the CWA.

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XI. BASIN PLANS

[As required by 40 CFR 130.6(c)(8) for WQMP]

A. Introduction

Basin plans were initially developed by the State for water quality planning in the early and mid-1970s. In the 1980s the State shifted to planning on a statewide basis rather than basin-by-basin. According to 40 CFR 130.6(c)(8), a WQMP must identify "any relationship to applicable basin plans developed under Section 209" of the CWA. Because New Mexico has chosen to do its planning on a statewide basis, no such basin plans are applicable to NM. For the same reason, the CPP requirement in 40 CFR 130.5(b)(2) to describe "the process for incorporating elements of any applicable areawide waste treatment plans under section 208, and applicable basin plans under section 209" does not apply to NM.

Although the State conducts water quality planning on a statewide level, implementation and restoration efforts focus on the watershed level. A successful watershed protection approach must be founded on cooperative interaction between the federal, state, and local levels of government, and between the public and private sectors.

Throughout the state, local government organizations and citizens are working to address local water issues relating to both quantity and quality. These organizations include voluntary watershed groups, soil and water conservation districts, county and municipal governments, and concerned citizens.

B. Strategy

The WQCC will continue water quality management planning on a statewide basis via this WQMP/CPP. SWQB will work with and encourage participation by local, state and federal organizations, watershed groups, other nongovernmental organizations, and concerned citizens in the development and implementation of strategies to address specific regional or watershed concerns.

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XII. GROUNDWATER

[As required by 40 CFR 130.6(c)(9)]

A. Groundwater Pollution Prevention Program

The WQCC has adopted comprehensive regulations (20.6.1 through 20.6.7 NMAC), including ground WQS and a discharge permitting program, for the protection of groundwater quality under the authority of the WQA. The *Ground and Surface Water Protection* regulations are codified at 20.6.2 NMAC, with supplemental permitting requirements for dairy facilities at 20.6.6 NMAC and for copper mines at 20.6.7 NMAC. In accordance with the WQA at NMSA 1978, Section 74-6-4, the WQCC has delegated responsibility for administering its regulations regarding groundwater protection to NMED and OCD. The WQCC reviews and changes its regulations as it deems appropriate.

The GWQB reviews and approves discharge permits for discharges that have the potential to impact groundwater quality. Ground water discharge permits address discharges from a wide variety of facilities, including large and small-scale domestic wastewater treatment plants, septic tank/leachfields, industrial facilities, power generating plants, mining facilities, dairies, food processing plants, commercial landfarms for remediation of contaminated soil, UIC wells and groundwater remediation systems. The program also addresses unauthorized discharges such as spills; performs enforcement actions to ensure compliance with permit requirements; and requires abatement of groundwater contamination related to permitted facilities. The discharge permitting process includes public notification, a public comment period and a public hearing in situations where there is substantial public interest. Permits are issued for five-year terms and must be renewed to provide continuous coverage. Currently, GWQB manages approximately 675 active permits.

The Underground Injection Control (UIC) Program is a federal groundwater protection program established by the SDWA. The purpose of the UIC Program is to prevent groundwater contamination by regulating the discharge of wastes into UIC wells. New Mexico has authority for administration of the UIC Program, which is jointly implemented by GWQB and OCD. These divisions administer the UIC Program under authority granted by the WQA (NMSA 1978, Section 74-6-4), the *Ground and Surface Water Protection* regulations (20.6.2 NMAC), the New Mexico Oil and Gas Act (NMSA 1978, Section 70-2-12(B)), OCD's *Oil and Gas Injection* regulations (19.15.26 NMAC), and the New Mexico Geothermal Resources Act (NMSA 1978, Sections 71-9-1 to 71-9-11).

UIC wells include:

- Any dug hole or well that is deeper than its largest surface dimension, where the principal function of the hole is emplacement of fluids,
- Any septic tank or cesspool used by generators of hazardous waste, or by owners or operators of hazardous waste management facilities, to dispose of fluids containing hazardous waste, or

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- Any subsurface distribution system, cesspool or other well which is used for the injection of wastes.

EPA has grouped UIC wells into five classes (Class I, II, III, IV and V), according to the type of fluid they inject and where the fluid is. *See* https://www.epa.gov/uic.

New Mexico administers the federal UIC Program through the groundwater discharge permits required by 20.6.2 NMAC. Facilities that discharge fluids into UIC wells are required to have groundwater discharge permits approved by either GWQB or OCD, depending on the type of operation. Discharge permits contain operational, monitoring, contingency, and closure plans with specific requirements to prevent and remediate any negative impacts that UIC wells may have on groundwater quality. GWQB permits and oversees the operation, monitoring, and closure of Class I, III, IV, and V wells. OCD regulates Class II wells, and also Class I, III, and V wells related to oil and gas development activities, geothermal activities, and brine solution mining.

B. Planning Strategy for Groundwater Protection

The WQCC will update its water protection regulations as necessary to address emerging issues. NMED and OCD will continue to administer the state regulations for groundwater protection in accordance with the WQCC's delegation of responsibilities.

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XIII. DETERMINATION OF COMPLIANCE WITH WATER QUALITY STANDARDS FOR THE PROTECTION OF HUMAN HEALTH CRITERIA

[As required by 20.6.4.12 NMAC]

A. Background

In accordance with 20.6.4.12(D) NMAC:

> *Compliance with the human health-organism only criteria shall be determined from the analytical results of representative grab samples, as defined in the water quality management plan. Human health-organism only criteria shall not be exceeded.*

The procedures and methods used in the scientific studies necessary to make compliance determinations are found in several documents developed by SWQB. These documents include the WQS (20.6.4 NMAC) and the Surface Water Quality Bureau's QAPP for Water Quality Management Programs, which are reviewed and approved by EPA. The Water Quality Management Programs QAPP specifically addresses both laboratory and field procedures, including data interpretation approaches and field sampling techniques. The 2002 action by WQCC concerning human health priority toxic pollutants relies on grab sample techniques to determine standards compliance. Accordingly, specification of this technique is appropriate.

SWQB interprets a grab sample as a discrete, individual sample taken within a short period of time (usually less than 15 minutes) and is representative of the conditions at the time of sampling. This definition is operationally sufficient for perennial, intermittent and ephemeral waters. As stated in the Bureau's QAPP, SWQB relies on standard procedures and laboratory quality assurance to ensure the repeatability of the data. Procedures used for the evaluation of quality assurance and quality control are found in the QAPP. The analytical results of the representative grab samples shall be used for the determination of compliance with applicable human health criteria.

B. Process for Determination of Compliance

The following procedures apply to determining compliance for enforcement purposes; they do not apply for purposes of determining attainment of designated uses. Sampling for determination of compliance with WQS human health criteria shall be accomplished as follows:

- A minimum of three individual grab samples, separated in time by no less than 15 minutes each, shall be taken during the same sampling/storm event from the same location. For the purpose of determining non-compliance, the analytical results of two or more of these samples must be greater than the applicable human health criteria. Results of all grab samples shall be recorded and reported.

Sampling and analysis shall be in accordance with SWQB's current QAPP and SOPs.

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XIV. PUBLIC PARTICIPATION

A. Requirements for Public Participation

This section applies to the CWA and WQA programs administered by SWQB described herein.

General public awareness and stakeholder involvement is crucial to the successful implementation of CWA programs. By seeking and considering invaluable public input and involvement, SWQB can more effectively promote best management practices and increase public involvement to produce better decisions, as well as greater public acceptance and support for these decisions.

Public participation requirements under the CWA are specified in 40 CFR 25.4. The rule requires agencies to "…conduct a continuing program for public information and participation in development and implementation of activities…" and includes the following provisions:

- Design informational documents and activities to encourage and facilitate public participation for meaningful involvement (40 CFR 25.4(b)(1));
- Provide at least one central location of reports, studies, plans, and other documents (40 CFR 25.4(b)(3));
- Develop and maintain a list of potentially affected and interested parties and engage with them under public consultation as outlined under 40 CFR 25.4(d) (40 CFR 25.4(b)(5);
- Provide notification generally within no less than 30 days of any action to allow time for public response (40 CFR 25.4(c)).

The specifics for adhering to these requirements are outlined in greater detail for each section in Table XIV-1. In addition to the federal requirements identified above, the agency has additional outreach requirements, which include:

- Tribal engagement in accordance with NMED's *Tribal Consultation and Collaboration Policy* (NMED Office of the Secretary 2020),
- Development of PIPs in accordance with *NMED's Limited English Proficiency (LEP) Accessibility and Outreach Policy 07-11, Non-Employee Disability Accessibility and Outreach Policy 07-10* and *Public Participation Policy 07-13*.
- Provide public notification consistent with the public participation and outreach activities outlined in the associated PIP.

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Table XIV-1. Public Participation Requirements

Program Element	Public Participation Actions
WQMP/CPP - All Updates	• Stakeholder identification and outreach to gather information and identify potential updates • Conduct public meetings (Optional*) • Minimum 30-day public comment period • Publish notice of public comment period and meetings in newspaper(s) or alternative media in affected area(s) (Optional*) • Email notice to SWQB mailing list (Optional*) • Post on NMED website (Optional*) • Present updates/revisions at a WQCC meeting which is open to public participation • Post WQCC and EPA approved WQMP/CPP on NMED website
Water Quality Standards at 20.6.4 NMAC & Ground and Surface Water Protection regulations at 20.6.2 NMAC	• Stakeholder identification and outreach to gather information and identify potential updates • Conduct public meetings (Optional*) • Minimum 30-day public comment period for draft proposal • Petition the WQCC at a public meeting to request a hearing for the proposed changes to the regulations (NMSA 1978, Section 74-6-6(A)) • Publish hearing notice in the New Mexico Register, in one newspaper of general circulation, in one newspaper in the affected area (as applicable) and mailed to the WQCC mailing list (NMSA 1978, Section 74-6-6(C)) 60 days prior to hearing date; (45-day notice requirement in 40 CFR 25.5, 30-day notice requirement in NMSA 1978, Section 74-6-6, 60-day notice requirement in 20.1.6.201 NMAC) • Publish hearing notice in additional newspapers or through alternative media in affected area(s) (Optional*) • Email hearing notice to SWQB mailing list (Optional*) • Post rulemaking information on NMED website (State Rules Act, NMSA 1978, § 14-4-2(E)) • Post rulemaking information on State's Sunshine Portal (State Rules Act) • Provide electronic mail notification of hearing notice with links to supporting documentation for proposed rulemaking to NMED's district managers to make available at NMED field offices (State Rules Act) • Send rulemaking information and notice of hearing by electronic mail (if provided) to persons who have identified as a stakeholder, participated in the rulemaking, or specifically made a request for notice (State Rules Act)

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Program Element	Public Participation Actions
	• Send written notice that includes, at a minimum, an internet and street address where the information may be found to persons who provide a postal address (State Rules Act) • Provide notice of hearing to the New Mexico legislative council for distribution to appropriate legislative committees (State Rules Act) • Public hearing before WQCC (20.1.6 NMAC) • Publication of approved regulation in the New Mexico Register with effective date of rule (1.24.10 NMAC) • Post WQCC and EPA approved regulations on NMED website •
Water Quality Surveys	• Conduct pre-monitoring community meetings prior to conducting the study to inform stakeholders in affected area about upcoming study plan, obtain contacts, and obtain watershed specific information from those living/working within the watershed (Optional*) • Post field sampling plans on NMED website (Optional*)
TMDL Documents	• Minimum 30-day public comment period (40 CFR 130.7) • Conduct public meeting(s) in affected watershed(s) (Optional*) • Publish notice of public comment period and meetings in newspaper(s) and/or alternative media in affected area(s) (Optional*) • Email notice to SWQB mailing list (Optional*) • Post on NMED website (Optional*) • Present updates/revisions at WQCC meeting which is open to public participation • Post WQCC and EPA approved TMDL on NMED website
Appendix B-2 of this WQMP/CPP	• Post on NMED website as new TMDLs with WLA are approved, existing WLA are revised, or new WLA are added to existing TMDLs.
State of New Mexico CWA §303(d) List (Appendix A of the §303(d)/§305(b) Integrated Report)	• Minimum 30-day public comment period (40 CFR 130.7) • Publish notice of comment period in newspaper(s) or alternative media in affected area(s) (Optional*) • Email notice to SWQB mailing list (Optional*) • Post on NMED website (Optional*) • Public participation at WQCC meeting • Post WQCC and EPA approved Integrated Report on NMED website

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Program Element	Public Participation Actions
CWA §303(d)/§305(b) Listing Methodology	• Minimum 30-day public comment period (Optional*) • Publish notice of comment period in newspaper(s) or alternative media in affected area(s) (Optional*) • Email notice of comment period to SWQB mailing list (Optional*) • Post final listing methodology on NMED website (Optional*)
Nonpoint Source Management Plan	• Stakeholder identification and outreach to gather information and identify potential updates • Conduct public meetings (Optional*) • Minimum 30-day public comment period • Publish notice of public comment period and meetings in newspaper(s) or alternative media in affected area(s) (Optional*) • Email notice to SWQB mailing list (Optional*) • Post on NMED website (Optional*) • Present updates/revisions at public WQCC meeting • Post WQCC and EPA approved NPSMP on NMED website
Request for Proposals (RFPs)	• Publish notice in at least three newspapers of general circulation within the state at least 20 calendar days before proposals are due (1.4.1 NMAC). • NMED Press Release (Optional*) • Post on NMED website (Optional*) • Email notice to SWQB mailing list (Optional*)
Competitive Sub-Grant Awards: Solicitation for Applications (SFAs)	• NMED Press Release (Optional*) • Post on NMED website (Optional*) • Email to SWQB mailing list (Optional*)

Program Element	Public Participation Actions
401 Certifications of 402 Federal Permits (NPDES)	Joint Notice with EPA Region 6 (40 CFR 124.10(c) and 20.6.2.2001 NMAC): • Minimum 30-day public comment period • Publish notice in one newspaper of general circulation (in area of discharge if individual permit) • Send notice to the applicant; appropriate local, state, tribal and federal agencies; and all parties who have specifically requested copies of public notices. • Post notice on NMED website • Email notice to SWQB mailing list (Optional*) When joint notice is impractical, NMED shall provide notice according to 20.6.2.2001 NMAC: • Minimum 30-day public comment period • Publish notice in one newspaper of general circulation (in area of discharge if individual permit) • Post notice on NMED website • Email notice to applicant (except for general permits), SWQB mailing list, and affected government agencies or interested parties
401 Certifications of 404 Federal Permits (Dredge and Fill)	Joint Notice with US Army Corps of Engineers (33 CFR 325.3; 33 CFR 330.5; 20.6.2001 NMAC): • Minimum 15-day public comment period • Send notice to the applicant; adjoining property owners; affected local, state, tribal and federal agencies; and all parties who have specifically requested copies of public notices. • Post notice on NMED website • Email notice to SWQB mailing list (Optional*) When joint notice is impractical, NMED shall provide notice according to 20.6.2.2002 NMAC: • Minimum 15-day public comment period • Publish notice in one newspaper of general circulation (in area of discharge if individual permit) • Post notice on NMED website • Email notice to applicant (except for general permits); SWQB mailing list; and affected government agencies or interested parties

B. Planning Strategy for Fulfilling Public Participation Requirements

SWQB will satisfy public participation requirements in accordance with appropriate law/regulation/policy by:

- Developing PIPs that take into consideration the composition and English language proficiency of the affected community or area.
- Accommodating persons with a disability that desire to participate in NMED activities.
- Providing the public with the information necessary for meaningful involvement and informing the public of how they can obtain pertinent documents/information. This information is provided in public notices, at public meetings or hearings, available upon request, or can be obtained from the SWQB website at www.nmenv.state.nm.us/swqb. Brochures, newsletters, fact sheets, press releases, and other media are also utilized, as appropriate, to provide the public with the pertinent documents/information. This information includes appropriate information and documents as well as guidelines on how public meetings or hearings will be conducted.
- Providing a central location of reports, studies, plans, and other documents. SWQB maintains an administrative record, including all study plans and associated documentation (i.e. data, field sheets, etc.). A library of all intensive water quality survey reports is maintained, and reports are available to the public upon request.
- Maintaining a stakeholder list of affected/interested parties. SWQB maintains a database of affected/interested parties. This list includes the WQCC mailing list, environmental organizations, the regulated community, watershed groups, and numerous individuals who sign up to receive information. The list is currently operated through Govdelivery and individuals can subscribe to SWQB News at the bottom of every SWQB webpage.
- Properly notifying stakeholders and interested parties in accordance with laws/statutes/policies of any upcoming program activities. SWQB uses a variety of tools to disseminate information to the public, including publishing notices in the required newspapers (and the New Mexico Register, if necessary), emailing notices to the Bureau's interested parties list and encouraging them to post and/or forward to other interested parties, issuing NMED press releases, and posting pertinent documents and public notices on SWQB's website (https://www.env.nm.gov/surface-water-quality/).

Whenever practical and possible, SWQB will expand outreach efforts to maximize public participation by seeking out innovative ways of informing and involving the public such as through social media, webinars, etc. SWQB will provide the public with information on their role in the public participation process by documenting public input and providing a response to public input by explaining how the input was taken into consideration through the public participation process. This information is attached to final documents and provided individually to those who participated in the public comment process.

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XV. REFERENCES

The following documents and regulations may be updated more frequently than the WQMP/CPP. The context of each reference should be used to determine if a specific version or the most current version of the document is being referenced.

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State of New Mexico
Continuing Planning Process
Appendix A

Antidegradation Policy Implementation Procedure for Regulated Activities

Originally Approved 2004
Approved Revision October 23, 2020

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Glossary

Alternatives Analysis: An evaluation of possible cost-effective, reasonable alternatives to regulated discharges that might degrade water quality, including less-degrading alternatives, non-degrading alternatives, and no-discharge alternatives, such as treatment process changes, relocated discharge facilities, land application, reuse, and subsurface discharges. The evaluation must provide substantive information pertaining to the cost and environmental impacts associated with the proposed discharge and the alternatives being evaluated, so that alternatives that are cost-effective and reasonable and least degrading are identified.

Antidegradation: A regulatory policy and implementation procedure approved by EPA and the WQCC to protect existing uses of surface waters and to specify how the WQCC will determine, on a case-by-case basis, whether and to what extent, existing water quality may be lowered in a surface water.

Assimilative Capacity: The difference between the baseline water quality concentration for a pollutant and the most stringent applicable water quality criterion for that pollutant.

Baseline Water Quality (BWQ): A characterization of selected pollutants in a perennial surface water as measured and expressed during a specified time period. Once established, baseline water quality is a fixed quantity/quality unless it is updated by NMED to reflect changes in water quality.

Bio-accumulative Pollutant: a pollutant, such as pesticides or other chemicals, that accumulates in aquatic organisms when ingestion and absorption rates are faster than metabolic and excretion rates (*see* human health-organism only criteria in 20.6.4.900 NMAC).

Degradation: A decline in the chemical, physical, or biological conditions of a surface water or other decline in water quality as measured on a pollutant-by-pollutant basis.

Detection Limit: The minimum measured concentration of a substance that can be reported with 99% confidence that the measured concentration is distinguishable from method blank results.

Designated Use: A use of a surface water specified in the *Standards for Interstate and Intrastate Surface Waters* (20.6.4 NMAC). Designated uses include domestic water supply, irrigation and irrigation storage, primary contact, secondary contact, livestock watering, wildlife habitat, aquatic life, and fish culture and water supply.

Effluent-Dependent Water: An effluent-dependent water is a surface water that without the point source discharge of wastewater would be an ephemeral water.

Ephemeral Surface Water: A surface water that contains water briefly only in direct response to precipitation; its bed is always above the water table of the adjacent region.

Existing Use: A use and the water quality necessary to support the use that has been attained in a surface water on or after November 28, 1975, whether or not it is a designated use in the surface water quality standards (20.6.4 NMAC) or if it is currently attaining the quality required for that use.

Existing Water Quality: Baseline water quality.

High Quality Water: A surface water with water quality that is better than the applicable water quality standard as determined on a pollutant by pollutant basis.

Intermittent Surface Water: A surface water that contains water for extended periods only at certain times of the year, such as when it receives seasonal flow from springs or melting snow.

Less-Degrading Alternative: A cost-effective, reasonable alternative to a proposed discharge that would result in fewer detrimental changes to water quality as characterized by the baseline water quality evaluation.

Loading Capacity: total assimilative capacity of a waterbody for the pollutant of concern at critical flow. The loading capacity is the maximum amount of pollutant loading that a waterbody can receive and still meet water quality standards.

Minimal Degradation: A deterioration or decline in water quality that results in the consumption of less than 10 percent of the available assimilative capacity for a pollutant.

National Pollutant Discharge Elimination System [NPDES]: The point source discharge permit program established by Section 402 of the Clean Water Act (33 U.S.C. § 1342).

Non-Degrading Alternative: A cost-effective, reasonable alternative to a proposed discharge that would result in no significant degradation of water quality as characterized by the baseline water quality evaluation.

Outstanding National Resource Water (ONRW): A surface water that is classified as an outstanding national resource water under 20.6.4.9 NMAC.

Perennial Surface Water: A surface water that typically contains water throughout the year and rarely experiences dry periods.

Regulated Discharge: A point source discharge regulated under Section 402 of the CWA, a discharge for Dredge and Fill material regulated under Section 404 of the CWA, and any discharged authorized by a federal permit or license that is subject to state water quality certification under Section 401 of the CWA.

Relative Percent Difference (RPD): RPD is an expression of the degree of variation between two water quality samples taken under similar conditions. RPD is calculated using the following equation, where S represents the concentration of the pollutant in the original sample and D represents the concentration of the pollutant in the new sample.

$$\boldsymbol{RPD = \frac{|S - D|}{(S + D)/2}\ x\ 100}$$

Short-Term Degradation: Degradation that is six months or less in duration, i.e., water quality returns to baseline water quality within six months after the discharge commences.

Significant Degradation: The consumption of 10 percent or more of the available assimilative capacity for any pollutant of concern at critical flow conditions or any consumption of assimilative capacity that exceeds a cumulative cap of 50% of assimilative capacity.

Significantly Improved Water Quality: For purposes of a BWQ re-evaluation, significantly improved water quality compares the original baseline water quality data to new water quality data acquired or submitted to the Department and calculates the relative percent difference (RPD) between the two data points. If the RPD is greater than or equal to 20% and sampling technique, sample processing and transport, and laboratory analyses are comparable, a new baseline characterization may be warranted.

Surface Waters of New Mexico: All surface waters situated wholly or partly within or bordering upon the state, including lakes, rivers, streams (including intermittent streams), mudflats, sandflats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, reservoirs or natural ponds. Surface waters of the state also means all tributaries of such waters, including adjacent wetlands, any manmade bodies of water that were originally created in surface waters of the state or resulted in the impoundment of surface

waters of the state, and any "waters of the United States" as defined under the Clean Water Act that are not included in the preceding description.

Temporary Degradation: Degradation that is six months or less in duration, i.e., water quality returns to baseline water quality within six months after the discharge commences; short-term degradation.

Tier 1 Protection: Policies and procedures that prohibit degradation which results in the loss of an existing use, or violation of water quality criteria; and prohibit degradation of existing water quality where pollutants of concern do not meet applicable water quality standards. Tier 1 defines the minimum level of protection for all waters and requires that water quality be maintained such that the existing and designated uses of the water are supported. This applies to waters that do not meet or meet but are not better than the water quality standards for existing or designated uses. Surface waters with this protection may already be of lower quality.

Tier 2 Protection: Policies and procedures that prohibit significant degradation of a surface water unless a review of reasonable alternatives and social and economic considerations shows that the lowering of water quality is necessary for important social and economic considerations in the area where the water is located. Tier 2 protection level applies to perennial and intermittent waters where data confirm high quality water (i.e., where existing water quality is better than applicable water quality standards as determined on a pollutant-by-pollutant basis).

Tier 3 Protection: Policies and procedures that prohibit any lowering of water quality in Outstanding New Mexico Waters as identified under 20.6.4.9 NMAC unless impacts are minimized and temporary.

Toxic Pollutant: A pollutant or combination of pollutants, including disease-causing agents, that after discharge and upon exposure, ingestion, inhalation or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will cause death, shortened life spans, disease, adverse behavioral changes, reproductive or physiological impairment or physical deformations in such organisms or their offspring.

Translator: Methodologies to guide the calculation of site-specific numeric targets (not criteria) based on a given narrative standard.

Water Contaminant: Any substance that, if discharged or spilled, could alter the physical, chemical, biological or radiological qualities of water.

Water Pollutant: A water contaminant in such quantity and of such duration as may with reasonable probability injure human health, animal or plant life or property, or to unreasonably interfere with the public welfare or the use of property. Pollutants may include liquid, solid, gaseous, or hazardous substances such as contaminants, toxic pollutants, solid waste, chemicals, pesticides, herbicides, fertilizers, incinerator residue, sewage, garbage, sewage sludge, munitions, petroleum products, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, dirt, and mining, industrial, municipal and agricultural wastes.

Water Quality Criteria: Elements of water quality standards that are expressed as pollutant concentrations, levels, or narrative statements representing a water quality that supports a designated use.

1 Overview of New Mexico's Antidegradation Approach

Water quality standards (WQS) are the foundation for a wide range of programs under the Clean Water Act (CWA). WQS consist of designated uses such as aquatic life and recreation, water quality criteria necessary to protect those uses, and antidegradation requirements. Each State must develop, adopt, and retain a statewide antidegradation policy regarding water quality standards and establish procedures for its implementation through the water quality management process. Antidegradation implementation is based on a set of procedures to be followed when evaluating activities that may impact the quality of New Mexico's surface waters. Antidegradation implementation is an integral component of a comprehensive approach to protecting and enhancing surface water quality.

Antidegradation protections consist of three levels, or tiers, of protection defined by New Mexico's water quality standards in 20.6.4.8 NMAC. Tier 1 protections provide a floor of protection, ensuring that existing instream water uses and the level of water quality necessary to protect those existing uses are maintained and protected. Tier 2 protections maintain and protect water quality that exceeds water quality numeric and narrative criteria, prohibiting any lowering of water quality unless necessary to accommodate social or economic need. Tier 3 protections are afforded to waters designated by the Water Quality Control Commission (WQCC) as Outstanding National Resource Waters (ONRWs). In ONRWs, no degradation is permitted except in limited, specifically defined instances, such as to accommodate public health or safety activities or to enable activities to restore or maintain water quality.
Antidegradation applies to all activities with the potential to adversely affect water quality or existing or designated uses, including:

- Any proposed new or increased point source or nonpoint source discharge of pollutants that would lower water quality or affect the existing or designated uses.
- Any proposed increase in pollutant loadings to a waterbody when the proposal is associated with existing activities.
- Any increase in flow alteration over an existing alteration.
- Any hydrologic modifications, such as dam construction and water withdrawals.

This document has been drafted to provide guidance to persons responsible for regulated discharges that may degrade water quality in New Mexico. Regulated discharges include those that require a permit and/or a water quality certification under Section 401 of the Clean Water Act (CWA) pursuant to state or federal law. The Nonpoint Source Management Plan, a separate document incorporated by reference into the WQMP/CPP, describes antidegradation implementation procedures applicable to nonpoint source discharges. The information contained in this document is intended to provide guidance only and is not a substitute for the provisions of any other laws, rules, or regulations.

The guidance that follows addresses implementation procedures for New Mexico's antidegradation rule at 20.6.4.8 NMAC, and the federal antidegradation policy at 40 CFR 131.12. NMED is required by 40 CFR 131.12(a) to develop and adopt a statewide antidegradation policy and to identify methods for implementing that policy. The guidance generally includes:

- Processes for identifying the antidegradation protection level (i.e., the "*tier*") that applies to a surface water;
- Procedures for determining baseline water quality (BWQ);

- Approaches for evaluating water quality degradation;
- Procedures for identifying and evaluating less degrading or non-degrading alternatives*;*
- Procedures for determining the importance of economic or social development to support significant degradation of high quality surface waters; and,
- Information on intergovernmental coordination and public participation processes*.*

1.1 DESIGNATED USES AND WATER QUALITY CRITERIA

Water quality standards, including designated uses and associated water quality criteria can be found at 20.6.4 NMAC. Under the Clean Water Act (CWA) and New Mexico's surface water quality standards, various uses are assigned to surface waters. Designated uses include domestic water supply, irrigation and irrigation storage, primary contact, secondary contact, livestock watering, wildlife habitat, aquatic life, and fish culture and water supply. Designated uses are accompanied by an established set of *water quality criteria* designed to ensure that the designated uses are achieved. In accordance with state regulations, designated uses can be established or changed only through administrative rulemaking. Most surface waters have several designated uses. Where more than one use exists, or has been designated for a surface water, the use with the most stringent water quality criteria must be maintained and protected.

1.2 COVERAGE AND GENERAL APPLICABILITY

In general, the antidegradation implementation procedures described in this guidance apply to every proposal for a new or increased permitted discharge of a pollutant to a "surface water of the State." Permitted discharges are those discharges regulated under the authority of the CWA and discharges regulated pursuant to 20.6.2 NMAC that have the potential to impact surface water quality. These include National Pollutant Discharge Elimination System (NPDES) point source discharges regulated under Section 402 of the CWA; discharges which result in the placement of dredged or fill material into surface waters regulated under Section 404 of the CWA; and any discharge authorized by federal permits and licenses that are subject to state water quality certification under Section 401 of the CWA.

These procedures do not apply to non-point sources (NPS). In instances when significant degradation is determined to be a concern and NPS sources are impacting water quality, NMED will work with stakeholders to identify and implement best management practices, as described in the Nonpoint Source Management Plan.

These procedures also do not apply to other water quality-related actions, including revision of Commission documents (e.g., New Mexico Water Quality Standards, Continuing Planning Process, Statewide Water Quality Management Plan, and New Mexico Nonpoint Source Management Plan); the Commission's establishment of Total Maximum Daily Loads (TMDLs); or the conduct of studies, including use attainability analyses, by any party, including NMED. These types of water quality-related actions already are subject to extensive requirements for review and public participation, as well as various limitations on degradation imposed by state and federal law.

Section 3 summarizes the antidegradation review approach used in New Mexico, which is based on the type of regulated discharge under consideration (e.g., by permit type), the receiving water, and the BWQ for relevant pollutants of concern in the receiving surface water.

1.3 COORDINATION WITH ASSESSMENT AND IMPAIRMENT LISTING

Section 305(b) of the CWA requires each state to prepare and submit to the U.S. Environmental Protection Agency (EPA) a biennial report describing water quality of all surface waters in the state. Each state must monitor water quality and review available data to determine if water quality standards are being met. From the assessment, the CWA Section 303(d) List ("303(d) list") is created which identifies surface waters that do not meet water quality standards. These waters are known as water quality limited waters or impaired waters. Identification of a surface water as impaired may be based on a violation of a numeric or narrative water quality criterion. NMED's antidegradation policy implementation procedure (i.e., this appendix) assigns a protection category for the receiving water based on whether water quality standards are being met.

To coordinate antidegradation reviews with the 305(b) reporting and 303(d) listing activities, NMED will implement the following protections:

- *Tier 1 Protection (applicable to all waters):* No further degradation is permitted in a surface water where the most current water quality for that criterion does not meet, or meets but is not better than, the applicable water quality standards. Impaired waters are identified on New Mexico's 303(d) list and targeted for future water quality management planning (e.g., TMDLs, Watershed Based Plans (WBPs), etc.) to improve water quality and attain WQS.
- *Tier 2 Protection (applicable to perennial and intermittent waters where data confirm high-quality water is present):* Where possible, NMED may award priority points for grant or other funding programs that target water quality protection and restoration and support actions needed to protect and restore water quality. NMED may also revise the BWQ based upon more recent water quality data included in the biennial assessment of surface waters.
- *Tier 3 Protection (applicable to all waters designated as an ONRW):* No degradation is allowed in an ONRW, except in limited, specifically defined instances, such as to accommodate public health or safety activities or to enable activities to restore or maintain water quality, as outlined in 20.6.4.8(A)(3) and 20.6.4.8(A)(4) NMAC. For activities that may cause short-term degradation, NMED may award priority points for grant or other funding programs that target water quality protection and support actions needed to protect and restore water quality.

In addition, NMED participates in reviews for Clean Water State Revolving Funding. Applications are reviewed for compliance with water quality standards for both surface and groundwater, and projects that directly implement a fix to a water quality problem are awarded priority points to allow more rapid implementation of those projects. This results in a more proactive approach from the Department to restore or maintain water quality in surface waters across the state.

1.4 INTERGOVERNMENTAL COORDINATION AND REVIEW PROCESS

Federal and state regulations require intergovernmental coordination and public participation for Tier 2 reviews and public participation in decisions that may result in water quality degradation. Coordinating antidegradation reviews among various agencies and other interested parties will involve significant cooperation in gathering data, conducting evaluations, analyzing alternatives and evaluating potential social and economic impacts. A list of agencies that may be involved in the intergovernmental coordination and review process is included as Appendix A.5 of this document.

For comprehensive Tier 2 reviews on perennial waters, determining BWQ, evaluating projected impacts, analyzing possible alternatives, and evaluating economic or social benefits, if applicable, must occur prior to issuing an individual NPDES permit. Therefore, it is recommended that an applicant discharging into a perennial water meet with NMED in a pre-application conference at least one year prior to permit issuance. Timely notification and early consultation with NMED will help ensure that the issuance of permits can proceed without disruption to facility design, construction, or other activities planned by the applicant.

1.5 PUBLIC NOTIFICATION AND PARTICIPATION

Information on BWQ, designated uses, water quality standards, applicability of protection tiers, impact analyses, alternatives analyses, agency decisions, and other matters related to antidegradation reviews will be documented by NMED and made part of the public record. Public notification of proposed actions and requests for public comment will be made in accordance with Chapter 8 of this appendix.

2 Tiered Protection Levels

2.1 TIER DEFINITIONS

Federal law requires that surface waters be protected from discharges that might degrade water quality. To implement this requirement, it is necessary to identify antidegradation protection levels, or tiers, appropriate to each surface water. The state antidegradation rule at 20.6.4.8 NMAC delineates three tiers of protection for New Mexico surface waters. These tiers are applied on a pollutant-by-pollutant basis. Although Tiers are defined on a pollutant-by-pollutant basis, ONRWs are identified on a waterbody basis as described further below in this section and in NMAC 20.6.4.9(D) NMAC. Under this approach, surface water quality might degrade for one or more pollutants of concern but be unaffected for other pollutants. Degradation may be further described as *de minimis* (consumption of less than 10% of the assimilative capacity for a pollutant of concern) or significant (consumption of 10% or more of the assimilative capacity for a pollutant). Minimal (*de minimis*) degradation is permitted under the antidegradation rule and does not trigger comprehensive Tier 2 antidegradation review requirements. Significant degradation triggers the comprehensive Tier 2 antidegradation implementation procedures described below. The tiered protection levels are applied as follows:

> **Tier 1** – Applies as the default protection level for all surface waters, including intermittent waters, ephemeral waters, effluent dependent waters, and other surface waters and requires that water quality be maintained such that the existing and designated uses of the water are supported. Tier 1 prohibits further degradation of existing water quality where a pollutant of concern does not meet or meets but water quality is <u>not</u> better than applicable water quality criteria. Tier 1 protection for impaired waters apply only to those pollutants that resulted in the 303(d) listing**.**
>
> **Tier 2** – Applies to perennial surface waters with high quality water (i.e., where existing water quality is better than applicable water quality standards as determined on a pollutant-by-pollutant basis). Tier 2 requires that existing high-quality water be maintained but allows for limited (*de-minimis*) degradation. The Tier 2 protection level prohibits significant degradation unless a review of reasonable alternatives and social and economic considerations supports a lowering of water quality. Tier 2 may also apply to intermittent waters if data are available and indicate a high-quality water (i.e., water quality better than applicable WQS). Tier 2 is the default protection level for all high-quality perennial and intermittent waters (i.e., water quality is better than the applicable WQS).
>
> **Tier 3** – Applies only to New Mexico Outstanding National Resource Waters (ONRWs) identified in 20.6.4.9(D) NMAC. Tier 3 prohibits any degradation and lowering of water quality in an ONRW unless impacts are minimal and temporary. Approval for any degradation must be obtained according to the process outlined in 20.6.4.8(A)(3) and 20.6.4.8(A)(4) NMAC.

Antidegradation is more about levels of protection than it is about levels of quality. In fact, for Tier 3 it could be said that antidegradation is all about protection, as the outstanding character may have little to do with actual water quality in the traditional sense of pollutant concentrations (e.g., waters may have particularly high ecological value). Numeric water quality criteria are considered in an antidegradation analysis, however NMED takes other considerations into account as warranted. For example, Tier 3 (ONRWs) analyses require consideration of the essential character or special use that makes the water an ONRW, such as high ecological or recreational value.

Most of the involvement in the antidegradation policy is regarding Tier 2 waters. This tier is where antidegradation procedures can work to maintain high quality water and is also where dischargers may have to expend extra effort to reduce their proposed degradation of water quality or demonstrate that allowing lower water quality is necessary to accommodate important economic and social development in the area in which the water is located.

2.2 DESIGNATION OF TIER CATEGORY

At a minimum, all surface waters in New Mexico are protected in accordance with Tier 1 antidegradation requirements. Tier 1 applies categorically to all intermittent and ephemeral streams, effluent dependent waters, and all surface waters on the 303(d) list on a pollutant-by-pollutant basis. Where a surface water is listed on the state's 303(d) list for one or more pollutants, and where existing water quality for other pollutants is better than water quality standards, the surface water will be afforded Tier 1 and Tier 2 protection on a pollutant-by-pollutant basis. That is, Tier 1 protection for the pollutants not meeting water quality standards and Tier 2 protection for pollutants that are better than water quality standards.

Perennial waters, and possibly some intermittent waters, that are found to have existing water quality better than applicable water quality standards are protected at the Tier 2 level. For Tier 2 protection, determinations regarding the significance of degradation are based on BWQ and the relative change in water quality projected to result from the discharge under review. In general, BWQ, as discussed in Chapter 4 of this appendix, defines existing water quality for purposes of antidegradation reviews. BWQ can be established for surface waters through monitoring and water quality assessments conducted by NMED, regulated entities, or by others (e.g., contractors). Tier 3 protection applies to ONRWs listed in 20.6.4.9(D) NMAC. Tier 3 protection will be afforded for all pollutants of concern in an ONRW.

Where a perennial water has been assessed but has not been listed as an impaired water or as an ONRW, the presumed antidegradation protection level is Tier 2 for all pollutants of concern. If a protection tier has not already been determined for a perennial surface water, NMED will establish the tier by identifying the use(s) of the segment, determining BWQ, and comparing the attributes of the surface water under study to the criteria for the tiers as cited above.

Upon establishing the appropriate tier(s) for a surface water, NMED will document its findings along with BWQ characterization and make this information available as part of the public record. Tier levels established by NMED may be revised, or alternate tier assignments may be assigned when waters are added or removed from the 303(d) list or are added to the list of ONRWs (see 20.6.4.9(D) NMAC).

Table 2-1 summarizes decision criteria for assigning protection tiers and the antidegradation requirements for each. More information on conducting the antidegradation reviews for waters requiring Tier 2 and Tier 3 protection can be found in Chapter 3 of this document.

Table 2-1. Tier Descriptions and Summary of Antidegradation Protection Requirements

Tier	Waters Included	Protection Requirements
1	All surface waters that meet but are not better than applicable water quality criteria, i.e., not considered "high quality," as determined on a pollutant by pollutant basis. All surface waters on the state's 303(d) list of impaired waters for the pollutant that resulted in the listing. Intermittent waters.[1] All ephemeral waters. All effluent dependent waters.	The minimum level of protection necessary to maintain the existing and designated uses of a surface water. Where a surface water is impaired or meets, but water quality is not better than, applicable water quality criteria, there shall be no lowering of the water quality with respect to the pollutant causing the impairment. Tier 1 protection applies regardless of any economic or social benefits associated with a proposed discharge.
2	For intermittent[1] and perennial waters reflecting high-quality waters, i.e., where the level of water quality is better than applicable water quality criteria as determined on a pollutant-by-pollutant basis. Tier 2 is the default protection level for high-quality perennial and intermittent waters that are not ONRWs or on the 303(d) list.	High-quality water in perennial and intermittent (if known) streams and lakes must be protected at a level that minimizes degradation of that water quality. No significant degradation of the Tier 2 pollutants in the surface water is allowed unless a comprehensive antidegradation review of reasonable alternatives demonstrates that the lowering of water quality is necessary for important social and economic considerations in the area in which the waters are located.
3	ONRWs.	No new or expanded direct discharges. No lowering of water quality allowed unless it is minimized and temporary, *and* degradation is approved according to 20.6.4.8 NMAC.

[1] For intermittent waters, if water quality data are available and assessable, and indicate a high-quality water (i.e., water quality better than applicable WQS), then Tier 2 protection applies on a pollutant-by-pollutant basis.

3 Antidegradation Review Requirements

The antidegradation review procedure is based on the protection tier assigned to the receiving water, the type of receiving water, existing (i.e., baseline) water quality in the receiving water, the projected impacts, and nature of the proposed discharge.

In general, the antidegradation review requirements described in this guidance apply to regulated discharges that have the potential to degrade water quality. These include NPDES point source discharges regulated under Section 402 of the CWA; discharges which result in the placement of dredged or fill material into surface waters regulated under Section 404 of the CWA; and any discharge authorized by federal permits and licenses that are subject to state water quality certification under Section 401 of the CWA.

3.1 ANTIDEGRADATION REVIEW REQUIREMENTS BY TIER

Tier 1: Reviews to Protect Existing Uses

Tier 1 reviews must ensure that the level of water quality necessary to protect existing uses is maintained and protected. In general, the "level of water quality necessary to protect existing uses" is defined by state-adopted surface water quality standards.

General Applicability

Tier 1 protection applies to all surface waters. In determining whether a surface water is afforded only Tier 1 protection, NMED will focus on whether the surface water meets or fails to meet applicable WQS.

Impaired Waters

For surface waters listed as impaired on the 303(d) list and for those waters that meet but are not better than the water quality criteria for a particular designated use, Tier 1 protection will be provided for the listed pollutants. Non-listed pollutants in 303(d) listed waters and those surface waters that are of high-quality may be afforded Tier 2 protection. Under Tier 1, no discharges will be permitted to cause further degradation for pollutants that do not meet applicable water quality standards. Where existing uses of a surface water are impaired, there will be no lowering of the water quality with respect to the pollutant(s) of concern causing the impairment.

Non-Perennial and Effluent Dependent Waters

Lack of flow in ephemeral and intermittent waters makes it difficult to characterize BWQ and conduct Tier 2 antidegradation reviews. Similarly, lack of flow and/or the nature of flow in effluent dependent waters also makes these waters difficult to characterize, other than simply characterizing the effluent being discharged. These non-perennial waters will receive Tier 1 protection for all pollutants of concern unless there is sufficient BWQ data to demonstrate a high-quality water for intermittent waters to which a Tier 2 evaluation would be appropriate. Applicable WQS must be maintained and protected for these surface waters.

For example, certain individual and general permit applicants will likely discharge to a non-perennial stream segment where there is no other existing discharge to the segment, little or no flow in the channel beyond the immediate area of the discharge, and no available ambient water quality data. No BWQ

evaluation will be required for these discharges. Antidegradation reviews for most discharges to non-perennial waters will focus on requirements that applicable WQS be met end-of-pipe (unless ambient water quality data are available for a BWQ evaluation), and technology-based requirements, e.g., best available technology (BAT), are applied as required by permit conditions. Antidegradation review for NPDES individual municipal separate storm sewer system (MS4) and general permits as well as dredge or fill permits under Section 404 of the CWA for will focus on meeting WQS in receiving waters by ensuring compliance with the permit or state certification of the permit pursuant to Section 401 of the CWA.

General (Narrative) Criteria under 20.6.4.13 NMAC

Total Dissolved Solids (TDS) – NMED will follow the guidance laid out in the Colorado River Salinity Control Forum. Compliance with the Forum requirements will be considered to meet the intent of the narrative standard.

Plant Nutrients – NMED will evaluate nutrient discharges in accordance with available thresholds (i.e., translators) and will use applicable thresholds for the Tier 1 antidegradation review. A similar approach has been taken with Raton and Santa Fe WWTPs, capping the facilities at their current level of discharge/degradation. Depending on the data available, limits will be derived using a percentile of the data set (85^{th}, 95^{th}, etc.) that is reasonably achievable and still maintains and protects existing water quality. There are no technologically based effluent limits (TBELs) available for nutrients for publicly-owned treatment works (POTWs) at this time, but based on the type of treatment system available, NMED will work with the facility to incorporate limitations that maintain or reduce current levels of nutrient loading.

Other General Criteria – If a narrative standard does not have associated numeric thresholds or translators, NMED will not evaluate the narrative standard for antidegradation purposes due to the impracticality of such an evaluation.

Tier 2: Reviews to Protect High Quality Waters

Tier 2 protection applies to high quality perennial and intermittent (if data are available and assessable) waters with water quality better than applicable WQS, as determined on a pollutant-by-pollutant basis. Existing water quality in high quality surface waters must be maintained and protected. Tier 2 prohibits significant degradation unless a review of reasonable alternatives and social and economic considerations support a lowering of water quality, and after opportunity for intergovernmental review and public comment and hearing. If degradation is allowed, it must not result in a violation of applicable WQS.

General Applicability

Any regulated discharge to a high quality water is subject to Tier 2 antidegradation review to determine if the discharge will significantly degrade water quality. Determinations issued under these provisions will be made in accordance with the public notification process described in Chapter 8 of this appendix. If NMED determines after an initial evaluation that comprehensive Tier 2 review requirements do not apply to a proposed discharge, the discharge must still achieve the requirements of the permit or conditions of the water quality certification.

Basic vs. Comprehensive Tier 2 Review

A basic Tier 2 antidegradation review is used to determine whether or not significant degradation will occur from a regulated discharge, i.e., whether or not 10% or more of the available assimilative capacity

for any pollutant of concern will be consumed as a result of the proposed discharge during critical flow conditions or any consumption of assimilative capacity that exceeds a cumulative cap of 50% of assimilative capacity. The BWQ and applicable WQS must be reviewed as part of a basic Tier 2 antidegradation review.

A comprehensive Tier 2 antidegradation review, which includes an alternatives analysis and social and economic demonstration for the degradation, is required for any new or expanded discharge that may significantly degrade a Tier 2 protected water.

No comprehensive Tier 2 antidegradation review is required for discharges regulated under a general NPDES permit or a Section 404 dredge or fill permit. These discharges will be required to meet the conditions of the general permit or Section 401 water quality certification.

Tier 3: Reviews to Protect Outstanding New Mexico Waters

Existing water quality in ONRWs must be maintained and protected. Any discharge that would degrade existing water quality in an ONRW is prohibited, unless the applicant demonstrates that the water quality impacts are temporary and necessary for public health and safety or restoration, and the applicant receives approval for the activity according to the process in 20.6.4.8 NMAC.

General Applicability

Tier 3 protection applies only to surface waters that are classified as ONRWs and identified under 20.6.4.9(D) NMAC.

Tier 3 Review

Discharges that impact ONRWs are subject to Tier 3 antidegradation review. New or expanded discharges that may cause degradation directly to an ONRW identified under 20.6.4.9(D) NMAC are prohibited, except in limited, specifically defined and temporary events, such as to accommodate public health or safety activities or to enable activities to restore or maintain water quality, as outlined in 20.6.4.8.A(3) and (4) NMAC. In general, temporary is defined as occurring for a period of six months or less and is not recurring. In addition, NMED will impose necessary controls on indirect discharges that occur upstream or to tributaries of an ONRW to maintain and protect existing water quality in the downstream ONRW.

Determinations regarding antidegradation reviews for activities that affect ONRWs, such as public health or safety activities or activities to restore or maintain water quality, will be made on a case-by-case basis after consideration of the following factors outlined in 20.6.4.8(A)(3) and 20.6.4.8(A)(4) NMAC:

- The degradation shall be limited to the shortest possible time and shall not exceed six months;
- The degradation shall be minimized and controlled by best management practices or in accordance with permit requirements as appropriate; all practical means of minimizing the duration, magnitude, frequency and cumulative effects of such degradation shall be utilized;
- The degradation shall not result in water quality lower than necessary to protect any existing use in the ONRW; and
- The degradation shall not alter the essential character (e.g., exceptional recreational or ecological significance) or special use (e.g., state special trout water; national or state park, monument, wildlife refuge; designated wilderness or wild river) of the ONRW, as supported by the proceedings and final decision establishing the water as an ONRW.

Prior to the WQCC's decision, NMED will provide a written recommendation to the commission. This recommendation will take into account the following factors:

- Change in ambient concentrations predicted at the appropriate critical flow condition(s)
- Change in loadings (i.e., the new or expanded loadings compared to total existing loadings to the segment)
- Reduction in available assimilative capacity
- Nature, persistence and potential effects of the pollutant
- Potential for cumulative effects
- Degree of confidence in the various components of any modeling technique utilized (e.g., degree of confidence associated with the predicted effluent variability)

The antidegradation review findings must be documented and public participation activities initiated, as per the procedures in 20.6.4.8(3)(a) NMAC. If the review finds that the proposed discharge will not be temporary, the proposed discharge will be denied. In all cases, Tier 1 protection must be maintained.

Emergency Response Action

If an emergency response action is occurring in proximity to an ONRW and is necessary to mitigate an immediate threat to public health or safety, it may proceed prior to notification to the WQCC and NMED, in accordance with the following as outlined in 20.6.4.8(A)(3)(c) NMAC:

- only actions that mitigate an immediate threat to public health or safety may be undertaken pursuant to this provision; non-emergency portions of the action shall comply with the requirements of 20.6.4.8 NMAC;
- the discharger shall make best efforts to comply with requirements noted above;
- the discharger shall notify the department of the emergency response action within seven days of initiation of the action; and,
- within 30 days of initiation of the emergency response action, the discharger shall provide a summary of the action taken, including all actions taken to comply with the requirements above.

Upstream Discharges & Tier 3 Review

A discharge upstream of an ONRW is prohibited where the proposed discharge would degrade existing water quality of the downstream ONRW on a longer than temporary basis. To determine whether the proposed discharge will result in the lowering of water quality in the downstream ONRW, the following factors may be considered:

- Change in ambient concentrations predicted at the appropriate critical flow condition(s)
- Change in loadings (i.e., the new or expanded loadings compared to total existing loadings to the segment)
- Reduction in available assimilative capacity
- Nature, persistence and potential effects of the pollutant
- Potential for cumulative effects
- Degree of confidence in the various components of any modeling technique utilized (e.g., degree of confidence associated with the predicted effluent variability)

If a preliminary determination is made that the requirements above will be met, the antidegradation review findings must be documented and the applicable public participation activities must be initiated. If the review finds that the proposed discharge will result in the lowering of water quality in a downstream ONRW, the proposed discharge will be denied.

3.2 ANTIDEGRADATION REVIEW REQUIREMENT BY TYPE OF PERMIT

Antidegradation review requirements for regulated discharges that may degrade water quality vary according to 1) classification, existing uses, and condition of the receiving water; 2) the type of discharge and permit under which the discharge is conducted; and 3) the range and severity of projected impacts on the surface water. For example, antidegradation review requirements for discharges authorized under general permits differ from antidegradation review requirements for discharges regulated by individual permits. This section outlines the antidegradation review requirements for regulated discharges that may degrade water quality, including those with individual and general NPDES permits and those covered under Section 404 of the CWA (Dredge or Fill permits).

Compliance with the requirements of general permits and prompt attention to conditions that might result in water quality degradation will help ensure that discharges authorized by general permits do not cause violations of WQS. Moreover, some new or expanded discharges formerly authorized by a general permit may not be eligible for such coverage in the future if NMED believes they could significantly degrade a surface water. In those cases, applicants will be required to seek coverage under an individual permit.

In order to implement New Mexico's antidegradation policy in an efficient manner, it is recommended that persons proposing individually-permitted discharges which might degrade water quality in a perennial water notify NMED before determining BWQ (see Chapter 4 of this appendix) or applying for a permit. Such an approach will help ensure that the antidegradation review proceeds smoothly, without delay, and that planned facilities will comply with applicable statutes and rules. Figure 3-1 summarizes the Tier 2 review process for individual NPDES permit reissuance and new or expanded NPDES permits. Figure 3-2 summarizes the review requirements for individual NPDES; NPDES Stormwater Permits; general NPDES permits; individual and nationwide Section 404 permits, and federal permits and licenses subject to Section 401 water quality certification.

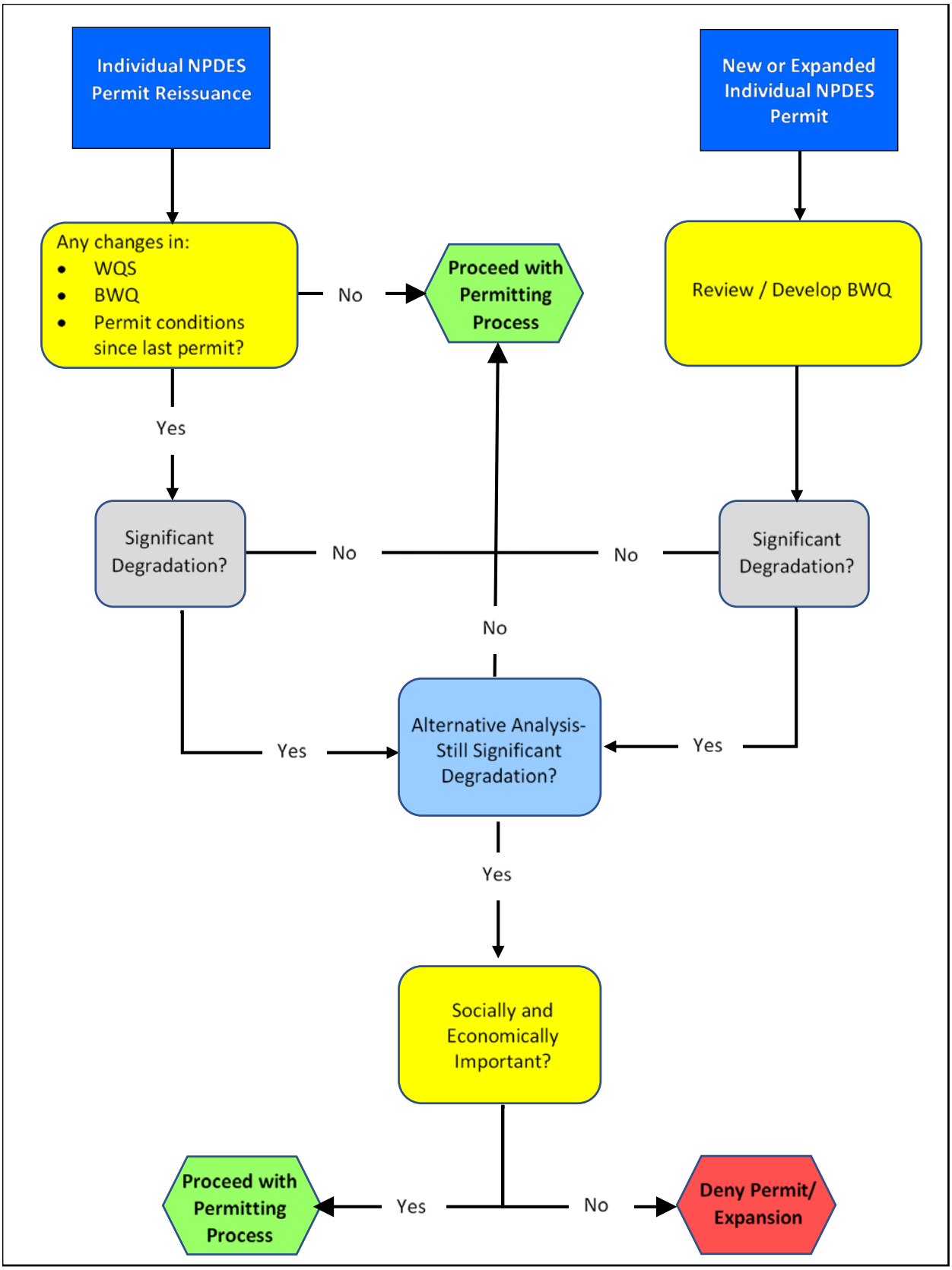


Figure 3-1. Tier 2 Antidegradation Review Process for Individual NPDES Permits

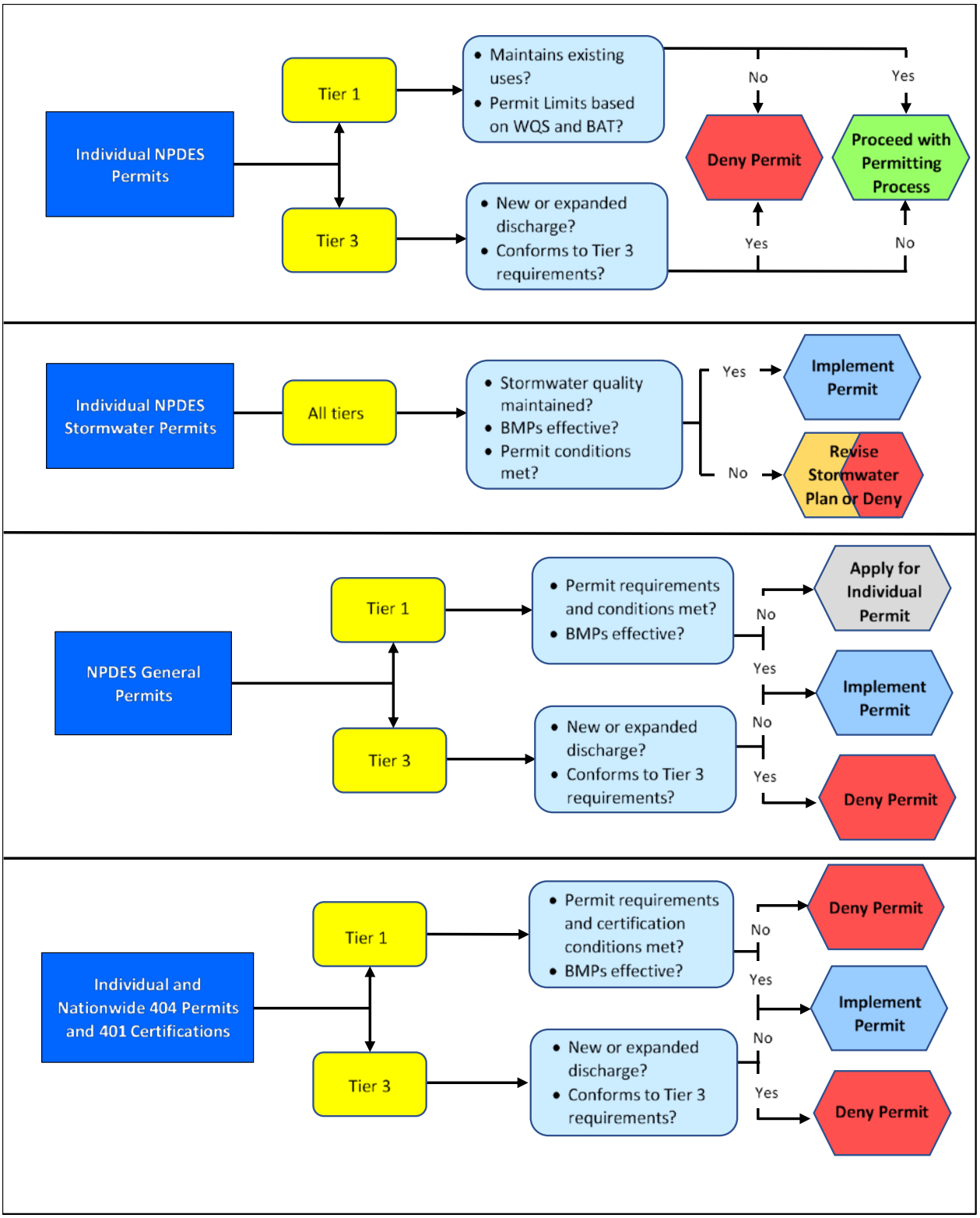


Figure 3-2. Antidegradation Review Requirements by Permit Type

3.3 INDIVIDUAL NPDES PERMITS

General Applicability

All point source discharges regulated by individual NPDES permits are subject to an antidegradation review at the time of issuance, modification, or renewal of a permit. All NPDES permits must ensure that water quality is protected at the appropriate tier based on available water quality information; however, at a minimum, the level of water quality necessary to maintain existing uses must be maintained and protected.

Reasonable Potential for Minor POTWs

Facilities less than 0.1 million gallons per day (MGD) are not required to sample or report any toxic substances on their NPDES permit applications, since studies indicated they have "no reasonable potential" to discharge toxic substances in amounts that would violate state WQS. Facilities greater than 0.1 MGD, but less than 1 MGD report some toxic substances that are present in facility discharges of that size.

Supporting information for this decision was published by EPA as "Evaluation of the Presence of Priority Pollutants in the Discharges of Minor POTW's," June 1996, and was sent to all state NPDES coordinators by EPA Headquarters. In this study, EPA collected and evaluated data on the types and quantities of toxic pollutants discharged by minor POTWs of varying sizes from less than 0.1 MGD to just under 1 MGD. The Study consisted of a query of the EPA Permit Compliance System (PCS) database from 1990 to 1996, an evaluation of minor POTW data provided by the State agencies, and on-site monitoring for selected toxics at 86 minor facilities across the nation.

Therefore, in the cases of facilities under 0.1 MGD, these facilities have already been assessed as having no reasonable potential to discharge toxic substances in toxic amounts. Additional historical records may provide information to assess reasonable potential.

Overview of the Antidegradation Review Procedure

The antidegradation review for individual NPDES permits will be based upon the assigned protection tier, the existing uses of the segment, applicable WQS, flow regime of the receiving water, pollutants of concern associated with the discharge, projected impacts on the receiving water, cumulative impacts from other pollutant sources, and the significance of any degradation that might occur as a result of the discharge.

All applicants will be required to identify pollutants reasonably expected to be in the discharge, estimate flow rates, and characterize pollutant concentrations and/or mass pollutant loads, as specified by NMED. In addition, applicants for new and expanded discharges to perennial waters under an individual permit are required to collect and submit existing or new information on BWQ needed to analyze the impact(s) of the discharge to a perennial water if ambient water quality data are not available. For the purpose of this analysis, expanded means an increase in design flow of the facility. In many cases, NMED's current water quality monitoring (conducted on a rotating basis in watersheds across the state) will provide applicable baseline data for use in these evaluations; however, for certain cases, the applicant may need to generate additional data for consideration in the antidegradation analysis if there are atypical pollutants of concern that are not normally monitored by NMED. For intermittent streams, the applicant

may choose to collect and submit water quality data for BWQ, which will help to evaluate appropriate and protective limits that may not be end-of-pipe requirements.

If feasible, it is recommended that an applicant discharging to a perennial water meet with NMED in a pre-application conference at least one year prior to individual NPDES permit issuance because of the substantial information requirements associated with development of effluent limits and, if necessary, a comprehensive Tier 2 antidegradation review.

Permit Limits and Antidegradation Requirements for Individual Permits

During the permit development process, EPA Region 6 will coordinate with NMED, who will evaluate existing water quality using both internal and applicant-supplied data, identify designated uses of the receiving water and analyze the impacts of the discharge as well as cumulative discharges that might affect the assimilative capacity of the receiving surface water for relevant pollutants of concern. Individual permit limits for discharges to perennial waters will be based upon applicable effluent guidelines, the characteristics of the discharge, and analyses designed to ensure that no significant degradation of the receiving water occurs. Permit limits for discharges to ephemeral, intermittent, and effluent dependent waters will be based on the WQS and EPA effluent guidelines and other technology-based requirements (e.g., secondary treatment requirements, BAT, MEP). Regardless of hydrology, all permit limits must ensure that existing uses are maintained and protected. NMED will use its authority under Section 401 of the Clean Water Act to conditionally certify federal permits that authorize discharges to Waters of the United States where the antidegradation analysis shows that stricter water quality controls are needed.

Proposed new or expanded discharges that may significantly degrade waters protected at the Tier 2 level must undergo a comprehensive antidegradation review to determine whether less degrading or non-degrading alternatives exist and whether significant degradation is necessary to accommodate important economic or social development in the area where the surface water is located. As it pertains to implementation of New Mexico's antidegradation policy, significant degradation is defined as the consumption of 10% or more of assimilative capacity of the receiving water for any pollutant of concern associated with the discharge during critical flow (e.g., 4Q3) conditions or any consumption of assimilative capacity that exceeds a cumulative cap of 50% of available assimilative capacity.

Early notification and consultation between the applicant, EPA, and NMED will help ensure that the NPDES permitting process proceeds efficiently. The following steps outline the general procedure for processing an NPDES permit:

- Applicant notifies NMED and EPA Region 6 of intent to apply for or renew permit coverage
- EPA determines eligibility for general permit or individual permit coverage
- Applicant consults with NMED on BWQ and available assimilative capacity in the receiving waterbody.
- NMED conducts antidegradation review and drafts a letter to document BWQ and available assimilative capacity; determination of minimal/significant degradation; and if a comprehensive Tier 2 antidegradation review is required. The letter is mailed to EPA and the permittee.
- If required, undergo comprehensive Tier 2 antidegradation review (alternatives analysis, economic/social documentation) – see Chapters 6 & 7 of this appendix.
- If significant degradation is deemed necessary based on the comprehensive Tier 2 review, conduct public participation and intergovernmental coordination consistent with Chapter 8 of this appendix.

- Applicant applies for permit after consultation with NMED.
- EPA (in consultation with NMED) develops draft permit limits based on effluent guidelines, applicable WQS, BWQ (if required), and antidegradation requirements.
- NPDES permitting process/comment period addresses both public notice requirements for antidegradation review and NPDES permitting.
- NMED prepares a Section 401 Water Quality Certification.
- Final permit drafted and issued.

Applicants seeking individual permit coverage for new or expanded discharges to a perennial surface water will be required to provide or collect BWQ information on pollutants of concern (e.g., pH, metals), if that information is not available (see Chapter 4). Data collection may be required depending on the availability of water quality data, nature of the proposed discharge, and the pollutants reasonably expected in the discharge.

Comprehensive Tier 2 Antidegradation Review Procedure for New or Expanded Discharges to Perennial Waters Requiring an Individual NPDES Permit

Degradation under Tier 2 will be deemed significant if the new or expanded discharge requiring an individual NPDES permit results in a reduction of available assimilative capacity (the difference between the BWQ and the applicable water quality criterion) of 10% or more at the defined critical flow condition(s) for the pollutant(s) of concern or any consumption of assimilative capacity that exceeds a cumulative cap of 50% of available assimilative capacity for the pollutant(s) of concern. Significant degradation will be determined on a pollutant-by-pollutant basis.

It should be noted that pollutants of concern for Tier 2 antidegradation reviews include those pollutants reasonably expected to be present in the discharge for which a numeric water quality criterion exists. If multiple water quality criteria apply, assimilative capacity will be calculated using the most stringent applicable WQS.

If a determination is made that significant degradation will occur, NMED will determine whether significant degradation is ***necessary*** by evaluating whether reasonable and cost-effective, less degrading or non-degrading alternatives to the proposed new or expanding discharge exist. The applicant will be responsible for conducting an alternatives analysis as described in this guidance. NMED will evaluate the alternatives analysis submitted by an applicant for consistency with the requirements outlined in Chapter 6. The alternatives analysis must provide substantive information on all reasonable, cost effective, less degrading or non-degrading alternative. Alternatives may include:

- Pollution prevention measures
- Reduction in scale of project
- Water reuse
- Treatment process changes
- Innovative treatment technology or technologies
- Advanced treatment technology or technologies
- Seasonal or controlled discharge options to avoid critical flow periods
- Improved operation and maintenance of existing treatment systems
- Alternative discharge locations, including subsurface discharges
- Zero discharge alternatives

As a rule of thumb, NMED will consider non-degrading or less degrading pollution control alternatives with costs that are less than 110 percent of the base costs of the pollution control measures associated with the proposed discharge to be cost-effective and reasonable (see Chapter 6.4 of this appendix).

If it is determined that reasonable, cost-effective, less degrading or non-degrading alternatives to the proposed discharge exist, the project design must be revised accordingly. In general, if such alternative(s) exist, the alternative or combination of alternatives that result in the least degradation must be implemented. If the regulated entity does not agree to adopt such reasonable and cost-effective alternatives, the alternatives analysis findings will be documented and the discharge will not be allowed. If significant degradation would occur even after application of reasonable less degrading or non-degrading alternatives, a determination must be made as to whether the proposed discharge is necessary to accommodate important economic or social development in the area in which the waters are located. NMED will evaluate the social and economic documentation for consistency with the requirements outlined in Chapter 7.

If the proposed discharge is determined to have social or economic importance in the area where the surface water is located, the basis for that preliminary determination will be documented and the Tier 2 review will continue. If significant degradation is proposed, the applicant also must show that the highest requirements for new and existing point source discharges are achieved, that all cost-effective and reasonable best management practices for non-point source pollution control are identified and effectively implemented and that Tier 1 protection is provided.

Tier 2 reviews include the public participation provisions outlined in Chapter 8. Once the intergovernmental coordination and public participation requirements are satisfied, NMED will make a final determination concerning the social or economic importance of the proposed discharge. All key determinations, including determinations to prohibit the discharge, must be documented and made a part of the public record (40 CFR 131.12 (b)).

3.4 INDIVIDUAL NPDES STORMWATER PERMITS

Urban areas with populations greater than 100,000 based on the 1990 census were considered Phase I Municipal Separate Storm Sewer Systems (MS4) communities and were required to apply for an individual NPDES stormwater permit. Urban areas as defined in the 2000 and subsequent census surveys every 10 years are considered Phase II MS4 communities. Stormwater discharges from Phase II MS4s are authorized by individual or general NPDES stormwater permits. However, neither Phase I nor Phase II MS4s authorized under individual stormwater permits are required to meet the same antidegradation requirements that apply to other individual NPDES permits outlined above.

In addition to MS4s, other entities can be required to obtain an individual NPDES stormwater permit by EPA on a case by case basis.

Overview of the Antidegradation Review for Individual Stormwater Permits

Antidegradation reviews for individual NPDES stormwater permits will be based on an adaptive management approach. This approach may include routine monitoring of stormwater quality at representative outfalls to adequately characterize stormwater discharges. The permittee will then evaluate, through effectiveness monitoring, whether storm water quality is being maintained, improving, or degrading and whether Best Management Practices (BMPs) identified in the permittee's stormwater pollution prevention plan are effective at controlling the discharge of pollutants. Future antidegradation

review of individual NPDES stormwater permits will consist of an analysis of the effectiveness of the BMPs and compliance with the requirements of the stormwater permit.

3.5 GENERAL NPDES PERMITS

A number of discharges to surface waters are authorized under general NPDES permits. These include stormwater runoff from municipalities required to comply with the Phase II MS4 stormwater permit, industrial activities covered by the stormwater program (Multi Sector General Permits), stormwater from construction sites one acre or larger (Construction General Permits), pesticide applications in or adjacent to surface waters (Pesticide General Permit), and concentrated animal feeding operations (CAFOs).

All NPDES general permits require preparation of a stormwater pollution prevention plan (SWPPP) that includes identification and control of all pollutants associated with the activities to minimize impacts to water quality. The permits also include requirements to implement site-specific interim and permanent BMPs and/or other controls to reduce (or eliminate) pollutant loading to minimize impacts to water quality. BMPs are designed to prevent to the maximum extent practicable an increase in pollutant load to the water body. BMPs also include measures to reduce flow velocity to assure that applicable water quality standards, including the antidegradation policy, are met. Compliance with the terms and conditions of the general permits is required to maintain authorization to discharge under the general permit. Discharges covered by a general permit that do not comply with general permit conditions or antidegradation requirements will be required to seek coverage under an individual permit.

Overview of the Antidegradation Review for General Permits

Regulated discharges authorized by general permits are not required to undergo a Tier 2 antidegradation review as part of the permitting process. However, new and reissued general permits must be evaluated to consider the potential for significant degradation as a result of the permitted discharges.

Discharges covered by general permits are transient or essentially non-existent (e.g., “no discharge”) with temporary or short-term impacts. Further, dischargers seeking coverage under a general permit are required in their SWPPP to identify pollutants on a pollutant-by-pollutant basis and to design and implement controls to minimize impacts to water quality. As a result, discharges that comply with general permits are not likely to cause significant degradation of water quality. In addition, activities covered under general permits (e.g., construction, industries, municipalities, dairies, feedlots, etc.) are considered to have social and economic importance to New Mexico. Therefore, antidegradation review for general permits will be based on whether or not the permit conditions are met and if the BMPs are effective at limiting (or eliminating) pollutant loading to minimize water quality impacts.

3.6 SECTION 404 PERMITS

Section 404 of the CWA regulates the placement of dredged or fill material into the “waters of the United States.” The U.S. Army Corps of Engineers (Corps) administers the permit program dealing with these discharges (e.g., wetland fills, in-stream sand/gravel work, etc.), in cooperation with the EPA and in consultation with other public agencies. Individual permits are issued for discharges with significant impacts. Discharges covered under Section 404 permits include any activity that results in the placement of dredged or fill material within the ordinary high-water mark of the waters of the U.S. or within wetlands recognized as waters of the U.S.

Overview of the Antidegradation Review for Regional or Nationwide Permits under Section 404 of the CWA

Antidegradation reviews involving the placement of dredged or fill material will be performed via the water quality certification process under Section 401 of the CWA. New Mexico manages its Section 401 water quality certification program to ensure that discharges resulting in the placement of dredged or fill material into surface waters do not cause water quality impairments or significant degradation of surface waters. New Mexico certifies general Section 404 permits ("regional" permits issued by the Albuquerque district of the Corps, and "nationwide" permits issued at the national level) in advance of individual projects that will be covered by the permits. New Mexico denied certification of the 2017 nationwide permits for projects in ONRWs, except for projects covered by Nationwide Permit 27 (for "Aquatic Habitat Restoration, Enhancement, and Establishment Activities"). Pursuant to Section 404, the Corps requires dischargers to obtain specific authorization from the Corps before commencing a discharge under a nationwide or regional permit. A Corps notification requirement (Regional Condition 2b) coupled with a state Section 401 certification condition provides NMED the opportunity to review projects proposed for authorization under a nationwide permit and confirm their consistency with the existing Section 401 certification. This review process often results in improvements in project design and BMP selection and ensures compliance with the antidegradation policy.

For new nationwide Section 404 permits, new regional Section 404 permits, or projects covered by existing Section 404 permits that have not yet received Section 401 certification (as of 2020, projects located in ONRWs and not covered by Nationwide Permit 27), NMED considers developing new Section 401 certifications. Based on this review, NMED may make one of three decisions: 1) grant the certification, 2) grant the certification with conditions, or 3) deny the certification.

NMED's Surface Water Quality Bureau (SWQB) will use the Section 401 certification process to evaluate whether a discharge will cause significant degradation to water quality. Pollutant loads from dredge or fill projects regulated under Section 404 of the CWA are often difficult or impossible to quantify in the same manner as practiced in NPDES permits. Dredge or Fill permits are often used for temporary construction measures in or near a watercourse that may result in disturbance or deposition of sediments in the water. The primary tool for limiting the discharge of pollutants (e.g., sediment and contaminated sediment) from these activities is through certification conditions mandating the installation and operation of BMPs that prevent pollutant transport to a watercourse and thereby degradation. The SWQB reviews dredge or fill projects pursuant to the State's water quality certification procedures as described under 20.6.2.2002 NMAC and Section 401of the CWA. To protect and maintain water quality, the SWQB has long employed a strategy of requiring the implementation of BMPs that are designed to prevent to the maximum extent possible the discharge of pollutants to a surface water.

Under the BMP-based approach adopted by New Mexico, regulated discharges that qualify for coverage under the Corps regional or nationwide Section 404 permits that have been certified by the state pursuant to Section 401 of the CWA will not be required to undergo a formal antidegradation review at the time of submitting a Preconstruction Notification and receiving authorization to discharge under the nationwide permit. Antidegradation requirements will be deemed to be met if all appropriate and reasonable BMPs related to erosion and sediment control, project stabilization, and prevention of water quality degradation (e.g., preserving vegetation, stream bank stability, and basic drainage hydrology) are applied and maintained. Applicants desiring to fulfill antidegradation review requirements under this approach will be responsible for ensuring that nationwide permit requirements and relevant water quality certification conditions are met.

Regulated discharges that may degrade waters protected at the **Tier 3** level must comply with the antidegradation requirements applicable to that protection level (i.e., only temporary impacts are allowed as authorized under procedures laid out in 20.6.4.8(A)(3) and 20.6.4.8(A)(4) NMAC) before a certification will be granted under Section 401 of the CWA. Any discharge authorized under an individual or nationwide permit (with the exception of Nationwide Permit 27) under Section 404 of the CWA currently requires an individual certification if it will discharge to an ONRW to ensure that impacts will be temporary.

NMED reserves the right to make case-specific determinations regarding the implementation of this approach during the Section 404 permitting or Section 401 water quality certification processes, which must be completed prior to the commencement of any discharges that result in the placement of dredged or fill material into New Mexico surface waters.

Impacts to Downstream or Adjacent Waters

It is important to note that where a discharge covered by a regional or nationwide general permit under Section 404 of the CWA, the permit only applies to the site of the fill and does not apply to activities or conditions downstream of or adjacent to the site of the fill.

Certain nationwide and regional permits require individual certification by the State of New Mexico in accordance with Section 401 of the CWA. During that individual certification process, NMED will evaluate any potential impacts to downstream waters and incorporate certification requirements to ensure compliance with all aspects of the antidegradation rule.

Overview of the Antidegradation Review for Individual Permits Under Section 404 of the CWA

The decision-making process for individual Section 404 permits is contained in the Section 404(b)(1) guidelines and contains all of the required elements for a Tier 1 and Tier 2 antidegradation review. (40 CFR Part 230). Prior to issuing a permit under the Section 404(b)(1) guidelines, the Corps must: 1) make a determination that the proposed discharges are unavoidable (i.e., necessary); 2) examine alternatives to the proposed discharge and authorize only the least damaging practicable alternative; and 3) require mitigation for all impacts associated with the discharge. A Section 404(b)(1) findings document is produced as a result of this procedure and is the basis for the permit decision. Public participation is also provided for in this process. Because the Section 404(b)(1) guidelines meet the requirements of a Tier 1 and Tier 2 antidegradation review, NMED will not conduct a separate review for the proposed discharge. Tier 1 and Tier 2 antidegradation review will be met through Section 401 certification of individual Section 404 permits and will rely upon the information contained in the Section 404(b)(1) findings document. Any discharge to a Tier 3 water authorized under an individual or nationwide permit under Section 404 (with the exception of Nationwide Permit 27) currently requires an individual Section 401 certification.

4 Determining Baseline Water Quality

Existing – or Baseline Water Quality (BWQ) – provides the reference against which predicted degradation associated with a regulated discharge is measured. This section describes how BWQ is characterized through:

- Establishment of BWQ information for perennial surface waters using existing water quality data.
- Approaches which consider the size and potential impacts of the proposed discharge when determining data needs for BWQ characterization and antidegradation review.
- Cooperative action by both NMED and the applicant to generate BWQ information where few or no data exist.

4.1 SUMMARY OF APPROACH

BWQ is used to evaluate an activity or discharge and determine whether it will degrade or lower water quality. Only an activity or discharge that might cause degradation is subject to a Tier 2 antidegradation evaluation. This evaluation is performed for each parameter or pollutant of concern for which the surface water is afforded Tier 2 protection.

In general, BWQ for perennial waters will be based upon existing data collected under NMED monitoring and assessment programs. Evaluations of BWQ will seek to gather information on pollutants of concern reasonably expected to be in discharges regulated by an individual NPDES permit, including suspended and settleable solids, sediment, nutrients, bacteria, biological oxygen demand, and metals. Information about other pollutants of concern will be handled on a case by case basis.

Where no, or few, data exist, NMED will advise the applicant on what data are needed and provide guidance to the applicant on how to collect and report the needed information to NMED. For perennial waters, the priority approach for evaluating BWQ is to use existing water quality data where available. Where adequate data are not available, the second priority approach is to collect BWQ data. Note that due to the lack of flow on intermittent, ephemeral, and effluent dependent, these types of surface waters will be subject to Tier 1 protection levels and appropriate water quality-based effluent limits designed to achieve applicable water quality standards. If ambient water quality information is available for an intermittent water, BWQ will be determined and Tier 2 requirements applied to the waterbody. Therefore, applicants proposing discharges to these surface waters will not be required to determine BWQ.

The regulated entity for a new or expanded discharge to a perennial water that will be regulated by an individual permit generally will be required to provide BWQ data for pollutants of concern that are reasonably expected to be discharged to help NMED determine BWQ, existing uses, and the applicable tier. **The regulated entity is advised to contact NMED prior to initiating an evaluation of BWQ to seek guidance and concurrence regarding the pollutants to be evaluated and the proposed sampling protocols.** This initial consultation may also be used by regulated entities to evaluate the availability of existing data that may be used as a supplement to, or in lieu of, new BWQ data.

Once BWQ is established for a surface water, it is the yardstick against which degradation is measured during all future antidegradation reviews for that surface water unless BWQ is updated by NMED to reflect changes in water quality. Antidegradation policy generally does not allow a lowering of BWQ. However, certain circumstances may allow for re-evaluation of BWQ. For example, if it is shown that there was an

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error in determining BWQ, then BWQ can be re-evaluated. Likewise, if water quality has improved, allowing for additional available assimilative capacity, then a request for re-evaluation of BWQ will be considered by NMED.

Table 4-1 shows the minimum BWQ information required, by size of discharge (design flow in million gallons per day), before permit development. Data collection for other pollutants may be required depending on the nature of the proposed discharge and the pollutants reasonably expected in the discharge. The BWQ requirements will be based on the surface water quality upstream of the facility.

Table 4-1. Minimum BWQ Information for Dischargers

Parameter/Pollutant	All Dischargers	Discharges >0.1 MGD	Discharges > 1.0 MGD
Flow	Y	Y	Y
Temperature	Y	Y	Y
BOD5/CBOD5/DO	Y	Y	Y
E. coli	Y	Y	Y
Total Suspended Solids	Y	Y	Y
pH	Y	Y	Y
Total Ammonia		Y	Y
Total Residual Chlorine		Y	Y
Total Nitrogen		Y	Y
Total Phosphorus		Y	Y
Total Dissolved Solids		Y	Y
Aluminum, either dissolved or TR			Y
Antimony, dissolved			Y
Arsenic, dissolved			Y
Beryllium, dissolved			Y
Barium, dissolved			Y
Boron, dissolved			Y
Cadmium, dissolved			Y
Chromium, dissolved[1]			Y
Cobalt, dissolved			
Copper, dissolved			Y
Cyanide, TR			
Lead, dissolved			Y
Manganese, dissolved			

[1] Upon consultation, NMED may require speciation of chromium into chromium III and chromium VI.

Parameter/Pollutant	All Dischargers	Discharges >0.1 MGD	Discharges > 1.0 MGD
Mercury [2]			Y
Molybdenum, either dissolved or TR			
Nickel, dissolved			Y
Selenium, either dissolved or TR			Y
Silver, dissolved			Y
Thallium, dissolved			Y
Uranium, dissolved			Y
Vanadium, dissolved			Y
Zinc, dissolved			Y
Hardness, dissolved – must be taken concurrently with metals sampling.			Y
Other constituents (i.e. organics, PCBs, or other applicable pollutants) based on consultation, type of facility	Y	Y	Y

4.2 BASELINE WATER QUALITY EVALUATION PROCEDURES

As needed, BWQ will be established if no BWQ characterization is available or if no information is available for a pollutant of concern reasonably expected to be discharged into the surface water. Data used for a BWQ characterization must meet the following criteria: 1) collected in accordance with an approved quality assurance project plan (QAPP); and 2) collected using specified sample collection and analysis protocols (SOP, SAP, etc.).

Given the complexity of the issue, BWQ characterizations may take some time to complete. It is recommended that regulated entities submit their BWQ monitoring plan and QAPP well in advance of any planned activities or permit application submittals, to facilitate and streamline the permitting process. In addition, environmental groups, trade organizations, the general public, and other governmental agencies may elect to generate BWQ data with the prior approval of NMED and under appropriate, documented quality assurance / quality control (QA/QC) procedures. The objective of this effort is to generate a reasonable, credible, and scientifically defensible characterization of existing water quality for antidegradation reviews.

During data generation projects by regulated entities or third parties, NMED may conduct field, laboratory, or QA/QC audits to verify that data generators are adhering to established sampling protocols, and may split samples for independent analysis. **Data generators that proceed without agency**

[2] Upon consultation, NMED may require speciation of total mercury or dissolved mercury. Methylmercury analysis may also be required.

notification and concurrence risk rejection of the data and significant delays in the permitting process. Potential generators of BWQ data are also encouraged to notify other regulated entities and stakeholders in the water quality segment or watershed of their intent to generate BWQ data. Stakeholder cooperation in the BWQ evaluation process may allow sharing of the cost of data generation and avoidance of conflict in subsequent permitting actions.

4.3 BWQ SAMPLING LOCATION

For new or expanded discharges into a perennial water where there are no existing water quality data on the surface water (i.e., where new data must be collected for evaluation of BWQ), the BWQ sampling location generally will be immediately upstream of the proposed discharge location. Determinations regarding BWQ characterization and accommodation of variations caused by seasonal impacts, water level fluctuations, or other factors will be made by NMED. Information submitted by permittees will be considered on a case-by-case basis.

Where there is adequate, existing water quality data from multiple sampling sites on a surface water, these stations can become the BWQ stations from which a composite BWQ characterization can be developed. Alternatively, NMED may choose one existing monitoring site as the BWQ station from which to characterize baseline water quality. NMED may request additional monitoring at the site if the existing data are insufficient, e.g., where no information has been collected on pollutants of concern reasonably expected in the proposed discharge. Applicants also may be required to collect BWQ data after the permit is issued to develop a BWQ profile during build-out of the activity's discharge capacity.

Sampling and Analysis Protocol

In general, BWQ will be established through existing monitoring and assessment programs sponsored or approved by NMED. NMED will consider the use of older data on a case-by-case basis, as deemed appropriate, if such data is representative of BWQ conditions. In cases where significant changes have occurred in the watershed, it may be appropriate to use a shorter period of record. The minimum elements of an acceptable BWQ monitoring plan include the collection of at least four samples (one sample per quarter) over a minimum one-year period. Data generators may sample more frequently than specified, but are expected to provide the results of all monitoring. Only NMED-approved monitoring results will be used in the establishment of BWQ. Applicants are advised to seek input from NMED prior to developing a BWQ sampling plan and/or collecting samples.

The sampling plan should address the following elements: experimental design of the sampling project; project goals and objectives; evaluation criteria for data results; background of the sampling project; identification of target conditions (including a discussion of whether any weather, seasonal variations, stream flow, lake level, or site access may affect the project); data quality objectives; types of samples scheduled for collection; sampling frequency; sampling period; sampling locations and rationale for site selection; and a list of field equipment (including tolerance range and any other specifications related to accuracy and precision).

Samples, containers, preservation techniques, holding times, and analysis should be conducted in accordance with *Guidelines Establishing Test Procedures and Analysis of Pollutants* at 40 CFR Part 136 and performed by a laboratory certified by the New Mexico Department of Health. The use of other validated analytical methodologies may be authorized where such use can be technically justified. Stream flow should be measured each time BWQ sampling is performed.

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It is important to note that the BWQ pollutant concentrations derived from the data generated will be assumed to be the concentration present during the normal annual low-flow period. All stream samples should be taken when there is a measurable surface flow in the segment at the BWQ sampling location. If environmental conditions prevent achieving the minimum collection requirements, the sampling period should be extended until at least 4 samples are obtained. Acceptable methods for flow measurement include those described in the *Standard Operating Procedure for Stream Flow Measurement* (NMED/SWQB 2015) or at https://www.env.nm.gov/wp-content/uploads/2017/06/ SOP_7.0_Discharge _4-7-15.pdf, or in the U.S Geologic Survey manual *Techniques of Water Resources Investigations of the United States Geologic Survey* (Chapter A8, Book 3, "Discharge Measurements at Gauging Stations") or at https://pubs.water.usgs.gov/TWRI3A8/.

4.4 POLLUTANTS OF CONCERN

Pollutants of concern are those pollutants reasonably expected to be present in a discharge and may adversely affect the water quality of a receiving water body. Not every chemical found in the discharge nor every pollutant for which there are water quality criteria will be of concern. Pollutants that rise to the level of concern will vary by discharge—its quality as well as size—and location of that discharge (i.e., quality of the receiving water).

New or expanded dischargers regulated by an individual permit may be required to generate BWQ data for any pollutants of concern associated with the proposed discharge to a perennial water. In addition to the pollutants of concern, regulated entities may also be requested to provide water quality data for parameters necessary to determine the appropriate value range of water quality criteria (e.g., pH, temperature, hardness). The applicant may also be required to collect data pertaining to impairments in the receiving waterbody. Again, the importance of consultation between BWQ data generators and NMED staff prior to BWQ data generation cannot be overstated.

4.5 INTERPRETATION OF DATA AND ESTABLISHMENT OF BWQ

Generators of BWQ data are expected to provide documentation of their adherence to approved or established protocols and certification that the submitted information is accurate and complete. NMED will review available data and determine BWQ for surface waters on a pollutant-by-pollutant basis. Data generators should make every effort to use the most sensitive, practical analytical methods available. **The use of less sensitive analytical methods may cause rejection of the data set.**

In general, NMED will calculate the geometric mean of all credible data to determine BWQ for a particular pollutant, except *E. coli* bacteria for which the geometric mean will be calculated. For data sets that contain "not detected" or "less than" analytical results, BWQ will be considered to be the detection limit where the reported detection limit is less than or equal to the applicable water quality standard for the pollutant. If at least one data point is detected above the detection limit and the rest of the data points are reported as "less than", then all the data reported as "less than" will be counted as ½ the detection limit when calculating the geometric mean for the BWQ determination.

For data sets where the detection limit is greater than the applicable standard for a pollutant and the reported data are "not detected" or "less than", NMED may request additional data that is analyzed at an appropriate detection level. If additional data are not provided, NMED will use ½ the detection limit when calculating the geometric mean for the BWQ determination.

NMED will use the initial BWQ value established for a particular pollutant in a surface water to judge the impact of all subsequent proposals for discharges involving that pollutant. BWQ re-evaluations may be appropriate if the data used in the original determination is shown to be inaccurate or invalid or if the water quality of the segment is significantly improved when compared with the original BWQ determination. Affected stakeholders may submit a request to NMED for a BWQ re-evaluation under those circumstances. Sampling and analysis will follow the approach in Section 4.3 of this policy, including collection of a minimum of four data points for the re-evaluation.

For a waterbody to show significant improvement, NMED will evaluate old versus new data using the Relative Percent Difference (RPD) of the data. In perennial waterbodies, if the RPD indicates that the water has improved (with respect to specific analytes) according to the matrix listed below, a BWQ re-evaluation may be warranted. Other considerations for a re-evaluation of BWQ include sampling techniques, sample processing and transport, and laboratory analyses.

Table 4-1

Analyte Class (as noted in 20.6.4.900 NMAC)	**Relative Percent Difference (RPD) threshold for BWQ Re-evaluation**
Persistent/Bio-accumulative (HH-OO)	No re-evaluation – NMED will consider bio-accumulative pollutants on a case by case basis
All other analytes	≥20% improvement in water quality

5 Evaluating the Level of Degradation of Proposed Discharges

Antidegradation reviews are required for all regulated discharges that have the potential to degrade water quality in New Mexico. The review procedures described in this chapter do not apply to non-point sources of pollution (addressed in the Nonpoint Source Management Plan), discharges covered under Section 404 of the CWA (addressed through certification conditions and implementation of BMPs) or NPDES general permits (addressed through the implementation of benchmarks and BMPs). The antidegradation procedures vary by the tier level of protection and by the type of surface water. For pollutants with Tier 2 protection levels, the degradation evaluation determines whether or not significant degradation will occur – i.e., whether or not 10% or more of the available assimilative capacity for any pollutant of concern will be consumed as a result of the proposed discharge during critical flow (e.g., 4Q3) conditions or the cumulative cap of 50% of available assimilative capacity is exceeded. The level of degradation will be evaluated from BWQ conditions.

For Tier 3 protection levels, the degradation evaluation must determine that no degradation will occur as a result of the proposed discharge unless the impacts are temporary. As a general rule of thumb, temporary impacts are defined as impacts of less than six months duration.

5.1 Applicability of Degradation to the Various Protection Tiers

The concept of degradation is relatively simple: any discharge that results in a decline of water quality (as determined on a pollutant-by-pollutant basis). Degradation is not allowed to cause or contribute to impairments that result in the loss of existing uses (i.e., the Tier 1 threshold), and is not allowed at all in Outstanding New Mexico Waters (ONRWs) unless it is temporary (i.e., the Tier 3 threshold) as determined by NMED and approved according to 20.6.4.8 NMAC.

Significant degradation may be allowed in surface waters protected at the Tier 2 level if the applicant for a new or expanded discharge characterizes the effluent and BWQ, completes an alternative analysis, and provides social and economic supporting documentation. For Tier 2 reviews, determining BWQ, evaluating projected impacts, analyzing possible alternatives, and evaluating economic or social benefits, if applicable, must occur ***prior to*** issuing an individual NPDES permit. Therefore, it is recommended that an applicant discharging to a perennial water meet with NMED in a pre-application conference **at least one year prior** to the anticipated date of NPDES permit issuance.

Decisions regarding significant degradation of Tier 2 protection levels will only be made after the required alternatives analysis along with economic and social benefits justification have been completed, after technology-based and nonpoint source control requirements are met, and after the intergovernmental coordination and public participation provisions in Chapter 8 have been satisfied.

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5.2 PROCEDURE FOR TIER 2 DEGRADATION EVALUATION

Tier 2 evaluation procedures vary by the type of surface water, as outlined below:

Discharges to Non-Perennial Waters

Many individual NPDES permit applicants will likely discharge to an ephemeral, intermittent, or effluent dependent water. Tier 2 degradation evaluation procedures do not apply to these discharges. Discharges to non-perennial waters will be required to meet applicable surface water quality standards and technology-based standards, e.g., best available technologies (BAT) at the "end-of-the-pipe" (i.e., Tier 1 degradation evaluation procedures).

In some limited cases, data may be available to determine BWQ in these non-perennial waters. If data are available and assessable and confirm a high-quality water, NMED would conduct a Tier 2 antidegradation review. Similar to perennial waters, no significant degradation of the Tier 2 pollutants would be allowed unless a comprehensive antidegradation review of reasonable alternatives and social and economic considerations supports a lowering of water quality.

Discharges to Perennial Waters

All other individually-permitted discharges to perennial waters must conduct an antidegradation review to determine whether or not significant degradation will occur, i.e., whether or not 10% or more of the available assimilative capacity for any pollutant of concern will be consumed as a result of the proposed discharge during critical flow (e.g., 4Q3) conditions or the cumulative cap of 50% of assimilative capacity is exceeded. The Tier 2 degradation review for new or expanded discharges is based on these characterizations:

- BWQ, as determined by data collected pursuant to Chapter 4
- The critical in-stream flow (e.g., 4Q3)
- The flow and pollutant loads resulting from the proposed discharge
- Projected changes in water quality that occur as a result of the proposed discharge

The results of the antidegradation review will be used to determine whether the proposed discharge will be subject to additional requirements as part of the permitting process, such as analyses of reasonable, cost-effective, less degrading or non-degrading alternatives and examination and justification of important economic and social costs and benefits (see Chapter 6 and Chapter 7, respectively).

Mixing Zones

If needed, a new or expanded facility who discharges to a perennial water may be evaluated for the applicability of a mixing zone analysis on a case by case basis.

5.3 CALCULATIONS TO DETERMINE SIGNIFICANCE OF DEGRADATION

At the Tier 2 protection levels, BWQ is better than the water quality standards for one or more pollutants. Therefore, no significant degradation from BWQ is allowed unless a comprehensive antidegradation review of reasonable alternatives and social and economic considerations supports a lowering of water quality. Degradation is generally assumed to be "significant" if a discharge consumes 10% or more of a surface water's assimilative capacity for any pollutant of

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concern (other than bio-accumulative pollutants as defined by the human health-organism only (HH-OO) criteria at 20.6.4.900 NMAC) under critical flow conditions or the discharge consumes any percentage of the cumulative assimilative capacity beyond 50%.

To determine if a discharge will cause significant degradation, assimilative capacity must be calculated and then evaluated under critical flow conditions. The first step in this process is to calculate the assimilative capacity and significant degradation limit. The assimilative capacity of the waterbody for any pollutant of concern under review is the difference between *observed* BWQ and the most stringent applicable water quality criterion. Figure 5-1 provides a simplified visual representation of assimilative capacity for a given pollutant (Pollutant X). In this example, the most stringent applicable water quality criterion for Pollutant X is 10 mg/L and the *observed* BWQ measurement is 3 mg/L. In Figure 5-1, the assimilative capacity of Pollutant X is the difference between the water quality criterion and the BWQ, or 10 mg/L minus 3 mg/L, and equals 7 mg/L. The "significant degradation" limit is 10% of the assimilative capacity (7 mg/L) or 0.7 mg/L. Thus, a regulated discharge undergoing a Tier 2 review would be considered *de minimis* (i.e., no significant degradation) if it did not cause the water quality in the receiving surface water to exceed the BWQ (3 mg/L) plus the significant degradation limit (0.7 mg/L), or 3.7 mg/L for Pollutant X.

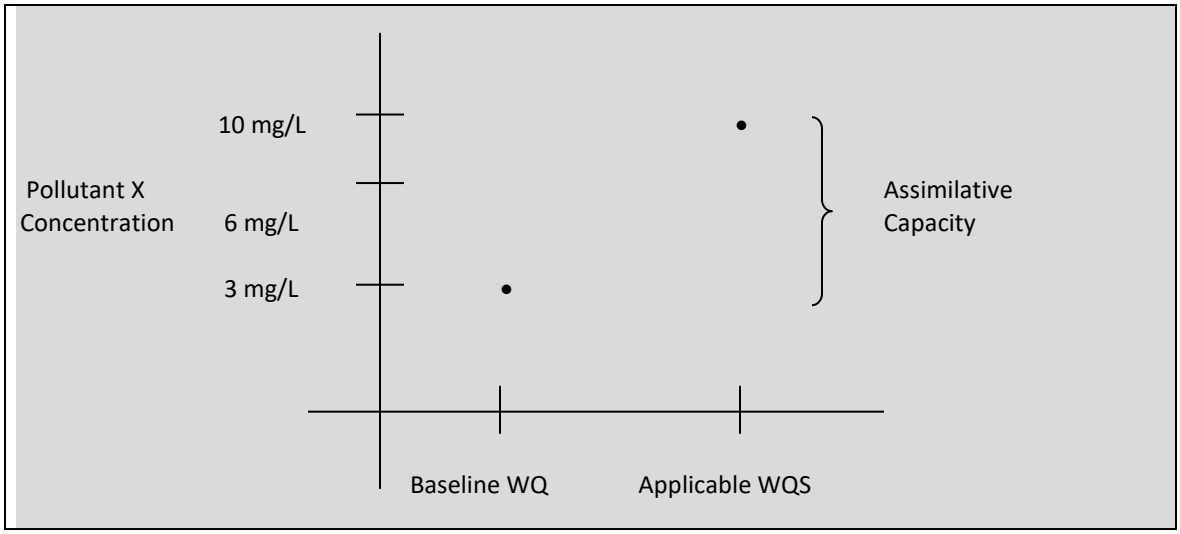


Figure 5-1. Simplified Representation of Assimilative Capacity

The second step to determine the significance of degradation is to evaluate the "significant" assimilative capacity concentration, identified in step one, under critical flow conditions. While NMED's antidegradation formula evaluates the assimilative capacity concentration similar to the example shown above in Figure 5-1, that resultant concentration is converted to a load using the receiving stream's critical flow and a conversion factor of 8.34. For example, the significant degradation concentration limit of 3.7 mg/L for Pollutant X in Figure 5-1 is converted to a loading capacity using the following formula:

$$Load\ Capacity\ \left(\frac{lbs}{day}\right) = concentration\left(\frac{mg}{L}\right) x\ flow\ (4Q3, million\ gallons\ per\ day)\ x\ 8.34$$

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Consideration of Multiple Discharges – 50% Cumulative Cap

To address degradation associated with multiple regulated discharges to the same receiving water over time, NMED is establishing a separate significance threshold of a 50% cumulative cap on the consumption of assimilative capacity. This approach creates a "backstop" so that multiple regulated discharges to a water body over time which individually do not consume 10% of the assimilative capacity do not result in the consumption of the majority of the assimilative capacity without NMED ever conducting a comprehensive Tier 2 antidegradation review. NMED has established this significance threshold at 50% of the assimilative capacity when BWQ is characterized. This means that once 50% of the assimilative capacity is used in a surface water for a pollutant of concern, any further lowering of water quality is considered significant degradation. NMED will conduct a comprehensive Tier 2 antidegradation review for each lowering of water quality once the 50% cumulative cap is exceeded, regardless of the amount of assimilative capacity that would be used by the regulated discharge.

Critical Flow

The calculations noted above are to be executed under critical flow conditions for the pollutants of concern. For point source discharges, critical flow for all criteria/pollutants, except HH-OO, is the minimum four consecutive day flow that occurs with a frequency of once in three years (4Q3) in the receiving water. (20.6.4.11(B)(2) NMAC). Critical lake and reservoir water levels will be determined on a case-by-case basis.

Calculations for Tier 2 Pollutants

The calculation to determine if a discharge will result in significant degradation is a variation of the mass balance equation that is used to determine water quality-based effluent limits:

$$(Q_d)(C_d) + (Q_s)(C_s) = (Q_r)(C_r)$$

Where:

Q_d =discharge flow cfs
Q_s =stream flow (4Q3)
Q_r =resulting in-stream flow (downstream of discharge, or Q_s+Q_d)
C_d =discharge concentration,
C_s =concentration in stream

C_r = resultant in-stream concentration

Solve for C_d:

$$C_d = \frac{[C_r(Q_d + Q_s)] - [(C_s)(Q_s)]}{Q_d}$$

For purposes of Tier 2 antidegradation reviews, NMED solves for the discharge concentration that uses 10% of the assimilative capacity:

Where:

C_{bwq} = BWQ
C_r = resultant in-stream concentration = [(WQS - C_{bwq}) x 0.1 + C_{bwq}]

$$C_d = \frac{[((WQS - C_{bwq}) \times 0.1 + C_{bwq})(Q_d+Q_s)] - [(C_s)(Q_s)]}{Q_d}$$

The calculated discharge concentration (C_d) is compared with the proposed discharge concentration. If the calculated concentration is greater than the proposed concentration, then a determination of "no significant degradation" is found. If the level of degradation is estimated to be less than 10% of the assimilative capacity, and less than 50% of the cumulative cap (if applicable), *and* existing uses are maintained, the antidegradation review process is complete and the permitting process may proceed.

If the discharge is found to consume more than 10% of available assimilative capacity (calculated < proposed) or exceeds the 50% cumulative cap, a comprehensive Tier 2 review is required. The regulated discharge would be required to conduct an alternatives analysis (Chapter 6) and demonstrate "important economic or social development" (Chapter 7) if allowances are sought to further reduce assimilative capacity. If such demonstrations are made, the WQCC may allow consumption of additional assimilative capacity (degradation) as long as intergovernmental and public participation processes are followed and water quality standards are not violated.

6 Identifying and Evaluating Pollution Control Alternatives for Tier 2 Protection

A regulated entity proposing a new or expanded discharge requiring an individual NPDES permit that would significantly degrade water quality in a Tier 2 surface water (i.e., consume 10% or more of the assimilative capacity or exceed the cumulative cap of 50% for any pollutant of concern) is required to prepare an evaluation of alternatives to the proposed discharge. The evaluation must provide substantive information pertaining to the cost and environmental impacts associated with the proposed discharge and the alternatives evaluated. This chapter provides guidance on how to evaluate alternatives when an impacts analysis determines that significant degradation may occur.

The intent of the alternatives analysis is to identify cost-effective and reasonable *less degrading* or *non-degrading* approaches for reducing discharge-related impacts so they do not result in significant degradation of the receiving water.

6.1 Less Degrading and Non-degrading Pollution Control Measures

Under New Mexico's antidegradation implementation procedures, applicants are required to analyze these alternatives if their proposed discharge will cause significant degradation of higher quality (i.e., Tier 2) waters. Less degrading or non-degrading pollution control alternatives identified and evaluated during this process should be reliable, demonstrated processes or practices that can be reasonably expected to result in a defined range of treatment or pollutant removal.

Applications containing proposals for new or experimental methods will be required to append information regarding likely performance results and may be approved at the discretion of NMED with the understanding that if the proposed technology does not meet projected pollutant control targets the applicant must adopt conventional or other pollution control measures that meet state antidegradation requirements.

Pollution control alternatives that may be evaluated when a proposed discharge will result in significant degradation of the receiving water segments may include the following:

- Alternative methods of production or operation
- Pollution prevention and treatment process changes
- Recycling/reusing wastewater (i.e., closed loop systems)
- Holding/transport facilities for treatment/discharge elsewhere
- Groundwater recharge (i.e., soil-aquifer treatment, injection)
- 100% reuse
- Advanced or innovative biological/physical/chemical treatment
- Pollution prevention and process changes
- Improvements in the collection system
- Improved operation and maintenance of existing treatment system

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- Seasonal or controlled discharges to avoid critical periods
- Alternative discharge locations, and associated water quality impacts at those locations
- Reduction in the scope of the proposed project

Applicants will be expected to address reasonable and cost-effective alternatives, or mix of alternatives, in their evaluations. NMED staff and the applicant will meet to discuss these and other issues early in the process. It is the responsibility of the applicant to screen for and propose a list of reasonable, cost-effective alternatives that will be evaluated in detail. NMED may require that additional alternatives be analyzed.

If the project results in significant degradation even after applying reasonable, cost-effective alternatives, the proposal must demonstrate 1) important social or economic development as outlined in Chapter 7; 2) the level of water quality necessary to protect existing uses is maintained (i.e., Tier 1 protection); 3) all cost-effective and reasonable BMPs for nonpoint source control are implemented; and 4) the highest statutory and regulatory requirements for all new and existing point sources are achieved (20.6.4.8(A)(2) NMAC).

6.2 IDENTIFYING COST COMPONENTS AND ASSESSING COSTS

An assessment of costs related to the alternatives summarized above is necessary to determine whether or not a prospective alternative pollution control measure is reasonable. General cost categories include:

- Capital costs
- Operating costs
- Other costs (one-time costs, savings, opportunity cost, salvage value)

In order to develop a standardized framework for projecting, evaluating, and comparing costs associated with various pollution control measures, applicants should use a "present worth" framework for generating and reporting cost information. Components of the present worth framework include:

$$P = C + O + [A * (P/A, d, n)] - S - L$$

Where:

P = Present worth,
C = Capital cost,
O = Other costs (expressed as dollars invested at the beginning of the project),
A = Annual operating cost,
d = Discount rate,
n = Useful life in years,
S = Present worth of salvage value of facilities,
L = Present worth of salvage value of land, and
$(P/A, d, n)$ = Equal series present worth factor, = $[(1 + d)^n -1] / [d (1+d)^n]$.

The present worth calculated for the alternative technologies depends on the right choice for the discount rate (d), and the useful life (n) of the equipment or facility. Recommended discount rates for New Mexico are provided by the New Mexico Water Infrastructure Finance Authority (WIFA). The useful life of the facility or equipment is based upon similar facilities or equipment handling similar wastes and flows and must be approved by NMED. Speculative costs for land, facilities,

etc., will not be allowed. For more information on the present worth calculation and other methods that may be used to assess costs, see Appendix A1, Direct Cost Comparison of Alternatives.

6.3 Evaluating Environmental Impacts Associated with Alternatives

Pollution control measures evaluated as alternatives to a proposed discharge may have environmental impacts that help define their overall value and/or desirability. Applicants are required to provide substantive information pertaining to both the cost and environmental impacts associated with pollution control alternatives evaluated for discharges that would significantly degrade Tier 2 level of protection. The information related to environmental impacts should include impacts on the natural environment (i.e., land, air, and water) resulting from implementation of the alternative. The types of impacts evaluated during this process may include:

- Sensitivity of stream uses
- Need for low-flow augmentation
- Sensitivity of groundwater uses in the area
- Potential to generate secondary water quality impacts (storm water, hydrology)
- System or technology reliability, potential for upsets/accidents
- Effect on endangered species
- Non-water quality environmental impacts
- Nature of pollutants discharged
- Dilution ratio for pollutants discharged
- Discharge timing and duration
- Siting of plant and collection facilities

Review of these impacts might be on a qualitative or quantitative basis, as appropriate. Non-water quality environmental impact analyses to be submitted by the applicant include estimations of the potential impact of the alternative(s) on odor, noise, energy consumption, air emissions, and solid waste generation. Odor and noise may be addressed qualitatively while other non-water quality impacts might need to be addressed quantitatively. The energy use, air emission, and solid waste generation impacts can be expressed as a percent increase/decrease as compared to the proposed discharge. Other factors that should be considered during the review include the technical, legal, and local considerations of the various alternatives examined. The schedule and the estimated time of completion of the project should also be provided for each alternative discussed.

6.4 Cost and Reasonableness Criteria for Alternatives Evaluation

In general, an alternative or suite of alternatives is considered to be cost-effective and reasonable if it is feasible and the cost is less than 110% of the *base costs* of pollution control measures for the proposed discharge in present worth costs. It should be noted that the 110% cost-effectiveness criterion is a general rule-of-thumb – if pollution control costs for alternatives that

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would result in water quality benefits exceed the 110% cost threshold, those alternatives may be required if the water quality and environmental benefits outweigh the economic costs.

When calculating the cost of a proposed discharge and any less- or non-degrading alternatives, it is important to identify the base cost for required pollution control measures for any proposed discharge. The base cost for NPDES-permitted facilities is the cost of treatment to meet applicable water quality standards or the cost of meeting federal technology-based requirements, whichever is more stringent and legally applicable. The base cost for Section 404 dredge-and-fill permits (e.g., wetland fills, mining streambed fills) is the cost of pollution controls to meet minimum Section 404 permit and Section 401 water quality certification requirements.

6.5 PROCEDURE FOR COMPARING COSTS OF VARIOUS ALTERNATIVES

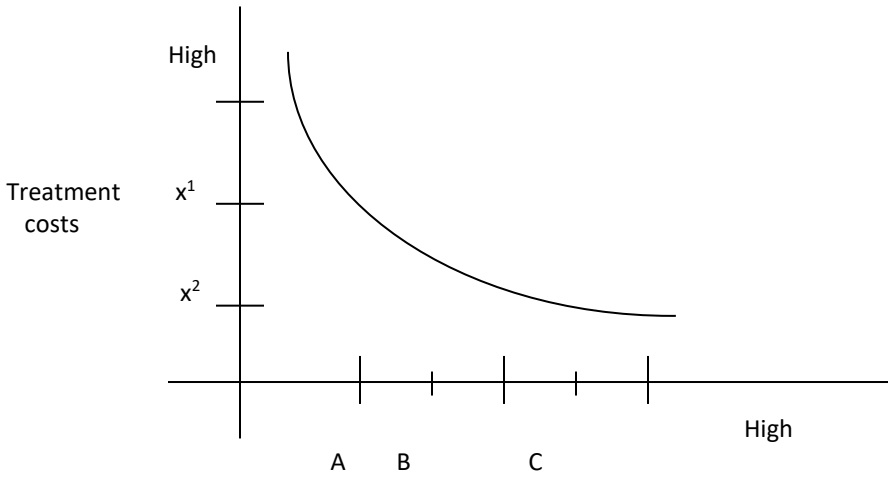
In reviewing costs for a variety of discharge scenarios, three reference costs can be identified (see Figure 6-1):

- The cost of treatment that results in no discharges of any pollutants of concern (the "no-discharge" cost).
- The cost of treatment that produces an effluent that results in no significant degradation of the receiving water, i.e., that does not consume more than 10% of the available assimilative capacity for any pollutant of concern.
- The cost of treating an effluent to a quality that meets specific effluent/ BAT limits or water quality criteria for any/all pollutants of concern (i.e., the conceptual minimum Tier 1 requirement).

The base cost for comparing the reasonableness and cost-effectiveness of less degrading or non-degrading alternatives is the cost of producing an effluent that meets water quality standards or the cost of meeting federally-required effluent concentration limits or best available technology, whichever is more stringent (level C in Figure 6-1).

Applicants will be required to submit cost information to NMED for base pollution control measures as defined above and alternative pollution control measures that would result in no significant degradation (level B). NMED may request cost or other information regarding preventing degradation (level A). NMED will evaluate the limitations of the alternatives analysis and may request additional analyses or information, as needed, to make a determination.

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A = The "no degradation" alternative
B = Activity modifications resulting in "no significant degradation," i.e., does not consume more than 10 percent of the available assimilative capacity for any other pollutant of concern (POC)
C = Activity modifications that achieve or maintain minimally required use-based water quality criteria or best available demonstrated control technology
x^1 = Costs for implementing the "no degradation" alternative
x^2 = Costs for less degrading alternative(s)

Figure 6-1. Comparison of Treatment Costs to Produce Effluents of Varying Quality

6.6 SUMMARY OF THE ALTERNATIVES ANALYSIS PROCESS

The preceding discussion describes the approach that will be followed by NMED for determining whether or not less- or non-degrading alternatives to the proposed new or expanded discharge will be required to prevent significant degradation of perennial surface water. The following steps summarize the alternatives analysis process and other relevant actions during comprehensive Tier 2 reviews:

- Based on characterizations of the new or expanded proposed discharge, BWQ, and projected impacts on the receiving water segment, NMED will determine whether or not the proposed discharge will significantly degrade water quality, i.e., consume more than 10% of the available assimilative capacity for any other pollutant of concern.
- If it is determined that significant degradation would likely occur due to the proposed discharge, an analysis of less degrading or non-degrading alternatives to the proposed discharge will be required.
- The applicant will be required to submit cost information for base pollution control measures associated with the proposed discharge, alternative pollution control measures that would result in no significant degradation, and for other less or non-degrading alternatives as appropriate.

- NMED will evaluate the proposed discharge, the less and non-degrading alternatives, and the costs and feasibility associated with each mix of options.
- NMED will approve the least degrading alternative – or mix of alternatives – that does not exceed the 110% base cost threshold (i.e., is cost-effective and reasonable).
- If the approved alternative (i.e., pollution control alternative or mix of alternatives) will not result in significant degradation of the receiving water segment, permitting of the discharge may proceed. If the approved alternative will still result in significant degradation of the receiving water, the applicant will be required to conduct an analysis of economic and social benefits so the WQCC can determine whether or not the discharge can be permitted.
- All water quality impacts in the alternatives analysis will be evaluated at the BWQ station and back-calculated to develop the upstream effluent limit (i.e., the degradation of proposed discharges including alternatives will be evaluated at the BWQ point, while permit limits and permit compliance will be developed and evaluated at the discharge point).

If the project results in significant degradation even after applying reasonable, cost-effective alternatives, in order to allow such degradation and lowering of water quality the proposal must demonstrate that the new or expanded discharge is important to economic and social development (as outlined in Chapter 7), protects existing uses (i.e., maintains Tier 1 protection), achieves the highest statutory and regulatory requirements for point sources, and implements cost-effective and reasonable BMPs for nonpoint source control (20.6.4.8(A)(2) NMAC). NMED encourages watershed planning to further protect surface water quality and CWA Section 319 grants are available for various groups to plan and implement on-the-ground improvement projects. In addition, Clean Water State Revolving Fund (CWSRF) loans are available for a wide range of wastewater or storm drainage projects that protect surface and ground water, including projects that control nonpoint source pollution.

7 Social and Economic Importance for Tier 2 Reviews

7.1 Regulatory Requirements for Social and Economic Analysis

As discussed in previous chapters, if an alternatives analysis has been conducted for a proposed new or expanded discharge to a Tier 2 protected water requiring an individual NPDES permit, and the least degrading, cost-effective alternative still results in significant degradation, an analysis of the social and economic importance of the discharge must be conducted. Under New Mexico's antidegradation policy, found at 20.6.4.8(A)(2) NMAC, the Commission may authorize a proposed discharge that would significantly lower the water quality of a Tier 2 water, if allowing lower water quality is necessary to accommodate important economic and social development in the area in which the surface water is located.

There are several steps in determining social and economic importance. First, the applicant conducts an analysis of the social and economic benefits/costs associated with the discharge. The applicant must document any social and economic benefits/costs associated with the proposed discharge and report them to NMED, including identifying and documenting general environmental justice issues in the area where the discharge will be located that may impact the benefits/costs analysis[3,4]. NMED then reviews the information and may require additional information and/or a more in-depth, substantial and widespread impact analysis if there is not enough information to make a decision or if the proposed discharge is complex. Additional information is included in Appendix A.3 and Appendix A.4. If enough information has been submitted, NMED will make a preliminary determination to deny or authorize the degradation. Finally, "after public comment and intergovernmental coordination, the WQCC analyzes all information and makes a final determination (20.6.4.8(A)(2) NMAC).

7.2 Role of the Applicant

The role of the applicant is to demonstrate the social and economic benefits of the proposed new or expanded discharge associated with allowing significant degradation of high-quality water. The report on social and economic benefits/costs (positive and negative) associated with the project is relatively simple and straightforward. NMED requires that up-to-date and accurate data are included in the report, and that estimates of job gains/losses, housing impacts, etc., be summarized completely and based on defensible estimates. Using the *Social and Economic Importance Worksheet*, Appendix A.2, the applicant must document how the proposed new or expanded discharge affects the social, economic, and environmental factors listed below.

Social, Economic, and Environmental Considerations

[3] For information on the EPA Region 6 EJ Action Plan, visit: https://www.epa.gov/environmentaljustice/region-6-new-mexico-ej-action-plan

[4] Environmental Justice Screening and Mapping Tool: https://www.epa.gov/ejscreen

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Below are the **economic and social** benefits/costs most commonly associated with this socio-economic analysis:

- Creating, expanding or maintaining employment
- Reducing the unemployment rate
- Increasing median household income
- Reducing the number of households below the poverty line
- Increasing needed housing supply
- Increasing the community tax base
- Providing necessary public services (e.g., fire department, school, infrastructure)
- Correcting a public health, safety, or environmental problem
- Improving quality of life for residents in the area

Below are the **environmental** benefits or costs most commonly associated with this analysis:

- Promoting/impacting fishing, recreation, and tourism industries
- Enhancing/impacting threatened and endangered species
- Providing increased flood control and sediment trapping through maintaining or creating wetlands and riparian zones or impacting wetlands and riparian zones
- Reserving assimilative capacity for future industry and development or reserving no capacity for future discharges.

The applicant may choose or may be required to describe additional factors as needed to strengthen its Social and Economic Importance Analysis. Appendix A.4, *Other Economic and Environmental Considerations*, provides examples of other issues that might be helpful to address in developing an analysis. All information provided should be based upon the most current, available data.

7.3 ROLE OF NMED

Prior to issuance of any proposed new or expanded discharge permit that would significantly lower the water quality of a Tier 2 protected water, NMED will ensure that the proposed discharge is necessary to accommodate important economic or social development in the area in which the waters are located. NMED may also collect and analyze additional information to assess the market and non-market social and economic benefits and costs of the proposed discharge, including by soliciting public information and comment where appropriate or by accessing information available from the New Mexico Community Data Collaborative (http://www.nmcdcmaps.org/), the Distressed Communities Index (https://eig.org/dci), or EPA, including EJSCREEN (https://www.epa.gov/healthresearch/tools-support-environmental-justice). In making a preliminary decision, NMED will rely primarily on the demonstration made by the applicant. NMED will analyze all information and make a preliminary determination on the facts on a case-by-case basis.

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If information available to NMED is not sufficient to make a preliminary determination regarding the socioeconomic importance of the proposed new or expanded discharge, NMED may require the project applicant to submit specific items of information needed to make a determination. NMED may also require use of quantitative models for large proposed discharge (e.g., major industrial wastewater treatment facility, large concentrated animal feeding operation, etc.).

Once the available information pertaining to the socioeconomic importance of the proposed new or expanded discharge has been reviewed by NMED, a preliminary determination to deny or authorize the degradation will be made. If the proposed discharge is determined to be necessary to accommodate important economic or social development in the area in which the affected waters are located, the substance and basis for that preliminary determination will be documented and the Tier 2 review will continue. NMED will make the preliminary determination available to the public and forward its preliminary determination to governmental agencies that may be impacted by the discharge.

Once the public participation and intergovernmental coordination requirements are satisfied, the WQCC will make a final determination concerning the social or economic importance of the proposed new or expanded discharge and whether to deny or authorize the discharge (20.6.4.8(A)(2) NMAC). All social and economic importance findings and other required findings, including determinations to deny issuance of a permit for a discharge, will be documented and made part of the public record.

8 Requirements for Intergovernmental Coordination and Public Participation

This chapter outlines public participation and intergovernmental coordination and review requirements. Antidegradation reviews for NPDES-permitted facilities will employ the public participation procedures that are available through the permitting process (e.g., draft permits, fact sheets, opportunities to comment, etc.). The NPDES permit fact sheet will include a discussion for the public of NMED's antidegradation review.

Once the intergovernmental coordination and public notice requirements outlined below are satisfied, NMED will make a final determination concerning the social or economic importance of the proposed new or expanded discharge in the area in which the affected receiving waters are located. All determinations, including determinations to prohibit the discharge, will be documented and made a part of the public record.

8.1 PUBLIC NOTIFICATION REQUIREMENTS

There are a number of opportunities for public participation in the review of new and increased discharges into Tier 1 waters. The WQCC adopts Total Maximum Daily Loads (TMDLs) with applicable wasteload allocations for point sources discharging to Tier 1 waters not meeting water quality objectives. This process includes public notice and comment. The EPA and Army Corps follow detailed procedures requiring public notice and comment when issuing NPDES and Section 404 dredge or fill permits. Finally, the NMED's Section 401 certifications can be appealed and a full hearing held before the WQCC.

Public notice and opportunity for public comment is also provided for all comprehensive Tier 2 reviews. NMED will publish notice and provide an opportunity to comment on the preliminary decision and statement of basis. The public comment period will be at least 30 days. Public notice and opportunity for comment may be combined with other public participation procedures, such as those related to NPDES permitting processes or intergovernmental coordination / review procedures. During the public comment period, any interested person may submit written comments and request a public hearing. A request for a public hearing must be in writing and must state the nature of the issues to be raised. If NMED determines that the request for public hearing raises issues of significant public interest within the scope of the antidegradation policy, the Department will hold a public hearing. The public hearing will be held in a location near the water affected by the discharge.

Discharges that may result in a significant degradation of water quality for Tier 2 pollutants may be approved by the WQCC, after full satisfaction of the intergovernmental coordination and public participation processes, provided that:

- The level of water quality necessary to protect existing uses is fully protected. Water quality shall be maintained and protected in all surface waters of the state (20.6.4.8(A)(1) NMAC).

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- The highest statutory and regulatory requirements for new and existing point sources are achieved.
- All cost-effective and reasonable best management practices for non-point source pollution control are implemented.
- Allowing lower water quality is necessary to accommodate important economic or social development in the area where the surface water is located.
- Watershed-based planning as a further means to protect surface waters is encouraged.

All comprehensive Tier 2 findings will be documented by NMED and made part of the administrative record. Review documents – including evaluations of BWQ, existing uses, the level of review conducted, alternatives analyses, social/economic studies, impacts analyses, and any decisions or findings – will be made available to the public.

For activities that may impact Tier 3 waters, NMED will publish notice and provide a 30-day public comment period. After the comment period, NMED will provide a recommendation to the Commission. NMED will provide notice of activities approved by the WQCC pursuant to 20.6.4.8(A)(3)(a) NMAC and of activities conducted pursuant to 20.6.4.8(A)(4) NMAC by posting a brief description, location, and timeframe for such activities on a dedicated Department website.

8.2 Opportunities for Public Participation

Public participation in the implementation of New Mexico's water quality antidegradation policy can be broad or specific. Opportunities for broad participation include involvement in the triennial review of the water quality standards program (i.e., use designations, water quality criteria determinations, antidegradation implementation procedures) and participation in rule development relative to permitting processes. In addition, any interested party may nominate a water segment for protection at the Tier 3 level by following the procedure for consideration outlined under 20.6.4.9 NMAC (see Chapter 2). Finally, interested groups can conduct volunteer monitoring under an NMED-approved plan to support BWQ determinations.

Wherever possible, NMED will seek to integrate public participation regarding antidegradation reviews with existing NMED public participation procedures (e.g., NPDES permitting procedures).

8.3 Intergovernmental Coordination and Review

Intergovernmental coordination is required prior to approving a new or expanded discharge requiring an individual NPDES permit that would significantly degrade a surface water protected at the Tier 2 level. This requirement seeks to ensure that all relevant public entities at the local, state, and federal levels are aware of any proposal to significantly lower water quality and are provided with an opportunity to review, seek additional information, and comment on the proposal. The intergovernmental coordination and review process occurs prior to the issuance of any final determination on the social and/or economic importance of the proposed discharge, and may occur in tandem with public notice procedures outlined in the previous section. The time period afforded to commenting agencies will be consistent with the requirements for submission of public comments.

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Intergovernmental coordination requirements will be satisfied by providing a written notice and request for comment to the appropriate agencies listed in Appendix A.5. Such notice will include summary information on the proposed new or expanded discharge, the receiving water segment, the BWQ of the receiving water segment, the tier designation, estimated impacts of the proposed discharge upon the receiving water, the alternatives reviewed, and the projected social or economic importance of the proposed discharge. In providing notice to these agencies, staff should note the importance of circulating the notice to local or regional constituents of the agencies involved so that NMED receives timely and complete responses from governmental entities that might have information regarding the proposal or might be affected by it.

8.4 APPEALS OF ANTIDEGRADATION REVIEW DECISIONS

Persons adversely affected by any final decision of the Department may appeal to the WQCC in accordance with the New Mexico Water Quality Act, NMSA 1978, Sections 74-6-1 to -17.

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Appendix A.1
Direct Comparison of Alternatives

Direct cost comparisons of alternatives are typically performed on the basis of present worth calculations or calculations of uniform annual cost (if the useful life of each alternative is different), using an applicable interest (discount) rate. The present worth calculation is a well-established method for integrating the upfront capital costs (and associated indebtedness) of a project with its ongoing annual costs of operation, and transforming the integrated costs to one equivalent value. The calculation yields the total equivalent dollars which would have to be invested at the beginning of a project in order to finance it for the life of the facility. The monetary costs considered in the calculations include the total value of the resources, which are attributable to the wastewater treatment, control, and management systems and the component parts. To determine these values, all monies necessary for capital construction costs, operational costs, and maintenance costs should be identified.

Capital construction costs used in cost comparison analysis consist of estimates of the construction costs, including overhead and profit; costs of land (including land purchased for the treatment works site and land used as part of the treatment process or for ultimate disposal of residues), relocation expenses, and right-of-way and easement acquisitions; costs of design engineering, field services (including cost of bond sales); startup costs such as operator training; financing costs and interest during construction; and the costs of any other site-related environmental controls, such as erosion and sediment control practices.

Operational and maintenance costs are usually considered on an annual basis and include operational staff salaries, cost of energy and fuels, cost of treatment chemicals, cost of routine replacement of equipment and equipment parts, and other expenditures necessary to ensure effective and dependable operation over the life of the facility. Annual operation and maintenance costs should be averaged to account for variations, which might occur, year-to-year due to varying production or wastewater volume.

The salvage value of equipment, tankage, and materials from the treatment works is part of the present worth calculation. Salvage value is estimated using straight-line depreciation during the useful life of the project and can generally only be claimed for equipment where it can be clearly demonstrated that a specific market or re-use opportunity will exist. Salvage value estimation should also take into account the costs of any restoration or decommissioning of treatment units and final disposal costs. It is possible in some cases that these costs may be high enough that the net salvage value will be negative.

Land purchased for the treatment works site is also assumed to have a salvage value at the end of the project useful life equal to its market value at the end of the analysis period. The local inflation rate for land in the use area should be used to project the market value at the end of the analysis period.

It is also important to evaluate any opportunity cost associated with different alternatives. Opportunity costs should not be considered for speculative growth or production increases claimed by an applicant. Any costs claimed should be clearly associated with integral portions of projects, which are realistically available, and are otherwise locally approvable.

The discount rate used in the present worth or uniform annual cost calculation for public sewerage projects should be that rate published by the NMED Construction Program Bureau and associated funding agencies for the planning review and evaluation of water resource projects. The rate is available from NMED. For private sector projects, the interest rate utilized should be that rate at which the applicant can borrow funds. Since the present worth calculation is being performed more to compare alternatives rather than to obtain a very accurate estimation of

actual costs, the fact that the same interest rate assumption be utilized for each alternative is more important than the actual interest rate selected.

Cost estimates have an associated level of precision. The cost estimates prepared by the project sponsor should include an estimate of the error for each alternative. The applicant is responsible for documenting and defending all cost estimates used in the analysis.

Cost estimate equations:

The equations below are the basic expressions of the present worth and equivalent annualized cost concepts. Additional mathematical factors and apportionment of costs are incorporated into the equations where appropriate.

I. The basic present worth calculation should be performed in accordance with the following equation:

$$P = C + O + [A * (P/A,d,n)] – S – L$$

where,

P = present worth

C = capital cost

A = annual operating costs

(P/A,d,n) = equal series present worth factor $[(1 + d)^n – 1] / [d (1 + d)^n]$

d = discount rate

n = useful life in years

S = present worth of salvage value of facilities

L = present worth of salvage value of land

O = other costs (if any)

A gradient factor may be added into the equations to account for inflation of annual operating costs, as opposed to using an average value throughout the project life, by simply adding the additional following term onto the right-hand side of the above equation:

$$[G * (P/G,d,n)]$$

where,

G = uniform increase in annual costs

(P/G,d,n) = present worth factor for a gradient =

$(1 – nd) [(1 + d)^n – 1] / [d^2 * (1 + d)^n]$.

II. If the alternatives have different useful lives, the cost comparison may be performed using the Equivalent Uniform Annual Cost Method. The equation for this method is:

$$EUA = (C + O) * (A/P,d,n) + A – [(S + L) * (A/F,d,n)]$$

where,

EUA = equivalent uniform annual cost

(A/P,d,n) = capital recovery factor $[(1 + d)^n – 1] / [d (1 + d)^n]$

(A/F,d,n) = uniform series sinking fund factor $d / [(1 + d)^n – 1)]$

To add a gradient factor, the following additional term is simply added to the right hand side of the above equation:

[G * (A/G,d,n)]

where,

(A/G,d,n) = EUA factor for a gradient = $[(1 + d)^n – 1 – nd] / d * [(1 + d)^n – 1]$.

Additional cost factors:

Other costs, such as opportunity costs, while presented above as one-time present losses, may also have an annual lost revenue component, which could be accounted for by apportioning the costs as both upfront and annual costs.

In general, it is the responsibility of the applicant for a permit or approval to prepare detailed cost estimates for all appropriate and approvable discharge, non-discharge, and combination discharge/non-discharge alternatives. The cost estimates may be prepared by a licensed professional engineer, accountant, economist or other professional qualified in the field, but they must be submitted under a professional engineer seal as part of the permit application.

The sources and rationale for all data and assumptions must be clearly indicated. NMED will review the cost estimates for completeness, accuracy, and validity of assumptions. Where deficiencies are discovered, NMED will either request additional information or obtain the information on its own, or both. Following the review process, NMED will advise the applicant on which alternatives (or combination discharge/non-discharge alternatives) are cost-effective, and processing of a permit application will proceed on that basis. In general, an alternative or suite of alternatives is considered to be cost-effective and reasonable if it is feasible and the cost is less than 110% of the base costs of pollution control measures for the proposed discharge (present worth costs).

Other factors:

While the basic concept behind the direct comparison is the present worth method, which has traditionally been used, other approaches and factors may be proposed by applicants and will be considered by the Department (e.g., EPA's Water Quality Standards Handbook – *Interim Economic Guidance for Water Quality Standards*, EPA-823-B-95-002, 1995).

Combined approach:

Aspects of the other approaches can be integrated or combined with the direct comparison approach. For instance, in EPA's guidance document, the 1 percent of median household income user-fee criteria can be applied as a first test of cost-effectiveness, even before the direct cost comparisons are considered. Only if the user-fees exceed the screening criteria would the direct comparison of the alternative come into play.

Where appropriate, NMED may require that the submitted demonstration of cost-effectiveness include information to support both a primary screening/affordability evaluation as well as a secondary alternative-to-alternative cost comparison.

Appendix A.2
Social and Economic Importance Worksheet

Social & Economic Worksheet

Social and Economic Benefits/Costs

Does your proposed activity:

1. Create or expand employment?

   Yes _____ Describe _____

   No _____ Describe _____

   Don't Know ___

   Not Applicable Why not? _____

2. Reduce the unemployment rate?

   Yes _____ Describe _____

   No _____ Describe _____

   Don't Know ___

   Not Applicable Why not? _____

3. Increase median family income?

   Yes _____ Describe _____

   No _____ Describe _____

   Don't Know ___

   Not Applicable Why not? _____

4. Reduce the number of households below the poverty line?

   Yes _____ Describe _____

   No _____ Describe _____

   Don't Know ___

   Not Applicable Why not? _____

5. Increase needed housing supply?

   Yes _____ Describe _____

   No _____ Describe _____

   Don't Know ___

   Not Applicable Why not? _____

6. Increase the community tax base?

   Yes _____ Describe _____

   No _____ Describe _____

   Don't Know ___

   Not Applicable Why not? _____

7. Provide necessary public services (e.g., fire department, school, infrastructure)?

   Yes _____ Describe _____

   No _____ Describe _____

   Don't Know ___

   Not Applicable Why not? _____

8. Correct a public health or environmental problem?

   Yes _____ Describe _____

   No _____ Describe _____

   Don't Know ___

   Not Applicable Why not? _____

9. Improve quality of life for residents in the area?

   Yes _____ Describe _____

   No _____ Describe _____

   Don't Know ___

   Not Applicable Why not? _____

Environmental Protection Benefits/Costs

Explain how your proposed activity positively or negatively affects the following:

1. The societal and economic benefits/costs of better health protection.

   Describe _____

   _____

   Don't Know ___

   Not Applicable Why not? _____

2. Fishing, recreation, and tourism industries.

   Describe _____

   _____

   Don't Know ___

   Not Applicable Why not? _____

3. The general societal value of maintaining the quality of the environment.

   Describe _____

   _____

   Don't Know ___

   Not Applicable Why not? _____

4. Threatened and endangered species.

   Describe _____

   _____

   Don't Know ___

   Not Applicable Why not? _____

5. Increased flood control and sediment trapping through maintaining wetlands and riparian zones.

   Describe _____

   _____

   Don't Know ___

   Not Applicable Why not? _____

6. Reservation of assimilative capacity for future industry and development.

   Describe _____

   _____

   Don't Know ___

   Not Applicable Why not? _____

If you need more space to "describe" how this discharge will impact the social, economic and environmental benefits/costs above, please attach additional sheet(s) to this form.

Likewise, if additional considerations are desired or required in your social and economic justification analysis, please refer to Appendix A.3 and Appendix A.4.

Appendix A.3
Information for Substantial and Widespread Impact Analysis (OPTIONAL)

Attachment 1 – Tier 2 Review of a Public Facility

Attachment 1 includes additional information that may be required by the Department to evaluate socio-economic factors of a public facility during a Tier 2 review. This evaluation is based on two types of impacts, referred to as "substantial" and "widespread". The Substantial Impacts analysis is found in Tables 1-3 – 1-7. The Widespread Impacts[12] analysis is found in Table 1-8.

SUBSTANTIAL IMPACTS - SUMMARY

Purpose of Substantial Impacts analysis: Determine whether a public facility can afford pollution controls in order to avoid any degradation of water quality.

The first step in a Substantial Impacts analysis is to provide data on the socio-economic factors listed in the worksheets in Tables 1-1 and 1-2. This data is then used to determine two indicators called the "Municipal Affordability Screener" (Table 1-3) and the "Secondary Affordability Test" (Tables 1-4 – 1-6). The results of these indicators are then compared in the "Assessment of Substantial Impacts Matrix" (Table 1-7) as a way to determine overall affordability to the community.

Widespread Impacts[5] - Summary

Purpose of Widespread Impacts Analysis: evaluates the social costs of pollution control requirements by: 1) defining the affected community; 2) evaluating the community's current characteristics; and 3) evaluating how community characteristics would change if discharger must avoid degradation to water quality.

If the conclusion from the Substantial Impacts analysis is "Questionable Affordability" or "Community cannot afford the pollution control", then a Widespread Impacts analysis may be completed to further resolve the affordability issue. This analysis is primarily a qualitative evaluation based on community socioeconomic factors that are expanded to a larger scale than the Substantial Impacts analysis.

[5] Widespread Impact Analysis forms derived from EPA's Water Quality Standards Academy Participant Manual Update-4, 2000 [EPA 823-B-00-005].

Table 1-1. Antidegradation Data Worksheet

SOCIO-ECONOMIC INDICATORS	DATA
CITY'S DEMOGRAPHICS	
Population_____(year)	
Current Population_____(year)	
Type of household moving away from _____(city)	
Number of households	
Median Household Income (U.S. Census, Census Designated Place)	
Median Household Income (Local Planning Board Estimates, City)	
Median Household Income (U.S. Census, State)	
Median Household Income (U.S. Census, County)	
Major Type of Employment	
Regional Economic Conditions	
% of Total Wastewater Flow from Residential & Municipal Sources	
Unemployment Rate (City)	
Unemployment Rate (County)	
Unemployment Rate (State)	
CITY'S FINANCIAL HISTORY	
Property Tax Revenues (year)	
Sales Tax & Miscellaneous Revenues (year)	
Total Government Revenues_____(year)	
Property Tax Revenues (FY_____)	
Sales Tax & Miscellaneous Revenues (FY_____)	
Total Government Revenues (FY_____)	
Current Market Value of Taxable Property (FY_____)	
Property Tax Delinquency Rate	
Bond Rating - insured sewer	
Bond Rating - non insured sewer	
Overall Net Debt (FY_____)	

Table 1-2. Antidegradation Data Worksheet

SOCIO-ECONOMIC INDICATOR	DATA
Cost of Treatment Options (pollution controls) that will Avoid Degradation of Water Quality	
Capital Improvements	
OPTION 1. (year)_____dollars	
OPTION 2. (year)_____dollars	
Annual Operating Costs	
OPTION 1. (year)_____dollars	
OPTION 2. (year)_____dollars	
FINANCING FOR WASTEWATER TREATMENT OPTIONS	
OPTION 1. Source of Financing	
Repayment Term, Vehicle	
Bond Rate	
Total Annual Cost of Existing Plant	
OPTION 2. Source of Financing	
Repayment Term, Vehicle	
Bond Rate	
Total Annual Cost of Existing Plant	

Table 1-3. Substantial Impacts Analysis – Part I

PART I. CALCULATING THE MUNICIPAL AFFORDABILITY SCREENER	
This screener is used to evaluate expected impacts to households. It indicates whether community households can afford to pay the total annualized pollution control costs to avoid water quality degradation.	
A. Calculate Average Annualized Cost Per Household	
1. Calculate the Total Annual Cost of the Project	
Interest Rate for Financing (*i) =*	_____(expressed as a fraction)
Time Period for Financing (*n) =*	_____(years)
Annualization Factor: $\frac{i}{(i+1)^n - 1}(+ i) =$	_____ (1)
Total Capital Cost of Project to be Financed =	_____ (2)
Annual Operating Costs of Project =	_____ (3)
Annualized Capital Cost [(1) *x* (2)] =	_____ (4)
Total Annual Cost of Project [(3) + (4)] =	_____ (5)
2. Calculate the Total Annual Cost to Households	
Total Annual Cost of Project (5) x Percentage of Total Wastewater Flow Attributable to Residential and Municipal Wastewater Flows =	_____ (6)
Total Annual Cost of Existing Plant ($) *x* Percentage of Total Wastewater Flow Attributable to Residential and Municipal Wastewater Flows =	_____ (7)
Total Annual Cost to Households [(6) + (7)] =	_____ (8)
3. Calculate the Average Annualized Cost Per Household Total Annual Cost to Households (8) = Number of Households	_____ (9)
B. Calculate Screener Value:	
Average Annualized Cost Per Household (9) (*x 100) =* Median Household Income	_____% municipal affordability screen (10)
What type of impact does the Municipal Affordability Screener Indicate in table below?	_____ impact

Little Impact	Mid-Range Impact	Large Impact
< 1.0 %	1.0% - 2.0%	> 2.0%

Explanation of Impacts:
Little Impact – high affordability; households can afford to pay pollution control costs
Mid-Range Impact – uncertain affordability
Large Impact – low affordability; pollution control costs may cause economic hardship on households

Is there a need to proceed to the Secondary Affordability Test? (yes, if large impact or mid- range impact)	_____(yes/no)

Table 1-4. Substantial Impacts Analysis – Part II

PART II. APPLYING THE SECONDARY AFFORDABILITY TEST

A. EVALUATING THE DEBT INDICATORS

Bond Rating:
This is a Measure of the Credit Worthiness of a Community

What is Bond Rating of (name of municipality)_____? _____

What is the resulting score? (assign score from table below)

Source of Bond Rating	Weak	Mid-Range	Strong
S&P	below BBB	BBB	above BBB
Moody's	below Baa	Baa	above Baa
Score	1	2	3

_____score points (11)

Overall Net Debt to Market Value of Taxable Property:
This measures Debt Burden on Residents within the Community

(municipality)_____Overall Net Debt = _____ (12)

(municipality)_____Market Value of Taxable Property = _____ (13)

Overall Net Debt (12) (x 100) = _____ % (13a)
Market Value of Taxable Property (13)

What is the resulting score? (assign score from table below)

	Weak	Mid-Range	Strong
Compare % from 13a	>5%	2% - 5%	<2%
Score	1	2	3

_____score points (14)

Explanation of Ratings:
Weak = negative effect on indicator from increased costs for pollution controls
Mid-Range = uncertain effect on indicator
Strong = indicator can withstand increased costs for pollution controls

Table 1-5. Substantial Impacts Analysis – Part II

PART II. APPLYING THE SECONDARY AFFORDABILITY TEST (continued)

B. EVALUATING THE SOCIOECONOMIC INDICATORS

Unemployment Rate:
This measures the General Economic Health of the Community

What is (municipality)_____Unemployment Rate? _____

Is this above, below, or equal to the State's rate?

What is the resulting Score? (assign score from table below)

	Weak	Mid-Range	Strong
Compare unemployment rate	Above State Average	State Average	Below State Average
Score	1	2	3

_____score points (15)

Median Household Income:
This Measure Provides an Overall Indication of Community Earning Capacity

What is (municipality) Median Household Income?

Is this above, below, or equal to the State's rate?

What is the resulting Score? (assign score from table below)

	Weak	Mid-Range	Strong
Compare median income	Below State Average	State Average	Above State Average
Score	1	2	3

score points (16)

Table 1-6. Substantial Impacts Analysis – Part II

<table>
<tr><td colspan="2">PART II. APPLYING THE SECONDARY AFFORDABILITY TEST (continued)</td></tr>
<tr><td>C. EVALUATING THE FINANCIAL MANAGEMENT INDICATORS</td><td></td></tr>
<tr><td>Property Tax Revenue to Full Market Value of Taxable Property:
This Measures Funding Capacity Available to Support Debt Based on Community's Wealth</td><td></td></tr>
<tr><td>What is (municipality)_____Property Tax Revenue?</td><td>_____ (17)</td></tr>
<tr><td>What is the Full Market Value of Taxable Property?</td><td>_____ (18)</td></tr>
<tr><td>Property Tax Revenue (17) (x 100) =
Full Market Value of Taxable Property (18)</td><td>_____% (18a)</td></tr>
<tr><td>What is the resulting Score? (assign score from table below)
<table>
<tr><td></td><td>Weak</td><td>Mid-Range</td><td>Strong</td></tr>
<tr><td>Compare % from 18a</td><td><2%</td><td>2% - 4%</td><td>>4%</td></tr>
<tr><td>Score</td><td>1</td><td>2</td><td>3</td></tr>
</table></td><td>_____score points (19)</td></tr>
<tr><td>Property Tax Collection Rate:
This Measures How Well the Local Government is Administrated</td><td></td></tr>
<tr><td>What is the Property Tax Collection Rate of (municipality)</td><td>_____%</td></tr>
<tr><td>What is the resulting Score? (assign score from table below)
<table>
<tr><td></td><td>Weak</td><td>Mid-Range</td><td>Strong</td></tr>
<tr><td>Compare tax collection rate</td><td><94%</td><td>94% - 98%</td><td>>98%</td></tr>
<tr><td>Score</td><td>1</td><td>2</td><td>3</td></tr>
</table></td><td>_____score points (20)</td></tr>
<tr><td>D. CALCULATE THE CUMULATIVE SECONDARY AFFORDABILITY TEST SCORE: This is the average score of all the indicators calculated above.</td><td></td></tr>
<tr><td>(11) + (14) + (15) + (16) + (19) + (20) =
6</td><td>_____cumulative score (21)</td></tr>
<tr><td>In what impact range does the cumulative secondary score fall?
<table>
<tr><td></td><td>Weak</td><td>Mid-Range</td><td>Strong</td></tr>
<tr><td>Compare cumulative score from 21</td><td>< 1.5</td><td>1.5 – 2.5</td><td>> 2.5</td></tr>
</table></td><td>_____ impact range</td></tr>
</table>

Table 1-7. Substantial Impacts Analysis – Part III

<table>
<tr><td colspan="2">Part III. Assessment of Substantial Impacts Matrix</td></tr>
<tr><td>THE MUNICIPAL AFFORDABILITY SCREENER (10) =</td><td>_____%</td></tr>
<tr><td>THE CUMULATIVE SECONDARY AFFORDABILITY TEST SCORE (21) =</td><td>_____score points</td></tr>
<tr><td>Where does (municipality)_____appear in the Substantial Impacts Matrix below?

Substantial Impacts Matrix
<table>
<tr><th rowspan="2">Secondary Assessment Score</th><th colspan="3">Municipal Affordability Screener</th></tr>
<tr><th><1.0%</th><th>1.0% - 2.0%</th><th>>2.0%</th></tr>
<tr><td>< 1.5</td><td>?</td><td>X</td><td>X</td></tr>
<tr><td>1.5 – 2.5</td><td>√</td><td>?</td><td>X</td></tr>
<tr><td>> 2.5</td><td>√</td><td>√</td><td>?</td></tr>
</table>
? = Questionable affordability
√ = Community can afford the pollution control
X = Community cannot afford the pollution control</td><td></td></tr>
<tr><td>Based on the Substantial Impacts Matrix above, what is the affordability status (afford, not afford, or questionable) of the (municipality)_____?

In other words, can the project proponent afford to upgrade the facility in order to avoid water quality degradation?</td><td>_____
Matrix Result</td></tr>
<tr><td>If the conclusion from the Substantial Impacts analysis is either “Cannot Afford” or “Questionable Affordability”, then proceed to the Widespread Impacts analysis for further evaluation.</td><td>Complete Widespread Impacts Analysis?

_____(yes/no)</td></tr>
</table>

Table 1-8. Widespread Impacts Analysis – Public Facility

1. Define the Affected Community

Evaluate the Discharger's Contribution to the Community:

- Contribution to economic base (e.g., property taxes and employment)
- Provides product or service upon which other businesses or thecommunity depend

2. Evaluate Community's Current Characteristics

Evaluate how community's current socioeconomic health may change if proposed project must avoid degradation to water quality by considering the following factors:

- Median household income
- Unemployment rate
- Rate of industrial development
- Developing and declining industries
- Percent of households below poverty line
- Ability of community to carry more debt
- Local and regional factors

Other applicable information on the local and regional economy that should also be reviewed includes:

- Annual rate of population change
- Current financial surplus as a percentage of total expenditures
- Percentage of property taxes actually collected
- Property tax revenues as a percentage of the market value of real property
- Overall debt outstanding as a percentage of market value of real property
- Overall debt per capita
- Percentage of outstanding debt due within 5 years

3. Evaluate How Community Characteristics Would Change if Discharger Must Avoid Degradation to Water Quality

Evaluate the projected adverse socioeconomic impacts of adding pollution controls to the project to meet antidegradation requirements by considering the following:

- Property Values
- Employment Rate
- Commercial Development Opportunities
- Tax Revenues
- Expenditure on Social Services
- State level impacts such as loss of revenues and increased expenditures

Attachment 2 – Tier 2 Review of a Private Facility

Attachment 2 includes additional information that may be required by the Department to evaluate socio-economic factors of a private facility during a Tier 2 review. This evaluation is based on two types of impacts, referred to as "substantial" and "widespread". The Substantial Impacts analysis is found in Table 2-2. The Widespread Impacts analysis is found in Table 2-3.

SUBSTANTIAL IMPACTS - SUMMARY

Purpose of Substantial Impacts analysis: Determine whether a private facility can afford pollution controls in order to avoid any degradation of water quality.

The first step in a Substantial Impacts analysis is to provide data on the socio-economic factors listed in the worksheet in Table 1. This data is then used to calculate four financial tests that in turn indicate the financial health of a private entity (Table 2).

WIDESPREAD IMPACTS - SUMMARY

Purpose of Widespread Impacts analysis: Evaluates the social costs of pollution control requirements by: 1) defining the affected community; 2) evaluating the community's current characteristics; and 3) evaluating how community characteristics would change if discharger must avoid degradation to water quality.

If the Substantial Impacts analysis (i.e., the four financial tests) indicates that the private entity's financial health is questionable, then a Widespread Impacts analysis may be completed to further resolve the affordability issue. This analysis is primarily a qualitative evaluation based on community socioeconomic factors that are expanded to a larger scale than the Substantial Impacts analysis.

Table 2-1. Data Worksheet for Financial Factors

Financial Factor	Data
Current Assets	
Current Liabilities	
Cash flow per given year	
Total debt of the entity	
Amount firm has borrowed (debt)	
Amount of stockholders' capital (equity)	
Pre-tax earnings	
Annualized pollution control cost	

Table 2-2. Substantial Impacts Analysis - Financial Tests Used to Measure the Financial Health of a Private Entity

1. Liquidity Test - Indicates how easily an entity can pay its short-term bills. Current Ratio = Current Assets / Current Liabilities NOTE: A ratio greater that 2 indicates affordability
2. Solvency Test - Indicates how easily an entity can pay its fixed and long-term bills. Beaver's Ratio = Cash flow per given year / Total debt of the entity NOTE: > 0.20 Indicates private entity is solvent < 0.15 Indicates private entity may go bankrupt
3. Leverage Test - Indicates how much money the entity can borrow. Debt-to-Equity Ratio = Amount firm has borrowed (debt) / Amount of Stockholders' capital (equity) NOTE: The larger the Debt-to-Equity Ratio, the less likely that the entity will be able to borrow funds
4. Earnings Test - Indicates how much the entity's profitability will change with the additional pollution control needed to avoid degradation of water quality. Earnings = Pre-tax – Annualized Pollution Control Cost NOTE: Compare earnings result with entity's revenues to measure post-compliance profit rate
Guidelines to evaluate financial tests: o Results of all four tests above should be considered jointly o Ratios and tests should be compared over several years o Financial ratios should also be compared against those of "healthy" entities o The role the entity plays in a parent firm's operations should also beconsidered

Table 2-3. Widespread Impacts Analysis – Private entity/facility

1. Define the Affected Community

Evaluate the Discharger's Contribution to the Community:

- Contribution to economic base (e.g., property taxes and employment)
- Provides product or service upon which other businesses or the community depend

2. Evaluate Community's Current Characteristics

Evaluate how community's current socioeconomic health would change if proposed project must avoid degradation to water quality by considering the following factors:

- Median household income
- Unemployment rate
- Rate of industrial development
- Developing and declining industries
- Percent of households below poverty line
- Ability of community to carry more debt
- Local and regional factors

Other applicable information on the local and regional economy that should also be reviewed includes:

- Annual rate of population change
- Current financial surplus as a percentage of total expenditures
- Percentage of property taxes actually collected
- Property tax revenues as a percentage of the market value of real property
- Overall debt outstanding as a percentage of market value of real property
- Overall debt per capita
- Percentage of outstanding debt due within 5 years

3. Evaluate How Community Characteristics Would Change if Discharger Must Avoid Degradation to Water Quality

Evaluate the projected adverse socioeconomic impacts of adding the pollution control to the project to meet antidegradation requirements by considering the following:

- Property Values
- Employment Rate
- Commercial Development Opportunities
- Tax Revenues
- Expenditure on Social Services
- State level impacts such as loss of revenues and increased expenditures

NMED Exhibit 3

Appendix A.4
Summary of Other Economic and Environmental Impact Categories

1. **Public Need/Social Service**
   - Health/Nursing Care
   - Police/Fire Protection
   - Infrastructure Need
   - Education (primary)

2. **Consistency with Local Zoning and Planning**
   - Sewage Facility Planning
   - Zoning Requirements
   - Land Use Plans
   - Patterns of Growth/Development

3. **Quality of Life**
   - Educational (post-secondary)
   - Cultural
   - Recreational

4. **Housing**
   - Quantity
   - Affordability

5. **Employment**
   - Number and Type of Jobs Relative to Local Unemployment Rate and Local Labor Force
   - State Local Mean Qualified Income

6. **Tax Revenues**
   - Tax Revenue Income for Relative to Increased Private Demand for Services
   - Public and Private Change in Property Value or Tax Status

7. **Development Potential**
   - Potential to Spur Increased Growth

8. **Sensitivity of Water Use**
   - Presence of Threatened and Endangered Species
   - Public Water Supply Use
   - Water Contact Sports

9. **Nature of Pollutants**
   - Synthetic
   - Bioaccumulative
   - Naturally Occurring

10. **Proposed Degree of Change in Water Quality**
    - Available Dilution
    - Amount of Assimilative Capacity Used

11. Proximity to Wetlands or Floodplain

Presence of Wetlands
Location with Respect to Stream Channel

12. Duration of Discharge

Permanent
Continuous
Short-term

13. Reliability of Treatment Technology

High Tech/Experimental
Energy Intensive
Maintenance Intensive
Natural System
Overall Reliability

14. Compliance Record

Current Violations
Historical Violations
Overall Record

15. Secondary Beneficial Impacts

Groundwater Recharge
Post-Construction Storm Water
Hydromodifications
Thermal Modification
Construction on Previously Undisturbed Lands
Discharge to Previously Undegraded Waters

Appendix A.5
List of Agencies Involved in Intergovernmental Coordination

Interagency Coordination for Antidegradation Review

In accordance with 20.6.2.2001 NMAC, and to the extent practicable, the Department will provide joint public notice with the EPA that the Department is reviewing a draft NPDES permit (which contains the antidegradation review) for the purpose of preparing a state certification or denial pursuant to Section 401 of the CWA. When joint notice is impractical, the Department provides notice that it is reviewing a draft NPDES permit for purpose of preparing a state certification or denial pursuant to Section 401 of the CWA by mailing or emailing the notice, as appropriate, to:

- the NPDES permit applicant or permittee;
- any user identified in the permit application of a privately-owned treatment works;
- any affected federal agency, such as EPA Region 6, the U.S. Fish & Wildlife Service and affected federal public land managers (i.e., U.S. Forest Service, BLM, and National Park Service);
- any affected state agency, such as the NM Office of the State Engineer, New Mexico Game & Fish Department, NM State Land Office, and New Mexico State Parks - EMNRD;
- any affected tribal agency;
- any affected local agency, including each applicable county department of health, environmental services or comparable department;
- any affected Council of Government (COG);
- any federal and state agencies with jurisdiction over fish, shellfish, and wildlife resources;
- the New Mexico Historic Preservation Office;
- the U.S. Army Corps of Engineers; and,
- any person who requests public notice in writing.

Appendix A.6
Antidegradation Policy and Implementation Plan (20.6.4.8 NMAC)

20.6.4.8 ANTIDEGRADATION POLICY AND IMPLEMENTATION PLAN:

A. Antidegradation Policy: This antidegradation policy applies to all surface waters of the state.

(1) Existing instream water uses and the level of water quality necessary to protect the existing uses shall be maintained and protected in all surface waters of the state.

(2) Where the quality of a surface water of the state exceeds levels necessary to support the propagation of fish, shellfish, and wildlife, and recreation in and on the water, that quality shall be maintained and protected unless the commission finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the state's continuing planning process, that allowing lower water quality is necessary to accommodate important economic and social development in the area in which the water is located. In allowing such degradation or lower water quality, the state shall assure water quality adequate to protect existing uses fully. Further, the state shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable BMPs for nonpoint source control. Additionally, the state shall encourage the use of watershed planning as a further means to protect surface waters of the state.

(3) No degradation shall be allowed in waters designated by the commission as outstanding national resource waters (ONRWs), except as provided in Subparagraphs (a) through (e) of this paragraph and in Paragraph (4) of this Subsection A.

(a) After providing a minimum 30-day public review and comment period, the commission determines that allowing temporary and short-term degradation of water quality is necessary to accommodate public health or safety activities in the area in which the ONRW is located. Examples of public health or safety activities include but are not limited to replacement or repair of a water or sewer pipeline or a roadway bridge. In making its decision, the commission shall consider whether the activity will interfere with activities implemented to restore or maintain the chemical, physical or biological integrity of the water. In approving the activity, the commission shall require that:

(i) the degradation shall be limited to the shortest possible time and shall not exceed six months;

(ii) the degradation shall be minimized and controlled by best management practices or in accordance with permit requirements as appropriate; all practical means of minimizing the duration, magnitude, frequency and cumulative effects of such degradation shall be utilized;

(iii) the degradation shall not result in water quality lower than necessary to protect any existing use in the ONRW; and

(iv) the degradation shall not alter the essential character or special use that makes the water an ORNW.

(b) Prior to the commission making a determination, the department or appropriate oversight agency shall provide a written recommendation to the commission. If the commission approves the activity, the department or appropriate oversight agency shall oversee implementation of the activity.

(c) Where an emergency response action that may result in temporary and short-term degradation to an ONRW is necessary to mitigate an immediate threat to public health or safety, the emergency response action may proceed prior to providing notification required by Subparagraph (a) of this paragraph in accordance with the following:

(i) only actions that mitigate an immediate threat to public health or safety may be undertaken pursuant to this provision; non-emergency portions of the action shall comply with the requirements of Subparagraph (a) of this paragraph;

(ii) the discharger shall make best efforts to comply with requirements (i) through (iv) of Subparagraph (a) of this paragraph;

(iii) the discharger shall notify the department of the emergency response action in writing within seven days of initiation of the action;

(iv) within 30 days of initiation of the emergency response action, the discharger shall provide a summary of the action taken, including all actions taken to comply with requirements (i) through (iv) of Subparagraph (a) of this paragraph.

(d) Preexisting land-use activities, including grazing, allowed by federal or state law prior to designation as an ONRW, and controlled by best management practices (BMPs), shall be allowed to continue so long as there are no new or increased discharges resulting from the activity after designation of the ONRW.

(e) Acequia operation, maintenance, and repairs are not subject to new requirements because of ONRW designation. However, the use of BMPs to minimize or eliminate the introduction of pollutants into receiving waters is strongly encouraged.

(4) This antidegradation policy does not prohibit activities that may result in degradation in surface waters of the state when such activities will result in restoration or maintenance of the chemical, physical or biological integrity of the water.

(a) For ONRWs, the department or appropriate oversight agency shall review on a case-by-case basis discharges that may result in degradation from restoration or maintenance activities, and may approve such activities in accordance with the following:

(i) the degradation shall be limited to the shortest possible time;

(ii) the degradation shall be minimized and controlled by best management practices or in accordance with permit requirements as appropriate, and all practical means of minimizing the duration, magnitude, frequency and cumulative effects of such degradation shall be utilized;

(iii) the degradation shall not result in water quality lower than necessary to protect any existing use of the surface water; and

(iv) the degradation shall not alter the essential character or special use that makes the water an ORNW.

(b) For surface waters of the state other than ONRWs, the department shall review on a case-by-case basis discharges that may result in degradation from restoration or maintenance activities, and may approve such activities in accordance with the following:

(i) the degradation shall be limited to the shortest possible time;

(ii) the degradation shall be minimized and controlled by best management practices or in accordance with permit requirements as appropriate, and all practical means of minimizing the duration, magnitude, frequency and cumulative effects of such degradation shall be utilized; and

(iii) the degradation shall not result in water quality lower than necessary to protect any existing use of the surface water.

(5) In those cases where potential water quality impairment associated with a thermal discharge is involved, this antidegradation policy and implementing method shall be consistent with Section 316 of the federal Clean Water Act.

(6) In implementing this section, the commission through the appropriate regional offices of the United States environmental protection agency will keep the administrator

advised and provided with such information concerning the surface waters of the state as he or she will need to discharge his or her responsibilities under the federal Clean Water Act.

B. Implementation Plan: The department, acting under authority delegated by the commission, implements the water quality standards, including the antidegradation policy, by describing specific methods and procedures in the continuing planning process and by establishing and maintaining controls on the discharge of pollutants to surface waters of the state. The steps summarized in the following paragraphs, which may not all be applicable in every water pollution control action, list the implementation activities of the department. These implementation activities are supplemented by detailed antidegradation review procedures developed under the state's continuing planning process. The department:

(1) obtains information pertinent to the impact of the effluent on the receiving water and advises the prospective discharger of requirements for obtaining a permit to discharge;

(2) reviews the adequacy of existing data and conducts a water quality survey of the receiving water in accordance with an annually reviewed, ranked priority list of surface waters of the state requiring total maximum daily loads pursuant to Section 303(d) of the federal Clean Water Act;

(3) assesses the probable impact of the effluent on the receiving water relative to its attainable or designated uses and numeric and narrative criteria;

(4) requires the highest and best degree of wastewater treatment practicable and commensurate with protecting and maintaining the designated uses and existing water quality of surface waters of the state;

(5) develops water quality based effluent limitations and comments on technology based effluent limitations, as appropriate, for inclusion in any federal permit issued to a discharger pursuant to Section 402 of the federal Clean Water Act;

(6) requires that these effluent limitations be included in any such permit as a condition for state certification pursuant to Section 401 of the federal Clean Water Act;

(7) coordinates its water pollution control activities with other constituent agencies of the commission, and with local, state and federal agencies, as appropriate;

(8) develops and pursues inspection and enforcement programs to ensure that dischargers comply with state regulations and standards, and complements EPA's enforcement of federal permits;

(9) ensures that the provisions for public participation required by the New Mexico Water Quality Act and the federal Clean Water Act are followed;

(10) provides continuing technical training for wastewater treatment facility operators through the utility operators training and certification programs;

(11) provides funds to assist the construction of publicly owned wastewater treatment facilities through the wastewater construction program authorized by Section 601 of the federal Clean Water Act, and through funds appropriated by the New Mexico legislature;

(12) conducts water quality surveillance of the surface waters of the state to assess the effectiveness of water pollution controls, determines whether water quality standards are being attained, and proposes amendments to improve water quality standards;

(13) encourages, in conjunction with other state agencies, implementation of the best management practices set forth in the New Mexico statewide water quality management plan and the nonpoint source management program, such implementation shall not be mandatory except as provided by federal or state law;

(14) evaluates the effectiveness of BMPs selected to prevent, reduce or abate sources of water pollutants;

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(15) develops procedures for assessing use attainment as required by 20.6.4.15 NMAC and establishing site-specific standards; and

(**16)** develops list of surface waters of the state not attaining designated uses, pursuant to Sections 305(b) and 303(d) of the federal Clean Water Act.

[20.6.4.8 NMAC - Rp 20 NMAC 6.1.1101, 10-12-00; A, 05-23-05; A, 08-01-07; A, 01-14-11]

State of New Mexico
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Appendix B

Approved Total Maximum Daily Loads for New Mexico

List of Approved TMDLs in New Mexico

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Arkansas-White-Red Rivers Basin	11080001	NM-2306.A_151	Caliente Canyon (Vermejo River to headwaters)	specific conductance	TMDL for the Canadian River Watershed-Part One (Mora River to Colorado border)	August 14, 2007	September 21, 2007
Arkansas-White-Red Rivers Basin	11080001	NM-2305.A_200	Canadian River (Cimarron River to CO border)	plant nutrients	TMDL for the Mainstem of the Canadian River (from TX to CO) and select tributaries	September 30, 2011	November 21, 2011
Arkansas-White-Red Rivers Basin	11080003	NM-2305.A_000	Canadian River (Conchas River to Mora River)	E.coli	TMDL for the Mainstem of the Canadian River (from TX to CO) and select tributaries	September 30, 2011	November 21, 2011
Arkansas-White-Red Rivers Basin	11080006	NM-2303_00	Canadian River (Ute Reservoir to Conchas Reservoir)	E.coli	TMDL for the Mainstem of the Canadian River (from TX to CO) and select tributaries	September 30, 2011	November 21, 2011
Arkansas-White-Red Rivers Basin	11080002	NM-2306.A_065	Cieneguilla Creek (Eagle Nest Lake to headwaters)	chronic aluminum	TMDL for Metals (Chronic Aluminum) in Cieneguilla	January 13, 2004	May 19, 2004
					Chronic aluminum TMDL withdrawal	April 11, 2017	May 12, 2017
				fecal coliform	TMDL for Fecal Coliform in Six-Mile, Cienguilla, and and Moreno Creeks	January 13, 2004	May 19, 2004
				turbidity, stream bottom deposits, total phosphorus	TMDL for Turbidity, Stream Bottom Deposits, and Total Phosphorus in the Canadian River Basin (Cimarron)		
				E. coli, plant nutrients, temperature	TMDL for the Cimarron River Watershed (Canadian River to headwaters)	August 10, 2010	September 3, 2010
Arkansas-White-Red Rivers Basin	11080002	NM-2305.1.A_10	Cimarron River (Canadian River to Cimarron Village)	plant nutrients	TMDL for the Cimarron River Watershed (Canadian River to headwaters)	August 10, 2010	September 3, 2010
Arkansas-White-Red Rivers Basin	11080002	NM-2306.A_040	Cimarron River (Cimarron Village to Turkey Creek)	arsenic, temperature	TMDL for the Cimarron River Watershed (Canadian River to headwaters)	August 10, 2010	September 3, 2010
Arkansas-White-Red Rivers Basin	11080002	NM-2306.A_130	Cimarron River (Turkey Creek to Eagle Nest Lake)	arsenic, plant nutrients	TMDL for the Cimarron River Watershed (Canadian River to headwaters)	August 10, 2010	September 3, 2010

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Arkansas-White-Red Rivers Basin	11080004	NM-2306.A_020	Coyote Creek (Mora River to Black Lake)	specific conductance, temperature	TMDL for the Canadian River Watershed-Part One (Mora River to Colorado border)	August 14, 2007	September 21, 2007
Arkansas-White-Red Rivers Basin	11080004	NM-2306.A_024	Little Coyote Creek (Black Lake to headwaters)	nutrients	TMDL for the Canadian River Watershed-Part One (Mora River to Colorado border)	August 14, 2007	September 21, 2007
Arkansas-White-Red Rivers Basin	11080002	NM-2306.A_121	Middle Ponil Creek (South Ponil Creek to headwaters)	temperature	TMDL for Temperature on Middle Ponil Creek	July 10, 2001	September 21, 2001
				turbidity	TMDL for Turbidity in Middle Ponil Creek and Ponil Creek		
Arkansas-White-Red Rivers Basin	11080002	NM-2306.A_124	Middle Ponil Creek (Greenwood Creek to headwaters)	plant nutrients	TMDL for the Waters of the Valle Vidal	September 30, 2011	November 8, 2011
Arkansas-White-Red Rivers Basin	11080004	NM-2305.A_00	Mora River (USGS gage east of Shoemaker to Hwy 434)	nutrients	TMDL for the Canadian River Watershed-Part One (Mora River to Colorado border)	August 14, 2007 June 10, 2015 (update)	September 21, 2007 July 22, 2015 (update)
Arkansas-White-Red Rivers Basin	11080004	NM-2306.A_000	Mora River (Hwy 434 to headwaters)	sedimentation, specific conductance	TMDL for the Canadian River Watershed-Part One (Mora River to Colorado border)	August 14, 2007 September 30, 2011 (update)	September 21, 2007 November 28, 2011 (update)
Arkansas-White-Red Rivers Basin	11080002	NM-2306.A_060	Moreno Creek (Eagle Nest Lake to headwaters)	fecal coliform	TMDL for Fecal Coliform in Six-Mile, Cieneguilla and Moreno Creeks in the Canadian River Basin (Cimarron)	January 13, 2004	May 19, 2004
				turbidity	TMDL for Turbidity, Stream Bottom Deposits, and Total Phosphorus in Canadian Basin (Cimarron)		
				temperature, plant nutrients	TMDL for the Cimarron River Watershed (Canadian River to headwaters)	August 10, 2010	September 3, 2010

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Arkansas-White-Red Rivers Basin	11080002	NM-2306.A_110	North Ponil Creek (South Ponil Creek to McCrystal Creek)	stream bottom deposits, turbidity, total phosphorus	TMDL for Turbidity, Stream Bottom Deposits, and Total Phosphorus in the Canadian Basin (Cimarron)	January 13, 2004	May 19, 2004
				temperature	TMDL for Temperature on North Ponil Creek	November 9, 1999	December 17, 1999
				E. coli	TMDL for the Cimarron River Watershed (Canadian River to headwaters)	August 10, 2010	September 3, 2010
Arkansas-White-Red Rivers Basin	11080002	NM-2306.A_162	North Ponil Creek (Seally Canyon to headwaters)	temperature	TMDL for the Waters of the Valle Vidal	September 30, 2011	November 8, 2011
Arkansas-White-Red Rivers Basin	11080006	NM-2303_10	Pajarito Creek (Canadian River to headwaters)	e.coli, plant nutrients	TMDL for the Mainstem of the Canadian River (from TX to CO) and select tributaries	September 30, 2011	November 21, 2011
Arkansas-White-Red Rivers Basin	1108002	NM-2306.A_100	Ponil Creek (Cimarron River to confluence of North and South Ponil	temperature,	TMDL for Temperature on Ponil Creek	July 10, 2001	September 21, 2001
				turbidity	TMDL for Turbidity in Middle Ponil Creek and Ponil Creek	July 10, 2001	September 21, 2001
				chronic aluminum	TMDL for Metals (Chronic Aluminum) in Ponil Creek		
Arkansas-White-Red Rivers Basin	11080006	NM-2303_10	Pajarito Creek (Canadian River to headwaters)	E.coli, plant nutrients	TMDL for the Mainstem of the Canadian River (from TX to CO) and select tributaries	September 30, 2011	November 21, 2011
Arkansas-White-Red Rivers Basin	11080002	NM-2306.A_100	Ponil Creek (Cimarron River to US 64)	E. coli	TMDL for the Cimarron River Watershed (Canadian River to headwaters)	August 10, 2010	September 3, 2010
Arkansas-White-Red Rivers Basin	11080002	NM-2306.A_101	Ponil Creek (US 64 to confl of North and South Ponil)	E. coli, plant nutrients	TMDL for the Cimarron River Watershed (Canadian River to headwaters)	August 10, 2010	September 3, 2010
Arkansas-White-Red Rivers Basin	11080002	NM-2306.A_051	Rayado Creek (Miami Lake Diversion to headwaters)	E. coli, temperature	TMDL for the Cimarron River Watershed (Canadian River to headwaters)	August 10, 2010	September 3, 2010
Arkansas-White-Red Rivers Basin	11080002	NM-2305.A_80	Rayado Creek (Cimarron River to Miami Lake Diversion)	stream bottom deposits	TMDL for Stream Bottom Deposits in Rayado Creek and Metals (Chronic Aluminum) in the Cimarron River	December 12, 2000	February 16, 2001
				plant nutrients	TMDL for the Cimarron River Watershed (Canadian River to headwaters)	August 10, 2010	September 3, 2010

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Arkansas-White-Red Rivers Basin	11080008	NM-2301_10	Revuelto Creek (Canadian River to headwaters)	boron	TMDL for the Mainstem of the Canadian River (from TX to CO) and select tributaries	September 30, 2011	November 21, 2011
Arkansas-White-Red Rivers Basin	11080004	NM-2305.3.A_20	Sapello River (Mora River to Manuelitas Creek)	sedimentation	TMDL for the Canadian River Watershed-Part One (Mora River to Colorado	August 14, 2007	September 21, 2007
Arkansas-White-Red Rivers Basin	11080002	NM-2306.A_064	Sixmile Creek (Eagle Nest Lake to headwaters)	fecal coliform	TMDL for Fecal Coliform in Six-mile, Cieneguilla, and Moreno Creeks in the Canadian River Basin (Cimarron)	January 13, 2004	May 19, 2004
				turbidity	TMDL for Turbidity, Stream Bottom Deposits, and Total Phosphorus in the Canadian River Basin (Cimarron)	January 13, 2004	May 19, 2004
				E. coli, temperature, plant nutrients	TMDL for the Cimarron River Watershed (Canadian River to headwaters)	August 10, 2010	September 3, 2010
Arkansas-White-Red Rivers Basin	11080002	NM-2306.A_120	South Ponil Creek (Ponil Creek to Middle Ponil)	temperature	TMDL for the Cimarron River Watershed (Canadian River to headwaters)	August 10, 2010	September 3, 2010
Arkansas-White-Red Rivers Basin	11080001	NM-2305.A_254	Una de Gato (Chicorica Creek to Hwy 64)	plant nutrients	TMDL for the Mainstem of the Canadian River (from TX to CO) and select tributaries	September 30, 2011	November 21, 2011
Arkansas-White-Red Rivers Basin	11080001	NM-2305.A_030	Una de Gato (Hwy 64 to headwaters)	plant nutrients	TMDL for the Mainstem of the Canadian River (from TX to CO) and select tributaries	September 30, 2011	November 21, 2011
Arkansas-White-Red Rivers Basin	11080002	NM-2306.A_068	Ute Creek (Cimarron River to headwaters)	arsenic, E. coli, temperature	TMDL for the Cimarron River Watershed (Canadian River to headwaters)	August 10, 2010	September 3, 2010
Arkansas-White-Red Rivers Basin	11080001	NM-2305.A_220	Vermejo River (Rail Canyon to York Canyon)	specific conductance, temperature	TMDL for the Canadian River Watershed-Part One (Mora River to Colorado border)	August 14, 2007	September 21, 2007
Arkansas-White-Red Rivers Basin	11080001	NM-2305.A_230	Vermejo River (York Canyon to headwaters)	temperature	TMDL for the Canadian River Watershed-Part One (Mora River to Colorado border)	August 14, 2007	September 21, 2007
Arkansas-White-Red Rivers Basin	11080001	NM-2306.A_153	York Canyon (Vermejo Park to headwaters)	specific conductance	TMDL for the Canadian River Watershed-Part One (Mora River to Colorado border)	August 14, 2007	September 21, 2007

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Arkansas-White-Red Rivers Basin	11040001	NM-2701_00	Dry Cimarron River (perennial reaches OK bnd to Long Canyon)	sulfate, total dissolved solids	TMDL for the Dry Cimarron River Watershed	April 14, 2009	June 2, 2009
Arkansas-White-Red Rivers Basin	11040001	NM-2701_02	Dry Cimarron River (Long Canyon to Oak Creek)	E.coli, total dissolved solids	TMDL for the Dry Cimarron River Watershed	April 14, 2009	June 2, 2009
Arkansas-White-Red Rivers Basin	11040001	NM-2701_20	Long Canyon (perennial reaches above Dry Cimarron)	E.coli, selenium	TMDL for the Dry Cimarron River Watershed	April 14, 2009	June 2, 2009
Arkansas-White-Red Rivers Basin	11040001	NM-2701_10	Oak Creek (Dry Cimarron to headwaters)	nutrients, E. coli	TMDL for the Dry Cimarron River Watershed	April 14, 2009	June 2, 2009
Arkansas-White-Red Rivers Basin	11080006	NM-2303_00	Canadian River (Ute Reservoir to Conchas Reservoir)	temperature	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019
Arkansas-White-Red Rivers Basin	11080005	NM-2305.A_010	Conchas River (Conchas Reservoir to Salitre Creek)	chronic aluminum, E.coli, plant nutrients	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019
Arkansas-White-Red Rivers Basin	11080004	NM-2306.A_021	Coyote Creek (Black Lake to headwaters)	temperature, plant nutrients	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019
Arkansas-White-Red Rivers Basin	11080004	NM-2306.A_020	Coyote Creek (Mora River to Amola Ridge)	plant nutrients	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019
Arkansas-White-Red Rivers Basin	11080004	NM-2306.A_022	Coyote Creek (Williams Canyon to Black Lake)	plant nutrients	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019
Arkansas-White-Red Rivers Basin	11080004	NM-2306.A_023	Coyote Creek (Amola Ridge to Williams Canyon)	plant nutrients	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019
Arkansas-White-Red Rivers Basin	11080001	NM-2305.A_255	Doggett Creek (Raton Creek to headwaters)	E.coli, plant nutrients	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019
Arkansas-White-Red Rivers Basin	11040001	NM-2701_00	Dry Cimarron River (perennial reaches OK bnd to Long Canyon)	temperature, plant nutrients	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019
Arkansas-White-Red Rivers Basin	11040001	NM-2701_02	Dry Cimarron River (Long Canyon to Oak Creek	plant nutrients	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019
Arkansas-White-Red Rivers Basin	11040001	NM-2701_01	Dry Cimarron River (Oak Creek to headwaters)	plant nutrients	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Arkansas-White-Red Rivers Basin	11080001	NM-2305.A_252	East Fork Chicorica Creek (Chicorica Creek to headwaters)	E.coli	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019
Arkansas-White-Red Rivers Basin	11040001	NM-2701_20	Long Canyon (perennial reaches above Dry Cimarron)	temperature, plant nutrients	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019
Arkansas-White-Red Rivers Basin	11080004	NM-2305.3.A_00	Mora River (USGS gage east of Shoemaker to Hwy 434)	E.coli	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019
Arkansas-White-Red Rivers Basin	11080006	NM-2303_10	Pajarito Creek (perennial portions Canadian River to Vigil Canyon)	temperature	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019
Arkansas-White-Red Rivers Basin	11080001	NM-2305.A_253	Raton Creek (Chicorica Creek to headwaters)	E.coli, plant nutrients	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019
Arkansas-White-Red Rivers Basin	11080001	NM-9000.A_019	Tinaja Creek (West Fork Tinaja Creek to headwaters)	E.coli	Canadian River Watershed TMDL	August 13, 2019	September 18, 2019
Lower Colorado River Basin	15040001	NM-2503_21	Black Canyon Creek (East Fork Gila River to headwaters)	temperature	TMDL for Temperature on Black Canyon Creek	November 13, 2001	April 5, 2002
Lower Colorado River Basin	15040001	NM-2503_43	Canyon Creek (Middle Fork Gila River to headwaters)	plant nutrients	TMDL for Plant Nutrients for Canyon Creek	December 11, 2001	April 10, 2002
				turbidity	TMDL for Turbidity for Canyon Creek		
Lower Colorado River Basin	15040004	NM-2603.A_50	Centerfire Creek (San Francisco R to headwaters)	conductivity	TMDL for Conductivity on Centerfire Creek	November 13, 2001	April 16, 2002
				plant nutrients	TMDL for Plant Nutrients on Centerfire Creek	December 11, 2001	
Lower Colorado River Basin	15040004	NM-2603.A_50	Centerfire Creek (San Francisco R to headwaters)	E.coli, turbidity	TMDL for Upper Gila, San Francisco, and Mimbres River Watersheds	September 9, 2014	September 11, 2014
Lower Colorado River Basin	13030202	NM-2803_11	Cold Springs Creek (Hot Springs Creek to headwaters)	cadmium, lead	TMDL for Upper Gila, San Francisco, and Mimbres River Watersheds	September 9, 2014	September 11, 2014
Lower	15040001	NM-2503_20	Gila River (East Fork)	chronic aluminum	TMDL for Metals (Chronic	November 13, 2001	April 15, 2002

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Colorado River Basin					Aluminum) for the East Fork of the Gila River and Taylor		

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Lower Colorado River Basin	15040003	NM-2502.A_21	Mangas Creek (Gila River to Mangas Springs)	plant nutrients	TMDL for Plant Nutrients on Mangas Creek	December 11, 2001	April 16, 2002
Lower Colorado River Basin	13030202	NM-2803_00	Mimbres R (Perennial reaches downstream of Willow Springs)	E.coli	TMDL for Upper Gila, San Francisco, and Mimbres River Watersheds	September 9, 2014	September 11, 2014
Lower Colorado River Basin	15040001	NM-2503_02	Mogollon Creek (Perennial reaches abv USGS gage)	chronic aluminum	TMDL for Metals (Chronic Aluminum) on Mogollon Creek	November 13, 2001	April 5, 2002
Lower Colorado River Basin	15040004	NM-2603.A_43	Negrito Creek (South Fork)	temperature	TMDL for Temperature on the South Fork of Negrito Creek from the Confluence with the North Fork to the	November 13, 2001	April 5, 2002
Lower Colorado River Basin	15040004	NM-2602_20	San Francisco River (Centerfire Creek to AZ border)	temperature	TMDL for Temperature on the San Francisco River from Centerfire Creek to the New Mexico/Arizona Border	November 13, 2001	April 12, 2002
				plant nutrients	TMDL for Plant Nutrients on the San Francisco River from Centerfire Creek upstream to the New Mexico/Arizona	December 11, 2001	August 5, 2002
Lower Colorado River Basin	15040004	NM-2602_10	San Francisco River (NM 12 at Reserve to Centerfire Creek)	E.coli, turbidity	TMDL for Upper Gila, San Francisco, and Mimbres River Watersheds	September 9, 2014	September 11, 2014
Lower Colorado River Basin	15040004	NM-2602_22	San Francisco River (Willow Springs Cyn to NM 12 at Reserve)	E.coli	TMDL for Upper Gila, San Francisco, and Mimbres River Watersheds	September 9, 2014	September 11, 2014

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Lower Colorado River Basin	15040001	NM-2503_04	Sapillo Creek (Gila River to Lake Roberts)	total organic carbon	TMDL for Total Organic Carbon (TOC) on Sapillo	December 11, 2001	April 12, 2002
				turbidity	TMDL for Turbidity on Sapillo Creek		
Lower Colorado River Basin	15040004	NM-2603.A_43	South Fork Negrito Creek (Negrito Creek to headwaters)	E.coli	TMDL for Upper Gila, San Francisco, and Mimbres River Watersheds	September 9, 2014	September 11, 2014
Lower Colorado River Basin	15040001		Taylor Creek (Beaver Creek to Wall Lake)	chronic aluminum	TMDL for Metals (Chronic Aluminum) for the East Fork of the Gila River and Taylor Creek	November 13, 2001	April 15, 2002
				temperature	TMDL for Temperature on Taylor Creek		August 5, 2002
Lower Colorado River Basin	15040004	NM-2603.A_40	Tularosa River (San Francisco R to Apache Creek)	conductivity	TMDL for Conductivity on the Tularosa River	November 13, 2001	April 5, 2002
Lower Colorado River Basin	15040004	NM-2603.A_40	Tularosa River (San Francisco River to Apache Creek)	E.coli, turbidity	TMDL for Upper Gila, San Francisco, and Mimbres River Watersheds	September 9, 2014	September 11, 2014
Lower Colorado River Basin	15040004	NM-2603.A_10	Whitewater Creek (San Francisco River to White-water Campgrd)	turbidity	TMDL for Temperature on Whitewater Creek	November 13, 2001	April 12, 2002
				chronic aluminum	TMDL for Chronic Aluminum on Whitewater Creek	December 11, 2001	
				chronic aluminum	TMDL withdrawal for Chronic Aluminum on Whitewater Creek	March 13, 2018	April 24, 2018
Lower Colorado River Basin	15040004	NM-2503_47	Willow Creek (Gilita Creek to headwaters)	chronic aluminum	TMDL for Upper Gila, San Francisco, and Mimbres River Watersheds	September 9, 2014	September 11, 2014

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Lower Rio Grande Basin	13030102	NM-2101_00	Rio Grande (International Mexico boundary to Leasburg Dam)	E. coli	TMDL for the Main Stem of the Lower Rio Grande (from the International boundary with Mexico to Elephant Butte Dam)	May 8, 2007	June 11, 2007
Lower Rio Grande Basin	13030102	NM-2101_10	Rio Grande (Leasburg Dam to Percha Dam)	E. coli	TMDL for the Main Stem of the Lower Rio Grande (from the International boundary with Mexico to Elephant Butte Dam)	May 8, 2007	June 11, 2007
Middle Rio Grande Basin	13020102	NM-2113_50	Abiquiu Creek (Rio Chama to headwaters)	dissolved oxygen	TMDLs for the Lower Chama Watershed (Below El Vado Reservoir to the confluence with the Rio Grande)	June 8, 2004	September 3, 2004
Middle Rio Grande Basin	13020102	NM-2116.A_030	Canjilon Creek (perennial portions Abiquiu Rsrv to headwaters)	specific conducance, temperature	TMDL for the Rio Chama Watershed (Abiquiu Reservoir to headwaters)	July 12, 2011	August 16, 2011
Middle Rio Grande Basin	13020102	NM-2116.A_010	Cañones Creek (Abiquiu Reservoir to headwaters)	chronic aluminum, fecal coliform, turbidity	TMDLs for the Lower Chama Watershed (Below El Vado Reservoir to the confluence with the Rio Grande)	June 8, 2004	September 3, 2004
Middle Rio Grande Basin	13020102	NM-2116.A_081	Chavez Creek (Rio Brazos to headwaters)	temperature	TMDLs for the Upper Chama Watershed (El Vado Reservoir to Colorado border)	September 9, 2003	March 4, 2004
Middle Rio Grande Basin	13020102	NM-2116.A_023	Poleo Creek (Rio Puerco de Chama to headwaters)	turbidity	TMDLs for the Lower Chama Watershed (Below El Vado Reservoir to the confluence with the Rio Grande)	June 8, 2004	September 3, 2004
Middle Rio Grande Basin	13020102	NM-2116.A_011	Polvadera Creek (Cañones Creek to headwaters)	temperature	TMDLs for the Lower Chama Watershed (Below El Vado Reservoir to the confluence with the Rio Grande)	June 8, 2004	September 3, 2004

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Middle Rio Grande Basin	13020102	NM-2116.A_080	Rio Brazos (Rio Chama to Chavez Creek)	temperature	TMDLs for the Upper Chama Watershed (El Vado Reservoir to Colorado border)	September 9, 2003	March 4, 2004
Middle Rio Grande Basin	13020102	NM-2116.A_041	Rio Capulin (Rio Gallina to headwaters)	E.coli	TMDL for the Rio Chama Watershed (Abiquiu Reservoir to headwaters)	July 12, 2011	August 16, 2011
Middle Rio Grande Basin	13020102	NM-2116.A_000	Rio Chama (El Vado Reservoir to Rio Brazos)	E.coli, temperature, plant nutrients	TMDL for the Rio Chama Watershed (Abiquiu Reservoir to headwaters)	July 12, 2011	August 16, 2011
Middle Rio Grande Basin	13020102	NM-2116.A_002	Rio Chama (Little Willow Creek to CO border)	E.coli, temperature	TMDL for the Rio Chama Watershed (Abiquiu Reservoir to headwaters)	July 12, 2011	August 16, 2011
Middle Rio Grande Basin	13020102	NM-2116.A_001	Rio Chama (Rio Brazos to Little Willow Creek)	temperature	TMDLs for the Upper Chama Watershed (El Vado Reservoir to Colorado border)	September 9, 2003	March 4, 2004
				E.coli, plant nutrients	TMDL for the Rio Chama Watershed (Abiquiu Reservoir to headwaters)	July 12, 2011	August 16, 2011
Middle Rio Grande Basin	13020102	NM-2116.A_110	Rio Chamita (Rio Chama to CO border)	chronic aluminum	TMDLs for the Upper Chama Watershed (El Vado Reservoir to Colorado border)	September 9, 2003	March 4, 2004
				chronic aluminum	Chronic aluminum TMDL withdrawal for Rio Chamita	March 13, 2018	April 24, 2018
Middle Rio Grande Basin	13020102	NM-2116.A_110	Rio Chamita (Rio Chama to CO border)	total ammonia, total phosphorus, fecal coliform	TMDL for the Rio Chamita from the confluence of the Rio Chama to the NM-CO border	August 10. 1999	September 30, 1999
				temperature	TMDL for Temperature on the Rio Chamita	November 9, 1999	December 17, 1999
				E.coli, plant nutrients	TMDL for the Rio Chama Watershed (Abiquiu Reservoir to headwaters)	July 12, 2011	August 16, 2011
Middle Rio Grande Basin	13020102	NM-2115_20	Rio Puerco de Chama (Abiquiu Res to Hwy 96)	E.coli, temperature	TMDL for the Rio Chama Watershed (Abiquiu Reservoir to headwaters)	July 12, 2011	August 16, 2011

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Middle Rio Grande Basin	13020102	NM-2116.A_060	Rio Nutrias (Rio Chama to headwaters)	turbidity	TMDLs for the Lower Chama Watershed (Below El Vado Reservoir to the confluence with the Rio Grande)	June 8, 2004	September 3, 2004
Middle Rio Grande Basin	13020102	NM-2113_30	Rio Tusas (Rio Vallecitos to headwaters)	plant nutrients	TMDL for the Rio Chama Watershed (Abiquiu Reservoir to headwaters)	July 12, 2011	August 16, 2011
Middle Rio Grande Basin	13020102	NM-2112.A_00	Rio Vallecitos (Rio Tusas to headwaters)	chronic aluminum, temperature, turbidity	TMDLs for the Lower Chama Watershed (Below El Vado Reservoir to the confluence with the Rio Grande)	June 8, 2004	September 3, 2004
Middle Rio Grande Basin	13020102	NM-2116.A_070	Rito de Tierra Amarilla (Rio Chama to HWY 64)	stream bottom deposits, temperature, turbidity	TMDLs for the Upper Chama Watershed (El Vado Reservoir to Colorado border)	September 9, 2003	March 4, 2004
Middle Rio Grande Basin	13020102	NM-2116.A_010	Cañones Creek (Abiquiu Reservoir to Chihuahueños Creek)	E.coli	Chama River Watershed TMDL	October 13, 2020	December 1, 2020
Middle Rio Grande Basin	13020102	NM-2116.A_022	Coyote Creek (Rio Puerco de Chama to headwaters)	sedimentation	Chama River Watershed TMDL	October 13, 2020	December 1, 2020
Middle Rio Grande Basin	13020102	NM-2112.A_03	Placer Creek (Hopewell Lake to headwaters)	temperature	Chama River Watershed TMDL	October 13, 2020	December 1, 2020
Middle Rio Grande Basin	13020102	NM-2116.A_023	Poleo Creek (Rio Puerco de Chama to headwaters)	sedimentation	Chama River Watershed TMDL	October 13, 2020	December 1, 2020
Middle Rio Grande Basin	13020102	NM-2116.A_060	Rio Nutrias (Perennial portions Rio Chama to headwaters)	E.coli	Chama River Watershed TMDL	October 13, 2020	December 1, 2020
Middle Rio Grande Basin	13020102	NM-2113_30	Rio Tusas (Perennial portions Rio Vallecitos to headwaters)	temperature	Chama River Watershed TMDL	October 13, 2020	December 1, 2020
Middle Rio Grande Basin	13020102	NM-2116.A_021	Rito Encino (Rio Puerco de Chama to headwaters)	sedimentation	Chama River Watershed TMDL	October 13, 2020	December 1, 2020
Middle Rio Grande Basin	13020102	NM-2116.A_112	Sixto Creek (Rio Chamita to CO border)	temperature	Chama River Watershed TMDL	October 13, 2020	December 1, 2020

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Middle Rio Grande Basin	13020201	NM-2118.A_12	Galisteo Creek (Perennial prt 2.2 mi abv Lamy to hdwts)	temperature	TMDL for Galisteo Creek	July 11, 2017	August 22, 2017
		NM-2118.A_10	Galisteo creek (Perennial prt Kewa bnd to 2.2 mi abv Lamy)	temperature	TMDL for Galisteo Creek	July 11, 2017	August 22, 2017
Middle Rio Grande Basin	13020201	NM-2110_00	Santa Fe River (Cochiti Pueblo bnd to Santa Fe WWTP)	chlorine, stream bottom deposits	TMDL for the Santa Fe River from the Cochiti Pueblo to the Santa Fe Wastewater Treatment Plant for Chlorine and Stream Bottom Deposits	January 11, 2000	March 20, 2000
				dissolved oxygen, pH	TMDL for the Santa Fe River for Dissolved Oxygen and pH	December 12, 2000	January 11, 2001
				E.coli	Santa Fe River E.coli TMDL	April 11, 2017	May 3, 2017
Middle Rio Grande Basin	13020201	NM-9000.A_061	Santa Fe River (Santa Fe WWTP to Guadalupe Street)	E.coli	Santa Fe River E.coli TMDL	April 11, 2017	May 3, 2017
Middle Rio Grande Basin	13020201	NM-9000.A_062	Santa Fe River (Guadalupe St to Nichols Reservoir)	E.coli	Santa Fe River E.coli TMDL	April 11, 2017	May 3, 2017
Middle Rio Grande Basin	13020101	NM-9000.A047	Sandia Canyon (Sigma Canyon to NPDES outfall 001)	dissolved copper	Sandia Canyon IR Category 4b demonstration project	September 9, 2014	November 11, 2014
Middle Rio Grande Basin	13020202	NM-2106.A_54	Clear Creek (Rio de las Vacas to San Gregio Lake)	total organic carbon, turbidity	TMDL Report for the Jemez River Watershed	December 16, 2002	June 3, 2003
Middle Rio Grande Basin	13020202	NM-2106.A_54	Clear Creek (Rio de las Vacas to San Gregio Lake)	E.coli, plant nutrients	Jemez River Watershed TMDL	September 13, 2016	September 23, 2016
Middle Rio Grande Basin	13020202	NM-2106.A_55	Clear Creek (San Gregorio Lake to headwaters)	Plant nutrients	Jemez River Watershed TMDL	September 13, 2016	September 23, 2016
Middle Rio Grande Basin	13020202	NM-2106.A_10	Jemez River (East Fork)	turbidity	TMDL Report for the Jemez River Watershed	December 16, 2002	June 3, 2003
Middle Rio Grande Basin	13020202	NM-2106.A_10	East Fork Jemez (East Fork Jemez to headwaters)	temperature	TMDL for the Jemez River Watershed (Valles Caldera National Preserve boundaries to headwaters)	August 8, 2006	October 11, 2006

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Middle Rio Grande Basin	13020202	NM-2016.A_10	East For Jemez (VCNP to headwaters)	plant nutrients	Jemez River Watershed TMDL	September 13, 2016	September 23, 2016
Middle Rio Grande Basin	13020202	NM-2106.A_13	East Fork Jemez River (San Antonio Creek to VCNP boundary)	temperature, arsenic	TMDL for the Jemez River Watershed (from San Ysidro to headwaters excluding the waters in the Valles Caldera National Preserve)	August 11, 2009	September 15, 2009
Middle Rio Grande Basin	13020202	NM-2016.A_12	Jaramillo Creek (East Fork Jemez to headwaters)	plant nutrients	Jemez River Watershed TMDL	September 13, 2016	September 23, 2016
Middle Rio Grande Basin	13020202	NM-2106.A_00	Jemez River (HWY 4 near Jemez Springs to East Fork)	stream bottom deposits, turbidity	TMDL for Turbidity and Stream Bottom Deposits for the Jemez River and Rio Guadalupe	June 8, 2004	July 30, 2004
				chronic aluminum	TMDL Report for the Jemez River Watershed	December 16, 2002	June 3, 2003
				chronic aluminum	Aluminum TMDL revision	March 13, 2018	April 27, 2018
Middle Rio Grande Basin	13020202	NM-2105.5_10	Jemez River (Rio Guadalupe to HWY 4 nr Jemez Springs)	stream bottom deposits, turbidity	TMDL for Turbidity and Stream Bottom Deposits for the Jemez River and Rio Guadalupe	June 8, 2004	July 30, 2004
				chronic aluminum	TMDL Report for the Jemez River Watershed	December 16, 2002	June 3, 2003
Middle Rio Grande Basin	13020202	NM-2105_75	Jemez River (Zia Pueblo bnd to Jemez Pueblo bnd)	E.coli	Jemez River Watershed TMDL	September 13, 2016	September 23, 2016
Middle Rio Grande Basin	13020202	NM-2105_75	Jemez River (Zia Pueblo bnd to Jemez Pueblo bnd)	arsenic, boron	TMDL for the Jemez River Watershed (from San Ysidro to headwaters excluding the waters in the Valles Caldera National Preserve)	August 11, 2009	September 15, 2009
Middle Rio Grande Basin	13020202	NM-2105_71	Jemez River (Jemez Pueblo bnd to Rio Guadalupe)	arsenic, boron	TMDL for the Jemez River Watershed (from San Ysidro to headwaters excluding the waters in the Valles Caldera National Preserve)	August 11, 2009	September 15, 2009
Middle Rio Grande Basin	13020202	NM-2105_71	Jemez River (Jemez Pueblo bnd to Rio Guadalupe)	E.coli	Jemez River Watershed TMDL	September 13, 2016	September 23, 2016

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Middle Rio Grande Basin	13020202	NM-2105.5_10	Jemez River (Rio Guadalupe to Soda Dam nr Jemez Springs)	arsenic, boron, temperature, nutrients	TMDL for the Jemez River Watershed (from San Ysidro to headwaters excluding the waters in the Valles Caldera National Preserve)	August 11, 2009	September 15, 2009
Middle Rio Grande Basin	13020202	NM-2105.5_10	Jemez River (Rio Guadalupe to Soda Dam nr Jemez Springs)	E.coli	Jemez River Watershed TMDL	September 13, 2016	September 23, 2016
Middle Rio Grande Basin	13020202	NM-2106.A_00	Jemez River (Soda Dam nr Jemez Springs to East Fork)	E.coli	Jemez River Watershed TMDL	September 13, 2016	September 23, 2016
Middle Rio Grande Basin	13020202	NM-2106.A_00	Jemez River (Soda Dam nr Jemez Springs to East Fork)	arsenic	TMDL for the Jemez River Watershed (from San Ysidro to headwaters excluding the waters in the Valles Caldera National Preserve)	August 11, 2009	September 15, 2009
Middle Rio Grande Basin	13020202	NM-2106.A_21	Redondo Creek (Sulphur Creek to headwaters)	total phosphorus	TMDL for Total Phosphorus for Redondo Creek	October 12, 1999	December 2, 1999
				temperature, turbidity	TMDL Report for the Jemez River Watershed	December 16, 2002	June 3, 2003
Middle Rio Grande Basin	13020202	NM-2106.A_12	Jaramillo Creek (VCNP boundary to headwaters)	temperature, turbidity	TMDL for the Jemez River Watershed (Valles Caldera National Preserve boundaries to headwaters)	August 8, 2006	October 11, 2006

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Middle Rio Grande Basin	13020202	NM-2106.A_52	Rio Cebolla (Fenton Lake to headwaters)	stream bottom deposits, temperature	TMDL Report for the Jemez River Watershed	December 16, 2002	June 3, 2003
Middle Rio Grande Basin	13020202	NM-2106.A_50	Rio Cebolla (Rio de las Vacas to Fenton Lake)	stream bottom deposits	TMDL Report for the Jemez River Watershed	December 16, 2002	June 3, 2003
Middle Rio Grande Basin	13020202	NM-2106.A_40	Rio de las Vacas (Rio Cebolla to Clear Creek)	nutrients	TMDL for the Jemez River Watershed (from San Ysidro to headwaters excluding the waters in the Valles Caldera National Preserve)	August 11, 2009	September 15, 2009
Middle Rio Grande Basin	13020202	NM-2106.A_40	Rio de las Vacas (Rio Cebolla to Rito de las Palomas)	temperature, total organic carbon	TMDL Report for the Jemez River Watershed	December 16, 2002	June 3, 2003
Middle Rio Grande Basin	13020202	NM-2106.A_30	Rio Guadalupe (Jemez River to confl with Rio Cebolla)	Plant nutrients	Jemez River Watershed TMDL	September 13, 2016	September 23, 2016
Middle Rio Grande Basin	13020202	NM-2106.A_30	Rio Guadalupe (Jemez River to confl with Rio Cebolla)	chronic aluminum	TMDL Report for the Jemez River Watershed	December 16, 2002	June 3, 2003
				stream bottom deposits, turbidity	TMDL for Turbidity and Stream Bottom Deposits for the Jemez River and the Rio Guadalupe	June 8, 2004	July 30, 2004
				temperature	TMDL for the Jemez River Watershed (from San Ysidro to headwaters excluding the waters in the Valles Caldera National Preserve)	August 11, 2009	September 15, 2009
Middle Rio Grande Basin	13020202	NM-2106.A_43	Rito de las Palomas (Rio de las Vacas to headwaters)	temperature, sedimentation	TMDL for the Jemez River Watershed (from San Ysidro to headwaters excluding the waters in the Valles Caldera National Preserve)	August 11, 2009	September 15, 2009
Middle Rio	13020202	NM-2106.A_42	Rito Penas Negras (Rio de las	stream bottom deposits,	TMDL Report for the Jemez	December 16, 2002	June 3, 2003

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Grande Basin			Vacas to headwaters)	temperature, total	River Watershed		
				nutrients	TMDL for the Jemez River Watershed (from San Ysidro to headwaters excluding the waters in the Valles Caldera National Preserve)	August 11, 2009	September 15, 2009

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Middle Rio Grande Basin	13020202	NM-2106.A_20	San Antonio Creek (East Fork Jemez River to headwaters)	temperature, turbidity	TMDL Report for the Jemez River Watershed	December 16, 2002	June 3, 2003
Middle Rio Grande Basin	13020202	NM-2106.A_20	San Antonio Creek (East Fork Jemez to VCNP bnd)	arsenic	TMDL for the Jemez River Watershed (from San Ysidro to headwaters excluding the waters in the Valles Caldera National Preserve)	August 11, 2009	September 15, 2009
Middle Rio Grande Basin	13020202	NM-2106.A_22	Sulphur Creek (Redondo Creek to headwaters)	conductivity, pH	TMDL Report for the Jemez River Watershed	December 16, 2002	June 3, 2003
Middle Rio Grande Basin	13020204	NM-2107.A_46	La Jara Creek (perennial reaches above Arroyo San Jose)	chronic aluminum	TMDL for the Rio Puerco Watershed-Part Two	August 14, 2007	September 21, 2007
Middle Rio Grande Basin	13020204	NM-2107.A_46	La Jara Creek (perennial reaches above Arroyo San Jose)	Total aluminum	Upper Rio Puerco TMDL	May 10, 2016	June 16, 2016
Middle Rio Grande Basin	13020203	NM-2105.1_00	Rio Grande (non-Pueblo Alameda to Angostura Diversion)	E. coli	TMDL for the Middle Rio Grande Watershed	April 13, 2010	June 30, 2010
Middle Rio Grande Basin	13020203	NM-2105.1_00	Rio Grande (Alameda Bridge to Santa Ana Pueblo bnd)	fecal coliform	Middle Rio Grande TMDL for Fecal Coliform	November 13, 2001	May 3, 2002
Middle Rio Grande Basin	13020203	NM-2105_50	Rio Grande (Isleta Pueblo boundary to Alameda bridge)	E. coli	TMDL for the Middle Rio Grande Watershed	April 13, 2010	June 30, 2010
				fecal coliform	Middle Rio Grande TMDL for Fecal Coliform	November 13, 2001	May 3, 2002
Middle Rio Grande Basin	13020203	NM-2105_40	Rio Grande (Rio Puerco to Isleta Pueblo boundary)	E. coli	TMDL for the Middle Rio Grande Watershed	April 13, 2010	June 30, 2010

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Middle Rio Grande Basin	13020203	NM-2105_10 NM-2105_11	Rio Grande (San Marcial at USGS gage to Rio Puerco)	aluminum, E. coli	TMDL for the Middle Rio Grande Watershed	April 13, 2010	June 30, 2010
				aluminum	Aluminum TMDL revision	March 13, 2018	April 27, 2018
Middle Rio Grande Basin	13020203	NM-9000.A_001	Tijeras Arroyo (Four Hills Bridge to Headwaters)	plant nutrients	Tijeras Arroyo Nutrients TMDL	September 12, 2017	October 12, 2017
Middle Rio Grande Basin	13020204	NM-2107.A_40	Rio Puerco (Arroyo Chijuilla to Northern Boundary Cuba)	sedimentation	TMDL for the Rio Puerco Watershed-Part One	November 14, 2006	August 10, 2007
				chronic aluminum, nutrients	TMDL for the Rio Puerco Watershed-Part Two	August 14, 2007	September 21, 2007
				chronic aluminum	Chronic aluminum TMDL withdrawal for Rio Puerco	March 13, 2018	April 24, 2018
Middle Rio Grande Basin	13020204	NM-2107.A_42	Nacimiento Creek (Perennial part Hwy 126 to San Gregorio Reservoir)	Turbidity, Total aluminum, uranium	Upper Rio Puerco TMDL	May 10, 2016	June 16, 2016
Middle Rio Grande Basin	13020204	NM-2107.A_44	Rio Puerco (Perennial part northern bnd Cuba to headwaters)	Sedimentation	Upper Rio Puerco TMDL	May 10, 2016	June 16, 2016
Middle Rio Grande Basin	13020207	NM-2107.A_01	Bluewater Creek (Bluewater Reservoir to headwaters)	temperature, nutrients	TMDL for the Rio Puerco Watershed-Part Two	August 14, 2007	September 21, 2007
Middle Rio Grande Basin	13020207	NM-2107.A_00	Bluewater Creek (non-tribal Rio San Jose to Bluewater Rsrv)	temperature, nutrients	TMDL for the Rio Puerco Watershed-Part Two	August 14, 2007	September 21, 2007
Middle Rio Grande Basin	13020207	NM-2107.A_10	Río Moquino (Laguna Pueblo to Seboyettia Creek)	temperature, nutrients	TMDL for the Rio Puerco Watershed-Part Two	August 14, 2007	September 21, 2007
Upper Rio Grande Basin	13020101	NM-98.A_002	Apache Canyon (Rio Fernando de Taos to headwaters)	E.coli	TMDL for the Upper Rio Grande Watershed	August 14, 2012	September 13, 2012
Upper Rio Grande Basin	13020101	NM-2120.A_705	Bitter Creek (Red River to headwaters)	stream bottom deposits, acute aluminum	TMDL for the Red River Watershed (Rio Grande River to headwaters)	January 10, 2006	March 17, 2006
Upper Rio Grande Basin	13020101	NM-2120.A_827	Comanche Creek (Costilla Creek to Little Costilla Creek)	temperature	TMDL for the Upper Rio Grande Watershed Part 1 (Pilar, NM to CO border)	November 9, 2004	December 17, 2004
Upper Rio Grande Basin	13020101	NM-2120.A_823	Cordova Creek (Costilla Creek to headwaters)	stream bottom deposits, total phosphorus, turbidity	TMDL for Turbidity, Stream Bottom Deposits, and Total Phosphorus for Cordova Creek	November 9, 1999	December 17, 1999

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Upper Rio Grande Basin	13020101	NM-2120.A_820	Costilla Creek (diversion above Costilla to Comanche Creek)	temperature	TMDL for the Upper Rio Grande Watershed Part 1 (Pilar, NM to CO border)	November 9, 2004	December 17, 2004
Upper Rio Grande Basin	13020101	NM-2118.A_34	Embudo Creek (Rio Grande to Canada de Ojo Sarco)	stream bottom deposits, turbidity	TMDL for the Upper Rio Grande Watershed Part 2 (Cochiti Reservoir to Pilar, NM)	April 12, 2005	June 2, 2005
Upper Rio Grande Basin	13020101	NM-2120.A_835	Gold Creek (Comanche Creek to headwaters)	temperature	TMDL for the Waters of the Valle Vidal	September 30, 2011	November 8, 2011
Upper Rio Grande Basin	13020101	NM-2120.A_837	Holman Creek (Comanche Creek to headwaters)	temperature	TMDL for the Waters of the Valle Vidal	September 30, 2011	November 8, 2011
Upper Rio Grande Basin	13020101	NM-2120.A_839	LaBelle Creek (Comanche Creek to headwaters)	temperature	TMDL for the Waters of the Valle Vidal	September 30, 2011	November 8, 2011
Upper Rio Grande Basin	13020101	NM-2118.A_34	Little Tesuque (Rio Tesuque to headwaters)	chronic aluminum	TMDL for the Upper Rio Grande Watershed Part 2 (Cochiti Reservoir to Pilar, NM)	April 12, 2005	June 2, 2005
Upper Rio Grande Basin	13020101	NM-2120.A_706	Placer Creek (Red River to headwaters)	acute aluminum	TMDL for the Red River Watershed (Rio Grande River to headwaters)	January 10, 2006	March 17, 2006
Upper Rio Grande Basin	13020101	NM-2119_10	Red River (Rio Grande to Placer Creek)	acute aluminum	TMDL for the Red River Watershed (Rio Grande River to headwaters)	January 10, 2006	March 17, 2006

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Upper Rio Grande Basin	13010005	NM-2120.A_900	Rio de los Pinos (Colorado border to headwaters)	temperature	TMDL for the Upper Rio Grande Watershed Part 1 (Pilar, NM to CO border)	November 9, 2004	December 17, 2004
Upper Rio Grande Basin	13020101	NM-2120.A_512	Rio Fernando de Taos (Rio Pueblo de Taos to headwaters)	specific conductance, temperature	TMDL for the Upper Rio Grande Watershed Part 1 (Pilar, NM to CO border)	November 9, 2004	December 17, 2004
Upper Rio Grande Basin	13020101	NM-98.A_001	Rio Fernando de Taos (Tienditas Creek to headwaters)	E.coli	TMDL for the Upper Rio Grande Watershed	August 14, 2012	September 13, 2012
Upper Rio Grande Basin	13020101	NM-2120.A_512	Rio Fernando de Taos (Rio Pueblo de Taos to USFS bnd at Canyon)	E.coli	TMDL for the Upper Rio Grande Watershed	August 14, 2012	September 13, 2012
Upper Rio Grande Basin	13020101	NM-2120.A_513	Rio Fernando de Taos (USFS bnd at Canyon to Tienditas Creek)	E.coli	TMDL for the Upper Rio Grande Watershed	August 14, 2012	September 13, 2012
Upper Rio Grande Basin	13020101	NM-2111_12	Rio Grande (non-pueblo Santa Clara to Embudo Creek)	turbidity	TMDL for the Upper Rio Grande Watershed Part 2 (Cochiti Reservoir to Pilar, NM)	April 12, 2005	June 2, 2005
Upper Rio Grande Basin	13020101	NM-2119_05	Rio Grande (Red River to NM-CO border)	temperature	TMDL for the Upper Rio Grande Watershed Part 1 (Pilar, NM to CO border)	November 9, 2004	December 17, 2004
Upper Rio Grande Basin	13020101	NM-2120.A_501	Rio Grande del Rancho (Rio Pueblo de Taos to Hwy 518)	specific conductance	TMDL for the Upper Rio Grande Watershed Part 1 (Pilar, NM to CO border)	November 9, 2004	December 17, 2004
Upper Rio Grande Basin	13020101	NM-2120.A_600	Rio Hondo (Rio Grande to USFS boundary)	temperature	TMDL for the Upper Rio Grande Watershed Part 1 (Pilar, NM to CO border)	November 9, 2004	December 17, 2004

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Upper Rio Grande Basin	13020101	NM-2120.A_602	Rio Hondo (South Fork of Rio Hondo to Lake Fork Creek)	total phosphorus, Total Nitrogen	TMDL for the Rio Hondo (South Fork of Rio Hondo to Lake Fork Creek)	June 14, 2005	September 14, 2005
Upper Rio Grande Basin	13020101	NM-2119_30	Rio Pueblo de Taos (Arroyo del Alamo to Rio Grande del Rancho)	stream bottom deposits, temperature	TMDL for the Upper Rio Grande Watershed Part 1 (Pilar, NM to CO border)	November 9, 2004	December 17, 2004
Upper Rio Grande Basin	13020101	NM-2120.A_511	Rio Pueblo de Taos (Rio Grande del Rancho to Taos Pueblo boundary)	temperature	TMDL for the Upper Rio Grande Watershed Part 1 (Pilar, NM to CO border)	November 9, 2004	December 17, 2004
Upper Rio Grande Basin	13020101	NM-2120.A_511	Rio Pueblo de Taos (Rio Grande del Rancho to Taos Pueblo boundary)	E.coli	TMDL for the Upper Rio Grande Watershed	August 14, 2012	September 13, 2012
Upper Rio Grande Basin	13020101	NM-2119_20	Rio Pueblo de Taos (Rio Grande to Arroyo del Alamo)	temperature	TMDL for the Upper Rio Grande Watershed Part 1 (Pilar, NM to CO border)	November 9, 2004	December 17, 2004
Upper Rio Grande Basin	13020101	NM-2118.A_52	Rio Quemado (Santa Cruz River to Rio Arriba County bnd)	E.coli	TMDL for the Upper Rio Grande Watershed	August 14, 2012	September 13, 2012
Upper Rio Grande Basin	13010005	NM-2120.A_901	Rio San Antonio (Montoya Canyon to headwaters)	temperature	TMDL for the Upper Rio Grande Watershed Part 1 (Pilar, NM to CO border)	November 9, 2004	December 17, 2004
Upper Rio Grande Basin	13010005	NM-2120.A_901	Rio San Antonio (Montoya Canyon to headwaters)	E.coli	TMDL for the Upper Rio Grande Watershed	August 14, 2012	September 13, 2012

List of Approved TMDLs in New Mexico

Appendix B - Water Quality Management Plan and Continuing Planning Process

Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Upper Rio Grande Basin	13020101	NM-2120.A_419	Rio Santa Barbara (Picuris Pueblo boundary to USFS boundary)	turbidity	TMDL for the Upper Rio Grande Watershed Part 2 (Cochiti Reservoir to Pilar, NM)	April 12, 2005	June 2, 2005
Upper Rio Grande Basin	13020101	NM-2120.A_419	Rio Santa Barbara (non-Pueblo Embudo Creek to USFS bnd)	E.coli	TMDL for the Upper Rio Grande Watershed	August 14, 2012	September 13, 2012
Upper Rio Grande Basin	13020101	NM-2111_50	Santa Cruz River (Santa Clara Pueblo bnd to Santa Cruz Dam)	E.coli	TMDL for the Upper Rio Grande Watershed	August 14, 2012	September 13, 2012
Pecos River Basin	13050003	NM-2801_10	Nogal Creek (Tularosa Creek to Mescalero Apache boundary)	E.coli	TMDL for the Sacramento Mountains (Rio Hondo, Tularosa and Rio Peñasco Watersheds)	August 11, 2015	September 21, 2015
Pecos River Basin	13060001	NM-2214.A_091	Bull Creek (Cow Creek to headwaters)	temperature	TMDL for the Pecos Headwaters Watershed (Ft. Sumner Reservoir to headwaters)	August 9, 2005	September 13, 2005
Pecos River Basin	13060001	NM-2214.A_102	Cow Creek (Bull Creek to headwaters)	temperature, turbidity	TMDL for the Pecos Headwaters Watershed (Ft. Sumner Reservoir to headwaters)	August 9, 2005	September 13, 2005
Pecos River Basin	13060001	NM-2214.A_090	Cow Creek (Pecos River to Bull Creek)	temperature, turbidity	TMDL for the Pecos Headwaters Watershed (Ft. Sumner Reservoir to headwaters)	August 9, 2005	September 13, 2005
Pecos River Basin	13060001	NM-2214.A_070	Dalton Canyon Creek (Pecos River to headwaters)	specific conductance	TMDL for the Upper Pecos River Watershed	September 10, 2013	September 25, 2013

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Pecos River Basin	13060001	NM-2212_12	Falls Creek (Tecolote Creek to headwaters)	specific conductance	TMDL for the Upper Pecos River Watershed	September 10, 2013	September 25, 2013

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Pecos River Basin	13060001	NM-2212_00	Gallinas River (Las Vegas diversion to headwaters)	temperature	TMDL for the Pecos Headwaters Watershed (Ft. Sumner Reservoir to headwaters)	August 9, 2005	September 13, 2005
Pecos River Basin	13060001	NM-2214.A_071	Macho Canyon Creek (Pecos River to headwaters)	specific conductance	TMDL for the Upper Pecos River Watershed	September 10, 2013	September 25, 2013
Pecos River Basin	13060001	NM-2213_22	Pecos Arroyo (Gallinas River to headwaters)	E.coli	TMDL for the Upper Pecos River Watershed	September 10, 2013	September 25, 2013
Pecos River Basin	13060001	NM-2214.A_002	Pecos River (Alamitos Canyon to Willow Creek)	turbidity	TMDL for the Pecos Headwaters Watershed (Ft. Sumner Reservoir to headwaters)	August 9, 2005	September 13, 2005
Pecos River Basin	13060001	NM-2214.A_003	Pecos River (Canon de Manzanita to Alamitos Canyon)	temperature, turbidity	TMDL for the Pecos Headwaters Watershed (Ft. Sumner Reservoir to headwaters)	August 9, 2005	September 13, 2005
Pecos River Basin	13060001	NM-2211.A_10	Pecos River (Santa Rosa Reservoir to Tecolote Creek)	E.coli	TMDL for the Upper Pecos River Watershed	September 10, 2013	September 25, 2013
Pecos River Basin	13060001	NM-9000.A_050	El Rito (Pecos River to headwaters)	E.coli	TMDL for the Upper Pecos River Watershed	September 10, 2013	September 25, 2013

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Pecos River Basin	13060001	NM-2114.A_030	Willow Creek (Pecos River to headwaters)	specific conductance	TMDL for the Upper Pecos River Watershed	September 10, 2013	September 25, 2013
Pecos River Basin	13060008	NM-2209.A_22	Carrizo Creek (Rio Ruidoso to Mescalero Apache boundary)	bacteria	TMDL for the Rio Hondo Watershed (Lincoln County) (Pecos River to Headwaters)	January 10, 2006	February 10, 2006
Pecos River Basin	13060008	NM-2209.A_22	Carrizo Creek (Rio Ruidoso to Mescalero Apache boundary)	E.coli	TMDL for the Sacramento Mountains (Rio Hondo, Tularosa and Rio Peñasco Watersheds)	August 11, 2015	September 21, 2015
Pecos River Basin	13060008	NM-2209.A_10	Rio Bonito (Angus Canyon to headwaters)	bacteria	TMDL for the Rio Hondo Watershed (Lincoln County) (Pecos River to Headwaters)	January 10, 2006	February 10, 2006
Pecos River Basin	13060008	NM-2209.A_10	Rio Bonito (NM 48 near Angus to headwaters	E.coli	TMDL for the Sacramento Mountains (Rio Hondo, Tularosa and Rio Peñasco	August 11, 2015	September 21, 2015
Pecos River Basin	13060008	NM-2208_30	Rio Hondo (Perennial Reaches Pecos to headwaters)	bacteria	TMDL for the Rio Hondo Watershed (Lincoln County) (Pecos River to Headwaters)	January 10, 2006	February 10, 2006
Pecos River Basin	13060008	NM-2208_20	Rio Ruidoso (Rio Bonito to US Highway 70)	total nitrogen, total phosphorus (plant nutrients)	TMDL for the Rio Hondo Watershed (Lincoln County) (Pecos River to Headwaters)	January 10, 2006 November 15, 2016 (update)	February 10, 2006 December 13, 2016 (update)

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Pecos River Basin	13060008	NM-2208_20	Rio Ruidoso (Eagle Creek to US Hwy 70 bridge)	E.coli, turbidity	TMDL for the Sacramento Mountains (Rio Hondo, Tularosa and Rio Peñasco Watersheds)	August 11, 2015	September 21, 2015
Pecos River Basin	13060008	NM-2209.A_20	Rio Ruidoso (US Highway 70 Mescalero Apache boundary)	temperature, turbidity	TMDL for the Rio Hondo Watershed (Lincoln County) (Pecos River to Headwaters)	January 10, 2006	February 10, 2006
Pecos River Basin	13060008	NM-2209.A_20	Rio Ruidoso (Carrizo Creek to Mescalero Apache boundary)	plant nutrients	Rio Ruidoso TMDL	November 15, 2016	December 13, 2016
Pecos River Basin	13060008	NM-2209.A_21	Rio Ruidoso (US Hwy 70 bridge to Carrizo Creek)	E.coli	TMDL for the Sacramento Mountains (Rio Hondo, Tularosa and Rio Peñasco Watersheds)	August 11, 2015	September 21, 2015
Pecos River Basin	13060008	NM-2209.A_21	Rio Ruidoso (US Hwy 70 bridge to Carrizo Creek)	plant nutrients	Rio Ruidoso TMDL	November 15, 2016	December 13, 2016
Pecos River Basin	13060010	NM-2208_01	Agua Chiquita (Perennial portions McEwan Canyon to headwaters)	Turbidity	TMDL for the Sacramento Mountains (Rio Hondo, Tularosa and Rio Peñasco Watersheds)	August 11, 2015	September 21, 2015
Pecos River Basin	13060010	NM-2208_00	Rio Penasco (Highway 24 to Cox Canyon)	Turbidity	TMDL for the Sacramento Mountains (Rio Hondo, Tularosa and Rio Peñasco Watersheds)	August 11, 2015	September 21, 2015
Pecos River Basin	13060011	NM-2201_00	Pecos River (TX border to Black River)	E.coli	Lower Pecos Watershed TMDL	September 13, 2016	September 23, 2016
Pecos River Basin	13060011	NM-2202.A_00	Pecos River (Black river to Six Mile Dam Lake)	E.coli	Lower Pecos Watershed TMDL	September 13, 2016	September 23, 2016

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
Pecos River Basin	13060011	NM-2212_10	Tecolote Creek (I-25 to Blue Creek)	temperature	Tecolote Creek TMDL	August 15, 2018	September 13, 2018

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
San Juan River Basin	14080104	NM-2403.A_00	Animas River (San Juan River to Estes Arroyo)	fecal coliform	TMDL for the San Juan River Watershed Part One (Navajo Nation Boundary at the Hogbackk to Navajo Dam)	June 14, 2005	August 26, 2005
				total nitrogen, total phosphorus	TMDL for the San Juan River Watershed Part Two (Navajo Nation Boundary at the Hogbackk to Navajo Dam)	December 13, 2005	January 17, 2006
San Juan River Basin	14080104	NM-2403.A_00	Animas River (San Juan River to Estes Arroyo)	E.coli, temperature	TMDL for the Animas River Watershed	September 10, 2013	September 30, 2013
San Juan River Basin	14080104	NM-2404_00	Animas River (Estes Arroyo to Southern Ute Indian Tribe bnd)	E.coli, total phosphorus	TMDL for the Animas River Watershed	September 10, 2013	September 30, 2013
San Juan River Basin	14080101	NM-9000.A_060	Gallegos Canyon (San Juan to Navajo Boundary)	selenium	TMDL for the San Juan River Watershed Part One (Navajo Nation Boundary at the Hogbackk to Navajo Dam)	June 14, 2005	August 26, 2005
San Juan River Basin	14080105	NM-2402.A_01	La Plata River (McDermott Arroyo to Colorado Border)	fecal coliform	TMDL for the San Juan River Watershed Part One (Navajo Nation Boundary at the Hogbackk to Navajo Dam)	June 14, 2005	August 26, 2005
				dissolved oxygen	TMDL for the San Juan River Watershed Part Two (Navajo Nation Boundary at the Hogbackk to Navajo Dam)	December 13, 2005	January 17, 2006
San Juan River Basin	14080105	NM-2403.A_00	La Plata River (San Juan River to McDermott Arroyo)	fecal coliform, stream bottom deposits	TMDL for the San Juan River Watershed Part One (Navajo Nation Boundary at the Hogback to Navajo Dam)	June 14, 2005	August 26, 2005

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Watershed	HUC	AU_ID	Waterbody	TMDL Paramenter	Document Name	WQCC Approval	EPA Approval
San Juan River Basin	14080105	NM-2401_10	San Juan River (Navajo Boundary at Hogback to Animas River)	fecal coliform	TMDL for the San Juan River Watershed Part One (Navajo Nation Boundary at the Hogback to Navajo Dam)	June 14, 2005	August 26, 2005
San Juan River Basin	14080101	NM-2401_00	San Juan River (Animas River to Canon Largo)	fecal coliform, stream bottom deposits	TMDL for the San Juan River Watershed Part One (Navajo Nation Boundary at the Hogbackk to Navajo Dam)	June 14, 2005	August 26, 2005

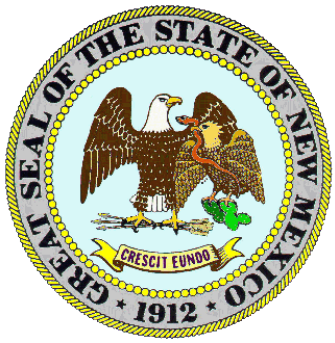
State of New Mexico
Water Quality Management Plan
& Continuing Planning Process

Appendix C

Hydrology Protocol

for the

Determination of Uses Supported by
Ephemeral, Intermittent, and Perennial Waters



Originally Approved May 2011
Approved Revision October 23, 2020

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EXECUTIVE SUMMARY

The *Hydrology Protocol* provides a methodology for distinguishing among ephemeral, intermittent and perennial streams and rivers in New Mexico. The results of the *Hydrology Protocol* may also aid in the designation of appropriate designated uses supported by those waterbodies as a result of flow regime. New Mexico's water quality standards (*Standards for Interstate and Intrastate Surface Waters*, 20.6.4 NMAC) set distinct protections for unclassified ephemeral, intermittent and perennial waters (*see* 20.6.4.97 to 99 NMAC) and also identify many classified waters by their hydrology, e.g. "perennial tributaries to" or "perennial reaches of" (*see* 20.6.4.101 to 899 NMAC). Hydrological determinations are key to assuring that the appropriate designated uses and water quality criteria are applied to a particular waterbody.

The *Hydrology Protocol* was specifically developed to generate documentation of the aquatic life and recreation uses supported by the hydrology of a given stream or river. This information can then be used to provide technical support for a Use Attainability Analysis (UAA). Under particular circumstances, the use of the *Hydrology Protocol* can be used for the expedited UAA process (20.6.4.15(C) NMAC), which facilitates the efficient application of the limited aquatic life and secondary contact uses to ephemeral waters, where appropriate, prior to undergoing the full administrative rule-making process. However, the *Hydrology Protocol* cannot be used in place of the UAA.

SWQB or any other party may conduct a *Hydrology Protocol* survey as part of a UAA in accordance with UAA requirements found under 40 CFR 131.10, 20.6.4.15 NMAC and the State's approved Water Quality Management Plan/Continuing Planning Process (WQMP/CPP), therefore the user/evaluator may be a member of SWQB, another regulatory agency, a contractor, or a member of the public.

The information gained from the protocol can also be used to identify unclassified waters within an otherwise classified standards segment. The details of these specific applications are described in Section II of *New Mexico's Water Quality Management Plan and Continuing Planning Process*, to which this *Hydrology Protocol* is an appendix. Other applications where a determination of stream hydrology is necessary are possible but results of the *Hydrology Protocol* must be evaluated cautiously within the specific decision framework of the study.

The protocol relies on hydrological, geomorphic and biological indicators related to the persistence of water and is organized into two levels of evaluations: Level 1 and Level 2. Data gathered during the Level 1 Evaluation should, in most cases, provide enough information to give a clear indication of the hydrological status of the stream. The "*Hydrology Determination Field Sheets,"* a.k.a. "*Field Sheets,*" was developed to record the information collected through application of the *Hydrology Protocol* and may be used to support the UAA process. The Level 1 Evaluation Field Sheets provide some of the necessary information needed in a Use Attainability Analysis to demonstrate a stream is ephemeral, intermittent or perennial. Attainment of a specific Clean Water Act Section 101(a)(2) aquatic life and recreational use may not be feasible due to the factor identified in 40 CFR 131.10(g)(2): *natural, ephemeral, intermittent, or low flow conditions or water levels prevent the attainment of the use*. The data obtained through a Hydrology Protocol survey provides some of

the information that would be necessary to demonstrate that attainment is not achievable but, is only one of the elements required under a UAA to demonstrate the evidence to support changing a designated use.

In certain instances, additional data and supporting information are necessary to determine the hydrological condition of the stream. The methods described as part of the Level 2 Evaluation may be conducted if the Level 1 Evaluation is inconclusive (i.e. the score falls within a gray zone, see Section 2, Table 5). The Level 2 Evaluation relies on more intense and focused data collection efforts and provides the evaluator with additional data and observations to make a final hydrological determination. The Level 2 Evaluation may be used for either an expedited or regular UAA as documentation to support the proper standards classification of a given stream.

Regardless of whether a Level 1 or Level 2 Evaluation is performed, the SWQB encourages the evaluator to gather as much information as possible to make an accurate assessment of the stream. Recommendations are provided in the protocol, but other data not included in these recommendations may be gathered as well.

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I. INTRODUCTION

Streams are drainage features that may exhibit ephemeral, intermittent or perennial characteristics or change from ephemeral to intermittent and intermittent to perennial along a gradient or continuum—sometimes with no single distinct point demarcating these transitions. Nevertheless, all stream systems are characterized by interactions among hydrological, biological, and geomorphic (physical) processes. According to Maidment (1993), *Streamflow* can be described as flowing surface water along a defined natural channel generated by a combination of:

- *Stormflow* – streamflow resulting from the relatively rapid runoff of precipitation from the land as interflow (rapid, unsaturated, subsurface flow), overland flow, or saturated flow from raised, near surface water tables close to the stream.
- *Baseflow* – return flow from sustained groundwater discharge into the channel.
- Contributions of discharge from upstream tributaries as stormflow or baseflow.
- Contributions of discharge from point source dischargers and irrigation return flows.

The *Hydrology Protocol* uses attributes of hydrological, biological and geomorphic processes to produce a quantitative score. The score is then used to characterize the stream as "ephemeral," "intermittent," or "perennial". The term "stream", as it pertains to the *Hydrology Protocol*, refers to a wadable, lotic water body (typically 1st, 2nd, or 3rd Strahler stream order) and the term "river" refers to a non-wadable, lotic water body (generally 4th Strahler stream order or higher). Throughout this document the terms are interchangeable with one another as the same process and procedures are used regardless of whether the channel is wadable or not.

II. DEFINITIONS

The *Hydrology Protocol* is based on the definitions of "ephemeral," "intermittent" and "perennial" adopted by the WQCC in 20.6.4.7 NMAC as follows:

> ***"Ephemeral"*** *when used to describe a surface water of the state means the water body contains water briefly only in direct response to precipitation; its bed is always above the water table of the adjacent region.*
>
> ***"Intermittent"*** *when used to describe a surface water of the state means the water body contains water for extended periods only at certain times of the year, such as when it receives seasonal flow from springs or melting snow.*
>
> ***"Perennial"*** *when used to describe a surface water of the state means the water body typically contains water throughout the year and rarely experiences dry periods.*

III. HYDROLOGY DETERMINATION AND RATING FORM

A. General Information

There are two levels of evaluation for the *Hydrology Protocol* (HP). Data gathered during the Level 1 Evaluation should, in most cases, provide enough information to give a clear indication of the hydrological status of the stream. However, a more in-depth Level 2 Evaluation may be used to gather more information and data for more complex borderline cases. The *Field Sheets* are used to record the information and data collected through application of the HP.

For waterbodies where an HP is being conducted with the intent to remove a designated use that is not an existing use, as defined under 40 CFR 131.3 and 20.6.4.7(E)(3) NMAC, a UAA must be prepared. Third-party UAAs conducted in accordance with 20.6.4.15(D) NMAC, must have a workplan, approved by the Department, prior to conducting an HP UAA.

Although the HP is used as supporting evidence in a UAA, it is beyond the scope of this document to provide guidance on preparing a UAA.

B. User/Evaluator Experience

In order to distinguish ephemeral streams and rivers from non-ephemeral ones or intermittent streams and rivers from perennial ones using the information presented in this protocol, the evaluator should have experience making geomorphic, hydrological, and biological observations in New Mexico or in the semi-arid climate of the southwestern U.S.

The *Hydrology Protocol* was designed to provide the necessary supporting documentation for a UAA based on natural hydrologic flow conditions. In accordance with 20.6.4.15 NMAC, NMED or any other party may conduct a UAA, therefore the User/Evaluator for the *Hydrology Protocol* may be a member of NMED, another regulatory agency, a contractor, and/or a member of the public. It should be noted that only the Department can submit an expedited UAA using the *Hydrology Protocol* for EPA's technical review and approval, as described under 20.6.4.15(C) NMAC.

C. Drought Conditions

Spatial and temporal variations in stream attributes occur in stream systems. These variations can affect persistence and volume of streamflow. The changes to the system's flow regime can be related to seasonal precipitation and evapotranspiration patterns, as well as influenced by recent weather and interannual climate variability.

Local drought and weather data should be reviewed prior to evaluating flow conditions in the field. Perennial streams will have water in their channels year-round in the absence of drought conditions. Therefore, it is *strongly* recommended that field evaluations be conducted outside of drought conditions whenever possible.

Drought conditions, for the purposes of this *Hydrology Protocol*, are defined as any time the Standardized Precipitation Index (SPI) is less than -1.5, indicating severely to extremely dry conditions as described by the National Drought Mitigation Center (NDMC 1995). The 12-month SPI will be used to determine drought conditions and noted on the *Field Sheets*. The 12-month SPI

should be verified through other sources such as the Standardized Precipitation Evapotranspiration Index (Beguería, et al. 2014) or the United States Drought Monitor to ensure that extreme or exceptional drought conditions are not indicated for the survey location.

The 12-month SPI was chosen for use in the *Hydrology Protocol* because SPIs of this time-scale can be linked to groundwater-surface water fluctuations and reservoir storage, it can provide an early warning of drought, and it can help assess drought severity. The SPI calculation for any location in New Mexico is based on 10 climate regions of New Mexico and long-term precipitation records (both rainfall and snowpack), and has available archived maps dating back to 1996. The 12-month SPI value for a particular stream is included as another piece of evidence to be evaluated before making a final stream determination. If the evaluator believes that extreme conditions such as severe drought or abnormal precipitation are influencing the overall rating, he may want to postpone a final decision until another evaluation can take place during more normal conditions.

D. Recent Rainfall Activity

Recent (generally considered to be within 48 hours) rainfall or snowmelt can also influence scoring; therefore, it is *strongly* recommended that field evaluations be conducted at least 48 hours after the last known major rainfall or snowmelt. Field observations regarding the presence or absence of recent high flows should be made and documented on the *Field Sheets* to supplement any available local rain gauge data and to determine if field observations were made at least 48 hours following a precipitation or runoff event. To reduce this source of variability, the Level 1 Field Evaluation should occur during stable baseflow conditions which will vary by region and elevation of the sample reach but are typically between late May and mid-July (to avoid snowmelt) or mid-September and early November (to avoid monsoons). The protocol and scoring mechanism were designed with redundancy (i.e. multiple indicators) to allow for defensible scoring even within 48 hours after a recent rainfall or during drought conditions. Nevertheless, performing field evaluations during or after severe conditions, such as floods or drought, is not optimal nor is it recommended.

E. Scoring

The *Field Sheets* are used to record the score for each attribute and determine the total numeric score for the sample reach under investigation. The *Field Sheets* specifically request information regarding: date, project, evaluator, site, Assessment Unit (AU), 12-month SPI value, latitude/longitude, as well as any other pertinent observations (such as indications of recent rain events). Additional notes for the Field Sheets should include the most recent precipitation date and amount from the closest rain gage, if available, and evidence of any anthropogenic influences and modifications. The *Field Sheets* are an official record, so all pertinent observations should be recorded on it.

In order to assess the natural variability encountered when making hydrological determinations in the field, a four-tiered, weighted scale was developed for evaluating and scoring each hydrological attribute. The scores that are applied to sets of geomorphic, hydrological and biological attributes are: poor, weak, moderate, and strong. *Moderate* scores are intended as an approximate qualitative midpoint between the two extremes of *Poor* and *Strong*. The score ranges were developed to better assess the often gradual and variable transitions of streams from ephemeral

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to non-ephemeral. The remaining qualitative description of *Weak* represents gradations that will often be observed in the field. Definitions of poor, weak, moderate and strong are provided in **Table 1**. These definitions are intended as guidelines and the evaluator must select the most appropriate category based upon experience and observations of the sample reach under review, its watershed, and physiographic region.

The quantitative score given to each attribute reflects the evaluator's qualitative assessment of the characteristic along the sample reach. These category range within each of the characteristics allows the evaluator flexibility in assessing variable features or attributes. In addition, the incremental category gradients reduce the variability of range in scores between different evaluators. There may be circumstances where intermediary scores between the categories presented for each indicator are appropriate. In those cases, document the rationale for the intermediary score on the *Field Sheets*.

Table 1. Guide to Scoring Categories

Category	Description
Strong	The characteristic* is easily observable (i.e. observed within less than one minute of searching).
Moderate	The characteristic is present and observable with minimal (i.e. one or two minutes) searching.
Weak	The characteristic is present, but you have to search intensely (i.e., ten or more minutes) to find it.
Poor	The characteristic is not observed.

*****geomorphic, hydrological or biological

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F. Level 1 Evaluation: Data Collection for the Hydrology Determination of NM Streams and Rivers

1. Level 1 Office Procedures

The following information should be gathered and reviewed prior to conducting field work for a Level 1 Field Evaluation. It is important to gather as much physical and geographic information as possible by conducting reconnaissance on the stream reach prior to going out to the study site to save time, money and other resources and identify any risks or concerns.

Geographical Information System (GIS) and Remote Sensing Tools
The following is a non-exhaustive list of suggested coverages and resources that can help identify and generate informative maps of the field of study area. In addition, the aerial photographs, GIS coverages and resources listed below can be used to calculate sinuosity prior to field work (see *Indicator* #1.7 (Sinuosity) for more information).

Useful resources include:

- Google Earth
- SWQB Mapper (https://gis.web.env.nm.gov/oem/?map=swqb)
- GIS software (ArcMAP, QGIS, etc.)

Useful coverages that can be added to a GIS project include (Note, not all information listed here will be available for every stream.):

- SWQB water quality stations
- SWQB assessment units
- National Hydrography Dataset (NHD) streams
- Southwest Regional Gap Analysis (http://swregap.nmsu.edu/default.htm)
- Office of the State Engineer (OSE) data
- The United States Geological Survey (USGS) quadrangle maps
- Aerial photographs
- National Hydrography Dataset
- Digital Geologic Map of NM
- National Land Cover Dataset
- Bureau of Land Management (BLM) Land Status
- United States Department of Agriculture (USDA) or Natural Resources Conservation Service (NRCS) soil survey
- Omernik Ecoregions
- NM Roads

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Streamflow

Historic or recent flow data from gages such as those managed by the USGS, OSE or Los Alamos National Laboratory (LANL) should be used to make hydrological determinations. Streamgage data, if available, may clearly indicate ephemeral, intermittent, or perennial flow patterns for the available period of record and will facilitate the scoring of Indicator #1.1 *Water in Channel*.

Useful resources include:

- USGS Current Water Data for New Mexico: https://waterdata.usgs.gov/nm/nwis/rt
- OSE Real-Time Water Measurement Information System: http://meas.ose.state.nm.us/
- Los Alamos Area Environmental Data (Intellus): https://www.intellusnm.com

Drought Conditions

The following resources will help determine drought conditions and recent rainfall activity. At a minimum, the 12-month Standardized Precipitation Index (SPI) should be recorded on the *field sheets* along with the date and source the SPI was evaluated. Note, not all information listed here will be available for every stream:

- Historic or recent flow data (known sources include SWQB, OSE, USGS, or localized sources such as Los Alamos National Laboratory for waters on the Pajarito Plateau)
- Standardized Precipitation Index (SPI)
    - https://hprcc.unl.edu/maps.php?map=ACISClimateMaps
- Standardized Precipitation Evapotranspiration Index (SPEI)
    - http://spei.csic.es/index.html
- Rain gauge stations within the County
- Airport/regional climate data
- The National Weather Service:
    - https://w2.weather.gov/climate/index.php?wfo=abq
- https://w2.weather.gov/climate/xmacis.php?wfo=abqhttps://water.weather.gov/ahps/United States Drought Monitor https://droughtmonitor.unl.edu/
- PRISM Climate Data:
    - http://www.prism.oregonstate.edu/mtd

Refer to *Drought Conditions* and *Recent Rainfall Activity* on pages 6-7 for more information.

Stream Segment Identification and Sample Reach Selection

This protocol describes a method for assessing geomorphic, hydrological, and biological indicators of stream flow duration. However, flow characteristics often vary along the length of a stream, resulting in gradual transitions in flow duration. Choosing the sample reach on which to conduct an assessment can influence the resulting conclusion about

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flow duration. Before a determination of hydrology can be made for a stream the appropriate sample reach, within the larger stream segment to which the UAA will apply, must be identified.

For SWQB stream segments are termed **assessment units** (**AUs**). AUs are river or stream reaches defined by various factors such as hydrologic or watershed boundaries, geology, topography, incoming tributaries, surrounding land use/land management, water quality standards, etc. AUs are designed to represent waters with assumed homogeneous water quality (WERF 2007). AUs in New Mexico average 10 miles in length and are typically no more than 25 miles in length. A **sample reach**, as used in this protocol, is a length of stream (40 times the average stream bankfull width or 160 meters, whichever is larger) that is chosen to represent a uniform set of physical, chemical, and biological conditions within an AU. It is the principal sampling unit for collecting hydrological, geomorphic and biological data using this protocol. Below are several factors to look for when determining the homogeneity of the AU and the representativeness of the sample reach:

- Are there significant tributaries (2nd order or higher) entering along the reach?
- Are there any changes in geology?
- Are there any dramatic shifts in land use?
- Is there a dramatic change in slope?
- Are there changes in riparian vegetation type and amount?
- Are there any point sources discharging into the reach?
- Are there any irrigation return flows discharging into the reach?

Many of these questions may be evaluated using maps and remote sensing products (e.g. Google Earth), however field reconnaissance along the length of the AU – to evaluate potential gradients in stream hydrology and to select representative sample reach(es) for hydrologic evaluation – should also be conducted.

The sample reach(es) selected for evaluation with the Hydrology Protocol should be as representative as possible of the natural characteristics of the AU. For example, if the stream is mostly vegetated, the sample reach should be located along an area of the channel that is mostly vegetated as opposed to an area that has no vegetation or is sparsely vegetated. It is the responsibility of the assessor(s) to verify and document the homogeneity of the AU and representativeness of the sample reach. SWQB typically defines a representative sample reach for conducting data collection as 40 times the average stream width or 160 meters, whichever is larger. If there are questions regarding the homogeneity of an AU (i.e., you answered “yes” to any of the questions above) then a hydrology evaluation should be performed on multiple sample reaches to identify potential transition point(s) between flow categories and accurately characterize the AU. One approach may be to examine air photos or satellite imagery and identify those areas with the greatest vegetation as potential study reaches with the greatest likelihood for “perennial” characteristics. Using the tools and resources described above may be helpful in confirming characteristics on the ground should an AU need to be re-evaluated.

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2. Level 1 Field Procedures

In order to distinguish between ephemeral, intermittent, and perennial streams and rivers using the information presented in this protocol, the field evaluator should have experience making geomorphic, hydrological, and biological observations in New Mexico or the semi-arid region of the southwestern U.S. Field evaluations should be performed at least 48 hours after the last known major rainfall or snowmelt event. In addition, it is *strongly* recommended that field evaluations be conducted outside of drought conditions whenever possible.

Field Equipment and Supplies

- Copy of *Hydrology Protocol* and associated *Field Sheets*.
- Site maps and satellite imagery (1:250 scale if possible)
- Global Positioning System (GPS) – used to determine latitude and longitude
- Clipboard/pencils/sharpies
- Two Metric Rulers
- Two Measuring Tapes
- Survey rod
- Bank pins
- Laser Level/Rod Eyes/Clinometer
- Compass (if not available as part of GPS unit)
- Camera – used to photograph and document site features
- Shovel or Soil Auger
- D-frame dip net/white sorting tray
  (optional) Munsell
- Soil color chart (optional)
- Long piece of string (optional)
- Mechanical tally counter (optional)
- Sand-gauge card (optional)

Sample Reach Selection

Before selecting a location for the survey, note the character of the stream while driving to the site to verify that the reach is representative of the AU being characterized. This initial examination allows the evaluator to study the nature of the channel, observe characteristics of the watershed, and observe characteristics that indicate what source of water (stormflow, or base flow plus tributary/point source discharges, if present) may predominantly or solely contribute to flow in the AU. These initial observations also aid in determining the magnitude (poor, weak, moderate or strong) of specific parameters. In addition, the assessor can identify if the sample reach is generally uniform (i.e. "representative") or if it should be assessed as two or more distinct reaches. Hydrology evaluations must not be made at one point without first walking up and down the channel

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for at least 160 meters.

Ideally, the visual examination would be from the stream origin to the downstream confluence with a larger stream or until a change in characteristics such as slope or geology is observed, but this is usually not feasible or practical. Furthermore, property access issues may arise on privately held property. Make sure the site is easily and safely accessible. If the site is on private property get the land owner's approval before conducting an evaluation.

Upon finding a representative area to conduct the survey, document the latitude and longitude (origination and termination) extent of the survey reach on the *Field Sheets*, the length of the survey area should be no less than 160 meters.

Photodocumentation

It is important to explain the rationale behind any conclusions reached using this protocol and sometimes photos are just the medium in which to do that. It is essential to take several photos of the sample reach, AU and/or watershed, as appropriate, to document the environmental conditions and any disturbances or modifications that are relevant to making a final hydrology determination. Multiple and varied photos will help evaluate and verify the homogeneity of the AU as well as the representativeness of the sample reach when and if a UAA is reviewed by NMED, EPA and the WQCC. Photos that document the evaluation attributes (e.g. riparian vegetation, benthic macroinvertebrates, etc.) are also encouraged and provide excellent supporting documentation for any conclusions reached.

The assessor should include a detailed description of each photo on the *Field Sheets*, including date, description of the photo (e.g. left bank, right bank, upstream, downstream, etc.), and GPS coordinates (if different from site location), and attach the photos to the *Field Sheets* to officially document the conditions at the time of the evaluation and to support any conclusions that were reached using this protocol.

3. Level 1 Scoring

Hydrological determinations are accomplished by evaluating 14 different attributes of the sample reach and assigning a numeric score to each attribute following the four–tiered, weighted scale described in Section 1 Scoring and summarized in Table 1. Total scores reflect the persistence of water with higher scores indicating intermittent and perennial systems. **Please see Section 2 – Guidance for Overall Score Interpretation for more details.**

4. Level 1 Indicators

1.1. Water in Channel

It is necessary to distinguish stormwater inflow (resulting from precipitation within the past 48 hours) from baseflow. Flow observations preferably should be taken at least 48 hours after the last substantial rainfall or runoff event. Local weather data and drought

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information should be reviewed before evaluating flow conditions. Perennial systems will have water in their channels year-round in the absence of drought conditions. Therefore, it is recommended that field evaluations be conducted outside of drought conditions whenever possible. Drought conditions are defined as any time the Standard Precipitation Index (SPI) is less than -1.5, indicating severely to extremely dry conditions (NDMC 1995). The 12-month SPI should be recorded on the *Field Sheets* to indicate climatic conditions at the time of sampling, and confirmed through other sources such as the Standardized Precipitation Evapotranspiration Index (Beguería, et al. 2014) or the United States Drought Monitor to ensure that extreme conditions are not indicated for the survey location.

Evidence of recent high flows should be noted on the *Field Sheets*. Such evidence includes moist or wet sediment on plants or debris and organic drift lines at or above bankfull or in the active floodplain. Artificial (i.e. point-source) discharges should also be noted on form. Site inspections should result in visually discernible stream flows as evidence of base flow contribution between rain events, even in low flow conditions. If base flows are present during a site inspection that is more than 48 hours after a major rainfall or runoff event, the sample reach is either perennial or intermittent. However, intermittent reaches do not always have water in them. A good rule of thumb for differentiating ephemeral reaches from intermittent ones is if they have water in them during the dry season or during a drought. Look for water in pool areas in the streambed. The presence or types of plants as well as saturated sediment underneath rocks located within the channel are also good indications of the presence of water during the dry season or during a drought.

If the stream is visited during the dry season (typically defined in NM as **late May to mid-July** and **mid-September to early November**, but also varies by region and elevation of the stream) and base flows are not evident, the stream may be ephemeral or intermittent. If there is no flowing water within 48 hours of a rain or runoff event, then the stream is more than likely ephemeral. The prerequisite for a stream to be determined as ephemeral is that there must be no evidence of base flows in the stream banks.

Strong – Flow is evident throughout the sample reach. Moving water is seen in riffle areas but may not be as evident throughout the runs.

Moderate – Water is present in the channel but flow is barely discernable in areas of greatest gradient change (i.e. riffles) or floating object is necessary to observe flow.

Weak – Dry channel with standing pools. There is some evidence of base flows (e.g. riparian vegetation growing along channel, saturated sediment under rocks, etc)

Poor – Dry channel. Dry under rocks and debris. No evidence of base flows was found.

If available, historic or recent flow data from streamgages such as those managed by the USGS, OSE, or LANL may clearly indicate ephemeral, intermittent, or perennial flow patterns for the available period of record and will facilitate the scoring of Indicator #1.1 *Water in Channel*.

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1.2. Fish (qualitative observations)

In most cases, fish are indicators of perennial systems, since fish will rarely inhabit an intermittent stream. Fluctuating water levels of intermittent streams provide unstable and stressful habitat conditions for fish communities. When looking for fish, all available habitats should be observed, including pools, riffles, root clumps, and other obstructions (to greatly reduce surface glare, the use of polarized sunglasses is recommended). In small streams, the majority of species usually inhabit pools and runs. Fish should be easily observed within a minute or two. Also, fish will seek cover once alerted to your presence, so be sure to look for them slightly ahead of where you are walking. Check several areas along the sample reach, especially underneath undercut banks.

Strong - Found easily and consistently throughout the sample reach.
Moderate - Found with little difficulty but not consistently throughout the sample reach.
Weak - Takes 10 or more minutes of extensive searching to find.
Poor - Fish are not present (after 10 or more minutes of searching).

1.3. Benthic Macroinvertebrates (qualitative observations)

The larval stages of many aquatic insects are good indicators that a stream is perennial because a continuous aquatic habitat is required for these species to mature. Turn over the rocks and other large substrate found in areas of visible flowing water, (i.e. riffles) and scan the undersides for benthic macroinvertebrates. Also observe the newly disturbed area where the rock once was for signs of movement. This method may be more suitable for mountainous areas where riffles predominate. For lower gradient systems and other areas of slow moving water, benthic macroinvertebrates may be located in a variety of habitats including root wads, undercut banks, pools, leaf-packs, and submerged aquatic vegetation. Note that some benthic macroinvertebrates will make small debris/sand cases, which can be covered with periphyton and easily confused for
excess debris picked up from the substrate. The use of a small net to sample a variety of habitats
including water under overhanging banks or roots, accumulations of organic debris (e.g. leaves) and the substrate may be helpful.

In DRY channels, focus the search on the sandy channel margins for mussel and aquatic snail shells, any remaining pools for macroinvertebrates, and under cobbles and other larger bed materials for caddisfly casings. Casings of emergent mayflies or stoneflies may be observed on dry cobbles or on stream-side vegetation.

Strong - Found easily and consistently throughout the sample reach.
Moderate - Found with little difficulty but not consistently throughout the sample reach.
Weak - Takes 10 or more minutes of extensive searching to find.
Poor - Benthic macroinvertebrates are not present (after 10 or more minutes of searching).

1.4. Presence of Filamentous Algae and Periphyton (qualitative observations)

These forms of algae are attached to the streambed substrate and require an aquatic environment to persist. They are visible as a pigmented mass or film, or sometimes hair-

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like growths on submerged surfaces of rocks, logs, plants and any other structures within the channel. Periphyton growth is influenced by chemical disturbances such as increased nutrient (nitrogen or phosphorus) inputs and physical disturbances such as increased sunlight to the stream from riparian zone disturbances.

Strong - Found easily and consistently throughout the sample reach.

Moderate - Found with little difficulty but not consistently throughout the sample reach.

Weak - Takes 10 or more minutes of extensive searching to find.

Poor - Filamentous algae and/or periphyton are not present (after 10 or more minutes of searching).

1.5. Differences in Vegetation

As a rule, only perennial and intermittent systems can support riparian areas that serve the entire suite of riparian ecological functions. Ephemeral streams generally do not possess the hydrological conditions that allow true riparian vegetation to grow. Although water flows down ephemeral channels periodically, the water table does not occur sufficiently close to the soil surface to allow water loving vegetation to access the greater quantity of water they need to grow. Vegetation growing along ephemeral watercourses may occur in greater densities or grow more vigorously than vegetation in the adjacent uplands, but generally there are no dramatic compositional differences between the two. Even along those ephemeral channels where vegetation composition differs somewhat from the adjacent uplands, that vegetation does not require as much soil moisture as true riparian plants.

Note if vegetation is absent or altered due to man-made activities on the Level 1 *Field Sheet*

Strong – Dramatic compositional differences in vegetation are present between the riparian corridor and the adjacent uplands. A distinct riparian vegetation corridor exists along the entire sample reach – riparian, aquatic, or wetland species dominate the length of the reach.

Moderate – A distinct riparian vegetation corridor exists along part of the sample reach. Compositional species difference between upland and riparian corridor. Riparian vegetation is interspersed with upland vegetation along the length of the reach.

Weak – Vegetation growing along the sample reach may occur in greater densities or grow more vigorously than in the adjacent uplands, but there are minimal compositional differences between the two.

Poor – No compositional or density differences in vegetation are present between the banks and the adjacent uplands. Vegetation growing along the riparian area does not occur in greater density or grow more vigorously than in the adjacent uplands.

1.6. Absence of Rooted Upland Plants in Streambed

This attribute relates flow to the absence of rooted plants, since flow will often act as a deterrent to plant establishment by removing seeds or preventing aeration to roots. Cases where rooted upland plants are present in the streambed may indicate ephemeral or intermittent flow. Focus should be on the presence of plants in the bed or thalweg and

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plants growing on any part of the bank should not be considered. Note, however, there will be exceptions to this attribute. For example, rooted plants can be found in shaded perennial streams with moderate flow but in all cases these plants will be water tolerant (i.e. obligate and/or facultative wetland plants).

Additionally, in some situations (e.g., high gradient sand bedded streams located within flashy watersheds) highly erosive flows and/or depth of scour in response to extreme rainfall events may limit the presence of rooted vegetation. Under these circumstances the assessor may use

professional judgment in selecting the appropriate scoring criteria, and should document on the
Field Sheets and with photos those factors that explain any alternative scoring methodology.

Strong – Rooted upland plants are absent within the streambed/thalweg.
Moderate – There are a few rooted upland plants present within the streambed/thalweg.
Weak – Rooted upland plants are consistently dispersed throughout the streambed/thalweg.
Poor – Rooted upland plants are prevalent within the streambed/thalweg.

*** If the sample reach being evaluated has a score ≤ 2 up to this point, the reach is determined to be ephemeral. If the reach being evaluated has a score≥ 18 at this point, the reach is determined to be perennial. You can STOP the evaluation. However, if the reach has a score between 2 and 18 you should continue the Level 1 Evaluation.***

1.7. Sinuosity
Sinuosity is a measure of a channel's "crookedness." Sinuosity is the result of the stream naturally dissipating its flow forces. Intermittent systems don't have a constant flow regime and, as a result, exhibit substantially less sinuous channel morphology. While ranking, take into consideration the size of the stream (e.g. 1st, 2nd, 3rd order, etc.), which may also influence the stream sinuosity. Sinuosity is best measured using aerial photography (Rosgen 1996).

Examples of sinuosity are provided in Figure 1. To calculate sinuosity using an aerial photograph, measure the stream length and related valley length for at least two meander wavelengths. A meander wavelength is the distance of one meander, or bend, along the down- valley axis of the stream. Divide the *stream* length (SL) by the *valley* length (VL) (Figure 2). If aerial photos are not available, sinuosity can be measured using a GPS's trip computer function to measure channel length and valley length. The higher the ratio (SL/VL), the more sinuous the stream.

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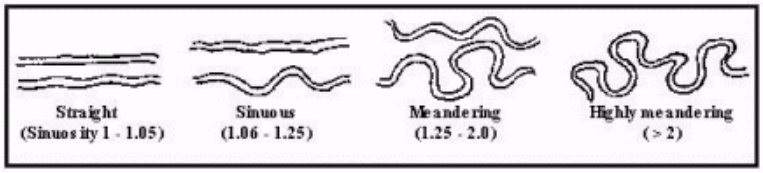


Figure 1. Examples of Stream Sinuosity (NCDWQ 2005)

In some surface waters (e.g., mountain stream settings or areas of complex and varied geology) channel sinuosity may be more reflective of external morphological factors, rather than the presence or absence of stream flow. Under these circumstances the assessor may use professional judgment in selecting the appropriate scoring criteria, and should document on the Level 1 *Field Sheets* and with photos those factors that explain any alternative scoring methodology.

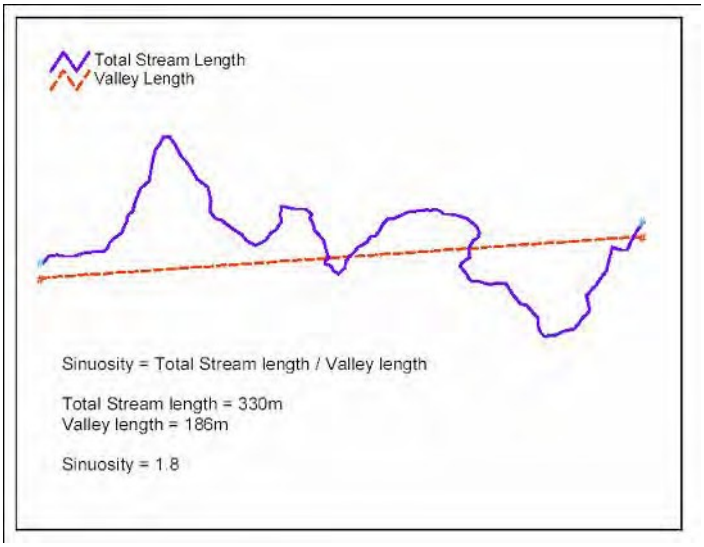


Figure 2. Stream Sinuosity (NCDWQ 2005)
******Note method used to determine sinuosity on the Field Sheets******

Strong – Stream sinuosity ratio is greater than 1.4. Stream has numerous, closely-spaced bends, few straight sections.

Moderate – Stream sinuosity ratio is between 1.4 and 1.2. Stream has good sinuosity with some straight sections.

Weak – Stream sinuosity ratio is between 1.2 and 1.0. Stream has very few bends and mostly straight sections.

Poor – Stream sinuosity ratio is equal to 1.0. Stream is completely straight with no bends.

1.8. Floodplain and Channel Dimensions

The relative importance of many fluvial processes in arid regions, especially the magnitude and frequency of their operation, differs considerably from more humid regions. As a result, channel forms also differ considerably from humid regions. Although one of the difficulties of characterizing dryland ephemeral streams is their enormous variability in form, they tend to be more incised with confined channels relative to intermittent and perennial streams (Knight et al. 1999).

When determining the vertical confinement of the stream, it is important to distinguish whether the flats adjacent to the channel are a frequent and active floodplain, terraces (abandoned floodplain), or are well outside of the flood-prone area. The ratio of the flood-prone area width to the bankfull, or active, channel width is used to determine the vertical confinement of the stream (Rosgen 1994). A larger ratio corresponds to a wide, active floodplain and a minimally confined channel, whereas a smaller ratio corresponds to a narrow or absent floodplain and a noticeably confined channel (**see scoring and "note" below*).

The flood-prone area width is measured at the elevation that corresponds to twice the maximum depth of the bankfull channel as taken from the established bankfull stage (Figure 3). The bankfull, or active, channel is defined as that which is filled with moderate sized flood events that would typically occur every one or two years and do not usually inundate the floodplain. Bankfull levels can be identified by:

- The presence of a floodplain at the elevation of initial flooding,
- The elevation associated with the *highest* depositional features,
- An obvious slope break that differentiates the channel from a relatively flat floodplain terrace higher than the channel,
- A transition from exposed sediments to terrestrial vegetation,
- Moss growth on rocks along the banks,
- Evidence of recent flooding,
- Presence of drift material caught on overhanging vegetation, and
- Transition from flood- and scour-tolerant vegetation to that which is relatively intolerant.

Field Protocol:

The evaluator(s) should start by selecting a location for the purpose of obtaining bankfull data. In general, the easiest location to measure bankfull channel width is within the narrowest segment of the sample reach. Deflectors such as rocks, logs, or unusual constrictions that make a stream especially narrow should be avoided.

1. Once a location is chosen, obtain a *rod reading* for an elevation at the "max depth" location by having one person hold a survey rod at the max depth location (thalweg) and a second person on the terrace adjacent to the stream using a clinometer and a meter stick or ski pole with one meter marked on it (if available, a surveyor's level can be used instead of a clinometer). Hold the clinometer at the one-meter mark on the ski pole, look through the clinometer holding it at zero, and read the height on the survey rod at the "max depth" location (Refer to **Figure 3**). Record the "max depth" *rod reading* on *Level 1 Field Sheets*.
2. Identify the bankfull stage using the indicators described above. Obtain a *rod reading* for an elevation at the "bankfull stage" location using the methods described in Step #1. Record the "bankfull stage" *rod reading* on Level 1 *Field Sheets*.
3. Subtract the "bankfull stage" reading from the "max depth" reading to obtain a maximum depth value. Multiply the maximum depth value by 2 for the "2x Max.

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Depth" value. Record the "2x Max. Depth" value on Level 1 *Field Sheets*.

4. Subtract the "2x Max Depth" value from the "max depth" *rod reading* for the "flood- prone area" location *rod reading*. Move the rod upslope, online with the cross-section, until a rod reading for the "flood-prone area" location is obtained.
5. Mark the flood-prone area (FPA) locations on each bank. Measure the distance between the two FPA locations. Record the **FPA Width** on Level 1 *Field Sheets*.
6. Measure the distance between the two Bankfull Stage locations. Record the **Bankfull Width** on Level 1 *Field Sheets*.
7. Divide the FPA Width by the Bankfull Width to calculate the Floodplain to Channel Ratio. Record the calculated ratio on Level 1 *Field Sheets*. <u>The Floodplain to Channel Ratio is used to score the stream for this indicator</u>.

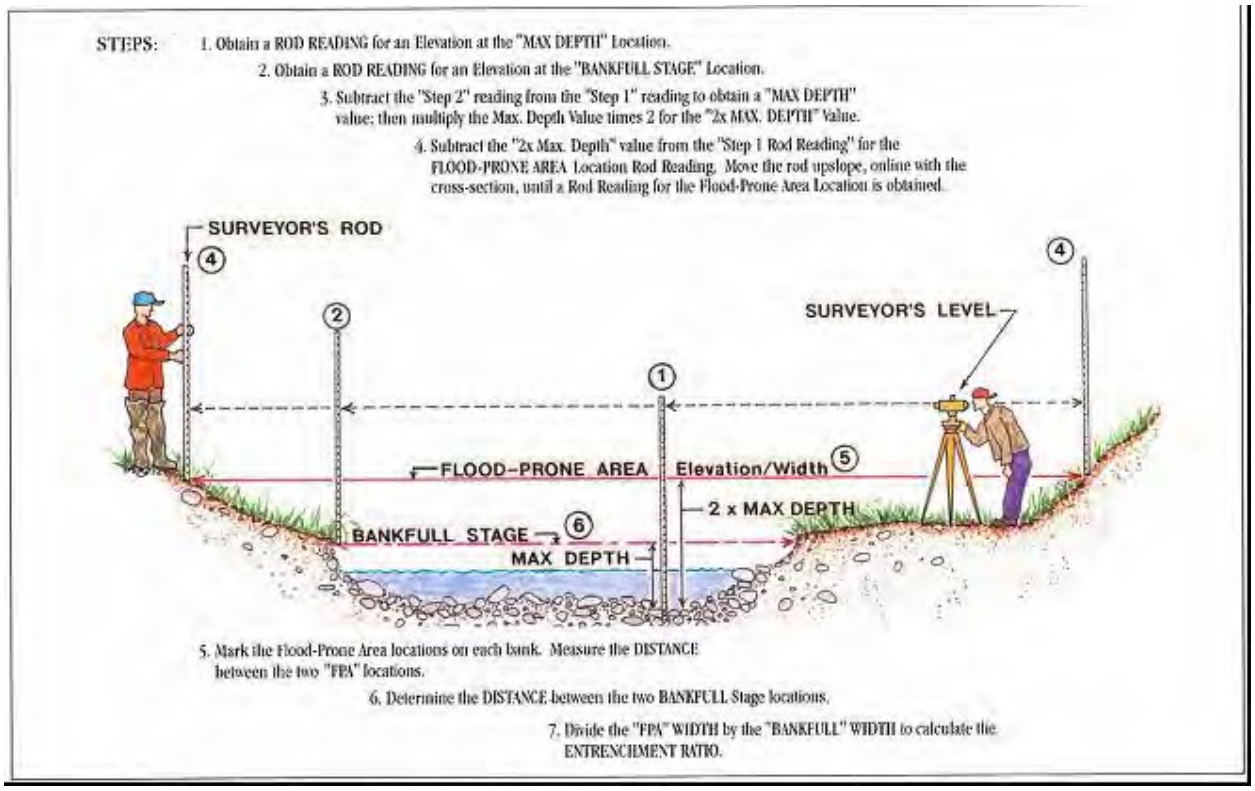


Figure 3. Determining a Flood-Prone Area elevation/width (Rosgen 1996)

In some surface waters (e.g., mountain stream settings or areas of complex and varied geology) the degree of channel confinement may be more reflective of external morphological factors rather than the presence or absence of stream flow. Under these circumstances the assessor may use professional judgment in selecting the appropriate survey location and scoring criteria and should document on the Level 1 *Field Sheets* and with photos those factors that explain the resulting 'representative' scores.

******Alternative methods for determining the Floodplain to Active Channel Ratio should be described and recorded on the Field Sheets******

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Strong - Ratio > 2.5*. Stream is minimally confined with a wide, active floodplain.

Moderate - Ratio between 1.2 and 2.5. Stream is moderately confined. Floodplain is present but may only be active during larger storm events.

Weak - Ratio < 1.2. Stream is incised with a noticeably confined channel. Floodplain is narrow or absent and disconnected from the channel during most storm events.

*NOTE: a larger ratio corresponds to a wide, active floodplain and a minimally confined channel, while a smaller ratio corresponds to a narrow or absent floodplain and a noticeably confined channel. If the channel is dry and bankfull stage cannot be determined, score this indicator based on your observations using the following scoring system:

Strong = stream is not incised/confined. Wide, active floodplain is connected to the channel.

Moderate = stream is moderately incised/confined. Flood-prone area width is narrow. Floodplain adjacent to the channel may be connected during large floods or represented by abandoned terraces.

Weak = stream is undeniably incised/confined. Flats adjacent to the stream are well outside of the flood-prone area.

1.9. In-channel Structure -- Riffle-Pool Sequences

A repeating sequence of riffle/pool (riffle/run in lower gradient systems, ripple/pool in sand bed systems, or step/pool in higher gradient systems) can be observed readily in perennial systems. Riffle-run (or ripple-run) sequences in low gradient systems are often created by in-channel woody structures such as roots and woody debris. When present, these characteristics can be observed even in a dry channel by closely examining the local profile of the channel. A riffle is a zone with relatively high channel slope gradient, shallow water, and high flow velocity and turbulence. In smaller streams, riffles are defined as areas of a distinct change in gradient where flowing water can be observed. The bottom substrate material in riffles contains the largest sedimentary particles that are moved by bankfull flow (bedload). A pool is a zone with relatively low channel slope gradient, deep water, and low velocity and turbulence. Fine textured sediments generally dominate the bottom substrate material in pools. Along the sample reach, take notice of the frequency between the riffles and pools.

Strong - Demonstrated by a frequent number of riffles followed by pools along the entire sample reach. There is an obvious transition between riffles and pools.

Moderate - Represented by a less frequent number of riffles and pools. Distinguishing the transition between riffles and pools is difficult.

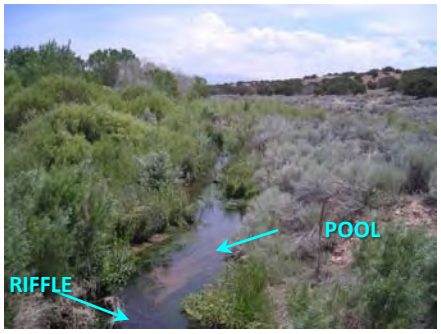
Weak - Mostly has areas of pools or of riffles.

Poor - No riffles or pools observed.

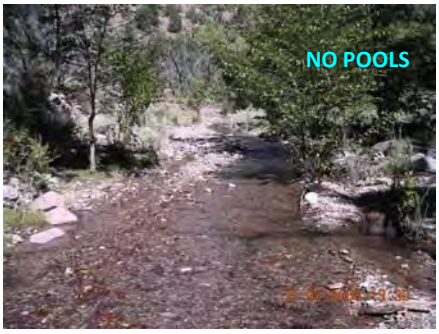
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Example of "**Strong**" Score – San Francisco River



Example of "**Moderate**" Score – Santa Fe River



Example of "**Weak**" Score – Mineral Creek



Example of "**Poor**" Score – Arroyo Chamiso

*** If the sample reach being evaluated has a score ≤ 5 at this point, the reach is determined to be ephemeral. If the reach being evaluated has a score ≥ 21 at this point, the reach is determined to be perennial. You can STOP the evaluation. However, if the reach has a score between 5 and 21 you should continue the Level 1 Evaluation.***

1.10. Particle size or Stream Substrate Sorting

This feature can be examined in two ways. The first is to determine if the sediment texture in the bottom of the channel is similar to the texture outside the channel. If this is the case, then there is evidence that erosive forces have not been active enough to down cut the channel and support an intermittent or perennial system. Sediment in the bed of ephemeral channels typically have the same or comparable texture (i.e. particle size) as areas close to but not in the channel. Accelerated stormflow resulting from human activities may produce deep, well-developed ephemeral or intermittent channels which have little or no coarse bottom materials indicative of upstream erosion and downstream transport. The bottom substrate of non-ephemeral systems often has accumulations of coarse sand and larger particles.

The second way this feature can be examined is to look at the distribution of the particles in the substrate in the channel. In lower-gradient, sand-bed streams one may need to look for size variations among sand grains – for instance, coarse versus fine sand. Note, however, the usefulness of this attribute may vary among ecoregions. For instance, in the plateaus or tablelands the variability in the size of substrate particles will probably be less than in the mountains.

Examples of Methods used to determine particle size and gradation:

- Sand Gauge Reference Card (best for sand dominated systems)
- Standard Sieve Analyses
- Wire Screen Method
- Pebble Count Method:
  - EPA's EMAP Pebble Count
  - Wolman Pebble Count
  - Zig Zag Pebble Count
  - USFS Pebble Count Sampling Frame

For whatever method is chosen, repeat procedure for an area close to but not in the channel for comparison purposes. Step outside the bankfull width or above the bank onto the floodplain or first terrace and repeat the procedure used in the bankfull channel. Avoid areas of dense vegetation and soil accumulation. Beware of cactus, snakes, and other hazards when "blindly" picking up particles outside of the channel or even in dry streambeds. For pebble counts, the objective is to measure at least 50 pebbles in the channel and 50 pebbles in areas close to but not in the channel for accurate distributional representations and comparisons.

Strong - Particle sizes in the channel are noticeably different from particle sizes outside the channel in the flood-prone area. There is a clear distribution of various sized substrates in the channel with finer particles accumulating in the pools, and larger particles accumulating in the riffles/runs.

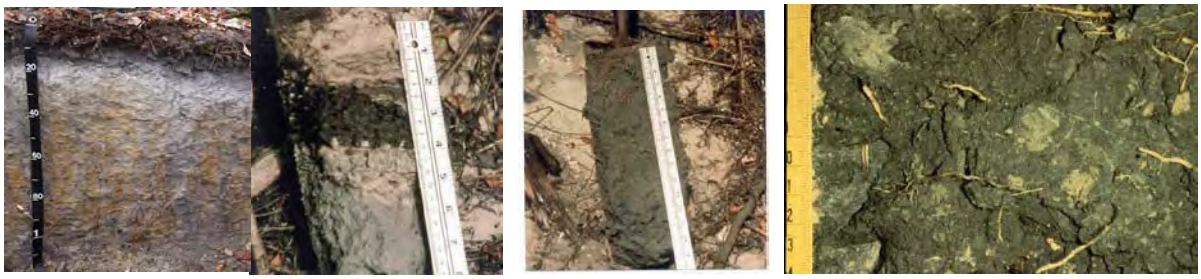
Moderate - Particle sizes in the channel are moderately similar to particle sizes outside the channel in the flood-prone area. Various sized substrates are present in the channel and are represented by a higher ratio of larger particles (gravel/cobble).

Weak - Particle sizes in the channel are similar or comparable to particle sizes outside the channel in the flood-prone area. Substrate sorting is not readily observed in the channel.

1.11. Hydric Soils

One of the most reliable methods for differentiating between ephemeral and non-ephemeral stream types during drier conditions requires investigation of the stream bank (i.e. from the stream bed to the top of the bank). Ephemeral streams usually have poor channel development and lack groundwater-induced base flows that normally result in hydric soils dominating the banks of intermittent and perennial streams. The presence of hydric soil indicators above the elevation of the channel bottom in floodplain soils adjacent to the channel indicates the presence of a seasonal high water table that can provide a critical period of base flow. Non-ephemeral stream banks typically are dominated by soils with hydric indicators, such as visually confirmed oxidized rhizospheres, a matrix of gray or black soils, and reducing conditions confirmed by a redox meter. The presence of hydric soils should be determined through visual observations, pungent odors, clay, etc. Additional information on field indicators of hydric soils is available from the Natural Resources Conservation Service at https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/use/hydric/. There are also

special considerations regarding the determination of hydric soils in arid regions. The United States Army Corps of Engineers (USACE) Wetlands Regulatory Assistance Program has divided New Mexico into three regions (Arid West, Western Mountains, and Great Plains). A regional map and regional supplements to the Corps of Engineers Wetland Delineation Manual are available at: https://www.usace.army.mil/Missions/Civil-Works/Regulatory-Program-and-Permits/reg_supp.



Examples of Hydric Soils in the Arid West – U.S. Army Corps of Engineers
(photos found at: http://www.usace.army.mil/CECW/Documents/cecwo/reg/trel08-28.pdf)

Note that hydric soil indicators may be poorly developed at the seasonal high-water table elevation in young, coarse textured, alluvial soil materials with low concentrations of clay, iron, and manganese, or floodplain soils where moving water fails to become reduced.

Present – Hydric soils are found within the sample reach.
Absent – Hydric soils are not found within the sample reach.

1.12. Sediment on Plants or Debris

The transportation and processing of sediment is a main function of streams. Therefore, evidence of sediment on plants or other debris in the channel may be an important indicator of recent high flows. Note that sediment production in stable, vegetated watersheds is considerably less than in disturbed watersheds. Are plants in the channel, on the streambank, or in the floodplain covered with sediment? Look for silt/sand accumulating in thin layers on debris or rooted aquatic vegetation in the runs and pools. Be aware of upstream land-disturbing construction activities, which may contribute greater amounts of sediments to the channel and can confound this indicator. Note these activities on the *Field Sheets* if these confounding factors are present.

Strong – Sediment found readily on plants and debris within the channel, on the streambank, and within the floodplain throughout the length of the sample reach.

Moderate – Sediment found on plants or debris within the channel although not prevalent along the sample reach. Mostly accumulated on plants and debris in pools.

Weak – Sediment on plants and debris is isolated in small amounts along the sample reach.

Poor – No sediment is present on plants or debris.

****Refer to Section 2 Overall Score Interpretation, for guidance on overall Level 1 score interpretation****

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Level 1 Supplemental Indicators

The following indicators do not occur consistently throughout New Mexico, which may be the reason why they were not statistically significant between waterbody types. Regardless, when they occur they are useful indicators in the determination of perenniality. Record the score on the Level 1 *Field Sheets* and include the score when calculating the total points.

1.13. Seeps and Springs

Seeps: Seeps have water dripping or slowly flowing out from the ground or from the side of a hill or incised streambank. Springs: Look for "mushy" or very wet, black decomposing leaf litter nearby in small depressions or in the channel. Springs and seeps often are present at grade controls and headcuts. The presence of this indicator suggests that groundwater is a source of streamflow except during a period of drought. Score this category based on the presence or absence of these features observed within the sample reach.

Present – Seeps and/or springs present in reach.
Absent – Seeps and/or springs were not present in reach

1.14. Iron Oxidizing Bacteria/Fungi

These features are often (although not exclusively) associated with groundwater. Iron oxidizing bacteria/fungi derive energy by oxidizing iron, originating from groundwater, in the ferrous form (Fe^{2+}) to the ferric form (Fe^{3+}). In large amounts, iron-oxidizing bacteria/fungi discolor the substrate giving it a red, rust-colored appearance. In small amounts, it can be observed as an oily sheen on the water's surface. This indicates that the stream water is derived from a groundwater source, and these features are most commonly seen in standing water on the ground's surface or in slow moving creeks and streams. Filmy deposits on the surface or banks of a stream are often associated with the greasy "rainbow" appearance of iron oxidizing bacteria. This is a naturally occurring phenomenon where there is iron in the groundwater. However, a sudden or unusual occurrence may indicate a petroleum product release from an underground fuel storage tank. One way to differentiate iron-oxidizing bacteria from oil releases is to trail a small stick or leaf through the film. If the film breaks up into small islands or clusters, it is most likely bacterial in origin. However, if the film swirls back together, it is most likely a petroleum discharge.

Present – Iron-oxidizing bacteria/fungi present in reach.
Absent – Iron-oxidizing bacteria/fungi not present in reach.

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Oily sheen on water's surface due to iron-oxidizing bacteria
(photos found at:
http://www.arlingtonva.us/departments/EnvironmentalServices/epo/EnvironmentalServicesEpoDr.aspx)



Iron-oxidizing bacteria in seepage spring at La Plata River, Farmington, NM

****Refer to Section 2 Overall Score Interpretation, for guidance on overall Level 1 score interpretation****

G. Level 2 Evaluation: Borderline Determinations

If, after conducting a Level 1 Evaluation, a hydrological determination cannot be made because more information is required, then a Level 2 Evaluation should be conducted between mid-August and mid-November to coincide with SWQB's biological index period.

1. Level 2 Office Procedures

Refer to the results of the **Level 1 Evaluation**. If this step was not completed in the Level 1 Evaluation or cannot be located then refer to *Drought Conditions* and *Recent Rainfall Activity* and the *Level 1 Office Procedures*, particularly *Stream Segment Identification and Sample Reach Selection*, for more information.

Additional Supporting Information

Additional supporting information may not be scored but can be used to support a Level 2 hydrological determination. Unfortunately, not all information listed here will be available for every assessment unit. Additional supporting information includes, but is not limited to:

Observation of flow:

Observation of flow under certain seasonal or hydrological conditions can directly support classifying a sample reach as perennial. Reaches with flow during the dry season or periods of drought are likely perennial. Although the presence of flow during a drought indicates perennial conditions, care must be taken in evaluating the upper limits of perenniality because some perennial systems may only contain isolated pools of water or be dry during periods of drought.

Thermograph Data:

- Historic or recent SWQB thermograph data may provide some insight on flow during certain seasonal or hydrological conditions
- Do thermograph and/or streamflow data (or lack thereof) warrant the use of equipment to estimate the onset and cessation of flow? (See *Indicator #2.1* below)

Key biological indicators:

As discussed below, the presence of aquatic organisms whose life cycle requires residency in flowing water for extended periods (especially those one year or greater) is a strong indication that a sample reach is perennial. If a reach is recognized as borderline, a qualified aquatic biologist or environmental scientist should evaluate the presence and abundance of such macroinvertebrates and vertebrates species before making a final hydrological determination.

- Current and/or historic fisheries data may be found at:
  - Natural Heritage New Mexico (https://nhnm.unm.edu/)
  - Museum of SW Biology (http://www.msb.unm.edu/index.html)
  - Sublette, James E. et al. 1990. *The Fishes of New Mexico – First Edition.* University of New Mexico Press. 393 p.
- SWQB Fisheries Data are available upon request by contacting the Surface Water Quality Bureau (505-827-0187 or https://www.env.nm.gov/surface-water-quality/).

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Other information that may be considered:

- Groundwater contour maps and/or nearby, local well logs.
- Information provided by a long-term resident and/or local professional who has observed the stream during various seasons and hydrological conditions.
- Review of historic information such as aerial photography.
- Professional judgment may be used in conjunction with the total score and supporting information in making the final determination.

2. **Level 2 Field Procedures**

In order to distinguish between ephemeral, intermittent, and perennial streams and rivers using the information presented in this protocol, the field evaluator should have experience making geomorphic, hydrological, and biological observations in New Mexico or the semi-arid region of the southwestern U.S. Field evaluations should be performed at least 48 hours after the last known major rainfall event or snowmelt. In addition, it is *strongly* recommended that field evaluations be conducted outside of drought conditions whenever possible. Drought conditions, for the purposes of this *Hydrology Protocol*, are defined as any time the 12-month SPI is less than -1.5, indicating severely to extremely dry conditions (NDMC 1995).

Refer to the results of the **Level 1 Evaluation**. If this step was not completed in the Level 1 Evaluation or cannot be located then refer to the *Level 1 Field Procedures*, specifically *Sample Reach Selection* and *Photodocumentation,* for more information.

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Level 2 Field Equipment and Supplies

Copy of *Hydrology Protocol* and associated *Field Sheets*
*Thermograph Deployment/Upload/Retrieval Field Sheet
*Fish Sampling Field Data Sheet
Site maps and aerial photographs (1:250 scale if possible)
Global Positioning System (GPS) –
used to determine latitude and longitude
Camera and Compass –
used to photograph and document site features
Clipboard/pencils/sharpies
Measuring tape
Survey flags for transect locations
Survey rod
Bank pins
Level
Shovel or Soil Auger
Thermographs with caps and tags
Zip ties/bailing wire
Hammer & T-post driver
Rebar & T-posts (various lengths)
Flagging
Wire/tie cutters
Kicknet (18 inch; 500µm net size)
Forceps
Sieve (500µm mesh)
Buckets –
to help sort macroinvertebrates
Sample containers (500-mL or 1-L)
Ethanol
Ethanol-proof sample labels
Ethanol-proof pen
Timepiece
Backpack electrofisher & accessories
Seine net
Buckets & aerators
Dip & aquarium nets
Voucher kit & formalin
Field guide
Collection permits
Measuring Board
One battery per site –
for electrofisher + back-up

*See the SWQB SOP webpage at https://www.env.nm.gov/surface-water-quality/sop for the current version

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3. Level 2 Indicators

2.1. Water in Channel (OPTIONAL)

Observation of flow under certain seasonal or hydrological conditions can directly support classifying a sample reach as perennial. Reaches with flow during the dry season or periods of drought are likely perennial. The longer the period from the last substantial rainfall the stronger the presence of flow supports the perennial determination. Although the presence of flow during a drought indicates perennial conditions, care must be taken in evaluating the upper limits of perenniality because some perennial systems may only contain isolated pools of water or be dry during periods of drought.

If available, historic or recent flow data from streamgages such as those managed by the USGS, OSE or LANL may clearly indicate ephemeral, intermittent, or perennial flow patterns for the available period of record and will facilitate the scoring of this indicator. If streamgage data are not available, temperature sensors (or electrical resistance sensors or pressure transducers) can be used to estimate the onset and cessation of flow (Constanz et al. 2001; Lawler 2002; Blasch et al. 2002). Periods of flow are characterized by those sections of the thermograph where the amplitude of the diel temperature signal is visibly dampened (Constanz et al. 2001). When the in-stream temperature data are compared graphically to the temperature data from a nearby site out of streamflow where little dampening has occurred, a flow signal is easily identifiable.

Strong – The water sensor is decidedly different from the air sensor. The streamflow signal is easily identifiable and occurs throughout the entire time of deployment (i.e. water sensor has a diel signal that is visibly dampened compared to air sensor throughout the deployment).

Moderate – The water sensor differs from the air sensor. A flow signal is identifiable during the majority of time; however, there are short periods of time when the water sensor has a diel signal that is comparable to the air sensor indicating periods of drying.

Weak – The water sensor differs somewhat from the air sensor. A flow signal is identifiable during certain days or weeks; however, there are long periods of time when the water and air sensors have similar diel signals (i.e. no dampening) indicating dry periods.

Poor – There are no substantial differences between the water and air sensors. The two thermographs are visibly comparable to one another indicating little to no water in the channel.

**If using an electrical resistance sensor or pressure transducer, use the following ratings:

Strong – The streamflow signal is easily identifiable and occurs throughout the entire time of deployment

Moderate – A streamflow signal is identifiable during the majority of time; however, there are short periods of time when the sensor indicates periods of drying.

Weak – A streamflow signal is identifiable during certain weeks or months; however, there are long periods of time when the sensor indicates a dry channel.

Poor – There is no sustained streamflow signal from the sensor (flow signal is only for very

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brief periods of time – on the timescale of days – indicating a flow response due to storm events). Or there is no discernible streamflow signal.

2.2. Hyporheic Zone/Groundwater Table

Hyporheic zone: Even when there is no visible flow above the channel bottom, there may likely be slow groundwater discharge into and downstream flow in the **hyporheic zone**. The hyporheic zone is the subsurface interface beneath and adjacent to a stream or river where surface water and shallow groundwater mix. It may be recognized by the accumulation of coarse textured sediments in the bottom of the channel that may be up to 2-3 ft deep in small streams. The saturated sediment in the hyporheic zone exchanges water, nutrients, and fauna with surface flowing waters. Consequently, the hyporheic zone is the site of groundwater discharge to the stream channel, downstream flow, and biological and chemical activity associated with aquatic functions of the stream.

Indicators of a hyporheic zone can be observed by digging a bore hole in the streambed when site conditions are conducive to manually digging a bore hole. Water standing in the bore hole or saturated sediment within the bore hole indicates the presence of a hyporheic zone. If conditions are not conducive to boring a hole in the streambed, one can look under rocks. Saturated or moist sediment underneath rocks located within the channel indicates the presence of a hyporheic zone.

Groundwater Table: The presence of a seasonal high water table or groundwater discharge (i.e. seeps or springs) from the bank, above the elevation of the channel bottom, indicates a relatively reliable source of base flow to a stream. When site conditions are conducive to manually digging a bore hole, indicators of a current water table can be observed by digging a bore hole in the adjacent floodplain approximately two feet away from the streambed. The presence of water standing in the hole above the elevation of the channel bottom after waiting for at least 30 minutes (longer for clayey soils) indicates the presence of a high groundwater table.

Strong – Considerable base flow is present. Hyporheic zone and/or groundwater table is readily observable throughout sample reach.

Moderate – Some base flow is present. Hyporheic zone and/or groundwater table is present, but not abundant throughout sample reach.

Weak – Water is standing in pools and the hyporheic zone is saturated, but there is not visible flow above the channel bottom. Indicators of groundwater discharge are present but require considerable time to locate.

Poor – Little to no water in the channel. No indication of a high groundwater table or hyporheic zone.

2.3. Bivalves

Clams cannot survive outside of water, thus one should examine the streambed or look for them where plants are growing in the streambed. Also, look for empty shells washed up on the bank. Some bivalves can be pea-sized or smaller. Since clams require a fairly constant aquatic environment in order to survive, the search for bivalves can be conducted while looking for other benthic macroinvertebrates. A small net may be useful.

Present – Bivalves are found within the sample reach.

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Absent – Bivalves are not found within the sample reach.

2.4. Amphibians

Salamanders and tadpoles can be found under rocks, on streambanks and on the bottom of the stream channel. They may also appear in the benthic sample. Frogs will alert you of their presence by jumping into the water for cover. Frogs and tadpoles typically inhabit the shallow, slower moving waters of the pools and near the sides of the bank. Amphibian eggs, also included as an indicator, can be located on the bottom of rocks and in or on other submerged debris. They are usually observed in gelatinous clumps or strings of eggs.

Present – Amphibians are found within the sample reach.
Absent – Amphibians are not found within the sample reach.

Any collection and identification of aquatic species should be performed by a qualified aquatic biologist, environmental scientist, or other professional.

2.5. Benthic Macroinvertebrates (quantitative observations)

The larval stages of many aquatic insects are good indicators that a stream is perennial because a continuous aquatic habitat is required for these species to mature. The Arid West Water Quality Research Project has published a final report on *Aquatic Communities of Ephemeral Stream Ecosystems* (AWWQRR 2006) that may be a useful supplement to this protocol. In addition, SWQB scientists have been looking for the presence of long-lived aquatic species as reliable determinants for perennial channels, North Carolina's Division of Water Quality has developed a list of benthic macroinvertebrate taxa that are perennial stream indicators (NCDWQ 2010) and West Virginia's Department of Environmental Protection maintains a list of macroinvertebrate species that have an extended aquatic life stage (WVDEP – Watershed Assessment Branch, (304) 926-0495). Further information on life histories of specific macroinvertebrates found through the application of this protocol can be researched, if necessary.

Examples of Methods and Equipment used to collect Benthic Macroinvertebrates:

- EPA's EMAP Protocol
- SWQB's Benthic Macroinvertebrate SOP
- Kick Net
- D-Frame Dip Net
- Rectangular Dip Net
- Surber Sampler
- Hess Sampler
- Approaches:
  - Targeted Riffle
  - Reach-Wide, Multi-Habitat
    - top/bottom of riffle, undercut banks, pools/runs, snags/roots/logs

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The goal is to collect as many different kinds of aquatic macroinvertebrates from as many different habitats as necessary to ensure an accurate site assessment. Be aware that each habitat type has different sampling protocols, and some have a greater diversity of organisms than others (**Table 2**). If you have many habitats from which to choose, consider sampling from those with the most diversity. If your stream has a rocky bottom, sample at two separate riffle areas and at one other habitat. If your stream has a soft bottom or does not have riffles, collect samples at submerged logs, snags or undercut banks.

Table 2. Relative diversity of various habitat types

Habitat Type	Stream Type	Habitat
Riffles	Rocky bottom	Most diverse
Undercut banks Snags,	Rocky, soft bottoms	↓
tree roots, logs	Rocky, soft bottoms	Least diverse

Strong – More than one taxa of benthic macroinvertebrate that requires water for their entire life cycle (rheophilic taxa) are present as later instar larvae. Overall there is a balanced distribution of taxa. A list of benthic organisms that indicate perennial features are listed in **Tables 3 and 4**.

Moderate – Only one rheophilic taxon was found in the sample, however sample is diverse. Overall there is a balanced distribution of taxa.

Weak – Rheophilic taxa are not present in the sample; however other types of benthic macroinvertebrates are present. Both diversity and abundance are low or not distributed evenly.

Poor – Benthic macroinvertebrates are not present.

Table 3. Ephemeroptera, Plecoptera, and Trichoptera (EPT) perennial indicator taxa

	Ephemeroptera (Mayflies)	Plecoptera (Stoneflies)	Trichoptera (Caddisflies)
Family:	Caenidae Ephemerellidae Ephemeridae Heptageniidae	Peltoperlidae Perlidae Perlodidae	Hydropsychidae Lepidostomatidae Molannidae Odontoceridae Philopotamidae Polycentropodidae Psychomyiidae Rhyacophilidae

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Table 4. Additional indicators of perennial features

	Megaloptera	**Odonata**	**Diptera**	**Coleoptera**	**Mollusca**
Family:	Corydalidae Sialidae	Aeshnidae Calopterygidae Cordulegastridae Gomphidae	Ptychopteridae	Psephenidae Elmidae	Unionidae Ancylidae Pleuroceridae
Family & *Genus*:			Tipulidae *Tipula* sp.	Dryopidae *Helichus* sp.	

2.6. Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa

The larval stages of many species of these three orders require a period of at least a year, submerged in a constantly flowing aquatic environment before reaching maturity and therefore are commonly associated with perennial systems. Studies conducted by North Carolina State University have found that benthic samples collected in intermittent systems frequently display crustaceans (crayfish, isopods, and amphipods) as the dominant order (NCDWQ 2005). In sample reaches with more perennial characteristics, EPT taxa were collected. In highly urbanized areas, these indicators may be absent due to degradation and, therefore, may not be appropriate to evaluate perennial or intermittent flow conditions. These lists should be carefully evaluated (family or genus level ID) since some genera, such as the *Baetis* mayflies for example, are very short-lived in their aquatic life stages.

Present – EPT taxa are found within the sample reach.
Absent – EPT taxa are not found within the sample reach.

Any collection and identification of aquatic species should be performed by a qualified aquatic biologist, environmental scientist, or other professional.

2.7. Fish (quantitative observations)

Fluctuating water levels of intermittent systems provide unstable and stressful habitat conditions for fish communities. When looking for fish, all available habitats should be observed, including pools, riffles, root clumps, and other obstructions (to greatly reduce surface glare, the use of polarized sunglasses is recommended). In small streams, the majority of species usually inhabit pools and runs. Check several areas along the sample reach, especially underneath undercut banks. In most cases, fish are indicators of perennial systems, since fish will rarely inhabit an intermittent stream.

Fish should be collected, measured, and classified to verify if fish are present in a water body and to help confirm the appropriate hydrological determination. Best professional judgment should be exercised to determine sampling methodology (e.g. shocking, seining, etc.) and to ensure that safety concerns are addressed.

Strong – Fish are present in all habitats (riffles, pools, runs, root clumps, undercut banks, etc.). Multiple age classes are present and evenly represented. Large-

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bodied fish may be present.

Moderate – Fish are evident in fewer numbers with one age class dominating. Some habitat is not occupied. Large-bodied fish may be present.

Weak – Fish are not readily visible, require 10 or more minutes to locate, and are typically found within one habitat type (e.g. pools, runs). Very sparse.

Poor – Fish are <u>not</u> found within the sample reach.

IV. OVERALL SCORE INTERPRETATION

The final determination of whether a stream is ephemeral, intermittent, or perennial is based on a variety of information including the total score, supporting information, and professional judgment. The use of the Level 1 Evaluation should, in most cases, provide enough information to accurately distinguish between ephemeral, intermittent, and perennial systems. Scores should reflect the persistence of water with higher scores indicating intermittent and perennial systems. However, if a stream is recognized as borderline (i.e. gray zone – see **Table 5**) or if observations are made during a severe or extreme drought (12-month SPI value less than -1.5), then a Level 2 Evaluation that relies on more intensive and focused data collection can be used to make a final hydrological determination or to verify the Level 1 evaluation.

For a Level 1 Evaluation a minimum total score of 9.0 is set as a guideline to distinguish ephemeral channels from non-ephemeral ones unless there are aquatic macroinvertebrates and/or fish, in which case at least one of the Clean Water Act Section 101(a)(2) objectives is attainable and the stream is at least intermittent. In addition, a Level 1 score greater than 22.0 distinguishes perennial streams from non-perennial streams. SWQB recognizes that there is inherent variability in nature, therefore Level 1 scores between 9 and 12 may be ephemeral but will be recognized as intermittent until further data collection and analysis through a Level 2 evaluation or detailed UAA can more clearly determine that the stream is ephemeral. Similarly, Level 1 scores between 19 and 22 may be intermittent but will be recognized as perennial until further data collection and analysis indicate that the stream is intermittent. **Table 5** summarizes interpretation of Level 1 scoring. In most instances, the use of a Level 1 Evaluation should be sufficient to make a final hydrological determination. A hydrological determination does not change the designated use for a waterbody without the completion of a UAA in accordance with 40 CFR 131.10, 20.6.4.15 NMAC and the State's approved Water Quality Management Plan/Continuing Planning Process (WQMP/CPP). **If after conducting Level 1 Evaluation, a hydrological determination <u>cannot be made</u> because more information is required, then a Level 2 Evaluation which uses more intensive data collection can be conducted.**

Table 5. Summary of Level 1 Score Interpretation

Waterbody Type	Level 1 Total Score	Hydrology Determination
Ephemeral	**Less than 9.0***	**Stream is ephemeral**
≥ 9.0 and < 12.0		Stream is recognized as intermittent until further analysis indicates that the stream is ephemeral
Intermittent	**≥ 12.0 and ≤ 19.0**	**Stream is intermittent**
> 19.0 and ≤ 22.0		Stream is recognized as perennial until further analysis indicates that the stream is intermittent
Perennial	**Greater than 22.0**	**Stream is perennial**

* If there are aquatic macroinvertebrates and/or fish the stream is at least intermittent.

If a sample reach is recognized as borderline (within the gray zones), reaches upstream and

downstream of the study area should be assessed to better evaluate the changes in stream classifications along a channel. Additional supporting information can be used to help make the final determination. This supporting information may include, but is not limited to:

Observation of flow: Observation of flow under certain seasonal or hydrological conditions can directly support classifying a stream reach as intermittent or perennial. Conditions supporting a perennial stream classification include:

Stream reaches with flow during the dry season or periods of drought are likely perennial. The longer the period from the last substantial rainfall the stronger the presence of flow supports the perennial stream determination. Although the presence of flow during a drought indicates perennial conditions, care must be taken in evaluating the upper limits of perenniality because some perennial streams may only contain isolated pools of water or be dry during periods of drought.

Key biological indicators: As discussed in the Level 2 Evaluation, the presence of aquatic organisms whose life cycle requires residency in flowing water for extended periods (especially those one year or greater) is a strong indication that a stream reach is perennial. If a stream or river is recognized as borderline, a qualified aquatic biologist/environmental scientist should evaluate the presence and abundance of such macroinvertebrate and vertebrate species before determining the final stream classification.

Other additional supporting information that may be considered:

- Groundwater contour maps or nearby, local well logs.
- Information provided by a long-term resident and/or local professional who has observed the stream during the various seasons and hydrological conditions.
- Review of historic information such as aerial photography.
- Professional judgment may be used in conjunction with the total score and supporting information in making the final determination.

The total score can be affected by seasonal or hydrological conditions as well as man-made impacts such as irrigation diversions or livestock impoundments associated with activities in the watershed. For example, a sample reach may score lower in drought conditions due to the lack of biological and/or certain hydrological indicators. However, a reach may score higher on certain indicators such as drift lines and alluvial deposits if directly below a stormwater outfall. The final hydrological determination should take these factors into account.

The *Hydrology Protocol* is considered to be an evolving, living document. Current thresholds are based on data collected by SWQB during the 2008 and 2009 field seasons from 57 stream reaches throughout the state of New Mexico. An analysis of these data was performed to determine which indicators clearly differentiated the three types of streams and to identify threshold values for scoring. In the event that new data indicate the threshold values used in this protocol are not appropriate and/or if new standards are adopted, SWQB will review the protocol, the related threshold values and differentiating scores. Revisions to the protocol will be proposed to the WQCC as needed in accordance with the process for updating the Water Quality Management Plan/Continuing Planning Process.

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NMED Exhibit 3

New Mexico Environment Department Surface Water Quality Bureau

LEVEL 1 Hydrology Determination Field Sheet

Date:	Time:	Evaluators:
Stream Name:	Site Description:	
WQS as found under NMAC (20.6.4):	Assessment Unit:	
Starting Latitude:	Ending Latitude:	
Starting Longitude:	Ending Longitude:	
Starting Elevation:	Ending Elevation:	
TOTAL POINTS*: **See Hydrology Protocol for determination*		

WEATHER CONDITIONS	DROUGHT CONDITIONS:	Nearest weather station:	PAST 48 HOURS**:	CURRENTLY**:
	12-mo. SPI Value: 12-mo. SPEI Value: Drought Condition: Obtained from: Date Obtained:	Precipitation past 48 hours:	___ storm (heavy rain) ___ rain (steady rain) ___ intermittant rain ___ % cloud cover ___ clear/sunny	___ storm (heavy rain) ___ rain (steady rain) ___ intermittant rain ___ % cloud cover ___ clear/sunny
	**Field evaluations should be performed at least 48 hours after the last major rainfall event.			

SITE OBSERVATIONS ALONG ENTIRE REACH	Nearest Stream Modification (description and proximity):
	Nearest Diversion (description and proximity):
	Nearest Discharge (description and proximity):
	Include any and all modifications/discharges and diversions regardless of perceived impact to hydrologic regime along with any field observations

CALCULATIONS FOR DETERMINING FLOODPLAIN AND CHANNEL DIMENSIONS (Use for 1.8 on Field Survey)	Thalwag Height (#1)	Bankfull Height (#2)	Change in Height (#1 - #2)	Change in Height x 2 (#3)	Flood-prone Area Height (#1-#3)
				Flood-prone width:	
				Bankfull Width:	
				Flood-prone Width to Bankfull Width Ratio:	
	Alternative Methods used (describe)?				

PHOTO DOCUMENTATION (include additional photographs as attachment)	Time	Photo #	Description	Identifiable References	Photographer

OTHER SITE CHARACTERISTIC NOTES/ SCHEMATICS	

NMED Exhibit 3

LEVEL 1 INDICATORS	Stream Condition (identify all that apply then choose most prominent score)			
	Strong	Moderate	Weak	Poor
1.1 Water In Channel	☐ Flow is evident throughout reach ☐ Flow is observed in riffles ☐ Flow may not be evident in runs	☐ Wet Channel ☐ Flow is barely discernable ☐ Floating object needed to observe flow	☐ Dry Channel with standing pools ☐ Saturated or moist sediment under rocks/debris ☐ Evidence of base flows	☐ Dry Channel ☐ Dry under rocks/debris ☐ No evidence of base flows
	6	**4**	**2**	**0**
	Notes/Comments:			
1.2 Fish in Channel	☐ Found easily ☐ Found consistently throughout reach	☐ Found with little difficulty ☐ Not consistent throughout reach	☐ Found with difficulty (10 or more minutes of searching)	☐ Not present (after 10 or more minutes of searching)
	3	**2**	**1**	**0**
	Species Observed and Notes/Comments:			
1.3 Benthic Macroinvertebrates in Channel	☐ Found easily ☐ Found consistently throughout reach	☐ Found with little difficulty ☐ Not consistent throughout reach	☐ Found with difficulty (10 or more minutes of searching)	☐ Not present (after 10 or more minutes of searching)
	3	**2**	**1**	**0**
	Species Observed and Notes/Comments:			
1.4 Filamentous Algae/Periphyton in Channel	☐ Found easily ☐ Found consistently throughout reach	☐ Found with little difficulty ☐ Not consistent throughout reach	☐ Found with difficulty (10 or more minutes of searching)	☐ Not present (after 10 or more minutes of searching)
	3	**2**	**1**	**0**
	Notes/Comments:			
1.5 Vegetation along cooridor (within floodplain)	☐ Dramatic compositional species difference between upland and riparian corridor ☐ Distinct riparian corridor exists along entire reach ☐ Riparian, aquatic or wetland species dominate entire reach	☐ Distinct riparian corridor exists but not along entire reach ☐ Compositional species difference between upland and riparian corridor ☐ Riparian species interspersed with upland species	☐ Minimal compositional species difference between upland and riparian corridor ☐ Vegetation growing along the riparian area occurs in greater density or grows more vigorously than in the adjacent uplands	☐ No compositional species difference between upland and riparian corridor ☐ Vegetation growing along the riparian cooridor does not occur in greater density or grow more vigorously than in the adjacent uplands
	3	**2**	**1**	**0**
	Species Observed and Notes/Comments:			
1.6 Rooted Upland Plants in Channel	☐ Rooted upland plants are absent within the streambed/thalweg	☐ There are a few rooted upland plants within the streambed/thalweg	☐ Rooted upland plants are consistently dispersed throughout the streambed/thalweg	☐ Rooted upland plants are prevalent within the streambed/thalweg
	3	**2**	**1**	**0**
	Species Observed and Notes/Comments:			
			SUBTOTAL (1.1-1.6)	

1.7 Sinuosity of Segment (for length no less than two meanders)	☐ Calculated ratio > 1.4 ☐ Numerous closely spaced bends ☐ Few straight sections	☐ Calculated ratio 1.4 <> 1.2 ☐ Mostly bends ☐ Some straight sections	☐ Calculated ratio 1.2 <> 1.0 ☐ Few bends ☐ Mostly straight sections	☐ Calculated ratio = 1.0 ☐ Completely straight
	3	2	1	0
	☐ Calculated ☐ Observed	Notes/Comments:		
1.8 Floodplain and Channel Dimensions	☐ Calculated ratio > 2.5 ☐ Minimally confined ☐ Wide, active floodplain	☐ Calculated ratio 2.5 <> 1.2 ☐ Moderately confined ☐ Floodplain active during larger events	☐ Calculated ratio < 1.2 ☐ Incised/confined channel ☐ Flooplain absent or narrow ☐ Floodplain not connected	
	3	1.5	0	
	☐ Calculated ☐ Observed	Notes/Comments:		
1.9 In-Channel Structure: Riffle-Pool Sequence	☐ Frequent number of riffle and pools observed throughout reach ☐ Obvious transition between riffles and pools	☐ Less frequent number of riffle and pools ☐ Transition between riffles and pools difficult to distinguish	☐ Mostly has areas of pools or of riffles	☐ No riffles or pools observed
	3	2	1	0
	Notes/Comments:			
			SUBTOTAL (1.1-1.9)	
1.10 Particle Size or Stream Substrate Sorting	☐ Particle sizes in the channel are noticeably different from particle sizes outside the channel in the flood-prone area. ☐ Clear distribution of various sized substrates in the stream channel.	☐ Particle sizes in the channel are moderately similar to particle sizes outside the channel in the flood-prone area. ☐ Various sized substrates are present in the stream channel. ☐ Higher ratio of larger particles (gravel/cobble).	☐ Particle sizes in the channel are similar or comparable to particle sizes outside the channel in the flood-prone area. ☐ Substrate sorting is not readily observed in the stream channel.	
	3	1.5	0	
	☐ Calculated ☐ Observed	Notes/Comments:		
1.11 Hydric Soils Within Flood-Prone Area	☐ Hydric soils were observed in reach		☐ Hydric soils were not observed in reach	
	3		0	
	Notes/Comments:			
1.12 Sediment on Plants and Debris	☐ Sediment found readily on plants and debris in: ☐ channel ☐ streambank ☐ floodplain	☐ Sediment found but not prevalent on plants and debris. ☐ Sediment mostly accumlated on plants and debris in pools	☐ Sediment on plants and debris is isolated in small amounts along the sample reach.	☐ No sediment is present on plants or debris.
	1.5	1	0.5	0
	Notes/Comments:			
1.13 Seeps and Springs	☐ Seeps and/or springs present in reach		☐ Seeps and/or springs not present in reach	
	1.5		0	
	Notes/Comments:			
1.14 Iron Oxidizing Bacteria/Fungi	☐ Iron-oxizing bacteria/fungi present in reach		☐ Iron-oxizing bacteria/fungi not pressent in reach	
	1.5		0	
	Notes/Comments:			
			TOTAL POINTS (1.1-1.14)	

Total <9, the stream is determined to be EPHEMERAL.
Total ≤9 and <12, the stream is determined to be INTERMITTENT until further analysis indicates otherwise
Total ≥ 12.0 and ≤ 19.0, the stream is determined to be INTERMITTENT
Total > 19.0 and ≤ 22.0, the stream is determined to be PERENNIAL until further analysis indicates otherwise
Total > 22.0, the stream is determined to be PERENNIAL.

WATER QUALITY CONTROL COMMISSION

DELEGATION OF RESPONSIBILITIES TO ENVIRONMENTAL IMPROVEMENT DIVISION AND OIL CONSERVATION DIVISION

In an effort to prevent duplication of effort and to clarify the division of responsibilities pursuant to the provisions of the Water Quality Act, NMSA Sections 74-6-1 et seq. (1978), as administered and enforced by the Water Quality Control Commission, the Commission hereby approves the following list of delegated duties and responsibilities for two of the agencies that are constituent agencies to which authority can be delegated, the Environmental Improvement Division ("EID") and the Oil Conservation Division ("OCD"). The Commission is specifically authorized to take this action by NMSA Section 74-6-4E (1978) and by other general provisions of the Water Quality Act. The Commission notes that pursuant to NMSA Section 74-6-9C (1978), constituent agencies may "report to the Commission and to other constituent agencies water pollution conditions that are believed to require action where the circumstances are such that the responsibility appears to be outside the responsibility assigned to the agency making the report." The Commission encourages OCD and EID to continue close communication and cooperation where responsibility is unclear, to ensure that water pollution is prevented or abated quickly, efficiently and consistently. In situations involving discharges or facilities under the jurisdiction of both agencies, the agencies shall mutually agree which shall be the lead agency and shall determine the method by which the discharge plan shall be evaluated and approved. In preparing this delegation statement, the Commission is cognizant of the limitations imposed on its authority by the Water Quality Act, especially NMSA Section 74-6-12G (1978) which prohibits it from taking any action which would "interfere with the exclusive authority of the Oil Conservation Commission over all persons and things necessary to prevent water pollution as a result of oil or gas operations...."

This delegation shall supersede all previous delegations to EID and OCD; reference to the dates and minutes of Commission meetings in which previous delegations were made are in parentheses and the minutes are attached. The specific grants of authority are not intended to be comprehensive. When a question of authority and jurisdiction arises, which is not specifically delegated, the general provisions below shall control.

1. General Provisions

As a general rule, OCD will administer and enforce applicable Commission regulations pertaining to surface and ground water discharges at oil and natural gas production sites, oil refineries, natural gas processing plants, geothermal installations, carbon dioxide facilities, natural gas transmission lines, and discharges

associated with activities of the oil field service industry. The Commission recognizes that OCD also administers regulations under both the Oil and Gas Act and the Geothermal Resources Act, and that OCD shall have discretion as to which regulations to enforce in any given situation. OCD shall have jurisdiction over all activities associated with exploration for or development, production, transportation before refinement, refinement, storage or treatment of unrefined oil and natural gas, or oil or gas products on refinery premises.

EID will administer and enforce Commission regulations regarding discharges from transmission, transportation and storage facilities for oil or oil by-products after refinement (including but not limited to gasoline stations), except those within refinery premises. EID will administer and enforce all Commission regulations pertaining to all other discharges to surface and ground water which are not specifically delegated to other departments and agencies. (Source: 1/13/69 and 5/8/84 Commission minutes)

2. Specific Grants of Authority

A. EID shall certify Section 404 dredge and fill material permits under the Clean Water Act ("CWA"). (Source: 1/13/76 and 6/14/83 Commission minutes)

B. EID shall administer the Wastewater Construction Grants program pursuant to Section 205 of the CWA. (Source: 6/14/83 Commission minutes)

C. EID shall certify NPDES permits pursuant to Title IV of the Federal Water Pollution Control Act Amendments of 1972 and S402 of the CWA. (Source: 10/1/74 and 8/14/84 Commission minutes)

D. EID shall certify hydropower licenses issued by the Federal Energy Regulatory Commission. (Source: 8/14/84 Commission minutes)

E. EID shall administer and enforce Commission regulations pertaining to the disposal of human excrement and bath water at oil and natural gas production sites, oil refineries, natural gas processing plants, geothermal installations, carbon dioxide facilities and natural gas transmission lines when the treatment facilities for the sewage are a separate and isolated discharge unmixed with any produced water, oil field waste or oil field service waste. (Such an isolated discharge would include: a small sewage treatment plant, package plant, or septic tank and drainfield.) If, on the other hand, sewage is in a discharge combined or mixed with produced water, oil field waste or oil field service waste, OCD shall have jurisdiction. (Source: 5/8/84 Commission minutes)

F. OCD shall administer and enforce Commission regulations at brine manufacturing operations and concerning discharges to ground or surface water at brine manufacturing operations, including all brine production wells, holding ponds and tanks. OCD shall have jurisdiction over all manufactured brine once it is transported, used or disposed of off brine plant premises for use in or directly related to oil and gas operations regulated by OCD. OCD shall regulate brine injection through its Class II Underground Injection control (UIC) Program if the brine is used in the drilling for or production of oil and gas. EID shall regulate brine injection through its UIC Program if the brine is used for other purposes. (Source: 6/23/89 Commission minutes)

G. EID shall administer and enforce all programs implemented by the state under PL 92-500 (The Federal Water Pollution Control Act) and its Amendments, unless directed otherwise by the Commission. (Source: 7/8/75 Commission minutes)

H. OCD shall have general jurisdiction over the oil field service industry. Many activities that would ordinarily be regulated by EID are regulated by OCD when those activities occur in the oil field service industry. The following list, which is not intended to be inclusive, serves to help clarify this delegation:

OCD	EID
waste oil handled or processed by oil field service companies or treating plants	used motor oil handlers
all underground and above-ground tanks on refinery premises, unless the tanks contain unmixed sewage; all underground and above-ground tanks not on refinery premises which contain crude petroleum, produced water or oil field service chemicals	all underground and above-ground tanks not on refinery premises, unless the tanks contain crude petroleum, produced water or oil field service chemicals
tanker trucks hauling, spilling or disposing of well-service chemicals, kill water, produced water, crude oil, tank bottom sludge and other oil field wastes and oil field service materials	tanker trucks spilling or disposing of non-oil and gas production wastes, non-oil and gas service materials, or refined petroleum products
washings from trucks and other equipment used in the transport, production or refining of oil and gas crude products, production wastes or service materials	washings from trucks and other equipment not used for oil and gas production related purposes

Both EID and OCD are authorized to continue to take appropriate legal action in their respective areas of delegation (including initiating proceedings in court) on behalf of the Commission on a finding of good cause to believe any person is violating or is threatening to violate a Commission regulation or the Water Quality Act. The agencies shall send a copy of each Complaint, Settlement Agreement and Judgment to the Commission Secretary for distribution to Commission members. (Source: NMSA Section 74-1-8.2(B) (1978), 2/8/71 and 1/11/83 Commission minutes)

WATER QUALITY CONTROL COMMISSION

By: Richard Mitzelfelt, Chairman

Date Aug 21, 1989

May 2, 2022

Dr. Earthea Nance
Regional Administrator
U.S. Environmental Protection Agency, Region 6
1201 Elm St., Suite 500
Dallas, TX 75270
Nance.Earthea@epa.gov

Re: Request for EPA's review and approval of the State of New Mexico's Triennial Review of Standards for Interstate and Intrastate Surface Waters (20.6.4 NMAC)

Dear Regional Administrator Nance:

Pursuant to §303(c) of the federal Clean Water Act ("CWA") and 40 CFR § 131.20, the New Mexico Environment Department ("Department" or "NMED") conducted a Triennial Review of water quality standards and hereby submits, on behalf of New Mexico's Water Quality Control Commission, the resultant amendments to New Mexico's *Standards for Interstate and Intrastate Surface Waters* 20.6.4 New Mexico Administrative Code (NMAC), which became effective for state purposes on April 23, 2022.

The Department engaged the U.S. Environmental Protection Agency ("EPA" or "Agency") Region 6 early and often in this multi-year process. The Department began outreach to tribes and identified stakeholders in January 2020, which was followed up with three stakeholder engagement meetings during the summer of 2020. The Department then submitted a petition for hearing before the New Mexico Water Quality Control Commission ("WQCC" or "Commission") on August 19, 2020. The WQCC heard the petition, set a hearing date, and appointed a hearing officer during their regularly scheduled public meeting on October 13, 2020. The Department solicited public participation on the proposed amendments from November 2, 2020 through January 6, 2021 and conducted two virtual public meetings during this period.

As provided in the supporting documentation for this submittal, the Department provided public notice of the hearing to tribes within New Mexico, identified stakeholders, subscribers to the NMED Surface Water Quality Bureau's ("SWQB") GovDelivery listserv, NMED District Managers, the New Mexico Legislative Council Service, and the New Mexico Small Business Advisory Commission. The Department also published notice on the Department's website, in the New Mexico Register, the Santa Fe New Mexican, the Albuquerque Journal, and on New Mexico's Sunshine Portal.

The WQCC held a public hearing on July 13, 14, 15, 16 and 21, 2021, during which the Department presented technical testimony in support of its proposed amendments and in response to amendments proposed by other parties. The WQCC deliberated on March 1 and 2, 2022 as detailed in the deliberation transcripts and Statement of Reasons and Decision, dated March 9, 2022. The Department filed the amended rule with the State Records and Archives on March 22, 2022, and the amendments became effective for State purposes on April 23, 2022. A corrected Statement of Reasons and Decision was issued by the WQCC on March 28, 2022, correcting some typographical errors and providing clarification of San Juan Water Commission's position on a number of topics. These corrections were non-substantiative to

the Commission's final decision. The Commission met all procedural requirements of New Mexico law for adopting water quality standards as noted in the Attorney General Certification included with this submittal.

In accordance with §303(c) of the CWA and 40 CFR § 131.20, the Department, on behalf of New Mexico's Water Quality Control Commission, hereby submits the amendments as adopted by the WQCC for EPA review and approval under the federal Clean Water Act. The Department has enclosed the following for EPA's consideration and to aid in the Agency's review:

- a list of supporting documents with publicly accessible links to the documents;
- the WQCC hearing transcripts for July 13, 14, 15, 16, and 21, 2021;
- the WQCC deliberation transcripts for March 1 and 2, 2022;
- the WQCC's Statement of Reasons and Decision supporting and approving the amendments to 20.6.4 NMAC; and
- the New Mexico Attorney General's certification that the rule was adopted in accordance with the laws of the State of New Mexico.

The NMED Cabinet Secretary delegated signatory authority to the Surface Water Quality Bureau Chief to submit surface water quality documents to EPA for approval. We look forward to hearing from you and your staff about this submission. If you have questions or concerns, please feel free to contact Jennifer Fullam at 505.946.8954 or Jennifer.Fullam@state.nm.us.

Sincerely,

Shelly Lemon

Digitally signed by Shelly Lemon
Date: 2022.05.01 17:03:42 -06'00'

Shelly Lemon, Chief
Surface Water Quality Bureau

Encls.: List of supporting documents with publicly accessible links
WQCC hearing transcripts for July 13, 14, 15, 16 and 21, 2021
WQCC deliberation transcripts for March 1 and 2, 2022
WQCC's Corrected Statement of Reasons and Decision supporting and approving the amendments to 20.6.4 NMAC, dated March 28, 2022
20.6.4 NMAC, with amendments effective April 23, 2022
New Mexico Attorney General's certification that the rule was adopted in accordance with the laws of the State of New Mexico

Cc: Charles Maguire, Division Director, Water Quality Division, EPA Region 6 (maguire.charles@epa.gov)
Richard Wooster, Water Quality Division, EPA Region 6 (wooster.richard@epa.gov)
Russell Nelson, Water Quality Division, EPA Region 6 (nelson.russell@epa.gov)
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John Verheul, NMED Deputy General Counsel (john.verheul@state.nm.us)
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Susan Lucas Kamat, NMED-SWQB, Point Source Regulation (susan.lucaskamat@state.nm.us)
Kris Barrios, NMED-SWQB, Monitoring, Assessment, and Standards (kristopher.barrios@state.nm.us)
Jennifer Fullam, NMED-SWQB, Standards Planning and Reporting (jennifer.fullam@state.nm.us)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 6
1201 ELM STREET, SUITE 500
DALLAS, TEXAS 75270

January 19, 2023

Shelly Lemon, Chief
Surface Water Quality Bureau
New Mexico Environment Department
1190 Saint Francis Drive, Suite N4050
Santa Fe, New Mexico 87505

RE: New Mexico's 2020 Triennial Revisions to 20.6.4 NMAC

Dear Ms. Lemon:

I am writing in response to your letter of May 2, 2022, requesting review and action on new and revised provisions in New Mexico's *Standards for Interstate and Intrastate Surface Waters* 20.6.4 New Mexico Administrative Code (NMAC). These revisions were submitted to the U.S. Environmental Protection Agency (EPA) as required under federal regulations at 40 CFR § 131.5. The revised water quality standards were certified by Mr. John Verheul, Special Assistant Attorney General of the State of New Mexico, as having been adopted by the Commission pursuant to the laws of the state of New Mexico and became effective as state law on April 23, 2022. The EPA received your submission letter as the New Mexico Environment Department (NMED) Cabinet Secretary delegated signatory authority on May 2, 2022.

I am pleased to inform you that in today's action, the EPA is approving the majority of the new and/or revised provisions, including non-substantive provisions within its discretionary authority, pursuant to CWA § 303(c) and its implementing regulations at 40 CFR Part 131, as detailed in **Section II** of the enclosed Technical Support Document (TSD). There are provisions described in **Section III** that the EPA determined it could not act on. Please note that the provisions the EPA has not acted on are not effective for CWA purposes as specified at 40 CFR §131.21(c). The EPA is not approving the New Mexico water quality standards for those waters or portions of waters located in Indian Country, as defined in 18 U.S.C. § 1151.

The EPA's approval of new and revised WQS is subject to the consultation requirements of Section 7(a)(2) of the Endangered Species Act (ESA), 16 U.S.C. §1536. Under Section 7(a)(2) of the ESA The EPA has the obligation to ensure that its approval of revisions to New Mexico's *Standards for Interstate and Intrastate Surface Waters* 20.6.4 NMAC will not jeopardize the continued existence of threatened and endangered species and critical habitat in New Mexico. The EPA is reserving action on specific aquatic life criteria described in **Section V** of the TSD pending completion of ESA consultation with the Service.

I would like to thank the Commission, the New Mexico Environment Department and its Surface Water Quality Bureau for their commitment and hard work in reviewing and revising the state's water quality standards. We appreciate your patience with the delay in action by the EPA resulting from the extensive ESA consultation detailed in **Section III** of the TSD. If you have any questions or concerns, please contact me at (214) 665-7101, or have your staff contact Russell Nelson at (214) 665-6646 or Jasmin Diaz-Lopez at (214) 665-2733.

Sincerely,



Troy C. Hill
Acting Director
Water Division

Enclosure

cc: James C. Kenney, Cabinet Secretary
Stephanie Stringer, Chair, WQCC (Stephanie.Stringer@state.nm.us)
Pamela Jones, Administrator, WQCC (Pamela.Jones@state.nm.us)
Robert Sanchez, Counsel, WQCC (rfsanchez@nmag.gov)
John Rhoderick, Acting Director, Water Protection Division (John.Rhoderick@state.nm.us)
Susan Lucas Kamat, SWQB, Point Source Regulation (susan.lucaskamat@state.nm.us)
Jennifer Fullam, SWQB, Standards Planning and Reporting (jennifer.fullam@state.nm.us)
Shawn Sartorius, Field Supervisor, ESFO, USFWS (shawn_sartorius@fws.gov)

INTERIM TECHNICAL SUPPORT DOCUMENT

EPA Action on the
New Mexico Water Quality Standards for
Interstate and Intrastate Surface Waters
20.6.4 NMAC

2020 Triennial Revisions

U.S. EPA REGION 6
WATER QUALITY PROTECTION DIVISION
January 17, 2023

NMED Exhibit 6

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NMED Exhibit 6

I. Introduction

Regulatory Requirements and Purpose

As described in § 303(c) of the Clean Water Act[1] (CWA) and in the standards regulation within the Code of Federal Regulations[2] (CFR) at 40 CFR § 131, specifically § 131.20(a), states and authorized tribes have primary responsibility for developing and adopting water quality standards to protect their waters. In addition, CWA § 303(c)(1) and 40 CFR § 131.20(a) require states to hold public hearings at least once every three years to review and, as appropriate, modify and adopt standards. As required by 40 CFR § 131.21, the Environmental Protection Agency (EPA) is obligated to review new and revised surface water quality standards that have been adopted by states and authorized tribes. Authority to approve or disapprove new and/or revised standards submitted to the EPA for review has been delegated to the Water Division Director at Region 6. Tribal or state water quality standards are not effective under the CWA until approved by the EPA.

The purpose of this Technical Support Document (TSD) is to provide the basis for the Environmental Protection Agency's (EPA) action on the New Mexico Water Quality Control Commission's (Commission) revisions to the *New Mexico Standards for Interstate and Intrastate Waters*[3] (20.6.4 NMAC).

Chronology of Events

The New Mexico Environment Department (NMED) initiated the state's current Triennial Review process through outreach to tribes and identified stakeholders in January 2020. The NMED's Surface Water Quality Bureau (SWQB) developed and subsequently published initial revisions to the New Mexico water quality standards at 20.6.4. NMAC and hosted two virtual informational meetings via WebEx online meeting platform to present and discuss initial proposed revisions to the New Mexico standards at 20.6.4 NMAC with interested parties and the public. The SWQB took public comment over a 30-day public comment period from November 2, 2020, to December 2, 2020, later extending that comment period to January 6, 2021. The EPA provided comments and recommendations to the SWQB on December 22, 2020, regarding significant issues that may need to be addressed in these revisions and subsequent revisions of the state's water quality standards and associated implementation.

The NMED submitted a petition for hearing before the New Mexico Water Quality Control Commission (Commission) on August 19, 2020. The Commission held a public hearing on July 13th – 16th and 21st, 2021, during which the NMED presented technical testimony in support of its proposed amendments and in response to amendments proposed by other entities. The Commission held its deliberative hearing on March 1st and 2nd 2022, adopting revisions to 20.6.4.

[1] Clean Water Act. 33 USC §§ 1251-1387.
[2] Water Quality Standards Regulation, 33 U.S.C. 1251et seq.
[3] New Mexico Administrative Code (NMAC). 2022. *State of New Mexico Standards for Interstate and Intrastate Surface Waters*. 20.6.4. New Mexico Water Quality Control Commission. As amended through April 23, 2022. (20.6.4 NMAC).

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NMAC. The New Mexico Attorney General's Office certified the new/revised water quality standards became effective as state law as of April 23, 2022. The revised *New Mexico Standards for Interstate and Intrastate Waters* (20.6.4 NMAC) were submitted to EPA for review and action on May 2, 2022.

Summary of Proposed Revisions

The NMED submitted revisions adopted by the Commission for the *New Mexico Standards for Interstate and Intrastate Waters* (20.6.4 NMAC) to the EPA for review and action. These revisions reflect several new and revised provisions which include, but are not limited to the following:

- Updating definitions (20.6.4.7 NMAC)
- Clarification of language under Review of Standards (20.6.4.10 NMAC)
- Clarification of language under Use Attainability Analysis (20.6.4.15 NMAC)
- Designated use revisions
    - Existing Use Analysis for nonperennial waters within Los Alamos National Laboratory currently classified under 20.6.4.128 NMAC
    - Existing Use Analysis for perennial classified waters with a secondary contact recreational use
- Updates to the numeric aquatic life and human health criteria (20.6.4.900 NMAC)
- Updates to the numeric ammonia criteria (20.6.4.900 NMAC)

Provisions that EPA is approving are discussed in **Section II** of this TSD. Those provisions the EPA has determined that it lacks adequate information to act on at this time are identified and discussed in detail in **Section III**.

Review of New/Revised Provisions

The new/revised provisions in the *New Mexico Standards for Interstate and Intrastate Waters* (20.6.4 NMAC) are presented in an underline/strikeout format to provide context to the reader. The EPA's responses to the new/revised provision may include an explanation of how the EPA interprets that particular provision in the context of (a) specific applicable federal regulation(s), policy or guidance as well as state provisions as appropriate.

The EPA has determined that some revisions adopted by the Commission did not substantively modify New Mexico's WQS at 20.6.4 NMAC. EPA considers nonsubstantive edits to existing WQS to constitute new or revised WQS that it has the authority to approve or disapprove under Section 303(c)(3). While these revisions do not substantively change the meaning or intent of the existing WQS, treating such revisions in this manner ensures public transparency as to which provisions are effective for CWA purposes. EPA notes that the scope of its review and action on nonsubstantive edits or editorial changes extends only to the edits or changes themselves. EPA is not re-opening, reconsidering, or taking any action on the underlying, previously approved WQS that are the subject of the nonsubstantive edits or editorial changes.

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II. New or Revised Provisions the EPA is Approving

In today's action, the EPA is approving the following new or revised provisions in the *New Mexico Standards for Interstate and Intrastate Waters* (20.6.4 NMAC) that were adopted by the Commission on March 2, 2022, and became effective as state law on April 23, 2022, pursuant to §303(c) of the CWA. The new and revised water quality standards will apply throughout the State of New Mexico, excluding areas of Indian country as defined in 18 U.S.C. §1151

20.6.4.6 Objective

D. These surface water quality standards serve to respond to the inherent threats of climate change and provide resiliency for the continued protection and enhancement of water quality.
[20.6.4.6 NMAC - Rp 20 NMAC 6.1.1006, 10/12/2000; A, 5/23/2005; A, 4/23/2022]

EPA Determination: *The amended language in this provision has been described as an effort to reflect the objective of the New Mexico WQS more accurately as they pertain to the threats from climate change consistent with the statewide climate strategy outlined in the Governor's Executive Order referenced in this provision. The EPA supports the NMED's commitment to provide resiliency in addressing threats to the state's waters posed by climate change. This provision is approved pursuant to CWA § 303(c) and is effective for CWA purposes.*

20.6.4.7. Definitions

Definitions are generally considered to be WQS in that they can affect the meaning and interpretation of a WQS provisions. The exception to this convention is when the use of a definition is limited to those provisions that are not WQS, e.g., implementation language. The EPA's decision on revisions to definitions depend on the effect the definition has on the viability of other WQS provisions in the New Mexico Standards for Interstate and Intrastate Waters (20.6.4 NMAC).

The Commission has made the following changes to 20.6.4.7 NMAC. In most instances, a change to a current definition such as structural changes e.g., renumbering of subparagraphs, etc. are considered nonsubstantive changes and are not described in detail unless relevant to understanding, interpretation or application of other provisions.

20.6.4.7 DEFINITIONS: Terms defined in the New Mexico Water Quality Act, but not defined in this part will have the meaning given in the Water Quality Act.

A. Terms beginning with numerals or the letter "A," and abbreviations for units.

[~~(7)~~](8) "Attainable Use**"** means a use that is achievable by the imposition of effluent limits required under sections 301(b) and 306 of the federal Clean Water Act and implementation of cost-effective and reasonable best management practices for nonpoint source control. An attainable use may or may not have criteria as stringent as the designated use.

***EPA Determination*:** *The revisions to this definition remain generally consistent with Chapter 2 of the EPA's Water Quality Standards Handbook.*[4] *This definition is approved pursuant to CWA § 303(c) and is effective for CWA purposes.*

C. Terms beginning with the letter "C".

(4) "Climate change" refers to any significant change in the measures of climate lasting for an extended period of time, typically decades or longer, and includes major changes in temperature, precipitation, wind patterns or other weather-related effects.

***EPA Determination*:** *The EPA considers this definition to be consistent with the CWA and Water Quality Standards regulation. This definition is approved pursuant to CWA § 303(c) and is effective for CWA purposes.*

(2) "Emerging contaminants" refer to water contaminants that may cause significant ecological or health effects at low concentrations. Emerging contaminants are generally chemical compounds recognized as having deleterious effects at environmental concentrations whose negative impacts have not been fully quantified and may not have regulatory numeric criteria.

***EPA Determination*:** *The EPA considers this definition to be consistent with the CWA and Water Quality Standards regulation. This definition is approved pursuant to CWA § 303(c) and is effective for CWA purposes.*

H. Terms beginning with the letter "H".

(1) "Hardness" means the measure of calcium and magnesium salts in water expressed as dissolved calcium carbonate (CaCO3) unless otherwise noted.

***EPA Determination*:** *The inclusion of this simple definition of "hardness" is intended to clarify the term and provide consistency when implementing New Mexico's hardness-based metals criteria for the protection of aquatic life at 20.6.4.900(I) NMAC. This definition is approved pursuant to CWA § 303(c) and is effective for CWA purposes.*

(2) "Harmonic mean flow" is the number of daily flow measurements divided by the sum of the reciprocals of the flows; that is, it is the reciprocal of the arithmetic mean of reciprocal daily flow measurements consistent with the equations in Paragraph (1) of Subsection B of 20.6.4.11 NMAC.

***EPA Determination*:** *The definition was moved from 20.6.4.11.B with minor, nonsubstantive edits. This definition is approved as a nonsubstantive revision pursuant to CWA § 303(c) and is effective for CWA purposes.*

L. Terms beginning with the letter "L".

(2) "**Limited aquatic life**" as a designated use, means the surface water is capable of supporting only a limited community of aquatic life. This subcategory includes surface waters that support aquatic species selectively adapted to take advantage of naturally occurring rapid environmental changes, [~~ephemeral or intermittent water,~~]low flow, high turbidity, fluctuating temperature, low dissolved oxygen content or unique chemical characteristics.

[4] U.S. EPA, Office of Water. (1994). Water Quality Standards Handbook. EPA-823-B-17-001 (2017). Retrieved from https://www.epa.gov/wqs-tech/water-quality-standards-handbook

EPA Determination: *Although ephemeral or intermittent waters may experience the limitations described, striking the reference to these waters, deleting the specific reference and referring to low flow broadens the application of the limited aquatic life use designation to waters that may have the limitations described although they may be intermittent or perennial. These revisions do not fundamentally alter the meaning of the revised definition. Redivisions to this definition are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

M. Terms beginning with the letter "M".

(1) "Marginal coldwater" in reference to an aquatic life use means that natural [~~intermittent or low flows, or other natural habitat~~] conditions severely limit maintenance of a coldwater aquatic life population during at least some portion of the year or historical data indicate that the temperature [~~in~~] of the surface water of the state may exceed that which could continually support aquatic life adapted to coldwater[~~25°C (77°F)~~].

EPA Determination: *Although the intent appears to be distinguishing the marginal coldwater aquatic life use designation from the coldwater aquatic life use, striking the reference to flow and natural habitat leaves this definition less specific. The reference to naturally variable conditions may be limited during the attainment of the coldwater aquatic life use "at least some portion of the year" indicates that the marginal coldwater aquatic life us can be applied as a seasonal use. While the EPA recognizes natural variability, it is important to note that establishing a seasonal or year-round marginal coldwater aquatic life use must be based on natural and not anthropogenic conditions. Striking the use-specific water temperature limitations is appropriate given temperature criteria are held in the description of the marginal coldwater aquatic life use in 20.6.4.900 NMAC. Revisions to this definition are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

P. Terms beginning with the letter "P".

(3) "Persistent toxic pollutants" means pollutants, generally organic, that are resistant to environmental degradation through chemical, biological and photolytic processes and can bioaccumulate in organisms, causing adverse impacts on human health and aquatic life.

EPA Determination: *The EPA considers this definition to be consistent with the CWA and Water Quality Standards regulationThis definition is approved pursuant to CWA § 303(c) and is effective for CWA purposes.*

S. Terms beginning with the letter "S"

(5) "Surface water(s) of the state"

(a) means all surface waters situated wholly or partly within or bordering upon the state, including the following:

(i) lakes[,];
(ii) rivers[,];
(iii) streams (including intermittent and ephemeral streams) [,];
(iv) mudflats[~~,~~];
(v) sandflats[~~,~~];
(vi) wetlands[~~,~~];
(vii) sloughs[~~,~~];
(viii) prairie potholes [~~,~~];
(ix) wet meadows[~~,~~];
(x) playa lakes[~~,~~];
(xi) reservoirs[~~,~~]; [~~or~~]and

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(xii) natural ponds.

(b) [~~Surface waters of the state~~] also means all tributaries of such waters, including adjacent wetlands, any manmade bodies of water that were originally created in surface waters of the state or resulted in the impoundment of surface waters of the state, and any "waters of the United States" as defined under the Clean Water Act that are not included in the preceding description.

(c) [~~Surface waters of the state~~] does not include private waters that do not combine with other surface or subsurface water or any water under tribal regulatory jurisdiction pursuant to Section 518 of the Clean Water Act. Waste treatment systems, including treatment ponds or lagoons designed and actively used to meet requirements of the Clean Water Act (other than cooling ponds as defined in 40 CFR Part 423.11(m) that also meet the criteria of this definition), are not surface waters of the state, unless they were originally created in surface waters of the state or resulted in the impoundment of surface waters of the state.

EPA Determination: *The inclusion of the term "ephemeral" in this definition clarifies that New Mexico's WQS apply to ephemeral waters. Other formatting changes, including striking the repetition of the term "Surface waters of the state" in sections (ii) and (iii) are nonsubstantive. Revisions to this definition are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

U. Terms beginning with the letter "U". ~~[RESERVED]~~

(1) **"Unclassified waters of the state"** means those surface waters of the state not identified in 20.6.4.101 through 20.6.4.899 NMAC.

EPA Determination: *The language in this definition has been drawn from 20.6.4.11(H) NMAC, which is integral to providing protection to unclassified waters in New Mexico. This new definition is approved as a nonsubstantive change to WQS pursuant to CWA § 303(c) and is effective for CWA purposes.*

(2) **"Use attainability analysis"** means a scientific study conducted for the purpose of assessing the factors affecting the attainment of a use.

EPA Determination: *This language for this definition appears to have been drawn from the provision at 20.6.4.15 NMAC. The new definition is approved as a nonsubstantive revision to WQS pursuant to CWA § 303(c) and is effective for CWA purposes.*

20.6.4.8 Antidegradation Policy and Implementation Plan

A. Antidegradation Policy: This antidegradation policy applies to all surface waters of the state.

(1) Existing [~~instream water~~] uses, as defined in Paragraph (4) of Subsection E of 20.6.4.7 NMAC, and the level of water quality necessary to protect the existing uses shall be maintained and protected in all surface waters of the state.

EPA Determination: *The reference to the definition of "existing uses" and subsequent corrections of the acronym "ONRW" are nonsubstantive. The revisions to this provision are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.9 Outstanding National Resource Waters

A. Procedures for nominating an ONRW: Any person may nominate a surface water of for designation as an ONRW by filing a petition with the commission pursuant to [~~the guidelines for water quality control commission regulation hearings~~]20.1.6 NMAC, Rulemaking Procedures - Water Quality Control Commission. A petition to designate a surface water of the state as an ONRW shall include:

EPA Determination: *The inclusion of the reference to the Commission's regulatory authority and procedures provides important clarity regarding the process for nominating waters as Outstanding National Resource Waters (ONRW). The revisions to this provision are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.10. Review of Standards; Need for Additional Studies

A. Section 303(c)(1) of the federal Clean Water Act requires that the state hold public hearings at least once every three years for the purpose of reviewing water quality standards and proposing, as appropriate, necessary revisions to water quality standards.

B. In accordance with 40 CFR 131.10(j) when an existing use is defined in 20.6.4.7 NMAC, is more stringent than the designated use and supporting evidence demonstrates the presence of that use, the designated use shall be amended to be no less stringent than the existing use.

[~~B.~~] C. It is recognized that, in some cases, numeric criteria [~~have been adopted that reflect use designations rather than existing conditions of surface waters of the state.~~]for a particular designated use may not adequately reflect the local conditions or the aquatic communities adapted to those localized conditions. In these cases, a water quality criterion may be modified to reflect the natural condition of a specific waterbody. The modification of the criterion does not change the designated use; the modification only changes the criterion for that specific waterbody. [~~Narrative criteria are required for many constituents because accurate data on background levels are lacking. More intensive water quality monitoring may identify surface waters of the state where existing quality is considerably better than the established criteria.~~]When justified by sufficient data and information, a numeric [~~the~~] water quality [~~criteria~~]criterion [~~will~~]may be adopted or modified in accordance with 20.6.4.10(F) and 20.6.4.10(G) NMAC, to protect the attainable uses of the waterbody.

D. The removal or amendment of a designated use to a designated use with less stringent criteria can only be done through a use attainability analysis in accordance with 20.6.4.15 NMAC.

The addition of the new provisions at 20.6.4.10 (B) NMAC clarifies that the existing uses may represent higher water quality than is being protected by the current designated use and associated criteria. These revisions require that the more stringent designated use be revised consistent with the requirements found in 40 CFR 131.10(i) as specified.

The revisions to 20.6.4.10 (C) NMAC also clarify the process that will use to determine conditions where a site-specific criteria analysis is warranted to supporting the designation of use that reflects the natural conditions of a waterbody. This approach is not the development of a subcategory of use as referred to in 40 CFR 131.10(k)(2) and is generally consistent with both 40 CFR §§ 131.10 and 131.11. It is worth noting that although 20.6.4.7 NMAC contains a definition for "natural causes," defining natural conditions can be very difficult to impossible without substantial historical data on habitat and water quality conditions. It is important to understand that the EPA would require extensive supporting information to support revisions based on natural causes prior to acting on such revisions.

EPA Determination: *The new provisions at 20.6.4.10(D) NMAC is a subdivision of 20.6.4.10(C) NMAC that specifies that the removal or amendment of a designated use with less stringent*

criteria can only be done through a use attainability analysis (UAA). The new provision is consistent with 40 CFR 131.10(j)(2). Subsequent revisions updating the lettering of subsequent paragraphs in this provision are not substantive. The revisions to this provision are approved pursuant to CWA § 303(c) and are effective for CWA purposes.

20.6.4.11. Applicability of Water Quality Standards

A. [RESERVED]

B. Critical low flow: The critical low flow of a stream at a particular site shall be used in developing point source discharge permit requirements to meet numeric criteria set in 20.6.4.97 through 20.6.4.900 NMAC and Subsection F of 20.6.4.13 NMAC.

(1) For human health-organism only criteria, the critical low flow is the harmonic mean flow [~~; "harmonic mean flow" is the number of daily flow measurements divided by the sum of the reciprocals of the flows; that is, it is the reciprocal of the mean of reciprocals~~]. For ephemeral waters the calculation shall be based upon the nonzero flow intervals and modified by including a factor to adjust for the proportion of intervals with zero flow. The equations are as follows:

***EPA Determination*:** *The deletion of this reference to harmonic mean flow is nonsubstantive given that the term is now defined in 20.6.4.7 NMAC. The revisions to this provision are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

H. Unclassified waters of the state: [~~Unclassified waters of the state are those surface waters of the state not identified in 20.6.4.101 through 20.6.4.899 NMAC.~~] An unclassified surface water of the state is presumed to support the uses specified in Section 101(a)(2) of the federal Clean Water Act. As such, it is subject to 20.6.4.98 NMAC if nonperennial or subject to 20.6.4.99 NMAC if perennial. The commission may include an ephemeral unclassified surface water of the state under 20.6.4.97 NMAC only if a use attainability analysis demonstrates pursuant to 20.6.4.15 NMAC that attainment of Section 101(a)(2) uses is not feasible.

EPA Determination: *Striking the first sentence of this provision referring to unclassified waters of the state that are "not identified in 20.6.4.101 through 20.6.4.899 NMAC" that has been moved to 20.6.7.7U(1) NMAC and is thus a nonsubstantive revision. This provision is approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.12. Compliance with Water Quality Standards

F. For compliance with hardness-dependent numeric criteria, [~~dissolved~~] hardness (as mg $CaCO_3$/L) shall be determined from a sample taken at the same time that the sample for the contaminant is taken.

***EPA Determination*:** *The NMED proposed, and the Commission adopted a definition of the term "hardness" to clarify the term and provide consistency when implementing New Mexico's hardness-based metals criteria for the protection of aquatic life at 20.6.4.900(I) NMAC. As described in the Commission's Statement of Reasons (SOR), the San Juan Water Commission recommended removing the word "dissolved" before "hardness" in 20.6.4.12(F) NMAC and 20.6.4.900(I) NMAC, so that it aligned with the new definition of "hardness," and to eliminate redundancy and clarify the term. The Commission agreed and approved striking the word "dissolved" in in 20.6.4.12(F) NMAC. The deletion of the word "dissolved" in this*

provision is approved as a nonsubstantive revision pursuant to CWA § 303(c) and is effective for CWA purposes.

G. Compliance schedules: [~~It shall be the policy of the commission to allow on a case-by-case basis~~ t]The commission may allow the inclusion of a schedule of compliance in a NPDES permit issued to an existing facility on a case-by-case basis. Such schedule of compliance will be for the purpose of providing a permittee with adequate time to make treatment facility modifications necessary to comply with water quality-based permit limitations determined to be necessary to implement new or revised water quality standards or wasteload allocation. Compliance schedules may be included in NPDES permits at the time of permit renewal or modification and shall be written to require compliance at the earliest practicable time. Compliance schedules shall also specify milestone dates so as to measure progress towards final project completion (e.g., design completion, construction start, construction completion, date of compliance).

EPA Determination: *The Commission previously adopted this compliance schedule authorizing provision consistent with 40 CFR 131.15. The nonsubstantive rephrasing here improves the clarity of the provisions and the intent to allow compliance schedules on a case-by-case basis. The revisions to this provision are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.13. General Criteria

F. Toxic pollutants:

(1) Except as provided in 20.6.4.16 NMAC, surface waters of the state shall be free of toxic pollutants from other than natural causes in amounts, duration, concentrations or combinations that affect the propagation of fish or that are toxic to humans, livestock or other animals, fish or other aquatic organisms, wildlife using aquatic environments for habitation or aquatic organisms for food, or that will or can reasonably be expected to bioaccumulate in tissues of fish, shellfish and other aquatic organisms to levels that will impair the health of aquatic organisms or wildlife or result in unacceptable tastes, odors or health risks to human consumers of aquatic organisms.

EPA Determination: *The inclusion of the term "duration" adds some clarity to this provision since the term refers to the averaging period, and a maximum allowable frequency of exceedance of the acute and chronic criteria. The revisions to this provision are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.14 Sampling and Analysis

F. Emerging Contaminants Monitoring: The department may require monitoring, analysis and reporting of emerging contaminants as a condition of a federal permit under Section 401 of the federal Clean Water Act.

EPA Determination: *This new subsection refers to existing authority held by the NMED to require sampling and monitoring of contaminants in NPDES permits consistent with its CWA § 401 authority. This is not a WQS that EPA has authority under CWA § 303(c) to review.*

20.6.4.15. Use Attainability Analysis

A. **Regulatory requirements for a use attainability analysis**. [~~A use attainability analysis is a scientific study conducted for the purpose of assessing the factors affecting the attainment of a use.~~] Whenever a use attainability analysis is conducted, it shall be subject to the requirements and limitations set forth in 40 CFR Part 131, Water Quality Standards; specifically, Subsections 131.3(g), 131.10(g), 131.10(h) and 131.10(j) shall be applicable. In accordance with 40 CFR 131.10(i), and 20.6.4.10 NMAC, the amendment of a designated use, based on an existing use with more stringent criteria, does not require a use attainability analysis.

(1) The commission may remove a designated use, that is not an existing use, specified in Section 101(a)(2) of the federal Clean Water Act or adopt subcategories of a use in Section 101(a)(2) of the federal Clean Water Act [~~use~~] requiring less stringent criteria only if a use attainability analysis demonstrates that attaining the use is not feasible because of a factor listed in 40 CFR 131.10(g). Uses in Section 101(a)(2) of the federal Clean Water Act [~~uses~~], which refer to the protection and propagation of fish, shellfish and wildlife and recreation in and on the water, are also specified in Subsection B of 20.6.4.6 NMAC.

(2) A designated use cannot be removed if it is an existing use unless a use requiring more stringent criteria is designated.

B. The mechanism to remove a designated use. A use attainability analysis shall assess the physical, chemical, biological, economic, or other factors affecting the attainment of a use. The analysis shall rely on scientifically defensible methods such as the methods described in the following documents:

(1) Technical Support Manual: Waterbody Surveys And Assessments For Conducting Use Attainability Analyses, volume I (November 1983) and volume III (November 1984) or latest editions, United States environmental protection agency, office of water, regulations and standards, Washington, D.C., for the evaluation of aquatic life or wildlife uses;

(2) the department's *Hydrology Protocol*, latest edition, approved by the commission, for identifying ephemeral, [~~and~~] intermittent, and perennial waters; or

(3) *Interim Economic Guidance For Water Quality Standards - Workbook*, March 1995, United States environmental protection agency, office of water, Washington, D.C. for evaluating economic impacts.

C. **Determining the highest attainable use**. If the use attainability analysis determines that the designated use is not attainable based on one of the factors in 40 CFR 131.10(g), the use attainability analysis shall then determine the highest attainable use for the protection and propagation of fish, shellfish and wildlife and recreation in and on the water based on methods described in Subsection B of this section.

D. Process to remove a designated use and establish the highest attainable use.

(1) The process for developing a use attainability analysis and petitioning the commission for removing a designated use and establishing the highest attainable use shall be done in accordance with the State's current *Water Quality Management Plan/Continuing Planning Process*.

[~~C.~~](2) If the findings of a use attainability analysis, conducted by the department, [~~based on~~] in accordance with the department's *Hydrology Protocol* (latest edition)[~~, approved by the commission,~~] demonstrates [~~to the satisfaction of the department~~]that federal Clean Water Act Section 101(a)(2) uses, that are not existing uses, are not feasible in an ephemeral water body due to the factor in 40 CFR 131.10(g)(2), the department may consider proceeding with the expedited use attainability analysis process in accordance with the State's current *Water Quality Management Plan/Continuing Planning Process*. The following elements must be met for the expedited use attainability analysis process to be authorized and implemented:

(a) The department is the primary investigator of the use attainability analysis;

(b) The use attainability analysis determined, through the application of the *Hydrology Protocol*, that the water being investigated is ephemeral and has no effluent discharges of sufficient volume that could compensate for the low-flow;

(c) The use attainability analysis determined that the criteria associated with the existing uses of the water being investigated are not more stringent than those in 20.6.4.97 NMAC;

(d) The designated uses in 20.6.4.97 NMAC have been determined to be the highest attainable uses for the water being analyzed;

(e) The department [~~shall~~]posted the use attainability analysis on its water quality standards website and [~~notify~~] notified its interested parties list of a 30-day public comment period. ;

(f) [~~After reviewing~~]The department reviewed and responded to any comments received during the 30-day public comment period, and

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(g) The department [~~may proceed by submitting~~]submitted the use attainability analysis and response to comments to region 6 EPA for technical approval. If EPA approves the revision under section 303(c) of the Clean Water Act [~~technical approval is granted~~], the water shall be subject to 20.6.4.97 NMAC for federal Clean Water Act purposes. The use attainability analysis, the technical support document,[~~approval,~~] and the applicability of 20.6.4.97 NMAC to the water shall be posted on the department's water quality standards website. The department shall periodically petition the commission to list ephemeral waters under Subsection C of 20.6.4.97 NMAC and to incorporate changes to classified segments as appropriate.

~~[D.]~~E. Use attainability analysis conducted by an entity other than the department. Any person may submit notice to the department stating their intent to conduct a use attainability analysis.

(1) The proponent shall provide such notice along with [~~develop~~]a work plan supporting [~~to conduct~~]the development of a use attainability analysis[~~. and shall submit the work plan]~~ to the department and region 6 EPA for review and comment.

(2) Upon approval of the work plan by the department, the proponent shall conduct the use attainability analysis in accordance with the applicable portions of Subsections A through D of this Section and implement public noticing in accordance with the approved work plan.

(3) Work plan elements. The work plan shall identify, at a minimum:

(a) the waterbody of concern and the reasoning for conducting a use attainability analysis.

(b) the [~~scope~~]source and validity of data [~~currently available and the scope of data to be gathered~~]to be used to demonstrate whether the current designated use is not attainable;[~~,~~]

(c) the factors in 40 CFR 131.10(g) affecting [~~use~~]the attainment of that use;

(d) [that will be analyzed] a description of the data being proposed to be used to demonstrate the highest attainable use;

(e) [~~and~~]the provisions for consultation with appropriate state and federal agencies;

(f) a description of how stakeholders and potentially affected tribes will be identified and engaged;

(g) a description of the public notice mechanisms to be employed; and [~~consultation with appropriate state and federal agencies~~]

(h) the expected timelines outlining the administrative actions to be taken for a rulemaking petition, pending the outcome of the use attainability analysis.

(4) [~~Upon approval of the work plan by the department, the proponent shall conduct the use attainability analysis in accordance with the approved work plan. The cost of such analysis shall be the responsibility of the proponent.~~] Upon completion of the use attainability analysis, the proponent shall submit the data, findings and conclusions to the department, and provide public notice of the use attainability analysis in accordance with the approved work plan.

(5) Pending the conclusions of the use attainability analysis and as described in the approved work plan, [~~T~~]the department or the proponent may petition the commission to modify the designated use [~~if the conclusions of the analysis support such action~~]. The cost of such use attainability analysis shall be the responsibility of the proponent. Subsequent costs associated with the administrative rulemaking process shall be the responsibility of the petitioner.

EPA Determination: *The majority of the revisions to 20.6.4.15 NMAC provide consistency with both designated use requirements in the CWA and its implementing regulations at 40 CFR 131.10 for amending a designated uses with less protective criteria. The revisions will ensure effective implementation of the UAA process as outlined in federal regulation and consistency with New Mexico's Water Quality Management Plan/Continuing Planning Process[5] (WQMP/CPP) document.*

[5] New Mexico Environment Department (2020), The NMED Statewide Water Quality Management Plan and Continuing Planning Process (WQMP/CPP). WQCC No. 20-34

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The EPA recommends that in its next triennial revision, the NMED amend 20.6.4.15(D)(2)(g) NMAC to clarify that the revisions must be adopted into NMAC before EPA can approve them under section 303(c) of the Clean Water Act. The provision at 20.6.4.15(D)(2)(g) NMAC does not supersede the CWA requirement that water quality standards be adopted by the state before they can be approved by the EPA as effective for CWA purposes. Any decisions on the effectiveness of new and revised water quality standards for CWA purposes will be made by the EPA following adoption by the Commission and submission by the NMED pursuant to §303(c) and 40 CFR 131. As detailed in initial comments on draft revisions to this provision, the EPA stated that it will not provide "technical approval" for any UAA to ensure that associated comments or recommendations are not misconstrued as a final decision or finding by the EPA under CWA §303(c). Although the EPA appreciates the NMED/SWQB effort to provide an opportunity for review of draft UAAs when resources allow, this subparagraph continues to state that the NMED will submit a UAA and response to comments to the EPA for technical approval.

The EPA is approving the revisions to 20.6.15 NMAC pursuant to CWA § 303(c) because they are otherwise consistent with the CWA and WQS regulations, with the caveat that the EPA will not provide "technical approval" of a UAA prior to approval by the Commission. The deletion of the first sentence defining a use attainability analysis is a nonsubstantive revision since the definition was moved to 20.6.4.7.U.(2) NMAC. The revisions to this provision are approved pursuant to CWA § 303(c) and are effective for CWA purposes.

20.6.4.97. Ephemeral Waters

20.6.4.97 EPHEMERAL WATERS: Ephemeral surface waters of the state as identified below and additional ephemeral waters as identified on the department's water quality standards website pursuant to Paragraph (2) of Subsection [~~C~~]D of 20.6.4.15 NMAC are subject to the designated uses and criteria as specified in this section. Ephemeral waters classified in 20.6.4.101-899 NMAC are subject to the designated uses and criteria as specified in those sections.

(g) the south fork of Cañon del Piojo from [~~Canon~~]Cañon del Piojo upstream 1.2 miles to an unnamed tributary.

EPA Determination: *The language in 20.6.4.97 NMAC was revised for consistency with 20.6.4.15 NMAC and is nonsubstantive. The grammatical correction in 20.6.4.97(C)(1)(g) is nonsubstantive. The revisions to this provision are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4. Rio Grande Basin

20.6.4.103 RIO GRANDE BASIN: [~~The main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam and perennial~~] Perennial reaches of tributaries to the Rio Grande in Sierra and Socorro counties not specifically identified under other sections of 20.6.4 NMAC, excluding waters on tribal lands.

A. Designated uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, secondary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[~~**C.** Remarks: flow in this reach of the Rio Grande main stem is dependent upon release from Elephant Butte dam.~~]

[20.6.4.103 NMAC - Rp 20 NMAC 6.1.2103, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]
[**NOTE:** This segment was divided effective 4/23/2022. The standards for the main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam, perennial reaches of Palomas creek, perennial reaches of Rio Salado, perennial reaches of Percha creek, perennial reaches of Alamosa creek, Las Animas creek, and perennial reaches of Abo arroyo are under 20.6.4.112 NMAC.]

The NMED expends significant effort as part of an ongoing process to ensure that appropriate designated uses are in place for all waters in New Mexico consistent with the CWA and the federal water quality standards regulation. As part of proposed triennial revisions in 2005, the NMED recommended and the Commission adopted designated use provisions for unclassified, waters based on hydrology through the creation of 20.6.4.97, 20.6.4.98 and 20.6.4.99 NMAC. Consistent with the CWA, 20.6.4.98 NMAC specifies that unclassified nonperennial surface waters of the state are presumed to support the uses specified in CWA § 101(a)(2). As part of these amendments, most unnamed nonperennial waters in regulatory segments 20.6.4.101 through 899 NMAC were revised to unclassified waters by adding the phrase "perennial reaches of tributaries to…" to classified regulatory segments 20.6.4.101 through 899 NMAC.

During its 2014 triennial review process, the NMED re-examined specific waters defined in 20.6.4.101-20.6.4.899 NMAC and found that some regulatory segments had not been amended consistent with the Commission's 2005 revisions and still contained language that applied perennial uses to nonperennial waters. During the Commission's 2015 hearing to review and revise the state's water quality standards, the NMED presented assessment information based on field data supporting its determination that the specified waters are capable of supporting primary contact recreation. However, the Commission did not adopt the recommended primary contact recreation use for these waters in its final 2017 order.

As part of the recent 2020 triennial revision process, in its review of classified waters within 20.6.4.101-899 NMAC the NMED again identified some regulatory segments that were not consistent with the Commission's 2005 revisions, leaving some segments with language that applied perennial designated uses to nonperennial waters. To address this, the NMED developed an Existing Use Analysis of Recreational Use for Classified Waters 20.6.4.101-20.6.4.899 NMAC (2021), focusing on classified waters in 20.6.4.103, 20.6.4.116, 20.6.4.204, 20.6.4.206, and 20.6.4.207 NMAC that retained the secondary contact recreational use. The Existing Use Analysis (EUA) was intended to allow a determination of whether there is evidence that primary contact recreation is attainable or the existing use in these waters.

The EUA explains that although the SWQB does not directly monitor or gather specific information on the actual occurrence of recreational uses. The determination of whether the primary contact use is existing or attainable was based on archived and current datasets for parameters specific to the primary contact use. Waters within these classified segments were assessed and parsed based on archived and data collected since 2010 through the NMED's Surface water Quality Information Database (SQUID). Archived and SQUID Escherichia coli (E. coli) and pH data is specifically associated with the primary contact use. To be considered for primary contact use designation, any waters must have pH data values ranging from 6.6 to 9.0 and E. coli data that fell at or below 410 cfu/100 mL in more than one sample event. Taking a conservative approach, the NMED excluded any waters that did not contain both E. coli and pH data from the analysis. The NMED determined that there was adequate

information and data to move forward with the analysis of five regulatory segments, including 20.6.4.103, 20.6.4.116, 20.6.4.204, 20.6.4.206 and 20.6.4.207 NMAC.

The EUA did not identify any available data to indicate whether the primary contact recreation use can be supported within the assessment unit (AU) specific to 20.6.4.103 NMAC that includes the perennial reaches of tributaries to the Rio Grande in Sierra & Socorro County. Thus, there is no basis to support a primary contact use designation in this AU. However, there were data available specific to other AUs within this regulatory segment for the perennial reaches of Percha creek, perennial reaches of Alamosa creek, Las Animas creek, and perennial reaches of Abo arroyo. The data indicate that these waters are capable of attaining a primary contact recreational use. Based on this data, the NMED recommended, and the Commission subdivided 20.6.4.103 NMAC, moving these perennial waters to the previously reserved regulatory segment 20.6.4.112 NMAC.

EPA Determination: *The EPA has determined that there are no data available to support designating the primary contact use for regulatory segment 20.6.4.103 NMAC. However, there are data that indicate that the primary contact recreation use is supported in the perennial reaches of Percha creek, perennial reaches of Alamosa creek, Las Animas creek, and perennial reaches of Abo arroyo in a separate regulatory segment. See the discussion specific to 20.6.4.112 NMAC below. The EPA is approving the revisions to 20.6.4.103 NMAC related to the redefinition of specific waters by subdividing regulatory segment 20.6.4.103 NMAC to ensure the appropriate designated uses are applied is consistent with the CWA and federal regulations. The revisions to this provision are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.108 RIO GRANDE BASIN: Perennial reaches of the Jemez river upstream of Soda dam near the town of Jemez Springs and [~~all its~~]perennial reaches of tributaries to the Jemez river except those not specifically identified under other sections of 20.6.4 NMAC [~~above Soda dam near the town of Jemez Springs, except San Gregorio lake and Sulphur creek above its confluence with Redondo creek~~], and perennial reaches of the Guadalupe river and perennial reaches of [~~all its~~] tributaries to the Guadalupe river, and Calaveras canyon.

A. Designated uses: domestic water supply, fish culture, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 400 µS/cm or less (800 µS/cm or less on Sulphur creek); the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less; and pH within the range of 2.0 to 8.8 on Sulphur creek.
[20.6.4.108 NMAC - Rp 20 NMAC 6.1.2106, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012; A, 4/23/2022]

The previous discussion for 20.6.4.103 NMAC referred to the rebuttable presumption that CWA § 101(a)(2) uses are attainable and must be assigned unless there is an affirmative demonstration that such uses are not attainable. It also referred to the NMED's efforts to meet specific requirements pursuant to 40 CFR § 131.20(a) and 40 CFR § 131.10(i).

The prior discussion for 20.6.4.103 NMAC also referred to both the NMED's recommendations and the revisions adopted by the Commission in its 2005 and 2017 rulemakings and their influence on the current 2020 triennial revisions related to nonperennial waters in classified regulatory segments in 20.6.4.101 through 899 NMAC. The NMED developed a UAA entitled

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Use Attainability Analysis for Select Nonperennial Reaches in Classified Waters 20.6.4.101-20.6.4.899 NMAC (2021) to evaluate classified waters defined in regulatory segments 20.6.4.108, 20.6.4.115, 20.6.4.206, 20.6.4.208, 20.6.4.209, 20.6.4.215, 20.6.4.220, 20.6.4.307 and 20.6.4.309 NMAC. The UAA evaluated attainment of the aquatic life, fish culture and water supply, domestic water supply, and irrigation uses in regulatory segments that were not amended in prior Commission revisions. The UAA did not consider the primary contact recreation use with the exception of the nonperennial tributaries to the Rio Hondo downstream of Bonney Canyon,

The NMED's UAA utilized the National Hydrology Dataset (NHD) to determine if there are nonperennial tributaries included in the regulatory segments referred to above. The NHD data confirmed the presence of intermittent waters within the regulatory segments identified. Based on the NHD data, the NMED determined that the nonperennial tributaries to the Jemez River above Soda dam and nonperennial tributaries to the Guadalupe River currently defined in 20.6.4.108 NMAC are not capable of supporting the designated high quality coldwater fishery and fish culture uses apply to the named waters. The data indicate that the highest attainable uses is the marginal warmwater aquatic life, retaining the primary contact recreation use.

***EPA Determination*:** *The revisions to this regulatory segment are consistent with the federal regulation at 40 CFR § 131.10(g)(2). The EPA has determined that the data in the NMED's UAA supports the conclusion that natural intermittent conditions prevent attainment of the designated aquatic life uses that currently apply to nonperennial tributaries to the Rio Vallecitos currently defined in 20.6.4.108 NMAC. Given the supporting data and the lack of evidence that the currently defined uses are attainable or existing uses in the nonperennial tributaries the Jemez River above Soda dam and nonperennial tributaries to the Guadalupe River, the revisions redefining intermittent waters currently in 20.6.4.108 NMAC to 20.6.4.98 NMAC are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.112 ~~[RESERVED]~~ **RIO GRANDE BASIN**: - The main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam, perennial reaches of Palomas Creek, perennial reaches of Rio Salado, perennial reaches of Percha Creek, perennial reaches of Alamosa Creek, Las Animas Creek, and perennial reaches of Abo Arroyo.

A. Designated uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

C. Remarks: flow in this reach of the Rio Grande main stem is dependent upon release from Elephant Butte dam.

[20.6.4.112 NMAC - Rp 20 NMAC 6.1.2109, 10/12/2000; A, 5/23/2005; Repealed, 12/1/2010; A, 4/23/2022]

As indicated in the discussion for regulatory segment 20.6.4.103 NMAC, the NMED reviewed classified waters within 20.6.4.101 through 899 NMAC and found that some regulatory segments were not amended consistent with the Commission's prior revisions, leaving some with language that applied perennial designated uses to nonperennial waters.

To address this, as part of the recent 2020 triennial review, the NMED developed the previously referenced EUA which provides supporting data indicating that there are waters currently

defined within regulatory segment within 20.6.4.103 NMAC that are capable of supporting the primary contact recreation use. Based on this data, the NMED proposed, and the Commission adopted the division of segment 20.6.4.103 NMAC to remove the waterbodies where the primary contact recreation use is attainable, incorporating those waters into previously reserved section 20.6.4.112 NMAC.

The revisions proposed by the NMED and subsequently adopted by the Commission subdivide regulatory segment 20.6.4.103 NMAC, retaining waters defined within the AU for tributaries to the Rio Grande in Sierra & Socorro County where inadequate or no data were available to support a designated recreational use change. Those AUs within this regulatory segment 20.6.4.103 NMAC where data indicate that the primary contact recreation use is attainable include the perennial reaches of Percha creek, perennial reaches of Alamosa creek, Las Animas creek, and perennial reaches of Abo arroyo now defined in the previously reserved 20.6.4.112 NMAC.

***EPA Determination*:** *The EPA has determined that the data in the NMED's EUA supports the conclusion that primary contact recreation is attainable in the perennial reaches of Percha creek, perennial reaches of Alamosa creek, Las Animas creek, and perennial reaches of Abo arroyo. Thus, the revisions to 20.6.4.112 NMAC related to the redefinition of specific waters and the designation of the primary contact recreation use is consistent with the CWA and federal regulations. The revisions to this provision are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.115 RIO GRANDE BASIN: The perennial reaches of Rio Vallecitos and [~~its~~]perennial reaches of tributaries to Rio Vallecitos except Hopewell lake, and perennial reaches of Rio del Oso and perennial reaches of El Rito creek above the town of El Rito.

A. Designated uses: domestic water supply, irrigation, high quality coldwater aquatic life, livestock watering, wildlife habitat and primary contact; public water supply on the Rio Vallecitos and El Rito creek.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.115 NMAC - Rp 20 NMAC 6.1.2112, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012; A, 4/23/2022]
[**NOTE:** The standards for Hopewell lake are in 20.6.4.134 NMAC, effective 7/10/2012]

As initially discussed in detail regarding the revisions to 20.6.4.108 NMAC, the same CWA and federal regulatory requirements are applicable here. The history of the NMED's prior recommendations and the revisions adopted by the Commission in its 2005 and 2017 rulemakings are also pertinent to the current 2020 triennial revisions for the nonperennial waters currently defined in classified regulatory segment 20.6.4.115 NMAC.

As part its 2020 triennial review, the NMED identified nonperennial reaches of tributaries in classified perennial waters defined in regulatory segments that were not revised in prior Commission rulemakings. In the previously referenced UAA, the NMED evaluated attainment of the aquatic life, fish culture and water supply, domestic water supply, and irrigation uses in regulatory segments that were not amended in prior Commission revisions. The NMED utilized NHD data to determine the highest attainable use for nonperennial reaches of tributaries to

regulatory segments including 20.6.4.115 NMAC. The NHD evaluation confirmed the presence of intermittent waters where natural low-flow, intermittent or ephemeral conditions that prevent attainment of the high quality coldwater aquatic life use nonperennial tributaries to the Rio Vallecitos. The data indicates that the highest attainable use supported in these nonperennial waters include marginal warmwater aquatic life and primary contact recreation.

EPA Determination: *The EPA has determined that the data in the NMED's UAA supports the conclusion that natural intermittent conditions prevent attainment of the designated aquatic life uses that currently apply to nonperennial tributaries to the Rio Vallecitos currently defined in 20.6.4.115 NMAC. The revisions to this regulatory segment are consistent with the federal regulation at 40 CFR § 131.10(g)(2). Given the supporting data and the lack of evidence that the currently defined uses are attainable or existing uses in these nonperennial tributaries to the Rio Vallecitos, the revisions redefining intermittent waters currently in 20.6.4.115 NMAC to 20.6.4.98 NMAC are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.116 RIO GRANDE BASIN: The Rio Chama from its mouth on the Rio Grande upstream to Abiquiu reservoir, perennial reaches of the Rio Tusas, perennial reaches of the Rio Ojo Caliente, perennial reaches of Abiquiu creek and perennial reaches of El Rito creek downstream of the town of El Rito.

A. Designated uses: irrigation, livestock watering, wildlife habitat, coldwater aquatic life, warmwater aquatic life and [~~secondary~~]primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 31°C (87.8°F) or less.

[20.6.4.116 NMAC - Rp 20 NMAC 6.1.2113, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022]

As discussed regarding the revisions to 20.6.4.103 NMAC the NMED's recommendations and the Commission's subsequent revisions adopted in its 2005 and 2017 rulemakings have similar implications for the 2020 triennial revisions for the nonperennial waters currently defined in classified regulatory segment 20.6.4.116 NMAC.

As initially discussed in detail regarding the revisions to 20.6.4.103, in its 2020 triennial review process the NMED reviewed classified waters within 20.6.4.101-899 NMAC and identified regulatory segments that had not been amended consistent with the Commission's prior revisions, leaving some nonperennial waters in regulatory segments defined by perennial designated uses. As discussed previously, the NMED's EUA focuses on classified waters that were designated for secondary contact recreation to determine if there is evidence that primary contact recreation is attainable or the existing use in these waters. As described in the discussion of 20.6.4.103 NMAC, the NMED utilized archived and SQUID data specifically associated with the primary contact use to determine if there was adequate information to support the designation of primary contact recreation for waters defined in multiple regulatory segments including 20.6.4.116 NMAC.

EPA Determination: *Based on an analysis of the data in the supporting EUA, the EPA has determined that waters defined within 20.6.4.116 NMAC are capable of attaining the primary contact use. The EPA also considers the Commission's revisions to this provision to be*

consistent with the CWA and federal regulations and are approved pursuant to CWA § 303(c) and are effective for CWA purposes.

20.6.4.128 RIO GRANDE BASIN: Ephemeral and intermittent [~~watercourses~~] waters within lands managed by U.S. department of energy (DOE) within LANL[ ], including but not limited to: Mortandad canyon, Cañada del Buey, Ancho canyon, Chaquehui canyon, Indio canyon, Fence canyon, Potrillo canyon, and portions of Cañon de Valle, Los Alamos canyon, Sandia canyon, Pajarito canyon and Water canyon not [~~specifically~~] identified in 20.6.4.126 NMAC or 20.6.4.140 NMAC. (Surface waters within lands scheduled for transfer from DOE to tribal, state or local authorities are specifically excluded.)

A. Designated uses: livestock watering, wildlife habitat, limited aquatic life and secondary contact.

B. Criteria: the use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the acute total ammonia criteria set forth in Subsection [~~K~~] L of 20.6.4.900 NMAC ([~~salmonids~~] *Oncorhynchus spp.* absent).

[20.6.4.128 NMAC - N, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

***EPA Determination*:** *The substantive revision to 20.6.4.128 NMAC is limited to the reference to a new regulatory segment, 20.6.4.140 NMAC. The refence to 20.6.4.140 NMAC does not have any impact the applicable designated uses or supporting criteria that apply to those waters that continue to be defined within 20.6.4.128 NMAC. The strikeout of the term "watercourses" and its replacement with the word "waters" and the strikeout of the term "salmonids" and its replacement with the more specific species reference of "Oncorhynchus ssp" are nonsubstantive. These revisions are approved pursuant to CWA § 303(c) and the revised language is effective for CWA purposes.*

20.6.4.140 RIO GRANDE BASIN: Effluent canyon from Mortandad canyon to its headwaters, intermittent portions of S-Site canyon from monitoring well MSC 16-06293 to Martin spring, and intermittent portions of Twomile canyon from its confluence with Pajarito canyon to Upper Twomile canyon. (Surface waters within lands scheduled for transfer from DOE to tribal, state or local authorities are specifically excluded.)

A. Designated uses: livestock watering, wildlife habitat, marginal warmwater aquatic life and secondary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.140 NMAC - N, 4/23/2022]

***EPA Determination*:** *The Commission's record for its 2015 triennial revisions included a document entitled Joint Stipulation Regarding Proposed Changes to 20.6.4.128 NMAC (WQCC 14-05(R)). This Joint Stipulation is significant because it was part of the effort to determine the appropriate designated uses for classified ephemeral and intermittent waters within regulatory segment 20.6.4.128 NMAC. The Joint Stipulation obligated the NMED, the Dept. of Energy/Los Alamos National Laboratory (DOE/LANL) and Amigos Bravos to meet, discuss and come to agreement on the appropriate level of protection for waters defined in 20.6.4.128 NMAC which lie within DOE/LANL's property. It is the EPA's understanding that if agreement was reached, the Joint Stipulation specifically obligated the NMED to petition the Commission proposing appropriate designated uses for waters defined within 20.6.4.128 NMAC no later than the next, now current (2020) triennial review. This effort is consistent with the requirements in 40 CFR 131.20(a), which requires states to re-examine any waterbody segment with standards that do not include the uses specified in CWA § 101(a)(2) every 3 years to determine if any new information has become available. If new information is available that indicate the uses specified*

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in CWA § 101(a)(2) may be attainable, the State is required to revise its standards accordingly. The Joint Stipulation did not preclude Amigos Bravos and DOE/LANL from filing separate petitions to revise designated uses if there was no agreement.

Consistent with the Joint Stipulation, the NMED, in coordination with the DOE/LANL and to a lesser extent Amigos Bravos conducted a number of Hydrology Protocol[6] surveys on waters within regulatory segment 20.6.4.128 NMAC from November 2016 to October 2019 to document aquatic life and recreation uses supported based on the hydrology of these waters. The NMED/SWQB's Hydrology Protocol is the only hydrologic condition survey method for surface waters approved as a component of the New Mexico Water Quality Management Plan/Continuing Planning Process (WQMP/CPP). The New Mexico WQMP/CPP has been approved by both the Commission and the EPA. See the federal regulations at 40 CFR 130.5.

The Hydrology Protocol (HP) is used to determine the hydrologic regime of surface waters based on hydrological, geomorphic, and biological indicators related to the persistence of water. Extensive information gathered and evaluated as part of an HP survey. HP assessment information can then be used to provide technical support for a UAA but cannot be used in place of a UAA. Although the initial presumption was that the waters that were assessed within 20.6.5.128 NMAC would either be intermittent or ephemeral, after conducting HP surveys, on some but not all DOE/LANL waters, it was determined that several of these waters were actually perennial, not ephemeral or intermittent as previously believed.

In testimony during the Commission's 2021 hearing, the NMED described its efforts to determine the appropriate designated uses for classified ephemeral and intermittent waters within DOE/LANL consistent with the requirements in the Joint Stipulation. Based on subset of the HP surveys discussed above, the parties concurred that portions of three tributaries within DOE/LANL currently classified as nonperennial waters in 20.6.4.128 NMAC were in fact perennial. These waterbodies include Effluent Canyon from its confluence with Mortandad Canyon to its headwaters; the upper portion of S-site Canyon from alluvial monitoring well MSC 16-06293 to Martin Spring; and Twomile Canyon from Pajarito Canyon upstream to its confluence with upper Twomile Canyon.

The hydrologic data generated in the previously referenced HP surveys indicated that there was reasonable evidence to suggest that the existing uses in these waters may support a more sensitive uses than those currently designated uses under 20.6.4.128 NMAC. Given the unexpected finding that these waters may support aquatic life and potentially recreation uses that require more stringent criteria than the current designated use, the NMED stated in its testimony to the Commission that "although a UAA is not required under federal regulations, other factors must be considered for any designated use amendment." The NMED prepared what it referred to as an "Existing Use Analysis" (EUA) to document both state and federal regulatory requirements and supporting data. Based on the presumption that a UAA as defined in 40 CFR 131.3(g) is not required, the NMED relied on 40 CFR § 131.10(i) and state provisions at 20.6.4.10(B) NMAC that require states to amend uses to be at least as stringent as existing uses. The NMED developed a EUA entitled Existing Use Analysis for Effluent Canyon, Upper S-

[6] New Mexico Environment Department (2011). New Mexico WQMP/CPP Appendix C: Hydrology Protocol.

Site Canyon and Twomile Canyon from Water Canyon upstream to its confluence with Upper Twomile Canyon (2021)[7] to support its determinations.

At the time of this analysis, Effluent Canyon, S-Site Canyon and Twomile Canyon were designated for limited aquatic life and secondary contact recreational uses. This EUA evaluated available information for the waters described. The analysis of hydrologic conditions considered stream and alluvial well hydrographs, confirmed with climatological data to determine hydrologic condition under ambient, baseflow conditions and not the result of a direct and immediate result of precipitation. In addition to considering hydrologic condition, data utilized included conventional water quality parameters for maximum water temperature, pH range, dissolved oxygen and E. coli, primarily from the DOE/LANL Intellus[8] database. This EUA was intended to provide the supporting evidence to determine if a designated use change is warranted based on existing uses.

Based on the analysis of the available data, including the presence/absence of benthic macroinvertebrates extrapolated from the Level 1 and Level 2 HP surveys, the NMED determined that the more protective marginal warmwater aquatic life is the existing use in Effluent Canyon, the upper reaches of S-Site Canyon and Twomile Canyon from its confluence with Pajarito to Upper Twomile Canyon. In evaluating recreational uses for these waters, the SWQB determined that the available data was insufficient to demonstrate whether primary contact recreation is the existing use. With no available E. coli data, no further analysis of the existing recreational was carried out. Without data available, the NMED assumed that the existing recreational use to be at least secondary contact.

Based on the data in the NMED's EUA, the EPA considers the determination that the marginal warmwater aquatic life is the existing use in Effluent Canyon, the upper reaches of S-Site Canyon and Twomile Canyon from its confluence with Pajarito to Upper Twomile Canyon to be supported. However, the EUA indicates that the available data was insufficient to demonstrate that primary contact recreation is the existing use. As a result, the NMED did not make a determination but made an assumption based on data that the existing recreational use is assumed to be "at least" secondary contact, stating in its testimony before the Commission that the secondary contact recreational use is the current designated recreational use and requires no amendment at this time. The EPA has determined that since the secondary contact use is at least as protective as designated under 20.6.4.128 NMAC, a UAA to support this presumption is not required. These revisions are approved pursuant to CWA § 303(c) and the revised language is effective for CWA purposes.

20.6.4. Pecos River Basin

20.6.4.204 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Avalon reservoir upstream to Brantley dam.

A. Designated uses: irrigation, livestock watering, wildlife habitat, [~~secondary~~] primary contact and warmwater aquatic life.

[7] New Mexico Environment Department. 2021. Existing Use Analysis for Effluent Canyon, Upper S-Site Canyon and Twomile Canyon from Water Canyon upstream to its confluence with Upper Twomile Canyon.
[8] Los Alamos National Laboratory (LANL). Intellus New Mexico. https://www.intellusnm.com/

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B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
[20.6.4.204 NMAC - Rp 20 NMAC 6.1.2204, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]
[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for Avalon Reservoir are under 20.6.4.219 NMAC.]

As discussed regarding the revisions to 20.6.4.103 NMAC the NMED's recommendations and the Commission's subsequent revisions adopted in its 2005 and 2017 rulemakings have similar implications for the 2020 triennial revisions for the nonperennial waters currently defined in classified regulatory segment 20.6.4.204 NMAC.

As initially discussed in detail regarding the revisions to 20.6.4.103, in its 2020 triennial review process the NMED reviewed classified waters within 20.6.4.101-899 NMAC and identified regulatory segments that had not been amended consistent with the Commission's prior revisions, leaving some nonperennial waters in regulatory segments defined by perennial designated uses. As discussed previously, the NMED's EUA focuses on classified waters that were designated for secondary contact recreation to determine if there is evidence that primary contact recreation is attainable or the existing use in these waters. As described in the discussion of 20.6.4.103 NMAC, the NMED utilized archived and SQUID data specifically associated with the primary contact use to determine if there was adequate information to support the designation of primary contact recreation for waters defined in multiple regulatory segments including 20.6.4.204 NMAC.

EPA Determination: *Based on an analysis of the data in the supporting EUA, the EPA has determined that the waters defined in 20.6.4.204 NMAC are capable of attaining the primary contact use. The Commission's revisions designating the of primary contact recreation in 20.6.4.204 NMAC is consistent with the CWA and federal regulations. The revisions to this provision are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.206 PECOS RIVER BASIN: [~~The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, perennial reaches of the Rio Hondo and its~~] Perennial reaches of the Rio Felix and perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon, excluding North Spring river [~~and perennial reaches of the Rio Felix~~].

A. Designated uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

[20.6.4.206 NMAC - Rp 20 NMAC 6.1.2206, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022]
[**NOTE:** This segment was divided effective 4/23/2022. The standards for the main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, and perennial reaches of the Rio Hondo are under 20.6.4.231 NMAC.]

As initially discussed in detail regarding the revisions to both 20.6.4.103 and 20.6.4.108 NMAC, the same CWA and federal regulatory requirements are applicable here. The history of the

NMED's prior recommendations and the revisions adopted by the Commission in its 2005 and 2017 rulemakings are also pertinent to the current 2020 triennial revisions related to both the hydrology and designated uses for waters currently defined in classified regulatory segment 20.6.4.206 NMAC.

As part its 2020 triennial review, the NMED identified regulatory segments that had not been amended consistent with the Commission's prior revisions, leaving some nonperennial waters in regulatory segments defined by perennial designated uses. In its UAA, the NMED considered both aquatic life and recreational uses as well as other uses specific to New Mexico. The NMED utilized NHD data to determine the highest attainable use for both perennial and nonperennial reaches of waters currently defined in regulatory segment 20.6.4.206 NMAC. The NHD evaluation confirmed that natural low-flow, intermittent or ephemeral conditions prevent attainment of the warmwater aquatic life use in nonperennial tributaries to the Rio Hondo downstream of Bonney Canyon as currently defined in 20.6.4.206 NMAC. The highest attainable use supported in these nonperennial waters include marginal warmwater aquatic life and primary contact recreation.

The NMED also relied on its EUA to determine if primary contact recreation is either an attainable or existing use in classified waters that are currently designated for secondary contact recreation. As discussed previously, this EUA utilized archived and SQUID data specifically associated with the primary contact use to determine if there was adequate information to support the designation of primary contact recreation for waters defined in multiple regulatory segments including 20.6.4.206 NMAC. There were insufficient or no data available to base a contact recreation use determination for the AU for the Rio Felix (Perennial reaches Pecos River to headwaters) or the perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon. However, there were data for the remainder of the AUs within 20.6.4.206 including the main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, and perennial reaches of the Rio Hondo. Based on this data, the NMED recommended, and the Commission subdivided 20.6.4.206 NMAC, establishing a new segment 20.6.4.231 NMAC.

EPA Determination: *The EPA has determined that the data in the NMED's UAA supports the conclusion that the primary contact recreation use is attainable in mainstem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, and perennial reaches of the Rio Hondo and with the redefinition of those waters into a new regulatory segment 20.6.4.231 NMAC. Further, the EPA has determined that the data in the UAA supports the conclusion that natural intermittent conditions prevent attainment of the designated aquatic life uses that currently apply to nonperennial tributaries currently defined in 20.6.4.206 NMAC, consistent with the federal regulation at 40 CFR § 131.10(g)(2). Given the supporting data and the lack of evidence that the currently defined uses are attainable or existing uses in these nonperennial tributaries, the revisions redefining intermittent waters currently in 20.6.4.206 NMAC to 20.6.4.98 NMAC are appropriate. These revisions are consistent with the CWA and federal regulations and are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.207 PECOS RIVER BASIN: The main stem of the Pecos river from Salt creek (near Acme) upstream to Sumner dam.

A. Designated uses: irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and [~~secondary~~]primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 8,000 mg/L or less, sulfate 2,500 mg/L or less and chloride 4,000 mg/L or less.

[20.6.4.207 NMAC - Rp 20 NMAC 6.1.2207, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

As discussed regarding the revisions to 20.6.4.103 NMAC the NMED's recommendations and the Commission's subsequent revisions adopted in its 2005 and 2017 rulemakings have similar implications for the 2020 triennial revisions for the nonperennial waters currently defined in classified regulatory segment 20.6.4.207 NMAC.

As initially discussed in detail regarding the revisions to 20.6.4.103, in its 2020 triennial review process the NMED reviewed classified waters within 20.6.4.101-899 NMAC and identified regulatory segments that had not been amended consistent with the Commission's prior revisions, leaving some nonperennial waters in regulatory segments defined by perennial designated uses. As discussed previously, the NMED's EUA focuses on classified waters that were designated for secondary contact recreation to determine if there is evidence that primary contact recreation is attainable or the existing use in these waters. As described in the discussion of 20.6.4.103 NMAC, the NMED utilized archived and SQUID data specifically associated with the primary contact use to determine if there was adequate information to support the designation of primary contact recreation for waters defined in multiple regulatory segments including 20.6.4.207 NMAC. There were sufficient data available to support a contact recreation use determination for all AUs for the Pecos River within 20.6.4.207 NMAC.

EPA Determination: *Based on an analysis of the data in the supporting EUA, the EPA has determined that the waters defined in 20.6.4.207 NMAC are capable of attaining the primary contact use. The Commission's revisions designating the of primary contact recreation in 20.6.4.207 NMAC is consistent with the CWA and federal regulations. The revisions to this provision are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.208 PECOS RIVER BASIN: Perennial reaches of the Rio Peñasco above state highway 24 near Dunken, [~~and its~~] perennial reaches of tributaries to the Rio Peñasco above state highway 24 near Dunken, perennial reaches of Cox canyon, perennial reaches of the Rio Bonito downstream from state highway 48 (near Angus), the Rio Ruidoso downstream of the U.S. highway 70 bridge near Seeping Springs lakes, perennial reaches of the Rio Hondo upstream from Bonney canyon and perennial reaches of Agua Chiquita.

A. Designated uses: fish culture, irrigation, livestock watering, wildlife habitat, coldwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: temperature 30°C (86°F) or less, and phosphorus (unfiltered sample) less than 0.1 mg/L.

[20.6.4.208 NMAC - Rp 20 NMAC 6.1.2208, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

As initially discussed in detail regarding the revisions to 20.6.4.108 NMAC, the same CWA and federal regulatory requirements are applicable here. The history of the NMED's prior recommendations and the revisions adopted by the Commission in its 2005 and 2017 rulemakings are also pertinent to the current 2020 triennial revisions for the nonperennial waters currently defined in classified regulatory segment 20.6.4.208 NMAC.

As part its 2020 triennial review, the NMED identified nonperennial reaches of tributaries in classified perennial waters defined in regulatory segments that were not revised in prior Commission rulemakings. In the previously referenced UAA, the NMED evaluated attainment of the aquatic life, fish culture and water supply, domestic water supply, and irrigation uses in regulatory segments that were not amended in prior Commission revisions. The NMED utilized NHD data to determine the highest attainable use for nonperennial reaches of tributaries to regulatory segments including 20.6.4.208 NMAC. The NHD evaluation confirmed the presence of intermittent waters where natural low-flow, intermittent or ephemeral conditions that prevent attainment of the coldwater aquatic life and fish culture uses in nonperennial tributaries to the Rio Peñasco above state highway 24 near Dunken, NM, as currently defined in 20.6.4.209 NMAC. The data indicates that the nonperennial tributaries in 20.6.4.208 NMAC are not capable of supporting the coldwater aquatic life and fish culture uses. The highest attainable use supported in these nonperennial waters include marginal warmwater aquatic life and primary contact recreation.

***EPA Determination*:** *The EPA has determined that the data in the NMED UAA supports the conclusion that natural intermittent conditions prevent attainment of the designated coldwater aquatic life uses that currently apply to tributaries currently defined in 20.6.4.208 NMAC. The revisions to this regulatory segment are consistent with the federal regulation at 40 CFR § 131.10(g)(2). Given the supporting data and the lack of evidence that the currently defined coldwater aquatic life uses are attainable or existing uses in these tributaries, the revisions redefining intermittent waters currently in 20.6.4.208 NMAC to 20.6.4.98 NMAC are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.209 PECOS RIVER BASIN: Perennial reaches of Eagle creek upstream of Alto dam to the Mescalero Apache boundary, perennial reaches of the Rio Bonito upstream of state highway 48 (near Angus) excluding Bonito lake, [~~and its~~] perennial reaches of tributaries to the Rio Bonito upstream of state highway 48 (near Angus)[-], [~~and~~] perennial reaches of the Rio Ruidoso upstream of the U.S. highway 70 bridge near Seeping Springs lakes [~~,~~] above and below the Mescalero Apache boundary and [~~its~~] perennial reaches of tributaries to the Rio Ruidoso upstream of the U.S. highway 70 bridge near Seeping Springs lakes [~~,~~] above and below the Mescalero Apache boundary.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 600 µS/cm or less in Eagle creek, 1,100 µS/cm or less in Bonito creek and 1,500 µS/cm or less in the Rio Ruidoso; phosphorus (unfiltered sample) less than 0.1 mg/L; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.209 NMAC - Rp 20 NMAC 6.1.2209, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012; A, 4/23/2022]

[**NOTE:** The standards for Bonito lake are in 20.6.4.223 NMAC, effective 7/10/2012]

As initially discussed in detail regarding the revisions to 20.6.4.108 NMAC, the same CWA and federal regulatory requirements are applicable here. The history of the NMED's prior recommendations and the revisions adopted by the Commission in its 2005 and 2017 rulemakings are also pertinent to the current 2020 triennial revisions for the nonperennial waters currently defined in classified regulatory segment 20.6.4.209 NMAC.

As part its 2020 triennial review, the NMED identified nonperennial reaches of tributaries in classified perennial waters defined in regulatory segments that were not revised in prior Commission rulemakings. In the previously referenced UAA, the NMED evaluated attainment of the aquatic life, fish culture and water supply, domestic water supply, and irrigation uses in regulatory segments that were not amended in prior Commission revisions. The NMED utilized NHD data to determine the highest attainable use for nonperennial reaches of tributaries to regulatory segments including 20.6.4.209 NMAC. The NHD evaluation confirmed the presence of intermittent waters where natural low-flow, intermittent or ephemeral conditions that prevent attainment of the high quality coldwater aquatic life and fish culture uses in nonperennial tributaries to the Rio Bonito and the Rio Ruidoso as currently defined in 20.6.4.209 NMAC. The NHD evaluation confirmed the presence of intermittent waters where natural low-flow, intermittent or ephemeral conditions that prevent attainment of the designated uses in classified waters currently defined in 20.6.4.209 NMAC. The nonperennial tributaries in 20.6.4.209 NMAC are not capable of supporting the coldwater aquatic life and fish culture uses. The highest attainable use supported in these nonperennial waters include marginal warmwater aquatic life and primary contact recreation.

EPA Determination: *The EPA has determined that the data in the NMED UAA supports the conclusion that natural intermittent conditions prevent attainment of the designated coldwater aquatic life uses that currently apply to the nonperennial tributaries to the Rio Bonito upstream of state highway 48 (near Angus, NM) and nonperennial tributaries to the Rio Ruidoso upstream of the U.S. highway 70 bridge near Seeping Springs lakes, above and below the Mescalero Apache boundary as currently defined in 20.6.4.209 NMAC. The revisions to this regulatory segment are consistent with the federal regulation at 40 CFR § 131.10(g)(2). Given the supporting data and the lack of evidence that establishes the currently defined coldwater use as an attainable or existing use in these nonperennial tributaries, the revisions redefining intermittent waters currently in 20.6.4.209 NMAC to 20.6.4.98 NMAC, which have the effect of changing the designation for the nonperennial tributaries for these waters from coldwater to marginal warmwater while maintaining the primary contact recreation use, are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.215 PECOS RIVER BASIN: Perennial reaches of the Gallinas river upstream of the diversion for the Las Vegas municipal reservoir, [~~and all its~~] perennial reaches of tributaries to the Gallinas river upstream of the diversion for the Las Vegas municipal reservoir, perennial reaches of Tecolote creek upstream of Blue creek[~~,~~] and all perennial reaches of tributaries [~~of~~]to Tecolote creek upstream of Blue creek.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, industrial water supply and primary contact; and public water supply on the Gallinas river.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are

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applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less (450 µS/cm or less in Wright Canyon creek); the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.215 NMAC - Rp 20 NMAC 6.1.2212, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 2/13/2018; A, 4/23/2022]
[**NOTE:** This segment was divided effective 2/13/2018. The standards for Tecolote creek from I-25 to Blue creek are under 20.6.4.230 NMAC.]

As initially discussed in detail regarding the revisions to 20.6.4.108 NMAC, the same CWA and federal regulatory requirements are applicable here. The history of the NMED's prior recommendations and the revisions adopted by the Commission in its 2005 and 2017 rulemakings are also pertinent to the current 2020 triennial revisions for the nonperennial waters currently defined in classified regulatory segment 20.6.4.215 NMAC.

As part its 2020 triennial review, the NMED identified nonperennial reaches of tributaries in classified perennial waters defined in regulatory segments that were not revised in prior Commission rulemakings. In the previously referenced UAA, the NMED evaluated attainment of the aquatic life, fish culture and water supply, domestic water supply, and irrigation uses in regulatory segments that were not amended in prior Commission revisions. The NMED utilized NHD data to determine the highest attainable use for nonperennial reaches of tributaries to regulatory segments including 20.6.4.215 NMAC. The NHD evaluation confirmed the presence of intermittent waters where natural low-flow, intermittent or ephemeral conditions that prevent attainment of the high quality coldwater aquatic life and fish culture uses in nonperennial tributaries to the Gallinas River as currently defined in 20.6.4.215 NMAC. The NHD evaluation confirmed the presence of intermittent waters where natural low-flow, intermittent or ephemeral conditions that prevent attainment of the coldwater designated use in classified waters currently defined in 20.6.4.215 NMAC. The nonperennial tributaries in 20.6.4.215 NMAC are not capable of supporting the coldwater aquatic life and fish culture uses. The highest attainable use supported in these nonperennial waters include marginal warmwater aquatic life and primary contact recreation.

EPA Determination: *The EPA has determined that the data in the NMED's UAA supports the conclusion that natural intermittent conditions prevent attainment of the coldwater designated aquatic life use that currently applies to the nonperennial tributaries to the Gallinas River upstream of the diversion for the Las Vegas municipal reservoir as currently defined in 20.6.4.215 NMAC. The revisions to this regulatory segment are consistent with the federal regulation at 40 CFR § 131.10(g)(2). Given the supporting data and the lack of evidence that establishes the currently defined uses as attainable or existing uses in these nonperennial tributaries, the revisions redefining intermittent waters currently in 20.6.4.215 NMAC to 20.6.4.98 NMAC, which have the effect of downgrading the aquatic life use from coldwater to marginal warmwater while maintaining primary contact recreation, are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.220 PECOS RIVER BASIN: Perennial reaches of the Gallinas river and [~~its~~] perennial reaches of tributaries to the Gallinas river from its mouth upstream to the diversion for the Las Vegas municipal reservoir, except Pecos Arroyo.

A. Designated uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life use and primary contact.

B. Criteria: the use-specific criteria set forth in 20.6.4.900 NMAC are applicable to the designated use, exept that the following segment specific criterion applies; temperature 30°C (86°F) or less.
[20.6.4.220 NMAC - N, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

As initially discussed in detail regarding the revisions to 20.6.4.108 NMAC, the same CWA and federal regulatory requirements are applicable here. The history of the NMED's prior recommendations and the revisions adopted by the Commission in its 2005 and 2017 rulemakings are also pertinent to the current 2020 triennial revisions for the nonperennial waters currently defined in classified regulatory segment 20.6.4.220 NMAC.

As part its 2020 triennial review, the NMED identified nonperennial reaches of tributaries in classified perennial waters defined in regulatory segments that were not revised in prior Commission rulemakings. In the previously referenced UAA, the NMED evaluated attainment of the aquatic life, fish culture and water supply, domestic water supply, and irrigation uses in regulatory segments that were not amended in prior Commission revisions. The NMED utilized NHD data to determine the highest attainable use for nonperennial reaches of tributaries to regulatory segments including 20.6.4.220 NMAC. The NHD evaluation confirmed the presence of intermittent waters where natural low-flow, intermittent or ephemeral conditions that prevent attainment of the marginal coldwater aquatic life use in nonperennial tributaries to the Gallinas River as currently defined in 20.6.4.220 NMAC. The NHD evaluation confirmed the presence of intermittent waters where natural low-flow, intermittent or ephemeral conditions that prevent attainment of the designated uses in classified waters currently defined in 20.6.4.220 NMAC. The nonperennial tributaries in 20.6.4.220 NMAC are not capable of supporting the marginal coldwater aquatic life use. The highest attainable uses in these waters include marginal warmwater aquatic life and primary contact recreation.

EPA Determination: *The EPA has determined that the data in the NMED UAA supports the conclusion that natural intermittent conditions prevent attainment of the designated marginal coldwater aquatic life uses that currently apply to the nonperennial tributaries to the Gallinas River from its mouth upstream to the diversion for the Las Vegas municipal reservoir as currently defined in 20.6.4.220 NMAC. The revisions to this regulatory segment are consistent with the federal regulation at 40 CFR § 131.10(g)(2). Given the supporting data and the lack of evidence that establishes the currently defined uses as attainable or existing uses in these nonperennial tributaries, the revisions redefining intermittent waters currently in 20.6.4.220 NMAC to 20.6.4.98 NMAC, which have the effect of downgrading the aquatic life use from coldwater to marginal warmwater while maintaining primary contact recreation, are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.231 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, perennial reaches of North Spring river and perennial reaches of the Rio Hondo downstream of Bonney canyon.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or

less and chloride 6,000 mg/L or less.
[20.6.4.231 NMAC - N, 4/23/2022]

As indicated in the discussion for regulatory segment 20.6.4.103 NMAC, the NMED's reviewed classified waters within 20.6.4.101 through 899 NMAC and found that some regulatory segments were not amended consistent with the Commission's prior revisions, leaving some with language that applied perennial designated uses to nonperennial waters.

To address this, as part of the recent 2020 triennial review, the NMED developed the previously referenced EUA that focuses on classified waters that are designated for secondary contact recreation to determine if there is evidence that primary contact recreation is attainable or the existing use in these waters. The data indicated that there are waters currently defined within regulatory segment within 20.6.4.206 NMAC that are capable of supporting the primary contact recreation use. The NMED recommended that a new regulatory segment be drawn from these waters contained in the AUs for the Pecos River (Rio Felix to Rio Hondo), Pecos River (Brantley Reservoir to Rio Penasco), Pecos River (Rio Penasco to Eagle Creek), Pecos River (Eagle Creek to Rio Felix), Rio Penasco (Perennial part Pecos River to HWY 24), Pecos River (Rio Hondo to Salt Creek), North Spring River (Rio Hondo to headwaters), Rio Hondo (Perennial prt North Spring River to Bonney Cyn), the Rio Hondo (Perennial part Pecos River to North Spring River) and the perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon,

EPA Determination: *The EPA has determined that the data in the NMED's EUA supports the conclusion that in the absence of specific data that primary contact recreation use is an attainable or existing use in Rio Felix (Perennial reaches Pecos River to headwaters) and perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon that these waters should retain the secondary contact recreation use and remain in 20.6.4.206 NMAC. The EPA has also determined that the supporting data indicate that primary contact recreation is an attainable or existing use in the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme. NM), the perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, NM, the perennial reaches of North Spring River and perennial reaches of the Rio Hondo downstream of Bonney canyon.*

Establishing the new regulatory segment 20.6.4.231 NMAC and the designation of the primary contact recreation use for those waters defined in this regulatory segment is consistent with the CWA and federal regulations. The revisions to this provision are approved pursuant to CWA § 303(c) and are effective for CWA purposes.

20.6.4. Canadian River Basin

20.6.4.307 CANADIAN RIVER BASIN: Perennial reaches of the Mora river from the USGS gaging station near Shoemaker upstream to the state highway 434 bridge in Mora, all perennial reaches of tributaries to the Mora river downstream from the USGS gaging station at La Cueva in San Miguel and Mora counties except lakes identified in 20.6.4.313 NMAC, perennial reaches of Ocate creek downstream of Ocate, [~~and its~~] perennial reaches of tributaries to Ocate creek downstream of Ocate, and perennial reaches of Rayado creek downstream of Miami lake diversion in Colfax county.

A. Designated uses: marginal coldwater aquatic life, warmwater aquatic life, primary contact, irrigation, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC

are applicable to the designated uses.
[20.6.4.307 NMAC - Rp 20 NMAC 6.1.2305.3, 10/12/2000; A, 5/23/2005; A, 2/1/2010; 7/10/2012; A, 4/23/2022]

As initially discussed in detail regarding the revisions to 20.6.4.108 NMAC, the same CWA and federal regulatory requirements are applicable here. The history of the NMED's prior recommendations and the revisions adopted by the Commission in its 2005 and 2017 rulemakings are also pertinent to the current 2020 triennial revisions for the nonperennial waters currently defined in classified regulatory segment 20.6.4.220 NMAC.

As part its 2020 triennial review, the NMED identified nonperennial reaches of tributaries in classified perennial waters defined in regulatory segments that were not revised in prior Commission rulemakings. In the previously referenced UAA, the NMED evaluated attainment of the aquatic life, fish culture and water supply, domestic water supply, and irrigation uses in regulatory segments that were not amended in prior Commission revisions. The NMED utilized NHD data to determine the highest attainable use for nonperennial reaches of tributaries to regulatory segments including 20.6.4.307 NMAC. The NHD evaluation confirmed the presence of intermittent waters where natural low-flow, intermittent or ephemeral conditions that prevent attainment of the marginal coldwater aquatic life use in the nonperennial tributaries to Ocate Creek downstream of Ocate as currently defined in 20.6.4.307 NMAC. The highest attainable use supported in these nonperennial waters include marginal warmwater aquatic life and primary contact recreation.

EPA Determination: *The EPA has determined that the data in the NMED's UAA supports the conclusion that natural intermittent conditions prevent attainment of the designated marginal coldwater aquatic life uses that currently apply to the nonperennial reaches of Ocate creek downstream of Ocate as currently defined in 20.6.4.307 NMAC. The revisions to this regulatory segment are consistent with the federal regulation at 40 CFR § 131.10(g)(2). Given the supporting data and the lack of evidence establishing the currently defined uses as attainable or existing uses in these nonperennial tributaries, the revisions redefining intermittent waters currently in 20.6.4.307 NMAC to 20.6.4.98 NMAC are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.309 CANADIAN RIVER BASIN: The Mora river and perennial reaches of its tributaries upstream from the state highway 434 bridge in Mora except lakes identified in 20.6.4.313 NMAC, all perennial reaches of tributaries to the Mora river upstream from the USGS gaging station at La Cueva, perennial reaches of Coyote creek, [~~and its~~] perennial reaches of tributaries to Coyote creek, the Cimarron river above state highway 21 in Cimarron, [~~and its~~] perennial reaches of tributaries to the Cimarron river above state highway 21 in Cimarron except Eagle Nest lake, all perennial reaches of tributaries to the Cimarron river north and northwest of highway 64 except north and south Shuree ponds, perennial reaches of Rayado creek above Miami lake diversion, [~~and its~~] perennial reaches of tributaries to Rayado creek above Miami lake diversion, Ocate creek and perennial reaches of its tributaries upstream of Ocate, perennial reaches of the Vermejo river upstream from Rail canyon and all other perennial reaches of tributaries to the Canadian river northwest and north of U.S. highway 64 in Colfax county unless included in other segments.

A. Designated uses: domestic water supply, irrigation, high quality coldwater aquatic life, livestock watering, wildlife habitat, and primary contact; and public water supply on the Cimarron river upstream from Cimarron, [~~and~~] on perennial reaches of Rayado creek and on perennial reaches of [~~its~~] tributaries to Rayado creek.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are

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applicable to the designated uses, except that the following segment-specific criteria apply, specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.309 NMAC - Rp 20 NMAC 6.1.2306, 10/12/2000; A, 7/19/2001; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012; A, 4/23/2022]
[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.310 NMAC. The standards for Shuree ponds are in 20.6.4.314 NMAC and the standards for Eagle Nest lake are in 20.6.4.315 NMAC, effective 7/10/2012]

As initially discussed in detail regarding the revisions to 20.6.4.108 NMAC, the same CWA and federal regulation requirements are applicable here. The history of the NMED's prior recommendations and the revisions adopted by the Commission in its 2005 and 2017 rulemakings are also pertinent to the current 2020 triennial revisions for the nonperennial waters currently defined in classified regulatory segment 20.6.4.309 NMAC.

As part its 2020 triennial review, the NMED identified nonperennial reaches of tributaries in classified perennial waters defined in regulatory segments that were not revised in prior Commission rulemakings. In the previously referenced UAA, the NMED evaluated attainment of the aquatic life, fish culture and water supply, domestic water supply, and irrigation uses in regulatory segments that were not amended in prior Commission revisions. The NMED utilized NHD data to determine the highest attainable use for nonperennial reaches of tributaries to regulatory segments including 20.6.4.309 NMAC. The NHD evaluation confirmed the presence of intermittent waters where natural low-flow, intermittent or ephemeral conditions that prevent attainment of the marginal coldwater aquatic life use in the nonperennial tributaries to Coyote Creek and Rayado Creek above Miami lake diversion as currently defined in 20.6.4.309 NMAC. The highest attainable use supported in these nonperennial waters include marginal warmwater aquatic life and primary contact recreation.

EPA Determination: *The EPA has determined that the data in the NMED's UAA supports the conclusion that natural intermittent conditions prevent attainment of the designated marginal coldwater aquatic life uses that currently apply to the nonperennial reaches of Ocate creek downstream of Ocate as currently defined in 20.6.4.309 NMAC. The revisions to this regulatory segment are consistent with the federal regulation at 40 CFR § 131.10(g)(2). Given the supporting data and the lack of evidence establishing the currently defined uses as attainable or existing uses in these nonperennial tributaries, the revisions redefining intermittent waters currently in 20.6.4.309 NMAC to 20.6.4.98 NMAC are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.311 **CANADIAN RIVER BASIN:** Lake Alice.
A. Designated uses: marginal coldwater aquatic life, irrigation, livestock watering, wildlife habitat, primary contact and public water supply.
B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
[20.6.4.311 NMAC - N, 12/1/2010; A, 4/23/2022]

20.6.4.312 **CANADIAN RIVER BASIN: Lake Maloya.**
A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat, primary contact and public water supply.
B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are

applicable to the designated uses.

[20.6.4.312 NMAC - N, 12/1/2010; A, 4/23/2022]

EPA Determination: *The revisions adding revision dates to both 20.6.4.311 and 312 NMAC are nonsubstantive and are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.318 CANADIAN RIVER BASIN: Doggett creek.

A. Designated uses: Warm water aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following site specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

C. Discharger-specific temporary standard:

(1) Discharger: City of Raton wastewater treatment plant

(2) NPDES permit number: NM0020273, Outfall 001

(3) Receiving waterbody: Doggett creek, 20.6.4.318 NMAC

(4) Discharge latitude/longitude: 36° 52' 13.91" N / 104° 25' 39.18" W

(5) Pollutant(s): nutrients; total nitrogen and total phosphorus

(6) Factor of issuance: substantial and widespread economic and social impacts (40 CFR 131.10(g)(6))

(7) Highest attainable condition: interim effluent condition of 8.0 mg/L total nitrogen and 1.6 mg/L total phosphorus as 30-day averages. The highest attainable condition shall be either the highest attainable condition identified at the time of the adoption, or any higher attainable condition later identified during any reevaluation, whichever is more stringent (40 CFR 131.14(b)(1)(iii)).

(8) Effective date of temporary standard: This temporary standard becomes effective for Clean Water Act purposes on the date of EPA approval.

(9) Expiration date of temporary standard: no later than 20 years from the effective date.

(10) Reevaluation period: at each succeeding review of water quality standards and at least once every five years from the effective date of the temporary standard (Paragraph (8) of Subsection H of 20.6.4.10[~~.F (8)~~] NMAC, 40 CFR 131.14(b)(1)(v)). If the discharger cannot demonstrate that sufficient progress has been made the commission may revoke approval of the temporary standard or provide additional conditions to the approval of the temporary standard. If the reevaluation is not completed at the frequency specified or the Department does not submit the reevaluation to EPA within 30 days of completion, the underlying designated use and criterion will be the applicable water quality standard for Clean Water Act purposes until the Department completes and submits the reevaluation to EPA. Public input on the reevaluation will be invited during NPDES permit renewals or triennial reviews, as applicable, in accordance with the State's most current approved water quality management plan and continuing planning process.

(11) Timeline for proposed actions. Tasks and target completion dates are listed in the most recent, WQCC-approved version of the New Mexico Environment Department, Surface Water Quality Bureau's "Nutrient Temporary Standards for City of Raton Wastewater Treatment Plant, NPDES No. NM0020273 to Doggett Creek."

[20.6.4.318 NMAC - N, 05/22/2020; A, 4/23/2022]

EPA Determination: *The revisions to 20.6.4.318 NMAC updating references in 20.6.4.10 NMAC to reflect the renumbering of subsections are nonsubstantive. These revisions are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4. San Juan River Basin

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20.6.4.405 SAN JUAN RIVER BASIN: The main stem of the San Juan river from [~~Canyon~~] Cañon Largo upstream to the Navajo dam.

A. Designated uses: high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply, industrial water supply and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 400 µS/cm or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.405 NMAC - Rp 20 NMAC 6.1.2405, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

20.6.4.408 SAN JUAN RIVER BASIN: The main stem of the San Juan river from its confluence with the Animas river upstream to its confluence with [~~Canyon~~] Cañon Largo.

A. Designated uses: public water supply, industrial water supply, irrigation, livestock watering, wildlife habitat, primary contact, marginal coldwater aquatic life and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 32.2°C (90°F) or less.

[20.6.4.408 NMAC - N, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

EPA Determination: *The revisions to both 20.6.4.405 and 408 NMAC are nonsubstantive. These revisions are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

20.6.4.900 Criteria Applicable to Existing or Attainable Uses

20.6.4.900 CRITERIA APPLICABLE TO EXISTING, DESIGNATED OR ATTAINABLE USES UNLESS OTHERWISE SPECIFIED IN 20.6.4.97 THROUGH 20.6.4.899 NMAC:

D. Primary contact: The monthly geometric mean of E. coli bacteria of 126 cfu/100 mL or MPN/100 ml, [~~and~~] a single sample of E. coli bacteria of 410 cfu/100 mL or MPN/100 mL, a single sample of total microcystins of 8 µg/L with no more than three exceedances within a 12-month period and a single sample of cylindrospermopsin of 15 µg/L with no more than three exceedances within a 12-month period, and pH within the range of 6.6 to 9.0 apply to this use. The results for *E. coli* may be reported as either colony forming units (CFU) or the most probable number (MPN) depending on the analytical method used.

EPA Determination: *The revisions to 20.6.4.900(D) includes clarifying language on the application of E. coli bacteria and the inclusion of criteria for microcystin and cylindropermopsin at a magnitude, duration and frequency consistent with EPA recommendations.[9] The revisions, including the addition of microcystin and cylindropermopsin criteria are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

H. Aquatic life:

6) Marginal warmwater: dissolved oxygen 5 mg/L or more, pH within the range of 6.6 to 9.0 and [~~maximum temperature~~] temperatures that may routinely exceed 32.2°C (90°F). Where a segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature.

[9] U.S. Environmental Protection Agency (2019). Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin (EPA 822-R-19-001)

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***EPA Determination*:** *The NMED proposed, and the Commission has adopted clarifying language specific to the marginal warmwater aquatic life designated use in 20.6.4.900(H)(6) NMAC to be consistent with the definition in 20.6.4.7(M)(2) NMAC. The revised language is intended to address the disparity between the marginal warmwater criteria represented as a maximum temperature of 32.2°C, and definition, which states that "…water temperature routinely exceeds 32.2°C (90°F)," which created a conflict in how the appropriate water quality criteria for marginal warmwater aquatic life uses were applied. The EPA recognizes that this discrepancy has resulted in a significant number of waters with a designated marginal warmwater aquatic life use being placed on New Mexico's CWA § 303(d) list as impaired for temperature. The EPA has determined that the revisions to the numeric temperature criterion for the marginal warmwater aquatic life use are consistent with the definition and would allow the NMED to assess these waters appropriately. The revisions to this provision, including the addition of the phrase "…temperature routinely exceed" are approved pursuant to CWA § 303(c) and are effective for CWA purposes.*

I. Hardness-dependent acute and chronic aquatic life criteria for metals are calculated using the following equations. The criteria are expressed as a function of [~~dissolved~~] hardness (as mg $CaCO_3$/L). With the exception of aluminum, the equations are valid only for [~~dissolved~~] hardness concentrations of 0-400 mg/L. For [~~dissolved~~] hardness concentrations above 400 mg/L, the criteria for 400 mg/L apply. For aluminum the equations are valid only for [~~dissolved~~] hardness concentrations of 0-220 mg/L. For [~~dissolved~~] hardness concentrations above 220 mg/L, the aluminum criteria for 220 mg/L apply. Calculated criteria must adhere to the treatment of significant figures and rounding identified in *Standard Methods For The Examination Of Water And Wastewater*, latest edition, American public health association.

(1) Acute aquatic life criteria for metals: The equation to calculate acute criteria in µg/L is $\exp(m_A[\ln(\text{hardness})] + b_A)$ (CF). Except for aluminum, the criteria are based on analysis of dissolved metal. For aluminum, the criteria are based on analysis of total recoverable aluminum in a sample that has a pH between 6.5 and 9.0 and is filtered to minimize mineral phases as specified by the department. [~~The EPA has disapproved the hardness-based equation for total recoverable aluminum in waters where the pH is less than 6.5 in the receiving stream for federal purposes of the Clean Water Act.~~] The equation parameters are as follows:

(2) Chronic aquatic life criteria for metals: The equation to calculate chronic criteria in µg/L is $\exp(m_C[\ln(\text{hardness})] + b_C)(CF)$**.** Except for aluminum, the criteria are based on analysis of dissolved metal. For aluminum, the criteria are based on analysis of total recoverable aluminum in a sample that has a pH between 6.5 and 9.0 and is filtered to minimize mineral phases as specified by the department.[~~The EPA has disapproved the hardness-based equation for total recoverable aluminum in waters where the pH is less than 6.5 in the receiving stream for federal purposes of the Clean Water Act.~~] The equation parameters are as follows:

***EPA Determination*:** *The NMED proposed, and the Commission adopted a definition of the term "hardness" to clarify the term and provide consistency when implementing New Mexico's hardness-based metals criteria for the protection of aquatic life at 20.6.4.900(I) NMAC. As described in the discussion of 20.6.4.12(F) NMAC in the Commission's SOR, the SJWC recommended removing the word "dissolved" before "hardness" in 20.6.4.12(F) NMAC and 20.6.4.900(I) NMAC, so that it aligned with the new definition of "hardness," and to eliminate redundancy and clarify the term. The Commission agreed and approved striking the word "dissolved" in 20.6.4.900(I) NMAC. These revisions do not alter or establish any new processes and would not change the implementation of the aluminum criteria. In addition, the reference to*

the latest edition of Standard Methods For The Examination Of Water And Wastewater[10] is consistent with 20.6.4.14(A)(2) NMAC. The deletion of the word "dissolved" throughout this provision and the reference to the Standard Methods are approved pursuant to CWA § 303(c) and revised language is effective for CWA purposes.

In its April 2012, action, the EPA disapproved the application of the hardness-based equation in 20.6.4.900(I)(1) and (2) for waters where the pH is below 6.5 as not protective of applicable designated uses. The EPA published updated §304(a) criteria for aluminum for freshwater (Aquatic Life Ambient Water Quality Criteria for Aluminum - 2018, EPA-822-R-18-001). The updated aluminum criteria are based on the latest science on aluminum toxicity to aquatic life and apply to waters within a pH range of 5.0 – 10.5. Although the EPA recommends that states update their aluminum criteria for waters within this pH range based on the updated §304(a) aluminum criteria, the EPA also recognizes that the conditions in New Mexico waters can be highly variable with pH levels as low as 3 standard units (SU). As a result, the EPA considers it protective to retain and continue to apply the 750 and 87 µg/L aluminium criteria as the applicable water quality standards for CWA purposes in waters where the pH is at or below 6.5. The revised language here and in 20.6.4.900(J)(1) clarifies that the previously approved 750 and 87 µg/L 304(a) criteria for aluminum will remain as the applicable criteria. See section 20.6.4.900(I)(3) NMAC below. These revisions are approved pursuant to CWA § 303(c) and are effective for CWA purposes.

In that 2012 action, the EPA also recommended that the State insert a footnote specifying that the hardness-based equations only apply at a pH of 6.5 to 9.0 to resolve the prior disapproval. The current revisions mean that the language referencing the EPA's partial disapproval of the hardness-based aluminum criteria as stated in 20.6.4.900(I)(1) and 20.6.4.900(I)(2) NMAC are no longer necessary and striking this language is appropriate.

(3) Selected values of calculated acute and chronic criteria (µg/L).

Hardness as $CaCO_3$, dissolved (mg/L)		**Al**	**Cd**	**Cr III**	**Cu**	**Pb**	**Mn**	**Ni**	**Ag**	**Zn**
[~~25~~] 25.0	Acute	512	[~~0.51~~] 0.490	[~~180~~] 183	[~~4~~] 3.64	[~~14~~] 13.9	[~~1,881~~] 1,880	[~~140~~] 145	[~~0.3~~] 0.30	[~~45~~] 45.4
	Chronic	205	[~~0.17~~] 0.253	[~~24~~] 23.8	[~~3~~] 2.74	[~~1~~] 0.541	1,040	[~~16~~] 16.1		[~~34~~] 34.4
[~~30~~] 30.0	Acute	658	[~~0.59~~] 0.581	[~~210~~] 212	[~~4~~] 4.32	[~~17~~] 17.0	[~~1,999~~] 2,000	[~~170~~] 169	[~~0.4~~] 0.40	[~~54~~] 53.5
	Chronic	263	[~~0.19~~] 0.290	[~~28~~] 27.6	[~~3~~] 3.20	[~~1~~] 0.664	[~~1,105~~] 1,100	[~~19~~] 18.8		[~~41~~] 40.5
[~~40~~] 40.0	Acute	975	[~~0.76~~] 0.761	[~~270~~] 269	[~~6~~] 5.67	[~~24~~] 23.5	2,200	[~~220~~] 16	[~~0.7~~] 0.66	[~~70~~] 69.5
	Chronic	391	[~~0.23~~] 0.360	[~~35~~] 35.0	[~~4~~] 4.09	[~~1~~] 0.916	[~~1,216~~] 1,220	[~~24~~] 24.0		[~~53~~] 52.7
[~~50~~] 50.0	Acute	[~~1,324~~] 1,320	[~~0.91~~] 0.938	[~~320~~] 323	[~~7~~] 6.99	[~~30~~] 30.1	2,370	260	[~~1.0~~] 0.98	[~~85~~] 85.2

[10] Baird, R. & Bridgewater, I. (2017). Standards methods for the examination of water and wastewater. 23rd edition. Washington, D.C., American Public Health Association.

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	Chronic	530	[~~0.28~~] 0.426	[~~42~~] 42.0	[~~5~~] 4.95	[~~1~~] 1.17	[~~1,309~~] 1,310	[~~29~~] 28.9		[~~65~~] 64.5
[~~60~~] 60.0	Acute	[~~1,699~~] 1,700	[~~1.07~~] 1.11	[~~370~~] 375	[~~8~~] 8.30	[~~37~~] 36.9	[~~2,519~~] 2,520	[~~300~~] 304	1.3	[~~101~~] 100
	Chronic	681	[~~0.31~~] 0.489	[~~49~~] 48.8	[~~6~~] 5.79	[~~1~~] 1.44	[~~1,391~~] 1,390	[~~34~~] 33.8		[~~76~~] 76.2
[~~70~~] 70.0	Acute	[~~2,099~~] 2,100	[~~1.22~~] 1.28	[~~430~~] 425	[~~10~~] 9.60	[~~44~~] 43.7	[~~2,651~~] 2,650	[~~350~~] 346	1.7	116
	Chronic	841	[~~0.35~~] 0.549	[~~55~~] 55.3	[~~7~~] 6.60	[~~2~~] 1.70	[~~1,465~~] 1,460	[~~38~~] 38.5		[~~88~~] 87.6
[~~80~~] 80.0	Acute	2,520	[~~1.37~~] 1.46	[~~470~~] 474	[~~11~~] 10.9	[~~51~~] 50.6	[~~2,772~~] 2,770	[~~390~~] 388	2.2	131
	Chronic	1,010	[~~0.39~~] 0.607	[~~62~~] 61.7	[~~7~~] 7.40	[~~2~~] 1.97	[~~1,531~~] 1,530	[~~43~~] ~~43.0~~		[~~99~~] 98.9
[~~90~~] 90.0	Acute	[~~2,961~~] 2,960	[~~1.51~~] 1.62	[~~520~~] 523	[~~12~~] 12.2	[~~58~~] 57.6	[~~2,883~~] 2,880	[~~430~~] 428	2.7	145
	Chronic	[~~1,186~~] 1,190	[~~0.42~~] 0.664	[~~68~~] 68.0	[~~8~~] 8.18	[~~2~~] 2.24	[~~1,593~~] 1,590	[~~48~~] 47.6		110
100	Acute	[~~3,421~~] 3,420	[~~1.65~~] 1.79	570	[~~13~~] 13.4	[~~65~~] 64.6	[~~2,986~~] 2,980	[~~470~~] 468	3.2	160
	Chronic	1,370	[~~0.45~~] 0.718	[~~74~~] 74.1	[~~9~~] 8.96	[~~3~~] 2.52	1,650	[~~52~~] 52.0		121
200	Acute	[~~8,838~~] 8,840	[~~2.98~~] 3.43	[~~1,010~~] 1,000	[~~26~~] 25.8	[~~140~~] 136	[~~3,761~~] 3,760	[~~840~~] 842	[~~11~~] 10	[~~301~~] 300
	Chronic	[~~3,541~~] 3,540	[~~0.75~~] 1.21	[~~130~~] 131	[~~16~~] 16.2	[~~5~~] 5.30	[~~2,078~~] 2,080	[~~90~~] 93.5		228
220	Acute	[~~10,071~~] 10,100	[~~3.23~~] 3.74	[~~1,087~~] 1,090	[~~28~~] 28.2	151	[~~3,882~~] 3,880	912	[~~13~~] 12	328
	Chronic	[~~4,035~~] 4,030	[~~0.80~~] 1.30	141	[~~18~~] 17.6	[~~6~~] 5.87	[~~2,145~~] 2,140	101		248
300	Acute		[~~4.21~~] 5.00	1,400	[~~38~~] 37.8	[~~210~~] 208	[~~4,305~~] 4,300	[~~1190~~] 1,190	21	[~~435~~] 434
	Chronic		[~~1.00~~] 1.64	[~~180~~] 182	[~~23~~] 22.9	[~~8~~] 8.13	[~~2,379~~] 2,380	[~~130~~] 132		329
400 and above	Acute		[~~5.38~~] 6.54	1,770	[~~50~~] 49.6	[~~280~~] 281	[~~4,738~~] 4,740	[~~1510~~] 1,510	35	564
	Chronic		[~~1.22~~] 2.03	[~~230~~] 231	[~~29~~] 29.3	[~~11~~] 10.9	[~~2,618~~] 2,620	[~~170~~] 168		428

EPA Determination: *The revisions to the table in 20.6.4.900(I)(3) NMAC represent the EPA's national recommended aquatic life water quality criteria for metals, or in some cases, criteria developed by the NMED. The criteria for hardness-based metals are specific to the water hardness (expressed as $CaCO_3$) at the time of sample collection, accounting for the potential for variations in hardness over time resulting in fluctuations in metals criteria. As part of its 2020 triennial review, the NMED verified the calculations for the hardness-based criteria values for mathematical accuracy. These revisions include the EPA's 2016 update to recommended acute and chronic hardness-based aquatic life criteria for cadmium that represent increased bioavailabity over New Mexico's current criteria. Based on this analysis and recalculations, the NMED proposed, and the Commission adopted the revised acute and chronic hardness-based metals criteria in this table depicting the graduating hardness levels of these metals criteria as a reference. The revisions to the selected values for aluminum, chromium III, copper, lead,*

manganese, nickel, silver and zinc in this table are approved as nonsubstantive revisions pursuant to CWA § 303(c) and are effective for CWA purposes.

*The EPA approval of aquatic life criteria is subject to consultation pursuant to Section 7(a)(2) of the Endangered Species Act (ESA). The EPA is taking no action on the revised aquatic life criterion for cadmium, pending ESA consultation (**Section III**). The revised criterion for cadmium is not effective for CWA purposes until the EPA concludes consultation with the U.S. Fish and Wildlife Service (Service). See **Section V** for additional information regarding the completion of the ESA consultation.*

J. Use-specific numeric criteria.

(1) Table of numeric criteria: The following table sets forth then numeric criteria applicable to existing, designated and attainable uses. For metals, criteria represent the total sample fraction unless otherwise specified in the table. Additional criteria that are not compatible with this table are found in Subsections A through I, K and L of this section.

NOTE; This is not a compete table but only includes revisions to the use-specific criteria table for brevity:

Pollutant	**CAS Number**	**DWS**	**Irr/Irr storage**	**LW**	**WH**	**Aquatic Life**			**Type**
						Acute	Chronic	HH-OO	
Aluminum, dissolved	7429-90-5		5,000			750 i	87 i		
Chloride	1688-70-06					860,000	230,000		
Iron	7439-89-6						1,000		
Acenaphthene	83-32-9	2,100						[~~990~~] 90	
Acrolein	107-02-8	18				3.0	3.0	[~~9~~] 400	
Acrylonitrile	107-13-1	0.65						[~~2.5~~] 70	C
Aldrin	309-00-2	0.021				3.0		[~~0.00050~~] 0.0000077	C,P
Anthracene	120-12-7	10,500						[~~40,000~~] 400	
Benzene	71-43-2	5						[~~510~~] 160	C
Benzidine	92-87-5	0.0015						[~~0.0020~~] 0.11	C
Benzo(a)anthracene	56-55-3	0.048						[~~0.18~~] 0.013	C
Benzo(a)pyrene	50-32-8	0.2						[~~0.18~~] 0.0013	C,P
Benzo(b)fluoranthene	205-99-2	0.048						[~~0.18~~] 0.0013	C
Benzo(k)fluoranthene	207-08-9	0.048						[~~0.18~~] 0.13	C
alpha-BHC	319-84-6	0.056						[~~0.049~~] 0.0039	C
beta-BHC	319-85-7	0.091						[~~0.17~~] 0.14	C
[~~Gamma~~] gamma-BHC (Lindane)	58-89-9	0.20				0.95		[~~1.8~~] 4.4	
Bis(2-chloroethyl) ether	111-44-4	0.30						[~~5.3~~] 22	C
Bis([2-chloroisopropyl] 2-chloro-1-methylethyl) ether	108-60-1	1,400						[~~65,000~~] 4,000	
Bis(2-ethylhexyl) phthalate	117-81-7	6						[~~22~~] 3.7	C
Bis(chloromethyl) ether	542-88-1							0.17	C
Bromoform	75-25-2	44						[~~1,400~~] 1,200	C
Butylbenzyl phthalate	85-68-7	7,000						[~~1,900~~] 1	C
Carbaryl	63-25-2					2.1	2.1		
Carbon tetrachloride	56-23-5							[~~16~~] 50	C
Chlordane	57-74-9	2				2.4	0.0043	[~~0.0081~~] 0.0032	C,P
Chlorobenzene	108-90-7	100						[~~1,600~~] 800	
Chlorodibromomethane	124-48-1	4.2						[~~130~~] 210	C
Chloroform	67-66-3	57						[~~4,700~~] 2,000	[~~C~~]
Chlorpyrifos	2921-88-2					0.083	0.041		
2-Chloronaphthalene	91-58-7	2,800						[~~1,600~~] 1,000	

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2-Chlorophenol	95-57-8	175						[~~150~~] 800	
Chrysene	218-01-9	0.048						[~~0.18~~] 1.3	C
Demeton	8065-48-3						0.1		
Diazinon	333-41-5					0.17	0.17		
2,4-Dichlorophenoxyacetic acid	94-75-7							12,000	
Dichlorodiphenyldichloroethane (DDD)	72-54-8							0.0012	K
Dichlorodiphenyldichloroethylene (DDE)	72-55-9							0.00018	C
Dichlorodiphenyltrichloroethane (DDT)	50-29-3							0.0003	C, P
4,4'-DDT and derivatives		1.0			0.001	1.1	0.001	[~~0.0022~~]	[~~C,P~~]
Dibenzo(a,h)anthracene	53-70-3	0.048						[~~0.18~~] 0.0013	C
Dibutyl phthalate	84-74-2	3,500						[~~4,500~~] 30	
1,2-Dichlorobenzene	95-50-1	600						[~~1,300~~] 3,000	
1,3-Dichlorobenzene	541-73-1	469						[960] 10	
1,4-Dichlorobenzene	106-46-7	75						[190] 900	
3,3'-Dichlorobenzidine	91-94-1	0.78						[~~0.28~~] 1.5	C
Dichlorobromomethane	75-27-4	5.6						[~~170~~] 270	C
1,2-Dichloroethane	107-06-2	5						[~~370~~] 6,500	C
1,1-Dichloroethylene	75-35-4	7						[~~7,100~~] 20,000	[C]
2,4-Dichlorophenol	120-83-2	105						[~~290~~] 60	
1,2-Dichloropropane	78-87-5	5.0						[~~150~~] 310	C
1,3-Dichloropropene	542-75-6	3.5						[~~210~~] 120	C
Dieldrin	60-57-1	0.022				0.24	0.056	[~~0.00054~~] 0.000012	C, P
Diethyl phthalate	84-66-2	28,000						[~~44,000~~] 600	
Dimethyl phthalate	131-11-3	350,000						[1,100,000] 2,000	
2,4-Dimethylphenol	105-67-9	700						[~~850~~] 3,000	
Dinitrophenols	25550-58-7							1,000	
2,4-Dinitrophenol	51-28-5	70						[~~5,300~~] 300	
2,4-Dinitrotoluene	121-14-2	1.1						[~~34~~] 17	C
Dioxin	1746-01-6	3.0E^{-05}						5.1E^{-08}	C, P
1,2-Diphenylhydrazine	122-66-7	0.44						2.0	C
alpha-Endosulfan	959-98-8	62				0.22	0.056	[~~89~~] 30	
beta-Endosulfan	33213-65-9	62				0.22	0.056	[~~89~~] 40	
Endosulfan sulfate	33213-65-9	62						[~~89~~] 40	
Endrin	72-20-8	2				0.086	0.036	[~~0.060~~] 0.03	
Endrin aldehyde	7421-93-4	10.5						[~~0.30~~] 1	
Ethylbenzene	100-41-4	700						[~~2,100~~] 130	
Fluoranthene	206-44-0	1,400						[~~140~~] 20	
Fluorene	86-73-7	1,400						[~~5,300~~] 70	
Guthion	86-50-0						0.01		
Heptachlor	76-44-8	0.40				0.52	0.0038	[~~0.00079~~]0.000059	C
Heptachlor epoxide	1024-57-3	0.20				0.52	0.0038	[~~0.00039~~] 0.00032	C
Hexachlorobenzene	118-74-1	1						[~~0.0029~~] 0.00079	C, P
Hexachlorobutadiene	87-68-3	4.5						[~~180~~] 0.1	
Hexachlorocyclohexane (HCH)-Technical	608-73-1							0.1	C
Hexachlorocyclopen-tadiene	77-47-4	50						[~~1,100~~] 4	
Hexachloroethane	67-72-1	25						[~~33~~] 1	C
Ideno(1,2,3-cd)pyrene	193-39-5	0.048						[~~0.18~~] 0.013	C
Isophorone	78-59-1	368						[~~9,600~~] 18,000	C
Malathion	121-75-5						0.1		
Methoxychlor	72-43-5						0.03	0.02	

Methyl bromide	74-83-9	49						[~~1,500~~] 10,000	
3-Methyl-4-chlorophenol	59-50-7							2,000	
2-Methyl-4,6-dinitrophenol	534-52-1	14						[~~280~~] 30	
Methylene chloride	75-09-2	5						[~~5,900~~] 10,000	C
Mirex	2385-85-5						0.001		
Nitrobenzene	98-95-3	18						[~~690~~] 600	
Nitrosamines	Various							12.4	C
Nitrosodibutylamine	924-16-3							2.2	C
Nitrosodiethylamine	55-18-5							12.4	C
N-Nitrosodimethylamine	62-75-9	0.0069						30	C
N-Nitrosodi-n-propylamine	621-64-7	0.050						5.1	C
N-Nitrosodiphenylamine	86-30-6	71						60	C
N-Nitrosopyrrolidine	930-55-2							340	C
Nonylphenol	84852-15-3					28	6.6		
Parathion	56-38-2					0.065	0.013		
~~[Polychlorinated Biphenyls (PCBs)]~~	~~[1336-36-3]~~	~~[0.50]~~			~~[0.014]~~	~~[2]~~	~~[0.014]~~	~~[0.00064]~~	~~[C,P]~~
Pentachlorobenzene	608-93-5							0.1	
Phenol	108-95-2	10,500						[860,000]300,000	
Polychlorinated Biphenyls (PCBs)	336-36-3	0.50			0.014	2	0.014	0.00064	[C, P]
Pyrene	129-00-0	1,050						[4,000] 30	
1,2,4,5-Tetrachlorobenzene	95-94-3							0.03	
1,1,2,2-Tetrachloroethane	79-34-5	1.8						[~~40~~] 30	C
Tetrachloroethylene	127-18-4	5						[~~33~~] 290	C, P
Toluene	108-88-3	1,000						[15,000] 520	
Toxaphene	8001-35-2	3				0.73	0.0002	[~~0.0028~~] 0.0071	C
1,2-Trans-dichloroethylene	156-60-5	100						[~~10,000~~] 4,000	
Tributyltin (TBT)	Various					0.46	0.072		
1,2,4-Trichlorobenzene	120-82-1	70						[~~70~~] 0.76	C
1,1,1-Trichloroethane	71-55-6	200						200,000	
1,1,2-Trichloroethane	79-00-5	5						[~~160~~] 89	C
Trichloroethylene	79-01-6	5						[300] 70	C
2,4,5-Trichlorophenol	95-95-4							600	
2,4,6-Trichlorophenol	88-06-2	32						[~~24~~] 28	C
2-(2,4,5-Trichlorophenoxy) propionic acid (Silvex)	93-72-1							400	
Vinyl chloride	75-01-4	2						[~~24~~] 16	C

(2) Notes applicable to the table of numeric criteria in Paragraph (1) of this subsection.

(i) The acute and chronic aquatic life criteria for dissolved aluminum only apply when the concurrent pH is less than 6.5 or greater than 9.0 S.U. If the concurrent pH is between 6.5 and 9.0 S.U. then the hardness-dependent total recoverable aluminum criteria in Paragraphs (1) and (2) of Subsection I of 20.6.4.900 NMAC apply.

EPA Determination: *As part of its 2020 triennial review, the NMED proposed, and the Commission adopted revisions adding new criteria and updating acute and chronic criteria for the protection of aquatic life and those based on human consumption of an aquatic organism (human health-organism only). New Mexico continues to adjust criteria for carcinogenic contaminants based on based on a lifetime risk of one cancer per 100,000 exposed persons (see 20.6.4.13(F)(2)(a)) in comparison to the EPA's lifetime risk level of more than one cancer per 1,000,000 exposed persons, consistent with EPA guidance. Revisions also reincorporate the previously approved chronic and acute dissolved aluminum criteria of 87 µg/L and 750 µg/L, respectively related to the EPA's 2012 disapproval. As specified in the note at 20.6.4.900(J)(2)(i)*

NMAC. these criteria are the applicable aluminum criteria for all waters with a pH less than 6.5 SU, outside the applicable range for hardness-based aluminum criteria.

In addition to the proposed changes to the aquatic life criteria described above, the revisions include completion of missing chemical abstract service numbers for several pollutants and nonsubstantive spelling corrections. These revisions are consistent with the EPA's recommended § 304(a) criteria and with language in 40 CFR §131.20(a). The revised human health criteria in 20.6.4.900(J)(1) and notes in (J)(2)(i) NMAC are not subject to ESA consultation and are approved pursuant to CWA § 303(c) and are effective for CWA purposes.

20.6.4.901 PUBLICATION REFERENCES: These documents are intended as guidance and are available for public review during regular business hours at the offices of the surface water quality bureau. Copies of these documents have also been filed with the New Mexico state records center in order to provide greater access to this information.

A. American public health association. 1992. *Standard Methods for The Examination of Water and Wastewater, 18th Edition.* Washington, D.C. 1048 p.

B. American public health association. 1995. *Standard Methods for The Examination of Water and Wastewater, 19th Edition.* Washington, D.C. 1090 p.

C. American public health association. 1998. *Standard Methods for The Examination of Water and Wastewater, 20th Edition.* Washington, D.C. 1112 p.

D. American public health association. 2018. *Standard Methods for The Examination of Water and Wastewater, 23rd Edition.* Washington, D.C. 1796 p.

[~~D.~~] **E.** United States geological survey. [1987] 1989. *Methods For Determination of Inorganic Substances In Water And Fluvial Sediments, Techniques of Water-Resource Investigations of The United States Geological Survey.* Washington, D.C. [80] 545 p.

[~~E.~~] **F.** United States geological survey. 1987. *Methods [~~for the determination of organic substances in water and fluvial sediments, techniques of water-resource investigations of the U.S. Geological survey~~] For The Determination Of Organic Substances In Water And Fluvial Sediments, Techniques Of Water-Resource Investigations Of The United States Geological Survey.* Washington, D.C. 80 p.

[~~F.~~] **G.** United States environmental protection agency. [~~1974~~] 1983. *Methods For Chemical Analysis Of Water And Wastes.* [~~National environmental research center, Cincinnati, Ohio~~] Office of research and development, Washington, DC. [~~(EPA-625-/6-74-003)~~] (EPA/600/4-79/020). [~~298~~] 491 p.

[~~G.~~] **H.** New Mexico water quality control commission. [~~2003~~] 2020. [*(208)*] *State Of New Mexico Water Quality Management Plan and Continuing Planning Process*. Santa Fe, New Mexico. [~~85~~] 277 p.

[~~H.~~] **I.** Colorado river basin salinity control forum. [2014] 2020. [2014] *2020 Review, Water Quality Standards For Salinity, Colorado River System.* Phoenix, Arizona. [99] 97 p.

[~~I.~~] **J.** United States environmental protection agency. 2002. *Methods For Measuring The Acute Toxicity Of Effluents And Receiving Waters To Freshwater And Marine Organisms.* Office of research and development, Washington, D.C. (5th Ed., EPA 821-R-02-012). 293 p. [~~http://www.epa.gov/ostWET/disk2/atx.pdf~~]

[~~J.~~] **K.** United States environmental protection agency. 2002. *Short-Term Methods For Estimating The Chronic Toxicity Of Effluents And Receiving Waters To Freshwater Organisms.* Environmental monitoring systems laboratory, Cincinnati, Ohio. (4th Ed., EPA 821-R-02-013). 335 p.

[~~K.~~] **L.** [~~Ambient-induced mixing, in~~] United States environmental protection agency. 1991. Ambient-induced mixing, in *Technical Support Document For Water Quality-Based Toxics Control*. Office of water, Washington, D.C. (EPA/505/2-90-001). [~~2~~] 335 p.

[~~L.~~] **M.** United States environmental protection agency. 1983. *Technical Support Manual: Waterbody Surveys And Assessments For Conducting Use Attainability Analyses, ~~Volume I~~*:. Office of water, regulations and standards, Washington, D.C. [~~251~~] 232 p.
[~~http://www.epa.gov/OST/library/wqstandards/uaavol123.pdf~~]

[~~M.~~] **N.** United States environmental protection agency. 1984. *Technical Support Manual: Waterbody Surveys And Assessments For Conducting Use Attainability Analyses, Volume* [*Iii*] *III: Lake Systems*. Office of water, regulations and standards, Washington, D.C. 208 p.

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[~~http://www.epa.gov/OST/library/wqstandards/uaavol123.pdf~~]
[20.6.4.901 NMAC - Rp 20 NMAC 6.1.4000, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022]

EPA Determination: *The EPA considers the updates to the publication references important, but they are not considered a water quality standard and not subject to action under CWA § 303(c).*

III. Provisions Where the EPA has or is Taking No Action

In today's action, the EPA is taking no action on the following new or revised provisions in the *New Mexico Standards for Interstate and Intrastate Waters* (20.6.4 NMAC) pursuant to §303(c) of the CWA. The following new or revised provisions where the EPA did not have adequate information to make a determination for action are not effective for CWA purposes until approved by the EPA as specified in 40 CFR 131.21(c).

20.6.4.7 Definitions

20.6.4.7 DEFINITIONS: Terms defined in the New Mexico Water Quality Act, but not defined in this part will have the meaning given in the Water Quality Act.

A. Terms beginning with numerals or the letter "A," and abbreviations for units.
(1) "4Q3" means the critical low flow as determined by the minimum average flow over four consecutive days that occurs with a frequency of once in three years.

As described in Chapter 5 of the EPA's WQS Handbook[11]*, referring to the Technical Support Document for Water Quality Based Controls (1991) and Appendix D of that document, the EPA describes and recommends two methods for calculating acceptable critical low-flow values: the traditional hydrologically based method developed by the United States Geological Survey (USGS) and a biologically based method developed by the EPA.*

The hydrologically based critical low-flow value is determined statistically using probability and extreme values for acute and chronic criteria (1Q10 and 7Q10). The advantage of this method is that it utilizes extreme value analytical techniques (e.g., log-Pearson Type III flow estimating technique) supported by past engineering and statistical practice. The disadvantages of this method are that it is independent of biological considerations, and it cannot easily utilize site-specific durations and frequencies that are sometimes specified in aquatic life criteria. When using hydrologically based critical low-flow values for aquatic life and human health criteria, the EPA recommends that states and tribes adopt the critical low-flow values for use in steady-state analyses so that criteria are implemented appropriately. If criteria are implemented using inappropriate critical low-flow values (i.e., calculated values that are too high), the resulting control of toxic pollutants may not be fully protective because the resulting ambient concentrations could exceed criteria when such low flows occur. In the case of aquatic life, more

[11] U.S. Environmental Protection Agency (EPA). 2017. Water Quality Standards Handbook: 2nd Edition. EPA-823-B-17-001. EPA Office of Water, Office of Science and Technology, Washington, DC. https://www.epa.gov/sites/production/files/2014-10/documents/handbook-chapter3.pdf

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frequent excursions than are allowable (e.g., more than once in three years) could result in unacceptable effects on aquatic organisms and designated uses if the appropriate value is not used in the calculations.

The biologically based critical low flow is determined empirically using the specific duration and frequency associated with the criterion (1B3 and 4B3). The biologically-based design flow is intended to examine the duration and frequency of biological exposure. The method directly uses site-specific durations (i.e., averaging periods) and frequencies specified in the aquatic life criteria (e.g., 1 day and 3 years for CMC and 4 days and 3 years for CCC). This method is empirical, not statistical, because it deals with the actual flow record itself, not with a statistical distribution that is intended to describe the flow record. Since biologically-based design flows are based on durations and frequencies specified in water quality criteria for individual pollutants and whole effluents, they can be based on the available biological, ecological and toxicological information concerning the stresses that aquatic organisms, ecosystems and their uses can tolerate.

The EPA compared hydrologically based design flow method and biologically-based design flow methods, the 1Q10 with the 1B3 and the 7Q10 with the 4B3 in 60 rivers. In most instances, the hydrologically based design flows (i.e., 1Q10, 7Q10) resulted in more than the allowed excursions. In other instances, the 1Q10 and 7Q10 allowed substantially more or fewer excursions than the intended number of excursions. In contrast, since the biologically-based method calculates the design flows directly from the national or site-specific duration and frequency, it always provided the maximum allowed number of excursions (and never provides more or fewer excursions than allowed).
It is unclear if this new definition of 4Q3 in intended as an alternative flow to address streams with limited or no flow at 7Q10. As noted in the WQS Handbook, Chpt.5, when a criterion specifies a four-day average concentration that should not be exceeded more than once every three years, this condition should not be interpreted as implying that a 4Q3 low flow is appropriate for use as the hydrologically based critical low-flow value for assessing impacts on the receiving water.

***EPA Determination*:** *Given that some aspects of this definition make it unclear how a 4Q3 is intended to be used as the hydrologically based critical low-flow value for assessing impacts on low-flow receiving waters, the EPA has determined that it needs additional information before the Agency can take action on this definition. This definition is not effective for CWA purposes until approved by the EPA.*

20.6.4.126 Rio Grande Basin

20.6.4.126 RIO GRANDE BASIN: Perennial waters within lands managed by the U.S. department of energy (DOE) within Los Alamos National Laboratory (LANL), including but not limited to [~~portions of~~] Cañon de Valle from [~~Los Alamos national laboratory (~~]LANL[~~)~~] stream gage E256 upstream to Burning Ground spring, Sandia canyon from Sigma canyon upstream to LANL NPDES outfall 001, Pajarito canyon from 0.5 miles below Arroyo de La Delfe upstream to Homestead spring, Arroyo de la Delfe from Pajarito canyon to Kieling spring, [~~into~~] Starmers gulch and Starmers spring and Water canyon from Area-A canyon upstream to State Route 501.

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A. Designated uses: coldwater aquatic life, livestock watering, wildlife habitat and secondary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.126 NMAC - N, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

The EPA has taken into consideration the extensive history of the designation of uses for waters within the DOE/LANL in its review of the revisions to 20.6.4.126 NMAC. The following discussion considers the NMED's initial proposed revisions and determinations, and those revisions brought by the DOE/LANL, the latter of which were adopted by the Commission. An important part of the recent history is related to the Joint Stipulation Regarding Proposed Changes to 20.6.4.128 NMAC (WQCC 14-05(R)). The Joint Stipulation agreement between the NMED, DOE/LANL, and Amigos Bravos is the result of amendments initially proposed by Amigos Bravos during the NMED's 2013 triennial review to revise the designated use for all waters in 20.6.4.128 NMAC from limited aquatic life to marginal warmwater aquatic life designated use, arguing that these waters were under-protected. Amigos Bravos withdrew its proposed revisions in exchange for DOE/LANL agreeing to share information on waters within its property boundary. The Joint Stipulation is significant because it outlines commitments made in the effort to determine the appropriate designated uses for ephemeral and intermittent waters within 20.6.4.128 NMAC. This process affected the revisions to 20.6.4.126 NMAC under consideration here.

Consistent with the Joint Stipulation, the NMED, in coordination with the DOE/LANL and to a lesser extent Amigos Bravos, conducted numerous Hydrology Protocol[12] surveys on waters within regulatory segment 20.6.4.128 NMAC from November 2016 to October 2019 to document aquatic life and recreation use support of these waters. The NMED's Hydrology Protocol (HP) assessments consider hydrologic, geomorphic, and biological indicators related to the persistence of water. The NMED's HP is the only hydrologic condition survey method for surface waters that is approved by both the Commission and the EPA as a component of the New Mexico's Water Quality Management Plan/Continuing Planning Process (WQMP/CPP). See 40 CFR 130.5 and 40 CFR 130.5(c). As detailed in the WQMP/CPP, HP assessment information can then be used to provide technical support for a UAA but cannot be used in place of a UAA to make use determinations.

This effort to determine the hydrologic regime and thus the appropriate designated uses is consistent with the requirements in 40 CFR 131.20(a). This federal regulation requires states to re-examine any waterbody segment with standards that do not include the uses specified in CWA § 101(a)(2) every 3 years to determine if any new information has become available. If new information is available that indicate the uses specified in CWA § 101(a)(2) may be attainable, federal regulations require states/authorized tribes to revise their standards accordingly. Although the initial presumption by the participants was that all waters assessed within 20.6.5.128 NMAC would be ephemeral or intermittent, after conducting HP surveys on some but not all waters within 20.6.5.128 NMAC, it was determined that several are perennial. These findings were not expected but were significant since the Joint Stipulation obligated the NMED, DOE/LANL, and Amigos Bravos to meet, discuss and come to agreement on the appropriate level of protections for waters found to be perennial. If agreement was reached, the Joint

[12] New Mexico Environment Department (2011). New Mexico WQMP/CPP Appendix C: Hydrology Protocol.

Stipulation specifically obligated the NMED to petition the Commission, proposing appropriate designated uses for those waters no later than the next, now the current 2020 triennial review. The Joint Stipulation did not preclude Amigos Bravos and DOE/LANL from filing separate petitions to revise designated uses if there was no agreement.

Based on the NMED's testimony before the Commission, it appears that the three parties concurred that Ancho Canyon from the Rio Grande to Ancho Springs; Pajarito Canyon from Starmers Gulch to Homestead Spring; Pajarito Canyon from 500 meters downstream of Arroyo de la Delfe to Arroyo de la Delfe, and DP Canyon from 100 meters downstream of grade control to 400 meters upstream of grade control are perennial waters. Although the basis is unclear, it appears that DP canyon was withdrawn following further discussion. Consistent with its commitments under the Joint Stipulation, the NMED initially proposed to classify waters where there was agreement, including DP canyon, Ancho canyon, and additional perennial portions of Water canyon waters within 20.6.126 NMAC.

However, the NMED did not move forward with its initial proposals for 20.6.126 NMAC. It is the EPA's understanding that prior to petitioning the Commission for a hearing (August 2020), the NMED anticipated the need to prepare a supporting UAA for to classify those waters referred to above within 20.6.4.126 NMAC. The determination through the HP assessments that some waters assumed to have been defined in 20.6.4.128 NMAC are perennial is significant since it means that these waters were not adequately protected under this regulatory segment. In its direct testimony, the NMED noted that the resources needed to develop a UAA for waters in 20.6.4.126 NMAC would affect its ability to meet its obligation under the Joint Stipulation to provide protection for those intermittent waters identified through HP assessments in 20.6.4.128 NMAC – those proposed to be classified in 20.6.4.140 NMAC discussed previously.

Given the decision to meet its obligation under the Joint Stipulation, the NMED relied on existing provisions in 20.6.4. NMAC to ensure protections for those waters that had been identified as perennial through the HP assessments. Those waters that were identified as perennial through the HP analyses are not specifically defined 20.6.4.128 NMAC and thus are "unclassified waters of the state" that "…are not identified in 20.6.4.101 through 20.6.4.899 NMAC." In its testimony before the Commission, the NMED referred to the provision at 20.6.4.11(H) NMAC which states that "An unclassified surface water of the state is presumed to support the uses specified in Section 101(a)(2) of the federal Clean Water Act. As such, it is subject to 20.6.4.98 NMAC if nonperennial or subject to 20.6.4.99 NMAC if perennial." This provision requires that those waters that were found to be perennial through the HP analyses are subject to under 20.6.4.99 NMAC consistent with the rebuttable presumption that CWA § 101(a)(2).

The DOE/LANL opposed the NMED's determination that those waters identified as perennial through HP assessments are in fact unclassified and protected under 20.6.4.99 NMAC. In its testimony before the Commission, the DOE/LANL's contended that the NMED could not "move" waters or portions of waters defined in 20.6.4.126 and 128 NMAC because they could not be "automatically unclassified to 20.6.4.99 NMAC, without a Commission decision…" However, there is no provision in 20.6.4 NMAC that requires the Commission to affirmatively act to define unclassified waters within 20.6.4.99 NMAC – the provisions at 20.6.4.11(H) and 20.6.4.99 NMAC require these protections for unclassified waters. The NMED noted that the application of HP analyses are explicitly addressed in the WQMP/CPP section entitled Establishing or

Revising a Designated Use using the Hydrology Protocol. This section states that "For waterbodies that are perennial but have not been classified under 20.6.4.101 to 899 NMAC, the State asserts perennial protections for these waters under 20.6.4.99 NMAC. Thus, the NMED did not "move" waters to 20.6.4.99 NMAC but appears to have followed the established provision at 20.6.4.11(H) and the specific processes outlined in New Mexico's WQMP/CPP to ensure protection of those unclassified perennial waters identified through the HP analyses.

In testimony before the Commission, the DOE/LANL described its proposed revisions to 20.6.4.126 NMAC as a reclassification of two segments from 20.6.4.128 NMAC: (1) Pajarito canyon from 0.5 miles below Arroyo de la Delfe upstream to Homestead Spring (the Pajarito "Lower Section" and "Upper Section" respectively); and (2) Arroyo de la Delfe from Pajarito canyon to Kieling Spring. In that testimony, the DOE/LANL stated that it proposed the more protective cold water aquatic life designated use as potentially obtainable based on the joint HP work done with NMED and additional analysis DOE/LANL itself conducted. The DOE/LANL referred to supporting data based on HP Level-1 and HP Leve1-2 field sheets, photographs conventional water chemistry parameters and benthic taxa summary for the Pajarito Lower and Upper Sections. Macroinvertebrate taxa requiring water for their entire life cycle were identified as well as EPT (Ephemeroptera, Plecoptera, and Trichoptera) taxa. Data for the fish, amphibians and bivalves were not identified during the HP assessments. However, DOE/LANL testimony contradicts its statement that no species of bivalve was identified through laboratory examination although also stating that amphibians are known to exist in these reaches.

While the biological data derived through the HP and any additional analyses of these waters is significant, the specific processes outlined in the WQMP/CPP is specific to ensuring protection of those unclassified perennial waters identified through the HP analyses. The NMED noted in its testimony that the application of HP analyses are explicitly addressed in the WQMP/CPP section entitled Establishing or Revising a Designated Use using the Hydrology Protocol. This section states that "For waterbodies that are perennial but have not been classified under 20.6.4.101 to 899 NMAC, the State asserts perennial protections for these waters under 20.6.4.99 NMAC. A survey using the Hydrology Protocol may be used to verify the hydrological regime for these unclassified perennial waters. A revision to incorporate the results of the Hydrology Protocol survey to classify a waterbody under 20.6.4.101 to 899 NMAC is done through the UAA process." Thus, HP assessment information can only be used to provide technical support for a UAA - it cannot be used in place of a UAA to make use determinations. Thus, the basis for the Commission's adoption of the DOE/LANL proposals for 20.6.4.126 NMAC appear to be inconsistent with state's own requirements in the WQMP/CPP. The EPA considers the WQMP/CPP requirement to be an important part of a well-supported designated use determination while not specifically required under federal regulation at 40 CFR 131.10(j).

Further, the DOE/LANL does not appears to have developed any new data related to the attainable contact recreation use specific to the Pajarito canyon and Arroyo de la Delfe in its testimony and stated that there is no new data to suggest that the non-primary contact recreational use has changed from the initial the NMED's 2007 UAA. The 2007 UAA does not refer to or provide any specific data on conditions in either Pajarito canyon or Arroyo de la Delfe related to attainment of the contact recreation use. Since Pajarito canyon and Arroyo de la Delfe have not been specifically defined in 20.6.4.101 through 20.6.4.899 NMAC, to support the inclusion of these waters in 20.6.4.126 NMAC, 40 CFR 131.10(g)(j) require that DOE/LANL must provide a supporting UAA for the secondary contact use designation in these waters.

Further, the EPA considers the revised language in 20.6.4.126 NMAC referring to the defined perennial waters as "including but not limited to" inconsistent with the definition of "classified waters of the state," which specifically refers to a surface water or reach of a surface water of the state where the Commission has adopted a segment description.

***EPA Determination*:** *The EPA does not have adequate information to make a definitive determination on the Commission's revisions to 20.6.4.126 NMAC. Based on both current and revised language in 20.6.4.126 NMAC, the EPA has identified the following overarching findings and questions:*

Waters within the DOE/LANL are defined within two separate regulatory segments, 20.6.4.126 and 20.6.4.128 NMAC. Waters within both regulatory segments are broadly defined as "Classified water(s) of the state." The current regulatory segment definition at 20.6.4.126 NMAC specifically delineates perennial waters by their upstream and downstream boundaries. Regulatory segment 20.6.4.128 NMAC defines ephemeral or intermittent waters more generally as ephemeral and intermittent waters within DOE/LANL as "including but not limited to" specific waters and "those not specifically identified in 20.6.4.126 NMAC." Given the definitions of classified and unclassified waters in 20.6.7 NMAC, the rebuttable presumption of CWA § 101(a)(2) uses, the closely related state regulatory provisions at 20.6.4.11(H), the Commission and EPA approved regulatory procedures in the New Mexico WQMP/CPP, the EPA agrees with the NMED's determination that waters that are not specifically defined within a regulatory segment that have or may be determined to be perennial through HP analyses are protected under 20.6.4.99 NMAC.

The EPA considers the new phrase "including but not limited to" and the striking of the term "specifically" in the first sentence in referring to specific waters to be inconsistent with the definitions of all other regulatory segment in 20.6.4.101 through 20.6.4.899 NMAC that specifically delineate protected waters. The exceptions are 20.6.4.128 NMAC and 20.6.4.808 NMAC, the latter which the EPA previously took no action on (see below). The EPA recommends that this exception language be removed from these regulatory segment definitions. Although the supporting HP (Level-1 and Level-2) hydrologic and biological data is significant in determining the appropriate aquatic life use determination for "Pajarito canyon from 0.5 miles below Arroyo de la Delfe upstream to Homestead Spring; and Arroyo de la Delfe from Pajarito canyon to Kieling Spring," the New Mexico WQMP/CPP only allows the results of HP analyses to supplement but not substitute for a UAA. Thus, the HP Level-1 and Level-2 field data should not have been used as the basis for revisions adding the specific segments described above to 20.6.4.126 NMAC.

The EPA finds that it does not have an adequate basis to make a determination on the Commission's revisions to 20.6.4.126 NMAC. The EPA requests that the NMED provide supporting information to allow the EPA to make such a determination. The EPA anticipates that the additional information would include clarification of the basis for the Commission's actions for those waters/tributaries that are or are not now defined in 20.6.4.99 NMAC and a detailed information related to the revisions to 20.6.4.126 NMAC. The EPA anticipates that this would include a supporting UAA developed by the DOE/LANL to support the coldwater aquatic life and secondary contact recreation uses for Pajarito canyon from 0.5 miles below Arroyo de la Delfe upstream to Homestead Spring; and Arroyo de la Delfe from Pajarito canyon to Kieling Spring, now defined in 20.6.4.126 NMAC consistent with the requirements in the New Mexico WQMP.

The revisions to this provision are not approved and are not effective for CWA purposes until approved by the EPA.

20.6.4.800 Closed Basins

20.6.4.808 and 809 Water Effect Ratios (WER)

20.6.4.808 CLOSED BASINS: Perennial and intermittent watercourses within Smelter Tailing Soils Investigation Unit lands at the Chino mines company, excluding those ephemeral waters listed in 20.6.4.809 NMAC and including, but not limited to the mainstem of Lampbright draw, beginning at the confluence of Lampbright Draw with Rustler canyon, all tributaries that originate west of Lampbright draw to the intersection of Lampbright draw with U.S. 180, and all tributaries of Whitewater creek that originate east of Whitewater creek from the confluence of Whitewater creek with Bayard canyon downstream to the intersection of Whitewater creek with U.S. 180.

A. Designated uses: Warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the acute and chronic aquatic life criteria for copper set forth in Subsection I of 20.6.4.900 NMAC shall be determined by multiplying that criteria by the water effect ratio ("WER") adjustment expressed by the following equation:

$$WER = \frac{[10^{0.588+(0.703 \times \log DOC)+(0.395 \times \log Alkalinity)}] \times (\frac{100}{Hardness})^{0.9422}}{19.31}]$$

For purposes of this section, dissolved organic carbon (DOC) is expressed in units of milligrams carbon per liter or mg C/L; alkalinity is expressed in units of mg/L as $CaCO_3$, and hardness is expressed in units of mg/L as $CaCO_3$. In waters that contain alkalinity concentrations greater than 250 mg/L, a value of 250 mg/L shall be used in the equation. In waters that contain DOC concentrations greater than 16 mg C/L, a value of 16 mg C/L shall be used in the equation. In waters that contain hardness concentrations greater than 400 mg/L, a value of 400 mg/L shall be used in the equation. The alkalinity, hardness and DOC concentrations used to calculate the WER value are those measured in the subject water sample. [20.6.4.808 NMAC - N, 3/2/2017]

20.6.4.809 CLOSED BASINS: Ephemeral watercourses within smelter tailing soils investigation unit lands at the Chino mines company, limited to Chino mines property subwatershed drainage A and tributaries thereof, Chino mines property subwatershed drainage B and tributaries thereof (excluding the northwest tributary containing Ash spring and the Chiricahua leopard frog critical habitat transect); Chino mines property subwatershed drainage C and tributaries thereof (excluding reaches containing Bolton spring, the Chiricahua leopard frog critical habitat transect and all reaches in subwatershed C that are upstream of the Chiricahua leopard frog critical habitat); subwatershed drainage D and tributaries thereof (drainages D-1, D-2 and D-3, excluding the southeast tributary in drainage D1 that contains Brown spring) and subwatershed drainage E and all tributaries thereof (drainages E-1, E-2 and E-3).

A. Designated uses: Limited aquatic life, livestock watering, wildlife habitat and secondary contact.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the acute aquatic life criteria for copper set forth in Subsection I of 20.6.4.900 NMAC shall be determined by multiplying that criteria by the water effect ratio ("WER") adjustment expressed by the following equation:

$$WER = \frac{[10^{0.588+(0.703 \times \log DOC)+(0.395 \times \log Alkalinity)}] \times (\frac{100}{Hardness})^{0.9422}}{19.31}$$

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For purposes of this section, dissolved organic carbon (DOC) is expressed in units of milligrams carbon per liter or mg C/L; alkalinity is expressed in units of mg/L as $CaCO_3$, and hardness is expressed in units of mg/L as $CaCO_3$. In waters that contain alkalinity concentrations greater than 250 mg/L, a value of 250 mg/L shall be used in the equation. In waters that contain DOC concentrations greater than 16 mg C/L, a value of 16 mg C/L shall be used in the equation. In waters that contain hardness concentrations greater than 400 mg/L, a value of 400 mg/L shall be used in the equation. The alkalinity, hardness and DOC concentrations used to calculate the WER value are those measured in the subject water sample. [20.6.4.809 NMAC - N, 3/2/2017]

EPA Determination: *The EPA previously took no action on the amendments to 20.6.4.97.C. (6)(b)(ii)-(vi) NMAC, 20.6.4.808 and 809 NMAC– Closed Basins and Water Effects Ratios (WER) in its June 8, 2017, as described the supporting TSD. The proposed revisions were based on a 3rd party proposal developed by Freeport-McMoRan/Chino Mines Company ("Chino Mines") supported by a report entitled "Application of the Hydrology Protocol to Smelter Tailings Soils Investigation Unit (STSIU) Drainages" (Chino report). The NMED submitted the Chino Mines report to EPA Region 6 for review and technical approval as a UAA pursuant to 20.6.4.15. C. and D. NMAC to support designated use and associated criteria downgrades in five subwatersheds contained in the area that drains the STSIU.*

In the supporting TSD, the EPA stated that there was not adequate information to fully assess the downgraded use designations for the Chino STSIU waters at 20.6.4.97.C.(6)(b)(ii)-(vi) NMAC. Thus, the EPA determined that it was premature to evaluate the criteria to support those uses adopted by the Commission for regulatory segments 20.6.4.808 and 809 NMAC. The EPA outlined its concerns with the proposal in detail and described the additional information that is needed to supplement the Chino report's conclusions. In addition, the EPA recommended that the NMED provide a comparison between the WER and the results of a Biotic Ligand Model to facilitate EPA's review of the site-specific aquatic life criteria for copper. However, to date, the NMED has not addressed the concerns outlined in the EPA's TSD or provided a BLM to allow a determination if the WER specific to waters within 20.6.4.808 and 809 NMAC. The EPA did not approve the proposed revisions to 20.6.4.97.C. (6)(b)(ii)-(vi) NMAC, 20.6.4.808 and 809 NMAC. The EPA reiterates that these provisions are not effective for CWA purposes until approved by the EPA. See 40 CFR § 131.21(c).

20.6.4.900 Criteria Applicable to Existing or Attainable Uses

I. Hardness-dependent acute and chronic aquatic life criteria for metals

(3) Selected values of calculated acute and chronic criteria (µg/L).

(1) Acute aquatic life criteria for metals: The equation to calculate acute criteria in µg/L is $\exp(m_A[\ln(\text{hardness})] + b_A)$ (CF). Except for aluminum, the criteria are based on analysis of dissolved metal. For aluminum, the criteria are based on analysis of total recoverable aluminum in a sample that has a pH between 6.5 and 9.0 and is filtered to minimize mineral phases as specified by the department. [~~The EPA has disapproved the hardness-based equation for total recoverable aluminum in waters where the pH is less than 6.5 in the receiving stream for federal purposes of the Clean Water Act.~~] The equation parameters are as follows:

Metal	m_A	b_A	Conversion factor (CF)
Aluminum (Al)	1.3695	1.8308	
Cadmium (Cd)	[~~0.8968~~] 0.9789	[~~-3.5699~~] -3.866	1.136672-[(ln hardness)(0.041838)]
Chromium (Cr) III	0.8190	3.7256	0.316
Copper (Cu)	0.9422	-1.700	0.960

Lead (Pb)	1.273	-1.460	1.46203-[(ln hardness)(0.145712)]
Manganese (Mn	0.3331	6.4676	
Nickel (Ni)	0.8460	2.255	0.998
Silver (Ag)	1.72	-6.59	0.85
Zinc (Zn)	0.9094	0.9095	0.978

(2) Chronic aquatic life criteria for metals: The equation to calculate chronic criteria in µg/L is $\exp(m_C[\ln(\text{hardness})] + b_C)(CF)$**.** Except for aluminum, the criteria are based on analysis of dissolved metal. For aluminum, the criteria are based on analysis of total recoverable aluminum in a sample that has a pH between 6.5 and 9.0 and is filtered to minimize mineral phases as specified by the department.[~~The EPA has disapproved the hardness-based equation for total recoverable aluminum in waters where the pH is less than 6.5 in the receiving stream for federal purposes of the Clean Water Act.~~] The equation parameters are as follows:

Metal	**m_C**	**b_C**	**Conversion factor (CF)**
Aluminum (Al)	1.3695	1.8308	
Cadmium (Cd)	[0.7647] 0.7977	[-4.2180] -3.909	1.101672-[(ln hardness)(0.041838)]
Chromium (Cr) III	0.8190	0.6848	0.860
Copper (Cu)	0.8545	-1.702	0.960
Lead (Pb)	1.273	-4.705	1.46203-[(ln hardness)(0.145712)]
Manganese (Mn	0.3331	5.8743	
Nickel (Ni)	0.8460	0.0584	0.997
Zinc (Zn)	0.9094	0.6235	0.986

EPA Determination: *In 2016, the EPA updated its recommendations for acute and chronic hardness-based aquatic life criteria for cadmium based on toxicological studies for protection of aquatic life. Consistent with 40 CFR §131.11, the NMED proposed, and the Commission adopted the updated hardness-based criteria for cadmium resulting in the revised factors found in table 20.6.4.900(J)(1) NMAC. The EPA's approval of aquatic life criteria for cadmium is subject to consultation pursuant to Section 7(a)(2) of the Endangered Species Act (ESA). The EPA is taking no action on the revised aquatic life criterion for cadmium and the corresponding revised factors in table 20.6.4.900(J)(1), pending the conclusion of ESA consultation. The criterion for cadmium is not effective for CWA purposes until approved by the EPA. See Section V for additional information regarding the completion of the ESA consultation.*

J. Use-specific numeric criteria.

(1) Table of numeric criteria: The following table sets forth then numeric criteria applicable to existing, designated and attainable uses. For metals, criteria represent the total sample fraction unless otherwise specified in the table. Additional criteria that are not compatible with this table are found in Subsections A through I, K and L of this section.

NOTE; This is not a compete table but only includes revisions to the use-specific criteria table for brevity:[13]

Pollutant	**CAS Number**	**DWS**	**Irr/Irr storage**	**LW**	**WH**	**Aquatic Life**			**Type**
						Acute	Chronic	HH-OO	
Chloride	1688-70-06					860,000	230,000		
Iron	7439-89-6						1,000		

[13] This table has been condensed from the original table in **J(1)** to include and highlight revisions to aquatic life criteria subject to ESA consultation. Full table can be found in ***Section II***.

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Acrolein	107-02-8	18				3.0	3.0		
Carbaryl	63-25-2					2.1	2.1		
Chlorpyrifos	2921-88-2					0.083	0.041		
Demeton	8065-48-3						0.1		
Guthion	86-50-0						0.01		
Malathion	121-75-5						0.1		
Methoxychlor	72-43-5						0.03		
Mirex	2385-85-5						0.001		
Parathion	56-38-2					0.065	0.013		
Tributyltin (TBT)	Various					0.46	0.072		

EPA Determination: *The EPA's approval of aquatic life criteria for acrolein, cadmium, carbaryl, chloride, chlorpyrifos, demeton, iron, guthion, malathion, methoxychlor, mirex, parathion, and tributyltin are subject to consultation pursuant to Section 7(a)(2) of the ESA. The EPA is taking no action on these revised aquatic life criteria, pending the conclusion of ESA consultation. The criteria for acrolein, cadmium, carbaryl, chloride, chlorpyrifos, demeton, iron, guthion, malathion, methoxychlor, mirex, parathion, and tributyltin are not effective for CWA purposes until approved by the EPA. See Section V for additional information regarding the completion of the ESA consultation.*

K. The criteria for total ammonia consider sensitive freshwater mussel species in the family Unionidae, freshwater non-pulmonate snails, and *Oncorhynchus* spp. (a genus of fish in the family Salmonidae), hence further protecting the aquatic community. The total ammonia criteria magnitude is measured as Total Ammonia Nitrogen (TAN) mg/L. TAN is the sum of and TAN mg/L magnitude is derived as a function of pH and temperature (EPA 2013).

L. The acute aquatic life criteria for TAN (mg/L) was derived by the EPA (2013) as the one-hour average concentration of TAN mg/L that shall not be exceeded more than once every three years on average. The EPA acute criterion magnitude was derived using the following equation:

$$\text{Acute TAN Criterion Magnitude for 1-hour average} = \text{MIN}\left(\left(\frac{0.275}{1+10^{7.204-pH}}+\frac{39}{1+10^{pH-7.204}}\right),\left(0.7249\text{x}\left(\frac{0.0114}{1+10^{7.204-pH}}+\frac{1.6181}{1+10^{pH-7.204}}\right)\text{x}\left(23.12\times 10^{0.036(20-T)}\right)\right)\right)$$

T (temperature °C) and pH are defined as the paired values associated with the TAN sample

(1) Temperature and pH-dependent values of the acute TAN criterion magnitude – when *Oncorhynchus* spp. absent.

	Temperature (°C)																				
pH	0-10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	51	48	44	41	37	34	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	49	46	42	39	36	33	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	46	44	40	37	34	31	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9
6.8	44	41	38	35	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	41	38	35	32	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	38	35	33	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9	7.3
7.1	34	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7

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7.2	31	29	27	25	23	21	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6
7.3	27	26	24	22	20	18	17	16	14	13	12	11	10	9.5	8.7	8	7.4	6.8	6.3	5.8	5.3
7.4	24	22	21	19	18	16	15	14	13	12	11	9.8	9	8.3	7.7	7	6.5	6	5.5	5.1	4.7
7.5	21	19	18	17	15	14	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4
7.6	18	17	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	2.9
7.8	13	12	11	10	9.3	8.5	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4	3.7	3.4	3.2	2.9	2.7	2.5
7.9	11	9.9	9.1	8.4	7.7	7.1	6.6	3	5.6	5.1	4.7	4.3	4	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	8.8	8.2	7.6	7	6.4	5.9	5.4	5	4.6	4.2	3.9	3.6	3.3	3	2.8	2.6	2.4	2.2	2	1.9	1.7
8.1	7.2	6.8	6.3	5.8	5.3	4.9	4.5	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4
8.2	6	5.6	5.2	4.8	4.4	4	3.7	3.4	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	4.9	4.6	4.3	3.9	3.6	3.3	3.1	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1	0.96
8.4	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79
8.5	3.3	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.98	0.9	0.83	0.77	0.71	0.65
8.6	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.5	1.3	1.2	1.1	1	0.96	0.88	0.81	0.75	0.69	0.63	0.58	0.54
8.7	2.3	2.2	2	1.8	1.7	1.6	1.4	1.3	1.2	1.1	1	0.94	0.87	0.8	0.74	0.68	0.62	0.57	0.53	0.49	0.45
8.8	1.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37
8.9	1.6	1.5	1.4	1.3	1.2	1.1	1	0.93	0.85	0.79	0.72	0.67	0.61	0.56	0.52	0.48	0.44	0.4	0.37	0.34	0.32
9.0	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37	0.34	0.32	0.29	0.27

(2) Temperature and pH-dependent values for the acute TAN criterion magnitude-when *Oncorhynchus* spp. are present.

	Temperature (°C)																
pH	0-14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	33	33	32	29	27	25	23	21	19	18	16	15	14	12	12	11	9.9
6.6	31	31	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	30	30	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9
6.8	28	28	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	26	26	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	24	24	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	8	7.3
7.1	22	22	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	20	20	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6
7.3	18	18	17	16	14	13	12	11	10	9.5	8.7	8	7.4	6.8	6.3	5.8	5.3
7.4	15	15	15	14	13	12	11	9.8	9	8.3	7.7	7	6.5	6	5.5	5.1	4.7
7.5	13	13	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4
7.6	11	11	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	9.6	9.6	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	3
7.8	8.1	8.1	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4	3.7	3.4	3.2	2.9	2.7	2.5
7.9	6.8	6.8	6.6	6	5.6	5.1	4.7	4.3	4	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	5.6	5.6	5.4	5	4.6	4.2	3.9	3.6	3.3	3	2.8	2.6	2.4	2.2	2	1.9	1.7
8.1	4.6	4.6	4.5	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4
8.2	3.8	3.8	3.7	3.5	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	3.1	3.1	3.1	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1	1

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8.4	2.6	2.6	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.9	0.9	0.8
8.5	2.1	2.1	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1	0.9	0.8	0.8	0.7	0.7
8.6	1.8	1.8	1.7	1.6	1.5	1.3	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.6	0.6	0.5
8.7	1.5	1.5	1.4	1.3	1.2	1.1	1	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5
8.8	1.2	1.2	1.2	1.1	1	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4
8.9	1	1	1	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.3
9.0	0.88	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3

M. The chronic aquatic life criteria for TAN (mg/L) was derived by the EPA (2013) as a thirty-day rolling average concentration of TAN mg/L that shall not be exceeded more than once every three years on average. In addition, the highest four-day average within the 30-day averaging period should not be more than 2.5 times the CCC (e.g., 2.5 x 1.9 mg TAN/L at pH 7 and 20°C, or 4.8 mg TAN/L) more than once in three years on average. The EPA chronic criterion magnitude was derived using the following equation:

Chronic TAN Criterion Magnitude for 30-day average=

$$0.8876 \times \left(\frac{0.0278}{1+10^{7.688-pH}} + \frac{1.1994}{1+10^{pH-7.688}}\right) \times \left(2.126 \times 10^{0.028\times(20-MAX(T,7))}\right)$$

'T' (temperature °C) and pH are defined as the paired values associated with the 'TAN sample.

Temperature and pH-Dependent Values of the Chronic TAN Criterion Magnitude.

	Temperature (°C)																							
pH	0-7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	4.9	4.6	4.3	4.1	3.8	3.6	3.3	3.1	2.9	2.8	2.6	2.4	2.3	2.1	2	1.9	1.8	1.6	1.5	1.5	1.4	1.3	1.2	1.1
6.6	4.8	4.5	4.3	4	3.8	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1
6.7	4.8	4.5	4.2	3.9	3.7	3.5	3.2	3	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1
6.8	4.6	4.4	4.1	3.8	3.6	3.4	3.2	3	2.8	2.6	2.4	2.3	2.1	2	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1
6.9	4.5	4.2	4	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1
7.0	4.4	4.1	3.8	3.6	3.4	3.2	3	2.8	2.6	2.4	2.3	2.2	2	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1
7.1	4.2	3.9	3.7	3.5	3.2	3	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1
7.2	4	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1	1	0.9
7.3	3.8	3.5	3.3	3.1	2.9	2.7	2.6	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1	1	0.9	0.9
7.4	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1	1	0.9	0.9	0.8
7.5	3.2	3	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7
7.6	2.9	2.8	2.6	2.4	2.3	2.1	2	1.9	1.8	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7
7.7	2.6	2.4	2.3	2.2	2	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6
7.8	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5
7.9	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5	0.5	0.5
8.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.4	0.4	0.4
8.1	1.5	1.5	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4
8.2	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3
8.3	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
8.4	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
8.5	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
8.6	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
8.7	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1

NMED Exhibit 6

8.8	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
8.9	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
9.0	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

[20.6.4.900 NMAC - Rp 20 NMAC 6.1.3100, 10/12/2010; A, 10/11/2002; A, 5/23/2005; A, 7/17/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022]

EPA Determination:

As part of its 2020 triennial review, the NMED proposed, and the Commission adopted the EPA's updated § 304(a) recommended acute and chronic aquatic life criteria for Total Ammonia Nitrogen (TAN). The associated revisions to 20.6.4.900(K), (L) and (M) NMAC, including the equations, temperature and pH-dependent values in the associated tables are all consistent with the values in EPA's current nationally recommended freshwater ammonia criteria. However, the EPA acknowledges that the value of 3.0 for pH 7.9 and 17°C in (L)(1), should be 6.0 when the equation for the Acute TAN Criterion Magnitude for 1-hour average is applied. This is a typographical error that is also present in EPA's Ammonia 2013 aquatic life criteria document and the EPA cautions NMED to beware of the difference in the criteria and correct in their next revision. Since the acute criterion equation is correct, this typographical error is nonsubstantive. These revisions are consistent with the EPA's recommended § 304(a) criteria and with language in 40 CFR §131.20(a). However, the EPA approval of aquatic life criteria is subject to consultation pursuant to Section 7(a)(2) of the ESA. The EPA is taking no action on the revised ammonia aquatic life criteria and narrative in 20.6.4.900(K), (L) and (M) NMAC and these provisions are not effective for CWA purposes until approved by the EPA. See Section V for additional information regarding the completion of the ESA consultation.

IV. Provisions the EPA Is Disapproving

[RESERVED]

V. Additional Considerations

Endangered Species Act Consultation

The EPA's approval of revised WQS and associated aquatic life criteria are subject to the consultation requirement of Section 7(a)(2) of the Endangered Species Act[14] (ESA). Under Section 7(a)(2) of the ESA, the EPA has the obligation to ensure that its approval of modifications to the *New Mexico Standards for Interstate and Intrastate Waters* (20.6.4 NMAC) will not jeopardize the continued existence of threatened and endangered species and critical habitat in New Mexico.

[14] Endangered Species Act, 16 U.S.C. §1536

NMED Exhibit 6

The EPA's current practice is to consult with the Service(s) where the EPA determines that approval of a new or revised WQS may affect federally listed species. The revisions to 20.6.4.900 (I), (J), (K), (L) and (M) NMAC being considered in today's action are subject to ESA consultation. Specifically, the EPA determined that its approval of acrolein, ammonia, cadmium, carbaryl, demeton, guthion, methoxychlor, mirex, parathion, and tributyltin criteria is subject to ESA consultation. The EPA has initiated informal consultation with the New Mexico Ecological Services Field Office (ESFO) for the approval of acrolein, ammonia, cadmium, carbaryl, demeton, guthion, methoxychlor, mirex, parathion, and tributyltin criteria and is currently reviewing comments. Once comments are fully addressed, the EPA will request written concurrence from the ESFO. The EPA anticipates formal consultation will be needed for the approval of revised iron and chloride aquatic life criteria in 20.6.4.900 (J), based on the EPA's preliminary Likely to Adversely Affect determination for some threatened and endangered aquatic dependent species residing in New Mexico.

NMED Exhibit 6

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 6
1201 ELM STREET, SUITE 500
DALLAS, TEXAS 75270

April 27, 2023

Shelly Lemon, Chief
Surface Water Quality Bureau
New Mexico Environment Department
1190 Saint Francis Drive, Suite N4050
Santa Fe, New Mexico 87505

RE: New Mexico's 2020 Triennial Revisions to 20.6.4 NMAC

Dear Ms. Lemon:

I am writing in regard to the U.S. Environmental Protection Agency's (EPA's) prior review of revisions to New Mexico's *Standards for Interstate and Intrastate Surface Waters* 20.6.4 New Mexico Administrative Code (NMAC), which were effective for state purposes on April 23, 2022, and submitted to the New Mexico Water Quality Control Commission (Commission) for EPA review on May 2, 2022 ("the 2020 Triennial Revisions").

On January 19, 2023, the EPA took action approving the majority of the new and/or revised provisions, including non-substantive provisions within its discretionary authority, pursuant to CWA § 303(c) and its implementing regulations at 40 CFR Part 131 as detailed in the accompanying Technical Support Document (TSD). However, the EPA determined it could not act on new and revised aquatic life criteria that were subject to the consultation requirements of Section 7(a)(2) of the Endangered Species Act (ESA), 16 U.S.C. §1536. Under Section 7(a)(2) of the ESA, the EPA has the obligation to ensure that its approval of revisions to New Mexico's *Standards for Interstate and Intrastate Surface Waters* 20.6.4 NMAC will not jeopardize the continued existence of threatened and endangered species and critical habitat in New Mexico. The EPA has since received concurrence on our not likely to adversely affect (NLAA) determination from the U.S. Fish and Wildlife Service (USFWS) through the New Mexico Ecological Services Field Office and is approving the aquatic life criteria for acrolein, cadmium, carbaryl, demeton, guthion, methoxychlor, mirex, parathion, and tributyltin. The EPA is reserving action on the remaining aquatic life criteria described in Section V of the TSD pending the completion of ESA formal consultation with the USFWS.

I would like to thank the Commission, the New Mexico Environment Department and its Surface Water Quality Bureau for their commitment and hard work in reviewing and revising the state's water quality standards. We appreciate your patience with the delay in action resulting from the extensive ESA consultation. If you have any questions or concerns, please contact me at (214) 665-8138, or have your staff contact Jasmin Diaz-Lopez at (214) 665-2733 or Russell Nelson at (214) 665-6646.

Sincerely,



Charles W. Maguire
Director
Water Division

cc: James C. Kenney, Cabinet Secretary
Stephanie Stringer, Chair, WQCC (Stephanie.Stringer@state.nm.us)
Pamela Jones, Administrator, WQCC (Pamela.Jones@state.nm.us)
Robert Sanchez, Counsel, WQCC (rfsanchez@nmag.gov)
John Rhoderick, Acting Director, Water Protection Division (John.Rhoderick@state.nm.us)
Susan Lucas Kamat, SWQB, Point Source Regulation (susan.lucaskamat@state.nm.us)
Jennifer Fullam, SWQB, Standards Planning and Reporting (jennifer.fullam@state.nm.us)
Shawn Sartorius, Field Supervisor, ESFO, USFWS (shawn_sartorius@fws.gov)

REGION 6
DALLAS, TX 75270

June 13, 2024

TRANSMITTED VIA EMAIL

Shelly Lemon, Chief
Surface Water Quality Bureau
New Mexico Environment Department
1190 Saint Francis Drive, Suite N4050
Santa Fe, New Mexico 87505
Shelly.Lemon@env.nm.gov

RE: New Mexico's 2020 Triennial Revisions to 20.6.4 NMAC

Dear Ms. Lemon:

I am writing regarding the U.S. Environmental Protection Agency's (EPA) prior review of revisions to New Mexico's *Standards for Interstate and Intrastate Surface Waters* 20.6.4 New Mexico Administrative Code (NMAC), which were effective for state purposes on April 23, 2022. These revisions were submitted by the New Mexico Environment Department (NMED) on behalf of the New Mexico Water Quality Control Commission (Commission) for EPA review on May 2, 2022. The EPA initially took action on the majority of these revisions on January 19, 2023. The EPA has an obligation to ensure that its approval of revisions to State and Tribal water quality standards will not jeopardize the continued existence of threatened and endangered species and critical habitat in New Mexico. As such, the EPA did not approve the new and revised aquatic life criteria for acrolein, ammonia, cadmium, carbaryl, chloride, chloropyrifos, demeton, guthion, iron, malathion, methoxychlor, mirex, parathion, and tributyltin in our January 19, 2023, letter. These new and revised aquatic life criteria listed above were subject to the consultation requirements of Section 7(a)(2) of the Endangered Species Act (ESA), 16 U.S.C. §1536.

The EPA received partial concurrence from the U.S. Fish and Wildlife Service (USFWS) through the New Mexico Ecological Services Field Office on our Not Likely to Adversely Affect (NLAA) determination for threatened and endangered species. Based on this concurrence, EPA approved the aquatic life criteria for acrolein, cadmium, carbaryl, demeton, guthion, methoxychlor, mirex, parathion, and tributyltin on April 27, 2023.

However, the EPA determined that its approval of chloride and iron aquatic life criteria would likely adversely affect (LAA) the Alamosa springsnail, Chupadera springsnail, Koster's springsnail, Noel's amphipod, Pecos assiminea, Roswell springsnail, Socorro springsnail, and the Texas hornshell mussel

and designated critical habitat for Texas hornshell mussel, Chupadera springsnail, Koster's springsnail, Noel's amphipod, Pecos assiminea, and Roswell springsnail. The USFWS did not concur on the EPA's NLAA determination for the effects of ammonia aquatic life criteria on the Texas hornshell and its critical habitat. Therefore, the EPA initiated formal consultation with the USFWS on the approval of ammonia, chloride, and iron aquatic life criteria. As required under formal consultation, the USFWS prepared a biological opinion to analyze the effects of a proposed action to the listed species or designated critical habitat and determined whether an action is likely to jeopardize the continued existence of a listed species or result in the destruction or adverse modification of critical habitat.

The EPA has since received the USFWS's biological opinion which concluded that the approval of the ammonia, chloride, and iron aquatic life criteria will not jeopardize the continued existence of the threatened and endangered species or critical habitat referred to previously. The EPA is currently working with the USFWS and National Marine and Fisheries Service in nationwide consultations on several pesticides, including malathion and chloropyrifos. In the interim, the criteria New Mexico adopted for these contaminants are effective as state law. The EPA is continuing to work with the USFWS to gain concurrence on these criteria.

I would like to thank the Commission, the New Mexico Environment Department and its Surface Water Quality Bureau for their patience with the delay in action resulting from the extensive ESA consultation. If you have any questions or concerns, please contact me at (214) 665-6647, or have your staff contact Jasmin Diaz-Lopez at (214) 665-2733.

Sincerely,

TROY HILL Digitally signed by TROY HILL
Date: 2024.06.13 09:35:04 -05'00'

Troy C. Hill, P.E.
Director
Water Division

cc: James C. Kenney, Cabinet Secretary
Bruce Thomson, Chair, WQCC
Pamela Jones, Administrator, WQCC, Pamela.Jones@state.nm.us
Robert Sanchez, Counsel, WQCC, rfsanchez@nmag.gov
John Rhoderick, Director, Water Protection Division, John.Rhoderick@state.nm.us
Susan Lucas Kamat, SWQB, Point Source Regulation, susan.lucaskamat@state.nm.us
Michael Baca, SWQB, Standards Planning and Reporting, michael.baca1@env.nm.gov
Shawn Sartorius, Field Supervisor, ESFO, USFWS, shawn_sartorius@fws.gov

2026 TRIENNIAL REVIEW

Draft Amendments to Water Quality Standards
Public Review Draft - 20.6.4 NMAC

Public Comment Period: August 15 – October 14, 2025

The New Mexico Environment Department is holding a 60-day public comment period on this document. Please see the preamble for information on submitting comments.

New Mexico Environment Department – Surface Water Quality Bureau
Harold L. Runnels Building, 1190 S. St. Francis Dr., P.O. Box 5469, Santa Fe, NM 87502

NMED Exhibit 9

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Preamble

The federal Clean Water Act (CWA) requires states to review Water Quality Standards (WQS) every three years, commonly known as the Triennial Review. This public review draft of 20.6.4 NMAC contains draft amendments to New Mexico's Surface WQS and initiates the 2026 Triennial Review process. The Department based these draft amendments on past Triennial Review results, CWA requirements, and monitoring and assessment information. During the Triennial Review, the CWA requires states to consider adopting the U.S. Environmental Protection Agency's (EPA) recommended CWA Section 304(a) Criteria and review segments lacking CWA Section 101(a)(2) uses (i.e., swimmable/fishable) to see if any new data would support including these uses. The Department includes a "Basis for Change" following each draft amendment to provide a rationale or citations to supporting information.

Deleted materials are indicated by strikethrough, and new text are indicated by underline. Only the portions of the rule (sections, subsections, paragraphs, etc.) with draft amendments are provided below, unless needed for context and clarity of scope. In addition to these draft amendments, the department will accept comments on any Section of 20.6.4 NMAC.

Comments may be submitted via email at michael.baca1@env.nm.gov or the Department's public comment portal (https://nmed.commentinput.com/comment/search) through October 14, 2025. More information about the Triennial Review process, including the entire WQCC and EPA approved versions of 20.6.4 NMAC may be found at https://www.env.nm.gov/surface-water-quality/wqs/.

NMED Exhibit 9

20.6.4.7 DEFINITIONS: Terms defined in the New Mexico Water Quality Act, but not defined in this part will have the meaning given in the Water Quality Act.

A. Terms beginning with numerals or the letter "A," and abbreviations for units.

(1) "4Q3" means the hydrologically based critical low flow as determined by the minimum average flow over four consecutive days that occurs with a frequency of once in three years.

BASIS FOR CHANGE: NMED proposes this amendment to clarify that the calculation utilized in New Mexico is hydrologically based. This definition was previously approved at 20.6.4.11 NMAC. However, EPA Region 6 did not approve this definition when it was moved to 20.6.4.7 NMAC during New Mexico's 2020 Triennial Review.

20.6.4.7.A(2) through 20.6.4.7.P(6) NMAC – No changes proposed.

P. Terms beginning with the letter "P".

(7) "Public water supply" means the use or storage of water to supply a public water system as defined by ~~New Mexico's Drinking Water Regulations, 20.7.10 NMAC~~ 40 CFR 141. Water provided by a public water system ~~may need to~~ shall undergo treatment to ~~achieve~~ comply with drinking water ~~quality~~ standards.

BASIS FOR CHANGE: NMED's Drinking Water Regulations at 20.7.10 NMAC, incorporate by reference the National Primary Drinking Water Regulations codified at 40 CFR Part 141. The definition for "public water system" is contained in the federal regulations and not in the NMAC as indicated in the existing language. NMED proposes an amendment to cite the federal regulation containing the definition.

The Drinking Water Regulations require disinfection, at a minimum, and filtration for most public water systems that use surface water sources or ground water sources under direct influence of surface water (See 40 CFR Part 141, Subpart H). Source water with low turbidity (< 5 NTU) and coliform concentrations (fecal < 20/100 ml and total <100/100ml) over the past six months are eligible for an exemption from filtration. NMED proposes changing "may" to "shall". While surface waters may appear clean, they can carry harmful contaminants and micro-organisms that can cause illnesses and must be treated prior to drinking. NMED proposes to amend language to indicate compliance with drinking water standards and treatment requirements.

20.6.4.7.Q through 20.6.4.7.S NMAC – No changes proposed.

T. Terms beginning with the letter "T".

(1) "TDS" means total dissolved solids, also termed "total filterable residue."

(2) "Temporary standard" means a time-limited designated use and criterion for a specific pollutant(s) or water quality parameter(s) that reflect the highest attainable condition during the term of the temporary standard.

(~~2~~3) "Toxic pollutant" means those pollutants, or combination of pollutants, including disease-causing agents, that after discharge and upon exposure, ingestion, inhalation or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will cause death, shortened life spans, disease, adverse behavioral changes, reproductive or physiological impairment or physical deformations in such organisms or their offspring.

(~~3~~4) "Tributary" means a perennial, intermittent or ephemeral waterbody that flows into a larger waterbody, and includes a tributary of a tributary.

(~~4~~5) "Turbidity" is an expression of the optical property in water that causes incident light to be scattered or absorbed rather than transmitted in straight lines.

NMED Exhibit 9

BASIS FOR CHANGE: NMED proposes to move the definition of "temporary standard" from 20.6.4.10.H(12) to 20.6.4.7.T(1) NMAC, to conform to State Records Center and Archives (SRCA) formatting guidelines.

20.6.4.7.U through 20.6.4.7.W(3) NMAC – No changes proposed.

W. Terms beginning with the letter "W".

(4) "Wetlands" means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and under normal circumstances do support, ~~a prevalence of~~ vegetation, typically adapted for life in saturated soil conditions in New Mexico. Wetlands are unique surface waters of the state that vary widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation and other factors and provide distinct chemical, biological, physical, and hydrological functions within a watershed. Wetlands that are constructed outside of a surface water of the state for the purpose of providing wastewater treatment and that do not impound a surface water of the state are not included in this definition.

BASIS OF CHANGE: NMED proposes to clarify the definition of wetlands. Wetlands provide a variety of important functions, and vary regionally and locally due to their soils, topography, climate, hydrology, water chemistry, vegetation, and other factors. Recognizing these characteristics and functions will help protect and maintain these features through the implementation of Clean Water Act (CWA) and New Mexico surface water quality programs such as CWA Section 303(d)/305(b) Reporting and water quality condition assessments, evaluating antidegradation provisions and appropriate mitigation ratios, and developing permit conditions for surface water discharges, including point source and dredge and fill discharges.

20.6.4.7.W(5) through 20.6.4.7.Z NMAC – No changes proposed.

20.6.4.8 ANTIDEGRADATION POLICY AND IMPLEMENTATION PLAN:

A. Antidegradation Policy: This antidegradation policy applies to all surface waters of the state.

(1) Existing uses, as defined in Paragraph (4) of Subsection E of 20.6.4.7 NMAC, and the level of water quality or wetland condition necessary to protect the existing uses shall be maintained and protected in all surface waters of the state. Wetland condition is a measure of ecological integrity and, by inference, wetland quality (i.e., functions) and quantity (i.e., acreage).

(2) Where wetland condition or the quality of a surface water of the state exceeds levels necessary to support the propagation of fish, shellfish, and wildlife, and recreation in and on the water, that quality shall be maintained and protected unless the commission finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the state's continuing planning process, that allowing lower water quality or wetland condition, including loss of wetland acreage or wetland functions, is necessary to accommodate important economic and social development in the area in which the water is located. In allowing such degradation or lower water quality, the state shall assure water quality adequate to protect existing uses fully. Further, the state shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable BMPs for nonpoint source control. Additionally, the state shall encourage the use of watershed planning as a further means to protect surface waters of the state.

(3) No degradation, including loss of wetland acreage or wetland functions, shall be allowed in waters designated by the commission as outstanding national resource waters (ONRWs), except as provided in Subparagraphs (a) through (e) of this paragraph and in Paragraph (4) of this Subsection A.

BASIS FOR CHANGE: As stated in the Objective of this Part, water quality standards consist of designated uses, criteria to support those uses, and an antidegradation policy, which collectively are used to protect and enhance surface water quality. NMED proposes new antidegradation language to incorporate wetlands antidegradation provisions. NMED equates loss of wetland

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condition (i.e., acreage or functions) to degradation and proposes language consistent with each Tier to provide wetland protections under New Mexico's antidegradation policy.

20.6.4.8.A(3)(a) through 20.6.4.9 NMAC – No changes proposed.

20.6.4.10 REVIEW OF STANDARDS; NEED FOR ADDITIONAL STUDIES:

20.6.4.10.A through 20.6.4.10.E NMAC – No changes proposed.

F. If the commission grants a rulemaking hearing for the amendment or adoption of a water quality standard, including ONRW nominations, site-specific criteria, use attainability analyses, and designating classified segments, the petitioner shall be responsible for the costs of the administrative rulemaking process. Costs include: venue, hearing officer, court reporter, original transcripts, translation services, interpretation services, and public notice requirements including publication in newspapers and in the New Mexico register. The petitioner shall coordinate with the commission administrator and the department on rulemaking hearing requirements.

BASIS FOR CHANGE: The Water Quality Control Commission (WQCC) historically depended on NMED, as the petitioner, to carry out administrative functions and pay the costs of a rulemaking. And, as petitioner, NMED fulfilled these responsibilities and costs to further the Department's proposed amendments. However, with more interest in water quality regulations and external parties proposing various standards amendments, NMED cannot predict when external rulemaking petitions will be filed and therefore cannot cover the hearing costs or administrative functions for these petitions. NMED cannot plan for unknown proposals in their grant workplans or request funding in their operating budget for unknown proposals, especially if the Department does not know if it will actually need the funding or if a non-NMED petitioner will complete the workplan deliverable as required. NMED proposes to clarify that the financial responsibility for the costs of the administrative rulemaking process lies with the petitioner, whether that be NMED, another state agency, or an external party. Additional costs for the development of a rulemaking petition may include technical experts, scientific reports, and additional stakeholder and public outreach, depending on public interest.

~~F~~**G. Site-specific criteria.**

(1) The commission may adopt site-specific numeric criteria applicable to all or part of a surface water of the state based on relevant site-specific conditions such as:

(a) actual species at a site are more or less sensitive than those used in the national criteria data set;

(b) physical or chemical characteristics at a site such as pH or hardness alter the biological availability and/or toxicity of the chemical;

(c) physical, biological or chemical factors alter the bioaccumulation potential of a chemical;

(d) the concentration resulting from natural background exceeds numeric criteria for aquatic life, wildlife habitat or other uses if consistent with Subsection G of 20.6.4.10 NMAC; or

(e) other factors or combination of factors that upon review of the commission may warrant modification of the default criteria, subject to EPA review and approval.

(2) Site-specific criteria must fully protect the designated use to which they apply. In the case of human health-organism only criteria, site-specific criteria must fully protect human health when organisms are consumed from waters containing pollutants.

(3) Any person may submit notice to the department stating their intent to derive site-specific criteria for a surface water of the state. The notice shall include a work plan supporting the development of site-specific criteria for the department's review and comment.

(4) Site-specific criteria shall be developed in accordance with the reviewed work plan, based on one or more of the site-specific conditions noted in paragraph 1, derived from a scientifically defensible method and protect the designated uses to which they apply.

(5) The work plan shall identify, at a minimum:

(a) the waterbody to consider and the reasoning for site-specific criteria;

(b) the methodology to be used to derive criteria;

(c) the source and validity of data to be used;

(d) the provisions for consultation with appropriate state and federal agencies;

(e) a description of how stakeholders and potentially affected Indian nations, tribes, or pueblos will be identified and engaged;

(f) a description of the public notice mechanisms to be employed; and

(g) the expected timelines and associated administrative actions to be taken for a rulemaking petition, pending the outcome of criteria development.

(6) Upon completion of site-specific criteria development, the data, findings and conclusions shall be submitted to the department, and public notice shall be provided in accordance with the approved work plan.

(~~3~~7) Any person may petition the commission to adopt site-specific criteria. A petition for the adoption of site-specific criteria shall:

(a) identify the specific waters to which the site-specific criteria would apply;

(b) explain the rationale for proposing the site-specific criteria;

(c) describe the methods used to notify and solicit input from potential stakeholders and from the general public in the affected area, and present and respond to the public input received;

(d) present and justify the derivation of the proposed criteria.

(48) A derivation of site-specific criteria shall rely on a scientifically defensible method, such as one of the following:

(a) the recalculation procedure, the water-effect ratio for metals procedure or the resident species procedure as described in the water quality standards handbook (EPA-823-B-94-005a, 2nd edition, August 1994);

(b) the streamlined water-effect ratio procedure for discharges of copper (EPA-822-R-01-005, March 2001);

(c) the biotic ligand model as described in aquatic life ambient freshwater quality criteria - copper (EPA-822-R-07-001, February 2007);

(d) the methodology for deriving ambient water quality criteria for the protection of human health (EPA-822-B-00-004, October 2000) and associated technical support documents; or

(e) a determination of the natural background of the water body as described in Subsection G of 20.6.4.10 NMAC.

BASIS FOR CHANGES: NMED proposes including work plan requirements for entities outside of the department for deriving site-specific criteria. A work plan will improve communication between outside agencies, regulated community, stakeholders, and the department. The work plan should clearly outline expectations and responsibilities for deriving criteria. Additionally, work plans are already required for conducting a Use Attainability Analysis by an entity other than NMED and this will bring more uniformity to the process of water quality standards amendments.

~~G~~H. Site-specific criteria based on natural background. The commission may adopt site-specific criteria equal to the concentration resulting from natural background where that concentration protects the designated use. The concentration resulting from natural background supports the level of aquatic life and wildlife habitat expected to occur naturally at the site absent any interference by humans. Domestic water supply, primary or secondary contact, or human health-organism only criteria shall not be modified based on natural background. A determination of natural background shall:

(1) consider natural spatial and seasonal to interannual variability as appropriate;

(2) document the presence of natural sources of the pollutant;

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(3) document the absence of human sources of the pollutant or quantify the human contribution; and

(4) rely on analytical, statistical or modeling methodologies to quantify the natural background.

BASIS FOR CHANGE: NMED proposes to renumber the subsection as the result of the proposed subsection at 20.6.4.10.F NMAC.

~~H~~I. **Temporary standards.**

~~**(12)** "Temporary standard" means a time-limited designated use and criterion for a specific pollutant(s) or water quality parameter(s) that reflect the highest attainable condition during the term of the temporary standard.~~

BASIS FOR CHANGE: NMED proposes to renumber the subsection as the result of the proposed subsection at 20.6.4.10.F NMAC. Additionally, NMED proposes to move the definition of "temporary standard" from 20.6.4.10.H(12) to 20.6.4.7.T(1) NMAC to conform to SRCA formatting guidelines.

20.6.4.11 APPLICABILITY OF WATER QUALITY STANDARDS:

20.6.4.11.A through 20.6.4.11.F NMAC – No changes proposed.

G. Human health-organism only criteria in Subsection J of 20.6.4.900 NMAC apply to those waters with a designated, existing or attainable aquatic life use. When limited aquatic life is a designated use, the human health-organism only criteria apply only for persistent toxic pollutants,~~if~~ unless adopted on a segment-specific basis. The human health-organism only criteria for persistent toxic pollutants, as identified in Subsection J of 20.6.4.900 NMAC, also apply to all tributaries of waters with a designated, existing or attainable aquatic life use.

BASIS FOR CHANGE: NMED proposes this amendment to remain consistent with the Limited Aquatic Life Designated Use language in 20.6.4.900(H)(7) NMAC.

20.6.4.11.H through 20.6.4.11.I NMAC – No changes proposed.

20.6.4.12 COMPLIANCE WITH WATER QUALITY STANDARDS: The following provisions apply to determining compliance for enforcement purposes; they do not apply for purposes of determining attainment of uses. The department has developed assessment protocols for the purpose of determining attainment of uses that are available for review from the department's surface water quality bureau.

20.6.4.12.A through 20.6.4.12.E NMAC – No changes proposed.

F. For compliance with ~~hardness-dependent~~ calculated numeric criteria~~,~~ that depend on water chemistry, ~~hardness (as mg $CaCO_3$/L)~~ all input parameters shall be determined from a sample taken at the same time that the sample for the contaminant is taken. If not all the input data are available to calculate a criterion, default input values may be used if justified and supported by ecoregional or other watershed data.

BASIS FOR CHANGE: NMED proposes amendments to acknowledge that New Mexico's water quality standards at 20.6.4.900.I NMAC contains numeric criteria calculations that are dependent on more than concurrent hardness as input values. NMED also proposes adding a statement regarding default input values when collection of concurrent data is not feasible and default values are justified and supported.

20.6.4.12.G through 20.6.4.12.H NMAC – No changes proposed.

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20.6.4.13 GENERAL CRITERIA: General criteria are established to sustain and protect existing or attainable uses of surface waters of the state. These general criteria apply to all surface waters of the state at all times, unless a specified criterion is provided elsewhere in this part. Surface waters of the state shall be free of any water contaminant in such quantity and of such duration as may with reasonable probability injure human health, animal or plant life or property, or unreasonably interfere with the public welfare or the use of property.

20.6.4.13.A through 20.6.4.13.M NMAC – No changes proposed.

N. Wetlands: Only wetlands of the state are subject to this general criterion. Wetlands shall be maintained and protected such that degradation through direct, indirect, or cumulative impacts does not result in the net loss of wetland acreage or biological, chemical, physical, and hydrological functions to the extent that such functions occur, as characterized by state-specific benchmarks. The functions of a wetland that are to be maintained and protected may include:

(1) erosion control through bank and shoreline stabilization;
(2) flood attenuation and flood protection;
(3) sediment and pollutant retention, which prevents or mitigates downstream migration;
(4) groundwater recharge and water storage for future use;
(5) low flow augmentation including baseflow maintenance;
(6) water filtration including removal or storage of nutrients and other contaminants;
(7) propagation or maintenance of aquatic and terrestrial species indigenous to wetlands;
(8) preservation of wildlife habitat including habitat for threatened or endangered species; or
(9) supporting biological diversity.

In addition, wetlands shall be suitable for recreation, wildlife habitat, and use by aquatic life and livestock.

BASIS FOR CHANGE: The above section was added to provide explicit water quality protections for New Mexico's wetlands. Wetlands are unique surface waters that provide important environmental, economic, and social benefits, such as water purification, flood control, groundwater recharge, climate change mitigation, recreation and tourism, infrastructure protection, and crucial habitat for fish, birds, mammals, and other wildlife. These benefits are the result of the unique characteristics of wetlands; however, New Mexico has lost over 50% of its wetlands. Wetlands of New Mexico remain ecologically and economically important. Providing explicit regulatory language to maintain and protect wetland condition is vital for keeping our remaining wetlands healthy and functioning for the benefit of all New Mexicans.

20.6.4.14 SAMPLING AND ANALYSIS:

20.6.4.14.A through 20.6.4.14.B NMAC – No changes proposed.

C. Sampling Procedures:

(1) Streams: Stream monitoring stations below discharges shall be located a sufficient distance downstream to ensure adequate vertical and lateral mixing.

(2) Lakes: Sampling stations in lakes shall be located at least 250 feet from a discharge.

(3) Lakes: Except for the restriction specified in Paragraph (2) of this subsection, lake sampling stations shall be located at any site where the attainment of a water quality criterion is to be assessed. ~~Water quality measurements taken at intervals in the entire water column at a sampling station shall be averaged for the epilimnion, or in the absence of an epilimnion, for the upper one-third of the water column of the lake to determine attainment of criteria, except that attainment of criteria for toxic pollutants shall be assessed during periods of complete vertical mixing, e.g., during spring or fall turnover, or by taking depth-integrated composite samples of the water column.~~

BASIS FOR CHANGE: NMED proposes striking the above section because it is more appropriate to provide this level of detail in Standard Operating Procedures (SOPs) available at:

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https://www.env.nm.gov/surface-water-quality/sop/. Specifically, this detailed sampling information should and does reside in "SOP 12.1 Lake Sampling," which is reviewed and updated every two years by the NMED SWQB staff with lake sampling and fisheries expertise. Removing this sampling detail from 20.6.4 NMAC to the SOPs provides flexibility to ensure NMED's lake monitoring techniques are aligned with current lake monitoring state of knowledge and best practices, based in part on resident fish species in the specific lake or reservoir being sampled when fisheries data are available.

20.6.4.14.D through 20.6.4.14.F NMAC – No changes proposed.

20.6.4.15 USE ATTAINABILITY ANALYSIS:

20.6.4.15.A NMAC – No changes proposed.

B. Methods for developing a use attainability analysis. A use attainability analysis shall assess the physical, chemical, biological, economic or other factors affecting the attainment of a use. The analysis shall rely on scientifically defensible methods such as the methods described in the following documents:

(1) the United States environmental protection agency's water quality standards handbook and use attainability analysis website for current recommendations and case studies;

(~~1~~2) *Technical Support Manual: Waterbody Surveys And Assessments For Conducting Use Attainability Analyses*, volume I (November 1983) and volume III (November 1984) or latest editions, United States environmental protection agency, office of water, regulations and standards, Washington, D.C., for the evaluation of aquatic life or wildlife uses;

(~~2~~3) the department's *Hydrology Protocol*, latest edition, approved by the commission, for identifying ephemeral, intermittent, and perennial waters; or

(~~3~~4) *Interim Economic Guidance For Water Quality Standards - Workbook*, March 1995, in conjunction with *Clean Water Act Financial Capability Assessment Guidance,* March 2024, United States environmental protection agency, office of water, Washington, D.C. for evaluating economic impacts.

BASIS FOR CHANGE: NMED proposes to add a reference to EPA's WQS Handbook and Use Attainability Analysis website that was updated in 2025. The WQS Handbook provides information on Designated Uses. The website contains information on how to conduct a UAA and provides EPA's collection of guidance documents on the topic in one area.

NMED proposes to include the updated March 2024 version of the CWA Financial Capability Assessment Guidance that was originally published by EPA in February of 2023. This guidance supplements the existing 1995 Interim Economic Guidance for WQS: Workbook and provides a framework for WQS decisions with economic considerations, like UAAs and Temporary Standards.

20.6.4.15.C NMAC – No changes proposed.

D. Process to amend a designated use through a use attainability analysis.

(1) The process for developing a use attainability analysis and petitioning the commission for removing a designated use and establishing the highest attainable use shall be done in accordance with the State's current *Water Quality Management Plan/Continuing Planning Process*.

(2) If the findings of a use attainability analysis, conducted by the department, in accordance with the department's *Hydrology Protocol* (latest edition) demonstrates that federal Clean Water Act Section 101(a)(2) uses, that are not existing uses, are not feasible in an ephemeral water body due to the factor in 40 CFR 131.10(g)(2), the department may consider proceeding with the expedited use attainability analysis process in accordance with the State's current *Water Quality Management Plan/Continuing Planning Process*. The following elements must be met for the expedited use attainability analysis process to be authorized and implemented:

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(a) The department is the primary investigator of the use attainability analysis;

(b) The use attainability analysis determined, through the application of the *Hydrology Protocol*, that the water being investigated is ephemeral and has no effluent discharges of sufficient volume that could compensate for the low-flow;

(c) The use attainability analysis determined that the criteria associated with the existing uses of the water being investigated are not more stringent than those in 20.6.4.97 NMAC;

(d) The designated uses in 20.6.4.97 NMAC have been determined to be the highest attainable uses for the water being analyzed;

(e) The department posted the use attainability analysis on its water quality standards website and notified its interested parties list of a 30-day public comment period;

(f) The department reviewed and responded to any comments received during the 30-day public comment period ; and

(g) The department submitted the use attainability analysis and response to comments to ~~region 6~~ EPA for technical ~~approval~~review.

(3) If EPA approves the designated use revision(s) under section 303(c) of the Clean Water Act, the water shall be subject to 20.6.4.97 NMAC for federal Clean Water Act purposes. The use attainability analysis, the technical support document, and the applicability of 20.6.4.97 NMAC to the water shall be posted on the department's water quality standards website. The department shall periodically petition the commission to list ephemeral waters under Subsection C of 20.6.4.97 NMAC and to incorporate changes to classified segments as appropriate.

BASIS FOR CHANGE: NMED proposes to remove reference to region 6 of EPA as this level of specificity is not required and does not enhance the practical application of the rule. NMED proposes to change approval to review in paragraph (2)(g). This proposal is based on EPA's recommendation in their Triennial Review Letter submitted to the department on January 19, 2023. This amended language clarifies that EPA will not provide technical approval of a Use Attainability Analysis before the Water Quality Control Commission approves and adopts standards into the NMAC.

NMED proposes to include a new paragraph (3) to conform to NMAC style and formatting guidelines. Include the term designated use and pluralize revision to clarify the element of the Water Quality Standards being amended.

E. Use attainability analysis conducted by an entity other than the department. Any person may submit notice to the department stating their intent to conduct a use attainability analysis.

(1) The ~~proponent~~ notice shall ~~provide such notice along with~~include a work plan supporting the development of a use attainability analysis ~~to~~for the department's ~~and region 6 EPA for~~ review and comment.

(2) Upon approval of the work plan by the department, ~~the proponent shall conduct~~ the use attainability analysis shall be conducted in accordance with the applicable portions of Subsections A through D of this Section and ~~implement~~ public ~~noticing~~notice provided in accordance with the approved work plan.

(3) Work plan elements. The work plan shall identify, at a minimum:

(a) the waterbody of concern and the reasoning for conducting a use attainability analysis;

(b) the source and validity of data to be used to demonstrate whether the current designated use is not attainable;

(c) the factors in 40 CFR 131.10(g) affecting the attainment of that use;

(d) a description of the data being proposed to be used to demonstrate the highest attainable use;

(e) the provisions for consultation with appropriate state and federal agencies;

(f) a description of how stakeholders and potentially affected tribes will be identified and engaged;

(g) a description of the public notice mechanisms to be employed; and

(h) the expected timelines outlining the administrative actions to be taken for a rulemaking petition, pending the outcome of the use attainability analysis.

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(4) Upon completion of the use attainability analysis, ~~the proponent shall submit~~ the data, findings and conclusions shall be submitted to the department, and ~~provide~~ public notice of the use attainability analysis provided in accordance with the approved work plan.

(5) Pending the conclusions of the use attainability analysis and as described in the approved work plan, the ~~department or the proponent~~ person conducting the use attainability analysis may petition the commission to modify the designated use. ~~The cost of such use attainability analysis shall be the responsibility of the proponent. Subsequent costs associated with the administrative rulemaking process shall be the responsibility of the petitioner.~~

BASIS FOR CHANGE: NMED proposes to remove the term "proponent" from the regulations as it is undefined and may cause confusion in the development of water quality petitions and the administrative rulemaking process. Additionally, all references to the costs of the administrative rulemaking process have been consolidated in 20.6.4.10(F) NMAC.

20.6.4.16 through 20.6.4.97 NMAC – No changes proposed.

20.6.4.98 INTERMITTENT WATERS: All non-perennial surface waters of the state, except those ephemeral waters included under section 20.6.4.97 NMAC, ~~or~~ classified in 20.6.4.101-899 NMAC, or wetlands protected under 20.6.4.13 NMAC.

A. Designated uses: livestock watering, wildlife habitat, marginal warmwater aquatic life and primary contact.

B. Criteria: the use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following site-specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

BASIS FOR CHANGE: NMED proposes adding clarification that wetlands are protected under proposed subsection N in 20.6.4.13 NMAC.

20.6.4.99 PERENNIAL WATERS: All perennial surface waters of the state except those classified in 20.6.4.101-899 NMAC, or wetlands protected under 20.6.4.13 NMAC.

A. Designated uses: Warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following site-specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

BASIS FOR CHANGE: NMED proposes adding clarification that wetlands are protected under proposed subsection N in 20.6.4.13 NMAC.

20.6.4.100 through 20.6.4.134 NMAC – No changes proposed.

20.6.4.135 RIO GRANDE BASIN: Bluewater lake and Santa Cruz lake.

A. Designated uses: coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: phosphorus (unfiltered sample) 0.1 mg/L or less for Bluewater lake; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

BASIS FOR CHANGE: NMED proposes to add Santa Cruz Lake to 20.6.4.135 NMAC based on available temperature, fisheries, and other water quality data; air-water temperature modeling performed during development of the 2024 approved temperature TMDL; and elevation and ecoregion data.

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20.6.4.136 through 20.6.4.205 NMAC – No changes proposed.

20.6.4.206 PECOS RIVER BASIN: Perennial reaches of the Rio Felix ~~and perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon, excluding North Spring river~~.

A. Designated uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

BASIS FOR CHANGE: NMED reviewed available 2021-2022 E. coli and pH data and determined a recreational use change from Secondary Contact to Primary Contact for Berrendo Creek, the only other perennial tributary to the Rio Hondo downstream of Bonney canyon, is warranted. Therefore, "perennial reaches of its tributaries" to the Rio Hondo downstream of Bonney canyon was added to 20.6.4.231 NMAC to assign Primary Contact to both perennial tributaries. No E. coli and pH data were available for perennial reaches of the Rio Felix.

20.6.4.207 NMAC – No changes proposed.

20.6.4.208 PECOS RIVER BASIN: Perennial reaches of the Rio Peñasco above ~~state highway 24 near Dunken~~Bear Canyon, perennial reaches of tributaries to the Rio Peñasco above ~~state highway 24 near Dunken~~Bear Canyon, perennial reaches of Cox canyon, perennial reaches of the Rio Bonito downstream from ~~state highway 48 (near~~ Angus canyon~~)~~, the Rio Ruidoso downstream of ~~the U.S. highway 70 bridge~~Palo Verde canyon near Seeping Springs lakes, perennial reaches of the Rio Hondo upstream from Bonney canyon and perennial reaches of Agua Chiquita.

A. Designated uses: fish culture, irrigation, livestock watering, wildlife habitat, coldwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: temperature 30°C (86°F) or less, and phosphorus (unfiltered sample) less than 0.1 mg/L.

BASIS FOR CHANGE: NMED proposes changing segment breaks from "state highway 24 near Dunken" to "Bear Canyon," from "state highway 48 (near Angus Canyon)" to "Angus Canyon," and from "U.S. highway 70 bridge" to "Palo Verde Canyon" because water quality segment breaks should be described by hydrologic features rather than road crossings wherever possible.

20.6.4.209 PECOS RIVER BASIN: Perennial reaches of Eagle creek upstream of Alto dam to the Mescalero Apache boundary, perennial reaches of the Rio Bonito upstream of ~~state highway 48 (near~~ Angus canyon~~)~~ excluding Bonito lake, perennial reaches of tributaries to the Rio Bonito upstream of ~~state highway 48 (near~~ Angus canyon~~)~~, perennial reaches of the Rio Ruidoso upstream of ~~the U.S. highway 70 bridge~~Palo Verde canyon near Seeping Springs lakes above and below the Mescalero Apache boundary and perennial reaches of tributaries to the Rio Ruidoso upstream of ~~the U.S. highway 70 bridge~~Palo Verde canyon near Seeping Springs lakes above and below the Mescalero Apache boundary.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 600 µS/cm or less in Eagle creek, 1,100 µS/cm or less in Bonito creek and 1,500 µS/cm or less in the Rio Ruidoso; phosphorus (unfiltered sample) less than 0.1 mg/L; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

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BASIS FOR CHANGE: NMED proposes changing segment breaks from "state highway 24 near Dunken" to "Bear Canyon," from "state highway 48 (near Angus Canyon)" to "Angus Canyon," and from "U.S. highway 70 bridge" to "Palo Verde Canyon" because water quality segment breaks should be described by hydrologic features rather than road crossings wherever possible.

20.6.4.210 through 20.6.4.212 NMAC – No changes proposed.

20.6.4.213 PECOS RIVER BASIN: McAllister lake.

A. Designated uses: coldwater aquatic life, ~~secondary~~ primary contact, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

BASIS FOR CHANGE: NMED reviewed available 2001 E. coli and pH data and determined a recreational use change from Secondary Contact to Primary Contact is warranted. There is also regular recreation and public access at this lake.

20.6.4.214 through 20.6.4.218 NMAC – No changes proposed.

20.6.4.219 PECOS RIVER BASIN: Avalon reservoir.

A. Designated uses: irrigation storage, livestock watering, wildlife habitat, ~~secondary~~ primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

BASIS FOR CHANGE: NMED reviewed all available E. coli and pH data to determine if a recreational use change from Secondary Contact to Primary Contact is warranted. Although no data could be located, recreation occurs regularly in this lake with BLM public access. Management at nearby Brantley Lake reports that this lake has "… a lot of public use including paddle boarding and kayaking, as well as high traffic for fishing and swimming. This reservoir does have a boat ramp, but limited use for big boats due to its shallow nature." NMED is collecting E. coli and pH data.

20.6.4.220 through 20.6.4.230 NMAC – No changes proposed.

20.6.4.231 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from ~~state highway 24 near Dunken~~ Bear canyon, ~~perennial reaches of North Spring river and~~ perennial reaches of the Rio Hondo and perennial reaches of its tributaries downstream of Bonney canyon.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

BASIS FOR CHANGE: NMED reviewed available 2021-2022 E. coli and pH data and determined a recreational use change from Secondary Contact to Primary Contact for Berrendo Creek, the only other perennial tributary to the Rio Hondo downstream of Bonney canyon, is warranted. Therefore, "perennial reaches of its tributaries" to the Rio Hondo downstream of

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Bonney canyon was added, and "perennial reaches of North Spring river" was removed, to assign Primary Contact to both perennial tributaries.

NMED also proposes changing the segment break from "state highway 24 near Dunken" to "Bear Canyon" because water quality segment breaks should be described by hydrologic features rather than road crossings wherever possible.

20.6.4.232 through 20.6.4.306 NMAC – No changes proposed.

20.6.4.307 CANADIAN RIVER BASIN: Perennial reaches of the Mora river from the USGS gaging station near Shoemaker upstream to the state highway 434 bridge in Mora, all perennial reaches of tributaries to the Mora river downstream from the USGS gaging station at La Cueva in San Miguel and Mora counties except ~~lakes~~ waters identified in 20.6.4.309 NMAC or 20.6.4.313 NMAC, perennial reaches of Ocate creek downstream of Ocate, perennial reaches of tributaries to Ocate creek downstream of Ocate, and perennial reaches of Rayado creek downstream of Miami lake diversion in Colfax county.

A. Designated uses: marginal coldwater aquatic life, warmwater aquatic life, primary contact, irrigation, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

BASIS FOR CHANGE: NMED proposes this revision because the entire Coyote Creek was covered by both this section and section 309 as written. Coyote Creek from the Mora River to Amola Ridge is predominantly in Level 4 Ecoregion 26I (Upper Canadian Plateau) and the corresponding Xeric sedimentation class. Thermograph data (2015) met MCWALU criteria (Tmax 27.3C). AWTC modeling results (1980-2010 input dataset) indicate attainment of MCWALU criteria (Tmax 25.2C, 6T3 21.0C). Therefore, this is the appropriate segment for this reach of Coyote Creek.

20.6.4.308 CANADIAN RIVER BASIN: Charette lakes.

A. Designated uses: coldwater aquatic life, warmwater aquatic life, ~~secondary~~ primary contact, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

BASIS FOR CHANGE: NMED reviewed available 2015-2016 E. coli and pH data and determined a recreational use change from Secondary Contact to Primary Contact is warranted. There is also public access with regular recreation occurring at this lake.

20.6.4.309 CANADIAN RIVER BASIN: The Mora river and perennial reaches of its tributaries upstream from the state highway 434 bridge in Mora except lakes identified in 20.6.4.313 NMAC, all perennial reaches of tributaries to the Mora river upstream from the USGS gaging station at La Cueva, perennial reaches of Coyote creek~~,~~ upstream of Amola ridge and perennial reaches of tributaries to Coyote creek upstream to Amola ridge, the Cimarron river above state highway 21 in Cimarron, perennial reaches of tributaries to the Cimarron river above state highway 21 in Cimarron except Eagle Nest lake, all perennial reaches of tributaries to the Cimarron river north and northwest of highway 64 except north and south Shuree ponds, perennial reaches of Rayado creek above Miami lake diversion, perennial reaches of tributaries to Rayado creek above Miami lake diversion, Ocate creek and perennial reaches of its tributaries upstream of Ocate, perennial reaches of the Vermejo river upstream from Rail canyon and all other perennial reaches of tributaries to the Canadian river northwest and north of U.S. highway 64 in Colfax county unless included in other segments.

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A. Designated uses: domestic water supply, irrigation, high quality coldwater aquatic life, livestock watering, wildlife habitat, and primary contact; and public water supply on the Cimarron river upstream from Cimarron, on perennial reaches of Rayado creek and on perennial reaches of tributaries to Rayado creek.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

BASIS FOR CHANGE: NMED proposes this revision because the entire Coyote Creek was covered by both this section and section 307 as written. See segment 307 Basis for Change.

20.6.4.310 through 20.6.4.317 NMAC – No changes proposed.

20.6.4.318 CANADIAN RIVER BASIN: Doggett creek.

A. Designated uses: Warm water aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following site-specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

C. Discharger-specific temporary standard:

(1) Discharger: City of Raton wastewater treatment plant

(2) NPDES permit number: NM0020273, Outfall 001

(3) Receiving waterbody: Doggett creek, 20.6.4.318 NMAC

(4) Discharge latitude/longitude: 36° 52' 13.91" N / 104° 25' 39.18" W

(5) Pollutant(s): nutrients; total nitrogen and total phosphorus

(6) Factor of issuance: substantial and widespread economic and social impacts (40 CFR 131.10(g)(6))

(7) Highest attainable condition: interim effluent condition of 8.0 mg/L total nitrogen and 1.6 mg/L total phosphorus as 30-day averages. The highest attainable condition shall be either the highest attainable condition identified at the time of the adoption, or any higher attainable condition later identified during any reevaluation, whichever is more stringent (40 CFR 131.14(b)(1)(iii)).

(8) Effective date of temporary standard: ~~This temporary standard becomes~~ effective for Clean Water Act purposes on ~~the date of EPA approval~~ July 24, 2020.

(9) Expiration date of temporary standard: no later than 20 years from the effective date.

(10) Reevaluation period: at each succeeding review of water quality standards and at least once every five years from the effective date of the temporary standard (Paragraph (8) of Subsection H of 20.6.4.10 NMAC, 40 CFR 131.14(b)(1)(v)). If the discharger cannot demonstrate that sufficient progress has been made the commission may revoke approval of the temporary standard or provide additional conditions to the approval of the temporary standard. If the reevaluation is not completed at the frequency specified or the Department does not submit the reevaluation to EPA within 30 days of completion, the underlying designated use and criterion will be the applicable water quality standard for Clean Water Act purposes until the Department completes and submits the reevaluation to EPA. Public input on the reevaluation will be invited during NPDES permit renewals or triennial reviews, as applicable, in accordance with the State's most current approved water quality management plan and continuing planning process.

(11) Timeline for proposed actions. Tasks and target completion dates are listed in the most recent, WQCC-approved version of the New Mexico Environment Department, Surface Water Quality Bureau's "Nutrient Temporary Standards for City of Raton Wastewater Treatment Plant, NPDES No. NM0020273 to Doggett Creek."

BASIS FOR CHANGE: The Temporary Standard became effective upon EPA's approval on July 24, 2020. NMED proposes this amendment to reflect the now established effective date.

NMED completed its reevaluation of the Raton Temporary Standard and presented its findings to the WQCC at its regular meeting on May 13, 2025. NMED found that the social and economic impact from installing controls to meet the underlying standard remained the same (40 CFR

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131.10(g)(6)). Additionally, the Highest Attainable Condition (HAC), reflected by the interim effluent condition for Total Nitrogen and Total Phosphorus, remained the same and implementation of a Pollutant Minimization Program should continue. Monitoring data from 2020-2024 showed a slight improvement in nutrient levels in Doggett Creek, but not enough to meet the underlying Water Quality Standard in the future. The WQCC adopted a resolution to continue the Temporary Standard and incorporate an updated actions and implementation schedule into the NPDES permit in the renewal process expected to begin in July 2025. NMED has submitted its reevaluation to EPA and remains in communication with them. Public comment on the Raton NPDES permit renewal will occur through separate processes from EPA (permit issuance) and NMED (401 permit certification). For more information visit https://www.env.nm.gov/surface-water-quality/ts-raton/.

20.6.4.319 through 20.6.4.402 NMAC – No changes proposed.

20.6.4.403 SAN JUAN RIVER BASIN: The Animas river from its confluence with the San Juan river upstream to Estes arroyo.

A. Designated uses: Public water supply, industrial water supply, irrigation, livestock watering, wildlife habitat, coolwater aquatic life, and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses~~, except that the following segment-specific criterion applies: temperature 29°C (84.2°F) or less~~.

BASIS FOR CHANGE: NMED Proposes to remove this segment-specific criteria because this is the default temperature for Coolwater aquatic life use per 20.6.4.900.H(4) NMAC so it is unnecessary.

20.6.4.404 through 20.6.4.501 NMAC – No changes proposed.

20.6.4.502 GILA RIVER BASIN: The main stem of the Gila river from Redrock canyon upstream to the confluence of the West Fork Gila river and East Fork Gila river and perennial reaches of tributaries to the Gila river downstream of Mogollon creek.

A. Designated uses: industrial water supply, irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, and primary contact~~ and warmwater aquatic life~~.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: 28°C (82.4°F) or less.

BASIS FOR CHANGE: NMED proposes removing the warmwater aquatic life use based on a thorough review and analysis of existing fisheries data, thermograph data, air-water temperature correlation (AWTC) modeling, and recreational fishing information. The Gila River from Mogollon Creek to Red Rock is predominantly in Level 4 Ecoregion 23b (Madrean Lower Montane Woodlands) and the corresponding Foothills sedimentation class. Thermograph data (2007, 2019, 2020) along this reach primarily indicate attainment of the WWALU default criteria, but there was evidence of attainment of the CoolWALU default criteria in the upper reaches of the section in 2007 (TMAX ~28°C). AWTC modeling results (1980-2010 input dataset) also indicate meeting WWALU criteria.

Despite both the predicted and actual water temperature values trending warmer, fisheries species and length data from Iron Bridge, Cherokee Canyon, and Ash Canyon document a fish assemblage dominated by transitional species — those whose temperature tolerances are intermediate between warmwater and coldwater taxa. The proportion of coldwater species

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increased from the 1980s to the 2020s. Additionally, fish size-class data indicate that the reach supports propagation of both coldwater and transitional species.

Removing the warmwater aquatic life use results in no change to applicable criteria because the most stringent criteria is used for Clean Water Act purposes (e.g. 303(d), permitting, TMDLs, etc.).

20.6.4.503 GILA RIVER BASIN: All perennial tributaries to the Gila river upstream of and including Mogollon creek.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance of 400 µS/cm or less for all perennial tributaries except West Fork Gila and tributaries thereto, specific conductance of 300 µS/cm or less; ~~32.2~~ 29°C (~~90~~84°F) or less in the east fork of the Gila river and Sapillo creek downstream of Lake Roberts; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

BASIS FOR CHANGE: NMED proposes lowering the segment-specific temperature criterion for East Fork Gila River and Sapillo Creek downstream of Lake Roberts of 32.2°C (90°F) to 29°C (84°F) based on a thorough review and analysis of existing fisheries data, thermograph data, air-water temperature correlation (AWTC) modeling, and recreational fishing information.

East Fork Gila River downstream of Taylor Creek is predominantly in Level 4 Ecoregion 23 (Conifer Woodlands and Savannas) and the corresponding Foothills sedimentation site class. Fisheries species and size class data for coldwater and transitional fish species Falls Spring area 1980 to present documents a predominance of transitional species, with a small proportion of propagating coldwater species no longer present post 2010. Thermograph data (2007, 2019) document attainment of the CoolWAL default criteria in 2019 (TMAX ~28°C). AWTC modeling (1980-2010 input dataset) indicate attainment of the MCWAL default criteria across the entire reach (TMAX ~28°C and 6T3 ~24°C). Recreational fishing information document presence of smallmouth bass (transitional species) and channel catfish (warmwater species).

Sapillo Creek is in Level 4 Ecoregion 23b (Madrean Lower Montane Woodlands) and the corresponding Foothills sedimentation site class. Thermograph data (2007) document attainment of HQCWAL default criteria (TMAX ~22°C). The very low temperatures are likely due to thermograph placement below the dam and may not be representative of the entire reach. AWTC modeling (1980-2010 input dataset) indicate attainment of the MCWAL default criteria (TMAX ~27°C, 6T3 ~23°C). Recreational fishing information document presence of wild brown and rainbow trout, and stocked Gila trout. The presence of wild trout indicate thermal conditions support propagation of coldwater fish species.

Thermograph data and AWTC modeling in combination with the fisheries data and recreational fishing reports indicate a segment-specific temperature criterion of 29°C (84°F) is existing and attainable for East Fork Gila River and Sapillo Creek downstream of Lake Roberts.

20.6.4.504 through 20.6.4.600 NMAC – No changes proposed.

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20.6.4.601 SAN FRANCISCO RIVER BASIN: The main stem of the San Francisco river from the New Mexico-Arizona line upstream to ~~state highway 12 at Reserve~~ the confluence with Largo canyon and perennial reaches of Mule creek.

A. Designated uses: irrigation, ~~marginal warmwater and~~ marginal coldwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

BASIS FOR CHANGE: NMED proposes moving the segment break from "state highway 12 at Reserve" approximately 0.65 miles downstream to "the confluence with Largo Canyon" because water quality segment breaks should be described by hydrologic features rather than road crossings wherever possible. See the BASIS FOR CHANGE at 20.6.4.602 NMAC for additional information.

In addition, NMED proposes removing the marginal warmwater aquatic life use based on a thorough review and analysis of existing fisheries data, thermograph data, air-water temperature correlation (AWTC) modeling, and recreational fishing information. The San Francisco River running from Box Canyon to Whitewater Creek is in Level 4 Ecoregion 23b (Madrean Lower Montane Woodlands) and the corresponding Foothills sedimentation class. Thermograph data (2019 & 2020) along this reach indicate attainment of the MCWAL default criteria (TMAX ~28, 6T3 ~23). AWTC modeling results (1980-2010 input dataset) indicate attainment of the WWAL criteria (TMAX ~30). Fisheries species and size class data from near Whitewater Creek document a predominantly transitional assemblage with a smaller proportion of coldwater species. Additionally, fish size class data indicate that the reach supports propagation of both coldwater and transitional species.

Removing the warmwater aquatic life use results in no change to applicable criteria because the most stringent criteria are used for Clean Water Act purposes (e.g. 303(d), permitting, TMDLs, etc.).

20.6.4.602 SAN FRANCISCO RIVER BASIN: The main stem of the San Francisco river from ~~state highway 12 at Reserve~~ the confluence with Largo canyon upstream to the New Mexico-Arizona line.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

BASIS FOR CHANGE: NMED proposes moving the segment break from "state highway 12 at Reserve" approximately 0.65 miles downstream to "the confluence with Largo Canyon" because water quality segment breaks should be described by hydrologic features rather than road crossings wherever possible.

20.6.4.603 through 20.6.4.899 NMAC – No changes proposed.

20.6.4.900 CRITERIA APPLICABLE TO EXISTING, DESIGNATED OR ATTAINABLE USES UNLESS OTHERWISE SPECIFIED IN 20.6.4.97 THROUGH 20.6.4.899 NMAC:

20.6.4.900.A through 20.6.4.900.C NMAC – No changes proposed.

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D. Primary contact: The monthly geometric mean of E. coli bacteria of 126 cfu/100 mL or MPN/100 ml, a single sample of E. coli bacteria of 410 cfu/100 mL or MPN/100 mL, a single sample of total microcystins of 8 µg/L ~~with no more than three exceedances within a 12-month period~~ and a single sample of cylindrospermopsin of 15 µg/L ~~with no more than three exceedances within a 12-month period~~, and pH within the range of 6.6 to 9.0 apply to this use. The results for *E. coli* may be reported as either colony forming units (CFU) or the most probable number (MPN) depending on the analytical method used.

BASIS FOR CHANGE: NMED proposes retaining the water quality criteria associated with harmful algal blooms (HABs) in the standards but removing the assessment methodology for microcsystins and cylindrospermopsin. Cyanotoxins are emerging contaminants and the science, technology, and best practices for monitoring them are evolving. Primary contact is a designated use addressing health risks during recreation on the water and criteria are critical for evaluating whether the water conditions are safe for recreation. HABs are unpredictable, are difficult to monitor, and can become a concern very quickly. Removing the assessment methodology allows NMED to keep up with the evolving science regarding cyanotoxin monitoring and assessment to ensure New Mexico's waters are safe for recreation and respond quickly to communicate potential risk to the public.

20.6.4.900.E through 20.6.4.900.G NMAC – No changes proposed.

H. Aquatic life: Surface waters of the state with a designated, existing or attainable use of aquatic life shall be free from any substances at concentrations that can impair the community of plants and animals in or the ecological integrity of surface waters of the state. Except as provided in Paragraph (7) of this subsection, the acute and chronic aquatic life criteria set out in Subsections I, J, K and L of this section and the human health-organism only criteria set out in Subsection J of this section are applicable to all aquatic life use subcategories. In addition, the specific criteria for aquatic life subcategories in the following paragraphs apply to waters classified under the respective designations.

(1) High quality coldwater: dissolved oxygen 6.0 mg/L or more, 4T3 temperature 20°C (68°F), maximum temperature 23°C (73°F), pH within the range of 6.6 to 8.8 and specific conductance a segment-specific limit between 300 µS/cm and 1,500 µS/cm depending on the natural background in the particular surface water of the state (the intent of this criterion is to prevent excessive increases in dissolved solids which would result in changes in community structure). Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 4T3 temperature applies.

(2) Coldwater: dissolved oxygen 6.0 mg/L or more, 6T3 temperature 20°C (68°F), maximum temperature 24°C (75°F) and pH within the range of 6.6 to 8.8. Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 6T3 temperature applies.

(3) Marginal coldwater: dissolved oxygen 6 mg/L or more, 6T3 temperature 25°C (77°F), maximum temperature 29°C (84°F) and pH within the range from 6.6 to 9.0. Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 6T3 temperature applies.

(4) Coolwater: dissolved oxygen 5.0 mg/L or more, maximum temperature 29°C (84°F) and pH within the range of 6.6 to 9.0.

(5) Warmwater: dissolved oxygen 5 mg/L or more, maximum temperature 32.2°C (90°F) and pH within the range of 6.6 to 9.0. Where a segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature.

(6) Marginal warmwater: dissolved oxygen 5 mg/L or more, pH within the range of 6.6 to 9.0 and temperatures that may routinely exceed 32.2°C (90°F). Where a segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature.

(7) Limited aquatic life: pH within the range of 6.0 to 9.0. The acute aquatic life criteria of Subsections I and J of this section apply to this subcategory. Chronic aquatic life criteria do not apply unless adopted on a segment-specific basis. Human health-organism only criteria apply only for persistent toxic pollutants unless adopted on a segment-specific basis.

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BASIS FOR CHANGE: NMED proposes including a default pH range for limited aquatic life within 6.0 to 9.0 SU in agreement with Technology Based Effluent Limits included in National Pollutant Discharge Elimination System (NPDES) Permits. Limited Aquatic life applies to waters listed in sections 97, 124, 128,136 and 809 of 20.6.4 NMAC. Section 136 waters include Primary Contact designated use and have existing pH criteria of 6.6 – 9.0 per 20.6.4.900.D NMAC. The most stringent criteria apply to waters with criteria for the same parameter for multiple designated uses; therefore, 6.6 – 9.0 would remain the applicable criteria for Section 136. In addition, literature shows that a pH range of 6.0 to 9.0 provides adequate protection for the life of freshwater fish and bottom-dwelling macroinvertebrates and a pH range of 5.0-9.0 is not directly lethal. Outside this range, aquatic life populations would be reduced and growth or reproduction impacted until lethal levels are reached (USEPA 1986; Robertson-Bryan, Inc. 2004). For more information regarding pH criteria see US EPA Quality Criteria for Water at https://www.epa.gov/sites/production/files/2018-10/documents/quality-criteria-water-1986.pdf and Road, W., and E. Grove. 2004. pH Requirements of Freshwater Aquatic Life. Technical Memorandum, Robertson-Bryan Inc., Central Valley California Water Resources Control Board.

20.6.4.900.I NMAC – No changes proposed.

J. Use-specific numeric criteria.

(1) Table of numeric criteria: The following table sets forth the numeric criteria in µg/L, unless otherwise indicated, applicable to existing, designated and attainable uses. For metals, criteria represent the total sample fraction unless otherwise specified in the table. Additional criteria that are not compatible with this table are found in Subsections A through I and K through M of 20.6.4.900 NMAC.

Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Aluminum, dissolved	7429-90-5		5,000			750 ~~i~~h	87 ~~i~~h		
Aluminum, total recoverable	7429-90-5					a	a		
Antimony, dissolved	7440-36-0	6						640	P
Arsenic, dissolved	7440-38-2	10	100	200		340	150	9.0	C,P
Asbestos (fibers/L)	1332-21-4	~~7,000,000 fibers/L~~7.0E06							
Barium, dissolved	7440-39-3	2,000							
Beryllium, dissolved	7440-41-7	4							
Boron, dissolved	7440-42-8		750	5,000					
Cadmium, dissolved	7440-43-9	5	10	50		a	a		
Chloride	1688-70-06					~~860,000~~ 8.6E05	~~230,000~~ 2.3E05		
Chlorine residual	7782-50-5				11	19	11		

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Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Chromium III, dissolved	16065-83-1					a	a		
Chromium VI, dissolved	18540-29-9					16	11		
Chromium, dissolved	7440-47-3	100	100	1,000					
Cobalt, dissolved	7440-48-4		50	1,000					
Copper, dissolved	7440-50-8	1300	200	500		a	a		
Cyanide, total recoverable	57-12-5	200			5.2	22.0	5.2	400	
Iron	7439-89-6						1,000		
Lead, dissolved	7439-92-1	~~15~~10	5,000	100		a	a		
Manganese, dissolved	7439-96-5					a	a		
Mercury	7439-97-6	2		10	0.77				P
Mercury, dissolved	7439-97-6					1.4	0.77		P
Methylmercury	22967-92-6							0.3 mg/kg in fish tissue	P
Molybdenum, dissolved	7439-98-7		1,000						
Molybdenum, total recoverable	7439-98-7					7,920	1,895		
Nickel, dissolved	7440-02-0	700				a	a	4,600	P
Nitrate as N (mg/L)		10 ~~mg/L~~							
Nitrite + Nitrate (mg/L)				132 ~~mg/L~~					
Selenium, dissolved	7782-49-2	50	b	50			1.5 in lentic water, i 3.1 in lotic water, i	4,200	P
Selenium, total recoverable	7782-49-2				5.0	~~20.0~~	~~5.0~~ 8.5 mg/kg Dry Weight in Whole-Body Fish Tissue 11.3 mg/kg Dry Weight in Fish Muscle Tissue		
Silver, dissolved	7440-22-4					a			
Thallium, dissolved	7440-28-0	2						0.47	P

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Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Uranium, dissolved	7440-61-1	30							
Vanadium, dissolved	7440-62-2		100	100					P
Zinc, dissolved	7440-66-6	10,500	2,000	25,000		a	a	26,000	P
Adjusted gross alpha (pCi/L)		15 ~~pCi/L~~		15 ~~pCi/L~~					
Radium 226 + Radium 228 (pCi/L)		5 ~~pCi/L~~		30.0 ~~pCi/L~~					
Strontium 90 (pCi/L)		8 ~~pCi/L~~							
Tritium (pCi/L)		20,000 ~~pCi/L~~		20,000 ~~pCi/L~~					
Acenaphthene	83-32-9	2,100						90	
Acrolein	107-02-8	18				3.0	3.0	400	
Acrylonitrile	107-13-1	0.65						70	C
Aldrin	309-00-2	0.021				3.0		~~0.000007 7~~ 7.7E-06	C,P
Anthracene	120-12-7	10,500						400	
Benzene	71-43-2	5						160	C
Benzidine	92-87-5	0.0015						0.11	C
Benzo(a)anthracene	56-55-3	0.048						0.013	C, P
Benzo(a)pyrene	50-32-8	0.2						0.0013	C,P
Benzo(b)fluoranthene	205-99-2	0.048						0.013	C, P
Benzo(k)fluoranthene	207-08-9	0.048						0.13	C, P
alpha-BHC	319-84-6	0.056						0.0039	C
beta-BHC	319-85-7	0.091						0.14	C
gamma-BHC (Lindane)	58-89-9	0.20				0.95		4.4	
Bis(2-chloroethyl) ether	111-44-4	0.30						22	C
Bis(2-chloro-1-methylethyl) ether	108-60-1	1,400						4,000	
Bis(2-ethylhexyl) phthalate	117-81-7	6						3.7	C
Bis(chloromethyl) ether	542-88-1							0.17	C
Bromoform	75-25-2	44						1,200	C
Butylbenzyl phthalate	85-68-7	7,000						1	C
Carbaryl	63-25-2					2.1	2.1		
Carbon tetrachloride	56-23-5	5						50	C
Chlordane	57-74-9	2				2.4	0.0043	0.0032	C,P
Chlorobenzene	108-90-7	100						800	
Chlorodibromomethane	124-48-1	4.2						210	C
Chloroform	67-66-3	57						2,000	
Chlorpyrifos	2921-88-2					0.083	0.041		P
2-Chloronaphthalene	91-58-7	2,800						1,000	
2-Chlorophenol	95-57-8	175						800	
Chrysene	218-01-9	0.048						1.3	C, P
Demeton	8065-48-3						0.1		
Diazinon	333-41-5					0.17	0.17		

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Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
2,4-Dichlorophenoxyacetic acid (2,4-D)	94-75-7	70						12,000	
Dichlorodiphenyldichloroethane (DDD)	72-54-8							0.0012	C
Dichlorodiphenyldichloroethylene (DDE)	72-55-9							0.00018	C
Dichlorodiphenyltrichloroethane (DDT)	50-29-3							0.0003	C,P
4,4'-DDT and derivatives		1.0			0.001	1.1	0.001		P
Dibenzo(a,h)anthracene	53-70-3	0.048						0.0013	C, P
Dibutyl phthalate	84-74-2	3,500						30	
1,2-Dichlorobenzene	95-50-1	600						3,000	
1,3-Dichlorobenzene	541-73-1	469						10	
1,4-Dichlorobenzene	106-46-7	75						900	
3,3'-Dichlorobenzidine	91-94-1	0.78						1.5	C
Dichlorobromomethane	75-27-4	5.6						270	C
1,2-Dichloroethane	107-06-2	5						6,500	C
1,1-Dichloroethylene	75-35-4	7						20,000	
2,4-Dichlorophenol	120-83-2	105						60	
1,2-Dichloropropane	78-87-5	5.0						310	C
1,3-Dichloropropene	542-75-6	3.5						120	C
Dieldrin	60-57-1	0.022				0.24	0.056	~~0.000012~~ 1.2E-05	C,P
Diethyl phthalate	84-66-2	28,000						600	
Dimethyl phthalate	131-11-3	~~350,000~~ 3.5E05						2,000	
2,4-Dimethylphenol	105-67-9	700						3,000	
Dinitrophenols	25550-58-7							1,000	
2,4-Dinitrophenol	51-28-5	70						300	
2,4-Dinitrotoluene	121-14-2	1.1						17	C
Dioxin	1746-01-6	3.0E-05						5.1E-08	C,P
1,2-Diphenylhydrazine	122-66-7	0.44						2.0	C
alpha-Endosulfan	959-98-8	62				0.22	0.056	30	
beta-Endosulfan	33213-65-9	62				0.22	0.056	40	
Endosulfan sulfate	1031-07-8	62						40	
Endrin	72-20-8	2				0.086	0.036	0.03	P
Endrin aldehyde	7421-93-4	10.5						1	
Ethylbenzene	100-41-4	700						130	
Fluoranthene	206-44-0	1,400						20	P
Fluorene	86-73-7	1,400						70	
Guthion	86-50-0						0.01		
Heptachlor	76-44-8	0.40				0.52	0.0038	~~0.000059~~ 5.9E-05	C, P

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Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Heptachlor epoxide	1024-57-3	0.20				0.52	0.0038	0.00032	C
Hexachlorobenzene	118-74-1	1						0.00079	C,P
Hexachlorobutadiene	87-68-3	4.5						0.1	C, P
Hexachlorocyclohexane (HCH)-Technical	608-73-1							0.1	C
Hexachlorocyclopentadiene	77-47-4	50						4	
Hexachloroethane	67-72-1	25						1	C
Indeno(1,2,3-cd)pyrene	193-39-5	0.048						0.013	C, P
Isophorone	78-59-1	368						18,000	C
Malathion	121-75-5						0.1		
Methoxychlor	72-43-5	40					0.03	0.02	P
Methyl bromide	74-83-9	49						10,000	
3-Methyl-4-chlorophenol	59-50-7							2,000	
2-Methyl-4,6-dinitrophenol	534-52-1	14						30	
Methylene chloride	75-09-2	5						10,000	C
Mirex	2385-85-5						0.001		P
Nitrobenzene	98-95-3	18						600	
Nitrosamines	Various							12.4	C
Nitrosodibutylamine	924-16-3							2.2	C
Nitrosodiethylamine	55-18-5							12.4	C
N-Nitrosodimethylamine	62-75-9	0.0069						30	C
N-Nitrosodi-n-propylamine	621-64-7	0.050						5.1	C
N-Nitrosodiphenylamine	86-30-6	71						60	C
N-Nitrosopyrrolidine	930-55-2							340	C
Nonylphenol	84852-15-3					28	6.6		
Parathion	56-38-2					0.065	0.013		
Pentachlorobenzene	608-93-5							0.1	
Pentachlorophenol	87-86-5	1.0				19	15	0.4	C
Perfluorooctane sulfonate (PFOS)	Various					71	0.25 in water 0.028 mg/kg Wet Weight in Invertebrate Whole-Body Tissue 0.201 mg/kg Wet Weight in Fish Whole-Body Tissues 0.087 mg/kg Wet Weight in Fish Muscle Tissue		P

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Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Perfluorooctanoic acid (PFOA)	Various					3,100	100 in water 1.18 mg/kg Wet Weight in Invertebrate Whole-Body Tissue 6.49 mg/kg Wet Weight Fish Whole-Body Tissue 0.133 mg/kg Wet Weight Fish Muscle Tissue		P
Phenol	108-95-2	10,500						~~300,000~~ 3.0E05	
Polychlorinated Biphenyls (PCBs)	1336-36-3	0.50			0.014	2	0.014	0.00064	C,P
Pyrene	129-00-0	1,050						30	
1,2,4,5-Tetrachlorobenzene	95-94-3							0.03	
1,1,2,2-Tetrachloroethane	79-34-5	1.8						30	C
Tetrachloroethylene	127-18-4	5						290	C,P
Toluene	108-88-3	1,000						520	
Toxaphene	8001-35-2	3				0.73	0.0002	0.0071	C, P
1,2-Trans-dichloroethylene	156-60-5	100						4,000	
Tributyltin (TBT)	Various					0.46	0.072		
1,2,4-Trichlorobenzene	120-82-1	70						0.76	C
1,1,1-Trichloroethane	71-55-6	200						~~200,000~~ 2.0E05	
1,1,2-Trichloroethane	79-00-5	5						89	C
Trichloroethylene	79-01-6	5						70	C
2,4,5-Trichlorophenol	95-95-4							600	
2,4,6-Trichlorophenol	88-06-2	32						28	C
2-(2,4,5-Trichlorophenoxy)propionic acid (Silvex)	93-72-1	50						400	
Vinyl chloride	75-01-4	2						16	C

(2) Notes applicable to the table of numeric criteria in Paragraph (1) of this subsection.

(a) Where the letter "a" is indicated in a cell, the criterion is based on receiving water characteristics and can be referenced in Subsection I of 20.6.4.900 NMAC.

(b) Where the letter "b" is indicated in a cell, the criterion can be referenced in Subsection C of 20.6.4.900 NMAC.

~~**(c)** Criteria are in µg/L unless otherwise indicated.~~

(~~d~~c) Abbreviations are as follows: CAS - chemical abstracts service (see definition for "CAS number" in 20.6.4.7 NMAC); DWS - domestic water supply; Irr/Irr storage- irrigation and irrigation storage; LW - livestock watering; WH - wildlife habitat; HH-OO - human health-organism only; C – criteria based on cancer-causing endpoint; P - persistent toxic pollutant.

(~~e~~d) The criteria are based on analysis of an unfiltered sample unless otherwise indicated. The acute and chronic aquatic life criteria for aluminum are based on analysis of total recoverable aluminum in a sample that is filtered to minimize mineral phases as specified by the department.

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(~~f~~e) The criteria listed under human health-organism only (HH-OO) are intended to protect human health when aquatic organisms are consumed from waters containing pollutants. These criteria do not protect the aquatic life itself; rather, they protect the health of humans who ingest fish or other aquatic organisms.

(~~g~~f) The dioxin criteria apply to the sum of the dioxin toxicity equivalents expressed as 2,3,7,8-TCDD dioxin.

(~~h~~g) The criteria for polychlorinated biphenyls (PCBs) apply to the sum of all congeners, to the sum of all homologs or to the sum of all aroclors.

(~~i~~h) The acute and chronic aquatic life criteria for dissolved aluminum only apply when the concurrent pH is less than 6.5 or greater than 9.0 S.U. If the concurrent pH is between 6.5 and 9.0 S.U. then the hardness-dependent total recoverable aluminum criteria in Paragraphs (1) and (2) of Subsection I of 20.6.4.900 NMAC apply.

(i) Selenium water column criteria include 30-day mean dissolved selenium concentrations for lentic systems, including lakes and impoundments, and lotic systems, including rivers and streams.

BASIS FOR CHANGE: NMED proposes several non-substantive changes to more prominently and uniformly display units for the table. Scientific notation applied to values less than 0.0001 and equal to or greater than 100,000 for ease of reading and uniformity with existing criteria in scientific notation. Changes to lettering as the result of moving note 2(c) to paragraph (1) proceeding the table.

New aquatic life use criteria

Per- and poly- fluoroalkyl substances (PFAS): NMED proposes to adopt EPA recommended acute and chronic 304(a) criteria for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) aquatic life uses. EPA published final freshwater aquatic life criteria for acute and chronic PFOA and PFOS exposure (Federal Register Vol. 89, pp 81077-81079, October 7, 2024). EPA developed chronic and acute freshwater-based criteria and chronic tissue-based criteria for PFOA and PFOS. Chronic freshwater-based and chronic tissue-based criteria are independently applicable and no one criterion takes primacy.

PFAS, including PFOA and PFOS, are human-made organic chemicals that are persistent in the environment and are found in environmental samples worldwide. At elevated concentrations, PFOA and PFOS are toxic to aquatic species, including fish. Due to the widespread distribution and toxic effects of PFOA and PFOS, NMED recommends adoption of EPA's recommended criteria to protect aquatic life.

Selenium: NMED proposes to adopt EPA recommended 304(a) chronic criteria for selenium aquatic life uses. EPA published selenium aquatic life criteria in 2016 (Federal Register Vol. 81, pp 45285-45287, July 13, 2016), but NMED elected not to adopt new criteria during previous triennial review due to lack of EPA implementation guidance to states or tribes. In 2024, EPA published technical support documents for the adoption and implementation of selenium water quality standards.

Selenium is a naturally occurring element that can enter surface waters from natural or anthropogenic sources. Selenium bioaccumulates in aquatic organisms and at high concentrations can cause reproductive impairment of egg-laying species like fish. Due to the negative effects of high concentrations of selenium to aquatic organisms, including fish

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propagation. NMED recommends adoption of EPA's recommended criteria to protect aquatic life.

New criteria for Domestic Water Supply (DWS) designated use proposed based on an EPA Maximum Contaminant Level (MCL) or Treatment Technique established under the National Primary Drinking Water Regulations. DWS criteria are only adopted for chemicals with an EPA recommended 304(a) criteria.

NMED proposes to review and update designations of persistent toxic pollutants in the numeric criteria table.

20.6.4.900.K NMAC – No changes proposed.

L. The acute aquatic life criteria for TAN (mg/L) was derived by the EPA (2013) as the one-hour average concentration of TAN mg/L that shall not be exceeded more than once every three years on average. The EPA acute criterion magnitude was derived using the following equation:

Acute TAN Criterion Magnitude for 1-hour average=

$$\text{MIN}\left(\left(\frac{0.275}{1+10^{7.204-pH}}+\frac{39}{1+10^{pH-7.204}}\right),\left(0.7249\text{x}\left(\frac{0.0114}{1+10^{7.204-pH}}+\frac{1.6181}{1+10^{pH-7.204}}\right)\text{x}\left(23.12\times 10^{0.036(20-T)}\right)\right)\right)$$

*T (*temperature C) and *pH* are defined as the paired values associated with the TAN sample.

(1) Temperature and pH-dependent values of the acute TAN criterion magnitude -when *Oncorhynchus* spp. absent.

	Temperature (°C)																				
pH	0-10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	51	48	44	41	37	34	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	49	46	42	39	36	33	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	46	44	40	37	34	31	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9
6.8	44	41	38	35	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	41	38	35	32	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	38	35	33	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9	7.3
7.1	34	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	31	29	27	25	23	21	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6
7.3	27	26	24	22	20	18	17	16	14	13	12	11	10	9.5	8.7	8	7.4	6.8	6.3	5.8	5.3
7.4	24	22	21	19	18	16	15	14	13	12	11	9.8	9	8.3	7.7	7	6.5	6	5.5	5.1	4.7
7.5	21	19	18	17	15	14	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4
7.6	18	17	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	2.9
7.8	13	12	11	10	9.3	8.5	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4	3.7	3.4	3.2	2.9	2.7	2.5
7.9	11	9.9	9.1	8.4	7.7	7.1	6.6	~~3~~6.0	5.6	5.1	4.7	4.3	4	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	8.8	8.2	7.6	7	6.4	5.9	5.4	5	4.6	4.2	3.9	3.6	3.3	3	2.8	2.6	2.4	2.2	2	1.9	1.7
8.1	7.2	6.8	6.3	5.8	5.3	4.9	4.5	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4
8.2	6	5.6	5.2	4.8	4.4	4	3.7	3.4	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	4.9	4.6	4.3	3.9	3.6	3.3	3.1	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1	0.96
8.4	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79
8.5	3.3	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.98	0.9	0.83	0.77	0.71	0.65
8.6	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.5	1.3	1.2	1.1	1	0.96	0.88	0.81	0.75	0.69	0.63	0.58	0.54
8.7	2.3	2.2	2	1.8	1.7	1.6	1.4	1.3	1.2	1.1	1	0.94	0.87	0.8	0.74	0.68	0.62	0.57	0.53	0.49	0.45

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8.8	1.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37
8.9	1.6	1.5	1.4	1.3	1.2	1.1	1	0.93	0.85	0.79	0.72	0.67	0.61	0.56	0.52	0.48	0.44	0.4	0.37	0.34	0.32
9.0	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37	0.34	0.32	0.29	0.27

BASIS FOR CHANGE: NMED proposes this non-substantive change to align with EPA's recommendation in their 2020 Triennial Review Technical Support Document. The published value is a typographical error carried over from previous EPA 304(a) criteria documents.

20.6.4.900.L(2) through 20.6.4.900.M NMAC – No changes proposed.

20.6.4.901 PUBLICATION REFERENCES: These documents are intended as guidance and are available for public review during regular business hours at the offices of the surface water quality bureau. Copies of these documents have also been filed with the New Mexico state records center ~~in order~~ to provide greater access to this information.

A. American public health association. 1992. *Standard Methods for The Examination of Water and Wastewater, 18th Edition.* Washington, D.C. 1048 p.

B. American public health association. 1995. *Standard Methods for The Examination of Water and Wastewater, 19th Edition.* Washington, D.C. 1090 p.

C. American public health association. 1998. *Standard Methods for The Examination of Water and Wastewater, 20th Edition.* Washington, D.C. 1112 p.

D. American public health association. 2018. *Standard Methods for The Examination of Water and Wastewater, 23rd Edition.* Washington, D.C. 1796 p.

E. American public health association. 2023. *Standard Methods for The Examination of Water and Wastewater, 24th Edition.* Washington, D.C. 1516 p.

~~E~~F. United States geological survey. 1989. *Methods For Determination of Inorganic Substances In Water And Fluvial Sediments, Techniques of Water-Resource Investigations of The United States Geological Survey.* Washington, D.C. 545 p.

~~F~~G. United States geological survey. 1987. *Methods For The Determination Of Organic Substances In Water And Fluvial Sediments, Techniques Of Water-Resource Investigations Of The United States Geological Survey.* Washington, D.C. 80 p.

~~G~~H. United States environmental protection agency. 1983. *Methods For Chemical Analysis Of Water And Wastes.* Office of research and development, Washington, DC. (EPA/600/4-79/020). 491 p.

~~H~~I. New Mexico water quality control commission. 2020. *State Of New Mexico Water Quality Management Plan and Continuing Planning Process*. Santa Fe, New Mexico. 277 p.

~~I~~J. Colorado river basin salinity control forum. ~~2020~~2023. ~~*2020*~~*2023 Review, Water Quality Standards For Salinity, Colorado River System.* Phoenix, Arizona. ~~97~~112 p.

~~J~~K. United States environmental protection agency. 2002. *Methods For Measuring The Acute Toxicity Of Effluents And Receiving Waters To Freshwater And Marine Organisms.* Office of research and development, Washington, D.C. (5th Ed., EPA 821-R-02-012). 293 p.

~~K~~L. United States environmental protection agency. 2002. *Short-Term Methods For Estimating The Chronic Toxicity Of Effluents And Receiving Waters To Freshwater Organisms.* Environmental monitoring systems laboratory, Cincinnati, Ohio. (4th Ed., EPA 821-R-02-013). 335 p.

~~L~~M. United States environmental protection agency. 1991. Ambient-induced mixing, in *Technical Support Document For Water Quality-Based Toxics Control*. Office of water, Washington, D.C. (EPA/505/2-90-001). 335 p.

~~M~~N. United States environmental protection agency. 1983. *Technical Support Manual: Waterbody Surveys And Assessments For Conducting Use Attainability Analyses, Volume I*:. Office of water, regulations and standards, Washington, D.C. 232 p.

~~N~~O. United States environmental protection agency. 1984. *Technical Support Manual: Waterbody Surveys And Assessments For Conducting Use Attainability Analyses, Volume III: Lake Systems*. Office of water, regulations and standards, Washington, D.C. 208 p.

BASIS FOR CHANGE: NMED proposes to remove unnecessary language in the initial paragraph of Section 901. NMED proposes adding the most recent edition of Standard Methods

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for the Examination of Water and Wastewater. This addition results in the re-lettering of the subsequent references to 20.6.4.901.F through 20.6.4.901.O NMAC. NMED proposes to update the Colorado River Basin Salinity Control Forum to the most recent version.

NMED Exhibit 9

From: New Mexico Environment Department
To: Baca, Michael, ENV
Subject: 2026 Triennial Review – Draft Amendments and Public Comment Period
Date: Friday, August 15, 2025 12:05:45 PM

Surface Water Quality Bureau

SWQB logo

Our mission is to preserve, protect, and improve New Mexico's surface water quality for present and future generations.

Oficina de Calidad de Aguas Superficiales

Nuestra misión es preservar, proteger y mejorar la calidad de las aguas superficiales de Nuevo México para las generaciones presentes y futuras.

The New Mexico Environment Department's (NMED) Surface Water Quality Bureau (SWQB) invites the public to comment on NMED's draft amendments to the State's Standards for Interstate and Intrastate Surface Waters, 20.6.4 New Mexico Administrative Code (NMAC). **The 60-day public comment period for the draft amendments begins August 15, 2025 and closes October 14, 2025.**

Please note that comments submitted to NMED SWQB on the Public Review Draft are for further developing the draft amendments prior to petitioning the Water Quality Control Commission for a rulemaking hearing. An additional public comment period will be held in conjunction with the rulemaking hearing pursuant to 20.1.6.204(B) NMAC.

Background

It is the objective of the federal Clean Water Act (CWA) to restore and maintain the chemical, physical, and biological integrity of the nation's waters, including those in New Mexico. As part of upholding the objective of the CWA, the State of New Mexico is required by statute to adopt water quality standards that protect the public health or welfare and enhance the quality of water, and are consistent with and serve the purposes of the New Mexico Water Quality Act (WQA) and the federal CWA. New Mexico's surface water quality standards are codified under 20.6.4 NMAC.

In accordance with Section 303(c)(1) of the CWA and 20.6.4.10 NMAC, States are required to hold public hearings at least once every three years to review, amend, and adopt water quality standards, as applicable. This is referred to as a "Triennial Review." Pursuant to Section 74-6-4(F) of the WQA, the Water Quality Control Commission (WQCC) delegated NMED the responsibility for organizing and proposing amendments to the state's surface water quality standards.

The last Triennial Review of the state's surface water quality standards was approved by the U.S. Environmental Protection Agency in January 2023. Therefore, NMED is initiating the current Triennial Review process by providing NMED's draft amendments to the public for comment. NMED intends to consider public comments and petition the WQCC by the end of 2025 for a hearing in the second half of 2026.

How to participate

Comments will be accepted via mail, email, and NMED's smart comment portal at https://nmed.commentinput.com/comment/search. The public review draft and all other related information may be found on NMED's website through the Smart Comment Portal or at https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. The public review draft contains draft amendments to the regulatory language along with rationale for each amendment.

For more information and to submit comments contact Michael Baca, Water Quality Standards Coordinator, NMED SWQB, P.O. Box 5469, Santa Fe, NM, 87502, (505) 470-1652 or michael.baca1@env.nm.gov. To stay up to date with the latest news from NMED, please sign up for our listserv at https://public.govdelivery.com/accounts/NMED/subscriber/new?topic_id=NMED_4.

Public Meeting

In addition, NMED SWQB will be hosting a virtual informational meeting via WebEx to present and discuss the draft amendments to the State's Standards for Interstate and Intrastate Surface Waters, 20.6.4 NMAC, and provide a forum for interested parties and the public to ask questions. Information regarding this meeting is as follows:

Wednesday, September 10, 2025 at 5:30 pm

To connect via video conference, go to: https://nmed-oit.webex.com/nmed-oit/j.php?MTID=mcef4d38bc6992f8d56094eb92a5cbe4d

Meeting number/access code:2861 793 5532
Password: XFer7qTYf32
Join by phone:+1-415-655-0001 US Toll

If you have difficulties logging on to the meeting at the scheduled time, please contact Lynette Guevara at 505-629-8811 or lynette.guevara@env.nm.gov.

Persons having a disability or requiring assistance or auxiliary aid to participate in this public process should contact the NMED Human Resources Bureau at least 10 days before any scheduled meeting, by mail at P.O. Box 5469, 1190 St. Francis Drive, Santa Fe, New Mexico, 87502, telephone 505-487-0348. TDD or TDY users please access HRB via the New Mexico Relay Network at 1-800-659-8331.

NMED does not discriminate on the basis of race, color, national origin, disability, age or sex in the administration of its programs or activities, as required by applicable laws and regulations. NMED is responsible for coordination of compliance efforts and receipt of inquiries concerning non-discrimination requirements implemented by 40 C.F.R. Parts 5 and 7, including Title VI of the Civil Rights Act of 1964, as amended; Section 504 of the Rehabilitation Act of 1973; the Age Discrimination Act of 1975, Title IX of the Education Amendments of 1972, and Section 13 of the Federal Water Pollution Control Act Amendments of 1972. If you have any questions about this notice or any of NMED's non-discrimination programs, policies or procedures, you may contact:

Kate Cardenas, Non-Discrimination Coordinator
New Mexico Environment Department
1190 St. Francis Dr., Suite N4050
P.O. Box 5469
Santa Fe, NM 87502
(505) 827-2855
nd.coordinator@env.nm.gov
https://www.env.nm.gov/general/environmental-justice-in-new-mexico/

If you believe that you have been discriminated against with respect to a NMED program or activity, you may contact the Non-Discrimination Coordinator identified above.

La Oficina de Calidad de Aguas Superficiales (SWQB, por sus siglas en inglés) del Departamento de Medio Ambiente de Nuevo México (NMED, por sus siglas en inglés) invita al público a que hagan comentarios sobre las enmiendas propuestas por el NMED a los Estándares Estatales para Aguas Superficiales Interestatales y Estatales, 20.6.4 Código Administrativo de Nuevo México (NMAC, por

sus siglas en inglés). **El período de 60 días de comentarios públicos para las enmiendas propuestas comienza el 15 de augusto de 2025 y se cierra el 14 de octubre de 2025.**

Tenga en cuenta que los comentarios presentados a NMED SWQB sobre el Borrador de Comentarios Públicos son para la consideración de NMED SWQB en el desarrollo adicional de las enmiendas propuestas antes de las fechas límite de la audiencia preliminar para presentar testimonios técnicos. Los comentarios destinados a formar parte del registro de audiencia de la WQCC 20-51 (R) deberán enviarse al administrador de audiencias de la WQCC de conformidad con el 20.1.6.204(B) NMAC.

El objetivo de la Ley Federal de Agua Limpia (CWA, por sus siglas en inglés) es restaurar y mantener la integridad química, física y biológica de las aguas del país, incluidas las de Nuevo México. Como parte de la defensa del objetivo de la CWA, el Estado de Nuevo México está obligado por ley a adoptar normas de calidad del agua que protejan la salud o el bienestar público y mejoren la calidad del agua, y que sean consistentes y sirvan a los propósitos de la Ley de Calidad del Agua de Nuevo México (WQA, por sus siglas en inglés) y la CWA federal. Los Estándares de calidad de las aguas superficiales de Nuevo México están codificadas en 20.6.4 NMAC.

De conformidad con la Sección 303 (c)(1) de la CWA y 20.6.4.10 NMAC, los estados están obligados a celebrar audiencias públicas al menos una vez cada tres años para revisar, enmendar y adoptar estándares de calidad del agua, según proceda. Esto se conoce como "Revisión Trienal". De conformidad con la Sección 74-6-4(F) de la WQA, la Comisión de Control de la Calidad del Agua (WQCC, por sus siglas en inglés) delegó al NMED la responsabilidad de organizar y proponer enmiendas a los Estándares de calidad de las aguas superficiales del estado.

La última revisión trienal de los Estándares de calidad de las aguas superficiales del estado fue aprobada por la Agencia de Protección Ambiental de los Estados Unidos en enero de 2023. Por lo tanto, el NMED inicio el actual proceso de Revisión Trienal y proporcionando las enmiendas propuestas por el NMED al público para comentarios. NMED entendía solicitar a la WQCC en diciembre de 2025 una fecha de audiencia en la segunda mitad de 2026.

Cómo participar

Los comentarios se aceptarán por correo postal, correo electrónico y el portal de comentarios inteligente de NMED en https://nmed.commentinput.com/comment/search. Las enmiendas propuestas, abiertas a comentarios públicos en este momento, se pueden encontrar en: https://www.env.nm.gov/surface-water-quality/wqs/.

Para más información y presenta comentarios contacta con Michael Baca, Water Quality Standards Coordinator, NMED SWQB, P.O. Box 5469, Santa Fe, NM, 87502, (505) 470-1652 ormichael.baca1@env.nm.gov. Regístrese para recibir actualizaciones del NMED, haga clic aquí https://public.govdelivery.com/accounts/NMED/subscriber/new?topic_id=NMED_4.

Además, NMED-SWQB organizará dos reuniones informativas virtuales a través de WebEx para presentar y discutir las enmiendas propuestas a los Estándares Estatales para Aguas Superficiales Interestatales y Estatales, 20.6.4 NMAC, y proporcionar un foro para que las partes interesadas y el público hagan preguntas. La información sobre estas reuniones es la siguiente:

Miércoles, 10 de septiembre, 2025 a las 5:30 pm

Para conectarse a través de videoconferencia, vaya a: https://nmed-oit.webex.com/nmed-oit/j.php?MTID=mcef4d38bc6992f8d56094eb92a5cbe4d
Número de reunión/código de acceso: 2861 793 5532
Contraseña: XFer7qTYf32
Únete por teléfono:+1-415-655-0001 US Toll

Si tiene dificultades para acceder a la reunión a la hora programada, comuníquese con Lynette Guevara at 505-629-8811 or lynette.guevara@env.nm.gov.

Las personas que tengan una discapacidad o que requieran asistencia o un dispositivo auxiliar para participar en este proceso público deben comunicarse con la Oficina de Recursos Humanos del NMED al menos 10 días antes de cualquier reunión programada, por correo postal en P.O. Box 5469, 1190 St. Francis Drive, Santa Fe, NM, 87502, teléfono 505-487-0348. Los usuarios de TDD o TDY pueden acceder a HRB a través de New Mexico Relay Network llamando al 1-800-659-8331.

NMED no discrimina por motivos de raza, color, origen nacional, discapacidad, edad o sexo en la administración de sus programas o actividades, según lo exigen las leyes y regulaciones aplicables. NMED es responsable de la coordinación de los esfuerzos de cumplimiento y la recepción de consultas sobre los requisitos de no discriminación implementados por 40 C.F.R. Partes 5 y 7, incluido el Título VI de la Ley de Derechos Civiles de 1964, según enmendada; Sección 504 de la Ley de Rehabilitación de 1973; la Ley de Discriminación por Edad de 1975, el Título IX de las Enmiendas de Educación de 1972 y la Sección 13 de las Enmiendas de la Ley de Control de la Contaminación del Agua de 1972. Si tiene alguna pregunta sobre este aviso o alguno de los programas, políticas o procedimientos de no discriminación de NMED o si cree que ha sido discriminado con respecto a un programa o actividad de NMED, puede comunicarse con:

Kate Cardenas, coordinadora de no discriminación, NMED
1190 St. Francis Dr.
Suite N4050, P.O. Box 5469
Santa Fe, NM 87502
teléfono (505) 827-2855
correo electrónico nd.coordinator@env.nm.gov

También puede visitar nuestro sitio web en https://www.env.nm.gov/general/environmental-justice-in-new-mexico/ para saber cómo y dónde presentar una queja de discriminación.

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New Mexico Environment Department



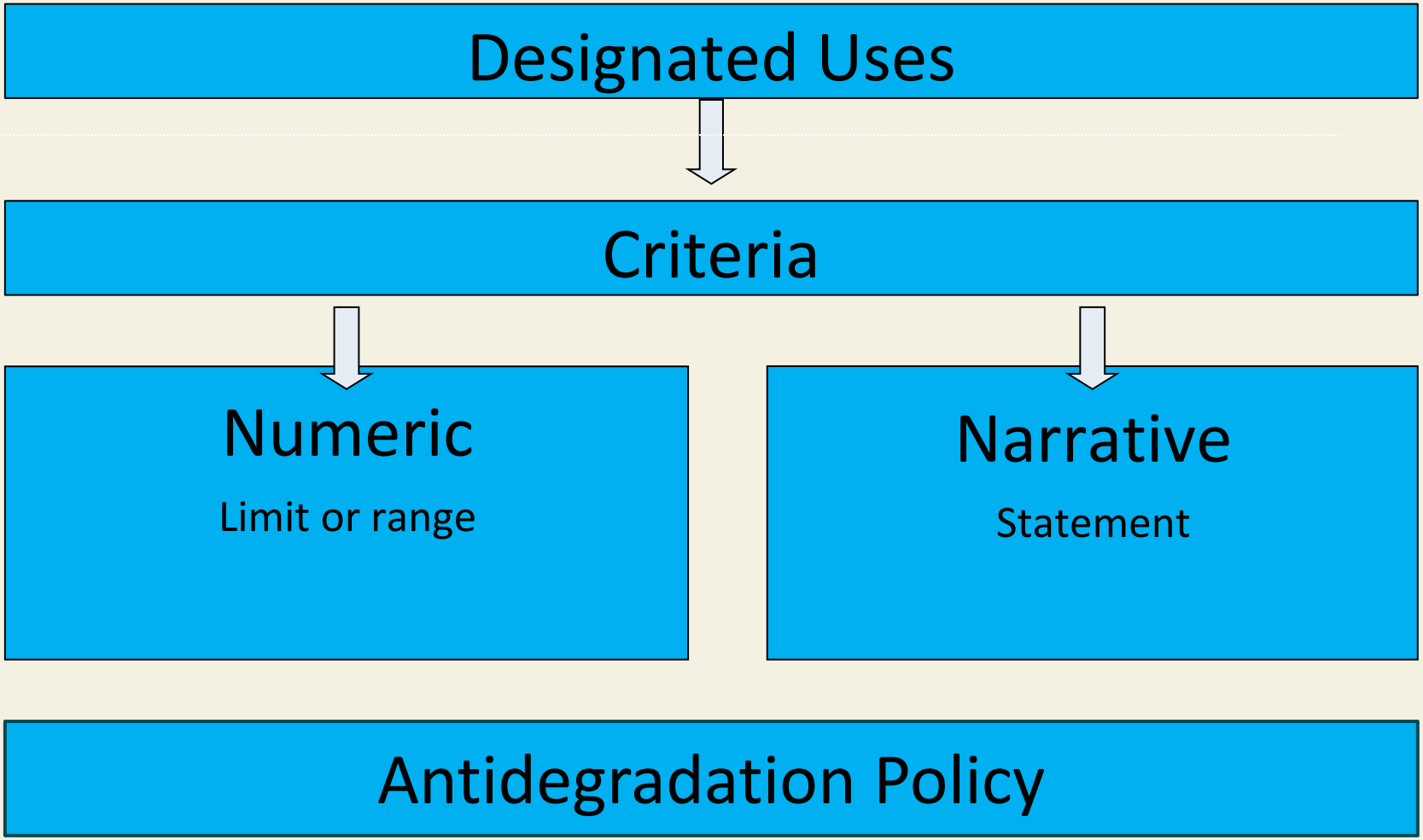
2026 Triennial Review-Public Meeting
SWQB - Standards and Outreach Team
September 10, 2025

NMED Exhibit 11

What is a Triennial Review?

- Required by Clean Water Act (CWA)
- Review of Surface Water Quality Standards (WQS)
  - 20.6.4 New Mexico Administrative Code (NMAC)
  - consider adopting EPA-recommended CWA Section 304(a) criteria to protect human health and aquatic life
  - review waters lacking CWA Section 101(a)(2) fishable/swimmable uses
    - i.e., Are there new data to support swimmable or fishable uses?
- Modify and adopt WQS as appropriate
- Must occur at least once every three years
- Public hearing in front of the NM Water Quality Control Commission (WQCC)

Water Quality Standards



NMED Exhibit 11

Designated Uses







Images courtesy of U.S. EPA https://www.epa.gov/wqs-tech/designated-uses

- Clean Water Act (CWA) designated uses:
  - Protection and propagation of fish, shellfish, and wildlife
  - Recreation in and on the water
  - Public water supply
  - Agriculture, industry, and navigation
- New Mexico's Designated Uses:
  - Aquatic Life – seven subcategories
  - Recreation - Primary and Secondary Contact
  - Wildlife Habitat
  - Water Supply – Industrial, Domestic, and Public
  - Livestock watering, irrigation/irrigation storage, and fish culture.

NMED Exhibit 11

Criteria

- Numeric Criteria
  - limit or range for a pollutant or physical condition
  - Derived from scientific toxicological studies
  - 20.6.4.900 NMAC – Default values by Designated Use
  - 20.6.4.97 - .899 NMAC - waterbody-specific values

- Narrative Criteria
  - Expressed a verbal statement
  - Referred to as General Criteria at 20.6.4.13 NMAC

Antidegradation

- Framework for maintaining and protecting water quality
  - Tier 1- All Waters of the State
  - Tier 2- Exceptional water quality
  - Tier 3- ONRW

Resources

- 2026 Triennial Review Webpage
  - https://www.env.nm.gov/surface-water-quality/2026-triennial-review/
  - Public Review Draft and supporting documents
  - Links to SmartComment, WQS and WQS Amendments webpages
  - Updated throughout rulemaking process
- Public Review Draft
  - Includes Table of Contents with Sections that include proposed amendments
  - Does not include sections where no amendments are being proposed
  - Track Changes shows proposed amendments then a “Basis for Change” explains the rationale for the amendment

Proposed Amendments - Overview

- 2026 Triennial Review Amendments:
  - Provide clarity and conform to NMAC style and formatting guidelines
  - Add or change definitions
  - Update administrative process
  - Revise designated uses
    - Required to review CWA Section 101(a)(2) fishable/swimmable goals
  - Revise/Adopt criteria
    - CWA Section 304(a) – EPA Recommended criteria

Proposed Amendments-Wetlands

- Definition of "wetlands" (20.6.4.7 NMAC)
  - Recognize wetlands unique functions and features
    - ecological, hydrological, and economic services.
- Narrative standard (20.6.4.13 NMAC)
  - Protect and maintain wetland function and size, and
  - State Permitting – support program development and implementation.
- Antidegradation policy and implementation plan (20.6.4.8 NMAC)

Proposed Amendments-Designated Uses

- Update recreational uses (20.6.4.213, 20.6.4.219, 20.6.4.231, 20.6.4.308 NMAC)
  - Pecos and Canadian River Basins
  - Secondary contact to Primary Contact Use
- Remove warmwater aquatic life use (20.6.4.502, 20.6.4.601 NMAC)
  - Gila and San Francisco river basins
    - Reviewed "dual" aquatic life use segments (cold and warm);
  - Available data support coldwater aquatic life use
    - Fisheries, temperature, and modeling data

Proposed Amendments-Petitioner's Responsibilities

- Administrative rulemaking costs (20.6.4.10 NMAC)
  - Specify "petitioners" are responsible
  - NMED or a third-party can be a petitioner

- Site-specific Criteria (20.6.4.10 NMAC)
  - Third-party demonstrations and requirements
  - In line with other processes to amend standards

Proposed Amendments – Criteria

- PFOA and PFOS (20.6.4.900.J NMAC)
  - CWA Section 304(a) recommended criteria - Aquatic Life Use
    - Water column concentrations,
    - Whole-body tissue concentrations for invertebrates,
    - Whole-body tissue concentrations for fish, and
    - Muscle tissue-only concentrations for fish.

Proposed Amendments - Criteria

- Selenium - Aquatic Life (20.6.4.900.J NMAC)
  - EPA recommended CWA Section 304(a) criteria
- Lead - Domestic Water Supply (20.6.4.900.J NMAC)
  - EPA recommended action level
- pH - Limited Aquatic Life (20.6.4.900.H NMAC)
  - Range supports aquatic life, and
  - in line with technology-based limits
    - NPDES Permitting
- 2,4-D, methoxychlor, and Silvex - Domestic Water Supply (20.6.4.900 NMAC)
  - EPA maximum contaminant level (MCL)

How You Can Participate

- Provide Public Comment to SWQB
  - August 15, 2025 – October 14, 2025
  - Public Comment Portal or email
- Attend WQCC meetings
- Anticipated public notice in newspaper and *NM Register*
  - Winter/Spring 2026
- Provide written or oral comment at WQCC meetings
  - Rulemaking Petition expected late 2025
  - Requesting a 2026 hearing
- Provide expert testimony at WQCC hearing
  - Instructions provided in the public notice of rulemaking
- Provide written comment to WQCC
  - Notice will provide more detail.

Smart Comment Demonstration

https://nmed.commentinput.com/comment/search

Tentative Timeline

- Oct 14, 2025: Public comment period closes
- Dec 9, 2025: Petition WQCC for hearing
- Spring 2026: Provide public notice of hearing
  - WQCC comment period
- Late Summer / Early Fall 2026: Triennial Review hearing

Questions/ Discussion

Written Comments

Wednesday, October 14, 2025

Michael Baca
Standards & Outreach Team Leader
WQS Coordinator, SWQB
michael.baca1@env.nm.gov

https://www.env.nm.gov/surface-water-quality/wqs/

2026 Triennial Review Team

Many people at NMED provided help in preparing and reviewing the proposed amendments including: Lynette Guevara, Nate Reynolds, Emily Miller, Stephani Clark Barkalow, the Watershed Protection Section - Wetlands Team, Brecken Scott, Shelly Lemon.

REGION 6
DALLAS, TX 75270

October 9, 2025

Michael Baca
Standards, Planning & Reporting Team Leader
Surface Water Quality Bureau
New Mexico Environment Department
1190 S. St. Francis Dr.
Santa Fe, NM 87505

Re: New Mexico Environment Department 2026 Triennial Review Public Draft – 20.6.4 NMAC

Dear Mr. Baca:

In response to the New Mexico Environment Department (NMED) announcement and extended public comment period on proposed revisions to the New Mexico *Standards for Interstate and Intrastate Surface Waters*, 20.6.4 New Mexico Administrative Code (NMAC), the Environmental Protection Agency (EPA) Region 6 would like provide comments and recommendations as part of the state's 2026 triennial review process.

The NMED's proposal includes both substantive and non-substantive revisions to New Mexico's water quality standards. The EPA has provided comments and recommendations on the substantive revisions where appropriate. The substantive revisions included definitions that influence implementation, regulatory segment and designated use determinations, and a number of new and revised criteria. The comments and recommendations provided in the enclosed document are intended to address these and other complex issues that may need to be addressed in incremental stages through the state's water quality standards and associated implementation over time. We would like to encourage discussions about these recommendations and suggestions as part the current and future water quality standards program-related planning. Where non-substantive revisions occur, typically grammatical, renumbering or other minor changes that do not alter the context or meaning of a provision, comments are typically not necessary.

It should be noted that the recommendations and suggestions provided here are preliminary and do not represent a finding under §303(c) of the Clean Water Act or Standards Regulation (40 CFR 131). Any decisions on new and revised water quality standards will be made by the EPA Region 6 following their adoption by the New Mexico Water Quality Control Commission and submission to the Region. The EPA would also like to take this opportunity to commend the NMED and the Surface Water Quality Board's efforts in the continuing development of New Mexico's water quality standards program. I look

forward to continuing work with you and your staff on the protection of New Mexico's water resources. If you have any questions, please contact Jasmin Diaz-Lopez at diazlopez.jasmin@epa.gov or (214) 665-2733.

Sincerely,

SELENA MEDRANO

Digitally signed by SELENA MEDRANO
Date: 2025.10.09 12:57:01 -05'00'

Selena Medrano
Acting Section Supervisor

Enclosure: EPA COMMENTS ON THE NEW MEXICO ENVIRONMENT DEPARTMENT'S PROPOSED TRIENNIAL REVISIONS TO THE STANDARDS FOR INTERSTATE AND INTRASTATE SURFACE WATERS (20.6.4 NMAC)

cc: Shelly Lemon, Chief, Surface Water Quality Bureau, New Mexico Environment Department (Shelly.Lemon@env.nm.gov)
Lynette Guevera, Program Manager - Monitoring, Assessment, and Standards Section, New Mexico Environment Department, (lynette.guevara@env.nm.gov)

EPA COMMENTS ON THE NEW MEXICO ENVIRONMENT DEPARTMENT'S PROPOSED TRIENNIAL REVISIONS TO THE STANDARDS FOR INTERSTATE AND INTRASTATE SURFACE WATERS (20.6.4 NMAC)

The following detail the Environmental Protection Agency's (EPA) comments and recommendations on the New Mexico Environment Department's (NMED) proposed revisions to the state's Standards for Interstate and Intrastate Surface Waters (20.6.4 NMAC). It should be noted that the comments and recommendations provided here or in any enclosures are preliminary and do not represent a finding under Section 303(c) of the Clean Water Act (CWA) or the Standards Regulation (40 CFR 131). Any decisions on new and revised water quality standards will be made by the EPA following their adoption and submission to Region 6 for review by the New Mexico Water Quality Control Commission (WQCC or Commission).

General Comments

As cited in new proposed language at NMAC 20.6.4.10(A), § 303(c)(1) of the CWA requires that "the Governor of a State or the State water pollution control agency of such State shall from time to time (but at least once each three year period beginning with October 18, 1972) hold public hearings for the purpose of reviewing applicable water quality standards and, as appropriate, modifying and adopting standards." The CWA requirement means that for a state's review to be considered a triennial review, the state must open the entirety of a state's water quality standard(s) (WQS) and solicit comments on the entire document.

For future triennial reviews, the EPA recommends that the NMED ensure a hearing that is open to the general public for the purpose of reviewing New Mexico's WQS is held three years from the date of the state's prior hearing to review its WQS to meet the requirement in § 303(c)(1) of the CWA. The purpose of this review is to, at a minimum, identify WQS changes necessary to meet the requirements of the CWA. This includes the requirement in 40 CFR § 131.20(a) to re-examining any waterbody segment with designated uses less than the CWA § 101(a)(2) uses to determine if those designations are still appropriate.

TITLE 20 ENVIRONMENTAL PROTECTION
CHAPTER 6 WATER QUALITY
PART 4 STANDARDS FOR INTERSTATE AND INTRASTATE SURFACE WATERS

20.6.4.7 DEFINITIONS: Terms defined in the New Mexico Water Quality Act, but not defined in this part will have the meaning given in the Water Quality Act.

A. Terms beginning with numerals or the letter "A," and abbreviations for units.

(1) "4Q3" means the hydrologically based critical low flow as determined by the minimum average flow over four consecutive days that occurs with a frequency of once in three years.

The EPA previously commented on the need to clarify this definition in its January 2023 303(c) Action Letter regarding its applicability. Given that the 4Q3 is hydrologically based for NMED, the proposed revision in appropriate.

T. Terms beginning with the letter "T".

(1) "TDS" means total dissolved solids, also termed "total filterable residue."

(2) "Temporary standard" means a time-limited designated use and criterion for a specific pollutant(s) or water quality parameter(s) that reflect the highest attainable condition during the term of the temporary standard.

(~~2~~3) "Toxic pollutant" means those pollutants, or combination of pollutants, including disease-causing agents, that after discharge and upon exposure, ingestion, inhalation or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will cause death, shortened life spans, disease, adverse behavioral changes, reproductive or physiological impairment or physical deformations in such organisms or their offspring.

(~~3~~4) "Tributary" means a perennial, intermittent or ephemeral waterbody that flows into a larger waterbody, and includes a tributary of a tributary.

(45) "Turbidity" is an expression of the optical property in water that causes incident light to be scattered or absorbed rather than transmitted in straight lines.

The EPA recommends adding "or water quality variance as defined by 40 CFR 131.3(o)" to the end of the definition for "temporary standard".

W. Terms beginning with the letter "W".

(4) "Wetlands" means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and under normal circumstances do support, ~~a prevalence of~~ vegetation, typically adapted for life in saturated soil conditions in New Mexico. Wetlands are unique surface waters of the state that vary widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation and other factors and provide distinct chemical, biological, physical, and hydrological functions within a watershed. Wetlands that are constructed outside of a surface water of the state for the purpose of providing wastewater treatment and that do not impound a surface water of the state are not included in this definition.

The EPA has no comment on this revision.

20.6.4.8 ANTIDEGRADATION POLICY AND IMPLEMENTATION PLAN:

A. Antidegradation Policy: This antidegradation policy applies to all surface waters of the state.

(1) Existing uses, as defined in Paragraph (4) of Subsection E of 20.6.4.7 NMAC, and the level of water quality or wetland condition necessary to protect the existing uses shall be maintained and protected in all surface waters of the state. Wetland condition is a measure of ecological integrity and, by inference, wetland quality (i.e., functions) and quantity (i.e., acreage).

(2) Where wetland condition or the quality of a surface water of the state exceeds levels necessary to support the propagation of fish, shellfish, and wildlife, and recreation in and on the water, that quality shall be maintained and protected unless the commission finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the state's continuing planning process, that allowing lower water quality or wetland condition, including loss of wetland acreage or wetland functions, is necessary to accommodate important economic and social development in the area in which the water is located. In allowing such degradation or lower water quality, the state shall assure water quality adequate to protect existing uses fully. Further, the state shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable BMPs for nonpoint

source control. Additionally, the state shall encourage the use of watershed planning as a further means to protect surface waters of the state.

(3) No degradation, including loss of wetland acreage or wetland functions, shall be allowed in waters designated by the commission as outstanding national resource waters (ONRWs), except as provided in Subparagraphs (a) through (e) of this paragraph and in Paragraph (4) of this Subsection A.

The EPA has no comment on this revision.

20.6.4.10 REVIEW OF STANDARDS; NEED FOR ADDITIONAL STUDIES:

~~F~~G. **Site-specific criteria.**

(1) The commission may adopt site-specific numeric criteria applicable to all or part of a surface water of the state based on relevant site-specific conditions such as:

(a) actual species at a site are more or less sensitive than those used in the national criteria data set;

(b) physical or chemical characteristics at a site such as pH or hardness alter the biological availability and/or toxicity of the chemical;

(c) physical, biological or chemical factors alter the bioaccumulation potential of a chemical;

(d) the concentration resulting from natural background exceeds numeric criteria for aquatic life, wildlife habitat or other uses if consistent with Subsection G of 20.6.4.10 NMAC; or

(e) other factors or combination of factors that upon review of the commission may warrant modification of the default criteria, subject to EPA review and approval.

(2) Site-specific criteria must fully protect the designated use to which they apply. In the case of human health-organism only criteria, site-specific criteria must fully protect human health when organisms are consumed from waters containing pollutants.

(3) Any person may submit notice to the department stating their intent to derive site-specific criteria for a surface water of the state. The notice shall include a work plan supporting the development of site-specific criteria for the department's review and comment.

(4) Site-specific criteria shall be developed in accordance with the reviewed work plan, based on one or more of the site-specific conditions noted in paragraph 1, derived from a scientifically defensible method and protect the designated uses to which they apply.

(5) The work plan shall identify, at a minimum:

(a) the waterbody to consider and the reasoning for site-specific criteria;

(b) the methodology to be used to derive criteria;

(c) the source and validity of data to be used;

(d) the provisions for consultation with appropriate state and federal agencies;

(e) a description of how stakeholders and potentially affected Indian nations, tribes, or pueblos will be identified and engaged;

(f) a description of the public notice mechanisms to be employed; and

(g) the expected timelines and associated administrative actions to be taken for a rulemaking petition, pending the outcome of criteria development.

(6) Upon completion of site-specific criteria development, the data, findings and conclusions shall be submitted to the department, and public notice shall be provided in accordance with the approved work plan.

(~~3~~7) Any person may petition the commission to adopt site-specific criteria. A petition for the adoption of site-specific criteria shall:

(a) identify the specific waters to which the site-specific criteria would apply;

(b) explain the rationale for proposing the site-specific criteria;

(c) describe the methods used to notify and solicit input from potential stakeholders and from the general public in the affected area, and present and respond to the public input received;

(d) present and justify the derivation of the proposed criteria.

(48) A derivation of site-specific criteria shall rely on a scientifically defensible method, such as one of the following:

(a) the recalculation procedure, the water-effect ratio for metals procedure or the resident species procedure as described in the water quality standards handbook (EPA-823-B-94-005a, 2nd edition, August 1994);

(b) the streamlined water-effect ratio procedure for discharges of copper (EPA 822R-01-005, March 2001);

(c) the biotic ligand model as described in aquatic life ambient freshwater quality criteria - copper (EPA-822-R-07-001, February 2007);

(d) the methodology for deriving ambient water quality criteria for the protection of human health (EPA-822-B-00-004, October 2000) and associated technical support documents; or

(e) a determination of the natural background of the water body as described in Subsection G of 20.6.4.10 NMAC.

The EPA supports the proposed revisions to 20.6.4.10 G that clarify the required process the NMED will use in establishing site-specific criteria.

The EPA continues to have concerns with subsection 20.6.4.10 G.(1)(e) from the state's 2011 triennial revisions and previously took no action on this definition under CWA § 303(c), meaning that it is not effective for CWA purposes. The EPA continues to have concerns with the undefined factors or combination of factors that may warrant modifications to default criteria. The EPA welcomes additional information that explains how additional factors will be considered when reviewed by the commission and how they will be applied to existing federal regulatory structure to assist in its determination.

20.6.4.11 APPLICABILITY OF WATER QUALITY STANDARDS:

G. Human health-organism only criteria in Subsection J of 20.6.4.900 NMAC apply to those waters with a designated, existing or attainable aquatic life use. When limited aquatic life is a designated use, the human health-organism only criteria apply only for persistent toxic pollutants, ~~if~~ unless adopted on a segment-specific basis. The human health-organism only criteria for persistent toxic pollutants, as identified in Subsection J of 20.6.4.900 NMAC, also apply to all tributaries of waters with a designated, existing or attainable aquatic life use.

The EPA supports the proposed revisions to 20.6.4.11.G to remain consistent with language in 20.6.4.900(H)(7)NMAC.

20.6.4.12 COMPLIANCE WITH WATER QUALITY STANDARDS: The following provisions apply to determining compliance for enforcement purposes; they do not apply for purposes of determining attainment of uses. The department has developed assessment protocols for the purpose of determining attainment of uses that are available for review from the department's surface water quality bureau.

F. For compliance with ~~hardness dependent~~ calculated numeric criteria~~,~~ that depend on water chemistry, ~~hardness (as mg CaCO3/L)~~ all input parameters shall be determined from a sample taken at the same time that the sample for the contaminant is taken. If not all the input data are available to calculate a criterion, default input values may be used if justified and supported by ecoregional or other watershed data.

The EPA supports the proposed revisions to 20.6.4.12.F to remain consistent language in 20.6.4.900.I NMAC.

20.6.4.13 GENERAL CRITERIA: General criteria are established to sustain and protect existing or attainable uses of surface waters of the state. These general criteria apply to all surface waters of the state at all times, unless a specified criterion is provided elsewhere in this part. Surface waters of the state shall be free of any water contaminant in such quantity and of such duration as may with reasonable probability injure human health, animal or plant life or property, or unreasonably interfere with the public welfare or the use of property.

N. Wetlands: Only wetlands of the state are subject to this general criterion. Wetlands shall be maintained and protected such that degradation through direct, indirect, or cumulative impacts does not result in the net loss of wetland acreage or biological, chemical, physical, and hydrological functions to the extent that such functions occur, as characterized by state-specific benchmarks. The functions of a wetland that are to be maintained and protected may include:

(1) erosion control through bank and shoreline stabilization;
(2) flood attenuation and flood protection;
(3) sediment and pollutant retention, which prevents or mitigates downstream migration;
(4) groundwater recharge and water storage for future use;
(5) low flow augmentation including baseflow maintenance;
(6) water filtration including removal or storage of nutrients and other contaminants;
(7) propagation or maintenance of aquatic and terrestrial species indigenous to wetlands;
(8) preservation of wildlife habitat including habitat for threatened or endangered species; or
(9) supporting biological diversity.

In addition, wetlands shall be suitable for recreation, wildlife habitat, and use by aquatic life and livestock.

In the last sentence of the proposed revision for 20.6.4.13, the EPA suggests that NMED clarify whether wetlands are being assigned these uses (recreation, wildlife habitat, aquatic life, and livestock) or that wetlands may be assigned any one of these uses.

20.6.4.15 USE ATTAINABILITY ANALYSIS:

B. Methods for developing a use attainability analysis. A use attainability analysis shall assess the physical, chemical, biological, economic or other factors affecting the attainment of a use. The analysis shall rely on scientifically defensible methods such as the methods described in the following documents:

(1) the United States environmental protection agency's water quality standards handbook and use attainability analysis website for current recommendations and case studies;

(~~1~~2) *Technical Support Manual: Waterbody Surveys And Assessments For Conducting Use Attainability Analyses*, volume I (November 1983) and volume III (November 1984) or latest editions, United States environmental protection agency, office of water, regulations and standards, Washington, D.C., for the evaluation of aquatic life or wildlife uses;

(~~2~~3) the department's *Hydrology Protocol*, latest edition, approved by the commission, for identifying ephemeral, intermittent, and perennial waters; or

(~~3~~4) *Interim Economic Guidance For Water Quality Standards - Workbook*, March 1995, in conjunction with *Clean Water Act Financial Capability Assessment Guidance*, March 2024, United States environmental protection agency, office of water, Washington, D.C. for evaluating economic impacts.

The EPA supports the proposed revisions to 20.6.4.15.B which includes additional reference material for developing a use attainability analysis. However, the EPA recommends that NMED repeats the "latest edition" language for all of their reference documents, including bullet (4), for the purposes of minimizing updates in this section.

20.6.4.15 USE ATTAINABILITY ANALYSIS:

D. Process to amend a designated use through a use attainability analysis.

(1) The process for developing a use attainability analysis and petitioning the commission for removing a designated use and establishing the highest attainable use shall be done in accordance with the State's current *Water Quality Management Plan/Continuing Planning Process*.

(2) If the findings of a use attainability analysis, conducted by the department, in accordance with the department's *Hydrology Protocol* (latest edition) demonstrates that federal Clean Water Act Section 101(a)(2) uses, that are not existing uses, are not feasible in an ephemeral water body due to the factor in 40 CFR 131.10(g)(2), the department may consider proceeding with the expedited use attainability analysis process in accordance with the State's current *Water Quality Management Plan/Continuing Planning Process*. The following elements must be met for the expedited use attainability analysis process to be authorized and implemented:

(a) The department is the primary investigator of the use attainability analysis;

(b) The use attainability analysis determined, through the application of the *Hydrology Protocol*, that the water being investigated is ephemeral and has no effluent discharges of sufficient volume that could compensate for the low-flow;

(c) The use attainability analysis determined that the criteria associated with the existing uses of the water being investigated are not more stringent than those in 20.6.4.97 NMAC;

(d) The designated uses in 20.6.4.97 NMAC have been determined to be the highest attainable uses for the water being analyzed;

(e) The department posted the use attainability analysis on its water quality standards website and notified its interested parties list of a 30-day public comment period;

(f) The department reviewed and responded to any comments received during the 30-day public comment period ; and

(g) The department submitted the use attainability analysis and response to comments to ~~region 6~~ EPA for technical ~~approval~~review.

(3) If EPA approves the designated use revision(s) under section 303(c) of the Clean Water Act, the water shall be subject to 20.6.4.97 NMAC for federal Clean Water Act purposes. The use attainability analysis, the technical support document, and the applicability of 20.6.4.97 NMAC to the water shall be posted on the department's water quality standards website. The department shall periodically petition the commission to list ephemeral waters under Subsection C of 20.6.4.97 NMAC and to incorporate changes to classified segments as appropriate.

The EPA supports the proposed revisions to 20.6.4.15.D which includes clarifying language for amending a designated used through a use attainability analysis.

20.6.4.135 RIO GRANDE BASIN: Bluewater lake and Santa Cruz lake.

A. Designated uses: coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: phosphorus (unfiltered sample) 0.1 mg/L or less for Bluewater lake; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

The EPA supports the proposed revisions to 20.6.4.135 which adds Santa Cruz Lake to the Rio Grande Basin with primary contact use. However, EPA recommends the following edits to clarify the distinction in criteria between Bluewater lake and Santa Cruz lake:

*"**B. Criteria:** The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: phosphorus (unfiltered sample) 0.1 mg/L or less is applicable to Bluewater lake only; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less is applicable to both lakes."*

20.6.4.206

PECOS RIVER BASIN: Perennial reaches of the Rio Felix ~~and perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon, excluding North Spring river.~~

A. Designated uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

According to 40 CFR 131.10(k) a UAA is not required when designating uses that include the uses specified in CWA Section 101(a)(2), when designating a subcategory of a 101(a)(2) use that requires criteria at least as stringent as previously applicable, or when removing or revising a non-101(a)(2) use. Since the use change from secondary contact to primary contact is more stringent, the EPA supports the proposed revisions to 20.6.4.206 which removes perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon from this segment and adds them to 20.6.4.231 NMAC which has a primary contact designated use.

20.6.4.213 PECOS RIVER BASIN: McAllister lake.

A. Designated uses: coldwater aquatic life, ~~secondary~~ primary contact, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

The EPA supports the proposed revisions to 20.6.4.213 which changes the designated use from secondary contact to primary contact for McAllister lake. Similar to proposed revisions in 20.6.4.206, no UAA is necessary for this change.

20.6.4.219 PECOS RIVER BASIN: Avalon reservoir.

A. Designated uses: coldwater aquatic life, ~~secondary~~ primary contact, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

The EPA supports the proposed revisions to 20.6.4.219 which changes the designated use from secondary contact to primary contact for Avalon reservoir. Similar to proposed revisions in 20.6.4.206 and 20.6.4.213 no UAA is necessary for this change.

20.6.4.231 PECOS RIVER BASIN: The main stem of the Pecos river from the headwater of Brantley resrvoir upstream to Salt creek (near Acme), the perennial reaches of the Rio Peñasco downstream from ~~state highway 24 near Dunken~~ Bear canyon, ~~perennial reaches of North Spring river and~~ perennial reaches of the Rio Hondo and perennial reaches of its tributaries downstream of Bonney canyon.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

The EPA supports the proposed revisions to 20.6.4.231 which results from changes to the designated use from secondary contact to primary contact for all perennial reaches of Rio Hondo and tributaries downstream of Bonney canyon. Similar to proposed revisions in 20.6.4.206, 20.6.4.213, and 20.6.4.219 no UAA is necessary for this change.

20.6.4.307 CANADIAN RIVER BASIN: Perennial reaches of the Mora river from the USGS gaging station near Shoemaker upstream to the state highway 434 bridge in Mora, all perennial reaches of tributaries to the Mora river downstream from the USGS gaging station at La Cueva in San Miguel and Mora counties except ~~lakes~~ waters identified in 20.6.4.309 NMAC or 20.6.4.313 NMAC, perennial reaches of Ocate creek downstream of Ocate, perennial reaches of tributaries to Ocate creek downstream of Ocate, and perennial reaches of Rayado creek downstream of Miami lake diversion in Colfax county.

A. Designated uses: marginal coldwater aquatic life, warmwater aquatic life, primary contact, irrigation, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

The EPA supports this revision which clarifies this segment of Coyote Creek, from Mora River to Amola Ridge, is meeting the marginal coldwater aquatic life use in 20.6.4.307 while the segment of Coyote Creek upstream of Amola Ridge in 20.6.4.309 is meeting high quality coldwater aquatic life use.

20.6.4.308 CANADIAN RIVER BASIN: Charette lakes.

A. Designated uses: coldwater aquatic life, warmwater aquatic life, ~~secondary~~ primary contact, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

The EPA supports the proposed revisions to 20.6.4.308 which results from changes to the designated use from secondary contact to primary contact for Charette lakes. Similar to the proposed revisions in 20.6.4.206, 20.6.4.213, 20.6.4.219, and 20.6.4.231, no UAA is necessary for this use change.

20.6.4.309 CANADIAN RIVER BASIN: The Mora river and all perennial reaches of its tributaries upstream from the state highway 434 bridge in Mora except lakes identified in 20.6.4.313 NMAC, all perennial reaches of tributaries to the Mora river upstream from the USGS gaging station at La Cueva, perennial reaches of Coyote creek, upstream of Amola ridge and perennial reaches of tributaries to Coyote creek upstream to Amola ridge, the Cimarron river above state highway 21 in Cimarron, perennial reaches of tributaries to the Cimarron river above state highway 21 in Cimarron except Eagle Nest lake, all perennial reaches of tributaries to the Cimarron river north and northwest of highway 64 except north and south Shuree ponds, perennial reaches of Rayado creek above Miami lake diversion, perennial reaches of tributaries to Rayado creek above Miami lake diversion, Ocate creek and perennial reaches of its tributaries upstream of Ocate, perennial reaches of the Vermejo river upstream from Rail canyon and all other perennial reaches of tributaries to the Canadian river northwest and north of U.S. highway 64 in Colfax county unless included in other segments.

A. Designated uses: domestic water supply, irrigation, high quality coldwater aquatic life, livestock watering, wildlife habitat, and primary contact; and public water supply on the Cimarron river upstream from Cimarron, on perennial reaches of Rayado creek and on perennial reaches of tributaries to Rayado creek.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

The EPA supports this revision which clarifies this segment of Coyote Creek, perennial reaches and tributaries upstream of Amola ridge, are meeting high quality coldwater aquatic life use and should be excluded from 20.6.4.307.

20.6.4.502 GILA RIVER BASIN: The main stem of the Gila river from Redrock canyon upstream to the confluence of the West Fork Gila river and East Fork Gila river and perennial reaches of tributaries to the Gila river downstream of Mogollon creek.

A. Designated uses: industrial water supply, irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, and primary contact ~~and warmwater aquatic life~~.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: 28°C (82.4°F) or less.

The EPA agrees with the NMED's basis for removing warmwater aquatic life. As specified in 40 CFR 131.10(k)(2) a UAA is not required when designating a subcategory of a 101(a)(2) use that requires criteria at least as stringent as previously applicable. Removing the less stringent warmwater criteria use will result in no changes to the applicable 101(a)(2) criteria given that the more stringent criteria, coldwater aquatic life, remains. However, the EPA suggests adding "temperature" before "28°C", to remain consistent with other segment specific criteria.

20.6.4.503 GILA RIVER BASIN: All perennial tributaries to the Gila river upstream of and including Mogollon creek.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance of 400 µS/cm or less for all perennial tributaries except West Fork Gila and tributaries thereto, specific conductance of 300 µS/cm or less; ~~32.2~~ 29°C (~~90~~84°F) or less in the east fork of the Gila river and Sapillo creek downstream of Lake Roberts; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

The EPA supports the revision to 20.6.4.503 given that existing data indicates segment-specific temperature criterion of 29°C (84°F) is existing and attainable for East Fork Gila River and Sapillo Creek

downstream of Lake Roberts. As specified in 40 CFR 131.10(k)(2) a UAA is not required when designating a subcategory of a 101(a)(2) use that requires criteria at least as stringent as previously applicable. However, the EPA suggests adding "temperature" before "29°C", to remain consistent with other segment specific criteria.

20.6.4.900 CRITERIA APPLICABLE TO EXISTING, DESIGNATED OR ATTAINABLE USES UNLESS OTHERWISE SPECIFIED IN 20.6.4.97 THROUGH 20.6.4.899 NMAC:

D. Primary contact: The monthly geometric mean of E. coli bacteria of 126 cfu/100 mL or MPN/100 ml, a single sample of E. coli bacteria of 410 cfu/100 mL or MPN/100 mL, a single sample of total microcystins of 8 µg/L ~~with no more than three exceedances within a 12 month period~~ and a single sample of cylindrospermopsin of 15 µg/L ~~with no more than three exceedances within a 12 month period~~, and pH within the range of 6.6 to 9.0 apply to this use. The results for *E. coli* may be reported as either colony forming units (CFU) or the most probable number (MPN) depending on the analytical method used.

The EPA recommends NMED consider retaining the language in 20.6.4.900 D. proposed for deletion. The frequency and duration aspects of criteria are important to help define the desired condition of the state's waters and ensure that the designated use is protected by the criteria. If NMED finds that its current frequency and duration are not appropriate, it should provide a scientifically sound basis for a revised frequency and duration that are protective of New Mexico's primary contact designated use. For example, please see the EPA's 2019 Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin, which explains how the frequency and duration aspects of the EPA's 304(a) recommended criteria are protective of primary contact recreation. The EPA welcomes discussions with NMED to develop a revised frequency and duration, and recognizes that these water quality standards can always be revised in future rulemakings if NMED determines that evolving science or new data suggest that a revision is necessary.

20.6.4.900

H. Aquatic life: Surface waters of the state with a designated, existing or attainable use of aquatic life shall be free from any substances at concentrations that can impair the community of plants and animals in or the ecological integrity of surface waters of the state. Except as provided in Paragraph (7) of this subsection, the acute and chronic aquatic life criteria set out in Subsections I, J, K and L of this section and the human health- organism only criteria set out in Subsection J of this section are applicable to all aquatic life use subcategories. In addition, the specific criteria for aquatic life subcategories in the following paragraphs apply to waters classified under the respective designations.

(7) Limited aquatic life: pH within the range of 6.0 to 9.0. The acute aquatic life criteria of Subsections I and J of this section apply to this subcategory. Chronic aquatic life criteria do not apply unless adopted on a segment-specific basis. Human health-organism only criteria apply only for persistent toxic pollutants unless adopted on a segment-specific basis.

The EPA supports the proposed pH criteria applicable to limited aquatic life.

20.6.4.900.

J. Use-specific numeric criteria.

Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Chromium III, dissolved	16065-83-1					a	a		
Chromium VI, dissolved	18540-29-9					16	11		
Chromium, dissolved	7440-47-3	100	100	1,000					
Cobalt, dissolved	7440-48-4		50	1,000					
Copper, dissolved	7440-50-8	1300	200	500		a	a		
Cyanide, total recoverable	57-12-5	200			5.2	22.0	5.2	400	
Iron	7439-89-6						1,000		
Lead, dissolved	7439-92-1	~~15~~10	5,000	100		a	a		
Manganese, dissolved	7439-96-5					a	a		
Mercury	7439-97-6	2		10	0.77				P
Mercury, dissolved	7439-97-6					1.4	0.77		P
Methylmercury	22967-92-6							0.3 mg/kg in fish tissue	P
Molybdenum, dissolved	7439-98-7		1,000						
Molybdenum, total recoverable	7439-98-7					7,920	1,895		
Nickel, dissolved	7440-02-0	700				a	a	4,600	P
Nitrate as N (mg/L)		10 ~~mg/L~~							
Nitrite + Nitrate (mg/L)				132 ~~mg/L~~					
Selenium, dissolved	7782-49-2	50	b	50			1.5 in lentic water, i 3.1 in lotic water, i	4,200	P
Selenium, total recoverable	7782-49-2				5.0	~~20.0~~	~~5.0~~ 8.5 mg/kg Dry Weight in Whole-Body Fish Tissue 11.3 mg/kg Dry Weight in Fish Muscle Tissue		
Silver, dissolved	7440-22-4					a			
Thallium, dissolved	7440-28-0	2						0.47	P

The EPA's national CWA section 304(a) recommended selenium criterion is composed of four criterion elements: two fish tissue criterion elements (i.e., egg-ovary and whole-body and/or muscle tissue) and two water column criterion elements (i.e., 30-day average and intermittent exposure). Currently, NMED is proposing to adopt the fish whole-body and muscle criteria, which together make up one of the two fish tissue criterion elements.

The EPA recommends that NMED considers adopting the egg ovary criterion and the intermittent exposure criterion elements. The egg-ovary criterion element supersedes all other criterion elements because it was derived directly from toxicity data and served as the basis for deriving all the other criterion elements. This hierarchy can be described in a state or authorized Tribe's WQS, in footnotes accompanying the criterion. For example, NMED can use the footnotes provided with the national CWA section 304(a) recommended selenium criterion (Table 1) to clearly and accurately describe the hierarchical structure. Another possibility is adopting the selenium criteria table as a separate section within 20.6.4.900 NMAC for clarity.

Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Heptachlor epoxide	1024-57-3	0.20				0.52	0.0038	0.00032	C
Hexachlorobenzene	118-74-1	1						0.00079	C,P
Hexachlorobutadiene	87-68-3	4.5						0.1	C, P
Hexachlorocyclohexane (HCH)-Technical	608-73-1							0.1	C
Hexachlorocyclopentadiene	77-47-4	50						4	
Hexachloroethane	67-72-1	25						1	C
Indeno(1,2,3-cd)pyrene	193-39-5	0.048						0.013	C, P
Isophorone	78-59-1	368						18,000	C
Malathion	121-75-5						0.1		
Methoxychlor	72-43-5	40					0.03	0.02	P
Methyl bromide	74-83-9	49						10,000	
3-Methyl-4-chlorophenol	59-50-7							2,000	
2-Methyl-4,6-dinitrophenol	534-52-1	14						30	
Methylene chloride	75-09-2	5						10,000	C
Mirex	2385-85-5						0.001		P
Nitrobenzene	98-95-3	18						600	
Nitrosamines	Various							12.4	C
Nitrosodibutylamine	924-16-3							2.2	C
Nitrosodiethylamine	55-18-5							12.4	C
N-Nitrosodimethylamine	62-75-9	0.0069						30	C
N-Nitrosodi-n-propylamine	621-64-7	0.050						5.1	C
N-Nitrosodiphenylamine	86-30-6	71						60	C
N-Nitrosopyrrolidine	930-55-2							340	C
Nonylphenol	84852-15-3					28	6.6		
Parathion	56-38-2					0.065	0.013		
Pentachlorobenzene	608-93-5							0.1	
Pentachlorophenol	87-86-5	1.0				19	15	0.4	C
Perfluorooctane sulfonate (PFOS)	Various					71	0.25 in water 0.028 mg/kg Wet Weight in Invertebrate Whole-Body Tissue 0.201 mg/kg Wet Weight in Fish Whole-Body Tissues 0.087 mg/kg Wet Weight in Fish Muscle Tissue		P

Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Perfluorooctanoic acid (PFOA)	Various					3,100	100 in water 1.18 mg/kg Wet Weight in Invertebrate Whole-Body Tissue 6.49 mg/kg Wet Weight Fish Whole-Body Tissue 0.133 mg/kg Wet Weight Fish Muscle Tissue		P

The EPA supports the proposed adoption of 304(a) aquatic life criteria for PFOS and PFOA. However, the EPA suggests that NMED consider designating a separate Subsection within 20.6.4.900 NMAC for these criteria in an effort to retain consistency with the criteria units and clarity between the different chronic values. Additionally, NMED could include a footnote that notes all five of these water column and tissue criteria are intended to be independently applicable and one criterion does not take primacy.

Amigos Bravos • American Rivers Action Fund •
Breath of My Heart Birthplace • Communities for Clean Water •
Concerned Citizens for Nuclear Safety • Gila Resources Information Project •
GreenLatinos • New Mexico Acequia Association •
New Mexico & El Paso Interfaith Power and Light • New Mexico Wild •
Partnership for Earth Spirituality • Sierra Club, Rio Grande Chapter •
Trout Unlimited • Western Environmental Law Center

October 14, 2025

Michael Baca
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RE: Comments on the New Mexico Environment Department's Proposed Amendments to New Mexico's Water Quality Standards (20.6.4 NMAC) – 2026 Triennial Review

Dear Mr. Baca,

The undersigned organizations submit the following comments in response to the New Mexico Environment Department Surface Water Quality Bureau's ("NMED") request for comments on draft proposed changes to 20.6.4 NMAC as part of the 2026 Triennial Review of Water Quality Standards. Collectively we represent thousands of New Mexicans that care about protecting clean water in New Mexico for drinking, irrigation, wildlife, recreation, and spiritual practices and traditions. We have come together to submit these comments with a common goal of ensuring that New Mexico's water quality standards are protective enough to support the diverse human and non-human uses of our state's water resources.

Generally, we note that the State's obligations pursuant to the Clean Water Act ("CWA") are to "protect the public health or welfare, enhance the quality of water," and wherever possible, to ensure that water quality allows for the "protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water." 33 U.S.C. § 1313(c)(2)(A); 33 U.S.C. § 1251(a)(2). Similarly, the New Mexico Water Quality Act ("WQA") directs the Commission to adopt standards that "shall at a minimum protect the public health or welfare, enhance the quality of water and serve the purposes of the Water Quality Act." NM Stat. 74-6-4(D). These goals, in particular the emphasis on standards that enhance the quality of water, represent what is a fundamental truth in New Mexico—that water is the lifeblood of our communities, ecosystems, economy, and way of life. We thank the Surface Water Quality Bureau of the New Mexico Environment Department (NMED) for all your ongoing work to implement these goals and to protect our state's water quality.

Below, we provide both comments on priorities we would like NMED to consider during this Triennial Review as well as specific comments on NMED's proposed amendments.

NMED Exhibit 13

I. PRIORITY ISSUES TO ADD TO NMED's PETITION DURING THE 2026 TRIENNIAL REVIEW

While we understand that NMED is constrained by staffing shortages and a heavy workload that includes multiple concurrent rulemaking processes, there are numerous issues that we urge NMED to add to your Triennial Review petition.

A. Outstanding Waters (20.6.4.8 NMAC and 20.6.4.9 NMAC)

i. Change "Outstanding National Resource Waters" to "Outstanding Waters"

The unwieldy name of Outstanding National Resource Waters (ONRWs) is constantly being confused and mixed up. People consistently call them Outstanding *Natural* Resource Waters or mix up the order of the letters in the acronym and call them ORNWs or some other combination. We suggest that NMED consider advocating for a change in name from "Outstanding National Resource Waters" to "Outstanding Waters". Not only will this make the name easier to remember, but it will also clear up the common misconception that ONRW protections are a federal designation, when in fact ONRWs are designated at the state level by the New Mexico Water Quality Control Commission. While there may be some argument for maintaining the existing name due to the fact that ONRW protections are laid out in the federal Clean Water Act and associated regulations, (specifically in Tier III of the federal antidegradation policy), these federal requirements and connections will not disappear by changing the name to something more approachable and easier to remember. This is especially the case if it is explicitly stated in 20.6.4 NMAC that Outstanding Waters are protected under Tier III of the federal antidegradation policy. Other states have adopted different names for their Tier III waters, Pennsylvania for example calls their Tier III waters "Exceptional Value Waters". Alternatively, instead of replacing the name completely, NMED could consider a different abbreviation of Outstanding National Resource Waters. Instead of "ONRW," the abbreviation could be changed to "Outstanding Waters" throughout the 20.6.4 NMAC

Recommendation: Replace the name "Outstanding National Resource Waters" or "ONRW" or both with "Outstanding Waters".

ii. Strengthen Outstanding Waters Implementation

Changes to the antidegradation policy and implementation plan are needed to ensure that if degradation is found in Outstanding Waters, appropriate steps are taken to address the degradation. Currently the Outstanding Waters language found at 20.6.4.8.A(3)(a) and (4)(a) NMAC includes primarily guidance on how to degrade Outstanding Waters on a short-term basis. While these components of the standards are important to ensure that restoration and responses to emergencies can occur, they should not be the only component of the Outstanding Waters protections found at 20.6.4.8 NMAC. Policy to protect the state's most precious waters should not primarily focus on avenues to degrade such waters. We recommend adopting specific requirements and steps in 20.6.4.8 NMAC to ensure that degradation is not occurring in New Mexico's designated Outstanding Waters. Currently, all of the Outstanding Waters in New Mexico are on United States Forest Service (USFS) lands. A good place to start in terms of implementation guidance would be to

set up steps and requirements for cross agency consultation and engagement. 20.6.4.8.B could also outline how implementation of Outstanding Waters protection shall be assessed and summarized in the 303d/305b Report. It is also essential to create a process that will be undertaken if degradation is found in Outstanding Waters. For example, there could be requirements in 20.6.4.8. to sample more frequently in any Outstanding Water where degradation has been detected. Other such actions could include engaging with landowners and other stakeholders to identify sources of degradation, prioritizing restoration dollars in these waters, and prohibiting all short and temporary degradation besides that associated with restoration.

Recommendation: Add language to 20.6.4.8 and 9 NMAC that outline steps the Department will take if increased degradation is detected in an ONRW.

B. Mixing Zones (20.6.4.11.E and F NMAC)

Climate change is creating massive, previously unseen, fluctuations of flow in New Mexico's rivers and streams, making it impossible to ensure that mixing zones are not harming public health or aquatic resources. If the flow in a receiving waterbody swings from large flood events to very low flows, as we can expect, and in fact are already seeing in a changing climate, it is difficult to determine the dilution factor to calculate a mixing zone. In addition, increased flooding events can result in increased pollutant loads in receiving waters from many different sources, making mixing zones all the more inappropriate. Therefore, a concrete step to make New Mexico standards more responsive to climate change is to stop allowing mixing zones. In addition, it is unclear how NMED enforces 20.6.4.11.E(5), which requires that a continuous passage either through or around a mixing where all standards are met be maintained at all times. Again, with climate change and extreme fluctuations of flows and temperatures meeting this requirement and demonstrating this requirement is met is extremely challenging. It would be simpler, safer, and easier for both NMED and permittees to demonstrate compliance if mixing zones were eliminated entirely. Alternatively, if mixing zones aren't prohibited outright, we urge NMED to put additional limitations on mixing zones, such as no mixing zones allowed in either impaired waterbodies, Outstanding Waters (ONRWs), or anywhere that domestic water supply or primary contact is designated.

Recommendation: Eliminate mixing zones in New Mexico as an appropriate step in response to the massive changes and fluctuations in flow we are seeing and expect to see as a result of a changing climate. Alternatively, if mixing zones are prohibited full scale, eliminate mixing zones in impaired waterbodies, Outstanding Waters, and anywhere with a domestic water supply or primary contact use is designated.

C. Applicability of Water Quality Standards – Exceptions (20.6.4.11.I.(1))

How are increased storm events due to climate change considered in this section? It appears that this section of the standards could be read to exempt climate change impacts, such as increased intensity of storm events and faster spring runoff, from applicability of water quality standards. Even without considering climate change impacts, this section is inappropriately broad, and we recommend deleting it. NMED itself has identified stormwater as "a leading cause of water pollution" in New Mexico.[1] It does not make sense to have a whole exception for the applicability of water quality standards during storm events. Fish still swim in our rivers during storm events and

[1] New Mexico Environment Department/Surface Water Quality Bureau (NMED/SWQB). 2024. 303d/305b Report for 2024-2026. Santa Fe, NM. Pg. 61.

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need dissolved oxygen to breathe. People boat and swim in waters that have stormflow impacts. In some cases, these impacts can be seen hours or even up to a day after a storm event. In addition, it is difficult to understand how this exception is implemented. For example, how does NMED determine what contaminants in stormwater runoff are from natural causes? Many of the contaminants we see in stormwater are from poor land use management, which certainly is not "natural". Climate change adds another layer of complexity and difficulty in implementing this exception, because with a changing climate we are likely to see increased intensity of storm events that will result in increased pollutant loading. Climate change is not a natural event, and water quality impacts from climate change should not be folded into this exception. While we strongly recommend deleting this section, if it remains in the standards, language could be added to constrain this section so that designated uses are better protected. This is especially important as climate change impacts to our water resources in New Mexico become the norm rather than the exception. Communities impacted by post wildfire flooding should be able to access the state resources such as state monitoring and identification of impairments, writing TMDLs, and applying section 319 restoration monies to impacted waterbodies, without the risk of those impairments falling under the exception at 20.6.4.11.I(1) NMAC.

Recommendation: Delete section (20.6.4.11.I(1)) in its entirety.

D. Compliance with Water Quality Standards (20.6.4.12.G. NMAC)

We recommend putting constraints on compliance schedules to guard against overuse and abuse of this important tool. For example, we suggest adding a time limit of 5-years and requirements for revisiting compliance schedules during permit renewals. In addition, if a permit is administratively extended, any compliance schedule included in the permit should be reviewed 5-years after issuance of the permit.

Recommendation: Include time constraints and review requirements for compliance schedules.

E. Incorporate Produced Water Constituents into 20.6.4.900 NMAC

With the passage of HB 546 and recent rulemakings considering the discharge of treated produced water to our state's surface water resources, it is imperative that NMED take steps to identify and propose numeric criteria for the numerous contaminants that do not currently have numeric water quality criteria standards in 20.6.4 NMAC. We urge NMED to look at the list submitted by the Environmental Defense Fund ("EDF") on 12/9/20, as part of the triennial review comment period for the 2020 Triennial Review, to see if there are available data and information that would enable NMED to propose criteria for toxic pollutants found in produced water for which we currently do not have a standard. EDF's 2020 comments clearly outline the need and the ability to adopt standards for toxic pollutants found in produced water:

> Through an extensive literature review, EDF has identified approximately 1,360 chemicals that can be found in produced water nationally and therefore have the potential to be found in New Mexico produced waters. An estimated 88 of those already have New Mexico surface water quality standards that could be immediately applied in a potential pilot testing or preliminary permitting program. Of the remainder, about 180 chemicals…… have an approved standard method associated with them,

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> and toxicity values that could be used to conduct human health or aquatic life risk assessments that are the prelude to developing water quality criteria to adopt into a WQS. In other words, EDF estimates that at least 180 potential produced water chemicals have the type of tools and data necessary to begin a process of considering associated water quality criteria and standard updates *today*.

On January 6, 2021, twenty NGO groups - many of whom have signed onto this letter - cited the EDF comment letter and called on NMED in to develop standards for toxic pollutants found in produced water.

It is through the development and adoption of specific criteria for the toxic substances typically found in produced water that we will get closer to safely discharging treated produced water, a goal that has been repeatedly expressed by this state administration. If the state is serious about discharging produced water to our surface waters, then the appropriate water quality criteria must be developed and adopted.

Specifically, as outlined in EDF's letter, there are data available, including in many cases approved analytical methods for developing standards for 180 constituents found in produced water for which New Mexico currently does not have standards. While we realize that developing numeric criteria can be a long and arduous process, it is essential that the standards are robust enough to protect the existing and designated uses of New Mexico's water resources *before* produced water is discharged into surface waterbodies. To help identify priority pollutants among the 180 identified by EDF, more work should be done to characterize produced water in New Mexico.

> *Recommendation: Identify several constituents found in produced water in New Mexico for which there are available data for inclusion in 20.6.4.900 NMAC during the 2026 Triennial Review. In addition, start now to develop numeric criteria for all 180 constituents common in produced water nationwide, for which there is an approved standard method and toxicity values and for which we do not currently have a standard, for adoption at a later date. NMED should also encourage and support increased characterization of produced water in New Mexico to help identify which of the 180 constituents are most common in New Mexico's produced water and therefore should be prioritized for standard development.*

II. COMMENTS ON NMED'S PROPOSED AMENDMENTS

We thank NMED for adding to the wetland definition; proposing a wetland general criterion; including wetland conditions in the antidegradation policy; and proposing new aquatic life use criteria for PFOA, PFOS, and selenium. Standards for wetlands, PFAS, and selenium are critical for implementing a state surface water permitting program, and we appreciate NMED's efforts and work on these topics. Our specific comments below are organized by overarching topic area:

A. Wetlands

i. Wetland Definition at 20.6.4.7.W NMAC

We support NMED's proposed language to this section and believe it will help in the development of the surface water permitting program.

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ii. Wetland General Criterion at 20.6.4.13.N NMAC

We support the creation of wetland water quality standards and believe they are necessary in the development and implementation of the surface water permitting program. However, we do not believe that a criterion to protect wetlands of the state belongs in the general criteria because all of the other criteria in that section are pollutants or conditions, not aquatic features or functions. The list of general criteria are often called the "free-froms", because general criteria typically call for waters to be "free-from" specific pollutants. In contrast, the proposed general criteria for wetlands outlines wetland conditions and functions that must be protected.

Instead, we suggest adding some of the proposed language for 20.6.4.13.N into the antidegradation policy and implementation sections at 20.6.5.8 and 9 NMAC because the language is about preventing degradation and maintaining and protecting wetlands. In addition, we also suggest creating a statewide wetland segment at 20.6.4.96 NMAC that includes all of the language currently proposed for 20.6.4.13.N. We also suggest adding carbon sequestration to the proposed list of some of the possible wetland functions.

The water quality standards must provide a way to determine whether wetlands have physical, biological, or chemical impairments. The narrative general criterion lists functions, but it provides no metrics or tools for such a determination. In EPA guidance for developing wetland water quality standards and in many states, numeric criteria are identified as indicators of wetland functional health or impairment. For example, base flow, dissolved oxygen, conductivity, pH, salinity, species diversity, water levels, and conditions such as water temperature variations, sedimentation patterns, and wetland hydroperiod can all be used to help determine quality and impacts to wetland functions.

We recommend establishing a section for wetlands, as there is for ephemeral waters and intermittent waters, listing wetland functions, designated uses, and relevant narrative and numeric criteria to be used along with functional assessments. This new section in the water quality standards will provide NMED the framework to assess and determine the health or impairment of wetland functions as needed for the purposes of the biennial Integrated Report as well as for the implementation of the state surface water permitting program.

Resources include (with links):

- Wetland Water Quality Standards: Resources (pdf)
- EPA Wetland Water Quality Standards: Program Building Activities Menu (pdf) - 2023
- Impacts on Quality of Inland Wetlands of the United States: A Survey of Indicators, Techniques, and Applications of Community Level Biomonitoring Data

Recommendation: Incorporate the narrative criterion language related to preventing degradation into the antidegradation policy and implementation sections, create a new statewide wetland segment at 20.6.4.96 NMAC, add carbon sequestration to the functions, and add a section that provides metrics and procedures to assess functions and determine impairments.

iii. Wetland Language in Antidegradation Policy and Implementation Plan.

We support the inclusion of wetlands in the antidegradation policy and implementation plan, especially the reference to wetland conditions as a measure of ecological integrity, as demonstrated by wetland functions.

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In addition to the proposed language, we recommend that NMED incorporate language in 20.6.4.8.A(2) that tracks with NMED's proposed language in the draft surface water quality regulations requiring avoidance and minimization of impacts to aquatic resources through an assessment of functions and any potential impacts to them. If degradation of aquatic resources is allowed through dredge and fill projects, we also recommend including language requiring compensatory mitigation. In addition, we recommend that NMED move the following language currently proposed for 20.6.4.13.N to 20.6.4.8 NMAC: "Wetlands shall be maintained and protected such that degradation through direct, indirect, or cumulative impacts does not result in the net loss of wetland acreage or biological, chemical, physical, and hydrological functions to the extent that such functions occur, as characterized by state-specific benchmarks."

The Antidegradation Policy must set the standards for preventing degradation. These rules should reference the wetlands that are high quality or exceptional in some way, and it must reference the process for determining when degradation is proposed or occurring.

> *Recommendation: Develop and include language that requires avoidance and minimization of impacts to aquatic resources including wetland functions using functional assessments as part of the antidegradation policy. Identify categories of exceptional wetlands and methods to determine how high quality will be determined. Move language about no net loss of wetlands from degradation from the new proposed general criterion section to the antidegradation policy.*

B. PFAS

PFOA, PFOS, PFBS, and thousands more compounds belong to a large class of synthetic chemicals known as per- and polyfluoroalkyl substances, or PFAS. PFAS contamination is a major water quality issue facing New Mexico that has resulted in economic losses to our state's dairy industry and substantial impacts to public health and wildlife populations. Developing standards for PFAS chemicals is essential to protect New Mexico's surface water resources.

We support NMED's proposal to adopt numeric criteria for PFOA and PFOS. In addition, we recommend NMED adopt the numeric human health criteria proposed by EPA in December 2024 for PFOA, PFOS and PFBS:

Table 1. Draft Human Health Criteria (HHC) for Three PFAS.

PFAS	Water + Organism HHC (ng/L; ppt)[1]	Organism Only HHC (ng/L; ppt)[1]
PFOA	0.0009	0.0036
PFOS	0.06	0.07
PFBS	400	500

[1] Values are provided in ng/L units to aid in comparison to method detection limit (MDL).

(From EPA's Technical Fact Sheet on Draft National Recommended Human Health Ambient Water Quality Criteria for PFOA, PFOS, and PFBS December 2024[2])

[2] https://www.epa.gov/system/files/documents/2024-12/draft-hhc-pfas-tech-fact-sheet.pdf

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Recommendation: We support NMED's proposed aquatic life criteria for PFOA and PFOS and urge NMED to also propose numeric Human Health criteria for PFOA, PFOS and PFBS as proposed by EPA in December 2024.

C. Site-Specific Criteria

We support the requirements of (notice to the department and submission of a workplan before an entity outside the department may develop site-specific criteria and petition the commission for their adoption. The draft rule doesn't provide any timeframes in this process. We recommend that the notice and workplan should be required at least 6 months before the commission is petitioned.

Recommendation: We recommend that entities outside of the department notice the department and provide a workplan for their intended development of site-specific criteria at least 6 months prior to petitioning the commission.

D. Use Attainability Analysis

EPA has not yet updated their Water Quality Standards Handbook. The changes proposed to three chapters in 2025 are still draft, however, reference to the handbook is appropriate.

The references to the Interim Economic Guidance for Water Quality Standards – Workbook, March 1995 and the Clean Water Act Financial Capability Assessment Guidance, March 2024 must be qualified to indicate that those documents do not adequately include metrics or tools to calculate the benefits of controlling pollution to communities or the costs of not controlling pollution to communities. Proponents of removing designated uses must include those considerations when employing factor 40 CFR 131.10(g)(6).

Recommendation: We recommend that the list of methods to be relied upon for developing use attainability analyses also include resources to assess and calculate the benefits of water pollution control and the costs of not controlling pollution.

Thank you for your consideration of our recommendations. Please don't hesitate to contact us if you have any questions.

Sincerely,

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2026 Triennial Review
Amigos Bravos' 10/14/25 red(green)line of proposed changes to 20.6.4 NMAC

Markup Key:

- NMED's proposed changes appear in red underline and ~~strikethrough~~
- Amigos Bravos' proposed changes appear in green underline and ~~strikethrough~~
- Amigos Bravos' comments on NMED changes and basis for Amigos Bravos proposed changes appear in *black italics* below specific sections for which changes are proposed.

20.6.4.7 DEFINITIONS: Terms defined in the New Mexico Water Quality Act, but not defined in this part will have the meaning given in the Water Quality Act.

A. Terms beginning with numerals or the letter "A," and abbreviations for units.

(1) "4Q3" means the hydrologically based critical low flow as determined by the minimum average flow over four consecutive days that occurs with a frequency of once in three years.

P. Terms beginning with the letter "P".

(7) "Public water supply" means the use or storage of water to supply a public water system as defined by ~~New Mexico's Drinking Water Regulations, 20.7.10 NMAC~~ 40 CFR 141. Water provided by a public water system ~~may need to~~ shall undergo treatment to ~~achieve~~ comply with drinking water ~~quality~~ standards.

T. Terms beginning with the letter "T".

(1) "TDS" means total dissolved solids, also termed "total filterable residue."

(2) "Temporary standard" means a time-limited designated use and criterion for a specific pollutant(s) or water quality parameter(s) that reflect the highest attainable condition during the term of the temporary standard.

(~~2~~3) "Toxic pollutant" means those pollutants, or combination of pollutants, including disease-causing agents, that after discharge and upon exposure, ingestion, inhalation or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will cause death, shortened life spans, disease, adverse behavioral changes, reproductive or physiological impairment or physical deformations in such organisms or their offspring.

(~~3~~4) "Tributary" means a perennial, intermittent or ephemeral waterbody that flows into a larger waterbody, and includes a tributary of a tributary.

(~~4~~5) "Turbidity" is an expression of the optical property in water that causes incident light to be scattered or absorbed rather than transmitted in straight l

W. Terms beginning with the letter "W".

(4) "Wetlands" means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and under normal circumstances do support, ~~a prevalence of~~ vegetation, typically adapted for life in saturated soil conditions in New Mexico. Wetlands are unique surface waters of the state that vary widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation and other factors and provide distinct chemical, biological, physical, and hydrological functions within a watershed. Wetlands that are constructed outside of a surface

water of the state for the purpose of providing wastewater treatment and that do not impound a surface water of the state are not included in this definition.

Amigos Bravos Comment on Section 20.6.7.W(4): *Amigos Bravos supports the changes to the Wetlands definition.*

20.6.4.8 ANTIDEGRADATION POLICY AND IMPLEMENTATION PLAN:

A. Antidegradation Policy: This antidegradation policy applies to all surface waters of the state.

(1) Existing uses, as defined in Paragraph (4) of Subsection E of 20.6.4.7 NMAC, and the level of water quality or wetland conditions necessary to protect the existing uses shall be maintained and protected in all surface waters of the state. Wetland conditions are ~~is a~~ measures of ecological integrity and, by inference, wetland quality (i.e., functions) and quantity (i.e., acreage).

(2) Where wetland conditions or the quality of a surface water of the state exceeds levels necessary to support the propagation of fish, shellfish, and wildlife, and recreation in and on the water, those conditions and that quality shall be maintained and protected unless the commission finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the state's continuing planning process, that allowing lower water quality or degraded wetland conditions, including loss of wetland acreage or wetland functions, is necessary to accommodate important economic and social development in the area in which the water is located. In allowing such degradation or lower water quality, the state shall assure wetland conditions and water quality adequate to protect existing uses fully. Further, the state shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources, that impacts to surface waters, including wetlands have been avoided and minimized to the maximum extent practicable for all new and existing dredge and fill projects, and that all cost-effective and reasonable BMPs for nonpoint source control have been implemented. Wetlands shall be maintained and protected such that degradation through direct, indirect, or cumulative impacts does not result in the net loss of wetland acreage or biological, chemical, physical, and hydrological functions to the extent that such functions occur, as characterized by state-specific benchmarks. Additionally, the state shall encourage the use of watershed planning as a further means to protect surface waters of the state.

(3) No degradation, including loss of ~~wetland~~ acreage or ~~wetland~~ functions of surface waters, including wetlands, shall be allowed in waters designated by the commission as outstanding national resource waters (ONRWs), except as provided in Subparagraphs (a) through (e) of this paragraph and in Paragraph (4) of this Subsection A

(4) This antidegradation policy does not prohibit activities that may result in degradation in surface waters of the state when such activities will result in restoration or maintenance of the chemical, physical or biological integrity of the water.

(b) For surface waters including wetlands of the state other than ONRWs, the department shall review on a case-by-case basis discharges that may result in degradation from permissible restoration or maintenance activities, and may approve such activities in accordance with the following:

(i) the degradation shall be limited to the shortest possible time;

(ii) the degradation shall be minimized and controlled by best management practices or in accordance with permit requirements as appropriate, and all practical means of minimizing the duration, magnitude, frequency and cumulative effects of such degradation shall be utilized; and

(iii) the degradation shall not result in water quality lower than necessary to protect any existing use of the surface water.

(5) If degradation, besides the short-term degradation allowed under Subsection A(3)(a) through (e) and Subsection A(4) of this Section, is detected in an Outstanding Water:

(a) increased monitoring of the Outstanding Water by the Department at a frequency of at least once a year shall be conducted; and

(b) additional actions as outlined in the continuing planning process shall be initiated to determine the source of the degradation and to identify mitigating measures.

~~(5)~~ **(6)** In those cases where potential water quality impairment associated with a thermal discharge is involved, this antidegradation policy and implementing method shall be consistent with Section 316 of the federal Clean Water Act.

~~(6)~~ **(7)** In implementing this section...

B. Implementation Plan: The department, acting under authority delegated by the commission, implements the water quality standards, including the antidegradation policy, by describing specific methods and procedures in the continuing planning process and by establishing and maintaining controls on the discharge of pollutants to surface waters of the state. The steps summarized in the following paragraphs, which may not all be applicable in every water pollution control action, list the implementation activities of the department. These implementation activities are supplemented by detailed antidegradation review procedures developed under the state's continuing planning process. The department:

(1) obtains information pertinent to the impact of the effluent on the receiving water and advises the prospective discharger of requirements for obtaining a permit to discharge;

(2) reviews the adequacy of existing data and conducts a water quality survey of the receiving water in accordance with an annually reviewed, ranked priority list of surface waters of the state requiring total maximum daily loads pursuant to Section 303(d) of the federal Clean Water Act;

(3) assesses the probable impact of the effluent on the receiving water relative to its ~~attainable~~ existing or designated uses and numeric and narrative criteria;

(16) develops list of surface waters including wetlands of the state not attaining designated uses, pursuant to Sections 305(b) and 303(d) of the federal Clean Water Act; and

(17) develops list of designated Outstanding Waters where degradation has been detected and identifies potential sources of pollution, enforcement actions to be taken, and BMPs to be implemented to halt or remedy the degradation.

Amigos Bravos Basis for Change for Section 20.6.4.8 NMAC:

Amigos Bravos supports the wetland language that NMED has proposed to add to 20.6.4.8 NMAC. In addition to NMED's proposed language, Amigos Bravos proposes to incorporate the language related to degradation that NMED has proposed for a new Section 20.6.4.13.N (General Criterion for Wetlands) into 20.6.4.8.A(2) as we believe the antidegradation section is a more appropriate place for that language. Amigos Bravos also proposes to include "wetlands" and language about dredge and fill permits into 20.6.4.8 NMAC to provide a consistent dredge and fill complement to the point source language currently included in this section.

Changes to the antidegradation policy and implementation plan are needed to ensure that if degradation is found in Outstanding Waters, appropriate steps are taken to address the degradation. Currently the Outstanding Waters language found at 20.6.4.8.A(3)(a) and (4)(a) NMAC includes primarily guidance on how to degrade Outstanding Waters on a short-term basis. While these components of the standards are important to ensure that restoration and responses to emergencies can occur, they should not be the only component of the Outstanding Waters protections found at 20.6.4.8 NMAC. Policy to protect the state's most precious waters should not primarily focus on avenues to degrade such waters. We recommend adopting specific requirements and steps in 20.6.4.8 NMAC to ensure that degradation is not occurring in New Mexico's designated Outstanding Water, and if it is found that there are adequate steps taken to

address it.

20.6.4.9 No changes proposed

20.6.4.10 REVIEW OF STANDARDS; NEED FOR ADDITIONAL STUDIES:

~~**F.** If the commission grants a rulemaking hearing for the amendment or adoption of a water quality standard, including ONRW nominations, site-specific criteria, use attainability analyses, and designating classified segments, the petitioner shall be responsible for the costs of the administrative rulemaking process. Costs include: venue, hearing officer, court reporter, original transcripts, translation services, interpretation services, and public notice requirements including publication in newspapers and in the New Mexico register. The petitioner shall coordinate with the commission administrator and the department on rulemaking hearing requirements.~~

F. Site-specific criteria.

(1) The commission may adopt site-specific numeric criteria applicable to all or part of a surface water of the state based on relevant site-specific conditions such as:

(a) actual species at a site are more or less sensitive than those used in the national criteria data set;

(b) physical or chemical characteristics at a site such as pH or hardness alter the biological availability and/or toxicity of the chemical;

(c) physical, biological or chemical factors alter the bioaccumulation potential of a chemical;

(d) the concentration resulting from natural background exceeds numeric criteria for aquatic life, wildlife habitat or other uses if consistent with Subsection G of 20.6.4.10 NMAC; or

(e) other factors or combination of factors that upon review of the commission may warrant modification of the default criteria, subject to EPA review and approval.

(2) Site-specific criteria must fully protect the designated use to which they apply. In the case of human health-organism only criteria, site-specific criteria must fully protect human health when organisms are consumed from waters containing pollutants.

(3) Any person may submit notice to the department stating their intent to derive site-specific criteria for a surface water of thestate no less than six months prior to petitioning the commission to adopt such criteria. The notice shall include a work plan supporting the development of site- specific criteria for the department's review and comment.

(4) Site-specific criteria shall be developed in accordance with the reviewed work plan, based on one or more of the site-specific conditions noted in paragraph 1, derived from a scientifically defensible method and protect the designated uses to which they apply.

(5) The work plan shall identify, at a minimum:

(a) the waterbody to consider and the reasoning for site-specific criteria;

(b) the methodology to be used to derive criteria;

(c) the source and validity of data to be used;

(d) the provisions for consultation with appropriate state and federal agencies;

(e) a description of how stakeholders and potentially affected Indian nations, tribes, or pueblos will be identified and engaged;

(f) a description of the public notice mechanisms to be employed; and

(g) the expected timelines and associated administrative actions to be taken for a rulemaking petition, pending the outcome of criteria development.

(6) Upon completion of site-specific criteria development, the data, findings and conclusions shall be submitted to the department, and public notice shall be provided in accordance with the approved work plan.

G. Site-specific criteria based on natural background. The commission may adopt site-specific criteria equal to the concentration resulting from natural background where that concentration protects the designated use. The concentration resulting from natural background supports the level of aquatic life and wildlife habitat expected to occur naturally at the site absent any interference by humans. Domestic water supply, primary or secondary contact, or human health-organism only criteria shall not be modified based on natural background. A determination of natural background shall:

H. Temporary standards.

~~**(12)** "Temporary standard" means a time-limited designated use and criterion for a specific pollutant(s) or water quality parameter(s) that reflect the highest attainable condition during the term of the temporary standard.~~.

Amigos Bravos Comments and Basis for Change for Section 20.6.4.10 NMAC:
While Amigos Bravos understands NMED's desire to limit the potential economic burden of lots of petitions and proposed changes to 20.6.4 NMAC, NMED's proposed change creates a pay to play situation where only the wealthier stakeholders in the state will have the ability to petition to change standards. Unfortunately, the wealthier stakeholders in the state are often dischargers that have a vested interest in weakening the standards of the waters into which they discharge. Amigos Bravos therefore opposes the proposed blanket requirement that petitioners pay for the hearings. Alternatively, we suggest that NMED add the requirement to pay for the hearing to the UAA and temporary standards sections to ensure that hearings related to those two procedures are paid for by the petitioner.

Amigos Bravos has also added a timeframe for the notice of development of site-specific criteria and workplan to assure that it is provided well before a petition is presented to the commission.

20.6.4.10 REVIEW OF STANDARDS

20.6.4.11 APPLICABILITY OF WATER QUALITY STANDARDS

~~**D**. Mixing zones: A limited mixing zone, contiguous to a point source wastewater discharge, may be allowed in any stream receiving such a discharge. Mixing zones serve as regions of initial dilution that allow the application of a dilution factor in calculations of effluent limitations. Effluent limitations shall be developed that will protect the most sensitive existing, designated or attainable use of the receiving water.~~

~~**E.** Mixing zone limitations: Wastewater mixing zones, in which the numeric criteria set under Subsection F of 20.6.4.13 NMAC, 20.6.4.97 through 20.6.4.899 NMAC or 20.6.4.900 NMAC may be exceeded, shall be subject to the following limitations:~~

~~**(1)** Mixing zones are not allowed for discharges to lakes, reservoirs, or playas; these effluents shall meet all applicable criteria set under Subsection F of 20.6.4.13 NMAC, 20.6.4.97 through 20.6.4.899 NMAC and 20.6.4.900 NMAC at the point of discharge.~~

~~**(2)** The acute aquatic life criteria, as set out in Subsection I, Subsection J, and Subsection K of 20.6.4.900 NMAC, shall be attained at the point of discharge for any discharge to a~~

~~surface water of the state with a designated aquatic life use.~~

~~**(3)** The general criteria set out in Subsections A, B, C, D, E, G, H and J of 20.6.4.13 NMAC, and the provision set out in Subsection D of 20.6.4.14 NMAC are applicable within mixing zones.~~

~~**(4)** The areal extent and concentration isopleths of a particular mixing zone will depend on site-specific conditions including, but not limited to, wastewater flow, receiving water critical low flow, outfall design, channel characteristics and climatic conditions and, if needed, shall be determined on a case-by-case basis. When the physical boundaries or other characteristics of a particular mixing zone must be known, the methods presented in Section 4.4.5, "Ambient-induced mixing," in "Technical support document for water quality-based toxics control" (March 1991, EPA/505/2-90-001) shall be used.~~

~~**(5)** All applicable water quality criteria set under Subsection F of 20.6.4.13 NMAC, 20.6.4.97 through 20.6.4.899 NMAC and 20.6.4.900 NMAC shall be attained at the boundaries of mixing zones. A continuous zone of passage through or around the mixing zone shall be maintained in which the water quality meets all applicable criteria and allows the migration of aquatic life presently common in surface waters of the state with no effect on their populations.~~

Alternatively, incorporate the following changes to 20.6.4.11.E NMAC:

E. Mixing zone limitations: Wastewater mixing zones, in which the numeric criteria set under Subsection F of 20.6.4.13 NMAC, 20.6.4.97 through 20.6.4.899 NMAC or 20.6.4.900 NMAC may be exceeded, shall be subject to the following limitations:

(1) Mixing zones are not allowed for discharges to lakes, reservoirs, or playas; these effluents shall meet all applicable criteria set under Subsection F of 20.6.4.13 NMAC, 20.6.4.97 through 20.6.4.899 NMAC and 20.6.4.900 NMAC at the point of discharge.

(2) Mixing zones are not allowed in Outstanding National Resource Waters; these effluents shall meet all applicable criteria set under Subsection F of 20.6.4.13 NMAC, 20.6.4.97 through 20.6.4.899 NMAC and 20.6.4.900 NMAC at the point of discharge.

(3) In impaired waterbodies mixing are not allowed for parameters that are causing impairment.

~~(2)~~ (4) The acute aquatic life criteria, as set out in Subsection I, Subsection J, and Subsection K of 20.6.4.900 NMAC, shall be attained at the point of discharge for any discharge to a surface water of the state with a designated aquatic life use.

~~(3)~~ (5) The general criteria set out in Subsections A, B, C, D, E, G, H and J of 20.6.4.13 NMAC, and the provision set out in Subsection D of 20.6.4.14 NMAC are applicable within mixing zones.

~~(4)~~ (6) The areal extent and concentration isopleths of a particular mixing zone will depend on site-specific conditions including, but not limited to, wastewater flow, receiving water critical low flow, outfall design, channel characteristics and climatic conditions and, if needed, shall be determined on a case-by-case basis.

~~(5)~~ (7) All applicable water quality criteria set under Subsection F of 20.6.4.13 NMAC, 20.6.4.97 through 20.6.4.899 NMAC and 20.6.4.900 NMAC shall be attained at the boundaries of mixing zones. A continuous zone of passage through or around the mixing zone shall be maintained in which the water quality meets all applicable criteria and allows the migration of aquatic life presently common in surface waters of the state with no effect on their populations.

F. Human health-organism only criteria in Subsection J of 20.6.4.900 NMAC apply to those waters with a designated, existing or attainable aquatic life use. When limited aquatic life is a designated use, the human health-organism only criteria apply only for persistent toxic pollutants, ~~if~~ unless adopted on a segment-specific basis. The human health-organism only criteria for persistent toxic pollutants, as identified in Subsection J of 20.6.4.900 NMAC, also apply to all tributaries of waters with a designated, existing or attainable aquatic life use.

G. Unclassified Waters of the State

H. Exceptions: Numeric criteria for temperature, dissolved solids, dissolved oxygen, sediment or turbidity adopted under the Water Quality Act do not apply when changes in temperature, dissolved solids, dissolved oxygen, sediment or turbidity in a surface water of the state are attributable to:

(1) natural causes (water quality impacts from climate change including post wildfire storm flooding and discharges from municipal separate storm sewers are not covered by this exception.); or

Amigos Bravos Basis for Change for Section 20.6.4.11: *Climate change is creating massive, previously unseen, fluctuations of flow in New Mexico's rivers and streams, making it impossible to ensure that mixing zones are not harming public health or aquatic resources. If the flow in a receiving waterbody swings from large flood events to very low flows, as we can expect, and in fact are already seeing in a changing climate, it is difficult to determine the dilution factor to calculate a mixing zone. In addition, increased flooding events can result in increased pollutant loads in receiving waters from many different sources, making mixing zones all the more inappropriate. Therefore, a concrete step to make New Mexico standards more responsive to climate change is to stop allowing mixing zones. In addition, it is unclear how NMED enforces 20.6.4.11.E(5), which requires that a continuous passage either through or around a mixing where all applicable criteria are met. Again, with climate change and extreme fluctuations of flows and temperature, demonstrating this requirement is met is extremely challenging. It would be simpler, safer, and easier for both NMED and permittees to demonstrate compliance if mixing zones were eliminated entirely. Alternatively, if mixing zones aren't prohibited outright, we urge NMED to put additional limitations on mixing zones, such prohibiting mixing zones in impaired waterbodies, Outstanding Waters (ONRWs), or anywhere that domestic water supply or primary contact is designated to ensure, at the very least, these special and sensitive waters are adequately protected.*

20.6.4.12 COMPLIANCE WITH WATER QUALITY STANDARDS: The following provisions apply to determining compliance for enforcement purposes; they do not apply for purposes of determining attainment of uses. The department has developed assessment protocols for the purpose of determining attainment of uses that are available for review from the department's surface water quality bureau.

F. For compliance with ~~hardness-dependent~~ calculated numeric criteria, that depend on water chemistry, ~~hardness (as mg CaCO3/L)~~ all input parameters shall be determined from a sample taken at the same time that the sample for the contaminant is taken. If not all the input data are available to calculate a criterion, default input values may be used if justified and supported by ecoregional or other watershed data.

G. Compliance schedules may be included in NPDES permits at the time of permit renewal or modification and shall be written to require compliance at the earliest practicable time, but not longer than 5-years. Compliance schedules shall also specify milestone dates so as to measure progress towards final project completion (e.g., design completion, construction start, construction completion, date of compliance). If a permit is administratively continued, a facility with a compliance schedule must show compliance at the end of the initial 5-year permit period.

Amigos Bravos Basis for Change for Section 20.6.4.12: *We recommend putting constraints on compliance schedules to guard against overuse and abuse of this important tool. For example, we suggest adding a time limit of 5-years and requirements for revisiting compliance schedules during permit renewals. In addition, if a permit is administratively extended, any compliance*

schedule included in the permit should be reviewed 5-years after issuance of the permit.

20.6.4.13 GENERAL CRITERIA: General criteria are established to sustain and protect existing or attainable uses of surface waters of the state. These general criteria apply to all surface waters of the state at all times, unless a specified criterion is provided elsewhere in this part. Surface waters of the state shall be free of any water contaminant in such quantity and of such duration as may with reasonable probability injure human health, animal or plant life or property, or unreasonably interfere with the public welfare or the use of property.

~~**N. Wetlands:** Only wetlands of the state are subject to this general criterion. Wetlands shall be~~ maintained and protected such that degradation through direct, indirect, or cumulative impacts does not result in the net loss of wetland acreage or biological, chemical, physical, and hydrological functions to the extent that such functions occur, as characterized by state-specific benchmarks. The functions of a wetland that are to be maintained and protected may include:

~~(1) erosion control through bank and shoreline stabilization;~~
~~(2) flood attenuation and flood protection;~~
~~(3) sediment and pollutant retention, which prevents or mitigates downstream migration;~~
~~(4) groundwater recharge and water storage for future use;~~
~~(5) low flow augmentation including baseflow maintenance;~~
~~(6) water filtration including removal or storage of nutrients and other contaminants;~~
~~(7) propagation or maintenance of aquatic and terrestrial species indigenous to wetlands;~~
~~(8) preservation of wildlife habitat including habitat for threatened or endangered species; or~~
~~(9) supporting biological diversity.~~

~~In addition, wetlands shall be suitable for recreation, wildlife habitat, and use by aquatic life and livestock.~~

Amigos Bravos Basis for Change for Section 20.6.4.13: *Amigos Bravos supports and appreciates NMED's specific proposed language for a wetland standard, however we believe that there are more appropriate places for this language. Specifically, we proposed to move this language to both the antidegradation policy (20.6.4.8 NMAC) and to a new wetland specific segment of the standards at 20.6.4.96 NMAC. We do not believe that a criterion to protect wetlands of the state belongs in the general criteria because all of the other criteria in that section are pollutants or conditions, not aquatic features or functions. The list of general criteria are often called the "free-froms", because general criteria typically call for waters to be "free-from" specific pollutants. In contrast, the proposed general criteria for wetlands outlines wetland conditions and functions that must be protected. Another concern with keeping this language in the general criteria section is that general criteria are very difficult to implement or enforce.*

20.6.4.14 SAMPLING AND ANALYSIS:

C. Sampling Procedures:

(1) Streams: Stream monitoring stations below discharges shall be located a sufficient distance downstream to ensure adequate vertical and lateral mixing.

(2) Lakes: Sampling stations in lakes shall be located at least 250 feet from a discharge.

(3) Lakes: Except for the restriction specified in Paragraph (2) of this

subsection, lake sampling stations shall be located at any site where the attainment of a water quality criterion is to be assessed. ~~Water quality measurements taken at intervals in the entire water column at a sampling station shall be averaged for the epilimnion, or in the absence of an epilimnion, for the upper one-third of the water column of the lake to determine attainment of criteria, except that attainment of criteria for toxic pollutants shall be assessed during periods of complete vertical mixing, e.g., during spring or fall turnover, or by taking depth-integrated composite samples of the water column.~~

20.6.4.15 USE ATTAINABILITY ANALYSIS:

A. Methods for developing a use attainability analysis. A use attainability analysis shall assess the physical, chemical, biological, economic or other factors affecting the attainment of a use. The analysis shall rely on scientifically defensible methods such as the methods described in the following documents:

(1) the United States environmental protection agency's water quality standards handbook and use attainability analysis website for current recommendations and case studies;

(~~1~~2) *Technical Support Manual: Waterbody Surveys And Assessments For Conducting Use Attainability Analyses*, volume I (November 1983) and volume III (November 1984) or latest editions, United States environmental protection agency, office of water, regulations and standards, Washington, D.C., for the evaluation of aquatic life or wildlife uses;

(~~2~~3) the department's *Hydrology Protocol*, latest edition, approved by the commission, for identifying ephemeral, intermittent, and perennial waters; ~~or~~

(~~3~~4) *Interim Economic Guidance For Water Quality Standards - Workbook*, March 1995, in conjunction with *Clean Water Act Financial Capability Assessment Guidance,* March 2024, United States environmental protection agency, office of water, Washington, D.C. for evaluating economic impacts; or

(5) Analysis of and analytical tools to calculate the benefits of pollution control such as:

(a) EPA's site on calculating impacts of Pollution Prevention Grants. https://www.epa.gov/p2/pollution-prevention-tools-and-calculators

(b) Benefit of Water Pollution Control on Property; Values, https://www.epa.gov/sites/default/files/2017-12/documents/ee-0009.pdf;

(c) Measuring the social benefits of water quality improvements to support regulatory objectives: Progress and future directions, https://www.pnas.org/doi/10.1073/pnas.2120247120#sec-4;

(d) A more comprehensive estimate of the value of water; or quality, https://www.sciencedirect.com/science/article/abs/pii/S0047272722000020

D. Process to amend a designated use through a use attainability analysis.

(1) The process for developing a use attainability analysis and petitioning the commission for removing a designated use and establishing the highest attainable use shall be done in accordance with the State's current *Water Quality Management Plan/Continuing Planning Process*.

(2) If the findings of a use attainability analysis, conducted by the department, in accordance with the department's *Hydrology Protocol* (latest edition) demonstrates that federal Clean Water Act Section 101(a)(2) uses, that are not existing uses, are not feasible in an ephemeral water body due to the factor in 40 CFR 131.10(g)(2), the department may consider proceeding with the expedited use attainability analysis process in accordance with the State's current *Water Quality Management Plan/Continuing Planning Process*. The following elements must be met for the expedited use attainability analysis process to be authorized and implemented:

(a) The department is the primary investigator of the use attainability

analysis;

(b) The use attainability analysis determined, through the application of the *Hydrology Protocol*, that the water being investigated is ephemeral and has no effluent discharges of sufficient volume that could compensate for the low-flow;

(c) The use attainability analysis determined that the criteria associated with the existing uses of the water being investigated are not more stringent than those in 20.6.4.97 NMAC;

(d) The designated uses in 20.6.4.97 NMAC have been determined to be the highest attainable uses for the water being analyzed;

(e) The department posted the use attainability analysis on its water quality standards website and notified its interested parties list of a 30-day public comment period;

(f) The department reviewed and responded to any comments received during the 30-day public comment period ; and

(g) The department submitted the use attainability analysis and response to comments to ~~region 6~~ EPA for technical ~~approval~~review.

(3) If EPA approves the designated use revision(s) under section 303(c) of the Clean Water Act, the water shall be subject to 20.6.4.97 NMAC for federal Clean Water Act purposes. The use attainability analysis, the technical support document, and the applicability of 20.6.4.97 NMAC to the water shall be posted on the department's water quality standards website. The department shall periodically petition the commission to list ephemeral waters under Subsection C of 20.6.4.97 NMAC and to incorporate changes to classified segments as appropriate.

E. Use attainability analysis conducted by an entity other than the department. Any person may submit notice to the department stating their intent to conduct a use attainability analysis.

(1) The ~~proponent~~ notice shall ~~provide such notice along with~~include a work plan supporting the development of a use attainability analysis ~~to~~for the department's ~~and region 6 EPA for~~ review and comment.

(2) Upon approval of the work plan by the department, ~~the proponent shall conduct~~ the use attainability analysis shall be conducted in accordance with the applicable portions of Subsections A through D of this Section and ~~implement~~ public ~~noticing~~notice provided in accordance with the approved work plan.

(3) Work plan elements. The work plan shall identify, at a minimum:

(a) the waterbody of concern and the reasoning for conducting a use attainability analysis;

(b) the source and validity of data to be used to demonstrate whether the current designated use is not attainable;

(c) the factors in 40 CFR 131.10(g) affecting the attainment of that use;

(d) a description of the data being proposed to be used to demonstrate the highest attainable use; identified and engaged;

(e) the provisions for consultation with appropriate state and federal agencies;

(f) a description of how stakeholders and potentially affected tribes will be

(g) a description of the public notice mechanisms to be employed; and

(h) the expected timelines outlining the administrative actions to be taken for a rulemaking petition, pending the outcome of the use attainability analysis.

(4) Upon completion of the use attainability analysis, ~~the proponent shall submit~~ the data, findings and conclusions shall be submitted to the department, and ~~provide~~ public notice of the use attainability analysis provided in accordance with the approved work plan.

(5) Pending the conclusions of the use attainability analysis and as described in the approved work plan, the ~~department or the proponent~~ person conducting the use attainability analysis may petition the commission to modify the designated use. ~~The cost of such use attainability analysis shall be the responsibility of the proponent. Subsequent costs associated with the administrative rulemaking process shall be the responsibility of the petitioner.~~

Amigos Bravos Basis for Change for Section 20.6.4.15: *EPA has not yet updated their Water Quality Standards Handbook. The changes proposed to three chapters in 2025 are still draft, however, Amigos Bravos agrees that reference to the handbook is appropriate.*

The references to the Interim Economic Guidance for Water Quality Standards – Workbook, March 1995 and the Clean Water Act Financial Capability Assessment Guidance, March 2024 must be qualified to indicate that those documents do not adequately include metrics or tools to calculate the benefits of controlling pollution to communities or the costs of not controlling pollution to communities. Proponents of removing designated uses must include those considerations when employing factor 40 CFR 131.10(g)(6).

Amigos Bravos recommends that the above references and/or similar state-of-the-art economic analysis and tools be included in the list of required scientifically defensible methods that shall be relied upon to develop a Use Attainability Analysis.

20.6.4.16 through 20.6.4.97 NMAC – No changes proposed

20.6.4.96 WETLANDS: All wetlands of the state, except those wetlands classified in other segments.

A. Designated uses: secondary contact, wildlife habitat, aquatic life, livestock.

B. Criteria: wetlands shall be maintained and protected such that degradation through direct, indirect, or cumulative impacts does not result in the net loss of wetland acreage or biological, chemical, physical, and hydrological functions to the extent that such functions occur, as characterized by state-specific benchmarks. The functions of a wetland that are to be maintained and protected may include: erosion control through bank and shoreline stabilization; flood attenuation and flood protection; sediment and pollutant retention, which prevents or mitigates downstream migration; groundwater recharge and water storage for future use; low flow augmentation including baseflow maintenance; water filtration including removal or storage of nutrients and other contaminants; propagation or maintenance of aquatic and terrestrial species indigenous to wetlands; preservation of wildlife habitat including habitat for threatened or endangered species; ~~or~~ supporting biological diversity; **or sequestering carbon.** The use-specific criteria in 20.6.4.900 NMAC, except for criteria set forth in Subsection I, J, K, L, are applicable to the designated uses until wetland-specific numeric criteria are developed.

Amigos Bravos Basis for Change for Section 20.6.4.96: *Amigos Bravos suggests creating a new segment for wetlands that would apply to all wetlands of the state until such a time that specific wetland segments or standards are developed for specific types of wetlands. Specifically, we recommend establishing a section for wetlands similar to those for ephemeral, intermittent, and perennial waters, that lists wetland functions, designated uses, and relevant narrative and numeric criteria to be used along with functional assessments.*

Water quality standards must provide a way to determine whether wetlands have physical, biological, or chemical impairments. The narrative general criterion lists functions, but it provides no metrics or tools for such a determination. In EPA guidance for developing wetland water quality standards and in many states, numeric criteria are identified as indicators of wetland functional

health or impairment. For example, base flow, dissolved oxygen, conductivity, pH, salinity, species diversity, water levels, and conditions such as water temperature variations, sedimentation patterns, and wetland hydroperiod can all be used to help determine quality and impacts to wetland functions. This new section will provide a way to apply a few of these parameters now and provide a place for additional parameters to be added later. In addition, this new section in the water quality standards will provide NMED the framework to assess and determine the health or impairment of wetland functions as needed for the purposes of both the biennial Integrated Report and the implementation of the state surface water permitting program.

20.6.4.98 INTERMITTENT WATERS: All non-perennial surface waters of the state, except those ephemeral waters included under section 20.6.4.97 NMAC, ~~or~~ classified in 20.6.4.101-899 NMAC, or wetlands protected under 20.6.4.~~13~~ 96 NMAC.

A. Designated uses: livestock watering, wildlife habitat, marginal warmwater aquatic life and primary contact.

B. Criteria: the use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following site-specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

20.6.4.99 PERENNIAL WATERS: All perennial surface waters of the state except those classified in 20.6.4.101-899 NMAC, or wetlands protected under 20.6.4.~~13~~ 96 NMAC.

A. Designated uses: Warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following site-specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

20.6.4.100 through 20.6.4.134 NMAC – No changes proposed.

20.6.4.135 RIO GRANDE BASIN: Bluewater lake and Santa Cruz lake.

A. Designated uses: coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: total phosphorus (unfiltered sample) 0.1 mg/L or less for Bluewater lake; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

Amigos Bravos Basis for Change for All Sections with a Phosphorus Standard: *There is inconsistency in the terms used for phosphorus throughout NMAC 20.6.4 and the proposed amendments. Please use the term "total phosphorus" throughout the document instead of "phosphorus" in some sections, and "total phosphorus" in other sections. For example, 20.6.4.318 Canadian River Basin: Doggett Creek specifies "total phosphorus" in the pollutant and highest attainable condition, but in several sections including 20.6.4.135 Rio Grande Basin: Bluewater Lake, the term "phosphorus" is used and we have confirmed with NMED staff that this is referring to total phosphorus. We have adjusted the amendments document to show where this should be modified in green underlines. There are six more places in NMAC 20.4.6 NMAC that weren't included for amendments in NMED's proposal that need the term "phosphorus" changed to "total phosphorus". Instead of pasting them all in this document we have identified them here: are sections: 20.6.4.109; 20.6.4.123;20.6.4.129; 20.6.4.223; 20.6.4.403; 20.6.4.406, and 20.6.4.40.*

20.6.4.206 PECOS RIVER BASIN: Perennial reaches of the Rio Felix ~~and perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon, excluding North Spring river~~.

A. Designated uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

20.6.4.207 NMAC – No changes proposed.

20.6.4.208 PECOS RIVER BASIN: Perennial reaches of the Rio Peñasco above ~~state highway 24 near Dunken~~Bear Canyon, perennial reaches of tributaries to the Rio Peñasco above ~~state highway 24 near Dunken~~Bear Canyon, perennial reaches of Cox canyon, perennial reaches of the Rio Bonito downstream from ~~state highway 48 (near~~ Angus canyon), the Rio Ruidoso downstream of ~~the U.S. highway 70 bridge~~Palo Verde canyon near Seeping Springs lakes, perennial reaches of the Rio Hondo upstream from Bonney canyon and perennial reaches of Agua Chiquita.

A. Designated uses: fish culture, irrigation, livestock watering, wildlife habitat, coldwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: temperature 30°C (86°F) or less, and total phosphorus (unfiltered sample) less than 0.1 mg/L.

20.6.4.209 PECOS RIVER BASIN: Perennial reaches of Eagle creek upstream of Alto dam to the Mescalero Apache boundary, perennial reaches of the Rio Bonito upstream of ~~state highway 48 (near~~ Angus canyon) excluding Bonito lake, perennial reaches of tributaries to the Rio Bonito upstream of ~~state highway~~ ~~48 (near~~ Angus canyon), perennial reaches of the Rio Ruidoso upstream of ~~the U.S. highway 70 bridge~~Palo Verde canyon near Seeping Springs lakes above and below the Mescalero Apache boundary and perennial reaches of tributaries to the Rio Ruidoso upstream of ~~the U.S. highway 70 bridge~~Palo Verde canyon near Seeping Springs lakes above and below the Mescalero Apache boundary.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 600 µS/cm or less in Eagle creek, 1,100 µS/cm or less in Bonito creek and 1,500 µS/cm or less in the Rio Ruidoso; total phosphorus (unfiltered sample) less than 0.1 mg/L; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

20.6.4.210 through 20.6.4.212 NMAC – No changes proposed.

20.6.4.213 PECOS RIVER BASIN: McAllister lake.

A. Designated uses: coldwater aquatic life, ~~secondary~~ primary contact, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

20.6.4.214 through 20.6.4.218 NMAC – No changes proposed.

20.6.4.219 PECOS RIVER BASIN: Avalon reservoir.

A. Designated uses: irrigation storage, livestock watering, wildlife habitat, ~~secondary~~ primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

20.6.4.220 through 20.6.4.230 NMAC – No changes proposed.

20.6.4.231 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from ~~state highway 24 near Dunken~~ Bear canyon, ~~perennial reaches of North Spring river and~~ perennial reaches of the Rio Hondo and perennial reaches of its tributaries downstream of Bonney canyon.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

20.6.4.232 through 20.6.4.306 NMAC – No changes proposed.

20.6.4.307 CANADIAN RIVER BASIN: Perennial reaches of the Mora river from the USGS gaging station near Shoemaker upstream to the state highway 434 bridge in Mora, all perennial reaches of tributaries to the Mora river downstream from the USGS gaging station at La Cueva in San Miguel and Mora counties except ~~lakes~~ waters identified in 20.6.4.309 NMAC or 20.6.4.313 NMAC, perennial reaches of Ocate creek downstream of Ocate, perennial reaches of tributaries to Ocate creek downstream of Ocate, and perennial reaches of Rayado creek downstream of Miami lake diversion in Colfax county.

A. Designated uses: marginal coldwater aquatic life, warmwater aquatic life, primary contact, irrigation, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

20.6.4.308 CANADIAN RIVER BASIN: Charette lakes.

A. Designated uses: coldwater aquatic life, warmwater aquatic life, ~~secondary~~ primary contact, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

20.6.4.309 CANADIAN RIVER BASIN: The Mora river and perennial reaches of its tributaries upstream from the state highway 434 bridge in Mora except lakes identified in 20.6.4.313 NMAC, all perennial reaches of tributaries to the Mora river upstream from the USGS gaging station at La Cueva, perennial reaches of Coyote creek, upstream of Amola ridge and perennial reaches of tributaries to Coyote creek upstream to Amola ridge, the Cimarron river above state highway 21 in Cimarron, perennial reaches of tributaries to the Cimarron river above state highway 21 in Cimarron except Eagle Nest

lake, all perennial reaches of tributaries to the Cimarron river north and northwest of highway 64 except north and south Shuree ponds, perennial reaches of Rayado creek above Miami lake diversion, perennial reaches of tributaries to Rayado creek above Miami lake diversion, Ocate creek and perennial reaches of its tributaries upstream of Ocate, perennial reaches of the Vermejo river upstream from Rail canyon and all other perennial reaches of tributaries to the Canadian river northwest and north of U.S. highway 64 in Colfax county unless included in other segments.Designated uses: domestic water supply, irrigation, high quality coldwater aquatic life, livestock watering, wildlife habitat, and primary contact; and public water supply on the Cimarron river upstream from Cimarron, on perennial reaches of Rayado creek and on perennial reaches of tributaries to Rayado creek.

A. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

20.6.4.310 through 20.6.4.317 NMAC – No changes proposed.

20.6.4.318 CANADIAN RIVER BASIN: Doggett creek.

A. Designated uses: Warm water aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses,
except that the following site-specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

C. Discharger-specific temporary standard:

(1) Discharger: City of Raton wastewater treatment plant

(2) NPDES permit number: NM0020273, Outfall 001

(3) Receiving waterbody: Doggett creek, 20.6.4.318 NMAC

(4) Discharge latitude/longitude: 36° 52' 13.91" N / 104° 25' 39.18" W

(5) Pollutant(s): nutrients; total nitrogen and total phosphorus

(6) Factor of issuance: substantial and widespread economic and social impacts (40 CFR
131.10(g)(6))

(7) Highest attainable condition: interim effluent condition of 8.0 mg/L total nitrogen and
1.6 mg/L total phosphorus as 30-day averages. The highest attainable condition shall be either the highest attainable condition identified at the time of the adoption, or any higher attainable condition later identified during any reevaluation, whichever is more stringent (40 CFR 131.14(b)(1)(iii)).

(8) Effective date of temporary standard: ~~This temporary standard becomes~~ effective for Clean Water Act purposes on ~~the date of EPA approval~~ July 24, 2020.

(9) Expiration date of temporary standard: no later than 20 years from the effective date.

(10) Reevaluation period: at each succeeding review of water quality standards and at least once every five years from the effective date of the temporary standard (Paragraph (8) of Subsection H of 20.6.4.10 NMAC, 40 CFR 131.14(b)(1)(v)). If the discharger cannot demonstrate that sufficient progress has been made the commission may revoke approval of the temporary standard or provide additional conditions to the approval of the temporary standard. If the reevaluation is not completed at the frequency specified or the Department does not submit the reevaluation to EPA within 30 days of completion, the underlying designated use and criterion will be the applicable water quality standard for Clean

Water Act purposes until the Department completes and submits the reevaluation to EPA. Public input on the reevaluation will be invited during NPDES permit renewals or triennial reviews, as applicable, in accordance with the State's most current approved water quality management plan and continuing planning process.

(11) Timeline for proposed actions. Tasks and target completion dates are listed in the most recent, WQCC-approved version of the New Mexico Environment Department, Surface Water Quality Bureau's "Nutrient Temporary Standards for City of Raton Wastewater Treatment Plant, NPDES No. NM0020273 to Doggett Creek.".

20.6.4.319 through 20.6.4.402 NMAC – No changes proposed.

20.6.4.403 SAN JUAN RIVER BASIN: The Animas river from its confluence with the San Juan river upstream to Estes arroyo.

A. Designated uses: Public water supply, industrial water supply, irrigation, livestock watering, wildlife habitat, coolwater aquatic life, and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses~~, except that the following segment-specific criterion applies: temperature 29°C (84.2°F) or less~~.

20.6.4.404 through 20.6.4.501 NMAC – No changes proposed.

20.6.4.502 GILA RIVER BASIN: The main stem of the Gila river from Redrock canyon upstream to the confluence of the West Fork Gila river and East Fork Gila river and perennial reaches of tributaries to the Gila river downstream of Mogollon creek.

A. Designated uses: industrial water supply, irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, and primary contact~~ and warmwater aquatic life~~.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: 28°C (82.4°F) or less.

20.6.4.503 GILA RIVER BASIN: All perennial tributaries to the Gila river upstream of and including Mogollon creek.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance of 400 µS/cm or less for all perennial tributaries except West Fork Gila and tributaries thereto, specific conductance of 300 µS/cm or less; ~~32.2~~ 29°C (~~90~~84°F) or less in the east fork of the Gila river and Sapillo creek downstream of Lake Roberts; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

20.6.4.504 through 20.6.4.600 NMAC – No changes proposed.

20.6.4.601 SAN FRANCISCO RIVER BASIN: The main stem of the San Francisco river from the New Mexico-Arizona line upstream to~~ state highway 12 at Reserve~~ the confluence with Largo canyon and perennial reaches of Mule creek.

A. Designated uses: irrigation,~~ marginal warmwater and~~ marginal coldwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

20.6.4.602 SAN FRANCISCO RIVER BASIN: The main stem of the San Francisco river from ~~state highway 12 at Reserve~~ the confluence with Largo canyon upstream to the New Mexico-Arizona line.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

20.6.4.603 through 20.6.4.899 NMAC – No changes proposed.

20.6.4.900 CRITERIA APPLICABLE TO EXISTING, DESIGNATED OR ATTAINABLE USES UNLESS OTHERWISE SPECIFIED IN 20.6.4.9~~7~~ 96 THROUGH 20.6.4.899 NMAC:

20.6.4.900.A through 20.6.4.900.C NMAC – No changes proposed.

D. Primary contact: The monthly geometric mean of E. coli bacteria of 126 cfu/100 mL or MPN/100 ml, a single sample of E. coli bacteria of 410 cfu/100 mL or MPN/100 mL, a single sample of total microcystins of 8 µg/L ~~with no more than three exceedances within a 12-month period~~ and a single sample of cylindrospermopsin of 15 µg/L ~~with no more than three exceedances within a 12-month period~~, and pH within the range of 6.6 to 9.0 apply to this use. The results for *E. coli* may be reported as either colony forming units (CFU) or the most probable number (MPN) depending on the analytical method used.

20.6.4.900.E through 20.6.4.900.G NMAC – No changes proposed.

H. Aquatic life: Surface waters of the state with a designated, existing or attainable use of aquatic life shall be free from any substances at concentrations that can impair the community of plants and animals in or the ecological integrity of surface waters of the state. Except as provided in Paragraph (7) of this subsection, the acute and chronic aquatic life criteria set out in Subsections I, J, K and L of this section and the human health- organism only criteria set out in Subsection J of this section are applicable to all aquatic life use subcategories. Total phosphorus (unfiltered sample) of .1mg/L apply to all surface waters of the state with a designated, existing or attainable use of aquatic life. In addition, the specific criteria for aquatic life subcategories in the following paragraphs apply to waters classified under the respective designations.

Amigos Bravos Comments and Basis for Change for Section 20.6.4.900.H NMAC: *While we commend the NMED for their current total phosphorous numeric standards of 0.1mg/L (100ug/L) for several specific water segments, all surface waters of the State should be monitored for total phosphorus levels in order to reduce the occurrences of eutrophication, low dissolved oxygen, and harmful algal blooms. We request that the NMED establish a 0.1mg/L (100ug/L), or similar, standard for total phosphorus in all surface waters of New Mexico to support the aquatic life use. This request is supported by the fact that phosphorus is the limiting nutrient for plant and algal growth in most freshwater systems, and research has shown that concentrations between 0.05 and 0.1mg/L can indicate eutrophic waters. Several scientific studies provide evidence for the link between total phosphorus levels and eutrophication in specific ecosystems, including:*

> ***ACS Publications (2016):*** *An article in Environmental Science & Technology titled "Reducing Phosphorus to Curb Lake Eutrophication is a Success" reviews case studies, including chemical treatment of lakes, that demonstrate controlling phosphorus is key to reversing eutrophication.*

In one example, total phosphorus declined from 500 to 30–40 µg/L (0.5 to 0.03-0.04mg/L) after treatment, suggesting a significant ecological response to low concentrations.

Elsevier (2024): *A study on wetlands in the UK found that total phosphorus concentrations frequently exceeded the Common Standards Monitoring (CSM) environmental quality standard of 0.1 mg/L, with significant spikes that may have adverse biological impacts. This research highlighted how exceeding this threshold can lead to ecological damage.*

We request that the NMED look to Minnesota and Wisconsin for examples of approaches to establish total phosphorus standards in all streams and lakes in New Mexico.

Minnesota has set numeric criteria for total phosphorus in streams ranging from 0.05mg/L (50ug/L) for northern streams to 0.15mg/L (150ug/L) for southern streams. For lakes, the range is from 0.012mg/L (12ug/L) to 0.09mg/L (90 ug/L).

Wisconsin has a similar set of criteria, with stream criteria ranging from 0.075mg/L (75ug/L) to 0.1mg/L (100ug/L) based on stream classification. For lakes, the criteria range from 0.015mg/L (15ug/L) to 0.04mg/L (40ug/L).

(1) **High quality coldwater:** dissolved oxygen 6.0 mg/L or more, 4T3 temperature 20°C (68°F), maximum temperature 23°C (73°F), pH within the range of 6.6 to 8.8 and specific conductance a segment- specific limit between 300 µS/cm and 1,500 µS/cm depending on the natural background in the particular surface water of the state (the intent of this criterion is to prevent excessive increases in dissolved solids which would result in changes in community structure). Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 4T3 temperature applies.

(2) **Coldwater:** dissolved oxygen 6.0 mg/L or more, 6T3 temperature 20°C (68°F), maximum temperature 24°C (75°F) and pH within the range of 6.6 to 8.8. Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 6T3 temperature applies.

(3) **Marginal coldwater:** dissolved oxygen 6 mg/L or more, 6T3 temperature 25°C (77°F), maximum temperature 29°C (84°F) and pH within the range from 6.6 to 9.0. Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 6T3 temperature applies.

(4) **Coolwater:** dissolved oxygen 5.0 mg/L or more, maximum temperature 29°C (84°F) and pH within the range of 6.6 to 9.0.

(5) **Warmwater:** dissolved oxygen 5 mg/L or more, maximum temperature 32.2°C (90°F) and pH within the range of 6.6 to 9.0. Where a segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature.

(6) **Marginal warmwater:** dissolved oxygen 5 mg/L or more, pH within the range of 6.6 to 9.0 and temperatures that may routinely exceed 32.2°C (90°F). Where a segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature.

(7) **Limited aquatic life:** pH within the range of 6.0 to 9.0. The acute aquatic life criteria of Subsections I and J of this section apply to this subcategory. Chronic aquatic life criteria do not apply unless adopted on a segment-specific basis. Human health-organism only criteria apply only for persistent toxic pollutants unless adopted on a segment-specific basis.

20.6.4.900.I NMAC – No changes proposed.

J. Use-specific numeric criteria.

(1) Table of numeric criteria: The following table sets forth the numeric criteria in µg/L, unless otherwise indicated, applicable to existing, designated and attainable uses. For metals, criteria represent the total sample fraction unless otherwise specified in the table. Additional criteria that are not compatible with this table are found in Subsections A through I and K through M of 20.6.4.900 NMAC.

Pollutant	**CAS Number**	**DWS**	**Irr/Irr storage**	**LW**	**WH**	**Aquatic Life**			**Type**
						Acute	Chronic	HH-OO	
Aluminum, dissolved	7429-90-5		5,000			750 ~~i~~h	87 ~~i~~h		
Aluminum, total recoverable	7429-90-5					a	a		
Antimony, dissolved	7440-36-0	6						640	P
Arsenic, dissolved	7440-38-2	10	100	200		340	150	9.0	C,P
Asbestos (fibers/L)	1332-21-4	~~7,000,000 fibers / L~~ 7.0E06							
Barium, dissolved	7440-39-3	2,000							
Beryllium, dissolved	7440-41-7	4							
Boron, dissolved	7440-42-8		750	5,000					
Cadmium, dissolved	7440-43-9	5	10	50		a	a		
Chloride	1688-70-06					~~860,000~~ 8.6E05	~~230,000~~ 2.3E05		
Chlorine residual	7782-50-5				11	19	11		

						Aquatic Life	

Pollutant	**CAS Number**	**DWS**	**Irr/Irr storage**	**LW**	**WH**	Acute	Chronic	HH-OO	**Type**
Chromium III, dissolved	16065-83-1					a	a		
Chromium VI, dissolved	18540-29-9					16	11		
Chromium, dissolved	7440-47-3	100	100	1,000					
Cobalt, dissolved	7440-48-4		50	1,000					
Copper, dissolved	7440-50-8	1300	200	500		a	a		
Cyanide, total recoverable	57-12-5	200			5.2	22.0	5.2	400	
Iron	7439-89-6						1,000		
Lead, dissolved	7439-92-1	~~15~~10	5,000	100		a	a		
Manganese, dissolved	7439-96-5					a	a		
Mercury	7439-97-6	2		10	0.77				P
Mercury, dissolved	7439-97-6					1.4	0.77		P
Methylmercury	22967-92-6							0.3 mg/kg in fish tissue	P
Molybdenum, dissolved	7439-98-7		1,000						
Molybdenum, total recoverable	7439-98-7					7,920	1,895		
Nickel, dissolved	7440-02-	700				a	a	4,600	P

	0								
Nitrate as N (mg/L)		10 ~~mg/L~~				3			
Nitrite + Nitrate (mg/L)				132 ~~mg/L~~					
Selenium, dissolved	7782-49-2	50	b	50			1.5 in lentic water, i 3.1 in lotic water, i	4,200	P
Selenium, total recoverable	7782-49-2				5.0	~~20.0~~	~~5.0~~ 8.5 mg/kg Dry Weight in Whole- Body Fish Tissue 11.3 mg/kg Dry Weight in Fish Muscle Tissue		
Silver, dissolved	7440-22-4					a			
Thallium, dissolved	7440-28-0	2						0.47	P

Pollutant	**CAS Number**	**DWS**	**Irr/Irr storage**	**LW**	**WH**	**Aquatic Life**			**Type**
						Acute	Chronic	HH-OO	
Uranium, dissolved	7440-61-1	30							
Vanadium, dissolved	7440-62-2		100	100					P
Zinc, dissolved	7440-66-6	10,500	2,000	25,000		a	a	26,000	P
Adjusted gross alpha (pCi/L)		15 ~~pCi/L~~		15 ~~pCi/L~~					

Radium 226 + Radium 228 (pCi/L)		5 ~~pCi/L~~		30.0 ~~pCi/L~~					
Strontium 90 (pCi/L)		8 ~~pCi/L~~							
Tritium (pCi/L)		20,000 ~~pCi/L~~		20,000 ~~pCi/L~~					
Acenaphthene	83-32-9	2,100						90	
Acrolein	107-02-8	18				3.0	3.0	400	
Acrylonitrile	107-13-1	0.65						70	C
Aldrin	309-00-2	0.021				3.0		~~0.000007~~ 7.7E-06	C,P
Anthracene	120-12-7	10,500						400	
Benzene	71-43-2	5						160	C
Benzidine	92-87-5	0.0015						0.11	C
Benzo(a)anthracene	56-55-3	0.048						0.013	C, P
Benzo(a)pyrene	50-32-8	0.2						0.0013	C,P
Benzo(b)fluoranthene	205-99-2	0.048						0.013	C, P
Benzo(k)fluoranthene	207-08-9	0.048						0.13	C, P
alpha-BHC	319-84-6	0.056						0.0039	C
beta-BHC	319-85-7	0.091						0.14	C
gamma-BHC (Lindane)	58-89-9	0.20				0.95		4.4	
Bis(2-chloroethyl) ether	111-44-4	0.30						22	C
Bis(2-chloro-1-methylethyl) ether	108-60-1	1,400						4,000	
Bis(2-ethylhexyl) phthalate	117-81-7	6						3.7	C
Bis(chloromethyl) ether	542-88-1							0.17	C
Bromoform	75-25-2	44						1,200	C
Butylbenzyl phthalate	85-68-7	7,000						1	C
Carbaryl	63-25-2					2.1	2.1		
Carbon tetrachloride	56-23-5	5						50	C
Chlordane	57-74-9	2				2.4	0.0043	0.0032	C,P
Chlorobenzene	108-90-	100						800	

	7								
Chlorodibromomethane	124-48-1	4.2						210	C
Chloroform	67-66-3	57						2,000	
Chlorpyrifos	2921-88-2					0.083	0.041		P
2-Chloronaphthalene	91-58-7	2,800						1,000	
2-Chlorophenol	95-57-8	175						800	
Chrysene	218-01-9	0.048						1.3	C, P
Demeton	8065-48-3						0.1		
Diazinon	333-41-5					0.17	0.17		

Pollutant	**CAS Number**	**DWS**	**Irr/Irr storage**	**LW**	**WH**	**Aquatic Life**			**Type**
						Acute	Chronic	HH-OO	
2,4-Dichlorophenoxyacetic acid (2,4-D)	94-75-7	70						12,000	
Dichlorodiphenyldichloroet- hane (DDD)	72-54-8							0.0012	C
Dichlorodiphenyldichloroet- hylene (DDE)	72-55-9							0.00018	C
Dichlorodiphenyltrichloroe- thane (DDT)	50-29-3							0.0003	C,P
4,4'-DDT and derivatives		1.0			0.001	1.1	0.001		P
Dibenzo(a,h)anthracene	53-70-3	0.048						0.0013	C, P
Dibutyl phthalate	84-74-2	3,500						30	
1,2-Dichlorobenzene	95-50-1	600						3,000	
1,3-Dichlorobenzene	541-73-1	469						10	
1,4-Dichlorobenzene	106-46-7	75						900	
3,3'-Dichlorobenzidine	91-94-1	0.78						1.5	C
Dichlorobromomethane	75-27-4	5.6						270	C
1,2-Dichloroethane	107-06-2	5						6,500	C
1,1-Dichloroethylene	75-35-4	7						20,000	
2,4-Dichlorophenol	120-83-	105						60	

	2								
1,2-Dichloropropane	78-87-5	5.0						310	C
1,3-Dichloropropene	542-75-6	3.5						120	C
Dieldrin	60-57-1	0.022				0.24	0.056	~~0.000012~~ 1.2E-05	C,P
Diethyl phthalate	84-66-2	28,000						600	
Dimethyl phthalate	131-11-3	~~350,000~~ 3.5E05						2,000	
2,4-Dimethylphenol	105-67-9	700						3,000	
Dinitrophenols	25550-58-7							1,000	
2,4-Dinitrophenol	51-28-5	70						300	
2,4-Dinitrotoluene	121-14-2	1.1						17	C
Dioxin	1746-01-6	3.0E-05						5.1E-08	C,P
1,2-Diphenylhydrazine	122-66-7	0.44						2.0	C
alpha-Endosulfan	959-98-8	62				0.22	0.056	30	
beta-Endosulfan	33213-65-9	62				0.22	0.056	40	
Endosulfan sulfate	1031-07-8	62						40	
Endrin	72-20-8	2				0.086	0.036	0.03	P
Endrin aldehyde	7421-93-4	10.5						1	
Ethylbenzene	100-41-4	700						130	
Fluoranthene	206-44-0	1,400						20	P
Fluorene	86-73-7	1,400						70	
Guthion	86-50-0						0.01		
Heptachlor	76-44-8	0.40				0.52	0.0038	~~0.000059~~ 5.9E-05	C, P

Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Heptachlor epoxide	1024-57-3	0.20				0.52	0.0038	0.00032	C
Hexachlorobenzene	118-74-1	1						0.00079	C,P
Hexachlorobutadiene	87-68-3	4.5						0.1	C, P
Hexachlorocyclohexane (HCH)-Technical	608-73-1							0.1	C
Hexachlorocyclopentadiene	77-47-4	50						4	
Hexachloroethane	67-72-1	25						1	C
Indeno(1,2,3-cd)pyrene	193-39-5	0.048						0.013	C, P
Isophorone	78-59-1	368						18,000	C
Malathion	121-75-5						0.1		
Methoxychlor	72-43-5	40					0.03	0.02	P
Methyl bromide	74-83-9	49						10,000	
3-Methyl-4-chlorophenol	59-50-7							2,000	
2-Methyl-4,6-dinitrophenol	534-52-1	14						30	
Methylene chloride	75-09-2	5						10,000	C
Mirex	2385-85-5						0.001		P
Nitrobenzene	98-95-3	18						600	
Nitrosamines	Various							12.4	C
Nitrosodibutylamine	924-16-3							2.2	C
Nitrosodiethylamine	55-18-5							12.4	C
N-Nitrosodimethylamine	62-75-9	0.0069						30	C
N-Nitrosodi-n-propylamine	621-64-7	0.050						5.1	C
N-Nitrosodiphenylamine	86-30-6	71						60	C
N-Nitrosopyrrolidine	930-55-							340	C

	2								
Nonylphenol	84852-15-3					28	6.6		
Parathion	56-38-2					0.065	0.013		
Pentachlorobenzene	608-93-5							0.1	
Pentachlorophenol	87-86-5	1.0				19	15	0.4	C
Perfluorooctane sulfonate (PFOS)	Various					71	0.25 in water 0.028 mg/kg Wet Weight in Invertebrate Whole-Body Tissue 0.201 mg/kg Wet Weight in Fish Whole-Body Tissues 0.087 mg/kg Wet Weight in Fish Muscle Tissue	7e-5	P

Pollutant	**CAS Number**	**DWS**	**Irr/Irr storage**	**LW**	**WH**	**Aquatic Life**			**Type**
						Acute	Chronic	HH-OO	
Perfluorooctanoic							100 in water 1.18 mg/kg Wet Weight in Invertebrate Whole-Body Tissue	3.6e-6	

acid (PFOA)	Various					3,100	6.49 mg/kg Wet Weight Fish Whole-Body Tissue 0.133 mg/kg Wet Weight Fish Muscle Tissue		P
Perfluorobutane sulfonate (PFBS)	Various							0.5	
Phenol	108-95-2	10,500						~~300,000~~ 3.0E05	
Polychlorinated Biphenyls (PCBs)	1336-36-3	0.50			0.014	2	0.014	0.00064	C,P
Pyrene	129-00-0	1,050						30	
1,2,4,5-Tetrachlorobenzene	95-94-3							0.03	
1,1,2,2-Tetrachloroethane	79-34-5	1.8						30	C
Tetrachloroethylene	127-18-4	5						290	C,P
Toluene	108-88-3	1,000						520	
Toxaphene	8001-35-2	3				0.73	0.0002	0.0071	C, P
1,2-Trans-dichloroethylene	156-60-5	100						4,000	
Tributyltin (TBT)	Various					0.46	0.072		
1,2,4-Trichlorobenzene	120-82-1	70						0.76	C
1,1,1-Trichloroethane	71-55-6	200						~~200,000~~ 2.0E05	
1,1,2-Trichloroethane	79-00-5	5						89	C
Trichloroethylene	79-01-6	5						70	C
2,4,5-Trichlorophenol	95-95-4							600	
2,4,6-Trichlorophenol	88-06-2	32						28	C
2-(2,4,5-Trichlorophenoxy)propi	93-72-1	50						400	

onic acid (Silvex)									
Vinyl chloride	75-01-4	2						16	C

(2) Notes applicable to the table of numeric criteria in Paragraph (1) of this subsection.

(a) Where the letter "a" is indicated in a cell, the criterion is based on receiving water characteristics and can be referenced in Subsection I of 20.6.4.900 NMAC.

(b) Where the letter "b" is indicated in a cell, the criterion can be referenced in Subsection C of 20.6.4.900 NMAC.

(c) Criteria are in µg/L unless otherwise indicated.

(~~d~~c) Abbreviations are as follows: CAS - chemical abstracts service (see definition for "CAS number" in 20.6.4.7 NMAC); DWS - domestic water supply; Irr/Irr storage- irrigation and irrigation storage; LW - livestock watering; WH - wildlife habitat; HH-OO - human health-organism only; C – criteria based on cancer-causing endpoint; P - persistent toxic pollutant.

(~~e~~d) The criteria are based on analysis of an unfiltered sample unless otherwise indicated. The acute and chronic aquatic life criteria for aluminum are based on analysis of total recoverable aluminum in a sample that is filtered to minimize mineral phases as specified by the department.

(~~f~~e) The criteria listed under human health-organism only (HH-OO) are intended to protect human health when aquatic organisms are consumed from waters containing pollutants. These criteria do not protect the aquatic life itself; rather, they protect the health of humans who ingest fish or other aquatic organisms.

(~~g~~f) The dioxin criteria apply to the sum of the dioxin toxicity equivalents expressed as 2,3,7,8-TCDD dioxin.

(~~h~~g) The criteria for polychlorinated biphenyls (PCBs) apply to the sum of all congeners, to the sum of all homologs or to the sum of all aroclors.

(~~i~~h) The acute and chronic aquatic life criteria for dissolved aluminum only apply when the concurrent pH is less than 6.5 or greater than 9.0 S.U. If the concurrent pH is between 6.5 and 9.0 S.U. then the hardness-dependent total recoverable aluminum criteria in Paragraphs (1) and (2) of Subsection I of 20.6.4.900 NMAC apply.

(h) Selenium water column criteria include 30-day mean dissolved selenium concentrations for lentic systems, including lakes and impoundments, and lotic systems, including rivers and streams.

Amigos Bravos Comments and Basis for Change for Section 20.6.4.900.J:

Comments and basis related to PFAS:

Amigos Bravos applauds and supports NMED's proposal to adopt PFAS standards. In addition, we recommend NMED add to their petition the numeric human health criteria proposed by EPA in December 2024 for PFOA, PFOS and PFBS.

PFOA, PFOS, PFBS, and thousands more compounds belong to a large class of synthetic chemicals known as per- and polyfluoroalkyl substances, or PFAS. PFAS contamination is a major water quality issue facing New Mexico that has resulted in economic losses to our state's dairy industry and substantial impacts to public health and wildlife populations. Developing standards

for PFAS chemicals is essential to protect New Mexico's surface water resources.

Amigos Bravos Comments and Basis for Change for Nitrate as N:
Strong nutrient standards are vital for protecting surface from eutrophication, harmful algae blooms, low dissolved oxygen levels, loss of biodiversity, contaminated drinking water, risks to human health, and economic losses in tourism and property values. The following comments focus on changes to the NMAC 20.6.4 that we believe would strengthen the State's ability to keep nutrient levels low in New Mexico's waters.

There is considerable science suggesting that the drinking water standard should be below 10mg/L, and that the water quality standard to protect aquatic life in surface water should be to 3mg/L as an indicator of potential pollution and environmental risk. We request that the NMED propose a numeric Nitrate as N standard of 3mg/L on all surface waters in New Mexico that have an aquatic life use. The following review peer-reviewed articles are just a few examples of data over the last 25 years to support this request:

i. ***Weyer et al. (2001)**: A groundbreaking study in the Environmental Health Perspectives journal showed an increased risk of bladder and ovarian cancer in older women drinking public drinking water with long-term average nitrate levels exceeding 2.46 mg/L (NO3-N), well below the 10 mg/L regulatory limit.*

ii. ***Dubrovsky et al. (2010)**: A national USGS study found that nitrate concentrations over 1 mg/L in groundwater were indicative of human activity and supported the idea that a 3 mg/L benchmark is a common threshold that signals a departure from natural background levels.*

iii. ***Ward et al. (2018)**: This updated review in the International Journal of Environmental Research and Public Health synthesizes numerous studies examining the health effects of drinking water nitrate, confirming associations with conditions like colorectal cancer, thyroid disease, and birth defects, even at levels below the current 10mg/L limit.*

iv. ***Springer study (2021)**: The paper "Fertilizers and nitrate pollution of surface and ground water" details how increases in nitrogen flow from human sources drive coastal eutrophication, which threatens biodiversity and fisheries.*

Comments related to the need to adopt standards for constituents found in produced water:
With the passage of HB 546 and recent rulemakings considering the discharge of treated produced water to our state's surface water resources, it is imperative that NMED take steps to identify and propose numeric criteria for the numerous contaminants that do not currently have numeric water quality criteria standards in 20.6.4 NMAC. We urge NMED to look at the list submitted by the Environmental Defense Fund ("EDF") on 12/9/20, as part of the triennial review comment period for the 2020 Triennial Review, to see if there are available data and information that would enable NMED to propose criteria for toxic pollutants found in produced water for which we currently do not have a standard. EDF's 2020 comments clearly outline the need and the ability to adopt standards for toxic pollutants found in produced water:

> *Through an extensive literature review, EDF has identified approximately 1,360 chemicals that can be found in produced water nationally and therefore have the potential to be found in New Mexico produced waters. An estimated*

> *88 of those already have New Mexico surface water quality standards that could be immediately applied in a potential pilot testing or preliminary permitting program. Of the remainder, about 180 chemicals…… have an approved standard method associated with them, and toxicity values that could be used to conduct human health or aquatic life risk assessments that are the prelude to developing water quality criteria to adopt into a WQS. In other words, EDF estimates that at least 180 potential produced water chemicals have the type of tools and data necessary to begin a process of considering associated water quality criteria and standard updates today.*

On January 6, 2021, twenty NGO groups - many of whom have signed onto this letter - cited the EDF comment letter and called on NMED in to develop standards for toxic pollutants found in produced water.

It is through the development and adoption of specific criteria for the toxic substances typically found in produced water that we will get closer to safely discharging treated produced water, a goal that has been repeatedly expressed by this state administration. If the state is serious about discharging produced water to our surface waters, then the appropriate water quality criteria must be developed and adopted.

Specifically, as outlined in EDF's letter, there are data available, including in many cases approved analytical methods for developing standards for 180 constituents found in produced water for which New Mexico currently does not have standards. While we realize that developing numeric criteria can be a long and arduous process, it is essential that the standards are robust enough to protect the existing and designated uses of New Mexico's water resources before produced water is discharged into surface waterbodies. To help identify priority pollutants among the 180 identified by EDF, more work should be done to characterize produced water in New Mexico.

Amigos Bravos recommends that NMED identify several constituents found in produced water in New Mexico for which there are available data for inclusion in 20.6.4.900 NMAC during the 2026 Triennial Review. In addition, start now to develop numeric criteria for all 180 constituents common in produced water nationwide, for which there is an approved standard method and toxicity values and for which we do not currently have a standard, for adoption at a later date. NMED should also encourage and support increased characterization of produced water in New Mexico to help identify which of the 180 constituents are most common in New Mexico's produced water and therefore should be prioritized for standard development.

20.6.4.900.K NMAC – No changes proposed.

L. The acute aquatic life criteria for TAN (mg/L) was derived by the EPA (2013) as the one-hour average concentration of TAN mg/L that shall not be exceeded more than once every three years on average. The EPA acute criterion magnitude was derived using the following equation:

Acute TAN Criterion Magnitude for 1-hour average=

$$\text{MIN}\left(\left(\frac{0.27}{1+10^{7.204-pH}}+\frac{39}{\quad}\right),\ \left(0.7249x\left(\frac{0.0114}{1+10^{\quad}}+\frac{1.6181}{1+10^{pH-7.204}}\right)x\left(23.12\times 10^{0.036(20-T)}\right)\right)\right)$$

T (temperature C) and *pH* are defined as the paired values associated with the TAN sample.

(1) Temperature and pH-dependent values of the acute TAN criterion magnitude - when *Oncorhynchus* spp. absent.

	Temperature (°C)																					
pH	0-10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	51	48	44	41	37	34	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	49	46	42	39	36	33	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	46	44	40	37	34	31	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9
6.8	44	41	38	35	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	41	38	35	32	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	38	35	33	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9	7.3
7.1	34	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	31	29	27	25	23	21	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6
7.3	27	26	24	22	20	18	17	16	14	13	12	11	10	9.5	8.7	8	7.4	6.8	6.3	5.8	5.3
7.4	24	22	21	19	18	16	15	14	13	12	11	9.8	9	8.3	7.7	7	6.5	6	5.5	5.1	4.7
7.5	21	19	18	17	15	14	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4
7.6	18	17	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	2.9
7.8	13	12	11	10	9.3	8.5	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4	3.7	3.4	3.2	2.9	2.7	2.5
7.9	11	9.9	9.1	8.4	7.7	7.1	6.6	~~3~~6.0	5.6	5.1	4.7	4.3	4	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	8.8	8.2	7.6	7	6.4	5.9	5.4	5	4.6	4.2	3.9	3.6	3.3	3	2.8	2.6	2.4	2.2	2	1.9	1.7
8.1	7.2	6.8	6.3	5.8	5.3	4.9	4.5	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4
8.2	6	5.6	5.2	4.8	4.4	4	3.7	3.4	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	4.9	4.6	4.3	3.9	3.6	3.3	3.1	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1	0.96
8.4	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79
8.5	3.3	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.98	0.9	0.83	0.77	0.71	0.65
8.6	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.5	1.3	1.2	1.1	1	0.96	0.88	0.81	0.75	0.69	0.63	0.58	0.54
8.7	2.3	2.2	2	1.8	1.7	1.6	1.4	1.3	1.2	1.1	1	0.94	0.87	0.8	0.74	0.68	0.62	0.57	0.53	0.49	0.45
8.8	1.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37
8.9	1.6	1.5	1.4	1.3	1.2	1.1	1	0.93	0.85	0.79	0.72	0.67	0.61	0.56	0.52	0.48	0.44	0.4	0.37	0.34	0.32
9.0	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37	0.34	0.32	0.29	0.27

20.6.4.900.L(2) through 20.6.4.900.M NMAC – No changes proposed.

20.6.4.901 PUBLICATION REFERENCES: These documents are intended as guidance and are available for public review during regular business hours at the offices of the surface water quality bureau. Copies of these documents have also been filed with the New Mexico state records center ~~in order~~ to provide greater access to this information.

A. American public health association. 1992. *Standard Methods for The Examination of Water and Wastewater, 18th Edition.* Washington, D.C. 1048 p.

B. American public health association. 1995. *Standard Methods for The Examination of Water and Wastewater, 19th Edition.* Washington, D.C. 1090 p.

C. American public health association. 1998. *Standard Methods for The Examination of Water and Wastewater, 20th Edition.* Washington, D.C. 1112 p.

D. American public health association. 2018. *Standard Methods for The Examination of Water and Wastewater, 23rd Edition.* Washington, D.C. 1796 p.

E. American public health association. 2023. *Standard Methods for The Examination of Water and Wastewater, 24th Edition.* Washington, D.C. 1516 p.

~~E~~F. United States geological survey. 1989. *Methods For Determination of Inorganic Substances In Water And Fluvial Sediments, Techniques of Water-Resource Investigations of The United States Geological Survey.* Washington, D.C. 545 p.

~~F~~G. United States geological survey. 1987. *Methods For The Determination Of Organic Substances In Water And Fluvial Sediments, Techniques Of Water-Resource Investigations Of The United States Geological Survey.* Washington, D.C. 80 p.

~~G~~H. United States environmental protection agency. 1983. *Methods For Chemical Analysis Of Water And Wastes.* Office of research and development, Washington, DC. (EPA/600/4-79/020). 491 p.

~~H~~I. New Mexico water quality control commission. 2020. *State Of New Mexico Water Quality Management Plan and Continuing Planning Process*. Santa Fe, New Mexico. 277 p.

~~I~~J. Colorado river basin salinity control forum. ~~2020~~2023. ~~*2020*~~*2023 Review, Water Quality Standards For Salinity, Colorado River System.* Phoenix, Arizona. ~~97~~112 p.

~~J~~K. United States environmental protection agency. 2002. *Methods For Measuring The Acute Toxicity Of Effluents And Receiving Waters To Freshwater And Marine Organisms.* Office of research and development, Washington, D.C. (5th Ed., EPA 821-R-02-012). 293 p.

~~K~~L. United States environmental protection agency. 2002. *Short-Term Methods For Estimating The Chronic Toxicity Of Effluents And Receiving Waters To Freshwater Organisms.* Environmental monitoring systems laboratory, Cincinnati, Ohio. (4th Ed., EPA 821-R-02-013). 335 p.

~~L~~M. United States environmental protection agency. 1991. Ambient-induced mixing, in *Technical Support Document For Water Quality-Based Toxics Control*. Office of water, Washington, D.C. (EPA/505/2-90- 001). 335 p.

~~M~~N. United States environmental protection agency. 1983. *Technical Support Manual: Waterbody Surveys And Assessments For Conducting Use Attainability Analyses, Volume I*:. Office of water, regulations and standards, Washington, D.C. 232 p.

~~N~~O. United States environmental protection agency. 1984. *Technical Support Manual: Waterbody Surveys And Assessments For Conducting Use Attainability Analyses, Volume III: Lake Systems*. Office of water, regulations and standards, Washington, D.C. 208 p.

October 14, 2025

Via SmartComment Portal

Attn: New Mexico Environment Department – Surface Water Quality Bureau
Bureau Chief Shelly Lemon
Harold L. Runnels Building,
1190 S. St. Francis Dr., P.O. Box 5469,
Santa Fe, NM 87502
shelly.lemon@env.nm.gov

Re: New Mexico Mining Association's Comments on the New Mexico Environment Department's Proposed Amendments to Standards for Interstate and Intrastate Surface Waters (20.6.4 NMAC) – Triennial Review

Dear Bureau Chief Lemon:

In accordance with the public notice the New Mexico Environment Department's ("NMED") Surface Water Quality Bureau ("SWQB") issued on August 15, 2025, the New Mexico Mining Association ("NMMA") hereby submits its comments on the SWQB's proposed amendments to the State's standards for interstate and intrastate surface waters (20.6.4 NMAC). NMMA appreciates the opportunity to provide comments on the proposed amendments.

The following comments are based on the Public Comment Draft of NMED's Proposed Amendments to 20.6.4 NMAC, issued August 15, 2025.

1. **Proposed Change to "Wetlands" Definition**

NMED proposes in 20.6.4.7.W(4) NMAC to delete from the definition of wetlands the provision regarding "the prevalence of" wetlands. NMED also proposes to add the following to the definition: "Wetlands are unique surface waters of the state that vary widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation and other factors and provide distinct chemical, biological, physical, and hydrological functions within a watershed."

NMMA opposes the modification to this definition for several reasons. First, the federal definition of wetlands emphasizes that wetlands are "areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, *a prevalence of* vegetation typically adapted for life in saturated soil conditions." 40 C.F.R. § 230.41 (emphasis added). By removing "the prevalence of", NMED's proposed definition omits the biological indicator (vegetation prevalence) that has long been a core diagnostic criterion used by the Corps of Engineers for determining whether an area qualifies as a wetland. This omission would create inconsistency with federal standards and introduce uncertainty to the method by which wetlands would be identified at the state level, since existing federal guidance

might no longer apply. In that case, NMED would have to develop new separate technical guidance or make determinations regarding what areas constitute "wetlands" on a case-by-case basis. Note that, if NMED chooses to base a revised definition on new technical guidance, then under the State Rules Act, Section 14-4-5.2.A(7), NMSA 1978, at the time of publication of the notice of the proposed rulemaking, NMED must provide "a citation to technical information, if any, that served as a basis for the proposed rule, and information on how the full text of the technical information may be obtained." That would have to include any information specified in section 74-6-4.D, NMSA 1978, to be utilized as a basis for the change to the definition of "wetlands" in 20.6.4 NMAC. If NMED is proposing to make all determinations regarding application of a new definition of wetlands on a case-by-case basis, NMMA is very concerned that such an approach would overwhelm NMED's capacity to make determinations in a timely manner, resulting in potential delays in permitting economic development, transportation and other projects within New Mexico.

Additionally, with regard to "wetlands" as defined in 20.6.4 in the context of federal law, the federal determination of wetlands has been narrowed by *Sackett v. EPA*, 598 U.S. 651 (2023), which held that wetlands are only subject to federal jurisdiction if they have a continuous surface connection to relatively permanent waters such that it is difficult to determine where the "water" ends, and the "wetland" begins. NMED's proposed definition arguably broadens the scope of wetlands contemplated by *Sackett* by focusing on their distinct biological, chemical, and hydrological functions rather than their hydrological connectivity to jurisdictional waters. This may lead to regulatory inconsistencies, as areas considered "wetlands" under New Mexico's definition may not qualify as wetlands under federal Clean Water Act jurisdiction. NMMA acknowledges that there is some divide at the federal level regarding the definition of wetlands, which is subject to ongoing litigation. However, it should be noted that even pre-*Sackett*, NMED's proposed definition would encompass areas not traditionally recognized as wetlands, such as ephemeral drainages, isolated playas, arroyo bottoms, or other riparian areas that exhibit hydric soils only seasonally or after storm events. Accordingly, the proposed definition exceeds the bounds of federal precedent and introduces a level of regulatory ambiguity that is neither supported by law nor practicable for implementation. This will result in complicating permitting, enforcement, and project coordination between federal and state agencies.

Recommendation: NMMA opposes the proposed definition of wetlands and suggests keeping the definition of wetlands as it is currently written in 20.6.4.7 (W)(4) NMAC.

2. No Net Loss of Wetlands

NMED proposes in 20.6.4.13.N NMAC to add a section providing water quality protections for New Mexico wetlands. This includes that "direct, indirect, or cumulative impacts, does not result in the net loss of wetland acreage or biological, chemical, physical, and hydrological functions…" NMMA opposes the Department's proposed section, as it goes beyond the legislative intent and plain-meaning definition of compensatory mitigation contained within Senate Bill 21[1] ("SB 21") and the Water Quality Act, NMSA 1978 Chapter 74, Article 6.

[1] SB 21 amended the Water Quality Act in 2025, which included the addition of the definition of compensatory mitigation.

NMED Exhibit 13

Compensatory mitigation is defined as "the process of restoring, establishing, enhancing or preserving wetlands, streams or other aquatic resources to offset unavoidable adverse impacts that remain after appropriate and practicable avoidance and minimization measures have been achieved." NMSA 1978 § 74-6-2 (F) (2025). Per the Water Quality Act, the Water Quality Control Commission ("WQCC") "shall not adopt or promulgate a standard or rule that exceeds a grant of rulemaking authority listed in the statutory section of the Water Quality Act authorizing the standard or rule." NMSA 1978 § 74-6-4 (C) (2025). By proposing that water quality protection results in no net loss of wetlands, the Department is requesting the WQCC to exceed its rulemaking authority and go beyond the bounds of statutory requirements. The statutory definition of compensatory mitigation does not include a provision for "no net loss" of wetlands, rather the standard is to "offset unavoidable adverse impacts that remain." NMED's proposed section shifts the regulatory focus from achieving practicable mitigation to achieving a specific measurable outcome, which the legislation did not authorize and is inconsistent with the intent and limits of SB 21.

Additionally, a "no net loss" standard implies a quantifiable accounting of wetland acreage, but the Department has not proposed a methodology for how such an accounting would occur. Without clear criteria regarding this standard, this requirement risks delays and uncertainty with permits as applicants would be unable to predict how mitigation or impacts would be evaluated. Moreover, the Department would have the obligation to comply with the State Rules Act, cited above, and the Water Quality Act, section 74-6-4.D, NMSA 1978, concerning the identification and availability of technical information on which a "no net loss" standard is founded and would be applied.

Recommendation: NMMA opposes section 20.6.4.13.N NMAC as it is proposed and suggests that the Department omit it from the proposed changes to the surface water quality standards or modify the language to ensure consistency with statutory definitions, including removal of "no net loss." Corresponding changes should be made where 20.6.4.13.N is referenced elsewhere, such as the proposed changes to 20.6.4.98 and 20.6.4.99 NMAC.

3. Additional Comments

Public Water Supply: NMMA questions the proposed change to the definition of "Public water supply." First, because the federal rules are incorporated into the New Mexico Drinking Water Regulations ("NMDWR"), we see no need to refer to 40 CFR 141. Also, NMMA believes that the second sentence of the definition is misplaced and unnecessary as part of the surface water quality standards and should be deleted, rather than edited. The language of that sentence as edited also falls outside the lawful scope of the surface water quality standards and would, at best, duplicate and, at worst, conflict with, requirements in the NMDWR.

Antidegradation Policy and Implementation Plan: For reasons discussed above relating to the proposed change in the definition of "wetlands," and because they are unnecessary, unclear and lacking in statutory authority, NMMA opposes all of the proposed changes to 20.6.4.8 NMAC.

NMED Exhibit 13

The New Mexico Mining Association appreciates the Department's efforts in developing the proposed rule and the opportunity to provide input through this public comment process. NMMA looks forward to continued collaboration with the Department to ensure that the final rule is clear, practicable, and consistent with legislative intent.

Sincerely,

Matt Thompson
Executive Director

October 13, 2025

New Mexico Environment Department
Surface Water Quality Bureau
P.O. Box 5469
Santa Fe, NM 87502

Attn: Michael Baca
Water Quality Standards Coordinator

Via E-mail to: michael.baca1@env.nm.gov

Re: San Juan Water Commission's Comments on Public Review Draft of Proposed Amendments to Water Quality Standards, 20.6.4 NMAC (2026 Triennial Review)

Dear Mr. Baca:

Pursuant to the New Mexico Environment Department's ("NMED") notice of a public comment period for the proposed amendments to the State's Standards for Interstate and Intrastate Surface Waters, 20.6.4 NMAC ("2026 Triennial Review"), I hereby provide the following comments on behalf of the San Juan Water Commission ("SJWC"). These comments are based on our review of NMED's August 25, 2025, Public Review Draft for the 2026 Triennial Review, as well as the information provided by NMED personnel at the virtual meeting held on September 10, 2025. SJWC appreciates the opportunity provided by NMED to comment on the Public Review Draft.

Substantive Comments

1. Selenium Criteria – 20.6.4.900(J)(1) NMAC. NMED proposes adoption of chronic criteria for selenium for aquatic life uses based on criteria adopted by EPA in 2016. The proposal includes both fish tissue-based and water-based criteria, but NMED has not indicated which type of criteria it intends to primarily apply when determining (i) whether to adopt or modify a TMDL, (ii) whether a state surface water is impaired, or (iii) what effluent limits to apply to an NPDES permit. As EPA has given primacy to the fish tissue-based criteria over the water-based criteria, NMED should indicate which criteria it intends to apply most frequently. *See* EPA's Aquatic Life Ambient Water Quality Criterion for Selenium in Freshwater 2016-Fact Sheet, EPA 822-F-16-005 (June 2016), at 2, n.1 ("EPA Fact Sheet"). Further, EPA's 2016 selenium criteria include a value for fish egg-ovary concentrations, and EPA recommends that it be included in state standards. NMED should explain why it has elected not to propose the fish egg-ovary criteria.

The proposed chronic water-based criteria for aquatic life (1.5 µg/L lentic and 3.1 µg/L lotic) are much stricter than existing water-based criteria, such as for domestic water supply and livestock watering (both 50 µg/L). As NMED is aware, some waters in the San Juan Basin have high natural background levels of selenium. In fact, NMED prepared a TMDL for selenium in Gallegos Canyon (San Juan River to Navajo Boundary) in 2005. Selenium was last addressed in depth during the1999 Triennial Review. At that time, SJWC presented evidence that studies conducted in the Upper Colorado River Basin showed that hatching success for the razorback sucker occurred in waters where average concentrations of selenium were higher than the criteria proposed by NMED. Further, SJWC presented evidence that application of a sediment-based selenium toxicity model capable of accounting for the organic content of streams indicated an allowable level of 31 µg/L of dissolved selenium in the San Juan Basin based on the potential for selenium uptake in the food chain. Put simply, the model reflected the reduced opportunity for food chain uptake of selenium in low organic, moving streams in the San Juan Basin. When data from high organic content water bodies was applied to the model, the model predicted allowable selenium levels in the range of 3-5 µg/L dissolved. As noted in EPA's Fact Sheet (at 1), "the latest scientific knowledge . . . indicates that selenium toxicity to aquatic life is primarily based on organisms consuming selenium-contaminated food rather than by being exposed only to selenium dissolved in water."

For these reasons, NMED should not propose state-wide chronic aquatic life standards for selenium, whether water-based or fish tissue-based. Rather, NMED should collect data specific to regions of the state, like the San Juan region, where there are high natural background selenium levels. Based on that data, NMED can propose site-specific criteria accounting for differing local conditions. In fact, EPA supports such site-specific criteria:

> States and authorized Tribes also have the additional option of adopting site-specific water column criterion elements, if desired . . . . The relationship between the concentration of selenium in the tissues of fish and the concentration of selenium in the water column can differ substantially between different aquatic systems. The chemical form of selenium, species of fish, the species and proportion of prey, and a variety of site-specific biogeochemical factors affect selenium bioaccumulation and thus determine the allowable concentration of selenium in ambient water that is protective of aquatic life.

EPA Technical Support for Adopting and Implementing the EPA's 2016 Selenium Criterion in Water Quality Standards, EPA 820-R-24-001 (April 2024), at 12-13.

Adoption of an unnecessarily strict selenium standard could have significant economic impacts in the San Juan region as the cost of reducing selenium discharges can be quite high. Such costs may reduce opportunities for future economic development and also negatively impact existing municipal and industrial projects.

2. Definition of "Wetlands" – 20.6.4.7(W)(4). NMED proposes modifying the definition of "wetlands" to add a sentence to "clarify" that: "Wetlands are unique surface waters of the state that vary widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation and other factors and provide distinct chemical, biological, physical, and hydrological functions within a watershed." SJWC objects to this proposal as unnecessary because this same statement applies equally to all types of surface waters of the state. NMED also proposes removing the requirement that wetlands contain "a prevalence of" vegetation typically adapted for life in saturated soil conditions in New Mexico. SJWC objects to this proposal on the ground that it makes the definition of a wetland too ambiguous for both NMED and permittees and provides permit writers with too much discretion in determining the existence and boundaries of a wetland.

3. Wetlands—Antidegradation Policy – 20.6.4.8(A) NMAC. NMED proposes several modifications to the antidegradation policy to add references to "wetland condition," "wetland acreage," and "wetland functions." SJWC objects to these proposals as unnecessary. The existing antidegradation policy "applies to all surface waters of the state," 20.6.4.8(A)(1) NMAC, and wetlands fall within the definition of "surface waters of the state," 20.6.4.6(S)(5)(a)(vi) NMAC.

4. General Criterion for Wetlands – 20.6.4.13(N) NMAC. NMED proposes adoption of a "general" criterion for wetlands:

> N. Wetlands: Only wetlands of the state are subject to this general criterion. Wetlands shall be maintained and protected such that degradation through direct, indirect, or cumulative impacts does not result in the net loss of wetland acreage or biological, chemical, physical, and hydrological functions to the extent that such functions occur, as characterized by state-specific benchmarks. The functions of a wetland that are to be maintained and protected may include:
>
> (1) erosion control through bank and shoreline stabilization;
> (2) flood attenuation and flood protection;
> (3) sediment and pollutant retention, which prevents or mitigates downstream migration;
> (4) groundwater recharge and water storage for future use;
> (5) low flow augmentation including baseflow maintenance;
> (6) water filtration including removal or storage of nutrients and other contaminants;
> (7) propagation or maintenance of aquatic and terrestrial species indigenous to wetlands;
> (8) preservation of wildlife habitat including habitat for threatened or endangered species; or
> (9) supporting diversity.
>
> In addition, wetlands shall be suitable for recreation, wildlife habitat, and use by aquatic life and livestock.

SJWC objects to this proposal as unnecessary, ambiguous, overbroad, and outside the scope of authority under the New Mexico Water Quality Act. As already noted, wetlands are protected to the same extent as any other water of the state, and therefore this section is unnecessary. Further, NMED's proposal is ambiguous with respect to its references to "indirect or cumulative impacts," "net loss of wetlands acreage," "hydrological functions," "state-specific benchmarks," and the wetland functions that "may" be included in the list of functions to be maintained and protected.

Under the Water Quality Act, the Water Quality Control Commission ("WQCC") has authority to adopt water quality standards to support designated uses assigned to a water body. The WQCC also may adopt regulations to prevent or abate water pollution. NMSA 1978, §§ 74-6-4(D), (E). "Water pollution" means "introducing or permitting the introduction into water, either directly or indirectly, of one or more water contaminants in such quantity and of such duration as may with reasonable probability injure human health, animal or plant life or property, or to unreasonably interfere with the public welfare or the use of property." *Id.*, §74-6-2(C). A "water contaminant" is "any substance that could alter, if discharged or spilled, the physical, chemical, biological or radiological qualities of water." *Id.*, § 74-6-2(B). SJWC submits that most of the functions listed by NMED, including erosion control, water storage and low flow augmentation, are outside the WQCC's authority under the Water Quality Act as they are unrelated to the introduction of water contaminants. Further, the WQCC has no authority to modify property rights in water, and the

mandated protection of functions such as water storage and low flow augmentation likely will impinge on the use of water rights. *Id.*, § 74-6-12(A).

5. Rulemaking – 20.6.4.10(F) NMAC. NMED proposes shifting all costs of rulemaking hearings to the petitioner, including paying for the venue, the hearing officer, the court reporter, transcripts, translation services, interpretation services, and public notice requirements. As NMED notes, the WQCC historically has covered these costs through NMED's budget. The WQCC has done so even when NMED was not the petitioner. Section 74-6-6 of the Water Quality Act requires a public hearing before a regulation or water quality standard is adopted. As hearings are a statutory function of the WQCC, it is the responsibility of the WQCC to fund those hearings. Indeed, that is a basic function of government. If funding is required to be provided from NMED's budget by virtue of the fact that the WQCC is administratively attached to that agency, then it is the duty of the WQCC and NMED to ensure that adequate rulemaking funding is sought from the Legislature. In fact, as an "administratively attached agency," the WQCC is authorized to submit its budgetary requests through NMED. NMSA 1978, § 9-1-7(A)(2). Requiring a non-NMED petitioner to bear the costs of a hearing will have a severe chilling effect on potential petitioners and leave NMED entirely in control of the WQCC's rulemaking agenda.

Timing of the Triennial Review Hearing

Given NMED's intent to "petition the WQCC by the end of 2025 for a hearing in the second half of 2026," SJWC requests that NMED seek a hearing date no earlier than September 2026. Several other significant WQCC rulemakings are in the pipeline, including the WATR Alliance produced water reuse petition and the anticipated rulemaking on the new state permitting program. Those rulemakings, together with the Triennial Review rulemaking, will require the expenditure of substantial time and expense resources by the WQCC, NMED, and the participating parties. In order to ensure a full and fair opportunity to participate, the Triennial Review should not be rushed, and parties should be given enough time to obtain expert witnesses and prepare direct and rebuttal expert reports and supporting exhibits.

Thank you for the opportunity to comment on NMED's proposed revisions to the State's surface water quality standards. SJWC reserves the right to supplement these comments, and to comment on any additional proposed changes, as the Triennial Review process proceeds.

Sincerely,

Aaron Chavez
Executive Director
San Juan Water Commission

Los Alamos National Laboratory
P.O. Box 1663, MS K490
Los Alamos, NM 87545
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Environmental Protection & Compliance Division Compliance Programs Group

Symbol: EPC-DO: 25-290
LA-UR: 25-30057
Date: October 14, 2025

Michael Baca, WQS Coordinator
Surface Water Quality Bureau
New Mexico Environment Department
Harold Runnels Building, Room
Santa Fe, NM 87502
michael.baca1@env.nm.gov

VIA ELECTRONIC MAIL

Subject: Comments of Triad National Security, LLC, Operator of the Los Alamos National Laboratory, on New Mexico Environment Department Public Review Draft for the 2026 Triennial Review and 20.6.4 NMAC

Dear Mr. Baca,

Triad National Security, LLC, the management and operating contractor for the Los Alamos National Laboratory, submits the enclosed comments in response to the New Mexico Environment Department's (NMED) Public Review Draft for the 2026 Triennial Review, which proposes changes to surface water quality standards in New Mexico Administrative Code Section 20.6.4.

The Los Alamos National Laboratory executes work across numerous missions, including national security, science, artificial intelligence, environmental monitoring, and energy. The Laboratory achieves its missions when it also protects the environment, complies with environmental requirements, and reduces or eliminates environmental risk. To support its missions, the Laboratory gathers wastewater from various generators, treats the wastewater, and discharges treated water to Rio Grande tributary waters. The Laboratory discharges clean water in compliance with federal and state regulations and permits, and through use of control technology and best practices. The Laboratory also compliantly manages stormwater and actions affecting wetlands.

Protecting the environment requires clear regulatory requirements and efficient regulatory processes. The Triennial Review provides an opportunity to clarify requirements and improve processes. In this Triennial Review, NMED is reviewing and proposing changes to surface water quality standards. NMED is accepting public comments and will incorporate comments, as appropriate, into draft regulations. Comments can help clarify regulatory requirements and improve regulatory processes.

The Laboratory appreciates the opportunity to provide comments for NMED's consideration and hopes the comments may be useful to NMED.

Sincerely,

SARAH HOLCOMB
(Affiliate)

Digitally signed by SARAH HOLCOMB (Affiliate)
Date: 2025.10.14 09:33:55 -06'00'

Sarah Holcomb
Group Leader
Environmental Compliance Programs
Triad National Security, LLC

Attachment: Comments from Triad National Security, LLC, Operator of the Los Alamos National Laboratory, on New Mexico Environment Department Public Review Draft for the 2026 Triennial Review and 20.6.4 NMAC

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ATTACHMENT 1

Comments from Triad National Security, LLC,
Operator of the Los Alamos National Laboratory,
on New Mexico Environment Department Public Review Draft for the 2026 Triennial Review and 20.6.4 NMAC

EPC-DO: 25-290

LA-UR: 25-30057

Date: 10/14/2025

INTRODUCTION

Triad National Security, LLC manages and operates the Los Alamos National Laboratory on behalf of the United States Department of Energy National Nuclear Security Administration. The Los Alamos National Laboratory is a Federally Funded Research and Development Center and National Security Laboratory that executes work across numerous missions, including national security, science, artificial intelligence, and energy. In support of its missions, certain Laboratory facilities receive, treat, and discharge clean water to various Rio Grande tributary waters. The Laboratory also manages stormwater discharges to various Rio Grande tributary waters, adopting control technologies and best practices. The Laboratory's discharges comply with federal and state law and with federal and state permits.

The Laboratory achieves its missions when it also protects the environment, complies with environmental requirements, and reduces or eliminates environmental risk. To protect the environment and to compliantly and effectively operate requires clear regulatory requirements and efficient regulatory processes.

Comment 1:

Many of the waters to which the Los Alamos National Laboratory discharges are federal jurisdictional waters or point sources. These waters are tributaries of, and connected and contribute flow to, a traditional navigable water - the Rio Grande. The waters form, individually and collectively, an integrated and cohesive river network. A river network is a hierarchical, interconnected group of channels that drains surface and subsurface water from a watershed to a river and includes the river itself. The waters are an integral, indistinguishable part of the Rio Grande's tributary system or river network.

Comment 2:

The language added in the "wetlands" definition in 20.6.4.7.W(4) NMAC is vague, and its intent and application are unclear.

- **What is included in, and what is exempt from the "wetlands" definition?**

  The new sentence states that wetlands are "unique" and "vary widely because of regional and local differences." While the "BASIS OF CHANGE" explanation states that recognizing wetlands' "characteristics and functions will help protect and maintain these features, it is not clear how the additional language will accomplish this. The new terms could be interpreted to either restrict or broaden the definition. How does the uniqueness and variety of wetlands impact interpretation of the existing definition which defines wetlands "under normal circumstances"? If wetlands "vary widely," how much can their features vary before they are no longer considered wetlands?

  Further, it is unclear whether the definition includes wetlands created or supported by human activities, such as discharges. If it does, what if the human activities cease? Does the definition include wetlands created or supported by drainage ditches or canals? By artificially irrigated areas? By recharge features? By environmental monitoring or remedial activities? By temporary sedimentation basins or ponds? By safety improvements? Is a feature a wetland if only human activities can maintain it as such? Wetlands created by, or whose continued functioning is contingent on, human activities should not be defined as wetlands or should be exempt from regulation.

- **The new language does not address changes to wetlands caused naturally, such as by reduced precipitation, or by changes in the timing or intensity of precipitation, or by changes to an adjacent watercourse.**

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- **Are wetlands regulated by the U.S. Army Corps of Engineers also going to be regulated by the State? Are there other "wetlands" that should be exempt from the "wetlands" definition?**

- **The wetland definition does not reference parameters or methods to determine how an area is determined to be a wetland.**

  The definition notes that wetlands "provide distinct chemical, biological, physical, and hydrologic functions within a watershed," but does not explain what functions may be indicative of a wetland; what functions may be associated with something that is not a wetland; or what functions require protection. For comparison, see e.g. the U.S. Army Corps of Engineers Wetland Delineation Manual.

  Consider adding the following language: "Wetlands identification/delineation shall rely on analysis of wetland hydrology indicators, hydrophytic vegetation and hydric soils through scientifically defensible methods as described in U.S. Army Corps of Engineers (USACE) Wetland Delineation Manual, latest edition, appropriate USACE Regional Supplement manuals, latest editions."

- **The addition of wetlands to the draft document does not provide enough guidance on types of waters to exempt from dredge/fill and wetland authorization requirements. Please consider expanding the types of waters to exclude from dredge/fill and wetland authorization requirements such as the following:**

  - Drainage ditches designed for at least the partial purpose of increasing drainage of a particular land area or infrastructure for purposes including agriculture, transportation (e.g., roadside), and stormwater management.
  - Stormwater control features that are constructed to convey, treat, or detain stormwater.
  - Artificially irrigated areas that would revert to uplands (any land area that, under normal circumstances, is not a wetland and does not lie below the ordinary high watermark) if irrigation ceased.
  - Wetlands that are adjacent to a ditch or canal and supported by water in the adjacent ditch or canal.
  - Recharge features, including ponds, for the purpose of facilitating recharge of aquifers or streams.
  - Construction of temporary sedimentation basins/ponds on a construction site, with construction that does not include placement or fill material into state waters.

- **The draft document also does not provide enough guidance on types of activities in wetlands and floodplains exempt from dredge/fill and wetland authorization requirements. Please consider adding the types of activities to exclude from dredge/fill and wetland authorization requirements such as the following:**

  - Site characterization, environmental monitoring, or environmental research activities (e.g., sampling and surveying of water, air, flora and fauna abundance, soil properties) in a floodplain or wetland.
  - Maintenance of drainage ditches or dikes, embankments, impoundments, water control features, and other water conveyance features that are human-made and intended to be maintained.
  - Maintenance of stormwater control features that are constructed to convey, treat, or temporarily store stormwater.

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- Maintenance, including emergency reconstruction of recently damaged parts, of currently serviceable structures, such as dikes, dams, riprap, culverts, bridge abutments or approaches, and transportation structures. Maintenance also includes minor deviations in a structure's configuration or filled area to accommodate changes in materials, construction techniques, regulatory requirements, or construction codes or safety standards.
- Routine maintenance of existing facilities and structures in a floodplain or wetland. Maintenance is routine when it is needed to maintain and preserve the facility of structure for its designated purpose (e.g., activities such as reroofing, plumbing repair, door and window replacement).
- Minor modification (e.g., upgrading lighting, heating, ventilation, air conditioning systems, installing or improving alarm and surveillance systems, adding environmental monitoring or control systems, adding) of an existing facility or structure in a floodplain or wetland to improve safety or environmental conditions unless the modification would involve draining, dredging, channelizing, filling, diking, impounding, or related activities.
- Activities for the purpose of providing emergency response to, preventative mitigation of, or recovery from damage caused by a fire, a flood, or other natural disasters so long as the activity is conducted in a manner that minimizes the loss of state waters to the extent practicable and in accordance with best management practices that do not interfere with efforts to address the underlying emergency.

Please see also Comment 3, incorporated here by reference.

Comment 3:

In 20.6.4.8.A, the definition of "wetland condition" is vague and the antidegradation policy's implementation is not clear.

- **What is meant by "by inference, wetland quality (i.e., functions) and quantity (i.e., acreage)"?**

  What is being inferred, and for what purpose is it being inferred? What functions are considered in evaluating wetland quality? What is the importance of "quantity" or "acreage"?

  How will the New Mexico Environment Department quantify or measure degradation specific to wetlands? Is there a "level" of wetland condition that is necessary to protect existing uses? If so, how is that level calculated? If "wetland condition" is meant as a descriptive or qualitative term, what "conditions" are considered in evaluating the "wetland condition"? Is that limited to a measure of the wetland's ecological integrity? If so, how is a wetland's ecological integrity measured?

- **The "loss of wetland acreage" is not defined.**

  How will loss of quantity or acreage be quantified on a year-to-year basis? How will a wetland's natural expansion or reduction based on precipitation or other natural events be accounted for? Is there a quantity or acreage below which wetlands will not be regulated, or is there some amount of lost quantity or acreage that will be accepted before there is an impact to wetlands requiring regulation?

NMED Exhibit 13

The State should provide quantifiable bounding limits on incidental loss of wetland acreage (e.g. greater than three-tenths of an acre of unavoidable adverse impacts to wetlands; OR greater than five-hundredths of an acre of unavoidable adverse impacts to streams).

The "loss of wetland acreage" does not acknowledge any difference between human-caused degradation and loss due to natural processes such as reduced annual precipitation or timing and intensity of received precipitation. This implies human intervention will be required to preserve wetlands that simply no longer receive enough rainfall to persist and further implies the need to supply another water source, such as pumped groundwater, to support such wetlands.

- **The New Mexico Environment Department's Water Quality Management Plan and Continuing Planning Process has not been updated to include how antidegradation analysis will be conducted for wetlands or how this may impact the permitting process.**

  When will any such updates be made? Will there be certain water quality standards applicable to each wetland or will water quality standards be applicable to all wetlands?

- **The antidegradation section does not provide for compensatory mitigation measures.**

  The current antidegradation section would benefit from greater clarity regarding implementation and from the inclusion of compensatory mitigation mechanisms. This would strengthen environmental protection and provide clear pathways for compliance.

  Every site has limitations, and it may not be practicable to avoid wetlands. The rule should include a means for compensatory mitigation measures to offset unavoidable adverse impacts that may remain after all appropriate and practicable avoidance and minimization has been achieved. Inclusion of means that create, enhance, restore, rehabilitate, or preserve wetlands should be considered as a means to avoid loss of wetland quantity or acreage on a State scale. Compensatory mitigation could include purchase of mitigation bank credits, an in-lieu fee program, or permittee-responsible mitigation.

  Please see also Comment 4, incorporated here by reference.

Comment 4:

Proposed Rule 20.6.4.10.F should be reconsidered.

- **The New Mexico Environment Department should not shift to the public the cost of correcting deficiencies in water quality standards.**

  Requiring petitioners to pay for administrative rulemaking processes will stifle efforts by the public to improve water quality standards. The proposed rule likewise creates a potential disincentive for New Mexico Environment Department to itself pursue necessary regulatory changes. Correcting deficiencies in water quality standards should be encouraged, not impeded. Petitioners should not be penalized for attempting to correct deficiencies in regulatory requirements or processes. Such corrections are in the public interest and are the costs of having, administering, and improving an environmental regulatory program.

NMED Exhibit 13

- **Potential costs to petitioners, moreover, are unclear and may be prohibitive.**

  The rule includes a non-exhaustive list of costs, several of which could be substantial. In its "BASIS FOR CHANGE" explanation, the New Mexico Environment Department identifies other additional costs, including actions that might be taken by persons other than petitioners. And costs could increase further "depending on public interest." These are the costs of having, administering, and improving an environmental regulatory program. These are costs incurred in the public's interest. These are not costs that should be borne by petitioners.

  At minimum, petitioners' costs should be clearly defined and should be limited to costs over which petitioners have control. For example, petitioners should not be required to cover the costs of a venue, Hearing Officer, or court reporter where parties other than petitioners decide to present argument or evidence, nor should petitioners be required to cover the costs of technical experts or scientific reports used or developed by parties other than petitioners.

Comment 5:

Some terms in proposed rule 20.6.4.10.G are ambiguous.

- **Subsection G(3)'s reference to "…their intent to derive…" is not clear.**

  Should this read "…their intent to develop…"?

- **In subsection G(4), should site-specific criteria be developed in accordance with a "reviewed" work plan or in accordance with an "approved" work plan?**

  Subsection G(6) contemplates an "approved" work plan, but it is not clear where or how in the process the work plan will be approved.[1]

The Laboratory agrees that work plan requirements will improve communication and should "clearly outline expectations *and responsibilities*"[2] for developing site-specific criteria. Clarifying the ambiguities in the proposed rule furthers these benefits.

Comment 6:

- **Proposed rule 20.6.4.13.N is unclear.**

  What are "wetlands *of the state*"? It is not clear how "of the state" qualifies "wetlands." Are any wetlands within the state excluded from this definition? What is an "indirect" impact? How far removed does an impact have to be, or how unforeseeable does an impact have to be, before it is no longer considered an "indirect" impact? Presuming "net loss" qualifies both acreage and functions, what is meant by the "net loss of…biological, chemical, physical, and hydrological functions to the extent that such functions occur"? What are the "state-specific benchmarks"? How is suitability for "recreation, wildlife habitat, and use by aquatic life and livestock" evaluated? What "recreational use" must wetlands be suitable for?

[1] For comparison, please see rule 20.6.4.15.E(2), which provides that "[u]pon approval of the work plan by the department, the proponent shall conduct the use attainability analysis…."

[2] Clearly defining responsibilities is a means of easing NMED's concern that rulemakings may result in unanticipated costs.

NMED Exhibit 13

Comment 7:

In proposed rules 20.6.4.98 and 20.6.4.99, the insertion of the exception for "wetlands protected under 20.6.4.13 NMAC" is confusing, in part because of the statement in 20.6.4.13 NMAC that "Only wetlands of the state are subject to this general criterion." If there are wetlands which are not wetlands of the state, are they now somehow subject to the criteria covering intermittent and perennial waters?

Comment 8:

It would be helpful to understand if the New Mexico Environment Department has the capacity and resources necessary to implement the proposed water quality standards efficiently and effectively. Additionally, clarification on how the Department plans to engage and collaborate with stakeholders, including the Los Alamos National Laboratory, would support successful implementation of the program. A transparent approach to coordination and resource planning will help ensure that the program is both effective and practical to all parties involved.

CONCLUSION

The Los Alamos National Laboratory is committed to improving regulatory requirements and processes. Such improvements can both protect water quality and facilitate compliance. The Laboratory appreciates the opportunity to comment on the Public Review Draft for the 2026 Triennial Review and hopes the New Mexico Environment Department may find its comments useful.

NMED Exhibit 13

Western Resource Advocates

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October 14, 2025

New Mexico Environment Department
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Santa Fe, NM 87502
Submitted via SmartComment Portal

Re: New Mexico's 2026 Triennial Review: Public Review Draft for the 2026 Triennial Review

On behalf of Western Resource Advocates, I submit the following comments on the Public Review Draft for the 2026 Triennial Review posted by the New Mexico Environment Department (NMED). Western Resource Advocates is a nongovernmental organization that has, for decades, worked to protect and promote the water quality, stream flows, and the habitat health of and equitable access to New Mexico's surface waters. The proposed changes to New Mexico's Water Quality Standards (WQS) proposed by NMED, as well as those we recommend below will help ensure that the state's surface waters, including its wetlands, are safe for humans, wildlife and aquatic ecosystems and provide invaluable services to the people of the state.

I. Recommendations for Additions to New Mexico Water Quality Standards

WRA encourages NMED to, as part of the triennial review process, propose and adopt numeric criteria for numerous contaminants for which there are no numerical WQS. We propose several pollutants for NMED consideration but encourage NMED to look beyond this subset to address additional contaminants that are impairing or impacting the designated or existing uses of New Mexico's surface water.

Additional Forms of PFAS Chemicals

WRA commends NMED for its proposal to add to its WQS aquatic life criteria for certain PFAS chemicals. However, NMED is recommending the adoption of only the of EPA acute and chronic aquatic life water quality criteria for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS).[1] In addition to these two PFAS chemicals, WRA recommends that NMED include standards for other PFAS chemicals based on the benchmarks developed by EPA at the same time it finalized its recommended criteria for PFOA and PFOS. These additional chemicals are:

- Perfluorobutanoic acid (PFBA)
- Perfluorohexanoic acid (PFHxA)
- Perfluorononanoic acid (PFNA)
- Perfluorodecanoic acid (PFDA)
- Perfluorobutanesulfonic acid (PFBS)
- Perfluorohexanesulfonic acid (PFHxS)

[1] 89 Fed. Reg. 81078 (October 7, 2024).

- Hexadecafluoro-2-decenoic acid (8:2 FTUCA), and
- Pentadecafluorodecanoic acid (7:3 FTCA).

The EPA's *Acute Freshwater Aquatic Life Benchmarks for Eight Data-Limited PFAS* establishes maximum concentrations for these eight PFAS.[2] The analysis provides information, based on best available science, that New Mexico should consider as it sets acute water quality criteria for these chemicals to protect waters designated for use as aquatic ecosystems.

We also note that NMED has announced its efforts to comply with the 2024 EPA rule establishing drinking water standards for the same two kinds of PFAS: PFOA and PFOS. However, the final April 2024 EPA rule also included National Primary Drinking Water Regulations (NPDWRs) for PFHxS, PFNA, HFPO-DA (commonly known as GenX), and a Hazard Index based on a mixture of these three PFAS plus PFBS, 89 Fed. Reg. 32532 (April 26, 2024), although the current administration is reconsidering these standards.[3] The EPA standards are based on the best available science examining the health impacts of PFAS chemicals in drinking water.

Since adopting the drinking water standard for PFOA and PFOS, NMED has monitored the levels of PFAS chemicals in some of New Mexico's surface and ground waters that serve as public water supplies.[4] These data show fairly high levels of PFBS and levels of PFHxS approaching the NPDWR. Some monitored surface waters were also contaminated by PFNA, PFBA, and PFHxA. For some surface waters, levels of PFAS chemicals plus PFBS approached the EPA's Hazard Index Value of 1.0 ng/l. Of course, the drinking water supplies data are limited and many surface waters that support aquatic life were not subject to testing.[5]

These data show first that monitoring for PFHxS, PFNA, HFPO-DA, PFBA, PFHxA and PFBS is available and cost effective. Moreover, they indicated that to protect drinking water supplies, standards for PFHxS, PFNA, HFPO-DA and PFBS are appropriate – standards that will protect both aquatic life and human health. Finally, the monitoring data shows that in what are likely some of New Mexico's cleanest, most protected surface waters, levels of PFHxS, PFNA, PFBA, PFHxA and PFBS, individually and in combination with other PFAS, are cause for concern.

While PFOA and PFOS are the most prevalent PFAS chemicals in the environment, their use has largely been phased out by manufacturers.[6] Many additional forms of PFAS chemicals, including those recommended here, are still in use today in household products, food packaging, clothing, firefighting foam, and hydraulic fracturing fluids.[7] Moreover, without standards in place to protect surface waters

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[2] https://www.epa.gov/system/files/documents/2024-09/pfas-report-2024.pdf

[3] https://www.epa.gov/newsreleases/epa-announces-it-will-keep-maximum-contaminant-levels-pfoa-pfos.

[4] https://cloud.env.nm.gov/resources/_translator.php/YzQ0ODBjZDZjNGMxZjIwNWRmYTVhZWY1N18xODI2Njc~.pdf

[5] Monitoring data of wells likewise shows concerning levels of PFHxS, PFNA, HFPO-DA and PFBS individually or in combination. There is no question that polluted surface waters can contamination wells.

[6] https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/fact-sheet-20102015-pfoa-stewardship-program

[7] https://psr.org/new-report-fracking-with-forever-chemicals/

from these contaminants, it is likely that manufacturers will not make efforts to move away from using these dangerous chemicals, and indeed, will find incentives to use chemicals that are not regulated by New Mexico. All of the PFAS chemicals listed above have been linked to human or animal health impacts, including in vitro impacts, and often both, in numerous scientific studies.[8]

New Mexico's Holloman Lake has some of the highest contamination of PFAS ever recorded in the world, which not only effects the wildlife in the area but also the surrounding communities that traditionally rely on the lake for fishing and hunting waterfowl.[9] Given PFAS chemicals toxicity for both humans and animals, their bioaccumulation in tissues, and extreme persistence and prevalence in the environment, it is essential that New Mexico establish stringent WQS for additional PFAS chemicals, especially in the event of anticipated rollbacks at the federal level.

Alkylphenols and Alkylphenol Ethoxylates

Alkylphenols and their precursors, alkylphenol ethoxylates, are common industrial surfactants used in a variety of products and practices, including the industrial processing of textiles and materials and the production of oil and gas. Several alkylphenols and alkylphenol ethoxylates, including nonylphenol and octylphenol, have been identified as endocrine disruptors and can have a significant negative effect on fish and other aquatic species reproduction when present in the environment.[10] Both of these chemicals have been shown to cause acute and chronic toxicity to fish, invertebrates, and algae at various contamination levels. Although information related to the impact of these chemicals on human health is incomplete, these chemicals have been shown to mimic estrogenic potential and adversely impact the nervous system, cognitive function, immune system, and reproductive potential for a variety of species when present in the environment.[11]

While the presence of alkylphenols and their ethoxylates in the environment has decreased over recent years, these chemicals remain prevalent in oil and gas operations, both from naturally occurring sources and as additives to hydraulic fracturing fluids.[12] Specifically, octylphenol and nonylphenol and their ethoxylates have been the subject of ongoing regulatory scrutiny, with multiple states, including Connecticut,[13] Minnesota,[14] and Washington[15] establishing WQS for nonylpheno, and Minnesota establishing WQS for octylphenol.[16] Both variants are regulated by the European Union's Water Framework Directive legislation.[17]Furthermore, the U.S. EPA has published Water Quality Criteria for ambient aquatic life for nonylphenol,[18] Given the evidence of the negative impacts of alkylphenols and alkylphenol ethoxylates on aquatic species and the potential for adverse consequences for public health,

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[8] https://www.nrdc.org/bio/anna-reade/big-reveal-hundreds-health-studies-next-gen-pfas
[9] https://sourcenm.com/2025/01/27/new-mexico-wildlife-and-plants-around-holloman-lake-have-highest-pfas-contamination-on-record/
[10] https://www.sciencedirect.com/topics/medicine-and-dentistry/alkylphenol
[11] https://www.sciencedirect.com/science/article/pii/S0048969718312439#bb1245
[12] https://www.sciencedirect.com/science/article/abs/pii/S0269749123007595?via%3Dihub
[13] https://portal.ct.gov/-/media/deep/water/water_quality_standards/waterqualitystandardsproposed122209pdf.pdf
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[15] https://apps.ecology.wa.gov/publications/documents/0610091.pdf
[16] https://www.health.state.mn.us/communities/environment/risk/docs/guidance/gw/octylphenolinfo.pdf
[17] https://environment.ec.europa.eu/topics/water/water-framework-directive_en
[18] https://www.epa.gov/sites/default/files/2019-03/documents/ambient-wqc-nonylphenol-final.pdf

WRA recommends that NMED establish WQS for nonylphenol and octylphenol as part of this triennial review. These New Mexico-specific standards can readily be based on those adopted by other states.

Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic Aromatic Hydrocarbons (PAHs) are a group of chemicals, widely distributed in the environmental, with significant adverse impacts on humans and animals. PAHs can occur in the environment from numerous sources, including natural processes, such as forest fires, and from industrial sources, such as tailpipe emissions, discharges from various manufacturing processes, and from hazardous material spills. Under current regulations, New Mexico has already established WQS for several PAH variants. However, the list is incomplete. The U.S. Government includes 17 PAHs in its public health profile, the following six of which are not regulated in New Mexico's Water Quality Standards:

- Acenaphthylene
- Anthracene
- Benzo[e]pyrene
- Benzo[g,h,i]perylene
- Benzo[j]fluoranthene
- Phenanthrene

The government's public health profile identifies 17 PAHs, including the preceding six, because there is significant information available on the toxicity of these chemicals. These PAHs are suspected to be more harmful than other PAHs, there is a greater chance of exposure to these chemicals than other forms, and they occur at higher concentrations at National Priorities List hazardous waste sites.[19] PAHs are known to be carcinogenic, can cause reproductive and birth defects, and have been linked to adverse impacts to immunological and neurological functioning in humans and animals.[20] Furthermore, several PAHs have been shown to persist in the environment, particularly in aquatic sediments,[21] and to have significant impacts on the health and fitness of important aquatic species.[22]As such, WRA recommends that NMED establish WQS for these additional six PAHs to protect human health and the environment from adverse impacts caused by potential exposure to these chemicals.

Formaldehyde and Acetone

Recognizing that toxics such as acetone and formaldehyde adversely impact human health, states like Pennsylvania have adopted human health criteria to protect public health from the adverse impacts of these chemicals. Pennsylvania's criteria were updated in 2022 based on EPA's 2015 human health criteria exposure inputs, which included new values for body weight, drinking water intake and fish consumption.[23] Pennsylvania also relied on EPA's recent health risk factors and current toxicity data to inform its recently adopted water quality standards for acetone and formaldehyde.

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[19] https://wwwn.cdc.gov/TSP/PHS/PHS.aspx?phsid=120&toxid=25
[20] https://doi.org/10.1080/10937404.2022.2164390
[21] https://www.sciencedirect.com/science/article/abs/pii/S0269749118306493
[22] https://www.sciencedirect.com/science/article/pii/S0048969724051131
[23] https://files.dep.state.pa.us/PublicParticipation/Public%20Participation%20Center/PubPartCenterPortalF

There is no question that the presence of these toxic pollutants in New Mexico's surface waters could reasonably be expected to interfere with the designated uses of those waters. Pennsylvania has included effluent limits for acetone and formaldehyde in its NPDES discharge permits and has recorded substantial concentrations of acetone in surface water monitoring samples. Therefore, because acetone and formaldehyde pose a threat to human health, because defensible WQS and reasonable monitoring protocols exist for these toxics and because the presence of these chemicals would interfere with the protection of the designated uses of New Mexico's waters, WRA recommends that NMED adopt WQS for acetone and formaldehyde based on Pennsylvania's human health criteria.

II. Proposed Additions to New Mexico WQS to Protect Wetlands

Many of the proposed changes to the New Mexico WQS identify the values and services provided by the state's wetlands and are intended to conserve and even improve the condition and function of these critical surface waters. WQS are the foundation of effective water quality-based pollution control. Initially, WQS designate the highest attainable uses for a water body, set criteria that reflect the current and evolving body of scientific information to protect those uses, and establish provisions to protect water bodies from further degradation. As surface waters of the state, wetlands are covered by the same safeguards that WQS provide for streams, rivers, ponds and lakes. WRA strongly supports the proposed amendments to New Mexico's WQS aimed at specifically extending WQS protections to wetlands.

As the proposed amendments to the WQS acknowledge, in addition to providing wildlife habitat, supporting biological diversity, and propagating and maintaining aquatic and terrestrial species, wetlands promote erosion control, flood attenuation and protection, sediment and pollutant retention, ground water recharge, flow augmentation and water filtration. The NMED proposal acknowledges that wetlands, due to their specific functions and sensitivities, are best protected by WQS directed at the role they play in the ecosystem. WRA appreciates and strongly supports NMED's recognition of the crucial role wetlands play in providing clean water, healthy aquatic ecosystems, recreation opportunities and flood control.

Given the invaluable ways that wetlands benefit water quality and natural systems, it is highly appropriate that NMED is proposing that wetlands of the state be maintained and protected so that direct, indirect and cumulative impacts do not result in a net loss of wetlands or adverse impacts to wetland function. *See* Draft 20.6.4.13.N. WRA also strongly supports the proposed changes to 20.6.4.8 that specifically incorporate wetlands into the state's antidegradation rule. These proposed amendments properly interject wetland-specific water quality standards into NMED decision-making.

However, safeguarding New Mexico's wetlands will require WQS that protect their ecological condition and the full range of wetland functions. To this end, NMED has proposed narrative, rather than numeric criteria as an initial step for developing WQS for wetlands. The draft WQS also apparently excluded wetlands from the protections of 20.6.4.900. However, as with water quality criteria for other surface waters, criteria for wetlands can and often should be numeric. Because numeric standards are typically more straight forward to monitor and enforce, we recommend that New Mexico adopt numeric standards in addition to the narrative standard whenever possible. For example, the current numeric standard for selenium for wildlife habitat is appropriate for wetlands that provide habitat for waterbirds. In this case,

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iles/Environmental%20Quality%20Board/2023/July_11_2023/04a_7-577_TR10_Proposed_HHcriteria_Rationale.pdf

a numeric standard for selenium is necessary to protect the function of wetlands as wildlife habitat as described in the proposed 20.6.4.13. Therefore, we recommend that rather than excluding wetlands from the 20.6.4.900 criteria for wildlife habitat, that those criteria also be applied to these crucial surface waters.

Thank you for this opportunity to comment on the Public Review Draft for the 2026 Triennial Review.

Brittany Fallon, PhD
Policy Manager
Western Resource Advocates.

Michael Ketterer

Today is the anniversary of an event that transpired to change European history at the Battle of Hastings. The elapsed 959 years since that fateful day is a time period exceeding the longevity of most human civilizations, and most endeavors throughout our recorded history. It takes substantial faith in the human condition to look forward another 959 years, and wonder what our technogenic landscape will look like, in say, the year 2984, as the next millennium nears.

Yet on this October 14, it is a mere eight decades since the reckless, negligent disposal of plutonium laden wastes at Acid Canyon, and other locations, was conducted by the present-day occupants of the Pajarito Plateau. Since the day in the early to mid 1940's, when manual laborers did as they told under the purview of compartmentalization, the riparian zone below the present-day Los Alamos Aquatic Center remains significantly contaminated with wastes abandoned under the exigency of the Manhattan Project. The sediment in present-day Acid Canyon remains contaminated to the extreme such that water samples collected in July 2024 contained in excess of 50 picocuries per liter of plutonium-239+240 (Pu).

The levels of Pu in the summer 2024 monsoon waters do not even meet the Federal gross alpha standard (sum of all alpha emitting isotopes) of 50 picocuries per liter. Said another way, the sediments in Acid Canyon and similar areas are still "too dirty" so that the monsoon flow in Acid Canyon and affected downstream areas, cannot ever meet as low as possible/appropriate drinking water standards. As a result, neither USEPA, the State of New Mexico, nor the current occupants of the Pajarito Plateau have shown any interest in addressing this localized but extreme problem of riparian zone contamination, which has been hiding in plain sight for decades.

In New Mexico, there is no relevant enforceable water standard that is specific for plutonium; nevertheless, Acid Canyon waters are out of compliance due to their non-specific alpha emitting content; New Mexico upholds a guidance/advisory recommended standard of 1.5 pCi/L for the Rio Grande and its tributaries; the Summer 2024 water samples exceeded this advisory level by more than an order of magnitude. However, it is reasonable for New Mexicans to receive the same level of protection by regulations from polluters such as the Department of Energy, as exist in all states.

In Colorado, where the US Department of Energy formerly operated the Rocky Flats plutonium pit production facility from 1952 to 1989, the remediation conducted in the early 2000's resulted in a tripartite agreement between DOE, USEPA, and the State of Colorado. In this agreement, the DOE agreed to comply with an enforceable standard for Pu in water of 0.15 pCi/L.

New Mexicans, as your vecino from Colorado who is familiar with DOE's obfuscations and lack of clarity in addressing Rocky Flats's neighbors, I urge you to adapt the same enforceable standards for plutonium, neptunium, americium and other substances as appropriate, as the DOE is legally obligated to comply with in Colorado. You deserve no less. You need to recognize that It is shameful that the Pajarito Plateau's current occupants, who consider themselves to be atop the summit of US scientific prowess, must make an argument that "80 picocuries per gram in the sediments are OK" and that this writer is the one who is off base. The presence of this contamination in the center of the US's alleged nuclear prowess shows our adversaries how non-serious we are about handling special nuclear materials.

A state that has plans to host the next Pu pit production enterprise had best consider adopting the standard in effect at the previous pit factory, which serves to protect the Rocky Flats downstreamers. Why should downstreamers in New Mexico settle for less? Even the passage of another millennium won't make a dent in the Pu inventory.

Michael E. Ketterer

NEW MEXICO WATER QUALITY CONTROL COMMISSION
NOTICE OF PUBLIC RULEMAKING HEARING

The New Mexico Water Quality Control Commission (Commission) will hold a public hearing beginning at 9:00 a.m. on September 28, 2026, and continuing through October 1, 2026, as necessary. The Commission may continue the hearing thereafter to hear all testimony, evidence, and public comments. The hearing will be held at the State Capitol Building, 490 Old Santa Fe Trail, Santa Fe, New Mexico 87501. Additionally, a virtual participation option will be provided with meeting links and details posted on the events calendar at https://www.env.nm.gov/events-calendar. The purpose of the hearing is to consider the docketed matter of WQCC 25-75 (R) to amend 20.6.4 NMAC, *Standards for Interstate and Intrastate Surface Waters*. The petitioner for this proposed regulatory change is the New Mexico Environment Department (NMED).

The federal Clean Water Act (CWA) requires states to evaluate existing water quality standards (WQS), consider new scientific information, provide public participation opportunities, and amend WQS as necessary, every three years. This process is commonly referred to as the Triennial Review and culminates in a public hearing. NMED proposed amendments in this matter based on public comments on 20.6.4 NMAC, communication with the Environmental Protection Agency (EPA), federal guidance documents, monitoring and fish data, as well as internal comments and implementation concerns. The amendments include new and revised definitions, clarification of third-party rulemaking procedures and costs, revisions to segment descriptions to match hydrological breaks, WQS for wetlands, clarification of implementation language, updated references, as well as new or revised designated uses, criteria, and antidegradation requirements.

The hearing will be conducted in accordance with the Water Quality Act, Sections 74-6-4 and 74-6-6 NMSA 1978, the State Rules Act, Section 14-4-5.3 NMSA 1978, 20.1.6 NMAC (*Rulemaking Procedures – Water Quality Control Commission)*, the Pre-Hearing Order for WQCC 25-75 (R), and other applicable procedures and authorities. The Commission may make a decision on the proposed rule at the conclusion of the hearing.

All interested persons will be given reasonable opportunity at the hearing to submit data, views or arguments orally or in writing, and examine witnesses testifying at the hearing. Persons wishing to present technical testimony must file a written notice of intent (NOI) with the Commission. The NOI shall:

(1) identify the person for whom the witness(es) will testify;
(2) identify each technical witness the person intends to present and state the qualifications of that witness, including a description of their educational and work background;
(3) include a copy of the direct testimony of each technical witness in narrative form;
(4) include the text of any recommended modifications to the proposed regulatory change; and
(5) list and attach all exhibits anticipated to be offered by that person at the hearing, including any proposed statement of reasons for adoption of rules.

Entries of appearance and NOIs for direct testimony must be filed with the Commission Administrator no later than 5:00 p.m. on July 30, 2026, and should reference the docket number, WQCC 25-75 (R), and the date of the hearing. Notices of intent to present technical testimony shall be filed electronically with the Commission Administrator at pamela.jones@env.nm.gov.

Persons wishing to present rebuttal testimony, shall file an NOI electronically with the Commission Administrator no later than 5:00 p.m. on August 28, 2026. Rebuttal NOIs should include a narrative of rebuttal testimony and the other required elements of a direct NOI, as detailed in items (1) – (5) above.

One paper copy of all NOIs for the Hearing Officer's use shall be delivered by 12:00 p.m. (noon) on September 25, 2026, to:

Pamela Jones, Commission Administrator
Water Quality Control Commission

P.O. Box 5469
Santa Fe, NM 87502

The Hearing Officer will provide an opportunity for non-technical public comment each day of the hearing in a manner that accommodates the public pursuant to 20.1.6.204 NMAC. Public comment sessions will be reserved for 4:00 p.m. each day, until the close of the hearing record.

Members of the public wishing to offer non-technical public comment may do so only once either in person or on the virtual platform with access provided and managed by the Administrator. Oral public comment is limited to 3 minutes; written public comment submitted to the Administrator is unlimited and must be received prior to adjournment of the hearing. Written public comments may be submitted electronically or as a single original document to the Administrator at the above address. Please submit electronic written comments regarding the proposed rule prior to adjournment of the hearing via the Smart Comment Portal at https://nmed.commentinput.com/comment/search or through email to pamela.jones@env.nm.gov with reference to WQCC 25-75 (R).

NMED based the proposed rule on a variety of technical information, including NMED monitoring data , CWA Section 304(a) guidance documents, past CWA 303(d)/305(b) Integrated Lists/Integrated Reports, and fish surveys. The proposed rule may be reviewed during regular business hours at the NMED Surface Water Quality Bureau, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, at NMED Field Offices, or on NMED's web site at https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. For copies of the proposed rule, how to obtain technical information, or questions about participating in the hearing, please contact Michael Baca at (505) 470-1652 or michael.baca1@env.nm.gov or Pamela Jones at (505) 660-4305 or pamela.jones@env.nm.gov.

Persons requiring assistance, an interpreter, or any other form of auxiliary aid or service (i.e., reader, amplifier, qualified sign language interpreter, etc.) to attend or participate in the hearing should contact Pamela Jones no later than September 14, 2026 at (505) 660-4305 or pamela.jones@env.nm.gov.

NMED does not discriminate on the basis of race, color, national origin, disability, age or sex in the administration of its programs or activities, as required by applicable laws and regulations. NMED is responsible for coordination of compliance efforts and receipt of inquiries concerning non-discrimination requirements implemented by 40 C.F.R. Parts 5 and 7, including Title VI of the Civil Rights Act of 1964, as amended; Section 504 of the Rehabilitation Act of 1973; the Age Discrimination Act of 1975, Title IX of the Education Amendments of 1972, and Section 13 of the Federal Water Pollution Control Act Amendments of 1972. If you have any questions about this notice or any of NMED's non- discrimination programs, policies or procedures, you may contact: Kate Cardenas, NMED Non-Discrimination Coordinator, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 or nd.coordinator@env.nm.gov. If you believe that you have been discriminated against with respect to an NMED program or activity, please contact the Non-Discrimination Coordinator.

COMISIÓN DE CONTROL DE CALIDAD DEL AGUA DE NUEVO MÉXICO
AVISO DE AUDIENCIA PÚBLICA DE REGLAMENTACIÓN

La Comisión de Control de Calidad del Agua de Nuevo México (la Comisión) celebrará una audiencia pública la cual comenzará a las 9:00 a.m. del 28 de septiembre de 2026 y continuará hasta el 1 de octubre de 2026, según sea necesario. La Comisión podrá continuar la audiencia posteriormente con el fin de escuchar todos los testimonios, pruebas y comentarios públicos. La audiencia se llevará a cabo en el edificio del Capitolio del Estado, 490 Old Santa Fe Trail, Santa Fe, Nuevo México 87501. Además, habrá disponible una opción de participación virtual con enlaces a las reuniones e información publicados en el calendario de eventos en https://www.env.nm.gov/events-calendar. El propósito de la audiencia es considerar el asunto registrado en WQCC 25-75 (R) con el objetivo de enmendar 20.6.4 NMAC, *Estándares de Aguas Superficiales Interestatales e Intraestatales*. El peticionario de esta enmienda regulatoria propuesta es el Departamento de Medio Ambiente de Nuevo México (NMED, por sus siglas en inglés).

La Ley de Agua Limpia (CWA) federal exige que los estados evalúen los estándares de calidad del agua (WQS) existentes, consideren la información científica más reciente, brinden oportunidades de participación pública y modifiquen los WQS según sea necesario, cada tres años. Este proceso se conoce generalmente como Revisión Trienal y culmina con una audiencia pública. El NMED propuso enmiendas en este asunto con base en comentarios públicos sobre 20.6.4 NMAC, comunicado con la Agencia de Protección Ambiental (EPA, por sus siglas en inglés), documentos de orientación federales, datos de peces y monitoreo, así como los comentarios internos y preocupaciones sobre la implementación. Las enmiendas incluyen definiciones nuevas y revisadas, aclaración de los procedimientos y costos de la reglamentación de terceros, revisiones de las descripciones de los segmentos con el fin de que coincidan con las rupturas hidrológicas, los WQS correspondientes a los humedales, la aclaración del lenguaje de implementación, las referencias actualizadas, así como los usos designados, criterios y requisitos de anti-degradación nuevos o revisados.

La audiencia se llevará a cabo de acuerdo con la Ley de Calidad del Agua, Secciones 74-6-4 y 74-6-6 NMSA 1978, Ley de Reglas Estatales, Sección 14-4-5.3 NMSA 1978, 20.1.6 NMAC, *Procedimientos de Reglamentación – Comisión de Control de Calidad del Agua*, la Orden previa a la audiencia para WQCC 25-75 (R) y otros procedimientos y autoridades aplicables. La Comisión puede decidir sobre la norma propuesta al concluir la audiencia.

A todas las personas interesadas se les dará una oportunidad razonable durante la audiencia para presentar datos, puntos de vista o argumentos de forma oral o por escrito, y examinar a los testigos que testifiquen en la audiencia. Las personas que deseen presentar un testimonio técnico deben presentar una notificación de intención (NOI) por escrito ante la Comisión. La NOI deberá:

(1) identificar a la persona por quien los testigos testificarán;
(2) identificar cada testigo técnico que la persona pretende presentar y declarar las calificaciones de ese testigo, incluyendo una descripción de sus antecedentes educativos y laborales;
(3) incluir una copia del testimonio directo de cada testigo técnico en forma narrativa;
(4) incluir el texto de cualquier modificación recomendada al cambio regulatorio propuesto; y
(5) enumerar y adjuntar todas las pruebas que se prevé que ofrecerá esa persona en la audiencia, incluyendo cualquier declaración propuesta de motivos para la adopción de reglas.

Las anotaciones de comparecencia y las NOI para un testimonio directo deben ser recibidas por el Administrador de la Comisión a más tardar a las 5:00 p.m. el 30 de julio de 2026, y debe hacer referencia al número de expediente, WQCC 25-75 (R) y la fecha de la audiencia. Las notificaciones de intención que incluyan un testimonio técnico se archivarán de manera electrónica ante el Administrador de la Comisión en pamela.jones@env.nm.gov.

Las personas que deseen presentar un testimonio de refutación deberán presentar una NOI vía electrónica ante el Administrador de la Comisión a más tardar a las 5:00 p.m. el 28 de agosto de 2026. Las NOI de refutación

deben incluir una narrativa del testimonio de refutación y los demás elementos requeridos de una NOI directa como se detalla en los puntos (1) a (5) anteriores.

Se entregará una copia impresa de todas las NOI para uso del funcionario de audiencias antes de las 12:00 p.m. el 25 de septiembre de 2026, a:

Pamela Jones, Administradora de la Comisión
Comisión de Control de Calida del Agua
P.O. Box 5469
Santa Fe, NM 87502

El funcionario de audiencias se ofrecerá una oportunidad para el público haga comentarios cada día de la audiencia se llevará a cabo de acuerdo con 20.1.6.204 NMAC. Se reserva las oportunidades de comentarios públicos a las 4:00 p.m. cada día hasta la conclusión de la audiencia.

Los miembros del público que deseen ofrecer comentarios públicos no técnicos podrán hacerlo solo una vez, ya sea en persona o en la plataforma virtual con acceso proporcionado y administrado por el Administrador. Los comentarios públicos orales se limitan a 3 minutos; Los comentarios públicos escritos presentados al Administrador son ilimitados y deben recibirse antes del aplazamiento de la audiencia. Los comentarios públicos escritos podrán presentarse por vía electrónica o como un documento original único. Favor de enviar sus comentarios electrónicos por escrito sobre la norma propuesta antes del aplazamiento de la audiencia a través del Portal de Comentarios Inteligentes en https://nmed.commentinput.com/comment/search o envíe un correo electrónico a pamela.jones@env.nm.gov con referencia a WQCC 25-75 (R).

El NMED utilizó una variedad de información técnica con el objetivo de respaldar la norma propuesta, incluyendo datos de monitoreo del NMED, documentos de orientación de la Sección 304(a) de CWA, listas integradas/informes integrados de CWA 303(d)/305(b) anteriores y estudios de peces. La norma propuesta puede revisarse durante el horario laboral habitual en la Oficina de Calidad del Agua Superficial del NMED, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, en los oficinas exteriores del NMED, o en el sitio web del NMED en https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. Si desea obtener copias de la norma propuesta, información técnicos, o preguntas acerca de la participación en la audiencia, comuníquese con Michael Baca al (505) 470-1652 o michael.baca1@env.nm.gov o Pamela Jones al (505) 660-4305 o pamela.jones@env.nm.gov.

Los individuos que requieran asistencia, un intérprete o cualquier otra forma de ayuda o servicio auxiliar (es decir, un lector, amplificador, intérprete de lenguaje de señas calificado, etc.) para poder asistir o participar en la audiencia deben comunicarse con Pamela Jones a más tardar el 14 de septiembre de 2026 al (505) 660-4305 o pamela.jones@env.nm.gov.

El NMED no discrimina por motivos de raza, color, origen nacional, discapacidad, edad o sexo en la administración de sus programas o actividades, según lo requerido por las leyes y regulaciones aplicables. El NMED es responsable de coordinar los esfuerzos de cumplimiento y recibir consultas relacionadas con los requisitos de no discriminación implementados por 40 C.F.R. Partes 5 y 7, incluyendo el Título VI de la Ley de Derechos Civiles de 1964, tal como estuviere modificada; Sección 504 de la Ley de Rehabilitación de 1973; la Ley de Discriminación por Edad de 1975, el Título IX de las Enmiendas a la Educación de 1972 y la Sección 13 de las Enmiendas a la Ley Federal de Control de la Contaminación del Agua de 1972. Si tiene alguna pregunta sobre este aviso o cualquiera de los programas, políticas o procedimientos de no discriminación del NMED, puede comunicarse con: Kate Cardenas, Coordinadora de No Discriminación del NMED, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 o nd.coordinator@env.nm.gov. Si cree que ha sido discriminado con respecto a un programa o actividad del NMED, comuníquese con la Coordinadora de No Discriminación.

Affidavit of Publication in New Mexico Register

I, Matthew Ortiz, certify that the agency noted on Invoice # SRCA - 8884 has published legal notice of rulemaking or rules in the NEW MEXICO REGISTER, VOLUME XXXVI, that payment has been assessed for said legal notice of rulemaking or rules, which appears on the publication date and in the issue number noted on Invoice # SRCA - 8884, and that Invoice # SRCA - 8884 has been sent electronically to the person(s) listed on the *Billing Information Sheet* provided by the agency.

Affiant: _____
Matthew Ortiz

Subscribed, sworn and acknowledged before me this 25th day of June 2026.

Notary Public: _____
My Commission Expires: 1/22/2028

PAMELA ANNE LUJAN Y VIGIL
Notary Public
State of New Mexico
Comm. # 2001927
My Comm. Exp. Jan 22, 2028

NMED Exhibit 14

Affidavit of Publication

STATE OF NEW MEXICO } SS
COUNTY OF BERNALILLO }

Ad Cost:	$326.48
Ad Number:	423770
Account Number:	1007595
Classification:	GOVERNMENT LEGALS

I, Michele Aster, the undersigned, Legal Representative of the Albuquerque Journal, on oath, state that this newspaper is duly qualified to publish legal notices or advertisements within the meaning of Section 3, chapter 167, Session Laws of 1937, and payment of fees has been made of assessed and a copy of which is hereto attached, was published in said publication in the daily edition, 1 time on the following date:

June 23, 2026

That said newspaper was regularly issued and circulated on those dates.
SIGNED:

Legal Representative

Subscribed to and sworn to me this 23th day of June 2026.

David Lindsey Montoya
Notary Public
County Bernalillo
ID#: 1140229
My commission expires: 04-26-2027

STATE OF NEW MEXICO
NOTARY PUBLIC
DAVID LINDSEY MONTOYA
COMMISSION NUMBER 1140229
EXPIRATION DATE 04-26-2027

NM DEPT OF ENVIRONMENT
NM DEPT OF ENVIRONMENT GWQB
NMED / GROUND WATER QUALITY
BUREAU JULIA
HAROLD RUNNELS BUILDING N2308
P O BOX 5469
SANTA FE, NM 87502

NEW MEXICO WATER QUALITY CONTROL COMMISSION
NOTICE OF PUBLIC RULEMAKING HEARING

The New Mexico Water Quality Control Commission (Commission) will hold a public hearing beginning at 9:00 a.m. on September 28, 2026, and continuing through October 1, 2026, as necessary. The Commission may continue the hearing thereafter to hear all testimony, evidence, and public comments. The hearing will be held at the State Capitol Building, 490 Old Santa Fe Trail, Santa Fe, New Mexico 87501. Additionally, a virtual participation option will be provided with meeting links and details posted on the events calendar at https://www.env.nm.gov/events-calendar. The purpose of the hearing is to consider the docketed matter of WQCC 25-75 (R) to amend 20.6.4 NMAC, Standards for Interstate and Intrastate Surface Waters. The petitioner for this proposed regulatory change is the New Mexico Environment Department (NMED).

The federal Clean Water Act (CWA) requires states to evaluate existing water quality standards (WQS), consider new scientific information, provide public participation opportunities, and amend WQS as necessary, every three years. This process is commonly referred to as the Triennial Review and culminates in a public hearing. NMED proposed amendments in this matter based on public comments on 20.6.4 NMAC, communication with the Environmental Protection Agency (EPA), federal guidance documents, monitoring and fish data, as well as internal comments and implementation concerns. The amendments include new and revised definitions, clarification of third-party rulemaking procedures and costs, revisions to segment descriptions to match hydrological breaks, WQS for wetlands, clarification of implementation language, updated references, as well as new or revised designated uses, criteria, and antidegradation requirements.

The hearing will be conducted in accordance with the Water Quality Act, Sections 74-6-4 and 74-6-6 NMSA 1978, the State Rules Act, Section 14-4-5.3 NMSA 1978, 20.1.6 NMAC (Rulemaking Procedures Water Quality Control Commission), the Pre-Hearing Order for WQCC 25-75 (R), and other applicable procedures and authorities. The Commission may make a decision on the proposed rule at the conclusion of the hearing.

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(3) include a copy of the direct testimony of each technical witness in narrative form;
(4) include the text of any recommended modifications to the proposed regulatory change; and
(5) list and attach all exhibits anticipated to be offered by that person at the hearing, including any proposed statement of reasons for adoption of rules.

Entries of appearance and NOIs for direct testimony must be filed with the Commission Administrator no later than 5:00 p.m. on July 30, 2026, and should reference the docket number, WQCC 25-75 (R), and the date of the hearing. Notices of intent to present technical testimony shall be filed electronically with the Commission Administrator at pamela.jones@env.nm.gov.

Persons wishing to present rebuttal testimony, shall file an NOI electronically with the Commission Administrator no later than 5:00 p.m. on August 28, 2026. Rebuttal NOIs should include a narrative of rebuttal testimony and the other required elements of a direct NOI, as detailed in items (1) (5) above.

One paper copy of all NOIs for the Hearing Officer's use shall be delivered by 12:00 p.m. (noon) on September 25, 2026, to:

Pamela Jones, Commission Administrator
Water Quality Control Commission
P.O. Box 5469
Santa Fe, NM 87502

The Hearing Officer will provide an opportunity for non-technical public comment each day of the hearing in a manner that accommodates the public pursuant to 20.1.6.204 NMAC. Public comment sessions will be reserved for 4:00 p.m. each day, until the close of the hearing record.

Members of the public wishing to offer non-technical public comment may do so only once either in person or on the virtual platform with access provided and managed by the Administrator. Oral public comment is limited to 3 minutes; written public comment submitted to the Administrator is unlimited and must be received prior to adjournment of the hearing. Written public comments may be submitted electronically or as a single original document to the Administrator at the above address. Please submit electronic written comments regarding the proposed rule prior to adjournment of the hearing via the Smart Comment Portal at https://nmed.commentinput.com/comment/search or through email to pamela.jones@env.nm.gov with reference to WQCC 25-75 (R).

NMED based the proposed rule on a variety of technical information, including NMED monitoring data , CWA Section 304(a) guidance documents, past CWA 303(d)/305(b) Integrated Lists/Integrated Reports, and fish surveys. The proposed rule may be reviewed during regular business hours at the NMED Surface Water Quality Bureau, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, at NMED Field Offices, or on NMED's web site at https://www.env.nm.gov/surface-water-quality/2026-triennial-review-/. For copies of the proposed rule, how to obtain technical information, or questions about participating in the hearing, please contact Michael Baca at (505) 470-1652 or michael.baca1@env.nm.gov or Pamela Jones at (505) 660-4305 or pamela.jones@env.nm.gov.

Persons requiring assistance, an interpreter, or any other form of auxiliary aid or service (i.e., reader, amplifier, qualified sign language interpreter, etc.) to attend or participate in the hearing should contact Pamela Jones no later than September 14, 2026 at (505) 660-4305 or pamela.jones@env.nm.gov.

NMED does not discriminate on the basis of race, color, national origin, disability, age or sex in the administration of its programs or activities, as required by applicable laws and regulations. NMED is responsible for coordination of compliance efforts and receipt of inquiries concerning non-discrimination requirements implemented by 40 C.F.R. Parts 5 and 7, including Title VI of the Civil Rights Act of 1964, as amended; Section 504 of the Rehabilitation Act of 1973; the Age Discrimination Act of 1975, Title IX of the Education Amendments of 1972, and Section 13 of the Federal Water Pollution Control Act Amendments of 1972. If you have any questions about this notice or any of NMED's non- discrimination programs, policies or procedures, you may contact: Kate Cardenas, NMED Non-Discrimination Coordinator, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 or nd.coordinator@env.nm.gov. If you believe that you have been discriminated against with respect to an NMED program or activity, please contact the Non-Discrimination Coordinator.

Journal: June 23, 2026.

Affidavit of Publication

STATE OF NEW MEXICO } SS
COUNTY OF BERNALILLO }

Ad Cost:	$361.70
Ad Number:	423790
Account Number:	1007595
Classification:	GOVERNMENT LEGALS

I, Michele Aster, the undersigned, Legal Representative of the Albuquerque Journal, on oath, state that this newspaper is duly qualified to publish legal notices or advertisements within the meaning of Section 3, chapter 167, Session Laws of 1937, and payment of fees has been made of assessed and a copy of which is hereto attached, was published in said publication in the daily edition, 1 time on the following date:

June 23, 2026

That said newspaper was regularly issued and circulated on those dates.
SIGNED:

Legal Representative

Subscribed to and sworn to me this 23th day of June 2026.

David Lindsey Montoya
Notary Public
County Bernalillo
ID#: 1140229
My commission expires: 04-26-2027

STATE OF NEW MEXICO
NOTARY PUBLIC
DAVID LINDSEY MONTOYA
COMMISSION NUMBER 1140229
EXPIRATION DATE 04-26-2027

NM DEPT OF ENVIRONMENT
NM DEPT OF ENVIRONMENT GWQB
NMED / GROUND WATER QUALITY
BUREAU JULIA
HAROLD RUNNELS BUILDING N2308
P O BOX 5469
SANTA FE, NM 87502

COMISION DE CONTROL DE CALIDAD DEL AGUA DE NUEVO MEXICO
AVISO DE AUDIENCIA PUBLICA DE REGLAMENTACION

La Comision de Control de Calidad del Agua de Nuevo Mexico (la Comision) celebrara una audiencia publica la cual comenzara a las 9:00 a.m. del 28 de septiembre de 2026 y continuara hasta el 1 de octubre de 2026, segun sea necesario. La Comision podra continuar la audiencia posteriormente con el fin de escuchar todos los testimonios, pruebas y comentarios publicos. La audiencia se llevara a cabo en el edificio del Capitolio del Estado, 490 Old Santa Fe Trail, Santa Fe, Nuevo Mexico 87501. Ademas, habra disponible una opcion de participacion virtual con enlaces a las reuniones e informacion publicados en el calendario de eventos en https://www.env.nm.gov/events-calendar. El proposito de la audiencia es considerar el asunto registrado en WQCC 25-75 (R) con el objetivo de enmendar 20.6.4 NMAC, Estandares de Aguas Superficiales Interestatales e Intraestatales. El peticionario de esta enmienda regulatoria propuesta es el Departamento de Medio Ambiente de Nuevo Mexico (NMED, por sus siglas en ingles).

La Ley de Agua Limpia (CWA) federal exige que los estados evaluen los estandares de calidad del agua (WQS) existentes, consideren la informacion cientifica mas reciente, brinden oportunidades de participacion publica y modifiquen los WQS segun sea necesario, cada tres anos. Este proceso se conoce generalmente como Revision Trienal y culmina con una audiencia publica. El NMED propuso enmiendas en este asunto con base en comentarios publicos sobre 20.6.4 NMAC, comunicado con la Agencia de Proteccion Ambiental (EPA, por sus siglas en ingles), documentos de orientacion federales, datos de peces y monitoreo, asi como los comentarios internos y preocupaciones sobre la implementacion. Las enmiendas incluyen definiciones nuevas y revisadas, aclaracion de los procedimientos y costos de la reglamentacion de terceros, revisiones de las descripciones de los segmentos con el fin de que coincidan con las rupturas hidrologicas, los WQS correspondientes a los humedales, la aclaracion del lenguaje de implementacion, las referencias actualizadas, asi como los usos designados, criterios y requisitos de anti-degradacion nuevos o revisados.

La audiencia se llevara a cabo de acuerdo con la Ley de Calidad del Agua, Secciones 74-6-4 y 74-6-6 NMSA 1978, Ley de Reglas Estatales, Seccion 14-4-5.3 NMSA 1978, 20.1.6 NMAC, Procedimientos de Reglamentacion Comision de Control de Calidad del Agua, la Orden previa a la audiencia para WQCC 25-75 (R) y otros procedimientos y autoridades aplicables. La Comision puede decidir sobre la norma propuesta al concluir la audiencia.

A todas las personas interesadas se les dara una oportunidad razonable durante la audiencia para presentar datos, puntos de vista o argumentos de forma oral o por escrito, y examinar a los testigos que testifiquen en la audiencia. Las personas que deseen presentar un testimonio tecnico deben presentar una notificacion de intencion (NOI) por escrito ante la Comision. La NOI debera:

(1) identificar a la persona por quien los testigos testificaran;
(2) identificar cada testigo tecnico que la persona pretende presentar y declarar las calificaciones de ese testigo, incluyendo una descripcion de sus antecedentes educativos y laborales;
(3) incluir una copia del testimonio directo de cada testigo tecnico en forma narrativa;
(4) incluir el texto de cualquier modificacion recomendada al cambio regulatorio propuesto; y
(5) enumerar y adjuntar todas las pruebas que se preve que ofrecera esa persona en la audiencia, incluyendo cualquier declaracion propuesta de motivos para la adopcion de reglas.

Las anotaciones de comparecencia y las NOI para un testimonio directo deben ser recibidas por el Administrador de la Comision a mas tardar a las 5:00 p.m. el 30 de julio de 2026, y debe hacer referencia al numero de expediente, WQCC 25-75 (R) y la fecha de la audiencia. Las notificaciones de intencion que incluyan un testimonio tecnico se archivaran de manera electronica ante el Administrador de la Comision en pamela.jones@env.nm.gov.

Las personas que deseen presentar un testimonio de refutacion deberan presentar una NOI via electronica ante el Administrador de la Comision a mas tardar a las 5:00 p.m. el 28 de agosto de 2026. Las NOI de refutacion deben incluir una narrativa del testimonio de refutacion y los demas elementos requeridos de una NOI directa como se detalla en los puntos (1) a (5) anteriores.

Se entregara una copia impresa de todas las NOI para uso del funcionario de audiencias antes de las 12:00 p.m. el 25 de septiembre de 2026, a:

Pamela Jones, Administradora de la Comision
Comision de Control de Calida del Agua
P.O. Box 5469
Santa Fe, NM 87502

El funcionario de audiencias se ofrecera una oportunidad para el publico haga comentarios cada dia de la audiencia se llevara a cabo de acuerdo con 20.1.6.204 NMAC. Se reserva las oportunidades de comentarios publicos a las 4:00 p.m. cada dia hasta la conclusion de la audiencia.

Los miembros del publico que deseen ofrecer comentarios publicos no tecnicos podran hacerlo solo una vez, ya sea en persona o en la plataforma virtual con acceso proporcionado y administrado por el Administrador. Los comentarios publicos orales se limitan a 3 minutos; Los comentarios publicos escritos presentados al Administrador son ilimitados y deben recibirse antes del aplazamiento de la audiencia. Los comentarios publicos escritos podran presentarse por via electronica o como un documento original unico. Favor de enviar sus comentarios electronicos por escrito sobre la norma propuesta antes del aplazamiento de la audiencia a traves del Portal de Comentarios Inteligentes en https://nmed.commentinput.com/comment/search o envie un correo electronico a pamela.jones@env.nm.gov con referencia a WQCC 25-75 (R).

El NMED utilizo una variedad de informacion tecnica con el objetivo de respaldar la norma propuesta, incluyendo datos de monitoreo del NMED, documentos de orientacion de la Seccion 304(a) de CWA, listas integradas/informes integrados de CWA 303(d)/305(b) anteriores y estudios de peces. La norma propuesta puede revisarse durante el horario laboral habitual en la Oficina de Calidad del Agua Superficial del NMED, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, en los oficinas exteriores del NMED, o en el sitio web del NMED en https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. Si desea obtener copias de la norma propuesta, informacion tecnicos, o preguntas acerca de la participacion en la audiencia, comuniquese con Michael Baca al (505) 470-1652 o michael.baca1@env.nm.gov o Pamela Jones al (505) 660-4305 o pamela.jones@env.nm.gov.

Los individuos que requieran asistencia, un interprete o cualquier otra forma de ayuda o servicio auxiliar (es decir, un lector, amplificador, interprete de lenguaje de senas calificado, etc.) para poder asistir o participar en la audiencia deben comunicarse con Pamela Jones a mas tardar el 14 de septiembre de 2026 al (505) 660-4305 o pamela.jones@env.nm.gov.

El NMED no discrimina por motivos de raza, color, origen nacional, discapacidad, edad o sexo en la administracion de sus programas o actividades, segun lo requerido por las leyes y regulaciones aplicables. El NMED es responsable de coordinar los esfuerzos de cumplimiento y recibir consultas relacionadas con los requisitos de no discriminacion implementados por 40 C.F.R. Partes 5 y 7, incluyendo el Titulo VI de la Ley de Derechos Civiles de 1964, tal como estuviere modificada; Seccion 504 de la Ley de Rehabilitacion de 1973; la Ley de Discriminacion por Edad de 1975, el Titulo IX de las Enmiendas a la Educacion de 1972 y la Seccion 13 de las Enmiendas a la Ley Federal de Control de la Contaminacion del Agua de 1972. Si tiene alguna pregunta sobre este aviso o cualquiera de los programas, politicas o procedimientos de no discriminacion del NMED, puede comunicarse con: Kate Cardenas, Coordinadora de No Discriminacion del NMED, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 o nd.coordinator@env.nm.gov. Si cree que ha sido discriminado con respecto a un programa o actividad del NMED, comuniquese con la Coordinadora de No Discriminacion.

Journal: June 23, 2026.

SANTA FE NEW MEXICAN

Founded 1849

NMED SURFACE WATER
STATE OF NEW MEXICO NMED / Surface Water Quality Bureau New Mexico Environment Department 1190 St. Francis Drive, Suite N4050
Santa Fe, NM 87502

ACCOUNT:	S2004
AD NUMBER:	120877
TAG LINE	LEGAL #95469
P.O.#:	45415

1 TIME(S)	$378.76
AFFIDAVIT	10.00
TAX	31.83
TOTAL	420.59

AFFIDAVIT OF PUBLICATION

STATE OF NEW MEXICO
COUNTY OF SANTA FE

I, Sebastian Garcia, being first duly sworn declare and say that I am Legal Advertising Representative of THE SANTA FE NEW MEXICAN, a daily newspaper published in the English language, and having a general circulation in the Counties of Santa Fe, Rio Arriba, San Miguel, and Los Alamos, State of New Mexico and being a newspaper duly qualified to publish legal notices and advertisements under the provisions of Chapter 167 on Session Laws of 1937; that the Legal No 95469 a copy of which is hereto attached was published in said newspaper 1 day(s) between 06/23/2026 and 06/23/2026 and that the notice was published in the newspaper proper and not in any supplement; the first date of publication being on the 23rd day of June, 2026 and that the undersigned has personal knowledge of the matter and things set forth in this affidavit.

/S/ _____
LEGAL ADVERTISEMENT RESPRESENTATIVE

Subscribed and sworn to before me on this 23rd day of June, 2026

Notary Catherine M McSweeney

Commission Expires: 11/04/2029

STATE OF NEW MEXICO
NOTARY PUBLIC
CATHERINE M MCSWEENEY
COMMISSION # 1135865
COMMISSION EXPIRES 11/04/2029

LEGAL #95469

NEW MEXICO WATER QUALITY CONTROL COMMISSION NOTICE OF PUBLIC RULEMAKING HEARING

The New Mexico Water Quality Control Commission (Commission) will hold a public hearing beginning at 9:00 a.m. on September 28, 2026, and continuing through October 1, 2026, as necessary. The Commission may continue the hearing thereafter to hear all testimony, evidence, and public comments. The hearing will be held at the State Capitol Building, 490 Old Santa Fe Trail, Santa Fe, New Mexico 87501. Additionally, a virtual participation option will be provided with meeting links and details posted on the events calendar at https://www.env.nm.gov/events-calendar. The purpose of the hearing is to consider the docketed matter of WQCC 25-75 (R) to amend 20.6.4 NMAC, ***Standards for Interstate and Intrastate Surface Waters.*** The petitioner for this proposed regulatory change is the New Mexico Environment Department (NMED).

The federal Clean Water Act (CWA) requires states to evaluate existing water quality standards (WQS), consider new scientific information, provide public participation opportunities, and amend WQS as necessary, every three years. This process is commonly referred to as the Triennial Review and culminates in a public hearing. NMED proposed amendments in this matter based on public comments on 20.6.4 NMAC, communication with the Environmental Protection Agency (EPA), federal guidance documents, monitoring and fish data, as well as internal comments and implementation concerns. The amendments include new and revised definitions, clarification of third-party rulemaking procedures and costs, revisions to segment descriptions to match hydrological breaks, WQS for wetlands, clarification of implementation language, updated references, as well as new or revised designated uses, criteria, and antidegradation requirements.

The hearing will be conducted in accordance with the Water Quality Act, Sections 74-6-4 and 74-6-6 NMSA 1978, the State Rules Act, Section 14-4-5.3 NMSA 1978, 20.1.6 NMAC (***Rulemaking Procedures – Water Quality Control Commission***), the Pre-Hearing Order for WQCC 25-75 (R), and other applicable procedures and authorities. The Commission may make a decision on the proposed rule at the conclusion of the hearing.

All interested persons will be given reasonable opportunity at the hearing to submit data, views or arguments orally or in writing, and examine witnesses testifying at the hearing. Persons wishing to present technical testimony must file a written notice of intent (NOI) with the Commission. The NOI shall:

(1) identify the person for whom the witness(es) will testify;
(2) identify each technical witness the person intends to present and state the qualifications of that witness, including a description of their educational and work background;
(3) include a copy of the direct testimony of each technical witness in narrative form;
(4) include the text of any recommended modifications to the proposed regulatory change; and
(5) list and attach all exhibits anticipated to be offered by that person at the hearing, including any proposed statement of reasons for adoption of rules.

Entries of appearance and NOIs for direct testimony must be filed with the Commission Administrator no later than 5:00 p.m. on July 30, 2026, and should reference the docket number, WQCC 25-75 (R), and the date of the hearing. Notices of intent to present technical testimony shall be filed electronically with the Commission Administrator at pamela.jones@env.nm.gov.

Persons wishing to present rebuttal testimony, shall file an NOI electronically with the Commission Administrator no later than 5:00 p.m. on August 28, 2026. Rebuttal NOIs should include a narrative of rebuttal testimony and the other required elements of a direct NOI, as detailed in items (1) – (5) above.

One paper copy of all NOIs for the Hearing Officer's use shall be delivered by 12:00 p.m. (noon) on September 25, 2026, to:

Pamela Jones, Commission Administrator
Water Quality Control Commission
P.O. Box 5469
Santa Fe, NM 87502

The Hearing Officer will provide an opportunity for non-technical public comment each day of the hearing in a manner that accommodates the public pursuant to 20.1.6.204 NMAC. Public comment sessions will be reserved for 4:00 p.m. each day, until the close of the hearing record.

Members of the public wishing to offer non-technical public comment may do so only once either in person or on the virtual platform with access provided and managed by the Administrator. Oral public comment is limited to 3 minutes; written public comment submitted to the Administrator is unlimited and must be received prior to adjournment of the hearing. Written public comments may be submitted electronically or as a single original document to the Administrator at the above address. Please submit electronic written comments regarding the proposed rule prior to adjournment of the hearing via the Smart Comment Portal at https://nmed.commentinput.com/comment/search or through email to pamela.jones@env.nm.gov with reference to WQCC 25-75 (R).

NMED based the proposed rule on a variety of technical information, including NMED monitoring data , CWA Section 304(a) guidance documents, past CWA 303(d)/305(b) Integrated Lists/Integrated Reports, and fish surveys. The proposed rule may be reviewed during regular business hours at the NMED Surface Water Quality Bureau, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, at NMED Field Offices, or on NMED's web site at https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. For copies of the proposed rule, how to obtain technical information, or questions about participating in the hearing, please contact Michael Baca at (505) 470-1652 or michael.baca1@env.nm.gov or Pamela Jones at (505) 660-4305 or pamela.jones@env.nm.gov.

Persons requiring assistance, an interpreter, or any other form of auxiliary aid or service (i.e., reader, amplifier, qualified sign language interpreter, etc.) to attend or participate in the hearing should contact Pamela Jones no later than September 14, 2026 at (505) 660-4305 or pamela.jones@env.nm.gov.

NMED does not discriminate on the basis of race, color, national origin, disability, age or sex in the administration of its programs or activities, as required by applicable laws and regulations. NMED is responsible for coordination of compliance efforts and receipt of inquiries concerning non-discrimination requirements implemented by 40 C.F.R. Parts 5 and 7, including Title VI of the Civil Rights Act of 1964, as amended; Section 504 of the Rehabilitation Act of 1973; the Age Discrimination Act of 1975, Title IX of the Education Amendments of 1972, and Section 13 of the Federal Water Pollution Control Act Amendments of 1972. If you have any questions about this notice or any of NMED's non-discrimination programs, policies or procedures, you may contact: Kate Cardenas, NMED Non-Discrimination Coordinator, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 or nd.coordinator@env.nm.gov. If you believe that you have been discriminated against with respect to an NMED program or activity, please contact the Non-Discrimination Coordinator.

PUB.: June 23, 2026

SANTA FE NEW MEXICAN

Founded 1849

NMED SURFACE WATER
STATE OF NEW MEXICO NMED / Surface Water Quality Bureau New Mexico Environment Department 1190 St. Francis Drive, Suite N4050
Santa Fe, NM 87502

ACCOUNT:	S2004
AD NUMBER:	120907
TAG LINE	LEGAL #95470
P.O.#:	45415

1 TIME(S)	$441.32
AFFIDAVIT	10.00
TAX	36.95
TOTAL	488.27

AFFIDAVIT OF PUBLICATION

STATE OF NEW MEXICO
COUNTY OF SANTA FE

I, Sebastian Garcia, being first duly sworn declare and say that I am Legal Advertising Representative of THE SANTA FE NEW MEXICAN, a daily newspaper published in the English language, and having a general circulation in the Counties of Santa Fe, Rio Arriba, San Miguel, and Los Alamos, State of New Mexico and being a newspaper duly qualified to publish legal notices and advertisements under the provisions of Chapter 167 on Session Laws of 1937; that the Legal No 95470 a copy of which is hereto attached was published in said newspaper 1 day(s) between 06/23/2026 and 06/23/2026 and that the notice was published in the newspaper proper and not in any supplement; the first date of publication being on the 23rd day of June, 2026 and that the undersigned has personal knowledge of the matter and things set forth in this affidavit.

ISI _____
LEGAL ADVERTISEMENT RESPRESENTATIVE

Subscribed and sworn to before me on this 23rd day of June, 2026

Notary Catherine M McSweeney

Commission Expires: 11/04/2029

STATE OF NEW MEXICO
NOTARY PUBLIC
CATHERINE M MCSWEENEY
COMMISSION # 1135865
COMMISSION EXPIRES 11/04/2029

LEGAL #95470

COMISIÓN DE CONTROL DE CALIDAD DEL AGUA DE NUEVO MÉXICO AVISO DE AUDIENCIA PÚBLICA DE REGLAMENTACIÓN

La Comisión de Control de Calidad del Agua de Nuevo México (la Comisión) celebrará una audiencia pública la cual comenzará a las 9:00 a.m. del 28 de septiembre de 2026 y continuará hasta el 1 de octubre de 2026, según sea necesario. La Comisión podrá continuar la audiencia posteriormente con el fin de escuchar todos los testimonios, pruebas y comentarios públicos. La audiencia se llevará a cabo en el edificio del Capitolio del Estado, 490 Old Santa Fe Trail, Santa Fe, Nuevo México 87501. Además, habrá disponible una opción de participación virtual con enlaces a las reuniones e información publicados en el calendario de eventos en https://www.env.nm.gov/events-calendar. El propósito de la audiencia es considerar el asunto registrado en WQCC 25-75 (R) con el objetivo de enmendar 20.6.4 NMAC, ***Estándares de Aguas Superficiales Interestatales e Intraestatales***. El peticionario de esta enmienda regulatoria propuesta es el Departamento de Medio Ambiente de Nuevo México (NMED, por sus siglas en inglés).

La Ley de Agua Limpia (CWA) federal exige que los estados evalúen los estándares de calidad del agua (WQS) existentes, consideren la información científica más reciente, brinden oportunidades de participación pública y modifiquen los WQS según sea necesario, cada tres años. Este proceso se conoce generalmente como Revisión Trienal y culmina con una audiencia pública. El NMED propuso enmiendas en este asunto con base en comentarios públicos sobre 20.6.4 NMAC, comunicado con la Agencia de Protección Ambiental (EPA, por sus siglas en inglés), documentos de orientación federales, datos de peces y monitoreo, así como los comentarios internos y preocupaciones sobre la implementación. Las enmiendas incluyen definiciones nuevas y revisadas, aclaración de los procedimientos y costos de la reglamentación de terceros, revisiones de las descripciones de los segmentos con el fin de que coincidan con las rupturas hidrológicas, los WQS correspondientes a los humedales, la aclaración del lenguaje de implementación, las referencias actualizadas, así como los usos designados, criterios y requisitos de antidegradación nuevos o revisados.

La audiencia se llevará a cabo de acuerdo con la Ley de Calidad del Agua, Secciones 74-6-4 y74-6-6 NMSA 1978, Ley de Reglas Estatales, Sección 14-4-5.3 NMSA 1978, 20.1.6NMAC, ***Procedimientos de Reglamentación – Comisión de Control de Calidad del Agua***, la Orden previa a la audiencia para WQCC 25-75 (R) y otros procedimientos y autoridades aplicables. La Comisión puede decidir sobre la norma propuesta al concluir la audiencia.

A todas las personas interesadas se les dará una oportunidad razonable durante la audiencia para presentar datos, puntos de vista o argumentos de forma oral o por escrito, y examinar a los testigos que testifiquen en la audiencia. Las personas que deseen presentar un testimonio técnico deben presentar una notificación de intención (NOI) por escrito ante la Comisión. La NOI deberá:

(1) identificar a la persona por quien los testigos testificarán;
(2) identificar cada testigo técnico que la persona pretende presentar y declarar las calificaciones de ese testigo, incluyendo una descripción de sus antecedentes educativos y laborales;
(3) incluir una copia del testimonio directo de cada testigo técnico en forma narrativa;
(4) incluir el texto de cualquier modificación recomendada al cambio regulatorio propuesto; y
(5) enumerar y adjuntar todas las pruebas que se prevé que ofrecerá esa persona en la audiencia, incluyendo cualquier declaración propuesta de motivos para la adopción de reglas.

Las anotaciones de comparecencia y las NOI para un testimonio directo deben ser recibidas por el Administrador de la Comisión a más tardar a las 5:00 p.m. el 30 de julio de 2026, y debe hacer referencia al número de expediente, WQCC 25-75 (R) y la fecha de la audiencia. Las notificaciones de intención que incluyan un testimonio técnico se archivarán de manera electrónica ante el Administrador de la Comisión en pamela.jones@env.nm.gov.

Las personas que deseen presentar un testimonio de refutación deberán presentar una NOI vía electrónica ante el Administrador de la Comisión a más tardar a las 5:00 p.m. el 28 de agosto de 2026. Las NOI de refutación deben incluir una narrativa del testimonio de refutación y los demás elementos requeridos de una NOI directa como se detalla en los puntos (1) a (5) anteriores.

Se entregará una copia impresa de todas las NOI para uso del funcionario de audiencias antes de las 12:00 p.m. el 25 de septiembre de 2026, a:

Pamela Jones,
Administradora de la Comisión
Comisión de Control de Calida del Agua
P.O. Box 5469
Santa Fe, NM 87502

El funcionario de audiencias se ofrecerá una oportunidad para el público haga comentarios cada día de la audiencia se llevará a cabo de acuerdo con 20.1.6.204 NMAC. Se reserva las oportunidades de comentarios públicos a las 4:00 p.m. cada día hasta la conclusión de la audiencia.

Los miembros del público que deseen ofrecer comentarios públicos no técnicos podrán hacerlo solo una vez, ya sea en persona o en la plataforma virtual con acceso proporcionado y administrado por el Administrador. Los comentarios públicos orales se limitan a 3 minutos; Los comentarios públicos escritos presentados al Administrador son ilimitados y deben recibirse antes del aplazamiento de la audiencia. Los comentarios públicos escritos podrán presentarse por vía electrónica o como un documento original único. Favor de enviar sus comentarios electrónicos por escrito sobre la norma propuesta antes del aplazamiento de la audiencia a través del Portal de Comentarios Inteligentes en https://nmed.commentinput.com/comment/search o envíe un correo electrónico a pamela.jones@env.nm.gov con referencia a WQCC 25-75 (R).

El NMED utilizó una variedad de información técnica con el objetivo de respaldar la norma propuesta, incluyendo datos de monitoreo del NMED, documentos de orientación de la Sección 304(a) de CWA, listas integradas/informes integrados de CWA 303(d)/305(b) anteriores y estudios de peces. La norma propuesta puede revisarse durante el horario laboral habitual en la Oficina de Calidad del Agua Superficial del NMED, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, en los oficinas exteriores del NMED, o en el sitio web del NMED en https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. Si desea obtener copias de la norma propuesta, información técnicos, o preguntas acerca de la participación en la audiencia, comuníquese con Michael Baca al (505) 470-1652 o michael.baca1@env.nm.gov o Pamela Jones al (505) 660-4305 o pamela.jones@env.nm.gov.

Los individuos que requieran asistencia, un intérprete o cualquier otra forma de ayuda o servicio auxiliar (es decir, un lector, amplificador, intérprete de lenguaje de señas calificado, etc.) para poder asistir o participar en la audiencia deben comunicarse con Pamela Jones a más tardar el 14 de septiembre de 2026 al (505) 660-4305 o pamela.jones@env.nm.gov.

El NMED no discrimina por motivos de raza, color, origen nacional, discapacidad, edad o sexo en la administración de sus programas o actividades, según lo requerido por las leyes y regulaciones aplicables. El NMED es responsable de coordinar los esfuerzos de cumplimiento y recibir consultas relacionadas con los requisitos de no discriminación implementados por 40 C.F.R. Partes 5 y 7, incluyendo el Título VI de la Ley de Derechos Civiles de 1964, tal como estuviere modificada; Sección 504 de la Ley de Rehabilitación de 1973; la Ley de Discriminación por Edad de 1975, el Título IX de las Enmiendas a la Educación de 1972 y la Sección 13 de las Enmiendas a la Ley Federal de Control de la Contaminación del Agua de 1972. Si tiene alguna pregunta sobre este aviso o cualquiera de los programas, políticas o procedimientos de no discriminación del NMED, puede comunicarse con: Kate Cardenas, Coordinadora de No Discriminación del NMED, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 o nd.coordinator@env.nm.gov. Si cree que ha sido discriminado con respecto a un programa o actividad del NMED, comuníquese con la Coordinadora de No Discriminación.

PUB.: June 23, 2026

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AFFIDAVIT OF PUBLICATION

Michael Baca
NM Environment Department - Surface Water Quality Bureau
1190 S Saint Francis DR
Santa Fe NM 87505-4173

STATE OF WISCONSIN, COUNTY OF BROWN

The Las Cruces Sun News, a newspaper published in the city of Las Cruces, Dona Ana County, State of New Mexico, and personal knowledge of the facts herein state and that the notice hereto annexed was Published in said newspapers in the issue:

06/25/2026

and that the fees charged are legal.
Sworn to and subscribed before on 06/25/2026

Legal Clerk

Notary, State of WI, County of Brown

4-6-27

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DENISE ROBERTS
Notary Public
State of Wisconsin

NMED Exhibit 14

NEW MEXICO WATER QUALITY CONTROL COMMISSION
NOTICE OF PUBLIC RULEMAKING HEARING

The New Mexico Water Quality Control Commission (Commission) will hold a public hearing beginning at 9:00 a.m. on September 28, 2026, and continuing through October 1, 2026, as necessary. The Commission may continue the hearing thereafter to hear all testimony, evidence, and public comments. The hearing will be held at the State Capitol Building, 490 Old Santa Fe Trail, Santa Fe, New Mexico 87501. Additionally, a virtual participation option will be provided with meeting links and details posted on the events calendar at https://www.env.nm.gov/events-calendar. The purpose of the hearing is to consider the docketed matter of WQCC 25-75 (R) to amend 20.6.4 NMAC, Standards for Interstate and Intrastate Surface Waters. The petitioner for this proposed regulatory change is the New Mexico Environment Department (NMED).

The federal Clean Water Act (CWA) requires states to evaluate existing water quality standards (WQS), consider new scientific information, provide public participation opportunities, and amend WQS as necessary, every three years. This process is commonly referred to as the Triennial Review and culminates in a public hearing. NMED proposed amendments in this matter based on public comments on 20.6.4 NMAC, communication with the Environmental Protection Agency (EPA), federal guidance documents, monitoring and fish data, as well as internal comments and implementation concerns. The amendments include new and revised definitions, clarification of third-party rulemaking procedures and costs, revisions to segment descriptions to match hydrological breaks, WQS for wetlands, clarification of implementation language, updated references, as well as new or revised designated uses, criteria, and antidegradation requirements.

The hearing will be conducted in accordance with the Water Quality Act, Sections 74-6-4 and 74-6-6 NMSA 1978, the State Rules Act, Section 14-4-5.3 NMSA 1978, 20.1.6 NMAC (Rulemaking Procedures – Water Quality Control Commission), the Pre-Hearing Order for WQCC 25-75 (R), and other applicable procedures and authorities. The Commission may make a decision on the proposed rule at the conclusion of the hearing.

All interested persons will be given reasonable opportunity at the hearing to submit data, views or arguments orally or in writing, and examine witnesses testifying at the hearing. Persons wishing to present technical testimony must file a written notice of intent (NOI) with the Commission. The NOI shall:

(1) identify the person for whom the witness(es) will testify;
(2) identify each technical witness the person intends to present and state the qualifications of that witness, including a description of their educational and work background;
(3) include a copy of the direct testimony of each technical witness in narrative form;
(4) include the text of any recommended modifications to the proposed regulatory change; and
(5) list and attach all exhibits anticipated to be offered by that person at the hearing, including any proposed statement of reasons for adoption of rules.

Entries of appearance and NOIs for direct testimony must be filed with the Commission Administrator no later than 5:00 p.m. on July 30, 2026, and should reference the docket number, WQCC 25-75 (R), and the date of the hearing. Notices of intent to present technical testimony shall be filed electronically with the Commission Administrator at pamela.jones@env.nm.gov.

Persons wishing to present rebuttal testimony, shall file an NOI electronically with the Commission Administrator no later than 5:00 p.m. on August 28, 2026. Rebuttal NOIs should include a narrative of rebuttal testimony and the other required elements of a direct NOI, as detailed in items (1) – (5) above.

One paper copy of all NOIs for the Hearing Officer's use shall be delivered by 12:00 p.m. (noon) on September 25, 2026, to:

Pamela Jones, Commission Administrator
Water Quality Control Commission
P.O. Box 5469
Santa Fe, NM 87502

The Hearing Officer will provide an opportunity for non-technical public comment each day of the hearing in a manner that accommodates the public pursuant to 20.1.6.204 NMAC. Public comment sessions will be reserved for 4:00 p.m. each day, until the close of the hearing record.

Members of the public wishing to offer non-technical public comment may do so only once either in person or on the virtual platform with access provided and managed by the Administrator. Oral public comment is limited to 3 minutes; written public comment submitted to the Administrator is unlimited and must be received prior to adjournment of the hearing. Written public comments may be submitted electronically or as a single original document to the Administrator at the above address. Please submit electronic written comments regarding the proposed rule prior to adjournment of the hearing via the Smart Comment Portal at https://nmed.commentinput.com/comment/search or through email to pamela.jones@env.nm.gov with reference to WQCC 25-75 (R).

NMED based the proposed rule on a variety of technical information, including NMED monitoring data , CWA Section 304(a) guidance documents, past CWA 303(d)/305(b) Integrated Lists/Integrated Reports, and fish surveys. The proposed rule may be reviewed during regular business hours at the NMED Surface Water Quality Bureau, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, at NMED Field Offices, or on NMED's web site at https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. For copies of the proposed rule, how to obtain technical information, or questions about participating in the hearing, please contact Michael Baca at (505) 470-1652 or michael.baca1@env.nm.gov or Pamela Jones at (505) 660-4305 or pamela.jones@env.nm.gov.

Persons requiring assistance, an interpreter, or any other form of auxiliary aid or service (i.e., reader, amplifier, qualified sign language interpreter, etc.) to attend or participate in the hearing should contact Pamela Jones no later than September 14, 2026 at (505) 660-4305 or pamela.jones@env.nm.gov.

NMED does not discriminate on the basis of race, color, national origin, disability, age or sex in the administration of its programs or activities, as required by applicable laws and regulations. NMED is responsible for coordination of compliance efforts and receipt of inquiries concerning non-discrimination requirements implemented by 40 C.F.R. Parts 5 and 7, including Title VI of the Civil Rights Act of 1964, as amended; Section 504 of the Rehabilitation Act of 1973; the Age Discrimination Act of 1975, Title IX of the Education Amendments of 1972, and Section 13 of the Federal Water Pollution Control Act Amendments of 1972. If you have any questions about this notice or any of NMED's non- discrimination programs, policies or procedures, you may contact: Kate Cardenas, NMED Non-Discrimination Coordinator, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 or nd.coordinator@env.nm.gov. If you believe that you have been discriminated against with respect to an NMED program or activity, please contact the Non-Discrimination Coordinator.

#12434242, Sun News, June 25, 2026

USA TODAY CO.

LocaliQ

PO Box 631667 Cincinnati, OH 45263-1667

AFFIDAVIT OF PUBLICATION

Michael Baca
NM Environment Department - Surface Water Quality Bureau
1190 S Saint Francis DR
Santa Fe NM 87505-4173

STATE OF WISCONSIN, COUNTY OF BROWN

The Las Cruces Sun News, a newspaper published in the city of Las Cruces, Dona Ana County, State of New Mexico, and personal knowledge of the facts herein state and that the notice hereto annexed was Published in said newspapers in the issue:

06/25/2026

and that the fees charged are legal.
Sworn to and subscribed before on 06/25/2026

Legal Clerk

Notary, State of WI, County of Brown

My commission expires

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Notary Public
State of Wisconsin

NMED Exhibit 14

COMISION DE CONTROL DE CALIDAD DEL AGUA DE NUEVO MEXICO
AVISO DE AUDIENCIA PÚBLICA DE REGLAMENTACIÓN

La Comisión de Control de Calidad del Agua de Nuevo México (la Comisión) celebrará una audiencia pública la cual comenzará a las 9:00 a.m. del 28 de septiembre de 2026 y continuará hasta el 1 de octubre de 2026, según sea necesario. La Comisión podrá continuar la audiencia posteriormente con el fin de escuchar todos los testimonios, pruebas y comentarios públicos. La audiencia se llevará a cabo en el edificio del Capitolio del Estado, 490 Old Santa Fe Trail, Santa Fe, Nuevo México 87501. Además, habrá disponible una opción de participación virtual con enlaces a las reuniones e información publicados en el calendario de eventos en https://www.env.nm.gov/events-calendar. El propósito de la audiencia es considerar el asunto registrado en WQCC 25-75 (R) con el objetivo de enmendar 20.6.4 NMAC, Estándares de Aguas Superficiales Interestatales e Intraestatales. El peticionario de esta enmienda regulatoria propuesta es el Departamento de Medio Ambiente de Nuevo México (NMED, por sus siglas en inglés).

La Ley de Agua Limpia (CWA) federal exige que los estados evalúen los estándares de calidad del agua (WQS) existentes, consideren la información científica más reciente, brinden oportunidades de participación pública y modifiquen los WQS según sea necesario, cada tres años. Este proceso se conoce generalmente como Revisión Trienal y culmina con una audiencia pública. El NMED propuso enmiendas en este asunto con base en comentarios públicos sobre 20.6.4 NMAC, comunicado con la Agencia de Protección Ambiental (EPA, por sus siglas en inglés), documentos de orientación federales, datos de peces y monitoreo, así como los comentarios internos y preocupaciones sobre la implementación. Las enmiendas incluyen definiciones nuevas y revisadas, aclaración de los procedimientos y costos de la reglamentación de terceros, revisiones de las descripciones de los segmentos con el fin de que coincidan con las rupturas hidrológicas, los WQS correspondientes a los humedales, la aclaración del lenguaje de implementación, las referencias actualizadas, así como los usos designados, criterios y requisitos de anti-degradación nuevos o revisados.

La audiencia se llevará a cabo de acuerdo con la Ley de Calidad del Agua, Secciones 74-6-4 y 74-6-6 NMSA 1978, Ley de Reglas Estatales, Sección 14-4-5.3 NMSA 1978, 20.1.6 NMAC, Procedimientos de Reglamentación – Comisión de Control de Calidad del Agua, la Orden previa a la audiencia para WQCC 25-75 (R) y otros procedimientos y autoridades aplicables. La Comisión puede decidir sobre la norma propuesta al concluir la audiencia.

A todas las personas interesadas se les dará una oportunidad razonable durante la audiencia para presentar datos, puntos de vista o argumentos de forma oral o por escrito, y examinar a los testigos que testifiquen en la audiencia. Las personas que deseen presentar un testimonio técnico deben presentar una notificación de intención (NOI) por escrito ante la Comisión. La NOI deberá:

(1) identificar a la persona por quien los testigos testificarán;
(2) identificar cada testigo técnico que la persona pretende presentar y declarar las calificaciones de ese testigo, incluyendo una descripción de sus antecedentes educativos y laborales;
(3) incluir una copia del testimonio directo de cada testigo técnico en forma narrativa;
(4) incluir el texto de cualquier modificación recomendada al cambio regulatorio propuesto; y
(5) enumerar y adjuntar todas las pruebas que se prevé que ofrecerá esa persona en la audiencia, incluyendo cualquier declaración propuesta de motivos para la adopción de reglas.

Las anotaciones de comparecencia y las NOI para un testimonio directo deben ser recibidas por el Administrador de la Comisión a más tardar a las 5:00 p.m. el 30 de julio de 2026, y debe hacer referencia al número de expediente, WQCC 25-75 (R) y la fecha de la audiencia. Las notificaciones de intención que incluyan un testimonio técnico se archivarán de manera electrónica ante el Administrador de la Comisión en pamela.jones@env.nm.gov.

Las personas que deseen presentar un testimonio de refutación deberán presentar una NOI vía electrónica ante el Administrador de la Comisión a más tardar a las 5:00 p.m. el 28 de agosto de 2026. Las NOI de refutación deben incluir una narrativa del testimonio de refutación y los demás elementos requeridos de una NOI directa como se detalla en los puntos (1) a (5) anteriores.

Se entregará una copia impresa de todas las NOI para uso del funcionario de audiencias antes de las 12:00 p.m. el 25 de septiembre de 2026, a:

Pamela Jones, Administradora de la Comisión
Comisión de Control de Calida del Agua
P.O. Box 5469
Santa Fe, NM 87502

El funcionario de audiencias se ofrecerá una oportunidad para el público haga comentarios cada día de la audiencia se llevará a cabo de acuerdo con 20.1.6.204 NMAC. Se reserva las oportunidades de comentarios públicos a las 4:00 p.m. cada día hasta la conclusión de la audiencia.

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El NMED utilizó una variedad de información técnica con el objetivo de respaldar la norma propuesta, incluyendo datos de monitoreo del NMED, documentos de orientación de la Sección 304(a) de CWA, listas integradas/informes integrados de CWA 303(d)/305(b) anteriores y estudios de peces. La norma propuesta puede revisarse durante el horario laboral habitual en la Oficina de Calidad del Agua Superficial del NMED, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, en los oficinas exteriores del NMED, o en el sitio web del NMED en https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. Si desea obtener copias de la norma propuesta, información técnicos, o preguntas acerca de la participación en la audiencia, comuníquese con Michael Baca al (505) 470-1652 o michael.baca1@env.nm.gov o Pamela Jones al (505) 660-4305 o pamela.jones@env.nm.gov.

Los individuos que requieran asistencia, un intérprete o cualquier otra forma de ayuda o servicio auxiliar (es decir, un lector, amplificador, intérprete de lenguaje de señas calificado, etc.) para poder asistir o participar en la audiencia deben comunicarse con Pamela Jones a más tardar el 14 de septiembre de 2026 al (505) 660-4305 o pamela.jones@env.nm.gov.

El NMED no discrimina por motivos de raza, color, origen nacional, discapacidad, edad o sexo en la administración de sus programas o actividades, según lo requerido por las leyes y regulaciones aplicables. El NMED es responsable de coordinar los esfuerzos de cumplimiento y recibir consultas relacionadas con los requisitos de no discriminación implementados por 40 C.F.R. Partes 5 y 7, incluyendo el Título VI de la Ley de Derechos Civiles de 1964, tal como estuviere modificada; Sección 504 de la Ley de Rehabilitación de 1973; la Ley de Discriminación por Edad de 1975, el Título IX de las Enmiendas a la Educación de 1972 y la Sección 13 de las Enmiendas a la Ley Federal de Control de la Contaminación del Agua de 1972. Si tiene alguna pregunta sobre este aviso o cualquiera de los programas, políticas o procedimientos de no discriminación del NMED, puede comunicarse con: Kate Cardenas, Coordinadora de No Discriminación del NMED, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 o nd.coordinator@env.nm.gov. Si cree que ha sido discriminado con respecto a un programa o actividad del NMED, comuníquese con la Coordinadora de No Discriminación.

#12434274, Sun News, June 25, 2026

BALLANTINE
COMMUNICATIONS

AFFIDAVIT OF PUBLICATION

STATE OF NEW MEXICO

County of San Juan

Odette Zerwas, the undersigned, authorized Representative of the Tri-City Record, on oath states that this newspaper is duly qualified to publish legal notices or advertisements within the meaning of Section 3, Chapter 167, Session Law of 1937, that payment therefore has been made of assessed as court cost; and that the notice, copy of which is hereto attached, was published in said paper in the regular daily edition, for 1 time(s) on the following date(s):

6/24/2026

Sworn and subscribed before me, a notary public in and for the county of La Plata and the State of Colorado, 6/24/26

Notary Public

PRICE: 380.82

Statement to come at the end of the month.

ACCOUNT NUMBER: 113997

KARI E PATHUIS
Notary Public
State of Colorado
Notary ID # 20254043032
My Commission Expires 11-20-2029

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NEW MEXICO WATER QUALITY CONTROL COMMISSION NOTICE OF PUBLIC RULEMAKING HEARING

The New Mexico Water Quality Control Commission (Commission) will hold a public hearing beginning at 9:00 a.m. on September 28, 2026, and continuing through October 1, 2026, as necessary. The Commission may continue the hearing thereafter to hear all testimony, evidence, and public comments. The hearing will be held at the State Capitol Building, 490 Old Santa Fe Trail, Santa Fe, New Mexico 87501. Additionally, a virtual participation option will be provided with meeting links and details posted on the events calendar at https://www.env.nm.gov/events-calendar. The purpose of the hearing is to consider the docketed matter of WQCC 25-75 (R) to amend 20.6.4 NMAC, *Standards for Interstate and Intrastate Surface Waters.* The petitioner for this proposed regulatory change is the New Mexico Environment Department (NMED).

NMED Exhibit 14

The federal Clean Water Act (CWA) requires states to evaluate existing water quality standards (WQS), consider new scientific information, provide public participation opportunities, and amend WQS as necessary, every three years. This process is commonly referred to as the Triennial Review and culminates in a public hearing. NMED proposed amendments in this matter based on public comments on 20.6.4 NMAC, communication with the Environmental Protection Agency (EPA), federal guidance documents, monitoring and fish data, as well as internal comments and implementation concerns. The amendments include new and revised definitions, clarification of third-party rulemaking procedures and costs, revisions to segment descriptions to match hydrological breaks, WQS for wetlands, clarification of implementation language, updated references, as well as new or revised designated uses, criteria, and antidegradation requirements.

The hearing will be conducted in accordance with the Water Quality Act, Sections 74-6-4 and 74-6-6 NMSA 1978, the State Rules Act, Section 14-4-5.3 NMSA 1978, 20.1.6 NMAC (Rulemaking Procedures – Water Quality Control Commission), the Pre-Hearing

Order for WQCC 25-75 (R), and other applicable procedures and authorities. The Commission may make a decision on the proposed rule at the conclusion of the hearing.

All interested persons will be given reasonable opportunity at the hearing to submit data, views or arguments orally or in writing, and examine witnesses testifying at the hearing. Persons wishing to present technical testimony must file a written notice of intent (NOI) with the Commission. The NOI shall:

(1) identify the person for whom the witness(es) will testify;
(2) identify each technical witness the person intends to present and state the qualifications of that witness, including a description of their educational and work background;
(3) include a copy of the direct testimony of each technical witness in narrative form;
(4) include the text of any recommended modifications to the proposed regulatory change; and
(5) list and attach all exhibits anticipated to be offered by that person at the hearing, including any proposed statement of reasons for adoption of rules.

Entries of appearance and NOIs for direct testimony must be filed with the Commission Administrator no later than 5:00

Administrator no later than 5:00 p.m. on July 30, 2026, and should reference the docket number, WQCC 25-75 (R), and the date of the hearing. Notices of intent to present technical testimony shall be filed electronically with the Commission Administrator at pamela.jones@env.nm.gov.

Persons wishing to present rebuttal testimony, shall file an NOI electronically with the Commission Administrator no later than 5:00 p.m. on August 28, 2026. Rebuttal NOIs should include a narrative of rebuttal testimony and the other required elements of a direct NOI, as detailed in items (1) – (5) above.

One paper copy of all NOIs for the Hearing Officer's use shall be delivered by 12:00 p.m. (noon) on September 25, 2026, to:

Pamela Jones, Commission Administrator
Water Quality Control Commission
P.O. Box 5469
Santa Fe, NM 87502

The Hearing Officer will provide an opportunity for non-technical public comment each day of the hearing in a manner that accommodates the public pursuant to 20.1.6.204 NMAC. Public comment sessions will be reserved for 4:00 p.m. each day, until the close of the hearing record.

hearing record.

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NMED based the proposed rule on a variety of technical information, including NMED monitoring data , CWA Section 304(a) guidance documents, past CWA 303(d)/305(b) Integrated Lists/Integrated Reports, and fish surveys. The proposed rule may be reviewed during regular business hours at the NMED Surface Water Quality Bureau, 1190 St. Frances Dr., Suite N2000,

Santa Fe, NM 87505, at NMED Field Offices, or on NMED's web site at https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. For copies of the proposed rule, how to obtain technical information, or questions about participating in the hearing, please contact Michael Baca at (505) 470-1652 or michael.baca1@env.nm.gov or Pamela Jones at (505) 660-4305 or pamela.jones@env.nm.gov.

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Title IX of the Education Amendments of 1972, and Section 13 of the Federal Water Pollution Control Act Amendments of 1972. If you have any questions about this notice or any of NMED's non-discrimination programs, policies or procedures, you may contact: Kate Cardenas, NMED Non-Discrimination Coordinator, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 or nd.coordinator@env.nm.gov. If you believe that you have been discriminated against with respect to an NMED program or activity, please contact the Non-Discrimination Coordinator.

Published in the Tri-City Record June 24, 2026

BALLANTINE
COMMUNICATIONS

AFFIDAVIT OF PUBLICATION

STATE OF NEW MEXICO

County of San Juan

Odette Zamora, the undersigned, authorized Representative of the Tri-City Record, on oath states that this newspaper is duly qualified to publish legal notices or advertisements within the meaning of Section 3, Chapter 167, Session Law of 1937, that payment therefore has been made of assessed as court cost; and that the notice, copy of which is hereto attached, was published in said paper in the regular daily edition, for 1 time(s) on the following date(s):

6/24/2026

Sworn and subscribed before me, a notary public in and for the county of La Plata and the State of Colorado, 6/24/26

Notary Public

PRICE: 441.68

Statement to come at the end of the month.

ACCOUNT NUMBER: 113997

KARI E PATHUIS
Notary Public
State of Colorado
Notary ID # 20254043032
My Commission Expires 11-20-2029

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35673

COMISIÓN DE CONTROL DE CALIDAD DEL AGUA DE NUEVO MÉXICO
AVISO DE AUDIENCIA PÚBLICA DE REGLAMENTACIÓN

La Comisión de Control de Calidad del Agua de Nuevo México (la Comisión) celebrará una audiencia pública la cual comenzará a las 9:00 a.m. del 28 de septiembre de 2026 y continuará hasta el 1 de octubre de 2026, según sea necesario. La Comisión podrá continuar la audiencia posteriormente con el fin de escuchar todos los testimonios, pruebas y comentarios públicos. La audiencia se llevará a cabo en el edificio del Capitolio del Estado, 490 Old Santa Fe Trail, Santa Fe, Nuevo México 87501. Además, habrá disponible una opción de participación virtual con enlaces a las reuniones e información publicados en el calendario de eventos en https://www.env.nm.gov/events-calendar. El propósito de la audiencia es considerar el asunto registrado en WQCC 25-75 (R) con el objetivo de enmendar 20.6.4 NMAC,

Estándares de Aguas Superficiales Interestatales e Intraestatales. El peticionario de esta enmienda regulatoria propuesta es el Departamento de Medio Ambiente de Nuevo México (NMED, por sus siglas en inglés).

La Ley de Agua Limpia (CWA) federal exige que los estados evalúen los estándares de calidad del agua (WQS) existentes, consideren la información científica más reciente, brinden oportunidades de participación pública y modifiquen los WQS según sea necesario, cada tres años. Este proceso se conoce generalmente como Revisión Trienal y culmina con una audiencia pública. El NMED propuso enmiendas en este asunto con base en comentarios públicos sobre 20.6.4 NMAC, comunicado con la Agencia de Protección Ambiental (EPA, por sus siglas en inglés), documentos de orientación federales, datos de peces y monitoreo, así como los comentarios internos y preocupaciones sobre la implementación. Las enmiendas incluyen definiciones nuevas y revisadas, aclaración de los procedimientos y costos de la reglamentación de terceros, revisiones de las descripciones de los segmentos con el fin de que coincidan con las rupturas hidrológicas, los WQS correspondientes a los

humedales, la aclaración del lenguaje de implementación, las referencias actualizadas, así como los usos designados, criterios y requisitos de anti-degradación nuevos o revisados.

La audiencia se llevará a cabo de acuerdo con la Ley de Calidad del Agua, Secciones 74-6-4 y 74-6-6 NMSA 1978, Ley de Reglas Estatales, Sección 14-4-5.3 NMSA 1978, 20.1.6 NMAC, Procedimientos de Reglamentación – Comisión de Control de Calidad del Agua, la Orden previa a la audiencia para WQCC 25-75 (R) y otros procedimientos y autoridades aplicables. La Comisión puede decidir sobre la norma propuesta al concluir la audiencia.

A todas las personas interesadas se les dará una oportunidad razonable durante la audiencia para presentar datos, puntos de vista o argumentos de forma oral o por escrito, y examinar a los testigos que testifiquen en la audiencia. Las personas que deseen presentar un testimonio técnico deben presentar una notificación de intención (NOI) por escrito ante la Comisión. La NOI deberá:

(1) identificar a la persona por quien los testigos testificarán;
(2) identificar cada testigo técnico que la persona pretende presentar y declarar

pretende presentar y declarar las calificaciones de ese testigo, incluyendo una descripción de sus antecedentes educativos y laborales;
(3) incluir una copia del testimonio directo de cada testigo técnico en forma narrativa;
(4) incluir el texto de cualquier modificación recomendada al cambio regulatorio propuesto; y
(5) enumerar y adjuntar todas las pruebas que se prevé que ofrecerá esa persona en la audiencia, incluyendo cualquier declaración propuesta de motivos para la adopción de reglas.

Las anotaciones de comparecencia y las NOI para un testimonio directo deben ser recibidas por el Administrador de la Comisión a más tardar a las 5:00 p.m. el 30 de julio de 2026, y debe hacer referencia al número de expediente, WQCC 25-75 (R) y la fecha de la audiencia. Las notificaciones de intención que incluyan un testimonio técnico se archivarán de manera electrónica ante el Administrador de la Comisión en pamela.jones@env.nm.gov.

Las personas que deseen presentar un testimonio de refutación deberán presentar una NOI vía electrónica ante el Administrador de la Comisión a más tardar a las 5:00 p.m. el 28 de agosto de 2026. Las NOI de refutación deben incluir una

refutación deben incluir una narrativa del testimonio de refutación y los demás elementos requeridos de una NOI directa como se detalla en los puntos (1) a (5) anteriores.

Se entregará una copia impresa de todas las NOI para uso del funcionario de audiencias antes de las 12:00 p.m. el 25 de septiembre de 2026, a:

Pamela Jones, Administradora de la Comisión
Comisión de Control de Calida del Agua
P.O. Box 5469
Santa Fe, NM 87502

El funcionario de audiencias se ofrecerá una oportunidad para el público haga comentarios cada día de la audiencia se llevará a cabo de acuerdo con 20.1.6.204 NMAC. Se reserva las oportunidades de comentarios públicos a las 4:00 p.m. cada día hasta la conclusión de la audiencia.

Los miembros del público que deseen ofrecer comentarios públicos no técnicos podrán hacerlo solo una vez, ya sea en persona o en la plataforma virtual con acceso proporcionado y administrado por el Administrador. Los comentarios públicos orales se limitan a 3 minutos; Los comentarios públicos escritos presentados al Administrador son ilimitados y deben recibirse

antes del aplazamiento de la audiencia. Los comentarios públicos escritos podrán presentarse por vía electrónica o como un documento original único. Favor de enviar sus comentarios electrónicos por escrito sobre la norma propuesta antes del aplazamiento de la audiencia a través del Portal de Comentarios Inteligentes en https://nmed.commentinput.com/comment/search o envíe un correo electrónico a pamela.jones@env.nm.gov con referencia a WQCC 25-75 (R).

El NMED utilizó una variedad de información técnica con el objetivo de respaldar la norma propuesta, incluyendo datos de monitoreo del NMED, documentos de orientación de la Sección 304(a) de CWA, listas integradas/informes integrados de CWA 303(d)/305(b) anteriores y estudios de peces. La norma propuesta puede revisarse durante el horario laboral habitual en la Oficina de Calidad del Agua Superficial del NMED, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, en los oficinas exteriores del NMED, o en el sitio web del NMED en https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. Si desea obtener copias de la norma propuesta, información técnicos, o preguntas acerca de la participación en la audiencia,

comuníquese con Michael Baca al (505) 470-1652 o michael.baca1@env.nm.gov o Pamela Jones al (505) 660-4305 o pamela.jones@env.nm.gov.

Los individuos que requieran asistencia, un intérprete o cualquier otra forma de ayuda o servicio auxiliar (es decir, un lector, amplificador, intérprete de lenguaje de señas calificado, etc.) para poder asistir o participar en la audiencia deben comunicarse con Pamela Jones a más tardar el 14 de septiembre de 2026 al (505) 660-4305 o pamela.jones@env.nm.gov.

El NMED no discrimina por motivos de raza, color, origen nacional, discapacidad, edad o sexo en la administración de sus programas o actividades, según lo requerido por las leyes y regulaciones aplicables. El NMED es responsable de coordinar los esfuerzos de cumplimiento y recibir consultas relacionadas con los requisitos de no discriminación implementados por 40 C.F.R. Partes 5 y 7, incluyendo el Título VI de la Ley de Derechos Civiles de 1964, tal como estuviere modificada; Sección 504 de la Ley de Rehabilitación de 1973; la Ley de Discriminación por Edad de 1975, el Título IX de las Enmiendas a la Educación de 1972 y la Sección 13 de las Enmiendas a la Ley Federal de

Enmiendas de la Ley Federal de Control de la Contaminación del Agua de 1972. Si tiene alguna pregunta sobre este aviso o cualquiera de los programas, políticas o procedimientos de no discriminación del NMED, puede comunicarse con: Kate Cardenas, Coordinadora de No Discriminación del NMED, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 o nd.coordinator@env.nm.gov. Si cree que ha sido discriminado con respecto a un programa o actividad del NMED, comuníquese con la Coordinadora de No Discriminación.

Published in the Tri-City Record June 24, 2026

AFFIDAVIT OF PUBLICATION
STATE OF NEW MEXICO

I, Noely L Martinez
Legals Clerk

Of the Roswell Daily Record, a daily newspaper published at Roswell, New Mexico, do solemnly swear that the clipping hereto attached was published in the regular and entire issue of said paper and not in a supplement thereof for a period of:

One time with the issue dated

June 25, 2026
Month Date Year

Clerk

Sworn and subscribed to before me

this July 7, 2026
Month Date Year

Notary Public

SARALEI FAJARDO
STATE OF NEW MEXICO
NOTARY PUBLIC
COMMISSION#
1086050
EXPIRES 4-27-2030

NMED Exhibit 14

LEGALS

Notice of Sale...

Publish June 11, 18, 25, July 2, 2026

STATE OF NEW MEXICO
COUNTY OF CHAVEZ
FIFTH JUDICIAL DISTRICT COURT

NG SOLUTIONS, LLC,

Plaintiff,

v. No. D-504-CV-2024-00397

DANIEL PORRAS, DREAMSPRING, INC., WESST CORP, INC., DAVID AMADOR BAIL BONDS, ONEMAIN FINANCIAL, INC., BANK OF THE SOUTHWEST N.A., SECRETARY OF HOUSING AND URBAN DEVELOPMENT NEW MEXICO DEPARTMENT OF WORKFORCE SOLUTIONS, and DIANA RAMIREZ,

Defendants.

NOTICE OF SALE

NOTICE IS HEREBY GIVEN that on July 8, 2026, at the hour of 11 :30am, the undersigned Special Master, David Washburn, or his designee, will, at the east entrance of the Chaves County Courthouse, at 400 N. Virginia Ave, Roswell, NM 88201, sell all of the rights, title, and interests of the above-named Defendant(s), in and to the hereinafter described real property to the highest bidder for cash. The property to be sold is located at 26 Mark Road, Roswell, NM 88201, and is more particularly described as follows:

S1/2SE1/4NE1/4SE1/4 OF SECTION 33, TOWNSHIP 10 SOUTH, RANGE 23 EAST, N.M.P.M., IN THE COUNTY OF CHAVES AND STATE OF NEW MEXICO

including any improvements, fixtures, and attachments, such as, but not limited to, mobile homes, (hereinafter the "Property"). If there is a conflict between the legal description and the street address, the legal description shall control.

The foregoing sale will be made to satisfy a foreclosure judgment rendered by this Court in the above-entitled and numbered cause on April 1 6, 2026 being an action to foreclose a mortgage on the Property. Plaintiffs judgment is in the amount of $341,692.57, and the same bears interest at the rate of 3.875% per annum, accruing at the rate of$36.28 per diem, from April 16, 2026 to the date of sale. The Court reserves entry of final judgment against Defendant(s), Daniel Porras, for the amount due after foreclosure sale, including interest, costs, and fees as may be assessed by the Court. Plaintiff has the right to bid at the foregoing sale in an amount equal to its judgment, and to submit its bid either verbally or in writing. Plaintiff may apply all or any part of its judgment to the purchase price in lieu of cash.

In accordance with the Court's decree, the proceeds of sale are to be applied first to the costs of sale, including the Special Master's fees, and then to satisfy the above-described judgment, including interest, with any remaining balance to be paid into the Court Registry in order to satisfy any future adjudication of priority lienholders.

NOTICE IS FURTHER GIVEN that in the event that the subject Note and Mortgage is not sooner paid off or reinstated, the undersigned Special Master will, as set forth above, offer for sale and sell the Property to the highest bidder for cash or equivalent, for the purpose of satisfying, in the adjudged order of priorities, the judgment and decree of foreclosure described herein, together with any additional costs and attorney's fees, including the costs of advertisement and publication for the foregoing sale, and, reasonable receiver and Special Master's fees in an amount to be fixed by the Court. The amount of Plaintiff's judgment due is $341,692.57, bearing interest at the rate of 3.875% per annum, accruing at the rate of $36.28 per diem, from April16, 2026 to the date of sale.

The foregoing sale may be postponed and rescheduled at the discretion of the Special Master, and is subject to all taxes, utility liens and other restrictions and easements of record, and subject to a one (1) month right of redemption held by the Defendant Daniel Porras upon entry of an order approving sale, and subject to the entry of an order of the Court approving the terms and conditions of sale.

Witness my hand this June 8, 2026.

/s/ David Washburn
DAVID WASHBURN, Special Master
8100 Wyoming Blvd NE
Suite M-4, Box 272
Albuquerque, NM 87113
Telephone: (505) 318-0300
E-mail: sales@nsi.legal

Notice to Creditors...

Publish June 11, 18, 25, 2026

STATE OF NEW MEXICO
PROBATE COURT
COUNTY OF CHAVES

IN THE MATTER OF THE ESTATE OF
RITA SUE ATKINS CIBAK, deceased.

No. PB 2026-073

NOTICE TO CREDITORS

NOTICE IS HEREBY GIVEN that the undersigned has been appointed as Personal Representative of the above-named Estate. All persons having claims against this Estate are required to present their claims within four (4) months after the date of the first publication of this Notice or the claims will be forever barred. Claims must be presented either to the undersigned Personal Representative, Richard Colvin Cibak, 1207 San Juan Drive, Roswell, NM 88201, or filed with the Chaves County Probate Court at PO Box 580, Roswell, New Mexico 88202-0580.

/s/ Richard Colvin Cibak
RICHARD COLVIN CIBAK

Public Hearing...

Publish June 10, 11, 25, 2026

NOTICE OF PUBLIC HEARING
FOR A RESTAURANT B - BEER, WINE & SPIRITS LICENSE WITH ON PREMISES CONSUMPTION AND WITH PATIO SERVICE

Notice is hereby given that a public hearing will be held to issue a Restaurant B Beer, Wine and Spirits License with on premises Consumption and with Patio Service, for Gelis Café, LLC, d/b/a Gelis Mexican Restaurant, located at 3601 N. Main Street, Roswell, NM 88201, by the Roswell City Council during the regular Council meeting on 6 at 6:00 p.m. at the Chaves County Administrative Center – Commission Chambers, #1 St. Mary's Place, Roswell, New Mexico 88203.

Applicant: GELIS CAFÉ, LLC
d/b/a/ Gelis Mexican Restaurant
3601 N. Main St.
Roswell, NM 88201

Propose Action: The Applicant Is Seeking a Restaurant B – Beer, Wine And Spirits License With On Premises Consumption And With Patio Service.

Licensees: GELIS CAFÉ, LLC
d/b/a/ Gelis Mexican Restaurant
3601 N. Main St.
Roswell, NM 88201

At the meeting, the City Council may take action approving or disapproving the proposed application.

/s/ Amalia Martinez
City Clerk

Request for Proposal...

Publish June 25, 2026

NOTICE TO OFFERORS
CITY OF ROSWELL
RFP NO. 26-008
ON-CALL CONSTRUCTION SERVICES & REPAIRS

The City of Roswell, New Mexico, is soliciting sealed proposals from qualified construction contractors to establish on-call construction contracts for renovation, repair, new construction, remodeling, and related construction services for City-owned facilities and infrastructure.

The City of Roswell has transitioned to a new eBid/RFP software system powered by OpenGov. All solicitations will be released electronically through OpenGov, and responses must be submitted electronically through this online platform. By using OpenGov, prospective offerors will receive all information regarding the solicitation, including addenda and changes to project requirements. OpenGov is a free service for all respondents.

Prior to submitting a proposal, respondents are required to set up a free OpenGov account. Register your company and access the solicitation at the City's eProcurement Portal:
https://procurement.opengov.com/portal/roswellnm or through the City of Roswell website at: www.roswell-nm.gov > Business & Development > OpenGov.

Only electronically submitted proposals will be accepted; the system will not accept proposals submitted after the due date and time.

Proposals are due no later than 2:00 p.m. on Tuesday, July 21, 2026. All questions must be submitted through the OpenGov portal by 5:00 p.m. on Wednesday, July 8, 2026.

All proposals received are subject to approval by the appropriate governing authority. Notice is hereby given that the City reserves the right to reject any or all proposals received and to determine the proposal(s) that best serve the interests of the City of Roswell.

Arely Peek
Procurement Officer

Hearing Publication...

Publish June 18, 25, July 2, 2026

FIFTH JUDICIAL DISTRICT COURT

COUNTY OF CHAVES
STATE OF NEW MEXICO

IN THE MATTER OF THE ESTATE OF

ALBERT TEGEDA JR., DECEASED.

No. D-504-PB-2026-00035
Judge Dustin K. Hunter

NOTICE OF HEARING
PUBLICATION

To: Unknown heirs of Albert Tegeda Jr., deceased, and all unknown persons who have or claim any interest in the estate of Albert Tegeda Jr., deceased, or in the matter being litigated in the hereinafter mentioned hearing.

You are hereby notified that a hearing on the Petition filed by Petitioner, Sergio Tegeda, requesting the Court enter a judicial order formally declaring that the decedent died intestate, a determination of the heirs of the decedent, and the appointment of the Petitioner as formal Personal Representative of the estate, without bond in an unsupervised administration, and the issuing of Letters of Administration to Petitioner, will be held on Wednesday August 19, 2026 at 8:40 a.m. MDT, via Google Meet with Judge Hunter online meet.google.com/bhi-ozpg-oan or via phone 1-419-684-0026 PIN: 407 848 371#.

Dated this 10th day of June 2026.

Sergio Tegeda
Petitioner

COLL BROS. LAW, LLC
By: Eric J. Coll
Attorneys for Petitioner
P.O. Box 2288
Roswell, New Mexico 88202
575-623-2288
ericjcoll@gmail.com

Notice of Resolution...

Publish June 18, 25, 2026

RESOLUTION PROPOSING CAPITAL IMPROVEMENTS TAX BALLOT QUESTION
State of New Mexico
Counties of Chaves and Roosevelt
Elida Municipal School District No. 2

The Board of Education met in regular session on the 9th day of March, 2026.
WHEREAS the Public School Capital Improvements Act (Sections 22-25-1 through 22-25-11 NMSA 1978) authorizes submission of a capital improvements tax question to voters; and

WHEREAS the Board has determined that the question should be submitted to the voters of the District;

NOW THEREFORE BE IT RESOLVED, that a Special Mail Ballot Election shall be held Thursday, August 13, 2026.

STATUTORY BALLOT QUESTION
PUBLIC SCHOOL CAPITAL IMPROVEMENTS ($2.00 MILL) TAX QUESTION

Shall the Board of Education of the Elida Municipal School District No. 2, Counties of Chaves and Roosevelt, State of New Mexico, be authorized to impose a property tax of $2.00 on each $1,000.00 of net taxable value of the property allocated to the District under the Property Tax Code for property tax years 2027, 2028, 2029, 2030, 2031, and 2032 for capital improvements in the District including payments made with respect to lease-purchase arrangements as defined in the Education Technology Equipment Act or the Public School Lease Purchase Act?

FOR THE TAX
AGAINST THE TAX

PREGUNTA SOBRE EL IMPUESTO PARA MEJORAS DE CAPITAL DE LAS ESCUELAS PÚBLICAS (2,00 MILLONES DE DÓLARES)

¿Se autorizará a la Junta de Educación del Distrito Escolar Municipal No. 2 de Elida, Condados de Chaves y Roosevelt, Estado de Nuevo México, a imponer un impuesto sobre la propiedad de $2.00 por cada $1,000.00 del valor neto imponible de la propiedad asignada al Distrito conforme al Código del Impuesto sobre la Propiedad para los años fiscales de propiedad 2027, 2028, 2029, 2030, 2031 y 2032, destinado a mejoras de capital en el Distrito, incluidos los pagos realizados con respecto a acuerdos de arrendamiento con opción de compra según se definen en la Ley de Equipos de Tecnología Educativa o en la Ley de Arrendamiento con Opción de Compra para Escuelas Públicas?

A FAVOR DEL IMPUESTO
EN CONTRA DEL IMPUESTO

Notice to Creditors...

Publish June 18, 25, July, 2, 2026

IN THE PROBATE COURT
STATE OF NEW MEXICO
COUNTY OF CHAVES PB-2026-075

IN THE MATTER OF THE ESTATE OF SARAH LYNN CLARK, also known as SARAH L. CLARK, also known as SARAH CLARK.

NOTICE TO CREDITORS

NOTICE IS HEREBY GIVEN that MATTHEW H. CLARK and JILL L. CLARK have been appointed Co-Personal Representatives of the estate of the decedent. All persons having claims against the estate of the decedent are required to present their claims within four (4) months after the date of the first publication of any published notice to creditors or sixty (60) days after the date of mailing or other delivery of this notice, whichever is later, or the claims will be forever barred. Claims must be presented either to the co-personal representatives or the attorney for the co-personal representatives at the addresses listed below, or filed with the Probate Court of Chaves County, New Mexico, located at #1 St. Mary's Place, Roswell, NM 88203:

Matthew H. Clark and Jill L. Clark, Co-Personal Representatives
1905 Scenic Dr.
Alamogordo, NM 88310

S. Thomas Overstreet, Esq., Attorney for Co-Personal Representatives
1011 New York Avenue
Alamogordo, NM 88310

Dated: June 12, 2026

OVERSTREET & ASSOCIATES, P.C.

/s/ S. Thomas Overstreet
S. Thomas Overstreet, Esq.
Attorney for Co-Personal Representatives
1011 New York Avenue
Alamogordo, NM 88310
Phone: (575) 437-5800
Fax: (575) 437-1567
E-mail: s.t.overstreet.law@gmail.com

Meeting and Sale...

Publish June 18, 25, 2026

NOTICE OF SPECIAL MEETING AND SALE
DEXTER CONSOLIDATED SCHOOL DISTRICT NO. 8

PUBLIC NOTICE IS HEREBY GIVEN that the Board of Education of the Dexter Consolidated School District No. 8, Dexter, New Mexico ("Board"), will meet in special session at the School Board Room, Central Office, Dexter, New Mexico at 6:00 a.m. on July 6, 2026, to consider a resolution granting final approval of a lease-purchase arrangement for the lease-purchase of education technology equipment in an amount not to exceed $650,000 as authorized by the Education Technology Equipment Act, NMSA 1978, §§ 6-15A-1 through 6-15A-17 ("Act").

It is the present intention of the Board that the lease-purchase arrangement contemplated hereby will be entered into and issued at a private sale to the New Mexico Finance Authority ("Finance Authority"), and be structured pursuant to the recommendations of the District's Municipal Advisor. The terms of the Lease-Purchase Agreement, which will be utilized in the lease-purchase arrangement, are summarized as follows:

The Lease-Purchase Agreement amount shall be $650,000 payable at closing for the purchase of education technology equipment. Payments shall begin on August 1, 2027, and be paid annually thereafter until paid in full according to the following schedule provided that in no event shall the term of the Lease-Purchase Agreement exceed five years:

2027	$305,000
2028	85,000
2029	90,000
2030	90,000
2031	80,000

The interest component of such payments shall be paid at the rate not to exceed the maximum rate provided by law.

The source of the funds for the lease shall be derived from an annual levy of ad valorem taxes sufficient to meet the payments of principal and interest due, provided the District may apply any other funds that may be in its general fund or investment income actually received from investments and available for that purpose to the payments due.

The District covenants that the Lease-Purchase Agreement shall at all times be free from taxation by the State, except for estate or gift taxes and taxes on transfers.

DATED this 8th day of June 2026.

BOARD OF EDUCATION OF THE
DEXTER CONSOLIDATED SCHOOL DISTRICT NO. 8
By: /s/ Luis Davalos
President

[SEAL]

ATTEST:

By /s/ Andrea Batista
Secretary

Notice of Pendency...

Publish June 25, July 2, 9, 2026

STATE OF NEW MEXICO
COUNTY OF CHAVEZ
FIFTH JUDICIAL DISTRICT COURT

No. D-504-CV-2025-00978

NUSENDA FEDERAL CREDIT UNION,
Plaintiff,

v.

JAMES E. BOLING,
Defendant.

NOTICE OF PENDENCY OF SUIT

To Defendant James Boling.

You are hereby notified that the above-named Plaintiff has filed a civil action against you in the above-entitled Court and cause, the general object thereof being to recover money due. That unless you respond to the Complaint within 30 days of completion of publication of this Notice, judgment by default will be entered against you.

Name, address, and phone number of Plaintiff's attorney: Wainwright and Associates, P.A., 3301 Coors Blvd. NW Suite R #274, Albuquerque, NM 87120, 505-842-1313.

WITNESS the Honorable James M. Hudson District Judge of the Fifth Judicial District Court of the State of New Mexico and the Seal of the District Court of Chaves County, on 1st day of April, 2026.

Stacy L. Mora
CLERK OF THE DISTRICT COURT

BY /s/ Crystal Ceballos
DEPUTY

Notice of Hearing...

Publish June 25, 2026

NEW MEXICO WATER
QUALITY CONTROL COMMISSION
NOTICE OF PUBLIC RULEMAKING HEARING

The New Mexico Water Quality Control Commission (Commission) will hold a public hearing beginning at 9:00 a.m. on September 28, 2026, and continuing through October 1, 2026, as necessary. The Commission may continue the hearing thereafter to hear all testimony, evidence, and public comments. The hearing will be held at the State Capitol Building, 490 Old Santa Fe Trail, Santa Fe, New Mexico 87501. Additionally, a virtual participation option will be provided with meeting links and details posted on the events calendar at https://www.env.nm.gov/events-calendar. The purpose of the hearing is to consider the docketed matter of WQCC 25-75 (R) to amend 20.6.4 NMAC, Standards for Interstate and Intrastate Surface Waters. The petitioner for this proposed regulatory change is the New Mexico Environment Department (NMED).

The federal Clean Water Act (CWA) requires states to evaluate existing water quality standards (WQS), consider new scientific information, provide public participation opportunities, and amend WQS as necessary, every three years. This process is commonly referred to as the Triennial Review and culminates in a public hearing. NMED proposed amendments in this matter based on public comments on 20.6.4 NMAC, communication with the Environmental Protection Agency (EPA), federal guidance documents, monitoring and fish data, as well as internal comments and implementation concerns. The amendments include new and revised definitions, clarification of third-party rulemaking procedures and costs, revisions to segment descriptions to match hydrological breaks, WQS for wetlands, clarification of implementation language, updated references, as well as new or revised designated uses, criteria, and antidegradation requirements.

The hearing will be conducted in accordance with the Water Quality Act, Sections 74-6-4 and 74-6-6 NMSA 1978, the State Rules Act, Section 14-4-5.3 NMSA 1978, 20.1.6 NMAC (Rulemaking Procedures – Water Quality Control Commission), the Pre-Hearing Order for WQCC 25-75 (R), and other applicable procedures and authorities. The Commission may make a decision on the proposed rule at the conclusion of the hearing.

All interested persons will be given reasonable opportunity at the hearing to submit data, views or arguments orally or in writing, and examine witnesses testifying at the hearing. Persons wishing to present technical testimony must file a written notice of intent (NOI) with the Commission. The NOI shall:
(1) identify the person for whom the witness(es) will testify;
(2) identify each technical witness the person intends to present and state the qualifications of that witness, including a description of their educational and work background;
(3) include a copy of the direct testimony of each technical witness in narrative form;
(4) include the text of any recommended modifications to the proposed regulatory change; and
(5) list and attach all exhibits anticipated to be offered by that person at the hearing, including any proposed statement of reasons for adoption of rules.

Entries of appearance and NOIs for direct testimony must be filed with the Commission Administrator no later than 5:00 p.m. on July 30, 2026, and should reference the docket number, WQCC 25-75 (R), and the date of the hearing. Notices of intent to present technical testimony shall be filed electronically with the Commission Administrator at pamela.jones@env.nm.gov.

Persons wishing to present rebuttal testimony, shall file an NOI electronically with the Commission Administrator no later than 5:00 p.m. on August 28, 2026. Rebuttal NOIs should include a narrative of rebuttal testimony and the other required elements of a direct NOI, as detailed in items (1) – (5) above.

One paper copy of all NOIs for the Hearing Officer's use shall be delivered by 12:00 p.m. (noon) on September 25, 2026, to:

Pamela Jones, Commission Administrator
Water Quality Control Commission
P.O. Box 5469
Santa Fe, NM 87502

The Hearing Officer will provide an opportunity for non-technical public comment each day of the hearing in a manner that accommodates the public pursuant

LEGALS

to 20.1.6.204 NMAC. Public comment sessions will be reserved for 4:00 p.m. each day, until the close of the hearing record.

Members of the public wishing to offer non-technical public comment may do so only once either in person or on the virtual platform with access provided and managed by the Administrator. Oral public comment is limited to 3 minutes; written public comment submitted to the Administrator is unlimited and must be received prior to adjournment of the hearing. Written public comments may be submitted electronically or as a single original document to the Administrator at the above address. Please submit electronic written comments regarding the proposed rule prior to adjournment of the hearing via the Smart Comment Portal at https://nmed.commentinput.com/comment/search or through email to pamela.jones@env.nm.gov with reference to WQCC 25-75 (R).

NMED based the proposed rule on a variety of technical information, including NMED monitoring data , CWA Section 304(a) guidance documents, past CWA 303(d)/305(b) Integrated Lists/Integrated Reports, and fish surveys. The proposed rule may be reviewed during regular business hours at the NMED Surface Water Quality Bureau, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, at NMED Field Offices, or on NMED's web site at https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. For copies of the proposed rule, how to obtain technical information, or questions about participating in the hearing, please contact Michael Baca at (505) 470-1652 or michael.baca1@env.nm.gov or Pamela Jones at (505) 660-4305 or pamela.jones@env.nm.gov.

Persons requiring assistance, an interpreter, or any other form of auxiliary aid or service (i.e., reader, amplifier, qualified sign language interpreter, etc.) to attend or participate in the hearing should contact Pamela Jones no later than September 14, 2026 at (505) 660-4305 or pamela.jones@env.nm.gov.

NMED does not discriminate on the basis of race, color, national origin, disability, age or sex in the administration of its programs or activities, as required by applicable laws and regulations. NMED is responsible for coordination of compliance efforts and receipt of inquiries concerning non-discrimination requirements implemented by 40 C.F.R. Parts 5 and 7, including Title VI of the Civil Rights Act of 1964, as amended; Section 504 of the Rehabilitation Act of 1973; the Age Discrimination Act of 1975, Title IX of the Education Amendments of 1972, and Section 13 of the Federal Water Pollution Control Act Amendments of 1972. If you have any questions about this notice or any of NMED's non- discrimination programs, policies or procedures, you may contact: Kate Cardenas, NMED Non-Discrimination Coordinator, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 or nd.coordinator@env.nm.gov. If you believe that you have been discriminated against with respect to an NMED program or activity, please contact the Non-Discrimination Coordinator.

Aviso de Audiencia...

Publicado el 25 de junio de 2026

COMISIÓN DE CONTROL DE CALIDAD DEL AGUA DE NUEVO MÉXICO
AVISO DE AUDIENCIA PÚBLICA DE REGLAMENTACIÓN

La Comisión de Control de Calidad del Agua de Nuevo México (la Comisión) celebrará una audiencia pública la cual comenzará a las 9:00 a.m. del 28 de septiembre de 2026 y continuará hasta el 1 de octubre de 2026, según sea necesario. La Comisión podrá continuar la audiencia posteriormente con el fin de escuchar todos los testimonios, pruebas y comentarios públicos. La audiencia se llevará a cabo en el edificio del Capitolio del Estado, 490 Old Santa Fe Trail, Santa Fe, Nuevo México 87501. Además, habrá disponible una opción de participación virtual con enlaces a las reuniones e información publicados en el calendario de eventos en https://www.env.nm.gov/events-calendar. El propósito de la audiencia es considerar el asunto registrado en WQCC 25-75 (R) con el objetivo de enmendar 20.6.4 NMAC, Estándares de Aguas Superficiales Interestatales e Intraestatales. El peticionario de esta enmienda regulatoria propuesta es el Departamento de Medio Ambiente de Nuevo México (NMED, por sus siglas en inglés).

La Ley de Agua Limpia (CWA) federal exige que los estados evalúen los estándares de calidad del agua (WQS) existentes, consideren la información científica más reciente, brinden oportunidades de participación pública y modifiquen los WQS según sea necesario, cada tres años. Este proceso se conoce generalmente como Revisión Trienal y culmina con una audiencia pública. El NMED propuso enmiendas en este asunto con base en comentarios públicos sobre 20.6.4 NMAC, comunicado con la Agencia de Protección Ambiental (EPA, por sus siglas en inglés), documentos de orientación federales, datos de peces y monitoreo, así como los comentarios internos y preocupaciones sobre la implementación. Las enmiendas incluyen definiciones nuevas y revisadas, aclaración de los procedimientos y costos de la reglamentación de terceros, revisiones de las descripciones de los segmentos con el fin de que coincidan con las rupturas hidrológicas, los WQS correspondientes a los humedales, la aclaración del lenguaje de implementación, las referencias actualizadas, así como los usos designados, criterios y requisitos de anti-degradación nuevos o revisados.

La audiencia se llevará a cabo de acuerdo con la Ley de Calidad del Agua, Secciones 74-6-4 y 74-6-6 NMSA 1978, Ley de Reglas Estatales, Sección 14-4-5.3 NMSA 1978, 20.1.6 NMAC, Procedimientos de Reglamentación – Comisión de Control de Calidad del Agua, la Orden previa a la audiencia para WQCC 25-75 (R) y otros procedimientos y autoridades aplicables. La Comisión puede decidir sobre la norma propuesta al concluir la audiencia.

A todas las personas interesadas se les dará una oportunidad razonable durante la audiencia para presentar datos, puntos de vista o argumentos de forma oral o por escrito, y examinar a los testigos que testifiquen en la audiencia. Las personas que deseen presentar un testimonio técnico deben presentar una notificación de intención (NOI) por escrito ante la Comisión. La NOI deberá:

(1) identificar a la persona por quien los testigos testificarán;
(2) identificar cada testigo técnico que la persona pretende presentar y declarar las calificaciones de ese testigo, incluyendo una descripción de sus antecedentes educativos y laborales;
(3) incluir una copia del testimonio directo de cada testigo técnico en forma narrativa;
(4) incluir el texto de cualquier modificación recomendada al cambio regulatorio propuesto; y
(5) enumerar y adjuntar todas las pruebas que se prevé que ofrecerá esa persona en la audiencia, incluyendo cualquier declaración propuesta de motivos para la adopción de reglas.

Las anotaciones de comparecencia y las NOI para un testimonio directo deben ser recibidas por el Administrador de la Comisión a más tardar a las 5:00 p.m. el 30 de julio de 2026, y debe hacer referencia al número de expediente, WQCC 25-75 (R) y la fecha de la audiencia. Las notificaciones de intención que incluyan un testimonio técnico se archivarán de manera electrónica ante el Administrador de la Comisión en pamela.jones@env.nm.gov.

Las personas que deseen presentar un testimonio de refutación deberán presentar una NOI vía electrónica ante el Administrador de la Comisión a más tardar a las 5:00 p.m. el 28 de agosto de 2026. Las NOI de refutación deben incluir una narrativa del testimonio de refutación y los demás elementos requeridos de una NOI directa como se detalla en los puntos (1) a (5) anteriores.

Se entregará una copia impresa de todas las NOI para uso del funcionario de audiencias antes de las 12:00 p.m. el 25 de septiembre de 2026, a:

Pamela Jones, Administradora de la Comisión
Comisión de Control de Calida del Agua
P.O. Box 5469
Santa Fe, NM 87502

El funcionario de audiencias se ofrecerá una oportunidad para el público haga comentarios cada día de la audiencia se llevará a cabo de acuerdo con 20.1.6.204 NMAC. Se reserva las oportunidades de comentarios públicos a las 4:00 p.m. cada día hasta la conclusión de la audiencia.

Los miembros del público que deseen ofrecer comentarios públicos no técnicos podrán hacerlo solo una vez, ya sea en persona o en la plataforma virtual con acceso proporcionado y administrado por el Administrador. Los comentarios públicos orales se limitan a 3 minutos; Los comentarios públicos escritos presentados al Administrador son ilimitados y deben recibirse antes del aplazamiento de la audiencia. Los comentarios públicos escritos podrán presentarse por vía electrónica o como un documento original único. Favor de enviar sus comentarios electrónicos por escrito sobre la norma propuesta antes del aplazamiento de la audiencia a través del Portal de Comentarios Inteligentes en https://nmed.commentinput.com/comment/search o envíe un correo electrónico a pamela.jones@env.nm.gov con referencia a WQCC 25-75 (R).

El NMED utilizó una variedad de información técnica con el objetivo de respaldar la norma propuesta, incluyendo datos de monitoreo del NMED, documentos de orientación de la Sección 304(a) de CWA, listas integradas/informes integrados de CWA 303(d)/305(b) anteriores y estudios de peces. La norma propuesta puede revisarse durante el horario laboral habitual en la Oficina de Calidad del Agua Superficial del NMED, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, en los oficinas exteriores del NMED, o en el sitio web del NMED en https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. Si desea obtener copias de la norma propuesta, información técnicos, o preguntas acerca de la participación en la audiencia, comuníquese con Michael Baca al (505) 470-1652 o michael.baca1@env.nm.gov o Pamela Jones al (505) 660-4305 o pamela.jones@env.nm.gov.

Los individuos que requieran asistencia, un intérprete o cualquier otra forma de ayuda o servicio auxiliar (es decir, un lector, amplificador, intérprete de lenguaje de señas calificado, etc.) para poder asistir o participar en la audiencia deben comunicarse con Pamela Jones a más tardar el 14 de septiembre de 2026 al (505) 660-4305 o pamela.jones@env.nm.gov.

El NMED no discrimina por motivos de raza, color, origen nacional, discapacidad, edad o sexo en la administración de sus programas o actividades, según lo requerido por las leyes y regulaciones aplicables. El NMED es responsable de coordinar los esfuerzos de cumplimiento y recibir consultas relacionadas con los requisitos de no discriminación implementados por 40 C.F.R. Partes 5 y 7, incluyendo el Título VI de la Ley de Derechos Civiles de 1964, tal como estuviere modificada; Sección 504 de la Ley de Rehabilitación de 1973; la Ley de Discriminación por Edad de 1975, el Título IX de las Enmiendas a la Educación de 1972 y la Sección 13 de las Enmiendas a la Ley Federal de Control de la Contaminación del Agua de 1972. Si tiene alguna pregunta sobre este aviso o cualquiera de los programas, políticas o procedimientos de no discriminación del NMED, puede comunicarse con: Kate Cardenas, Coordinadora de No Discriminación del NMED, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 o nd.coordinator@env.nm.gov. Si cree que ha sido discriminado con respecto a un programa o actividad del NMED, comuníquese con la Coordinadora de No Discriminación.

Notice to Creditors...

Publish June 18, 25, July 2, 2026

STATE OF NEW MEXICO
COUNTY OF CHAVES
FIFTH JUDICIAL DISTRICT COURT

IN THE MATTER OF THE ESTATE
OF BARBARA J. WITT,
Deceased.

D-504-PB-2026-00015
Honorable James M. Hudson

NOTICE TO CREDITORS

NOTICE IS HEREBY GIVEN that Woodson Wayne Witt, II has been appointed Personal Representative of this Estate. All persons having claims against this Estate are required to present their claims within four (4) months after the date of the first publication of this Notice to Creditors or sixty (60) days after the date of mailing or other delivery of this Notice to Creditors, whichever is later or the claims will be forever barred. Claims must be presented either to the Personal Representative or his attorneys, Kraft Law Finn, LLP (Richard L. Kraft) at P .0. Box 850, Roswell, NM 88202-0850 or filed with the District Court of Chaves County, 400 N. Virginia, Roswell, New Mexico 88201.

DATED this 12th of June, 2026.

RESPECTFULLY SUBMITTED:

KRAFT LAW, LLP.

By: /s/ Richard L. Kraft
Richard L. Kraft
P.O. Box 850
Roswell, NM 88202-0850
(575) 625-2000
(575) 625-2010 (facsimile)
Attorneys for Personal Representative

Notice for Creditors...

Publish June 18, 25, July 2, 2026

IN THE DISTRICT COURT
COUNTY OF CHAVES
STATE OF NEW MEXICO

IN THE MATTER OF THE)
ESTATE OF RANDOLPH CARLTON CROW)
deceased.)

No. D-504-PB-2026-00043

NOTICE TO CREDITORS

NOTICE IS HEREBY GIVEN that the undersigned has been appointed Personal Representative of the above-referenced estate. All persons having claims against the estate are required to present their claims within four months after the date of the first publication of this Notice, or the claims will be forever barred. Claims must be presented either to the undersigned Personal Representative, P.O. Box 265, Dexter, New Mexico 88230, or filed with the District Court.

/s/ Susan Shaw
Susan Shaw
Personal Representative of the Estate
of Randolph Carlton Crow, deceased
P.O. Box 265
Dexter, NM 88230

575 LAW GROUP, LLC

/s/ Grey Robinson
Grey Robinson
310 N. Canyon
Carlsbad, NM 88220
(575) 628-8248
(575) 628-0016 Fax
grey@575lawgroup.com

Invitation to Bid...

Publish June 18, 25, 2026

LEGAL NOTICE
INVITATION TO BID
ITB 2026-0803 – MILK PRODUCTS

Hagerman Municipal Schools is accepting sealed bids for the delivery of milk products.

Bid documents may be obtained from the District website at www.bobcat.net or by contacting:

Raquel Morales, Chief Procurement Officer
Hagerman Municipal Schools
P.O. Drawer B
Hagerman, NM 88232
(575) 752-3254
rmorales@bobcat.net

Sealed bids will be received until **10:00 a.m. MDT** on **July 9, 2026**, at Hagerman Municipal Schools, 406 N. Cambridge Ave., Hagerman, NM 88232.

Bids must be clearly marked:

"ITB 2026-0803 – Milk Products"

Hagerman Municipal Schools reserves the right to reject any or all bids and waive minor technical irregularities.

Notice of Intent...

Publish June 25, 2026

CITY OF ROSWELL, NEW MEXICO
NOTICE OF INTENT TO ADOPT ORDINANCE

Notice is hereby given of the title and of a general summary of the subject matter contained in an Ordinance (the "Ordinance") to be considered for adoption by the City Council of the City of Roswell, New Mexico (the "City") at 6:00 p.m. on July 9, 2026 at the Chaves County Administrative Center, Commission Chambers, #1 St. Mary's Place, Roswell, New Mexico. Complete copies of the Ordinance are available for publis inspection during the normal and regular business hours of the City Clerk, City Hall, 425 North Richardson, Roswell, New Mexico.

The title of the Ordinance is:

AUTHORIZING THE EXECUTION AND DELIVERY OF A LOAN AGREEMENT BY AND BETWEEN THE CITY OF ROSWELL, NEW MEXICO (THE "GOVERNMENTAL UNIT") AND THE NEW MEXICO FINANCE AUTHORITY (THE "FINANCE AUTHORITY"), EVIDENCING A SPECIAL, LIMITED OBLIGATION OF THE GOVERNMENTAL UNIT TO PAY A PRINCIPAL AMOUNT NOT TO EXCEED $11,750,000, TOGETHER WITH INTEREST THEREON, FOR THE PURPOSE OF (1) REFINANCING, PAYING AND DISCHARGING THE GOVERNMENTAL UNIT'S OUTSTANDING JOINT WATER AND SEWER IMPROVEMENT REVENUE BONDS, SUBORDINATE SERIES 2017 ISSUED ON FEBRUARY 21, 2017, (2) FUNDING A LOAN AGREEMENT RESERVE ACCOUNT; AND (3) PAYING EXPENSES; PROVIDING FOR THE PAYMENT OF THE PRINCIPAL OF AND INTEREST ON THE LOAN AGREEMENT SOLELY FROM THE NET REVENUES FROM THE GOVERNMENTAL UNIT'S JOINT WATER AND SEWER UTILIITY SYSTEM; APPROVING THE DELEGATION OF AUTHORITY TO MAKE CERTAIN DETERMINATIONS REGARDING THE LOAN AGREEMENT PURSUANT TO THE SUPPLEMENTAL PUBLIC SECURITIES ACT; RATIFYING ACTIONS HERETOFORE TAKEN; APPROVING THE FORMS OF THE LOAN AGREEMENT AND OTHER DETAILS CONCERNING THE LOAN AGREEMENT; REPEALING ALL ACTION INCONSISTENT WITH THIS ORDINANCE; AND AUTHORIZING THE TAKING OF OTHER ACTIONS IN CONNECTION WITH THE EXECUTION AND DELIVERY OF THE LOAN AGREEMENT

A summary of the subject matter of this Ordinance is contained in its title. This notice constitutes compliance with Section 3-17-3, NMSA 1978.

Notice of Intent...

Publish June 25, 2026

CITY OF ROSWELL, NEW MEXICO
NOTICE OF INTENT TO ADOPT ORDINANCE

Notice is hereby given of the title and of a general summary of the subject matter contained in an Ordinance (the "Ordinance") to be considered for adoption by the City Council of the City of Roswell, New Mexico (the "City") at 6:00 p.m. on July 9, 2026 at the Chaves County Administrative Center, Commission Chambers, #1 St. Mary's Place, Roswell, New Mexico. Complete copies of the Ordinance are available for public inspection during the normal and regular business hours of the City Clerk, City Hall, 425 North Richardson, Roswell, New Mexico.

The title of the Ordinance is:

AUTHORIZING THE EXECUTION AND DELIVERY OF A LOAN AGREEMENT AND INTERCEPT AGREEMENT BY AND BETWEEN THE CITY OF ROSWELL, NEW MEXICO (THE "GOVERNMENTAL UNIT") AND THE NEW MEXICO FINANCE AUTHORITY, EVIDENCING A SPECIAL, LIMITED OBLIGATION OF THE GOVERNMENTAL UNIT TO PAY A PRINCIPAL AMOUNT NOT TO EXCEED $25,100,000, TOGETHER WITH INTEREST THEREON, FOR THE PURPOSE OF DEFRAYING THE COST TO (I) acquire, construct, purchase, equip, furnish, make additions to, renovate, rehabilitate, beautify, or otherwise improve THE CITY'S flood recovery projects, (II) FUND A LOAN AGREEMENT RESERVE ACCOUNT, AND (III) PAY EXPENSES; PROVIDING FOR THE PLEDGE AND PAYMENT OF THE PRINCIPAL AND INTEREST DUE UNDER THE LOAN AGREEMENT SOLELY FROM THE REVENUES OF THE 0.375% MUNICIPAL FLOOD RECOVERY GROSS RECEIPTS TAX IMPOSED PURSUANT TO A GOVERNMENTAL UNIT ORDINANCE, AND SECTION 7-19(D)-19, NMSA 1978, AS AMENDED; APPROVING THE DELEGATION OF AUTHORITY TO MAKE CERTAIN DETERMINATIONS REGARDING THE LOAN AGREEMENT PURSUANT TO THE SUPPLEMENTAL PUBLIC SECURITIES ACT; PROVIDING FOR THE DISTRIBUTION OF MUNICIPAL FLOOD RECOVERY GROSS RECEIPTS TAX REVENUES TO BE REDIRECTED BY THE STATE TAXATION AND REVENUE DEPARTMENT TO THE NEW MEXICO FINANCE AUTHORITY OR ITS ASSIGNS FOR THE PAYMENT OF PRINCIPAL AND INTEREST DUE ON THE LOAN AGREEMENT PURSUANT TO AN INTERCEPT AGREEMENT; APPROVING THE FORM AND TERMS OF, AND OTHER DETAILS CONCERNING THE LOAN AGREEMENT AND INTERCEPT AGREEMENT; RATIFYING ACTIONS HERETOFORE TAKEN; REPEALING ALL ACTION INCONSISTENT WITH THIS ORDINANCE; AND AUTHORIZING THE TAKING OF OTHER ACTIONS IN CONNECTION WITH THE EXECUTION AND DELIVERY OF THE LOAN AGREEMENT AND INTERCEPT AGREEMENT

A summary of the subject matter of this Ordinance is contained in its title. This notice constitutes compliance with Section 3-17-3, NMSA 1978.

Foreclosure Sale...

Publish June 25, July 2, 9, 16, 2026

NOTICE OF FORECLOSURE SALE STATE OF NEW MEXICO COUNTY OF CHAVES FIFTH JUDICIAL DISTRICT U.S. BANK TRUST NATIONAL ASSOCIATION, NOT IN ITS INDIVIDUAL CAPACITY BUT SOLELY AS OWNER TRUSTEE FOR RCAF ACQUISITION TRUST, Plaintiff, vs. Case No.: D-504-CV-2023-00541 VIRGINIA DURAN, KNOWN HEIR OF THE ESTATE OF JOE R. HICKS, DECEASED; UNKNOWN HEIRS, DEVISEES, AND LEGATEES OF THE ESTATE OF GEORGIA M. BASINGER, DECEASED; UNKNOWN HEIRS, DEVISEES, AND LEGATEES OF THE ESTATE OF JOE R. HICKS, DECEASED; ALMETRA STRANGE, KNOWN HEIR OF THE ESTATE OF JOE R. HICKS, DECEASED; PRESELL GILDER, KNOWN HEIR OF THE ESTATE OF JOE R. HICKS, DECEASED; ANGELA FLORES, KNOWN HEIR OF THE ESTATE OF JOE R. HICKS, DECEASED; ALICE HICKS, KNOWN HEIR OF THE ESTATE OF JOE R. HICKS, DECEASED; NEW MEXICO MORTGAGE FINANCE AUTHORITY; BENEFICIAL NEW MEXICO INC. D/B/A BENEFICIAL MORTGAGE CO., Defendants . PLEASE TAKE NOTICE that the above-entitled Court, having appointed me or my designee as Special Master in this matter with the power to sell, has ordered me to sell the real property (the "Property") situated in Chaves County, New Mexico, commonly known as 714 Georgia, Roswell, NM 88203, and more particularly described as follows: LOTS 12, 13 AND 14 IN BLOCK 5 OF GILLILAND ACRES, A SUBDIVISION IN THE COUNTY OF CHAVES AND STATE OF NEW MEXICO, AS SHOWN ON THE OFFICIAL PLAT FILED IN THE CHAVES COUNTY CLERK'S OFFICE ON JANUARY 29, 1951 AND RECORDED IN BOOK B OF PLAT RECORDS, AT PAGE 145. Including a 1999 Southern energy CC2870C mobile home, with VIN DSETX05583AB If there is a conflict between the legal description and the street address, the legal description shall control. The sale is to begin at 9:00 AM on August 27, 2026 outside the main entrance of the Chaves County Courthouse, 400 North Virginia, City of Roswell, County of Chaves, State of New Mexico, at which time I will sell to the highest and best bidder for cash, in lawful currency of the United States of America, the Property to pay expenses of sale, and to satisfy the foreclosure Judgment granted on June 10, 2026 in the total amount of $31,453.30 with interest at the rate of 7.32% per annum from January 9, 2026 through the date of the sale. The sale is subject to the entry of an Order by this Court approving the sale. NOTICE IS FURTHER GIVEN that the real property and improvements concerned with herein will be sold subject to any and all patent reservations, easements, and all taxes and utility liens, special assessments and taxes that may be due. U.S. Bank Trust National Association, Not In Its Individual Capacity But Solely As Owner Trustee For RCAF Acquisition Trust, its attorneys, and the undersigned Special Master, disclaim all responsibility for, and the purchaser at the sale takes the property "as is," in its present condition, subject to the valuation of the property by the County Assessor as real or personal property, affixture of any mobile or manufactured home to the land, deactivation of title to a mobile or manufactured home on the property, if any, environmental contamination on the property, if any, and zoning violations concerning the property, if any. NOTICE IS FURTHER GIVEN that the purchaser at such sale shall take title to the above described real property subject to a one (1) month right of redemption. PROSPECTIVE PURCHASERS AT SALE ARE ADVISED TO MAKE THEIR OWN EXAMINATION OF THE TITLE AND THE CONDITION OF THE PROPERTY AND TO CONSULT THEIR OWN ATTORNEY BEFORE BIDDING. By: Robert Doyle c/o Legal Process Network P.O. Box 279 Sandia Park, NM 87047 1 NM-23-953600-JUD IDSPub #0315560 6/25/2026 7/2/2026 7/9/2026 7/16/2026

Notice of Meeting...

Publish June 25, 2026

LEGAL NOTICE
EASTERN NEW MEXICO UNIVERSITY
BOARD OF REGENTS
NOTICE OF MEETING
Friday, July 10, 2026 – 10:30 a.m.
Santa Ana Hotel and Casino – VIP Sportsbook Upperdeck Conference Room, Bernalillo, NM. The Eastern New Mexico University Board of Regents will hold its next regular meeting on Friday, July 10, 2026, at the Santa Ana Star Hotel and Casino – VIP Sportsbook Upperdeck Conference Room, Bernalillo, NM. Regents will act upon business so presented and may meet in executive session. The agenda is available 72 hours prior to the meeting and is accessible at the President's Office located in the ENMU-Portales campus Administration Building and on the ENMU website http://www.enmu.edu/about/board-meetings.shtml. The public is invited to attend the meeting. Eastern New Mexico University is an EEO/AA institution.

Notice of Meeting...

Publish June 25, 2026

The NMMI Governing Board of Regents will hold a meeting on Thursday, July 9th, 2026, at 10:00 AM, Lusk Hall, 2nd floor. The agenda with Zoom link will be posted in accordance to the Board Open Meetings Resolution, 72 hours prior to the meeting, here: https://www.nmmi.edu/about-nmmi/administration/board-of-regents/agenda/

AFFIDAVIT OF PUBLICATION
STATE OF NEW MEXICO

I, Noely L Martinez
Legals Clerk

Of the Roswell Daily Record, a daily newspaper published at Roswell, New Mexico, do solemnly swear that the clipping hereto attached was published in the regular and entire issue of said paper and not in a supplement thereof for a period of:

One time with the issue dated

June 25, 2026
Month Date Year

Clerk

Sworn and subscribed to before me

this July 7, 2026
Month Date Year

Notary Public

SARALEI FAJARDO
STATE OF NEW MEXICO
NOTARY PUBLIC
COMMISSION#
1086050
EXPIRES 4-27-2030

NMED Exhibit 14

LEGALS

to 20.1.6.204 NMAC. Public comment sessions will be reserved for 4:00 p.m. each day, until the close of the hearing record.

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NMED based the proposed rule on a variety of technical information, including NMED monitoring data , CWA Section 304(a) guidance documents, past CWA 303(d)/305(b) Integrated Lists/Integrated Reports, and fish surveys. The proposed rule may be reviewed during regular business hours at the NMED Surface Water Quality Bureau, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, at NMED Field Offices, or on NMED's web site at https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. For copies of the proposed rule, how to obtain technical information, or questions about participating in the hearing, please contact Michael Baca at (505) 470-1652 or michael.baca1@env.nm.gov or Pamela Jones at (505) 660-4305 or pamela.jones@env.nm.gov.

Persons requiring assistance, an interpreter, or any other form of auxiliary aid or service (i.e., reader, amplifier, qualified sign language interpreter, etc.) to attend or participate in the hearing should contact Pamela Jones no later than September 14, 2026 at (505) 660-4305 or pamela.jones@env.nm.gov.

NMED does not discriminate on the basis of race, color, national origin, disability, age or sex in the administration of its programs or activities, as required by applicable laws and regulations. NMED is responsible for coordination of compliance efforts and receipt of inquiries concerning non-discrimination requirements implemented by 40 C.F.R. Parts 5 and 7, including Title VI of the Civil Rights Act of 1964, as amended; Section 504 of the Rehabilitation Act of 1973; the Age Discrimination Act of 1975, Title IX of the Education Amendments of 1972, and Section 13 of the Federal Water Pollution Control Act Amendments of 1972. If you have any questions about this notice or any of NMED's non- discrimination programs, policies or procedures, you may contact: Kate Cardenas, NMED Non-Discrimination Coordinator, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 or nd.coordinator@env.nm.gov. If you believe that you have been discriminated against with respect to an NMED program or activity, please contact the Non-Discrimination Coordinator.

Aviso de Audiencia...

Publicado el 25 de junio de 2026

COMISIÓN DE CONTROL DE CALIDAD DEL AGUA DE NUEVO MÉXICO
AVISO DE AUDIENCIA PÚBLICA DE REGLAMENTACIÓN

La Comisión de Control de Calidad del Agua de Nuevo México (la Comisión) celebrará una audiencia pública la cual comenzará a las 9:00 a.m. del 28 de septiembre de 2026 y continuará hasta el 1 de octubre de 2026, según sea necesario. La Comisión podrá continuar la audiencia posteriormente con el fin de escuchar todos los testimonios, pruebas y comentarios públicos. La audiencia se llevará a cabo en el edificio del Capitolio del Estado, 490 Old Santa Fe Trail, Santa Fe, Nuevo México 87501. Además, habrá disponible una opción de participación virtual con enlaces a las reuniones e información publicados en el calendario de eventos en https://www.env.nm.gov/events-calendar. El propósito de la audiencia es considerar el asunto registrado en WQCC 25-75 (R) con el objetivo de enmendar 20.6.4 NMAC, Estándares de Aguas Superficiales Interestatales e Intraestatales. El peticionario de esta enmienda regulatoria propuesta es el Departamento de Medio Ambiente de Nuevo México (NMED, por sus siglas en inglés).

La Ley de Agua Limpia (CWA) federal exige que los estados evalúen los estándares de calidad del agua (WQS) existentes, consideren la información científica más reciente, brinden oportunidades de participación pública y modifiquen los WQS según sea necesario, cada tres años. Este proceso se conoce generalmente como Revisión Trienal y culmina con una audiencia pública. El NMED propuso enmiendas en este asunto con base en comentarios públicos sobre 20.6.4 NMAC, comunicado con la Agencia de Protección Ambiental (EPA, por sus siglas en inglés), documentos de orientación federales, datos de peces y monitoreo, así como los comentarios internos y preocupaciones sobre la implementación. Las enmiendas incluyen definiciones nuevas y revisadas, aclaración de los procedimientos y costos de la reglamentación de terceros, revisiones de las descripciones de los segmentos con el fin de que coincidan con las rupturas hidrológicas, los WQS correspondientes a los humedales, la aclaración del lenguaje de implementación, las referencias actualizadas, así como los usos designados, criterios y requisitos de anti-degradación nuevos o revisados.

La audiencia se llevará a cabo de acuerdo con la Ley de Calidad del Agua, Secciones 74-6-4 y 74-6-6 NMSA 1978, Ley de Reglas Estatales, Sección 14-4-5.3 NMSA 1978, 20.1.6 NMAC, Procedimientos de Reglamentación – Comisión de Control de Calidad del Agua, la Orden previa a la audiencia para WQCC 25-75 (R) y otros procedimientos y autoridades aplicables. La Comisión puede decidir sobre la norma propuesta al concluir la audiencia.

A todas las personas interesadas se les dará una oportunidad razonable durante la audiencia para presentar datos, puntos de vista o argumentos de forma oral o por escrito, y examinar a los testigos que testifiquen en la audiencia. Las personas que deseen presentar un testimonio técnico deben presentar una notificación de intención (NOI) por escrito ante la Comisión. La NOI deberá:

(1) identificar a la persona por quien los testigos testificarán;
(2) identificar cada testigo técnico que la persona pretende presentar y declarar las calificaciones de ese testigo, incluyendo una descripción de sus antecedentes educativos y laborales;
(3) incluir una copia del testimonio directo de cada testigo técnico en forma narrativa;
(4) incluir el texto de cualquier modificación recomendada al cambio regulatorio propuesto; y
(5) enumerar y adjuntar todas las pruebas que se prevé que ofrecerá esa persona en la audiencia, incluyendo cualquier declaración propuesta de motivos para la adopción de reglas.

Las anotaciones de comparecencia y las NOI para un testimonio directo deben ser recibidas por el Administrador de la Comisión a más tardar a las 5:00 p.m. el 30 de julio de 2026, y debe hacer referencia al número de expediente, WQCC 25-75 (R) y la fecha de la audiencia. Las notificaciones de intención que incluyan un testimonio técnico se archivarán de manera electrónica ante el Administrador de la Comisión en pamela.jones@env.nm.gov.

Las personas que deseen presentar un testimonio de refutación deberán presentar una NOI vía electrónica ante el Administrador de la Comisión a más tardar a las 5:00 p.m. el 28 de agosto de 2026. Las NOI de refutación deben incluir una narrativa del testimonio de refutación y los demás elementos requeridos de una NOI directa como se detalla en los puntos (1) a (5) anteriores.

Se entregará una copia impresa de todas las NOI para uso del funcionario de audiencias antes de las 12:00 p.m. el 25 de septiembre de 2026, a:

Pamela Jones, Administradora de la Comisión
Comisión de Control de Calida del Agua
P.O. Box 5469
Santa Fe, NM 87502

El funcionario de audiencias se ofrecerá una oportunidad para el público haga comentarios cada día de la audiencia se llevará a cabo de acuerdo con 20.1.6.204 NMAC. Se reserva las oportunidades de comentarios públicos a las 4:00 p.m. cada día hasta la conclusión de la audiencia.

Los miembros del público que deseen ofrecer comentarios públicos no técnicos podrán hacerlo solo una vez, ya sea en persona o en la plataforma virtual con acceso proporcionado y administrado por el Administrador. Los comentarios públicos orales se limitan a 3 minutos; Los comentarios públicos escritos presentados al Administrador son ilimitados y deben recibirse antes del aplazamiento de la audiencia. Los comentarios públicos escritos podrán presentarse por vía electrónica o como un documento original único. Favor de enviar sus comentarios electrónicos por escrito sobre la norma propuesta antes del aplazamiento de la audiencia a través del Portal de Comentarios Inteligentes en https://nmed.commentinput.com/comment/search o envíe un correo electrónico a pamela.jones@env.nm.gov con referencia a WQCC 25-75 (R).

El NMED utilizó una variedad de información técnica con el objetivo de respaldar la norma propuesta, incluyendo datos de monitoreo del NMED, documentos de orientación de la Sección 304(a) de CWA, listas integradas/informes integrados de CWA 303(d)/305(b) anteriores y estudios de peces. La norma propuesta puede revisarse durante el horario laboral habitual en la Oficina de Calidad del Agua Superficial del NMED, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, en los oficinas exteriores del NMED, o en el sitio web del NMED en https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. Si desea obtener copias de la norma propuesta, información técnicos, o preguntas acerca de la participación en la audiencia, comuníquese con Michael Baca al (505) 470-1652 o michael.baca1@env.nm.gov o Pamela Jones al (505) 660-4305 o pamela.jones@env.nm.gov.

Los individuos que requieran asistencia, un intérprete o cualquier otra forma de ayuda o servicio auxiliar (es decir, un lector, amplificador, intérprete de lenguaje de señas calificado, etc.) para poder asistir o participar en la audiencia deben comunicarse con Pamela Jones a más tardar el 14 de septiembre de 2026 al (505) 660-4305 o pamela.jones@env.nm.gov.

El NMED no discrimina por motivos de raza, color, origen nacional, discapacidad, edad o sexo en la administración de sus programas o actividades, según lo requerido por las leyes y regulaciones aplicables. El NMED es responsable de coordinar los esfuerzos de cumplimiento y recibir consultas relacionadas con los requisitos de no discriminación implementados por 40 C.F.R. Partes 5 y 7, incluyendo el Título VI de la Ley de Derechos Civiles de 1964, tal como estuviere modificada; Sección 504 de la Ley de Rehabilitación de 1973; la Ley de Discriminación por Edad de 1975, el Título IX de las Enmiendas a la Educación de 1972 y la Sección 13 de las Enmiendas a la Ley Federal de Control de la Contaminación del Agua de 1972. Si tiene alguna pregunta sobre este aviso o cualquiera de los programas, políticas o procedimientos de no discriminación del NMED, puede comunicarse con: Kate Cardenas, Coordinadora de No Discriminación del NMED, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 o nd.coordinator@env.nm.gov. Si cree que ha sido discriminado con respecto a un programa o actividad del NMED, comuníquese con la Coordinadora de No Discriminación.

Notice to Creditors...

Publish June 18, 25, July 2, 2026

STATE OF NEW MEXICO
COUNTY OF CHAVES
FIFTH JUDICIAL DISTRICT COURT

IN THE MATTER OF THE ESTATE
OF BARBARA J. WITT,
Deceased.

D-504-PB-2026-00015
Honorable James M. Hudson

NOTICE TO CREDITORS

NOTICE IS HEREBY GIVEN that Woodson Wayne Witt, II has been appointed Personal Representative of this Estate. All persons having claims against this Estate are required to present their claims within four (4) months after the date of the first publication of this Notice to Creditors or sixty (60) days after the date of mailing or other delivery of this Notice to Creditors, whichever is later or the claims will be forever barred. Claims must be presented either to the Personal Representative or his attorneys, Kraft Law Finn, LLP (Richard L. Kraft) at P .0. Box 850, Roswell, NM 88202-0850 or filed with the District Court of Chaves County, 400 N. Virginia, Roswell, New Mexico 88201.

DATED this 12th of June, 2026.

RESPECTFULLY SUBMITTED:

KRAFT LAW, LLP.

By: /s/ Richard L. Kraft
Richard L. Kraft
P.O. Box 850
Roswell, NM 88202-0850
(575) 625-2000
(575) 625-2010 (facsimile)
Attorneys for Personal Representative

Notice for Creditors...

Publish June 18, 25, July 2, 2026

IN THE DISTRICT COURT
COUNTY OF CHAVES
STATE OF NEW MEXICO

IN THE MATTER OF THE)
ESTATE OF RANDOLPH CARLTON CROW)
deceased.)

No. D-504-PB-2026-00043

NOTICE TO CREDITORS

NOTICE IS HEREBY GIVEN that the undersigned has been appointed Personal Representative of the above-referenced estate. All persons having claims against the estate are required to present their claims within four months after the date of the first publication of this Notice, or the claims will be forever barred. Claims must be presented either to the undersigned Personal Representative, P.O. Box 265, Dexter, New Mexico 88230, or filed with the District Court.

/s/ Susan Shaw
Susan Shaw
Personal Representative of the Estate
of Randolph Carlton Crow, deceased
P.O. Box 265
Dexter, NM 88230

575 LAW GROUP, LLC

/s/ Grey Robinson
Grey Robinson
310 N. Canyon
Carlsbad, NM 88220
(575) 628-8248
(575) 628-0016 Fax
grey@575lawgroup.com

Invitation to Bid...

Publish June 18, 25, 2026

LEGAL NOTICE
INVITATION TO BID
ITB 2026-0803 – MILK PRODUCTS

Hagerman Municipal Schools is accepting sealed bids for the delivery of milk products.

Bid documents may be obtained from the District website at www.bobcat.net or by contacting:

Raquel Morales, Chief Procurement Officer
Hagerman Municipal Schools
P.O. Drawer B
Hagerman, NM 88232
(575) 752-3254
rmorales@bobcat.net

Sealed bids will be received until **10:00 a.m. MDT** on **July 9, 2026**, at Hagerman Municipal Schools, 406 N. Cambridge Ave., Hagerman, NM 88232.

Bids must be clearly marked:

"ITB 2026-0803 – Milk Products"

Hagerman Municipal Schools reserves the right to reject any or all bids and waive minor technical irregularities.

Notice of Intent...

Publish June 25, 2026

CITY OF ROSWELL, NEW MEXICO
NOTICE OF INTENT TO ADOPT ORDINANCE

Notice is hereby given of the title and of a general summary of the subject matter contained in an Ordinance (the "Ordinance") to be considered for adoption by the City Council of the City of Roswell, New Mexico (the "City") at 6:00 p.m. on July 9, 2026 at the Chaves County Administrative Center, Commission Chambers, #1 St. Mary's Place, Roswell, New Mexico. Complete copies of the Ordinance are available for publis inspection during the normal and regular business hours of the City Clerk, City Hall, 425 North Richardson, Roswell, New Mexico.

The title of the Ordinance is:

AUTHORIZING THE EXECUTION AND DELIVERY OF A LOAN AGREEMENT BY AND BETWEEN THE CITY OF ROSWELL, NEW MEXICO (THE "GOVERNMENTAL UNIT") AND THE NEW MEXICO FINANCE AUTHORITY (THE "FINANCE AUTHORITY"), EVIDENCING A SPECIAL, LIMITED OBLIGATION OF THE GOVERNMENTAL UNIT TO PAY A PRINCIPAL AMOUNT NOT TO EXCEED $11,750,000, TOGETHER WITH INTEREST THEREON, FOR THE PURPOSE OF (1) REFINANCING, PAYING AND DISCHARGING THE GOVERNMENTAL UNIT'S OUTSTANDING JOINT WATER AND SEWER IMPROVEMENT REVENUE BONDS, SUBORDINATE SERIES 2017 ISSUED ON FEBRUARY 21, 2017, (2) FUNDING A LOAN AGREEMENT RESERVE ACCOUNT; AND (3) PAYING EXPENSES; PROVIDING FOR THE PAYMENT OF THE PRINCIPAL OF AND INTEREST ON THE LOAN AGREEMENT SOLELY FROM THE NET REVENUES FROM THE GOVERNMENTAL UNIT'S JOINT WATER AND SEWER UTILIITY SYSTEM; APPROVING THE DELEGATION OF AUTHORITY TO MAKE CERTAIN DETERMINATIONS REGARDING THE LOAN AGREEMENT PURSUANT TO THE SUPPLEMENTAL PUBLIC SECURITIES ACT; RATIFYING ACTIONS HERETOFORE TAKEN; APPROVING THE FORMS OF THE LOAN AGREEMENT AND OTHER DETAILS CONCERNING THE LOAN AGREEMENT; REPEALING ALL ACTION INCONSISTENT WITH THIS ORDINANCE; AND AUTHORIZING THE TAKING OF OTHER ACTIONS IN CONNECTION WITH THE EXECUTION AND DELIVERY OF THE LOAN AGREEMENT

A summary of the subject matter of this Ordinance is contained in its title. This notice constitutes compliance with Section 3-17-3, NMSA 1978.

Notice of Intent...

Publish June 25, 2026

CITY OF ROSWELL, NEW MEXICO
NOTICE OF INTENT TO ADOPT ORDINANCE

Notice is hereby given of the title and of a general summary of the subject matter contained in an Ordinance (the "Ordinance") to be considered for adoption by the City Council of the City of Roswell, New Mexico (the "City") at 6:00 p.m. on July 9, 2026 at the Chaves County Administrative Center, Commission Chambers, #1 St. Mary's Place, Roswell, New Mexico. Complete copies of the Ordinance are available for public inspection during the normal and regular business hours of the City Clerk, City Hall, 425 North Richardson, Roswell, New Mexico.

The title of the Ordinance is:

AUTHORIZING THE EXECUTION AND DELIVERY OF A LOAN AGREEMENT AND INTERCEPT AGREEMENT BY AND BETWEEN THE CITY OF ROSWELL, NEW MEXICO (THE "GOVERNMENTAL UNIT") AND THE NEW MEXICO FINANCE AUTHORITY, EVIDENCING A SPECIAL, LIMITED OBLIGATION OF THE GOVERNMENTAL UNIT TO PAY A PRINCIPAL AMOUNT NOT TO EXCEED $25,100,000, TOGETHER WITH INTEREST THEREON, FOR THE PURPOSE OF DEFRAYING THE COST TO (I) acquire, construct, purchase, equip, furnish, make additions to, renovate, rehabilitate, beautify, or otherwise improve THE CITY'S flood recovery projects, (II) FUND A LOAN AGREEMENT RESERVE ACCOUNT, AND (III) PAY EXPENSES; PROVIDING FOR THE PLEDGE AND PAYMENT OF THE PRINCIPAL AND INTEREST DUE UNDER THE LOAN AGREEMENT SOLELY FROM THE REVENUES OF THE 0.375% MUNICIPAL FLOOD RECOVERY GROSS RECEIPTS TAX IMPOSED PURSUANT TO A GOVERNMENTAL UNIT ORDINANCE, AND SECTION 7-19(D)-19, NMSA 1978, AS AMENDED; APPROVING THE DELEGATION OF AUTHORITY TO MAKE CERTAIN DETERMINATIONS REGARDING THE LOAN AGREEMENT PURSUANT TO THE SUPPLEMENTAL PUBLIC SECURITIES ACT; PROVIDING FOR THE DISTRIBUTION OF MUNICIPAL FLOOD RECOVERY GROSS RECEIPTS TAX REVENUES TO BE REDIRECTED BY THE STATE TAXATION AND REVENUE DEPARTMENT TO THE NEW MEXICO FINANCE AUTHORITY OR ITS ASSIGNS FOR THE PAYMENT OF PRINCIPAL AND INTEREST DUE ON THE LOAN AGREEMENT PURSUANT TO AN INTERCEPT AGREEMENT; APPROVING THE FORM AND TERMS OF, AND OTHER DETAILS CONCERNING THE LOAN AGREEMENT AND INTERCEPT AGREEMENT; RATIFYING ACTIONS HERETOFORE TAKEN; REPEALING ALL ACTION INCONSISTENT WITH THIS ORDINANCE; AND AUTHORIZING THE TAKING OF OTHER ACTIONS IN CONNECTION WITH THE EXECUTION AND DELIVERY OF THE LOAN AGREEMENT AND INTERCEPT AGREEMENT

A summary of the subject matter of this Ordinance is contained in its title. This notice constitutes compliance with Section 3-17-3, NMSA 1978.

Foreclosure Sale...

Publish June 25, July 2, 9, 16, 2026

NOTICE OF FORECLOSURE SALE STATE OF NEW MEXICO COUNTY OF CHAVES FIFTH JUDICIAL DISTRICT U.S. BANK TRUST NATIONAL ASSOCIATION, NOT IN ITS INDIVIDUAL CAPACITY BUT SOLELY AS OWNER TRUSTEE FOR RCAF ACQUISITION TRUST, Plaintiff, vs. Case No.: D-504-CV-2023-00541 VIRGINIA DURAN, KNOWN HEIR OF THE ESTATE OF JOE R. HICKS, DECEASED; UNKNOWN HEIRS, DEVISEES, AND LEGATEES OF THE ESTATE OF GEORGIA M. BASINGER, DECEASED; UNKNOWN HEIRS, DEVISEES, AND LEGATEES OF THE ESTATE OF JOE R. HICKS, DECEASED; ALMETRA STRANGE, KNOWN HEIR OF THE ESTATE OF JOE R. HICKS, DECEASED; PRESELL GILDER, KNOWN HEIR OF THE ESTATE OF JOE R. HICKS, DECEASED; ANGELA FLORES, KNOWN HEIR OF THE ESTATE OF JOE R. HICKS, DECEASED; ALICE HICKS, KNOWN HEIR OF THE ESTATE OF JOE R. HICKS, DECEASED; NEW MEXICO MORTGAGE FINANCE AUTHORITY; BENEFICIAL NEW MEXICO INC. D/B/A BENEFICIAL MORTGAGE CO., Defendants . PLEASE TAKE NOTICE that the above-entitled Court, having appointed me or my designee as Special Master in this matter with the power to sell, has ordered me to sell the real property (the "Property") situated in Chaves County, New Mexico, commonly known as 714 Georgia, Roswell, NM 88203, and more particularly described as follows: LOTS 12, 13 AND 14 IN BLOCK 5 OF GILLILAND ACRES, A SUBDIVISION IN THE COUNTY OF CHAVES AND STATE OF NEW MEXICO, AS SHOWN ON THE OFFICIAL PLAT FILED IN THE CHAVES COUNTY CLERK'S OFFICE ON JANUARY 29, 1951 AND RECORDED IN BOOK B OF PLAT RECORDS, AT PAGE 145. Including a 1999 Southern energy CC2870C mobile home, with VIN DSETX05583AB If there is a conflict between the legal description and the street address, the legal description shall control. The sale is to begin at 9:00 AM on August 27, 2026 outside the main entrance of the Chaves County Courthouse, 400 North Virginia, City of Roswell, County of Chaves, State of New Mexico, at which time I will sell to the highest and best bidder for cash, in lawful currency of the United States of America, the Property to pay expenses of sale, and to satisfy the foreclosure Judgment granted on June 10, 2026 in the total amount of $31,453.30 with interest at the rate of 7.32% per annum from January 9, 2026 through the date of the sale. The sale is subject to the entry of an Order by this Court approving the sale. NOTICE IS FURTHER GIVEN that the real property and improvements concerned with herein will be sold subject to any and all patent reservations, easements, and all taxes and utility liens, special assessments and taxes that may be due. U.S. Bank Trust National Association, Not In Its Individual Capacity But Solely As Owner Trustee For RCAF Acquisition Trust, its attorneys, and the undersigned Special Master, disclaim all responsibility for, and the purchaser at the sale takes the property "as is," in its present condition, subject to the valuation of the property by the County Assessor as real or personal property, affixture of any mobile or manufactured home to the land, deactivation of title to a mobile or manufactured home on the property, if any, environmental contamination on the property, if any, and zoning violations concerning the property, if any. NOTICE IS FURTHER GIVEN that the purchaser at such sale shall take title to the above described real property subject to a one (1) month right of redemption. PROSPECTIVE PURCHASERS AT SALE ARE ADVISED TO MAKE THEIR OWN EXAMINATION OF THE TITLE AND THE CONDITION OF THE PROPERTY AND TO CONSULT THEIR OWN ATTORNEY BEFORE BIDDING. By: Robert Doyle c/o Legal Process Network P.O. Box 279 Sandia Park, NM 87047 1 NM-23-953600-JUD IDSPub #0315560 6/25/2026 7/2/2026 7/9/2026 7/16/2026

Notice of Meeting...

Publish June 25, 2026

LEGAL NOTICE
EASTERN NEW MEXICO UNIVERSITY
BOARD OF REGENTS
NOTICE OF MEETING
Friday, July 10, 2026 – 10:30 a.m.
Santa Ana Hotel and Casino – VIP Sportsbook Upperdeck Conference Room, Bernalillo, NM. The Eastern New Mexico University Board of Regents will hold its next regular meeting on Friday, July 10, 2026, at the Santa Ana Star Hotel and Casino – VIP Sportsbook Upperdeck Conference Room, Bernalillo, NM. Regents will act upon business so presented and may meet in executive session. The agenda is available 72 hours prior to the meeting and is accessible at the President's Office located in the ENMU-Portales campus Administration Building and on the ENMU website http://www.enmu.edu/about/board-meetings.shtml. The public is invited to attend the meeting. Eastern New Mexico University is an EEO/AA institution.

Notice of Meeting...

Publish June 25, 2026

The NMMI Governing Board of Regents will hold a meeting on Thursday, July 9th, 2026, at 10:00 AM, Lusk Hall, 2nd floor. The agenda with Zoom link will be posted in accordance to the Board Open Meetings Resolution, 72 hours prior to the meeting, here: https://www.nmmi.edu/about-nmmi/administration/board-of-regents/agenda/

SILVER CITY DAILY PRESS AND INDEPENDENT

THE SILVER CITY INDEPENDENT PUBLISHING COMPANY, LLC

300 West Market Street • P.O. Box 1371 • Silver City, New Mexico 88062-1371
(575) 388-1576 • fax (575) 388-1196 • www.scdailypress.com

INVOICE FOR PUBLICATION OF LEGAL NOTICE

NM Environment Dept

Date:	Description:	PO#	Lines:	Price/Line:	Total:
6/23/26	Public Hearing (spn)		301	$0.68	$204.68
	9/28/2025			$0.52	$0.00
				$0.52	$0.00
				$0.52	$0.00
				$0.52	$0.00
				$0.52	$0.00
				$0.52	$0.00
					$204.68
				Tax:	$16.60
				Grand Total:	$221.28

Please include copy of invoice with payment to ensure proper credit.

Affidavit of Publication

STATE OF NEW MEXICO) S S

COUNTY OF GRANT

Nickolas C. Seibel, being first duly sworn, on his oath says: That he is the publisher of the Silver City Daily Press and Independent, a newspaper published in the Town of Silver City, in the County of Grant and the State of New Mexico, and that said newspaper is now, and was at all times herein mentioned, a newspaper of general circulation.

That the advertisement, copy of which is hereto attached, was published in said hereinbefore mentioned newspaper once each and every week for 1 consecutive week(s), the first publication thereof having been made on 6/23/2026 and the last publication thereof having been made on 6/23/2026. That said newspaper was regularly printed, published and issued with said notice herein upon the following dates, to wit::

6/23/26	

Nickolas C. Seibel

Subscribed and sworn to before me on this 30th day of June, 2026

Notary

MELANIE KAE ROGERS
Notary Public - State of New Mexico
Commission # 1073686
My Comm. Expires Aug 2, 2026



Legal

NEW MEXICO WATER QUALITY CONTROL COMMISSION NOTICE OF PUBLIC RULEMAKING HEARING

The New Mexico Water Quality Control Commission (Commission) will hold a public hearing beginning at 9:00 a.m. on September 28, 2026, and continuing through October 1, 2026, as necessary. The Commission may continue the hearing thereafter to hear all testimony, evidence, and public comments. The hearing will be held at the State Capitol Building, 490 Old Santa Fe Trail, Santa Fe, New Mexico 87501. Additionally, a virtual participation option will be provided with meeting links and details posted on the events calen-

NMED Exhibit 14

SILVER CITY DAILY PRESS AND INDEPENDENT

THE SILVER CITY INDEPENDENT PUBLISHING COMPANY, LLC

300 West Market Street • P.O. Box 1371 • Silver City, New Mexico 88062-1371
(575) 388-1576 • fax (575) 388-1196 • www.scdailypress.com

INVOICE FOR PUBLICATION OF LEGAL NOTICE

NM Environment Dept

Date:	Description:	PO#	Lines:	Price/Line:	Total:
6/23/26	Public Hearing (eng)		261	$0.68	$177.48
	9/28/2025			$0.52	$0.00
				$0.52	$0.00
				$0.52	$0.00
				$0.52	$0.00
				$0.52	$0.00
				$0.52	$0.00
					$177.48
				Tax:	$14.40
				Grand Total:	$191.88

Please include copy of invoice with payment to ensure proper credit.

Affidavit of Publication

STATE OF NEW MEXICO) S S

COUNTY OF GRANT

Nickolas C. Seibel, being first duly sworn, on his oath says: That he is the publisher of the Silver City Daily Press and Independent, a newspaper published in the Town of Silver City, in the County of Grant and the State of New Mexico, and that said newspaper is now, and was at all times herein mentioned, a newspaper of general circulation.

That the advertisement, copy of which is hereto attached, was published in said hereinbefore mentioned newspaper once each and every week for 1 consecutive week(s), the first publication thereof having been made on 6/23/2026 and the last publication thereof having been made on 6/23/2026. That said newspaper was regularly printed, published and issued with said notice herein upon the following dates, to wit::

6/23/26	

Nickolas C. Seibel

Subscribed and sworn to before me on this 30th day of June, 2026.

Melanie Kae Rogers
Notary

MELANIE KAE ROGERS
Notary Public - State of New Mexico
Commission # 1073686
My Comm. Expires Aug 2, 2026

Legal

COMISIÓN DE CONTROL DE CALIDAD DEL AGUA DE NUEVO MÉXICO AVISO DE AUDIENCIA PÚBLICA DE REGLAMENTACIÓN

La Comisión de Control de Calidad del Agua de Nuevo México (la Comisión) celebrará una audiencia pública la cual comenzará a las 9:00 a.m. del 28 de septiembre de 2026 y continuará hasta el 1 de octubre de 2026, según sea necesario. La Comisión podrá continuar la audiencia posteriormente con el fin de escuchar todos los testimonios,

NMED Exhibit 14

NEW MEXICO WATER QUALITY CONTROL COMMISSION
NOTICE OF PUBLIC RULEMAKING HEARING

The New Mexico Water Quality Control Commission (Commission) will hold a public hearing beginning at 9:00 a.m. on September 28, 2026, and continuing through October 1, 2026, as necessary. The Commission may continue the hearing thereafter to hear all testimony, evidence, and public comments. The hearing will be held at the State Capitol Building, 490 Old Santa Fe Trail, Santa Fe, New Mexico 87501. Additionally, a virtual participation option will be provided with meeting links and details posted on the events calendar at https://www.env.nm.gov/events-calendar. The purpose of the hearing is to consider the docketed matter of WQCC 25-75 (R) to amend 20.6.4 NMAC, *Standards for Interstate and Intrastate Surface Waters*. The petitioner for this proposed regulatory change is the New Mexico Environment Department (NMED).

The federal Clean Water Act (CWA) requires states to evaluate existing water quality standards (WQS), consider new scientific information, provide public participation opportunities, and amend WQS as necessary, every three years. This process is commonly referred to as the Triennial Review and culminates in a public hearing. NMED proposed amendments in this matter based on public comments on 20.6.4 NMAC, communication with the Environmental Protection Agency (EPA), federal guidance documents, monitoring and fish data, as well as internal comments and implementation concerns. The amendments include new and revised definitions, clarification of third-party rulemaking procedures and costs, revisions to segment descriptions to match hydrological breaks, WQS for wetlands, clarification of implementation language, updated references, as well as new or revised designated uses, criteria, and antidegradation requirements.

The hearing will be conducted in accordance with the Water Quality Act, Sections 74-6-4 and 74-6-6 NMSA 1978, the State Rules Act, Section 14-4-5.3 NMSA 1978, 20.1.6 NMAC (*Rulemaking Procedures – Water Quality Control Commission)*, the Pre-Hearing Order for WQCC 25-75 (R), and other applicable procedures and authorities. The Commission may make a decision on the proposed rule at the conclusion of the hearing.

All interested persons will be given reasonable opportunity at the hearing to submit data, views or arguments orally or in writing, and examine witnesses testifying at the hearing. Persons wishing to present technical testimony must file a written notice of intent (NOI) with the Commission. The NOI shall:

(1) identify the person for whom the witness(es) will testify;
(2) identify each technical witness the person intends to present and state the qualifications of that witness, including a description of their educational and work background;
(3) include a copy of the direct testimony of each technical witness in narrative form;
(4) include the text of any recommended modifications to the proposed regulatory change; and
(5) list and attach all exhibits anticipated to be offered by that person at the hearing, including any proposed statement of reasons for adoption of rules.

Entries of appearance and NOIs for direct testimony must be filed with the Commission Administrator no later than 5:00 p.m. on July 30, 2026, and should reference the docket number, WQCC 25-75 (R), and the date of the hearing. Notices of intent to present technical testimony shall be filed electronically with the Commission Administrator at pamela.jones@env.nm.gov.

Persons wishing to present rebuttal testimony, shall file an NOI electronically with the Commission Administrator no later than 5:00 p.m. on August 28, 2026. Rebuttal NOIs should include a narrative of rebuttal testimony and the other required elements of a direct NOI, as detailed in items (1) – (5) above.

One paper copy of all NOIs for the Hearing Officer's use shall be delivered by 12:00 p.m. (noon) on September 25, 2026, to:

Pamela Jones, Commission Administrator
Water Quality Control Commission
P.O. Box 5469
Santa Fe, NM 87502

The Hearing Officer will provide an opportunity for non-technical public comment each day of the hearing in a manner that accommodates the public pursuant to 20.1.6.204 NMAC. Public comment sessions will be reserved for 4:00 p.m. each day, until the close of the hearing record.

Members of the public wishing to offer non-technical public comment may do so only once either in person or on the virtual platform with access provided and managed by the Administrator. Oral public comment is limited to 3 minutes; written public comment submitted to the Administrator is unlimited and must be received prior to adjournment of the hearing. Written public comments may be submitted electronically or as a single original document to the Administrator at the above address. Please submit electronic written comments regarding the proposed rule prior to adjournment of the hearing via the Smart Comment Portal at https://nmed.commentinput.com/comment/search or through email to pamela.jones@env.nm.gov with reference to WQCC 25-75 (R).

NMED based the proposed rule on a variety of technical information, including NMED monitoring data , CWA Section 304(a) guidance documents, past CWA 303(d)/305(b) Integrated Lists/Integrated Reports, and fish surveys. The proposed rule may be reviewed during regular business hours at the NMED Surface Water Quality Bureau, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, at NMED Field Offices, or on NMED's web site at https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. For copies of the proposed rule, how to obtain technical information, or questions about participating in the hearing, please contact Michael Baca at (505) 470-1652 or michael.baca1@env.nm.gov or Pamela Jones at (505) 660-4305 or pamela.jones@env.nm.gov.

Persons requiring assistance, an interpreter, or any other form of auxiliary aid or service (i.e., reader, amplifier, qualified sign language interpreter, etc.) to attend or participate in the hearing should contact Pamela Jones no later than September 14, 2026 at (505) 660-4305 or pamela.jones@env.nm.gov.

NMED does not discriminate on the basis of race, color, national origin, disability, age or sex in the administration of its programs or activities, as required by applicable laws and regulations. NMED is responsible for coordination of compliance efforts and receipt of inquiries concerning non-discrimination requirements implemented by 40 C.F.R. Parts 5 and 7, including Title VI of the Civil Rights Act of 1964, as amended; Section 504 of the Rehabilitation Act of 1973; the Age Discrimination Act of 1975, Title IX of the Education Amendments of 1972, and Section 13 of the Federal Water Pollution Control Act Amendments of 1972. If you have any questions about this notice or any of NMED's non- discrimination programs, policies or procedures, you may contact: Kate Cardenas, NMED Non-Discrimination Coordinator, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 or nd.coordinator@env.nm.gov. If you believe that you have been discriminated against with respect to an NMED program or activity, please contact the Non-Discrimination Coordinator.

COMISIÓN DE CONTROL DE CALIDAD DEL AGUA DE NUEVO MÉXICO
AVISO DE AUDIENCIA PÚBLICA DE REGLAMENTACIÓN

La Comisión de Control de Calidad del Agua de Nuevo México (la Comisión) celebrará una audiencia pública la cual comenzará a las 9:00 a.m. del 28 de septiembre de 2026 y continuará hasta el 1 de octubre de 2026, según sea necesario. La Comisión podrá continuar la audiencia posteriormente con el fin de escuchar todos los testimonios, pruebas y comentarios públicos. La audiencia se llevará a cabo en el edificio del Capitolio del Estado, 490 Old Santa Fe Trail, Santa Fe, Nuevo México 87501. Además, habrá disponible una opción de participación virtual con enlaces a las reuniones e información publicados en el calendario de eventos en https://www.env.nm.gov/events-calendar. El propósito de la audiencia es considerar el asunto registrado en WQCC 25-75 (R) con el objetivo de enmendar 20.6.4 NMAC, *Estándares de Aguas Superficiales Interestatales e Intraestatales*. El peticionario de esta enmienda regulatoria propuesta es el Departamento de Medio Ambiente de Nuevo México (NMED, por sus siglas en inglés).

La Ley de Agua Limpia (CWA) federal exige que los estados evalúen los estándares de calidad del agua (WQS) existentes, consideren la información científica más reciente, brinden oportunidades de participación pública y modifiquen los WQS según sea necesario, cada tres años. Este proceso se conoce generalmente como Revisión Trienal y culmina con una audiencia pública. El NMED propuso enmiendas en este asunto con base en comentarios públicos sobre 20.6.4 NMAC, comunicado con la Agencia de Protección Ambiental (EPA, por sus siglas en inglés), documentos de orientación federales, datos de peces y monitoreo, así como los comentarios internos y preocupaciones sobre la implementación. Las enmiendas incluyen definiciones nuevas y revisadas, aclaración de los procedimientos y costos de la reglamentación de terceros, revisiones de las descripciones de los segmentos con el fin de que coincidan con las rupturas hidrológicas, los WQS correspondientes a los humedales, la aclaración del lenguaje de implementación, las referencias actualizadas, así como los usos designados, criterios y requisitos de anti-degradación nuevos o revisados.

La audiencia se llevará a cabo de acuerdo con la Ley de Calidad del Agua, Secciones 74-6-4 y 74-6-6 NMSA 1978, Ley de Reglas Estatales, Sección 14-4-5.3 NMSA 1978, 20.1.6 NMAC, *Procedimientos de Reglamentación – Comisión de Control de Calidad del Agua*, la Orden previa a la audiencia para WQCC 25-75 (R) y otros procedimientos y autoridades aplicables. La Comisión puede decidir sobre la norma propuesta al concluir la audiencia.

A todas las personas interesadas se les dará una oportunidad razonable durante la audiencia para presentar datos, puntos de vista o argumentos de forma oral o por escrito, y examinar a los testigos que testifiquen en la audiencia. Las personas que deseen presentar un testimonio técnico deben presentar una notificación de intención (NOI) por escrito ante la Comisión. La NOI deberá:

(1) identificar a la persona por quien los testigos testificarán;
(2) identificar cada testigo técnico que la persona pretende presentar y declarar las calificaciones de ese testigo, incluyendo una descripción de sus antecedentes educativos y laborales;
(3) incluir una copia del testimonio directo de cada testigo técnico en forma narrativa;
(4) incluir el texto de cualquier modificación recomendada al cambio regulatorio propuesto; y
(5) enumerar y adjuntar todas las pruebas que se prevé que ofrecerá esa persona en la audiencia, incluyendo cualquier declaración propuesta de motivos para la adopción de reglas.

Las anotaciones de comparecencia y las NOI para un testimonio directo deben ser recibidas por el Administrador de la Comisión a más tardar a las 5:00 p.m. el 30 de julio de 2026, y debe hacer referencia al número de expediente, WQCC 25-75 (R) y la fecha de la audiencia. Las notificaciones de intención que incluyan un testimonio técnico se archivarán de manera electrónica ante el Administrador de la Comisión en pamela.jones@env.nm.gov.

Las personas que deseen presentar un testimonio de refutación deberán presentar una NOI vía electrónica ante el Administrador de la Comisión a más tardar a las 5:00 p.m. el 28 de agosto de 2026. Las NOI de refutación deben incluir una narrativa del testimonio de refutación y los demás elementos requeridos de una NOI directa como se detalla en los puntos (1) a (5) anteriores.

Se entregará una copia impresa de todas las NOI para uso del funcionario de audiencias antes de las 12:00 p.m. el 25 de septiembre de 2026, a:

Pamela Jones, Administradora de la Comisión
Comisión de Control de Calida del Agua
P.O. Box 5469
Santa Fe, NM 87502

El funcionario de audiencias se ofrecerá una oportunidad para el público haga comentarios cada día de la audiencia se llevará a cabo de acuerdo con 20.1.6.204 NMAC. Se reserva las oportunidades de comentarios públicos a las 4:00 p.m. cada día hasta la conclusión de la audiencia.

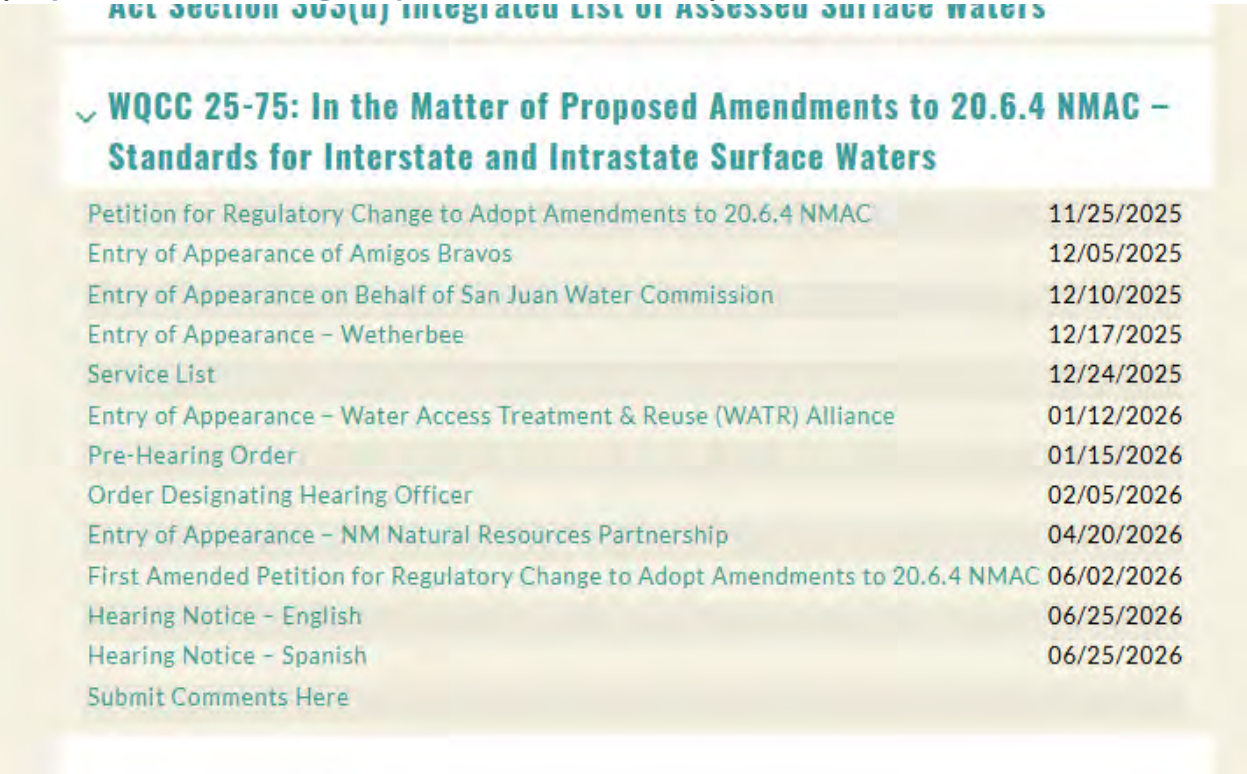
Los miembros del público que deseen ofrecer comentarios públicos no técnicos podrán hacerlo solo una vez, ya sea en persona o en la plataforma virtual con acceso proporcionado y administrado por el Administrador. Los comentarios públicos orales se limitan a 3 minutos; Los comentarios públicos escritos presentados al Administrador son ilimitados y deben recibirse antes del aplazamiento de la audiencia. Los comentarios públicos escritos podrán presentarse por vía electrónica o como un documento original único. Favor de enviar sus comentarios electrónicos por escrito sobre la norma propuesta antes del aplazamiento de la audiencia a través del Portal de Comentarios Inteligentes en https://nmed.commentinput.com/comment/search o envíe un correo electrónico a pamela.jones@env.nm.gov con referencia a WQCC 25-75 (R).

El NMED utilizó una variedad de información técnica con el objetivo de respaldar la norma propuesta, incluyendo datos de monitoreo del NMED, documentos de orientación de la Sección 304(a) de CWA, listas integradas/informes integrados de CWA 303(d)/305(b) anteriores y estudios de peces. La norma propuesta puede revisarse durante el horario laboral habitual en la Oficina de Calidad del Agua Superficial del NMED, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, en las oficinas exteriores del NMED, o en el sitio web del NMED en https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. Si desea obtener copias de la norma propuesta, información técnicos, o preguntas acerca de la participación en la audiencia, comuníquese con Michael Baca al (505) 470-1652 o michael.baca1@env.nm.gov o Pamela Jones al (505) 660-4305 o pamela.jones@env.nm.gov.

Los individuos que requieran asistencia, un intérprete o cualquier otra forma de ayuda o servicio auxiliar (es decir, un lector, amplificador, intérprete de lenguaje de señas calificado, etc.) para poder asistir o participar en la audiencia deben comunicarse con Pamela Jones a más tardar el 14 de septiembre de 2026 al (505) 660-4305 o pamela.jones@env.nm.gov.

El NMED no discrimina por motivos de raza, color, origen nacional, discapacidad, edad o sexo en la administración de sus programas o actividades, según lo requerido por las leyes y regulaciones aplicables. El NMED es responsable de coordinar los esfuerzos de cumplimiento y recibir consultas relacionadas con los requisitos de no discriminación implementados por 40 C.F.R. Partes 5 y 7, incluyendo el Título VI de la Ley de Derechos Civiles de 1964, tal como estuviere modificada; Sección 504 de la Ley de Rehabilitación de 1973; la Ley de Discriminación por Edad de 1975, el Título IX de las Enmiendas a la Educación de 1972 y la Sección 13 de las Enmiendas a la Ley Federal de Control de la Contaminación del Agua de 1972. Si tiene alguna pregunta sobre este aviso o cualquiera de los programas, políticas o procedimientos de no discriminación del NMED, puede comunicarse con: Kate Cardenas, Coordinadora de No Discriminación del NMED, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855 o nd.coordinator@env.nm.gov. Si cree que ha sido discriminado con respecto a un programa o actividad del NMED, comuníquese con la Coordinadora de No Discriminación.

Provide to the Public Notice of Rulemaking Hearing: Screen shots of the WQCC Docketed Matters Website accessed on June 25, 2026 (https://www.env.nm.gov/opf/docketed-matters/).



Act Section 303(d) Integrated List of Assessed Surface Waters

WQCC 25-75: In the Matter of Proposed Amendments to 20.6.4 NMAC – Standards for Interstate and Intrastate Surface Waters

Petition for Regulatory Change to Adopt Amendments to 20.6.4 NMAC	11/25/2025
Entry of Appearance of Amigos Bravos	12/05/2025
Entry of Appearance on Behalf of San Juan Water Commission	12/10/2025
Entry of Appearance – Wetherbee	12/17/2025
Service List	12/24/2025
Entry of Appearance – Water Access Treatment & Reuse (WATR) Alliance	01/12/2026
Pre-Hearing Order	01/15/2026
Order Designating Hearing Officer	02/05/2026
Entry of Appearance – NM Natural Resources Partnership	04/20/2026
First Amended Petition for Regulatory Change to Adopt Amendments to 20.6.4 NMAC	06/02/2026
Hearing Notice – English	06/25/2026
Hearing Notice – Spanish	06/25/2026
Submit Comments Here	

Provide to the Public Notice of Rulemaking Hearing: Screen shots of the NMED SWQB 2026 Trennial Review Website accessed on June 23, 2026 (https://www.env.nm.gov/surface-water-quality/2026-triennial-review/).



MENU

2026 Triennial Review

In accordance with Section 303(c)(1) of the Clean Water Act and 20.6.4.10 New Mexico Administrative Code, states are required to hold public hearings at least once every three years to review water quality standards, as applicable. This is referred to as a "Triennial Review. Pursuant to Section 74-6-4(F) of the State's Water Quality Act, the Water Quality Control Commission delegated the New Mexico Environment Department the responsibility for organizing and proposing amendments to the surface water quality standards, codified under 20.6.4 NMAC. The U.S. Environmental Protection Agency approved the 2020 Triennial Review on January 20, 2023.

NMED released a Public Review Draft for the 2026 Triennial Review and accepted comments on the standards and proposed amendments from August 15, 2025 – October 14, 2025. Additionally, SWQB held a virtual public meeting on September 10, 2025. After considering public comment, NMED petitioned the WQCC at their December 09, 2025 regular meeting. The WQCC granted the petition and appointed a hearing officer to preside over a rulemaking hearing from September 28 – October 1, 2026. The hearing officer issued a Pre-hearing Order on January 15, 2026 to govern the proceeding and set a schedule for participation.

Please see the table below for important documents, links to more information and resources, and a link to NMED's events calendar. You may also sign up for the SWQB's email listserv at: https://www.env.nm.gov/surface-water-quality and click on the "Subscribe to SWQB News" button on the bottom of the home page. SWQB will be updating this website throughout the process with rulemaking information and notifying listserv subscribers about public participation opportunities and rulemaking actions related to the Triennial Review. For additional information, contact Michael Baca, WQS Coordinator, at michael.baca1@env.nm.gov or (505) 470-1652.

Please visit the WQCC Docketed Matters webpage for the official rulemaking record including pre-hearing orders, technical testimony, and exhibits.

Document/Link	Author	Date
Frequently Used		
20.6.4 NMAC – Proposed Amendments	SWQB	06.02.26
NMED Events Calendar	SWQB	08.20.2025 11.26.2025
SmartComment Portal	SWQB	08.15.2025
Pre-hearing Engagement		

SmartComment Portal	SWQB	08.15.2025
Pre-hearing Engagement		
Public Review Draft of 20.6.4 NMAC, (Draft Amendments with basis of change)	SWQB	08.15.2025
Public Involvement Plan and Limited English Proficiency Analysis	SWQB	08.15.2025
Notice of Public Review Draft Comment Period and Informational Meetings English and Español	SWQB	08.15.2025
Informational Meeting Presentation Slides	SWQB	09.23.2025
Informational Meeting Recording	SWQB	09.23.2025
EPA Comment – Public Review Draft	SWQB	10.09.2025
Public Comments – Combined	SWQB	10.14.2025
Hearing and Rulemaking Information		
WQCC Docketed Matters	OPF	11.26.2025
Petition for Rulemaking Hearing	NMED	11.26.2025
Pre-hearing Order	OPF	1.15.2026
Amended Petition	SWQB	6.8.2026
Public Notice of Rulemaking – English and Español	NMED	TBD
Technical Information and Resources		
WQS: Regulations and Resources	EPA	3.15.2026
40 CFR Pt 131 – Water Quality Standards	CFR	3.9.2026
Water Quality Data	EPA	3.15.2026
WQS Handbook	EPA	3.15.2026
WQ Criteria	EPA	3.15.2026
Wetland WQS	EPA	3.15.2026
CWA 303(d)/305(b) Integrated Report	NMED	3.15.2026

Return to our Water Quality Standards webpage

Visit our WQS Amendments webpage for previous Triennial Review information.

Public Notice of Rulemaking Hearing posted on NMED's Public Notice Webpage accessed on June 23, 2026 (https://www.env.nm.gov/public-notices/).



NMED New Mexico Environment Department

HOME | ABOUT | LICENSES AND PERMITS | COMPLIANCE AND ENFORCEMENT | PFAS IN NM | FUNDING | ONLINE SER

Public Notices

This page lists public notices for rulemakings, permitting actions and any appeals of the action. Any rulemaking hearing or specific permitting or enforcement matter appealed to a board, commission or Environment Department Secretary is found on our Docketed Matters webpage once it is docketed.

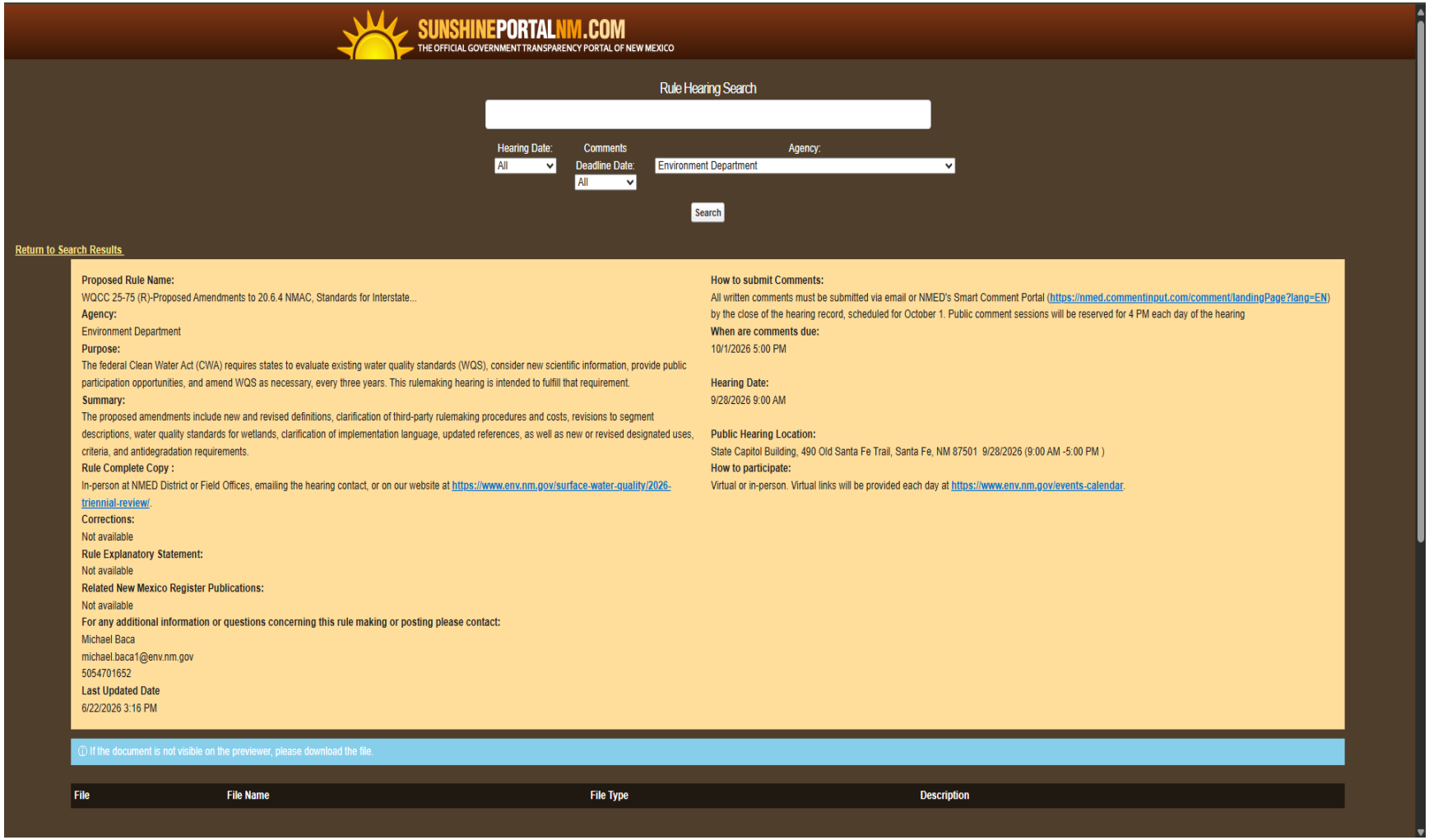
Page Search: Search Page

Statewide/Across Multiple Counties

WQCC 25-75 (R) – Public Notice of Rulemaking Hearing

- **Public Notice** – WQCC 25-75 (R) Rulemaking Hearing – **Triennial Review**
- **Public Notice Type:** Public hearing on proposed amendments to 20.6.4 NMAC – *Standards for Interstate and Intrastate Surface Waters*
- **Public Notice**
  - English
  - Spanish
- **Public Review Documents**
  - Surface Water Quality Bureau 2026 Triennial Review
  - SWQB Webpage about New Mexico Water Quality Standards (WQS)
- NMED Public Comment Portal
  Tutorial videos on how to use the Public Comment Portal are available in both English and Spanish.
- **Comment deadline:** Through the close of the hearing record.
- **Public Comment Contact:** Michael Baca, WQS Coordinator, (505) 470-1652 or michael.baca1@env.nm.gov or Pamela Jones, WQCC Administrator, (505) 660-4305 or pamela.jones@env.nm.gov
- Public Involvement Plan
- **Virtual Participation** – Visit NMED's Events Calendar for themeeting link for each day of the hearing.

Provide to the Public Notice of Rulemaking Hearing: Screen shot of the New Mexico Sunshine Portal accessed on June 23, 2026 (https://statenm.my.salesforce-sites.com/public/SSP_RuleHearingSearchPublic).



NMED Exhibit 15

From:	Baca, Michael, ENV
To:	Kesler, Michael, ENV; Vigil, Thomas X, ENV; Reyes, Damon, ENV
Cc:	Scott, Brecken, ENV; Nevarez, Marci, ENV; Clark-Barkalow, Stephani, ENV
Subject:	WQCC 25-75 (R) Triennial Review of Water Quality Standards, 20.6.4 NMAC
Date:	Monday, June 22, 2026 2:31:00 PM
Attachments:	Proposed 20.6.4 NMAC - 02Jun26.pdf NMED_2026_TR_hearing_notice.pdf ESP-NMED_2026_TR_hearing_notice.pdf

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Hello District Managers,

The Water Quality Control Commission is holding a Rulemaking Hearing for the Triennial Review of Water Quality Standards at 20.6.4 NMAC. We are "providing to the pubic" notice of the rulemaking through NMED's offices and need your help distributing the attached notices and proposed amendments. Please have staff post the notices in the district and field offices under your purview. The proposed rule should also be available for review if requested by the public. The material should be available through the end of the hearing, which is currently scheduled for October 1. Also, staff may direct the public to me or the Triennial Review website for more information or copies of materials.

Please let me know if you have any questions. As always, we appreciate EHB's assistance in this important matter.

Best,

Mike
Michael Baca | WQS Coordinator
NMED SWQB | www.env.nm.gov/surface-water-quality/
michael.baca1@env.nm.gov | (505) 470-1652

Science | Innovation | Collaboration | Compliance

From: New Mexico Environment Department
To: Baca, Michael, ENV
Subject: WQCC 25-75 (R) – Public Notice of Rulemaking Hearing
Date: Tuesday, June 23, 2026 10:04:37 AM

Surface Water Quality Bureau

SWQB logo

Our mission is to preserve, protect, and improve New Mexico's surface water quality for present and future generations.

Oficina de Calidad de Aguas Superficiales

Nuestra misión es preservar, proteger y mejorar la calidad de las aguas superficiales de Nuevo México para las generaciones presentes y futuras.

The New Mexico Water Quality Control Commission (Commission) will hold a public hearing beginning at 9:00 a.m. on September 28, 2026, and continuing through October 1, 2026, as necessary. The Commission may continue the hearing thereafter to hear all testimony, evidence, and public comments. The hearing will be held at the State Capitol Building, 490 Old Santa Fe Trail, Santa Fe, New Mexico 87501. Additionally, a virtual participation option will be provided with meeting links and details posted on the events calendar at https://www.env.nm.gov/events-calendar. The purpose of the hearing is to consider the docketed matter of WQCC 25-75 (R) to amend 20.6.4 NMAC, *Standards for Interstate and Intrastate Surface Waters*. The petitioner for this proposed regulatory change is the New Mexico Environment Department (NMED).

The federal Clean Water Act (CWA) requires states to evaluate existing water quality standards (WQS), consider new scientific information, provide public participation opportunities, and amend WQS as necessary, every three years. This process is commonly referred to as the Triennial Review and culminates in a public hearing. NMED proposed amendments in this matter based on public comments on 20.6.4 NMAC, communication with the Environmental Protection Agency (EPA), federal guidance documents, monitoring and fish data, as well as internal comments and implementation concerns. The amendments include new and revised definitions, clarification of third-party rulemaking procedures and costs, revisions to segment descriptions to match hydrological breaks, WQS for wetlands, clarification of implementation language, updated references, as well as new or revised designated uses, criteria, and antidegradation requirements. NMED based the proposed rule on a variety of technical information, including NMED monitoring data , CWA Section 304(a) guidance documents, past CWA 303(d)/305(b) Integrated Lists/Integrated Reports, and fish surveys.

All interested persons will be given reasonable opportunity at the hearing to submit data, views or arguments orally or in writing, and examine witnesses testifying at the hearing.

The Hearing Officer will provide an opportunity for non-technical public comment each day of the hearing in a manner that accommodates the public pursuant to 20.1.6.204 NMAC. Public comment sessions will be reserved for 4:00 p.m. each day, until the close of the hearing record.

Members of the public wishing to offer non-technical public comment may do so only once either in person or on the virtual platform with access provided and managed by the Administrator. Oral public comment is limited to 3 minutes; written public comment submitted to the Administrator is unlimited and must be received prior to adjournment of the hearing. Written public comments may be submitted electronically or as a single original document to the Administrator at the above address. Please submit electronic written comments regarding the proposed rule prior to adjournment of the hearing via the Smart Comment Portal at https://nmed.commentinput.com/comment/search or through email to pamela.jones@env.nm.gov with reference to WQCC 25-75 (R).

Persons wishing to present technical testimony must file a written notice of intent (NOI) with the Commission. Entries of Appearance and NOIs for direct testimony must be filed with the Commission Administrator no later than 5:00 p.m. on July 30, 2026. The entire public notice of rulemaking and the proposed rule may be reviewed during regular business hours at the NMED Surface Water Quality Bureau, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, at NMED Field Offices, or on NMED's web site at https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. For copies of the proposed rule, how to obtain technical information, or questions about participating in the hearing, please contact Michael Baca at (505) 470-1652 or michael.baca1@env.nm.gov or Pamela Jones at (505) 660-4305 or pamela.jones@env.nm.gov.

Persons requiring assistance, an interpreter, or any other form of auxiliary aid or service (i.e., reader, amplifier, qualified sign language interpreter, etc.) to attend or participate in the hearing should contact Pamela Jones no later than September 14, 2026 at (505) 660-4305 or pamela.jones@env.nm.gov.

NMED does not discriminate on the basis of race, color, national origin, disability, age or sex in the administration of its programs or activities, as required by applicable laws and regulations. NMED is responsible for coordination of compliance efforts and receipt of inquiries concerning non-discrimination requirements implemented by 40 C.F.R. Parts 5 and 7, including Title VI of the Civil Rights Act of 1964, as amended; Section 504 of the Rehabilitation Act of 1973; the Age Discrimination Act of 1975, Title IX of the Education Amendments of 1972, and Section 13 of the Federal Water Pollution Control Act Amendments of 1972. If you have any questions about this notice or any of NMED's non-discrimination programs, policies or procedures, you may contact:

Kate Cardenas, Non-Discrimination Coordinator
New Mexico Environment Department
1190 St. Francis Dr., Suite N4050
P.O. Box 5469
Santa Fe, NM 87502
(505) 827-2855
nd.coordinator@env.nm.gov
https://www.env.nm.gov/general/environmental-justice-in-new-mexico/

If you believe that you have been discriminated against with respect to a NMED program or activity, you may contact the Non-Discrimination Coordinator identified above.

La Comisión de Control de Calidad del Agua de Nuevo México (la Comisión) celebrará una audiencia pública la cual comenzará a las 9:00 a.m. del 28 de septiembre de 2026 y continuará hasta el 1 de octubre de 2026, según sea necesario. La Comisión podrá continuar la audiencia posteriormente con el fin de escuchar todos los testimonios, pruebas y comentarios públicos. La audiencia se llevará a cabo en el edificio del Capitolio del Estado, 490 Old Santa Fe Trail, Santa Fe, Nuevo México 87501. Además, habrá disponible una opción de participación virtual con enlaces a las reuniones e información publicados en el calendario de eventos en https://www.env.nm.gov/events-calendar. El propósito de la audiencia es considerar el asunto registrado en WQCC 25-75 (R) con el objetivo de enmendar 20.6.4 NMAC, *Estándares de Aguas Superficiales Interestatales e Intraestatales*. El peticionario de esta enmienda regulatoria propuesta es el Departamento de Medio Ambiente de Nuevo México (NMED, por sus siglas en inglés).

La Ley de Agua Limpia (CWA) federal exige que los estados evalúen los estándares de calidad del agua (WQS) existentes, consideren la información científica más reciente, brinden oportunidades de participación pública y modifiquen los WQS según sea necesario, cada tres años. Este proceso se conoce generalmente como Revisión Trienal y culmina con una audiencia pública. El NMED propuso enmiendas en este asunto con base en comentarios públicos sobre 20.6.4 NMAC, comunicado con la

Agencia de Protección Ambiental (EPA, por sus siglas en inglés), documentos de orientación federales, datos de peces y monitoreo, así como los comentarios internos y preocupaciones sobre la implementación. Las enmiendas incluyen definiciones nuevas y revisadas, aclaración de los procedimientos y costos de la reglamentación de terceros, revisiones de las descripciones de los segmentos con el fin de que coincidan con las rupturas hidrológicas, los WQS correspondientes a los humedales, la aclaración del lenguaje de implementación, las referencias actualizadas, así como los usos designados, criterios y requisitos de anti-degradación nuevos o revisados. El NMED utilizó una variedad de información técnica con el objetivo de respaldar la norma propuesta, incluyendo datos de monitoreo del NMED, documentos de orientación de la Sección 304(a) de CWA, listas integradas/informes integrados de CWA 303(d)/305(b) anteriores y estudios de peces.

A todas las personas interesadas se les dará una oportunidad razonable durante la audiencia para presentar datos, puntos de vista o argumentos de forma oral o por escrito, y examinar a los testigos que testifiquen en la audiencia.

El funcionario de audiencias se ofrecerá una oportunidad para el público haga comentarios cada día de la audiencia se llevará a cabo de acuerdo con 20.1.6.204 NMAC. Se reserva las oportunidades de comentarios públicos a las 4:00 p.m. cada día hasta la conclusión de la audiencia.

Los miembros del público que deseen ofrecer comentarios públicos no técnicos podrán hacerlo solo una vez, ya sea en persona o en la plataforma virtual con acceso proporcionado y administrado por el Administrador. Los comentarios públicos orales se limitan a 3 minutos; Los comentarios públicos escritos presentados al Administrador son ilimitados y deben recibirse antes del aplazamiento de la audiencia. Los comentarios públicos escritos podrán presentarse por vía electrónica o como un documento original único. Favor de enviar sus comentarios electrónicos por escrito sobre la norma propuesta antes del aplazamiento de la audiencia a través del Portal de Comentarios Inteligentes en https://nmed.commentinput.com/comment/search o envíe un correo electrónico a pamela.jones@env.nm.gov con referencia a WQCC 25-75 (R)

Las personas que deseen presentar un testimonio técnico deben presentar una notificación de intención (NOI) por escrito ante la Comisión. Las anotaciones de comparecencia y las NOI para un testimonio directo deben ser recibidas por el Administrador de la Comisión a más tardar a las 5:00 p.m. el 30 de julio de 2026. El aviso de audiencia pública completa y la norma propuesta puede revisarse durante el horario laboral habitual en la Oficina de Calidad del Agua Superficial del NMED, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, en las oficinas exteriores del NMED, o en el sitio web del NMED en https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. Si desea obtener copias de la norma propuesta, información técnicos, o preguntas acerca de la participación en la audiencia, comuníquese con Michael Baca al (505) 470-1652 o michael.baca1@env.nm.gov o Pamela Jones al (505) 660-4305 o pamela.jones@env.nm.gov.

Los individuos que requieran asistencia, un intérprete o cualquier otra forma de ayuda o servicio auxiliar (es decir, un lector, amplificador, intérprete de lenguaje de señas calificado, etc.) para poder asistir o participar en la audiencia deben comunicarse con Pamela Jones a más tardar el 14 de septiembre de 2026 al (505) 660-4305 o pamela.jones@env.nm.gov.

NMED no discrimina por motivos de raza, color, origen nacional, discapacidad, edad o sexo en la administración de sus programas o actividades, según lo exigen las leyes y regulaciones aplicables. NMED es responsable de la coordinación de los esfuerzos de cumplimiento y la recepción de consultas sobre los requisitos de no discriminación implementados por 40 C.F.R. Partes 5 y 7, incluido el Título VI de la Ley de Derechos Civiles de 1964, según enmendada; Sección 504 de la Ley de Rehabilitación de 1973; la Ley de Discriminación por Edad de 1975, el Título IX de las Enmiendas de Educación de 1972 y la Sección 13 de las Enmiendas de la Ley de Control de la Contaminación del Agua de 1972. Si tiene alguna pregunta sobre este aviso o alguno de los programas, políticas o procedimientos de no discriminación de NMED o si cree que ha sido discriminado con respecto a un

programa o actividad de NMED, puede comunicarse con:

Kate Cardenas, coordinadora de no discriminación, NMED
1190 St. Francis Dr.
Suite N4050, P.O. Box 5469
Santa Fe, NM 87502
teléfono (505) 827-2855
correo electrónico nd.coordinator@env.nm.gov

También puede visitar nuestro sitio web en https://www.env.nm.gov/general/environmental-justice-in-new-mexico/ para saber cómo y dónde presentar una queja de discriminación.

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From: New Mexico Environment Department
To: Baca, Michael, ENV
Subject: WQCC 25-75 (R) - Amend 20.6.4 NMAC, Standards for Interstate and Intrastate Surface Waters.
Date: Thursday, June 25, 2026 2:19:27 PM

Banner

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The New Mexico Water Quality Control Commission (Commission) will hold a public hearing beginning at 9:00 a.m. on September 28, 2026, and continuing through October 1, 2026, as necessary. The Commission may continue the hearing thereafter to hear all testimony, evidence, and public comments. The hearing will be held at the State Capitol Building, 490 Old Santa Fe Trail, Santa Fe, New Mexico 87501. Additionally, a virtual participation option will be provided with meeting links and details posted on the events calendar at https://www.env.nm.gov/events-calendar. The purpose of the hearing is to consider the docketed matter of WQCC 25-75 (R) to amend 20.6.4 NMAC, *Standards for Interstate and Intrastate Surface Waters*. The petitioner for this proposed regulatory change is the New Mexico Environment Department (NMED).

The federal Clean Water Act (CWA) requires states to evaluate existing water quality standards (WQS), consider new scientific information, provide public participation opportunities, and amend WQS as necessary, every three years. This process is commonly referred to as the Triennial Review and culminates in a public hearing. NMED proposed amendments in this matter based on public comments on 20.6.4 NMAC, communication with the Environmental Protection Agency (EPA), federal guidance documents, monitoring and fish data, as well as internal comments and implementation concerns. The amendments include new and revised definitions, clarification of third-party rulemaking procedures and costs, revisions to segment descriptions to match hydrological breaks, WQS for wetlands, clarification of implementation language, updated references, as well as new or revised designated uses, criteria, and antidegradation requirements. NMED based the proposed rule on a variety of technical information, including NMED monitoring data , CWA Section 304(a) guidance documents, past CWA 303(d)/305(b) Integrated Lists/Integrated Reports, and fish surveys.

All interested persons will be given reasonable opportunity at the hearing to submit data, views or arguments orally or in writing, and examine witnesses testifying at the hearing.

The Hearing Officer will provide an opportunity for non-technical public comment each day of the hearing in a manner that accommodates the public pursuant to 20.1.6.204 NMAC. Public comment sessions will be reserved for 4:00 p.m. each day, until the close of the hearing record.

Members of the public wishing to offer non-technical public comment may do so only once either in person or on the virtual platform with access provided and managed by the Administrator. Oral public comment is limited to 3 minutes; written public comment submitted to the Administrator is unlimited and must be received prior to adjournment of the hearing. Written public comments may be submitted electronically or as a single original document to the Administrator at the above address. Please submit electronic written comments regarding the proposed rule prior to adjournment of the hearing via the Smart Comment Portal at https://nmed.commentinput.com/comment/search or through email to pamela.jones@env.nm.gov with reference to WQCC 25-75 (R).

Persons wishing to present technical testimony must file a written notice of intent (NOI) with the Commission. Entries of Appearance

and NOIs for direct testimony must be filed with the Commission Administrator no later than 5:00 p.m. on July 30, 2026. The entire public notice of rulemaking and the proposed rule may be reviewed during regular business hours at the NMED Surface Water Quality Bureau, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, at NMED Field Offices, or on NMED's web site at https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. For copies of the proposed rule, how to obtain technical information, or questions about participating in the hearing, please contact Michael Baca at (505) 470-1652 or michael.baca1@env.nm.gov or Pamela Jones at (505) 660-4305 or pamela.jones@env.nm.gov.

Persons requiring assistance, an interpreter, or any other form of auxiliary aid or service (i.e., reader, amplifier, qualified sign language interpreter, etc.) to attend or participate in the hearing should contact Pamela Jones no later than September 14, 2026 at (505) 660-4305 or pamela.jones@env.nm.gov.

La Comisión de Control de Calidad del Agua de Nuevo México (la Comisión) celebrará una audiencia pública la cual comenzará a las 9:00 a.m. del 28 de septiembre de 2026 y continuará hasta el 1 de octubre de 2026, según sea necesario. La Comisión podrá continuar la audiencia posteriormente con el fin de escuchar todos los testimonios, pruebas y comentarios públicos. La audiencia se llevará a cabo en el edificio del Capitolio del Estado, 490 Old Santa Fe Trail, Santa Fe, Nuevo México 87501. Además, habrá disponible una opción de participación virtual con enlaces a las reuniones e información publicados en el calendario de eventos en https://www.env.nm.gov/events-calendar. El propósito de la audiencia es considerar el asunto registrado en WQCC 25-75 (R) con el objetivo de enmendar 20.6.4 NMAC, *Estándares de Aguas Superficiales Interestatales e Intraestatales.* El peticionario de esta enmienda regulatoria propuesta es el Departamento de Medio Ambiente de Nuevo México (NMED, por sus siglas en inglés).

La Ley de Agua Limpia (CWA) federal exige que los estados evalúen los estándares de calidad del agua (WQS) existentes, consideren la información científica más reciente, brinden oportunidades de participación pública y modifiquen los WQS según sea necesario, cada tres años. Este proceso se conoce generalmente como Revisión Trienal y culmina con una audiencia pública. El NMED propuso enmiendas en este asunto con base en comentarios públicos sobre 20.6.4 NMAC, comunicado con la Agencia de Protección Ambiental (EPA, por sus siglas en inglés), documentos de orientación federales, datos de peces y monitoreo, así como los comentarios internos y preocupaciones sobre la implementación. Las enmiendas incluyen definiciones nuevas y revisadas, aclaración de los procedimientos y costos de la reglamentación de terceros, revisiones de las descripciones de los segmentos con el fin de que coincidan con las rupturas hidrológicas, los WQS correspondientes a los humedales, la aclaración del lenguaje de implementación, las referencias actualizadas, así como los usos designados, criterios y requisitos de anti-degradación nuevos o revisados. El NMED utilizó una variedad de información técnica con el objetivo de respaldar la norma propuesta, incluyendo datos de monitoreo del NMED, documentos de orientación de la Sección 304(a) de CWA, listas integradas/informes integrados de CWA 303(d)/305(b) anteriores y estudios de peces.

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Las personas que deseen presentar un testimonio técnico deben presentar una notificación de intención (NOI) por escrito ante la Comisión. Las anotaciones de comparecencia y las NOI para un testimonio directo deben ser recibidas por el Administrador de la Comisión a más tardar a las 5:00 p.m. el 30 de julio de 2026. El aviso de audiencia pública completa y la norma propuesta puede revisarse durante el horario laboral habitual en la Oficina de Calidad del Agua Superficial del NMED, 1190 St. Frances Dr., Suite N2000, Santa Fe, NM 87505, en las oficinas exteriores del NMED, o en el sitio web del NMED en https://www.env.nm.gov/surface-water-quality/2026-triennial-review/. Si desea obtener copias de la norma propuesta, información técnicos, o preguntas acerca de la participación en la audiencia, comuníquese con Michael Baca al (505) 470-1652 o michael.baca1@env.nm.gov o Pamela Jones al (505) 660-4305 o pamela.jones@env.nm.gov.

Los individuos que requieran asistencia, un intérprete o cualquier otra forma de ayuda o servicio auxiliar (es decir, un lector, amplificador, intérprete de lenguaje de señas calificado, etc.) para poder asistir o participar en la audiencia deben comunicarse con Pamela Jones a más tardar el 14 de septiembre de 2026 al (505) 660-4305 o pamela.jones@env.nm.gov.

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From:	Baca, Michael, ENV
To:	Baca, Michael, ENV
Cc:	Clark-Barkalow, Stephani, ENV; Scott, Brecken, ENV
Bcc:	brittany.fallon@westernresources.org; serafina.seluja@gknet.com; michael.e.ketterer@gmail.com; Rachel Conn; cpaiz@sjwc.org; mharsh@lanl.gov; ewolf@americanrivers.org; beata@breathofmyheart.org; communitiesforcleanwater@gmail.com; jarends@nuclearactive.org; grip@gilaresources.info; carlosmatutes@greenlatinos.org; clara@nm-ipl.org; lamorena@lasacequias.org; tricia@nmwild.org; joankansas@swcp.com; camilla.feibelman@sierraclub.org; dan.roper@tu.org; fox@westernlaw.org; sholcomb@lanl.gov
Subject:	WQCC 25-75 (R) - Public Notice of Rulemaking Hearing: 2026 Triennial Review
Date:	Tuesday, June 23, 2026 3:24:00 PM
Attachments:	Proposed 20.6.4 NMAC - 02Jun26.pdf NMED_2026_TR_hearing_notice.pdf ESP-NMED_2026_TR_hearing_notice.pdf
Importance:	High

Good afternoon,

Thank you for providing comment on the Surface Water Quality Bureau's draft amendments to 20.6.4 NMAC for the 2026 Triennial Review (August 2025-Public Review Draft). We considered comments and at the end of last year, we successfully petitioned the Water Quality Control Commission (WQCC) for a rulemaking hearing that is scheduled to start at 9:00 am on September 28, 2026, at the State Capitol Building in Santa Fe. A virtual option will be available each day of the hearing with a link provided on NMED's events calendar.

After further consideration of comments, we filed an amended petition at the beginning of this month that included the current version of the proposed rule (attached). The WQCC is currently accepting written comment on the proposed rule through our Comment Portal or the Commission Administrator at pamela.jones@env.nm.gov. Oral public comment periods will be provided by the hearing officer at 4:00 p.m. each day of the hearing. Please keep in mind that all comments must be received by the WQCC before the adjournment of the hearing, which could occur earlier than the scheduled date of October 1. Finally, Entries of Appearance and NOIs are due to the Commission Administrator (pamela.jones@env.nm.gov) by July 30 at 5:00 p.m. Additional information and deadlines may apply, and full participation details should be consulted in the attached notices.

For more information about the rulemaking visit our 2026 Triennial Review webpage and the WQCC's Docketed Matters webpage. Please let me know if you have any questions or concerns regarding this hearing or if you would like to discuss any issues further.

Respectfully,

Michael Baca | WQS Coordinator

NMED SWQB | www.env.nm.gov/surface-water-quality/
michael.baca1@env.nm.gov | (505) 470-1652

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From:	Baca, Michael, ENV
To:	lcs@nmlegis.gov
Cc:	Scott, Brecken, ENV; Clark-Barkalow, Stephani, ENV
Subject:	WQCC 25-75 (R) - Public Notice of Rulemaking: Triennial Review of 20.6.4 NMAC
Date:	Tuesday, June 23, 2026 10:56:00 AM
Attachments:	Proposed 20.6.4 NMAC - 02Jun26.pdf NMED_2026_TR_hearing_notice.pdf
Importance:	High

Good morning,

In accordance with the State Rules Act, please see the attached notice of rulemaking hearing and proposed amendments to 20.6.4 NMAC, *Standards for Interstate and Intrastate Surface Waters*. The hearing is scheduled to start at 9:00 am on September 28, 2026 at the Capitol Building (virtual available). The Surface Water Quality Bureau of the New Mexico Environment Department proposed the amendments as part of the federally required Triennial Review of Water Quality Standards. The amendments were the result of early public comments on draft amendments, communication with the Environmental Protection Agency, federal guidance documents, as well as internal data, comments, and concerns with implementation of the standards. For more information about the rulemaking please visit our 2026 Triennial Review webpage.

Please let me know if you have any questions or concerns regarding this rulemaking hearing.

Respectfully,

Michael Baca | WQS Coordinator
NMED SWQB | www.env.nm.gov/surface-water-quality/
michael.baca1@env.nm.gov | (505) 470-1652

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From:	Baca, Michael, ENV
To:	Baca, Michael, ENV
Cc:	Clark-Barkalow, Stephani, ENV
Bcc:	fmartinez@poamail.org; jayson.romero@cochiti.org; clint.lente@isletapueblo.com; romona.montoya@isletapueblo.com; aduran@pojoaque.org; clarice.madalena@jemezpueblo.org; cltecube@yahoo.com; dinoc@santaclarapueblo.org; dmartinez@poamail.org; doug.mckenna@santaana-nsn.gov; environment@picurispueblo.org; ecruz@ydsp-nsn.gov; bvaldivieso@ydsp-nsn.gov; gjojola@pol-nsn.gov; gtortalita@ziapueblo.org; monte.scammahorn@fortsillapache-nsn.gov; kevin.montoya@kewa-nsn.us; larry.phillips; mvigil@taospueblo.com; Stout, Pinu"u; administrativeassistantppe@picurispueblo.org; rmartinez@sanipueblo.org; s.etsitty@navajo-nsn.gov; sagem@pueblooftesuque.org; kollin.homer@ashiwi.org; vatencio@nambepueblo.org; Woodrow "Cody" Crumbo; bmaxey@nambepueblo.org; floyd.toribio@ziapueblo.org
Subject:	2026 Triennial Review - Public Review Draft
Date:	Friday, August 15, 2025 11:54:00 AM
Attachments:	20.6.4 NMAC - 2026 TR Public Review Draft .pdf 2026 TR - Tribal Environmental Directors (Final).pdf
Importance:	High

Greetings Tribal Environmental Directors and Natural Resource Managers,

The New Mexico Environment Department (NMED) Surface Water Quality Bureau (SWQB) is initiating its Triennial Review of Water Quality Standards (WQS) at 20.6.4 NMAC. As required by the Clean Water Act every three years, the SWQB drafted amendments the WQS and we are holding a 60-day public comment period from August 15 – October 14, 2025. We plan on holding a public meeting regarding the Triennial Review on September 10, 2025 at 5:30 PM. The public meeting will be held virtually and may be accessed through this link: https://nmed-oit.webex.com/nmed-oit/j.php?MTID=mcef4d38bc6992f8d56094eb92a5cbe4d. Please see the attached letter, Public Review Draft, and our website (https://www.env.nm.gov/surface-water-quality/2026-triennial-review/) for more information.

The SWQB will consider all stakeholder feedback and comments and revise the draft amendments appropriately prior to petitioning for a rulemaking hearing. The SWQB plans on petitioning the Water Quality Control Commission in December 2025 for a summer/fall 2026 public rulemaking hearing.

Please note: *this action is separate from NMED SWQB efforts to develop a state permitting program*. If you have any questions or would like to schedule a meeting to discuss the Triennial Review, please do not hesitate to email or call. If you would like to stay informed regarding this or other SWQB actions or projects, please visit our website and subscribe to our email lists.

Respectfully,

Michael Baca | WQS Coordinator
NMED SWQB | www.env.nm.gov/surface-water-quality/
michael.baca1@env.nm.gov | (505) 470-1652

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From:	Baca, Michael, ENV
To:	Baca, Michael, ENV
Cc:	Clark-Barkalow, Stephani, ENV
Bcc:	"Woodrow "Cody" Crumbo"; "larry.phillips"; "earl.conway@cochiti.org"; "rmartinez@sanipueblo.org"; "fmartinez@poamail.org"; "ramona.montoya@isletapueblo.com"; "clarice.madalena@jemezpueblo.org"; "gjojola@pol-nsn.gov"; "bmaxey@nambepueblo.org"; "environment@picurispueblo.org"; "aduran@pojoaque.org"; Stout, Pinu"u; "gkaufman@sandiapueblo.nsn.us"; "doug.mckenna@santaana-nsn.gov"; "dinoc@santaclarapueblo.org"; "mvigil@taospueblo.com"; "sagem@puebllooftesuque.org"; "brad.knipper@ziapueblo.org"; "kollin.homer@ashiwi.org"; "cltecube@yahoo.com"; "jnelson@mescalerodrmp.org"; "s.etsitty@navajo-nsn.gov"; "ecruz@ydsp-nsn.gov"; "scott.sclow@utemountain.org"; "tbelone@enipc.org"
Subject:	WQCC 25-75 (R): Public Notice of Rulemaking - 2026 Triennial Review of 20.6.4 NMAC
Date:	Tuesday, June 23, 2026 12:17:00 PM
Attachments:	Proposed 20.6.4 NMAC - 02Jun26.pdf NMED_2026_TR_hearing_notice.pdf 2026 Triennial Review - Public Review Draft.msg
Importance:	High

Greetings Tribal Environmental Directors and Natural Resource Managers,

Please see the attached notice of rulemaking hearing and proposed amendments to 20.6.4 NMAC, *Standards for Interstate and Intrastate Surface Waters*. The Surface Water Quality Bureau of the New Mexico Environment Department proposed the amendments as part of the federally required Triennial Review of Water Quality Standards. The amendments were the result of early public comments on draft amendments and a public meeting (see attached email), communication with the Environmental Protection Agency, federal guidance documents, as well as internal data, comments, and concerns with implementation of the standards.

The hearing is scheduled to start at 9:00 am on September 28, 2026 at the State Capitol Building in Santa Fe, with a virtual option available. A virtual link will be provided on NMED's events calendar each day of the hearing, currently scheduled through October 1. For more information about the rulemaking, please visit our 2026 Triennial Review webpage or the Water Quality Control Commission's Docketed Matters webpage.

Please let me know if you have any questions or concerns regarding this rulemaking hearing or if you would like to discuss this further. Please Cc the NMED Tribal Liaison (carman.melendrez@env.nm.gov) when responding by email.

Respectfully,

Michael Baca | WQS Coordinator
NMED SWQB | www.env.nm.gov/surface-water-quality/
michael.baca1@env.nm.gov | (505) 470-1652

July 7, 2026

Via electronic mail

Small Business Regulatory Advisory Council
New Mexico Economic Development Department
Attn: Krystal Speedy
Executive Assistant to Cabinet Secretary Rob Black
1100 S. St. Francis Drive
Santa Fe, New Mexico 87505-4147
krystal.speedy@edd.nm.gov

Re: Notice of proposed amendments to 20.6.4 NMAC *Standards for Interstate and Intrastate Surface Waters*, Water Quality Control Commission Docketed Matter No. WQCC 25-75(R)

Dear Council Members,

The New Mexico Environment Department (NMED) has petitioned the Water Quality Control Commission (WQCC) proposing adoption of amendments to 20.6.4 NMAC, *Standards for Interstate and Intrastate Surface Waters*, as part of the Triennial Review as required by federal and state law. At its December 9, 2025 meeting, the WQCC granted a public hearing to hear NMED's proposal and docketed the matter as WQCC 25-75(R). NMED filed these proposed rule changes pursuant to Sections 74-6-4(R), 74-6-5, and 74-6-6 of the New Mexico Water Quality Act and 20.1.6.200 NMAC. NMED filed an amended petition with a revised proposed rule on June 2, 2026.

The federal Clean Water Act (CWA) requires states to evaluate existing water quality standards (WQS), consider new scientific information, provide public participation opportunities, and amend WQS as necessary, every three years. This process is commonly referred to as the Triennial Review and culminates in a public hearing. NMED proposed amendments in this matter based on early public comments on 20.6.4 NMAC, communication with the U.S. Environmental Protection Agency (EPA), federal guidance documents, monitoring and fish data, as well as internal comments and implementation concerns. The amendments include new and revised definitions, clarification of third-party rulemaking procedures and costs, revisions to segment descriptions to match hydrological breaks, WQS for wetlands, clarification of implementation language, updated references, as well as new or revised designated uses, criteria, and antidegradation requirements. NMED does not anticipate the proposed rules to have an adverse effect on small business, however, NMED has considered regulatory methods that accomplish the proposed rules' objectives while minimizing adverse effects on small business.

The public rulemaking hearing for this matter is scheduled for September 28 - October 1, 2026. The original petition, amended petition, proposed rules, pre-hearing order(s), entries of appearance, notices of intent to present testimony, public comments, and other related documents can be found on the WQCC Docketed matters webpage at: https://www.env.nm.gov/opf/docketed-matters/ under docketed matter

WQCC 25-75(R). The proposed rules and rulemaking timeline can also be found on a SWQB dedicated webpage at: https://www.env.nm.gov/surface-water-quality/2026-triennial-review/.

Pursuant to Section 14-4A-4 of the New Mexico Small Business Regulatory Relief Act, I have included a copy of the entire rule, including the proposed regulatory change to 20.6.4 NMAC attached to NMED's amended petition filed with the WQCC. Note that the WQCC may further amend this proposal as the rulemaking process moves forward and it considers adopting all parties proposed amendments and alternative regulatory language. Please let me know if SBRAC has any concerns or questions regarding the proposed rule change, or if they would like to have further discussions with NMED regarding the Surface Water Quality Bureau's 2026 Triennial Review.

Sincerely,

Brecken Scott

Digitally signed by Brecken Scott
Date: 2026.07.07 11:22:46 -06'00'

Brecken Scott
Assistant General Counsel

Enclosures

Office Of Water
Washington, DC 20460

800B24001
March 2024

Clean Water Act Financial Capability Assessment Guidance

March 2024 Revision*

*This document revises the version of the Clean Water Act Financial Capability Assessment Guidance published in February 2023 to make an editorial correction in Section III.d.5, second paragraph on page 41.

EPA United States Environmental Protection Agency

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I. Introduction

a. Background

The objective of the Clean Water Act (CWA) is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters."[1] Municipal discharges that violate the CWA can pose significant threats to public health and the environment. When a community is out of compliance with the CWA, the Agency's expectation is that the community will achieve compliance with the CWA as soon as practicable.[2] Financial capability is one of many factors EPA considers when evaluating schedules for implementation of long-term CWA control plans; the Agency also considers the need to expeditiously restore water quality in communities that may have suffered from years of CWA violations. The public health and environmental considerations that EPA assesses when developing CWA implementation schedules include environmental justice and mitigation of environmental and public health impacts in low-income and overburdened communities.

Communities, in consultation with regulators and the public, are responsible for evaluating and selecting pollution controls that will meet CWA requirements. EPA encourages communities to utilize integrated planning[3] and innovative technologies, such as green infrastructure,[4] to achieve CWA compliance in a timely, flexible, and cost-effective manner. After controls have been selected, a financial capability assessment (FCA) is used to aid in assessing a community's financial capability as a part of negotiating implementation schedules under both permits and enforcement agreements. Elements of the same methodology can also be used to understand the economic impacts of installing the pollution controls needed to meet CWA requirements to determine if a variance can be granted, if degradation of high-quality water is warranted, or, in some cases, if a designated use cannot be attained. The updated Financial Capability Assessment Guidance (FCA Guidance) is intended to: 1) standardize what EPA will generally consider when determining a community's financial capability to implement control measures needed to meet CWA requirements and 2) assist states and authorized tribes in assessing the degree of economic and social impact of potential water quality standards (WQS) decisions. It is not a methodology for defining water affordability.

The FCA Guidance sets forth two alternatives that communities can choose to employ to assess financial capability when negotiating compliance schedules. Alternative 1 considers metrics that measure the financial

[1] 33 U.S.C. § 1251.

[2] Compliance schedules included in NPDES permits must "require compliance as soon as possible, but not later than the applicable statutory deadline under the CWA." 40 C.F.R. § 122.47(a)(1). The CSO Control Policy requires that "each long-term CSO control plan . . . should [] include both fixed-date project implementation schedules (which may be phased) and a financing plan to design and construct the project as soon as practicable." 59 Fed. Reg. 18688, 18691 (April 19, 1994).

[3] For more information about integrated planning for municipal stormwater and wastewater, see https://www.epa.gov/npdes/integrated-planning-municipal-stormwater-and-wastewater.

[4] Section 502 of the CWA defines green infrastructure as "...the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters."

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impact of the current and proposed CWA controls on residential users, the financial capability of the community, and the lowest quintile income and poverty prevalence within the community's service area. Alternative 2 utilizes dynamic financial and rate models that evaluate the impacts of debt service on customer bills. Additional information such as a community's total water costs (i.e., costs for wastewater, stormwater, and drinking water infrastructure investment) may also be submitted and considered when negotiating the length of an implementation schedule for a community's CWA requirements.

Additionally, EPA recommends the application of the methodologies from Alternative 1 of the FCA Guidance for the consideration of economic impacts to public entities when making decisions on WQS variances and antidegradation reviews. In appropriate cases, these methodologies also inform decisions about revisions to designated uses, subject to additional analyses.

EPA is committed to working with state, tribal, local, and non-government partners to assist communities in meeting CWA requirements in a manner that recognizes unique local financial challenges. We strongly encourage additional subsidy or grant consideration from governmental funding sources for entities that are seeking extended schedules because of financial capability constraints. Federal funding initiatives and programs such as the Bipartisan Infrastructure Law (BIL), American Rescue Plan Act (ARPA), State Revolving Fund (SRF) loans, Water Infrastructure Finance and Innovation Act (WIFIA), and others provide billions of dollars for state, local, territorial, and tribal governments. The BIL has provided $11.7 billion in additional funds to the Clean Water State Revolving Fund (CWSRF). The state match requirement has been reduced to 10% for the first two years and 49% of the money will be provided as grants or principal forgiveness loans to communities. These resources create a historic opportunity for communities to address long-standing clean water needs.

EPA plans to work with communities to identify funding sources and financing strategies that can be used to reduce costs to complete necessary projects. In addition, state, local, and tribal governments' equitable support of communities with limited resources can help those communities meet the challenges of funding necessary water infrastructure improvements, especially where there are disadvantaged and lower income communities with environmental justice, compliance, enforcement, and other concerns. EPA's review of our SRFs and WIFIA, for example, indicate that disadvantaged community funding can substantially improve compliance and mitigate pollution by getting needed projects underway while maintaining affordable water service. EPA, in accordance with Executive Order 14008, is working towards a goal to direct 40 percent of the overall benefits of federal investments in the development of critical clean water infrastructure to disadvantaged communities.

EPA has a responsibility to ensure that recipients and subrecipients of federal financial assistance from EPA—including states, municipalities, and other public and private entities—comply with federal civil rights laws that prohibit discrimination on the basis of race, color, national origin (including limited English proficiency), disability, sex, and age,[5] including Title VI of the Civil Rights Act of 1964. Whenever a community receives

[5] Title VI of the Civil Rights Act of 1964, 42 U.S.C. §§ 2000(d) et seq. (Title VI); Section 504 of the Rehabilitation Act of 1973, as amended, 29 U.S.C., 29 U.S.C. § 794, Title IX of the Education Amendments of 1972, as amended, 20 U.S.C. §§ 1681 et seq.; Age Discrimination Act of 1975, 42 U.S.C. §§ 6101 et seq.; Federal Water Pollution Control Act Amendments of 1972, Pub. L. 92 500 § 13, 86 Stat. 903 (codified as amended at 33 U.S.C. § 1251 (1972)); 40 C.F.R. Parts 5 and 7.

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funding from EPA, including through the CWSRF and the Drinking Water State Revolving Fund, EPA intends to ensure compliance with civil rights laws by recipients of such funding. It is EPA's obligation to ensure no community is excluded from receiving or denied benefit of EPA funding based on race, color, national origin (including limited English proficiency), age, disability, or sex.[6]

b. History of Relevant Guidance

1. FCA Guidance and FCA Framework

EPA's 1997 *Combined Sewer Overflows – Guidance for Financial Capability Assessment and Schedule Development* (1997 FCA Guidance) sets forth a two-phased approach for evaluating a National Pollutant Discharge Elimination System (NPDES) permittee's financial capability to fund combined sewer overflow (CSO) controls in accordance with the CSO Control Policy.[7] In the first phase, the Residential Indicator (RI) calculates the cost per household as a percentage of median household income (MHI) for the service area of the permittee. In the second phase, the Financial Capability Indicators (FCI) evaluates the municipality or wastewater utility's overall fiscal health and local demographics relative to national norms. The Residential Indicator and Financial Capability Indicators results are brought together in a matrix that evaluates the impact a proposed CWA program imposes on the municipality or utility ("high," "medium," or "low"). This two-phased approach is referred to as the FCA. While developed for use in assessing a community's capability to fund CSO controls, EPA has also used the 1997 FCA Guidance to inform schedules to implement sanitary sewer overflow (SSO) and other CWA control measures.

EPA developed the 2014 *Financial Capability Assessment Framework for Municipal Clean Water Act Requirements* (2014 FCA Framework) to encourage the use of the flexibility available under the 1997 FCA Guidance. Both the 1997 FCA Guidance and the 2014 FCA Framework were developed with extensive public input. The results of the FCA analyses provide an important benchmark for EPA decision-makers to consider in CWA permitting and enforcement actions to support consistency across the country. EPA has used both the 1997 FCA Guidance and the 2014 FCA Framework to support consent decree negotiations with over 100 wastewater utilities throughout the United States and U.S. territories.

2. Integrated Planning Framework

In 2012, EPA developed the *Integrated Municipal Stormwater and Wastewater Planning Approach Framework* (Integrated Planning Framework) that offers a voluntary opportunity for a municipality to develop an integrated plan to meet multiple CWA requirements. Integrated planning is a process that municipalities can use to achieve clean water and human health goals while addressing aging infrastructure, changing

[6] For more information about the federal civil rights laws enforced by EPA, including Title VI, please visit https://www.epa.gov/ocr/title-vi-laws-and-regulations and https://www.epa.gov/ogc/external-civil-rights-compliance-office-title-vi.

[7] Through the NPDES program, EPA established a national framework for controlling CSOs, called the CSO Control Policy. 59 Fed. Reg. 18688 (April 19, 1994). CWA § 402(q) requires that each permit, order, or decree for a discharge from a municipal combined storm and sanitary sewer conform to the CSO Control Policy. Communities with CSOs must comply with the CSO Control Policy and have a permit to discharge. See https://www.epa.gov/npdes/combined-sewer-overflows-csos.

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population and precipitation patterns, and competing priorities for funding. With the release of the Integrated Planning Framework, the Agency clarified that an FCA could include the following costs: stormwater and wastewater; ongoing asset management or system rehabilitation programs; existing CWA related capital improvement programs; collection systems and treatment facilities; and other CWA obligations required by state or other regulators. On January 14, 2019, the Water Infrastructure Improvement Act (WIIA) (H.R. 7279) added a new section 402(s) to the CWA to include the 2012 Integrated Planning Framework.

3. Interim Economic Guidance for Water Quality Standards

The 1995 *Interim Economic Guidance for Water Quality Standards* (1995 WQS Guidance) is used for developing supporting analyses for revisions to designated uses, justifications for WQS variances, and antidegradation reviews to allow lowering of water quality. The public sector portion of the 1995 WQS Guidance uses a substantively identical two-phased approach, data, and metrics as the 1997 FCA Guidance. However, the terminology used in the two guidance documents is different.

The first step of the public sector analysis of the 1995 WQS Guidance involves determining a Municipal Preliminary Screener Score (MPS) to assess the impact of the cost to households of the pollution control technology needed to meet water quality-based requirements. The MPS is the cost as a percentage of the median household income (i.e., the ratio of the total per-household costs and the median household income). In the 1997 FCA Guidance, this same ratio is called the Residential Indicator.

The second step of the public sector analysis of the 1995 WQS Guidance involves determining the Secondary Score to evaluate the community's financial capability, using six measures of a community's financial health - bond rating, net debt as a percent of the full market property value, unemployment rate, median household income, property tax revenues as a percent of full market property value, and property tax collection rate. In the 1997 FCA Guidance, these same six measures are used to calculate the Financial Capability Indicators.[8]

In the 1995 WQS Guidance, the MPS and the Secondary Score are brought together into a matrix to determine the degree of economic and social impact to support a binary (i.e., yes/no) WQS decision, whereas the matrix in the 1997 FCA Guidance is used to determine a community's financial capability to support schedule negotiations.

Because the 1995 WQS Guidance and the 1997 Guidance are substantially aligned, the FCA Guidance supplements the public sector sections of the 1995 WQS Guidance to assist states and authorized tribes in assessing the degree of economic and social impact of potential WQS decisions. The FCA Guidance does not revise the recommended methodology in the private sector sections of the 1995 WQS Guidance. Section III of the FCA Guidance applies to the consideration of economic impacts to public entities when evaluating WQS variances and antidegradation reviews. In appropriate cases, these methodologies also inform decisions about revisions to designated uses, subject to the additional analyses described in Section III.

[8] One difference is that the 1995 Economic Guidance's Secondary Score compares the community's median household income to the state median household income, whereas the 1997 FCA Guidance's Financial Capability Indicator compares the community's median household income to the national median household income.

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c. Use of the Updated FCA Guidance

The FCA Guidance advances the ability of communities to demonstrate financial impacts, increases the transparency of EPA's consideration of these impacts, and will improve the agency's ability to consistently apply FCA methodologies across the country. The FCA Guidance helps communities submit consistent and comprehensive information relevant to the entire community's capability to fund CWA control measures and programs. Specifically, the FCA Guidance includes templates and calculations that communities can use to submit information regarding lowest quintile income (LQI), drinking water costs, financial models or studies, and other relevant information. The templates and calculations include references to applicable publicly available data sources that can be used in compiling this information. The Residential Indicator and Financial Capability Indicators are based on factors for consideration of financial capability as identified in the CSO Control Policy.[9] The development of the Lowest Quintile Poverty Indicator was guided by the following criteria:

1. Readily available from publicly available data sources;
2. Clearly defined and understood;
3. Simple, direct, and consistent;
4. Valid and reliable measures, according to conventional research standards; and
5. Applicable for comparative analyses among permittees.[10]

EPA also encourages communities to submit any additional documentation that would create a more accurate and complete picture of their financial capability that may affect the conclusion of the analyses described in this guidance.

When used for schedule development, EPA does not view or use the FCA Guidance as a rigid metric that points to a given schedule length or threshold over which the costs are deemed unaffordable. It is a common misconception that the FCA Guidance can be used to cap spending on CWA programs or projects at a percentage of MHI. The FCA Guidance does not remove obligations to comply with the CWA nor does it reduce regulatory requirements. Rather, EPA uses the FCA Guidance to assess a community's financial capability for the purpose of developing a reasonable implementation schedule for necessary improvements that will not burden the community. In practice, EPA considers each community's financial capability on a holistic case-by-case basis. Where appropriate, EPA has and will continue to consider supplemental information submitted by the community (as encouraged by the 2014 FCA Framework) and may agree to

[9] These factors are: i) Median household income; ii) Total annual wastewater and CSO control costs per household as a percent of median household income; iii) Overall net debt as a percent of full market property value; iv) Property tax revenues as a percent of full market property value; v) Property tax collection rate; vi) Unemployment; and vii) Bond rating. 59 Fed. Reg. at 18894. While allowing for consideration of these listed factors in developing implementation schedules, the CSO Policy also explains that NPDES authorities should ensure that "CWA requirements are complied with as soon as practicable." Id. at 18690.

[10] See National Academy of Public Administration, *Developing a New Framework for Community Affordability of Clean Water Services* (2017).

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implementation schedules that are different than the schedules suggested by the FCA Guidance's baseline analysis.

The updated FCA Guidance incorporates aspects of EPA's 1997 FCA Guidance and EPA's 2014 FCA Framework. Going forward, the FCA Guidance replaces the 1997 FCA Guidance to evaluate a community's capability to fund CWA control measures in both the permitting and enforcement context.

In addition, as described in Section I.b of this guidance, the 1997 FCA Guidance is substantively identical to the public sector sections of the 1995 WQS Guidance, which is used for evaluating WQS decisions, including revisions to designated uses, WQS variances, and antidegradation reviews for high-quality waters. Going forward, the FCA Guidance (particularly Section III) supplements, and should be used in conjunction with, the public sector sections of the 1995 WQS Guidance to assist states and authorized tribes in assessing the degree of economic impact of potential WQS decisions. The FCA Guidance does not revise the recommended methodology in the private sector sections of the 1995 WQS Guidance.

Worksheets for calculation of the Residential Indicator and Financial Capability Indicators are included as Appendices A and B. These Appendices include standardized instructions and practice tips, such as costs that can be included when considering CWA costs per household as a percent of MHI. MHI represents the mid-point of income in a geographical area determined by the American Community Survey (ACS). The median is generally used to derive a central tendency since it is not largely affected by outlier values. However, EPA recognizes that there can also be significant impacts on customers at the low end of the income spectrum. For communities with households that have difficulty paying for their water services, these challenges can be indicated by looking at the community's LQI and other poverty indicators along with its MHI.

When considering an extended schedule for addressing sewer overflows, Section II.8 of EPA's longstanding CSO Control Policy states that implementation schedules should incorporate consideration of grant and loan availability, user fees and rate structures, and other viable funding mechanisms and sources of funding. 59 Fed. Reg. 18688, 18694 (April 19, 1994). As outlined in Section II.a.4 of this guidance, the Financial Alternatives Analysis walks communities through these considerations and how certain steps may mitigate financial impacts. This step should inform EPA's consideration of an extended CWA schedule or WQS revision related to economic impacts, particularly those that may be driven by lowest quintile income and/or poverty considerations. For example, a community's Residential Indicator and Financial Capability Indicators may show that the community as a whole has the resources to invest in water infrastructure, but those investments could potentially impose a significant burden on lower-income households unless steps are taken to avoid that result. In such cases, Appendix C of this guidance describes measures communities can implement to reduce that burden. To the extent that financial burdens remain for the community and its low-income households, EPA will work with the community and/or utility to develop an appropriate schedule length as suggested by the recommended implementation schedule benchmarks in Exhibit 9.

Appendices C and D provide information related to accessing federal funding as well as other sources of water infrastructure financing. These types of programs can help a community come into compliance more quickly and reduce the financial impacts on ratepayers. As described below, the assessment of availability of such funding should be part of a community's FCA, and a community should consider available subsidized funding and other financing arrangements as part of a financing plan to achieve compliance as soon as

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practicable.[11] EPA's Water Finance Clearinghouse (https://clearinghouse.epa.gov/wfc) can also be used to identify federal, state, and non-governmental sources of funding and financing that may help communities access capital to meet their water infrastructure needs. The Water Finance Clearinghouse can provide information on rate structures, financial plans, and customer assistance programs. In addition, EPA's Municipal Ombudsman (https://www.epa.gov/ocir/municipal-ombudsman) serves as a resource for communities seeking to comply with the Clean Water Act and will coordinate with the appropriate EPA offices to assist communities with information on federal financial assistance, technical assistance, and integrated planning.

II. Updated FCA Guidance for Schedule Development

The FCA Guidance encourages communities to provide information under either Alternative 1 or Alternative 2 to evaluate financial capability for CWA implementation schedules. Alternative 1 of the FCA Guidance involves evaluating a NPDES permittee's financial capability to fund CWA controls by calculating the Residential Indicator and the Financial Capability Indicators. The Residential Indicator considers the cost per household as a percentage of MHI for the service area of the permittee using data collected by the U.S. Census Bureau. The Financial Capability Indicators evaluate the municipality or wastewater utility's overall fiscal health and local demographics relative to national norms. The FCA Guidance adds a new critical metric: the Lowest Quintile Poverty Indicator (LQPI) Score. These critical metrics are considered in accordance with the Expanded FCA Matrix (Exhibit 5) and supplemented by a Financial Alternatives Analysis. The FCA Guidance includes recommended implementation schedule benchmarks applicable to Alternative 1 (Exhibit 9). Alternative 2 of the FCA Guidance involves analyzing financial and rate models in addition to calculating the LQPI Score and performing a Financial Alternatives Analysis.

It should be emphasized that these alternatives might not present the most complete picture of a community's financial capability to fund its CWA requirements. However, these metrics do provide a common basis for financial impact discussions among the community, the state or tribe, and EPA. Communities are encouraged to submit any additional documentation (Other Metrics) for consideration that would create a more accurate and complete picture of their financial capability. The FCA Guidance includes Other Metrics with Standardized Instructions and Other Metrics with Submission of Information to be Determined by the Community. Both alternatives permit consideration of Other Metrics and may support an extended implementation schedule as suggested by Exhibit 9's recommended implementation schedule benchmarks. See Sections II.c and II.d for more information on additional metrics.

[11] The CSO Control Policy requires that "each long-term CSO control plan . . . should [] include both fixed-date project implementation schedules (which may be phased) and a financing plan to design and construct the project as soon as practicable." 59 Fed. Reg. at 18691.

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Alternative 1: Critical Metrics

- Residential Indicator – cost per household as a percentage of MHI
- Financial Capability Indicators – six socioeconomic, debt, and financial indicators used to benchmark a community's financial strength
- Lowest Quintile Poverty Indicator – one lowest quintile income element (weighted at 50%) and five poverty elements (weighted at 10% each) used to benchmark the severity and prevalence of poverty within the community's service area
- Financial Alternatives Assessment – consideration of feasible alternatives to reduce costs and address impacts to low-income households

Alternative 2: Critical Metrics

- Financial and Rate Models
- Lowest Quintile Poverty Indicator
- Financial Alternatives Analysis

Other Metrics with Standardized Instructions

- Drinking Water Costs
- Water Affordability Programs
- Asset Management Costs
- Stormwater Management Costs
- Comparisons to County, State, and National Data

Other Metrics with Submission Information Determined by the Community (see Appendix E for examples)

a. Alternative 1: Critical Metrics and Instructions

1. Residential Indicator

The first step of Alternative 1 is to calculate the Residential Indicator by following the instructions for Worksheets 1 and 2 in Appendix A. This indicator is the community's average cost per household (CPH) for wastewater treatment (WWT) and CWA controls as a percentage of the local MHI. It reflects the residential share of current and planned controls needed to meet the requirements of the CWA. The value range for this indicator characterizes whether the costs impose a "low," "mid-range," or "high" financial impact on residential users.

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Exhibit 1. Residential Indicator Score

RESIDENTIAL INDICATOR FINANCIAL IMPACT	RESIDENTIAL INDICATOR (CPH AS % MHI)[12]
Low	Less than 1.0 Percent of MHI
Mid-Range	1.0 to 2.0 Percent of MHI
High	Greater than 2.0 Percent of MHI

2. Financial Capability Indicators

The second step of Alternative 1 is to calculate the Financial Capability Indicators by following the instructions for Worksheets 3 to 9 in Appendix B. The six Financial Capability Indicators are used to evaluate the debt, socioeconomic, and financial conditions that affect a community's financial capability to implement the CWA controls. These indicators help characterize the community's financial capability as "weak," "mid-range," or "strong."

Exhibit 2. Financial Capability Indicators Score

FINANCIAL CAPABILITY INDICATORS SCORE	SOCIOECONOMIC, DEBT, AND FINANCIAL INDICATORS
Weak	Below 1.5
Mid-Range	1.5 to 2.5
Strong	Above 2.5

3. Lowest Quintile Poverty Indicator Score

The third step of Alternative 1 is to calculate the Lowest Quintile Poverty Indicator Score. EPA recognizes that considering lowest quintile income is an important measure to supplement the Residential Indicator and Financial Capability Indicators, as MHI does not account for the variability of income distribution from community to community. The calculation of the Lowest Quintile Poverty Indicator aids in assessing the severity and prevalence of poverty in a community's service area.

A Lowest Quintile Poverty Indicator Score can be calculated by using the list of indicators in Exhibit 3 to benchmark the severity and prevalence of poverty within the community's service area. These indicators (other than "Trend in Household Growth") are evaluated using a ±25% benchmark to national values, like the

[12] In the mid-1990s EPA developed the 1% and 2% Residential Indicator benchmarks after conducting an analysis of the costs of wastewater services as a percentage of household income using EPA's Municipality's Ability to Pay Model (MABEL) database. The analysis also examined the National Wastewater User Fee Study of the Construction Grants program database, which captured annual residential expenditures as a percentage of median household income. The 2% benchmark was calculated to be two standard deviations above the average expenditure per household.

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methodology used to calculate the FCI. For instance, if the national Percentage of Population with Income Below 200% of Federal Poverty Level is 32%, then a community with a value less than 24% would equal a "strong" score for this indicator, a value of 24% to 40% would equal a "mid-range" score, and a value above 40% would equal a "weak" score. Using a ±25% benchmark closely aligns with the middle quintile of data for the parameter, which can characterize the "middle class" of Americans. This bracketing of the middle 50% is a commonly used methodology to characterize outliers on either end of the data distribution.

"Trend in Household Growth," the fifth indicator, is evaluated using >1%, 0-1%, and <0% benchmarks.[13] To calculate "Trend in Household Growth":

- Collect total number of occupied housing units (i.e., households) data, based on the 5-year ACS, for the most recent year and five years earlier from Census Table B25002.
    - Refer to https://data.census.gov/cedsci/all?q=B25002.
- Enter historical household data into the Geometric Average Growth Rate formula below to calculate the five-year trend.

$$5-Year\ Geometric\ Average\ Growth\ Rate = (1 + (HH_n - HH_{n-5})/HH_{n-5})^{1/5} - 1$$

$$HH = Number\ of\ Occupied\ Housing\ Units$$

$$n = Most\ Recent\ Census\ Data\ Year$$

For example, if a community had 15,500 occupied housing units in the most recent census data year and had 15,000 occupied units five census data years prior, the 5-year average geometric growth rate would be 0.66%.

$$5-Year\ Geometric\ Average\ Growth\ Rate = (1 + (15{,}500 - 15{,}000)/15{,}000)^{\frac{1}{5}} - 1 = 0.66\%$$

If the community's service area includes more than one jurisdiction, the LQPI indicators should be weighted based the number of households in each jurisdiction throughout the community's entire service area. For an example of how to calculate a weighted average, see Appendix A.

[13] This indicator is "strong" if the five-year average household growth is greater than 1 percent. The indicator is "weak" if the five-year average household growth is negative (less than 0 percent). The indicator is "mid-range" if the five-year average household growth is 0 percent to 1 percent.

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Exhibit 3. Instructions for Calculation of the Lowest Quintile Poverty Indicator Score

Determine Lowest Quintile Poverty Indicator Score using the template below.

INDICATOR (CENSUS DATA CODE)	STRONG (SCORE = 3)	MID-RANGE (SCORE = 2)	WEAK (SCORE = 1)	WEIGHT	ACTUAL VALUE	SCORE
LQPI #1 Upper Limit of Lowest Quintile Income (B19080)	More than **25%** above national LQI	**±25%** of national LQI	More than **25%** below national LQI	50%		
LQPI #2 Percentage of Population with Income Below 200% of Federal Poverty Level (S1701)	More than **25%** below national value	**±25%** of national value	More than **25%** above national value	10%		
LQPI #3 Percentage of Households Receiving Food Stamps/SNAP Benefits (S2201)	More than **25%** below national value	**±25%** of national value	More than **25%** above national value	10%		
LQPI #4 Percentage of Vacant Housing Units (B25002)	More than **25%** below national value	**±25%** of national value	More than **25%** above national value	10%		
LQPI #5 Trend in Household Growth (B25002)	>1%	0%-1%	<0%	10%		
LQPI #6 Percentage of Unemployed Population 16 and Over in Civilian Labor Force[14] (DP03)	More than **25%** below national value	**±25%** of national value	More than **25%** above national value	10%		
Score for LQPI #1						
Average Score for LQPI #2 to #6 (Sum of 2 through 6 divided by 5)						
Lowest Quintile Poverty Indicator Score (Sum of two lines above divided by 2)						
Lowest Quintile Poverty Indicator Benchmarks Low Impact (Above 2.5) Medium Impact (1.5 to 2.5) High Impact (Below 1.5)						

EPA strongly encourages additional subsidy or grant consideration from governmental funding sources for entities that show a "medium" or "high" impact LQPI Score.

[14] The Financial Capability Indicators and Poverty Indicators both evaluate unemployment rate for the population in the civilian labor force, although using two different standards for evaluation. The Financial Capability Indicators bounds for unemployment rate are +/- 1 percentage point of the national average (e.g., for a national average of 4 percent, the lower bound would be 3 percent and the higher bound would be 5 percent). The Poverty Indicators bounds for unemployment rate are +/- 25% of the national average. It can be useful to evaluate the same variable with different bounding methods, especially for years when unemployment rates spike across the country. On the other hand, when unemployment rates are low, the two should have a similar result. As part of the Financial Capability Indicators assessment, the unemployment rate is relevant to the general economic well-being of residential users in the permittee's service area. The unemployment rate is also relevant as a Poverty Indicator for benchmarking the prevalence of poverty within the service area.

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4. Financial Alternatives Analysis: Grant and Loan Availability; Previous and Current Residential, Commercial, and Industrial Sewer User Fees and Rate Structures; and Other Viable Funding Mechanisms and Sources of Financing

Another step of Alternative 1 is to perform a Financial Alternatives Analysis.[15] The goal of this step is to seek ways to minimize financial impacts while ensuring residents also enjoy the benefits of infrastructure investments and improved water quality. Where CWA compliance costs impact residents, particularly low-income households, a longer schedule may not always be the best solution to address impacts to those residents. In particular, if a community shows strong economic indicators in other categories, there may be better options for the community to address the potential financial burden faced by its residents or take other steps to reduce the costs of needed CWA controls. If the intended goal is to help impacts to residents, an extended CWA schedule may, in fact, have the opposite effect if it delays addressing pollution in the neighborhoods where they live. Nonetheless, EPA understands the significant impacts that additional costs can pose to communities, especially underserved and lower-income communities.

A Financial Alternatives Analysis should document whether the community has considered feasible steps to reduce costs and address impacts to low-income households, including use of variable rate structures, customer assistance programs (CAPs), and applications for grants or subsidies from the CWSRF. This demonstration should provide the results of the "checklist" of financing and funding considerations in Appendix C and describe the specific programs being implemented. The community should provide a list of the programs or steps considered, the actions that would be necessary to put such measures into place, and the plan for taking those actions. Where available tools are not included in the community's plans, the requester should provide a written explanation of why those approaches are not being pursued. EPA has provided an Example Financial Alternatives Worksheet in Appendix C that can help document this information.

Financial Alternatives Already Implemented

Most communities will have already considered or implemented some or many of the financial alternatives as general good practices of utility management. Performing the Financial Alternatives Analysis at the beginning of an FCA may help provide the community with a clearer understanding of all costs associated with the implementation of CWA controls, such as reduced costs associated with low-interest loans, increased revenue from utility fees, or the costs associated with programs that assist low-income households. Where a community has implemented certain financial alternatives, the associated costs or cost savings from those alternatives can be accounted for in the Residential Indicator under Alternative 1 and as part of a Financial and Rate Model analysis under Alternative 2. Communities should demonstrate how the CWA work

[15] The Financial Alternatives Analysis expands on the Secondary Financial Considerations in EPA's 1997 FCA Guidance and provides a template for the CSO Control Policy's additional construction and financing schedule considerations of: grant and loan availability; previous and current residential, commercial, and industrial sewer user fees and rate structures; and other viable funding mechanisms and sources of financing. See 59 Fed. Reg. at 18694. This analysis is also consistent with the Integrated Planning Framework, which states that integrated plans should include a financial strategy and capability assessment that ensures investments are sufficiently funded, operated, maintained and replaced over time and include consideration of current and planned rates and fees.

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included as costs in an FCA will be implemented, including appropriate assurances that those expenditures will be made.

Consideration of Additional Feasible Financial Alternatives[16]

Extended CWA compliance schedules or WQS revisions that lower the goals for a water body potentially widen water quality and health disparities among communities, creating environmental justice concerns. On one hand, low-income households may be paying a higher percentage of their total income for basic services and clean water, but on the other hand, if the community is out of compliance with the CWA, overburdened and/or low-income neighborhoods will likely continue to suffer impacts to human health and the environment from raw sewage overflows and inadequately controlled stormwater discharges. Residents in low-income communities also may be more dependent on nearby waters for recreation, fishing, and drinking water. The first-line responsibility for balancing financial impacts while achieving clean water improvements rests with the local community. However, EPA is committed to carefully reviewing financial impacts and using the tools and technical assistance at the Agency's disposal to help local communities mitigate environmental—and related financial and societal—impacts of CWA noncompliance for communities.

Use of variable rate structures, CAPs, and applications for grants or subsidies from the CWSRF are all potential tools to enable shorter compliance schedules by allowing increased total spending on compliance without burdening low-income customers. Shorter compliance schedules provide water quality and public health improvements that deliver important social, environmental, and economic benefits to the community. Communities can demonstrate through the Financial Alternatives Analysis that it has taken or is pursuing feasible steps included in Appendix C to lower costs of compliance, reduce or mitigate the financial impact of water service costs on the community's low-income households, and to achieve compliance as expeditiously as possible.[17]

In evaluating this demonstration, EPA expects to look comprehensively at the community's financial strategy, including, but not limited to, an analysis of the community's approach to covering costs through rate structure and design as well as its other initiatives to assist low-income customers while assuring necessary and timely compliance with environmental requirements. As described in Exhibit 9, this analysis can support longer compliance schedules where there is a holistic financial strategy to balance the financial and environmental impacts of extended CWA compliance schedules. Without the types of information developed in a Financial Alternatives Analysis, it will likely be more difficult for EPA to assess possible financial impacts and whether those impacts might outweigh the environmental impacts of extended noncompliance, so the recommendations for compliance schedules for communities that have not performed a Financial

[16] A financial or funding consideration listed in Appendix C may be prohibited by state law. Other mechanisms to achieve the same goals may be feasible alternatives. There are examples, which can be found in Appendix C, of communities that have implemented similar or analogous mechanisms to reduce financial impacts within the limits of the relevant legal boundaries. Note that for municipalities subject to federal civil actions, CWA Section 309(e) provides that to the extent that the laws of a State prevent the municipality from raising revenues needed to comply with any resulting judgement, then the State "shall be liable for payment of any judgment, or any expenses incurred as a result of complying with any judgment."

[17] In particular, NPDES permittees with long-term CSO control plans are "ultimately responsible for aggressively pursuing financial arrangements" for the implementation of such plans. 59 Fed. Reg. at 18690.

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Alternatives Analysis are shorter than for those communities that have developed a comprehensive Financial Alternatives Analysis.

Considerations for Sanitary Districts and Sewer Authorities

Whether a particular financial alternative is feasible may be different for entities such as a sanitary district or sewer authority. For instance, a utility may not be the rate setting authority for its entire service area if it serves wholesale customers. Certain utilities may need to work with the municipality or municipalities it serves to obtain the information to complete the Financial Alternatives Analysis. Users of this guidance should document any relevant differences in feasibility or practicality (see, e.g., Column B of the Example Financial Alternatives Worksheet) for consideration by EPA. Understanding such differences allows for development of schedules that are responsive to circumstances unique to each community while advancing the mutual goal to protect clean water.

Considerations for Resource Constraints, In Particular for Small Communities

Not all communities have the capability to fully evaluate the tools identified in Appendix C. If there are resource concerns with completing a Financial Alternatives Analysis, the community should seek support through EPA's Water Finance Center by sending an email to WaterTA@epa.gov. If resource constraints remain, the community should provide information on current and planned efforts to reduce costs and relieve impacts on low-income residential households in a format that represents a good-faith effort relative to the size of the community's service area. EPA understands that for small communities, particularly those serving less than 3,000 persons, it may not be feasible to make a good faith effort to document the financial alternatives in Appendix C. The agency will be mindful of those resource constraints when developing compliance schedules.

5. Expanded Financial Capability Assessment Matrix

The final step of Alternative 1 uses the Expanded FCA Matrix to incorporate the critical metrics described above to provide a framework for understanding the overall financial impact to the community's service area. First, combine the Residential Indicator Score and Financial Capability Indicators Score in the Financial Capability Matrix (Exhibit 4) to determine an FCA Score, then combine FCA Score and Lowest Quintile Poverty Indicator Score in the Expanded FCA Matrix (Exhibit 5). As explained above, a "high" impact or "medium" impact Expanded FCA Matrix result does not mean that CWA compliance is unaffordable; rather, it means that it may be appropriate for the community's CWA compliance schedule to be extended beyond a normal engineering/construction schedule, as suggested by the recommended implementation schedule benchmarks in Exhibit 9.

Financial Capability Matrix

The Financial Capability Matrix determines the FCA Score by combining the Residential Indicator Score and Financial Capability Indicators Score. The matrix is included below as Exhibit 4.

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Exhibit 4. Financial Capability Matrix

FINANCIAL CAPABILITY INDICATORS SCORE	RESIDENTIAL INDICATOR SCORE		
	LOW IMPACT (BELOW 1.0%)	MID-RANGE (1.0% TO 2.0%)	HIGH IMPACT (ABOVE 2.0%)
Strong (Above 2.5)	Low Impact	Low Impact	Medium Impact
Mid-Range (1.5 to 2.5)	Low Impact	Medium Impact	High Impact
Weak (Below 1.5)	Medium Impact	High Impact	High Impact

Expanded FCA Matrix

The Expanded FCA Matrix determines the community's overall impact level when combining the FCA Score (from Exhibit 4) and the LQPI Score (from Section II.a.3). The Expanded FCA Matrix is included below as Exhibit 5.

Exhibit 5. Expanded Financial Capability Assessment Matrix

FCA SCORE (RI AND FCI)	LOWEST QUINTILE POVERTY INDICATOR SCORE		
	LOW IMPACT	MEDIUM IMPACT	HIGH IMPACT
Low Impact	Low Impact	Low Impact	Medium Impact
Medium Impact	Low Impact	Medium Impact	High Impact
High Impact	Medium Impact	High Impact	High Impact

The results of the Expanded FCA Matrix correspond to the recommended implementation schedules in Exhibit 9. Showing a "medium" or "high" impact in the Expanded FCA Matrix does not mean that capital investments in critical infrastructure projects should stop. Communities should continue to make capital investments to meet water quality standards even where the Expanded FCA Matrix results indicate a "medium" or "high" impact, though extensions of schedules as suggested by Exhibit 9's recommended implementation schedule benchmarks may offer flexibility for communities. While EPA is committed to taking financial capability into consideration, it is also critically important that all communities—including low-income communities—are ensured the protections of the CWA and the benefits of safe, clean water. To achieve both goals, communities may sequence projects beyond a normal engineering/construction schedule where the community shows these impacts cannot be addressed through measures such as alternative rate structures, assistance programs, or other sources of funding.[18] EPA's Integrated Planning Framework might

[18] The length of financing can be just as important as the length of a construction implementation schedule when trying to keep rates low for a community's low-income households. For instance, a community could fund a 20-year implementation schedule with a 30-year or more loan, and in some cases, with low interest or negative interest loans and debt forgiveness from state revolving funds.

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be instructive in these circumstances. As noted above, an FCA should not be used to cap spending on CWA programs or projects at a percentage of MHI or LQI.

See Section II.e (Schedule Development) to see how the Expanded FCA Matrix score may be used in the CWA compliance schedule development process. See Section III for equivalent tables for evaluating economic impacts of WQS decisions for the public sector.

b. Alternative 2: Critical Metrics and Instructions

1. Financial and Rate Models

Alternative 2 provides an opportunity for communities that wish to use financial and rate model analyses to submit this more detailed information to assist in developing an appropriate schedule for implementing CWA control measures.

Cash flow forecasting is a useful tool that allows communities to determine, on an annual basis, the revenue necessary to cover costs (including the costs of compliance projects) and to meet debt covenants over the implementation period. The community should plan and allow for uncertainty when deciding how to adjust water and sewer rates to finance its major capital improvements. Communities should decide how much should be financed through debt and how much should be directly paid for by sewer rates as costs are incurred. In evaluating potential rate increases, communities should also balance revenue requirements against the likelihood that users will reduce usage or cease paying utility bills, causing the yield of the revenues from the rate increase to be less than expected or desired, potentially causing the community to experience "rate shock."[19] In addition, within limits, communities have significant discretion regarding the timing of sewer rate increases. For example, communities may elect to raise rates more than the absolute minimum necessary in early years, thereby creating a cushion against economic uncertainties in later years and providing a strong financial base for bond financing. These model calculations inform the annual rate increases and can help a community evaluate a suite of potential compliance schedules. EPA has provided a list of resources related to water infrastructure financing and rate setting in Appendix D.

While useful, financial and rate models may be complicated or costly to develop, particularly for mid-size or small communities, and may be difficult for a regulator to evaluate. For this reason, submission of this information is at the discretion of a community. This type of information can be used as an analytic tool to assist in developing schedules for implementing CWA control measures in lieu of the critical metrics and schedule benchmarks set forth under Alternative 1. Alternative 2 may be particularly useful in situations where the community already uses such modeling for its internal financial planning or where multiple constraints affect the community's ability to achieve compliance with the CWA (in terms of costs or timing). However, EPA does not recommend the use of financial and rate model analysis under Alternative 2 in lieu of Alternative 1 for WQS decisions. Instead, for evaluating economic impacts of WQS decisions for the public sector, the use of financial and rate models could be used in a manner similar to the Other Metrics in

[19] Rate shock can increase the difficulty of managing program implementation schedules, because financing is contingent on an adequate revenue stream to support the debt service and additional coverage.

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Sections II.c and II.d of the FCA Guidance, i.e., as additional information for consideration in conjunction with the use of the Alternative 1 critical metrics.

Communities can provide forward-looking, year-by-year financial modeling of capital expenditures to support a proposed schedule for completing projects necessary to come into compliance with the CWA. Such modeling is commonly used to determine the revenues and rate increases necessary to support the financing of operations and major projects. The typical steps in this process include:

- Determining revenue requirements based on operating costs, debt service payments, asset management, and necessary capital expenditures;
- Allocating the costs of service to customer classes; and
- Developing a schedule of rates and charges necessary to meet revenue requirements.

Financial and rate models provided in the context of CWA compliance are normally in spreadsheet form with multiple tabs, including inputs and assumptions, debt service schedules, operations and maintenance costs, and schedule of necessary capital improvements. The model then determines the "revenue requirements" necessary to support the proposed or alternative compliance plans, including financing and rate increases. The models are set up so that it is possible to evaluate alternative scenarios in terms of cost, length of time to complete a program, or assumptions related to financing strategies. Simpler modeling for smaller communities is possible based on the same concepts, if percentage revenue increases will be passed through to a typical residential customer bill at the same rate of increase.

To assist EPA's review of modeling analyses, EPA recommends that communities using Alternative 2 submit the following supporting data and documentation:

- The last three years of financial reports for the wastewater system.
- A summary of historical rate increases for the past five years.
- The most recent approved Budget and Capital Improvement Plan for the wastewater system.
- Model documentation (e.g., creator, peer review status, version).
- A summary of all model input assumptions and their bases, for example: bond rating, ability to borrow, legislative caps on ability to borrow, selected funding mechanism, access to CWSRF financing, ability to pay back debt, the current operating cost and debt service baseline, current revenue, growth in customers, and inflation in costs and household income.
- An identification of dollar values as either constant (year) or nominal dollars.
- A summary of the model results, explaining the community's view of the conclusions relevant to its financial capability to implement the necessary work to achieve compliance.
- A fully functional model of the scenarios presented, with all formulas and interactions among separate worksheets intact. The model should include a tab that clearly describes the input assumptions used.

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- A clear description of the baseline financial status and data in terms of year and source documents that the modeling is built from. This should include the basis for the current residential bill that is used to evaluate impacts on households with median income levels. In general, this will be similar to the results in the Residential Indicator analysis but analyzes only current costs.[20]
- All source and supporting documentation that was relied upon when developing the model, including certified financial statements.
- Evaluation of multiple scenarios in terms of program length or other key assumptions and uncertainties.

Communities and EPA have found a summary of scenarios such as the example shown below in Exhibit 6 to be useful. Other examples would yield different results. To develop year-by-year forward-looking rate model scenarios, such as those shown in Exhibit 6, a community should:

1. Include calculation of the service area Residential Indicator based on the percentage of residential flow and households (not the number of accounts). Current costs (operations and maintenance expenses, debt service at present time, and other recurring asset management costs) should be included and consistent with the model inputs for the current year. Future costs should include the total capital expenditures and changes in operations and maintenance costs as a result of the required work, and also reflect the community's financing plan, again consistent with model assumptions.
2. Determine whether the modeling will be in current dollars or inflated dollars. If inflated, the modeled costs, including proposed capital expenditures, should be adjusted over time. In addition, MHI values should be escalated using the historic rate of increase of MHI or the Consumer Price Index (CPI). The community should provide the basis for all escalation factor assumptions applied in the model.
3. Define a proposed end year for the completion of investments needed to meet CWA requirements. Examining several alternative scenarios is preferred to better understand the impact of various program lengths.
4. Incorporate existing debt service schedules as well as the assumed financing approach for the proposed program costs. This would likely include a mix of already available reserves, cash from incoming revenues, and new debt financing from either the municipal bond market or state-subsidized funding sources.
5. Iterate through proposed capital investment schedules to develop model scenarios and related revenue requirements.

[20] In general, EPA is finding that per household billed usage is in the range of 5 to 6 CCF (centum cubic feet, or one hundred cubic feet). If the community serves a significant number of households in multi-family structures, then the usage will likely be lower. EPA may accept the community's current "typical bill" usage assumption, if consistent with nationwide averages, or real information on usage from actual billing. A community's inability to obtain per household usage information for families living in multi-family structures that are not billed separately for utilities does not preclude consideration of usage information from actual billing.

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6. Translate the revenue requirements into annual increases in rates and bills for customers. Apply the annual percentage increases to the baseline or current average household bill.

Where local data are available, communities are encouraged to implement Alternative 2 using local data. For EPA to consider this information, a community should submit all supporting data and documentation, as described above.

Exhibit 6. Examples of Rate Increase Scenarios and Median Household Impacts for Each Scenario

SCENARIO:	COMMUNITY PROPOSED SCENARIO				OTHER SCENARIOS							
END YEAR:	2047				2036				2041			
MEASURE:	RATE INC.	CPH ($)	MHI ($)	RI	RATE INC.	CPH ($)	MHI ($)	RI	RATE INC.	CPH ($)	MHI ($)	RI
2018	7.5%	647	67,753	1.0%	8.4%	639	67,753	0.9%	6.5%	629	67,753	0.9%
2019	7.5%	588	69,272	0.8%	8.4%	584	69,272	0.8%	6.5%	566	69,272	0.8%
2020	7.5%	629	70,825	0.9%	8.4%	630	70,825	0.9%	6.5%	601	70,825	0.8%
2021	7.5%	672	72,413	0.9%	8.4%	678	72,413	0.9%	6.5%	637	72,413	0.9%
2022	7.5%	719	74,037	1.0%	8.4%	731	74,037	1.0%	6.5%	675	74,037	0.9%
2023	7.5%	770	75,697	1.0%	8.4%	789	75,697	1.0%	6.5%	716	75,697	0.9%
2024	7.5%	824	77,394	1.1%	8.4%	850	77,394	1.1%	6.5%	760	77,394	1.0%
2025	7.5%	882	79,129	1.1%	8.4%	917	79,129	1.2%	6.5%	806	79,129	1.0%
2026	7.5%	944	80,903	1.2%	8.4%	990	80,903	1.2%	6.5%	856	80,903	1.1%
2027	5%	989	82,717	1.2%	8.4%	1,069	82,717	1.3%	6.4%	907	82,717	1.1%
2028	5%	1,037	84,572	1.2%	8.4%	1,154	84,572	1.4%	6.4%	962	84,572	1.1%
2029	5%	1,086	86,468	1.3%	8.4%	1,246	86,468	1.4%	6.4%	1,020	86,468	1.2%
2030	5%	1,138	88,407	1.3%	8.4%	1,345	88,407	1.5%	6.4%	1,082	88,407	1.2%
2031	5%	1,193	90,389	1.3%	8.4%	1,453	90,389	1.6%	6.4%	1,148	90,389	1.3%
2032	5%	1,251	92,416	1.4%	8.4%	1,570	92,416	1.7%	6.4%	1,218	92,416	1.3%
2033	5%	1,311	94,488	1.4%	8.4%	1,697	94,488	1.8%	6.4%	1,292	94,488	1.4%
2034	5%	1,374	96,607	1.4%	8.4%	1,834	96,607	1.9%	6.4%	1,372	96,607	1.4%
2035	5%	1,440	98,773	1.5%	8.3%	1,980	98,773	2.0%	6.4%	1,456	98,773	1.5%
2036	5%	1,510	100,988	1.5%	8.3%	2,139	100,988	2.1%	6.4%	1,545	100,988	1.5%
2037	5%	1,582	103,252	1.5%	0%	2,141	103,252	2.1%	6.4%	1,640	103,252	1.6%
2038	5%	1,659	105,567	1.6%	0%	2,144	105,567	2.0%	6.4%	1,741	105,567	1.6%
2039	5%	1,739	107,934	1.6%	0%	2,146	107,934	2.0%	6.4%	1,848	107,934	1.7%
2040	1.39%	1,764	110,354	1.6%	0%	2,148	110,354	2.0%	6.4%	1,962	110,354	1.8%
2041	1.39%	1,790	112,828	1.6%	0%	2,151	112,828	1.9%	6.4%	2,084	112,828	1.8%
2042	1.39%	1,816	115,358	1.6%	0%	2,153	115,358	1.9%	0%	2,086	115,358	1.8%
2043	1.39%	1,842	117,944	1.6%	0%	2,156	117,944	1.8%	0%	2,089	117,944	1.8%
2044	1.39%	1,869	120,588	1.5%	0%	2,158	120,588	1.8%	0%	2,091	120,588	1.7%
2045	1.39%	1,896	123,292	1.5%	0%	2,161	123,292	1.8%	0%	2,094	123,292	1.7%
2046	1.39%	1,923	126,056	1.5%	0%	2,164	126,056	1.7%	0%	2,097	126,056	1.7%
2047	0%	1,926	128,882	1.5%	0%	2,166	128,882	1.7%	0%	2,099	128,882	1.6%

Key:
Rate Inc. = Annual Rate Increase for Wastewater
CPH = Annual Cost per Household for Wastewater and Stormwater Combined
MHI = Median Household Income
RI = Residential Indicator (i.e., CPH as a percent of MHI)

Key:
2018-2022 Actual (Historical) Data
Scenario End Year 2047
Scenario End Year 2036
Scenario End Year 2041

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EPA intends to use this information, along with the LQPI Score and information from the Financial Alternatives Analysis, when developing schedules for implementing control measures. The goal is to work with communities to reduce rate shock and to avoid wastewater utility rates that represent an overly burdensome percentage of household income. In addition, a community should consider the public health and environmental impacts described in Section II.e.1 when determining the sequencing and priority of projects. Unlike Alternative 1, EPA has not recommended benchmark percentages of household income for Alternative 2. However, EPA intends to keep the percentage of household income spent on wastewater utility bills within reasonable bounds when establishing compliance schedules. Where drinking water costs are substantial and impacting households, a community may submit information on those costs as part of its financial and rate model. See Section II.c.1 for more direction. Schedules developed using Alternative 2 should be generally consistent with the recommended scheduling boundaries in Exhibit 9. Communities are encouraged to provide local information to EPA to support any predictions of a likely occurrence of rate shock. Other Metrics, such as drinking water costs, may also impact rate shock.

Another analysis that EPA and communities have found helpful, shown below by example in Exhibit 7, evaluates the maximum potential bill impact relative to household size. Typically, as household size increases, monthly water usage increases.[21] One-person households generally use significantly less water than three- or four-person households, but also have on average fewer financial resources. Displaying data in this manner (i.e., by household size) provides a more nuanced view of the impact of costs based on likely usage.

The data in Exhibit 7 is an example of how a community can evaluate the feasibility of a capital improvement program relative to various household sizes, using the results of a modeling program. This can provide information about the specific impact of program costs relative to household size by comparing a table that shows the impacts of current rates on various household sizes to a table that shows the impacts of future rates (incorporating required program costs) on various household sizes. Tables like the ones shown in Exhibit 7 can be created by following the below steps:

- To develop a table showing current rate impacts (see example in Exhibit 7.a):
    - Obtain current data for Percent of Service Area per household size (column 2) and MHI by household size (column 3), available in the ACS database.
    - Using current rates, calculate the monthly household bill for each centum cubic feet (CCF) usage column (top portion of each row).
    - Calculate impact for each CCF usage column (bottom portion of each row) by multiplying the household bill by 12 to arrive at an annual bill, then dividing the annual bill by the MHI for each household size.

[21] A Water Research Foundation study found that as of 2016 the average household (2.65 people) daily water use was 138 gallons, while the average per capita usage was 58.6 gallons. The report notes that there is considerable range in usage across the United States due to the influence of climate and weather patterns. See, Water Research Foundation, *Residential End Uses of Water, Version 2: Executive Report*, April 2016. Accessed at https://www.waterrf.org/research/projects/residential-end-uses-water-version-2.

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Exhibit 7. Example Showing Projected Impact of Program Costs by Household Size[22]

7.a – Table Showing Impacts of Current Wastewater Rates on MHI

			CCF							
Household Size	% of SA HHs	MHI (current) per HH Size	2	3	4	5	6	7	8	9
1	**26.83%**	$30,540	$19.08	$26.10	$33.12	$40.14	$47.16	$54.18	$61.20	$68.22
			0.75%	**1.03%**	**1.30%**	**1.58%**	**1.85%**	**2.13%**	**2.40%**	**2.68%**
2	**33.76%**	$64,063	$19.08	$26.10	$33.12	$40.14	$47.16	$54.18	$61.20	$68.22
			0.36%	**0.49%**	**0.62%**	**0.75%**	**0.88%**	**1.01%**	**1.15%**	**1.28%**
3	**16.33%**	$72,063	$19.08	$26.10	$33.12	$40.14	$47.16	$54.18	$61.20	$63.18
			0.32%	**0.43%**	**0.55%**	**0.67%**	**0.79%**	**0.90%**	**1.02%**	**1.05%**
4	**13.37%**	$87,972	$19.08	$26.10	$33.12	$40.14	$47.16	$54.18	$61.20	$68.22
			0.26%	**0.36%**	**0.45%**	**0.55%**	**0.64%**	**0.74%**	**0.83%**	**0.93%**
5	**6.37%**	$88,630	$19.08	$26.10	$33.12	$40.14	$47.16	$54.18	$61.20	$68.22
			0.26%	**0.35%**	**0.45%**	**0.54%**	**0.64%**	**0.73%**	**0.83%**	**0.92%**
6	**2.22%**	$63,028	$19.08	$26.10	$33.12	$40.14	$47.16	$54.18	$61.20	$68.22
			0.36%	**0.50%**	**0.63%**	**0.76%**	**0.90%**	**1.03%**	**1.17%**	**1.30%**
7	**1.11%**	$48,621	$19.08	$26.10	$33.12	$40.14	$47.16	$54.18	$61.20	$68.22
			0.47%	**0.64%**	**0.82%**	**0.99%**	**1.16%**	**1.34%**	**1.51%**	**1.68%**

Low Impact	Mid-Range Impact	High Impact

[22] SA = Service Area; MHI = Median Household Income; CCF = Centum Cubic Feet.

7.b – Table Showing Modeled Impacts of 2047 Wastewater Rates on MHI

			CCF							
Household Size	% of SA HHs	MHI (escalated to 2047) per HH Size	2	3	4	5	6	7	8	9
1	**26.83%**	$51,188	$70.33	$100.38	$130.43	$160.48	$190.53	$220.58	$250.63	$280.68
			1.65%	**2.35%**	**3.06%**	**3.76%**	**4.47%**	**5.17%**	**5.88%**	**6.58%**
2	**33.76%**	$107,376	$70.33	$100.38	$130.43	$160.48	$190.53	$220.58	$250.63	$280.68
			0.79%	**1.12%**	**1.46%**	**1.79%**	**2.13%**	**2.47%**	**2.80%**	**3.14%**
3	**16.33%**	$120,786	$70.33	$100.38	$130.43	$160.48	$190.53	$220.58	$250.63	$280.68
			0.70%	**1.00%**	**1.30%**	**1.59%**	**1.89%**	**2.19%**	**2.49%**	**2.79%**
4	**13.37%**	$147,450	$70.33	$100.38	$130.43	$160.48	$190.53	$220.58	$250.63	$280.68
			0.57%	**0.82%**	**1.06%**	**1.31%**	**1.55%**	**1.80%**	**2.04%**	**2.28%**
5	**6.37%**	$148,553	$70.33	$100.38	$130.43	$160.48	$190.53	$220.58	$250.63	$280.68
			0.57%	**0.81%**	**1.05%**	**1.30%**	**1.54%**	**1.78%**	**2.02%**	**2.27%**
6	**2.22%**	$105,642	$70.33	$100.38	$130.43	$160.48	$190.53	$220.58	$250.63	$280.68
			0.80%	**1.14%**	**1.48%**	**1.82%**	**2.16%**	**2.51%**	**2.85%**	**3.19%**
7	**1.11%**	$81,494	$70.33	$100.38	$130.43	$160.48	$190.53	$220.58	$250.63	$280.68
			1.04%	**1.48%**	**1.92%**	**2.36%**	**2.81%**	**3.25%**	**3.69%**	**4.13%**

Low Impact	Mid-Range Impact	High Impact

- To develop a table showing modeled future rate impacts (see example in Exhibit 7.b):
  - As part of the community's modeling, escalate MHI based on an inflationary adjustment to the year at the end or highest point of the model (in the example in Exhibit 7.b, this is 2047).
  - Calculate the monthly household bill for each CCF usage column based on the rates at the end or highest cost point in the community's model (in the example in Exhibit 7.b, this is the example community's 2047 modeled rates).
  - Calculate impact for each CCF usage column by multiplying the household bill by 12 to arrive at an annual bill, then dividing the annual bill by the MHI for each household size.

EPA views these data as additional ways for communities to understand the impacts of program costs on various sizes of households. The results can be informative to the rate setting and design process. It can also help identify the segments of customers likely to require customer assistance support.

As mentioned above, EPA does not recommend the use of financial and rate model analysis under Alternative 2 in lieu of Alternative 1 in WQS decisions. Instead, for evaluating economic impacts of WQS decisions for the public sector, the use of financial and rate models could be used in a manner similar to the Other Metrics in Sections II.c and II.d of the FCA Guidance, i.e., as additional information for consideration in conjunction with the use of the Alternative 1 critical metrics.

2. Lowest Quintile Poverty Indicator and Financial Alternatives Analysis

In addition to the Financial and Rate Model analysis, a community or EPA should calculate an LQPI Score to benchmark the severity and prevalence of poverty within the service area. The community should also perform a Financial Alternatives Analysis to document whether the community has considered feasible steps to reduce costs and address impacts to low-income households (as identified in Appendix C), including use of variable rate structures, CAPs, and applications for grants or subsidies from the CWSRF. Without the information provided by a Financial Alternatives Analysis, it will likely be more difficult for EPA to assess possible financial impacts and whether those impacts might outweigh the environmental impacts of extended noncompliance, so the recommendations for compliance schedules for communities that have not performed a Financial Alternatives Analysis are shorter than for those communities that have developed a comprehensive Financial Alternatives Analysis.

c. Other Metrics with Standardized Instructions

The FCA Guidance provides standardized instructions to increase transparency and clarity regarding how EPA considers the following factors, discussed in detail below: drinking water costs, a community's water affordability programs, asset management costs, stormwater management costs, and comparisons to county, state, and national data.[23] As noted above, Other Metrics may be considered under Alternative 1 or Alternative 2 and may support an extended implementation schedule generally consistent with Exhibit 9's

[23] Where the costs of multiple CWA obligations are included in an FCA, each of those costs should be enumerated separately to provide an understanding of how each contributes to the overall analysis.

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recommended implementation schedule benchmarks. Additionally, use of these Other Metrics may be considered in evaluating economic impacts of WQS decisions for the public sector.

1. Drinking Water Costs

EPA recognizes that both clean water and drinking water costs are often paid for through charges on a single bill. For this reason, the FCA Guidance more explicitly provides guidance on incorporating a community's drinking water requirements into an FCA evaluation. Given the widespread, increasing costs of delivering reliable drinking water in communities, EPA is providing standardized instructions along with an explanation of how it intends to develop implementation schedules that will account for impacts of drinking water requirements, when significant.

Consideration of Drinking Water Costs under Alternative 1

Drinking water information can be used in Alternative 1 to supplement the critical metrics and the results of the Expanded FCA Matrix. If information on significant drinking water costs is submitted and supported by the documentation detailed below, under Alternative 1, EPA in its discretion may permit a community to move from a "low" impact to a "medium" impact, or from a "medium" impact to a "high" impact in the FCA Guidance Implementation Schedule Benchmarks (Exhibit 9). Or, if a community is already experiencing a "high" impact, EPA may use this additional information to support an extended schedule as suggested by the recommended schedule benchmarks in Exhibit 9. Similarly, significant drinking water costs may be taken into account in evaluating economic impacts of WQS decisions for the public sector.

If a community submits information on drinking water costs under Alternative 1, EPA requests that the community provide detailed descriptions and cost estimates for the drinking water requirements. The community should submit the following supporting documentation:

1. Describe the specific improvements and costs required.
2. Describe the underlying requirements for the drinking water improvements (for example, whether the drinking water improvements are required by a state or federal permit, regulation, or enforcement action).
3. Describe the relationship of the wastewater system service area to the drinking water system service area(s) geographically and in terms of households served, specifically the overlap of drinking water system service area relative to wastewater system service area.
4. If the drinking water system and wastewater system are operated by the same utility, identify and explain any issues related to future financing and financial capability expected.
5. Provide the last three years of financial reports for the drinking water system.
6. Provide the current and approved future rate schedules for the drinking water system.
7. In addition to the Residential Indicator for wastewater costs, provide a cost per household analysis for drinking water costs following the Residential Indicator worksheets in Appendix A.
8. Propose an implementation schedule that integrates the CWA improvements and drinking water improvements, including a detailed description of the proposed sequencing of the improvements.

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Consideration of Drinking Water Costs under Alternative 2

Drinking water information can be used in Alternative 2 to evaluate the impacts of rates for both wastewater and drinking water on household bills. Schedules developed using Alternative 2 should be generally consistent with the recommended scheduling boundaries in Exhibit 9. If a community submits information on drinking water costs as part of its financial and rate model, EPA requests that the community provide detailed descriptions and cost estimates for the drinking water requirements. The community should submit the following supporting documentation:

1. Describe the specific improvements and costs required.
2. Describe the underlying requirements for the drinking water improvements (for example, whether the drinking water improvements are required by a state or federal permit, regulation, or enforcement action).
3. Describe the relationship of the wastewater system service area to the drinking water system service area(s) geographically and in terms of households served, specifically the overlap of drinking water system service area relative to wastewater system service area.
4. If the drinking water system and wastewater system are operated by the same utility, identify and explain any issues related to future financing and financial capability expected.
5. Provide the last three years of financial reports for the drinking water system, the current approved budget, and the most recent approved Capital Improvement Program budget.
6. Provide the current and approved future rate schedules for the drinking water system.
7. Provide a drinking water rate model analysis.
8. Provide all source and supporting documentation that was relied upon when developing the drinking water rate model, including certified financial statements.
9. Propose an implementation schedule that integrates the CWA improvements and drinking water improvements, including a detailed description of the proposed sequencing of the improvements.

2. Water Affordability Programs

Households on fixed or lower incomes, as well as households that face a temporary crisis such as a job loss or illness, may have difficulty paying water and sewer bills. Many communities are implementing a variety of tools to assist low-income customers. These programs can include bill discount programs, arrearage forgiveness, and emergency assistance. Additionally, some utilities seek to distribute revenue responsibilities equitably within customer classes. Some of those programs include nontraditional rate structures that are designed to send a more precise pricing signal or to approach the economics of water service differently. EPA encourages the establishment of these innovative programs that help households address issues with affordability and help protect public health throughout the community. At the same time, these programs help ensure the utility can sustainably provide its core services, price services appropriately, and preserve a broad customer base. See Appendix C for a more detailed description of these types of programs. EPA's Compendium of Drinking Water and Wastewater Customer Assistance Programs (https://www.epa.gov/waterfinancecenter/compendium-drinking-water-and-wastewater-customer-

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assistance-programs) describes the benefits, implementation, and examples of water affordability programs throughout the country.

Water affordability programs can allow utilities to meet specific customer needs while also meeting the utility's financial needs and obligations. These programs can improve on-time-payment rates and reduce debt collection costs, as well as the administrative and legal costs associated with disconnection and reconnection of water services. However, these programs can sometimes result in increased costs and decreased revenues for wastewater utilities.

If a community has developed a rate structure or assistance program to assist individual households, the community may provide information on costs needed to administer the program as well as the revenue lost from the assistance provided. If affordability program costs are included in an FCA as CWA costs, the community should provide appropriate assurances that the program has been and will continue to be implemented (e.g., applicable board certification, local ordinance, or other appropriate documentation). EPA also recommends that the following information should be submitted to assist in documenting costs and benefits:

- Type of program;
- Program eligibilities;
- Number of customers participating in the program;
- Number of customers eligible for the program (if known);
- Program costs;[24]
- Revenue lost (e.g., discounted rates, collection fees foregone);
- How the program is funded;
- Program benefits; and
- Number of disconnections prevented (if known).

Submission of the above information should allow EPA to confirm that the appropriate program costs are being included as part of a community's FCA. Such costs can be included in the calculation of the Residential Indicator[25] under Alternative 1 and as part of a Financial and Rate Model analysis under Alternative 2. To be considered, EPA requests that the community clearly identify if water affordability program costs have been included in these sections of the FCA, the line items in which these costs appear, and the amounts. Additionally, use of this additional analysis in the same manner may be considered in evaluating economic impacts of WQS decisions for the public sector.

[24] The University of North Carolina Environmental Finance Center's Water Utility Customer Assistance Program Cost Estimation Tool is designed to help water utilities estimate the costs of implementing a water affordability program. See https://efc.sog.unc.edu/resource/bill-payment-assistance-program-cost-estimation-water-utilities.

[25] As current and projected CWA related expenses. See Appendix A, Worksheet 1, Lines Number 100 and 103.

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3. Asset Management Costs

Asset management is a critical foundation for understanding near- and long-term operational and capital needs. This information forms the basis for capital planning and a capital funding strategy. Asset management is the practice of managing infrastructure capital assets to minimize the total cost of owning and operating them, while delivering the service level required. It helps answer the following three core questions for long-term infrastructure planning:

1. What assets do you have and where are they located?
2. When do your assets need to be repaired or replaced?
3. How much is each asset going to cost you in the near-term and the long-term?

By implementing asset management practices, a community should have a clearer picture of infrastructure-related expenses and future investment needs, which should inform the financial planning process.

A community may provide the following information on its asset management costs if the community can verify that asset management practices are being implemented. These include:

- Implementing projects in the community's Capital Improvement Program;
- Inventorying assets;
- Linking maintenance schedules to the asset inventory;
- Assessing the condition and remaining useful life of the assets in the inventory;
- Determining the capital expenditures needed to replace assets; and
- Planning a funding and financing strategy for operation and maintenance and capital expenditures.

Submission of information verifying the above practices should allow EPA to confirm that the appropriate asset management costs are being included as part of a community's FCA. Such costs may be reflected in the Residential Indicator under Alternative 1 and as part of a Financial and Rate Model analysis under Alternative 2. To be considered, EPA requests that the community clearly identify when asset management costs have been included in these sections of the FCA, the line items in which these costs appear, and the amounts. Additionally, use of this additional analysis in the same manner may be considered in evaluating economic impacts of WQS decisions for the public sector.

4. Stormwater Management Costs

EPA's continued commitment to integrated planning recognizes that many local governments and authorities have increased investments in their stormwater infrastructure through capital projects to rehabilitate existing systems, improve operation and maintenance, reduce impermeable surfaces, make use of green infrastructure, and address additional regulatory requirements. As programs are implemented to improve water quality and attain CWA objectives, many state and local government partners find themselves facing difficult economic challenges with limited resources and financial capability.

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For inclusion as part of an FCA, EPA recommends that municipalities explicitly separate stormwater costs from wastewater costs. The following information should be submitted to verify that submitted stormwater costs are not within a community's wastewater-related funds:

- Identify the municipal fund that the stormwater activity is conducted within (for example, identify whether stormwater management is in a separate stormwater enterprise fund, incorporated into the wastewater enterprise fund, or conducted within the general fund).
- Describe the specific stormwater activities and associated costs (for example, provide costs for stormwater program development, implementation, and enforcement as well as costs for designing, building, and maintaining stormwater infrastructure).
- Include supporting documentation for cost estimates.
- Describe the underlying requirement for the stormwater activities and costs (for example, whether it is required by a state or federal permit, regulation, or enforcement action).
- Identify projected, current, and historical stormwater fees.

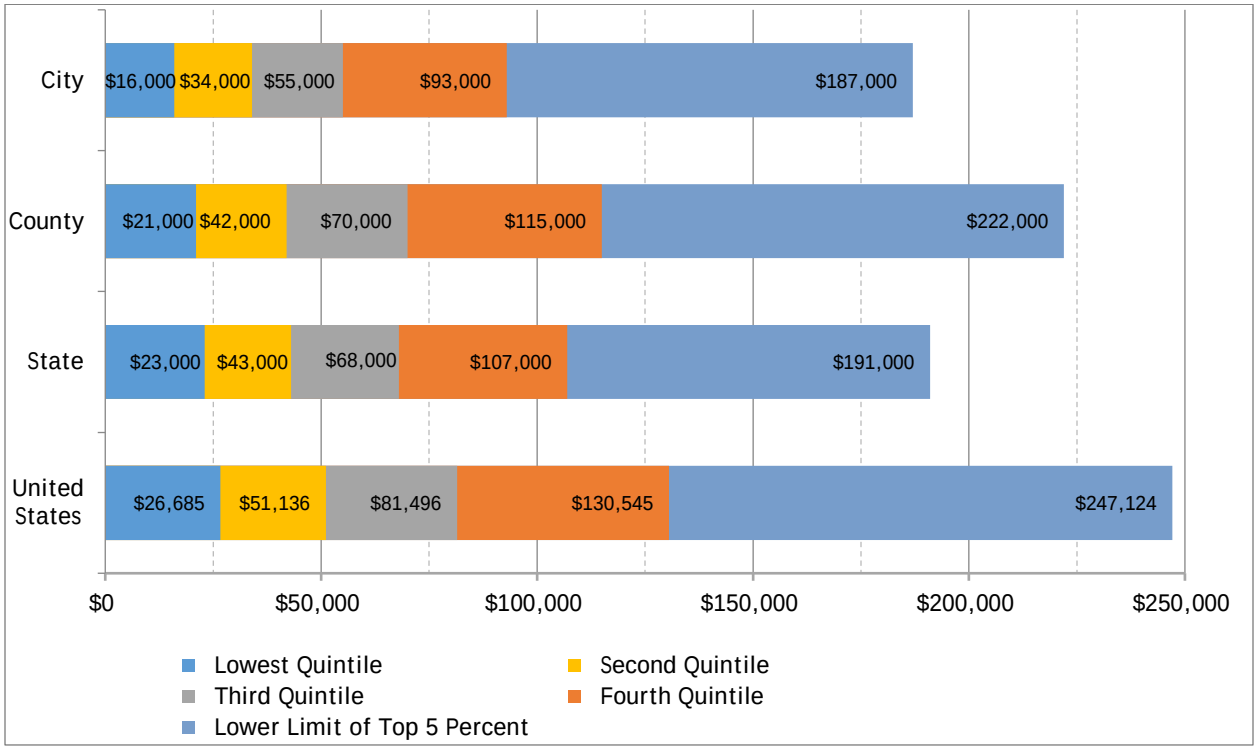
Submission of the above information should allow EPA to confirm that the appropriate stormwater costs are included as part of a community's FCA and provide EPA with the appropriate assurances that those expenditures will be made. Such costs may be incorporated in the Residential Indicator under Alternative 1 and as part of a Financial and Rate Model analysis under Alternative 2. EPA requests that the community clearly identify when stormwater management costs have been included in these sections of the FCA, the line items in which these costs appear, and the amounts. Additionally, use of this additional analysis in the same manner may be considered in evaluating economic impacts of WQS decisions for the public sector.

5. Comparisons to County, State, and National Data

For any of the Other Metrics submitted by a community, the community can provide a graphic or chart that shows the community's data compared with county, state, and national data. An example is shown below in Exhibit 8. This information could be used to assist EPA in assessing a community's circumstances in relation to national averages and as compared to other benchmark communities. Such a comparison can be used to highlight a community's unique or atypical circumstances. Additionally, use of such comparisons in the same manner may be considered in evaluating economic impacts of WQS decisions for the public sector.

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Exhibit 8. Comparison of Quintile Distribution in City to County, State, and Nation



d. Other Metrics with Submission of Information Determined by the Community

EPA continues to encourage communities to provide additional financial and demographic information regarding the community's financial capability to implement CWA requirements or to evaluate economic impacts of WQS decisions for the public sector. This information would supplement the information provided under either Alternative 1 or Alternative 2.

Additional examples of Other Metrics that may be submitted are listed in Appendix E. The examples described in Appendix E are not intended to be a complete list, nor a list of factors that will be relevant in every community. Rather, they provide an illustration of information that may prove useful in some instances. For such information to illustrate that a community's situation is atypical, EPA encourages communities to compare any additional information on their circumstances to national averages or to that of other communities in their state or geographic area (see example in Exhibit 8).

e. Schedule Development

When developing implementation schedules to construct control measures to meet CWA requirements, a community should consider public health, environmental justice, and environmental impacts as well as financial capability. The community should first develop a tentative implementation schedule based on logical engineering sequencing and normal construction practices. The community should complete a critical

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path analysis to identify the shortest implementation schedule that will achieve required control objectives. As a result of negotiations with state NPDES and EPA authorities, it may be appropriate to modify the tentative design and construction schedule based on the environmental and financial considerations listed in the FCA Guidance. In addition to completing an analysis under Alternative 1 or 2, a community should consider the following public health and environmental impacts when determining the sequencing and priority of projects.[26]

1. Environmental and Public Health Considerations

Discharges to Sensitive Areas: The CSO Control Policy states that a community's long-term control plan (LTCP) should give the highest priority to "sensitive areas." Sensitive areas, as determined by NPDES permitting authorities in coordination with state and Federal agencies, as appropriate, include the following: Outstanding National Resource Waters; National Marine Sanctuaries; waters with threatened or endangered species and their habitat; waters with primary contact recreation; public drinking water intakes and their designated protection areas; and shellfish beds. For discharges to sensitive areas, the CSO Control Policy states that LTCPs should: prohibit new or significantly increased overflows; eliminate or relocate overflows; or, where elimination or relocation is not feasible, provide treatment to meet WQS and regularly assess the feasibility of prohibition, relocation, or elimination.[27]

During the LTCP planning process, a community should characterize existing CSO conditions and identify receiving waters that are sensitive areas. The LTCP should give priority to sensitive areas and any implementation schedule should sequence projects to mitigate impacts on sensitive areas as early as possible. Giving highest priority to sensitive areas might mean in some cases that discharges to non-sensitive areas would be addressed later in the implementation schedule than would be the case under a normal engineering and construction schedule.

The identification of an area as "sensitive" is based on the designated use of a water body established by a state or authorized tribe as part of its water quality standards. If a use is not attainable for one of the reasons in 40 CFR 131.10(g) and is not an existing use (as defined in 40 CFR 131.3), a state or authorized tribe may revise the designated use with a supporting use attainability analysis (UAA) and must then adopt the highest attainable use.

Use Impairment: LTCPs should also give priority to receiving waters that experience recurring adverse impacts on aquatic life, human health, or aesthetics. Such waters may be the subject of public concern. As a result of public participation and discussion with the permitting authority, the community should develop an implementation schedule that gives highest priority to waters with impaired uses and addresses them as soon as possible. As is the case with sensitive areas, giving highest priority to certain use-impaired waters might mean that discharges to other waters would be addressed later in the implementation schedule than would be the case under a normal engineering and construction schedule.

[26] In addition, in accordance with the Integrated Planning Framework, integrated plans that are incorporated into permits and enforcement actions should prioritize the most significant human health and environmental needs first.

[27] See 59 Fed. Reg. at 18696.

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Public Health: While SSOs cannot be permitted, they can be the subject of CWA enforcement actions. Even where an SSO does not reach a water of the United States, it can be a violation of a permit obligation to properly maintain and operate a sanitary sewer system. Accordingly, where basement backups of raw sewage and the ejection of raw sewage from manholes onto streets are CWA permit violations, reducing exposure to this raw sewage should be a priority in any schedule that is negotiated with the community to protect public health.

Environmental Justice: The guiding principle of environmental justice is the fair treatment and involvement of all people regardless of race, color, culture, national origin, income, and educational levels with respect to the development, implementation, and enforcement of protective environmental laws, regulations, and policies. Communities can use EPA's EJSCREEN tool[28] when assessing whether there may be environmental justice concerns within their service area, such as areas with: people of color and/or low-income households; potential environmental quality issues; and/or existing environmental quality impairments in an area with demographic factors that suggest the community is sensitive to environmental pollution.[29] Any implementation schedule should sequence projects to mitigate public health and environmental impacts to areas with potential environmental justice concerns as early as possible. For WQS decisions, in addition to completing an economic analysis under Section III and considering any other financial metrics, a community or state is strongly encouraged to consider opportunities to mitigate impacts of WQS decisions on areas with potential environmental justice concerns. See Section III for additional discussion. Before seeking an to extend a CWA compliance schedule, EPA also encourages communities to actively involve the affected public by holding public meetings. The affected public includes rate payers, industrial users of the sewer system, persons who reside downstream from the CSOs, persons who use and enjoy these downstream waters, community organizations, and any other interested persons (including low-income communities, people of color, and immigrant populations). For any change to WQS, a public hearing is required per 40 CFR 131.20.

2. Alternative 1 Schedule Development

This guidance does not dictate specific implementation schedules based on financial capability. It does, however, provide recommended implementation schedule benchmarks in Exhibit 9 to aid all parties in negotiating reasonable and effective schedules for implementation of CWA controls. Exhibit 9 should be used after all critical metrics in Alternative 1 have been calculated to determine the community's overall impact level using the Expanded FCA Matrix and a Financial Alternatives Analysis has been performed, where appropriate.

The results of the Expanded FCA Matrix correspond to the recommended implementation schedule benchmarks in Exhibit 9, below. EPA has developed these schedule benchmarks to account for the consideration of the LQPI Score and the Financial Alternatives Analysis. Based on EPA's experience

[28] EPA has developed an environmental justice mapping and screening tool called EJSCREEN. It is based on nationally consistent data and an approach that combines environmental and demographic indicators in maps and reports. Screening results should be supplemented with additional information and local knowledge to get a better understanding of the issues in a selected location. EJSCREEN is available at https://www.epa.gov/ejscreen.

[29] Overview of Demographic Indicators in EJSCREEN is available at https://www.epa.gov/ejscreen/overview-demographic-indicators-ejscreen.

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considering financial capability for enforcement-related compliance schedules over the past nearly three decades, EPA has found that, absent the consideration of Other Metrics, it is financially feasible for communities to implement measures for compliance with the CWA that would have a "medium" impact within 15 years and to implement measures that would have a "high" impact within 20 years. In unusually high impact situations, implementation schedules generally up to 25 years have been negotiated with state NPDES and EPA authorities based on consideration of Other Metrics.

CWA compliance schedules should seek to achieve the earliest practicable compliance date considering physical and financial feasibility.[30] Where a community has not completed a comprehensive Financial Alternatives Analysis, the recommendations for compliance schedules are shorter than for those communities that have developed a comprehensive Financial Alternatives Analysis. This is because, without the types of information developed in a Financial Alternatives Analysis, it will likely be more difficult for EPA to assess possible financial impacts and whether those impacts might outweigh the environmental impacts of extended noncompliance. Where communities seek to extend compliance schedules based on an updated FCA, the environmental, public health, environmental justice, and additional financial considerations discussed in Appendix C and throughout this Section II.e (Schedule Development) should be key elements of any such updated analysis. In addition, reopening a previously approved compliance schedule to seek a schedule extension also involves consideration of whether additional control measures may be required for compliance with the CWA.

Exhibit 9. Recommended Implementation Schedule Benchmarks for Alternative 1

EXPANDED FCA MATRIX RESULT	RECOMMENDED IMPLEMENTATION SCHEDULE BENCHMARKS
Low Impact	Normal Engineering/Construction Schedule
Medium Impact	Total schedule generally up to 10 years
Medium Impact with Comprehensive Financial Alternatives Analysis	Total schedule generally up to 15 years
High Impact	Total schedule generally up to 15 years (or 20 years based on further negotiation with EPA and state NPDES authorities)
High Impact with Comprehensive Financial Alternatives Analysis	Total schedule generally up to 20 years (or 25 years based on further negotiation with EPA and state NPDES authorities)

It is important to note that EPA evaluates financial capability on a continuum and that each decision is subject to consideration of unique facts at issue for the community. Although the Expanded FCA Matrix categorizes impact as "high," "medium," or "low," this does not necessarily mean that communities will be given the specified number of years within that category or that schedules will be rigidly set according to the break points between the categories. For example, two communities whose total residential household costs are 1.1% and 1.9% of MHI are both categorized in the FCA Guidance as having a "mid-range" impact for the Residential Indicator. All other things being equal, the appropriate schedules for those communities are likely to be different. Similarly, all other things being equal, two communities whose LQIs are 24% below the

[30] See 59 Fed. Reg. at 18690.

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national LQI and 26% below the national LQI would be more likely to have similar overall compliance timeframes, even though one community is ranked as having a "mid-range" score and the other as having a "weak" score. Where schedules of work are phased, the goal should still be to complete the project within the recommended time frames and prioritize the most environmentally important projects as early as possible. In addition, communities should continue to make capital investments to meet water quality standards even if they are "high" impact communities.

Finally, the types of data described in the FCA Guidance are not exhaustive. Other Metrics submitted by the community may affect the length of the schedule regardless of where the community is on the "high," "medium," and "low" continuum. Consistent with previous policy, EPA plans to consider any relevant financial or demographic information presented that illustrates unique or atypical circumstances faced by a community. Where appropriate, this information can result in schedules that are different than the schedules suggested by the baseline analysis in the FCA Guidance.

Exhibit 10 below describes four hypothetical schedule determinations where the critical metrics, Other Metrics, and environmental considerations were assessed together to develop implementation schedules.

Exhibit 10. Example Schedule Development for Hypothetical Communities

SCHEDULING CONSIDERATION	COMMUNITY #1	COMMUNITY #2	COMMUNITY #3	COMMUNITY #4
Engineering/Construction Schedule	9 years	9 years	9 years	9 years
Sensitive Areas	n/a	2 years to remove discharges from sensitive areas	n/a	n/a
Use Impairment	n/a	2 years to remove discharges from waters with impaired uses	n/a	n/a
Environmental Justice	Potential EJ concerns identified	n/a	n/a	Potential EJ concerns identified
Financial Capability	FCA Result = Low Impact	FCA Result = Medium Impact	FCA Result = High Impact	FCA Result = High Impact
Significant Drinking Water Costs	n/a	2 additional years	2 additional years	2 additional years
Comprehensive Financial Alternatives Analysis	No	Yes	No	Yes
Schedule:	9 years (reduction of discharges in areas with EJ concerns within first 3 years)	17 years (removal of discharge from sensitive area and waters with impaired uses within first 2 years)	17 years	22 years (reduction of discharges in areas with EJ concerns within first 5 years)

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3. Alternative 2 Schedule Development

Under Alternative 2, EPA plans to consider the impacts on households as well as the LQPI Score and Financial Alternatives Analysis when approving implementation schedules that seek to avoid rates that represent an overly burdensome percentage of household income.

Under Alternative 2, communities are encouraged to submit any additional documentation (Other Metrics) that would create a more accurate and complete picture of their financial capability. Any Other Metrics that have been submitted for consideration should supplement the financial and rate model, LQPI Score, and Financial Alternatives Analysis. In addition, communities should consider the public health and environmental impacts described in Section II.e.1 when determining the sequencing and priority of projects. Schedules developed using Alternative 2 should be generally consistent with Exhibit 9's recommended implementation schedule benchmarks.

III. Updated FCA Guidance for Economic Impact Analysis for WQS Decisions for the Public Sector

In addition to recommending analyses communities can use to assess financial capability when negotiating compliance schedules, the FCA Guidance supplements the public sector sections of the 1995 WQS Guidance to assist states and authorized tribes in assessing the degree of economic and social impact of potential WQS decisions. The FCA Guidance does not revise the recommended methodology in the private sector sections of the 1995 WQS Guidance.

EPA recommends the following expanded multi-step approach to evaluate economic impacts for WQS decisions:

1. Determine the Initial Economic Impact using the Municipal Preliminary Screener (MPS) and Secondary Score (SS) as recommended by the 1995 WQS Guidance.
2. Determine the Lowest Quintile Poverty Indicator (LQPI) score.
3. Perform a Financial Alternatives Analysis.
4. Combine the results of the Initial Economic Impact and the LQPI score in an Expanded Economic Impact Matrix.

EPA intends for the FCA Guidance to supplement the public sector portion of the 1995 WQS Guidance. Specifically, the FCA Guidance supplements the calculations and analyses in the public sector portion of the 1995 WQS Guidance[31] with additional analyses, an Expanded Economic Impact Matrix, and recommendations to consider when making WQS decisions. EPA intends the FCA Guidance, together with the text in the public sector sections of the 1995 WQS Guidance, to guide states and authorized tribes in evaluating the economic

[31] Online spreadsheet tools for the public sector can be found at https://www.epa.gov/wqs-tech/spreadsheet-tools-evaluate-economic-impacts-public-sector. EPA may update these online tools in the future.

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impact of potential WQS decisions related to financial capability. EPA is also recommending certain additional analyses or actions when considering revisions to designated uses that are based on economic impacts.

WQS decisions relevant to this document include revisions to designated uses, WQS variances, and antidegradation reviews. The WQS regulations at 40 CFR 131.10(g)(6), commonly referred to as "Factor 6," allow revisions to designated uses or the adoption of WQS variances if a state or authorized tribe can demonstrate that attaining the use is not feasible because controls more stringent than the technology-based requirement would result in both substantial and widespread economic and social impacts.[32] In addition, the WQS regulations at 40 CFR 131.12(a)(2) allow lowering of water quality if it is necessary to accommodate important economic or social development in the area in which the high-quality waters are located.[33] Although the analyses recommended in the 1995 WQS Guidance to support WQS decisions and the 1997 FCA Guidance to determine the length of compliance schedules are essentially the same, as explained in Section I.b, there is an important difference in the way the information from those analyses were applied: the 1997 FCA Guidance was intended for development of implementation schedules to construct control measures to meet CWA requirements, whereas the 1995 WQS Guidance was intended to support binary "yes or no" decisions.

This section is organized as follows:

- Section III.a describes the Agency's rationale and expectations for the use of this guidance as it relates to Factor 6 for WQS variances and revisions to designated uses and why there are additional considerations for changes to designated uses.
- Section III.b discusses the consideration of other opportunities to mitigate the negative impacts of WQS decisions that may affect communities with potential environmental justice concerns.
- Section III.c describes consideration of any additional information and documentation to better understand a community's financial capability.
- Section III.d describes the multi-step approach to evaluate economic impacts of WQS decisions on the public sector. Importantly, Section III.d.5 describes how application of the results from the Financial Alternatives Analysis are combined with the results of the Expanded Economic Impact Matrix.

[32] The analysis in this guidance only serves to determine if impacts are "substantial." A state or authorized tribe would still need to conduct an analysis to demonstrate the substantial impacts are "widespread."

[33] The analysis is this guidance only serves to determine whether the economic or social development in the area in which the waters are located is "important." A state or authorized tribe would still need to conduct an analysis of pollution control alternatives, consistent with 40 CFR 131.12(a)(2)(ii), to determine if such a lowering is "necessary."

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a. Rationale and Expectations for the Use of this Guidance as it Relates to Factor 6 for WQS Variances and Revisions to Designated Uses

Unlike the revision of a designated use, a WQS variance is time-limited, is for a specific pollutant from a specific source(s) or a specific water body, and reflects the highest attainable condition for a specified period. A WQS variance provides a transparent mechanism to allow states and authorized tribes to make water quality improvements towards the eventual attainment of the designated use with timeframes that are justified and enforceable in NPDES permits. The metrics and thresholds in the 1997 FCA Guidance, 1995 WQS Guidance, and Alternative 1 of this FCA Guidance are based on an analysis of financial and economic data that reflect conditions during a particular period of time and are dynamic – i.e., a "snapshot" of financial and socio-economic data. As such, the metrics and analyses of the FCA Guidance are well-suited and most appropriate for evaluating requests for WQS variances under 40 CFR 131.10(g)(6) because the time-limited nature of a WQS variance ensures that changes in financial conditions would be considered if and when there is a request for a subsequent variance or at the time of reevaluation for a WQS variance with a duration longer than five years.

EPA has had considerable experience and success negotiating the schedule of water quality improvements under CWA consent decrees using the analytical approach in the 1997 FCA Guidance and evaluating time-limited WQS variances based on 40 CFR 131.10(g)(6) using the analytical approach in the 1995 WQS Guidance; however, the same cannot be said for revisions of designated uses (including revisions to less stringent use subcategories). While the analyses and metrics of Alternative 1 recommended in this FCA Guidance may be considered in evaluating requests for use revisions or a change to a less stringent use subcategory, EPA recommends caution in doing so because the analyses and metrics do not include a temporal component. To that end, EPA recommends states and authorized tribes first explore whether there are other factors under 40 CFR 131.10(g) that preclude attainment of the designated use when considering a revision to a designated use or a change to a less stringent use subcategory. These other factors involve evaluating environmental conditions that are less likely to change over time and are more likely to impact all segments of a community evenly, as opposed to evaluating economic conditions that are dynamic and more likely to be unevenly distributed within in a community.

When states and authorized tribes choose to pursue a use change or a change to a less stringent use subcategory based on 40 CFR 131.10(g)(6), they must first demonstrate the use is not an existing use as defined in 40 CFR 131.3. Additionally, an appropriate demonstration supporting a revision to a use or a change to a less stringent use subcategory must satisfy all the requirements in the WQS regulations at 40 CFR part 131, including those at 40 CFR 131.10, and would include the expanded multi-step approach to evaluate economic impacts as described in Section III.d. Further, there are additional analyses and actions EPA recommends when considering a revision to a designated use or a change to a less stringent use subcategory: 1) a trend analysis of the LQPI Score (see Section II.a.3) over the most recent 10-year period to ensure that the prevalence and severity of poverty is representative of the community's low-income households over time; and 2) an evaluation of up-to-date economic information (including consideration of future debt capacity) when evaluating an initial request or when conducting triennial reviews in accordance with WQS

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regulations[34] to determine whether the original designated use or more stringent use subcategory is now attainable.

b. WQS Decisions with Potential Environmental Justice Concerns

In addition to completing an economic analysis that includes the Financial Alternatives Analysis described in Section III.d.3 and the consideration of any other applicable financial metrics, a community, state, or authorized tribe is strongly encouraged to consider other opportunities to mitigate the negative impacts of WQS decisions that may affect areas with potential environmental justice concerns. For example, EPA recommends activities required in a WQS variance be sequenced in a manner that mitigates impacts to areas with potential environmental justice concerns as early as possible. In addition, EPA recommends the state or authorized tribe provide opportunities for public comments on potential environmental justice concerns during the public hearings required by the WQS regulations when proposing changes to designated uses and during subsequent triennial reviews.

c. Consideration of Additional Community-Specific Information

Because the critical metrics and analysis EPA recommends in the FCA Guidance may not always provide a complete picture of a community's financial capability, EPA encourages states and authorized tribes to include any additional information and documentation they deem relevant to understanding the economic impacts of potential WQS decisions on a community. In addition to the recommended critical metrics in Alternative 1, financial and rate models in Alternative 2 (as discussed in Section II.b.1) and Other Metrics (as discussed in Sections II.c and II.d) may provide additional information for consideration in WQS decision-making. However, EPA does not recommend the use of financial and rate models alone for supporting WQS decisions. Although financial and rate models may provide information on the impact of different rate scenarios over time that may be useful for determining a compliance schedule or the appropriate term of a WQS variance, these models alone do not provide sufficient information to determine if required wastewater treatment projects would result in substantial economic and social impacts. Nor do they indicate whether lowering of water quality would be necessary to accommodate important economic or social development. Furthermore, the binary "yes or no" decision-making associated with WQS actions would be difficult using financial and rate models alone because Alternative 2 does not include specific thresholds for determining reasonable rates that would be uniformly applicable across all communities.

[34] 40 CFR 131.20(a): "The State shall from time to time, but at least once every 3 years, hold public hearings for the purpose of reviewing applicable water quality standards adopted pursuant to §§ 131.10 through 131.15 and federally promulgated water quality standards and, as appropriate, modifying and adopting standards. The State shall also re-examine any waterbody segment with water quality standards that do not include the uses specified in section 101(a)(2) of the Clean Water Act every 3 years to determine if any new information has become available. If such new information indicates that the uses specified in section 101(a)(2) of the Act are attainable, the State shall revise its standards accordingly …".

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d. Steps to Evaluate Potential Economic Impacts on Public Entities

1. Determine the Initial Economic Impact

Calculate the Municipal Preliminary Screener (MPS) and Secondary Score (SS) for use in this step as recommended in the 1995 Guidance and the online tools at: https://www.epa.gov/wqs-tech/spreadsheet-tools-evaluate-economic-impacts-public-sector. Then, apply the MPS and SS results to Exhibit 11 below to determine the initial economic impact on the public entity. Exhibit 11 below is effectively the same as Table 2-2 in the public sector section of the 1995 WQS Guidance.

Exhibit 11. Initial Economic Impact

SECONDARY SCORE (SS)	MUNICIPAL PRELIMINARY SCREENER (MPS) (COST AS A PERCENT OF MEDIAN HOUSEHOLD INCOME)		
	BELOW 1.0%	1.0% TO 2.0%	ABOVE 2.0%
Below 1.5 (Weak Economy)	Impact Unclear	Substantial Impact	Substantial Impact
1.5 to 2.5 (Mid-Range Economy)	Impact Not Likely to be Substantial	Impact Unclear	Substantial Impact
Above 2.5 (Strong Economy)	Impact Not Likely to be Substantial	Impact Not Likely to be Substantial	Impact Unclear

2. Determine the Lowest Quintile Poverty Indicator Score

Calculate the Lowest Quintile Poverty Indicator (LQPI) score as described in Section II.a.3.

3. Perform a Financial Alternatives Analysis

EPA recommends performance of a Financial Alternatives Analysis. The goal of this step is to seek ways to minimize financial impacts while ensuring residents also enjoy the benefits of infrastructure investments and improved water quality. WQS revisions that lower the goals for a water body may create environmental justice concerns by potentially widening water quality and health disparities among communities. On one hand, low-income households may be paying a higher percentage of their total income for basic services and clean water, but on the other hand, if WQS decisions lower the water quality goals of a community, overburdened and/or low-income neighborhoods will likely continue to suffer impacts to human health and the environment from lower water quality.

When CWA compliance costs impact residents (particularly low-income households), WQS variances, designated use changes, or lowering water quality through antidegradation reviews may not be the best solution to address impacts to those residents. In particular, if a community shows strong economic indicators in other categories, there may be better options for the community to address the potential financial burden faced by its residents or take other steps to reduce the costs of needed CWA controls. If the intended goal is to address impacts to residents, allowing lowering of water quality may have the opposite

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effect by increasing pollution in the neighborhoods where they live. Nonetheless, EPA understands the significant impacts that additional costs can pose to communities, especially underserved and lower-income communities.

A Financial Alternatives Analysis can support lowering of water quality where there is a holistic financial strategy to balance the financial and environmental impacts. The analysis should document whether the community has considered feasible steps to reduce costs and address impacts to low-income households, including use of variable rate structures, CAPs, and applications for grants or subsidies from the CWSRF. Use of variable rate structures, CAPs, and grants or subsidies from the CWSRF are all potential tools to enable meeting water quality standards or avoiding the lowering of water quality associated with antidegradation reviews without burdening low-income customers. The demonstration of a comprehensive Financial Alternatives Analysis should include the results of the "checklist" of financing and funding considerations in Appendix C[35] and describe the specific programs being implemented. The community[36] should provide a list of the programs or steps considered, the actions that would be necessary to put such measures into place, and the plan for taking those actions. Where available tools are not included in the community's plans, it should provide a written explanation of why those approaches are not being pursued. EPA has provided an Example Financial Alternatives Worksheet in Appendix C that can help document this information. A community can demonstrate through the Financial Alternatives Analysis that it has taken or is pursuing feasible steps included in Appendix C to lower costs of compliance and reduce or mitigate the financial impact of water service costs on the community's low-income households. The first-line responsibility for balancing financial impacts while achieving clean water improvements rests with the local community. However, EPA is committed to carefully reviewing financial impacts and using the tools and technical assistance at the Agency's disposal to help local communities mitigate environmental (and related financial and societal) impacts of CWA noncompliance for communities.

EPA recognizes that whether a particular financial alternative is feasible may be different for entities such as a sanitary district or sewer authority. For instance, a utility may not be the rate setting authority for its entire service area if it serves wholesale customers. Certain utilities may need to work with the municipality or municipalities it serves as well as their state or authorized tribe to obtain the information to complete the Financial Alternatives Analysis. Users of this guidance should document any relevant differences in feasibility or practicality (see, e.g., Column B of the Example Financial Alternatives Worksheet) for consideration by EPA. Understanding such differences allows for WQS decisions that are responsive to circumstances unique to each community while advancing the goal of protecting clean water.

Performing the Financial Alternatives Analysis, especially at the beginning of an economic impact analysis for WQS decisions, may help provide the community with a clearer understanding of all costs associated with the

[35] A financial or funding consideration listed in Appendix C may be prohibited by state law. Other mechanisms to achieve the same goals may be feasible alternatives. There are examples, which can be found in Appendix C, of communities that have implemented similar or analogous mechanisms to reduce financial impacts within the limits of the relevant legal boundaries.

[36] For WQS decisions, a community may perform the Financial Alternatives Analysis and provide it to the state or authorized tribe. However, regardless of who performs the Financial Alternatives Analysis, the state or authorized tribe is responsible for evaluating the information and documenting how the information supports the WQS decision. Where required, the state or authorized tribe would also provide this information to EPA.

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implementation of CWA controls, such as reduced costs associated with low-interest loans, increased revenue from utility fees, or the costs associated with programs that assist low-income households. Where a community has implemented certain financial alternatives, the associated costs or cost savings from those alternatives could be accounted for in the Municipal Preliminary Screener and Secondary Score. Communities should demonstrate how the CWA-associated costs in the financial capability assessment will be implemented, including appropriate assurances that those expenditures will be made. Without the types of information developed in the Financial Alternatives Analysis, it will likely be more difficult for EPA to assess possible economic impacts and whether those impacts might outweigh the environmental impacts of a WQS variance, the revision of a designated use, or the lowering of water quality through an antidegradation review. Thus, recommendations for WQS decisions, as shown in Exhibit 13, are more conservative without a Financial Alternatives Analysis.

Considerations for Resource Constraints, In Particular for Small Communities

EPA recognizes that not all communities have the capability to fully evaluate the tools identified in Appendix C. If there are resource concerns with completing a Financial Alternatives Analysis, the community should seek support in completing a Financial Alternatives Analysis through EPA's Water Finance Center by sending an email to WaterTA@epa.gov. If resource constraints remain, the community should provide information on current and planned efforts to relieve impacts on low-income residential households in a format that represents a good-faith effort relative to the size of the community's service area. Without the types of information developed in a Financial Alternatives Analysis, it will likely be more difficult for EPA to assess likely impacts to low-income households and determine whether those impacts outweigh the environmental impacts of lower water quality from WQS revisions or antidegradation reviews. EPA understands for small communities, particularly those serving a population less than 3,000, it may not be feasible to make a good faith effort. The Agency will be mindful of those resource constraints when evaluating WQS decisions. In addition, the Agency recommends that the NPDES permitting authority be mindful of such constraints when conducting antidegradation reviews.

4. Combine the Initial Economic Impact and LQPI Score

Use the Expanded Economic Impact Matrix in Exhibit 12 below to combine the results from the Initial Economic Impact (Exhibit 11) and the LQPI score (from Step 2).

Exhibit 12. Expanded Economic Impact Matrix

INITIAL ECONOMIC IMPACT (MPS AND SS)	LOWEST QUINTILE POVERTY INDICATOR (LQPI) SCORE		
	LOW IMPACT	MEDIUM IMPACT	HIGH IMPACT
Impact Not Likely to be Substantial	Impact Not Likely to be Substantial	Impact Not Likely to be Substantial	Impact Unclear
Impact Unclear	Impact Not Likely to be Substantial	Impact Unclear	Substantial Impact
Substantial Impact	Impact Unclear	Substantial Impact	Substantial Impact

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5. Recommendations for Making WQS Decisions Related to Economic Impacts for the Public Sector

Exhibit 13 shows EPA's recommendations for making WQS decisions after applying the Expanded Economic Impact Matrix from Exhibit 12, including consideration of financial alternatives where appropriate and additional analyses when evaluating changes to designated uses. EPA notes that Exhibit 13 does not indicate that WQS decisions should be rigidly determined according to the break points between the categories. Information on Other Metrics or analysis of financial and rate models may provide additional information that could influence WQS decisions. Further, EPA recommends that in addition to completing the economic analyses recommended in this section and considering any other financial metrics, opportunities to mitigate impacts of WQS decisions to areas with potential environmental justice concerns should be considered (see Section III.b).

The Financial Alternatives Analysis provides especially critical information to facilitate WQS decisions that strive to restore and maintain water quality to the greatest extent possible consistent with the objectives of the CWA. Performance of a Financial Alternatives Analysis in accordance with Section III.d.3 and Appendix C including loans, grants, customer assistance programs, and alternative rate structures may reveal the ability to attain the designated use or avoid the need to lower water quality, and the ability to mitigate impacts to low-income communities. An appropriate economic justification for a WQS variance, revision of a designated use, or lowering of water quality associated with an antidegradation review should demonstrate that implementation of feasible financial alternatives under current or reasonably expected future economic conditions (including consideration of future debt capacity) would still result in substantial economic impact that would preclude the designated use from being attained[37] or would justify lowering water quality to accommodate important economic or social development.

Performance of a Financial Alternatives Analysis provides important information when interpreting the outcome of Exhibit 12. As previously noted, without the types of information developed in a Financial Alternatives Analysis, it will likely be more difficult for EPA to assess possible economic impacts and whether those impacts might outweigh the environmental impacts of a WQS variance, the revision of a designated use, or the lowering of water quality through an antidegradation review. Thus, as shown in Exhibit 13, recommendations for WQS decisions are more conservative without a Financial Alternatives Analysis.

[37] The regulations at 40 CFR 131.10(g) require adoption of the highest attainable use when adopting a new or revised water quality standard based on the required use attainability analysis. A Financial Alternatives Analysis could inform the determination of the highest attainable use.

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Exhibit 13. Recommendations for Making WQS Decisions for the Public Sector

RESULTS OF EXPANDED ECONOMIC IMPACT MATRIX	DID NOT PERFORM A FINANCIAL ALTERNATIVES ANALYSIS[38]	PERFORMED A COMPREHENSIVE FINANCIAL ALTERNATIVES ANALYSIS
IMPACT NOT LIKELY TO BE SUBSTANTIAL	**WQS variances and designated use revisions:** Not likely to demonstrate substantial economic impacts (40 CFR 131.10(g)(6)).[39] **Antidegradation reviews:** Not likely that economic or social development in the area in which the waters are located is important (40 CFR 131.12(a)(2)).[40]	
IMPACT UNCLEAR	**WQS variances and designated use revisions:** Not likely to demonstrate substantial impacts (40 CFR 131.10(g)(6)). **Antidegradation reviews:** Not likely that economic or social development in the area in which the waters are located is important (40 CFR 131.12(a)(2)).	**WQS variances:** Substantial impact (40 CFR 131.10(g)(6)) is likely unclear. Consider evaluation of other metrics (described in Sections II.c and II.d) or financial and rate models (Alternative 2 in Section II.b.1). **Designated use revisions:** Consider the Expanded Economic Matrix results in concert with the results of the Financial Alternatives Analysis and additional analyses and actions described in Section III.a for use changes. Also, consider evaluation of other metrics (described in Sections II.c and II.d) or financial and rate models (Alternative 2 in Section II.b.1). If substantial impacts remain unclear, consider whether a use change is appropriate at this time. **Antidegradation reviews:** Unclear that economic or social development in the area in which the waters are located is important (40 CFR 131.12(a)(2)). Consider evaluation of other metrics (described in Sections II.c and II.d) or financial and rate models (Alternative 2 in Section II.b.1).
SUBSTANTIAL IMPACT	**WQS variances:** Substantial impact is unclear (40 CFR 131.10(g)(6)). Consider evaluation of other metrics (described in Sections II.c and II.d) or financial and rate models (Alternative 2 in Section II.b.1). **Designated use revision:** Substantial impact is unclear (40 CFR 131.10(g)(6)). Consider additional analyses and actions described in Section III.a. Consider evaluation of other metrics (described in Sections II.c and II.d) or financial and rate models (Alternative 2 in Section II.b.1). Depending on result of such additional analyses, consider whether a use change is appropriate at this time. **Antidegradation reviews:** Unclear that economic or social development in the area in which the waters are located is important (40 CFR 131.12(a)(2)). Consider evaluation of other metrics (described in Sections II.c and II.d) or financial and rate models (Alternative 2 in Section II.b.1).	**WQS variances:** Substantial impacts likely (40 CFR 131.10(g)(6)). **Designated use revision:** Consider the results of the Expanded Economic Matrix in concert with the results of the Financial Alternatives Analysis and additional analyses and actions described in Section III.a for use changes to determine whether overall results continue to support a demonstration of substantial impact (40 CFR 131.10(g)(6)). **Antidegradation reviews:** Likely that economic or social development in the area in which the waters are located is important (40 CFR 131.12(a)(2)).

[38] EPA understands small communities, particularly those serving a population less than 3,000, may have resource constraints to make a good faith effort to conduct a Financial Alternatives Analysis. The Agency will be mindful of those resource constraints when evaluating WQS decisions. In addition, the Agency recommends that the NPDES permitting authority be mindful of such constraints when conducting antidegradation reviews.

[39] The analysis in this guidance only serves to determine if impacts are "substantial." A state or authorized tribe would still need to conduct an analysis to demonstrate the substantial impacts are "widespread."

[40] The analysis is this guidance only serves to determine whether the economic or social development in the area in which the waters are located is "important." A state or authorized tribe would still need to conduct an analysis of pollution control alternatives, consistent with 40 CFR 131.12(a)(2)(ii), to determine if such a lowering is "necessary."

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IV. List of Appendices

Appendix A. Residential Indicator Worksheets

Appendix B. Financial Capability Indicators Worksheets

Appendix C. Financial Alternatives Analysis Checklist and Example Financial Alternatives Worksheet

Appendix D. Resource Reference Guide for Utility/Community Financial Assistance

Appendix E. Examples of Other Metrics Relevant to Consideration of Financial Capability

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Appendix A. Residential Indicator Worksheets

Residential Indicator Worksheets UPDATED (2023)

This appendix contains an updated version of the steps necessary to prepare the Residential Indicator. The worksheets and instructions are largely identical to EPA's 1997 *Combined Sewer Overflows – Guidance for Financial Capability Assessment and Schedule Development*. Since data sources have evolved, this update recognizes the inputs that can be found today. In addition, "Practice Tips" in text boxes are incorporated to provide additional guidance on aspects of the Residential Indicator calculation that EPA has found are common questions and can benefit from additional direction.

CRITICAL METRIC: THE RESIDENTIAL INDICATOR

The Residential Indicator measures the financial impact of the current and proposed Clean Water Act (CWA) controls on residential users. Development of this indicator starts with the determination of the current and proposed wastewater system control costs per household (CPH). Second, the service area's CPH estimate and the median household income (MHI) are used to calculate the Residential Indicator. Finally, the Residential Indicator is compared to established financial impact ranges to determine whether required CWA controls will produce a possible "high," "mid-range," or "low" financial impact on the permittee's residential users. Worksheets are provided to aid in developing the Residential Indicator.

Developing CPH Estimate

The first step in developing the CPH is to determine the permittee's total wastewater treatment (WWT) and collection system costs by adding together the current costs for existing wastewater treatment operations and the projected costs for any proposed CWA controls. The next step is to calculate the residential share of the total system costs. The final step is to calculate the CPH by dividing the residential share of total costs by the number of households in the permittee's total wastewater service area.

PRACTICE TIP: The total wastewater service area should include all retail and wholesale areas served.

Current wastewater system costs are defined as current annual wastewater operating and maintenance expenses (excluding depreciation) plus current annual debt service (principal and interest). This fairly represents cash expenses for current wastewater treatment operations. (Expenses for funded depreciation, capital replacement funds, or other types of capital reserve funds are not included in current WWT costs, because they represent a type of savings account rather than an actual operation and maintenance expense.)

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PRACTICE TIPS:

For a service area with wholesale customers, current costs should also include the wholesale customers' operations and maintenance (O&M) and debt service incurred to provide retail service and delivery of wastewater to the primary community. This information can be inserted as an explicit line item so that the calculation is transparent.

The community may provide more detailed breakout of O&M costs as sub-parts. These may include historical average asset management and payment-in-lieu of taxes (PILOT). Note that the community should perform a sensitivity analysis on the addition of PILOT to determine the overall impact on residential households with and without PILOT.

Estimates of total projected costs are made for any proposed CWA controls. Any concerns about including specific proposed WWT projects, combined sewer overflow (CSO) or other CWA controls in the projected costs, or the length of the planning period, should be discussed with the appropriate NPDES permitting and enforcement authorities. These costs should be provided in consistent year dollars and include projected increased operation and maintenance expenses plus projected debt service costs for any proposed WWT and CWA controls. The information and calculations used to develop the CPH and the Residential Indicator are presented in Worksheets 1 and 2 and their instructions.

Worksheet 1 Instructions

Current Costs: Enter the requested data on lines 100 through 109 of Worksheet 1. The operation and maintenance costs on lines 100 and 103 should include all significant cost categories, such as labor, chemicals, utilities, administration, and equipment replacement. Do not include depreciation on line 100 or line 103.

PRACTICE TIP: Divide lines 100 and 103 into sub-lines to further break out costs (e.g., 100a: O&M Expenses for Core Service Area City; 100b: O&M Expenses for Wholesale Community). An additional line item can be provided for asset management, along with an explanation of the basis for the value.

Projected Costs: Projected costs for compliance are identified on Lines 103 and 104. Costs should be provided in current dollars, preferably consistent with the year of the most recent demographic and current financial data. Adjust the projected annual WWT and CWA costs to current dollars using the appropriate cost indices, preferably for the geographical region of permittee.

PRACTICE TIP: Future capital costs should be in the same year dollars as the current cost data. Use the appropriate engineering construction cost index to adjust projected capital costs or related increased operations costs as necessary.

The annualized debt service cost information for the projected WWT facilities and projected CWA controls (Line 104) can be calculated using an annualization factor, which reflects the local borrowing interest rate and

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borrowing term of the permittee. For example, if the adjusted projected debt costs (current dollars) are $25,000,000 and typical borrowing terms include an interest rate of eight percent over 20 years, then costs can be annualized with the following calculation:

$$Annual\ Debt\ Service\ Costs = Adjusted\ Debt\ Costs\ \times Annualization\ Factor$$

$$Annual\ Debt\ Service\ Costs = \$25{,}000{,}000\ \times\ .1019 = \$2{,}547{,}500$$

The annualization factor for the example is calculated using the following formula:

$$Annualization\ Factor = \frac{Interest\ Rate}{(1\ +\ Interest\ Rate)^{years}\ -\ 1} + Interest\ Rate$$

$$Annualization\ Factor = \frac{.08}{(1 + .08)^{20} - 1} + .08 = .1019$$

Alternatively, annual debt service costs can be calculated in Excel spreadsheets using the following formula:

$$= -PMT(Interest\ Rate, Term\ of\ Loan\ in\ Years, Present\ Value\ of\ Projected\ Costs)$$

The annualized debt service cost for the projected CWA controls is entered on line 104. Line 104 should include future cash-financed capital. Divide lines 101 and 104 into sub-lines to further categorize debt service costs (e.g., 104a: Annual Revenue Bond Debt Service; 104b: Annual Pay-Go Costs). Add the current and projected wastewater treatment and projected CWA control costs to estimate the total WWT and CWA costs (line 102 + line 105).

PRACTICE TIP: The debt service should be estimated based on the source and type of debt or other financing expected to be used to pay for necessary capital expenditures, including state clean water revolving and pooled funds.

Residential Share: Calculate the residential share of the total cost (line 106) and enter on line 107. The residential share of total costs (line 107) is computed by multiplying the percent of total wastewater flow including infiltration and inflow attributable to residential users by the total costs (line 106).

For example, for a permittee with the following characteristics:

Total Costs:	$12,000,000
Residential Flow:	10.5 Million Gallons per Day
Total Flow:	13.1 Million Gallons per Day

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PRACTICE TIPS:

The residential share represents costs for all households, whether in single-family homes or in multi-unit condominiums or apartment buildings. Residential costs exclude the portion of expenses attributable to commercial, governmental, and industrial customers. Permittees that treat multi-unit household as commercial accounts within the billing system need to estimate the flows attributable to those households.

In general, the residential share is based on billed flow for residential households. If supported by documentation, the residential share may be adjusted for infiltration and inflow (I&I) based on how the permittee addresses I&I in its bills.

The residential share of the total cost is:

$$Residential\ Share\ of\ Costs = Total\ Costs\ \ x\ \frac{Residential\ Wastewater\ Flow}{Total\ Wastewater\ Flow}$$

$$Residential\ Share\ of\ Costs = \$12{,}000{,}000\ \times \frac{10.5\ Million\ Gallons\ per\ Day}{13.1\ Million\ Gallons\ per\ Day}\ = \$9{,}600{,}000$$

Calculate the CPH (line 109) by dividing total residential share costs (line 107) by the total number of households (line 108) in the permittee's total wastewater service area. The Residential Share percentage in this example is 80.2 percent.

Data Sources

The permittee's latest audited Annual Comprehensive Financial Report should be available to develop the current wastewater treatment costs.[1] In order to comply with accounting requirements, most permittees develop a combined statement of revenues, expenses, and changes in fund balance. These Annual Comprehensive Financial Reports should be available directly from the permittee, or, in some states, from central records kept by the state auditor or other state offices. The permittee may have a separate financial report, or its financial data may be incorporated into a municipality's report.

[1] For many communities, this Financial Report was previously characterized as a Comprehensive Annual Financial Report (CAFR), but the Governmental Accounting Standards Board has since indicated that the CAFR should now be referred to as the "Annual Comprehensive Financial Report."

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Projected costs in the wastewater service area should be available through the permittee's planning documents. Wastewater service area boundaries also should be available from the permittee, frequently in electronic format. The Census Bureau annually collects American Community Survey (ACS) data on the number of households by Census-designated place. If the permittee's service area is relatively contiguous with political boundaries, then do a search for "Census QuickFacts" with the name of the town or county. Alternatively, Census Table B25002 (refer to https://data.census.gov/cedsci/all?q=B25002) is a resource if a more nuanced estimate is required. Note that "occupied housing units" equals households. The permittee should use the most recent 5-Year ACS Household data in its FCA calculations.

PRACTICE TIPS:

Note that the volume of residential usage may not only include volume for residential customer accounts, but residential households may also be served through multi-unit structures in commercial accounts, such as apartment buildings. Census data can provide information on the number of households in multi-family structures, providing a basis for adjusting the residential usage. The residential share tends to be lower for communities with more commercial or industrial customers, and generally higher in suburban, predominately residential areas.

Particularly for more complex service areas, electronic Geographic Information System (GIS) shapefiles can be analyzed with census electronic files to better characterize the service area households. Many utilities already have GIS mappings of the service area to assist in management of the system. In addition, note that in Census terminology, a "household" is equal to an "occupied housing unit," so data characterizing occupied housing units may be helpful to understanding the nature of the permittee's service area. In addition, the permittee should not use "residential customer" counts to estimate households, as more than one household may occupy a residential customer site, and households may live in commercial multi-unit customer properties.

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COST PER HOUSEHOLD: Worksheet 1

		LINE NUMBER
Current WWT Costs		
Annual Operations and Maintenance Expenses (Excluding Depreciation)		100
Annual Debt Service (Principal and Interest)		101
Subtotal of Current Costs (Line 100 + Line 101)		102
Projected WWT and CWA Costs (Current Dollars)		
Estimated Annual Operations and Maintenance Expenses (Excluding Depreciation)		103
Annual Debt Service (Principal and Interest)		104
Subtotal of Projected Costs (Line 103 + Line 104)		105
Total Current and Projected WWT and CWA Costs (Line 102 + Line 105)		106
Residential Share of Total WWT and CWA Costs		107
Total Number of Households in Service Area		108
Cost per Household (Line 107 ÷ Line 108)		109

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Developing the MHI Estimate

The second step in developing the Residential Indicator is to determine the median household income (MHI) for the permittee's entire wastewater service area. Information and calculations used to develop the MHI value are presented in Worksheet 2 and its instructions.

Worksheet 2 Instructions

Enter the requested information on Worksheet 2, lines 201 through 203. If the permittee's service area is relatively contiguous with political boundaries, then do a search for "Census QuickFacts" with the name of the town or county. Alternatively, Census Table B19013 (refer to https://data.census.gov/cedsci/all?q=B19013) is a resource if a more nuanced estimate is required. The permittee should use the most recent 5-Year Average MHI data in its FCA calculations.

PRACTICE TIP: For more complex service areas, electronic Geographic Information System (GIS) shapefiles can be analyzed with census electronic shapefiles, allowing a more precise characterization of the MHI for service area households. Many permittees already have GIS mappings of the service area to assist in management of the system.

On Worksheet 2, calculate the adjusted MHI by entering the most recent 5-Year census MHI value on line 201. Then enter the MHI Adjustment Factor, if any, on line 202. Finally, multiply the MHI (line 201) by the Adjustment Factor (line 202) and enter the Adjusted MHI on line 203.

PRACTICE TIP: In general, an adjustment factor is not required given that the Census data is the most up-to-date information available. Identify the year of the Census data, and if an adjustment is made, provide an explanation.

If the permittee's service area includes more than one jurisdiction, it may be necessary to develop a weighted MHI for the entire service area. The Bureau of Census's designated MHI areas generally encompass most permittee's service areas. For this reason, the calculation of a weighted MHI usually will not be necessary to reasonably represent the permittee's MHI. When a weighted MHI must be calculated, a weight would be assigned to each jurisdiction to reflect its share of the total households.

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The following example illustrates how to develop a weighted MHI value. If a permittee is a regional authority that serves three local jurisdictions, the weighted average MHI would be calculated as follows:

JURISDICTION	MHI	NUMBER OF HOUSEHOLDS (HH)
A	$30,000	100,000
B	$45,000	25,000
C	$25,000	50,000
		175,000

$$Weighted\ MHI = MHI_A \left(\frac{HH_A}{Total\ HH}\right) + MHI_B \left(\frac{HH_B}{Total\ HH}\right) + MHI_C \left(\frac{HH_C}{Total\ HH}\right)$$

$$\$30{,}000\left(\frac{100{,}000}{175{,}000}\right) + \$45{,}000\left(\frac{25{,}000}{175{,}000}\right) + \$25{,}000\left(\frac{50{,}000}{175{,}000}\right)$$

$$\$17{,}143 + \$6{,}429 + \$7{,}143 = \$\mathbf{30{,}715}$$

Data Sources

Median household income is available for most communities from the latest annual Census ACS data collection. In the few cases where a local jurisdiction's MHI is not available, the surrounding county's MHI may be sufficient. The Census Bureau provides annual 5-Year Average Median Household Income data in Table B19013.

Developing the Residential Indicator

Worksheet 2 Instructions

To calculate the Residential indicator (line 205 of Worksheet 2), divide the total annual control cost per household (line 109 transferred to line 204) by the Adjusted MHI (line 203) and multiply by 100.

Analyzing the Residential Indicator

The Residential Indicator will be used in the Expanded Financial Capability Matrix to help permittees, and EPA and state NPDES authorities determine reasonable and workable long-term wastewater system control schedules.

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To assess the financial impact CWA controls may have on the permittee's residential users, the Residential Indicator is compared to the financial impact ranges that reflect EPA's previous experience with water pollution control programs. These ranges are as follows:

FINANCIAL IMPACT	RESIDENTIAL INDICATOR (CPH AS % MHI)
Low	Less than 1.0 Percent of MHI
Mid-Range	1.0 to 2.0 Percent of MHI
High	Greater than 2.0 Percent of MHI

When the Residential Indicator is less than 1.0 percent, 1.0 to 2.0 percent, and greater than 2.0 percent, the financial impact on residential users to implement the CWA controls will be characterized as "low," "mid-range," and "high," respectively. Unless there are significant weaknesses in a permittee's financial and socioeconomic conditions, second phase reviews for permittees that have a low residential indicator score (less than 1.0) are unlikely to result in longer implementation schedules. Permittees with low residential indicators may wish to forego the second phase analysis and proceed with the normal engineering and construction implementation schedule developed as part of the planning process.

In situations where a permittee believes that there are unique circumstances that would affect the conclusion of the first phase, the permittee may submit documentation of its unique financial conditions to the appropriate state NPDES and EPA authorities for consideration.

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RESIDENTIAL INDICATOR: Worksheet 2

		LINE NUMBER
Median Household Income (MHI)		
Census Year MHI		201
MHI Adjustment Factor		202
Adjusted MHI (Line 201 x Line 202)		203
Annual WWT and CWA Control Cost per Household (CPH) (Line 109)		204
Residential Indicator		
Annual Wastewater and CWA Control Costs per Household as a percent of Adjusted Median Household Income (CPH as % MHI) (Line 204 ÷ Line 203 × 100)		205

FINANCIAL IMPACT	RESIDENTIAL INDICATOR (CPH AS % MHI)
Low	Less than 1.0 Percent of MHI
Mid-Range	1.0 to 2.0 Percent of MHI
High	Greater than 2.0 Percent of MHI

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Appendix B. Financial Capability Indicators Worksheets

Financial Capability Indicator Worksheets UPDATED (2023)

This appendix contains an updated version of the steps necessary to prepare the Financial Capability Indicators. The worksheets and instructions are largely identical to EPA's 1997 *Combined Sewer Overflows – Guidance for Financial Capability Assessment and Schedule Development*. Since data sources have evolved, this update recognizes the inputs that can be found today. In addition, "Practice Tips" in text boxes are incorporated to provide additional guidance on aspects of the Financial Capability Indicators that EPA has found are common questions and can benefit from additional direction.

CRITICAL METRIC: PERMITTEE FINANCIAL CAPABILITY INDICATORS

Selected indicators are assessed to evaluate the financial capability of the permittee. These indicators will examine the permittee's debt burden, socioeconomic conditions, and financial operations. The second-phase review examines three general categories of financial capability indicators for the permittee:

- **Debt Indicators.** Assess current debt burden of the permittee or the communities within the permittee's service area and their ability to issue additional debt to finance the CWA controls. The indicators selected for this purpose are:
    - Bond Ratings (General Obligation and/or Revenue Bond Fund)
    - Overall Net Debt as a Percent of Full Market Property Value
- **Socioeconomic Indicators.** Assess the general economic well-being of residential users in the permittee's service area. The indicators selected for this purpose are:
    - Unemployment Rate
    - Median Household Income
- **Financial Management Indicators.** Evaluate the permittee's overall ability to manage financial operations. The indicators selected for this purpose are:
    - Property Tax Revenue Collection Rate
    - Property Tax Revenues as a Percent of Full Market Property Value

Even though the financial capability analysis reflects current conditions, pending changes in the service area should be considered in development of the second phase indicators. For example, if the current unemployment rate is high, but there is a new plant opening that will stimulate economic growth, the unemployment indicators for the service area would need to be modified to reflect the projected impact of

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the new plant. The permittee should submit documentation of such conditions to the appropriate EPA and state NPDES authorities for consideration. When the permittee is a sanitary district, sewer authority or similar entity, the second phase indicators related to property values and tax revenues may not be applicable. In those circumstances, the permittee may simply use the remaining indicators or submit other related documentation that will help assess its financial capability to implement the necessary wastewater system controls.

DEBT INDICATORS

The debt indicators described below were selected to assess the current debt burden conditions and the ability to issue new debt. These indicators are the bond rating and overall net debt as a percent of full market property value. When these indicators are not available for the permittee, other financial data which illustrates debt burden and debt issuing capacity may be used to assess the permittee's financial capability in this area.

Bond Rating (Worksheet 3)

The information needed to evaluate the bond ratings is presented in Worksheet 3. Recent bond ratings for the permittee and service area communities summarize a bond rating agency's assessment of a permittee's or community's credit capacity. General obligation (G.O.) bonds are bonds issued by a local government and repaid with taxes (usually property taxes). They are the primary long-term debt funding mechanism in use by local governments. General obligation bond ratings reflect financial and socioeconomic conditions experienced by the community as a whole.

"Revenue bond" ratings, by comparison, reflect the financial conditions and management capability of the wastewater utility. They are repaid with revenues generated from user fees. Revenue bonds are sometimes referred to as water or sewer bonds. In some cases, these bonds may have been issued by the state on behalf of local communities.

Bond ratings normally incorporate an analysis of a wide variety of quantitative and qualitative financial capability indicators. These analyses evaluate the long-term trends and current conditions for the indicators. The ultimate bond ratings reflect a general assessment of the permittee's current financial conditions. However, if security enhancements like bond insurance have been used for a revenue bond issue, the bond rating may be higher than justified by the local conditions.

PRACTICE TIP: If the permittee's or community's rating was enhanced through bond insurance, the uninsured rating should be stated in the bond prospectus, and that value should be provided in the FCA analysis.

Many small and medium-sized communities have not used debt financing for projects and, as a result, have no bond rating. The absence of bond rating does not indicate strong or weak financial health. When a bond rating is not available, this indicator may be excluded from the financial analysis.

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Worksheet 3 Instructions

Enter the most recent bond ratings on Worksheet 3, lines 301 and 302. Note that ratings are requested for general obligation bonds and revenue bonds. When there are several different bond ratings, enter the most recent bond rating on Line 303 as the summary bond rating.

Data Sources

Municipal bond reports from rating agencies (e.g., Moody's Bond Record, Standard & Poor's Corporation, and Fitch) provide recent ratings. Municipal bond prospectuses typically list the bond rating in the upper-right corner of the cover page and within the “Ratings” section of the report. General Obligation and Revenue Bond prospectuses are available at: https://emma.msrb.org/. Municipalities also may have reports from rating agencies summarizing updates of the rating status.

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BOND RATING: Worksheet 3

		LINE NUMBER
Most Recent General Obligation Bond Rating		
Date		
Rating Agency		
Rating		301
Most Recent Revenue (Water/Sewer or Sewer) Bond		
Date		
Rating Agency		
Bond Insurance (Yes/No)		
Rating		302
Summary Bond Rating		303

Benchmarks

Moody's Investor Services

"Baa" is the minimum investment grade rating. See *Moody's on Municipals – an Introduction to Issuing Debt* for a description of bond ratings.

Moody's Investor Services' Rating

- Weak: Ba, B, Caa, Ca, C
- Mid-Range: Baa
- Strong: Aaa, AA, A

Standard & Poor's; Fitch

"BBB" is the minimum investment grade rating. See Standard & Poor's *Municipal Finance Criteria* and Fitch's *Rating Definitions* for a description of bond ratings.

Standard & Poor's and Fitch Ratings

- Weak: BB, B, CCC, CC, C, D
- Mid-Range: BBB
- Strong: AAA, AA, A

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Overall Net Debt as a Percent of Full Market Property Value

Description

Overall net debt is debt repaid by property taxes in the permittee's service area. It excludes debt which is repaid by special user fees (e.g., revenue debt). This indicator provides a measure of the debt burden on residents within the permittee's service area and measures the ability of local governmental jurisdictions to issue additional debt. It includes the debt issued directly by the local jurisdiction and debt of overlapping entities, such as school districts. This indicator compares the level of debt owed by the service area population with the full market value of real property used to support that debt and serves as a measure of financial wealth in the permittee's service area. Information needed to develop overall net debt as a percent of full market value is identified on Worksheet 4.

Worksheet 4 Instructions

Enter requested data on Worksheet 4, lines 401 - 405.

- Line 401 - Direct Net Debt - Enter the amount of each jurisdiction's general obligation debt outstanding that is supported by the property in the permittee's service area. General obligation bonds are secured by the “full faith and credit” of the community and are payable from general tax revenues. This debt amount excludes general obligation bonds that are payable from some dedicated user fees or specific revenue source other than the general tax revenues. These general obligation bonds are called “double-barreled bonds.”
- Line 402 - Debt of Overlapping Entities - The Statistical Section of the permittee’s Annual Comprehensive Financial Report (ACFR) generally lists the outstanding debt attributable to the permittee’s service area. If not, calculate the permittee's service area's share of any debt from overlapping entities using the process illustrated below:
    - Identify in Column A below each overlapping entity that has incurred debt that must be partially supported by the permittee's service area. (Check the Statistical Section of the permittee’s ACFR or State assessor's office for this information).
    - Identify the total amount of tax-supported outstanding debt for each overlapping entity in Column B. Money in a sinking fund is not included in the outstanding debt since it represents periodic deposits into an account to ensure the availability of sufficient monies to make timely debt service payments.
    - Identify the percentage of each overlapping entity's outstanding debt charged to persons or property in the permittee's service area in Column C. The percentage is based on the estimated full market value of real property of the respective jurisdictions.
    - Multiply the total outstanding debt of each overlapping entity by the percentage identified for the permittee’s service area (Column B x C).
    - Add the figures in Column D to arrive at total overlapping debt for permittee's service area.

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(A) OVERLAPPING ENTITIES	(B) OUTSTANDING DEBT (LESS SINKING FUND)	(C) PERCENT CHARGEABLE TO PERMITTEE'S SERVICE AREA	(D) OUTSTANDING DEBT ATTRIBUTABLE TO PERMITTEE'S SERVICE AREA
County	$10,500,000	25%	$2,625,000
School District	$16,800,000	95%	$15,960,000
Total Overlapping Debt			$18,585,000

- Line 403 - Overall Net Debt - Add lines 401 and 402.
- Line 404 - Market Value of Property - The property value should reflect the full market value of real property excluding personal property within the permittee's service area. It is possible that the tax assessed property value will not reflect full market value. This occurs when the tax assessment ratio is less than one. In such cases the full market value of property is computed by dividing the total tax assessment value by the assessment ratio (the assessment ratio represents the percentage of the full market value that is taxed at the established tax rate). For example, if the assessed value is $1,000,000 and the assessment ratio is 50 percent then the full market value of real property is $1,000,000/.50 = $2,000,000.
- Line 405 - Overall Net Debt as a Percent of Full Market Property Value - Divide line 403 by line 404 and multiply by 100.

Data Sources

Debt information is generally available in the Statistical Section of the community's Annual Comprehensive Financial Report. In most cases the most recent Annual Comprehensive Financial Report is on file in the finance department of the community's website. Overlapping debt is also generally provided in a community's Annual Comprehensive Financial Report. Market value of real property is available in the Statistical Section of the community's Annual Comprehensive Financial Report. If not, the property assessment data should be readily available through the community, county, or State's assessor office. The boundary of most permittee's service areas generally conforms to one or more community boundaries. Therefore, prorating community data to reflect specific service area boundaries is not normally necessary for evaluating the general financial capability of the permittee.

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OVERALL NET DEBT AS A PERCENT OF FULL MARKET PROPERTY VALUE: Worksheet 4

		LINE NUMBER
Direct Net Debt (G.O. Bond Excluding Double-Barreled Bonds)		401
Debt of Overlapping Entities (Proportionate Share of Multijurisdictional Debt)		402
Overall Net Debt (Lines 401 + 402)		403
Full Market Value of Property		404
Overall Net Debt as a Percent of Full Market Property Value (Line 403 divided by Line 404 x 100)		405

Benchmarks

- Weak: Above 5%
- Mid-range: 2-5%
- Strong: Below 2%

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SOCIOECONOMIC INDICATORS

The socioeconomic indicators are used to assess the general economic well-being of residential users in the permittee's service area. The indicators used to assess economic conditions are unemployment rate and median household income. When the permittee has additional socioeconomic data, it may want to submit the data to the appropriate EPA and state NPDES authorities to facilitate a better understanding of the permittee's unique economic conditions. Several examples of this type of socioeconomic data could be poverty rate, population growth, and employment projections.

Unemployment Rate

Unemployment information is entered on Worksheet 5. The unemployment rate is defined as the percent of a permittee's service area residents on the unemployment rolls.

Worksheet 5 Instructions

Unemployment values are entered on lines 501 - 503 on Worksheet 5. If the unemployment rate for a permittee's service area is not available, the unemployment rate for the county in which the service area is located may be used as a substitute. On line 503, enter the average national unemployment rate.

Data Sources

The Bureau of Labor Statistics (BLS) maintains current unemployment rate figures for municipalities and counties with a population over 25,000. National and state unemployment data are also available for comparison purposes. This information can be obtained from the BLS Data Tools webpage at https://www.bls.gov/data. The most recent year of unemployment data should be used.

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UNEMPLOYMENT RATE: Worksheet 5

		LINE NUMBER
Unemployment Rate – Permittee		501
Source		
Unemployment Rate – County (use if permittee's rate is unavailable)		502
Source		
Benchmark		
Average National Unemployment Rate:		503
Source		

Benchmarks

Compare the permittee's unemployment values with the national average values. National averages are readily available through the Bureau of Labor Statistics.

- Weak: More than 1 percentage point above the National Average
- Mid-range: ± 1 percentage point of the National Average
- Strong: More than 1 percentage point below National Average

For example, if the national average unemployment rate is 6 percent, an unemployment rate greater than 7 percent would be considered weak, while an unemployment rate less than 5 percent would be considered strong.

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Median Household Income

Median household income (MHI) is defined as the median amount of total income dollars received per household during a calendar year in a given area. It serves as an overall indicator of community earning capacity. Worksheet 6 is used to present information for this indicator.

Worksheet 6 Instructions

Median household income was discussed during the first phase assessment and is presented on Worksheet 2. On line 601 of Worksheet 6, enter the adjusted MHI from Worksheet 2 (line 203). Enter the national MHI value for the same year on Line 602.

Data Sources

Median household income is available through Census Bureau ACS data at the following website: https://data.census.gov/. Refer to Table B19013: "Median Household Income in the Past 12 Months (in [Current Year] Inflation-Adjusted Dollars)."

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MEDIAN HOUSEHOLD INCOME: Worksheet 6

		LINE NUMBER
Median Household Income – Permittee (Line 203, Worksheet 2)		601
Source		
Benchmark		
National MHI		602
Source		
Relationship to Benchmark		
Permittee MHI Relationship to National MHI ((Line 601-Line 602)/Line 602)		603

Benchmarks

Compare the permittee's MHI to the adjusted national MHI:

- Weak: More than 25% below National MHI
- Mid-Range: ± 25% of the National MHI
- Strong: More than 25% above National MHI

FINANCIAL MANAGEMENT INDICATORS

The financial management indicators used to evaluate a permittee's financial management ability are property tax revenue as a percent of full market value of real property and property tax revenue collection rate.

Property Tax Revenues as a Percent of Full Market Property Value

This indicator can be referred to as the "property tax burden" since it indicates the funding capacity available to support debt based on the wealth of the community. It also reflects the effectiveness of management in providing community services.

Worksheet 7 Instructions

Property tax burden is computed on Worksheet 7. The full market value of real property was calculated in Worksheet 4, line 404. Enter the full market value on line 701. Enter the most recent year's property tax revenue on line 702. General fund revenues are primarily property tax receipts.

PRACTICE TIP: Property tax revenues should include both current year collections and collections of payments in arrears from prior year assessments.

Data Sources

Property tax revenue collection data and market value of real property are generally available in the Statistical Section of the community's Annual Comprehensive Financial Report. If not, property assessment and tax revenue collection data should be readily available through the community, county, or state assessor's office. Occasionally, the assessment and tax revenue data of communities partially serviced by the permittee may have to be prorated to provide a clearer picture of the permittee's property tax burden.

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PROPERTY TAX REVENUES AS A PERCENT OF FULL MARKET PROPERTY VALUE: Worksheet 7

		LINE NUMBER
Full Market Value of Real Property (Line 404)		701
Total Property Tax Revenues		702
Property Tax Revenue as a Percent of Full Market Property Value (702 ÷ 701 × 100)		703

Benchmarks

- Weak: Above 4%
- Mid-range: 2-4%
- Strong: Below 2%

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Property Tax Revenue Collection Rate

The property tax revenue collection rate is an indicator of the efficiency of the tax collection system and the acceptability of tax levels to residents.

Worksheet 8 Instructions

The property tax revenue collection rate is calculated on Worksheet 8. Total property tax revenues collected was listed in Worksheet 7, Line 702. Enter this value on line 801. Enter the property taxes levied on line 802. Divide the property tax revenue collected by the property taxes levied and multiply by 100 to present the collection rate as a percentage on line 803.

Data Sources

Property taxes levied and property tax revenues are available in a community's Annual Comprehensive Financial Report. Property taxes levied can also be computed by multiplying the assessed value of real property (see Worksheet 4, Line 404) by the property tax rate, both of which are available from a community's financial statements or the state assessor's office. Occasionally, the assessment and tax revenue data of communities partially serviced by the permittee may have to be prorated to provide a clearer picture of the permittee's property tax revenue collection rate.

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PROPERTY TAX REVENUE COLLECTION RATE: Worksheet 8

		LINE NUMBER
Property Tax Revenue Collected (Line 702)		801
Property Taxes Levied		802
Property Tax Revenue Collection Rate (Line 801 ÷ Line 802 × 100)		803

Benchmarks

- Weak: Below 94%
- Mid-range: 94-98%
- Strong: Above 98%

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Analyzing Permittee Financial Capability Indicators

This section describes how the indicators in the second phase may be used to generate an overall score of a permittee's financial capability. The indicators are compared to national benchmarks to form an overall assessment of the permittee's financial capability and its effect on implementation schedules in the long-term CWA control plan.

In situations where a permittee believes that there are unique circumstances that would affect the conclusion of the second phase, the permittee may submit documentation of its unique financial conditions to the appropriate EPA and state NPDES authorities for consideration. The purpose of additional information is to clarify unique circumstances which are not fairly represented by the overall scores of the selected indicators. An example could be where a state or community imposes restrictions on property taxes.

Worksheet 9 Instructions

The indicators generated from the worksheets are compared to the state, national, or industry benchmarks presented in Table B-1. Information compiled from Worksheets 3 through 8 is summarized in Column A on Worksheet 9. Score each of these values using the rating standards in Table B-1 and the following score benchmarks and enter the appropriate number in Column B. The score definitions are:

Benchmarks	**Score**
• Weak:	1
• Mid-Range:	2
• Strong:	3

To calculate an average score for the indicators, total the values in Column B and divide by the number of entries. Enter the average score on Line 907.

If it is not possible to develop one or more of the six indicators, the permittee should explain why the indicator is inappropriate or unavailable. Since the point of the analysis is to measure the overall financial impact of the wastewater system controls, the debt and socioeconomic indicators are generally better measures of this impact than the financial management indicators. Consequently, if one of the debt or socioeconomic indicators is not available, the two financial management indicators should be averaged and used as a single indicator to average with the available debt and socioeconomic indicators. This averaging is necessary so that undue weight is not given to the financial management indicators.

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Table B-1. Summary of Financial Capability Indicators Benchmarks

INDICATOR	STRONG	MID-RANGE	WEAK
Bond Rating	AAA – A (S&P) or Aaa – A (Moody's) or AAA – A (Fitch Ratings)	BBB (S&P) or BAA (Moody's) or BBB (Fitch Ratings)	BB - D (S&P) or Ba – C (Moody's) or BB - D (Fitch Ratings)
Overall Net Debt as a Percent of Full Market Property Value	Below 2%	2% - 5%	Above 5%
Unemployment Rate	More than 1 Percentage Point Below the National Average	± 1 Percentage Point of National Average	More than 1 Percentage Point Above the National Average
Median Household Income	More than 25% Above National MHI	± 25% of National MHI	More than 25% Below National MHI
Property Tax Revenues as a Percent of Full Market Property Value	Below 2%	2% - 4%	Above 4%
Property Tax Collection Rate	Above 98%	94% - 98%	Below 94%

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SUMMARY OF PERMITTEE FINANCIAL CAPABILITY INDICATORS: Worksheet 9

INDICATOR	COLUMN A: ACTUAL VALUE	COLUMN B: SCORE	LINE NUMBER
Bond Rating (Line 303)			901
Overall Net Debt as a Percent of Full Market Property Value (Line 405)			902
Unemployment Rate (Line 501)			903
Median Household Income (Line 601)			904
Property Tax Revenues as a Percent of Full Market Property Value (Line 703)			905
Property Tax Revenue Collection Rate (Line 803)			906
Permittee Indicators Score (Sum of Column B ÷ Number of Entries)			907
Financial Capability Indicators Rating			

FINANCIAL CAPABILITY INDICATORS RATING	SOCIOECONOMIC, DEBT, AND FINANCIAL INDICATORS
Weak	Below 1.5
Mid-Range	1.5 to 2.5
Strong	Above 2.5

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Appendix C. Financial Alternatives Analysis Checklist and Example Worksheet

Water infrastructure projects are a major undertaking for communities of all sizes and economic status. The Financial Capability Assessment (FCA) Guidance can serve as a planning tool for evaluating the financial resources a community has available to implement Clean Water Act (CWA) controls. It has been developed to assist in negotiating implementation schedules for CWA controls and in making certain water quality standards (WQS) decisions for public entities. Navigating the complex process of investing in water infrastructure is challenging, especially if financial resources are limited or if customers have difficulty paying their bills. This guidance is intended to help facilitate that process.

CWA compliance schedules should consider available subsidized funding and other financing arrangements as part of a financing plan to achieve compliance as soon as practicable.[1] Determining the costs and thoroughly planning how to fund and finance a project will help a community manage this process. Communities should also consider approaches that can be used to reduce or mitigate the financial impact of water services on low-income households, while still allowing the community to complete critical infrastructure improvements within a reasonable schedule. When developing an FCA, communities should complete a Financial Alternatives Analysis documenting whether the community has considered feasible steps to reduce costs and address impacts to low-income households. These steps include use of variable rate structures, customer assistance programs (CAPs), and applications for grants or subsidies from the Clean Water State Revolving Fund (CWSRF).

A Financial Alternatives Analysis demonstration should provide the results of the "checklist" of financing and funding considerations below and describe the specific programs being implemented to reduce financial burdens. The community should provide a list of the programs or steps already implemented or being considered, the actions that would be necessary to put such measures into place, and the plan for taking those actions. Where available tools are not included in the community's plans to mitigate financial impacts, the requester should provide a written explanation of why those approaches are not being pursued. Attached is an Example Financial Alternatives Worksheet that can help document this information. Finally, Appendix D: Resource Reference Guide provides useful links, explanations, and descriptions of alternative funding and financing approaches.

[1] Compliance schedules included in National Pollutant Discharge Elimination System (NPDES) permits must "require compliance as soon as possible, but not later than the applicable statutory deadline under the CWA." 40 C.F.R. § 122.47(a)(1). The CSO Control Policy requires that "each long-term CSO control plan . . . should [] include both fixed-date project implementation schedules (which may be phased) and a financing plan to design and construct the project as soon as practicable." 59 Fed. Reg. 18688, 18691 (April 19, 1994). In addition, EPA's Integrated Planning Framework states that integrated plans should include a financial strategy and capability assessment that ensures investments are sufficiently funded, operated, maintained and replaced over time and include consideration of current and planned rates and fees. See *Integrated Municipal Stormwater and Wastewater Planning Approach Framework*.

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Whether a particular financial alternative is feasible may be different for entities such as a sanitary district or sewer authority. For instance, a utility may not be the rate setting authority for its entire service area if it serves wholesale customers. Certain utilities may need to work with the municipality or municipalities it serves to obtain the information to complete the Financial Alternatives Analysis. Users of this guidance should document any relevant differences in feasibility or practicality (see, e.g., Column B of the Example Financial Alternatives Worksheet) for consideration by EPA. Understanding such differences allows for development of schedules that are responsive to circumstances unique to each community while advancing the mutual goal to protect clean water. Communities are also expected to work within the boundaries of applicable legal requirements or restrictions, including state regulations, when pursuing alternative funding approaches for their infrastructure projects.[2] In the event that a financial or funding consideration listed below is prohibited by state law or simply not possible, some version of the financial alternative may still be feasible if there are other avenues of reducing financial impacts that can be implemented within the limits of the relevant legal boundaries or state authorities. A summary of state regulatory policies related to customer assistance programs and innovative ways such programs have been funded in communities is available at https://efc.sog.unc.edu/resource/navigating-legal-pathways-rate-funded-customer-assistance-programs-guide-water-and/.

If a community needs assistance evaluating feasible options for funding and financing, EPA can provide technical assistance upon request to help complete the Financial Alternatives Analysis. Through the Water Infrastructure and Resiliency Finance Center (https://www.epa.gov/waterfinancecenter) and support from the Environmental Finance Centers (EFCs) and other EPA contractors and partners, EPA can provide technical assistance. This technical assistance is funded, in part, through the Bipartisan Infrastructure Law (BIL) and other EPA infrastructure assistance programs. It can include support to complete the Financial Alternatives Analysis and other more specific requests, such as completing State Revolving Fund applications, identifying funding options, assisting with rate design and analysis, and helping with asset management planning. Communities can request assistance with the Financial Alternatives Analysis and BIL-related funding by emailing WaterTA@epa.gov. States that need assistance with the review of completed Financial Alternatives Analysis may also contact the Water Finance Center by sending an email to WaterTA@epa.gov.

[2] For municipalities that are subject to federal civil actions, CWA Section 309(e) provides that "the State in which such municipality is located shall be joined as a party." To the extent that the laws of that State prevent the municipality from raising revenues needed to comply with any resulting judgement, then the State "shall be liable for payment of any judgment, or any expenses incurred as a result of complying with any judgment."

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Financial Alternatives "Checklist"

1. Financing Options for Capital Costs

Reducing overall capital costs through low interest rate loans, flexible loan terms, grants, etc. can help lessen the burden on low-income residents in a water utility's service area. The below questions can help identify potential lower cost alternatives to a community's current financing approach while still allowing for progress on capital improvement projects.

a) Has the community discussed financing options, including timing, terms, and potential grants or forgiveness, with the responsible State Revolving Fund?

More information on CWSRF projects and accessing these funds can be found in Appendix D: Resources Reference Guide.

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *The Clean Water State Revolving Fund (CWSRF) is a federal-state partnership that provides communities low-cost financing for a wide range of water quality infrastructure projects. These loans, which could be offered as grants or principal forgiveness loans, can help bring down the overall financing needs of an infrastructure project. Information about the CWSRF is available at https://www.epa.gov/cwsrf.*
- *Contacts for the State CWSRF programs are available at https://www.epa.gov/cwsrf/state-cwsrf-program-contacts.*
- *The Subsidized Loan Calculator Tool allows a utility to compare a loan through a State Revolving Fund program to a commercial loan at the market rate. The tool offers 3 different ways to look at savings: the interest savings in nominal dollars; the total cost of each option in nominal dollars; and the total cost of each option in real dollars. The tool is available at https://efc.sog.unc.edu/resource/what-value-srf-loan-subsidized-loan-calculator/.*
- *The Financing Alternatives Comparison Tool (FACT) is a financial analysis tool that helps municipalities, utilities, and environmental organizations identify the most cost-effective method to fund a wastewater or drinking water management project. FACT produces a comprehensive analysis that compares financing options for these projects by incorporating financing, regulatory, and other important costs. FACT is available at https://www.epa.gov/cwsrf/financing-alternatives-comparison-tool.*

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b) What additional funding sources beyond the SRF including non-SRF grants from states, EPA, and other federal agencies, grants, low-cost loans, or extended term loans has the community considered?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *By looking at all possible grants or low-cost loans, communities can obtain additional funding to cover their capital costs without increasing the burden on their customers. Many states have dedicated funds for wastewater projects. Check your state's environmental and/or public health agency website to find state specific loan and grant information to fund wastewater infrastructure projects.*
- *Numerous potential funding sources can be found in Appendix D: Resources Reference Guide. This section explains the types of funding available (including grants, loans, private sector funding, etc.) and includes links. Additionally, funding sources can be searched for in the Water Finance Clearinghouse database by state, eligible borrower, and funding type at https://www.epa.gov/waterdata/water-finance-clearinghouse.*

c) Has the community considered special assessment districts to finance geographically defined project work?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *Special assessments are used to provide and fund projects for a specific geographic area. Special assessment districts provide the legal arrangement to charge those receiving the service for capital and/or operating costs of the project. CWA projects may be funded with special assessments. For example, in Michigan, neighborhoods with significant basement flooding problems have approved the use of special assessments to fund corrections to their wastewater collection system that include correction of combined sewer overflow problems.*

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d) Has the community considered other revenue sources to reduce the direct burden on ratepayers such as sales or property taxes, rental income from water tower leases, or other potential sources of support?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *Many utilities have created additional revenue streams to pay for new infrastructure investments to reduce rate increases for their customers. Non-rate-based revenue can help to improve the organization's overall financial health by creating new sources of income for unexpected expenses and diversifying the utility's income in communities with decreasing volumes of water sold and collected (e.g., due to declining populations or water conservation programs). Examples of approaches communities have used to successfully bring in additional revenue can be found in Appendix D: Resources Reference Guide. Review this section and explore if any of these, or other approaches, could be used by your community to generate additional revenue.*

e) Has the community evaluated how it can reduce overall operating and program costs?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *A case study of a community that successfully reduced operating costs to free up revenue for capital improvements is available at https://efc.sog.unc.edu/resource/small-town-financial-viability-case-study-town-of-ahoskie-north-carolina/.*
- *Examples of strategies used by utilities with resource constraints to reduce costs, increase municipal capacity, and capture cost efficiencies by exploiting economies of scale can be found at https://graham.umich.edu/water/cs-managing-public-water.*

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2. Rate Design

Management of water systems is often sustained by customer revenues. Developing a rate structure that best supports the system's priorities and objectives will help systems meet their CWA obligations and reduce the burden on its customers. In completing this Financial Alternatives Analysis, communities should review how they currently set rates and review ways, within the boundaries of any applicable legal requirements or restrictions, including their state regulations, that rate design could be adjusted to offset costs to their most vulnerable residents while still making progress on their capital infrastructure projects. Options might include percentage of income plans, lifeline rates, payment restructuring programs, and customer charge waivers. Communities that need assistance with rate review and alternative approaches can contact EPA's Water Infrastructure and Resiliency Finance Center for technical assistance. Communities may also consult the Utility Financial Sustainability Tools and Rates Dashboards available at https://efc.sog.unc.edu/dashboards/ developed by the Environmental Finance Center at the University of North Carolina Chapel Hill. Communities can also use the Affordability Tool that is based in Tableau to provide a user-friendly experience of assessing a utility's water and wastewater rates. This tool is available at https://efcnetwork.org/tools-publications/water-and-wastewater-residential-rates-affordability-assessment-tool-tableau/.

For some communities, there may be legal restrictions related to rate-setting. When exploring alternative rate design approaches, communities should cite any legislative barriers, for example, in the "Challenges" section of the Example Financial Alternatives Worksheet. Even where there are legal barriers to certain types of financial alternatives, there may be other pathways to help low-income customers. Case studies of innovative approaches used by some communities to assist low-income residents beyond rate design can be found at https://efc.sog.unc.edu/wp-content/uploads/sites/1172/2021/06/Navigating-Pathways-to-Rate-Funded-CAPs.pdf, along with state specific regulations related to establishing customer assistance programs.

a) Describe the rate structure currently being used in the community. In what ways has the community evaluated modifications to its rate structure that could increase revenue and/or reduce burden on the lowest income residents?

Answers to this question serve to provide baseline information on rate approaches currently used by the community and highlight where alternative approaches could be used, if practical, to increase revenue or reduce burdens on lowest income residents.

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *EPA has information on rate designs available at https://www.epa.gov/waterfinancecenter/financial-technical-assistance-and-tools-water-infrastructure. Additionally, the EFC's Rate Dashboard available at https://efc.sog.unc.edu/dashboards/ is a tool that can be used to compare rate approaches.*
- *Communities can use the Affordability Tool developed by the EFC to assess a utility's water and wastewater rates. See https://efcnetwork.org/tools-publications/water-and-wastewater-residential-rates-affordability-assessment-tool-tableau/.*

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b) Has the community prepared a forward-looking financial plan and rate analysis within the last five years? If so, was the plan implemented?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *Forward looking financial planning and rate reviews should be part of every utility's best management practices. There are several online tools available including the EFC's online tools:*
  - *https://efc.sog.unc.edu/resource/plan-pay-scenarios-fund-your-capital-improvement-plan/*
  - *https://efcnetwork.org/tools-publications/water-and-wastewater-residential-rates-affordability-assessment-tool-tableau/*
- *Communities who need additional assistance in conducting a rate review or financial plan can contact the EPA's Water Infrastructure and Resiliency Finance Center for technical assistance (WaterTA@epa.gov).*

c) Has the community assessed the water use across its industrial, commercial, and residential customer base? If so, has the community/utility allocated wastewater costs to reflect the demands of each user group on the collection and treatment system? For example, does the community have separate rate structures for commercial, industrial, and wholesale customers reflecting their particular demands on the collection and treatment system? Has the community considered established tiered or conservation rates?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *Multiple rate structures allow the utility to recover the costs of various types of commercial and industrial customers. For some communities, there may be legal restrictions related to rate-setting. If these exist for your community, cite any legislative barriers in the "Challenges" section of the Example Financial Alternatives Worksheet (or other form of documentation you are providing for the Financial Alternatives Analysis).*

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d) Does the community use inclining block rates for residential customers that charge higher per gallon rates for higher increments of use?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *Utilities should seek to understand who their high-water users are and what the household structure and income-level of these customers are. Utilities can learn more about rate setting at https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=901U1200.TXT.*
- *Communities can also assess their rates and compare two rate structures side-by-side, enabling the utility to assess the affordability of its current rates alongside alternative rates using this tool developed by the EFCs: https://efcnetwork.org/tools-publications/water-and-wastewater-residential-rates-affordability-assessment-tool-tableau/.*

e) If charging a flat fee, has the community considered switching to a volumetric fee so that high-output customers pay for the wastewater they generate?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *While simple to implement, a flat fee charge for sanitary sewer service does not create any incentive for users to manage their water use, which is usually the basis for a wastewater bill. There are situations, especially with smaller utilities, where a flat charge is used because there is no water meter, or because of the costs of implementing a more sophisticated rate structure.*
- *Communities can use the rate analysis model available at https://efc.sog.unc.edu/resource/water-and-wastewater-rates-analysis-model to help evaluate water and/or wastewater rates for the next year by projecting the utility's expenses, revenues from rates, and fund balance.*

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3. Ratepayer Support Options for Lower Income Residential Customers

Utilities have adopted a variety of strategies to help residential customers with low or fixed incomes pay water or wastewater bills they cannot afford. Rate design, discussed above, can provide a sustainable approach for utilities that can allow lower income customers to consistently pay bills in full and on time. Some utilities have set up CAPs to help lower bills. CAPs can vary from utility to utility and can be particularly useful for households with a temporary need for assistance. Any utility that is concerned about the affordability of its rates on their low-income residential customers and is considering starting a CAP to provide financial assistance to these households can help determine costs by using the tool available at https://efc.sog.unc.edu/resource/bill-payment-assistance-program-cost-estimation-water-utilities/. Detailed summaries of regulatory policies on the design and funding of CAPs in each of the 50 states, the District of Columbia, and Puerto Rico can be found at https://efc.sog.unc.edu/wp-content/uploads/sites/1172/2021/06/Navigating-Pathways-to-Rate-Funded-CAPs.pdf. This document also includes case studies that demonstrate what can be done under a supportive regulatory environment or when a utility would like to create a robust, high-impact CAP within the limits of a more restrictive regulatory framework.

a) Has the community implemented, or considered implementing, a CAP?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *Households with low and/or fixed incomes, or households facing a temporary crisis such as job loss or illness may have difficulty paying water and sewer bills. Local not-for-profit or governmental organizations also may have short- or longer-term assistance for utility bills. Many wastewater and drinking water utilities use CAPs to meet specific customer needs and the financial needs of their drinking water delivery and/or wastewater management services.*
- *EPA produced a document of current CAP programs at water utilities. This document is designed to help drinking water and wastewater utilities build on their existing CAPs or adopt new CAPs by learning from the experiences of other utilities. Compendium of Drinking Water and Wastewater Customer Assistance Programs (EPA) is available at https://www.epa.gov/sites/production/files/2016-04/documents/dw-ww_utilities_cap_combined_508.pdf.*
- *Navigating Legal Pathways to CAPs (Environmental Finance Center at UNC Chapel Hill) is available at https://efc.sog.unc.edu/project/navigating-legal-pathways-rate-funded-customer-assistance-programs.*
- *Low Income Household Water Assistance Program (LIHWAP) provides funds to assist low-income households with water and wastewater bills. LIHWAP grants are available to states, the District of Columbia, the Commonwealth of Puerto Rico, U.S. Territories, and federally and state-recognized Indian tribes and tribal organizations that received fiscal year 2021 Low Income Household Energy Assistance Program (LIHEAP) grants. More information about LIHWAP is available at https://www.acf.hhs.gov/ocs/programs/lihwap.*

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b) If you have a CAP, what is the enrollment rate? What efforts have been made to ensure low-income households are informed about the program and enroll? Are there ways to make the application process easier for customers to enroll, e.g., by providing for enrollment in-person, online, and mail, in multiple languages, if appropriate; partnering with local organizations to help with outreach and enrollment; allowing for automatic enrollment or using proof of eligibility for other income-qualified benefits?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *Guidance on Developing CAPs (Water Research Foundation) is available at https://www.waterrf.org/research/projects/customer-assistance-programs-multi-family-residential-and-other-hard-reach.*
- *Best Practices in Customer Payment Assessment Programs (Water Research Foundation), is a review of best practices in utility programs to assist payment-troubled customers, assembled into a reference guide for use by utility management teams in developing and improving such programs. It is available at https://aquadoc.typepad.com/files/water_affordability_4004.pdf.*

c) Has the community considered other types of customer support beyond a CAP for lower income residential customers? Has the utility considered methods to include renters with water bill assistance?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *Utilities have implemented a variety of programs to provide households with short-term or long-term reductions through a Bill Discount, Flexible Terms, Lifeline Rate, Temporary Assistance, Income-based rates, and water conservation assistance. Example customer support approaches are found below. In the Example Financial Alternatives Worksheet or other form of documentation, identify if these examples or other types of programs are being used or explored. These might be feasible in your community or there might be legal or regulatory constraints to their implementation. Examples and case studies of these approaches are available at https://www.epa.gov/sites/default/files/2016-04/documents/dw-ww_utilities_cap_combined_508-front2.pdf.*
- *Example Customer Assistance Approaches:*
  - ***Lifeline Rate**—A low flat rate for an initial amount of usage to cover most or all of a household's basic needs such as drinking, cooking, and sanitation. Water consumption above the lifeline amount could be charged at a higher rate. May be applied to all customers or just low-income customers. For example, a community could charge a low flat rate for the first 50 gallons per person per day and a higher for usage beyond 50 gallons per person per day. Communities could evaluate household size of their low-income customers using Census data or use a default household size of between 1 and 2 people and consumption allowance between 1.5 and 3 kgal for fixed income households.*
  - ***Percentage-of-Income Payment Plan**—Rate design that prevents water bills from exceeding a certain percentage of the customer's income. Case studies of how this has been done in other communities can be found at https://waterassistanceprograms.org/.*

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KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- ***Bill Discount***—*Reduces an eligible low-income customer's bills by a flat dollar amount or a percent discount. This approach can be used to reduce the fixed service charge, the volumetric consumption charge, or both. Additionally, discounts can be tiered by income. Review barriers for your state at https://efc.sog.unc.edu/wp-content/uploads/sites/1172/2021/06/Navigating-Pathways-to-Rate-Funded-CAPs.pdf*
- ***Water Conservation Programs***—*Programs that reduce water use can lower utility operating costs and reduce customer bills. More information about these programs is available at https://www.epa.gov/system/files/documents/2021-07/ws-assistance-that-saves-efficiency-and-affordability.pdf. An analysis of the impact of these approaches in California is available at https://www.calwater.com/docs/conservation/Economic-Value-of-Water-Efficiency-Lower-Water-Bills.pdf.*

d) Are there policies in place to protect customers, including vulnerable populations, from shutoffs?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *Some utilities have developed programs and policies to prevent shutoffs. Examples of these programs include:*
  - *Chicago Utility Billing Relief Program. https://chicago.docugateway.com/main/quest/billing_relief/.*
  - *Philadelphia's Assistance Programs to ensure that residents who cannot pay bills will still have water services. https://www.phila.gov/2022-05-31-avoid-a-water-shutoff-new-protection-policies-and-expanded-assistance/.*

e) Does the community have reduced rates for vulnerable populations, such as seniors on fixed incomes?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *Some utilities have developed programs and policies to provide lower rates for seniors and/or low-income customers. Examples of these programs include:*
  - *Ayer, MA. https://www.ayer.ma.us/department-public-works/pages/sr-citizen-water-sewer-bill-discount-policy.*
  - *Acton, MA. https://www.actonwater.com/customer-service/senior-citizen-water-bill-discount-policy.*
  - *Revere, MA. https://www.revere.org/departments/water-and-sewer-billing#discount.*
  - *Examples from WA State. https://mrsc.org/Home/Explore-Topics/Public-Works/General-Utility-Topics/Senior-and-Low-Income-Utility-Rate-Discounts.aspx.*

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4. Financial and Utility Management

Effective utility management practices are the foundation for building and sustaining the financial capacity of water infrastructure systems. Management practices should address all aspects of a system's operations and maintenance. EPA's Effective Utility Management (EUM) Initiative takes a broad look at all aspects of water sector system sustainability from product quality to customer satisfaction. It is supported through the collaboration of EPA and professional associations across the water sector. The case studies, webinars, and frameworks developed under EUM can help inform communities on overall utility and financial management and assist in completing this section. EPA's Effective Water Utility Management Practices website is available at https://www.epa.gov/sustainable-water-infrastructure/effective-water-utility-management-practices.

a) Is the utility accounted for as a proprietary/enterprise fund or a separate independent utility?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *It is important that the utility is operated as a separate financial and business entity either within a broader governmental entity (i.e., city or county), or as an independent utility district. The wastewater utility may be effectively combined with the water utility, sharing administrative costs of billing, management, and staff. However, the financial results of the wastewater operation should be separable from the water operation.*

b) Are all rate revenues or other user charges used to fund the utility's operations? Do the rates charged recover the full cost of providing wastewater services (taking into consideration capital costs, operation and maintenance expenses, and environmental costs)?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *It is important that the utility's revenues are dedicated to the functions of the utility. If revenues are being transferred to other purposes, the utility is likely to be unable to meet its mission efficiently because of financial constraints.*

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c) Does the utility have programs to optimize maintenance and asset management to reduce life cycle costs?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *Systems implementing asset management develop detailed asset inventories, perform operation and maintenance tasks, conduct long-range financial planning, and undertake other activities that build system capacity. Asset management is a key element of long-term sustainability. EPA has a guide for state staff and technical assistance providers to assist small- and medium-sized drinking water or wastewater systems in identifying resources to implement asset management practices. This guide can assist in establishing an asset management plan in your community. The* Reference Guide for Asset Management Tools *is available at https://www.epa.gov/dwcapacity/reference-guide-asset-management-tools.*
- *The EFCs have also produced several tools and documents related to asset management in the water sector (https://www.efc.csus.edu/asset-management/).*
- *Technical Assistance is available for asset management plans from the EPA Water Technical Assistance page (*https://www.epa.gov/water-infrastructure/water-technical-assistance-waterta).

d) Are partnerships with other utilities, including joint procurement, or shared management and staffing arrangements, regionalization, or consolidations options to provide economies of scale and reduce per customer costs feasible in this community?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *Water system partnerships address common challenges that water systems face, leading to reduced overall operating costs through economies of scale and leveraging of existing resources. EPA has a website to find cooperative tools to address their drinking water challenges available at https://www.epa.gov/dwcapacity/learn-about-water-system-partnerships. It explores the different types of partnerships to consider, and outlines examples of successful partnerships across the country*
- *Case studies and analysis of strategies used by utilities with resource constraints to partner to reduce costs, increase municipal capacity, and capture cost efficiencies by exploiting economies of scale can be found at https://graham.umich.edu/water/cs-managing-public-water.*
- *Agricultural-municipal partnerships offer another innovative approach to reduce nutrients in a watershed at a potentially lower cost than traditional infrastructure upgrades. The Water Finance Center hosted a webinar on the potential benefits of these types of partnerships and will release a learning module highlighting the financing approaches used in the case studies available at https://www.epa.gov/system/files/documents/2021-07/ag-muni-partnerships-webinar-slides.pdf.*

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e) Has the utility or related municipality instituted a stormwater management program when evaluating long-term control plan schedules? If so, are impervious area-based stormwater fees used to fund the stormwater compliance costs?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- *Many communities around the country are establishing separate stormwater enterprise funds through utility fees or other separate funding mechanisms to create sustainable funding revenues for stormwater costs. The Western Kentucky University Stormwater Utility Survey provides a summary of these utilities at https://digitalcommons.wku.edu/cgi/viewcontent.cgi?article=1003&context=seas_faculty_pubs.*
- *There are different approaches to establishing more equitable stormwater rates. An overview of these approaches can be found at https://efc.sog.unc.edu/stormwater-fee-structure-design-is-one-fee-structure-more-equitable/ and can provide context of approaches that might be used in your community.*
- *EPA's Sewer Overflow and Stormwater Reuse Grant Program is available at https://www.epa.gov/cwsrf/sewer-overflow-and-stormwater-reuse-municipal-grants-program.*
- *Section 319 Grant Program for Nonpoint Source Pollution Control Efforts is available at https://www.epa.gov/nps/319-grant-program-states-and-territories.*

f) Does the utility provide direct financial assistance (through rebates, upfront subsidies, or direct replacement of fixtures) for efficiency improvements including leak repairs or replacement of inefficient fixtures or appliances?

KEY RESOURCES, TOOLS, AND INFORMATION SOURCES

- ***Water Conservation Programs** -Programs that reduce water use can lower utility operating costs and reduce customer bills. More information about these programs is available at https://www.epa.gov/system/files/documents/2021-07/ws-assistance-that-saves-efficiency-and-affordability.pdf. Analysis of the impact of these approach in California is available at https://www.calwater.com/docs/conservation/Economic-Value-of-Water-Efficiency-Lower-Water-Bills.pdf.*

g) Does the wastewater collection system and adjoined publicly owned treatment works pay a property tax to the city? Paying property taxes (i.e., a payment in lieu of taxes or PILOT) should be examined as it can erode the utility's financial capability to implement necessary improvements.

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EXAMPLE FINANCIAL ALTERNATIVES WORKSHEET: This worksheet can be used to help document completion of a Financial Alternatives Analysis to support developing implementation schedules for CWA controls and making certain water quality standards (WQS) decisions for public entities. Communities can list actions that they have taken and planned commitments for each alternative. Descriptions of resources and case studies related to financial alternatives are described in Appendix C.

FINANCIAL ALTERNATIVES ANALYSIS	DESCRIBE HOW FINANCIAL ALTERNATIVE HAS BEEN IMPLEMENTED OR CONSIDERED. WHERE CONSIDERED, INCLUDE ANY PLANS FROM COMMUNITY TO PURSUE ALTERNATIVE	WHERE TOOLS NOT PURSUED, DESCRIBE ANY ASSOCIATED CHALLENGES WITH THE ALTERNATIVE (E.G., IMPACT TO BOND RATING, INTEREST RATE NOT FAVORABLE)	DESCRIBE OUTCOMES OF ALTERNATIVE (E.G., GRANT APPLIED FOR, LOAN NOT PURSUED)
1. Financing Options for Capital Costs:			
a) Has the community discussed financing options, including timing, terms, and potential grants or forgiveness, with the responsible State Revolving Fund?			
b) What additional funding sources beyond the SRF such as grants, low-cost loans, or extended term loans has the community considered?			
c) Has the community considered special assessment districts to finance geographically defined project work?			
d) Has the community considered other revenue sources such as sales or property taxes, rental income from water tower leases, or other potential sources of support?			
e) Has the community evaluated how it can reduce overall operating and program costs?			
Other Considerations:			

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FINANCIAL ALTERNATIVES ANALYSIS	DESCRIBE HOW FINANCIAL ALTERNATIVE HAS BEEN IMPLEMENTED OR CONSIDERED. WHERE CONSIDERED, INCLUDE ANY PLANS FROM COMMUNITY TO PURSUE ALTERNATIVE	WHERE TOOLS NOT PURSUED, DESCRIBE ANY ASSOCIATED CHALLENGES WITH THE ALTERNATIVE (E.G., IMPACT TO BOND RATING, INTEREST RATE NOT FAVORABLE)	DESCRIBE OUTCOMES OF ALTERNATIVE (E.G., GRANT APPLIED FOR, LOAN NOT PURSUED)
2. Rate Design:			
a) In what ways has the community evaluated modifications to its rate structure that could increase revenue and/or reduce burden on the lowest income residents?			
b) Has the community prepared a forward-looking financial plan and rate analysis within the last five years? If so, was the plan implemented?			
c) Does the community have identified separate rate structures for commercial, industrial, and wholesale customers reflecting their particular demands on the collection and treatment system? Has the utility considered tiered based rates?			
d) Does the community use inclining block rates that charge higher per gallon rates for higher increments of use?			
e) If charging a flat fee, has the community considered switching to a volumetric fee so that high-output customers pay for the wastewater they generate?			
Other Considerations:			

FINANCIAL ALTERNATIVES ANALYSIS	DESCRIBE HOW FINANCIAL ALTERNATIVE HAS BEEN IMPLEMENTED OR CONSIDERED. WHERE CONSIDERED, INCLUDE ANY PLANS FROM COMMUNITY TO PURSUE ALTERNATIVE	WHERE TOOLS NOT PURSUED, DESCRIBE ANY ASSOCIATED CHALLENGES WITH THE ALTERNATIVE (E.G., IMPACT TO BOND RATING, INTEREST RATE NOT FAVORABLE)	DESCRIBE OUTCOMES OF ALTERNATIVE (E.G., GRANT APPLIED FOR, LOAN NOT PURSUED)
3. Ratepayer Support Options for Lower Income Residential Customers:			
a) Does the community currently have, or looked into, setting up a CAP?			
b) If you have a CAP, what is the enrollment rate? What efforts have been made to ensure low-income households are informed about the program and enroll? Are there ways to make the application process easier for customers to enroll, e.g., by providing for enrollment in-person, online, and mail, in multiple languages, if appropriate; partnering with local organizations to help with outreach and enrollment; allowing for automatic enrollment or using proof of eligibility for other income-qualified benefits?			
c) Has the community considered other types of customer support beyond a CAP for lower income residential customers?			
d) Are there policies in place to protect customers, including vulnerable populations, from shutoffs?			
e) Does the community have reduced rates for vulnerable populations, such as seniors on fixed incomes?			
Other Considerations:			

FINANCIAL ALTERNATIVES ANALYSIS	DESCRIBE HOW FINANCIAL ALTERNATIVE HAS BEEN IMPLEMENTED OR CONSIDERED. WHERE CONSIDERED, INCLUDE ANY PLANS FROM COMMUNITY TO PURSUE ALTERNATIVE	WHERE TOOLS NOT PURSUED, DESCRIBE ANY ASSOCIATED CHALLENGES WITH THE ALTERNATIVE (E.G., IMPACT TO BOND RATING, INTEREST RATE NOT FAVORABLE)	DESCRIBE OUTCOMES OF ALTERNATIVE (E.G., GRANT APPLIED FOR, LOAN NOT PURSUED)
4. Financial and Utility Management:			
a) Is the utility accounted for as a proprietary/enterprise fund or a separate independent utility?			
b) Are all rate revenues or other user charges used to fund the utility's operations? Do the rates charged recover the full cost of providing wastewater services (taking into consideration capital costs, operation and maintenance expenses, and environmental costs)?			
c) Does the utility have programs to optimize maintenance and asset management to reduce life cycle costs?			
d) Are partnerships with other utilities, including joint procurement, or shared management and staffing arrangements, regionalization or consolidations options to provide economies of scale and reduce per customer costs feasible in this community?			
e) Has the utility or related municipality instituted a stormwater management program when evaluating long-term control plan schedules? If so, are impervious area-based stormwater fees used to fund the stormwater compliance costs?			
f) Does the utility provide direct financial assistance (through rebates, upfront subsidies, or direct replacement of fixtures) for efficiency improvements including leak repairs or replacement of inefficient fixtures or appliances?			
Other Considerations:			

Appendix D. Resource Reference Guide for Utility / Community Financial Assistance

Resource Topic Areas

1. EPA Provided Technical Assistance
2. Public Funding and Financing Sources
3. Regional Specific Funding Sources
4. Community Funding and Financing Sources

Summary of Funding and Financing Resources

1. EPA Provided Technical Assistance

I. Environmental Finance Centers

Grants; https://www.epa.gov/waterfinancecenter/efcn

The Environmental Finance Centers (EFCs) deliver targeted technical assistance to local governments, states, tribes, and non-governmental organizations to protect public health, safeguard the environment, and mitigate environmental justice concerns. The EFCs serve an important role in helping to ensure that communities that have difficulty in securing public funding receive the help they need to access resources to support infrastructure improvements. The most up-to-date information on each EFC and areas of specialization can be found at: https://www.epa.gov/waterfinancecenter/efcn. Requests for technical assistance can be made by emailing WaterTA@epa.gov.

II. EPA - Training and Technical Assistance for Small Systems Funding

Grants; https://www.epa.gov/dwcapacity/training-and-technical-assistance-small-systems-funding

EPA provides technical assistance through national providers via grant funding to support small drinking water and wastewater systems that serve small and rural communities. EPA is committed to helping communities across America upgrade and maintain water infrastructure that is essential to public health and environmental protection.

III. EPA - Environmental Justice Small Grants Program

Grants; https://www.epa.gov/environmentaljustice/environmental-justice-small-grants-program

EPA's Environmental Justice Small Grants Program supports and empowers communities working on solutions to local environmental and public health issues. The program is designed to help communities understand and address exposure to multiple environmental harms and risks.

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2. Public Funding and Financing Sources

I. EPA/State Clean Water State Revolving Fund (CWSRF)

Loans; Grants; https://www.epa.gov/cwsrf

Many communities explore national- and state-level sources when seeking financial support for infrastructure projects. The most common sources considered are the CWSRF and Drinking Water State Revolving Fund (DWSRF), which are federal funds distributed to the states for distribution. These federal-state partnerships provide low-cost financing to help communities address water infrastructure needs. Communities can restructure existing SRF loans and take out multiple SRF loans. SRFs can offer: below market interest rates, in some cases as low as 0%; possible "additional subsidization" (i.e., money that does not need to be repaid); possible negative interest rates; possible principal forgiveness or grants; up to 30-year repayment for clean water projects and 40-year repayment for drinking water projects; possible loans for planning and design of infrastructure projects. States develop CWSRF priority lists as part of their Intended Use Plans, but do not have to fund in priority order.

II. EPA Water Infrastructure Finance and Innovation Act (WIFIA)

Loans; https://www.epa.gov/wifia

The WIFIA program provides long-term, low-cost supplemental financing for the planning, design, and implementation of water infrastructure projects of national or regional significance. Eligible public, private, and public-private borrowers can utilize WIFIA loans to finance a wide variety of wastewater, drinking water, water reuse, stormwater, nonpoint source pollution prevention, and other water quality improvement capital projects. The anticipated total eligible project costs must be at least $20 million, or $5 million for small communities (population of 25,000 or less). WIFIA loans are designed to provide supplemental financing for water infrastructure projects. The WIFIA loan can finance up to 49 percent of eligible project costs, or 80 percent for small communities. WIFIA loans can be paired with a variety of other funding sources, including State Revolving Fund loans and municipal bonds, and offer distinct benefits that are not readily available in the capital markets. The WIFIA program is borrower-focused, with flexible terms for credit assistance to stimulate investment while minimizing costs for ratepayers. It offers credit assistance with terms of up to 35 years after completion of project construction. It also offers borrowers the advantage of developing customized terms, including sculpted repayment terms to match the specific needs of a project, payment deferment for up to 5 years after completion of project construction, and interest-only payment periods. Additionally, the WIFIA program lends at a low, fixed interest rate equal to the Treasury rate for a comparable maturity.

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III. EPA – Environmental Justice Collaborative Problem-Solving (CPS) Cooperative Agreement Program

Grants; https://www.epa.gov/environmental-justice/environmental-justice-collaborative-problem-solving-cooperative-agreement-0

EPA's Environmental Justice CPS Cooperative Agreement Program provides funding for eligible applicants for projects that address local environmental and public health issues within an affected community. The CPS Program assists recipients in building collaborative partnerships to help them understand and address environmental and public health concerns in their communities.

IV. U.S. Department of Agriculture (USDA) – Rural Utility Services (RUS) Water and Environment Program (WEP)

Loans; Grants; https://www.rd.usda.gov/programs-services/all-programs/water-environmental-programs

WEP provides funding for the construction of water and waste facilities in rural communities and is the only Federal program exclusively focused on rural water and waste infrastructure needs of rural communities with populations of 10,000 or less. WEP also provides funding to organizations that provide technical assistance and training to rural communities in relation to their water and waste activities.

V. U.S. Housing and Urban Development (HUD) – Community Development Block Grant (CDBG) State Program

Grants; https://www.hudexchange.info/programs/cdbg-state/

Under the State CDBG Program, states award grants to smaller units of general local government that do not receive CDBG funds directly from HUD. These are called non-entitlement areas. Eligible activities include construction of public facilities and improvements, such as water and sewer facilities, streets, neighborhood centers, and the conversion of school buildings for eligible purposes. Not less than 70 percent of CDBG funds must be used for activities that benefit low- and moderate-income persons. Eligible grantees are as follows: non-entitlement areas are cities with populations of less than 50,000 people (except cities that are designated principal cities of Metropolitan Statistical Areas); counties with populations of less than 200,000 people.

VI. HUD – Community Development Block Grant (CDBG) Entitlement Program

Grants; https://www.hudexchange.info/programs/cdbg-entitlement/cdbg-entitlement-program-eligibility-requirements/

The CDBG Entitlement Program awards grants to entitlement community grantees to carry out a wide range of community development activities directed toward revitalizing neighborhoods, economic development, and providing improved community facilities and services. Eligible activities include construction of public facilities and improvements, such as water and sewer facilities, streets, neighborhood centers, and the conversion of school buildings for eligible purposes. Not less than 70 percent of CDBG funds must be used for activities that benefit low- and moderate-income persons. Eligible grantees include: principal cities of Metropolitan Statistical Areas (MSAs); other metropolitan

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cities with populations of at least 50,000; qualified urban counties with populations of at least 200,000 (excluding the population of entitled cities).

VII. U.S. Department of Commerce – Economic Development Administration (EDA)- Investments for Public Works and Economic Adjustment Assistance Programs

Grants; https://www.eda.gov/funding/programs

The role of wastewater service providers working with their local economic development office has grown in recent years. Increasing a community's rate base through community economic development can improve the ability to attract capital for utility infrastructure projects. Most communities have an economic development office or a representative whose specific mission is to attract new businesses to the area. EDA invests in traditional public works projects, including water and sewer systems improvements, industrial parks, business incubator facilities, expansion of port and harbor facilities, skill-training facilities, and brownfields redevelopment. This empowers distressed communities to revitalize, expand, and upgrade their physical infrastructure, and generate or retain long-term, private sector jobs and investment.

VIII. U.S. Department of Commerce – Economic Development Administration (EDA)- Planning Program and Local Technical Assistance Program

Grants; https://www.eda.gov/funding/funding-opportunities

EDA assists eligible recipients in developing economic development plans and studies designed to build capacity and guide the economic prosperity and resiliency of an area or region. The Local Technical Assistance program strengthens the capacity of local or State organizations, institutions of higher education, and other eligible recipients to undertake and promote effective economic development programs through projects such as feasibility studies and impact analyses.

3. Regional Specific Funding Sources

I. Appalachian Regional Commission (ARC) Grants

Grants; https://www.arc.gov/funding/ARCGrantsandContracts.asp

ARC awards grants and contracts from funds appropriated to the Commission annually by Congress. Program grants are awarded to state and local agencies and governmental entities (such as economic development authorities), local governing boards (such as county councils), and nonprofit organizations (such as schools and organizations that build low-cost housing). ARC provides funds for basic infrastructure services, including water and sewer facilities, that enhance economic development opportunities or address serious health issues for residential customers.

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II. Federal Emergency Management Agency (FEMA) – Building Resilient Infrastructure and Communities (BRIC)

Grants; https://www.fema.gov/grants/mitigation/building-resilient-infrastructure-communities

BRIC will support states, local communities, tribes, and territories as they undertake hazard mitigation projects, reducing the risks they face from disasters and natural hazards. BRIC is a new FEMA pre-disaster hazard mitigation program that replaces the existing Pre-Disaster Mitigation program.

4. Community Funding Sources

I. Municipal Bonds

A bond is a debt obligation issued by a nonprofit organization (state, city, county, or other) to finance its capital expenditures. It is a debt investment in which an investor loans money to an entity (state, city, county, or other), which borrows the funds for a defined period at a variable or fixed interest rate. The interest paid on municipal bonds is tax-exempt, making them an attractive low-cost way to obtain capital.

II. Utility Revenue Streams

Utilities fund most their infrastructure investments through local revenue-generating mechanisms (e.g., customer rates and other fees for water, wastewater, and stormwater services). See the *Progressive Rate Structures* section below.

Many utilities have also created additional revenue streams to pay for new infrastructure investments to reduce rate increases for their customers. Non-rate-based revenue can help to improve the organization's overall financial health by creating new sources of income for unexpected expenses and diversifying the utility's income in communities with decreasing volumes of water sold and collected (e.g., due to declining populations or water conservation programs). Some examples of how utilities have approached this include:

- ***Leasing space on water towers****:* Water towers are valuable real estate because they are often located in or near towns. Because of their proximity to population centers, water utilities have been able to sell space on their towers for cellphone antennas and advertising.
- ***Selling grid service to a local electric utility:*** Grid service refers to an arrangement where a local electric utility pays the water utility for agreeing to temporarily curtail some of its electric load when needed to help the electric utility match supply to demand. The water utility is still paid for agreeing to this arrangement even if it is never asked to shed load.
- ***Selling water and wastewater line protection:*** Homeowners own the lateral service lines that connect the main distribution lines to their home. Replacement cost is generally $2,500–$3,500, and is the responsibility of the homeowner. Some utilities have sold a service that acts as an "insurance" for customers, guaranteeing the utility will fix their lateral service lines when

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necessary. This can make use of the utility's existing expertise and resources to provide a sought-after service to the customer.

- ***Other sources of revenue generated from taxes*:** Other sources of local revenue can include general revenues appropriated to support wastewater services and portions of payroll taxes, property taxes, sales taxes, and toll severance taxes devoted to support wastewater services.
- ***Your elected officials:*** Consider talking to your elected officials about your infrastructure needs.

Additional examples of how communities have implemented these revenue building strategies is available in EPA's *Water Infrastructure Financial Leadership Successful Financial Tools for Local Decision Makers* document, available at https://www.epa.gov/sites/production/files/2017-09/documents/financial_leadership_practices_document_final_draft_9-25-17_0.pdf.

III. Taxes (Income Taxes, Sales Taxes, Property Taxes)

Taxes may be used as a limited funding source for annual wastewater system costs. Options include income taxes, sales taxes, and property taxes. Taxes may not be used to pay operating costs for some projects funded through the SRFs. However, user charge regulations do not require that capital outlays or debt service be covered in the user charge system. As a result, taxes can be used to repay bonds or loans for CWA projects that are subject to CWA Title II requirements. Projects funded with other sources such as local bonds, state loans, etc. do not have these restrictions.

- **Income taxes:** Individual or corporate income taxes have historically had less applicability to environmental program funding than other taxes such as property taxes, and targeted sales taxes. Income taxes are used to fund environmental programs, but their use is largely at the state level.
- **Sales taxes**: Many local jurisdictions raise funds through sales taxes. Communities may dedicate a portion of local option sales tax revenues to water pollution control, or may impose a local option sales tax on a specific product or service.
- **Property taxes**: Local governments use ad valorem property taxes as the primary source of funding for general government operations. Ad valorem property taxes are based on the value of property. As a result, residents with larger and/or more expensive homes pay more in properly taxes than residents with less expensive homes.

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Summary of Resources Related to Water Infrastructure Financing

Funding Sources

- Water Finance Clearinghouse: https://clearinghouse.epa.gov/wfc
- Clean Water State Revolving Fund: https://www.epa.gov/cwsrf
- Drinking Water State Revolving Fund: https://www.epa.gov/dwsrf
- Water Infrastructure Finance and Innovation Act (WIFIA): https://www.epa.gov/wifia
- The Environmental Justice Collaborative Problem-Solving (CPS) Cooperative Agreement Program: https://www.epa.gov/environmental-justice/environmental-justice-collaborative-problem-solving-cooperative-agreement
- Environmental Justice Small Grants Program: https://www.epa.gov/environmentaljustice/environmental-justice-small-grants-program
- Source Reduction Assistance (SRA) Grant Program: https://www.epa.gov/p2/grant-programs-pollution-prevention
- CoBank's Rural Water and Wastewater Lending: https://www.cobank.com/corporate/industry/water
- National Rural Water Association (NRWA)'s Rural Water Loan Fund: https://nrwa.org/members/products-services-portfolio/rural-water-loan-fund/
- Pisces Foundation Water Grant: https://piscesfoundation.org/what-we-do/water/
- U.S. Army Corps of Engineers' Emergency Streambank and Shoreline Protection: https://www.mvr.usace.army.mil/Business-With-Us/Outreach-Customer-Service/Flood-Risk-Management/Section-14/
- U.S. Department of Agriculture (USDA)'s Water and Waste Disposal Guaranteed Loan Program: https://www.rd.usda.gov/programs-services/water-waste-disposal-loan-guarantees
- USDA's Water & Environmental Programs (WEP): https://www.rd.usda.gov/programs-services/all-programs/water-environmental-programs
- USDA's Water & Wastewater Projects Revolving Fund Program: https://www.rd.usda.gov/programs-services/revolving-funds-for-financing-water-and-wastewater-projects
- USDA's Water & Waste Disposal Loan & Grant Program: https://www.rd.usda.gov/programs-services/water-waste-disposal-loan-grant-program
- USDA's Water & Waste Disposal Predevelopment Planning Grants: https://www.rd.usda.gov/programs-services/water-waste-disposal-predevelopment-planning-grants
- U.S. Department of Commerce – Economic Development Administration (EDA)'s Investments for Public Works and Economic Adjustment Assistance Programs: https://www.eda.gov/funding/programs
- EDA's Planning Program and Local Technical Assistance Program: https://www.eda.gov/funding/funding-opportunities
- U.S. Department of Health and Human Services – Indian Health Service (IHS)'s Sanitation Facilities Construction (SFC) Program: https://www.ihs.gov/dsfc/

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- U.S. Department of Housing and Urban Development (HUD)'s Community Development Block Grant (CDBG) Program: https://www.hud.gov/program_offices/comm_planning/communitydevelopment
- HUD's CDBG – Disaster Recovery Program: https://www.hudexchange.info/programs/cdbg-dr/
- HUD's Section 108 Loan Guarantee Program: https://www.hudexchange.info/programs/section-108/
- U.S. Federal Emergency Management Agency (FEMA)'s Hazard Mitigation Grant Program (HMGP): https://www.fema.gov/grants/mitigation
- FEMA's Public Assistance (PA) Grant Program: https://www.fema.gov/assistance/public
- FEMA's Pre-Disaster Mitigation (PDM) Grant: https://www.fema.gov/grants/mitigation/pre-disaster
- FEMA's Flood Mitigation Assistance Program (FMA): https://www.fema.gov/grants/mitigation/floods
- U.S. Small Business Administration (SBA)'s Business Physical Disaster Loans: https://www.sba.gov/funding-programs/disaster-assistance

Bipartisan Infrastructure Law (BIL) Resources

- Overview BIL https://www.epa.gov/infrastructure
- Closing America's Wastewater Access Gap Community Initiative https://www.epa.gov/water-infrastructure/closing-americas-wastewater-access-gap-community-initiative
- Bipartisan Infrastructure Law SRF Memorandum https://www.epa.gov/dwsrf/bipartisan-infrastructure-law-srf-memorandum
- Frequent Questions about BIL State Revolving Funds https://www.epa.gov/dwsrf/frequent-questions-about-bil-state-revolving-funds
- 2022 Bipartisan Infrastructure Law Clean Water and Drinking Water State Revolving Funds (SRFs) https://www.epa.gov/infrastructure/water-infrastructure-investments

Compendiums and Documents on Rating Setting and CAPs

- Drinking Water and Wastewater Utility Customer Assistance Programs: https://www.epa.gov/waterfinancecenter/compendium-drinking-water-and-wastewater-customer-assistance-programs
- Water Infrastructure Financial Leadership: https://www.epa.gov/waterfinancecenter/water-infrastructure-financial-leadership

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Appendix E. Examples of Other Metrics Relevant to Consideration of Financial Capability

Examples of Information Related to Residential Impacts:

1. Income distribution by quintile, geography, or other breakdown, illustrating how income distribution in the service area differs from comparable data on the national level or for similar cities.
2. Where cities have adopted differential rates for low-income customers, the income distribution that led to that rate structure.
3. Information about service area poverty rates and trends.
4. Projected, current, and historical sewer and stormwater fees as a percentage of household income, quintile, geography or other breakdown.
5. Information on sewer and water usage for various classes of ratepayers or by type of dwelling unit.
6. Information on the percent of households who own versus rent.

Examples of Information Related to Financial Strength:

1. Historical population trends or population projections.
2. Service area unemployment data and trends, or other labor market indicators, including unemployment on an absolute basis.
3. Rate or revenue models, including dynamic financial planning models showing the projections of impacts over the program period. All revenue sources tied to CWA obligations may be included as appropriate.
4. Rate determination studies used to develop and support recent rate increases.
5. Data and trends on late payments, disconnection notices, service terminations, uncollectable accounts, or revenue collection rates.
6. Historical increases in rates or other dedicated revenue streams.
7. State or local legal restrictions or limitations on property taxes, other revenue streams or debt levels.
8. Other costs or financial obligations, such as those that relate to drinking water or other infrastructure, that significantly affect a permittee's ability to raise revenue.
9. Circumstances that may affect a permittee's bond rating. For instance, incurring debt beyond certain thresholds may negatively impact the permittee's bond rating, thus reducing the ability to raise capital.
10. Financial plans that show the implications of incurring additional debt for a permittee's ability to secure financing, including projections of metrics such as debt ratios, debt service coverage, debt per

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customer, days of cash on hand, days of working capital, and other metrics used by rating agencies. Such data should be benchmarked to metrics such as rating agency medians and relative to similar entities. This will be especially relevant where the permittee does not have a bond rating.

11. Extraordinary stressors such as those from natural disasters, municipal bankruptcies, unusual capital market conditions, or other situations which impact a permittee's ability to raise revenue or acquire needed financing. When such stressors occur, they may also provide support for making changes to existing schedules.

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STATE OF NEW MEXICO
WATER QUALITY CONTROL COMMISSION

IN THE MATTER OF:

PETITION FOR REGULATORY CHANGE TO
ADOPT AMENDMENTS TO 20.6.4 NMAC –
Standards For Interstate and Intrastate Surface Waters **WQCC 25-75 (R)**

DIRECT TECHNICAL TESTIMONY OF SHELLY LEMON

I. INTRODUCTION

My name is Shelly Lemon and I am the Bureau Chief of the New Mexico Environment Department ("NMED" or "Department") Surface Water Quality Bureau ("SWQB"). I present this written direct testimony **(NMED Exhibit 19)** on behalf of the SWQB concerning the Bureau's proposed amendments to the State of New Mexico's Standards for Interstate and Intrastate Surface Waters ("Standards"), codified as Title 20, Chapter 6, Part 4 of the New Mexico Administrative Code (20.6.4 NMAC) , as submitted in NMED's First Amended Petition filed June 2, 2026 and proposed for adoption by the Water Quality Control Commission ("Commission" or "WQCC") at the hearing scheduled to commence on Monday, September 28, 2026 (WQCC 25-75(R)). Section 303(c)(1) of the federal Clean Water Act ("CWA") requires that the State hold public hearings at least once every three years to review and amend, as appropriate, its water quality standards. The Department proposes amendments to the Standards consistent with 20.6.4 NMAC, Section 303(c)(1) of the CWA, and Title 40 of the Code of Federal Regulations ("C.F.R.") Section 131.20. 40 C.F.R. § 131.20. This process is known as the State's "Triennial Review."

My testimony provides the supporting evidence and reasoning behind the following proposed changes related to wetlands, including:

- amending the definition of "wetlands";

- amending New Mexico's antidegradation policy to explicitly protect wetlands; and
- adding a new narrative, general criterion specific to wetlands to recognize that wetlands are different from other surface waters and warrant distinct considerations.

II. QUALIFICATIONS

I hold a Bachelor of Science degree in Biology from the University of Arizona, and a Master of Science degree in Hydrology from the University of Arizona. Before joining the Department, I was a Research Assistant for the Center for Sustainability of Semi-Arid Hydrology and Riparian Areas, a former National Science Foundation Science and Technology Center at the University of Arizona, and have also been a high school and middle school science teacher. I have been with the Surface Water Quality Bureau since 2004, serving first as a Total Maximum Daily Load ("TMDL") Scientist, and then the Nutrients and Lake Team Supervisor, Monitoring Team Supervisor, and Program Manager of the Monitoring, Assessment, and Standards Section, as well as the Municipal Team Supervisor for the Point Source Regulation Section.

I have held the position of Bureau Chief of the Department's Surface Water Quality Bureau since March of 2017 and was the acting Bureau Chief prior to that for eight months. As Bureau Chief, I manage and oversee three technical sections and 47 FTE who fulfill the state's responsibilities under the federal Clean Water Act and New Mexico Water Quality Act, including developing and revising water quality standards; collecting water quality data; assessing and reporting on the status of water quality; developing planning documents to improving water quality-limited waterbodies; managing and implementing projects that reduce nonpoint source pollution, protect and restore wetlands, and improve water quality; certifying federal NPDES and 404 dredge and fill permits to ensure they meet New Mexico's laws and regulations; and

implementing surface water protection regulations related to point source discharges, discharges of dredge or fill materials, and spills or refuse in surface waters.

Related to water quality standards amendments, I have served as an expert witness for the Department in both the 2013 and 2020 Triennial Reviews (WQCC 14-05 and WQCC 20-51), a temporary standard for Doggett Creek related to the Raton Wastewater Treatment Plant (WQCC 19-46), and a third-party Hydrology Protocol (HP) Use Attainability Analysis (UAA) for San Isidro Arroyo and its tributaries (WQCC 19-03). I have also provided technical support and participated in the rulemaking hearings for recent third-party proposals related to copper site-specific criteria for the Pajarito Plateau (WQCC 24-31), a UAA for Sandia Canyon (WQCC 24-65), and a HP-UAA for Tijeras Arroyo (WQCC 25-28). I have also provided technical expertise and review for several other amendments, including the Department's Santa Fe River HP-UAA (WQCC 12-07) and two third-party Outstanding National Resource Water (ONRW) proposals—the Upper Pecos River ONRWs (WQCC 21-51) and the Upper Rio Grande-Jemez ONRWs (WQCC 21-62).

In addition, since 2020 I have served on the Association of Clean Water Administrators (ACWA) Board of Directors representing New Mexico, other Region 6 States (Texas, Oklahoma, Arkansas, and Louisiana), and the National Association, including serving as Vice President in 2025 and President in 2026. I have included a copy of my resume as **NMED Exhibit 23**.

III. "WETLANDS" DEFINITION – 20.6.4.7(W)(4) NMAC

The Department proposes to amend the definition of "wetlands" in Subsection W of 20.6.4.7 NMAC to provide clarity and maintain consistency with other state or federal regulations. The Department proposes to rearrange the first and last sentences to be more succinct and clearer, but the proposed changes still mirror the existing definition:

"Wetlands mean those areas that are inundated by surface or ground water at a frequency and duration that typically support vegetation adapted for life in saturated soil conditions in New Mexico…"

"…Wetlands constructed for wastewater treatment outside of, and do not impound, a surface water of the state are not included in the definition."

The Department also proposes to add language to the definition to reflect established science and acknowledge the unique characteristics of New Mexico's landscape, as follows:

"…Wetlands are unique surface waters of the state that vary widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation and other factors and provide distinct chemical, biological, physical, and hydrological functions within a watershed. For certain types of wetlands, like playa lakes, water may only be present at certain times of the year, resulting in a cyclic nature of drying and refilling..."

Scientific studies overwhelmingly confirm that wetlands provide essential functions. Wetlands improve water quality by trapping sediment, transforming nutrients, and filtering pollutants. They also store floodwaters, reduce peak flows, and recharge groundwater, maintaining surface water systems during dry periods. **(NMED Exhibit 20)**. These hydrological and chemical functions occur even in non-floodplain (e.g., isolated) wetlands, which research shows are physically and chemically connected to downstream waters and contribute to water availability and quality over large distances. **(NMED Exhibit 25)**.

The definition's explicit inclusion of wetlands that vary seasonally, such as playa lakes, is critical. Despite their temporary nature, playas and other intermittent and ephemeral wetlands provide habitat for migratory birds, amphibians, and other wildlife, and they support biodiversity. In eastern New Mexico, playas are also a primary pathway for recharging the Ogallala Aquifer, a vital water source for rural communities and agriculture. **(NMED Exhibit 21)**.

Statewide, wetlands play an important role in the ecology of the landscape. They support hundreds of species and offer recreational, economic, and water-quality benefits. **(NMED Exhibit 24)**. The proposed definition aligns with New Mexico's long-term wetland management

goals, which emphasize protecting and restoring naturally functioning wetlands and developing a narrative standard specific to wetlands. **(NMED Exhibit 22)**.

Adopting the amended definition will ensure robust, scientifically grounded protection of New Mexico's diverse wetland resources and support their essential role in sustaining water quality, watershed health, wildlife habitat, and community resilience. Adopting this definition will also provide clear guidance with implementing various surface water quality programs, such as identifying outstanding national resource waters (ONRWs), conducting functional assessments to identify baseline conditions, determining temporary standards, analyzing the risk to water quality degradation and establishing discharge limitations and requirements, calculating a project's functional loss or lift, and evaluating restoration and mitigation effectiveness.

IV. ANTIDEGRADATION POLICY – 20.6.4.8(A) NMAC

The Department proposes to amend New Mexico's antidegradation policy in Subsection A of 20.6.4.8 NMAC to explicitly include wetland considerations and provide consistency with the surface water permitting regulations in 20.6.2 NMAC (e.g., protecting functions and acreage). Federal law requires that surface waters be protected from discharges that might degrade water quality. 40 C.F.R. § 131.12. To implement this requirement, it is necessary to identify antidegradation protection levels, or tiers, appropriate to each surface water.

At a minimum, all surface waters including wetlands in New Mexico are protected in accordance with "Tier 1" antidegradation requirements. S*ee* 20.6.4.8(A)(1) NMAC. Tier 1 requires that existing uses be maintained and protected. Tier 1 prohibits further degradation of a surface water. For wetlands, the Department proposes to protect "wetland condition" (i.e., functions and acreage) under the State's antidegradation policy. Research shows that wetlands are integral to maintaining water quality and there are noticeable benefits of intact wetland function: wetlands

filter and remove pollutants, improve flood-control capacity and climate resilience, contribute to ground water recharge and buffer streamflow variability, and support wildlife and migratory species alongside recreational and economic benefits for nearby communities. These facts reinforce that wetland condition directly influences water quality as well as a variety of ecological and social values and underscores the importance of preventing wetland loss and degradation. **(NMED Exhibit 26)**.

The Department proposes to add "wetland condition" to the Tier 2 protection level. "Tier 2" applies to surface waters with high-quality water, that is where existing water quality *or wetland condition* is better than applicable Standards. *See* 20.6.4.8(A)(2) NMAC. Tier 2 requires that existing high-quality surface waters be maintained but allows for limited degradation; however, the Tier 2 protection level prohibits significant degradation unless a review of reasonable alternatives and social and economic considerations supports a lowering of water quality *or wetland condition, including loss of wetland acreage or functions*. The Department also proposes a few other changes to streamline and clarify this Paragraph to, "…ensure the highest statutory and regulatory requirements for all new and existing point sources and implementation of all cost-effective and reasonable best management practices for nonpoint source control." Finally, the Department proposes to include wetlands under the Tier 3 level of protection. "Tier 3" applies to Outstanding National Resource Waters (ONRWs) and prohibits any degradation and lowering of water quality, *including loss of wetland acreage or functions*, in an ONRW unless impacts are minimal and temporary. *See* 20.6.4.8(A)(3) NMAC.

By clarifying that degradation includes loss of wetland acreage and functions, the proposed amendments ensure protection of the full suite of ecosystem services wetlands provide. This approach aligns with current scientific understanding and research, and strengthens New

Mexico's ability to safeguard surface water resources, wildlife habitat, community resilience, and economic vitality.

V. GENERAL CRITERION FOR WETLANDS – 20.6.4.13(N) NMAC

The Department proposes a new general criterion for wetlands in Subsection N of 20.6.4.13 NMAC. General criteria are established to sustain and protect existing or attainable uses of surface waters. The proposed criterion is specific to wetlands and clearly mandates that wetlands be maintained and protected from direct, indirect, and cumulative impacts that would lead to a net loss of acreage or essential biological, chemical, physical, and hydrological functions.

Wetlands provide important ecological and hydrological services when they are healthy. New Mexico's wetlands control and weaken floods and contribute to bank stabilization; improve water quality by filtering pollutants and sediment from water; provide a home and nursery for many species of animals and plants and create habitat that is less vulnerable to wildfire and drought; provide breeding, feeding, and stopover grounds for migratory birds and serve as migration corridors for other wildlife; create opportunities for fishing, hunting, birding and wildlife viewing, nature photography, camping, and hiking; recharge aquifers and store water for future uses; absorb water and slowly release it, helping to maintain baseflows; and accumulate carbon in the soil, helping to reduce the amount of carbon reaching the atmosphere.

In addition, robust, science-based wetland protection provides broad economic benefits. Healthy wetlands support agriculture and grazing, municipal water supplies, recreation and tourism, economic development, and property values. Degraded or lost wetlands, by contrast, impose costs related to sedimentation, flood and wildfire risk, drinking water treatment, and crop losses. Every dollar invested in wetland protection typically yields multiple dollars in avoided damage and boosted local economic activity. Collectively, New Mexico's wetlands strengthen

local economic activity from ranching and farming to outdoor recreation and tourism while reducing public costs associated with flood damage, wildfires, water treatment, and habitat loss.

The Department's proposed criterion ensures that wetlands and their essential ecosystem services and economic benefits are protected statewide. This criterion is necessary for the maintenance, protection, and enhancement of New Mexico's wetlands because it establishes water quality goals for these unique surface waters and highlights the fact that wetlands provide essential ecosystem services (for free!) and act as natural infrastructure critical to watershed and climate resilience, water sustainability, and New Mexico's long-term economic well-being.

VI. CONCLUSION

The Department recommends that the Commission adopt the proposed amendments to the Standards, filed with the Department's First Amended Petition (NMED Exhibit 27) and based upon the testimony of the SWQB's witnesses. This concludes my direct testimony.

United States
Environmental Protection
Agency

Office of Water
Office of Wetlands,
Oceans and Watersheds (4502T)

EPA 843-F-01-002c
March 2002

Functions and Values of Wetlands



Dave Davis

Long regarded as wastelands, wetlands are now recognized as important features in the landscape that provide numerous beneficial services for people and for fish and wildlife. Some of these services, or functions, include protecting and improving water quality, providing fish and wildlife habitats, storing floodwaters, and maintaining surface water flow during dry periods. These beneficial services, considered valuable to societies worldwide, are the result of the inherent and unique natural characteristics of wetlands.

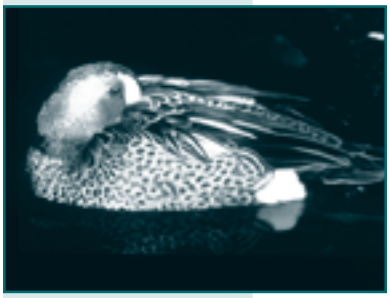


Wetlands are considered valuable because they clean the water, recharge water supplies, reduce flood risks, and provide fish and wildlife habitat. In addition, wetlands provide recreational opportunities, aesthetic benefits, sites for research and education, and commercial fishery benefits.

Functions Versus Values

Wetland functions include water quality improvement, floodwater storage, fish and wildlife habitat, aesthetics, and biological productivity. The value of a wetland is an estimate of the importance or worth of one or more of its functions to society. For example, a value can be determined by the revenue generated from the sale of fish that depend on the wetland, by the tourist dollars associated with the wetland, or by public support for protecting fish and wildlife.

Although large-scale benefits of functions can be valued, determining the value of individual wetlands is difficult because they differ widely and do not all perform the same functions or perform functions equally well. Decision-makers must understand that impacts on wetland functions can eliminate or diminish the values of wetlands.



Water storage. Wetlands function like natural tubs or sponges, storing water and slowly releasing it. This process slows the water's momentum and erosive potential, reduces flood heights, and allows for ground water recharge, which contributes to base flow to surface water systems during dry periods. Although a small wetland might not store much water, a network of many small wetlands can store an enormous amount of water. The ability of wetlands to store floodwaters reduces the risk of costly property damage and loss of life—benefits that have economic value to us. For example, the U.S. Army Corps of Engineers found that protecting wetlands along the Charles River in Boston, Massachusetts, saved $17 million in potential flood damage.

Water filtration. After being slowed by a wetland, water moves around plants, allowing the suspended sediment to drop out and settle to the wetland floor. Nutrients from fertilizer application, manure, leaking septic tanks, and municipal sewage that are dissolved in the water are often absorbed by plant roots and microorganisms in the soil. Other pollutants stick to soil particles. In many cases, this filtration process removes much of the water's nutrient and pollutant load by the time it leaves a wetland. Some types of wetlands are so good at this filtration function that environmental managers construct similar artificial wetlands to treat storm water and wastewater.



Red-osier dogwood

Biological productivity. Wetlands are some of the most biologically productive natural ecosystems in the world, comparable to tropical rain forests and coral reefs in their productivity and the diversity of species they support. Abundant vegetation and shallow water provide diverse habitats for fish and wildlife. Aquatic plant life flourishes in the nutrient-rich environment, and energy converted by the plants is passed up the food chain to fish, waterfowl, and other wildlife and to us as well. This function supports valuable commercial fish and shellfish industries.



The Great Flood of 1993 in the upper Mississippi River Basin caused billions of dollars in property damage and resulted in 38 deaths. Historically, 20 million acres of wetlands in this area had been drained or filled, mostly for agricultural purposes. If the wetlands had been preserved rather than drained, much property damage and crop loss could have been avoided.

DID YOU KNOW?

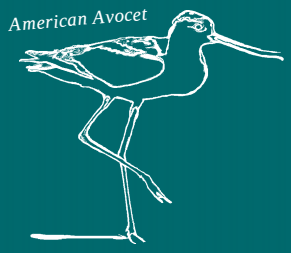
- In 1991 wetland-related ecotourism activities such as hunting, fishing, bird-watching, and photography added approximately $59 billion to the national economy.
- According to the Pacific Coast Federation of Fishermen's Associations, almost $79 billion per year is generated from wetland-dependent species, or about 71 percent of the nation's entire $111 billion commercial and recreational fishing industry in 1997.
- An acre of wetland can store 1–1.5 million gallons of floodwater.
- Up to one-half of North American bird species nest or feed in wetlands.
- Although wetlands keep only about 5 percent of the land surface in the conterminous United States, they are home to 31 percent of our plant species.



Steve Delaney

Seventy-five percent of commercially harvested fish are wetland-dependent. Add shellfish species and that number jumps to 95 percent.

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Technical Aspects of Wetlands: Wetland Hydrology, Water Quality, and Associated Functions, Virginia Carter. United States Geological Survey Water Supply Paper 2425. Available on-line at http://water.usgs.gov/nwsum/WSP2425/hydrology.html.

Wetlands Functions and Values. Visit the North Carolina State University Water Quality Group's on-line informational database, WATERSHEDSS, at http://h2osparc.wq.ncsu.edu/info/wetlands/funval.html.

NMED Exhibit 20

PLAYA LAKES: Understanding Their Importance and How to Protect Them and Improve Their Function

Rossana Sallenave and Amy Ganguli[1]

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The College of Agricultural, Consumer and Environmental Sciences is an engine for economic and community development in New Mexico, improving the lives of New Mexicans through academic, research, and Extension programs.

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***Figure 1*. Playa lakes, like this one near Portales, NM, provide critical habitat for migratory waterfowl and shorebirds.** (Photo courtesy of William Jaremko-Wright, New Mexico Highlands University.)

WHAT ARE PLAYA LAKES?

Playa lakes are one of the most important types of ephemeral or temporary wetlands in the arid Southwest (Figure 1). These shallow, generally circular depressions with clay-lined basins form at the lowest point in an enclosed watershed. They can range in size from a few acres to up to 200 acres. Because they are closed basins, the only water playas receive is from precipitation and catchment runoff, while water is lost via evaporation from soil and vegetation and recharge of the underlying aquifer. Playa lakes can remain dry for several years—even decades (Figure 2). Then, after a rainfall event, they can fill with up with water and create temporary wetlands. In New Mexico, ephemeral or non-perennial waters make up over 80% of the state's waters and are expressly protected by the state's water quality standards. Although playas exist in arid regions throughout the world, the High Plains of the U.S. has the world's highest number of playas (as many as 50,000), of which 85% are found on the Llano Estacado, a portion of the Southern High Plains spanning the Texas–New Mexico border. In the Southern High Plains region, playas are the principal source of surface water.

Because playas store water in parts of the country that receive very little rainwater and where there are no permanent rivers or streams, they are vital to communities, ranchers, and rural agricultural economies, and support a vast array of wildlife. Despite their ephemeral nature, these water resources provide critical

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***Figure 2*. A dry playa near Watrous, NM.**

ecosystem services, such as recharging groundwater supplies for a growing population; providing habitat for migratory birds, waterfowl, and other wildlife; and supporting a growing wildlife-related recreational industry.

PLAYAS PROVIDE ECOSYSTEM SERVICES

The term "ecosystem services" refers to the many different benefits provided to humans by ecosystems. Examples of ecosystems include agroecosystems, grassland ecosystems, and aquatic ecosystems. Healthy playa wetlands provide numerous ecosystem services that benefit society, including wildlife habitat, clean water, floodwater storage, and groundwater recharge.

Wildlife and biodiversity

Playas are sources of great plant and animal biodiversity, providing critical habitat for millions of migratory birds and waterfowl, as well as providing essential habitat for amphibians, reptiles, mammals, and several species of unique invertebrates (MacKay et al., 1990; Haukos and Smith, 1994). In New Mexico, ephemeral playas have been identified by the New Mexico Department of Game and Fish (2016) as one of ten key aquatic habitats, and they provide habitat for several threatened and endangered species and species of concern in New Mexico. In the Southern High Plains, playa wetlands are essential staging and feeding areas in one of the most important inland migratory corridors in North America for birds, including waterfowl, shorebirds, and many other migratory and resident birds (Figures 3A–3C). They also provide cover and habitat for native species during dry cycles.

In addition to their importance to birds, playas support a remarkable variety of invertebrate species that have evolved to exploit the extreme hydrological conditions of these wetlands. Tadpole shrimp and fairy shrimp (Figures 4A and 4B) are primitive branchiopod crustaceans that bridge periods of drought by laying drought-resistant, resting eggs or cysts that can lie dormant and viable for years in unflooded soil (Brendonck, 1996; Brendonck and Meester, 2003). Soon after being immersed in water, a portion of the eggs will hatch, and within a few weeks adult tadpole and fairy shrimp lay eggs before the ephemeral waterbodies dry up again. These crustaceans are important sources of food for some insects, amphibians, and waterfowl, making them an extremely important link in the food web, particularly as a supply of energy for migratory birds (Smith, 2003).

Playa wetlands also provide critical habitat for a number of amphibian species native to the Southwest, particularly anurans (frogs and toads). During most of the year, desert anurans are underground in burrows. However, immediately after the summer monsoon rains, they emerge from their burrows and can be heard calling from newly filled sites. Anuran species that have been observed in both natural playas and human-made cattle tanks in New Mexico include the Mexican spadefoot (*Spea multiplicata*), plains spadefoot (*Spea bombifrons*), Couch's spadefoot (*Scaphiopus couchii*), Great Plains toad (*Anaxyrus cognatus*), and green toad (*Anaxyrus debilis*) (Figures 5A and 5B).

Aquifer recharge and water quality

Playas have been shown to be a primary source of groundwater recharge in arid regions. In the High Plains, playas are critical zones of recharge for the Ogallala Aquifer (also known as the High Plains Aquifer) as the water filters through cracks in the playas' clay lining and back into

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the aquifer. The Ogallala Aquifer is a vast underground water-bearing formation that spans 174,000 square miles in parts of eight states, including six counties in eastern New Mexico. The aquifer provides almost all the water used in the region. However, current usage far outpaces its ability to recharge. Recharge occurs from within the playa basins as well as along the perimeters of undisturbed playas. Although the exact amount of recharge attributable to any single playa or group of playas is unknown, some studies suggest that recharge rates in unaltered playa basins may be greater than 3 inches per year (Gurdak and Roe, 2009).

In addition to contributing to the significant recharge of aquifers, healthy playas also improve the quality of that water. Studies have shown that playa lakes in their natural state surrounded by buffers of native grasses and vegetation can catch and filter sediments and slow runoff, which allows salts and contaminants to be intercepted before entering the playas. These natural buffers also intercept sediments and prevent them from clogging playas' natural clay bottoms, which affects infiltration of water.

THREATS TO THE ECOSYSTEM SERVICES PROVIDED BY PLAYAS

Changes in land use, primarily as a result of agriculture and urbanization, have led to widespread losses and deterioration of playa wetlands (Haukos and Smith, 1994; Hall et al., 2004). Common impairments to playas include sedimentation (considered to be the greatest threat) and contamination from urban and agricultural runoff, both of which affect playas' integrity and function. Urban expansion has resulted in many playas being filled, leveled, and bisected with roads. Urban playas have often been used to store stormwater accumulation from urban runoff. Common contaminants in urban runoff include heavy metals, hydrocarbons, pesticides, fertilizers, and chemicals associated with automobiles. Because urban playas rarely have adequate vegetative buffers to intercept surface runoff, these pollutants become concentrated in playas, and can contaminate underlying aquifers.

Rural playas are often altered by creating pits within the playas to hold water long enough to provide drinking water for livestock and to use for irrigation water. Over 70% of playas in the Southern High Plains larger than 10 acres have pits. Other playas have been plowed and cultivated during dry cycles to increase acreage. Modifying the playas in these ways breaks up the clay soils lining the bottom of unaltered playas and removes the grassy buffers along the playa perimeters, leading to increased sedimentation and erosion. This increased sedimentation, coupled with the breakup of the clay layer, prevents cracks from forming in the bottoms of playas, thereby reducing or restricting water infiltration and aquifer recharge. In other areas, such as West Texas, playas are often used to catch runoff from oil and gas operations.



***Figures 3A–C*. Playa wetlands are essential staging and feeding areas for migrating waterfowl, such as northern pintail (A), and shorebirds, such as long-billed curlew (B) and American avocet (C).** (Photos courtesy of William Jaremko-Wright, New Mexico Highlands University.)

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***Figures 4A and 4B*. Tadpole shrimp (held in hand on left) and fairy shrimp (orange-colored in left photo, in upper right-hand corner in right photo) collected from a playa lake near Las Cruces, NM.**





***Figures 5A and 5B*. Playa wetlands provide critical habitat for a number of amphibian species, including Mexican spadefoot (A) and Great Plains toad (B).** (Photos courtesy of Dr. Wiebke Boeing, New Mexico State University.)

Unsustainable rangeland management practices, such as poorly managed grazing, have also led to the deterioration of many rural playa wetlands. If not managed properly, grazing can result in reduced water quality through a reduction of the valuable filtering capacity of playa vegetation. In addition, heavy use by livestock can result in soil erosion and sedimentation, as well as soil compaction. Higher levels of grazing result in a shift from perennial and more intact plant communities toward annuals.

Protecting these ephemeral wetlands is further complicated by the fact that they are almost entirely located on privately owned lands, leading to a lack of consistent management strategies among playas.

HOW CAN WE PROTECT AND IMPROVE PLAYA LAKES?

Conservation practices

Because unsustainable land use practices and activities surrounding playa wetlands have led to their deterioration, playas should be actively managed in order to maintain and improve their functions, the critical wetland habitat they provide, and groundwater recharge. A number of conservation practices can be implemented by playa owners to help improve natural playa functions.

- Practice improved grazing management. Both forage production and playa fillings are linked to wetter climatic cycles, and therefore overlap. During these grazing windows, the negative effects of intense livestock use of playas can be mitigated through practices such as herding, or implementing grazing systems that allow for deferrals so livestock can be moved to other areas during these critical times. Other strategies include developing alternative upland watering systems, and fencing to manage livestock around a playa.

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- Plant and protect vegetative buffers around playas to filter sediments and prevent other contaminants from reaching the playa.
- Remove exotic/invasive plants and promote natural plant communities.
- Remediate (fill) pits with appropriate soils in playa bottoms.

These management practices aimed at conserving and restoring playa wetlands all help create wildlife habitat and natural playa plant communities, improve natural playa function, and promote groundwater recharge. Another important consideration regarding playa restoration is that most playas are on private property, and the impacts of playa wetland deterioration may cross landowner property boundaries. Therefore, restoration efforts will require collaborative partnerships between landowners, conservationists, and funding entities to adequately address playa impairments. Examples of collaborative playa restoration projects in eastern New Mexico are detailed in the *Wetlands Action Plan for Playa Lakes, Curry County, New Mexico* (Martin, 2014).

Get involved, become informed, and spread the word!

In comparison to other wetlands, playas and the role they play are not well understood. As a result, they are underappreciated and often overlooked, even by some playa landowners. Outreach efforts play a critical role in informing and educating the public on the importance of playa wetlands, as well as in engaging and maintaining community support for conservation efforts of playas. Conservation efforts focus on reducing sedimentation, improving water quality, and restoring playa function and ecological integrity. A great place to begin learning more about playas is by visiting the non-profit organization Playa Lakes Joint Venture (https://pljv.org/), a regional partnership of federal and state agencies, conservation groups, and private industry whose purpose is to conserve bird habitat throughout the western Great Plains, where playas (more than 80,0000) are the most abundant wetland in the region.

AVAILABLE PLAYA ASSESSMENT AND RESTORATION RESOURCES

A number of federal and state programs exist that provide technical and financial assistance to landowners interested in restoring playas on their properties and protecting the land from future development.

The USDA-Natural Resources Conservation Service (NRCS) provides technical and financial support to landowners with wetland restoration efforts through the Wetlands Reserve Program (WRP; https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/home/?cid=STELPRDB1049327). This voluntary program assists landowners who wish to protect, restore, and enhance wetlands on their property. Although not all playas meet the wetland criteria required by WRP, many playas may be eligible for the program, and landowners are encouraged to consider the program to enhance their wetland.

The WRP also offers landowners the opportunity to protect, restore, and enhance wetlands on their property through the purchase of a wetland reserve easement. Wetland reserve easements are designed to provide landowners with a financial incentive to restore degraded wetlands. NRCS pays an easement fee and the entire cost to restore the wetland; the owner retains title, access control, and hunting rights, but must protect the wetland for future generations. More information on wetland easement programs, eligibility, and how to enroll can be found at https://www.nrcs.usda.gov/wps/portal/nrcs/detail/null/?cid=nrcseprd416653.

The Environmental Quality Incentives Program (EQIP; https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/) is another NRCS voluntary program available to agricultural producers who want to improve and protect the condition of their land. The program provides financial and technical assistance to implement structural and conservation practices that address natural resource (soil, water, plants, animals) concerns. The costs are typically shared by the landowner and NRCS, with landowners providing 25% and NRCS providing 75%. Requests by landowners are awarded based on a ranking system and availability of funds.

In New Mexico

The Wetlands Program of the New Mexico Environment Department's (NMED) Surface Water Quality Bureau (SWQB) (https://www.env.nm.gov/surface-water-quality/wetlands/) promotes the protection and restoration of different types of wetland ecosystems throughout New Mexico, including ephemeral wetlands such as playas. The program assists communities, local governments, stakeholders, and others with technical information, planning, training, and other guidance in their wetlands restoration efforts. Examples of playa restoration projects in eastern New Mexico that involved collaborative efforts of landowners, local government, NMED, and the Nature Conservancy are detailed in the *Wetlands Action Plan for Playa Lakes, Curry County, New Mexico* (Martin, 2014). This wetland action plan provides a summary of programs available to help landowners utilize their playas while protecting their natural functions and ecological integrity. Other programs and sources of funding that have been used by playa landowners in eastern New Mexico to restore playas include the U.S. Fish and Wildlife Service (USFWS) Private Stewardship Grants Program (https://training.fws.gov/courses/csp/csp3115/resources/ESA_Folder/private_stewardship5_04.pdf) and the USFWS North American Wetlands Conservation Act (NAWCA;

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https://www.fws.gov/birds/grants/north-american-wetland-conservation-act/standard-grants.php).

The New Mexico Rapid Assessment Method (NMRAM) Playa Wetland Field Guide (Muldavin et al., 2017) is a useful guide for resource managers to help assess funding needs of any playa restoration project. It provides procedures for conducting a rapid assessment of playa wetlands in the Southern High Plains of eastern New Mexico. This should help NMED prioritize wetlands in need of restoration, identify causes of degradation, and help develop methods for protecting playas. Details of the field guide can be found at https://www.env.nm.gov/wp-content/uploads/sites/25/2018/04/Playa-RAM-Field-Guide-with-Appendices.pdf.

SUMMARY

Playa lakes are one of the most important types of ephemeral or temporary wetlands in the arid and semi-arid Southwest. Despite their ephemeral nature, these critical water resources recharge groundwater supplies for a growing population; provide habitat for migratory birds, waterfowl, and other wildlife; and support a growing wildlife-related recreational industry. In the Southern High Plains region, playas are the principal source of surface water and are vital to communities, ranchers, and rural agricultural economies. Unfortunately, changes in land use, primarily as a result of agriculture and urbanization, have led to widespread losses and deterioration of playa wetlands. Common impairments to playas include sedimentation (considered to be the greatest threat), pits (deep holes excavated in the basin of the playa), and contamination from urban and agricultural runoff, all of which affect the integrity and function of playas.

Active management of playas is needed to maintain and improve their functions, groundwater recharge, and the critical wetland habitat they provide. A number of conservation practices can be implemented by playa owners to help improve natural playa functions. These management practices all help create wildlife habitat and natural playa plant communities, improve natural playa function, and promote groundwater recharge. Since most playas are on private property, restoration efforts will require collaborative partnerships between landowners, conservationists, and funding entities to adequately address playa impairments.

A number of federal and state programs exist that provide technical and financial assistance to landowners interested in restoring playas on their properties and protecting the land from future development. The USDA-Natural Resources Conservation Service (NRCS) and U.S. Fish and Wildlife Service (USFWS) have a number of programs and grants available for the restoration and protection of playa wetlands. In New Mexico, the Wetlands Program of the New Mexico Environment Department's (NMED) Surface Water Quality Bureau (SWQB) promotes the protection and restoration of different types of wetland ecosystems throughout New Mexico, including playas.

ACKNOWLEDGMENTS

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WETLANDS PROGRAM PLAN FOR NEW MEXICO

(Previously EPA Approved 4.9.2019)

Since 2003, the New Mexico Environment Department Surface Water Quality Bureau (SWQB) Wetlands Program and its partners have made substantial progress in the development of a robust program that focuses on measures that will restore and protect New Mexico wetlands. This updated Wetlands Program Plan describes the achievements made since this Plan was approved in 2010 by EPA and previously updated in 2012, 2015, 2017 and 2019. It also lays out a pathway to continue program development for the next five years. This current version of the Wetlands Program Plan for New Mexico incorporates revisions described in the March 2020 Revised Draft of the ESTP Core Elements Framework. Through this updated 5-year Wetlands Program Plan we hope to continue progress towards a comprehensive and sustainable Wetlands Program for New Mexico.

WETLANDS PROGRAM GOALS

The Mission of the SWQB Wetlands Program is to protect, restore and increase self-sustaining and naturally functioning wetlands and riparian areas. The Wetlands Program emphasizes the role of wetlands in preventing and reducing water quality impairments and providing habitat and life requirements for wildlife. To this end the Wetlands Program has formulated the following long-term objectives:

1. Promote wetland protection and restoration as a goal of established watershed groups and other partnerships.

2. Increase wetland area (no net loss) as well as restore wetland functions and ecological services and develop a system for tracking gains and losses by wetland type.

3. Assist communities, agencies, tribes, stakeholders, local governments and others with wetlands technical information, project design and planning, training and other guidance.

4. Develop protection, adaptation and mitigation strategies for wetland resources threatened by the effects of a drying climate in the west, including drying of wetlands in the landscape, loss of mountain snowpack, increased large-scale catastrophic fires and subsequent flooding, scour and sediment delivery.

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5. Develop and refine narrative water quality standards for wetlands and for specific wetland types and use these standards to promote more effective CWA §401 Certification.

6. Develop a toolbox of successful restoration techniques that are specific to wetland types and ecoregions.

PARTNERSHIP GOALS

The principal goal which informs the work of the SWQB Wetlands Program and its many public and private partners is a desire to restore and maintain wetlands, allowing them to fully function as natural systems. This goal can be accomplished through collaborative partnerships that contribute to completing large-scale major restoration projects, and to restoring numerous wetlands within a watershed an acre at a time.

A second overarching goal is to create a sustainable wetlands plan of action by developing sustainable funding sources. SWQB Wetlands Program and its partners are considering ways to achieve sustainability through potential funding, programs, and management activities such as wetlands banks, in lieu fee programs, state-sponsored programs such as the River Stewardship Program, participation in NGO-sponsored programs such as the Rio Grande Water Fund, through partnerships associated with the New Mexico Mapping Consortium, Geospatial Advisory Committee, and our Northern and Southern Wetlands Roundtables, by continuing to obtain matching grants through foundations, by organizing and assisting voluntary programs, and by obtaining in-kind resources and assistance through the efforts of watershed groups, NGOs and their volunteers.

The priority technical goals within the next five years are to identify and maintain simple, effective and efficient methods for monitoring wetlands, to work with our partners towards a complete inventory and baseline assessment of New Mexico's wetland resources, and to share these data for the benefit of wetlands.

Partnerships can aid in the protection of wetlands on the regional and local level. SWQB Wetlands Program can assist partners in the implementation of wetlands protection on the regional and local level by providing information, training and data that supports local efforts to protect wetlands.

SWQB WETLANDS PROGRAM EFFORTS

Currently SWQB Wetlands Program development is primarily supported by EPA Wetlands Program Development Grants competitively awarded by EPA Region 6 under the CWA §104(b)(3). The State of New Mexico provides a portion of funding for Wetlands Program staff through the Corrective Action Fund Program. The SWQB Wetlands Program and its core elements are

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included in the comprehensive update to the Water Quality Management Plan (WQMP) and Continuing Planning Process (CPP) which was approved by the New Mexico Water Quality Control Commission and EPA Region 6 in October 2020 https://www.env.nm.gov/surface-water-quality/wqmp-cpp/.

In 2003, the SWQB Wetlands Program began the development of a wetland restoration program (Wetlands Action Plan Program), which is part of a larger mission to improve and protect the state's watersheds and water quality. Through the CWA §319(h) Nonpoint Source Management Program (NPS), SWQB provides funding for watershed groups to develop Watershed Based Plans to reduce pollutants in their watersheds. The Wetlands Action Plan Program provides an opportunity and support for these established watershed groups to broaden their planning and resource improvement efforts to include wetlands, riparian and buffer areas within their watersheds. To this end, the SWQB Wetlands Program is incorporated into the NPS Management Plan for New Mexico, and implementation activities and projects are eligible to compete for funding under CWA Section 319 so long as those activities/projects meet the established watershed management and water quality protection objectives of CWA Section 319 and are described in a completed Wetlands Action Plan.

The State has incorporated wetlands monitoring and assessment into SWQB's Water Quality Monitoring and Assessment Program and wetlands assessment into the 10-year Monitoring Strategy. Wetlands monitoring and assessment contributes to progress toward meeting two overarching national goals of "No Net Loss" in wetlands extent and an "Overall Increase" in wetlands extent, functions, and quality. Effective wetland monitoring and assessment enables New Mexico to meet federal Clean Water Act requirements under Section 305(b) to assess the condition of all navigable waters, including wetlands. The SWQB Wetlands Program has focused its efforts on establishing wetlands assessment and monitoring that can be implemented with the assistance of its many partners. The assessment and monitoring goals of the SWQB Wetlands Program include:

- Continue to expand an inventory and classification of wetlands resources statewide;
- Develop and utilize assessment protocols to verify wetland condition, degradation, impacts and the causes of stress, and recovery;
- Document wetland gains and losses;
- Identify vulnerable wetland types, develop strategies to anticipate potential sources of stress and to create/maintain resilience of these wetland/riparian systems confronted by the effects of a drying climate;
- Document results of wetland restoration projects and innovative techniques for restoration;
- Assess wetland resources to determine potential strategies for recovery of wildlife habitat and wildlife corridors;

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- Use information generated by wetlands assessment to prioritize wetlands projects and protection within specific watersheds or regions;
- Use information generated by wetlands assessment to assist the United States Department of the Army Corps of Engineers (USACE) in developing meaningful Before-After Mitigation Impact (BAMI) documentation of wetland compensatory mitigation and to use these data to establish mitigation credits and ratios;
- Identify ecologically important and high-quality wetlands through wetlands mapping and assessment for future Outstanding National Resource Waters (ONRW) nomination and protection;
- Monitor ONRW wetlands to identify pollution and degradation, and to use these data to ensure that degradation is prevented, and sources of pollution are abated;
- Assist partners and programs in using SWQB Wetlands assessment tools and generating data to protect and restore wetlands.

The State's regulatory program applies to all surface waters of the State including wetlands. These regulations provide for certification of CWA §402 NPDES permits, and CWA §404 dredge and fill permits under CWA §401, establishing water quality standards under CWA §303 (c) and reporting under CWA §§303(d) and 305(b). The Wetlands Program is currently working with the USACE, Albuquerque District to complete and adopt a regulatory module of the New Mexico Rapid Assessment Method (NMRAM) to assist and improve evaluation of compensatory mitigation through the BAMI procedures. Overall, New Mexico is making progress towards establishing a baseline for wetlands in the state to provide a picture of wetland types and condition. A rapid assessment protocol for the State's wetland resources is under development and use, which focuses on vulnerable and threatened wetland types. The protocol will be used consistently by the SWQB Wetlands Program and participating partners. Mapping and classifying wetlands in the state is progressing through partnerships and projects by SWQB Wetlands Program and others, and numerous demonstration restoration efforts using innovative techniques are in progress or in place.

New Mexico's wetlands including isolated wetlands are incorporated within the water quality standards definitions and are considered "surface waters of the State" (20.6.4.7 NMAC). Isolated and ephemeral wetlands (such as playas) are included in the definition. The interests of the state are critically linked both economically, ecologically and culturally to good water quality in all of the state's waters including isolated wetlands. Non-perennial waters make up over 80% of the state's waters and are expressly protected by the State's standards. Currently, the SWQB Wetlands Program is working to protect and restore vulnerable isolated wetlands, and development of water quality standards specific to wetland types including isolated and ephemeral wetlands is ongoing.

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The SWQB nominated and the Water Quality Control Commission (WQCC) adopted all naturally occurring wetlands within US Forest Service Wilderness Areas in New Mexico as Outstanding National Resource Waters (ONRW) in 2009. Although wetlands have been included in previous ONRW nominations in the Valle Vidal and the Rio Santa Barbara areas, this action was New Mexico's first success in applying Best Management Practices and improved anti-degradation policy to ONRW wetlands. The SWQB Wetlands Program will continue to identify ecologically important wetlands in other parts of the State. Updating and expanding a directory of Reference Standard Wetlands (best condition), and wetlands in ecologically important or threatened areas to which ONRW status or other protective measures should apply will help aid in these efforts.

WETLANDS PROGRAM PROGRESS

In 2020, the Covid-19 pandemic has caused a snow-ball effect that delayed our well-developed plans. NMED staff travel was restricted in 2020 by order of the New Mexico Governor, so that field work was pushed back to Spring 2021. Our COVID-safe field practices now allow us to work with multiple safety measures, and as we ramp up for field work, we are dealing with competition for field vehicles, over-booked contractor schedules, and weather issues. NMED employees and most state employees have been teleworking since March 16, 2020. However, the SWQB Wetlands Program has still made significant achievements in the last two years and has made some positive and productive changes from lessons learned during the pandemic.

Since the Wetlands Program Plan was developed in 2010 and subsequently updated in 2012, 2015 2017, and 2019 progress has been made on activities that expand the capacity of the Wetlands Program. Below is a list that highlights some of these accomplishments.

- Since 2015, the Wetlands Program has expanded its New Mexico Wetlands Roundtable to include a Southern Wetlands Roundtable that is exclusively geared towards southern New Mexico issues and needs. Both the New Mexico Northern and Southern Wetlands Roundtables meet semiannually. Before pandemic safety precautions were implemented in March 2020, the Southern Wetlands Roundtable was conducted in the southern part of New Mexico in Las Cruces to include those partners more proactively and to address wetlands issues unique to the more arid conditions of southern New Mexico. The Northern Wetlands Roundtable was conducted in the northern part of the New Mexico principally in Santa Fe. Both the Southern and Northern Wetland Roundtables include agency, tribal and NGO participants, as well as students, watershed group members, and others interested in New Mexico wetlands. In March 2020, the scheduled in-person Southern and Northern Wetlands Roundtables were cancelled and subsequently conducted as virtual meetings using WEBEX. This change was remarkably successful in attracting participants that cannot travel to Wetlands Roundtable meetings, including out-of-state presenters and attendees. The Roundtables will continue as hybrid of in-person and webinar-based meetings in the

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future to engage as many partners as possible in wetlands and water resources issues, information sharing, technical transfer and resource protection.

- Mapping and classification of wetlands within nearly 20 million acres in the Canadian River basin and Dry Cimarron watersheds, Jemez Mountains and the Upper Rio Grande and adjacent areas, in the Sacramento Mountains and adjacent areas, and all wetlands on USFS Wilderness Areas is complete and included in the National Wetlands Inventory (NWI) database and on-line mapper. Mapping of wetlands in the Middle Rio Grande and surrounding areas in the mid-eastern portion of the state, in the Gila Region, in the Lower Rio Grande, in northwestern New Mexico surrounding the San Juan-Animas watersheds and the Estancia Basin, in the bootheel region in southwestern New Mexico and the eastern plains are currently in progress. In addition to polygonal and linear wetland feature mapping, the landscape position, landform, water body type, water flow path classification and descriptors (LLWW) are being applied to all wetlands mapped, and wetland functions are being identified and ranked. The wetlands are also being classified according to the Hydrogeomorphic (HGM) classification in order to prepare for NMRAM data collection and to identify classified segments for wetlands narrative water quality standards. In early 2020, the NWI began requiring any new mapping submitted to the NWI database to conform to new standards (NWI Version 2.0). The current ongoing mapping projects and the completed Sacramento Mountains project are all undergoing updates to conform to the new standards for inclusion in NWI. Participation in the New Mexico Geospatial Advisory Committee and the New Mexico Wetlands Roundtables assists in coordination of wetlands mapping throughout the State. Sixteen Map Book PDFs and instructions for making additional map books were created for use by watershed groups and others. These map books succinctly show map overlays of the different wetland classifications and wetland functions in a given area and are usable by those without GIS capability. The first SWQB Wetlands Program on-line Story Map (ESRI) for the Sacramento Mountains area is complete and can be found at: Sacramento Story Map and a Story Map for the entire state is in progress.

- The New Mexico Rapid Assessment Method (NMRAM) provides procedures, rationale and the metric measurement protocols for conducting a rapid assessment of wetlands. The assessment is a multi-step process including delineating a target Wetland of Interest and one or more Sampling Areas to be assessed. For each Sampling Area, metrics grouped into three attribute categories, Landscape Context, Biotic, and Abiotic are measured and rated. Landscape Context metrics are assessed using maps and/or a geographic information system (GIS) and preferably completed before going into the field to help familiarize the team with the site. The Biotic and Abiotic attributes are evaluated in the field along with a set of field-based stressor checklists and documentary photographs. Worksheets are provided to guide the taking and recording of data.

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The worksheets together with maps and photographs make up the *NMRAM Assessment Package* that becomes the supporting record of a project. The NMRAM is designed so that scores of individual metrics can be considered together, weighted, and rolled up into a single rank score representing the overall condition and function of a Wetland of Interest.

The Wetlands Program has completed the development of current versions of NMRAM for Montane Riverine Wetlands (Version 2.4), Lowland Riverine Wetlands (Version 2.3), Playa Wetlands (Version 1.2), and Springs Ecosystems (Version 1.0). The Field Guides and data collection worksheets are available at https://www.env.nm.gov/surface-water-quality/wetlands-rapid-assessment-methods/.

- The Montane Riverine Wetlands NMRAM was initially developed for montane riverine wetlands in the Upper Rio Grande watershed. SWQB Wetlands Program and its partners updated and validated the method for montane riverine wetlands in the Gila and Mimbres watersheds, and the Canadian and Dry Cimarron watershed for Montane Riverine Wetlands Version 2.4.
- The development of NMRAM Lowland Riverine Wetlands Version 1.1 was completed on the Gila and Mimbres watersheds – watersheds that are considered relatively intact. The Wetlands Program and its partners updated versions from data analyses in the Rio Grande and Lower Pecos, lowland riverine systems that have considerable alteration, for Lowland Riverine Wetlands Version 2.3. The Wetlands Program will further refine lowland riverine methods in the San Juan/Animas watersheds in the northwestern part of New Mexico to increase the reference domain for its use and to test its efficacy for supporting water quality standards development for lowland riverine wetlands.
- Development of NMRAM for Springs Ecosystems Version 1.0 in southwestern New Mexico is complete. Further refinement and utility of NMRAM for Spring Ecosystems in other reference domains in New Mexico is a future goal of the Wetlands Program.
- The Playa Wetlands NMRAM was developed for the thousands of playas of the Southern High Plains in eastern New Mexico. Through the Wetlands Program mapping efforts, depressional wetlands termed “playas” span the entire state but have a variety of unique hydrologic and hydrogeomorphic attributes as well as distinctive vegetation and other attributes. A future goal of the wetlands Program is to characterize New Mexico depressional wetlands and mineral flats so that NMRAM can be accurately applied.
- NMRAM development for confined valley riverine wetlands, and for headwater slope wetlands are in progress.
- A Version of NMRAM for Riverine Wetlands for Regulatory use (Version 1.3) by the Corps of Engineers and the regulated public is complete and will undergo final approval for use by the Corps of Engineers. The NMRAM Riverine Wetlands Regulatory Version 1.3 is still applicable and essential under the newest Waters of the US (WOTUS) rules.

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The Wetlands Program engages partners with expertise and local knowledge in development and refinement of these NMRAM versions through the assistance of an advisory committee for each subclass of NMRAM. Future versions of NMRAM will include episodic riverine wetlands, more subclasses of springs and other high-altitude and slope wetland types, as well as depressional and mineral flat wetlands.

A Statewide database for NMRAM data is currently being prepared for integration with other water quality databases (Surface Water Quality Information Database) (SQUID)) at NMED and is nearly ready for data input and on-line access for montane riverine wetlands, lowland riverine wetlands, confined valley riverine wetlands and playas NMRAM data. Electronic data collection worksheets have been developed for NMRAM, and development of Sampling Area reports is underway. The SWQB Wetlands Program is also developing SOPs for data entry into SQUID that describes the Verification and Validation process completed for data entry by SWQB.

- Wetlands perform ecological functions that help improve and maintain environmental quality. Healthy natural wetland ecosystems typically provide functions most effectively in terms of cost and performance. Twelve wetland ecological functions (WEFs) were identified as most pertinent for New Mexico. The NMRAM focuses on evaluating wetland condition as a measure of ecological integrity and, by inference, the natural functional capacity of wetlands. A cross walk between NMRAM metrics and WEFs was developed in 2019 including the rationale behind each metric and how it applies to the designated functions. The goal is to provide the relationship for using NMRAM to help develop wetlands standards aimed at minimizing loss and protecting wetlands acreage, quality, and function for the different subclasses of wetlands in New Mexico.

- A Wetlands Vegetation Index of Biotic Integrity (VIBI) for montane riverine wetlands was completed in 2013. The results of this project demonstrate the use of detailed vegetation data to assess the ecological condition of Montane Riverine wetlands. Wetlands restoration and management can then be improved to prevent disturbance and provide protection to suites of plants known to correlate with the lowest levels of human disturbance (reference sites). In turn, the VIBI can also be used to improve management of wetlands based on vegetation attributes and habitat characteristics. VIBI is another important tool that improves the State's ability to protect, manage, and restore its wetlands resources.

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- Our 10-year Strategy for Wetlands Assessment and Monitoring was completed in 2012, incorporated into the Monitoring and Assessment Strategy for New Mexico and is available at SWQB. The SWQB Wetlands Program is currently updating and refining this Strategy for the next ten years as part of the current five-year program commitment.

- Eighteen Wetlands Action Plans have been completed since the program started in 2003 and three new WAPS are underway. They are currently available on the SWQB Wetlands Program website at https://www.env.nm.gov/surface-water-quality/wap/ . They can also be accessed along with other watershed-based plans at https://www.env.nm.gov/surface-water-quality/wbp/ . The most current Wetlands Action Plan, "Arid-Land Spring Cienegas of New Mexico" describes a strategy for locating, restoring and protecting arid-land spring cienegas, important unique groundwater-supported wetlands that provide habitats for rare and unique plants and aquatic animals and are essential sources of water and pasture in arid regions throughout New Mexico.

- Progress toward implementing WAPs in priority watersheds is reported in the NPS Annual Report to EPA. In 2020, the NMED SWQB Watershed Protection Section incorporated WAPs into the Solicitation for Applications for Watershed Project Implementation. Applicants were allowed to apply for funding under watershed-based plans as well as completed Wetland Action Plans found at https://www.env.nm.gov/surface-water-quality/wap to implement activities and projects identified in the current WAP as well as update existing WAPs.

- One more Wetlands Demonstration Restoration Project was completed by SWQB Wetlands Program since 2019. "Keyline Design for Restoration of Headwater Slope Wetlands in the Holman Creek Wetlands Complex" demonstrated the application of Keyline Design principles to slope wetlands in a headwater ecosystem. These types of wetlands have precipitation-driven and groundwater-driven hydrologic characteristics. These wetlands are also important sinks for atmospheric carbon. Careful planning and integrated restoration techniques are highlighted using Keyline Design principles, and monitoring groundwater-supported wetlands is still ongoing at the project site. Other projects around the state are reported by our partners at the New Mexico Wetlands Roundtables and special projects by our partners are featured as the "NGO Spotlight". Thus far, New Mexico Wetlands Program has completed 10 Wetlands Demonstration Restoration Projects improving and expanding the State's wetlands restoration techniques toolbox that is shared and used statewide and nationally. Details of these projects can be found at https://www.env.nm.gov/surface-water-quality/wetlands-projects/ .

- Five Technical Guides are completed. The newest Technical Guide, "Applying Keyline Design Principles to Slope Wetland Restoration in a Headwater Ecosystem," is available from the SWQB Wetlands Program. Other Technical Guides include 1)

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"Exploring Springs and Wetlands and their Relationship with Surface Flows, Geology, and Groundwater in the La Cienega Area, Santa Fe County, New Mexico" 2) "New Mexico Wetlands Technical Guide: Wetland Functions"; 3) "Characterization and Restoration of Slope Wetlands in New Mexico"; 4) "The Plug and Pond Treatment: Restoring Sheet Flow to High Elevation Slope Wetlands in New Mexico," are also available in hard copy from SWQB and at New Mexico Environment Department Surface Water Quality. In addition, a landowner's guide, "Healthy Streamside Wetlands, A Guide to Good Stewardship for Southwestern Bosque and Riparian Wetlands," is available at New Mexico Environment Department Surface Water Quality and in hard copy from SWQB.

- In addition to our Wetlands Roundtables, the Wetlands Program provides workshops and training sessions to our partners and others. These workshops and trainings engage and inform partners, enhance partners capacity to proactively monitor and restore wetlands, influence stakeholders to be more involved in wetland issues, and increase the role and capacity of the Wetlands Program. In 2020 annual NMRAM trainings available to watershed groups, agencies, contractors, tribes and others were postponed due to Covid restrictions but are expected to resume in summer 2021. As a supplement to the NMRAM trainings, Botany Booster trainings are held to improve the technical expertise of participants to collect biotic data and will also resume in 2021. The Keyline Design Project was highlighted in a half day conference workshop by the Quivira Coalition in November 2019. The Wetlands Program staff also participated in the 2021 ASWM-sponsored Annual State/Tribal/Federal Coordination Virtual Meeting serving on a panel for sharing wetland mapping for a variety of uses. Weekend restoration workshops at the East Fork of the Jemez River on the Valles Caldera National Preserve are also planned to resume in 2021. Participants at the workshops learn about and implement innovative wetlands restoration techniques. These techniques included building innovative restoration structures of natural and on-site materials that re-direct flow, spread water, arrest erosion, raise the water table in wetlands, and attract beaver and other wildlife, as well as constructing barriers in strategic locations to protect sensitive wetlands from livestock and wildlife grazing.

  The SWQB Wetlands Program conducted a three-day "Wetlands Across Borders, Playas of the Southern High Plains" workshop in Clovis, New Mexico in late 2017. The meeting consisted of one and one-half days of presentations and panel discussions about playa ecology, conservation, restoration and other important topics about playas. The meeting was followed by three track options – New Mexico Rapid Assessment Method Training for Playa Wetlands, a Playas and Roads workshop, or a half-day field trip to look at local playas. The meeting was advertised to over 1600 potential participants through the local SWCDs and through contacts in Texas, Colorado and Oklahoma since those states have Southern High Plains playas and their communities are facing similar critical water issues.

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Two two-and-a-half day workshops targeting tribal, NMDOT, other agency and county roads staff in the playa region of the Southern High Plains and the San Juan region in northwestern New Mexico were conducted in 2017 and 2018 to provide the principals of geomorphology and natural channel design to roads construction and maintenance. The workshops updated the participants on new techniques, best management practices and construction specifications for successful playa, stream and riparian restoration integrated with road design and maintenance techniques. The workshops demonstrated that highway construction projects have the potential to not only "do no harm" but even to improve the health of the waterbody or watercourse, introducing a new paradigm of road design and maintenance. The SWQB Wetlands Program will continue to demonstrate new techniques for restoring playas and playa clusters as the focus of partner planning restoration and monitoring efforts.

A workshop to organize the first "All Hands" monitoring effort was conducted and on-site monitoring with volunteer groups was initiated only to be postponed by Covid restrictions in 2020. Currently "All Hands Phase 2" is being planned and promoted and will use virtual training modules to supplement on-the-ground training techniques and certification of participants to use NMRAM. "Restoration Crew Leader" training was completed in 2019 providing trainees the skills to manage restoration teams and complete restoration in a safe and efficient manner. These efforts will increase participation by agencies and volunteers in restoration and data collection for wetlands.

- Review of our current Water Quality Standards to identify ways to improve and update regulations to be more applicable to wetlands and wetland subclasses is underway. Completing a review of other State's wetland regulations and participating with the Association of State Wetland Managers (ASWM) in a wetlands water quality standards project has augmented this effort. In 2016, the Wetlands Program participated in the Association of Clean Water Administrators (ACWA) development of templates for wetlands narrative water quality standards and provided a webinar on how New Mexico is using those templates and the steps taken to develop meaningful and defensible narrative wetlands water quality standards.

  The Wetlands Program has developed a nine-step process for the development of wetlands water quality standards for New Mexico.

  1. Mapping and classification update
  2. Identifying wetland functions by wetland type (designated uses)

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3. Hydrogeomorphic classification applied to mapped wetlands
4. Measuring the condition of wetlands by wetland type
5. Identifying stressors that affect wetland condition (impairments)
6. Database development
7. Unique identifiers for each wetland (Assessment Units)
8. Using these data to develop a defensible narrative standard by wetlands type
9. Plan for outreach to the public regarding the development and uses of wetland water quality standards.

A draft white paper describing water quality standards for Playas of the Southern High Plains in New Mexico is under development and review and incorporates the template for wetlands narrative water quality standards. Since the 2001 Supreme Court decision known as SWANCC (Solid Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers, 531 U.S. 159), playas are not jurisdictional waters under the federal Clean Water Act. Even with the current state standards, the New Mexico Environment Department would currently not be able to enforce any permit conditions in the absence of a state surface water quality permitting system. However, the development of the standard paves the way for future protection of playas as the principal natural source of surface water and groundwater recharge on the Southern High Plains of New Mexico.

The SWQB Wetlands Program will develop wetlands water quality standards for other subclasses of wetlands including Montane Riverine Wetlands and Headwater Slope Wetlands as well as other isolated wetland types in need of state protection. The Wetlands Program will use data generated through assessment and monitoring to evaluate stressor load reductions that will improve wetland condition (Total maximum levels of stress (TMLS). The goal is to develop and refine narrative water quality standards for wetlands to be more applicable to and protective of subclasses of wetlands in New Mexico.

OVERVIEW OF FIVE-YEAR GOALS AND OBJECTIVES

To effectively develop basic program functions that form the foundation of wetlands management and protection, the following outlines core elements, actions and activities to protect and restore New Mexico's wetlands over the next five-year period. The completion of these activities is dependent on financial, staffing and other resources available to the Wetlands Program and its partners.

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Program Development Activities for BUILDING AND MAINTAINING PARTNERSHIPS

Overall Objective: The SWQB Wetlands Program relies on a substantial number of partners to implement the work on the ground. A core function of the five-year plan is to continue building and maintaining partnerships to implement the Wetlands Program Plan, and to train and inform partners at all levels.

Action: Continue to build and maintain partnerships							
Activity	**2021**	**2022**	**2023**	**2024**	**2025**	**Partners**	**Activity Lead**
Maintain and expand participation in State Wetlands Roundtables (presently in its 15th year) composed of governmental, NGO, watershed group and tribal partners to address challenges to New Mexico's wetlands resources. Update and refine Roundtables' venues to include hybrid in-person and virtual meetings.	x	x	x	x	x	State, federal, NGO, watershed group and tribal government partners on Roundtable	SWQB Wetlands Program
Maintain the Northern Wetlands Roundtable meetings to discuss resources for developing and maintaining initiatives, and addressing challenges to monitoring, restoring and protecting New Mexico's wetlands.	x	x	x	x	X	Governmental, tribal, NGO partners on Northern Roundtable	SWQB Wetlands Program, NGO co-sponsorship
Maintain the Southern Wetlands Roundtable to discuss regulations, restoration, monitoring, challenges and partnerships unique to the southern part of the state.	x	x	x	x	x	Governmental, tribal and NGO partners on Southern Roundtable	SWQB Wetlands Program, NGO co-sponsorship
Work with Roundtables to ensure cooperation to achieve Wetlands Program Plan goals. Develop annual actions and dialogue to further the goals of this Plan.	x	x	x	x	x	Wetlands Roundtables	SWQB Wetlands Program

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Continue to identify and participate in public/private partnerships such as the Rio Grande Water Fund with the goal of generating sustainable funding for restoration, protection, education, research and policy.	x	x	x	x	x	Foundations, private businesses, water utilities, tribal, federal, state and private partners	The Nature Conservancy, NMED signatory
Action: **Identify and maintain simple, effective and efficient methods for monitoring wetlands through partnerships**							
Activity	**2021**	**2022**	**2023**	**2024**	**2025**	**Partners**	**Activity Lead**
Identify long-term sustainable wetlands monitoring strategy for watershed wetlands that can be maintained by local government, citizen science or watershed groups.	x	x	x			Local governments and Watershed Groups, Roundtables	Roundtables, WAP-participating Watershed Groups
Work collectively with all partners towards a long-term solution to wetlands monitoring, particularly the funding of long-term monitoring.	x	x	x	x	x	Roundtables	Northern and Southern Roundtables
Create a toolbox of wetlands monitoring metrics and protocols for partners to determine restoration success and adaptive management that can be scalable to support both large-scale and small-scale projects.		x	x	x	x	Roundtables, Project Contractors, Watershed Groups	SWQB Wetlands Program, Watershed Groups
Engage group participation through a demonstration "All Hands Phase 2" monitoring effort to collect NMRAM data. Continue effort each year at select sites.	x	x	x	x		Agencies, NGOs, trained technicians	SWQB Wetlands Program
Develop tools (i.e., story maps, map books, field guides, virtual training modules, mobile apps) to teach and disseminate wetlands assessment and mapping products to partners, watershed groups and local governments.	x	x	x	x	x	Local governments and Watershed Groups, Roundtables	SWQB Wetlands Program

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Action: Identify opportunities to create sustainable ways to fund and accomplish wetlands restoration and protection work.							
Activity	**2021**	**2022**	**2023**	**2024**	**2025**	**Partners**	**Activity Lead**
Investigate the feasibility of creating a "short term funding source" that will support funding of small-scale restoration projects. This source could make funds available up front to landowners who receive grants as reimbursement for expense incurred.	x	x	x	x	x	Roundtables, Foundations, Banks, State Revolving Fund (SRF), River Stewardship Program	SWQB Wetlands Program, Roundtables
Create Strategy to coordinate and leverage multiple funding sources. Encourage partners to work towards a large-scale project with a large impact supported by numerous funding sources, such as accomplished in the Bitter Lakes area. eg. Middle Rio Grande - Inter-Mountain West Joint Venture, Rio Grande Water Fund	x	x	x	x	x	Northern and Southern Roundtable participants	Agencies and NGOs at Roundtables

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Program Development Activities for MONITORING AND ASSESSMENT Core Element

Overall Objective: Develop a full and complete wetlands assessment and monitoring strategy consistent with *Elements of a State Water Quality Monitoring and Assessment Program for Wetlands* (EPA, 2006) that the State can use to inform management decisions and achieve goals that protect and restore wetlands resources.

Action: Continue to develop Elements of a State Water Quality Monitoring and Assessment Strategy for Wetlands							
Activity	**2021**	**2022**	**2023**	**2024**	**2025**	**Partners**	**Activity Lead**
Continue to develop monitoring design and sample sites that best serve the State's assessment and wetland management objectives.	x	x	x	x	x	Roundtables, UNM Natural Heritage, State Agencies, EPA, federal land management agencies.	SWQB MASS and Wetlands Program
Participate in National Wetlands Monitoring and Assessment Work Group (NWMAWG) to stay abreast of new developments in wetland monitoring, assessment, and data analysis. Participate in 2021 NWCA.	x	x	x	x	x	NWMAWG, EPA	SWQB Wetlands Program
Update the State of New Mexico 2012 Wetlands Assessment and Monitoring Strategy.	x	x	x	x		SWQB Staff, Agencies and Roundtables	SWQB Wetlands Program
Action: Assess and monitor wetland resources by the development and use of Landscape, Rapid Assessment and Intensive Monitoring tools							
Activities	**2021**	**2022**	**2023**	**2024**	**2025**	**Partners**	**Activity Lead**
Participate in the State Mapping Consortium, Geospatial Advisory Committee, and National Wetlands Mapping Consortium, and on the NHD update representing wetlands until New Mexico has, at a minimum, National Wetlands Inventory coverage, classification and functional descriptors of all wetlands resources.	x	x	x	x	x	USFWS NWI, USFS, Geospatial Advisory Committee, Roundtables, Tribes, ASWM	SWQB Wetlands Program, Geospatial Advisory Committee

NMED Exhibit 22

Complete mapping and classification of all non-tribal lands in New Mexico, including quadrangles in central New Mexico "checkerboard area" adjacent to Navajo Tribal lands, along the Rio Grande, and in southern and eastern New Mexico, including the bootheel area, and the Pecos mainstem until statewide coverage is complete. Ensure edge matching between project areas and checkerboard areas.	x	x	x	x	x	USFWS, SLO, ACOE, NMBGMR, Department Homeland Security, ASWM, USFS, BLM, USFWS, private stakeholders and counties	SWQB Wetlands Program, mapping contractors
Complete application of NWI 2.0 to all New Mexico mapped areas. Review and ensure all wetlands in USFS wilderness and roadless areas are updated. Complete mapping gaps analyses to ensure current mapping and application of wetland classifications are complete.	x	x	x	x	x	USFWS, SLO, NMBGMR, Department Homeland Security, ACOE, ASWM, USFS, BLM, USFWS, private stakeholders and counties	SWQB Wetlands Program, mapping contractors
Using mapping and classification products to identify depressional wetlands and mineral flats that are considered "playas" and describe and categorize these waterbodies into subclasses throughout New Mexico.						USFWS, SLO, NMBGMR, Department Homeland Security, ACOE, ASWM, USFS, BLM, USFWS, private stakeholders and counties	SWQB Wetlands Program

NMED Exhibit 22

Assist in comprehensive vegetation mapping for wetlands and riparian areas statewide, collaborate with tribes and include new areas not mapped.	x	x	x	x	x	USFS, USFWS, BLM, NWI, UNM Natural Heritage, NMDGF, BOR Mapping Advisory Com.	SWQB Wetlands Program, NMDGF, UNM Natural Heritage
Continue to develop and promote the use of the New Mexico Rapid Assessment Method (NMRAM) for other wetlands subclasses through training and other venues. (Conduct one training per year) Organize one "all hands" data collection by trained partners each year. Conduct Botany Booster trainings as needed.	x	x	x	x	x	UNM Natural Heritage, ACOE, NMDOT, EPA, NMDGF, Tribes, Consultants, Watershed Groups, Others.	SWQB Wetlands Program
Revise and apply NMRAM to other wetland types and to other parts of the State. Continue to collect NMRAM data following the SWQB Water Quality Assessment Rotational Schedule at least every other year. Continue to revise NMRAM subclass modules as new data validates current NMRAM metrics and NMRAM analyses suggest the need for metric and scoring revisions. (See NMRAM development schedule below.)	x	x	x	x	x	SWQB Wetlands Program, UNM Natural Heritage, NMRAM Advisory Committees, consultants, others.	SWQB Wetlands Program
Test NMRAM to ensure that designated uses and proposed narrative standards for wetland subclasses are aligned to NMRAM condition rank scoring (Rank A (supporting), rank B (Supporting at Risk) and C or D (Non-Supporting).		x	x	x	x	UNM Natural Heritage	SWQB Wetlands Program
Update and expand database of reference standard wetlands using newly mapped wetland areas and classification as a basis for preliminary selection. Encourage volunteers and partners to assess reference standard wetlands using NMRAM.	x	x	x	x	x	UNM Natural Heritage and mapping contractors	SWQB Wetlands Program

NMED Exhibit 22

Update the State's Quality Assurance Project Plan to include common wetland monitoring methods and protocols.	x	x	x	x		SWQB and EPA quality assurance officers	SWQB Wetlands Program
Develop a strategy and identify sample areas to sample repeatedly for wetlands status and trends.		x	x	x	x	UNM Natural Heritage Program	SWQB Wetlands Program
Develop monitoring methods and indicators of carbon sequestration and carbon and nitrogen exchange in response to wetland restoration.		x	x	x	x	UNM Natural Heritage, NMSU and other partners	SWQB Wetlands Program
Support NMRAM metrics and methods through level three data (e.g., Indicators of Ecological Integrity.)				x	x	UNM Natural Heritage	SWQB Wetlands Program
Action: Track Monitoring data in a system that is accessible, updated on a timely basis, and integrated with other water quality data							
Activity	**2021**	**2022**	**2023**	**2024**	**2025**	**Partners**	**Activity Lead**
Continue development of web-based database for wetlands coordinated with other SWQB databases (Surface Water Quality Information Database (SQUID)) and data. Share data with agencies and through statewide information portal.	x	x	x	x	x	NMED OIT, UNM Natural Heritage, NM Water Data Collaborative	SWQB Wetlands Program and NMED OIT
Develop a system for geo-referencing data and displaying data collection sites for reporting and analysis.	x	x	x	x	x	NMED OIT and geospatial staff	SWQB Wetlands Program and NMED OIT
Develop and implement verification and validation packet for transferring data to SWQB, so data can be used for assessment against WQS, enforcement of WQS under the NM Water Quality Act (74-6-10 NMSA), development of the Integrated List, TMDL development, or WQS amendments.	x	x	x			Watershed Groups, Consultants, volunteer teams collecting NMRAM data.	SWQB Wetlands Program and SWQB Standards Section, SWQB QA/QC Officer EPA QA Officer.

NMED Exhibit 22

Program Development Activities for WETLANDS REGULATORY PROGRAM Core Element

Overall Objective: Promote the use of new and proven methods to protect and restore wetlands by regulated project proponents.

Action: Adopt procedures and strengthen processes that protect wetlands through regulatory measures							
Activity	**2021**	**2022**	**2023**	**2024**	**2025**	**Partners**	**Activity Lead**
Maintain and improve the State's wetlands resources through development of sufficient mitigation ratios when mitigation is the only option. Include "no net loss" of function.	x	x	x	x	x	USACE, BUR, NMDOT, regulated community	USACE
Improve regulatory programs like the certification of Dredge and Fill under CWA § 401 that provide mechanisms for regulation of wetlands activities. Work more closely with USACE to provide input from §§404/401 public interest reviews.	x	x	x	x	x	USACE	SWQB 401 Cert Program and SWQB Wetlands Program
Explore the feasibility, find sites and sponsors of In-Lieu Fee Programs, and Mitigation Banks	x	x	x	x	x	USACE, NMDOT, Roundtable, NGOs	USACE
Expand the activities and content reported for wetlands in the combined CWA §§303(d) and 305(b) report, and in the NPS Management Plan.	x	x	x			Agencies	SWQB staff, SWQB Wetlands Program
Develop and improve ordinances and jurisdiction that protect wetlands/riparian areas/ buffer at the local level, and that ensure that vulnerable and isolated wetlands are protected from impacts. Use WAPs to help accomplish this.	x	x	x	x	x	County governments, local governments, watershed groups with WAPs	SWQB Wetlands Program, Roundtables

NMED Exhibit 22

Develop a tracking process to track wetlands gains and losses from a variety of activities that either impact or restore wetlands.			x	x	x	USACE, NRCS	SWQB Wetlands Program
Continue development, training and use of USACE NMRAM in BAMI procedures.	x	x	x	x	x	USACE, UNM Natural Heritage, regulated community	USACE, SWQB Wetlands Program
Contribute to CWA updates, revision, and initiatives that assures the CWA protects all wetlands.	x	x	x	x	x	ASWM, EPA, USACE, other states.	SWQB Wetlands Program

Program Development Activities for VOLUNTARY RESTORATION AND PROTECTION Core Element

Overall Objective: Meet the wetlands goals in the watershed restoration activities established in the State's Non-Point Source Management Plan.

Action: Expand and improve Wetlands Action Plan (WAP) Program							
Activity	**2021**	**2022**	**2023**	**2024**	**2025**	**Partners**	**Activity Lead**
Work with other agencies and organizations to coordinate wetlands restoration, activities and funding through development of WAPs. Incorporate potential mitigation sites into WAPs and include information on updating ordinances or other protection at the local level.	x	x	x	x	x	USFS, NMDGF, BOR, BLM, USACE, other agencies, Roundtables, SWQB WPS	SWQB Wetlands Program and Watershed Groups
Integrate WAPs and watershed-based plans intended to implement NPS TMDLs and incorporate wetlands objectives in NPS pollution abatement.	x	x	x	x	x	SWQB WPS, Watershed Groups	SWQB Wetlands Program
Develop and demonstrate innovative designs and techniques for restoring wetlands.	x	x	x	x	x	Consultants, NGOs, NMDGF, Roundtables, NRCS, restoration contractors.	SWQB Wetlands Program

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Seek out, develop and demonstrate improved methods for protecting wetlands i.e., headwaters, slope, alluvial fans, high elevation wetlands, springs, cienegas, playas and depressional wetlands as high priority areas.			x	x	x	NGOs, BLM, USFS, SLO, NMDGF, USFWS, NRCS, landowners, watershed groups, local government.	SWQB Wetlands Program, Roundtables.
Research, develop and demonstrate re-establishment techniques and innovative designs for lentic wetlands around lakeshores, ponds and man-made tanks.			x	x	x	BLM, USFS, SLO, NRCS, NMDGF, USFWS, NGOs, Universities.	SWQB Wetlands Program,
Develop and demonstrate innovative designs and protocols for restoration of at-risk wetlands and aquatic resources with wetland dependent priority species. Improve resilience and protection of at-risk wetland resources from flooding, fire and drought.	x	x	x	x	x	Federal, state and local agencies, tribes, NMDGF, USFWS	SWQB Wetlands Program
Encourage WAP partners to locate and protect slope wetlands (seeps and springs) and depressional wetlands in their watersheds and include information in WAPs.			x	x	x	NGOs, Watershed groups.	SWQB Wetlands Program
Update and improve SWQB Wetlands Website to augment communication with WAP partners, provide technical transfer of restoration techniques and guidance, display new WAPs, create links, and update with relevant activities of Wetlands Program.	x	x	x	x	x	Watershed groups, agencies, stakeholders, project contractors.	SWQB Wetlands Program
Integrate mapping and classification products into existing and future WAPs. Encourage the use of NMRAM to assess the condition of wetlands identified in watershed based WAPs and regional WAPs and include NMRAM data in WAPs. Provide mapping, classification and NMRAM training at least once per year to partners creating WAPs.	x	x	x	x	x	Watershed groups, consultants, NGO and Agency Roundtables, Tribes	SWQB Wetlands Program, UNM Natural Heritage, mapping contractors

NMED Exhibit 22

Action: Create strategies that build capacity on public lands in New Mexico							
Activity	**2021**	**2022**	**2023**	**2024**	**2025**	**Partners**	**Activity Lead**
Develop strategies that shape policy for land and water use on public lands to promote restoration of wetlands.	x	x	x	x	x	Agencies. NMDGF, EMNRD, USFS, BLM, BOR, SLO.	SWQB Wetlands Program
Promote the preservation of wildlife habitat, wildlife corridors, and keystone species habitat related to wetlands and consistent with the State Wildlife Action Plan.	x	x	x	x	x	Agencies, NM DGF, Local Governments	SWQB Wetlands Program
Develop demonstration projects that emphasize pro-active climate change resilience activities including restoration and protection of wetlands and riparian corridors on federal lands.			x	x	x	USFS, USFWS, NPS, BLM	SWQB Wetlands Program,
Encourage federal agencies to monitor and protect ONRW wetlands.	x	x	x	x	x	Government Agencies, Agency Roundtables	SWQB Wetlands Program
Action: Create strategies that build capacity at the local level							
Activity	**2021**	**2022**	**2023**	**2024**	**2025**	**Partners**	**Activity Lead**
Develop strategies for working with private landowners and develop incentives for private landowners through watershed groups to restore, protect wetlands. Target isolated wetlands (e.g., cienegas, playas, springs) on private lands.	x	x	x	x	x	NRCS, NGOs, Agencies, Consultants	Southern and Northern Roundtables, Watershed Groups
Create technical materials and disseminate information to private landowners, tribes and others on incentives, methods and trainings to restore and protect wetlands.	x	x	x	x	x	NRCS, NGOs, Agencies, Consultants, Tribes, Roundtables.	SWQB Wetlands Program

NMED Exhibit 22

Continue to refine information that provides economic justification and other value, including cultural/traditional and aesthetic for restoring wetlands.	x	x	x			ASWM, Tribes, watershed groups and others	SWQB Wetlands Program
Develop avenues for outreach to different groups who could be involved in wetlands as part of Wetlands Roundtable, Quivira Coalition Conference workshops, or other venue. Conduct statewide and interstate wetlands workshops. Reach out to new partners, new opportunities, at new venues.		x	x	x		SWQB WPS, Quivira Coalition, Roundtables, irrigation districts, Prairie Partnerships, other states' groups, others.	SWQB Wetlands Program
Assist partners by building their volunteer labor base and creating match opportunities. Train volunteer crew leaders in restoration techniques so that more volunteers are accommodated and are more productive on-site.	x	x	x	x	x	NGOs, Agencies, watershed groups.	SWQB Wetlands Program
Assist partners in finding match opportunities by participating in development and organization of large-scale wetland restoration/protection projects.	x	x	x	x	x	Local Governments, IWJV, PLJV, TNC, NM Wildlife Federation, USFWS Partners for Wildlife, others.	SWQB Wetlands Program
Develop and use incentives for landowners, road agencies and others within and adjacent to depressional wetlands (e.g., playas) watersheds to improve watershed conditions that benefit landowners and wetland resources.	x	x	x	x		USFWS Partners for Fish and Wildlife, NGOs, County Roads, NMDOT, private landowners, municipalities.	SWQB Wetlands Program

NMED Exhibit 22

Program Development Activities for WATER QUALITY STANDARDS FOR WETLANDS Core Element

Overall Objective: Prepare for the future adoption of water quality standards for specific wetland types and ensure that ONRW wetlands are appropriately protected.

Action: Develop water quality standards for wetlands							
Activity	**2021**	**2022**	**2023**	**2024**	**2025**	**Partners**	**Activity Lead**
Review wetlands data to identify criteria that define physical, chemical and biological condition that is expected in wetlands.	x	x	x	x	x	ASWM, ACWA, other states.	Wetlands Program, SWQB Standards Team, EPA
Assess results of NMRAM data and other current state resources, data and information to develop and substantiate draft wetlands narrative standards by subclass (montane riverine, lowland riverine, confined riverine and playas).	x	x	x	x	x	ASWM, SWQB Staff, NMDGF, EPA, UNM Natural Heritage, others.	SWQB Wetlands Program
Assign functions to all mapped wetland subclasses; and develop appropriate wetland specific designated uses for four wetland subclasses (montane riverine, lowland riverine, confined riverine and playas).	x	x	x	x	x	NMDGF, Playa Lakes Joint Venture, Roundtables, Watershed Groups, stakeholders, others.	SWQB Wetlands Program, SWQB Standards Team, EPA
Assign Water Quality Classified Segments to wetlands using wetland mapping and classification information as a basis.	x	x	x	x	x	Wetland mapping contractors, SWQB MASS.	Wetlands Program SWQB Standards Team, EPA

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Draft narrative criteria that qualitatively describe the condition that must be achieved to support the designated uses. Use data from reference standard sites (best obtainable) for the montane riverine, lowland riverine, confined riverine and playas subclasses.	x	x	x	x	x	SWQB Staff, technical advisory committee, others.	Wetlands Program, SWQB Standards Team, EPA
Draft narrative water quality standards for wetlands for subclasses – montane riverine, lowland riverine, confined riverine and playas.	x	x	x	x	x	SWQB Staff, technical advisory committee, others.	Wetlands Program, SWQB Standards Team, EPA
Develop technical documents to support the narrative criteria that will be used in determining attainment of the standard.	x	x	x	x	x	SWQB Staff, technical advisory committee, others.	Wetlands Program, SWQB Standards Team, EPA
Scope venues and communities for Wetlands WQS outreach.		x	x	x	x	Watershed Groups, NGOs and Roundtable partners	SWQB Wetlands Program
Identify ecologically important and high-quality wetlands through wetlands mapping and assessment for future Outstanding National Resource Waters (ONRW) nomination and protection. Assist partners in developing ONRW nominations.	x	x	x	x	x	UNM Natural Heritage Program, Watershed Groups, NGOs and Roundtable partners	SWQB Wetlands Program, SWQB Standards Team
Action: Apply anti-degradation policies for ONRW wetlands							
Activity	**2021**	**2022**	**2023**	**2024**	**2025**	**Partners**	**Activity Lead**
Work with USFS liaison to NMED to continue to appropriately protect and maintain condition and functions of ONRW wetlands	x	x	x	x	x	SWQB Staff, USFS liaison to NMED	SWQB Wetlands Program

NMED Exhibit 22

Review Anti-Degradation Implementation Policy to determine if additional language related to wetlands functions, condition and hydrologic regime is appropriate.			x	x	x	SWQB Staff	SWQB Standards Team and SWQB Wetlands Program

ACRONYMS

ACOE	Department of the Army Corps of Engineers
ACWA	Association of Clean Water Administrators
ASWM	Association of State Wetland Managers
BAMI	Before-After Mitigation Impact
BLM	Bureau of Land Management
BOR	Bureau of Reclamation
CPP	Continuing Planning Process
CWA	Clean Water Act
EPA	Environmental Protection Agency
HGM	Hydrogeomorphic
IWJV	Intermountain West Joint Venture
LLWW	Landscape position, landform, water body type, water source
MASS	Monitoring, Assessment and Standards Section
NGO	Non-Governmental Organization
NHD	National Hydrologic Dataset
NMAC	New Mexico Administrative Code
NMBGMR	New Mexico Bureau of Geology and Mineral Resources
NMDGF	New Mexico Department of Game and Fish
NMDOT	New Mexico Department of Transportation
NMED	New Mexico Environment Department
NMRAM	New Mexico Rapid Assessment Method
NMEMNRD	New Mexico Energy, Minerals and Natural Resources Department
NPDES	National Pollutant Discharge Elimination System

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NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
NWI	National Wetlands Inventory
NWMAWG	National Wetlands Monitoring and Assessment Work Group
OIT	Office of Information Technology
ONRW	Outstanding National Resource Waters
PLJV	Playa Lakes Joint Venture
SLO	New Mexico State Land Office
SQUID	Surface Water Quality Information Database
SRF	State Revolving Fund
SWQB	Surface Water Quality Bureau
TMDL	Total Maximum Daily Load
TNC	The Nature Conservancy
UNM	University of New Mexico
US	United States
USACE	United State Department of the Army Corps of Engineers
USFS	US Forest Service
USFWS	US Fish and Wildlife Service
USGS	US Geological survey
VIBI	Vegetation Index of Biotic Integrity
WAP	Wetlands Action Plan
WPP	Wetlands Program Plan
WPS	Watershed Protection Section
WQCC	Water Quality Control Commission
WQMP	Water Quality Management Plan
WQS	Water Quality Standards

NMED Exhibit 22

This Diagram shows the progression of New Mexico Rapid Assessment Method (NMRAM)development by the SWQB Wetlands Program. The update dates in yellow are proposed updates to the current NMRAM Versions. Lowland Riverine Wetland NMRAM is proposed to be tested and updated for the San Juan/Animas watersheds in Northwestern New Mexico. The Playas NMRAM will be tested, and supplemental metrics added to ensure applicability to the Playas of the Southern High Plains narrative water quality standard currently under development. The Springs NMRAM will be updated and applied to spring ecosystems in other parts of New Mexico to expand the reference domain. The NMRAM subclasses in green are proposed modules for future development.

NMED Exhibit 22

NMRAM MODULES BY WETLAND SUBCLASS

NMRAM Manual Updates

Survey data into database

Current	Montane Riverine Chapter 2014 Update 2021	Montane Riverine Field Guide 2.4	Montane Riverine Data Collection Worksheets Package 2.4	Montane Riverine Module Database
	Lowland Riverine Chapter 2016 Update 2024	Lowland Riverine Field Guide 2.3 Update 2024	Lowland Riverine Data Collection Worksheets Package 2.3 Update 2024	Lowland Riverine Module Database
	ACOE Reg-NMRAM Chapter 2017 Update 2021	ACOE Reg-NMRAM Field Guide 1.4	ACOE Reg-NMRAM Data Collection Worksheets Package 1.4	ACOE Database
	Playas Chapter 2017 Update 2023	Playas Field Guide 1.2 Update 2023	Playas Data Collection Worksheets Package 1.2 Update 2023	Playas Module Database
	Springs Chapter 2019 Update 2024	Springs Field Guide 1.0 Update 2024	Springs Data Collection Worksheets Package 1.0 Update 2024	Springs Module Database
	Confined Valleys Riverine Chapter 2021	Confined Riverine (Canyon) Field Guide 1.3	Confined Riverine (Canyon) Data Collection Worksheets Package 1.3	Confined Riverine (Canyon) Module Database
Future	Headwater Slope Chapter 2022	Headwater Slope Field Guide 1.0	Headwater Slope Data Collection Worksheets Package 1.0	Headwater Slope Module Database
	Statewide Playas Chapter 2024	Statewide Playas Field Guide 1.0	Statewide Playas Data Collection Worksheets 1.0	Statewide Playas Module Database
	Desert Mineral Flats (Discharge Playas) Chapter 2024	Desert Mineral Flats (Discharge Playas) Field Guide 1.0	Desert Mineral Flats (Discharge Playas) Data Collection Worksheets 1.0	Desert Mineral Flats (Discharge Playas) Module Database
	Subalpine Riverine Chapter 2025	Subalpine Riverine Field Guide 1.0	Subalpine Riverine Data Collection Worksheets Package 1.0	Subalpine Riverine Module Database
	Ephemeral Riverine and Alluvial Fan Chapter 2025	Ephemeral Riverine and Alluvial Fan Field Guide 1.0	Ephemeral Riverine & Alluvial Fan Data Collection Worksheets Package 1.0	Ephemeral Riverine and Alluvial Fan Module Database

Spatial data

Tabular data

NMRAM Wetland Atlas Web-served Geodatabase

SQUID Database

NMED Exhibit 22

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EDUCATION

M.S. Hydrology
University of Arizona – Tucson, AZ

B.S. Biology
Minor in Chemistry/Math
University of Arizona – Tucson, AZ

PROFESSIONAL EXPERIENCE

Bureau Chief – Surface Water Quality Bureau, NM Environment Department

August 2016 – Present (Full-Time) NMED – Surface Water Quality Bureau, Santa Fe, NM

- Manage the Surface Water Quality Bureau of the New Mexico Environment Department by planning, setting, and achieving goals set forth in the Department's Strategic Plan, EPA approved work plans, and program planning documents.
- Contribute to and implement Department strategic goals, objectives, and actions.
- Develop and respond to legislative proposals and develop regulatory initiatives to promote and enhance surface water quality protections in New Mexico.
- Served as an expert witness during the 2025 NM Legislative Session; testified at five (5) legislative committee hearings; provided technical support and professional opinions; and supported the bill sponsors during both the House and Senate floor votes to advocate for the passage of Senate Bill 21.
- Collaborate with the public, stakeholders, and decision makers (legislators, Governor's Office, etc.) to ensure that the goals of the Department are achieved.
- Oversee an operating budget of approximately $15 million dollars that requires administration of general funds, special revenue funds, interagency transfers, and federal grants, including oversight of the Bureau's grants and contracts management.
- Develop, tailor, and implement administrative, programmatic, and financial operation procedures to ensure accountability and facilitate successful completion of projects.
- Directly or indirectly supervise 47 technical and administrative staff including hiring, work performance evaluations, and discipline, if needed. Ensure performance goals are met and activities are conducted in accordance with applicable statutes, policies, rules, permits, orders, and grant commitments.
- Provide leadership and substantive expertise on technical and policy working groups, particularly in support of Department priority initiatives.
- Periodically meet with managers and staff to evaluate program effectiveness, identify strengths, weaknesses, and opportunities, and develop strategies to improve Bureau programmatic operating functions.
- Facilitate coordination between EPA, and other public and private entities involved in surface water quality protection, management, and regulation.
- Ensure that information requests are responded to in a timely and professional manner.
- Oversee short-term investigations in response to citizen complaints, accidental spills, and other emergencies.
- Work with the Bureau's webmaster to create, update, and maintain webpages, resources, and links associated with activities of the Bureau.

Program Manager for Monitoring, Assessment and Standards

June 2015 – October 2016 (Full-Time) NMED – Surface Water Quality Bureau, Santa Fe, NM

- Managed the Surface Water Quality Bureau's monitoring, assessment, and standards programs including writing, submitting, and managing the Clean Water Act Section 106 grants on an annual basis with semi-annual updates.
- Oversaw and evaluated the performance of 15 staff.
- Participated in the development and revision of state surface water quality standards and regulations including the 2013 Triennial Review presented during the Water Quality Control Commission's October 2015 hearing and subsequent deliberations.
- Planned water quality surveys throughout New Mexico that met budgetary constraints and data quality objectives.
- Reviewed, integrated, and assessed data for use in Clean Water Act required activities.
- Prepared water quality reports (e.g. watershed survey summaries, use attainability analyses, TMDLs, etc.) for the public and as a deliverable to EPA.
- Reviewed, updated, and developed protocols to standardize tasks including sample collection, data assessment, and report writing.
- Represented the Bureau at meetings, professional conferences, workshops, and Water Quality Control Commission meetings.
- Conducted short-term investigations in response to citizen complaints, accidental spills, and other emergencies.
- Maintained analytical results in the Bureau's water quality database, prepared retrievals of stored data, and scheduled uploads of data to EPA's national database.
- Worked with the Bureau's webmaster to create, update, and maintain webpages, resources, and links associated with activities of the Section and Bureau.

Municipal Team Leader – Point Source Regulation Section

March 2014 – May 2015 (Full-Time) NMED – Surface Water Quality Bureau, Santa Fe, NM

- Reviewed and evaluated the performance of the Municipal Team by providing meaningful, frequent, and ongoing input on work performance and prioritization of workloads.
- Cooperated with and supported the efforts of other Bureau sections. Facilitated positive working relationships with other state and federal agencies, stakeholders, and cooperators involved in National Pollutant Discharge Elimination System (NPDES) permitting activities.
- Reviewed, analyzed data, and prepared comments on NPDES permits submitted to the Bureau for certification under Section 401 of the Federal Clean Water Act. Ensured consistency in NPDES permit certifications.
- Investigated regulated facilities for compliance/non-compliance with applicable state and federal surface water quality laws, standards, and regulations, and prepared and submitted comprehensive inspection reports that documented the status of the facilities regarding the federal NPDES permit program and regulations.
- Collected accurate and detailed information and useable evidence during site investigations to supplement information contained in NPDES permits, to evaluate violations of state surface water quality standards and regulations, and to assist EPA with enforcement.

- Reviewed, analyzed, and prepared well-written, clear, concise, and factual comments on proposed or new amended federal and state agency policies and procedures, regulations, and technical recommendations.
- Developed standard operating procedures for wastewater sampling and compliance sampling. Evaluated and acquired sampling equipment necessary for monitoring NPDES permitted facilities.

Reviewed, analyzed data, and prepared comments relevant to regulatory requirements and surface water quality studies and findings on Environmental Assessments (EA) and Environmental Impact Statements (EIS) submitted to SWQB for review.

Acting Program Manager for Monitoring, Assessment and Standards

July 2012 – July 2013 (Full-Time) NMED – Surface Water Quality Bureau, Santa Fe, NM

- Managed the Surface Water Quality Bureau's monitoring, assessment, and standards programs including writing, submitting, and managing the Clean Water Act Section 106 Monitoring Initiative grant on an annual basis with semi-annual updates.
- Oversaw and evaluated the performance of 15 staff.
- Participated in the development and revision of state surface water quality standards and regulations.
- Planned water quality surveys throughout New Mexico that met budgetary constraints and data quality objectives.
- Reviewed, integrated, and assessed data for use in Clean Water Act required activities.
- Prepared water quality reports (e.g. watershed survey summaries, use attainability analyses, TMDLs, etc.) for the public and as a deliverable to EPA.
- Developed protocols to standardize tasks including sample collection, data assessment, and report writing.
- Represented the Bureau at meetings, professional conferences, workshops, and Water Quality Control Commission meetings.
- Conducted short-term investigations in response to citizen complaints, accidental spills, and other emergencies.
- Maintained analytical results in the Bureau's water quality database, prepared retrievals of stored data, and scheduled uploads of data to the EPA's national database.
- Worked with the Bureau's webmaster to create, update, and maintain webpages, resources, and links associated with activities of the Section and Bureau.

Monitoring Team Leader – Monitoring, Assessment and Standards

April 2011 – July 2013 (Full-Time) NMED – Surface Water Quality Bureau, Santa Fe, NM

- Managed the statewide ambient monitoring program for the Bureau. The Monitoring Team is responsible for collecting water quality data and associated flow measurements in surface waters of the state. Data collected by the Monitoring Team is used to determine if the water body meets water quality standards and ensure designated uses are supported.
- Oversaw and evaluated the performance of 5 staff.
- Planned water quality surveys throughout New Mexico that met budgetary constraints and data quality objectives.
- Ensured adequate and appropriate data were collected to support a variety of Clean Water Act required activities (e.g., water quality standards amendments, TMDL development, NPDES permits, nonpoint source monitoring effectiveness, etc.).

- Prepared watershed survey summaries for the public and as a deliverable to EPA.
- Developed protocols to standardize tasks including sample collection, data assessment, and report writing. Specifically, responsible for developing, updating, and revising the *Field Sampling Plan* and *Physical Habitat* standard operating procedures.
- Maintained analytical results in the Bureau's water quality database, prepared retrievals of stored data, and scheduled uploads of data to EPA's national database.
- Conducted short-term investigations in response to citizen complaints, accidental spills, and other emergencies.
- Worked with the Bureau's webmaster to create, update, and maintain monitoring webpages, resources, and links.
- Represented the Bureau at meetings, professional conferences, and workshops.

Nutrients and Lakes Team Leader & TMDL Writer – Monitoring and Assessment

August 2004 – April 2011 (Full-Time) NMED – Surface Water Quality Bureau, Santa Fe, NM

- Prepared watershed planning documents (i.e., TMDLs) to improve water quality and conducted public meetings to address stakeholder comments and concerns.
- Presented the final draft documents to the NM Water Quality Control Commission for inclusion and adoption into the State's Water Quality Management Plan.
- Oversaw the nutrient criteria development program for NM's streams, rivers, and lakes.
- Headed efforts in hydrology and monitoring design to develop a *Hydrology Protocol* that distinguishes between ephemeral, intermittent, and perennial waters in New Mexico and to create a practical yet thorough 10-year monitoring and assessment strategy for the Bureau.
- Managed and evaluated the performance of 3 technical staff.

Graduate Research Assistant – Sustainability of semi-Arid Hydrology and Riparian Areas

January 2002 – January 2004 (20 hrs/wk) SAHRA – University of Arizona, Tucson, AZ

- Designed, coordinated, and implemented a hydrologic research project to determine the influence of land use and regional hydrology on surface water quality in a semi-arid stream.
- Organized and prepared an objective, scientifically sound thesis describing the methods, results, conclusions, and management implications of this research.
- Co-authored the journal article, "Spatial variability in dissolved organic matter and inorganic nitrogen concentrations in a semiarid stream, San Pedro River, Arizona" for the *Journal of Geophysical Research* Volume: 112, Issue: G3.

Graduate Teaching Assistant

January 2002 – December 2003 (20 hrs/wk) University of Arizona, Tucson, AZ

- Assisted in the instruction of an "Introduction to Global Change" class for undergraduates and a "Fundamentals of Water Quality" class for graduates.
- Developed hands-on activities to enhance global awareness and environmental stewardship.
- Designed and facilitated a final project to encourage critical analysis and informed decision-making.

OTHER PROFESSIONAL EXPERIENCE

Middle School Science Teacher

August 2013 – March 2014 (Full-Time) Academy of Technology and the Classics, Santa Fe, NM

- Taught life science and physical science in a traditional high school setting.
- Provided students with awareness, knowledge, and appreciation of science through activities, laboratories, simulations, and web-based experiences.
- Applied a variety of teaching and assessment strategies to properly evaluate the diversity of learning styles and abilities of 130 students.
- Maintained a website and an electronic gradebook to inform students and parents of lesson plans, class progress, and individual achievement.
- Provided students and parents with the opportunity for feedback and personal attention during phone calls, weekly tutorials, and conferences.
- Designed and implemented a rigorous yet age-appropriate curriculum that met New Mexico's state standards for middle school science.
- Created and implemented a classroom management plan that promoted student learning, mutual respect, and a healthy classroom environment.

High School Science Teacher

August 1998 – June 2001 (Full-Time) Chino Valley High School, Chino Valley, AZ

- Instructed biology, hydrology, and marine science in a traditional high school setting.
- Provided students with science-based experiences through laboratory activities, class field trips, and field research.
- Applied a variety of teaching and assessing strategies to adapt to a diversity of learning styles and abilities.
- Created a marine science curriculum to meet the requirements of a laboratory science.
- Prepared an Arizona Public Service mini-grant proposal that funded an environmental project at the school.

Science Instructor

Summer 1997; Summer 1998 Nizhoni/Upward Bound Summer Academy, Flagstaff, AZ
(Full-Time, 6 weeks each summer)

- Taught a summer program to low income, first-generation college students on the NAU campus to introduce them to collegiate life and promote a successful transition from high school to post-secondary education.
- Integrated humanities, math, and science content through the problem-solving process. Interdisciplinary approach focused on the study of environmental problems in the Verde River area near Cottonwood, Arizona, specifically drafting, revising, editing, and publishing an environmental impact statement about a proposed housing project.

Naturalist

January – May 199 (Full-Time) San Joaquin Outdoor Education, La Honda, CA
September 1995 – May 1996 (Full-Time)

- Residential outdoor education program for 5th and 6th graders that focused on exploring the natural world.
- Incorporated an interdisciplinary, multi-sensory, discovery-oriented approach to learning consistent with California State Standards.

- Led theme-oriented, educational hikes to help students gain an appreciation of and sense of responsibility for the earth's natural resources.
- Modeled responsible social participation in the cabin and camp community by creating and incorporating group understanding and respect.

Science Instructor and Dive Master

June 1993 – December 1994 (Full-Time) Catalina Island Marine Institute, Avalon, CA
Summer 1995, Summer 1996 (Full-Time, 10 weeks each summer)

- Taught groups of 4th – 12th grade students a marine science, oceanography, and island ecology curriculum.
- Implemented an active, hands-on, experientially oriented program that included snorkeling, kayaking, marine labs, hiking, and a variety of evening programs.
- Increased science literacy and created excitement about science through a combination of labs, aquariums, and touch tanks on land and snorkeling, kayaking, and collecting data in the field.
- Taught SCUBA and science classes at a residential enrichment summer camp with an emphasis on ocean-related activities.

New Mexico
Wetland Resources

Wetlands cover about 482,000 acres (0.6 percent) of New Mexico, a reduction of about 33 percent from the wetland acreage that existed about 200 years ago (Dahl, 1990). New Mexico's wetland acreage places the State 34th in total wetland acreage among the 48 conterminous States.

Wetlands are ecologically important and economically valuable to the State. Wetlands provide important wildlife habitat. For example, in the Rio Grande Valley, wetlands provide habitat for 246 species of birds, 10 species of amphibians, 38 species of reptiles, and 60 species of mammals (U.S. Fish and Wildlife Service, 1990). Wetlands also provide stopover, feeding, and breeding grounds for migratory waterfowl (fig. 1).

Riparian (streamside) wetlands along perennial streams are important as migration corridors for a variety of waterfowl and other wildlife. The playa lakes in eastern New Mexico are vital links in a chain of wetlands along the Central Flyway, which extends from central Canada to the coast of Texas. Areas of springs and marshes provide essential habitat for many rare and endangered species and for indigenous fish and wildlife in the western part of the State.

Wetlands contribute to flood attenuation, bank stabilization, and improved water quality. New Mexico's tourist industry benefits from the beauty of the State's diverse wetlands. These wetlands provide opportunities for recreational activities that include fishing, hunting, bird watching, nature photography, camping, and hiking.

TYPES AND DISTRIBUTION

Wetlands are lands transitional between terrestrial and deepwater habitats where the water table usually is at or near the land surface or the land is covered by shallow water (Cowardin and others, 1979). The distribution of wetlands and deepwater habitats in New Mexico is shown in figure 2*A*; only wetlands are discussed herein.

Wetlands can be vegetated or nonvegetated and are classified on the basis of their hydrology, vegetation, and substrate. In this summary, wetlands are classified according to the system proposed by Cowardin and others (1979), which is used by the U.S. Fish and Wildlife Service (FWS) to map and inventory the Nation's wetlands. At the most general level of the classification system, wetlands are grouped into five ecological systems: Palustrine, Lacustrine, Riverine, Estuarine, and Marine. The Palustrine System includes only wetlands, whereas the other systems comprise wetlands and deepwater habitats. Wetlands of the systems that occur in New Mexico are described below.

System	Wetland description
Palustrine	Wetlands in which vegetation is predominantly trees (forested wetlands); shrubs (scrub-shrub wetlands); persistent or nonpersistent emergent, erect, rooted, herbaceous plants (persistent- and nonpersistent-emergent wetlands); or submersed and (or) floating plants (aquatic beds). Also, intermittently to permanently flooded open-water bodies of less than 20 acres in which water is less than 6.6 feet deep.
Lacustrine	Wetlands within an intermittently to permanently flooded lake or reservoir. Vegetation, when present, is predominantly nonpersistent emergent plants (nonpersistent-emergent wetlands), or submersed and (or) floating plants (aquatic beds), or both.
Riverine	Wetlands within a channel. Vegetation, when present, is same as in the Lacustrine System.



Figure 1. Bosque del Apache National Wildlife Refuge. These riparian wetlands provide habitat for migratory and resident waterfowl, fish, and other wildlife. *(Photograph by Lisa Carter, U.S. Geological Survey.)*

Although wetlands occur in all areas of New Mexico, they are most numerous in the eastern and northern areas of the State (fig. 2*A*). In the Southern Rocky Mountains (fig. 2*B*), wetlands are mostly in high mountain valleys and intermountain basins. In the Great Plains, wetlands occur along the flood plains of the Canadian and Pecos Rivers and in association with playa lakes. In the Colorado Plateaus and Basin and Range, wetlands are sparsely distributed, with the exception of wetlands associated with the San Juan, San Francisco, and Gila Rivers.

Palustrine wetlands are distributed statewide. In New Mexico, palustrine wetlands include forested wetlands in river flood plains and near springs and seeps; scrub-shrub wetlands such as bottomland shrubland; emergent wetlands, such as marshes, fens, alpine snow glades, and wet and salt meadows; aquatic bed wetlands in shallow ponds and small lakes; and sparsely or nonvegetated wetlands such as playa lakes. Palustrine wetlands along rivers, streams, springs, lakes, and ponds are called riparian wetlands. Riparian wetlands along the State's major rivers provide habitat for fish, wildlife, and diverse plant life. They also provide habitat for migrating, overwintering, and nesting waterfowl. One of the more notable riparian wetlands in New Mexico is in the Bosque del Apache National Wildlife Refuge. The 57,191-acre refuge lies along 9 miles of the Rio Grande in south-central New Mexico. Marshes within the refuge are ideal winter habitat for migratory birds, including ducks, geese, sandhill cranes, and whooping cranes. Efforts are being made to maintain and restore native riparian cottonwood habitat in the refuge for a variety of birds and other wildlife. Many western species of riparian trees and shrubs, such as willows and cottonwoods, have been lost because of nonnatural streamflow regimes (Howe and Knopf, 1991). The nonnatural flows followed the completion of water projects in the first half of the 20th century, resulting in rapid colonization and expansion of the exotic Russian-olive and salt cedar.

The playa lakes of eastern New Mexico provide habitat for migrating, overwintering, and nesting waterfowl in the Central Flyway (U.S. Fish and Wildlife Service, 1990). The estimated number of playa lakes in the State is 1,700, and they range in area from less than 1 acre to more than 600 acres (Nelson and others, 1983). The

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playa lakes range in wetness from dry lake bed to shallow lake and can be fresh or saline. The freshwater playas are numerous, small to medium in size, and serve as zones of recharge to the underlying aquifer (Osterkamp and Wood, 1987). The saline playas are larger and fewer than the freshwater playas and are areas of discharge from the underlying aquifer. Most playa lakes in New Mexico are palustrine. However, playa lakes larger than 20 acres are classified as lacustrine wetlands, as are the shallow areas of large reservoirs.

Riverine wetlands occur in the shallow river channels of perennial streams. There are about 3,500 miles of streams in New Mexico (Ong and others, 1993).

HYDROLOGIC SETTING

Wetlands form where a persistent water supply is at or near the land surface. The location and persistence of the supply of water is a function of precipitation and runoff patterns, evaporation potential, topography, and the presence of a shallow water table.

Precipitation and runoff rates differ annually and with location and season. Average annual precipitation in New Mexico (fig. 2*C*) ranges from about 8 inches in the northwestern corner of the State and in the southern Rio Grande Valley to 24 inches in the mountains of the northern and southern parts of the State. Runoff (fig. 2*D*) is greatest in the northern mountains and smallest in the desert areas of the southern and eastern parts of the State. Much of the runoff from the mountains occurs during concurrent snowmelt and rainfall in the spring and summer.

Average annual pan evaporation varies across the State and ranges from about 40 to 112 inches per year (Nelson and others, 1983). Most evaporation occurs from March through September and decreases with increasing altitude. Because annual evaporation exceeds annual rainfall, most of the State has a net annual moisture deficit. The moisture deficit is a limiting factor in the formation of wetlands and to the continued existence of some of the more fragile wetlands. Even those areas of the State having the highest precipitation and lowest evaporation (high mountain regions) can be unfavorable for development of wetlands because of steep topography, shifting stream channels, and unfavorable soil conditions (Cooper, 1986).

Shallow water tables and groundwater discharge into topographic depressions, streams, and springs maintain wetlands in many areas of New Mexico. These wetlands can be along small streams that have perennial flow in only short reaches or along larger, perennial streams. In intermountain basins, wetlands are maintained by a shallow water table and springs whose source is recharge from precipitation and runoff that occur during spring and summer.

Climatic, topographic, and hydrologic characteristics differ among and sometimes within the physiographic provinces. New Mexico's diverse physiography, climate, and topography result in diverse hydrologic settings for wetland formation.

In the Colorado Plateaus and Basin and Range Provinces (fig. 2*B*), wetlands occur in springs and seeps, around oxbow lakes, along streams and rivers, around reservoirs, and in other areas where the water table is near the land surface. The arid climate of this region results in a low density and acreage of wetlands. Wetlands, although few in number, are vital to wildlife of these physiographic provinces.

In the Great Plains, wetlands occur in riparian zones along perennial streams, around oxbow lakes, in isolated natural depressions with permanent or seasonal water supply, in playa lakes, and in association with other lakes, reservoirs, channelized streams, rivers, and irrigation ditches. Playa lakes make up the largest area of wetlands in this province.

The area of playa lakes has topography classified as either smooth plains, irregular plains, or tablelands (Nelson and others, 1983). Smooth plains are largely on upland terrain, and irregular plains and tablelands are mostly on lowland terrain. Because of the flatness of the terrain, there is generally little stream drainage, and playa lakes collect most of the surface runoff. The playa lakes are

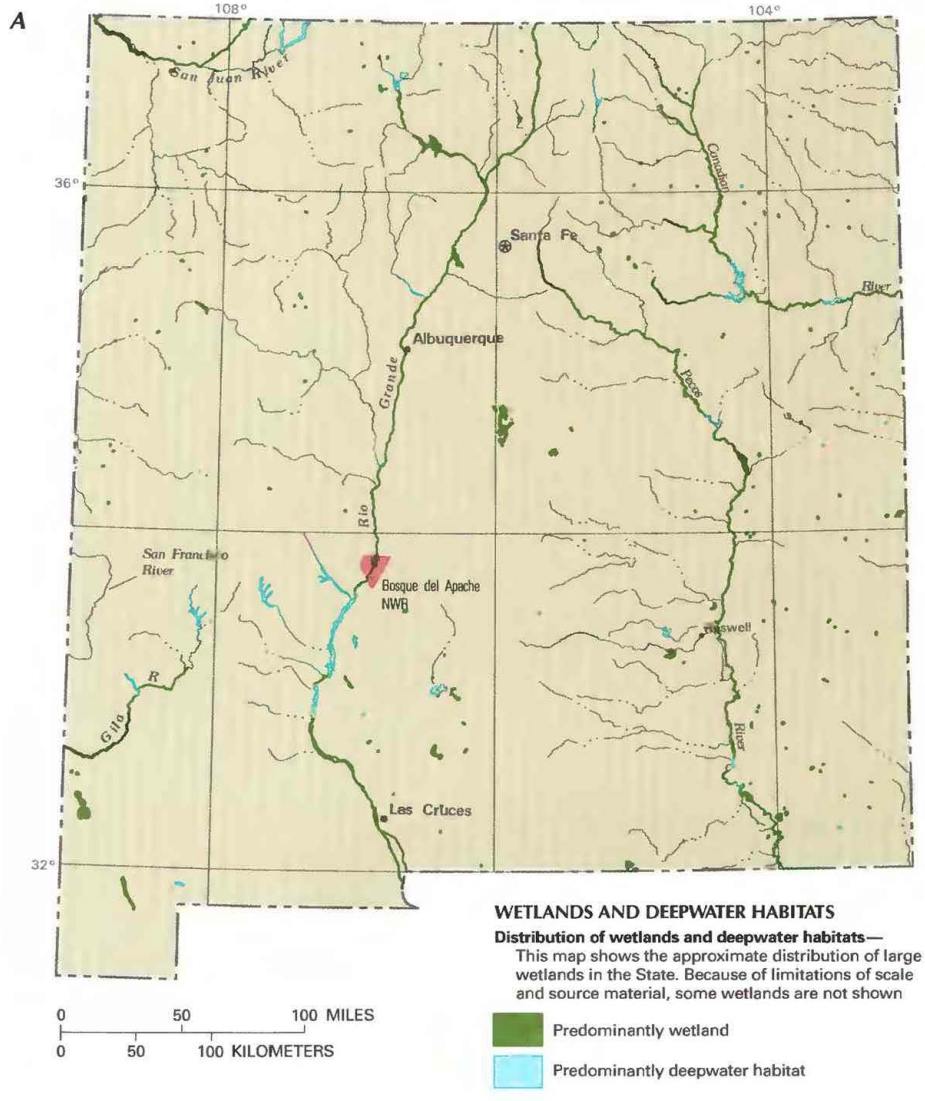


Figure 2. Wetland distribution in New Mexico and physical and climatological features that control wetland distribution in the State. ***A***, Distribution of wetlands and deepwater habitats. *(Sources: A, T.E. Dahl, U.S. Fish and Wildlife Service, unpub. data, 1991.)*

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usually shallow depressions that have large surface area relative to the total volume of water contained in them. Consequently, most playa lakes have small storage capacities.

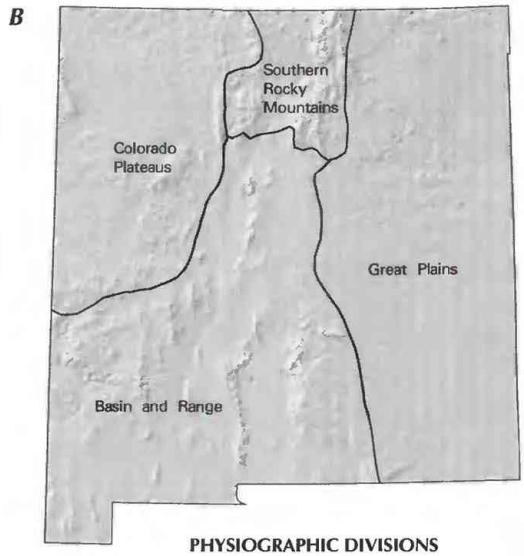
Studies by Osterkamp and Wood (1987) indicate that freshwater playa lakes in the Great Plains of New Mexico originate wherever surface depressions collect precipitation runoff. The lakes enlarge as a result of dissolution of carbonates by water infiltrating the unsaturated zone above the underlying aquifer and subsequent subsidence of the lake bed. Over time, the older central lake acquires a layer of clay-rich deposits that largely restricts water movement from the playa lake to the underlying aquifer. Water probably is removed from freshwater playa lakes primarily by recharge to the underlying aquifer from the areas around the lake where lake-bed sediments have not yet accumulated (Osterkamp and Wood, 1987) and by evaporation that in some years ranges as high as 96 to 112 inches per year (Nelson and others, 1983). There is no general agreement on the origin of saline playa lakes; however, Wood and Jones (1990) propose that the source of the salinity is from the concentration by evaporation of runoff and shallow, fresh ground water that discharges from the underlying aquifer.

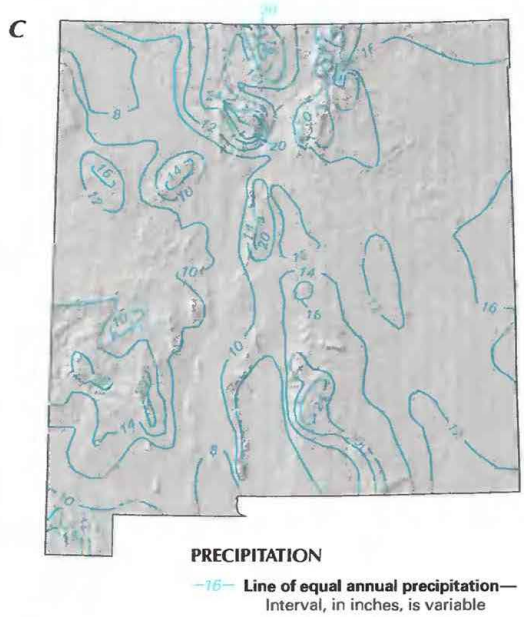
In the Southern Rocky Mountains, wetlands occur in two physiographically and climatically distinct settings, mountain valleys and intermountain basins. Generally, mountain valleys are geologically young and therefore steep. The valleys have been shaped over time either by running water throughout their entire length or by glaciers at higher altitudes and running water at lower altitudes. At high altitudes in some mountain valleys, glaciation formed large cirque basins in which remnant glaciers or late-melting snow maintains spring, seep, and snow-bed wetlands. Also, at these high altitudes, ponds form in depressions behind slumping saturated soils or in depressions caused by the weight of accumulated snow. Below the cirque basins, wetlands occur in the glaciated, U-shaped valleys, on saturated cliff faces, at the sloping floor near the sides of the valley, in glacial kettle ponds, in oxbow lakes, in depressions on glacial moraines, in lakes created by terminal or lateral moraines, in landslide-formed lakes, in seeps and springs, and in beaver ponds. In steep, V-shaped, nonglaciated areas of mountain valleys, wetlands occur as narrow riparian wetlands, near seeps and springs, and in beaver ponds (Windell and others, 1986).

Intermountain basins were filled by sediments derived from erosion of the surrounding mountains. The large, flat valleys are drained by low-gradient meandering streams and rivers. Intermountain-basin wetlands occur along these streams and rivers, in constructed and natural impoundments, around oxbow lakes, and in other areas where the water table is near the land surface. The shallow water table is maintained by underlying aquifers, impermeable substrates, or annual floods (Windell and others, 1986).

TRENDS

The FWS has estimated that from the 1780's to the 1980's, wetland acreage in New Mexico decreased by 33 percent—from about 720,000 to 482,000 acres (Dahl, 1990). Much of the decrease is attributable to the loss of native vegetation along streams because





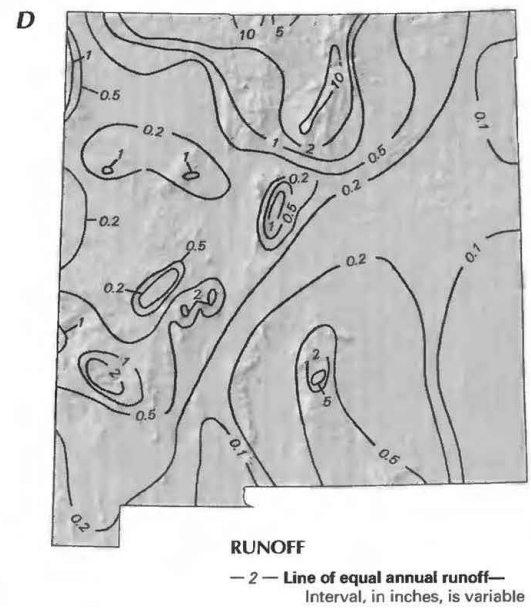


Figure 2. Continued. Wetland distribution in New Mexico and physical and climatological features that control wetland distribution in the State. ***B***, Physiography. ***C***, Average annual precipitation. ***D***, Average annual runoff. *(Sources: B, Physiographic divisions from Fenneman, 1946; landforms data from EROS Data Center. C and D, Gold and Denis, 1986.)*

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of a change in streamflow resulting from reservoir construction or agricultural water diversions. The loss of native vegetation along streams alters riparian-wetland functions and allows the proliferation of nonnative vegetation (Howe and Knopf, 1991).

Wetland losses in rural areas can be attributed to conversion to cropland, dewatering or diverting water for irrigation, and overgrazing by livestock. Development of urban areas has caused wetland loss or degradation owing to encroachment of residential and commercial construction, dewatering for municipal and industrial water supply, channelization, and contamination from inadequately treated sewage and industrial waste. Other causes of wetland loss or degradation are clear cutting, burning, hard-rock mining and related activities that produce toxic acidic or alkaline runoff, placer mining, erosion and sedimentation, sand and gravel mining, road and railroad construction, and dam and reservoir construction in wetland areas (Windell and others, 1986).

Some human activities have helped to form wetlands or enlarge existing ones. The construction of reservoirs between 1916 and 1985, which provided for storage of more than 5.9 million acre-feet of surface water (Garrabrant and Garn, 1990), resulted in the formation of wetlands along the edge of those water bodies. However, such gains are at the expense of the original, natural riparian wetlands. Farm-pond construction also contributes to the formation of wetlands around the edge of the pond. More than one-half of the State's cropland is irrigated (Garrabrant and Garn, 1990), and leaking ditches and seeps and return flow associated with irrigation have contributed to the formation of wetlands.

CONSERVATION

Many government agencies and private organizations participate in wetland conservation in New Mexico. The most active agencies and organizations and some of their activities are listed in table 1.

Federal wetland activities.—Development activities in New Mexico wetlands are regulated by several Federal statutory prohibitions and incentives that are intended to slow wetland losses. Some of the more important of these are contained in the 1899 Rivers and Harbors Act; the 1972 Clean Water Act and amendments; the 1985 Food Security Act; the 1990 Food, Agriculture, Conservation, and Trade Act; and the 1986 Emergency Wetlands Resources Act.

Section 10 of the Rivers and Harbors Act gives the U.S. Army Corps of Engineers (Corps) authority to regulate certain activities in navigable waters. Regulated activities include diking, deepening, filling, excavating, and placing of structures. The related section 404 of the Clean Water Act is the most often-used Federal legislation protecting wetlands. Under section 404 provisions, the Corps issues permits regulating the discharge of dredged or fill material into wetlands. Permits are subject to review and possible veto by the U.S. Environmental Protection Agency, and the FWS has review and advisory roles. Section 401 of the Clean Water Act grants to States and eligible Indian Tribes the authority to approve, apply conditions to, or deny section 404 permit applications on the basis of a proposed activity's probable effects on the water quality of a wetland.

Most farming, ranching, and silviculture activities are not subject to section 404 regulation. However, the "Swampbuster" provision of the 1985 Food Security Act and amendments in the 1990 Food, Agriculture, Conservation, and Trade Act discourage (through financial disincentives) the draining, filling, or other alteration of wetlands for agricultural use. The law allows exemptions from penalties in some cases, especially if the farmer agrees to restore the altered wetland or other wetlands that have been converted to agricultural use. The Wetlands Reserve Program of the 1990 Food, Agriculture, Conservation, and Trade Act authorizes the Federal Government to purchase conservation easements from landowners who agree to protect or restore wetlands. The Consolidated Farm Service Agency (formerly the Agricultural Stabilization and Conservation Service) administers the Swampbuster provisions and Wetlands Reserve Program. The Natural Resources Conservation Service (formerly the Soil Conservation Service) determines compliance with Swampbuster provisions and assists farmers in the identification of wetlands and in the development of wetland protection, restoration, or creation plans.

Table 1. Selected wetland-related activities of government agencies and private organizations in New Mexico, 1993

[Source: Classification of activities is generalized from information provided by agencies and organizations. •, agency or organization participates in wetland-related activity; ..., agency or organization does not participate in wetland-related activity. MAN, management; REG, regulation; R&C, restoration and creation; LAN, land acquisition; R&D, research and data collection; D&I, delineation and inventory]

Agency or organization	MAN	REG	R&C	LAN	R&D	D&I
FEDERAL						
Department of Agriculture						
Consolidated Farm Service Agency	...	•	...	...	...	...
Forest Service	•	...	•	•	•	•
Natural Resources Conservation Service		•	•		•	•
Department of Defense						
Army Corps of Engineers	•	•	•			•
Military reservations	•					
Department of the Interior						
Bureau of Land Management	•		•	•	•	•
Bureau of Reclamation	•		•	...	•	•
Fish and Wildlife Service	•		•	•	•	•
Geological Survey					•	
National Biological Service	...		...	...	•	...
National Park Service	•	...	•	•	•	•
Environmental Protection Agency		•			•	•
STATE						
Department of Game and Fish	•	•	•	•	•	•
Energy, Mineral, and Natural Resources Department	..	...	•	...	...	
Environment Department	•	•	...	•	•	..
State Engineer Office	•	•				•
University of New Mexico						
Natural Heritage Program					•	•
COUNTY AND LOCAL GOVERNMENTS						
Albuquerque Open Space Division	•		•	•	•	•
Santa Fe County					•	•
PRIVATE ORGANIZATIONS						
National Audubon Society			•		...	
Sierra Club			•	...	•	
The Nature Conservancy				•		

The 1986 Emergency Wetlands Resources Act encourages wetland protection through funding incentives. The act requires States to address wetland protection in their Statewide Comprehensive Outdoor Recreation Plans to qualify for Federal funding for State recreational land; the National Park Service provides guidance to States in developing the wetland component of their plans.

The U.S. Forest Service (FS) manages five National Forests in New Mexico that contain diverse wetlands and riparian ecosystems. The FS also coordinates with State agencies and private landowners on wetland-conservation activities.

The FWS manages six National Wildlife Refuges in New Mexico that provide habitat for migrating birds, endangered species, and other wildlife and wildlife-oriented public recreation. Under the 1986 Emergency Wetlands Resources Act, the FWS evaluated eight priority wetland sites in the State for acquisition (U.S. Fish and Wildlife Service, 1990).

A goal of the Bureau of Land Management (BLM) is to restore, maintain, and improve riparian wetland area conditions on public land in New Mexico. The BLM is responsible for the management of 12.8 million acres of public land in the tristate area of New Mexico,

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Oklahoma, and Kansas, which includes 27,600 acres of riparian wetland (Bureau of Land Management, 1990).

State wetland activities.—The principal State agencies in New Mexico that regulate or manage wetlands are the Department of Game and Fish, Environment Department, and the State Engineer Office. Also involved is the State Park and Recreation Division of the Energy, Mineral, and Natural Resources Department, which developed the New Mexico Wetlands Priority Conservation Plan (New Mexico Energy, Minerals, and Natural Resources Department, 1988). This plan is a component of the 1986 Statewide Comprehensive Outdoor Recreation Plan. The goals of agencies managing wetlands in New Mexico are to provide habitat for fish and wildlife and for diverse plant species, to maintain wetlands for erosion and flood control, and to enhance wetlands as agricultural, recreational, and scenic resources.

State management of wetlands in New Mexico began with an assessment of State wetlands by the State Park and Recreation Division (New Mexico Energy, Minerals, and Natural Resources Department, 1988). The steps in the assessment were to locate wetlands, determine their types, assess their quality, prioritize them according to their value and benefit, and rate the probable effect on them of each of the major causes of wetland losses. The Division considers the seven major causes of loss or degradation of wetlands in New Mexico to be (1) municipal water development, (2) natural water-table fluctuation, (3) development of land surfaces, (4) pollution, (5) erosion, tree cutting, or siltation, (6) invasion by nonnative plant species, and (7) poor management. The assessment of the quality of wetlands is based on habitat conditions, the dominance of native or rare species, the presence of terrestrial animals, and the uniqueness of the wetland in New Mexico. State government acquisition of wetlands will be based on whether the public values and benefits of wetlands can be maintained or realized under present ownership (New Mexico Energy, Minerals, and Natural Resources Department, 1988).

County and local wetland activities.—The Open Space Division of the city of Albuquerque acquires, manages, and restores wetlands. The Division also conducts feasibility studies and inventories wetlands in areas under its jurisdiction. The county of Santa Fe is involved in research and inventory of wetlands in the county.

Private wetland activities.—Private organizations involved in wetland management and conservation in New Mexico include the National Audubon Society, the Sierra Club, and The Nature Conservancy. A principal activity of the National Audubon Society and the Sierra Club is the restoration and creation of wetlands. The Sierra Club also conducts research in wetlands. The Nature Conservancy acquires wetlands and other ecologically valuable habitats for conservation. A major goal of these private organizations is to inform the public about the value of wetlands.

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HYDROLOGICAL, PHYSICAL, AND CHEMICAL FUNCTIONS AND CONNECTIVITY OF NON-FLOODPLAIN WETLANDS TO DOWNSTREAM WATERS: A REVIEW[1]

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Abstract

We reviewed the scientific literature on non-floodplain wetlands (NFWs), freshwater wetlands typically located distal to riparian and floodplain systems, to determine hydrological, physical, and chemical functioning and stream and river network connectivity. We assayed the literature for source, sink, lag, and transformation functions, as well as factors affecting connectivity. We determined NFWs are important landscape components, hydrologically, physically, and chemically affecting downstream aquatic systems. NFWs are hydrologic and chemical sources for other waters, hydrologically connecting across long distances and contributing compounds such as methylated mercury and dissolved organic matter. NFWs reduced flood peaks and maintained baseflows in stream and river networks through hydrologic lag and sink functions, and

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sequestered or assimilated substantial nutrient inputs through chemical sink and transformative functions. Landscape-scale connectivity of NFWs affects water and material fluxes to downstream river networks, substantially modifying the characteristics and function of downstream waters. Many factors determine the effects of NFW hydrological, physical, and chemical functions on downstream systems, and additional research quantifying these factors and impacts is warranted. We conclude NFWs are hydrologically, chemically, and physically interconnected with stream and river networks though this connectivity varies in frequency, duration, magnitude, and timing.

Keywords

connectivity; function; non-floodplain; river networks; wetlands

INTRODUCTION

Wetlands are landscape elements existing along a continuum of connectivity, climatically and hydrologically interacting with other landscape elements through space and time (Ward 1989; Cohen et al. 2016). Instream, riparian, and floodplain wetlands experience fast and/or near-continuous hydrologically mediated connections and interactions. Wetlands are also connected through extremely slow or diffuse pathways (e.g., deep groundwater or atmospherically connected; Rains et al. 2015; Cohen et al. 2016). Researchers are using increasingly advanced and novel methods to quantify wetland locations along this conceptual connectivity continuum (e.g., Jones 2015; Klaus et al. 2015; Vanderhoof et al. 2016; Brooks et al. 2018; Thorslund et al., unpublished data).

Wetlands are functionally part of the landscape, performing hydrological, chemical, and biological functions affecting downstream systems (e.g., Marton, Creed, et al. 2015; Rains et al. 2015; Cohen et al. 2016; Biggs et al. 2017; Schofield et al. 2018). Paradoxically, some functional contributions of wetlands might be inversely related to their rate of connectivity or position along the connectivity continuum (i.e., slower connections could result in larger effects). For instance, wetlands that intercept storm runoff store water and process entr materials (e.g., nutrients). While the subsequent connection with downstream waters may be slow or diffuse (e.g., via groundwater or atmospheric), the functional effect of retaining nutrients and stormwater may be great.

However, functional connections for wetlands are challenging to quantify, requiring elucidation of both the connection pathway and the variable of interest. Descriptors of connectivity include the frequency, duration, magnitude, timing, and rate of change of fluxes to, and exchanges with, downstream waters (Poff et al. 1997; Poff et al. 2007). Current estimates are that ~45 million wetland hectares exist in the conterminous United States (U.S.) (Dahl 2011), and each hectare exists along a continuum of connectivity. There is thus a need to analyze and synthesize the available peer-reviewed scientific literature on the connectivity and quantifiable functional effects of wetlands on other waters to establish a baseline understanding of the interchange of materials, organisms, and energy among and between landscape elements (e.g., Hynes 1975; Forman 1995). This information, the connectivity and effects of wetlands on other waters, provides management agencies and

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stakeholders with information germane to the sustainable use and management of aquatic resources. Armed with sufficiently robust scientific information, federal, state, and local agencies can endeavor to establish and promulgate guidelines and regulations designed to safeguard aquatic resource integrity while concurrently providing guidance on wise management and growth.

To address this data need, the USEPA (2015) analyzed and synthesized over 1,300 peer-reviewed publications in a 408-page report, summarizing the state of science on the connectivity between streams, wetlands, and downgradient systems, which is the topic of this featured collection (Alexander et al. 2018). Connectivity as used by USEPA (2015, A-2; Leibowitz et al. 2018) and maintained here in this updated review refers to "[t]he degree to which components of a river system are joined by various transport mechanisms; … determined by the characteristics of both the physical landscape and the biota of the specific system." The primary transport mechanisms considered in this expanded and updated review are surface water and shallow groundwater flows and the transport and transformation of physical and chemical materials, all of which connect watersheds in four dimensions (i.e., longitudinal, lateral, vertical, and temporal, Ward 1989; see also Covino 2017).

This contribution, as well as others (e.g., Alexander et al. 2018; Fritz et al. 2018; Goodrich et al. 2018; Leibowitz et al. 2018; Schofield et al. 2018), builds on the findings of USEPA (2015) with updated literature and scientific advances in quantifying aquatic system connectivity. While USEPA (2015) addresses wetlands in riparian and floodplain areas as well as wetlands not so situated, this review is specifically focused on hydrological, physical, and chemical connectivity of non-floodplain wetlands (NFWs), freshwater wetlands not spatially located within riparian areas or floodplains of river networks, further described below. In the U.S., NFWs may cover more than 6.6 million hectares and comprise >16% of the total freshwater wetland acreage (Lane and D'Amico 2016; Figure 1). Biological connectivity and functions of NFWs are covered in a separate review (Schofield et al. 2018). The review is organized into the following sections: (1) Definitions and Conceptual Approach; (2) Hydrological, Physical, and Chemical Functions of NFWs; and (3) Synthesis and Implications.

EFINITIONS AND CONCEPTUAL APPROACH

Floodplain and Non-Floodplain Wetlands: Definitions

All rivers and streams have riparian areas, defined as transitional zones between terrestrial and aquatic ecosystems distinguished by gradients in biophysical conditions, ecological processes, and organisms. However, not all portions of river and stream networks — the hierarchical, interconnected populations of perennial, intermittent, and ephemerally flowing channels that drain water to a river — have floodplains. Floodplains are level areas bordering stream or river channels that are formed by sediment deposition from those channels under present climatic conditions. Floodplain and associated river channel forms (e.g., meandering, braided, anastomosing) are determined by interacting fluvial factors, including sediment size and supply, channel gradient, and streamflow (Church 2002, 2006). As stream channels increase in size and decrease in slope, a mixture of erosion and deposition processes usually is at work. At some point in the lower portions

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of river networks, sediment deposition becomes the dominant process and floodplains form. Floodplains are inundated during moderate to high water events (Leopold 1994; Osterkamp 2008).

Like riparian areas, wetlands are transitional areas between terrestrial and aquatic ecosystems. Wetlands include areas such as swamps, bogs, fens, marshes, ponds, and pools (Mitsch et al. 2009). According to Cowardin et al. (1979), an area is classified as a wetland if it has one or more of the following three attributes: (1) the area supports predominantly hydrophytes (i.e., water-loving plants) at least periodically; (2) the land has substrate that is predominantly undrained hydric soil; or (3) the land has nonsoil substrate that is saturated with water or covered by shallow water at some time during the growing season of each year. Note that the Cowardin et al. (1979) definition requires only one of these characteristics, in contrast to the U.S. federal regulatory definition, which requires all three (33 Code of Federal Regulations 328.3(b); see also USACE 1987). Thus, as used in this review, a wetland need not meet the U.S. federal regulatory definition.

Floodplain wetlands are portions of floodplains that meet the aforementioned Cowardin et al. (1979) definition of a wetland. Floodplain wetlands have hydrologic connections to streams and rivers that are predominantly bidirectional (i.e., from wetlands to streams and rivers and vice versa) through lateral movement of surface water and groundwater between the channel and floodplain areas, either through overbank flooding (i.e., lateral expansion of the network) or hyporheic flow (USEPA 2015).

NFWs are found in landscape settings where the potential exists for predominantly unidirectional, lateral hydrologic flows from wetlands (sensu Cowardin et al. 1979) to the river network through surface water or groundwater. Such a setting would typically include upgradient areas such as hillslopes or upland areas outside of the floodplain (e.g., Lane et al. 2017). Any wetland setting where water could normally only flow from the wetland toward a river network (i.e., unidirectionally) would be considered a non-floodplain setting, regardless of the magnitude and duration of flows and of travel times (sensu Ward 1989).

Thus, the terms “floodplain” and “non-floodplain” are meant to describe the landscape setting in which wetlands occur and do not refer to a particular Cowardin et al. (1979) wetland type or class. Many wetland types occur in both settings. For example, a palustrine emergent wetland (Cowardin et al. 1979) could be located outside a floodplain, or it could be located within a floodplain and subject to bidirectional hydrologic flows. A wetland that is classified as depressional in the hydrogeomorphic approach could have any combination of inlets and outlets or none at all (Smith et al. 1995). Such a wetland would be grouped with floodplain wetlands if it had both an input and output channel, since it would have bidirectional flow. A depressional wetland with a surface outlet channel and no inlet or with no outlets and inlets, however, would be considered non-floodplain because water could flow downgradient only from the wetland to the river network, and not from a stream to the wetland. For instance, wetlands that serve as origins for streams are grouped with NFWs because they have unidirectional flow through their outlet channel.

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Hence, the hydrologic connections with river networks fundamentally differ for floodplain wetlands and NFWs. Hydrologic connections between NFWs and river networks originate via surface water spillage or merging, or near-surface groundwater flow when water inputs exceed outputs (e.g., evapotranspiration, deep groundwater loss) and available storage. A major consequence of the two different landscape settings is that while waterborne materials can be transported only from the NFW to the river network, waterborne materials can be transported both from the floodplain wetland to the river network and from the river network to the floodplain wetland (see Fritz et al. 2018). In the latter case, there is a mutual, interacting effect on the structure and function of both the floodplain wetland and river network. In contrast, a NFW can materially affect a river through the transport of waterborne materials, but the opposite is generally not true. Note that we limit our use of floodplain and non-floodplain landscape settings to the direction of hydrologic flow; the terms cannot be used to describe directionality of geochemical or biological flows. For example, mobile organisms can move between a stream and NFW and vice versa (e.g., Subalusky et al. 2009a, b; Mushet et al. 2013). In Alaska, transport of live salmon or their carcasses from streams to riparian areas by brown bears (*Ursus arctos*) accounts for more than 20% of riparian nitrogen budgets (Helfield and Naiman 2006). Although this example is in a floodplain setting, it shows how geochemical fluxes can be decoupled from hydrologic flows. Furthermore, we recognize that there may be exceptions to our unidirectional flow paradigm. For instance, flooding events may create conditions that belie the typical unidirectional flow regime. We consider the “normal” or typical flow patterning in determining the flow regime, though that, too, is replete with qualifiers.

Wetland Functions in This Review

Leibowitz et al. (2008) identified three functions by which wetlands (and streams) influence material fluxes into downstream waters: source, sink, and refuge. USEPA (2015) expanded on this framework to include two additional functions: lag and transformation (Leibowitz et al. 2018). These five functions (summarized and defined in Table 1) provide the conceptual framework for understanding how physical and chemical connections between NFWs and downstream waters influence river systems. This rubric similarly provides a framework to link other landscape elements (Forman 1995) within watersheds (i.e., providing a means to compare functions between streams, floodplain wetlands, and NFWs; USEPA 2015). This review focused on four of the five functions: source, sink, transformation, and lag in NFWs. Schofield et al. (2018) analyze biological connectivity and the refuge function of streams, floodplain wetlands, and NFWs.

Literature Review Approach

We focused entirely on peer-reviewed, publicly accessible sources of information about surface water and shallow (or near-surface) groundwater connections and interactions of NFWs that influence the function and condition of downstream surface waters. We conducted keyword searches using terms including the types of waters, connections, and downstream effects of interest (e.g., [wetland* AND [river* OR stream*] AND [connect* OR isolat*]]). We used science citation databases and search engines available through Web of Science and Google Scholar to search primary (original research) and secondary (review) literature. These searches included references citing or cited in relevant publications

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obtained through initial searches. We additionally reviewed and included citations provided by peer-review panels and in public comments on drafts of the USEPA (2015) report, which we co-authored. In addition, we expanded and updated the findings from USEPA (2015) by incorporating recently published material in this review. Finally, as most authors do not use the aforementioned term “non-floodplain wetland” in describing their study objects, we ascribed wetland typology and setting based on information in the paper and/or our knowledge of the study areas available in the peer-reviewed literature.

HYDROLOGICAL, PHYSICAL, AND CHEMICAL FUNCTIONS OF NFWS

We examined the NFW literature and herein report findings demonstrating source, sink, transformation, and lag functions with potential links to downstream systems. We then review the hydrologic and physical pathways by which NFWs may affect downstream waters. Finally, we couple the two, providing updated analyses and syntheses of our findings from the literature on the individual and cumulative effects of NFWs on downstream waters.

NFW Source Function

Hydrologic Source.—An NFW functions as a hydrologic source to downgradient ecosystems when total water inputs minus outputs (e.g., evapotranspiration, groundwater recharge) exceed the storage capacity of the wetland basin and subsequent outflow connects it via surface water to another aquatic system. This occurs when water inputs to the wetland — contributing area precipitation (including snowmelt) and saturation excess flow or near-surface groundwater discharge — fill the available soil pore space and topographic volume of NFWs. Subsequent inputs minus outputs exceed total wetland storage capacity and flow through a surface or near-surface water pour-point downgradient in what has been termed “fill-and-spill” hydrology (Spence and Woo 2003; Tromp-van Meerveld and McDonnell 2006).

NFWs can serve as the hydrologic sources or origins of headwater streams (Fergus et al. 2017; Fritz et al. 2018) when the unidirectional excess flow continues directly into an adjacent, downgradient stream system (USEPA 2015; Figure 2a). These surface connections can be perennial, intermittent, ephemeral, or episodic. White and Crisman (2016) reported that 90% of headwater streams analyzed across Florida originated from wetlands and seeps (a type of NFW). Perennial streams emanated from wetlands more frequently than impermanent streams, while the opposite was found for seeps (White and Crisman 2016). Seeps, springs, and some wetlands are expressions of groundwater at the surface (e.g., Winter and Rosenberry 1995; Euliss et al. 2004; Hayashi et al. 2016). Morley et al. (2011) reported that NFWs primarily supplied by groundwater discharge (i.e., seeps) provided 40%–80% of the water volume for the streams to which they were connected via perennial surface flow. Tufford (2011) monitored four headwater seepage wetlands in the South Carolina Coastal Plain and found that the water table dynamics varied seasonally and annually, intermittently creating hydrologic sources that connected NFW seeps to a downgradient floodplain through swales (i.e., landscape features lacking defined beds and banks or channels that convey flow especially during storm events or snowmelt; USEPA 2015; e.g., Figure 2b).

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In addition to a wetland filling and spilling and reaching the stream network, wetlands can also fill-and-merge within a basin (Huang et al. 2011; Barton et al. 2013; Leibowitz et al. 2016; Wu and Lane 2016), creating NFW complexes that frequently exchange materials within and among the surface water–connected wetland systems (Figure 3; Wu and Lane 2016; Calhoun et al. 2017). Like fill-and-spill wetlands, fill-and-merge wetlands are hydrologic sources when the maximum capacity of the bounding basin is exceeded and the wetland complex connects via continuous surface water to another aquatic system (Shaw et al. 2012; Wu and Lane 2017). That is, fill-and-merge wetlands become fill-and-spill systems when the internal storage is exceeded and no additional merging can occur within a given basin (see also the discussion on NFW Hydrologic Lag Functions, below).

While part of the hydrologic cycle (see Cohen et al. 2016), water in these wetland complexes may or may not eventually connect as surface water or near-surface groundwater into a stream network. For instance, Wilcox et al. (2011) found that nearly 20% of precipitation that fell on a Texas Gulf Coast complex of depressional wetlands spilled into a nearby water body, the Armand Bayou, over a four-year study period. By contrast, Vanderhoof and Alexander (2016) examined two nonadjacent Landsat imagery path/row combinations in the Prairie Pothole Region (PPR) across both drought and deluge conditions over a 21-year period and reported that under wet conditions, 21% of the wetlands merged with at least one other wetland and 7% of wetlands connected with lakes and streams, most via connecting to other “stepping-stone” wetlands (Vanderhoof and Alexander 2016). Vanderhoof et al. (2016) and Vanderhoof et al. (2017) showed that filling and merging of wetlands, and of wetlands and streams, was a function of landscape position relative to other aquatic systems as well as antecedent and prevailing hydrologic conditions. Brooks et al. (2018) conducted a water isotope analysis of surface water origins in a watershed within the PPR, determining that NFWs cumulatively contributed water to streamflow in 11 of 12 sampling events (based on the surface water evaporative enrichment signal in the stream). They furthermore determined that the surface (or near-surface) water connections between the NFWs and the stream networks occurred year-round and that landscape storage and subsequent downgradient flow sustained flow in the stream network.

The scientific literature we found focused primarily on wetland-to-wetland connectivity, not wetland-to-stream. Nevertheless, the literature on wetland-to-wetland connectivity demonstrates NFWs exhibiting surface water connections with other water bodies, while illustrating the variable nature of these hydrologic connections. For instance, Leibowitz and Vining (2003) reported that fill-and-spill dynamics affected 28% of NFWs within a 40-km^2 area in the PPR of North America, including 22 wetland complexes (i.e., two or more connected wetlands) during a wetter-than-average year. Conversely, none of the connections observed by Leibowitz and Vining (2003) existed in a drier year. Bowling et al. (2003) analyzed a 471 km^2 Alaskan watershed using synthetic aperture radar and reported inundation and connectivity of wetlands and tundra varied between 15% and 67% over two years, depending on available antecedent surface water storage. Leibowitz et al. (2016) explored longer term connectivity in the PPR, determining that some wetlands were filling and spilling to other wetlands over days to weeks, whereas others connected via fill-and-merge hydrology were surficially connected over decades. Kahara et al. (2009) analyzed typological changes in the abundance of different NFW basins, reporting that wetland

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merging increased with increasing annual precipitation and this changed the abundance of different NFW types (e.g., temporary, seasonal, and semipermanently inundated or saturated wetlands). For instance, one area of the PPR showed decreases in the areal extent of temporary (−47%) and seasonal (−25%) NFWs with increased precipitation, but these losses were offset by concomitant increases in semipermanent wetland area (+185%).

Hydrologically connected wetlands have different physical and hydrologic source properties than relatively unconnected systems. Cook and Hauer (2007) found wetlands that merged due to snowmelt in a Montana prairie setting had longer hydroperiods and volume, as well as higher specific conductance and primary productivity, than nonmerged wetlands. Similarly, Leibowitz et al. (2016) reported differences in dissolved ions, water levels, and macroinvertebrates between merged wetlands and those that did not merge but connected over shorter durations via fill-and-spill hydrology. These field-based measures may inform future connectivity assessments. For instance, Ali et al. (2017) recently developed an electrical conductivity (EC) indicator of potential groundwater-driven wetland-to-stream connectivity. Similarly, Thorslund et al. (unpublished data) analyzed stream and NFW chloride concentrations across several North American study sites; a mass-balance analysis demonstrated NFWs were active sites of catchment-scale flow-generation, though with abundant local to regional heterogeneity.

NFWs can recharge near-surface and deeper groundwater (see Figure 2c), or function simply as an aquatic system embedded within an upland or terrestrial area and not as a vertical or lateral hydrologic “source” for any other waters (e.g., see Figure 2d, Hayashi et al. 2016; but see Cohen et al. 2016). For instance, Hayashi et al. (1998a, b) demonstrated that a NFW received 30%–60% of snowmelt runoff from its basin, but that summer evapotranspiration at the wetland margin effectively removed an abundance of the runoff into the wetland, leaving little water for deep-groundwater recharge (see NFW Sink Function, below).

Much of the literature on NFWs as hydrologic sources has focused on stream baseflow. Groundwater discharge wetlands connected via overland/near-surface flow to streams, such as fens or seeps (e.g., Tufford 2011), are important sources of stream baseflow (Morley et al. 2011). Moreover, as noted, wetlands can be focal points for groundwater recharge, which may contribute to baseflow. Rains (2011), for example, found that perched and flow-through wetland ponds in southwestern Alaska were sites of net groundwater recharge. Given the high prevalence of ponds on the landscape (Rains 2011), these wetlands could substantially affect stream baseflow via groundwater inputs (see Groundwater Connectivity below).

In summary, NFWs are hydrologically dynamic, and are frequently sources of surface waters to other wetlands and other aquatic bodies. NFWs serve as the hydrologic origins or sources of headwater streams (White and Crisman 2016; Fritz et al. 2018). An abundance of research in the North American PPR has demonstrated fill-and-spill and fill-and-merge behaviors, as well as surface water connections to stream and lake systems (e.g., Vanderhoof and Alexander 2016; Vanderhoof et al. 2016; Vanderhoof et al. 2017; Brooks et al. 2018). NFW fill-and-spill behavior occurs in other physiographic regions (e.g., California vernal pools, Rains et al. 2006; Delmarva Ponds, Jones et al. 2018) suggesting similar controlling landscape and climatological factors. Wetlands that merge or connect with other systems

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were found to substantially affect the physical and chemical characteristics of the receiving water (e.g., Cook and Hauer 2007; Leibowitz et al. 2016; Ali et al. 2017; Brooks et al. 2018).

Chemical Source.—NFWs can be major chemical sources to other waters, contributing dissolved organic compounds (e.g., Mulholland and Kuenzler 1979; Urban et al. 1989; Eckhardt and Moore 1990; Koprivnjak and Moore 1992; Kortelainen 1993; Clair et al. 1994; Hope et al. 1994; Dillon and Molot 1997; Gergel et al. 1999), methylated mercury (MeHg) (St. Louis et al. 1994; Ullrich et al. 2001), nutrients (e.g., phosphorus, Flaig and Reddy 1995; Lane and Autrey 2016), and salts (e.g., Hayashi et al. 1998a, b; Euliss et al. 2004; Heagle et al. 2013; Nachshon et al. 2014; Ali et al. 2017). For instance, boreal forest basins composed of NFWs in central Ontario, Canada, exported between 11.4 and 31.5 kg C/ha/yr as dissolved organic carbon to downstream waters (Creed et al. 2003). While dissolved organic materials such as carbon are important sources of energy for aquatic communities (Hobbie 1992; Reddy and DeLaune 2008), they can have negative effects on downstream waters because contaminants, such as MeHg (see below) can adsorb to dissolved organic matter (Thurman 1985; Driscoll et al. 1995) and under some conditions dissolved organic compound exports can increase the acidity of downstream waters. For instance, Gorham et al. (1986) addressed watershed factors associated with lake and forest acidification in Nova Scotia, Canada. In addition to atmospheric deposition of acid precipitates, they found that the ratio of non-floodplain muskeg peatlands to lakes was significantly correlated with lake acidification, as muskeg wetland–dominated watersheds exported high-molecular-weight organic acids via either overland or shallow groundwater flow. Further linking NFWs to lakes, Gorham et al. (1986) reported that even small amounts of dissolved organic carbon can greatly affect lake water pH; the pH of waters with a dissolved organic carbon value of 4.5 mg/L (the log-normal mean) was 100 times more acidic than waters with a dissolved organic carbon value of <1 mg/L (the minimum concentration).

Wetland soils are important sources of methylmercury, a particularly toxic and mobile form of the element frequently entrained and transferred downgradient with dissolved organic compounds (Grigal 2002). Mercury enters the global atmosphere primarily through waste incineration and coal combustion; it can directly enter wetland systems or can be deposited on terrestrial areas and then transported into riparian areas and wetlands via rainfall and runoff (St. Louis et al. 1994). Ullrich et al. (2001) noted that methylmercury production was linked to low pH, low salinity, and presence of decomposable organic matter in reducing environments, factors that are present in wetlands. The redox conditions found in the presence of a fluctuating water table are thought to be a strong driver of mercury methylation (Heyes et al. 2000; Branfireun and Roulet 2002; Branfireun 2004). Once formed through microbial or other processes in wetlands, mercury and methylmercury export is controlled by the export of organic matter, such as dissolved organic compounds and humic and fulvic acids (Linqvist et al. 1991; Mierle and Ingram 1991; Driscoll et al. 1995). For example, Branfireun et al. (1996) reported 58% of MeHg-laden peat porewater leaving a headwater catchment study area occurred during stormflow, 41% during baseflow, and 1% transported via groundwater. St. Louis et al. (1994) found that boreal forest catchments in Minnesota with NFWs had lower total mercury concentrations than catchments lacking

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NFWs, but had yields of MeHg from wetlands that were 26–79 times higher than upland areas. This yielded 1.84–5.55 mg MeHg/ha/yr to streams in the Great Lakes basin, where mercury could be incorporated into lake-wide food webs. Porvari and Verta (2003) found that bioaccumulating methylmercury export from non-floodplain peatlands to downstream waters ranged from 0.03 to 3.8 ng MeHg/L, and that catchments with greater wetland abundances had greater methylmercury export.

Nutrients that are mobilized into wetlands via near-surface runoff may create high concentrations in the wetland soils (Flaig and Reddy 1995; Reddy and DeLaune 2008; Hoffmann et al. 2009). The nutrients may stay absorbed to (or bonded with) the soils until a rainfall or precipitation event creates a concentration gradient in the wetland such that the nutrients, such as phosphorus, are released from the soil into the water column (see Chemical Sink function, below). For example, a suggested agricultural nutrient runoff management practice to decrease nutrient loading to Lake Okeechobee, Florida, suggested by Flaig and Reddy (1995) is to use NFWs for phosphorus assimilation. However, they note that the capacity is finite and, furthermore, that the NFWs could become nutrient sources if loading rates are high enough and the wetlands are subsequently connected (e.g., via ditches or major precipitation events). Lane and Autrey (2016, 45) analyzed phosphorus (P) concentrations in NFWs across Florida and concluded that NFWs "… have high potential to retain P, but that the entrained P may be remobilized … depending on storm and groundwater input P concentrations." Hoos et al. (2013) found nitrate-nitrogen concentrations in streams to be positively associated with the abundance of a likely NFW type (East Gulf Coastal Plain Near-Coast Pine Flatwoods) in their application of the SPARROW (Spatially Referenced Regression on Watershed Attributes) model. They hypothesized that the short-term hydroperiod of the NFWs created aerobic conditions for nitrate formation in wetland soils, and (similar to phosphorus example above) the nutrients were mobilized during precipitation events that connected the wetland to the stream (including shallow groundwater flows).

NFWs can also be sources of elevated salts which, like mercury, can originate in wetland catchments and be entrained or dissolved and hydrologically transported to NFWs. Hayashi et al. (1998a, b) noted that snowmelt in a PPR non-floodplain basin transported 4–5 kg/yr of chloride from the surrounding area to the wetland, suggesting a sink function. However, with growing-season evapotranspiration, the solute also moved from the wetland into the surrounding upland; mass balance equations suggested that 0.1–0.6 kg/yr of chloride was lost to deep groundwater. Nachshon et al. (2014) analyzed 20 years of surface and near-surface salinity data in an upland/NFW setting in Canada's PPR. They found that NFWs existed across a continuum of salinities (e.g., Euliss et al. 2004), ranging from diluted freshwater systems with EC of <500 μS/cm to brackish systems (EC between 500 and 5,000 μS/cm) to brackish-saline wetlands (EC > 5,000 μS/cm). Summer rainfall flushed accumulated salts from the landscape to NFWs along surface and near-surface flowpaths. Some NFWs became salinity sources to other wetlands when fill-and-spill dynamics (noted above) or near-surface potentiometric heads forced high-density waters downgradient; terminal or receiving wetlands could be considered a chemical sink for high-salinity waters (see Chemical Sink functions, below). These findings suggest that NFWs can be salinity sinks at the landscape scale, but at the local or wetland scale, they may be sources of

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elevated chloride to the proximal upland areas (Hayashi et al. 1998a, b; Nachshon et al. 2014) or to other systems if they merge (as noted above; see Cook and Hauer 2007; Vanderhoof et al. 2016; Vanderhoof et al. 2017). Interestingly, Nachshon et al. (2014, 1261) noted that if a series of extremely wet years in the PPR was followed by extreme drought, "… salt concentrations in the upper soil horizons of the wetlands [could be found] at concentrations that were never measured before …" with potential impacts on other waters if or when connectivity subsequently occurred through merging or filling.

In summary, biogeochemical characteristics (e.g., high microbial activity in anoxic soils with available carbon) and physical characteristics (e.g., evapotranspiration) in NFWs create conditions conducive to chemical source functions. Examples from the literature on MeHg and salinity, hydrologically exported through dissolved organic matter entrainment or dissolution, demonstrate some of the mechanisms by which processes and functions internal to NFWs may affect other systems (see Factors Affecting Hydrologic Connectivity of NFWs, below). Conditions such as drainage ditches or subsurface tiling that expedite the delivery of NFW-sourced compounds can have negative consequences on receiving systems (e.g., Nair et al. 2015).

NFW Sink Function

Hydrologic Sink.—In addition to serving as a hydrologic source, NFWs can serve as hydrologic sinks when the storage capacity is not exceeded by net inflows (e.g., surface water and groundwater) minus outflows from evaporation or transpiration (e.g., Haan and Johnson 1968; Boelter and Verry 1977; Bullock and Acreman 2003). Storage volumes in NFWs can vary greatly. Field-measured storage volume in 10 NFWs in southern Florida ranged from 900 to 20,488 m^3 and averaged 6,836 ± 7,163 m^3 (Haag et al. 2005). Lane and D'Amico (2010) used light detection and ranging (LIDAR) data and calculated that over 8,500 NFWs in central Florida had a median storage value of 876 m^3 (1,619 m^3 average), and that this varied by Cowardin et al. (1979) wetland type. However, Evenson et al. (2016) calculated that ~50% of the >24,000 NFWs in the ~1,800 km^2 Pipestem Creek, North Dakota watershed had small storage capacities (<100 m^3). Wu and Lane (2016) used LIDAR collected during drought conditions to identify over 12,000 NFW depressions in a North Dakota watershed. They found that surface area in NFWs with standing water averaged over 2 ha and these wetlands currently stored, on average, ~32,000 m^3 of water despite a drought during the data collection period. Dry wetlands (74% of the total) averaged two orders of magnitude less storage per wetland, ~366 m^3 (Wu and Lane 2016).

Rainfall and snowmelt runoff can flow into NFWs where high evaporation and low discharge rates, coupled with high surface storage capacity, can result in large hydrologic sink functioning at the watershed scale (Shaw et al. 2012). The proportion of NFW area to wetland catchment area (A_w/A_c) is a proxy measure to account for NFW hydrologic sink functions: higher A_w/A_c values suggest greater potential hydrologic sink functioning as more precipitation would be routed to NFWs. Wu and Lane (2017) reported A_w/A_c of ~14% in a study of over 30,000 depressions in the PPR using LIDAR. A large-scale analysis by Watmough and Schmoll (2007) reported A_w/A_c of 8% in the Canadian PPR, similar to the 9% reported by Hayashi et al. (2016). NFWs stored from 11% to 20% of the precipitation

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in their respective watersheds in a PPR region study by Gleason et al. (2007). Hayashi et al. (2004, 95) analyzed isotopic signatures in a 152 km^2 basin in the PPR and found that, "… the majority of [over-winter precipitation storage] is probably stored in wetlands (i.e. fens and bogs) covering 30% of the basin …" Bowling et al. (2003) reported that 24%–42% of snowpack in an Alaskan watershed could be maintained in surface storage (i.e., stored in NFWs).

Evaporation and transpiration losses in particular can be substantial in NFWs. For instance, Lide (1997) estimated that evaporation accounted for 78% of water losses from a wetland system; Duever et al. (1994) noted that evapotranspiration can account for 70%–90% of input precipitation. Van der Kamp et al. (1999) reported that ~75% of input precipitation to a studied Canadian NFW was lost to evapotranspiration at the wetland margins. Bowling et al. (2003) estimated ~50% of snowmelt in an Alaskan basin was evaporated from open water areas (i.e., NFWs).

It is the aboveground volume in NFW wetlands that makes them so effective at landscape water storage. Wetlands effectively store water because their aboveground portions frequently contain a largely empty volume for water storage, in contrast to belowground water storage which is only partly available for water storage due to the presence of soil particles (Johnson 1967; McLaughlin et al. 2014). As noted, stored surface water is acted upon by evaporation, transpiration, and deep groundwater recharge sink functions that result in the water being, in essence, removed from the local — and landscape — hydrologic processes. Among the benefits of water storage in NFWs is that this reduces streamflow (Vining 2002) and the downstream flooding associated with peak streamflow (e.g., Hubbard and Linder 1986; Evenson et al. 2015, 2016; Fossey and Rousseau 2016; Evenson et al., in press). Hubbard and Linder (1986), for example, calculated the water retention capacity of more than 200 non-floodplain prairie pothole wetlands in northeastern South Dakota. They observed that a large amount of snowmelt and precipitation could be cumulatively held by many small wetlands, reducing the potential for flooding at downstream locations. Jones et al. (2018) analyzed NFWs in the Delmarva region (Delaware, Maryland, and Virginia) and identified that 48% of 102,000 depressional NFWs were affected by some sort of ditch; plugging or filling those ditches could increase landscape-scale water storage capacity by 80%. Vanderhoof et al. (in press) analyzed Landsat imagery between 1985 and 2015 covering over 300,000 km^2 of the PPR (North and Northwest Drift Plains) and the Northwestern Great Plains (NGP). The NFWs of the PPR had 2.6 times the surface water extent of the NGP (under median climatic conditions), demonstrating that the PPR wetlands were serving, "… a surface water storage function during wet periods, reducing the amount of water contributing to downstream flooding." Evenson et al. (in press) modeled the hydrologic effects of 13,000 NFWs in the PPR and found that NFWs attenuated peak flows; increased flooding likelihood came from wetland area (and concomitant volume) losses.

Hayashi et al. (1998a, b) determined that NFWs received 30%–60% of snowmelt runoff in their Canadian study area. Similarly, a U.S. Geological Survey study in the PPR found that wetlands, including both depressional (including NFWs) and nondepressional types, stored about 11%–20% of the precipitation that fell in a given watershed, and that storage could be increased by wetland restoration (Gleason et al. 2007). Evenson et al. (2015) simulated the

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effects of 280 NFWs on watershed hydrology in a North Carolina watershed, finding that NFWs decreased peak flows through the lag function (see below). Vining (2002) concluded that wetland storage in the Starkweather Coulee Subbasin of North Dakota likely resulted in decreased streamflow. Fossey and Rousseau (2016) modeled both riparian and NFW effects, finding NFWs decreased peak flows by 7%–16% depending on the severity of flow (2-, 20-, or 100-year return interval stormflows); NFWs were found to maintain baseflows under drought conditions. Rovansek et al. (1996) found snowmelt to be the most important source of water for wetlands and ponds in the Alaskan Arctic Coastal Plain, and that these wetlands and ponds functioned as surface storage, thereby removing water from snowmelt floods. In contrast, both Roulet and Woo (1986) and Ford and Bedford (1987) found surface storage in cold-weather regions to be limited by frozen soils and ice, limiting the lag (and sink) function in wetlands.

Regression equations developed to predict peak flows during flooding events frequently use lake and wetland storage areas as variables. Using this approach for Wisconsin watersheds, Novitzki (1979) estimated that peak flood flows were only 20% as large in watersheds with 40% lake and wetland area relative to watersheds without lakes or wetlands. Johnston et al. (1990) found that small losses of wetlands in watersheds with <10% wetlands could have major effects on flood flow in basins around Minneapolis, Minnesota. Wang et al. (2010) modeled the influence of wetlands on hydrologic processes in Manitoba and Minnesota and found that the loss of 10%–20% of the wetlands in the study basins would increase peak discharge by 40%. Similarly, Yang et al. (2010) calculated restoration of 600 ha of wetlands in a ~25,000-ha watershed would decrease peak stream discharge by 23%. Peak streamflows were shown to be negatively correlated with lake and wetland storage in Minnesota (Jacques and Lorenz 1988), although a later study found peak flows to be correlated with lake storage only and not wetland storage (Lorenz et al. 2010).

Though NFWs affect floodwaters through hydrologic sink functions, there is a finite capacity to this function. Shaw et al. (2012, 3148) observed, “[h]ighfrequency, low runoff volume [precipitation or snowmelt] events … can be completely or partially attenuated through impoundment by landscape depressions ….” However, Shaw et al. (2012) continued and noted that once a NFW and soil macropore storage volume capacity threshold is exceeded by precipitation and downgradient connections are created by runoff, the contributing area of the basin is substantially increased and storage in wetland depressions has little effect on downstream flood severity. Shaw et al. (2012) found that only 39% of NFWs in a PPR study area contributed to the basin pour-point flow during snowmelt; the remaining 61% of NFWs acted as hydrologic sinks. In a modeling analysis, Evenson et al. (in press) found larger NFWs served as gate-keepers (i.e., wetlands with a high water storage capacity threshold), storing surface runoff and attenuating peak flows in a downstream network. Modeled loss of the larger systems by Evenson et al. (in press) led to larger contributing areas affecting streamflow. Smaller wetlands (<3.0 ha) in Evenson et al. (in press) comprised 95% of the study wetlands but only 35% of the cumulative storage capacity. The modeled effects of losses in small wetland landscape storage resulted in a 90% decrease in landscape residence time, as surface flow following precipitation or snowmelt events drained across the landscape essentially unimpeded by depression water storage.

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In summary, the literature regarding hydrologic sink functioning of NFWs is abundant (e.g., Shaw et al. 2012; Shook et al. 2015; Vanderhoof et al., in press). With seasonally dependent high evapotranspiration rates and basin storage, NFWs perform hydrologic sink functions that affect downstream systems, particularly by reducing peak flows. The effects of this function are similar to the lag function (below), which also affects water flow to downgradient pour points. Structural limitations, such as the maximum storage capacity of a NFW or NFW complex, create thresholds affecting hydrologic sink functioning (e.g., Roulet and Woo 1986; Ford and Bedford 1987; Shaw et al. 2012; Evenson et al., in press).

Chemical Sink.—NFWs retain compounds through chemical (and physical) processes such as denitrification, ammonia volatilization, microbial and plant biomass assimilation, sedimentation, sorption and precipitation reactions, biological uptake, and long-term storage in plant detritus (Reddy et al. 1999; Reddy and DeLaune 2008). Marton, Creed, et al. (2015) reviewed the literature on sediment, carbon, phosphorus, and nitrogen storage and transformation in geographically isolated (i.e., non-floodplain) wetlands, concluding (and titling their review) that, “Geographically isolated wetlands are important biogeochemical reactors on the landscape.” Storage or sink rates for NFWs reported from the literature by Marton, Creed, et al. (2015) were: sediment (230–3,600 $g/m^2/yr$), carbon (21–317 $g/m^2/yr$), and phosphorus (0.01–5.0 $g/m^2/yr$) (see NFW Chemical Transformation Function, below for nitrogen findings). The substantial rate variation reported by Marton, Creed, et al. (2015; see also Marton, Chowdhury, et al. 2015) was ascribed to spatial (i.e., size, shape, landscape position) and temporal (i.e., temperature, soil moisture, redox, etc.) variables.

Many studies have addressed chemical sink functions of wetlands, with an abundance of papers focusing on nutrients, namely nitrogen and phosphorus. NFWs inundated with human sewage were shown to remove more than 95% of the phosphorus, nitrate, ammonium, and total nitrogen (Dierberg and Brezonik 1984; Ewel and Odum 1984 and chapters therein). Craft and Chiang (2002) determined that wetland soils stored a disproportionately large share of nitrogen compared with upland soils in spite of uniform soil organic matter across the landscape. A bog NFW in Massachusetts was reported to sequester nearly 80% of the system’s various nitrogen inputs, including precipitation that had a range of 1.2–1.9 mg N/L (Hemond 1983). Hoos et al. (2013) modeled nitrogen and phosphorus dynamics in the southeast U.S. using the SPARROW model and reported the abundance of two typical NFW types (Atlantic Coastal Plain Peatland Pocosin and Southern Coastal Plain Nonriverine Cypress Dome) were factors significantly associated with decreased transport of those nutrients. According to Heagle et al. (2013), the repeated wet–dry cycling of closed-basin NFWs in their PPR study area resulted in substantial subsurface accumulation of sulfate; up to 10^7 kg was estimated in the soils of a 5-ha PPR NFW. Craft and Chiang (2002) quantified sediment accumulation rates between floodplain and non-floodplain wetlands in southwestern Georgia (951 and 1,289 g/m^2, respectively); no difference was found between accumulation rates for organic carbon, total nitrogen, or total phosphorus. Craft et al. (2017) summarized published mean nutrient and sediment storage functions from nine NFW studies and 17 floodplain wetlands; NFW storage of organic carbon was 152% that of floodplain wetlands, but 12%–14% of nitrogen and phosphorous and ~25% that of sediment, though no meta-analysis statistics were conducted. Lane and Autrey (2017) reported that nitrogen

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and carbon soil accumulation rates in NFWs, measured using cesium-137 radioisotope concentrations in three ecoregions in the U.S., averaged 3.1 ± 3.1 g N/m^2/yr and 43.4 ± 39.0 g organic C/m^2/yr, respectively. Sediment accretion averaged 0.6 ± 0.4 mm/yr and did not differ by ecoregion, whereas phosphorus accumulation in NFWs was significantly greater in the Erie Drift Plain (0.10 ± 0.10 g P/m^2/yr) vs. the Middle Atlantic Coastal Plain (0.01 ± 0.01 g P/m^2/yr) or Southern Coastal Plain wetlands (0.04 ± 0.04 g P/m^2/yr) (Lane and Autrey 2017). Lane and Autrey (2016) found that phosphorus-sorption capacity varied by Cowardin et al. (1979) wetland type, with forested NFWs having three times the sorption capacity of emergent marsh NFWs (1,275 mg P/kg soil and 418 mg P/kg soil, respectively). In another example, phosphorus retention in NFW marshes of the lower Lake Okeechobee, Florida Basin ranged from 0.3 to 8.0 mg soluble reactive P/m^2/day (Dunne et al. 2006). This retention represents a sizeable amount of phosphorus removal, because only about 7% of the watershed was comprised of NFWs. Similarly, NFWs in the Lake Okeechobee Basin were found to have greater storage of total phosphorus than the uplands in which they were embedded (236 kg/ha and 114 kg/ha, respectively; Cheesman et al. 2010). Marton et al. (2014) found that NFWs in Ohio had greater phosphorus-sorption capacities than uplands (297 mg P/kg soil and 86 mg P/kg soil, respectively). These findings were echoed by Dunne et al. (2007), who reported that more phosphorus was stored in NFW plant biomass and soil than in corresponding upland compartments, with wetland surface soils (0–10 cm) representing the largest phosphorus reservoir (>87%) and soil organic matter accounting for >69% of the soil total phosphorus variability. They further suggested that restoring 5%–20% of the NFW area in priority basins draining to Lake Okeechobee, Florida could increase phosphorus storage in NFWs by up to 13 kg P/ha (Dunne et al. 2007). However, Bhadha et al. (2011) found that NFW phosphorus losses from infiltration to groundwater accounted for 14% of phosphorus flux, which suggests that near-surface flow dynamics are also important to managing phosphorus at the landscape level (and reiterating that NFWs may be chemical and hydrologic sources to other systems; Nair et al. 2015). Marton et al. (2014) reported that natural NFWs outperformed both restored and riparian systems in phosphorus retention. However, other studies have also shown that floodplain wetlands have a higher sink capacity than NFWs for phosphorus retention (Craft and Casey 2000; Cohen et al. 2007). Wolf et al. (2013) found greater sedimentation and nitrogen sedimentation in floodplain wetlands vs. NFWs, but reported phosphorus mineralization did not differ between types in floodplain and non-floodplain settings.

Cheng and Basu (2017) conducted a meta-analysis using over 600 published reports on wetland, lake, and reservoir nutrient retention rates. Smaller wetlands were more reactive (i.e., greater retention rates) than larger wetlands and the ratio of sediment contact area to volume was critical to these findings. Cohen et al. (2016, 1980) reported that NFWs are “unambiguously small” and that each order of magnitude increase in wetland size decreases the likelihood that a wetland is a NFW by a factor of three to eight times depending on the ecoregional setting. McCauley et al. (2015) noted that consolidation drainage in the PPR results in landscape changes from many, smaller wetlands to fewer, larger wetlands. Van Meter and Basu (2015), Serran and Creed (2016), and Serran et al. (2017) found that smaller wetlands have been disproportionately lost across the Prairie Pothole landscape. Evenson et al. (in press) found that small NFW removal resulted in decreased inundation time at the

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landscape scale. Integrating the findings from Marton, Creed, et al. (2015), McCauley et al. (2015), Cohen et al. (2016), Cheng and Basu (2017), and Evenson et al. (in press) suggests biogeochemical functions are affected by the loss of NFWs.

Other pollutants and compounds can be mitigated by NFW sink processes (and/or transformation; see below). For example, microbial methanogenesis completely removed the pesticide atrazine from a mountainous bog in North Carolina (Kao et al. 2002). The environmental contaminants cobalt (Co) and nickel (Ni) were remediated by wetland plants common in forested NFWs; plant concentrations were found to range from 1 to 530 mg Co/kg and up to 250 mg Ni/kg (Brooks et al. 1977). An extensively studied NFW bog in Massachusetts annually stored 54 mg/m^2 magnesium, 36 mg/m^2 potassium, and 46 mg/m^2 lead; the bog also provided acid rain buffering for downstream waters (Hemond 1980).

In summary, the literature is replete with examples of substantive chemical sink functions performed by NFWs. The studies reviewed focused on nutrient compounds (i.e., nitrogen and phosphorus) describing the rates and associated mechanisms across a wide range of NFW types and ecoregions. Factors affecting processing rates include source concentrations and biogeochemical conditions (frequently determined by temporal and spatial conditions and characteristics; e.g., Cheng and Basu 2017; Evenson et al., in press). The collective implication of these studies is that the sink function of NFWs is significant. For instance, in a meta-analysis of NFW biogeochemical functions, Marton, Creed, et al. (2015, 415) estimated that NFW losses in the PPR have negatively affected downstream systems due to lost sink functionality, resulting in "… an increase of between 5 and 140 Tg per year (1 Tg = 10^{12} g) of sediment entering surface waters and decreases of 0.84–13 Tg per year C sequestration, 0.00040–0.20 Tg per year P storage, and 0.032–0.21 Tg per year [in lost] denitrification potential." However, intact NFWs, such as the >1.2 million ha identified by Lane et al. (2012) in the southeastern U.S., "… have the potential to sequester 0.25–3.8 Tg of organic C each year … 1.4–42.7 Tg of sediment, [and] 0.00012–0.059 Tg of P …" (Marton, Creed, et al. 2015, 415).

NFW Chemical Transformation Function

Freshwater wetlands and peatlands are active areas for microbially mediated transformations (Boon 2000, 2006) such as the aforementioned mercury methylation and reactive nitrogen (Nr) transformation to N_2 through denitrification. Galloway and Cowling (2002, 71) define Nr as, "… biologically active, photochemically reactive, and radiatively active N compounds in the atmosphere and biosphere … [including] inorganic reduced forms of N (e.g., NH_3, NH_4^+), inorganic oxidized forms (e.g., NO_x, HNO_3, N_2O, NO_3^-), and organic compounds (e.g., urea, amines, proteins)." Transformations of Nr to N_2 are prevalent in wetlands that are exposed to Nr and have anoxic conditions, labile carbon, and facultative microbial communities (Reddy and DeLaune 2008). Jordan et al. (2011) reported ~20% of the Nr load reaching wetlands in the contiguous U.S. was removed through plant uptake, denitrification, absorption, burial, and anaerobic ammonium oxidation. As noted, Cohen et al. (2016) determined that wetlands typifying non-floodplain systems (e.g., vernal pools, prairie potholes, etc.) were typically small. With this small size, they found, came a high perimeter length per unit area; since wetland edges are areas of most active biogeochemical

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processing, these wetland systems are of particular importance in landscapelevel functioning (such as transformative processes; see Cohen et al. 2016; Holgerson and Raymond 2016). Indeed, Ghermandi et al. (2010) found that water quality exported from wetlands was inversely related to size. Cheng and Basu (2017) constructed a nutrient-removal model in wetland systems based on over 600 published studies and found that 50% of the total nitrogen load was removed by wetlands smaller than ~0.03 ha (~300 m^2) in size. Losing smaller wetlands, they conclude, "… will lead to a greater fraction of the landscape removal potential lost because of the higher reactivity of smaller wetlands" (5051).

Marton, Creed, et al. (2015) reviewed the literature on biogeochemical processes in NFWs, reporting that denitrification rates ranged from 0.8 to 2.0 $g/m^2/yr$ and varied with spatial and temporal variables; input NO_3^- concentrations were found to also control transformation rates. Racchetti et al. (2011) reported that 60%–100% of NO_3^- inputs to geographically isolated (i.e., non-floodplain) wetlands were transformed. NFWs in Michigan were found by Whitmire and Hamilton (2008) to remove nitrate-nitrogen (NO_3-N) and sulfate (SO_4^{2-}) at rates of 0.04–0.55 mg NO_3-N/L/ha and 0.06–0.30 mg SO_4^{2-}/L/ha. These rates are significant, considering that nitrate concentration in Michigan groundwater was reported to average 0.5 mg NO_3-N/L (Whitmire and Hamilton 2008), though groundwater concentrations >3 mg NO_3-N/L are considered contaminated (Madison and Brunett 1985). Prairie pothole NFWs in the upper Midwest removed >80% of the nitrate load via denitrification (Moraghan 1993). A large marsh NFW removed 86% of nitrate, 78% of ammonium, and 20% of phosphate through assimilation and sedimentation, sorption, and other mechanisms, including transformation (Davis et al. 1981). In a study of NFWs of North Carolina and Florida, Lane et al. (2015) reported average denitrification rates of 6.89 ± 5.02 μg N/kg soil dry weight (DW)/h; differences were found based on vegetation structure, with emergent marsh NFWs denitrifying at almost triple the rate of forested NFWs. This was hypothesized to result from the greater abundance of labile carbon in the marsh wetlands (Lane et al. 2015). Marton, Chowdhury, et al. (2015) analyzed NFWs in Indiana and found denitrification rates of 88.8 μg N/kg DW/h. NFWs studied in Maryland and Delaware had microbially mediated denitrification rates of 0.06–0.76 mg N/kg soil/day (Jordan et al. 2007). Because these NFWs comprised >70% of the wetland area in the study basin, this value indicates a significant watershed denitrification capacity. Marton, Chowdhury, et al. (2015) found that NFWs denitrified at twice the rate of upland systems, 12.3 ± 4.5 ng N/g soil/h vs. 5.3 ± 1.7 ng N/g soil/h. NFW samples amended with carbon, nitrogen, or both have been found to dramatically increase the denitrification rate (e.g., Lane et al. 2015; Marton, Chowdhury, et al. 2015) suggesting that NFWs have substantial chemical transformation functioning that may be limited by inputs (see also Ullah and Faulkner 2006; Dodla et al. 2008). Using spatial data from Lane et al. (2012), Marton, Creed, et al. (2015) estimated that the intact NFWs of the southeastern U.S. collectively transform, or denitrify, 0.0095–0.063 Tg N/yr.

In summary, NFWs perform substantial chemical transformation functions, the rates of which frequently depend on factors such as temperature, available energy sources, soil characteristics (e.g., anaerobic or aerobic conditions), and chemical compound concentration (e.g., Marton, Creed, et al. 2015; Marton, Chowdhury, et al. 2015). Much of the literature we

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found focuses on transformation of nitrogen species to N_2, though other compounds were also discussed (e.g., SO_4^{2-}; MeHg in the chemical source functions, above).

NFW Hydrologic Lag Function

While hydrologic sinks discussed above affect the volume of water on the landscape due to processes such as evapotranspiration, hydrologic lags delay water delivery without substantially affecting quantity through temporary storage or by routing water through flowpaths with long travel times. The lag, sink, and source functions work in conjunction with one another. In essence, the lag function can be viewed as the time-integrated sink and source functions. That is, water initially stored by wetlands can be released over time, reducing peak flows and increasing low or baseflows. Fossey and Rousseau (2016) modeled both riparian and NFW effects, finding NFWs decreased peak flows by 7%–16% depending on the severity of flow (2-, 20-, or 100-year return interval stormflows), while maintaining baseflows under drought conditions. Fossey and Rousseau (2016) concluded that, "… at any event scale any type of wetlands [e.g., floodplain and non-floodplain wetlands] plays a role in reducing peak flows … and sustaining low flows." As noted above, Evenson et al. (2015) simulated the effects of 280 NFWs on the hydrology in a North Carolina watershed, finding that NFWs decreased peak flows through the lag function.

The lag function is a result of two mechanisms affecting flow. First, a lag occurs when surface and near-surface groundwater inputs to a NFW fill available space below a spill elevation. With lag functions (vs. sink functions), the wetland storage capacity is ultimately exceeded resulting in surface runoff or near-surface flow. When storage capacity is exceeded by storm events during otherwise dry periods, watersheds containing extensive wetlands can require more time for water discharge to rise and fall in response to storm events due to the lag function (Lindsay et al. 2004). Second, a lag occurs through the routing of water to near-surface groundwater and then to stream systems. Water routed through near-surface groundwater-to-stream systems, as opposed to movement via surface water, would be expected to take longer (i.e., to lag) due to the tortuous pathways required by soil particles (and rocks, roots, etc.) — see Groundwater Connectivity, below.

The ability of wetlands to reduce flooding via storage and the lag function varies, with topography exerting an influence (e.g., slope). Using stable hydrogen and oxygen isotopes of water, McEachern et al. (2006) found that snowmelt in boreal forests was discharged rapidly in a sloped watershed. In contrast, in a lowland watershed, much of the snowmelt was stored by wetlands, particularly by bog NFWs with headwater stream channel outlets. In northern Canada, stream runoff was positively correlated with slope and the presence of channel fens, but negatively correlated with lowland depressional NFWs (Quinton et al. 2003). A literature review of wetlands having no direct inlets or outlets to a river system concluded that those wetlands reduced or delayed flooding (Bullock and Acreman 2003). Findings by Bullock and Acreman (2003) were more varied for slope wetlands with direct connectivity to a river: 26 of 62 studies found reduced flooding, while 27 of the 62 studies concluded that those wetlands increased flooding.

Antecedent moisture conditions and currently available wetland storage also affect the lag function. Boelter and Verry (1977) noted that two storms of nearly equal volume and

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intensity produced different runoff responses from the same peatland. One storm occurring in the spring at a time of already high water tables led to runoff. The other, in midsummer at a time of low water tables, increased the water depth in the NFW but did not exceed the wetland's water storage capacity, precluding runoff. This mechanism has been observed in simulations of prairie pothole wetland hydrology, in which wetlands reduced streamflow until storage capacity was exceeded (Haan and Johnson 1968; Shaw et al. 2012). Thus, NFWs can function as a sink in dry periods if storage capacity is not exceeded and evaporation rates surpass groundwater recharge (see Hydrologic Sink function, above). These same wetlands can function as sources in wet periods if NFW storage capacity has been exceeded. Finally, the same wetlands can create a lag during the filling process in advance of the spilling event by initially storing inputs but producing surface runoff if their storage capacity is exceeded. This phenomenon explains in part how wetlands can both increase and decrease streamflows (Bullock and Acreman 2003) — see also Factors Affecting Hydrologic Connectivity of NFWs, below.

Thus, NFWs provide hydrologic lag functions when depressions fill with precipitation, snowmelt, or other surface and near-surface inputs. The lag functional is dependent on a NFW basin spill threshold; after such a point is passed, the contributing area transitions from terminating at the NFW to affecting flow in downstream systems (e.g., Boelter and Verry 1977; Shaw et al. 2012; Jones et al. 2018; Brooks et al. 2018; Evenson et al., in press). Hydrologic models have demonstrated that when contributing area flow terminates at a NFW, near-surface and groundwater recharge functions maintain baseflow in downgradient streams (e.g., Evenson et al. 2015; Fossey and Rousseau 2016). Similarly, basin filling from overland or near-surface inputs creates a temporal lag that can decouple stormflow events, even in systems where pervasive overland flow connects landscape elements within watersheds to a downgradient pour-point (Bullock and Acreman 2003; Brooks et al. 2018). However, when NFW storage volume is at capacity, the lag function is effectively bypassed (Shaw et al. 2012).

Factors Affecting Hydrologic Connectivity of NFWs

Surface Water Connectivity.—Multiple factors affect whether a potential surface connection exists between a NFW and another water body and, if and when actualized, the duration, frequency, and magnitude of that connection. These factors can be organized into three major categories: (1) those characteristic of the intervening area between the NFW and the receiving water body; (2) those intrinsic to the NFW or NFW complex itself; and (3) exogenous forcing factors, such as climate. In the first category, intervening distance is a first-order factor (Cohen et al. 2016). Le and Kumar (2014) analyzed NFWs in five study areas across the U.S. and found that potential hydrologic connectivity, as determined by nearest-neighbor distances, followed a universal power law distribution, with most wetlands connecting over short distances. The short intervening distances between wetlands can cause rapid increases in hydrologic connectivity during precipitation/snowmelt events as different parts of the watershed connect (or fill, merge, and spill) and the watershed contributing area increases quickly (Le and Kumar 2014). Neff and Rosenberry (2017) found that the quantity of modeled NFW groundwater provided to the stream network decreased with increasing distance from the network. Vanderhoof et al. (2016) and Vanderhoof and Alexander (2016)

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found that hydrologic connections between NFWs and streams were positively correlated with stream density, suggesting that connections increase with decreasing distances between wetlands and streams. However, with wet conditions, wetlands were observed connecting to streams over long distances (up to 37 km; Vanderhoof and Alexander 2016). Ameli and Creed (2017) found that both surface water and groundwater inputs from NFWs contributed to river flows, with surface inputs affecting flows up to 8 km from the river system (and groundwater flows affecting the river system up to 30 km away). Human activity can alter this relationship. Historical loss of NFWs in Iowa has increased distances between wetlands that remain (e.g., McCauley et al. 2015; Van Meter and Basu 2015). For example, human activities have also increased the mean distance of Iowa and Nebraska NFWs to streams due to relatively higher rates of drainage and loss of upland-embedded NFWs farther away from the stream network (Uden et al. 2014; Van Meter and Basu 2015).

Other characteristics of the intervening area between NFWs and the stream network include topography, vegetation, soil, and human alterations, all of which can affect flow characteristics. For instance, slope has been positively correlated with streamflow (McEachern et al. 2006), as areas of lower slope typically have a lower potentiometric head. Quinton et al. (2003) reported that stream runoff was negatively correlated with the abundance of lowland bog NFWs. Precipitation events on soils with low infiltration capacity are more likely to result in overland flow whereas soils with higher infiltration capacity are more likely to result in groundwater flowpaths. In their literature review, Bullock and Acreman (2003) found that studies of NFWs with no direct surface water connectivity reduced or delayed flooding downstream. However, 42% (i.e., 26 of 62) of the slope (NFW) wetland studies that were reviewed resulted in reduced flooding and 44% (i.e., 27 of 62) of those increased downstream flooding, which suggest antecedent moisture conditions, wetland storage, and characteristics of the connection between the NFWs and another system (e.g., vegetation, roughness, pore space, hydraulic conductance, etc.) affect connectivity dynamics.

Storage is a function intrinsic to NFWs, affecting connectivity via the fill-and-spill or fill-and-merge of surface waters. As described above, spilling or runoff from a wetland occurs when wetland storage minus losses (via evaporation or groundwater recharge) are exceeded by inputs (via precipitation, groundwater discharge, or overland flow). The inputs and losses are driven in part by climate. Everything being equal, under wetter conditions, wetland storage capacity is more likely to be exceeded. In the PPR, temporary overland connectivity between NFWs has been observed in wet years (e.g., Leibowitz and Vining 2003; Cook and Hauer 2007; Leibowitz et al. 2016). Brooks et al. (2018) found that on average, 33% of the Missouri Coteau (part of the PPR) was connected using Landsat imagery analyses, and determined that this was mostly via the fill-and-merge process between NFWs as the stream network was poorly developed in their study area. Although these studies focused on NFW-to-NFW connections, their findings illustrate that connectivity is a dynamic process, and that NFWs can exhibit temporary surface water connections with other water bodies during wet periods (e.g., Wilcox et al. 2011; Vanderhoof and Alexander 2016; Vanderhoof et al. 2016; Brooks et al. 2018).

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Research into the frequency, duration, magnitude, and timing of surface connections of NFWs to river networks has received less attention than those of riparian and floodplain wetlands (see Fritz et al. 2018), though this has changed markedly in recent years through advances in hydrologic modeling, statistical approaches, and remote sensing and geostatistical analyses, especially in the North American PPR and portions of the Atlantic Coastal Plain (e.g., Wilcox et al. 2011; Lang et al. 2012; Golden et al. 2014; Golden et al. 2015; Huang et al. 2014; Evenson et al. 2015; Shook et al. 2015; Fossey and Rousseau 2016; Vanderhoof et al. 2016; Vanderhoof et al. 2017; Ameli and Creed 2017; Jin et al. 2017; Thorslund et al., unpublished data). Where connections have been reported, the duration of a connection is more often described (i.e., whether the connection is perennial, intermittent, or ephemeral). The frequency of a connection, in the case of intermittent or ephemeral flows, or the magnitude of that connection (i.e., the amount of flow between a wetland and a river network) has been less empirically studied or reported due in part to the difficulties in attributing source waters (but see McDonough et al. 2015; Vanderhoof et al. 2016; Brooks et al. 2018; Thorslund et al., unpublished data). A combination of small-scale field-based studies coupled with larger scale remote sensing applications and modeling will effectively quantify surface water connectivity of non-floodplain systems (Golden et al. 2017; see Brooks et al. 2018).

Groundwater Connectivity.—In addition to surface water connections, groundwater flow can connect NFWs with other water bodies, potentially over great distances (e.g., 30 km; Ameli and Creed 2017). Studies have shown NFWs can receive groundwater discharge, contribute to groundwater recharge, or connect via both pathways (Lide et al. 1995; Devito et al. 1996; Matheney and Gerla 1996; Rosenberry and Winter 1997; Pyzoha et al. 2008). For example, a study of four North Dakota prairie NFWs by Arndt and Richardson (1989) demonstrated groundwater connections as one wetland recharged groundwater, one was a flow-through wetland, and one was a groundwater discharge system (Euliss et al. 2004). Using stable isotopes, Matheney and Gerla (1996) concluded that although most of the water in a depressional NFW came from precipitation, groundwater connections accounted for the high salinity of the wetland soil. High salinity can be indicative of net groundwater discharge to a wetland (Brinson 1993; Ali et al. 2017). Min et al. (2010) reported that 38% of rainfall that entered four NFWs in Florida was recharged to groundwater. Bullock and Acreman (2003) found 69 studies making reference to groundwater recharge from wetlands; of these, 32 observed groundwater recharge from a wetland whereas 18 did not. Rosenberry and Winter (1997) determined that groundwater mounding may prevent connections that would otherwise follow topography. Neff and Rosenberry (2017) conducted a model analysis suggesting that groundwater mounding could be short-circuited by the presence of sand layers promoting lateral conductivity or drought conditions decreasing the presence of the water table mounds.

Groundwater flow-through wetlands are sites of both groundwater discharge and recharge, in essence a surface expression of the groundwater system (Richardson et al. 1992; Kehew et al. 1998; Ferone and Devito 2004). This dynamic has been shown in many locations, including prairie pothole NFWs (Richardson et al. 1992), NFWs in glacially formed landscapes in southwest Michigan (Kehew et al. 1998), Alaskan pond NFWs (Rains 2011),

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Florida cypress dome NFW systems (Sun et al. 1995), and small Wisconsin lakes (Born et al. 1979). The lakes and NFWs of the Nebraska Sand Hills are also predominantly flow-through and an expression of a large regional groundwater system (Winter 1999).

Like surface water, groundwater connections can vary in duration, frequency, and magnitude, and these connections can be affected by a number of factors. Whether a wetland recharges groundwater, is a site of groundwater discharge, or both, is determined by topography, geology, soil features, and seasonal position of the water table relative to the wetland (Neff and Rosenberry 2017). Shedlock et al. (1993), for example, concluded that groundwater discharged into a NFW bog along Lake Michigan through a breach in the sediments underlying the wetland. In dry periods when water tables are low, water tends to move from wetlands into the groundwater, while in wetter periods with higher water tables, water can flow in the opposite direction from shallow groundwater into the wetlands (Phillips and Shedlock 1993; Pyzoha et al. 2008; McLaughlin et al. 2014). Lide et al. (1995) observed both groundwater flow into and from a Carolina bay NFW, with discharge to the wetland when the water table was high and recharge to the groundwater when the water table was low. Sun et al. (1995) observed similar phenomena in a Florida cypress dome NFW. This exchange and temporary storage of water represents a lag function (see NFW Hydrologic Lag Function, above; see also McLaughlin et al. 2014) that can make NFWs particularly important for groundwater recharge during dry periods. Rosenberry and Winter (1997) indicated that groundwater discharge to a wetland often alternates with flow from the wetland to groundwater, and the direction of flow is controlled by the balance of recent precipitation with current evapotranspiration demands.

The magnitude and transit time of groundwater flow from a wetland to other surface waters depends on the intervening distance and the properties of the rock or unconsolidated sediments between the water bodies (i.e., the hydraulic conductivity of the material). In some carbonate or volcanic rocks, for example, groundwater can flow relatively freely through large openings; while in unconsolidated material, such as gravel, sand, silt, or clay, the spaces between particles determine the time required for water to flow a given distance (Winter et al. 2003). In porous material, such as gravel, water can travel a kilometer in a few days; in fine-textured materials, such as silt or clay, hundreds to thousands of years might be required for water to travel the same distance (Winter and LaBaugh 2003).

In agricultural regions, the transit time of subsurface flows is increased substantially by artificial subsurface drainage pipes, known as tile drains (Schiller et al. 2012). Wetlands in these areas are sometimes fitted with inlets that connect directly to tile drains, quickly moving temporarily ponded water through the subsurface and to outlets that discharge directly to ditches or streams (Tomer et al. 2010). Ditching wetlands can not only make them into sources of water but also sources of nutrients and ions from their legacy performing sink functions on the landscape (e.g., Brunet and Westbrook 2012; Nair et al. 2015).

In summary, NFWs can recharge groundwater, receive discharging groundwater, or be flow-through wetlands, and sometimes all three in a given water-year (Sun et al. 1995). Impermeable layers underlying some NFWs may create perched systems with low groundwater connectivity to other systems; these layers may also be breached or be

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discontinuous underneath larger wetlands, permitting connections to near-surface or deeper groundwater. NFW connections to groundwater encompass sink, source, and lag functions affecting downgradient base and stormflows; groundwater connections can be relatively quick, or ponderously slow. Further examinations into the NFW groundwater connections and factors affecting these interactions and subsequent connections to downstream systems require additional analyses and research, especially in areas outside of the North American PPR.

SYNTHESIS AND IMPLICATIONS: HYDROLOGICAL, PHYSICAL, AND CHEMICAL EFFECTS OF NFWS ON DOWNSTREAM WATERS

NFWs lack well-defined surface water inlets and/or outlets to other water bodies and may include depressions, slopes, flats, and other similar wetland types, as well as regionally described systems such as some Prairie Potholes, playa lakes, vernal pools, and Carolina bays (e.g., Tiner 2003). NFWs are abundant aquatic systems throughout the U.S.; Lane and D' (2016) conducted a coterminous U.S. spatial analysis using a geospatial floodplain proxy to identify more than 8.4 million potential NFWs covering more than 6.6 million hectares (see Figure 1). Hydrologic flows through NFWs are predominantly unidirectional, in contrast to bidirectional flows that occur in riparian and floodplain wetlands. Much of the updated literature we examined on NFWs indicates that these systems have important hydrologic and water quality functions that affect downstream waters and rivers (Creed et al. 2017). In USEPA (2015), the literature did not sufficiently support a definitive conclusion regarding non-floodplain connectivity of particular groups or classes of wetlands, though USEPA (2015) acknowledged that NFWs which intersect surficial and near-surface runoff can perform substantive chemical sink and transformative functions. Recent scientific contributions to the literature, additional sources now included in this updated review, and advances in hydrologic modeling (e.g., Evenson et al. 2015, 2016; Fossey and Rousseau 2016; Ameli and Creed 2017; Cheng and Basu 2017; Evenson et al., in press; Thorslund et al., unpublished data), remote sensing analyses (e.g., Vanderhoof et al. 2016; Vanderhoof et al. 2017; Jones et al. 2018), field-based observations (e.g., Shaw et al. 2012; Ali et al. 2017), and emerging coupled field and remote sensing studies (e.g., Brooks et al. 2018) have further informed our analyses and synthesis of the literature such that we now conclude all NFWs are interconnected with stream and river networks (Cohen et al. 2016), though this connectivity varies in frequency, duration, magnitude, and timing (Ward 1989; Covino 2017). This complex landscape-scale connectivity, in turn, affects water and material fluxes — the resultants of substantial hydrological, physical, and chemical functioning in NFWs — that modify the characteristics and function of downstream waters (e.g., Marton, Creed, et al. 2015; Rains et al. 2015; Cohen et al. 2016; Calhoun et al. 2017).

It is evident that NFWs that are connected to the river network through surface water are hydrologic sources and will have an influence on downstream waters, regardless of whether the outflow is permanent, intermittent, ephemeral, or episodic (e.g., Wilcox et al. 2011; Rains et al. 2015; Calhoun et al. 2017; Brooks et al. 2018). Such NFWs include wetlands that are the origins of streams or are connected downstream to the river network through ditches, as well as those connected through swales. It is the quality (i.e., concentrations

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of entrained or dissolved compounds) and quantity of surface water exports from NFWs that informs this conclusion. The finding may have important research and management implications. For instance, White and Crisman (2016) concluded that NFWs are headwaters to ~90% of mapped streams they studied in Florida, and Nadeau and Rains (2007) estimated that up to 60% of stream km in the conterminous U.S. may be first- or second-order systems (i.e., headwaters). However, the most highly refined spatial stream data available for the U.S., the National Hydrography Dataset (NHD; 1:24,000), does not typically identify stream systems of <1.6 km, and there are significant omission errors. For instance, Lang et al. (2012) reported that the NHD identified 66% of stream length compared with a product developed using higher resolution LIDAR data. Thus, it is evident that NFWs serve as abundant stream origins in certain parts of the country, though the origins of the vast majority of streams in the U.S. are unmapped and hence unreported.

NFWs that do not connect to the river network through surface water can still be a source of water (or be connected) through local, intermediate, or regional groundwater flows, often covering great distances (e.g., over 30 km, Ameli and Creed 2017) and providing meaningful hydrologic inputs that maintain baseflows (e.g., 313 m^3/day modeled to provide to river flow from groundwater recharging NFWs; Ameli and Creed 2017). Connectivity between these NFWs and downstream waters will vary within a watershed as a function of local factors (e.g., position, topography, and soil characteristics) as well as time, as the river network and water table expand and contract in response to local climate (e.g., Vanderhoof et al. 2016; Vanderhoof et al. 2017).

NFWs that lack a surface or near-surface/groundwater hydrologic connection to other water bodies also influence downstream systems by acting as sinks, creating lags, and/or transforming material. These wetlands can effectively reduce peak flow and flooding, while potentially increasing low flows. The physical storage of water in NFWs, dependent on available volume (e.g., not affected by volume storage reductions due to frozen soils or ice), is incontrovertibly and empirically occurring across the landscape (e.g., Boelter and Verry 1977; Shaw et al. 2012; Brooks et al. 2018). However, once a NFW (or complex) has reached capacity, the storage capacity and impact on downgradient flow mitigation is effectively negligible.

Chemical sink and transformation functions of NFWs have effects on the water quality of downstream waters when these wetlands intersect the flowpath between pollutant source and downstream waters. Wetland chemical sink functions are likely to be greatest when the wetland is located downgradient from pollutant sources and upgradient from a stream or river. The ability of NFWs to perform sink functions is such that maintaining, restoring, and protecting these wetlands have been promulgated as part of watershed nutrient management plans (e.g., Zhang et al. 2009). The literature demonstrates that transformation and sink functions in NFWs provide significant removal of certain pollutants (e.g., transformation of nitrogen species; sink of phosphorus species; but see MeHg studies noted above). The rates depend on pollutant source-area contributions, modes of transportation (i.e., entrained or dissolved), as well as hydrology, temperature, available carbon, and other factors (Marton, Creed, et al. 2015; Marton, Chowdhury, et al. 2015; Cohen et al. 2016; Cheng and Basu 2017).

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The updated literature we reviewed provides ample evidence that NFWs can and do provide hydrologic and chemical functions that affect material fluxes to other waters, including other wetlands within a basin, streams and lakes, and groundwater. These results suggest the cumulative influence of many individual NFWs within watersheds can strongly affect the spatial scale, magnitude, frequency, and duration of hydrologic and chemical fluxes or transfers of water and materials to downstream waters.

Caveats associated with this review include the fact that the term “non-floodplain wetland” was infrequently used in the literature, and our designation as such was frequently based on the context, study location, or other information available in the published research that may have resulted in errors of commission. Errors of omission occurred in this review, as the welcome increase in scientific literature on NFW functions portends a better understanding of their downstream effects. Increasing the spatial distribution of NFW studies to encompass the full breadth of ecoregions and wetland typologies will result in increased certainty of the conclusions. Contributions were dominated by studies from researchers of the North American PPR; our understanding will be further improved by additional studies in other areas and ecoregions.

The updated literature supports the following conclusions in this review on the hydrological, physical, and chemical functions of NFWs and their effects on downstream systems:

1. NFWs exist across a gradient of connectivity from poorly connected systems to well-connected wetlands and wetland complexes.
2. All NFWs are therefore interconnected with stream and river networks, though this connectivity varies in frequency, duration, magnitude, and timing. This complex landscape-scale connectivity affects water and material fluxes — the resultants of substantial hydrological, physical, and chemical functioning in NFWs — that modify the characteristics and function of downstream waters.
3. NFWs can be hydrologically connected directly to river networks through natural or constructed channels, nonchannelized surface flows, or subsurface flows, the latter of which can travel long distances to affect downstream waters. Through this connection, NFWs act as a source of water and other materials to downstream waters.
4. Water storage by NFWs well outside of riparian or floodplain areas affects streamflow through the sink and lag functions.
5. NFWs act as sinks, sources, and transformers for various pollutants, especially nutrients.
6. The connectivity of NFWs with other systems, as well as the relative size of their contributing area, may vary in space and time along with their functions that affect watershed-scale hydrodynamics and chemical fluxes.
7. There are a number of factors that influence the magnitude, frequency, and duration of connections between wetlands and streams. These include spatial proximity, wetland storage capacity, climate, and characteristics of intervening area between wetlands and the stream (e.g., soil permeability).

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NFWs are abundant landscape elements important for multiple functions taking place across temporal and spatial scales that contribute to watershed integrity (e.g., Creed et al. 2017). The connectivity of NFWs with other systems, as well as the relative size of their contributing area, may vary in space and time along with their functions that affect watershed-scale hydrodynamics and chemical fluxes. We agree with Shook et al. (2015), as well as Cohen et al. (2016) who in particular note that, "[w]atershed discharge integrates the entire continuum of hydrologic connectivity, not just rapid or surface-connected flow paths." A corollary to this conclusion is that as hydrology mediates and facilitates much of the physical and chemical functions of NFWs, the material concentration of watershed discharge reflects the time and space-varying contributions and effects of all landscape elements, including NFWs (cf. Hynes 1975).

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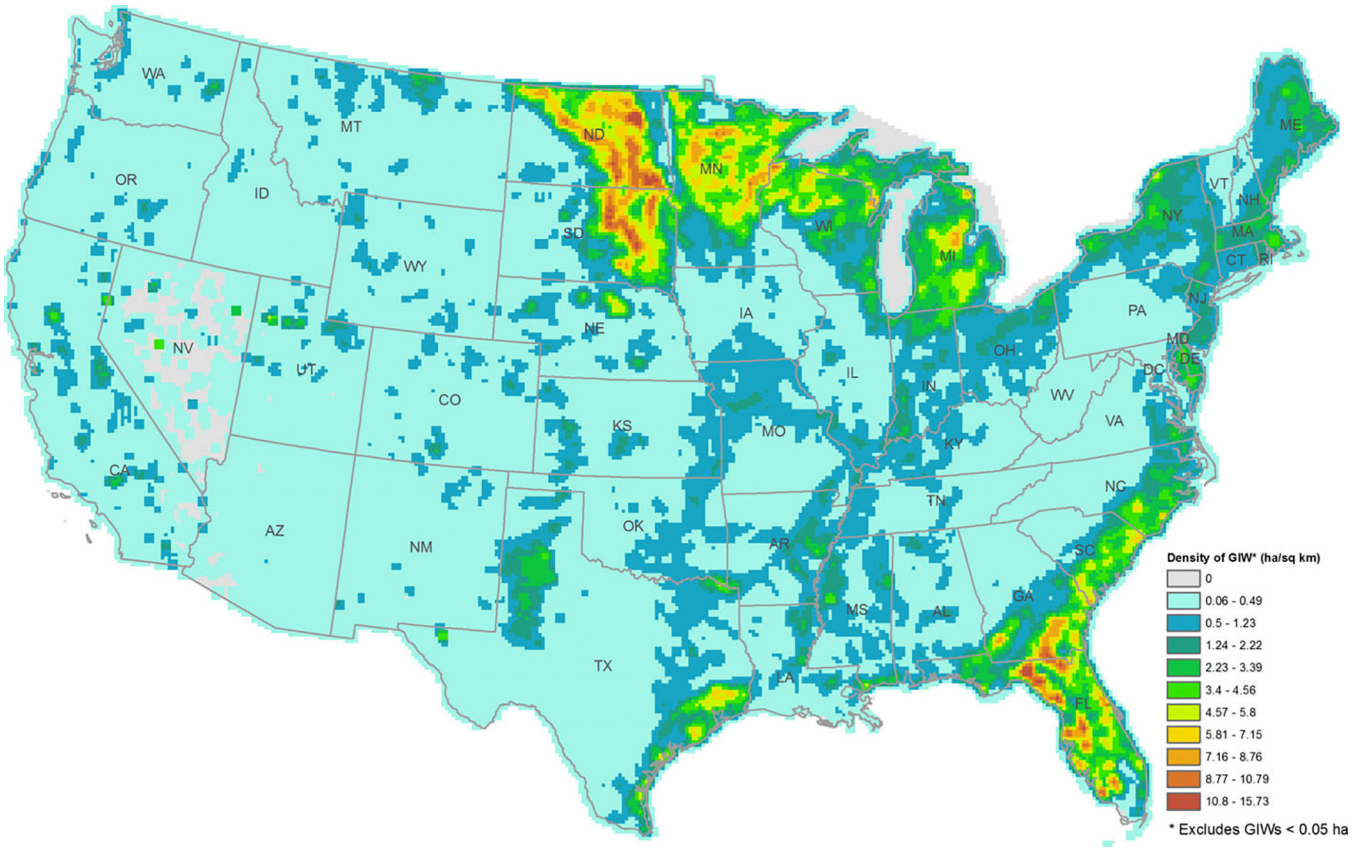


FIGURE 1.

Spatial distribution (heat map of ha/km^2) of NFWs (or "geographically isolated wetlands," GIWs in Lane and D'Amico 2016) derived from geographic information system analyses of a floodplain proxy (Lane and D'Amico 2016). Approximately 8.4 million NFWs covering more than 6.6 million ha were reported by Lane and D'Amico (2016). Source: Figure reproduced from Lane and D'Amico (2016). State abbreviations are given in the figure.

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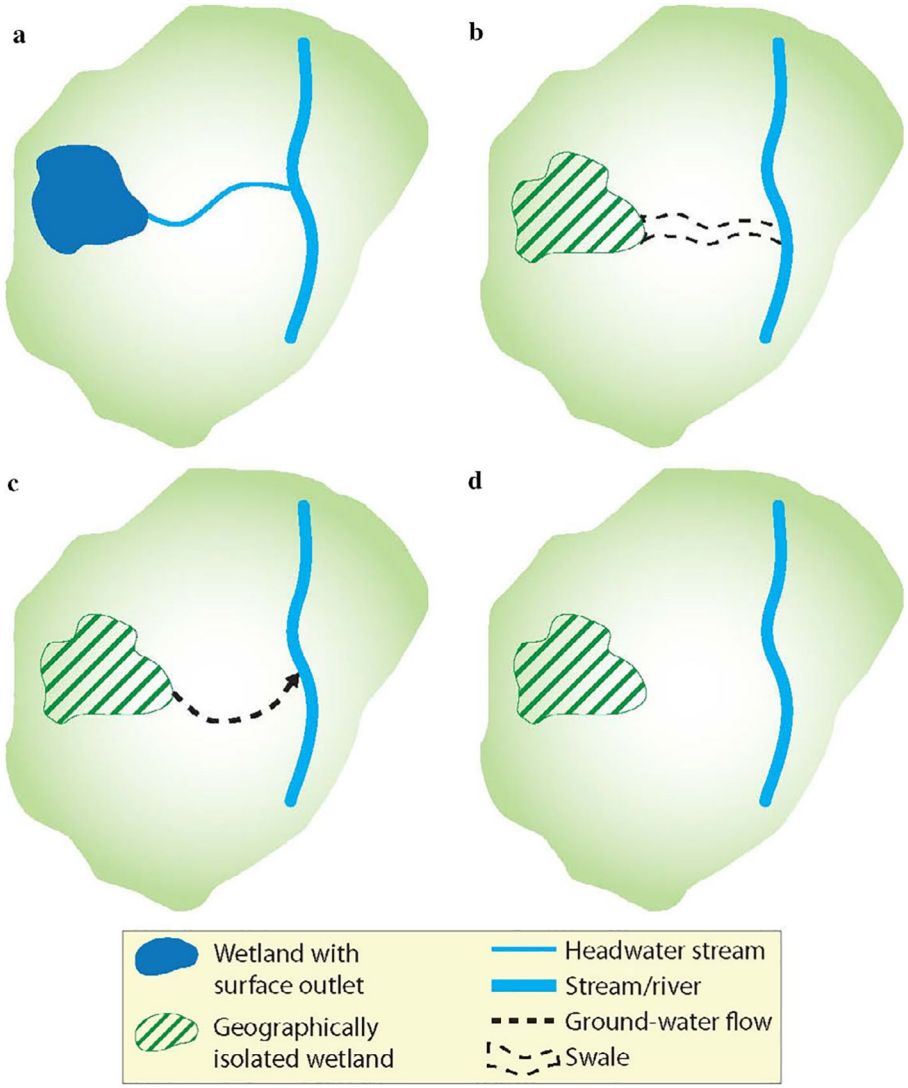


FIGURE 2.

Types of hydrologic connections between NFWs and streams or rivers. (a) A wetland connected to a river by surface flow through a headwater stream channel. (b) A wetland connected to a river by surface flow through a nonchannelized swale. (c) A NFW connected to a river by groundwater flow (flowpath can be local, intermediate, or regional). (d) A NFW that is hydrologically isolated from a river. Note that in a–c, flows connecting the wetland and river may be perennial, intermittent, or ephemeral. Source: Figure reproduced from USEPA (2015).

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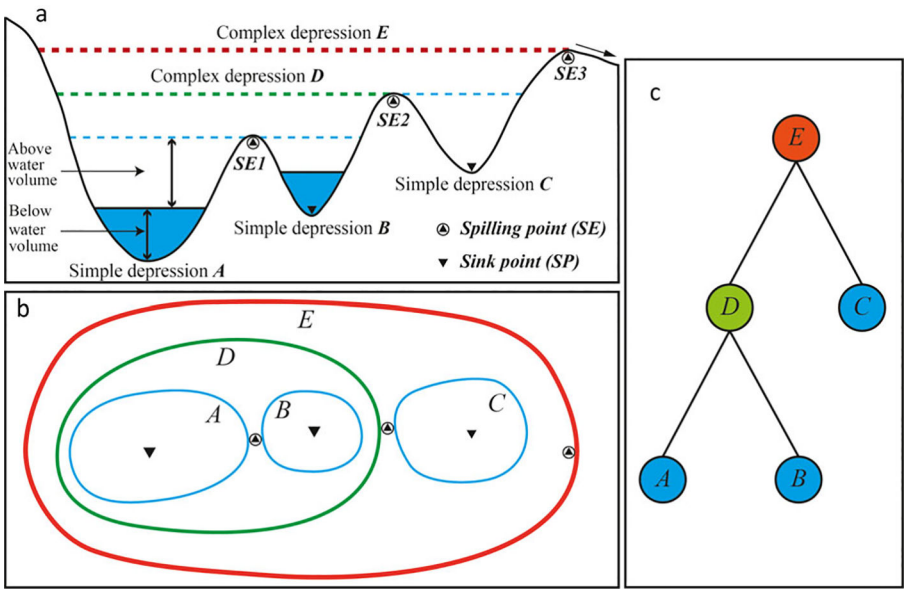


FIGURE 3.

Conceptual model of simple and complex depressions that merge and spill: (a) profile view, (b) plan view, (c) hierarchical view. A schematic example of fill-and-merge behavior where simple depressions (e.g., Simple depression A, Simple depression B) merge with increasing inundation to form Complex depression D. Additional inundation merges Simple depression C with Complex depression D to create Complex depression E, which “spills” at spill elevation #3 (SE3) to another water body. Source: Wu and Lane (2016); reproduced with permission of Springer.

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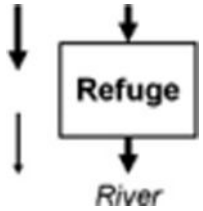
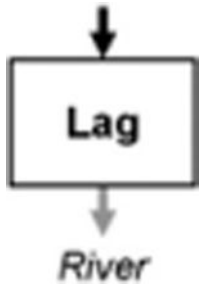
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TABLE 1.

Functions by which NFWs affect material and energy fluxes to downstream waters.

Function	Definition	Wetland examples
	Net increase in a material or energy flux (exports > imports)	Phytoplankton production from floodplain (Schemel et al. 2004; Lehman et al. 2008)
	Net decrease in a material or energy flux (exports < imports)	Sediment deposition, denitrification (Johnson 1991)
	Avoidance of a nearby sink function, thereby preventing a net decrease in material or energy flux (exports = imports)	Riparian wetlands as aquatic refuges in dryland rivers (Leigh et al. 2010)
	Temporary storage and subsequent release of materials or energy without affecting cumulative flux (exports = imports); delivery is delayed and can be prolonged	Flood attenuation (Bullock and Acreman 2003)
	Conversion of a material or energy into a different form; the amount of the base material or energy is unchanged (base exports = base imports), but its composition (e.g., mass of the different forms) can vary	Mercury methylation (Galloway and Branfireun 2004; Selvendiran et al. 2008)

Source: Table reproduced from USEPA (2015).

Note: This review focused on source, sink, lag, and transformation functions; see Schofield et al. (2018) for refuge functions.

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A review of the wetland's restoration mechanisms and its economic and social benefits

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ABSTRACT

Our Earth has given many ecosystems that will heal themselves from the degradations. One of those ecosystems is the wetland, which is a precious natural sponge, naturally purifying and replenishing the water, heading off floods, and mainly giving tremendous biodiversity to the flora and fauna. However, human activities are degrading the wetlands and polluting them indiscriminately with solid wastes and domestic and industrial wastewater discharge. With the Ramsar Convention on Wetlands, nations around the world have acknowledged the critical benefits of wetland restoration and development. In this review article, we contributed to address the general wetland policies in the world, both nationally (India) and regionally (Tamil Nadu). In this paper, we will be discussing the reviews on the characteristics of wetland ecosystems, indices of biodiversity, risks to the wetland's restoration tactics, its main obstacle, and the financial advantages of wetlands. After clearly analyzing 226 previous research and review articles, a clear coherence between the explored hypothesis of wetland restoration mechanisms and the resulting economic and social benefits was arrived. Our findings indicate that effective restoration not only enhances ecosystem services but also leads to significant economic gains and improved community well-being. This alignment underscores the importance of investing in wetland restoration for sustainable development.

Key words: financial benefits, Indian wetlands, indicators, wetland management, wetland policies

HIGHLIGHTS

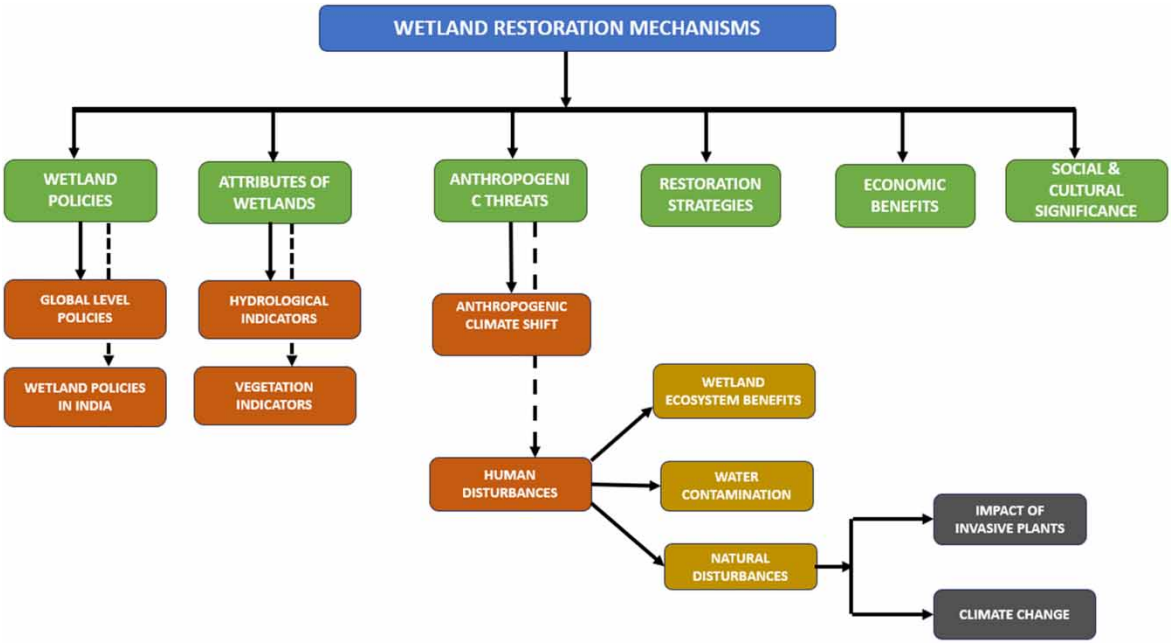
- Wetlands ecosystems influence climate change.
- Human activities are degrading the wetlands and polluting them indiscriminately.
- Wastewater discharge in wetlands is a regular phenomenon.
- We contributed to address the general wetland policies in the global, national (India), and regional (Tamil Nadu) level.

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GRAPHICAL ABSTRACT



1. INTRODUCTION

Wetlands, which include bogs, marshes, and swamps, are essential habitats that are defined by the presence of water (Mitsch & Gosselink 2015). Ecologically, they support a rich biodiversity, providing habitat for numerous plant and animal species crucial for global biodiversity (MEA 2005). Socially, wetlands offer recreational opportunities and cultural significance, serving as venues for birdwatching, fishing, and traditional practices (MEA 2005). Economically, wetlands contribute to livelihoods through activities such as fisheries, agriculture, and tourism, generating income and supporting local economies (Barbier *et al.* 1997). In addition, they play a vital role in water purification, flood regulation, and carbon sequestration, providing essential ecosystem services that benefit both nature and society (Zedler & Kercher 2005). Currently, there are more than 2,400 Ramsar Sites worldwide. They cover an area of over 2.5 million km^2, which is larger than Mexico (Ramsar Convention on Wetlands 2018). Wetlands are home to a third or more of all threatened and endangered species. Wetland management strategies involve legal protections and restoration projects to conserve and enhance ecosystem functions while promoting sustainable use and involving local communities to balance ecological health with human needs. After all, the constant monitoring of the functions is the most important thing to retain its natural form. Many publishers are facing issues related to ecological restoration, cutting-edge technology, and policies since new technologies necessitate the use of novel approaches (Wei *et al.* 2023). Globally, wetlands have been degraded by about 35% since 1970 (Darrah *et al.* 2019; Let & Pal 2023). Worldwide up to 90% of the wetlands are considered as most threatened and demolished due to illegal land reclamations, encroachments, and pollution (Abramovitz 1996; Casazza *et al.* 2021).

As per the United Nations (UN) Millennium Ecosystem Assessment (2005), compared to other natural ecosystems, wetlands are the most degraded system in our earth (Murali 2021). Agenda 15 for 2030 (Sustainable Development Goal (SDG)15) of the UN outlines the objectives of stopping and reversing land degradation, stopping biodiversity loss, combating desertification, protecting, restoring, and promoting sustainable use of terrestrial ecosystems. Most of the literature studies have shown the impacts of socioecological aspects on the wetlands globally (Barbier *et al.* 1997; MEA 2005; Zedler & Kercher 2005). There is still a need for increased public awareness of environmental monitoring, sophisticated instruments, and data to be able to stop the loss of wetland habitat (Darrah *et al.* 2019). Though some unique wetlands have been recognized as Ramsar sites, people are not aware of the wetlands and their ecosystem functioning, and still, many wetlands are considered wastelands and getting polluted and degraded. According to Kexin *et al.* (2022), wetlands' degradation areas are divided or named into some classifications such as undegraded, lightly degraded, moderately degraded, and extremely

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degraded. Nearly some indicators were denoted from three main factors: hydrology indicators, soil indicators, and biota indicators (Fennessy *et al.* 2007). These factors are the main indicators for the well-function analysis of the wetlands (Barbier *et al.* 1997).

Due to a lack of vulnerability assessments, many wetlands in India are still unrecognized by the local population. The wetlands provide an important environmental resource by regulating the climates and giving opportunities for some benefits like fishing, irrigation, and some recreation (Engelhardt & Ritchie 2001; Adekola & Mitchell 2011; Malekmohammadi & Jahanishakib 2017). A framework for the assessment of wetland ecological risk has been presented by Duan *et al.* (2022). It includes factors related to abiotic characteristics for both internal and external hazards. Many ecological restoration solutions have been tried and implemented in the last 10 years, but there are still some gaps in the systematic planning, problem-solving after the restoration is successful, and overall process of the study that needs to be identified and investigated. The main challenge for wetland managers is clinching of long-term sustainability through the securing of wetlands ecological values against the socioecological activities (Pirali Zefrehei *et al.* 2022).

Mostly socioeconomic developments play a critical role in the degradation of wetlands' landscape dynamics (Jian *et al.* 2022) as shown in Figure 1; the wetlands have provided supporting, regulating, provisioning, and cultural ecosystem services (Tamil Nadu Wetland Mission). An Overview of the wetland and health was discussed by Dale & Connelly (2012). The authors have discussed the health issues related to wetlands in three different categories: constructed wetlands, manipulated wetlands, and the specific diseases associated with them. They have discussed mosquito-borne diseases like the Ross River virus, Barmah River virus, and West Nile River Virus and water-borne diseases such as schistosomiasis and cholera (Dale & Connelly 2012). Human health will continue to deteriorate as wetlands continue to deteriorate, particularly for vulnerable populations in emerging nations where water quality and quantity are declining. The water quality of the Vembanad Lake specifically in the Kumarakom area was analyzed (Rajan & Pradeep Kumar 2012). So, a wetland must be protected and restored at any cost. After the successful restoration process, constant monitoring and maintenance are the most important things to the conservation of wetlands. By capturing sediments, nutrients, and pollutants through processes including sedimentation, microbial activity, and plant uptake, wetlands serve as natural filters that enhance the quality of water (Mitsch & Gosselink 2015). However, excessive nutrients, heavy metals, and organic contaminants can be introduced into wetland ecosystems by increased agricultural runoff, industrial discharges, and urbanization. This can result in eutrophication, a loss of biodiversity, and a degradation of ecosystem services (Zedler & Kercher 2005). Effective management and restoration efforts are essential to maintain the water quality and ecological integrity of wetlands, ensuring they continue to provide critical services such as



Figure 1 | Ecosystem services of wetlands (*Source:* Tamil Nadu Wetland Mission).

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water purification and habitat support (Kadlec & Wallace 2009). Remote sensing spatiotemporal analysis of water quality and the relationship of water quality and land use were studied by Sun *et al.* (2023). One of the world's most high-yielding environments is wetlands; they support a rich biodiversity with interconnection of species of plants and high concentrations of fauna.

The objective of this review is to explore various wetland restoration mechanisms and evaluate their economic and social benefits. It aims to highlight how effective restoration can enhance ecosystem services and support sustainable community development.

2. WETLAND POLICIES

2.1. Global level policies

Global wetland policies are crucial frameworks for protecting and maintaining these important ecosystems, which offer crucial services including preventing flooding, removing pollutants from water, and preserving biodiversity. The cornerstone of global efforts to conserve wetlands is the Ramsar Convention, which was created in 1971 and encourages the prudent use and sustainable management of wetlands everywhere (Ramsar Convention Secretariat). The Convention encourages member countries to designate Ramsar sites wetlands of international importance and implement measures to protect and restore them. Furthermore, as a crucial component of global environmental management, the 1992 Convention on Biological Diversity (CBD) highlights the preservation and sustainable use of biodiversity, including wetlands. CBD member countries commit to integrating biodiversity considerations into national policies and promoting ecosystem resilience, crucial for wetland ecosystems facing threats from climate change and human activities.

In this world, many people depend on wetlands and rivers for their daily livelihoods (Ramsar 2018; CIFOR 2021; Nygren & Lounela 2023), which will affect the natural balance. The UN Environment Programme Executive Director claims that fast degradation and loss of wetlands worldwide is caused by policies and actions that frequently fail to take into account the multitude of functions that wetlands offer (UNEP State of Finance for Nature Report 2023). In light of the warnings issued by international scientists that biodiversity loss, ecosystem degradation, and climate destabilization all exacerbate wetland loss, which represents a global emergency, new strategies are required to ensure that wetlands are protected and that their benefits to people are sustained (Davies *et al.* 2020). People from the United States started to recognize that the wetlands had plenty of benefits among the other natures (Votteler & Muir 2002). Some of the management practices applied to wetlands by the Conservation Foundation is shown in Table 1.

Table 1 | The management practices applied to wetlands

Physical way	Chemical way	Biological way
• Filling	• Changing nutrient levels	• Grazing
• Draining	• Introducing toxics	• Disrupting natural populations
• Excavating	• Chemical water treating	• Invasive plants
• Diverting water away		
• Clearing		
• Flooding		

Source: Votteler & Muir (2002).

Section 404 of the US Environment Protection Act (US EPA) controls the discharge of dredged or fill material, which is classed as a pollutant, into US waterways by requiring potential dischargers to obtain a permit for such actions (Ainslie 1994). According to a study of wetland mitigation methods in eight states, more wetland acreage was lost in the USA than was required to be created or restored, resulting in a net loss of acreage when mitigation was included in a wetlands permit (Kentula *et al.* 1992). In the past 300 years, Canada has faced terrific wetland loss (Austen & Hanson 2007) and without rules, individuals working for government agencies are left to use their best judgment, which results in inconsistent policy application (Farnese & Belcher 2006; Austen & Hanson 2007). Canada's policy goals are to maintain the biological and socioeconomic systems for the time being and to encourage the preservation of wetlands in the country going forward (Austen & Hanson 2007). The 'Wetland

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Protection Law' (WPL) was enacted on 24 December 2021, following three National People's Congress discussions, and it went into effect on 1 June 2022 with Wetland restoration, supervision, inspection, and legal obligations, as well as the preservation and use of wetland resources (Mo *et al.* 2023). Ahmed & Haque (2023) analyzed the effects of Bangladesh's wetland management and policy on the rights and means of subsistence of nearby wetland-dependent populations. Nongovernmental organizations (NGOs), Indigenous people, and local communities have worked to recognize the rights of nature; on occasion, courts, local and national legislatures, and international organizations have also provided support (La Follette & Maser 2020).

Recognizing wetlands is made possible by a special wetland policy. Other sectoral management objectives do not cover ecosystems and require specific management and conservation measures (Ramsar 2010). Capitalism is a method of growth in which economic benefits and commercialism are emphasized over wetland preservation and management (NUWAGABA 2023). Sectoral objectives for wetland management increasingly reflect the UN's inclusive requirements for sustainable development agendas. These goals are in line with the SDGs, especially those concerning life below water (SDG 14), life on land (SDG 15), and clean water and sanitation (SDG 6). They also make sure that social justice, ecological preservation, and economic viability are incorporated into management practices (Ramsar 2010).

2.2. Wetland policies in India

The primary legislative framework for wetland protection in India includes The National Plan for Conservation of Aquatic Ecosystems, the Ramsar Convention, the Wetlands (Conservation & Management) Rules (2017), and the National Wetland Inventory and Assessment (NWIA). Wetlands Rules (2017) rules provide guidelines for identifying and notifying wetlands, restricting certain activities, and empowering state governments to manage and protect wetlands (Sinha & Mohanty 2002). The rules also set up a Central Wetlands Regulatory Authority and State Wetlands Authorities. These rules emphasize involving local communities in wetland management, recognizing the traditional knowledge and practices that support sustainable wetland use. The NWIA program, funded by ISRO, provides a scientific basis for wetland management (Attri 2017). These data aid in the formulation of management plans and monitoring efforts. India's commitment to the Ramsar Convention reflects its dedication to international standards of wetland conservation. The designation of Ramsar sites helps attract global attention and funding for wetland conservation (Prasad *et al.* 2002). Despite these robust frameworks, several challenges persist. The effectiveness of policies often varies due to differences in state-level execution and monitoring capacities (Devabalane 2015). Rapid urbanization, industrial activities, and agricultural runoff contribute to wetland degradation. Public awareness and involvement in wetland conservation are often limited, affecting community participation.

The EPA 1986, in India, plays a crucial role in wetland conservation by empowering the government to enforce regulations against pollution and habitat destruction. It facilitates formulating and implementing policies aimed at preserving wetland ecosystems and maintaining their ecological balance. This Act underscores the importance of protecting wetlands for environmental and socioeconomic benefits. In India, the National Forest Commission stressed the significance of protecting wetlands as essential parts of forest ecosystems. It recommended integrated management practices and stricter regulations to protect wetlands from degradation and encroachment. These recommendations have been pivotal in shaping policies for wetland conservation in India (National Forest Commission, 2006). The National Environment Policy 2006 in India underscores the need for wetland conservation to maintain ecological balance and support biodiversity. It advocates for sustainable management practices, legal protection, and community involvement in wetland preservation. The strategy offers a thorough framework for addressing risks and encouraging wetland restoration (MoEF 2006). In India, the National Policy and Macro Level Action Strategy on Biodiversity (1999) aims to conserve biological diversity through sustainable use and equitable sharing of benefits (MoEF 2006). It emphasizes the protection of natural habitats, including wetlands, and integrates biodiversity considerations into sectoral planning (MoEF 2006). A strategic framework for national biodiversity protection is provided by this policy.

To safeguard marine resources, foreign vessels' fishing operations in India's exclusive economic zone are governed by the Maritime Zones of India (Regulation of Fishing by Foreign Vessels, Act 1981). It establishes guidelines and restrictions to prevent overfishing and ensure sustainable exploitation of marine life. This act is crucial for conserving India's maritime biodiversity and ensuring national jurisdiction over marine resources. The Territorial Waters Continental Shelf Exclusive Economic Zone & Other Maritime Zones Act (1976) defines India's maritime boundaries and regulates the use of marine resources. To explore, exploit, and conserve marine

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resources, it gives India sovereign powers over its exclusive economic zone, continental shelf, and territorial waters. This Act is fundamental for managing India's maritime jurisdiction and protecting its marine environment. In India, the Wildlife (Protection) Amendment Act (2022) strengthened the measures for wildlife conservation by enhancing penalties for offenses and expanding protected areas. It aimed to combat wildlife crime and regulate trade in endangered species more effectively. This amendment significantly contributed to the preservation of India's diverse wildlife heritage.

Figure 2 shows the locations of wetlands in India which got international importance as of 2023. Among all the States, Tamil Nadu has more Ramsar sites. The international importance of the wetland is very necessary to conserve and protect, which will increase not only the richness of biodiversity but also the country's economic growth. The government of India must enhance legislation awareness and try to improvise among the other NGOs, private institutions, and citizens. Global and national wetland policy development should be the primary focus of wetlands conservation awareness and development. According to Devabalane (2015), conservation and sustainable development is the need of the hour. Participation from the community can assist in achieving these goals, which will be beneficial for the successful implementation of policies and long-term strategic initiatives with action plans for sustainable management. The historical, religious, and intellectual lives of the Indian people are intertwined with the biodiversity of India (Devabalane 2015; Nomani 2019).

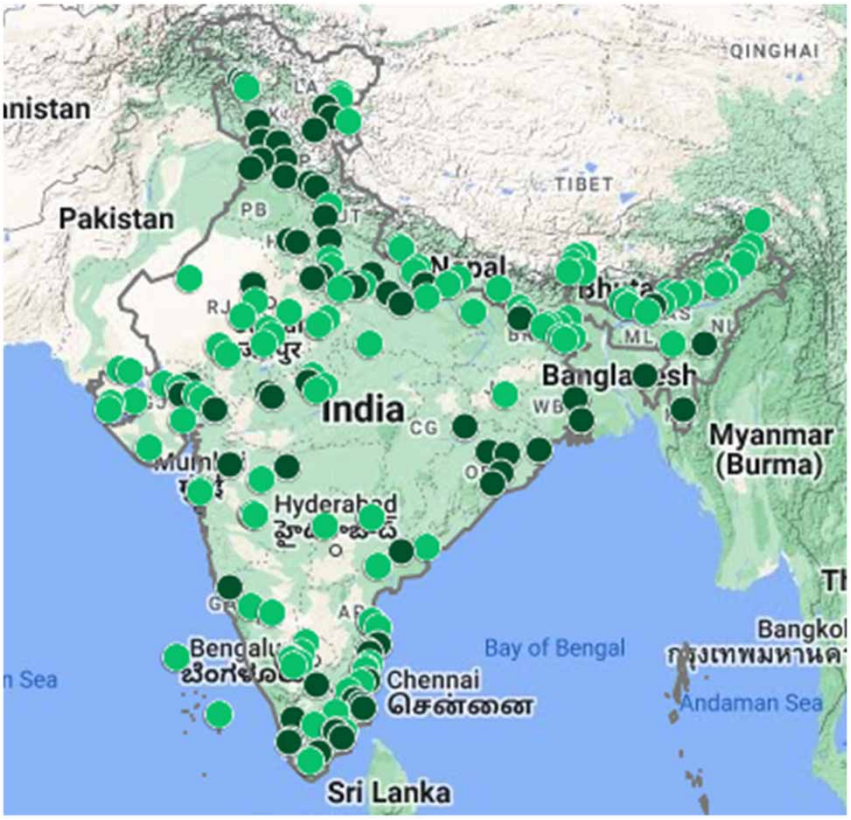


Figure 2 | Ramsar wetlands of India (*Source:* Wetlands of India Portal 2023).

India, like the USA, has a robust regulatory framework, but enforcement and compliance remain challenging. The EU's integrated approach could serve as a model for better coordination across different sectors. India's emphasis on community participation is notable, aligning with Australia's approach, but more efforts are needed to enhance local engagement. India's use of remote sensing and GIS technologies is on par with global practices, yet the application of these data for effective management needs improvement. India's active participation in the Ramsar Convention is commendable, similar to practices in Australia and the EU.

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3. ATTRIBUTES OF WETLANDS – INDICATORS

Wetlands are vital ecosystems characterized by attributes such as hydrology, soil type, and vegetation, which serve as key indicators of their health and functionality. Hydrology, the presence and movement of water, is crucial for sustaining wetland ecosystems (Mitsch & Gosselink 2015). Soil type, often hydric soils, indicates prolonged saturation and supports wetland plant species (USDA NRCS 2010). Vegetation, including hydrophytic plants, provides habitat, stabilizes soil, and contributes to water quality (Tiner 1999). These indicators collectively help assess wetland conditions and guide conservation efforts.

3.1. Hydrological indicators

As the wetlands are interconnected with the biotic and abiotic factors together, the hydrological connectivity with the wetland is more important. Billah *et al.* (2022) have found more than 200 indicators that provide the complex of biodiversity in the Salt Marsh. The 'Ecological Character' of wetlands and the 'Wise Use' notion are specified by the Ramsar Convention, suggesting that wetland ecosystem services may be utilized to some degree. There has been lot of research on hydrological indicators to study the wetland (Table 2).

Table 2 | Hydrological indicators and the successful methods/technologies

S. No	Hydrological indicators	Methods/technologies	References
1.	Water salinity, water depth, water temperature, salt marsh diversity, soil water content, soil redox, soil conductivity, soil organic matter, sediment texture, soil bulk density, soil conductivity, soil pH, soil salinity, pore water salinity, soil organic matter	–	Billah *et al.* (2022)
2.	Wetland depth, consistency in water appearance, stability of hydrology, eco deficit, and failure	Remote sensing (NDWI, MNDWI – range of variability approach and flow duration curve methods, FDC curve, range of variability approach (RVA) approach)	Pal & Sarda (2020)
3.	Land–water threshold dynamics, hydro-potential zones, hydro-geomorphic dynamics, hydro-period, and water presence frequency	The satellite imagery based remote sensing indices (NDWI and NDVI have been calculated using the Landsat imageries, MNND)	Mukherjee & Pal (2021)
4.	Land–water threshold dynamics, hydro-potential zones, hydro-geomorphic dynamics, hydro-period, and water presence frequency	The satellite imagery based remote sensing indices (NDWI and NDVI have been calculated using the Landsat imageries, MNND)	Mukherje & Pal (2021)
5.	Hydrological variability	Time series remote sensing data (image-based hydrological attributes integration, histogram comparison approach (HCA), RVA)	Pal & Sarda (2021)
6.	Net wetness and water depth wetness over a period Shoreline dynamics	NDWI Theil–Sen estimator slope hydrogeomorphic (HGM)	Singh & Sinha (2021)
7.	Index of hydrological connectivity (IHC), root parameters, and soil properties	Field dye-tracing experiments, back propagation (BP) neural networks, global sensitivity and uncertainty analyses, and statistical analysis	Zhang *et al.* (2021)
8.	Hydro-period, water presence frequency, water depth calculation	Time series Satellite Images – Landsat	Khatun *et al.* (2021)
10.	Hydrological connectivity composite index (average annual precipitation, artificial influence rate, water area rate)	LANDSAT – (eCognition developer, ArcGIS, ENVI)	Xia *et al.* (2021)

Remote sensing using machine learning methods is a highly used method to determine the hydrological indicators in the wetlands, reflecting the divergence in accuracy. The hydrological parameters listed in the above table have been studied using a variety of remote sensing approaches, including field dye-tracing studies, histogram comparison approach, and time series remote sensing data. To determine the basic hydrological parameters simple cluster analysis and ANOVA (Santoro *et al.* 2023) could be used. Time series analysis was carried out

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to study the hydrological parameters in three water bodies meant for fish culture in East Kolkata Wetlands (Roy *et al.* 2016). The increased load of these parameters adversely impacted the population of phytoplankton standing stock.

3.2. Vegetation indicators

By providing food for the wetland's animals and enhancing the water quality, the flora of the wetland performs a crucial function. Hence, the vegetation in the wetland is one of the biological indicators and could be used to monitor the hydrological changes, nitrogen content, silt, and turbidity and even the concentration of the metals and other contaminants (Table 3). Zonal variation of the flora can change due to the drainage and flooding (EPA, United States). How plants use water in different water settings is crucial to understanding the patterns of wetland vegetation and undertaking ecological regulation of wetlands (Zhang *et al.* 2023a, 2023b).

Table 3 | Vegetation indicators and the successful methods/technologies

S. No.	Vegetation indicators	Methods/technologies	References
1.	Wetland ecological index (WEI), improved hyperspectral image-based vegetation index	LANDSAT, Mann–Kendall test, and Theil–Sen median trend analysis	Zhang *et al.* (2023a, 2023b)
2.	Macrophyte community	SNAP – ESA Sentinel Application Platform v8, ML algorithms	Piaser & Villa (2023)
3.	Vegetation species	GEOBIA, UAV, spatial scale, aerial images, resampled images, machine learning classifier	Chen *et al.* (2023)
4.	Vegetation phenology (bud burst, canopy growth, flowering, and senescence)	ENVI 5.6, NDVI time series	Gao *et al.* (2023)
5.	Relationships between vegetation cover and water quality indexes	Self-organizing map (SOM) and geographically and temporally weighted regression (GTWR)	Feng *et al.* (2023)
6.	ENDVI, EVSI, NDVI, and WAVI	PlanetScope and RapidEye images – LANDSAT 5 TM	Zhang *et al.* (2022)
7.	Vegetation cover, stem density, stem height	–	Billah *et al.* (2022)
8	3D vegetation structure (vegetation height, biomass)	Airborne laser scanning (ALS)	Koma *et al.* (2021)
9.	Mean biomass, sedge, grass, perennial plan, annual plant, total number of species, species richness index, Pielou evenness index, and Simpson diversity index	Pearson correlation, remote sensing	Luo *et al.* (2022)

As a result of changes in the external environment, plants can modify their water sources to satisfy their growing needs (Yue *et al.* 2021). According to Yamanaka *et al.* (2020), wetland vegetation is made up of hygrophytes and hydrophytes, which are aquatic macrophytes that are free-floating and adaptable with sunken leaves. Compared to channelized watercourses, the drainage pumping station, remnant ponds, and flood control basins each had significantly higher levels of species richness and wetland plant coverage. While phenology features are so effective at resolving identical spectral conditions, phenology events are very helpful for classifying different types of vegetation, notably coastal wetland vegetation properties of the diverse species of plants (Gao *et al.* 2023). The value of high-resolution satellite photographs, such as Planet Scope and Rapid Eye, was that they supported distinct phases of scientific inquiry (Mejia Avila *et al.* 2023). Based on its flexibility and quantitative adaptability, the Soil Quality Index may be compared more precisely in various vegetation species of wetland habitats (Zhang *et al.* 2022).

The above general overview of the vegetation indicators shows that this will help understand the evaluation of functional indicators. Water bodies should be purified by the natural flora in the ecosystem, which controls the discharge of pollutants (Feng *et al.* 2023). The flora of the wetland progressively evolved tactics of survival, such as altering its life cycle and morphology through long-term evolution, controlling the physiological mechanism

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(Yao *et al.* 2020). Due to their sedentary nature, wetland plants have a significant potential for use as indicators of the health of the ecosystem (Dybiec *et al.* 2020).

4. ANTHROPOGENIC THREATS FACED BY WETLANDS

4.1. The impact of anthropogenic climate shifts on wetland health

In just 50 years since 1970, 35% of the world's wetlands have vanished. Because they sustain a wide range of species populations and ecosystems and carry out ecological, hydrological, physiographic, and cultural functions, wetlands are essential to many forms of life (Ramsar Convention on Wetlands 2018). For the last two decades, the wetlands faced much destruction on their landscapes, hydrological connectivity, and quality of water due to both anthropogenic activities and natural causes (Nahlik & Fennessy 2016). Wetlands provide water storage, act as a buffer against inland and coastal storms, cool the surrounding areas, and store floodwaters, making them essential to the more immediate and localized aspects of climate resilience. One of the key driving mechanisms for landscape change is human disturbance. Due to growing human activity and global climate change, many wetlands have seen substantial degradation; their extent has decreased, they have deteriorated, and their value and purpose have lost significance (Davidson *et al.* 2019; Zhu *et al.* 2022a, 2022b). Although it is widely accepted that climate variability and human activity both contribute significantly to the process of wetland degradation, their respective contributions may change over time (Zhu *et al.* 2022a, 2022b). Wetlands play a crucial regulatory role in helping aquatic creatures adapt to the effects of climate change. Among the places most affected by climate change globally are aquatic ecosystems, and wetlands are no exception (Choudhury *et al.* 2021). Due to climate change, which causes such wetlands to dry out in certain months and some years, the wetlands are currently experiencing an intense drought (Melaki *et al.* 2021). Multiple contaminants released by human activity have always entered natural watersheds, triggering physiochemical and biological alterations to waterbodies (Zhu *et al.* 2022a, 2022b). Therefore, investigating the origins, distribution, and exposure risk of the water characteristics requires the application of water quality evaluation (Wu *et al.* 2021; Zhu *et al.* 2022a, 2022b).

Wetland conservation is promoted by the Ramsar Convention, which has produced a report on the declining and threatening state of wetlands (Finlayson & Gardner 2020). The threats shown in Figure 3 affect the wetland heavily. A variety of social and economic forces interact to cause wetland loss or deterioration. The often-cited human-caused reasons of wetland loss and degradation include wetland draining and conversion for crop production; aquaculture; conversion for logging; construction of canals, dykes, and dams; and urbanization.

4.2. Human disturbances on wetlands

One of the key driving mechanisms for landscape change is human disturbance. The regional ecological processes and functions are influenced by the regional landscape pattern, which also dictates the shape of the spatial distribution of its resources and environment (Cui *et al.* 2021). Liu *et al.* (2021) said that from the standpoint of structure process function coupling, essential ecological aspects of regional wetland restoration were quantified, including healthy and dynamic intertidal wetland systems and they derived a conceptual ecological model of regional wetland restoration. The wetlands begin to degrade severely when a combination of internal pressure sources, external key drivers, ecological effect, and ecological features is present. The degradation and loss of wetlands have been related to a number of variables, including overfishing and overexploitation, global climate change, infrastructure expansion, land conversion, eutrophication and pollution, infrastructure growth, infrastructure withdrawal, and population growth (Chen *et al.* 2019).

Numerous coastal wetlands have degraded because of increased urbanization and climate change, compromising the ecosystem services they provide. Few studies, particularly in quickly emerging regions, have examined how these historical degradation trends will persist in the future (Hu *et al.* 2020). Human activity, particularly aquaculture and urbanization, was found to be substantially connected with wetland deterioration. Illegal encroachments often happen near the wetlands. Contributing problems include inadequate drainage systems, stormwater drain encroachment, blockages from negligent construction debris and solid waste management, loss of natural flood-storage sites, and loss of pervious space in urbanizing landscapes (Ramachandra *et al.* 2012). Sediments are a naturally occurring substrate that aids in the cycling of nutrients, assists the growth of aquatic plants, and increases biological productivity (Dar *et al.* 2022); hence, the people do not think about the disturbance of wetland sediment. Furthermore, due to unplanned urbanization, industry, and encroachments that cause degradation, wetlands are among the most vulnerable habitats in the world (Murali 2021).

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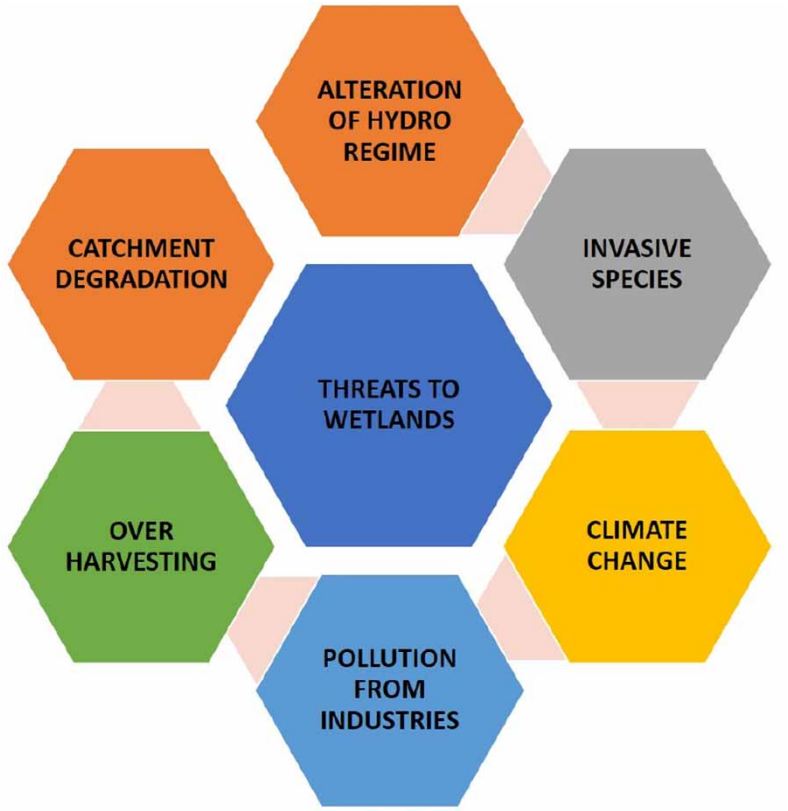


Figure 3 | Threats to the wetlands.

The non-human entity's legal personality may be necessary for the effective enforcement or defense of its rights (Cadaru 2019).

Pollution caused by the discharge of garbage into aquatic habitats endangers all life forms both directly and indirectly (Bhat *et al.* 2022). The human disturbance score protocol technique, which takes into account pollution levels (chemical, physical, and biological contamination), hydrological alterations (water abstraction, drainage, and dams), and changes in land use (urbanization, agriculture, and industry) is used to determine the extent of human disturbance to the wetlands. These factors collectively assess the extent of anthropogenic pressure on ecosystems was utilized (Krishnaraj & Mathesh 2022). Sewage water disposal is the main problem in the urban wetlands as people are thinking it as a wasteland so that thought should be changed by giving awareness about the benefits and services of urban wetlands. If immediate action is not taken, the hydrological and edaphic characteristics will be vanished completely. Hence, human disturbances in wetlands have to be avoided.

4.2.1. Wetland ecosystem benefits

Because they offer so many advantages on an ecological, economic, and social level, wetland ecosystems are extremely valued. Wetlands provide habitat to a diverse range of plant and animal species, many of which are uncommon or endangered, and thus sustain high biodiversity ecologically (Mitsch & Gosselink 2015). They act as natural water filters, improving water quality by trapping pollutants, sediments, and nutrients (Zedler & Kercher 2005). Wetlands play a crucial role in flood regulation, absorbing excess water during heavy rains and releasing it slowly, which reduces the impact of floods and erosion downstream (Costanza *et al.* 1997). Economically, wetlands contribute to livelihoods through activities such as fishing, agriculture, and tourism (Barbier *et al.* 1997). Socially, they offer recreational opportunities and cultural value to local communities (MEA 2005). Furthermore, according to Brigham *et al.* (2006), wetlands function as carbon sinks, storing carbon dioxide and reducing the effects of climate change. Their ability to store and release water also supports groundwater recharge, ensuring a sustainable supply of fresh water (Carter 1996). Overall, wetlands are essential for maintaining environmental health and resilience, supporting human well-being, and providing critical ecosystem services.

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4.2.2. Contaminations of water in wetlands

Wetlands are highly susceptible to various forms of water contamination due to their role as natural filters for surface and groundwater. One of the primary sources of contamination is agricultural runoff, which often carries pesticides, herbicides, and fertilizers into wetland areas. These chemicals can be toxic to aquatic life, reducing biodiversity and disrupting ecosystem functions (Ritter *et al.* 2002). Increased levels of nitrogen and phosphorus in particular can lead to eutrophication, which can result in toxic algal blooms that lower oxygen levels and produce dead zones (Smith *et al.* 1999; Balakumar & Das 2015). In addition, industrial discharges, including heavy metals and other pollutants, can accumulate in wetland sediments, posing long-term environmental and health risks (Forstner & Wittmann 2012).

Urbanization significantly contributes to wetland water contamination through stormwater runoff, which collects pollutants from roads, rooftops, and other impermeable surfaces. Common contaminants include oil, grease, heavy metals, and debris, which can severely impact water quality and aquatic habitats (Paul & Meyer 2001). Untreated sewage and landfill leachate are two examples of improper waste disposal that can introduce a variety of contaminants into wetland habitats, including infections, medications, and personal care items (Kinney *et al.* 2006). These contaminants threaten wildlife and pose significant risks to human health, particularly when wetlands are used for recreational purposes or as a source of drinking water. The research work carried on various pollutants is shown in Table 4.

Table 4 | Pollutants found in wetland waters along with their sources

Pollutant	Source	Reference
Nitrogen (N)	Agricultural runoff, wastewater, atmospheric deposition	Smith (2003)
Phosphorus (P)	Fertilizers, detergents, sewage	Sharpley & Wang (2014)
Heavy metals	Industrial discharge, mining, urban runoff	Alloway (2013)
Pesticides	Agricultural runoff, urban runoff	Stehle & Schulz (2015)
Sediments	Soil erosion, construction activities, deforestation	Wood & Armitage (1997)
Pathogens	Sewage, livestock waste, wildlife excrement	Gerba & Smith (2005)
Organic matter	Wastewater, agricultural runoff, decaying vegetation	Correll (1998)
Pharmaceuticals	Human and veterinary drug waste, wastewater treatment plants	Kümmerer (2009)

By changing hydrological cycles and raising the frequency of extreme weather events like heavy rains and floods, which can wash additional pollutants into wetlands, climate change exacerbates the contamination of wetlands (Erwin 2009). Rising temperatures can enhance the release and mobility of contaminants, such as mercury and other persistent organic pollutants, from sediments (Obrist *et al.* 2018). Emerging contaminants, including microplastics and endocrine-disrupting chemicals, are increasingly being detected in wetland environments, presenting new challenges for water quality management (Rochman *et al.* 2013). Wetland ecosystems are susceptible to complex and unpredictable effects from these contaminants, which emphasizes the need for careful monitoring and adaptive management techniques to save these essential habitats.

4.3. Natural disturbances on wetlands

4.3.1. Climate change

Wetlands are vulnerable to both direct and indirect effects of climate change, including changes in temperature, the intensity and frequency of rainfall, and the frequency of extreme weather phenomena like drought, flooding, and storms. Environment change is predicted to hasten the loss and degradation of many wetlands because of the intricate relationships that exist between wetlands and the environment. As a result of their extensive inundation and high temperatures, tropical and subtropical wetlands produce more than 80% of the natural sources and at least 50% of the total wetland methane emissions (Meng *et al.* 2016). Climate change significantly impacts wetland dynamics by altering hydrological cycles, increasing temperature, and causing sea-level rise, which can lead to changes in wetland areas, shifts in species composition, and reduced water quality (Erwin 2009). The

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equilibrium of these ecosystems is upset when extreme weather events occur more frequently and intensely (IPCC 2014). In addition, changes in precipitation patterns can affect the seasonal availability of water, further stressing wetland environments (Erwin 2009). Sea-level rise particularly affects coastal wetlands, causing habitat loss and saltwater intrusion, which further stress plant and animal communities (Nicholls 2004). These factors collectively threaten the ecological integrity and functioning of wetlands, making their conservation increasingly challenging (Junk *et al.* 2013). If wetlands are destroyed, burned, or drained, millions of years' worth of carbon dioxide could be released into the sky, turning them into a carbon source. Wetlands are essential to comprehending how climate change impacts the ecosystem because they have the inherent capacity to regulate the amount of greenhouse gasses in the atmosphere. Climate change affects the wetland's aerobic and anaerobic conditions, which in turn affects the pace at which methane and carbon dioxide are generated (Salimi *et al.* 2021). The UN General Assembly and the Ramsar Convention have recognized that coastal 'blue carbon' habitats have the potential to be instrumental in reducing climate change through carbon sequestration (Australian Govt, Dept of Environmental & Energy) and also stated that around 10% of annual global emissions of carbon dioxide from fossil fuels come from peatlands that have been burned and drained. Mangrove wetlands are responsible for the sea-level rising and atmospheric CO_2 concentration (Wang & Gu 2021). Sea-level rise, coral bleaching, and altering hydrology all influence wetlands, putting Arctic and montane wetlands in particular danger (Convention on Wetlands 2021). It will be crucial to ascertain the precise anticipated future changes in each region's climate as well as to carry out appropriate monitoring to find out how well actual conditions match the climate change model for that location (Erwin 2009). Many investigations have been done based on the greenhouse gas emissions and nutrient releases caused by a natural wetland, a peatland, and a man-made wetland in reaction to climate change (Salimi *et al.* 2021). The impact of urban development (Li *et al.* 2022a, 2022b) around the wetland ecosystem will cause climate change and hydrological effects.

4.3.2. Impact of invasive plants

Typically, invasive species are hazardous because they change the ecosystems they invade; however, recent research has revealed that some well-established invasive species can improve some ecological services. The mean yearly denitrification rates of the invasive *Phragmites australis* sediments were higher than those of native marsh species. The potential health and socio-ecological risks are caused by invasive alien plant species (Rai & Singh 2020) as well as it affects the synergistic consequences of habitat fragmentation, climate change, and altered land use. Some of the invasive species commonly found in the wetlands are shown in Figure 4.

The invasion of invasive species into wetland ecosystems is influenced by multiple mechanisms, prominently driven by eutrophication. By increasing nutrient availability and changing the competitive dynamics of native flora and fauna, eutrophication, which is mainly brought on by excessive nutrient inputs from agricultural runoff, sewage discharge, and atmospheric deposition of nitrogen and phosphorus compounds, accelerates the growth of invasive species (Smith *et al.* 1999; Hilt *et al.* 2006). Invasive plants like *P. australis* and *Typha* spp. proliferate due to this nutrient enrichment, outcompeting native species that have adapted to lower nutrient levels (Chambers *et al.* 1999; Meyerson *et al.* 2000). Furthermore, eutrophication-induced changes in water quality and habitat structure can create favorable conditions for invasive species establishment and spread, disrupting the ecological balance of wetland ecosystems (Davis *et al.* 2000; Gordon *et al.* 2005).

Clonal fragmentation and floatability (Roiloa *et al.* 2020) have been discussed as successful dispersal strategies for invasive species. There are some chances that the removal of invasive plants can increase species and phylogenetic diversity in the wetlands (Lishawa *et al.* 2019). Harvesting of the invasive plants will reduce the loads of heavy nutrients and produce new more biomass (Carson *et al.* 2018). Plant invasion increased yearly N_2O emission rates in grasslands but did not affect forests. According to some contextual methods (Bezabih Beyene *et al.* 2022), invaded coastal wetlands had the largest increases in annual CH_4 emission rates, while invaded grasslands had the highest increases in annual CH_4 uptake rates. Native woody species of wetlands would particularly experience habitat loss, while non-native, non-wetland species would gain from climate change and see an expansion in their ranges (Zhong *et al.* 2022). Effective management strategies must therefore prioritize reducing nutrient inputs and restoring natural hydrological regimes to mitigate the impacts of eutrophication and curb the spread of invasive species in wetlands.

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Figure 4 | Invasive plants of wetlands.

5. RESTORATION STRATEGIES FOR WETLANDS

Since each type of wetland has a unique ecology marshland, mangroves, peat lands, and bogs, for example, restoration tactics will also differ depending on the wetland's characteristics, landscape, hydrological connectivity, and types of anthropogenic activity surrounding it. The United States conducted the first research on rebuilding and restoring damaged wetlands (Zhou *et al.* 2020). Between 1970 and 2015, over 35% of the world's natural wetlands disappeared (An *et al.* 2019). Assistance and administration are the two primary responsibilities. The process of restoring wetlands involves putting them back in their natural state after being disturbed or altered by human activity, restoring the hydrological conditions and ecological system while giving priority to the balance of various organisms in wetlands, temperature, and plants using natural and ecological laws (Cai *et al.* 2021). The following strategies are used for ecological restoration of wetlands:

- Plant restoration
- Animal restoration
- Microorganism restoration (Cai *et al.* 2021).

In India, ecological plant restoration strategies for wetlands typically involve a combination of approaches aimed at enhancing biodiversity, improving ecosystem functions, and restoring hydrological regimes. Key strategies include the establishment of native plant species through seed banking and propagation programs, such as those undertaken by organizations like the Salim Ali Centre for Ornithology and Natural History (SACON) and the National Biodiversity Authority (NBA) (SACON 2020; NBA n.d.). These efforts focus on selecting species that are adapted to local environmental conditions and are crucial for maintaining habitat structure and supporting native fauna. In addition, community-based initiatives play a significant role, involving local stakeholders in wetland restoration activities to ensure sustainable management practices and promote socioeconomic benefits (Gupta *et al.* 2019). Restoration projects also integrate measures to control invasive species and mitigate anthropogenic impacts, such as pollution and habitat degradation, which threaten wetland

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ecosystems across the country (Menon *et al.* 2021). By implementing these strategies, India aims to conserve and restore its wetland biodiversity while safeguarding the ecological services these vital ecosystems provide.

The strategies for animal restoration primarily focus on habitat restoration and conservation measures aimed at supporting native fauna populations. Key approaches include creating protected areas and wildlife sanctuaries, such as the Chilika Lake Wildlife Sanctuary in Odisha and the Bharatpur Bird Sanctuary in Rajasthan, which provide essential habitats and breeding grounds for diverse bird species (Sundar 2009; Sivaperuman *et al.* 2017). In addition, efforts are made to control invasive species that threaten local wildlife, as seen in initiatives to manage invasive fish species in wetland ecosystems such as the Vembanad-Kol Wetland in Kerala (Easa & Shaji 2004). Community participation is integral to these restoration efforts, with local stakeholders engaged in monitoring and conservation activities to ensure sustainable management practices and

Table 5 | Various restoration strategies and technologies

S. No.	Restoration strategies	Description	Reference
1.	Artificial water replenishment	This method is modeled using a code model for environmental fluid dynamics with the help of water quality indicators	Liu *et al.* (2022)
2.	i. Tree planting	i. The post-planting development of trees is dependent on external circumstances, and the process takes significantly longer than other restoration strategies	Karim *et al.* (2022)
	ii. Tallgrass prairie planting	ii. The regeneration of tallgrass prairie from an agricultural site provides numerous benefits to soil microbial populations and the ecosystem services they provide	
	iii. Wetland creations	iii. This will aid in preventing the extinction of aquatic and riparian species in wetland ecosystems	
3.	Reshaping channel morphology	To reclaim the original form of a river/flood plain, which including straightening a channel shape into a plea/meander	Cai *et al.* (2021)
4.	Marsh terracing – remote sensing	Soil berms constructed within small coastal ponds to increase marsh area and reduce wave energy by using Remote sensing	Osorio *et al.* (2020)
5.	Phytoremediation, microbial restoration, water replenishment, and water–soil engineering restoration	An assessment was made of wetland restoration technology development in China and other countries	Zhou *et al.* (2020)
6.	Seed-based approaches	To recreate the underlying vegetation structure and composition that underpins these critical functions and services	Kettenring & Tarsa (2020)
7.	Rainwater catchment system	The soil would be wet for a long period if rainwater collecting systems were designed for the marsh and its environs	Qaderi & Rahnama (2020)
8.	Blue carbon accounting model (BlueCAM)	Tidal barrier removal and alteration can result in large greenhouse gas mitigation benefits for coastal wetlands (mangroves, seagrass, saltmarsh, and supratidal forests)	Lovelock *et al.* (2022)
9.	Infiltration experiment	To some degrees, optimum saltwater concentrations promote soil water infiltration and circulation	Wang *et al.* (2023)
10.	Control of Invasive plants	The plants which cause various threat to wetlands has to be identified and removed	Dehez (2023), Marangi *et al.* (2023) and Marchante *et al.* (2023)
11.	Recovery of tidal exchange	Tidal exchange has been recovered and repaired by a variety of methods, including culvert building, canal and/or channel excavations	Wasser (2019) and Billah *et al.* (2022)

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the preservation of wetland-dependent species (Ghosh *et al.* 2020). Through these integrated approaches, India aims to safeguard its wetland biodiversity and enhance ecological resilience in the face of ongoing environmental challenges.

Microbial restoration strategies involve measures to restore natural microbial communities that play vital roles in nutrient cycling, water purification, and overall wetland resilience. Key approaches include restoring hydrological regimes to promote anaerobic conditions favorable for beneficial microbial activity, such as denitrification and organic matter decomposition (Singh *et al.* 2018). Various restoration strategies and technologies are shown in Table 5. In addition, efforts are made to reduce nutrient pollution and control invasive species that can disrupt microbial communities, as seen in initiatives targeting nutrient runoff and invasive aquatic plants in wetlands like the Keoladeo National Park in Rajasthan (Bhatnagar *et al.* 2007; Kundu *et al.* 2014). Integrated management plans also emphasize monitoring microbial biodiversity and ecosystem function to assess restoration success and inform adaptive management strategies (Mandal *et al.* 2016). Through these efforts, India aims to restore and sustain the ecological functions of its wetland microbial communities while mitigating threats to their integrity.

Every restoration project is different, and there is no 'prescription' for restoring wetlands (Zhu *et al.* 2019). Many approaches to conservation have been applied, but there are very less methods to remove and control invasive plants. Even though we are given many possibilities to restore the wetlands, the success of the restoration is based on how we monitor and develop the wetlands.

6. KEY CHALLENGES OF WETLAND RESTORATION

Early theories of ecosystem deterioration and restoration understate the complexity of wetland restoration (Zedler 2000). Restoration of wetlands and bays is complicated by several issues that are more social, cultural, economic, and stakeholder than ecological (Root-Bernstein & Frascaroli 2016). The natural ecological environment is under a lot of pressure because of the overconsumption of natural resources and severe environmental pollution brought on by urban sprawl and modernization. While using various wetland restoration strategies, there are some challenges we are going to face. The evaluation techniques and index systems utilized in ecology security evaluation are variable as a result of various ecosystem kinds, research objectives, and disciplinary backgrounds (Fan & Fang 2020). Degradation and restoration, for instance, have been shown as straight arrows traveling along parallel courses in opposite directions (Dobson *et al.* 1997; Zedler 2000). In some wetlands, the weak legal system and unclear system are the main obstacles in the restoration process. The lack of awareness in people quietly leads to some failures after the successful restoration. The difficulty of establishing long-term protection of compensation zones presents another legal challenge (Blicharska *et al.* 2022). In quite a while, there have been few science-based recommendations for how to make decisions on what to avoid, as well as standards for locations where avoidance is most crucial (Bigard *et al.* 2020). Clarke *et al.* (2021) recorded the viewpoints of environmental organizations, individuals who use and travel to the area for environmentally friendly activities, as well as locals engaged in fishing operations. Hughes *et al.* (2016) encountered an assortment of practical difficulties, such as the requirement for high levels of varying expertise, high prices, incommensurate monitoring outputs, and the requirement for careful control of monitoring outcomes. To target wetland restoration areas more effectively, ecological health, water quality improvement, and hydrological health should be considered (Clare & Creed 2022). Addo-Bankas *et al.* (2022) observed that the chemical processes offer a threat to the environment and may result in secondary pollutants like sludge, and in terms of mechanical techniques, the high installation costs as well as the long-term environmental effects that have been seen make them undesirable.

7. OVERALL ECONOMIC BENEFITS OF WETLANDS

The contribution of wetlands to the Earth is not enough to detail, but the local and national economies are getting benefitted throughout the year. Wetlands provide significant economic advantages to a variety of industries, including agriculture, fisheries, water supply, tourism, and the control of nitrogen cycles and water tables. It also contributed in the retention of floodplains, production of timber, energy resources (plant matter and peat), wildlife resources, and chances for leisure and tourism (Lambert 2003). They contain some of the most productive ecosystems on the planet and provide ecological services (Gardner & Finlayson 2018). The water quality, flood control, fisheries, and some recreational activities (EPA, United States) are the major values from wetlands. Wetlands provide several nonmonetary benefits in addition to their numerous economic ones. To find out more

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about how much drainage practices benefit farmers financially, researchers are examining the productivity of agriculture in drained wetland basins (Clare *et al.* 2021). The constructed wetlands are more profitable (Canning *et al.* 2022) for the fresh water biodiversity in the field of agricultural productivity. Wetlands have a critical part in the idea of climate change because they both reduce greenhouse gas emissions and preserve long-term carbon storage (Malerba *et al.* 2022). Wetlands provide recreational opportunities as well as touristic incentives (Gardner & Finlayson 2018). Socioeconomic assessment techniques are quite useful for assessing elements such as the feasibility and economic effectiveness of several adaption alternatives (Riera-Spiegelhalder *et al.* 2023). Using the soil and water assessment tool (SWAT) model (Scott-Shaw *et al.* 2022), the hydrological advantage of wetland rehabilitation was ascertained.

The Environment, Climate Change & Forests (FR.9) Department is aiming to restore 100 targeted wetland areas and calculating the total economic value of wetland ecosystems helping local communities throughout the state (Dept. of Environment, Climate Change & Forests 2022). Wetland pricing is a method of estimating habitat benefits and services and enables financial specialists to perform a cost–benefit analysis that may encourage environmental investment (Lambert 2003). Parameterization and modeling used stable isotope data to derive the economic value (Taylor *et al.* 2018) so that we can express the model outputs and commercial values of a wetland. A mixed-method approach, such as semistructured questionnaires, remote sensing and GIS, and focused group discussions, might be used occasionally (Huq *et al.* 2020). To choose the best course of action for financial results, Dominici *et al.* (2022) integrated a number of multimethodological techniques, including the SWOT (strengths, weaknesses, opportunities, and threats) analysis, holistic diagnosis (HD), and systemic design (SD) (Battistoni *et al.* 2020). If decision-makers in the area are aware of the significance of wetlands for carbon sequestration, they may be able to adopt policies to manage wetlands in a way that maximizes their value and stops more wetland losses (Gallant *et al.* 2020). The market price method (Aryal *et al.* 2021) was used to calculate the market price and average home consumption. The great degree of local diversity, such as the closeness to metropolitan areas, the amount of waterfowl, and the demographics of the local people, presents a hurdle for estimating the recreational value of wetlands (Pattison-Williams *et al.* 2018). Only two of the ecosystem services offered by wetlands are direct benefits to the community, such as increased fish stock richness because of reduced nitrogen concentrations in the natural wetland and the availability of clean water (Ranjan 2021). It is imperative for the stakeholders to preserve the socioeconomic significance of the wetlands, especially without compromising the surrounding ecosystem and aquatic habitat.

8. EXPLORING THE SOCIAL AND CULTURAL SIGNIFICANCE OF WETLAND ECOSYSTEMS

Wetland ecosystems serve as integral spaces for various social and cultural activities worldwide, including in India, where they play significant roles in local traditions and livelihoods. These ecosystems provide essential resources such as fishing grounds, agricultural lands, and water sources crucial for communities' sustenance and economic activities (Biswas *et al.* 2017). In cultural contexts, wetlands often hold spiritual significance, serving as sites for rituals and ceremonies among indigenous and local communities (Nayak & Tripathy 2020). In addition, wetlands contribute to recreational activities like birdwatching, boating, and ecotourism, generating income and promoting environmental awareness (Gopal 2013). The East Kolkata Wetlands exemplify such dual-use scenarios, where traditional wastewater treatment practices coexist with biodiversity conservation and cultural practices (Ghosh *et al.* 2020). Recognizing these social and cultural dimensions is crucial for developing sustainable management strategies that balance conservation with human needs and traditions, ensuring the continued benefits of wetlands for generations to come.

9. CONCLUSION

The review on wetland restoration strategies and economic benefits underscores the efficacy of restoration efforts in enhancing ecosystem health and resilience while emphasizing the substantial economic returns from restored wetlands, demonstrating their value for sustainable development. This review conducted on studies and their evidence showcases the intensity of previous literature on the wetlands.

- The global wetland policies display the combined overall functions of wetland policies around the world, technologies and methods used in wetland conservation, and the economic benefits derived from them. From the earlier studies, it is understood that despite robust policy frameworks, challenges persist in implementing and

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enforcing wetland conservation measures at a global level. Variations in national priorities, capacities, and financial resources hinder uniform adherence to conservation goals.

- India has established a comprehensive legislative framework for wetland conservation. These frameworks provide a structured approach to identify, conserve, and manage wetlands, supported by institutional mechanisms such as the Central Wetlands Regulatory Authority and State Wetlands Authorities. Despite the existence of strong policy frameworks, India faces issues such as inadequate funding, conflicting development priorities, and varying enforcement capacities across states hinder the full realization of conservation goals. Addressing these challenges requires enhanced coordination among stakeholders, capacity building at the local level, and greater public participation to ensure sustainable management and protection of India's diverse wetland ecosystems.
- Monitoring hydrological and vegetation indicators helps identify changes in wetland health over time and informs management strategies aimed at preserving or restoring these vital habitats.
- Hence, integrated management with stakeholder engagement helps address multiple anthropogenic threats simultaneously. Planning land use, pollution management, community involvement, and legislative interventions are all important components of effective conservation methods that aim to lessen human impacts on wetlands and guarantee their long-term survival.

Based on the above studies, further research can be focused on selection of most degraded wetlands, identifying anthropogenic activities such as pollution around the wetlands, finding the relationship between hydrological indicators and vegetation indicators, recognizing the invasive plants and suitable plans to remove them, integrated management and restoration plan for wetlands to achieve sustainability, and constant monitoring of the wetlands to evaluate their health. Wetland restoration is not only the role of the government but also lies in the understanding of its importance and sustainable measures to be taken by the local network and environmentalists. Proper monitoring systems should be used to conserve the wetland ecosystems and can act as a good tool for the sustainability of the natural ecosystems.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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TITLE 20 ENVIRONMENTAL PROTECTION
CHAPTER 6 WATER QUALITY
PART 4 STANDARDS FOR INTERSTATE AND INTRASTATE SURFACE WATERS

20.6.4.1 ISSUING AGENCY: Water Quality Control commission.
[20.6.4.1 NMAC - Rp 20 NMAC 6.1.1001, 10/12/2000]

20.6.4.2 SCOPE: Except as otherwise provided by statute or regulation of the water quality control commission, this part governs all surface waters of the state of New Mexico, which are subject to the New Mexico Water Quality Act, Sections 74-6-1 through 74-6-17 NMSA 1978.
[20.6.4.2 NMAC - Rp 20 NMAC 6.1.1002, 10/12/2000; A, 5/23/2005]

20.6.4.3 STATUTORY AUTHORITY: This part is adopted by the water quality control commission pursuant to Subsection C of Section 74-6-4 NMSA 1978.
[20.6.4.3 NMAC - Rp 20 NMAC 6.1.1003, 10/12/2000]

20.6.4.4 DURATION: Permanent.
[20.6.4.4 NMAC - Rp 20 NMAC 6.1.1004, 10/12/2000]

20.6.4.5 EFFECTIVE DATE: October 12, 2000, unless a later date is indicated in the history note at the end of a section.
[20.6.4.5 NMAC - Rp 20 NMAC 6.1.1005, 10/12/2000]

20.6.4.6 OBJECTIVE:

A. The purpose of this part is to establish water quality standards that consist of the designated use or uses of surface waters of the state, the water quality criteria necessary to protect the use or uses and an antidegradation policy.

B. The state of New Mexico is required under the New Mexico Water Quality Act (Subsection C of Section 74-6-4 NMSA 1978) and the federal Clean Water Act, as amended (33 U.S.C. Section 1251 *et seq*.) to adopt water quality standards that protect the public health or welfare, enhance the quality of water and are consistent with and serve the purposes of the New Mexico Water Quality Act and the federal Clean Water Act. It is the objective of the federal Clean Water Act to restore and maintain the chemical, physical and biological integrity of the nation's waters, including those in New Mexico. This part is consistent with Section 101(a)(2) of the federal Clean Water Act, which declares that it is the national goal that wherever attainable, an interim goal of water quality that provides for the protection and propagation of fish, shellfish and wildlife and provides for recreation in and on the water be achieved by July 1, 1983. Agricultural, municipal, domestic and industrial water supply are other essential uses of New Mexico's surface water; however, water contaminants resulting from these activities will not be permitted to lower the quality of surface waters of the state below that required for protection and propagation of fish, shellfish and wildlife and recreation in and on the water, where practicable.

C. Pursuant to Subsection A of Section 74-6-12 NMSA 1978, this part does not grant to the water quality control commission or to any other entity the power to take away or modify property rights in water.

D. These surface water quality standards serve to respond to the inherent threats of climate change and provide resiliency for the continued protection and enhancement of water quality.
[20.6.4.6 NMAC - Rp 20 NMAC 6.1.1006, 10/12/2000; A, 5/23/2005; A, 4/23/2022]

20.6.4.7 DEFINITIONS: Terms defined in the New Mexico Water Quality Act, but not defined in this part will have the meaning given in the Water Quality Act.

A. Terms beginning with numerals or the letter "A," and abbreviations for units.

(1) **"4Q3"** means the hydrologically based critical low flow as determined by the minimum average flow over four consecutive days that occurs with a frequency of once in three years.

(2) **"4T3 temperature"** means the temperature not to be exceeded for four or more consecutive hours in a 24-hour period on more than three consecutive days.

(3) **"6T3 temperature"** means the temperature not to be exceeded for six or more consecutive hours in a 24-hour period on more than three consecutive days.

(4) **Abbreviations** used to indicate units are defined as follows:

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(a) **"cfu/100 mL"** means colony-forming units per 100 milliliters; the results for *E. coli* may be reported as either colony forming units (CFU) or the most probable number (MPN), depending on the analytical method used;

(b) **"cfs"** means cubic feet per second;

(c) **"dw"** means dry weight;

(d) **"iwbt"** means invertebrate whole body tissue;

(e) **"fmt"** means fish muscle tissue;

(f) **"fwbt"** means fish whole body tissue;

[~~(c)~~]**g** **"µg/L"** means micrograms per liter, equivalent to parts per billion when the specific gravity of the solution equals 1.0;

[~~(d)~~] **(h)** **"µS/cm"** means microsiemens per centimeter; one µS/cm is equal to one µmho/cm;

[~~(e)~~] **(i)** **"mg/kg"** means milligrams per kilogram, equivalent to parts per million;

[~~(f)~~] **(j)** **"mg/L"** means milligrams per liter, equivalent to parts per million when the specific gravity of the solution equals 1.0;

[~~(g)~~] **(k)** **"MPN/100 mL"** means most probable number per 100 milliliters; the results for *E. coli* may be reported as either CFU or MPN, depending on the analytical method used;

[~~(h)~~] **(l)** **"NTU"** means nephelometric turbidity unit;

[~~(i)~~] **(m)** **"pCi/L"** means picocuries per liter;

[~~(j)~~] **(n)** **"pH"** means the measure of the acidity or alkalinity and is expressed in standard units (su);

(o) **"ww"** means wet weight.

(5) **"Acute toxicity"** means toxicity involving a stimulus severe enough to induce a response in 96 hours of exposure or less. Acute toxicity is not always measured in terms of lethality, but may include other toxic effects that occur within a short time period.

(6) **"Adjusted gross alpha"** means the total radioactivity due to alpha particle emission as inferred from measurements on a dry sample, including radium-226, but excluding radon-222 and uranium. Also excluded are source, special nuclear and by-product material as defined by the Atomic Energy Act of 1954.

(7) **"Administrative rulemaking costs"** include expenses related to providing a venue, hearing officer, court reporter, transcripts, translation services, interpretation services, and public notice requirements including publication in newspapers and in the New Mexico register in relation to holding a public rulemaking hearing. For petitioners other than the department, these costs do not include publishing in the New Mexico register, posting information to state websites, securing a venue, hiring a hearing officer, or filing adopted rules.

[~~(7)~~]**(8)** **"Aquatic life"** means any plant or animal life that uses surface water as primary habitat for at least a portion of its life cycle, but does not include avian or mammalian species.

[~~(8)~~]**(9)** **"Attainable Use"** means a use that is achievable by the imposition of effluent limits required under sections 301(b) and 306 of the federal Clean Water Act and implementation of cost-effective and reasonable best management practices for nonpoint source control. An attainable use may or may not have criteria as stringent as the criteria for the designated use.

B. Terms beginning with the letter "B".

(1) **"Best management practices" or "BMPs":**

(a) for national pollutant discharge elimination system (NPDES) permitting purposes means schedules of activities, prohibitions of practices, maintenance procedures and other management practices to prevent or reduce the pollution of "waters of the United States;" BMPs also include treatment requirements, operating procedures and practices to control plant site runoff, spillage or leaks, sludge or waste disposal or drainage from raw material storage; or

(b) for nonpoint source pollution control purposes means methods, measures or practices selected by an agency to meet its nonpoint source control needs; BMPs include but are not limited to structural and nonstructural controls and operation and maintenance procedures; BMPS can be applied before, during and after pollution-producing activities to reduce or eliminate the introduction of pollutants into receiving waters; BMPs for nonpoint source pollution control purposes shall not be mandatory except as required by state or federal law.

(2) **"Bioaccumulation"** refers to the uptake and retention of a substance by an organism from its surrounding medium and food.

(3) "Bioaccumulation factor" is the ratio of a substance's concentration in tissue versus its concentration in ambient water, in situations where the organism and the food chain are exposed.

(4) "Biomonitoring" means the use of living organisms to test the suitability of effluents for discharge into receiving waters or to test the quality of surface waters of the state.

C. Terms beginning with the letter "C".

(1) "CAS number" means an assigned number by chemical abstract service (CAS) to identify a substance. CAS numbers index information published in chemical abstracts by the American chemical society.

(2) "Chronic toxicity" means toxicity involving a stimulus that lingers or continues for a relatively long period relative to the life span of an organism. Chronic effects include, but are not limited to, lethality, growth impairment, behavioral modifications, disease and reduced reproduction.

(3) "Classified water of the state" means a surface water of the state, or reach of a surface water of the state, for which the commission has adopted a segment description and has designated a use or uses and applicable water quality criteria in 20.6.4.101 through 20.6.4.899 NMAC.

(4) "Climate change" refers to any significant change in the measures of climate lasting for an extended period of time, typically decades or longer, and includes major changes in temperature, precipitation, wind patterns or other weather-related effects.

(5) "Closed basin" is a basin where topography prevents the surface outflow of water and water escapes by evapotranspiration or percolation.

(6) "Coldwater" in reference to an aquatic life use means a surface water of the state where the water temperature and other characteristics are suitable for the support or propagation or both of coldwater aquatic life.

(7) "Coolwater" in reference to an aquatic life use means the water temperature and other characteristics are suitable for the support or propagation of aquatic life whose physiological tolerances are intermediate between and may overlap those of warm and coldwater aquatic life.

(8) "Commission" means the New Mexico water quality control commission.

(9) "Criteria" are elements of state water quality standards, expressed as constituent concentrations, levels or narrative statements, representing a quality of a [~~water~~] waterbody that supports a use. When criteria are met, water quality will protect the designated use.

D. Terms beginning with the letter "D".

(1) "DDT and derivatives" means 4,4'-DDT (CAS number 50293), 4,4'-DDE (CAS number 72559) and 4,4'-DDD (CAS number 72548).

(2) "Department" means the New Mexico environment department.

(3) "Designated use" means a use specified in 20.6.4.97 through 20.6.4.899 NMAC for a surface water of the state whether or not it is being attained.

(4) "Dissolved" refers to the fraction of a constituent of a water sample that passes through a 0.45-micrometer pore-size filter. The "dissolved" fraction is also termed "filterable residue."

(5) "Domestic water supply" means a surface water of the state that could be used for drinking or culinary purposes after disinfection.

E. Terms beginning with the letter "E".

(1) "E. coli" means the bacteria Escherichia coli.

(2) "Emerging contaminants" refer to water contaminants that may cause significant ecological or human health effects at low concentrations. Emerging contaminants are generally chemical compounds recognized as having deleterious effects at environmental concentrations whose negative impacts have not been fully quantified and may not have regulatory numeric criteria.

(3) "Ephemeral" when used to describe a surface water of the state means the [~~water body~~] waterbody contains water briefly only in direct response to precipitation; its bed is always above the water table of the adjacent region.

(4) "Existing use" means a use actually attained in a surface water of the state on or after November 28, 1975, whether or not it is a designated use.

F. Terms beginning with the letter "F".

(1) "Fish culture" means production of coldwater or warmwater fishes in a hatchery or rearing station.

(2) "Fish early life stages" means the egg and larval stages of development of fish ending when the fish has its full complement of fin rays and loses larval characteristics.

G. Terms beginning with the letter "G" [RESERVED]

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H. Terms beginning with the letter "H".

(1) "Hardness" means the measure of dissolved calcium and magnesium salts in water expressed in units of dissolved calcium carbonate (CaCO3) concentration unless otherwise noted.

(2) "Harmonic mean flow" is the number of daily flow measurements divided by the sum of the reciprocals of the flows; that is, it is the reciprocal of the arithmetic mean of reciprocal daily flow measurements consistent with the equations in Paragraph (1) of Subsection B of 20.6.4.11 NMAC.

(3) "High quality coldwater" in reference to an aquatic life use means a perennial surface water of the state in a minimally disturbed condition with considerable aesthetic value and superior coldwater aquatic life habitat. A surface water of the state to be so categorized must have water quality, stream bed characteristics and other attributes of habitat sufficient to protect and maintain a propagating coldwater aquatic life population.

(4) "Human health-organism only" means the health of humans who ingest fish or other aquatic organisms from waters that contain pollutants.

I. Terms beginning with the letter "I".

(1) "Industrial water supply" means the use or storage of water by a facility for process operations unless the water is supplied by a public water system. Industrial water supply does not include irrigation or other agricultural uses.

(2) "Intermittent" when used to describe a surface water of the state means the [~~water body~~] waterbody contains water for extended periods only at certain times of the year, such as when it receives seasonal flow from springs or melting snow.

(3) "Interstate waters" means all surface waters of the state that cross or form a part of the border between states.

(4) "Intrastate waters" means all surface waters of the state that are not interstate waters.

(5) "Irrigation" means application of water to land areas to supply the water needs of beneficial plants.

(6) "Irrigation storage" means storage of water to supply the needs of beneficial plants.

J. Terms beginning with the letter "J". [**RESERVED**]

K. Terms beginning with the letter "K". [**RESERVED**]

L. Terms beginning with the letter "L".

(1) "LC-50" means the concentration of a substance that is lethal to fifty percent of the test organisms within a defined time period. The length of the time period, which may vary from 24 hours to one week or more, depends on the test method selected to yield the information desired.

(2) "Limited aquatic life" as a designated use, means the surface water is capable of supporting only a limited community of aquatic life. This subcategory includes surface waters that support aquatic species selectively adapted to take advantage of naturally occurring rapid environmental changes, low-flow, high turbidity, fluctuating temperature, low dissolved oxygen content or unique chemical characteristics.

(3) "Livestock watering" means the use of a surface water of the state as a supply of water for consumption by livestock.

M. Terms beginning with the letter "M".

(1) "Marginal coldwater" in reference to an aquatic life use means that natural habitat conditions severely limit maintenance of a coldwater aquatic life population during at least some portion of the year or historical data indicate that the temperature of the surface water of the state may exceed that which could continually support aquatic life adapted to coldwater.

(2) "Marginal warmwater" in reference to an aquatic life use means natural intermittent or low flow or other natural habitat conditions severely limit the ability of the surface water of the state to sustain a natural aquatic life population on a continuous annual basis; or historical data indicate that natural water temperature routinely exceeds 32.2°C (90°F).

(3) "Maximum temperature" means the instantaneous temperature not to be exceeded at any time.

(4) "Minimum quantification level" means the minimum quantification level for a constituent determined by official published documents of the United States environmental protection agency.

N. Terms beginning with the letter "N".

(1) "Natural background" means that portion of a pollutant load in a surface water resulting only from non-anthropogenic sources. Natural background does not include impacts resulting from historic or existing human activities.

(2) "Natural causes" means those causal agents that would affect water quality and the effect is not caused by human activity but is due to naturally occurring conditions.

(3) "Nonpoint source" means any source of pollutants not regulated as a point source that degrades the quality or adversely affects the biological, chemical or physical integrity of surface waters of the state.

O. Terms beginning with the letter "O".

(1) "Organoleptic" means the capability to produce a detectable sensory stimulus such as odor or taste.

(2) "Oversight agency" means a state or federal agency, such as the United States department of agriculture forest service, that is responsible for land use or water quality management decisions affecting nonpoint source discharges where an outstanding national resource water is located.

P. Terms beginning with the letter "P".

(1) "Playa" means a shallow closed basin lake typically found in the high plains and deserts.

(2) "Perennial" when used to describe a surface water of the state means the [~~water body~~] waterbody typically contains water throughout the year and rarely experiences dry periods.

(3) "Persistent toxic pollutants" means pollutants, generally organic, that are resistant to environmental degradation through chemical, biological and photolytic processes and can bioaccumulate in organisms, causing adverse impacts on human health and aquatic life.

(4) "Point source" means any discernible, confined and discrete conveyance from which pollutants are or may be discharged into a surface water of the state, but does not include return flows from irrigated agriculture.

(5) "Practicable" means that which may be done, practiced or accomplished; that which is performable, feasible, possible.

(6) "Primary contact" means any recreational or other water use in which there is prolonged and intimate human contact with the water, such as swimming and water skiing, involving considerable risk of ingesting water in quantities sufficient to pose a significant health hazard. Primary contact also means any use of surface waters of the state for cultural, religious or ceremonial purposes in which there is intimate human contact with the water, including but not limited to ingestion or immersion, that could pose a significant health hazard.

(7) "Public water supply" means the use or storage of water to supply a public water system, as defined by [~~New Mexico's Drinking Water Regulations,~~] 40 CFR Part 141, and incorporated by reference into 20.7.10 NMAC, Drinking Water. Drinking [~~Water~~] water provided by a public water system [~~may need to~~] using surface water as a supply, shall undergo treatment to [~~achieve~~] comply with drinking water [~~quality~~] standards.

Q. Terms beginning with the letter "Q". [**RESERVED**]

R. Terms beginning with the letter "R". [**RESERVED**]

S. Terms beginning with the letter "S".

(1) "Secondary contact" means any recreational or other water use in which human contact with the water may occur and in which the probability of ingesting appreciable quantities of water is minimal, such as fishing, wading, commercial and recreational boating and any limited seasonal contact.

(2) "Segment" means a classified water of the state described in 20.6.4.101 through 20.6.4.899 NMAC. The water within a segment should have the same uses, similar hydrologic characteristics or flow regimes, and natural physical, chemical and biological characteristics and exhibit similar reactions to external stresses, such as the discharge of pollutants.

(3) "Specific conductance" is a measure of the ability of a water solution to conduct an electrical current.

(4) "State" means the state of New Mexico.

(5) "Surface water(s) of the state"

(a) means all surface waters situated wholly or partly within or bordering upon the state, including the following:

(i) lakes;

(ii) rivers;

(iii) streams (including intermittent and ephemeral streams);

(iv) mudflats;

(v) sandflats;

(vi) wetlands;

(vii) sloughs;

(viii) prairie potholes;

(ix) wet meadows;
(x) playa lakes;
(xi) reservoirs; and
(xii) natural ponds.

(b) also means all tributaries of such waters, including adjacent wetlands, any manmade bodies of water that were originally created in surface waters of the state or resulted in the impoundment of surface waters of the state, and any "waters of the United States" as defined under the Clean Water Act that are not included in the preceding description.

(c) does not include private waters that do not combine with other surface or subsurface water or any water under tribal regulatory jurisdiction pursuant to Section 518 of the Clean Water Act. Waste treatment systems, including treatment ponds or lagoons designed and actively used to meet requirements of the Clean Water Act (other than cooling ponds as defined in 40 CFR Part 423.11(m) that also meet the criteria of this definition), are not surface waters of the state, unless they were originally created in surface waters of the state or resulted in the impoundment of surface waters of the state.

T. Terms beginning with the letter "T".

(1) "TDS" means total dissolved solids, also termed "total filterable residue."

(2) "Temporary standard" means a time-limited designated use and criterion for a specific pollutant(s) or water quality parameter(s) that reflect the highest attainable condition during the term of the temporary standard or water quality variance as defined by 40 CFR 131.3(o).

[~~(2)~~](3) **"Toxic pollutant"** means those pollutants, or combination of pollutants, including disease-causing agents, that after discharge and upon exposure, ingestion, inhalation or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will cause death, shortened life spans, disease, adverse behavioral changes, reproductive or physiological impairment or physical deformations in such organisms or their offspring.

[~~(3)~~](4) **"Tributary"** means a perennial, intermittent or ephemeral waterbody that flows into a larger waterbody, and includes a tributary of a tributary.

[~~(4)~~](5) **"Turbidity"** is an expression of the optical property in water that causes incident light to be scattered or absorbed rather than transmitted in straight lines.

U. Terms beginning with the letter "U".

(1) "Unclassified waters of the state" means those surface waters of the state not identified in 20.6.4.101 through 20.6.4.899 NMAC.

(2) "Use attainability analysis" means a scientific study conducted for the purpose of assessing the factors affecting the attainment of a use.

V. Terms beginning with the letter "V" [RESERVED]

W. Terms beginning with the letter "W".

(1) "Warmwater" with reference to an aquatic life use means that water temperature and other characteristics are suitable for the support or propagation or both of warmwater aquatic life.

(2) "Water contaminant" means any substance that could alter if discharged or spilled the physical, chemical, biological or radiological qualities of water. "Water contaminant" does not mean source, special nuclear or by-product material as defined by the Atomic Energy Act of 1954, but may include all other radioactive materials, including but not limited to radium and accelerator-produced isotopes.

(3) "Water pollutant" means a water contaminant in such quantity and of such duration as may with reasonable probability injure human health, animal or plant life or property, or to unreasonably interfere with the public welfare or the use of property.

(4) "Wetlands" means those areas that are inundated or saturated by surface or ground water at a frequency and duration [~~sufficient to~~] that typically support [~~, and under normal circumstances do support, a prevalence of~~] vegetation [~~typically~~] adapted for life in saturated soil conditions in New Mexico. Wetlands are unique surface waters of the state that vary widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation and other factors and provide distinct chemical, biological, physical, and hydrological functions within a watershed. For certain types of wetlands, like playa lakes, water may only be present at certain times of the year, resulting in a cyclic nature of drying and refilling. Wetlands [~~that are~~] constructed [~~outside of a surface water of the state~~] for [~~the purpose of providing~~] wastewater treatment outside of, and [~~that~~] do not impound, a surface water of the state are not included in this definition.

(5) "Wildlife habitat" means a surface water of the state used by plants and animals not considered as pathogens, vectors for pathogens or intermediate hosts for pathogens for humans or domesticated livestock and plants.

X. Terms beginning with the letters "X" through "Z". [RESERVED]

[20.6.4.7 NMAC - Rp 20 NMAC 6.1.1007, 10/12/2000; A, 7/19/2001; A, 5/23/2005; A, 7/17/2005; A, 8/1/2007; A, 12/1/2010; A, 1/14/2011; A, 3/2/2017; A, 4/23/2022; A, MM/DD/YYYY]

20.6.4.8 ANTIDEGRADATION POLICY AND IMPLEMENTATION PLAN:

A. Antidegradation Policy: This antidegradation policy applies to all surface waters of the state.

(1) Existing uses, as defined in Paragraph (4) of Subsection E of 20.6.4.7 NMAC, and the level of water quality or wetland condition necessary to protect the existing uses shall be maintained and protected in all surface waters of the state. Wetland condition is a measure of ecological integrity and, by inference, wetland quality (i.e., functions) and quantity (i.e., acreage).

(2) Where wetland condition or the quality of a surface water of the state exceeds levels necessary to support the propagation of fish, shellfish, and wildlife, and recreation in and on the water, that quality shall be maintained and protected unless the commission finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the state's continuing planning process, that allowing lower water quality or wetland condition, including loss of wetland acreage or wetland functions, is necessary to accommodate important economic and social development in the area in which the water is located. In allowing such degradation or lower water quality, the state shall assure water quality adequate to protect existing uses fully. Further, the state shall [~~assure that there shall be achieved~~]ensure the highest statutory and regulatory requirements for all new and existing point sources and implementation of all cost-effective and reasonable best management practices (BMPs) for nonpoint source control. Additionally, the state shall encourage the use of watershed planning as a further means to protect surface waters of the state.

(3) No degradation, including loss of wetland acreage or wetland functions, shall be allowed in waters designated by the commission as outstanding national resource waters (ONRWs), except as provided in Subparagraphs (a) through (e) of this paragraph and in Paragraph (4) of [~~this~~] Subsection A of 20.6.4.8 NMAC.

(a) After providing a minimum 30-day public review and comment period, the commission determines that allowing temporary and short-term degradation of water quality is necessary to accommodate public health or safety activities in the area in which the ONRW is located. Examples of public health or safety activities include but are not limited to replacement or repair of a water or sewer pipeline or a roadway bridge. In making its decision, the commission shall consider whether the activity will interfere with activities implemented to restore or maintain the chemical, physical or biological integrity of the water. In approving the activity, the commission shall require that:

(i) the degradation shall be limited to the shortest possible time and shall not exceed six months;

(ii) the degradation shall be minimized and controlled by [~~best management practices~~]BMPs or in accordance with permit requirements as appropriate; all practical means of minimizing the duration, magnitude, frequency and cumulative effects of such degradation shall be utilized;

(iii) the degradation shall not result in water quality lower than necessary to protect any existing use in the ONRW; and

(iv) the degradation shall not alter the essential character or special use that makes the water an ONRW.

(b) Prior to the commission making a determination, the department or appropriate oversight agency shall provide a written recommendation to the commission. If the commission approves the activity, the department or appropriate oversight agency shall oversee implementation of the activity.

(c) Where an emergency response action that may result in temporary and short-term degradation to an ONRW is necessary to mitigate an immediate threat to public health or safety, the emergency response action may proceed prior to providing notification required by Subparagraph (a) of this paragraph in accordance with the following:

(i) only actions that mitigate an immediate threat to public health or safety may be undertaken pursuant to this provision; non-emergency portions of the action shall comply with the requirements of Subparagraph (a) of this paragraph;

(ii) the discharger shall make best efforts to comply with requirements (i) through (iv) of Subparagraph (a) of this paragraph;

(iii) the discharger shall notify the department of the emergency response action in writing within seven days of initiation of the action;

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(iv) within 30 days of initiation of the emergency response action, the discharger shall provide a summary of the action taken, including all actions taken to comply with requirements (i) through (iv) of Subparagraph (a) of this paragraph.

(d) Preexisting land-use activities, including grazing, allowed by federal or state law prior to designation as an ONRW, and controlled by [~~best management practices (~~]BMPs[~~)~~], shall be allowed to continue so long as there are no new or increased discharges resulting from the activity after designation of the ONRW.

(e) Acequia operation, maintenance, and repairs are not subject to new requirements because of ONRW designation. However, the use of BMPs to minimize or eliminate the introduction of pollutants into receiving waters is strongly encouraged.

(4) This antidegradation policy does not prohibit activities that may result in degradation in surface waters of the state when such activities will result in restoration or maintenance of the chemical, physical or biological integrity of the water.

(a) For ONRWs, the department or appropriate oversight agency shall review on a case-by-case basis discharges that may result in degradation from restoration or maintenance activities, and may approve such activities in accordance with the following:

(i) the degradation shall be limited to the shortest possible time;

(ii) the degradation shall be minimized and controlled by [~~best management practices~~]BMPs or in accordance with permit requirements as appropriate, and all practical means of minimizing the duration, magnitude, frequency and cumulative effects of such degradation shall be utilized;

(iii) the degradation shall not result in water quality lower than necessary to protect any existing use of the surface water; and

(iv) the degradation shall not alter the essential character or special use that makes the water an ONRW.

(b) For surface waters of the state other than ONRWs, the department shall review on a case-by-case basis discharges that may result in degradation from restoration or maintenance activities, and may approve such activities in accordance with the following:

(i) the degradation shall be limited to the shortest possible time;

(ii) the degradation shall be minimized and controlled by [~~best management practices~~]BMPs or in accordance with permit requirements as appropriate, and all practical means of minimizing the duration, magnitude, frequency and cumulative effects of such degradation shall be utilized; and

(iii) the degradation shall not result in water quality lower than necessary to protect any existing use of the surface water.

(5) In those cases where potential water quality impairment associated with a thermal discharge is involved, this antidegradation policy and implementing method shall be consistent with Section 316 of the federal Clean Water Act.

(6) In implementing this section, the commission through the appropriate regional offices of the United States environmental protection agency will keep the administrator advised and provided with such information concerning the surface waters of the state as he or she will need to discharge his or her responsibilities under the federal Clean Water Act.

B. Implementation Plan: The department, acting under authority delegated by the commission, implements the water quality standards, including the antidegradation policy, by describing specific methods and procedures in the continuing planning process and by establishing and maintaining controls on the discharge of pollutants to surface waters of the state. The steps summarized in the following paragraphs, which may not all be applicable in every water pollution control action, list the implementation activities of the department. These implementation activities are supplemented by detailed antidegradation review procedures developed under the state's continuing planning process. The department:

(1) obtains information pertinent to the impact of the effluent on the receiving water and advises the prospective discharger of requirements for obtaining a permit to discharge;

(2) reviews the adequacy of existing data and conducts a water quality survey of the receiving water in accordance with an annually reviewed, ranked priority list of surface waters of the state requiring total maximum daily loads pursuant to Section 303(d) of the federal Clean Water Act;

(3) assesses the probable impact of the effluent on the receiving water relative to its attainable or designated uses and numeric and narrative criteria;

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(4) requires the highest and best degree of wastewater treatment practicable and commensurate with protecting and maintaining the designated uses and existing water quality of surface waters of the state;

(5) develops water quality based effluent limitations and comments on technology based effluent limitations, as appropriate, for inclusion in any federal permit issued to a discharger pursuant to Section 402 of the federal Clean Water Act;

(6) requires that these effluent limitations be included in any such permit as a condition for state certification pursuant to Section 401 of the federal Clean Water Act;

(7) coordinates its water pollution control activities with other constituent agencies of the commission, and with local, state and federal agencies, as appropriate;

(8) develops and pursues inspection and enforcement programs to ensure that dischargers comply with state regulations and standards, and complements EPA's enforcement of federal permits;

(9) ensures that the provisions for public participation required by the New Mexico Water Quality Act and the federal Clean Water Act are followed;

(10) provides continuing technical training for wastewater treatment facility operators through the utility operators training and certification programs;

(11) provides funds to assist the construction of publicly owned wastewater treatment facilities through the wastewater construction program authorized by Section 601 of the federal Clean Water Act, and through funds appropriated by the New Mexico legislature;

(12) conducts water quality surveillance of the surface waters of the state to assess the effectiveness of water pollution controls, determines whether water quality standards are being attained, and proposes amendments to improve water quality standards;

(13) encourages, in conjunction with other state agencies, implementation of the [~~best management practices~~]BMPs set forth in the New Mexico statewide water quality management plan and the nonpoint source management program, such implementation shall not be mandatory except as provided by federal or state law;

(14) evaluates the effectiveness of BMPs selected to prevent, reduce or abate sources of water pollutants;

(15) develops procedures for assessing use attainment as required by 20.6.4.15 NMAC and establishing site-specific standards;[~~and~~]

(16) develops list of surface waters of the state not attaining designated uses, pursuant to Sections 305(b) and 303(d) of the federal Clean Water Act[~~.~~]; and

(17) develops list of ONRWs where impairment has been documented and potential sources of impairment.

[20.6.4.8 NMAC - Rp 20 NMAC 6.1.1101, 10/12/2000; A, 5/23/2005; A, 8/1/2007; A, 1/14/2011; A, 4/23/2022; A, MM/DD/YYYY]

20.6.4.9 OUTSTANDING NATIONAL RESOURCE WATERS:

A. Procedures for nominating an ONRW: Any person may nominate a surface water of the state for designation as an ONRW by filing a petition with the commission pursuant to 20.1.6 NMAC, Rulemaking Procedures - Water Quality Control Commission. A petition to designate a surface water of the state as an ONRW shall include:

(1) a map of the surface water of the state, including the location and proposed upstream and downstream boundaries;

(2) a written statement and evidence based on scientific principles in support of the nomination, including specific reference to one or more of the applicable ONRW criteria listed in Subsection B of this section;

(3) water quality data including chemical, physical or biological parameters, if available, to establish a baseline condition for the proposed ONRW;

(4) a discussion of activities that might contribute to the reduction of water quality in the proposed ONRW;

(5) any additional evidence to substantiate such a designation, including a discussion of the economic impact of the designation on the local and regional economy within the state of New Mexico and the benefit to the state; and

(6) affidavit of publication of notice of the petition in a newspaper of general circulation in the affected counties and in a newspaper of general statewide circulation.

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B. Criteria for ONRWs: A surface water of the state, or a portion of a surface water of the state, may be designated as an ONRW where the commission determines that the designation is beneficial to the state of New Mexico, and:

(1) the water is a significant attribute of a state special trout water, national or state park, national or state monument, national or state wildlife refuge or designated wilderness area, or is part of a designated wild river under the federal Wild and Scenic Rivers Act; or

(2) the water has exceptional recreational or ecological significance; or

(3) the existing water quality is equal to or better than the numeric criteria for protection of aquatic life and contact uses and the human health-organism only criteria, and the water has not been significantly modified by human activities in a manner that substantially detracts from its value as a natural resource.

C. Pursuant to a petition filed under Subsection A of this section, the commission may classify a surface water of the state or a portion of a surface water of the state as an ONRW if the criteria set out in Subsection B of this section are met.

D. Waters classified as ONRWs: The following waters are classified as ONRWs:

(1) Rio Santa Barbara, including the west, middle and east forks from their headwaters downstream to the boundary of the Pecos Wilderness; and

(2) the waters within the United States forest service Valle Vidal special management unit including:

(a) Rio Costilla, including Comanche, La Cueva, Fernandez, Chuckwagon, Little Costilla, Powderhouse, Holman, Gold, Grassy, LaBelle and Vidal creeks, from their headwaters downstream to the boundary of the United States forest service Valle Vidal special management unit;

(b) Middle Ponil creek, including the waters of Greenwood Canyon, from their headwaters downstream to the boundary of the Elliott S. Barker wildlife management area;

(c) Shuree lakes;

(d) North Ponil creek, including McCrystal and Seally Canyon creeks, from their headwaters downstream to the boundary of the United States forest service Valle Vidal special management unit; and

(e) Leandro creek from its headwaters downstream to the boundary of the United States forest service Valle Vidal special management unit.

(3) the named perennial surface waters of the state, identified in Subparagraph (a) below, located within United States department of agriculture forest service wilderness. Wilderness are those lands designated by the United States congress as wilderness pursuant to the Wilderness Act. Wilderness areas included in this designation are the Aldo Leopold wilderness, Apache Kid wilderness, Blue Range wilderness, Chama River Canyon wilderness, Cruces Basin wilderness, Dome wilderness, Gila wilderness, Latir Peak wilderness, Pecos wilderness, San Pedro Parks wilderness, Wheeler Peak wilderness, and White Mountain wilderness.

(a) The following waters are designated in the Rio Grande basin:

(i) in the Aldo Leopold wilderness: Byers Run, Circle Seven creek, Flower canyon, Holden Prong, Indian canyon, Las Animas creek, Mud Spring canyon, North Fork Palomas creek, North Seco creek, Pretty canyon, Sids Prong, South Animas canyon, Victorio Park canyon, Water canyon;

(ii) in the Apache Kid wilderness Indian creek and Smith canyon;

(iii) in the Chama River Canyon wilderness: Chavez canyon, Ojitos canyon, Rio Chama;

(iv) in the Cruces Basin wilderness: Beaver creek, Cruces creek, Diablo creek, Escondido creek, Lobo creek, Osha creek;

(v) in the Dome wilderness: Capulin creek, Medio creek, Sanchez canyon/creek;

(vi) in the Latir Peak wilderness: Bull creek, Bull Creek lake, Heart lake, Lagunitas Fork, Lake Fork creek, Rito del Medio, Rito Primero, West Latir creek;

(vii) in the Pecos wilderness: Agua Sarca, Hidden lake, Horseshoe lake (Alamitos), Jose Vigil lake, Nambe lake, Nat lake IV, No Fish lake, North Fork Rio Quemado, Rinconada, Rio Capulin, Rio de las Trampas (Trampas creek), Rio de Truchas, Rio Frijoles, Rio Medio, Rio Molino, Rio Nambe, Rio San Leonardo, Rito con Agua, Rito Gallina, Rito Jaroso, Rito Quemado, San Leonardo lake, Santa Fe lake, Santa Fe river, Serpent lake, South Fork Rio Quemado, Trampas lake (East), Trampas lake (West);

(viii) in the San Pedro Parks wilderness: Agua Sarca, Cañon Madera, Cave creek, Cecilia Canyon creek, Clear creek (North SPP), Clear creek (South SPP), Corralitos creek, Dove creek, Jose Miguel creek, La Jara creek, Oso creek, Rio Capulin, Rio de las Vacas, Rio Gallina, Rio Puerco de Chama, Rito

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Anastacio East, Rito Anastacio West, Rito de las Palomas, Rito de las Perchas, Rito de los Pinos, Rito de los Utes, Rito Leche, Rito Redondo, Rito Resumidero, San Gregorio lake;

(ix) in the Wheeler Peak wilderness: Black Copper canyon, East Fork Red river, Elk lake, Horseshoe lake, Lost lake, Sawmill creek, South Fork lake, South Fork Rio Hondo, Williams lake.

(b) The following waters are designated in the Pecos River basin:

(i) in the Pecos wilderness: Albright creek, Bear creek, Beatty creek, Beaver creek, Carpenter creek, Cascade canyon, Cave creek, El Porvenir creek, Hollinger creek, Holy Ghost creek, Horsethief creek, Jack's creek, Jarosa canyon/creek, Johnson lake, Lake Katherine, Lost Bear lake, Noisy brook, Panchuela creek, Pecos Baldy lake, Pecos river, Rio Mora, Rio Valdez, Rito Azul, Rito de los Chimayosos, Rito de los Esteros, Rito del Oso, Rito del Padre, Rito las Trampas, Rito Maestas, Rito Oscuro, Rito Perro, Rito Sebadilloses, South Fork Bear creek, South Fork Rito Azul, Spirit lake, Stewart lake, Truchas lake (North), Truchas lake (South), Winsor creek;

(ii) in the White Mountain wilderness: Argentina creek, Aspen creek, Bonito creek, Little Bonito creek, Mills canyon/creek, Rodamaker creek, South Fork Rio Bonito, Turkey canyon/creek.

(c) The following waters are designated in the Gila River basin:

(i) in the Aldo Leopold wilderness: Aspen canyon, Black Canyon creek, Bonner canyon, Burnt canyon, Diamond creek, Falls canyon, Fisherman canyon, Running Water canyon, South Diamond creek;

(ii) in the Gila wilderness: Apache creek, Black Canyon creek, Brush canyon, Canyon creek, Chicken Coop canyon, Clear creek, Cooper canyon, Cow creek, Cub creek, Diamond creek, East Fork Gila river, Gila river, Gilita creek, Indian creek, Iron creek, Langstroth canyon, Lilley canyon, Little creek, Little Turkey creek, Lookout canyon, McKenna creek, Middle Fork Gila river, Miller Spring canyon, Mogollon creek, Panther canyon, Prior creek, Rain creek, Raw Meat creek, Rocky canyon, Sacaton creek, Sapillo creek, Sheep Corral canyon, Skeleton canyon, Squaw creek, Sycamore canyon, Trail canyon, Trail creek, Trout creek, Turkey creek, Turkey Feather creek, Turnbo canyon, West Fork Gila river, West Fork Mogollon creek, White creek, Willow creek, Woodrow canyon.

(d) The following waters are designated in the Canadian River basin: in the Pecos wilderness Daily creek, Johns canyon, Middle Fork Lake of Rio de la Casa, Middle Fork Rio de la Casa, North Fork Lake of Rio de la Casa, Rito de Gascon, Rito San Jose, Sapello river, South Fork Rio de la Casa, Sparks creek (Manuelitas creek).

(e) The following waters are designated in the San Francisco River basin:

(i) in the Blue Range wilderness: Pueblo creek;

(ii) in the Gila wilderness: Big Dry creek, Lipsey canyon, Little Dry creek, Little Whitewater creek, South Fork Whitewater creek, Spider creek, Spruce creek, Whitewater creek.

(f) The following waters are designated in the Mimbres Closed basin: in the Aldo Leopold wilderness Corral canyon, Mimbres river, North Fork Mimbres river, South Fork Mimbres river.

(g) The following waters are designated in the Tularosa Closed basin: in the White Mountain wilderness Indian creek, Nogal Arroyo, Three Rivers.

(h) The wetlands designated are identified on the *Maps and List of Wetlands Within United States Forest Service Wilderness Areas Designated as Outstanding National Resource Waters* published at the New Mexico state library and available on the department's website.

(4) The following waters are designated in the headwaters Pecos river watershed:

(a) The Pecos river from Dalton Canyon creek to the Pecos wilderness boundary;

(b) In the Dry Gulch-Pecos river subwatershed, Dalton Canyon creek from the Pecos river upstream to the headwaters, Wild Horse creek from Dalton Canyon creek upstream to the headwaters, Macho Canyon creek from the Pecos river upstream to the headwaters and Sawyer creek from the Pecos river upstream to the headwaters;

(c) In the Indian creek-Pecos river subwatershed, Indian creek from the Pecos river upstream to the headwaters, Holy Ghost creek from the Pecos river upstream to the Pecos wilderness boundary, Doctor creek from Holy Ghost creek upstream to the headwaters, Davis creek from the Pecos river upstream to the headwaters and Willow creek from the Pecos river upstream to the headwaters;

(d) In the Rio Mora subwatershed, Rio Mora from the Pecos river upstream to the Pecos wilderness boundary and Bear creek from the Rio Mora upstream to the Pecos wilderness boundary;

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(e) In the Rio Mora-Pecos river subwatershed, Carpenter creek from the Pecos river upstream to the Pecos wilderness boundary, Winsor creek from the Pecos river upstream to the Pecos wilderness boundary and Jack's creek from the Pecos river upstream to the Pecos wilderness boundary; and,

(f) In the Panchuela creek subwatershed, Panchuela creek from the Pecos river upstream to the Pecos wilderness boundary;

(g) Unnamed tributaries to waters in Subparagraphs (a) through (f), Paragraph (4) of this Subsection (D) as identified in the *Maps and Lists for Unnamed Tributaries to Perennial Waters and Wetlands in the Headwaters Pecos River Watershed,* published at the New Mexico state library and available on the department's website.

(h) Unnamed wetlands adjacent to waters in Subparagraphs (a) through (f), Paragraph (4) of this Subsection (D) as identified in the *Maps and Lists for Unnamed Tributaries to Perennial Waters and Wetlands in the Headwaters Pecos River Watershed*, published at the New Mexico state library and available on the department's website.

(5) the Rio Grande from directly above the Rio Pueblo de Taos to the New Mexico-Colorado state border.

(6) the Rio Hondo from the Carson National Forest boundary to its headwaters; and Lake Fork creek from the Rio Hondo to its headwaters.

(7) the East Fork Jemez river from San Antonio creek to its headwaters; San Antonio creek from the East Fork Jemez river to its headwaters; and Redondo creek from Sulphur creek to its headwaters.

(8) The following waters located within a national or state park, national or state monument, or national or state wildlife refuge:

(a) in the Valles Caldera national preserve: La Jara creek, Sulphur creek, San Luis creek, Jaramillo creek, and Rito de los Indios;

(b) in the Bandelier national monument: Rito de los Frijoles, Lummis canyon, Alamo canyon, Capulin creek, and Medio creek;

(c) in the Cimarron canyon state park: Cimarron river;

(d) in the Pecos national historical park: Pecos river;

(e) in the Rio Grande del Norte national monument: Rio San Antonio.

(9) The following waters located within a designated wilderness area: in the Columbine – Hondo wilderness areas: Columbine creek, Deer creek, Placer fork, Willow fork, Goose creek, Bear creek, Long canyon, Gavilan canyon, Italianos creek, Yerba creek, Manzanita creek, Gallina creek, Lobo creek, San Cristobal creek, and Lama canyon.

(10) The following wild rivers as designated by the federal Wild and Scenic Rivers Act:

(a) Rio Chama from the US forest service boundary to confluence with the Rio Nutrias;

(b) Red River from the confluence with the Rio Grande to four miles upstream.

(11) The following state special trout waters not already included in Paragraphs 8 through 10 of this Subsection:

(a) in the Edward Sargent wildlife management area: Rio Chamita, Nabor creek, Sixto creek, and Rio Chama;

(b) Rio Chama from Heron Reservoir outlet to Cottonwood flats;

(c) Rio de los Pinos from United States forest service road 87A to private land 2.5 miles upstream, Tanques creek, Canada Tio Grande;

(d) Cabresto creek from United States forest service boundary to headwaters, Frijoles creek, Palociento creek, and West Fork Luna creek;

(e) Rio Cebolla from Seven Springs day use area to its headwaters, Rio Gaudalupe from the confluence with Deer creek upstream to confluence with Stable creek;

(f) Capulin creek from the Dome wilderness boundary to headwaters.

[20.6.4.9 NMAC - Rn, Subsections B, C and D of 20.6.4.8 NMAC, 5/23/2005; A, 5/23/2005; A, 7/17/2005; A, 2/16/2006; A, 12/1/2010; A, 1/14/2011; A, 4/23/2022; A, 9/24/2022; A, 3/15/2025]

20.6.4.10 REVIEW OF STANDARDS; NEED FOR ADDITIONAL STUDIES:

A. Section 303(c)(1) of the federal Clean Water Act requires that the state hold public hearings at least once every three years for the purpose of reviewing water quality standards and proposing, as appropriate, necessary revisions to water quality standards.

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B. In accordance with 40 CFR 131.10(i), when an existing use, as defined under 20.6.4.7 NMAC, is higher quality water than prescribed by the designated use and supporting evidence demonstrates the presence of that use, the designated use shall be amended accordingly to have criteria no less stringent than the existing use.

C. It is recognized that, in some cases, numeric criteria for a particular designated use may not adequately reflect the local conditions or the aquatic communities adapted to those localized conditions. In these cases, a water quality criterion may be modified to reflect the natural condition of a specific waterbody. The modification of the criterion does not change the designated use; the modification only changes the criterion for that specific waterbody When justified by sufficient data and information, a numeric water quality criterion may be adopted or modified in accordance with Subsections [~~F~~]G [~~of 20.6.4.10~~] and [~~Subsection G~~]H of 20.6.4.10 NMAC, to protect the attainable uses of the waterbody.

D. The removal or amendment of a designated use to a designated use with less stringent criteria can only be done through a use attainability analysis in accordance with 20.6.4.15 NMAC.

E. It is also recognized that contributions of water contaminants by diffuse nonpoint sources of water pollution may make attainment of certain criteria difficult. Revision of these criteria may be necessary as new information is obtained on nonpoint sources and other problems unique to semi-arid regions.

F. Any person may petition the commission to adopt, amend, or repeal any regulation within the jurisdiction of the commission in accordance with 20.1.6.200 NMAC, including ONRW nominations, site-specific criteria, use attainability analyses, temporary standards, and designating classified segments. If the commission grants a rulemaking hearing in response to a petition, the petitioner shall be responsible for the administrative rulemaking costs. The petitioner shall coordinate with the commission administrator and the department on the administrative rulemaking costs and hearing requirements.

[~~F~~]G. Site-specific criteria.

(1) The commission may adopt site-specific numeric criteria applicable to all or part of a surface water of the state based on relevant site-specific conditions such as:

(a) actual species at a site are more or less sensitive than those used in the national criteria data set;

(b) physical or chemical characteristics at a site such as pH or hardness alter the biological availability and/or toxicity of the chemical;

(c) physical, biological or chemical factors alter the bioaccumulation potential of a chemical;

(d) the concentration resulting from natural background exceeds numeric criteria for aquatic life, wildlife habitat or other uses if consistent with Subsection G of 20.6.4.10 NMAC; or

(e) other factors or combination of factors that upon review of the commission may warrant modification of the default criteria, subject to EPA review and approval.

(2) Site-specific criteria must fully protect the designated use to which they apply. In the case of human health-organism only criteria, site-specific criteria must fully protect human health when organisms are consumed from waters containing pollutants.

(3) Any person may submit notice to the department stating their intent to develop site-specific criteria for a surface water of the state. The notice shall include a work plan supporting the development of site-specific criteria for the department's comment.

(4) Site-specific criteria shall be developed in accordance with the work plan, based on one or more of the site-specific conditions in Paragraph (1) of Subsection G of 20.6.4.10 NMAC, derived from a scientifically defensible method and protect the designated uses to which they apply.

(5) The work plan shall identify, at a minimum:

(a) the waterbody to consider and the reasoning for site-specific criteria;

(b) the methodology to be used to derive criteria;

(c) the source and validity of data to be used;

(d) the provisions for consultation with appropriate state and federal agencies;

(e) a description of how stakeholders and potentially affected Indian nations, tribes, or pueblos will be identified and engaged;

(f) a description of the public notice mechanisms to be employed; and

(g) the expected timelines and associated administrative actions to be taken for a rulemaking petition, pending the outcome of criteria development.

(6) Upon completion of site-specific criteria development, the data, findings and conclusions shall be submitted to the department, and public notice shall be provided in accordance with the work plan.

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[~~(3)~~](7) Any person may petition the commission to adopt site-specific criteria. A petition for the adoption of site-specific criteria shall:

(a) identify the specific waters to which the site-specific criteria would apply;

(b) explain the rationale for proposing the site-specific criteria;

(c) describe the methods used to notify and solicit input from potential stakeholders and from the general public in the affected area, and present and respond to the public input received;

(d) present and justify the derivation of the proposed criteria.

[~~(4)~~](8) A derivation of site-specific criteria shall rely on a scientifically defensible method, such as one of the following:

(a) the recalculation procedure, the water-effect ratio for metals procedure or the resident species procedure as described in the water quality standards handbook (EPA-823-B-94-005a, 2nd edition, August 1994);

(b) the streamlined water-effect ratio procedure for discharges of copper (EPA-822-R-01-005, March 2001);

(c) the biotic ligand model as described in aquatic life ambient freshwater quality criteria - copper (EPA-822-R-07-001, February 2007);

(d) the methodology for deriving ambient water quality criteria for the protection of human health (EPA-822-B-00-004, October 2000) and associated technical support documents; or

(e) a determination of the natural background of the [~~water body~~] waterbody as described in Subsection G of 20.6.4.10 NMAC.

[~~G~~]H. **Site-specific criteria based on natural background.** The commission may adopt site-specific criteria equal to the concentration resulting from natural background where that concentration protects the designated use. The concentration resulting from natural background supports the level of aquatic life and wildlife habitat expected to occur naturally at the site absent any interference by humans. Domestic water supply, primary or secondary contact, or human health-organism only criteria shall not be modified based on natural background. A determination of natural background shall:

(1) consider natural spatial and seasonal to interannual variability as appropriate;

(2) document the presence of natural sources of the pollutant;

(3) document the absence of human sources of the pollutant or quantify the human contribution; and

(4) rely on analytical, statistical or modeling methodologies to quantify the natural background.

[~~H~~]I. **Temporary standards.**

(1) Any person may petition the commission to adopt a temporary standard applicable to all or part of a surface water of the state as provided for in this section and applicable sections in 40 CFR Part 131, Water Quality Standards; specifically, Section 131.14. The commission may adopt a proposed temporary standard if the petitioner demonstrates that:

(a) attainment of the associated designated use may not be feasible in the short term due to one or more of the factors listed in 40 CFR 131.10(g), or due to the implementation of actions necessary to facilitate restoration such as through dam removal or other significant wetland or [~~water body~~] waterbody reconfiguration activities as demonstrated by the petition and supporting work plan requirements in Paragraphs (4) and (5) of Subsection [~~H~~]I of 20.6.4.10 NMAC;

(b) the proposed temporary standard represents the highest degree of protection feasible in the short term, limits the degradation of water quality to the minimum necessary to achieve the original standard by the expiration date of the temporary standard, and adoption will not cause the further impairment or loss of an existing use;

(c) for point sources, existing or proposed discharge control technologies will comply with applicable technology-based limitations and feasible technological controls and other management alternatives, such as a pollution prevention program; and

(d) for restoration activities, nonpoint source or other control technologies shall limit downstream impacts, and if applicable, existing or proposed discharge control technologies shall be in place consistent with Subparagraph (c) of Paragraph (1) of Subsection [~~H~~]I of 20.6.4.10 NMAC.

(2) A temporary standard shall apply to specific designated use(s), pollutant(s), or permittee(s), and to specific [~~water body~~] waterbody segment(s). The adoption of a temporary standard does not exempt dischargers from complying with all other applicable water quality standards or control technologies.

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(3) Designated use attainment as reported in the federal Clean Water Act, Section 305(b)/303(d) Integrated Report shall be based on the original standard and not on a temporary standard.

(4) A petition for a temporary standard shall:

(a) identify the currently applicable standard(s), the proposed temporary standard for the specific pollutant(s), the permittee(s), and the specific surface [~~water body~~] waterbody segment(s) of the state to which the temporary standard would apply;

(b) include the basis for any factor(s) specific to the applicability of the temporary standard (for example critical flow under Subsection B of 20.6.4.11 NMAC);

(c) demonstrate that the proposed temporary standard meets the requirements in this subsection;

(d) present a work plan with timetable of proposed actions for achieving compliance with the original standard in accordance with Paragraph (5) of Subsection [~~H~~]I of 20.6.4.10 NMAC;

(e) include any other information necessary to support the petition.

(5) As a condition of a petition for a temporary standard, in addition to meeting the requirements in this Subsection, the petitioner shall prepare a work plan in accordance with Paragraph (4) of Subsection [~~H~~]I of 20.6.4.10 NMAC and submit the work plan to the department for review and comment. The work plan shall identify the factor(s) listed in 40 CFR 131.10(g) or Subparagraph (a) of Paragraph (1) of Subsection [~~H~~]I of 20.6.4.10 NMAC affecting attainment of the standard that will be analyzed and the timeline for proposed actions to be taken to achieve the uses attainable over the term of the temporary standard, including baseline water quality, and any investigations, projects, facility modifications, monitoring, or other measures necessary to achieve compliance with the original standard. The work plan shall include provisions for review of progress in accordance with Paragraph (8) of Subsection [~~H~~]I of 20.6.4.10 NMAC, public notice and consultation with appropriate state, tribal, local and federal agencies.

(6) The commission may condition the approval of a temporary standard by requiring additional monitoring, relevant analyses, the completion of specified projects, submittal of information, or any other actions.

(7) Temporary standards may be implemented only after a public hearing before the commission, commission approval and adoption pursuant to Subsection [~~H~~]I of 20.6.4.10 NMAC for all state purposes, and the federal Clean Water Act, Section 303 (c) approval for any federal action.

(8) All temporary standards are subject to a required review during each succeeding review of water quality standards conducted in accordance with Subsection A of 20.6.4.10 NMAC. The petitioner shall provide a written report to the commission documenting the progress of proposed actions, pursuant to a reporting schedule stipulated in the approved temporary standard. The purpose of the review is to determine progress consistent with the original conditions of the petition for the duration of the temporary standard. If the petitioner cannot demonstrate that sufficient progress has been made the commission may revoke approval of the temporary standard or provide additional conditions to the approval of the temporary standard.

(9) The commission may consider a petition to extend a temporary standard. The effective period of a temporary standard shall be extended only if demonstrated to the commission that the factors precluding attainment of the underlying standard still apply, that the petitioner is meeting the conditions required for approval of the temporary standard, and that reasonable progress towards meeting the underlying standard is being achieved.

(10) A temporary standard shall expire no later than the date specified in the approval of the temporary standard. Upon expiration of a temporary standard, the original standard becomes applicable.

(11) Temporary standards shall be identified in 20.6.4.97-899 NMAC as appropriate for the surface water affected.

[~~**(12)** "Temporary standard" means a time-limited designated use and criterion for a specific pollutant(s) or water quality parameter(s) that reflect the highest attainable condition during the term of the temporary standard.~~]

[20.6.4.10 NMAC - Rp 20 NMAC 6.1.1102, 10/12/2000; Rn, 20.6.4.9 NMAC, 5/23/2005; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022; A, MM/DD/YYYY]

20.6.4.11 APPLICABILITY OF WATER QUALITY STANDARDS:

A. [**RESERVED**]

B. Critical low flow: The critical low flow of a stream at a particular site shall be used in developing point source discharge permit requirements to meet numeric criteria set in 20.6.4.97 through 20.6.4.900 NMAC and Subsection F of 20.6.4.13 NMAC.

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(1) For human health-organism only criteria, the critical low flow is the harmonic mean flow. For ephemeral waters the calculation shall be based upon the nonzero flow intervals and modified by including a factor to adjust for the proportion of intervals with zero flow. The equations are as follows:

$$\text{Harmonic Mean} = \frac{n}{\sum 1/Q}$$

where n = number of flow values
and Q = flow value

$$\text{Modified Harmonic Mean} = \left[\frac{\sum_{i=1}^{Nt-N0} \frac{1}{Qi}}{Nt - N0}\right]^{-1} x \left[\frac{Nt - N0}{Nt}\right]$$

where Qi = nonzero flow
Nt = total number of flow values
and N_0 = number of zero flow values

(2) For all other narrative and numeric criteria, the critical low flow is the minimum average four consecutive day flow that occurs with a frequency of once in three years (4Q3). The critical low flow may be determined on an annual, a seasonal or a monthly basis, as appropriate, after due consideration of site-specific conditions.

C. Guaranteed minimum flow: The commission may allow the use of a contractually guaranteed minimum streamflow in lieu of a critical low flow determined under Subsection B of this section on a case-by-case basis and upon consultation with the interstate stream commission. Should drought, litigation or any other reason interrupt or interfere with minimum flows under a guaranteed minimum flow contract for a period of at least 30 consecutive days, such permission, at the sole discretion of the commission, may then be revoked. Any minimum flow specified under such revoked permission shall be superseded by a critical low flow determined under Subsection B of this section. A public notice of the request for a guaranteed minimum flow shall be published in a newspaper of general circulation by the department at least 30 days prior to scheduled action by the commission. These water quality standards do not grant to the commission or any other entity the power to create, take away or modify property rights in water.

D. Mixing zones: A limited mixing zone, contiguous to a point source wastewater discharge, may be allowed in any stream receiving such a discharge. Mixing zones serve as regions of initial dilution that allow the application of a dilution factor in calculations of effluent limitations. Effluent limitations shall be developed that will protect the most sensitive existing, designated or attainable use of the receiving water.

E. Mixing zone limitations: Wastewater mixing zones, in which the numeric criteria set under Subsection F of 20.6.4.13 NMAC, 20.6.4.97 through 20.6.4.899 NMAC or 20.6.4.900 NMAC may be exceeded, shall be subject to the following limitations:

(1) Mixing zones are not allowed for discharges to lakes, reservoirs, or playas; these effluents shall meet all applicable criteria set under Subsection F of 20.6.4.13 NMAC, 20.6.4.97 through 20.6.4.899 NMAC and 20.6.4.900 NMAC at the point of discharge.

(2) The acute aquatic life criteria, as set out in Subsection I, Subsection J, and Subsection [~~K~~]L of 20.6.4.900 NMAC, shall be attained at the point of discharge for any discharge to a surface water of the state with a designated aquatic life use.

(3) The general criteria set out in Subsections A, B, C, D, E, G, H and J of 20.6.4.13 NMAC, and the provision set out in Subsection D of 20.6.4.14 NMAC are applicable within mixing zones.

(4) The areal extent and concentration isopleths of a particular mixing zone will depend on site-specific conditions including, but not limited to, wastewater flow, receiving water critical low flow, outfall design, channel characteristics and climatic conditions and, if needed, shall be determined on a case-by-case basis. When the physical boundaries or other characteristics of a particular mixing zone must be known, the methods presented in Section 4.4.5, "Ambient-induced mixing," in "Technical support document for water quality-based toxics control" (March 1991, EPA/505/2-90-001) shall be used.

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(5) All applicable water quality criteria set under Subsection F of 20.6.4.13 NMAC, 20.6.4.97 through 20.6.4.899 NMAC and 20.6.4.900 NMAC shall be attained at the boundaries of mixing zones. A continuous zone of passage through or around the mixing zone shall be maintained in which the water quality meets all applicable criteria and allows the migration of aquatic life presently common in surface waters of the state with no effect on their populations.

F. Multiple uses: When a surface water of the state has more than a single designated use, the applicable numeric criteria shall be the most stringent of those established for such water.

G. Human health-organism only criteria in Subsection J of 20.6.4.900 NMAC apply to those waters with a designated, existing or attainable aquatic life use. When limited aquatic life is a designated use, the human health-organism only criteria apply only for persistent toxic pollutants, [~~if~~] unless adopted on a segment-specific basis. The human health-organism only criteria for persistent toxic pollutants, as identified in Subsection J of 20.6.4.900 NMAC, also apply to all tributaries of waters with a designated, existing or attainable aquatic life use.

H. Unclassified waters of the state: An unclassified surface water of the state is presumed to support the uses specified in Section 101(a)(2) of the federal Clean Water Act. As such, it is subject to 20.6.4.98 NMAC if nonperennial or subject to 20.6.4.99 NMAC if perennial. The commission may include an ephemeral unclassified surface water of the state under 20.6.4.97 NMAC only if a use attainability analysis demonstrates pursuant to 20.6.4.15 NMAC that attainment of Section 101(a)(2) uses is not feasible.

I. Exceptions: Numeric criteria for temperature, dissolved solids, dissolved oxygen, sediment or turbidity adopted under the Water Quality Act do not apply when changes in temperature, dissolved solids, dissolved oxygen, sediment or turbidity in a surface water of the state are attributable to:

(1) natural causes (discharges from municipal separate storm sewers are not covered by this exception.); or

(2) the reasonable operation of irrigation and flood control facilities that are not subject to federal or state water pollution control permitting; major reconstruction of storage dams or diversion dams except for emergency actions necessary to protect health and safety of the public are not covered by this exception.

[20.6.4.11 NMAC - Rp 20 NMAC 6.1.1103, 10/12/2000; A, 10/11/2002; Rn, 20.6.4.10 NMAC, 5/23/2005; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022; A, MM/DD/YYYY]

20.6.4.12 COMPLIANCE WITH WATER QUALITY STANDARDS: The following provisions apply to determining compliance for enforcement purposes; they do not apply for purposes of determining attainment of uses. The department has developed assessment protocols for the purpose of determining attainment of uses that are available for review from the department's surface water quality bureau.

A. Compliance with acute water quality criteria shall be determined from the analytical results of a single grab sample. Acute criteria shall not be exceeded.

B. Compliance with chronic water quality criteria shall be determined from the arithmetic mean of the analytical results of samples collected using applicable protocols. Chronic criteria shall not be exceeded more than once every three years.

C. Compliance with water quality standards for total ammonia shall be determined by performing the biomonitoring procedures set out in Subsections D and E of 20.6.4.14 NMAC, or by attainment of applicable ammonia criteria set out in Subsections K, L and M of 20.6.4.900 NMAC.

D. Compliance with the human health-organism only criteria shall be determined from the analytical results of representative grab samples, as defined in the water quality management plan. Human health-organism only criteria shall not be exceeded.

E. The commission may establish a numeric water quality criterion at a concentration that is below the minimum quantification level. In such cases, the water quality standard is enforceable at the minimum quantification level.

F. For compliance with [~~hardness-dependent~~]calculated numeric criteria[~~, hardness (as mg $CaCO_3$/L)~~] that depend on water chemistry, all input parameters shall be determined from a sample taken at the same time that the sample for the contaminant is taken. If all input data are not available to calculate criteria, default input values may be used. Default values shall be justified in writing and supported by ecoregional or other watershed data.

G. Compliance schedules: The commission may allow the inclusion of a schedule of compliance in a NPDES permit issued to an existing facility on a case-by-case basis. Such schedule of compliance will be for the purpose of providing a permittee with adequate time to make treatment facility modifications necessary to comply with water quality based permit limitations determined to be necessary to implement new or revised water quality standards or wasteload allocation. Compliance schedules may be included in NPDES permits at the time of

permit renewal or modification and shall be written to require compliance at the earliest practicable time. Compliance schedules shall also specify milestone dates so as to measure progress towards final project completion (e.g., design completion, construction start, construction completion, date of compliance).

H. It is a policy of the commission to allow a temporary standard approved and adopted pursuant to Subsection [~~H~~]I of 20.6.4.10 NMAC to be included in the applicable federal Clean Water Act permit as enforceable limits and conditions. The temporary standard and any schedule of actions may be included at the earliest practicable time, and shall specify milestone dates so as to measure progress towards meeting the original standard. [20.6.4.12 NMAC - Rp 20 NMAC 6.1.1104, 10/12/2000; A, 10/11/2002; Rn, 20.6.4.11 NMAC, 5/23/2005; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022; A, MM/DD/YYYY]

20.6.4.13 GENERAL CRITERIA: General criteria are established to sustain and protect existing or attainable uses of surface waters of the state. These general criteria apply to all surface waters of the state at all times, unless a specified criterion is provided elsewhere in this part. Surface waters of the state shall be free of any water contaminant in such quantity and of such duration as may with reasonable probability injure human health, animal or plant life or property, or unreasonably interfere with the public welfare or the use of property.

A. Bottom deposits and suspended or settleable solids:

(1) Surface waters of the state shall be free of water contaminants including fine sediment particles (less than two millimeters in diameter), precipitates or organic or inorganic solids from other than natural causes that have settled to form layers on or fill the interstices of the natural or dominant substrate in quantities that damage or impair the normal growth, function or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.

(2) Suspended or settleable solids from other than natural causes shall not be present in surface waters of the state in quantities that damage or impair the normal growth, function or reproduction of aquatic life or adversely affect other designated uses.

B. Floating solids, oil and grease: Surface waters of the state shall be free of oils, scum, grease and other floating materials resulting from other than natural causes that would cause the formation of a visible sheen or visible deposits on the bottom or shoreline, or would damage or impair the normal growth, function or reproduction of human, animal, plant or aquatic life.

C. Color: Color-producing materials resulting from other than natural causes shall not create an aesthetically undesirable condition nor shall color impair the use of the water by desirable aquatic life presently common in surface waters of the state.

D. Organoleptic quality:

(1) Flavor of fish: Water contaminants from other than natural causes shall be limited to concentrations that will not impart unpalatable flavor to fish.

(2) Odor and taste of water: Water contaminants from other than natural causes shall be limited to concentrations that will not result in offensive odor or taste arising in a surface water of the state or otherwise interfere with the reasonable use of the water.

E. Plant nutrients: Plant nutrients from other than natural causes shall not be present in concentrations that will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the state.

F. Toxic pollutants:

(1) Except as provided in 20.6.4.16 NMAC, surface waters of the state shall be free of toxic pollutants from other than natural causes in amounts, duration, concentrations, or combinations that affect the propagation of fish or that are toxic to humans, livestock or other animals, fish or other aquatic organisms, wildlife using aquatic environments for habitation or aquatic organisms for food, or that will or can reasonably be expected to bioaccumulate in tissues of fish, shellfish and other aquatic organisms to levels that will impair the health of aquatic organisms or wildlife or result in unacceptable tastes, odors or health risks to human consumers of aquatic organisms.

(2) Pursuant to this section, the human health-organism only criteria shall be as set out in 20.6.4.900 NMAC. When a human health-organism only criterion is not listed in 20.6.4.900 NMAC, the following provisions shall be applied in accordance with 20.6.4.11, 20.6.4.12 and 20.6.4.14 NMAC.

(a) The human health-organism only criterion shall be the recommended human health criterion for "consumption of organisms only" published by the U.S. environmental protection agency pursuant to Section 304(a) of the federal Clean Water Act. In determining such criterion for a cancer-causing toxic pollutant, a cancer risk of 10^{-5} (one cancer per 100,000 exposed persons) shall be used.

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(b) When a numeric criterion for the protection of human health for the consumption of organism only has not been published by the U.S. environmental protection agency, a quantifiable criterion may be derived from data available in the U.S. environmental protection agency's Integrated Risk Information System (IRIS) using the appropriate formula specified in *Methodology for Deriving Ambient Water Quality Criteria for The Protection Of Human Health (2000)*, EPA-822-B-00-004.

(3) Pursuant to this section, the chronic aquatic life criteria shall be as set out in 20.6.4.900 NMAC. When a chronic aquatic life criterion is not listed in 20.6.4.900 NMAC, the following provisions shall be applied in sequential order in accordance with 20.6.4.11, 20.6.4.12 and 20.6.4.14 NMAC.

(a) The chronic aquatic life criterion shall be the "freshwater criterion continuous concentration" published by the U.S. environmental protection agency pursuant to Section 304(a) of the federal Clean Water Act;

(b) If the U.S. environmental protection agency has not published a chronic aquatic life criterion, a geometric mean LC-50 value shall be calculated for the particular species, genus or group that is representative of the form of life to be preserved, using the results of toxicological studies published in scientific journals.

(i) The chronic aquatic life criterion for a toxic pollutant that does not bioaccumulate shall be ten percent of the calculated geometric mean LC-50 value; and

(ii) The chronic aquatic life criterion for a toxic pollutant that does bioaccumulate shall be: the calculated geometric mean LC-50 adjusted by a bioaccumulation factor for the particular species, genus or group representative of the form of life to be preserved, but when such bioaccumulation factor has not been published, the criterion shall be one percent of the calculated geometric mean LC-50 value.

(4) Pursuant to this section, the acute aquatic life criteria shall be as set out in 20.6.4.900 NMAC. When an acute aquatic life criterion is not listed in 20.6.4.900 NMAC, the acute aquatic life criterion shall be the "freshwater criterion maximum concentration" published by the U.S. environmental protection agency pursuant to Section 304(a) of the federal Clean Water Act.

(5) Within 90 days of the issuance of a final NPDES permit containing a numeric criterion selected or calculated pursuant to Paragraph (2), Paragraph (3) or Paragraph (4) of Subsection F of this section, the department shall petition the commission to adopt such criterion into these standards.

G. Radioactivity: The radioactivity of surface waters of the state shall be maintained at the lowest practical level and shall in no case exceed the criteria set forth in the New Mexico Radiation Protection Regulations, 20.3.1 and 20.3.4 NMAC.

H. Pathogens: Surface waters of the state shall be free of pathogens from other than natural causes in sufficient quantity to impair public health or the designated, existing or attainable uses of a surface water of the state.

I. Temperature: Maximum temperatures for surface waters of the state have been specified in 20.6.4.97 through 20.6.4.900 NMAC. However, the introduction of heat by other than natural causes shall not increase the temperature, as measured from above the point of introduction, by more than 2.7°C (5°F) in a stream, or more than 1.7°C (3°F) in a lake or reservoir. In no case will the introduction of heat be permitted when the maximum temperature specified for the reach would thereby be exceeded. These temperature criteria shall not apply to impoundments constructed offstream for the purpose of heat disposal. High water temperatures caused by unusually high ambient air temperatures are not violations of these criteria.

J. Turbidity: Turbidity attributable to other than natural causes shall not reduce light transmission to the point that the normal growth, function or reproduction of aquatic life is impaired or that will cause substantial visible contrast with the natural appearance of the water. Activities or discharges shall not cause turbidity to increase more than 10 NTU over background turbidity when the background turbidity, measured at a point immediately upstream of the activity, is 50 NTU or less, nor to increase more than twenty percent when the background turbidity is more than 50 NTU. However, limited-duration turbidity increases caused by dredging, construction or other similar activities may be allowed provided all practicable turbidity control techniques have been applied and all appropriate permits, certifications and approvals have been obtained.

K. Total dissolved solids (TDS): TDS attributable to other than natural causes shall not damage or impair the normal growth, function or reproduction of animal, plant or aquatic life. TDS shall be measured by either the "calculation method" (sum of constituents) or the filterable residue method. Approved test procedures for these determinations are set forth in 20.6.4.14 NMAC.

L. Dissolved gases: Surface waters of the state shall be free of nitrogen and other dissolved gases at levels above one hundred ten percent saturation when this supersaturation is attributable to municipal, industrial or other discharges.

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M. Biological integrity: Surface waters of the state shall support and maintain a balanced and integrated community of aquatic organisms with species composition, diversity and functional organization comparable to those of natural or minimally impacted water bodies of a similar type and region.

N. Wetlands: This general criterion applies to wetlands only. Wetlands shall be maintained and protected such that degradation through direct, indirect, or cumulative impacts does not result in the net loss of wetland acreage or biological, chemical, physical, and hydrological functions to the extent that such functions occur, as characterized by state-specific benchmarks. The functions of a wetland that are to be maintained and protected may include:

(1) erosion control through bank and shoreline stabilization;
(2) flood attenuation and flood protection;
(3) sediment and pollutant retention, which prevents or mitigates downstream migration;
(4) groundwater recharge and water storage for future use;
(5) low flow augmentation including baseflow maintenance;
(6) water filtration including removal or storage of nutrients and other contaminants;
(7) propagation or maintenance of aquatic and terrestrial species indigenous to wetlands;
(8) preservation of wildlife habitat including habitat for threatened or endangered species; or
(9) supporting biological diversity.

In addition, wetlands shall support recreation, wildlife habitat, aquatic life and livestock watering uses.

[20.6.4.13 NMAC - Rp 20 NMAC 6.1.1105, 10/12/2000; A, 10/11/2002; Rn, 20.6.4.12 NMAC, 5/23/2005; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022; A, MM/DD/YYYY]

20.6.4.14 SAMPLING AND ANALYSIS:

A. Sampling and analytical techniques shall conform with methods described in the following references unless otherwise specified by the commission pursuant to a petition to amend these standards:

(1) "*Guidelines Establishing Test Procedures For The Analysis Of Pollutants Under The Clean Water Act*," 40 CFR Part 136 or any test procedure approved or accepted by EPA using procedures provided in 40 CFR Parts 136.3(d), 136.4, and 136.5;

(2) *Standard Methods For The Examination Of Water And Wastewater*, latest edition, American public health association;

(3) *Methods For Chemical Analysis Of Water And Waste*, and other methods published by EPA office of research and development or office of water;

(4) *Techniques Of Water Resource Investigations Of The U.S. Geological Survey*;

(5) *Annual Book Of ASTM Standards*: volumes 11.01 and 11.02, water (I) and (II), latest edition, ASTM international;

(6) *Federal Register*, latest methods published for monitoring pursuant to Resource Conservation and Recovery Act regulations;

(7) *National Handbook Of Recommended Methods For Water-Data Acquisition*, latest edition, prepared cooperatively by agencies of the United States government under the sponsorship of the U.S. geological survey; or

(8) *Federal Register*, latest methods published for monitoring pursuant to the Safe Drinking Water Act regulations.

B. Bacteriological Surveys: The monthly geometric mean shall be used in assessing attainment of criteria when a minimum of five samples is collected in a 30-day period.

C. Sampling Procedures:

(1) Streams: Stream monitoring stations below discharges shall be located a sufficient distance downstream to ensure adequate vertical and lateral mixing.

(2) Lakes: Sampling stations in lakes shall be located at least 250 feet from a discharge.

(3) Lakes: Except for the restriction specified in Paragraph (2) of this subsection, lake sampling stations shall be located at any site where the attainment of a water quality criterion is to be assessed.

[~~Water quality measurements taken at intervals in the entire water column at a sampling station shall be averaged for the epilimnion, or in the absence of an epilimnion, for the upper one-third of the water column of the lake to determine attainment of criteria, except that attainment of criteria for toxic pollutants shall be assessed during periods of complete vertical mixing, e.g., during spring or fall turnover, or by taking depth-integrated composite samples of the water column.~~]

D. Acute toxicity of effluent to aquatic life shall be determined using the procedures specified in U.S. environmental protection agency "*Methods for Measuring The Acute Toxicity of Effluents and Receiving Waters To*

Freshwater and Marine Organisms" (5th Ed., 2002, EPA 821-R-02-012), or latest edition thereof if adopted by EPA at 40 CFR Part 136, which is incorporated herein by reference. Acute toxicities of substances shall be determined using at least two species tested in whole effluent and a series of effluent dilutions. Acute toxicity due to discharges shall not occur within the wastewater mixing zone in any surface water of the state with an existing or designated aquatic life use.

E. Chronic toxicity of effluent or ambient surface waters of the state to aquatic life shall be determined using the procedures specified in U.S. environmental protection agency "*Short-Term Methods For Estimating The Chronic Toxicity Of Effluents And Receiving Waters To Freshwater Organisms*" (4th Ed., 2002, EPA 821-R-02-013), or latest edition thereof if adopted by EPA at 40 CFR Part 136, which is incorporated herein by reference. Chronic toxicities of substances shall be determined using at least two species tested in ambient surface water or whole effluent and a series of effluent dilutions. Chronic toxicity due to discharges shall not occur at the critical low flow, or any flow greater than the critical low flow, in any surface water of the state with an existing or designated aquatic life use more than once every three years.

F. Emerging Contaminants Monitoring: The department may require monitoring, analysis and reporting of emerging contaminants as a condition of a federal permit under Section 401 of the federal Clean Water Act.

[20.6.4.14 NMAC - Rp 20 NMAC 6.1.1106, 10/12/2000; Rn, 20.6.4.13 NMAC, 5/23/2005 & A, 5/23/2005; A, 12/1/2010; A 4/23/2022; A, MM/DD/YYYY]

20.6.4.15 USE ATTAINABILITY ANALYSIS:

A. Regulatory requirements for a use attainability analysis. Whenever a use attainability analysis is conducted, it shall be subject to the requirements and limitations set forth in 40 CFR Part 131, Water Quality Standards; specifically, Subsections 131.3(g), 131.10(g), 131.10(h) and 131.10(j) shall be applicable. In accordance with 40 CFR 131.10(i), and 20.6.4.10 NMAC, the amendment of a designated use, based on an existing use with more stringent criteria, does not require a use attainability analysis.

(1) The commission may remove a designated use, that is not an existing use, specified in Section 101(a)(2) of the federal Clean Water Act or adopt subcategories of a use in Section 101(a)(2) of the federal Clean Water Act requiring less stringent criteria only if a use attainability analysis demonstrates that attaining the use is not feasible because of a factor listed in 40 CFR 131.10(g). Uses in Section 101(a)(2) of the federal Clean Water Act, which refer to the protection and propagation of fish, shellfish and wildlife and recreation in and on the water, are also specified in Subsection B of 20.6.4.6 NMAC.

(2) A designated use cannot be removed if it is an existing use unless a use requiring more stringent criteria is designated.

B. Methods for developing a use attainability analysis. A use attainability analysis shall assess the physical, chemical, biological, economic or other factors affecting the attainment of a use. The analysis shall rely on scientifically defensible methods such as the methods described in the latest edition(s) of the following documents:

(1) *Water Quality Standards Handbook*, United States environmental protection agency, office of water, Washington, D.C., for current guidance and case studies for developing and implementing water quality standards;

[~~**(1)**~~]**(2)** *Technical Support Manual: Waterbody Surveys And Assessments For Conducting Use Attainability Analyses*, volume I (November 1983) and volume III (November 1984) [~~or latest editions~~], United States environmental protection agency, office of water, regulations and standards, Washington, D.C., for the evaluation of aquatic life or wildlife uses;

[~~**(2)**~~]**(3)** [~~the department's~~] *Water Quality Management Plan and Continuing Planning Process, Hydrology Protocol*, [~~latest edition, approved by the~~] water quality control commission, Santa Fe, NM, for identifying ephemeral, intermittent, and perennial waters; or

[~~**(3)**~~]**(4)** *Interim Economic Guidance For Water Quality Standards - Workbook*, March 1995, in conjunction with *Clean Water Act Financial Capability Assessment Guidance*, March 2024, United States environmental protection agency, office of water, Washington, D.C. for evaluating economic impacts.

C. Determining the highest attainable use. If the use attainability analysis determines that the designated use is not attainable based on one of the factors in 40 CFR 131.10(g), the use attainability analysis shall demonstrate the support for removing the designated use and then determine the highest attainable use, as defined in 40 CFR 131.3(m), for the protection and propagation of fish, shellfish and wildlife and recreation in and on the water based on methods described in Subsection B of this section.

D. Process to amend a designated use through a use attainability analysis.

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(1) The process for developing a use attainability analysis and petitioning the commission for removing a designated use and establishing the highest attainable use shall be done in accordance with the State's current *Water Quality Management Plan/Continuing Planning Process*.

(2) If the findings of a use attainability analysis, conducted by the department, in accordance with the department's *Hydrology Protocol* (latest edition) demonstrates that federal Clean Water Act Section 101(a)(2) uses, that are not existing uses, are not feasible in an ephemeral [~~water body~~] waterbody due to the factor in 40 CFR 131.10(g)(2), the department may consider proceeding with the expedited use attainability analysis process in accordance with the State's current *Water Quality Management Plan/Continuing Planning Process*. The following elements must be met for the expedited use attainability analysis process to be authorized and implemented:

(a) The department is the primary investigator of the use attainability analysis;

(b) The use attainability analysis determined, through the application of the *Hydrology Protocol*, that the [~~water~~] waterbody being investigated is ephemeral and has no effluent discharges of sufficient volume that could compensate for the low-flow;

(c) The use attainability analysis determined that the criteria associated with the existing uses of the [~~water~~] waterbody being investigated are not more stringent than those in 20.6.4.97 NMAC;

(d) The designated uses in 20.6.4.97 NMAC have been determined to be the highest attainable uses for the [~~water~~] waterbody being analyzed;

(e) The department posted the use attainability analysis on its water quality standards website and notified its interested parties list of a 30-day public comment period;

(f) The department reviewed and responded to any comments received during the 30-day public comment period; and

(g) The department submitted the use attainability analysis and response to comments to [~~region 6~~] EPA for technical [~~approval~~] review.

(3) If EPA approves the designated use revision(s) under section 303(c) of the Clean Water Act, the water shall be subject to 20.6.4.97 NMAC for federal Clean Water Act purposes. The use attainability analysis, the technical support document, and the applicability of 20.6.4.97 NMAC to the water shall be posted on the department's water quality standards website. The department shall periodically petition the commission to list ephemeral waters under Subsection C of 20.6.4.97 NMAC and to incorporate changes to classified segments as appropriate.

E. Use attainability analysis conducted by an entity other than the department. Any person may submit notice to the department stating their intent to conduct a use attainability analysis.

(1) The [~~proponent~~] notice shall [~~provide such notice along with~~] include a work plan supporting the development of a use attainability analysis [~~to~~] for the department's [~~and region 6 EPA for~~] review and comment.

(2) Upon approval of the work plan by the department, [~~the proponent shall conduct~~] the use attainability analysis shall be conducted in accordance with the applicable portions of Subsections A through D of this Section and [~~implement~~] public [~~noticing~~] notice provided in accordance with the approved work plan.

(3) Work plan elements. The work plan shall identify, at a minimum:

(a) the waterbody of concern and the reasoning for conducting a use attainability analysis;

(b) the source and validity of data to be used to demonstrate whether the current designated use is not attainable;

(c) the factors in 40 CFR 131.10(g) affecting the attainment of that use;

(d) a description of the data being proposed to be used to demonstrate the highest attainable use;

(e) the provisions for consultation with appropriate state and federal agencies;

(f) a description of how stakeholders and potentially affected tribes will be identified and engaged;

(g) a description of the public notice mechanisms to be employed; and

(h) the expected timelines outlining the administrative actions to be taken for a rulemaking petition, pending the outcome of the use attainability analysis.

(4) Upon completion of the use attainability analysis, [~~the proponent shall submit~~] the data, findings and conclusions shall be submitted to the department, and [~~provide~~] public notice of the use attainability analysis provided in accordance with the approved work plan.

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(5) Pending the conclusions of the use attainability analysis and as described in the approved work plan, the [~~department or the proponent~~] person conducting the use attainability analysis may petition the commission to modify the designated use. [~~The cost of such use attainability analysis shall be the responsibility of the proponent. Subsequent costs associated with the administrative rulemaking process shall be the responsibility of the petitioner.~~]

[20.6.4.15 NMAC - Rp 20 NMAC 6.1.1107, 10/12/2000; Rn, 20.6.4.14 NMAC, 5/23/2005; A, 5/23/2005; A, 7/17/2005; A, 12/1/2010; A, 4/23/2022; A, MM/DD/YYYY]

20.6.4.16 PLANNED USE OF A PISCICIDE: The use of a piscicide registered under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), 7 U.S.C. Section 136 *et seq*., and under the New Mexico Pesticide Control Act (NMPCA), Section 76-4-1 *et seq*. NMSA 1978 (1973) in a surface water of the state, shall not be a violation of Subsection F of 20.6.4.13 NMAC when such use is covered by a federal national pollutant discharge elimination system (NPDES) permit or has been approved by the commission under procedures provided in this section. The use of a piscicide which is covered by a NPDES permit shall require no further review by the commission and the person whose application is covered by the NPDES permit shall meet the additional notification and monitoring requirements outlined in Subsection G of 20.6.4.16 NMAC. The commission may approve the reasonable use of a piscicide under this section if the proposed use is not covered by a NPDES permit to further a Clean Water Act objective to restore and maintain the physical or biological integrity of surface waters of the state, including restoration of native species.

A. Any person seeking commission approval of the use of a piscicide not covered by a NPDES permit shall file a written petition concurrently with the commission and the surface water bureau of the department. The petition shall contain, at a minimum, the following information:

(1) petitioner's name and address;

(2) identity of the piscicide and the period of time (not to exceed five years) or number of applications for which approval is requested;

(3) documentation of registration under FIFRA and NMPCA and certification that the petitioner intends to use the piscicide according to the label directions, for its intended function;

(4) target and potential non-target species in the treated waters and adjacent riparian area, including threatened or endangered species;

(5) potential environmental consequences to the treated waters and the adjacent riparian area, and protocols for limiting such impacts;

(6) surface water of the state proposed for treatment;

(7) results of pre-treatment survey;

(8) evaluation of available alternatives and justification for selecting piscicide use;

(9) documentation of notice requesting public comment on the proposed use within a 30-day period, including information as described in Paragraphs (1), (2) and (6) of Subsection A of 20.6.4.16 NMAC, provided to:

(a) local political subdivisions;

(b) local water planning entities;

(c) local conservancy and irrigation districts; and

(d) local media outlets, except that the petitioner shall only be required to publish notice in a newspaper of circulation in the locality affected by the proposed use.

(10) copies of public comments received in response to the publication of notice and the petitioner's responses to public comments received;

(11) post-treatment assessment monitoring protocol; and

(12) any other information required by the commission.

B. Within 30 days of receipt of the petition, the department shall review the petition and file a recommendation with the commission to grant, grant with conditions or deny the petition. The recommendation shall include reasons, and a copy shall be sent to the petitioner by certified mail.

C. The commission shall review the petition, the public comments received under Paragraphs (9) and (10) of Subsection A of 20.6.4.16 NMAC, the petitioner's responses to public comments and the department's technical recommendations for the petition. A public hearing shall be held if the commission determines there is substantial public interest. The commission shall notify the petitioner and those commenting on the petition of the decision whether to hold a hearing and the reasons therefore in writing.

D. If the commission determines there is substantial public interest a public hearing shall be held within 90 days of receipt of the department's recommendation in the locality affected by the proposed use in

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accordance with 20.1.3 NMAC, Adjudicatory Procedures - Water Quality Control Commission. Notice of the hearing shall be given in writing by the petitioner to individuals listed under Subsection A of 20.6.4.16 NMAC as well as to individuals who provided public comment under that subsection at least 30 days prior to the hearing.

E. In a hearing provided for in this section or, if no hearing is held, in a commission meeting, the registration of a piscicide under FIFRA and NMPCA shall provide a rebuttable presumption that the determinations of the EPA Administrator in registering the piscicide, as outlined in 7 U.S.C. Section 136a(c)(5), are valid. For purposes of this Section the rebuttable presumptions regarding the piscicide include:

(1) Its composition is such as to warrant the proposed claims for it;

(2) Its labeling and other material submitted for registration comply with the requirements of FIFRA and NMPCA;

(3) It will perform its intended function without unreasonable adverse effects on the environment; and

(4) When used in accordance with all FIFRA label requirements it will not generally cause unreasonable adverse effects on the environment.

(5) "Unreasonable adverse effects on the environment" has the meaning provided in FIFRA, 7 U.S.C. Section 136(bb): "any unreasonable risk to man or the environment, taking into account the economic, social, and environmental costs and benefits of the use of any pesticide."

F. After a public hearing, or commission meeting if no hearing is held, the commission may grant the petition in whole or in part, may grant the petition subject to conditions, or may deny the petition. In granting any petition in whole or part or subject to conditions, the commission shall require the petitioner to implement post-treatment assessment monitoring and provide notice to the public in the immediate and near downstream vicinity of the application prior to and during the application.

G. Any person whose application is covered by a NPDES permit shall provide written notice to local entities as described in Subsection A of 20.6.4.16 NMAC and implement post-treatment assessment monitoring within the application area as described in Subsection F of 20.6.4.16 NMAC.

[20.6.4.16 NMAC - Rn, Paragraph (6) of Subsection F of 20.6.4.12 NMAC, 5/23/2005; A, 5/23/2005; A, 3/2/2017]

20.6.4.17 - 20.6.4.49 [**RESERVED**]

20.6.4.50 BASINWIDE PROVISIONS - Special provisions arising from interstate compacts, international treaties or court decrees or that otherwise apply to a basin are contained in 20.6.4.51 through 20.6.4.59 NMAC.

[20.6.4.50 NMAC - N, 5/23/2005]

20.6.4.51 [**RESERVED**]

20.6.4.52 PECOS RIVER BASIN - In order to protect existing and designated uses, it is a goal of the state of New Mexico to prevent increases in TDS in the Pecos river above the following benchmark values, which are expressed as flow-weighted, annual average concentrations, at three USGS gaging stations: at Santa Rosa 500 mg/L; near Artesia 2,700 mg/L; and near Malaga 3,600 mg/L. The benchmark values serve to guide state action. They are adopted pursuant to the New Mexico Water Quality Act, not the Clean Water Act.

[20.6.4.52 NMAC - N, 12/1/2010]

20.6.4.53 [**RESERVED**]

20.6.4.54 COLORADO RIVER BASIN - For the tributaries of the Colorado river system, the state of New Mexico will cooperate with the Colorado river basin states and the federal government to support and implement the salinity policy and program outlined in the most current "review, water quality standards for salinity, Colorado river system" or equivalent report by the Colorado river salinity control forum.

A. Numeric criteria expressed as the flow-weighted annual average concentration for salinity are established at three points in the Colorado river basin as follows: below Hoover dam, 723 mg/L; below Parker dam, 747 mg/L; and at Imperial dam, 879 mg/L.

B. As a part of the program, objectives for New Mexico shall include the elimination of discharges of water containing solids in solution as a result of the use of water to control or convey fly ash from coal-fired electric generators, wherever practicable.

[20.6.4.54 NMAC - Rn, Paragraphs (1) through (3) of Subsection K of 20.6.4.12 NMAC, 5/23/2005; A, 5/23/2005]

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20.6.4.55 - 20.6.4.96 [**RESERVED**]

20.6.4.97 EPHEMERAL WATERS: Ephemeral surface waters of the state as identified below and additional ephemeral waters as identified on the department's water quality standards website pursuant to Paragraph (2) of Subsection D of 20.6.4.15 NMAC are subject to the designated uses and criteria as specified in this section. Ephemeral waters classified in 20.6.4.101-899 NMAC are subject to the designated uses and criteria as specified in those sections.

A. Designated uses: livestock watering, wildlife habitat, limited aquatic life and secondary contact.

B. Criteria: the use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses.

C. Waters:

(1) the following waters are designated in the Rio Grande basin:

(a) Cunningham gulch from Santa Fe county road 55 upstream 1.4 miles to a point upstream of the Lac minerals mine, identified as Ortiz mine on U.S. geological survey topographic maps;

(b) an unnamed tributary from Arroyo Hondo upstream 0.4 miles to the Village of Oshara water reclamation facility outfall;

(c) an unnamed tributary from San Pedro creek upstream 0.8 miles to the PAA-KO community sewer outfall;

(d) Inditos draw from the crossing of an unnamed road along a power line one-quarter mile west of McKinley county road 19 upstream to New Mexico highway 509;

(e) an unnamed tributary from the diversion channel connecting Blue canyon and Socorro canyon upstream 0.6 miles to the New Mexico firefighters academy treatment facility outfall;

(f) an unnamed tributary from the Albuquerque metropolitan arroyo flood control authority (AMAFCA) Rio Grande south channel upstream of the crossing of New Mexico highway 47 upstream to I-25;

(g) the south fork of Cañon del Piojo from Cañon del Piojo upstream 1.2 miles to an unnamed tributary;

(h) an unnamed tributary from the south fork of Cañon del Piojo upstream 1 mile to the Resurrection mine outfall;

(i) Arroyo del Puerto from San Mateo creek upstream 6.8 miles to the Ambrosia Lake mine entrance road;

(j) an unnamed tributary from San Mateo creek upstream 1.5 miles to the Roca Honda mine facility outfall;

(k) San Isidro arroyo, including unnamed tributaries to San Isidro arroyo, from Arroyo Chico upstream to its headwaters;

(l) Arroyo Tinaja, including unnamed tributaries to Arroyo Tinaja, from San Isidro arroyo upstream to 2 miles northeast of the Cibola national forest boundary;

(m) Mulatto canyon from Arroyo Tinaja upstream to 1 mile northeast of the Cibola national forest boundary; and

(n) Doctor arroyo, including unnamed tributaries to Doctor arroyo, from San Isidro arroyo upstream to its headwaters, and excluding Doctor Spring and Doctor arroyo from the spring to its confluence with the unnamed tributary approximately one-half mile downstream of the spring.

(2) the following waters are designated in the Pecos river basin:

(a) an unnamed tributary from Hart canyon upstream 1 mile to South Union road;

(b) Aqua Chiquita from Rio Peñasco upstream to McEwan canyon; and

(c) Grindstone canyon upstream of Grindstone reservoir.

(3) the following waters are designated in the Canadian river basin:

(a) Bracket canyon upstream of the Vermejo river;

(b) an unnamed tributary from Bracket canyon upstream 2 miles to the Ancho mine; and

(c) Gachupin canyon from the Vermejo river upstream 2.9 miles to an unnamed west tributary near the Ancho mine outfall.

(4) in the San Juan river basin an unnamed tributary of Kim-me-ni-oli wash upstream of the mine outfall.

(5) the following waters are designated in the Little Colorado river basin:

(a) Defiance draw from County Road 1 to upstream of West Defiance Road; and

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(b) an unnamed tributary of Defiance draw from McKinley county road 1 upstream to New Mexico highway 264.

(6) the following waters are designated in the closed basins:

(a) in the Tularosa river closed basin San Andres canyon downstream of South San Andres canyon; and

(b) in the Mimbres river closed basin San Vicente arroyo from the Mimbres river upstream to Maudes canyon.

[20.6.4.97 NMAC - N, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 12/17/2019; A, 4/23/2022]

20.6.4.98 INTERMITTENT WATERS: All non-perennial surface waters of the state, except those ephemeral waters included under section 20.6.4.97 NMAC or classified in 20.6.4.101-899 NMAC.

A. Designated uses: livestock watering, wildlife habitat, marginal warmwater aquatic life and primary contact.

B. Criteria: the use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following site-specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.98 NMAC - N, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, MM/DD/YYYY]

20.6.4.99 PERENNIAL WATERS: All perennial surface waters of the state except those classified in 20.6.4.101-899 NMAC.

A. Designated uses: Warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following site-specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.99 NMAC - N, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, MM/DD/YYYY]

20.6.4.100 [**RESERVED**]

20.6.4.101 RIO GRANDE BASIN: The main stem of the Rio Grande from the international boundary with Mexico upstream to one mile downstream of Percha dam.

A. Designated uses: irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criterion applies: temperature 34°C (93.2°F) or less.

(2) At mean monthly flows above 350 cfs, the monthly average concentration for: TDS 2,000 mg/L or less, sulfate 500 mg/L or less and chloride 400 mg/L or less.

C. Remarks: sustained flow in the Rio Grande below Caballo reservoir is dependent on release from Caballo reservoir during the irrigation season; at other times of the year, there may be little or no flow.

[20.6.4.101 NMAC - Rp 20 NMAC 6.1.2101, 10/12/2010; A, 12/15/2001; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.102 RIO GRANDE BASIN: The main stem of the Rio Grande from one mile downstream of Percha dam upstream to Caballo dam.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

C. Remarks: sustained flow in the Rio Grande downstream of Caballo reservoir is dependent on release from Caballo reservoir during the irrigation season; at other times of the year, there may be little or no flow.

[20.6.4.102 NMAC - Rp 20 NMAC 6.1.2102, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.103 RIO GRANDE BASIN: Perennial reaches of tributaries to the Rio Grande in Sierra and Socorro counties not specifically identified under other sections of 20.6.4 NMAC, excluding waters on tribal lands.

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A. Designated uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, secondary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.103 NMAC - Rp 20 NMAC 6.1.2103, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

[**NOTE:** This segment was divided effective 4/23/2022. The standards for the main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam, perennial reaches of Palomas creek, perennial reaches of Rio Salado, perennial reaches of Percha creek, perennial reaches of Alamosa creek, Las Animas creek, and perennial reaches of Abo arroyo are under 20.6.4.112 NMAC.]

20.6.4.104 RIO GRANDE BASIN: Caballo and Elephant Butte reservoir.

A. Designated uses: irrigation storage, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.104 NMAC - Rp 20 NMAC 6.1.2104, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.105 RIO GRANDE BASIN: The main stem of the Rio Grande from the headwaters of Elephant Butte reservoir upstream to Alameda bridge (Corrales bridge), excluding waters on Isleta pueblo.

A. Designated uses: irrigation, marginal warmwater aquatic life, livestock watering, public water supply, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At mean monthly flows above 100 cfs, the monthly average concentration for: TDS l,500 mg/L or less, sulfate 500 mg/L or less and chloride 250 mg/L or less.

[20.6.4.105 NMAC - Rp 20 NMAC 6.1.2105, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.106 RIO GRANDE BASIN: The main stem of the Rio Grande from Alameda bridge (Corrales bridge) upstream to the Angostura diversion works, excluding waters on Santa Ana pueblo, and intermittent water in the Jemez river below the Jemez pueblo boundary, excluding waters on Santa Ana and Zia pueblos, that enters the main stem of the Rio Grande. Portions of the Rio Grande in this segment are under the joint jurisdiction of the state and Sandia pueblo.

A. Designated uses: irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact; and public water supply on the Rio Grande.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At mean monthly flows above 100 cfs, the monthly average concentration for: TDS 1,500 mg/L or less, sulfate 500 mg/L or less and chloride 250 mg/L or less.

[20.6.4.106 NMAC - Rp 20 NMAC 6.1.2105.1, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.107 RIO GRANDE BASIN: The Jemez river from the Jemez pueblo boundary upstream to Soda dam near the town of Jemez Springs and perennial reaches of Vallecito creek.

A. Designated uses: coldwater aquatic life, primary contact, irrigation, livestock watering and wildlife habitat; and public water supply on Vallecito creek.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F).

[20.6.4.107 NMAC - Rp 20 NMAC 6.1.2105.5, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.108 RIO GRANDE BASIN: Perennial reaches of the Jemez river upstream of Soda dam near the town of Jemez Springs and perennial reaches of tributaries to the Jemez river except those not specifically identified under other sections of 20.6.4 NMAC, and perennial reaches of the Guadalupe river and perennial reaches of tributaries to the Guadalupe river, and Calaveras canyon.

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A. Designated uses: domestic water supply, fish culture, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 400 µS/cm or less (800 µS/cm or less on Sulphur creek); the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less; and pH within the range of 2.0 to 8.8 on Sulphur creek.

[20.6.4.108 NMAC - Rp 20 NMAC 6.1.2106, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012; A, 4/23/2022]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.124 NMAC. The standards for San Gregorio lake are in 20.6.4.134 NMAC, effective 7/10/2012]

20.6.4.109 RIO GRANDE BASIN: Perennial reaches of Bluewater creek excluding Bluewater lake and waters on tribal lands, Rio Moquino upstream of Laguna pueblo, Seboyeta creek, Rio Paguate upstream of Laguna pueblo, the Rio Puerco upstream of the northern boundary of Cuba, and all other perennial reaches of tributaries to the Rio Puerco, including the Rio San Jose in Cibola county from the USGS gaging station at Correo upstream to Horace springs excluding waters on tribal lands.

A. Designated uses: coldwater aquatic life, domestic water supply, fish culture, irrigation, livestock watering, wildlife habitat and primary contact; and public water supply on La Jara creek.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: phosphorus (unfiltered sample) 0.1 mg/L or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.109 NMAC - Rp 20 NMAC 6.1.2107, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012]

[**NOTE:** The standards for Bluewater lake are in 20.6.4.135 NMAC, effective 7/10/2012]

20.6.4.110 RIO GRANDE BASIN: The main stem of the Rio Grande from Angostura diversion works upstream to Cochiti dam, excluding the reaches on San Felipe, Kewa and Cochiti pueblos.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact, coldwater aquatic life and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: pH within the range of 6.6 to 9.0 and temperature 25°C (77°F) or less.

[20.6.4.110 NMAC - Rp 20 NMAC 6.1.2108, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.111 RIO GRANDE BASIN: Perennial reaches of Las Huertas creek from the San Felipe pueblo boundary to the headwaters.

A. Designated uses: high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

[20.6.4.111 NMAC - Rp 20 NMAC 6.1.2108.5, 10/12/2000; A, 7/25/2001; A, 5/23/2005; A-12/1/2010]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.125 NMAC.]

20.6.4.112 RIO GRANDE BASIN: The main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam, perennial reaches of Palomas creek, perennial reaches of Rio Salado, perennial reaches of Percha creek, perennial reaches of Alamosa creek, Las Animas creek, and perennial reaches of Abo arroyo.

A. Designated uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

C. Remarks: flow in this reach of the Rio Grande main stem is dependent upon release from Elephant Butte dam.

[20.6.4.112 NMAC - Rp 20 NMAC 6.1.2109, 10/12/2000; A, 5/23/2005; Repealed, 12/1/2010; A, 4/23/2022]

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20.6.4.113 RIO GRANDE BASIN: The Santa Fe river and perennial reaches of its tributaries from the Cochiti pueblo boundary upstream to the outfall of the Santa Fe wastewater treatment facility.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact and coolwater aquatic life.

B. Criteria: The use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 30°C (86°F) or less.

[20.6.4.113 NMAC - Rp 20 NMAC 6.1.2110, 10/12/2000; A, 10/11/2002; A, 5/23/2005; A, 12/1/2010; A, 2/14/2013]

20.6.4.114 RIO GRANDE BASIN: The main stem of the Rio Grande from the Cochiti pueblo boundary upstream to Rio Pueblo de Taos excluding waters on San Ildefonso, Santa Clara and Ohkay Owingeh pueblos, Embudo creek from its mouth on the Rio Grande upstream to the Picuris Pueblo boundary, the Santa Cruz river from the Santa Clara pueblo boundary upstream to the Santa Cruz dam, the Rio Tesuque except waters on the Tesuque and Pojoaque pueblos, and the Pojoaque river from the San Ildefonso pueblo boundary upstream to the Pojoaque pueblo boundary. Some Rio Grande waters in this segment are under the joint jurisdiction of the state and San Ildefonso pueblo.

A. Designated uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, primary contact and warmwater aquatic life; and public water supply on the main stem Rio Grande.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: 6T3 temperature 22°C (71.6°F) and maximum temperature 25°C (78.8°F). In addition, the following criteria based on a 12-month rolling average are applicable to the public water supply use for monitoring and public disclosure purposes only:

Radionuclide	pCi/L
Americium-241	1.9
Cesium-137	6.4
Plutonium-238	1.5
Plutonium-239/240	1.5
Strontium-90	3.5
Tritium	4,000

(2) At mean monthly flows above 100 cfs, the monthly average concentration for: TDS 500 mg/L or less, sulfate 150 mg/L or less and chloride 25 mg/L or less.

[20.6.4.114 NMAC - Rp 20 NMAC 6.1.2111, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.115 RIO GRANDE BASIN: The perennial reaches of Rio Vallecitos, perennial reaches of tributaries to Rio Vallecitos except Hopewell lake, and perennial reaches of Rio del Oso and perennial reaches of El Rito creek above the town of El Rito.

A. Designated uses: domestic water supply, irrigation, high quality coldwater aquatic life, livestock watering, wildlife habitat and primary contact; public water supply on the Rio Vallecitos and El Rito creek.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.115 NMAC - Rp 20 NMAC 6.1.2112, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012; A, 4/23/2022]

[**NOTE:** The standards for Hopewell lake are in 20.6.4.134 NMAC, effective 7/10/2012]

20.6.4.116 RIO GRANDE BASIN: The Rio Chama from its mouth on the Rio Grande upstream to Abiquiu reservoir, perennial reaches of the Rio Tusas, perennial reaches of the Rio Ojo Caliente, perennial reaches of Abiquiu creek and perennial reaches of El Rito creek downstream of the town of El Rito.

A. Designated uses: irrigation, livestock watering, wildlife habitat, coldwater aquatic life, warmwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 31°C (87.8°F) or less.

[20.6.4.116 NMAC - Rp 20 NMAC 6.1.2113, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022]

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20.6.4.117 RIO GRANDE BASIN: Abiquiu reservoir.

A. Designated uses: irrigation storage, livestock watering, wildlife habitat, primary contact, coldwater aquatic life and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

[20.6.4.117 NMAC - Rp 20 NMAC 6.1.2114, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.118 RIO GRANDE BASIN: The Rio Chama from the headwaters of Abiquiu reservoir upstream to El Vado reservoir and perennial reaches of the Rio Gallina and Rio Puerco de Chama north of state highway 96. Some Rio Chama waters in this segment are under the joint jurisdiction of the state and the Jicarilla Apache tribe.

A. Designated uses: irrigation, livestock watering, wildlife habitat, coldwater aquatic life, warmwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 26°C (78.8°F) or less.

[20.6.4.118 NMAC - Rp 20 NMAC 6.1.2115, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.119 RIO GRANDE BASIN: All perennial reaches of tributaries to the Rio Chama above Abiquiu dam, except Canjilon lakes a, c, e and f and the Rio Gallina and Rio Puerco de Chama north of state highway 96 and excluding waters on Jicarilla Apache reservation, and the main stem of the Rio Chama from the headwaters of El Vado reservoir upstream to the New Mexico-Colorado line. Some Cañones creek and Rio Chama waters in this segment are under the joint jurisdiction of the state and the Jicarilla Apache tribe.

A. Designated uses: domestic water supply, fish culture, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact; and public water supply on the Rio Brazos and Rio Chama.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less (1,000 µS or less for Coyote creek); the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.119 NMAC - Rp 20 NMAC 6.1.2116, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012]

[**NOTE:** The standards for Canjilon lakes a, c, e and f are in 20.6.4.134 NMAC, effective 7/10/2012]

20.6.4.120 RIO GRANDE BASIN: El Vado and Heron reservoirs.

A. Designated uses: irrigation storage, livestock watering, wildlife habitat, public water supply, primary contact and coldwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.120 NMAC - Rp 20 NMAC 6.1.2117, 10/12/2000; A. 5/23/2005; A, 12/1/2010]

20.6.4.121 RIO GRANDE BASIN: Perennial tributaries to the Rio Grande in Bandelier national monument and their headwaters in Sandoval county and all perennial reaches of tributaries to the Rio Grande in Santa Fe county unless included in other segments and excluding waters on tribal lands.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact; and public water supply on Little Tesuque creek, the Rio en Medio, and the Santa Fe river.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.121 NMAC - Rp 20 NMAC 6.1.2118, 10/12/2000; A. 5/23/2005; A, 12/1/2010; A, 2/14/2013]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segments are under 20.6.4.126, 20.6.4.127 and 20.6.4.128 NMAC.]

20.6.4.122 RIO GRANDE BASIN: The main stem of the Rio Grande from Rio Pueblo de Taos upstream to the New Mexico-Colorado line, the Red river from its mouth on the Rio Grande upstream to the

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mouth of Placer creek, and the Rio Pueblo de Taos from its mouth on the Rio Grande upstream to the mouth of the Rio Grande del Rancho. Some Rio Grande and Rio Pueblo de Taos waters in this segment are under the joint jurisdiction of the state and Taos pueblo.

A. Designated uses: coldwater aquatic life, fish culture, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.122 NMAC - Rp 20 NMAC 6.1.2119, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.123 RIO GRANDE BASIN: Perennial reaches of the Red river upstream of the mouth of Placer creek, all perennial reaches of tributaries to the Red river, and all other perennial reaches of tributaries to the Rio Grande in Taos and Rio Arriba counties unless included in other segments and excluding waters on Santa Clara, Ohkay Owingeh, Picuris and Taos pueblos.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact; and public water supply on the Rio Pueblo and Rio Fernando de Taos.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 400 µS/cm or less (500 µS/cm or less for the Rio Fernando de Taos); the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less; and phosphorus (unfiltered sample) less than 0.1 mg/L for the Red river.

[20.6.4.123 NMAC - Rp 20 NMAC 6.1.2120, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.129 NMAC.]

20.6.4.124 RIO GRANDE BASIN: Perennial reaches of Sulphur creek from its confluence with Redondo creek upstream to its headwaters.

A. Designated uses: limited aquatic life, wildlife habitat, livestock watering and secondary contact.

B. Criteria: the use-specific criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: pH within the range of 2.0 to 9.0, maximum temperature 30ºC (86ºF), and the chronic aquatic life criteria of Subsections I and J of 20.6.4.900 NMAC.

[20.6.4.124 NMAC - N, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.125 RIO GRANDE BASIN: Perennial reaches of San Pedro creek from the San Felipe pueblo boundary to the headwaters.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

[20.6.4.125 NMAC - N, 5/23/2005; A, 12/1/2010]

20.6.4.126 RIO GRANDE BASIN: Perennial waters within lands managed by the U.S. department of energy (DOE) within Los Alamos National Laboratory (LANL), including but not limited to: Cañon de Valle from LANL stream gage E256 upstream to Burning Ground spring, Sandia canyon at Sigma canyon upstream to Sandia canyon at Bedrock Road, Pajarito canyon from 0.5 miles below Arroyo de La Delfe upstream to Homestead spring, Arroyo de la Delfe from Pajarito canyon to Kieling spring, Starmers gulch and Starmers spring and Water canyon from Area-A canyon upstream to State Route 501.

A. Designated uses: coldwater aquatic life, livestock watering, wildlife habitat and secondary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.126 NMAC - N, 5/23/2005; A, 12/1/2010; A, 4/23/2022; A, 11/8/2025]

20.6.4.127 RIO GRANDE BASIN: Perennial portions of Los Alamos canyon upstream from Los Alamos reservoir and Los Alamos reservoir.

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A. Designated uses: coldwater aquatic life, livestock watering, wildlife habitat, irrigation and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.127 NMAC - N, 5/23/2005; A, 12/1/2010]

20.6.4.128 RIO GRANDE BASIN: Ephemeral and intermittent waters within lands managed by U.S. department of energy (DOE) within LANL, including but not limited to: Mortandad canyon, Cañada del Buey, Ancho canyon, Chaquehui canyon, Indio canyon, Fence canyon, Potrillo canyon, and portions of Cañon de Valle, Los Alamos canyon, Sandia canyon, Pajarito canyon and Water canyon not identified in 20.6.4.126 NMAC or 20.6.4.140 NMAC. (Surface waters within lands scheduled for transfer from DOE to tribal, state or local authorities are specifically excluded.)

A. Designated uses: livestock watering, wildlife habitat, limited aquatic life and secondary contact.

B. Criteria: the use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the acute total ammonia criteria set forth in Subsection L of 20.6.4.900 NMAC (*Oncorhynchus* spp. absent).

[20.6.4.128 NMAC - N, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

[**NOTE:** This section was divided effective 4/23/2022. The standards for some intermittent waters within LANL are in 20.6.4.140 NMAC.]

20.6.4.129 RIO GRANDE BASIN: Perennial reaches of the Rio Hondo.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 400 µS/cm or less and phosphorus (unfiltered sample) less than 0.1 mg/L.

[20.6.4.129 NMAC - N, 5/23/2005; A, 12/1/2010]

20.6.4.130 RIO GRANDE BASIN: The Rio Puerco from the Rio Grande upstream to Arroyo Chijuilla, excluding the reaches on Isleta, Laguna and Cañoncito Navajo pueblos. Some waters in this segment are under the joint jurisdiction of the state and Isleta, Laguna or Cañoncito Navajo pueblos.

A. Designated uses: irrigation, warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At mean monthly flows above 100 cfs, the monthly average concentration for: TDS l,500 mg/L or less, sulfate 500 mg/L or less and chloride 250 mg/L or less.

[20.6.4.130 NMAC - N, 12/1/2010]

20.6.4.131 RIO GRANDE BASIN: The Rio Puerco from the confluence of Arroyo Chijuilla upstream to the northern boundary of Cuba.

A. Designated uses: warmwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.131 NMAC - N, 12/1/2010]

20.6.4.132 RIO GRANDE BASIN: Rio Grande (Klauer) spring

A. Designated uses: domestic water supply, wildlife habitat, livestock watering, coldwater aquatic life use and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.132 NMAC - N, 12/1/2010]

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20.6.4.133 RIO GRANDE BASIN: Bull Creek lake, Cow lake, Elk lake, Goose lake, Heart lake, Hidden lake (Lake Hazel), Horseshoe lake, Horseshoe (Alamitos) lake, Jose Vigil lake, Lost lake, Middle Fork lake, Nambe lake, Nat II lake, Nat IV lake, No Fish lake, Pioneer lake, San Leonardo lake, Santa Fe lake, Serpent lake, South Fork lake, Trampas lakes (east and west) and Williams lake.

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.133 NMAC - N, 7/10/2012]

20.6.4.134 RIO GRANDE BASIN: Cabresto lake, Canjilon lakes a, c, e and f, Fawn lakes (east and west), Hopewell lake and San Gregorio lake.

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.134 NMAC - N, 7/10/2012]

20.6.4.135 RIO GRANDE BASIN: Bluewater lake and Santa Cruz lake.

A. Designated uses: coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: phosphorus (unfiltered sample) 0.1 mg/L or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.135 NMAC - N, 7/10/2012; A, MM/DD/YYYY]

20.6.4.136 RIO GRANDE BASIN: The Santa Fe river from the outfall of the Santa Fe wastewater treatment facility to Guadalupe street.

A. Designated uses: limited aquatic life, wildlife habitat, primary contact, livestock watering, and irrigation.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.136 NMAC - N, 2/14/2013]

20.6.4.137 RIO GRANDE BASIN: The Santa Fe river from Guadalupe street to Nichols reservoir.

A. Designated uses: coolwater aquatic life, wildlife habitat, primary contact, livestock watering, and irrigation.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.137 NMAC - N, 2/14/2013]

20.6.4.138 RIO GRANDE BASIN: Nichols and McClure reservoirs.

A. Designated uses: high quality coldwater aquatic life, wildlife habitat, primary contact, public water supply and irrigation.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.138 NMAC - N, 2/14/2013]

20.6.4.139 RIO GRANDE BASIN: Perennial reaches of Galisteo creek and perennial reaches of its tributaries from Kewa pueblo upstream to 2.2 miles upstream of Lamy.

A. Designated uses: coolwater aquatic life, primary contact, irrigation, livestock watering, domestic water supply and wildlife habitat; and public water supply on Cerrillos reservoir.

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B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.139 NMAC - N, 2/14/2013]

20.6.4.140 RIO GRANDE BASIN: Effluent canyon from Mortandad canyon to its headwaters, intermittent portions of S-Site canyon from monitoring well MSC 16-06293 to Martin spring, and intermittent portions of Twomile canyon from its confluence with Pajarito canyon to Upper Twomile canyon. (Surface waters within lands scheduled for transfer from DOE to tribal, state or local authorities are specifically excluded.)

A. Designated uses: livestock watering, wildlife habitat, marginal warmwater aquatic life and secondary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
[20.6.4.140 NMAC - N, 4/23/2022]

20.6.4.141 RIO GRANDE BASIN: Sandia canyon from Sandia canyon at Bedrock Road upstream to LANL NPDES outfall 001.

A. Designated uses: coolwater aquatic life, livestock watering, wildlife habitat and secondary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following additional segment-specific criterion applies: a 6T3 temperature of 25°C (77°F).
[20.6.4.141 NMAC - N, 11/8/2025]

20.6.4.142 - 20.6.4.200 [RESERVED]

20.6.4.201 PECOS RIVER BASIN: The main stem of the Pecos river from the New Mexico-Texas line upstream to the mouth of the Black river (near Loving).

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria:

(l) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: dissolved boron for irrigation use 2,000 µg/L or less.

(2) At all flows above 50 cfs: TDS 20,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 10,000 mg/L or less.
[20.6.4.201 NMAC - Rp 20 NMAC 6.1.2201, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.202 PECOS RIVER BASIN: The main stem of the Pecos river from the mouth of the Black river upstream to lower Tansil dam, including perennial reaches of the Black river, the Delaware river and Blue spring.

A. Designated uses: industrial water supply, irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria:

(l) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 34°C (93.2°F) or less.

(2) At all flows above 50 cfs: TDS 8,500 mg/L or less, sulfate 2,500 mg/L or less and chloride 3,500 mg/L or less.

C. Remarks: diversion for irrigation frequently limits summer flow in this reach of the main stem Pecos river to that contributed by springs along the watercourse.
[20.6.4.202 NMAC - Rp 20 NMAC 6.1.2202, 10/12/2000; A, 5/23/2005; A, 12/1/2010]
[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for Lower Tansil Lake and Lake Carlsbad are under 20.6.4.218 NMAC.]

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20.6.4.203 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Lake Carlsbad upstream to Avalon dam.

A. Designated uses: industrial water supply, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: temperature 34°C (93.2°F) or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.203 NMAC - Rp 20 NMAC 6.1.2203, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for Lower Tansil Lake and Lake Carlsbad are under 20.6.4.218 and for Avalon Reservoir are under 20.6.4.219 NMAC.]

20.6.4.204 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Avalon reservoir upstream to Brantley dam.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.204 NMAC - Rp 20 NMAC 6.1.2204, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for Avalon Reservoir are under 20.6.4.219 NMAC.]

20.6.4.205 PECOS RIVER BASIN: Brantley reservoir.

A. Designated uses: irrigation storage, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.205 NMAC - Rp 20 NMAC 6.1.2205, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.206 PECOS RIVER BASIN: Perennial reaches of the Rio Felix[~~ and perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon, excluding North Spring river~~].

A. Designated uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

[20.6.4.206 NMAC - Rp 20 NMAC 6.1.2206, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022; A, MM/DD/YYYY]

[**NOTE:** This segment was divided effective 4/23/2022. The standards for the main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, and perennial reaches of the Rio Hondo are under 20.6.4.231 NMAC.]

20.6.4.207 PECOS RIVER BASIN: The main stem of the Pecos river from Salt creek (near Acme) upstream to Sumner dam.

A. Designated uses: irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 8,000 mg/L or less, sulfate 2,500 mg/L or less and chloride 4,000 mg/L or less.

[20.6.4.207 NMAC - Rp 20 NMAC 6.1.2207, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

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20.6.4.208 PECOS RIVER BASIN: Perennial reaches of the Rio Peñasco above [~~state highway 24 near Dunken~~] Bear Canyon, perennial reaches of tributaries to the Rio Peñasco above [~~state highway 24 near Dunken~~] Bear Canyon, perennial reaches of Cox canyon, perennial reaches of the Rio Bonito downstream from [~~state highway 48 (near Angus)~~] Angus canyon, the Rio Ruidoso downstream of [~~the U.S. highway 70 bridge~~] Palo Verde canyon near Seeping Springs lakes, perennial reaches of the Rio Hondo upstream from Bonney canyon and perennial reaches of Agua Chiquita.

A. Designated uses: fish culture, irrigation, livestock watering, wildlife habitat, coldwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: temperature 30°C (86°F) or less, and phosphorus (unfiltered sample) less than 0.1 mg/L.

[20.6.4.208 NMAC - Rp 20 NMAC 6.1.2208, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022; A, MM/DD/YYYY]

20.6.4.209 PECOS RIVER BASIN: Perennial reaches of Eagle creek upstream of Alto dam to the Mescalero Apache boundary, perennial reaches of the Rio Bonito upstream of [~~state highway 48 (near Angus)~~] Angus canyon excluding Bonito lake, perennial reaches of tributaries to the Rio Bonito upstream of [~~state highway 48 (near Angus)~~] Angus canyon, perennial reaches of the Rio Ruidoso upstream of [~~the U.S. highway 70 bridge~~] Palo Verde canyon near Seeping Springs lakes above and below the Mescalero Apache boundary and perennial reaches of tributaries to the Rio Ruidoso upstream of [~~the U.S. highway 70 bridge~~] Palo Verde canyon near Seeping Springs lakes above and below the Mescalero Apache boundary.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 600 µS/cm or less in Eagle creek, 1,100 µS/cm or less in Bonito creek and 1,500 µS/cm or less in the Rio Ruidoso; phosphorus (unfiltered sample) less than 0.1 mg/L; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.209 NMAC - Rp 20 NMAC 6.1.2209, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012; A, 4/23/2022; A, MM/DD/YYYY]

[**NOTE:** The standards for Bonito lake are in 20.6.4.223 NMAC, effective 7/10/2012]

20.6.4.210 PECOS RIVER BASIN: Sumner reservoir.

A. Designated uses: irrigation storage, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.210 NMAC - Rp 20 NMAC 6.1.2210, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.211 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Sumner reservoir upstream to Tecolote creek excluding Santa Rosa reservoir.

A. Designated uses: fish culture, irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 3,000 mg/L or less, sulfate 2,000 mg/L or less and chloride 400 mg/L or less.

[20.6.4.211 NMAC - Rp 20 NMAC 6.1.2211, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012]

[**NOTE:** The standards for Santa Rosa reservoir are in 20.6.4.225 NMAC, effective 7/10/2012]

20.6.4.212 PECOS RIVER BASIN: Perennial tributaries to the main stem of the Pecos river from the headwaters of Sumner reservoir upstream to Santa Rosa dam.

A. Designated uses: irrigation, coldwater aquatic life, livestock watering, wildlife habitat and primary contact.

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B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.
[20.6.4.212 NMAC - Rp 20 NMAC 6.1.2211.1, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.213 PECOS RIVER BASIN: McAllister lake.

A. Designated uses: coldwater aquatic life, secondary contact, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.
[20.6.4.213 NMAC - Rp 20 NMAC 6.1.2211.3, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.214 PECOS RIVER BASIN: Storrie lake.

A. Designated uses: coldwater aquatic life, warmwater aquatic life, primary contact, livestock watering, wildlife habitat, public water supply and irrigation storage.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.214 NMAC - Rp 20 NMAC 6.1.2211.5, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.215 PECOS RIVER BASIN: Perennial reaches of the Gallinas river upstream of the diversion for the Las Vegas municipal reservoir, perennial reaches of tributaries to the Gallinas river upstream of the diversion for the Las Vegas municipal reservoir, perennial reaches of Tecolote creek upstream of Blue creek and all perennial reaches of tributaries to Tecolote creek upstream of Blue creek.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, industrial water supply and primary contact; and public water supply on the Gallinas river.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less (450 µS/cm or less in Wright Canyon creek); the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.215 NMAC - Rp 20 NMAC 6.1.2212, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 2/13/2018; A, 4/23/2022]
[**NOTE:** This segment was divided effective 2/13/2018. The standards for Tecolote creek from I-25 to Blue creek are under 20.6.4.230 NMAC.]

20.6.4.216 PECOS RIVER BASIN: The main stem of the Pecos river from Tecolote creek upstream to Cañon de Manzanita.

A. Designated uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 30°C (86°F) or less.

(2) At all flows above 10 cfs: TDS 250 mg/L or less, sulfate 25 mg/L or less and chloride 5 mg/L or less.
[20.6.4.216 NMAC - Rp 20 NMAC 6.1.2213, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.217 PECOS RIVER BASIN: Perennial reaches of Cow creek and all perennial reaches of its tributaries and the main stem of the Pecos river from Cañon de Manzanita upstream to its headwaters, including perennial reaches of all tributaries thereto except lakes identified in 20.6.4.222 NMAC.

A. Designated uses: domestic water supply, fish culture, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact; and public water supply on the main stem of the Pecos river.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.217 NMAC - Rp 20 NMAC 6.1.2214, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012]
[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segments are under 20.6.4.220 and 20.6.4.221 NMAC.]

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20.6.4.218 PECOS RIVER BASIN: Lower Tansil lake and Lake Carlsbad.

A. Designated uses: industrial water supply, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 34°C (93.2°F) or less.

[20.6.4.218 NMAC - N, 5/23/2005; A, 12/1/2010]

20.6.4.219 PECOS RIVER BASIN: Avalon reservoir.

A. Designated uses: irrigation storage, livestock watering, wildlife habitat, [~~secondary~~] primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.219 NMAC - N, 5/23/2005; A, 12/1/2010; A, MM/DD/YYYY]

20.6.4.220 PECOS RIVER BASIN: Perennial reaches of the Gallinas river and perennial reaches of tributaries to the Gallinas river from its mouth upstream to the diversion for the Las Vegas municipal reservoir, except Pecos Arroyo.

A. Designated uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 30°C (86°F) or less.

[20.6.4.220 NMAC - N, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

20.6.4.221 PECOS RIVER BASIN: Pecos Arroyo.

A. Designated uses: livestock watering, wildlife habitat, warmwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL, single sample 940 cfu/100 mL.

[20.6.4.221 NMAC - N, 5/23/2005; A, 12/1/2010]

20.6.4.222 PECOS RIVER BASIN: Johnson lake, Katherine lake, Lost Bear lake, Pecos Baldy lake, Spirit lake, Stewart lake and Truchas lakes (north and south).

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.222 NMAC - N, 7/10/2012]

20.6.4.223 PECOS RIVER BASIN: Bonito lake.

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering, wildlife habitat and public water supply.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: specific conductance 1100 µS/cm or less; phosphorus (unfiltered sample) less than 0.1 mg/L; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.223 NMAC - N, 7/10/2012]

20.6.4.224 PECOS RIVER BASIN: Monastery lake.

A. Designated uses: coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.224 NMAC - N, 7/10/2012]

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20.6.4.225 PECOS RIVER BASIN: Santa Rosa reservoir.

A. Designated uses: coolwater aquatic life, irrigation, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.225 NMAC - N, 7/10/2012]

20.6.4.226 PECOS RIVER BASIN: Perch lake.

A. Designated uses: coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.226 NMAC - N, 7/10/2012]

20.6.4.227 PECOS RIVER BASIN: Lea lake.

A. Designated uses: warmwater aquatic life, primary contact and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.227 NMAC - N, 7/10/2012]

20.6.4.228 PECOS RIVER BASIN: Cottonwood lake and Devil's Inkwell.

A. Designated uses: coolwater aquatic life, primary contact and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.228 NMAC - N, 7/10/2012]

20.6.4.229 PECOS RIVER BASIN: Mirror lake.

A. Designated uses: warmwater aquatic life, primary contact and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.229 NMAC - N, 7/10/2012]

20.6.4.230 PECOS RIVER BASIN: Perennial reaches of Tecolote creek from I-25 to Blue creek.

A. Designated uses: domestic water supply, coolwater aquatic life, irrigation, livestock watering, wildlife habitat, and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.230 NMAC - N, 2/13/2018]

20.6.4.231 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from [~~state highway 24 near Dunken~~]Bear Canyon, [~~perennial reaches of North Spring river and~~]perennial reaches of the Rio Hondo and perennial reaches of its tributaries downstream of Bonney canyon.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

[20.6.4.231 NMAC - N, 4/23/2022; A, MM/DD/YYYY]

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20.6.4.232 - 20.6.4.300 [RESERVED]

20.6.4.301 CANADIAN RIVER BASIN: The main stem of the Canadian river from the New Mexico-Texas line upstream to Ute dam, and any flow that enters the main stem from Revuelto creek.

A. Designated uses: irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) TDS 6,500 mg/L or less at flows above 25 cfs.

[20.6.4.301 NMAC - Rp 20 NMAC 6.1.2301, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.302 CANADIAN RIVER BASIN: Ute reservoir.

A. Designated uses: livestock watering, wildlife habitat, public water supply, industrial water supply, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.302 NMAC - Rp 20 NMAC 6.1.2302, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.303 CANADIAN RIVER BASIN: The main stem of the Canadian river from the headwaters of Ute reservoir upstream to Conchas dam, the perennial reaches of Pajarito and Ute creeks and their perennial tributaries.

A. Designated uses: irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.303 NMAC - Rp 20 NMAC 6.1.2303, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.304 CANADIAN RIVER BASIN: Conchas reservoir.

A. Designated uses: irrigation storage, livestock watering, wildlife habitat, public water supply, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.304 NMAC - Rp 20 NMAC 6.1.2304, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.305 CANADIAN RIVER BASIN: The main stem of the Canadian river from the headwaters of Conchas reservoir upstream to the New Mexico-Colorado line, perennial reaches of the Conchas river, the Mora river downstream from the USGS gaging station near Shoemaker, the Vermejo river downstream from Rail canyon and perennial reaches of Raton, Chicorica (except Lake Maloya and Lake Alice) and Uña de Gato creeks.

A. Designated uses: irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) TDS 3,500 mg/L or less at flows above 10 cfs.

[20.6.4.305 NMAC - Rp 20 NMAC 6.1.2305, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

[**NOTE:** This segment was divided effective 12/1/2010. The standards for Lake Alice and Lake Maloya are under 20.6.4.311 and 20.6.4.312 NMAC, respectively.]

20.6.4.306 CANADIAN RIVER BASIN: The Cimarron river downstream from state highway 21 in Cimarron to the Canadian river and all perennial reaches of tributaries to the Cimarron river downstream from state highway 21 in Cimarron.

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A. Designated uses: irrigation, warmwater aquatic life, livestock watering, wildlife habitat and primary contact; and public water supply on Cimarroncito creek.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) TDS 3,500 mg/L or less at flows above 10 cfs.

[20.6.4.306 NMAC - Rp 20 NMAC 6.1.2305.1, 10/12/2000; A, 7/19/2001; A, 5/23/2005; A, 12/1/2010]

20.6.4.307 CANADIAN RIVER BASIN: Perennial reaches of the Mora river from the USGS gaging station near Shoemaker upstream to [~~the state highway 434 bridge in Mora~~]Rio la Casa, all perennial reaches of tributaries to the Mora river downstream from the USGS gaging station at La Cueva in San Miguel and Mora counties except [~~lakes~~]waters identified in 20.6.4.309 NMAC or 20.6.4.313 NMAC, perennial reaches of Ocate creek downstream of Ocate, perennial reaches of tributaries to Ocate creek downstream of Ocate, and perennial reaches of Rayado creek downstream of Miami lake diversion in Colfax county.

A. Designated uses: marginal coldwater aquatic life, warmwater aquatic life, primary contact, irrigation, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.307 NMAC - Rp 20 NMAC 6.1.2305.3, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012; A, 4/23/2022; A, MM/DD/YYYY]

20.6.4.308 CANADIAN RIVER BASIN: Charette lakes.

A. Designated uses: coldwater aquatic life, warmwater aquatic life, [~~secondary~~]primary contact, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.308 NMAC - Rp 20 NMAC 6.1.2305.5, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, MM/DD/YYYY]

20.6.4.309 CANADIAN RIVER BASIN: The Mora river and perennial reaches of its tributaries upstream from [~~the state highway 434 bridge in Mora~~] Rio la Casa except lakes identified in 20.6.4.313 NMAC, all perennial reaches of tributaries to the Mora river upstream from the USGS gaging station at La Cueva, perennial reaches of Coyote creek upstream of Amola ridge, and perennial reaches of tributaries to Coyote creek upstream to Amola ridge, the Cimarron river above state highway 21 in Cimarron, perennial reaches of tributaries to the Cimarron river above state highway 21 in Cimarron except Eagle Nest lake, all perennial reaches of tributaries to the Cimarron river north and northwest of highway 64 except north and south Shuree ponds, perennial reaches of Rayado creek above Miami lake diversion, perennial reaches of tributaries to Rayado creek above Miami lake diversion, Ocate creek and perennial reaches of its tributaries upstream of Ocate, perennial reaches of the Vermejo river upstream from Rail canyon and all other perennial reaches of tributaries to the Canadian river northwest and north of U.S. highway 64 in Colfax county unless included in other segments.

A. Designated uses: domestic water supply, irrigation, high quality coldwater aquatic life, livestock watering, wildlife habitat, and primary contact; and public water supply on the Cimarron river upstream from Cimarron, on perennial reaches of Rayado creek and on perennial reaches of tributaries to Rayado creek.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.309 NMAC - Rp 20 NMAC 6.1.2306, 10/12/2000; A, 7/19/2001; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012; A, 4/23/2022; A, MM/DD/YYYY]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.310 NMAC. The standards for Shuree ponds are in 20.6.4.314 NMAC and the standards for Eagle Nest lake are in 20.6.4.315 NMAC, effective 7/10/2012]

20.6.4.310 CANADIAN RIVER BASIN: Perennial reaches of Corrumpa creek.

A. Designated uses: livestock watering, wildlife habitat, irrigation, primary contact and coldwater aquatic life.

B. Criteria:

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(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: temperature 25°C (77°F) or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

(2) TDS 1,200 mg/L or less, sulfate 600 mg/L or less, chloride 40 mg/L or less.

[20.6.4.310 NMAC - N, 5/23/2005; A, 12/1/2010]

20.6.4.311 CANADIAN RIVER BASIN: Lake Alice.

A. Designated uses: marginal coldwater aquatic life, irrigation, livestock watering, wildlife habitat, primary contact and public water supply.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.311 NMAC - N, 12/1/2010; A, 4/23/2022]

20.6.4.312 CANADIAN RIVER BASIN: Lake Maloya.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat, primary contact and public water supply.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.312 NMAC - N, 12/1/2010; A, 4/23/2022]

20.6.4.313 CANADIAN RIVER BASIN: Encantada lake, Maestas lake, Middle Fork lake of Rio de la Casa, North Fork lake of Rio de la Casa and Pacheco lake.

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.313 NMAC - N, 7/10/2012]

20.6.4.314 CANADIAN RIVER BASIN: Shuree ponds (north and south).

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.314 NMAC - N, 7/10/2012]

20.6.4.315 CANADIAN RIVER BASIN: Eagle Nest lake.

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering, wildlife habitat and public water supply.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.315 NMAC - N, 7/10/2012]

20.6.4.316 CANADIAN RIVER BASIN: Clayton lake.

A. Designated uses: coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.316 NMAC - N, 7/10/2012]

20.6.4.317 CANADIAN RIVER BASIN: Springer lake.

A. Designated uses: coolwater aquatic life, irrigation, primary contact, livestock watering, wildlife habitat, and public water supply.

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B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.317 NMAC - N, 7/10/2012; A, 3/2/2017]

20.6.4.318 CANADIAN RIVER BASIN: Doggett creek.

A. Designated uses: Warm water aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following site-specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

C. Discharger-specific temporary standard:

(1) Discharger: City of Raton wastewater treatment plant

(2) NPDES permit number: NM0020273, Outfall 001

(3) Receiving waterbody: Doggett creek, 20.6.4.318 NMAC

(4) Discharge latitude/longitude: 36° 52' 13.91" N / 104° 25' 39.18" W

(5) Pollutant(s): nutrients; total nitrogen and total phosphorus

(6) Factor of issuance: substantial and widespread economic and social impacts (40 CFR 131.10(g)(6))

(7) Highest attainable condition: interim effluent condition of 8.0 mg/L total nitrogen and 1.6 mg/L total phosphorus as 30-day averages. The highest attainable condition shall be either the highest attainable condition identified at the time of the adoption, or any higher attainable condition later identified during any reevaluation, whichever is more stringent (40 CFR 131.14(b)(1)(iii)).

(8) Effective date of temporary standard: [~~This temporary standard becomes~~]effective for Clean Water Act purposes on [~~the date of EPA approval~~]July 24,2020.

(9) Expiration date of temporary standard: no later than 20 years from the effective date.

(10) Reevaluation period: at each succeeding review of water quality standards and at least once every five years from the effective date of the temporary standard (Paragraph (8) of Subsection [~~H~~]I of 20.6.4.10 NMAC, 40 CFR 131.14(b)(1)(v)). If the discharger cannot demonstrate that sufficient progress has been made the commission may revoke approval of the temporary standard or provide additional conditions to the approval of the temporary standard. If the reevaluation is not completed at the frequency specified or the Department does not submit the reevaluation to EPA within 30 days of completion, the underlying designated use and criterion will be the applicable water quality standard for Clean Water Act purposes until the Department completes and submits the reevaluation to EPA. Public input on the reevaluation will be invited during NPDES permit renewals or triennial reviews, as applicable, in accordance with the State's most current approved water quality management plan and continuing planning process.

(11) Timeline for proposed actions. Tasks and target completion dates are listed in the most recent, WQCC-approved version of the New Mexico Environment Department, Surface Water Quality Bureau's "Nutrient Temporary Standards for City of Raton Wastewater Treatment Plant, NPDES No. NM0020273 to Doggett Creek."

[20.6.4.318 NMAC - N, 05/22/2020; A, 04/23/2022; A, MM/DD/YYYY]

20.6.4.319 - 20.6.4.400 [RESERVED]

20.6.4.401 SAN JUAN RIVER BASIN: The main stem of the San Juan river from the Navajo Nation boundary at the Hogback upstream to its confluence with the Animas river. Some waters in this segment are under the joint jurisdiction of the state and the Navajo Nation.

A. Designated uses: public water supply, industrial water supply, irrigation, livestock watering, wildlife habitat, primary contact, marginal coldwater aquatic life and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 32.2°C (90°F) or less.

[20.6.4.401 NMAC - Rp 20 NMAC 6.1.2401, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.408 NMAC.]

20.6.4.402 SAN JUAN RIVER BASIN: La Plata river from its confluence with the San Juan river upstream to the New Mexico-Colorado line.

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A. Designated uses: irrigation, marginal warmwater aquatic life, marginal coldwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 32.2°C (90°F) or less.

[20.6.4.402 NMAC - Rp 20 NMAC 6.1.2402, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.403 SAN JUAN RIVER BASIN: The Animas river from its confluence with the San Juan river upstream to Estes arroyo.

A. Designated uses: Public water supply, industrial water supply, irrigation, livestock watering, wildlife habitat, coolwater aquatic life, and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses[~~, except that the following segment-specific criterion applies: temperature 29°C (84.2°F) or less~~].

[20.6.4.403 NMAC - Rp 20 NMAC 6.1.2403, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, MM/DD/YYYY]

20.6.4.404 SAN JUAN RIVER BASIN: The Animas river from Estes arroyo upstream to the Southern Ute Indian tribal boundary.

A. Designated uses: Coolwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply, industrial water supply and primary contact.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: phosphorus (unfiltered sample) 0.l mg/L or less.

[20.6.4.404 NMAC - Rp 20 NMAC 6.1.2404, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.405 SAN JUAN RIVER BASIN: The main stem of the San Juan river from Cañon Largo upstream to the Navajo dam.

A. Designated uses: high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply, industrial water supply and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 400 µS/cm or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.405 NMAC - Rp 20 NMAC 6.1.2405, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

20.6.4.406 SAN JUAN RIVER BASIN: Navajo reservoir in New Mexico.

A. Designated uses: coldwater aquatic life, warmwater aquatic life, irrigation storage, livestock watering, wildlife habitat, public water supply, industrial water supply and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: phosphorus (unfiltered sample) 0.1 mg/L or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.406 NMAC - Rp 20 NMAC 6.1.2406, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.407 SAN JUAN RIVER BASIN: Perennial reaches of the Navajo river from the Jicarilla Apache reservation boundary to the Colorado border and perennial reaches of Los Pinos river in New Mexico.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, public water supply, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: phosphorus (unfiltered sample) 0.1 mg/L or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.407 NMAC - Rp 20 NMAC 6.1.2407, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.408 SAN JUAN RIVER BASIN: The main stem of the San Juan river from its confluence with the Animas river upstream to its confluence with Cañon Largo.

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A. Designated uses: public water supply, industrial water supply, irrigation, livestock watering, wildlife habitat, primary contact, marginal coldwater aquatic life and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 32.2°C (90°F) or less.

[20.6.4.408 NMAC - N, 5/23/2005; A, 12/1/2010; A, 4/23/2022]

20.6.4.409 SAN JUAN RIVER BASIN: Lake Farmington.

A. Designated uses: public water supply, wildlife habitat, livestock watering, primary contact, coldwater aquatic life and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

[20.6.4.409 NMAC - N, 12/1/2010]

20.6.4.410 SAN JUAN RIVER BASIN: Jackson lake.

A. Designated uses: coolwater aquatic life, irrigation, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.410 NMAC - N, 7/10/2012]

20.6.4.411 - 20.6.4.450: [**RESERVED**]

20.6.4.451 LITTLE COLORADO RIVER BASIN: The Rio Nutria upstream of the Zuni pueblo boundary, Tampico draw, Agua Remora, Tampico springs.

A. Designated uses: coolwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.451 NMAC - N, 12/1/2010]

20.6.4.452 LITTLE COLORADO RIVER BASIN: Ramah lake.

A. Designated uses: coldwater aquatic life, warmwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

[20.6.4.452 NMAC - N, 12/1/2010]

20.6.4.453 LITTLE COLORADO RIVER BASIN: Quemado lake.

A. Designated uses: coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.453 NMAC - N, 7/10/2012]

20.6.4.454 - 20.6.4.500 [**RESERVED**]

20.6.4.501 GILA RIVER BASIN: The main stem of the Gila river from the New Mexico-Arizona line upstream to Redrock canyon and perennial reaches of streams in Hidalgo county.

A. Designated uses: irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.501 NMAC - Rp 20 NMAC 6.1.2501, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.502 GILA RIVER BASIN: The main stem of the Gila river from Redrock canyon upstream to the confluence of the West Fork Gila river and East Fork Gila river and perennial reaches of tributaries to the Gila river downstream of Mogollon creek.

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A. Designated uses: industrial water supply, irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, and primary contact[~~ and warmwater aquatic life~~].

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 28°C (82.4°F) or less.

[20.6.4.502 NMAC - Rp 20 NMAC 6.1.2502, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A. MM/DD/YYYY]

20.6.4.503 GILA RIVER BASIN: All perennial tributaries to the Gila river upstream of and including Mogollon creek.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance of 400 µS/cm or less for all perennial tributaries except West Fork Gila and tributaries thereto, specific conductance of 300 µS/cm or less; temperature [~~32.2~~]29°C ([~~90~~]84°F) or less in the east fork of the Gila river and Sapillo creek downstream of Lake Roberts; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.503 NMAC - Rp 20 NMAC 6.1.2503, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, MM/DD/YYYY]

20.6.4.504 GILA RIVER BASIN: Wall lake, Lake Roberts and Snow lake.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: specific conductance 300 µS/cm or less.

[20.6.4.504 NMAC - Rp 20 NMAC 6.1.2504, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.806 NMAC.]

20.6.4.505 GILA RIVER BASIN: Bill Evans lake.

A. Designated uses: coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.505 NMAC - N, 7/10/2012]

20.6.4.506 - 20.6.4.600 [RESERVED]

20.6.4.601 SAN FRANCISCO RIVER BASIN: The main stem of the San Francisco river from the New Mexico-Arizona line upstream to [~~state highway 12 at Reserve~~]the confluence with Largo canyon, and perennial reaches of Mule creek.

A. Designated uses: irrigation, [~~marginal warmwater and~~]marginal coldwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.601 NMAC - Rp 20 NMAC 6.1.2601, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, MM/DD/YYYY]

20.6.4.602 SAN FRANCISCO RIVER BASIN: The main stem of the San Francisco river from [~~state highway 12 at Reserve~~]the confluence with Largo canyon upstream to the New Mexico-Arizona line.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

[20.6.4.602 NMAC - Rp 20 NMAC 6.1.2602, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, MM/DD/YYYY]

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20.6.4.603 SAN FRANCISCO RIVER BASIN: All perennial reaches of tributaries to the San Francisco river above the confluence of Whitewater creek and including Whitewater creek.

A. Designated uses: domestic water supply, fish culture, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 400 µS/cm or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less; and temperature 25°C (77°F) or less in Tularosa creek.

[20.6.4.603 NMAC - Rp 20 NMAC 6.1.2603, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.604 - 20.6.4.700 [**RESERVED**]

20.6.4.701 DRY CIMARRON RIVER: Perennial portions of the Dry Cimarron river above Oak creek and perennial reaches of Oak creek.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: temperature 25°C (77°F) or less, the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

(2) TDS 1,200 mg/L or less, sulfate 600 mg/L or less and chloride 40 mg/L or less.

[20.6.4.701 NMAC - Rp 20 NMAC 6.1.2701, 10/12/2000; A, 5/23/2005 A, 12/1/2010]

[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.702 NMAC.]

20.6.4.702 DRY CIMARRON RIVER: Perennial portions of the Dry Cimarron river below Oak creek, and perennial portions of Long canyon and Carrizozo creeks.

A. Designated uses: coolwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

(2) TDS 1,200 mg/L or less, sulfate 600 mg/L or less and chloride 40 mg/L or less.

[20.6.4.702 NMAC - N, 5/23/2005; A, 12/1/2010; A, 7/10/2012]

20.6.4.703 - 20.6.4.800 [**RESERVED**]

20.6.4.801 CLOSED BASINS: Rio Tularosa upstream of the old U.S. highway 70 bridge crossing east of Tularosa and all perennial tributaries to the Tularosa basin except Three Rivers and Dog Canyon creek, and excluding waters on the Mescalero tribal lands.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.801 NMAC - Rp 20 NMAC 6.1.2801, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, 2/13/2018]

[**NOTE:** This segment was divided effective 2/13/2018. The standards for Dog Canyon creek are under 20.6.4.810 NMAC.]

20.6.4.802 CLOSED BASINS: Perennial reaches of Three Rivers.

A. Designated uses: irrigation, domestic water supply, high quality coldwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

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[20.6.4.802 NMAC - Rp 20 NMAC 6.1.2802, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.803 CLOSED BASINS: Perennial reaches of the Mimbres river downstream of the confluence with Allie canyon and all perennial reaches of tributaries thereto.

A. Designated uses: Coolwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less and temperature of 30°C (86°F) or less.

[20.6.4.803 NMAC - Rp 20 NMAC 6.1.2803, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

20.6.4.804 CLOSED BASINS: Perennial reaches of the Mimbres river upstream of the confluence with Allie canyon to Cooney canyon, and all perennial reaches of East Fork Mimbres (McKnight canyon) downstream of the fish barrier, and all perennial reaches thereto.

A. Designated uses: Irrigation, domestic water supply, coldwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.804 NMAC - Rp 20 NMAC 6.1.2804, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 2/28/2018; A, 3/2/2017]

[**NOTE:** The segment covered by this section was divided effective 3/2/2017. The standards for the additional segment are covered under 20.6.4.807 NMAC.]

20.6.4.805 CLOSED BASINS: Perennial reaches of the Sacramento river (Sacramento-Salt Flat closed basin) and all perennial tributaries thereto.

A. Designated uses: domestic water supply, livestock watering, wildlife habitat, marginal coldwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.805 NMAC - Rp 20 NMAC 6.1.2805, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.806 CLOSED BASINS: Bear canyon reservoir.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: specific conductance 300 µS/cm or less.

[20.6.4.806 NMAC - N, 5/23/2005; A, 12/1/2010]

20.6.4.807 CLOSED BASINS: Perennial reaches of the Mimbres river upstream of Cooney canyon and all perennial reaches thereto, including perennial reaches of East Fork Mimbres river (McKnight canyon) upstream of the fish barrier.

A. Designated uses: Irrigation, domestic water supply, high quality coldwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.807 NMAC - N, 3/2/2017]

20.6.4.808 CLOSED BASINS: Perennial and intermittent watercourses within Smelter Tailing Soils Investigation Unit lands at the Chino mines company, excluding those ephemeral waters listed in 20.6.4.809 NMAC and including, but not limited to the mainstem of Lampbright draw, beginning at the confluence of Lampbright Draw with Rustler canyon, all tributaries that originate west of Lampbright draw to the intersection of Lampbright draw with U.S. 180, and all tributaries of Whitewater creek that originate east of Whitewater creek from the confluence of Whitewater creek with Bayard canyon downstream to the intersection of Whitewater creek with U.S. 180.

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A. Designated uses: Warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the acute and chronic aquatic life criteria for copper set forth in Subsection I of 20.6.4.900 NMAC shall be determined by multiplying that criteria by the water effect ratio ("WER") adjustment expressed by the following equation:

$$WER = \frac{[10^{0.588+(0.703 \times \log DOC)+(0.395 \times \log Alkalinity)}] \times (\frac{100}{Hardness})^{0.9422}}{19.31}$$

For purposes of this section, dissolved organic carbon (DOC) is expressed in units of milligrams carbon per liter or mg C/L; alkalinity is expressed in units of mg/L as $CaCO_3$, and hardness is expressed in units of mg/L as $CaCO_3$. In waters that contain alkalinity concentrations greater than 250 mg/L, a value of 250 mg/L shall be used in the equation. In waters that contain DOC concentrations greater than 16 mg C/L, a value of 16 mg C/L shall be used in the equation. In waters that contain hardness concentrations greater than 400 mg/L, a value of 400 mg/L shall be used in the equation. The alkalinity, hardness and DOC concentrations used to calculate the WER value are those measured in the subject water sample.

[20.6.4.808 NMAC - N, 3/2/2017]

20.6.4.809 CLOSED BASINS: Ephemeral watercourses within smelter tailing soils investigation unit lands at the Chino mines company, limited to Chino mines property subwatershed drainage A and tributaries thereof, Chino mines property subwatershed drainage B and tributaries thereof (excluding the northwest tributary containing Ash spring and the Chiricahua leopard frog critical habitat transect); Chino mines property subwatershed drainage C and tributaries thereof (excluding reaches containing Bolton spring, the Chiricahua leopard frog critical habitat transect and all reaches in subwatershed C that are upstream of the Chiricahua leopard frog critical habitat); subwatershed drainage D and tributaries thereof (drainages D-1, D-2 and D-3, excluding the southeast tributary in drainage D1 that contains Brown spring) and subwatershed drainage E and all tributaries thereof (drainages E-1, E-2 and E-3).

A. Designated uses: Limited aquatic life, livestock watering, wildlife habitat and secondary contact.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the acute aquatic life criteria for copper set forth in Subsection I of 20.6.4.900 NMAC shall be determined by multiplying that criteria by the water effect ratio ("WER") adjustment expressed by the following equation:

$$WER = \frac{[10^{0.588+(0.703 \times \log DOC)+(0.395 \times \log Alkalinity)}] \times (\frac{100}{Hardness})^{0.9422}}{19.31}$$

For purposes of this section, dissolved organic carbon (DOC) is expressed in units of milligrams carbon per liter or mg C/L; alkalinity is expressed in units of mg/L as $CaCO_3$, and hardness is expressed in units of mg/L as $CaCO_3$. In waters that contain alkalinity concentrations greater than 250 mg/L, a value of 250 mg/L shall be used in the equation. In waters that contain DOC concentrations greater than 16 mg C/L, a value of 16 mg C/L shall be used in the equation. In waters that contain hardness concentrations greater than 400 mg/L, a value of 400 mg/L shall be used in the equation. The alkalinity, hardness and DOC concentrations used to calculate the WER value are those measured in the subject water sample.

[20.6.4.809 NMAC - N, 3/2/2017]

20.6.4.810 CLOSED BASINS: Perennial reaches of Dog Canyon creek.

A. Designated uses: coolwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply, and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.810 NMAC - N, 2/13/2018]

20.6.4.811 - 20.6.4.899 [**RESERVED**]

20.6.4.900 CRITERIA APPLICABLE TO EXISTING, DESIGNATED OR ATTAINABLE USES UNLESS OTHERWISE SPECIFIED IN 20.6.4.97 THROUGH 20.6.4.899 NMAC:

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A. Fish culture and water supply: Fish culture, public water supply and industrial water supply are designated uses in particular classified waters of the state where these uses are actually being realized. However, no numeric criteria apply uniquely to these uses. Water quality adequate for these uses is ensured by the general criteria and numeric criteria for bacterial quality, pH and temperature.

B. Domestic water supply: Surface waters of the state designated for use as domestic water supplies shall not contain substances in concentrations that create a lifetime cancer risk of more than one cancer per 100,000 exposed persons. Those criteria listed under domestic water supply in Subsection J of this section apply to this use.

C. Irrigation and irrigation storage: the following numeric criteria and those criteria listed under irrigation in Subsection J of this section apply to this use:

(1)	dissolved selenium	0.13 mg/L
(2)	dissolved selenium in presence of >500 mg/L SO_4	0.25 mg/L.

D. Primary contact: The following criteria apply to this use:

(1) [~~The monthly geometric mean of~~] E. coli bacteria (monthly geometric mean) [~~of~~] 126 cfu/100 mL or MPN/100 ml[~~,~~].

(2) [~~a single sample of~~]E. coli bacteria (single sample) [~~of~~] 410 cfu/100 mL or MPN/100 mL[~~,~~].

(3) [~~a single sample of~~]total microcystins[~~of~~] 8 µg/L[~~with no more than three exceedances within a 12-month period and~~].

(4) [~~a single sample of~~]cylindrospermopsin[~~of~~] 15 µg/L[~~with no more than three exceedances within a 12-month period, and~~].

(5) pH [~~within the range of~~] 6.6 to 9.0[~~apply to this use. The results for E. coli may be reported as either colony forming units (CFU) or the most probable number (MPN) depending on the analytical method used.~~]

E. Secondary contact: The following criteria apply to this use:

(1) [~~The monthly geometric mean of~~]E. coli bacteria (monthly geometric mean)[~~of~~] 548 cfu/100 mL or MPN/100 mL[~~and~~].

(2) [~~single sample of~~]E. coli bacteria (single sample) 2507 cfu/100 mL or MPN/100 mL[~~apply to this use. The results for E. coli may be reported as either colony forming units (CFU) or the most probable number (MPN), depending on the analytical method used~~].

F. Livestock watering: the criteria listed in Subsection J of this section for livestock watering apply to this use.

G. Wildlife habitat: Wildlife habitat shall be free from any substances at concentrations that are toxic to or will adversely affect plants and animals that use these environments for feeding, drinking, habitat or propagation; can bioaccumulate; or might impair the community of animals in a watershed or the ecological integrity of surface waters of the state. The numeric criteria listed in Subsection J for wildlife habitat apply to this use.

H. Aquatic life: Surface waters of the state with a designated, existing or attainable use of aquatic life shall be free from any substances at concentrations that can impair the community of plants and animals in or the ecological integrity of surface waters of the state. Except as provided in Paragraph (7) of this subsection, the acute and chronic aquatic life criteria set out in Subsections I, J, K and L of this section and the human health-organism only criteria set out in Subsection J of this section are applicable to all aquatic life use subcategories. In addition, the specific criteria for aquatic life subcategories in the following paragraphs apply to surface waters classified under the respective designations.

(1) High quality coldwater: Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 4T3 temperature applies.

(a)	dissolved oxygen	6.0 mg/L or more.
(b)	4T3 temperature	20°C (68°F)[~~,~~].
(c)	maximum temperature	23°C (73°F)[~~,~~].
(d)	pH [~~within the range of~~]	6.6 to 8.8. [~~and~~]
(e)	specific conductance [~~a segment-specific limit between~~]	300 µS/cm and 1,500 µS/cm. This specific conductance criterion is a segment-specific range depending on the natural background in the particular surface water of the state [~~(the intent of this criterion is~~] intended to prevent excessive increases in dissolved solids which would result in changes in community structure[~~)~~]. [~~Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 4T3 temperature applies.~~]

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(2) Coldwater: Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 6T3 temperature applies.

(a) dissolved oxygen 6.0 mg/L or more[~~,~~].

(b) 6T3 temperature 20°C (68°F)[~~,~~].

(c) maximum temperature 24°C (75°F) [~~and~~].

(d) pH [~~within the range of~~] 6.6 to 8.8.

[~~Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 6T3 temperature applies.~~]

(3) Marginal coldwater: Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 6T3 temperature applies.

(a) dissolved oxygen 6 mg/L or more[~~,~~].

(b) 6T3 temperature 25°C (77°F)[~~,~~].

(c) maximum temperature 29°C (84°F) [~~and~~].

(d) pH [~~within the range from~~] 6.6 to 9.0. [~~Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 6T3 temperature applies.~~]

(4) Coolwater: Where a segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature.

(a) dissolved oxygen 5.0 mg/L or more[~~,~~].

(b) maximum temperature 29°C (84°F) [~~and~~].

(c) pH [~~within the range of~~] 6.6 to 9.0.

(5) Warmwater: Where a segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature.

(a) dissolved oxygen 5 mg/L or more[~~,~~].

(b) maximum temperature 32.2°C (90°F) [~~and~~].

(c) pH [~~within the range of~~] 6.6 to 9.0.

[~~Where a segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature.~~]

(6) Marginal warmwater: Where a segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature.

(a) dissolved oxygen 5 mg/L or more[~~,~~].

(b) pH [~~within the range of~~] 6.6 to 9.0 [~~and~~].

(c) maximum temperature[~~s~~] [~~that~~] may [~~routinely~~] exceed 32.2°C (90°F). [~~Where a segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature.~~]

(7) Limited aquatic life: pH within the range of 6.0 to 9.0. The acute aquatic life criteria of Subsections I and J of this section apply to this subcategory. Chronic aquatic life criteria do not apply unless adopted on a segment-specific basis. Human health-organism only criteria apply only for persistent toxic pollutants unless adopted on a segment-specific basis.

I. Hardness-dependent acute and chronic aquatic life criteria for metals are calculated using the following equations, excluding aquatic life criteria for copper (Cu) for the Pajarito plateau surface waters in the Rio Grande basin as described in Paragraph (4) of Subsection I of 20.6.4.900 NMAC. The criteria are expressed as a function of hardness (as mg $CaCO_3$/L). With the exception of aluminum, the equations are valid only for hardness concentrations of 0-400 mg/L. For hardness concentrations above 400 mg/L, the criteria for 400 mg/L apply. For aluminum the equations are valid only for hardness concentrations of 0-220 mg/L. For hardness concentrations above 220 mg/L, the aluminum criteria for 220 mg/L apply. Calculated criteria must adhere to the treatment of significant figures and rounding identified in *Standard Methods For The Examination Of Water And Wastewater*, latest edition, American public health association.

(1) Acute aquatic life criteria for metals: The equation to calculate acute criteria in µg/L is $\exp(m_A[\ln(\text{hardness})] + b_A)(CF)$. Except for aluminum, the criteria are based on analysis of dissolved metal. For aluminum, the criteria are based on analysis of total recoverable aluminum in a sample that has a pH between 6.5 and 9.0 and is filtered to minimize mineral phases as specified by the department. The equation parameters are as follows:

Metal	m_A	b_A	Conversion factor (CF)
Aluminum (Al)	1.3695	1.8308	
Cadmium (Cd)	0.9789	-3.866	1.136672-[(ln hardness)(0.041838)]

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Chromium (Cr) III	0.8190	3.7256	0.316
Copper (Cu)	0.9422	-1.700	0.960
Lead (Pb)	1.273	-1.460	1.46203-[(ln hardness)(0.145712)]
Manganese (Mn)	0.3331	6.4676	
Nickel (Ni)	0.8460	2.255	0.998
Silver (Ag)	1.72	-6.59	0.85
Zinc (Zn)	0.9094	0.9095	0.978

(2) Chronic aquatic life criteria for metals: The equation to calculate chronic criteria in µg/L is $\exp(m_C[\ln(\text{hardness})] + b_C)(CF)$. Except for aluminum, the criteria are based on analysis of dissolved metal. For aluminum, the criteria are based on analysis of total recoverable aluminum in a sample that has a pH between 6.5 and 9.0 and is filtered to minimize mineral phases as specified by the department. The equation parameters are as follows:

Metal	**m_C**	**b_C**	**Conversion factor (CF)**
Aluminum (Al)	1.3695	0.9161	
Cadmium (Cd)	0.7977	-3.909	1.101672-[(ln hardness)(0.041838)]
Chromium (Cr) III	0.8190	0.6848	0.860
Copper (Cu)	0.8545	-1.702	0.960
Lead (Pb)	1.273	-4.705	1.46203-[(ln hardness)(0.145712)]
Manganese (Mn)	0.3331	5.8743	
Nickel (Ni)	0.8460	0.0584	0.997
Zinc (Zn)	0.9094	0.6235	0.986

(3) Selected values of calculated acute and chronic criteria (µg/L).

Hardness as $CaCO_3$, dissolved (mg/L)		**Al**	**Cd**	**Cr III**	**Cu**	**Pb**	**Mn**	**Ni**	**Ag**	**Zn**
25.0	Acute	512	0.490	183	3.64	13.9	1,880	145	0.30	45.4
	Chronic	205	0.253	23.8	2.74	0.541	1,040	16.1		34.4
30.0	Acute	658	0.581	212	4.32	17.0	2,000	169	0.40	53.5
	Chronic	263	0.290	27.6	3.20	0.664	1,100	18.8		40.5
40.0	Acute	975	0.761	269	5.67	23.5	2,200	216	0.66	69.5
	Chronic	391	0.360	35.0	4.09	0.916	1,220	24.0		52.7
50.0	Acute	1,320	0.938	323	6.99	30.1	2,370	260	0.98	85.2
	Chronic	530	0.426	42.0	4.95	1.17	1,310	28.9		64.5
60.0	Acute	1,700	1.11	375	8.30	36.9	2,520	304	1.3	100
	Chronic	681	0.489	48.8	5.79	1.44	1,390	33.8		76.2
70.0	Acute	2,100	1.28	425	9.60	43.7	2,650	346	1.7	116
	Chronic	841	0.549	55.3	6.60	1.70	1,460	38.5		87.6
80.0	Acute	2,520	1.46	474	10.9	50.6	2,770	388	2.2	131
	Chronic	1,010	0.607	61.7	7.40	1.97	1,530	43.0		98.9
90.0	Acute	2,960	1.62	523	12.2	57.6	2,880	428	2.7	145
	Chronic	1,190	0.664	68.0	8.18	2.24	1,590	47.6		110
100	Acute	3,420	1.79	570	13.4	64.6	2,980	468	3.2	160
	Chronic	1,370	0.718	74.1	8.96	2.52	1,650	52.0		121
200	Acute	8,840	3.43	1,000	25.8	136	3,760	842	10	300
	Chronic	3,540	1.21	131	16.2	5.30	2,080	93.5		228
220	Acute	10,100	3.74	1,090	28.2	151	3,880	912	12	328

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Hardness as $CaCO_3$, dissolved (mg/L)		Al	Cd	Cr III	Cu	Pb	Mn	Ni	Ag	Zn
	Chronic	4,030	1.30	141	17.6	5.87	2,140	101		248
300	Acute		5.00	1,400	37.8	208	4,300	1,190	21	434
	Chronic		1.64	182	22.9	8.13	2,380	132		329
400 and above	Acute		6.54	1,770	49.6	281	4,740	1,510	35	564
	Chronic		2.03	231	29.3	10.9	2,620	168		428

(4) Copper criteria for Pajarito plateau surface waters: Pajarito plateau surface waters extend from Guaje canyon in the north to the Rito de los Frijoles watershed in the south, from their headwaters to their confluence with the Rio Grande and all tributaries and streams thereto. The equations used to calculate copper criteria, for purposes of this Part, use dissolved organic carbon (DOC) in units of milligrams carbon per liter (mg C/L); and hardness in units of mg/L as $CaCO_3$. In waters that contain DOC concentrations greater than 29.7 mg/L, a value of 29.7 mg/L shall be used in the following equations. In waters that contain hardness concentrations greater than 207 mg/L, a value of 207 mg/L shall be used in the following equations.

(a) Acute aquatic life criteria: The equation to calculate acute criteria in µg/L is $\exp(-22.914+1.017\times\ln(DOC)+0.045\times\ln(hardness)+5.176\times pH-0.261\times pH^2)$.

(b) Chronic aquatic life criteria: The equation to calculate chronic criteria in µg/L is $\exp(-23.391+1.017\times\ln(DOC)+0.045\times\ln(hardness)+5.176\times pH-0.261\times pH^2)$.

J. Use-specific numeric criteria.

(1) Table of numeric criteria: The following table sets forth the numeric criteria in µg/L, unless otherwise indicated, applicable to existing, designated and attainable uses. For metals, criteria represent the total sample fraction unless otherwise specified in the table. Additional criteria that are not compatible with this table are found in Subsections A through I and K through M of 20.6.4.900 NMAC.

Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Aluminum, dissolved	7429-90-5		5,000			750 i	87 i		
Aluminum, total recoverable	7429-90-5					a	a		
Antimony, dissolved	7440-36-0	6						640	P
Arsenic, dissolved	7440-38-2	10	100	200		340	150	9.0	C,P
Asbestos (fibers/L)	1332-21-4	[~~7,000,000 fibers/L~~] 7.0 E06							
Barium, dissolved	7440-39-3	2,000							
Beryllium, dissolved	7440-41-7	4							
Boron, dissolved	7440-42-8		750	5,000					
Cadmium, dissolved	7440-43-9	5	10	50		a	a		
Chloride	1688-70-06					[~~860,000~~] 8.6E05	[~~230,000~~] 2.3E05		
Chlorine residual	7782-50-5				11	19	11		
Chromium III, dissolved	16065-83-1					a	a		
Chromium VI, dissolved	18540-29-9					16	11		
Chromium, dissolved	7440-47-3	100	100	1,000					
Cobalt, dissolved	7440-48-4		50	1,000					
Copper, dissolved	7440-50-8	1300	200	500		a	a		
Cyanide, total recoverable	57-12-5	200			5.2	22.0	5.2	400	
Iron	7439-89-6						1,000		
Lead, dissolved	7439-92-1	[~~15~~] 10	5,000	100		a	a		
Manganese, dissolved	7439-96-5					a	a		
Mercury	7439-97-6	2		10	0.77				P

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Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Mercury, dissolved	7439-97-6					1.4	0.77		P
Methylmercury (mg/kg-ww-fmt)	22967-92-6							0.3 [~~mg/kg in fish tissue~~]	P
Molybdenum, dissolved	7439-98-7		1,000						
Molybdenum, total recoverable	7439-98-7					7,920	1,895		
Nickel, dissolved	7440-02-0	700				a	a	4,600	P
Nitrate as N (mg/L)		10 [~~mg/L~~]							
Nitrite + Nitrate (mg/L)				132 [~~mg/L~~]					
Selenium, dissolved	7782-49-2	50	b	50			1.5 (lentic), c 3.1 (lotic), c	4,200	P
Selenium, total recoverable	7782-49-2				5.0	[~~20.0~~]	[~~5.0~~]		
Selenium, total recoverable (mg/kg-dw-fwbt)							8.5		
Selenium, total recoverable (mg/kg-dw-fmt)							11.3		
Silver, dissolved	7440-22-4					a			
Thallium, dissolved	7440-28-0	2						0.47	P
Uranium, dissolved	7440-61-1	30							
Vanadium, dissolved	7440-62-2		100	100					P
Zinc, dissolved	7440-66-6	10,500	2,000	25,000		a	a	26,000	P
Adjusted gross alpha (pCi/L)		15 [~~pCi/L~~]		15 [~~pCi/L~~]					
Radium 226 + Radium 228 (pCi/L)		5 [~~pCi/L~~]		30.0 [~~pCi/L~~]					
Strontium 90 (pCi/L)		8 [~~pCi/L~~]							
Tritium (pCi/L)		20,000 [~~pCi/L~~]		20,000 [~~pCi/L~~]					
Acenaphthene	83-32-9	2,100						90	
Acrolein	107-02-8	18				3.0	3.0	400	
Acrylonitrile	107-13-1	0.65						70	C
Aldrin	309-00-2	0.021				3.0		[~~0.0000077~~] 7.7E-06	C,P
Anthracene	120-12-7	10,500						400	
Benzene	71-43-2	5						160	C
Benzidine	92-87-5	0.0015						0.11	C
Benzo(a)anthracene	56-55-3	0.048						0.013	C,P
Benzo(a)pyrene	50-32-8	0.2						0.0013	C,P
Benzo(b)fluoranthene	205-99-2	0.048						0.013	C,P
Benzo(k)fluoranthene	207-08-9	0.048						0.13	C,P
alpha-BHC	319-84-6	0.056						0.0039	C
beta-BHC	319-85-7	0.091						0.14	C
gamma-BHC (Lindane)	58-89-9	0.20				0.95		4.4	
Bis(2-chloroethyl) ether	111-44-4	0.30						22	C
Bis(2-chloro-1-methylethyl) ether	108-60-1	1,400						4,000	
Bis(2-ethylhexyl) phthalate	117-81-7	6						3.7	C

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Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Bis(chloromethyl) ether	542-88-1							0.17	C
Bromoform	75-25-2	44						1,200	C
Butylbenzyl phthalate	85-68-7	7,000						1	C
Carbaryl	63-25-2					2.1	2.1		
Carbon tetrachloride	56-23-5	5						50	C
Chlordane	57-74-9	2				2.4	0.0043	0.0032	C,P
Chlorobenzene	108-90-7	100						800	
Chlorodibromomethane	124-48-1	4.2						210	C
Chloroform	67-66-3	57						2,000	
Chlorpyrifos	2921-88-2					0.083	0.041		P
2-Chloronaphthalene	91-58-7	2,800						1,000	
2-Chlorophenol	95-57-8	175						800	
Chrysene	218-01-9	0.048						1.3	C,P
Demeton	8065-48-3						0.1		
Diazinon	333-41-5					0.17	0.17		
2,4-Dichlorophenoxyacetic acid (2,4-D)	94-75-7	70						12,000	
Dichlorodiphenyldichloroethane (DDD)	72-54-8							0.0012	C
Dichlorodiphenyldichloroethylene (DDE)	72-55-9							0.00018	C
Dichlorodiphenyltrichloroethane (DDT)	50-29-3							0.0003	C,P
4,4'-DDT and derivatives		1.0			0.001	1.1	0.001		P
Dibenzo(a,h)anthracene	53-70-3	0.048						0.0013	C,P
Dibutyl phthalate	84-74-2	3,500						30	
1,2-Dichlorobenzene	95-50-1	600						3,000	
1,3-Dichlorobenzene	541-73-1	469						10	
1,4-Dichlorobenzene	106-46-7	75						900	
3,3'-Dichlorobenzidine	91-94-1	0.78						1.5	C
Dichlorobromomethane	75-27-4	5.6						270	C
1,2-Dichloroethane	107-06-2	5						6,500	C
1,1-Dichloroethylene	75-35-4	7						20,000	
2,4-Dichlorophenol	120-83-2	105						60	
1,2-Dichloropropane	78-87-5	5.0						310	C
1,3-Dichloropropene	542-75-6	3.5						120	C
Dieldrin	60-57-1	0.022				0.24	0.056	[~~0.000012~~] 1.2E-05	C,P
Diethyl phthalate	84-66-2	28,000						600	
Dimethyl phthalate	131-11-3	[~~350,000~~] 3.5E05						2,000	
2,4-Dimethylphenol	105-67-9	700						3,000	
Dinitrophenols	25550-58-7							1,000	
2,4-Dinitrophenol	51-28-5	70						300	
2,4-Dinitrotoluene	121-14-2	1.1						17	C
Dioxin	1746-01-6	3.0E-05						5.1E-08	C,P
1,2-Diphenylhydrazine	122-66-7	0.44						2.0	C
alpha-Endosulfan	959-98-8	62				0.22	0.056	30	
beta-Endosulfan	33213-65-9	62				0.22	0.056	40	
Endosulfan sulfate	1031-07-8	62						40	

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Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Endrin	72-20-8	2				0.086	0.036	0.03	P
Endrin aldehyde	7421-93-4	10.5						1	
Ethylbenzene	100-41-4	700						130	
Fluoranthene	206-44-0	1,400						20	P
Fluorene	86-73-7	1,400						70	
Guthion	86-50-0						0.01		
Heptachlor	76-44-8	0.40				0.52	0.0038	[~~0.000059~~] 5.9E-05	C,P
Heptachlor epoxide	1024-57-3	0.20				0.52	0.0038	0.00032	C
Hexachlorobenzene	118-74-1	1						0.00079	C,P
Hexachlorobutadiene	87-68-3	4.5						0.1	C,P
Hexachlorocyclohexane (HCH)-Technical	608-73-1							0.1	C
Hexachlorocyclopen-tadiene	77-47-4	50						4	
Hexachloroethane	67-72-1	25						1	C
Indeno(1,2,3-cd)pyrene	193-39-5	0.048						0.013	C,P
Isophorone	78-59-1	368						18,000	C
Malathion	121-75-5						0.1		
Methoxychlor	72-43-5	40					0.03	0.02	P
Methyl bromide	74-83-9	49						10,000	
3-Methyl-4-chlorophenol	59-50-7							2,000	
2-Methyl-4,6-dinitrophenol	534-52-1	14						30	
Methylene chloride	75-09-2	5						10,000	C
Mirex	2385-85-5						0.001		P
Nitrobenzene	98-95-3	18						600	
Nitrosamines	Various							12.4	C
Nitrosodibutylamine	924-16-3							2.2	C
Nitrosodiethylamine	55-18-5							12.4	C
N-Nitrosodimethylamine	62-75-9	0.0069						30	C
N-Nitrosodi-n-propylamine	621-64-7	0.050						5.1	C
N-Nitrosodiphenylamine	86-30-6	71						60	C
N-Nitrosopyrrolidine	930-55-2							340	C
Nonylphenol	84852-15-3					28	6.6		
Parathion	56-38-2					0.065	0.013		
Pentachlorobenzene	608-93-5							0.1	
Pentachlorophenol	87-86-5	1.0				19	15	0.4	C
Perfluorooctane sulfonate (PFOS)	Various					71	0.25		P
PFOS (mg/kg-ww-iwbt)	Various						0.028		P
PFOS (mg/kg-ww-fwbt)	Various						0.201		P
PFOS (mg/kg-ww-fmt)	Various						0.087		P
Perfluorooctanoic acid (PFOA)	Various					3,100	100		P
PFOA (mg/kg-ww-iwbt)	Various						1.18		P
PFOA (mg/kg-ww-fwbt)	Various						6.49		P
PFOA (mg/kg-ww-fmt)	Various						0.133		P
Phenol	108-95-2	10,500						[~~300,000~~] 3.0E05	
Polychlorinated Biphenyls (PCBs)	1336-36-3	0.50			0.014	2	0.014	0.00064	C,P
Pyrene	129-00-0	1,050						30	
1,2,4,5-Tetrachlorobenzene	95-94-3							0.03	
1,1,2,2-Tetrachloroethane	79-34-5	1.8						30	C

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Pollutant	CAS Number	DWS	Irr/Irr storage	LW	WH	Aquatic Life			Type
						Acute	Chronic	HH-OO	
Tetrachloroethylene	127-18-4	5						290	C,P
Toluene	108-88-3	1,000						520	
Toxaphene	8001-35-2	3				0.73	0.0002	0.0071	C,P
1,2-Trans-dichloroethylene	156-60-5	100						4,000	
Tributyltin (TBT)	Various					0.46	0.072		
1,2,4-Trichlorobenzene	120-82-1	70						0.76	C
1,1,1-Trichloroethane	71-55-6	200						[~~200,000~~] 2.0E05	
1,1,2-Trichloroethane	79-00-5	5						89	C
Trichloroethylene	79-01-6	5						70	C
2,4,5-Trichlorophenol	95-95-4							600	
2,4,6-Trichlorophenol	88-06-2	32						28	C
2-(2,4,5-Trichlorophenoxy) propionic acid (Silvex)	93-72-1	50						400	
Vinyl chloride	75-01-4	2						16	C

(2) Notes applicable to the table of numeric criteria in Paragraph (1) of this subsection.

(a) Where the letter "a" is indicated in a cell, the criterion is based on receiving water characteristics and can be referenced in Subsection I of 20.6.4.900 NMAC.

(b) Where the letter "b" is indicated in a cell, the criterion can be referenced in Subsection C of 20.6.4.900 NMAC.

(c) [~~Criteria are in µg/L unless otherwise indicated.~~] Selenium water column criteria include 30-day mean dissolved selenium concentrations for lentic systems, including lakes and impoundments, and lotic systems, including rivers and streams.

(d) In addition to the definitions for units provided in Subsection A of 20.6.4.7 NMAC, [~~Abbreviations~~] abbreviations in the table are as follows: CAS - chemical abstracts service [~~(see definition for "CAS number" in 20.6.4.7 NMAC)~~]; DWS - domestic water supply; Irr/Irr storage- irrigation and irrigation storage; LW - livestock watering; WH - wildlife habitat; HH-OO - human health-organism only; C – criteria based on cancer-causing endpoint; P - persistent toxic pollutant.

(e) The criteria are based on analysis of an unfiltered sample unless otherwise indicated. The acute and chronic aquatic life criteria for aluminum are based on analysis of total recoverable aluminum in a sample that is filtered to minimize mineral phases as specified by the department.

(f) The criteria listed under human health-organism only (HH-OO) are intended to protect human health when aquatic organisms are consumed from waters containing pollutants. These criteria do not protect the aquatic life itself; rather, they protect the health of humans who ingest fish or other aquatic organisms.

(g) The dioxin criteria apply to the sum of the dioxin toxicity equivalents expressed as 2,3,7,8-TCDD dioxin.

(h) The criteria for polychlorinated biphenyls (PCBs) apply to the sum of all congeners, to the sum of all homologs or to the sum of all aroclors.

(i) The acute and chronic aquatic life criteria for dissolved aluminum only apply when the concurrent pH is less than 6.5 or greater than 9.0 S.U. If the concurrent pH is between 6.5 and 9.0 S.U. then the hardness-dependent total recoverable aluminum criteria in Paragraphs (1) and (2) of Subsection I of 20.6.4.900 NMAC apply.

K. The criteria for total ammonia consider sensitive freshwater mussel species in the family Unionidae, freshwater non-pulmonate snails, and *Oncorhynchus* spp. (a genus of fish in the family Salmonidae), hence further protecting the aquatic community. The total ammonia criteria magnitude is measured as Total Ammonia Nitrogen (TAN) mg/L. TAN is the sum of NH_4^+ and NH_3. TAN mg/L magnitude is derived as a function of pH and temperature (EPA 2013).

L. The acute aquatic life criteria for TAN (mg/L) was derived by the EPA (2013) as the one-hour average concentration of TAN mg/L that shall not be exceeded more than once every three years on average. The EPA acute criterion magnitude was derived using the following equation:

Acute TAN Criterion Magnitude for 1-hour average=

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$$\text{MIN}\left(\left(\frac{0.275}{1+10^{7.204-pH}}+\frac{39}{1+10^{pH-7.204}}\right),\left(0.7249\text{x}\left(\frac{0.0114}{1+10^{7.204-pH}}+\frac{1.6181}{1+10^{pH-7.204}}\right)\text{x}\left(23.12\times10^{0.036(20-T)}\right)\right)\right)$$

*T (*temperature C) and *pH* are defined as the paired values associated with the TAN sample.

(1) Temperature and pH-dependent values of the acute TAN criterion magnitude -when *Oncorhynchus* spp. absent.

	Temperature (°C)																				
pH	0-10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	51	48	44	41	37	34	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	49	46	42	39	36	33	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	46	44	40	37	34	31	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9
6.8	44	41	38	35	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	41	38	35	32	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	38	35	33	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9	7.3
7.1	34	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	31	29	27	25	23	21	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6
7.3	27	26	24	22	20	18	17	16	14	13	12	11	10	9.5	8.7	8	7.4	6.8	6.3	5.8	5.3
7.4	24	22	21	19	18	16	15	14	13	12	11	9.8	9	8.3	7.7	7	6.5	6	5.5	5.1	4.7
7.5	21	19	18	17	15	14	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4
7.6	18	17	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	2.9
7.8	13	12	11	10	9.3	8.5	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4	3.7	3.4	3.2	2.9	2.7	2.5
7.9	11	9.9	9.1	8.4	7.7	7.1	6.6	[~~3~~] 6.0	5.6	5.1	4.7	4.3	4	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	8.8	8.2	7.6	7	6.4	5.9	5.4	5	4.6	4.2	3.9	3.6	3.3	3	2.8	2.6	2.4	2.2	2	1.9	1.7
8.1	7.2	6.8	6.3	5.8	5.3	4.9	4.5	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4
8.2	6	5.6	5.2	4.8	4.4	4	3.7	3.4	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	4.9	4.6	4.3	3.9	3.6	3.3	3.1	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1	0.96
8.4	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79
8.5	3.3	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.98	0.9	0.83	0.77	0.71	0.65
8.6	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.5	1.3	1.2	1.1	1	0.96	0.88	0.81	0.75	0.69	0.63	0.58	0.54
8.7	2.3	2.2	2	1.8	1.7	1.6	1.4	1.3	1.2	1.1	1	0.94	0.87	0.8	0.74	0.68	0.62	0.57	0.53	0.49	0.45
8.8	1.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37
8.9	1.6	1.5	1.4	1.3	1.2	1.1	1	0.93	0.85	0.79	0.72	0.67	0.61	0.56	0.52	0.48	0.44	0.4	0.37	0.34	0.32
9.0	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37	0.34	0.32	0.29	0.27

(2) Temperature and pH-dependent values for the acute TAN criterion magnitude-when *Oncorhynchus* spp. are present.

	Temperature (°C)																
pH	0-14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	33	33	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	31	31	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	30	30	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9
6.8	28	28	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	26	26	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	24	24	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	8	7.3
7.1	22	22	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7

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7.2	20	20	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6
7.3	18	18	17	16	14	13	12	11	10	9.5	8.7	8	7.4	6.8	6.3	5.8	5.3
7.4	15	15	15	14	13	12	11	9.8	9	8.3	7.7	7	6.5	6	5.5	5.1	4.7
7.5	13	13	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4
7.6	11	11	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	9.6	9.6	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	3
7.8	8.1	8.1	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4	3.7	3.4	3.2	2.9	2.7	2.5
7.9	6.8	6.8	6.6	6	5.6	5.1	4.7	4.3	4	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	5.6	5.6	5.4	5	4.6	4.2	3.9	3.6	3.3	3	2.8	2.6	2.4	2.2	2	1.9	1.7
8.1	4.6	4.6	4.5	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4
8.2	3.8	3.8	3.7	3.5	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	3.1	3.1	3.1	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1	1
8.4	2.6	2.6	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.9	0.9	0.8
8.5	2.1	2.1	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1	0.9	0.8	0.8	0.7	0.7
8.6	1.8	1.8	1.7	1.6	1.5	1.3	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.6	0.6	0.5
8.7	1.5	1.5	1.4	1.3	1.2	1.1	1	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5
8.8	1.2	1.2	1.2	1.1	1	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4
8.9	1	1	1	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.3
9.0	0.88	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3

M. The chronic aquatic life criteria for TAN (mg/L) was derived by the EPA (2013) as a thirty-day rolling average concentration of TAN mg/L that shall not be exceeded more than once every three years on average. In addition, the highest four-day average within the 30-day averaging period should not be more than 2.5 times the CCC (e.g., 2.5 x 1.9 mg TAN/L at pH 7 and 20°C, or 4.8 mg TAN/L) more than once in three years on average. The EPA chronic criterion magnitude was derived using the following equation:

Chronic TAN Criterion Magnitude for 30-day average=

$$0.8876 \times \left(\frac{0.0278}{1+10^{7.688-pH}} + \frac{1.1994}{1+10^{pH-7.688}}\right) \times \left(2.126 \times 10^{0.028\times(20-MAX(T,7))}\right)$$

*T (*temperature °C) and *pH* are defined as the paired values associated with the TAN sample.

Temperature and pH-Dependent Values of the Chronic TAN Criterion Magnitude.

	Temperature (°C)																							
pH	0-7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	4.9	4.6	4.3	4.1	3.8	3.6	3.3	3.1	2.9	2.8	2.6	2.4	2.3	2.1	2	1.9	1.8	1.6	1.5	1.5	1.4	1.3	1.2	1.1
6.6	4.8	4.5	4.3	4	3.8	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1
6.7	4.8	4.5	4.2	3.9	3.7	3.5	3.2	3	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1
6.8	4.6	4.4	4.1	3.8	3.6	3.4	3.2	3	2.8	2.6	2.4	2.3	2.1	2	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1
6.9	4.5	4.2	4	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1
7.0	4.4	4.1	3.8	3.6	3.4	3.2	3	2.8	2.6	2.4	2.3	2.2	2	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1
7.1	4.2	3.9	3.7	3.5	3.2	3	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1
7.2	4	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1	1	0.9
7.3	3.8	3.5	3.3	3.1	2.9	2.7	2.6	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1	1	0.9	0.9
7.4	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1	1	0.9	0.9	0.8
7.5	3.2	3	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7
7.6	2.9	2.8	2.6	2.4	2.3	2.1	2	1.9	1.8	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7
7.7	2.6	2.4	2.3	2.2	2	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6

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7.8	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5
7.9	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5	0.5	0.5
8.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.4	0.4	0.4
8.1	1.5	1.5	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4
8.2	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3
8.3	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
8.4	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
8.5	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
8.6	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
8.7	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
8.8	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
8.9	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
9.0	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

[20.6.4.900 NMAC - Rp 20 NMAC 6.1.3100, 10/12/2010; A, 10/11/2002; A, 5/23/2005; A, 7/17/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022; A, 5/22/2025; A, MM/DD/YYYY]

20.6.4.901 PUBLICATION REFERENCES: These documents are intended as guidance and are available for public review during regular business hours at the offices of the surface water quality bureau. Copies of these documents have also been filed with the New Mexico state records center [~~in order~~] to provide greater access to this information.

A. American public health association. 1992. *Standard Methods for The Examination of Water and Wastewater, 18th Edition.* Washington, D.C. 1048 p.

B. American public health association. 1995. *Standard Methods for The Examination of Water and Wastewater, 19th Edition.* Washington, D.C. 1090 p.

C. American public health association. 1998. *Standard Methods for The Examination of Water and Wastewater, 20th Edition.* Washington, D.C. 1112 p.

D. American public health association. 2018. *Standard Methods for The Examination of Water and Wastewater, 23rd Edition.* Washington, D.C. 1796 p.

E. American public health association. 2023. Standard Methods for The Examination of Water and Wastewater, 24th Edition. Washington, D.C. 1516 p.

[~~E.~~]**F.** United States geological survey. 1989. *Methods For Determination of Inorganic Substances In Water And Fluvial Sediments, Techniques of Water-Resource Investigations of The United States Geological Survey.* Washington, D.C. 545 p.

[~~F.~~]**G.** United States geological survey. 1987. *Methods For The Determination Of Organic Substances In Water And Fluvial Sediments, Techniques Of Water-Resource Investigations Of The United States Geological Survey.* Washington, D.C. 80 p.

[~~G.~~]**H.** United States environmental protection agency. 1983. *Methods For Chemical Analysis Of Water And Wastes.* Office of research and development, Washington, DC. (EPA/600/4-79/020). 491 p.

[~~H.~~]**I.** New Mexico water quality control commission. 2020. *State Of New Mexico Water Quality Management Plan and Continuing Planning Process*. Santa Fe, New Mexico. 277 p.

[~~I.~~]**J.** Colorado river basin salinity control forum. [~~2020~~]. [~~*2020*~~] *2023 Review, Water Quality Standards For Salinity, Colorado River System.* Phoenix, Arizona. [~~97~~] 112 p.

[~~J~~]**K.** United States environmental protection agency. 2002. *Methods For Measuring The Acute Toxicity Of Effluents And Receiving Waters To Freshwater And Marine Organisms.* Office of research and development, Washington, D.C. (5th Ed., EPA 821-R-02-012). 293 p.

[~~K.~~]**L.** United States environmental protection agency. 2002. *Short-Term Methods For Estimating The Chronic Toxicity Of Effluents And Receiving Waters To Freshwater Organisms.* Environmental monitoring systems laboratory, Cincinnati, Ohio. (4th Ed., EPA 821-R-02-013). 335 p.

[~~L.~~]**M.** United States environmental protection agency. 1991. Ambient-induced mixing, in *Technical Support Document For Water Quality-Based Toxics Control*. Office of water, Washington, D.C. (EPA/505/2-90-001). 335 p.

[~~M.~~]**N.** United States environmental protection agency. 1983. *Technical Support Manual: Waterbody Surveys And Assessments For Conducting Use Attainability Analyses, Volume I*:. Office of water, regulations and standards, Washington, D.C. 232 p.

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[~~N~~]**O.** United States environmental protection agency. 1984. *Technical Support Manual: Waterbody Surveys And Assessments For Conducting Use Attainability Analyses, Volume III: Lake Systems*. Office of water, regulations and standards, Washington, D.C. 208 p.

[20.6.4.901 NMAC - Rp 20 NMAC 6.1.4000, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022; A, MM/DD/YYYY]

HISTORY of 20.6.4 NMAC:

Pre-NMAC History:

Material in the part was derived from that previously filed with the commission of public records - state records center and archives:

WQC 67-1, Water Quality Standards, filed 7/17/1967, effective 8/18/1967
WQC 67-1, Amendment Nos. 1-6, filed 3/21/1968, effective 4/22/1968
WQC 67-1, Amendment No. 7, filed 2/27/1969, effective 3-30/1969
WQC 67-1, Amendment No. 8, filed 7/14/1969, effective 8/15/1969
WQC 70-1, Water Quality Standards for Intrastate Waters and Tributaries to Interstate Streams, filed July 17, 1970;
WQC 67-1, Amendment Nos. 9 and 10, filed 2/12/1971, effective 3/15/1971
WQC 67-1, Amendment No. 11, filed 3/4/1971, effective 4/5/1971
WQC 73-1, New Mexico Water Quality Standards, filed 9/17/1973, effective 10/23/1973
WQC 73-1, Amendment Nos. 1 and 2, filed 10/3/1975, effective 11/4/1975
WQC 73-1, Amendment No. 3, filed 1/19/1976, effective 2/14/1976
WQC 77-2, Amended Water Quality Standards for Interstate and Intrastate Streams in New Mexico, filed 2/24/1977, effective 3/11/1977
WQC 77-2, Amendment No. 1, filed 3/23/1978, effective 4/24/1978
WQC 77-2, Amendment No. 2, filed 6/12/1979, effective 7/13/1979
WQCC 80-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, filed 8/28/1980, effective 9/28/1980
WQCC 81-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, filed 5/5/1981, effective 6/4/1981
WQCC 81-1, Amendment No. 1, filed 5/19/1982, effective 6/18/1982
WQCC 81-1, Amendment No. 2, filed 6/24/1982, effective 7/26/1982
WQCC 85-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, filed 1/16/1985, effective 2/15/1985
WQCC 85-1, Amendment No. 1, filed 8/28/1987, effective 9/28/1987
WQCC 88-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, filed 3/24/1988, effective 4/25/1988
WQCC 91-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, filed 5/29/1991, effective 6/29/1991
WQCC 91-1, Amendment No. 1, filed 10/11/1991, effective 11/12/1991

History of the Repealed Material:

WQC 67-1, Water Quality Standards, - Superseded, 10/23/1973
WQC 73-1, New Mexico Water Quality Standards, - Superseded, 3/11/1977
WQC 77-2, Amended Water Quality Standards for Interstate and Intrastate Streams in New Mexico, - Superseded, 9/28/1980
WQCC 80-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, - Superseded, 6/4/1981
WQCC 81-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, - Superseded, 2/15/1985
WQCC 85-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, - Superseded, 4/25/1988
WQCC 88-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, - Superseded, 6/29/1991
WQCC 91-1, Water Quality Standards for Interstate and Intrastate Streams in New Mexico, - Superseded, 1/23/1995
20 NMAC 6.1, Standards for Interstate and Intrastate Streams, - Repealed, 2/23/2000
20 NMAC 6.1, Standards for Interstate and Intrastate Surface Waters, - Repealed, 10/12/2000

NMED Exhibit 27

STATE OF NEW MEXICO
WATER QUALITY CONTROL COMMISSION

IN THE MATTER OF:

PETITION FOR REGULATORY CHANGE TO
ADOPT AMENDMENTS TO 20.6.4 NMAC –
Standards For Interstate and Intrastate Surface Waters **WQCC 25-75 (R)**

DIRECT TECHNICAL TESTIMONY OF LYNETTE GUEVARA

I. INTRODUCTION

My name is Lynette Guevara and I present this written testimony (**NMED Exhibit 28)** on behalf of the New Mexico Environment Department (NMED or Department) Surface Water Quality Bureau (SWQB or Bureau) concerning the SWQB's proposed amendments to the State of New Mexico's Standards for Interstate and Intrastate Surface Waters (Standards), codified as Title 20, Chapter 6, Part 4 of the New Mexico Administrative Code (20.6.4 NMAC). My testimony outlines the reason behind the following proposed changes:

- amend and update language in 20.6.4.8 NMAC regarding best management practices and maintain a list of ONRWs with documented impairment;
- amend language in 20.6.4.12 NMAC to acknowledge that New Mexico's water quality standards at 20.6.4.900(I) NMAC contain numeric criteria calculations that are dependent on more than concurrent hardness as input values;
- strike language in the Sampling and Analysis section at 20.6.4.14(C) NMAC;
- amend 20.6.4.135 NMAC to include Santa Cruz Lake;
- amend 20.6.4.208, 20.6.4.209, 20.6.4.231, 20.6.4.307, 20.6.4.309, and 20.6.4.403 NMAC to describe the water quality segment breaks by hydrologic feature rather than road crossing and remove unnecessary language; and

- amend 20.6.4.206, 20.6.4.219, 20.6.4.231, and 20.6.4.309 NMAC to change the recreational use designation from secondary contact to primary contact for specified classified waters.

II. QUALIFICATIONS

Since October 2022, I have been the Program Manager for the Monitoring, Assessment, and Standards Section (MASS) for the SWQB, providing grant, project, and program management to three team supervisors with three to five technical staff each. The Monitoring Team's core responsibility is the collection and data management of ambient surface water quality data for all streams, rivers, lakes, and reservoirs around the state on a rotational, watershed schedule. The Standards and Outreach Team's core responsibility is the development and maintenance of New Mexico's water quality standards (WQS) at 20.6.4 NMAC, outreach activities, and data quality assurance procedures. The TMDL and Assessment Team's core responsible is the development and maintenance of SWQB's assessment methodologies (used to determine whether the state's waterbodies are attaining water quality standards and supporting designated uses based on available data), the Clean Water Act (CWA) § 303(d)/§ 305(b) Integrated Report, and the development of total maximum daily load (TMDL) planning documents for each waterbody not meeting standards. The data, assessment, reporting, and planning products created and managed by MASS provide vital information to SWQB's permitting and watershed restoration sections.

I began work with the Department at SWQB in August 2001 as the CWA §303(d)/§305(b) Assessment Coordinator, a role I held for 19 years among other duties including TMDL writing, database design and oversite, and project management. I have had various supervisory and technical roles related to water quality monitoring, assessment, reporting, and standards revisions

during my 25 years with the Department, all focused on water quality. I have collaborated with the U.S. Environmental Protection Agency (EPA) and their contractors as well as surrounding state colleagues numerous times to develop improved surface water assessment methodologies and data reporting tools.

From 1997-2001, I designed, implemented, and supervised water quantity and quality monitoring as well as watershed restoration projects for the Navajo Nation Water Management Branch and Navajo Nation Environmental Protection Agency. I have a Bachelor of Business Administration degree from Gonzaga University and a Master of Science degree in Watershed Science from Colorado State University. I have contributed to several publications as detailed in my updated resume (**NMED Exhibit 29)**.

III. AMENDMENTS ASSOCIATED WITH ONRW IMPLEMENTATION PLAN AND REPORTING

The Department is proposing to amend and update language in 20.6.4.8 NMAC regarding the first occurrence of "best management practices" (BMPs) and use "BMPs" thereafter for consistency and efficiency. In new subsection 20.6.4.8(B)(17) NMAC, the Department proposes to add language to clarify that the Department maintains and publishes a list of Outstanding National Resource Waters (ONRWs) with documented impairments through our Integrated List (Appendix A of the State of New Mexico CWA § 303(d)/§ 305(b) Integrated Report, which is available on the Bureau's website[1] **(NMED Exhibit 30).** All assessment units (AUs, map lines or polygons that represent a single lake or reservoir, length of a stream reach or river, or surface waters within a delineated area such as a sub-watershed) designated as ONRWs are noted as such

[1] https://www.env.nm.gov/surface-water-quality/303d-305b/

in the associated "AU Comment" field including the related ONRW bundle and year established. For example, the Integrated List AU entry for "McCrystal Creek (North Ponil to headwaters)" includes an "AU Comment" that states "ONRW (Valle Vidal, 2006)." Along with many other GIS layers relevant to surface water quality including layers that delineate assessed and impaired waters, SWQB created and maintains a GIS layer of all ONRWs approved by the Water Quality Control Commission (WQCC) by short title and year established on the publicly available Surface Water Quality OpenEnviroMap[2].

In addition, in cooperation with stakeholders, the Department collaborated to create and maintain a Memorandum of Understanding (MOU) with the U.S. Forest Service Southwestern Region[3] (**NMED Exhibit 31).** The MOU serves to increase communication, coordination, and notification of activities with the potential to impact water quality in ONRWs by the Forest Service to the Department. For example, **NMED Exhibit 32** is an example of the recent notification the Forest Service sent SWQB to keep us aware of response activities for the McCauley Springs Fire with potential impacts to ONRWs in the area. The SWQB has also initiated efforts to increase volunteer monitoring of surface water quality with an initial focus on ONRWs through modifying existing grant funding and associated work plans to fund outreach coordination activities and recently met with New Mexico Wild to discuss how we can collaborate with and support each other's volunteer monitoring efforts, starting with a goal of increased ONRW monitoring during the upcoming 2027 SWQB Upper Rio Grande ambient water quality survey.

[2] https://gis.web.env.nm.gov/oem/?map=swqb
[3] https://www.env.nm.gov/surface-water-quality/watershed-protection-section/

IV. AMENDMENTS ASSOCIATED WITH COMPLIANCE WITH WATER QUALITY STANDARDS DEPENDENT ON RECEIVING WATER CHARACTERISTICS

The Department proposes to amend language in 20.6.4.12(F) NMAC to clarify that New Mexico's water quality standards at 20.6.4.900(I) NMAC contain numeric criteria calculations that are dependent on more than concurrent hardness as input values to consider receiving water characteristics. For example, copper criteria for Pajarito Plateau surface waters at 20.6.4.900(I)(4) NMAC are dependent on hardness, dissolved organic carbon, and pH. The Department further clarifies that if concurrently collected receiving water data (preferred) are not available, default values that are justified in writing and supported by ecoregional or other watershed data may be acceptable to acknowledge that concurrent collection of or access to several additional input parameters is not always possible or practical due to potential field equipment failure, increased laboratory analysis costs, or other sampling constraints. EPA defines "ecoregions" as delineated areas where the type, quality, and quantity of environmental resources are generally similar **NMED Exhibit 33)**. EPA identifies and categorizes ecoregions into four hierarchical levels by analyzing the patterns and composition of biotic and abiotic characteristics that affect or reflect differences in ecosystem quality and integrity. These characteristics include geology, landforms, soils, vegetation, climate, land use, wildlife, and hydrology. EPA prepared guidance on the data analysis approaches EPA used to develop recommendations for default values for water quality parameters used in the copper biotic ligand model when input data are lacking (**NMED Exhibit 34).**

V. AMENDMENTS ASSOCIATED WITH SAMPLING AND ANALYSIS

The Department proposes to strike the last sentence of 20.6.4.14(C)(3) NMAC that dictates precisely how and when lentic water quality samples shall be collected. The current wording is confusing and has resulted in differing interpretations over the years. For example, it is unclear to some attempting to interpret the phrase "Water quality measurements…" if it is referring specifically to basic field parameters such as temperature, pH, dissolved oxygen, and specific conductance as collected by a sonde or if it was intended to cover all collected samples. In addition, the exception for "attainment of criteria for toxic pollutants" does not make sense in the case of cyanotoxin sampling intended to determine if there is a suspected harmful algal bloom forming because these toxins are related to recreational uses and activities so should therefore be sampled at shallow recreational lake stations near the shore and dock areas where primary contact is most likely versus at depth in the middle of the lake.

The Department believes it is a better and more standard practice to provide this level of sampling specifics in relevant Standard Operating Procedures (SOPs) that can be reviewed and updated periodically with the latest limnological monitoring knowledge. Specifically, detailed procedural sampling information should and does reside in SWQB's SOP 12.1 - Lake Sampling[4] (**NMED Exhibit 35**), which is reviewed and updated a minimum of every two years by the SWQB monitoring staff with lake sampling, fisheries, and quality assurance technical expertise. Documenting sampling procedure details such as these in the SOPs provides the Department flexibility to ensure SWQB's lake monitoring techniques are aligned with the current lake monitoring state of knowledge and best practices such as those proposed and maintained by EPA's

[4] https://www.env.nm.gov/surface-water-quality/sop/

National Lakes Assessment (NLA) (**NMED Exhibit 36**) and aligned with professional limnology and the North American Lake Management Society (NALMS) framework. Being able to directly align and standardize New Mexico's sampling and analysis protocols with EPA, NALMS, and surrounding states allows SWQB to collate regional data into larger datasets that we can then use to statistically analyze and use as model inputs to improve data analysis and assessment methodologies.

V. AMENDMENTS ASSOCIATED WITH CLASSIFIED WATER SEGMENT DESCRIPTIONS AND USES

A. Amend 20.6.4.135 NMAC to include Santa Cruz Lake

The Department proposes to amend lake-specific segment 20.6.4.135 NMAC with a designated coldwater aquatic life use (CWAL) to include Santa Cruz Lake based on similarities to Bluewater Lake, physical location, fisheries data and management, and available temperature and modeling data; available air-water temperature and other modeling performed during SWQB's development of the 2024 WQCC and EPA approved temperature TMDL; and elevation and ecoregion data.

Santa Cruz Lake is a reservoir located in north-central New Mexico in the Sangre de Cristo foothills at an elevation of 6,286 feet. The Santa Cruz Irrigation District owns the concrete gravity dam completed in 1929 to create Santa Cruz Lake for the purposes of irrigation and recreation. The New Mexico Office of the State Engineer is the regulatory authority. Water released from Santa Cruz Lake is primarily used for irrigation, and lake levels can drop significantly during times of high irrigation need. The reservoir has a surface area of approximately 100 acres, with an estimated normal storage of approximately 3,000 acre-feet. Santa Cruz Lake is fed by the Rio Medio and the Rio Frijoles, which converge just upstream of the lake to form the Santa Cruz River.

The reservoir is the primary focus of the Santa Cruz Recreational Area, managed and maintained by the Bureau of Land Management (BLM), providing hiking, fishing, camping, paddling, and boating opportunities for the public **(NMED Exhibit 37)**.

The New Mexico Department of Wildlife (NMDOW) stocks Santa Cruz Lake with triploid (sterile, non-reproducing) rainbow trout to maintain a put-and-take fishery, defined as where waters are stocked with catchable trout to be immediately harvested by anglers especially where angler demand significantly exceeds natural production. The NMDOW also acknowledges a wild population of brown trout, with a note that irrigation withdrawals causing dramatic drops in lake levels through the summer can limit wild trout potential (**NMED Exhibit 38**). Although "no swimming" signs are posted at Santa Cruz Lake as a safety precaution due to the dam design and excessive amounts of fishhooks and other foot hazards in the sediment, it does occur and there is also incidental full immersion when falling off paddleboards and other watercraft.

In 2011, the Department petitioned the WQCC for a rulemaking to consider amendments to the WQS for 62 lakes that were classified with streams[5]. As a result, the WQCC and EPA approved the creation of 19 lake-specific water quality standard segments in 20.6.4 NMAC **(NMED Exhibit 39)**. Both the Department and the WQCC promoted and supported this action to recognize that lakes and streams are different and warrant specific recognition of this fact in 20.6.4 NMAC. This reality is supported by the need to classifying waters into water quality "segments" that are assigned the same designated uses and criteria through the following definition of "segment" at 20.6.4.7(S)(2) NMAC:

> a classified water of the state described in 20.6.4.101 through 20.6.4.899 NMAC. The water within a segment should have the same uses, similar hydrologic characteristics

[5] https://www.env.nm.gov/surface-water-quality/lakes-amendment/

or flow regimes, and natural physical, chemical and biological characteristics and exhibit similar reactions to external stresses, such as the discharge of pollutants.

Some segment descriptions are unclearly written and can be interpreted to include both lakes and stream or river reaches leading to confusion during assessment and permitting processes, and do not adhere to the intention of the definition of "segment." Lakes and streams have very different hydrologic characteristics and residence times that affect physical characteristics such as bottom sediments, temperature, and dissolved oxygen, as well as nutrient cycling. This in turn impacts resident biological communities that respond to these differing characteristics. Recreational patterns and levels also generally vary between streams and lakes. Classifying lakes into lake-specific segments separately from streams allows for the correct identification of existing and designated uses and application of appropriate criteria to protect those uses.

The WQCC approved 20.6.4.135 NMAC during this action to provide clear, concise water quality protection for Bluewater Lake within Bluewater Lake State Park. This 610-acre reservoir is at an elevation of 7,375 feet and is located within Bluewater Lake State Park in northwestern New Mexico. Bluewater Lake was created for irrigation purposes and shares many characteristics with Santa Cruz Lake. In addition, they are both popular water bodies for picnicking, fishing, boating, paddleboarding, and nearby camping. Similar to Santa Cruz Lake, NMDOW stocks Bluewater Lake with triploid (sterile, non-reproducing) rainbow trout to maintain a put-and-take fishery.

Unlike most other lakes and reservoirs in New Mexico, Santa Cruz Lake is not currently identified under a lake-specific water quality standard segment. This has made it unclear what WQS segment Santa Cruz Lake falls under because it is not currently explicitly noted in any lake-specific or other classified segment like other lakes. Given the active put-and-take rainbow trout

fishery and noted wild brown trout population, assigning Santa Cruz Lake to the default perennial waters segment under 20.6.4.99 NMAC with warmwater aquatic life, higher default primary contact *E. coli* criteria, and no irrigation use would be under protective of current swimmable and fishable goals, and irrigation and recreation purposes. Therefore, the Department proposes to amend section 20.6.4.135 NMAC to include Santa Cruz Lake. The table below provides a comparison of designated uses in the segments noted above:

Designated Uses	**Default Perennial 20.6.4.99**	**Proposed 20.6.4.135**
Coldwater aquatic life		X
Warmwater aquatic life	X	
Domestic water supply		X
Irrigation		X
Primary contact	X	X
Livestock watering	X	X
Wildlife habitat	X	X

Available water quality data confirms that the segment-specific *E. coli* sample 235 cfu/100 mL or less can be achieved (**NMED Exhibit 40**). Irrigation is clearly an applicable and ongoing use because the dam was built to create the reservoir to provide irrigation. The Department does not have sufficient information to either confirm or refute domestic water supply as an existing use.

Existing fisheries and modeled lake temperatures at Santa Cruz Lake are consistent with the definition of coldwater aquatic life use descriptions and associated 6T3 and maximum temperature criteria of 20°C (68°F) and 24°C (75°F), respectively. The Department prepared a temperature TMDL for Santa Cruz Lake in 2024. During TMDL development, ecosystem parameters were used to model predicted typical water temperature. Model results indicated that

Santa Cruz Lake summer water levels typically peaked between 24°C and 25°C from 1995 – 2021 (**NMED Exhibit 41**).

The existing lake-specific segment in the Rio Grande Basin that best describes Santa Cruz Lake is 20.6.4.135 NMAC given the lake elevation and latitude, fisheries data and management, available temperature data, and modeling results. Adding Santa Cruz Lake to the existing lake-specific segment 20.6.4.135 NMAC provides regulatory clarity and appropriately protects existing and attainable uses of this important water resource.

B. Amendments to 20.6.4.208, 20.6.4.209, 20.6.4.231, 20.6.4.307, and 20.6.4.309 NMAC to describe segment breaks by hydrologic features rather than road crossings

The Department proposes to amend several water quality segment breaks in 20.6.4 NMAC to describe the segment breaks by hydrologic features rather than by road crossings. Water quality segment breaks at roads have no hydrologic, ecological, or environmental significance, and are an artifact of human activities. In addition, SWQB believes WQS breaks at highway crossings in 20.6.4 NMAC may simply be an artifact of historic water quality sampling stations established several decades ago at road crossings, particularly in locations surrounded by private land where the bridge right of way was the only available water quality sampling access point.

The Department proposed to amend the Rio Penasco segment description break at "state highway 24 near Dunken" to "Bear Canyon *(sic)*" in 20.6.4.208 and 20.6.4.231 NMAC. During direct testimony development, the Department recognized a typographical error and changes its proposal to amend the segment description break at "state highway 24 near Dunken" to "Big Cherry Canyon" (**NMED Exhibit 42**) in 20.6.4.208 and 20.6.4.231 NMAC as noted in green:

> **20.6.4.208 PECOS RIVER BASIN: Perennial reaches of the Rio Peñasco above [~~state highway 24 near Dunken~~] Big Cherry Canyon, perennial reaches of tributaries to the Rio Peñasco above [~~state highway 24 near Dunken~~] Big Cherry Canyon, perennial reaches of Cox canyon, perennial reaches of**

the Rio Bonito downstream from [~~state highway 48 (near Angus)~~] Angus canyon, the Rio Ruidoso downstream of [~~the U.S. highway 70 bridge~~] Palo Verde canyon near Seeping Springs lakes, perennial reaches of the Rio Hondo upstream from Bonney canyon and perennial reaches of Agua Chiquita.

…

20.6.4.231 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from [~~state highway 24 near Dunken~~] Big Cherry Canyon, [~~perennial reaches of North Spring river and~~]perennial reaches of the Rio Hondo and perennial reaches of its tributaries downstream of Bonney canyon.

This proposed action moves the segment break approximately 4.05 miles downstream. The revised segment break moves the break to the outlet of the same U.S. Geological Survey (USGS) 12-digit Hydrologic Unit Code (HUC) watershed (Copeland Canyon-Rio Penasco); and is in the same EPA Level IV Ecoregion (26q – Southern New Mexico Dissected Plains), and land use type (private). There are no point source discharge permits impacted by this proposed change.

The Department proposes to amend the Rio Bonito segment description break at "state highway 48 (near Angus)" to "Angus Canyon" in 20.6.4.208 and 20.6.4.209 NMAC (**NMED Exhibit 43**). The revised segment break moves the break approximately 0.05 miles downstream; and is in the same USGS 12-digit HUC watershed (Middle Rio Bonito), EPA Level IV Ecoregion (23e – Conifer Woodlands and Savannas), and land use type (private). There are no point source discharge permits impacted by this proposed change. The Department also proposes to amend the Rio Ruidoso segment description break at "the U.S. highway 70 bridge" to "Palo Verde Canyon" in 20.6.4.208 and 20.6.4.209 NMAC (**NMED Exhibit 44**). The revised segment break moves the break moves the break approximately 0.58 miles upstream; and is in the same USGS 12-digit HUC watershed (Middle Rio Ruidoso), EPA Level IV Ecoregion (23b – Madrean Lower Montane Woodlands), and land use type (private). NPDES permit NM0029165 is in the area but not impacted by this proposed change because it remains under 20.6.4.208 NMAC. The proposed

amendment to delete "perennial reaches of North Spring river" and replace with "perennial reaches of its tributaries" is explained below in Section C.

In sections 20.6.4.307 and 20.6.4.309 NMAC, the Department proposes to amend the Mora River segment description break at "the state highway 434 bridge in Mora" to "Rio la Casa" (**NMED Exhibit 45)**. This proposed action moves the segment break approximately 1.72 miles upstream to the confluence with tributary Rio La Casa at the USGS 12-digit HUC watershed outlet. The EPA Level IV Ecoregion will change because stretch of river contains the break from ecoregion 21c (Crystalline Mid-Elevation Forests) and 21f (Sedimentary Mid-Elevation Forests). The land use type remains the same (private). The NPDES permit NM0031097 (Mora High School permit for dewatering their football field that naturally floods occasionally) immediately upstream of the highway crossing would be impacted by this proposed change because it would now fall under 20.6.4.307 NMAC with a less stringent aquatic life use. SWQB would re-assess and open any related TMDLs as needed to revise any relevant permit waste load allocations to provide the information for the 7/31/2028 permit renewal.

The Department also proposes to expand the exceptions list of waters identified in 20.6.4.307 NMAC by striking the word "lakes" and adding "…20.6.4.309 NMAC or…" while concurrently revising the reference to Coyote Creek in 20.6.4.309 NMAC to "perennial reaches of Coyote creek upstream of Amola ridge and perennial reaches of tributaries to Coyote creek upstream to Amola ridge" (**NMED Exhibit 46)**. The whole of Coyote Creek is covered by both 20.6.4.307 and 20.6.4.309 NMAC as currently written. Amola Ridge is a prominent geologic formation where Coyote Creek transitions from the high plains to a thin band of foothills as reflected in the EPA Level III Ecoregion change from category 21 (Southern Rockies) to 26 (Southwest Tablelands) and specifically acknowledged by a narrow band of EPA Level IV

Ecoregion 21d where the Department proposes the segment break. As such, Coyote Creek from the Mora River to Amola Ridge is in the corresponding Xeric sedimentation class until Amola Ridge where it transitions into first the Foothills sedimentation class and then further upstream into the Mountain sedimentation class based on EPA Level III and IV ecoregions as documented in the Sedimentation assessment methodologies (**NMED Exhibit 47**). For these reasons, Amola Ridge is the appropriate geological and topographic segment break point between 20.6.4.307 and 20.6.4.309 NMAC on Coyote Creek to discern which stream reaches of Coyote Creek are covered by these two WQS segments. Adding this break point provides clarity to permitting and CWA §303(d)/§305(b) assessment processes.

C. Amendments to 20.6.4.206, 20.6.4.219, 20.6.4.231, 20.6.4.308, associated with Recreational Use Analysis

Per CFR 131.20(a), states shall re-examine any waterbody segment with water quality standards that do not include the uses specified in section 101(a)(2) of the CWA (i.e., fishable/swimmable uses) every three years to determine if any new information has become available. If this information indicates that the uses specified in 101(a)(2) of the CWA are attainable, the state shall revise its standards accordingly.

Based on the findings in the Department's *Recreational Use Analysis for Classified Waters 20.6.4.101-20.6.4.899 NMAC* (**NMED Exhibit 48**), the Department proposes to amend language in segments 20.6.4.206 and 20.6.4.231 NMAC, as well as 20.6.4.219 and 20.6.4.308 NMAC.

The Department proposes to strike from 20.6.4.206 NMAC's segment description "and perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon, excluding North Spring river" and concurrently add "perennial reaches of its tributaries" to the Rio Hondo downstream of Bonney canyon to 20.6.4.231 NMAC (**NMED Exhibit 49**). Berrendo Creek and

North Spring River are the only two perennial tributaries to the Rio Hondo downstream of Bonney Canyon. The Department reviewed available 2021-2022 *E. coli* and pH data and determined a recreational use change from Secondary Contact to Primary Contact is warranted because all available pH data were within 6.6 to 9, and 5 of 6 *E. coli* measurements were below 410 cfu/100 mL. Therefore, the Department proposed concurrent changes to both 20.6.4.206 and 20.6.4.231 NMAC to reflect the assignment of Primary Contact to both Berrendo Creek and North Spring River. No *E. coli* and pH data were available for perennial reaches of the Rio Felix to determine if a change from secondary to primary contact was warranted; therefore, Secondary Contact remains the recreational designated use for the revised 20.6.4.206 NMAC. In addition, while preparing direct testimony and exhibits, the Department noticed a reference to "state highway 24 near Dunken" in the "NOTE" portion of 20.6.4.206 NMAC. To be consistent with the proposed segment break change to "Big Cherry Canyon" for the reason stated in Paragraph B earlier in my testimony, the Department proposes to make the below change in this 20.6.4.206 NMAC "NOTE" section for consistency along with adding "and perennial reaches of its tributaries downstream of Bonney canyon" as shown in green below:

20.6.4.206 PECOS RIVER BASIN: Perennial reaches of the Rio Felix[~~ and perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon, excluding North Spring river~~].

A. Designated uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

[20.6.4.206 NMAC - Rp 20 NMAC 6.1.2206, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022; A, MM/DD/YYYY]

[**NOTE:** This segment was divided effective 4/23/2022. The standards for the main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from [~~state highway 24 near Dunken~~]Big Cherry Canyon, and perennial reaches of the Rio Hondo and perennial reaches of its tributaries downstream of Bonney canyon are under 20.6.4.231 NMAC.]

The Department proposes to amend 20.6.4.219 NMAC (Avalon Reservoir) to change the recreational use from Secondary Contact to Primary Contact. Recreation at Avalon Reservoir is managed by the Carlsbad Irrigation District under agreement with the Bureau of Reclamation. The recreation area is open year-round. Management at nearby Brantley Lake reports that Avalon Reservoir has "… a lot of public use including paddle boarding and kayaking, as well as high traffic for fishing and swimming." The Department reviewed available 2025-2026 *E. coli* and pH data and determined a recreational use change from Secondary Contact to Primary Contact is warranted because all available pH data were within 6.6 to 9, and 8 of 8 *E. coli* measurements were below 410 cfu/100 mL.

The Department proposed to amend 20.6.4.308 NMAC (Charette Lakes) to change the recreational use from Secondary Contact to Primary Contact Lake. NMDOW manages these lakes as part of the Charette Lakes Wildlife Area. There is public access with regular recreation. The Department reviewed available Lower Charette Lake 2025-2026 *E. coli* and pH data and determined a recreational use change from Secondary Contact to Primary Contact is warranted because all available pH data were within 6.6 to 9, and 6 of 6 *E. coli* measurements were below 410 cfu/100 mL. There are no data available for Upper Charette Lake, which has more wetland, and marsh-like characteristics. Therefore, the Department proposes to keep secondary contact as a designated use for Section 308, but recommends adding primary contact for Lower Charette Lake based on the data as follows (noted in green):

20.6.4.308 CANADIAN RIVER BASIN: Charette lakes.
Designated uses: coldwater aquatic life, warmwater aquatic life, secondary contact, livestock watering, [~~and~~] wildlife habitat; and primary contact on Lower Charette lake.

D. Remove unnecessary language in 20.6.4.403 NMAC

The Department proposes to amend segment 20.6.4.403(B) NMAC to remove "except that the following segment-specific criterion applies: temperature 29°C (84.2°F) or less." This is the exact same value as the default temperature criterion at 20.6.4.900(H)(4) for coolwater aquatic life, which is the designated use for this segment, so it is redundant and unnecessary.

VI. CONCLUSION

The Department recommends that the Commission adopt the proposed amendments to the Standards filed with the Department's First Amended Petition (**NMED Exhibit 27**) and based upon the testimony of the SWQB's witnesses.

This concludes my direct testimony.

LYNETTE STEVENS GUEVARA

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Santa Fe, NM 87505 505.629-8811 lynette.guevara@env.nm.gov

Summary of Qualifications:

Thirty+ years of experience in natural resources protection and management with emphasis on water quality monitoring, assessment, restoration, and reuse. Major strengths include project management and collaboration, data management and interpretation, technical report preparation and editing, and developing tools and techniques to increase efficiency.

Professional Experience:

11/22 – present New Mexico Environment Dept. Surface Water Quality Bureau, Santa Fe, NM

Monitoring, Assessment, and Standards Section Program Manager

- Manage a group of fourteen technical staff including mentoring three team supervisors to:
  - Monitor, assess, and report on surface water quality conditions around New Mexico
  - Develop, revise, and maintain New Mexico's surface water quality standards
  - Develop, maintain, and promote total maximum daily load (TMDL) planning documents to address water quality impairments
  - Provide related assistance and support to other Bureau sections and stakeholders as needed
- Participate in grant writing, budget tracking, funding allocations, hiring, and performance reviews
- Review, update, and develop protocols to standardize tasks including sample collection, data assessment, and report writing
- Prepare and implement EPA grants applications and revisions, associated workplans, and budgets designed to achieve Department and Bureau goals
- Participate on various EPA and state counterpart workgroups and technical teams regarding water quality policy, implementation, guidance, and strategies to achieve related goals and deliverables
- Maintain and promote improvements of water quality data storage and retrieval in the Bureau's water quality database, and prepare scheduled uploads of data to EPA's national database
- Initiate, allocate funding, and manage contracts related to the development of NMED's Harmful Algal Blooms Advisory Program
- Work with the Bureau's web authors to create, update, and maintain webpages, resources, and links associated with Section activities.

11/20- 10/22 New Mexico Environment Dept. Ground Water Quality Bureau, Santa Fe, NM

Pollution Prevention Section Reuse Team Leader

- Serve as in-house expert for above-ground use of reclaimed domestic wastewater and aquifer recovery and storage permits to encourage successful implementation of water reuse projects
- Maintain individual groundwater discharge permit case load, provide review and comment on all permits with reuse components, and contribute to the oversight of all discharge permits managed by the Section
- Research and propose IT modernization tools to provide e-Permitting and e-Reporting tools to increase efficiency, compliance, and transparency
- Manage CWA 319 grant including workplans, budgeting, and reporting
- Hire, supervise, and manage a team of three water resource professionals

08/01 – 11/20 New Mexico Environment Dept. Surface Water Quality Bureau, Santa Fe, NM

State on New Mexico Clean Water Act §303(d)/ §305(b) Assessment Coordinator (2001-2020)
Project management duties performed to create the biennial Clean Water Act §303(d)/§305(b) Integrated Report and List to Congress:

- Collated and assessed chemical, physical, and biological data to determine surface water quality impairments based on current surface water quality standards
- Developed and applied assessment protocols used to determine water quality attainment
- Developed automated assessment procedures in R statistical programming language
- Collaborated with NMED IT and EPA Office of Water to merge and improve NMED inhouse and national water quality monitoring and assessment databases
- Presented to the NM Water Quality Control Commission (WQCC) and EPA Region 6 for approval
- Prepared and presented testimony to the NM WQCC regarding Outstanding National Resource Waters nominations in the Valle Vidal and to defend impairment determinations
- Participated in various EPA and state counterpart workgroups and national conferences regarding Clean Water Act policy, procedures, and deliverables
- Collaborated with the USDA National Sedimentation Lab to develop sedimentation assessment protocols for the San Juan River basin
- Collaborated with the EPA Office of Research and Development and EPA Region 6 to develop sedimentation and nutrient assessment protocols and monitoring techniques

Monitoring and Assessment Section Program Manager (2004-2006)

- Manage a group of twelve technical staff including three team supervisors to:
    - Monitor, assess, and report on surface water quality conditions around New Mexico
    - Develop, maintain, and promote total maximum daily load (TMDL) planning documents to address water quality impairments
    - Provide related assistance and support to other Bureau sections and stakeholders as needed
- Participate in grant writing, budget tracking, funding allocations, hiring, and performance reviews
- Review, update, and develop protocols to standardize tasks including sample collection, data assessment, and report writing
- Prepare and implement EPA grants applications and revisions, associated workplans, and budgets designed to achieve Department and Bureau goals
- Participate on various EPA and state counterpart workgroups and technical teams regarding water quality policy, implementation, guidance, and strategies to achieve related goals and deliverables
- Maintain and promote improvements of water quality data storage and retrieval in the Bureau's water quality database, and prepare scheduled uploads of data to EPA's national database

Monitoring and Assessment Section TMDL, GIS and Database Team Leader (2001-2003)

- Supervised and managed three technical staff to develop total maximum daily load (TMDL) water quality planning documents, GIS tools, and water quality databases for the Section
- Prepared and completed performance evaluations, developed team timelines and specific tasks needed to accomplish goals, and participated in the evolution of the Monitoring and Assessment Section
- Developed, public noticed, and presented TMDL water quality planning documents to stakeholders and the NM WQCC to address identified water quality impairments

05/97 – 08/01 Navajo Nation, Window Rock, AZ

Hydrologist II, Navajo Nation EPA Water Quality Program (02/99 -08/01)

- Project management, including the proposal and implementation of watershed restoration projects; designing monitoring networks; preparing outreach materials, presentations, and technical reports; and coordinating activities with federal tribal and federal land management partners

- Developed bioassessment monitoring program, associated quality assurance project plans, and provided training to staff and students
- Coordinated surface water quality sampling, interpreted data, and prepared summary reports

Hydrologist II/Supervisor, Navajo Nation Water Management Branch (05/97 -02/99)

- Supervised and managed stream gage and watershed restoration staff, including hiring, training, evaluations, budgeting, and ensuring deliverables were met
- Project management of watershed restoration projects with tribal and federal land management partners, including the development of RFPs, contracts, workplans, work schedules, permits, project budgets, and monitoring networks
- Maintained nine active continuous stream gages - coordinated with USGS, ordered needed equipment, surveyed benchmarks, measured stream flow, developed rating curves, and assisted with water monitoring design of irrigation canals

10/93 - 09/96 National Park Service Water Resources Division, Ft. Collins, CO

Assistant Contaminants Specialist

- Performed literary and electronic searches of aquatic contaminants research and regulations for inclusion into an electronic contaminants database on a wide variety of water quality, ecotoxicological, risk assessment, and statistical topics; technical editing; report writing; and project lead on petroleum contaminants
- Generated technical response to parks on special projects relating to specific park contaminants issues, rehabilitation, and land use management
- Designed and implemented study using benthic macroinvertebrates as indicators of water quality at Bandelier National Monument, NM (Colorado State University thesis project)

1991-1993 Environmental Information Systems Analyst, Genwest Systems, Inc., Edmonds, WA

- Designed and developed information management databases and graphics for NOAA's Hazardous Materials Response and Assessment Division (HMRAD)
- Updated emergency response chemical database and design of CERCLA site tracking database
- On-site marine spill response with NOAA HMRAD and US Coast Guard, including installation of computer command center, preparation of situation maps, and integration of data collected from all agencies for media and response team briefing packets
- Assisted in preparation of company proposal to acquire base NOAA funding

Education:

Bachelor of Business Administration (Marketing), Gonzaga University, Spokane, WA
Post-baccalaureate coursework at University of Washington and Shoreline CC, Seattle, WA
Master of Science (Watershed Science), Colorado State University, Fort Collins, CO

Computer Skills:

MS Office, Oracle database design team, SSTEMP modeling, RStudio programming, ArcGIS, website maintenance

Publications and Presentations:

Guevara, L. 2003. The challenges and opportunities of implementing TMDLs in states with no instream flow program. In proceedings of *ASAE Conference on Emerging TMDL Issues*. Albuquerque, NM.

Guevara, L. 2012. Determining sediment impairment in New Mexico using biologic and geomorphic sediment

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Stevens, L.I. 1996. Benthic macroinvertebrates as indicators of water quality. Master's thesis. Department of Earth Resources, Colorado State University, Ft. Collins, CO.

Viera, N., W. Clements, L. Guevara, and B. Jacobs. 2004. Resistance and resilience of stream insect communities to repeated hydrologic disturbances after a wildfire. Freshwater Biology 49: 1243-1259.



EPA-Approved

2026-2028 State of New Mexico Clean Water Act §303(d)/§305(b) Integrated Report

June 10, 2026

Prepared by:
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Water Quality Control Commission Approval date: March 10, 2026 (Appendix A)

EPA approval date: June 8, 2026

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COVER PHOTO: Storrie Lake, September 2025, NMED/SWQB

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Abbreviations and Acronyms

ACWA	Association of Clean Water Administrators
ATTAINS	Assessment & Total Maximum Daily Load Tracking & Implementation System
AU	Assessment Unit
BLM	Bureau of Land Management
BMPs	Best Management Practices
CALM	Comprehensive Assessment and Listing Methodology
CFR	Code of Federal Regulations
CPB	Construction Programs Bureau (NMED)
CWA	Clean Water Act
CWSRF	Clean Water State Revolving Fund
DDT	dichlorodiphenyltrichloroethane
DO	Dissolved Oxygen
DWB	Drinking Water Bureau (NMED)
DWSRLF	Drinking Water State Revolving Loan Fund
E. coli	*Escherichia coli*
EMNRD	Energy, Minerals, and Natural Resources Department (New Mexico)
EPA	United States Environmental Protection Agency
FY	Fiscal Year
GIS	Geographic Information System
GWQB	Ground Water Quality Bureau
HUC	Hydrologic Unit Code
IR	Integrated Report
MS4	Municipal Separate Storm Sewer Systems
NAIP	National Agriculture Imagery Program
NARS	National Aquatic Resources Surveys
NHD	National Hydrography Dataset
NMAC	New Mexico Administrative Code
NMDOW	New Mexico Department of Wildlife (formerly Game and Fish)
NMDOH	New Mexico Department of Health
NMED	New Mexico Environment Department
NMFA	New Mexico Finance Authority
NMISC	New Mexico Interstate Stream Commission
NMOSE	New Mexico Office of the State Engineer
NMRAM	New Mexico Rapid Assessment Method
NMSA	New Mexico Statutes Annotated
NMWQCC	New Mexico Water Quality Control Commission
N-STEPS	Nutrient Scientific Technical Exchange Partnership and Support
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
PCBs	Polychlorinated Biphenyls
PSRS	Point Source Regulation Section

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QA/QC	Quality Assurance/ Quality Control
RSP	River Stewardship Program
SDWA	Safe Drinking Water Act
SLD	State Laboratory Division
SOPs	Standards Operating Procedures
SQUID	Surface Water Quality Information Database
SWCD	Soil and Water Conservation District
SWQB	Surface Water Quality Bureau
TMDL	Total Maximum Daily Load
UOCP	Utility Operator Certification Program
USACE	United States Army Corp of Engineers
USBLM	United States Bureau of Land Management
USBOR	United States Bureau of Reclamation
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WBP	Watershed-Based Plan
WPP	Wetlands Program Plan
WPS	Watershed Protection Section
WQA	Water Quality Act (New Mexico)
WQMP/CPP	Water Quality Management Plan / Continuing Planning Process
WQS	Water Quality Standards
WQX	Water Quality Exchange
WWTP	Wastewater Treatment Plant

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Executive Summary

Purpose of the 2026-2028 CWA §303(d)/§305(b) Integrated Report

The protection of water quality in New Mexico is vitally important to the health and well-being of all New Mexicans and the aquatic life and wildlife that inhabit its waters. New Mexico uses a variety of mechanisms, including state, federal, and local programs, to protect and restore the quality of its ground and surface waters. The Clean Water Act (CWA) and New Mexico Water Quality Act (WQA) provide the basic underpinnings of surface water protection with the water quality standards codified in the State of New Mexico Standards for Interstate and Intrastate Surface Waters [20.6.4 NMAC]. Water quality standards are comprised of designated uses for surface waters of the state, associated water quality criteria necessary to protect these uses, and an antidegradation policy. Designated uses in New Mexico include aquatic life, fish culture, primary and secondary contact (including cultural, religious or ceremonial purposes), public water supply, industrial water supply, domestic water supply, irrigation, livestock watering, and wildlife habitat. The New Mexico Environment Department (NMED) Surface Water Quality Bureau (SWQB) coordinates with local, state, and federal agencies and organizations to monitor, assess, protect, and restore surface water quality throughout New Mexico and fulfill the requirements set forth in the law.

The SWQB begins the process of addressing impairments by identifying and reporting impaired waterbodies (i.e., waterbodies not attaining their designated uses). SWQB has designed this report, the State of New Mexico CWA §303(d)/§305(b) Integrated Report (IR), to fulfill this need as well as to satisfy the statutory requirements of sections 303(d), 305(b), and 314 of the CWA. The IR includes information on surface water quality and water pollution control programs in New Mexico and describes the relative condition of water quality in New Mexico to the United States Environmental Protection Agency (EPA), United States Congress, and stakeholders. SWQB prepares the IR with input from several other NMED bureaus and programs, and the New Mexico Water Quality Control Commission (NMWQCC) approves the Integrated List (Appendix A), otherwise known as the list of impaired waters. Once approved, the Integrated List incorporated by reference into the New Mexico Water Quality Management Plan and Continuing Planning Process (WQMP/CPP, NMWQCC 2020).

Specific Focus of the 2026-2028 CWA §303(d)/§305(b) Integrated Report

The SWQB surveyed the Sacramento Mountains and Chama River in 2023 and 2024, therefore these watersheds are the primary focus of revised or retained assessment conclusions this listing cycle. Additional focus areas based on submitted or acquired datasets include various reaches statewide based on EPA and USGS data downloaded from the Water Quality Portal, SWQB Effectiveness monitoring data, the San Juan River Basin based on data collected by the multijurisdictional monitoring program, Upper Rio Grande and various stream reaches in and around Taos and Red River sampled by watershed monitoring groups as well as Chevron Questa Mine data from Red River submitted by Ground Water Quality Bureau, streams on the Pajarito Plateau using data collected in association with Los Alamos National Laboratory Data and submitted by N3B, and data collected in the Mimbres river drainage by Silver City Watershed Keepers. Assessment conclusions based on data from previous rotational surveys and previously submitted outside data in non-focus areas are typically carried over to the next list until more current data are available to assess, unless, for example, a water quality standard change necessitates a re-assessment. For this assessment cycle, the top causes of impairment remained the same; temperature, *E. coli,* and nutrients/eutrophication are the three most common causes of river and stream water quality impairment in New Mexico. Mercury and PCBs

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in fish tissue, temperature, and nutrients/eutrophication are the most common causes of water quality impairment in lakes and reservoirs.

During development of the IR, SWQB further evaluates impaired waterbodies to determine if changes to the standard may be appropriate, whether more data collection is necessary to confirm the impairment, or whether a total maximum daily load (TMDL) or alternative water quality improvement plan should be scheduled for development. TMDLs and other planning documents provide information on the probable source(s) of the water quality impairment which is used to determine the best approach to improve water quality. SWQB combines field observations, available geographic information system (GIS) layers and land use imagery, and both stakeholder and staff watershed knowledge to develop draft Probable Source lists, which are finalized in TMDL documents and summarized in the IR. Most surface water quality impairments identified in New Mexico are due to nonpoint sources of water pollution. Agricultural practices (including rangeland grazing), road/bridge runoff, on-site liquid waste treatment systems (septic), streambank modifications and/or destabilization, waterfowl and wildlife, drought related impacts, loss of riparian habitat and rural development are the leading probable sources of impairment in New Mexico's rivers and streams where TMDLs or alternative planning documents have been prepared. The most common probable sources of impairment in lakes and reservoirs where TMDLs or alternative planning documents have been prepared are rangeland grazing, wildlife, recreational pollution sources, road/bridge runoff, site clearance due to new development or infill, on-site treatment systems, rural development, silviculture harvesting, and waterfowl.

The EPA recommends and the SWQB has prepared the 2026-2028 IR consistent with previous guidance memorandums, including EPA's significant 2006 IR Guidance supplemented by subsequent memorandums typically released by EPA for each listing cycle (EPA 2017a, 2021, 2023, 2025). Following the streamlining of the EPA submittal process in 2015 and the subsequent implementation and improvement of the EPA's Assessment and Total Maximum Daily Load Tracking and Implementation System (ATTAINS), SWQB organized and updated the post-2018 Integrated Reports to better describe New Mexico's current water quality framework, focus on required IR elements not reported electronically via ATTAINS, and provide hyperlinks to additional information regarding specific programs or restoration activities.

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I. Water Quality Identification and Control in New Mexico

A. Pollution Identification and Reporting

The New Mexico Legislature adopted the Water Quality Act (WQA) in 1967 and the New Mexico Pollutant Discharge Elimination System (NMPDES) Act in 2025 [NMSA 1978, §§ 74-6C-1 to 74-6C-11] to protect water quality in New Mexico. Since then, the Legislature has revised the WQA [NMSA 1978, §§ 74-6-1 to -17] numerous times to improve the management and protection of New Mexico's water resources. The WQA created the New Mexico Water Quality Control Commission (NMWQCC), and several of the revisions expanded the duties and powers of the NMWQCC. The NMWQCC is the State water pollution control agency for all purposes of the federal Clean Water Act (CWA) and may take all necessary actions under the WQA to secure the benefits of the WQA [NMSA 1978, § 74-6-3(E)].



Monitoring Team staff sample the Rio Gallina in the Chama River Watershed in August 2024

These duties include adoption of water quality standards and the adoption of regulations to prevent or abate water pollution in the State or in any specific geographic area or watershed of the State or for any class of waters. The WQA defines water as "all water, including water situated wholly or partly within or bordering upon the State, whether surface or subsurface, public or private, except private waters that do not combine with other surface or subsurface water." [NMSA 1978, § 74-6-2(E)]. The NMWQCC assigns responsibilities for water quality management activities to constituent agencies, primarily the New Mexico Environment Department (NMED). [NMSA 1978, § 74-6-4(G)].

The *State of New Mexico CWA §303(d)/§305(b) Integrated Report* (Integrated Report or IR) is designed to satisfy the statutory requirements of sections 303(d), 305(b), and 314 of the CWA. The IR provides information on water quality and water pollution control programs in New Mexico to the EPA and the United States Congress, as well as to the public. The SWQB prepares the IR with input from several other NMED bureaus and programs and presents the final draft 303(d)/305(b) Integrated List portion of the IR (Appendix A) to the NMWQCC for approval. The primary focus of the IR is surface water quality, although groundwater is also briefly discussed according to reporting requirements.

The SWQB has prepared the 2026-2028 IR consistent with EPA "Integrated Reporting Guidance under CWA sections 303(d), 305(b) and 314" memorandums, including the most recent 2025 guidance document. The most important component of the IR for surface water pollution identification is the CWA §303(d)/§305(b) Integrated List, provided as Appendix A. This list details the extent to which surface water quality goals (i.e., designated uses) documented in New Mexico's water quality standards (20.6.4 NMAC) are being met. Designated uses are the desirable, attainable, and existing uses of a surface water segment as specified in 20.6.4.97 through 20.6.4.899 NMAC. These surface water segments are further broken down into one or

more “assessment units” (e.g., stream reaches or waterbodies) for IR categorization and reporting purposes. In accordance with current EPA integrated listing guidance, New Mexico determines and assigns Fully Supporting, Not Supporting, and Not Assessed to each individual designated use to determine an IR category for every reported assessment unit (AU) on the Integrated List. New Mexico’s IR categories are defined in Table 1. A designated use assignment of “Not Assessed” means that a determination of Fully Supporting or Not Supporting could not be made based on available data and information. An AU is considered “impaired” when one or more pollutants prevent a waterbody from meeting its designated use(s). These pollutants are identified as “cause(s)” on the Integrated List.

Waterbodies classified as IR Category 5 (i.e., 5A, 5B, 5C, 5-R) officially constitute the *CWA §303(d) List of Impaired Waters,* however New Mexico and the EPA recognize that waterbodies assigned IR Category 4 are also still impaired (Figure 1). In this case, a Total Maximum Daily Load (TMDL) planning document is either already in place (IR Category 4A), not required because the impairment is not caused by a “pollutant” (IR Category 4C), or other pollution control requirements are in place and expected to result in attainment of the water quality standard within a reasonable amount of time (IR Category 4B).

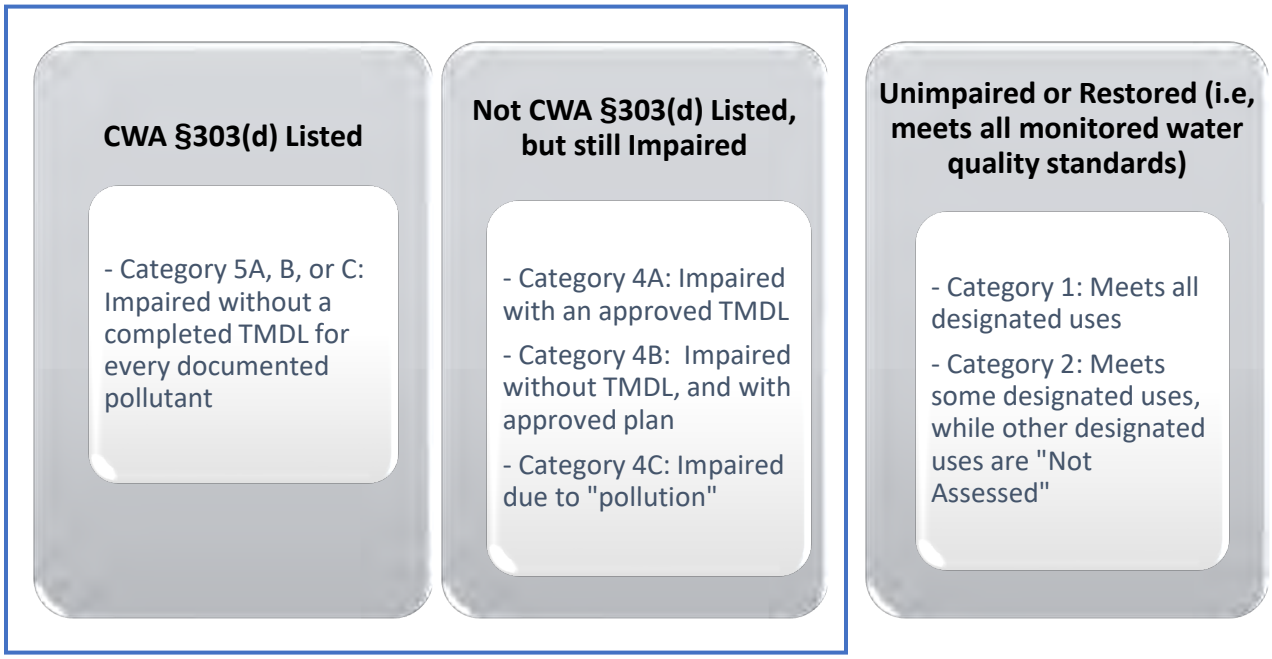


Figure 1. Relationship between CWA section 303(d), Impairments, and IR Categories

For additional information on the Clean Water Act §303(d) Listing of Impaired Waters, visit:
https://www.epa.gov/tmdl/program-overview-303d-listing-impaired-waters

To view this and New Mexico’s previous CWA §303(d)/§305(b) Integrated Reports, visit:
https://www.env.nm.gov/surface-water-quality/303d-305b/

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Table 1. New Mexico's Integrated Report Categories

Category	Description
1	All designated uses are supported.
2	Available data and/or information indicate that some designated or existing uses are supported based on numeric and narrative parameters that were tested.
2A	Attaining with prior action still in place. The waterbody or parameter is no longer impaired but a previously developed action (e.g., Approved TMDL, Advance Restoration Approach, etc.) exists.
3A	There are insufficient available data and/or information to make a support determination (no data available).
3B	There are insufficient available data and/or information to make a support determination. No data points exceed an applicable water quality criterion.
3C	There are insufficient available data and/or information to make a support determination. Data point(s) exceed an applicable water quality criterion.
4A	Available data and/or information indicate that at least one designated or existing use is not being supported, and a TMDL has already been established.
4B	Available data and/or information indicate that at least one designated or existing use is not being supported, but a TMDL is not needed because other pollution control requirements are reasonably expected to result in attainment of the water quality standard in the near future.
4C	Available data and/or information indicate that at least one designated or existing use is not being supported, but a TMDL is not needed because impairment is not caused by a pollutant.
5A	Available data and/or information indicate that at least one designated or existing use is not being supported and necessary TMDLs are underway or scheduled.
5B	Available data and/or information indicate that at least one designated or existing use is not being supported. A review of the water quality standard is required to verify the appropriate designated or existing use and/or criterion.
5C	Available data and/or information indicate that at least one designated or existing use is not being supported but additional data are necessary to verify the listing before TMDLs are scheduled.
5-R	Formerly 5-ALT. Available data and/or information indicate that at least one designated or existing use is not being supported and an advance restoration approach is in progress or under development.

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B. New Mexico's Surface Water Synopsis

New Mexico is characterized by high mountains, expansive plains and plateaus, river gorges, and broad valleys. Land surface elevations in New Mexico vary from just under 3,000 feet above sea level at the Texas border in the southeastern portion of the state to just over 13,000 feet in the northern mountains. New Mexico is the fifth largest of the fifty states, with a total area of 121,607 square miles. Of this, approximately 34% is federal land, 12% is State land, 11% is Native American land, and 43% is privately owned (USBLM 2019). New Mexico is one of the driest states in the U.S., with statewide average annual precipitation around 13–14 inches. Annual totals vary widely from less than about seven inches in desert valleys to more than 20 inches in the mountains[1]. Statewide, the annual average precipitation is much less than evaporation from open water surfaces (USBOR 1976). In fact, 96.6% of our rain and snowfall returns to the atmosphere[2]. About half the annual precipitation is received during the summer period within brief but intense summer storms, commonly referred to as the "monsoon season." Much of the winter precipitation falls as snow in the high mountains and as snow or rain at lower elevations. Like much of the western U.S., New Mexico continues to experience long-term drought.

Surface water basins include upper portions of several of the region's principal drainage systems: the San Juan River, Little Colorado River and Gila River watersheds contribute to the Lower Colorado River Basin; the Canadian River and Dry Cimarron River watersheds contribute to the Arkansas-White-Red River Basin; and the Rio Grande and Pecos River watersheds contribute to the Rio Grande basin (Figure 2). Other waters of the State in New Mexico include streams that are in topographically closed basins and drain internally (20.6.4 NMAC).



Rio Chama and Rio Gallina confluence, August 2024

The New Mexico Office of the State Engineer (NMOSE) is charged with administering the state's water resources with respect to quantity. The State Engineer has authority over the supervision, measurement, appropriation, and distribution of all surface and groundwater in New Mexico, including streams and rivers that cross state boundaries. [NMSA 1978, § 72-2-9]. The related New Mexico Interstate Stream Commission (NMISC) has broad powers to investigate, protect, conserve, and develop New Mexico's waters including both interstate and intrastate stream systems. The NMISC's authority under state law includes negotiating with other states to settle interstate stream controversies. [NMSA 1978, § 72-14-3]. New Mexico is a party to eight interstate stream basins. To ensure basin compliance, NMISC staff analyze, review, and implement projects in New Mexico and analyze streamflow, reservoir, and other data on the stream systems. The NMISC is also authorized by statute to investigate and develop the water supplies of the state and institute legal proceedings in the name of the state for planning, conservation, protection and development of public waters. [NMSA 1978, §

[1] https://nm.water.usgs.gov/drought/newmexicosummary.html
[2] https://mainstreamnm.org/data-and-reports/#prev

72-14-3]. New Mexico has sixteen water planning regions, each with its own water plan. New Mexico's State Water Plan was revised in 2023, and the 50-year Water Action Plan was published in 2024 (NMOSE/NMISC 2023, 2024). The regional and state water plans are vital tools intended to guide water management to best meet all the state's water user's needs – now and into the future.

For additional information on New Mexico's Office of the State Engineer or Interstate Stream Commission, visit: http://www.ose.state.nm.us/

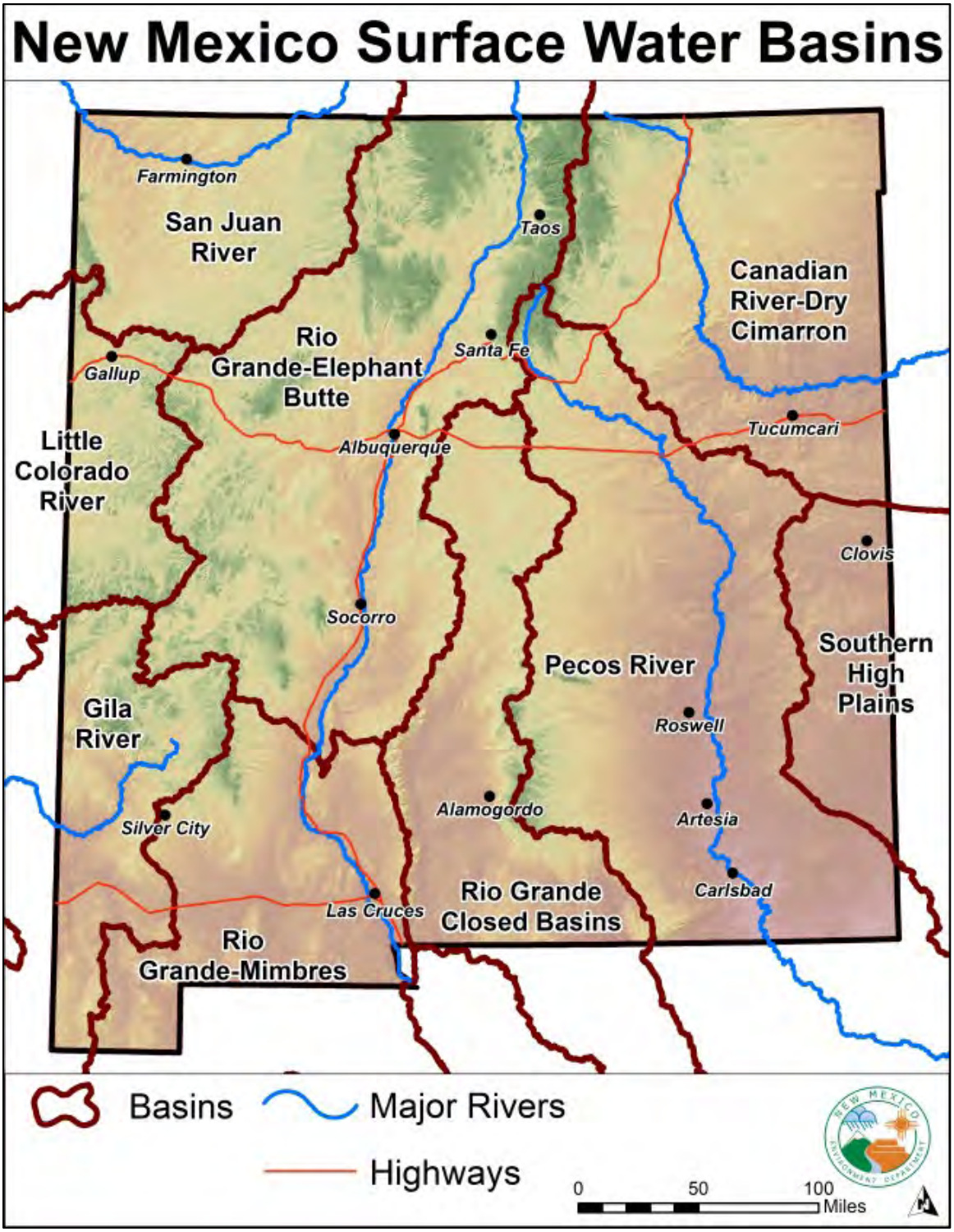


Figure 2. New Mexico Surface Water Basins

Topic	Value
State population[1]	2,130,256
State Surface Area[2]	121,602 mi^2
Total miles of perennial non-tribal rivers / streams[3]	6,592 miles
Total miles of non-perennial non-tribal river / streams[4]	193,191 miles
Number of significant public lakes/reservoirs[4]	173
Acres of significant public lakes/reservoirs[5]	85,369 acres
Acres of freshwater wetlands[6]	519,781 acres

[1] United States Census Bureau July 1, 2024, estimate.

[2] Calculated using the most recent US Census state boundary in RGIS and a NAD83 UTM 13 projection.

[3] Includes both public and private non-tribal stream miles under established Assessment Units in NM's Integrated List (Appendix A) with a Water Type of "STREAM, PERENNIAL" or "RIVER." Note that the perennial rivers/streams layer in NHD+ does not include anything that is "artificial path" or "channelized" (e.g. portions of the lower Rio Grande or Lower Pecos).

[4] Derived by NMED SWQB staff based on flowlines lengths and waterbody areas in the USGS National Hydrography Dataset (NHD) Plus High Resolution (USGS 2026). Flowline segments assigned FCode 46003 (intermittent) and 46007 (ephemeral) in NHD+ HR were clipped to the NM minus tribal lands boundary, which was created using the tribal lands layer from the most recent Census (2020; last updated 2025-09-23). Ephemeral and intermittent waters in this category were then tallied to determine total non-perennial mileage. Once the NHD+ HR layer was clipped to the NM minus tribal lands boundary, the NHD+ HR 46003 and 46007 streams/rivers were projected using NAD83 UTM 13 to calculate the length of each segment in miles. The change from the 2024-2026 IR is due to the updated NHD+ HR layer that includes more detailed flowlines than previous versions and shifting state water boundaries. Total miles of non-perennial non-tribal river/streams may shift due to different projections and/or changing tribal boundaries over time.

[5] Includes significant publicly-owned, or publicly recreated, natural lakes, playa lakes, and reservoirs under established Assessment Units in NM's Integrated List (Appendix A) in NHD+ high resolution (2018).

[5] Compiled from Mapping and Classification of Wetlands in New Mexico (GSS Final Reports on file at SWQB Wetlands Program). Excludes streams and rivers, lakes and riparian wetlands already associated with the metrics above.

Table 2. Summary of New Mexico's Surface Water Resources

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Table 2 provides a summary of New Mexico's water resources. Prior to the 2020-2022 IR, Assessed Waters geographic information system (GIS) layers depicted AUs[3] were based on the National Hydrography Dataset (NHD) Medium Resolution surface drainage network and waterbodies, however this was updated with the 2020-2022 IR and all IR Assessed Waters GIS information since then has been based on NHD Plus High-Resolution data.

C. New Mexico's Surface Water Quality Framework

Under the authority of the WQA and the CWA, the SWQB developed and the NMWQCC adopted the basic framework for water quality management in New Mexico as described in the *State of New Mexico Statewide Water Quality Management Plan/Continuing Planning Process* (WQMP/CPP) (NMWQCC 2020). The SWQB uses this integrated planning and management strategy to protect or attain the desired uses and levels of surface water quality within a waterbody. The iterative process implemented to identify water quality problems, develop solutions to address them, and assess the effectiveness of the implemented solutions is shown in Figure 3. Problem identification begins with establishing water quality standards and follows with collecting data to assess and identify impaired waters. Problem solving involves the development of TMDLs and other planning documents which help guide National Pollutant Discharge Elimination System (NPDES) permit limits, CWA section 319 restoration projects, and alternative restoration plans to help a waterbody achieve water quality standards. Progress is then measured, and water quality goals and approaches are updated accordingly. The sections below provide greater details on each component and associated programs and approaches.

For additional information on New Mexico's WQMP/CPP, visit:
https://www.env.nm.gov/surface-water-quality/wqmp-cpp/

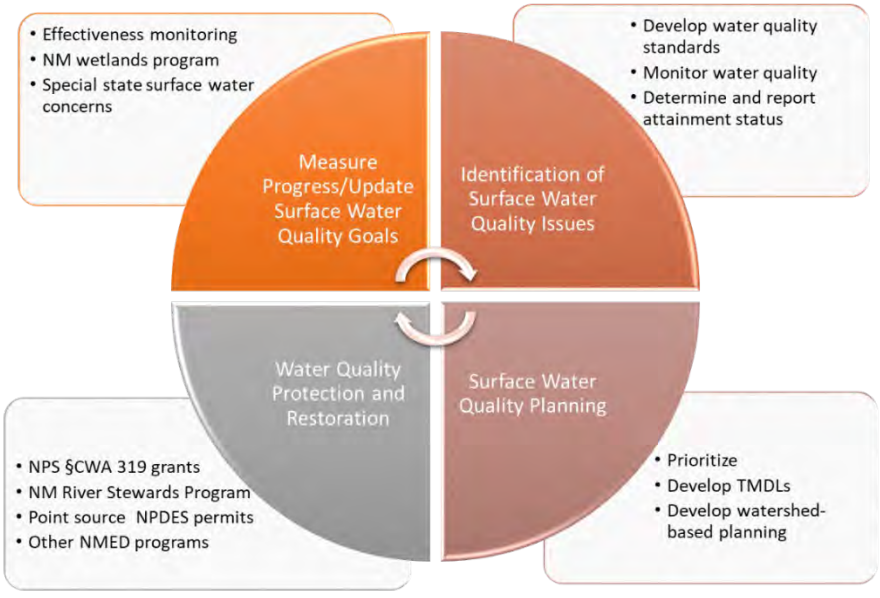


Figure 3. General Framework for Identifying and Restoring New Mexico's Surface Waters

[3] https://gis.web.env.nm.gov/oem/?map=swqb

II. Identification of Surface Water Quality Issues

A. Develop Water Quality Standards



SWQB staff sampling turbid waters in the Rio Chama, July 2024

The first step to identify surface water quality issues is to set surface water quality goals through the development and maintenance of New Mexico's *Standards for Interstate and Intrastate Surface Waters* codified at 20.6.4 NMAC. The SWQB's Standards and Outreach Team maintains and refines New Mexico's surface Water Quality Standards (WQS) in 20.6.4 NMAC, proposing changes for approval by the NMWQCC as appropriate. The WQS define the water quality goals for a waterbody by designating uses, assigning criteria to protect those uses, and establishing provisions to apply and implement the WQS. New Mexico continually evaluates the WQS using applicable guidance documents, data, public input, and other sources of information to identify sections that may need to be changed or provisions to be added.

Section 303(c)(1) of the CWA, federal regulations at 40 C.F.R. § 131.20, and state rules at 20.6.4.10 NMAC require NMED to hold a public hearing at least once every three years from the EPA's most recent approval to review WQS, and amend existing or adopt new WQS, as applicable. This process is known as the "triennial review" and is also governed by the WQA, which provides authority for the adoption of WQS by the NMWQCC.

The last Triennial Review public hearing was held before the NMWQCC in July 2021. The WQCC deliberated the proposed rule amendments and adopted the amended WQS in 20.6.4 NMAC (effective September 22, 2022). SWQB subsequently submitted the amended WQS to EPA for review and approval. EPA partially approved the standards to be effective for CWA purposes on January 20, 2023.

The SWQB initiated the 2026 triennial review in 2025. The SWQB published draft amendments to the WQS based on EPA's review and communications regarding previous Triennial Reviews, EPA's recommended CWA section 304(a) criteria, data review for waters lacking Section 101(a)(2) designated uses, and internal programmatic needs, including previous Integrated Lists. The SWQB conducted a 60-day public comment period and held a public meeting where the SWQB solicited input on New Mexico's WQS from tribes, EPA, other state and federal agencies, watershed/river conservation groups, municipalities, water districts, industrial/trade groups, private organizations, and citizens.

After considering comments, the SWQB petitioned the NMWQCC for a hearing for the 2026 Triennial Review. The NMWQCC granted the request and scheduled the hearing for September 28 – October 1, 2026. The SWQB will provide public notice, education, and participation opportunities such as public meetings or

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webinars, individual meetings, or office hours as part of stakeholder outreach for the triennial review and associated rulemaking process.

The process and requirements for adopting, amending, or revising New Mexico's WQS are codified at 20.1.6 NMAC, *Rulemaking Procedures - Water Quality Control Commission*. Once the stakeholder engagement process is complete, the SWQB will petition the NMWQCC for a rulemaking hearing. If granted a hearing, the SWQB will provide a formal public comment period for proposed changes to the standards. Notice of the public hearing will be provided in accordance with the State Rules Act (NMSA 1978, § 14-4-5.2) and 20.1.6 NMAC. Anyone may provide public comment to the SWQB or to the NMWQCC through the end of the hearing. Additionally, interested parties may also submit and provide written and oral technical testimony for the administrative record. After the hearing is complete and the administrative record is closed, the NMWQCC will deliberate on the matter after which a Statement of Reasons will be issued if they choose to adopt proposed changes. The Department will then begin the process for filing the adopted standards with the State Records Center for inclusion in the NMAC and submit that version to EPA for their review and approval process.

The NMWQCC may adopt new or amended WQS outside of the Triennial Review process, including designating waters as Outstanding National Resource Waters (ONRWs), changing the designated use(s) of a waterbody through a Use Attainability Analysis (UAA), or adopting Site-Specific Criteria (SSC). Additionally, anyone can petition the NMWQCC for a rulemaking hearing and follow the process outlined above to adopt proposed standards. Prior to petitioning the commission, the WQS and federal regulations outline additional administrative and technical requirements. These requirements include workplans containing scientifically defensible methods for developing WQS, and public involvement plans to provide public participation opportunities throughout the process and ensure early engagement with stakeholders, including the SWQB if the petitioner is an outside agency or entity.

Since the previous listing cycle, the NMWQCC has held four hearings to adopt new and amended WQS. In 2024, the NMWQCC designated over 240 stream miles as ONRWs, the highest level of protection under the Antidegradation Policy and Implementation Plan at 20.6.4.8 NMAC. Pursuant to 20.6.4.9(B) and (C) NMAC, a surface water of the state may be designated and classified as an ONRW where the Commission determines it will benefit the state of New Mexico and it meets at least one of the eligibility criteria listed in 20.6.4.9(B)(1)-(3) NMAC. SWQB staff worked with interested third parties to identify and nominate waters eligible for ONRW designation under 20.6.4.9(B)(1) NMAC. An informal public comment period and public meeting were held before petitioning the commission for a hearing, with over 700 people, organizations, and state agencies providing comments in support of the nominations. The rulemaking hearing was held on December 10, 2024, with the NMWQCC deliberating and approving the designation of the nominated waters as ONRWs at the conclusion of the hearing. EPA approved the 2024 ONRW designations with an effective date of April 10, 2025, for federal CWA implementation purposes.

Newport News Nuclear BWXT-Los Alamos; Triad National Security, LLC; and the U.S. Department of Energy, Office of Environmental Management, Los Alamos Field Office, as the operators and contractors for the Los Alamos National Laboratory (LANL), petitioned the NMWQCC to amend WQS to adopt site-specific criteria applicable to the Pajarito Plateau under 20.6.4.900.I.(4) NMAC. The Petitioners developed acute and chronic Copper Site-Specific Water Quality Criteria (Cu SSWQC) based on a multiple linear regression analysis of 531 sampling events and output from EPA's copper biotic ligand model. Additionally, they engaged with stakeholders before requesting and being granted a hearing. The hearing was held on January 14, 2025, with the WQCC deliberating and voting to adopt the proposed amendments at the conclusion of the hearing. EPA approved the Cu SSWQC with an effective date for federal purposes of August 14, 2025.

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Additionally, the operators and contractors for LANL conducted a UAA and determined that naturally occurring thermal conditions prevented the attainment of the coldwater aquatic life use (ALU) in upper Sandia Canyon (see 2018-2020 303(d)/305(b) Integrated Report). As a result, they petitioned the NMWQCC to split Sandia Canyon into an upper segment at 20.6.4.141 NMAC and lower segment at 20.6.4.126 NMAC. The designated use and criteria for lower Sandia Canyon remained as coldwater ALU[4]under 20.6.4.126 NMAC, while upper Sandia Canyon was changed to coolwater ALU[5] with an additional segment specific 6T3 temperature[6] criteria of 25°C. The Petitioners held early engagement opportunities prior to the hearing that was conducted on May 13, 2025, with no public opposition to the proposed amendment. The WQCC deliberated and approved the amendments at the end of the hearing, with an effective date for state implementation purposes of November 8, 2025. The WQS amendment was submitted to EPA on January 19. 2026 and is currently under review.

National Technology & Engineering Solutions of Sandia, LLC (NTESS), on behalf of the United States Department of Energy, National Nuclear Security Administration, Sandia Field Office, as management and operating contractor for Sandia National Laboratories, conducted a UAA to determine if Tijeras Arroyo, from the Rio Grande to Four Hills Bridge, exhibits characteristics of an ephemeral (20.6.4.97 NMAC), instead of intermittent water body (20.6.4.98 NMAC). The UAA documented the chemical, biological, and physical conditions following the SWQB's Hydrology Protocol. NTESS concluded that the reach was ephemeral and petitioned the NMQCC for a hearing to amend the standards at 20.6.4.97 NMAC. As with other NMWQCC hearings, early engagement and public participation opportunities were provided throughout the process. The hearing was held on December 9, 2025, with the WQCC deliberating and voting to adopt the proposed amendments at the conclusion of the hearing. The rule was published in the NM Register on February 24, 2026 and became effective for state implementation purposes on March 14, 2026. The WQS amendment was submitted to EPA after March 14, 2026 and is currently under review.

B. Monitor Water Quality

The second step to identify surface water quality issues is to collect water quality data and information through organized, quality-controlled monitoring. The purpose of the SWQB's Monitoring Program is to ensure relevant water quality data for New Mexico's surface waters are collected with the most robust scientific methods in a way that is transparent to water quality agencies and the public. The Monitoring Program serves all surface water quality monitoring needs to the extent possible given available resources, NMED priorities, and strategic goals. The waterbody types currently monitored by the program are streams, rivers, lakes, and reservoirs.

Clear goals and objectives are required to implement an effective monitoring program. To meet federal and state requirements and expectations, the SWQB has developed a monitoring strategy per EPA Guidance (EPA 2003b, NMED/SWQB 2016). The strategy provides a detailed description of the SWQB's monitoring objectives and designs, as well as approaches to data quality assurance and management. Key topics are briefly discussed below.

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[4] Coldwater aquatic life criteria include dissolved oxygen = 6.0 mg/L, maximum temperature = 24°C; 6T3 = 20°C, and a pH of 6.6 – 8.8.

[5] Coolwater aquatic life criteria include dissolved oxygen = 5.0 mg/L, maximum temperature = 29°C, and a pH of 6.6 – 9.0.

[6] 6T3 means the temperature not to be exceeded for six or more consecutive hours in a 24-hour period on more than three consecutive days.

1. Monitoring design

Monitoring staff develop and implement field sampling plans to ensure all necessary chemical, biological, and physical data needed to determine attainment of New Mexico's water quality standards are collected during the survey. The SWQB strives to implement ambient sampling using a rotational watershed monitoring approach. Monitoring occurs during the non-winter months generally from March through November over one to two years, resulting in approximately one-fifth of the states primarily perennial waters being monitored every one to two years. Monitoring focuses primarily on physical, chemical, and biological conditions in perennial waters; and includes sampling for most pollutants that have numeric or narrative water quality criteria in New Mexico.



SWQB staff conducting flow measurements in Rio Ojo Caliente, July 2024

To achieve the goals of New Mexico's surface water quality framework, the SWQB rotational surveys utilize a targeted monitoring design to address data needs identified for assessment, TMDLs, potential standards revisions, and point source monitoring. The SWQB selects monitoring sites that are intended to be representative of the AU based on the data needs for an AU and site accessibility. Each AU is typically represented by one monitoring station which receives four to eight site visits during the survey. Through public outreach, inter-agency coordination, and a scoring system which considers a variety of factors, the SWQB prioritizes AUs. High-ranking priority waters receive the greatest amount of monitoring, whereas lower ranking waters receive less based on available staff and financial resources at the time. The current rotational monitoring schedule is shown in Figure 4.

For survey years 2023-2024, the SWQB conducted a two-year survey of the Rio Chama and the Sacramento Mountains basins. Data and information gathered during this survey are the focus of the 2026-2028 IR attainment determinations in the 303(d)/305(b) Integrated List (Appendix A).

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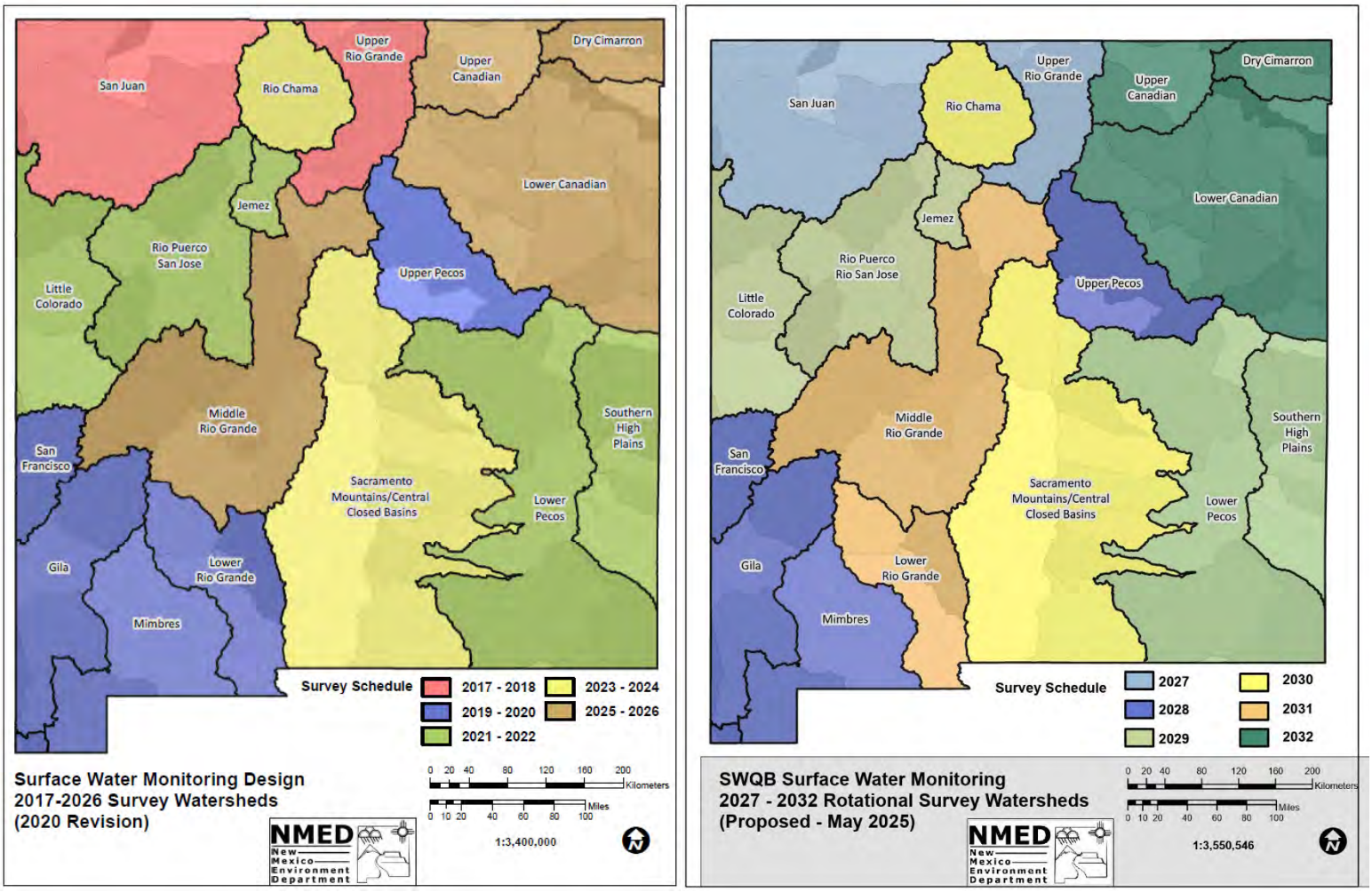


Figure 4. New Mexico's Surface Water Quality Monitoring Schedule (NMED/SWQB – current vs. proposed May 2025 (preliminary draft, under revision))

To review New Mexico's 10-Year Monitoring Strategy, visit:
https://www.env.nm.gov/surface-water-quality/protocols-and-planning/.

CWA section 314 requires an assessment of "…significant publicly-owned lakes." New Mexico has 173 significant publicly-owned lakes, reservoirs, and playas identified on the Integrated List (Appendix A). Lake monitoring is incorporated into the rotational survey design. The SWQB determined the list of significant publicly-owned lakes, reservoirs, and playas using the following criteria:

- Lakes, reservoirs or playas over 10 acres because of their many varied uses including public recreation areas;
- Lakes, reservoirs, or playas smaller than 10 acres with cultural, recreational, or ecological significance; or
- Lakes, reservoirs or playas specifically included in 20.6.4.101-20.6.4.899 NMAC.

2. Probabilistic monitoring (2024-2026)

The EPA requires states to incorporate probabilistic sampling designs into their monitoring programs. Probabilistic studies enable states to generate statistically-based conclusions regarding selected water quality concerns. Accordingly, the SWQB is incorporating the 2025-2026 Rio Grande Probabilistic Monitoring Survey into its monitoring program. In New Mexico, SWQB has defined "Large Rivers" as systems that cannot be monitored effectively with methods developed for wadeable streams and generally have drainage areas greater than 2,300 square miles. The Rio Grande in New Mexico falls under the large river definition. While methods for monitoring and assessing wadeable perennial streams are well established, methods for large rivers are less advanced. The probabilistic survey is focused on providing data for the development and refinement of nutrient monitoring and assessment methods for the Upper and Middle Rio Grande.

Planning for the 2025-2026 probabilistic survey began in 2024. Fifty sites were randomly selected from a sampling frame of the Rio Grande from the Colorado border to above Elephant Butte Reservoir. SWQB developed the sampling frame using the USGS National Hydrography Dataset-High Resolution (NHDHR) validated with SWQB Assessed Streams information. Staff at the EPA National Health and Environmental Effects Research Laboratory in Corvallis, OR, conducted random site generation. Three hundred and fifty sites from the sampling frame were randomly selected with the first fifty sites serving as the sample population and the remaining 300 sites as alternates.

Year 1 of the survey focused primarily on randomly selected sites located within the Upper Rio Grande. At each sampling location, SWQB staff collected water chemistry and biological nutrient stressor and response indicators. Sites that did not meet the sampling frame parameters (i.e., reservoirs) or were inaccessible (unsafe or landowner access denied) were excluded through office and field reconnaissance. Excluded sites were replaced by alternate sites in successive order. Completion of the Rio Grande Probabilistic Survey is planned for 2026, at which point SWQB will work with partners to develop numeric translators of New Mexico's narrative nutrient criteria for the Upper and Middle Rio Grande.



SWQB staff collect periphyton samples from the Upper Rio Grande near Pilar, NM

3. *Quality assurance*

The SWQB is committed to maintaining a quality assurance program that ensures confidence in the environmental data produced by its various water quality programs. The SWQB implements water quality management programs in accordance with the current EPA-approved version of NMED's Quality Management Plan[7] (QMP), which documents the quality system for planning, implementing, documenting, and assessing the effectiveness of activities supporting water quality management programs.

All data collected by the SWQB for water quality attainment determinations are collected and analyzed following established standard operating procedures[8] (SOPs). In addition, all data are handled in accordance with the most current version of the EPA-approved Quality Assurance Project Plan[9] (QAPP). The QAPP describes the quality assurance procedures, quality control specifications, and other technical activities that must be implemented to ensure that the results of the project or tasks to be performed will meet project specifications. By establishing a quality system, New Mexico ensures that water quality management decisions are based on a systematic process and on data of known and acceptable quality. This also ensures that the public funds expended in these efforts are soundly invested. For the SWQB to utilize data collected by outside agencies or stakeholder groups, a review of quality assurance procedures for submitted data is conducted to ensure that submitted data are of equal or greater quality to those collected by the SWQB under the QAPP.

To review New Mexico's QMP, QAPP, and various SOPs, visit:
https://www.env.nm.gov/surface-water-quality/protocols-and-planning/

4. *Data management and survey reporting*

The SWQB's in-house Surface Water Quality Information Database (SQUID) is an integral tool for coordinated storing, assessing, and reporting of water quality data and conclusions between the SWQB programs, to EPA, and to New Mexico's stakeholders. This Oracle© database, developed and maintained by NMED's Office of Information Technology, allows for required electronic reporting of monitoring data to the EPA's water quality exchange (WQX) database and WQS attainment conclusions to the EPA's Assessment and Total Maximum Daily Load Tracking and Implementation System (ATTAINS) database[10]. SQUID also contains many survey planning and tracking tools and reports. SQUID has been updated to be compatible with the EPA's ATTAINS database per EPA guidance (EPA 2023). ATTAINS is a primary data source for How's My Waterway[11], which was designed to provide the public with information about the condition of their local waters based on data that states, federal, tribal, local agencies and others have provided to the EPA.



Following the completion of each rotational watershed survey, the SWQB monitoring staff prepare water quality survey reports. These sampling summary

[7] https://www.env.nm.gov/surface-water-quality/protocols-and-planning/
[8] https://www.env.nm.gov/surface-water-quality/sop/
[9] https://www.env.nm.gov/surface-water-quality/protocols-and-planning/
[10] https://www.epa.gov/waterdata/attains
[11] https://www.epa.gov/waterdata/hows-my-waterway

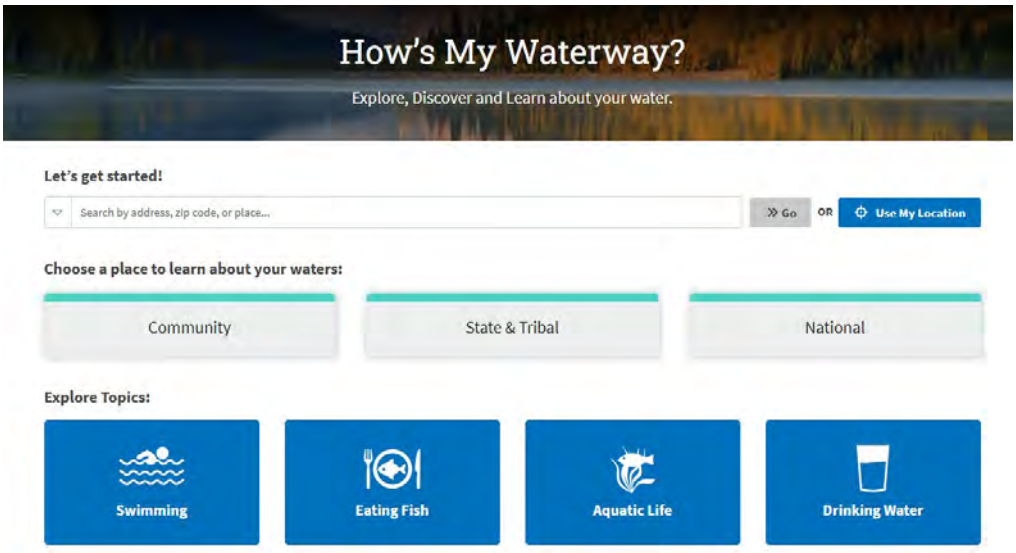
reports are an update to the associated field sampling plan, detailing the monitoring goals that were accomplished during the survey as well as any deviations from the planned monitoring.

To access SWQB's field sampling plans and survey reports, visit:
https://www.env.nm.gov/surface-water-quality/water-quality-monitoring/

5. Data upload to the EPA ATTAINS database and How's My Waterway?

How's My Waterway is a user-friendly, public-facing tool created by EPA to help people explore the condition of their local waters using data submitted by state, federal, tribal, and local agencies. For New Mexico, this information is drawn directly from the NMED Surface Water Quality Bureau's Integrated Reporting (IR) process for Clean Water Act Sections 303(d) and 305(b). Each IR cycle, SWQB evaluates available water quality data, determines designated use attainment, identifies impairments, and submits these assessment decisions to EPA through the ATTAINS database. Once EPA finalizes the state's Production ATTAINS dataset, those assessment results are published in How's My Waterway. In this way, How's My Waterway turns the technical outputs of the Integrated Reporting process into an accessible, map-based view of local water conditions and ongoing protection and restoration efforts.

Users can explore their watershed through an interactive map interface that displays water quality conditions at community, state, and national scales. The tool provides information on swimming safety, fish consumption, aquatic life, and drinking water, along with details on restoration and protection efforts, identified issues, and monitoring locations. Users can also view information on permitted dischargers, including facilities with discharge violations, and access summaries of restoration plans and projects occurring in their watershed. These features allow the public to see not only current water quality status but also the regulatory and restoration activities happening in their watersheds.



To explore your watershed on How's My Waterway? Visit:
https://mywaterway.epa.gov/

C. Determine and Report Attainment Status

The third step in identifying surface water quality issues is to compare collated water quality data to current water quality standards using consistent, documented processes. New Mexico's listing methodology is described in the Comprehensive Assessment and Listing Methodology[12] (CALM). This document explains how the SWQB evaluates surface water quality data and other information to determine whether surface water quality standards are being met as documented in Appendix A. The listing methodologies described in the CALM are reviewed each odd-numbered year (i.e., 2025) to ensure the methods are clearly defined and consistent with applicable water quality standards, and to incorporate relevant new EPA guidance.

Outside sources of data are solicited and acquired via a public notice process prior to developing the draft IR and associated Integrated List (Appendix A). Simultaneously, the revised CALM is public noticed to solicit input into New Mexico's listing methodologies. In general, all readily available data less than five years old that have been reviewed and accepted for consistency with the SWQB's data collection activities and quality assurance procedures are used to determine whether the applicable water quality standards are attained. Data older than five years old are given a lower priority in assessment than newer data, particularly if newer data indicate a change in water quality or the older data fails to meet data quality requirements. Provisional data is not used to make designated use support determinations.

To review New Mexico's listing methodologies (CALM), visit:
https://www.env.nm.gov/surface-water-quality/calm/

Common surface water quality data sources collated to determine use impairment in New Mexico include, but are not limited to, the following:

- SWQB chemical/physical, biological, habitat, or bacteriological data collected during rotational watershed surveys;
- Chemical/physical, biological, habitat, or bacteriological data from SWQB studies or projects collected by SWQB staff or their cooperators;
- SWQB Effectiveness Monitoring data;
- USGS chemical/physical, biological, habitat, or bacteriological data;
- Statewide datasets downloaded from the Water Quality Portal[13];
- Los Alamos area environmental data publicly available for download from *Intellus New Mexico*[14]; and
- Citizen or volunteer monitoring data.

For additional information regarding the SWQB's data submittal process, visit:
https://www.env.nm.gov/surface-water-quality/data-submittals/

[12] https://www.env.nm.gov/surface-water-quality/calm/
[13] https://www.waterqualitydata.us/
[14] http://www.intellusnmdata.com/

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The Rio Chama and Sacramento Mountain watersheds were surveyed by the SWQB in 2023-2024 and hence are the primary focus of revised or retained assessment conclusions in the Integrated List for this 2026-2028 cycle. Other datasets that were either submitted or acquired this cycle and assessed as reported include:

- 2022-2024 data for various stream reaches in and around Taos and Red River collected by Sentinels-Rio de Taos and submitted by Amigos Bravos.
- 2022-2025 San Juan River Basin Multijurisdictional monitoring program data stored in SQUID
- 2022-2025 SWQB Effectiveness monitoring data downloaded from SQUID
- 2022-2025 EPA and USGS data from various locations throughout New Mexico downloaded from the Water Quality Portal[15],
- Chevron Questa Mine data from Red River submitted by Ground Water Quality Bureau,
- 2021-2025 Los Alamos National Laboratory Data submitted by N3B, and
- Silver City Watershed Keepers data (submitted)

The assessment conclusions in non-focus areas based on data from previous rotational surveys and previously submitted outside data are typically carried over to the next list until more current data are available to assess unless, for example, a water quality standard change or a significant listing methodology change necessitates a re-assessment.

New Mexico maintains assessment information in SQUID and uploads this information to ATTAINS per EPA guidance (EPA 2025). Use of SQUID allows SWQB to automatically generate the entire Integrated List (Appendix A), the associated assessment rationale, the official CWA §303(d) List of Impaired Waters, as well as a variety of summary reports. The SWQB maintains an extensive web site that provides access to the current and several past CWA §303(d)/§305(b) reports and supporting information.

To access the current and past CWA §303(d)/§305(b) reports and supporting information, visit:
https://www.env.nm.gov/surface-water-quality/303d-305b/

The assessment rationale document maintained by the SWQB is a historical record of impaired surface waters (i.e., Category 5 waters) provided to reviewers and users of the list – including the EPA – to help track listing and de-listing information used in the development of New Mexico's Integrated List. The EPA does not require this specific document and does not take action to approve or disapprove its contents. The assessment rationale was originally created as a separate word processing document. All AUs do not have detailed assessment rationale entries because prior to the 2018-2020 IR the assessment rationale generally did not contain entries on AUs that have not been assessed or have never been found to be impaired. The assessment rationale is now a database field in SQUID, making it easier to provide assessment notes by IR cycle on all AUs being assessed. Assessment rationale entries by IR cycle, starting with the 2018-2020 IR, are also uploaded to the EPA's ATTAINS database.

All AUs are assigned IR categories as described in New Mexico's CALM[16]. Assessment units noted with IR Category 5A, 5B, 5C or 5-R on the Integrated List in Appendix A comprise New Mexico's official CWA §303(d) List of Impaired Waters. A listing of Category 5-only waters is included in the beginning of Appendix A. To

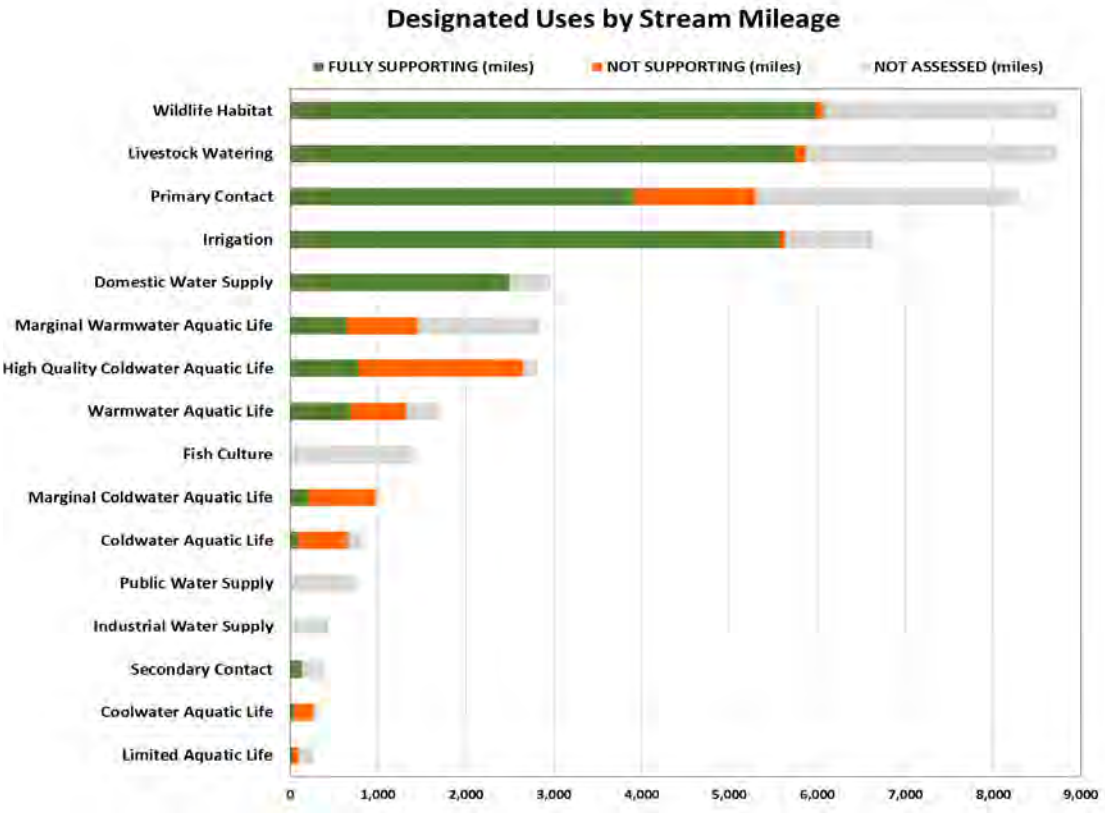
[15] https://www.waterqualitydata.us/
[16] https://www.env.nm.gov/surface-water-quality/calm/

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see details on a specific AU, refer to the AU entry on the full Integrated List in Appendix A and associated assessment rationale entry. Starting with the 2018-2020 IR, each AU entry on the Integrated List now also contains a "PARAMETER IR CATEGORY." This useful field provides additional planning information regarding each cause of impairment or AU-cause pair. For example, a parameter IR category of 5B lets the user know that a review of the applicable water quality standard is needed prior to scheduling TMDL development. New Mexico has several temperature listings that fall under the 5B parameter IR category.

New Mexico's Integrated List also includes an estimated year in the "TMDL DATE" field for all parameter IR category 5A AU-cause pairs. The estimated year is generally based on the SWQB's rotational monitoring schedule, prioritization strategy in the SWQB's long-term vision document (NMED/SWQB 2015), and severity of the impairment. The "TMDL DATE", as well as the projected "MONITORING SCHEDULE" year, is ultimately dependent upon personnel and financial resources which can change on an annual basis. If a TMDL has already been developed for the noted cause of impairment, the EPA TMDL approval date (MM/DD/YYYY) is reported in the TMDL date field.

A summary of the attainment status by river/stream mileage, lake acreage and subwatershed (currently only AUs for Upper Pecos, Rio Chama, and Sacramentos watershed areas) for each designated use, as found in New Mexico's WQS (20.6.4 NMAC), is presented in Figures 5, 6, and 7, respectively. For more information on subwatershed AU development see section 3 below. A full summary with associated mileage and acreage is available in Appendix B. In New Mexico, the CWA goal of "fishable" is reported under the various aquatic life uses while the "swimmable" goal is reported under primary and secondary contact uses.



NOTE: All Fish Culture, Public Water Supply, and Industrial Water Supply designated uses are defaulted to "Not Assessed" because no numeric criteria apply uniquely to these uses per 20.6.4.900.A NMAC.

Figure 5. New Mexico's Designated Use Attainment Status by River/Stream Mileage

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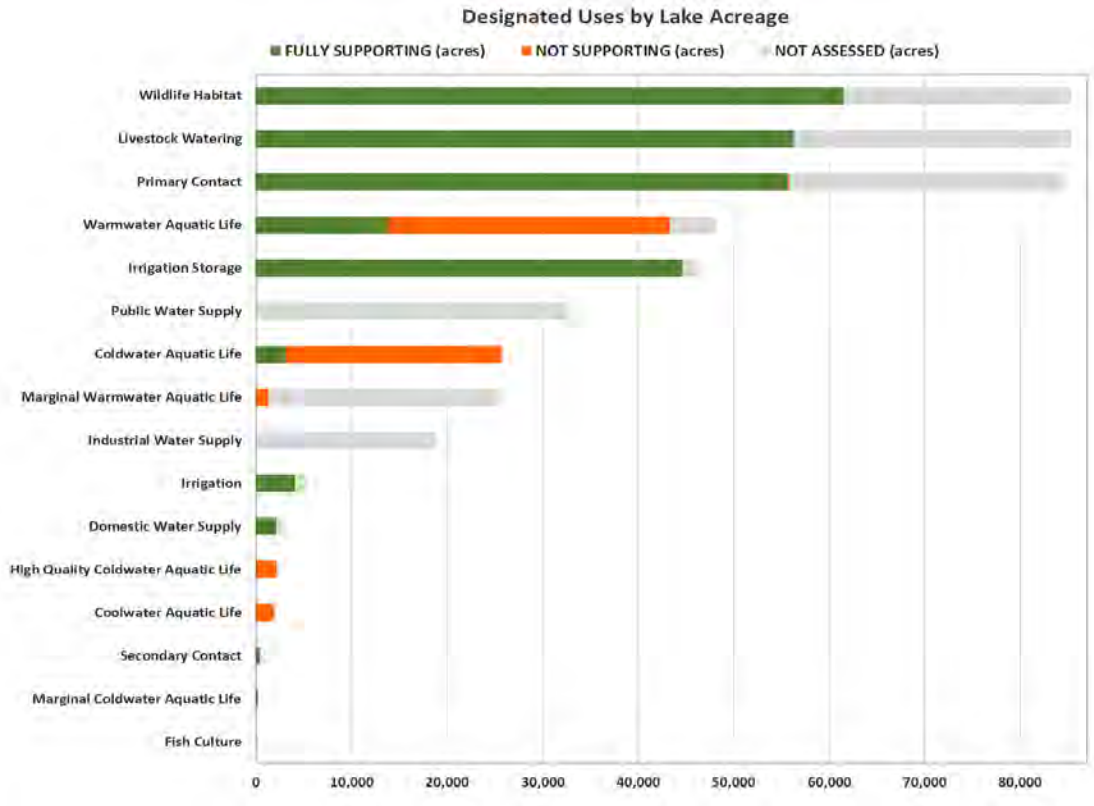
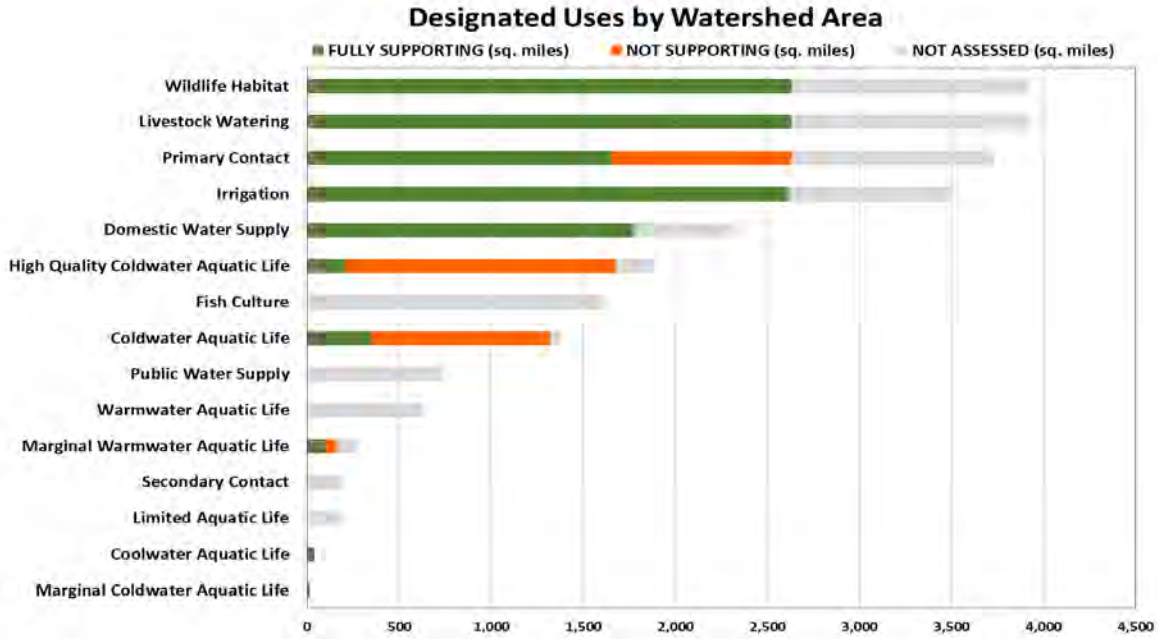


Figure 6. New Mexico's Designated Use Attainment Status by Lake/Reservoir Acreage



NOTE: All Fish Culture, Public Water Supply, and Industrial Water Supply designated uses are defaulted to "Not Assessed" because no numeric criteria apply uniquely to these uses per 20.6.4.900.A NMAC.

Figure 7. New Mexico's Designated Use Attainment Status by Watershed Area

The causes of impairments are summarized by major waterbody type (rivers/streams, lakes/reservoirs and subwatersheds) in the following section.

1. River and Stream Assessment Results

New Mexico's surface waters are assigned to one of the IR categories defined in Table 1 and summarized in Table 3. Individual IR categories for every AU are provided in the Integrated List (Appendix A).

Table 3. Integrated Report Categories for New Mexico's Rivers and Streams

IR Category	Total Size (miles)	Number of River/Stream Assessment Units
1	942	83
2	796	77
3A	1,931	154
3B	4	1
3C	28	4
4A	1,508	105
4C	235	16
5A	1,432	93
5B	840	65
5C	906	88
5-R	6	1
TOTAL	**8,629**	**687**

The largest grouping of assessed lotic (i.e., flowing) waters are IR Category 5. These AUs, along with the Category 5 lake/reservoir waterbodies, comprise New Mexico's official CWA §303(d) List of Impaired Surface Waters. A list of Category 5-only waters was generated from SQUID and is included in the beginning of Appendix A.

IR Category 4A represents stream reaches where SWQB has developed TMDL planning documents for all documented causes of impairment in a particular AU.

These AUs are technically still impaired (see Figure 1) even though the EPA does not officially consider them to be part of the Clean Water Act §303(d) List. Several of these stream reaches also have TMDLs for more than one parameter.

AUs are listed in IR Category 1 and 2 if there are sufficient data and information meeting the requirements of the CALM that can be evaluated to support a determination that some or all uses are attained based on numeric and narrative water quality criteria.

AUs are listed in IR Category 3 when sufficient data to support an attainment determination for any designated use are not available according to the requirements of the assessment and listing methodology[17]. Reasons include access, monitoring and/or analytical logistics (such as the need for automated sampling equipment), and staff and financial resource constraints. The SWQB prioritizes IR Category 3 AUs during rotational survey planning.

The leading impairment causes for New Mexico's rivers and streams are presented in Figure 8. The SQUID-generated summary report of all Cause and Source statistics is provided in Appendix B. Standard EPA impairment cause categories included in SQUID were used to label the graphic. See Appendix B for subcategory information.

Excessive temperature, *E. coli*, and nutrients/eutrophication are identified as the top three causes of impairment of designated uses in New Mexico's streams and rivers based on current WQS (20.6.4

[17] https://www.env.nm.gov/surface-water-quality/calm/

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NMAC), available data, and applicable listing methodologies. Dissolved oxygen (DO) and nutrient/eutrophication impairments may be redundant in some cases, as DO impairment is often a response resulting from excessive nutrients.

E. coli sampling during watershed surveys has been a SWQB priority since the 2006 listing cycle, using a mobile *E. coli* sampling unit that resolved a chronic issue with meeting the short holding time. Implementation of this sampling method continues to result in the identification of additional contact use impairments due to exceedance of the *E. coli* criteria each listing cycle.

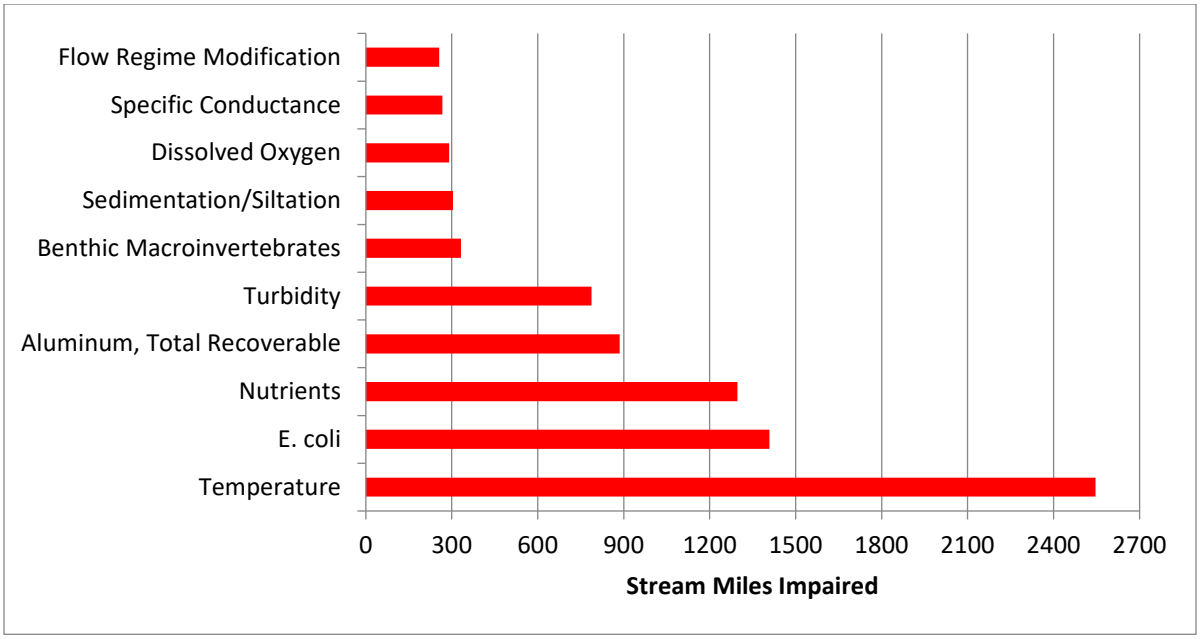


Figure 8. Top Causes of Surface Water Impairment for Rivers and Streams (2026)

2. Lake and Reservoir Assessment Results

One major challenge regarding both lake monitoring and lake TMDL development has been the loss of specific CWA section 314 funds to address this need. In the past, states received this funding specifically targeted for lake monitoring. States must now carve out their own funding for lake monitoring from core CWA section 106 funds. New revenue sources must be identified to increase lake and reservoir monitoring to support future TMDL development and provide water quality information to the public who utilize these lakes and reservoirs, allowing more scientifically rigorous data and information to be collected could confirm the current cause and source impairment information in New Mexico's lakes and reservoirs.

Table 4 shows the number of New Mexico's lakes and reservoirs assigned to each IR category as defined in Table 1. Individual IR categories are presented for every AU on the Integrated List in Appendix A.

By acreage, the majority of assessed lentic (i.e., not flowing) AUs in New Mexico fall under Category 5. Over 90% of these acres are freshwater reservoirs as opposed to natural lakes. New Mexico has very few natural lakes compared to the number of in-line and off-line reservoirs. These AUs, along with the IR Category 5 river/stream AUs, comprise New Mexico's official CWA §303(d) List of Impaired Surface Waters. A list of Category 5-only waters was generated from SQUID and is included in Appendix A.

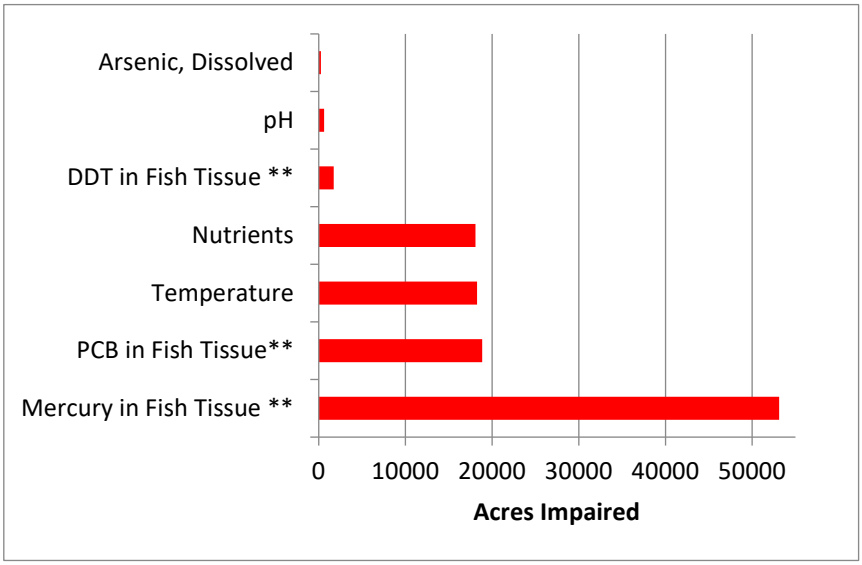
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AUs are listed in IR Category 3 when current data are not available to support an attainment determination. Reasons for this generally include access issues, monitoring and/or analytical logistics, and staff and financial resource constraints. Many of these lakes that are "Not Assessed" are very small in size, such as high elevation natural lakes. These lakes are logistically difficult to sample because they require long, steep hikes. The SWQB sampled a representative subset of these lakes during 2007 as part of a nutrient criteria development grant. Also included in this category are a large portion of the 20,000+ acres of playa lakes that were part of a SWQB special study in the late 1980s and early 1990s when the EPA provided specific CWA section 314 monitoring funding. Attainment status for playas or lakes where adequate resources have not been available to re-monitor in more recent years were changed to "Not Assessed" during the 2008 listing cycle because these data were over 15 years old. Playas or lakes where data from only one sampling event were previously used to make Full Support determinations were changed to "Not Assessed" during the 2014 listing cycle because this is insufficient data to make attainment determinations under current assessment protocols[18].

A summary of the impairment causes for New Mexico's lakes and reservoirs is presented in Figure 9. The SQUID-generated report that was used to generate the below figure is included in Appendix B. Standard EPA cause categories included in SQUID were used to label the graphic. See Appendix B for specific acreage and subcategory information.

Table 4. Integrated Report Categories for New Mexico's Lakes and Reservoirs

Category	Total Size (acres)	Number of Assessment Units
1	323	9
2	8,584	19
3A	21,320	99
4A	2,032	4
5A	15,088	20
5B	282	4
5C	37,740	18
TOTAL	**85,369**	**173**



NOTES: **Based on current fish consumption advisories and 0.3 mg/kg methylmercury in fish tissue criterion.

Figure 9. Top Causes of Surface Water Impairment for Lakes and Reservoirs (2026)

Mercury in fish tissue, PCBs in fish tissue, and temperature are the top three causes of impairment of designated uses in New Mexico's lakes and reservoirs based on

[18] https://www.env.nm.gov/surface-water-quality/calm/

current WQS, available data, and current listing methodologies[19]. Nutrients are becoming an increasingly common impairment in lakes and reservoirs, and nutrients/eutrophication is now nearly tied with temperature for the 3rd most common cause of impairment. The EPA considers fish or shellfish consumption advisories and supporting fish tissue data to be existing and readily available data that demonstrate non-attainment of CWA goals stating that waters should be "fishable" [CWA §101(a), EPA 2005]. New Mexico currently has fish consumption advisories based on mercury, dichlorodiphenyltrichloroethane (DDT), and PCB levels in fish tissue (NMED, *et al*. 2021). All waterbodies listed in the advisory are listed as impaired except waterbodies where available mercury in fish tissue data is below the New Mexico water quality criterion of 0.3 mg/kg methylmercury in fish tissue.

3. Subwatershed Assessment Results

Table 5. Integrated Report Categories for New Mexico's Subwatershed-based AUs

Category	Total Size (square miles)	Number of Assessment Units
1	351	7
2	361	10
3A	711	14
4A	46	1
5A	2,411	34
5C	41	3
TOTAL	**3,921**	**69**

New Mexico's surface waters are assigned to one of the IR categories defined in Table 1 and summarized in Table 5, with AU specific categories provided in the Integrated List (Appendix A). This reporting cycle includes the pilot use of subwatershed-based Assessment Units (AUs), which represent a shift from traditional linear AU delineations to watershed-scale polygons that better capture the full range of activities influencing surface water quality. This approach, used as the sole method or in combination with linear AUs in several other states, aligns with EPA's ATTAINS reporting requirements and established national methodologies. Each subwatershed AU is assessed as a single unit using data from the station located lowest in the watershed (at or near the pour point), ensuring that monitoring results reflect cumulative upstream conditions. Linear AUs associated with these new polygons will be retired in the next assessment cycle, and several of the newly delineated units include Outstanding National Resource Waters (ONRWs) as of 2023.

These results highlight the dominant stressors affecting watershed-scale conditions and provide a more integrated understanding of surface water quality across New Mexico's surface water systems.

The leading impairment causes for New Mexico's subwatersheds are presented in Figure 10. The SQUID-generated summary report of all Cause and Source statistics is provided in Appendix B. Standard EPA impairment cause categories included in SQUID were used to label the graphic. See Appendix B for subcategory information.
Excessive temperature, *E. coli*, and total recoverable aluminum are identified as the top three causes of impairment of designated uses in New Mexico's subwatershed AUs based on current WQS (20.6.4 NMAC), available data, and applicable listing methodologies.

[19] https://www.env.nm.gov/surface-water-quality/calm/

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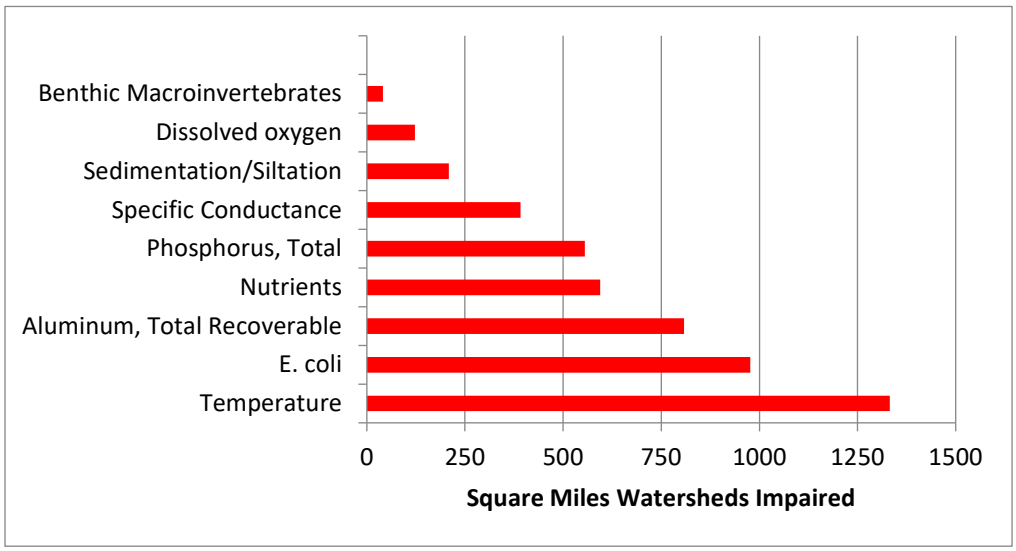


Figure 10. Top Causes of Surface Water Impairment for Subwatershed AUs (2026)

III. Surface Water Quality Planning

A. Prioritize Impairments and Concerns

After water quality impairments and issues are identified, New Mexico engages in water quality planning to address the concern. The first surface water quality planning step is to prioritize impairment listings for subsequent TMDL development or alternative plans to implement restoration strategies with a more holistic approach. The SWQB continues to be involved in national conversations with the EPA and the Association of Clean Water Administrators (ACWA) regarding the Long-Term Vision for the CWA section 303(d) Program (Vision)[20]. The goals of the Vision are prioritization of watershed or waters for restoration and protection; assessment of priority waters; protection of unimpaired waters; alternative approaches to restoration and protection; engagement with the stakeholders; and integration with other CWA programs. As a result of the Vision and goals, the TMDL program in New Mexico is focusing on state water quality priorities, while continuing to evaluate TMDL alternatives and protection of waterbodies that are not impaired. This document, referred to as a Prioritization Framework, summarizes the prioritization of monitoring and TMDL



A herd of wild horses observe monitoring in Alto Reservoir, May 2024

[20] https://www.epa.gov/tmdl/Vision

activities in New Mexico. The first Prioritization Framework was provided to EPA Region 6 staff for review in January 2015. The list of TMDL priorities through 2022 were determined using the process outlined in the Prioritization Framework and were provided to EPA Region 6 in July 2015. 100% of the TMDL priorities outlined in the 2015 Prioritization Framework were completed and submitted to EPA by September 30, 2022.

The Federal fiscal year (FFY) 2022-2032 Long-term Vision Prioritization document (Vision 2.0) was due to EPA by April 1, 2024. This new Vision document includes a list of TMDL program priorities through Federal FY 2032. For the period between the 2015 Vision document and the new Vision document, EPA requested that states provide their federal FY 2023-2024 TMDL priorities as a "bridge metric" in the 2022-2024 Integrated Report. The FFY 2025-26 metrics listed in Appendix B of the 2022-2032 Vision 2.0 document are due to EPA by September 30, 2026, and the FFY 2027-2028 are due to EPA by September 30, 2028.

To review the SWQB's prioritization framework, visit:
https://www.env.nm.gov/surface-water-quality/tmdl/

B. Develop Total Maximum Daily Loads



Santa Cruz Lake, part of the 2024 Canadian and Upper Rio Grande Basin Lakes TMDL

CWA section 303(d)(1) requires that states develop a list of waters within the State that are not supporting their designated uses established in the WQS and to establish a TMDL for each pollutant for those "impaired waters." A TMDL is defined as the "calculation of the maximum amount of a pollutant allowed to enter a waterbody so that the waterbody will meet and continue to meet water quality standards for that pollutant. A TMDL determines a pollutant reduction target and allocates load reductions necessary to the source(s) of the pollutant."[21]

To accomplish this requirement, New Mexico develops a TMDL planning document – a comprehensive plan for a given pollutant and waterbody starting from the relevant WQS, discussing existing water quality data and developing a plan to ensure that WQS are achieved and maintained for that waterbody. At the core of a TMDL is the allocation of pollutant loads to existing and reasonably foreseeable increases from point sources and nonpoint sources in the watershed. As such, TMDLs are an integral part of New Mexico's WQMP/CPP and incorporated by reference (NMWQCC 2020). TMDLs also inform the EPA in developing effluent limits for NPDES permits and help guide the SWQB in prioritizing watershed protection and restoration projects funded under the CWA section 319 and other programs.

[21] https://www.epa.gov/tmdl/overview-total-maximum-daily-loads-tmdls

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Since the previous listing cycle, the SWQB received EPA approval of the Canadian and Upper Rio Grande Basin Lakes TMDL (6 AU-pollutant pairs) and Gila/Mimbres/San Francisco and Lower Rio Grande Basin TMDL (12 AU-pollutant pairs) in August 2024. The SWQB received EPA approval of the Upper Rio Grande TMDL (36 AU-pollutant pairs) in February 2025.

TMDLs include a list of "probable sources" in the contributing watershed. These are defined as activities that may contribute pollutants or stressors to a waterbody. The probable source list included with any cause of impairment includes all activities occurring or likely to occur in the watershed that have the potential to contribute to the identified impairment. It is not intended to single out any landowner or single land management activity, and has therefore been labeled "probable," and generally includes several possible items. Probable sources listed for any waterbody have not been proven to be a source or the only sources of the identified impairment. The list is based on qualitative field observations made by field staff for AUs sampled during rotational watershed surveys and watershed restoration projects. This is combined with knowledge of known land management activities that have the potential to contribute to the identified impairment. The SWQB updated its standard operating procedure for probable source determination in 2020[22]. Specifically, probable source observations are first recorded during rotational watershed surveys by SWQB staff. Information gathered from the surveys is used to generate a draft Probable Source list in consequent draft TMDL planning documents and shared with SWQB staff familiar with the waterbodies of concern based on their work with permits, watershed-based planning projects, or monitoring in the watershed for review and comment.



Free-range cattle graze near a streambed in the Rio Chama watershed

These draft Probable Source lists are finalized with watershed group/stakeholder input received during any one of the following: pre-survey public meeting, TMDL public meeting, watershed-based planning activities, and various public comment periods. The SWQB continues to maintain probable sources documented in approved TMDLs in SQUID to provide a summary discussion of the primary sources of impairment in New Mexico. This fulfills the CWA section 305(b)(1)(E) requirement to provide "a description of the nature and extent of nonpoint sources of pollutants."

A summary of the top impairment sources as documented in approved TMDLs for New Mexico's rivers and streams is presented in Figure 11. The SQUID-generated report that was used to generate the below figure is included in Appendix

[22] https://www.env.nm.gov/surface-water-quality/sop/

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B. Standard EPA source categories included in SQUID were used to label the graphic. See Appendix B for specific values and subcategory information. In most instances, more than a single probable source contributes to water quality impairment. The total mileage values reported are summations of AU mileages for all AU-impairment pairs assigned to each probable source. The top sources for lakes are source(s) unknown, rangeland grazing, wildlife other than waterfowl, recreational pollution sources, road/bridge runoff, site clearance (new development or infill), on-site treatment systems (septic), rural (residental areas), silviculture harvesting, and waterfowl.

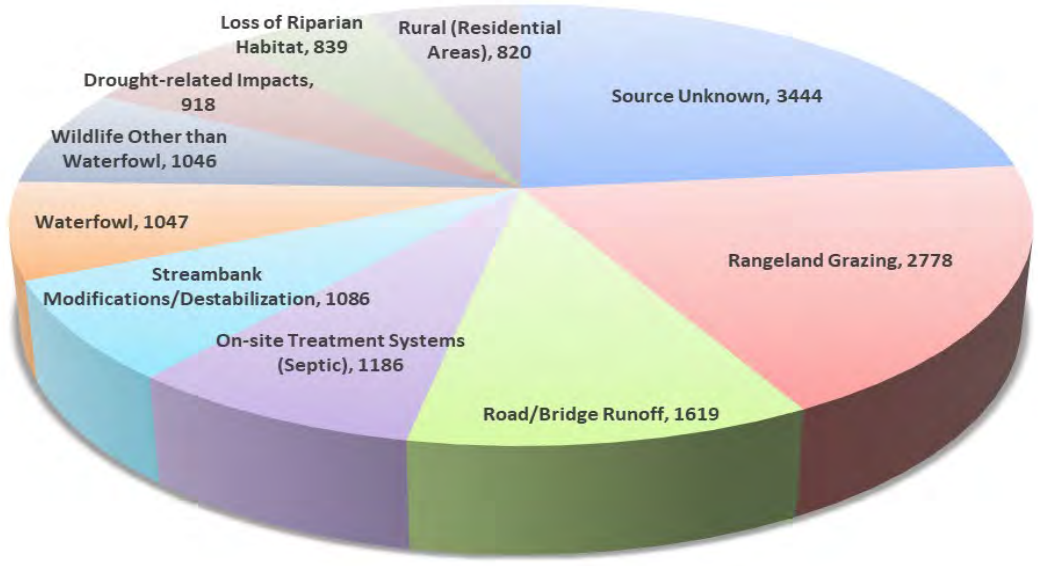


Figure 11. Top Probable Sources of Surface Water Impairment in Rivers/Streams as reported in approved TMDLs (total AU-impairment pair mileage shown)

As seen in the summary graphic, the majority of water quality impairments identified in New Mexico's streams and rivers continues to be due to nonpoint sources (NPS) of water pollution. NPS pollution can be directly related to land use practices on a broad geographic scale and is generally caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up natural and human-caused pollutants, which are deposited into rivers/streams, lake/reservoirs, wetlands, and groundwater.

For more information on SWQB's TMDL program and to access individual approved TMDL planning documents, visit: https://www.env.nm.gov/surface-water-quality/tmdl/

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C. Develop Watershed-Based Plans



Freshwater emergent wetland of Wolf Creek, New Mexico. Credit: Hermit's Peak Watershed Alliance, from the Wolf Creek Update to the Watershed Based Plan for the Mora River - Upper Canadian Plateau

New Mexico's NPS Management Program is designed as a cooperative effort among federal and state agencies and watershed stakeholders and is administered by NMED's SWQB Watershed Protection Section (WPS). The EPA-approved 2024 NPS Management Program Plan guides the program with the overarching goal "to implement an adaptive watershed-based restoration and protection program with the substantive involvement of stakeholders, for all watersheds within New Mexico, to meet and maintain water quality standards and designated uses of surface water, and to protect ground water resources."[23] The plan's objectives include watershed-based planning, restoring and protecting ground and surface water quality, education, and interagency cooperation activities to meet the program goal. The NPS Management Program encourages development of WBPs or alternative-WBPs, as appropriate and as described in the EPA's *Nonpoint Source Program and Grants Guidelines for States and Territories* (EPA 2024) and further underscores the development of WBPs by prioritizing watershed restoration projects in areas that have EPA-approved WBPs.

In addition to development of TMDLs, the SWQB works with stakeholders to develop nine-element watershed-based plans (WBPs) to identify on-the-ground implementation projects and best management practices (Table 6) to address water quality impairments and improve surface water quality. In areas where stakeholder interest is high but TMDLs or WBPs have not yet been developed, SWQB works with active stakeholders to encourage planning including development of alternative WBPs to address short-term water quality impairments such as those originating from post-fire runoff or developing Advanced Restoration Plans to complete TMDLs and WBPs in tandem. WBPs are used by local watershed groups and other interested stakeholders to build on the TMDL process with more detailed characterization of pollutant sources, management measures, information and education programs, and monitoring. This approach facilitates coordinated watershed restoration efforts, the development of effective watershed associations, engaged stakeholders, and the implementation of effective best management practices (BMPs) to reduce NPS pollution.

[23] https://www.env.nm.gov/surface-water-quality/nps-plan/

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Table 6. Common BMPs Implemented Throughout New Mexico to address Nonpoint Source Pollution

NPS Pollution Category	Examples of Best Management Practices (BMPs) utilized in New Mexico
Agriculture	• Residue Management (contour strip cropping, stubble munching, conservation tillage) • Improved irrigation practices (low output sprinklers, vegetation control) • Nutrient Management (split fertilizer applications, nutrient balancing, crop rotation)
Construction	• Sediment Control Structures (silt fences, hay bales, sediment retention ponds) • Heavy equipment cleaning and spill kits • Conduct construction activities during no-flow or low-flow conditions
Fire Suppression/Fuels Management	• Forest thinning / fuels reduction • Post wildfire watershed rehabilitation
Grazing	• Alternate watering sources (trick tanks, upland dirt tanks, and upland wells) • Planned/rotational grazing • Cattle guards to control access • Fencing (pasture cross fencing, creation of additional pastures for improved stock rotation methods, and riparian exclosure fencing)
Loss of Riparian Habitat	• Habitat restoration and rehabilitation - Removal of non-native plant species - Planting native vegetation • Grazing exclosure(s) or planned grazing
Recreational Activities	• Revegetation of impacted areas • Trail maintenance/reconstruction • Provide and maintain waste and sanitation facilities • Limit off-road vehicle use • Restrict vehicular access to riparian areas • Recreational area closure or relocation • Education/Outreach
Resource Extraction	• Sediment Control Structures (silt fences, hay bales, sediment retention ponds) • Stabilizing, relocating, and channeling runoff around mine and mill tailings
Septic Systems	• Identify and replace malfunctioning systems • Outreach to encourage preventative maintenance • Connect to centralized wastewater treatment system
Streambank Modification/ Hydromodification	• Streambank Stabilization via: - Revetment (e.g. vanes, j-hooks) - Grade control (e.g. cross vanes) - Grazing exclosures or rotation - Terracing / revegetation of slopes - Installing vortex weirs - Replacing undersized culverts - Brush control
Urban Stormwater	• Education/Outreach activities • Develop stormwater management plan • Propose new ordinance and/or development codes • Propose new construction standards • Install swales, French drains, detention ponds • Collect and treat runoff

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IV. Water Quality Protection and Restoration

A. CWA Section 319 Watershed Restoration Grants



One-rock dam built in the Gallinas River during Phase IV of the CWA section 319 project. Photo credit: Hermit's Peak Watershed Alliance (2025)

SWQB provides funding to protect and restore water quality in New Mexico via CWA section 319 for both on-the-ground implementation and planning projects, the state-funded River Stewardship Program (see below), and the newly launched Watershed Protection Assistance Program (see below). Planning projects include the development of a Watershed-Based Plan (WBP), Wetlands Action Plan (WAP), or an alternative-WBP depending on the identified needs of the watershed(s). On-the-ground implementation projects utilize Best Management Practices (BMPs) to reduce NPS pollutants from entering ground and surface waters to improve water quality. CWA section 319 funding for implementation projects is also available to protect water quality soon after a wildfire occurs and for demonstration projects in watersheds that do not already have a WBP, WAP, or alternative-WBP already in place. CWA section 319 grants may include education and outreach activities and are designed to encourage partnerships to address nonpoint source pollution in New Mexico's watersheds.

Since 1998, the NPS Management Program has implemented over 100 watershed restoration projects. New Mexico's current and recently completed CWA section 319 watershed restoration implementation projects can be found on the SWQB Watershed Protection webpage[24]. In addition, CWA section 319(h)(11) requires New Mexico to report to EPA Region 6 annually the progress in meeting milestones in the NPS Management Program plan, reductions in NPS pollutant loading, and improvements in streams that do not meet water quality standards. The SWQB maintains a website providing NPS Annual Reports from calendar year 2000 to present.

Information on projects completed in specific years can be found in the SWQB's *NPS Management Program Annual Reports* at:
https://www.env.nm.gov/surface-water-quality/nps-annual-reports/

[24] See: https://www.env.nm.gov/surface-water-quality/watershed-protection-section/. Direct link for the current list: https://www.env.nm.gov/surface-water-quality/wp-content/uploads/sites/18/2025/02/NMED-319-and-River-Stewardship-Program-Projects-February-2025.pdf

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B. New Mexico's River Stewardship Program

A key part of the NPS Management Program is the state-funded River Stewardship Program (RSP). The goal of the RSP is to fund projects that enhance the health of rivers by addressing the root causes of poor water quality and stream habitat. The RSP builds on collaboration and restoration techniques developed and implemented during successful CWA section 319 and state funded implementation projects around the state.



Pecos River at Cowles. RSP project on the Pecos River near Cowles, New Mexico with rock and structures creating pool habitat on the Pecos River

Specific RSP objectives include:

- Restoring or maintaining hydrology of streams and rivers to better handle overbank flows and thus reduce flooding downstream;
- Enhancing economic benefits of healthy river systems such as improved opportunities to hunt, fish, float or view wildlife; and
- Providing state matching funds required for federal CWA grants.

RSP projects, like CWA section 319 projects described above, are selected through a competitive, statewide application or Request for Proposals process. RSP projects are distributed statewide. Eligible applicants include municipalities, counties, soil and water conservation districts, irrigation districts, for-profit organizations, non-profit organizations, and Indian Nations, Pueblos and Tribes. Evaluation criteria favor projects that improve water quality, enhance fish and wildlife habitat, support local economies, and reduce downstream flood hazards.

Although RSP projects are not required to implement watershed-based plans, each RSP project proposal is evaluated for its alignment with local, state, tribal or federal planning documents, and watershed-based plans often provide a strong basis in planning for proposals to be competitive. New Mexico's current and recently completed RSP and CWA section 319 projects are displayed in Figure 12.

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C. Watershed Protection Assistance Program

In 2025, the SWQB created the Watershed Protection Assistance Program (WPAP) to provide small funding opportunities of $75,000 or less to improve surface water quality and river habitat. The program is supplemental to RSP and provides funding to support small projects, planning activities, ongoing projects, or monitoring activities.

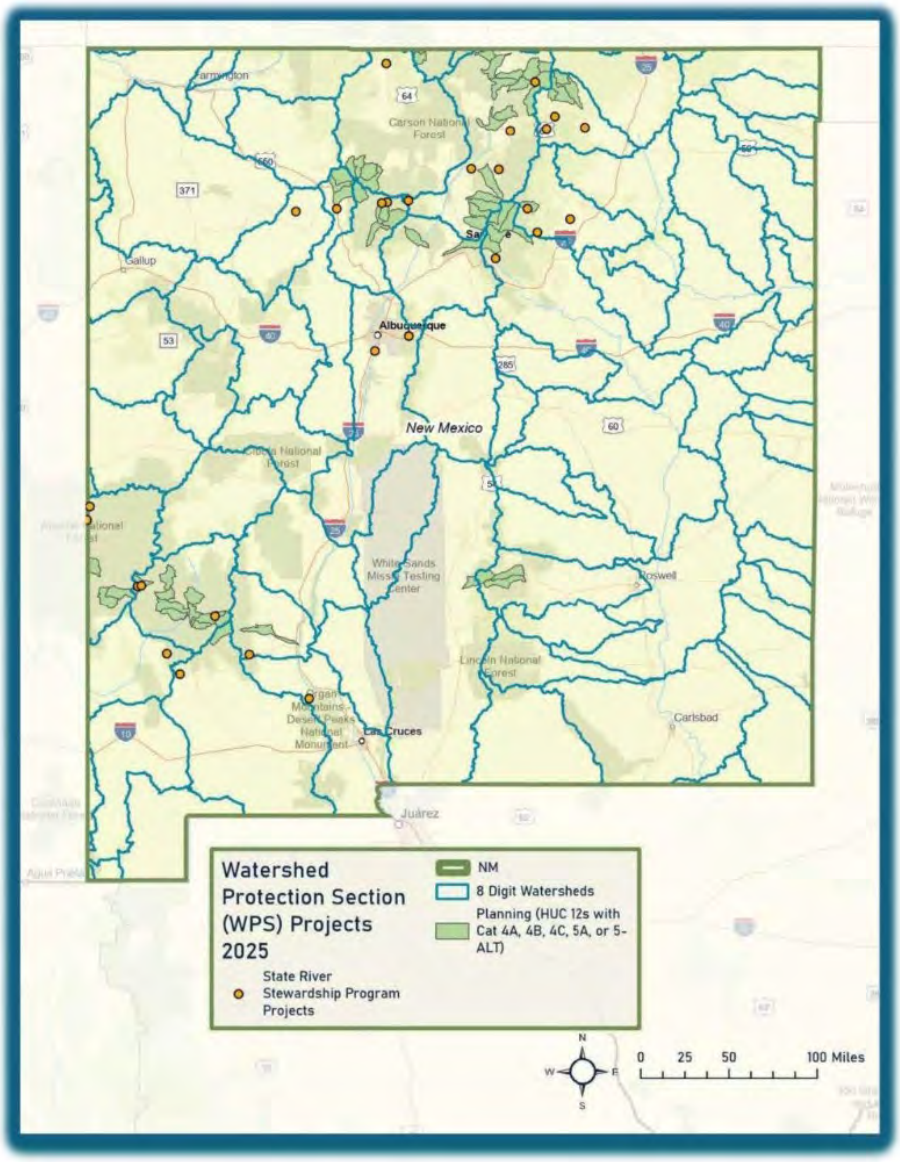


Figure 12. Active CWA Section 319 and River Stewardship Program (RSP) restoration and planning projects, 2025

Current and recent Section 319 and River Stewardship Program projects lists are available at: https://www.env.nm.gov/surface-water-quality/wp-content/uploads/sites/18/2024/02/RS8103_NMED-319-and-River-Stewardship-Program-Projects.pdf

D. Point Source Regulation and Other State Certifications

Point source pollution results from discharge of contaminants through discrete conveyances such as pipes, ditches, conduits, or wells. In New Mexico, the EPA under CWA section 402 administers the discharge of pollutants through the National Pollutant Discharge Elimination System (NPDES) program. State certification of federal permits[25] is required under CWA section 401 and ensures that the permits are compatible with state laws, protect the state's water quality standards, and implement the state's WQMP/CPP (NMWQCC 2020). In New Mexico, the NMED is the CWA section 401 authority for certifications (excluding Nation, Tribe or Pueblo receiving waters). The primary goal of the SWQB Point Source Regulation Section (PSRS) is to protect public health and the environment by assuring that regulated point source discharges to surface waters comply with appropriate state and federal statutes and regulations, including applicable New Mexico water quality standards and applicable waste load allocations developed through the TMDL process.



Bloomfield WWTP Outfall observed by SWQB PSRS staff (January 2025)



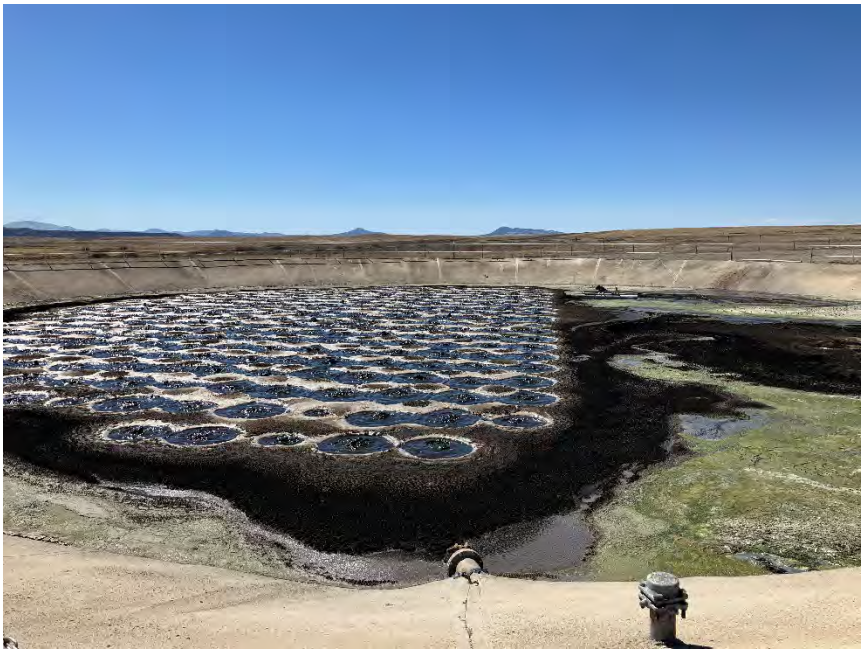
Gallinas River at Las Vegas WWTP (January 2025)

PSRS fulfilled this responsibility, certifying 14 NPDES individual permits and 1 general permit in state FY 2024, and 21 individual permits in state FY 2025. State FY 2024 certifications included details on the data submittals related to the new per- and polyfluorinated substances (PFAS) monitoring requirements. State FY 2025 certifications included one condition for new dissolved boron effluent limits and one condition for nutrient (total nitrogen and total phosphorus) and dissolved oxygen monitoring. State FY 2025 certifications included a request for seven permittees to develop public communication plans to notify the downstream users of facility overflows, upsets, and bypass events; three permittees to notify downstream Nations, Tribes, and Pueblos of facility overflows, upsets, and bypass events; and three permittees to notify the downstream State of Texas of facility overflows, upsets, and bypass events. PSRS issued one general permit comment set and two downstream user comments in state FY 2024, and one

[25] A list of EPA-issued NPDES permits in New Mexico can be found at: https://www.epa.gov/npdes-permits/new-mexico-npdes-permits.

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general permit comment set in FY2025. In state FY 2024 PSRS completed one antidegradation analysis and related revisions for a new direct discharge to a water of the U.S. In state FY 2025 PSRS completed seven antidegradation analyses for new or increased direct discharges to waters of the U.S.



Raton WWTP Sludge Aeration Basin (March 2026)

PSRS employees are credentialed by the EPA to conduct compliance inspections on behalf of the EPA. PSRS serves as a local point of contact to provide information to operators and other agencies regarding the federal regulatory program and to offer compliance assistance to individual facilities. Inspections help to ensure compliance with applicable effluent limitations and permit conditions and are carried out in accordance with the EPA NPDES Compliance Inspection Manual (EPA 2017b) using current EPA-approved forms, checklists, and computer applications. PSRS and EPA use the data and information collected to evaluate compliance and to support state or federal enforcement and permitting activities. PSRS conducted ten NPDES individual permits compliance inspections in state FY 2024, and twelve NPDES individual permit compliance inspections in state FY 2025.

The EPA executed 74 NPDES enforcement actions in state FY 2024, and 41 enforcement actions in state FY 2025. State enforcement of NPDES permitted discharges has not occurred. State enforcement would be based in large part upon meeting the applicability requirement of 20.6.2.2100 NMAC, which applies to any discharger who is given written notice of a NPDES permit violation from the EPA and who has not corrected the violation. The regulatory applicability clause is designed to prevent dual regulation by state and federal government, while still allowing the State to act in cases where the federal program has been unable to gain compliance within a prescribed time. Furthermore, the NMED has the authority under 20.6.2.1220 NMAC to issue compliance orders, including penalties, for a discharge that exceeds any water quality standard in state regulations, or is not complying with a condition or provision of an approved or modified discharge plan or permit. In state FY 2024, New Mexico issued an administrative compliance order to the City of Santa Fe for *E. coli* and nutrient (total nitrogen and total phosphorus) exceedances of the water quality standards in 20.6.4 NMAC. The state may also enforce provisions of 20.6.2.2201 NMAC prohibiting disposal of refuse in a watercourse.

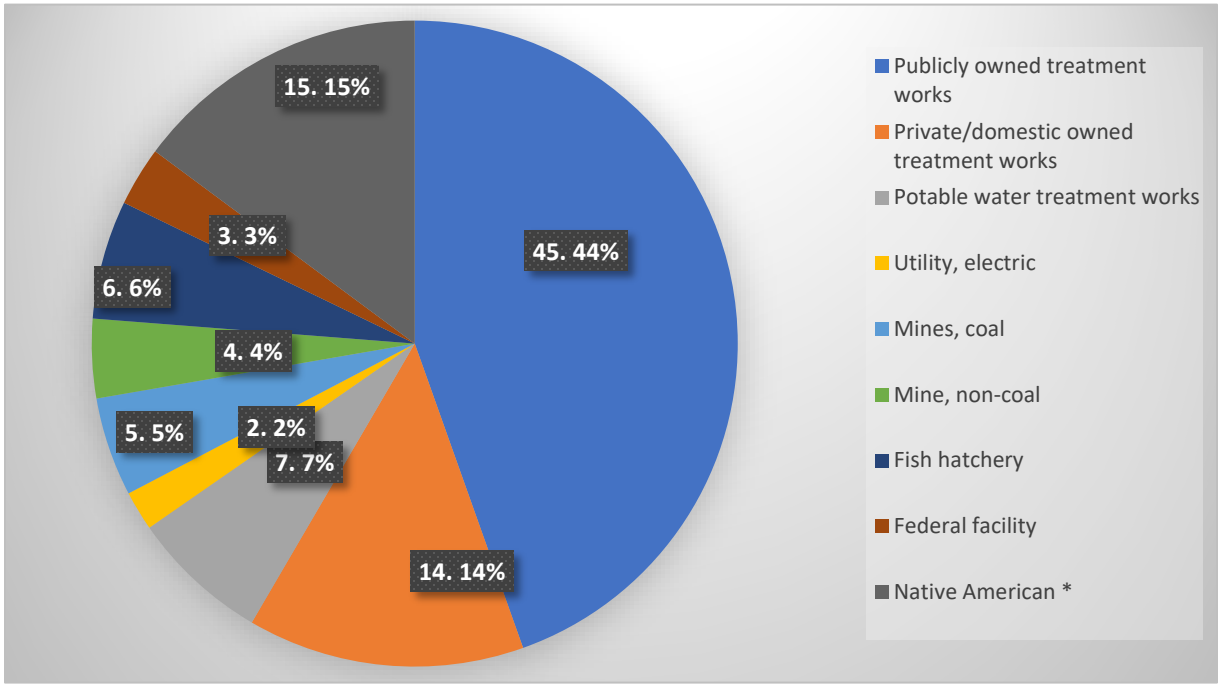
In addition to conducting individual permit inspections, PSRS also conducts both construction site and industrial facility stormwater inspections in accordance with the provisions of the Construction General Permit or the Multi Sector General Permit. The PSRS conducts outreach to construction site and industrial facility owners and operators to inform them of requirements under the CWA. PSRS conducted ten NPDES construction and industrial facility stormwater inspections in state FY 2024, and ten NPDES construction and industrial facility stormwater inspections in state FY 2025.

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PSRS also assists with implementation of the Phase I and II Municipal Separate Storm Sewer Systems (MS4) (i.e., urban stormwater) permitting program in New Mexico. PSRS anticipates working with EPA Region 6 on the reissuance of the statewide MS4 permit, to combine the administratively continued 2007 small MS4 permit NMR040000 and the administratively continued 2014 Middle Rio Grande Watershed-Based MS4 permit NMR04A000, in 2026.[26]

PSRS also assists with implementation of the Pesticide General Permit (PGP) and the Concentrated Animal Feeding Operations (CAFO) General Permit, and Hydrostatic Test General Permit. PSRS is working with EPA on the reissuance of the PGP, planned for October 2026. PSRS anticipates working with EPA Region 6 in 2026 on reissuance of the administratively continued 2016 CAFO General Permit for New Mexico. PSRS will continue to provide assistance in conducting audits of these programs as needed.

Figure 13 illustrates the distribution of individual NPDES permitted facilities by type and percentages. Because of the large percentage of wastewater treatment plants in the state, these facilities continue to cause adverse effects on water quality in local areas, in part due to poor operation and maintenance, the lack of certified operators, or limited funding to implement technological improvements and/or upgrades to treatment facilities.



NOTE: * SWQB does not certify permits for Tribal receiving waters. Only downstream-user comments are provided to EPA for Tribal receiving waters and Tribal permits.

Figure 13. Distribution of Individual NPDES permits in New Mexico, as of March 2026 (101 permits total)

[26] See https://www3.epa.gov/npdes/pubs/fact2-1.pdf and https://www.epa.gov/npdes/stormwater-discharges-municipal-sources for additional details on Phase I and II MS4s.

The U.S. Army Corps of Engineers (USACE) administers Section 10 of the Rivers and Harbors Appropriation Act and CWA section 404. The USACE Regulatory Division issues permits (Standard Individual Permits, Regional Permits, Regional General Permits, and Nationwide Permits [NWPs]), which authorize certain activities to discharge dredged or fill material into a water of the U.S. Under CWA section 401, States and Tribes are provided the opportunity to certify CWA section 404 permits to ensure that the federal permit will comply with Surface Water Quality Standards (2.4.6 NMAC) and applicable state law. NMED typically certifies CWA section 404 permits with conditions that include BMPs for protecting water quality from adverse environmental impacts. During Federal fiscal year 2024 (October 1, 2023, to September 30, 2024), WPS staff reviewed 57 projects covered by NWPs, seven projects covered by Regional General Permits (RGPs), and one project requiring an Individual Permit. In Federal fiscal year 2025 (October 1, 2024, to September 30, 2025), WPS staff reviewed 54 projects covered by NWPs, four projects covered by RGPs, and one project covered by an Individual Permit.

For more information on State Certifications, see:
https://www.env.nm.gov/surface-water-quality/point-source-regulation-section/
https://www.env.nm.gov/surface-water-quality/dredgeandfillactivities/
https://www.env.nm.gov/public-notices/
https://nmed.commentinput.com/comment/landingPage?lang=EN

E. Other NMED Water Pollution Control Programs

CWA section 303(d) and section 305(b) are primarily implemented by the SWQB. However, because surface water quality is utilized and affected in diverse ways by different activities and needs, the NMED has other bureaus and programs that also address water pollution control in New Mexico under the WQA. A few are highlighted below.

1. Drinking Water Bureau

a) Source Water Protection Program

Systems utilizing surface water sources for drinking water require more sampling of treated water than systems using a groundwater source due to the potential for rapid changes in source water quality. While the quality of the source water does not impact the required quality of the produced drinking water, the quality of the source water will influence treatment considerations and associated costs to comply with all maximum contaminant levels. Just over 60 public drinking water systems use, or purchase water obtained from either surface water or groundwater under the direct influence of surface water. When chlorine is used as part of drinking water treatment, disinfection byproducts can form when organic carbon reacts with the chlorine. Typically, systems can adjust treatment and operations as an effort to return to compliance relative quickly; however, additional infrastructure is sometimes required to remove organic carbon. A system is required to notify the public whenever violations of the SDWA occur.

For additional information on DWB's Source Water Protection Program, visit:
https://www.env.nm.gov/drinking_water/source-water-protection/



City of Santa Fe's Nichols Reservoir (filled (top) and under construction (bottom)). Nichols Reservoir, located within the Santa Fe Municipal Watershed, plays a critical role in supplying drinking water to households and businesses in and around Santa Fe.

In addition to providing oversight to systems, DWB's Source Water Protection Program (SWPP) works with systems to identify potential or actual sources of contamination that might have adverse effects on the source waters and to develop a plan to protect those drinking water sources. The Program assists systems with conducting assessments of potential sources of contamination for their surface water sources. The identified sources of contamination are evaluated based on the number and chemical properties of the associated contaminants, their likelihood of release, their proximity to the surface water source, and chemical monitoring history. Over the past two years the SWPP has been updating and refining the methodology for source water assessments and plans. This includes hydrological analyses of contributing watersheds to delineate source water assessment areas, a new risk assessment for contaminant sources, and a combined and iterative source water assessment and protection plan approach.

In 2021, DWB assisted with the completion of source water assessments and protection plans for the City of Santa Fe for both their groundwater and surface water sources. In 2025, the SWPP resumed assistance to the Village of Ruidoso for an updated source water protection plan that was paused due to wildfires in 2022 and 2024. Ruidoso uses both groundwater and surface water sources that will benefit from this effort.

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Once the Ruidoso project is complete, 86% of New Mexico's population that relies on streams or reservoirs for drinking water sources will be served by public water systems with active source water plans.

For additional information on NMED's Drinking Water Bureau, visit:
https://www.env.nm.gov/drinking_water/

b) Utility Operator Certification Program

The Utility Operator Certification Program (UOCP) administers the certification program for water and wastewater operators at all public water and wastewater utilities in New Mexico. This includes development, scheduling, and administration of certification examinations; processing applications for certification and renewal; evaluating and tracking all continuing education courses for certified operators; tracking compliance with operator certification requirements; and working with the New Mexico Water Quality Control Commission and the Utility Operator Certification Advisory Board. NMED administers the UOCP pursuant to the New Mexico Utility Operators Certification Act (NMSA 1978, §§ 61-33-1 to -10) and the utility operator certification regulations within the New Mexico Administrative Code (20.7.4 NMAC).

The UOCP ensures that the roughly 2,486 active operators of drinking water systems and wastewater treatment systems in New Mexico are appropriately trained and qualified. The Program tracks required continuing education credit hours (10 hours/year/operator) and certification renewals (renewal required every three years for each certification). UOCP also provides training for operators and coordinates with other assistance providers in the state for additional free training.

UOCP updates:

- In 2020, the UOCP received an EPA Environmental Justice Cooperative Agreement grant in partnership with San Juan College, the Navajo Tribal Utility Authority, and the Ute Mountain Ute Tribe to develop a water utility recruitment, training, and placement program. The project was completed in 2024. Project deliverables included formation of an advisory committee, as well as development and implementaiton of a training curriculum.
- In 2022, the UOCP partnered with the New Mexico Department of Work Force Solutions (DWS) and Water Professionals International (WPI), formerly know as the Association of Boards of Certifications (ABC),to provide operator certification examination through computer-based testing. As a result of switching from paper-booklet exams to computer-based testing (CBT), the UOCP has seen a steady increase in demand for examinations due to the flexibility and ease of access introduced by the partnership with WPI and DWS. In addition, passing rates have greatly improved, from roughly 25% to 40%. The UOCP will continue to identify and implement innovative ways to improve and streamline the UOCP program.
- In 2024, the UOCP successfully completed transition to a data management system within a web-based platform called Certemy. The data management system is custom-tailored to the UOCP water operator certification application work flow process. The system supports that data management needs of both the UOCP and the water operators. The UOCP continued to work closely with Certemy on finetune adjustment of UOCP data management system.
- In 2024, the UOCP experienced significant staff turnover and extensive recruitment efforts were initiated. In 2025, three new UOCP employees have successfully kept the UOCP services running

through the efficiencies made possibly by CBT and the new data management system. Recruitment efforts continue for expanding the UOCP team.

- In October 2025, the UOCP developed a two-year plan to modernize New Mexico utility operator certification. The plan includes development of need-to-know guidebooks, piloting comprehensive operator trianing courses, and rulemaking to revise the utility operator certificaiton rules.

Table 7. Number of Exams Taken per Year

Year	Total Exams Taken	Tests taken as of January
2026	_	30
2025	818	29
2024	710	81

Certified utility operators are required to acquire the appropriate number of training credits to renew a certification. The chart below indicates there are currently 3,389 active certifications and 888 of those certified utility operators hold multiple certifications. During the reporting period, 636 certifications became inactive due to not being renewed.

Table 8. Number of Certifications

Current status	
Inactive Utility Operator Certifications	636
Active Utility Operator Certifications	3,389
Multiple Certifications	888

2. Ground Water Quality Bureau

New Mexico's groundwater resources are of vital importance in sustaining life and must be preserved and protected for both present and future generations. Fifty five percent (54%) of New Mexicans depend solely on groundwater for drinking water. As of 2020 the Office of the State Engineer reported surface water shortages in all areas of the state with many areas shorted more than 60%. Communities must now augment their water supplies with groundwater pumping to mitigate the surface water shortages. Public systems with water derived from groundwater sources serve ninety two percent of New Mexicans (over 1,939,687 people). Just over fourteen percent (14.4%) of the State's population depend on private wells for drinking water (NMOSE 2020). Nearly half of the total water annually withdrawn for all uses in New Mexico, including agriculture and industry, is groundwater, the only practicable source of water in many areas of the State. Overall, the quality of these waters is assumed to be good, although there are significant pollution problems known to affect certain areas of New Mexico. New Mexico lacks a comprehensive, statewide, ambient groundwater quality monitoring program.

New Mexico relies on several programs to protect and maintain groundwater quality. The primary statute dealing with groundwater quality management is the WQA, which authorizes the NMWQCC to adopt

groundwater quality protection regulations and standards (20.6.2 NMAC). Key features of the WQA and the NMWQCC regulations relating to groundwater include:

- A requirement for dischargers to obtain a groundwater discharge permit to prevent groundwater contamination from discharges that have the potential to impact groundwater quality, including discharges to underground injection control wells;
- Requirements for reporting and addressing spills and releases;
- Development of groundwater quality standards;
- Requirements to abate groundwater pollution; and
- Provisions for civil and criminal penalties for violation of the regulations and standards.

The role of the NMED Ground Water Quality Bureau (GWQB) is to protect the environmental quality of New Mexico's groundwater resources; and to identify, investigate, and oversee clean-up contaminated sites which pose risks to human health and the environment. Specifically, the GWQB:

- Issues and oversees groundwater pollution prevention (i.e., discharge) permits;
- Implements, along with the SWQB, the NMED's responsibilities under the New Mexico Mining Act to ensure that environmental issues are addressed and standards are met;
- Oversees groundwater investigation and remediation activities;
- Identifies, investigates and remediates inactive hazardous waste sites through implementation of the federal Superfund program;
- Oversees agreements between the state and responsible parties; and
- Implements the Voluntary Remediation Program.



Clovis Water Fair (August 2025)

The GWQB strives to increase industry and public understanding and awareness of the importance of safe groundwater supplies in sustaining the quality of life in New Mexico for this and future generations, and the importance of protecting groundwater quality through pollution prevention initiatives. The GWQB also offers free water quality screening for domestic wells at water fairs routinely held around New Mexico through NMED's CWA section 319 grant funding.

Groundwater quality monitoring is typically required at permitted facilities to determine baseline groundwater quality, serve as a sentinel detection method, and as part of remediation efforts to determine whether remediation efforts are effective. While household septic tanks or unauthorized cesspools are the predominant source of nonpoint source contamination of groundwater in New Mexico, other diffuse sources may also cause groundwater quality degradation. These sources can include minerals from evapotranspiration, land disturbance by



Observation of Groundwater Well Drilling

mineral exploration, urban runoff, or application of agricultural chemicals. Point source categories include publicly and privately-owned sewage treatment plants with discharges of over 5,000 gallons per day, dairy operations, mines, food processing operations, industrial discharges, landfills, leaking above and underground storage tanks, petroleum processing and storage, and accidental spills or leaks.

Programs established under the New Mexico Oil and Gas Act, Hazardous Waste Act, Ground Water Protection Act, Solid Waste Act, Emergency Management Act, Voluntary Remediation Act, and Environmental Improvement Act also contain provisions designed to protect groundwater quality and implement the groundwater regulations and water quality standards directly or by reference. For example, the Voluntary Remediation Program provides state oversight of assessment and cleanup efforts of contaminated sites that are not involved in regulatory or enforcement actions. Upon completion of the process a Certificate of Completion is issued documenting that property conditions meet applicable standards. Lenders and prospective purchasers are provided with liability protection, thus allowing these properties to transact, or be redeveloped more easily. In addition, the State cooperates with local and federal governments on various programs relevant to groundwater pollution control.

Programs established under the New Mexico Oil and Gas Act, Hazardous Waste Act, Ground Water Protection Act, Solid Waste Act, Emergency Management Act, Voluntary Remediation Act, and Environmental Improvement Act also contain provisions designed to protect groundwater quality and implement the groundwater regulations and water quality standards directly or by reference. For example, the Voluntary Remediation Program provides state oversight of assessment and cleanup efforts of contaminated sites that are not involved in regulatory or enforcement actions. Upon completion of the process a Certificate of Completion is issued documenting that property conditions meet applicable standards. Lenders and prospective purchasers are provided with liability protection, thus allowing these properties to transact, or be redeveloped more easily. In addition, the State cooperates with local and federal governments on various programs relevant to groundwater pollution control.

For more information on NMED's Ground Water Quality Bureau (including updates to the petition to amend groundwater regulations), visit: https://www.env.nm.gov/gwqb/

3. Compliance and Enforcement Division

Compliance is a core value of the New Mexico Environment Department. Assuring compliance with state licenses, permits and rules and enforcing against violations when they occur is critical to protecting the public and their environment. Further, enforcing state licenses, permits, and rules ensures a level playing field because facilities that fail to comply with such requirements may incur an economic advantage over competitors. Compliance with state-issued licenses, permits and rules is not optional – it's required.

On July 1, 2025, the Compliance and Enforcement Division (CED) of NMED was created and is responsible for offering compliance assistance, promptly enforcing against entities when violations occur, and resolving violations of federal and state regulatory programs. The Water Protection Compliance and Enforcement Bureau (WPCEB) within CED has the enforcement authority over New Mexico's Water Quality Act and corresponding WQCC regulations as it relates to ground and surface water quality. WPCEB is also responsible for the compliance and enforcement of New Mexico's Drinking Water Regulations (20.7.10 NMAC) and the federal Safe Drinking Water Act (SDWA). Furthermore, once NMED has EPA approval for the NMPDES program and NMED begins issuing permits, WPCEB will include enforcement activities stemming from noncompliance with NMED issued permits.

a) Public Water System Supervision Group or Program - Compliance

NMED's WPCEB is responsible for regulating public water systems who are responsible (obligated to provide/charged with providing) for providing a safe and sustainable supply of drinking water to their consumers. NMEDs mission is to preserve, protect, and improve New Mexico's drinking water quality for present and future generations, by implementing the requirements of New Mexico's Drinking Water Regulations (20.7.10 NMAC) and the federal Safe Drinking Water Act (SDWA), which establish the standards for drinking water throughout the State. These regulations and standards are set to limit the presence or concentration of harmful contaminants such as pesticides, volatile organics, and radiochemical, chemical, and bacteriological contaminants in drinking water. The SDWA originally focused on treatment as the means of providing safe drinking water at the tap. The 1996 SDWA amendments greatly enhanced existing law by recognizing source water protection, operator training, funding for water system improvements, and public information as important components of safe drinking water. NMED has adopted the SDWA amendments, to ensure the quality of drinking water in New Mexico is protected from source to tap.

Regulated public drinking water systems must monitor the quality of water served to consumers for regulated contaminants; and ensure compliance with New Mexico's Drinking Water Regulations and the SDWA. The water samples are analyzed for contaminants according to an established schedule, to ensure water quality meets the standard of federal and state requirements. Regulatory oversight to New Mexico's public drinking water systems, is accomplished through the review of data and documents, the completion of regularly scheduled onsite facility inspections, the development of compliance guidance, and issuance of notices of violation when water systems do not meet compliance standards. Enforcement action may be taken to return the system to compliance if a water system does not make progress toward achieving compliance. WPCEB may issue an Administrative Compliance Order to compel the water system to achieve compliance. These actions typically include providing technical, managerial, or financial assistance to help improve the overall capacity of a system and encouraging systems to regionalize and combine resources when possible.

V. Measure Progress/ Update Surface Water Quality Goals

The fourth phase of New Mexico's implementation of the CWA framework for surface waters is to continually grow and improve water quality identification and control techniques through measuring progress towards and updating surface water quality goals. Identification goals are reviewed and updated through activities such as the triennial review of water quality standards; the biennial revisions and improvements to the IR listing methodologies, especially related to developing numeric thresholds for narrative water quality criteria; and development of tools to identify, measure condition, and restore additional waterbody types such as wetlands. Progress towards meeting these goals is continually evaluated through rotational surface water quality monitoring, wetlands mapping, site inspections, consideration of special needs and concerns that hamper the ability to identify and address water quality impairments, and effectiveness monitoring of restoration implementation activities. Two specific SWQB programs that focus on these areas are highlighted below, along with special water quality issues and concerns in New Mexico.

A. Effectiveness Monitoring Program

An important goal of the NPS Management Program is to monitor the effects of NPS pollution control projects on water quality. These projects are primarily stream restoration measures funded under CWA section 319, but also include projects funded through the RSP and the Wetlands Program. Effectiveness monitoring has focused primarily on projects addressing stream temperature impairments in mountain streams in northern and central New Mexico. Temperature monitoring is ongoing on the following streams: Comanche Creek, Holman Creek, Rito Peñas Negras, Rio de las Vacas, Willow Creek, Jaramillo Creek, and San Antonio Creek.

Stream temperature monitoring provides data for statistical analysis using the before/after upstream/downstream study design, in which the relationship between the upstream and downstream stations is tested for a significant difference before and after restoration. Initial results from the data analysis indicate that peak summer temperatures in many streams have improved but still exceed the associated aquatic life water quality criteria in some streams.

A common restoration technique for temperature impairments is to exclude cattle and elk grazing by building fence exclosures (i.e., structures intended to exclude animals from these areas to remove grazing impacts) and planting native vegetation to bring back the riparian cover. Although this technique is expected to be effective, there is a significant lag time between planting and sufficient vegetation growth to effectively shade the stream. Data collection and analysis is extended for several years to account for this lag time. These projects are expected to have beneficial effects which will continue to increase as riparian vegetation continues to grow and provide shade to the adjacent stream.



Rock armor to protect the road crossing at San Antonio creek above VC02 (stream temperature monitoring location)

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Watershed-scale change to attain water quality standards is usually a long-term effort. Economic changes, societal values, climate cycles, and climate change may exert as much influence on water quality as isolated projects or shifts in land management practices. NMED's Effectiveness Monitoring Program seeks to recognize water quality standards attainment attributable to projects or intentional land management improvements. A key NPS Management Program milestone is for NMED to submit one or more nominations per year to the EPA for recognition as an NPS Success Story. New Mexico's recognized NPS Success Stories are listed in Table 9.

Table 9. New Mexico NPS success stories

Waterbody	Year
Rio de las Vacas (Rio Cebolla to Clear Creek)	2025
Rito de los Indios (San Antonio Creek to headwaters)	2025
Redondo Creek (Sulphur Creek to headwaters)	2024
Cold Springs Creek (Hot Springs Creek to headwaters)	2022
San Antonio Creek (Valles Caldera boundary to headwaters)	2021
Jaramillo Creek (East Fork Jemez to headwaters)	2018
Bluewater Creek (Perennial portions Bluewater Reservoir to headwaters)	2017
Polvadera Creek (Cañones Creek to headwaters)	2015
Willow Creek (Pecos River to headwaters)	2014
Sitting Bull Creek (Last Chance Canyon to Sitting Bull Springs)	2014
Comanche Creek (Costilla Creek to headwaters)	2013
Santa Fe River (Paseo del Cañon to Santa Fe WWTP)	2011
Rio Cebolla (Rio de las Vacas to Fenton Lake)	2010

For more information on New Mexico restoration success stories, visit:
https://www.epa.gov/nps/success-stories-about-restoring-and-protecting-water-bodies-impaired-nonpoint-source-pollution

B. New Mexico's Wetlands Program

Wetlands are important features of the natural landscape because they function as filters that trap excess sediment, nutrient runoff and other pollutants, thereby improving water quality in adjacent streams and waterbodies. Wetlands mitigate extreme weather events common to New Mexico (and becoming more common due to climate change), such as drought and flashfloods by allowing water to slow down and infiltrate, thus augmenting groundwater storage and aquifer recharge, and attenuating the power and intensity of flashfloods. Wetlands support vegetation that provides a moist green fire break in the event of wildfires. They serve as the headwater sources of perennial streams including some of our State's outstanding streams and fisheries. Wildlife benefit greatly from wetlands, which support greater diversity of terrestrial and aquatic species.

Among the modern threats to New Mexico's wetlands are groundwater pumping that lowers already shallow water tables, invasive exotic plants and animals that are outcompeting natural species, and erosion and channelization of flow that drain wetlands. This latter threat has severely impacted many of New Mexico's wetlands by limiting, and in many cases eliminating, the water-land relationship that would

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normally have allowed the establishment of wetland vegetation and ecosystems. The results include the loss of natural flood attenuation, nutrient cycling, habitat connectivity, particulate retention, carbon sequestration, dynamic and long-term surface water storage, moderation of groundwater flow or discharge, and maintenance of vertebrate and invertebrate communities and habitat structure.



Lordsburg Playa in 2021. Photo credit: Esha Chiocchio

The SWQB's Wetlands Program administers CWA section 104(b)(3) Wetland Program Development grants. The overall goal of the Wetlands Program is to protect, restore and increase self-sustaining and naturally functioning wetlands and riparian areas. The Wetlands Program has the following long-term objectives, as specified in the 2021 Wetlands Program Plan[27]:

1. Promote wetland protection and restoration as a goal of established watershed groups and partnerships.
2. Increase wetland area (no net loss) as well as restore wetland functions and ecological services and develop a system for tracking gains and losses by wetland type.
3. Assist communities, agencies, tribes, stakeholders, local governments and others with wetlands technical information, project design and planning, training and other guidance.
4. Develop protection, adaptation, and mitigation strategies for wetland resources threatened by the effects of a drying climate in the west, including drying of wetlands in the landscape, loss of mountain snowpack, increased large-scale catastrophic fires and subsequent flooding, scour and sediment delivery.
5. Develop and refine narrative water quality standards for wetlands and for specific wetland types and use these standards to promote more effective Clean Water Act Section 401 Certification.
6. Develop a toolbox of successful restoration techniques that are specific to wetland types and ecoregions.

[27] https://www.env.nm.gov/surface-water-quality/wp-content/uploads/sites/18/2022/01/2021-New-Mexico-Wetlands-Program-Plan.pdf

The Wetlands Program emphasizes the role of wetlands in preventing and reducing water quality issues and providing habitat and life requirements for aquatic and wildlife, including protected species. The following activities support the long-term objectives and goals of the Wetlands Program and include:

- Completing the inventory of wetlands resources through landscape level mapping and classification
- Determining the ecological condition of wetlands in New Mexico through the development and implementation of wetlands rapid assessment methods
- Implementing innovative wetland restoration demonstration projects and sharing the outcomes in Technical Guides or other publications
- Engaging watershed groups, communities, and other citizens groups in the development of Wetlands Action Plans
- Promoting maintenance of instream flow to support streamside and floodplain wetlands and provide other water quality benefits
- Promoting agricultural water use management and supporting wetlands as filtration systems for agricultural runoff
- Promoting land management techniques to restore wetland-supporting beaver habitat
- Increasing wetland acreage in New Mexico through the restoration and protection of wetland corridors
- Ensuring adequate protection of all wetlands at the state level including closed basin and isolated wetlands
- Participating in wetland and riparian education and outreach for schools and interest groups
- Providing a statewide forum for sharing information about wetlands by hosting Wetlands Roundtables meetings



Rainbow over a wetland in the Costilla/Valle Vidal area

For more information on New Mexico Wetlands Program, visit:
https://www.env.nm.gov/surface-water-quality/wetlands/

C. Special State Surface Water Concerns and Recommendations

Agencies and other stakeholders that implement New Mexico's water management programs work continuously to protect surface water quality. However, there are still many challenges in meeting the objectives of the CWA and the WQA. Below are significant surface water quality issues in New Mexico.

Climate Change



A dry Rio Gallina streambed above the Rio Chama, December 2025

New Mexico acknowledges the impact of climate change on the state's water resources because the science shows that these changes will lead to further problems and uncertainties. Droughts are increasing in both frequency and severity in many regions of the world, including the southwestern U.S., due to climate change. In general, droughts and the immediate recovery period have substantial water quality effects on the waterbody and its watershed. For example, decreases in stream flow typically increase pollutant concentrations due to less dilution. Other water quality impacts associated with climate change and drought include higher water temperatures, enhanced algal production, toxic algal blooms, and lower dissolved oxygen levels. As temperature and precipitation patterns undergo extreme cycles, more frequent and more powerful storms will increase pollutant runoff from the watershed, physically modify and erode riparian habitat, and disrupt biological communities that depend on these habitats. In addition, shifting temperature and precipitation patterns affect vegetation composition and density and increase the propensity for wildfire. Climate change will add additional stress to New Mexico's water resources and make attainment of water quality standards more difficult to achieve.

As surface waters become stressed by climate change, drought, wildfires, overuse, and groundwater mining, many perennial and intermittent streams and springs will experience reductions in flow. Currently, many perennial "rivers" and "tributaries" in New Mexico contain non-perennial sections. As a result of climate change, the overall length of "perennial" waters may diminish and the need for clean water will strain these systems even further.

To address some of these concerns, in 2019 Governor Lujan Grisham signed Executive Order 2019-003 on Addressing Climate Change and Energy Waste Prevention, which created an Interagency Climate Change Task Force and directed State agencies to integrate climate change mitigation and adaptation practices into their programs, policies, and operations. In January 2024, Governor Lujan Grisham announced the 50-Year Water Action Plan, which describes how the state can prepare for and mitigate the impacts from climate change and secure a clean and sustainable water supply for present and future generations. The IR ties in directly with various initiatives for resource management in the State of New Mexico, including executive order 2019-003 and the 50-Year Water Action Plan. Water quality challenges identified in this report are important to address as improved watershed health is New Mexico's most effective tool in increasing waterbody and watershed resilience to climate change.

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Stormwater Management

Controlling stormwater runoff and its impact is a serious issue facing communities across New Mexico. Urban and highway stormwater runoff is rainfall or snowmelt that runs off the ground or impervious surfaces such as buildings, roads, and parking lots, and drains into natural or man-made drainage systems. In most cases, it drains directly into streams, rivers, lakes, or wetlands without receiving any treatment to remove pollutants. Because of this, stormwater is a leading cause of water pollution.



Rio Grande at Pena Blanca, NM

Changes in land use have a major effect on both the quantity and quality of stormwater runoff. Urbanization, if not properly planned and managed, can dramatically alter the natural hydrology of an area because it increases impervious cover, decreases the amount of rainwater that can naturally infiltrate into the soil, and consequently increases the volume and rate of stormwater runoff. Stormwater runoff also typically contains elevated concentrations of a variety of emerging contaminants (e.g., PFAS, microplastics, pharmaceuticals, etc.) as well as pollutants that exceed water quality standards (e.g., copper, lead, and zinc; polyaromatic hydrocarbons [PAHs] and pesticides; oil and grease; nutrients [nitrogen and phosphorus]; sediment; and E. coli bacteria). Untreated stormwater entering our waterways can kill aquatic life and result in the contamination of fish tissue and drinking water supplies; prohibit or limit swimming, fishing or boating; and present dangers to public health and safety. Municipal separate storm sewer systems (MS4s) in urbanized areas transport polluted stormwater runoff to local and then downstream waterbodies. To prevent harmful pollutants from being washed or dumped into designated MS4 areas or watersheds, certain operators are required to obtain National Pollutant Discharge Elimination System (NPDES) MS4 permit coverage and develop stormwater management programs (SWMPs). The SWMP describes the stormwater control practices that will be implemented consistent with permit requirements to minimize the discharge of pollutants from the urbanized area. Furthermore, effective water quality protection requires the “treatment” of stormwater utilizing various preventive and control measures (e.g., best management practices, low impact development, structural controls) to reduce the impact of impervious surfaces and minimize increases in stormwater runoff.

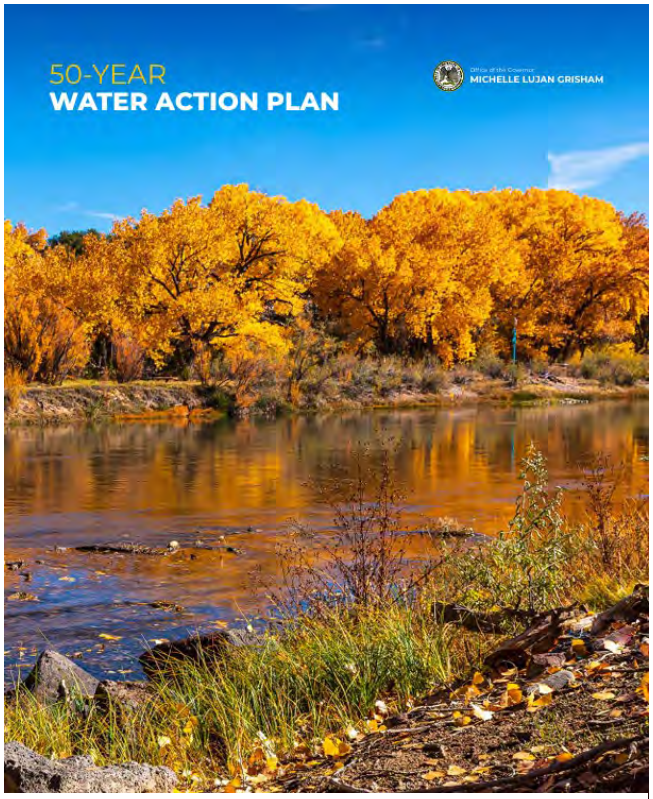
Although MS4 designated areas or watersheds are generally based on population, EPA may also designate certain small MS4 areas when discharges are contributing to violations of applicable water quality standards based on their residual designation authority. One such example in New Mexico is EPA’s November 2023 determination that stormwater discharges in Los Alamos County contribute to water quality standards violations and require Clean Water Act permit coverage. NMED provided support to EPA for the special designation and confirmed that both NMED and LANL studies verify elevated levels of metals and PCBs in urban stormwater from the area. In this determination, EPA identified Los Alamos County, LANL, and NMDOT as entities required to obtain coverage under the sMS4 permit. This important designation is a major step towards eliminating or reducing the transport of sediment-laden stormwater, along with various water contaminants, to one of New Mexico’s most important rivers -- the Rio Grande.

One of the eleven priorities in the 50-Year Water Action Plan focuses on building modern stormwater infrastructure to prevent surface water pollution and address emerging contaminants. By 2045, a long-term goal of the Plan is to have major stormwater management and flood prevention projects, including those that utilize green infrastructure practices, completed or substantially underway in all cities, towns, and villages in New Mexico. If realized, this investment to control and mitigate stormwater would limit pollution, protect water quality, increase groundwater recharge, create opportunities for water reuse, and decrease the risks of loss of life and property destruction from flooding.

Waters of the U.S., Sackett v. EPA, and NM's State Permitting – NPDES Primacy Goals

"Waters of the United States" (WOTUS) is a term used to establish the scope of federal jurisdiction under the CWA and is important for implementing Clean Water Act programs within states. The CWA does not define WOTUS but provides discretion for EPA and the U.S. Department of the Army (U.S. Army Corps of Engineers) (the "Agencies") to define "waters of the United States" in regulations. The Agencies promulgated regulations in 1979 to define WOTUS and the scope of federal regulation, and have since amended their WOTUS regulations in 2015, 2020, 2023, and 2025.

In November 2025, the Agencies published a proposed updated WOTUS rule that codifies and aligns with the U.S. Supreme Court's decision in *Sackett v. EPA*. The *Sackett* decision and proposed WOTUS rule significantly reduce national Clean Water Act safeguards, which now only include protections for traditionally navigable waters (TNWs), impoundments and tributaries of TNWs that are relatively permanent, standing, or continuously flowing bodies of water, and wetlands with a "continuous surface connection" to these protected waters. The proposed rule defines "relatively permanent" as water existing year-round or at least during the wet season. In addition, the proposed rule excludes interstate waters as a standalone category of protected waters.



New Mexico 50-Year Water Action Plan

Rivers, streams, lakes, wetlands, and other surface waters sustain the state's culture, economy, and natural ecosystems. Currently, New Mexico relies on the Agencies to regulate discharges of pollutants into waters within our borders. However, the 50-Year Water Action Plan[28] identifies the need to protect surface water by controlling pollution through a discharge permitting program. Specifically, Action C2 of the 50-Year Water Action Plan prioritizes the development and implementation of, "...a State surface water discharge permitting program to protect watersheds and reduce the amount of pollution entering New Mexico's rivers, lakes, streams and wetlands." New Mexico is one of only three states that does not issue and enforce their own

[28] www.nm.gov/wp-content/uploads/2024/01/New-Mexico-50-Year-WaterAction-Plan.pdf

NPDES permits. Given the many water challenges facing our state, it is time to put regulatory control over surface water discharges at the state level and take ownership of this important water quality program to ensure clean water for drinking, recreational, agricultural, cultural, and other uses.

Leading up to the 2025 Regular Legislative Session, SWQB organized a Surface Water Advisory Panel (SWAP), a diverse group of stakeholders that may be affected by the new permitting program. The SWAP was convened in the Fall of 2024 and over the course of six meetings provided feedback, comments, and concerns to the SWQB regarding potential legislation and rules pertaining to a state-led permitting program. Key discussion areas were regulatory scope and program clarity, public engagement and communication, program funding, and sector-specific operational considerations. A summary of the SWAP meetings and key points made can be found in the SWAP Executive Summary, available on the SWQB SWAP webpage at: https://www.env.nm.gov/surface-water-quality/swap/.

The first piece to establishing a state-run permitting program is legislation to give NMED the authority to develop and implement a program. Senate Bill 21 (SB21), passed during the 2025 Regular Session and signed into law on April 8, 2025, does two critical things to protect water quality. First, it empowers New Mexico to regulate discharges of pollutants from point sources and dredge and fill activities into "surface waters of the state" (SWOTS) that are no longer protected by the Clean Water Act. And second, it provides authority for the State to take over the federal National Pollutant Discharge Elimination System (NPDES) permitting program from EPA. As a result of SB21, NMED is currently building a surface water quality permitting program to protect SWOTS but has not yet implemented the program.



NMED Surface Water Quality Bureau Chief Shelly Lemon and Representative Kristina Ortez present SB 21 & 22 during the 2025 legislative session.

NMED is also pursuing authorization from EPA to administer and enforce the NPDES program to protect WOTUS within our borders. The final version of SB21 can be viewed here: https://www.nmlegis.gov/Legislation/Legislation?Chamber=S&LegType=B&LegNo=21&year=25.

The second piece to establishing a state-run permitting program is rules to implement SB21. NMED solicited comments and feedback on draft rules from the SWAP, tribal environmental directors, various stakeholder groups, and the public. NMED incorporated the comments and feedback received, as appropriate, into proposed surface water permitting rules for both the NMPDES Program and State Permitting Program. The NMPDES regulations are included in 20.6.5 NMAC and serve as the foundation for NMED's application to EPA for NPDES delegation to allow the state to regulate and enforce discharges into WOTUS. Meanwhile, the State Permitting Program regulations are amendments to existing regulations in 20.6.2 NMAC and are the framework for the state-led permitting program for discharges into SWOTS, including discharges of dredged and fill material. The U.S. Army Corps of Engineers will continue to regulate discharges of dredged and fill material into WOTUS under the authority of the Clean Water Act. The draft rules are available at: https://www.env.nm.gov/surface-water-quality/amendments-to-20-6-2-nmac-and-proposed-new-rule-20-6-5-nmac-review/.

For more information on New Mexico State Permitting Program development, including NPDES authorization ("primacy"), **visit:** https://www.env.nm.gov/surface-water-quality/spp/

Wildfires

New Mexico has experienced a growing number of wildfires with increasing size and severity. Wildfires can produce significant watershed changes that may impact water quality, fish and other aquatic organisms, drinking water supplies and wastewater treatment systems. The primary water quality concerns after a wildfire are: (1) the introduction of sediment and debris into the surface waters; (2) the increase of nitrate and other plant nutrients from burned vegetation; (3) the introduction of radionuclides and heavy metals from ash, soils, and geologic sources; and (4) the introduction of fire-retardant chemicals into waterbodies. The magnitude of these effects is largely dependent on the size, intensity, and severity of the fire, and on the condition (e.g., healthy or poor) of the watershed at the time of burning.



Post-wildfire flooding, Carrizo Creek, July 2024



Carrizo Creek flooding, July 2024

A watershed may take decades to completely recover from the effects of wildfire, during which time the waters may exceed WQS for one or more pollutants. Assessing the water quality of an area after a wildfire can be challenging as it may be difficult to determine the cause of any impairments and the time at which fire-caused conditions are no longer influencing the watershed. Whether natural or human-caused, with the increasing frequency and magnitude of wildfires in response to drought and climate change, a standard approach for monitoring, assessing, and listing wildfire affected areas needs to be developed.

In 2024, the South Fork and Salt Fires devasted Sacramento Mountains watersheds, burning over 25,000 acres of forested headwaters and destroying roughly 1,400 structures in the Village of Ruidoso. The severity of the South Fork and Salt Fires led to major evacuations and a federal disaster declaration to assist with response to burned areas and catastrophic post-fire flooding occurring in the Village of Ruidoso during the summers of 2024 and 2025. Many of the watersheds impacted by the fire were intensively monitored in the 2021-2022 SWQB rotational survey, including probabilistic surveys. There are several impairments for nutrients, total phosphorus, temperature, turbidity, and *E. coli* within the fire perimeter, including the following assessment units (AUs): Rio Ruidoso (Carrizo Creek to Mescalero Apache boundary), Grindstone Canyon Reservoir, and Carrizo Creek (Rio Ruidoso to Mescalero Apache boundary). After these fires, and to improve outreach for surface water quality issues in southeast New Mexico, SWQB hired a new staff

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member in 2025 located in NMED's Ruidoso Field Office to help focus on post-fire recovery efforts. Fortunately, the Village of Ruidoso had just started the process of developing a watershed-based plan for the area before the 2024 fires. The scope of the watershed-based plan has grown from three to five subwatersheds (130600080103 Upper Rio Ruidoso, 130600080101 Carrizo Creek, 130600080106 Middle Rio Ruidoso, 130600080102 Cherokee Bill Canyon, and 130600080105 Devils Canyon) to address the post-fire landscape and improvement of surface water quality impairments.

For more information on Wildfire Impacts on Surface Water Quality in New Mexico, visit:
https://www.env.nm.gov/surface-water-quality/wildfire-impacts-on-surface-water-quality/

Nutrient Reduction Strategy

The EPA, through its National Water Program Guidance, continues to place a high priority on states addressing nutrient pollution and identifying nutrient-impaired waters through adoption of numeric water quality criteria for nitrogen and phosphorous in our nation's waters, although the EPA has allowed appropriate flexibility to states to make incremental improvements to address excess nutrients through other measures (Fox 2022). As documented in the New Mexico Nutrient Reduction Strategy (NMED/SWQB 2014), New Mexico is currently not pursuing adoption of numeric nutrient criteria. Instead, New Mexico is pursuing continued refinement of numeric thresholds for our narrative criteria and associated listing methodologies. Specific accomplishments this listing cycle include:



NMED staff conducting nutrient data collection in the Rio Grande, July 2025

- In collaboration with EPA, initiated and completed a Nutrient Scientific Technical Exchange Partnership and Support (N-STEPS) project to refine numeric nutrient threshold values in New Mexico's listing methodology for lakes and reservoirs;
- Continued protection of water-quality limited segments in accordance with both state (20.6.4.8 NMAC) and federal (40 C.F.R. § 131.12) antidegradation policies and implementation procedures to ensure that Tier 1 waters (i.e., waters identified as "impaired") are not further degraded and that NPDES nutrient effluent limitations, at a minimum, protect existing instream uses;
- Continued improvements to nutrient TMDLs that recognize the nutrient threshold concentrations necessary to protect designated aquatic life uses while developing approaches to implement waste load allocations and load reductions that are achievable; and
- Completed a project with EPA to create a preliminary draft update of the New Mexico Nutrient Reduction Strategy, scheduled for SWQB completion in calendar year 2026.

Harmful Algal Blooms



Harmful Algal Bloom at Quemado Lake, October 2025

As part of the 2020 Triennial Review, SWQB proposed and the WQCC and EPA approved the following addition to 20.6.4.900.D NMAC:

". . . a single sample of total microcystins of 8 µg/L with no more than three exceedances within a 12-month period and a single sample of cylindrospermopsin of 15 µg/L with no more than three exceedances within a 12-month period. . ."



Harmful Algal Bloom at Quemado Lake, October 2025

SWQB then updated SOP 12.1, "Lake Sampling", for microcystin sample collection that is accessible on the SWQB website Standard Operating Procedures and added methodologies for microcystin and cylindrospermopsin as well as cyanobacteria assessment protocols to the Comprehensive Assessment and Listing Methodology. SWQB has started collecting microcystin data as part of the lake monitoring program. In the effort to disseminate information to the public, SWQB created and maintains a new webpage for Harmful Algal Blooms that includes a frequently asked questions (FAQs) section, tips on identifying blooms, and an outlet for the public to report suspected blooms. The website also provides an interagency collaboration tool to disseminate information including links to the most current early warning satellite-based tools, recommended monitoring and response strategies, and information regarding human health through our NMDOH and NMED DWB partners. SWQB also initiated and is leading a related interagency working group on addressing harmful algal blooms in New Mexico. The harmful algal blooms working group will help SWQB communicate with water and land use managers to streamline the process of identifying and addressing emerging environmental and public health concerns as blooms establish in New Mexico's lakes. Since the science of harmful algal blooms is rapidly evolving, SWQB will continue working to implement the most current and effective strategies in addressing them.

VI. Financial Resource Analysis

A. Resources Applied to Surface Water Quality Management

Protecting and preserving water quality to ensure adequate, safe, and reliable water resources for the long term is a top priority for the NMED. The quality of the state's water resources has an impact on every resident and is linked to the economic vitality and quality of life New Mexicans cherish.

Like most states, New Mexico is faced with the challenge of addressing an array of complex surface water quality issues with limited financial resources. As the complexity of environmental needs continues to increase, there is an expectation that the SWQB will continue to meet and exceed the mandates of state and federal legislative and regulatory requirements. This pressure makes it essential that New Mexico evaluate information regarding the fiscal implications and potential benefits of its water quality programs. However, and as referenced throughout this report, there are also local, state, and even private resources that directly or indirectly affect the state's water quality. Table 10 summarizes the amount of funds the SWQB expended in State fiscal year (FY) 2025 to implement a comprehensive water quality management program. Match dollars, provided locally as cash or in-kind support for nonpoint source and wetland projects, are not included in this table.

Table 10. State Fiscal Year 2025 Expenditures for New Mexico's Surface Water Quality Management Implemented Through NMED SWQB

Surface Water Quality Management Program	Federal	State	Total
Monitoring & Assessment (Includes Monitoring, Assessment, TMDL, and Fish Consumption Advisory Programs)	$ 759,511	$ 873,348[1]	$ 1,632,859
Point Source Regulation	$ 342,711	$ 635,162[1]	$ 977,873
State Permitting Program	--	$ 1,661,809	$1,661,809
Nonpoint Source Management	$ 1,167,611	$ 628,431	$ 1,796,042
Wetlands Program	$ 401,885	$ 367,762	$ 769,647
Water Quality Standards (includes planning and reporting activities)	$ 171,356	$ 317,581[1]	$ 488,937
River Stewardship Program (RSP)	--	$ 5,618,314	$ 5,618,314
WIIN Act Gold King Mine Activities: San Juan-Animas Watershed	$ 163,763	--	$ 163,763
Total	**$ 3,006,836[2]**	**$ 10,102,408[3]**	**$ 13,109,244**

NOTES: The above numbers are based on NMED State FY 2025 actual expenditures.

1 = funding includes State Level of Effort Match for the CWA § 106 Grant ($220,100).

2 = This amount has remained relatively stagnant for more than a decade, averaging $3,488,851 Federal investment in New Mexico's surface water quality programs since fiscal year 2011. Federal support continues to decrease when accounting for inflation.

3 = The substantial change in Total State funds expended ($10,102,408 compared to the 14-year average of $1,931,022) is primarily due to increased State support and investment for the SWQB River Stewardship Program and State Permitting Program, and implementation of the Land of Enchantment Legacy Fund.

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B. Capital Investments in Municipal Facilities



Chapelle MDWCA RIP 00044 Construction of New Waterline.

The estimated annual costs for operating and maintaining various sizes of wastewater treatment facilities in New Mexico is summarized in Table 11. Most of these operation and maintenance costs are funded through fees included in monthly water/sewer rates. Many entities do not include replacement cost in their rate structure; therefore, New Mexico is encouraging communities to utilize the Asset Management approach to rate setting. Asset Management helps wastewater treatment systems prepare for both anticipated and unexpected problems by evaluating the system's current physical, financial, and managerial situation. It requires entities to make fundamental decisions about the water system's purpose, structure, and functions. For more information refer to *Asset Management: A Handbook for Small Water Systems* (EPA 2003a).

Table 11. Estimated Annual Operation and Maintenance Costs for Wastewater Treatment Facilities in New Mexico

Wastewater Treatment Plant Facility Size	Estimated Annual Operation and Maintenance Costs
Small WWTP < 1 MGD	$300,000 per year
Medium WWTP 1-4 MGD	$780,000 per year
Large WWTP > 5 MGD	$1,500,000 per year

Source: Utility Operator Certification Program; MGD = million gallons per day

The NMED Construction Programs Bureau (CPB) administers the Clean Water State Revolving Fund (CWSRF), the Rural Infrastructure Revolving Loan Program (RIP), and the Special Appropriations Capital Outlay Program (SAP). The CWSRF provides funding for a variety of wastewater projects including nonpoint source and solid waste projects; the RIP provides funding for water, wastewater, and solid waste projects; and the SAP oversees legislatively assigned water, wastewater, and environmentally related projects. Technical assistance and oversight are provided for all projects to ensure environmentally sound, high-quality projects free of waste, fraud, and abuse. Table 12 summarizes the programs administered by the CBP, and shows the amounts disbursed in state FY 2024 and FY 2025.

Table 12. Summary of Improvement and Construction Costs for New Mexico Water, Wastewater, and Solid Waste Facilities

Program	Description	Funds Disbursed in FY 2024	Funds Disbursed in FY 2025
State Appropriations Program	State Legislature capital outlay appropriated for the construction of community water supply, wastewater facility, and solid waste facility projects.	$ 58,741,195	$ 38,476,741
Clean Water State Revolving Fund (CWSRF) Program	Revolving loan fund to provide a source of low-cost financing for a wide range of wastewater or storm drainage projects that protect surface and groundwater quality and public health. Funds may also be used for nonpoint source water pollution control projects, such as solid waste projects and septic tank installations	$ 23,705,717	$ 26,676,073
Rural Infrastructure Program	Revolving loan fund to provide financial assistance to local authorities for the planning, design, and construction or modification of water supply, wastewater, and solid waste facilities.	$ 1,979,066	$ 2,585,946
	Water-Related Projects TOTAL	**$ 84,425,978**	**$ 67,738,760**



City of Roswell Flood Emergency Sewer Line Repairs CWSRF 150 ($1.04 million)



City of Anthony South Anthony Arroyo Flood Control Project: CWSRF 067 ($676,115), OSG 001 ($323,520), and OSG 003 ($576,001)

Benefits of these expenditures can be seen directly and indirectly throughout communities in New Mexico. The state's water quality programs, including expenditures for pollutant-reducing infrastructure, result in prevention of water quality degradation from point and NPS sources of pollution, protection of aquatic life and habitat in receiving streams, reduction of pollutant loads that could have financial and public health

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impacts in areas where surface water is a source of drinking water, increased public awareness regarding the need for water quality protection, and sustainable resource management practices.

The NMED DWB and New Mexico Finance Authority (NMFA) administer the Drinking Water State Revolving Loan Fund (DWSRLF), which provides low-cost loans to eligible public drinking water systems. Representative projects include repair and replacement of failing distribution lines, water treatment upgrades to maintain compliance with the SDWA, and the construction and rehabilitation of wells to ensure an adequate water supply.

C. Investing in Water Quality Management Programs

Protecting the nation's water from pollution and contaminants relies on cooperation between EPA, states, and tribes; however, over the past two decades state and federal funding for water quality programs has not been sustainable to a point where some basic services may no longer be supported (see tables and figure below). Counter to this fact, a 2021 Gallup poll[29] found that, "of six environmental problems facing the U.S., Americans remain most worried about those that affect water quality. Majorities express 'a great deal' of worry about the pollution of both drinking water (56%) and rivers, lakes and reservoirs (53%)." Similarly, in the State of New Mexico, a bipartisan team conducted a phone poll among 506 likely 2022 voters to evaluate support for a General Obligation Bond for land and water conservation.[30] The survey showed a large and diverse majority supported a general obligation bond in support of land and water conservation, reflecting voters' commitment to the land, water, and heritage of this state. In an open-ended question, voters were asked to state in their own words why they would support the bond. In response, 44 percent volunteered "protect water," which was by far the leading response. In addition, 87 percent noted "conserving and protecting sources of drinking water" as very important and 81 percent noted "protecting water quality in local streams and rivers" as very important. In fact, the top six responses included activities related to surface water quality management programs! Clearly, water quality protection is on the minds and in the hearts of New Mexicans.

State water quality programs play an integral role in building water infrastructure including providing technical assistance to small, rural, disadvantaged, and underserved communities; marketing investments in green infrastructure; processing loan and grant applications; prioritizing projects to meet the greatest need; conducting environmental reviews; performing engineering analyses; certifying and funding projects; monitoring compliance; and providing fiscal accountability. Core Water Quality Protection program components include: water quality standards development and implementation; monitoring and assessment of surface water quality; point source regulation, NPDES permit certification, and compliance inspections; spill response and enforcement; TMDL and watershed-based planning; nonpoint source pollution control, dredge and fill permit certification; watershed restoration, education and outreach; wetlands mapping and condition assessment; water infrastructure and grants management; and groundwater protection.

The Clean Water Act (CWA) section (§) 106 Water Pollution Control Grant Program gives states the flexibility to conduct essential pollution prevention, inspection, monitoring, permitting, and compliance activities as EPA's co-regulator. The CWA § 319 Non-Point Source Pollution Control Program buttresses the quality of our

[29] Water Pollution Remains Top Environmental Concern in U.S.

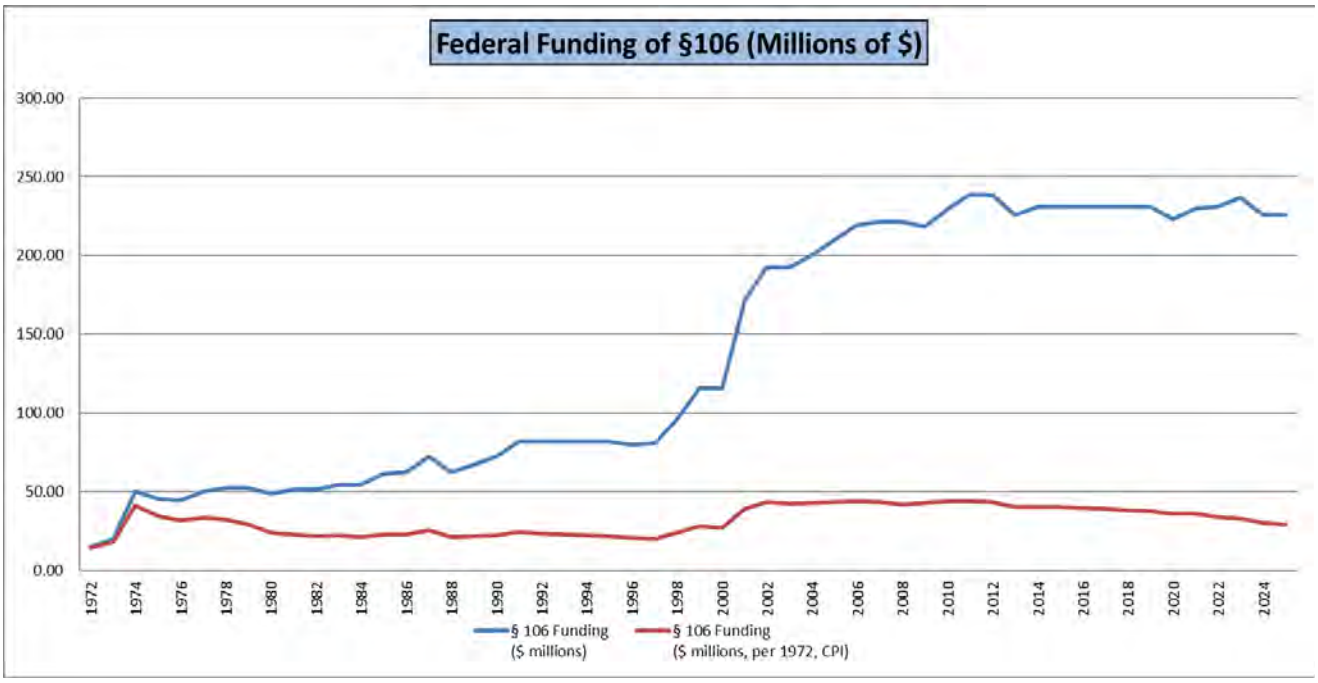
[30] Telephone survey conducted October 19-25, 2021. This survey carries a margin of error of +/- 4.38 percent at a 95 percent confidence interval.

national waterbodies in the face of ever-increasing and evolving non-point source contributions to pollutant loadings. Wetlands Program Development grants assist states, tribes, and local governments in building programs to protect, manage and restore wetlands, and support projects relating to the prevention, reduction, and elimination of water pollution. Table 13 provides a break-down of the Federal fiscal year appropriations for National Water Program federal grants (dollars in millions) over the past several years.

Table 13. Funding Levels for Federal Categorical Grant Programs Nationally (Dollars in Millions)

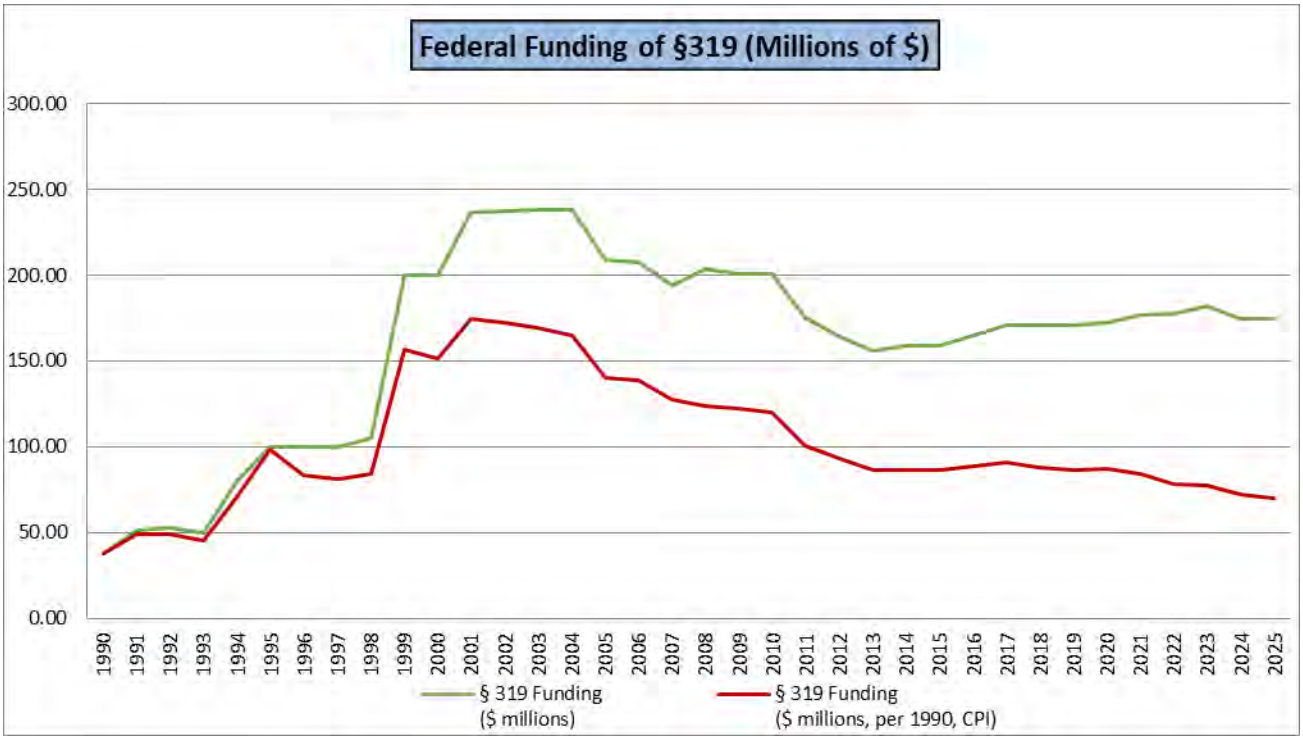
National Program	FFY 2020 P.L. 116-94 (H.R. 1865)	FFY 2021 Omnibus P.L. 116-260	FFY 2022 (H.R. 2471)	FFY 2023 Omnibus P.L.	FFY 2024 (H.R. 4366)	FFY 2025 (H.R. 8998; S. 4802; Continuing Resolution)
Pollution Control (CWA §106)	$223.29	$230	$231	$237	$225.7	$225.7
Nonpoint Source (CWA §319)	$172.35	$177	$178	$182	$174.5	$174.5
Wetlands Program Development	$14.18	$14.19	$48	$14	$14	$14
TOTALS	**$409.82**	**$421.19**	**$457.00**	**$433.00**	**$414.20**	**$414.20**

Figures 14 and 15 demonstrate that although some federal funding did increase in the 1990s, funding levels adjusted for inflation have generally declined starting around 2002.



NOTE: CPI = consumer price index (to adjust for inflation)

Figure 14. Federal CWA Section 106 Funding Over Time



NOTE: CPI = consumer price index (to adjust for inflation)

Figure 15. Federal CWA Section 319 Funding Over Time

Funding challenges remain a perennial challenge and can exist on the state level as well. Any cuts or sweeps of state funding result in placing more burden on federal grants to fill those gaps, but federal assistance grants do not increase to meet these demands. Table 14 provides a break-down of State of New Mexico expenditures for surface water quality programs by funding source and fiscal year.

Table 14. Expenditures for Surface Water Quality Protection Programs in NM (Dollars in Millions)

State Fiscal Year	Federal Grant Expenditures	State Expenditures	Total Expenditures
2011	$3,537,500	$2,091,900	$5,629,400
2013	$3,808,761	$1,967,221	$5,775,981
2015	$3,226,845	$1,147,312	$4,374,157
2017	$3,086,395	$2,001,255	$5,087,650
2020	$3,661,537	$1,113,509	$4,775,046
2021	$3,773,760	$1,637,655	$5,411,414
2023	$3,809,176	$3,558,300[1]	$7,371,476
AVERAGE (2011-2023)	**$3,557,711**	**$1,931,022[2]**	**$5,488,732**
2025	$3,006,836	$10,102,408[3]	$13,109,244

1 The change in FY 2023 state expenditures compared to prior years is due to increased financial support for river restoration through the SWQB River Stewardship Program and ONRT restoration projects.
2 State expenditures for FY 2025 were not included in the average calculation.

3 The dramatic change in FY 2025 state expenditures compared to prior years is due to increased legislative appropriations for the SWQB River Stewardship Program and the State Permitting Program development, and implementation of the Land of Enchantment Legacy Fund.

With over 61% of assessed surface waters in New Mexico listed as impaired because they fail to meet water quality standards coupled with increasing demands for clean water and stressors related to climate change, there is an abundant need for surface water quality program investments in our state. Moreover, if water quality overall is poorer because water quality management programs are limited due to funding restrictions, then treatment of the water to achieve beneficial uses (such as safe drinking water, livestock watering, irrigation, wildlife habitat, and recreation) will cost more.

Sustainable and recurring funding to protect New Mexico's surface water resources is essential to meet New Mexico's hydrologic complexity and ensure that New Mexico has the programmatic capacity to meet increasing demands for clean water. Not only do increases in state and federal investment help reverse declines in water quality, but they also create jobs, stimulate economic growth, support tourism, provide recreational opportunities, benefit private-sector development, and improve public health with a clean environment.



Blue skies over Heron Reservoir in the Chama watershed

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VII. Public Participation and Agency Coordination

A. CWA §303(d)/§305(b) Integrated Report Public Participation

All individuals living and working in the New Mexico affect water quality and are affected by water quality. Public awareness and involvement are therefore crucial to the successful implementation of water quality programs. New Mexico's water quality programs promote a multi-stakeholder, consensus-based public participation process. By actively pursuing and considering public input and involvement, New Mexico can more effectively effect changes in behavior and actively improve decision-making concerning water quality with greater public acceptance and support for those decisions.

There are several opportunities for public and other stakeholder participation in the development of the IR, from data collection through impairment determination and reporting. The public participation requirements of specific water quality programs are specified in 40 C.F.R. § 25.4 and described in the WQMP/CPP (NMWQCC 2020). At a minimum, the public participation process for New Mexico's water quality programs consists of the following:

- Providing the public with the information and assistance necessary for meaningful involvement;
- Providing a central location for reports, studies, plans, and other documents;
- Maintaining a list of affected or interested parties and stakeholders; and
- Notifying stakeholders in a timely fashion prior to consideration of major decisions (generally at least 30 days).

What is a Stakeholder?
For the purposes of this report, a stakeholder is defined as any organization, governmental entity, or individual that has a vested interest in or may be impacted by a state directed approach to environmental regulation, pollution prevention, or energy conservation.

Prior to development of the draft Integrated List for each listing cycle, the public has an opportunity to provide comments to the listing methodology (i.e., CALM) through a public participation process that includes a minimum 30-day public comment period with public notification as defined in the WQMP/CPP (NMWQCC 2020). The SWQB typically announces the "call for outside data" at the same time. The CALM used to develop the draft 2026-2028 Integrated List (Appendix A) was released for public comment in this manner. A draft of this listing methodology was opened for a 30-day public comment period from June 16, 2025 – July 18, 2025. Comments received were reviewed, considered, and incorporated as deemed appropriate.

The public participation associated with the development of the Integrated List (Appendix A) included notifying stakeholders of a 45-day public comment period December 8, 2025 – January 22, 2026. Public notices were posted to NMED's website and sent through the GovDelivery e-mail delivery service. The SWQB responded in writing to each comment received in Appendix C of the IR. These responses were forwarded to all commenters prior to the March 10th, 2026 NMWQCC meeting, at which the Integrated List was presented and approved.

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B. Coordination with state and federal government agencies

Successful surface water quality management and protection is dependent on cooperative interaction between the federal, state, local, and tribal levels of government, and between the public and private sectors. The NPS Management Program relies on established resource protection programs, federal and state NPS pollution prevention programs, and activities of other land management and resource protection agencies to address NPS pollution. In addition to NMED, numerous other New Mexico and federal agencies conduct activities that utilize, protect, and restore surface water quality, including but not limited to:

- Office of the State Engineer (NMOSE);
- Interstate Stream Commission (NMISC);
- Office of Natural Resources Trustee (ONRT);
- Department of Wildlife (NMDW);
- Department of Agriculture (NMDA);
- Energy, Minerals, and Natural Resources Department (EMNRD);
- Department of Health (NMDOH);
- Outdoor Recreation Division (NMORD);
- Department of Homeland Security and Emergency Management (NMDHSEM);
- Federal Emergency Management Agency (FEMA);
- U.S. Army Corps of Engineers (USACE);
- U.S. Bureau of Land Management (USBLM);
- U.S. Bureau of Reclamation (USBOR);
- U.S. Forest Service (USFS);
- Natural Resources Conservation Service (NRCS); and
- Soil and Water Conservation Districts (SWCDs).



2025 Trout Fire burn scar at head of Allie Canyon, Gila National Forest, July 2025.

These and other agencies work with stakeholders during development and implementation of water quality management activities. Coordination is crucial and focuses on informing and including stakeholders on water quality management related activities, seeking input, soliciting data and information, and working collaboratively to implement solutions to water quality problems and concerns. For example, regular coordination between the USFS and the SWQB continues to be an integral part of the NPS Management Program and has facilitated cooperation on many successful NPS pollution reduction projects. As previously mentioned in the state certification section (Chapter IV, section C), the NPS Management Program also coordinates with the USACE to implement the State's CWA section 401 certification responsibilities for CWA section 404 permits.

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Trout Fire revegetation response two months post-aerial seeding, Gila National Forest, September 2025.

In 2025, the NMED SWQB worked with closely with the U.S. Forest Service Gila National Forest, New Mexico Department of Wildlife, and Freeport McMoRan to support post-fire watershed recovery from impacts of the Trout Fire. This multi-agency, cross-jurisdictional collaboration resulted in a quick response to provide aerial seeding for severely burned areas of the Trout Fire prior to monsoon season to help substantially mitigate downstream impacts to water quality and riparian and aquatic habitat.

Additionally, numerous stakeholder focus groups have been developed for specific issues and meet on a regular basis to coordinate efforts. The NMED participates in many of these groups to address a variety of water quality issues. Examples of such groups include the New Mexico Municipal League Environmental Quality Association, the New Mexico Forest and Watershed Health Coordinating Group, and individual watershed groups' regular meetings.

C. Fish Consumption Advisory Program



Fish consumption advisory sampling in collaboration with New Mexico Department of Wildlife on Bluewater Lake, May 2022

Fish are a lean, low-calorie source of protein, and can be an important part of a balanced diet. However, some fish may contain contaminants that, when consumed in certain quantities, could pose health risks. When contaminant levels may be unsafe, consumption advisories recommend that people limit or avoid eating certain species of fish caught in certain places. NMDOH, NMDoW, and the SWQB work together to implement New Mexico's Fish Consumption Advisory Program. The EPA considers fish or shellfish consumption advisories and supporting fish tissue data to be existing and readily available data that demonstrate non-attainment of CWA goals stating that waters should be "fishable" [CWA §101(a), EPA 2005]. The basis for fish consumption impairments each listing cycle is the most recent, available fish consumption advisories at the time the IR drafted, except in cases where there is a consumption advisory due to mercury, but available fish tissue data indicate New Mexico's methylmercury criterion of 0.3 mg/kg in fish tissue is not exceeded[31].

[31] https://www.env.nm.gov/surface-water-quality/calm/

The Program's monitoring strategy involves screening a select number of sites for chemical contamination where sport, subsistence, or commercial fishing is conducted. Site selection is prioritized based on SWQB and NMDOW sampling resources, and targets areas where it is known that many fish are harvested or where there are known or suspected contamination issues. This screening helps identify those waters where fish tissue contamination may pose unacceptable health risks to human consumers. Fish consumption advisories relay fish tissue contamination information to the public. These advisories are only guidelines and do not constitute legal restrictions that prevent people from eating contaminated fish from New Mexico lakes and streams. Fish consumption advisories pertain to consumption of fish only. There are no known contaminant-related health risks associated with activities such as camping, swimming, boating, or handling fish in areas where there are fish consumption advisories. Currently, advisories have been issued for mercury, DDT and PCBs in fish tissue at several reservoirs, lakes and rivers (NMED, et al. 2025).



Pike caught at Lake Farmington for fish tissue analysis



Catch, Release or Eat?

Licenses and General Information: **1-888-248-6866**

Southeast Consumption Advisory[2] *(How to Use the Chart, page 36)*

WATER	SPECIES	SIZE							CONTAMINANT
		<15"	15–17"	18–21"	22–25"	26–30"	30"+		
Brantley Lake	Channel catfish		4	4	2	½			Mercury, DDT
	Largemouth bass		2	2					Mercury, DDT
	White bass	½	½	1					Mercury, DDT
Carlsbad Municipal Lakes (Lake Carlsbad and Bataan Lake)	Carp			4	4				DDT, PCBs
	Channel catfish			1	2				DDT
	Spotted bass			NA*					Mercury, DDT, PCBs
Pecos River (North boundary of Brantley WMA to US 70)	Carp		NA*	NA*					DDT, PCBs
	Channel catfish		NA*	NA*	NA*				DDT, PCBs
Pecos River (Brantley WMA)	Channel catfish		4	4	2	½			Mercury, DDT
	Largemouth bass		2	2					Mercury, DDT
	White bass	½	½	1					Mercury, DDT
Pecos River (Texas border to Carlsbad Municipal Lakes)	Carp		NA*	NA*	NA*				DDT, PCBs
	Channel catfish			4					DDT, PCBs
Santa Rosa Lake	Bluegill	3							Mercury
	Channel catfish		3	2	2	2	1		Mercury
	Crappie	3	3						Mercury
	Smallmouth bass		2						Mercury
	Walleye			3	1	1	1		Mercury
Sumner Lake	Carp		4	4	4				Mercury
	Channel catfish	4	3	3	2				Mercury
	Flathead catfish		4		2				Mercury
	Walleye			3	1	½	0		Mercury
	White bass	3	2						Mercury

NA * No Advisory

[2] Warm water bag and possession limits are listed on page 37-42.

Information on fish consumption advisories in the NMDOW 2025-2026 NM Fishing Rules and Info booklet

New Mexico fish consumption advisories are available online at: https://www.env.nm.gov/surface-water-quality/fish-consumption-advisories/

D. Additional SWQB Outreach Efforts

The SWQB supports or implements several outreach activities throughout the year, including but not limited to:

- Publishing the *Clearing the Waters* newsletter[32];
- Developing and maintaining the extensive SWQB web site[33];
- Coordinating and/or participating in both on-the-ground restoration workshops and technical forums for sharing implementation techniques and research;
- Participating in education opportunities, such as Science, Technology, Engineering, and Math (STEM) events, for local schools and statewide events to promote water quality education;
- Soliciting stakeholder input of important guiding SWQB documents, such as revisions to the Nonpoint Source Management Plan[34]; and
- Presenting on a variety of surface water quality issues and programs at various state and national workshops and meetings.



McCrystal Creek restoration project, a collaboration between the Carson National Forest, Trout Unlimited, Cimarron Watershed Alliance and the Philmont Scout Ranch (2025)



SWQB staff presented at the Rio Rancho Children's Water Festival in 2024 and 2025

[32] https://www.env.nm.gov/surface-water-quality/newsletters/
[33] https://www.env.nm.gov/surface-water-quality/
[34] https://www.env.nm.gov/surface-water-quality/nps-plan/

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Appendices

Appendix A—Integrated List
Appendix B—Designated Use Attainment, Sources, and Causes Tables
Appendix C—Response to Comments

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2026-2028
State of New Mexico
Clean Water Act
§303(d)/§305(b)
Integrated Report

Appendix A

Integrated List

Prepared by:
New Mexico Environment Department
Surface Water Quality Bureau
1190 St. Francis Drive
Santa Fe, New Mexico 87505
https://www.env.nm.gov/surface-water-quality/

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NEW MEXICO ENVIRONMENT DEPARTMENT SURFACE WATER QUALITY BUREAU
2026-2028 STATE OF NEW MEXICO
CLEAN WATER ACT SECTIONS 303(D)/ 305(B)
INTEGRATED LIST OF ASSESSED SURFACE WATERS

PREFACE

I. Format and Organization of Integrated List and Assessment Rationale

In 2013, the New Mexico Environment Department (NMED) merged the Surface Water Quality Bureau's (SWQB) in-house water quality database with NMED's *Assessment Database* to create the *Surface water QUality Information Database* (SQUID) so both data and assessment conclusions could be housed in one database. The SWQB took this opportunity to also re-design and streamline the *CWA §303(d)/§305(b) Integrated Report: Appendix A List of Assessed Waters* (Integrated List) format for ease of review, to incorporate additional information, and to reduce the total number of pages. The associated Assessment Rationale (previously called the *Record of Decision* or ROD) that houses additional details on any water body or Assessment Unit (AU) that is currently or has ever been documented as "impaired" is also now housed in SQUID. If there was no action on a specific impaired AU during a particular listing cycle, there may be no entry for that cycle.

The Rio Chama and Sacramento Mountain watersheds were surveyed by the SWQB in 2023-2024 and hence are the primary focus of revised or retained assessment conclusions in the Integrated List for this 2026-2028 cycle. Other datasets that were either submitted or acquired this cycle and assessed as reported include:

- 2022-2024 data for various stream reaches in and around Taos and Red River collected by Sentinels-Rio de Taos and submitted by Amigos Bravos.
- 2022-2025 San Juan River Basin Multijurisdictional monitoring program data stored in SQUID
- 2022-2025 SWQB Effectiveness monitoring data downloaded from SQUID
- 2022-2025 EPA and USGS data from various locations throughout New Mexico downloaded from the Water Quality Portal[1],
- Chevron Questa Mine data from Red River submitted by Ground Water Quality Bureau,
- 2020-2025 Los Alamos National Laboratory Data submitted by N3B, and
- Silver City Watershed Keepers data (submitted)

The assessment conclusions in non-focus areas based on data from previous rotational surveys and previously submitted outside data are typically carried over to the next list until more current data are available to assess unless, for example, a water quality standard change or a significant listing methodology change necessitates a re-assessment.

All AUs are assigned IR categories as described in New Mexico's Comprehensive Assessment and Listing

[1] https://www.waterqualitydata.us/

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Methodology (CALM)[2]. AUs noted with IR Category 5A, 5B, or 5C on the Integrated List in Appendix A comprise New Mexico's official CWA §303(d) List of Impaired Waters. A listing of Category 5-only waters is included in the beginning of Appendix A. To see details on a specific AU, refer to the particular AU entry on the full Integrated List in Appendix A and associated assessment rationale entry.

Starting with the 2018-2020 IR, each AU entry on the Integrated List also contains a "PARAMETER IR CATEGORY." This useful field provides additional planning information regarding each particular cause of impairment or AU cause pair. For example, a parameter IR category of 5B lets the user know that a review of the applicable water quality standard is needed prior to scheduling TMDL development. New Mexico has several temperature listings that fall under the 5B parameter IR category.

New Mexico's Integrated List also includes an estimated year in the "TMDL DATE" field for all parameter IR category 5A AU cause pairs. The estimated year is generally based on the SWQB's rotational monitoring schedule, prioritization strategy in the SWQB's long-term vision document (NMED/SWQB 2015), and severity of the impairment. The "TMDL DATE", as well as the projected "MONITORING SCHEDULE" year, is ultimately dependent upon personnel and financial resources which can change on an annual basis. If a TMDL has already been developed for the noted cause of impairment, the EPA TMDL approval date (MM/DD/YYYY) is reported in the TMDL date field.

II. Useful Definitions

INTEGRATED LIST FIELD HEADINGS AND CODES --

ASSESSED	This field generally notes the last Integrated Reporting Cycle when data for this particular watershed were assessed and reported.
Assessment Unit (AU)	Descriptive name of a specific waterbody (stream reach or lake). Limited to 60 characters.
ATTAINMENT	The use attainment status for the associated USE (Fully Supporting, Not Supporting, Not Assessed)
ASSESSED	This field generally notes the last Integrated Report Cycle when data for this particular watershed were assessed and reported.
AU ID	An internal database code that is unique to an assessment unit, and is not intended to provide any specific information to the reader of the list.
CAUSE(S)	Parameters and/or constituents that are causing non-attainment of the associated USE
DO	The amount of dissolved oxygen in the water; usually reported in mg/L.

[2] https://www.env.nm.gov/surface-water-quality/calm/

E. coli	Abbreviation of *Escherichia coli*. These bacteria found in the environment, foods, and intestines of people and animals.
FIRST LISTED	This field generally notes the first Integrated Reporting Cycle when the associated impairment was noted.
FS	Full Support or Fully Supporting
HUC	8-digit Hydrologic Unit Codes (HUC) that identify various watersheds. The US Geologic Survey defines these codes and associated watershed names.
IR	Integrated Report
IR Category (AU)	Overall water quality standards attainment category for each assessment unit as determined by combining individual designated use support decisions. The unique IR categories for New Mexico are described as follows as follows:
IR Category (Parameter)	Water quality standards attainment category for each listed cause of impairment. The unique IR categories for New Mexico are described as follows as follows:
IR Category 1	Attaining the water quality standards for all designated and existing uses. AUs are listed in this category if there are data and information that meet all requirements of the assessment and listing methodology and support a determination that the water quality criteria are attained.
IR Category 2	Attaining some of the designated or existing uses based on numeric and narrative parameters that were tested, and no reliable monitored data is available to determine if the remaining uses are attained or threatened. AUs are listed in this category if there are data and information that meet requirements of the assessment and listing methodology to support a determination that some, but not all, uses are attained based on numeric and narrative water quality criteria that were tested. Attainment status of the remaining uses is unknown because there is no reliable monitored data with which to make a determination.
IR Category 3/3A	Insufficient of no reliable monitored data and/or information to determine if any designated or existing use is attained. No data available -- AUs are listed in this subcategory when there are no available data to assess. These are considered high priority for follow up monitoring.
IR Category 3/3B	Insufficient monitored data and/or information to determine if any designated or existing use is attained. Limited data (n = 1 to 3) available, no exceedances -- AUs are listed in this subcategory when there are no exceedances of any applicable criteria in the limited data set. Their

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	priority for follow up monitoring depends on the parameter and concentration (for example, measurements near the criteria would increase the priority for additional sampling).
IR Category 3/3C	Insufficient monitored data and/or information to determine if any designated or existing use is attained. Limited data (n = 1 to 3) available, exceedance(s) -- AUs are listed in this subcategory when there are exceedances of one or more applicable criteria in the limited data set. These are considered high priority for follow up monitoring.
IR Category 4A	Impaired for one or more designated uses but does not require development of a TMDL because TMDL has been completed. AUs are listed in this subcategory once all TMDL(s) have been developed and approved by USEPA that, when implemented, are expected to result in full attainment of the standard. Where more than one pollutant is associated with the impairment of an AU, the AU remains in IR Category 5A (see below) until all TMDLs for each pollutant have been completed and approved by USEPA.
IR Category 4B	Impaired for one or more designated uses but does not require development of a TMDL because other pollution control requirements are reasonably expected to result in attainment of the water quality standard in the near future. Consistent with the regulation under 40 CFR 130.7(b)(i), (ii), and (iii), AUs are listed in this subcategory where other pollution control requirements required by local, state, or federal authority are stringent enough to implement any water quality standard (WQS) applicable to such waters.
IR Category 4C	Impaired for one or more designated uses but does not require development of a TMDL because impairment is not caused by a pollutant. AUs are listed in this subcategory if a pollutant does not cause the impairment. For example, USEPA considers flow alteration to be “pollution” vs. a “pollutant.”
IR Category 5/5A	Impaired for one or more designated or existing uses and a TMDL is underway or scheduled. AUs are listed in this category if the AU is impaired for one or more designated uses by a pollutant. Where more than one pollutant is associated with the impairment of a single AU, the AU remains in IR Category 5A until TMDLs for all pollutants have been completed and approved by USEPA.
IR Category 5/5B	Impaired for one or more designated or existing uses and a review of the water quality standard will be conducted. AUs are listed in this category when it is possible that water quality standards are not being met because one or more current designated use is inappropriate. After a review of the water quality standard is conducted, a Use Attainability Analysis (UAA) will be developed and submitted to USEPA for consideration, or the AU will be moved to IR Category 5A and a TMDL will

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	be scheduled.
IR Category 5/5C	Impaired for one or more designated or existing uses and Additional data will be collected before a TMDL is scheduled. AUs are listed in this category if there is not enough data to determine the pollutant of concern or there is not adequate data to develop a TMDL. For example, AUs with biological impairment will be listed in this category until further research can determine the particular pollutant(s) of concern. When the pollutant(s) are determined, the AU will be moved to IR Category 5A and a TMDL will be scheduled. If it is determined that the current designated uses are inappropriate, it will be moved to IR Category 5B and a UAA will be developed. If it is determined that "pollution" is causing the impairment (vs. a "pollutant"), the AU will be moved to IR Category 4C.
IR Category 5-R (previous 5-ALT)	Advance restoration approach is in progress or under development. EPA created this optional subcategory as an organizing tool to clearly articulate which impaired waterbodies have or will have alternative approaches to attain WQS (EPA 2015). The advance restoration approach needs to clearly demonstrate how the WQS will be achieved. The description of the advance restoration approach and the waters to which it applies will be included during public review of the draft Integrated Report, so that the public has an opportunity to view the proposed advance restoration approaches. Additional details on what must be included in the description are found in EPA's listing guidance (EPA 2015).
LOCATION DESCRIPTION	The name of the 8-digit Hydrologic Unit Code (HUC) watershed of the assessment unit as defined by the United States Geologic Survey.
MONITORING SCHEDULE	These proposed dates are primarily based on SWQB's most recent rotational watershed monitoring schedule. This date, as well as the "TMDL DATE" date, is ultimately dependent upon personnel, financial, and laboratory resources which change on an annual basis.
NS	Non-Support or Not Supporting
PCBs	Polychlorinated biphenyls; highly-persistent compounds that are fat soluble and accumulate in the food chain
PROBABLE SOURCE(S)	This field contains either 1) "Source Unknown" if no TMDLs have yet been developed, or 2) the Probable Sources noted in associated TMDLs that may be contributing to the noted impairment(s).
SC	specific conductance
SIZE	Streams and/or rivers = Miles, Lakes and/or playas = Acres, per EPA's current reporting requirement

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TMDL	Total Maximum Daily Load
TMDL DATE	This field contains either 1) future estimated ("est.") TMDL development year primarily based on SWQB's rotational monitoring schedule, prioritization schedule, date since last intensively surveyed, upcoming permit renewals, etc.; 2) the EPA TMDL approval date (MM/DD/YYYY) if a TMDL has already been developed and approved; or 3) nothing if the water quality standard is under review (IR Category 5B) or additional data are needed (IR Category 5C). This date, as well as the "Monitoring Schedule" date, is ultimately dependent upon personnel and financial resources which change on an annual basis.
TR	total recoverable
USE	Any designated uses specified in the State of New Mexico Standards for Interstate and Intrastate Surface Waters (20.6.4 NMAC) that apply to the given assessment unit and/or any documented existing uses that apply to the given assessment unit. Uses that exist but are not officially designated in the NMAC are also listed here with a note in "Assessment Unit Comments."
WATER TYPE	This field contains the EPA-defined water type that most accurately describes the "normal" hydrologic character of the assessment unit to the best of SWQB's knowledge given available flow data, GIS layers, and Hydrology Protocol survey results (where available).
WQS REF	Applicable Water Quality Standard segment as described in the most recent State of New Mexico Standards for Interstate and Intrastate Surface Waters (20.6.4 NMAC) that applies to the given assessment unit.

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III. Abbreviations in Assessment Unit Names

The size of the assessment unit name is limited to 60 characters by the database. Therefore, the following abbreviations were used when necessary:

abv	=	above
AZ	=	Arizona
blw	=	below
bnd	=	boundary
BNSF	=	Burlington Northern – Santa Fe
Campgrd	=	Campground
Ck	=	Creek
Cny	=	Canyon
CO	=	Colorado
CR	=	County Road
confl	=	confluence
Div	=	Diversion
E	=	East
Fk	=	Fork
FS	=	Forest Service (usually road)
hdwtrs	=	headwaters
HWY	=	Highway
I	=	Interstate highway
Irr	=	irrigation
LANL	=	Los Alamos National Laboratory
M	=	Middle
mi	=	mile
N	=	North
NM	=	New Mexico
nr	=	near
NWR	=	National Wildlife Refuge
OK	=	Oklahoma
prt	=	Portion (i.e., reaches)
R	=	River or Rio
rd	=	road
RR	=	railroad
Rsvr	=	Reservoir
S	=	South
SFNF	=	Santa Fe National Forest
Spr	=	Spring
SR	=	state road
trib	=	tributary
TX	=	Texas
VCNP	=	Valles Caldera National Preserve
xing	=	crossing
USFS	=	United States Forest Service
W	=	West
WWTP	=	waste water treatment plant

NMED Exhibit 30

(Table of Contents of Category 5 waters on the following Integrated §303(d)/§305(b) List)

HUC: 11040001 - Cimarron Headwaters

- Dry Cimarron River (Oak Creek to headwaters)

HUC: 11080001 - Canadian Headwaters

- Canadian River (Chicorica Creek to CO border)
- Maxwell Lake 13
- Stubblefield Lake
- VanBremmer Creek (HWY 64 to headwaters)
- Vermejo River (Rail Canyon to York Canyon)
- York Canyon (Vermejo R to Left Fork York Canyon)

HUC: 11080002 - Cimarron

- Cimarron River (Canadian River to Ponil Creek)
- Cimarron River (State hwy 21 in Cimarron to Turkey Creek)
- Cimarron River (Turkey Creek to Eagle Nest Lake)
- Greenwood Creek (Middle Ponil Creek to headwaters)
- North Ponil Creek (Seally Canyon to headwaters)
- Ponil Creek (Cimarron River to HWY 64)
- Ponil Creek (HWY 64 to confl of North and South Ponil)
- Rayado Creek (Cimarron River to Miami Lake Diversion)
- Saladon Creek (Cieneguilla Creek to headwaters
- Springer Lake

HUC: 11080003 - Upper Canadian

- Charette Lake (Lower)
- Charette Lake (Upper)
- Wheaton Creek (Manuelas Creek to headwaters)

HUC: 11080004 - Mora

- Coyote Creek (Black Lake to headwaters)
- Rito Cebolla (Mora River to Rito Morphy)
- Sapello River (Mora River to Arroyo Jara)

HUC: 11080005 - Conchas

- Conchas Reservoir

HUC: 11080006 - Upper Canadian-Ute Reservoir

- Canadian River (TX border to Ute Reservoir)
- Ute Reservoir

HUC: 11080008 - Revuelto

- Revuelto Creek (Canadian River to headwaters)

HUC: 11100101 - Upper Beaver

- Clayton Lake

HUC: 13010005 - Conejos

- Beaver Creek (Rio de los Pinos to headwaters)
- Canada Tio Grande (Rio San Antonio to headwaters)
- Rio Nutritas (Rio San Antonio to headwaters)
- Rio San Antonio (CO border to Montoya Canyon)
- Rio San Antonio (Montoya Canyon to headwaters)
- Rio de los Pinos (New Mexico reaches)

HUC: 13020101 - Upper Rio Grande

- Acid Canyon (Pueblo Canyon to headwaters)
- Arroyo del Palacio (Rio Grande to headwaters)
- Bitter Creek (Red River to headwaters)
- Cabresto Creek (Red River to headwaters)
- Cabresto Lake
- Canada Agua (Arroyo La Mina to headwaters)
- Comanche Creek (Costilla Creek to headwaters)
- Costilla Creek (CO border to Diversion abv Costilla)
- Costilla Creek (Comanche Creek to Costilla Dam)
- DP Canyon (100m dwnstm grade ctrl to 400m upstm grade ctrl)
- DP Canyon (400m upstream of grade control to upper LANL bnd)
- DP Canyon (Los Alamos Canyon to 100m dwnstm of grade ctrl)
- Embudo Creek (Canada de Ojo Sarco to Picuris Pueblo bnd)
- Embudo Creek (Rio Grande to Canada de Ojo Sarco)
- Goose Lake
- Graduation Canyon (Pueblo Canyon to headwaters)
- Holman Creek (Comanche Creek to headwaters)
- Los Alamos Canyon (DP Canyon to upper LANL bnd)
- Los Alamos Canyon (NM-4 to DP Canyon)
- Pioneer Creek (Red River to headwaters)
- Pojoaque River (San Ildefonso bnd to Pojoaque bnd)
- Pueblo Canyon (Acid Canyon to headwaters)
- Pueblo Canyon (Los Alamos Canyon to Los Alamos WWTP)

- Pueblo Canyon (Los Alamos WWTP to Acid Canyon)
- Red River (Placer Creek to East Fork Red River)
- Rio Fernando de Taos (R Pueblo d Taos to USFS bnd at canyon)
- Rio Fernando de Taos (Tienditas Creek to headwaters)
- Rio Grande (Embudo Creek to Rio Pueblo de Taos)
- Rio Grande (Ohkay Owingeh bnd to Embudo Creek)
- Rio Grande (Rio Pueblo de Taos to Red River)
- Rio Grande (Santa Clara Pueblo bnd to Ohkay Owingeh bnd)
- Rio Grande del Rancho (R Pueblo de Taos to Rito de la Olla)
- Rio Pueblo (Picuris Pueblo bnd to headwaters)
- Rio Pueblo de Taos (R Grande del Rancho to Taos Pueblo bnd)
- Rio Pueblo de Taos (Rio Grande to Arroyo del Alamo)
- Santa Cruz River (Santa Clara Pueblo bnd to Santa Cruz Dam)
- South Fork Acid Canyon (Acid Canyon to headwaters)
- Vidal Creek (Comanche Creek to headwaters)
- Walnut Canyon (Pueblo Canyon to headwaters)

HUC: 13020102 - Rio Chama

- Abiquiu Creek subwatershed
- Abiquiu Reservoir
- Arroyo Seco subwatershed
- Arroyo del Toro (Rio Chama to headwaters)
- Canada de Horno (Rio Chama to headwaters)
- Canjilon Ck (Perennial portions Abiquiu Rsrv to headwaters)
- Canones Creek (Abiquiu Rsvr to Chihuahuenos Ck)
- Canones Creek (Rio Chama to Jicarilla Apache bnd)
- Canones Creek subwatershed
- Chihuahuenos Creek (Canones Creek to headwaters)
- Daggett Canyon-Canones Creek subwatershed
- El Rito Creek (Perennial reaches HWY 554 to headwaters)
- El Rito Creek (Perennial reaches Rio Chama to HWY 554)
- Heron Reservoir
- Hopewell Lake
- Laguna del Campo
- Lower El Rito subwatershed
- Lower Rio Gallina subwatershed
- Lower Rio Nutrias subwatershed
- Lower Rio Puerco de Chama subwatershed
- Lower Rio Vallecitos subwatershed

- Lower Rio del Oso subwatershed
- Middle Rio Vallecitos subwatershed
- Polvadera Creek subwatershed
- Rio Brazos subwatershed
- Rio Chama (Abiquiu Creek to Abiquiu Dam)
- Rio Chama (Abiquiu Reservoir to El Vado Reservoir)
- Rio Chama (El Vado Reservoir to Rito de Tierra Amarilla)
- Rio Chama (Little Willow Creek to CO border)
- Rio Chama (Ohkay Owingeh to Abiquiu Creek)
- Rio Ojo Caliente (Arroyo El Rito to Rio Vallecitos)
- Rio Puerco de Chama (Abiquiu Reservoir to HWY 96)
- Rio Tusas subwatershed
- Rio del Oso (Rio Chama to La Canada del Almagre)
- Rito Encino (Rio Puerco de Chama to headwaters)
- Rito de Tierra Amarilla (HWY 64 to headwaters)
- Rito de Tierra Amarilla (Rio Chama to HWY 64)
- Rito de Tierra Amarilla subwatershed
- Upper El Rito subwatershed
- Upper Rio Chama subwatershed
- Upper Rio Gallina subwatershed
- Upper Rio Nutrias subwatershed
- Upper Rio Ojo Caliente subwatershed
- Upper Rio Vallecitos subwatershed

HUC: 13020201 - Rio Grande-Santa Fe

- Ancho Canyon (Above Ancho Springs to North Fork Ancho)
- Ancho Canyon (North Fork to headwaters)
- Ancho Canyon (Rio Grande to Ancho Springs)
- Arroyo de la Delfe (Above Kieling Spring to headwaters)
- Arroyo de la Delfe (Pajarito Canyon to Kieling Spring)
- Canada del Buey (within LANL)
- Canon de Valle (LANL gage E256 to Burning Ground Spr)
- Canon de Valle (below LANL gage E256)
- Canon de Valle (upper LANL bnd to headwaters)
- Chaquehui Canyon (within LANL)
- Mortandad Canyon (within LANL)
- North Fork Ancho Canyon (Ancho Canyon to headwaters)
- Pajarito Canyon (0.5 mi ds of and to Arroyo de la Delfe)
- Pajarito Canyon (Above Homestead Spring to LANL boundary)

- Pajarito Canyon (Lower LANL bnd to Twomile Canyon)
- Pajarito Canyon (Starmers Gulch to Homestead Spring)
- Pajarito Canyon (Twomile Cyn to 0.5 mi ds of A. de La Delfe)
- Pajarito Canyon (upper LANL bnd to headwaters)
- Potrillo Canyon (above Water Canyon)
- Rio Grande (Cochiti Reservoir to San Ildefonso bnd)
- Rio Grande (non-pueblo Angostura Div to Cochiti Rsrv)
- Rito de los Frijoles (Rio Grande to headwaters)
- Sandia Canyon (Bedrock Road to NPDES outfall 001)
- Sandia Canyon (Sigma Canyon to Bedrock Road)
- Sandia Canyon (within LANL below Sigma Canyon)
- Santa Fe River (Cienega Creek to Santa Fe WWTP)
- Santa Fe River (Cochiti Pueblo bnd to Cienega Creek)
- Santa Fe River (Guadalupe St to Nichols Rsvr)
- Santa Fe River (Nichols Reservoir to headwaters)
- Santa Fe River (Santa Fe WWTP to Guadalupe St)
- Ten Site Canyon (Mortandad Canyon to headwaters)
- Three Mile Canyon (Pajarito Canyon to headwaters)
- Twomile Canyon (Pajarito to Upper Twomile canyon)
- Twomile Canyon (Upper Twomile canyon to headwaters)
- Water Canyon (upper LANL bnd to headwaters)
- Water Canyon (within LANL below Area-A Cyn)

HUC: 13020202 - Jemez

- American Creek (Rio de las Palomas to headwaters)
- Calaveras Creek (Rio Cebolla to headwaters)
- Clear Creek (Rio de las Vacas to San Gregorio Lake)
- Clear Creek (San Gregorio Lake to headwaters)
- East Fork Jemez (San Antonio Creek to VCNP bnd)
- East Fork Jemez (VCNP to headwaters)
- Fenton Lake
- Jaramillo Creek (East Fork Jemez to headwaters)
- Jemez River (Jemez Pueblo bnd to Rio Guadalupe)
- Jemez River (Soda Dam nr Jemez Springs to East Fork)
- La Jara Creek (East Fork Jemez to headwaters)
- Redondo Creek (Sulphur Creek to headwaters)
- Rio Cebolla (Fenton Lake to headwaters)
- Rio Cebolla (Rio de las Vacas to Fenton Lake)
- Rio de las Vacas (Clear Creek to headwaters)

- Rito Penas Negras (Rio de las Vacas to headwaters)
- Rito de las Palomas (Rio de las Vacas to headwaters)
- Rito de los Indios (San Antonio Creek to headwaters)
- San Antonio Creek (East Fork Jemez to VCNP bnd)
- San Antonio Creek (VCNP bnd to headwaters)
- San Gregorio Lake
- Sulphur Creek (Redondo Creek to headwaters)
- Sulphur Creek (San Antonio Creek to Redondo Creek)
- Vallecito Ck (Perennial Prt Div abv Ponderosa to headwaters)

HUC: 13020203 - Rio Grande-Albuquerque

- Rio Grande (Arroyo de las Canas to Rio Puerco)
- Rio Grande (Isleta Pueblo boundary to Tijeras Arroyo)
- Rio Grande (Rio Puerco to Isleta Pueblo bnd)
- Rio Grande (San Marcial at USGS gage to Arroyo de las Canas)
- Rio Grande (Tijeras Arroyo to Alameda Bridge)
- Rio Grande (non-pueblo Alameda Bridge to HWY 550 Bridge)

HUC: 13020204 - Rio Puerco

- Nacimiento Ck (Perennial prt HWY 126 to Clear Creek)
- Rio Puerco (Arroyo Chijuilla to northern bnd Cuba)
- Rio Puerco (Perennial prt northern bnd Cuba to headwaters)
- Rio Puerco (non-pueblo Arroyo Chico to Arroyo Chijuilla)
- Rio Puerco (non-pueblo Rio Grande to Arroyo Chico)

HUC: 13020207 - Rio San Jose

- Arroyo del Valle (Laguna Pueblo bnd to headwaters)
- Bluewater Lake
- Rio Paguate (Laguna Pueblo bnd to headwaters)

HUC: 13020209 - Rio Salado

- Rio Salado (Rio Grande to Alamo Navajo bnd)

HUC: 13020211 - Elephant Butte Reservoir

- Elephant Butte Reservoir
- Rio Grande (Elephant Butte Rsvr to San Marcial at USGS)

HUC: 13030101 - Caballo

- Caballo Reservoir
- Las Animas Ck (perennial prt Animas Gulch to headwaters)

- Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)

HUC: 13030202 - Mimbres

- Bear Canyon Reservoir
- Gallinas Creek (Little Gallinas Creek to headwaters)
- Mimbres R (Perennial reaches Allie Canyon to Cooney Cny)
- Pinos Altos Creek (San Vicente Creek to headwaters)
- San Vicente Creek (Perennial prt Maudes Cny to Silva Creek)

HUC: 13050003 - Tularosa Valley

- Dog Canyon Creek (perennial portions)
- Fresnal Canyon (La Luz Creek to Salado Canyon)
- Fresnal Canyon subwatershed
- Karr Canyon (Fresnal Canyon to headwaters)
- Lake Holloman
- Nogal Creek (Tularosa Creek to Mescalero Apache bnd)
- Three Rivers subwatershed
- Upper Rio Tularosa subwatershed

HUC: 13050004 - Salt Basin

- Sacramento R (Perennial prt Scott Able Canyon to headwaters)

HUC: 13060001 - Pecos Headwaters

- Carpenter Creek subwatershed
- Cow Creek (Bull Creek to headwaters)
- Cow Creek (Pecos River to Bull Creek)
- El Porvenir Creek (Gallinas River to SFNF bnd)
- El Porvenir Creek (SFNF bnd to Hollinger Canyon)
- Elk Creek (Cow Creek to headwater)
- Gallinas River (Aguilar Creek to USGS Gage 08382000)
- Gallinas River (Las Vegas Diversion to USFS bnd)
- Gallinas River (Pecos Arroyo to Las Vegas Diversion)
- Gallinas River (Pecos River to Aguilar Creek)
- Gallinas River (USFS bnd to headwaters)
- Gallinas River (USGS Gage 08382000 to Pecos Arroyo)
- Glorieta Ck (Perennial prt Pecos R to Glorieta Camps WWTP)
- Holy Ghost and Doctor Creek subwatershed
- Indian Creek subwatershed
- McAllister Lake

- Panchuela Creek subwatershed
- Pecos River (Alamitos Canyon to Jack's Creek)
- Pecos River (Canon de Manzanita to Alamitos Canyon)
- Pecos River (Cow Creek to Canon de Manzanita)
- Pecos River (Jack's Creek to headwaters)
- Pecos River (Santa Rosa Reservoir to Tecolote Creek)
- Pecos River (Sumner Reservoir to Santa Rosa Reservoir)
- Pecos River (Tecolote Creek to Villanueva State Park)
- Pecos River (Villanueva State Park to Cow Creek)
- Santa Rosa Reservoir
- Storrie Lake
- Sumner Reservoir
- Tecolote Creek (I-25 to Blue Creek)
- Tres Lagunas (Northeast)
- Willow Creek subwatershed

HUC: 13060003 - Upper Pecos

- Pecos River (Salt Creek to Crockett Draw)

HUC: 13060007 - Upper Pecos-Long Arroyo

- Figure Eight Lake
- Lake Van
- Pecos River (Eagle Creek to Rio Felix)
- Pecos River (Rio Felix to Rio Hondo)
- Pecos River (Rio Penasco to Eagle Creek)

HUC: 13060008 - Rio Hondo

- Alto Lake
- Berrendo Creek (Rio Hondo to Middle Berrendo Creek)
- Carrizo subwatershed
- Grindstone Canyon Reservoir
- Lower Bonito subwatershed
- Lower Eagle Creek subwatershed
- Lower Rio Ruidoso subwatershed
- Middle Rio Ruidoso subwatershed
- North Spring River (Rio Hondo to headwaters)
- Rio Bonito (Perennial prt NM 48 near Angus to headwaters)
- Rio Hondo subwatershed
- S. Fork Eagle Creek (Eagle Creek to Mescalero Apache bnd)

- Upper Bonito subwatershed
- Upper Rio Ruidoso subwatershed

HUC: 13060010 - Rio Penasco

- Agua Chiquita (perennial portions McEwan Cny to headwaters)

HUC: 13060011 - Upper Pecos-Black

- Black River (Perennial prt Pecos River to Blue Spring)
- Brantley Reservoir
- Lower Tansil Lake/Lake Carlsbad (Carlsbad Municipal Lake)
- Pecos River (Avalon Reservoir to Brantley Reservoir)
- Pecos River (Black River to Six Mile Dam)
- Pecos River (Six Mile Dam to Lower Tansil Lake)
- Pecos River (TX border to Black River)
- Six Mile Dam Lake

HUC: 13070002 - Delaware

- Delaware River (Pecos River to TX border)

HUC: 13070007 - Landreth-Monument Draws

- Jal Lake

HUC: 14080101 - Upper San Juan

- Gallegos Canyon (San Juan River to Navajo bnd)
- Los Pinos River (Navajo Reservoir to CO border)
- Navajo Reservoir
- Navajo River (Jicarilla Apache Nation to CO border)
- San Juan River (Animas River to Canon Largo)
- San Juan River (NM reach upstream of Navajo Reservoir)

HUC: 14080104 - Animas

- Animas River (Estes Arroyo to So. Ute Indian Tribe bnd)
- Animas River (San Juan River to Estes Arroyo)
- Lake Farmington (Beeline Reservoir)

HUC: 14080105 - Middle San Juan

- La Plata R (McDermott Arroyo to So. Ute Indian Tribe bnd)
- La Plata River (San Juan River to McDermott Arroyo)
- San Juan River (Navajo bnd at Hogback to Animas River)
- Shumway Arroyo (San Juan River to Ute Mtn Ute bnd)

- Stevens Arroyo (Perennial prts San Juan R to headwaters)

HUC: 15020003 - Carrizo Wash

- Quemado Lake

HUC: 15020004 - Zuni

- McGaffey Lake
- Ramah Reservoir

HUC: 15020006 - Upper Puerco

- Puerco River (non-tribal AZ border to Gallup WWTP)

HUC: 15040001 - Upper Gila

- Beaver Creek (Perennial prt Taylor Ck to Mule Canyon)
- Diamond Ck (Perennial prt East Fork Gila R to Bailey Ck)
- East Fork Gila River (Gila River to Taylor Creek)
- Gila River (Mogollon Ck to East and West Forks of Gila R)
- Gilita Creek (Perennial reaches abv Willow Creek)
- Iron Creek (Middle Fork Gila R to headwaters)
- Lake Roberts
- Little Creek (West Fork Gila River to headwaters)
- Middle Fork Gila River (Canyon Creek to Gilita Creek)
- Middle Fork Gila River (West Fork Gila R to Canyon Creek)
- Snow Lake
- Taylor Creek (Perennial reaches Beaver Creek to headwaters)
- Turkey Creek (Gila River to headwaters)
- West Fork Gila R (Gila River to Middle Fork)
- West Fork Gila R (Middle Fork to headwaters)

HUC: 15040002 - Upper Gila-Mangas

- Bear Creek (Gila River nr Cliff to headwaters)
- Bill Evans Lake
- Gila River (AZ border to Red Rock)
- Gila River (Mangas Creek to Mogollon Creek)
- Gila River (Red Rock to Mangas Creek)

HUC: 15040004 - San Francisco

- Centerfire Creek (San Francisco R to headwaters)
- Mineral Creek (Silver Creek to South Fork Mineral)
- Negrito Creek (Tularosa River to confl of N and S forks)

- North Fork Negrito Creek (Negrito Creek to headwaters)
- San Francisco River (Box Canyon to Whitewater Creek)
- San Francisco River (Centerfire Creek to AZ border)
- San Francisco River (NM 12 at Reserve to Centerfire Creek)
- San Francisco River (Pueblo Ck to Willow Springs Cyn)
- San Francisco River (Whitewater Ck to Pueblo Ck)
- San Francisco River (Willow Springs Cyn to NM 12 at Reserve)
- Stone Creek (San Francisco R to AZ border)
- Trout Creek (Perennial prt San Francisco R to headwaters)
- Tularosa River (Apache Creek to headwaters)
- Tularosa River (San Francisco R to Apache Creek)

Uses Abbreviation Key	
ColdWAL	Coldwater Aquatic Life
CoolWAL	Coolwater Aquatic Life
DWS	Domestic Water Supply
FC	Fish Culture
HQColdWAL	High Quality Coldwater Aquatic Life
IW Storage	Industrial Water Storage
IW Supply	Industrial Water Supply
IRR	Irrigation
IRR Storage	Irrigation Storage
LAL	Limited Aquatic Life
LW	Livestock Watering
MCWAL	Marginal Coldwater Aquatic Life
MWWAL	Marginal Warmwater Aquatic Life
MWS	Municipal Water Storage
PC	Primary Contact
PWS	Public Water Supply
SC	Secondary Contact
WWAL	Warmwater Aquatic Life
WH	Wildlife Habitat

HUC: 11040001 Cimarron Headwaters

Archuleta Creek (Dry Cimarron R to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11040001 Cimarron Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2701_50	20.6.4.99	STREAM, PERENNIAL	9.92 MILES	2008	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Carrizozo Creek (OK bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11040001 Cimarron Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2701_40	20.6.4.702	STREAM, PERENNIAL	45.57 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU may not be entirely perennial.

Dry Cimarron R (Perennial prt Jesus Canyon to Long Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11040001 Cimarron Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2701_04	20.6.4.702	STREAM, PERENNIAL	20.67 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU is likely interrupted.

Dry Cimarron R (Perennial prt OK bnd to Sloan Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11040001 Cimarron Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2701_00	20.6.4.702	STREAM, PERENNIAL	9.4 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Temperature	2004	9/17/2019	4A
		Nutrients	2018	9/17/2019	4A
IRR	Not Supporting	Sulfate	2008	6/2/2009	4A
		Total Dissolved Solids (TDS)	2004	6/2/2009	4A
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDLs were prepared for sulfate and TDS (2009); and temperature and nutrients (2019). This AU is likely interrupted.					

Dry Cimarron R (Perennial prt Sloan Creek to Jesus Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11040001 Cimarron Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2701_03	20.6.4.702	STREAM, PERENNIAL	27.31 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Nutrients	2018	9/17/2019	4A
		Temperature	2004	9/17/2019	4A
IRR	Not Supporting	Total Dissolved Solids (TDS)	2004	6/2/2009	4A
		Sulfate	2008	6/2/2009	4A
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDLs were prepared for sulfate and TDS (2009); and temperature and nutrients (2019). This AU is likely interrupted.					

Dry Cimarron River (Long Canyon to Oak Ck)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11040001 Cimarron Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2701_02	20.6.4.702	STREAM, PERENNIAL	25.21 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Nutrients	2018	9/17/2019	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDLs were prepared for E. coli and TDS (2009), and nutrients (2019).					

Dry Cimarron River (Oak Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 11040001 Cimarron Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2701_01	20.6.4.701	STREAM, PERENNIAL	27.91 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients Temperature	2018 2018	9/17/2019	4A 5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: A TMDL was prepared for nutrients (2019). Coldwater may not be an existing or attainable use - WQS review needed.					

Long Canyon (Perennial reaches abv Dry Cimarron)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11040001 Cimarron Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2701_20	20.6.4.702	STREAM, PERENNIAL	8.56 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Selenium, Total Recoverable	2008	6/2/2009	4A
		Temperature	2004	9/17/2019	4A
		Nutrients	2018	9/17/2019	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2008	6/2/2009	4A
WH	Not Supporting	Selenium, Total Recoverable	2008	6/2/2009	4A

AU Comment: TMDLs were prepared for E. coli,selenium (2009) and temperature, plant nutrients (2019). The upper portion of the AU above the springs do not appear to be perennial.

Oak Creek (Perennial prt Dry Cimarron to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4C	HUC: 11040001 Cimarron Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2701_10	20.6.4.701	STREAM, PERENNIAL	12.46 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Flow Regime Modification	2018		4C
		Nutrients	2008	6/2/2009	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2008	6/2/2009	4A
WH	Fully Supporting				

AU Comment: TMDLs were prepared for E. coli and nutrients (2009).

HUC: 11080001 Canadian Headwaters

Bracket Canyon (Vermejo R to hdwtrs)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_008	20.6.4.97	STREAM, EPHEMERAL	3.1 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013.
Chevron Mining Inc. Ancho Mine permit NM0030180

Caliente Canyon (Vermejo River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_151	20.6.4.309	STREAM, PERENNIAL	20.26 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Specific Conductance	2004	9/21/2007	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: HQCWAL is probably not attainable due to low flows and high background temperatures. TMDL for specific conductance.

Canadian River (Chicorica Creek to CO border)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_201	20.6.4.305	STREAM, PERENNIAL	61.03 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Temperature	2018		5/5B
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Canadian River (Cimarron River to Chicorica Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_200	20.6.4.305	STREAM, PERENNIAL	39.3 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Nutrients	2008	11/21/2011	4A
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: A TMDL was prepared for nutrients (2011).					

Chicorica Creek (Canadian River to East Fork Chicorica)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_250	20.6.4.305	STREAM, PERENNIAL	21.34 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Chicorica Creek (East Fork Chicorica to Lake Maloya)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_251	20.6.4.305	STREAM, PERENNIAL	2.2 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Doggett Creek (Raton Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_255	20.6.4.318	STREAM, PERENNIAL	3.38 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Not Supporting	E. coli	2008	9/17/2019	4A
WWAL	Not Supporting	Nutrients	1998	9/17/2019	4A
WH	Fully Supporting				
AU Comment: TMDLs were prepared for E.coli and plant nutrients (2019). Discharger-specific nutrient temporary standard for the City of Raton WWTP (NM0020273) approved in 2020.					

East Fork Chicorica Creek (Chicorica Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_252	20.6.4.98	STREAM, INTERMITTENT	8.17 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Not Supporting	E. coli	2018	9/17/2019	4A
WH	Fully Supporting				
AU Comment: This AU went dry during the 2015-2016 survey. No diversions visible from aerial photograph. TMDL prepared for E.coli (2019).					

Gachupin Canyon (Vermejo R to w trib nr mine outfall)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_010	20.6.4.97	STREAM, EPHEMERAL	3.96 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013. Chevron Mining Inc. Ancho Mine permit NM0030180					

Hunter Creek (Throttle Reservoir to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_040	20.6.4.98	STREAM, INTERMITTENT	6.84 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Laguna Madre			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_058	20.6.4.99	LAKE, PLAYA	117.39 ACRES	2010	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Lake Alice (Sugarite Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.B_10	20.6.4.311	RESERVOIR	6.41 ACRES	2014	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Not Assessed				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

Lake Maloya			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.B_20	20.6.4.312	RESERVOIR	115.54 ACRES	2026	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients	2018	8/20/2024	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: TMDL (Canadian and URG Lakes) for plant nutrients EPA approved August 2024. Samples collected by the New Mexico Environment Department (NMED) in late 2025 showed the presence of harmful algae and toxins, and a HABs Health Watch was issued for this lake.
Harmful algae blooms, or HABs, occur when certain types of algae grow excessively in water, posing potential health risks to people and animals. HABs can appear blue, bright green, brown or red and may resemble scum or floating grass clippings on the water's surface. These blooms can produce toxins that are harmful to humans and animals. For more information visit: https://www.env.nm.gov/surface-water-quality/habs/

Leandro Creek (Vermejo River to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_161	20.6.4.309	STREAM, PERENNIAL	12.32 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006). Rio Grande Cutthroat Trout restoration in 1998 by NMG&F.					

Maxwell Lake 12			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_080	20.6.4.99	LAKE, PLAYA	63.06 ACRES	2014	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Maxwell Lake 13			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_081	20.6.4.99	LAKE, PLAYA	171.19 ACRES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	pH	2018		5/5C
WH	Fully Supporting				
AU Comment: None.					

Maxwell Lake 14			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_082	20.6.4.99	LAKE, PLAYA	85 ACRES	2014	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Raton Creek (Chicorica Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_253	20.6.4.305	STREAM, PERENNIAL	18.7 MILES	2020	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Nutrients	1998	9/17/2019	4A
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: TMDLs prepared for E.coli and plant nutrients (2019). Discharger-specific nutrient temporary standard for the City of Raton WWTP (NM0020273) approved in 2020.

Stubblefield Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_101	20.6.4.99	LAKE, PLAYA	367.69 ACRES	2010	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	Mercury - Fish Consumption Advisory	2004		5/5C
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Tinaja Creek (Canadian R to West Fork Tinaja Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_018	20.6.4.98	STREAM, INTERMITTENT	6.34 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: Application of the SWQB Hydrology Protocol (survey date 6/9/09) indicate this assessment unit is intermittent (Hydrology Protocol score of 14.0 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol).					

Tinaja Creek (West Fork Tinaja Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_019	20.6.4.98	STREAM, INTERMITTENT	21.25 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Not Supporting	E. coli	2018	9/17/2019	4A
WH	Fully Supporting				
AU Comment: Application of the SWQB Hydrology Protocol (survey date 6/9/09) indicate this assessment unit is intermittent (Hydrology Protocol score of 14.0 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol). TMDL prepared for E.coli (2019).					

Una de Gato Creek (Chicorica Creek to HWY 64)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_254	20.6.4.305	STREAM, PERENNIAL	12.63 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Nutrients	2008	11/21/2011	4A
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: A TMDL was prepared for nutrients (2011).					

Una de Gato Creek (HWY 64 to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_030	20.6.4.305	STREAM, PERENNIAL	22.1 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Nutrients	2008	11/21/2011	4A
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: A TMDL was prepared for nutrients (2011).

Unnamed tributary (Bracket Cny to mine area)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_009	20.6.4.97	STREAM, EPHEMERAL	2.23 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013.
Chevron Mining Inc. Ancho Mine permit NM0030180

VanBremmer Creek (HWY 64 to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_140	20.6.4.309	STREAM, PERENNIAL	37.29 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2004		5/5B
		Turbidity	2004		5/5B
		Specific Conductance	2004		5/5B
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Vermejo River (Canadian River to Rail Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4C	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_210	20.6.4.305	STREAM, PERENNIAL	25.82 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Flow Regime Modification			4C
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Often extremely low or no flow due to diversion. Application of the SWQB Hydrology Protocol (survey date 6/9/2009) indicate this assessment unit should be perennial (Hydrology Protocol score of 30.0 but 0.3% no flow days at USGS gage 07203000 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol).

Vermejo River (Rail Canyon to York Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_220	20.6.4.309	STREAM, PERENNIAL	22.64 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature Turbidity	2006 2018	9/21/2007	4A 5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

Vermejo River (Rock Creek to North Fork Vermejo R)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_231	20.6.4.309	STREAM, PERENNIAL	10.21 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2006	9/21/2007	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Vermejo River (York Canyon to Rock Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_230	20.6.4.309	STREAM, PERENNIAL	11.58 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2006	9/21/2007	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

York Canyon (Vermejo R to Left Fork York Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 11080001 Canadian Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_153	20.6.4.309	STREAM, PERENNIAL	8.56 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Specific Conductance	2004	9/21/2007	4A
		Turbidity	2004		5/5B
		Dissolved oxygen	2018		5/5B
		Temperature	2018		5/5B
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: TMDL for specific conductance (2007).					

HUC: 11080002 Cimarron

American Creek (Cieneguilla Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5-R	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_066	20.6.4.309	STREAM, PERENNIAL	5.99 MILES	2020	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2018	4/15/2022	5-R
IRR	Fully Supporting				
LW	Not Assessed				
PC	Not Supporting	E. coli	2020	4/15/2022	5-R
WH	Fully Supporting				

AU Comment: American Creek ARP for aluminum and E.coli EPA accepted May 2022.

Bonito Creek (Rayado Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.1.A_20	20.6.4.309	STREAM, PERENNIAL	6.5 MILES	2000	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Cieneguilla Creek (Eagle Nest Lake to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_065	20.6.4.309	STREAM, PERENNIAL	18.87 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2008	9/3/2010	4A
		Turbidity	1998	5/19/2004	4A
		Sedimentation/Siltation	1998	5/19/2004	4A
		Nutrients	2008	9/3/2010	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2008	9/3/2010	4A
WH	Fully Supporting				
AU Comment: TMDLs were prepared/updated for turbidity, sedimentation/siltation, fecal coliform, and dissolved Al chronic (2004); and nutrients, e. coli, and temperature (2010). Dissolved Al TMDL removed 2017 because WQC no longer applicable.					

Cimarron River (Canadian River to Ponil Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.1.A_10	20.6.4.306	STREAM, PERENNIAL	29.39 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	Nutrients	2008	9/3/2010	4A
		Temperature	2018		5/5B
WH	Fully Supporting				
AU Comment: TMDL for chronic aluminum (assessed incorrectly -- aluminum was de-listed). TMDLs were prepared for nutrients in 2010.					

Cimarron River (Ponil Creek to Cimarron Village)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.1.A_11	20.6.4.306	STREAM, PERENNIAL	11.84 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	Nutrients	2008	9/3/2010	4A
WH	Fully Supporting				
AU Comment: TMDL for chronic aluminum (assessed incorrectly -- aluminum was de-listed). TMDLs were prepared for nutrients in 2010.					

Cimarron River (State hwy 21 in Cimarron to Turkey Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_040	20.6.4.309	STREAM, PERENNIAL	4.46 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature Turbidity	2008 2018	9/3/2010 2023 (est.)	4A 5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: TMDL for chronic dissolved aluminum. TMDLs for temperature and arsenic (2010).					

Cimarron River (Turkey Creek to Eagle Nest Lake)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_130	20.6.4.309	STREAM, PERENNIAL	19.63 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Nutrients	2008	9/3/2010	4A
		Temperature	2018	9/3/2010	4A
		Turbidity	2018	2023 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: ONRW (Special Designation Streams, 2024). De-list letter for total phosphorus. TMDLs for nutrients and arsenic (2010).					

Clear Creek (Cimarron River to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_131	20.6.4.309	STREAM, PERENNIAL	3.98 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Eagle Nest Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.B_00	20.6.4.315	RESERVOIR	1817.29 ACRES	2026	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Nutrients	2018	8/20/2024	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: TMDL (Canadian and URG Lakes) for plant nutrients EPA approved August 2024.
Samples collected by the New Mexico Environment Department (NMED) in late 2025 showed the presence of harmful algae and toxins, and a HABs Warning Advisory was issued for this lake.
Harmful algae blooms, or HABs, occur when certain types of algae grow excessively in water, posing potential health risks to people and animals. HABs can appear blue, bright green, brown or red and may resemble scum or floating grass clippings on the water's surface. These blooms can produce toxins that are harmful to humans and animals. For more information visit: https://www.env.nm.gov/surface-water-quality/habs/

Frolic Creek (Moreno Creek to Headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3B	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_062	20.6.4.309	STREAM, PERENNIAL	3.98 MILES	2024	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: See assessment rationale. Very small stream, but landowner states stream flows year-round; benthic macroinvertebrates are present.

Greenwood Creek (Middle Ponil Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_122	20.6.4.309	STREAM, PERENNIAL	5.28 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2018		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006).					

McCrystal Creek (North Ponil to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_112	20.6.4.309	STREAM, PERENNIAL	9.36 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Turbidity	2010	9/30/1999	4A
		Temperature	2000	11/8/2011	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006).					

Middle Ponil Creek (Greenwood Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_124	20.6.4.309	STREAM, PERENNIAL	11.8 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Turbidity	2018	9/27/2001	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006). TMDL for nutrients (2011).					

Middle Ponil Creek (South Ponil to Greenwood Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_121	20.6.4.309	STREAM, PERENNIAL	11.89 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2000	9/27/2001	4A
		Turbidity	2000	9/27/2001	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006). TMDL for temperature and turbidity (2001); de-list letter for total phosphorus.					

Monte Verde Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.B_40	20.6.4.99	LAKE, FRESHWATER	25.95 ACRES	2024	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: See assessment rationale.					

Moreno Creek (Eagle Nest Lake to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_060	20.6.4.309	STREAM, PERENNIAL	16.64 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2008	9/3/2010	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for turbidity and fecal coliform. TMDLs for temperature and plant nutrients (2010).					

North Ponil Creek (Seally Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_162	20.6.4.309	STREAM, PERENNIAL	8.52 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Supporting	Gross Alpha, Adjusted	2008		5/5C
		Radium	2008		5/5C
HQColdWAL	Not Supporting	Temperature	2008	11/8/2011	4A
		Turbidity	2010	9/30/1999	4A
		Aluminum, Total Recoverable	2020	2023 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006). TMDL for turbidity (1999, revised 2004) and temperature (2011).					

North Ponil Creek (South Ponil Creek to Seally Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_110	20.6.4.309	STREAM, PERENNIAL	17.84 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Turbidity	2004	5/19/2004	4A
		Temperature	2004	12/31/1999	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2008	9/3/2010	4A
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006). TMDL for temp, turbidity, SBD (sedimentation/siltation), and total phosphorus; de-list letter for total phosphorus. TMDL for E. coli (2010).					

Ponil Creek (Cimarron River to HWY 64)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_100	20.6.4.306	STREAM, PERENNIAL	11.19 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	Dissolved oxygen	2018		5/5C
WH	Fully Supporting				

AU Comment: TMDL for turbidity, temp, and Al chronic; de-list letter for total phosphorus. TMDL for e. coli (2010).

Ponil Creek (HWY 64 to confl of North and South Ponil)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5B	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_101	20.6.4.309	STREAM, PERENNIAL	7.54 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Specific Conductance	2018		5/5B
		Turbidity	1998	9/27/2001	4A
		Temperature	1998	9/27/2001	4A
		Nutrients	2008	9/3/2010	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2010	9/3/2010	4A
WH	Fully Supporting				

AU Comment: TMDL for turbidity, temp, and Al chronic; de-list letter for total phosphorus. De-listed for Al chronic in 2008. TMDLs for e. coli and plant nutrients (2010).

Rayado Creek (Cimarron River to Miami Lake Diversion)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_80	20.6.4.307	STREAM, PERENNIAL	21.68 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Nutrients	2008	9/3/2010	4A
		Sedimentation/Siltation	2004	2/16/2001	4A
PC	Not Supporting	E. coli	2018	2023 (est.)	5/5A
WWAL	Not Supporting	Sedimentation/Siltation	2004	2/16/2001	4A
WH	Fully Supporting				
AU Comment: TMDL for SBD (sedimentation/siltation). TMDLs for nutrients (2010).					

Rayado Creek (Miami Lake Diversion to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_051	20.6.4.309	STREAM, PERENNIAL	22.38 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2008	9/3/2010	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: TMDLs for temperature and e. coli (2010).					

Saladon Creek (Cieneguilla Creek to headwaters			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_069	20.6.4.309	STREAM, PERENNIAL	5.73 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2018		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2018		5/5B
WH	Fully Supporting				
AU Comment: None.					

Seally Canyon (North Ponil to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_111	20.6.4.309	STREAM, PERENNIAL	6.6 MILES	2008	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Valle Vidal, 2006)					

Shuree Pond (North)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.B_30	20.6.4.314	RESERVOIR	6.19 ACRES	2026	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Nutrients	2018	8/20/2024	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006). TMDL (Canadian and URG Lakes) for Nutrients EPA approved August 2024.					

Shuree Pond (South)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.B_31	20.6.4.133	RESERVOIR	3.47 ACRES	2008	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006).					

Sixmile Creek (Eagle Nest Lake to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_064	20.6.4.309	STREAM, PERENNIAL	5.32 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2008	9/3/2010	4A
		Turbidity	1998	5/19/2004	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2008	9/3/2010	4A
WH	Fully Supporting				
AU Comment: TMDL for turbidity and fecal coliform. TMDLs for temperature, e. coli, and nutrients (2010).					

South Ponil Creek (Middle Ponil Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_123	20.6.4.309	STREAM, PERENNIAL	11.14 MILES	2014	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: Rio Grande Cutthroat Trout restoration in 2000 by NMG&F.					

South Ponil Creek (Ponil Creek to Middle Ponil Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_120	20.6.4.309	STREAM, PERENNIAL	5.91 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2008	9/3/2010	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: TMDL for temperature (2010).

Springer Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.1.B_10	20.6.4.317	RESERVOIR	329.44 ACRES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Mercury - Fish Consumption Advisory	2004		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable". Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Tolby Creek (Cimarron River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_132	20.6.4.309	STREAM, PERENNIAL	6.74 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Turkey Creek (Cimarron River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_129	20.6.4.309	STREAM, PERENNIAL	6.22 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Ute Creek (Perennial prt Cimarron River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_068	20.6.4.309	STREAM, PERENNIAL	8.65 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2008	9/3/2010	4A
WH	Fully Supporting				
AU Comment: TMDLs for arsenic, e. coli, and temperature (2010).					

West Agua Fria Creek (Cieneguilla Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080002 Cimarron	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_067	20.6.4.309	STREAM, PERENNIAL	5.91 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

HUC: 11080003 Upper Canadian

Canadian River (Conchas Reservoir to Mora River)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080003 Upper Canadian	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_000	20.6.4.305	RIVER	41.91 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: A TMDL was prepared for e. coli (2011).

Canadian River (Mora River to Cimarron River)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080003 Upper Canadian	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_100	20.6.4.305	RIVER	73.42 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Charette Lake (Lower)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 11080003 Upper Canadian	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.5_10	20.6.4.308	RESERVOIR	241.35 ACRES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	2018		5/5B
		Mercury - Fish Consumption Advisory	2004		5/5C
LW	Fully Supporting				
SC	Fully Supporting				
WWAL	Not Supporting	Mercury - Fish Consumption Advisory	2004		5/5C
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.
Samples collected by the New Mexico Environment Department (NMED) in late 2025 showed the presence of harmful algae and toxins, and a HABs Health Watch was issued for this lake.
Harmful algae blooms, or HABs, occur when certain types of algae grow excessively in water, posing potential health risks to people and animals. HABs can appear blue, bright green, brown or red and may resemble scum or floating grass clippings on the water's surface. These blooms can produce toxins that are harmful to humans and animals. For more information visit: https://www.env.nm.gov/surface-water-quality/habs/

Charette Lake (Upper)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 11080003 Upper Canadian	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.5_20	20.6.4.308	RESERVOIR	62.37 ACRES	2016	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Mercury - Fish Consumption Advisory	2016		5/5C
LW	Fully Supporting				
SC	Fully Supporting				
WWAL	Not Supporting	Mercury - Fish Consumption Advisory	2016		5/5C
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Manueles Creek (Ocate Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 11080003 Upper Canadian	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_090	20.6.4.309	STREAM, PERENNIAL	9.29 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Ocate Ck (Perennial prt Canadian R to Sweetwater Ck)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4C	HUC: 11080003 Upper Canadian	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_70	20.6.4.307	STREAM, PERENNIAL	22.95 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
MCWAL	Not Supporting	Flow Regime Modification	2018		4C
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Ocate Ck (Perennial prt Charette Lakes Div to Ocate Village)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4C	HUC: 11080003 Upper Canadian	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_72	20.6.4.307	STREAM, PERENNIAL	11.16 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
MCWAL	Not Supporting	Flow Regime Modification	2018		4C
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Ocate Ck (Perennial prt Sweetwater Ck to Charette Lakes Div)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4C	HUC: 11080003 Upper Canadian	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_71	20.6.4.307	STREAM, PERENNIAL	15.32 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
MCWAL	Not Supporting	Flow Regime Modification	2018		4C
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Ocate Creek (Ocate Village to Wheaton Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4C	HUC: 11080003 Upper Canadian	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_070	20.6.4.309	STREAM, PERENNIAL	5.1 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Supporting	Flow Regime Modification			4C
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Wagon Mound Salt Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 11080003 Upper Canadian	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_106	20.6.4.99	LAKE, PLAYA	178.38 ACRES	1998	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Wheaton Creek (Manuelas Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 11080003 Upper Canadian	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_091	20.6.4.309	STREAM, PERENNIAL	12.82 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2018		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

HUC: 11080004 Mora

Coyote Creek (Amola Ridge to Williams Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_023	20.6.4.309	STREAM, PERENNIAL	13.12 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: HQCWAL may not be attainable in this AU - WQS review needed. TMDL prepared for plant nutrients (2019).

Coyote Creek (Black Lake to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_021	20.6.4.309	STREAM, PERENNIAL	7.91 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2018	9/17/2019	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2018		5/5C
WH	Fully Supporting				

AU Comment: TMDLs were prepared for plant nutrients and temperature (2019).

Coyote Creek (Mora River to Amola Ridge)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_020	20.6.4.309	STREAM, PERENNIAL	13.06 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Specific Conductance	1998	9/21/2007	4A
		Temperature	1998	9/21/2007	4A
		Nutrients	2018	9/17/2019	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: HQCWAL may not be attainable in this AU - WQS review needed. TMDL prepared for plant nutrients (2019).					

Coyote Creek (Williams Canyon to Black Lake)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_022	20.6.4.309	STREAM, PERENNIAL	12.2 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Nutrients	2018	9/17/2019	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL prepared for plant nutrients (2019).					

Encantada (Enchanted) Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.B_10	20.6.4.313	LAKE, FRESHWATER	2.46 ACRES	2014	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

La Jara Creek (Coyote Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_54	20.6.4.98	STREAM, INTERMITTENT	16.52 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Little Coyote Creek (Black Lake to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_024	20.6.4.309	STREAM, PERENNIAL	7.14 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Nutrients	2004	9/21/2007	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Lujan Creek (Luna Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_002	20.6.4.309	STREAM, PERENNIAL	7.95 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Luna Creek (Mora River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_001	20.6.4.309	STREAM, PERENNIAL	8.52 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Maestas (Lost) Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.B_20	20.6.4.313	LAKE, FRESHWATER	2.93 ACRES	2014	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Maestas Creek (Manuelitas Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_81	20.6.4.307	STREAM, PERENNIAL	4.42 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Manuelitas Creek (Rito San Jose to Maestas Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_25	20.6.4.307	STREAM, PERENNIAL	3.72 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Manuelitas Creek (Sapello River to Rito San Jose)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_21	20.6.4.307	STREAM, PERENNIAL	15.52 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Middle Fork Lake of Rio de la Casa			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.B_10	20.6.4.313	LAKE, FRESHWATER	4.63 ACRES	2014	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Mora River (Canadian River to USGS gage east of Shoemaker)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_020	20.6.4.305	STREAM, PERENNIAL	41.63 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Mora River (HWY 434 to Luna Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_000	20.6.4.309	STREAM, PERENNIAL	19.01 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Specific Conductance	1998	9/21/2007	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for specific conductance (SC) and sedimentation/siltation (2007, updated 2011). SC impairment may be due to natural sources - WQS needed.					

Mora River (USGS gage east of Shoemaker to HWY 434)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_00	20.6.4.307	STREAM, PERENNIAL	56.33 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Nutrients	2004	7/22/2015	4A
PC	Not Supporting	E. coli	2018	9/17/2019	4A
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDLs for DO (2010) and plant nutrients (2015) and E.coli (2019).					

Morphy (Murphy) Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.B_30	20.6.4.99	RESERVOIR	25.29 ACRES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

North Fork Lake of Rio de la Casa			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.B_20	20.6.4.313	LAKE, FRESHWATER	3.43 ACRES	2014	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Pacheco Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_093	20.6.4.313	LAKE, FRESHWATER	1.65 ACRES	2014	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Rio la Casa (Mora River to confl of North and South Forks)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_030	20.6.4.309	STREAM, PERENNIAL	5.96 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: Linework at the bottom of this AU was updated on 10/15/25 to reflect the correct flowline. NHD+ flowline was incorrect and followed a diversion instead of the streambed channel.					

Rito Cebolla (Mora River to Rito Morphy)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_40	20.6.4.307	STREAM, PERENNIAL	11.15 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Dissolved oxygen	2018		5/5B
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Rito Morphy (Rito Cebolla to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_42	20.6.4.307	STREAM, PERENNIAL	9.09 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: Dry during spring and summer 2002 sampling.					

Rito San Jose (Manuelitas Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_22	20.6.4.307	STREAM, PERENNIAL	9.39 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Rito de Gascon (Rito San Jose to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_24	20.6.4.307	STREAM, PERENNIAL	4.27 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Santiago Creek (Rito Cebolla to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4C	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_41	20.6.4.307	STREAM, PERENNIAL	10.43 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
MCWAL	Not Supporting	Flow Regime Modification	2018		4C
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Sapello River (Arroyo Jara to Manuelitas Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_23	20.6.4.307	STREAM, PERENNIAL	19.46 MILES	2022	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
MCWAL	Not Supporting	Sedimentation/Siltation	2006	9/21/2007	4A
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: Sedimentation TMDL prepared (2007). HQCWAL may not be attainable - WQS review needed					

Sapello River (Manuelitas Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_30	20.6.4.307	STREAM, PERENNIAL	17.99 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Sapello River (Mora River to Arroyo Jara)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5B	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_20	20.6.4.307	STREAM, PERENNIAL	8.86 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Temperature	2018		5/5B
		Dissolved oxygen	2018		5/5C
		Sedimentation/Siltation	2006	9/21/2007	4A
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: Sedimentation TMDL prepared (2007).					

Sparks Creek (Maestas Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_26	20.6.4.307	STREAM, PERENNIAL	4.4 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

West Fork Luna Creek (Luna Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2306.A_003	20.6.4.98	STREAM, INTERMITTENT	2.98 MILES	2026	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

Wolf Creek (Mora River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4C	HUC: 11080004 Mora	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.3.A_10	20.6.4.307	STREAM, PERENNIAL	24.98 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
MCWAL	Not Supporting	Flow Regime Modification			4C
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: According to the manager of the Black Willow Ranch, Wolf Cr. used to be perennial, but then the well serving the facility at Valmora was deepened or otherwise improved and pumping has increased. Now Wolf Cr. goes dry.					

HUC: 11080005 Conchas

Conchas Reservoir			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 11080005 Conchas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2304_00	20.6.4.304	RESERVOIR	3411.26 ACRES	2026	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR Storage	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WWAL	Not Supporting	PCBS - Fish Consumption Advisory	2010		5/5C
		Mercury - Fish Consumption Advisory	2004		5/5C
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Conchas River (Conchas Reservoir to Salitre Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080005 Conchas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_010	20.6.4.305	STREAM, PERENNIAL	42.64 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Nutrients	2018	9/17/2019	4A
		Aluminum, Total Recoverable	2018	9/17/2019	4A
PC	Not Supporting	E. coli	2018	9/17/2019	4A
WH	Fully Supporting				

AU Comment: This entire AU may not be perennial. TMDLs were prepared for chronic aluminum, E.coli, and plant nutrients (2019).

Conchas River (Salitre Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080005 Conchas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2305.A_011	20.6.4.305	STREAM, PERENNIAL	44.51 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This entire AU may not be perennial.					

HUC: 11080006 Upper Canadian-Ute Reservoir

Canadian R basin inlet/oulets, drains, canals, conveyances			AU IR CATEGORY	LOCATION DESCRIPTION	
				HUC: 11080006 Upper Canadian-Ute Reservoir	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_02x	unclassified	DITCH OR CANAL	0 MILES		2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
AU Comment: This is a catch-all unassessed AU for lake inlets/outlets, irrigation canals, drains, and conveyances in the Canadian River basin.					

Canadian River (TX border to Ute Reservoir)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 11080006 Upper Canadian-Ute Reservoir	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2301_00	20.6.4.301	RIVER	41.88 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Temperature	2018		5/5B
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Canadian River (Ute Reservoir to Conchas Reservoir)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080006 Upper Canadian-Ute Reservoir	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2303_00	20.6.4.303	RIVER	59.42 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Temperature	2018	9/17/2019	4A
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Application of the SWQB Hydrology Protocol (survey date 7/1/09) indicate this assessment unit is perennial (Hydrology Protocol score of 20.0 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol). A TMDL was prepared for e. coli (2011) and temperature (2019).

No Name Creek (Pajarito Creek to Breen's Pond)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080006 Upper Canadian-Ute Reservoir	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2303_11	20.6.4.303	STREAM, PERENNIAL	1.19 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This AU receives effluent from Tucumcari WWTP via an underground pipe to Breen's Pond.

Pajarito Creek (Perennial prt Canadian R to Vigil Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 11080006 Upper Canadian-Ute Reservoir	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2303_10	20.6.4.303	STREAM, PERENNIAL	28.73 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Temperature	2018	9/17/2019	4A
		Nutrients	2008	11/21/2011	4A
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: TMDLs were prepared for e. coli and nutrients (2011) and temperature (2019).

Pajarito Creek (Vigil Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080006 Upper Canadian-Ute Reservoir	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2303_12	20.6.4.98	STREAM, INTERMITTENT	46.67 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Tucumcari Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080006 Upper Canadian-Ute Reservoir	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_103	20.6.4.99	LAKE, PLAYA	358.05 ACRES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Ute Reservoir			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 11080006 Upper Canadian-Ute Reservoir	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2302_00	20.6.4.302	RESERVOIR	5988.19 ACRES	2026	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WWAL	Not Supporting	Mercury - Fish Consumption Advisory	2004		5/5C
WH	Fully Supporting				
AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.					

HUC: 11080007 Ute

Chicosa Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 11080007 Ute	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_029	20.6.4.98	LAKE, PLAYA	19 ACRES	1998	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: Part of playa lake study. Data are old.

Palo Blanco Creek (Ute Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080007 Ute	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2303_22	20.6.4.98	STREAM, INTERMITTENT	27.34 MILES	2008	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Ute Creek (Perennial prt Bueyeros Ck to Garcia Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080007 Ute	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2303_20	20.6.4.303	STREAM, PERENNIAL	24.45 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Ute Creek (Perennial prt Garcia Creek to Palo Blanco Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 11080007 Ute	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2303_21	20.6.4.303	STREAM, PERENNIAL	28.02 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Ute Creek (Ute Reservoir to Bueyeros Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11080007 Ute	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2303_23	20.6.4.98	STREAM, INTERMITTENT	67.09 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

HUC: 11080008 Revuelto

Revuelto Creek (Canadian River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 11080008 Revuelto	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2301_10	20.6.4.98	STREAM, INTERMITTENT	44.42 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Not Supporting	Temperature	2018		5/5B
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Often dry except for irrigation return flows and stormwater runoff. Application of the SWQB Hydrology Protocol (survey date 7/1/09) indicate this assessment unit is intermittent - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol). A TMDL was prepared for boron (2011). There is an inconsistency between the marginal warmwater ALU description in 20.6.4.7.M(2) and the associated temperature criterion in 20.6.4.900.H(6) NMAC that needs review.

HUC: 11100101 Upper Beaver

Clayton Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 11100101 Upper Beaver	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_030	20.6.4.316	RESERVOIR	148.04 ACRES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Mercury - Fish Consumption Advisory	2004		5/5C
		Nutrients	2018	2023 (est.)	5/5A
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable". Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.
Samples collected by the New Mexico Environment Department (NMED) in late 2025 showed the presence of harmful algae and toxins, and a HABs Warning Advisory was issued for this lake.
Harmful algae blooms, or HABs, occur when certain types of algae grow excessively in water, posing potential health risks to people and animals. HABs can appear blue, bright green, brown or red and may resemble scum or floating grass clippings on the water's surface. These blooms can produce toxins that are harmful to humans and animals. For more information visit: https://www.env.nm.gov/surface-water-quality/habs/

Corrumpa Creek (OK border to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11100101 Upper Beaver	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2701_30	20.6.4.310	STREAM, PERENNIAL	90.77 MILES	2008	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Seneca Creek (Perennial reaches abv Clayton Lake)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 11100101 Upper Beaver	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_904	20.6.4.99	STREAM, PERENNIAL	12.6 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				

AU Comment: Application of the SWQB Hydrology Protocol (6/30/09 survey date) indicate this assessment unit is perennial (Hydrology Protocol score of 23.0 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol).

HUC: 11100103

Unassessed Tribal Waters			AU IR CATEGORY	LOCATION DESCRIPTION	
				HUC: 11100103	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-TRIBAL	Unassessed	RIVER	0 MILES		
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**

AU Comment: **THIS IS A CATCH-ALL AU FOR ANY WQ SAMPLING STATIONS THAT ARE ON TRIBAL LAND, AND HENCE EXCLUDED FROM IR.

HUC: 12050001 Yellow House Draw

Little Tule Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 12050001 Yellow House Draw	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_076	20.6.4.98	LAKE, PLAYA	8.39 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Tule Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 12050001 Yellow House Draw	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_104	20.6.4.98	LAKE, PLAYA	47.88 ACRES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: Part of playa lake study. Data are old.					

HUC: 12050002 Blackwater Draw

Dennis Chavez Lake (Curry)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 12050002 Blackwater Draw	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_036	20.6.4.99	LAKE, PLAYA	3.86 ACRES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Fully Supporting				
AU Comment: None.					

Green Acres Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 12050002 Blackwater Draw	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_046	20.6.4.99	LAKE, PLAYA	11.44 ACRES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Ingram Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 12050002 Blackwater Draw	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_050	20.6.4.99	LAKE, PLAYA	57.57 ACRES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Oasis Park Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 12050002 Blackwater Draw	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_092	20.6.4.99	RESERVOIR	1.32 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MCWAL	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: Marginal Coldwater and Warmwater Aquatic Life are existing uses. NM EMNRD issue a drinking water warning in 2017 due to high nitrates in drinking water (see http://www.emnrd.state.nm.us/SPD/oasisstatepark.html).					

Williams Playa (Curry)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 12050002 Blackwater Draw	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_108	20.6.4.98	LAKE, PLAYA	17.67 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

HUC: 12050005 Running Water Draw

Ned Houk Park Lakes			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 12050005 Running Water Draw	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_089	20.6.4.99	RESERVOIR	41.76 ACRES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MCWAL	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				

AU Comment: None.

HUC: 12080003 Monument-Seminole Draws

Chaparral (Park) Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 12080003 Monument-Seminole Draws	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_028	20.6.4.99	RESERVOIR	9.86 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MCWAL	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Green Meadows Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 12080003 Monument-Seminole Draws	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_047	20.6.4.99	RESERVOIR	11.49 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MCWAL	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

HUC: 12080004 Mustang Draw

Lane Salt Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 12080004 Mustang Draw	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_072	20.6.4.98	LAKE, PLAYA	393.76 ACRES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: Part of playa lake study. Data are old.					

Middle Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 12080004 Mustang Draw	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_084	20.6.4.98	LAKE, PLAYA	8.11 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

HUC: 13010002 Alamosa-Trinchera

Unassessed NPDES Outfalls			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13010002 Alamosa-Trinchera	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-NPDES	Unassessed	RIVER	0 MILES		
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: **THIS IS A CATCH ALL AU FOR NPDES RECEIVING WATERS THAT DONT HAVE SPECIFIC AUs ESTABLISHED. AS THESE SPECIFIC AUs ARE ESTABLISHED, NPDES OUTFALL STATIONS WILL ASSIGNED TO THOSE AUs ACCORDINGLY. THIS AU IS EXCLUDED from the IR Reports, and covers permits in various HUCs (had to choose just one to establish the AU).

HUC: 13010005 Conejos

Beaver Creek (Rio de los Pinos to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13010005 Conejos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_904	20.6.4.123	STREAM, PERENNIAL	8.13 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2020	2021 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013).

Canada Tio Grande (Rio San Antonio to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13010005 Conejos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_903	20.6.4.123	STREAM, PERENNIAL	10.58 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2012	2021 (est.)	5/5A
		Dissolved oxygen	2020	2021 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2020	2021 (est.)	5/5A
WH	Fully Supporting				
AU Comment: ONRW (Special Designation Streams, 2024).					

Laguna Larga			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13010005 Conejos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_057	20.6.4.99	RESERVOIR	35.53 ACRES	2004	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: Coldwater Aquatic Life is an existing use.					

Lagunitas Lake No. 1			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13010005 Conejos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_063	20.6.4.123	RESERVOIR	3.11 ACRES	2012	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Lagunitas Lake No. 2			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13010005 Conejos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_064	20.6.4.123	RESERVOIR	3.83 ACRES	2012	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Lagunitas Lake No. 3			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13010005 Conejos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_065	20.6.4.123	RESERVOIR	1.72 ACRES	2012	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Rio Nutritas (Rio San Antonio to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13010005 Conejos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_905	20.6.4.123	STREAM, PERENNIAL	7.99 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2020	2021 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2020	2021 (est.)	5/5A
WH	Fully Supporting				
AU Comment: None.					

Rio San Antonio (CO border to Montoya Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13010005 Conejos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_902	20.6.4.123	STREAM, PERENNIAL	11.86 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2020	2021 (est.)	5/5A
		Dissolved oxygen	2012	2021 (est.)	5/5A
		Temperature	2012	2021 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Special Designation Streams, 2024).					

Rio San Antonio (Montoya Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13010005 Conejos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_901	20.6.4.123	STREAM, PERENNIAL	20.87 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2004	12/17/2004	4A
		Aluminum, Total Recoverable	2020	2021 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2012	9/13/2012	4A
WH	Fully Supporting				
AU Comment: TMDL for temperature and E. coli.					

Rio de los Pinos (New Mexico reaches)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13010005 Conejos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_900	20.6.4.123	STREAM, PERENNIAL	20.63 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature Aluminum, Total Recoverable	2004 2020	12/17/2004 2021 (est.)	4A 5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Special Designation Streams, 2024). TMDL for temperature.					

Tanques Creek (Rio Nutritas to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13010005 Conejos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_906	20.6.4.98	STREAM, INTERMITTENT	2.77 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

HUC: 13020101 Upper Rio Grande

Acid Canyon (Pueblo Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_002	20.6.4.98	STREAM, INTERMITTENT	0.37 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5B
MWWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
		Copper, Dissolved	2010		5/5B
		Aluminum, Total Recoverable	2018		5/5B
PC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C

AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC. Metals listings based on exceedances of acute criteria.

Agua Caliente (Rio Grande to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_430	20.6.4.123	STREAM, PERENNIAL	6.34 MILES	2004	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

Alamitos Creek (Rio Pueblo to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_411	20.6.4.123	STREAM, PERENNIAL	6.81 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: There are threatened Rio Grande cutthroat trout in this reach.					

Apache Canyon (Rio Fernando de Taos to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_002	20.6.4.123	STREAM, PERENNIAL	1.46 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: NMEDs Hydrology Protocol (https://www.env.nm.gov/surface-water-quality/hp/) was performed at this AU on 5/23/11. According to the protocol and supporting information, this AU falls under the "perennial" definition in 20.6.4.7 NMAC.					

Arroyo Seco Creek (perennial prt HWY 522 to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2119_31	20.6.4.99	STREAM, PERENNIAL	9 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Arroyo del Palacio (Rio Grande to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_004	20.6.4.98	STREAM, INTERMITTENT	10.61 MILES	2012	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2012	2023 (est.)	5/5A
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.					

Bayo Canyon (San Ildefonso bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_007	20.6.4.98	STREAM, INTERMITTENT	6.05 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.					

Bear Canyon (Red River to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_712	20.6.4.98	STREAM, INTERMITTENT	2.8 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

Bitter Creek (Red River to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_705	20.6.4.123	STREAM, PERENNIAL	9.22 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Turbidity	2012		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for SBD (sedimentation/siltation) and Al acute.					

Bobcat Creek (Red River to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_716	20.6.4.123	STREAM, PERENNIAL	5.76 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Bull Creek Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_023	20.6.4.133	LAKE, FRESHWATER	0.84 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Cabresto Creek (Red River to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_701	20.6.4.123	STREAM, PERENNIAL	17.98 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Dissolved oxygen	2020	2021 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Special Designation Streams, 2024).					

Cabresto Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_20	20.6.4.134	RESERVOIR	22.46 ACRES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	pH	2020	2026 (est.)	5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Canada Agua (Arroyo La Mina to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_003	20.6.4.98	STREAM, INTERMITTENT	1.61 MILES	2012	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2012	2023 (est.)	5/5A
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.					

Canada de los Tanos (Rio Quemado to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_121	20.6.4.123	STREAM, PERENNIAL	3.05 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Capulin Creek (R Fernando de Taos to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_514	20.6.4.98	STREAM, INTERMITTENT	4.35 MILES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Fully Supporting				
WH	Not Assessed				
AU Comment: NMEDs Hydrology Protocol (https://www.env.nm.gov/surface-water-quality/hp/) was performed at this AU on 5/23/11. According to the protocol and supporting information, this AU falls under the "intermittent" definition in 20.6.4.7 NMAC.					

Casias Creek (Costilla Reservoir to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_831	20.6.4.123	STREAM, PERENNIAL	7.82 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Chamisal Creek (abv Embudo Creek except Picuris Pueblo)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_402	20.6.4.123	STREAM, PERENNIAL	9.32 MILES	2004	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: None.					

Chuckwagon Creek (Comanche Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_833	20.6.4.123	STREAM, PERENNIAL	2.7 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Turbidity	2020	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL (Upper Rio Grande) for turbidity EPA approved February 2025.					

Columbine Creek (Red River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_702	20.6.4.123	STREAM, PERENNIAL	5.76 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Special Designation Streams, 2024).					

Comanche Creek (Costilla Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_827	20.6.4.123	STREAM, PERENNIAL	13.12 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Dissolved oxygen	2020	2021 (est.)	5/5A
		Temperature	1998	12/17/2004	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006). TMDL for temperature. Rio Grande Cutthroat trout re-introduction area.					

Cordova Creek (Costilla Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_823	20.6.4.123	STREAM, PERENNIAL	6.07 MILES	2012	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Turbidity	2012	12/17/1999	4A
		Sedimentation/Siltation	2004	12/17/1999	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for total phosphorus, SBD (sedimentation/siltation), and turbidity.					

Costilla Creek (CO border to Diversion abv Costilla)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_810	20.6.4.123	STREAM, PERENNIAL	3.26 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Flow Regime Modification	2020		4C
		Dissolved oxygen		2021 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This AU is de-watered by diversion; thermograph and gage data confirm that channel goes dry.

Costilla Creek (Comanche Creek to Costilla Dam)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_830	20.6.4.123	STREAM, PERENNIAL	5.07 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Benthic Macroinvertebrates	2020		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Valle Vidal, 2006).

Costilla Creek (Costilla Reservoir to CO border)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_829	20.6.4.123	STREAM, PERENNIAL	8.71 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Costilla Creek (Diversion abv Costilla to Comanche Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_820	20.6.4.123	STREAM, PERENNIAL	19.59 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2002	12/17/2004	4A
		Aluminum, Total Recoverable	2020	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006). TMDL for temperature. TMDL (Upper Rio Grande) for aluminum EPA approved February 2025.					

Costilla Creek (Rio Grande to CO border)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_800	20.6.4.123	STREAM, PERENNIAL	2.28 MILES	2004	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Flow Regime Modification			4C
IRR	Fully Supporting				
LW	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: This reach reportedly goes dry due to irrigation diversion in all but the wettest years.					

Cow Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_40	20.6.4.133	LAKE, FRESHWATER	0.6 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

DP Canyon (100m dwnstm grade ctrl to 400m upstm grade ctrl)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_24	20.6.4.128	STREAM, PERENNIAL	0.31 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
		Aluminum, Total Recoverable	2018		5/5B
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5B
SC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
AU Comment: Hydrology Protocol survey results indicate this AU is perennial.					

DP Canyon (400m upstream of grade control to upper LANL bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_14	20.6.4.128	STREAM, EPHEMERAL	0.76 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
		Aluminum, Total Recoverable	2018		5/5B
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5B
SC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
AU Comment: None.					

DP Canyon (Los Alamos Canyon to 100m dwnstm of grade ctrl)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_10	20.6.4.128	STREAM, INTERMITTENT	0.76 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
		Aluminum, Total Recoverable	2018		5/5B
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5B
SC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
AU Comment: None.					

Deer Creek (Columbine Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_450	20.6.4.98	STREAM, INTERMITTENT	3.3 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

Eagle Rock Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_10	20.6.4.122	RESERVOIR	3.39 ACRES	2004	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
FC	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

East Fk Rio Santa Barbara (R Santa Barbara to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_424	20.6.4.123	STREAM, PERENNIAL	6.64 MILES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Rio Santa Barbara, 2005).					

East Fork Red River (Red River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_715	20.6.4.123	STREAM, PERENNIAL	6.79 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Elk Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_039	20.6.4.133	LAKE, FRESHWATER	0.66 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Embudo Creek (Canada de Ojo Sarco to Picuris Pueblo bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2111_40	20.6.4.114	STREAM, PERENNIAL	5.16 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Temperature	2020	2021 (est.)	5/5C
		Dissolved oxygen	2020	2021 (est.)	5/5A
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Embudo Creek (Rio Grande to Canada de Ojo Sarco)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2111_41	20.6.4.114	STREAM, PERENNIAL	6.3 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Temperature	2012	2021 (est.)	5/5C
		Turbidity	1998	6/2/2005	4A
		Sedimentation/Siltation	1998	6/2/2005	4A
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for turbidity and sedimentation/siltation (SBD). Temperature impairment listed as 5C. Further data collection merited because of a fire which occurred upstream during the survey and prior to the maximum temperature reading on the thermograph from which the listing came.					

Fawn Lake (East)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_60	20.6.4.134	RESERVOIR	1.86 ACRES	2012	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Fawn Lake (West)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_61	20.6.4.134	RESERVOIR	1.18 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Fernandez Creek (Comanche Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_834	20.6.4.123	STREAM, PERENNIAL	2.85 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Nutrients	2020	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006). TMDL (Upper Rio Grande) for plant nutrients EPA approved February 2025.					

Frijoles Creek (Rito de la Olla to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_505	20.6.4.98	STREAM, INTERMITTENT	3.72 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

Gallina Creek (wilderness boundary to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_660	20.6.4.98	STREAM, INTERMITTENT	1.32 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

Gavilan Canyon (Rio Hondo to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_439	20.6.4.98	STREAM, INTERMITTENT	2.29 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

Gold Creek (Comanche Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_835	20.6.4.123	STREAM, PERENNIAL	3.55 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2008	11/8/2011	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006). TMDL for temperature (2011).					

Goose Creek (Red River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_711	20.6.4.123	STREAM, PERENNIAL	5.45 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Special Designation Streams, 2024).					

Goose Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5B	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_12	20.6.4.133	LAKE, FRESHWATER	3.82 ACRES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	pH	2020	2026 (est.)	5/5B
		Dissolved oxygen	2020	2026 (est.)	5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: WQS review needed. This high alpine lake groundwater-fed lake may not be capable of meeting current WQS due to geology.					

Graduation Canyon (Pueblo Canyon to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5B	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_005	20.6.4.98	STREAM, INTERMITTENT	0.69 MILES	2010	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
		Copper, Dissolved	2010		5/5B
PC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC. Metals listings based on exceedances of acute criteria.					

Grassy Creek (Comanche Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_836	20.6.4.123	STREAM, PERENNIAL	3.48 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2020	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2020	9/29/2022	4A
WH	Fully Supporting				

AU Comment: ONRW (Valle Vidal, 2006). TMDL (Upper Rio Grande) for E.coli and Temperature EPA approved February 2025.

Guaje Canyon (San Ildefonso bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_005	20.6.4.98	STREAM, INTERMITTENT	12.62 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: Although the next survey date is noted as 2017, SWQB does not plan monitoring of these watersheds in the next ten years. However, ongoing water quality data will continue to be collected on the Pajarito Plateau by LANL and NMED DOE-OB. Application of the SWQB Hydrology Protocol (survey date 7/22/08) indicate this assessment unit is ephemeral (Hydrology Protocol score of 8.25 with 93.3% days with no flow at LANL gage E089 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol). The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to a waterbody under 20.6.4.97 NMAC. Until such time, this waterbody will remain under 20.6.4.98 NMAC.

Heart Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_70	20.6.4.133	LAKE, FRESHWATER	3.63 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Hidden Lake (Lake Hazel)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_80	20.6.4.133	LAKE, FRESHWATER	2.86 ACRES	2004	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Holman Creek (Comanche Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_837	20.6.4.123	STREAM, PERENNIAL	3.52 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature Turbidity	2008 2020	11/8/2011	4A 5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006). TMDL for temperature (2011).					

Horseshoe Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_90	20.6.4.133	LAKE, FRESHWATER	5.66 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013). High elevation cirque lake (difficult access).					

Horseshoe Lake (Alamitos)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_25	20.6.4.133	LAKE, FRESHWATER	6 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Italianos Creek (Rio Hondo to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_440	20.6.4.123	STREAM, PERENNIAL	2.93 MILES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

Jicarita Creek (Rio Santa Barbara to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_442	20.6.4.123	STREAM, PERENNIAL	3.41 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Jose Vigil Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.B_20	20.6.4.133	LAKE, FRESHWATER	1.82 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Kwage Canyon (Pueblo Canyon to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_003	20.6.4.98	STREAM, INTERMITTENT	1.16 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.					

La Cueva Creek (Costilla Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_838	20.6.4.123	STREAM, PERENNIAL	3.28 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006).					

LaBelle Creek (Comanche Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_839	20.6.4.123	STREAM, PERENNIAL	2.94 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Sedimentation/Siltation	2020	9/29/2022	4A
		Aluminum, Total Recoverable	2020	9/29/2022	4A
		Temperature	2008	11/8/2011	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2020	9/29/2022	4A
WH	Fully Supporting				

AU Comment: ONRW (Valle Vidal, 2006). TMDL for temperature (2011). TMDL (Upper Rio Grande) for E.coli, Sedimentation/Siltation, and Total Aluminum EPA approved February 2025.

Lake Fork (Cabresto Creek to Cabresto Lake)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_707	20.6.4.123	STREAM, PERENNIAL	1.14 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Not Assessed				
PC	Fully Supporting				
WH	Not Assessed				

AU Comment: None.

Lake Fork (Cabresto Lake to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_708	20.6.4.123	STREAM, PERENNIAL	4.69 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Not Assessed				
PC	Fully Supporting				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Lake Fork Creek (Rio Hondo to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_606	20.6.4.123	STREAM, PERENNIAL	4.04 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Upper Rio Grande, 2023).					

Lama Canyon (wilderness boundary to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_690	20.6.4.98	STREAM, INTERMITTENT	1.7 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

Latir Creek (Costilla Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_824	20.6.4.123	STREAM, PERENNIAL	6.96 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Little Costilla Creek (Comanche Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_840	20.6.4.123	STREAM, PERENNIAL	5.08 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006).					

Little Tesuque Creek (Rio Tesuque to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_34	20.6.4.121	STREAM, PERENNIAL	8.98 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: TMDL for aluminum.					

Lobo Creek (wilderness boundary to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_670	20.6.4.98	STREAM, INTERMITTENT	3.55 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

Long Canyon (Rio Hondo to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_438	20.6.4.98	STREAM, INTERMITTENT	2.54 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

Los Alamos Canyon (DP Canyon to upper LANL bnd)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_063	20.6.4.128	STREAM, EPHEMERAL	4.44 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Cyanide, Total Recoverable	2018		5/5C
		Polychlorinated Biphenyls (PCBs)	2006		5/5C
		Selenium, Total Recoverable	2018		5/5C
.....	.....	.....	.....	.....	.....
LW	Not Supporting	Gross Alpha, Adjusted	2004		5/5C
.....	.....	.....	.....	.....	.....
SC	Not Assessed				
.....	.....	.....	.....	.....	.....
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2006		5/5C
		Selenium, Total Recoverable	2018		5/5C
		Mercury, Total	2006		5/5C
		Cyanide, Total Recoverable	2018		5/5C
AU Comment: None.					

Los Alamos Canyon (Los Alamos Rsvr to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-127.A_00	20.6.4.127	STREAM, PERENNIAL	3.04 MILES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Fully Supporting				
.....	.....	.....	.....	.....	.....
IRR	Fully Supporting				
.....	.....	.....	.....	.....	.....
LW	Fully Supporting				
.....	.....	.....	.....	.....	.....
PC	Not Assessed				
.....	.....	.....	.....	.....	.....
WH	Fully Supporting				
AU Comment: None.					

Los Alamos Canyon (NM-4 to DP Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_006	20.6.4.128	STREAM, EPHEMERAL	3.08 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2006		5/5C
		Cyanide, Total Recoverable	2018		5/5C
		Aluminum, Total Recoverable	2018		5/5B
LW	Not Supporting	Radium	2018		5/5C
		Gross Alpha, Adjusted	2004		5/5B
SC	Not Assessed				
WH	Not Supporting	Cyanide, Total Recoverable	2018		5/5C
		Polychlorinated Biphenyls (PCBs)	2006		5/5C
		Selenium, Total Recoverable	2022		5/5C
AU Comment: None.					

Los Alamos Canyon (San Ildefonso bnd to NM-4)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_000	20.6.4.98	STREAM, INTERMITTENT	0.75 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Los Alamos Canyon (upper LANL bnd to Los Alamos Rsvr)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_049	20.6.4.98	STREAM, INTERMITTENT	1.05 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.					

Los Alamos Reservoir			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_077	20.6.4.127	RESERVOIR	2.21 ACRES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Lost Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_13	20.6.4.133	LAKE, FRESHWATER	8.62 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Mallette Creek (Red River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_704	20.6.4.123	STREAM, PERENNIAL	4.73 MILES	2002	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: None.					

Manzanita Creek (Rio Hondo to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_441	20.6.4.123	STREAM, PERENNIAL	3.36 MILES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

Middle Fk Rio Santa Barbara (R Santa Barbara to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_423	20.6.4.123	STREAM, PERENNIAL	4.53 MILES	2004	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Rio Santa Barbara, 2005).					

Middle Fork Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_55	20.6.4.133	LAKE, FRESHWATER	8.29 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Middle Fork Red River (Red River to Middle Fork Lake)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_714	20.6.4.123	STREAM, PERENNIAL	2.71 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Nambe Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.B_10	20.6.4.133	LAKE, FRESHWATER	1.51 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Nat Lake II			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_087	20.6.4.133	LAKE, FRESHWATER	0.64 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Nat Lake IV			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_088	20.6.4.133	LAKE, FRESHWATER	0.58 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

No Fish Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_65	20.6.4.133	LAKE, FRESHWATER	0.86 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

North Fork Tesuque Creek (Tesuque Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_32	20.6.4.121	STREAM, PERENNIAL	2.4 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2020	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: Industrial water supply and municipal water supply may not be actual uses for this stream reach. TMDL (Upper Rio Grande) for Total Aluminum EPA approved February 2025.					

Palociento Creek (Rito de la Olla to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_504	20.6.4.98	STREAM, INTERMITTENT	2.8 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

Pioneer Creek (Red River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_703	20.6.4.123	STREAM, PERENNIAL	5.36 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Sedimentation/Siltation	2012	2021 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for turbidity.					

Pioneer Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_97	20.6.4.133	LAKE, FRESHWATER	1.08 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Placer Creek (Red River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_706	20.6.4.123	STREAM, PERENNIAL	3.41 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Turbidity	2020	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL (Upper Rio Grande) for turbidity EPA approved February 2025.					

Placer Fork (Columbine Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_444	20.6.4.123	STREAM, PERENNIAL	4.07 MILES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

Pojoaque River (San Ildefonso bnd to Pojoaque bnd)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2111_20	20.6.4.114	STREAM, PERENNIAL	0.68 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2012	2021 (est.)	5/5A
PC	Fully Supporting				
WWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2012	2021 (est.)	5/5A
WH	Fully Supporting				
AU Comment: None.					

Policarpio Canyon (La Junta Ck to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_443	20.6.4.123	STREAM, PERENNIAL	3.58 MILES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Powderhouse Creek (Costilla Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_832	20.6.4.123	STREAM, PERENNIAL	5.15 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006).					

Pueblo Canyon (Acid Canyon to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5B	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_043	20.6.4.98	STREAM, INTERMITTENT	3.78 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Supporting	Gross Alpha, Adjusted	2002		5/5B
MWWAL	Not Supporting	Aluminum, Total Recoverable	2018		5/5B
		Polychlorinated Biphenyls (PCBs)	2006		5/5C
PC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2006		5/5C
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC. Metals listings based on exceedances of acute criteria.					

Pueblo Canyon (Los Alamos Canyon to Los Alamos WWTP)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-99.A_001	20.6.4.98	STREAM, INTERMITTENT	2.78 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5C
MWWAL	Not Supporting	Selenium, Total Recoverable	2018		5/5C
		Polychlorinated Biphenyls (PCBs)	2010		5/5C
		Aluminum, Total Recoverable	2018		5/5B
PC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
		Selenium, Total Recoverable	2018		5/5C

AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC. Metals ALU listings based on exceedances of acute criteria.

Pueblo Canyon (Los Alamos WWTP to Acid Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_006	20.6.4.98	STREAM, INTERMITTENT	3.27 MILES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5B
MWWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
PC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C

AU Comment: Application of the SWQB Hydrology Protocol (survey date 7/21/08) indicate this assessment unit is ephemeral (Hydrology Protocol score of 3.75 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol). The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this waterbody will remain under 20.6.4.98 NMAC.

Red River (Placer Creek to East Fork Red River)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_710	20.6.4.123	STREAM, PERENNIAL	6.01 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Benthic Macroinvertebrates	2020		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Red River (Rio Grande to Placer Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2119_10	20.6.4.122	STREAM, PERENNIAL	21.16 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Turbidity	2020	9/29/2022	4A
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Special Designation Streams, 2024). TMDL for dissolved aluminum 2006 (withdrawn in 2013 because dissolved aluminum criteria no longer apply). TMDL (Upper Rio Grande) for turbidity EPA approved February 2025.					

Rendija Canyon (Guaje Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_045	20.6.4.98	STREAM, INTERMITTENT	8.9 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.					

Rio Chiquito (Picuris Pueblo bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_421	20.6.4.123	STREAM, PERENNIAL	10.91 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Rio Chiquito (Rio Grande del Rancho to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_502	20.6.4.123	STREAM, PERENNIAL	19.13 MILES	2002	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: None.					

Rio Chupadero (USFS bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_40	20.6.4.121	STREAM, PERENNIAL	6.05 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Sedimentation/Siltation	2020	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL (Upper Rio Grande) for Sedimentation/Siltation EPA approved February 2025.					

Rio Fernando de Taos (R Pueblo d Taos to USFS bnd at canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_512	20.6.4.123	STREAM, PERENNIAL	5.21 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	1998	12/17/2004	4A
		Turbidity	2020		5/5C
		Specific Conductance	1998	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2008	9/13/2012	4A
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: TMDLs for temperature and specific conductance (2004). TMDL (Upper Rio Grande) for Specific Conductance EPA approved February 2025.

Rio Fernando de Taos (Tienditas Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_001	20.6.4.123	STREAM, PERENNIAL	6.84 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2024	2026 (est.)	5/5A
		Specific Conductance	2024	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2008	9/13/2012	4A
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: TMDL (Upper Rio Grande) for Specific Conductance EPA approved February 2025.
The SWQB Watershed Protection Section completed a special study of E. coli levels with associated flow observations in the upper 3 miles of Rio Fernando de Taos and the Apache Canyon tributary to assess potential impacts from livestock grazing in 2006. The study demonstrated instances when grazing on the Flechado Allotment probably increased E. coli levels in Apache Canyon and this portion of Rio Fernando de Taos in 2006. The USFS Carson National Forest in cooperation with SWQB collected E. coli data in 2007 (combined with 2006 data and assessed for 2008 cycle). NMEDs Hydrology Protocol (https://www.env.nm.gov/surface-water-quality/hp/) was performed at this AU on 5/23/11. According to the protocol and supporting information, this AU falls under the perennial definition in 20.6.4.7 NMAC.

Rio Fernando de Taos (UFSF bnd at canyon to Tienditas Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_513	20.6.4.123	STREAM, PERENNIAL	11.54 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Supporting	Specific Conductance	2020	9/29/2022	4A
IRR	Not Assessed				
LW	Not Assessed				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Not Assessed				
AU Comment: TMDL (Upper Rio Grande) for specific conductance EPA approved February 2025. NMED's Hydrology Protocol (https://www.env.nm.gov/surface-water-quality/hp/) was performed at this AU on 5/23/11. According to the protocol, this AU falls under the "perennial" definition in 20.6.4.7 NMAC.					

Rio Frijoles (Rio Medio to Pecos Wilderness)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_60	20.6.4.121	STREAM, PERENNIAL	15.35 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Turbidity	2020	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013). TMDL (Upper Rio Grande) for turbidity EPA approved February 2025.					

Rio Grande (Embudo Creek to Rio Pueblo de Taos)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2111_12	20.6.4.114	RIVER	15.35 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Turbidity	2012		5/5C
PC	Fully Supporting				
PWS	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Rio Grande (Klauer) spring			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-132.S_01	20.6.4.132	SPRING	0 MILES	2012	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
DWS	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Not Assessed				
AU Comment: Limted data collection during 2009 URG survey (e. coli, gross alpha, and cyanide only).					

Rio Grande (Ohkay Owingeh bnd to Embudo Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2111_10	20.6.4.114	RIVER	14.07 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Turbidity	1998	6/2/2005	4A
		Mercury - Fish Consumption Advisory	2020		5/5C
		DDT - Fish Consumption Advisory	2020		5/5C
		Temperature	2022	9/29/2022	4A
PC	Fully Supporting				
PWS	Not Assessed				
WWAL	Not Supporting	DDT - Fish Consumption Advisory	2020		5/5C
WH	Fully Supporting				

AU Comment: TMDL for turbidity (2005). TMDL (Upper Rio Grande) for temperature EPA approved February 2025.
Fish Tissue Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable". Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern. 2022 TMDL pending WQCC approval

Rio Grande (Red River to CO border)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2119_05	20.6.4.122	RIVER	29.06 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	2004	12/17/2004	4A
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Upper Rio Grande, 2023). TMDL for temperature.

Rio Grande (Rio Pueblo de Taos to Red River)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2119_00	20.6.4.122	RIVER	23.13 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	2020	2021 (est.)	5/5B
		pH	2020		5/5C
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Upper Rio Grande, 2023). Temperature in this AU is predominately controlled by groundwater and geology.

Rio Grande (Santa Clara Pueblo bnd to Ohkay Owingeh bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2111_11	20.6.4.114	RIVER	0.69 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Mercury - Fish Consumption Advisory	2020		5/5C
		Temperature	2020	9/29/2022	4A
		Turbidity	1998	6/2/2005	4A
PC	Fully Supporting				
PWS	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: TMDL for turbidity (2005). TMDL (Upper Rio Grande) for temperature EPA approved February 2025.
Fish Tissue Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable". Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern. 2022 TMDL pending WQCC approval

Rio Grande del Rancho (R Pueblo de Taos to Rito de la Olla)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_501	20.6.4.123	STREAM, PERENNIAL	10.57 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Specific Conductance	2004	12/17/2004	4A
		Dissolved oxygen	2020	2021 (est.)	5/5A
		Temperature	2012	2021 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2014	2021 (est.)	5/5A
WH	Fully Supporting				
AU Comment: TMDL for specific conductance.					

Rio Grande del Rancho (Rito de la Olla to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_500	20.6.4.123	STREAM, PERENNIAL	17.49 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Rio Hondo (Lake Fork Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_607	20.6.4.129	STREAM, PERENNIAL	1.92 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Upper Rio Grande, 2023).					

Rio Hondo (Rio Grande to USFS bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_600	20.6.4.129	STREAM, PERENNIAL	8.74 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2002	12/17/2004	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for temperature.					

Rio Hondo (South Fork Rio Hondo to Lake Fork Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_602	20.6.4.129	STREAM, PERENNIAL	3.97 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Upper Rio Grande, 2023). A protective TMDL was prepared for nutrients in 2005.					

Rio Hondo (USFS bnd to South Fork Rio Hondo)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_601	20.6.4.129	STREAM, PERENNIAL	4.54 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Upper Rio Grande, 2023).					

Rio Medio (Rio Frijoles to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_53	20.6.4.121	STREAM, PERENNIAL	17.88 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2020	9/29/2022	4A
		Aluminum, Total Recoverable	2020	9/29/2022	4A
		Turbidity	2020	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). TMDL (Upper Rio Grande) for Temperature, Turbidity and Total Recoverable Aluminum EPA approved February 2025.

Rio Nambe (Nambe Pueblo bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_43	20.6.4.121	STREAM, PERENNIAL	9.23 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2020	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). Watershed impacted by 2012 Santa Fe National Forest Pacheco Fire. TMDL (Upper Rio Grande) for temperature EPA approved February 2025.

Rio Pueblo (Picuris Pueblo bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_410	20.6.4.123	STREAM, PERENNIAL	20.44 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2020	2021 (est.)	5/5C
		Aluminum, Total Recoverable	2020	2021 (est.)	5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: Temperature and aluminum impairments listed as 5C. Further data collection merited because of a fire which occurred in a headwaters of the canyon during the survey and prior to the maximum temperature reading on the thermograph from which the listing came.

Rio Pueblo de Taos (Arroyo del Alamo to R Grande del Rancho)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2119_30	20.6.4.122	STREAM, PERENNIAL	5.46 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	2004	12/17/2004	4A
		Nutrients	2012	9/29/2022	4A
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: TMDL for temperature and sedimentation/siltation (SBD, 2004). TMDL (Upper Rio Grande) for Nutrients EPA approved February 2025.

Rio Pueblo de Taos (R Grande del Rancho to Taos Pueblo bnd)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_511	20.6.4.123	STREAM, PERENNIAL	3.09 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2004	12/17/2004	4A
		Specific Conductance	2024		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2012	9/13/2012	4A
WH	Fully Supporting				
AU Comment: TMDL for temperature.					

Rio Pueblo de Taos (Rio Grande to Arroyo del Alamo)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2119_20	20.6.4.122	STREAM, PERENNIAL	2.38 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Turbidity	2020	9/29/2022	4A
		Temperature	2004	12/17/2004	4A
		Dissolved oxygen	2020	2026 (est.)	5/5A
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for temperature (2004). TMDL (Upper Rio Grande) for turbidity EPA approved February 2025.					

Rio Quemado (Rio Arriba Cnty bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_120	20.6.4.123	STREAM, PERENNIAL	16.34 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2020	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2020	9/29/2022	4A
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). The 2012 Rio Quemado E.coli TMDL was assigned to the E.coli impairment. TMDL (Upper Rio Grande) for E.coli and Total Aluminum EPA approved February 2025.

Rio Quemado (Santa Cruz River to Rio Arriba Cnty bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_52	20.6.4.121	STREAM, PERENNIAL	3.84 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2020	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2012	9/13/2012	4A
WH	Fully Supporting				

AU Comment: TMDL for E. coli (2012). TMDL (Upper Rio Grande) for Total Aluminum EPA approved February 2025.

Rio Santa Barbara (USFS bnd to confl of E and W forks)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_420	20.6.4.123	STREAM, PERENNIAL	5.33 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Rio Santa Barbara, 2005).					

Rio Santa Barbara (non-pueblo Embudo Ck to USFS bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_419	20.6.4.123	STREAM, PERENNIAL	4.34 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for turbidity (2005, de-list 2012) and E. coli (2012).					

Rio Tesuque (Pojoaque Pueblo to Tesuque Pueblo bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2111_30	20.6.4.114	STREAM, PERENNIAL	1.4 MILES	2004	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Not Assessed				
MCWAL	Fully Supporting				
PC	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: Marginal CWAL and WWAL may not be attainable -- reach may not be perennial.

Rio Tesuque (Tesuque Pueblo to Little Tesuque Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2111_31	20.6.4.114	STREAM, PERENNIAL	2.08 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Rio de Truchas (Perennial portions Rio Grande to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_300	20.6.4.123	STREAM, PERENNIAL	22.97 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Rio de las Trampas (Rio Embudo to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_401	20.6.4.123	STREAM, PERENNIAL	18.68 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Rio en Medio (Aspen Ranch to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_42	20.6.4.121	STREAM, PERENNIAL	3.09 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Sedimentation/Siltation	2020	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: TMDL (Upper Rio Grande) for Sedimentation/Siltation EPA approved February 2025.					

Rio en Medio (non-pueblo lands Pojoaque R to Aspen Ranch)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_41	20.6.4.121	STREAM, PERENNIAL	6.84 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: None.					

Rito de la Olla (Rio Grande del Rancho to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_503	20.6.4.123	STREAM, PERENNIAL	14.47 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Romero Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_05	20.6.4.123	LAKE, FRESHWATER	2.61 ACRES	2012	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

San Cristobal Creek (Rio Grande to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_680	20.6.4.123	STREAM, PERENNIAL	10.29 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Special Designation Streams, 2024).					

San Leonardo Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_14	20.6.4.133	LAKE, FRESHWATER	4.6 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Sanchez Canyon (Costilla Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_822	20.6.4.123	STREAM, PERENNIAL	6.32 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Turbidity	2020	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL (Upper Rio Grande) for turbidity EPA approved February 2025.					

Santa Clara Creek (Santa Clara Pueblo bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_110	20.6.4.123	STREAM, PERENNIAL	0.88 MILES	2004	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Santa Cruz Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.B_00	20.6.4.121	RESERVOIR	92.95 ACRES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2012	8/20/2024	4A
		Aluminum, Total Recoverable	2020	8/20/2024	4A
		Nutrients	2020	8/20/2024	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: TMDL (Canadian and URG Lakes) for Plant Nutrients, Temperature, Total Aluminum EPA approved August 2024. Samples collected by the New Mexico Environment Department (NMED) in late 2025 showed the presence of harmful algae and toxins, and a HABs Health Watch was issued for this lake. Harmful algae blooms, or HABs, occur when certain types of algae grow excessively in water, posing potential health risks to people and animals. HABs can appear blue, bright green, brown or red and may resemble scum or floating grass clippings on the water's surface. These blooms can produce toxins that are harmful to humans and animals. For more information visit: https://www.env.nm.gov/surface-water-quality/habs/

Santa Cruz River (Santa Clara Pueblo bnd to Santa Cruz Dam)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2111_50	20.6.4.114	STREAM, PERENNIAL	8.37 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Temperature	2012	2026 (est.)	5/5A
		Aluminum, Total Recoverable	2020	9/29/2022	4A
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: 2012 E.coli TMDL. TMDL (Upper Rio Grande) for Total Aluminum EPA approved February 2025.

Santa Cruz River (Santa Cruz Reservoir to Rio Medio)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_51	20.6.4.121	STREAM, PERENNIAL	1.01 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2020	9/29/2022	4A
		Aluminum, Total Recoverable	2020	9/29/2022	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL (Upper Rio Grande) for Temperature and Total Aluminum EPA approved February 2025.					

Serpent Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_95	20.6.4.133	LAKE, FRESHWATER	0.84 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

South Fork Acid Canyon (Acid Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_029	20.6.4.98	STREAM, INTERMITTENT	0.09 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Supporting	Gross Alpha, Adjusted	2014		5/5B
MWWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2014		5/5C
		Copper, Dissolved	2014		5/5B
PC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2014		5/5C

AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC. Metals listings based on exceedances of acute criteria.

South Fork Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_58	20.6.4.133	LAKE, FRESHWATER	0.6 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: ONRW (USFS Wilderness Areas, 2013).

South Fork Rio Hondo (Rio Hondo to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_608	20.6.4.129	STREAM, PERENNIAL	4.9 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

South Fork Tesuque Creek (Tesuque Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_33	20.6.4.121	STREAM, PERENNIAL	1.38 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Tesuque Creek (Rio Tesuque to confl of forks)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_31	20.6.4.121	STREAM, PERENNIAL	7.55 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Application of the SWQB Hydrology Protocol (survey date 6/4/2009) indicate this assessment unit is perennial (Hydrology Protocol score of 31.3 but 0.6% no flow days at USGS gage 08302500 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol).

Tienditas Creek (R Fernando de Taos to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_515	20.6.4.99	STREAM, PERENNIAL	6.62 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Trampas Lake (East)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_86	20.6.4.133	LAKE, FRESHWATER	2.6 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Trampas Lake (West)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_85	20.6.4.133	LAKE, FRESHWATER	2.66 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Unnamed Arroyo (Rio Pueblo de Taos to Taos WWTP)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-99.A_005	20.6.4.98	STREAM, INTERMITTENT	2.8 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Fully Supporting				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: This channel is effluent-dominated, with batch discharge and periods of no discharge due to reuse at the golf course.					

Ute Creek (Costilla Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_821	20.6.4.123	STREAM, PERENNIAL	9.01 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2020	9/29/2022	4A
WH	Fully Supporting				
AU Comment: TMDL (Upper Rio Grande) for E.coli EPA approved February 2025.					

Vidal Creek (Comanche Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_841	20.6.4.123	STREAM, PERENNIAL	5.85 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2020	9/29/2022	4A
		Dissolved oxygen	2020	2026 (est.)	5/5A
		Temperature	2014	2026 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2020	9/29/2022	4A
WH	Fully Supporting				
AU Comment: ONRW (Valle Vidal, 2006). TMDL (Upper Rio Grande) for E.coli and Total Recoverable Aluminum EPA approved February 2025.					

Walnut Canyon (Pueblo Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_004	20.6.4.98	STREAM, INTERMITTENT	0.38 MILES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Not Supporting	Copper, Dissolved	2014		5/5B
		Polychlorinated Biphenyls (PCBs)	2010		5/5C
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC. Metals listings based on exceedances of acute criteria.

West Fk Rio Santa Barbara (R Santa Barbara to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_422	20.6.4.123	STREAM, PERENNIAL	6.58 MILES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: ONRW (Rio Santa Barbara, 2005).

West Fork Red River (Middle Fork Red R to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_713	20.6.4.123	STREAM, PERENNIAL	2.77 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Williams Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.B_75	20.6.4.133	LAKE, FRESHWATER	5.94 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Willow Fork (Placer Fork to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_445	20.6.4.98	STREAM, INTERMITTENT	2.61 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

Yerba Creek (Rio Hondo to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020101 Upper Rio Grande	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2120.A_437	20.6.4.98	STREAM, INTERMITTENT	3.15 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

HUC: 13020102 Rio Chama

Abiquiu Creek (Rio Chama to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2113_50	20.6.4.116	STREAM, PERENNIAL	12.99 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Dissolved oxygen	1998	9/3/2004	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
WWAL	Not Supporting	Dissolved oxygen	1998	9/3/2004	4A
WH	Fully Supporting				
AU Comment: TMDL for dissolved oxygen. Impacts to watershed in 2012.This AU has been absorbed into the new subwatershed-based AU"Abiquiu Creek subwatershed". Refer to AU ID W_NM-212-02 from this cycle onwards.					

Abiquiu Creek subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-212-02	20.6.4.116	WATERSHED	46.04 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Aluminum, Total Recoverable	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2026	2027 (est.)	5/5A
WWAL	Not Assessed				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Abiquiu Reservoir			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2114_00	20.6.4.117	RESERVOIR	3257.91 ACRES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients	2026	2027 (est.)	5/5A
		Mercury - Fish Consumption Advisory	2010		5/5C
		PCBS - Fish Consumption Advisory	2006		5/5C
IRR Storage	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Assessed				
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable". Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Arroyo Seco subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-209-05	20.6.4.119	WATERSHED	161.82 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2026	2027 (est.)	5/5A
		Specific Conductance	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2026	2027 (est.)	5/5A
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Arroyo del Toro (Rio Chama to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_006	20.6.4.98	STREAM, INTERMITTENT	6.89 MILES	2012	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2012		5/5C
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC..

Canada de Horno (Rio Chama to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_005	20.6.4.98	STREAM, INTERMITTENT	3.99 MILES	2012	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2012		5/5C
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.

Canada de la Laguna-Willow Creek subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-203-03	20.6.4.119	WATERSHED	1.43 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Canjilon Ck (Perennial portions Abiquiu Rsrv to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_030	20.6.4.119	STREAM, PERENNIAL	37.43 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Specific Conductance	2006	8/16/2011	4A
		Turbidity	2006		5/5C
		Temperature	2006	8/16/2011	4A
		Nutrients	2010		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: TMDLs prepared for temperature and SC in 2011. This AU has been absorbed into the new subwatershed-based AU "Arroyo Seco subwatershed". Refer to AU ID W_NM-209-05 from this cycle onwards.

Canjilon Lake (a)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.B_10	20.6.4.134	RESERVOIR	5.11 ACRES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Canjilon Lake (b)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.B_11	20.6.4.119	RESERVOIR	1.67 ACRES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Canjilon Lake (c)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.B_12	20.6.4.134	RESERVOIR	4.04 ACRES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Canjilon Lake (d)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.B_13	20.6.4.119	RESERVOIR	1.21 ACRES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Canjilon Lake (e)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.B_14	20.6.4.134	RESERVOIR	4.69 ACRES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Canjilon Lake (f)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.B_15	20.6.4.134	RESERVOIR	2.77 ACRES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Canones Creek (Abiquiu Rsvr to Chihuahuenos Ck)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_010	20.6.4.119	STREAM, PERENNIAL	8.35 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2014		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2014	11/30/2020	4A
WH	Fully Supporting				
AU Comment: Escherichia coli (E. coli) TMDL EPA approved November 2020. Turbidity TMDL (2004). Coolwater ALU may be the attainable ALU - WQS needed. This AU has been absorbed into the new subwatershed-based AU "Canones Creek subwatershed". Refer to AU ID W_NM-210-05 from this cycle onwards.					

Canones Creek (Chihuahuenos Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_012	20.6.4.119	STREAM, PERENNIAL	11.54 MILES	2016	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU has been absorbed into the new subwatershed-based AU "Canones Creek subwatershed". Refer to AU ID W_NM-210-05 from this cycle onwards.					

Canones Creek (Rio Chama to Jicarilla Apache bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_100	20.6.4.119	STREAM, PERENNIAL	8.38 MILES	2016	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2014		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: This AU has been absorbed into the new subwatershed-based AU "Daggett Canyon-Canones Creek subwatershed". Refer to AU ID W_NM-202-06 from this cycle onwards.					

Canones Creek subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-210-05	20.6.4.119	WATERSHED	56.42 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Nutrients	2026	2027 (est.)	5/5A
		Specific Conductance	2026	2027 (est.)	5/5A
		Temperature	2026	2027 (est.)	5/5A
		Aluminum, Total Recoverable	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2026	2027 (est.)	5/5A
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Cecilia Canyon Creek (Rio Capulin to USFS bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_042	20.6.4.119	STREAM, PERENNIAL	5.08 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). This AU has been absorbed into the new subwatershed-based AU "Rio Capulin subwatershed". Refer to AU ID W_NM-206-01 from this cycle onwards.

Chavez Creek (Rio Brazos to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_081	20.6.4.119	STREAM, PERENNIAL	13.09 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2004	3/4/2004	4A
IRR	Fully Supporting				
LW	Not Assessed				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: TMDL for temperature. HQCWAL may not be attainable. This AU has been absorbed into the new subwatershed-based AU "Rio Brazos subwatershed". Refer to AU ID W_NM-201-06 from this cycle onwards.

Chihuahuenos Creek (Canones Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_016	20.6.4.119	STREAM, PERENNIAL	9.53 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Sedimentation/Siltation	2014	2023 (est.)	5/5A
		Aluminum, Total Recoverable	2014		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Canones Creek subwatershed". Refer to AU ID W_NM-210-05 from this cycle onwards.

Clear Creek (Rio Gallina to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_043	20.6.4.119	STREAM, PERENNIAL	3.57 MILES	2010	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013). This AU has been absorbed into the new subwatershed-based AU "Upper Rio Gallina subwatershed". Refer to AU ID W_NM-206-03 from this cycle onwards.					

Coyote Creek (Rio Puerco de Chama to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_022	20.6.4.119	STREAM, PERENNIAL	15.68 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Sedimentation/Siltation	2014	11/30/2020	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: Sedimentation/Siltation TMDL EPA approved November 2020. This AU has been absorbed into the new subwatershed-based AU "Coyote Creek subwatershed". Refer to AU ID W_NM-208-02 from this cycle onwards.					

Coyote Creek subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-208-02	20.6.4.119	WATERSHED	45.08 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Daggett Canyon-Canones Creek subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-202-06	20.6.4.119	WATERSHED	9.46 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2026	2027 (est.)	5/5A
		Aluminum, Total Recoverable	2026	2027 (est.)	5/5A
		Dissolved oxygen	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

East Fork Rio Brazos (Jicarilla Apache bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_088	20.6.4.119	STREAM, PERENNIAL	8.64 MILES	2000	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

El Rito Creek (Perennial reaches HWY 554 to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2112.A_20	20.6.4.115	STREAM, PERENNIAL	23.96 MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2014		5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: This AU has been absorbed into the new subwatershed-based AU "El Rito subwatershed". Refer to AU ID W_NM-211-03 from this cycle onwards.					

El Rito Creek (Perennial reaches Rio Chama to HWY 554)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2113_40	20.6.4.116	STREAM, PERENNIAL	13.72 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients	2014		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
WWAL	Not Supporting	Nutrients	2014		5/5C
WH	Fully Supporting				
AU Comment: This AU has been absorbed into the new subwatershed-based AU "El Rito subwatershed". Refer to AU ID W_NM-211-03 from this cycle onwards.					

El Vado Reservoir			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2117_00	20.6.4.120	RESERVOIR	3108.43 ACRES	2016	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Fully Supporting				
IRR Storage	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: None.					

Heron Reservoir			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2117_10	20.6.4.120	RESERVOIR	4497.01 ACRES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients	2026	2027 (est.)	5/5A
		Temperature	2014	2027 (est.)	5/5A
		Mercury - Fish Consumption Advisory	2026		5/5C
IRR Storage	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Hopewell Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2112.B_00	20.6.4.134	RESERVOIR	15.66 ACRES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	pH	2026	2027 (est.)	5/5A
		Nutrients	2014	2027 (est.)	5/5A
IRR Storage	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Samples collected by the New Mexico Environment Department (NMED) in late 2025 showed the presence of harmful algae and toxins, and a HABs Health Watch was issued for this lake.
Harmful algae blooms, or HABs, occur when certain types of algae grow excessively in water, posing potential health risks to people and animals. HABs can appear blue, bright green, brown or red and may resemble scum or floating grass clippings on the water's surface. These blooms can produce toxins that are harmful to humans and animals. For more information visit: https://www.env.nm.gov/surface-water-quality/habs/

Jarosa Creek (Rio Vallecitos to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2112.A_01	20.6.4.115	STREAM, PERENNIAL	7.29 MILES	2000	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: None.					

Laguna del Campo			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_025	20.6.4.99	RESERVOIR	1.59 ACRES	2016	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	Nutrients	2014	2021 (est.)	5/5C
WH	Fully Supporting				
AU Comment: Previously named "Burns Lake (Rio Arriba)."					

Little Willow Creek (Rio Chama to to Jicarilla Apache bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_120	20.6.4.119	STREAM, PERENNIAL	0.45 MILES	2000	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: Rio Grande Cutthroat Trout restoration in 1992-1996 by NMG&F.					

Lower El Rito subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-211-03.A	20.6.4.116	WATERSHED	30 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Dissolved oxygen	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2026	2027 (est.)	5/5A
WWAL	Not Assessed				
WH	Fully Supporting				
AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.					

Lower Rio Gallina subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-206-08	20.6.4.118	WATERSHED	51.57 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Sedimentation/Siltation	2026	2027 (est.)	5/5A
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Lower Rio Nutrias subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-207-04	20.6.4.119	WATERSHED	56.74 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Specific Conductance	2026	2027 (est.)	5/5A
		Aluminum, Total Recoverable	2026	2027 (est.)	5/5A
		Temperature	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2026	2027 (est.)	5/5A
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Lower Rio Ojo Caliente subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-215-06	20.6.4.98	WATERSHED	97.05 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Lower Rio Puerco de Chama subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-208-04.B	20.6.4.118	WATERSHED	36.39 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	2026	2027 (est.)	5/5A
		Aluminum, Total Recoverable	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2026	2027 (est.)	5/5A
WWAL	Not Assessed				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Lower Rio Vallecitos subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-214-04	20.6.4.115	WATERSHED	87.31 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2026	2027 (est.)	5/5C
		Temperature	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Lower Rio del Oso subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-216-02.B	20.6.4.98	WATERSHED	9.1 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Not Supporting	Aluminum, Total Recoverable	2026	2027 (est.)	5/5A
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Middle Rio Gallina subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-206-05	20.6.4.118	WATERSHED	40.98 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Middle Rio Vallecitos subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-214-02	20.6.4.115	WATERSHED	54.5 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Nabor Creek (Rio Chamita to CO border)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_111	20.6.4.98	STREAM, INTERMITTENT	3.25 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: ONRW (Special Designation Streams, 2024). This AU has been absorbed into the new subwatershed-based AU "Nabor Creek subwatershed". Refer to AU ID W_NM-202-04.B from this cycle onwards.

Nabor Creek subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-202-04.B	20.6.4.98	WATERSHED	1.99 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Nabor Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.B_20	20.6.4.119	RESERVOIR	4.46 ACRES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Placer Creek (Hopewell Lake to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2112.A_03	20.6.4.115	STREAM, PERENNIAL	4.93 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2014	11/30/2020	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: Temperature TMDL EPA approved November 2020. This AU has been absorbed into the new subwatershed-based AU "Upper Rio Vallecitos subwatershed". Refer to AU ID W_NM-214-01 from this cycle onwards.					

Placer Creek (Rio Vallecitos to Hopewell Lake)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2112.A_02	20.6.4.115	STREAM, PERENNIAL	2.48 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: This AU has been absorbed into the new subwatershed-based AU "Upper Rio Vallecitos subwatershed". Refer to AU ID W_NM-214-01 from this cycle onwards.					

Poleo Creek (Rio Puerco de Chama to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_023	20.6.4.119	STREAM, PERENNIAL	8.01 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Sedimentation/Siltation	2014	11/30/2020	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: Sedimentation/Siltation TMDL EPA approved November 2020. TMDL for turbidity (2004). This AU has been absorbed into the new subwatershed-based AU "Poleo Creek subwatershed". Refer to AU ID W_NM-208-01 from this cycle onwards.					

Poleo Creek subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-208-01	20.6.4.119	WATERSHED	46.16 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Supporting	Sedimentation/Siltation	2026	11/30/2020	4A
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Polvadera Creek (Canones Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_011	20.6.4.119	STREAM, PERENNIAL	14.27 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: TMDL for temperature (2004).

Polvadera Creek subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-210-04	20.6.4.119	WATERSHED	34.6 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Rio Brazos (Chavez Creek to Jicarilla Apache bnd)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_084	20.6.4.119	STREAM, PERENNIAL	22.7 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Rio Brazos subwatershed". Refer to AU ID W_NM-201-06 from this cycle onwards.

Rio Brazos (Rio Chama to Chavez Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_080	20.6.4.119	STREAM, PERENNIAL	3.93 MILES	2016	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	1998	3/4/2004	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: TMDL for temperature (approved by EPA March 2004). This AU has been absorbed into the new subwatershed-based AU "Rio Brazos subwatershed". Refer to AU ID W_NM-201-06 from this cycle onwards.

Rio Brazos subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-201-06	20.6.4.119	WATERSHED	162.15 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2026	2027 (est.)	5/5A
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
PWS	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Rio Capulin (Rio Gallina to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_041	20.6.4.119	STREAM, PERENNIAL	12.6 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2010	8/16/2011	4A
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). TMDL prepared for E. coli (2011). This AU has been absorbed into the new subwatershed-based AU "Rio Capulin subwatershed". Refer to AU ID W_NM-206-01 from this cycle onwards.

Rio Capulin subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-206-01	20.6.4.119	WATERSHED	32.49 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Rio Cebolla (Rio Chama to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_050	20.6.4.119	STREAM, PERENNIAL	23.46 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU has been absorbed into the new subwatershed-based AU "Rio Cebolla subwatershed". Refer to AU ID W_NM-205-03 from this cycle onwards.					

Rio Cebolla subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-205-03	20.6.4.119	WATERSHED	133.36 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.					

Rio Chama (Abiquiu Creek to Abiquiu Dam)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2113_01	20.6.4.116	RIVER	8.19 MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Dissolved oxygen	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Assessed				
WH	Fully Supporting				

AU Comment: Formerly part of Rio Chama (Ohkay Owingeh to Abiquiu Dam) (NM-2113_00).

Rio Chama (Abiquiu Reservoir to El Vado Reservoir)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2115_00	20.6.4.118	RIVER	37.35 MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Aluminum, Total Recoverable	2026	2027 (est.)	5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Assessed				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013) + ONRW (Special Designation Streams, 2024).

Rio Chama (El Vado Reservoir to Rito de Tierra Amarilla)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_003	20.6.4.119	STREAM, PERENNIAL	9.54 MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2026	2027 (est.)	5/5C
		Temperature	2010	8/16/2011	4A
		Nutrients	2010	8/16/2011	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2010	8/16/2011	4A
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: ONRW (Special Designation Streams, 2024). TMDLs were prepared for e. coli , nutrients, and temperature in 2011.

Rio Chama (Little Willow Creek to CO border)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_002	20.6.4.119	STREAM, PERENNIAL	9.01 MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2026	2027 (est.)	5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: ONRW (Special Designation Streams, 2024). TMDLs were prepared for e. coli and temperature in 2011. This AU has been absorbed into the new subwatershed-based AU "Upper Rio Chama subwatershed". Refer to AU ID W_NM-202-04.A from this cycle onwards.

Rio Chama (Ohkay Owingeh to Abiquiu Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2113_00	20.6.4.116	RIVER	20.13 MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	2026	2027 (est.)	5/5A
		Aluminum, Total Recoverable	2026	2027 (est.)	5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Assessed				
WH	Fully Supporting				

AU Comment: Formerly Rio Chama (Ohkay Owingeh to Abiquiu Dam) (NM-2113_00).

Rio Chama (Rio Brazos to Little Willow Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_001	20.6.4.119	STREAM, PERENNIAL	13.42 MILES	2016	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	1998	3/4/2004	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: TMDLs were prepared for temperature (2004), and e. coli and nutrients (2011). This AU has been absorbed into the new subwatershed-based AU "Upper Rio Chama subwatershed". Refer to AU ID W_NM-202-04.A from this cycle onwards.

Rio Chama (Rito de Tierra Amarilla to Rio Brazos)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_000	20.6.4.119	STREAM, PERENNIAL	6.43 MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2010	8/16/2011	4A
		Nutrients	2010	8/16/2011	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: TMDLs were prepared for e. coli , nutrients, and temperature in 2011.

Rio Chamita (Rio Chama to CO border)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_110	20.6.4.119	STREAM, PERENNIAL	13.87 MILES	2020	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Ammonia, Total	1998	9/30/1999	4A
		Nutrients	2006	8/16/2011	4A
		Temperature	1998	12/31/1999	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2010	8/16/2011	4A
WH	Fully Supporting				

AU Comment: ONRW (Special Designation Streams, 2024). TMDL for ammonia, total phosphorus, fecal coliform, temp (1999), and dissolved aluminum (2004). TMDLs were prepared for E. coli and nutrients (2011). Dissolved Al TMDL withdrawn 2018 because no longer an applicable WQC. This AU has been absorbed into the new subwatershed-based AU "Upper Rio Chama subwatershed". Refer to AU ID W_NM-202-04.A from this cycle onwards.

Rio Gallina (HWY 96 to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_040	20.6.4.119	STREAM, PERENNIAL	9.67 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). This AU has been absorbed into the new subwatershed-based AU "Upper Rio Gallina subwatershed". Refer to AU ID W_NM-206-03 from this cycle onwards.

Rio Gallina (Perennial prt Rio Chama to HWY 96)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2115_10	20.6.4.118	STREAM, PERENNIAL	27.63 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				

AU Comment: This AU has been absorbed into the new subwatershed-based AUs "Lower Rio Gallina subwatershed" and "Middle Rio Gallina subwatershed". Refer to AU ID W_NM-206-05 and W_NM-206-08 from this cycle onwards.

Rio Nutrias (Perennial prt Rio Chama to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_060	20.6.4.119	STREAM, PERENNIAL	41.06 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Turbidity	2004	9/3/2004	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2014	11/30/2020	4A
WH	Fully Supporting				
AU Comment: Escherichia coli (E. coli) TMDL EPA approved November 2020.TMDL for turbidity (2004). This AU has been absorbed into the new subwatershed-based AUs "Upper Rio Nutrias subwatershed" and "Lower Rio Nutrias subwatershed". Refer to AU ID W_NM-207-01 and W_NM-207-04 from this cycle onwards.					

Rio Ojo Caliente (Arroyo El Rito to Rio Vallecitos)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2113_10	20.6.4.116	STREAM, PERENNIAL	8.68 MILES	2016	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients	2014	2023 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
WWAL	Not Supporting	Nutrients	2014	2023 (est.)	5/5A
WH	Fully Supporting				
AU Comment: This AU has been absorbed into the new subwatershed-based AU "Upper Rio Ojo Caliente subwatershed". Refer to AU ID W_NM-215-02 from this cycle onwards.					

Rio Ojo Caliente (Rio Chama to Arroyo El Rito)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2113_11	20.6.4.98	STREAM, INTERMITTENT	16.05 MILES	2020	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Lower Rio Ojo Caliente subwatershed". Refer to AU ID W_NM-215-06 from this cycle onwards.

Rio Puerco de Chama (Abiquiu Reservoir to HWY 96)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2115_20	20.6.4.118	STREAM, PERENNIAL	13.55 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients	2010		5/5C
		Temperature	1998	8/16/2011	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2010	8/16/2011	4A
WWAL	Not Supporting	Nutrients	2010		5/5C
WH	Fully Supporting				

AU Comment: TMDLs prepared for temperature and e. coli (2011). This AU has been absorbed into the new subwatershed-based AU "Lower Rio Puerco de Chama subwatershed". Refer to AU ID W_NM-208-04.B from this cycle onwards.

Rio Puerco de Chama (HWY 96 to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_020	20.6.4.119	STREAM, PERENNIAL	12.47 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). This AU has been absorbed into the new subwatershed-based AU "Upper Rio Puerco de Chama subwatershed". Refer to AU ID W_NM-208-03 from this cycle onwards.

Rio Tusas (Perennial prt Rio Vallecitos to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2113_30	20.6.4.116	STREAM, PERENNIAL	46.34 MILES	2016	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients	2010	8/16/2011	4A
		Temperature	2016	11/30/2020	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
WWAL	Not Supporting	Nutrients	2010	8/16/2011	4A
WH	Fully Supporting				

AU Comment: Temperature TMDL EPA approved November 2020. TMDL was prepared for nutrients (2011). This AU has been absorbed into the new subwatershed-based AU "Rio Tusas subwatershed". Refer to AU ID W_NM-213-05 from this cycle onwards.

Rio Tusas subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-213-05	20.6.4.116	WATERSHED	197.8 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients	2026	2027 (est.)	5/5A
		Aluminum, Total Recoverable	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Assessed				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Rio Vallecitos (Rio Tusas to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2112.A_00	20.6.4.115	STREAM, PERENNIAL	36.77 MILES	2020	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	1998	9/3/2004	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: TMDL for Al chronic, temperature, and turbidity. HQCWAL may not be attainable - WQS review needed. This AU has been absorbed into the new subwatershed-based AUs "Lower Rio Vallecitos subwatershed", "Middle Rio Vallecitos subwatershed" and "Upper Rio Vallecitos subwatershed". Refer to AU ID W_NM-214-04, W_NM-214-02 and W_NM-214-01 from this cycle onwards.

Rio del Oso (Perennial prt La Canada del Almagre to hdwts)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2112.A_11	20.6.4.115	STREAM, PERENNIAL	13.49 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Upper Rio del Oso subwatershed'. Refer to AU ID W_NM-216-02.A from this cycle onwards.

Rio del Oso (Rio Chama to La Canada del Almagre)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2112.A_10	20.6.4.98	STREAM, INTERMITTENT	4.76 MILES	2020	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2012		5/5C
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Lower Rio del Oso subwatershed". Refer to AU ID W_NM-216-02.B from this cycle onwards.

Rito Encino (Rio Puerco de Chama to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_021	20.6.4.119	STREAM, PERENNIAL	10.3 MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2014		5/5C
WH	Fully Supporting				

AU Comment: Sedimentation/Siltation TMDL EPA approved November 2020. This AU has been absorbed into the new subwatershed-based AU Rito Encino subwatershed". Refer to AU ID W_NM-208-04.A from this cycle onwards.

Rito Encino subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-208-04.A	20.6.4.119	WATERSHED	29.13 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Rito Redondo (Rito Resumidero to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_026	20.6.4.119	STREAM, PERENNIAL	2.85 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013). This AU has been absorbed into the new subwatershed-based AU "Upper Rio Puerco de Chama subwatershed". Refer to AU ID W_NM-208-03 from this cycle onwards.					

Rito Resumidero (Perennial prt R Puerco de Chama to hdwt)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_025	20.6.4.119	STREAM, PERENNIAL	5.55 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Supporting	Flow Regime Modification	2014		4C
IRR	Not Assessed				
LW	Not Assessed				
PC	Fully Supporting				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013). The entire stream is diverted just upstream of the SWQB historic sampling station. This AU has been absorbed into the new subwatershed-based AU "Upper Rio Puerco de Chama subwatershed". Refer to AU ID W_NM-208-03 from this cycle onwards.					

Rito de Tierra Amarilla (HWY 64 to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_072	20.6.4.119	STREAM, PERENNIAL	6.27 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2014	2023 (est.)	5/5A
		Aluminum, Total Recoverable	2014		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Rito de Tierra Amarilla subwatershed'. Refer to AU ID W_NM-204-01 from this cycle onwards.

Rito de Tierra Amarilla (Rio Chama to HWY 64)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_070	20.6.4.119	STREAM, PERENNIAL	18.39 MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Specific Conductance	2014		5/5B
		Temperature	1998	3/4/2004	4A
		Nutrients	2016		5/5C
		Turbidity	1998	3/4/2004	4A
IRR	Fully Supporting				
LW	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: TMDLs for temperature, turbidity, and sedimentation/siltation (2004). WQS review recommended-Cool water ALU more appropriate on basis of ecoregion (21d) and fish community. This AU has been absorbed into the new subwatershed-based AU "Rito de Tierra Amarilla subwatershed'. Refer to AU ID W_NM-204-01 from this cycle onwards.

Rito de Tierra Amarilla subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-204-01	20.6.4.119	WATERSHED	61.18 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2026	2027 (est.)	5/5A
		Aluminum, Total Recoverable	2026	2027 (est.)	5/5A
		Specific Conductance	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Sixto Creek (Rio Chamita to CO border)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_112	20.6.4.119	STREAM, PERENNIAL	0.97 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2014	11/30/2020	4A
IRR	Not Assessed				
LW	Not Assessed				
PC	Fully Supporting				
WH	Not Assessed				

AU Comment: ONRW (Special Designation Streams, 2024). Temperature TMDL EPA approved November 2020.

Tonita Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.B_40	20.6.4.119	LAKE, FRESHWATER	0.58 ACRES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Trout Lakes			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.B_32	20.6.4.99	RESERVOIR	2.35 ACRES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: This AU is comprised of three separate lakes.					

Upper El Rito subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-211-03.B	20.6.4.115	WATERSHED	135.13 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Upper Rio Chama subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-202-04.A	20.6.4.119	WATERSHED	67.62 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2026	2027 (est.)	5/5A
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
PWS	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Upper Rio Gallina subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-206-03	20.6.4.119	WATERSHED	24.27 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Upper Rio Nutrias subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-207-01	20.6.4.119	WATERSHED	34.08 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Specific Conductance	2026	2027 (est.)	5/5A
		Temperature	2026	2027 (est.)	5/5A
		Dissolved oxygen	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2026	2027 (est.)	5/5A
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Upper Rio Ojo Caliente subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-215-02	20.6.4.116	WATERSHED	90.09 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients	2026	2027 (est.)	5/5A
		Aluminum, Total Recoverable	2026	2027 (est.)	5/5A
DWS	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Assessed				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Upper Rio Puerco de Chama subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-208-03	20.6.4.119	WATERSHED	46.76 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Upper Rio Vallecitos subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-214-01	20.6.4.115	WATERSHED	48.55 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Supporting	Dissolved oxygen	2026	2027 (est.)	5/5A
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
PWS	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Upper Rio del Oso subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-216-02.A	20.6.4.115	WATERSHED	32.02 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

West Fork Rio Brazos (Jicarilla Apache bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_087	20.6.4.119	STREAM, PERENNIAL	7.72 MILES	2000	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Willow Creek (Jicarilla Apache bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_140	20.6.4.119	STREAM, PERENNIAL	16.81 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Not Assessed				
PC	Fully Supporting				
WH	Not Assessed				
AU Comment: None.					

Wolf Creek (Rio Chama to CO border)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020102 Rio Chama	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2116.A_130	20.6.4.119	STREAM, PERENNIAL	5.14 MILES	2020	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

HUC: 13020201 Rio Grande-Santa Fe

Alamo Canyon (Rio Grande to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_71	20.6.4.121	STREAM, PERENNIAL	15.15 MILES	2004	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024).					

Alamo Creek (Cienega Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2110_20	20.6.4.113	STREAM, PERENNIAL	6.67 MILES	2004	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
MCWAL	Not Assessed				
SC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Ancho Canyon (Above Ancho Springs to North Fork Ancho)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_054	20.6.4.128	STREAM, EPHEMERAL	1.7 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2014		5/5C
LW	Fully Supporting				
SC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs) Mercury, Total	2014 2018		5/5C 5/5C

AU Comment: None.

Ancho Canyon (North Fork to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_046	20.6.4.128	STREAM, EPHEMERAL	4.49 MILES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
LW	Not Assessed				
SC	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

Ancho Canyon (Rio Grande to Ancho Springs)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_154	20.6.4.128	STREAM, PERENNIAL	0.74 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2014		5/5C
LW	Fully Supporting				
SC	Not Assessed				
WH	Not Supporting	Mercury, Total	2018		5/5C
		Polychlorinated Biphenyls (PCBs)	2014		5/5C
AU Comment: Hydrology Protocol survey results indicate this AU is perennial.					

Apache Canyon (perennial prt Galisteo Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_14	20.6.4.121	STREAM, PERENNIAL	11.58 MILES	2016	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Arroyo Hondo (south of Old Pecos Trail to headwater)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2110_11	20.6.4.98	STREAM, INTERMITTENT	9.2 MILES	2008	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Arroyo de la Delfe (Above Kieling Spring to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_16	20.6.4.128	STREAM, EPHEMERAL	0.28 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Copper, Dissolved	2018		5/5B
		Polychlorinated Biphenyls (PCBs)	2018		5/5C
		Aluminum, Total Recoverable	2018		5/5B
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5B
SC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2018		5/5C
AU Comment: None.					

Arroyo de la Delfe (Pajarito Canyon to Kieling Spring)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_36	20.6.4.126	STREAM, PERENNIAL	0.34 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Copper, Dissolved	2018		5/5B
		Aluminum, Total Recoverable	2018		5/5B
		Polychlorinated Biphenyls (PCBs)	2018		5/5C
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5B
SC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2018		5/5C
AU Comment: Hydrology Protocol survey results indicate this AU is perennial.					

Canada del Buey (San Ildefonso Pueblo to LANL bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_053	20.6.4.98	STREAM, INTERMITTENT	1.68 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.					

Canada del Buey (within LANL)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_00	20.6.4.128	STREAM, EPHEMERAL	5.26 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
LW	Not Supporting	Gross Alpha, Adjusted	2006		5/5B
SC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Canada del Rancho (Arroyo Hondo to outfall)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_0121	20.6.4.98	STREAM, INTERMITTENT	1.28 MILES	2016	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: Receiving water for Ranchland Utility Company - NM0030368.					

Canon de Valle (LANL gage E256 to Burning Ground Spr)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-126.A_00	20.6.4.126	STREAM, PERENNIAL	0.31 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
LW	Fully Supporting				
SC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
AU Comment: None.					

Canon de Valle (below LANL gage E256)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_01	20.6.4.128	STREAM, EPHEMERAL	2.45 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Fully Supporting				
LW	Not Supporting	Gross Alpha, Adjusted	2006		5/5B
SC	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

Canon de Valle (upper LANL bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_051	20.6.4.98	STREAM, INTERMITTENT	3.5 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5B
MWWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

Canon de Valle (within LANL above Burning Ground Spr)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_02	20.6.4.128	STREAM, EPHEMERAL	1.1 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Capulin Creek (Rio Grande to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_72	20.6.4.121	STREAM, PERENNIAL	13.64 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013) + ONRW (Special Designation Streams, 2024). The 1996 Dome Fire extensively burned this watershed, leading to increased erosion of the already erosive natural geology in the area (Bandelier Tuff).

Chaquehui Canyon (within LANL)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_03	20.6.4.128	STREAM, EPHEMERAL	3 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2018		5/5C
LW	Fully Supporting				
SC	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

Cienega Creek (Perennial prt of Santa Fe R to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2110_10	20.6.4.113	STREAM, PERENNIAL	14.35 MILES	2016	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Middle reaches often go dry due to diversion.

Cunningham Gulch (CR 55 to above mine area)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_011	20.6.4.97	STREAM, EPHEMERAL	2.57 MILES	2016	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013.
LAC Minerals permit NM0028711

Deer Creek (Galisteo Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_13	20.6.4.98	STREAM, INTERMITTENT	6.14 MILES	2016	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Effluent Canyon (Mortandad Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_18	20.6.4.140	STREAM, INTERMITTENT	0.38 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Fence Canyon (above Potrillo Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_04	20.6.4.128	STREAM, EPHEMERAL	2.99 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Fish Ladder Canyon (Canon del Valle to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_19	20.6.4.128	STREAM, EPHEMERAL	0.96 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Galisteo Ck (Perennial prt 2.2 mi abv Lamy to hdwts)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_12	20.6.4.121	STREAM, PERENNIAL	10.68 MILES	2016	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	1998	8/22/2017	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for temperature (2017).					

Galisteo Ck (Perennial prt Kewa bnd to San Cristobal Ck)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_10	20.6.4.139	STREAM, PERENNIAL	20.76 MILES	2016	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Temperature	1998	8/22/2017	4A
DWS	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Application of the SWQB Hydrology Protocol at various locations in this AU indicate this AU has perennial, intemittent and ephemeral portions - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol). TMDL for temperature (2017).

Galisteo Ck (Perennial prt San Cristobal to 2.2 mi abv Lamy)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_15	20.6.4.139	STREAM, PERENNIAL	12.57 MILES	2016	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Temperature	1998	8/22/2017	4A
DWS	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Application of the SWQB Hydrology Protocol at various locations in this AU indicate this AU has perennial, intemittent and ephemeral portions - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol). TMDL for temperature (2017).

Indio Canyon (above Water Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_05	20.6.4.128	STREAM, EPHEMERAL	1.17 MILES	2010	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Las Huertas Ck (Perennial prt Santa Ana bnd to hdwtrs)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2108.5_00	20.6.4.111	STREAM, PERENNIAL	14.61 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
HQColdWAL	Not Supporting	Flow Regime Modification	2018		4C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Lummis Canyon (Alamo Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_001	20.6.4.98	STREAM, INTERMITTENT	8.62 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Special Designation Streams, 2024). This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.					

McClure Reservoir			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.B_50	20.6.4.138	RESERVOIR	84.87 ACRES	2016	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
PWS	Not Assessed				
WH	Not Assessed				

AU Comment: This AU was reclassified from segment 121 into a new segment 138. Amendment was effective February 14, 2013. EPA approved the changes June 5, 2013.

Medio Creek (Rio Grande to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_73	20.6.4.98	STREAM, EPHEMERAL	6.59 MILES	2010	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: ONRW (USFS Wilderness Areas, 2013) + ONRW (Special Designation Streams, 2024).

Mortandad Canyon (within LANL)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_042	20.6.4.128	STREAM, EPHEMERAL	4.32 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Fully Supporting				
LW	Not Supporting	Gross Alpha, Adjusted	2004		5/5B
SC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2014		5/5C

AU Comment: None.

Nichols Reservoir			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.B_40	20.6.4.138	RESERVOIR	26.27 ACRES	2016	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
PWS	Not Assessed				
WH	Not Assessed				
AU Comment: This AU was reclassified from segment 121 into a new segment 138. Amendment was effective February 14, 2013. EPA approved the changes June 5, 2013.					

North Fork Ancho Canyon (Ancho Canyon to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5B	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_055	20.6.4.128	STREAM, EPHEMERAL	3.88 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5B
SC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
AU Comment: None.					

Pajarito Canyon (0.5 mi ds of and to Arroyo de la Delfe)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_036	20.6.4.126	STREAM, PERENNIAL	0.49 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Silver, Dissolved	2018		5/5C
		Polychlorinated Biphenyls (PCBs)	2016		5/5C
		Copper, Dissolved	2016		5/5B
LW	Not Supporting	Gross Alpha, Adjusted	2006		5/5B
SC	Not Assessed				
WH	Fully Supporting				

AU Comment: Metals listings based on exceedances of acute criteria. During the 2022 cycle this AU was split from NM-128.A_06 as a result of Hydrology Protocol surveys that documented a perennial reach downstream of Arroyo de la Delfe. Hydrology Protocol survey results indicate this AU is perennial.

Pajarito Canyon (Above Homestead Spring to LANL boundary)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_07	20.6.4.128	STREAM, EPHEMERAL	0.99 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Aluminum, Total Recoverable	2018		5/5C
LW	Not Supporting	Gross Alpha, Adjusted	2006		5/5C
SC	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

Pajarito Canyon (Arroyo de La Delfe to Starmers Gulch)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-126.A_01	20.6.4.126	STREAM, PERENNIAL	0.33 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Fully Supporting				
LW	Fully Supporting				
SC	Not Assessed				
WH	Fully Supporting				

AU Comment: Spring fed.

Pajarito Canyon (Lower LANL bnd to Twomile Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_08	20.6.4.128	STREAM, EPHEMERAL	5.01 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
		Aluminum, Total Recoverable	2018		5/5B
LW	Not Supporting	Gross Alpha, Adjusted	2006		5/5B
SC	Not Assessed				
WH	Not Supporting	Cyanide, Total Recoverable	2018		5/5C
		Polychlorinated Biphenyls (PCBs)	2010		5/5C
AU Comment: Metals listings based on exceedances of acute criteria.					

Pajarito Canyon (Rio Grande to LANL bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_040	20.6.4.98	STREAM, INTERMITTENT	2.95 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.					

Pajarito Canyon (Starmers Gulch to Homestead Spring)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_37	20.6.4.126	STREAM, PERENNIAL	0.13 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Aluminum, Total Recoverable	2018		5/5C
LW	Not Supporting	Gross Alpha, Adjusted	2006		5/5C
SC	Not Assessed				
WH	Fully Supporting				
AU Comment: Hydrology Protocol survey results indicate this AU is perennial.					

Pajarito Canyon (Twomile Cyn to 0.5 mi ds of A. de La Delfe)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5B	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_06	20.6.4.128	STREAM, EPHEMERAL	1.61 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Silver, Dissolved	2018		5/5C
		Copper, Dissolved	2016		5/5C
		Polychlorinated Biphenyls (PCBs)	2016		5/5C
LW	Not Supporting	Gross Alpha, Adjusted	2006		5/5B
SC	Not Assessed				
WH	Fully Supporting				
AU Comment: Metals listings based on exceedances of acute criteria.					

Pajarito Canyon (upper LANL bnd to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_048	20.6.4.98	STREAM, INTERMITTENT	2.6 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5B
PC	Not Assessed				
WWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
		Cyanide, Total Recoverable	2018		5/5C
		Aluminum, Total Recoverable	2018		5/5B
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
		Mercury, Total	2018		5/5C
AU Comment: None.					

Potrillo Canyon (above Water Canyon)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_09	20.6.4.128	STREAM, EPHEMERAL	6.45 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Fully Supporting				
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5C
SC	Not Assessed				
WH	Fully Supporting				
AU Comment: None.					

Rio Chiquito (Cochiti Pueblo bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_041	20.6.4.98	STREAM, INTERMITTENT	14.31 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.

Rio Grande (Cochiti Reservoir to San Ildefonso bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2111_00	20.6.4.114	RIVER	18.2 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Not Supporting	Gross Alpha, Adjusted	2012	2027 (est.)	5/5A
MCWAL	Not Supporting	Turbidity	2004		5/5C
		Aluminum, Total Recoverable	2020	2027 (est.)	5/5A
		Polychlorinated Biphenyls (PCBs)	2012	2027 (est.)	5/5A
		Temperature	2020	2027 (est.)	5/5A
		Mercury - Fish Consumption Advisory	2020		5/5C
PC	Fully Supporting				
PWS	Not Assessed				
WWAL	Not Supporting	Mercury - Fish Consumption Advisory	2020		5/5C
WH	Fully Supporting				

AU Comment: Some of the impairment listings are based solely on stormwater data. Procedures are in place, under the purview of the Buckman Direct Diversion Board, that are intended to not allow public water supply withdrawal from the Buckman Diversion during significant storm events. Fish Tissue Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable". Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Rio Grande (non-pueblo Angostura Div to Cochiti Rsrv)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2108_00	20.6.4.110	RIVER	2.41 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	2016	2023 (est.)	5/5A
IRR	Fully Supporting				
LW	Not Supporting	Gross Alpha, Adjusted	2016	2023 (est.)	5/5A
PC	Fully Supporting				
WWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2016	2023 (est.)	5/5A
WH	Fully Supporting				

AU Comment: There is only ~1.5 miles of non-pueblo stream reach between Angostura Diversion and Cochiti Reservoir.

Rito de los Frijoles (Rio Grande to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_70	20.6.4.121	STREAM, PERENNIAL	14.33 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	DDT - Fish Consumption Advisory	2004		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Special Designation Streams, 2024). The National Park Service continues to have a fishing ban in effect due to legacy DDT contamination as well as protection of cultural and natural resources.

S-Site Canyon (Martin Spring to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_202	20.6.4.128	STREAM, EPHEMERAL	0.17 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

S-Site Canyon (Monitoring well MSC16-06293 to Martin Spring)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_201	20.6.4.140	STREAM, INTERMITTENT	0.21 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

S-Site Canyon (Water Canyon to monitoring well MSC 16-06293)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_20	20.6.4.128	STREAM, EPHEMERAL	1.78 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

San Cristobal Creek (Galisteo Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_11	20.6.4.98	STREAM, INTERMITTENT	23.7 MILES	2004	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

San Pedro Creek (San Felipe bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_004	20.6.4.125	STREAM, PERENNIAL	25.78 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Sandia Canyon (Bedrock Road to NPDES outfall 001)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_047	20.6.4.141	STREAM, PERENNIAL	1.714 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Temperature	2018		5/5B
		Aluminum, Total Recoverable	2018	9/15/2021	4B
		Polychlorinated Biphenyls (PCBs)	2006		5/5C
LW	Fully Supporting				
SC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2006		5/5C
AU Comment: None.					

Sandia Canyon (Sigma Canyon to Bedrock Road)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_047_B	20.6.4.126	STREAM, PERENNIAL	1.028 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2006		5/5C
		Temperature	2018		5/5B
		Aluminum, Total Recoverable	2018	9/15/2021	4B
LW	Fully Supporting				
SC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2006		5/5C
AU Comment: None.					

Sandia Canyon (within LANL below Sigma Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_11	20.6.4.128	STREAM, EPHEMERAL	3.4 MILES	2026	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2006		5/5C
		Aluminum, Total Recoverable	2018	9/15/2021	4B
LW	Not Supporting	Gross Alpha, Adjusted	2006		5/5C
SC	Not Assessed				
WH	Not Supporting	Mercury, Total	2006	9/15/2021	4B
		Polychlorinated Biphenyls (PCBs)	2006		5/5C
AU Comment: None.					

Santa Fe Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.B_30	20.6.4.133	LAKE, FRESHWATER	3.82 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013). This lake is in the upper portion of the Santa Fe Municipal Watershed. Access is restricted to protect the water supply reservoirs.					

Santa Fe River (Cienega Creek to Santa Fe WWTP)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2110_00	20.6.4.113	STREAM, PERENNIAL	7.35 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Nutrients	2008	2021 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2016	5/3/2017	4A
WH	Fully Supporting				
AU Comment: TMDL for SBD (sedimentation/siltation), DO, pH, and chlorine. TMDL for E. coli (2017). Santa Fe River below the WWTP is effluent-dominated.					

Santa Fe River (Cochiti Pueblo bnd to Cienega Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2110_02	20.6.4.113	STREAM, PERENNIAL	5.92 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Nutrients	2008	2023 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for SBD (sedimentation/siltation) (2000), DO, and pH.					

Santa Fe River (Guadalupe St to Nichols Rsvr)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_062	20.6.4.137	STREAM, INTERMITTENT	4.43 MILES	2016	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2018	2023 (est.)	5/5A
		Aluminum, Total Recoverable	2016	2023 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2016	5/3/2017	4A
WH	Fully Supporting				
AU Comment: TMDL for E. coli (2017).					

Santa Fe River (Nichols Reservoir to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2118.A_21	20.6.4.121	STREAM, PERENNIAL	13.39 MILES	2016	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2016		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013). A WQS review may be warranted in this "closed" municipal drinking water supply watershed.					

Santa Fe River (Santa Fe WWTP to Guadalupe St)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_061	20.6.4.136	STREAM, EPHEMERAL	10.16 MILES	2016	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LAL	Not Supporting	Aluminum, Total Recoverable	2016	2023 (est.)	5/5A
LW	Fully Supporting				
PC	Not Supporting	E. coli	2010	5/3/2017	4A
WH	Fully Supporting				
AU Comment: TMDL for E. coli (2017).					

Starmers Gulch (Pajarito Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_21	20.6.4.126	STREAM, PERENNIAL	0.32 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Ten Site Canyon (Mortandad Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_17	20.6.4.128	STREAM, EPHEMERAL	1.53 MILES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5B
SC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
AU Comment: None.					

Three Mile Canyon (Pajarito Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_091	20.6.4.128	STREAM, EPHEMERAL	2.33 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Fully Supporting				
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5C
SC	Not Assessed				
WH	Fully Supporting				
AU Comment: None.					

Twomile Canyon (Pajarito to Upper Twomile canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_15	20.6.4.140	STREAM, INTERMITTENT	2.15 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5B
MWWAL	Not Supporting	Copper, Dissolved	2018		5/5B
		Aluminum, Total Recoverable	2018		5/5B
		Polychlorinated Biphenyls (PCBs)	2010		5/5C
SC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
AU Comment: Metals listings based on exceedances of acute criteria.					

Twomile Canyon (Upper Twomile canyon to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5B	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_151	20.6.4.128	STREAM, EPHEMERAL	1.32 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Copper, Dissolved	2018		5/5B
		Aluminum, Total Recoverable	2018		5/5B
		Polychlorinated Biphenyls (PCBs)	2010		5/5C
LW	Not Supporting	Gross Alpha, Adjusted	2010		5/5B
SC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
AU Comment: Metals listings based on exceedances of acute criteria.					

Unnamed tributary (Arroyo Hondo to Oshara outfall)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_012	20.6.4.97	STREAM, EPHEMERAL	0.36 MILES	2016	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013. Oshara Village water reclamation facility, permit NM0030813					

Unnamed tributary (San Pedro Cr to PAAKO outfall)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_013	20.6.4.97	STREAM, EPHEMERAL	1.86 MILES	2016	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013. PAA-KO comm sewer assoc, permit NM0029724					

Water Canyon (Area-A Canyon to NM 501)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-126.A_03	20.6.4.126	STREAM, PERENNIAL	1.31 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Fully Supporting				
LW	Fully Supporting				
SC	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

Water Canyon (Rio Grande to lower LANL bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_044	20.6.4.98	STREAM, INTERMITTENT	0.57 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.

Water Canyon (upper LANL bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_052	20.6.4.98	STREAM, INTERMITTENT	2.91 MILES	2018	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Not Supporting	Aluminum, Total Recoverable	2018		5/5C
PC	Not Assessed				
WH	Not Supporting	Mercury, Total	2018		5/5C

AU Comment: Application of the SWQB Hydrology Protocol (survey date 7/21/08) indicate this assessment unit is intermittent (Hydrology Protocol score of 9.8 with 24.1% days with no flow at LANL gage E252 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol).

Water Canyon (within LANL above NM 501)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_12	20.6.4.99	STREAM, PERENNIAL	0.03 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: HP survey results show this AU is perennial.					

Water Canyon (within LANL below Area-A Cyn)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020201 Rio Grande-Santa Fe	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-128.A_13	20.6.4.128	STREAM, EPHEMERAL	8.81 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Aluminum, Total Recoverable	2018		5/5B
		Polychlorinated Biphenyls (PCBs)	2010		5/5C
LW	Not Supporting	Gross Alpha, Adjusted	2006		5/5B
SC	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2010		5/5C
		Mercury, Total	2018		5/5A
AU Comment: None.					

HUC: 13020202 Jemez

American Creek (Rio de las Palomas to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_44	20.6.4.108	STREAM, PERENNIAL	4.99 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2024	2026 (est.)	5/5A
IRR	Fully Supporting				
LW	Not Assessed				
PC	Not Supporting	E. coli	2024	2026 (est.)	5/5A
WH	Not Assessed				

AU Comment: Coldwater ALU is an existing use (salmonids seen during 2013 survey). WQS review needed.

Calaveras Creek (Rio Cebolla to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_53	20.6.4.108	STREAM, PERENNIAL	9.51 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2016		5/5B
IRR	Fully Supporting				
LW	Not Assessed				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Natural conditions may contribute to high aluminum concentrations in the Jemez Mountains; aluminum criteria may need review to identify appropriate/attainable levels.

Clear Creek (Rio de las Vacas to San Gregorio Lake)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_54	20.6.4.108	STREAM, PERENNIAL	5.37 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Nutrients	2016	9/23/2016	4A
		Aluminum, Total Recoverable	2024		5/5A
IRR	Fully Supporting				
LW	Not Assessed				
PC	Fully Supporting				
WH	Not Assessed				

AU Comment: ONRW (USFS Wilderness Areas, 2013). Temperature TMDL EPA approved November 2021. TMDL for turbidity and TOC (2003). The lake level dropped and no longer spills water into Clear Creek. Water is drained from the lake into Nacimiento Creek by a stand pipe. This AU is not perennial for its entire length.

Clear Creek (San Gregorio Lake to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_55	20.6.4.108	STREAM, PERENNIAL	3.75 MILES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Nutrients	2016	9/23/2016	4A
		Aluminum, Total Recoverable	2016		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). Natural conditions may contribute to high aluminum concentrations in the Jemez Mountains; aluminum criteria may need review to identify appropriate/attainable levels.

East Fork Jemez (San Antonio Creek to VCNP bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_13	20.6.4.108	STREAM, PERENNIAL	11.76 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2008	9/15/2009	4A
		Aluminum, Total Recoverable	2016		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Upper Rio Grande, 2023). TMDLs for turbidity (2003). TMDLs for temperature and arsenic (2009). Natural conditions may contribute to high aluminum concentrations in the Jemez Mountains; aluminum criteria may need review to identify appropriate/attainable levels.

East Fork Jemez (VCNP to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_10	20.6.4.108	STREAM, PERENNIAL	10.44 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2024	10/11/2006	4A
		Aluminum, Total Recoverable	2016		5/5B
		Nutrients	2016	9/23/2016	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Upper Rio Grande, 2023). Natural conditions may contribute to high aluminum concentrations in the Jemez Mountains; aluminum criteria may need review to identify appropriate/attainable levels.

Fenton Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.B_00	20.6.4.108	RESERVOIR	27.95 ACRES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Supporting	Nutrients	2004	2021 (est.)	5/5A
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Jaramillo Creek (East Fork Jemez to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_12	20.6.4.108	STREAM, PERENNIAL	12.16 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Sedimentation	2024	2026 (est.)	5/5A
		Nutrients	2016	9/23/2016	4A
		Aluminum, Total Recoverable	2016		5/5B
		Turbidity	2004	10/11/2006	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2024	2026 (est.)	5/5A
WH	Not Assessed				

AU Comment: ONRW (Special Designation Streams, 2024). TMDLs for temperature and turbidity. Natural conditions may contribute to high aluminum concentrations in the Jemez Mountains; aluminum criteria may need review to identify appropriate/attainable levels.

Jemez River (Jemez Pueblo bnd to Rio Guadalupe)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2105_71	20.6.4.107	STREAM, PERENNIAL	1.98 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Arsenic, Dissolved	2008	9/15/2009	4A
		Temperature	2016		5/5A
		Turbidity	2024	2015 (est.)	5/5A
IRR	Not Supporting	Boron, Dissolved	2008	9/15/2009	4A
		Arsenic, Dissolved	2008	9/15/2009	4A
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDLs for arsenic and boron (2009). Coolwater may be the attainable ALU - WQS review needed.					

Jemez River (Rio Guadalupe to Soda Dam nr Jemez Springs)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2105.5_10	20.6.4.107	STREAM, PERENNIAL	10.48 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Aluminum, Total Recoverable	2016	4/26/2018	4A
		Turbidity	1998	7/30/2004	4A
		Temperature	2008	9/15/2009	4A
		Arsenic, Dissolved	2008	9/15/2009	4A
IRR	Not Supporting	Boron, Dissolved	2008	9/15/2009	4A
		Arsenic, Dissolved	2008	9/15/2009	4A
LW	Fully Supporting				
PC	Not Supporting	E. coli	2016	9/23/2016	4A
WH	Not Assessed				
AU Comment: TMDL for Al acute (2003), turbidity, and SBD (1999) (sedimentation/siltation). De-listed for SBD in 2008. TMDLs for arsenic, boron, plant nutrients, and temperature (2009). The dissolved aluminum TMDL was revised to a total recoverable aluminum TMDL in 2018 using the current applicable WQC. Natural conditions may contribute to high aluminum concentrations in the Jemez Mountains; aluminum criteria may need review to identify appropriate/attainable levels.					

Jemez River (Soda Dam nr Jemez Springs to East Fork)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_00	20.6.4.108	STREAM, PERENNIAL	4.37 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Supporting	Arsenic, Dissolved	2008	9/15/2009	4A
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2008		5/5B
		Turbidity	1998	7/30/2004	4A
		Aluminum, Total Recoverable	2018	4/26/2018	4A
		Arsenic, Dissolved	2008	9/15/2009	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2016	9/23/2016	4A
WH	Fully Supporting				

AU Comment: TMDL for Al (2003), turbidity, and SBD (1999) (sedimentation/siltation); de-list letter for plant nutrients. De-listed for SBD in 2008. TMDL for arsenic (2009). The dissolved aluminum TMDL was revised to a total recoverable aluminum TMDL in 2018 using current applicable WQC. Natural conditions may contribute to high aluminum concentrations in the Jemez Mountains; aluminum criteria may need review to identify appropriate/attainable levels.

Jemez River (Zia Pueblo bnd to Jemez Pueblo bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2105_75	20.6.4.106	STREAM, PERENNIAL	2.15 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Supporting	Boron, Dissolved	2008	9/15/2009	4A
LW	Fully Supporting				
MWWAL	Not Supporting	Arsenic, Dissolved	2008	9/15/2009	4A
PC	Not Supporting	E. coli	2016	9/23/2016	4A
WH	Fully Supporting				

AU Comment: Temperature TMDL EPA approved November 2021. TMDLs for arsenic and boron (2009).

La Jara Creek (East Fork Jemez to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_11	20.6.4.108	STREAM, PERENNIAL	5.4 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2016		5/5B
		Temperature	2024	2026 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Special Designation Streams, 2024). Natural conditions may contribute to high aluminum concentrations in the Jemez Mountains; aluminum criteria may need review to identify appropriate/attainable levels.

Redondo Creek (Sulphur Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_21	20.6.4.108	STREAM, PERENNIAL	6.34 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	pH	2016		5/5B
		Specific Conductance	2024		5/5B
		Temperature	2018	6/2/2003	4A
		Aluminum, Dissolved	2024	2026 (est.)	5/5A
		Dissolved oxygen	2024		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Upper Rio Grande, 2023). TMDL for turbidity, total phosphorus, and temperature. Previously split at the Valles Caldera Boundary, the upper (NM-2016.A_25) and lower AUs were merged back into this AU ID. AU may not be perennial -- HP and WQS review needed

Rio Cebolla (Fenton Lake to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_52	20.6.4.108	STREAM, PERENNIAL	15.68 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Turbidity	2010		5/5C
		Nutrients	2016		5/5C
		Aluminum, Total Recoverable	2024	2026 (est.)	5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Special Designation Streams, 2024). TMDL for temperature and SBD (sedimentation/siltation). De-listed for temperature 2008. Rio Grande Cutthroat restoration in 1994 by NMG&F. Natural conditions may contribute to high aluminum concentrations in the Jemez Mountains; aluminum criteria may need review to identify appropriate/attainable levels.

Rio Cebolla (Rio de las Vacas to Fenton Lake)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_50	20.6.4.108	STREAM, PERENNIAL	7.25 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2016		5/5A
		Sedimentation/Siltation	1996	6/2/2003	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2024	2026 (est.)	5/5A
WH	Fully Supporting				

AU Comment: TMDL for SBD (sedimentation/siltation).

Rio Guadalupe (Jemez River to confl with Rio Cebolla)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_30	20.6.4.108	STREAM, PERENNIAL	13.79 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Nutrients	2016	9/23/2016	4A
		Turbidity	2016	12/2/1999	4A
		Specific Conductance	2016	11/24/2021	4A
		Temperature	2008	9/1/2009	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Special Designation Streams, 2024). Specific conductance TMDL EPA approved November 2021. TMDL for Al chronic (2003), turbidity, and SBD (1999) (sedimentation/siltation); de-list letter for total phosphorus. De-listed for sedimentation/siltation in 2008. A TMDL was prepared for temperature (2009).

Rio de las Vacas (Clear Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_46	20.6.4.108	STREAM, PERENNIAL	10.66 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	pH	2024	2026 (est.)	5/5C
		Aluminum, Total Recoverable	2016		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). Natural conditions may contribute to high aluminum concentrations in the Jemez Mountains; aluminum criteria may need review to identify appropriate/attainable levels.

Rio de las Vacas (Rio Cebolla to Clear Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_40	20.6.4.108	STREAM, PERENNIAL	15.61 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	1998	6/2/2003	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for temperature and TOC (2003). A TMDL was prepared for plant nutrients (2009).					

Rito Cafe (Rito Penas Negras to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_41	20.6.4.108	STREAM, PERENNIAL	4.49 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Rito Penas Negras (Rio de las Vacas to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_42	20.6.4.108	STREAM, PERENNIAL	10.1 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	1998	6/2/2003	4A
		Nutrients	2008	9/15/2009	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2024	2026 (est.)	5/5A
WH	Fully Supporting				

AU Comment: TMDL for temperature, TOC, and SBD (sedimentation/siltation) (2003). A TMDL was prepared for plant nutrients (2009). AU may not be perennial -- HP and WQS review needed.

Rito de las Palomas (Rio de las Vacas to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_43	20.6.4.108	STREAM, PERENNIAL	5.8 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Turbidity	2010		5/5B
		Specific Conductance	2024	2006 (est.)	5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). TMDLs were prepared for temperature and sedimentation/siltation (2009). AU may not be perennial -- HP and WQS review needed.

Rito de los Indios (San Antonio Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_24	20.6.4.108	STREAM, PERENNIAL	4.57 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Nutrients	2016		5/5A
		Aluminum, Total Recoverable	2024	2026 (est.)	5/5B
		Temperature	2016	11/24/2021	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Special Designation Streams, 2024). Temperature and turbidity TMDL EPA approved November 2021.

San Antonio Creek (East Fork Jemez to VCNP bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_20	20.6.4.108	STREAM, PERENNIAL	12.62 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	1998	6/2/2003	4A
		Aluminum, Total Recoverable	2016		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Upper Rio Grande, 2023). TMDL for turbidity and temperature (2003). TMDL for arsenic (2009). Natural conditions may contribute to high aluminum concentrations in the Jemez Mountains; aluminum criteria may need review to identify appropriate/attainable levels.

San Antonio Creek (VCNP bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_26	20.6.4.108	STREAM, PERENNIAL	19.5 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Aluminum, Total Recoverable	2016		5/5B
		Nutrients	2016		5/5B
		Temperature	1998	6/2/2003	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Upper Rio Grande, 2023). TMDL for temperature (2003). Natural conditions may contribute to high aluminum concentrations in the Jemez Mountains; aluminum criteria may need review to identify appropriate/attainable levels. In addition, the low pH in this AU is likely contributing to increased metals concentrations. AU may not be perennial -- HP and WQS review needed.

San Gregorio Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.B_10	20.6.4.134	RESERVOIR	35.93 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Nutrients	2016	2021 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). This reservoir has a headgate on one end of the dam that is the beginning of Nacimiento Creek (Rio Puerco Watershed). The dam also has a spillway that empties into Clear Creek, which is in the Jemez watershed. The water level June 2004 did not reach this spillway.

San Luis Creek (San Antonio Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_28	20.6.4.98	STREAM, INTERMITTENT	5.75 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: ONRW (Special Designation Streams, 2024).

Sulphur Creek (Redondo Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_22	20.6.4.124	STREAM, PERENNIAL	8.02 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Supporting	Aluminum, Dissolved	2024	2026 (est.)	5/5B
LW	Fully Supporting				
SC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Special Designation Streams, 2024). TMDL were previously prepared for pH and conductivity. WQS change to 20.6.4.124 resulted in de-list (pH is naturally low in this watershed). Natural conditions may contribute to high aluminum concentrations in the Jemez Mountains; aluminum criteria may need review to identify appropriate/attainable levels.

Sulphur Creek (San Antonio Creek to Redondo Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_27	20.6.4.108	STREAM, PERENNIAL	1.01 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Aluminum, Dissolved	2024		5/5B
		Turbidity	2010		5/5B
IRR	Not Supporting	Aluminum, Dissolved	2024		5/5B
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Natural conditions may contribute to high aluminum concentrations in the Jemez Mountains; aluminum criteria may need review to identify appropriate/attainable levels. In addition, the low pH in this AU is likely contributing to increased metals concentrations. HP needed -- this AU may not be perennial. pH applicable to 20.6.4.108 NMAC not attainable given naturally low pH in upstream AU.

Tributary D (Jaramillo Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_47	20.6.4.98	STREAM, INTERMITTENT	0.96 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Vallecito Ck (Jemez Pueblo bnd to Div abv Ponderosa)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2105.5_20	20.6.4.98	STREAM, INTERMITTENT	3.51 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Supporting	Arsenic, Dissolved	2016	11/24/2021	4A
PC	Not Assessed				
WH	Not Assessed				

AU Comment: Dissolved arsenic TMDL EPA approved November 2021.

Vallecito Ck (Perennial Prt Div abv Ponderosa to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2105.5_21	20.6.4.107	STREAM, PERENNIAL	13.14 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Sedimentation/Siltation	2016	2023 (est.)	5/5A
		Turbidity	2010	2023 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: Sometimes referred to as Paliza Creek because it flows through Paliza Canyon.					

Virgin Canyon (Rio Guadalupe to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020202 Jemez	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2106.A_31	20.6.4.108	STREAM, PERENNIAL	15.75 MILES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

HUC: 13020203 Rio Grande-Albuquerque

Abo Arroyo (Rio Grande to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2103.A_40	20.6.4.112	STREAM, PERENNIAL	38.75 MILES	2024	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Canon de Domingo Baca (Arroyo de Domingo Baca to outfall)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_020	20.6.4.98	STREAM, INTERMITTENT	3.66 MILES	2016	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.

Cedro Canyon (Tijeras Arroyo to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_018	20.6.4.98	STREAM, INTERMITTENT	9.59 MILES	2016	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.

La Canada de la Loma Arena (La Constancia Ditch to outfall)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_021	20.6.4.98	STREAM, INTERMITTENT	0.31 MILES	2016	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.					

La Joya Lakes			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2103.B_10	20.6.4.105	RESERVOIR	83.17 ACRES	2016	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
PWS	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Rio Grande (Arroyo de las Canas to Rio Puerco)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2105_11	20.6.4.105	RIVER	30.48 MILES	2016	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Copper, Dissolved	2016	2023 (est.)	5/5A
		Aluminum, Total Recoverable	2016	4/26/2018	4A
PC	Not Supporting	E. coli	2008	6/30/2010	4A
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: TMDLs for e. coli and dissolved aluminum (2010). The dissolved aluminum TMDL was revised to a total recoverable aluminum TMDL in 2018 using the current applicable WQC.

Rio Grande (Isleta Pueblo boundary to Tijeras Arroyo)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2105_50	20.6.4.105	RIVER	5.14 MILES	2022	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	PCBS - Fish Consumption Advisory	2010		5/5C
		Mercury - Fish Consumption Advisory	2020		5/5C
		Dissolved oxygen	2008		5/5C
PC	Not Supporting	E. coli	2008	6/30/2010	4A
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: TMDL for E. coli. Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Rio Grande (Middle) drains, canals, conveyances			AU IR CATEGORY	LOCATION DESCRIPTION	
				HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_01x	unclassified	DITCH OR CANAL	0 MILES		2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**

AU Comment: This is a catch-all unassessed AU for lake inlets/outlets, irrigation canals, drains, and conveyances in the Middle Rio Grande basin.

Rio Grande (Rio Puerco to Isleta Pueblo bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2105_40	20.6.4.105	RIVER	39.41 MILES	2026	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Temperature	2010	2023 (est.)	5/5A
PC	Not Supporting	E. coli	2008	6/30/2010	4A
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: TMDL for E. coli (2010).					

Rio Grande (San Marcial at USGS gage to Arroyo de las Canas)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2105_10	20.6.4.105	RIVER	30.13 MILES	2026	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Temperature Aluminum, Total Recoverable	2016 2016	2023 (est.) 4/26/2018	5/5A 4A
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: TMDLs for e. coli and dissolved aluminum (2010). The dissolved aluminum TMDL was revised to a total recoverable aluminum TMDL in 2018 using the current applicable WQC.					

Rio Grande (Tijeras Arroyo to Alameda Bridge)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2105_51	20.6.4.105	RIVER	15.6 MILES	2026	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Temperature	2010	2023 (est.)	5/5A
		PCBS - Fish Consumption Advisory	2010		5/5C
		Dissolved oxygen	2008	2023 (est.)	5/5A
		Mercury - Fish Consumption Advisory	2020		5/5C
PC	Not Supporting	E. coli	2020	6/30/2010	4A
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: TMDL for E. coli. Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Rio Grande (non-pueblo Alameda Bridge to HWY 550 Bridge)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2105.1_00	20.6.4.106	RIVER	12.12 MILES	2026	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Not Supporting	Gross Alpha, Adjusted	2012	2023 (est.)	5/5A
MWWAL	Not Supporting	PCBS - Fish Consumption Advisory	2010		5/5C
		Polychlorinated Biphenyls (PCBs)	2012	2023 (est.)	5/5A
		Mercury - Fish Consumption Advisory	2020		5/5C
PC	Not Supporting	E. coli	2020	6/30/2010	4A
PWS	Not Assessed				
WH	Not Supporting	Polychlorinated Biphenyls (PCBs)	2012	2023 (est.)	5/5A

AU Comment: TMDL for E. coli (2010). Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Rio Grande (non-pueblo HWY 550 Bridge to Angostura Div)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2105.1_02	20.6.4.106	RIVER	2.41 MILES	2026	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Not Supporting	E. coli	2020	6/30/2010	4A
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: TMDL for fecal coliform. De-listed for fecal coliform because this criteria was replaced with E. coli during the 2005 triennial review. TMDL for E. coli 2010.

Tijeras Arroyo (Four Hills Bridge to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_001	20.6.4.99	STREAM, PERENNIAL	15.65 MILES	2018	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	Nutrients	2008	10/11/2017	4A
WH	Fully Supporting				

AU Comment: This entire AU may not be perennial. This upper AU is often referred to as Tijeras Creek or Tijeras Canyon. TMDL for nutrients (2017).

Tijeras Arroyo (Rio Grande to Four Hills Bridge)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_070	20.6.4.97	STREAM, EPHEMERAL	13.42 MILES	2008	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: The WQCC approved the 2025 Tijeras Arroyo UAA. As a result of the amendment Tijeras Arroyo (Rio Grande to Four Hills Bridge) has been placed in 20.6.4.97 NMAC.

Unnamed tributary (South Diversion Channel to I-25)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_015	20.6.4.97	STREAM, EPHEMERAL	0.87 MILES	2016	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013.

Unnamed tributary (div channel to Fire Academy outfall)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020203 Rio Grande-Albuquerque	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_014	20.6.4.97	STREAM, EPHEMERAL	1.32 MILES	2016	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013.
Firefighters Academy, permit NM0029726 has since been terminated.

HUC: 13020204 Rio Puerco

Arroyo San Jose (Rio Puerco to La Jara Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_39	20.6.4.98	STREAM, INTERMITTENT	6.37 MILES	2006	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: Application of the SWQB Hydrology Protocol (survey date 9/16/08) indicate this assessment unit is ephemeral (Hydrology Protocol score of 6.5- see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol). The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this waterbody will remain under 20.6.4.98 NMAC.

Canon del Piojo S Fk (main canyon to ranch pond)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_016	20.6.4.97	STREAM, EPHEMERAL	4.76 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013. Resurrection Mining, permit NM0028169					

La Jara Creek (Perennial reaches abv Arroyo San Jose)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_46	20.6.4.109	STREAM, PERENNIAL	10.3 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Aluminum, Total Recoverable	2014	6/16/2016	4A
DWS	Fully Supporting				
FC	Not Assessed				
IRR	Fully Supporting				
LW	Not Assessed				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013). TMDL for aluminum (2016).					

Nacimiento Ck (Perennial prt HWY 126 to Clear Creek)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_42	20.6.4.109	STREAM, PERENNIAL	7.77 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Aluminum, Total Recoverable	2014	6/16/2016	4A
		Temperature	2024	2026 (est.)	5/5A
		Turbidity	2014	6/16/2016	4A
DWS	Fully Supporting				
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDLs for turbidity, aluminum, and uranium (2016).					

Nacimiento Creek (Rio Puerco to HWY 126)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_47	20.6.4.98	STREAM, INTERMITTENT	2.15 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Rio Puerco (Arroyo Chijuilla to northern bnd Cuba)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_40	20.6.4.131	STREAM, PERENNIAL	9.22 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	Nutrients	2006	9/21/2007	4A
		Sedimentation/Siltation	2004	8/10/2007	4A
		Aluminum, Total Recoverable	2024	2026 (est.)	5/5A
WH	Fully Supporting				

AU Comment: TMDLs were prepared for sedimentation, chronic dissolved Al, and nutrients (2007). Dissolved Al TMDL withdrawn 2018 because no longer an applicable WQC.

Rio Puerco (Perennial prt northern bnd Cuba to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_44	20.6.4.109	STREAM, PERENNIAL	14.83 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Aluminum, Total Recoverable	2024	2026 (est.)	5/5A
		Sedimentation/Siltation	2014	6/16/2016	4A
DWS	Fully Supporting				
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2024	2026 (est.)	5/5A
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). TMDL for sedimentation/siltation (2016).

Rio Puerco (non-pueblo Arroyo Chico to Arroyo Chijuilla)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2105_22	20.6.4.130	STREAM, INTERMITTENT	45.86 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2024	2026 (est.)	5/5A
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Rio Puerco (non-pueblo Rio Grande to Arroyo Chico)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2105_20	20.6.4.130	STREAM, INTERMITTENT	113.29 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2012	2022 (est.)	5/5A
WWAL	Not Supporting	Aluminum, Total Recoverable	2024	2026 (est.)	5/5A
WH	Fully Supporting				
AU Comment: None.					

Rito Leche (Intermittent reaches above HWY 126)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_43	20.6.4.98	STREAM, INTERMITTENT	7.02 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Rito Leche (Rio Puerco to Hwy 126)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_53	20.6.4.98	STREAM, INTERMITTENT	1.59 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Fully Supporting				
WH	Not Assessed				

AU Comment: None.

Rito de los Pinos (Arroyo San Jose to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_45	20.6.4.98	STREAM, INTERMITTENT	8.87 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: ONRW (USFS Wilderness Areas, 2013). Application of the SWQB Hydrology Protocol (survey date 9/16/08) indicate this assessment unit is ephemeral (Hydrology Protocol score of 0.0 and 3.5 at two stations - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol). The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to a waterbody under 20.6.4.97 NMAC. Until such time, this waterbody will remain under 20.6.4.98 NMAC.

San Miguel Arroyo (San Pablo Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_51	20.6.4.98	STREAM, INTERMITTENT	11.09 MILES	2006	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: Application of the SWQB Hydrology Protocol (survey date 6/16/09) indicate this assessment unit is intermittent (Hydrology Protocol score of 17.0 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol).

San Pablo Canyon (Rio Puerco to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_41	20.6.4.98	STREAM, INTERMITTENT	13 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Application of the SWQB Hydrology Protocol on 9/18/08 at the station immediately above the Rio Puerco indicate this AU is ephemeral (Hydrology Protocol of 5.5), while surveys on 9/19/11 and 10/27/11 at FR 20/533 indicate intermittent (Hydrology Protocol scores of 19 and 16.5, respectively). See https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol.

Senorito Creek (Nacimiento Mine to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_54	20.6.4.109	STREAM, PERENNIAL	3.54 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Fully Supporting				
DWS	Fully Supporting				
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Senorito Creek (San Pablo Canyon to Nacimiento Mine)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_52	20.6.4.98	STREAM, INTERMITTENT	6.18 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

Unnamed tributary (Canon del Piojo S Fk to mine outfall)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020204 Rio Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_017	20.6.4.97	STREAM, EPHEMERAL	0.92 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013. Resurrection Mining, permit NM0028169

HUC: 13020205 Arroyo Chico

Arroyo Chico (Rio Puerco to San Isidro Arroyo)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020205 Arroyo Chico	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_016	20.6.4.98	STREAM, INTERMITTENT	33.61 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Arroyo Tinaja (San Isidro Arroyo to two mi blw USFS bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020205 Arroyo Chico	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_023	20.6.4.97	STREAM, EPHEMERAL	28.09 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012 and updated in 2019. EPA provided technical approval January 30, 2013, and April 9, 2020.
Lee Ranch Mine permit NM0029581

Doctor Arroyo (San Isidro Arroyo to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020205 Arroyo Chico	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_25	20.6.4.97	STREAM, EPHEMERAL	8.06 MILES	2020	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC. EPA provided technical approval April 9, 2020. Lee Ranch Mine permit NM0029581. ** This AU excludes Doctor Spring and Doctor arroyo from the spring to its confluence with the unnamed tributary approximately one-half mile downstream of the spring.					

Inditos Draw (breached road berm to hdwtrs)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020205 Arroyo Chico	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_021	20.6.4.97	STREAM, EPHEMERAL	3.6 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013. Lee Ranch Coal Co El Segundo mine, permit NM0030996					

Mulatto Canyon (Arroyo Tinaja to one mi blw USFS bnd)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13020205 Arroyo Chico	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_024	20.6.4.97	STREAM, EPHEMERAL	4.26 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013. Lee Ranch Mine permit NM0029581					

San Isidro Arroyo (Arroyo Chico to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020205 Arroyo Chico	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_022	20.6.4.97	STREAM, EPHEMERAL	25.77 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012 and updated in 2019. EPA provided technical approval January 30, 2013, and April 9, 2020.
Lee Ranch Mine permit NM0029581

San Lucas Canyon (San Miguel Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020205 Arroyo Chico	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_014	20.6.4.98	STREAM, INTERMITTENT	14.74 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

San Miguel Creek (Arroyo Chico to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020205 Arroyo Chico	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_015	20.6.4.98	STREAM, INTERMITTENT	30.15 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

HUC: 13020206 North Plains

Laguna Americana			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020206 North Plains	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_053	20.6.4.98	LAKE, PLAYA	25.3 ACRES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: Part of playa lake study. Data are old.

Springs (isolated)			AU IR CATEGORY	LOCATION DESCRIPTION	
				HUC: 13020206 North Plains	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-8888_00	unclassified	SPRING	0 MILES		2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**

AU Comment: None.

HUC: 13020207 Rio San Jose

Arroyo del Puerto (San Mateo Ck to mine entrance rd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020207 Rio San Jose	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_018	20.6.4.97	STREAM, EPHEMERAL	8.26 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013.

Arroyo del Valle (Laguna Pueblo bnd to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13020207 Rio San Jose	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_030	20.6.4.98	STREAM, INTERMITTENT	13.23 MILES	2018	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Supporting	Gross Alpha, Adjusted	2018	2021 (est.)	5/5A
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU will remain under 20.6.4.98 NMAC.					

Bluewater Creek (Perennial prt Bluewater Rsvr to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 13020207 Rio San Jose	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_01	20.6.4.109	STREAM, PERENNIAL	18.31 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	1998	9/21/2007	4A
DWS	Fully Supporting				
IRR	Fully Supporting				
LW	Not Assessed				
PC	Fully Supporting				
WH	Not Assessed				
AU Comment: TMDLs were prepared for temperature and plant nutrients (2007). WQS temperature review is warranted in this AU.					

Bluewater Creek (Perennial prt R San Jose to Bluewater Rsvr)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020207 Rio San Jose	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_00	20.6.4.109	STREAM, PERENNIAL	11.44 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients	1998	9/21/2007	4A
		Temperature	2006	9/21/2007	4A
DWS	Fully Supporting				
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: Non-tribal portions only. TMDLS were completed for temperature and nutrients (2007).					

Bluewater Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020207 Rio San Jose	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.B_00	20.6.4.135	RESERVOIR	617.1 ACRES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients	2014	11/24/2021	4A
		Mercury - Fish Consumption Advisory	2024		5/5C
DWS	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Fully Supporting				
WH	Not Assessed				
AU Comment: Total nitrogen and total phosphorus TMDL EPA approved November 2021.					

Rio Moquino (Laguna Pueblo to Seboyettia Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13020207 Rio San Jose	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_10	20.6.4.109	STREAM, PERENNIAL	2.13 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients	2006	9/21/2007	4A
		Temperature	1998	9/21/2007	4A
DWS	Not Assessed				
FC	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: TMDLs were completed for temperature and nutrients (2007). There may not be adequate flow in the lower portions of this reach to sustain a CWAL.					

Rio Paguate (Laguna Pueblo bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020207 Rio San Jose	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_30	20.6.4.109	STREAM, PERENNIAL	10.78 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Phosphorus, Total	2026		5/5A
DWS	Not Assessed				
FC	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: The USGS gage used to make the original impairment determinations is downstream of Jackpile Mine, which is on pueblo land and not in the AU.					

Rio San Jose (Grants BNSF RR crossing to Bluewater Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3C	HUC: 13020207 Rio San Jose	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_028	20.6.4.98	STREAM, INTERMITTENT	16.47 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU may have naturally ephemeral portions.					

Rio San Jose (non-tribal HWY 117 to Grants BNSF RR crossing)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13020207 Rio San Jose	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_003	20.6.4.99	STREAM, PERENNIAL	9.19 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: The upper AU may be naturally ephemeral.					

Seboyeta Creek (Rio Moquino to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020207 Rio San Jose	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2107.A_20	20.6.4.109	STREAM, PERENNIAL	18.19 MILES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
DWS	Not Assessed				
FC	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: Access issues.					

Unnamed tributary (San Mateo Cr to mine outfall)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13020207 Rio San Jose	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_019	20.6.4.97	STREAM, EPHEMERAL	3.09 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassifie Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013.
Strathmore Roca Honda, permit NM0031020

HUC: 13020209 Rio Salado

Rio Salado (Rio Grande to Alamo Navajo bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020209 Rio Salado	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2103.A_10	20.6.4.112	STREAM, PERENNIAL	44.47 MILES	2024	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Temperature	2016		5/5C
PC	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: A second thermograph should be deployed to confirm the temperature listing.

Rio Salado (non-pueblo lands)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020209 Rio Salado	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_002	20.6.4.98	STREAM, INTERMITTENT	6.88 MILES	1998	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: Application of the SWQB Hydrology Protocol (survey date 9/10/2008) indicate this assessment unit is intermittent (Hydrology Protocol score of 11.25 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol).

HUC: 13020211 Elephant Butte Reservoir

Alamosa Creek (Perennial reaches abv Monticello diversion)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13020211 Elephant Butte Reservoir	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2103.A_30	20.6.4.112	STREAM, PERENNIAL	13.44 MILES	2024	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Elephant Butte Reservoir			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13020211 Elephant Butte Reservoir	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2104_00	20.6.4.104	RESERVOIR	10908.5 ACRES	2022	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR Storage	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	Mercury - Fish Consumption Advisory	2004		5/5C
		PCBS - Fish Consumption Advisory	2010		5/5C
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern. The actual size of this AU at any given time depends on fluctuating surface area and reservoir volume.

Rio Grande (Elephant Butte Rsvr to San Marcial at USGS)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13020211 Elephant Butte Reservoir	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2105_00	20.6.4.105	RIVER	32.99 MILES	2016	2025
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Aluminum, Total Recoverable	2016	2023 (est.)	5/5A
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: The actual length of this AU at any given time depends on Elephant Butte's fluctuating surface area.

HUC: 13030101 Caballo

Caballo Reservoir			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13030101 Caballo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2102.B_00	20.6.4.104	RESERVOIR	4440.7 ACRES	2022	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR Storage	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	Mercury - Fish Consumption Advisory	2004		5/5C
		Nutrients	2016	2024 (est.)	5/5A
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Cuchillo Negro Creek (Rio Grande to Willow Spring Draw)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13030101 Caballo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_012	20.6.4.98	STREAM, INTERMITTENT	10.53 MILES	2016	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.					

Las Animas Ck (perennial prt Animas Gulch to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13030101 Caballo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2103.A_50	20.6.4.112	STREAM, PERENNIAL	27.18 MILES	2024	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Dissolved oxygen	2014		5/5C
		Benthic Macroinvertebrates	2010		5/5C
PC	Not Assessed				
WWAL	Not Supporting	Benthic Macroinvertebrates	2010		5/5C
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Las Animas Ck (perennial prt R Grande to Animas Gulch)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13030101 Caballo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2103.A_51	20.6.4.112	STREAM, PERENNIAL	12.93 MILES	2026	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
MCWAL	Not Supporting	Temperature	2022	9/8/2023	4A
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				

AU Comment: TMDL (Gila, Mimbres, SFR) for temperature EPA approved August 2024.

Palomas Creek (perennial portion R Grande to N and S Forks)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13030101 Caballo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2103.A_60	20.6.4.112	STREAM, PERENNIAL	24.13 MILES	2024	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Percha Ck (Caballo Rsvr to Wicks Gulch)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13030101 Caballo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2103.A_21	20.6.4.98	STREAM, INTERMITTENT	12.65 MILES	2020	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Percha Ck (Perennial prt Wicks Gulch to Middle Percha Ck)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 13030101 Caballo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2103.A_20	20.6.4.112	STREAM, PERENNIAL	12.76 MILES	2024	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment:					

Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13030101 Caballo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2103.A_00	20.6.4.112	RIVER	14.5 MILES	2024	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Dissolved oxygen	2006		5/5C
PC	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: The dissolved oxygen impairment may indicate excessive nutrients. Protocols for nutrients in large rivers are under development.					

South Fork Palomas Ck (Palomas Ck to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13030101 Caballo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2103.A_61	20.6.4.112	STREAM, PERENNIAL	23.43 MILES	2014	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
MCWAL	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

HUC: 13030102 El Paso-Las Cruces

Burn Lake (Dona Ana)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13030102 El Paso-Las Cruces	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_024	20.6.4.99	RESERVOIR	20.36 ACRES	2018	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Rio Grande (International Mexico bnd to TX border)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13030102 El Paso-Las Cruces	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2101_00	20.6.4.101	RIVER	7.95 MILES	2022	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Supporting	Boron, Dissolved	2014	9/8/2023	4A
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for E. coli (2007). TMDL (Gila, Mimbres, SFR) for Boron EPA approved August 2024.					

Rio Grande (Leasburg Dam to one mile below Percha Dam)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13030102 El Paso-Las Cruces	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2101_10	20.6.4.101	RIVER	42.61 MILES	2014	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Not Supporting	E. coli	2006	6/11/2007	4A
WH	Fully Supporting				
AU Comment: TMDL for e. coli.					

Rio Grande (NM192 bridge W of Mesquite to Picacho Bridge)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13030102 El Paso-Las Cruces	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2101_03	20.6.4.101	RIVER	13.87 MILES	2014	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for E. coli.					

Rio Grande (Picacho Bridge to Leasburg Dam)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13030102 El Paso-Las Cruces	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2101_02	20.6.4.101	RIVER	17.58 MILES	2014	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for E. coli.					

Rio Grande (TX border to NM192 bridge W of Mesquite)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13030102 El Paso-Las Cruces	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2101_01	20.6.4.101	RIVER	14.11 MILES	2024	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for E. coli.					

Rio Grande (one mile below Percha Dam to Caballo Reservoir)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13030102 El Paso-Las Cruces	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2102.A_00	20.6.4.102	RIVER	3.2 MILES	2022	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

South Fork Las Cruces Arroyo (Las Cruces Arroyo to hdwtrs)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13030102 El Paso-Las Cruces	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_013	20.6.4.98	STREAM, INTERMITTENT	8.11 MILES	2016	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU will remain under 20.6.4.98 NMAC.					

Tierra Blanca Creek (Rio Grande to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13030102 El Paso-Las Cruces	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2103.A_70	20.6.4.98	STREAM, INTERMITTENT	36.09 MILES	2014	2031
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Fully Supporting				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

HUC: 13030200

Unassessed waters with no AU			AU IR CATEGORY	LOCATION DESCRIPTION	
				HUC: 13030200	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-UNASSESSED	Unassessed	RIVER	0 MILES		
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**

AU Comment: None.

HUC: 13030202 Mimbres

Allie Canyon (Mimbres River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2804_20	20.6.4.804	STREAM, PERENNIAL	9.01 MILES	2004	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Bear Canyon (Mimbres River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2804_10	20.6.4.804	STREAM, PERENNIAL	12.06 MILES	2004	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Bear Canyon Reservoir			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2504_30	20.6.4.806	RESERVOIR	29.78 ACRES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	2012	2024 (est.)	5/5C
		Nutrients	2004	2021 (est.)	5/5A
		Mercury - Fish Consumption Advisory	2004		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Cameron Creek (San Vicente Arroyo to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2803_32	20.6.4.98	STREAM, INTERMITTENT	24.05 MILES	2018	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.

Cold Springs Creek (Hot Springs Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2803_11	20.6.4.803	STREAM, PERENNIAL	9.6 MILES	2026	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Lead, Dissolved	2012	9/11/2014	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Application of the SWQB Hydrology Protocol (survey date 5/26/09) indicate this assessment unit is perennial (Hydrology Protocol score of 20.0 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol). Metal pollutants due to legacy mining in the upper watershed. The Forest Service began a comprehensive reclamation effort in 2019 which was underway during the 2019 survey and completed prior to 2020 survey.

Gallinas Creek (Little Gallinas Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2803_20	20.6.4.803	STREAM, PERENNIAL	14.34 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Nutrients	2012		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Application of the SWQB Hydrology Protocol (5/26/09 survey date) indicate this assessment unit is perennial (Hydrology Protocol score of 18.5 to 22.5 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol).

Gallinas Creek (Mimbres River to Little Gallinas Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2803_21	20.6.4.98	STREAM, PERENNIAL	7.47 MILES	2020	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Hanover Creek (Whitewater Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2803_31	20.6.4.98	STREAM, INTERMITTENT	7.7 MILES	2004	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.					

Hot Springs Ck (Perennial prt of Mimbres R to USFS bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2803_10	20.6.4.803	STREAM, PERENNIAL	5.96 MILES	2020	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: The perennial portion is privately owned -- SWQB was denied access during watershed surveys (2002 and 2009).					

Hot Springs Ck (USFS bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2803_12	20.6.4.98	STREAM, INTERMITTENT	5.26 MILES	2020	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

McKnight Canyon (Mimbres River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2804_30	20.6.4.804	STREAM, PERENNIAL	15.01 MILES	2012	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Gila Trout restoration in 1972 by NMG&F.

Mimbres R (Perennial reaches Allie Canyon to Cooney Cny)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2804_00	20.6.4.804	STREAM, PERENNIAL	11.04 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	1998	2024 (est.)	5/5B
DWS	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: CWAL may not be attainable; WQS review needed. Coolwater fishes present.

Mimbres R (Perennial reaches Cooney Cyn to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2804_40	20.6.4.807	STREAM, PERENNIAL	12.6 MILES	2026	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2022	9/8/2023	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). TMDL (Gila, Mimbres, SFR) for temperature EPA approved August 2024. AU flows mostly through a designated wilderness area with only the very bottom of the AU accessible by road. Chihuahua Chub at lower end of AU.

Mimbres R (Perennial reaches downstream of Allie Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2803_00	20.6.4.803	STREAM, PERENNIAL	30.45 MILES	2018	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2012	9/11/2014	4A
WH	Fully Supporting				

AU Comment: This AU near the ecoregion boundary and is more closely associated with ecoregion 24b (Chihuahuan Desert). AU is subject to irrigation diversions/returns.

Pinos Altos Creek (San Vicente Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2803_33	20.6.4.98	STREAM, INTERMITTENT	6.34 MILES	2026	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Supporting	Dissolved oxygen	2026	2030 (est.)	5/5C
PC	Fully Supporting				
WH	Not Assessed				

AU Comment: None.

San Vicente Arroyo (Mimbres R to Maudes Cny)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_026	20.6.4.97	STREAM, EPHEMERAL	31.7 MILES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Hydrology Protocol-based UAA concluded this reach was ephemeral. UAA was approved by EPA in Oct 2013. Perennial reaches of San Vicente above Maudes Canyon remain classified in 20.6.4.803.

San Vicente Creek (Perennial prt Maudes Cny to Silva Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_025	20.6.4.803	STREAM, PERENNIAL	5.65 MILES	2026	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Nutrients	2012		5/5A
IRR	Not Assessed				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2026	2030 (est.)	5/5A
WH	Fully Supporting				

AU Comment: San Vicente below Maudes Canyon was approved by EPA as ephemeral 97 in Dec 2013. Perennial reaches of San Vicente above Maudes Canyon remain classified in 20.6.4.803.

Whitewater Creek (San Vicente Arroyo to Chino Mine)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13030202 Mimbres	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2803_30	20.6.4.98	STREAM, INTERMITTENT	27.35 MILES	2018	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

HUC: 13050001 Western Estancia

Laguna del Pero			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13050001 Western Estancia	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_054	20.6.4.98	LAKE, PLAYA	4476.81 ACRES	1998	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: Water is too saline for cattle, so livestock watering may not be an existing or attainable use.

Mike's Playa			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13050001 Western Estancia	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_085	20.6.4.98	LAKE, PLAYA	21.21 ACRES	1998	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: Water is too saline for cattle, so livestock watering may not be an existing or attainable use.

HUC: 13050003 Tularosa Valley

Dog Canyon Creek (perennial portions)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2801_20	20.6.4.810	STREAM, PERENNIAL	6.06 MILES	2018	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Temperature	2006		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: A UAA to create 20.6.4.810 NMAC for this water body with coolwater aquatic life use was approved by the WQCC (effective 2/28/18 for state purposes). This AU has been absorbed into the new subwatershed-based AU "Dog Canyon subwatershed". Refer to AU ID W_NM-317-03 from this cycle onwards.

Dog Canyon subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-317-03	20.6.4.810	WATERSHED	39.65 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Fully Supporting				
DWS	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Fresnal Canyon (La Luz Creek to Salado Canyon)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2801_41	20.6.4.801	STREAM, PERENNIAL	2.7 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Flow Regime Modification	2014		4C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2014		5/5C
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This reach is often dry below Salado Canyon where the Alamogordo diversion is installed. This AU has been absorbed into the new subwatershed-based AU "Fresnal Canyon subwatershed" . Refer to AU ID W_NM-315-01 from this cycle onwards.

Fresnal Canyon (Salado Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2801_44	20.6.4.801	STREAM, PERENNIAL	10.49 MILES	2018	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Fresnal Canyon subwatershed" . Refer to AU ID W_NM-315-01 from this cycle onwards.

Fresnal Canyon subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-315-01	20.6.4.801	WATERSHED	41.4 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Karr Canyon (Fresnal Canyon to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2801_42	20.6.4.801	STREAM, PERENNIAL	6.64 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Sedimentation/Siltation	2014	2023 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Fresnal Canyon subwatershed" . Refer to AU ID W_NM-315-01 from this cycle onwards.

La Luz Creek (Fresnal Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2801_40	20.6.4.98	STREAM, INTERMITTENT	13.96 MILES	2020	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "La Luz Creek subwatershed" . Refer to AU ID W_NM-315-03 from this cycle onwards.

La Luz Creek subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-315-03	20.6.4.98	WATERSHED	59.8 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Lake Holloman			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_113	20.6.4.99	LAKE, PLAYA	147.57 ACRES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Not Supporting	pH	2026	2027 (est.)	5/5A
WWAL	Not Supporting	pH	2026	2027 (est.)	5/5A
		Arsenic, Dissolved	2010	2027 (est.)	5/5A
WH	Fully Supporting				

AU Comment: Lake is actually an impounded playa. Although the reservoir is associated with Holloman Air Force Base, the public does have access. The New Mexico Department of Health is warning people not to swim in or drink from Lake Holloman in southern New Mexico as of May 10, 2019. the lake already is off limits to swimming but state officials reiterated their warning saying people should wash their hands if they get water or foam from the lake on them. They also warned pet owners to avoid letting their animals drink or come into contact with the water or foam. This lake has very high salinity, and is thus not suitable for livestock watering or supporting a viable fishery. Limited aquatic life might be a more realistic use based on salinity.

Lake Lucero (North)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_068	20.6.4.98	LAKE, PLAYA	3325.66 ACRES	1998	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Lake Lucero (South)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_069	20.6.4.98	LAKE, PLAYA	1962.25 ACRES	1998	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Lake Stinky			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_070	20.6.4.99	LAKE, PLAYA	73.6 ACRES	1998	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Lower Rio Tularosa subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-312-06	20.6.4.99	WATERSHED	45.39 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Lower San Andres Canyon subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-317-05.B	20.6.4.97	WATERSHED	116.15 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Malpais Springs			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_079	20.6.4.99	LAKE, PLAYA	14.95 ACRES	1998	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: Habitat for White Sands pup fish.					

Mound Springs			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_086	20.6.4.99	LAKE, PLAYA	0.51 ACRES	1998	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: Habitat for White Sands pup fish.					

Nogal Creek (Tularosa Creek to Mescalero Apache bnd)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2801_10	20.6.4.801	STREAM, PERENNIAL	4.36 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	2014	2023 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2014	9/21/2015	4A
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: This AU has been absorbed into the new subwatershed-based AU "Upper Rio Tularosa subwatershed". Refer to AU ID W_NM-312-05 from this cycle onwards.					

Salado Canyon (Fresnal Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2801_43	20.6.4.801	STREAM, PERENNIAL	5.09 MILES	2016	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: This AU has been absorbed into the new subwatershed-based AU "Fresnal Canyon subwatershed" . Refer to AU ID W_NM-315-01 from this cycle onwards.					

Salt Creek (Tularosa Valley)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2801_50	20.6.4.99	STREAM, PERENNIAL	48.45 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

San Andres Canyon (S San Andres Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2801_31	20.6.4.801	STREAM, PERENNIAL	6.34 MILES	2006	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
PWS	Not Assessed				
WH	Not Assessed				

AU Comment: This AU has very remote access. This AU has been absorbed into the new subwatershed-based AU "Upper San Andres Canyon subwatershed". Refer to AU ID W_NM-317-05.A from this cycle onwards.

San Andres Canyon (Taylor Ranch Rd to S San Andres Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2801_30	20.6.4.97	STREAM, EPHEMERAL	3.79 MILES	2006	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Hydrology Protocol-based UAA concluded this reach was ephemeral. UAA was approved by EPA in Oct 2013. Surface water has been piped in this AU.

Three Rivers (Perennial prt HWY 54 to USFS exc Mescalero)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4C	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2802_00	20.6.4.802	STREAM, PERENNIAL	15.07 MILES	2008	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Supporting	Flow Regime Modification			4C
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: There is extensive irrigation in the reach from surface water diversion as well as ground water pumping in the lower portion of the assessment unit. Therefore, this AU is listed under Category 4C with an impairment of Low Flow Alteration diversion (flow modification) "pollution" is de-watering this reach. This AU has been absorbed into the new subwatershed-based AU "Three Rivers subwatershed". Refer to AU ID W_NM-311-04 from this cycle onwards.

Three Rivers (USFS bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2802_01	20.6.4.802	STREAM, PERENNIAL	4.28 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). This AU has been absorbed into the new subwatershed-based AU "Three Rivers subwatershed". Refer to AU ID W_NM-311-04 from this cycle onwards.

Three Rivers subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-311-04	20.6.4.802	WATERSHED	265.87 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Tularosa Ck (perennial prt downstream of old HWY 70 xing)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2801_00	20.6.4.99	STREAM, PERENNIAL	19.46 MILES	2006	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Lower Rio Tularosa subwatershed" . Refer to AU ID W_NM-312-06 from this cycle onwards.

Tularosa Creek (Old HWY 70 xing to Mescalero Apache bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2801_01	20.6.4.801	STREAM, PERENNIAL	5.19 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Upper Rio Tularosa subwatershed". Refer to AU ID W_NM-312-05 from this cycle onwards.

Upper Rio Tularosa subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-312-05	20.6.4.801	WATERSHED	22.39 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Upper San Andres Canyon subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13050003 Tularosa Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-317-05.A	20.6.4.801	WATERSHED	12.27 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
PWS	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

HUC: 13050004 Salt Basin

Lower Sacramento subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13050004 Salt Basin	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-401-01.B	20.6.4.98	WATERSHED	38.38 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Sacramento R (Arkansas Canyon to Scott Able Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13050004 Salt Basin	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2805_00	20.6.4.98	STREAM, INTERMITTENT	9.11 MILES	2006	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: 2013 application of the hydro protocol indicate this AU is intermittent. This AU has been absorbed into the new subwatershed-based AU "Lower Sacramento subwatershed" . Refer to AU ID W_NM-401-01.B from this cycle onwards.

Sacramento R (Perennial prt Scott Able Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13050004 Salt Basin	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2805_02	20.6.4.805	STREAM, PERENNIAL	8.57 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Sedimentation/Siltation	2014	2023 (est.)	5/5A
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Upper Sacramento subwatershed" . Refer to AU ID W_NM-401-01.A from this cycle onwards.

Scott Able Canyon (Sacramento R to road NF-64 abv canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13050004 Salt Basin	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2805_01	20.6.4.805	STREAM, INTERMITTENT	3.08 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Lower Sacramento subwatershed". Refer to AU ID W_NM-401-01.B from this cycle onwards.

Upper Sacramento subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13050004 Salt Basin	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-401-01.A	20.6.4.805	WATERSHED	14.37 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

HUC: 13060001 Pecos Headwaters

Alamitos Canyon (Pecos River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_022	20.6.4.98	STREAM, INTERMITTENT	9.29 MILES	2012	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU likely needs to be split. The lower portion includes the reconstructed portion through Terrero Mine reclamation.

Beaver Creek (El Porvenir Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2212_04	20.6.4.215	STREAM, PERENNIAL	6.77 MILES	2012	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Blue Creek (Tecolote Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2212_15	20.6.4.215	STREAM, PERENNIAL	4.31 MILES	2012	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Blue Hole			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2211.B_10	20.6.4.212	LAKE, FRESHWATER	0.2 ACRES	2020	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Fully Supporting				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: Dissolved oxygen is naturally low due to groundwater influx. This unique water may warrant its own WQ standard segment.

Blue Hole Cienega Creek (El Rito Creek to Blue Hole)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_056	20.6.4.99	STREAM, PERENNIAL	0.5 MILES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				

AU Comment: The Blue Hole Cienega is fenced -- there is no livestock access.

Brown's Marsh			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_022	20.6.4.99	LAKE, PLAYA	8.45 ACRES	2004	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

Bull Creek (Cow Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.A_091	20.6.4.217	STREAM, PERENNIAL	16.75 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: A TMDL was written for temperature.					

Burro Canyon (Gallinas River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2212_06	20.6.4.215	STREAM, PERENNIAL	5.19 MILES	2012	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Carpenter Creek subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-2217_006	20.6.4.217	WATERSHED	2.25 SQUARE MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Supporting	Benthic Macroinvertebrates	2022	2024 (est.)	5/5C
		Sedimentation/Siltation	2022	2024 (est.)	5/5C
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: ONRW (Upper Pecos, 2023). Carpenter Creek from the Pecos River upstream to the headwaters, plus unnamed tributaries and associated wetlands as cited in NMAC 20.6.4.9 D. (h)(4) subsection (e).

Cow Creek (Bull Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.A_102	20.6.4.217	STREAM, PERENNIAL	24.84 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Benthic Macroinvertebrates	2022	2024 (est.)	5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: TMDLs for temperature and turbidity.

Cow Creek (Pecos River to Bull Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.A_090	20.6.4.217	STREAM, PERENNIAL	16.1 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	1998	9/13/2005	4A
		Benthic Macroinvertebrates	2022	2024 (est.)	5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDLs for temperature and turbidity. HQCWAL may not be attainable.					

Dalton Cyn subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-2217_000	20.6.4.217	WATERSHED	14.63 SQUARE MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Upper Pecos, 2023). Dalton Canyon Creek from the Pecos River upstream to the headwaters and Wild Horse Creek from Dalton Canyon creek upstream to the headwaters, plus unnamed tributaries and associated wetlands as cited in NMAC 20.6.4.9 D. (h)(4) subsection (b). Portions went dry during the 2001, 2010 and 2019 surveys. HQCWAL may not be attainable -- WQS review needed					

Davis Creek subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-2098_001	20.6.4.98	WATERSHED	1.88 SQUARE MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Upper Pecos, 2023). Davis Creek from the Pecos River upstream to the headwaters, plus unnamed tributaries and associated wetlands as cited in NMAC 20.6.4.9 D. (h)(4) subsection (c).					

El Porvenir Creek (Gallinas River to SFNF bnd)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2212_01	20.6.4.215	STREAM, PERENNIAL	2.68 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Benthic Macroinvertebrates	2022	2024 (est.)	5/5C
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

El Porvenir Creek (SFNF bnd to Hollinger Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2212_05	20.6.4.215	STREAM, PERENNIAL	4.89 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2022	2024 (est.)	5/5A
		Dissolved oxygen	2022	2024 (est.)	5/5A
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

El Rito (Pecos River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_050	20.6.4.212	STREAM, PERENNIAL	12.97 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Elk Creek (Cow Creek to headwater)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.A_103	20.6.4.217	STREAM, PERENNIAL	2.91 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Benthic Macroinvertebrates	2022	2024 (est.)	5/5C
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Falls Creek (Tecolote Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2212_12	20.6.4.98	STREAM, INTERMITTENT	7.01 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Gallinas River (Aguilar Creek to USGS Gage 08382000)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2213_211	20.6.4.220	STREAM, PERENNIAL	30.84 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Temperature	2012	2023 (est.)	5/5A
		Turbidity	2012	2023 (est.)	5/5A
		Nutrients	2006	2023 (est.)	5/5A
PC	Not Supporting	E. coli	2022	2024 (est.)	5/5A
WH	Fully Supporting				

AU Comment: None.

Gallinas River (Las Vegas Diversion to USFS bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2212_00	20.6.4.215	STREAM, PERENNIAL	8.2 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	1998	9/13/2005	4A
		Benthic Macroinvertebrates	2022	2024 (est.)	5/5C
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: A TMDL was prepared for temperature.

Gallinas River (Pecos Arroyo to Las Vegas Diversion)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2213_23	20.6.4.220	STREAM, PERENNIAL	11.1 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Dissolved oxygen	2022	2024 (est.)	5/5A
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Gallinas River (Pecos River to Aguilar Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2213_20	20.6.4.98	STREAM, INTERMITTENT	20.98 MILES	2012	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Not Supporting	Dissolved oxygen	2012		5/5C
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: USGS 08382500 gage data from 1/1/1951 to 9/7/2011 documents 8848 days (40%) with zero daily flow. Sonde was in isolated pool - redeployment recommended.

Gallinas River (USFS bnd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2212_02	20.6.4.215	STREAM, PERENNIAL	9.86 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Benthic Macroinvertebrates	2022	2024 (est.)	5/5C
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: None.					

Gallinas River (USGS Gage 08382000 to Pecos Arroyo)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2213_21	20.6.4.220	STREAM, PERENNIAL	11.75 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Nutrients	2006	2023 (est.)	5/5A
		Turbidity	2012	2023 (est.)	5/5A
		Temperature	2012	2023 (est.)	5/5A
PC	Not Supporting	E. coli	2022	2024 (est.)	5/5A
WH	Fully Supporting				
AU Comment: None.					

Glorieta Ck (Perennial prt Glorieta Camps WWTP to hdwtrs)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4C	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.A_082	20.6.4.217	STREAM, INTERMITTENT	6.24 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Flow Regime Modification	2014		4C
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: Very limited data. Low flow alterations affecting stream condition (impoundments on Glorieta Camps property).					

Glorieta Ck (Perennial prt Pecos R to Glorieta Camps WWTP)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.A_081	20.6.4.217	STREAM, PERENNIAL	8.98 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Nutrients Specific Conductance	2012 2004		5/5B 5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: Flow in this AU is effluent dominated. HQCW use and associated criteria may not be attainable. WQS under review.					

Hollinger Creek (El Porvenir Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2212_03	20.6.4.215	STREAM, PERENNIAL	5.87 MILES	2012	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Holy Ghost and Doctor Creek subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-2217_003	20.6.4.217	WATERSHED	16.09 SQUARE MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Benthic Macroinvertebrates	2022	2024 (est.)	5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Upper Pecos, 2023). Holy Ghost from the Pecos River upstream to the headwaters, plus Doctor Creek from Holy Ghost creek upstream to the headwaters, plus unnamed tributaries and associated wetlands as cited in NMAC 20.6.4.9 D. (h)(4) subsection (c).					

Indian Creek subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-2217_002	20.6.4.217	WATERSHED	7.83 SQUARE MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Specific Conductance	2022	2024 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Upper Pecos, 2023). Indian Creek from the Pecos River upstream to the headwaters, plus unnamed tributaries and associated wetlands as cited in NMAC 20.6.4.9 D. (h)(4) subsection (c).					

Jack's Creek subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-2217_009	20.6.4.217	WATERSHED	7.17 SQUARE MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Upper Pecos, 2023). Jacks creek from the Pecos River upstream to the headwaters, plus unnamed tributaries and associated wetlands as cited in NMAC 20.6.4.9 D. (h)(4) subsection (e).					

Johnson Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.B_10	20.6.4.222	LAKE, FRESHWATER	2.49 ACRES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Lake Bentley			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_067	20.6.4.99	LAKE, PLAYA	47.85 ACRES	2004	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Fully Supporting				
AU Comment: None.					

Lake Katherine			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.B_20	20.6.4.222	LAKE, FRESHWATER	10.86 ACRES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013). Access is difficult -- high elevation lake.					

Lost Bear Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.B_30	20.6.4.222	LAKE, FRESHWATER	0.51 ACRES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Macho Canyon Creek subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-2217_001	20.6.4.217	WATERSHED	12.16 SQUARE MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Upper Pecos, 2023). Macho Canyon Creek from the Pecos River upstream to the headwaters, plus unnamed tributaries and associated wetlands as cited in NMAC 20.6.4.9 D. (h)(4) subsection (b). Portions went dry during the 2001, 2010 and 2019 surveys. HQCWAL may not be attainable -- WQS review needed.					

McAllister Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2211.3_00	20.6.4.213	LAKE, PLAYA	85.41 ACRES	2002	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Arsenic, Dissolved	2006	2021 (est.)	5/5C
LW	Fully Supporting				
SC	Fully Supporting				
WH	Fully Supporting				
AU Comment: This lake was dry as of the 2019-2020 Upper Pecos sampling survey. The human health criterion for arsenic (9.0 ug/L) was exceeded during 4 of 6 sampling events in 2001. No fish consumption advisory was issued.					

Monastery Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.B_40	20.6.4.224	RESERVOIR	5.79 ACRES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

North Fork Blue Creek (Blue Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2212_17	20.6.4.215	STREAM, PERENNIAL	3.28 MILES	2004	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Not Assessed				
PC	Not Assessed				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

Panchuela Creek subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-2217_008	20.6.4.217	WATERSHED	22.49 SQUARE MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Benthic Macroinvertebrates	2022	2024 (est.)	5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Upper Pecos, 2023). Panchuela creek from the Pecos River upstream to the headwaters, plus unnamed tributaries and associated wetlands as cited in NMAC 20.6.4.9 D. (h)(4) subsection (f).

Pecos Arroyo (Gallinas River to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2213_22	20.6.4.221	STREAM, PERENNIAL	14.29 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for E. coli.					

Pecos Baldy Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.B_50	20.6.4.222	LAKE, FRESHWATER	6.44 ACRES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Pecos River (Alamitos Canyon to Jack's Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.A_002	20.6.4.217	STREAM, PERENNIAL	21.83 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Benthic Macroinvertebrates	2022	2024 (est.)	5/5C
		Temperature	2020	2022 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: ONRW (Upper Pecos, 2023).TMDL for turbidity.					

Pecos River (Canon de Manzanita to Alamitos Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.A_003	20.6.4.217	STREAM, PERENNIAL	5.74 MILES	2020	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2004	9/13/2005	4A
		Dissolved oxygen	2022	2024 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: ONRW (Special Designation Streams, 2024). TMDLs were written for temperature and turbidity. De-list for turbidity. Dissolved oxygen impairment added 2022 cycle.					

Pecos River (Cow Creek to Canon de Manzanita)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2213_02	20.6.4.216	STREAM, PERENNIAL	20.07 MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Benthic Macroinvertebrates	2022	2024 (est.)	5/5C
		Turbidity	2022	2024 (est.)	5/5C
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Pecos River (Jack's Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.A_000	20.6.4.217	STREAM, PERENNIAL	14.66 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Benthic Macroinvertebrates	2022	2024 (est.)	5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013). Rio Grande Cutthroat Trout restoration in 1992-1996 by NMG&F above Pecos Falls.					

Pecos River (Santa Rosa Reservoir to Tecolote Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2211.A_10	20.6.4.211	STREAM, PERENNIAL	54.28 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Nutrients	2022	2024 (est.)	5/5A
PC	Not Supporting	E. coli	2012	9/25/2013	4A
WH	Fully Supporting				

AU Comment: USGS 08382600 gage data from 1/1/1976 to 9/7/2011 documents 3596 days (28%) with zero daily flow.

Pecos River (Sumner Reservoir to Santa Rosa Reservoir)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2211.A_00	20.6.4.211	STREAM, PERENNIAL	54.52 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Nutrients	2012	2022 (est.)	5/5A
PC	Not Supporting	E. coli	2022	2024 (est.)	5/5A
WH	Fully Supporting				

AU Comment: None.

Pecos River (Tecolote Creek to Villanueva State Park)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2213_00	20.6.4.216	STREAM, PERENNIAL	19.46 MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Turbidity	2022	2024 (est.)	5/5A
		Aluminum, Total Recoverable	2022	2024 (est.)	5/5A
PC	Not Supporting	E. coli	2022	2024 (est.)	5/5A
WH	Fully Supporting				
AU Comment: The AU boundary is the downstream end of the state park.					

Pecos River (Villanueva State Park to Cow Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2213_01	20.6.4.216	STREAM, PERENNIAL	20.01 MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Turbidity	2022	2024 (est.)	5/5A
PC	Not Supporting	E. coli	2022	2024 (est.)	5/5A
WH	Fully Supporting				
AU Comment: The AU boundary is the downstream end of the state park.					

Perch Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2211.B_40	20.6.4.226	LAKE, FRESHWATER	3.49 ACRES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Assessed				
LW	Not Assessed				
PC	Fully Supporting				
WH	Not Assessed				
AU Comment: This is a sinkhole lake.					

Power Dam Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2202.B_10	20.6.4.212	RESERVOIR	9.75 ACRES	2004	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Rio Mora and Bear Creek subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-2217_005	20.6.4.217	WATERSHED	53.74 SQUARE MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (Upper Pecos, 2023). Rio Mora upstream to the headwaters and Bear Creek from the Rio Mora upstream to the headwaters, plus unnamed tributaries and associated wetlands as cited in NMAC 20.6.4.9 D. (h)(4) subsection (d).					

Santa Rosa Reservoir			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2211.B_00	20.6.4.225	RESERVOIR	1225.22 ACRES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Nutrients	2022	2024 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Nutrients	2022	2024 (est.)	5/5A
		Mercury - Fish Consumption Advisory	2004		5/5C
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable". Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Sawyer Creek subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-2098_000	20.6.4.98	WATERSHED	1.19 SQUARE MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: ONRW (Upper Pecos, 2023). Sawyer Creek from the Pecos River upstream to the headwaters, plus unnamed tributaries and associated wetlands as cited in NMAC 20.6.4.9 D. (h)(4) subsection (b).

Spirit Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.B_80	20.6.4.222	LAKE, FRESHWATER	2.85 ACRES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Stewart Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.B_70	20.6.4.222	LAKE, FRESHWATER	3.04 ACRES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013). Access is difficult -- high elevation lake.					

Storrie Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2211.5_00	20.6.4.214	RESERVOIR	502.16 ACRES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	2024	2026 (est.)	5/5A
		Mercury - Fish Consumption Advisory	2006		5/5C
		PCBS - Fish Consumption Advisory	2022		5/5C
IRR Storage	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
PWS	Not Assessed				
WWAL	Not Supporting	PCBS - Fish Consumption Advisory	2022		5/5C
		Mercury - Fish Consumption Advisory	2006		5/5C
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Sumner Reservoir			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2210_00	20.6.4.210	RESERVOIR	1261.58 ACRES	2020	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR Storage	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	Mercury - Fish Consumption Advisory	2004		5/5C
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Tecolote Creek (Blue Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2212_09	20.6.4.215	STREAM, PERENNIAL	6.7 MILES	2012	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Tecolote Creek (I-25 to Blue Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2212_10	20.6.4.230	STREAM, PERENNIAL	22.68 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Temperature Benthic Macroinvertebrates Nutrients	1998 2022 2012	9/12/2018 2024 (est.)	4A 5/5C 5/5C
DWS	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2022	2024 (est.)	5/5A
WH	Fully Supporting				

AU Comment: A UAA to create 20.6.4.230 NMAC for this water body with coolwater aquatic life use was approved by the WQCC (effective 2/28/18 for state purposes).

Tecolote Creek (Pecos River to I-25)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2212_08	20.6.4.98	STREAM, INTERMITTENT	26.89 MILES	2012	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU may be ephemeral.The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU will remain under 20.6.4.98 NMAC.

Tres Lagunas (Northeast)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2211.B_30	20.6.4.212	RESERVOIR	34.3 ACRES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	pH	2010		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Tres Lagunas NE is one of three small on-line impoundments on a perennial tributary to the Pecos River origionally constructed by the railroad for flood control and eventual irrigation storage. In the years since the construction, the lake has filled with sediment, now averaging one meter in depth. As a result, WQS segment 20.6.4.212 is likely not appropriate for this waterbody.

Tres Lagunas (Southeast)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2211.B_31	20.6.4.212	RESERVOIR	12.09 ACRES	2012	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Tres Lagunas (West)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2211.B_32	20.6.4.212	RESERVOIR	10.76 ACRES	2012	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Truchas Lake (North)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.B_60	20.6.4.222	LAKE, FRESHWATER	0.65 ACRES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Truchas Lake (South)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2214.B_61	20.6.4.222	LAKE, FRESHWATER	2.55 ACRES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Unnamed subwatersheds from Dalton Cyn Ck to wilderness bndry			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-2098_002	20.6.4.98	WATERSHED	17.62 SQUARE MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (Upper Pecos, 2023). Unnamed tributaries and associated wetlands from Dalton Canyon Creek to the wilderness boundary, as cited in NMAC 20.6.4.9 D. (h)(4) subsection (a).					

Wallace Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_107	20.6.4.99	LAKE, PLAYA	18.23 ACRES	2004	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Willow Creek subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-2217_004	20.6.4.217	WATERSHED	8.17 SQUARE MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Sedimentation/Siltation	2022	2024 (est.)	5/5A
		Specific Conductance	2004	9/25/2013	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Upper Pecos, 2023). Willow Creek upstream to the headwaters, plus unnamed tributaries and associated wetlands as cited in NMAC 20.6.4.9 D. (h)(4) subsection (c). Continuing monitoring data following Terrero Mine reclaimation indicate improved water quality with respect to metals (previous listed for cadmium and zinc).

Winsor Creek subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-2217_007	20.6.4.217	WATERSHED	7.26 SQUARE MILES	2024	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (Upper Pecos, 2023). Winsor Creek upstream to the headwaters, plus unnamed tributaries and associated wetlands as cited in NMAC 20.6.4.9 D. (h)(4) subsection (e).

Wright Canyon Creek (Tecolote Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060001 Pecos Headwaters	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2212_18	20.6.4.215	STREAM, PERENNIAL	2.51 MILES	2012	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

HUC: 13060003 Upper Pecos

Bosque Redondo Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060003 Upper Pecos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_021	20.6.4.99	RESERVOIR	30.56 ACRES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MCWAL	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Pecos River (Crockett Draw to Yeso Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13060003 Upper Pecos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2207_01	20.6.4.207	RIVER	46.86 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
SC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Pecos River (Salt Creek to Crockett Draw)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060003 Upper Pecos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2207_00	20.6.4.207	RIVER	22.53 MILES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Temperature	2016	2023 (est.)	5/5A
SC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Pecos River (Truchas Creek to Sumner Reservoir)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13060003 Upper Pecos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2207_03	20.6.4.207	RIVER	20.39 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
SC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Pecos River (Yeso Creek to Truchas Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13060003 Upper Pecos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2207_02	20.6.4.207	RIVER	26.09 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Fully Supporting				
SC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Yeso Creek (Pecos River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060003 Upper Pecos	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_011	20.6.4.98	STREAM, INTERMITTENT	47.56 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

HUC: 13060007 Upper Pecos-Long Arroyo

Bitter Lake (Bitter Lake NWR)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_014	20.6.4.99	LAKE, PLAYA	156.55 ACRES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Bitter Lake NWR - Unit 15			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_019	20.6.4.99	RESERVOIR	79.38 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Bitter Lake NWR - Unit 16			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_017	20.6.4.99	RESERVOIR	67.12 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Bitter Lake NWR - Unit 3			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_016	20.6.4.99	RESERVOIR	71.96 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Bitter Lake NWR - Unit 5			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_015	20.6.4.99	RESERVOIR	62.74 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Bitter Lake NWR - Unit 6			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_020	20.6.4.99	RESERVOIR	90.48 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Bitter Lake NWR - Unit 7			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_018	20.6.4.99	RESERVOIR	106.38 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Cottonwood Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_004	20.6.4.228	LAKE, SALINE	0.27 ACRES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: Water is naturally too saline for livestock watering. This is a sink hole lake.					

Eagle Creek (Pecos River nr Artesia to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_008	20.6.4.98	STREAM, INTERMITTENT	70.15 MILES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: Application of the SWQB Hydrology Protocol (survey date 10/28/08) indicate this assessment unit is ephemeral (Hydrology Protocol score of 5.0 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol). The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to a waterbody under 20.6.4.97 NMAC. Until such time, this waterbody will remain under 20.6.4.98 NMAC.					

Figure Eight Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5B	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_044	20.6.4.99	LAKE, SALINE	2.71 ACRES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
PC	Not Assessed				
WWAL	Not Supporting	Nutrients	2016		5/5A
WH	Not Assessed				
AU Comment: Livestock use is not allowed at this lake. A segment-specific DO criterion may be warranted in this small sinkhole lake.					

Inkwell Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_002	20.6.4.228	LAKE, SALINE	0.35 ACRES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: Water is naturally too saline for livestock consumption. This is a sinkhole lake.					

Lake Van			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_071	20.6.4.99	RESERVOIR	40.64 ACRES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Supporting	Temperature	2016	2021 (est.)	5/5A
WH	Not Assessed				
AU Comment: None.					

Lea Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_001	20.6.4.227	LAKE, SALINE	17.33 ACRES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: Water is naturally too saline for livestock consumption. This is a sinkhole lake.					

Mirror Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_003	20.6.4.229	LAKE, SALINE	1.97 ACRES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: Water is naturally too saline for livestock watering. This is a sinkhole lake.					

Pecos River (Eagle Creek to Rio Felix)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2206.A_03	20.6.4.231	RIVER	34.68 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	Temperature	2016	2023 (est.)	5/5A
WH	Fully Supporting				
AU Comment: None.					

Pecos River (Rio Felix to Rio Hondo)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2206.A_00	20.6.4.231	RIVER	28.62 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	Temperature	2016	2023 (est.)	5/5A
WH	Fully Supporting				
AU Comment:					

Pecos River (Rio Hondo to Salt Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2206.A_20	20.6.4.231	RIVER	19.51 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Pecos River (Rio Penasco to Eagle Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2206.A_02	20.6.4.231	RIVER	13.67 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2024	2026 (est.)	5/5A
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Unnamed tributary (Hart Canyon to South Union Rd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060007 Upper Pecos-Long Arroyo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_020	20.6.4.97	STREAM, EPHEMERAL	2.13 MILES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013.					

HUC: 13060008 Rio Hondo

Alto Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2209.B_30	20.6.4.98	RESERVOIR	15.14 ACRES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
IRR Storage	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Nutrients	2014	2027 (est.)	5/5A
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Water in this reservoir is used by the city of Ruidoso when available -- it is often dry. Copper sulfate has been used as an algalcide in the past to protect this drinking water supply.

Berrendo Creek (Rio Hondo to Middle Berrendo Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2208_11	20.6.4.206	STREAM, PERENNIAL	3.33 MILES	2024	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Not Assessed				
SC	Fully Supporting				
WWAL	Not Supporting	Nutrients	2024	2026 (est.)	5/5A
WH	Not Assessed				

AU Comment: None.

Bonito Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2209.B_10	20.6.4.223	RESERVOIR	46.02 ACRES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: This lake was several impacted by the Little Bear Fire.					

Carrizo Creek (Rio Ruidoso to Mescalero Apache bnd)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2209.A_22	20.6.4.209	STREAM, PERENNIAL	2.11 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2014	9/21/2015	4A
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: A TMDL for E. coli (2015). This AU has been absorbed into the new subwatershed-based AU "Carrizo subwatershed". Refer to AU ID W_NM-801-01 from this cycle onwards.					

Carrizo subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-801-01	20.6.4.209	WATERSHED	4.88 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Specific Conductance	2026	2027 (est.)	5/5A
		Sedimentation/Siltation	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Eagle Creek (Alto Lake to S. Fork Eagle Creek)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_017	20.6.4.98	STREAM, INTERMITTENT	2.99 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: Impacted by 2012 Little Bear Fire. This AU has been absorbed into the new subwatershed-based AU "Lower Eagle Creek subwatershed". Refer to AU ID W_NM-801-05.B from this cycle onwards.

Eagle Creek (Rio Ruidoso to Alto Lake)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_007	20.6.4.98	STREAM, INTERMITTENT	17.07 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Not Assessed				

AU Comment: Impacted by 2012 Little Bear Fire. This AU has been absorbed into the new subwatershed-based AU "Lower Eagle Creek subwatershed" . Refer to AU ID W_NM-801-05.B from this cycle onwards.

Eagle Creek (S. Fork Eagle Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2209.A_01	20.6.4.209	STREAM, PERENNIAL	2.62 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
PWS	Not Assessed				
WH	Not Assessed				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Upper Eagle Creek subwatershed" . Refer to AU ID W_NM-801-05.A from this cycle onwards.

Grindstone Canyon (Carrizo Creek to Grindstone Rsvr)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_008	20.6.4.98	STREAM, INTERMITTENT	0.99 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: All water in this AU (including outfall from Grindstone Rsvr and spring water) is pumped back into Grindstone Rsvr from approximately 500 yards downstream of the dam. This AU has been absorbed into the new subwatershed-based AU "Carrizo subwatershed". Refer to AU ID W_NM-801-01 from this cycle onwards.

Grindstone Canyon (Grindstone Rsvr to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_009	20.6.4.97	STREAM, EPHEMERAL	1.12 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Hydrology Protocol-based UAA concluded this reach was ephemeral. UAA was approved by EPA in Oct 2013. This AU has been absorbed into the new subwatershed-based AU "Carrizo subwatershed". Refer to AU ID W_NM-801-01 from this cycle onwards.

Grindstone Canyon Reservoir			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2209.B_20	20.6.4.209	RESERVOIR	28.66 ACRES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Nutrients	2026	2027 (est.)	5/5A
		Temperature	2014		5/5B
IRR Storage	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: None.					

Little Creek (Eagle Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_019	20.6.4.98	STREAM, INTERMITTENT	18.26 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC. This AU has been absorbed into the new subwatershed-based AU "Lower Eagle Creek subwatershed" . Refer to AU ID W_NM-801-05.B from this cycle onwards.					

Lower Bonito subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-802_08	20.6.4.208	WATERSHED	250.2 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients	2026	2027 (est.)	5/5A
		Phosphorus, Total	2026	2027 (est.)	5/5A
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2026	2027 (est.)	5/5A
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Lower Eagle Creek subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-801-05.B	20.6.4.98	WATERSHED	50.11 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Supporting	Sedimentation/Siltation	2026	2027 (est.)	5/5A
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Lower Rio Ruidoso subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-801-07	20.6.4.208	WATERSHED	78.48 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Aluminum, Total Recoverable	2026	2027 (est.)	5/5A
		Phosphorus, Total	2026	2027 (est.)	5/5A
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2026	2027 (est.)	5/5A
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Middle Rio Ruidoso subwatershed			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-801-06	20.6.4.209	WATERSHED	23.86 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Phosphorus, Total	2026	2027 (est.)	5/5A
		Temperature	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2026	2027 (est.)	5/5A
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

North Spring River (Rio Hondo to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2206.A_40	20.6.4.231	STREAM, PERENNIAL	6.25 MILES	2024	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Not Assessed				
PC	Fully Supporting				
WWAL	Not Supporting	Selenium, Total Recoverable	2024	2026 (est.)	5/5A
WH	Not Assessed				

AU Comment: None.

Rio Bonito (Perenial prt Rio Ruidoso to NM 48 near Angus)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4C	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2208_10	20.6.4.208	STREAM, PERENNIAL	33.62 MILES	1998	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Flow Regime Modification			4C
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Stream reach has very low flow during certain times of the year due to dam forming Bonito Lake for drinking water uses. This AU was impacted by the 2012 Little Bear Fire. This AU has been absorbed into the new subwatershed-based AU "Lower Bonito subwatershed". Refer to AU ID W_NM-802_08 from this cycle onwards.

Rio Bonito (Perennial prt NM 48 near Angus to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2209.A_10	20.6.4.209	STREAM, PERENNIAL	13.63 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2014	2023 (est.)	5/5A
		Flow Regime Modification	2006		4C
		Benthic Macroinvertebrates			5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
			2014		
PC	Not Supporting	E. coli		9/21/2015	4A
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). A small portion of this AU is dewatered due to dam. A TMDL was developed for E. Coli (2015). This AU was impacted by the 2012 Little Bear Fire. This AU has been absorbed into the new subwatershed-based AU "Upper Bonito subwatershed". Refer to AU ID W_NM-802-01 from this cycle onwards.

Rio Hondo (HWY 285 to Bonney Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2208_25	20.6.4.98	STREAM, INTERMITTENT	50.56 MILES	2020	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Rio Hondo (Perennial prt Pecos R to HWY 285)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2208_26	20.6.4.231	STREAM, PERENNIAL	10.23 MILES	2024	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Rio Hondo (Perennial reaches Bonney Canyon to Rio Ruidoso)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4C	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2208_30	20.6.4.208	STREAM, PERENNIAL	25.47 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Flow Regime Modification	2014		4C
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: A TMDL was developed for fecal coliform. This reach was impacted by 2012 fire and subsequent flooding. This AU has been absorbed into the new subwatershed-based AU "Rio Hondo subwatershed" . Refer to AU ID W_NM-804-03 from this cycle onwards.

Rio Hondo subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-804-03	20.6.4.208	WATERSHED	126.68 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Phosphorus, Total	2026	2027 (est.)	5/5A
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2026	2027 (est.)	5/5A
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Rio Ruidoso (Carrizo Ck to Mescalero Apache bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2209.A_20	20.6.4.209	STREAM, PERENNIAL	4.96 MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Phosphorus, Total	2014	12/12/2016	4A
		Temperature	1998	2/10/2006	4A
		Nutrients	2018	12/12/2016	4A
		Turbidity	1998	2/10/2006	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: TMDLs for temperature and turbidity (prior to split at Carrizo Ck). TMDL for nutrients (2016). This AU has been absorbed into the new subwatershed-based AU "Upper Rio Ruidoso subwatershed" . Refer to AU ID W_NM-801-03 from this cycle onwards.

Rio Ruidoso (Eagle Ck to US Hwy 70 Bridge)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2208_20	20.6.4.208	STREAM, PERENNIAL	9.12 MILES	2020	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Turbidity	2014	9/21/2015	4A
		Nutrients	1998	12/12/2016	4A
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2014	9/21/2015	4A
WH	Fully Supporting				

AU Comment: TMDL for nutrients. This AU has been absorbed into the new subwatershed-based AU "Lower Rio Ruidoso subwatershed" . Refer to AU ID W_NM-801-07 from this cycle onwards.

Rio Ruidoso (North Fork abv Mescalero Apache bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2209.A_24	20.6.4.209	STREAM, PERENNIAL	2.28 MILES	2006	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

Rio Ruidoso (Perennial prt Rio Bonito to Eagle Ck)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2208_21	20.6.4.208	STREAM, PERENNIAL	13.02 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
FC	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Lower Rio Ruidoso subwatershed" . Refer to AU ID W_NM-801-07 from this cycle onwards.

Rio Ruidoso (US Hwy 70 Bridge to Carrizo Ck)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2209.A_21	20.6.4.209	STREAM, PERENNIAL	7.97 MILES	2020	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2014	2/10/2006	4A
		Nutrients	2014	12/12/2016	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2014	9/21/2015	4A
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: TMDLs for temperature and turbidity (prior to split at Carrizo Ck), E. coli, and nutrients. This AU has been absorbed into the new subwatershed-based AU "Middle Rio Ruidoso subwatershed". Refer to AU ID W_NM-801-06 from this cycle onwards.

S. Fork Eagle Creek (Eagle Creek to Mescalero Apache bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2209.A_00	20.6.4.209	STREAM, PERENNIAL	0.76 MILES	1998	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Specific Conductance	2026	2030 (est.)	5/5C
		Flow Regime Modification			4C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This reach often dries up from April on. Wells in the vicinity contribute to the drying of the stream according to USFS personnel (2/4/09). This AU has been absorbed into the new subwatershed-based AU "Upper Eagle Creek subwatershed" . Refer to AU ID W_NM-801-05.A from this cycle onwards.

South Fork Rio Bonito (Rio Bonito to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2209.A_11	20.6.4.209	STREAM, PERENNIAL	5.73 MILES	1998	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Not Assessed				
PC	Not Assessed				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013).b This AU has been absorbed into the new subwatershed-based AU "Upper Bonito subwatershed". Refer to AU ID W_NM-802-01 from this cycle onwards.

Upper Bonito subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-802-01	20.6.4.209	WATERSHED	46.04 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Sedimentation/Siltation	2026	2027 (est.)	5/5A
		Phosphorus, Total	2026	2027 (est.)	5/5A
		Temperature	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2026	2027 (est.)	5/5A
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Upper Eagle Creek subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-801-05.A	20.6.4.209	WATERSHED	6.3 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Upper Rio Ruidoso subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060008 Rio Hondo	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-801-03	20.6.4.209	WATERSHED	29.94 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2026	2027 (est.)	5/5A
		Phosphorus, Total	2026	2027 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2026	2027 (est.)	5/5A
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

HUC: 13060009 Rio Felix

Rio Felix (Intermittent pt Lincoln cyn to Mescalero Apache)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060009 Rio Felix	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2206.A_33	20.6.4.98	STREAM, INTERMITTENT	6.78 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Rio Felix (Intermittent reaches abv Hagerman Canal)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060009 Rio Felix	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2206.A_31	20.6.4.98	STREAM, INTERMITTENT	66.88 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Rio Felix (Perennial prt Pecos River to Hagerman Canal)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060009 Rio Felix	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2206.A_30	20.6.4.206	STREAM, PERENNIAL	5.23 MILES	2020	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Rio Felix (Perennial prt abv Old School rd to Lincoln Cyn)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060009 Rio Felix	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2206.A_32	20.6.4.206	STREAM, PERENNIAL	3.05 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

HUC: 13060010 Rio Penasco

Agua Chiquita (Rio Penasco to McEwan Cny)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060010 Rio Penasco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2208_02	20.6.4.97	STREAM, EPHEMERAL	14.96 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Fully Supporting				
LW	Not Assessed				
SC	Not Assessed				
WH	Fully Supporting				

AU Comment: Hydrology Protocol-based UAA concluded this reach was ephemeral. UAA was approved by EPA in Oct 2013. This AU has been absorbed into the new subwatershed-based AU "Lower Agua Chiquita Creek subwatershed" . Refer to AU ID W_NM-002-04 from this cycle onwards.

Agua Chiquita (perennial portions McEwan Cny to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060010 Rio Penasco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2208_01	20.6.4.208	STREAM, PERENNIAL	21.48 MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Turbidity	2014	9/21/2015	4A
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2016	2023 (est.)	5/5A
WH	Fully Supporting				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Upper Agua Chiquita Creek subwatershed" . Refer to AU ID W_NM-002-02 from this cycle onwards.

Lower Agua Chiquita Creek subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060010 Rio Penasco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-002-04	20.6.4.97	WATERSHED	72.71 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Lower Rio Penasco subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060010 Rio Penasco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-005-04	20.6.4.231	WATERSHED	93.99 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Middle Rio Penasco subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13060010 Rio Penasco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-005-03	20.6.4.208	WATERSHED	130.19 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Fully Supporting				
DWS	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Rio Penasco (HWY 24 to Cox Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 13060010 Rio Penasco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2208_00	20.6.4.208	STREAM, PERENNIAL	36.05 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Turbidity	2014	9/21/2015	4A
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Coolwater may be a more appropriate ALU designation. WQS is under review. This AU has been absorbed into the two new subwatershed-based AUs "Middle Rio Penasco subwatershed" and "Upper Rio Penasco subwatershed". Refer to AU ID W_NM-005-03 and W_NM-003-04 from this cycle onwards.

Rio Penasco (Pecos River to Bluewater Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060010 Rio Penasco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2206.A_11	20.6.4.98	STREAM, INTERMITTENT	45.71 MILES	2020	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Rio Penasco (Perennial prt Bluewater Creek to HWY 24)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060010 Rio Penasco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2206.A_10	20.6.4.231	STREAM, PERENNIAL	20.41 MILES	2024	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: This AU has been absorbed into the new subwatershed-based AU "Lower Rio Penasco subwatershed". Refer to AU ID W_NM-005-04 from this cycle onwards.					

Rio Penasco (Perennial prt Cox Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060010 Rio Penasco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2208_03	20.6.4.208	STREAM, PERENNIAL	14.77 MILES	2014	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Fully Supporting				
FC	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This AU has been absorbed into the new subwatershed-based AU "Upper Rio Penasco subwatershed" . Refer to AU ID W_NM-003-04 from this cycle onwards.

Upper Agua Chiquita Creek subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 13060010 Rio Penasco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-002-02	20.6.4.208	WATERSHED	67.05 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Fully Supporting				
DWS	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

Upper Rio Penasco subwatershed			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060010 Rio Penasco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
W_NM-003-04	20.6.4.208	WATERSHED	151.17 SQUARE MILES	2026	2030
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: This was a new assessment unit created in 2025. The AU has been created using a subwatershed-based approach, which means that the AU is visualized as a polygon showing the watershed instead of a singular linear waterway. This subwatershed-based approach is a pilot of this type of AU in New Mexico, but has been used as the sole approach or in combination with linear AU's in other states throughout the U.S. Creating a single assessment conclusion for the watershed unit as a whole aligns with EPA's ATTAINS reporting requirements, and is also consistent with established methodologies in other states. Subwatershed AU's will be assessed in a similar manner as linear AUs, by using the station lowest in the AU (at or near the pourpoint) to capture activities within the AU as a whole. The linear AU associated with the new subwatershed AU's will be retired next assessment cycle.

HUC: 13060011 Upper Pecos-Black

Avalon Reservoir			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2204.B_00	20.6.4.219	RESERVOIR	521.6 ACRES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR Storage	Fully Supporting				
LW	Not Assessed				
SC	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Black River (Double Canyon to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2202.A_14	20.6.4.98	STREAM, INTERMITTENT	20.99 MILES	2020	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Black River (Perennial prt Blue Spring to Double Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2202.A_13	20.6.4.202	STREAM, PERENNIAL	17.76 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Not Assessed				

AU Comment: None.

Black River (Perennial prt Pecos River to Blue Spring)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2202.A_10	20.6.4.202	STREAM, PERENNIAL	17.63 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Not Assessed				
PC	Fully Supporting				
WWAL	Not Supporting	Nutrients	2024	2026 (est.)	5/5A
WH	Not Assessed				

AU Comment: None.

Blue Spring (Black River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2202.A_11	20.6.4.202	STREAM, PERENNIAL	3.63 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Not Assessed				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Not Assessed				

AU Comment: None.

Brantley Reservoir			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2205_00	20.6.4.205	RESERVOIR	1602.54 ACRES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR Storage	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Supporting	DDT - Fish Consumption Advisory	2006		5/5C
		Mercury - Fish Consumption Advisory	2020		5/5C
WH	Not Assessed				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Harroun Dam (Ten Mile) Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_048	20.6.4.98	RESERVOIR	65.07 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Laguna Gatuna			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_055	20.6.4.98	LAKE, PLAYA	391.73 ACRES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: Naturally saline lake, so livestock watering not attainable or existing.					

Laguna Quatro			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_059	20.6.4.98	LAKE, PLAYA	260.76 ACRES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: Hypersaline due to potash mining activities, so livestock watering likely not attainable or existing.					

Laguna Tres			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_061	20.6.4.98	LAKE, PLAYA	929.46 ACRES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Laguna Uno			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_066	20.6.4.98	LAKE, PLAYA	462.25 ACRES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Lower Tansil Lake/Lake Carlsbad (Carlsbad Municipal Lake)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2203.B_00	20.6.4.218	RESERVOIR	134.28 ACRES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Supporting	PCBS - Fish Consumption Advisory	2010		5/5C
		DDT - Fish Consumption Advisory	2016		5/5C
WH	Not Assessed				
AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.					

Pecos River (Avalon Reservoir to Brantley Reservoir)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2204.A_00	20.6.4.204	RIVER	10.77 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	DDT - Fish Consumption Advisory	2010		5/5C
		Mercury - Fish Consumption Advisory	2020		5/5C
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable". Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Pecos River (Black River to Six Mile Dam)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2202.A_00	20.6.4.202	RIVER	16.59 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	PCBS - Fish Consumption Advisory	2010		5/5C
		DDT - Fish Consumption Advisory	2020		5/5C
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Pecos River (Brantley Reservoir to Rio Penasco)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2206.A_01	20.6.4.231	RIVER	12.89 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Not Assessed				
AU Comment: None.					

Pecos River (Lake Carlsbad to Avalon Reservoir)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4C	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2203.A_00	20.6.4.203	RIVER	3.97 MILES	2006	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
LW	Fully Supporting				
PC	Not Assessed				
WWAL	Not Supporting	Flow Regime Modification			4C
WH	Fully Supporting				
AU Comment: Usually dry - water diverted to Carlsbad main canal.					

Pecos River (Six Mile Dam to Lower Tansil Lake)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2202.A_01	20.6.4.202	RIVER	3.67 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
WWAL	Not Supporting	DDT - Fish Consumption Advisory	2020		5/5C
		PCBS - Fish Consumption Advisory	2010		5/5C
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Pecos River (TX border to Black River)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2201_00	20.6.4.201	RIVER	35.74 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	DDT - Fish Consumption Advisory	2020		5/5C
		PCBS - Fish Consumption Advisory	2010		5/5C
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Rattlesnake Spring Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2202.A_12	20.6.4.99	LAKE, FRESHWATER	0.13 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Not Assessed				
AU Comment: None.					

Sitting Bull Creek (Last Chance Canyon to Sitting Bull Spr)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_007	20.6.4.99	STREAM, PERENNIAL	1.83 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Six Mile Dam Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2202.B_20	20.6.4.202	RESERVOIR	59.66 ACRES	2016	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	Nutrients	2016	2021 (est.)	5/5A
WH	Fully Supporting				
AU Comment: The USGS High Res layer does not include a polygon for this surface water feature. The lower end of the upper river AU was extended to the diversion dam.					

Williams Sink (Eddy)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 13060011 Upper Pecos-Black	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_109	20.6.4.98	LAKE, PLAYA	105.08 ACRES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: Potash activities have lead to hypersaline conditions which likely make livestock watering not attainable or existing.

HUC: 13070002 Delaware

Delaware River (Pecos River to TX border)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 13070002 Delaware	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2202.A_20	20.6.4.202	STREAM, PERENNIAL	8.49 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Not Assessed				
PC	Fully Supporting				
WWAL	Not Supporting	Nutrients	2024	2026 (est.)	5/5A
WH	Fully Supporting				

AU Comment: None.

HUC: 13070007 Landreth-Monument Draws

Jal Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 13070007 Landreth-Monument Draws	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2201_01	20.6.4.99	LAKE, FRESHWATER	8.65 ACRES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Supporting	Nutrients	2024	2026 (est.)	5/5C
WH	Not Assessed				

AU Comment: None.

HUC: 14080101 Upper San Juan

Gallegos Canyon (San Juan River to Navajo bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 14080101 Upper San Juan	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_060	20.6.4.99	STREAM, PERENNIAL	0.65 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Not Supporting	E. coli	2020	2021 (est.)	5/5A
WWAL	Not Supporting	Temperature	2020	2021 (est.)	4C
		Selenium, Total Recoverable	2004	8/26/2005	4A
WH	Not Supporting	Selenium, Total Recoverable	2004	8/26/2005	4A

AU Comment: TMDL was prepared for selenium (2005).

Los Pinos River (Navajo Reservoir to CO border)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 14080101 Upper San Juan	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2407.A_10	20.6.4.407	STREAM, PERENNIAL	1.37 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	2020	2021 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

Navajo Reservoir			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 14080101 Upper San Juan	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2406_00	20.6.4.406	RESERVOIR	12680.2 ACRES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	2012		5/5C
		Mercury - Fish Consumption Advisory	2004		5/5C
IW Supply	Not Assessed				
IRR Storage	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Navajo River (Jicarilla Apache Nation to CO border)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 14080101 Upper San Juan	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2407.A_00	20.6.4.407	STREAM, PERENNIAL	5.88 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Phosphorus, Total	2020	2021 (est.)	5/5A
		Turbidity	2020		5/5C
		Temperature	2012		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2020	2021 (est.)	5/5A
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: Fisheries data indicate coolwater may be a more appropriate ALU -- WQS review needed.

San Juan River (Animas River to Canon Largo)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 14080101 Upper San Juan	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2401_00	20.6.4.408	RIVER	26.5 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Aluminum, Total Recoverable	2026	2030 (est.)	5/5A
		pH	2024		5/5C
		Sedimentation/Siltation	2004	8/26/2005	4A
PC	Not Supporting	E. coli	2006	2/26/2010	4A
PWS	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: TMDLs were prepared for sedimentation, fecal coliform and E. coli.

San Juan River (Canon Largo to Navajo Reservoir)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 14080101 Upper San Juan	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2405_10	20.6.4.405	RIVER	19.29 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
HQColdWAL	Fully Supporting				
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

San Juan River (NM reach upstream of Navajo Reservoir)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 14080101 Upper San Juan	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2405_11	20.6.4.99	RIVER	0.56 MILES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Not Supporting	E. coli	2020	2021 (est.)	5/5A
WWAL	Not Supporting	Aluminum, Total Recoverable	2020	2021 (est.)	5/5A
WH	Fully Supporting				
AU Comment: None.					

HUC: 14080104 Animas

Animas River (Estes Arroyo to So. Ute Indian Tribe bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 14080104 Animas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2404_00	20.6.4.404	RIVER	19.4 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Nutrients	2020	2021 (est.)	5/5A
		Temperature	1998	2021 (est.)	5/5A
		Turbidity	2012		5/5C
		Phosphorus, Total	2012	9/30/2013	4A
		Aluminum, Total Recoverable	2026	2030 (est.)	5/5A
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: TMDL for E. coli and total phosphorus.					

Animas River (San Juan River to Estes Arroyo)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 14080104 Animas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2403.A_00	20.6.4.403	RIVER	16.73 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Temperature	2012	9/30/2013	4A
		Aluminum, Total Recoverable	2026	2030 (est.)	5/5A
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WH	Fully Supporting				
AU Comment: TMDL for nutrients, temperature, and E. coli.					

Lake Farmington (Beeline Reservoir)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 14080104 Animas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_006	20.6.4.409	RESERVOIR	211.32 ACRES	2020	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Mercury - Fish Consumption Advisory	2004		5/5C
LW	Fully Supporting				
PC	Fully Supporting				
PWS	Not Assessed				
WWAL	Not Supporting	Mercury - Fish Consumption Advisory	2004		5/5C
WH	Fully Supporting				
AU Comment: This is the City of Farmingtons drinking water supply reservoir. Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.					

HUC: 14080105 Middle San Juan

Jackson Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 14080105 Middle San Juan	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_005	20.6.4.410	RESERVOIR	66.29 ACRES	2014	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

La Plata R (McDermott Arroyo to So. Ute Indian Tribe bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 14080105 Middle San Juan	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2402.A_01	20.6.4.402	STREAM, PERENNIAL	8.52 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Nutrients	2012	2021 (est.)	5/5A
MWWAL	Not Supporting	Nutrients	2012	2021 (est.)	5/5A
PC	Not Supporting	E. coli	2006	8/26/2005	4A
WH	Fully Supporting				

AU Comment: TMDLs for DO and e. coli.

La Plata River (San Juan River to McDermott Arroyo)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 14080105 Middle San Juan	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2402.A_00	20.6.4.402	STREAM, PERENNIAL	17.82 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Sedimentation/Siltation	2004	8/26/2005	4A
		Dissolved oxygen	1998	2021 (est.)	5/5C
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: This AU is no longer perennial throughout.					

San Juan River (Navajo bnd at Hogback to Animas River)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 14080105 Middle San Juan	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2401_10	20.6.4.401	RIVER	22.8 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Aluminum, Total Recoverable	2026	2030 (est.)	5/5A
		Sedimentation/Siltation	2012		5/5C
PC	Not Supporting	E. coli	2006	8/26/2005	4A
PWS	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDLs were prepared for fecal coliform and E. coli.					

Shumway Arroyo (San Juan River to Ute Mtn Ute bnd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 14080105 Middle San Juan	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_021	20.6.4.98	STREAM, INTERMITTENT	13.35 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Fully Supporting				
PC	Not Supporting	E. coli	2020	2021 (est.)	5/5A
WH	Fully Supporting				

AU Comment: Application of the SWQB Hydrology Protocol (survey date 6/17/09) indicate this assessment unit is intermittent (Hydrology Protocol score of 18.8 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol).

Stevens Arroyo (Perennial prts San Juan R to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 14080105 Middle San Juan	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2401_11	20.6.4.99	STREAM, PERENNIAL	9.82 MILES	2024	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Not Supporting	E. coli	2020	2021 (est.)	5/5A
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

HUC: 14080106 Chaco

Unnamed tributary (Kim-me-ni-oli Wash to hdwtrs)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 14080106 Chaco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_025	20.6.4.97	STREAM, EPHEMERAL	9.15 MILES	2012	2027
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013.
Lee Ranch Coal Co, El Segundo Mine, permit NM0030996

HUC: 15020003 Carrizo Wash

Crater Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 15020003 Carrizo Wash	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_033	20.6.4.98	LAKE, PLAYA	3.07 ACRES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

El Caso Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 15020003 Carrizo Wash	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_038	20.6.4.98	LAKE, PLAYA	20.08 ACRES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: None.

Gabaldon Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 15020003 Carrizo Wash	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_045	20.6.4.98	LAKE, PLAYA	9.46 ACRES	1998	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: Part of playa lake study. Data are old.

Largo Creek (Carrizo Wash to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 15020003 Carrizo Wash	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_906	20.6.4.98	STREAM, INTERMITTENT	79.53 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.					

Little El Caso Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 15020003 Carrizo Wash	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_075	20.6.4.98	LAKE, PLAYA	3.14 ACRES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Pine Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 15020003 Carrizo Wash	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_095	20.6.4.98	LAKE, PLAYA	16.75 ACRES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Quemado Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 15020003 Carrizo Wash	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_096	20.6.4.453	RESERVOIR	112.25 ACRES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Mercury - Fish Consumption Advisory	2024	2026 (est.)	5/5C
		Nutrients	2014	2021 (est.)	5/5A
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Samples collected by the New Mexico Environment Department (NMED) in late 2025 showed the presence of harmful algae and toxins, and a HABs Warning Advisory was issued for this lake.
Harmful algae blooms, or HABs, occur when certain types of algae grow excessively in water, posing potential health risks to people and animals. HABs can appear blue, bright green, brown or red and may resemble scum or floating grass clippings on the water's surface. These blooms can produce toxins that are harmful to humans and animals. For more information visit: https://www.env.nm.gov/surface-water-quality/habs/

HUC: 15020004 Zuni

Cebolla Creek (Ramah Reservoir to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3	HUC: 15020004 Zuni	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_032	20.6.4.98	STREAM, INTERMITTENT	11.09 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: Application of the SWQB Hydrology Protocol on 5/19/2009 indicate this assessment unit is intermittent (Hydrology Protocol score of 10.5), while survey data from 10/12/11 indicate ephemeral at the station above the falls (score of 0.0). The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.

Cebolla Creek (Zuni Pueblo bnd to Ramah Rsvr)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3	HUC: 15020004 Zuni	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_031	20.6.4.98	STREAM, INTERMITTENT	5.01 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: Application of the SWQB Hydrology Protocol on 5/19/2009 indicate this assessment unit is intermittent (Hydrology Protocol score of 10.5), while survey data from 10/12/11 indicate ephemeral at the station above the falls (score of 0.0). This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.

McGaffey Lake			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 15020004 Zuni	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_083	20.6.4.98	RESERVOIR	11.42 ACRES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Not Supporting	Nutrients	1998	2021 (est.)	5/5A
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Lake often goes dry. Department of Game and Fish dredged the lake in 2003 to return it to its original design capacity.

Ramah Reservoir			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 15020004 Zuni	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_110	20.6.4.452	RESERVOIR	144.97 ACRES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients	2014	2021 (est.)	5/5A
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Rio Nutria (Tampico Draw to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3	HUC: 15020004 Zuni	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_033	20.6.4.451	STREAM, EPHEMERAL	12.42 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: Coolwater may not be attainable -- WQS under review.					

Rio Nutria (Zuni Pueblo bnd to Tampico Draw)			AU IR CATEGORY	LOCATION DESCRIPTION	
			1	HUC: 15020004 Zuni	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_029	20.6.4.451	STREAM, PERENNIAL	0.34 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

Tampico Draw (Rio Nutria to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3	HUC: 15020004 Zuni	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_080	20.6.4.451	STREAM, PERENNIAL	9.82 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

HUC: 15020006 Upper Puerco

Defiance Draw (CR 1 to W Defiance Road)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 15020006 Upper Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_026	20.6.4.97	STREAM, EPHEMERAL	5.24 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013.
Chevron McKinley mine, permit NM0029386

Puerco River (Gallup WWTP to South Fork Puerco R)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 15020006 Upper Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_201	20.6.4.98	STREAM, INTERMITTENT	10.4 MILES	2026	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Not Assessed				

AU Comment: None.

Puerco River (South Fork Puerco R to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 15020006 Upper Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_202	20.6.4.98	STREAM, INTERMITTENT	44.72 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Puerco River (non-tribal AZ border to Gallup WWTP)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 15020006 Upper Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_200	20.6.4.99	STREAM, PERENNIAL	23.38 MILES	2024	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Not Supporting	E. coli	2024	2026 (est.)	5/5A
WWAL	Not Supporting	Ammonia, Total	2014	2022 (est.)	5/5A
WH	Fully Supporting				

AU Comment: This AU is effluent-dependent.

South Fork Puerco River (Puerco R to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 15020006 Upper Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.A_203	20.6.4.98	STREAM, INTERMITTENT	35.18 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Unnamed tributary to Defiance Draw (CR 1 to NM 264)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 15020006 Upper Puerco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-97.A_027	20.6.4.97	STREAM, EPHEMERAL	5.7 MILES	2014	2029
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LAL	Not Assessed				
LW	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				

AU Comment: Ephemeral AU subject to 20.6.4.97 NMAC, included in UAA for 18 Unclassified Non-Perennial Watercourses with NPDES Permitted Facilities, June 2012. EPA provided technical approval January 30, 2013.
Chevron/McKinley Mine, permit NM0029386

HUC: 15040001 Upper Gila

Beaver Creek (Perennial prt Taylor Ck to Mule Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_25	20.6.4.503	STREAM, PERENNIAL	17.69 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2014		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Temperature WQC is under review.

Black Canyon Creek (East Fork Gila River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_21	20.6.4.503	STREAM, PERENNIAL	25.51 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	1996	4/5/2002	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). TMDL for temperature. WQC is under review. Gila Trout Recovery stream.

Canyon Creek (Middle Fork Gila River to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			4A	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_43	20.6.4.503	STREAM, PERENNIAL	14.41 MILES	2002	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Turbidity	1998	4/10/2002	4A
		Nutrients	1998	4/10/2002	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013). TMDL turbidity and plant nutrients.					

Diamond Ck (Perennial prt Bailey Ck to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_24	20.6.4.503	STREAM, PERENNIAL	13.84 MILES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Diamond Ck (Perennial prt East Fork Gila R to Bailey Ck)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_22	20.6.4.503	STREAM, PERENNIAL	13.3 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Supporting	Benthic Macroinvertebrates	2022	2024 (est.)	5/5C
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013). The USFS states that the reach is intermittent in the lower sections and contains a native warmwater fishery. The existing and attainable aquatic life use for the perennial portions in this lower AU is likely coolwater. WQS review needed.					

East Fork Gila River (Gila River to Taylor Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_20	20.6.4.503	STREAM, PERENNIAL	27.6 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Benthic Macroinvertebrates	2010		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013). WQS review needed; HQCWAL may be unattainable.					

Gila River (Mogollon Ck to East and West Forks of Gila R)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2502.A_30	20.6.4.502	STREAM, PERENNIAL	42.24 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Temperature	2010		5/5B
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013). Marginal CWAL may not be attainable. WQS under review.					

Gilita Creek (Middle Fork Gila R to Willow Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_45	20.6.4.503	STREAM, PERENNIAL	6.35 MILES	2026	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2002	9/8/2023	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013). 2023 TMDL pending WQCC approval. TMDL (Gila, Mimbres, SFR) for temperature EPA approved August 2024.					

Gilita Creek (Perennial reaches abv Willow Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_48	20.6.4.503	STREAM, PERENNIAL	6.65 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2022	2024 (est.)	5/5B
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: WQS review needed. AU has been impacted by several large scale wildfires and recreation in the upper reach.					

Hoyt Creek (Wall Lake to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_26	20.6.4.98	STREAM, INTERMITTENT	20.29 MILES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Iron Creek (Middle Fork Gila R to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_44	20.6.4.503	STREAM, PERENNIAL	13.19 MILES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2014		5/5B
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013). Temperature WQS is under review. Lower end of AU may go dry. Gila Trout recovery stream.					

Lake Roberts			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2504_20	20.6.4.504	RESERVOIR	67.33 ACRES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Nutrients	2014	2021 (est.)	5/5A
		Temperature	2024	2026 (est.)	5/5A
		Mercury - Fish Consumption Advisory	2016		5/5C
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable." Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.

Little Creek (West Fork Gila River to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_31	20.6.4.503	STREAM, PERENNIAL	17.11 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2022	2024 (est.)	5/5A
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: ONRW (USFS Wilderness Areas, 2013). AU affected by the 18,000 acre “Good” fire in 2020. Gila trout in upper portion of AU.

Middle Fork Gila River (Canyon Creek to Gilita Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_41	20.6.4.503	STREAM, PERENNIAL	12.5 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2002		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013).Temperature WQC is under review. The 2012 Whitewater Baldy Complex Fire severely burned portions of the watershed. Portions of upper watershed burned by 26,000 acre “Cub” fire in 2020.

Middle Fork Gila River (West Fork Gila R to Canyon Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_40	20.6.4.503	STREAM, PERENNIAL	24.21 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2002		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). Temperature WQC is under review. The 2012 Whitewater Baldy Complex Fire severely burned portions of the watershed.

Mogollon Creek (Gila River to USGS Gage 09430600)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_05	20.6.4.98	STREAM, INTERMITTENT	12.95 MILES	2002	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Mogollon Creek (Perennial prt USGS Gage 09430600 to hwtrs)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_02	20.6.4.503	STREAM, PERENNIAL	16.86 MILES	2018	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). TMDL Al chronic; de-list letter for SBD (sedimentation/siltation), chronic lead. Gila Trout restoration in 1986 and 1996 by NMG&F.

Sapillo Creek (Gila River to Lake Roberts)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			1	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_04	20.6.4.503	STREAM, PERENNIAL	11.92 MILES	2018	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013). TMDL turbidity and TOC; de-list letter for biological impairment. De-listed for turbidity (2010 cycle).					

Snow Canyon Ck (Perennial prt Gilita Ck to Snow Lake)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_46	20.6.4.99	STREAM, PERENNIAL	0.28 MILES	2002	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Assessed				
LW	Fully Supporting				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: This reach exists due to dam leakage only, so an existing aquatic life use of coldwater was added to match the source of this flow.					

Snow Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5A	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2504_40	20.6.4.504	RESERVOIR	93.58 ACRES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	pH	2016	2021 (est.)	5/5A
		Nutrients	2014	2021 (est.)	5/5A
		Temperature	2024	2026 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Samples collected by the New Mexico Environment Department (NMED) in late 2025 showed the presence of harmful algae and toxins, and a HABs Health Watch was issued for this lake.
Harmful algae blooms, or HABs, occur when certain types of algae grow excessively in water, posing potential health risks to people and animals. HABs can appear blue, bright green, brown or red and may resemble scum or floating grass clippings on the water's surface. These blooms can produce toxins that are harmful to humans and animals. For more information visit: https://www.env.nm.gov/surface-water-quality/habs/

Taylor Creek (Perennial reaches Beaver Creek to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_23	20.6.4.503	STREAM, PERENNIAL	24.15 MILES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	1998	8/5/2002	4A
		Nutrients	2014	2022 (est.)	5/5A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: Temperature WQC is under review.

Turkey Creek (Gila River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_03	20.6.4.503	STREAM, PERENNIAL	17.63 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2002		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013). The temperature WQC is under review.					

West Fork Gila R (Gila River to Middle Fork)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_10	20.6.4.503	STREAM, PERENNIAL	5.08 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2002		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: The temperature WQC is under review. Wildfire impacts. AU may be impacted by hot springs adjacent to river.					

West Fork Gila R (Middle Fork to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_30	20.6.4.503	STREAM, PERENNIAL	32.16 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2010		5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: ONRW (USFS Wilderness Areas, 2013). Temperature WQC is under review. Impacted by two large fires (“Good” and “Cub”) in 2020.					

White Creek (West Fork Gila River to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_32	20.6.4.503	STREAM, PERENNIAL	9.03 MILES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: ONRW (USFS Wilderness Areas, 2013).					

Willow Creek (Gilita Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 15040001 Upper Gila	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_47	20.6.4.503	STREAM, PERENNIAL	7.34 MILES	2026	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
HQColdWAL	Not Supporting	Temperature	2014	9/8/2023	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). Native fish re-introduction with fish barrier (2016). Watershed Based Plan approved in 2021. Stream continues to adjust following large fires in 2012, 2018. TMDL (Gila, Mimbres, SFR) for temperature EPA approved August 2024.

HUC: 15040002 Upper Gila-Mangas

Bear Creek (Gila River nr Cliff to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 15040002 Upper Gila-Mangas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_01	20.6.4.502	STREAM, PERENNIAL	33.65 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Temperature	2022	2024 (est.)	5/5B
PC	Not Assessed				
WWAL	Not Supporting	Temperature	2022	2024 (est.)	5/5B
WH	Fully Supporting				

AU Comment: According to SWQB Silver City staff, the Cypress Mine contributed to this stream reach previously going dry. This mine is now closed. WQS review of Marginal Coldwater ALU - may be unattainable.

Bill Evans Lake			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5C	HUC: 15040002 Upper Gila-Mangas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2502.B_00	20.6.4.505	RESERVOIR	62.48 ACRES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
CoolWAL	Not Supporting	Mercury - Fish Consumption Advisory	2012		5/5C
		PCBS - Fish Consumption Advisory	2016		5/5C
LW	Fully Supporting				
PC	Fully Supporting				
WWAL	Not Supporting	PCBS - Fish Consumption Advisory	2016		5/5C
		Mercury - Fish Consumption Advisory	2012		5/5C
WH	Fully Supporting				
AU Comment: Land management agencies have posted contact recreation warnings due to toxic blue green algae in the past. SWQB does not have water quality standards or assessment procedures related to blue green algae at this time. Fish Consumption Advisory listings are based on NM's current fish consumption advisories for this water body. Per USEPA guidance, these advisories demonstrate non-attainment of CWA goals stating that all waters should be "fishable". Therefore, the impaired designated use is the associated aquatic life even though human consumption of the fish is the actual concern.					

Bitter Creek (AZ border to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			3/3A	HUC: 15040002 Upper Gila-Mangas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2503_49	20.6.4.98	STREAM, INTERMITTENT	6.27 MILES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Blue Creek (Gila River to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 15040002 Upper Gila-Mangas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2501_10	20.6.4.502	STREAM, PERENNIAL	37.4 MILES	2010	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
MCWAL	Fully Supporting				
PC	Not Assessed				
WWAL	Fully Supporting				
WH	Not Assessed				
AU Comment: None.					

Carlisle Creek (Gila River to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 15040002 Upper Gila-Mangas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2502.A_02	20.6.4.98	STREAM, INTERMITTENT	17.51 MILES	2002	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Fully Supporting				
AU Comment: This AU may be ephemeral. The process detailed in 20.6.4.15 NMAC Subsection C must be completed in order to classify a waterbody under 20.6.4.97 NMAC. Until such time, this AU remains classified under Intermittent Waters - 20.6.4.98 NMAC.					

Gila River (AZ border to Red Rock)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 15040002 Upper Gila-Mangas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2501_00	20.6.4.501	RIVER	26.76 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MWWAL	Not Supporting	Temperature	2010	2022 (est.)	5/5C
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: Dry 1/2 sampling events during 2019-2020 GMSF survey.					

Gila River (Mangas Creek to Mogollon Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 15040002 Upper Gila-Mangas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2502.A_10	20.6.4.502	RIVER	17.41 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Temperature	2010		5/5B
PC	Fully Supporting				
WWAL	Fully Supporting				
WH	Fully Supporting				
AU Comment: Marginal CWAL may not be attainable. WQS under review.					

Gila River (Red Rock to Mangas Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 15040002 Upper Gila-Mangas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2502.A_00	20.6.4.502	RIVER	20.26 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Temperature	2010	2022 (est.)	5/5B
		Nutrients	2010	2022 (est.)	5/5C
PC	Fully Supporting				
WWAL	Not Supporting	Nutrients	2010	2022 (est.)	5/5C
WH	Fully Supporting				

AU Comment: None.

Mangas Creek (Gila River to Mangas Springs)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 15040002 Upper Gila-Mangas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2502.A_21	20.6.4.502	STREAM, PERENNIAL	6.86 MILES	2026	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Temperature	2010	9/8/2023	4A
		Nutrients	2004	4/16/2002	4A
PC	Not Supporting	E. coli	2022	9/8/2023	4A
WWAL	Not Supporting	Nutrients	2004	4/16/2002	4A
WH	Fully Supporting				

AU Comment: TMDL for nutrients. The source spring for Mangas Creek produces unusually high concentrations of nitrates, the source(s) of which are unknown. TMDL (Gila, Mimbres, SFR) for E.coli and Temperature EPA approved August 2024.

Mangas Creek (Mangas Springs to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 15040002 Upper Gila-Mangas	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2502.A_22	20.6.4.502	STREAM, PERENNIAL	18.4 MILES	2002	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IW Supply	Not Assessed				
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Fully Supporting				
PC	Not Assessed				
WWAL	Fully Supporting				
WH	Fully Supporting				

AU Comment: None.

HUC: 15040003 Animas Valley

Burro Cienaga (Lordsburg Playa to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 15040003 Animas Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-98.A_010	20.6.4.98	STREAM, INTERMITTENT	53.86 MILES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

North Lordsburg Playa			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 15040003 Animas Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_091	20.6.4.98	LAKE, PLAYA	3015.54 ACRES	2002	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

Sacaton (No Name) Playa			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 15040003 Animas Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_097	20.6.4.98	LAKE, PLAYA	1186.7 ACRES	2002	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

South Lordsburg Playa			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 15040003 Animas Valley	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-9000.B_099	20.6.4.98	LAKE, PLAYA	7412.21 ACRES	2002	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				

AU Comment: None.

HUC: 15040004 San Francisco

Apache Creek (Tularosa River to Hardcastle Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_44	20.6.4.98	STREAM, INTERMITTENT	9.17 MILES	2000	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				

AU Comment: De-list letter for conductivity. Application of the SWQB Hydrology Protocol (survey date 10/9/2008) indicate this assessment unit is intermittent (Hydrology Protocol score of 11.8 - see https://www.env.nm.gov/surface-water-quality/hp/ for additional details on the protocol).

Centerfire Creek (San Francisco R to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5B	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_50	20.6.4.603	STREAM, PERENNIAL	19.76 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	1998	2022 (est.)	5/5B
		Specific Conductance	1998	4/16/2002	4A
		Turbidity	2014	9/11/2014	4A
		Nutrients	1998	4/16/2002	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2014	9/11/2014	4A
WH	Fully Supporting				
AU Comment: TMDL for plant nutrients and conductivity. Temperature WQC under review. AU has numerous ephemeral to intermittent reaches.					

Dry Blue Creek (AZ bnd to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			2	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_70	20.6.4.99	STREAM, PERENNIAL	9.87 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Mineral Creek (San Francisco Creek to Silver Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_22	20.6.4.98	STREAM, INTERMITTENT	4.12 MILES	2002	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Mineral Creek (Silver Creek to South Fork Mineral)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_20	20.6.4.603	STREAM, PERENNIAL	13.19 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2022	2024 (est.)	5/5C
IRR	Not Assessed				
LW	Fully Supporting				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: Lower end of AU is canyon bound, shallow, and subject to heat loading. Formerly "Mineral Creek (Silver Creek to headwaters)" this AU was split where the creek forks.					

Mule Creek (San Francisco R to Mule Springs)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2601_01	20.6.4.601	STREAM, PERENNIAL	11.74 MILES	2026	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Nutrients	2022	9/8/2023	4A
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: TMDL (Gila, Mimbres, SFR) for plant nutrients EPA approved August 2024.

Negrito Creek (Tularosa River to confl of N and S forks)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_42	20.6.4.603	STREAM, PERENNIAL	13.02 MILES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2002		5/5B
IRR	Not Assessed				
LW	Not Assessed				
PC	Fully Supporting				
WH	Not Assessed				

AU Comment: Reach went dry during 2011 Gila survey upstream of sampling station. Limited WQ data available. WQS under review.

North Fork Mineral Creek (South Fork to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_23	20.6.4.98	STREAM, INTERMITTENT	2.7 MILES	2026	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: Formerly part of "Mineral Creek (Silver Creek to headwaters)"					

North Fork Negrito Creek (Negrito Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_45	20.6.4.603	STREAM, PERENNIAL	16.36 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2022	2024 (est.)	5/5B
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: HQCWAL use may not be attainable; WQS review needed					

S A Creek (Perennial prt of Centerfire Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-99.A_002	20.6.4.99	STREAM, PERENNIAL	14.49 MILES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
PC	Not Assessed				
WWAL	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

Saliz Canyon Creek (San Francisco R to Cottonwood Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_30	20.6.4.603	STREAM, PERENNIAL	7.35 MILES	2020	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Assessed				
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

San Francisco River (AZ border to Box Canyon)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2601_00	20.6.4.601	STREAM, PERENNIAL	17.42 MILES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
MCWAL	Not Assessed				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

San Francisco River (Box Canyon to Whitewater Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2601_10	20.6.4.601	STREAM, PERENNIAL	6.15 MILES	2026	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Benthic Macroinvertebrates	2010		5/5C
MWWAL	Fully Supporting				
PC	Not Supporting	E. coli	2022	9/8/2023	4A
WH	Fully Supporting				
AU Comment: TMDL (Gila, Mimbres, SFR) for E.coli EPA approved August 2024.					

San Francisco River (Centerfire Creek to AZ border)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2602_20	20.6.4.602	STREAM, PERENNIAL	15.18 MILES	2026	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	1998	8/5/2002	4A
		Benthic Macroinvertebrates	2012		5/5C
		Sedimentation/Siltation	2022	9/8/2023	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL for temperature and plant nutrients (2002). Delisted for nutrients during 2010 listing cycle. TMDL (Gila, Mimbres, SFR) for Sedimentation/Siltation EPA approved August 2024. Irrigation diversion near Head of Ditch dewaters the AU. Temperature WQS under review.					

San Francisco River (NM 12 at Reserve to Centerfire Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5C	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2602_10	20.6.4.602	STREAM, PERENNIAL	16.29 MILES	2026	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
ColdWAL	Not Supporting	Temperature	2014	9/8/2023	4A
		Benthic Macroinvertebrates	2022	2024 (est.)	5/5C
		Turbidity	2014	9/11/2014	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: TMDL (Gila, Mimbres, SFR) for temperature EPA approved August 2024. TMDL for turbidity (2014).					

San Francisco River (Pueblo Ck to Willow Springs Cyn)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2601_21	20.6.4.601	STREAM, PERENNIAL	22.78 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Not Assessed				
LW	Not Assessed				
MCWAL	Not Supporting	Temperature	2022		5/5B
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: CWAL may not be attainable; WQS review needed.					

San Francisco River (Whitewater Ck to Pueblo Ck)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2601_20	20.6.4.601	STREAM, PERENNIAL	14.97 MILES	2014	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Temperature	2022	2024 (est.)	5/5A
MWWAL	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				
AU Comment: None.					

San Francisco River (Willow Springs Cyn to NM 12 at Reserve)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2601_22	20.6.4.601	STREAM, PERENNIAL	10.86 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
IRR	Fully Supporting				
LW	Fully Supporting				
MCWAL	Not Supporting	Temperature	2022	2024 (est.)	5/5A
MWWAL	Fully Supporting				
PC	Not Supporting	E. coli	2014	9/11/2014	4A
WH	Fully Supporting				
AU Comment: None.					

Silver Creek (Mineral Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_21	20.6.4.98	STREAM, INTERMITTENT	9.79 MILES	2002	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Fully Supporting				
MWWAL	Not Assessed				
PC	Not Assessed				
WH	Fully Supporting				
AU Comment: None.					

South Fork Mineral Creek (North Fork to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			3/3A	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_24	20.6.4.98	STREAM, INTERMITTENT	1.82 MILES	2026	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
LW	Not Assessed				
MWWAL	Not Assessed				
SC	Not Assessed				
WH	Not Assessed				
AU Comment: None.					

South Fork Negrito Creek (Negrito Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_43	20.6.4.603	STREAM, PERENNIAL	17.6 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	1998	4/5/2002	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2014	9/11/2014	4A
WH	Fully Supporting				
AU Comment: TMDL for temperature. The temperature WQC is under review.					

Stone Creek (San Francisco R to AZ border)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5B	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_61	20.6.4.603	STREAM, PERENNIAL	1.67 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2022		5/5B
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: Temperature WQC is under review. Fish records include trout species prior to Wallow Fire which severely impacted watershed.					

Trout Creek (Perennial prt San Francisco R to headwaters)			**AU IR CATEGORY**	**LOCATION DESCRIPTION**	
			5/5B	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_60	20.6.4.603	STREAM, PERENNIAL	16.07 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Supporting	Benthic Macroinvertebrates Temperature	2022 2014	2024 (est.)	5/5C 5/5B
IRR	Not Assessed				
LW	Not Assessed				
PC	Fully Supporting				
WH	Not Assessed				
AU Comment: Temperature WQC is under review.					

Tularosa River (Apache Creek to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5B	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_41	20.6.4.603	STREAM, PERENNIAL	19.19 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Not Assessed				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2014	2024 (est.)	5/5B
IRR	Not Assessed				
LW	Not Assessed				
PC	Not Assessed				
WH	Not Assessed				
AU Comment: HQCWAL may not be attainable; WQS review needed.					

Tularosa River (San Francisco R to Apache Creek)			AU IR CATEGORY	LOCATION DESCRIPTION	
			5/5A	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_40	20.6.4.603	STREAM, PERENNIAL	23.34 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature Turbidity	2014 2014	2022 (est.) 9/11/2014	5/5A 4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Not Supporting	E. coli	2014	9/11/2014	4A
WH	Fully Supporting				
AU Comment: TMDL for specific conductance.					

Whitewater Creek (San Francisco R to Whitewater Campgrd)			AU IR CATEGORY	LOCATION DESCRIPTION	
			2	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_10	20.6.4.603	STREAM, PERENNIAL	6.12 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Fully Supporting				
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: TMDLs for turbidity and dissolved Al (2002). The 2012 Whitewater Baldy Complex Fire severely burned portions of the watershed. Dissolved Al TMDL withdrawn 2018 because no longer an applicable WQC.

Whitewater Creek (Whitewater Campgrd to headwaters)			AU IR CATEGORY	LOCATION DESCRIPTION	
			4A	HUC: 15040004 San Francisco	
AU ID	**WQS REF**	**WATER TYPE**	**SIZE**	**ASSESSED**	**MONITORING SCHEDULE**
NM-2603.A_12	20.6.4.603	STREAM, PERENNIAL	14.01 MILES	2022	2028
USE	**ATTAINMENT**	**CAUSE(S)**	**FIRST LISTED**	**TMDL DATE**	**PARAMETER IR CATEGORY**
DWS	Fully Supporting				
FC	Not Assessed				
HQColdWAL	Not Supporting	Temperature	2022	9/8/2023	4A
IRR	Fully Supporting				
LW	Fully Supporting				
PC	Fully Supporting				
WH	Fully Supporting				

AU Comment: ONRW (USFS Wilderness Areas, 2013). The 2012 Whitewater Baldy Complex Fire severely burned portions of the watershed. The Whitewater Creek Native Fish Restoration Project began October 2018 to restore native fish in this reach. TMDL (Gila, Mimbres, SFR) for temperature EPA approved August 2024.

Uses Abbreviation Key	
ColdWAL	Coldwater Aquatic Life
CoolWAL	Coolwater Aquatic Life
DWS	Domestic Water Supply
FC	Fish Culture
HQColdWAL	High Quality Coldwater Aquatic Life
IW Storage	Industrial Water Storage
IW Supply	Industrial Water Supply
IRR	Irrigation
IRR Storage	Irrigation Storage
LAL	Limited Aquatic Life
LW	Livestock Watering
MCWAL	Marginal Coldwater Aquatic Life
MWWAL	Marginal Warmwater Aquatic Life
MWS	Municipal Water Storage
PC	Primary Contact
PWS	Public Water Supply
SC	Secondary Contact
WWAL	Warmwater Aquatic Life
WH	Wildlife Habitat

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Appendix B

Designated Use Attainment Status, Cause, and Probable Source Summary Tables

Prepared by:
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Surface Water Quality Bureau
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Santa Fe, New Mexico 87505
https://www.env.nm.gov/surface-water-quality/

Table B-1: Designated Use Attainment Status Summary for Streams/Rivers

Designated Use	*Total Size (mi)*	Size Assessed (mi)	*Size Fully Supporting (mi)*	*Size Not Supporting (mi)*	*Size Not Assessed (mi)*
Coldwater Aquatic Life	816.64	660.09	82.51	577.58	156.55
Coolwater Aquatic Life	357.26	262.82	45.14	217.68	94.44
High Quality Coldwater Aquatic Life	2812.96	2652.97	777.99	1874.98	159.99
Limited Aquatic Life	270.14	100.06	30.51	69.55	170.08
Marginal Coldwater Aquatic Life	1019.26	971.74	217.16	754.58	47.52
Marginal Warmwater Aquatic Life	2834.10	1453.21	643.30	809.91	1380.89
Warmwater Aquatic Life	1701.03	1324.53	693.37	631.16	376.50
Primary Contact	8315.58	5301.60	3917.50	1384.10	3013.98
Secondary Contact	407.362	127.22	127.22	0	280.14
Domestic Water Supply	2963.55	2496.28	2483.39	12.89	467.27
Irrigation	6635.5	5631.82	5571.54	60.28	1003.68
Livestock Watering	8722.44	5869.52	5747.07	122.45	2852.92
Wildlife Habitat	8722.94	6069.60	5985.90	83.70	2653.34
Fish Culture*	1410.98	--	--	--	1410.98
Industrial Water Supply*	428.51	--	--	--	428.51
Public Water Supply*	759.62	--	--	--	759.62

* = All Fish Culture, Public Water Supply, and Industrial Water Supply designated uses are defaulted to "Not Assessed" because no numeric criteria apply uniquely to these uses per 20.6.4.900.A NMAC.

Table B-2: Designated Use Attainment Status Summary for Watersheds

Designated Use	*Total Size (sq mi)*	Size Assessed (sq mi)	*Size Fully Supporting (sq mi)*	*Size Not Supporting (sq mi)*	*Size Not Assessed (sq mi)*
Coldwater Aquatic Life	1372.7	1319.45	348.41	971.04	53.25
Coolwater Aquatic Life	39.65	39.65	39.65	0	0
High Quality Coldwater Aquatic Life	1888.94	1677.05	209.64	1467.41	211.89
Limited Aquatic Life	188.86	0	0	0	188.86
Marginal Coldwater Aquatic Life	14.37	14.37	14.37	0	0
Marginal Warmwater Aquatic Life	277.12	159.38	100.17	59.21	117.74
Warmwater Aquatic Life	632.25	0	0	0	632.25
Domestic Water Supply	2328.47	1775.22	1775.22	0	553.25
Fish Culture*	1609.9	--	--	--	1609.9
Irrigation	3507.83	2612.93	2612.93	0	894.9
Livestock Watering	3921.02	2630.32	2630.32	0	1290.7
Primary Contact	3732.16	2630.32	1653.63	976.69	1101.84
Public Water Supply*	742.34	--	--	--	742.34
Secondary Contact	188.86	0	0	0	188.86
Wildlife Habitat	3921.02	2630.32	2630.32	0	1290.7

* = All Fish Culture, Public Water Supply, and Industrial Water Supply designated uses are defaulted to "Not Assessed" because no numeric criteria apply uniquely to these uses per 20.6.4.900.A NMAC.

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Table B-3: Designated Use Attainment Status Summary for Lakes/Reservoirs

Designated Use	*Total Size (acres)*	Size Assessed (acres)	*Size Fully Supporting (acres)*	*Size Not Supporting (acres)*	*Size Not Assessed (acres)*
Coldwater Aquatic Life	25822.69	25748.96	3108.63	22640.33	73.73
Coolwater Aquatic Life	1953.62	1877.43	0	1877.43	76.19
High Quality Coldwater Aquatic Life	2359.58	2108.55	57.64	2050.91	251.03
Marginal Coldwater Aquatic Life	249.46	154.47	154.47	0	94.99
Marginal Warmwater Aquatic Life	25522.29	1251.78	0	1251.78	24270.51
Warmwater Aquatic Life	48092.43	43375.41	13748.98	29626.43	4717.02
Domestic Water Supply	2991.82	2095.74	2095.74	0	896.08
Irrigation	5300.95	4060.6	4060.6	0	1240.35
Irrigation Storage	46251.35	44648.81	44648.81	0	1602.54
Livestock Watering	85346.41	56285.58	56285.58	0	29060.83
Primary Contact	84458.31	55769.74	55622.17	147.57	28688.57
Secondary Contact	910.73	389.13	389.13	0	521.6
Wildlife Habitat	85369.04	61466.23	61466.23	0	23902.81
Fish Culture*	36.38	--	--	--	36.38
Industrial Water Supply*	18862.33	--	--	--	18862.33
Public Water Supply*	32606.8	--	--	--	32606.8

* = All Fish Culture, Public Water Supply, and Industrial Water Supply designated uses are defaulted to "Not Assessed" because no numeric criteria apply uniquely to these uses per 20.6.4.900.A NMAC.

Table B-4: Cause Summary for Stream/River/Watershed Water Quality Impairments

Cause Name (GROUP CAUSE NAME in BOLD)	*Total Size*	*Units*
AMMONIA	**37.25**	**MILES**
Ammonia, Total	37.25	MILES
CAUSE UNKNOWN - IMPAIRED BIOTA	**331.48**	**MILES**
Benthic Macroinvertebrates	331.48	MILES
CAUSE UNKNOWN - IMPAIRED BIOTA	**40.83**	**SQUARE MILES**
Benthic Macroinvertebrates	40.83	SQUARE MILES
FISH CONSUMPTION ADVISORY	**109.24**	**MILES**
DDT - Fish Consumption Advisory	109.24	MILES
HYDROLOGIC ALTERATION	**255.38**	**MILES**
Flow Regime Modification	255.38	MILES
MERCURY	**119.39**	**MILES**
Mercury - Fish Consumption Advisory	94.79	MILES
Mercury, Total	24.6	MILES
METALS (OTHER THAN MERCURY)	**1337.512**	**MILES**
Aluminum, Dissolved	16.38	MILES
Aluminum, Total Recoverable	885.712	MILES
Arsenic, Dissolved	39.32	MILES
Copper, Dissolved	38.2	MILES
Lead, Dissolved	9.6	MILES
Sedimentation/Siltation	304.01	MILES
Selenium, Total Recoverable	42.19	MILES
Silver, Dissolved	2.1	MILES
METALS (OTHER THAN MERCURY)	**1016.96**	**SQUARE MILES**
Aluminum, Total Recoverable	807.78	SQUARE MILES
Sedimentation/Siltation	209.18	SQUARE MILES
NUTRIENTS	**1337.93**	**MILES**
Nutrients	1296.91	MILES
Phosphorus, Total	41.02	MILES
NUTRIENTS	**1149.71**	**SQUARE MILES**
Nutrients	594.51	SQUARE MILES
Phosphorus, Total	555.2	SQUARE MILES
ORGANIC ENRICHMENT/OXYGEN DEPLETION	**290.32**	**MILES**
Dissolved oxygen	290.32	MILES
ORGANIC ENRICHMENT/OXYGEN DEPLETION	**122.09**	**SQUARE MILES**
Dissolved oxygen	122.09	SQUARE MILES

Cause Name (GROUP CAUSE NAME in BOLD)	*Total Size*	*Units*
PATHOGENS	**1384.1**	**MILES**
E. coli	1384.1	MILES
PATHOGENS	**976.69**	**SQUARE MILES**
E. coli	976.69	SQUARE MILES
PH/ACIDITY/CAUSTIC CONDITIONS	**66.63**	**MILES**
pH	66.63	MILES
POLYCHLORINATED BIPHENYLS (PCBS)	**300.694**	**MILES**
PCBS - Fish Consumption Advisory	88.86	MILES
Polychlorinated Biphenyls (PCBs)	211.834	MILES
RADIATION	**142.57**	**MILES**
Gross Alpha, Adjusted	130.97	MILES
Radium	11.6	MILES
SALINITY/TOTAL DISSOLVED SOLIDS/CHLORIDES/SULFATES	**340.16**	**MILES**
Specific Conductance	266.74	MILES
Sulfate	36.71	MILES
Total Dissolved Solids (TDS)	36.71	MILES
SALINITY/TOTAL DISSOLVED SOLIDS/CHLORIDES/SULFATES	**391.12**	**SQUARE MILES**
Specific Conductance	391.12	SQUARE MILES
SEDIMENT	**12.16**	**MILES**
Sedimentation	12.16	MILES
TEMPERATURE	**2546.512**	**MILES**
Temperature	2546.512	MILES
TEMPERATURE	**1332.4**	**SQUARE MILES**
Temperature	1332.4	SQUARE MILES
TOXIC INORGANICS	**45.21**	**MILES**
Boron, Dissolved	22.56	MILES
Cyanide, Total Recoverable	22.65	MILES
TURBIDITY	**787.43**	**MILES**
Turbidity	787.43	MILES

Table B-5: Cause Summary for Lake/Reservoir Water Quality Impairments

Cause Name (GROUP CAUSE NAME in BOLD)	*Total Size (acres)*
FISH CONSUMPTION ADVISORY	**1736.82**
DDT - Fish Consumption Advisory	1736.82
MERCURY	**53104.1**
Mercury - Fish Consumption Advisory	53104.1
METALS (OTHER THAN MERCURY)	**325.93**
Aluminum, Total Recoverable	92.95
Arsenic, Dissolved	232.98
NUTRIENTS	**18098.45**
Nutrients	18098.45
ORGANIC ENRICHMENT/OXYGEN DEPLETION	**3.82**
Dissolved oxygen	3.82
PH/ACIDITY/CAUSTIC CONDITIONS	**636.15**
pH	636.15
POLYCHLORINATED BIPHENYLS (PCBS)	**18841.23**
PCBS - Fish Consumption Advisory	18841.23
TEMPERATURE	**18273.66**
Temperature	18273.66

Table B-6: Probable Source Summary for Stream/River Water Quality Impairments*

Probable Source Name (GROUP SOURCE NAME in BOLD)	*Total Size (miles)*
AGRICULTURE	**4643.08**
Animal Feeding Operations (Nps)	88.78
Animal Shows And Racetracks	15.3
Confined Animal Feeding Operations - Cafos (Point Source)	91.68
Crop Production (Dry Land)	567.08
Crop Production (Irrigated)	560.29
Grazing In Riparian Or Shoreline Zones	186.94
Livestock (Grazing or Feeding Operations)	355.01
Rangeland Grazing	2778
AQUACULTURE	**21.16**
Aquaculture (Permitted)	21.16
CONSTRUCTION	**379.16**
Road/Bridge/Infrastructure Construction	69.71
Site Clearance (New Development or Infill)	309.45
HABITAT ALTERATIONS (NOT DIRECTLY RELATED TO HYDROMODIFICATION)	**1174.25**
Habitat Modification	335.46
Loss of Riparian Habitat	838.79
HYDROLOGIC ALTERATION	**3571.28**
Baseflow Depletion	142.83
Channelization	784.15
Dam or Impoundment	668.18
Dredging for Navigation Channels	100.56
Streambank Modifications/Destabilization	1086.27
Water Diversions	789.29
INDUSTRIAL	**29.11**
Industrial Point Source Discharge	29.11
MUNICIPAL DISCHARGES/SEWAGE	**1606.13**
Municipal Point Source Discharges	420.06
On-site Treatment Systems (Septic)	1186.07
NATURAL/WILDLIFE	**3335.56**
Drought-related Impacts	918.36
Natural Sources	323.75
Waterfowl	1047.23
Wildlife Other than Waterfowl	1046.22
OTHER	**1476.42**
Low Water Crossing	656.34

Rural (Residential Areas)	820.08
RECREATION AND TOURISM (NON-BOATING)	**767.08**
Golf Courses	7.95
Off-road Vehicles	66.98
Recreational Pollution Sources	692.15
RESOURCE EXTRACTION	**168.21**
Abandoned Mine Lands	45.88
Mine Tailings	66.58
Petroleum/Natural Gas Activities	26.5
Sand/Gravel/Rock Mining Or Quarries	27.12
Surface Mining	2.13
SILVICULTURE (FORESTRY)	**1057.17**
Forest Roads (Road Construction and Use)	98.53
Silviculture Activities	292.02
Silviculture Fire Suppression	125.06
Silviculture Harvesting	19.01
Watershed Runoff following Forest Fire	522.55
SPILLS/DUMPING	**312.98**
Illegal Dumps Or Other Inappropriate Waste Disposal	312.98
UNKNOWN	**3443.74**
Source Unknown	3443.74
URBAN-RELATED RUNOFF/STORMWATER	**2820.72**
Impervious Surface/Parking Lot Runoff	610.51
MS4 Discharges	68.51
Municipal (High Density Area)	89.2
Road/Bridge Runoff	1619.45
Urban Runoff/Storm Sewers	107.75
Wastes from Pets	325.3

NOTES: These tables were generated using SQUID. In most instances, more than a single cause or probable source of water quality impairment **is present** in any assessment unit (AU). When AUs have more than one cause or source of impairment, the associated AU Size is tallied in each cause or probable source category

* As reported in EPA-approved TMDLs.

Table B-7: Probable Source Summary for Lake/Reservoir Water Quality Impairments *

Probable Source Name (GROUP SOURCE NAME in BOLD)	*Total Size (acres)*
AGRICULTURE	**4156.89**
Crop Production (Dry Land)	1817.29
Grazing In Riparian Or Shoreline Zones	121.73
Rangeland Grazing	2217.87
CONSTRUCTION	**3913.43**
Construction Stormwater Discharge (Permitted)	1817.29
Site Clearance (New Development or Infill)	2096.14
HYDROLOGIC ALTERATION	**5451.87**
Baseflow Depletion	1817.29
Channelization	1817.29
Dam or Impoundment	1817.29
MUNICIPAL DISCHARGES/SEWAGE	**3913.43**
Municipal Point Source Discharges	1817.29
On-site Treatment Systems (Septic)	2096.14
NATURAL/WILDLIFE	**4278.62**
Drought-related Impacts	121.73
Waterfowl	1939.02
Wildlife Other than Waterfowl	2217.87
OTHER	**3913.43**
Low Water Crossing	1817.29
Rural (Residential Areas)	2096.14
RECREATION AND TOURISM (NON-BOATING)	**2339.6**
Off-road Vehicles	121.73
Recreational Pollution Sources	2217.87
RESOURCE EXTRACTION	**3634.58**
Abandoned Mine Lands	1817.29
Mine Tailings	1817.29
SILVICULTURE (FORESTRY)	**2496.72**
Forest Roads (Road Construction and Use)	6.19
Silviculture Fire Suppression	278.85
Silviculture Harvesting	2096.14
Watershed Runoff following Forest Fire	115.54
SPILLS/DUMPING	**278.85**
Illegal Dumps Or Other Inappropriate Waste Disposal	278.85

UNKNOWN	**76102.34**
Source Unknown	76102.34
URBAN-RELATED RUNOFF/STORMWATER	**4708.4**
Impervious Surface/Parking Lot Runoff	394.39
Road/Bridge Runoff	2217.87
Urban Runoff/Storm Sewers	1817.29
Wastes from Pets	278.85

NOTES: These tables were generated using SQUID. In most instances, more than a single cause or probable source of water quality impairment **is present** in any assessment unit (AU). When AUs have more than one cause or source of impairment, the associated AU Size is tallied in each cause or probable source category

* As reported in EPA-approved TMDLs.

2026-2028
State of New Mexico
Clean Water Act
§303(d)/§305(b)
Integrated Report

Appendix C

Response to Comments

Prepared by:
New Mexico Environment Department
Surface Water Quality Bureau
1190 St. Francis Drive
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https://www.env.nm.gov/surface-water-quality/

RESPONSE TO COMMENTS

ON THE
2026-2028 STATE OF NEW MEXICO
CLEAN WATER ACT
§303(d)/§305(b)
INTEGRATED LIST OF ASSESSED SURFACE WATERS

February 27, 2026

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PLEASE NOTE:

Original letters and emails were converted to Microsoft Word when possible. When not possible (i.e. due to unreadable PDFs), screenshots of each comment were inserted into the Word document followed by the response. Submitted comments were converted to Calibri font with standard page margins for ease of collation. All original comment letters/emails are on file at the NMED-SWQB office in Santa Fe, NM and are available electronically.

SUMMARY OF CHANGES TO THE DRAFT 2026-2028 INTEGRATED LIST DUE TO SOLICITED PUBLIC COMMENTS AND/OR DUE TO ADDITIONAL STAFF REVIEW DURING THE COMMENT PERIOD:

New Mexico Environment Department ("NMED") solicited public comments on the draft 2026-2028 Integrated List during a 45-day period (December 8, 2025, through January 22, 2026) and made the following changes during and after the public comment period:

1. *Tijeras Arroyo (Rio Grande to Four Hills Bridge) (NM-9000.A_070) – On 12/9/25 the WQCC approved the Tijeras Arroyo UAA. As a result of the amendment, Tijeras Arroyo (Rio Grande to Four Hills Bridge) has been placed in 20.6.4.97 NMAC.*
2. *Added an Assessment Rationale note to Navajo Reservoir (NM-2406_00) that recent (2025 buoy) LTD data provide documentation that a temperature impairment persists.*
3. *For assessment unit (AU) NM-2112.A_20 (El Rito Creek, perennial reaches from HWY 554 to the headwaters), there were 0 exceedances out of 4 samples for the E. coli criterion at the historic monitoring station. As a result, the E. coli impairment has been removed from this soon-to-be-retired AU. The new watershed-based AU that now includes this station continues to show attainment of the E. coli criterion based on the most recent dataset (2023–2024). However, it remains impaired for temperature (IR Category 5A) due to 4T3 and Tmax exceedances recorded on the 2023 thermograph. Assessment Rationale comments were added to clarify the distinction between the historic AU and the current watershed-based AU.*
4. *DP Canyon (100m downstream of grade control to 400m upstream of grade control) (NM-128.A_24) – reformatted data submitted during the July 2025 call for data was re-assessed, 0/5 exceedances of the new site-specific copper criteria described in Paragraph (4) of Subsection I of 20.6.4.900 NMAC, therefore copper (dissolved) impairment removed.*
5. *Pueblo Canyon (Acid Canyon to headwaters) (NM-9000.A_043) – reformatted data submitted during the July 2025 call for data was re-assessed, 0/5 exceedances of the new site-specific copper criteria described in Paragraph (4) of Subsection I of 20.6.4.900 NMAC, therefore copper (dissolved) impairment removed.*
6. *Assessment Rationale comments were added to the other Pajarito Plateau AUs (NM-97.A_002, NM-128.A_36, NM-97.A_029, NM-128.A_15) that were re-assessed using the new site-specific copper criteria in Paragraph (4) of Subsection I of 20.6.4.900 NMAC, noting that these reassessments did not result in any changes.*

COMMENT SET 1 – New Mexico Farm and Livestock Bureau (NMF&LB)

Submitted on 1/22/26 via the NMED Public Comment Portal at: https://nmed.commentinput.com/comment/search

Katie Adams

New Mexico Farm and Livestock Bureau (NMF&LB) appreciates the opportunity to provide comments on the 2026-2028 State of New Mexico Clean Water Act Integrated List of Assessed Surface Waters Draft.

NEW MEXICO FARM & LIVESTOCK BUREAU

2220 NORTH TELSHOR BOULEVARD ● LAS CRUCES, NEW MEXICO 88011 ● (575) 532-4700

January 22nd, 2026

New Mexico Environment Department
Surface Water Quality Bureau

Submitted Via Electronic

RE: 2026-2028 of New Mexico Clean Water Act Integrated List of Assessed Surface Waters Draft

Surface Water Quality Bureau,

New Mexico Farm and Livestock Bureau (NMF&LB) appreciates the opportunity to provide comments on the 2026-2028 State of New Mexico Clean Water Act Integrated List of Assessed Surface Waters Draft.

New Mexico Farm and Livestock Bureau works to ensure the support of federal regulation of the Clean Water Act within the state for the beneficial use of stakeholders and the impact of imposed regulations. NMF&LB recognizes the continuing efforts to provide the state with clean water and supports the EPA's commitment to following the guidelines put in place by the Clean Water Act and their efforts in assessing and protecting water quality standards for the surface waters within our state.

Water, being a valuable asset for our farmers and ranchers, we ask that the Surface Water Quality Bureau and New Mexico Environment Department consider and create systems in which our rural agriculturalists are able to continue production uninterrupted when waters are classified as impaired. NMF&LB recognizes and supports actions that are used to ensure the future of agriculture for generations to come, any regulatory burden that removes farmer and rancher access to vital inputs such as water, does not ensure the future of agriculture in our rural communities.

As the Surface Water Quality Bureau and New Mexico Environmental Department continues to assess the integrated list of Surface Waters and impaired waters within the state of New Mexico, we respectfully request that you consider having accurate and appropriate representation in the agricultural and rural areas of expertise when deciding on impaired surface waters to be added to the integrated list and how that can affect our agricultural stakeholders in irrigation and livestock management.

Once again, NMF&LB appreciates the opportunity to participate in providing public comment on regulation that will have an impact on the capabilities of farmers and ranchers such as the 2026-2028 State of New Mexico Clean Water Act Integrated List of assessed Surface Waters Draft. NMF&LB looks forward to further engaging in this process and appreciates your consideration of our members' viewpoints.

New Mexico Farm and Livestock Bureau is New Mexico's largest agricultural organization, representing members involved in all aspects of agriculture from dairy and livestock to fruits and vegetables. Our mission is to promote and protect agriculture in the great State of New Mexico. We are charged with the important task of representing our members' interests when it comes to impending regulations and programs.

***NMED RESPONSE**:*

Thank you for your comments on the 2026–2028 State of New Mexico Clean Water Act Integrated List of Assessed Surface Waters Draft. The Surface Water Quality Bureau (SWQB) appreciates the New Mexico Farm and Livestock Bureau's engagement and your commitment to both clean water and the long-term viability of agriculture in New Mexico. We recognize the essential role water plays in sustaining agricultural production and remain committed to implementing the Clean Water Act in a transparent and collaborative manner that supports farmers and ranchers while ensuring scientifically based water quality assessments.

Public participation is a core requirement of the Clean Water Act and is strongly supported by the U.S. Environmental Protection Agency. Consistent with these expectations, the Comprehensive Assessment and Listing Methodology (CALM) was open for an extended public comment period from June 16 through July 18, 2025, and the draft Integrated List was open for an extended public comment period from December 8, 2025 through January 22, 2026, during which specific listing decisions could be reevaluated given supporting data. While NMED did not receive additional comments to reconsider individual impairments during the comment period, we remain committed to ensuring agricultural voices are included in future stages of water quality planning. EPA emphasizes that residents, landowners, and agricultural producers often have unique knowledge of watershed conditions, and this local insight can meaningfully improve both listing decisions and the development of water quality restoration strategies. SWQB values the perspectives of agricultural stakeholders and welcomes continued participation from rural communities. The Water Quality Control Commission, whose membership includes the Director of the New Mexico Department of Agriculture, will consider the final List following a presentation by SWQB staff at the regular monthly meeting on March 10, 2026.

The Integrated List is a Clean Water Act deliverable and a key document used by multiple NMED programs, including permitting and watershed planning, to guide water quality improvement efforts. Impairment decisions are considered by SWQB's Point Source Regulation Section during regulatory and permitting processes. The List is also used by SWQB's Watershed Protection Section to inform watershed-based planning and restoration projects.

Stakeholders also have opportunities for public engagement during the development of Total Maximum Daily Loads (TMDLs), which guide future regulatory and restoration efforts. Public participation is a required and essential component of the TMDL process, including reviewing draft TMDLs, providing data, and offering local context. Completion of a TMDL can lead to additional monitoring, planning, and on the ground restoration projects to address watershed conditions contributing to impairments. Thank you again for your engagement and for representing the interests of New Mexico's agricultural producers. SWQB looks forward to continued dialogue with the New Mexico Farm and Livestock Bureau as we advance the Integrated Report, TMDL development, and future water quality initiatives. We encourage interested organizations to subscribe to GovDelivery alerts and check the NMED events calendar for upcoming engagement opportunities.

Submitted on 1/22/26 via the NMED Public Comment Portal at: https://nmed.commentinput.com/comment/search

Alesia Hallmark

Gila Resources Information Project
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22 January 2024

Surface Water Quality Board
New Mexico Environment Department

Public comment on the **2026-2028 Clean Water Act 303(d)/305(b) Integrated List of Assessed Surface Waters**

To whom it may concern,

I am writing this letter as a representative of the Gila Resources Information Project (GRIP), a 503(c) non-profit organization in Silver City, NM that has been promoting healthy communities by protecting our local environment since 1988. GRIP, along with its watershed monitoring and education program, the Silver City Watershed Keepers, has worked to protect and restore watershed functioning and monitor local water quality in and around the Town of Silver City. GRIP has received multiple River Stewardship grants to restore stream and riparian habitat along San Vicente Creek and conducts quarterly water quality monitoring within this watershed.

We are submitting public comments on the 2026-2028 Clean Water Act 303(d)/305(b) Integrated List of Assessed Surface Waters in order to better understand how waterway impairments are classified and how Outstanding National Resource Waters are being protected. *Our goal is to understand how we can best monitor water quality and submit high-quality data to the New Mexico Environment Department for waterways in the Town of Silver City and in the surrounding Grant County and Gila bioregion.*

How are waterways classified as impaired?
Within the Integrated List of Assessed Surface Waters, reaches may be designated as impaired in terms of physical, biological, and chemical factors.

Within Grant County, some surface waters are listed as being impaired. Specifically, the Gila River and Bear Creek are listed as being temperature-impaired and San Vicente Creek (Perennial prt Maudes Cny to Silva Creek), the waterway that flows through downtown Silver City and that is center of our Big Ditch Park and urban trail system, has been listed as being impaired for nutrients and *E. coli*. While the 2025 Comprehensive and Listing Methodology (CALM) discusses the thresholds and number of tests needed to classify a waterway as impaired, it does not specify which specific products or testing methods are acceptable for use.

- We would like to know what metrics were used to designate these waters as impaired? If other water monitoring entities were testing San Vicente Creek, for example, can we access those reports that were cited as part of this designation process?

***NMED RESPONSE**:*

Thank you for your comment and for your interest in understanding how waterways are assessed and how high-quality data can be submitted for consideration in the Integrated List of Impaired Waters. The metrics used to determine whether a waterbody is impaired are outlined in the Comprehensive Assessment and Listing Methodology (CALM), which describes the physical, chemical, and biological criteria applied during assessment.

San Vicente Creek (Perennial portion from Maudes Canyon to Silva Creek) has been listed as impaired for nutrients since 2012. The Assessment Rationale document notes that data collected during the 2019-2020 Gila/Mimbres/San Francisco survey supported a retained nutrient impairment (TN median threshold exceedance). Recent data submitted by the Silver City Watershed Keepers indicated six out of eight exceedances of the dissolved oxygen (DO) criterion. Because low DO is a common response to excess nutrient loading, these results were used as support for the persistent nutrient impairment, and the listing category was updated from IR Category 5C to 5A. In addition, two out of eight samples exceeded the E. coli criterion, which resulted in E. coli being added as a new impairment. The data used for these determinations were submitted by the Silver City Watershed Keepers and by your organization during the call for outside data on 7/16/2025 and 9/8/2025. If you would like to discuss the specific decision-making process in more detail, we would be happy to schedule a meeting.

Regarding acceptable testing methods, Appendix A of the CALM describes the data quality levels required for assessment, including the types of sampling methods, laboratory procedures, and documentation needed for data to be considered "Level 3," which is the level required for use in impairment determinations. SWQB accepts data from external monitoring entities when it meets these quality requirements. A data determination letter was prepared for Silver City Watershed Keepers data explaining the data quality level determination and rationale. If other organizations have collected data on San Vicente Creek or other Grant County waters, those datasets would be included in the administrative record if they met CALM criteria and were submitted during the data solicitation period. You may request access to any such records through NMED, and we can assist you in identifying what was submitted and used.

We appreciate your engagement and your interest in participating in a rigorous, science-based data collection process. Public involvement and high-quality local monitoring are essential components of maintaining accurate assessments of New Mexico's surface waters, and we welcome continued collaboration.

- If a standard or limit was crossed (i.e. phosphorus Total Maximum Daily Load above 1 ppm), what was that limit and was the observed value in our waters? It would be informative to know if waters barely crossed a threshold or were 10x the threshold.

***NMED RESPONSE**:*

Thank you for your comment and for your interest in understanding how nutrient standards are applied when determining impairments. Appendix C of the Comprehensive Assessment and Listing Methodology (CALM) describes how nutrient thresholds, specifically total nitrogen (TN) and total phosphorus (TP), are derived. These thresholds are not single statewide values; instead, they vary based on site-specific factors such as the ecoregion, geology, and natural background conditions of the watershed. This approach ensures that the criteria used to assess a waterbody are appropriate for its natural setting. While some surface waters in the New Mexico Water Quality Standards (20.6.4 NMAC) have segment-specific TP criteria adopted directly into the water quality standards, those numeric criteria apply only to the specific segments where they are designated. For all other wadeable perennial streams without segment-specific nutrient criteria, the nutrient thresholds in CALM Appendix C are used for assessment purposes. This framework ensures that nutrient assessments rely on the most appropriate criteria for each

waterbody, whether those criteria are formally adopted in the standards or derived through the CALM process.

When a waterbody is listed as impaired for nutrients, the associated Total Maximum Daily Load (TMDL) includes a percent reduction table that summarizes the magnitude of exceedances observed in the data. This table provides information on how far the measured values were above the applicable threshold, which can help illustrate whether exceedances were slight or substantially higher than the criterion.

For example, San Vicente Creek (Perennial, Maudes Canyon to Silva Creek) was assessed during SWQB's 2019-2020 rotational survey of the Gila/Mimbres/San Francisco watersheds. Four total nitrogen (TN) samples were collected (0.92, 1.645, 2.342, and 2.451 mg/L), resulting in a site-median TN concentration of 1.9935 mg/L. This median exceeds the applicable "moderate" site-class TN threshold of 0.42 mg/L. Because the median TN concentration remains above the threshold, the existing nutrient impairment for this assessment unit was retained.

If you are interested in the specific values observed in another particular waterbody, we would be happy to walk through the dataset with you. Waterbody-specific data used in the assessment are available upon request, and our staff can help explain how those values compared to the applicable thresholds.

Thank you again for your engagement and for your interest in understanding the technical basis for impairment decisions.

- How often should waters be re-tested to determine their impairment level? We are unsure whether to test for nutrient limitations every quarter, once annually, or at a different frequency

***NMED RESPONSE**:*

Thank you for your interest in collecting high quality data to support water quality assessments. For nutrient monitoring, sampling once per quarter is generally appropriate, which typically results in 6–8 samples per year depending on flow conditions. This frequency provides enough temporal coverage to evaluate whether nutrient criteria are being met (and calculate a median value) while ensuring that samples are spaced far enough apart to represent independent conditions.

A complete nutrient assessment relies on evaluating total nitrogen (TN), total phosphorus (TP), and daily delta dissolved oxygen (DO) together, because each plays a different role in understanding whether excess nutrients are causing ecological harm. TN and TP serve as causal indicators, while delta DO is the response indicator that reveals whether those elevated nutrients are driving biological effects such as excessive algal growth and associated swings in oxygen levels. Since delta DO reflects the actual ecological response, a waterbody cannot be listed as impaired for nutrients without it. TN, TP, and grab DO data still provide valuable supporting information and can signal emerging trends, but they cannot independently confirm impairment. Because of this, in addition to collecting enough TN and TP samples to calculate a reliable site median, long-term DO monitoring (ideally at least seven days of continuous data during the growing season) is recommended to support sound nutrient-impairment decision-making and ensure assessments are based on both cause and response. SWQB's Standard Operating Procedures (SOPs) provide detailed guidance on how to collect high-quality water quality data, including recommended sampling methods, appropriate temporal spacing, and proper use of field and laboratory equipment. These procedures help ensure that data collected for assessments are scientifically defensible, comparable across years and watersheds, and suitable for determining attainment of water quality standards. SWQB's SOPs are publicly available here: https://www.env.nm.gov/surface-water-quality/sop/.

Sampling frequency and data quality expectations are described in both the Surface Water Quality Bureau's Quality Assurance Project Plan (QAPP) and the Comprehensive Assessment and Listing Methodology (CALM). The CALM specifies that a minimum of n = 4 samples is required to assess nutrients (total phosphorus or total nitrogen). SWQB may collect duplicate or replicate samples during special investigations, but we do not routinely collect them for standard chemical monitoring. This is because laboratory quality assurance procedures already address analytical precision, and replicate field samples do not distinguish environmental variability from sampling or analytical error in a way that improves assessment decisions.

The CALM also explains how temporal independence is applied during assessments. For Clean Water Act §303(d)/§305(b) purposes, grab samples collected within a seven-day period are considered duplicates unless they represent distinct hydrologic events. In these cases, the maximum (or minimum, depending on the criterion) value is used to ensure that any exceedance is captured. For certain parameters, such as turbidity, at least four samples must be collected at least 21 days apart within the same calendar year to be considered assessable. Samples captured within 21 days are considered replicates, and the most conservative value is used for assessment.

If you are planning a monitoring program and would like guidance on designing a sampling schedule that meets CALM and QAPP requirements, we would be happy to discuss your goals and help ensure your data can be used in future assessments. Please reach out to the SWQB QA officer Emily Miller (Emily.Miller@env.nm.gov). You may also find it helpful to review the field sampling plans available on our monitoring webpage, which provide useful examples of how SWQB structures its own monitoring efforts: https://www.env.nm.gov/surface-water-quality/water-quality-monitoring/. Thank you again for your engagement and commitment to rigorous water quality monitoring.

- Which tests or products are acceptable to use? In the past, we have used LaMotte Nitrate-Nitrogen test kits, CHEMetrics Nitrate kits, and H2Ok water testing kits to quantify nitrogen levels. We know that we could also submit water samples to various private and state labs. These kits and lab tests range in purchase price and toxicity of test reagents, so of course we would like to collect the highest quality data while minimizing costs and potential environmental or personal exposure to toxic chemicals.

***NMED RESPONSE**:*

Thank you for your interest in collecting high quality data while also considering cost and safety. The Surface Water Quality Bureau's Quality Assurance Project Plan (QAPP), Standard Operating Procedure (SOP) 8.2, and Appendix A of the Comprehensive Assessment and Listing Methodology (CALM) provide guidance on which analytical methods are acceptable for use in Clean Water Act assessments.

In general, any method used for nitrogen, phosphorus, or other chemical parameters must be sufficiently sensitive, meaning the method's detection limit must fall below the applicable water quality standard or the assessment threshold described in the CALM. This ensures that the data can reliably detect exceedances when they occur. Many field test kits, such as LaMotte, CHEMetrics, or H2Ok, can be useful for screening or educational purposes, but they often do not meet the sensitivity, precision, or documentation requirements needed for Level 3 data, which is the level required for impairment determinations.

For data to be used in the Integrated Report, methods must meet or be equivalent to the QAPP's requirements for accuracy, precision, calibration, and quality assurance. This typically means using laboratory-based analytical methods (e.g., EPA-approved methods) or field instruments that have been properly calibrated and documented. Submitting samples to a certified laboratory is often the most reliable way to ensure that data meet these requirements, though we understand that cost is an important consideration.

If you are planning a monitoring program and would like help identifying methods, laboratories or kits that meet CALM and QAPP requirements, or help determining when a field kit may be appropriate versus when laboratory analysis is needed, we would be happy to discuss your goals and provide guidance. Please reach out to the SWQB QA officer Emily Miller (Emily.Miller@env.nm.gov). Thank you again for your commitment to collecting high quality water quality data.

- While the CALM protocols specify how many above-threshold readings are required to classify (or de-classify) a waterway as impaired, we don't believe follow-up testing procedures or frequency are recommended. If we, for example, observe high nitrate values in San Vicente Creek, should we take a follow-up sample within a certain time frame or submit a follow-up sample to a designated lab to confirm the test value? A recommendation would be helpful, especially if local water monitoring organizations want to help test and classify more remote or understudied surface waters.

***NMED RESPONSE**:*

Thank you for your interest in collecting high-quality data; please see the earlier response regarding nutrient sampling frequency, assessment requirements, and recommended monitoring approaches. If you would like assistance designing a monitoring schedule that meets CALM and QAPP requirements, you may contact the SWQB QA Officer, Emily Miller (Emily.Miller@env.nm.gov), and additional examples are available on our monitoring webpage: https://www.env.nm.gov/surface-water-quality/water-quality-monitoring/.

What is the status of Outstanding National Resource Waters?

The Clean Water Act allows for the designation of our state's highest quality and most important waterways as Outstanding National Resource Waters (ONRWs). In Grant County, many reaches are designated as ONRW - USFS Wilderness Streams, marking their importance to our citizens and also their protected status. The Clean Water Act and New Mexico's anti-degradation policies state that ONRWs should receive enhanced protection from degradation in perpetuity.

We would like to know what efforts have been made, by the NM Environment Department or the U.S. Forest Service, to monitor for disturbance or changes to the chemical, physical or biological integrity of the ONRWs in the Gila Bioregion. We, and other environmental monitoring organizations, could contribute to future surveys if we knew the type and frequency of surveys desired on ONRWs.

- What tests or surveys have been conducted since these waters were designated as ONRWs? Have they been surveyed using the full suite of CALM protocols? For example, are ONRWs surveyed once for chemical impairments or are biological, physical, and chemical surveys being conducted once annually?

- What monitoring is planned or desired in the next 5 years? To avoid redundant surveys, it would be useful to share a proposed survey schedule of ONRWs that will be conducted by the state as well as sharing a call for watershed monitoring organizations to conduct more surveys. This would allow us and similar organizations to apply for funding and permits/permissions in time to support ONRW monitoring.

***NMED RESPONSE**:*

Thank you for your comment and for your continued interest in the protection and monitoring of Outstanding National Resource Waters (ONRWs) in the Gila region.

NMED works with the U.S. Forest Service (USFS) under an established Memorandum of Understanding (MOU) for the management of Forest Service waters, including ONRWs. While NMED conducts water quality assessments and antidegradation review, the USFS remains the designated management agency for ONRWs on national forest lands. Under the MOU, the two agencies coordinate on ONRW protection protocols, evaluate potential degradation, and, when impairments are confirmed, work jointly with stakeholders to identify causes and appropriate actions. When resources allow, NMED and the USFS may increase sampling frequency in affected ONRWs.

Regarding past monitoring, NMED last surveyed the Gila/San Francisco/Mimbres watershed in 2019–2020 as part of the statewide rotational monitoring program, with previous surveys in 2014 and 2007. These surveys included chemical, physical, and limited biological monitoring using the most current quality assurance plans, SOPs, and CALM assessment methods available at the time. Chemical sampling is conducted multiple times within a survey period to meet minimum data requirements.

For future monitoring, please see NMED's most recently published Integrated Report for the monitoring schedule planned through 2030, including Figure 4: New Mexico's Surface Water Quality Monitoring Schedule (NMED/SWQB 2016, 2020 revision). We are tentatively planning to sample the Gila in 2028. Some sites within the planned survey watersheds may fall within ONRWs; however, all ONRWs may not be specifically targeted for sampling within the rotational monitoring framework due to resource and access limitations.

NMED welcomes and encourages watershed organizations to conduct additional monitoring on ONRWs, as there is a significant need for focused watershed-level data collection across many areas of the state. Collaboration from external organizations can help fill important data gaps. NMED now offers the Watershed Protection Assistance Program (WPAP) that provides up to $75,000 via one-time grants to do projects, such as water quality monitoring or effectiveness monitoring, which might be of interest to understanding the status of ONRWs in the Gila and inform restoration project development.

NMED's monitoring team conducts an informational public meeting and notifies the public on proposed field sampling plans, including watersheds and specific water quality stations, beginning in the winter prior to each survey year (typically February). We encourage interested organizations to subscribe to GovDelivery alerts and check the NMED events calendar for upcoming engagement and funding opportunities.

Organizations interested in more in-depth ONRW monitoring on USFS-managed lands may also wish to coordinate directly with the U.S. Forest Service to explore collaborative study opportunities.

Thank you for considering these comments and taking the time to address our questions.

Sincerely,

Alesia Hallmark

Program Coordinator, Silver City Watershed Keepers
Gila Resources Information Project

***NMED RESPONSE**: Thank you for your questions and comments. Please reach out if you would like to discuss any of these issues in more depth.*

COMMENT SET 3 – Pueblo of Santa Ana

Submitted on 1/22/26 via email

PUEBLO OF SANTA ANA
2 DOVE ROAD
SANTA ANA, NM 87004

January 22, 2026
Attn: Mrs. Meredith Zeigler
Harold Runnels Building
1190 St. Francis Dr.
Suite N45050
Santa Fe, NM 87505

Re: Public Comment for the State of New Mexico Clean Water Act (CWA) §303(d)/§305(b) Integrated List of Assessed Surface Waters

Dear Mrs. Zeigler

The Pueblo of Santa Ana (the Pueblo) respectfully submits its public comment for the State of New Mexico Clean Water Act (CWA) §303(d)/§305(b) Integrated List of Assessed Surface Waters. The Rio Grande and the Rio Jemez remain as an important and critical component of the way of life for people of Santa Ana Pueblo, as it has for countless centuries. The integrity of both river systems is a critical piece for a healthy river and here at the Pueblo we strive to support the health of both rivers by implementing sampling and monitoring to best support the regulations of the Pueblo of Santa Ana's Water Quality Standards.
We would like to highlight some of our concerns from the integrated list of the assessed surface waters in NM.

- HUC 1320202: Jemez River (Jemez Pueblo to Zia Pueblo)
  - Boron
  - Arsenic
  - E.coli
- HUC 13020201: Rio Grande (Cochiti to Angostura)
  - PCBs
- HUC 13020102: Abiquiu Reservoir
  - Mercury
  - PCBs
- HUC 13020203: Rio Grande (Angostura to 550 Bridge)
  - E.coli

We respectfully request if the NMED could implement more monitoring and sampling in the following areas mentioned. The Pueblo is open and willing to work with NMED to help support this effort. It is in the best interests of both parties to preserve our respective histories, cultures, and traditions to ensure the continued integrity of the Rio Grande and Rio Jemez.

Sincerely,

Tammy Montoya, Department of Natural Resources-
Water Resources Division Manager

***NMED RESPONSE**:*

Thank you for your comment and for the Pueblo of Santa Ana's continued commitment to protecting the Rio Grande and Rio Jemez. NMED deeply values the Pueblo's long-standing relationship with these waters and appreciates your partnership in supporting their health and integrity.

Regarding the specific assessment units identified:

• HUC 1320202 – Jemez River (Jemez Pueblo to Zia Pueblo): This reach was sampled during NMED's 2021–2022 rotational watershed survey. A Total Maximum Daily Load (TMDL) addressing the identified impairments is scheduled for public comment by mid-2026.

• HUC 13020201 – Rio Grande (Cochiti to Angostura): This segment was sampled in 2025 and will be again in 2026 as part of the Middle Rio Grande watershed survey. PCB samples were collected twice during the previous season and twice again during the current season to support assessment of the impairment.

• HUC 13020102 – Abiquiu Reservoir: The mercury and PCB impairments for this reservoir originate from fish tissue data and associated consumption advisories, rather than detections in the water column. Fish tissue was most recently collected in 2024. Results indicated a reduction in recommended meals per month for mercury in brown trout and walleye, with no change to the existing PCB advisory. Mercury and PCB advisories were originally issued in 2000 and 2006, respectively, with a combined advisory noted in 2009.

• HUC 13020203 – Rio Grande (Angostura to 550 Bridge): This reach is currently being sampled (2025-2026) as part of the ongoing watershed survey. Four E. coli samples (n=4) will be collected at two monitoring stations (30RGrand517.3 and 50RGrand508.0) during this survey cycle. The locations of these stations can be viewed on SWQB's interactive map viewer: https://gis.web.env.nm.gov/oem/?map=swqb.

The Assessment Rationale, or Record of Decision (ROD), provides a concise history of each waterbody's assessment decisions, documenting how impairments, data, and criteria have evolved over time. The most recent Assessment Rationale can be accessed here, under "2026-2028 Supporting Documents and Websites": https://www.env.nm.gov/surface-water-quality/303d-305b/.

NMED welcomes the Pueblo's collaboration on ongoing and future monitoring efforts. Your participation in the current watershed survey and in future survey cycles would be greatly appreciated. Continued coordination between NMED and the Pueblo strengthens our shared goal of protecting the cultural, ecological, and historical significance of the Rio Grande and Rio Jemez. Please reach out to the Monitoring, Assessment and Standards (MASS) Program Manager Lynette Guevara (Lynette.Guevara@env.nm.gov) and the Monitoring Team Supervisor Miguel Montoya (Miguel.Montoya@env.nm.gov).

Thank you again for your thoughtful comments and for your ongoing partnership in safeguarding these vital waters.

COMMENT SET 4 –Newport News Nuclear BWXT-Los Alamos, LLC (N3B)/U.S. Department of Energy (DOE) Environmental Management Los Alamos Field Office's (EM-LA's)

The following dataset was submitted on 1/23/26 after the closure of the public comment period on 1/22/26.

As a courtesy to the submitter, the comment and NMED response have been provided below.

N3B-Los Alamos
1200 Trinity Drive, Suite 150
Los Alamos, New Mexico 87544
(505) 257-7690

RECEIVED
JAN 23 2026
SURFACE WATER
QUALITY BUREAU
RECEIVED
JAN 22 2026
SURFACE WATER
QUALITY BUREAU

Environmental Management
Los Alamos Field Office
1200 Trinity Drive, Suite 400
Los Alamos, New Mexico 87544
(240) 562-1122

Date: January 22, 2026
Refer To: N3B-2026-0007

Meredith Zeigler and Emily Miller
Surface Water Quality Bureau
New Mexico Environment Department
1190 S. St. Francis Drive
Santa Fe, NM 87502-5469

Subject: Submittal of Comments in Response to the New Mexico Environment Department Surface Water Quality Bureau's Public Comment Period on the Draft 2026-2028 §303(d)/30S(b) Integrated Report

Dear Ms. Zeigler and Ms. Miller:

Enclosed please find the Newport News Nuclear BWXT-Los Alamos, LLC (N3B)/U.S. Department of Energy (DOE) Environmental Management Los Alamos Field Office's (EM-LA's) "Comments in Response to the New Mexico Environment Department Surface Water Quality Bureau's Public Comment Period on the Draft 2026-2028 §303(d)/305(b) Integrated Report." These comments are being provided to the New Mexico Environment Department Surface Water Quality Bureau based on the recent amendment to New Mexico Administrative Code to include the site-specific water quality criteria for copper on the Pajarito Plateau.

If you have questions, please contact Joel Hebdon at (505) 649-3346 (joel.hebdon@em-la.doe.gov) or Brian Harcek at (505) 692-4261 (brian.harcek@em.doe.gov).

Sincerely,

Lawrence Rodriguez
Program Manager
Environmental Remediation
N3B-Los Alamos

Sincerely,

Digitally signed by BRIAN HARCEK
Date: 2026.01.22 15:17:17-07'00'

Brian Harcek, Director
Office of Quality and Regulatory Compliance
U.S. Department of Energy
Environmental Management
Los Alamos Field Office

Enclosure(s): Electronic files emailed:

1. Comments in Response to the New Mexico Environment Department Surface Water Quality Bureau's Public Comment Period on the Draft 2026–2028 §303(d)/305(b) Integrated Report (EM2026-0021)

cc (letter and enclosure[s] emailed):
Laurie King, EPA Region 6, Dallas, TX
Steve Yanicak, NMED-DOE-OB
Geraldine Lucero-Torres, NA-LA
Rebecca Serrano, NA-LA
John Evans, EM-LA
Jessica Kunkle, EM-LA
Renee Martinez, EM-LA
Thomas McCrory, EM-LA
Robert Reine, EM-LA
Jeffrey Silvera, EM-LA
William Alexander, N3B
Mark Barth, N3B
Sarah Chambers, N3B
Cami Charonko, N3B
Brian Clayman, N3B
Silas DeRoma, N3B
Robert Edwards III, N3B
Kate Ellers, N3B
Joel Hebdon, N3B
Deborah Kerrigan, N3B
Mark Lesinski, N3B
Leslie Martinez, N3B
Christian Maupin, N3B
Lucia Ross, N3B
Bradley Smith, N3B
Jennifer von Rohr, N3B
Amanda White, N3B
emla.docs@em.doe.gov
n3brecords@em-la.doe.gov
Public Reading Room (EPRR)
PRS website

Comments in Response to the New Mexico Environment Department Surface Water Quality Bureau's Public Comment Period on the Draft 2026–2028 §303(d)/305(b) Integrated Report

During the New Mexico Environment Department Surface Water Quality Bureau's (NMED-SWQB's) Comprehensive Assessment and Listing Methodology (CALM) data call and public comment period in June and July of 2025, Newport News Nuclear BWXT-Los Alamos, LLC (N3B) and the U.S. Department of Energy (DOE) Environmental Management Los Alamos Field Office (EM-LA) submitted data to support the review of 10 assessment units (AUs) on the Pajarito Plateau to remove the copper impairments that are no longer applicable based on the approved and New Mexico Administrative Code– (NMAC-) incorporated site-specific water quality criteria (SSWQC) for copper on the Pajarito Plateau. The SSWQC for copper on the Pajarito Plateau was approved by the New Mexico Water Quality Control Commission on January 14, 2025, and published in the NMAC on May 22, 2025; https://www.env.nm.gov/surface-water-quality/wp-content/uploads/sites/18/2025/04/20.006.0004-NMAC-22May25.pdf. See Appendix A for the full comments and data submitted to NMED-SWQB on July 17, 2025.

N3B and EM-LA have reviewed NMED-SWQB's Public Comment Draft 2026–2028 §303(d)/ 305(b) Integrated Report (Draft Integrated Report) released on December 9, 2025. In that draft document, N3B/EM-LA noted that of the 10 AUs N3B/EM-LA submitted for review, NMED-SWQB has proposed the delisting of 4 AUs but has provided no explanations as to the status of the other six AUs. See Table 1.1 below for a summary of each AU.

N3B/EM-LA is requesting that NMED-SWQB review the six AUs that have no changes noted in the Draft Integrated Report and provide reasoning for why the copper impairment has not been proposed for removal from these six AUs. The data and rationale for delisting of these six AUs was submitted to NMED-SWQB during the CALM data call, included for reference as Appendix A.

If NMED-SWQB is using the criterion of an AU requiring at least 4 samples with no exceedances within the last 5 years, 2 additional AUs meet this criterion for copper delisting. DP Canyon (100 m downstream of grade control to 400 m upstream of grade control) and Pueblo Canyon (Acid Canyon to headwaters) have 10 samples and 5 samples, respectively, within the past 5 years with no exceedances. The other 4 AUs (Acid Canyon [Pueblo Canyon to headwaters], Arroyo de la Delfe [Pajarito Canyon to Kieling Spring], South Fork Acid Canyon [Acid Canyon to headwaters], and Twomile Canyon [Pajarito to Upper Twomile Canyon]) have limited data available from within the last 5 years, but the samples that have been taken either have never shown any exceedances (Arroyo de la Delfe, South Fork Acid Canyon, and Twomile Canyon) or have shown no exceedances since 2009 (Acid Canyon). N3B/EM-LA is requesting that these 6 AUs be reevaluated for removal of the copper impairment. The data for these AUs were submitted in the CALM data call and are included as Appendix A to this comment for reference.

REFERENCE

New Mexico Environment Department – Surface Water Quality Bureau (NMED-SWQB). 2025. "Comprehensive Assessment and Listing Methodology (CALM), Public Comment Draft." Available at: https://www.env.nm.gov/surface-water-quality/wp-content/uploads/sites/18/2025/06/CALM_2025_Public-Comment-Draft_main_plus_appendices.pdf

Table 1.1
Assessment Units Eligible for Copper Delisting Under Revised Site-Specific Water Quality Criteria for the Pajarito Plateau and NMED-SWQB's Draft 2026–2028 Assessment Listing

Assessment Unit Name and ID	Gaging Station Name and Number within Assessment Unit	Data Date Range	Number of Copper Samples	Number of Exceedances in the last 5 Years	Rationale for Delisting Copper	2026–2028 Draft Assessment Listing Status
Acid Canyon (Pueblo Canyon to headwaters) (NM-97.A_002)	Acid above Pueblo (E056)	2008–2022	21	0	No acute exceedances in 21 samples collected from 2008–2022, 1 chronic exceedance in 2009, which is greater than 5 years old	No change and no rationale to support the lack of a change
Arroyo de la Delfe (Pajarito Canyon to Kieling Spring) (NM-128.A_36)	La Delfe above Pajarito (E242.5)	2015–2024	6	0	No acute/chronic exceedances in 6 samples collected from 2015–2024	No change and no rationale to support the lack of a change
DP Canyon (100m dwnstm grade ctrl to 400m upstm grade ctrl) (NM-128.A_24)	DP below grade ctrl structure (E039.1)	2013–2025	44	0	No acute/chronic exceedances in 44 samples collected from 2013–2025	No change and no rationale to support the lack of a change
DP Canyon (400m upstream of grade control to upper LANL bnd) (NM-128.A_14)	DP above TA-21 (E038)	2013–2025	36	0	No acute/chronic exceedances in 36 samples collected from 2013–2025	Copper impairment delisted for this AU
Mortandad Canyon (within LANL) (NM-9000.A_042)	Mortandad above Ten Site (E201)	2013–2022	7	0	No acute/chronic exceedances in 7 samples collected from 2013–2022	Copper impairment delisted for this AU
	Mortandad below Effluent Canon (E200)	2005–2024	32	0	No acute exceedances in 32 samples collected from 2005–2024; 3 chronic exceedances occurred in 2006, 2008, and 2018, which are greater than 5 years old	
Pajarito Canyon (Lower LANL bnd to Twomile Canyon) (NM-128.A_08)	Pajarito above SR-4 (E250)	2013–2021	5	0	No acute/chronic exceedances in 5 samples collected from 2013–2021	Copper impairment delisted for this AU
	Pajarito above Threemile (E245.5)	2013–2024	23	0	No acute/chronic exceedances in 23 samples collected from 2013–2024	
Pueblo Canyon (Acid Canyon to headwaters) (NM-9000.A_043)	Pueblo above Acid (E055)	2009–2025	15	0	No acute/chronic exceedances in 15 samples collected from 2009–2025	No change and no rationale to support the lack of a change.
Sandia Canyon (within LANL below Sigma Canyon) (NM-128.A_11)	Sandia above Firing Range (E124)	2014–2023	10	0	No acute/chronic exceedances in 10 samples collected from 2014–2023	Copper impairment delisted for this AU
	Sandia above SR-4 (E125)	2013–2024	3	0	No acute/chronic exceedances in 3 samples collected from 2013–2024	
South Fork Acid Canyon (Acid Canyon to headwaters) (NM-97.A_029)	South Fork of Acid Canyon (E055.5)	2013–2018	9	0	No acute/chronic exceedances in 9 samples collected from 2013–2018	No change and no rationale to support the lack of a change
Twomile Canyon (Pajarito to Upper Twomile Canyon) (NM-128.A_15)	Twomile above Pajarito (E244)	2014–2025	9	0	No acute/chronic exceedances in 9 samples collected from 2014–2025	No change and no rationale to support the lack of a change

***NMED RESPONSE**:*

These public comments were received outside of the public comment period, however, as a courtesy, SWQB reviewed the comments and re-assessed the data submitted during the 2025 call for outside data. Please see the "Summary of Changes to the Draft 2026-2028 Integrated List Due to Solicited Public Comments and/or Due to Additional Staff Review During the Comment Period" #4 through 6 at the beginning of this document, and the 2026-2028 Integrated List and associated Assessment Rationale at https://www.env.nm.gov/surface-water-quality/303d-305b/ for more details.

REFERENCES

New Mexico Environment Department/Surface Water Quality Bureau (NMED/SWQB). 2025. Procedures for Assessing Standards Attainment for the State of New Mexico CWA §303(d)/ §305(b) Integrated Report: Comprehensive Assessment and Listing Methodology (CALM). Santa Fe, NM. Available at: https://www.env.nm.gov/surface-water-quality/calm/.

New Mexico Environment Department/Surface Water Quality Bureau (NMED/SWQB). 2026. State of New Mexico Surface Water Quality Survey Reports. Santa Fe, NM. Available at: https://www.env.nm.gov/surface-water-quality/water-quality-monitoring/

New Mexico Environment Department/Surface Water Quality Bureau (NMED/SWQB). 2024. Quality Assurance Project Plan for Water Quality Management Programs. Santa Fe, NM. Available at: https://www.env.nm.gov/surface-water-quality/qapps/

New Mexico Environment Department/Surface Water Quality Bureau (NMED/SWQB). 2025. Standard Operating Procedures. Santa Fe, NM. Available at: https://www.env.nm.gov/surface-water-quality/sop/

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FS Agreement No. 23-MU-11031600-095

Cooperator Agreement No. 23-667-2090-27688

MEMORANDUM OF UNDERSTANDING
Between The
NEW MEXICO ENVIRONMENT DEPARTMENT
And The
USDA, FOREST SERVICE
SOUTHWESTERN REGION

This MEMORANDUM OF UNDERSTANDING (MOU) is hereby made and entered into by and between the New Mexico Environment Department hereinafter referred to as "Environment Department," and the United States Department of Agriculture (USDA), Forest Service, Southwestern Region, hereinafter referred to as the "Forest Service."

Background: The New Mexico Water Quality Protection Agreement is a decades-old MOU between the Environment Department and U.S. Forest Service that was last signed in June 2017. The Environment Department is responsible for overseeing water infrastructure systems and water quality issues throughout New Mexico. The Environment Department closely coordinates with U.S. Forest Service on many programs that focus on protecting the quality of New Mexico's waters and assuring safe and effective infrastructure for delivering clean water to communities throughout the state, which is documented in this MOU.

Title: Water Quality Protection in New Mexico

I. PURPOSE: The purpose of this MOU is to document the cooperation between the parties to have a common objective of improving and protecting the quality of New Mexico's waters by implementing progressive watershed-based restoration protection programs to meet applicable water quality standards in accordance with the following provisions.

II. STATEMENT OF MUTUAL BENEFIT AND INTERESTS:

Whereas:

The New Mexico Water Quality Act, NMSA 1978, §§ 74-6-1 to -17, creates the New Mexico Water Quality Control Commission (Commission) and identifies the Commission as the State water pollution control agency for all purposes of the Clean Water Act in New Mexico;

The Commission has designated the Environment Department as the State's lead agency to implement Sections 208 and 319 of the Clean Water Act;

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The Commission has authorized the Environment Department to enter into agreements with federal agencies for the purpose of water quality management, while retaining enforcement authority to ensure compliance with 20.6.4 NMAC;

The Forest Service is authorized and directed by acts of Congress, including but not limited to the Organic Act of June 4, 1897, as amended (16 U.S.C. § 551) and the Multiple-Use Sustained Yield Act of June 12, 1960 (16 U.S.C. §§ 528-31), and by regulations issued by the Secretary of Agriculture to administer and protect the lands and resources of National Forest System (NFS) lands and to cooperate with other agencies;

The Forest Service, under Section 313 of the Clean Water Act, 33 U.S.C. §1323, is directed to meet federal, state, interstate, and local substantive and procedural requirements respecting control and abatement of water pollution in the same manner and to the same extent as a non-governmental entity; and

The Commission has designated the Forest Service as the management agency for implementation of the New Mexico Nonpoint Source Management Program on NFS lands.

Therefore, it is mutually advantageous, and in the public interest, for the parties to coordinate their efforts to:

A. Respond to the water quality objectives defined by Congress in the federal Water Pollution Control Act (Clean Water Act), as amended. The objective of the Clean Water Act is to restore and maintain the chemical, physical, and biological integrity of the nation's waters;

B. Fulfill the goals and policies of the State of New Mexico as defined in the New Mexico Nonpoint Source Pollution Management Program developed pursuant to Section 319, 33 U.S.C. § 1329, of the Clean Water Act, and as defined in New Mexico's Standards for Interstate and Intrastate Waters (20.6.4 NMAC);

C. Identify the responsibilities and activities to be performed by each agency in carrying out the New Mexico Water Quality Management Plan (WQMP) developed pursuant to section 208, 33 U.S.C, § 1288, of the Clean Water Act and Nonpoint Source Management Program as related to activities on NFS lands, as that term is defined by 16 U.S.C. § 1609(a); and

D. To foster a collaborative effort in implementing watershed approaches to restore those watersheds not meeting clean water, natural resource, and public health goals and to sustain healthy conditions in other watersheds.

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In consideration of the above premises, the parties agree as follows:

III. THE ENVIRONMENT DEPARTMENT SHALL:

A. Recommend that the Commission continue its designation of the Forest Service as the Designated Management Agency for implementation of the New Mexico Nonpoint Source Pollution Management Program on NFS lands;

B. Share timely drafts of Environment Department proposed water quality laws, regulations, standards, and policies to the Forest Service for review and comment during their development;

C. Participate in the Forest Service Land Resource Management Plan (LRMP) implementation process in a manner consistent with the Environment Department's regulatory responsibility and authority, in order to make recommendations on necessary LRMPs and implementing projects, activities, or Best Management Practices (BMPs);

D. Review water quality standards when the Forest Service and/or the Surface Water Quality Bureau monitoring indicates that criteria or designated uses may not be appropriate;

E. Coordinate with the Forest Service in all phases of Total Maximum Daily Load (TMDL) development on NFS lands in ensuring that the Forest Service has the timely opportunity to-share input on monitoring site locations and TMDL plans to restore impaired waters;

F. Share information to the Forest Service regarding the Clean Water Act Section 319(h), 33 U.S.C. § 1329(h), grant process;

G. In addition to the other provisions of this MOU, when an Outstanding National Resource Water (ONRW) located on NFS lands could be affected by Forest Service resource management decisions or determined to be impaired through the Environment Department's assessment process, the Surface Water Quality Bureau shall:

    1. Respond to the Forest Service regarding whether a proposed authorization of a use of NFS lands will comply with all requirements of the State's Antidegradation Policy and Implementation Procedures;

    2. Where a Clean Water Act Section 401 certification is required for a proposed authorization of a use on NFS lands, make determinations about compliance with the State's Antidegradation Policy and Implementation Procedures through the Section 401 certification process;

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3. Coordinate with the Forest Service to develop shared protocols for implementing ONRW protections, including strategies to prevent future degradation in ONRW streams and wetlands;

4. Inform the Forest Service of potential ONRW degradation as soon as practicable after the Surface Water Quality Bureau determines potential degradation (including but not limited to potential new ONRW impairments identified through assessment of verified and validated data during the development of the Clean Water Act Section 303(d)/305(b) Integrated Report);

5. If potential degradation of an ONRW has been determined, collaborate with Forest Service to review available verified and validated water quality and other data to determine whether degradation has occurred, and in cases where degradation is confirmed, conduct a joint meeting with the Forest Service and interested parties and stakeholders, including the original petitioners of the ONRW, to identify potential sources of degradation and identify action steps to address and/or remedy the degradation; and

6. In cases where degradation of an ONRW has been confirmed, coordinate with the Forest Service to increase water quality sampling efforts and frequency, if resources are sufficient to do so. The goal is to collect additional data to be able to assess water quality standards attainment every two-year Clean Water Act 303(d) listing cycle until the ONRW attains its designated uses and meets standards.

H. Recognize past projects and management actions that have, and may continue to, improve watershed conditions on NFS lands;

I. Offer timely guidance and assistance regarding the Clean Water Act Section 401 water quality certification process for Forest Service conducted projects and activities subject to Clean Water Act Section 404 requirements; and

J. Coordinate with the Forest Service for appropriate authorization for activities on NFS lands as deemed necessary by the Forest Service.

IV. THE FOREST SERVICE SHALL:

A. Serve as the Designated Management Agency within the context of the WQMP for all NFS lands within the State;

B. Recognize New Mexico identified designated uses of water and nonpoint source management program objectives;

C. Ensure all LRMPs, where water quality is an issue, meet requirements of the New Mexico water quality standards (20.6.4 NMAC), WQMP and the

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Nonpoint Source Management Program developed pursuant to federal regulations, the Clean Water Act, and the State Continuing Planning Process;

D. Identify program elements needed to support State programs and projects adopted pursuant to Sections 208 and 319 of the Clean Water Act and incorporate them into the Forest Service program planning (including under the National Environmental Policy Act) and budgeting system;

E. The Forest Service can notify the NMED using their email address env.review@env.nm.gov and to other staff and bureaus upon request, for Forest Service projects and actions in New Mexico made available for public review through the National Environmental Policy Act (NEPA).

F. In addition to other provisions of this MOU, when an ONRW located on NFS lands could be affected by Forest Service resource management decisions or determined to be impaired through the Environment Department's assessment process, the Forest Service shall:

1. Serve as the oversight agency for ONRWs located on NFS lands and implement all elements applicable to oversight agencies of the State's Antidegradation Policy for ONRWs (Paragraphs 3 and 4 of Subsection A of 20.6.4.8 NMAC);

2. The Forest Service may inquire with the Surface Water Quality Bureau and a response in writing regarding whether a proposed action will comply with all applicable antidegradation requirements;

3. Coordinate with the Surface Water Quality Bureau to develop shared protocols for implementing ONRW protections, including strategies to prevent future degradation in ONRW streams and wetlands;

4. Notify the Surface Water Quality Bureau, as soon as practicable after the Forest Service detects or determines potential degradation of an ONRW;

5. If potential degradation of an ONRW has been determined, collaborate with the Surface Water Quality Bureau to review available verified and validated water quality and other data to determine whether degradation has occurred, and in cases where degradation is confirmed conduct a joint meeting with the Bureau and interested parties and stakeholders, including the original petitioners of the ONRW, to identify potential sources of degradation and identify action steps to address and/or remedy the degradation;

6. In cases where degradation of an ONRW has been confirmed, collaborate the Surface Water Quality Bureau to increase water quality sampling efforts and frequency in order to submit verified and validated water quality data to the Surface Water Quality Bureau for assessment. The goal

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is for the Bureau to be able to assess water quality standards attainment every two-year Clean Water Act 303(d) assessment cycle until the ONRW attains is designated uses and meets standards; and

7. Consider whether a proposed action will impact water quality in an ONRW when conducting analyses under the National Environmental Policy Act (NEPA).

G. Best Management Practices:

1. Ensure that all work schedules and plans for implementation of projects that have potential to impact water quality contain site-specific BMPs, developed through the LRMP implementation process;

2. Consider technical, economic, and institutional feasibility and potential water quality impacts from the proposed activity in the selection of BMPs, but in no case shall economic and institutional feasibility be used as a basis to allow violations of water quality standards (20.6.4 NMAC); and

3. Comply with BMPs on selected activities to ensure they are implemented and are effective and adjust as necessary.

H. Ensure that all new and renewed authorizations for use of NFS lands contain provisions for compliance with all federal, state, and local water pollution control and abatement statutes, regulations, standards, and ordinances, including compliance with Clean Water Act Section 401, 33 U.S.C. § 1341, as enforceable conditions to those authorizations;

I. Consult with the Surface Water Quality Bureau in situations where the Forest Service does not administer the entire watershed and the parties have mutually determined there will be a significant water quality impact due to an activity within the watershed, that the impact will preclude attainment of water quality standards on or off NFS lands, and that the water does not currently meet water quality standards;

J. Share the Surface Water Quality Bureau appropriate and timely opportunity to participate in project and activity plans, beginning with the scoping phase, that have the potential to impact watershed condition, riparian areas, or water quality, including projects requiring Clean Water Act Section 401, U.S.C. §1341 certification;

K. Share with the Surface Water Quality Bureau, to the same extent as required of non-governmental entities, with an annual general assessment of water quality accomplishments, monitoring results, problems, and priorities, including activities that meet the goals and objectives of TMDL plans to restore impaired waters;

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L. Share with the Surface Water Quality Bureau water quality and watershed assessment data collected on NFS lands, including GIS data;

M. Forest Service wills strive to increase internal education and training to increase employee awareness of, and sensitivity to, the importance of maintaining and improving water quality and the requirements of State and federal water quality regulations and standards;

N. Collaborate in the TMDL development process, including providing input to the Surface Water Quality Bureau on monitoring locations and implementation plans;

O. Share Clean Water Act Section 404, 33 U.S.C. § 1344, applications or pre-construction notifications for Forest Service conducted activities to the Surface Water Quality Bureau in a timely manner for Clean Water Act Section 401, 33 U.S.C. § 1344, water quality certification review;

V. IT IS MUTUALLY UNDERSTOOD AND AGREED BY AND BETWEEN THE PARTIES THAT:

A. They will work together in setting priorities for planning watershed actions and in developing watershed-based plans and watershed restoration action plans for watersheds not meeting clean water or natural resource goals;

B. Coordinate efforts on preventative or mitigative land management practices, generally referred to as BMPs, to improve or protect the quality of waters on or downstream of NFS lands;

C. Coordinate efforts on identifying existing or potential nonpoint source water pollution problems on NFS lands, including ONRWs;

D. Coordinate efforts to assess or monitor water quality or watershed conditions on NFS lands using consistent scientific approaches when applicable;

E. Share data, data analysis, and watershed assessment results to improve future planning and management activities on NFS lands;

F. Use such water quality information for validating existing water quality criteria and designated uses and, when appropriate, develop the data into proposed standards revisions for consideration by the Commission during regularly scheduled water quality standards reviews;

G. Share training opportunities;

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H. Collaborate and support not otherwise available to the other party, to the extent the supplying party's program priorities, budget, and availability of expertise allow;

I. Meet, no less than annually, to maintain coordination and communication, report on water quality management progress and problems, and review proceedings under this MOU, and:

J. Work together to evaluate complaints regarding potential water quality standards violations to assure that sources of potential violations are addressed.

K. PRINCIPAL CONTACTS. Individuals listed below are authorized to act in their respective areas for matters related to this agreement.

Principal Cooperator Contacts:

Cooperator Program Contact	Cooperator Administrative Contact
Abraham Franklin, Program Manager Watershed Protection Section Surface Water Quality Bureau New Mexico Environment Dept. P.O. Box 5469 Santa Fe, NM 87502 Telephone: (505) 946-8952 Email: wpsprogram.manager@state.nm.us	Christina Keyes, Chief Financial Officer Administrative Services Division New Mexico Environment Department P.O. Box 5469 Santa Fe, NM 87502 Telephone: 505-795-2173 Email: christina.keyes@env.nm.gov

Principal Forest Service Contacts:

Forest Service Program Manager Contact	Forest Service Administrative Contact
Kerry Jones NMED Liaison 11 Forest Lane Santa Fe, NM 87508 Telephone: (505) 438-5673 Email: kerry.jones@usda.gov	Lisa Street 333 Broadway Blvd SE Albuquerque, NM 87102 Telephone: 303-579-5992 Email: lisa.street@usda.gov

L. NOTICES. Any communications affecting the operations covered by this agreement given by the Forest Service or the Environmental Department is sufficient only if in writing and delivered in person, mailed, or transmitted electronically by e-mail or fax, as follows:

To the Forest Service Program Manager, at the address specified in the MOU.

To the Environmental Department at the Environmental Department's address shown in the MOU or such other address designated within the MOU.

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Notices are effective when delivered in accordance with this provision, or on the effective date of the notice, whichever is later.

M. PARTICIPATION IN SIMILAR ACTIVITIES. This MOU in no way restricts the Forest Service or the Environmental Department from participating in similar activities with other public or private agencies, organizations, and individuals.

N. ENDORSEMENT. Any of the Environmental Department's contributions made under this MOU do not by direct reference or implication convey Forest Service endorsement of the Environmental Department's products or activities.

O. NONBINDING AGREEMENT. This MOU creates no right, benefit, or trust responsibility, substantive or procedural, enforceable by law or equity. The parties shall manage their respective resources and activities in a separate, coordinated and mutually beneficial manner to meet the purpose(s) of this MOU. Nothing in this MOU authorizes any of the parties to obligate or transfer anything of value.

Specific, prospective projects or activities that involve the transfer of funds, services, property, to a party requires the execution of separate agreements and are contingent upon numerous factors, including, as applicable, but not limited to: agency availability of appropriated funds and other resources; cooperator availability of funds and other resources; agency and cooperator administrative and legal requirements (including agency authorization by statute); etc. This MOU neither provides, nor meets these criteria. If the parties elect to enter into an obligation agreement that involves the transfer of funds, services, property, and/or anything of value to a party, then the applicable criteria must be met. Additionally, under a prospective agreement, each party operates under its own laws, regulations, and/or policies, and any Forest Service obligation is subject to the availability of appropriated funds and other resources. The negotiation, execution, and administration of these prospective agreements must comply with all applicable law.

Nothing in this MOU is intended to alter, limit, or expand the agencies' statutory and regulatory authority.

P. USE OF FOREST SERVICE INSIGNIA. In order for the Environmental Department to use the Forest Service insignia on any published media, such as a Web page, printed publication, or audiovisual production, permission must be granted from the Forest Service's Office of Communications. A written request must be submitted and approval granted in writing by the Office of Communications (Washington Office) prior to use of the insignia.

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Q. MEMBERS OF U.S. CONGRESS. Pursuant to 41 U.S.C. 22, no U.S. member of, or U.S. delegate to, Congress shall be admitted to any share or part of this agreement, or benefits that may arise therefrom, either directly or indirectly.

R. FREEDOM OF INFORMATION ACT (FOIA). Public access to MOU or agreement records must not be limited, except when such records must be kept confidential and would have been exempted from disclosure pursuant to Freedom of Information regulations (5 U.S.C. 552).

S. TEXT MESSAGING WHILE DRIVING. In accordance with Executive Order (EO) 13513, "Federal Leadership on Reducing Text Messaging While Driving," any and all text messaging by Federal employees is banned: a) while driving a Government owned vehicle (GOV) or driving a privately owned vehicle (POV) while on official Government business; or b) using any electronic equipment supplied by the Government when driving any vehicle at any time. All cooperators, their employees, volunteers, and contractors are encouraged to adopt and enforce policies that ban text messaging when driving company owned, leased or rented vehicles, POVs or GOVs when driving while on official Government business or when performing any work for or on behalf of the Government.

T. PUBLIC NOTICES. It is the Forest Service's policy to inform the public as fully as possible of its programs and activities. The Environmental Department is encouraged to give public notice of the receipt of this agreement and, from time to time, to announce progress and accomplishments. Press releases or other public notices should include a statement substantially as follows:

"Water Resources Program of the Forest Service, Department of Agriculture, Southwestern Region."

The Environmental Department may call on the Forest Service's Office of Communication for advice regarding public notices. The Environmental Department is requested to provide copies of notices or announcements to the Forest Service Program Manager and to The Forest Service's Office of Communications as far in advance of release as possible.

U. FOREST SERVICE ACKNOWLEDGED IN PUBLICATIONS, AUDIOVISUALS AND ELECTRONIC MEDIA. The Environmental Department shall acknowledge Forest Service support in any publications, audiovisuals, and electronic media developed as a result of this MOU.

V. NONDISCRIMINATION STATEMENT – PRINTED, ELECTRONIC, OR AUDIOVISUAL MATERIAL. The Environmental Department shall include the following statement, in full, in any printed, audiovisual material, or electronic media for public distribution developed or printed with any Federal funding.

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In accordance with Federal law and U.S. Department of Agriculture policy, this institution is prohibited from discriminating on the basis of race, color, national origin, sex, age, or disability. (Not all prohibited bases apply to all programs.)

To file a complaint of discrimination, write USDA, Director, Office of Civil Rights, Room 326-W, Whitten Building, 1400 Independence Avenue, SW, Washington, DC 20250-9410 or call (202) 720-5964 (voice and TDD). USDA is an equal opportunity provider and employer.

If the material is too small to permit the full statement to be included, the material must, at minimum, include the following statement, in print size no smaller than the text:

"This institution is an equal opportunity provider."

W. TERMINATION. Any of the parties, in writing, may terminate this MOU in whole, or in part, at any time before the date of expiration.

X. DEBARMENT AND SUSPENSION. The Environmental Department shall immediately inform the Forest Service if they or any of their principals are presently excluded, debarred, or suspended from entering into covered transactions with the federal government according to the terms of 2 CFR Part 180. Additionally, should the Environmental Department or any of their principals receive a transmittal letter or other official Federal notice of debarment or suspension, then they shall notify the Forest Service without undue delay. This applies whether the exclusion, debarment, or suspension is voluntary or involuntary.

Y. MODIFICATIONS. Modifications within the scope of this MOU must be made by mutual consent of the parties, by the issuance of a written modification signed and dated by all properly authorized, signatory officials, prior to any changes being performed. Requests for modification should be made, in writing, at least 30 days prior to implementation of the requested change.

Z. COMMENCEMENT/EXPIRATION DATE. This MOU is executed as of the date of the last signature and is effective through five years for the date of last signature at which time it will expire.

AA. AUTHORIZED REPRESENTATIVES. By signature below, each party certifies that the individuals listed in this document as representatives of the individual parties are authorized to act in their respective areas for matters related to this MOU.

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In witness whereof, the parties hereto have executed this MOU as of the last date written below.

DocuSigned by:
Danielle L Gilbair
BD8C44EB00D548E...

4/28/2023

JAMES C. KENNEY, Secretary or Designee — Date
New Mexico Environment Department

SHERRI SCHWENKE
Digitally signed by SHERRI SCHWENKE
Date: 2023.05.02 19:37:41 -06'00'

SHERRI K. SCHWENKE, Deputy Regional Forester — Date
Forest Service, Southwestern Region

The authority and format of this agreement have been reviewed and approved for signature.

Digitally signed by LISA STREET
Date: 2023.04.27 11:08:58 -06'00'

LISA STREET — Date
Forest Service Grants Management Specialist

Burden Statement

According to the Paperwork Reduction Act of 1995, an agency may not conduct or sponsor, and a person is not required to respond to a collection of information unless it displays a valid OMB control number. The valid OMB control number for this information collection is 0596-0217. The time required to complete this information collection is estimated to average 3 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information.

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at 202-720-2600 (voice and TDD).

To file a complaint of discrimination, write USDA, Director, Office of Civil Rights, 1400 Independence Avenue, SW, Washington, DC 20250-9410 or call toll free (866) 632-9992 (voice). TDD users can contact USDA through local relay or the Federal relay at (800) 877-8339 (TDD) or (866) 377-8642 (relay voice). USDA is an equal opportunity provider and employer.

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Notification of Emergency Action with the potential to impact Outstanding National Resource Waters on New Mexico National Forests

(To be completed within 7 days of initiating an emergency action that could impact water quality in an ONRW.)

Forest/Ranger District: Santa Fe National Forest, Jemez Ranger District	**Date: 6/26/2026**

Forest contact: *Kevin Carns, kevin.carns@usda.gov*

General Action: *(For wildfires, be sure to include the name and wildfire number, in addition to the suppression actions that may occur.)*
McCauley Springs Fire (NMSNF-312) located at 35.827, -106.626 is adjacent to the East Fork Jemez River (San Antonio Creek to Headwaters) ONRW and the San Antonio Creek (East Fork Jemez River to Headwaters), Redondo Creek (Sulphur Creek to Headwaters) ONRWs are located within the planning area. Additionally, Alamo Canyon, Capulin Creek, La Jara Creek, and San Luis Creek Special Designation Streams are located within the planning area. Full suppression strategy is planned that utilizes tactics to minimize disturbance to soil and water resources. Aerial application of fire retardant has been used and continued use is expected.

ONRWs that could be impacted: East Fork Jemez River (San Antonio Creek to Headwaters), San Antonio Creek (East Fork Jemez River to Headwaters), and Redondo Creek.

HUC 10 - Upper Jemez River 1302020202

	Water Name
Non-Wilderness	East Fork Jemez River (San Antonio Creek to Headwaters)
Non-Wilderness	San Antonio Creek (East Fork Jemez River to Headwaters)
Non-Wilderness	Redondo Creek (Sulphur Creek to Headwaters)

See attached map.

Describe suppression activities that could take place that could impact water quality:

Actions related to emergency fire suppression that are in the vicinity of an ONRW include: water and fire retardant drops and mixed (handline and/or dozer) fire line construction.

Describe what BMPS will be used to address water quality impacts from the suppression activities indicated:

Incident objectives include:

Protect water quality in Watersheds, Water systems, Eligible and Designated Wild and Scenic Rivers, ONRW Streams, Riparian Zones, Springs and Seeps by limiting fire intensities, uncharacteristic fire effects, suppression activities and sedimentation that would negatively affect:

- *Ecosystem function*
- *Water quality*
- *Downstream water users, water systems and acequias*

Aerially delivered fire retardant should not be applied to any mapped terrestrial or aquatic avoidance areas to prevent the potential of impacts to federally listed threatened or endangered species and on mountain peaks within Valles Caldera. The only exception to using aerially applied fire retardant in avoidance areas is for the protection of human life or public safety. The Incident Commander is the decision maker.

Consult with READs to avoid damage to historic cultural sites, traditional use areas, water resources, T&E Habitat, range infrastructure and trail systems.

Consult with READs prior to any using heavy equipment such as dozers on federal lands. REAF/ARCF must be assigned to equipment.

Maximize the use of existing roads, trails, fire lines, dozer lines to reduce impacts to previously undisturbed areas.

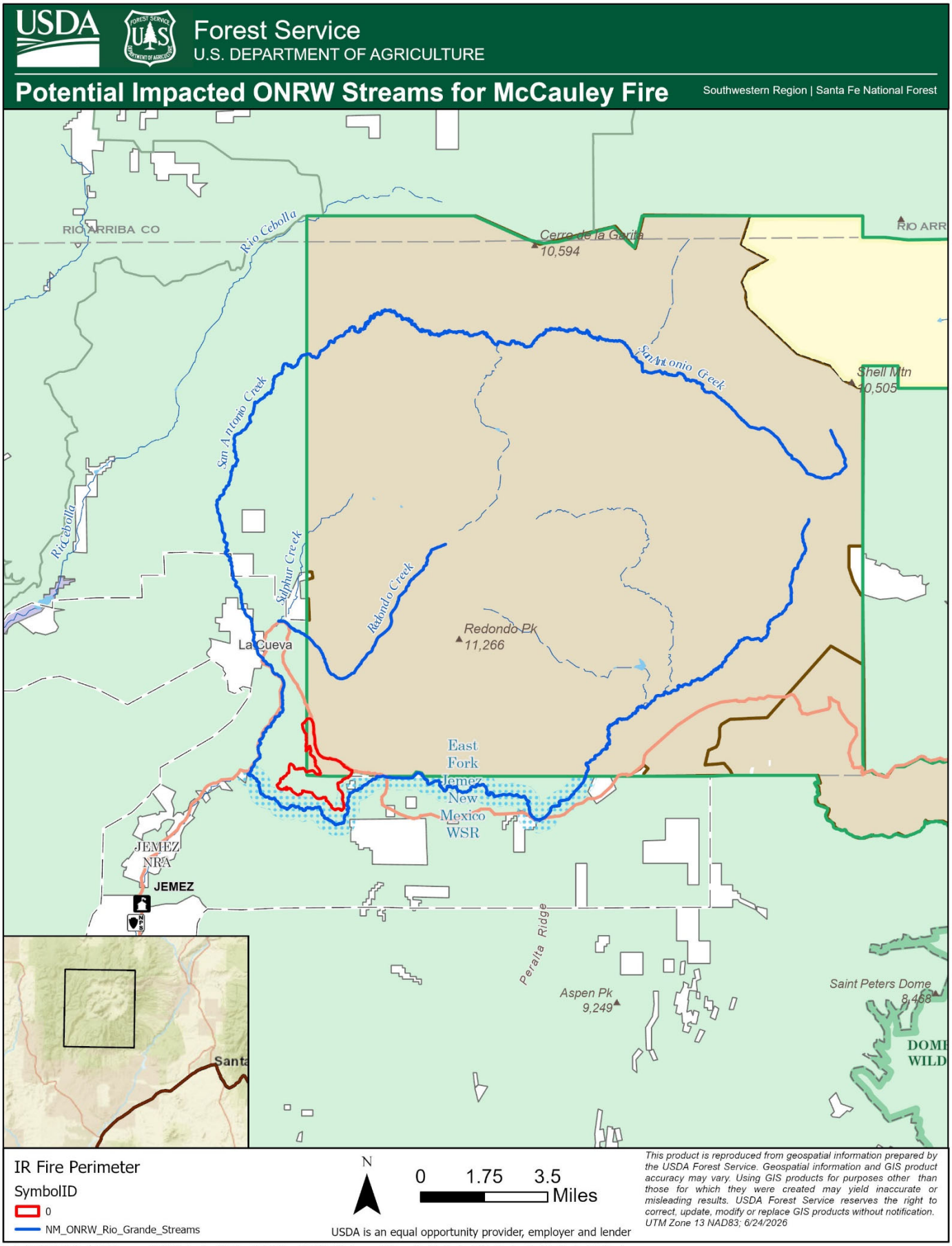
Consult with READs on wildfire suppression rehabilitation/repair standards to repair infrastructure, protect biological and cultural resources, stabilize areas affected within the burn perimeter, and protect identified potential values at risk.

Describe any monitoring requirements that will be conducted to assess impacts to ONRWs and evaluate BMPS:

Fire will continue to be monitored by fire and Forest resources including resource advisors (READs). Retardant drops will continue to be tracked to confirm avoidance zones.

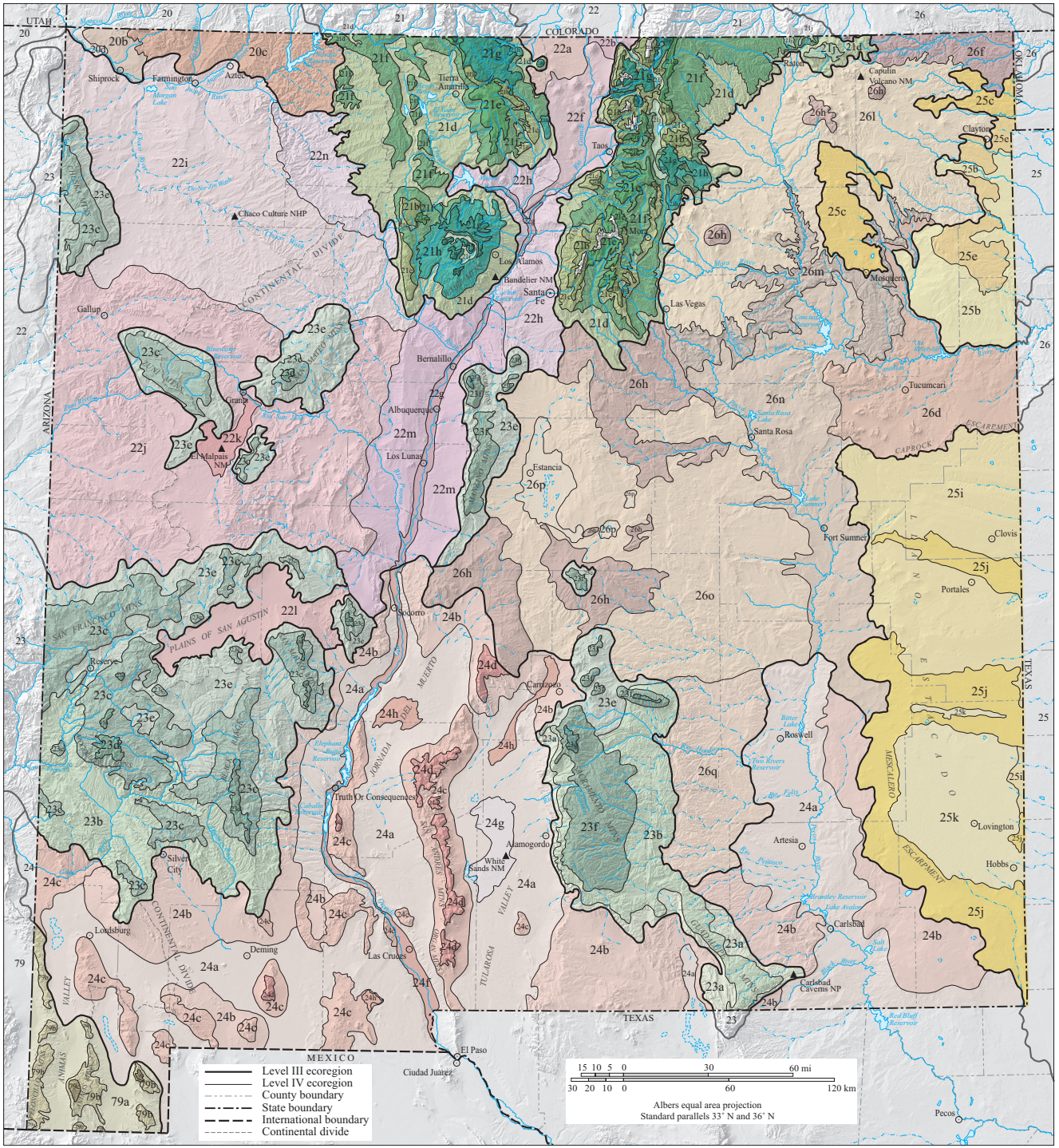
Expected completion date of Forest Service actions that could impact ONRWs:

The McCauley Springs Fire currently has no expected completion date for Forest Service actions that could impact ONRWs.



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Ecoregions of New Mexico



20 Colorado Plateaus
- 20b Shale Deserts and Sedimentary Basins
- 20c Semiarid Benchlands and Canyonlands
- 20d Arid Canyonlands

21 Southern Rockies
- 21a Alpine Zone
- 21b Crystalline Subalpine Forests
- 21c Crystalline Mid-Elevation Forests
- 21d Foothill Woodlands and Shrublands
- 21e Sedimentary Subalpine Forests
- 21f Sedimentary Mid-Elevation Forests
- 21g Volcanic Subalpine Forests
- 21h Volcanic Mid-Elevation Forests
- 21j Grassland Parks

22 Arizona/New Mexico Plateau
- 22a San Luis Shrublands and Hills
- 22b San Luis Alluvial Flats and Wetlands
- 22f Taos Plateau
- 22g Rio Grande Floodplain
- 22h North Central New Mexico Valleys and Mesas
- 22i San Juan/Chaco Tablelands and Mesas
- 22j Semiarid Tablelands
- 22k Lava Malpais
- 22l Plains of San Agustin
- 22m Albuquerque Basin
- 22n Near-Rockies Valleys and Mesas

23 Arizona/New Mexico Mountains
- 23a Chihuahuan Desert Slopes
- 23b Madrean Lower Montane Woodlands
- 23c Montane Conifer Forests
- 23d Arizona/New Mexico Subalpine Forests
- 23e Conifer Woodlands and Savannas
- 23f Rocky Mountain Conifer Forests
- 23g Rocky Mountain Subalpine Forests

24 Chihuahuan Deserts
- 24a Chihuahuan Basins and Playas
- 24b Chihuahuan Desert Grasslands
- 24c Low Mountains and Bajadas
- 24d Chihuahuan Montane Woodlands
- 24f Rio Grande Floodplain
- 24g Gypsiferous Dunes
- 24h Lava Malpais

25 High Plains
- 25b Rolling Sand Plains
- 25c Moderate Relief Plains
- 25e Canadian/Cimarron High Plains
- 25i Llano Estacado
- 25j Shinnery Sands
- 25k Arid Llano Estacado

26 Southwestern Tablelands
- 26d Semiarid Canadian Breaks
- 26f Mesa de Maya/Black Mesa
- 26h Pinyon-Juniper Woodlands and Savannas
- 26l Upper Canadian Plateau
- 26m Canadian Canyons
- 26n Conchas/Pecos Plains
- 26o Central New Mexico Plains
- 26p Pluvial Lake Basins
- 26q Southern New Mexico Dissected Plains

79 Madrean Archipelago
- 79a Apachian Valleys and Low Hills
- 79b Lower Madrean Woodlands
- 79c Madrean Pine-Oak and Mixed Conifer Forests

CITING THIS MAP: Griffith, G.E., Omernik, J.M., McGraw, M.M., Jacobi, G.Z., Canavan, C.M., Schrader, T.S., Mercer, D., Hill, R., and Moran, B.C., 2006, Ecoregions of New Mexico (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,400,000).

Ecoregion maps, publications, GIS files, and contact information are available at www.epa.gov/wed/pages/ecoregions.htm.

United States Environmental Protection Agency

Office of Water
EPA 820-R-15-106
March 2016

Draft Technical Support Document: Recommended Estimates for Missing Water Quality Parameters for Application in EPA's Biotic Ligand Model



Disclaimer Page

This technical support document (herein referred to as the "Missing Parameters TSD") summarizes data analysis approaches EPA used to develop recommendations for default values for water quality parameters used in the copper BLM when data are lacking. When published in final form, this document will provide information to states, tribes, and the regulated community interested in using the Biotic Ligand Model to protect aquatic life from toxic effects of copper. Under the CWA, states and tribes are to establish water quality criteria to protect designated uses. State and tribal decision makers retain the discretion to adopt approaches on a case-by-case basis when appropriate. This document does not substitute for the CWA or EPA's regulations; nor is it a regulation itself. Thus, it cannot impose legally binding requirements on EPA, states, tribes, or the regulated community, and might not apply to a particular situation based upon the specific circumstances. EPA may change this document in the future. This document has been approved for publication by the Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency.

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http://water.epa.gov/scitech/swguidance/standards/criteria/aqlife/copper/2007_index.cfm

Cover photo: Credit USEPA

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Acknowledgements

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Acronyms or Abbreviations

Acronym/Abbreviation	Definition
ACR	Acute to Chronic Ratio
ASE	Average Standard Error
BLM	Biotic Ligand Model
BOD	Biochemical Oxygen Demand
CCC	Criterion Continuous Concentration
CMC	Criterion Maximum Concentration
CWA	Clean Water Act
df	Degrees of Freedom
DOC	Dissolved Organic Carbon
Ecoregion	Areas in which ecosystems and the type, quality, and quantity of environmental resources are generally similar. In this document is represented by EPA Level III Ecoregions
EMAP	Environmental Monitoring and Assessment Program
EPA	United States Environmental Protection Agency
FSC	Fixed Site Criteria
GI	Geochemical Ions; ion parameters for the Biotic Ligand Model (Ca, Mg, Cl, Na, K, SO_4, alkalinity)
GIS	Geographic Information System
GLEC	Great Lakes Environmental Center
HUC	Hydrologic Unit Code (a two to eight digit code that identifies each hydrologic unit)
IQR	Interquartile range
IWQC	Instantaneous Water Quality Criteria
LCL	Lower Confidence Limit
LDC	Legacy Data Center (EPA historical STORET database, recently renamed)
LR	Linear Regression
mg/L	Milligrams per liter
NHD	National Hydrography Dataset
NHD-Plus	National Hydrography Dataset Plus
NOCD	National Organic Carbon Database (combined organic carbon data from two databases: USGS WATSTORE and EPA STORET)
NRC	National Research Council
NRSA	National River and Stream Assessment
NWIS	National Waters Information System
PCS	Permit Compliance System
RPDs	Relative Percent Differences
PCA	Principal Components Analysis
pH	Negative logarithm of the hydrogen ion concentration (in moles per liter); scale range from 0 to 14
POC	Particulate Organic Carbon
POTWs	Publicly Owned Treatment Works
RMSE	Root Mean Square Error

Acronym/Abbreviation	Definition
RSS	Residual Sum of Squares
SPLOM	Scatter Plot Matrices
SO	Strahler Stream Order
STORET	EPA STOrage and RETrieval Data Warehouse (recently renamed Legacy Data Center, LDC)
TDS	Total Dissolved Solids
TSD	Technical support document
TSS	Total Suspended Solids
TOC	Total Organic Carbon
UCL	Upper Confidence Limit
U.S.	United States
USGS	United States Geological Survey
WATSTORE	USGS National WATer Data STOrage and REtrieval System (predecessor of NWIS)
WSA	Wadeable Stream Assessment
WQC	Water Quality Criteria
µS/cm	Microsiemens per centimeter
µg/L	Micrograms per liter

Executive Summary

The United States (U.S.) Environmental Protection Agency (EPA) developed revised freshwater aquatic life criteria for copper using the Biotic Ligand Model (BLM) in 2007. The 2007 Freshwater Copper BLM predicts acute copper toxicity based on site-specific water quality parameters, and calculates aquatic life criteria based on the predicted copper toxicity. The current freshwater copper BLM requires 10 input parameters to calculate copper criteria: temperature, pH, dissolved organic carbon (DOC), alkalinity, calcium, magnesium, sodium, potassium, sulfate, and chloride, the last seven of which are also referred to as geochemical ions (GI). Previously available hardness-based copper criteria incorporated consideration only of the effects of hardness on bioavailability, while the BLM incorporates consideration of all of the water chemistry parameters that have a major influence on metal bioavailability. This allows the BLM-based criteria to be customized to the particular water body under consideration. However, given the broad geographical range over which the BLM is likely to be applied, and the limited availability of data for input parameters in many areas, a practical method to estimate missing water quality parameters was needed to successfully run the BLM. This technical support document (herein referred to as the "Missing Parameters TSD") summarizes data analysis approaches EPA used to develop recommendations for default values for water quality parameters used in the Freshwater Copper BLM when data are lacking. These default values could also be used to fill in missing water quality input parameters in the application of other metal BLM models as well, when data are lacking. EPA used three approaches to develop these default value recommendations:

- Conducted geostatistics and conductivity analyses to predict GI parameters
- Applied stream order to refine prediction of GI parameters
- Mined the National Organic Carbon Database (NOCD) to estimate DOC

In brief, EPA found that an approach that used correlation (with conductivity and discharge as explanatory variables), combined with geostatistical techniques (kriging), and a consideration of stream order produced the best estimates for BLM GI parameters. Tables 8, 9, and 10 present estimated inputs for each GI and water hardness in each ecoregion categorized by stream order for low, medium, and high order streams, respectively. Recommended GI values are based on the 10^{th} percentile of ecoregional Level III values for the appropriate stream order (size) and are expected to yield appropriately protective criteria values when applied in the BLM model. In Table 20 of Section 4, EPA provides estimates for DOC by ecoregion based on an analysis of a compilation of national organic carbon databases. The 10^{th} percentile of ecoregional Level III values are recommended for DOC. There was insufficient data to refine the DOC estimates by stream order. EPA recommends measurement of pH and temperature directly to use as an input in the BLM. Temperature is a commonly measured parameter, and should be easily obtainable for use in the BLM. The following paragraphs summarize the contents of each section in this report.

Section 1 provides an introduction to this study, including background on the BLM. In developing the approaches outlined in this study, EPA relied upon several previous studies that attempted to estimate values for BLM input water quality parameters; these studies are outlined briefly in Section 1 and are described in detail in Appendices A through D. This earlier work demonstrates that protective water

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quality criteria (WQC) for copper generally corresponded to a low percentile of the distribution of instantaneous water quality criteria (IWQC) predicted by the BLM.

Section 2 provides a discussion of the approach taken by EPA to estimate BLM GI parameter values using geostatistics, which are a suite of statistical methodologies that use spatial coordinates to formulate models used in estimation and prediction. Section 2 also describes how EPA supplemented the geostatistical approach with conductivity as an explanatory variable, because conductivity data are abundant and correlate well to the BLM GI parameters.

Section 3 provides an analysis and discussion of the EPA approach to estimation of BLM GI parameters incorporating stream order as a variable, with a goal of providing BLM users with tables of recommended GI parameter estimates based upon both ecoregion and stream order. For each Level III ecoregion, we recalculated the 10^{th} percentiles of the distributions of all daily water quality parameters measured at all NWIS stations taking into account stream orders or ranges (groups) of stream orders within each ecoregion. Values of the BLM GI parameters generally increased with stream order. Based upon this trend, we grouped the estimates for each parameter by stream order: 1 through 3 (headwater streams), 4 through 6 (mid-reaches), and 7 through 9 (rivers).

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Section 5 provides a summary of the three approaches used to develop EPA's recommendations. Taken together, the approaches presented in this TSD describe EPA's recommendations for default input parameters in the BLM to derive protective freshwater aquatic life criteria when data are lacking. However, it should be noted that site-specific data are always preferable for developing criteria based on the BLM and should be used when possible. Users of the BLM are encouraged to sample their water body of interest, and to analyze the samples for the constituent (parameter) concentrations as a basis for determining BLM inputs where possible.

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1 INTRODUCTION

1.1 Background and Objective

The United States (U.S.) Environmental Protection Agency (EPA) has a congressional mandate to develop and publish criteria for water quality that reflects the effects of pollutants on aquatic life and human health under 304(a)(1) of the Clean Water Act (CWA). The CWA was intended to protect the chemical, physical, and biological integrity of the Nation's waters. Section 304(a)(1) of the CWA, 33 U.S.C. § 1314(a)(1), directs the Administrator of EPA to publish water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water, including ground water. Under this authority, EPA developed revised aquatic life criteria for copper that are based on the Biotic Ligand Model (BLM) in 2007. The BLM predicts metal toxicity based on site-specific water quality parameters, and derives acute and chronic criteria from the predicted toxicity. Derivation of water quality criteria using the BLM requires 10 input parameters (temperature, pH, dissolved organic carbon (DOC), alkalinity, calcium, magnesium, sodium, potassium, sulfate, and chloride). Data regarding these parameters may not be available for many receiving waters. Given that the BLM is likely to be applied over a broad geographical range, and that limited data are available for many areas, a practical method to estimate missing water quality parameters was needed to facilitate full use of the BLM in water quality standards across the U.S. This technical support document (herein referred to as the "Missing Parameters TSD") summarizes data analysis approaches EPA used to develop recommendations for default values for water quality parameters that may be used in the BLM when data are lacking. The section of the CWA related to the development of the information presented in this technical support document is CWA Section 304(a)(2). CWA Section 304(a)(2) generally requires EPA to develop and publish information on the factors necessary to restore and maintain the chemical, physical, and biological integrity of navigable waters. Section 304(a)(2) also allows EPA to provide information on the conditions necessary for the protection and propagation of shellfish, fish, and wildlife in receiving waters and for allowing recreational activities in and on the water.

The objective of this report is to summarize recommendations that BLM users can apply to estimate values for missing input water quality parameters.

1.2 Input Data and the BLM

The BLM calculates metal toxicity to aquatic organisms as a function of the concentrations of certain chemical constituents of water, including, for example, ions that can complex with metals and limit biological availability, and ions that compete with metals for binding sites at the ion exchange tissues of aquatic organisms (e.g., at the fish gill). The BLM predicts the metal criteria concentrations, such as copper in freshwater, which will vary according to changes in the associated water quality parameters.

An appropriately protective acute and chronic copper (or other metals) criteria must reflect the variability of water quality parameters at the site. In previous analyses, EPA found that protective water quality criteria for copper generally correspond to approximately the 2.5th percentile of the

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distribution of instantaneous water quality criteria (IWQC) predicted by the BLM[1] (USEPA, 2002). Thus, predictions made for a site using the corresponding low percentile of the water quality parameter distributions are appropriately protective. Copper BLM predictions are most sensitive to the following five important parameters: DOC, pH, and calcium, magnesium, and sodium concentrations (taken together). Estimates are most sensitive to DOC, and vary in direct proportion to a change in value (i.e., they are 100% sensitive to DOC). Estimates are 50% sensitive to a change in pH, and 20% sensitive to the combined concentrations of calcium, magnesium, and sodium.

1.3 Previous Studies

EPA has conducted previous studies to develop tools to estimate BLM water quality parameters for sites where there may be few (or no) water quality data available. Brief summaries of these previous studies are provided below, and more detailed descriptions are provided in Appendices A through D.

1.3.1 An Examination of Spatial Trends in Surface Water Chemistry in the Continental United States: Implications for the Use of Default Values as Inputs to the BLM for Prediction of Acute Metal Toxicity to Aquatic Organisms (Carlton, 2006)

A large database of surface water chemistry monitoring data was examined to look for spatial trends in five chemical constituents that are key inputs to a model for predicting metal toxicity to aquatic organisms: pH, dissolved organic carbon, alkalinity, calcium, and sodium. Continuous prediction maps of concentrations were generated using various kriging techniques to interpolate between site-median values measured at several thousand separate locations throughout the continental U.S. Continuous concentration surfaces were then averaged over 8-digit Hydrologic Unit (HUC) polygons to produce block-averaged mean estimates of site-median concentrations. Pairwise comparisons indicated distinct trends between various HUC-averaged predicted constituents. The same analyses performed on data from 772 locations where all five constituents had been measured revealed similar relationships between monitored constituents. Principal components analyses (PCA) performed on these data sets showed that 80 to 90 percent of the variance in both cases could be explained by a single component with loadings on three of the five constituents. The use of kriging to produce appropriate quantile maps for block-averaging is suggested as a possible approach for developing regional values to use as default model inputs, when site-specific monitoring data are lacking. Refer to Appendix A for more information.

1.3.2 Approaches for Estimating Missing BLM Input Parameters: Correlation Approaches to Estimate BLM Input Parameters Using Conductivity and Discharge as Explanatory Variables (USEPA, 2007)

In this 2007 report, EPA developed regression models to project BLM water quality parameters from conductivity data. EPA assessed supplementing the geostatistical approach with classical estimation methods, such as regression and correlation by assessing the degree of correlation between conductivity and each of the BLM water quality parameters using National Water Information System

[1] This was the median for 17 sites; the range was 1 to 36%.

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(NWIS) data from three states (Colorado, Utah, and Wyoming). These states were selected because of the large spatial and temporal variability observed.

EPA concluded that conductivity is significantly correlated with BLM water quality parameters between sites, especially for the low-end distribution statistics of interest for parameter estimation. Since conductivity data are abundant and correlate well with BLM water quality parameters, EPA determined it is reasonable to incorporate conductivity in spatial projections of BLM parameters. Correlation coefficients were lower for pH and DOC than for the geochemical ions (GIs) and alkalinity, but were also significant. Refer to Appendix B for more information.

1.3.3 Copper Biotic Ligand Model (BLM) Software and Supporting Documents Preparation: Development of Tools to Estimate BLM Parameters (USEPA, 2008)

In order to predict parameters based on geographic location, this 2008 report investigated how to project BLM water quality parameters for a given site based on other site data using geostatistical methods. There are a number of ways in which the conductivity regressions can be used to project BLM water quality inputs. The regressions allow estimates of the BLM water quality inputs from either: (1) a limited number of conductivity measurements, or (2) a low-end conductivity value estimated by geostatistical methods.

The first approach, projecting BLM water quality inputs from conductivity measurements, was demonstrated for a limited number of test sites. Regression models were developed to project 10^{th} percentiles of BLM water quality input parameters from the 10^{th} percentile of measured conductivity distributions at sites in Colorado, Utah, and Wyoming. The 10^{th} percentile is the value below which 10 percent of the observations may be found. The regression models were tested using data and copper BLM predictions for four sites, and produced highly consistent results. The regression models for pH and DOC, the most sensitive of the BLM water quality parameters, were not sufficiently accurate to make reliable BLM parameter predictions. However, regression models for the GI parameters (calcium, magnesium, sodium, potassium, chloride, sulfate, and alkalinity) were reasonably accurate, as judged by comparing model predictions made using projected values of the these BLM input parameters to model predictions made using measured input data. No estimate for site-specific pH was superior to the observed weak conductivity regression. To improve upon this estimate, it was necessary to use actual site-specific pH data. For DOC, the Level III ecoregion (referred to herein as simply “ecoregion”) and water body type-specific DOC concentration percentiles tabulated by EPA for the National Bioaccumulation Factors Technical Support Document (USEPA, 2003) appear to be far better estimates of lower-percentile DOC concentrations than the estimates made using the conductivity regression.

EPA also provided a proof of concept for the second approach, which was to see whether combining the kriged conductivities with the conductivity-hardness regression would project the 10^{th} percentiles of hardness better than direct kriging of the hardness data. EPA found that both approaches produce estimates of hardness that correlate significantly with the measured data (correlation coefficient $r=0.80$ for direct kriging of hardness; $r=0.95$ for conductivity kriging + regression). However, the kriging + regression approach fits the hardness data substantially better than direct kriging. Refer to Appendix C for more information.

1.3.4 Approaches for Estimating Missing BLM Input Parameters: Projections of Total Organic Carbon as a Function of Biochemical Oxygen Demand (USEPA, 2006a)

DOC concentrations downstream of an effluent discharge are necessary inputs for the BLM to predict toxicity associated with a wastewater discharge. Effluent DOC is monitored by very few publicly-owned treatment works (POTWs) according to data retrieved from EPA's Permit Compliance System (PCS). Biochemical oxygen demand (BOD) is monitored by most POTWs. EPA developed regressions to project total organic carbon (TOC) concentrations from BOD values using effluent samples at all POTWs reporting data for both parameters in EPA's PCS. EPA concluded that this regression gives reasonable estimates of TOC in POTWs effluents and are likely the best available estimates of effluent TOC to determine DOC concentrations for the BLM. Refer to Appendix D for more information.

1.4 Approaches to Estimate Water Quality Parameters for the BLM

Building upon the studies described above, this report uses three approaches to develop default estimates for parameters needed for the BLM when empirical data are lacking. The three approaches are listed below and are detailed in the following sections:

- Section 2: Using Geostatistics and Conductivity to Predict GI Parameters
- Section 3: Using Stream Order to Refine Prediction of GI Parameters
- Section 4: Using the National Organic Carbon Database to estimate DOC

EPA recommends that temperature and pH be measured directly in the field.

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2 USING GEOSTATISTICS AND CONDUCTIVITY TO PREDICT GI PARAMETERS

The following section describes studies that demonstrate how geostatistical techniques, coupled with conductivity correlations, can be used to predict BLM input parameters for GIs when site-specific data are unavailable. In a previous study (USEPA, 2008) EPA demonstrated that combining kriging with regressions to estimate inputs based on conductivity improves the accuracy of GI estimates. In this section EPA has expanded on this approach and developed national estimates at the Level III ecoregion in the continental U.S.

The current freshwater copper BLM requires 10 input parameters that reflect water chemistry in order to calculate copper criteria: temperature, pH, DOC, alkalinity, calcium, magnesium, sodium, potassium, sulfate, and chloride, the last seven of which are GIs. The concentrations of GIs vary in surface waters due to dissolution, weathering, ground water-surface water interactions, and other geologic processes in the watershed, in addition to dilution by snowmelt and precipitation. Consequently, the concentrations of GI parameters tend to vary according to the regional geology. For example, alkalinity has noticeable geographic trends. Areas dominated by carbonate rocks, such as limestone as in the prairie states, tend toward high alkalinity. Areas dominated by igneous rocks, such as granite, such as parts of the northeast, tend toward low hardness and alkalinity.

In this section we expand on the EPA 2008 proof of concept (in Appendix C) using geostatistics to develop default missing GI parameter values based on geography. Geostatistics are statistical methodologies that use spatial coordinates to help formulate models used in estimation and prediction (ESRI, 2003). Geostatistical techniques are attractive because they explain parameter variation arising from spatial correlations, which are not used in conventional statistics. We have supplemented the geostatistical approach by adding conductivity as an additional explanatory variable. Conductivity is one of the most widely monitored water quality indicators in the U.S. Because conductivity data are abundant and correlate well to the BLM GI parameters, we incorporated conductivity in spatial projections of BLM parameters. Based on the proof of concept described above (and in Appendix C), we expected that this approach, which can be implemented by co-kriging (i.e., an interpolation technique that allows for better estimates by the incorporation of well-sampled, correlated secondary data) in geostatistical software, would allow more robust spatial projections of BLM water quality parameters.

2.1 Data Source and Processing

Water quality data for conductivity and BLM GI water quality parameters were retrieved from the United States Geological Survey (USGS) National Water Information System (NWIS). NWIS contains data from millions of sampling events at tens of thousands of individual sampling locations (stations) in the continental U.S. (Figure 1). Not all water quality parameters of relevance to the BLM were monitored at each location. The numbers of sampling events at individual locations also range widely, with a mean of 15, and a mode of one (i.e., most sites were only sampled once). Examination of the spatial distribution of numbers of sampling events per site reveals that the Midwestern and Western states tended to be sampled most intensively (Carleton, 2006). Because environmental sampling data tend to be lognormally distributed, disparities in numbers of samples may tend to produce higher mean and median values at locations that have been sampled more frequently. As spatial distributions of representative (e.g., median) concentrations are examined, it should be kept in mind that apparent

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geographic trends in concentration may be in part simply the result of uneven sampling intensity (Carleton, 2006).

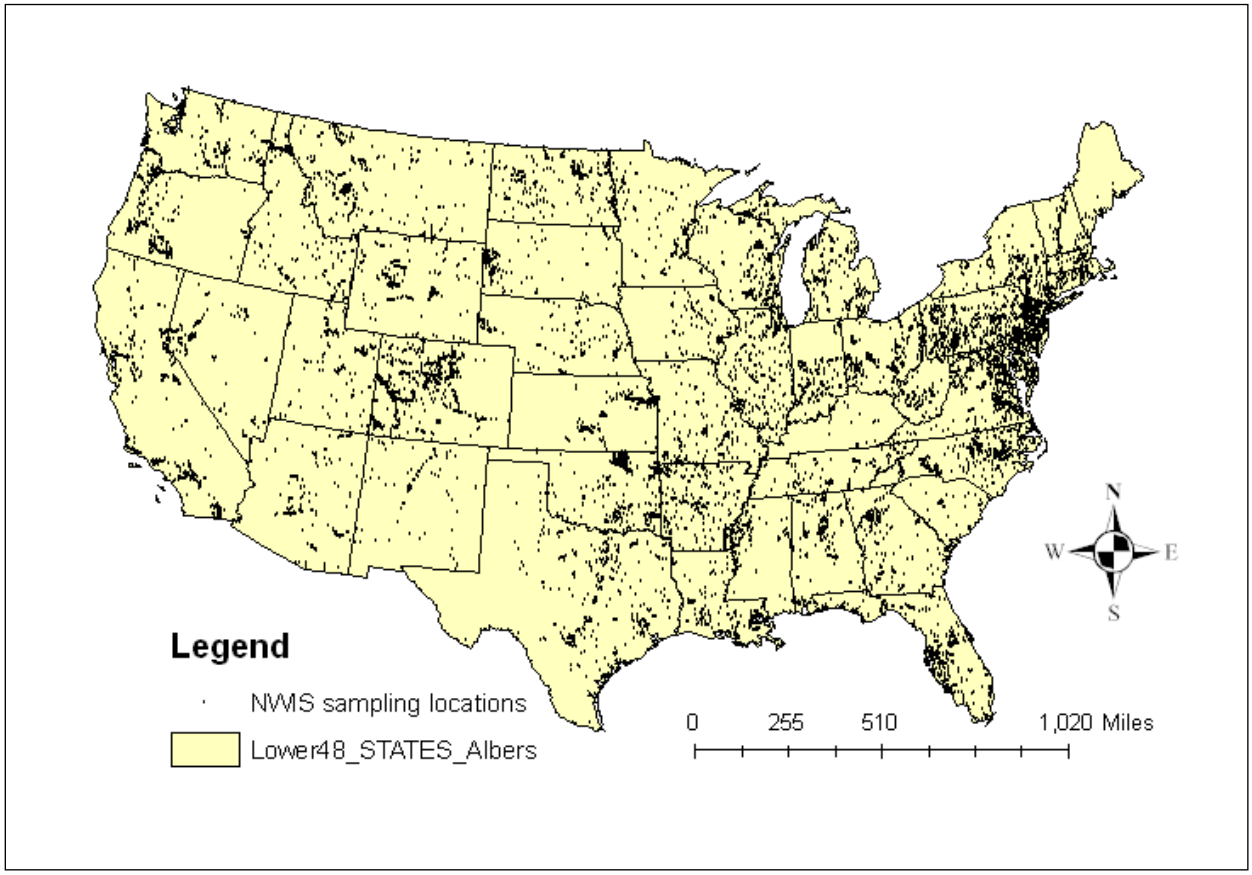


Figure 1. NWIS sample collection locations in the continental U.S. (Carleton, 2006)

We focused our efforts on data collected from rivers and streams between 1984 and 2009. Data collected prior to 1984 were excluded because a number of the analytical methods used by USGS prior to that date have been replaced by methods with improved precision and lower detection limits. Furthermore, only sites with 40 or more samples were included in the analysis. With support from USGS staff, we obtained a complete download of national water quality data from NWIS, which totaled 4,714,165 measurements from 959,946 samples, collected at 5,901 sites. These data included measurements for BLM water quality input parameters required to calculate copper criteria using the BLM: pH, DOC, alkalinity, calcium, magnesium, sodium, potassium, sulfate, and chloride. Data were also collected on filtered (dissolved) copper, and the spatial coordinates (latitude and longitude) of each sampling station were also retrieved. No data were collected on temperature. Only the GI data were included in the geostatistical analysis. A summary of the water quality data retrieved from NWIS is provided in Table 1.

Table 1. Summary of water quality data retrieved from NWIS			
BLM Water Quality Parameter	**NWIS Parameter Code**	**Parameter Description**	**Number of Observations**
Conductivity[1]	00094	Specific conductance, water, unfiltered, field, microsiemens per centimeter at 25 degrees Celsius	553,700
	00095	Specific conductance, water, unfiltered, laboratory, microsiemens per centimeter at 25 degrees Celsius	799
pH	00400	pH, water, unfiltered, field, standard units	352,336
	00403	pH, water, unfiltered, laboratory, standard units	151,161
Dissolver Organic Carbon	00681	Organic carbon, water, filtered, laboratory, milligrams per liter	30,008
Alkalinity	00410	Acid neutralizing capacity, water, unfiltered, fixed endpoint (pH 4.5) titration, field, milligrams per liter as calcium carbonate	35,232
	00417	Acid neutralizing capacity, water, unfiltered, fixed endpoint (pH 4.5) titration, laboratory, milligrams per liter as calcium carbonate	15,264
	00419	Acid neutralizing capacity, water, unfiltered, incremental titration, field, milligrams per liter as calcium carbonate	10,198
	00418	Alkalinity, water, filtered, fixed endpoint (pH 4.5) titration, field, milligrams per liter as calcium carbonate	2,686
Calcium	00915	Calcium, water, filtered, laboratory, milligrams per liter	146,608
Magnesium	00925	Magnesium, water, filtered, laboratory, milligrams per liter	145,938
Sodium	00930	Sodium, water, filtered, laboratory, milligrams per liter	136,310
Potassium	00935	Potassium, water, filtered, laboratory, milligrams per liter	132,659
Sulfate	00945	Sulfate, water, filtered, laboratory, milligrams per liter	147,824
Chloride	00940	Chloride, water, filtered, laboratory, milligrams per liter	146,601

[1] Conductivity is not a BLM parameter, but was used as an explanatory variable for the other water quality parameters.

The data were screened using established quality assurance procedures. All data were checked to confirm that they contained numerical values without null (missing) records and remark codes were

identified and reviewed. Minimum and maximum values for each parameter were confirmed to be within expected ranges and frequency distributions were plotted and examined for each of the parameters to identify outliers. We also confirmed that the spatial coordinate data placed each sampling location within the continental U.S. Additional data processing included the following steps:

- For the data at each station, the observations for each variable were averaged on a daily basis. This was done to reduce the influence of high frequency sampling at a few stations.
- Data were edited by censoring parameter(s) with fewer than 10 to 20 daily values at a station. The 10^{th} percentile for that parameter at that station was censored to improve the reliability of the lower-tail (i.e., 10^{th}) percentile statistics.
- Tenth (rank order/nonparametric) percentiles of the distributions of all water quality parameters measured at each station were calculated.

It should be emphasized that all of the statistical and geostatistical analyses and predictions presented in this report are based on the 10^{th} percentiles of the concentration distribution measured for each parameter at every station. The estimates of water quality parameter values for "missing" data are therefore also 10^{th} percentile concentrations. We selected the 10^{th} percentile of the site parameter distributions as a statistic that is a practical compromise between a lower-bound concentration and a percentile that can be reliably determined from small sample sizes. Initial testing with the BLM suggested that protective water quality criteria (WQC) for copper generally corresponded to approximately the 2.5^{th} percentile of the distribution of instantaneous water quality criteria (IWQC) predicted by the BLM. Thus, BLM predictions made for a site using the corresponding low percentiles of the water quality parameter distributions should (logically) also be a conservative approximation of a protective criterion. As a more reliably determined statistic, the 10^{th} percentile of water quality parameters will also derive reasonably protective criteria, especially for small sample sizes where there may be greater uncertainty at lower percentile estimates. The 10^{th} percentile estimates presented in this document were initially developed to implement the copper BLM published by EPA in 2007 and will apply to other metals as well.

2.2 Geostatistical Analysis of National Data for Geochemical Ions

The ESRI ArcGIS Geostatistical Analyst tool was used to create statistically valid two-dimensional surface models for conductivity and for each of the BLM GI parameters. Using the 10^{th} percentile daily average concentrations at each sampling location from the NWIS data, Geostatistical Analyst was used to create predictions for unmeasured locations throughout the continental U.S. For each parameter, the surface models were fit by minimizing the statistical error of the predicted surface. Surface fitting involved three steps: exploratory spatial data analysis, structural analysis (modeling the semivariogram to analyze surface properties of data from nearby locations), and surface prediction and assessment of the results. The semivariogram represents autocorrelation of measured data points spatially.

Modeling of the semivariogram was based on cross-validation, which calculates error statistics that serve as diagnostics to indicate whether the model is reasonable for map production. Cross-validation was used to select the models that provided the most accurate predictions. The following criteria were used to evaluate goodness of fit for the semivariogram model:

- Mean Standardized Error: close to 0;
- Root Mean Square Error (RMSE): as small as possible;

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- Root-Mean-Square Standardized Error: close to 1; and,
- RMSE close to Average Standard Error ASE).

The difference between the prediction and the measured data value is the prediction error. For a model that provides accurate predictions, the mean prediction error should be close to 0 if the predictions are unbiased. The root-mean-square standardized prediction error should be close to 1 if the standard errors are accurate, and RMSE should be small if the predictions are close to the measured values (ESRI, 2003).

A tabulation of the geostatistical model selected for each water quality parameter, the number of data points interpolated, and the resulting error statistics are presented in Table 2. We used the optimal parameters for a spherical semivariogram as calculated by the Geostatistical Analyst. No transformations were applied to the data. Anisotropy (directional influence on the semivariogram) was not incorporated in the semivariogram models.

Table 2. Model selection and cross validation statistics for geostatistical fitting of 10th percentiles of BLM GI parameters

Parameter	Geostatistical model	Number of samples	Mean standardized error	Root mean square error	RMS standardized error	Average standard error
Conductivity	Universal kriging	4833	-0.01038	1361	1.081	1259
Alkalinity	Universal cokriging with conductivity	1372	-0.001115	36.62	1.09	33.23
Calcium	Universal cokriging with conductivity	2590	0.0001694	26.81	1.186	22.02
Magnesium	Universal cokriging with conductivity	2578	-0.002258	15.92	1.16	13.58
Sodium	Universal cokriging with conductivity	2439	-0.002929	156.3	1.583	95.78
Potassium	Universal cokriging with conductivity	2379	-0.001184	3.488	1.429	2.381
Sulfate	Universal cokriging with conductivity	2650	-0.0000225	114.5	1.29	87.04
Chloride	Universal cokriging with conductivity	2792	0.001653	375.2	1.51	247

2.2.1 Kriging of Conductivity Data

Universal kriging with a constant trend was used to map the surface of 10th percentile conductivity values. Kriging weights the surrounding measured values to derive a prediction for each location. The weights are based on the distances between the measured points and the prediction location, as well as the overall spatial arrangement among the measured points. The kriged prediction surface of 10th percentiles of conductivity is mapped in Figure 2. As the kriging results show, conductivities are highest in the south-central and southwestern regions, as well as along the Gulf and southern Atlantic coasts. Regions of lower conductivity are found in a number of parts of the country.

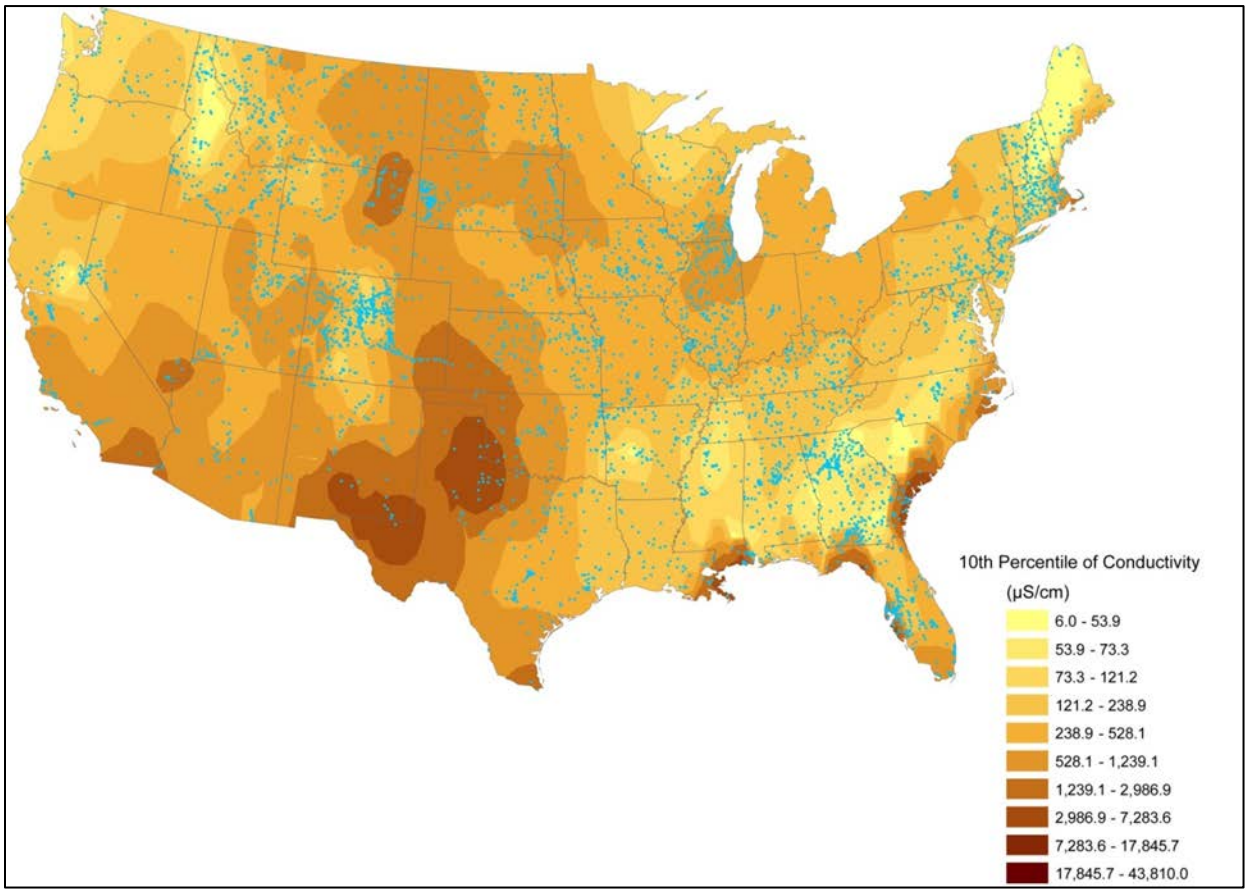


Figure 2. Kriged prediction surface for 10th percentile of conductivity in the continental U.S. (sample locations in blue)

2.2.2 Co-kriging of GI Data

Co-kriging was used to improve surface predictions of the BLM GI parameters by taking into account secondary variables, in this case conductivity. As demonstrated above, conductivity is significantly correlated to all of the BLM GIs. Universal co-kriging with conductivity, assuming a constant trend, was used to map the surface of 10th percentile BLM GIs concentrations. For each of these parameters, co-kriging produced cross-validation errors that were superior in terms of the goodness-of-fit criteria to errors produced by universal kriging. Prediction surfaces for calcium and alkalinity are mapped in Figures 3 and 4. The spatial distribution of calcium (Figure 3) shares a number of similarities with the mapping of conductivity (Figure 2). The co-kriged alkalinity surface (Figure 4) is rather different, with high alkalinity values reflecting geographic features (such as the carbonate geology of the prairie states) and low alkalinity values that reflect the granitic geology of the northeast. Prediction surfaces for the other BLM GI's are generally similar to those for conductivity and calcium.

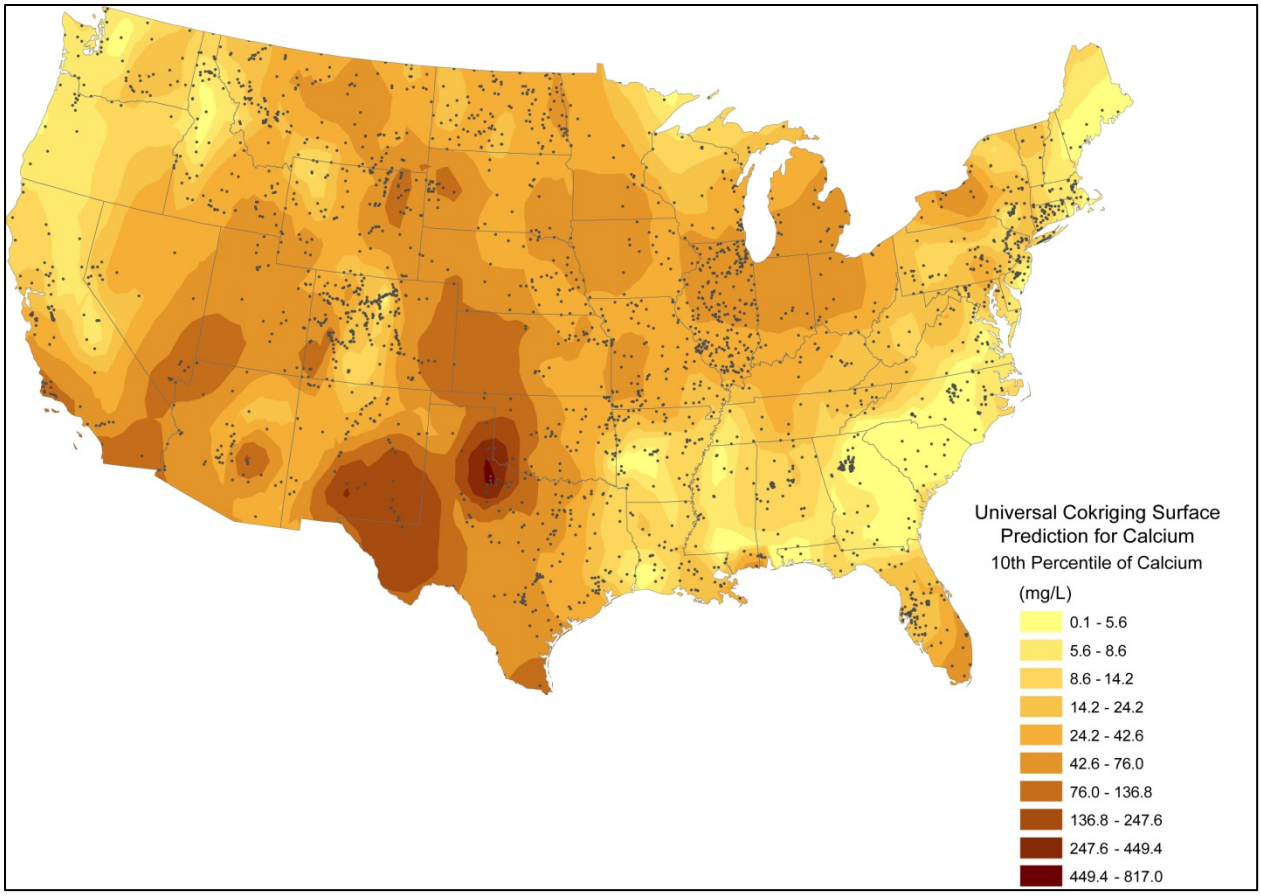


Figure 3. Co-kriged prediction surface for 10th percentile of calcium in the continental U.S.

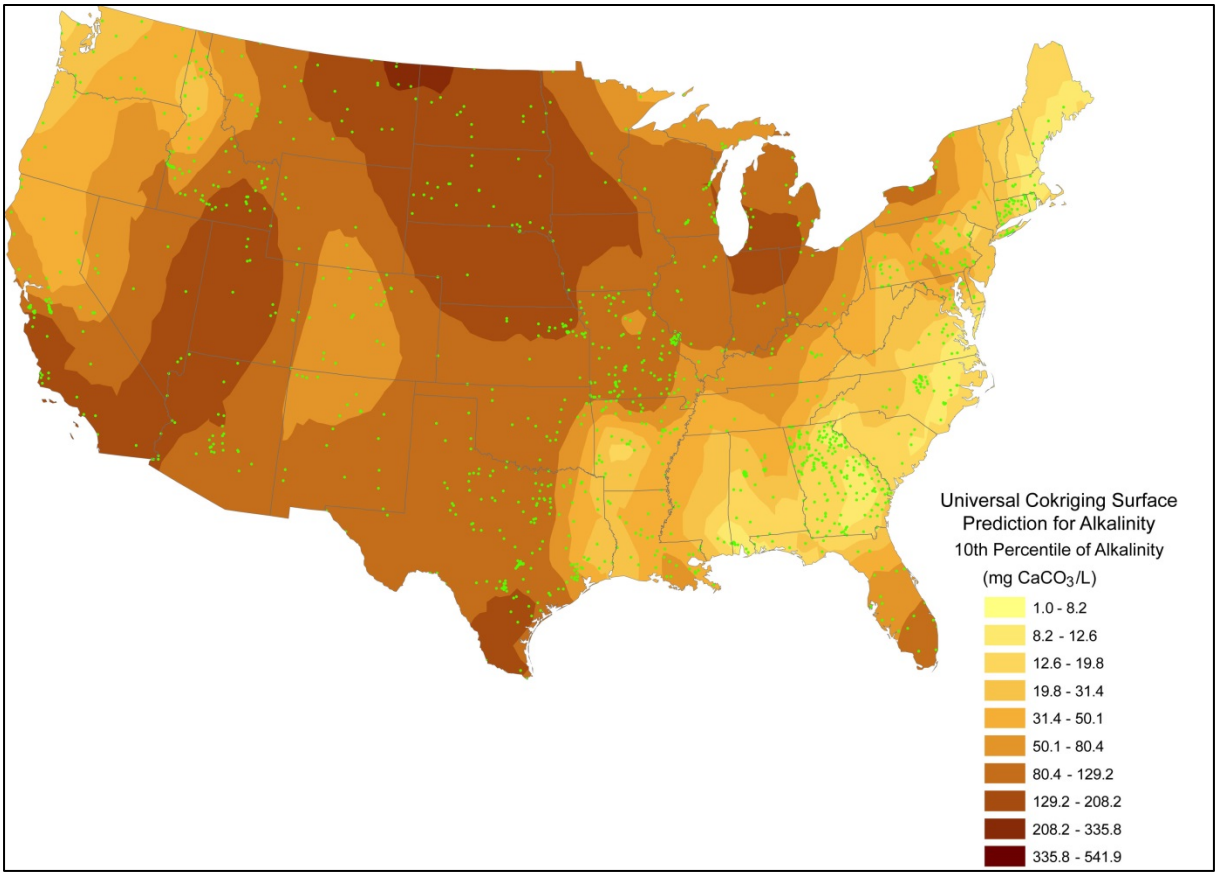


Figure 4. Co-kriged prediction surface for 10th percentile of alkalinity in the continental U.S.

2.2.3 Projection of Geostatistical Predictions onto Level III Ecoregions

Although maps of the geostatistical predictions are informative, a tabulation of the results is preferable for the purpose of providing guidance to BLM users. We chose to spatially average the geostatistical predictions of BLM water quality parameters according to the Level III ecoregions of the continental U.S. (Table 3), as these ecoregions provide a sound basis for spatial averaging of the water quality predictions. Ecoregions are designed to serve as a spatial framework for environmental resource management and denote areas within which ecosystems (and the type, quality, and quantity of environmental resources) are generally similar. They typically provide a logical and useful spatial (geographical) framework for organizing the results of environmental measurements (Omernik and Griffith, 2014). Ecoregions can be distinguished by landscape-level characteristics that cause ecosystem components to reflect different patterns in different regions (Omernik, 1987). "Level III Ecoregions of the Continental U.S." map layer shows ecoregion delineation based on common patterns of geology, physiography, vegetation, climate, soils, land use, wildlife, water quality, and hydrology. The map layer in Figure 5 was compiled by EPA (USEPA, 2013a) (http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm).

Table 3. Level III ecoregions of the U.S. organized according to broader Level I ecoregions	
Level I Ecological Regions	
Level III Ecoregion	**Name of Ecoregion**
Marine West Coast Forest	
1	Coast Range
2	Puget Lowland
3	Willamette Valley
111	Ahklun and Kilbuck Mountains
113	Alaska Peninsula Mountains
115	Cook Inlet
119	Pacific Coastal Mountains
120	Coastal Western Hemlock-Sitka Spruce Forests
Northwestern Forested Mountains	
4	Cascades
5	Sierra Nevada
9	Eastern Cascades Slopes and Foothills
11	Blue Mountains
15	Northern Rockies
16	Idaho Batholith
17	Middle Rockies
19	Wasatch and Uinta Mountains
21	Southern Rockies
41	Canadian Rockies
77	North Cascades
78	Klamath Mountains
105	Interior Highlands
116	Alaska Range
117	Copper Plateau
118	Wrangell Mountains
Mediterranean California	
6	Southern and Central California Chaparral and Oak Woodlands
7	Central California Valley
8	Southern California Mountains
North American Deserts	
10	Columbia Plateau
12	Snake River Plain
13	Central Basin and Range
14	Mojave Basin and Range
18	Wyoming Basin
20	Colorado Plateaus
22	Arizona/New Mexico Plateau

Table 3. Level III ecoregions of the U.S. organized according to broader Level I ecoregions	
Level I Ecological Regions	
Level III Ecoregion	**Name of Ecoregion**
24	Chihuahuan Deserts
80	Northern Basin and Range
81	Sonoran Basin and Range
Temperate Sierras	
23	Arizona/New Mexico Mountains
Great Plains	
25	Western High Plains
26	Southwestern Tablelands
27	Central Great Plains
28	Flint Hills
29	Central Oklahoma/Texas Plains
30	Edwards Plateau
31	Southern Texas Plains
34	Western Gulf Coastal Plain
40	Central Irregular Plains
42	Northwestern Glaciated Plains
43	Northwestern Great Plains
44	Nebraska Sand Hills
45	Piedmont
46	Northern Glaciated Plains
47	Western Corn Belt Plains
48	Lake Agassiz Plain
Eastern Temperate Forest	
32	Texas Blackland Prairies
33	East Central Texas Plains
35	South Central Plains
36	Ouachita Mountains
37	Arkansas Valley
38	Boston Mountains
39	Ozark Highlands
51	North Central Hardwood Forests
52	Driftless Area
53	Southeastern Wisconsin Till Plains
54	Central Corn Belt Plains
55	Eastern Corn Belt Plains
56	Southern Michigan/Northern Indiana Drift Plains
57	Huron/Erie Lake Plains
59	Northeastern Coastal Zone
60	Northern Appalachian Plateau and Uplands

Table 3. Level III ecoregions of the U.S. organized according to broader Level I ecoregions	
Level I Ecological Regions	
Level III Ecoregion	**Name of Ecoregion**
61	Erie Drift Plain
63	Middle Atlantic Coastal Plain
64	Northern Piedmont
65	Southeastern Plains
66	Blue Ridge
67	Ridge and Valley
68	Southwestern Appalachians
69	Central Appalachians
70	Western Allegheny Plateau
71	Interior Plateau
72	Interior River Valleys and Hills
73	Mississippi Alluvial Plain
74	Mississippi Valley Loess Plains
75	Southern Coastal Plain
82	Laurentian Plains and Hills
83	Eastern Great Lakes and Hudson Lowlands
84	Atlantic Coastal Pine Barrens
Northern Forests	
49	Northern Minnesota Wetlands
50	Northern Lakes and Forests
58	Northeastern Highlands
62	North Central Appalachians
Tropical Wet Forests	
76	Southern Florida Coastal Plain
Southern Semi-Arid Highlands	
79	Madrean Archipelago
Taiga	
101	Arctic Coastal Plain
102	Arctic Foothills
103	Brooks Range
104	Interior Forested Lowlands and Uplands
106	Interior Bottomlands
107	Yukon Flats
108	Ogilvie Mountains
Tundra	
109	Subarctic Coastal Plains
110	Seward Peninsula
112	Bristol Bay-Nushagak Lowlands
114	Aleutian Islands

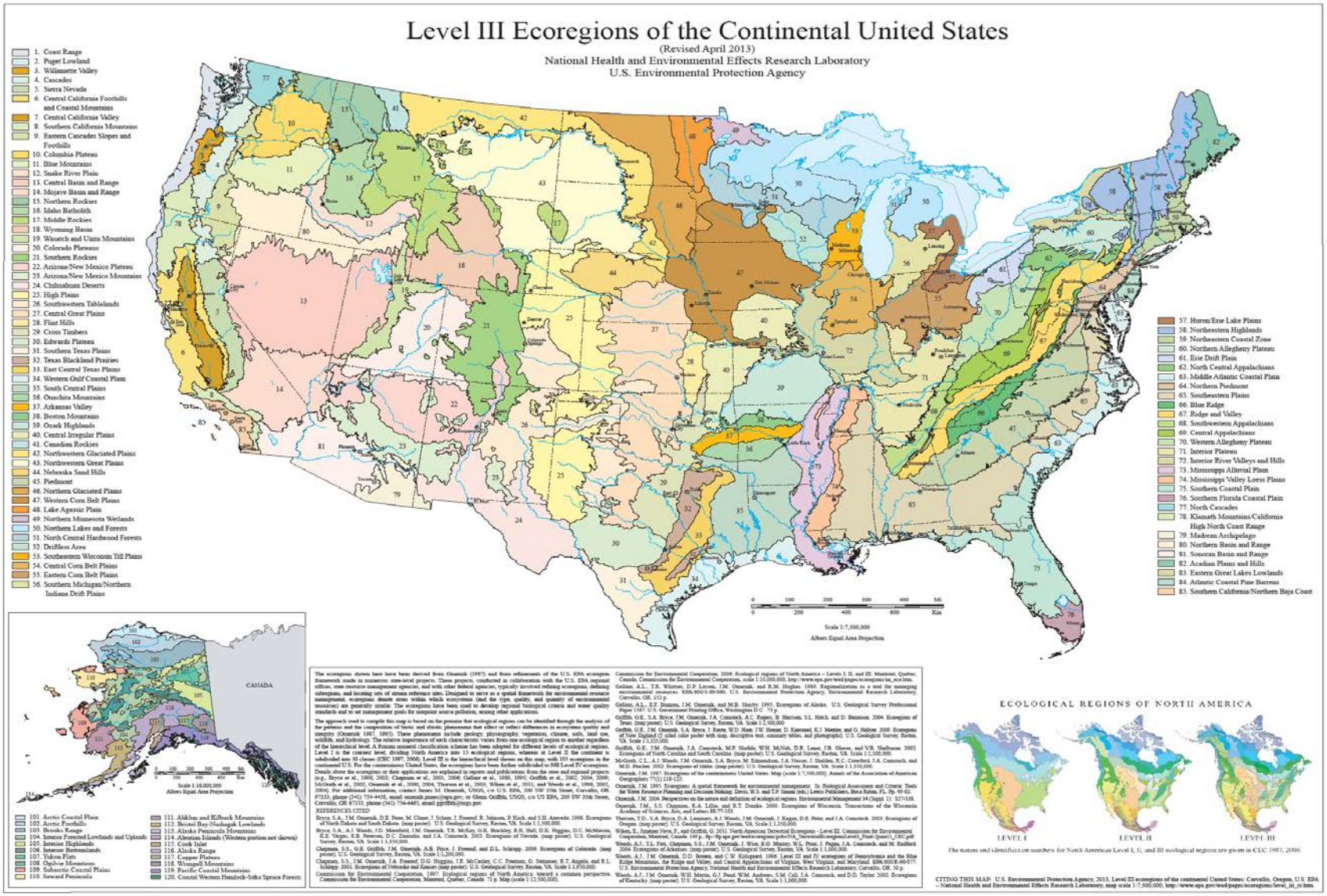


Figure 5. Map of Level III ecoregions in the U.S.

(Image taken from ftp://ftp.epa.gov/wed/ecoregions/us/Eco_Level_III_US.pdf)

Using the differences in land and water interactions, regional variations in attainable water quality, distinct biogeographical patterns (MacArthur, 1972), and similarities and differences in ecosystems to delineate ecoregions makes the application of ecoregions in environmental analyses a powerful tool with which to organize environmental information. The approach can take into account regional factors related to attainable water quality, and thus can be used to designate lakes for protection and to establish lake-restoration goals that are appropriate for each ecoregion (National Research Council (NRC), 1992). The NRC of the National Academy of Sciences has similarly endorsed the use of the concept in restoring and managing streams, rivers, and wetlands (NRC, 1992).

The theory of ecoregion delineation states that natural water quality characteristics of lakes and streams within a single ecoregion will be more similar than the characteristics between ecoregions (Perry and Vanderklein, 1996). Water quality characteristics exist in a landscape framework; neither normal nor impacted conditions of water resources can be separated from controlling influences of the surrounding landscape. The ecoregion concept has been applied and tested rather extensively in streams, rivers, and lakes. Testing and validation has been conducted in many diverse areas of the U.S., including several streams in Arkansas, Colorado, Kansas, Minnesota, Ohio, and Oregon, and in lakes of Michigan, Minnesota, Ohio, and Wisconsin (NRC, 1992).

Carleton (2006) used HUCs instead of ecoregions as the basis for averaging geostatistical results. HUCs are spatial delineations used for river basin management. Although a river basin may offer a logical framework for water supply management, for water quality management river basins are less applicable. The assumption that basins share similar properties is not always borne out, because river basins are often linked only by the water that flows through them. As Carleton (2006) noted, the use of HUCs for spatial averaging of surface water concentrations presents other conceptual difficulties. Only about 45% of HUCs are actual watersheds (Omernik, 2003); the rest receive drainage from additional upgradient areas. Concentrations measured in flowing waters reflect the soil, vegetation, and land use properties of the aggregate upstream drainage areas rather than of the sampling locations themselves (Smith et al., 1997).

2.2.3.1 Averaging Methods

To average the geostatistical predictions, a uniform grid was laid over the predicted surfaces and the predictions were sampled at the grid points falling within the polygons representing each ecoregion. The grid spacing was sized so that at least 30 points were sampled within each ecoregion. Unbiased log means were then calculated from the sampled concentration predictions in each ecoregion. The logarithmic transformation was applied because this normalized the concentration distributions in almost all of the ecoregions.

2.2.3.2 Tabulations of Ecoregional Estimated BLM Water Quality Parameters

The average predicted 10^{th} percentile concentrations for conductivity and the GI parameters for each of the Level III ecoregions in the continental U.S. are presented in Table 4. For each of these parameters, there is considerable variation between the ecoregional averages nationally. Chloride concentrations exhibit the greatest variation, with ecoregional 10^{th} percentile averages that range from 0.7 to 573 milligrams per liter (mg/L). Alkalinity was the least variable, but the ecoregional 10^{th} percentile average concentrations still ranged from 12 to 163 mg/L.

Table 4. Predicted 10th percentile concentrations for conductivity (µS/cm), BLM GI water quality parameters (mg/L) and hardness in each Level III ecoregion in the continental U.S.										
		Unbiased log mean of 10th percentile concentrations								
Level III Ecoregion	Ecoregion Name	Conductivity	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Chloride	Sulfate	Hardness[1]
1	Coast Range	102	8.4	3.2	4.1	0.64	33	3.2	4.8	34.12
2	Puget Lowland	80	7.1	1.9	2.8	0.64	22	2.3	5.6	25.54
3	Willamette Valley	91	8.2	2.9	4.4	0.90	30	4.7	3.8	32.39
4	Cascades	107	6.6	2.9	3.5	0.74	35	2.2	3.2	28.39
5	Sierra Nevada	195	8.3	4.7	8.8	1.3	58	5.8	11	40.02
6	Southern and Central California Chaparral and Oak Woodlands	600	42	24	48	2.5	124	56	136	203.4
7	Central California Valley	378	21	16	25	1.7	91	21	58	118.1
8	Southern California Mountains	772	63	25	63	3.8	150	54	171	260
9	Eastern Cascades Slopes and Foothills	212	8.2	3.8	6.0	1.0	44	3.2	5.0	36.08
10	Columbia Plateau	166	15	5.2	9.3	1.8	40	3.3	10	58.82
11	Blue Mountains	142	11	3.9	7.7	1.4	49	3.3	7.1	43.49
12	Snake River Plain	273	33	10	13	2.3	109	10	22	123.5
13	Central Basin and Range	426	43	16	45	3.6	120	45	83	173.1
14	Mojave Basin and Range	976	69	27	81	6.3	138	85	258	283.2
15	Northern Rockies	90	11	3.1	2.3	0.67	44	0.72	4.4	40.21
16	Idaho Batholith	91	13	3.8	3.6	0.88	62	1.9	5.9	48.08
17	Middle Rockies	300	30	10	14	1.9	105	7.6	55	116
18	Wyoming Basin	446	35	13	33	1.7	96	7.2	104	140.8
19	Wasatch and Uinta Mountains	426	61	27	61	3.3	155	55	155	263.2
20	Colorado Plateaus	639	65	26	57	2.6	117	28	197	269.1
21	Southern Rockies	259	26	8.0	12	1.4	55	3.8	56	97.8
22	Arizona/New Mexico Plateau	697	50	15	65	3.0	96	65	143	186.5
23	Arizona/New Mexico Mountains	879	66	18	85	3.4	102	100	189	238.8
24	Chihuahuan Deserts	2712	176	50	379	8.6	106	573	608	645
25	High Plains	1770	104	35	191	6.0	112	281	353	403.5
26	Southwestern	2147	114	34	316	4.9	94	512	374	424.4

Table 4. Predicted 10th percentile concentrations for conductivity (µS/cm), BLM GI water quality parameters (mg/L) and hardness in each Level III ecoregion in the continental U.S.

Level III Ecoregion	Ecoregion Name	Unbiased log mean of 10th percentile concentrations Conductivity	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Chloride	Sulfate	Hardness[1]
	Tablelands									
27	Central Great Plains	1228	84	24	176	6.9	121	245	204	308.4
28	Flint Hills	406	42	8.5	30	4.3	121	42	45	139.85
29	Central Oklahoma/Texas Plains	925	60	16	107	4.1	95	164	108	215.6
30	Edwards Plateau	596	48	14	38	2.7	98	62	52	177.4
31	Southern Texas Plains	798	56	14	58	3.8	129	73	91	197.4
32	Texas Blackland Prairies	364	39	5.8	21	3.2	92	26	33	121.28
33	East Central Texas Plains	367	36	6.3	23	3.8	98	29	29	115.83
34	Western Gulf Coastal Plain	565	43	10	62	3.9	87	86	78	148.5
35	South Central Plains	160	12	2.8	11	2.3	34	15	15	41.48
36	Ouachita Mountains	116	7.9	2.8	8.4	1.3	34	10	11	31.23
37	Arkansas Valley	192	16	4.7	15	1.8	51	20	16	59.27
38	Boston Mountains	152	18	3.3	4.3	1.3	53	6.7	8.2	58.53
39	Ozark Highlands	258	31	10	4.5	1.6	96	6.0	20	118.5
40	Central Irregular Plains	310	39	8.5	11	3.0	100	13	50	132.35
41	Canadian Rockies	164	22	8.7	15	0.57	80	1.7	38	90.67
42	Northwestern Glaciated Plains	545	37	20	61	5.9	163	8.1	147	174.5
43	Northwestern Great Plains	828	49	24	84	5.3	151	10	247	220.9
44	Nebraska Sand Hills	486	47	13	35	6.9	151	10	96	170.8
45	Piedmont	75	5.8	1.9	4.0	1.5	19	3.9	4.1	22.29
46	Northern Glaciated Plains	524	40	20	38	9.1	163	13	106	182
47	Western Corn Belt Plains	464	48	16	16	3.4	136	16	45	185.6
48	Lake Agassiz Plain	441	42	18	16	5.1	140	8.6	62	178.8
49	Northern Minnesota	229	24	10	3.2	1.4	95	2.6	8.4	101

Table 4. Predicted 10th percentile concentrations for conductivity (µS/cm), BLM GI water quality parameters (mg/L) and hardness in each Level III ecoregion in the continental U.S.										
		Unbiased log mean of 10th percentile concentrations								
Level III Ecoregion	Ecoregion Name	Conductivity	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Chloride	Sulfate	Hardness[1]
	Wetlands									
50	Northern Lakes and Forests	166	19	6.5	2.5	0.78	83	3.4	6.1	74.15
51	North Central Hardwood Forests	295	31	12	5.6	1.7	115	8.9	15	126.7
52	Driftless Area	348	34	15	5.1	1.6	107	10	17	146.5
53	Southeastern Wisconsin Till Plains	510	39	20	16	2.1	112	31	25	179.5
54	Central Corn Belt Plains	546	53	24	14	1.7	124	30	46	230.9
55	Eastern Corn Belt Plains	463	49	15	11	2.0	116	23	32	184
56	Southern Michigan/Northern Indiana Drift Plains	463	52	15	14	1.9	134	28	29	191.5
57	Huron/Erie Lake Plains	467	52	15	13	2.2	125	27	32	191.5
58	Northeastern Highlands	97	11	1.9	5.7	0.69	24	10	7.4	35.29
59	Northeastern Coastal Zone	176	8.3	2.0	14	1.3	15	22	8.4	28.95
60	Northern Appalachian Plateau and Uplands	271	33	7.3	37	1.3	53	64	22	112.43
61	Erie Drift Plain	364	31	8.1	19	2.3	64	29	38	110.71
62	North Central Appalachians	184	13	3.9	7.1	1.0	41	11	15	48.49
63	Middle Atlantic Coastal Plain	793	6.7	2.3	6.8	1.8	15	83	22	26.18
64	Northern Piedmont	208	21	5.8	10	1.9	39	17	15	76.28
65	Southeastern Plains	121	7.4	2.2	5.5	1.5	19	15	7.2	27.52
66	Blue Ridge	121	11	3.2	3.0	1.3	23	3.4	6.0	40.62
67	Ridge and Valley	163	17	4.5	4.6	1.4	33	6.3	15	60.95
68	Southwestern Appalachians	151	13	3.2	2.5	1.3	42	3.2	11	45.62
69	Central Appalachians	193	16	5.6	4.6	1.3	34	4.5	33	62.96

Table 4. Predicted 10th percentile concentrations for conductivity (µS/cm), BLM GI water quality parameters (mg/L) and hardness in each Level III ecoregion in the continental U.S.										
		Unbiased log mean of 10th percentile concentrations								
Level III Ecoregion	Ecoregion Name	Conductivity	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Chloride	Sulfate	Hardness[1]
70	Western Allegheny Plateau	276	23	7.3	10	1.7	46	14	47	87.43
71	Interior Plateau	237	27	5.9	4.4	1.5	65	7.0	20	91.69
72	Interior River Valleys and Hills	326	34	12	11	2.4	87	17	46	134.2
73	Mississippi Alluvial Plain	255	14	5.5	17	2.6	44	22	13	57.55
74	Mississippi Valley Loess Plains	102	10	2.9	3.9	1.6	38	4.5	8.4	36.89
75	Southern Coastal Plain	726	18	5.0	20	2.0	41	390	38	65.5
76	Southern Florida Coastal Plain	682	49	6.6	25	2.4	103	43	15	149.56
77	North Cascades	93	6.5	2.3	2.3	0.64	27	1.2	4.9	25.68
78	Klamath Mountains	156	8.7	4.6	4.0	0.66	44	2.1	3.5	40.61
79	Madrean Archipelago	625	42	11	45	2.8	92	39	78	150.1
80	Northern Basin and Range	298	26	8.2	20	2.7	89	15	24	98.62
81	Sonoran Basin and Range	991	64	24	115	4.4	121	131	192	258.4
82	Laurentian Plains and Hills	104	4.8	0.78	2.5	0.48	12	2.7	4.4	15.198
83	Eastern Great Lakes and Hudson Lowlands	294	34	6.8	21	1.3	61	40	26	112.88
84	Atlantic Coastal Pine Barrens	261	7.4	2.7	10	1.7	23	16	11	29.57

[1] Water Hardness calculated as equivalents CaCO3 = 2.5 (Ca^{2+}) + 4.1 (Mg^{2+})

2.2.3.3 Confirmation of Results

To confirm the results of the geostatistical predictions, a number of comparisons were made between the ecoregional average predictions and averages based directly on the data. For each GI parameter, we compared the ecoregional average predictions against the corresponding averages calculated from the data for each ecoregion.

Scatter plot matrices provide a visual presentation of the correlations between different parameters. Scatter plot matrices were developed for the ecoregional averages of conductivity and GI parameters. Figure 6 is the scatter plot matrix for ecoregional averages based on the data, and Figure 7 is the scatter plot matrix for ecoregional averages based on the geostatistical predictions. Comparison of

these figures shows that the predicted averages capture the same trends in terms of distributions and parameter correlations as those that are found for the ecoregional data. The similarities in the distributions and correlation structures between the ecoregional averages in Figures 6 and 7 demonstrate that the geostatistical ecoregion predictions are reasonable.

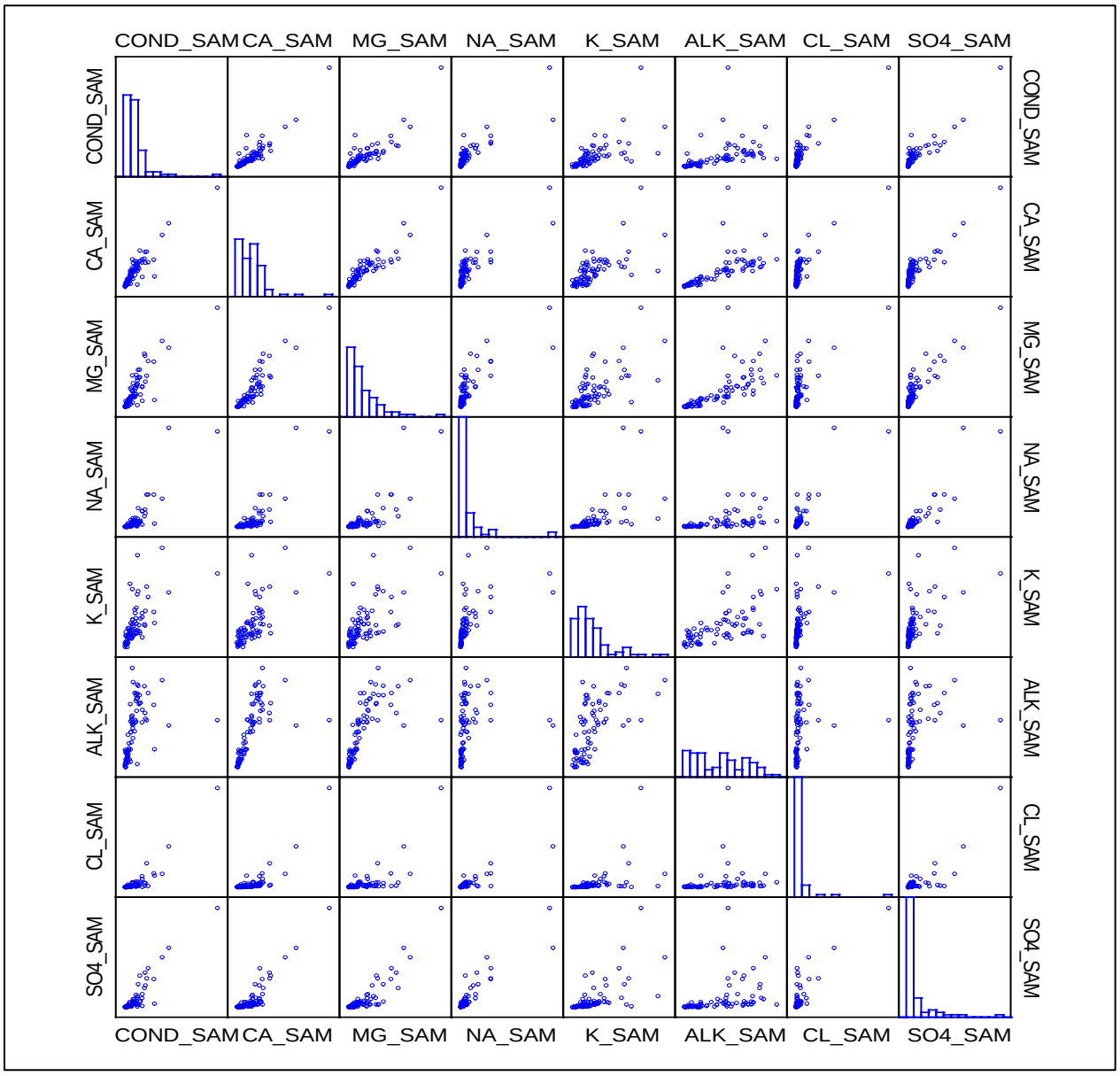


Figure 6. Scatter plot matrix of ecoregional average 10th percentiles of data for conductivity (COND_SAM) and GI parameters (calcium=CA_SAM, magnesium=MG_SAM, sodium=NA_SAM, potassium=K_SAM, alkalinity=ALK_SAM, chloride=CL_SAM, sulfate=SO4_SAM)

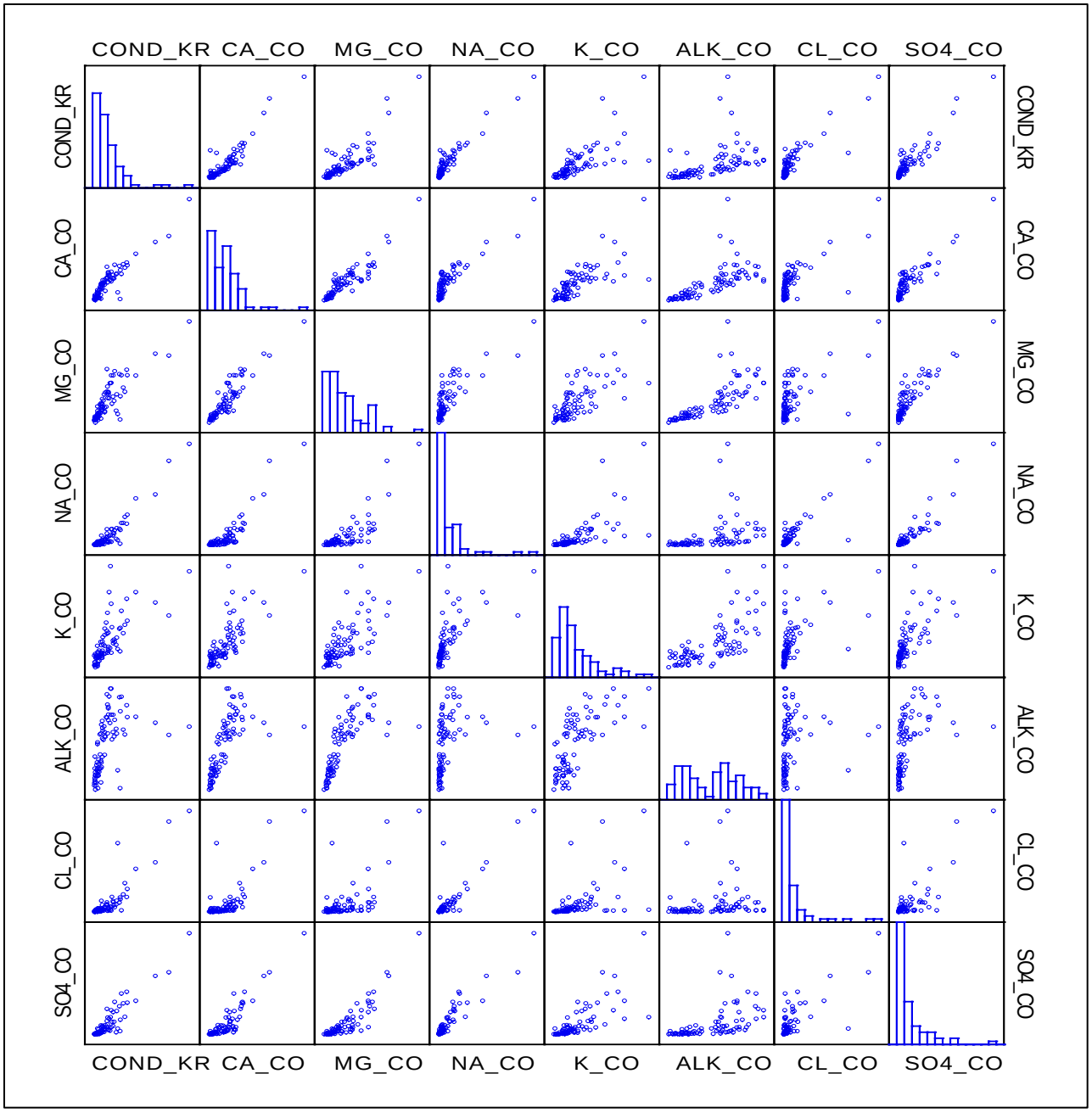


Figure 7. Scatter plot matrix of ecoregional average 10th percentiles of geostatistical predictions of conductivity (COND_KR) and BLM GI parameters (calcium=CA_CO, magnesium=MG_SCO, sodium=NA_CO, potassium=K_CO, alkalinity=ALK_CO, chloride=CL_CO, sulfate=SO4_CO)

In addition to scatter plots, correlation coefficient matrices between the parameters in each of the two data sets were generated. The Spearman (rank order) correlation coefficients for data-based ecoregional averages are presented in Table 5; correlation coefficients for ecoregional average geostatistical predictions are presented in Table 6. Although not identical, the correlation coefficients are similar between the two datasets, again demonstrating that the geostatistical predictions are reasonable.

Table 5. Spearman rank correlation matrix for unbiased log means of 10th percentile concentrations measured in Level III ecoregions								
	Conductivity	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Chloride	Sulfate
Conductivity	1							
Calcium	0.895	1						
Magnesium	0.877	0.927	1					
Sodium	0.865	0.819	0.813	1				
Potassium	0.823	0.758	0.73	0.859	1			
Alkalinity	0.769	0.881	0.898	0.698	0.679	1		
Chloride	0.815	0.774	0.702	0.855	0.788	0.595	1	
Sulfate	0.894	0.864	0.85	0.883	0.786	0.725	0.744	1

Table 6. Spearman rank correlation matrix for unbiased log means of 10th percentile predicted (kriged/cokriged) concentrations in Level III ecoregions								
	Conductivity	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Chloride	Sulfate
Conductivity	1							
Calcium	0.872	1						
Magnesium	0.843	0.924	1					
Sodium	0.87	0.82	0.778	1				
Potassium	0.842	0.803	0.753	0.836	1			
Alkalinity	0.747	0.868	0.901	0.672	0.745	1		
Chloride	0.829	0.715	0.592	0.826	0.725	0.461	1	
Sulfate	0.889	0.873	0.875	0.893	0.831	0.751	0.715	1

As a final test of the accuracy of the geostatistical predictions, we regressed the ecoregional averages based on the geostatistical predictions against the ecoregional averages based on the data. Scatter plots and fitted regression lines are shown for each of the parameters: conductivity (Figure 8), alkalinity (Figure 9), calcium (Figure 10), magnesium (Figure 11), sodium (Figure 12), potassium (Figure 13), sulfate (Figure 14), and chloride (Figure 15). Statistics for the linear regressions are provided in Table 7. For each of the parameters, the predicted and data-based ecoregional averages are significantly correlated. In each case, the linear regression coefficient is nearly 1.0, with a highly significant P value. As with the previous comparisons, the linear regression results demonstrate that the accuracy of the geostatistical predictions is high.

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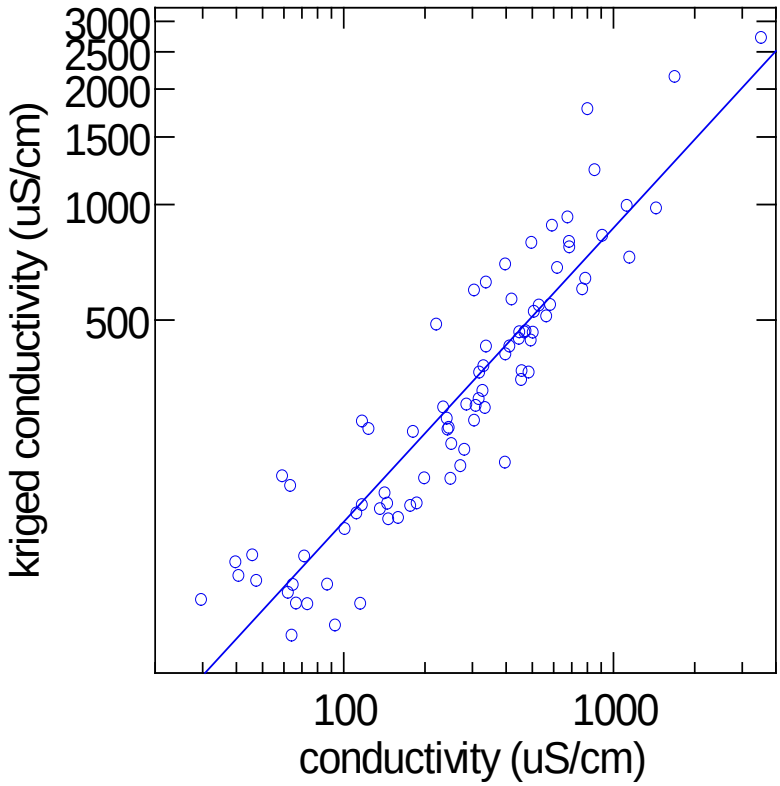


Figure 8. Ecoregional averages of kriged 10th percentiles of conductivity versus data

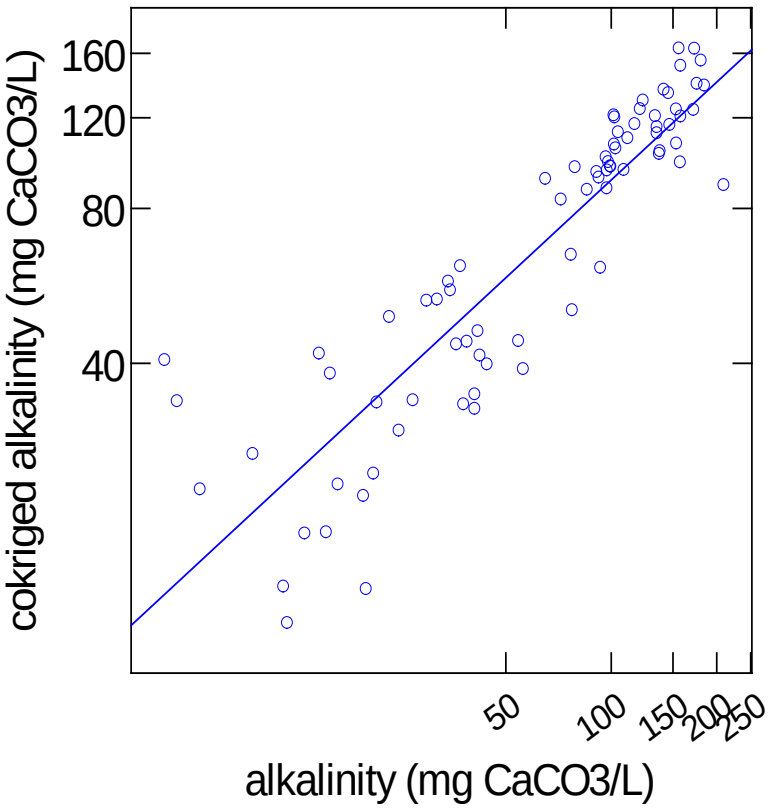


Figure 9. Ecoregional averages of cokriged 10th percentiles of alkalinity versus data

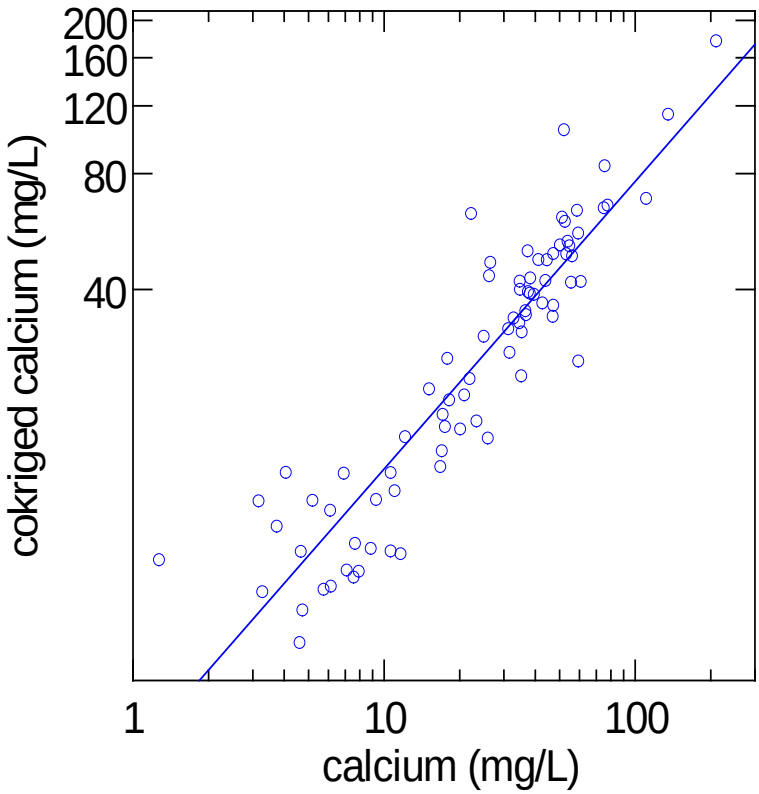


Figure 10. Ecoregional averages of cokriged 10th percentiles of calcium versus data

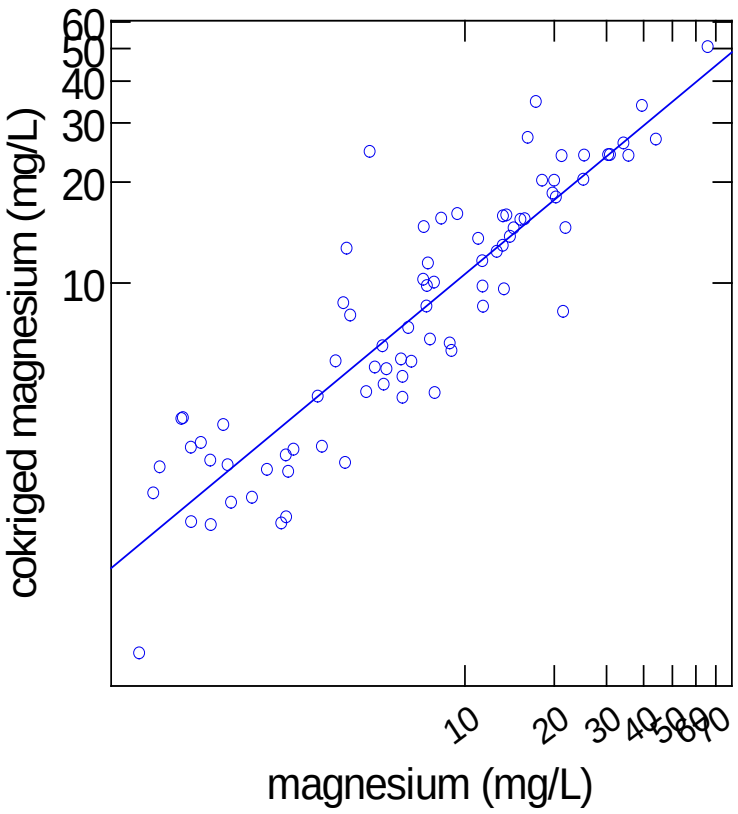


Figure 11. Ecoregional averages of cokriged 10th percentiles of magnesium versus data

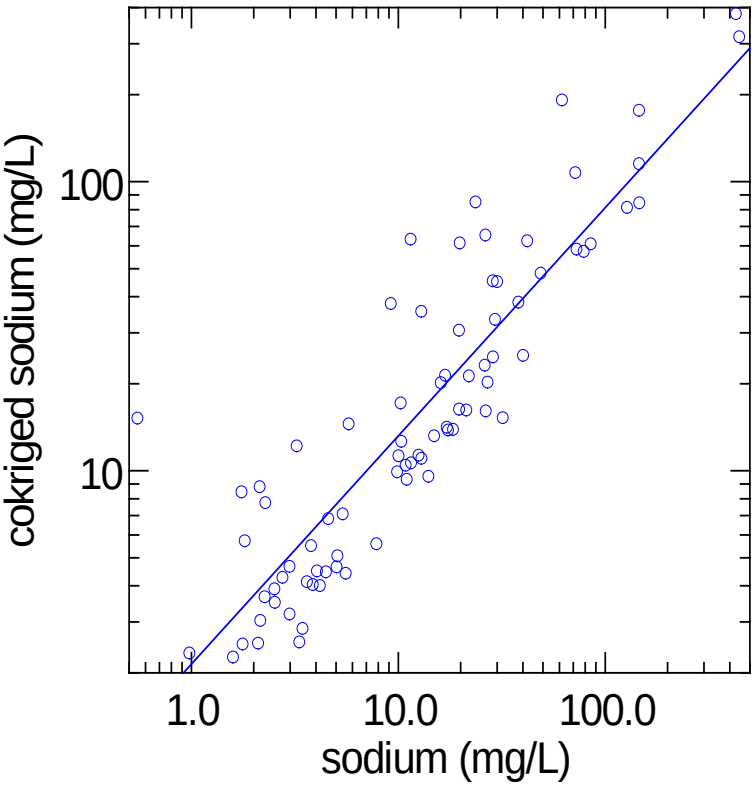


Figure 12. Ecoregional averages of cokriged 10th percentiles of sodium versus data

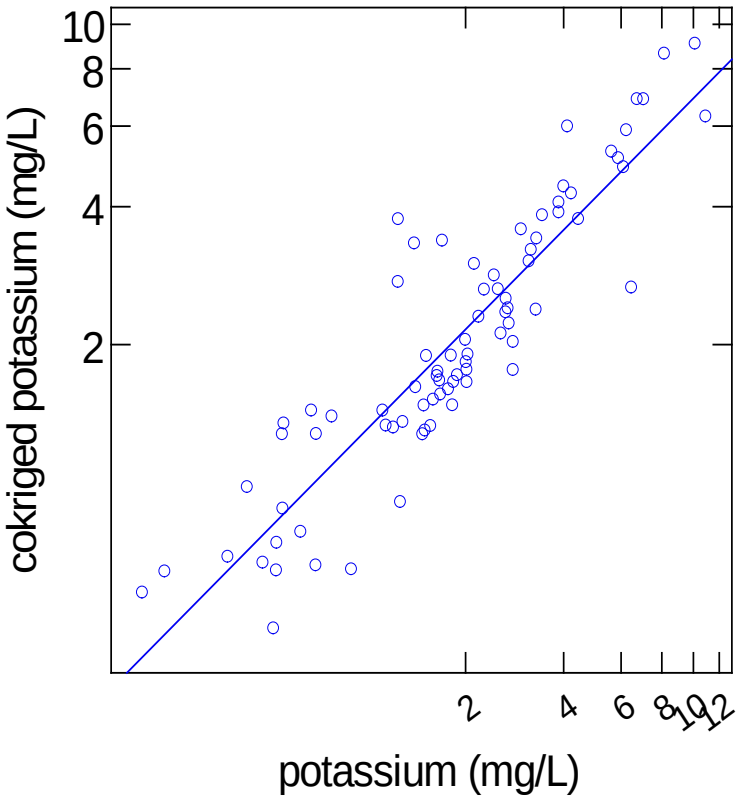


Figure 13. Ecoregional averages of cokriged 10th percentiles of potassium versus data

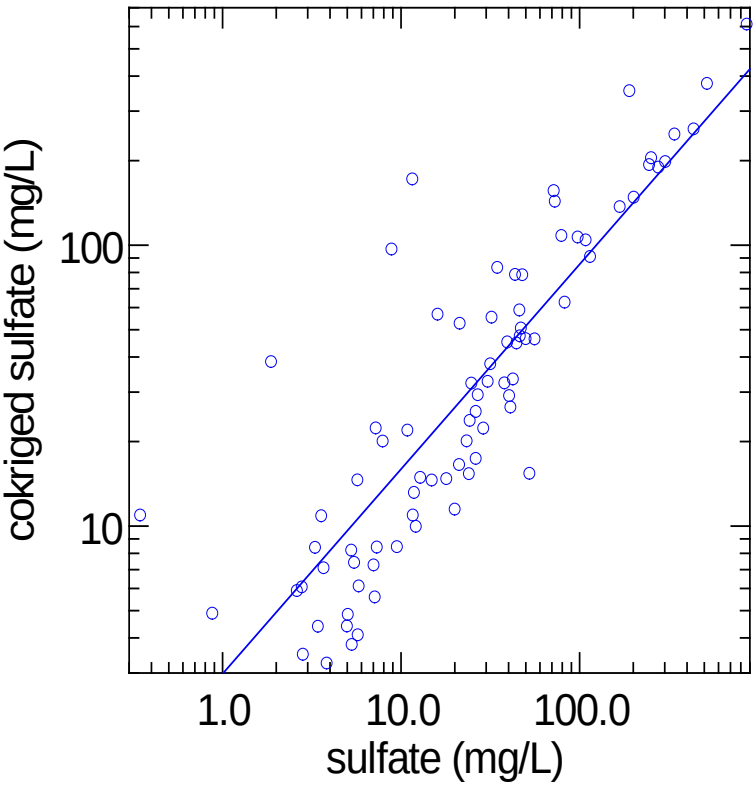


Figure 14. Ecoregional averages of cokriged 10th percentiles of sulfate versus data

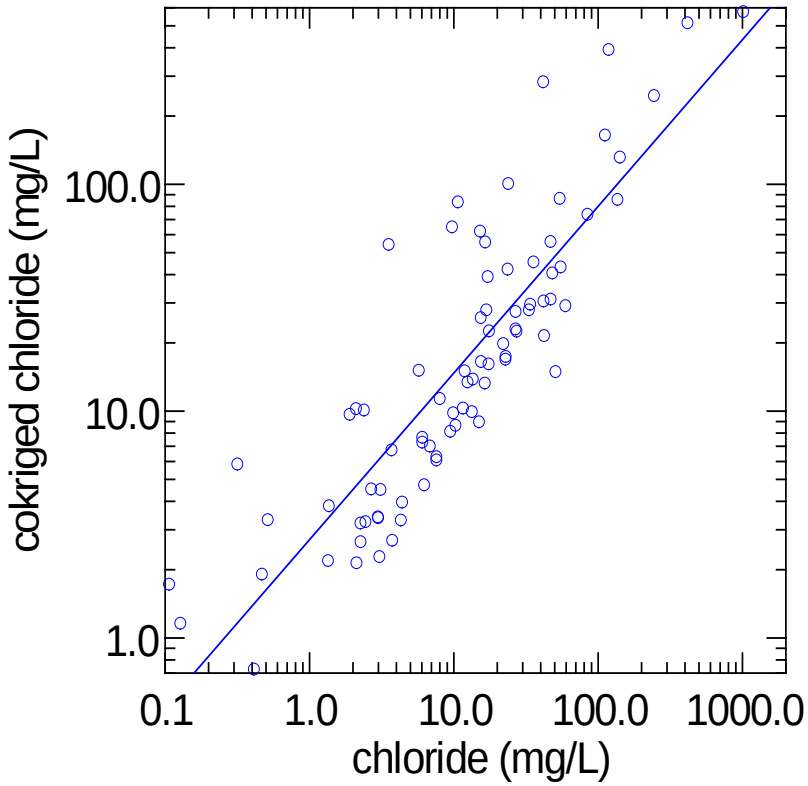


Figure 15. Ecoregional averages of cokriged 10th percentiles of chloride versus data

Table 7. Correlation coefficients and linear regression (LR) statistics between ecoregional average 10th percentiles of data and geostatistical predictions

Parameter	Correlation coefficient, r	LR coefficient	P (2 Tail)	LR constant	P (2 Tail)
Conductivity	0.908	0.98	<0.001	-20.992	0.495
Alkalinity	0.915	1.209	<0.001	-12.161	0.028
Calcium	0.922	1.061	<0.001	-1.994	0.365
Magnesium	0.885	1.097	<0.001	-1.169	0.22
Sodium	0.93	1.101	<0.001	-4.78	0.169
Potassium	0.906	1.073	<0.001	-0.184	0.297
Sulfate	0.865	1.264	<0.001	-13.599	0.041
Chloride	0.839	1.039	<0.001	-7.271	0.386

2.2.3.4 Conclusions for Selection of Water Quality Parameters

In this section we used geostatistics to estimate an intermediate step in generating missing GI parameter values based on geography. We supplemented the geostatistical approach by adding conductivity as an additional explanatory variable to generate a more robust spatial estimate of the GI water quality inputs for the BLM because conductivity is one of the most widely monitored water quality indicators in the U.S. and correlates well with GIs. In section 3, these estimates are further refined by stream order. We present here the average predicted 10^{th} percentile concentrations for the BLM GI water quality parameters, as presented in Table 4 by ecoregions. Because they are based on the 10^{th} percentiles of the daily average data from each USGS monitoring station, they are expected to yield copper criteria that are reasonably protective of aquatic life when applied as missing data for parameters in the BLM model. These data could also be used to fill in missing water chemistry parameters in the application of other metal BLM models. The most appropriate parameter selection however would include consideration of stream order in GIs estimates. Section 3 presents further refinements of estimates of the GI parameters by stream order and EPA's recommendations for default GI parameters for the BLM when data are lacking.

As with any estimate or prediction, it is appropriate to seek alternative estimates for the purpose of comparison or confirmation. If conductivity data are available for the site, either site-specific measurement data or data of opportunity from a database such as the NWIS, the regressions in EPA (2008; Appendix C) can be used to make independent estimates of the missing BLM water quality parameters. If the regression projections differ from the geostatistical average predictions, the lower (more conservative) estimate is recommended for application to ensure protection of aquatic life. As always, users of the BLM should be also encouraged to sample the water body of interest and to analyze for the constituent (parameter) concentrations as a basis for determining reliable BLM inputs.

2.2.3.5 Guidance Regarding Selection of Water Quality Parameters: pH and DOC

Although the geostatistical and regression-based approaches can be used to reliably estimate GI parameters used as BLM inputs, the same approaches do not produce accurate site-specific estimates for the two most important BLM inputs: pH and DOC. The BLM is less sensitive to the GI parameters than to pH and DOC predicting site-specific criteria for copper. Since our analysis indicates that there is little or no trend in relationships between conductivity and pH, and direct kriging produced similarly ambiguous predictions, site-specific data for pH must be used for BLM application at a site.

For DOC, analysis of NWIS data indicated a weak relationship with conductivity, so the regression approach is not appropriate for this parameter. In 2008, EPA recommended use of the ecoregional DOC concentration percentiles tabulated by EPA for the *Development of National Bioaccumulation Factors Technical Support Document* (USEPA, 2003) because they appeared to offer reasonable estimates of lower percentile DOC concentrations, and were based on substantially more DOC data than were available in the NWIS. In Section 4 of this report we further tested these ecoregional DOC concentrations for use in the BLM where site-specific data are not available.

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3 USING STREAM ORDER TO REFINE PREDICTION OF GI PARAMETERS

The following section discusses how stream order was used to address anthropogenic impacts. The goal is to provide BLM users with tables of appropriately protective estimates of GI parameters, building on the ecoregional work described in Section 2.

Estimations of values for the GI parameters (alkalinity, calcium, magnesium, sodium, potassium, sulfate, and chloride) tend to vary regionally. As demonstrated in Section 2, the spatial variation of these factors is generally known or at least predictable, and therefore spatial or geographic analysis of data can be used to estimate GI input parameter values. However, these values also vary due to anthropogenic impact. In the case of conductivity and GI parameters, a positive correlation between ion concentrations and measures of human activity, such as population density, urban and agricultural land use, road density, point and nonpoint pollutant sources, among other activities, is expected and may confound the pattern of geographic variability both within and between ecoregions.

One way to account for surface water quality variability within ecoregions is to distinguish water bodies according to the Strahler stream order (SO). The SO is used to define stream size based on a hierarchy of tributaries (Strahler, 1952; 1957) and may range from 1st order (a stream with no tributaries) to 12th order (the Amazon, at its mouth). First through 3rd order streams are called headwater streams (source waters of a stream). Over 80% of Earth's waterways are headwater streams (Strahler, 1957). A stream that is 7th order or larger constitutes a river. For example, the Ohio River is 8th order and the Mississippi River is 10th order. According to the River Continuum Concept, changes in water quality are commonly observed between the upper, middle, and lower reaches of a stream (FISRWG, 1998; Ward, 1992; USEPA, 2015).

In this section we consider variability in GIs by determining the SO of each surface water sampling location in the USGS NWIS[2] database, and explore methods of incorporating SO variation in the parameter estimates. Tables are provided in this section showing tabulations of parameter estimates based upon both ecoregion and SO to maximize the accuracy of estimated input parameters.

3.1 Determining SO of NWIS Surface Water Sampling Locations

GIS was used to determine the SO of each NWIS surface water sampling location. Flowlines and catchments with SO were obtained from the NHD-Plus V2 geospatial hydrologic framework (McKay et al., 2012).[3] The point locations corresponding to the latitude-longitude coordinates of the NWIS sampling stations were snapped to the NHD-Plus flowlines using ArcGIS. A spatial join was then performed between these shapefiles and the NHD-Plus flowlines to link stream order to the sampling locations. Some of the NHD-Plus flowlines did not have SO data associated with the record. When a sampling location occurred on a flowline that didn't have a SO, the SO from the catchment was used. When the catchment also did not have a SO, the SO of the nearest stream was applied. SO was added as an attribute to the information for each station in the database.

[2] http://waterdata.usgs.gov/nwis
[3] http://www.horizon-systems.com/NHDPlus/NHDPlusV2_home.php

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3.2 Estimating BLM Parameters for Ecoregions and SO

Estimated (10th percentile) BLM water quality parameters were presented in Section 2 for 84 Level III ecoregions of the continental U.S. In the work presented here, the parameter estimates were recalculated for individual SOs or ranges (groups) of SOs within each ecoregion.

3.3 Results

The distribution of NWIS sampling locations by SO is presented in Figure 16. The largest proportion of sampled locations (78%) was found to be in SO 1 through 4.

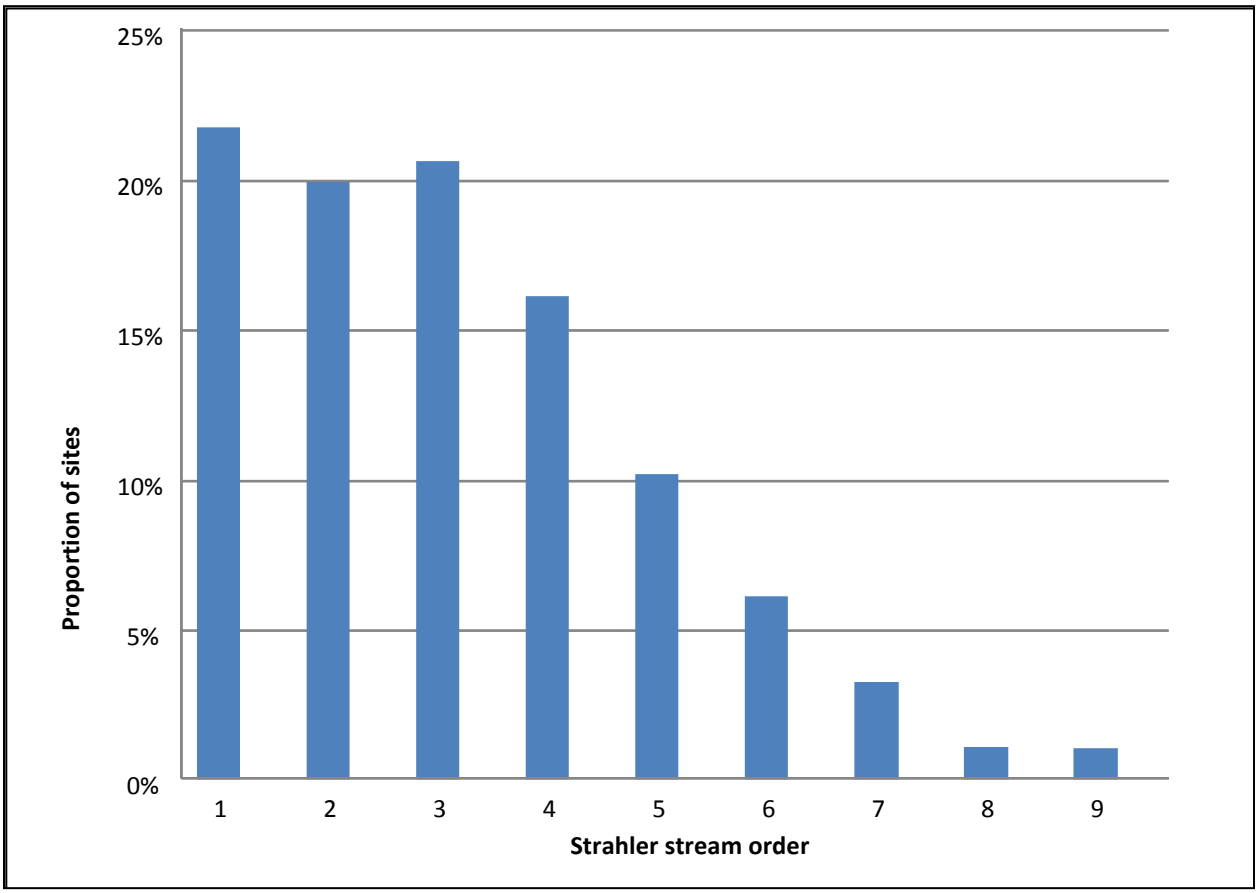


Figure 16. Distribution of NWIS surface water sampling locations by SO

3.3.1 Dependence of Ecoregional Parameter Estimates on SO

Box plots were constructed to examine how the GIs estimates varied with SO. Box plots of conductivity (Figure 17), alkalinity (Figure 18), calcium (Figure 19), magnesium (Figure 20), sodium (Figure 21), potassium (Figure 22), sulfate (Figure 23) and chloride (Figure 24) all show a general increase in the magnitude of the estimate with SO. This trend was most apparent and consistent when comparing medium stream orders (SO 4-6) to higher stream orders (SO ≥7). In addition, the upper quartile parameter estimates were generally higher in SOs 4 through 6 than in lower order streams (SO ≤3). Based upon these trends, we grouped the estimates for each parameter by SO: 1 through 3 (headwater

streams), 4 through 6 (mid-reaches) and 7 through 9 (rivers). There were no data for rivers with SO>9. Grouping simplified the presentation of results and improved the robustness of the parameter estimates, without losing significance of the SO trends. Parameter estimates for these three SO groups are included in the box plots in Figures 18 through 24, labeled as "13," "46," and "79." The classes depicted as 13, 46, and 79 reflect groupings according to SO (i.e., 1 through 3, 4 through 6, and 7 through 9).

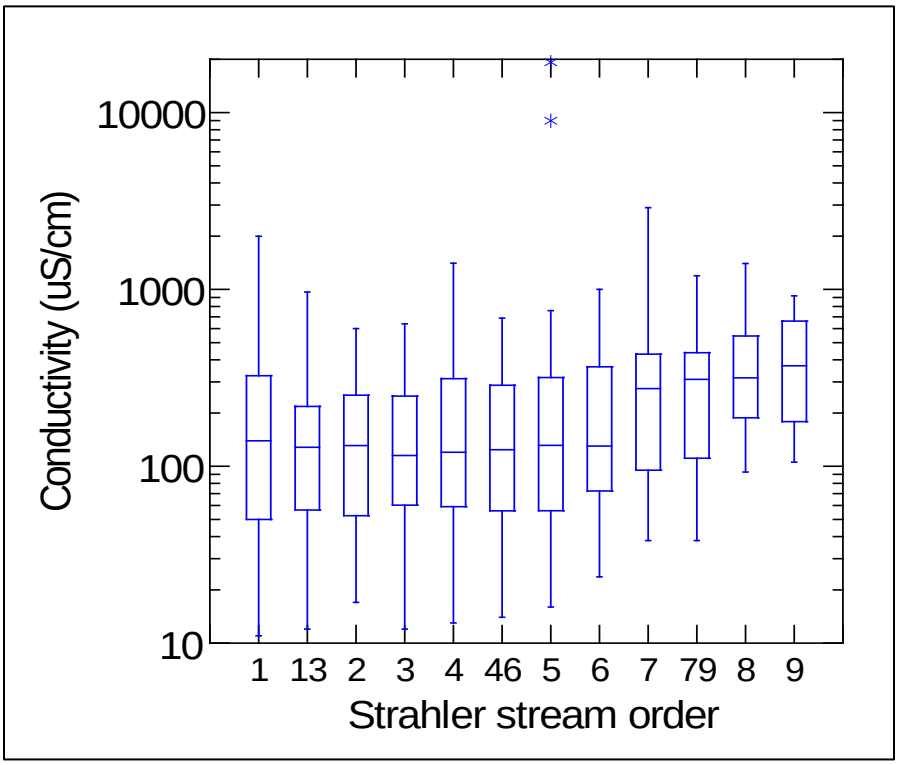


Figure 17. Box plot of estimated ecoregional conductivities as a function of SO

Note: Classifications depicted as 13, 46, and 79 reflect groupings according to stream order (i.e., 1 through 3, 4 through 6, and 7 through 9) as described in the text. For box plots, the bottom and top of each "box" displays the 25th and 75th percentile concentrations defined as the interquartile range (IQR) (i.e., the box contains 50% of the data values), respectively. The median is displayed as the horizontal line within the box. The "whiskers" show the relative distribution of data points outside of the IQR and represent 1.5 times the IQR. Data not included between the whiskers are plotted as outliers with a star/asterisk.

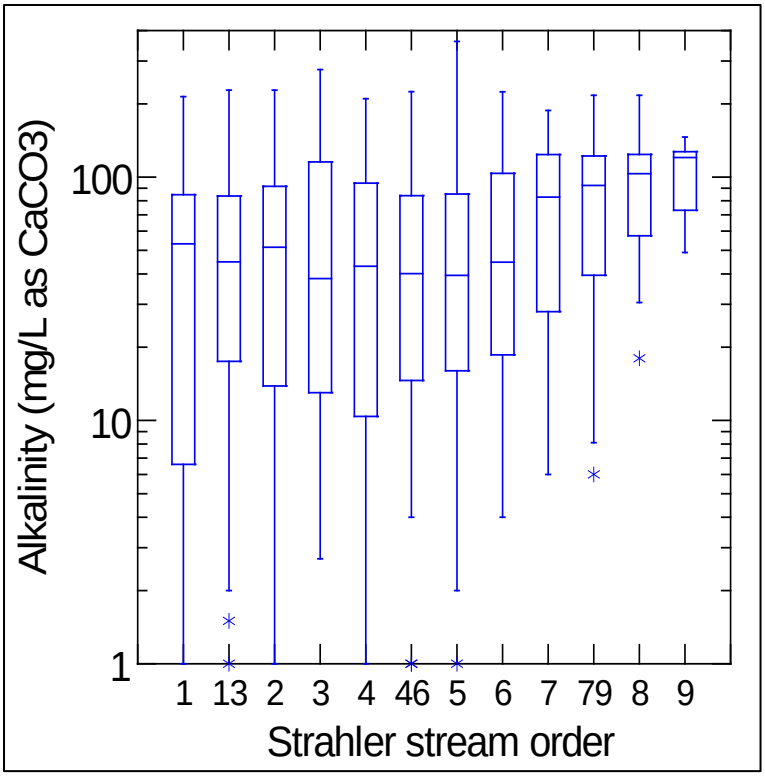


Figure 18. Box plot of estimated ecoregional alkalinity concentrations as a function of SO

(Refer to note in Figure 17.)

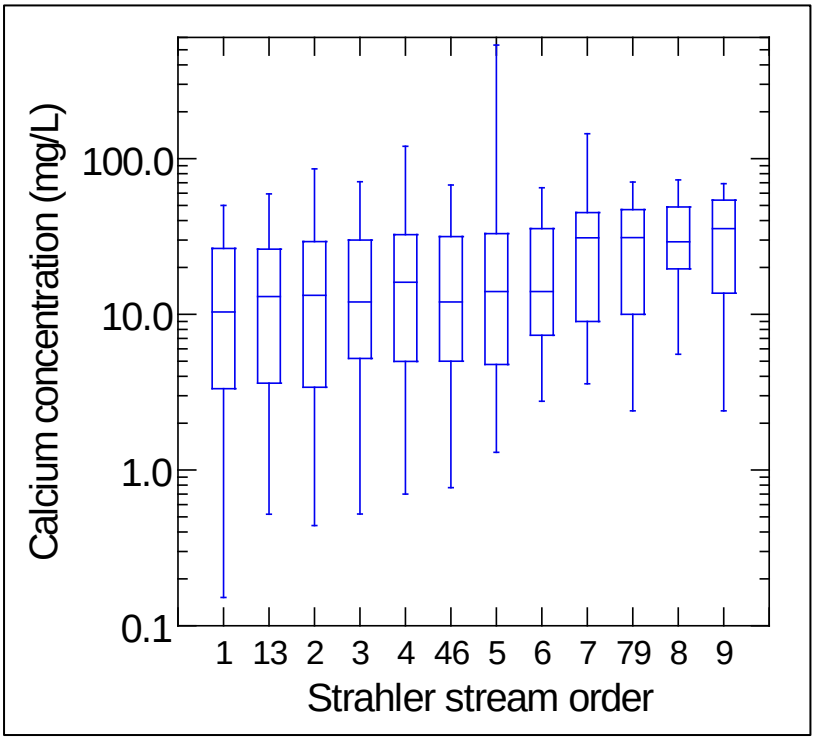


Figure 19. Box plot of estimated ecoregional calcium concentrations as a function of SO

(Refer to note in Figure 17.)

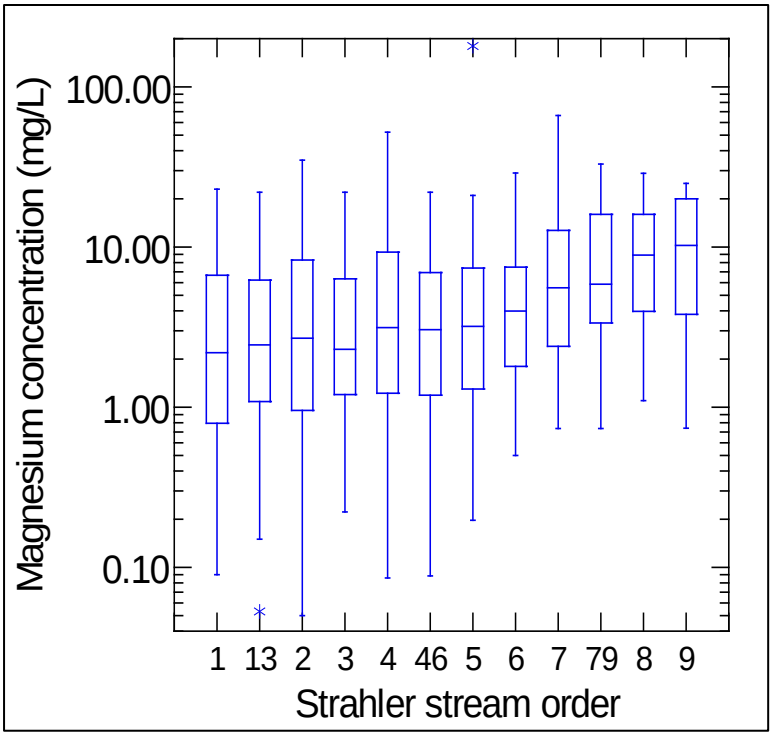


Figure 20. Box plot of estimated ecoregional magnesium concentrations as a function of SO

(Refer to note in Figure 17.)

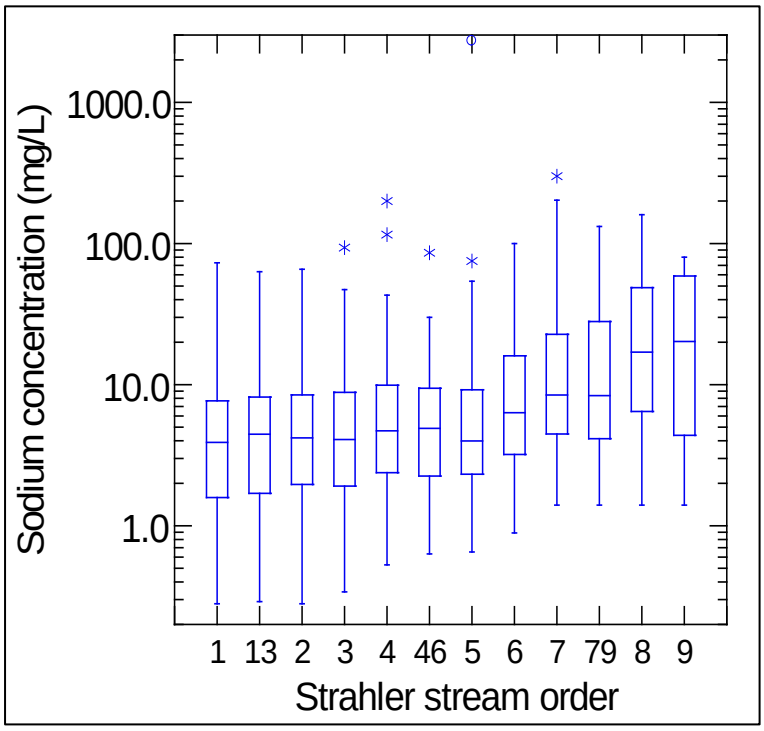


Figure 21. Box plot of estimated ecoregional sodium concentrations as a function of SO

(Refer to note in Figure 17.)

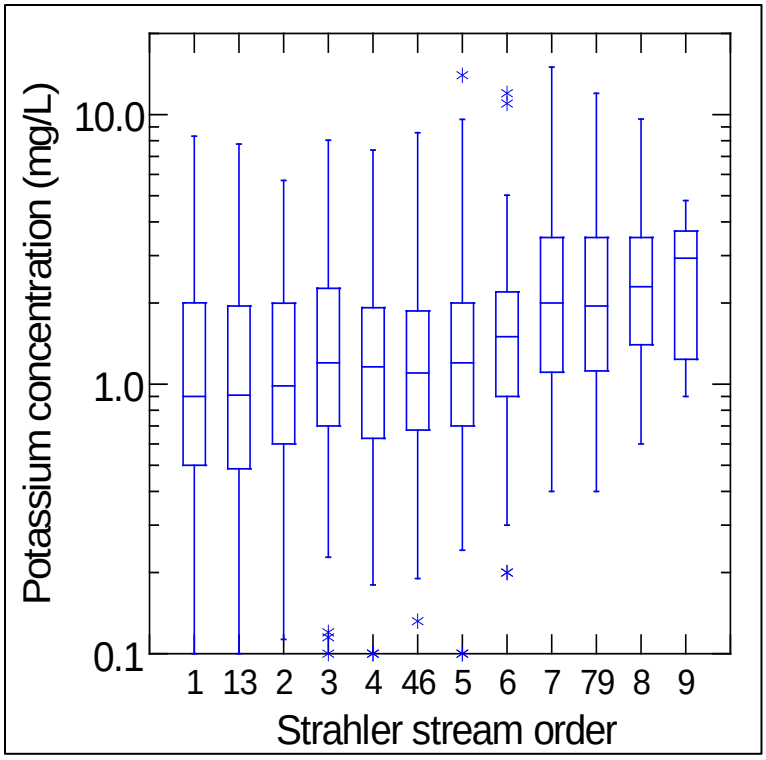


Figure 22. Box plot of estimated ecoregional potassium concentrations as a function of SO

(Refer to note in Figure 17.)

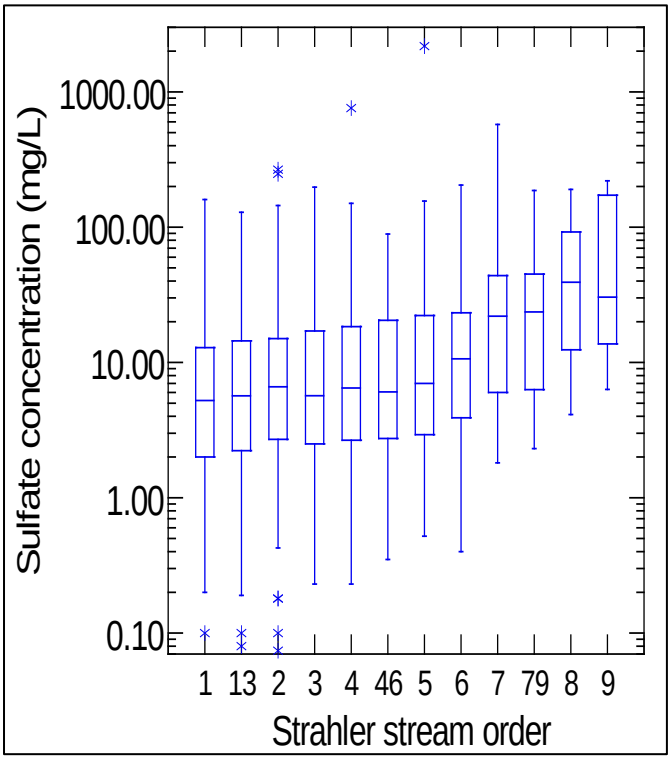


Figure 23. Box plot of estimated ecoregional sulfate concentrations as a function of SO

(Refer to note in Figure 17.)

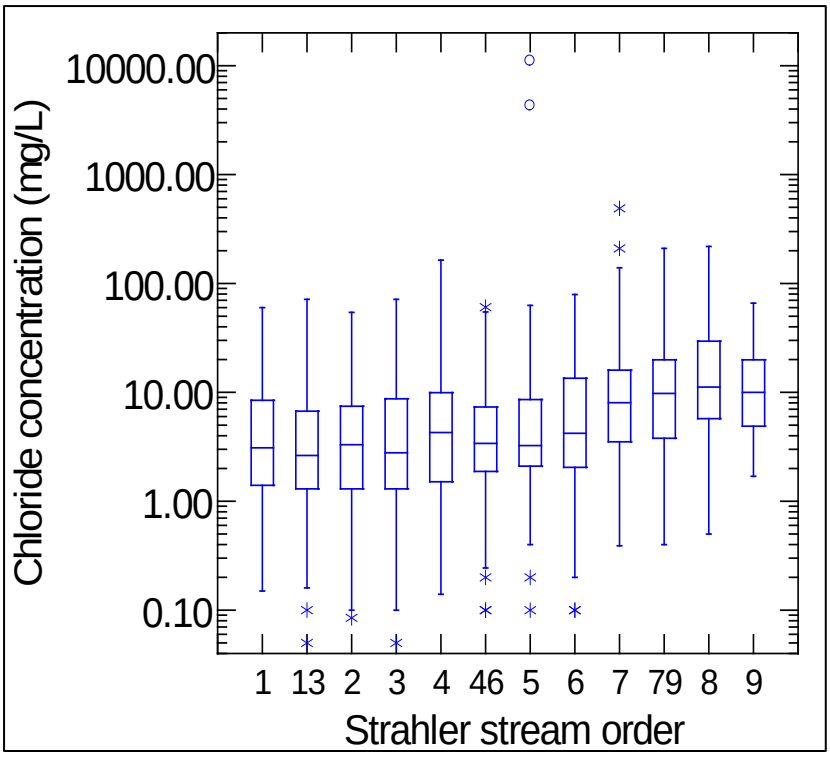


Figure 24. Box plot of estimated ecoregional chloride concentrations as a function of SO

(Refer to note in Figure 17.)

The range of values across SOs overlap greatly due to the inclusion of data across ecoregions. Tenth percentile estimates of conductivity increase with SO group in 58% of ecoregions when comparing low to medium SO groups, and 84% of ecoregions when comparing medium to high SO groups. The same trend was evident for the GIs. For example, 10th percentiles of calcium increased with SO group in 68% of ecoregions for low versus medium SO and 83% of ecoregions for medium versus high SO. In general, parameter estimates (10th percentiles of conductivity and ion concentrations) increased with SO, and the increase was most apparent and consistent for higher SOs (SO ≥7).

3.3.2 SO-Based Parameter Estimates

Tenth percentile parameter estimates for conductivity, GIs and hardness are grouped by SO and Level III ecoregions in Tables 8 through10. Tenth percentile parameter estimates for SOs 1 through 3 are presented in Table 8, for SOs 4 through 6 are presented in Table 9, and SOs 7 through 9 are presented in Table 10. The tables include the sample size for instances in which parameter estimates are highly uncertain due to limited data, i.e., cases where sample size is <10. Water quality data were limited in four ecoregions (11, 16, 49, and 78) for SO group 1 through 3, in Ecoregion 76 for SO group 4 through 6, and in 28 ecoregions for SO group 7 through 9. With the exception of the specific ecoregions and SO classes where data are limited, the parameter estimates in Tables 8 through 10 are recommended as improved default values for use in the BLM when data are not available for a location in a specific Level III ecoregion and SO group.

Table 8. Recommended 10th percentile conductivity, GIs, and hardness estimates for SO Group 1 through 3 (number of stations shown in parentheses if n<10)

Ecoregion	Conductivity	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Chloride	Sulfate	Hardness
1	58	6.0	0.8	1.3	0.1	44	0.6	1.1	18.28
2	74	8.8	2.8	3.9	0.5		2.8	3.3	33.48
3	68	9.9	3.8	5.6	1.5		2.3	1.5	40.33
4	16	1.0	0.2	1.8	0.2		0.5	0.2	3.32
5	28	0.6	0.1	0.3	0.1	38	0.1	0.1	1.91
6	279	3.6	8.2	8.4	0.9	73	8.9	7.2	42.62
7	164	19	6.0	14	1.8	120	8.6	6.6	72.1
8	157	29	4.3	10	1.5	70 (7)	2.6	0.4	90.13
9	55	4.4 (8)	0.9 (8)	2.3 (9)	0.4 (9)	35 (2)	0.2	0.2	14.69
10	137	24.0	9.4	10.2	1.4	127	4.6	11	98.54
11	88	8.6 (2)	3.2 (2)			169 (2)			34.62
12	133	13	2.0	6.1	0.8	35	1.4	3.7	40.7
13	109	9.4	1.6	2.7	0.6	45	0.5	3.7	30.06
14	967	15	2.8	6.0	3.0	90 (7)	2.7	6.3	48.98
15	24	3.1	0.8	0.9	0.4	9.0	0.2	1.3	11.03
16	21								
17	93	6.9	1.6	1.5	0.5	31	0.3	3.0	23.81
18	92	22	6.3	4.7	0.9		3.3	7.3	80.83
19	76	59	11	5.1	0.6	96	2.5	44	192.6
20	189	59	12	19	1.4	157	6.7	129	196.7
21	37	3.5	0.7	0.8	0.3	18	0.2	1.9	11.62
22	115	13	1.1	2.3	0.8	55	1.2	7.2	37.01
23	62	6.3	1.8	3.7	0.7	20	0.8	4.3	23.13
24	453	43	7.9	35	3.4	32	20	74	139.89
25	194	43	11	31	3.7	228	7.3	35	152.6
26	199	18	3.0	63	3.4	53	3.6	11	57.3
27	293	21	5.0	9.9	1.5	122	5.1	13	73
28	346	50	8.2	4.4	0.8	125	1.5	22	158.62
29	217	30	4.0	17	2.9	74	8.2	9.9	91.4
30	189	25	1.8	1.6	0.9	99	2.6	4.9	69.88
31	639	48	5.5	47	2.9		71	51	142.55
32	183	26	1.7	5.9	1.9	52	5.1	15	71.97
33	132	24	2.1	5.8	2.3	29	8.1	6.0	68.61
34	141	13	2.3	9.8	2.6	44	13	4.7	41.93
35	25	0.9	0.5	1.9	0.2	5.0	3.0	1.7	4.3
36	19	0.9	0.7	0.9	0.3	4.0	1.3	2.0	5.12
37	107	23	3.5	23	3.3	36	2.5	3.5	71.85
38	51	0.9 (7)	0.6 (7)	0.63 (7)	0.6 (7)	35	1.1	1.8	4.71
39	172	26	1.9	1.3	0.7	62	2.0	4.2	72.79

Ecoregion	Conductivity	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Chloride	Sulfate	Hardness
40	223	20	4.6	8.4	2.8	46	5.2	23	68.86
41	93	13	3.8	0.4	0.1	60 (9)	0.1	1.6	48.08
42	256	23	7.3	7.4	1.6	91	1.3	14	87.43
43	327	17	16	26	3.7	144	2.7	119	108.1
44	156	21	3.2	6.5	4.7	80 (2)	0.7	5.5	65.62
45	44	2.7	0.8	2.5	1.2	12	2.4	1.9	10.03
46	400	32	13	15	7.8	94	5.4	60	133.3
47	380	41	11	4.8	1.3	83	12	15	147.6
48	295	31	15	4.9	2.5		4.3	13	139
49	402 (4)					227 (1)			
50	69	5.1	1.0	1.2	0.3	32	0.4	1.2	16.85
51	137	28	11	2.0	0.9	53 (4)	3.3	4.5	115.1
52	432	42	12	2.9	0.7	75	4.8	12	154.2
53	502	27	8.0	11	2.0	42	25	22	100.3
54	574	51	22	8.4	1.2	202	28	44	217.7
55	420	40	11	7.8	1.5	130	19	16	145.1
56	219	28	7.4	3.6	0.9	79	6.3	16	100.34
57	446	35	10	6.8	2.3	84	19	33	128.5
58	25	1.2	0.4	0.3	0.2	1.5	0.4	4.2	4.64
59	69	3.6	1.1	6.2	0.9	3.0	10	5.8	13.51
60	61	4.7	1.2	1.5	0.4	17	1.5	6.6	16.67
61	131	13.0	2.5	8.0	1.1	33	7.8	8.3	42.75
62	32	1.8	0.7	0.8	0.3	2.0	0.8	4.4	7.37
63	108	1.1	0.8	2.8	0.8	5.0	5.5	3.2	6.03
64	134	12.0	4.6	7.0	1.3	19	10	11	48.86
65	25	0.7	0.5	1.5	0.3	3.0	2.6	0.7	3.8
66	12	0.5	0.3	0.7	0.3	3.0	0.7	1.1	2.48
67	81	4.7	2.0	2.0	0.7	3.0	1.8	7.1	19.95
68	32	1.9	1.2	1.3	0.7	3.0	1.4	3.6	9.67
69	36	2.8	0.8	0.4	0.4	4.0	1.0	8.1	10.28
70	125	5.6	4.0	2.7	1.4	12	2.4	16	30.4
71	179	10	1.8	1.1	0.7	54	2.2	2.8	32.38
72	180	17	5.3	5.2	1.7	69	3.5	21	64.23
73	102	6.9	2.7	3.4	2.0	31	2.0	2.9	28.32
74	52	3.2	1.4	2.5	1.5	9.3	2.6	3.9	13.74
75	75	6.6	1.5	4.5	0.5	9.0	9.0	1.5	22.65
76	430	41	1.8	7.8	0.3	116	30	0.1	109.88
77	14	1.6	0.4	0.4	0.2	7.0	0.2	0.7	5.64
78	19						2.1		
79	340	30	6.2	25	2.8	92 (2)	13	23	100.42
80	78	6.3	1.1	4.3	2.2	24	0.2	2.5	20.26
81	203	19	2.4	10	2.8	52	2.6	6.1	57.34

Ecoregion	Conductivity	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Chloride	Sulfate	Hardness
82	37	1.5	0.5	4.3	0.2		6.6	1.8	5.8
83	198	16	3.9	5.0	1.0	51	21	29	55.99
84	50	0.8	0.6	2.8	0.6	1.0	5.0	4.4	4.46

Table 9. Recommended 10th percentile conductivity, GIs, and hardness estimates for SO group 4 through 6 (number of stations shown in parentheses if n<10)

Ecoregion	Conductivity	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Chloride	Sulfate	Hardness
1	52	3.6	1.0	2.0	0.2	15	1.6	2.2	13.1
2	49	5.3	1.2	1.3	0.1	16	0.8	1.8	18.17
3	62	7.1	2.5	4.3	0.8	29	4.6	2.8	28
4	35	3.5	1.0	2.8	0.4	16	0.8	0.8	12.85
5	18	0.9	0.1	0.6	0.2	5.0	0.4	0.4	2.66
6	316	9.1	4.8	5.4	1.0	32	2.3	4.1	42.43
7	67	6.5	2.5	2.9	0.9	33	1.7	3.2	26.5
8	93	9.0	1.5	8.4	1.0	17	3.2	6.0	28.65
9	52	5.5	0.8	2.4	0.5	22	0.9	2.2	17.03
10	83	8.6	3.2	4.0	0.9	33	1.4	3.1	34.62
11	52	3.7	0.8	1.6	0.7	16	0.3	0.7	12.53
12	95	13	2.5	4.9	1.2	40	2.2	3.8	42.75
13	124	12	3.4	9.6	1.8	68	3.9	8.1	43.94
14	688	58	13	86	7.9	225	55	86	198.3
15	34	3.5	1.1	0.9	0.4	16	0.2	1.2	13.26
16	22	2.4	0.4	1.3	0.4	10	0.2	0.6	7.64
17	123	10	2.5	1.4	0.6	44	0.5	2.2	35.25
18	145	15	4.0	7.1	0.9	57	1.4	16	53.9
19	135	34	9.1	6.7	1.3		7.3	9.5	122.31
20	260	38	9.6	16	1.5	107	4.0	55	134.36
21	74	6.5	1.3	1.9	0.6	18	0.4	3.2	21.58
22	215	25	4.3	9.5	1.3	62	2.4	18	80.13
23	289	31	9.5	5.6	1.1	101	3.5	2.4	116.45
24	240	24	5.1	18	1.5	80	7.0	21	80.91
25	220	14	3.4	8.7	1.6	84	4.1	29	48.94
26	367	39	9.1	29	2.8	79	11	56	134.81
27	351	39	7.1	11	5.1	79	5.6	16	126.61
28	298	68	14	9.6	2.1	150	7.4	39	227.4
29	351	39	6.8	20	2.7	80	20	19	125.38
30	377	44	12	6.5	0.8	140	10	13	159.2
31	447	54	9.4	10	1.8	142	12	29	173.54
32	311	35	2.8	12	2.8	94	12	22	98.98
33	334	33	5.0	16	2.1	45	23	28	103
34	125	10	3.5	13	2.7	40	12.2	3.1	39.35

Ecoregion	Conductivity	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Chloride	Sulfate	Hardness
35	67	4.2	1.1	6.5	1.5	10	3.5	5.0	15.01
36	24	1.0	0.8	1.1	0.5	4.0	1.5	2.0	5.78
37	55	3.8	2.3	5.2	1.3	9.6	2.0	2.0	18.93
38	41	8.4	1.0	1.2	0.8	13	1.5	3.2	25.1
39	160	19	1.8	1.6	0.9	73	2.3	3.6	54.88
40	258	33	5.7	6.8	2.7	64	6.7	20	105.87
41	133	19	4.5	0.7	0.2		0.1	1.9	65.95
42	285	22	9.2	12	2.3	141	2.3	34	92.72
43	342	28	8.5	13	2.7	145	2.2	45	104.85
44	232	27	3.8	9.4	7.0	184 (1)	2.5	2.7	83.08
45	44	3.0	1.2	3.0	1.3	13	2.9	2.9	12.42
46	480	32	17	30	8.6	153	9.1	89	149.7
47	390	43	10	7.0	1.7	109	8.5	19	148.5
48	422	40	18	8.5	4.1	170	7.0	32	173.8
49	75	7.9	2.4	2.3	0.7	25	2.3	4.5	29.59
50	78	7.9	2.4	1.2	0.4	37	0.9	2.7	29.59
51	125	19	6.5	2.3	0.9	102	3.0	3.6	74.15
52	221	15	6.3	4.2	1.5	50	6.4	10	63.33
53	389	36	19	9.1	2.2	138	18	20	167.9
54	520	49	22	7.4	1.0	148	22	37	212.7
55	413	43	12	5.6	1.9	162	19	22	156.7
56	389	44	14	10	1.5	133	18	21	167.4
57	489	56	15	10	2.6	108	22	31	201.5
58	38	4.9	0.9	2.9	0.5	5.0	4.3	6.1	15.94
59	81	5.1	1.4	7.8	1.1	10	11	7.3	18.49
60	101	12	2.5	5.3	1.0	20	3.9	8.4	40.25
61	178	20	4.7	8.4	1.8	47	61	11	69.27
62	50	3.9	0.9	4.0	0.6	5.0	2.6	6.1	13.44
63	65	3.6	0.9	3.9	1.2	8.0	6.6	3.2	12.69
64	175	13	4.7	9.9	1.2	48	15	13	51.77
65	43	2.8	0.9	2.2	0.8	6.0	3.4	1.7	10.69
66	14	1.0	0.3	0.8	0.5	4.0	0.4	1.1	3.73
67	89	7.9	2.0	2.9	1.0	14	3.4	8.8	27.95
68	42	4.0	0.9	1.0	0.8	16	1.4	4.4	13.69
69	115	6.8	1.5	1.7	0.6	9.0	1.8	8.8	23.15
70	108	11	3.1	4.2	1.2	11	4.5	22	40.21
71	145	18	2.6	1.4	1.0	53	2.8	3.7	55.66
72	251	25	7.7	8.2	2.1	61	10	30	94.07
73	99	6.4	2.4	3.9	2.2	34	3.0	5.0	25.84
74	46	2.3	1.0	2.2	1.1	11	2.0	1.0	9.85
75	57	2.2	1.0	3.8	0.5	1.0	6.1	1.7	9.6
76									

Ecoregion	Conductivity	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Chloride	Sulfate	Hardness
77	44	4.7	1.5	1.1	0.2	34 (3)	0.1	0.9	17.9
78	92	7.9	3.2	4.0	0.6	36	2.1	2.4	32.87
79	371	33	7.1	25	2.0	89	6.5	18	111.61
80	204	15	5.7	4.1	0.8	54	2.0	9.3	60.87
81	146	30	5.7	11	2.0	54	4.5	25	98.37
82	29	3.5	0.7	2.1	0.4	9.2	2.3	5.4	11.62
83	97	11	1.9	3.2	0.7	54	22	25	35.29
84	41	0.8	0.5	2.4	0.7	1.0	4.4	4.5	4.05

Table 10. Recommended 10th percentile conductivity, GIs, and hardness estimates for SO group 7 through 9 (number of stations shown in parentheses if n<10)

Ecoregion	Conductivity	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Chloride	Sulfate	Hardness
1	111	12	3.4	4.3	0.8	56	2.3	6.3	43.94
2									
3	58	5.0	1.6	3.4	0.6	20	2.7	2.3	19.06
4	118	13	3.6	3.7	0.9	52	1.7	6.9	47.26
5									
6	101	9.0	4.5	4.9	0.9		1.7	3.1	40.95
7	122	10	5.0	6.2	1.0	56	3.5	4.8	45.5
8									
9									
10	71	5.7	1.5	2.0	0.7	16	0.8	4.2	20.4
11	72	8.5	1.5	3.3	0.7	32	0.8	5.0	27.4
12	310	37	10	13	2.5	122	11	30	133.5
13	430	38	10	32	5.6	175	15	27	136
14	810	64	23	69	3.2	121	55	181	254.3
15	51	5.2	1.5	1.4	0.5	20	0.4	3.1	19.15
16									
17	189	20	5.6	3.7	1.1	69	1.3	13	72.96
18	342	35	11	14	1.3	119	2.5	45	132.6
19	608	55	20	44	2.2	145	13.1	149	219.5
20	373	39	12	25	1.7	102	9.7	85	146.7
21									
22	279	28	4.9	15	1.9	80	4.5	37	90.09
23									
24	554	60	11	76	4.3	107	49	145	195.1
25	830	64	20	60	4.6	127	16	184	242
26	876	56	20	61	3.5	128	24	187	222
27	648	61	16	43	6.2	96	25	112	218.1
28	395	41	8.9	15	6.4	119	10	36	138.99
29	1194	71	19	132	4.7	89	210	130	255.4

Ecoregion	Conductivity	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Chloride	Sulfate	Hardness
30									
31	817	59	16	76	4.1	102	88	141	213.1
32	438	45	6.2	28	3.9	107	37	38	137.92
33	428	46	5.3	31	4.7	128	42	28	136.73
34	477	47	6.9	36	4.3	103	49	35	145.79
35	85	6.9	1.6	5.8	1.4	46	5.0	8.0	23.81
36	179	2.4	0.7 (3)	1.4 (3)	1.7 (3)		20	21	8.87
37	355	28	7.0	29	2.9	73	30	28	98.7
38									
39	215	28	7.7	2.8	1.1	96	3.4	6.0	101.57
40	310	34	5.2	6.4	3.0	96	7.3	24	106.32
41									
42	338	49	18	26	3.4	144	8.7	87	196.3
43	394	36	12	24	2.4	122	6.2	74	139.2
44									
45	53	4.1	1.7	6.0	1.5	13	5.0	7.3	17.22
46	642	52	25	49	12	176	22	149	232.5
47	570	48	12	15	3.7	159	11	44	169.2
48	425	44	19	14	5.3	188	9.9	61	187.9
49									
50									
51	353	44	16	7.2	2.1	217	10	13	175.6
52	115	12	4.4	2.9	1.1	40	4.4	5.0	48.04
53	544	53	33	7.9	1.8		19	22	267.8
54	388	41	18	9.7	2.1	131	16	25	176.3
55	502	48	18	20	3.0	182 (4)	32	33	193.8
56									
57	405	43	12	9.5	2.8	104	20	30	156.7
58									
59	65	3.9	0.7	8.5	0.8	6.0	13	6.0	12.62
60									
61									
62									
63	80	3.6	1.4	5.1	2.0	8.5	6.5	7.4	14.74
64	148	14	3.5	4.6	1.3	28	8.0	20	49.35
65	69	4.7	1.2	3.7	1.2	15	4.1	5.7	16.67
66									
67	96	15	3.4	4.7	1.2	28	5.7	12	51.44
68	138	17	3.5	4.1	1.1	57 (8)	5.7	12	56.85
69									
70	225	21	5.4	9.8	1.4	29	10	44	74.64
71	183	23	4.3	3.2	1.4	56	3.8	13	75.13

Ecoregion	Conductivity	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Chloride	Sulfate	Hardness
72	310	34	10	8.3	2.3	88	12	23	126
73	146	14	3.7	3.4	1.7	54	3.5	6.0	50.17
74									
75	70	4.8	1.2	3.2	1.0	15	4.6	3.9	16.92
76									
77									
78									
79									
80	71	8.9 (3)	2.4 (3)	7.7 (3)	2.1 (3)		2.1 (3)	5.1	32.09
81	898	64	23	80	3.8	123	69	160	254.3
82	38	4.0	0.8	1.9	0.4	8.1	2.4	4.5	13.28
83	174	18	3.2	6.1	0.8	41	10	12	58.12
84									

At the level of individual ecoregions, the trends in parameter estimates as a function of SO group often reflect the assessment presented in the previous section. In the majority of ecoregions, most of the parameter estimates increase with SO group, as illustrated in Figure 25 for Ecoregion 46, the Northern Glaciated Plains. However, other trends were observed as well. In Ecoregion 83 (Eastern Great Lakes Lowland), conductivity and cation concentrations were approximately equal in the low and high SO groups and lower in the medium SO group, as shown in Figure 26. Figure 27 illustrates the trends in Ecoregion 54, the Central Corn Belt Plains. In this ecoregion (and several others), most of the parameter estimates decreased with SO group. The explanation for different trends within ecoregions, which may reflect different causes, is beyond the scope of this effort.

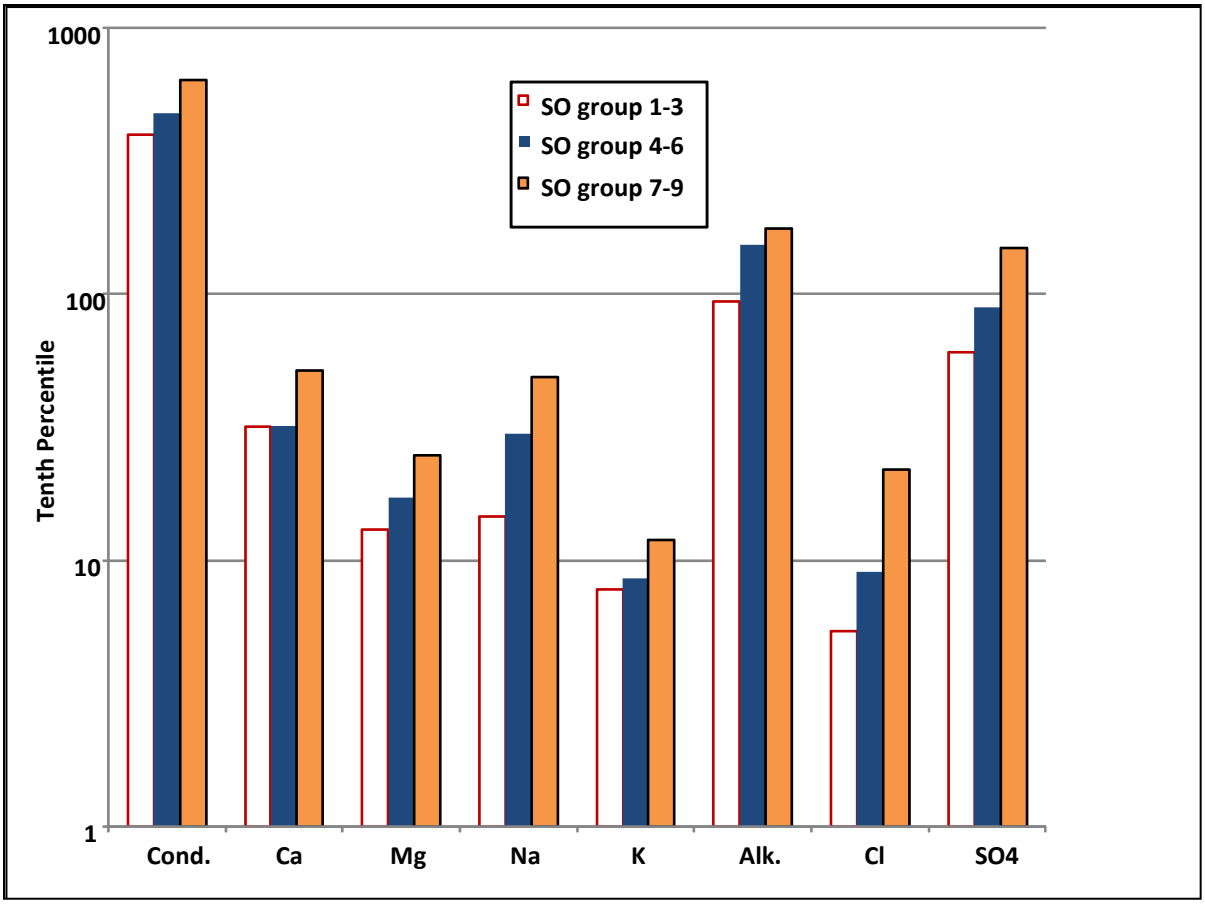


Figure 25. BLM parameter estimates (10th percentile values) for each SO group in Ecoregion 46 (Northern Glaciated Plains)

Key: Stream order: 1-3 are headwater streams, 4-6 are mid-reaches, and 7-9 are rivers.

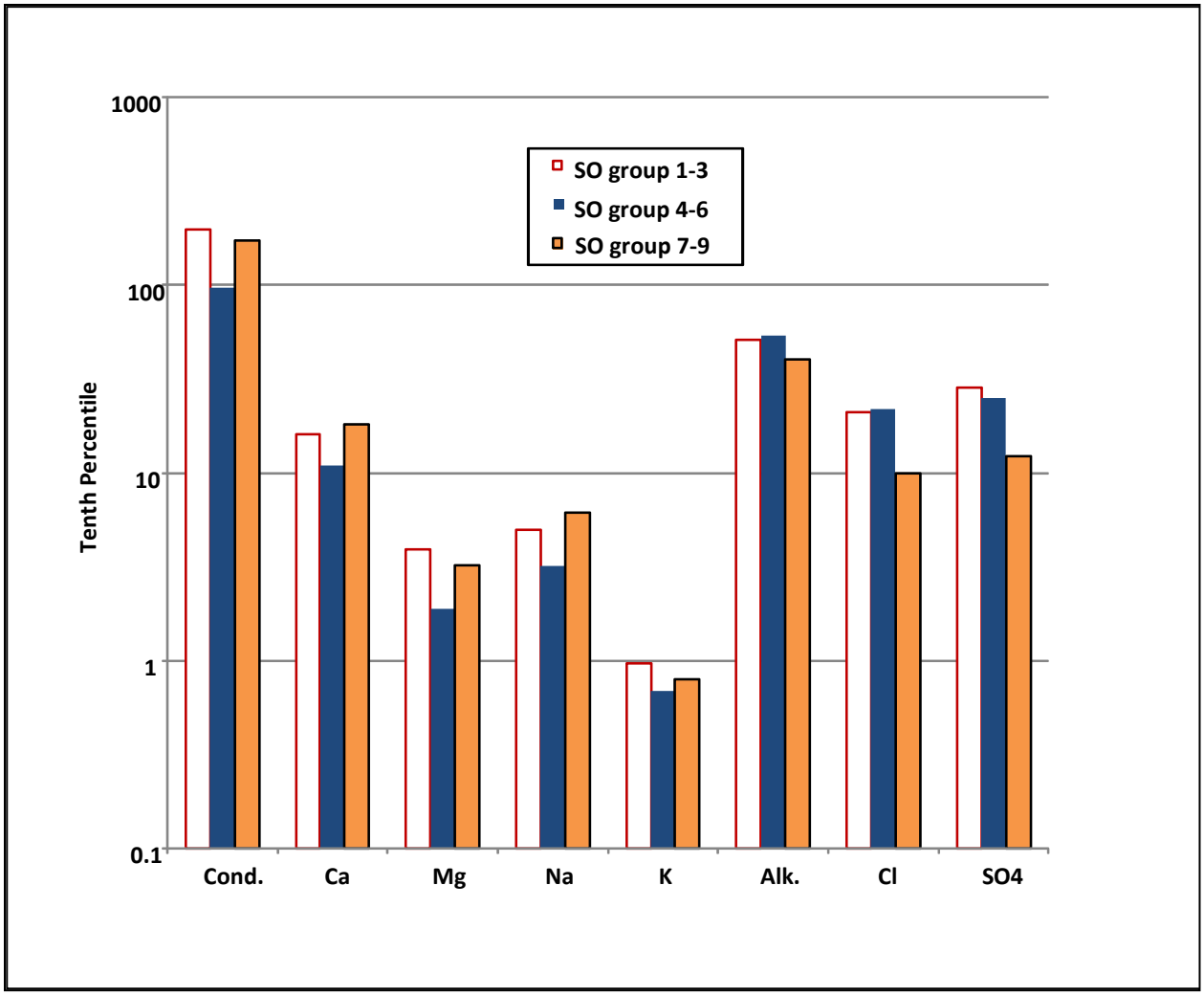


Figure 26. BLM parameter estimates for each SO group in Ecoregion 83 (Eastern Great Lakes Lowland)

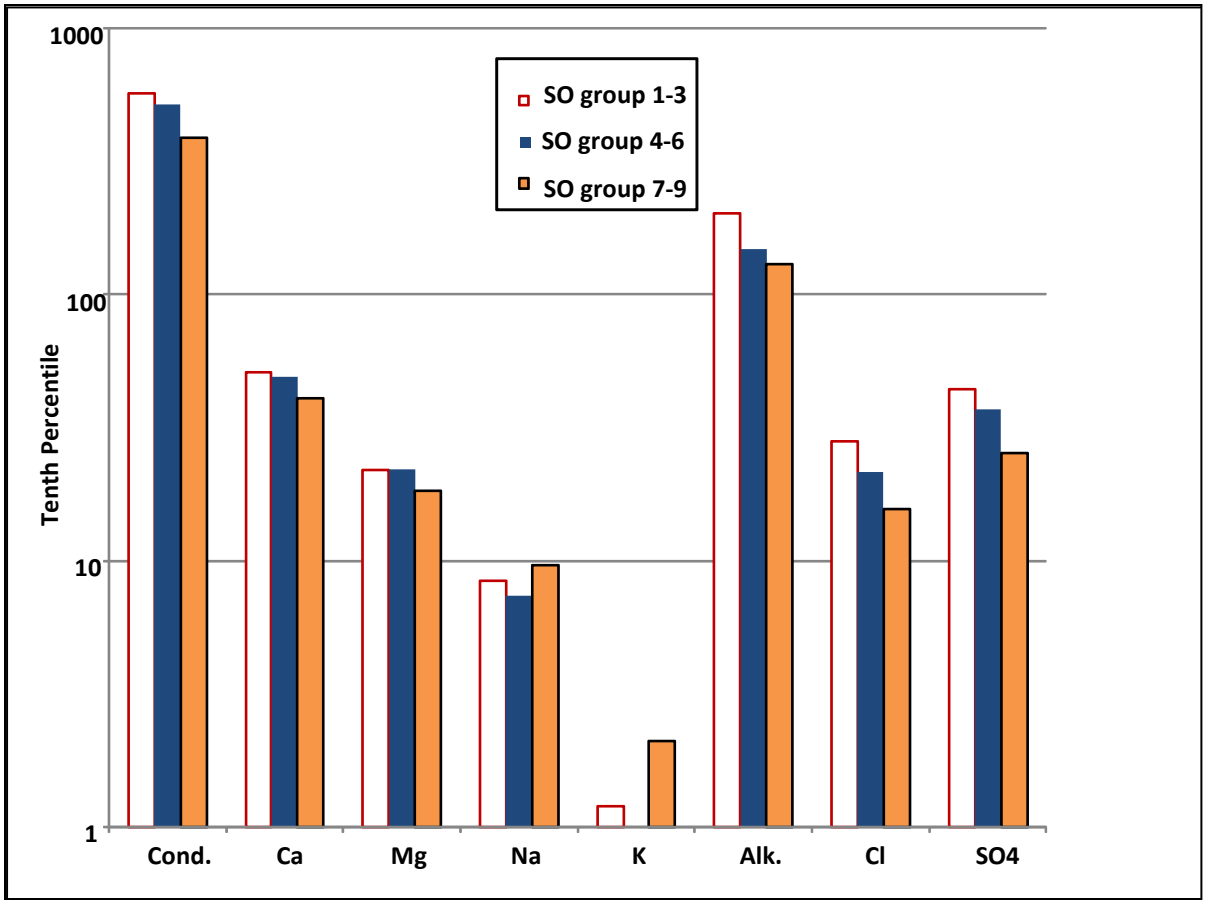


Figure 27. BLM parameter estimates for each SO group in Ecoregion 54 (Central Corn Belt Plains)

3.3.3 Comparison of Parameter Estimates to Results of Probability-Based Surface Water Sampling

There have been relatively few efforts to estimate GI concentrations in surface water at the national scale. Carleton (2006) developed a prototype geostatistical approach to estimate BLM parameters averaged over 8-digit HUC polygons. Carleton examined data from the NWIS and noted several limitations of this dataset in terms of uneven spatial sampling intensity. Carleton's prototype did not incorporate SO in the analysis, nor did it generate BLM parameter estimates.

Griffith (2014) compiled data from probability-based surface water quality sampling surveys conducted by EPA between 1985 and 2009, mostly from wadeable streams (SO group 1 through 4). These surveys included the National Acid Precipitation Assessment Program surveys, EMAP and regional EMAP surveys, WSA, and NRSA. The probability-based sample designs ensured that the results of these surveys represented the character of streams across the continental U.S. The water quality parameters included the same GIs as discussed above, and the results were presented on the same Level III ecoregion-specific basis.

We compared current results to those of Griffith (2014) because the lack of a probability-based sample design is a potential source of bias in the NWIS dataset. Parameter estimates based on the NWIS data for SO group 1 through 3 were compared to the corresponding estimates calculated by Griffith (2014). While Griffith did not tabulate 10th percentiles, he did tabulate first quartile (i.e., 25th percentile)

statistics for each ecoregion in supplemental material published with his article. Accordingly, we calculated 25th percentiles of the ecoregional NWIS data in SO class 1 through 3 (in addition to the 10th percentiles) to facilitate this comparison. The 25th percentiles from the two datasets are compared for conductivity in Figure 28 and calcium in Figure 29. The scatter plots reveal significant log-linear relationships between 25th percentiles for the two datasets; the coefficient of determination (R^2) was 0.668 for conductivity and 0.551 for calcium. For conductivity, the 25th percentiles differed by more than a factor of 2 in 17% of the Level III ecoregions; for calcium, 26% of the ecoregional results differed by more than a factor of 2.

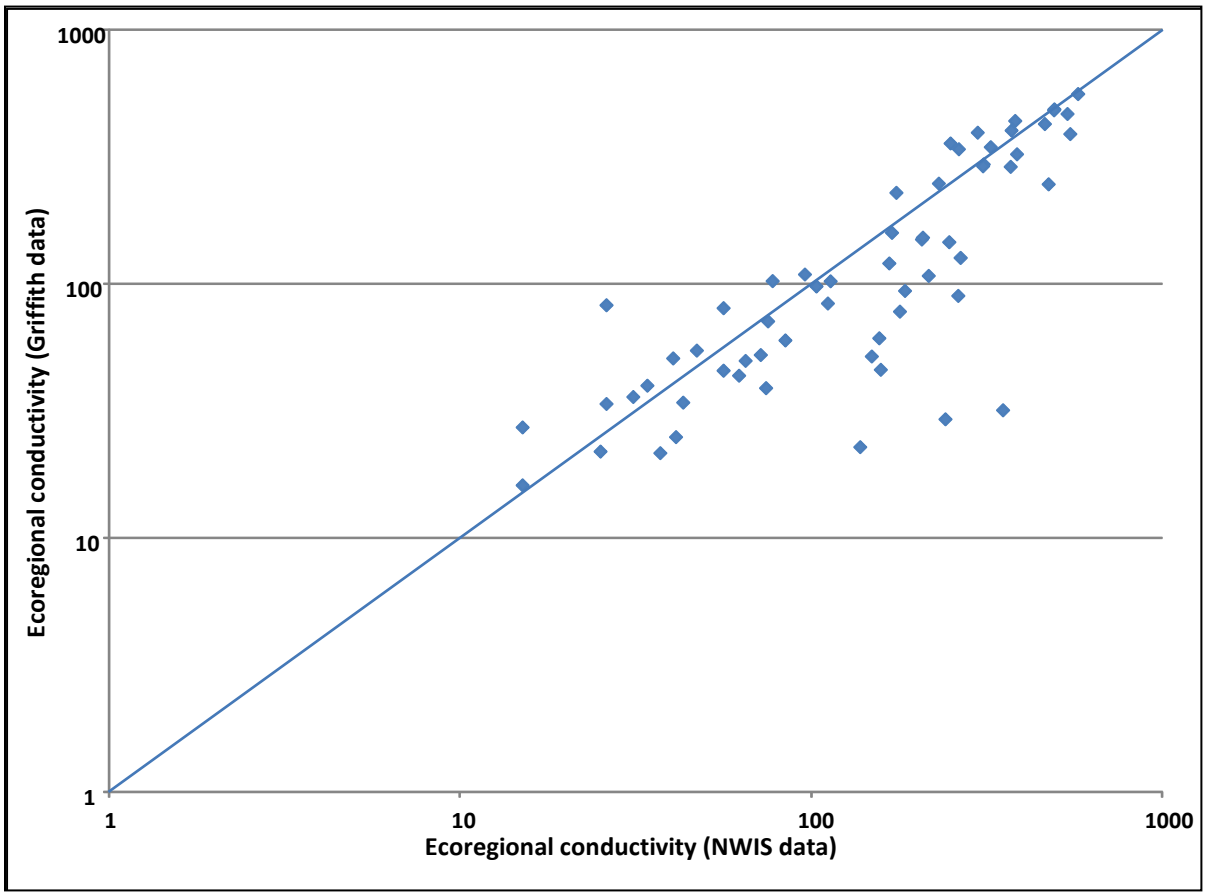


Figure 28. Scatter plot of ecoregional 25th percentile conductivity for NWIS Data (SO Class 1-3) versus ecoregional 25th percentile conductivity for Griffith data (mostly SO 1-4)

Solid diagonal line represents 1:1 agreement.

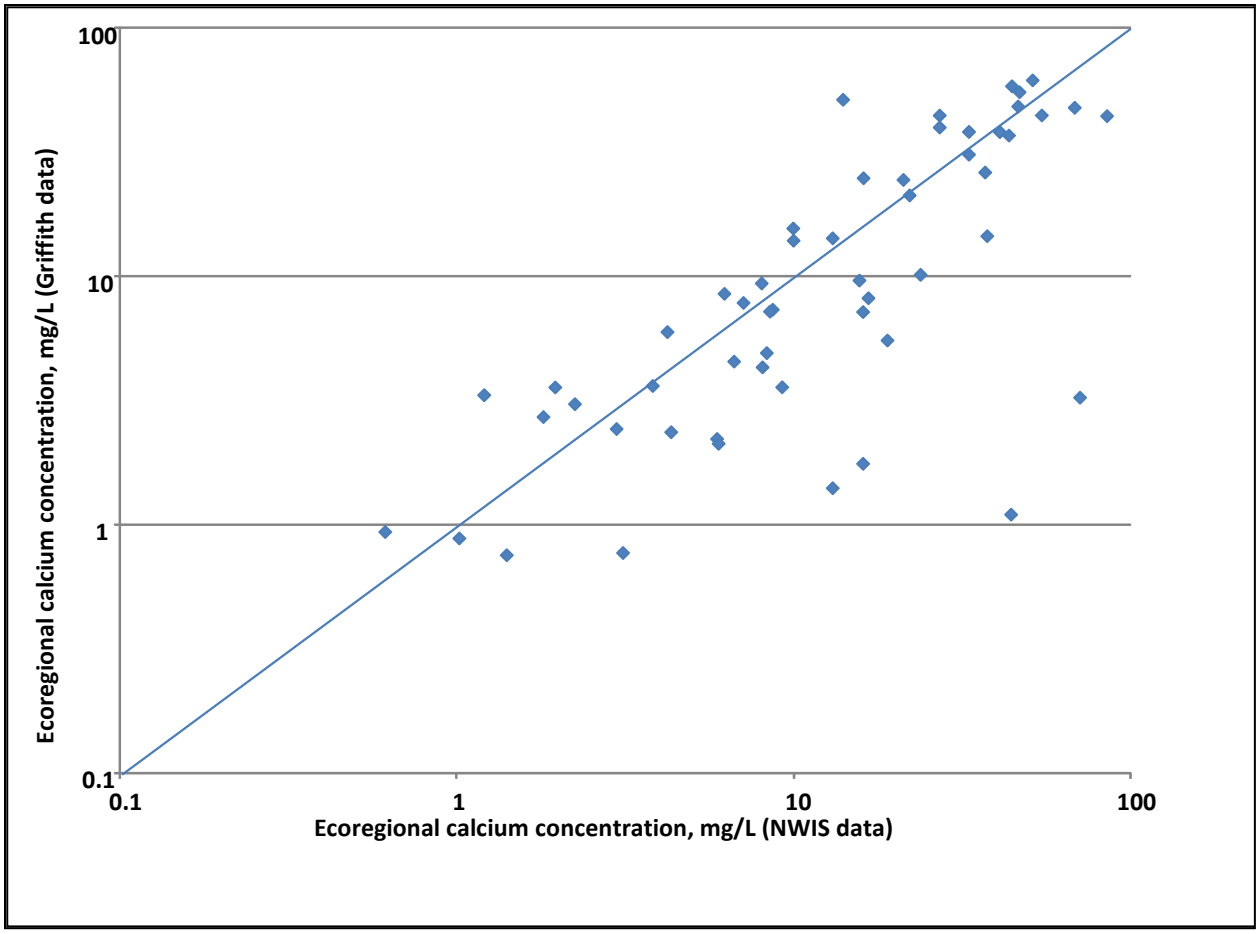


Figure 29. Scatter plot of ecoregional 25th percentile calcium concentration for NWIS data (SO class 1-3) versus ecoregional 25th percentile calcium concentration for Griffith data (mostly SO 1-4)

Solid diagonal line represents 1:1 agreement.

These results suggest reasonable overall consistency between datasets, as well as significant disparity in specific ecoregions. For example, agreement was especially poor in Ecoregions 19 (Wasatch and Uinta Mountains), 37 (Arkansas Valley), 38 (Boston Mountains), 39 (Ozark Highlands), 75 (Southern Coastal Plain), and 78 (Klamath Mountains). NWIS data were examined at the station-specific level to understand why these ecoregional 25th percentiles of conductivity and calcium in the low SO group were so inconsistent with corresponding percentiles presented by Griffith. Table 11 presents salient characteristics of the conductivity data for Ecoregion 19, including the number of stations, samples per station, 25th percentile conductivity, the lowest station-specific 25th percentile conductivity in the NWIS data, and other remarks. In that ecoregion, conductivity data were reported for 62 stations in the NWIS database; the number of observations per station ranged from 1 to 189, with a median of 22 observations per station. In comparison, the EPA data analyzed by Griffith reported conductivity data for 32 stations, with a single observation per station. The 25th percentile conductivity based on NWIS data was 240 versus 22.9 microsiemens per centimeter (µS/cm) based on Griffith's analysis of EPA data. When recalculated for individual stations in Ecoregion 19 low SO group, the 25th percentile conductivities varied widely, from 18.25 to 1590 µS/cm. Griffith reported a median conductivity of 213

µS/cm (nine times larger than the 25th percentile), indicating considerable variability in that data as well.

Table 11. Characteristics of the conductivity data for Ecoregion 19 in the low SO group.		
	NWIS data	Griffith data
Number of stations	62	32
Samples per station	1 – 189	1
Median samples per station	22	1
25th percentile conductivity (µS/cm)	240	22.9
Range of station-specific 25th percentile conductivity (µS/cm)	18.25-1590	
Other remarks	25th percentiles of conductivity reported by Griffith were marginally higher than the *minimum* station-specific 25th percentiles calculated from the NWIS data	Median conductivity = 213 µS/cm (19x the 25th percentile value) indicates high variability

The same information is tabulated for Ecoregions 37, 38, 75, and 78 in Tables 12 through 15. Although the details regarding the data vary in each of these ecoregions, a number of commonalities emerge from these examinations:

- In four ecoregions, the number of NWIS stations in SO group 1 through 3 was small relative to other ecoregions (the median number of ecoregional stations in SO group 1 through 3 was 68).
- In three ecoregions, 10th and 25th percentiles of conductivity and/or calcium decreased with SO group, contrary to the general trend.
- In three ecoregions, 25th percentiles of conductivity reported by Griffith were marginally higher than the minimum station-specific 25th percentiles calculated from the NWIS data for the corresponding ecoregion and low SO group.

Table 12. Characteristics of the conductivity data for Ecoregion 37 in the low SO group.		
	NWIS data	Griffith data
Number of stations	34	45
Samples per station	1 – 129	1
Median samples per station	2	1
25th percentile conductivity (µS/cm)	350	32
Range of station-specific 25th percentile conductivity (µS/cm)	29-846.5	
Other remarks	10th and 25th conductivity percentiles *decrease* with SO group; Small number of NWIS stations; 25th percentiles of conductivity reported by Griffith were marginally higher than the *minimum* station-specific 25th percentiles calculated from the NWIS data	

Table 13. Characteristics of the conductivity data for Ecoregion 38 in the low SO group		
	NWIS data	Griffith data
Number of stations	31	38
Samples per station	1 – 8	1
Median samples per station	3	1
25th percentile conductivity (µS/cm)	137	22.9
Range of station-specific 25th percentile conductivity (µS/cm)	22-384	
Other remarks	10th and 25th conductivity percentiles *decrease* with SO group; Small number of NWIS stations; 25th percentiles of conductivity reported by Griffith were marginally higher than the *minimum* station-specific 25th percentiles calculated from the NWIS data	

Table 14. Characteristics of the calcium data for Ecoregion 75 in the low SO group.		
	NWIS data	Griffith data
Number of stations	360	42
Samples per station	1 – 177	1
Median samples per station	17	1
25th percentile calcium (mg/L)	13	1.41
Range of station-specific 25th percentile calcium (mg/L)	0.02-91	
Other remarks	10th and 25th calcium percentiles *decrease* with SO group	

Table 15. Characteristics of the conductivity data for Ecoregion 78 in the low SO group.		
	NWIS data	Griffith data
Number of stations	15	45
Samples per station	1 – 18	1
Median samples per station	8	1
25th percentile conductivity (µS/cm)	26	98.4
Range of station-specific 25th percentile conductivity (µS/cm)	19-326.5	
Other remarks	Small number of NWIS stations; 6 of 15 stations were Ashland Creek (OR) or tributaries	

It is possible that the disparities noted above arise in part from non-representative sampling in the NWIS data. For example, representativeness of NWIS data is questionable in Ecoregion 78 because 40% of the stations were sampled in a single water body. There was also a difference in the way data for repeated sampling at individual stations were processed, due to differences between the NWIS data and data compiled by Griffith. In the NWIS data, water quality was sampled repeatedly at a significant

number of stations, and we included daily averages of all of these measurements in the calculation of 10^{th} percentile estimates. In the probabilistic EPA surveys analyzed by Griffith, individual stations were usually sampled once. In the case of repeated sampling at a station, Griffith used data from only the first sample reported for the station in the statistics he calculated. This difference implies that our estimates of BLM parameters incorporate temporal as well as spatial variability in water quality, while Griffith's results do not. Thus, it would be unrealistic to expect complete agreement between these results. It should also be reiterated that sampling bias in SO is probably not a factor in these disparities because the estimates from the NWIS data were based on measurements from stream orders 1 through 3, which is generally consistent with the data compiled by Griffith (2014).

It is particularly of concern when percentiles based on NWIS data are higher than those calculated based on Griffith data because this suggests the parameter estimates may result in non-conservative BLM predictions of copper, or others metals, criteria. To evaluate this concern, we ran the BLM (version 2.1.2) using the 25^{th} percentile GI estimates of Griffith and those from the current analysis for NWIS SO group 1 through 3 for each ecoregion in which parameters were available. If the 25^{th} percentile of a GI was not available, the value was projected from the 25^{th} percentile of conductivity using regressions based on NWIS data. If the 25^{th} percentile of conductivity was not available (this occurred in 24 ecoregions), no BLM prediction was made. The inputs for pH and DOC were ecoregional values. There were 60 ecoregions where BLM predictions of copper criteria using the 25^{th} percentile GI estimates from NWIS and Griffith could be compared. The criteria estimated in these ecoregions using GI input parameters from the two sources agree very well, as shown in Figure 30. The R^2 was 0.9897, and relative percent differences (RPDs) ranged from -21 to 39% with an average RPD of 3% and a median of 0.1%.

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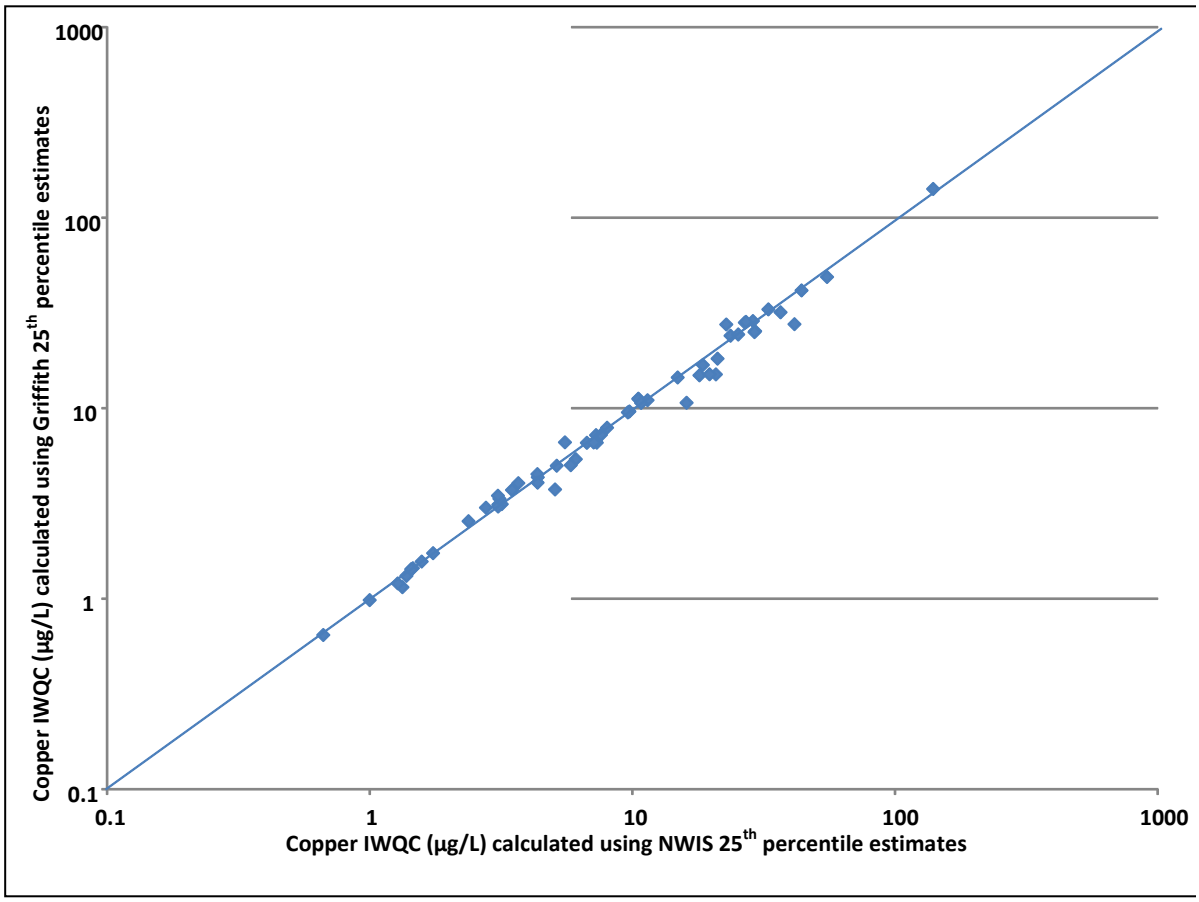


Figure 30. BLM predictions of copper criteria made with GI water quality parameters based on ecoregional 25th percentile from NWIS data (SO class 1-3) versus ecoregional 25th percentile calcium Concentration for Griffith data (mostly SO 1-4).

R^2 = 0.99. Solid diagonal line represents 1:1 agreement

While it is possible that the GI estimates presented here as recommended input values for use in the BLM for copper could be improved, it is not clear that such improvement would result in substantially better predictions of protective copper criteria based on the BLM. This is because BLM predictions for copper are much more sensitive to pH and DOC.

3.4 Summary

In this section we have incorporated SO variation in the GI water quality parameter estimates to refine the default parameters estimates for use in the BLM when data are not available.

EPA found that values of the GI parameter estimates generally increased with SO. This trend was most apparent and consistent for higher order streams (SO≥7). Tenth percentile estimates of conductivity increase with stream order group in 58% of ecoregions (comparing low to medium SO groups) and 84% of ecoregions (comparing medium to high SO groups). The same trend was evident for the GIs that are input parameters to the BLM.

We compared the parameter estimates for SO group 1 through 3 to those calculated by Griffith (2014). This comparison revealed significant log-linear relationships between 25th percentiles for the two datasets; the coefficient of determination (R^2) was 0.668 for conductivity and 0.551 for calcium. For conductivity, the 25th percentiles differed by more than a factor of 2 in 17% of the Level III ecoregions; for calcium, 26% of ecoregional results differed by more than a factor of 2. There is also considerable variability in the relationship between ecoregional statistics based on NWIS versus Griffith's data. Possible causes of these disparities may be due to sampling bias in the NWIS database, limited numbers of samples in some ecoregions, and differences in the degree and treatment of repeated sampling at individual locations.

NWIS percentiles higher than Griffith (2014) suggest that the recommended parameter estimates may result in non-conservative BLM predictions of copper criteria. The BLM was run to predict copper criteria for 60 ecoregions using 25th percentile GI estimates as parameter inputs from NWIS and Griffith's data. The criteria predicted using the two sets of GI parameter inputs agreed favorably. The R^2 was 0.990, and RPDs ranged from -21 to 39% with an average RPD of 3% and a median of 0.1%. These results demonstrated that the recommended default GI parameter estimates are reasonably conservative.

EPA incorporated SO variation in the parameter estimates to refine recommended input values for use in the BLM. EPA found the 10th percentile ecoregion, SO group specific estimates to be reasonably protective inputs and recommends their use where site-specific parameters are not readily available.

4 DOC ESTIMATION USING THE NATIONAL ORGANIC CARBON DATABASE

The following section summarizes our investigation into whether ecoregion and water body-type-specific DOC concentration percentiles tabulated by EPA for the *Development of National Bioaccumulation Factors Technical Support Document* (hereafter referred to as the National Organic Carbon Database (NOCD)) (USEPA, 2003)) offer reasonable estimates of lower-percentile DOC concentrations. A summary of the NOCD's data sources, analysis, and uncertainty associated with ecoregional statistics derived from the NOCD is provided below. This section also discusses how we recalculated ecoregional DOC percentiles for rivers and streams, and then tested for bias in the NOCD. Finally, we compared results based on the NOCD and data from the Wadeable Stream Assessment (WSA) (USEPA, 2006b)) and the National River and Stream Assessment (NRSA) (USEPA, 2013)).

4.1 Description of the NOCD

The NOCD is a compilation of pre-2003 organic carbon data derived from two sources: EPA's Storage and Retrieval Data Warehouse (STORET), recently renamed the STORET Legacy Data Center (LDC), and USGS's National Water Data Storage and Retrieval System (WATSTORE), the predecessor of NWIS. A complete background on the NOCD is available in USEPA 2003.

EPA's LDC database contains water quality monitoring data collected by academia, volunteer groups, and tribes, as well as federal, state, and local agencies. Geographically, the LDC data represent all 50 states and all U.S. territories and jurisdictions, along with portions of Canada and Mexico. The database queried for this investigation is often referred to as the "historical" or "old" STORET database because it contains water quality data dating back to the early part of the 20th century through the end of 1998. Data from 1999 to the present are stored in the "modernized" STORET Data Warehouse.[4] The LDC contains raw biological, chemical, and physical data for both surface water and groundwater. Each sampling result is accompanied by: information on sample collection location (latitude, longitude, state, county, HUC, and a brief site description), date the sample was gathered, the medium sampled, and the name of the organization that sponsored the monitoring.

We retrieved data from LDC and WATSTORE in January 2000. Approximately 800,000 records containing data on particulate organic carbon (POC), dissolved organic carbon (DOC), or total organic carbon (TOC) were obtained for the period beginning in 1970 through the latest year that data were available (1999 for WATSTORE and 1998 for LDC). This initial retrieval was limited to samples taken from ambient surface waters (i.e., samples from wells, springs, effluents, and other non-ambient sources were excluded). Additionally, this retrieval included multiple types of organic carbon measurements to ensure that the data would be sufficiently comprehensive.

WATSTORE was established in 1972 to provide an effective and efficient means for processing and maintaining water data collected through USGS activities and to facilitate release of that data to the public. The WATSTORE database resides on the central computer facilities of the USGS and contains results of approximately two million analyses of both surface and groundwater that provide data on

[4] Refer to http://www.epa.gov/storet/dbtop.html for more information on the STORET Data Warehouse and the LDC.

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chemical, physical, biological, and radiological characteristics. EPA queried WATSTORE, the Water Quality File, to retrieve DOC data.

After retrieval, the data from LDC and WATSTORE were combined into a single database. The data were then processed and screened to ensure that only the most appropriate data would be retained. This screening process is outlined below:

- Values that were coded in such a way as to suggest uncertainty in the measurement were deleted from the database.
- The database was restricted to the following water body types: estuaries, lakes, reservoirs, and streams (including rivers).
- "Pseudo-ecoregions" were added for the five Great Lakes.
- The time period for the data was restricted to 1980 through 1999.
- Some values for DOC were reported to be below analytical detection levels. In this situation, the value was assumed to be half of the reported detection level. Values with "high" detection levels (i.e., >1.0 mg/L for DOC) were deleted from the database because of the greater uncertainty involved in estimating definitive values of DOC in these situations.
- A small fraction of the DOC and POC concentrations obtained from the LDC database exceeded concentrations considered to represent upper limits of DOC concentrations reported in U.S. water bodies (i.e., 0.2% exceeded 60 mg/L for DOC). These extreme values were based on a review of organic carbon data by Thurman (1985), who reported extreme values of DOC concentrations as high as 50 mg/L in dystrophic lakes and 60 mg/L in tributaries draining wetland systems. Therefore, values for DOC above 60 mg/L were removed from the database.

The NOCD that resulted from processing and screening data retrieved from the LDC and WATSTORE databases has some limitations, which are described below:

- The WATSTORE and LDC databases do not reflect a random sampling of U.S. surface waters. They contain datasets with a diversity of sampling design and thus data may be biased towards locations and water bodies with known water quality impairments.
- These data also reflect spatial bias due to unequal sampling efforts in different areas. For example, about half of the DOC and POC values in the databases were from samples collected in Maryland, New York, Ohio, Florida, and Delaware. Therefore some states are disproportionally represented, even when one considers the relative surface water area likely to be contained within each state.
- WATSTORE and LDC generally contain more data from sampling sites in larger river and stream systems, and areas subjected to proportionately greater human influence compared with random statistical sampling.

4.2 Recalculation of Ecoregional DOC Percentiles for Rivers and Streams

Lower percentile (1^{st}, 5^{th}, 10^{th}, and 25^{th} percentiles) DOC concentrations were calculated from all data for rivers and streams in each Level III ecoregion (Table 16). Nonparametric (i.e., rank) percentiles were calculated following the recommendations of Dierickx (2008) and Hyndman and Fan (1996). We also calculated confidence limits for the percentiles using the method presented in Berthouex and Brown

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(1994). Upper and lower 95% confidence limits (UCLs and LCLs) were calculated if 20 or more DOC concentrations were available for an ecoregion (Berthouex and Brown, 1994).

Table 16. Lower percentile values of DOC in U.S. streams and rivers by ecoregion, including 95% confidence limits for percentile concentrations if n>20.

Level III Ecoregion	Ecoregion Name	n (count)	1%	1% (LCL)	1% (UCL)	5%	5% (LCL)	5% (UCL)	10%	10% (LCL)	10% (UCL)	25%	25% (LCL)	25% (UCL)
1	Coast Range	91	≤0.2	≤0.2	0.6	0.9	≤0.2	1.1	1.12	0.78	1.4	1.8	1.4	2
2	Puget Lowland	835	0.84	0.47	1	1.9	1.7	2	2.5	2.3	2.7	3.9	3.5	4.1
3	Willamette Valley	66	≤0.5	≤0.5	0.73	0.8	≤0.5	1.08	1.07	0.68	1.2	1.48	1.2	2
4	Cascades	101	0	≤0	0.2	0.3	≤0	0.44	0.5	0.3	0.5	0.7	0.5	0.9
5	Sierra Nevada	32	≤1.9	≤1.9	1.9	1.9	≤1.9	2.3	2.09	≤1.9	2.3	2.55	2.13	3.11
6	Southern and Central California Chaparral and Oak Woodlands	480	1.1	≤0	1.5	1.8	1.7	1.9	2.1	1.9	2.2	3	2.67	3.2
7	Central California Valley	180	1.21	≤0.8	1.8	2.11	1.66	2.48	2.71	2.3	3.5	5.3	4.4	6.26
8	Southern California Mountains	6	≤4.4			≤4.4			≤4.4			5.45		
9	Eastern Cascades Slopes and Foothills	13	≤1.3			≤1.3			1.42			1.75		
10	Columbia Plateau	73	≤0.7	≤0.7	1.3	1.67	≤0.7	2.03	2.04	1.29	2.34	2.9	2.3	3.2
11	Blue Mountains	26	≤1	≤1	1.05	1.07	≤1	1.45	1.34	≤1	1.81	1.9	1.28	2.61
12	Snake River Plain	50	≤2	≤2	2	2	≤2	2.2	2.2	≤2	2.43	3.08	2.27	3.68
13	Central Basin and Range	1553	0.8	0.69	0.9	1.2	1.2	1.3	1.5	1.4	1.6	2	2	2.1
14	Mojave Basin and Range	35	≤2.5	≤2.5	2.55	2.58	≤2.5	3	2.84	≤2.5	3.32	3.6	2.99	3.8
15	Northern Rockies	778	0.7	0.6	0.72	0.9	0.9	1	1	1	1.1	1.3	1.3	1.4
16	Idaho Batholith	29	≤1.2	≤1.2	1.2	1.2	≤1.2	1.4	1.4	≤1.2	1.8	1.9	1.39	2.31
17	Middle Rockies	87	≤0	≤0	0	0	≤0	0.14	0.18	0	0.46	1.1	0.42	1.4
18	Wyoming Basin	150	2.05	≤1.9	3.03	3.56	2.26	4.18	4.31	3.59	4.6	5.48	5.1	5.8
19	Wasatch and Uinta Mountains	46	≤1.5	≤1.5	1.5	1.57	≤1.5	1.82	1.8	≤1.5	2.51	2.88	1.9	3.6
20	Colorado Plateaus	798	1.5	0.36	1.6	2.4	2	2.6	3	2.7	3.25	4.3	4.1	4.6
21	Southern Rockies	1129	0.2	0.1	0.3	0.5	0.4	0.5	0.6	0.6	0.6	0.8	0.8	0.9
22	Arizona/New Mexico Plateau	281	1.65	≤1.2	2.01	2.2	2.09	2.4	2.62	2.3	2.91	3.7	3.3	3.9
23	Arizona/New Mexico Mountains	37	≤1.3	≤1.3	1.41	1.48	≤1.3	2.35	2.16	≤1.3	2.64	2.8	2.33	3.57
24	Chihuahuan Deserts	116	0.5	≤0.5	0.64	1	0.5	2.15	2.34	1	3	3.68	3	4.44
25	High Plains	439	0.3	≤0.1	0.4	0.8	0.5	3	4.4	3.2	4.9	7	6.42	7.78
26	Southwestern Tablelands	167	1.94	≤1.8	2.04	2.5	2	2.98	3.28	2.52	3.7	4.4	4	4.9
27	Central Great Plains	228	0.59	≤0.4	2.01	3	1.8	3.2	3.8	3	4	5	4.8	5.71
28	Flint Hills	10	≤4.9			≤4.9			4.9			5.15		
29	Central Oklahoma/Texas Plains	289	1.9	≤1	2.09	3	2.5	3.38	3.8	3	4	4.8	4.21	5
30	Edwards Plateau	200	0.5	≤0.5	0.5	0.5	0.5	0.82	1	0.5	1	1	1	1.6
31	Southern Texas Plains	58	≤0.5	≤0.5	0.5	0.5	≤0.5	1	1	0.5	1.34	2	1	2
32	Texas Blackland Prairies	829	0.5	0.5	0.5	1	1	1	2	2	2	3	3	3.99

Level III Ecoregion	Ecoregion Name	n (count)	1%	1% (LCL)	1% (UCL)	5%	5% (LCL)	5% (UCL)	10%	10% (LCL)	10% (UCL)	25%	25% (LCL)	25% (UCL)
33	East Central Texas Plains	268	1	≤1	1.95	2.6	2	3	3	3	3	3.83	3.1	4
34	Western Gulf Coastal Plain	399	2.8	≤1.7	3	3.7	3	4	4	4	4	5	5	5.9
35	South Central Plains	523	1.45	≤0.4	2.07	3.92	3.2	4	4.6	4.1	4.98	5.7	5.4	6
36	Ouachita Mountains	198	0	≤0	0.47	0.8	0.4	1.1	1.1	0.86	1.6	2.38	2.08	2.8
37	Arkansas Valley	184	0.49	≤0.4	0.65	0.8	0.55	1.4	1.9	0.85	2.39	3.73	3	4.4
38	Boston Mountains	21	≤0.4	≤0.4	0.4	0.4	≤0.4	0.5	0.42	≤0.4	0.5	0.5	0.4	0.74
39	Ozark Highlands	233	1.67	≤1.5	2	2	2	2.12	2.3	2	2.5	3	2.7	3.15
40	Central Irregular Plains	434	2.71	≤1.4	3	3.5	3.1	3.6	4	3.6	4	4.9	4.6	5
41	Canadian Rockies	36	≤0.3	≤0.3	0.35	0.39	≤0.3	0.6	0.57	≤0.3	0.9	0.93	0.6	1.03
42	Northwestern Glaciated Plains	36	≤3	≤3	3.05	3.09	≤3	6.63	5.05	≤3	11.23	13.25	6.12	16.34
43	Northwestern Great Plains	679	2.22	0.72	3.19	4.4	3.8	5.2	6.2	5.6	6.73	9.9	9.19	10
44	Nebraska Sand Hills	4	≤1.4			≤1.4			≤1.4			1.4		
45	Piedmont	309	0.4	≤0	0.5	0.7	0.6	0.9	1	0.8	1.1	1.7	1.4	2.1
46	Northern Glaciated Plains	142	4.03	≤3.3	8.01	9.13	5.11	9.82	9.9	9.16	11	12	11	12.86
47	Western Corn Belt Plains	193	0.44	≤0.2	2.43	2.77	2.28	2.96	3.14	2.8	3.5	3.9	3.6	4.3
48	Lake Agassiz Plain	261	3.1	≤0.8	4.52	6.41	4.72	7.1	7.6	6.87	7.97	9	8.7	9.22
49	Northern Minnesota Wetlands	44	≤7.8	≤7.8	8.25	9.05	≤7.8	11	11	≤7.8	12	13	11	14.88
50	Northern Lakes and Forests	403	2	≤0.1	2.2	2.72	2.36	3.08	3.7	3.06	4.5	5.8	5.5	6.2
51	North Central Hardwood Forests	153	0.54	≤0	2.19	2.67	1.42	2.9	3.1	2.7	3.77	4.95	3.9	5.6
52	Driftless Area	49	≤1.7	≤1.7	2.31	2.4	≤1.7	3.25	3.1	≤1.7	4.31	4.5	3.4	5.8
53	Southeastern Wisconsin Till Plains	439	2	≤0.25	2.1	3.4	2.7	4.3	5.3	4.3	5.6	6.8	6.5	7
54	Central Corn Belt Plains	202	1	≤0.7	1.68	2.12	1.61	2.5	2.73	2.2	3	3.9	3.57	4.8
55	Eastern Corn Belt Plains	1398	0	0	0	0	0	0.2	3.8	3	4	5.2	5	5.3
56	S. Michigan/N. Indiana Drift Plains	287	1.4	≤1.4	1.92	2.7	2.05	3.43	3.8	3.17	4.2	5.4	4.9	5.7
57	Huron/Erie Lake Plains	3825	0	0	0	3.9	3.7	4.07	4.7	4.52	4.8	5.8	5.7	5.9
58	Northeastern Highlands	14044	0.25	0.25	0.25	0.25	0.25	0.5	0.64	0.62	0.65	0.95	0.94	0.97
59	Northeastern Coastal Zone	102	0.05	≤0	1.6	2.02	≤0	2.6	2.63	1.74	2.92	3.28	3	3.63
60	Northern Appalachian Plateau and Uplands	354	0.6	≤0.5	0.8	1	0.87	1.1	1.3	1.1	1.4	2	1.9	2.3
61	Erie Drift Plains	919	0	0	0	4.8	4.6	4.9	5.1	5	5.1	5.5	5.4	5.6
62	North Central Appalachians	106	0.41	≤0.4	0.5	0.5	≤0.4	0.7	0.7	0.5	0.78	0.98	0.8	1.2
63	Middle Atlantic Coastal Plain	16730	1.1	1.01	1.2	1.8	1.8	1.8	2.2	2.2	2.2	2.7	2.7	2.7
64	Northern Piedmont	1525	0.43	0.3	0.5	1	0.99	1	1.3	1.2	1.4	2.2	2.1	2.4
65	Southeastern Plains	3813	1	0.51	1.1	2	1.9	2.03	2.4	2.38	2.5	3.3	3.2	3.3
66	Blue Ridge	699	0	0	0	0.4	0.3	0.4	0.5	0.4	0.5	0.6	0.6	0.7
67	Ridge and Valley	733	0.1	0.1	0.1	0.4	0.3	0.5	0.6	0.5	0.7	1.05	1	1.1
68	Southwestern Appalachians	47	≤0.5	≤0.5	0.5	0.58	≤0.5	0.9	0.9	≤0.5	1	1	0.9	1.38
69	Central Appalachians	864	0.3	0.15	0.4	0.6	0.5	0.6	0.7	0.7	0.8	1.1	1.1	1.2
70	Western Allegheny Plateau	1795	0	0	0	0.78	0.2	1	1.6	1.4	1.7	2.7	2.5	2.9
71	Interior Plateau	559	0.1	≤0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.2	0.3

Level III Ecoregion	Ecoregion Name	n (count)	1%	1% (LCL)	1% (UCL)	5%	5% (LCL)	5% (UCL)	10%	10% (LCL)	10% (UCL)	25%	25% (LCL)	25% (UCL)
72	Interior River Valleys and Hills	328	1.32	≤0.15	1.8	2.1	1.9	2.4	2.69	2.4	3.05	4.2	3.6	4.6
73	Mississippi Alluvial Plain	503	1.7	≤1	2.14	2.82	2.4	3.1	3.4	3.2	3.6	4.3	4.1	4.5
74	Mississippi Valley Loess Plains	21	≤1.4	≤1.4	1.41	1.41	≤1.4	2.61	1.72	≤1.4	2.7	2.7	1.46	4.72
75	Southern Coastal Plain	4223	0.9	0.9	1.09	5.3	4.7	6	8	7.6	8.3	12.1	11.9	12.3
76	Southern Florida Coastal Plain	-	-			-			-			-		
77	North Cascades	50	≤0.2	≤0.2	0.2	0.26	≤0.2	0.4	0.4	≤0.2	0.4	0.48	0.4	0.5
78	Klamath Mountains	8	≤1.7			≤1.7			≤1.7			2.3		
79	Madrean Archipelago	9	≤2.6			≤2.6			2.6			4.05		
80	Northern Basin and Range	16	≤1.6			≤1.6			1.81			2.5		
81	Sonoran Basin and Range	133	1.33	≤1.3	1.7	1.8	1.38	2.1	2.2	1.8	2.6	3.85	2.94	4.4
82	Laurentian Plains and Hills	21	≤4.6	≤4.6	4.7	4.69	≤4.6	5.68	5.52	≤4.6	7.98	8.45	5.15	9.3
83	Eastern Great Lakes and Hudson Lowlands	1430	0	0	0	0	0	0.2	1.9	1	2	5.1	5	5.5
84	Atlantic Coastal Pine Barrens	243	1	≤0.9	1.1	1.22	1.1	1.5	1.6	1.32	2	2.6	2.4	3
	Lake Erie	9	≤1.1			≤1.1			1.18			1.4		
	Lake Michigan	5	≤2.6			≤2.6			≤2.6			2.6		
	Lake Ontario	14	≤0.4			≤0.4			0.4			2.2		
	Lake Superior	7	≤1.2			≤1.2			≤1.2			1.4		

As was the case for the BLM GI input parameters, we consider low percentiles of the ecoregional DOC concentration distributions to be reasonably protective inputs to the BLM for sites where DOC measurements are not available.

4.3 Testing for Bias in the NOCD

EPA conducted an evaluation of bias in the NOCD (USEPA, 2003) using data from EPA's Environmental Monitoring and Assessment Program's (EMAP) 1997 to 1998, which sampled mid-Atlantic streams and rivers (USEPA, 2006b). This effort is described below in Section 4.3.1.

We also evaluated the bias in the NOCD using independent data from EPA's Wadeable Streams Assessment (WSA), which included DOC measurements from a statistically based random sample of approximately 2,000 wadeable, perennial 1st through 5th order streams (USEPA, 2006c). In Section 4.3.2, we compare the WSA data to the ecoregion-specific DOC concentration percentiles calculated from the NOCD.

4.3.1 Previous Efforts Using EMAP Data

Ideally, the data used to generate the distribution of national organic carbon concentration values should originate from a random sampling of U.S. surface waters, and should be appropriately stratified and weighted by spatial and temporal factors that would be expected to influence organic carbon concentrations in aquatic ecosystems (e.g., water body type, hydrologic and watershed characteristics, ecoregion, season). However, these data are not available on a national scale. The strength of this analysis is that the data from USGS's WATSTORE and EPA's LDC databases include a large number of

records (e.g., >110,000 DOC values), a representation of DOC values for all 50 states, and reasonably long period over which data were collected (1980 through 1999 for these analyses).

Data generated by EMAP are based on a stratified, random sampling strategy that was specifically designed to minimize the influence of sampling bias on the data and to enable statistically based extrapolations across geographic regions (Herlihy et al., 2000). At the time the NOCD was developed, the EMAP databases containing DOC measurements were limited to smaller geographic scales and specific water body types.

Previously, to address the question of sampling bias and its impact on the representativeness of the NOCD values, EPA made quantitative comparisons that involved contrasting geographically distinct subsets of the WATSTORE/LDC databases with geographically similar subsets of data produced by EMAP. DOC data from EMAP's 1997 to 1998 sampling of mid-Atlantic streams and rivers were compared with similar geographic subsets from the WATSTORE/LDC databases. The mid-Atlantic EMAP database was chosen because sufficient DOC data were available for rivers and streams to make meaningful comparisons at the state and ecoregion levels. Similar comparisons are made for four mid-Atlantic ecoregions (Piedmont, Ridge and Valley, Central Appalachians, Western Allegheny Plateau) which is well represented in the WATSTORE/LDC databases (USEPA, 2003).

Based on both sets of comparisons, it is apparent that the agreement between the WATSTORE/LDC and EMAP data was best at the middle to lower tails of the distributions, and poorest at the higher end of the distributions. At the lower tails of the distributions (e.g., 10^{th}, 25^{th} percentiles) the WATSTORE/LDC DOC data are generally within 30% of the EMAP data (Ecoregion 70 being the only exception). The median DOC values of the WATSTORE/LDC data show a slightly higher bias compared with median values from the EMAP data, but are usually within a factor of 1.5 (Ecoregions 47 and 70 are about a factor of 2 greater). This result is expected, given the greater focus of the WATSTORE/LDC sampling sites on larger river and stream systems, and on areas subjected to proportionately greater human influence compared with the EMAP sampling sites. Since EPA is interested in supporting the generation of BLM values that are protective of aquatic life, the lack of bias noted for the lower tails of the DOC concentration distributions is noteworthy.

4.3.2 Testing for Bias Using Data from the WSA

A more comprehensive evaluation of the effects of sampling bias on the NOCD can now be made using the results of national statistically-designed water quality sampling surveys. We assembled a database of organic carbon data from 1,313 randomly selected sites throughout the continental U.S. collected for the WSA. GIS procedures were used to associate each site with the Level III ecoregion corresponding to its location.

The 1,392 sites sampled for the WSA were identified using a probability-based sample design, a technique in which every element in the population has a known probability of being selected for sampling (USEPA, 2006). This ensured that the results of the WSA reflect the full range of variation among wadeable streams across the U.S. The target population for the WSA was wadeable, perennial streams in the conterminous U.S. (lower 48 states). The WSA used the National Hydrography Dataset (NHD), a comprehensive set of digital spatial data on surface waters (USGS, 2012), to identify the location of wadeable perennial streams. Rules for site selection included weighting to provide balance in the number of stream sites from each of the 1^{st} through 5^{th} SO size classes (Strahler, 1952, 1957),

and controlled spatial distribution to ensure that sample sites were distributed across the U.S.). The basic sampling design drew 50 sampling sites randomly distributed in each of the EPA Regions and WSA ecoregions. The unbiased site selection of the survey design ensures that assessment results represent the condition of the streams throughout the nation.

4.3.2.1 Selection of Statistical Test to Assess Potential Bias in DOC Data

The most appropriate statistical test for determining bias in the NOCD is the comparison of WSA and organic carbon database DOC data within each ecoregion as independent groups of data to determine if one group tends to contain larger values (Helsel and Hirsch, 2002; USGS, 2002). The WSA and organic carbon database DOC data are independent because there is no natural structure in the order of observations across groups. A nonparametric statistical test is most appropriate since no assumptions regarding normality of the data are required. As noted by Helsel and Hirsch (2002), nonparametric tests are, in general, never worse than their parametric counterparts in their ability to detect departures from the null hypothesis, and may be better. These considerations led us to select the rank-sum test, a nonparametric procedure for determining whether data are significantly different between two independent groups. This test is also known as the Wilcoxon Rank-Sum Test or, alternatively, the Mann-Whitney U-Test.

In its most general form, the rank-sum test is a test to determine whether one group tends to produce larger observations than another group. It has as its null hypothesis:

H_0: Prob [x > y] = 0.5

where x are data from one group and y are from another group (the probability of an x value being higher than any given y value is one-half). The test is typically used to determine whether two groups come from the same population (same median and other percentiles), or alternatively whether they differ only in location (central value or median). If both groups of data are from the same population, about half of the time an observation from either group could be expected to be higher than that from the other, so the above null hypothesis applies. If the groups belong to different populations the null hypothesis does not apply.

In practice, the rank-sum test takes several forms, depending upon the size of the smaller sample (*n* observations) and the larger sample (*m* observations). Walpole and Myers (1978; Section 13.2) present the details of four alternative forms of the rank-sum test, depending on the sizes of *n* and *m*. The exact form of the rank-sum test is the only form appropriate for comparing groups of sample sizes of 10 or smaller per group. When both groups have samples sizes greater than 10 (*n*, *m* > 10), the large-sample approximation may be used.

4.3.2.2 Rank-Sum Test Comparing WSA DOC Data to NOCD

Table 17 presents the results of the rank-sum test comparing Level III ecoregional DOC data from the WSA (USEPA, 2006b) and the NOCD. The left-hand columns present statistics (sample size, median, and Mann-Whitney U_x, and U_y) for the ecoregion-specific DOC data from the two datasets. The next six columns to the right present the test statistics for the appropriate form of the rank-sum test. The right-hand column provides a summary interpretation of the test for each ecoregion indicating whether the null hypothesis (H_0: DOC concentrations from both datasets are not different) should be rejected at the 5% level of significance, in favor of the alternative hypothesis (H_1: DOC concentrations are higher in the

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national organic carbon database). In other words, rejection of the null hypothesis implies that DOC concentrations from the National Organic Carbon Database are biased high in that ecoregion relative to the WSA data.

Table 17. Results of rank-sum test comparing Level III ecoregional DOC data from WSA and NOCD

Level III Ecoregion	Ecoregion Name	WSA dataset			NOC database			M-W test (n1>10 and n2>10)		One large sample (n2>20)		Exact test (n2<20)	Exact test (n2<9)	Interpretation of test 1-sided @ 0.05
		n	median DOC	Ux	n	median DOC	Uy	Z	P	Z	P	critical U (0.05 level of signif.)	P	(H0: same mean of distributions)
1	Coast Range	38	1.41	2535.5	91	2.2	922.5	4.17	1.54E-05					reject H0
2	Puget Lowland	3	0.96	2289	835	6.6	216			-2.48	6.63E-03			reject H0
3	Willamette Valley	2	2.47	84	66	2.9	48			-0.65	2.57E-01			do not reject H0
4	Cascades	23	0.75	1673	100	1.4	627	3.39	3.46E-04					reject H0
5	Sierra Nevada	14	0.91	448	32	3.6	0	5.35	5.96E-08					reject H0
6	Southern and Central California Chaparral and Oak Woodlands	32	2.5	12372	479	4.6	2957	5.82	0					reject H0
7	Central California Valley	2	4.2	302	180	13	58			-1.65	4.98E-02			reject H0 (P~5%)
8	Southern California Mountains	41	1.66	245	6	8.9	1			-3.89	5.03E-05			reject H0
9	Eastern Cascades Slopes and Foothills	19	0.97	209	13	2.3	38	3.28	5.18E-04					reject H0
10	Columbia Plateau	8	2.59	477	73	3.6	107			-2.93	1.70E-03			reject H0
11	Blue Mountains	77	1.59	1625	26	3.1	376.5	4.74	1.07E-06					reject H0
12	Snake River Plain													no test

Level III Ecoregion	Ecoregion Name	WSA dataset			NOC database			M-W test (n1>10 and n2>10)		One large sample (n2>20)		Exact test (n2<20)	Exact test (n2<9)	Interpretation of test 1-sided @ 0.05
		n	median DOC	Ux	n	median DOC	Uy	Z	P	Z	P	critical U (0.05 level of signif.)	P	(H0: same mean of distributions)
13	Central Basin and Range	42	1.93	47300	1553	3	17926	4.986	2.98E-07					reject H0
14	Mojave Basin and Range	2	2.65	67	35	5.6	3			-2.15	1.58E-02			reject H0 (P~1.6%)
15	Northern Rockies	19	1.54	9149	778	1.8	5634	1.77	3.81E-02					reject H0 (P~3.8%)
16	Idaho Batholith	19	1.21	495	29	2.4	56	4.63	1.85E-06					reject H0
17	Middle Rockies	70	1.43	3142	81	1.9	2529	1.14	0.126					do not reject H0
18	Wyoming Basin	29	2.29	4006	150	7.3	344	7.17	0					reject H0
19	Wasatch and Uinta Mountains	25	2.11	978	46	4.8	172	4.85	5.96E-07					reject H0
20	Colorado Plateaus	24	2.22	15697	798	6.3	3455	5.34	5.96E-08					reject H0
21	Southern Rockies	43	2.05	18637	1129	1.3	29911	-2.59	4.83E-03					reject H0
22	Arizona/New Mexico Plateau	7	1.83	1723	281	5.6	244			-3.40	3.40E-04			reject H0
23	Arizona/New Mexico Mountains	31	1.94	984	37	5.3	163	5.02	2.38E-07					reject H0
24	Chihuahuan Deserts	1	1.48	110	116	6	6			-1.54	6.18E-02			do not reject H0
25	High Plains	6	3.5	2450	439	11	184.5			-3.62	1.48E-04			reject H0
26	Southwestern Tablelands	17	4.21	2246	167	6.3	593	3.95	3.90E-05					reject H0
27	Central Great Plains	12	4.71	2189	228	7	547	3.50	2.31E-04					reject H0
28	Flint Hills	2	4.91	19	10	8.7	1					1		reject H0

Level III Ecoregion	Ecoregion Name	WSA dataset			NOC database			M-W test (n1>10 and n2>10)		One large sample (n2>20)		Exact test (n2<20)	Exact test (n2<9)	Interpretation of test 1-sided @ 0.05
		n	median DOC	Ux	n	median DOC	Uy	Z	P	Z	P	critical U (0.05 level of signif.)	P	(H0: same mean of distributions)
29	Central Oklahoma/ Texas Plains	6	5.58	1098	289	6.7	636			-1.12	1.32E-01			do not reject H0
30	Edwards Plateau													no test
31	Southern Texas Plains													no test
32	Texas Blackland Prairies	2	7.37	880	829	6	778			-0.15	4.40E-01			do not reject H0
33	East Central Texas Plains	3	15.03	108.5	268	5	695.5			2.17	9.85E-01			do not reject H0
34	Western Gulf Coastal Plain	9	7.47	1860	399	7	1732			-0.183	0.427			do not reject H0
35	South Central Plains	24	7.7	6744	523	7.7	5808	0.62	2.68E-01					do not reject H0
36	Ouachita Mountains	6	2.2	963.5	196	3.7	212.5			-2.66	3.88E-03			reject H0
37	Arkansas Valley	3	4.61	327	184	7	225			-0.55	2.92E-01			do not reject H0
38	Boston Mountains	3	2.18	19	21	0.8	44			1.09	8.62E-01			do not reject H0
39	Ozark Highlands	10	1.8	2248	233	4.1	82			-4.98	3.26E-07			reject H0
40	Central Irregular Plains	8	6.7	1772	434	6.3	1700			-0.10	4.60E-01			do not reject H0
41	Canadian Rockies	5	0.8	127.5	36	1.1	52.5			-1.49	6.76E-02			do not reject H0
42	Northwestern Glaciated Plains	13	9.27	362	36	18	106	2.90	1.87E-03					reject H0
43	Northwestern Great Plains	81	7.45	43205	679	14	11794	8.41	0					reject H0

Level III Ecoregion	Ecoregion Name	WSA dataset			NOC database			M-W test (n1>10 and n2>10)		One large sample (n2>20)		Exact test (n2<20)	Exact test (n2<9)	Interpretation of test 1-sided @ 0.05
		n	median DOC	Ux	n	median DOC	Uy	Z	P	Z	P	critical U (0.05 level of signif.)	P	(H0: same mean of distributions)
44	Nebraska Sand Hills	1	6.46	0	4	3.2	4						0.2	do not reject H0
45	Piedmont	28	2.11	5379	308	3.4	3245	2.17	1.51E-02					reject H0 (P~1.5%)
46	Northern Glaciated Plains	17	14.62	1443	142	15	971	1.315	9.42E-02					do not reject H0
47	Western Corn Belt Plains	42	2.84	6200	193	5.1	1907	5.38	5.96E-08					reject H0
48	Lake Agassiz Plain	13	10.38	1962	261	10	1431	0.95	1.71E-01					reject H0 (P~1.7%)
49	Northern Minnesota Wetlands	1	11.71	37	44	17	7			-1.15	1.24E-01			do not reject H0
50	Northern Lakes and Forests	20	12.28	3099	403	8.1	4961	-1.74	4.05E-02					reject H0 (P~4%)
51	North Central Hardwood Forests	7	8.08	573.5	152	9.2	490.5			-0.35	3.64E-01			do not reject H0
52	Driftless Area	11	2.4	509	49	7.6	30	4.58	2.38E-06					reject H0
53	Southeastern Wisconsin Till Plains	5	3	2067	439	8	128.5			-3.40	3.41E-04			reject H0
54	Central Corn Belt Plains	9	2.69	1498	202	6.1	320			-3.29	5.07E-04			reject H0
55	Eastern Corn Belt Plains	6	2.83	7199	1325	6.8	751			-3.43	3.00E-04			reject H0

Level III Ecoregion	Ecoregion Name	WSA dataset			NOC database			M-W test (n1>10 and n2>10)		One large sample (n2>20)		Exact test (n2<20)	Exact test (n2<9)	Interpretation of test 1-sided @ 0.05
		n	median DOC	Ux	n	median DOC	Uy	Z	P	Z	P	critical U (0.05 level of signif.)	P	(H0: same mean of distributions)
56	Southern Michigan/Northern Indiana Drift Plains	9	4.62	1967	287	7	616			-2.67	3.77E-03			reject H0
57	Huron/Erie Lake Plains	3	5.05	8246	3762	7.1	3040			-1.38	8.33E-02			do not reject H0
58	Northeastern Highlands	23	3.54	79049	14044	1.4854	2E+05	-4.24	1.13E-05					reject H0
59	Northeastern Coastal Zone	10	4.01	561	101	4.2	449			-0.58	2.82E-01			do not reject H0
60	Northern Appalachian Plateau and Uplands	5	3.74	831	354	3.2	939			0.23	5.93E-01			do not reject H0
61	Erie Drift Plain	9	2.99	7834	901	6.2	275.5			-4.82	7.32E-07			reject H0
62	North Central Appalachians	4	3.34	102	106	1.7	322			1.76	9.60E-01			do not reject H0
63	Middle Atlantic Coastal Plain	2	18.54	16060	16726	3.4	17392			0.10	5.39E-01			do not reject H0
64	Northern Piedmont	15	2.18	18010	1524	4	4850	3.84	6.11E-05					reject H0
65	Southeastern Plains	18	2.55	49987	3801	4.3	18432	3.38	3.61E-04					reject H0
66	Blue Ridge	16	1.09	4915	686	0.9	6061	0.71	2.37E-01					do not reject H0
67	Ridge and Valley	27	1.56	10612	733	1.7	9180	0.64	2.61E-01					do not reject H0
68	Southwestern Appalachians	9	1.91	212.5	47	1.7	210.5			-0.02	4.91E-01			do not reject H0

Level III Ecoregion	Ecoregion Name	WSA dataset			NOC database			M-W test (n1>10 and n2>10)		One large sample (n2>20)		Exact test (n2<20)	Exact test (n2<9)	Interpretation of test 1-sided @ 0.05
		n	median DOC	Ux	n	median DOC	Uy	Z	P	Z	P	critical U (0.05 level of signif.)	P	(H0: same mean of distributions)
69	Central Appalachians	10	1.84	3651	864	1.6	4990			0.84	8.01E-01			do not reject H0
70	Western Allegheny Plateau	19	2.17	25890	1735	4	7075	4.28	9.18E-06					reject H0
71	Interior Plateau	14	2.24	2153	559	0.4	5674	-2.88	2.00E-03					reject H0
72	Interior River Valleys and Hills	14	3.86	3143	328	6.2	1449	2.34	9.70E-03					reject H0 (P~0.97%)
73	Mississippi Alluvial Plain	10	8.31	1646	503	5.5	3384			1.87	9.69E-01			do not reject H0
74	Mississippi Valley Loess Plains	1	1.26	21	21	5.4	0			-1.66	4.90E-02			reject H0 (P~4.9%)
75	Southern Coastal Plain	6	6.7	20141	4222	15.5	5191			-2.50	6.18E-03			reject H0
76	Southern Florida Coastal Plain													no test
77	North Cascades	54	0.82	1169	50	0.7	1531	1.18	1.19E-01					do not reject H0
78	Klamath Mountains	43	0.77	343	8	2.6	1			-4.43	4.74E-06			reject H0
79	Madrean Archipelago	3	1	27	9	7.9	0					3		reject H0
80	Northern Basin and Range	26	1.51	372.5	16	3.2	43.5	4.26	1.02E-05					reject H0
81	Sonoran Basin and Range	3	1.72	364	133	5.1	35			-2.44	7.40E-03			reject H0
82	Laurentian Plains and Hills	5	5.68	94	21	9.9	11			-2.70	3.47E-03			reject H0

Level III Ecoregion	Ecoregion Name	WSA dataset			NOC database			M-W test (n1>10 and n2>10)		One large sample (n2>20)		Exact test (n2<20)	Exact test (n2<9)	Interpretation of test 1-sided @ 0.05
		n	median DOC	Ux	n	median DOC	Uy	Z	P	Z	P	critical U (0.05 level of signif.)	P	(H0: same mean of distributions)
83	Eastern Great Lakes and Hudson Lowlands	12	6.72	8228	1346	7	7925	0.11	4.55E-01					do not reject H0
84	Atlantic Coastal Pine Barrens	2	12.62	150	243	5.7	336			0.93	8.24E-01			do not reject H0

4.3.3 Results and Implications of Bias Testing

The results of the rank-sum test indicate that DOC concentrations from the NOCD are biased high (i.e., the null hypothesis was not rejected) in 52 of 81 (64%) of Level III ecoregions in which comparable data were available (no comparison was possible in four ecoregions). For those ecoregions where the null hypothesis was not rejected, BLM users can be confident that the lower percentile DOC concentrations listed in Table 16 are representative for that ecoregion.

For ecoregions where the null hypothesis was rejected, the result suggests that the DOC data from the national organic carbon database are from biased samples. Recall discussion of both database in Sections 4.3, 4.3.1, and 4.3.2 that WSA is a random design sampling that ensures unbiased site selection. Whereas the NOCD is more influenced by locations with known water quality impairments and reflect unequal sampling efforts potentially creating a bias. It is likely that the percentile DOC concentrations tabulated for those ecoregions in Table 16 also reflect this bias towards high concentrations. This was confirmed by comparing the probability distributions of DOC concentrations in the ecoregions where n and m were large (n, m > 30).

In large-sample ecoregions where the null hypothesis was rejected by the rank-sum test (Ecoregions 1, 6, 11, 13, 23, 43, and 47), the probability distributions also show that the DOC concentration percentiles are substantially different, with the NOCD showing higher values. An example of such a comparison of DOC probability distribution is shown in Figure 31. On the other hand, in such large-sample ecoregions where the null hypothesis was not rejected (Ecoregions 17, 21, and 77), the probability distributions show that the DOC concentration percentiles are comparable. An example of such a probability distribution is shown in Figure 32. In all cases where it was possible to compare the DOC probability distributions, the results of the rank-sum test were confirmed.

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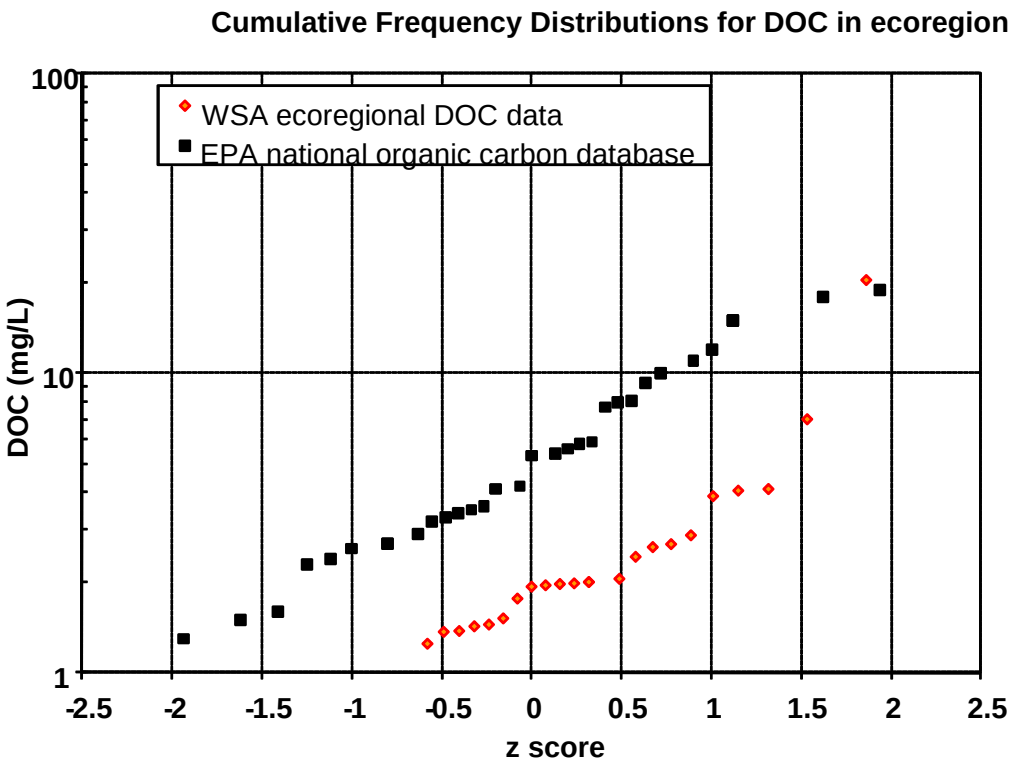


Figure 31. Comparison of probability distributions of DOC concentrations in Ecoregion 23

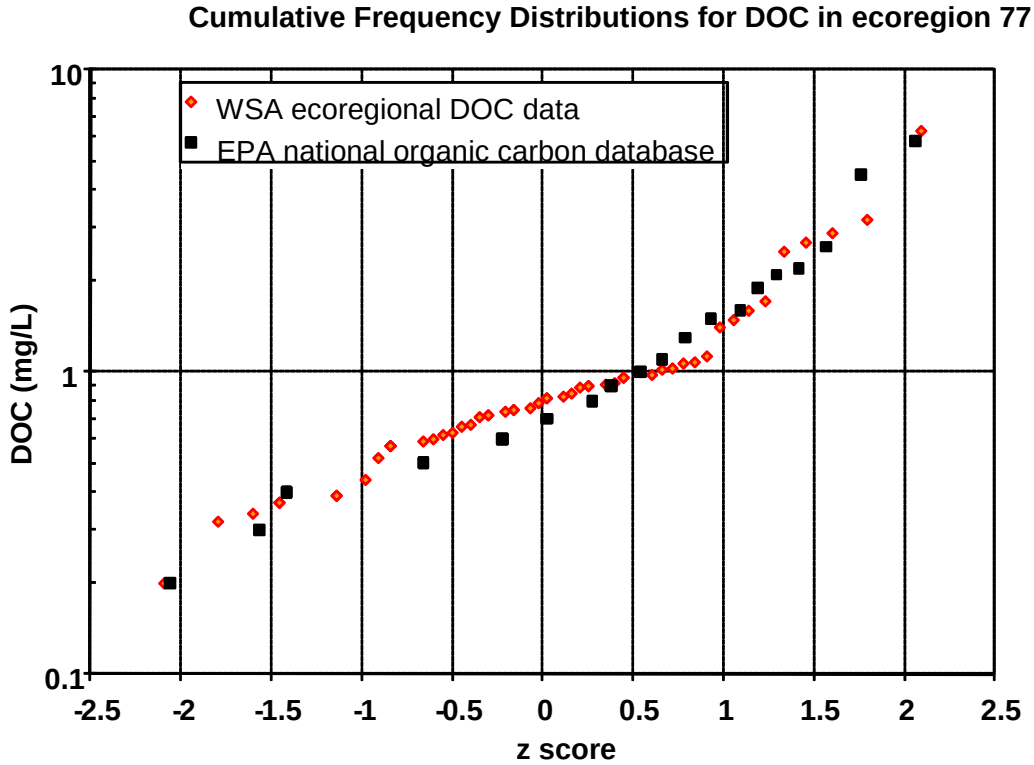


Figure 32. Comparison of probability distributions of DOC concentrations in Ecoregion 77

Because using a DOC concentration that is biased high as input to the BLM may lead to a non-conservative (high) site-specific copper criterion, it would be inappropriate to use the 10th percentile DOC concentrations in Table 16 for ecoregions in which the data from the NOCD come from biased samples.

We have not addressed the issue of whether the streams sampled for the WSA are representative in terms of DOC concentrations for all lotic (flowing) waters. It is possible that larger rivers may have DOC concentrations that are different from streams. For this reason, we recommend that the estimated ecoregional DOC values be compared to data from EPA's NRSA (NRSA, USEPA, 2013b; EPA 841-D-13-001). If necessary, adjustment of the estimated DOC values can be made at that time.

4.4 Comparing NOCD to WSA/NRSA DOC Data

The representativeness of the DOC data in the NOCD was evaluated by statistically comparing the data, at the ecoregional level, with the combined DOC data from two smaller random statistical surveys of rivers and streams. The two smaller surveys were:

(1) the 2004-05 WSA (1,313 sites), and

(2) the 2008-09 NRSA (2,113 sites).

The NRSA was the first nationally consistent survey assessing the ecological condition of the full range of flowing waters in the conterminous U.S. The target population includes the Great Rivers (such as the Mississippi and the Missouri), small perennial streams, and urban and non-urban rivers. Run-of-the-river ponds and pools are included, along with tidally influenced streams and rivers up to the leading edge of dilute sea water.

NRSA sampling locations were selected by random selection. The locations of perennial streams were identified using the EPA-USGS National Hydrography Dataset Plus (NHD-Plus), a comprehensive set of digital spatial data on surface waters at the 1:100,000 scale. Information about stream order was also obtained from the NHD-Plus. The 1,924 sites sampled for the NRSA were identified using a probability-based sample design. Details about the NRSA probabilistic sampling design are described in Section 1.1 of the NRSA: Field Operations Manual (USEPA, 2007; EPA-841-B-07-009). Site selection rules included weighting to provide balance in the number of river and stream sites from each of the size classes. Site selection was also controlled for spatial distribution to make sure sample sites were distributed across the U.S. Among these randomly selected sample sites were 359 of the original 2004 WSA sites. These were revisited as part of the NRSA to examine whether conditions have changed. When sites were selected for sampling, research teams conducted office evaluations and field reconnaissance to determine if the sites were accessible or if a river or stream labeled as perennial in NHD-Plus was, in fact, flowing during the sampling season. If a river or stream was not flowing or was determined to be inaccessible, it was dropped from the sampling effort and replaced with a perennial river or stream from a list of replacement sites within the random design.

The DOC data from these two smaller datasets were combined and described, hereafter, as WSA/NRSA data. GIS was used to determine which sampling sites were in each Level III ecoregion. The statistical test used was the non-parametric Wilcoxon 2-sample test, with a null hypothesis that DOC concentrations in the two different DOC sample datasets were equal. The alternative hypothesis was that DOC concentrations in the NCOD were significantly greater than those in the WSA/NRSA data,

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indicating positive bias possibly due to over-representation of impacted sites. The test was applied for each of 84 Level III ecoregions at alpha=0.05.

Table 18 below includes the number of data (n) in each ecoregion, and the 10th percentiles of DOC based upon data from the EPA DOC database (NOCD) and the combined WSA/NRSA data. For each ecoregion, the table also provides the result of the Wilcoxon 2-sample test, in terms of whether the null hypothesis (the two samples are equal) should be accepted or rejected. The null hypothesis was rejected in 59 of 83 ecoregions, indicating bias in DOC concentrations higher in the national organic carbon dataset for the majority of ecoregions. In these 59 ecoregions, low-end percentiles based on DOC concentrations in the WSA/NRSA data were selected as reasonably protective estimates of ecoregional DOC concentrations.

Table 18. DOC concentrations (mg/L) in each Level III ecoregion based upon data from the NOCD and the combined WSA/NRSA data: number of data (n); 10th percentiles; and results of the Wilcoxon 2-sample test

Ecoregion	NOC database		WSA/NRSA database		H_0 (equal means)
	n	10%	n	10%	
1	91	1.1	60	0.7	reject
2	835	2.5	8	0.36	reject
3	66	1.1	12	0.4	reject
4	100	0.5	37	0.3	reject
5	32	2.1	21	0.5	reject
6	479	2.1	42	0.8	reject
7	180	2.7	7	1.1	reject
8	6	4.4	43	0.7	reject
9	13	1.4	25	0.5	reject
10	73	2.0	22	1.0	reject
11	26	1.3	91	0.8	reject
12	50	2.2	6	1.2	reject
13	1553	1.5	82	0.7	reject
14	35	2.8	8	0.8	reject
15	778	1.0	39	0.8	reject
16	29	1.4	34	0.8	reject
17	81	0.2	94	0.7	accept
18	150	4.3	52	1.1	reject
19	46	1.8	41	0.9	reject
20	798	3.0	61	1.2	reject
21	1129	0.6	76	0.8	accept
22	281	2.6	27	0.7	reject
23	37	2.2	48	0.7	reject
24	116	2.3	10	1.4	reject
25	439	4.4	29	1.3	reject

Ecoregion	NOC database		WSA/NRSA database		H_0 (equal means)
	n	10%	n	10%	
26	167	3.3	47	1.9	reject
27	228	3.8	92	2.2	reject
28	10	4.9	8	1.2	reject
29	289	3.8	30	1.7	reject
30	200	1.0	4	1.0	accept
31	58	1.0	4	0.3	accept
32	829	2.0	9	3.1	accept
33	268	3.0	5	5.6	accept
34	399	4.0	18	2.8	accept
35	523	4.6	66	3.3	reject
36	196	1.1	18	0.7	reject
37	184	1.9	18	1.4	reject
38	21	0.4	7	0.5	accept
39	233	2.3	39	0.8	reject
40	434	4.0	32	3.3	reject
41	36	0.6	7	0.6	reject
42	36	5.1	43	2.5	reject
43	679	6.2	234	2.3	reject
44	4	1.4	4	1.0	accept
45	308	1.0	93	1.1	reject
46	142	9.9	28	6.1	reject
47	193	3.1	103	1.7	reject
48	261	7.6	26	5.4	reject
49	44	11.0	9	6.0	accept
50	403	3.7	77	2.7	accept
51	152	3.1	44	3.2	reject
52	49	3.1	49	1.1	reject
53	439	5.3	12	1.9	reject
54	202	2.7	21	1.8	reject
55	1325	3.6	30	2.1	reject
56	287	3.8	38	2.9	reject
57	3762	4.7	14	1.5	accept
58	14044	0.6	92	1.2	accept
59	101	2.6	81	2.7	accept
60	354	1.3	29	1.4	reject
61	901	5.1	26	1.8	reject
62	106	0.7	22	0.9	accept
63	16726	2.2	45	1.7	accept
64	1524	1.3	47	1.0	reject
65	3801	2.4	108	1.4	reject
66	686	0.5	40	0.6	accept

Ecoregion	NOC database		WSA/NRSA database		H_0 (equal means)
	n	10%	n	10%	
67	733	0.6	88	0.9	accept
68	47	0.9	17	0.8	accept
69	864	0.7	31	1.1	accept
70	1735	1.5	67	1.5	reject
71	559	0.1	54	1.1	accept
72	328	2.7	65	2.2	reject
73	503	3.4	107	2.8	reject
74	21	1.7	18	1.2	accept
75	4222	8.0	41	3.6	reject
76	1	na	0	na	na
77	50	0.4	61	0.4	accept
78	8	1.7	56	0.6	reject
79	9	2.6	9	0.8	reject
80	16	1.8	49	1.0	reject
81	133	2.2	13	1.0	reject
82	21	5.5	18	2.8	reject
83	1346	1.0	32	2.6	reject
84	243	1.6	4	3.3	accept

In the 24 ecoregions where the null hypothesis was not rejected (i.e., no significant difference in DOC concentrations was found between datasets), the data were combined and the percentiles of the combined dataset were recalculated (Table 19). In these 24 ecoregions, low-end percentiles based on DOC concentrations in the combined data (NOCD and WSA/NRSA) were selected as reasonably protective estimates of ecoregional DOC concentrations.

Recommended DOC estimated values for 83 of the 84 ecoregions are summarized in Table 20. In the remaining ecoregion (76; Southern Florida Coastal Plain), there were insufficient data in either dataset (NOC database or WSA/NRSA) to calculate DOC concentration percentiles.

Table 19. DOC concentrations (mg/L) in 24 ecoregions where no significant difference in DOC concentrations was found between national organic carbon database (NOCD) and the WSA/NRSA datasets: number of data (n); 10th percentiles from combined NOCD & WSA/NRSA data

Ecoregion	n	DOC (mg/L) 10%
17	175	0.6
21	1205	0.6
30	204	1.0
31	62	1.0
32	838	2.0

Ecoregion	n	DOC (mg/L) 10%
33	273	3.0
34	417	4.0
38	28	0.5
44	8	1.0
49	53	10.4
50	480	3.5
57	3776	4.6
58	14136	0.6
59	182	2.7
62	128	0.7
63	16771	2.2
66	726	0.5
67	821	0.6
68	64	0.9
69	895	0.7
71	613	0.1
74	39	1.5
77	111	0.4
84	247	1.6

Table 20. Recommended ecoregional DOC concentrations (mg/L) based upon combined data from the NOCD and the WSA/NRSA data in 83 Level III ecoregions: number of observations (n); 10th percentiles; and source of data for each ecoregion

Ecoregion	n	DOC (mg/L) 10%	Data Source
1	60	0.7	WSA/NRSA
2	8	0.3	WSA/NRSA
3	12	0.4	WSA/NRSA
4	37	0.3	WSA/NRSA
5	21	0.5	WSA/NRSA
6	42	0.8	WSA/NRSA
7	7	1.1	WSA/NRSA
8	43	0.7	WSA/NRSA
9	25	0.5	WSA/NRSA
10	22	1.0	WSA/NRSA
11	91	0.8	WSA/NRSA
12	6	1.2	WSA/NRSA
13	82	0.7	WSA/NRSA
14	8	0.8	WSA/NRSA
15	39	0.8	WSA/NRSA

Ecoregion	n	DOC (mg/L) 10%	Data Source
16	34	0.8	WSA/NRSA
17	175	0.6	NOCD & WSA/NRSA
18	52	1.1	WSA/NRSA
19	41	0.9	WSA/NRSA
20	61	1.2	WSA/NRSA
21	1205	0.6	NOCD & WSA/NRSA
22	27	0.7	WSA/NRSA
23	48	0.7	WSA/NRSA
24	10	1.4	WSA/NRSA
25	29	1.3	WSA/NRSA
26	47	1.9	WSA/NRSA
27	92	2.2	WSA/NRSA
28	8	1.2	WSA/NRSA
29	30	1.7	WSA/NRSA
30	204	1.0	NOCD & WSA/NRSA
31	62	1.0	NOCD & WSA/NRSA
32	838	2.0	NOCD & WSA/NRSA
33	273	3.0	NOCD & WSA/NRSA
34	417	4.0	NOCD & WSA/NRSA
35	66	3.3	WSA/NRSA
36	18	0.7	WSA/NRSA
37	18	1.4	WSA/NRSA
38	28	0.5	NOCD & WSA/NRSA
39	39	0.8	WSA/NRSA
40	32	3.3	WSA/NRSA
41	7	0.6	WSA/NRSA
42	43	2.5	WSA/NRSA
43	234	2.3	WSA/NRSA
44	8	1.0	NOCD & WSA/NRSA
45	93	1.1	WSA/NRSA
46	28	6.1	WSA/NRSA
47	103	1.7	WSA/NRSA
48	26	5.4	WSA/NRSA
49	53	10.4	NOCD & WSA/NRSA
50	480	3.5	NOCD & WSA/NRSA
51	44	3.2	WSA/NRSA
52	49	1.1	WSA/NRSA
53	12	1.9	WSA/NRSA
54	21	1.8	WSA/NRSA
55	30	2.1	WSA/NRSA
56	38	2.9	WSA/NRSA
57	3776	4.6	NOCD & WSA/NRSA

Ecoregion	n	DOC (mg/L) 10%	Data Source
58	14136	0.6	NOCD & WSA/NRSA
59	182	2.7	NOCD & WSA/NRSA
60	29	1.4	WSA/NRSA
61	26	1.8	WSA/NRSA
62	128	0.7	NOCD & WSA/NRSA
63	16771	2.2	NOCD & WSA/NRSA
64	47	1.0	WSA/NRSA
65	108	1.4	WSA/NRSA
66	726	0.5	NOCD & WSA/NRSA
67	821	0.6	NOCD & WSA/NRSA
68	64	0.9	NOCD & WSA/NRSA
69	895	0.7	NOCD & WSA/NRSA
70	67	1.5	WSA/NRSA
71	613	0.1	NOCD & WSA/NRSA
72	65	2.2	WSA/NRSA
73	107	2.8	WSA/NRSA
74	39	1.5	NOCD & WSA/NRSA
75	41	3.6	WSA/NRSA
77	111	0.4	NOCD & WSA/NRSA
78	56	0.6	WSA/NRSA
79	9	0.8	WSA/NRSA
80	49	1.0	WSA/NRSA
81	13	1.0	WSA/NRSA
82	18	2.8	WSA/NRSA
83	32	2.6	WSA/NRSA
84	247	1.6	NOCD & WSA/NRSA

4.5 Conclusions

EPA tested the 10th percentiles of ecoregional DOC concentrations against data from the Southern Rocky Mountains (Level III Ecoregion 21) as input to the copper BLM. Broad ranges of errors (including some that were larger than an order-of magnitude) were observed in BLM predictions made with the DOC estimates, in comparison to predictions made with actual measured site data. Although the copper criteria values predicted using the parameter estimates for DOC were found to be protective in 90% of the cases, in many of these cases these predictions were overly-protective (e.g., IWQC lower by a factor of 4 to 5). For this reason, BLM users should be cautious when considering lower percentiles of the distribution of DOC as estimates for missing input parameters to the BLM. In general, it is preferable to use site-specific measurements of DOC as BLM input because: (1) copper toxicities (and BLM model predictions) are highly sensitive to DOC concentrations and (2) reasonably protective DOC concentrations can be difficult to estimate at the ecoregional level, when data are limited.

For many ecoregions, the EPA recommended percentiles in Table 20 are based upon a relatively small number of DOC data, which can be a cause for concern in terms of the reliability of these values. For

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example, in 47 ecoregions the DOC percentiles were calculated from 50 or fewer concentration values, and in seven ecoregions the DOC percentiles were calculated from fewer than 10 values. In the former case (n≤50), the lower 95% confidence limit of the 10^{th} percentile cannot be calculated (Berthouex and Brown, 1994), while in the latter (n<9) the 10^{th} percentile itself is below the lowest concentration value. Because of these and other limitations on the DOC database and the importance of this parameter in criteria calculation, users are encouraged to sample for DOC as a basis for determining BLM input rather than using default parameters where possible.

5 SUMMARY AND RECOMMENDATIONS

The BLM predicts acute copper toxicity based on site-specific water quality parameters, and calculates aquatic life criteria based on the predicted copper toxicity. The BLM requires 10 input parameters to calculate copper criteria: temperature, pH, DOC, alkalinity, calcium, magnesium, sodium, potassium, sulfate, and chloride, the last seven of which are also referred to as GIs. Given the broad geographical range over which the BLM is likely to be applied, and the limited availability of data for input parameters in many areas, a practical method to estimate missing water quality parameters was developed to support the use of the copper BLM for copper aquatic life criteria.

In this report we described three approaches EPA used to estimate default input parameters for GI and DOC for BLM that could be used where site-specific data are not available. EPA's goal was to provide estimates for these missing input parameters that are reasonably protective. EPA used geostatistics to predict ecoregional input parameters from national water quality databases, and developed correlations between GI parameters and conductivity. These estimates were further refined using stream order.

Our analysis of national data indicates that there is no relationship between conductivity and pH, and geostatistical methods were found to produce similarly ambiguous results. Because pH is one of the most important BLM inputs for predicting criteria for copper, we conclude that site-specific data for pH are needed for successful BLM application. Temperature is a commonly measured parameter and should be easy to obtain by users for input in the BLM.

5.1 Recommendations for BLM inputs for geochemical ions where site-specific data are not available

In Section 2 we used geostatistics to estimate missing GI parameter values based on geography. We supplemented the geostatistical approach by adding conductivity as an additional explanatory variable to generate a more robust spatial estimate of the GI water quality inputs for the BLM because conductivity is one of the most widely monitored water quality indicators in the U.S. and correlates well with GIs. We presented average predicted 10^{th} percentile concentrations for the BLM GI water quality parameters Level III ecoregions. We further refined these estimates by considering the effect of stream order (size) in Section 3. We found that values of the GI estimates generally increased with stream order, a trend that was most apparent and consistent for higher order streams. Tables 8, 9, and 10 present best estimates of GI input parameters for the BLM. Estimated inputs are provided for each GI in each ecoregion categorized by stream order for low, medium, and high order streams, respectively. EPA recommends these 10^{th} percentile Level III ecoregion, stream order group-specific values be used in the BLM where site-specific data are not available.

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5.2 Recommendations for BLM inputs for DOC where site-specific data are not available

In Section 4 we determined that the geostatistical and regression-based approaches used to estimate GI input parameters for the BLM do not produce accurate site-specific estimates for DOC. Because previous analyses indicate that DOC is the most important BLM input for estimating criteria for copper, we further refined our approach in Section 4 based on analyses using the NOCD to estimate lower-percentile DOC concentrations. Based on statistical comparisons to an independent probabilistic dataset, we found that DOC concentrations from the NOCD are reasonably protective estimates of DOC for use as input parameters for the BLM for some ecoregions. For other ecoregions, EPA recommends using estimates based on the WSA dataset. Recommended 10^{th} percentile DOC estimated values for 83 of the 84 ecoregions are summarized in Table 20. In the remaining ecoregion (76; Southern Florida Coastal Plain), there were insufficient data in either dataset (NOC database or WSA/NRSA) to calculate DOC concentration percentiles. Because limitations in the DOC database and the importance of this parameter in criteria calculation, users are encouraged to sample for DOC as a basis for determining BLM input rather than using default parameters wherever possible.

5.3 Recommendations for BLM inputs for pH where site-specific data are not available

In Section 2 we determined that geostatistical and regression-based approaches used to estimate GI input parameters for the BLM did not produce accurate site-specific estimates for pH. Our analysis of national data indicates that there is no relationship between conductivity and pH, and geostatistical methods were found to produce similarly ambiguous results. Because pH is one of the most important BLM inputs for predicting criteria for copper, we conclude that site-specific data for pH are needed for successful BLM application. Temperature along with pH is similarly recommended to acquire site-specific data for BLM application with the advantage of both of these been easy parameters to measure.

5.4 Conclusions

The approaches described in this TSD can be used to provide reasonable default values for input parameters in the BLM to derive protective freshwater aquatic life criteria for copper when data are lacking. These data could also be used to provide reasonable default values to fill in missing water quality input parameters in the application of other metal BLM models as well when data are lacking. Default recommended values for GI parameters are 10^{th} percentile ecoregional, stream-order specific values. Default recommended values for DOC are 10^{th} percentile ecoregional values. Both pH and temperature should be measured values when using the BLM. It should be noted that site-specific data are always preferable for use in the BLM and should be used to develop copper criteria via the BLM when possible. Users of the BLM are encouraged to sample their water body of interest, and to analyze the samples for the constituent (parameter) concentrations as a basis for determining BLM inputs where possible.

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Appendix A: An Examination of Spatial Trends in Surface Water Chemistry in the Continental United States: Implications for the Use of Default Values as Inputs to the Biotic Ligand Model for Prediction of Acute Metal Toxicity to Aquatic Organisms

Internal EPA Report (2006)
James N. Carleton
EPA, Office of Water, Office of Science & Technology.

A.1 Abstract

A large database of surface water chemistry monitoring data was examined to look for spatial trends in five chemical constituents that are key inputs to a model for predicting metal toxicity to aquatic organisms. Continuous prediction maps of concentrations were generated using various kriging techniques to interpolate between site-median values measured at several thousand separate locations throughout the continental United States (U.S.). Continuous concentration surfaces were then averaged over 8-digit Hydrologic Unit Code (HUC) polygons to produce block-averaged mean estimates of site-median concentrations. Pairwise comparisons indicated distinct trends between various HUC-averaged predicted constituents. The same analyses performed on data from 772 locations where all five constituents had been measured revealed similar relationships between monitored constituents. Principal components analyses performed on these data sets showed that 80 to 90% of the variance in both cases could be explained by a single component with loadings on three of the five constituents. The use of kriging to produce appropriate quantile maps for block-averaging is suggested as a possible approach for developing regional values to use as default model inputs, when site-specific monitoring data are lacking.

A.2 Background

The U.S. Environmental Protection Agency is planning in the near future to release proposed water quality criteria for copper (*Note: EPA's BLM-based Freshwater Copper Aquatic Life Ambient Water Quality Criteria document was released in 2007, EPA-822-R-07-001*). These criteria are unlike most water quality criteria in that acceptable (safe) concentrations for aquatic life support, rather than being defined as simple numerical values that apply everywhere, will be addressed through the use of a chemical speciation model – the Biotic Ligand Model (BLM) (EPA, 2003). The BLM calculates metal toxicity to aquatic organisms as a function of simultaneous concentrations of additional chemical constituents of water, for example other ions that can either complex with copper and render it biologically unavailable, or compete with copper for binding sites at the point of entry into a vulnerable organism (i.e. at the fish gill). While the BLM has the potential to improve the accuracy of metal ecotoxicity predictions, its use requires input concentrations of nine separate chemical constituents and water temperature. Of these nine chemical constituents (Alkalinity (alk), calcium (Ca), magnesium (Mg), sodium (Na), sulfate (SO42-), potassium (K), chloride (Cl), dissolved organic carbon (DOC), and pH), model-predicted toxicity is most sensitive to five: Ca, alk, pH, Na, and DOC. States or other entities wishing to use the BLM to assess compliance with the proposed criteria in specific waters, or to develop effluent permit limits, will therefore require monitoring information on a suite of chemical

constituents – information that is not always available. One possible way to deal with such missing information is to develop reasonably protective default values for these various model inputs, especially the five to which the BLM is most sensitive. Given that ambient surface water chemistry reflects, among other things, the influences of local soil types and land uses, it may make sense that any such defaults be developed on some kind of regional or local basis.

The exercise described in this report comprises a geospatial examination of a large amount of water chemistry monitoring data collected in recent years by the U.S. Geological Survey, and recorded in their National Water Information System (NWIS) database. The data includes monitoring information from several thousand separate surface water sampling locations throughout the U.S. (Figure A-1). The latitudes and longitudes of each sampling location are part of the data record. The primary objective of this analysis is to look for any obvious spatial trends in typical concentrations of the five most sensitive constituents, and to suggest procedures for making use of these trends to define regional default values for use as inputs to the BLM. For purposes of expediency, the geographic extent of this analysis is limited to the continental U.S.

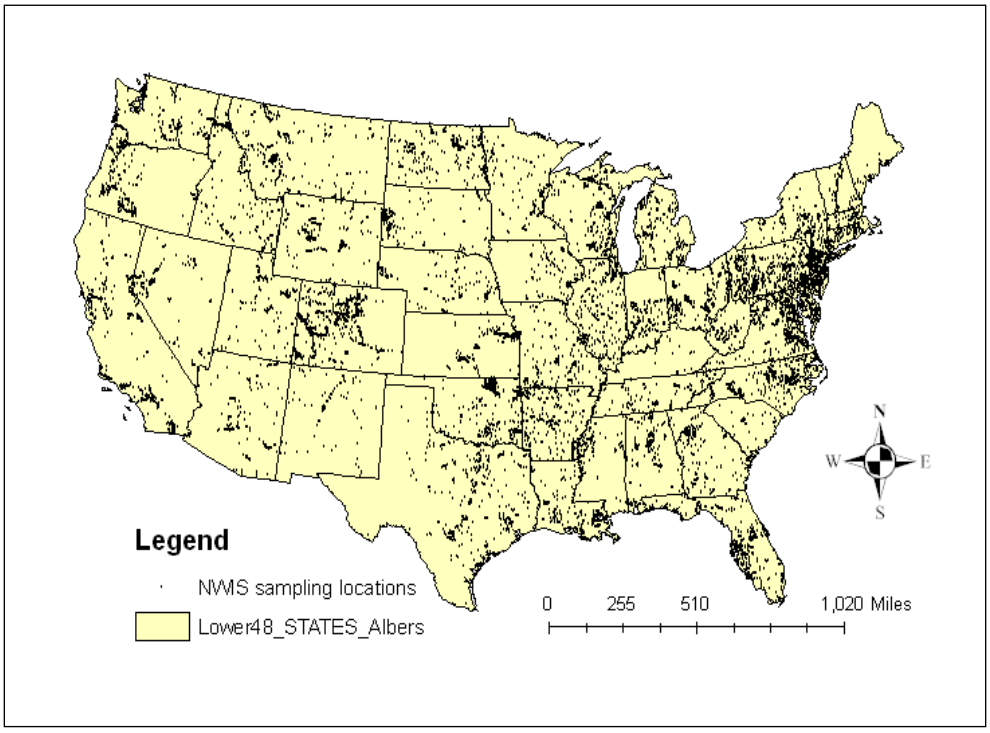


Figure A-1. NWIS sample collection locations in the continental U.S.

A.3 Description of Data

Although NWIS contained data from 207,153 sampling events at 13,824 individual sampling locations in the continental U.S. (Figure A-1), all 10 constituents of relevance to the BLM were not monitored at each location. For the five constituents of interest, the numbers of discrete sampling locations were as follows: alk, 5,900; Ca, 10,940; DOC, 3,726; Na, 10,424; pH, 11,780. Numbers of sampling events at individual locations ranged from 1 to 2,605, with a mean of 15, and a mode of one (i.e. most sites were

only sampled once). Examination of the spatial distribution of numbers of sampling events per site reveals that the most intensive sampling tended to occur in Midwestern and western states (Figure A-2). Because environmental sampling data tend to be lognormally distributed, disparities in numbers of samples may tend to produce higher mean and median values at more-frequently-sampled locations. As spatial distributions of representative (e.g., median) concentrations are examined, it should be kept in mind that apparent geographic trends in concentration may be in part simply the result of uneven sampling intensity.

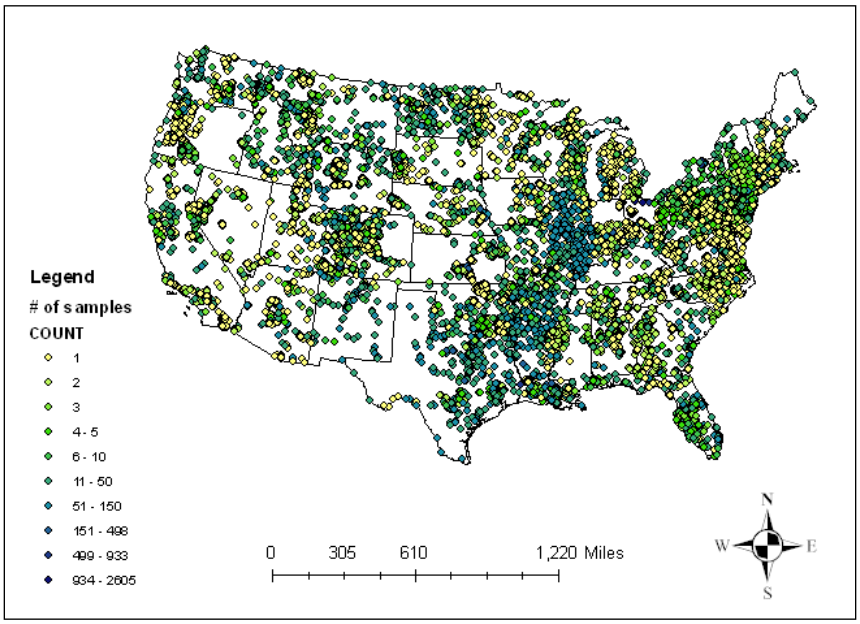


Figure A-2. Intensity of sampling (number of separate sampling dates) at each NWIS site

A.4 Data Analysis

Because environmental data tend to be positively skewed, the median statistic was chosen as providing the best central-tendency representation of each location's concentration. For the purpose of looking for general spatial trends in the five constituents, the first step involved simply mapping the sampling locations as points, color-graded by median concentration. Figure A-3, for example, shows some apparent trends in alkalinity across the country, with lower concentrations along the eastern seaboard, and higher concentrations in parts of the Midwest. Similar kinds of trends at the national scale were also seen with the other constituents.

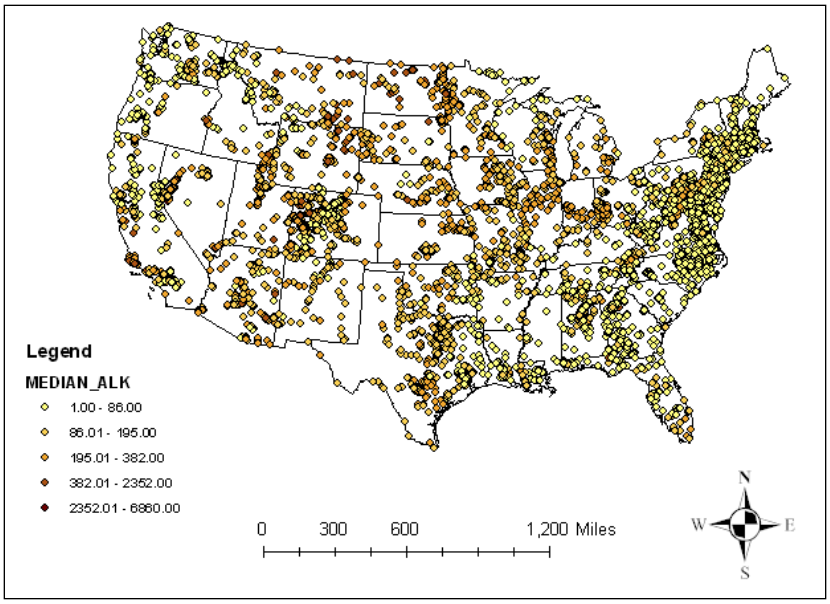


Figure A-3. Median measured alkalinity (mg/L as CaCO3) at NWIS locations

The next step in data visualization involved the calculation of median concentrations averaged over each 8-digit HUC containing sampling locations. These display essentially the same information as the point displays (Figure A-3), but with a degree of smoothing and summarization provided by the spatial averaging process, to make visual interpretation of general trends easier (Figure A-4).

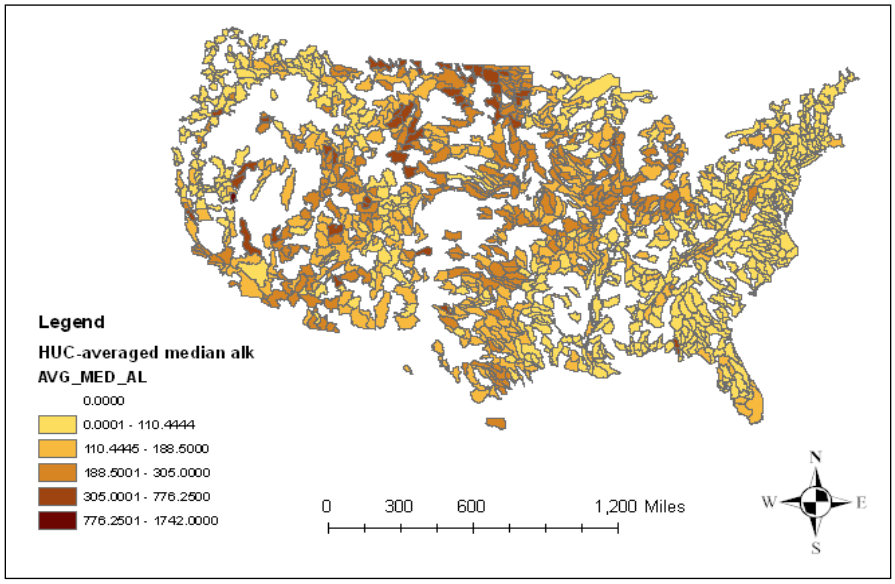


Figure A-4. HUC-averaged mean median observed alkalinity in the continental U.S.

The use of 8-digit HUCs as the areal units over which to calculate representative concentrations for default BLM inputs makes some physical sense: HUCs are areas that are defined by some degree of

interconnection between associated surface water features. HUCs may be either watersheds in their own right or downstream sections of larger watersheds (Omernik, 2003). In either case, all flowing surface water that passes through a HUC eventually (in theory) passes through the same downstream "pour point". One advantage of using HUCs is that they divide the land area into roughly equally sized areas at a level of resolution roughly consistent with gross variations in median concentration (Figure A-3). One problem with using HUCs for spatial aggregation is that not all HUCs contain NWIS sampling locations, as the blank areas in Figure A-4 make clear. The third step in this analysis therefore involved the use of kriging to create continuous surfaces of interpolated concentrations that cover the entire area of interest. Spatial averaging of the results over each HUC was then used to provide estimates of expected concentrations for all HUCs, including those lacking NWIS samples.

For each of the five key constituents, the Geostatistical Analyst extension in ArcGIS was used to explore the data, and to look for sets of kriging model options that provided the best fit to the data. The criteria used to evaluate goodness of fit were as follows:

1. Mean Standardized Error as small as possible
2. RMSE as small as possible
3. Root-Mean-Square Standardized Error close to 1.0
4. RMSE and Average Standard Error close together

Trial and error parameter selection was used to search for a set of model options that best attained each of these four goals simultaneously. For each constituent, 10 to 20 combinations were tried, until a best option for each emerged, as determined by judgment of the author. The results are as follows:

Alk: Universal kriging, log transformation, constant trend, 50% global, 50% local, spherical semivariogram, no anisotropy.

Ca: Ordinary kriging, log transformation, constant trend, 50% global, 50% local, exponential semivariogram, anisotropy.

DOC: Universal kriging, log transformation, constant trend, 50% global, 50% local, hole-effect semivariogram, anisotropy.

Na: Universal kriging, log transformation, constant trend, 50% global, 50% local, hole-effect semivariogram, anisotropy.

pH: Ordinary kriging, no transformation, constant trend, 50% global, 50% local, spherical semivariogram, no anisotropy.

Prediction surface maps were generated for each constituent using the above sets of kriging options. Figure A-5, which displays the results for alkalinity, shows patterns that are generally consistent with those in the data (Figures A-3 and A-4). Figure A-6 shows the predicted alkalinities projected into three dimensions using ArcScene.

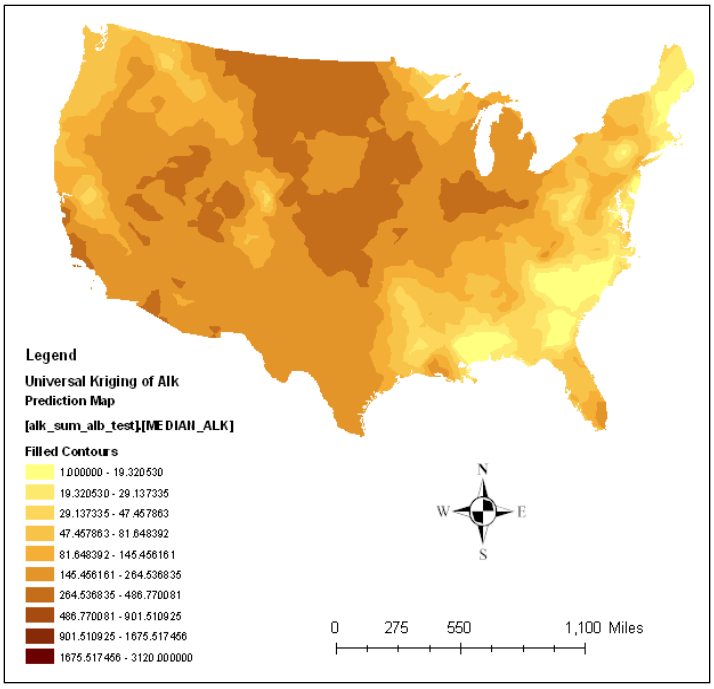


Figure A-5. Kriging prediction map of median alkalinity

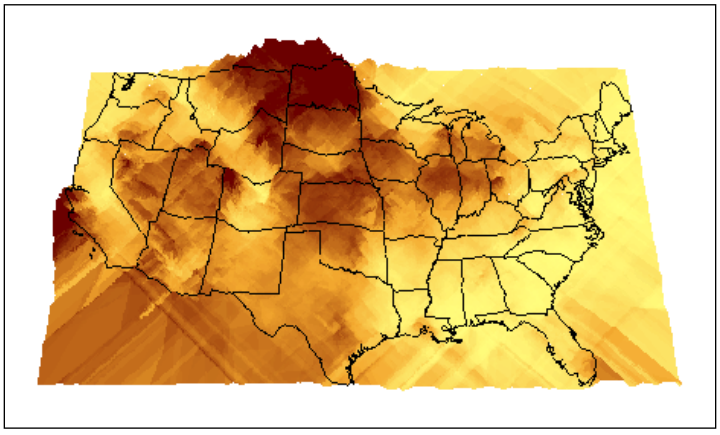


Figure A-6. Kriging map of alkalinity, projected into vertical dimension

This technique demonstrates broad geographic trends most dramatically, for example emphasizing the fact that the highest alkalinities are apparently found in northern North Dakota and Montana. Figure A-7 shows the predicted values averaged over HUC polygons by using the Zonal Statistics function of ArcGIS Spatial Analyst.

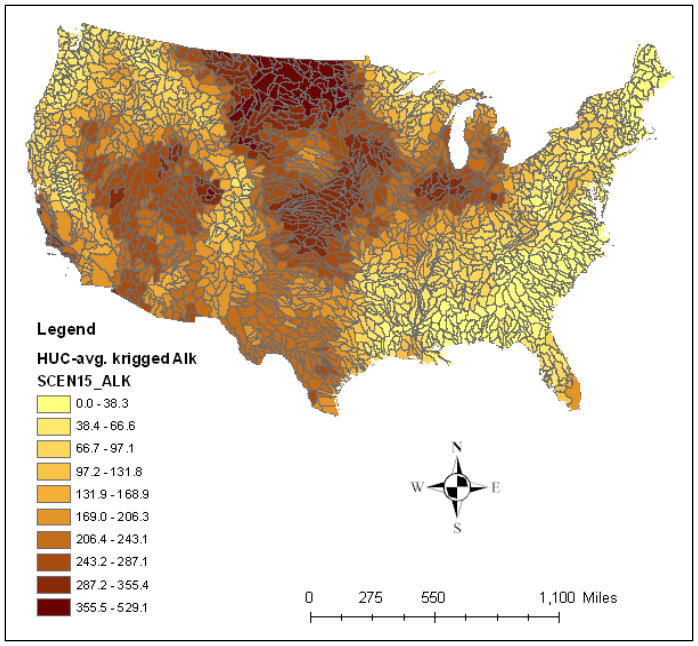


Figure A-7. Kriging-based alkalinity predictions, averaged over 8-digit HUC polygons

For HUCs containing NWIS sampling locations, linear regression plots of predicted versus measured concentrations (Figure A-8) provided a check on the accuracy of the kriging predictions. R-squared values for the five constituents were: 0.537 (alk), 0.238 (Ca), 0.686 (DOC), 0.351 (Na), and 0.139 (pH). In most cases, a handful of outliers appeared to be responsible for smaller-than-expected correlation coefficients.

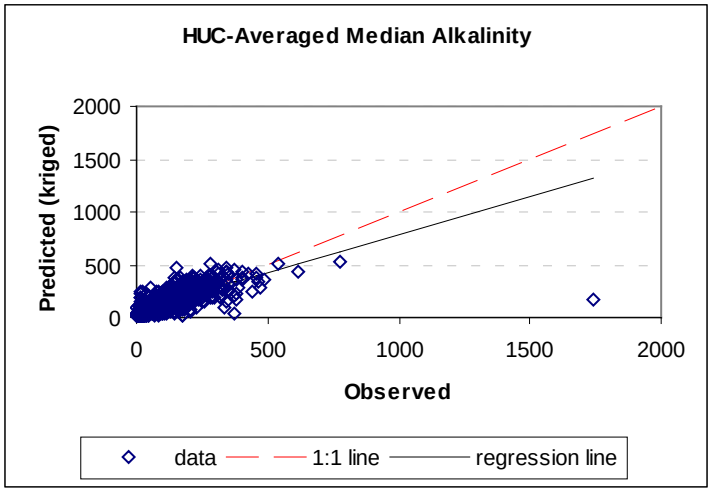


Figure A-8. Kriging-predicted vs. calculated HUC-averaged alkalinity; r^2=0.537

A scatter plot matrix of cross-constituent comparisons revealed some interesting, non-random relationships between HUC-averaged concentrations (Figure A-9). For comparative purposes, a subset of 772 sampling locations was also identified, at which sampling for all five of the constituents had taken place. Coincident concentrations of all constituents allowed a scatter plot matrix of this data (Figure A-10) to also be constructed. Similarities between the kinds of relationships in Figure A-9 and A-10 suggest that the predicted HUC mean median values are reasonable.

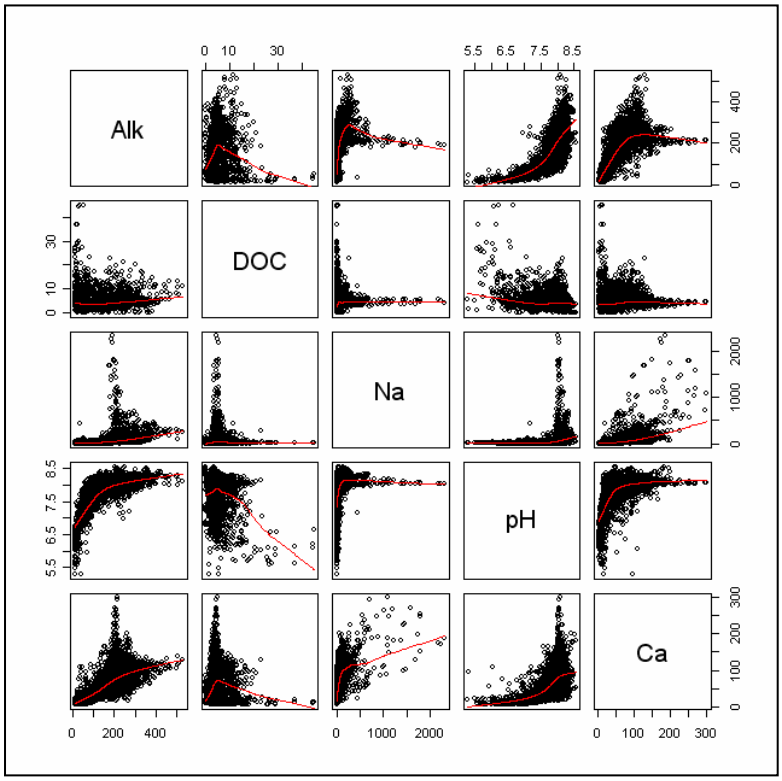


Figure A-9. Scatter plot matrix of median concentration kriged predictions, averaged over 8-digit HUCs regions covering the continental U.S.

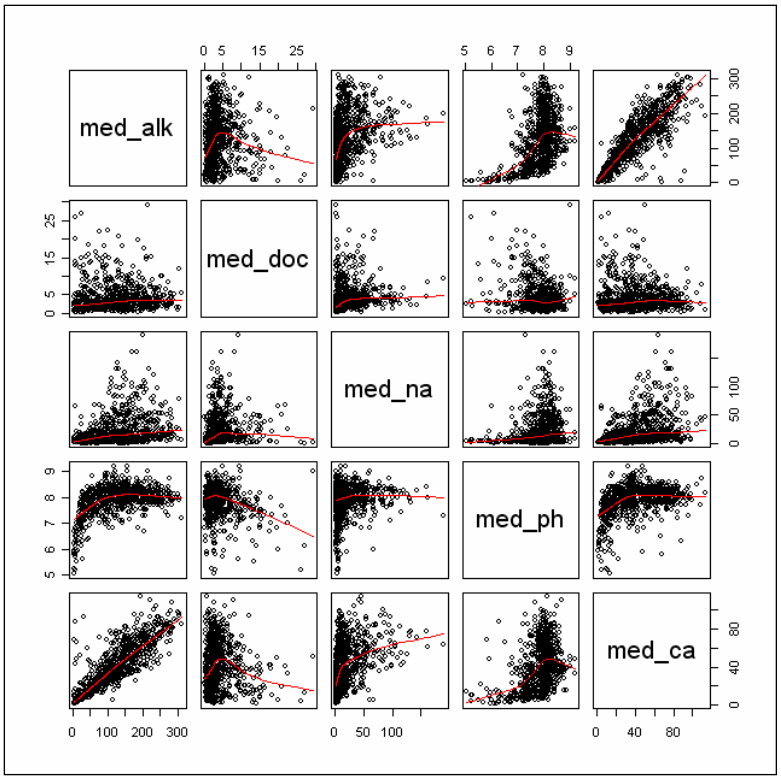


Figure A-10. Scatter plot matrix of median concentrations from 772 monitoring locations in the continental U.S.

In addition to scatter plots, correlation coefficient matrices between constituents in each of the two data sets (HUC-mean kriged median values and site median values for 772 locations) were generated (Table A-1). Although not identical, the coefficients were generally similar between the two datasets, again suggesting that the kriging predictions are reasonable.

Table A-1. Matrices of correlation coefficients between constituent concentrations

2096 HUC-averaged predicted median values					
	Alk	DOC	Na	pH	Ca
Alk	1				
DOC	-0.01456	1			
Na	0.327599	-0.02661	1		
pH	0.761675	-0.27746	0.286512	1	
Ca	0.698379	-0.02585	0.531727	0.58514	1
772 site-median values					
	Alk	DOC	Na	pH	Ca
Alk	1				
DOC	0.019145	1			
Na	0.327028	0.165445	1		
pH	0.453161	-0.24067	0.169238	1	
Ca	0.842484	-0.05097	0.387617	0.374592	1

Principal components analyses (PCA) were also run on both the HUC-averaged predictions and the 772 sets of monitored constituent concentrations to look for linear combinations of variables that might explain most of the observed variation. Figures A-11 and A-12 show the resulting plots of the variance explained by each component, and Table A-2 lists the loadings of the components onto the original variables. The first component comprised 80 and 88% of the variance in the HUC-based and site-based analyses, respectively. As Table A-2 indicates, this component loaded entirely onto alk, Na, and Ca in both cases. For the HUCs, component 1 was primarily loaded on Na, while for the sites, it primarily loaded on alk.

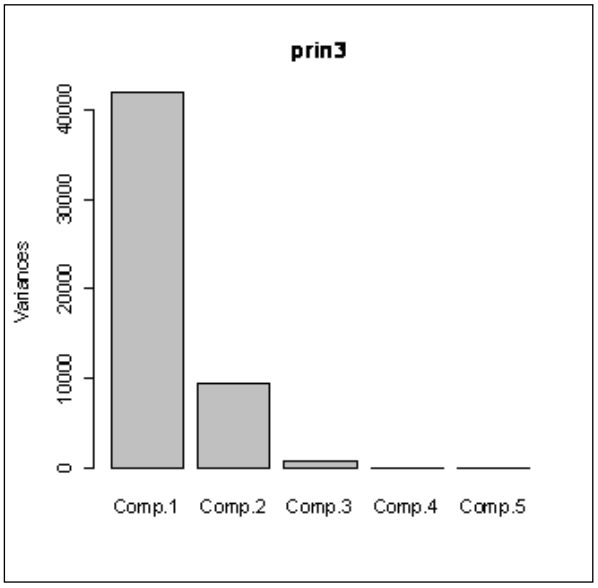


Figure A-11. Variance plot from PCA of HUC-average kriging-predicted concentrations

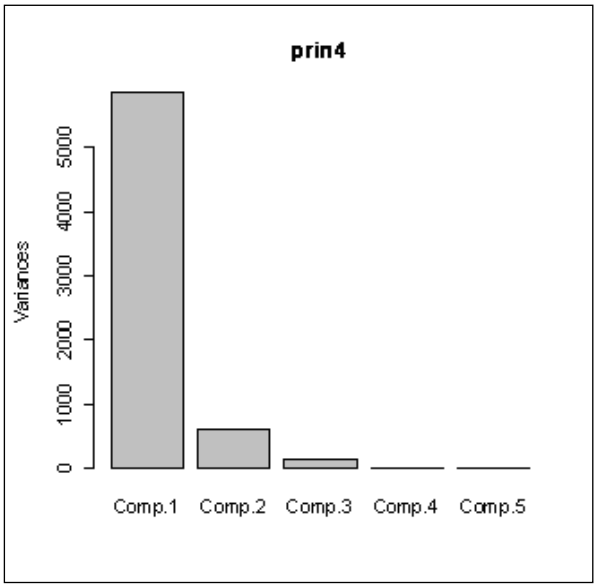


Figure A-12. Variance plot from PCA of site-median measured concentrations

Table A-2. Loadings onto original variables from PCA on HUC-averaged predictions and site-median concentrations

HUCs:					
	Comp.1	Comp.2	Comp.3	Comp.4	Comp.5
Alk	0.219	0.932	-0.289		
DOC				0.999	
Na	0.965	-0.25			
pH					-0.999
Ca	0.142	0.263	0.954		
Sites:					
	Comp.1	Comp.2	Comp.3	Comp.4	Comp.5
Alk	0.952	0.162	0.259		
DOC				-0.997	
Na	0.13	-0.982	0.133		
pH					0.999
Ca	0.277		-0.955		

A.5 Developing Regional Defaults

Besides prediction maps of best-estimate median concentrations, the Geostatistical Analyst can be used, with the same sets of kriging parameters listed previously, to generate quantile surface maps that represent reasonably protective inputs to the BLM than standard kriging predicted values. The five key inputs examined in this paper are all positively associated with BLM-predicted LC50s. Thus, lower values of all of them tend to result in lower (i.e., more protective) site-specific criteria. Lower quantile predictions can be used to produce protective regional default inputs. As an example, Figure A-13 displays the 25th percentile prediction map for alkalinity. When these values are block-averaged over the HUC polygons, the resulting alkalinities are lower than 67% of the site-minimum alkalinities (Figure A-14) measured inside the same areas.

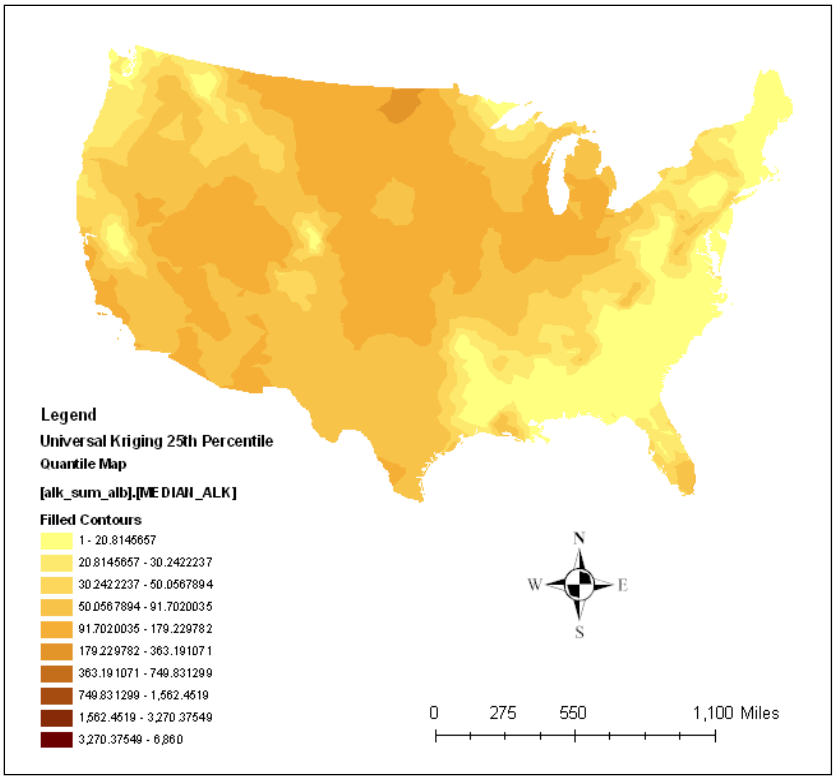


Figure A-13. Kriging 25th percentile map of median alkalinity

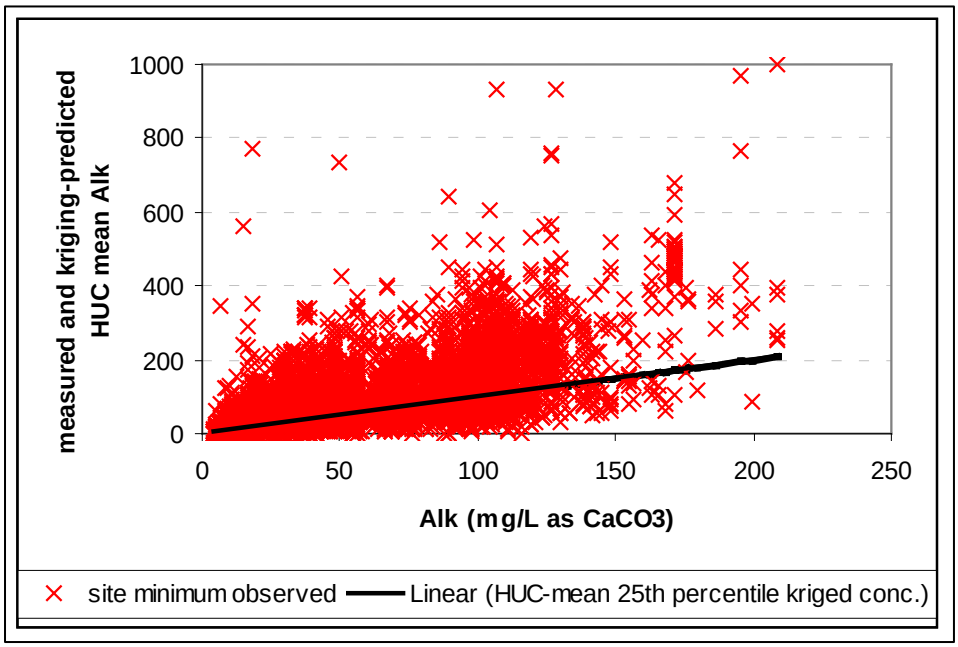


Figure A-14. Comparison of observed site-minimum alkalinities with HUC-mean 25th percentile kriging-predicted values

A.6 Discussion

The use of HUCs for spatial averaging of surface water concentrations is not without conceptual difficulties. First, only about 45% of HUCs are actual watersheds (Omernik, 2003); the rest receive drainage from additional upgradient areas. Concentrations measured in flowing waters reflect the soil, vegetation and land use properties of the aggregate upstream drainage areas, rather than of the sampling locations themselves (Smith et al., 1997). Assignment of measured concentrations to a HUC through block averaging may understate the spatial relevance of the samples for HUCs that are only parts of watersheds. One way to address this concern might be to use, as the aggregation polygons, only samples from watersheds that are entirely contained within single ecoregions (Omernik, 1987). However, this would have the unacceptable consequence of excluding large areas, and perhaps much of the data, from analysis. Another critical problem with this idea is that watershed boundaries for all of the NWIS sampling locations are not readily available, so there is currently no basis for deciding which points should be included or excluded. One advantage provided by the use of HUCs is that they divide the entire land mass of interest in this case into roughly equal sized polygons, at a level of resolution that appears to be roughly compatible with that of observed concentration trends. Block averaging using other sets of similarly sized polygons, such as counties, might serve equally well for empirically capturing broad spatial variability in concentrations. However the resulting concentrations would be less useful because they would lack even the incomplete degree of organization by connected hydrology that HUCs provide.

A.7 Conclusions

Kriging-predicted median concentrations of five water quality constituents, averaged over 8-digit HUCs, showed similar inter-constituent relationships as median concentrations from 772 specific sampling locations. PCA analyses revealed that in both cases, most of the observed variability was related to variations in three of the five constituents: alk, Na, and Ca. Results suggest that block averaging of kriging predictions over irregularly spaced sampling points can provide estimates that preserve much of the interrelationships between different measured entities. The use of suitable low-quantile kriging predictions is suggested as a way to estimate reasonably protective concentrations to serve as regional default inputs to the BLM.

A.8 References

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Appendix B: Approaches for Estimating Missing Biotic Ligand Model Input Parameters. Correlation approaches to estimate Biotic Ligand Model input parameters using conductivity and discharge as explanatory variables

B.1 Introduction

Derivation of water quality criteria for copper and other metals from predictions of bioavailability generated by the Biotic Ligand Model (BLM) introduces a number of issues. For example, obtaining the data needed to apply the BLM may be problematic for many dischargers and receiving waters. The BLM requires 10 input parameters to characterize water quality at a particular site; the most important ones for predicting copper bioavailability and toxicity include pH, dissolved organic carbon (DOC), calcium, magnesium, sodium, alkalinity, and temperature. In stream segments with only small dischargers, or possibly no dischargers at all, the data needed to apply the BLM may not be available. Water quality criteria that rely upon BLM predictions would be greatly facilitated by the development of practical approaches to estimate values for BLM water quality parameters, which could be applied when data for one or more of these parameters are missing at a site.

Given the broad geographical range over which the BLM is likely to be applied, potentially over the entire Nation, and the limited information that is available for many areas, a practical method to estimate missing water quality parameters is needed. The geostatistical methods employed by the U.S. Environmental Protection Agency (EPA) (Carleton, 2006) presented a viable system to estimate missing water quality parameters required by the BLM. The prototype work developed by Carleton applied kriging to predict average concentrations of alkalinity, DOC, sodium, pH and calcium over hydrologic units (8-digit Hydologgic Unit Codes [HUCs]), using the U.S. Geological Service (USGS) National Water Information Service (NWIS) as the source of spatial data. Comparison of measured concentrations with kriging predictions were encouraging for several of the BLM water quality parameters, although the errors and uncertainties associated with these predictions were not fully explored.

The geostatistical approach utilizes knowledge of spatial correlation to project values of a water quality parameter at sites where it has not been measured. The accuracy of these projections depends upon the availability of sufficient and spatially-proximate data for the specific parameter of interest. In addition, the seasonal and annual temporal variation in water quality must also be addressed in order to apply the BLM at a site. Water quality parameters often experience large changes during periods of snowmelt or intense rainfall. In many rivers and streams, the chemical composition and physical properties of water are following trends associated with increased land use in watersheds, water diversion for irrigation, regulation of river flow by dams, and other anthropogenic disturbances.

The acute BLM predicts an *instantaneous* acute copper criterion (i.e., a maximum short-term, non-toxic concentration of copper), which will vary according to changes in the water quality parameters. An appropriately protective copper criterion must therefore reflect the variability of water quality parameters at the site. In previous analyses we found that protective water quality criteria for copper

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generally corresponded to approximately the 2.5th percentile of the distribution of instantaneous water quality criteria (IWQC) predicted by the BLM.[5] BLM criteria predictions made for a site using the corresponding percentiles (i.e., 2.5%) of the water quality parameter distributions will be a conservative approximation of this protective criterion. The sensitivity of criteria predictions to the most important BLM water quality inputs is proportional (sensitivity to DOC is ~100%[6], [H^+] is ~50%, calcium, magnesium and sodium is ~20%). Relevant site-specific water quality parameters will be values from the lower "tail" of the measured or estimated distributions.

There may be great value in supplementing the geostatistical approach with classical estimation methods, such as regression and correlation. Examination of the NWIS data used to develop the geostatistical approach suggests that two variables, discharge (flow rate) and conductivity, may be useful for estimating BLM input water quality parameters. The USGS maintains the most comprehensive routine water flow and water quality data for streams and rivers in the Nation. Discharge may be a relevant explanatory variable because the USGS measures or estimates flow on a daily basis for a large number of stream and river segments. Among water quality parameters, the data for conductivity are the most complete and cover the longest time period (Wang and Yin, 1997). The literature also indicates that conductivity is one of the most widely monitored water quality indicators in the U.S. In part, this is because conductivity measurements are usually included in automated multiparameter systems for monitoring changes in the quality of surface waters (Allen and Mancy, 1972).

Conductivity is useful as a general measure of stream water quality. Each stream tends to have a relatively constant range of conductivity that, once established, can be used as a baseline for comparison with regular conductivity measurements (USEPA, 1997). Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionize (dissolve into ionic components) when washed into the water. On the other hand, streams that run through areas with clay soils tend to have higher conductivity because of the presence of materials that ionize when washed into the water. Ground water inflows can have the same effects depending on the bedrock they flow through.

Conductivity reflects the strength of major ions in water and is a good estimator of total dissolved solids (TDS). Linear relationships between conductivity and TDS have been developed for many USGS monitoring sites. Conductivity is also linearly related to the sum of cations (McCutcheon et al., 1993). In addition, conductivity measurements provide information about the total concentration of ionic species in a water sample (Tyson, 1988). Figure B-1 illustrates how conductivity relates to hardness and anion concentrations in a river that has a rather saline base flow maintained by irrigation drainage and groundwater inflows. The chemical characteristics of the base flow are generally constant but they are subject to seasonal dilution by runoff. Relationships between conductivity and chloride and sulfate concentrations are well defined. A similarly good association with hardness (calcium+magnesium) is

[5] This was the median for 17 sites; the range was 1 to 36%.

[6] 100% sensitivity implies that a model prediction (in this case, the criteria predicted by the BLM) varies in direct proportion to the change in the value of a specified input parameter.

indicated. Lines drawn by eye through the points for chloride and sulfate show slight curvature, but the departure from linearity is insignificant. It seems evident that a record of conductivity at this station could be used to compute the other chemical characteristics of the water with a good level of accuracy for major ions, except at high flow when the relationships would not be as well defined (Hem, 1985).

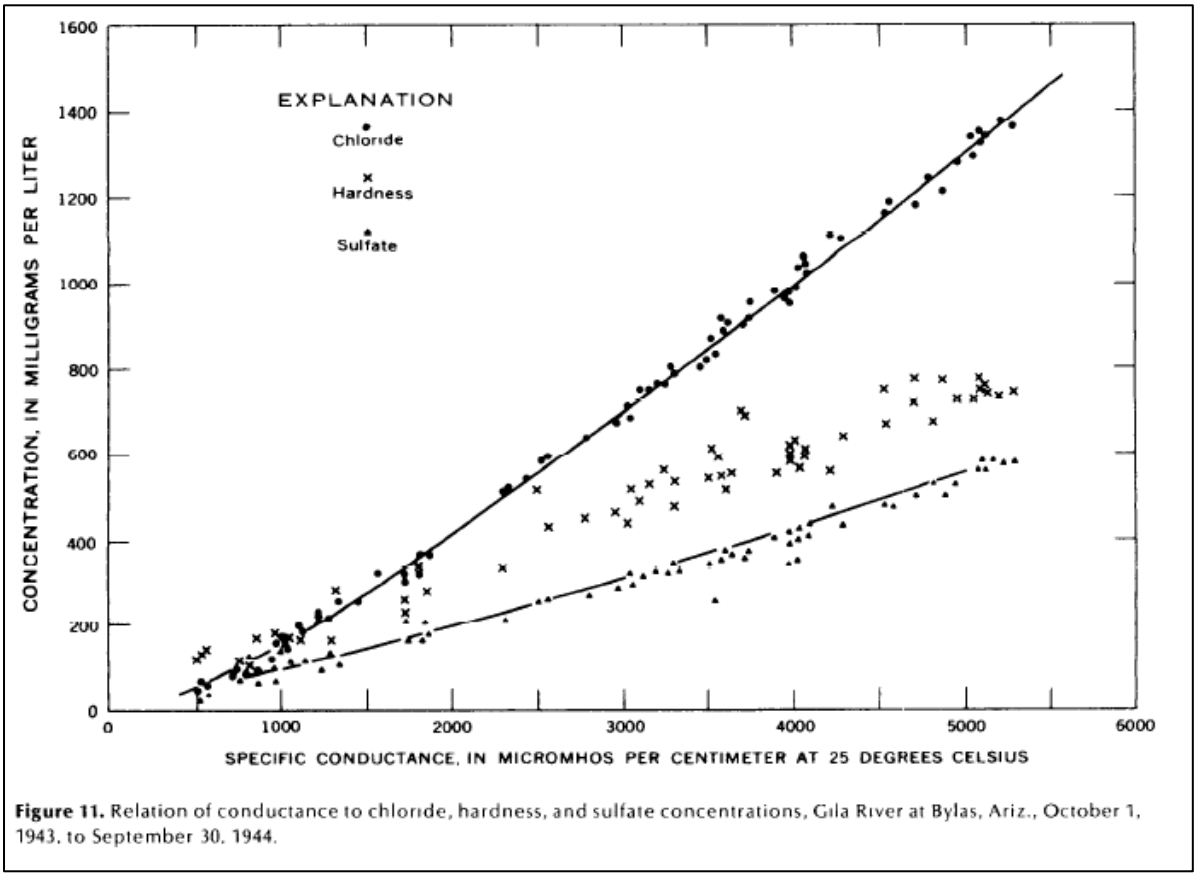


Figure 11. Relation of conductance to chloride, hardness, and sulfate concentrations, Gila River at Bylas, Ariz., October 1, 1943, to September 30, 1944.

Figure B-1. Relation of conductivity to chloride, hardness and sulfate concentrations in the Gila River at Bylas, Arizona

(reprinted from Hem, 1985)

Wang and Yin (1997) established conductivity as a general water quality indicator based on spatial data. The concentration of major base metal cations in water explained the positive correlation between conductivity and hardness. This also explained a rather weak correlation between conductivity and the pH value. Its relationship with other materials, however, most likely resulted from the dilution effect of stream flow. Conductivity was negatively correlated with discharge (ρ=-0.729), and the same was found for most water quality variables that were positively correlated with conductivity. With increasing stream flow, the concentration of the dissolved material decreased, as did the conductivity. Wang and Yin's analysis suggests that conductivity could be used as a general indicator of water quality, which is positively related to dissolved materials and soluble metals. As it is

widely monitored and has relatively long records, conductivity has the potential to be a very useful variable for estimating missing water quality input parameters for the BLM.

We explored this possibility by assessing the degree of correlation between conductivity and each of the BLM water quality parameters. We used NWIS data from three contiguous states in the Western U.S. (Colorado, Utah and Wyoming) for this analysis. These states were selected because of the large spatial and temporal variability observed in BLM water quality parameters, and because they provided us a tractable dataset for analysis.

Discharge was included as one of the parameters in this correlation analysis. However, discharge is most often used to explain water quality variation at a particular site (Hem, 1985). The concentration of dissolved solids in the water of a stream is related to many factors, but it seems obvious that one of the more direct and important factors is the volume of water from rainfall available for dilution and transport of weathering products. Presumably, therefore, the concentrations of dissolved solids should be an inverse function of the rate of discharge of water over all or at least most of the recorded range (Hem, 1985). Regressing water quality parameter measurements against discharge is a common practice in environmental engineering, and many references on this subject are available (McDiffett et al.,1989; Chanat and Hornberger, 2002; Christensen et al., 2005; Godsey and Kirchner, 2005). We should also point out that correlating the variation in water quality parameters to streamflow is also necessary for effluent dilution calculations associated with use of the BLM (for example, the probabilistic dilution framework incorporated in the BLM-Monte software [HydroQual, 2001]).

B.2 Data

Data for discharge, conductivity, and BLM water quality parameters (temperature, pH, DOC, alkalinity calcium, magnesium, sodium, potassium, sulfate, and chloride,) were retrieved from the USGS NWIS web interface (http://nwis.waterdata.usgs.gov/usa/nwis/qwdata). Data were selected for 790 stream and river stations in Colorado, Utah, and Wyoming reporting 100 or more water quality observations. This latter constraint was imposed to eliminate the large number of stations reporting very few (often one) water quality observations. Even when the analysis was restricted to sites with more than 100 water quality observations, there were frequently a marginal number of data for the multiple parameters needed to measure between-parameter correlations. We also restricted the analysis to observations made since 1975 to avoid the possible influence of pre-Clean Water Act discharges on water quality.

Natural logarithms of the discharge data were used in the analysis, because discharge was clearly lognormally distributed at the majority of sites. In cases where a parameter was measured simultaneously by more than one method (field pH versus laboratory pH, for example), the reported results were averaged for analysis. We did not consider other approaches for selecting data based on preference for a particular analytic method (Roberson et al., 1963).

B.3 Results

Table B-1 provides an inventory of the number of observations, and number of sites with data, for several of the parameters in the state of Colorado (these numbers reflect the full NWIS dataset, uncensored for minimum number of observations or date). From this table, it is apparent that a vast amount of conductivity data exists, both in terms of the total number of observations and the number of sites reporting this parameter in comparison to the BLM water quality parameters. For example,

there are almost four times as many observations of conductivity as there are for calcium, and they are measured at more than twice the number of sites. Discharge data is similarly abundant.

Table B-1. Number of observations and sites reported in NWIS for streams and rivers in Colorado

Parameter	Number of Observations	Number of Sites
pH	62,005	3668
alkalinity	8136	839
calcium	45,490	2708
conductivity	168,110	6101
discharge	127,275	3340

To quantify the relationship between conductivity levels and values of water quality parameters required by the BLM, we performed correlation analyses on the NWIS water quality data for the three states. We estimated correlations for several statistics that summarized the distribution of conductivity and water quality values at each station. These included median levels, as well as the first quartile and fifth quantile. The last two statistics represent the lower end of the distribution of parameter values at a site, and are appropriate statistics for calculation of BLM instantaneous criteria. A non-parametric correlation (Spearman's rank correlation) was employed to avoid the problems of unknown data distributions and possibly non-linear relationships. To determine the statistical significance of the rank correlation coefficient (ρ), the significance level (P) was also calculated. The Spearman's rank correlation was also used to examine the relationship between stream discharge and the water quality variables to reveal the effect of dilution.

For the median site concentrations, we found that six BLM water quality parameters, two-thirds of the nine variables examined in this study, had non-zero rank correlation coefficients at the 0.001 significance level (Table B-2). As expected, strong positive correlations between conductivity and salt concentrations were found. For example, the correlation coefficients between conductivity and the concentration of salt cations and anions (sodium, potassium, magnesium, calcium, sulfate and chloride) were all higher than 0.80. However, median site conductivity was not significantly correlated to several other important BLM parameters including pH, DOC, and alkalinity. In terms of the site medians, there appears to be limited correlation between conductivity and the BLM water quality parameters. Furthermore, for the median site concentrations neither conductivity nor any of the BLM water quality parameters were significantly correlated to discharge.

Table B-2. Results of Spearman rank tests for correlation (ρ) between median values of variables at each site.

Probability values (P) are not exact due to the presence of ties in the data

	Conductivity	Discharge
Conductivity		ρ: 0.012 P: 0.892
pH	ρ: 0.175 P: 0.019	ρ: 0.441 P: 0.008
DOC	ρ: 0.866 P: 0.333	ρ: P:
Ca	ρ: 0.867 P: <0.001	ρ: -0.371 P: 0.068
Mg	ρ: 0.882 P: <0.001	ρ: -0.516 P: 0.008
Na	ρ: 0.921 P: <0.001	ρ: 0.139 P: 0.695
K	ρ: 0.846 P: <0.001	ρ: -0.128 P: 0.551
SO_4	ρ: 0.905 P: <0.001	ρ: -0.514 P: 0.010
Alkalinity	ρ: -0.600 P: 0.350	ρ: P:
Cl	ρ: 0.827 P: <0.001	ρ: -0.866 P: 0.333

We then repeated the correlation analysis for the site first quartiles (Table B-3) and fifth quantiles (Table B-4). For both of these low-end distribution statistics, *all* of the BLM water quality parameters were significantly correlated to conductivity, having non-zero rank correlation coefficients at the 0.001 significance level, as listed in Tables B-3 and B-4. The correlation coefficients are lower for pH and DOC than for the salts and alkalinity, but are nevertheless significant. Apparently, the correlation structure between conductivity and the BLM water quality parameters is much stronger at the lower end of the site distributions. Ambiguity in correlations between conductivity and BLM water quality parameters disappears when low-end distribution statistics are analyzed. As was the case for the median site concentrations; neither conductivity nor any of the BLM water quality parameters were correlated with discharge for the low-end distribution statistics.

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Table B-3. Results of Spearman rank tests for correlation (ρ) between the first quartile of values at each site.

Probability values (P) are not exact due to the presence of ties in the data

	Conductivity	Discharge
Conductivity		ρ: 0.057 P: 0.144
pH	ρ: 0.287 P: <0.001	ρ: 0.070 P: 0.168
DOC	ρ: 0.618 P: <0.001	ρ: -0.149 P: 0.031
Ca	ρ: 0.920 P: <0.001	ρ: -0.060 P: 0.305
Mg	ρ: 0.935 P: <0.001	ρ: -0.107 P: 0.066
Na	ρ: 0.910 P: <0.001	ρ: -0.075 P: 0.129
K	ρ: 0.773 P: <0.001	ρ: -0.109 P: 0.075
SO_4	ρ: 0.941 P: <0.001	ρ: -0.068 P: 0.247
Alkalinity	ρ: 0.829 P: <0.001	ρ: 0.099 P: 0.381
Cl	ρ: 0.752 P: <0.001	ρ: 0.004 P: 0.958

Table B-4. Results of Spearman rank tests for correlation (ρ) between the fifth quantile of values at each site.

Probability values (P) are not exact due to the presence of ties in the data

	Conductivity	Discharge
Conductivity		ρ: 0.056 P: 0.213
pH	ρ: 0.382 P: <0.001	ρ: 0.032 P: 0.579
DOC	ρ: 0.558 P: <0.001	ρ: -0.107 P: 0.134
Ca	ρ: 0.920 P: <0.001	ρ: 0.017 P: 0.791
Mg	ρ: 0.929 P: <0.001	ρ: -0.056 P: 0.383
Na	ρ: 0.845 P: <0.001	ρ: -0.089 P: 0.078

K	ρ: 0.694 P: <0.001	ρ: -0.065 P: 0.353
SO_4	ρ: 0.908 P: <0.001	ρ: 0.017 P: 0.790
Alkalinity	ρ: 0.784 P: <0.001	ρ: 0.184 P: 0.102
Cl	ρ: 0.706 P: <0.001	ρ: 0.034 P: 0.671

To further illustrate these correlations, scatter plot matrices (or SPLOMs) were prepared for the first quartiles (Figure B-2) and fifth quantiles (Figure B-3). SPLOMs show scatter plots for each combination of parameters, arrayed as a matrix, with parameters labeled along the borders of the plot. Histograms for each parameter are plotted on the main diagonal. The correlations between conductivity and each of the BLM water quality parameters are apparent by examining the second row (from the top) of scatter plots in Figures B-2 and B-3. Likewise, the lack of correlation between these parameters and discharge is apparent in the top row of the scatter plots in these same figures.

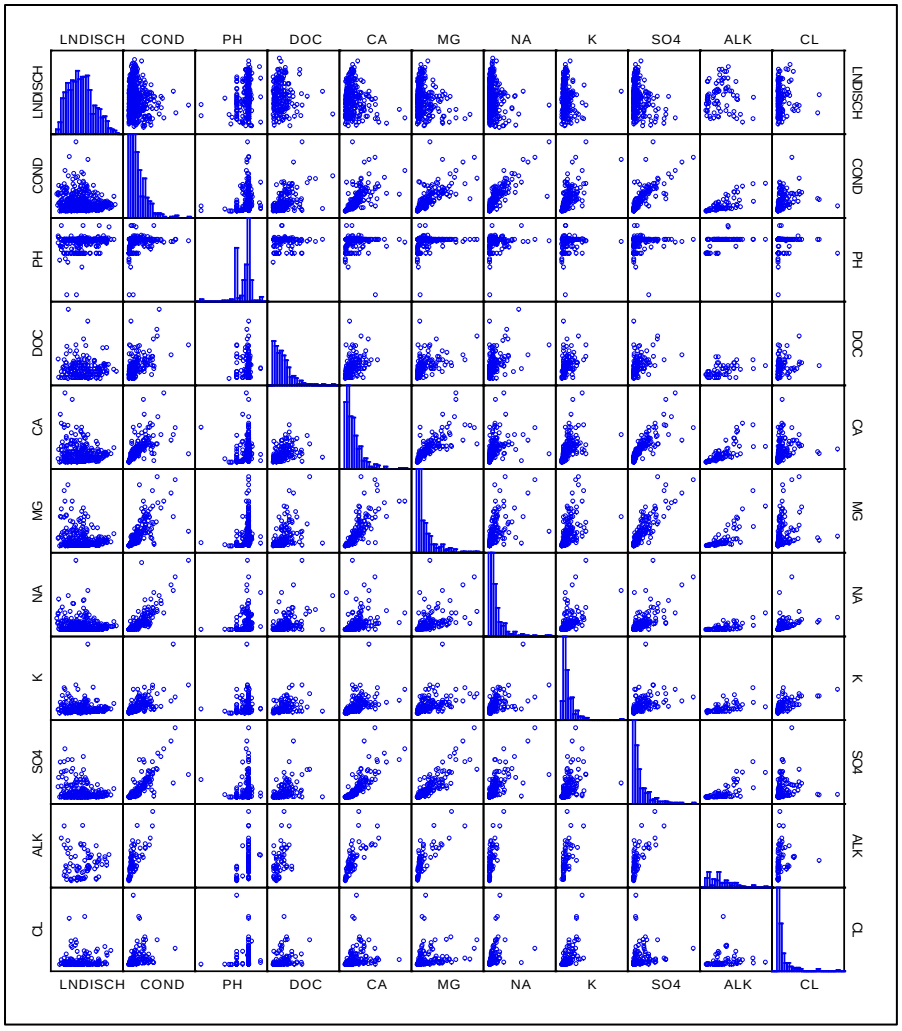


Figure B-2. Scatter plot matrix for first quartile of site-specific data for discharge (LNDISCH), conductivity (COND), and BLM water quality parameters

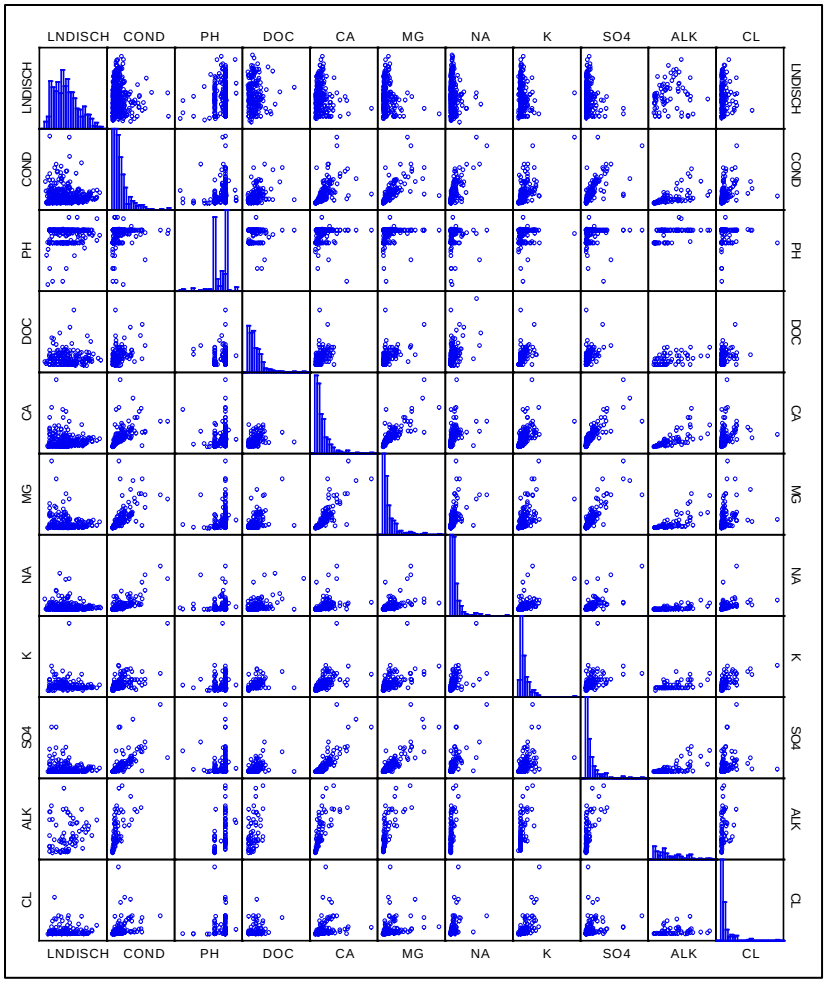


Figure B-3. Scatter plot matrix for fifth quantile of site-specific data for discharge (LNDISCH), conductivity (COND), and BLM water quality parameters

To understand why the correlations between conductivity and the other BLM water quality parameters are so much stronger for the low-end distribution statistics than for the medians, it is necessary to examine the site-specific data itself. Figure B-4 is a SPLOM of the conductivity, discharge, and BLM water quality parameter data for a representative USGS station in Colorado. The histograms for conductivity, salts, and alkalinity are remarkable in that the distribution of each is clearly bimodal (i.e., two separate peaks are evident in the histograms). This was observed for many of the sites in this dataset (not shown). In Figure B-5, the conductivity and discharge data for this site are plotted as a time series, which reveals why the water quality data are bimodal: high values of conductivity (> 5,000 micromhos/cm) occur when streamflow discharge is low, and low values of conductivity (< 2,000 micromhos/cm) occur when the discharge is high. At this station (and many others in this region), streamflow discharge is high in the May-June period coinciding with snowmelt at higher elevations. Feth and others (1964) reported conductivities of melted snow in the Western US ranging from about 2 to 42 picomhos/cm. Thus, the low values of conductivity (as well as concentrations of the salts and alkalinity) are the result of annual dilution from snow melt. At most other times, conductivity and salt and alkalinity concentration values are much higher. Depending upon how the water quality samples

are allocated at a site, the median concentration of these parameters may fall in either mode of the bimodal distribution, resulting in quite different values that appear almost random. Fortunately, the low-end distribution statistics avoid this seeming randomness because they consistently reflect sampling from the lower mode of the concentration distribution.

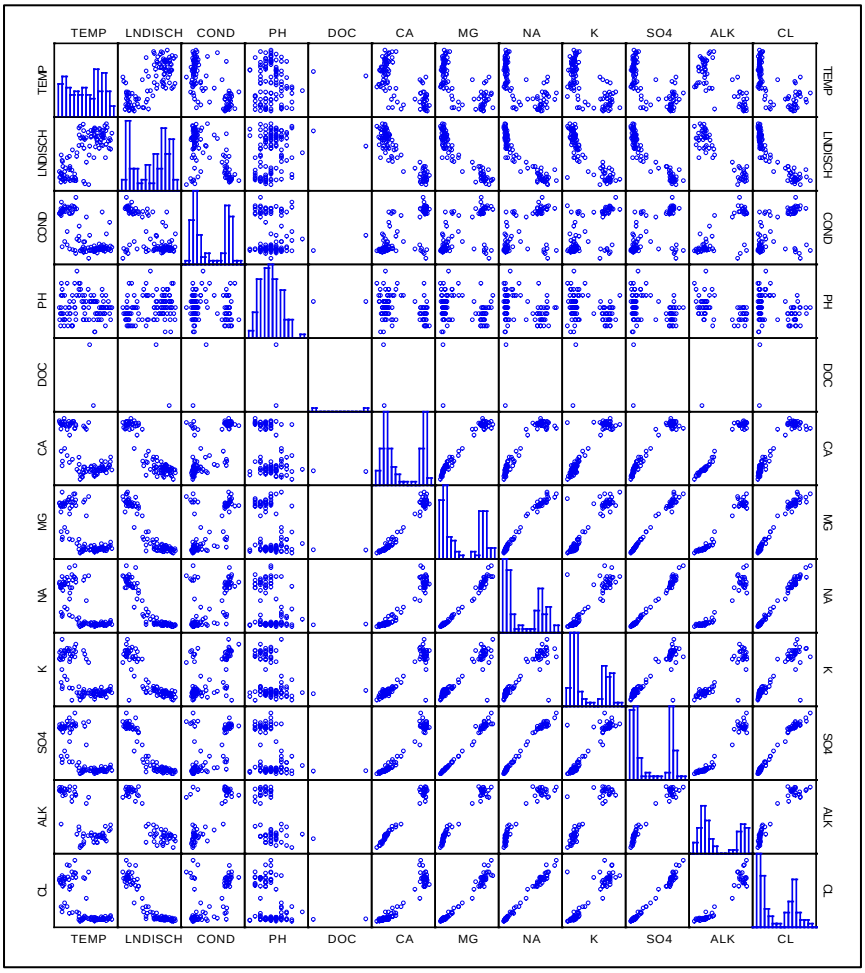


Figure B-4. Scatter plot matrix of BLM water quality parameter data from NWIS Station 384551107591901 (Sunflower Drain at Highway 92, near Read, Delta County, Colorado)

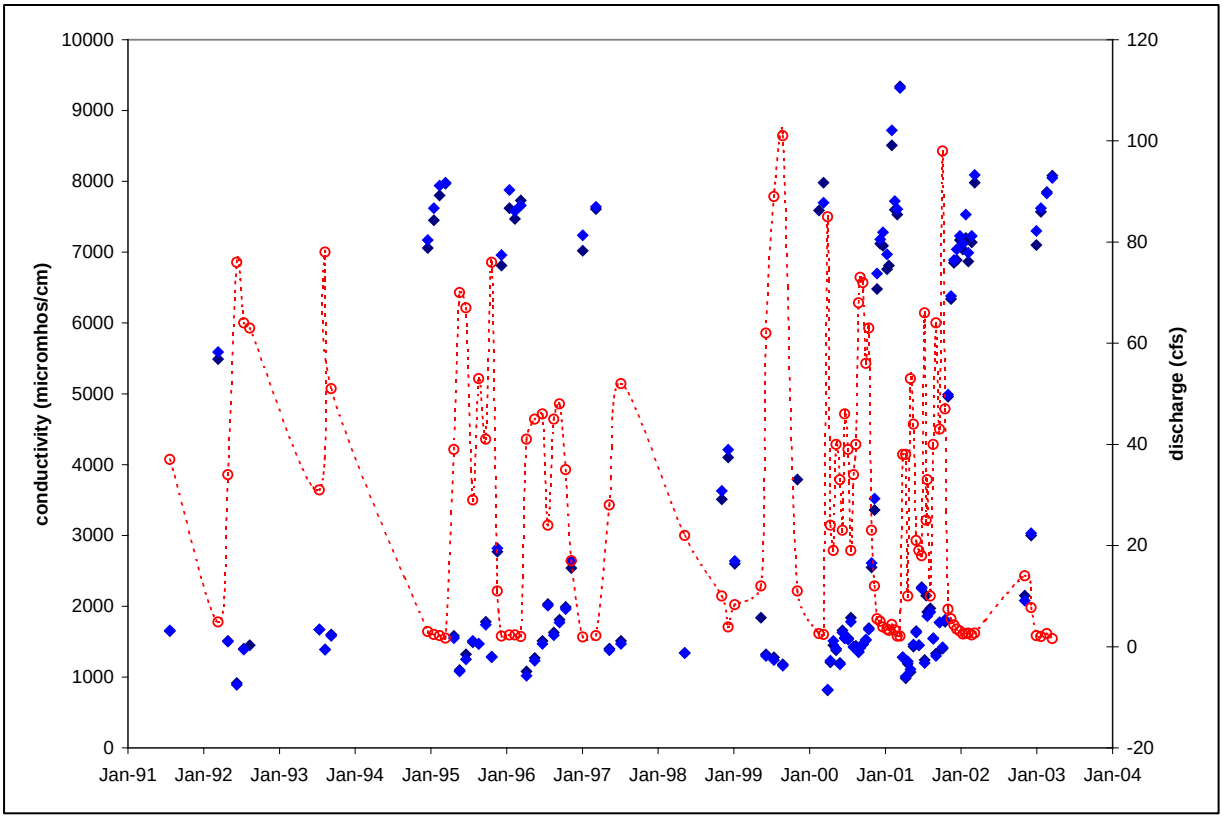


Figure B-5. Time series plot of conductivity (diamond symbols) and discharge (open circles connected by dashed line) at Station 384551107591901 (Sunflower Drain at Highway 92, near Read, Delta County, Colorado)

Figure B-4 also illustrates that, in terms of explaining site-specific variability, discharge is a much better predictive variable for a number of the BLM water quality parameters than conductivity. Each of these parameters (alkalinity calcium, magnesium, sodium, potassium, sulfate, and chloride) is clearly correlated to discharge, but not to conductivity. Discharge correlations are observed at many locations, and are commonly used to project water quality for various applications (Hem, 1985).

B.4 Discussion

Incorporating classical water quality correlation approaches, using conductivity and discharge as explanatory variables, within the geostatistical approach prototyped by EPA, appears promising. Conductivity, but not discharge, is significantly correlated to BLM water quality parameters between sites, especially for the low-end distribution statistics of interest for criteria calculations. Since conductivity data is abundant and it correlates well to BLM water quality parameters, it is reasonable to incorporate conductivity in spatial projections of BLM parameters. This may simplify the geostatistical approach and allow more robust spatial extrapolation of BLM water quality parameters.

Conversely, discharge is correlated to concentrations of a number of BLM parameters (salts and alkalinity) within many sites. Streamflow is a good explanatory variable for a number of the BLM water quality parameters (the salts and alkalinity) because their variabilities largely reflect dilution at high flow rates. Discharge data are also plentiful, so we believe that incorporating classical methods of

correlating concentration to discharge may be a useful means to address within-station variability for BLM water quality parameters.

It should also be recognized that geostatistical and/or correlation approaches appear to most often fail for those water quality parameters which are the most sensitive and important to the BLM, namely DOC and pH. Additional sampling effort will likely be required to address these deficiencies. In the case of pH, it is worth noting that many surface water sampling crews carry electronic multiparameter instruments which measure pH, conductivity, and temperature simultaneously in the field. Therefore, data collection strategies which incorporate these three measurements may be especially effective.

Measurement of DOC is considerably more difficult and expensive. It may be worthwhile to investigate whether ultraviolet (UV) absorption spectroscopy could be used as a surrogate measurement technique for DOC. The organic ligands that bind metals are humic and fulvic compounds (HydroQual, 2005). At least some of these compounds can be measured by UV absorption spectroscopy or related methods (Kalbitz et al., 2000; Wang and Hsieh, 2001), which may be easier and less expensive than DOC analysis.

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Appendix C: Development of Tools to Estimate Biotic Ligand Model Parameters

C.1 Introduction

The U.S. Environmental Protection Agency (EPA) explored using regression models that project BLM water quality parameters from conductivity data for sites where there may be few or no data available to characterize water. We demonstrated previously (USEPA, 2007) that conductivity (specific conductance) is significantly correlated to Biotic Ligand Model (BLM) water quality parameters between a large number of monitoring sites in three western states (Colorado, Utah, and Wyoming), especially for the low-end distribution statistics of interest for site-specific fixed water quality criteria calculations. Since conductivity data are also abundant, it is reasonable to incorporate conductivity in spatial projections of BLM parameters.

C.2 Regression Analysis

Water quality data were retrieved from the U.S. Geological Survey (USGS) National Water Information System (NWIS; http://waterdata.usgs.gov/nwis/qw). We focused our efforts on data collected from rivers and streams in the western states of Colorado, Utah, and Wyoming between 1984 and 2005. Data from these three states were selected because conductivity was known to vary substantially, and the legacy of past mining in the region made the contamination of waterbodies by trace metals a possibility. Data collected prior to 1984 was excluded because a number of the analytical methods used by USGS prior to that date have been replaced by methods with improved precision and lower detection limits. Furthermore, only sites with 40 or more samples were included in the analysis. Data were retrieved for all BLM water quality input parameters including pH, dissolved organic carbon (DOC) (or total organic carbon (TOC), if no DOC data were available) and the geochemical ions (GIs). We also retrieved discharge measurements and filtered (dissolved) copper concentration data, although these data were not included in the regression analysis.

In work described in Appendix B, we found that the correlation structure between conductivity and the BLM water quality parameters was much stronger at the lower end of the concentration distributions. For various low-end distribution statistics, all of the BLM water quality parameters were significantly correlated to conductivity, having non-zero rank correlation coefficients at the 0.001 significance level. The correlation coefficients for pH and DOC were lower than for the GIs, but were nevertheless significant. We exploited this feature of the data in our current work. For each site, we estimated the 10^{th} percentile (i.e., the value exceeded by 90% of the data) of conductivities and the 10^{th} percentile of BLM water quality parameter values. We then fit regression models to project 10^{th} percentiles of BLM parameter values as a function of 10^{th} percentiles of conductivities.

We also fit regression models to the full NWIS dataset (data for all rivers and streams sampled in Colorado, Utah, and Wyoming between 1984 and 2005). This was done out of concern that the lower percentile data might be skewed due to sampling bias, censoring, fewer sites, etc. The results of both approaches are presented below.

C.2.1 pH

The following regression model appeared to be optimum for projecting the 10^{th} percentile of pH from the 10^{th} percentile of conductivity at the sites for which appropriate data were available:

$$\ln(pH) = 1.85 + 0.0352 \cdot \ln(EC)$$

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We did not fit a regression model to the full NWIS dataset, because no trend was evident between conductivity and pH.

C.2.2 DOC

The following regression model appeared to be optimum for projecting the 10th percentile of DOC concentrations from the 10th percentile of conductivity at the sites for which appropriate data were available:

$$\ln(DOC) = 0.671 \cdot \ln(EC) - 1.60$$

As with pH, we did not fit a regression model to the full NWIS dataset, since no trend was evident between conductivity and DOC.

C.2.3 Alkalinity

The following regression model appeared to be optimum for projecting the 10th percentile of alkalinity concentrations from the 10th percentile of conductivity at the sites for which appropriate data were available:

$$\ln(alkalinity) = 1.14 \cdot \ln(EC) - 4.68$$

For the full NWIS dataset, the following regression model was developed to project alkalinity concentrations from conductivity:

$$\ln(alkalinity) = 0.652 \cdot \ln(EC) + 0.530$$

C.2.4 Calcium

The following regression model appeared to be optimum for projecting the 10th percentile of calcium concentrations from the 10th percentile of conductivity at the sites for which appropriate data were available:

$$\ln(Ca) = 1.14 \cdot \ln(EC) - 4.35$$

For the full NWIS dataset, the following regression model was developed to project calcium concentrations from conductivity:

$$\ln(Ca) = 0.866 \cdot \ln(EC) - 1.51$$

C.2.5 Magnesium

The following regression model appeared to be optimum for projecting the 10th percentile of magnesium concentrations from the 10th percentile of conductivity at the sites for which appropriate data were available:

$$\ln(Mg) = 1.27 \cdot \ln(EC) - 4.81$$

For the full NWIS dataset, the following regression model was developed to project magnesium concentrations from conductivity:

$$\ln(Mg) = 0.986 \cdot \ln(EC) - 3.48$$

C.2.6 Sodium

The following regression model appeared to be optimum for projecting the 10th percentile of sodium concentrations from the 10th percentile of conductivity at the sites for which appropriate data were available:

$$\ln(Na) = 0.578 \cdot \ln(EC) - 2.62$$

For the full NWIS dataset, the following regression model was developed to project sodium concentrations from conductivity:

$$\ln(Na) = 1.32 \cdot \ln(EC) - 4.96$$

C.2.7 Potassium

The following regression model appeared to be optimum for projecting the 10th percentile of potassium concentrations from the 10th percentile of conductivity at the sites for which appropriate data were available:

$$\ln(K) = 0.882 \cdot \ln(EC) - 3.29$$

For the full NWIS dataset, the following regression model was developed to project potassium concentrations from conductivity:

$$\ln(K) = 0.647 \cdot \ln(EC) - 3.04$$

C.2.8 Sulfate

The following regression model appeared to be optimum for projecting the 10th percentile of sulfate concentrations from the 10th percentile of conductivity at the sites for which appropriate data were available:

$$\ln(SO_4) = 1.16 \cdot \ln(EC) - 4.85$$

For the full NWIS dataset, the following regression model was developed to project sulfate concentrations from conductivity:

$$\ln(SO_4) = 1.43 \cdot \ln(EC) - 4.47$$

C.2.9 Chloride

For the full NWIS dataset, the following regression model was developed to project chloride concentrations from conductivity:

$$\ln(\text{chloride}) = 1.39 \cdot \ln(EC) - 6.15$$

Unfortunately, there were an insufficient number of sites reporting chloride data for a regression model to be developed for the 10th percentile of chloride.

C.3 Application of Conductivity Regressions

There are a number of ways in which the conductivity regressions could be used to project BLM water quality inputs. However, the most important situation may be when a fixed copper criteria value must be calculated for a site where there may be little data available to characterize water quality. In such cases, the regressions allow some or all of the BLM water quality inputs to be projected from either (1)

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a limited number of conductivity measurements or (2) a low-end conductivity value estimated by geostatistical or other methods. The first approach, projecting BLM water quality inputs from conductivity measurements, will be demonstrated in this section for a limited number of test sites. The second approach, projecting the BLM water quality inputs based on conductivities estimated by geostatistical methods, is demonstrated in the following section (Section C4).

The regression models presented above for projecting BLM water quality inputs from conductivity were tested using data and BLM predictions from a number of sites. For each site, a fixed copper criteria value was calculated using the Monte Carlo method described in EPA 2002. The BLM version 2.2.3 was used for all BLM calculations. Fixed copper criteria values were determined by the Monte Carlo method, utilizing site-specific data for parameter distributions and variance-covariance structure of all BLM water quality parameter inputs as well as filtered copper concentrations. The test sites (below) were selected on the basis of convenience, number of water quality observations, and geographic location.

The BLM water quality inputs projected from the conductivity regressions are low-end percentiles appropriate for predicting the instantaneous criterion (IC) predicted by the BLM to estimate the fixed site criteria (FSC) value. We suggested this approximation previously, based on the observation that protective FSC for copper generally corresponded to approximately the 2.5^{th} percentile of the distribution of IC predicted by the BLM. BLM estimates made for a site using the corresponding percentiles of the water quality parameter distributions will be a conservative approximation of this protective criteria values. For the present work, we are using this approach to test the 10^{th} percentile water quality parameter values projected from the conductivity regressions.

Previously we noted that filtered copper concentrations were correlated to BLM input water quality parameters at many sites. Furthermore, we found that the degree of correlation between copper concentrations and BLM input parameters appeared to be an important site-specific factor in determining the relationship between the FSC and the IC. Copper concentrations are not required to run the BLM in its toxicity prediction mode, but they are used in the Monte Carlo method to determine the FSC. Because of this, we calculated the FSC both with and without (neglecting) the correlation between copper concentrations and BLM input parameters at each test site.

C.3.1 Naugatuck River, Connecticut

The USGS has sampled the Naugatuck River near Waterville, Connecticut (Station 01208049) since 1967. Ninety-one water samples collected since 1984 provided near-concurrent measurements of all BLM water quality inputs and filtered copper concentrations. The water is low in hardness and alkalinity, slightly acidic (mean pH = 7.32), and fairly low in conductivity (10^{th} percentile = 134 µS/cm at 25º C). Organic carbon concentrations are representative for rivers and streams in this region and nationwide (logmean TOC = 4.02 mg/L), and the filtered copper concentrations are low (logmean filtered copper = 3.62 µg/L). The FSC for copper at this site was calculated to be 11.4 µg/L when the correlation between copper concentrations and BLM parameters was considered, and 7.0 µg/L when this correlation was neglected. Test results at this site are show in Table C-1.

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Table C-1. Copper Fixed Site Criterion predictions for the Naugatuck River, Connecticut using various calculation methods

Calculation Method	DOC (mg/L)	pH	Geochemical Ions	Copper Fixed Site Criterion (µg/L)
Monte Carlo FSC with [copper] correlated to inputs (r =0.7)	Data	Data	Data	11.4
Monte Carlo FSC with no [copper] correlation	Data	Data	Data	7.0
IC calculated with 10th % of input data	2.8 (10th % of data)	7.1 (10th % of data)	(10th % of data)	6.4
IC calculated with input from 10th % of conductivity and correlations	5.49 (projected from correlations)	7.55 (projected from correlations)	(projected from correlations)	21.5
IC calculated with input from 10th % of conductivity and correlations except DOC	2.7 (10th % from L3 ecoregion)	7.55 (projected from correlations)	(projected from correlations)	10.5
IC calculated with input from 10th % of conductivity and correlations except pH & DOC	2.7 (10th % from L3 ecoregion)	7.1 (10th % of data)	(projected from correlations)	5.7
IC calculated with input from 10th % of conductivity and correlations except pH & DOC	2.8 (10th % of data)	7.1 (10th % of data)	(projected from correlations)	5.9

The BLM was then applied to predict IC for copper, using low-end percentiles of the measured BLM water quality inputs. Using the 10th percentile values of all measured input data, an IC of 6.4 µg/L was predicted. This IC is 43% smaller than the FSC calculated considering the copper correlation, but only 21% smaller than the FSC neglecting this correlation. When the 10th percentiles of all of the BLM water quality inputs were instead projected from conductivity using the regression models, the predicted ICs were 21.7 µg/L (using the regressions based on 10th percentiles of the three-state data) and 21.5 µg/L (using the regressions based on all of the data). These results illustrate two important points. First, the BLM predictions based on water quality inputs all projected from conductivity correlations are quite different from BLM predictions based on site data; this will be further considered below. Secondly, however, the BLM predictions based on projected water quality inputs do not really depend on which correlations are used.

Clearly, this result shows that the regression models are unable to accurately project all BLM water quality inputs at this site. However, this was almost entirely due to inaccuracy in the pH and organic carbon projections. To demonstrate this, we recalculated the IC several times, using better estimates of the organic carbon and/or pH data, but all other BLM water quality inputs projected from conductivity using the regression models. The first recalculation was made using the 10th percentile of DOC from rivers and streams in the Northeastern Coastal Zone, the Level III ecoregion where the

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Naugatuck River is located.[7] In this case the predicted IC was 10.5 µg/L, a value much closer to the FSCs as well as the IC calculated using the 10th percentile values of all the measured input data. A second recalculation was made using the 10th percentile of the pH data, together with the ecoregional 10th percentile of DOC and all other BLM water quality inputs projected from conductivity using the regression models. Finally, a third recalculation was made in which the 10th percentiles of both pH and DOC data were input, with the remaining BLM water quality inputs projected from conductivity using the regression models. For both of these cases, the ICs were within about 10% of the prediction made using the 10th percentile values of all the measured input data. In summary, if BLM predictions are made for copper IC using measured values of pH and organic carbon, minimal error results from projecting the other BLM water quality inputs using conductivity and the regression models. As will be shown in the following sections, the same result was found for the other test sites.

The correlation between filtered copper concentrations and BLM parameters and output was quite strong at this location (r = 0.70 between filtered copper and IC predictions). As a result, the FSC corresponds to an elevated percentile (40%) of the IC predictions. If this correlation is neglected in the Monte Carlo method, the FSC corresponds to only the 14th percentile of the IC predictions. This suggests that the relationship between FSC and IC (in terms of the percentile of the IC distribution corresponding to the FSC) may be somewhat site-specific. Regardless of this complication, the conductivity regressions appear to project reliable low-end percentile estimates of the BLM water quality inputs other than pH and organic carbon. This was demonstrated by repeating the analysis described above using 5th, 2.5th, and 1st percentile input values and projections, each of which produced comparable results (not shown).

C.3.2 San Joaquin River, California

The USGS has sampled the San Joaquin River near Vernalis, California (Station 1130500) since 1950. Water samples collected since 1984 provided 283 near-concurrent measurements of all BLM water quality inputs and 77 filtered copper concentrations. The water has moderate values of hardness and alkalinity, neutral pH, and moderately high conductivity (10th percentile = 307 µS/cm at 25º C). DOC concentrations are representative for rivers and streams in this region and nationwide (logmean DOC = 5.35 mg/L), and the filtered copper concentrations are low (logmean filtered copper = 1.75 µg/L). The FSC for copper at this site was calculated to be 39.1 µg/L, and the correlation between copper concentrations and BLM parameters was strong (r = 0.624 between filtered copper and IC predictions). This FSC value corresponds to the 46th percentile of the distribution of IC. When the FSC for copper was recalculated assuming no correlation between copper concentrations and BLM parameters, the value decreased to 11.1 µg/L (corresponding to the 4.5th percentile of the IC distribution). Test results at this site are tabulated Table C-2.

[7] Ecoregion and water body-type specific DOC concentration percentiles were tabulated for the *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000), Technical Support Document Volume 2: Development of National Bioaccumulation Factors* (EPA-822-R-03-030).

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Table C-2. Copper Fixed Site Criterion predictions for the San Joaquín River, California using various calculation methods

Calculation Method	DOC (mg/L)	pH	Geochemical Ions	Fixed Site Criterion (µg/L)
Monte Carlo FSC with [copper] correlated to inputs (r =0.6)	Data	Data	Data	39.1
Monte Carlo FSC with no [copper] correlation	Data	Data	Data	11.1
IC calculated with 10th % of input data	2.7 (10th % of data)	7.5 (10th % of data)	(10th % of data)	11.9
IC calculated with input from 10th % of conductivity and correlations	9.38 (projected from correlations)	7.77 (projected from correlations)	(projected from correlations)	54.0
IC calculated with input from 10th % of conductivity and correlations except DOC	2.79 (10th % from L3 ecoregion)	7.77 (projected from correlations)	(projected from correlations)	16.0
IC calculated with input from 10th % of conductivity and correlations except pH & DOC	2.79 (10th % from L3 ecoregion)	7.5 (10th % of data)	(projected from correlations)	11.6
IC calculated with input from 10th % of conductivity and correlations except pH & DOC	2.7 (10th % of data)	7.5 (10th % of data)	(projected from correlations)	11.2

The BLM was then applied to predict IC for copper, using low-end percentiles of the BLM water quality inputs. Using the 10th percentile values of all measured input data, an IC of 11.9 µg/L was predicted, which is 70% smaller than the FSC calculated considering the copper concentration correlation but 7% higher than the FSC neglecting this correlation. When the 10th percentiles of all of the BLM water quality inputs were instead projected from conductivity using the regression models, the predicted IC were 50.0 µg/L (using the regressions based on 10th percentiles of the three-state data) and 54.0 µg/L (using the regressions based on all of the data). Again, the BLM predictions based on projected water quality inputs do not really depend on which correlations are used. And, as was the case at the Naugatuck River site, the regression models were unable to accurately project all BLM water quality inputs at this site, although the error is again almost entirely due to inaccuracy in the pH and organic carbon projections. As in the previous case, we demonstrated this by recalculating the IC several times, using better estimates of the organic carbon and/or pH data, but all other BLM water quality inputs projected from conductivity using the regression models. The first recalculation was made using the 10th percentile of DOC from rivers and streams in the Central California Valley, the Level III ecoregion where the San Joaquin River is located. In this case the predicted IC was 16.0 µg/L, a value much closer to the uncorrelated FSCs as well as the IC calculated using the 10th percentile values of all the measured input data. A second recalculation was made using the 10th percentile of the pH data, together with the ecoregional 10th percentile of DOC and all other BLM water quality inputs projected from conductivity using the regression models. Finally, a third recalculation was made in which the 10th percentiles of both pH and DOC data were input, with the remaining BLM water quality inputs projected from conductivity using the regression models. For both of these cases, the ICs were within

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about 5% of the prediction made using the 10th percentile values of all the measured input data. BLM predictions made for copper IC at this site using measured values of pH and organic carbon, but all other BLM water quality inputs projected using conductivity regressions, were found to be accurate in comparison to model predictions made using all measured input data.

C.3.3 South Platte River, Colorado

The South Platte River has been sampled by the USGS at Denver, Colorado (Station 06714000) since 1972. Water samples collected since 1984 provided 93 near-concurrent measurements of all BLM water quality inputs and 10 filtered copper concentrations. The water is moderately high in hardness and alkalinity, neutral pH, and moderate conductivity (10th percentile = 229 µS/cm at 25° C). Organic carbon concentrations are representative for rivers and streams in this region (logmean DOC = 5.50 mg/L), and the filtered copper concentrations are low (logmean filtered copper = 3.27 µg/L). The FSC for copper at this site was calculated to be 35.4 µg/L. This FSC value corresponds to the 32nd percentile of the distribution of IC. Moderate correlation between copper concentrations and BLM parameters was observed at this site (r = 0.50 between filtered copper and IC predictions). When the FSC for copper was recalculated assuming no correlation between copper concentrations and BLM parameters, the value decreased to 20 µg/L (corresponding to the 4.3rd percentile of the IC distribution). Test results at this site are shown in Table C-3.

Table C-3. Copper Fixed Site Criterion predictions for the South Platte River, Colorado using various calculation methods

Calculation Method	DOC (mg/L)	pH	Geochemical Ions	Copper Fixed Site Criterion (µg/L)
Monte Carlo FSC with [copper] correlated to inputs (r =0.5)	Data	Data	Data	35.4
Monte Carlo FSC with no [copper] correlation	Data	Data	Data	20.0
IC calculated with 10th % of input data	4.1 (10th % of data)	7.5 (10th % of data)	(10th % of data)	17.3
IC calculated with input from 10th % of conductivity and correlations	7.7 (projected from correlations)	7.7 (projected from correlations)	(projected from correlations)	37.5
IC calculated with input from 10th % of conductivity and correlations except DOC	4.5 (10th % from L3 ecoregion)	7.7 (projected from correlations)	(projected from correlations)	21.6
IC calculated with input from 10th % of conductivity and correlations except pH & DOC	4.5 (10th % from L3 ecoregion)	7.5 (10th % of data)	(projected from correlations)	17.3
IC calculated with input from 10th % of conductivity and correlations except pH & DOC	4.1 (10th % of data)	7.5 (10th % of data)	(projected from correlations)	15.9

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The BLM was applied to predict IC for copper, using low-end percentiles of the BLM water quality inputs. Using the 10th percentile values of all measured input data, an IC of 17.3 µg/L was predicted, which is 51% smaller than the FSC calculated considering the copper concentration correlation but only 14% smaller than the FSC neglecting this correlation. When the 10th percentiles of all of the BLM water quality inputs were instead projected from conductivity using the regression models, the predicted IC was 37.5 µg/L. As was the case at the previous sites, the regression models were again unable to accurately project pH and organic carbon concentrations for input to the BLM. We demonstrated this by recalculating the IC several times, using better estimates of the organic carbon and/or pH data, but all other BLM water quality inputs projected from conductivity using the regression models. The first recalculation was made using the 10th percentile of DOC from rivers and streams in the Western High Plains, the Level III ecoregion where the South Platte River is located. In this case the predicted IC was 21.6 µg/L, a value much closer to the uncorrelated FSCs as well as the IC calculated using the 10th percentile values of all the measured input data. A second recalculation was made using the 10th percentile of the pH data, together with the ecoregional 10th percentile of DOC and all other BLM water quality inputs projected from conductivity using the regression models. Finally, a third recalculation was made in which the 10th percentiles of both pH and DOC data were input, with the remaining BLM water quality inputs projected from conductivity using the regression models. For both of these cases, the ICs were within 10% of the prediction made using the 10th percentile values of all the measured input data. As with the previous cases, the BLM predictions made for copper IC at this site using measured values of pH and organic carbon, but where all other BLM water quality inputs were projected using conductivity regressions, were found to be accurate in comparison to model predictions made using all measured input data.

C.3.4 Halfmoon Creek, Colorado

The USGS has sampled Halfmoon Creek near Malta, Colorado (Station 07083000) since 1959. Seventy-three water samples collected since 1984 provided near-concurrent measurements of all BLM water quality inputs and 18 filtered copper concentrations. The water is very low in hardness and alkalinity, slightly acidic (mean pH = 7.76), and low in conductivity (10th percentile = 50.1 µS/cm at 25° C). Organic carbon concentrations are low (logmean DOC = 0.92 mg/L), as are the filtered copper concentrations (logmean filtered copper = 1.75 µg/L). The FSC for copper at this site was calculated to be 1.56 µg/L, corresponding to the 6th percentile of the distribution of IC. The correlation between copper concentrations and BLM parameters was negligible at this site, so the Monte Carlo FSC were not calculated twice (i.e., with and without the copper correlation) as was done at the other sites. Test results at this site are shown in Table C-4.

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Table C-4. Copper Fixed Site Criterion predictions for the Halfmoon Creek, Colorado using various calculation methods

Calculation Method	DOC (mg/L)	pH	Geochemical Ions	Copper Fixed Site Criterion (µg/L)
Monte Carlo FSC with [copper] correlated to inputs (r =0.01)	Data	Data	Data	1.56
IC calculated with 10th % of input data	0.6 (10th % of data)	7.2 (10th % of data)	(10th % of data)	1.42
IC calculated with input from 10th % of conductivity and correlations	2.8 (projected from correlations)	7.3 (projected from correlations)	(projected from correlations)	7.43
IC calculated with input from 10th % of conductivity and correlations except DOC	0.6 (10th % from L3 ecoregion)	7.3 (projected from correlations)	(projected from correlations)	1.58
IC calculated with input from 10th % of conductivity and correlations except pH & DOC	0.6 (10th % from L3 ecoregion)	7.2 (10th % of data)	(projected from correlations)	1.39
IC calculated with input from 10th % of conductivity and correlations except pH & DOC	0.6 (10th % of data)	7.2 (10th % of data)	(projected from correlations)	1.39

The BLM was then applied to predict IC for copper, using low-end percentiles of the BLM water quality inputs. Using the 10th percentile values of all measured input data, an IC of 1.42 µg/L was predicted, only 9% smaller than the FSC. When the 10th percentiles of all of the BLM water quality inputs were instead projected from conductivity using the regression models, the predicted IC was 7.43 µg/L. Again, this result clearly shows that the regression models are unable to accurately project all BLM water quality inputs at this site. As in the previous examples, this was almost entirely due to inaccuracy in the pH and organic carbon projections. As in the previous cases, we demonstrated this by recalculating the IC several times, using better estimates of the organic carbon and/or pH data, but all other BLM water quality inputs projected from conductivity using the regression models. The first recalculation was made using the 10th percentile of DOC from rivers and streams in the Southern Rockies, the Level III ecoregion where Halfmoon Creek is located. In this case the predicted IC was 1.58 µg/L, a value within about 10% of the FSC as well as the IC calculated using the 10th percentile values of all the measured input data. A second recalculation was made using the 10th percentile of the pH data, together with the ecoregional 10th percentile of DOC and all other BLM water quality inputs projected from conductivity using the regression models. Finally, a third recalculation was made in which the 10th percentiles of both pH and DOC data were input, with the remaining BLM water quality inputs projected from conductivity using the regression models. For both of these cases, the ICs were within about 2% of the prediction made using the 10th percentile values of all the measured input data. As in the previous examples, if BLM predictions are made for copper IC using measured values of pH and organic carbon, minimal error results from projecting the other BLM water quality inputs using conductivity and the regression models.

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C.3.5 Summary of Site-Specific Test Results

The results of this work can be summarized as follows:

Regression models were developed to project 10th percentiles of BLM water quality parameters from the 10th percentile of conductivity distributions at sites in Colorado, Utah, and Wyoming. The regression models were tested using data and copper BLM predictions for four sites, and produced highly consistent results. The regression models for pH and DOC, the most sensitive of BLM water quality parameters, were not sufficiently accurate to make reliable BLM predictions. However, regression models for the GI parameters (alkalinity, calcium, magnesium, sodium, potassium, sulfate, and chloride,) were reasonably accurate, as judged by comparison of model predictions made using projected values of the GI BLM input parameters to model predictions made using all measured input data. The regression models used to project GI parameters from conductivity were calculated two different ways; however, the BLM predictions of IC were not sensitive to this difference.

We were unable to find an estimate for site-specific pH that was superior to the (admittedly poor) conductivity regression. To improve upon this estimate it was necessary to use actual site-specific pH data. This appears to be the general case for reliable site-specific BLM application.

For DOC, the ecoregion and water body-type specific DOC concentration percentiles tabulated by EPA for the National Bioaccumulation Factors Technical Support Document appear to be far better estimates of lower-percentile DOC concentrations than the projections made using the conductivity regression. These tabulations are based on an organic carbon database compiled prior to 2003 from a number of sources including EPA's STOrage and RETrieval Data Warehouse (STORET) and the USGS NWIS. The utility of these tabulations could be improved by updating them to incorporate newer information. For example, EPA recently released data from the Wadeable Stream Assessment, which included DOC measurements from a statistically based random sample of ~2,000 streams. Other statistically-based national water quality surveys, including national assessments of lakes and large rivers, will also be providing additional data in future years.

The Monte Carlo method developed to calculate FSC for copper was applied at each of the four sites, both with and without the correlation between filtered copper concentrations and the BLM water quality parameters that were found to be significant at three of the sites. We also approximated the FSC using the 10th percentile of the distribution of IC predicted by the BLM at each site. When copper concentration correlations were considered in the FSC calculations, the 10th percentile of the IC distributions was found to be highly conservative approximations of the FSC, underestimating the FSC by 44 to 70%. This is illustrated in Figure C-1, which also shows the good agreement between IC predicted with the BLM using site-specific data and IC predicted using measured pH and organic carbon but projected values of the GI BLM input parameters. Ecoregion and water body-type specific DOC concentration percentiles ("L3-DOC" in the figure below) were also an improvement over the projections based on conductivity regressions.

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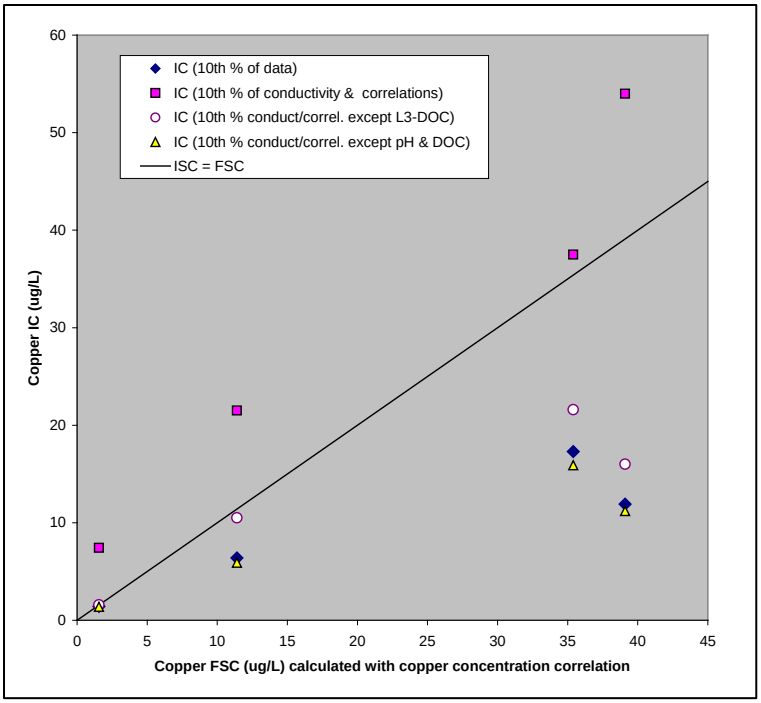


Figure C-1. Instantaneous Criteria (IC) predicted with the BLM using site-specific data and IC predicted using measured pH and organic carbon and projected values of the GI BLM input parameters

When copper concentration correlations were neglected in the FSC calculations, the 10th percentile of the IC distributions did a much better job approximating the FSC. This is shown in Figure C-2. In this case, the 10th percentile of the IC distributions was within 15% of the FSC. This figure also shows the good agreement between IC predicted with data and projected values of the GI BLM input parameters.

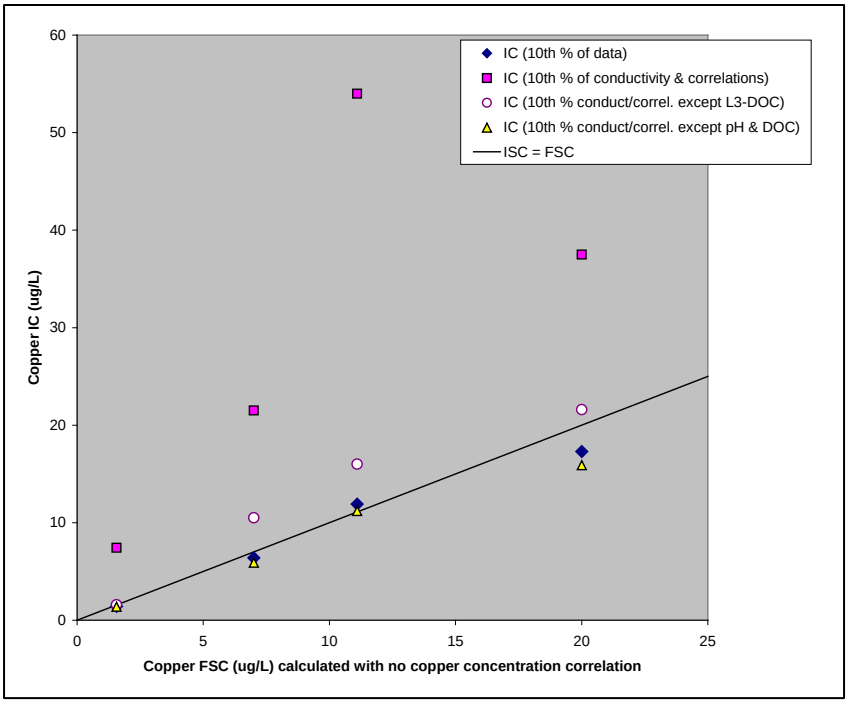


Figure C-2. 10th percentile of the IC distributions using data and projected (predicted) values of the GI BLM parameters

The degree of correlation between filtered copper concentrations and BLM input water quality parameters appears to be an important site-specific factor in determining the relationship between the FSC and the IC. Figure C-3 plots the percentile of the IC corresponding to the FSC for each site as a function of the correlation coefficient between the copper concentrations and the IC, for two cases: (1) FSC calculated by the Monte Carlo method including the observed correlations between concentrations of copper and BLM input water quality parameters, and (2) FSC calculated with no correlation between concentrations of copper and BLM input water quality parameters. In the first case (plotted with dark diamond symbols), the percentile of the IC corresponding to the FSC increases substantially (6th to 46th percentile) as the correlation coefficient between the copper concentrations and the IC increases. If the correlation between concentrations of copper and BLM input water quality parameters is neglected (the second case, plotted in lighter square symbols), the percentile of the IC corresponding to the FSC is considerably lower (4.3rd to 14th percentile). This suggests that correlations between copper concentrations and BLM input parameters should be given careful consideration when calculating FSC.

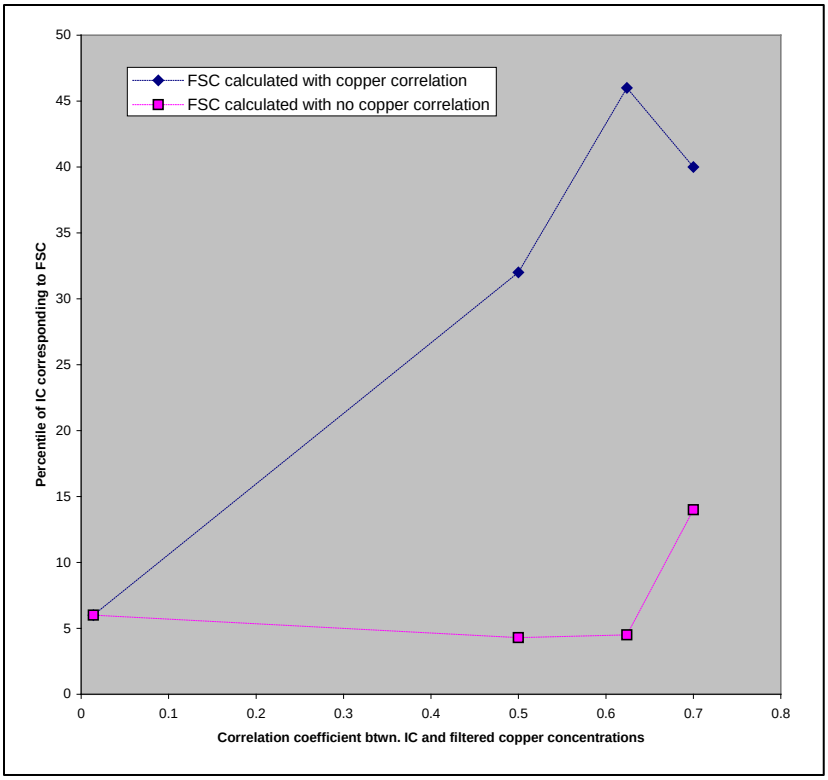


Figure C-3. Percentile of the IC corresponding to the FSC for each site as a function of the correlation coefficient between the copper concentrations and the IC when the FSC is calculated with Copper correlation and when FSC is calculated without Copper correlation

C.4 Combining GI-Conductivity Regressions with Geostatistical Techniques

Geostatistical techniques are attractive because they explain parameter variation arising from spatial correlations, which are otherwise ignored by (and may, in fact, violate the assumptions of) conventional statistics. BLM input water quality parameters (except for pH and DOC) are GIs, the concentrations of which vary in surface water due to dissolution, weathering, ground water-surface water interactions, and other geologic processes in the watershed. Consequently, the concentrations of GI parameters tend to vary according to the regional geology. For example, water hardness has noticeable geographic trends. Areas with limestone geology, such as in the prairie states, tend toward high hardness and alkalinity. Areas of with granite geology, such as parts of the Northeast, tend toward low hardness and alkalinity. The estimation of GI parameter values based on geography thus seems possible. EPA has provided a prototype of a geostatistical approach[8] that demonstrated this potential. That work applied kriging to predict median concentrations of five of the BLM water quality input parameters (pH, DOC, alkalinity, sodium, and calcium) averaged over 8-digit HUCs, using the USGS NWIS as the source of spatial data. Comparison of measured concentrations with kriging predictions were encouraging, especially for DOC and alkalinity. Geostatistical techniques to project BLM GI input

parameters might well be developed from the same nationwide monitoring data used to develop a correlation approach. By the same token, geostatistical techniques based on these data may suffer the same problems experienced when developing the correlation approach. Most significantly, the NWIS data are not randomly distributed in either time or space, and the measurements of the BLM GI parameters are generally uneven (considerable differences in terms of the number of observations for different parameters) and/or inconsistent (i.e., relatively few concurrent measurements of BLM GI parameters).

There may be great value in supplementing the geostatistical approach with classical estimation methods, such as regression and correlation. Examination of the NWIS data suggests that conductivity may be useful for estimating BLM input water quality parameters in conjunction with geostatistics. The literature indicates that conductivity is one of the most widely monitored water quality indicators in the US. Among water quality parameters, the data for conductivity are the most complete and cover the longest time period (Wang and Yin, 1997). In part, this is because conductivity measurements are usually included in automated multiparameter systems for monitoring changes in the quality of surface waters (Allen and Mancy, 1972). A vast amount of conductivity data exists, both in terms of the total number of observations and the number of sites reporting this parameter in comparison to the BLM GI quality parameters. For example, NWIS data for the state of Colorado have almost four times as many observations of conductivity as for calcium, and they are measured at more than twice the number of sites. There are 20 times as many observations of conductivity as for alkalinity, and they are measured at more than seven times the number of sites. Since conductivity data are abundant, and correlate well to the BLM GI parameters (GLEC, 2007), it is reasonable to incorporate conductivity in spatial projections of BLM parameters. This may simplify the geostatistical approach and allow more robust spatial projections of BLM water quality parameters.

Although combining GI-conductivity regressions with geostatistical techniques seems promising for the reasons mentioned above, this approach had never been demonstrated. We conducted a simple test using NWIS conductivity and hardness data from the state of Colorado. We used data from Colorado because many more stations were sampled in comparison to the surrounding states.

The data were processed in a manner similar to the methods used to develop the regressions in Section C.2. For each station, we calculated the 10^{th} percentiles of conductivity and hardness. A regression model was fit to the full dataset (data for all rivers and streams sampled in Colorado between 1984 to 2005). The following regression model was developed to project hardness from conductivity:

$$\ln(\text{hardness}) = 0.984 \cdot \ln(EC) - 0.870$$

We also kriged the 10^{th} percentiles of conductivity and hardness, using latitude and longitude coordinates reported by USGS for each sampling station. Figure C-4 shows the kriged surface of the 10^{th} percentile of conductivity at all stations in Colorado, Utah, and Wyoming. Data are far more abundant in Colorado, as shown by the density of the dots representing the locations of sampling stations. Figure C-5 shows the kriged surface of the 10^{th} percentile of hardness at all stations in Colorado. Kriging was done using the Vertical Mapper program, version 3.1; no attempts were made to optimize the kriging of conductivity or hardness by parameter adjustment.

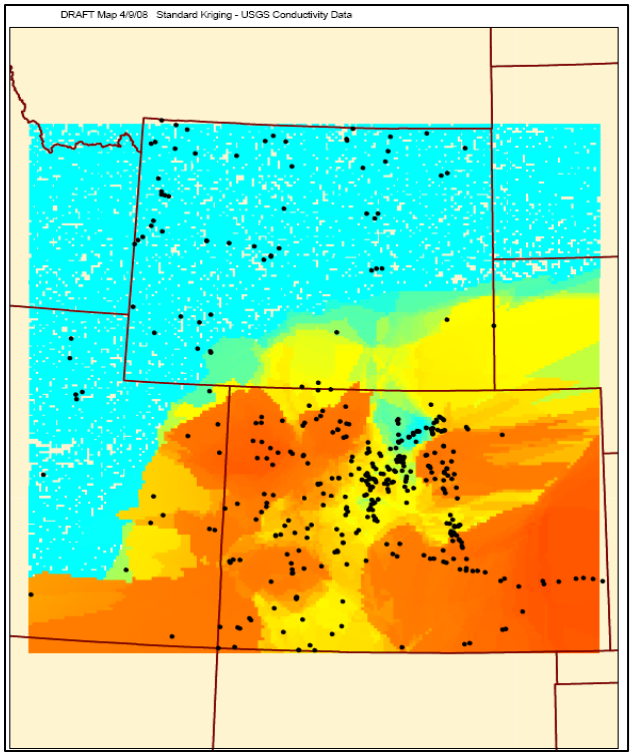


Figure C-4. Kriged surface of the 10th percentile of conductivity at all stations in Colorado, Utah and Wyoming

Dots represent sampling stations; notice that data are far more abundant in Colorado.

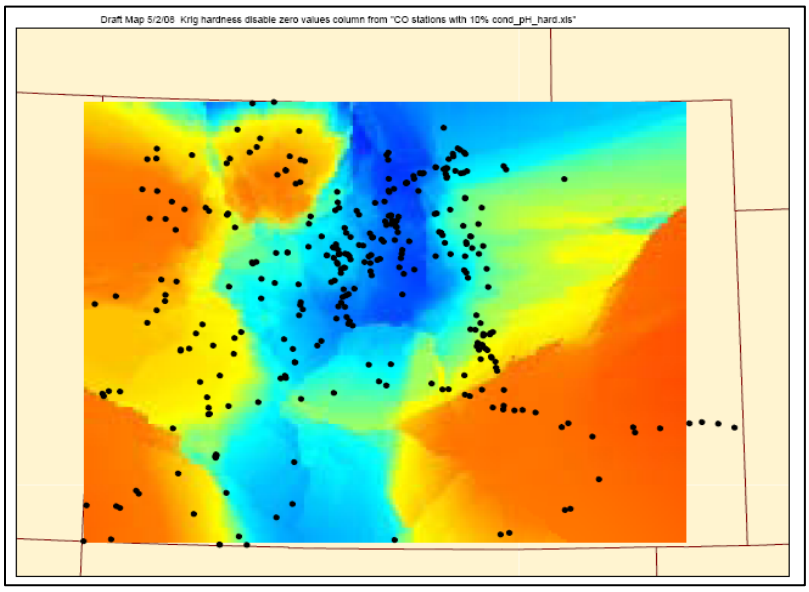


Figure C-5. Kriged surface of the 10th percentile of hardness at all stations in Colorado

Our goal was to see whether combining the kriged conductivities with the conductivity-hardness regression would project the 10th percentiles of hardness better than direct kriging of the hardness

data. For the combined kriging/regression approach, we determined the kriged conductivity values at all of the sampling locations and then projected the 10th percentiles of hardness at these locations using the regression equation. We also determined the directly-kriged 10th percentiles of hardness at all of the sampling locations.

The hardness estimates obtained by each approach were then compared to the 10th percentiles of hardness measured at each station. The results of this comparison are shown graphically in Figure C-6. Both approaches produce estimates of hardness that correlate significantly with the measured data (correlation coefficient r= 0.80 for direct kriging of hardness; r= 0.950 for conductivity kriging + regression projection). However, the kriging+regression approach fits the hardness data substantially better than direct kriging. To quantify this, we calculated the residual sum of squares (RSS), a composite measure of the discrepancy between the data and our alternative hardness estimates. The smaller this discrepancy is, the better the estimation will be. In natural log space, the RSS for the kriging+regression approach is 18.6 (135 degrees of freedom, or df) while the log-space RSS for the direct kriging approach is 73.4 (136 df). Thus, for this test case substantially better estimates of the 10th percentile of hardness were made by the kriging/regression approach compared to direct kriging.

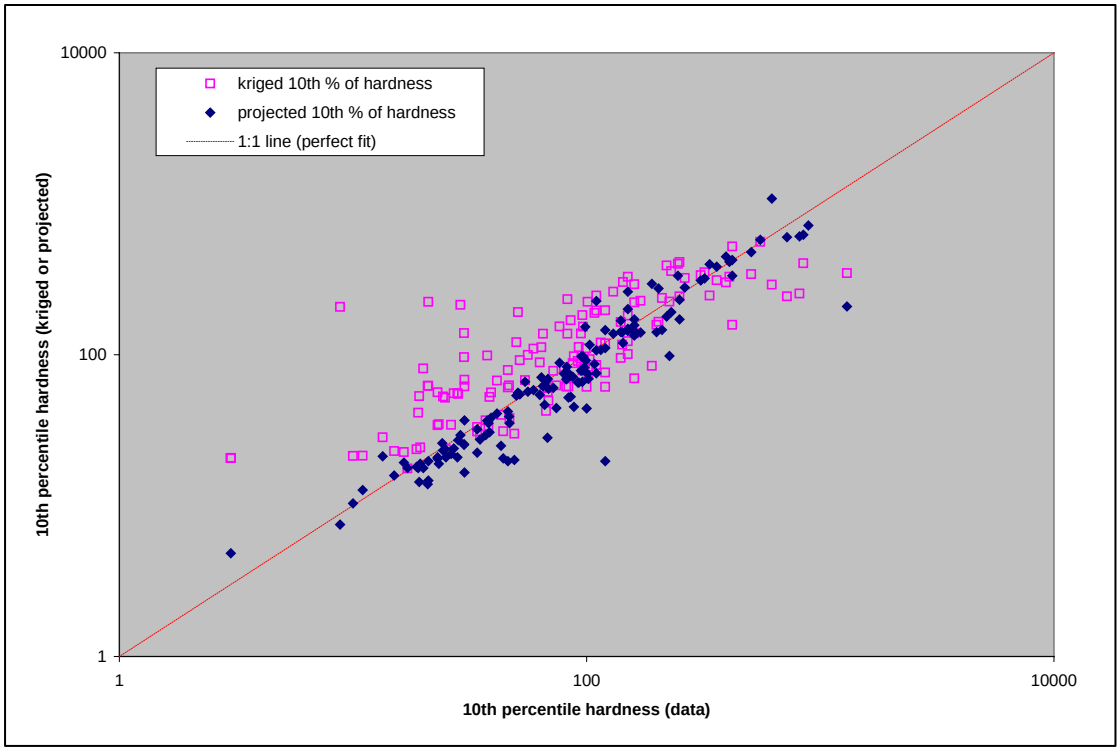


Figure C-6. Comparison of the 10th percentile of hardness at all stations in Colorado with estimates based on (a) direct kriging of hardness data and (b) kriging of conductivity to station locations and projecting conductivity to hardness via regression ("kriging/regression")

As this test demonstrated, combining kriging with regressions to project BLM GI inputs from conductivity appears to improve the accuracy of estimates of parameters used as BLM inputs. Applying the conductivity kriging/regression projection approach on a broader scale should be considered as a

"next step" in developing tools to estimate BLM water quality parameters for sites where there may be few or no data available to characterize water quality. Since direct kriging of most BLM GI parameters has already been done using data from NWIS, it will also be worthwhile to continue comparing the alternative estimates to the observed data in order to obtain the best estimates.

We should also note that although the kriging/regression approach can be used to improve the accuracy of estimates of GI parameters used as BLM inputs, this approach cannot be expected to produce accurate site-specific estimates for the two most important BLM inputs: pH and DOC. As shown in Section C.3, accurate estimates of the GI parameters are less important than pH and DOC in terms of predicting appropriate site-specific IC and FSC. Since our analysis of NWIS data indicates there to be either little no trend between conductivity and pH, and direct kriging produced similarly ambiguous predictions, we must conclude that site-specific data for pH must either be available or be collected for BLM application at a site. This may not be a significant obstacle, since pH data can be cheaply and readily acquired.

Lack of methods to accurately estimate DOC is a bigger problem, since measurements of this parameter are comparatively rare and DOC is a relatively expensive measurement to make. For DOC, analysis of NWIS data again indicates no trend with conductivity, so the kriging/regression approach is not appropriate for this parameter. However, other analyses conducted suggested that DOC could be kriged with some success. And, as was demonstrated for the test sites in Section C.3, the ecoregion and water body-type specific DOC concentration percentiles tabulated by EPA for the National Bioaccumulation Factors Technical Support Document appear to offer reasonable estimates of lower-percentile DOC concentrations. Further development of these approaches for estimating site-specific DOC appears worthwhile, for example by incorporating new data from the Wadeable Stream Assessment and other statistically-based national water quality surveys.

C.5 References

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Appendix D: Approaches for Estimating Missing Biotic Ligand Model Input Parameters: Projections of Total Organic Carbon as a Function of Biochemical Oxygen Demand

D.1 Introduction

The 2007 Update of the Ambient Water Quality Criteria for Copper (EPA-822-R-07-001) employs the Biotic Ligand Model (BLM) to estimate bioavailability of this metal in toxicity tests used in Criterion Maximum Concentration derivation, which requires data on the 10 input parameters for the BLM, including dissolved organic carbon (DOC). Data for DOC concentrations, in both effluents and receiving waters, are extremely limited. The BLM is very sensitive to DOC concentrations (HydroQual, 2005), which means that to ensure accurate predictions of copper bioavailability and toxicity reliable data on DOC concentrations in the water are needed. Effluent DOC concentrations, which are necessary for application of the BLM to predict copper toxicity associated with a wastewater discharge, are monitored by very few publicly-owned treatment works (POTWs).

Projections of DOC concentrations from biochemical oxygen demand (BOD) values may be a viable solution for surmounting the lack of data on DOC. Effluent BOD (most typically 5-day BOD) is monitored by most POTWs. We expect a positive correlation between BOD and DOC, because the two parameters are conceptually related. While DOC quantifies the concentration of many organic compounds dissolved in water, BOD is a routine surrogate test for estimating the load of organic carbon into the environment. Ideally, one might expect an almost stoichiometric relationship between organic carbon (i.e., DOC) and the oxygen consumed during its metabolization (i.e., BOD). For instance, Fadini et al. (2004) evaluated the possible replacement of BOD for DOC measurements in a number of different wastewater categories. A statistical relationship between effluent BOD and DOC would provide estimates of DOC concentrations, needed for application of the BLM, from routine BOD monitoring data. The effluent contribution to in-stream DOC could then be estimated, for example, by using a dilution model for a site.

Evidence, from analyses of effluent monitoring data from the New York State Department of Environmental Conservation (NYSDEC) Contaminant Assessment and Reduction Project (CARP), suggests that most of the total organic carbon (TOC) in POTW effluent is in the form of DOC. Therefore, a regression between BOD and TOC could be used as a surrogate for the relationship between BOD and DOC. The advantage of using TOC is the greater availability of data. TOC is reported for a significant number of major POTW dischargers.

D.2 Data

In 2006, monitoring data from all major POTWs reporting TOC and 5-day BOD in the United States were downloaded from the U.S. Environmental Protection Agency (EPA) Permit Compliance System (PCS) web site http://www3.epa.gov/enviro/facts/pcs-icis/search.html. Nine POTWs had 30 or more synchronous records of TOC and BOD, while 23 POTWs had at least 10 synchronous records. These numbers include both monthly average and maximum monthly values.

Review of the data indicated several extremely high (>1,000 milligrams per liter [mg/L]) effluent TOC values for discharger CA0079243. We assumed that they presented errors in the reported unit, and divided them by 1,000 to convert from units of microgram per liter (µg/L) to mg/L. TOC and BOD

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records were matched by POTW, location (e.g., upstream, downstream, influent or effluent), year and month. Thus, "synchronous" measurements do not necessarily correspond to samples collected on the same day and time. The resulting table had 341 records.

D.3 Results

D.3.1 TOC and BOD at All Monitoring Locations

The first statistical evaluation involved data for all monitoring locations at the eight POTWs reporting 30 or more synchronous records of TOC and BOD. Table D-1 presents the results of least squares regression of the average monthly data: TOC*avg* = *a* + *b* BOD*avg*. A scatter plot of this data is shown in Figure D-1. Table D-2 presents the results of least squares regression of the maximum monthly data: TOC*max* = *a* + *b* BOD*max*. A scatter plot of this data is shown in Figure D-2. Bimodal distributions are observed for TOC and especially BOD in this data set. It should be noted that the BOD concentrations of 200 mg/L or higher were measured in samples of untreated (influent) wastewater; TOC concentrations were also quite high in these samples. Both scatter plots (Figures D-1 and D-2) show a fairly strong correlation between TOC and BOD in the combined data for all POTWs. The linear relationship between TOC and BOD is better defined in the average data (Figure D-1).

Table D-1. Least squares regression of average monthly TOC and BOD data for all monitoring locations

POTW	Location	Intercept (a)	Slope (b)	r^2	df
CA0054372	Effluent Gross Value				
CA0105295	Effluent Gross Value	7.551	-0.379	0.009	41
CA0105295	Raw Sew/Influent	19.935	0.142	0.104	59
CA8000326	Effluent Gross Value*				
CA8000383	Effluent Gross Value	4.952	0.725	0.344	31
CA8000383	Raw Sew/Influent	59.586	0.107	0.038	30
ID0020443	Upstream Monitoring*				
ID0020443	Downstream Monitoring	3.500	-0.400	0.190	2
ID0023981	Effluent Gross Value	6.268	0.281	0.196	26
ID0023981	Upstream Monitoring	3.200	-0.300	0.127	3
LA0073521	Effluent Gross Value*				
TN0023353	Effluent Gross Value	2.628	0.391	0.438	35
All POTWs	All locations	4.828	0.237	0.873	243

*note: POTW/location without regression results indicates less than 2 synchronous data records

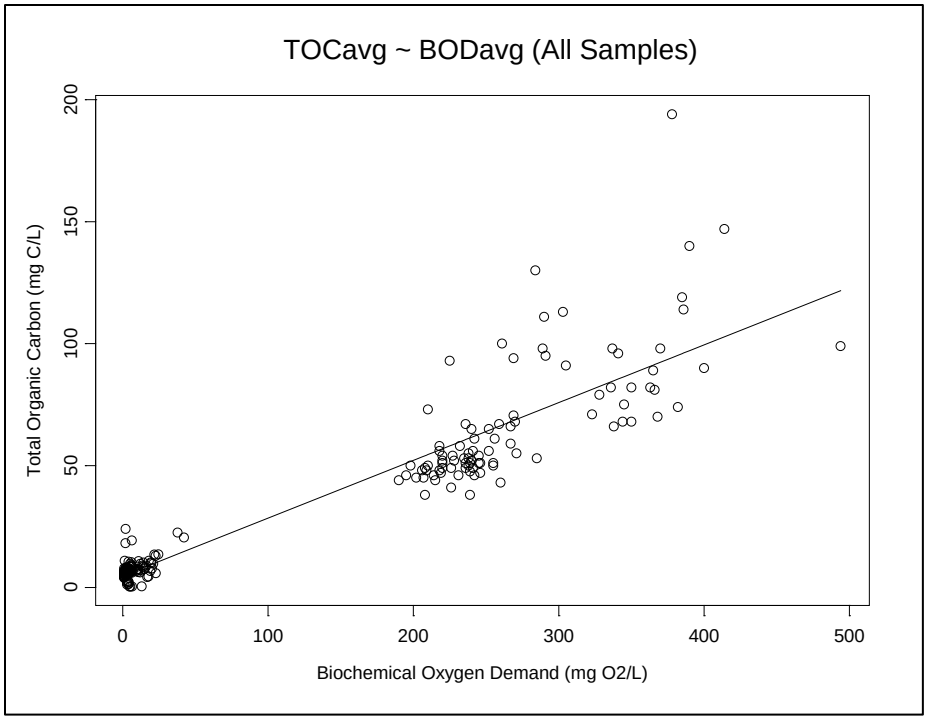


Figure D-1. Scatter Plot of Average Monthly Data (all Monitoring Locations)

Table D-2. Least squares regression of maximum monthly TOC and BOD data for all monitoring locations

POTW	Location	Intercept (a)	Slope (b)	r^2	df
CA0054372	Effluent Gross Value	9.420	0.499	0.154	29
CA0105295	Effluent Gross Value	8.567	-0.114	0.007	50
CA0105295	Raw Sew/Influent	56.439	0.062	0.046	59
CA8000326	Effluent Gross Value	7.307	0.006	0.000	28
CA8000383	Effluent Gross Value	6.674	0.507	0.235	31
CA8000383	Raw Sew/Influent	149.293	0.047	0.052	30
ID0020443	Upstream Monitoring	0.300	1.175	0.039	4
ID0020443	Downstream Monitoring	3.500	-0.400	0.190	2
ID0023981	Effluent Gross Value	6.210	0.208	0.202	28
ID0023981	Upstream Monitoring	3.200	-0.300	0.127	3
LA0073521	Effluent Gross Value	12.989	-0.818	0.110	18
TN0023353	Effluent Gross Value*				
All POTWs	All locations	11.183	0.196	0.700	302

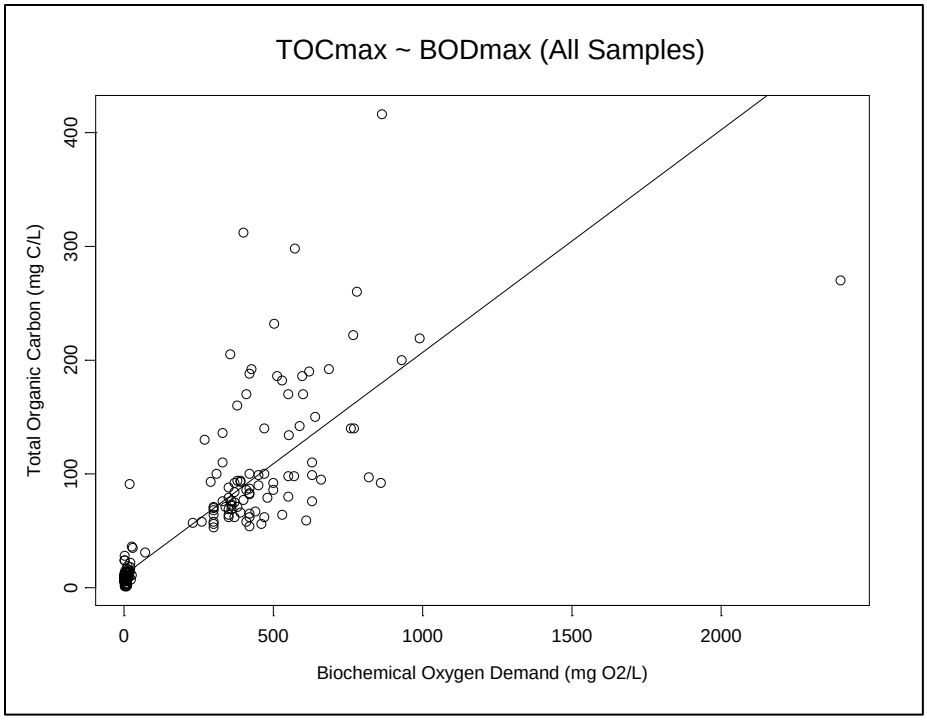


Figure D-2. Scatter Plot of Maximum Monthly Data (all Monitoring Locations)

Results of regression analyses revealed large differences in slopes of the linear model TOC = *a* + *b* BOD among locations and POTWs. Slopes for individual regressions ranged from –0.40 to 0.73 for average, and from -0.82 to 0.50 for maximum BOD and TOC values. Coefficients of determination (r^2) for the regressions were low; for most of them $r^2 < 0.2$. Pooling the data from all POTWs and locations increased the r^2 to 0.87 for average and 0.70 for maximum BOD and TOC values.

Diagnosis of regression analyses revealed that variance in both the average and maximum TOC rose with increasing values of biochemical oxygen demand. Such patterns were also evident from a simple inspection of the plots cited above. Homogeneity of variance, though, is a core assumption of ordinary least squares regression, and its violation compromises the quality of results generated by the analysis. The solution was to perform quantile regression analysis because it does not assume that variance of the response is homogeneous along the range of the independent variable. The fitted model for the 50^{th} quantile (median) was:

$$TOC_{avg} = 5.5647 + 0.2088\ BOD_{avg} \quad (243\ df,\ R^1 = 0.77)$$

D.3.2 TOC and BOD at Effluent Monitoring Locations

Although the quantile regression model above provided a reasonable fit of the data at all monitoring locations, we were specifically interested in the relationship between TOC and BOD measured in POTW effluents. Therefore, we conducted a separate statistical analysis of effluent monitoring data from the 17 POTWs with more than one synchronous record of TOC and BOD retrieved from PCS. TOC and BOD records were again matched by POTW, year, and month. The resulting data tabulation had 373 records.

The results of least squares regression of the average monthly effluent data: TOC*avg* = *a* + *b* BOD*avg* are presented in Table D-3. A scatter plot of this data is shown in Figure D-3. Table D-4 presents the results of least squares regression of the effluent maximum monthly data: TOC*max* = *a* + *b* BOD*max*. A scatter plot of this data is shown in Figure D-4.

Table D-3. Least squares regression of average monthly TOC and BOD data for effluent monitoring locations

POTW	Intercept (a)	Slope (b)	r^2	df
CA0054372				
CA0077691				
CA0079103				
CA0079243				
CA0102822				
CA0105295	7.5512	-0.3789	0.009	41
CA0107492				
CA0109991				
CA8000073				
CA8000326				
CA8000383	4.9522	0.7254	0.344	31
ID0023981	6.2679	0.2808	0.196	26
LA0069868				
LA0073521				
TN0023353	2.6284	0.3909	0.438	35
TN0023531	37.6422	-1.1348	0.076	3
TN0023574	7.4142	0.0882	0.016	25
All POTWs	5.8740	0.2859	0.245	174

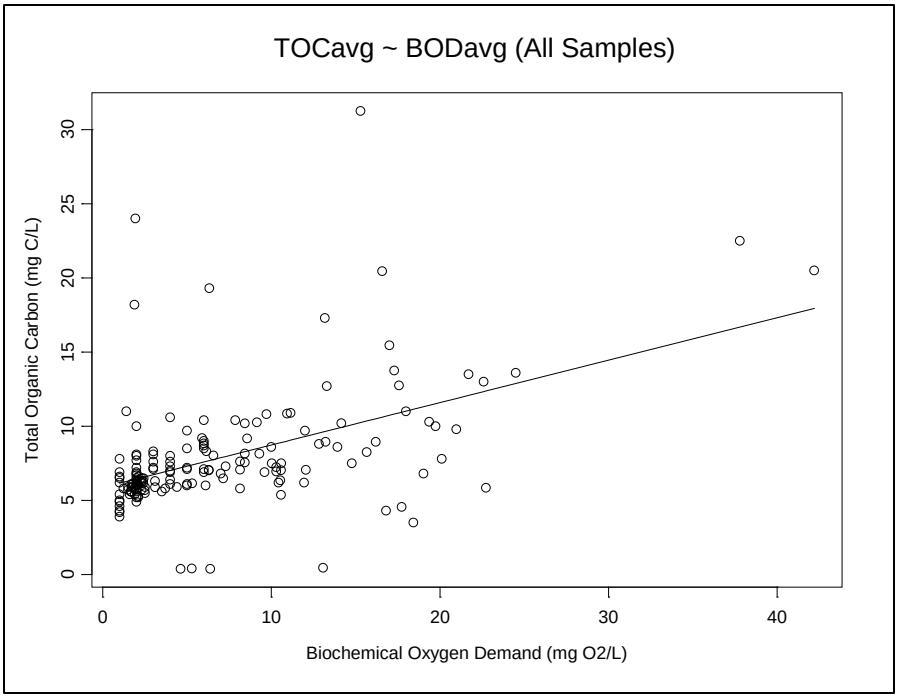


Figure D-3. Scatter Plot of Average Monthly Data (Effluent Monitoring Locations)

Table D-4. Least squares regression of maximum monthly TOC and BOD data for effluent monitoring locations

POTW	Intercept (a)	Slope (b)	r^2	df
CA0054372	9.4197	0.4993	0.154	29
CA0077691	4.2750	0.7008	0.422	6
CA0079103	23.3517	-0.1278	0.035	16
CA0079243	5.7979	-0.0367	0.008	8
CA0102822	6.3526	0.1780	0.195	28
CA0105295	8.5667	-0.1143	0.007	50
CA0107492	5.9043	1.0676	0.027	2
CA0109991	3.0331	0.8458	0.167	11
CA8000073	9.0000	0.0000	0.000	8
CA8000326	7.3073	0.0056	0.000	28
CA8000383	6.6743	0.5070	0.235	31
ID0023981	6.2101	0.2083	0.202	28
LA0069868	7.6475	0.1139	0.535	5
LA0073521	12.9886	-0.8184	0.110	18
TN0023353				
TN0023531				
TN0023574				
All POTWs	6.6930	0.4311	0.276	299

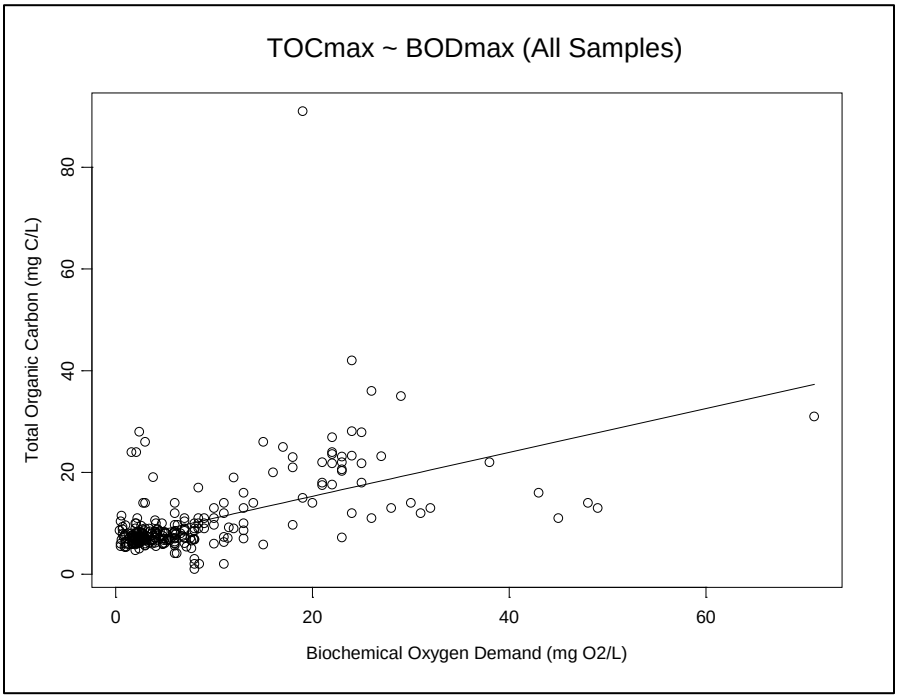


Figure D-4. Scatter Plot of Maximum Monthly Data (Effluent Monitoring Locations)

Results of the effluent regression analyses revealed large differences in slopes of the linear model TOC = *a* + *b* BOD among POTWs. Slopes for individual regressions ranged from –1.13 to 0.73 for average, and from -0.82 to 1.07 for maximum BOD and TOC values. Coefficients of determination (r^2) for the regressions were low; all $r^2 < 0.55$ and for most of them $r^2 < 0.24$. Low coefficients of determination were also recorded for regressions of TOC on BOD values from all POTWs ($r^2 = 0.245$ and 0.276, for average and maximum values, respectively). Further investigations of the effluent regression analyses were performed, because visual inspection of Figures D-3 and D-4 suggested the presence of outliers in the data.

We examined the fit of the linear model, TOC*avg* = *a* + *b* BOD*avg*, by inspecting its residuals (Figure D-5). Studentized residuals were plotted against projected (fitted) TOC values in the left pane, and against quantiles of the standard normal distribution in the right pane. Four suspiciously-low average TOC points in Figure D-4 are labeled '324', '308', plus the two points adjacent to the latter (left pane). This plot reveals that residuals for high-TOC points '489' and '64' are far larger in magnitude than residuals for the four suspiciously-low points. Residuals for these two points greatly deviate from the normal distribution (right pane). Furthermore, points '335' and '336' have much greater leverage than any other (leverages for '335': 0.164, '336': 0.127). Fitting the linear model without points '489', '64', '335', and '336' results in the following parameter values:

TOC*avg* = 6.0388 + 0.2171 BOD*avg* ($r^2 = 0.185$, 170 df) (Equation 1)

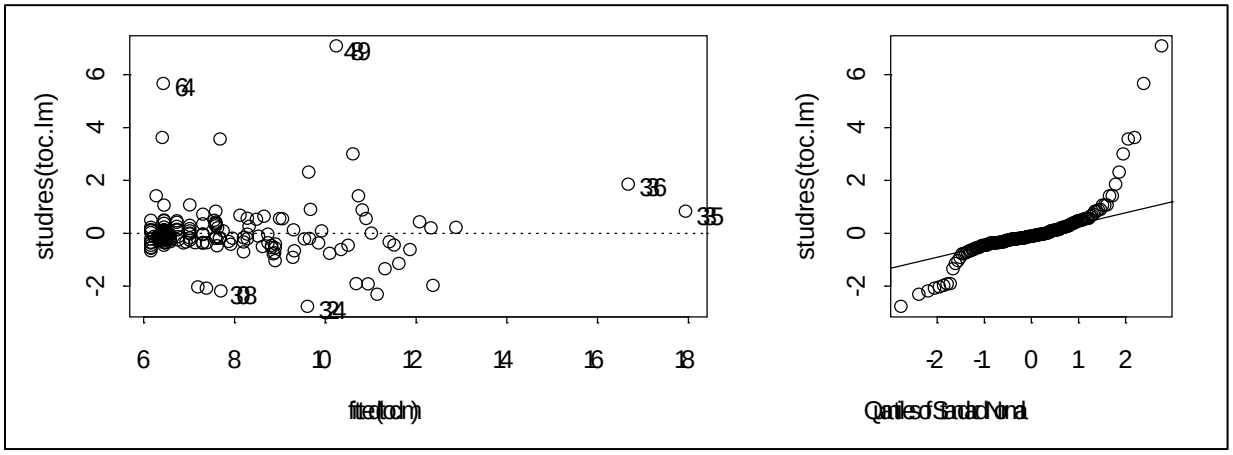


Figure D-5. Residuals of the linear model, TOCavg = a + b BODavg

(Left: plot of Studentized residuals (studres) against projected (fitted) TOC values; Right: plot of studies against quantiles of the standard normal distribution).

It should be noted that this model (Equation 1) projects average TOC concentrations very similar to the regression based upon the uncensored data (i.e., within ± 2 mg/L), for the range of BOD concentrations of interest (less than 30 mg/L).

Diagnosis of the regression analysis, TOC*max* = *a* + *b* BOD*max*, revealed an excessively high residue for the (19, 91) point and very high leverage for the (71, 31) point. The projected regression line without those two points was:

$TOC_{max} = 6.6242 + 0.4095\ BOD_{max}$ ($r^2 = 0.352$, 297 df) (Equation 2)

This model (Equation 2) fits a single slope for all data. Our results, though, revealed large differences in slopes of regression lines among POTWs (Table D-4). We tested the significance of such differences with an *F*-test, which required fitting two additional models, one with the same slope for all POTWs and the other with a distinct slope for each POTW. The *F*-test compares model fits while taking into account the loss in degrees of freedom associated with the computation of multiple slopes. The estimated *F*-value ($F = 4.92$, 13 df) was highly significant ($P < 0.001$), indicating that distinct slopes are necessary to accurately project maximum TOC from maximum BOD values.

D.3.3 TOC and DOC at CARP Effluent Monitoring Locations

Effluent discharge samples were collected from 11 New Jersey POTWs in 2000 and 2001 for the NYSDEC CARP project (www.dec.state.ny.us/website/dow/bwam/CARP). These samples were analyzed for DOC, particulate organic carbon (POC), and total suspended solids (TSS) by the U.S. Geological Survey. TOC was calculated by adding together DOC and POC concentrations. The results are shown in Table D-5. Effluent DOC concentrations are generally much higher than POC because most of the particulate organic matter is removed from wastewater during secondary treatment. A scatter plot of the TOC and DOC data, Figure D-6, shows the strong linear correlation between TOC and DOC that results from the predominance of DOC in effluent. These data are replotted in Figure D-7 for TOC concentrations less than 50 mg/L.

Table D-5. CARP organic carbon and total suspended solids (TSS) monitoring data for New Jersey discharger

DATE	SITE	DOC (mg/L)	POC (mg/L)	TOC (mg/L)	TSS (mg/L)
Oct. 2-4, 2000	PVSC	43.0	10.5	53.5	51.4
	MCMUA	0.10	6.75	6.85	36.3
	BCMUA	22.2	10.6	32.8	54.1
	JMEU	8.51	8.29	16.8	19.2
	RVMUA	12.2	3.81	16.0	22.1
	LRMUA	8.76	4.71	13.5	9.3
Dec. 11-15, 2000	PVSC	50.3	5.35	55.7	25.9
	MCMUA	260	9.22	269	62.6
	BCMUA	20.0	2.73	22.8	14.4
	JMEU	23.0	5.23	28.2	31.1
	RVMUA	23.4	8.73	32.1	42.0
	LRMUA	10.4	11.4	21.8	55.2
	NHH	14.0	3.07	17.1	22.5
	NBC	28.6	6.67	35.3	23.3
	NBW	21.8	3.38	25.2	7.8
	NHWNY	18.7	5.66	24.3	18.1
	SMUA	15.8	2.89	18.6	6.6
May 21-23, 2001	PVSC	34.5	14.2	48.7	41.1
	BCMUA	15.0	9.17	24.1	11.9

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DATE	SITE	DOC (mg/L)	POC (mg/L)	TOC (mg/L)	TSS (mg/L)
	RVMUA	9.26	10.2	19.5	12.0
	LRMUA	14.7	9.34	24.1	10.9
	EMUA	0.25	0.15	0.40	19.9
August 6-9, 2001	PVSC	123	8.74	132	35.6
	MCMUA	20.6	5.34	25.9	22.6
	BCMUA	109	15.4	125	45.6
	JMEU	131	8.58	140	18.1
	RVMUA	8.78	3.39	12.2	6.7
	LRMUA	7.33	5.01	12.3	17.9
	NBC	191	8.39	199	17.4
	NBW	23.4	9.82	33.3	13.5
	EMUA	14.7	5.33	20.1	7.5
	NHWNY	17.7	12.1	29.8	13.8
	SMUA	10.7	2.67	13.4	3.8

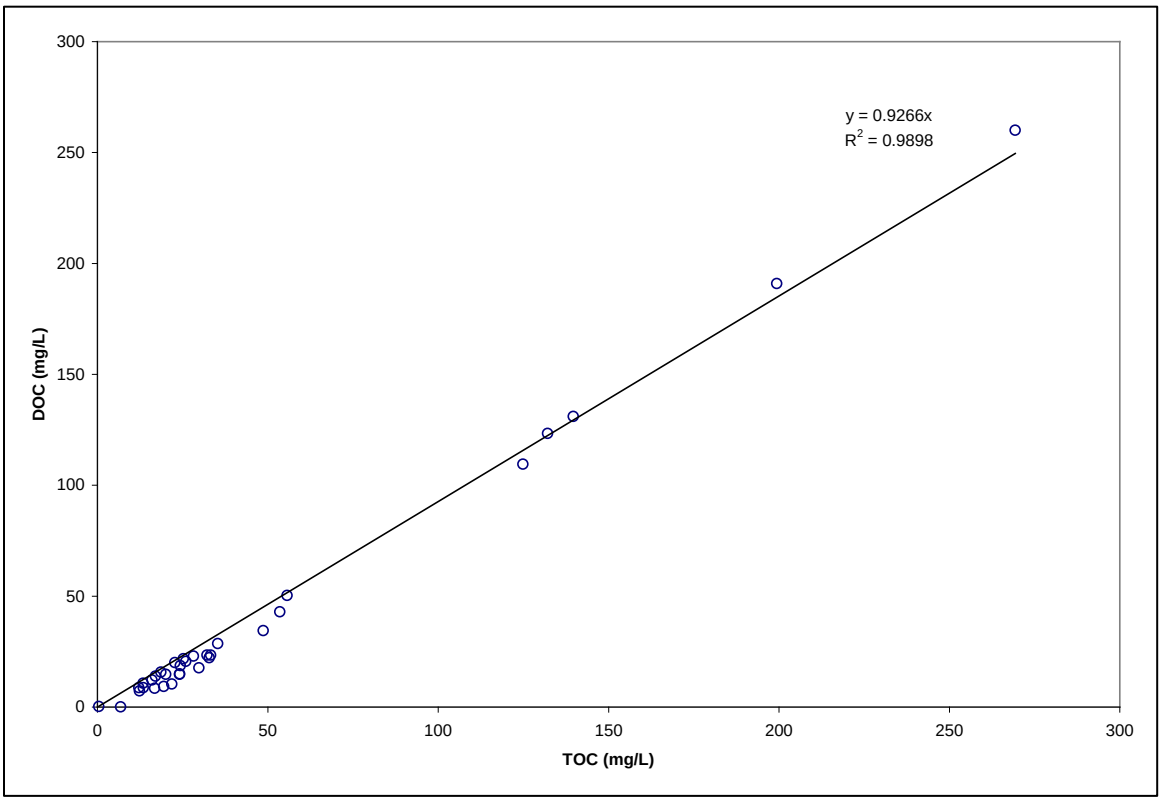


Figure D-6. Scatter plot of TOC versus DOC in CARP effluent monitoring data

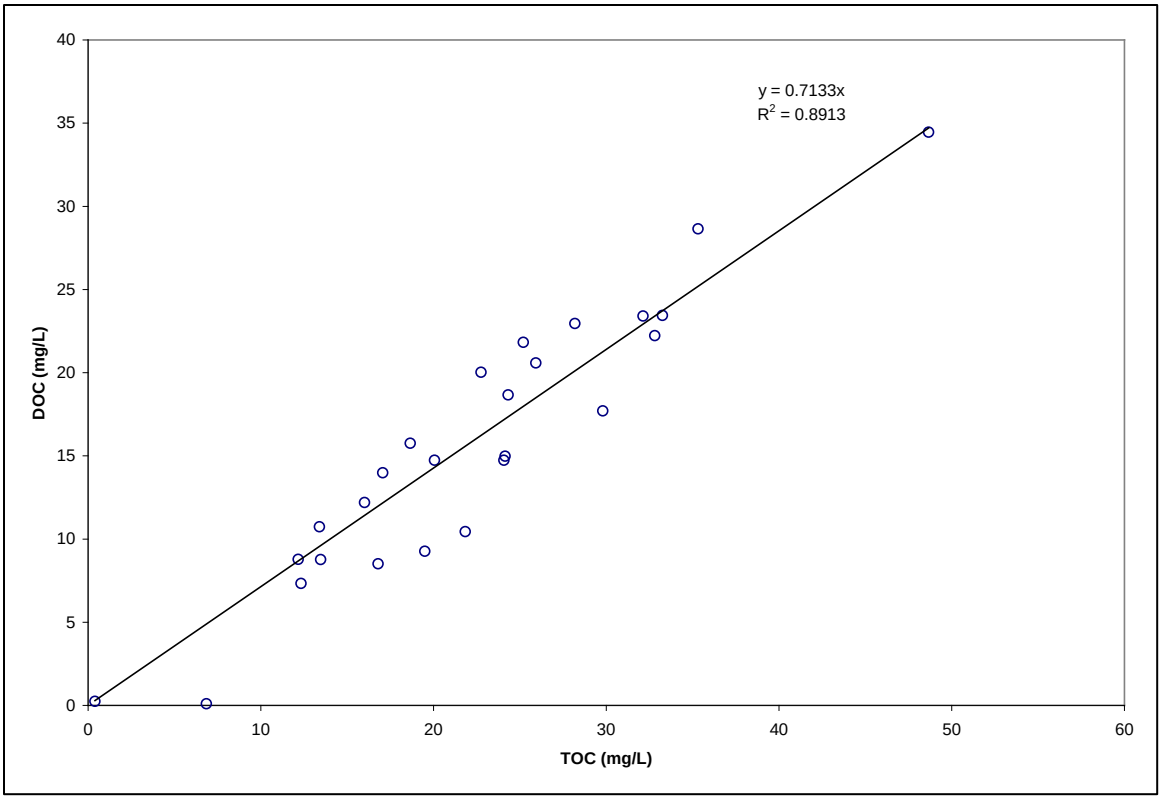


Figure D-7. Scatter plot of TOC versus DOC in CARP effluent monitoring data (TOC <50 mg/L)

Least squares regression of the CARP effluent data (Table D-5) produces the following model:

DOC = 0.9266 TOC (r^2 = 0.9898, 32 df)

This regression was forced through the origin by constraining the intercept to be zero. At the limit of removal efficiency (i.e., as effluent TOC approaches zero), any remaining TOC should be in the form of DOC, as mentioned above. This argument justifies forcing the regression through the origin. If only the data for which TOC falls in the expected range for effluent concentrations (TOC < 50 mg/L) are considered, the regression (again forced though the origin) is:

DOC = 0.7133 TOC (r^2 = 0.8913, 25 df)

For either case, the CARP effluent data show the strong linear relationship between TOC and DOC. Because TOC and DOC are linearly related in POTW effluent, the relationships between BOD and TOC reported above (Sections D.1 and D.2) also apply to DOC.

D.4 Discussion

Initially, we attempted to correlate BOD and TOC concentration measurements using data for all monitoring locations retrieved from PCS for major POTWs. We produced significant linear regression models for both average (Figure D-1) and maximum monthly (Figure D-2) data. Coefficients of determination were 0.87 and 0.70, respectively, for these data when combined for all locations. However, these correlations were substantially influenced by very high (i.e., greater than 50 mg/L) concentrations of BOD and TOC measured in untreated wastewater.

When we repeated the statistical analysis using effluent monitoring data, we found large differences in the slopes of the linear model TOC = *a* + *b* BOD among POTWs. Low coefficients of determination were also recorded for regressions of TOC on BOD values from all POTWs (r^2 = 0.245 and 0.276, for average and maximum values, respectively). In part, this may reflect random errors in the measurements of BOD and TOC, since data quality issues including loss of precision tend to be more frequent and significant at lower concentrations. The greater scatter in the plots of effluent BOD and TOC (Figures D-3 and D-4) may also reflect the limitations of working with the monthly average and maximum data reported by PCS.

Direct inspection of the TOC data in Figures D-3 and D-4 is nevertheless instructive. Aside from some extreme high and low values, the great majority of effluent TOC concentrations are in the range of 5 to 10 mg/L, especially for effluents with BOD concentrations below 10 mg/L. This is true for both average and maximum monthly TOC values. Table D-6 presents summary statistics for average monthly effluent TOC, for all data as well as data categorized according to the following BOD ranges: ≤5 mg/L, 5 to 10 mg/L, 10 to 20 mg/L and > 20 mg/L. As noted in Table D-6, four very low TOC values (≤ 0.5 mg/L) were judged to be anomalies and were therefore censored from the data for these statistics. The same summary statistics are presented for maximum monthly effluent TOC in Table D-7. In this context, the regressions of TOC on BOD values from effluent samples at all POTWs are quite reasonable, despite the low coefficients of determination. For average monthly effluent data, the regression of TOC on BOD is:

$$TOC_{avg} = 5.8740 + 0.2859\ BOD_{avg} \quad (r^2 = 0.245,\ 174\ df)$$

Table D-6. Summary statistics for POTW average monthly effluent TOC concentrations, categorized according to average monthly effluent BOD concentration

TOC_{avg}	BODavg level				
	≤5 mg/L	>5-10 mg/L	>10-20 mg/L	>20 mg/L	All levels
Mean	6.75	8.45	9.83	13.32	7.98
Median	6.17	8.15	8.70	13.25	6.90
Standard Deviation	2.47	2.41	5.26	5.79	3.76
5^{th} quantile	4.90	6.08	4.46	6.53	4.96
95^{th} quantile	10.00	10.58	18.40	21.8	14.52
n	98*	32*	34*	8	172*

*Four suspiciously-low TOC values were censored from the data for these statistics

Table D-7. Summary statistics for POTW maximum monthly effluent TOC concentrations, categorized according to maximum monthly effluent BOD concentration

TOCmax	BODmax level				
	≤5 mg/L	>5-10 mg/L	>10-20 mg/L	>20 mg/L	All levels
Mean	7.95	7.88	14.73	20.57	10.08
Median	7.30	7.85	11.00	20.60	7.90
Standard Deviation	3.28	2.74	15.97	7.75	7.60
5^{th} quantile	5.50	3.00	2.00	11.00	5.4
95^{th} quantile	10.94	12.00	25.55	35.3	23.6
n	164	72	30	35	301

Given the substantial limitations imposed by the data available from PCS, we believe that this regression gives reasonable estimates of TOC in POTW effluents. These are also probably the best available estimates of effluent TOC for dilution calculations to determine DOC concentrations for use in the BLM (for example, the probabilistic dilution framework incorporated in the BLM-Monte software [HydroQual, 2001]). As shown in Section D.3, effluent DOC concentrations can be reliably predicted from TOC values:

$$DOC = 0.7133\ TOC \qquad (r^2 = 0.8913,\ 25\ df)$$

It should be noted that the regressions presented here should not be applied to project water quality in natural receiving waters unimpacted by POTW effluent, because they are based solely on POTW effluent monitoring data. The characteristics of the constituents DOC, TOC, and BOD, as well as the relationships between them, may be quite dissimilar between natural waters and effluents.

NMED Exhibit 34

D.5 References

Fadini, S.F., Jardim, W.F., J.R. Guimarães. 2004 Evaluation of organic load measurement techniques in a sewage and waste stabilisation pond. Journal of the Brazilian Chemical Society. 15(1): 131-135 (http://jbcs.sbq.org.br/jbcs/2004/vol15_n1/19-152-02.pdf).

HydroQual, Inc. 2001. BLM-Monte User's Guide, Version 2.0. HydroQual, Mahwah, NJ. October, 2001.

HydroQual, Inc. 2005. Biotic Ligand Model Windows Interface, Version 2.1.2, User's Guide and Reference Manual. HydroQual, Mahwah, NJ. June, 2005.

New Mexico Environment Department (NMED) Surface Water Quality Bureau (SWQB)

Standard Operating Procedure (SOP) for

LAKE SAMPLING

Approval Signatures

Emily Miller Digitally signed by Emily Miller
Date: 2025.05.22 15:59:48 -06'00'

Emily Miller
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Date

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Date: 2025.05.22 17:50:17 -06'00'

Lynette Guevara
Program Manager – Monitoring, Assessment, and Standards Section

Date

1.0 Purpose and Scope

The purpose of this document is to describe the sample collection techniques, preservation requirements, equipment, and quality control activities associated with chemical, physical, and core biological sampling of surface water in lentic environments. The following describes accepted approaches used in the studies of lentic systems of New Mexico. For purposes of this document, the term “lake” shall include natural lakes and ponds, as well as reservoirs, impoundments, and any other human-made lentic waters. Where appropriate this SOP references the chemical sampling techniques used for lotic waters (SWQB SOP 8.2 Chemical Sampling in Lotic Environments) and only discusses where lake sampling differs.

2.0 Responsibilities

The Monitoring, Assessment, and Standards Section (MASS) Program Manager coordinates with the Project Manager(s), Technical Staff, and the QAO as applicable to ensure quality data is collected, verified, and validated to support program commitments. The Program Manager will provide input on the scope and intent of the SOP as it pertains to the program’s goals and objectives.

The Quality Assurance Officer (QAO) is involved in the development and revision of this SOP to ensure the SOP meets the requirements of the SWQB’s Quality Assurance Project Plan. The QAO, the MASS Program Manager, and SWQB subject matter experts (e.g., the MASS Monitoring Team Supervisor and assigned field staff scientists) will determine if any revisions to this SOP are needed at a minimum of every two (2) years in accordance with the most current SOP 1.1 for the Creation and Maintenance of SOPs (https://www.env.nm.gov/surface-water-quality/sop/). Pending the review and approval of the document, the QAO will ensure the SOP is accessible through the SWQB’s website.

The Project Manager (e.g., Monitoring Team Supervisor and assigned field staff scientists) are responsible for organizing and planning data collection activities and ensuring monitoring activities adhere to applicable SOPs and Field Sampling Plans.

Bureau personnel who conduct sampling activities in lentic environments, or who supervise those who do, are responsible for implementing this procedure, using the most up to date field sheets, and are required to sign the SOP acknowledgment statement for Lake Sampling.

3.0 Background and Precautions

3.1 Background

Water quality samples will be collected according to 20.6.4.14.C(3) NMAC which states:

> *"Lake sampling stations shall be located at any site where the attainment of a water quality criterion is to be assessed. Water quality measurements taken at intervals in the entire water column at a sampling station shall be averaged for the epilimnion, or in the absence of an epilimnion, for the upper one-third of the water column of the lake to*

> *determine attainment of criteria, except that attainment of criteria for toxic pollutants shall be assessed during periods of complete vertical mixing, e.g., during spring or fall turnover, or by taking depth-integrated composite samples of the water column.*"

Based on current staff and funding levels, state fiscal year change over financial constraints (July 1), and New Mexico's assessment protocols and related impairments, lake sampling should occur during the growing season, preferably June through September. Assessment details for determining lake impairments can be found in the current Comprehensive Assessment and Listing Methodology (CALM) (NMED/SWQB 2023b or current).

Methods of sample collection, preservation and handling used in this SOP are in accordance, except where otherwise noted, with methods described in the following references:

- "Guidelines establishing test procedures for the analysis of pollutants under the Clean Water Act," 40 CFR Part 136 or any test procedure approved or accepted by EPA using procedures provided in 40 CFR Parts 136.3(d), 136.4 and 136.5;
- Standard Methods for the Examination of Water and Wastewater, latest edition, American Public Health Association (APHA 2017);
- Methods for Chemical Analysis of Water and Waste, and other methods published by EPA Office of Research and Development or Office of Water;
- Techniques of Water Resource Investigations of the USGS;
- Annual Book of American Society for Testing and Materials (ASTM) Standards. Volumes 11.01 and 11.02, Water (I) and (II), latest edition, ASTM International;
- Federal Register, latest methods published for monitoring pursuant to Resource Conservation and Recovery Act regulations;
- National Handbook of Recommended Methods for Water-Data Acquisition, latest edition, prepared cooperatively by agencies of the U.S. Government under the sponsorship of the USGS.
- Federal Register, latest methods published for monitoring pursuant to the Safe Drinking Water Act regulations.
- Clean Lakes Program Guidance Manual (USEPA 1980).
- Subsection C Paragraph (3) of 20.6.4.14 NMAC in the State of New Mexico Standards for Interstate and Intrastate Surface Waters (NMAC 2020).
- Chemical Sampling SOP 8.2 (NMED/SWQB 2024b or current).

3.2 Precautions

All water sampling field activities in lentic waters will be conducted in accordance with this SOP. Site conditions or project-specific data collection objectives may necessitate the use of alternative field procedures not included in this SOP. The use of field methods other than those presented in this SOP must be approved by the MASS Program Manager or QAO and alternative methods must be accurately documented on field forms.

Organic samples collected with equipment that is not constructed of glass, fluoropolymer, or stainless steel are inconsistent with sampling methods described in Table II of 40 CFR Part 136.3 (e). However,

previous results from samples collected using non-compliant equipment have not shown detections of organic analytes that would implicate the sampling equipment as a potential source of contamination. Regardless, organic results obtained using non-compliant equipment should be flagged with a SWQB validation code.

3.3 Safety

Use gloves when handling caustic and acidic substances and waters suspected to have high bacterial contamination. Follow lab safety procedures if preparing Lugol's solution. All reagent containers and chemicals must be properly stored, labeled, and properly disposed. Take precautions to minimize exposure to chemicals in the lab and in the field.

Boating Safety

All personnel operating and working aboard watercraft must complete a US Coast Guard boating safety course every three years. Do not operate the watercraft in hazardous weather conditions such as thunderstorms or high winds/rough water. If weather conditions become hazardous while out on water sampling must cease and you must return to boat ramp as safely as possible. Before leaving the boat ramp, check that engine coolant water is discharging and isn't clogged with debris. Failure to do so may lead to engine overheating. All personnel must wear US Coast Guard type lll personal flotation devices (PFD) while on board a watercraft.

Before launching the boat, make sure the drain plug(s) is securely fastened to the drain and that the following safety equipment is present onboard the watercraft:

- Oars
- First aid kit
- Fire extinguisher
- PFDs for all onboard
- Throw rope
- Cell phone or radio
- Whistle

4.0 Definitions

For common definitions and acronyms not defined in this SOP, refer to the most up to date SWQB Quality Management Plan for Environmental Data Operations.

Depth-integrated composite sample or composite sample – Multiple samples collected at different depths and integrated to represent entire water column or specific region of water column.

Epilimnion – The top-most layer in a thermally stratified lake, occurring above the deeper hypolimnion.

Euphotic zone – the depth of water in a lake that is exposed to enough light for photosynthesis to occur estimated at 2.8 times the Secchi depth (French et al. 1982).

Hypolimnion – The dense, bottom layer of water in a thermally-stratified lake. It is the layer that lies below the thermocline.

Grab sample – Water sample collected at the surface of the lake.

Littoral – The shallow or nearshore areas of a body of water.

Oligotrophic – An oligotrophic lake has low nutrient concentrations and low plant growth with abundant oxygen in deeper parts.

Profile measurement – Interval measurements taken with a sonde, which include temperature, DO (concentration and percent saturation), pH, turbidity, salinity, and specific conductivity.

SLD – Department of Health Scientific Laboratory Division.

Thermocline – Zone of the water column where the temperature changes one degree C or more per meter of depth. In a thermally stratified lake, the thermocline is a relatively thin transition between the warmer, shallower layer (epilimnion) and the colder, deeper layer (hypolimnion).

Constituents/Analytes Acronyms:

DO – Dissolved Oxygen

DOC – Dissolved Organic Carbon

TOC- Organic Carbon

HAB – Harmful Algal Bloom

Rads – Radionuclide Sample

TDS – Total Dissolved Solids

TSS – Total Suspended Solids

5.0 Equipment

Required equipment for lakes sampling is detailed in the Lake/Reservoir Sampling Equipment Checklist. Lugol's solution must be prepared in the laboratory prior to the field sampling event as follows:

Lugol's Solution Preparation Steps:

1. Using a Mettler balance or equivalent. Measure 25 g KI and 12.5 g of I_2.
2. Cover the I_2 reagent with tinfoil as it is light sensitive and will evaporate.

3. Combine 225 ml DI water and dry chemicals in a large flask. This must be performed in a fume hood.

4. Add a magnetic stir bar and place on a hotplate equipped with stirring action.

5. Warm slightly while stirring to facilitate dissolution of the dry chemicals. ***Do Not Boil!***

6. In about an hour, once the solution is completely dissolved, pour into an opaque container using a glass funnel.

7. Add 25 ml Glacial Acetic acid to container and cap tightly.

8. Invert several times to mix solution.

9. Label container with date, contents, and pH (usually around 2.4 s.u.)

6.0 Lake Sample Collection (Step-by Step Process Description)

Lake water samples must be collected in accordance with 20.6.4.14.C(3) NMAC and this SOP. For biological data (i.e., phytoplankton, chlorophyll a, zooplankton, E. *coli and* microcystins) refer to Section 6.3-6.8 of this SOP.

Lake sampling stations shall be located at least 250 feet from a point source discharge when data will be used for assessment of water quality standards.

All lake samples which require preservation and filtration will be processed within 15 minutes of sample collection in accordance with 40 CFR 136.3 (e) Table II. However, due to wind, waves, weather and unforeseen events, preservation may not occur within 15 mins of sample collection but as soon as practically possible.

A plastic (acrylic), polyethylene, or fluoropolymer Kemmerer must be used for collecting water chemistry samples for TSS/TDS, anions, nutrients, DOC, metals, phytoplankton, and chlorophyll *a*. Organic samples must be collected using a fluoropolymer (i.e., PTFE, Teflon®) Kemmerer and composited in a glass or fluoropolymer carboy.

6.1 Lake Profile Measurements at Monitoring Location

Prior to beginning lake sampling ensure the Lake and Reservoir Field Sheets are drafted for planned sampling stations (monitoring Location IDs, RIDs, etc.).

The first step is to locate the index site for sampling parameters except E. coli and microcystin (and other harmful algal bloom related parameters) that are generally sampled near shoreline recreational areas (see sections 6.7. and 6.8 of this SOP for more information).

The index sampling site may deviate from the current established lake sampling stations. If this is the case, note in the Comments section of SQUID. The index site is located near the mid-point of the reservoir rather than at the deepest point, which may be near the dam. The index site should be representative of the waterbody. If this would result in an index site that is very shallow or otherwise non-representative of the reservoir as a whole, choose a point near the center of a main basin, where depths and the water column will be more representative of the reservoir.

Next, record wind speed, wind direction, % cloud cover, water color (Forel-Ule Color scale).

At the lake index station, use a calibrated multi-parameter sonde to measure the depth profile for dissolved oxygen (DO) concentration and percent saturation, specific conductance, salinity, temperature, turbidity and pH. Sondes must be calibrated according to SWQB SOP 6.1 Sondes (NMED/SWQB 2024a or current) prior to data collection.

Lake Depth Profile Data Collection Procedure

1. Data are collected beginning at the surface and proceeding at one-meter intervals up to 30 meters (m) depth or the top one third of the lake, whichever is greatest.

2. After 30 meters or the top one third of the lake, collect measurements every five meters.

3. Measurements are taken at the surface to within one meter of the bottom of the lake or to the maximum depth allowed by current equipment (60m).

4. Measurements must be recorded on the Depth Profile section of the Lake and Reservoir Field Sheet prior to finalization of field sheet.

Examination of Lake Depth Profile for Presence of a Thermocline

1. If depth profile measurements are transferable at the time of sample collection the macro enabled field sheet will provide notification of a thermocline. However, this is not always possible due to cell service and space limitations while sampling.

2. If measurements are not transferable at the time of collection results will have to be visually inspected utilizing Steps 3 and 4 of this section.

3. Review temperature results collected in depth profile for greater than one-degree Celsius (C°) change per meter for identifying a thermocline.

4. When determining a thermocline, rapid changes in other parameters, such as pH and DO, also may indicate where stratification is occurring. See Table 1 for example.

> NOTE: One degree or more change in temperature from nonconsecutive measurements is not considered a thermocline. The 1° C change must be observed in successive measurements (e.g., 2 meters to 3 meters).

STATION_NAME	SAMPLE_DATE	Depth	SALINITY	SPECIFIC CONDUCTANCE	PH	TEMPERATURE	% Dissolved Oxygen Local	Dissolved Oxygen (mg/L)	TURBIDITY
Snow Lake at Dam (Deep) - 77SnowLkDamDp	2011-08-16 11:40:00	0	0.08	175	9.21	22.07	122.9	8.16	24
Snow Lake at Dam (Deep) - 77SnowLkDamDp	2011-08-16 11:40:00	1	0.08	174	9.12	20.73	94.5	6.47	13
Snow Lake at Dam (Deep) - 77SnowLkDamDp	2011-08-16 11:40:00	2	0.08	175	9.02	20.35	81.5	5.61	9.4
Snow Lake at Dam (Deep) - 77SnowLkDamDp	2011-08-16 11:40:00	3	0.09	185	8	19.19	3	0.21	12.7
Snow Lake at Dam (Deep) - 77SnowLkDamDp	2011-08-16 11:40:00	4	0.09	192	7.8	18.17	1	0.08	10.2
Snow Lake at Dam (Deep) - 77SnowLkDamDp	2011-08-16 11:40:00	5	0.09	198	7.68	17.57	0.1	0.01	9.6
Snow Lake at Dam (Deep) - 77SnowLkDamDp	2011-08-16 11:40:00	6	0.1	201	7.59	17.07	0	0	10.7
Snow Lake at Dam (Deep) - 77SnowLkDamDp	2011-08-16 11:40:00	6.5	0.1	204	7.47	16.88	0	0	22

Table 1. Example of thermocline present between 2 and 3 meters with sharp decline in dissolved oxygen

Determine Euphotic Zone utilizing Secchi Depth Measurements

The NMED SWQB uses 2.8 times the Secchi depth in meters to estimate euphotic zone (French et al. 1982).

Secchi Depth Measurements

1. Measure Secchi depth on the shaded side of the boat with sunglasses removed and record on Lake and Reservoir Field Sheet.

2. Multiply the Secchi depth (meters) by 2.8 or click on “Calc” button on field sheet.

3. Ensure the euphotic zone has been documented on the Lake and Reservoir Field Sheet.

6.2 Collecting Lake Water Samples for Chemical Analysis

During periods of lake stratification (i.e., when **thermocline is present**) TSS/TDS, nutrients, DOC, dissolved metals, total metals, radionuclides and organics are integrated from the top, middle and bottom of the **entire water column** by taking three Kemmerer samples (Figure 1) and compositing in a 5-gallon carboy (glass or fluoropolymer for collecting organics). If any of the Kemmerer samples fall at the same depth as the thermocline, collect from one meter above. For the bottom sample, keep the Kemmerer at least 1 meter away from the bottom to avoid stirring up sediments.

Thermocline Present – Sampling Procedure for TSS/TDS, Anions, Nutrients, DOC, Metals, Radionuclides

1. Begin by reviewing the depth profile for determining sample location, see Figure 1.

2. Next, double rinse the Kemmer (i.e., acrylic, polyethylene, or fluoropolymer) and 5-gallon polyethylene carboy (or polyethylene bucket).

3. Proceed with collecting surface (i.e., top) sample and deposit in carboy.

4. Next, collect sample from the middle of water column and deposit in carboy.

5. Last, collect water sample from the bottom of the water column at least 1 meter from bottom of lake and deposit in carboy.

6. Pour water quality samples off composited sample into their respective containers; 1-liter Cubitainers® or other containers as prescribed per the analysis to be performed.

7. Next, preserve samples as prescribed by applicable method.

Thermocline Present – Sampling Procedure for Organics
Same as above, however a fluoropolymer (i.e., PTFE, Teflon®) Kemmerer must be used and samples must be composited in a glass or fluoropolymer carboy.

Thermocline Present – Sampling Procedure for Chlorophyll a and Phytoplankton
Follow Figure 1 below and Section 6.3 of this SOP for the collection of chlorophyll a and phytoplankton samples. Samples should be taken from the top, middle and bottom of the euphotic zone and composited into a polyethylene carboy (or polyethylene bucket) and then processed according to their respective procedures prescribed in this SOP.

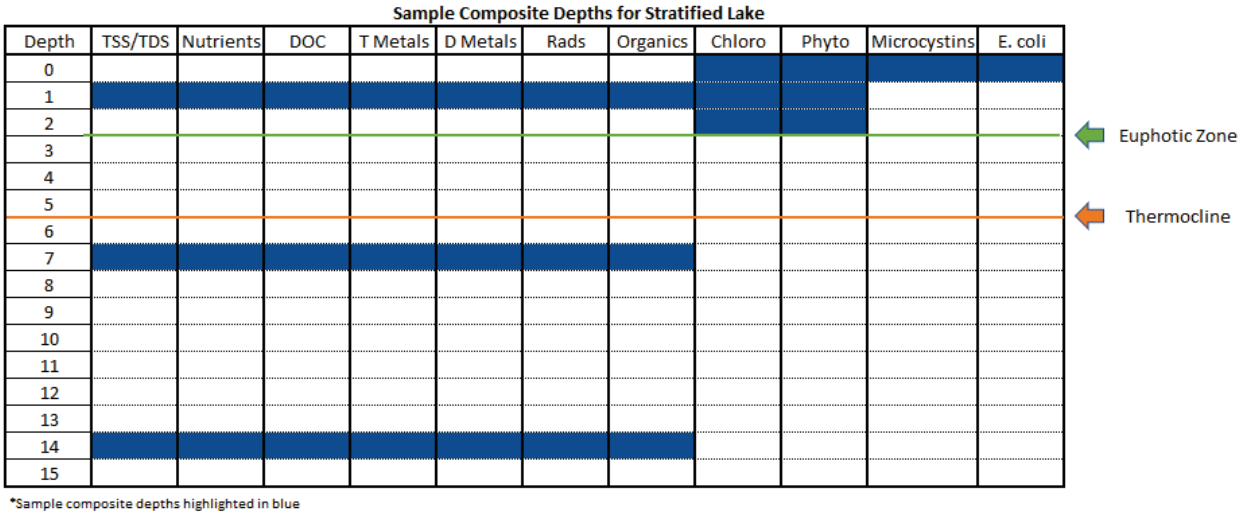


Figure 1. Sample collection methods when a thermocline is present.

Absence of Thermocline (no epilimnion)
When the lake is well mixed (i.e. **thermocline is not present**), all samples except microcystins and *E. coli* are collected from the top, middle, and bottom of the **euphotic zone** (Figure 2), or the upper 1/3 of the water column, whichever is shallowest. If the lake max depth is 3 meters or less, samples must be collected at two meters or less from the surface of lake. If the lake is one and a half meters or less the vertical Kemmerer cannot be used and water samples must be taken from just below the surface.

Thermocline Absent – Sampling Procedure for TSS/TDS, Anions, Nutrients, DOC, Metals, Radionuclides, Chlorophyll a and Phytoplankton

1. Begin by reviewing depth profile for determining sample location within the euphotic zone, see Figure 2

2. Next, double rinse the Kemmer (i.e., acrylic, polyethylene, or fluoropolymer) and 5-gallon polyethylene carboy (or polyethylene bucket).

3. Proceed with collecting lake sample from top of euphotic zone and depositing into carboy.

4. Next, collect lake sample from middle of euphotic zone and deposit in carboy.

5. Last, collect water sample from bottom of euphotic zone (must be at least 1 meter from bottom of lake) and deposit in carboy.

6. Pour water quality samples off composited sample into their respective containers; 1-liter Cubitainers® or other containers as prescribed per the analysis to be performed.

7. Next, preserve samples as prescribed by applicable method.

Thermocline Absent – Sampling Procedure for Organics

Same as above, however a fluoropolymer (i.e., PTFE, Teflon®) Kemmerer must be used and samples must be composited in a glass or fluoropolymer carboy.

Sample Composite Depths for Unstratified Lake

Depth	TSS/TDS	Nutrients	DOC	T Metals	D Metals	Rads	Organics	Chloro	Phyto	Microcystins	E. coli
0										■	■
1	■	■	■	■	■	■	■	■	■		
2											
3	■	■	■	■	■	■	■	■	■		
4											
5	■	■	■	■	■	■	■	■	■		
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											

← Euphotic Zone

*Sample composite depths highlighted in blue

Figure 2. Sample collection methods when a thermocline is not present

6.3. Sampling for Phytoplankton and Chlorophyll a

Phytoplankton and chlorophyll a samples are composited from the top, middle, and bottom of the euphotic zone in **both** stratified and mixed lakes (Figures 1 & 2).

1. Begin by determining sample locations within the euphotic zone.

> If the lake max depth is 2 meters or less, samples must be collected at one meter or less from the surface. If the lake is one and a half meters or less in depth, the Kemmerer cannot be and water samples must be taken just below the surface as a grab sample using a Cubitainer®.

2. Composite samples from the appropriate depths with a clean Kemmerer (acrylic, fluoropolymer or glass) and fill a 1-liter Cubitainer® for phytoplankton and 1-gallon Cubitainer® for chlorophyll a. Samples can be poured off from TSS/TDS, anions, nutrients, DOC, metals, and radionuclides composite if the lake is **well mixed (no thermocline).**

6.4 Phytoplankton sample Preservation

1. Preserve sample within 2 hours of collection using approximately 10 milliliters of Lugol's solution until the sample appearance looks like a weak tea color.

2. Store samples in the dark and on ice or under refrigeration (EPA 2012).

3. At the end of the sampling season after all samples are collected (but no longer than one year from earliest sample collection) ship samples to the contracted lab for identification and enumeration.

6.5 Chlorophyll *a* Preservation and Processing

Confirm sample processing methods from selected lab prior to processing. If processing methods differ from below, follow instructions provided by the contract lab.

The 1-gallon Cubitainer® must be stored on ice and out of sunlight and filtered as soon as possible after collection.

Filtering procedure for chlorophyll a processing is described below.

Processing of Chlorophyll a Samples

1. Begin by double rinsing the chlorophyll flask and funnel with DI water.

2. Filter sample water through a Whatman Glass Fiber Grade GF/F or GF/C filter until substantial color development is on the filter medium, indicating adequate chlorophyll pigment is present. Volume of sample filtered must be documented.

> NOTE: If clogging or filtering time is a concern, use the larger retention of the GF/C filter. It has been shown that there is no difference between chlorophyll concentrations collected on Whatman GF/F of GF/C filters (Prepas et al. 1988).

3. Do not exceed a vacuum pressure of 6in. Hg (20kPa) during filtration.

> If filtering must be delayed, hold sample water on ice or at 4°C and protect from exposure to light by using opaque bottles and storing in the dark.

4. Excessively long filtration times (>10 min) and high pressures may damage cells and result in a loss of chlorophyll (EPA 1997).

5. Remove the filter from the filtering apparatus, fold it in half, place it in a petri dish labeled with sample identification and filter volume

6. Then wrap the petri dish with aluminum foil, put in a zip lock bag and place on dry ice.

7. Record the volume of water filtered on the field sheet

8. Upon returning to the SWQB lab, store samples in a freezer until they are shipped to the contract lab.

Samples should be sent to the laboratory for processing as soon as possible after collection; however, samples on filters taken from water having pH 7 or higher can be frozen for up to 28 days before analysis, if necessary. Samples from acidic water (< pH 7) should be processed promptly after filtration to prevent possible chlorophyll degradation from residual acidic water on filter.

6.6 Zooplankton Sample Collection

The objective of zooplankton sample collection is to sample a sufficient volume of water to obtain at least 300 organisms per sample from oligotrophic lakes. Oligotrophic lakes are low in nutrient concentrations, low plant growth and contain abundant oxygen in the deeper parts. This will be verified with the depth profile measurements, visual examination of lake for excessive plant growth and reviewing historical sampling events. Zooplankton sample collection is completed by collecting two vertical samples using fine mesh (50 µm) and coarse mesh (150 µm) Wisconsin style nets with collection bucket attached at the cod end following the Sample Collection Procedure below. Figure 3 provides the equipment and supplies needed for the collection of zooplankton. Figure 4 is an illustration of the zooplankton nets and collection buckets required for sampling.

Type	**Item**	**Quantity per site**
Form	-Lake Field Sheet	1
Collection	-Plankton net fine (50µm) and collection bucket	1
	- Plankton net course (150 µm) and collection bucket	1
	- Calibrated line (30 m, calibrated, marked in .5 m intervals)	1
	- Funnel	1
	- Squirt bottle – de-ionized (DI) water	1
	- Squirt bottle- lake water	1
	- Effervescent sodium bicarbonate (e.g., Alka seltzer) tablets	1
	- Pail (for narcotization and concentration of samples)	1
Storing and Preservation	- HDPE bottle (125ml or 250 ml)	2

	- Ethanol (95%) - Labels for fine and course samples	1 As needed

Figure 3. Equipment and supplies for Zooplankton Sample Collection

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Version 1.2, May 2022

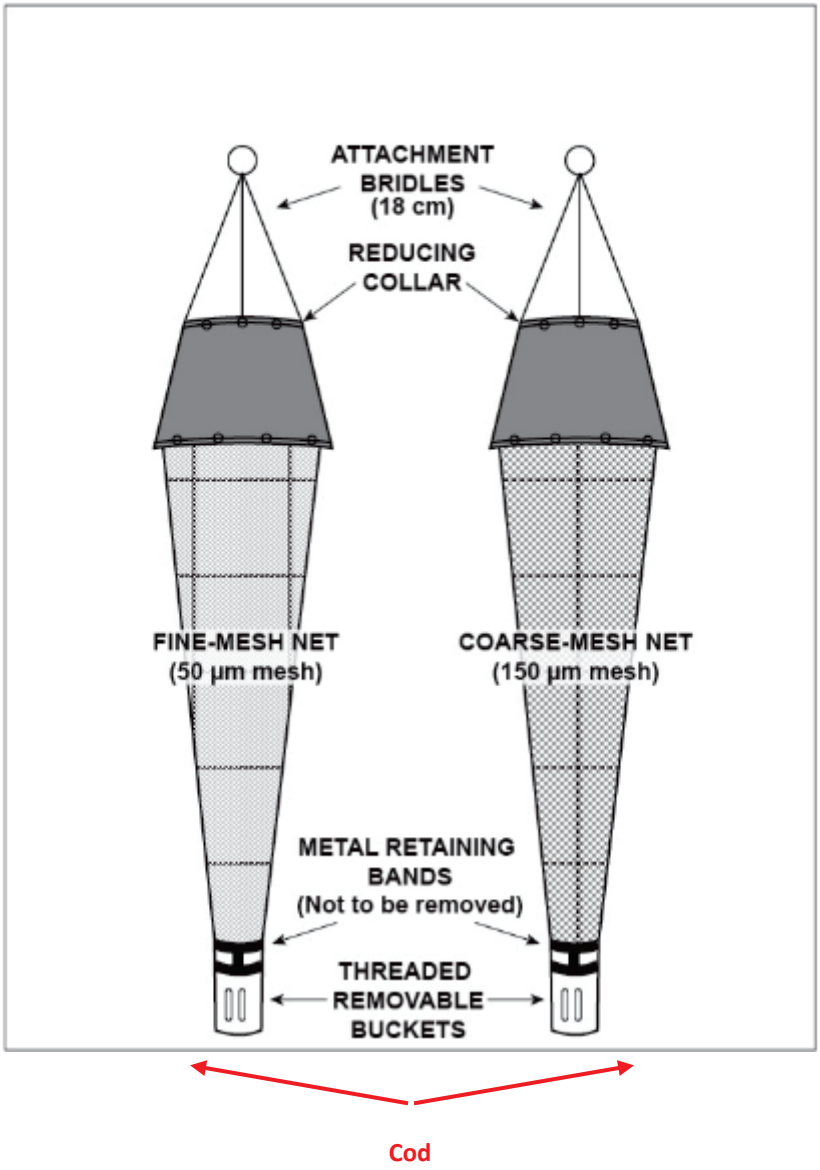


Figure 4. Wisconsin Net and Collection Diagram for Zooplankton

The procedures for collecting and processing zooplankton samples are presented below.

Sample Collection

1. Determine and record the number of tows required to achieve the standard cumulative 5-meter(m) tow on the Lake field sheet.
    a. For lakes deeper than 7 m, you will take a single 5 m tow with each net.
    b. For lakes with a depth less than 7 m, you will determine and record the number of tows that will be required to achieve a standard cumulative 5 m tow for each net (Figure 5). For example, if the lake is 6 m deep, you will take two 2.5 m tows with each net. All lakes less than 7 m deep require at least two tows because the collection bucket should never touch the sediment due to potential fouling.

Depth of lake (m)	Length of Tow	Number of Tows
7 or more	5 m	1
4 to <7	2.5 m	2
2 to <4	1 m	5
less than 2	0.5 m	10

Figure 5. Lengths and numbers of zooplankton tows based on lake depth.

    c. The zooplankton collection methods vary slightly depending on the number of tows required to achieve a standard cumulative 5 m tow.
        i. If the number of tows = 1: follow steps 2 through 13 described below.
        ii. If the number of tows ≥ 2, follow steps 2 through 12 described below. After step 12, pour the contents of the collection bucket into a clean (i.e., DI rinsed) 1- gallon pail. Rinse the collection bucket with DI. While taking care not to tip the zooplankton sample in the pail, repeat steps 2 through 12 for the second tow. Add the contents of the collection bucket from the second tow to the pail. Continue to take zooplankton tows and add samples from the collection bucket into the pail until the target number of tows (2, 5, or 10) is reached. On the last tow, pour the contents of the pail into the collection bucket to filter the excess water. Rinse the bucket with DI water and pour the contents of this rinse into the collection bucket with the zooplankton sample. Once the zooplankton sample has been filtered down to an appropriate volume in the collection bucket, continue on to step 13.

2. Prior to each use, carefully clean and thoroughly rinse the interior of the nets and buckets with DI water.

3. Carefully inspect the nets and buckets for holes or tears.

4. Attach the collection buckets to the “cod” end of the nets and secure. Make sure the correct bucket is attached to the correct net (i.e., the mesh sizes match).

5. Attach the bridled end of the net to a calibrated line with markings every 0.5 m.

6. Carefully and slowly lower the first net in a constant upright position over the side of the boat.

7. Continue lowering the net to the correct depth (remember to account for the length of the bridle). If more than one tow is needed, be sure to take additional tows from different locations around the boat.

8. Retrieve the net by pulling back to the surface at a steady rate (0.3 m/s or 1 ft/s) without stopping.

9. Once at the surface, slowly dip the net up and down in the water without submersing the net mouth to rinse contents into the collection bucket.

10. Complete the rinsing of the net contents by spraying lake water against the outside of the net with a squirt bottle or similar tool (a peristaltic pump may be used at low speed). Be careful not to splash or squirt lake water into the net mouth, or additional organisms may be collected.

11. If additional rinsing is needed on the interior of the net, use a squirt bottle or similar tool with DI water to avoid introducing additional organisms.

12. Once all organisms have been rinsed into the collection bucket, hold the collection bucket in a vertical position, and carefully remove the bucket from the net.

13. Repeat steps 5-12 with the second net on the opposite side (or end) of the boat.

Sample Processing

1. Set the collection buckets in a pail filled half full of lake water, inset two (2) CO_2 (e.g., Alka-Seltzer) tablets outside of the collection buckets. Wait 30 to 60 seconds for the CO2 tablets to dissolve.

2. Ensure that the organisms in the collection buckets are submerged in the water but be careful not to submerge the top of the collection buckets, or sample loss will occur. Wait until zooplankton movement has stopped (usually about one-two minute)

> Note: The CO_2 narcotizes the zooplankton to relax their external structure to facilitate identification

3. Raising and lowering the collection buckets in the pail can help water exchange within the bucket to disperse CO_2 tablets.

4. Check the sample label on the collection buckets to verify which sample has been collected (coarse or fine mesh).

5. Use small volumes of DI water from a squirt bottle to rinse the contents of the mesh net collection bucket into the 125 or 250 mL polyethylene bottle. Rinse the collection bucket with DI water three to four times or until the majority of zooplankton have been removed without allowing the bottle to fill more than half full (~60-70 mL or 120-130 mL of sample and rinse water combined).

6. After the zooplankton have been transferred and the sample bottle is half full of sample and rinsate, fill the bottle to the shoulder with 95% ethanol. Use a funnel, if necessary, when transferring the sample, rinsate or ethanol to the sample bottle.

7. In some cases, the volume of zooplankton collected in the collection bucket may exceed 125-250 mLs. Under this scenario do not try to force the entire sample into a single bottle, or the preservative will not function properly, and the sample may be lost. In such cases, fill the first bottle half full, and then use a second bottle to preserve the additional amount of sample. Complete the label on second bottle. Ensure the Lake field sheet is properly labeled.

8. Seal sample bottles with electrical tape.

9. On the Lake Field Sheet, indicate that the sample is preserved.

10. Verify that all information on the labels and the form is complete and correctly recorded.

11. Repeat steps 2-9 for the second sample collected.

Sample Storage
Zooplankton samples should be stored in a secure location while awaiting delivery to the laboratory for analysis, samples may remain at room temperature. Contact the contract laboratory for transportation requirements. Samples should be analyzed within 1 year of sample collection, if sealed properly as described sample processing.

Storage and Cleaning of Zooplankton Nets
Briefly soak zooplankton nets in a 1% bleach solution and dry after each use. Do not dry in sunlight because the mesh is photosensitive.

6.7 *E. coli* Sampling

Collect *E. coli* samples from the surface of the water at lake sampling location in accordance with the procedures in Bacteriological Sampling SOP 9.1 (NMED/SWQB 2023c or current). Lake sampling stations sampled for E. coli should be conducted at high recreational areas along beaches/shore. Record the GPS coordinates of the monitoring site on the field form if differs from index site.

6.8 Microcystin Samples

Microcystin samples are collected to identify Harmful Algal Blooms (HABs) in areas of a lake where HABs have been observed or are of concern due to heavy recreation (swim beach, boat launch, etc.). Record the GPS coordinates of the monitoring site on the field form if differs from index site. Sampling should be performed from mid-summer to late-fall when HABs are most likely.

1. Begin by collecting surface grab samples using a 1-liter Cubitainer™.
   Note: If long, filamentous algae are present, leave headspace in Cubitainer™ and shake vigorously to ensure sample is homogenized.

2. Immediately store sample on ice away from sunlight.

3. Samples must be maintained at 0-10° C until arrival at lab.

4. If samples are not processed by laboratory within 5 days of collection samples must be maintained at -20 ° C until sent to laboratory for processing.

Maximum hold time for samples is not to exceed 14 days after collection unless stored at -20 ° C, however, most laboratories requires samples to be delivered within 5 days of collection. Be sure to notify the laboratory as soon as possible prior to sampling to ensure they are prepared for sample processing and relay any additional requirements for sample collection and processing.

At sites where E. coli and microcystin samples are collected, record the water color using the Forel-Ule Color scale, collect grab data using a calibrated sonde and a Secchi depth as outlined in this SOP. If samples are taken from the shore/beach a Secchi depth may not be collected. Ensure GPS location is recorded. A nutrient and phytoplankton sample at each microcystin location may also be collected dependent on project objectives.

6.9 Sampling Harmful Algal Blooms (HAB) at Recreational Stations

See SWQB SOP on HABs, under Specialized Monitoring.

6.10 Deployment of Bouy in New Mexico Lakes

The SWQB deploys buoy(s) at priority lakes within New Mexico. Buoy deployment is highly specialized and requires assistance from the SWQB Monitoring Team. Loggers are attached to buoys and are deployed to collect long-term data in lakes. At the time of deployment and retrieval a lake profile is required using a calibrated sonde. All required quality control processes detailed in SWQB SOPS are adhered to so that the data can be used for its intended purpose(s). For more information contact the Monitoring Team Supervisor. Please be sure to take extra caution when deploying buoys from the Jon Boat or rafts due to safety concerns.

7.0 Data and Records Management

All field data and samples collected following the procedures outlined in this SOP are entered in SWQB's water quality database as part of a Lake Sampling Event. A second staff member verifies that the data are entered correctly. Date of entry and verification are noted on the field sheet.

Sampling events and data are stored in the SQUID database. Hard copy forms are stored in the project binder located in the SWQB file storage cabinets. Electronic forms are stored within the project file within the shared server. Per 1.21.2.436 NMAC, water quality records are to be maintained for five years from the close of file.

Enter all field form data into appropriate electronic Lake Field Sheet (form can be found on the SWQB SOP website). Save these forms in the project folder on the SWQB network. Open a blank/new electronic SLD Submittal Auto form and follow the instructions to create submittals. Copy and save the combined data tab into its own Excel file. In the electronic field form, copy the profile tab into its own Excel file and save within the project file.

Uploading field sampling event data into the SQUID database:

- Select the Data Management tab.
- Select Imports.
- Select Sampling Event Data.
- Navigate to the project file and select the file with the combined data and import.

Uploading Depth Profile into the SQUID database:

- In SQUID under the Projects tab locate the project and sampling event you want to add a depth profile to.
- Select “Add Depth Profile” located in the same row as the Lake-Chemical sampling event
- Choose the appropriate .csv or .xlsx file and click “Upload File”

Phytoplankton and Zooplankton Data Upload

Data received from the contracted lab must be formatted properly in new Excel upload sheet in order to be entered into SQUID. Copy and paste lab data received from the contracted lab into the appropriate columns of the upload spread sheet. Follow the format presented in Figure 6. For taxon data you must combine the genus and species columns from the lab spread sheet. The easiest way to do this is to use the Excel formula (=GENUS&” “&SPECIES). For example: (=J2&” “&K2). Copy and re-paste cells values to remove the formula but keep text. In SQUID, under the Data Management Tab, select imports then biological results. Select appropriate file and select “insert” then select “process results”. Make sure both columns match (for “count” row select “number of natural units”). Click process results and ensure there are no import errors. Click “Import Results” to finish upload process.

	A	B	C	D	E	F	G	H	I
1	LAB ID	Sample ID	Water Body	Collection Date	Status	Taxon	Life Stage	Exclude	Number of Natural Units
2	Water Quality Lab	2530652	Snow Lake	9/3/2019	Final	Achnanthidium minutissimum	Adult	N	1
3	Water Quality Lab	2530652	Snow Lake	9/3/2019	Final	Cylotella striata	Adult	N	77
4	Water Quality Lab	2530652	Snow Lake	9/3/2019	Final	Plagioselmis nannoplanctica	Adult	N	35
5	Water Quality Lab	2530652	Snow Lake	9/3/2019	Final	Rhodomonas lacustris	Adult	N	2
6	Water Quality Lab	2530660	Bill Evans Lake	9/4/2019	Final	Cryptomonas erosa	Adult	N	4
7	Water Quality Lab	2530660	Bill Evans Lake	9/4/2019	Final	Plagioselmis nannoplanctica	Adult	N	71
8	Water Quality Lab	2530660	Bill Evans Lake	9/4/2019	Final	Chroococcus microscopicus	Adult	N	9

Figure 6. Proper phytoplankton spreadsheet formatting for data upload

***E. Coli* Data Upload**

See SWQB SOP 9.1 Bacteriological Sampling and Analysis (NMED/SWQB 2023c or current) for upload instructions into SQUID.

Chlorophyll *a* Data Upload

Results from the laboratory are uploaded to SQUID using the *Chlorophyll a Analysis Sheet*.
Uploading data into the SQUID database:

- Select the Data Management tab.
- Select Imports.
- Select Biological Results.
- Navigate to the project file and select the file with the combined data
- Click upload

Water Chemistry, Metals, Organics, Radionuclides and Microcystin data Upload
Data are received electronically from applicable laboratories and are uploaded to SWQB SQUID database. For most analytical analysis of samples, the SWQB uses the Air and Heavy Metals, Organics, Water, and Radiochemistry Sections of SLD Chemistry Bureau. SLD uses a software-based Laboratory Information Management System (LIMS) to issue standardized result reports which include detection limits, quantitation limits, and data qualifiers. For more information on the upload process contact the Monitoring Team Supervisor or the SWQB QAO.

8.0 Quality Control and Quality Assurance

The SWQB controls the quality of lake sampling data by using standardized methods that are documented in this SOP. All personnel who conduct lake sampling must be familiar with these protocols, sign the acknowledgment form associated with this specific SOP and collect data in accordance with the procedures as they are defined in this SOP. In addition to standardized methods, proper training of field personnel represents a critical aspect of meeting the data quality objectives in order to fulfill the goals of the SWQB's QAPP (NMED/SWQB 2024).

QA/QC activities for sampling (bacteriological, water chemistry, metals, organics, radionuclides and microcystin) are the same as described in the Chemical Sampling SOP in Lotic Environments (SOP 8.2) and Bacteriological Sampling (SOP 9.1).

Any SWQB personnel who conduct lake sampling are required to receive training in the field and be supervised by MASS Monitoring Team Supervisor for all aspects of sample collections. Any MASS Monitoring staff who conduct training in the field must have conducted at least 1 field season of lake sampling prior to training of other staff or unsupervised sampling. Once training has occurred and all aspects of lake sampling procedures have been observed as correct, personnel may conduct unsupervised lake sampling for the SWQB with approval from Monitoring Team Supervisor. This process will ensure comparability and accuracy of data used for water quality assessments, refinement of water quality standards and TMDL development.

Assurance of field data collection for lake sampling are done through adherence to the processes outlined in this and other applicable SOPs and oversight of the process by the QAO. If at any time the QAO determines this process is not being adhered to, the QAO has the authority to cease activities specific to this SOP with prior support and approval by the SWQB Bureau Chief and MASS Program Manager, until such a time that the issue can be resolved.

9.0 Related Forms

- Lake/Reservoir Sampling Equipment Checklist
- Lake/Reservoir Field Sheet
- Chlorophyll *a* Analysis Sheet
- Upload form for Phytoplankton and Zooplankton

10.0 Revision History

Originally modified from SOP 2007.

Revision 1 – March 2012 –clarified sampling procedures for conditions with a thermocline present (stratified) and when a thermocline is absent (mixed); added guidance on sampling lakes where low DO is a suspected water quality concern

Revision 2 – March 2013 – added information regarding compliant and non-compliant sampling equipment for organic samples to be consistent with SOP 8.2 Chemical Sampling and 40 CFR Part 136; added clarification for sampling in shallow lakes (≤ 3 meters in depth) and use of larger filters for chlorophyll

Revision 3 – March 2014 – revised language and figures to clarify sampling depths during different mixing conditions. Added the use of either a contract lab or in-house analysis.

Revision 4 – August 13, 2020 – revised language and figures to include organics sampling. Clarified sampling depths in compliance with 20.6.4.14(C)(3). Added Lugol's solution formula. Added microcystin sampling. Added process for depth profile data upload into SQUID. Added DOC sampling. Updated sampling location figures. Added sampling at recreational sites. Added phytoplankton and chlorophyll-*a* lab result upload instructions. Added boating safety section. Standard Operating No. changed from 12.0 to 12.1.
Miguel Montoya, QAO; Jonathan Celmer, SME; Kris Barrios, MASS Program Manager

Revision 5 – May 22, 2025 – addition of zooplankton sample collection and processing. Updated *E. coli* sample location. Deleted duplicative language on processes.
Emily Miller, QAO; Lynette Guevara, MASS Program Manager

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United States Environmental Protection Agency
Office of Water
Washington, DC
EPA 841-B-21-011

National Lakes Assessment 2022

Field Operations Manual

Version 1.2, May 2022



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Version History

Version	Date	Revisions and Comments
0.0	December 2021	Internal EPA version for project QAC review and comments
0.0	February 2022	• Updated introduction to be consistent with other NLA 2022 manuals • Corrected typos, formatting, numbering of tables and figures • Updated field data and tracking form names to be consistent with the NLA App • Updated sample bottle types • Added ESA conservation measures (Section 6.4, Section 10 and Appendix C)
1.0	February 2022	Final approved document • Corrected NLA App entry inconsistencies • Clarified whole fish sample storage and shipping (Section 7.3) • Revised ESA conservation measures (Section 6.4, Section 10 and Appendix C) • Updated base kit list
1.1	March 2022	• Added a project identifier (NLA2022) for bloomWatch reports (Section2.2.4.5) • Clarified DO probe calibration requirements (Section 5.2.2.3) • Added direction to homogenize last integrated sample if the last pull does not fit in container (Section 5.5.3) • Updated Figure 5-4 with attachment bridle length • Corrected shipping timeframe for T-2 samples in Table B-1 • Corrected cross reference errors, formatting and typos
1.2	May 2022	• Corrected atrazine preservation and shipping. Atrazine samples are to be kept chilled until analysis (Section 5.5.3.2, Section 8.4 and Appendix B (T-2 Frozen Batched Samples)) • Added Appendix D: NLA Handpicked Sites: Resampling of the National Eutrophication Study Lakes

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NOTICE

The intention of the National Lakes Assessment 2022 (NLA 2022) project is to provide a comprehensive "State of the Lakes" assessment for lakes, ponds, and reservoirs across the United States. The complete documentation of overall project management, design, methods, and standards and Quality Assurance/Quality Control (QA/QC) measures is contained in this document and companion documents, including:

National Lakes Assessment 2022: Quality Assurance Project Plan (QAPP) (EPA 841-B-21-009)

National Lakes Assessment 2022: Site Evaluation Guidelines (SEG) (EPA 841-B-16-008)

National Lakes Assessment 2022: Laboratory Operations Manual (LOM) (EPA 841-B-16-010)

These documents together comprise the integrated set of QAPP documents. This document (*Field Operations Manual [FOM]*) contains a brief introduction and procedures to follow at the base location and on-site, including methods for sampling water chemistry (grabs and *in situ*), phytoplankton, zooplankton, *Enterococci*, environmental DNA (eDNA), algal toxins, benthic macroinvertebrates, physical habitat, and contaminants in fish tissue. These methods are based on both the guidelines developed and followed in the Western Environmental Monitoring and Assessment Program (Baker, et. al., 1997), methods employed by several key states that were involved in the planning phase of this project and prior National Lakes Assessments. Methods described in this document are to be used specifically in work relating to the NLA 2022. All Project Cooperators should follow these guidelines. Mention of trade names or commercial products in this document does not constitute endorsement or recommendation for use. Details on specific methods for site evaluation and sample processing can be found in the appropriate companion document.

The suggested citation for this document is:

USEPA. 2022. National Lakes Assessment 2022. Field Operations Manual. Version 1.2. EPA 841-B-16-011. U.S. Environmental Protection Agency, Washington, DC.

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ACRONYMS/ABBREVIATIONS

ANC	Acid neutralizing capacity
CPR	Cardiopulmonary resuscitation
DBH	Diameter at breast height
DI	Deionized
DO	Dissolved oxygen
DOC	Dissolved organic carbon
ESA	Endangered Species Act
FLC	Field Logistics Coordinator
FOM	Field Operations Manual
GIS	Geographic information system
GPS	Global positioning system
HAB	Harmful Algal Bloom
HDPE	High density polyethylene
HQ	Headquarters
IM	Information Management
LOM	Laboratory Operations Manual
MPCA	Minnesota Pollution Control Agency
NARS	National Aquatic Resource Surveys
NH_4	Ammonium
NHD	National Hydrography Dataset
NIST	National Institute of Standards and Technology
NLA	National Lakes Assessment
NO_3	Nitrate
OSHA	Occupational Safety and Health Administration
PBS	Phosphate buffered saline
PCBs	Polychlorinated biphenyls
PDOP	Position Dilution of Precision
PFAS	Polyfluoroalkyl substances
PFD	Personal Flotation Device
PHab	Physical habitat
QA	Quality assurance
QAPP	Quality Assurance Project Plan
QA/QC	Quality assurance/quality control
QCS	Quality control check solution
QRG	Quick Reference Guide
SEG	Site Evaluation Guidelines
SOPs	Standard Operating Procedures
TSS	Total suspended solids
UL	Underwriters Laboratory

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USGS	United States Geological Survey
UTM	Universal Transverse Mercator

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1.0 BACKGROUND

This manual describes field protocols and daily operations for crews to use in the National Lakes Assessment 2022 (NLA 2022). The NLA 2022 is a statistical assessment of the condition of our nation's lakes, ponds, and reservoirs (subsequently referred to in this manual as "lakes"). The survey is designed to address three key questions about the quality of the nation's lakes:

1. What percent of the nation's lakes are least, moderately, and most disturbed for key indicators of trophic state, ecological health, and human use (recreation)?
2. What is the relative importance of key stressors such as nutrients and pathogens?
3. What changes are occurring in the condition of the nation's lakes?

The surveys are also designed to help expand and enhance state and tribal monitoring programs. Through these surveys, states and tribes have the opportunity to collect data that can be used to supplement their existing monitoring programs or to begin development of new programs.

The NLA 2022 is one of a series of water surveys being conducted by states, tribes, the U.S. Environmental Protection Agency (EPA), and other partners. In addition to lakes, partners will also study coastal waters, wadeable streams, rivers, and wetlands in a revolving sequence. The purpose of these surveys is to generate statistically-valid reports on the condition of our nation's water resources and identify key stressors to these systems.

The NLA 2022 is designed to be completed during the summer growing season before fall lake turnover (June through September[a]). Field crews will collect a variety of measurements and indicators from an "index site" located at the deepest point of the lake up to 50 meters (or near the middle of the lake if the lake is a reservoir), and document conditions of the littoral zone and shoreline from stations around the lake.

1.1 Selection of Sampling Locations

EPA selected sampling locations using a probability-based survey design (Stevens and Olsen, 2004). Sample surveys have been used in a variety of fields (e.g., election polls, monthly labor estimates, and forest inventory analysis) to determine the status of populations or resources of interest using a representative sample of relatively few members or sites. Using this survey design allows data from the subset of sampled lakes to be applied to the larger target population and assessments with known confidence bounds to be made.

With input from the states and other partners, EPA used the following framework to guide the site selection process:

1. The National Hydrography Dataset Plus High Resolution (NHDplusHR) data layer was used to derive a list of lakes for potential inclusion in the NLA 2022.
2. For purposes of this survey, "lakes" refers to natural and man-made freshwater lakes, ponds,

[a] The NLA index period is June through September. Sampling in May could be approved for lakes in areas where stratification is expected earlier in the year. Please coordinate these requests with your Regional EPA Coordinator and the NLA Technical Lead.

and reservoirs greater than one hectare (approximately 2.5 acres) in the conterminous U.S., excluding the Great Lakes.

Mine ponds, retention basins, cooling ponds, and tidally-influenced lakes were excluded from this study. For more information on the site exclusion criteria refer to the National Lakes Assessment 2022: Site Evaluation Guidelines (EPA 841-B-21-008).

3. The sample size was set to include 1,000 lake sampling events.

EPA used an unequal probability design to select 904 lakes and reservoirs greater than 1 hectare (ha) in size (note: in NLA 2007, the lower size limit was 4 ha) in the continental United States. The design includes 2 revisits in each state resulting in the target total of 1,000 site visits. Revisit samples are collected for quality assurance purposes including evaluation of the ability of an indicator to distinguish *among* sites from differences *within* individual sites. Of the 904 lakes, approximately 50% of the lakes are new lakes selected for 2022 and 50% are previously sampled lakes as part of the NLA 2017. The NLA 2017 lakes are referred to as *resample lakes*. Also, of the 904 lakes, approximately 70% of the lakes (i.e., 636 lakes) are designated for whole fish composite sample collection for human health. An "oversample" list of additional lakes was also generated to allow for replacement of non-target or otherwise unsampleable sites. The oversample list will also accommodate any state wishing to conduct a state scale survey.

Lakes selected for the NLA 2022 are distributed among five size class categories and are spatially distributed across the lower 48 states and nine aggregated Omernik Level 3 ecoregions (USEPA, 2013).

Related NLA 2022 documents include the following:

National Lakes Assessment 2022: Quality Assurance Project Plan (EPA 841-B-21-009)

National Lakes Assessment 2022: Site Evaluation Guidelines (EPA 841-B- 21-008)

National Lakes Assessment 2022: Laboratory Operations Manual (EPA 841- 21-010)

These documents are available at: https://www.epa.gov/national-aquatic-resource-surveys/manuals-used-national-aquatic-resource-surveys.

1.2 Selection and Description of Survey Indicators

As part of the indicator selection process, EPA and the NLA 2022 Steering Committee evaluated indicators used in prior NLAs, refined methodologies, and identified new indicators for NLA 2022. The Steering Committee, comprised of state representatives from each of the EPA regions, provided advice and recommendations to the Agency on matters related to the NLA 2022. Key screening and evaluation criteria included indicator applicability on a national scale, the ability of an indicator to reflect various aspects of ecological condition, and cost-effectiveness (e.g., Kurtz et al., 2001). EPA used the Committee's recommendations to refine methods and develop final documents.

The remainder of this section briefly describes the indicators that the NLA 2022 will use to assess trophic status, ecological integrity, human use value, and lake characteristics (Table 1.1). Some indicators provide a basis for evaluating more than one category. For example, an assessment of zooplankton allows for an examination of ecological integrity and trophic status, and to a certain extent, human use.

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1.2.1 Trophic Status and Water Quality Indicators

Lakes are classified according to their trophic state. “Trophic” means nutrition or growth. A eutrophic (“well-nourished”) lake has high nutrients and high plant growth. An oligotrophic lake has low nutrient concentrations and low plant growth. Mesotrophic lakes fall somewhere in between eutrophic and oligotrophic lakes.

Chlorophyll-a, total phosphorus, and Secchi disk transparency are most often used to estimate biomass and define the trophic state of a particular lake. Other variables are measured in conjunction with the trophic state variables to supplement and enhance understanding of lake processes that affect primary productivity.

1.2.1.1 Chlorophyll-a

Chlorophyll is the pigment that allows plants (including algae) to use sunlight to convert simple molecules into organic compounds via the process of photosynthesis. Of the several kinds of chlorophyll, chlorophyll-*a* is the predominant type found in green plants and algae. Measuring chlorophyll-*a* concentrations in water is a surrogate for actually measuring algae biomass and it is used to estimate trophic status.

1.2.1.2 Secchi Disk Transparency

A Secchi disk is a black and white patterned disk commonly used to measure the clarity of water based on the distance the disk can be seen when it is lowered into the water column. The Secchi disk measurement is used to estimate the euphotic zone depth in the field which is generally defined as two-times the Secchi disk depth.

1.2.1.3 Vertical Profile Measurements

Depth profiles for temperature, pH, and dissolved oxygen (DO) are taken with a calibrated water quality probe meter or multi-parameter probe sonde from the index site in each lake. This information is used to determine the extent of stratification and the availability of the appropriate temperature range and level of DO necessary to support aquatic life.

1.2.1.4 Water Chemistry and Associated Measurements

Water chemistry measurements are used to determine the acidic conditions, trophic state and nutrient enrichment, and water chemistry type.

1.2.1.5 Atrazine Pesticide Screen

Atrazine pesticides are herbicides used to control the growth of weeds. Although applied to the land, these chemicals can enter lakes via transport in water (e.g., runoff, groundwater, etc.) or atmospheric transport. This screen will provide information about the occurrence and concentration of atrazine pesticides in water samples from lakes across the nation.

1.2.2 Biological Indicators

Ecological integrity describes the ecological condition of a lake based on different assemblages of the aquatic community and their physical habitat (PHab). The indicators include zooplankton, benthic macroinvertebrates, and the physical habitat of the shoreline and littoral zones.

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1.2.2.1 Benthic Macroinvertebrate Assemblage

Benthic macroinvertebrates are bottom-dwelling animals without backbones ("invertebrates") that are large enough to be seen with the naked eye ("macro"). Examples of macroinvertebrates include crayfish, snails, clams, aquatic worms, leeches, and the larval and nymph stages of many insects, including dragonflies, mosquitoes, and mayflies. Populations in the benthic assemblage respond to a wide array of stressors in different ways so that it is often possible to determine the type of stress that has affected a macroinvertebrate assemblage (e.g., Klemm et al., 1990). Because many macroinvertebrates have relatively long life cycles of a year or more and are relatively immobile, the structure and function of the macroinvertebrate assemblage is a response to exposure of present or past conditions. For the NLA, the benthic macroinvertebrate assemblage occupying the littoral zone will be assessed, rather than the profundal assemblage occupying the deeper regions of lakes.

1.2.2.2 Zooplankton Assemblage

Zooplankton are animal microorganisms that consist of crustaceans (e.g., copepods and cladocerans), rotifers ("wheel-animals"), pelagic insect larvae (e.g., phantom midges), and aquatic mites. The zooplankton assemblage constitutes an important element of the food web, where zooplankton transfer energy from algae (primary producers) to larger invertebrate predators and fish. The zooplankton assemblage responds to environmental stressors such as nutrient enrichment and acidification (e.g., Stemberger and Lazorchak 1994, Dodson et al. 2005). The effects of these environmental stressors on zooplankton can be detected through changes in species composition, abundance, and body size distribution.

1.2.3 **Physical Habitat Characterization**

The characterization of shoreline and littoral zone (the nearshore areas of a lake) physical habitat (PHab) conditions serves three purposes. First, habitat information is essential to the interpretation of expected lake ecological condition in the absence of human disturbance (anthropogenic impacts). Second, the habitat evaluation is a reproducible, quantified estimate of habitat condition, serving as a benchmark against which to compare future habitat changes that might result from anthropogenic activities. Third, the specific selections of habitat information collected aid in the diagnosis of probable causes of ecological degradation in lakes.

In addition to information collected in the field by the shoreline and littoral surveys, the physical habitat description of each lake includes many map-derived variables such as lake surface area, shoreline length, and shoreline complexity. Furthermore, an array of information, including watershed topography and land use, supplements the physical habitat information. The shoreline and littoral characterizations concentrate on information best derived "on the ground". As such, these results provide the linkage between large watershed-scale influences and those influences that directly affect aquatic organisms day to day. Together with water chemistry, the habitat measurements and observations describe the variety of physical and chemical conditions that are necessary to support biological diversity and foster long-term ecosystem stability. These characteristics of lakes and their shorelines are the very aspects that are often changed as a result of anthropogenic activities.

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1.2.4 Human Health and Recreational Use Indicators

Human health indicators address the ability of the lake population to support recreational uses such as swimming, fishing, and boating. The protection of these uses is one of the requirements of the Clean Water Act. The NLA 2022 human health indicators include the extent of cyanobacterial harmful algal bloom (cyanoHAB), algal toxins (microcystins and cylindrospermopsin), fecal indicator (*enterococci*) and fish fillet contaminants.

1.2.4.1 CyanoHAB Visual Observations and Real-time Reporting

Cyanobacteria are microscopic organisms found naturally at low concentrations in freshwater systems. Under optimal conditions (such as high light and calm weather, usually in summer), cyanobacteria occasionally form harmful algal blooms (HABs), or dense aggregation of cells, that float on the surface of the water. At higher concentrations, cyanoHAB events may be so dense that they resemble bright green paint that has been spilled in the water. These blooms potentially affect water quality, human health (e.g., *Microcystis* can produce microcystin, a liver toxin), and natural resources. Decomposition of large blooms can lower the concentration of DO in the water, resulting in hypoxia (low oxygen) or anoxia (no oxygen) which may result in fish kills. Field crews will be submitting real-time reports of a potential cyanoHAB events to the state and tribal organizations that monitor water quality for recreational use support and swimming advisories. These organizations may use this information to determine if follow up monitoring and reporting is needed.

1.2.4.2 Algal toxins (microcystins and cylindrospermopsin)

Microcystins and cylindrospermopsin are two types of toxins produced by cyanobacteria. During a cyanoHABs event, the toxin concentration can rapidly increase and may become elevated before a visible bloom is observed. Elevated cyanotoxin concentrations in surface waters can persist after the bloom fades, so human exposures can occur even after the visible signs of a bloom are gone or have moved downstream. Exposure to elevated-levels of microcystins can potentially lead to liver damage; the kidneys and liver appear to be the primary target organs for cylindrospermopsin toxicity.

1.2.4.3 Fecal indicator (Enterococci)

Enterococci are bacteria whose presence indicates that water may be contaminanted by human or animal wastes. Microbes in these wastes can cause short term effects, such as diarrhea, cramps, nausea, headaches, or other symptoms. They may pose a special health risk for infants, young children, and people with severely compromised immune systems.

1.2.4.4 Fish Fillet Contaminants Indicator

Fish are important integrators of toxic contaminants that are bioavailable in the water column and in sediment. EPA monitors the occurrence of toxic chemicals in fish fillet samples to assess the potential health impacts for people who consume fish. Collecting whole fish composite samples and submitting them to the laboratory for filleting and homogenization during the NLA 2022 provides sufficient tissue for analysis of multiple chemical contaminants of concern (e.g., mercury, polychlorinated biphenyls or PCBs, and per- and polyfluoroalkyl substances or PFAS).

1.2.5 **Other Indicators**

1.2.5.1 Lake Characterizations

Observations and impressions about the lake and its surrounding catchment by field crews will be useful for ecological value assessment, development of associations and stressor indicators, and data verification and validation.

1.2.5.0 Environmental DNA

Two water samples will be collected and analyzed for environemtnal DNA (eDNA). Consistent with NLA 2017, one sample will be collected from the index site. The second sample will be a composite sample from 10 littoral stations. This research measure will be used to explore indicator development for future NLAs.

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Table 1-1 Summary table of indicators and sampling location.

Indicator Type	Indicator	Specifications/Location in Lake			
		Desktop Evaluation	**Boat Launch**	**Index Site**	**Littoral Site**
Trophic and Chemical Indicators	Vertical profile measurements (DO, Temperature, pH)			X	
	Secchi Disk transparency			X	
	Water chemistry (NH_4, NO_3), major anions and cations, alkalinity (ANC), DOC, TSS, silica, conductivity, nutrients (total and dissolved TN and TP)			Integrated water sample	
	Chlorophyll-*a*			Integrated water sample	
	Atrazine pesticide screen			Integrated water sample	
Biological	Benthic macroinvertebrate assemblage				10 stations
	Zooplankton assemblage (composition, structure, and size distribution)			Vertical tow (2 mesh sizes) through water column	
Physical Habitat	Physical habitat characterization				10-12 stations
Human Health	Fecal indicator (*Enterococci*)		Grab sample; lakes >10,000 ha		Grab sample; last station, lakes < 10,000 ha
	Phytoplankton (cyanobacteria)			Integrated water sample	
	CyanoHAB visual observations		X	X	X
	Algal toxins (microcystins and cylindrospermopsin)			Integrated water sample	
	Fish fillet contaminants		Whole fish composite sample (for fillet analysis) collected lake wide		
Other Indicators	eDNA		1L Grab sample; lakes >10,000 ha	1L Grab sample	10 sample composite; 1L total
	Lake area, basin morphometry, and characteristics of watershed	Using GIS			

2.0 LOGISTICS

2.1 Roles and Contact Information

Effective communication between field crews, EPA coordinators, and NLA 2022 contractor support staff is essential for the survey to proceed with maximum efficiency and to ensure collection of high quality data. This section provides:

- A general description of the roles of key NLA 2022 personnel in providing logistical and technical support to the field crews;
- Flow of communication between Field Crews and these individuals (i.e., *who to call for specific types of questions or support needs*); and
- Contact information.

The **EPA Headquarters (HQ) Project Management Team** consists of the Project Leader, Logistics Leader, and Project QA Lead, along with the EPA Technical Lead for the Fish Fillet Contaminants Indicator. The Team is responsible for overseeing all aspects of the project and ensuring technical and QA requirements are properly carried out. The Team is the final authority on all decisions regarding field sampling, site evaluation, site replacement, and laboratory analysis.

The **EPA Regional Coordinators** are the primary EPA point of contact for Field Crews operating in their Region. Field Crews should direct all technical and logistical questions to their EPA Regional Coordinator, who will work with the EPA HQ Team to resolve the issue. Field Crews should also work with their EPA Regional Coordinator to schedule an **Assistance Visit** to occur within the first two weeks of field sampling. An Assistance Visit is part of the QA component of the NLA 2022 QAPP. To meet the requirements of the QAPP, each Field Crew will allow an EPA employee or contractor to observe that crew sampling for one day. The Assistance Visit is used to confirm the protocols are implemented as intended and to suggest corrective actions, if needed, to the Field Crew's sampling approach.

The **Information Management (IM) Coordinator** provides the Field Crews with packets of forms and labels for each site scheduled to be sampled. Crews will request these packets through a fillable PDF Request form. The IM Team also tracks the transition of each NLA 2022 sample from the field to the laboratory.

The Contract **Field Logistics Coordinator (FLC)** is responsible for tracking the Field Crew's sampling activities and overall progress throughout the field season, ensuring that requests for supplies and equipment are filled, and assisting Field Crews with questions concerning field logistics, equipment, and supplies as they arise during the field season. The FLC will also review submitted status and tracking forms to ensure that the correct samples have been taken and that those samples are being sent to the laboratories in an appropriate timeframe.

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Table 2-1 Personnel to call for specific types of questions and support needs.

Personnel	Call
EPA Regional Coordinators	First, to ask any questions about NLA, including questions on field protocols Grant questions Schedule Field Assistance Visit
EPA HQ Project Management Team	Ask questions about site access, site evaluation, and site replacement Ask questions about shipping locations and sample handling procedures Ask questions about Field Methods Ask questions about Target Fish species Ask questions about Survey Design Ask questions about QA procedures Ask questions about Laboratory Methods If you can't reach Regional Coordinator, IM Coordinator, or Field Logistics Coordinator If you are unsure who to call
Personnel	**ONLY Call**
Information Management (IM) Coordinator	Order field forms or site kits Submit a status report Notify EPA about change in sampling schedule Ask questions about submitting data packet If EPA Regional Coordinator directs you to them
Contract Logistics Coordinator	Order replacement items for site kits, base kits, or miscellaneous supplies Ask questions about shipping contract, or to order more shipping forms If EPA Coordinator directs you to them If you can't reach an EPA HQ or Regional Coordinator and it is an urgent question

Table 2-2 Contact information

Title	Name	Contact Information
EPA HQ Project Lead	Lareina Guenzel, OW	guenzel.lareina@epa.gov 202-566-0455
EPA HQ Project QA Lead	Sarah Lehmann, OW	lehmann.sarah@epa.gov 202-566-1379
EPA HQ Logistics Lead	Brian Hasty, OW	hasty.brian@epa.gov 202-564-2236
Contract Field Logistics Coordinator	Chris Turner, Great Lakes Environmental Center, Inc.	cturner@glec.com 715-829-3737

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Title	Name	Contact Information
EPA HQ Fish Fillet Contaminants Indicator Leads	Leanne Stahl, OW/OST	stahl.leanne@epa.gov 202-566-0404
	John Healey, OW/OST	Healey.john@epa.gov 202-566-0176
Contract Fish Fillet Contaminants Indicator Trainer	Blaine Snyder	Blaine.snyder@tetratech.com 410-902-3158
Information Management (IM) Coordinator	Michelle Gover, GDIT	gover.michelle@epa.gov 541-754-4793
Regional EPA Coordinators	Hilary Snook, Region 1	snook.hilary@epa.gov 617-918-8670
	Emily Nering, Region 2	nering.emily@epa.gov 732-321-6764
	Frank Borsuk, Region 3	borsuk.frank@epa.gov 304-234-0241
	Leah Ettema, Region 3	ettema.leah@epa.gov 304-234-0245
	Chris McArthur, Region 4	mcarthur.christopher@epa.gov 404-562-9391
	Mari Nord, Region 5	nord.mari@epa.gov 312-886-3017
	Rob Cook, Region 6	cook.robert@epa.gov 214-665-7141
	Gary Welker, Region 7	welker.gary@epa.gov 913-551-7177
	Liz Rogers, Region 8	Rogers.liz@epa.gov 303-312-6974
	Tom Johnson, Region 8	Johnson.tom@epa.gov 303-312-6226
	Tina Yin, Region 9	yin.christina@epa.gov 415-972-3579
	Matthew Bolt, Region 9	Bolt.matthew@epa.gov 415-972-3578
	Lil Herger, Region 10	herger.lillian@epa.gov 206-553-1074

2.2 Key Information and Materials

2.2.1 Site Maps

Geospatial files in the form of geographic information system (GIS) design point and polygon files and state leaflet maps have been provided on the NLA SharePoint sites to assist in the site evaluation process. From these files, crews should generate their own site maps with relevant information displayed. The site maps will be helpful in the planning and preparation for visiting and sampling a

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particular NLA 2022 site. These maps should become part of your site packet. See more information on the site packet in Section 4.1.

2.2.2 **Forms**

Forms are the key to data collection and tracking for the NLA 2022. For NLA 2022 we have developed electronic forms which will be accessed via the NLA App. Paper forms will only be provided as backups to the App forms.

2.2.2.1 Field Forms

The NLA App is the primary way crews will record measures, observations, and collection information during the course of the field day. Additional information regarding specifics of data entry is contained in Section 3.2.

- **Electronic Field Forms:** This form of data collection will be collected through an Apple iPad which will be provided for all state, tribal, and EPA crews. Each of the field forms are separated into sections for easier data entry. It is important for a field crew to familiarize themselves with the NLA App prior to field sampling. Field crews should note that each individual field form must be submitted by only one device. For example, if there are 5 field forms (A,B,C,D,E) and iPad 1 submits forms A, B, and D, then iPad 2 should not submit those 3 forms or data will be overwritten. In this example, iPad 2 could still submit forms C and E with no issues. While a data or Wi-Fi connection is required to submit the data, no data connection is required for the data collection process.

- **Paper Field Forms:** Extra paper field forms will only be provided to field crews to serve as backup copies in case of problems with electronic field forms. As soon as possible, the completed paper field forms should be transcribed to the NLA App for data submission. The original completed version of the forms must also be scanned, emailed to the EPA Logistic Lead and stored by the field crew for two years.

2.2.2.2 Tracking Form

The **Tracking** form in the App describes the status and location of all samples and specimens collected during the sampling of an NLA site and is transmitted electronically to the IM Team at specified times. When samples are shipped to the lab, a packing slip is included in the shipping container to convey to the lab which samples are included in the shipment. These packing slips (which are pre-printed with the same sample IDs as the individual sample labels) are included in the Label Packet with each Site Kit.

The **Tracking** form is divided into several shipping groups, each labelled with a shipping group number (e.g., T-1, T-2, T-3, etc.). Sample labels, packing slips, and FedEx shipping labels also carry these shipping group numbers to help Field Crews group correct items together for shipping. See APPENDIX B: SHIPPING GUIDELINES for more information.

2.2.3 **Equipment and Supplies**

2.2.3.1 Request Form

Field Crews will submit requests for site kits, whole fish composite sample kits, and other needed supplies via an electronic **Request** form provided by the FLC. This form will be submitted to the NARS IM Coordinator who will ensure that the request reaches the appropriate entity. Crews must submit basic

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sampling information (i.e., tentative start date and number of sites crews are planning to sample) to the FLC at or before the time of submitting request forms. Crews should submit the **Request** form at least two weeks prior to their desired sampling date. The **Request** form will be in fillable PDF format. Users must enter the required information, save a copy of the form to their computer or device and attach the updated copy to an email to sampletracking@epa.gov. The IM Team will send email notification that the request has been received.

2.2.3.2 Base Kit

The Base Kit is comprised of the subset of durable equipment and supplies needed for NLA 2022 sampling and is provided by EPA through the FLC. Typically one Base Kit is provided to each Field Crew and contains some of the equipment that is used throughout the field season. SeeAPPENDIX A: EQUIPMENT & SUPPLIES for a list of the items provided by EPA in the Base Kit. EPA anticipates that Base Kitequipment will be available for use in future NLA efforts.

2.2.3.3 Site Kit

A Site Kit contains the subset of consumable supplies (i.e., items used up during sampling or requiring replacement after use) provided by EPA through the FLC. The site kit will contain all the sample bottles necessary for sampling a single lake. A new Site Kit should be requested for each site sampled, and crews should consider having at least one additional site kit available as a spare should any supplies be lost See APPENDIX A: EQUIPMENT & SUPPLIES for the consumable items that will be provided by EPA.

2.2.3.4 Whole Fish Composite Sample Kit

A sampling kit for the whole fish composite sample will be provided for all designated fish sampling sites. In the survey design, “FT” in the “Panel_Use” identifies lakes designated for fish sampling. This sampling kit contains consumable supplies provided by EPA. Field crews should request a new whole fish sampling kit for each designated fish site to be sampled. See APPENDIX A: Equipment & Supplies for the consumable items that will be provided by EPA.

2.2.3.5 Field Crew Supplied Items

The field crew will also supply particular items for the field sampling day. These items might include supplies from the NLA 2007, NLA 2012, or NLA 2017, typical field equipment (like a global position system (GPS) receiver or multi-paramter probe), or boat equipment. See APPENDIX A: EQUIPMENT & SUPPLIES for the items that the field crew will need to provide.

2.2.4 **Other Resources**

The complete documentation of overall project management, design, methods and standards, and QA/QC measures is contained in this document and companion documents (listed in NOTICE and described below). The NLA 2022 participants must agree to follow the QAPP, including the protocols and design, and the associated documents – the NLA 2022 FOM, LOM, and SEG.

2.2.4.1 Quick Reference Guide

Field crews will NOT receive a NLA 2022 QRG. All components of the QRG will be contained in the FOM and as “i” buttons in the NLA App. The electronic version of the FOM will be provided on the EPA issued Apple iPads and will be a searchable document. Detailed steps to complete protocols can be found in the FOM. Many of the tables and figures in the FOM will also be included in the App.

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2.2.4.2 Site Evaluation Guidelines

The NLA 2022 SEG (EPA 841-B-16-001) outlines the process to compile the final list of candidate lakes for sampling. The process includes locating a candidate lake, evaluating the lake to determine if it meets the criteria for inclusion in the target population and is accessible for sampling, and if not, replacing it with an alternate candidate lake.

2.2.4.3 Quality Assurance Project Plan

Large-scale and/or long-term monitoring programs such as those envisioned for national surveys and assessments require a rigorous QA program that can be implemented consistently by all participants throughout the duration of the monitoring period. QA is a required element of all EPA-sponsored studies that involve the collection of environmental data (USEPA 2000a, 2000b). Field crews will be provided a copy of the NLA 2022 QAPP (EPA 841-B-16-003) and the field crew leader is required to sign the QAPP signature page prior to beginning field sampling activities. The QAPP contains more detailed information regarding QA/QC activities and procedures associated with general field operations, sample collection, measurement data collection for specific indicators, and data reporting activities. For more information on the project level QA procedures, refer to the NLA 2022 QAPP.

2.2.4.4 Laboratory Operations Manual

The methods used for the laboratory sample analysis is available in the NLA 2022 Laboratory Operations Manual (LOM) (EPA 841-B-21-010).

2.2.4.5 Realtime cyanoHAB Reports

Field crew leads are to report a cyanoHAB event if a bloom is occuring at the time of sampling. The Apple iPads are preloaded with the bloomWatch application to support realtime reporting of a bloom to the appropriate state, tribal and/or watershed organization authority. Alternatively, field crews are encouraged to download state-specific monitroing and reporting tools that will be in use for the 2022 recreation season. Additional information on state-specific HABs monitoring programs can be found here (https://www.epa.gov/cyanohabs/state-habs-monitoring-programs-and-resources). To submit a report to bloomWatch or a state-specific tool, the field crews should should be prepared with emails for state officals that are to receive these report (i.e., officals that monitor and report on cyanobacterial bloom events). Field crews must select the preferred reporting approach and be familiar with its input needs (e.g., extent, photos, email contacts etc.) prior to initiating field work. All reports submitted via the bloomWatch app should add the project identifier 'NLA2022' in the comment section in the app.

3.0 DAILY FIELD ACTIVITIES SUMMARY

This section presents a general overview of the activities that a field crew conducts during a typical 1-day sampling visit to a lake. The following sections include general guidelines for health and safety, recording data, and using standardized field data forms and sample labels.

3.1 Health and Safety

Collection and analysis of samples can involve risks to personal safety and health, and **the safety of the field crew must always be the primary consideration during sampling**. This section describes general safety considerations, some safety equipment, and safety guidelines for field operations.

This section does not substitute for an official Health and Safety Plan. The crew MUST ALWAYS carefully follow the protocols in their Health and Safety Plan for the NLA field work that was approved by the state, tribe, or other organization with which the field crew is affiliated. The crew should carry a copy of this approved Health and Safety plan in the field.

3.1.1 General Considerations

It is the responsibility of the group safety officer or project leader to ensure that the necessary safety courses are taken by all field personnel and that all safety policies and procedures are followed. Each state, tribe, or other organization must have a specific safety plan for the sampling the NLA sites, including a communications plan that addresses safety and emergency situations. The plan should have a daily check-in procedure for field personnel, and emergency contacts for police, ambulance, fire departments, hospitals, and search and rescue personnel. Important considerations related to field safety are listed below. It is the responsibility of the group safety officer or project leader to ensure that the necessary safety courses are taken by all field personnel and that all safety policies and procedures are followed. Sources of information regarding health and safety considerations and/or safety-related training include the American Red Cross (http://www.redcross.org/m/phssmrd/take-a-class), the National Institute for Occupational Safety and Health (1981) (see the most recent revisions at https://www.cdc.gov/niosh/docs/81-123/, and the U.S. Coast Guard (http://www.uscgboating.org/recreational-boaters/boating-safety-courses.php).

3.1.1.1 Recommended Training

- First aid;
- Cardiopulmonary resuscitation (CPR);
- Vehicle safety (e.g., operation of 4-wheel drive vehicles, trailer towing and maneuvering);
- Boating and water safety;
- Field safety (weather, personal safety, orienteering, site reconnaissance prior to sampling);
- Equipment design, operation, and maintenance; and
- Handling of chemicals and other hazardous materials.

3.1.1.2 Communications

A communications plan to address safety and emergency situations is essential. All field personnel need to be fully aware of all lines of communication. Field personnel should have a daily check-in procedure

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with their supervisor for safety. An emergency communications plan should include contacts for police, ambulance, fire departments, hospitals, and search and rescue personnel. Below are some items to address:

- Check-in schedule;
- Sampling itinerary (vehicle used & description, time of departure & return, and travel route);
- Contacts for police, ambulance, hospitals, fire departments, and search and rescue personnel;
- Emergency services available near each sampling site and base location; and
- Cell (or satellite) phone number, if possible.

3.1.1.3 Personal Safety

Proper field clothing should be worn to prevent hypothermia, heat exhaustion, sunstroke, drowning, or other dangers. Field personnel should be able to swim, and a personal flotation device (PFD) must be used. Chest waders made of rubberized or neoprene material and suitable footwear must always be worn with a belt to prevent them from filling with water in case of a fall. Below are some personal safety items to address:

- Field clothing and other protective gear including lifejackets for all crew members;
- Medical and personal information (allergies, personal health conditions, and required medications);
- Personal contacts (family, telephone numbers, etc.); and
- Physical exams and immunizations.

Many hazards lie out of sight in the bottoms of lakes, rivers, and streams. Broken glass or sharp pieces of metal embedded in the substrate can cause serious injury if care is not exercised when walking or working with the hands in such environments. Infectious agents and toxic substances that can be absorbed through the skin or inhaled may also be present in the water or sediment. Personnel who may be exposed to water known or suspected to contain human or animal wastes that carry causative agents or pathogens must be immunized against tetanus, hepatitis, typhoid fever, and polio. Biological wastes can also be a threat in the form of viruses, bacteria, rickettsia, fungi, or parasites.

Lakes and surrounding landscapes can be home to dangerous organisms. Field crews should take care to minimize contact with biting insects, bees, poisonous snakes and dangerous animals. Insect repellent and protective clothing will help to limit exposure. At the end of each field day, workers should inspect their bodies for ticks. Any person allergic to bee stings, other insect bites, or plants (i.e., poison ivy, poison oak, poison sumac, etc.) should take proper precautions and have any needed medications on hand. In addition, field crew members should always be aware of their surroundings to protect themselves from dangerous animals, such as alligators, mountain lions, bears, and wolves.

3.1.1.4 Sampling Equipment

Field crew members should be familiar with hazards associated with the use of sampling equipment and establish appropriate safety practices prior to their use. They must ensure that all equipment is in safe working condition.

Because boats are used to access NLA sampling sites, personnel must be trained in operating the type of boat in use incouding appropriate state or other certifications. Personnel must consider and prepare for

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hazards associated with the operation of motor vehicles, boats, winches, tools, and other incidental equipment. Boat operators should be familiar with U.S. Coast Guard rules and regulations for safe boating contained in a pamphlet, *Federal Requirements for Recreational Boats*, available from a local U.S. Coast Guard Director or Auxiliary or State Boating Official and online (U.S. Coast Guard, https://www.uscgboating.org/images/420.PDF). All boats with motors must have fire extinguishers, boat horns, life jackets or flotation cushions, and flares or communication devices.

3.1.2 Safety Equipment

Appropriate safety apparel such as life jackets, waders, gloves, safety glasses, etc. must be available and used when necessary. First aid kits, fire extinguishers, and blankets must be readily available in the field. Cellular or satellite telephones and/or portable radios should be provided to field crews working in remote areas for use in case of an emergency. Supplies such as anti-bacterial soap and an adequate supply of clean water or ethyl alcohol must be available for cleaning exposed body parts that may have been contaminated by pollutants in the water or sediments.

3.1.2.1 Safety Guidelines for Field Operations

General safety guidelines for field operations are presented below.

Personnel participating in field activities on a regular or infrequent basis should be in sound physical condition and have a physical examination annually or in accordance with Regional, State, or organizational requirements.

All surface waters and sediments should be considered potential health hazards due to potential toxic substances or pathogens. Persons must become familiar with the health hazards associated with using chemical fixing and/or preserving agents. Chemical wastes can be hazardous due to flammability, explosiveness, toxicity, causticity, or chemical reactivity. All chemical wastes must be discarded according to standardized health and hazards procedures (e.g., National Institute for Occupational Safety and Health [1981]; for the most recent revisions see https://www.cdc.gov/niosh/docs/81-123/;.)

During the course of field research activities, field crews may observe violations of environmental regulations, may discover improperly disposed hazardous materials, or may observe or be involved with an accidental spill or release of hazardous materials. In such cases it is important that the proper actions be taken and that field personnel do not expose themselves to something harmful. The following guidelines should be applied:

1. First and foremost, protect the health and safety of all personnel. Take any necessary steps to avoid injury or exposure to hazardous materials. If you have been trained to take action such as cleaning up a minor fuel spill during fueling of a boat, do it. However, you should always err on the side of personal safety.
2. Field personnel should never disturb or retrieve improperly disposed hazardous materials from the field to bring back to a facility for "disposal." To do so may worsen the impact, may incur personal liability or liability for the crew members and their respective organizations, may cause personal injury, or may cause unbudgeted expenditure of time and money for proper treatment and disposal of the material. However, it is important not to ignore environmental incidents. Notify the proper local, state, and/or federal authorities of any incident of this type so that they may take the necessary actions to properly respond to the incident.
3. For most environmental incidents, the following emergency telephone numbers should be

provided to all field crews: State or Tribal department of environmental quality or protection, U.S. Coast Guard, and the EPA regional office. In the event of a major environmental incident, the National Response Center may need to be notified at 1-800-424-8802.

Specific Safety Guidelines are below:

- Two persons must be present during all sample collection activities, and no one should be left alone while in the field.
- Minimize exposure to lake water and sediments as much as possible. Use gloves when necessary, and clean exposed body parts as soon as possible after contact.
- All electrical equipment must bear the approval seal of Underwriters Laboratories (UL) and must be properly grounded to protect against electric shock.
- Use heavy gloves when hands are used to agitate the substrate during collection of benthic macroinvertebrate samples.
- Use appropriate protective equipment (e.g., gloves, safety glasses, specialized garments, etc.) when handling and using hazardous chemicals.
- Persons working in areas where venomous snakes may be encountered must check with the local Drug and Poison Control Center for recommendations on what should be done in case of a bite from a venomous snake.
- Any person allergic to bee stings, other insect bites, or plants (i.e., poison ivy, oak, sumac, etc.) must take proper precautions and have any needed medications handy (e.g., an “Epi-Pen”).
- Protect yourself against the bite of deer or wood ticks because of the potential risk of acquiring pathogens that can cause Rocky Mountain spotted fever, Lyme disease, and other diseases.
- Be familiar with the symptoms of hypothermia and know what to do in case symptoms occur. Hypothermia can kill a person at temperatures much above freezing (up to 10°C or 50°F) if he or she is exposed to wind or becomes wet.
- Be familiar with the symptoms of heat/sun stroke and be prepared to move a suffering individual into cooler surroundings and hydrate immediately.
- Handle and dispose of chemical wastes properly. Do not dispose of any chemicals in the field.

3.1.3 COVID Precautions

Safety is the number one concern for all personnel. In implementing the NLA, crews should follow their agencies’ guidance on maintaining social distance, use of personal protective equipment, travel restrictions, sanitizing equipment, vehicles and boats, and if necessary, hotel rooms. NLA training and assistance visits will be implemented in a manner that considers Covid-19 safety requirements and restrictions.

3.2 Recording Data and Other Information

All samples need to be identified and tracked; and associated information for each sample must be recorded. It is imperative that field and sample information be recorded accurately, consistently, and legibly. The cost of a sampling visit coupled with the short index period severely limits the ability to resample a lake if the initial information recorded was inaccurate. As mentioned in Section 2.2.2, there are two forms for collecting sample data: electronic field forms and backup paper field forms. See below for important information pertaining to data entry for each of these forms.

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3.2.1 Field Forms

The NLA 2022 field data and tracking forms are formatted in the NLA App so that the data you record can be electronically submitted to the NARS IM database. It is important that field data and sample information are recorded accurately and consistently. General guidelines for recording field measurements are presented in **Table 3-1.** More detailed instructions for filling out specific forms are provided in each protocol chapter of this manual.

Table 3-1 Guidelines for recording field measurements and tracking information.

ACTIVITY	GUIDELINES
Field Measurements	
Data Recording	• Record observations and measurement values only using the official NLA App (provided on EPA owned Apple iPads for all regional, state, and tribal crews). • If you make an error when recording data and changes are required, it is best to enter the new value and resubmit that electronic form. • Use the correct crew ID assigned during field training. • Use the units and formats specified on individual data forms for recording data. • For any sample or data where additional explanation is needed, use the provided comment bubble adjacent to the data
Sample Collection	
Sample Labels and Tags	• Use a writing instrument that leaves clear, dark text to record information (e.g., a No. 2 pencil on paper tags or a water or smear proof fine-point indelible marker on adhesive labels). Use the sample-type appropriate adhesive labels with preprinted Sample ID numbers for each sample. Be sure to fill in any requested information about the sample on the sample label and affix it to the outside of the sample container. Cover completed labels with clear tape. • Place a waterproof paper tag inside each benthic macroinvertebrate collection jar with the required information written with a No. 2 lead pencil.
Sample Collection Information	• Record that each sample has been collected on the appropriate data form. Be sure to cross-check the Sample ID number from labels and tags with the Sample IDs populated in the **Tracking** form .
QA and Tracking	
Before Leaving Site: Review of Data Forms and Comparison of Sample Labels and Data Forms	• Review all data forms for accuracy and completeness. • Review all sample labels for accuracy, completeness, and legibility. • Verify that the information recorded on the sample labels and tags is consistent with all Sample IDs listed on the **Tracking** form in the NLA App.
Before Shipping Samples: Review of Sample Labels and Tracking Form	• Complete all sections in the **Tracking** form required for all samples being shipped. Review the **Tracking** form for consistency and correctness. • Compare labels on samples with the Sample IDs recorded on the **Tracking** form for accuracy and completeness before shipping samples.
Review of Data Forms	• The Field Crew Leader should review the completed forms in the NLA App as soon as is practicable to ensure they are complete and all data forms are consistent and correct

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ACTIVITY	GUIDELINES
	• Confirm that the forms have been reviewed by selecting the reviewed bubble in the App for each electronic data form. • If any revisions are made, re-submit the updated form(s) as soon as possible to update the IM Database. • After each submission, a data summary email will be sent to the email address which submitted the data. This data summary contains a list of the data forms and their most recent submissions date/time as well as a list of the most critical data points collected at the site. The Field Crew Leader should review this data summary to ensure that the data forms were successfully received and that critical values are present and correct.

3.3 Sampling Scenario

Field methods for the NLA 2022 are designed to be completed in one field day for most lakes. Depending on the time needed for both the sampling and traveling for that day, an additional day may be needed for pre-departure and post-sampling activities (e.g., cleaning equipment, repairing gear, shipping samples, and traveling to the next lake). Remote lakes with lengthy or difficult approaches may require more time to gain access to the lake, and field crews will need to plan accordingly.

A field crew typically will consist of at least two people. Two people are always required in the boat together to execute the sampling activities and to ensure safety. Any additional crew members may either remain on shore to provide logistical support or be deployed in a second boat to assist in data collection. Figure 3-1 and Figure 3-2 present a daily field sampling scenario showing how the workload may be split between crew members. Each field crew should define roles and responsibilities for each crew member to organize field activities efficiently. Minor modifications to the sampling scenario may be made by crews; however, the sequence of sampling events presented in Figure 3-1 cannot be changed and is based on the need to protect some types of samples from potential contamination and to minimize the possibility of holding time exceedance once samples are collected. The following sections further define the sampling sequence and the protocols for sampling activities.

***NOTE**: When sampling large lakes (lakes > 10,000 hectares), field crews may omit the physical habitat, benthic macroinvertebrate, and littoral eDNA sampling efforts altogether.*

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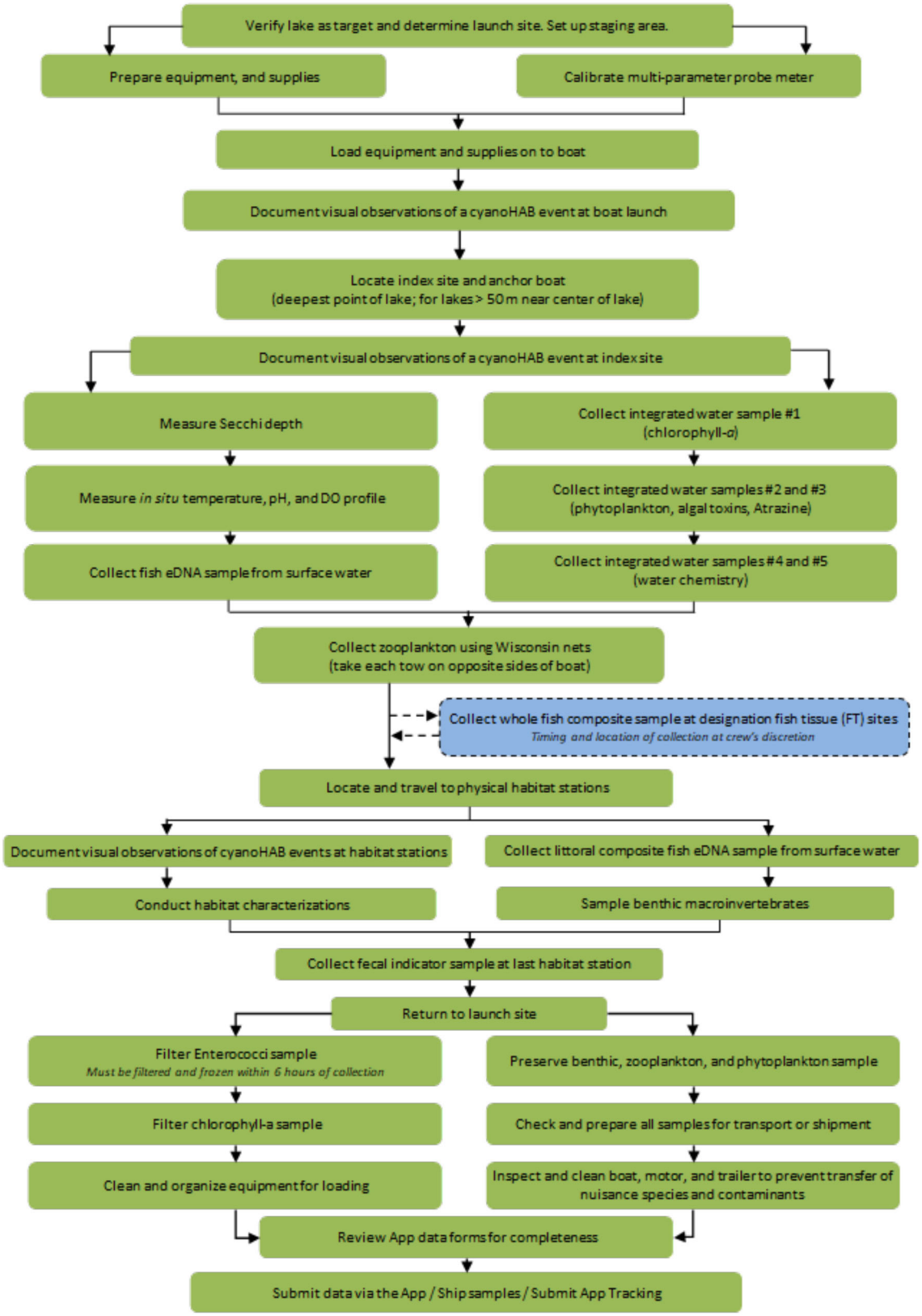


Figure 3-1 Daily operations summary

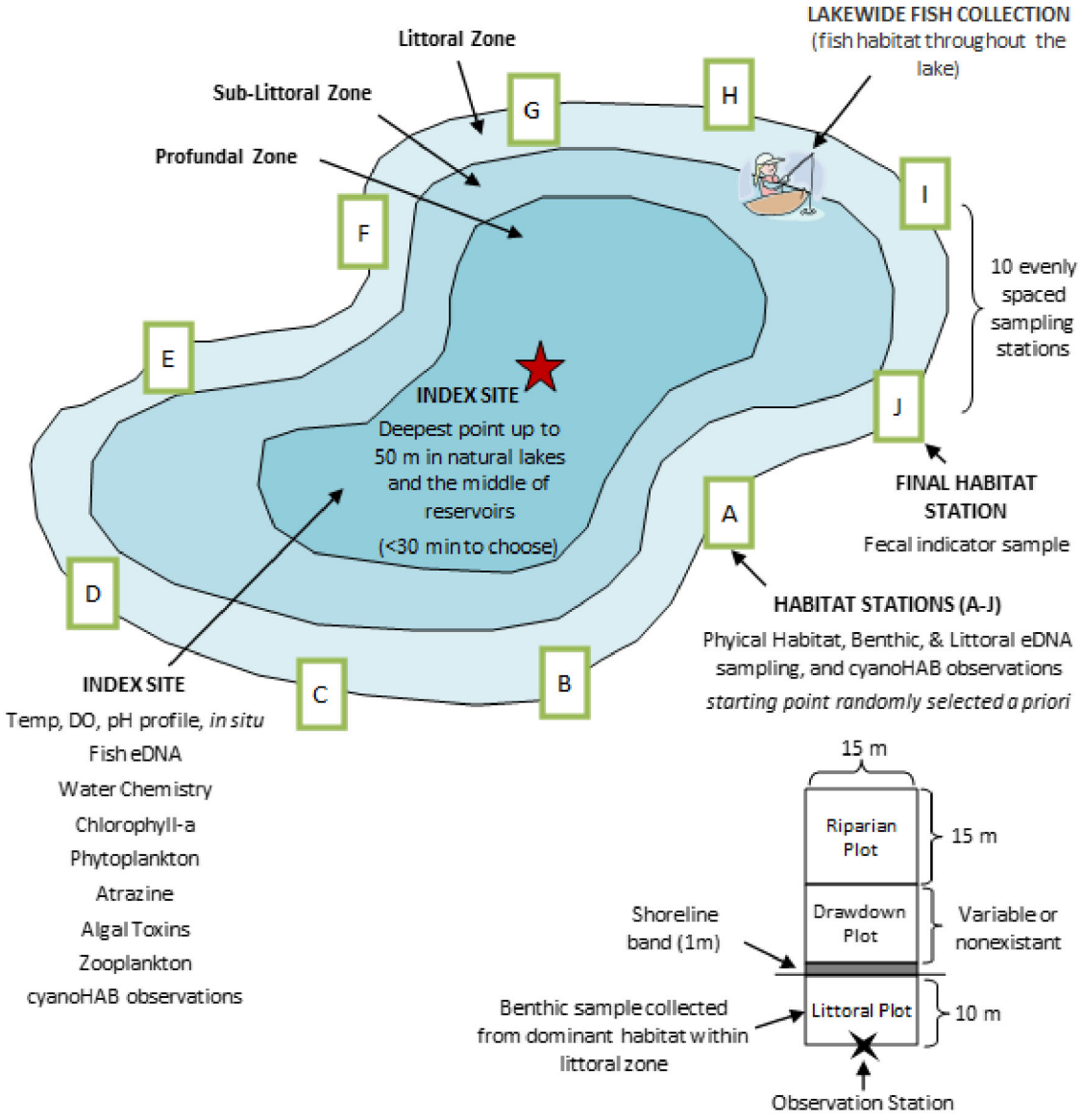


Figure 3-2 Location of sample collection points and physical habitat (PHab) stations.

The field crew arrives at the lake in the early morning to complete the sampling in a single day. The sampling sequence is to:

1. verify lake, calibrate equipment, locate, and travel to the index site;
2. document visual observations of a cyanoHAB event at boat launch and index site;
3. conduct depth profile measurements of DO, temperature, and pH;
4. take Secchi disk transparency depth measurement;
5. collect fish eDNA sample;
6. use the integrated sampler to collect water chemistry, chlorophyll-*a*, atrazine, algal toxin, and phytoplankton samples;
7. collect zooplankton samples;

8. collect fish eDNA sample for composite sample from the littoral plot at the ten PHAb stations (A,B,C,D,E,F,G,H,I,J) prior to initiating physical habitat characterization or benthic sampling;
9. document visual observations of cyanoHABs and conduct physical habitat characterization around the margin of the lake at ten PHab stations (A,B,C,D,E,F,G,H,I,J);
10. collect benthic samples at ten PHAb stations (A,B,C,D,E,F,G,H,I,J) concurrent with physical habitat characterization;
11. collect whole fish composite samples;
12. collect fecal indicator sample at last PHab station (<10,000 ha lakes) or boat launch when exiting lake (>10,000 ha lakes);
13. filter enterococci and chlorophyll-*a* samples;
14. preserve and prepare all samples for shipment;
15. review App field forms ;
16. report sampling event; and
17. ship time-sensitive samples (water chemistry, chlorophyll-*a*, eDNA, and fecal indicator samples).

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4.0 BASE SITE ACTIVITIES

Field crews are to conduct a number of activities at their base site (i.e., office or laboratory, camping site, or motel). These include tasks that must be completed both before departure to the lake site and after return from the field (Figure 4-1). Close attention to these activities is required to ensure that the field crews know:

- where they are going;
- that access is permissible and possible;
- that equipment and supplies are available and in good working order to complete the sampling effort; and
- that samples are packed and shipped appropriately.

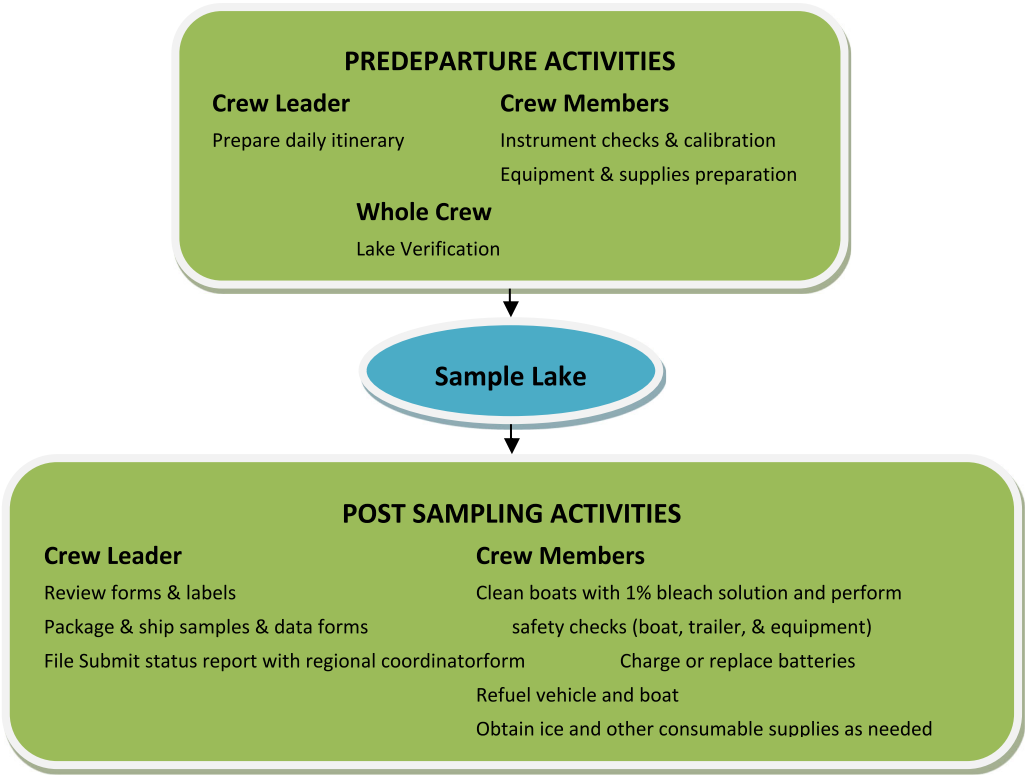


Figure 4-1 Overview of base site activities

4.1 Pre-departure Activities

Pre-departure activities include developing daily itineraries, checking and calibrating instruments, and preparing equipment and supplies. Procedures for these activities, which will take place at your office or laboratory, camping site, or motel, are described in the following sections.

4.1.1 Daily Itineraries and Site Packets

The Field Crew Leader is responsible for developing daily itineraries and a site packet. A site packet contains information key to the planning and preparation for visiting and sampling a particular NLA site.

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Development of site packets should have been initiated during site evaluation and reconnaissance (See NLA 2022 Site Evaluation Guidelines); however, the field crew may need to gather additional information for the site packet during preparation for the sampling visit. Also, it is the responsibility of the field crew to obtain access permissions and any needed permits as part of developing the site packet.

Prior to a field crew traveling to a NLA site for sampling, the information for the site packet must be gathered and reviewed. Site packet development entails compiling maps, contact information, copies of permission letters, and access instructions. The Field Crew Leader must be sure to lay out the physical habitat (PHab) stations on a site map before the sampling day (see Section 6.2.3). Additional activities include confirming the best access routes, calling the landowners or local contacts, and confirming lodging plans. The site packet may include the following documents:

- **Site maps**: Generated by crew (see Section 2.2.1 Site Maps).
- **Other Maps, Imagery, or GIS Data:** Any other maps, aerial photos, GIS data, or sources of information compiled by Field Crews and/or their partners that could be helpful to sampling the NLA sites.
- **Land Ownership Status, Requirements and Permissions for Access:**
    - Landowner identity and contact information.
    - Results of communication with landowners.
    - Documentation of permission to access private land.
    - Permissions for crossing private lands to reach sites located on public lands.
    - For public land, response of relevant agency to notification that you will be accessing a site, and, if needed, permissions to do so.
- **Permits:** Any permits or documentation required for site access, or for data collection activities or sample/specimen collection.
- **Information for Accessing the Site:**
    - Contact information for landowners.
    - Notes about whether landowner(s) want to be informed when Field Crew is on site.
    - Contact information for individuals who must be available to open gates or allow entry to a site, and the time and location for meeting them.
    - Notes on locked gates, pets, livestock, or other things that could impede access.
    - Notes about active hunting, farming, mining, or other activities on or near the site.
    - Current conditions that could prevent access (e.g., high water, forest fires, road closures, etc.).
- **Site Evaluation Notes:**
    - Site Evaluation notes, annotated aerial photos, sketch map, and completed site evaluation form that can aid with planning for accessing or sampling a site.
- **Driving and Hiking Routes to the Site:**
    - Detailed driving directions may be obtained from the NLA Google Earth files.
    - Results from the Site Evaluation may include driving directions and notations about site access or logistically challenging conditions on the site, which can be useful in relocating the site or helpful in anticipating special circumstances.

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- **Preliminary Plan for Establishing Physical Habitat Stations:** As part of the base location activities to prepare for field work, review aerial photos and maps of the site and make a plan for laying out the PHab stations. This plan should be included in the site packet.
- **Federally Protected Species (EPA Regional and Contract Crews ONLY):** See Section 10.0.
- Any other site specific information (e.g., road construction and road closings) useful to the Field Crew.

4.1.2 Instrument Checks and Calibration

Test and calibrate instruments prior to sampling. You can calibrate instruments and probes prior to departure for the lake site or at the lake, with the exception of the DO probe. Because of the potential influence of altitude, calibrate the DO probe at the lake site (NOTE: some newer instruments may allow for calibration independent of altitude). Field instruments include a multi-parameter probe unit for measuring temperature, DO, and pH and a GPS receiver. Field crews should have access to backup instruments if any instruments fail the manufacturer performance tests or calibrations.

4.1.2.1 Depth sounding equipment

Crews are responsible for checking the accuracy of their devices against a sounding line at the beginning of the field season to verify that the device is providing accurate depth information.

4.1.2.2 Multi-parameter probe Meter Performance Test

Test and pre-calibrate the multi-parameter probe meter prior to departure from the base site, following either the Standard Operating Procedure (SOP) developed for the instrument or the manufacturer's calibration and maintenance procedures. Field crews should perform a QC check of the pH meter calibration (and conductivity meter calibration, if this optional measurement is taken) at regular intervals designated by the manufacturer. Field crews will be responsible for preparing or purchasing their own QC solution.

4.1.2.3 Global Positioning System Use and Battery Check

A GPS unit is used to locate the launch, index site and each of the physical habitat stations. Therefore, it is imperative that the Field Crew understands how to operate their GPS unit. The Global Positioning System (GPS) uses signals sent from multiple orbiting satellites to a ground-based sensor in order to fix a position on the earth. GPS uses signals sent from multiple orbiting satellites to a ground-based sensor in order to fix a position on the earth. Position accuracy depends on the Position Dilution of Precision (PDOP) which is a measure of the geometry of the satellite spread over the location of the observer. Low PDOP values are typically conveyed to the user as a measure of accuracy or precision and represent more advantageous satellite geometry and therefore less locational error. For NLA, crews should regularly monitor the accuracy reading on their GPS and should record coordinates only after achieving the lowest amount of error possible.

GPS uses many alternative mathematical models to describe the spherical shape of the earth and each is a separate datum. Commonly used datums include NAD27 CONUS, NAD83, and WGS84. Each represents a different interpretation of the shape of the earth. The NARS standard is **NAD83**. Thus, all GPS units should be switched to this standard - prior to completing any field activities. Crews should also confirm that the NAD83 datum is being used when the GPS is turned on prior to data collection. If the GPS is not

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set for NAD83 and the unit cannot be changed readily, note the datum used on the data forms for later conversion.

GPS devices use a variety of units for position designation based on an imaginary latitude and longitude coordinate grid system laid across the earth (degrees, minutes, seconds, or degrees and decimal minutes, and UTM (a metric system). The NARS standard is **decimal degrees** for reporting all GPS positions.

Refer to the GPS user's manual to provide specific instructions on setting the Datum, coordinate system, and units to NLA standards. Turn on the GPS receiver and check the batteries prior to departure. Replace batteries immediately if a battery warning is displayed.

4.1.2.4 Electronic Data Capture Device Battery Check (Apple iPad)

Charge the Apple iPad each night and check the power prior to departure. External battery packs are often available for these devices if battery life is a concern.

Table 4-1 Instrument checks and calibration

Equipment	Preparation
GPS Unit	Check the batteries prior to departure Ensure map datum is set to NAD83 Ensure locational units are set to decimal degrees • latitude xx.xxxxxx; longitude -xxx.xxxxxx Perform manufacturer checks as necessary to ensure accuracy
Multi-parameter Probe	Calibrate per manufacturer guidelines (DO to be calibrated at lake) Check the batteries prior to departure Perform QC Check as directed by manufacturer and/or laboratory protocols (field crews will supply QC check solution)
Electronic Data Capture Device (Apple iPad)	Check the power prior to departure Ensure NLA Data collection App is installed, up to date, and functioning

4.1.3 Equipment and Supply Preparation

Check your inventory of supplies and equipment prior to departure using the equipment and supplies checklists provided in the Appendix; use of the lists is strongly recommended. Pack meters, probes, and sampling gear in such a way as to minimize physical shock and vibration during transport. If necessary, prepare stock preservation solutions as described in Table 4-2. Follow the regulations of the Occupational Safety and Health Administration (OSHA).

Table 4-2 Stock solutions, uses, and methods for preparation.

Solution	Use	Preparation
Bleach (1%)	Clean nets, other gear, and inside of boat.	Add 40 mL bleach to 4,000 mL distilled water.
Lugol's	Preservative for phytoplankton samples.	Lugol's will be supplied with base kit. If preparation is needed: Dissolve 100 g KI in 1 L of distilled water. Dissolve 50 g iodine (crystalline) in 100 mL glacial acetic acid. Mix these two solutions. Remove any precipitates. Store in the dark.
95% Ethanol	Preservative for benthic invertebrate samples and zooplankton samples.	No preparation needed (use stock solution as is).

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Refuel vehicle(s) and conduct maintenance activities the night before a sampling trip. Check trailer lights, turn signals, and brake lights before departure. In addition, inspect your vehicles, boats, and trailers every morning before departure. Pay particular attention to the trailer hitch, electrical connections, tie downs, tire pressure, and the overall condition of the boats.

Label and package as many of the sample containers as possible in the site kit prior to departure. Container labels should not be covered with clear tape until all information is completed during sampling at the lake. Store an extra kit of sampling supplies (Cubitainers®, bottles, filters, foil, gloves, forms, pencils, permanent markers, and labels) in the vehicles. Inventory these extra supply kits prior to each lake visit. Be sure to order field sampling site kits well in advance (two week minimum) by submitting the electronic **Request** form.

4.1.4 General Equipment and Supplies for all Activities

Table 4-3 indicates equipment and supplies that will be used for all activities.

Table 4-3 Equipment and supplies – all activities.

Type	Item	Quantity
Forms	NLA App pre-installed on Apple iPad	2
Reference	NLA 2022 Field Operations Manual (FOM) NLA 2022 Quality Assurance Project Plan (QAPP) NLA 2022 Site Evaluation Guidelines (SEG) NLA 2022 Fact Sheets	1 1 1 10
Documentation	Clipboard Pencils (#2, for benthos inner sample tags) Permanent markers (fine tip, for adhesive labels) Labels Field Notebook (optional) Clear tape strips (to cover sample labels)	1 1 1 1 As needed
Collection	Access permission documents/permit (if required)	1

4.2 Lake Verification

4.2.1 Equipment and Supply List

Table 4-4 is the checklist for equipment and supplies required to conduct protocols described in this section. It is similar to, but may be somewhat different from, the checklist that is used at a base site to assure that all equipment and supplies are taken to, and available at, the lake. Field crews should use the checklist presented in this section to ensure that the equipment and supplies are organized and available on the boat in order to conduct protocols correctly and efficiently.

Table 4-4 Equipment and supplies – lake verification.

Type	Item	Quantity
Form	NLA Verification Form	1
Collection	Depth Finder (hand-held or boat mounted sonar) GPS unit (with manual, reference card, extra battery) Anchor (with 75 m line or sufficient to anchor in 50 m depth)	1 1 1-2

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4.2.2 Lake Verification at the Launch Site

Before sampling activities begin, you must verify that you are at the correct lake and whether it meets the criteria for sampling. Confirming that you are at the correct lake is based on map coordinates, locational data from the GPS when possible, and any other evidence such as signs or conversations with local residents. The Design Name for the site is pre-populated in the App (UNKNOWN if no name), crews should populate the Lake Name if known. Record locational coordinates for the lake on the **Verification** form. If GPS coordinates are obtained, fill in the bubble to indicate GPS and record the latitude, longitude in decimal degrees.

Determine the number of satellites being used by the GPS and select if 3 or fewer satellites or if 4 or more satellites were used. All coordinates will be recorded in the NAD83 datum. Compare the map coordinates pre-populated in the App for the lake with the GPS coordinates you record and verify that you are at the correct lake. [Note: The map coordinates in the App represent the “labeling point” in NHD and may not be near either the index site or the launch site]. Verification that you are at the target lake can be confirmed via other methods (e.g., map, landowner confirmation). If GPS coordinates are not available, do not record any information, but try to obtain the information at a later time during the visit. A GPS location may be taken at any time during a lake visit and recorded by flagging the launch site coordinates and providing a comment.

Record directions to the lake and a description of the launch site on the **Verification** form regardless of whether the site is sampled or not. This information is very important and will be used in the future if the lake is revisited by another sampling crew. Provide information about signs, road numbers, gates, landmarks, and any additional information you feel will be useful to another sampling crew in locating this lake in the future. It is also helpful to describe the distance traveled (miles) between turns. Also describe the launch site. For example: Can the boat be launched with a trailer? Are there fees? Is the launch paved or does it consist of soft sand? What landmarks are at the launch? Due to privacy concerns, do not record landowner contact information (e.g., name, address, phone, email address) on the **Verification** form.

In addition to, or in the absence of, an accurate GPS reading, use as many of the following methods as possible to verify the site:

- Obtain confirmation from a local person familiar with the area.
- Identify confirming roads and signs.
- Compare the lake shape to that shown on a topographic map (United States Geological Survey (USGS) 7.5-minute map or equivalent).
- Determine lake position relative to identifiable topographic features shown on the map.

If the lake shape on the USGS topographic map does not correspond with the actual lake shape from your site map, and you cannot verify the lake by any other means, check "Not Verified" and provide comments on the **Verification** form. At each lake, evaluate whether or not the lake meets the NLA operational definition of a “lake”:

- ≥ one ha in total surface area;
- ≥ 1,000 square meters of open water;
- ≥ one meter in depth;
- Not saline (due to saltwater intrusion or tidal influence); and

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- Not used for aquaculture, disposal-tailings, mine-tailings, sewage treatment, evaporation, or other unspecified disposal use.

If the lake does not meet this definition, select the "non-target" bubble in the lake sampled section on the **Verification** form and provide an explanation for not sampling the lake. Add any additional explanation as required. (For complete details on the Site Evaluation process, refer to the companion document *Site Evaluation Guidelines* [EPA 841-B-06-003]).

Record the names of each crew member on the **Verification** form. At the launch site, document visual observations of a potential cyanobacterial bloom in the NLA App and photo document the bloom according to the reporting mechanism selected by the field crew (i.e., bloomWatch or state-specific reporting mechanism).

Regardless of whether the lake is sampled or not, the field crew must fill out and submit a **Verification** form for every lake that is visited with the intent to sample.

4.2.3 Locating Index Site

When determining lake origin, i.e., lake vs. reservoir in the field, a body of water that was a stream or river and subsequently dammed to create a lake is considered a reservoir. A lake which has had its level raised because of a dam is an “enhanced” lake and will be considered a natural lake for NLA 2022.

For natural lakes, go to the deepest point in the lake to locate the index site (or middle of the lake for reservoirs). If the deepest point exceeds 50 m in depth, do not establish the index site at this location; instead, choose a point as close to the middle of the lake as you can without exceeding 50 m in depth. The procedure below outlines sonar operation and procedures for finding the index site.

For reservoirs, the index site is located near the mid-point of the reservoir rather than at the deepest point, which may be near the dam. If this would result in an index site that is very shallow or otherwise non-representative of the reservoir as a whole, choose a point near the center of a main basin, where depths and the water column will be more representative of the reservoir.

Once in the general area, use the sonar unit to locate the deepest point (≤ 50 m). When an acceptable site is located, anchor the boat. Lower the anchor slowly to minimize disturbance to the water column and sediment. Determine the coordinates of the index site by GPS (if satellite coverage is available) and record on the **Index Samples** form. In addition, select if 3 or fewer or 4 or more satellites were used. If satellite coverage is not available at that time, try again before leaving the index site. The following is the procedure to be used to locate the index site:

1. Operate sonar unit according to manufacturer's specific operating procedures. If possible, depth readings should be made and recorded in metric units (be sure to specify units on the **Index Samples** form).
2. Use the sonar in the area expected to be the deepest. Spend no more than 30 minutes searching for the deepest point; the maximum depth for the index site is 50 meters.
3. Anchor the boat.
4. Determine the coordinates using GPS. Record GPS coordinates on the **Index Samples** form.

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4.3 Post Sampling Activities

Upon return to the launch site after sampling, review all labels and completed data forms for accuracy and completeness, and make a final inspection of samples. If information is missing from the forms or labels, the Field Crew Leader gathers and records the missing information. The Field Crew Leader selects the red circle at the top of each data form after review. Other post sampling activities include: sample filtering, inspection and cleaning of sampling equipment, inventory and sample preparation, sample shipment, and communications.

4.3.1 Equipment Cleanup and Check for Invasive Species

You must inspect all equipment, including nets, boat, and trailer, and clean off any plant and animal material. This effort ensures that introductions of invasive species such as Eurasian watermilfoil (*Myriophyllum spicatum*) quagga mussels (*Dreissena rostriformis* bugensis), and zebra mussels (*Dreissena polymorpha*) do not occur between lakes. Prior to leaving a lake, drain all bilge water or live wells in the boat. Inspect, clean, and handpick plant and animal remains from vehicle, boat, motor, and trailer that contact lake water. Inspect and remove any remnants of vegetation or animal life. Before moving to the next lake, if a commercial car wash facility is available, thoroughly clean vehicle, boat, and trailer (hot water pressurized rinse – no soap). Rinse equipment and boat with 1% bleach solution or other approved biological disinfectant to prevent spread of exotics. Procedures are below.

1. Clean for biological contaminants (e.g., Eurasian watermilfoil, zebra mussels, and alewife):
    a. Prior to departing from a lake, drain all bilge water from the boat.
    b. At the lake, inspect motors, boat, and the trailer for evidence of plant fragments, especially in or near the propeller and water intakes. Remove all plant fragments.
    c. At the lake or base site, dry out and inspect nets and buckets and remove any remnant vegetation or animal life. Disinfect gear with 1% bleach solution or other approved biological disinfectant.
    d. If a commercial car wash facility is available, thoroughly clean vehicle and boat (hot water pressurized rinse--no soap).
2. Clean and dry other equipment prior to storage:
    a. Rinse chlorophyll-*a* collection bottle three times with DI water after each use.
    b. Rinse graduated cylinders, integrated sampler, and other sampling devices three times with DI water after each use.
    c. Briefly soak zooplankton nets and fishing nets in a 1% bleach solution or other approved biological disinfectant and dry after each use. Do not dry in sunlight because the mesh is photosensitive.
    d. Rinse coolers with water to clean off any dirt or debris on the outside and inside.
    e. Rinse boots and waders with water to clean off any dirt, debris, or biological contaminants on the outside and inside.
3. Inventory equipment and supply needs and request supplies via the electronic **Request** form (forms or site kits) or from the FLC (other items or urgent requests).
4. Remove multi-parameter probe meter and GPS from carrying cases and set up for pre-departure checks and calibration. If present (i.e., not using optical DO sonde), examine the oxygen membranes for cracks, wrinkles, or bubbles. Replace if necessary.
5. Recharge/replace batteries as necessary.
6. Recheck field forms from the day's sampling activities. Make corrections and completions where possible, and initial each form after review.

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4.3.2 Shipment of Samples and Forms

You must ship or deliver time-sensitive samples (i.e., all chilled samples) to the appropriate analytical laboratories as soon as possible after collection and no later than the day after collection. These samples will be shipped in two groups for next day delivery. Other frozen and non-chilled samples may be shipped or delivered in batches provided they can be adequately stored. Report all sample shipments to the NARS IM Coordinator (by submitting the **Tracking** form in the NLA App) as soon as possible so that and they can be tracked if they do not arrive when expected.

Field crews are to fill out the pertinent section(s) of the **Tracking** for each sample shipment. In each section of the tracking form, the following information must be recorded:

- Package tracking number
- Date sample(s) were sent
- Sample type code:
  - ENTE – Fecal Indicator (*Enterococci*)
  - BENT – Benthic macroinvertebrates
  - CHEM – Water Chemistry
  - CHLX – Chlorophyll-*a*
  - FDNA – eDNA (index)
  - LDNA - eDNA (littoral)
  - MICZ – Algal toxin (microcystins and cylindrospermopsin)
  - PHYX – Phytoplankton
  - TRIA – Atrazine Pesticide Screen
  - ZOCN – Zooplankton coarse (150-micron mesh)
  - ZOFN – Zooplankton fine (50-micron mesh)
  - FTIS - Human health fish tissue sample
- Sample ID number from preprinted sample label
- Number of containers for each sample
- Any additional shipping comments

See APPENDIX B: SHIPPING GUIDELINES for further information.

4.3.3 Communications

After the Field Crew Leader has reviewed form content at the end of the sampling day, click the SUBMIT menu button and choose the form(s) that you wish to submit. After you have chosen which form to submit, click the green submit button at the bottom of the form list. An email will pop up on your device addressed to NARSFieldData@epa.gov. Copy yourself and any other crew members or managers and click send. To ensure that the email was sent, check the SENT mailbox on your email App and look for the recent email containing the data. If the email is not in the SENT mailbox, it was not sent and you should try again after verifying an internet connection.

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After each submission, a data summary email will be sent to the email address which submitted the data. This data summary contains a list of the data forms and their most recent submission date/time as well as a list of the most critical data points collected at the site. The Field Crew Leader should review this data summary to ensure that the data forms were successfully received and that critical values are present and correct.

At any point, if it is determined that data needs to be revised or updated, crews should feel free to do so in the App and re-submit any edited data forms using the steps above. Newly revised data will supersede previous data. It is not necessary to re-submit data forms that were unchanged.

Each field crew must submit the **Verification** form in the NLA App after each site visit (whether the site is sampled or not). General communications information, including contact information for the NARS IM Center, is outlined in Section 2.1.

If the field crew documented the potential occurrence of a cyanoHAB event at one or more station in the lake, the Field Crew leader is responsible for reporting the bloom to the appropriate state, tribal and/or watershed organization. See Section 2.2.4.5 for potential reporting mechanisms.

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5.0 INDEX SITE ACTIVITIES

Field crews will collect several different measurements and indicators at the index site (as described in Table 1-1): cyanoHABs assessment, a temperature, DO, and pH depth profile, secchi transparency, fish eDNA, chlorophyll-*a*, phytoplankton, algal toxins, water chemistry, atrazine, and zooplankton samples. A detailed description of the individual elements is provided below.

5.1 CyanoHABs Visual Assessment

When arriving at the index site, field crew views and documents visual observations of a potential cyanobacterial bloom in the NLA App and photo documents the bloom according to the reporting mechanism selected by the field crew (i.e., bloomWatch or state-specific reporting mechanism).

5.2 Temperature, DO, and pH profile

5.2.1 Summary of Method

Use a multi-parameter water quality meter (or sonde) to measure temperature, DO, and pH at predefined depth intervals. Measurement intervals for the profile are based on the site depth (see Section 5.2.3). Once the profile is completed, make another DO measurement at the surface and compare it to the initial reading to see if the probe is functioning correctly and holding calibration. If the lake is thermally stratified, note the top and bottom of the metalimnion based on the temperature readings (observed as a change of ≥1 °C per meter of depth).

The meters and probes are delicate; take care to avoid putting the probe into contact with sediments which could foul the probes. An accurate measure of the site depth will help prevent contact between the sediment and the probes.

5.2.2 Equipment and Supplies

Table 5-1 is the checklist for equipment and supplies required to conduct protocols described in this section.

Table 5-1 Equipment and supplies – temperature, pH, and DO profiles.

Type	Item	Quantity
Forms	NLA Profile Calibration NLA Index Profile	1 1
Collection: **Water column depth**	Depth Finder (hand-held or boat mounted sonar) Sounding line (50 m, calibrated, marked in 0.5 m intervals) with clip OR Sounding rod (calibrated) for very shallow lakes	1 1
Collection: **Profile measurements & calibration**	Multi-parameter water quality meter (with temperature, pH, and DO probes) Sounding line or 50-meter tape Sounding weight Squirt bottle (1 L Nalgene) – De-ionized (DI) Squirt bottle (1 L Nalgene) – lake water Calibration cups and standards QC check solution Barometer or elevation chart to use for calibration	1 1 1 1 1

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5.2.2.1 Multi-parameter Sonde

The multi-parameter sonde must be heavy enough to minimize sway and wobbling as it is lowered and raised in the water column. The instrument must be stabilized prior to taking a reading. Experiment with the sonde prior to sampling and add weight to the cable if needed.

5.2.2.2 Temperature Meter Calibration

Check the accuracy of the sensor against a thermometer (a non-mercury type is recommended) that is traceable to the National Institute of Standards and Technology (NIST) at least once per sampling season. The entire temperature range encountered in the NLA 2022 should be incorporated in the testing procedure and a record of test results kept on file.

5.2.2.3 DO Probe Calibration

Crews are to calibrate the DO probe at the lake prior to each sampling event. The probe calibration is to be completed in the field against an atmospheric standard (ambient air saturated with water, or water saturated with air for optical probes) prior to launching the boat. In addition, manufacturers typically recommend periodic comparisons with a DO chemical analysis procedure (e.g., Winkler titration) to check accuracy and linearity. Small "mini-Winkler" titration kits are suitable for this check and can be taken into the field.

5.2.2.4 pH Meter Calibration

Calibrate the pH electrode daily, prior to each sampling event in accordance with the manufacturer's instructions and your organization's existing SOP. Conduct a QC check with a different standard to verify the calibration and periodically evaluate instrument precision (see Section 2). Ideally, a quality control solution (QCS) should be used that is similar in ionic strength to the lake water samples you will be measuring. Standard buffer solutions used to calibrate electrodes may not be representative of typical lake waters.

5.2.2.5 Conductivity Calibration

A field conductivity measurement is optional for the NLA 2022. If the Field Crew opts to take conductivity measurements, the conductivity meter must be calibrated prior to each sampling event. Calibrate the meter in accordance with the manufacturer's instructions. Ensure that the conductivity meter is temperature corrected to 25 °C.

5.2.3 **Depth Profile Procedure**

Below are the step-by-step procedures for measuring temperature, pH, and DO profiles at the index site.

1. Calibrate Instrument
    a. Check meter and probes and calibrate according to manufacturer's specifications.
    b. Enter calibration information on the **Profile Calibration** form.
2. Record Site Conditions:
    a. Observe site conditions and fill out the "Site Conditions" portion of the **Index Samples** form. Conditions to be reported include:
        i. Precipitation ("None", "Light," or "Heavy")
        ii. Surface conditions ("Flat," "Ripples," "Choppy," or "Whitecaps")
    b. Presence or absence of odor or scum. If present, select "Yes" and describe the odor or scum.

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3. Determine Site Depth:
    a. Accurately measure the depth using a sounding line with a weight or other means and record on the **Index Samples** form.
    b. Indicate method used.
4. Determine Measurement Intervals:
    a. The number of readings and the depth intervals taken depends on the site depth. Below is a list of rules for determining the intervals:
        i. The profile will always begin with a measurement just below the surface (e.g., approximately 10 cm or the minimum depth required to keep all probes submerged).
        ii. The last (deepest) measurements will always be at 0.5 m above the bottom.
        iii. If the site is < 3.0 m deep, record measurements beginning just below the surface and at 0.5 m intervals, until 0.5 m above the bottom.
        iv. If the depth is between 3.0-20 m (inclusive), record measurements beginning just below the surface and then at 1.0 m intervals until reaching 0.5 m above the bottom.
        v. If the depth exceeds 20 m, record measurements beginning just below the surface, then at 1.0 m intervals until you reach 20 m, then at 2.0 m intervals until 0.5 m above the bottom.
        vi. If the metalimnion is encountered (observed as a change of ≥1 °C per meter of depth), take measurements at least every meter within the metalimnion.
5. Measure Temperature, DO, and pH:
    a. Lower the sonde in the water and measure the vertical profile of temperature, DO and pH at the predetermined depth intervals. Be careful not to let the probe touch the bottom.
    b. Record the intervals and measurements on the **Profile Data** form.
    c. Use the provided comment bubble to provide extra information about any measurements that the crew feels needs further comment or when a measurement cannot be made.
6. Duplicate Surface DO Measurement
    a. When the profile is completed, take another DO measurement at the surface, record it, and compare it to the initial surface DO reading.
    b. Mark ‘Yes’ or ‘No’ on the form if the second DO reading is within 0.5 mg/L of the initial surface reading. This provides information regarding measurement precision and possible calibration drift during the profile.
        i. If measurement is not within 0.5 mg/L, verify your calibration.
        ii. If DO is found to be out of calibration, re-calibrate and re-record DO measurements.
7. Determine the Metalimnion:
    a. If the lake is thermally stratified, note the top and bottom of the metalimnion in the Metalimnion column.
    b. For standardization purposes, the metalimnion has been defined in the protocol as an area where water temperature changes at least 1 degree Celsius per meter.
    c. If you suspect that the metalimnion exists but does not change at the specified rate, estimate the top and bottom of the metalimnion to the best of your ability, use the provided comment bubble to flag the data, and explain.
    d. In deep sites where measurement intervals are 2.0 meters apart, decrease the interval

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to 1.0 meters while taking measurements within the metalimnion.

5.3 Secchi Disk Transparency

5.3.1 Summary of Method

A Secchi disk is a black and white patterned disk used to measure a lake's clarity (see Figure 5-1). Take the reading on the shady side of the boat, without sunglasses, hat, or other viewing aids. Record the depths where the disk disappears when descending and reappears when retrieving.

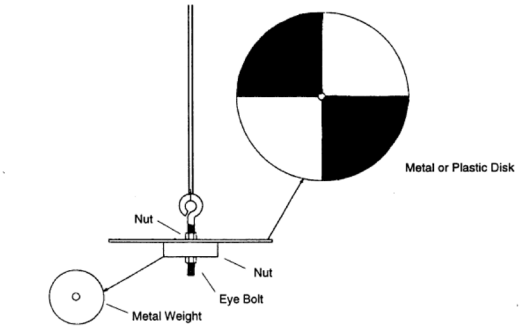


Figure 5-1 Secchi disk diagram (USEPA, 1991).

5.3.2 Equipment and Supplies

Table 5-2 is the checklist for equipment and supplies required to conduct protocols described in this section.

Table 5-2 Equipment and supplies – Secchi disk transparency.

Type	Item	Quantity
Form	NLA Index Samples	1
Collection	Metric tape measure Secchi Disk (20 cm diameter) Sounding line (50 m, calibrated, marked in 0.5 m intervals) with clip	1 1 1

5.3.3 Procedure for Determining Secchi Transparency

Because different people measuring Secchi transparency at the same site may obtain different results (due to differences in vision and interpreting disk disappearance and reappearance), it is recommended that one crew member conduct Secchi disk measurements at all lakes.

If the lake is shallow and the water clear, the Secchi disk might reach the bottom and still be visible. If this is the case, it is important to not stir up the bottom sediments while anchoring the boat. Move the boat away from the anchor before taking the reading. If the disk is visible at the bottom of the lake, indicate this by filling in the "clear to bottom" check box on the **Index Samples** form and record the water depth in both the disappearance and reappearance fields.

States that wish to take additional measurements for comparisons using a view scope are encouraged to do so after completing the Secchi disk measurements are completed following the NLA protocols.

The following procedure is to be followed when collecting NLA Secchi disk measurements:

1. Confirm that the lowering line is firmly attached to the Secchi disk.
2. Remove sunglasses and hat. Also, do not use view scopes or other visual aids. If wearing prescription sunglasses, temporarily replace them with regular clear lens prescription glasses.
3. Lower the Secchi disk over the shaded side of the boat until it disappears.
4. Read the depth indicated on the lowering line. If the disappearance depth is <1.0 meter, determine the depth to the nearest 0.05 meter by marking the line at the nearest depth marker and measuring the remaining length with a tape measure or meter stick. Otherwise, record the disappearance depth to the nearest 0.1 meter. Record the disappearance depth on the **Index Samples** form.
5. Lower the disk a bit farther and then slowly raise the disk until it reappears and record the reappearance depth, using the same level of precision as before.
6. Calculate the euphotic zone depth by multiplying the depth where the Secchi disk reappears by two. Use this calculation to determine the depth at which water samples will be taken with the integrated water sampler:
    - 6.1 If euphotic zone is less than 2 meters, water samples will be collected only within the euphotic zone.
    - 6.2 If euphotic zone is greater than 2 meters, water samples will be taken from the top 2 meters of the water column.
    - 6.3 If the Secchi is clear to the bottom and the lake is less than 2.5 m deep, water samples will be collected 0.5 m from the depth at the index site.
7. Record the depth that will be targeted for the integrated water samples.
8. Note any conditions that might affect the accuracy of the measurement in the comments field.

5.4 eDNA Sample Collection - Index

5.4.1 Summary of Method

Collect water samples for eDNA with a grab sample collected at the water surface from the boat.

5.4.2 Equipment and Supplies

Table 5-3 provides the equipment and supplies needed for field operations to collect fish eDNA samples at the index site.

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Table 5-3 Equipment and supplies - index eDNA samples.

Type	Item	Quantity
Form	NLA Index Samples	1
Documentation	Label: FDNA - Index Clear tape strips (to cover sample labels)	1 As needed
Collection	Index eDNA bottle (1 L clear, square) Gloves (latex/nitrile, non-powdered)	1 1 pair
Storing and preserving	Wet ice Cooler Plastic electrical tape	As needed 1 As needed

5.4.3 Sampling Procedure

While anchored at the index site, collect a grab sample from the water surface using the 1 liter index eDNA bottle.

1. Make sure all necessary data has been written on the sample label, the label is placed on the outside of the bottle, and the label is completely covered with clear tape.
2. Put on surgical gloves (non-powdered). Do not handle any food, drink, sunscreen, or insect repellant until after the water samples have been collected, or implement measures to reduce contamination by such chemicals, if applied, such as washing, wearing long gloves, etc.
3. Remove the cap from the bottle.
4. Do not rinse the bottle and avoid touching the inside of the bottle or the inside of the cap.
5. Dip the sample container into the surface water (do not fully submerge mouth of bottle). At the surface of the water, angle the mouth of the sample container away from the boat. Collect any surface scums, if present, at the site.
6. Fill the 1 L bottle to the 1000 mL mark, leaving headspace for air. This headspace is important since the sample will be frozen.
7. If the bottle is filled above the 1000 mL mark, discard excess water.
8. Carefully replace the cap. Seal the cap with plastic electrical tape.
9. Immediately after sample is collected, place in a cooler with ice to minimize exposure to light and begin chilling the sample.
10. Upon return to the vehicle or a base location, freeze the sample. The sample will be sent frozen with dry ice.

5.5 Water Sample Collection and Preservation

5.5.1 Summary of Method

Collect water samples using an “integrated sampler”, which is based on a design by the Minnesota Pollution Control Agency (MPCA) (see

Figure 5-2). The device is a PVC tube 6.6 feet (2 meters) long with an inside diameter of 1.24 inches (3.2 centimeters) fitted with a stopper plug on one end and a valve on the other. The device allows collection

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of water from the upper two meters of the water column (e.g., within the euphotic zone). If the euphotic zone is < 2.0 m deep (as calculated in the Secchi Disk Transparency section of the form), lower the integrated sampler only to the depth of the euphotic zone, and take additional grab samples as necessary to collect the total volume needed for the samples.

5.5.2 Equipment and Supplies

Table 5-4 provides the equipment and supplies needed to collect water samples at the index site.

Table 5-4 Equipment and supplies – water samples.

Type	Item	Quantity
Form	NLA Index Samples	1
Documentation	Labels: water chemistry, algal toxins, phytoplankton, atrazine, and chlorophyll-*a*	1 per sample
	Clear tape strips (to cover sample labels)	As needed
Collection	Integrated sampler device (MPCA design)	1
	Funnel	1
	Gloves (latex/nitrile, non-powdered)	1
Storing & Preservation	Cubitainer® (4L) – water chemistry	1
	HDPE bottle (60 mL, white, wide-mouth) – atrazine	1
	HDPE bottle (500 mL, white, round) – algal toxins (MICZ)	1
	HDPE bottle (1 L, white, narrow-mouth) – phytoplankton	1
	Poly bottle (2 L, brown) – chlorophyll-*a*	1
	Wet ice	As needed
	Lugol's solution (250 mL bottle)	5-10 mL
	Cooler	1
	Plastic electrical tape	As needed

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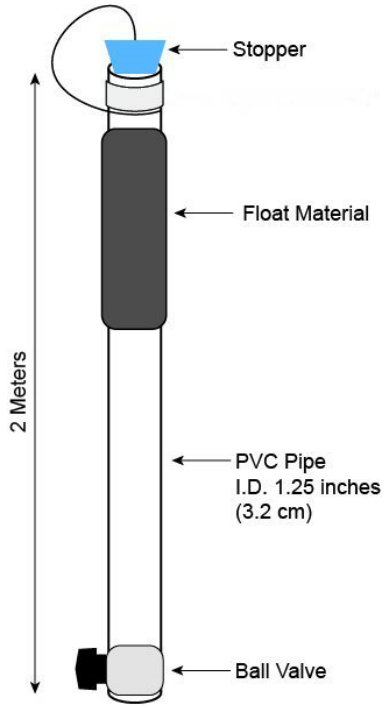


Figure 5-2 Integrated water sampler device (MPCA).

5.5.3 Sampling Procedure

Assuming the euphotic zone is ≥ 2 meters and the depth of the lakes is greater than 2.5 m, collect four integrated water samples (Figure 5-3). Sample #1 is emptied into a 2 L sample bottle for ***chlorophyll-a*** filtering. Sample #2 is to be transferred from the sampler to the 4 L Cubitainer®, mixed thoroughly, and, poured off into one 1 L sample bottle for ***phytoplankton*** processing, one 500 mL bottle for the ***algal toxins*** samples, and one 60 mL bottle for the ***atrazine*** pesticide sample. Samples #3 and #4 are to be transferred from the sampler to the 4 L Cubitainer® for the ***water chemistry*** sample. If the euphotic zone is <2 meters, only collect water from the euphotic zone and increase the number of grab samples accordingly. Additionally, if the secchi is clear to the bottom and the lake is less than 2.5 m deep, water samples will be collected 0.5 m from the depth at the index site.

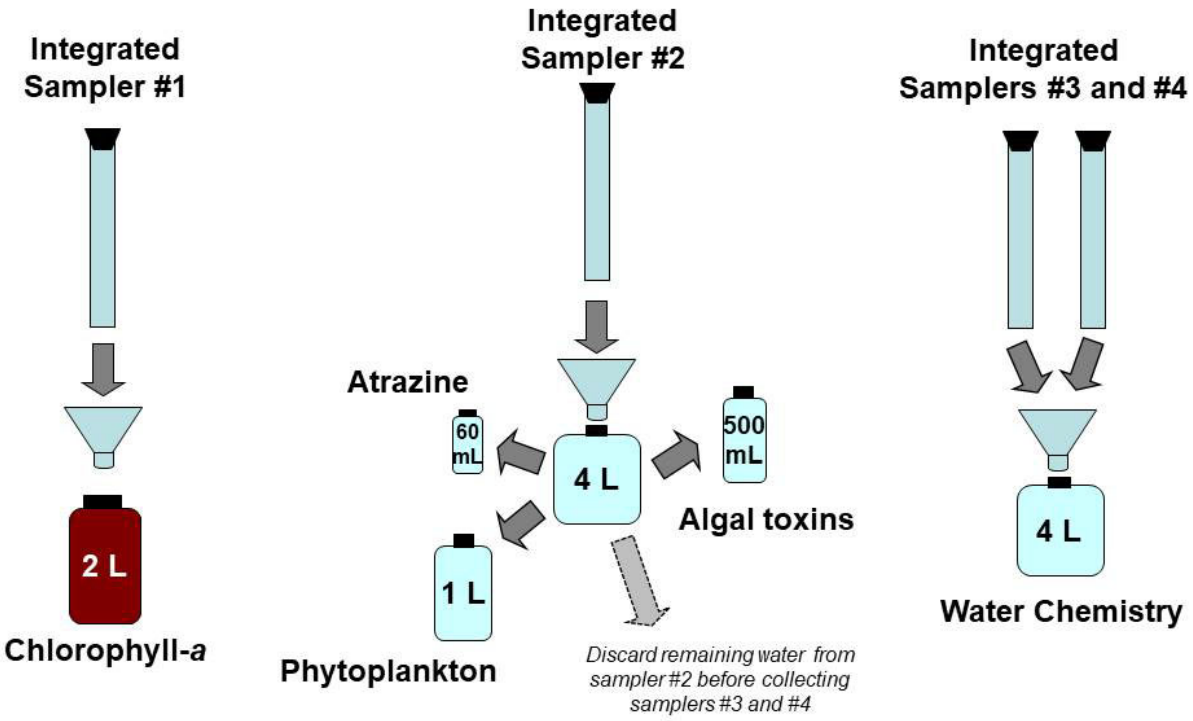


Figure 5-3 Procedure for using the integrated sampler device to collect depth integrated samples.

5.5.3.1 Sample Collection

1. Make sure all necessary data has been written on the sample labels and labels are completely covered with clear tape.
2. Put on surgical gloves (non-powdered). Do not handle any food, drink, sunscreen, or insect repellant until after samples have been collected, or implement measures to reduce contamination by such chemicals, if applied, such as washing, wearing long gloves, etc.
3. Rinse each water sample collection container and lid with surface water three times.
4. Remove the rubber stopper cap and open the valve on the bottom end of the integrated sampler. Rinse by submerging it three times in the lake and draining after each rinse. Complete rinsing on the opposite side of the boat from which you plan to sample. Do not take samples near the motor or other sources of contamination.
5. Slowly lower the sampler into the lake as vertically as possible. For a 2 m sample, stop lowering the device when the upper end is just above the surface. If the euphotic zone is < 2.0 m deep (as calculated in the Secchi Disk Transparency section of the form), the integrated sampler will be lowered only to the depth of the euphotic zone; additional

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samples will be taken to collect the volume needed for the samples (8 L total). In clear shallow lakes, samples will be collected 0.5 m from the depth at the index site.

6. Cap the upper end with the rubber stopper firmly and slowly raise the sampler.
7. When the bottom of the sampler is near the surface, reach underwater and close the valve on the bottom end.
8. Lift the sampler into the boat, keeping it as vertical as possible. When possible, move the containers to a shaded area of the boat to avoid exposing the sample to direct sunlight when dispensed.
9. Carefully open the valve and dispense the contents of sample #1 (or more, as necessary to fill bottle**) into the 2 L brown bottle. This is the chlorophyll-*a* sample, which will be filtered on shore (see Section 8.2). Place the bottle on ice until filtration can be initiated.

   ***if the last sample pull does not completely fit in the container, homogenize the sample in the integrated tube prior to dispensing*
10. Repeat the collection process in steps 5-8 and dispense the contents of sample #2 (or more, as necessary) into the 4 L Cubitainer® and mix well.
11. Fill the 1 L phytoplankton bottle from the 4 L Cubitainer®, allowing enough headspace to add at least 5 mL of Lugol's preservative.
12. Fill the 500 mL bottle from the 4 L Cubitainer®, leaving headspace so that the bottle doesn't burst when frozen. This is the algal toxin sample. Seal the cap with plastic electrical tape. Place the bottle in the cooler with ice.
13. Fill the 60 mL bottle from the 4 L Cubitainer® to just below the shoulder, leaving headspace so that the bottle does not burst when frozen. This is the atrazine sample. Seal the cap with plastic electrical tape. Place the bottle in the cooler with ice.
14. Discard the residual water in the Cubitainer®.
15. Pour the contents of sample #3 and sample #4 (or more, as necessary) from the integrated sampler into the 4 L Cubitainer®, removing as much air from the Cubitainer® as possible. This is the water chemistry sample. Seal the cap with plastic electrical tape. Place the Cubitainer® in the cooler with ice.

5.5.3.2 Sample Preservation

1. All samples are to be kept in a cooler on wet ice until preservation as needed.
2. For the phytoplankton sample, add 5 mL of Lugol's solution to the 1 L phytoplankton bottle. (Fill the provided plastic transfer pipette up to the bulb with Lugol's three times to get 5 mL). Cap the bottle and invert until well mixed. The sample should resemble the color of weak tea. If needed, add additional Lugol's 2-3 mL at a time up to a maximum of 10 mL. Seal the cap with plastic electrical tape.
3. Upon return to a base location with a freezer or portable freezer, freeze the algal toxin and eDNA samples. These samples will be sent frozen with dry ice.

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5.6 Zooplankton Collection

5.6.1 Summary of Method

Collect two vertical samples using a fine mesh (50 µm) and coarse mesh (150 µm) Wisconsin nets with collection bucket attached at the cod end. Each net is slowly lowered over the side of the boat into the water. The net is retrieved back to the surface at a slow, steady rate. Lift the net out of the water; rinse it from the outside to free organisms from the side of the net and to concentrate them in the collection bucket. Narcotize the organisms with an effervescent sodium bicarbonate tablet (e.g., Alka-Seltzer® tablet). Transfer the sample from the collection bucket to a 125 mL sample container and preserve each sample with 95% ethanol. You will repeat the procedure with the other net on the opposite side (or end) of the boat. The cumulative tow length for each net is 5 m. In shallow lakes, multiple tows with each net are required to achieve the cumulative tow length. The objective is to sample a sufficient volume of water to obtain at least 300 organisms per sample from all but the most oligotrophic lakes.

5.6.2 Equipment and Supplies

Table 5-5 provides the equipment and supplies needed to collect a zooplankton sample. Figure 5-4 is an illustration of the zooplankton nets and collection buckets.

Table 5-5 Equipment and supplies – zooplankton collection.

Type	Item	Quantity
Form	NLA Index Samples	1
Documentation	Labels: zooplankton course and zooplankton fine	1 per sample
	Clear tape strips (to cover sample labels)	As needed
Collection	Plankton net fine (50 µm) and collection bucket	1
	Plankton net course (150 µm) and collection bucket	1
	Sounding line (50 m, calibrated, marked in 0.5 m intervals) with clip	1
	Funnel	1
	Squirt bottle (1 L Nalgene) – de-ionized (DI)	1
	Squirt bottle (1 L Nalgene) – lake water	1
	Effervescent sodium bicarbonate (Alka seltzer) tablets	1
	Pail (narcotization and concentration chambers)	1
		2
Storing & Preservation	HDPE bottle (125 mL, white, wide-mouth)	2
	Ethanol (95%)	1
	Plastic electrical tape	As needed

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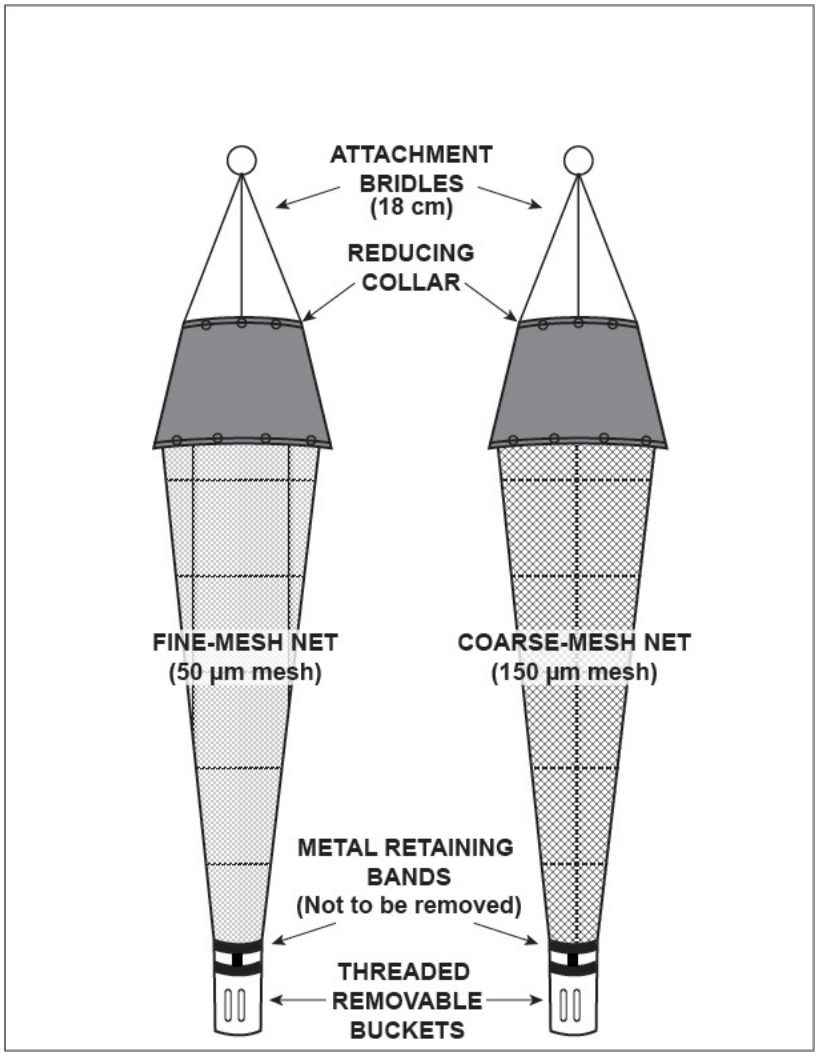


Figure 5-4 Wisconsin net and collection bucket diagram.

5.6.3 Sampling Procedure

The procedures for collecting and processing zooplankton samples are presented below.

5.6.3.1 Sample Collection

1. Determine and record the number of tows required to achieve the standard cumulative 5 m tow on the **Index Samples** form.
    a. For lakes deeper than 7 m, you will take a single 5 m tow with each net.
    b. For lakes with a depth less than 7 m, you will determine and record the number of tows that will be required to achieve a standard cumulative 5 m tow for each net (Table 5-6). For example, if the lake is 6 meters deep, you will take two 2.5 m tows with each net. All lakes less than 7 m deep require at least two tows because the collection bucket should never touch the sediment due to potential fouling.

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Table 5-6 Lengths and numbers of zooplankton tows based on Index Site depth

Depth of lake (m)	Length of Tow	Number of Tows
7 or more	5 m	1
4 to <7	2.5 m	2
2 to <4	1 m	5
less than 2	0.5 m	10

c. The zooplankton collection methods vary slightly depending on the number of tows required to achieve a standard cumulative 5 m tow.
    i. If the number of tows = 1: follow steps 2 through 13 described below.
    ii. If the number of tows ≥ 2, follow steps 2 through 12 described below. After step 12, pour the contents of the collection bucket into a clean (i.e., DI rinsed) 1-gallon pail. Rinse the collection bucket with DI. While taking care not to tip the zooplankton sample in the pail, repeat steps 2 through 12 for the second tow. Add the contents of the collection bucket from the second tow to the pail. Continue to take zooplankton tows and add samples from the collection bucket into the pail until the target number of tows (2, 5, or 10) is reached. On the last tow, pour the contents of the pail into the collection bucket to filter the excess water. Rinse the bucket with DI water and pour the contents of this rinse into the collection bucket with the zooplankton sample. Once the zooplankton sample has been filtered down to an appropriate volume in the collection bucket, continue on to step 13.

2. Prior to each use, carefully clean and thoroughly rinse the interior of the plankton nets and buckets with DI water.
3. Carefully inspect the nets and buckets for holes or tears.
4. Attach the collection buckets to the “cod” end of the nets and secure. Make sure the correct bucket is attached to the correct net (i.e., the mesh sizes match).
5. Attach the bridled end of the plankton net to a 0.25” calibrated line with markings every 0.5 m (use the same line as was used with the Secchi disk).
6. Carefully and slowly lower the first net in a constant upright position over the side of the boat.
7. Continue lowering the net to the correct depth (remember to account for the length of the bridle). If more than one tow is needed, be sure to take additional tows from different locations around the boat.
8. Retrieve the net by pulling back to the surface at a steady rate (0.3 m or 1 ft/s) without stopping.
9. Once at the surface, slowly dip the net up and down in the water without submersing the net mouth to rinse contents into the collection bucket.
10. Complete the rinsing of the net contents by spraying lake water against the outside of the net with a squirt bottle or similar tool. Be careful not to splash or squirt lake water into the net mouth, or additional organisms may be collected.
11. If additional rinsing is needed on the interior of the net, use a squirt bottle with DI water only to avoid introducing additional organisms.

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12. Once all organisms have been rinsed into the collection bucket, hold the collection bucket in a vertical position, and carefully remove the bucket from the net.
13. Repeat steps 5-12 with the second net on the opposite side (or end) of the boat.

5.6.3.2 Sample Processing

1. Set the collection buckets in a pail filled half full of lake water to which 2 CO_2 (e.g., Alka-Seltzer) tablets have been added outside of the collection buckets. Wait 30 to 60 seconds for the CO_2 tablets to dissolve before placing the collection buckets into the water. Ensure that the organisms in the collection buckets are submerged in the water, but be careful not to submerge the top of the collection buckets, or sample loss will occur. The CO_2 narcotizes the zooplankton to relax their external structure prior to preservation in 95% ethanol. This facilitates taxonomic identification. Wait until zooplankton movement has stopped (usually about one minute). Raising and lowering the collection buckets in the pail can help water exchange within the bucket.
2. Check the sample label on the bottle to verify which sample has been collected (coarse or fine mesh).
3. Use small volumes of DI water from a squirt bottle to rinse the contents of the mesh net collection bucket into the 125 mL polyethylene bottle. Rinse the collection bucket with DI water three to four times or until the majority of zooplankton have been removed without allowing the bottle to fill more than half full (~60-70 mL of sample and rinse water combined). After the zooplankton have been transferred and the sample bottle is half full with sample and rinsate, fill the bottle to the shoulder with 95% ethanol. Use a funnel, if necessary, when transferring the sample, rinsate or ethanol to the 125 mL sample bottle
4. In some cases, the volume of zooplankton collected in the collection bucket may exceed 125 mL. Under this scenario do not try to force the entire sample into a single bottle, or the preservative will not function properly and the sample may be lost. In such cases, fill the first bottle half full, and then use a second bottle to preserve the additional amount of sample. Use an “extra jar” label (i.e., one with no sample ID pre-printed on it) for identification purposes. Complete the label and print in the sample number assigned to the first container on the label of the second container. On the form, record a “2” in the “No. Jars” field.
5. On the **Index Samples** form, fill in the bubble to indicate that the sample is preserved.
6. Verify that all information on the labels and the form is complete and correctly recorded.
7. Repeat steps 2-6 for the second sample collected.

6.0 LITTORAL AND SHORELINE ACTIVITIES

To better understand near-shore habitats and their condition, travel to 10 evenly spaced physical habitat (PHab) stations around the lake and document conditions and characteristics observed within defined plot areas. The full set of measurements, observations, and sampling described in this chapter includes:

- water sample for eDNA analyses at each of the 10 stations;
- measures or observations of physical habitat cover and structure in the littoral, shoreline, draw-down, and riparian zone plots at the 10 PHab stations;
- visual assessment of a cyanobacterial bloom;
- sampling of benthic macroinvertebrates at each of the 10 stations; and
- water sample for Enterococci at the last station sampled (for lakes 10,000 ha or less) or boat launch (for lakes >10,000 ha).

For lakes with a surface area of greater than 10,000 ha (defined as large lakes), crews are **not** required to travel to the 10 PHab stations to make physical habitat measurements and collect benthic macroinvertebrate samples. The requirement was waived on large lakes because of the increased level of effort required to travel around the shorelines of these large lakes. Nevertheless, we encourage crews to complete the physical habitat characterizations and macroinvertebrate collections on large lakes, just as they are done on smaller lakes, so that large lake physical habitat information can be included in the national assessment.

Note: When large islands are present, more than 10 PHab sites will be identified and assessed for a lake.

6.1 Littoral eDNA Sample Collection

6.1.1 Summary of Method

Collect a grab sample for eDNA at each of the 10 shoreline PHab stations. Grab samples are collected at the water surface from the boat and added to a single 1L littoral composite sample. If more than 10 PHab stations are identified for the lake, littoral eDNA samples will only be collected from the 10 standard PHab stations around the perimeter of the lake. For “large lakes” (greater than 10,000 ha) the entire 1L sample is to be collected from the launch site at the end of the day with the enterococci sample.

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6.1.2 Equipment and Supplies

Table 6-1 provides the equipment and supplies needed for field operations to collect the littoral eDNA sample.

Table 6-1. Equipment and supplies – fish littoral eDNA samples.

Type	Item	Quantity
Form	NLA Littoral Samples	1
Documentation	Label: LDNA - littoral Clear tape strips (to cover sample labels)	1 As needed
Collection	Littoral eDNA bottle (1 L clear, square) Littoral eDNA collection bottle (125 mL clear, square) Gloves (latex/nitrile, non-powdered)	1 1 1-2 pairs
Storing and preserving	Wet ice Cooler Plastic electrical tape	As needed 1 As needed

6.1.3 Sampling Procedure

When arriving at the PHab station, prior to the collection of PHab and benthic macroinvertebrate sample , collect a 100 mL littoral eDNA sub-sample from an undisturbed area in the littoral plot. Sub-samples from all stations are added to the 1 L littoral eDNA composite bottle.

1. At the first PHab station, make sure all necessary data has been written on the littoral eDNA label, the label is placed on the outside of the 1L littoral eDNA bottle, and the label is completely covered with clear tape. Samples from 10 physical habitat stations will be added to this bottle.
2. Put on surgical gloves (non-powdered). Do not handle any food, drink, sunscreen, or insect repellant until after the water samples have been collected, or implement measures to reduce contamination by such chemicals, if applied, such as washing, wearing long gloves, etc.
3. Identify an area in or near the littoral plot that is about 1 m deep (~waist deep) to collect the sample. Avoid sampling shallower water and water at the shoreline due to potential sediment contamination. If the entire littoral plot is less than 1 m deep, you may collect the sample outside the littoral plot (e.g., as you are approaching the plot from a location that is about 1 m deep).
4. Remove the cap from the 125 mL collection bottle. Avoid touching the inside of the bottle or the inside of the cap.
6. Dip the sample container into the surface water (do not fully submerge mouth of bottle) in an undisturbed area of the lake. At the surface of the water, angle the mouth of the sample container away from the boat or body and fill the collection bottle to the 100 mL mark. Collect any surface scums, if present, at the site. If more than 100 mL is collected, pour off excess.Remove the cap from the 1L composite bottle. Do not rinse this bottle and avoid touching the inside of the bottle or the inside of the cap.

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7. Add the 100 mL sample to the 1 L composite bottle. Cap both bottles and place both bottles in a cooler with wet ice while transporting to the next station to minimize exposure to light and begin chilling the sample.
8. REPEAT steps 2-6 at the next PHab station, up to a total of ten stations (1L sample total).
9. At the last (10th) PHab station, ensure the sample does not exceed the 1000 mL mark, leaving headspace for air. This headspace is important since the sample will be frozen. If the bottle is filled above the 1000 mL mark, cap the bottle, gently mix 3 times, and discard excess water down to the 1000 mL mark.
10. Carefully replace the cap. Seal the cap with plastic electrical tape.
11. Immediately place the 1L bottle in a cooler with ice and keep the sample chilled throughout the sampling day.
12. Discard the 125 mL collection bottle after collecting all 10 subsamples. A new collection bottle will be sent in each site kit.
13. Upon return to the vehicle or a base location, freeze the sample. The sample will be sent frozen with dry ice.

**At large lakes (lakes over 10,000 hectares) when littoral sampling is not conducted, the entire 1L littoral eDNA sample will be collected at the launch site with the enterococci sample.

6.2 Physical Habitat Characterization

6.2.1 Summary of Method

Prior to the sampling visit, determine the approximate locations of the 10 PHab stations and mark them on a Site Map (see Chapter 3), if applicable. Figure 3-2 shows example placement and distribution of PHab stations around a lake. At each of the 10 PHab stations, you will set up a plot as shown in Figure 6-1 based on visually estimated dimensions. The plot measures 15 m wide and includes: a littoral plot extending 10 m out from the shoreline; a drawdown zone plot extending inland from the shoreline to the normal high-water level; a 1 m shoreline zone band at the shore just above the present water line; and a 15 m wide riparian plot that begins at the normal high water mark and extends 15 m landward. The drawdown zone plot extends a variable distance inland depending on the degree of drawdown and, if the distance from the present shoreline to the normal high water mark is negligible (i.e., <1m), there will be no drawdown zone plot.

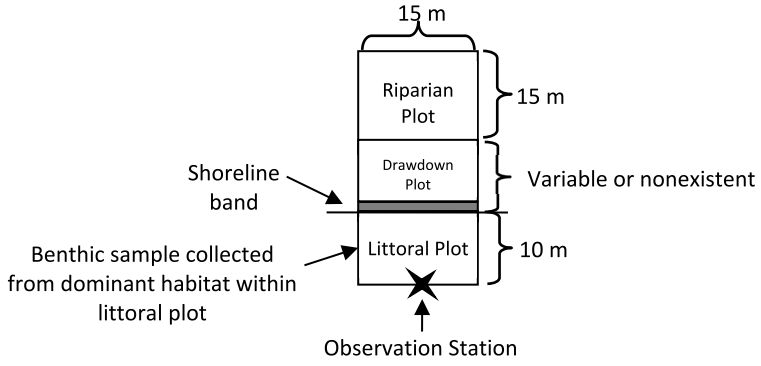


Figure 6-1 Dimensions and layout of a physical habitat station.

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As described below, you will record observations from each of the zones on the **Physical Habitat** form.

6.2.2 Equipment and Supplies

Table 6-2 lists the equipment and supplies needed to locate the PHab stations and conduct the physical habitat characterization.

Table 6-2 Equipment and supplies – physical habitat assessment.

Type	Item	Quantity
Forms	NLA Verification	1
	NLA Physical Habitat	10-12
Collection	Depth Sounder (hand-held or boat mounted sonar)	1
	Sounding rod (3 m, marked in 0.1 m increments, calibrated, PVC)	1
	GPS unit (with manual, reference card, extra battery)	1
	Rangefinder (for estimating horizontal drawdown)	1 (optional)
	Clinometer (for use as a level to measure vertical drawdown)	1 (optional)
	Surveyors rod (for measuring vertical drawdown)	1 (optional)
	50-meter tape (measurements as needed)	1
	Binoculars (for making observations of distant riparian)	1
	Map wheel or string (for measuring shoreline distances on site map)	1
	Anchor (with 75 m line or sufficient to anchor in 50 m depth)	1
	Buoy (for marking observation point)	1

6.2.3 Locating the Physical Habitat Stations and Defining the Shoreline Boundary

6.2.3.1 Base Site Activities

It is important that you set up PHab stations in the office to minimize bias in site selection and to ensure efficient location of stations once at the lake.

1. Using a lake map, select a random starting point on the lake outline. Any reasonable method may be used select the starting point (e.g., toss a pencil randomly on the map, letting the sharp end point to the nearest shoreline location). This random starting point is your “A” station.
2. It is important that the remaining nine stations be located at equal distances around the lake (see Figure 3-2). These will be your “B” through “J” stations. Field crews can do this manually (by either using a string to trace the perimeter of the lake, which can then be straightened and marked in equal intervals, or by using a map wheel) or electronically (with GIS or other digital mapping tools) to measure the perimeter of the lake and divide by 10.
3. Using a GIS or other digital mapping tool application to locate the coordinates of the 10 stations that can then be entered as GPS waypoints greatly facilitates correctly locating PHab stations by boat in the field, especially on large lakes.
4. Mark the physical habitat stations on a site map, if applicable.

Note: In revisit lakes (see Section 9.1 for more information), crews will re-randomize and relocate the PHab stations. The stations are re-randomized because the revisit data is used to examine variability of the entire lake assessment.

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6.2.3.2 Littoral and Shoreline Activities

Using the site maps and GPS, proceed by boat around the lake, locate, and stop at each of the 10 PHab stations. Position the boat at a distance of 10 m from shore, anchor if necessary, and make the measurements and semi-quantitative observations specified on the **Physical Habitat** form in the NLA App. Complete a separate **Physical Habitat** form for each station (see tabs A-L at the top of the form).

Make every reasonable attempt to record physical habitat observations and measurements for all 10 PHab stations. Where physical habitat observation and measurements are impossible, record comments as specified in Table 3-1.

6.2.3.3 Shoreline and Station Location Adjustments

Once in the field, you may encounter situations that require you to modify the shoreline and/or station location(s) from the intended locations marked on the site map. If this occurs, make the corrections and adjustments on the **Physical Habitat** form and note the reasons in the comments section of the form. The general guidelines for locating or modifying the location of the littoral and shoreline stations are summarized below.

1. Locate station using maps, aerial photos, or GPS units.
2. Define shore as either the current waterline OR the boundary between open water and the edge of dense vegetation (terrestrial, wetland, or emergent vegetation) or extensive very shallow water (shoreline defined by limit for navigating your boat).
3. If the shoreline observed in the field differs from the mapped shoreline, mark “Station Relocated” and enter a comment on the **Physical Habitat** form stating the apparent reason (e.g., drought, lake drawdown, flooding, dredging, limited boat access, etc.).
4. If a PHab station is inaccessible because of shoreline changes, mark “Station Relocated” at the top of the **Physical Habitat** form, and position one or more new stations at approximately equal intervals.
5. If a station is eliminated, select the check box at the top of the form.
6. If the shoreline observed in the field differs radically from the site map and you are sure you are at the correct lake, you can sketch a map of the lake. Use a string to measure the new outline, divide it into 10 equal parts, and lay out the 10 station locations.

6.2.3.3.1 Islands

Islands may be an additional source of shoreline habitat on a lake and those will be accounted for by adding island physical habitat stations. Island stations are in addition to the 10 stations (A-J). The guidelines for adding island stations follow:

- If the combined shoreline of all islands make up 10-20% of the lake’s total shoreline, add one PHab station (stations will now be labeled A through K)
- If the combined shoreline of all islands make up more than 20% of the lake’s total shoreline, add two PHab stations (stations will now be labeled stations A through L)
- Island stations are designated by marking the “Is it an island?” bubble on the form, by a new station letter (K or L), and by marking the island location and station on a site map.

Island stations, i.e., K and L, should be selected at random (e.g., toss a pencil randomly on a map, letting the sharp end point to the nearest island location, if needed, repeat to identify station L).

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6.2.3.3.2 Ambiguous Shorelines

The shoreline is defined as the interface between "lake-like" conditions and riparian or wetland conditions. In most cases, the shoreline will be easily identified as the current waterline. In some instances, however, the shoreline might not be obvious. Listed below are some general situations and rules that should be applied to ambiguous shorelines.

- If there has been a significant drop in lake level due to drought, purposeful drawdown, dam repair, or other reasons, shallow areas may be exposed that are usually covered with water. In this case, consider the current waterline as shoreline for the purposes of this survey, not the normal waterline.
- If there are extensive very shallow areas or shoals, consider the shoreline to be the boundary between the shallow area and deeper open water, as defined by ease of access by a small sampling boat.
- If access to the true shoreline is prevented by an area of dense aquatic or terrestrial vegetation, consider the shoreline to be the boundary between the vegetation and deeper open water. Again, define the operational shoreline by ease of access by a small sampling boat. This may result in a riparian zone that can be more of a wetland than an upland vegetation plot.
- If a river or stream enters a lake, the shoreline begins where no flow is visible.
- If there is flooding, try to find the position of the normal high water mark. The normal high water mark may be evident by the extent of flooded trees or other terrestrial vegetation.

6.2.3.3.3 Actual shoreline is different than appears on the map

The goal of the physical habitat survey is to characterize the lakeshore based on observations of conditions at 10 evenly spaced PHab stations around the lake. Adjustments to station locations might be needed if the field crew runs into unusual conditions or problems. Below are some rules concerning modifications to the station location(s).

- If only a small portion of the shoreline differs and it does not affect, or only slightly affects, a PHab site location, sketch the lake shoreline on the site map and reposition the station (if needed).
- If the difference causes a contraction of the shoreline and a PHab station location is lost, sketch the lake shoreline on the site map and make a decision to either: (a) keep the station, relocate it on the revised shoreline map and adjust some or all other stations in order to keep stations evenly spaced around the lake (i.e., keep 10 stations), or (b) eliminate the station altogether (i.e., reduce the number of stations).
- If the Site Map does not in any way match the lake shoreline, draw a new sketch map approximating the shoreline, and re-establish the 10 PHab stations. A quick way to locate 10 evenly-spaced PHab stations is to: (a) lay a piece of string on the lake perimeter, (b) pick up the string, measure it, and mark out 10 equal parts, and (c) lay the string back on the perimeter and use the marks to locate the 10 sites on the map.

6.2.3.3.4 PHab Station is inaccessible

- If a PHab station is inaccessible, you must make a decision to either: (a) relocate the station and adjust some or all other stations so that they are evenly spaced around the lake (i.e., keep 10 stations), or (b) eliminate the station altogether (i.e., reduce the number of

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stations). The size of the lake will help drive this decision.

- Draw all adjustments to the shoreline based on field observations directly on the Site Map and explain the adjustments in the comments section of the **Physical Habitat** form.

6.2.3.3.5 Identifying Relocated and New Stations on the Form

Use the following notations when recording station location modifications.

- If you relocate a station, note the new location on the Site Map and fill in the bubble corresponding to the original station letter (e.g., "C") on the **Physical Habitat** form. In addition, fill in the "Station Relocated" bubble on the form to indicate that the station has been moved from its originally intended location.
- If a station is lost and cannot be replaced, cross out the original station location on the Site Map, fill in the bubble corresponding to the original station letter, and fill in the "Dropped" bubble on the **Physical Habitat** form.

6.2.4 Establishing the Physical Habitat Plots at each station

Establish a plot for physical habitat characterization at each PHab station by visually estimating the plot dimensions. Most littoral, shore, and near-shore observations and measurements can be made from the boat at the observation point 10 m off-shore (estimated by eye). Limit observations at each station to the area that is within the defined plot dimensions (additional observations of human activities are made adjacent to or behind the defined plots). After setting plot dimensions, you may need to move around within the littoral plot to see or probe the bottom, or even go onto shore to make observations.

6.2.4.1 Physical Habitat Plot Dimensions

You will identify up to four distinct zones within each physical habitat plot (Figure 6-1), where you estimate the zone dimensions by eye or with the aid of a rangefinder.

6.2.4.1.1 Littoral

This within-lake zone is a fixed size that is 15 m wide along the shoreline and extending 10 m offshore into the lake.

6.2.4.1.2 Shoreline

The shoreline band is a fixed 15 m wide strip along the shore from the present water line to 1 m inland. If the horizontal drawdown distance is <1 m, the shoreline band is within the riparian plot; if the horizontal drawdown is ≥1 m, the shoreline band is within the drawdown plot. The shoreline boundary is defined as the approximate interface between "lake-like" conditions and riparian or wetland conditions. In cases where the lake shoreline is not obvious (e.g., where there is evidence of large seasonal change in lake level), define the shoreline as the current waterline. In cases where the lake shoreline is not visible, define the lake shoreline as the approximate boundary between open water and swamp or marsh conditions into which your boat could not easily move.

6.2.4.1.3 Drawdown

Under all circumstances, vertical height and horizontal distance of drawdown or water level fluctuations are measured or estimated. When horizontal drawdown is ≥1 m, establish a drawdown zone plot with a fixed width (15 m) but with a variable extent inland. The inland extent of the drawdown plot is equal to the horizontal extent of drawdown and may differ among the 10 PHab stations, depending on the topography at each station. It is determined by your judgment and measurement of the horizontal

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drawdown distance from the shore to the normal high water mark at each station.

The vertical height can be visually estimated or measured using a clinometer as a level in combination with a survey rod or metric tape measure. Similarly, the horizontal distance up the bank between the current lake level and the evidence of the normal high water level can be estimated visually, or measured with with a laser range finder, survey rod or metric tape measure when distances are greater than approximately 15m.

The intent of the drawdown assessment is to capture and track changes in the magnitude of lake level fluctuation or progressive decline or drawdown of lake levels relative to the normal high water mark. The normal high water mark is best indicated by the terrestrial vegetation and substrate present. In most regions of the US, summertime lake levels will be below the high water mark, so the NLA assessment may register a small amount of drawdown for most lakes. Negligible drawdown depends, to some extent, on the size of the lake. For NLA, an assessment of the vegetation and potential fish cover in the drawdown plot is not required when horizontal exposure of the littoral bottom is <1m. The vertical and horizontal drawdown must still be measured and recorded in order to establish the range of natural variability in lake level fluctuations. If no drawdown is present at the lake, enter zeros for both the vertical and horizontal drawdown distances.

6.2.4.1.4 Riparian

At stations that have <1 m horizontal distance of lake-level fluctuations or anthropogenic drawdown, there will be no drawdown zone and you will therefore define the riparian plot as a 15 m x 15 m square located at the water's edge, as presented in Figure 6-1, extending 15 m inland. When a drawdown plot is defined (i.e., stations that have ≥1m horizontal drawdown), the riparian zone plot is a 15m x 15m square just inland of the drawdown plot (i.e., a fixed size 15 m wide along the shoreline and extending 15m inland from the normal high-water mark).

6.2.4.2 Physical Habitat Station Layout Procedures

6.2.4.2.1 Normal High Water

1. Using the present shoreline, place the littoral plots lakeward from the current water's edge or the operational shoreline as defined in previous sections.
2. Draw or sight a straight line inland perpendicular to the shoreline. If this line does not intersect with the normal high water mark, move the littoral plot laterally in either direction until the perpendicular line intersects the normal high water mark. Choose to move the plot left or right based on the direction which results in the least distance moved.
3. Establish a 1 m shoreline band at the current water's edge or the operational shoreline.
4. Establish the riparian plot inland from the current water's edge or the operational shoreline identified above. If using an operational shoreline, the riparian plot may include shallow water and/ or impenetrable wetland.
5. The left and right edges of the riparian plot, the shoreline band, and the littoral plot should all align with one another.

6.2.4.2.2 Below Normal High Water (Drawdown)

1. Using the present shoreline, place the littoral plots from the current water's edge or the operational shroreline lakeward as defined in previous sections.

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2. Draw or sight a straight line inland perpendicular to the shoreline. If this line does not intersect with the normal high water mark, move the littoral plot laterally in either direction until the perpendicular line intersects the normal high water mark. Choose to move the plot left or right based on the direction which results in the least distance moved.
3. Establish a 1 m shoreline band at the current water's edge or the operational shoreline.
4. Establish the riparian plot inland from the normal high water mark identified above.
5. Establish a drawdown plot between the littoral and riparian plots. If the drawdown plot is greater than 1 m, cover estimates will be assessed in this plot.
6. The left and right edges of the riparian plot, the shoreline band, the littoral plot, and the drawdown plot should all align with one another.

6.2.4.2.3 Above Normal High Water (Flooding)

1. Establish the littoral plots lakeward from the normal high water mark, which may be evident by the extent of flooded trees or other terrestrial vegetation, lakeward.
2. Establish the riparian plot inland from the normal high water mark. In flooded situations, the riparian zone might be dry, partly flooded, or completely flooded with lake water.
3. Establish a 1 m shoreline band at the current water's edge. In flooded situations, the shoreline band might be within or inland from the riparian plot.
4. The left and right edges of the riparian plot, shoreline band, and the littoral plot should all align with one another.

6.2.5 **General Observations**

Begin the physical habitat characterization with general observations.

1. Set up your plots within your physical habitat station.
2. Measure and record the lake depth 10 m from the shore at each PHab station (observation point)
3. Note on the **Physical Habitat** form whether there is shoreline flooding (i.e., observed water level presently above the normal high water mark) by checking the box.
    a. If flooding is present, try to find the position of the normal high water mark, which may be evident by the extent of flooded trees or other terrestrial vegetation. Measure the depth at this point; record this as the "depth of flooding." Measure or estimate the distance from this normal high water position landward towards the margin of flooding; this establishes the location of the 1m shoreline band and the horizontal distance of flooding. The riparian plot is located as a 15 x 15 meter square abutting the normal high water mark, regardless of whether it is dry, partly flooded, or completely flooded with lake water.
    b. If the current water level is not above normal high water, enter zeros for height and horizontal distance of flooding.
4. Note on the **Physical Habitat** form whether the horizontal drawdown distance is greater than 1m by checking the box. **Regardless of the amount of drawdown of lake level fluctuation, measure or estimate it by recording the vertical height and the horizontal distance between the present lake level and the normal high water line**. Note that these measurements or estimates may be zeros if the water level is at or above the normal high-water mark, but should

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never be left blank. If the horizontal drawdown distance is <1m, the drawdown zone cover and human influence estimates are left blank in the form.

5. Record the bank angle description that best reflects the current shoreline that is dominant within your field of vision in the 1 m shoreline band:
    a. Near vertical/undercut (>75 degrees);
    b. steep (>30 to 75 degrees; need hands to climb up);
    c. gradual, (5 to 30 degrees; can walk up); or
    d. flat (< 5 degrees).

    NOTE: Complete this estimate even if there is no drawdown.
6. Record the presence or absence of water surface scums, algal mats, or oil slicks within the littoral zone.

6.2.6 Estimate Substrate Characteristics

You will estimate and assign percentage areal cover for substrate types (e.g. bedrock, boulders, cobble, gravel, sand, silt/clay/muck, woody debris, organic matter, and vegetation) and also for fish habitat cover, aquatic macrophytes, and terrestrial vegetation. The categories are as follows:

- 0 = absent (0% cover)
- 1 = sparse (<10% cover)
- 2 = moderate (10 – 40% cover)
- 3 = heavy (>40 – 75% cover)
- 4 = very heavy (>75% cover)

When estimating cover combinations in the substrate section of the **Physical Habitat** form, combinations consider that the combined cover of the various types of substrate should add up to approximately 100%. Because you are assigning cover percentage categories, look at various combinations of the high and low end of each class. Accordingly, more than one class might be given sparse (1), moderate (2), or heavy (3) ratings. One dominant class with no clear subdominant class might be ranked very heavy (4) with all the remaining classes either sparse (1) or absent (0). Two dominant classes with more than 40 percent cover can both be given a 3.

Estimate the areal cover of bottom substrate types and particle size classes observed within the littoral and the shoreline zones. Cover categories range from absent to very heavy. Record all observations by filling in the appropriate bubbles on the **Physical Habitat** form. In most cases these estimates can be made from the boat or can be made while wading, if preferred. Substrate types not present should be assigned zero cover.

- If the bottom substrate is not visible, you should probe the bottom beneath the boat with the sounding rod (you may have to move closer to shore if you are too deep to use the rod). Soft sediment can be brought to the surface for examination. Hard sediments can be "felt" with the sounding rod. Sandy substrate can be "felt" or "heard" by twisting the sounding rod and detecting grittiness. Estimating cover of various substrate types will typically require multiple probes within the littoral plot. If you have to move into shallow water to use the sounding rod to observe sediment characteristics, use the provided comment bubble to flag the observation and record the depth where you observed the sediment.
- If the bottom is covered with materials other than mineral substrates, choose “Woody Debris”, “Organic (leaf pack, detritus)”, or “Vegetation/Other”.

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- If the substrate is concealed and remote sampling is not possible, identify that the substrate is “not observed” in a comment bubble associated with each zone.

Record the color of sediment within the littoral plot. Select "None” or “Other" if the sediment does not match one of the color categories options on the **Physical Habitat** form.

Record sediment odor within the littoral zone. For sediment odor, the choices are "H_2S" (sulfurous, rotten egg), "Anoxic" (sewage odor), "Chemical" (strong odor like turpentine, paint, etc.), "Oil", or “Other" (including musty, organic, and fishy odors). If "Other" is indicated, explain the observation in the comment section of the form.

6.2.7 Estimate Aquatic Macrophyte Cover

Note and record whether macrophytes extend lake-ward from the observation point (e.g., further than 10 meters from the shoreline).

Estimate the areal cover of submerged, emergent (i.e., has erect portions above the water surface), floating/floating leafed (either rooted or non-rooted vegetation), and total macrophytes within the littoral zone. Cover categories range from absent to very heavy, as described in 6.2.6. Each of the three types of aquatic macrophyte (submergent, emergent, floating) can have cover ranging from 0 – 100%. They are evaluated independently, so the sum of their separate covers is theoretically 0% to 100% times the number of types. So, in contrast to substrate cover percentages, the combined cover of submergent, floating, and emergent aquatic macrophytes could theoretically add up to 300% due to the overlap of plant types within the water column. The fourth question on the form about aquatic macrophyte cover asks how much areal cover is there if you ignore the types and just estimate how much of the littoral plot has aquatic macrophyte cover of any type, where this value is constrained to 0-100%.

As with substrate, estimating aquatic macrophyte cover may require multiple probes within the littoral plot. Record all observations by filling in the appropriate bubbles on the **Physical Habitat** form. These estimates can be made from the boat or while wading.

- If you cannot see or probe the bottom, move closer to shore, use the provided comment bubble to flag your observation and note your new location and depth in the comments field on the form.

6.2.8 Estimate Fish Habitat Cover

Estimate the areal cover of potential fish habitat observed within the littoral plot and, when present, in the separate drawdown zone plot. Littoral fish habitat cover features are within or partially within the water and conceal fish from aquatic and terrestrial predators such as large fish, otters, kingfishers, and osprey. When evaluating cover of potential fish habitat in the drawdown zone, however, estimate the percentage cover that would be present at normal high water conditions, when these features would be inundated. Cover categories range from absent to very heavy, as specified in Section 6.2.6. Record all observations by filling in the appropriate bubbles on the **Physical Habitat** form. In most cases these estimates can be made from the boat. Estimating fish habitat cover may require multiple probes within the littoral plot. If certain cover types are not present, mark absent (0% cover) as your entry. In contrast to the cover of substrate types, the sum of the various types of fish habitat features can exceed 100%, sometimes summing to several hundred percent. Each type of fish cover can have cover ranging from 0 to 100%. They are evaluated independently, so the sum of their covers is theoretically 0 to 100% times the number of cover types.

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Estimate and record cover for the following fish habitat types:

- Aquatic macrophytes and Inundated Herbaceous Vegetation: Submerged, floating, or emergent live aquatic or non-woody herbaceous plants
- Woody Debris/Snags: Inundated or partially inundated dead trees, branches, or rootwads with diameter >0.3 m (1 ft)
- Woody brush/woody debris: Inundated dead or living woody vegetation <0.3 m diameter.
- Inundated Live Trees: Inundated portions of trees >0.3 m in diameter
- Overhanging Vegetation: <1 m from the water surface (do not include higher overhanging vegetation, which might provide perches for birds such as kingfishers)
- Ledges or Sharp Drop-offs: Overhanging banks, submerged rock shelves, and steep sloping rock walls
- Boulders: Larger than basketball size
- Human Structures: Docks, barges, houseboats, swimming platforms, tires, car bodies, and habitat enhancement structures (e.g., log rafts)

Note: In the drawdown zone you will estimate the potential fish cover. The potential fish cover estimates are made only if there is a visible drawdown zone extending ≥1 m from the shoreline. For these observations, the question is “What cover would there be if the drawdown zone were inundated – i.e., it were to become part of the littoral zone? “ Then, for example, a bunch of dried aquatic macrophtes would be “Aquatic and Inundated Herbaceous Vegetation”, as would newly-grown terrestrial grasses. Cyprus trees left “high and dry” would qualify as “Inundated Live Trees >0.3m diameter” and overhanging vegetation rooted above the drawdown zone could be “Overhanging Vegetation within 1m of the Surface”.

6.2.9 Estimate the Cover and Type of Riparian and Drawdown Zone Vegetation

Three independent layers of riparian vegetation will be examined, each of which can range in cover from 0 to 100%. The ground layer components must add up to 100% because this layer includes bare ground and water. The mid-layer and upper layer do not include ground or water, so vegetation within these layers do not have to add up to 100%.

The areal cover of different types of vegetation will be estimated in the riparian plot and, when present, in the drawdown zone. Vegetation cover is divided into three layers, which are described below. Remember that individual plants can contribute cover to more than one layer and cumulatively the three layers can potentially add up to 300% cover (up to 100% per layer). Also note that some things other than vegetation are possible entries for the "Ground Cover" layer (e.g., water or barren ground). Within each layer, the summed cover cannot exceed 100%, but, the ground layer covers must add up to 100%. As with the other visual cover estimates, you are assigning cover percentage categories, so the summed cover is estimated by looking at various combinations of the high and low end of each percentage cover class.

6.2.9.1 Canopy Vegetation (greater than 5 m high)

Record the type of vegetation in the canopy as deciduous, coniferous (needle-leafed evergreen), broadleaf evergreen, or mixed, where mixed is defined as a segment where chosen if there is more than one of these types of vegetation that has at least 10% areal coverage. If no canopy exists in the plot, do not mark any of the bubbles.

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Estimate the areal cover of big (trunk >0.3 m diameter at breast height [dbh]) and small (trunk <0.3 m dbh) trees. Cover categories range from absent to very heavy, as described in Section 6.2.6. Record all observations by filling in the appropriate bubbles on the **Physical Habitat** form.

Total cover in the canopy layer can range anywhere from 0% to 100% depending on conditions present.

6.2.9.2 Understory Vegetation (5m to 0.5m high)

Record the type of vegetation in the understory as deciduous, coniferous, broadleaf evergreen, or mixed, where mixed is defined as above. If no understory exists in the plot, do not mark any of the bubbles.

Estimate the areal cover of all woody vegetation (which includes both the trunks and branches of trees and shrubs, woody stems of perennial plants, etc.) and tall herbs, grasses, and forbs. Cover categories range from absent to very heavy, as specified in Section 6.2.6. Record all observations by filling in the appropriate bubbles on the **Physical Habitat** form. Total cover in the understory layer can range anywhere from 0% to 100% depending on conditions present.

6.2.9.3 Ground Cover (lower than 0.5m high)

Estimate the areal cover of woody vegetation; tall herbs, grasses, and forbs; standing water or inundated vegetation; and barren, bare dirt, or buildings. Areas of exposed rock or bedrock should be considered 'barren'. Cover categories range from absent to very heavy, as specified in Section 6.2.6. Record all observations by filling in the appropriate bubbles on the **Physical Habitat** form.

Ground cover is the only layer in which cover estimates should add up to roughly 100% (as opposed to ranging from 0-100% in the other two layers). Certain ground cover types should be considered mutually exclusive, i.e., if ground layer vegetation overlays barren ground, record the vegetation cover even though there is barren ground beneath it.

6.2.9.4 Considerations for Drawdown conditions

Drawdown Zone vegetation entries are located to the right of Riparian Zone Vegetation on the **Physical Habitat** form. They are filled out only if there is a drawdown zone extending ≥1 m from shore. Unlike the case with potential fish cover, record these vegetation estimates just as you see them --- i.e., do not in this case imagine that the drawdown zone is under water. For example: there must be water on the ground (e.g., puddles) to have an entry for "standing water or inundated vegetation" in the drawdown zone. Large trees rooted above the drawdown zone can contribute cover over the drawdown zone. Dried aquatic macrophyte vegetation cover is entered under "Herbs, Grasses, & Forbs" with comment that it is dried aquatic macrophytes. There may also be a lot of zeros for vegetation in the drawdown zone (especially if the drawdown is fairly recent).

6.2.10 **Record Evidence of Human influence**

You will record any observations of human influences within the littoral, riparian, and, when present, drawdown zone plots. Human influences within the littoral plot will be recorded in different locations on the form depending on whether or not there is a drawdown plot.

- When drawdown or lake level fluctuations are minimal, i.e., <1 m horizontal distance, there is no drawdown zone plot, and the drawdown zone human influence field will be left blank. Human influences in the littoral plot are recorded along with the influences in riparian zone plot and recorded in the riparian zone portion of the form.

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- When a drawdown zone extending ≥1 m from shore is present, a drawdown plot is defined and human influences within both the drawdown and littoral zone are recorded in the drawdown portion of the **Physical Habitat** form.

Within each zone, observations are recorded as not present (0), present outside and/or adjacent to (P), or contained within (C) the plot area (Figure 6-2). Record all observations by filling in the appropriate bubbles on the **Physical Habitat** form. The proximity "P" zones have a defined width of 15 m as shown in Figure 6-2. If there is no drawdown zone plot, all C and P human disturbances in the littoral plot are recorded on the riparian part of the form along with human influences present in the riparian zone, and the drawdown portion of the human influences section will be left blank. In contast, if there is a drawdown zone, all C and P human disturbances in the littoral plot are recorded in the drawdown part of the form along with human influences present in the drawdown zone.

For each zone and influence, indicate the presence only of the influence 'closest' to the plot itself. Do not mark "P" for a particular influence type if it is already marked "C" in that zone (use the more influential proximity code). Human Disturbances absent (0) and within-plot (C) are straightforward. For 'Present but outside or adjacent to the plots' (P), use these guidelines:

- A disturbance is marked "P" if the disturbance is seen entirely outside of any of the plots, but is adjacent to (i.e., within 15 meters left or right hand side of the entire Littoral-Drawdown-Riparian plot), or behind, the riparian plot within the defined areas.
- A disturbance is also marked "P" if the disturbance is seen behind, but entirely outside of all of the plots but is visible looking on-shore through the three plot zones (littoral, drawdown, and riparian)
- As a result, a single disturbance that is adjacent to both plots would be marked "P" in both the Riparian-Littoral and the Drawdown zones.
- If there is a drawdown plot, the presence of a human influence item WITHIN THE LITTORAL PLOT is recorded as "C" in the DRAWDOWN portion of the form (e.g., consider the littoral and drawdown zones to be a single plot when drawdown is present).
- If there is NO DRAWDOWN PLOT, i.e., the riparian plot abuts the shoreline, then human disturbances in the littoral plot are recorded by entering "C" in the Riparian portion of the form (e.g., consider the littoral and riparian zones to be a single plot when no drawdown is present).

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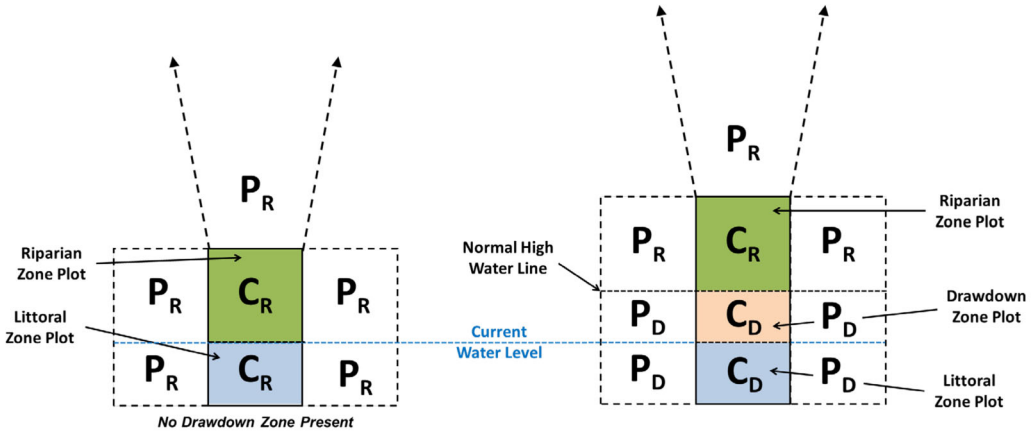


Figure 6-2 Human disturbance and proximity determinations

C_R = Marked on form as contained within riparian plot
P_R = Marked on form as adjacent to riparian plot
C_D = Marked on form as contained within drawdown zone
P_D = Marked on form as adjacent to drawdown zone

6.3 CyanoHABs Visual Assessment

Field crew views and documents visual observations of a potential cyanobacterial bloom in the NLA App and photo documents the bloom according to the reporting mechanism selected by the field crew (i.e., bloomWatch or state-specific reporting mechanism).

6.4 Benthic Macroinvertebrate Sampling

6.4.1 Summary of Method

Benthic macroinvertebrates are collected using a semi-quantitative sampling of multiple habitats in the littoral zone of lakes using a 500 µm mesh D-frame dip net (Figure 6-3). Sample collection is stratified on the following specific habitat types: rocky/cobble/large woody debris; macrophyte beds; fines (including mud, sand, or silt); and leaf packs.



Figure 6-3 D-frame net (500 µm mesh) used for collecting benthic macroinvertebrates.

6.4.2 Equipment and Supplies

Table 6-3 provides the equipment and supplies needed for field operations to collect benthic macroinvertebrates.

Table 6-3 Equipment and supplies – benthic macroinvertebrate collection.

Type	Item	Quantity
Form	NLA Littoral Samples	1
Documentation	Inner and outer labels: Benthic samples	1
	Labels: Benthic extra jar	As needed
	Scissors	1
	Clear tape strips (to cover sample labels)	As needed
Collection	Kick net (500 µm D-shaped, modified) with 4-foot handle	1
	Spare net(s) and/or spare bucket assembly for end of net	As needed
	Bucket (5-gallon capacity, plastic)	1
	Sieve bucket (500 µm)	1
	Watchmakers' forceps	1
	Squirt bottle (1 L Nalgene) – lake water	1
	Spoon (stainless steel)	1
	Funnel	1
	HDPE bottle (1 L, white, wide-mouth)	1 or more
	Ethanol (95%)	2 gal
	Gloves (latex/nitrile, non-powdered, box)	2 pair
Storing and preserving	Cooler	1
	Plastic electrical tape	As needed

6.4.3 Sampling Procedure

6.4.3.1 Site Selection and Sample Collection

The process for selecting the PHab stations is described in Section 6.1. All benthic samples should be collected from the dominant habitat type within the 10 m x 15 m littoral zone component of each of the PHab stations (Figure 3-2). The sampling process is described below. As part of the 2022 survey, new conservation measures for native freshwater mussels were added to the benthic sampling protocol[b].

6.4.3.2 Sample Processing in the Field

Use a 500-mm mesh sieve bucket placed inside a larger bucket full of lake water while sampling to carry the composite sample as you travel around the lake.

6.4.3.2.1 Benthic macroinvertebrate sampling

1. After locating the sample site according to procedures described in the physical habitat section, identify the dominant habitat type within the plot from the classifiers below:

[b] For this protocol, native freshwater mussels only refer to bivalves in the families Unionidae and Margaritiferidae. See Appendix C for examples of freshwater mussels. The conservation measures do not apply to the invasive quagga and zebra mussels, nor do they apply to any other mussel or clam (e.g., native fingernail clams, invasive Asiatic clam).

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- Rocky/cobble/large woody debris;
- Macrophyte beds;
- Fines (including mud, sand or silt); or
- Leaf pack.

2. Prior to collecting the sample and when the water clarity allows, inspect the targeted substrate for the presence of native freshwater mussels. If native freshwater mussels are present, move to an area within the same habitat type where native mussels are absent and the previously identified mussels will not be exposed to sampling pressures. Check the box in the NLA App that identifies native mussels were observed and the collection location was shifted.
3. Use the D-frame dip net (equipped with 500-µm mesh) to sweep through one linear meter of the dominant habitat type at a single location within the 10 m x 15 m littoral zone sampling area, making sure to disturb the substrate enough to dislodge organisms.
    - When safe to do so, it is preferable that you exit the boat and disturb the substrate (e.g., overturn rocks, logs) using your feet while sweeping the net through the disturbed area.
    - Because a dip-net is being used for sampling, the maximum depth for sampling will be approximately 1 m (the length of the dip-net handle); therefore, in cases in which the depth of the lake quickly drops off, it may be necessary to sample in the nearest several meters to the shore.
4. After completing the 1 m sweep, remove all organisms and debris from the net and place them in a bucket following sample processing procedures described in the following section.
5. Inspect the sample for native freshwater mussels after each sweep. If one or more native mussels were unintentionally collected:
    a. In the bucket, gently rise each mussel with lake water to remove invertebrates that may be on its shell.
    b. Carefully return the native mussel to the same habitat it was sampled from and away from further sampling pressures. They are NOT to be pushed into the substrate but to be placed gently on their side on top of the same substrate type or as instructed by local permit.
    c. Check the box in the NLA App that native freshwater mussels were removed from the sample and returned to the lake.
    d. <u>For EPA contractor and regional crews:</u> when sampling a lake where ESA-listed freshwater mussels have the potential to be present, crews must report the encounter in the **Federal ESA** form in the NLA App.
    e. Never intentionally collect and retain a native freshwater mussel that has the potential to be an ESA-listed species.
6. Proceed to the next sampling station and repeat steps 1-5. The organisms and detritus collected at each station on the lake should be combined in a single bucket to create a single composite sample for the lake. After sampling at all PHab stations is complete, process the composite sample in the bucket according to procedures described in the following section. One to five bottles should be sufficient to hold the composited sample from each lake.

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- If there is a large amount of debris (rocks, sticks, etc.) accumulating in the composite sample, remove debris between sampling stations, after the debris is inspected, picked, and/or washed to ensure no organisms are lost.
- If your first collection at a sampling station results in too much debris, discard it, move the location within the same habitat station, and take another sample.
- It is recommended that crews carry a sample bottle containing a small amount of ethanol with them to enable them to immediately preserve larger predaceous invertebrates such as hellgrammites and water beetles. Doing so will help reduce the chance that other specimens will be consumed or damaged prior to the end of the field day. Crews should NEVER, however, attempt to 'field-pick' the samples.

6.4.3.2.2 Preparing composite samples for benthic macroinvertebrates

1. Pour the entire contents of the bucket through a sieve (or into a sieve bucket) with 500 µm mesh size. Remove any large objects and wash off any clinging organisms back into the sieve before discarding. Once again review the sample for native freshwater mussels and follow the steps identified above in the sampling process.
2. Using a wash bottle filled with clean lake water, rinse all the organisms from the bucket into the sieve. This is the composite sample for the lake.
3. Estimate the total volume of the sample in the sieve and determine how many jars (1 L jars, each no more than half-full with sample) will be required.
4. Fill in a sample label with the Site ID and date of collection. Attach the completed label to the jar and cover it with a strip of clear tape. Record the sample ID number for the composite sample on the **Littoral Samples** form. For each composite sample, make sure the number on the form matches the number on the label.
5. Wash the contents of the sieve to one side by gently agitating the sieve in the water. Wash the sample into a jar using as little water from the wash bottle as possible. Use a large-bore funnel if necessary. If the jar is too full, pour off some water through the sieve until the jar is not more than half full, or use a second jar if necessary. Carefully examine the sieve for any remaining organisms and use watchmakers' forceps to place them into the sample jar.
6. If additional jars are needed, use a pre-printed benthos extra jar label or, if needed, fill in a blank sample label that does not have a pre-printed ID number on it. Record the ID number from the pre-printed label prepared in Step 4 in the "SAMPLE ID" field of the label. Attach the label to the additional jars and cover them with a strip of clear tape. Record the number of jars required for the sample on the **Littoral Sample**s form. **Make sure the number you record matches the actual number of jars used.** Write "Jar *N* of *X*" on each sample label using a waterproof marker ("*N*" is the individual jar number, and "*X*" is the total number of jars for the sample).
7. Place a waterproof label inside each jar with the following information written with a number 2 lead pencil:
   - Site ID;
   - Site name;
   - Date of collection;
   - Sample type;
   - Collector(s) names or initials; and
   - Sample ID.

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8. Completely fill the jar with 95% ethanol (no headspace). It is very important that sufficient ethanol be used, or the organisms will not be properly preserved. Existing water in the jar should not dilute the concentration of ethanol below 70%. **NOTE:** Prepared composite samples can be transported back to the vehicle before adding ethanol if necessary. In this case, fill the jar with lake water, which is then drained using the net (or sieve) across the opening to prevent loss of organisms, and replaced with ethanol at the vehicle.
9. Replace the cap on each jar. Slowly tip the jar to a horizontal position, then gently rotate the jar to mix the preservative. Do not invert or shake the jar. After mixing, seal each jar with plastic electrical tape.
10. Store labeled composite samples in a container with absorbent material that is suitable for use with 70% ethanol until transport or shipment to the laboratory.

6.5 Fecal Indicator Sample (Enterococci)

6.5.1 Summary of Method

Field teams are to collect a water sample within or near the littoral zone of the **last PHab station** where the water is about waist deep (1 meter). The water sample should be collected when the crew first arrives at the station (i.e., prior to substrate assessment and collection of the benthic macroinvertebrate sample). For "large lakes" (greater than 10,000 ha) the sample is to be collected from the launch site at the end of the day. **Filters must be frozen within six hours of collection.** Teams are to use a pre-sterilized, 250 ml bottle and collect the sample at about 0.3 meter (12 inches) below the water. Following collection, samples are placed in coolers and maintained on ice prior to filtration of two 50 mL volumes. Again, samples must be filtered and frozen on dry ice within six hours of collection.

6.5.2 Equipment and Supplies

Table 6.4 provides the equipment and supplies needed to collect the fecal indicator sample.

Table 6-4 Equipment and supplies: fecal indicator sample

Type	Item
Form	NLA Littoral Samples
Collection	Nitrile gloves Pre-sterilized, 250 ml sample bottle Sodium thiosulfate tablet Wet ice Cooler

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6.5.3 Sampling Procedure

The procedure for collecting the fecal indicator sample is presented in Table 6-5.

Table 6-5 Procedure: fecal indicator (enterococci) sample collection

Enterococci Sample
1. **Put on nitrile gloves**.
2. Identify an undisturbed area within or near the littoral zone of the final habitat station where the water is about waist deep (1 meter). For "large lakes" (greater than 10,000 ha) the sample is to be collected from the launch site at the end of the day.
3. Lower the uncapped, inverted 250 ml sample bottle to a **depth of 1 foot (0.3 m) below the water surface,** avoiding surface scum, vegetation, and substrates.
4. Point the mouth of the container away from the body or boat. Right the bottle and raise it through the water column, allowing bottle to fill completely.
5. After removing the container from the water, discard a small portion of the sample to allow for proper mixing before filtering (down to the 250 mL mark on the bottle).
6. **Add the sodium thiosulfate tablet, cap, and gently shake the bottle 25 times**.
Storage
7. Store the sample in a cooler on ice to chill (do not freeze immediately). Chill for at least 15 minutes before filtering.
8. Sample must be filtered and all filters frozen within six hours of collection.

6.5.4 Sample Processing in the Field

You will need to process two separate filters for the *Enterococci* sample. All the filters required for an individual site should be sealed in plastic bags until use to avoid external sources of contamination. Please refer to Section 8.2 for more information regarding prcessing the *Enterococci* samples.

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7.0 LAKE WIDE FISH SAMPLE COLLECTION

7.1 Summary of Method

Procedures for the whole fish composite sample are described in detail in Section 7.3**.**The objective is to collect one whole fish composite sample from the 636 designated lakes. This subsample is approximately 70% of the survey design (904 lakes total). Sites with "FT" in the design panel (i.e. Panel_Use) identify lakes designated for fish sampling. The two revisit sites in each state are also designated as fish sampling sites. Crews should collect fish during the *first* site visit for a revisit site, to allow for a second opportunity, if fish cannot be collected during the first visit.

The focus is on obtaining predator fish species that:

- are commonly consumed by humans;
- satisfy legal requirements of harvestable size for each lake site (or at least consumable size if no legal harvest requirements exist); and
- are sufficiently abundant within the lake.

Each fish sample will be a **composite of five adult whole fish** of the same species that are similar in size (i.e., the smallest individual in the sample is no less than 75% of the total length of the largest individual). See the last paragraph in 7.1 for clarification about the acceptable number of predator fish in a composite sample.

Collection of the whole fish composite sample is a lakewide activity. It does not need to be associated with the index site or PHab stations. Field crews may target areas in the lake with high quality habitat for the target fish species, except for areas near a lake inlet or adjacent to riverine habitat. Crews are to avoid these areas (a minimum of a 5-meter buffer zone) since they are more likely to contain nonresident fish. Additionally, when sampling run-of- the river reservoirs, crews should focus their sampling efforts in lacustrine habitats and avoid the river-reservoir transtion zone (i.e., do not sample in habitats with flowing water). Crews should make a reasonable effort to collect a whole fish composite sample before determining a fish sample cannot be collected. This may take *up to* three hours, depending on the waterbody.

If a lake designated for fish sampling is determined target and sampleable, but the crew was unable to collect a whole fish composite sample, no site replacement is needed. If a lake designated for fish sampling is dropped (i.e., determined non-target or not accessible), a replacement site is identified following procedures described in the NLA 2022 SEG and a whole fish composite sample must be collected at the replacement site. At revisit sites, this sample is only collected at one of the two site visits; however, crews that are unsuccessful at collecting the whole fish composite sample during visit 1 are expected to attempt the collection of that sample during visit 2. Whole fish composite samples are shipped to the laboratory designated for interim storage of the samples.

This section contains the sampling procedures and target predator fish species for the whole fish composite sample collection. Note that the target fish species list (Table 7-2) includes 12 primary target predator fish species and 10 secondary predator fish species. Field crews must attempt to collect a primary target predator fish species wherever possible. If primary target predator species are not available at a particular site, then the field crew collects a composite of one of the secondary predator fish species. In the event that a crew is unable to collect fish which are on either of the predator species

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lists, then the on-site biologist can select an appropriate **pelagic predator**. If the field crew has any questions they should contact the NLA Fish Fillet Indicator Trainer or the EPA Technical Lead for the Fish Fillet Contaminants Indicator (Table 2.2).

Field crews are encouraged to collect fish for the composite sample using hook and line or electrofishing. Crews may also seine or use gill nets when this would be an efficient approach to sample the target fish species and when allowed by the sampling permit. Crews are not to use trawling to collect the fish. **Crews may not purchase fish for the whole fish composite sample**.

The whole fish composite sample should consist of five similarly sized (i.e., the total length of the smallest specimen is no less than 75% of the total length of the largest specimen) adult predator fish of the same species. The minimum acceptable length for a fish in any composite sample is 190 mm. **Field crews should make every effort to consistently obtain five fish for the composite sample; however, a sample of fewer than five fish is acceptable. Conversely, for the exceptions where field crews collect five fish that are small, they should collect up to five additional fish (for an overall composite of up to 10 fish)** to provide adequate tissue for analysis. Fish retained as the fish composite sample should remain intact and be submitted as whole specimens.

7.2 Equipment and Supplies

Table 7-1 lists the equipment and supplies necessary for field crews to collect whole fish composite samples. A human health fish sampling kit will be provided to field crews for whole fish sampling sites (separately from site kits) as requested by the crew (see Appendix A). Additional fish collection supplies can be ordered through the **Request** form. A list of frequently asked questions and responses will be provided with the fish sampling supplies to clarify situations that field crews may encounter while collecting whole fish composite samples. Detailed procedures for collecting and processing the whole fish composite samples are presented below.

Table 7-1. Equipment & supplies: whole fish composite sample collection for human health

Type	Item
Form	NLA Whole Fish Sample in NLA App
Collection	scientific collection permit electofisher, hook and line, trap nets (or other device allowed in the sample collection permit) sampling vessel (including boat, motor, trailer, oars, gas, and safety equipment) nitrile gloves* Coast Guard-approved personal floatation devices Global Positioning System (GPS) livewell and/or buckets measuring board (millimeters)
Storing and preserving	aluminum foil (solvent rinsed)* polyethylene tubing (food-grade)* large plastic (composite) bags*

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	plastic cable ties* human health fish sample coolers* dry ice (for preservation) or wet ice (for temporary transport)
Documentation	human health fish sample labels (individual fish labels and composite bag labels)** fine-tipped indelible markers (for labels) Tyvek label tag with grommet (for composite bag)* clear tape

*Provided by EPA in FTIS kits.

**Provided by EPA in site kits.

7.3 Sampling Procedure

Note: *Do not handle any food, drink, sunscreen, or insect repellant until after the composite sample has been collected, measured, and wrapped (or implement measures to reduce contamination by such chemicals if applied such as washing, wearing long gloves, etc.).*

1. Put on clean nitrile gloves before handling the fish.
2. Rinse potential target species/individuals in ambient water to remove foreign material from the external surface and place them in clean holding containers (e.g., livewells, buckets).
3. For each human health fish composite sample, select five whole fish. Criteria for inclusion in the human health fish composite sample:
    a. All fish are of the same primary target species or secondary fish species (See Table 7-2) ***Note:*** *It is essential that field crews accurately identify the organisms submitted for analysis. Do not submit organisms from different species in a single sample.*
    b. All fish are adult fish; and
    c. All fish are of similar size, so that the smallest individual in a composite is no less than 75% of the total length of the largest individual. The minimum acceptable fish length is 190 mm.
4. Measure each fish selected for the composite from the anterior-most part of the fish to the tip of the longest caudal fin ray (when the lobes of the caudal fin are depressed dorsoventrally) to determine total body length in millimeters.
5. On the **Whole Fish Sample** form in the NLA App:
    - Verify the date of the fish collection on the top of the form. The date in this field will be automatically entered based on the date recorded on the **Verification** form. If you have not filled out the Verification Form or if the date of the fish collection is different, you can edit the date here. Note however that changing the value on this form will not change the value on the Verification Form.
    - Ensure the sample identification number is entered.
    - Check the boxes verifying that all samples are of similar length and the same species.
    - Record species selected for analysis, individual specimen lengths (total length in mm), and any relevant comments. Extra rows are provided in the App in the event that additional specimens are collected to ensure adequate tissue for analysis (refer to Frequently Asked Questions for further clarification).

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- Make sure the sample ID and specimen numbers recorded in the App match those on the sample labels.

6. Wearing clean nitrile gloves, remove each fish selected for analysis from the clean holding container(s). Dispatch each fish using the most humane method available.
7. Wrap each fish specimen in extra heavy-duty aluminum foil, with the dull side in contact with the fish (foil is solvent rinsed and baked and will be provided by EPA).
8. Prepare a sample label for each sample specimen, ensuring that the label information matches the information recorded on the **Whole Fish Sample** form in the App. **Be sure to record the common name and specimen length on each label.**
9. Cut separate lengths of food grade tubing (provided by EPA) long enough to contain each individual fish, allowing extra length on each end to seal with cable ties. Place each foil-wrapped specimen into the appropriate length of tubing. Seal the ends of each tube with a plastic cable tie. Attach the appropriate sample label to the plastic tubing by wrapping clear tape around the label and then completely around the wrapped fish (so that the clear tape wraps over itself).
10. Double-bag the entire set of specimens in the composite by placing all fish composited from the site inside a large plastic bag (provided by EPA). If additional bags are required for large fish specimens or fish samples, please use plastic bags of similar thickness as those provided by EPA.
11. Fill out a Sample Identification Label for the outer bag, ensuring that the label information matches the information recorded on the **Whole Fish Sample** form in the App. **Be sure to record the common name and specimen length range on the label.**
12. Affix the sample label to a composite bag tag (Tyvek tag) and cover with clear plastic tape. Thread a cable tie through the grommet in the tag and seal the outer bag with the cable tie.

SAMPLE STORAGE AND SHIPPING PREPARATION

1. After the fish sample is packaged, immediately place the fish sample in a cooler of dry ice and use either of the following options: (1) replenish dry ice at least daily until the sample can be properly frozen at ≤-20°C in a laboratory or other interim facility or (2) pack cooler with 50 pounds of block dry ice and ship to Microbac Laboratories (Baltimore, MD) before the end of the day.
   - If a fish sample is held on dry ice in the field, the field crew should replenish the supply of dry ice at least daily until the sample can be properly frozen or shipped.
   - Packaged fish samples may be placed on wet ice in coolers if they will be immediately transported to a nearby laboratory or other interim facility to be frozen before shipment (wet ice should be replenished frequently before it melts).
   - Keep all specimens in a particular fish composite sample in the same cooler for transport. Ship only one fish composite sample in a cooler.
2. Crews have two options for freezing and shipping fish composite samples, depending on site logistics:
   a. Ship the samples via priority overnight delivery service (i.e., Federal Express), packed on dry ice, so that they arrive at Microbac Laboratories (Baltimore, MD) within 24 hours from the time of sample collection. Do NOT ship on Fridays, Saturdays, or the day before federal holidays. Fish samples must be packed on sufficient dry ice (**50 pounds minimum**, with blocks of dry ice layered to ensure direct contact between fish and dry

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ice) to keep them frozen for up to 48 hours. **Do not use dry ice pellets for shipping the whole fish composite sample.** Remember to record the tracking number on the **Tracking** form in the App before submitting it to NARS IM.

b. Add fish samples to a freezer capable of maintaining temperatures of ≤-20°C within 24 hours of collection, and store the frozen samples until shipment within two weeks of sample collection. If fish samples cannot be stored in a freezer within 24 hours of collection, the field crew should replenish the supply of dry ice in the cooler containing the samples, at least daily, until the samples can be properly frozen or shipped. Frozen fish samples will subsequently be packed on at least 50 pounds of layered blocks of dry ice and shipped to Microbac Laboratories (Baltimore. MD) via priority overnight delivery service. Refer to reminders in option 2a (above) about not shipping on Fridays, Saturdays, or the day before federal holidays and about including sample tracking numbers on App tracking forms.

Table 7-2. Primary and secondary NLA target species for human health fish collection

PRIMARY PREDATOR HUMAN HEALTH FISH TARGET SPECIES		
FAMILY	SCIENTIFIC NAME	COMMON NAME
Centrarchidae	*Micropterus salmoides*	Largemouth Bass
	Micropterus dolomieu	Smallmouth Bass
	Pomoxis nigromaculatus	Black Crappie
	Pomoxis annularis	White Crappie
Percidae	*Sander vitreus*	Walleye
	Perca flavescens	Yellow Perch
Moronidae	*Morone chrysops*	White Bass
Esocidae	*Esox lucius*	Northern Pike
Salmonidae	*Salvelinus namaycush*	Lake Trout
	Salmo trutta	Brown Trout
	Oncorhynchus mykiss	Rainbow Trout
	Salvelinus fontinalis	Brook Trout
SECONDARY PREDATOR HUMAN HEALTH FISH SPECIES		
FAMILY	SCIENTIFIC NAME	COMMON NAME
Centrarchidae	*Lepomis macrochirus*	Bluegill
	Ambloplites rupestris	Rock Bass
	Micropterus punctulatus	Spotted Bass
Percidae	*Sander canadensis*	Sauger
Moronidae	*Morone saxatilis*	Striped Bass
	Morone americana	White Perch
Esocidae	*Esox niger*	Chain Pickerel
Salmonidae	*Oncorhynchus clarkii*	Cutthroat Trout
	Coregonus clupeaformis	Lake Whitefish
	Prosopium williamsoni	Mountain Whitefish

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8.0 FINAL LAKE ACTIVITIES

Prior to leaving the lake, make a general visual assessment of the lake and its surrounding catchment. This assessment is based on the collective observations of all crew members. The objective of the lake assessment is to record field crew observations of catchment and lake characteristics that are useful for future data interpretation, ecological value assessment, development of associations, and verification of stressor data. While often subjective, these observations and impressions are extremely valuable.

In addition, review all data forms and sample labels for completeness, accuracy, and legibility. Make sure all samples are labeled, sealed, and properly preserved. Activities described in this section are summarized in Figure 8-1.

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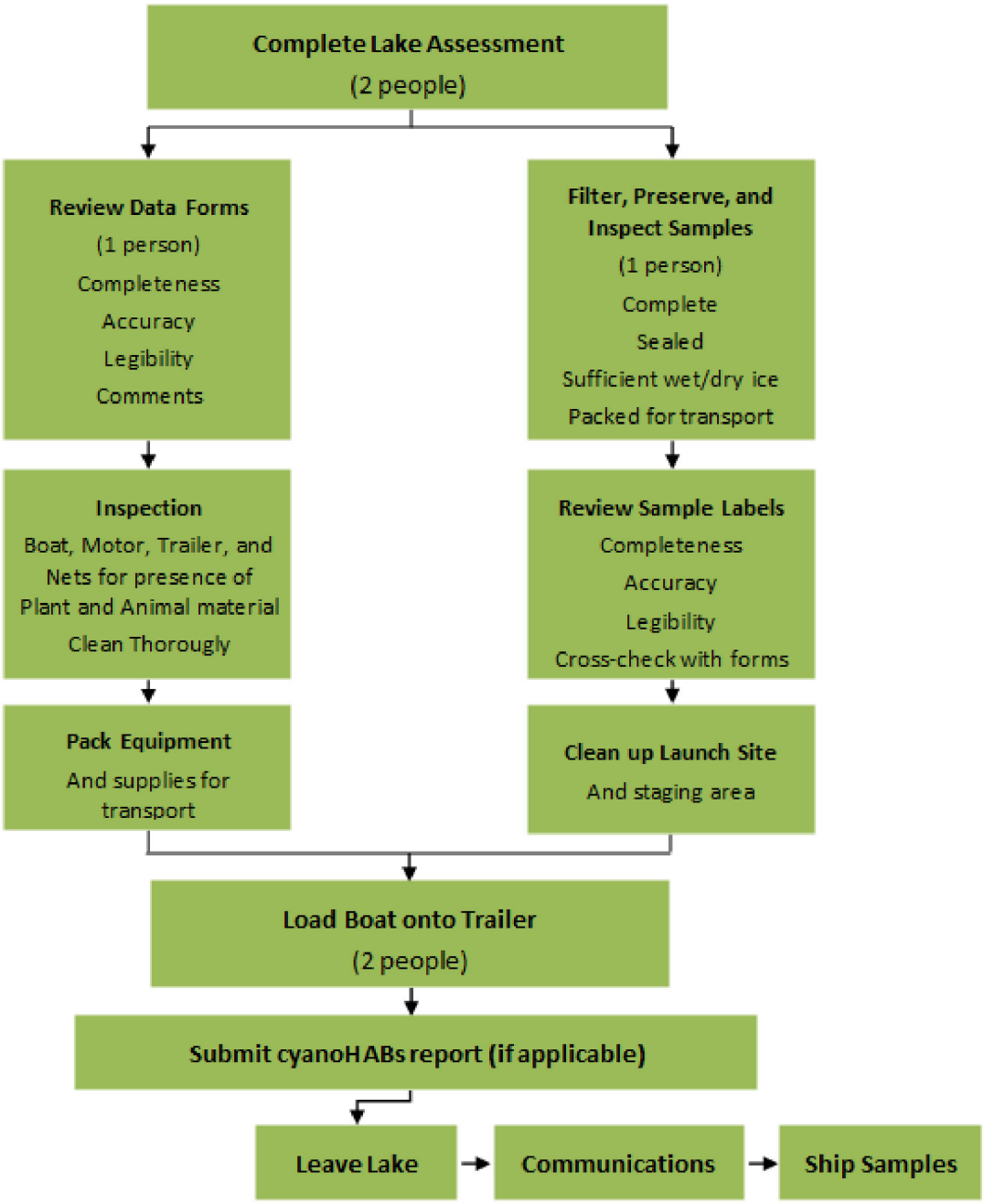


Figure 8-1 Final lake activities summary

8.1 General Lake Assessment

Complete the **Assessment** form at the end of lake sampling, recording all observations from the lake that were noted by all crew members during the course of the visit. This form is designed as a template for recording pertinent field observations. It is by no means comprehensive, and any additional observations should be recorded in the comments section. The form consists of six major sections: 1) Lake/Catchment Site Activities and Disturbances Observed, 2) General Lake Information, 3) Shoreline

Characteristics, 4) Qualitative Macrophyte Survey, 5) Waterbody Character, and 6) Qualitative Assessment of Environmental Values. In 2022, new questions were added to assist the determination of natural and human-made lakes.

8.1.1 Lake/Catchment Site Activities and Disturbances Observed

Record any of the sources of potential stressors listed in Table 8-1 on the **Assessment** form. These potential stressors may have been observed while on the lake, while driving or walking through the lake catchment, or while flying over the lake and catchment. For activities and stressors that you observe, rate their abundance or influence as low (L), moderate (M), or heavy (H) by filling in the correct bubble next to each disturbance listed. Leave the line blank for any disturbance not observed. The distinction between low, moderate, and heavy will be subjective. For example, if there are two to three houses on a lake, fill in the "L" bubble for low next to "Houses." If the lake is ringed with houses, rate it as heavy (H). Similarly, a small patch of clear-cut logging on a hill overlooking the lake would rate a low ranking. Logging activity right on the lake shore, however, would get a heavy disturbance ranking. The section for “Lake Site Activities and Disturbances Observed” includes residential, recreational, agricultural, industrial, and lake management categories.

Table 8-1 Site activities and disturbances observed during final lake assessment.

Observe lake activities or disturbances listed and record as L (low), M (moderate), or H (heavy) intensity on the Assessment form (except as noted below):	
Residences	Presence of any houses and residential buildings around the lake.
Maintained Lawns	Presence of any maintained lawns around the lake.
Construction	Presence of any recent construction in the immediate area around the lake or signs of recent sedimentation events (depositional fans).
Pipes/Drain	Presence of any pipes or drains feeding into or out of the lake. If known, record the type of activity with which the pipe is associated (e.g., storm sewer, plant intake) in the "Comments" section of the form.
Dumping	Any evidence of landfill or dumping around the lake, including garbage pits and informal dumping of large amounts of trash or cars and appliances along roads or lakeshore. This does not include small amounts of litter. If informal dumping areas exist, note that they are informal sites in the "Comments" section of the form.
Roads	Presence of any maintained roads in the immediate area around the lake.
Bridges/Causeways	Presence of any bridges or causeways across or in the immediate vicinity of the lake.
Sewage Treatment	Presence of sewage treatment facility.
Hiking Trails	Presence of formal hiking trails around the lake.
Parks, Campgrounds	Presence of organized public or private parks, campgrounds, beaches or other recreational areas around the lake.
Primitive Parks, Camping	Presence of informal or primitive parks, camping areas, beaches or other recreational areas (e.g., swimming holes) around the lake.
Resorts	Level of resort activity; this could include motels, resorts, golf courses, and stores.
Marinas	Presence of any marinas.
Trash/Litter	Relative abundance of trash or litter around the lake.
Surface Films, Scum or Slicks	Relative abundance of surface films, scum, or slicks on the lake.
Cropland	Presence of cropland.

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Observe lake activities or disturbances listed and record as L (low), M (moderate), or H (heavy) intensity on the Assessment form (except as noted below):	
Pasture	Presence of pastures.
Livestock Use	Presence of livestock use.
Orchards	Presence of orchards.
Poultry	Presence of poultry operations.
Feedlot	Presence of feedlot or concentrated animal feeding operations.
Water Withdrawal	Any evidence of water withdrawal from the lake.
Industrial Plants	Any industrial activity (e.g., canning, chemical, pulp) around the lake or in the catchment. Describe the type of industry in the "Comments" section of the form.
Mines/Quarries	Any evidence of mining or quarrying activity in the catchment or around the lake.
Oil/Gas Wells	Any evidence of oil or gas wells in the catchment or around the lake.
Power Plants	Presence of any power plants.
Logging	Any evidence of logging or fire removal of trees in the lake area.
Evidence of Fire	Any evidence of forest fires in the lake area.
Odors	Presence of any strong odors.
Commercial	Any commercial activity (e.g., convenient stores, shopping centers, restaurants) around the lake or in the catchment.
Liming	Any evidence of liming activities.
Chemical Treatment	Presence of any chemical treatment facilities.
Angling Pressure	Estimate of the intensity of fishing activity in the lake.
Drinking Water Treatment	Presence of any drinking water treatment facilities.
Macrophyte Control	Any evidence of dredging or other activities to control macrophyte growth; describe these in the "Comments" section of the form.
Water Level Fluctuations	Any evidence of water level fluctuations due to lake management.
Fish Stocking	Any evidence of fish stocking in the lake.
Record any other oddities observed or additional information for any specific activity in the "Comments" section of the form.	

8.1.2 General Lake Information

Observations regarding the general characteristics of the lake are described in Table 8-2. Record these observations on the **Assessment** form. The hydrologic lake type is a very important variable for defining subpopulations for acidic deposition effects. Note if there are any stream outlets from the lake, even if they are not flowing. If no lake outlets are observed, record the lake as a seepage lake. If the lake was created by a manmade dam (not that a dam is present just to raise the water level), record the lake as a reservoir. Otherwise record the lake as a drainage lake. Note any flight hazards that might interfere with either low-altitude fly-overs by aircraft (for future aerial photography or videography) or landing on the lake for sampling purposes (either by float plane or helicopter). When estimating the intensity of motor boat usage, in addition to the actual number of boats observed on the lake during the visit, use other observations such as the presence of boat houses, docks, and idle craft**.** Note your opinion as to the swimmability of the lake in general. Observe any regular change in the lake levels and estimate the typical elevation change.

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Table 8-2 General lake information observed during final lake assessment.

Record general information about the lake as a whole	
Hydrologic Lake Type	Note if there are any stream outlets from the lake, even if they are not flowing. If no lake outlets are observed, record the lake as a seepage lake. If the lake was created by a manmade dam (not that a dam is present just to raise the water level), record the lake as a reservoir. Otherwise record the lake as a drainage lake.
Outlet Dams	Note the presence of any dams (or other flow control structures) on the lake outlet(s). Differentiate between artificial (man-made) structures and natural structures (beaver dams).
Motor Boat Density	Record your impression of the density of motor boat usage on this lake (high or low). If there is a restriction on the size of motor boat engines, check "Restricted." If motor boats are banned, check "Banned." Consider the day of the week and weather in your assessment as well as the number of boathouses, idle craft. Count jet skis and any other motorized craft, which could stir up the lake, as motor boats.
Swimmability	Record a subjective impression about the aesthetics of swimming in this lake (swimmability) along the range of "good" to "not swimmable."
Lake Level Changes	Examine the lake shoreline for evidence of lake level changes (e.g., bathtub ring). If there are none, check "zero;" otherwise try to estimate the extent of vertical changes in lake level from the present conditions based on other shoreline signs. Estimates should be made to the nearest 0.1 m.

8.1.3 Shoreline Characteristics

Shoreline characteristics of interest during the final lake assessment are described in Table 8-3. Record observations related to this portion of the assessment on the **Assessment** form. To estimate the extent of major vegetation types, limit the assessment to the immediate lake shoreline (i.e., within 20 m of the water). Also estimate the percentage of the immediate shoreline that has been developed or modified by humans.

Table 8-3 Shoreline characteristics observed during final lake assessment.

Record percent of shoreline characteristics (within 20 meters of water):	
Forest	Deciduous, coniferous, or mixed forest, including sapling vegetation.
Grass	Meadows, lawns, or other open vegetation.
Shrub	Shrub vegetation
Wetland	Forested and non-forested wetlands (submerged terrestrial vegetation).
Bare Ground	Non-vegetated areas such as beaches, sandy areas, paved areas, and exposed rock.
Agriculture	Cropland, orchard, feedlot, pastureland, or other horticultural activity.
Shoreline Modifications	Actual shoreline that has been modified by the installation of riprap, revetments, piers, or other human modifications.
Development	Immediate shoreline area developed by human activity; include lawns, houses, stores, malls, marinas, golf courses, or any other human-built land use.

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8.1.4 Qualitative Macrophyte Survey

Aquatic macrophytes (aquatic plants large enough to be seen without magnification) are important indicators of lake trophic status. The most important indicator for this survey is the percentage of the entire lake area (not just near the shore) covered with macrophytes, as perceived by observers. For both "emergent/floating" and "submergent" coverage, choose one of the four percentage groupings (<5%, 5-25%, 26-75%, >75%) on the **Assessment** form. In some cases, it will be fairly easy to estimate the percentage from observations made at the PHab stations. In other cases, it will be an educated guess, especially if the water is turbid or the lake is deep. After recording the areal percentage of macrophyte coverage, record the typical density of the plants in the observed macrophyte beds as absent, sparse, moderate, or high. Record your estimates on the **Assessment** form.

8.1.5 Waterbody Character

Rate the ***waterbody character*** which is the physical habitat integrity of the waterbody. Waterbody character is largely a function of riparian and littoral habitat structure, volume change, trash, turbidity, slicks, scums, color, and odor. The NLA 2022 attempts to define waterbody character through two attributes: degree of human disturbance and aesthetics. Rate each of these attributes on a scale of 1 to 5. For development, give the lake a "5" if it is pristine, with no signs of any human disturbance. A "1" would indicate that a lake is highly disturbed; for example, the entire lake is ringed with houses, seawalls, docks, etc. For aesthetics (whether the lake is appealing or not) base the decision on any factors about the lake that disturb you (trash, algal growth, weed abundance, overcrowding). Fill in the bubble next to the number that best describes your opinion about how suitable the lake is for recreation and aesthetic enjoyment today:

1. Enjoyment is nearly impossible;
2. Level of enjoyment is substantially reduced;
3. Enjoyment is slightly impaired;
4. There are very minor aesthetic problems; it is otherwise excellent for swimming, boating, and enjoyment; or
5. It is beautiful and could not be any nicer.

8.1.6 Qualitative Assessment of Environmental Values

The primary goal of this study is to assess three major ecological values with respect to lakes: trophic state, ecological integrity, and human health (through use of the lake). Based on your field experience, record your own assessment of these values on the **Assessment** form. Write comments on these values in this section.

1. ***Ecological integrity*** is the ability to support and maintain a balanced, integrated, adaptive community with a biological diversity, composition, and functional organization comparable to natural lakes of the region. Record your overall impression of the "health" of the biota in the lake. Note any possible causes of impairment. The presence of higher order consumers (fish-eating birds and mammals) is an indication of a healthy food web and should be noted here. Similarly, the absence of an organism that you might expect to see is an important observation.
2. ***Trophic state*** is the rate or amount of phytoplankton and macrophytes produced or present in a lake. Give your visual impression of the trophic status as oligotrophic (little or no biomass in the lake water), mesotrophic (intermediate amounts of biomass in the lake water), eutrophic (large

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amounts of biomass in the lake water), or hypereutrophic (choked lake, with more biomass than water). Give your overall impression of algal abundance and general type (e.g., filamentous). List any observed potential nutrient sources to the lake (e.g., septic tanks and agricultural runoff).

3. ***Recreational value*** is the ability to support recreational uses such as swimming, fishing, and boating. Record your overall impression of the lake as a site for recreation. Note any possible causes of impairment or risk to human health. Note the presence or absence of people using the lake for recreational activities.

Use the comments section on the **Assessment** form to note any other pertinent information about the lake or its catchment. Here the field crew can record any observations that may be useful for future data interpretation, especially data that was not captured during other sampling or data collection activities.

8.1.7 CyanoHAB assessment and report

In the **Assessment** form, field crews document the presence of potential cyanobacterial blooms that were observed in areas of the lake that were not associated with the launch site, index site or physical habitat stations (i.e., not previously reported the NLA App). Crews are to photo document the bloom according to the reporting mechanism selected by the field crew (i.e., bloomWatch or state-specific reporting mechanism).

If the field crew documented the potential occurrence of a cyanoHAB event at one or more station in the lake, the Field Crew leader is responsible for reporting the bloom to the appropriate state, tribal or local organization. See Section 2.2.4.5 for potential reporting mechanisms. A cyanoHAB report will only be submitted when a potential bloom was observed. Reports are not needed to document the lack of a bloom. All reports submitted via the bloomWatch app should add the project identifier ‘NLA2022’ in the comment section in the app.

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8.2 Filtering: Processing the Fecal Indicator (Enterococci) and Chlorophyll-*a* Samples

8.2.1 Equipment and Supplies: Fecal Indicator

Table 8-4 provides the equipment and supplies needed for field crews to collect the fecal indicator sample.

Table 8-4 Equipment and Supplies: Fecal Indicator (Enterococci) Sample

Type	Item	Quantity
Form	NLA Littoral Samples form	1
For recording measurements	Fine-tipped indelible markers for filling out sample labels	1
	Fecal Indicator sample labels: vial	
	Fecal Indicator sample labels: bag label)	2
	Filter blank label if collecting filter blank	1
For processing samples	Nitrile gloves	1
	Sterile centrifuge tube (50 mL, screw top) in zip top bag	1
	Filtration apparatus with collection flask	1
	Sterile filter holder, Nalgene 145/147	1
	Vacuum pump (electric pump may be used if available)	1
	Sterile phosphate buffered saline (PBS)	1
	Osmotics 47 mm polycarbonate sterile filters	1+
	Sterile disposable forceps	1
	Petri dishes (60 x 15, disposable)	1
	Sterile microcentrifuge tubes containing sterile glass beads	2
	Additional sterile microcentrifuge tube if collecting filter blank	1
	Bubble bag	1
	Zip-top bag	1
	Dry ice	As needed
	Cooler	1

8.2.2 Procedures for Processing the Fecal Indicator (*Enterococci*) Sample

The fecal indicator sample **must be filtered before the chlorophyll-*a*** sample since the filtering apparatus needs to be sterile. The procedures for processing the fecal indicator sample are presented in **Table 8-5**. The sample must be filtered and frozen within six hours of collection.

Table 8-5 Procedure: Processing Fecal Indicator (*Enterococci*) Sample

Filtering for the fecal indicator (Enterococci) Sample
Prior to beginning the filtering process, chill the Enterococci sample and PBS on WET ice for at least 15 minutes and chill the microcentrifuge tubes on DRY ice. 1. Put on nitrile gloves. 2. Set up sample filtration apparatus on flat surface and attach vacuum pump. Set out 50 mL sterile PP tube, sterile 60 mm Petri dish, chilled phosphate buffered saline (PBS), Osmotics 47 mm polycarbonate sterile filter box, and two sterile filter forceps. 3. Chill Filter Extraction tubes with beads on dry ice. 4. Aseptically transfer two polycarbonate filters from filter box to base of opened Petri dish. Close filter box and set aside (this step is to prevent wind from disturbing the remaining filters in the box but is optional in calm/controlled environments). 5. Remove the pre-loaded cellulose nitrate (CN) filter (the filter with grid design on it) from funnel and discard. Be sure to leave the support pad in the filter funnel. 6. Load filtration funnel with sterile polycarbonate filter on support pad (shiny side up). 7. Gently shake sample collection bottle 25 times to mix well. 8. Measure 25 mL of the mixed water sample in the sterile graduated sterile PP tube and pour into filter funnel. 9. Replace cover on filter funnel and pump to generate a vacuum (do not generate more than 7 inches of Hg of vacuum [3.44 psig]). Keep pumping until all liquid is in filtrate collection flask. 10. If the first 25 mL volume passes readily through the filter, measure and add another 25 mL and continue filtration. If it was very difficult to filter the first 25 mL, proceed to step 11. If the filter clogs before completely filtering the first or second 25 mL volume, discard the filter and repeat the filtration using a lesser volume. 11. Pour approx. 10 mL of the chilled phosphate buffered saline (PBS) into the graduated PP tube used for the sample. Cap the tube and shake 5 times. Remove the cap and pour rinsate into filter funnel to rinse filter. 12. Filter the rinsate and repeat with another 10 mL of PBS, ensuring all PBS is filtered through. 13. Remove filter funnel from base without disturbing filter. Using sterile disposable forceps remove the filter (touching only the filter edges) and fold it in half, in quarters, in eighths, and then in sixteenths (filter will be folded four times). 14. Insert filter into chilled filter extraction tube (with beads). Filter should be inserted open end down (pointed side up) into the tube. Replace and tighten the screw cap. 15. Record the volume of sample filtered through the filter on the small yellow label (marked as FILTER 1) and apply the label to the extraction tube (DO NOT cover with clear tape). 16. Record the volume of sample filtered through the filter on the outer bag label and apply the label to the bubble bag (DO NOT cover with clear tape). 17. Insert tube(s) into bubble bag and zip-top bag on dry ice for preservation during transport and shipping.

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18. Record the volume of water sample filtered through each filter and the volume of buffer rinsate each filter was rinsed with on the **Littoral Samples** form. Record the filtration start time and finish time for the sample as well as the time the filters were frozen.
19. Repeat steps 6 to 15 for the remaining 50 mL sub-sample volume to be filtered. Make every effort to filter the same volume of sample through each of the two filters.

Processing procedure—fecal indicator (*Enterococci*) filter blank

Enterococci filter blanks will be prepared at all revisit sites during the first visit. Prepare the filter blanks **before** filtering the lake sample.

1. Set up sample filtration apparatus using same procedure as used for the lake sample. Chill Filter Extraction tubes with beads on dry ice.
2. Aseptically transfer 1 polycarbonate filter from filter box to base of opened Petri dish. Close filter box and set aside (this step is to prevent wind from disturbing the remaining filters in the box but is optional in calm/controlled environments).
3. Remove the pre-loaded cellulose nitrate (CN) filter (the filter with grid design on it) from funnel and discard. Be sure to leave the support pad in the filter funnel.
4. Load filtration funnel with sterile polycarbonate filter on support pad (shiny side up).
5. Measure 10 mL of the chilled phosphate buffered saline (PBS) in the sterile graduated PP tube and pour into filter funnel.
6. Replace cover on filter funnel and pump to generate a vacuum (do not generate more than 7 inches of Hg of vacuum [3.44 psig]). Keep pumping until all liquid is in filtrate collection flask.
7. Remove filter funnel from base without disturbing filter. Using sterile disposable forceps remove the filter (touching only the filter edges) and fold it in half, in quarters, in eighths, and then in sixteenths (filter will be folded 4 times).
8. Insert filter into chilled filter extraction tube (with beads). Filter should be inserted open end down (pointed side up) into the tube. Replace and tighten the screw cap.
9. Record the volume of PBS filtered through the filter on the small yellow label (marked as BLANK) and apply the label to the extraction tube (DO NOT cover with clear tape). Note that there is a specific label for the blank sample. At sites where a blank is not collected, this label will be discarded.
10. Insert tube(s) into bubble bag and zip-top bag on dry ice for preservation during transport and shipping.
11. Package and submit this sample to the lab with the standard samples.
12. Indicate that you have collected a filter blank by filling in the “Blank Collected” button on the **Littoral Samples** form.

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8.2.3 Equipment and Supplies: Chlorophyll-*a*

Table 8-6 provides the equipment and supplies needed to process the chlorophyll-*a* sample. Much of this equipment will have been used previously for the filtering of the Enterococci sample.

Table 8-6 Equipment and supplies – chlorophyll-*a* processing.

Type	Item	Quantity
Form	NLA Index Samples	1
Documentation	Labels: Chlorophyll-*a* sample label	1
	Chlorophyll-*a* outer bag label	1
	Clear tape strips (to cover sample labels)	As needed
Processing	Poly bottle (2 L, brown)	1
	Centrifuge tube (50 mL, screw top) in zip top bag	1
	Sterile disposable forceps	1
	Filtration chamber (with filter holder)	1
	Filtration flask (with silicone stopper and adapter)	1
	Filtration pump (hand vacuum)	1
	Graduated cylinder (250 mL)	1
	Squirt bottle (1 L Nalgene) – de-ionized (DI)	1
	Test tube holder	1
	Whatman 0.7 µm GF/F glass fiber filter	1
Storing and preserving	Cooler	1
	Plastic electrical tape	As needed
	Foil squares	1
	Zip top bag	1
	Wet ice	As needed

8.2.4 Procedures for Processing the Chlorophyll-*a* Samples

The procedure for processing the chlorophyll-*a* sample is presented below. Whenever possible, sample processing should be done in subdued light, out of direct sunlight.

1. Place a glass fiber filter in the filter holder apparatus with the grid side down. Do not handle the filter with bare hands; use clean forceps.
2. Gently shake the chlorophyll-*a* sample collection bottle to homogenize the sample, measure and pour 250 mL of water into the filter holder using the graduated cylinder, replace the cap of the filter holder, and pump the sample through the filter. Take care not to exceed 7 inches of Hg (approximately 3.4 psi) in the vacuum gauge on the filtration pump. If 250 mL of lake water will not pass through the filter, discard the filter, rinse the apparatus with DI water, and repeat the procedures using a new filter and 100 mL of lake water. **NOTE: If the water is green or turbid, use a smaller volume to start.**
3. Observe the filter for visible color. If no visible color is present, repeat step 3 until color is visible on the filter or until a maximum of 2,000 mL have been filtered.
4. Once visible color is present and/or 2,000 mL of lake water has been filtered, record the actual sample volume filtered on the **Index Sample**s form and on the sample label. Rinse the graduated cylinder and upper portion of the filtration apparatus thoroughly with DI water to

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include any remaining cells adhering to the sides and pump through the filter. Monitor the level of water in the lower chamber to ensure that it does not contact the filter or flow into the pump.

5. Disconnect the upper portion of the filter apparatus from the lower portion. Remove the filter from the holder with clean forceps. Avoid touching the colored portion of the filter. Fold the filter in half, with the colored side folded in on itself.
6. Place the folded filter into a 50 mL screw-top centrifuge tube and replace the cap. Tighten the cap as tightly as possible. The cap will seal tightly after an additional ¼ turn past the point at which initial resistance is met. Failure to tighten the lid completely could allow water to infiltrate into the sample and may compromise its integrity. Seal the cap of the centrifuge tube with plastic electrical tape
7. Record the sample volume filtered on a chlorophyll-*a* label and attach it to the centrifuge tube. Ensure that all written information is complete and legible. Cover with a strip of clear tape. Double check that the "total volume of water filtered" on the **Index Samples** form matches the total volume recorded on the sample label.
8. Wrap the tube in aluminum foil and place in a zip top bag. Place the completed outer label on the outside of the bag. Place this bag on ice in a cooler.
9. Remove the filter holder silicone stopper and adapter from the filtration flask. Pour off water from the filtration flask.
10. Discard filter chamber, forceps and filter holder. New sterile items will be used at each site.
11. Retain the filter flask, graduated cylinder, silicone stopper, and adapter. Rinse these items with DI water between sites. After returning to the office or lab: thoroughly rinse the graduated cylinder, the brown sample collection bottle and cap with tap water, complete a final rinse with DI water, and store for next sample event.

8.3 Preservation of Samples

Preserve the samples as specified in the specific protocol sections. Record the preservation information on the index and littoral sample collection forms.

8.4 Preparation of Samples for Shipping

General information regarding the preparation and shipment of samples is available in Section 4.3.2. General steps that apply to samples are the following:

- Purge the Cubitainer® of any air bubbles, seal the cap tightly and wrap plastic electrical tape clockwise around the cap. Place the Cubitainer® in a cooler with wet ice.
- Seal all pertinent caps tightly.
- Wrap plastic electrical tape clockwise around the caps, and then place the bottles in the cooler with wet ice.
- Keep chilled samples (water chemistry and chlorophyll-*a* filter) on wet ice until shipment (daily).
- Keep the atrazine samples chilled on wet ice in the field and then refrigerate until shipment (batched weekly).

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- Keep the algal toxins, eDNA, and fecal indicator samples chilled on wet ice in the field and FREEZE as soon as practicable. Keep frozen until shipping (batched weekly).

**** The enterococci sample does not get tape around the cap and the sample label is not placed on the sample bottle. This sample will be shipped on dry ice.**

8.5 Data Forms and Sample Inspection

After the **Assessment** form is completed, the Field Crew Leader reviews all of the data forms and sample labels for accuracy, completeness, and legibility. The other crew member inspects all sample containers and package them in preparation for transport, storage, or shipment.

Ensure that all required data forms for the lake have been completed. Confirm that the Site ID, crew ID, and date of visit are correct. On each form, verify that all information has been recorded accurately and comments are used to explain data as needed. After reviewing each form, select the red circle at the top, which will turn green after selection. This is an indication to the crew that the form has been reviewed, but forms can be submitted before final review and amended at a later date if needed.

Ensure that all samples are labeled, all labels are completely filled in, and each label is covered with clear tape. NOTE: Do not tape over the enterococci labels. Make sure that all sample containers are properly sealed.

8.6 Launch Site Cleanup

Load the boat on the trailer and inspect the boat, motor, and trailer for evidence of plant material. Clean the boat, motor, and trailer as completely as possible before leaving the launch site. Inspect all nets for pieces of macrophyte or other organisms and remove as much as possible before packing the nets for transport. Pack all equipment and supplies in the vehicle and trailer for transport; keep them organized as presented in the equipment checklists (APPENDIX A: EQUIPMENT & SUPPLIES). Lastly, be sure to clean up all waste material at the launch site and dispose of or transport it out of the site if a trash can is not available. See Section 4.3 for additional information and follow appropriate state, tribal or other applicable protocols.

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9.0 FIELD QUALITY CONTROL

Standardized training and data forms provide the foundation to help assure that data quality standards for field sampling are met. These methods for field sampling and data collection are the primary guidelines for all cooperators and field crews. In addition, repeat sampling and field evaluation and assistance visits will address specific aspects of the data quality standards for the NLA 2022.

9.1 Revisit Site

Approximately 10% of the target sites visited (96 lakes) will be revisited during the same field season by the same field crew that initially sampled the lake. If a site selected for repeat sampling is dropped, then the alternate site assigned to replace it should be revisited. The NLA 2022 Site Evaluation Guidelines provides further information regarding the replacement of revisit sites. The primary purpose of this "revisit" set of sites is to provide variance estimates that can be used to evaluate the survey design for its potential to estimate status and detect trends in the target population of lakes. The time period between the initial (Visit 1) and repeat visit (Visit 2) to a lake must be at least two weeks and should be as long as possible.

Visit 2 will include the full set of indicators and associated parameters with two notable exceptions. A fecal indicator blank will be collected at Visit 1 only and human health fish tissue will only be collected at only one of the two site visits. Crews should collect fish during Visit 1 for a revisit site, to allow for a second opportunity if fish cannot be collected during the first visit. If the crew collects fish on Visit 1, they do not need to collect fish on Visit 2. If they are unable to collect fish on Visit 1, the crew should collect fish on Visit 2.

9.2 Field Evaluation and Assistance Visits

No national program of accreditation for field work currently exists. For this reason, a rigorous program of field evaluation and assistance visits has been developed to support the NLA 2022.

9.2.1 General Information

Evaluation and assistance visits will be conducted with each field crew early in the sampling and data collection process, if possible, and corrective actions will be conducted in real time. These visits provide both a quality check for the uniform evaluation of the data collection methods and an opportunity to conduct procedural reviews, as required, minimizing data loss due to improper technique or interpretation of field procedures and guidance. Through uniform training of field crews and review cycles conducted early in the data collection process, sampling variability associated with specific implementation or interpretation of the protocols will be significantly reduced. The assistance visit also provides the field crews with an opportunity to clarify procedures and offer suggestions for future improvements based on their sampling experience preceding the visit. The field evaluations, while performed by a number of different supporting collaborator agencies and participants, will be based on the uniform training, plans, and checklists. This review and assistance task will be conducted for each unique field crew collecting and contributing data under this program; hence no data will be recorded to the project database that was produced by an 'unaudited' process or individual. The field evaluations will be based on the evaluation plan and field evaluation checklist. The checklist will be made available to all parties associated with NLA.

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One or more designated EPA, state, or contractor staff members who are qualified in the procedures of the NLA 2022 field sampling operations will visit trained state, tribal, contractor, and EPA field sampling crews during sampling operations on site. If membership of a field crew changes, and at least two of the members have not been evaluated previously, the field crew must be evaluated again during sampling operations as soon as possible to ensure that all members of the field crew understand and can perform the procedures.

The purpose of this on-site visit will be to identify and correct deficiencies during field sampling operations. The process will involve the following preparation steps and field day activities .Additionally, conference calls with crews may be held approximately every two weeks to discuss issues and clarifications as they come up throughout the sampling season.

9.2.2 Preparation Activities

1. Each Field Crew Evaluator will schedule an assistance visit with their designated crews in consultation with the QA Officer, Regional NLA Coordinator, and respective Field Sampling Crew Leader. **Evaluators should be prepared to spend additional time in the field if needed (see below).** Ideally, each Field Crew will be evaluated within the first two weeks of beginning sampling operations, so that procedures can be corrected or additional training provided, if needed.
2. Each Field Crew Evaluator will ensure that field crews are aware of their visit plans and all capacity and safety equipment will be provided for the Field Crew Evaluator.
3. Each Field Crew Evaluator will need to bring along the following in Table 9-1.

Table 9-1 Equipment and supplies – field evaluation and assistance visits.

Type	Item	Quantity
Form	Field Evaluation and Assistance Visit Checklist (sent from EPA)	1
Documentation	NLA 2022 Field Operations Manual	1
	NLA 2022 Quality Assurance Project Plan	1
	Clipboard	1
	Pencils (#2, for data forms)/Pen	1
	Field notebook (optional)	1
Gear	Field gear (e.g., protective clothing, sunscreen, insect repellent, hat, water, food, backpack, cell phone)	As needed

9.2.3 Field Day Activities

1. The Field Crew Evaluator will review the Field Evaluation and Assistance Visit Checklist with each crew during the field sampling day and establish and plan and schedule for their evaluation activities for the day.
2. The Field Crew Evaluator will view the performance of a field crew through one complete set of sampling activities as detailed on the checklist.
    - Scheduling might necessitate starting the evaluation midway on the list of tasks at a site, instead of at the beginning. In that case, the Field Crew Evaluator will follow the crew to the next site to complete the evaluation of the first activities on the list.

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- If the field crew misses or incorrectly performs a procedure, the Field Crew Evaluator will note this on the checklist and *immediately point this out so the mistake can be corrected on the spot*. The role of the Field Crew Evaluator is to provide additional training and guidance so that the procedures are being performed consistently with the FOM, all data are recorded correctly, and paperwork is properly completed at the site.

3. When the sampling operation has been completed, the Field Crew Evaluator will review the results of the evaluation with the field crew before leaving the site (if practicable), noting positive practices and problems (i.e., weaknesses [might affect data quality]; deficiencies [would adversely affect data quality]). The Field Crew Evaluator will ensure that the field crew understands the findings and will be able to perform the procedures properly in the future.
    - The Field Crew Evaluator will review the list and record responses or concerns from the field crew, if any; on the checklist (this may happen throughout the field day).
    - The Field Crew Leader will sign the checklist after this review.

9.2.4 Post Field Day Activities

1. The Field Crew Evaluator will review the checklist that evening and provide a summary of findings, including lessons learned and concerns.
    - If the Field Crew Evaluator finds major deficiencies in the field crew operations (e.g., less than two members, equipment, or performance problems) the Field Crew Evaluator must contact the EPA NLA 2022 Project Lead. The EPA NLA 2022 Project Lead will contact the EPA Technical Lead for the Human Health Fish Fillet Contaminants Indicator in OST and the EPA NARS QA Project Officer to determine the appropriate course of action.
2. The Field Crew Evaluator will retain a copy of the checklist and submit to the NLA logistics lead.
3. The EPA NLA 2022 Project Lead and EPA NARS QA Project Officer or authorized designee will review the returned Field Evaluation and Assistance Visit Checklist, note any issues, and check off the completion of the evaluation for each field crew.

9.2.5 Summary

Table 9-2 summarizes the plan, checklist, and corrective action procedures.

Table 9-2 Summary of field evaluation and assistance visit information.

Field Evaluation Plan	The Field Crew Evaluator: • Arranges the field evaluation visit in consultation with the QA Officer, Regional NLA Coordinator, and respective Field Sampling Crew Leader, ideally within the first two weeks of sampling • Observes the performance of a crew through one complete set of sampling activities • Takes note of errors the field crew makes on the checklist and immediately point these out to correct the mistake • Reviews the results of the evaluation with the field crew before leaving the site, noting positive practices, lessons learned, and any concerns
Field Evaluation Checklist	The Field Crew Evaluator: • Observes all pre-sampling activities and verifies that equipment is properly calibrated and in good working order, and protocols are followed • Checks the sample containers to verify that they are the correct type and size, and checks the labels to be sure they are correctly and completely filled out

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	• Confirms that the field crew has followed NLA protocols for locating the lake and determining the index site on the lake • Observes the index site sampling, confirming that all protocols are followed • Observes the littoral sampling and habitat characterization, confirming that all protocols are followed • Records responses or concerns, if any, on the Field Evaluation and Assistance Checklist
Corrective Action Procedures	• If the Field Crew Evaluator's findings indicate that the Field Crew is not performing the procedures correctly, safely, or thoroughly, the Evaluator must continue working with this Field Crew until certain of the crew's ability to conduct the sampling properly so that data quality is not adversely affected. • If the Field Crew Evaluator finds major deficiencies in the Field Crew operations the Evaluator must contact the EPA NLA 2022 Project Lead who, in turn, must contact the EPA Technical Lead for the Human Health Fish Fillet Contaminants indicator if any of the major deficiencies relate to this indicator.

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10.0 EPA Regional and Contracted Crews Only: Endangered Species Act Conservation Measures

A generally applicable element of all NLA sampling is that field crews make every effort not to disrupt nontarget habitats. NLA protocols are specifically designed to sample target lakes, ponds and reservoirs and to avoid non-target habitats (e.g., rivers, marine, riparian, and wetlands). This section identifies conservation and mitigations measures that are to be performed by EPA regional and contracted crews (EPA crews) at all sites where federally listed species under the Endangered Species Act (ESA) are possible, as appropriate. Before sampling or accessing an NLA site, EPA field crews will receive a list of their sites screened for ESA-listed species possible at the sites. Crews will use this information to familiarize themselves with the ESA species and to implement appropriate conservation measures. Any additional ESA documentation used to supplement the EPA provided ESA information, such as contact between the crew and local U.S. Fish and Wildlife Service office ("FWS" or "Service"), will be retained and provided electronically to the NLA ESA lead periodically throughout the field season.

The below mitigations are not an exhaustive list of requirements for EPA crews. Crews are expected to implement any additional conservation measures required by local permit. Crews should also be aware of any relevant and reasonable state conservation measures, these may be completed at the discretion of the crew lead. Field crew leads are expected to be cognizant of the federally listed species, listed species critical habitats, and state species of concern that have the potential to occur at or near a given sampling site, including habitats that will be used to access the sampling site. They are responsible for making their crew members aware of potential occurrences of listed species and their critical habitat. Efforts should be made to minimize risks to listed species and their critical habitats and avoid the take of listed species while implementing the NLA field protocols. For sites without ESA listed species possible, the following mitigations are not required.

10.1 Always Applicable

- Crews refrain from intentionally targeting known ESA species in any way (handling, harassing, feeding etc.).
- If a known or suspected ESA-listed species is accidently encountered while sampling, it will be returned as quickly as possible to the appropriate habitat and away from further sampling pressures.
- Any samples taken as part of the NLA survey protocol will be inspected carefully for the presence of ESA organisms or other resources from listed taxa groups that could be associated with collecting a non-listed species (such as glochidia on fish gills on a collected sample). Any samples collected must be carefully inspected for their presence and, if found, removed prior to sample preservation.
- Crews will wait to allow a listed species to naturally move away from the sampling area (do not herd or harass).
- All encounters with any ESA species are to be recorded in the **Federal ESA** form in the NLA App, which documents the species, number of individuals, the encounter type, and the disposition of the individual after the encounter.

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10.2 When Entering or Leaving a Site and Shorline Activities

- Be aware of the habitat requirements for each life cycle stage and avoid unnecessary activity within that habitat. Crews are to limit damaging ESA species habitat when accessing or working a site.
    - Whenever available crews will use existing roads, pathways, or trails to the sampling site for activities including transporting equipment and boats. Crews will adhere to a "stay on trail" rule and refrain from roaming from designated pathways. If a trail is not available, crews will attempt to navigate to and from the site on durable surfaces which can tolerate repeated trampling. If no areas can be found that would tolerate repeated trampling without notable impacts, then crews are to walk in a single file line to and from the site whenever possible.
- When walking through or at a site, avoid stepping on vegetation mounds or holes which may contain listed reptiles, nests, or burrowing species. Whenever possible, avoid areas where listed species are congregating.
- Crews will utilize public boat docks whenever possible. Private boat docks can also be used with owner permission.
- Before putting a vessel or sampling equipment in the water, visually investigate the area for ESA species and avoid areas where observed ESA are present.
- Special Consideration: Shoreline, burrowing and sub-surface nesting ESA species possible
    - Piping Plover and other listed birds which utilize ground nesting in sandy areas: in addition to the applicable species-specific mitigations listed in FWS documentations, crews are to avoid traversing across a beach or sandy area if such species may be present. If an area is cordoned off, crews are not to enter a closed area.
    - When walking through or at a site, avoid stepping on vegetation mounds or holes which may contain listed reptiles, nests, or burrowing species (see below for more information).

10.3 Index Site Activities

Listed species that may be encountered are fish, birds, mammals, invertebrates, amphibians, and reptiles.

- Prior to introducing any equipment that disturbs the water column or aquatic habitat, the area should be carefully inspected for the presence of listed species. Avoid collecting or disturbing listed species.

10.4 Littoral Activities

Listed species that may be encountered are fish, freshwater mussels (Unionidae and Margaritiferidae), birds, mammals, invertebrates, amphibians, and reptiles.

- Prior to introducing any equipment that disturbs the water column or aquatic habitat, the area should be carefully inspected for the presence of listed species. Avoid collecting or disturbing listed species.
- Follow all freshwater mussel handling and documentation protocols in Section 6.4.

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10.5 Lake Wide Activites: Fish Sample Collection

10.5.1 Sites with ESA fish possible

- When identifying a suspected fish ESA-listed species, each individual of the species is to be kept in their own bucket of fresh water. The water in the bucket is to be obtained from the collection site. The species will only be kept in the bucket for the time it takes to quickly and urgently identify that species and to provide recovery time as needed. During identification, each individual may not be continually handled for more than 1-minutes.
- Crews must not perform active electrofishing for longer than 3 hours.
    - If performing fish sampling at sites where Bull Trout (*Salvelinus confluentus*) are possible, no electrofishing is allowed.
- No gillnetting, trawling, or seining are allowed.
- All other allowable fishing methods should not exceed 4 hours.
- Crews will not perform fishing methods before sunrise or after sunset at sites where encounters with ESA-listed species are possible.
- Crews are to return any ESA-listed fish back into the lake (alive) as quickly as feasible. No ESA fish may be kept for collection.

10.5.2 Sites with ESA freshwater mussles possible (indirect impacts to lake habitat-based bivalves' host fishes)

- Crews must not perform active electrofishing for longer than 3 hours.
- No gillnetting, trawling, or seining are allowed.
- All other allowable fishing methods should not exceed 4 hours.
- Any collected target fish must be inspected for glochidia. If glochidia are found, the fish must be returned alive to the site away from further sampling pressures. All fish with glochidia must be reported in the **Federal ESA** form the app.
    - If glochidia on gills are found, crews are to be very aware of the likelihood of mussels present and make sure to properly execute the mussel conservation methods.

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11.0 LITERATURE CITED

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APPENDIX A: EQUIPMENT & SUPPLIES

Base Kit

A Base Kit will be provided to the field crews for all sampling sites that they will go to. Some items are sent in the base kit as extra supplies to be used as needed.

Base Kit Item	Quantity	Protocol
Centrifuge tube (50 mL, screw top) - extras	2	Chlorophyll-*a*
Centrifuge tube stand	1	Enterococci, Chlorophyll-*a*
Electrical tape*	2	General
Filter forceps (flat blade) - extras	6	Enterococci, Chlorophyll-*a*
Filters - Millipore 47mm polycarbonate 0.4 µ (Box of 50)	1	Enterococci
Filters - Whatman 0.7 µm GF/F glass fiber (box of 100)	1	Chlorophyll-*a*
Filtration chamber (with filter holder) - extras	5	Enterococci, Chlorophyll-*a*
Filtration chamber adapter	3	Enterococci, Chlorophyll-*a*
Filtration flask (side arm, 500 mL)	1	Enterococci, Chlorophyll-*a*
Filtration pump (hand vacuum)	1	Enterococci, Chlorophyll-*a*
Filtration flask stopper (silicone)	2	Enterococci, Chlorophyll-*a*
Foil squares (package of 25)*	1	Chlorophyll-*a*
Funnel	1	Water samples Zooplankton Benthics
Gloves (latex/nitrile, non-powdered, box of 100)	1	General
Graduated cylinder (250 mL)	1	Chlorophyll-*a*
HDPE bottle (1 L, white, wide-mouth) – extras	6	Benthics
HDPE bottle (125 mL, white, wide-mouth) – extras	6	Zooplankton
Littoral eDNA collection bottle (125 mL, clear, square) - extras	3	Littoral eDNA collection
Integrated water sampler device (MPCA design)†	1	Water Samples
Kick net (500 µm D-shaped, modified) with 4 foot handle†	1	Benthics
Lugol's solution (250 mL bottle)	1	Phytoplankton
Metric tape measure (8 meter)	1	Secchi Physical Habitat
Microcentrifuge tubes (extras)	5	Enterococci
Packing tape (extra rolls)*	2	General
Packing tape (on holder)*	1	General
Pail (narcotizing/concentrating chamber)	2	Zooplankton
Petri dishes (60x15, disposable)	20	Enterococci
Plankton net course (150 µm; 30 cm diameter net with a 20 cm reducing collar)	1	Zooplankton

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Base Kit Item	Quantity	Protocol
Plankton net fine (50 µm; 30 cm diameter net with a 20 cm reducing collar)	1	Zooplankton
Plankton net carry case for 2 nets	1	Zooplankton
Plastic tranfer pipette for Lugol's	5	Phytoplankton
Poly bottle (2 L, brown)	1	Chlorophyll-*a*
Rubbermaid action packer	1	General
Secchi disk (20 cm diameter) with weight†	1	Secchi
Sieve bucket (500 µm)†	1	Benthics
Small tote with lid	1	General
Sodium Thiosulfate (25 tablets in vial)	1	Enterococci
Sounding line (50 m, marked in 0.5 m intervals) with clip	1	Depth Secchi Zooplankton
Sounding rod (3 m , marked in 0.1 m increments, PVC, 2-section)†	1	Index Site Depth Physical Habitat
Sounding weight with clip	1	Depth
Spoon (stainless steel)	1	Benthics
Squirt bottle (1 L Nalgene) – for de-ionized (DI) water	1	General
Squirt bottle (1 L Nalgene) – for lake water	1	General
Surveyor's tape (50m)†	1	Depth Physical Habitat
Tape strips (3M, pad of 25)*	6	General
Watchmaker's forceps	1	Benthics

*Items may need to be replenished by field crews during field season
† Item supplied if needed

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Site Kit

A Site Kit will be provided upon request to the field crews for each sampling site. Please submit an electronic **Request** form well in advance of field sampling to request the Site Kits. Each site kit will also include necessary coolers and shipping supplies for all samples collected.

Site Kit Item	Quantity Per Site Kit	Protocol(s)
Centrifuge tube (50 mL, screw top) in bag	1	Chlorophyll-*a*
CO2 (Alka seltzer) tablets (packet of 2)	1	Zooplankton
Cooler liners (1 per cooler)	-	General
Cubitainer® (4L)	1	Water Chemistry
FedEx Express shipping labels (1 per cooler)	-	Sample shipping
Gloves (latex/nitrile, non-powdered)	4 pair	Sample collection
Filtration unit (sterile 250 mL filter funnel, cap, and filter holder)	1	Enterococci Chlorophyll-*a*
Filter forceps (sterile, flat blade)	2	Enterococci Chlorophyll-a
HDPE bottle (1 L, white, narrow mouth)	1	Phytoplankton
HDPE bottle (60 mL, white, wide-mouth)	1	Atrazine
HDPE bottle (125 mL, white, wide-mouth)	2	Zooplankton
HDPE bottle (1 L, white, wide-mouth)	2	Benthics
Littoral eDNA collection bottle (125 mL, clear, square)	1	Littoral eDNA collection
Enterococci bottle (250 mL, sterile, clear, narrow-mouth)	1	Enterococci collection
HDPE bottle (500 mL, white, wide-mouth)	1	Algal Toxins (MICZ)
eDNA bottle (1 L, clear, square, narrow-mouth)	2	eDNA (Index and Littoral)
Phosphate buffered saline (sterile PBS)	1	Enterococci
Microcentrifuge tubes w/glass beads (in bubble & Zip bags)	2	Enterococci

Human Health Fish Sampling Kit

A **human health fish sampling kit** will be provided to the field crews for designated human health fish sampling sites (separately from site kits). Please submit an electronic **Request** form **well in advance** of field sampling. Kits must be requested at least two weeks before sampling is to take place. Prior to sampling, inspect each site kit to ensure all supplies are included. These human health fish sampling kits include:

Human Health Fish Sampling Kit Item	Quantity
Aluminum foil (solvent-rinsed and oven dried)	5 packs
Cable ties	24
Cooler	1
Dry ice Shipping Label	1
FedEx airbill (Pre-addressed)	1
Frequently Asked Questions handout	1
Heavy-duty food grade polyethylene tubing	1 roll
Large plastic composite bag	1
Nitrile gloves	10
NLA 2022 Human Health Fish Fillet Contaminants Site List	1
Tyvek tag	1

Electronic Forms & Labels

Apple iPads Labels will be supplied by the NARS IM Center upon request.

Item	Quantity	Protocol
Apple iPads: Field forms packet (paper backup copies as needed): NLA 2022 Verification NLA 2022 Profile Calibration NLA 2022 Profile Data NLA 2022 Index Samples NLA 2022 Littoral Samples NLA 2022 Physical Habitat NLA 2022 Assessment NLA 2022 Tracking NLA 2022 Whole Fish Sample NLA 2022 Federal ESA	2 1	General General
Labels packet (for samples)	1	General

Field Crew Supplied Equipment

This equipment will need to be supplied by the field crew. Some items are optional.

Field Crew Supplied Item	Quantity	Protocol(s)
Access instructions	1	Site Evaluation
Access permission documents/permit (if required)	1	Site Evaluation
Barometer or elevation chart to use for calibration	1	Calibration
Binoculars	1	Physical Habitat
Bleach (or bleach alternative)	1	General
Buckets (5 gallon capacity, plastic)	2	Benthic Macroinvertebrates
Buoy (for marking observation point)	1	Physical Habitat
Calibration cups and standards (for multi-parameter meter)	1	Calibration
Calibration QC check solution (for multi parameter meter, pH and conductivity)	1	Calibration
Clinometer	1	Physical Habitat
Clipboard	1	General
Depth Finder (hand-held or boat mounted sonar)	1	Index Site Profile Physical Habitat
Electronic data capture devices (tablet/phone/computer) with NARS App and extra battery pack (if needed)	1-2 (optional)	General
Ethanol (95%)		Benthic Macroinvertebrates Zooplankton
Field gear (e.g., protective clothing, sunscreen, insect repellent, hat, water, food, backpack, cell phone)		General
Field notebook - optional	1	General

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Field Crew Supplied Item	Quantity	Protocol(s)
Field thermometer (not mercury)	1	Calibration
Fishing gear (e.g., electrofishing unit, fishing rods, nets, livewell and/or buckets, measuring board etc.)		Whole Fish Sample
GPS unit (with manual, reference card, extra battery)	1	Lake Verification Index Site Coordinates Physical Habitat
Kick net (500 µm D-shaped) with 4 foot handle (spare)	1	Benthic Macroinvertebrates
Laser rangefinder (for estimating drawdown) - optional	1	Physical Habitat
Map wheel or string (for measuring shoreline distances on site map)	1	Physical Habitat
Multi-parameter water quality meter (with temperature, pH, and DO probes)	1	Index Site Profile
Multi-parameter communication cable (50 m)	1	Index Site Profile
Net(s) and/or bucket assembly for end of net (spares)	1	Zooplankton
NLA 2022 Fact Sheets	20	General
Pen	1	General
Pencils (#2, for data forms)	2	General
Permanent marker (fine tip, for labels)	2	General
Scissors	1	General
Shipping tape	1	Shipping
Surveyors rod - optional	1	Physical Habitat
Water (deionized)		General

Boat Equipment List

This is suggested boat equipment.

Item
Anchor (with 75 m line or sufficient to anchor in 50 m depth)
Boat horn
Boat plug (extra)
Bow/stern lights
Emergency tool kit
Fire extinguisher
First aid kit
Gas Can
Hand bilge pump
Life jackets
Motor
Oars or paddles
Second anchor for windy conditions and littoral sampling (w/ 75m line)
Sonar unit

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Spare prop shear pin
Type IV PFD (throwable life saving device)

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APPENDIX B: SHIPPING GUIDELINES

General Shipping Guidelines

Samples will be shipped by the field crews according to the chart below. The Field Crew Leader will complete the appropriate section(s) of the **Tracking** form for the samples and will submit tracking via the NLA App. The Field Crew Leader will place the samples and the packing slip (in a waterproof bag or plastic sleeve) in the shipment cooler, and then the Field Crew Leader will attach the appropriate pre-addressed FedEx label from the site kit or cooler marked for the appropriate lab. The field crew will either drop off the cooler for shipment at a local FedEx location or arrange for a pick up at the hotel or other appropriate facility. If the field crew has chosen a pick up, they must follow up with the facility at which it has been left and/or track the package through FedEx tracking tools to ensure that the shipment cooler has actually been picked up by FedEx. Once the package is in the possession of FedEx, the IM Team and Field Logistics Coordinator (FLC) will track the package to its destination and take steps necessary to ensure timely delivery.

A packing slip must be filled out to accompany each sample shipment. Be very careful to fill in the information correctly and legibly, especially the Site ID. When using a packing slip that was paired with a sample label sheet, the Sample ID numbers will be pre-printed on the packing slips. The packing slip is to be placed in a resealable plastic bag/pouch secured to the inside of the cooler lid. Seal the shipping container with clear packing tape. In the NLA App, fill in the shipping details in the pertinent section(s) of the **Tracking** form and submit the **Tracking** form to the NARS IM Center to indicate that samples will be in transit to the laboratory. The **Tracking** form must be submitted the same day that the samples are shipped.

Before shipping, it is very important to preserve each sample as directed in the sample collection portion of the appropriate chapter in the NLA 2022 FOM. General directions for sample processing, shipping and tracking are found below:

- Preserve the samples as specified for each indicator before shipping.
- Be aware of the holding times for each type of sample.
- Always line the cooler with a heavy duty plastic bag (cooler liner) when shipping preserved samples or when shipping wet ice.
- When shipping frozen batched samples, use the foil-backed dry ice liner and foam pad inside the cooler.
- When shipping with dry ice, it’s best to layer or intermix dry ice and samples to increase the contact between samples and dry ice.
- When shipping samples preserved with ethanol, surround the jars with crumpled newspaper or other absorbent material.

When wet ice is used for shipment:

- Ensure that the ice is fresh before shipment and use adequate amounts of ice to ensure samples will remain cold for up to 48 hours.
- Place samples and all ice inside the cooler liner and seal the cooler liner to avoid leakage of melted ice.

- Secure the cooler with clear packing tape.

When dry ice is used for shipment:

Note: Not all FedEx locations will accept shipments containing dry ice. Dry ice shipments can be shipped from "FedEx staffed" locations, which is how these locations are referred to online. You can also arrange for a pick-up from your lab or hotel. Dry ice shipments usually cannot be shipped from FedEx Office® locations, FedEx Retail locations such as Walgreens/Walmart/OfficeMax, or at FedEx Authorized ShipCenter® locations. These types of locations are differentiated on FedEx.com in the "Find FedEx Locations" feature. Please be sure to call in advance to ensure your location will accept the package for shipment.

- Label the cooler with a Class 9 Dangerous Goods label
    - Place the label on the front side of the cooler, not the top.
    - If it is not already completed, fill out the upper corners of the label with the shipper and recipient information as on the FedEx airbill.
    - Declare the weight (in kg) of the dry ice in the lower right hand corner of the label, ensuring it is the same weight listed on the airbill.
- Ensure that the dry ice is fresh before shipment, and use adequate amounts of dry ice to ensure samples will remain frozen for up to 48 hours.
- Secure the cooler with clear packing tape. Do not completely seal the entire edge of the cooler such that the pressure inside the cooler could build.
- Place the provided FedEx airbill on the top of the cooler or on a handle tag secured to one of the cooler's handles.
    - Ensure the label indicates the amount of dry ice in the package and matches the weight listed on the dry ice label.

Tracking Forms and Shipment Types

Whenever NLA samples are shipped, one or more sections of the **Tracking** form is completed to relay important shipping information to the IM Team, FLC and the destination lab. The **Tracking** form is submitted electronically at the time of shipping and a packing slip is included as a hard copy in the shipping container with the samples.

Each section for the **Tracking** form has been assigned a "T" number to help crews identify the correct section of the form to use when sending samples. This "T" number is located on the top of each tracking form section). Crews will also find reference to the same "T" numbers on the individual sample labels and on the top of the pre-printed FedEx return labels provided in the site kits or with batch coolers. The FedEx return labels are pre-paid and allow crews to ship samples to any of the nationally contracted laboratories. States using their own labs for certain samples will need to arrange for shipping on their own.

When crews order site kits (via the **Request** form), a set of packing slips will accompany each set of labels in the site kit. Sample IDs for the suite of samples collected at a single site will be pre-populated

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on both the labels and the packing slips. By entering the water chemistry sample ID in the **Tracking** form, the rest of the sample IDs will auto-populate in the **Tracking** form. It is important to keep the labels and packing slips organized so the sample IDs will match when shipping occurs.

Crews include the pertinent packing(s) slip in the cooler (placed in the plastic sleeve affixed to the inside of the cooler lid) when they send samples to the labs, and they also must submit the completed section of the **Tracking** form that is associated with that sample shipment via the NLA App. If a cooler contains samples from more than one site, then multiple packing slips must be placed in the cooler and the **Tracking** form for each site must be submitted.

When a crew visits a site with the intent to sample, they complete and submit the **Verification** form via the NLA App. It is very important to submit this form as soon as possible after every attempted sampling event to provide key items such as the date of the event, the crew ID, and whether the site wa ssampled. Prompt status reports allow the FLC to closely track sampling progress. More importantly, it enables NARS IM to track samples that were collected at each successfully sampled site versus those that were not, and to immediately track the shipment of the time-sensitive samples after each sampling event. Submitting the **Verification** form is crucial to report the date of a completed sampling event and must be submitted (along with sample tracking information) on the same day that samples are shipped.

Procedure for filling out and submitting tracking via the App

1. After ensuring all of the samples to be shipped are properly preserved and prepared for shipment, access the **Tracking** form in the App.
2. Ensure the correct water chemistry sample ID has been entered at the top of the form. Doing so will populate the sample IDs of all other collected samples. Samples that were not collected will display a blank sample ID field and the not collected bubble will be transferred from the individual sample collection forms. The not collected bubbles are not editable in the **Tracking** form; to change the collection status of a sample, access the pertinent sample collection forms (e.g., Index Samples, Littoral Samples, and/or Whole Fish Sample forms).
3. In the pertinent section of the **Tracking** form , check the box under the 'To Ship' column for each sample being sent in the shipment.
4. Click the 'Enter Shipping Details' button and fill out the resulting popup window with the destination lab, date shipped, tracking number, sender and sender's phone number.
5. Click the 'save shipping info' button to save the details and the **Tracking** form .
6. Once the shipping details have been saved in the App, a date will appear in the shipped column of the **Tracking** form . If the shipping details for a sample need to be edited, click the date in the shipped column to access the saved shipping details. Editing the details in this manner changes ONLY one sample at a time. The only way to enter shipping details for an entire group of samples is during the initial details entry.
    a. If the status of the sample needs to change from shipped to **not** shipped, click the date in the shipped column to access the saved shipping details and delete all the shipping info. Click the "save shipping info" button after deleting all the shipping information.

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The sample will no longer be marked as shipped and the "to ship" checkbox will reappear.

7. After all pertinent shipping details have been saved, click the SUBMIT menu button and select the button next to 'Tracking' and any other the forms that you wish to submit. Click the green submit button at the bottom of the form list. An email will pop up on your device addressed to NARSFieldData@epa.gov. Copy yourself, any other crew members or managers and click send. To ensure that he email was sent, check the SENT mailbox on your email app and look for the recent email containing the data. If the email is not in the SENT mailbox, it was not sent and you should try again after verifying an internet connection.
8. At any point, if it is determined that data needs to be revised or updated, crews should feel free to do so in the App and re-submit any edited data or tracking forms using the steps above. Newly revised data will automatically take the place of previous data. It is not necessary to re-submit data or tracking forms that were unchanged however.
9. After submission, a data summary will be automatically emailed back to the email address from which the submission was received. The Field Crew Leader or his/her designee should review this data summary for accuracy and make any corrections necessary and re-submit the pertinent form(s).

Shipping Groups:

T-1 – Daily Water Chemistry Samples

- Complete the T-1 section of the **Tracking** form for the samples that are shipped immediately after each sampling event (e.g., same day as sampling or the next day):
  - water chemistry
  - chlorophyll-*a*
- These samples are shipped together in the site kit cooler with a heavy duty liner bag and ample wet ice.
- Samples from two sites may be shipped together in a single cooler if they were collected on the same day.
- Send the **Tracking** form and all data forms from the site to the IM Team via the NLA App.
- Ship all of the samples to the lab in the same cooler with the packing slip that was provided with the label packet. If any sample listed on the packing slip is not being shipped, line out the sample ID to indicate that the sample is not in the cooler. If samples from multiple sites are shipped together, then multiple packing slips must be used.
- Samples need to be shipped on as much fresh wet ice as will fit in the cooler liner. Water chemistry and chlorophyll-*a,* samples should be shipped within 24 hours of collection (i.e., the same day as sampling or the following day).

T-2 – Frozen Batched Samples

- Complete this section of the **Tracking** form when shipping the frozen batched samples:
  - Enterococci (frozen)
  - eDNA (index and littoral; frozen)

- algal toxins (frozen)
- atrazine (chilled)

- These samples are shipped together in a cooler (ordered via the **Request** form) with a two-piece dry ice liner and 20 pounds of dry ice.
- 2-3 site's worth of samples may be shipped together in a single cooler.
- Ship all of the samples to the lab in the same cooler with the packing slip that was provided with the label packet. If any sample listed on the packing slip is not being shipped, line out the sample ID to indicate that the sample is not in the cooler. If samples from multiple sites are shipped together, then multiple packing slips must be used.
- To pack the T2 cooler:
    1. Place the foam pad in the bottom of the T2 cooler and line the cooler with the foil-backed dry ice liner.
    2. Place frozen samples from up to three sites and dry ice (approximately 20 lbs) inside the dry ice liner, intermixing samples and dry ice.
    3. Please the enterococci samples on top of the frozen bottles to prevent damage during shipping.
    4. Place the foil-backed separator pad on top of the frozen samples and dry ice creating a thermal barrier within the cooler.
    5. Place the chilled atrazine samples (up to 3) inside the atrazine sleeve and insert the foam plug into the end of the sleeve.
    6. Place the sleeve ON TOP of the second foam pad inside the dry ice liner (such that the foam pad is used as a separator between the dry ice and the atrazine samples).
    7. Close the "lid" portion of the dry ice liner.
    8. Insert the T2 packing slip(s) into the provided pouch inside the cooler lid.
    9. Close the cooler lid, taping and applying FedEx shipping label as usual.
- Frozen batched samples should be shipped at least every week.
- In cases where a state lab is processing some, but not all of the samples, first select “To Ship” checkboxes for the samples being sent to the national lab and select the appropriate lab in the shipping details popup window. The T-2 packing slip should be placed in the cooler being shipped to the national lab and should only indicate the sample(s) being shipped in that cooler. Line out the sample IDs to indicate which samples are not in the cooler. Select “To Ship” checkboxes for the remaining samples being sent to the state lab and select the appropriate lab in the shipping details popup window.
- Verify the sample IDs for the sample(s) being shipped.
- Submit the **Tracking** form to NARS IM in the NLA App using the steps above.

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T-3 – Non-Chilled Batched Samples

- Complete this section of the **Tracking** form for shipping batches of non-chilled samples:
  - Benthic macroinvertebrates
  - Zooplankton (course and fine)
  - Phytoplankton
- These samples are shipped together in a cooler (ordered via the **Request** form) with a heavy duty liner bag and no ice.
- The number of samples that will fit in a cooler will depend largely on the number of benthos bottles collected from each site. In most cases, samples from three to six site visits will fit in a cooler together. NEVER split samples from one site into more than one cooler.
- Ship all of the samples to the lab in the same cooler with the packing slip that was provided with the label packet. If samples from multiple sites are shipped together, then multiple packing slips must be used.
- Place 1-liter benthos bottles upright in the lined cooler and use newspaper or cardboard to fill any empty space between benthos bottles to keep them in an upright position during shipping.
- Place bagged zooplankton bottles on top of the upright benthos bottles.
- Non-chilled batched shipped samples should be shipped within two weeks of collection.
- In cases where a state lab is processing some, but not all of the samples, first select “To Ship” checkboxes for the samples being sent to the national lab and select the appropriate lab in the shipping details popup window. The T-3 packing slip should be placed in the cooler being shipped to the national lab and should only indicate the sample(s) being shipped in that cooler. Line out the sample IDs to indicate which samples are not in the cooler. Select “To Ship” checkboxes for the remaining samples being sent to the state lab and select the appropriate lab in the shipping details popup window.
- Verify the sample IDs for the sample(s) being shipped.
- Submit the **Tracking** form to NARS IM in the NLA App using the steps above.

***NOTE**: Federal regulations and FedEx rules allow for ground shipping of certain quantities of flammable liquids WITHOUT the need for special certifications and labeling. Flammable liquids may NOT be shipped via air carrier unless shipper is trained and qualified to do so and specific documentation and labeling requirements are met.*

The Code of Federal Regulations (49 CFR Section 173.150) lists the exceptions which allow shipping of flammable liquids via ground carrier without labeling or special certifications. Ethanol and formalin can be considered to be in either Packaging Group 2 or 3, so we use the more stringent PG 2 as our guideline. The limited quantity exclusion allows ground shipping of PG 2 flammable liquids provided that the individual containers inside the package are not over 1.0 liters each, that the gross weight of the package does not exceed 66 pounds, and that the outer packaging is a sturdy container. Please ensure that your shipment meets these criteria to ensure the legal ground shipment of these samples.

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1T4 – Whole Fish Composite Sample – *designated sites only*

- Complete this section of the App tracking form for shipping frozen whole fish tissue samples (FTIS).
- Only one fish composite sample may be shipped in a single cooler.
- Ship the sample to the lab in the whole fish tissue kit cooler with the packing slip that was provided with the label packet.
- Samples need to be shipped with a minimum of 50 pounds of dry ice (blocks of dry ice only).
- Human health fish composite samples should be shipped within 1 week of collection.
- Verify the sample ID for the sample being shipped.
- Submit the **Tracking** form to NARS IM in the NLA App using the steps above.

Shipping Addresses

USEPA Laboratory, Corvallis, Oregon (Water Chemistry, Chlorophyll-*a*)
Attn: Judy Greydanus, CSS
c/o U.S. EPA
Willamette Research Station
3080 SE Clearwater Dr.
Corvallis, OR 97333

Microbac Laboratories, Inc. (Whole Fish Composite Samples)
Attn: Sample Receiving
2101 Van Deman Street
Baltimore, MD 21224

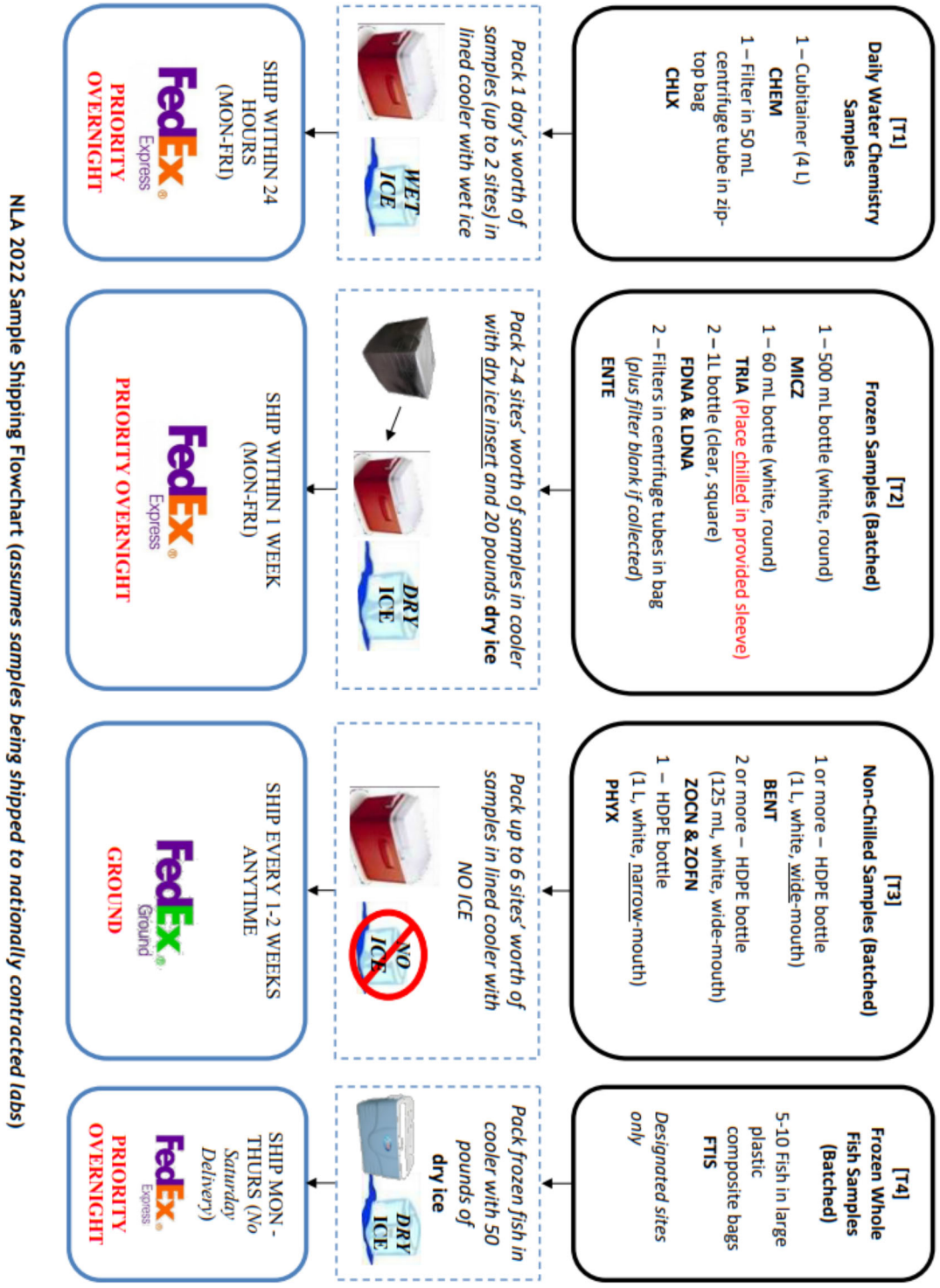
Great Lakes Environmental Center, Inc. (All other samples)
Attn: Mike Dunlop
739 Hastings Street
Traverse City, MI 49686

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Table B-1. Sample preservation, packaging, and holding times

Sample Group & Lab	Sample Type	Sample Code	Location	Sample Target Volume	Container	Preparation/ Preservation	Shipping Time Frame	Packaging for Shipping
T-1 – Daily Water Chemistry Samples **WRS Laboratory - Corvallis, OR**	Water chemistry (raw, unfiltered site water)	CHEM	Index	4 L	Cubitainer (4 L)	Wet ice in field	Immediate (ship within 24 hours of sampling)	**Water Chemistry Cooler** with wet ice PRIORITY OVERNIGHT
	Chlorophyll-*a*	CHLX	Index Collection	2 L	Poly bottle (2 L, brown)	Wet ice in field		
			Processing	Stain on filter – max 2 L filtration	centrifuge tube (50 mL), in zip-top bag	Wet ice in field (after filtration)		
T2 – Frozen Batched Samples **GLEC – Traverse City, MI**	Fecal indicator (*Enterococci*)	ENTE	Last habitat station *	200 mL	Sterile 250 mL bottle (clear, square)	Dry Ice	Batch up to one week maximum	**Frozen Batched Cooler** with 2-piece dry ice liner and 20 pounds dry ice PRIORITY OVERNIGHT
	eDNA	FDNA	Index	1 L	Clear square bottle (1 L)	Wet ice in field, freeze ASAP		
		LDNA	Littoral Stations (10) *	1 L	Clear square bottle (1 L)	Wet ice in field, freeze ASAP		
	Algal toxins	MICZ	Index	500 mL	HDPE bottle (500 mL, white, wide-mouth)	Wet ice in field, freeze ASAP		
	Atrazine	TRIA	Index	50 mL	HDPE bottle (60 mL, white, wide-mouth)	Wet ice in field, keep chilled Place chilled in provided sleeve		
T3 – Non-Chilled Batched Samples **GLEC – Traverse City, MI**	Phytoplankton	PHYX	Index	1 L	HDPE bottle (1 L, white narrow mouth)	Lugol's added in field Wet ice in field	Batch up to two weeks maximum	**Non-Chilled Batched Cooler** with absorbent material No Ice GROUND
	Zooplankton (coarse – 150 µm) (fine – 50 µm	ZOCN ZOFN	Index	Vertical tow(s) 5-meter total length	HDPE bottle (125 mL, white, wide-mouth)	95% ethanol added in field		
	Benthic invertebrates	BENT	Littoral Stations (10+) *	All organisms in grabs	HDPE bottle (1 L, white, wide-mouth)	95% ethanol added in field (at least 500 mL per bottle)		
T4 - Whole Fish Composite Sample **Microbac Laboratories, Inc. – Baltimore, MD**	Whole fish	FTIS	Lakewide	5-10 whole fish (minimum fish length 190 mm)	Wrapped individually in solvent rinsed foil Sealed in poly tubing Large outer plastic bag	Dry ice in field, hold in freezer	Ship weekly (except on Fridays, Saturdays, or the day before Federal holidays) to FTIS lab. Only ship one sample per cooler.	**Ship in provided FTIS cooler with 50 pounds of DRY ICE** PRIORITY OVERNIGHT

** At large lakes (lakes over 10,000 hectares) littoral sampling is encouraged but not required. If littoral stations are not visited, BENT will NOT be collected; ENTE and LDNA will be collected at the launch site; LDNA will then be a single 1L grab sample*



NLA 2022 Sample Shipping Flowchart (*assumes samples being shipped to nationally contracted labs*)

Figure B-1. Sample shipping flowchart

APPENDIX C: NATIVE FRESHWATER MUSSEL EXAMPLES

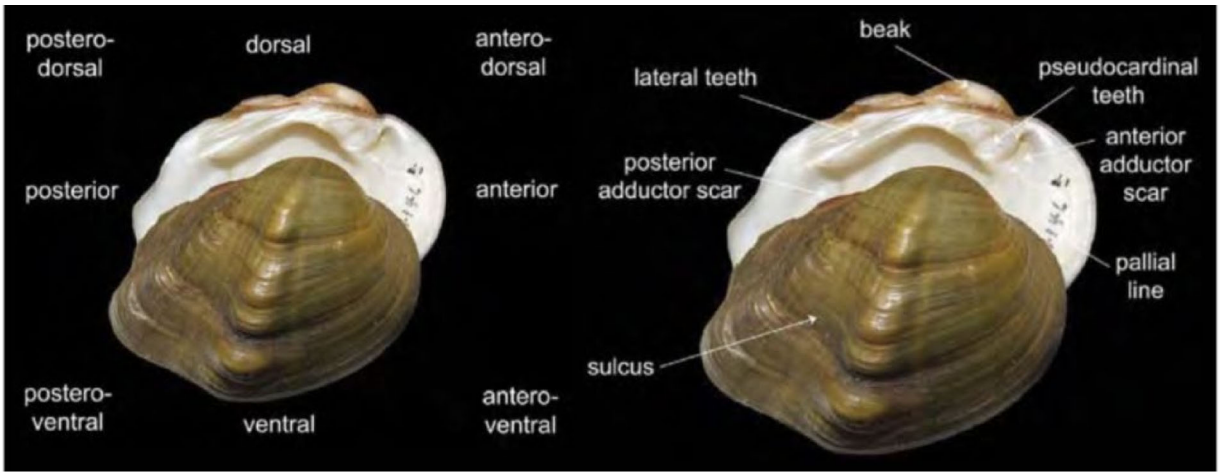


Figure C-1. Bivalve anatomy and orientation (Grabarkiewicz, J. and W. Davis 2008).

Narrow Pigtoe (*Fusconaia escambia*)[c]



Up to 3in (7.5cm) in length

Pink Mucket (*Lampsilis abrupta*)



Up to 4.1in (10.5cm) in length

Rayed Bean (*Villosa fabalis*)



Up to 1.5in (3.8 cm)in lnegth

Sheepnose (*Plethobasus cyphyus*)



Up to 5in (12.7cm) in length

Snuffbox (*Epioblasma triquetra*)[d]



Up to 2.8in (7.1 cm) in length

[c] Most photos, unless stated otherwise, were obtained through the ECOS website maintained by the U.S. Fish and Wildlife Service.

[d] Photo by G. Thomas Watters, Ohio State University

APPENDIX D: NLA 2022 HANDPICKED SITES: RESAMPLING OF THE NATIONAL EUTROPHICATION STUDY LAKES

Background

In 1972, the US Congress passed the landmark environmental legislation that became known as the Clean Water Act (CWA). The CWA has become a model for countries around the world and is heralded as the gold standard of environmental legislation. This year, 2022, marks the 50th Anniversary of the CWA, which coincides with the 4th iteration of the National Lakes Assessment (NLA). One hallmark of the CWA was inclusion of monitoring and measuring progress as an integral component to restoration and protection efforts. To that effect, the U.S. initiated a survey in 1972 to measure and report on the acceleration of eutrophication in lakes by assessing nutrient pollution known as the National Eutrophication Survey (NES). Importantly, the year 2022 also represents the 50th Anniversary of this landmark national survey.

Today, the NARS program is an EPA, State and Tribal partnership designed to address the need for monitoring the long-term progress toward the water quality objective and goals of the CWA. Through NARS, EPA and our partners are providing information on the condition and trends in coastal waters, lakes, rivers and streams, and wetlands. As a part of the NLA starting in 2007, ~200 of the original ~800 NES lakes were included as a subpopulation in the survey design and resampled. These ~200 lakes were selected using a probability-based design, similar to the broader NLA, which allowed change estimates to be made for the broader population of ~800 NES lakes. This ~200 lake subpopulation was used to report on the changes in trophic condition in the 2007 report.

As part of the celebration of the 50th Anniversary of the CWA, a resurvey of the NES lakes is taking place in conjunction with the NLA 2022. The statistically valid sampling design for NES sampling since the NLA 2007 survey will allow EPA to track environmental progress by assessing the change in condition of the NES lakes in the intervening 50 years (1972, 2007, 2012, 2017, and 2022). In additions to reporting on the condition of the NES lakes, the NES 2022 resampling will combine field data with watershed information to identify the progress we have made, the challenges we still face, and highlight the importance of water quality in our lives.

Field Crews and Coordination

The NES 2022 will rely on many of the key contacts and coordinators for NLA 2022 (See **Table 2-2**). All ten EPA Regions are supporting the NES field work in addition to the NLA field sampling contractors. In some regions, the field crew leads are the same as the regional NLA coordinator (**Table D-1**).

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Table D-1 NES EPA Regional Crew Contact information

Title	Name	Contact Information
Regional EPA NLA Coordinators	Hilary Snook*, Region 1	snook.hilary@epa.gov 617-918-8670
	Emily Nering*, Region 2	nering.emily@epa.gov 732-321-6764
	Frank Borsuk*, Region 3	borsuk.frank@epa.gov 304-234-0241
	Leah Ettema, Region 3	ettema.leah@epa.gov 304-234-0245
	Chris McArthur, Region 4	mcarthur.christopher@epa.gov 404-562-9391
	Mari Nord*, Region 5	nord.mari@epa.gov 312-886-3017
	Rob Cook*, Region 6	cook.robert@epa.gov 214-665-7141
	Gary Welker*, Region 7	welker.gary@epa.gov 913-551-7177
	Liz Rogers, Region 8	Rogers.liz@epa.gov 303-312-6974
	Tom Johnson, Region 8	Johnson.tom@epa.gov 303-312-6226
	Tina Yin, Region 9	yin.christina@epa.gov 415-972-3579
	Matthew Bolt, Region 9	Bolt.matthew@epa.gov 415-972-3578
	Lil Herger*, Region 10	herger.lillian@epa.gov 206-553-1074
Regional EPA Field Crew Leads and/or Alternate Leads		
	Tom Faber, Region 1	Faber.tom@epa.gov 617-918-8672
	Raffaela Marano, Region 3	Marano.raffaela@epa.gov 215-814-2397
	Jerry Ackerman, Region 4	ackerman.jerry@epa.gov 706-355-8721
	Sue Dye, Region 4	dye.sue@epa.gov 706-355-8628
	Jonathan Burian, Region 5	Burian.Jonathan@epa.gov
	Laura Webb, Region 7	Webb.Laura@epa.gov
	Bill Schroder, Region 8	Schroeder.william@epa.gov 303-462-9472
	Ryan Monahan, Region 8	Monahan.ryan@epa.gov 303-462-9477
	Peter Husby, Region 9	Husby.peter@epa.gov

Title	Name	Contact Information
		510-412-2311
	Bob Hopeman, Region 9	Hopeman.Bob@epa.gov 510-415-2388
	Peter Leinenbach, Region 10	leinenbach.peter@epa.gov

*Regional NLA coordinator and NES field crew lead

Project and Data Quality Objectives

NES dataset provides a unique opportunity to assess change in lake condition in the intervening 50 years (1972, 2007, 2012, 2017, and 2022). In addition to the analysis of the filed collected data, analyses will include information on the types of management practices implemented at and near the lakes (wastewater treatment, etc.), population changes and other stressors to evaluate water quality changes in lakes with restoration and protection activities.

The NES 2022 resampling study is designed to address the following objectives:

1. How as the trophic condition of the NES lakes changed in the last 50 years (1972, 2007, 2012, 2017, and 2022). Are conditions better or worse?
2. Have stressors within the watersheds changed since the 1970s?
3. What stressors contribute to the current trophic condition of the NES lakes?

NES Indicators

The original NES study included the collection of lake profile data, water chemistry, chlorophyll -a, and secchi. The NES 2022 resurvey will continue to focus on measurements of trophic condition and will include the NLA indicators identified in **Table D-2.**

Table D-2 NLA 2022 NES site water quality indicators.

Indicator Type	Indicator	NES 1970s	NLA/NES 2007	NLA/NES 2022
Trophic and Chemical Indicators	*Vertical profile measurements* (DO, Temperature, pH)	x	x	X
	Secchi disk transparency	x	x	X
	Water chemistry (NH_4, NO_3), major anions and cations, alkalinity (ANC), DOC, TSS, silica, conductivity, nutrients (total and dissolved TN and TP)	x	x	x
	Chlorophyll-*a*	x	x	x
Human Health	CyanoHAB visual observations at index site and boat launch			x

Indicator Type	Indicator	NES 1970s	NLA/NES 2007	NLA/NES 2022
	Algal toxins (microcystins and cylindrospermopsin)			x
	Phytoplankton (cyanobacteria cell count)		x	x
Other Indicators	eDNA			Water chemistry filter only
	Lake area, basin morphometry, and characteristics of watershed	x	x	x

Study Design

In NLA 2007, 210 NES lakes were included in the survey design and resampled. This subpopulation was used to report on the changes in trophic condition in the 2007 report. The NES 2022 design is a random design of the NES 2007 lakes stratified by EPA Region. Due to resource limitation, all 210 lakes cannot be sampled, therefore we identified the target number of lakes in each Region (**Table D-3**). In Regions with 12 or less lakes, all NES lakes will be targeted for sampling. In Regions with greater than 12 sites, 60% of the lakes will be targeted for sampling. Note that 3 lakes will likely be sampled as part of the NLA probabilistic sampling efforts. The selection of target lakes must happen in the order of the site ID; however, sampling may happen in any order.

Table D-3 Target number of hand-picked lakes for sampling by EPA Region.

Row Labels	NES Lakes per Region	Target # of Sites	Lakes in the NLA 2022 Design	Total # of Target Lakes by Region	Regional sites	Contractor Sites
Region_1	5	5-6	1 (likely)	6	5	0
Region_2	6	6		6	6	0
Region_3	9	9		9	10**	0
Region_4	35	24*	1	25	24*	0
Region_5	48	29		29	28**	0
Region_6	32	19		19	5	14
Region_7	10	10		10	10	0
Region_8	38	23		23	9	14
Region_9	13	13		13	8	5
Region_10	12	11	1	12	6	5
Total	206	146	3	152	82	38

* Region 4 will sample the first 3 oversample lakes given there proximity to the target lakes, increasing the total number of lakes sampled by R4 to 24.

**One OH lake in Region 5 will be sampled by R3.

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Field Methods and Procedures

Field Crew Training

The NES field crew leads and crew members are encouraged to participate in all portions of the NLA 2022 training. In the event crew members are not able to complete the full training program, below is the required list of training material for NES sampling teams:

1. Review the NLA QAPP, SEG and FOM (see Daily Field Activities below for FOM details)
2. Review the following training videos and take the associated quizzes:
    a. Block 1 – Background (all 4 videos)
    b. Block 2 – Launch sites activities and index sampling (videos 2-1 through 2-5; no zooplankton)
    c. Block 5 – Final lake activities (all 3 videos)
3. Participate in a Q&A session
4. Attend a regional in-person training (requirement for field crew leads only)

The NLA also includes Endangered Species Act (ESA) training for federal field crews. Although the NES sampling does not include the NLA biological indicators that are most likely to effect ESA listed species (i.e., benthic macroinvertebrates and fishing), all NES crew leads are to participate in the training in the event listed species are encountered while in the field.

Daily Field Activities

The NES sampling will include the following field activities:

1. All base site activities (see **Section 4.0**).
2. The following index site activities (see **Section 5.0**):
    a. CyanoHABS Visual Assessment
    b. Temperature, DO and pH profile
    c. Secchi Dish Transparency
    d. Water sample collection for chlorophyll-a, phytoplankton, algal toxins and water chemistry
        i. NES sampling <u>will not include</u> the collection of eDNA, atrazine, and zooplankton samples
3. All final lake activities
    a. Filtering only includes the chlorophyll-a sample (see **Sections 8.2.3** and **8.2.4**)

Field Forms and Sample Shipment

Table D-4 identifies the NLA field forms that will be used for the NES sampling. Many forms will include samples that are not part of NES field work. For the samples that are not collected at NES lakes (i.e., atrazine, all littoral samples, eDNA, zooplankton), the field crew is to identify that no sample was collected in the assoiceated forms. The Physical Habitat form <u>will not</u> be submitted.

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Table D-4 NES field forms.

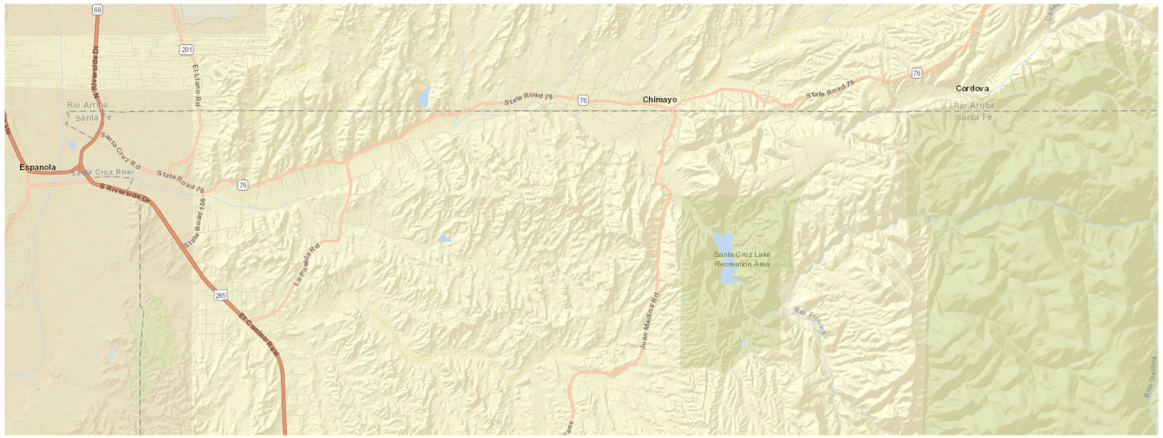
Form	Fill out	Submit?
Verification	Entire form	Yes
Calibration	Entire form	Yes
Index Samples	Entire form; mark FDNA, TRIA, ZOCN, and ZOFN as not collected	Yes
Profile	Entire form	Yes
Littoral Samples	Bottom of form only; mark BENT, LDNA, and ENTE as not collected	Yes
Physical Habitat	None	No
Assessment	Entire form	Yes
Whole Fish Sample	Top of form only; mark 'No'	Yes
Federal ESA	Fill in a pertinent section if an ESA-listed species is encountered	If data are entered
Tracking	T1, T2, and T3 sections when shipping samples from those groups	Yes

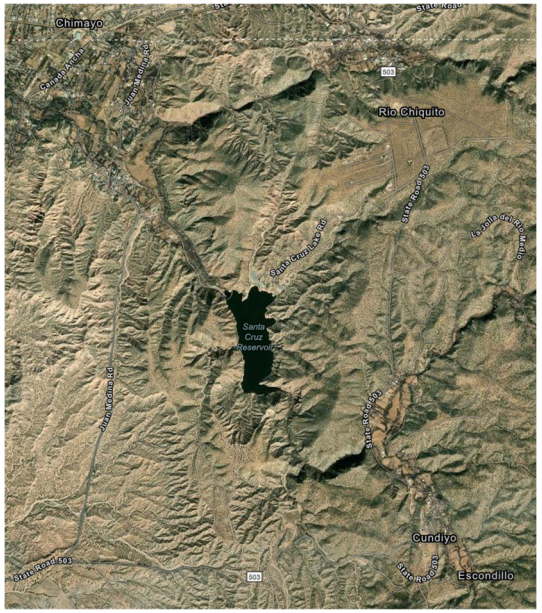
Sample shipments will include:

- T-1 (daily water chemistry samples);
- T-2 (frozen batched samples – algal toxins only); and
- T-3 (non-chilled batched samples – phytoplankton only).

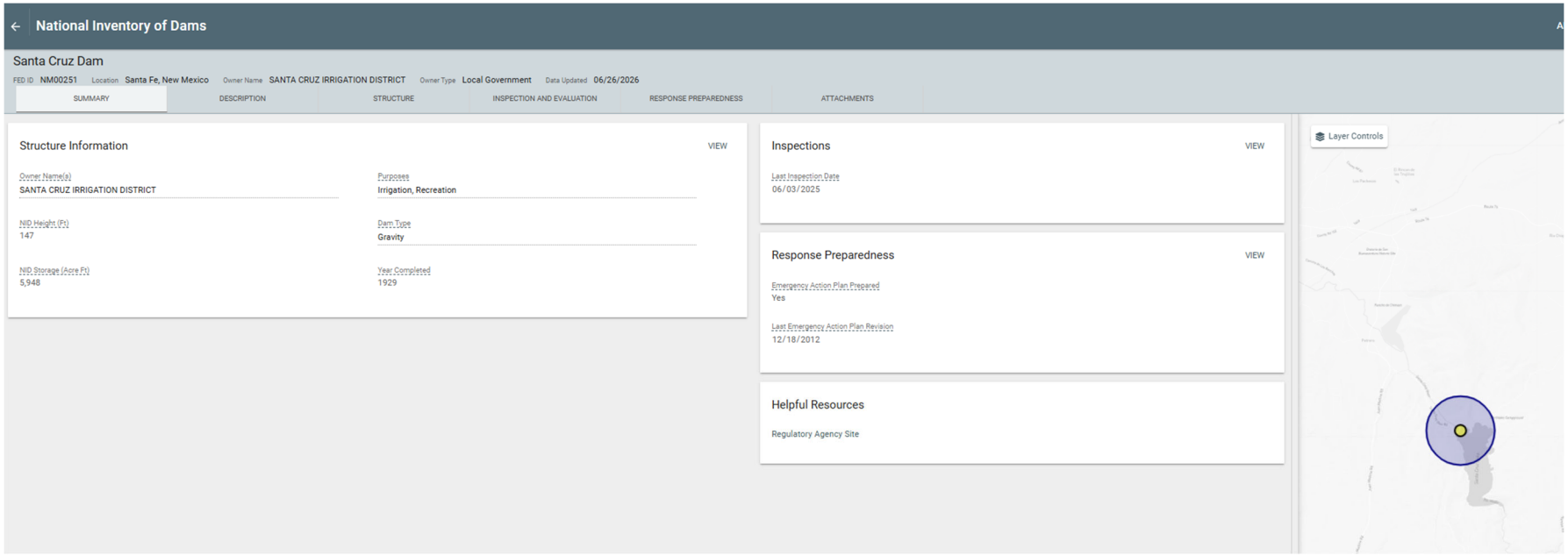
See **APPENDIX B: SHIPPING GUIDELINES** for additional details.

Santa Cruz Lake location (generated from https://gis.web.env.nm.gov/oem/?map=swqb):

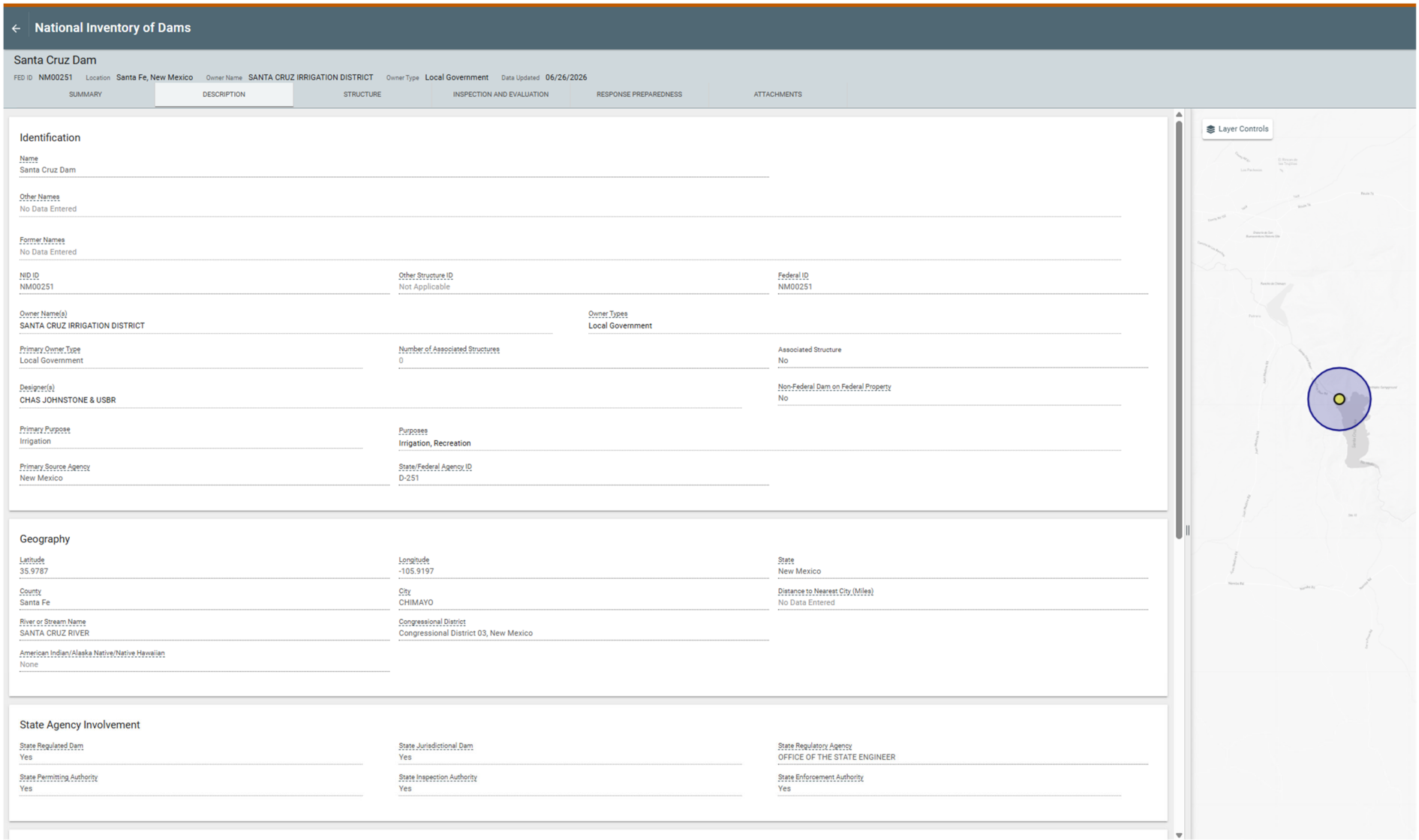




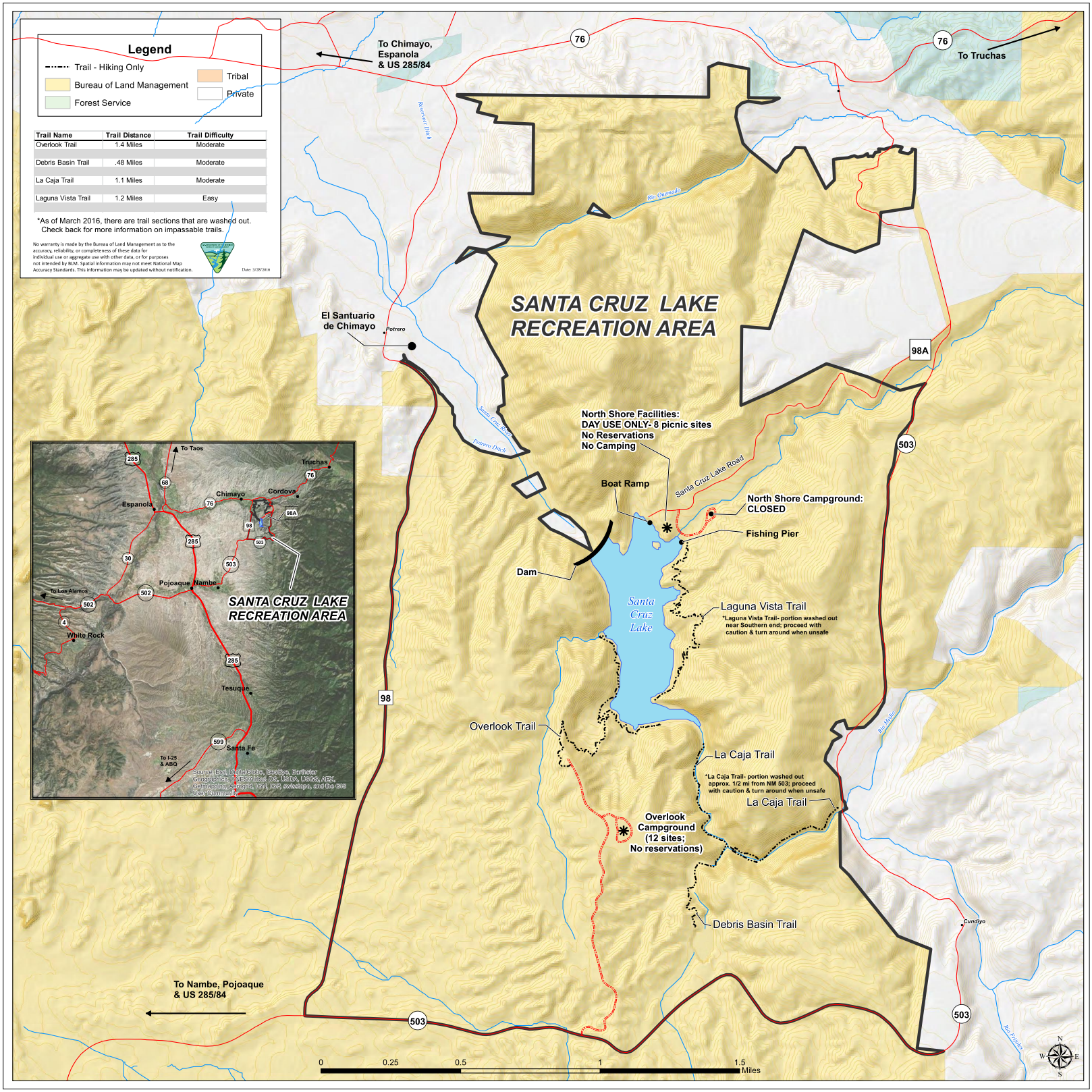
Santa Cruz Dam National Inventory of Dams information (available at https://nid.sec.usace.army.mil/nid/#/dams/system/NM00251/summary



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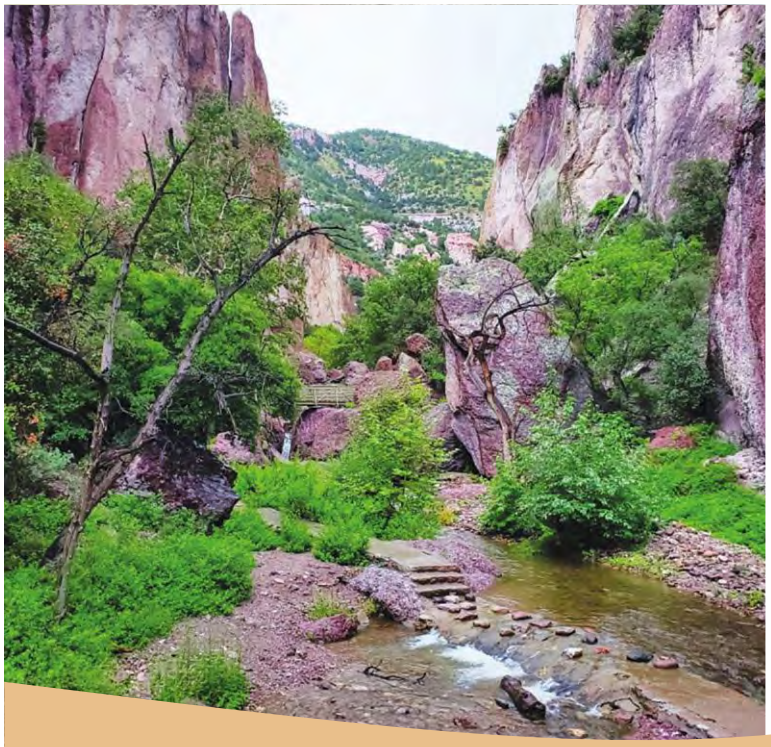
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New Mexico Department of Game and Fish

Conserving New Mexico's Wildlife for Future Generations

2022 Statewide Fisheries Management Plan

Approved by the New Mexico State Game Commission on June 17, 2022

This plan is supported by



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Welcome to the Fisheries of New Mexico!

In 2016 the Department published its first comprehensive Statewide Fisheries Management Plan. The intent of the Plan was to provide the public and our partner agencies with a clear roadmap for our plans to manage fisheries across the state. It established population management parameters for a number of sportfish species and laid out a management approach for nearly all of the waters in the state. At the time of its publication, the Department described it as "as summary of the conventional knowledge, vision, and decades of work by the Department and its partners who work to conserve our aquatic resources." As with any plan, the Statewide Fisheries Management Plan requires occasional updates in order to continue to reflect contemporary knowledge and vision for the management of our extraordinarily diverse fisheries. With this update our aim is to highlight accomplishments since 2016, refine species management parameters, identify changes in management approaches to specific waters, describe regulatory and administrative updates, and lay out new ideas for fisheries and their management. We have also added an index of waterbodies to the end of this update that will help readers find information about specific waters within the Plan.

The years since publication of the 2016 Plan have brought plenty of challenges to New Mexico's diverse angling opportunities. Some of these challenges, like drought, are familiar while others are completely novel. The global pandemic that resulted from the spread of Covid-19 touched all aspects of life in New Mexico and fishing was no exception. The Department saw a modest increase in fishing license sales from 2019 to 2020 but with access to popular angling locations undergoing an array of ever-changing closures and many people engaging in outdoor recreation, our anglers perceived substantial changes in use at many of their favorite fishing spots. It is simply too early to tell if the increased engagement in angling is an anomaly or a "new normal" but we are committed to continuing to track both fishing and fish populations to ensure the sustainability of our fisheries.

We hope that our anglers, partners, and the public find this updated plan useful in understanding the Department's evolving approaches to managing our diverse native fish communities and world-class sport fisheries.

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Glossary of Terms

Adult fish: Fish that have reached a sufficient size and age to be sexually mature.

Aquatic invasive species: Any non-native plant, animal, or pathogen that can harm our economy, environment, human, animal, or plant health.

Angler catch rates: Number of fish caught by anglers over a specified period of time (e.g., one fish per hour).

Angler day: One visit to a waterbody by an angler generally fishing for about four hours.

Angler harvest rates: Number of fish harvested by anglers over a specified period of time (e.g., one fish harvested per angler day).

Augmentation: Stocking fish into an existing population to increase abundance. Synonymous with supplemental stocking.

Basin: An entire river system or an area drained by a river and its tributaries. Synonymous with drainage.

Black bass: A group of popular sportfish in the family Centrarchidae which in New Mexico includes Largemouth, Smallmouth, and Spotted bass.

Catchables: Size category of fish that are at harvestable size. Length categories for catchables include: trout ≥9 inches, Channel Catfish ≥14 inches, and Largemouth Bass ≥14 inches.

Conservation Population (Rio Grande Cutthroat Trout): Those populations with 10 percent or less introgression (hybridization) from non-native trout.

Core Conservation Population (Rio Grande Cutthroat Trout): Those populations with 1 percent or less introgression (hybridization) from nonnative trout.

Cutthroat Trout: Any trout which has orange or red slash marks below the jaw, other than Rio Grande Cutthroat Trout. This includes Snake River Cutthroat Trout and any hybrid cutthroat trout that are less than 90 percent Rio Grande Cutthroat Trout.

Delisting: The removal of a species from the federal Endangered Species Act or the New Mexico Wildlife Conservation Act. Delisting is a result of successful recovery efforts or species extinction.

Downlisting: The reclassification of a species from endangered to threatened under the Endangered Species Act or New Mexico Wildlife Conservation Act. Downlisting is the result of progress towards delisting.

Drainage: An entire river system or an area drained by a river and its tributaries. Synonymous with basin.

Fingerling: Size category of fish in early life stages, also known as juveniles. Length categories for fingerling include: trout 2 to 6 inches, Channel Catfish 2 to 6 inches, and Largemouth Bass 1.5 to 5 inches.

Fry: Size category of fish in the earliest life stages from after hatching to fingerling size. Length categories for fry include: trout ≤2 inches, Channel Catfish ≤2 inches, and Largemouth Bass ≤1.5 inches.

Game or sportfish: Include black bass, catfish, perch, pike, sunfish, temperate bass, tiger muskie, trout, and Walleye as defined by 17-2-3 NMSA 1978.

Green Chile Water: A type of Special Trout Water with a reduced bag limit of two trout per day and tackle restricted to artificial fly and lure with a single barbless hook.

Hybridization: Mating between two individuals of different species resulting in offspring of an intermediate form. In New Mexico, this is most common between native trout and Rainbow Trout.

Low Density Bass Waters: Waters that may maintain a population of bass, however this population is often limited by extreme environmental conditions. Often these populations experience a boom or bust progression driven by environmental conditions.

Native Fish Waters: Waters where the primary management goal is conservation or recovery of native fish species.

Native species: A species living within its historical range and habitat.

Native Trout Conservation Waters: Waters managed to conserve native trout by allowing unlimited harvest of non-native trout to suppress these species and reduce competition while maintaining catch-and-release regulations for native trout.

Proportional Stock Density: A commonly used index to describe a “balanced” population of fish composed of young and adult fish. A measurement of fish population size structure. A high Proportional Stock Density (80 to 100) is a population skewed toward larger individuals. A low Proportional Stock Density (0 to 40) is a population skewed toward smaller individuals.

Protected species: All animals defined as protected wildlife species and game fish under Section 17-2-3 NMSA 1978; all animals listed as endangered or threatened species or subspecies as stated in 19.33.6 NMAC: and all animals listed under Sections 17-2-13, 17-2-14 or 17-2-4.2 NMSA 1978.

Put, Grow, and Take Catfish Waters: Consist of medium size reservoirs stocked with subcatchable Channel Catfish that grow in the waterbody to catchable size. Most Put, Grow, and Take waters have insufficient natural reproduction rates to support existing angler harvest.

Put, Grow, and Take Trout Waters: Waters stocked with subcatchable, fingerling or fry trout with the expectation that the fish will grow to larger sizes within the receiving water.

Put and Take Catfish Waters: Waters stocked with catchable size Channel Catfish to be immediately harvested by anglers especially where angler demand significantly exceeds natural production.

Put and Take Trout Waters: Waters stocked with catchable trout to be immediately harvested by anglers especially where angler demand significantly exceeds natural production.

Quality Trout Waters: Waters managed to provide higher trout densities and five percent of the population is greater than 12 inches or larger.

Recreational Bass Waters: Waters that exhibit conditions for producing fish that reach legal length limits. In most instances these waters maintain self-sustaining populations but may receive supplemental stocking.

Recreational Trout Waters: Waters that contain self-sustaining trout populations of moderate density (> 80/acre) and multiple year classes present.

Recovery populations/waters: Recovery populations and recovery waters are those that contribute toward recovery goals as identified in federal or state species recovery plans.

Red Chile Water: A type of Special Trout Water with catch-and-release and tackle restricted to artificial fly and lure with a single barbless hook.

Red Chile Native Trout Conservation: A type of Special Trout Water with catch-and-release on native trout and unlimited harvest on non-native trout and tackle restricted to artificial fly and lure with a single barbless hook.

Relative weight: An index of fish condition (length to weight relationship) compared to expected weight for a fish at a certain length. For most species, fish with a relative weight 80% or higher are considered in healthy condition.

Self-sustaining population: A population that naturally reproduces at levels sufficient to support long-term population persistence. If a population is self-sustaining, it is generally not stocked.

Special Summer Catfish Waters: Small lakes, ponds, and stream reaches, generally in urban areas, stocked with large, catchable Channel Catfish (approximately 17 inches or greater) multiple times per year (May to September) with reduced harvest limit of two fish per day.

Special Trout Waters: Waters where harvest of trout is prohibited or limited and terminal tackle type may be restricted (e.g., artificial lure or fly only, single barbless hook).

Stocking schedule: A plan that specifies the dates, species of fish, numbers of fish, sizes of fish, and waters to be stocked throughout the state over a calendar year.

Subcatchables or sub-adults: Size category of fish that are smaller than catchable length but larger than fingerlings. Length categories for subcatchables include: trout 6 to 9 inches, Channel Catfish 6 to 14 inches, and Largemouth Bass 5 to 14 inches.

Suppression: Actively removing unwanted fish via angling regulations or mechanical means such as electrofishing or nets.

Trophy Bass Waters: Adopted in 2018, these are waters with a reduced harvest limit of two fish per day. The minimum length limit for Largemouth Bass and Spotted Bass is 14 inches statewide. Trophy Bass Waters provide ideal conditions for producing fish larger than 5 pounds and provide opportunities to catch fish exceeding 8 pounds. These waters are highly productive, have high growth rates, and excellent habitat for all life stages of bass. These waters often produce fish at or near state records.

Triploid: Fish with three sets of chromosomes, unlike fertile fish that have two sets of chromosomes (a diploid fish). A triploid fish is sterile.

Trophy Trout Waters: Waters managed to produce large size trout where five percent of the population or angler catches are 20 inches or larger.

Urban Bass Waters: Bass may occur in these waters or may be stocked as a tool to manage other fish species. While bass in these waters may provide angling opportunities, they are not the focal species and population parameters have not been set for Urban Bass Waters. Retired brood bass are occasionally stocked into Urban Bass Waters to provide additional angling opportunity and/or manage sunfish populations.

Watershed: A land area that channels rainfall and snowmelt to creeks, streams, and rivers, and eventually to outflow points such as reservoirs, bays, and the ocean.

Wild Catfish Waters: Waters consisting of self-sustaining Channel Catfish, Blue Catfish, or Flathead Catfish. Some wild populations receive supplemental stocking of Channel Catfish.

Wild Trout Waters: Waters with self-sustaining trout populations.

Winter Trout Waters: Subset of Put and Take Trout Waters where the Department stocks trout during cooler months when water temperatures are suitable for trout (November through March).

X-mas Chile Water: A type of Special Trout Water with a reduced bag limit of two trout per day and no additional tackle restrictions.

Introduction and Purpose of Plan

Despite our arid landscape, New Mexico is home to dozens of fish species that provide quality and unique angling opportunities. Our state also hosts a high diversity of native fish, some of which are only found within our borders. Ranging from world-class Rainbow Trout angling, to high mountain Rio Grande Cutthroat Trout, to pupfish tolerant of salt levels greater than seawater, our fisheries truly fit New Mexico's landscape. Such diversity also presents ever-growing challenges to fisheries management and conservation. Each year, approximately 249,000 anglers spend nearly 3.8 million days fishing in New Mexico and contribute approximately $266 million to our state's economy. The New Mexico Department of Game and Fish (Department) is a primary steward of these fisheries resources within the state and is charged with managing fish in New Mexico. In close collaboration with local, state, federal, tribal, and non-governmental organizations, the Department actively engages in various management programs and activities at statewide and regional levels to invest in the long-term conservation and management of our fisheries.

Management of fisheries in New Mexico is a complex and challenging venture. Climate change, population growth, resource development, habitat alteration, competing resource interests, cyclical drought, and conflicting management directions all create programmatic challenges at a statewide level. In addition, competing species, hybridization, aquatic invasive species (AIS), illegal fish introductions, and the occurrence of threatened or endangered species present challenges for management of individual waters and at the watershed scale. Faced with these challenges, the Department and its partners must consider dozens of factors when implementing current actions and planning for the future. Demands placed upon our fisheries resources require a clear definition and communication of current and future management expectations for a waterbody to ensure continued angling opportunities, appropriate conservation actions, consistent planning expectations, and pursuit of the Department's mission.

The purpose of this Statewide Fisheries Management Plan is to express the Department's vision for the fishery resources of the State. At the core of this vision is a balance between providing angling opportunity and conserving native fishes. This balance will ensure the economic and cultural vitality of the State by maintaining angling opportunities, recovering or stabilizing state or federally protected species, and preventing the need for new listings under state or federal law. This plan identifies broad management classifications and, in some cases, specific actions for individual waters to clearly define priorities, actions, and possible changes to current management. The Department first adopted this comprehensive fisheries management plan in 2016 as a means to consider nearly all native and non-native fishes in New Mexico. The Department's prior operational plan for aquatic management and non-game management had

lapsed in 1995 and was limited to sportfishing. With approval from the New Mexico State Game Commission in April 2016, this plan began to provide a clearer picture of what to expect in particular waters to secure New Mexico's fishery resources now and into the future.

This document is an update to the 2016 Plan that will reflect contemporary information for waters across the state, report progress made towards priorities and projects identified by the original plan, identify new and ongoing priorities, refine management parameters for sport fisheries which were first adopted in 2016, and provide an index to more easily locate individual waters within the plan.

Scope and Organization of Plan

This plan is intended to identify the priority species for a water, the general management type used to support a species or community, and designate general management direction for all waters within the jurisdiction of the Department. The general management direction also identifies areas which have been or may be considered for expanding sportfishing opportunities or to implement federal or state recovery plans. This plan is not intended to identify a comprehensive list of activities or research needs at the individual water or species scale. The Department has and will continue to develop water or species-specific management or recovery plans to provide fine-scale detail, where warranted, and potentially adopt or coordinate with federal recovery plans. The Department recognizes the myriad threats posed to the state's fisheries by the additive and compounding effects of climate change, drought, wildfire, increasing demand for water, and invasive species. However, this update does not present a detailed threats analysis for these or other factors, instead maintaining a focus on the near-term management approach for virtually every fishery in the state. Regardless, many of the accomplishments and priorities identified in this update are in response to threats. For example, stream habitat improvement projects aim to narrow and deepen channels and restore vegetative cover to streambanks in order to maintain cooler stream temperatures and thereby build resilience to climate change and other factors. Further, many of the species' conservation and recovery plans listed on pages 30 and 31 below specifically contemplate climate change and other threats. This plan does not override previously adopted plans unless otherwise noted.

Several waters within New Mexico, in whole or part, fall within the jurisdiction of Native American tribes, nations, or pueblos. This plan is not intended to set any management direction for those waters under their sole jurisdiction. The Department will, however, work cooperatively to seek common management direction and coordinate joint activities for all waters, especially those which cross jurisdictional boundaries. The Department has successfully

planned and implemented fisheries management actions with multiple tribes, nations, and pueblos in recent years and hopes to continue and expand this coordination into the future.

This plan is divided into two major sections. The first section includes a description of the fisheries management and conservation program within the Department's Fisheries Management Division, angler survey information, and a summary of funding sources. This information provides a background on the organizational structure and funding available for Department activities and contributions in the state. This section also describes the Department's ongoing management efforts for specific taxa or groups of fishes. Objective parameters were first developed in 2016 for some species to demonstrate desired population abundance or angler catch rates for some fisheries, where appropriate. The Department has since identified needs to refine existing and adopt additional parameters based upon contemporary fisheries research projects and data analysis (e.g., Channel Catfish stocking analysis and minimum relative weight for Walleye). The Department will continue to use these parameters to assess the status of particular taxa and guide potential management actions such as stocking or angling regulation changes.

The second section includes delineations of specific waters with focal species identified, a management type associated with each species, as well as brief descriptions of management directions for each water. These directions may include current and future management such as stocking strategies, special regulation potential, restoration needs, among others. In some cases, the management direction is a departure from past management or clarifies past inconsistencies between Department activities. This section is a collection of most recent fisheries data, environmental and social realities, and future possibilities for fisheries in New Mexico. This information was developed through extensive discussions among Department staff, partner agencies, researchers, anglers, and the general public and has continually evolved over the past several decades into its current form. Overall, this section defines the Department's long-range planning and management within a particular water or water segment.

Overview of Department Fisheries Program

Statutory Authority

Enabling legislation for the New Mexico State Game Commission and the Department is found in Chapter 17 of New Mexico Statutes Annotated. This chapter empowers the State Game Commission to set regulations for open or closed seasons, establish bag or possession limits, authorize or prohibit the killing or taking of game fish, and prescribe the manner and method for taking game fish (17-2-1 NMSA 1978 *et seq.*). Protected species are generally limited to sportfish and state or federally listed threatened and endangered species. Specific fishing rules

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adopted by the State Game Commission include Fisheries (19.31.4 NMAC), Hunting and Fishing – Manner and Method of Taking (19.31.10 NMAC), Commercial Use of Fish (19.31.9 NMAC), and Importation of Live Non-domesticated Animals, Birds, and Fish (19.35.7 NMAC). The Department typically seeks renewal of the Fisheries rule by the State Game Commission on a four-year cycle. The most recent changes were adopted in November 2021 and went into effect on April 1, 2022.

The New Mexico Wildlife Conservation Act (17-2-37 NMSA 1978) empowers the State Game Commission to adopt a list of species of wildlife indigenous to the state that are determined to be threatened or endangered within the state. Once listed as threatened or endangered by the State Game Commission, it is unlawful for any person to possess, transport, export, process, sell or offer for sale any species of listed wildlife. The New Mexico Wildlife Conservation Act (NMWCA) also prescribes a listing or delisting process, a biennial review process to evaluate species status, and drafting of state recovery plans.

Department Fisheries Program

The Fisheries Management Division is divided into a Hatchery Section and a Research and Management Section. Six state hatcheries rear fish to support ongoing fisheries management activities in New Mexico. These hatcheries focus on both warm and coldwater fishes as well as native and non-native sportfish. They largely exist in rural communities and many offer youth angling opportunities on their properties. Four of the six facilities culture Rainbow Trout to support the extensive network of fisheries for that species across the state. Beginning in 2008, the Department switched to rearing only all-female, triploid Rainbow Trout. These fish are sterile and minimize hybridization concerns with native trout. In total, the Department's hatcheries produce nearly 4.0 million Rainbow Trout per year. The Hatchery Section also coordinates acquisitions of fish and fish eggs from external sources, such as private vendors, other states, and federal facilities. These acquisitions support fisheries management programs by providing species traditionally not reared at New Mexico state hatcheries, diversifying genetic integrity of existing populations, and meeting demands that exceed internal production capacity.

The Lisboa Springs State Fish Hatchery near Pecos, NM primarily focuses on rearing of Rainbow Trout for supporting regional put and take fisheries. The facility also occasionally raises Pecos River Strain Rio Grande Cutthroat Trout for stocking into recreational fisheries.

The Seven Springs State Fish Hatchery is located in the Jemez Mountains near Jemez Springs, NM. The hatchery is the Department's facility for spawning, hatching, rearing, and stocking Rio Grande Strain Rio Grande Cutthroat Trout. The hatchery maintains a broodstock for the fish and has also routinely integrated eggs from wild Rio Grande Cutthroat Trout populations into the

brood. The Rio Grande Cutthroat Trout produced at Seven Springs have been integral to species restoration efforts in places like the Rio Costilla. The hatchery also provides Rio Grande Cutthroat Trout for recreational purposes, mostly into put, grow, and take fisheries although some catchable fish are produced. In the near-future the Department intends to develop a Pecos Strain Rio Grande Cutthroat Trout broodstock at the hatchery to support restoration efforts in that basin.

Red River State Fish Hatchery near Questa, NM raises Rainbow Trout for regional put and take and put, grow, and take fisheries. The facility also recently began receiving fingerling Rio Grande Strain Rio Grande Cutthroat Trout from Seven Springs State Fish Hatchery. The intent of this effort is to grow additional Rio Grande Cutthroat Trout to catchable size for increased recreational opportunities for the species.

The Los Ojos State Fish Hatchery near Chama, NM also focuses on producing recreational Rainbow Trout, including put and take and put, grow, and take fisheries. Los Ojos is also the state's sole Kokanee rearing facility. Kokanee eggs are collected and fertilized from Heron Reservoir, and sometime other locations, before being hatched, reared, and stocked into put, grow, and take fisheries. Additionally, since 2018 the hatchery has annually received YY Brook Trout eggs, hatched, reared, and then provided them for research purposes.

Glenwood State Fish Hatchery in Glenwood, NM is currently being renovated to facilitate the propagation of native Gila Trout to support conservation for this unique trout species. Initially, the facility will produce Gila Trout for recreational fisheries. Ultimately, the Department hopes to expand operations in the future to include assisting with recovery stocking efforts for the species.

The Rock Lake State Fish Hatchery in Santa Rosa, NM is the Department's only warmwater facility. The hatchery hosts a broodstock of Largemouth Bass which are spawned and reared on station before being stocked into large and small impoundments across the state. The hatchery also and rears Walleye that are spawned in the wild each year. Walleye eggs are then brought to the facility, hatched, and stocked into reservoirs as fry. In addition to warmwater operations, Rock Lake has coldwater facilities and rears Rainbow Trout for put and take fisheries across the region.

The Research and Management Section is organized into teams of sportfish biologists, native fish biologists, and AIS staff, as well as a fish health specialist and an environmental compliance specialist. The Sportfish Program is charged with managing fisheries that provide recreational angling opportunities for warmwater species such as bass and catfish and coldwater species such as trout and salmon. The Native Fish Program is charged with managing New Mexico's native fisheries and aquatic invertebrates such as Arkansas River Shiner, Rio Grande Cutthroat

Trout, Roundtail Chub, and Texas hornshell (a freshwater mussel). The Sportfish and Native Fish Programs are each currently composed of ten full-time permanent employees. Biologists are typically assigned a watershed or suite of species though coordination among biologists is necessary to consider all aspects of the Department's management efforts.

Current AIS intervention efforts include education and outreach, coordination of intervention efforts, and seasonal watercraft inspection and decontamination. Coordination of AIS intervention at the state and regional levels helps to protect New Mexico fisheries as well as significant water resources infrastructure, and public boating access. The Department, along with state, federal and private partners, work diligently to stop the introduction and spread of AIS. Of particular concern is invasion of our lakes by zebra and quagga mussels. Introduction of these mussels pose a risk to our native aquatic wildlife, water-based recreation including boating and fishing, and surface water delivery systems. For more information on AIS please visit the Department's AIS webpage at www.wildlife.state.nm.us/ais.

Annual fish health testing is completed at all hatcheries to ensure they are free of significant fish pathogens such as whirling disease. Fish health testing for wild fish is completed on select waters when fish or eggs are moved within or among watersheds or to a hatchery facility. Fish health testing for wild salmonids is also completed to document presence or absence of whirling disease. Importation permits and associated fish health certifications are reviewed to ensure fish and eggs imported into New Mexico are free of significant pathogens, comply with New Mexico state regulations, and comply with interagency fish health agreements.

Environmental compliance is required when conducting many activities, including but not limited to rearing fish at hatcheries, fish monitoring and surveys, habitat projects, and stocking fish. The Department is required to comply with all state and federal laws and obtain permits or authorization when necessary. Compliance includes meeting the requirements of the Clean Water Act, Endangered Species Act (ESA), National Historic Preservation Act, and the National Environmental Policy Act.

Nearly all divisional activities are implemented in close coordination with local, state, or federal agencies as well as non-governmental organizations who own land, water or are actively engaged in aquatic conservation efforts in New Mexico. Together, these programs provide a comprehensive management approach for New Mexico's aquatic resources.

Fisheries Management Division Programmatic Priorities

Priorities for the entire Department are identified in the Department's Strategic Plan (NMDGF 2020). Identified Objectives and Strategies specifically relevant to the Fisheries Management Division include:

- That by 2023, the Department develops appropriate population objectives based on sustainable wildlife management practices (Objective 2, pg. 8)
    - Collaborate with sportsmen, land management agencies, landowners and other affected interests to establish broadly supported resource-based management objectives for game animals and game fish (Strategy 2.1)
- Maintain an overall angler satisfaction rate of 80% regarding angler opportunity, fishing experiences, and the Department's management of sport fishing issues through 2023 (Objective 4, pg. 10)
    - Monitor angler issues, interests, and satisfaction and employ findings to inform and evaluate management decisions (Strategy 4.1)
    - Maintain a hatchery system and associated facilities to culture fish and supplement fish populations through stocking in accordance with fisheries management plans (Strategy 4.2)
    - Construct, operate, and maintain a warmwater fish hatchery and associated Watershed Education and Training (WET) Center (Strategy 4.3)
    - Continue to promulgate rules that protect fish stocks from overexploitation and equitably distribute fishing opportunity (Strategy 4.4)
    - Minimize losses of fish populations and hatchery stocks due to diseases (Strategy 4.5)
    - Increase opportunities for anglers to pursue native game fish (Strategy 4.6)
- By 2023 realize a level of public opportunity for recreational hunting and fishing as indicated by 110,000 and 200,000 certified annual licensees, respectively (Objective 5, pg. 11)
    - Identify and implement methods by which hunting and fishing opportunity and participation might be increased (Strategy 5.1)
- Restore up to 70 user-days of public hunting and up to 200 user-days of fishing opportunity for selected diminished game species and furbearers by 2023 (Objective 6, pg. 12)
    - Develop and implement long-range and operational plans for the restoration, management, and use of selected diminished game species and furbearers for which limited sport fishing, hunting, or trapping opportunity may be restored without compromising species conservation (Strategy 6.1)
- That through 2023 hunting and fishing opportunities are maintained through prevention and control of wildlife disease and invasive species (Objective 7, pg. 12)

    - Detect, monitor, manage, and prevent the spread of wildlife diseases and invasive species through coordination with the New Mexico Department of Health, the New Mexico Livestock Board, the New Mexico Department of Agriculture, USDA Animal Plant and Health Inspection Service, USDA Wildlife Services, and USDA Veterinary Services and other appropriate agencies (Strategy 7.1)
- Conserve, enhance, or positively affect an additional 500,000 acres of wildlife habitat statewide by 2023 (Objective 8, pg. 13)
    - Collaborate with federal, state, and local agencies, tribal governments, non-governmental organizations, and private interests that manage significant land and water areas in New Mexico to plan and implement habitat improvement projects consistent with the habitat enhancement prescriptions in the State Wildlife Action Plan (Strategy 8.1)
- By 2023, attain measurable progress toward the restoration of wildlife identified as being at risk of depletion or extinction (Objective 10, pg. 16)
    - Pursuant to the Wildlife Conservation Act (WCA), conduct biennial reviews of all indigenous wildlife currently listed as threatened or endangered by the state, investigate and assess the status of species the Department suspects to be threatened or endangered, and recommend changes to the status if warranted (Strategy 10.1)
    - Develop and implement plans for the management and recovery of state listed threatened or endangered species (Strategy 10.2)
    - Provide public, state, and private entities with guidance for conserving and improving populations of threatened or endangered wildlife (Strategy 10.3)
    - Collaborate with state, federal, and tribal governments in the recovery of federally listed species occurring in, or extirpated from, New Mexico (Strategy 10.4)

In furtherance of the Department's Strategic Plan, the Fisheries Management Division developed a set of divisional priorities to focus management and conservation efforts for division staff and resources:

1. Rearing and Stocking Fish – This priority includes all efforts at the six Department hatcheries to meet developed stocking schedules for Channel Catfish, Gila Trout, Largemouth Bass, Rainbow Trout, Rio Grande Cutthroat Trout, Striped Bass, and tiger muskie. Stocking schedules are routinely modified to reflect changing environmental conditions, altered angler use, changing priority areas, and addition or loss of angler access. This priority specifically addressed Department Strategies 4.2 and 4.3.

2. Evaluation of Hatchery Stocking – This priority includes investigating and altering the use of hatchery produced resources to more efficiently stock waters, maximize angler catch rates, and ensure equitable distribution of fish. Examples of such investigations include Largemouth Bass or Rainbow Trout stocking strategies, appropriate stocking rates for tiger muskie, and put, grow, and take opportunities for Rio Grande Cutthroat Trout. This priority specifically addressed Department Strategies 2.1, 4.1, 4.4, 4.6, 5.1, and 6.1.
3. Species Recovery Efforts – This priority includes development and implementation of various aquatic species recovery efforts to improve or stabilize the status of federal or state protected species. Specifically, priority actions will include augmentation programs, habitat restoration, removal or exclusion of competing or hybridizing species, and restoring habitat connectivity. In addition, significant efforts are directed towards addressing or preventing the further decline of other species that could need state or federal protection in the future. This priority specifically addressed Department Strategies 4.6, 6.1, 10.1, 10.2, 10.3, and 10.4.
4. Aquatic Invasive Species – This priority seeks to galvanize support by state, federal, and non-governmental entities to collaboratively protect the states waters from AIS and prevent the spread or negative effects from previously established fish pathogens. The introduction or spread of species such as zebra mussel or quagga mussel, rock snot, or whirling disease could produce devastating effects on individual fisheries, local or state economies, and/or water resource infrastructure. This priority specifically addresses Department Strategy 4.5 and 7.1.
5. Habitat Restoration – The Department expends significant resources restoring and augmenting riparian habitats for the benefit of fish and wildlife. Future habitat enhancements are anticipated in the Cimarron River, Costilla Creek, Whitewater Creek, Willow Creek (Gila) and lakes in the Carlsbad area. This priority specifically addresses Department Strategy 5.1, 8.3 and 10.4.
6. Statewide Fisheries Management – This priority refers to ongoing efforts to constantly adapt to changes in environmental conditions and provide the best possible angling opportunities to New Mexico anglers. This priority specifically addresses Department Strategies 4.1 and 4.3.

Angler Survey Data

Dating to the 1970s, the Fisheries Management Division has assessed angler days, catch rates, species preference, and/or angler satisfaction via mail, phone, or web-based surveys. From 2000 to 2016, annual phone surveys of resident and non-resident anglers were completed. Since 2017 surveys have been completed via a web-based method. The purpose of these surveys is to assess annual angler satisfaction, seek input on emerging issues, and refine

existing management programs. For example, individualized surveys could be conducted for topics such as bait fishing, Gila Trout angling, or fish importation.

New Mexico anglers consistently prefer to fish for coldwater species such as trout and salmon with approximately 11% preferring solely warmwater species in 2021 (Figure 1). A significant percentage of anglers prefer both warmwater and coldwater species. Of the coldwater species in New Mexico, Rainbow Trout and Brown Trout are consistently preferred over other coldwater species (www.wildlife.state.nm.us/fishing/fisheries-management/). Black bass, catfish, and Walleye are the most preferred species of warmwater fish. Since 1997, an average of 60% of anglers release most of the fish they catch compared to 40% who prefer to harvest most of their catch with an increasing trend of anglers that practice catch-and-release (Figure 2). About half of anglers prefer to pursue stocked fish compared to wild fish (Figure 3). These data are essential to proactively address the desires and preferences of New Mexico anglers within the environmental and sociopolitical context of our state.

In late 2019 and early 2020 the world became aware of the emerging SARS-COV-2 virus and the Covid-19 disease that could occur from its transmission. The resulting global pandemic has affected nearly every aspect of life in New Mexico since 2020, including angling. While most of the information that we have regarding the precise effects of the pandemic on angling is anecdotal, there is little doubt that during the summer and fall of 2020 patterns of use in New Mexico's fisheries differed from normal. The Department's license sales and angler use data yield insight into these changes and suggest how this change may carry forward. Surprisingly, despite the increase in angling pressure observed by Department staff, partners, and the public in locations that remained open to angling, overall license sales increased by only 1% from the 2019-20 to 2020-21 license years and the average number of days each angler fished declined slightly from 2019 levels (Figure 4). The closures of normally popular waters at State Parks, Department-owned properties, municipal waterbodies, and many other locations likely shifted angling pressure to waters that remained open. Changes in patterns of work, school, and child care also likely led to increased angling pressure at dates and times outside of normal. Based on available statewide data, which show a modest increase in licenses sold and little change in overall angler days, we expect that as closures lift and normalcy returns to other aspects of life that angling pressure is also likely to return to pre-pandemic levels. Of course, the future is impossible to predict with certainty and the Department is committed to managing the state's fisheries and their use in a sustainable manner.

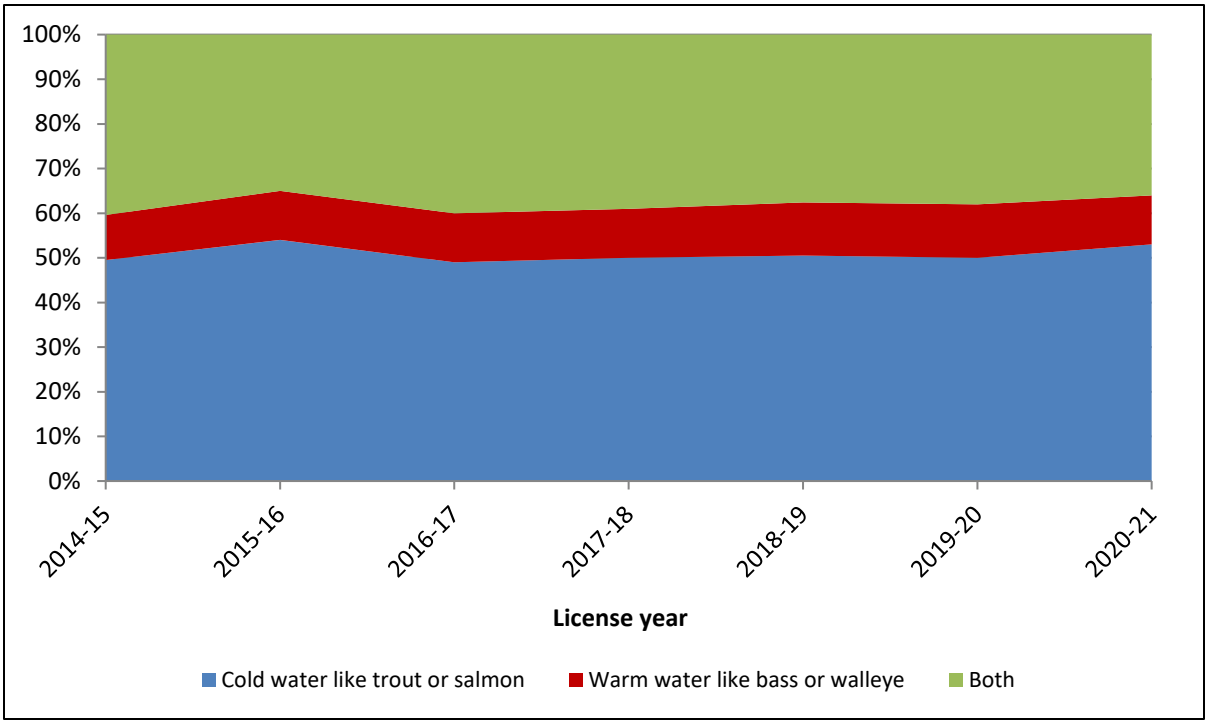


Figure 1. Summary of New Mexico angler preferences for coldwater (e.g., trout and salmon) or warmwater (e.g., bass and catfish) angling in the state. Percentages are derived from annual angler surveys, 2014-15 to 2020-21 license years. Note, 2014-15 to 2015-16 license years data from phone survey and 2016-17 to 2020-21 license years data from web-based survey.

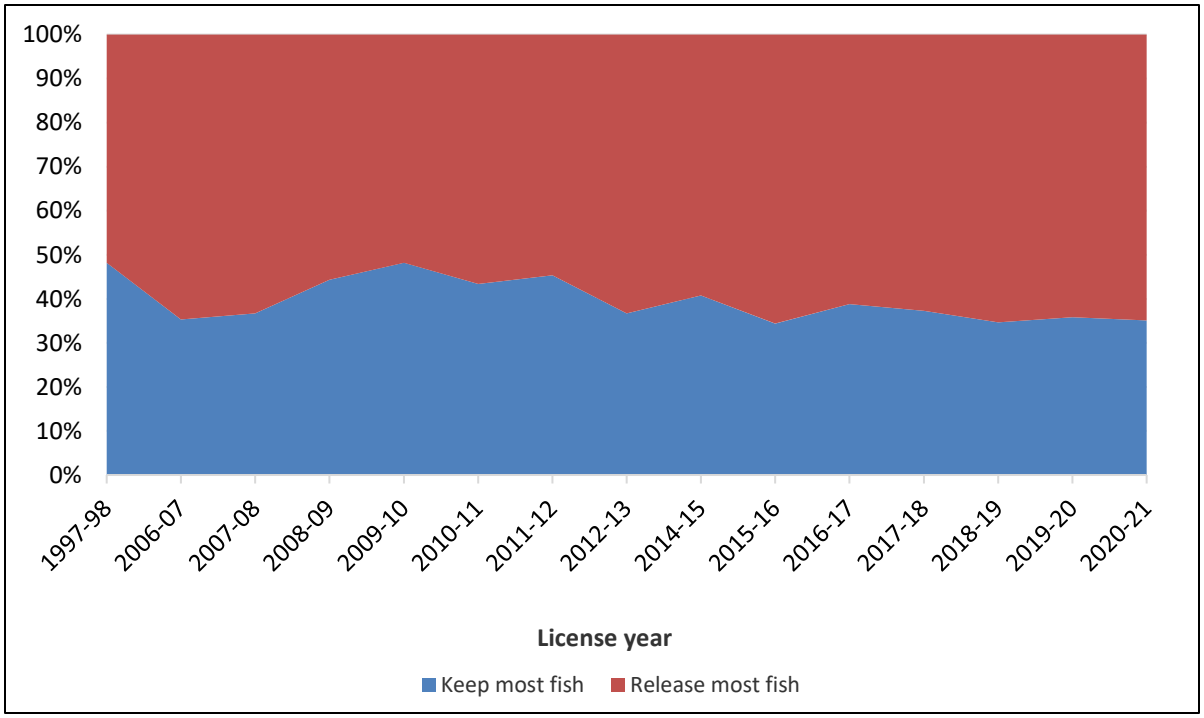


Figure 2. Summary of New Mexico angler preference for harvesting game species derived from annual angler surveys, 1997-98 to 2020-21 license years. Note, 1997-98 to 2015-16 license years data from phone survey and 2016-17 to 2020-21 license years data from web-based survey.

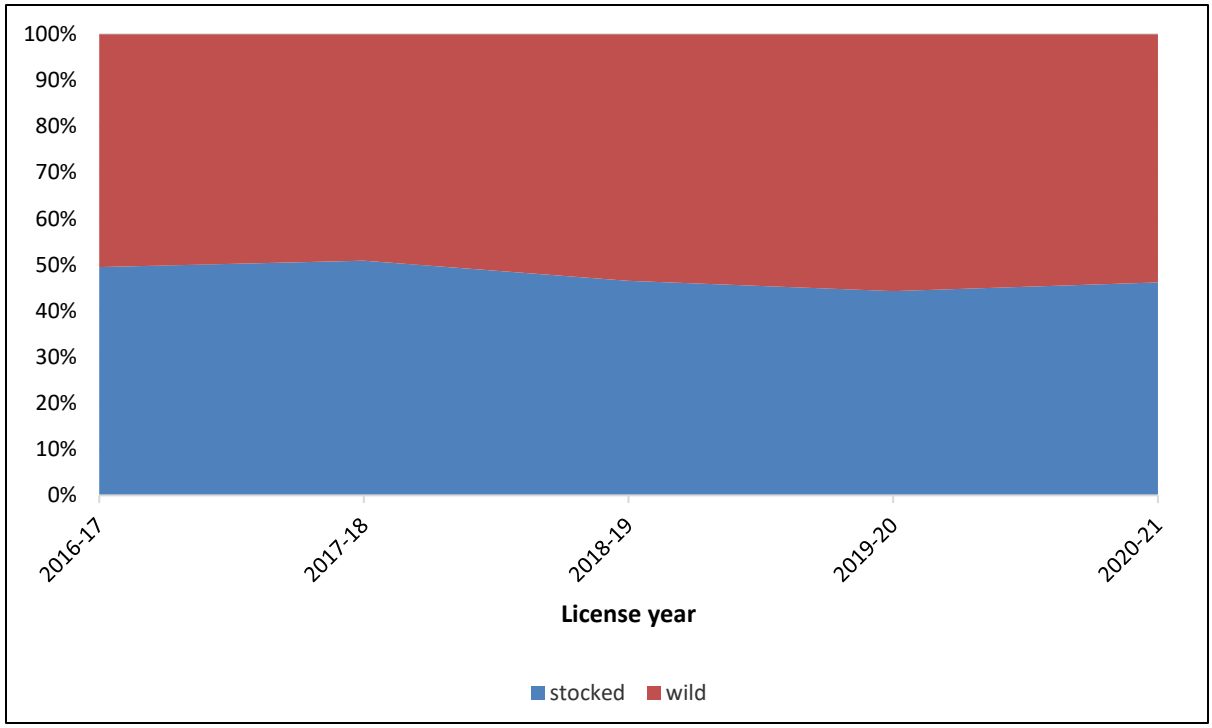


Figure 3. Summary of New Mexico angler preference for fishing in areas they expect to find stocked fish or wild fish 2016-17 to 2020-21 license years.

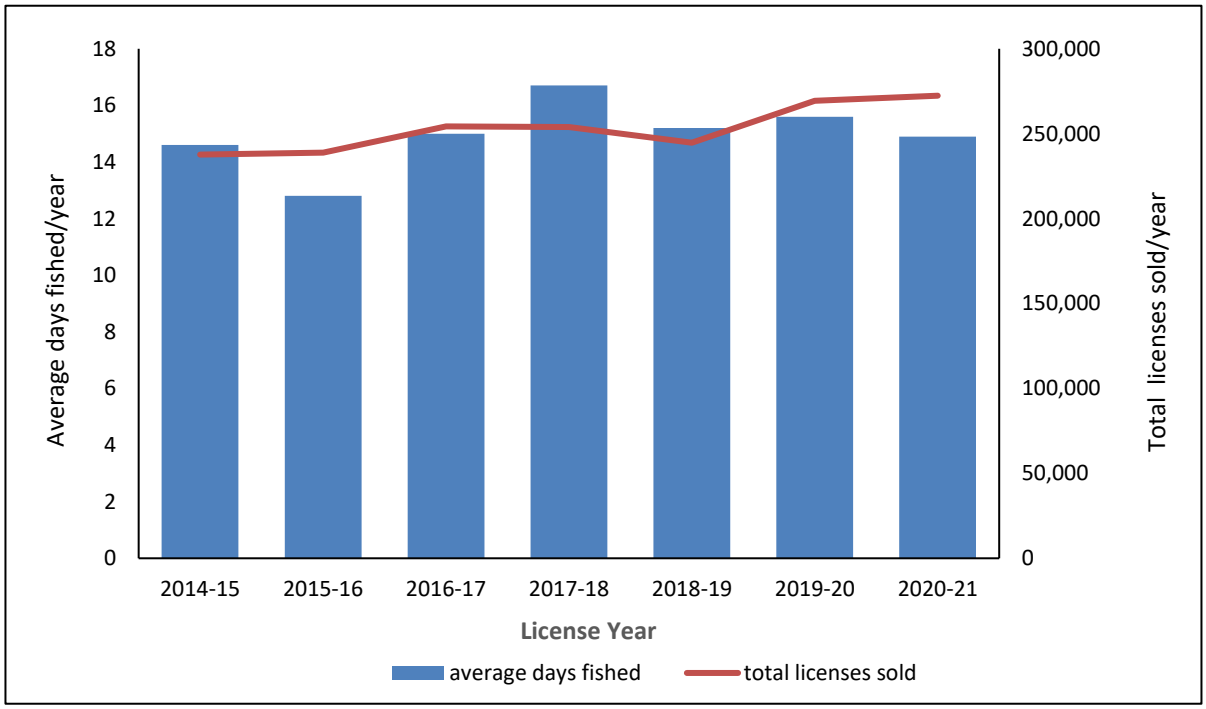


Figure 4. Total number of New Mexico fishing licenses, including combo licenses (e.g., Game Hunting and Fishing), and average days fished by each angler from 2014-15 to 2020-21 license years.

Funding

The Fisheries Management Division receives a portion of the Department's annual budget which is primarily funded by legislative appropriations from the Game Protection Fund. The Game Protection Fund is funded entirely through the sale of hunting and fishing licenses. The Fisheries Management Division leverages expenditures from the Game Protection Fund for reimbursement from various federal grant programs. The primary source of federal funds is the Sportfish Restoration Act program administered by the Wildlife and Sportfish Restoration program of the U.S. Fish and Wildlife Service (FWS). This federal grant program is funded via federal excise taxes on fishing tackle and motorboat fuel. For every dollar of Game Protection Fund spent, the Department is reimbursed $0.75 through the Sportfish Restoration Act program. This program is the primary funding source for the Department's hatchery operations, sportfish research and management, AIS outreach and education, Rio Grande Cutthroat Trout conservation efforts, habitat restoration, and fish health investigations.

Various federal grant programs also provide cost share opportunities for imperiled fish and aquatic invertebrate species. In all cases, the Game Protection Fund provides the base funding until reimbursement is obtained from the federal program. The Department receives an annual allocation of ESA Section 6 funding from the FWS to implement conservation activities for threatened or endangered species with the same reimbursement requirements as the Sportfish Restoration Act program discussed above. The Department also receives an annual allocation of State Wildlife Grant funding from FWS to support conservation programs for Species of Greatest Conservation Need as identified in the Department's State Wildlife Action Plan. The total amount of State Wildlife Grant funds used by the Fisheries Management Division varies annually. The Department supports several ongoing research efforts either through State Wildlife Grant or Section 6 funds. The Department also receives funding through different Bureau of Reclamation (BOR) project mitigation programs such as Central Arizona Project mitigation funds and San Juan River Basin Recovery Implementation Program funds. Species that benefit from these state and federal funding sources include Colorado Pikeminnow, Gila Trout, Loach Minnow, Pecos Pupfish, Rio Grande Chub, Rio Grande Sucker, Socorro isopod, Spikedace, Texas hornshell, and dozens of others throughout the state. The FWS also provides funding for AIS prevention through Sportfish Restoration Grants and other sources.

In Fiscal Year 2021, funding for the Fisheries Management Division was primarily derived from Sportfish Restoration Act and the unreimbursed Department costs (Figure 5). State Wildlife Grants provided 10% and Section 6 and BOR program funding each provided 2% of the Fisheries Management Division's budget. Lastly, 1% of the budget came from various FWS programs for AIS prevention.

In addition to the direct funding discussed here, the Department's many partner agencies, NGO's, and private individuals contribute immeasurably to fish and aquatic habitat in New Mexico through direct expenditures and volunteerism.

In 2021 the State Game Commission updated the Department's Habitat Stamp Program in a manner that will increase funding and dedicate a portion of the program to fish habitat projects. This funding source is not reflected in the Fiscal Year 2021 information included here but it is anticipated to be a substantial source of additional funding for fish habitat projects beginning in Fiscal Year 2022.

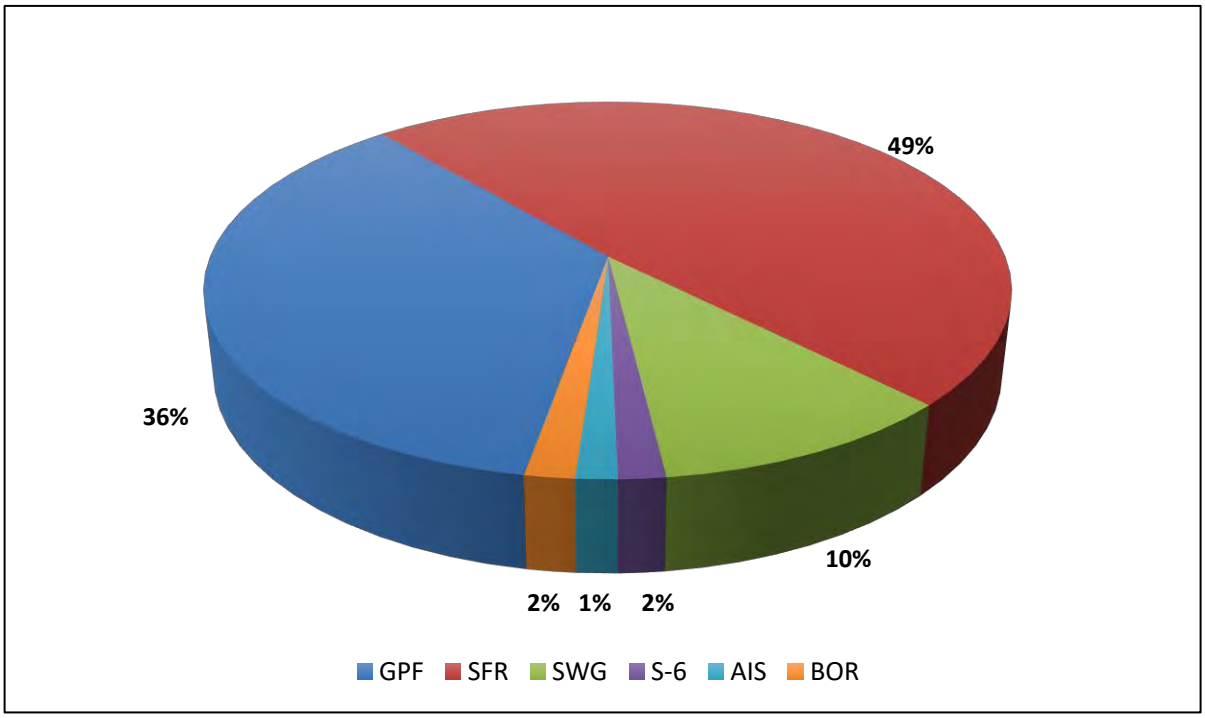


Figure 5. Summary of Fiscal Year 2021 funding sources for the $8.8 million Fisheries Management Division budget. Game Protection Fund (GPF) are unreimbursed state funds. The remaining sources are reimbursed federal funding sources including Sportfish Restoration (SFR), State Wildlife Grants (SWG), Endangered Species Act Section 6 (S-6), Aquatic Invasive Species (AIS) Grants, and Bureau of Reclamation (BOR) Programs.

Specific Information for Fish Species, Taxa, or Communities

The individual characteristics of a particular water in New Mexico along with active management such as stocking or regulation development help determine community composition and available management actions to sustain, suppress, or expand a particular fishery. Below are descriptions of individual species or groups of fish which are popular sportfish species for a water, a focal species for management at a particular water, or the focus of a significant recovery program in which the Department participates. Individual abundance or density indices, growth rates, angler catch rates, and other metrics are identified for some species to provide objective parameters for measuring management success and possible

indicators of challenges within a fishery. Parameters were amended for some species in this plan update to more accurately reflect species potential, refine management goals, and as part of adaptive management (Appendix A). For some sportfish, individual demographic parameters are not available or the species is too rare to effectively monitor. For others, state or federal recovery plans are better suited for identifying such criteria.

Catfish

Three species of catfish provide recreational angling opportunities in New Mexico. Channel Catfish are native to the central United States, south central Canada, portions of the Atlantic Coast of the United States, and have been widely introduced throughout the United States and northern Mexico. In New Mexico, Channel Catfish are native to the Canadian drainage and widely introduced to all other drainages in the state. Blue Catfish are native to the Mississippi, Missouri, and Ohio drainages of the central and southern United States and along the Texas Gulf Coast. In New Mexico, it is considered native to the Rio Grande downstream of Bernalillo County and in the Pecos River downstream of Puerto de Luna. In the Rio Grande drainage, Blue Catfish is currently known to occur in Elephant Butte and Caballo reservoirs. Flathead Catfish are found in the central United States south into eastern Mexico. Flathead Catfish are native to the Rio Grande and Pecos River drainages and were introduced to the Gila River prior to 1950. Flathead Catfish were also introduced into Clayton Lake by the Department in 2017 as a management tool to reduce and control the Black Bullhead population.

The Department has four management classes for catfish in New Mexico. These management classes are primarily focused on Channel Catfish though Blue and Flathead catfish provide quality angling opportunities in select waters. Management classes for catfish in New Mexico are: Wild, Put and Take, Special Summer Catfish Waters, and Put, Grow, and Take waters. The definition of each management type can be found in the Glossary of Terms. Channel Catfish are acquired for stocking from other state and federal agencies or purchased from private producers. Blue and Flathead catfish are not stocked by the Department at this time, but Flathead Catfish have been transplanted to other waters as a management tool.

A long-term analysis of Put, Grow, and Take stocking proved this strategy unsuccessful in providing a Channel Catfish fishery in most waters tested. The Put, Grow, and Take stocking strategy will likely only be used on a limited or experimental basis in the future.

In some waters, Channel Catfish populations are purposefully suppressed to facilitate native species recovery, like in the San Juan River downstream of Shiprock, NM. Current suppression efforts are implemented using mechanical means (e.g., electrofishing) by the San Juan River Basin Recovery Implementation Program.

Management strategies for Put and Take Catfish Waters and Special Summer Catfish Waters are focused on maximizing stocked fish return to the angler and equitable distribution of angling opportunity, predominantly in an urban environment. Alternatively, strategies for Wild Waters are focused on maintaining viable populations through time especially those that are entirely dependent upon natural reproduction. As a result, the objective parameters established for Put and Take and Special Summer Catfish waters relate to angler catch rates compared to population statistics documented during Department monitoring efforts for Wild Waters.

Channel Catfish Parameters:

Put and Take and Special Summer Catfish Waters

- Average harvest rate: 1 fish/angler day during stocking season (late May to early September)

Wild

- Multiple size-classes of adults present exhibiting a balanced population and consistent natural reproduction

Black Bass

Black bass in New Mexico include Largemouth Bass, Smallmouth Bass and Spotted Bass. The native range of Smallmouth Bass includes southern Canada, south to the Tennessee River and Alabama and west to eastern Oklahoma and western Arkansas. In New Mexico, Smallmouth Bass were first stocked into Throttle Reservoir (Colfax County) in 1914 and since that time have been stocked throughout the state. Smallmouth Bass now occur in every major basin in New Mexico including river systems such as the lower Gila River and upper Rio Grande. Two subspecies of Largemouth Bass exist or have been stocked in New Mexico: Northern Largemouth Bass and the Florida Largemouth Bass. Florida Largemouth Bass were stocked into reservoirs within the southern part of the state in the 1980s with limited long-term success in terms of contributing to the fishery. Northern Largemouth Bass are native to New Mexico's Pecos Drainage and possibly the Rio Grande Drainage but have been introduced to all other basins in the state. Spotted Bass were stocked into Cochiti Lake and Lake Sumner in the 1980s and currently exist in Bataan Lake, Brantley Lake, Lake Carlsbad, and Lake Sumner. Largemouth Bass are the most popular warmwater species in the state followed consistently by Smallmouth Bass.

Most populations of black bass are self-sustaining in the state though many Largemouth Bass fisheries receive supplemental stockings from Rock Lake State Fish Hatchery. Local conditions of a particular water, however, can limit or inhibit consistent reproduction. For example, sudden reservoir level decreases that negatively affect nests built in shallow areas can reduce or

eliminate fish spawning and recruitment. Stocking rates and schedules have been developed for multiple Largemouth Bass waters. A consistent brood population of Largemouth Bass is raised at Rock Lake State Fish Hatchery to meet stocking needs. Smallmouth and Spotted bass are not routinely stocked by the Department at this time.

Statewide regulations vary for black bass among species and management direction. Harvest in most waters is limited to five fish per day. Trophy Bass Waters were adopted in 2018 and feature a reduced harvest limit of two fish per day. The minimum length limit for Largemouth Bass and Spotted Bass is 14 inches statewide. The statewide minimum length limit for Smallmouth Bass is 12 inches with the exception of 14 inches at Conchas and Ute lakes. The purpose of this regulation is to protect fish from harvest until reaching a more desirable length. Effective April 1, 2022, the minimum length limit for Smallmouth Bass was removed on the Rio Grande near Pilar, NM to reduce population densities and competition to address potential stunting.

The Department has four black bass management types: Trophy, Recreational, Low Density, and Urban. The definition of each fish type can be found in the Glossary of Terms. These management types were developed to help set or maintain realistic expectations for black bass populations in the state. Once set, the Department may seek to manipulate physical, biological, or social variables to attain the desired outcomes via habitat improvement, forage or other species management, or harvest regulations. Each parameter is used as an indicator for different aspects of overall population health. For example, the abundance parameter (Catch Per Unit Effort) is different for Trophy Waters (where overall abundance of larger fish is desired) compared to Recreational Bass Waters (where an abundance of multiple size classes is desired). Alternatively, parameters for recruitment are based upon the survey catch rate of Age-2 bass whereas Catch Per Unit Effort is based upon catch rates of fish greater than a particular length. Proportional Stock Density is a commonly used index to describe a “balanced” population of fish composed of young and adult fish. Low or high Proportional Stock Density indicates a skewing of the population towards small or large fish, respectively. All of these parameters are used to measure different elements of the population. Below are specific descriptions of black bass management types and objective parameters for each management type. All Smallmouth Bass waters are designated as Recreational Bass Waters with no specific parameters developed for stream systems. Several waters contain multiple species of black bass; however, parameters are compared independently for the focal management species designated for a particular water.

Black Bass Parameters:

Trophy Bass Waters (Largemouth Bass only)

- Catch Per Unit Effort: > 5 fish/hour of electrofishing that are > than 20 inches in length

- Recruitment: > 10 Age-2 bass/hour of electrofishing
- Size Structure: Proportional Stock Density between 50 and 70
- Growth: Mean length of Age-4 bass > 14 inches
- Body Condition: Average relative weight of at least 90

Recreational Bass Waters

- Catch Per Unit Effort: 20 to 40 fish/hour of electrofishing
- Recruitment: > 5 Age-2 bass/hour of electrofishing
- Size Structure: Proportional Stock Density between 40 and 60
- Body Condition: Average relative weight of at least 80

Low Density Bass Waters

- Catch Per Unit Effort: 0 to 20 fish/hour of electrofishing
- Body Condition: Average relative weight of at least 80

Temperate Basses

The temperate basses include Striped Bass, White Bass, and hybrid striped bass. Striped Bass are native to the Atlantic Coast and the eastern part of the Gulf of Mexico (Sublette et al. 1990). Striped Bass have been stocked in Elephant Butte Reservoir intermittently depending on availability. Striped Bass also inhabit Lake Powell, AZ/UT and could potentially swim upstream into the San Juan River. There is no evidence that Striped Bass have successfully reproduced in New Mexico and the population in Elephant Butte Reservoir is maintained by stocking fry or fingerlings obtained from other states or private hatcheries. White Bass are native to the central Mississippi Drainage down to the Gulf of Mexico and a few watersheds in Texas. They were first introduced into New Mexico in 1969 into Willow Lake and can be found in many lakes and reservoirs throughout the state, excluding the Gila Basin. White Bass successfully reproduce in New Mexico reservoirs and are not stocked by the Department.

Management strategies for Striped and White bass are different due to differences in life history and “trophy” fish potential. The Department manages the Striped Bass fishery at Elephant Butte Reservoir to increase the likelihood of fish growing to trophy size. Such a size structure is slightly biased towards a greater proportion of adults in the population compared to juveniles as measured by Proportional Stock Density. Regulations for Striped Bass at Elephant Butte Reservoir are currently set as one fish per day and no length limit. There is no harvest, possession or length limit for any Striped Bass in the San Juan River to support endangered fish recovery efforts in that basin. Because White Bass populations are highly cyclical, current regulations limit harvest to 25 fish per day with no length limit. This management approach is intended to support liberal harvest of White Bass when abundant. Considering the cyclical nature of White Bass, no specific management parameters have been developed.

Hybrid striped bass, an artificial cross between Striped Bass and White Bass, are being considered as a new management species in New Mexico to expand angling opportunity. Hybrid striped bass, also known as wipers, Palmetto bass, or sunshine bass, are a popular recreational species in other states due to their rapid growth potential, adaptability to various water quality parameters, and availability from state and private hatcheries. A pilot project to establish a hybrid striped bass fishery in Caballo Lake has been proposed and is anticipated for implementation in 2022.

Striped Bass Parameters at Elephant Butte Reservoir

- Catch Per Unit Effort: 1 fish/net night
- Size Structure: Proportional Stock Density between 50 and 70
- Body Condition: Average relative weight of at least 85

Walleye

Native to the upper midwestern United States and Canada, Walleye were first introduced into New Mexico in 1959 to expand angling opportunity in the State's reservoirs. Walleye are highly piscivorous (i.e., fish eating) with Gizzard Shad and Yellow Perch as their dominant prey. In New Mexico, natural spawning success is typically low to nonexistent and most populations are dependent upon annual stocking. The Department has conducted Walleye field spawns (i.e., egg collection) from various reservoirs since the 1970's. In the spring, eggs are collected, fertilized, and transported to the Rock Lake State Fish Hatchery for incubation and hatching. When local spawns provide inadequate egg collection, eggs are obtained from other state or federal hatcheries. Walleye are then stocked into reservoirs as fry, typically at a rate of 500 per surface acre. All Walleye populations are currently managed with statewide regulations of five fish per day. Effective April 1, 2022 there is no length limit for Walleye statewide.

Walleye Parameters

- Catch Per Unit Effort: ≥ 4 fish/net night
- Body Condition: Average relative weight of at least 80

Tiger Muskellunge and Northern Pike

Tiger muskellunge or "tiger muskie" are a sterile hybrid between Northern Pike and Muskellunge. Both Northern Pike and Muskellunge are native to the upper midwest and northeast United States. Northern Pike were first introduced into New Mexico in the 1960s and tiger muskie were first introduced in the early 2000s. Several self-sustaining populations of Northern Pike exist in the state and the Department does not stock them. The Department stocked tiger muskie in Bluewater and Quemado reservoirs in the early 2000s to control Goldfish and White Sucker. These are still the only waters the Department manages with this

hybrid species and a popular sport fishery has grown around the opportunity. The Department must continually stock tiger muskie to maintain a population. Challenges with tiger muskie management include maintaining enough tiger muskie to control unwanted fish at low abundances, providing a unique angling experience for tiger muskie, and maintaining or expanding angling for other species including trout.

Statewide regulations for Northern Pike are 10 fish per day with no length limit. No specific population parameters have been developed for Northern Pike. Regulations at Eagle Nest Lake for Northern Pike are mandatory harvest with unlimited take. These regulations are intended to suppress the illegally introduced species at Eagle Nest Lake and minimize potential deleterious effects on the popular trout and salmon fisheries.

Current regulations for tiger muskie are one fish over 40 inches per day at Bluewater and Quemado reservoirs. The Department conducts routine surveys of tiger muskie at each lake to estimate the density of fish (number of fish/surface acre of lake habitat) and evaluate population size structure. Coupled with carefully developed stocking rates, the Department has refined the balance between tiger muskie density, potential harvest, trophy fishing opportunities, and other recreational angling opportunities.

Tiger Muskie Parameters

- Density: 4 fish/surface acre (10-year average of surface area)
- Unwanted Fish Catch Per Unit Effort: <20 fish/hour electrofishing of Goldfish and White Sucker in target waters
- Body Condition: Average relative weight of at least 90 for fish ≥30 inches

Other Warmwater Species

Several additional sportfish species inhabit New Mexico waters which provide alternative yet less popular fisheries. They also provide important forage sources for larger predatory fishes. These species include Black and White crappie, Yellow Perch, and several species within the sunfish family such as Bluegill and Green Sunfish. Active management specifically for these species is not common, and the Department does not typically rear them, although some waters have one or more of these species identified as a focal species. Some urban fishing ponds provide excellent habitat for sunfish species and provide exciting opportunities for young anglers. Sunfish can overpopulate small ponds so, where warranted, Largemouth Bass are occasionally stocked to reduce sunfish density and increase growth rates. Currently, Yellow Perch are managed as self-sustaining populations and by statewide regulation of 30 fish per day with no length limit. The Department occasionally transplants Yellow Perch within the state to establish or supplement prey base and could do this for other species. Sunfish in New Mexico are not actively managed other than by a statewide limit of 20 fish per day with no size limit

and occasional supplemental stocking. Crappie are managed by a statewide regulation of 20 fish per day with no length limit. No specific parameters have been developed for these fish species.

Trout and Salmon

Several salmonid species inhabit New Mexico waters. Trout native to New Mexico include Gila Trout, historically found in coldwater reaches within the Gila River basin, and Rio Grande Cutthroat Trout, historically found in coldwater reaches of the Canadian, Pecos, and Rio Grande River basins. Both species have declined considerably from their historical distribution and Gila Trout are currently listed as "Threatened" under the ESA and the NMWCA.

Introduced species include Brook Trout, Brown Trout, kokanee, Lake Trout, Rainbow Trout, and other subspecies of Cutthroat Trout. Rainbow Trout are native to Pacific slope drainages in North America and were first introduced to New Mexico in 1896. Due primarily to stocking, Rainbow Trout are the most widely distributed and sought-after trout in the state. Brown Trout were transplanted from Europe, while Brook Trout are native to lakes and streams in eastern North America. Other subspecies of Cutthroat Trout which have been stocked in New Mexico include Snake River and Yellowstone cutthroat trout which have hybridized with our native trout and Rainbow Trout. Lake Trout have been introduced to several lakes in New Mexico but currently only inhabit Heron and El Vado reservoirs. Kokanee are inland Sockeye Salmon and have been stocked into several large coldwater reservoirs in the state. The Department conducts annual field spawns for kokanee to maintain these populations. While wild populations of Rainbow Trout exist in the state, the majority of Rainbow Trout angling opportunities are maintained via stocking. The Department currently stocks Rainbow Trout in approximately 150 waters statewide (https://www.wildlife.state.nm.us/fishing/weekly-report/).

The Department employs three management strategies for trout and salmon fisheries. Management strategies include: Put and Take, Put, Grow, and Take, and Wild waters; see the Glossary of Terms for a definition of each fishery type. In some cases, different management strategies may be employed for different species within the same water. Put and Take Trout Waters range from popular mountain streams with high angler use to large reservoirs and urban ponds. In nearly all cases, Put and Take Trout Waters are stocked consistently throughout a stocking season with catchable Rainbow Trout.

In limited cases, surplus catchable Gila Trout and Rio Grande Cutthroat Trout are stocked to increase recreational angling opportunities. A Framework for Management of Gila Trout Angling was approved by both the Department and the FWS which includes waters which will be stocked with Gila Trout for recreational purposes as well as recovery waters which are open

to angling. Different regulations are in place for Put and Take Trout Waters though the daily bag limit is generally 5 fish per day for Rainbow Trout and 2 fish per day for Cutthroat Trout. In some cases, Special Trout Water regulations are in place to equitably distribute angling opportunities and increase the retention time of stocked catchable trout within a waterbody.

Put, Grow, and Take Trout Waters may have limited habitat to support natural reproduction or angler harvest exceeds the number of fish produced via natural reproduction. In other cases, the Department stocks native trout with hopes of increasing the opportunity for anglers to catch a native trout within historical habitats. Waters managed as Put, Grow, and Take Trout Waters range from high mountain lakes, large coldwater reservoirs, to small streams. All kokanee fisheries and some triploid Rainbow Trout, recreational Rio Grande Cutthroat Trout, and recreational Gila Trout are managed as Put, Grow, and Take Waters. Rio Grande Cutthroat Trout that are surplus to restoration needs, discussed below, are stocked with hopes of contributing 5 to 15% of the overall trout abundance in select reaches. Harvest regulations are similar for Put and Take Waters and Put, Grow, and Take Waters. Daily bag limit for kokanee during the non-snagging season is 5 fish per day. During the annual snagging seasons at select waters, the daily bag limit is 12 fish per day. Snagging of kokanee is permitted because these fish will die after reaching spawning condition. In some cases, Special Trout Water regulations are in place to increase growth potential of stocked fish to larger sizes (e.g., San Juan River tailwater).

Wild Trout Waters include populations of trout that are maintained entirely via natural reproduction. Fisheries may be composed of a single species or include several species. Wild Trout Waters include Brook, Brown, Cutthroat, Gila, Lake, and Rainbow trout. The recovery populations of Gila Trout that are open to angling and Conservation Populations of Rio Grande Cutthroat Trout are included in Wild Trout Waters. At this time, five wild populations of Gila Trout are open to angling in New Mexico along with dozens open for Rio Grande Cutthroat Trout. Considering the conservation status of these species, these waters are formally designated as Native Fish Waters and are discussed further below. Specific criteria for both Conservation Populations of Rio Grande Cutthroat Trout and Gila Trout populations which are open to angling are discussed in the relevant conservation and recovery planning documents for each species. Since Wild Trout Waters are entirely supported by natural reproduction, avoiding overfishing via harvest regulations is of significant importance. The wild Lake Trout population in Heron Reservoir is managed to limit harvest and promote a stable population with a limited daily bag limit of 2 fish per day. Most Wild Trout Waters are subject to the statewide daily bag limit of 5 fish per day while others have Special Trout Water regulations.

Special Trout Waters have unique regulations intended to manipulate or protect the population through reduced bag limits and/or restrictions of allowable terminal tackle. In 2018, Special

Trout Water regulations were restructured with a New Mexico chile theme. Red Chile Waters prohibit harvest and limit terminal tackle (e.g., artificial lure or fly only, single barbless hook) and are geared toward producing trophy size trout (e.g., San Juan River tailwater), conserving native trout species, or protecting waters with special angling interest. Green Chile Waters allow daily harvest of two trout while still limiting terminal tackle. Green Chile Waters allow opportunity to harvest fish while still providing a unique experience of a quality fishery. X-mas Chile Waters allow daily harvest of two trout with any legal terminal tackle and are focused on providing quality fisheries without limiting any one angler group. In addition, a subset of Red Chile Waters, known as Native Trout Conservation Waters, were adopted to conserve native trout by allowing unlimited harvest of non-native trout to suppress these species and reduce competition.

Management strategies for Put and Take Trout Waters are focused on maximizing stocked fish return to the angler and spreading angling opportunity throughout an entire season and among anglers. Conversely, Put, Grow, and Take Trout Waters and Wild Trout Waters seek to provide angling opportunity yet ensure populations are maintained through time. As a result, objective parameters for Put and Take Trout Waters are focused on angler harvest rates and stocking rates. These parameters measure how effectively the Department allocates catchable Rainbow Trout and how those fish return to anglers. Objective parameters for Put, Grow, and Take Trout Waters are intended to establish desired population density and growth rates of stocked fish. Considering the diversity of Wild Trout Waters in the state, no single population parameters will fit all populations. In this case, general indicators of desired population status were developed for Wild Trout Waters.

Trout Parameters

Put and Take:

- Angler Harvest Rate: 1 fish/angler day during stocking season
- Stocking Rate: Stock at least 1 fish/angler day

Put, Grow, and Take:

Rainbow Trout

- Catch Per Unit Effort: 10 fish/hour of electrofishing
- Size Structure: 50% of Rainbow Trout surveyed > 10 inches in length

Rio Grande Cutthroat Trout

- Trout Community: > 5% of trout abundance composed of Rio Grande Cutthroat Trout

Kokanee

- Catch Per Unit Effort: 20 fish/net night with pelagic set nets

- Age structure: Equal contribution of Age-3 and Age-4 fish in annual spawning population

Wild:

Recreational Trout Waters

- Size Structure: Multiple year classes of trout including young of year
- Density: > 80 adult trout/acre of habitat

Quality Trout Waters

- Quality Potential: 5% of trout ≥ 12 inches
- Density: ≥ 400 adult trout/acre of habitat

Trophy Trout Waters

- Trophy Potential: 5% of trout ≥ 20 inches
- Angler Catch Rate: ≥ 1 fish/hour
- Density: ≥ 1,250 adult trout/acre of habitat

Native Species

New Mexico waters historically supported at least 66 native fish species. Several species or subspecies have been extirpated though over 50 still exist in the state. Many of these native species have declined from historical levels due to a variety of factors and are protected under the NMWCA or the ESA. Some native species such as Gila Trout and Rio Grande Cutthroat Trout are better known to the public compared to rare endemic fishes such as Loach Minnow or White Sands Pupfish. In some areas, conservation efforts and angling opportunity are complementary. The purpose of Departmental conservation efforts for native fishes is to address or mitigate existing threats to species to preclude the need to list a species under federal or state law, increase the distribution of species to warrant downlisting or removal from listing status, and maintain the ecological roles that many of these species play in our landscape. Improving the status of these taxa also benefit New Mexico anglers by minimizing potential restrictions imposed on sportfish activities where conflicts exist with listed species. The Department allocates significant resources to native fish conservation efforts in every river basin in the state.

Native fish management in New Mexico varies by species, drainage, and available resources to improve species status. They are also part of a fish assemblage that could include native, non-native, and sportfish species. In many cases, some native fish coexist with other species or can thrive in a modified environment. In those cases, native fish are managed in conjunction with typical management activities such as monitoring, regulation of sportfish take, alteration of species stocking or location, or species importation evaluations. In areas with no known direct conflict between sportfish and native fish management, the Department does not specifically

take actions to the detriment of native fish, though species management is typically focused on sportfish. In others, the aquatic environment has been altered to a degree where certain native fish do not persist in any significant manner. Sportfish management can be in direct conflict with native fish or communities due to predation, interbreeding, or competition. How Department management is focused on instances of altered waters and species hinges upon the feasibility of certain management actions to benefit a species or community, competing resource development (e.g., dams and water withdrawals), and existing programs currently addressing a particular species. All of this must be carefully balanced with existing or potential angler use within all watersheds in the state. To facilitate species recovery for some native fishes, sport fisheries have been targeted for suppression or complete removal.

Gila Trout is listed as threatened under the ESA and the NMWCA. The FWS downlisted Gila Trout from endangered to threatened in 2006 and issued a special rule, also known as a "4d" rule. This special rule permits take of Gila Trout when conducted in accordance with applicable state fish and wildlife conservation laws including fishing activities under state laws and regulations, educational and scientific purposes, the enhancement of propagation, and other conservation actions consistent with the ESA. The Department has been engaged in Gila Trout recovery efforts for decades. Downlisting and delisting criteria for Gila Trout are defined in the Gila Trout Recovery Plan (2003) and a revision of this plan is drafted and expected to be finalized in 2022. The Department plans to continue to conduct restoration efforts including piscicide treatments to remove competing or hybridizing non-native trout species, habitat protection via fish migration barriers, and development of angling regulations, in accordance with the recovery plan and future revisions. The Framework for Management of Gila Trout Angling (2015) provides additional guidance for recreational stocking efforts as well as monitoring of streams open to angling.

Warmwater reaches of the Gila River Basin support several endemic and imperiled native species including Loach Minnow, Roundtail Chub, and Spikedace. These species are negatively affected by non-native predators and their distribution has declined significantly from historical levels. While non-native predators are a threat to some Gila River fishes, other activities have altered habitats that negatively affect native fisheries. Active conservation efforts in the Gila River basin for native fish include active suppression of non-native fishes in certain reaches and repatriating rare fishes to historically occupied habitats. Future activities to benefit native species could include angling regulations to encourage removal of non-native predators from priority reaches, non-native fish removal via piscicide treatments, and habitat protection via fish barriers. The Department participates in various recovery activities for fish as described below.

Federal listing of Rio Grande Cutthroat Trout was determined to be not warranted in 2014 and it was removed from the candidate species list under the ESA. In 2019, as a result of ongoing litigation, a Federal Court for the District of Colorado vacated the previous decision and Rio Grande Cutthroat Trout were returned to Candidate status. The Department has been a signatory to the Rangewide Conservation Agreement for Rio Grande Cutthroat Trout since 2002 and a complementary Conservation Strategy since 2013. The purpose of these documents is to memorialize formal commitments by the Department and other federal, state, and tribal cooperators to Rio Grande Cutthroat Trout conservation efforts including desired population numbers within certain watersheds. The Department will continue ongoing restoration efforts that benefit Rio Grande Cutthroat Trout similar to those described for Gila Trout above. This will include mechanical suppression efforts and angling regulations intended to suppress non-native trout in designated reaches. The Department has also included Rio Grande Sucker and Rio Grande Chub into restoration planning efforts to restore the entire native fish community when appropriate.

Warmwater reaches of the San Juan River and tributaries currently support Colorado Pikeminnow, Razorback Sucker, and, to a lesser extent, Roundtail Chub. Both Colorado Pikeminnow and Razorback Sucker are federally protected and their recovery is the primary purpose for the San Juan River Basin Recovery Implementation Program (SJRBRIP) in which the Department participates. Management activities conducted as part of that program include annual monitoring, non-native fish suppression (Channel Catfish removal), and participation in the SJRBRIP Biology Committee meetings. The Department plans to continue participation in these efforts, craft new approaches to recovery, as well as develop other potential conservation efforts that could benefit Roundtail Chub.

Multiple conservation plans, agreements, and state and federal recovery plans also guide Department actions for native fish management and conservation. Many of these plans and agreements summarize threats to each species and include approaches to address those threats. Below is a list of conservation planning documents organized by the primary basin to which they are relevant. Some plans are applicable to multiple drainages. Copies of these plans can be found on the Department website at https://www.wildlife.state.nm.us/fishing/fisheries-management/.

Gila River Basin

- Colorado River Basin Chubs Recovery Plan, 2006 (State)
- Framework for Management of Gila Trout Angling, 2015
- Gila Trout Recovery Plan, 2003 (Federal)
- Loach Minnow Recovery Plan, 1991 (Federal)
- Spikedace Recovery Plan, 1991 (Federal)

Mimbres River Basin

- Chihuahua Chub Recovery Plan, 1986 (Federal)
- Fishes of the Rio Yaqui Recovery Plan, 1995 (Federal)

Rio Grande and Pecos River Basins

- Conservation Agreement for Pecos Pupfish, 2013
- Conservation Agreement for Rio Grande Chub and Rio Grande Sucker, 2018
- Conservation Agreement for Rio Grande Cutthroat Trout in the States of Colorado and New Mexico, 2013
- Pecos Bluntnose Shiner Recovery Plan, 1992 (Federal)
- Pecos Gambusia Recovery Plan, 1983 (Federal)
- Recovery and Conservation Plan for Four Invertebrate Species: Noel's Amphipod, Pecos Assiminea, Koster's Springsnail, and Roswell Springsnail, 2005 (State)
- Recovery Plan for Four Invertebrates of the Pecos River Valley: Noel's Amphipod, Pecos Assiminea, Koster's Springsnail, and Roswell Springsnail, 2019 (Federal)
- Rio Grande Chub Conservation Strategy, 2021
- Rio Grande Cutthroat Trout Conservation Strategy, 2013
- Rio Grande Silvery Minnow Recovery Plan, 2010 (Federal)
- Rio Grande Sucker Conservation Strategy for, 2021
- Texas Hornshell Recovery Plan (State), 2007
- Texas Hornshell Draft Recovery Plan, 2020 (Federal)

San Juan River Basin

- Colorado Pikeminnow Recovery Plan, 2002 (Federal)
- Colorado River Basin Chubs Recovery Plan, 2006 (State)
- Range-wide Conservation Agreement and Strategy for Roundtail Chub, Bluehead Sucker, and Flannelmouth Sucker, 2006
- Razorback Sucker Recovery Plan, 2002 (Federal)

Zuni Basin

- Zuni Bluehead Sucker Recovery Plan, 2004 (State)

Tularosa River Basin

- Cooperative Agreement for Protection and Maintenance of White Sands Pupfish, 2020
- White Sands Pupfish Conservation Plan, 2015 (State)

Major Accomplishments since 2016

Since adoption of the Statewide Fisheries Management Plan in 2016, major accomplishments by the Department and our partners include:

- Gila Trout have been restored to 24 miles of habitat in Whitewater Creek. Removal of nonnative trout was completed in 2019 and stocking of Gila Trout began in 2020 and will continue through at least 2022
- The Glenwood State Fish Hatchery is currently undergoing a major renovation to become the Department's Gila Trout facility. When complete, the facility will house a broodstock to propagate Gila Trout for species recovery and expanded angling opportunities
- In 2021, the Department purchased the property adjacent to the Glenwood State Fish Hatchery including water rights significant to the hatchery's operations. The purchase included portions of Whitewater Creek and the San Francisco River that are occupied habitat for endangered Loach Minnow and Spikedace, thus securing an important refuge for both species
- From 2016 to 2020 the proportion of stocked catchable Rainbow Trout over 10 inches increased from 61% to 73%
- Rio Grande Cutthroat Trout have been restored to 90 miles of stream and Costilla Reservoir. The Department anticipates completing removal of nonnative fishes from the final areas of the project in 2022 and for stocking to begin in 2023
- Five fish migration barriers were constructed since 2016. Barriers were completed in Willow Creek (Gila Drainage), Willow Creek (Pecos Drainage), the BLM Overflow Wetlands on the Pecos River, and Costilla Creek. Each barrier protects a population of Gila Trout, Pecos Pupfish, or Rio Grande Cutthroat Trout and provides benefits for other native fish like Rio Grande Chub and Rio Grande Sucker
- In 2017, the Department transitioned angler surveys to a web-based survey method from traditional methods (e.g., phone and mail). The surveys provide insight on annual angler satisfaction, seek input on current topics, refine existing management programs, and monitor trends in angler use and harvest. Gila Trout were also added to the survey to explore increased angler interest for this species
- Since 2016, the Department has improved fish habitat on seven streams and rivers, totaling 14.5 miles, and one 60-acre lake
- In 2018, warmwater fish production at Rock Lake State Fish Hatchery converted to primarily Largemouth Bass. Since that conversion, the hatchery has refined spawning practices, increased annual stocking by an average of 8700%, and stocked 1,017,697 Largemouth Bass in 25 waters statewide

- The Department expanded youth angling opportunities by opening Rock Lake State Fish Hatchery settling ponds to anglers 11 years old and younger, providing Rainbow Trout and Largemouth Bass to support multiple fishing derbies, and expanded Rio Grande Cutthroat Trout stocking at the Seven Springs Kids Pond. In addition, age-restricted waters were simplified to four basic types and daily harvest limits were aligned with statewide regulations at multiple waters to reduce confusion and increase opportunity
- In 2021, the Department provided two new tools to the state's anglers: Fishing Conditions and Trip Planner that synthesizes fishing report data to help anglers find the best times and places to fish for certain species and a new Fishing Waters Map that is a wealth of information about fishing locations throughout New Mexico. Both can be found at www.wildlife.state.nm.us/fishing/fishing-conditions-trip-planner/
- In July 2017, the State Game Commission amended 19.30.14 NMAC to increase protection of New Mexico's waters from AIS by requiring inspections for out of state watercraft, advanced notice for watercraft 26 feet or larger being transported into the state, and hull plug to be removed during transport. The new rule also implements a watercraft inspection seal program. The amended rule along with the Department's ongoing AIS inspection and decontaminations have thus far succeeded in preventing zebra and quagga mussels from becoming established in the state
- In February 2021, the State Game Commission amended 19.35.7 NMAC to update and clarify importation rules associated with fish health
- The Special Trout Water system was simplified to four basic regulation packages with a New Mexico chile theme. These regulations were tailored to improve angler understanding, facilitate native trout restoration, and maximize biotic potential in these trout fisheries
- The State Game Commission designated three waters as Trophy Bass Waters that included a regulatory change and focused stocking strategy to protect and enhance angling opportunities for trophy sized Largemouth Bass

Identified Priority Projects and Needs for Further Investigation and Research

The 2016 Plan identified a number of programmatic fisheries priorities including evaluation of hatchery stocking, habitat restoration, AIS monitoring and prevention, species recovery efforts, and statewide fisheries management. The 2016 priorities and details regarding progress made toward them can be found in Appendix B. Below are the ongoing and new priorities, in many cases these priorities are direct responses to challenges and threats, like climate change and reduced water availability.

Evaluation of Hatchery Stocking

Trout

- Investigate potential for reducing or eliminating stocking of catchable trout from five waters or reaches which support wild trout and reallocate to higher use systems including lakes and ponds
- Continue to evaluate allocation of catchable and subcatchable trout
- Continue to investigate areas where native trout, surplus to recovery efforts, can be used to increase angling opportunities for native trout including high mountain lakes
- Investigate opportunities for additional native trout production to expand angling opportunities for Gila and Rio Grande Cutthroat trout
- Monitor and adjust kokanee stocking strategies in accordance with varying reservoir levels and differing spawning success

Catfish

- Refine Channel Catfish stocking strategies to best allocate private-sourced catfish

Walleye

- Monitor and adjust Walleye stocking strategies in accordance with varying reservoir levels and differing spawning success

Black Bass

- Establish long-term stocking goals for Largemouth Bass produced at Rock Lake State Fish Hatchery
- Investigate success of stocked Largemouth Bass
- Investigate genetic composition of wild bass in New Mexico's reservoirs to identify potential of diversifying hatchery brood and stocking strategies

Temperate Bass

- Investigate potential of hybrid striped bass as a management species and identify candidate reservoirs for stocking
- Stock hybrid striped bass into Caballo Lake and monitor for success

Habitat Restoration

- Work with partners and volunteers, design and implement instream, riparian, and reservoir habitat restoration efforts on Commission owned Wildlife Management Areas including monitoring and maintenance of existing projects
- Work with partners and volunteers, design and implement instream, riparian, and reservoir habitat restoration efforts on non-Commission owned properties

- Implement fish habitat improvement projects under the Department's 2021 updated Habitat Stamp Program

Aquatic Invasive Species

- Maintain prevention efforts including watercraft inspection stations
- Review and update the 2008 New Mexico Aquatic Invasive Species Management Plan

Fish Health

- Maintain hatchery and wild fish health program to mitigate risk from known fish pathogens
- Provide recommendations for fish health risk assessments, management practices, and hatchery improvements
- Develop and test a Fish Quality and Health Assessment tool for stocked Rainbow Trout that aligns with angler expectation for fish quality and appearance

Environmental Compliance

- Complete a comprehensive, statewide Biological Assessment for ESA Section 7 compliance for all Departmental fish monitoring and surveys in New Mexico
- Maintain all environmental compliance for Fisheries Management Division activities

Species Recovery Efforts

Native Trout Restoration

- Continue Rio Grande Cutthroat Trout restoration in the Costilla Creek watershed as well as identify restoration waters in the Pecos River and Canadian River watersheds
- Continue Gila Trout restoration in the Gila River Basin
- Install, enhance, and maintain fish migration barriers used to protect restored and existing populations of native trout
- Assess and act on opportunities for restoration created by wildfire or other disturbances as they occur, as done in Mineral, Willow, and Whitewater creeks (Gila Basin), and Rito de los Frijoles and Las Animas Creek (Rio Grande Basin)
- Continue investigating use and effects of YY trout to aid in native trout restoration efforts
- Incorporate other native fishes into restoration efforts including warmwater reaches, where possible. Examples include Rio Grande Sucker, Rio Grande Chub, Spikedace, and Loach Minnow.

Rio Grande Basin Warmwater Fishes

- Investigate distribution and genetic status of Rio Grande Chub and Rio Grande Sucker throughout the state
- Implement restoration activities for Rio Grande Chub and Rio Grande Sucker as described each species Conservation Strategies

Gila River Basin Warmwater Fishes

- Identify potential restoration and repatriation opportunities for Spikedace, Loach Minnow, and Roundtail Chub in the Middle Fork Gila River, San Francisco River drainage, and other locations
- Incorporate native trout into restoration efforts to complement coldwater reaches and other sensitive or listed taxa recovery efforts, where possible

San Juan River Basin Fishes

- Investigate opportunities to increase passage for native fish
- Identify potential restoration and repatriation opportunities for Roundtail Chub
- Investigate potential use and effects of YY fish to aid non-native fish suppression efforts

Lower Pecos River Basin Fishes

- Investigate genetic status of Pecos Pupfish populations

Statewide Fisheries Management

- Work to encourage expanded youth angling opportunities
- Investigate regulatory structure to manage potential hybrid striped bass fisheries in Caballo Lake and other waters
- Investigate potential regulatory structure to allow expanded use of set lines including ice fishing tip-ups and jug-lines for catfish
- Update, refine, and improve angler information sources including but not limited to the Fishing Conditions and Trip Planner and Fishing Waters Map
- Investigate angler use and harvest in native trout populations
- Refine an approach for resolving sportfish/native fish conflicts
- Work with NGO's to develop and implement conservation projects with direct volunteer involvement such as habitat improvement for sport and native fish, fish stocking, and nonnative fish control

Watershed Descriptions and Fisheries Management

To initiate the management reach delineations below, the National Hydrography Dataset (NHD) flowline and waterbody files for New Mexico were imported into existing Department geodatabases. Department staff identified management reaches based upon available fish distribution datasets and management activities. Management reaches were based upon individual waters, in some cases, but also grouped into watersheds or sub-watersheds where feasible. Once identified, corresponding features from the NHD datasets were exported into a new dataset. Additional spatial information, including hydrologic unit codes and geographic names information system (GNIS) codes, were appended into the new dataset. Non-spatial information including priority fish species, management type, and management direction for each were then incorporated. Some reservoirs were not included in the NHD and were digitized using the National Agriculture Imagery Program (U.S. Department of Agriculture) aerial photography from 2011 to 2014.

The term "Fish Species" in the tables below refers to individual species that are a management focus for the water identified. The management reaches that are identified for a species or suite of species does not necessarily mean that the entire reach is occupied by those species due to variation in water quality, flow regime, and habitat availability. Some of the mapped reaches could be dry or wet depending upon an individual water year. In many cases, the species identified are not a comprehensive list of species present within the water or could identify a species that does not yet inhabit a water. Activities such as monitoring or restoration will be focused on the focal species identified with potential community benefits for others when possible. Failure to mention a species does not imply that the Department intends to actively remove a species from a water. The maps included are intended for management direction only and do not reflect absolute distribution. Individual species accounts, datasets, and distributions are available from the Department, other state or federal agencies, and the BISON-M database maintained by the Department.

"Management Type" refers to general categories of activities such as stocking strategy, self-sustaining populations, or population suppression. The Native Fish designation includes all activities which could help to monitor, support, or restore the identified species as well as other members of the community.

"Management Direction" includes a brief synopsis of the Department's expected management for a water or species in that water. Stocking rates will generally follow the Department's stocking schedule (www.wildlife.state.nm.us/fishing/weekly-report/) which may be modified over time. Stocking rates that vary by year or water levels are specifically noted in the tables below.

Canadian Watershed and Clovis Area Waters

The Canadian Watershed, in northeast New Mexico, encompasses about one-sixth of the land area of the state or about 10.9 million acres (New Mexico Water Quality Control Commission 2002). Canadian River tributaries flow east and southeast from their origins on the east slopes of the Sangre de Cristo cordillera of northern New Mexico and southern Colorado. As it traverses the Great Plains in a southerly and then easterly direction several perennial tributaries, including the Cimarron, Conchas, Mora, and Vermejo rivers, join the South Canadian River before it exits New Mexico near the town of Logan. The Upper Canadian, Middle Canadian, Upper Beaver, and the Dry Cimarron are the only perennial sub-basins.

Settlement and irrigation withdrawal along high mountain valleys in the Mora River dates to the 1700's. Numerous impoundments and diversions have been built throughout the upper drainage for irrigation and municipal water. Livestock grazing continues to be the primary land use throughout the drainage. Two large dams on the Canadian River, Conchas Dam (constructed 1938) and Ute Dam (constructed 1962), impound reservoirs and modify natural flows as the river approaches the New Mexico-Texas border. These reservoirs provide suitable habitat for sportfish such as Largemouth Bass, Smallmouth Bass, and Walleye.

Historical fisheries management in the Canadian River Watershed has focused primarily on trout management in the headwaters with warmwater species in lower elevation habitats. Popular trout populations open to the general public include the Cimarron River, Eagle Nest Lake, Lake Maloya, and Morphy Lake. Popular warmwater fisheries within the drainage occur in Conchas and Ute lakes. Significant portions of the Canadian Watershed are privately owned which limits general public access to these areas without landowner permission. The Department also leases several waters from landowners to expand angling opportunities either through long-term leases or the Department's Open Gate Program. For example, the Department pays the Interstate Stream Commission $100,000 annually to obtain access to Ute Lake for the general public. Other examples of the Department leasing fishing access include Morphy and Springer lakes.

Several imperiled fish inhabit the New Mexico reaches of the Canadian River watershed. Arkansas River Shiner, federally threatened, inhabits the Canadian River below Ute Dam to the stateline. Peppered Chub, state threatened and currently proposed for federal listing as endangered, also inhabits the Canadian River below Ute Dam to the stateline. The state endangered Southern Redbelly Dace inhabits a small reach of Coyote Creek and is a disjunct population from other populations in the Mississippi River drainage. In addition, state threatened Suckermouth Minnow occur in the Canadian Basin. There is currently limited conflict among non-native sportfish and native fish management. Where some overlap exists, introduced species such as Brown Trout and Southern Redbelly Dace seem to co-exist.

Nevertheless, the Department has identified reaches to monitor and proactively manage the fish communities.

HUC 11080001 Canadian Headwaters, HUC 11080002 Cimarron

Management Direction for HUC 11080001 Canadian Headwaters

Water	Fish Species	Management Type	Management Direction
Canadian River and Tributaries (headwaters downstream to Cimarron River confluence)	Central Stoneroller	Native Fish	Maintain distribution
	Creek Chub	Native Fish	Maintain distribution
Lake Maloya (Sugarite Canyon)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
Lake Alice	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
Vermejo River and Tributaries (headwaters downstream to Canadian River confluence)	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout in Ricardo, Leandro, and Little Vermejo drainages. Conservation Population of Rio Grande Cutthroat Trout in the Vermejo River down to approximately Vermejo Park Ranch headquarters. Most of the watershed is privately owned. Leandro Creek portions located on Valle Vidal with Special Trout Water regulation (Red Chile Native Trout Conservation Water)
	Central Stoneroller	Native Fish	Maintain distribution
	Creek Chub	Native Fish	Maintain distribution
	Brook Trout	Suppression	Periodically remove Brook Trout in collaboration with private landowner to maintain the Rio Grande Cutthroat Trout population. Leandro Creek portions located on Vermejo Park Ranch have an ongoing YY Brook Trout stocking study. Unlimited angler harvest
Stubblefield Reservoir	Walleye	Put, Grow, and Take	Stock Walleye at 500 fry/surface acre. Actual stocking varies with reservoir elevation. Prone to drying during drought necessitating supplemental stocking of all species such as Bluegill, Crappie, Green Sunfish, Fathead Minnow, and Yellow Perch
	Channel Catfish	Put and Take	Stock catchable Channel Catfish as available

Management Direction for HUC 11080001 Canadian Headwaters			
Water	**Fish Species**	**Management Type**	**Management Direction**
	Yellow Perch	Wild	Supplement Yellow Perch from other sources as necessary during drought periods
	Largemouth Bass	Wild/ Supplemental stocking	Manage as Low-Density Bass Water and maintain statewide bass regulations. Supplement Largemouth Bass as necessary during drought periods
Maxwell Lake 13	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout during spring and fall. Fishing season is March 1 through October 31. Lake closed during winter for waterfowl resting. Prone to drying during drought necessitating supplemental stocking of all species such as Bluegill, Crappie, Green Sunfish, Fathead Minnow, and Yellow Perch
	Channel Catfish	Put and Take	Stock catchable Channel Catfish as available
	Yellow Perch	Wild	Supplement Yellow Perch from other sources as necessary during drought periods
	Largemouth Bass	Wild/ Supplemental stocking	Manage as Low-Density Bass Water and maintain statewide bass regulations. Supplement Largemouth Bass as necessary during drought periods
	Walleye	Put, Grow, and Take	Stock Walleye at 500 fry/surface acre. Actual stocking varies with reservoir elevation, low priority water
Maxwell Lake 14	Channel Catfish	Put and Take	Stock catchable Channel Catfish as available. Fishing season is March 1 through October 31. Lake closed during winter for waterfowl resting. Prone to drying during drought necessitating supplemental stocking of all species such as Bluegill, Crappie, Green Sunfish, Fathead Minnow, and Yellow Perch
	Yellow Perch	Wild/ Supplemental stocking	Supplement Yellow Perch from other sources as necessary during drought periods
	Largemouth Bass	Wild/ Supplemental stocking	Manage as Low Density Bass Water and maintain statewide bass regulations. Supplement Largemouth Bass as necessary during drought periods
	Walleye	Put, Grow, and Take	Stock Walleye at 500 fry/surface acre. Actual stocking varies with reservoir elevation, low priority water
Laguna Madre	Channel Catfish	Put and Take	Stock catchable Channel Catfish as available. Prone to drying during drought necessitating supplemental stocking of all species such as Bluegill, Crappie, Green Sunfish, Fathead Minnow, and Yellow Perch
	Yellow Perch	Wild	Supplement Yellow Perch from other sources as necessary during drought periods

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Management Direction for HUC 11080001 Canadian Headwaters

Water	Fish Species	Management Type	Management Direction
	Largemouth Bass	Wild/ Supplemental stocking	Manage as Low Density Bass Water and maintain statewide bass regulations. Supplement Largemouth Bass as necessary during drought periods
	Walleye	Put, Grow, and Take	Stock Walleye at 500 fry/surface acre. Actual stocking varies with reservoir elevation, low priority water

Management Direction for HUC 11080002 Cimarron

Water	Fish Species	Management Type	Management Direction
Cimarron River and Tributaries (Eagle Nest Dam downstream to Cimarron, NM)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Brown Trout	Wild	Special Trout Water regulation (Red Chile Water), from east end of Tolby Campground downstream 1.4 miles to the first Highway 64 bridge. Manage as a Quality Trout Water within the Special Trout Water reach
Gravel Pit Lakes	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
Clear Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout
Cimarron River and Tributaries (Cimarron, NM downstream to confluence with Canadian River)	Central Stoneroller	Native Fish	Maintain distribution. Significant portions of this area are on private land
	Creek Chub	Native Fish	Maintain distribution
Eagle Nest Lake	Triploid Rainbow Trout	Put, Grow, and Take	Stock subadult and catchable triploid Rainbow Trout. Consistently monitor to document effects of Northern Pike
	Kokanee	Put, Grow, and Take	Stock kokanee fry. Consistently monitor to document effects of Northern Pike
	Yellow Perch	Wild	Yellow Perch source for transplants to other waters
	Northern Pike	Suppression	Unlimited and mandatory harvest on Northern Pike to manage as unwanted species. Illegally introduced into the lake and are negatively affecting trout and salmon fishery
Springer Lake	Channel Catfish	Put and Take	Stock catchable Channel Catfish as available
	Northern Pike	Wild	Maintain regulations to support northern pike fishery

Management Direction for HUC 11080002 Cimarron			
Water	**Fish Species**	**Management Type**	**Management Direction**
	Largemouth Bass	Wild/ Supplemental stocking	Manage as Low Density Bass Water and maintain statewide bass regulations. Supplement Largemouth Bass as necessary during drought periods
Ponil Creek and Tributaries	Trout	Wild	Maintain regulations to support angling for wild trout
	Creek Chub	Native Fish	Maintain distribution
South Ponil Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout on Philmont Scout Ranch
McCrystal Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Water)
	Creek Chub	Native Fish	Maintain distribution
Rayado Creek	Creek Chub	Native Fish	Maintain distribution
Shuree Ponds	Triploid Rainbow Trout	Put and Take	Stock triploid Rainbow Trout annually. Size at stocking is typically > 15 inches in length. Special Trout Water regulation (Green Chile Water). One pond reserved for anglers 11 years of age or younger
Middle Ponil Creek (Headwaters downstream to Shuree Creek)	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Water). Investigate potential to restore area to support Core Conservation Population
North Ponil Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout present from McCrystal Creek downstream to FS Road 1950. Thermal barrier present at Seally Canyon confluence
	Creek Chub	Native Fish	Maintain distribution

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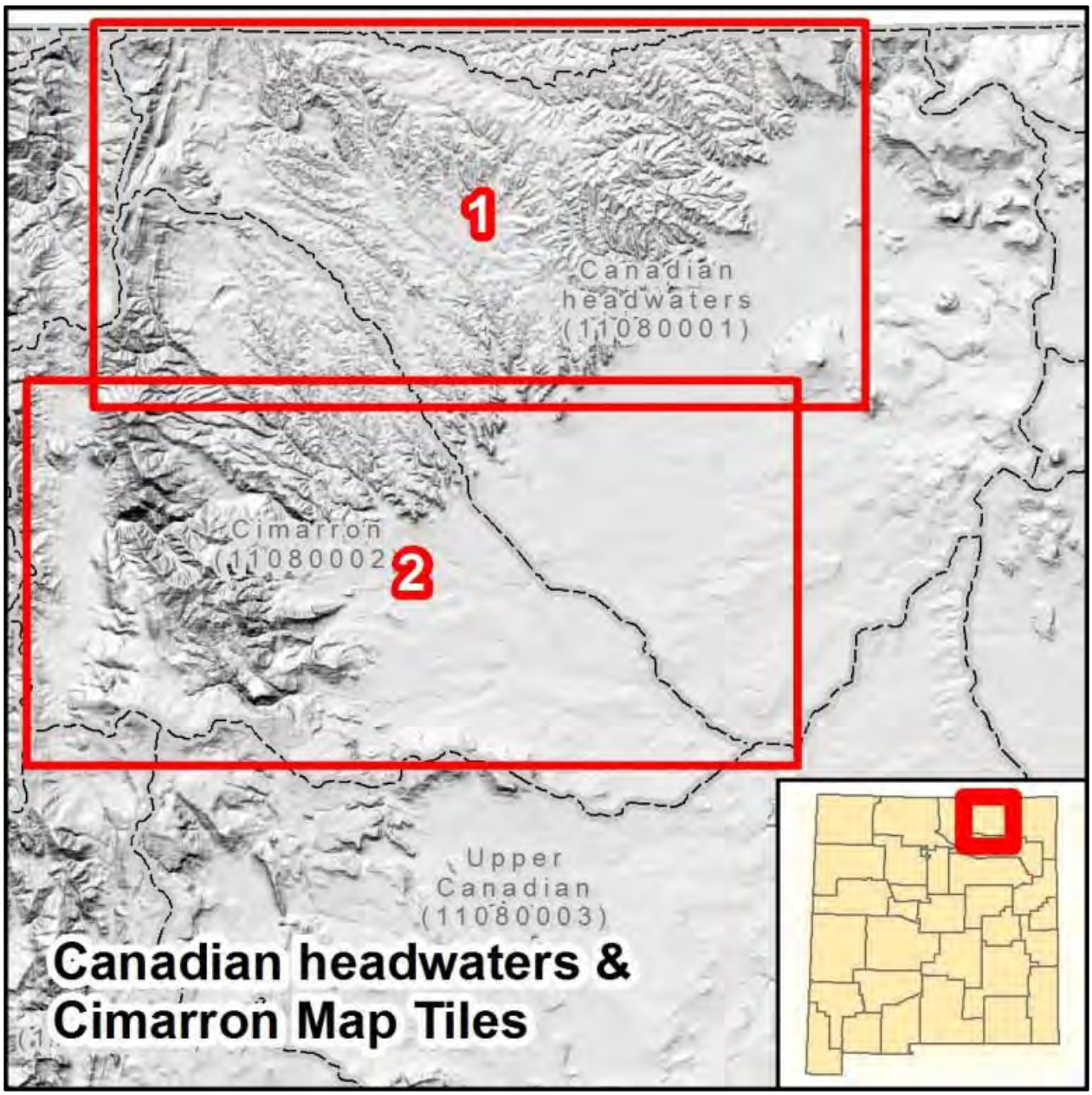


Figure 6. Canadian Headwaters and Cimarron Map Tiles

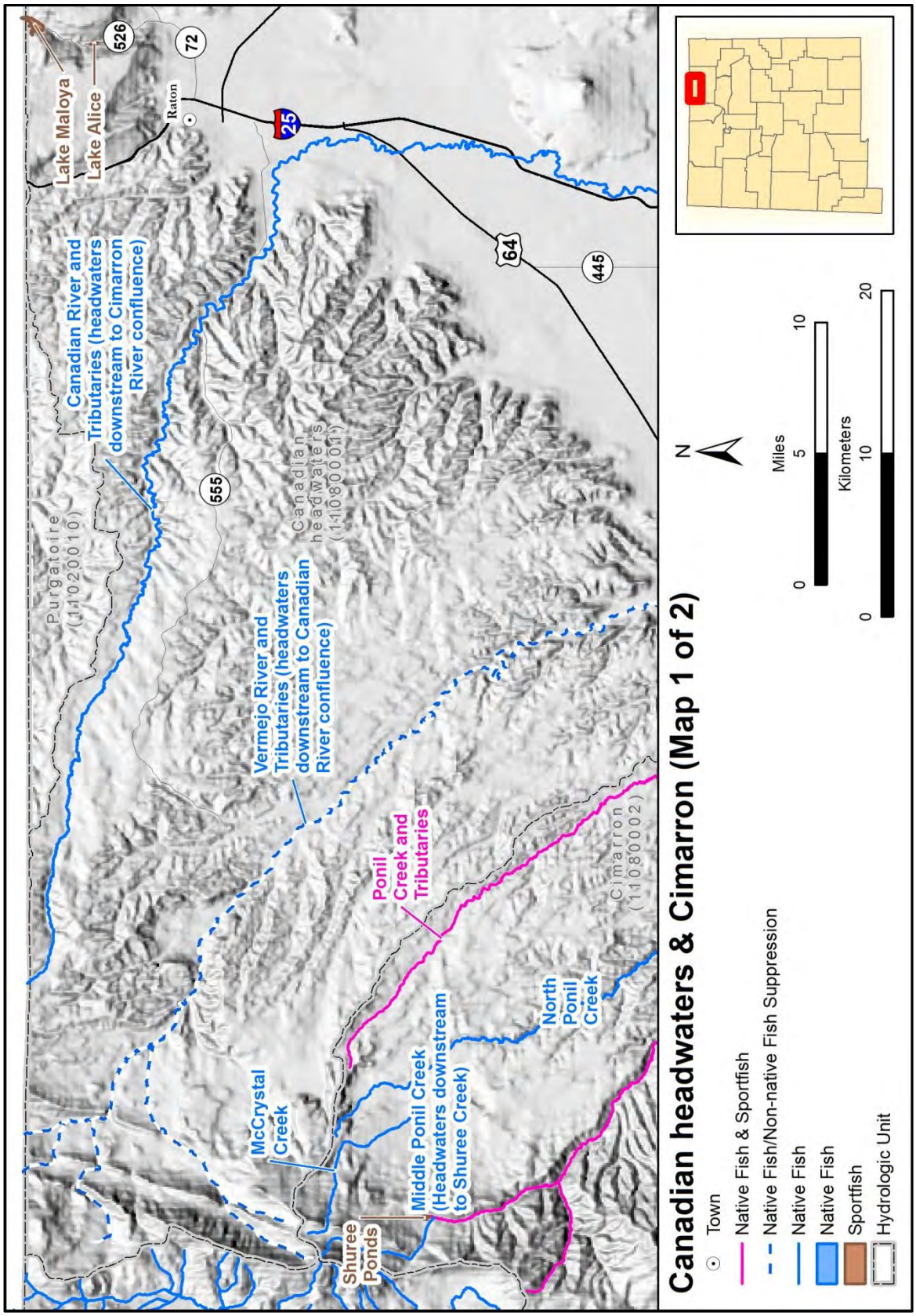


Figure 7. Canadian headwaters and Cimarron (Map 1 of 2)

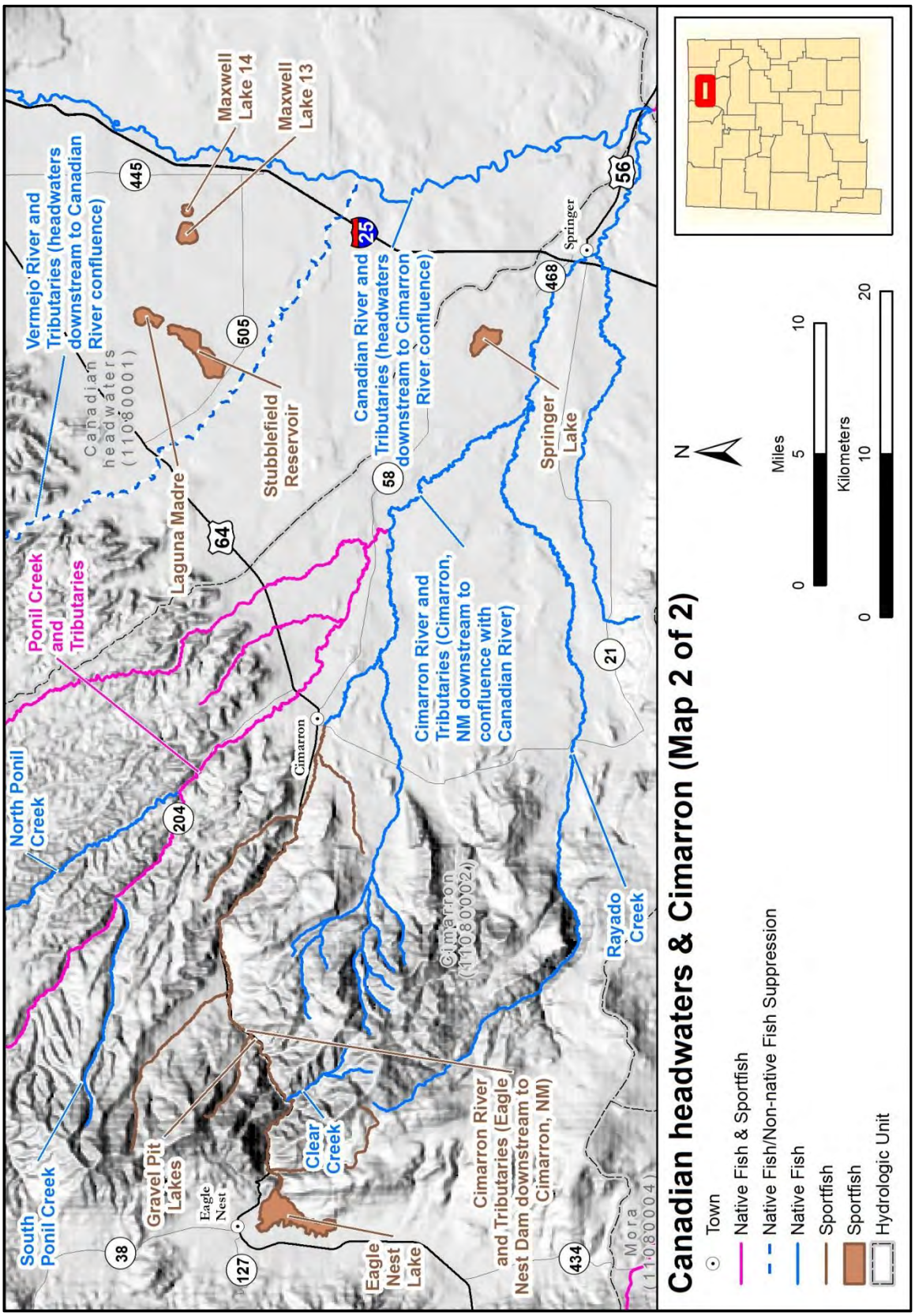


Figure 8. Canadian headwaters and Cimarron (Map 2 of 2)

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HUC 11080003 Upper Canadian, 11080005 Conchas

Management Direction for HUC 11080003 Upper Canadian, 11080005 Conchas

Water	Fish Species	Management Type	Management Direction
Canadian River and Tributaries (Cimarron River confluence downstream to Conchas Lake)	Channel Catfish	Wild	Maintain regulations to support angling for Channel Catfish
	Sand Shiner	Native Fish	Maintain distribution
	Suckermouth Minnow	Native Fish	Maintain distribution
Ocate Creek and headwaters	Brown Trout	Wild	Almost entirely on private land. Maintain regulations to support angling for wild trout
	Creek Chub	Native Fish	Maintain distribution
	Central Stoneroller	Native Fish	Maintain distribution
Lower Charette Lake	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Yellow Perch	Wild	Yellow Perch source for transplants to other waters
	Walleye	Put, Grow, and Take	Initiate Walleye stocking to establish a fishery
Conchas Lake	Largemouth Bass	Wild/Supplemental stocking	Manage as a Recreational Bass Water. Supplement with Largemouth Bass fingerlings as available
	Smallmouth Bass	Wild	Manage as a Recreational Bass Water. Special regulation for Smallmouth Bass (14-inch minimum size limit)
	White Bass	Wild	Maintain regulations to support White Bass fishery
	Walleye	Put, Grow, and Take	Stock Walleye at 500 fry/surface acre. Actual stocking varies with reservoir elevation. Maintain as a brood population as primary Walleye egg source

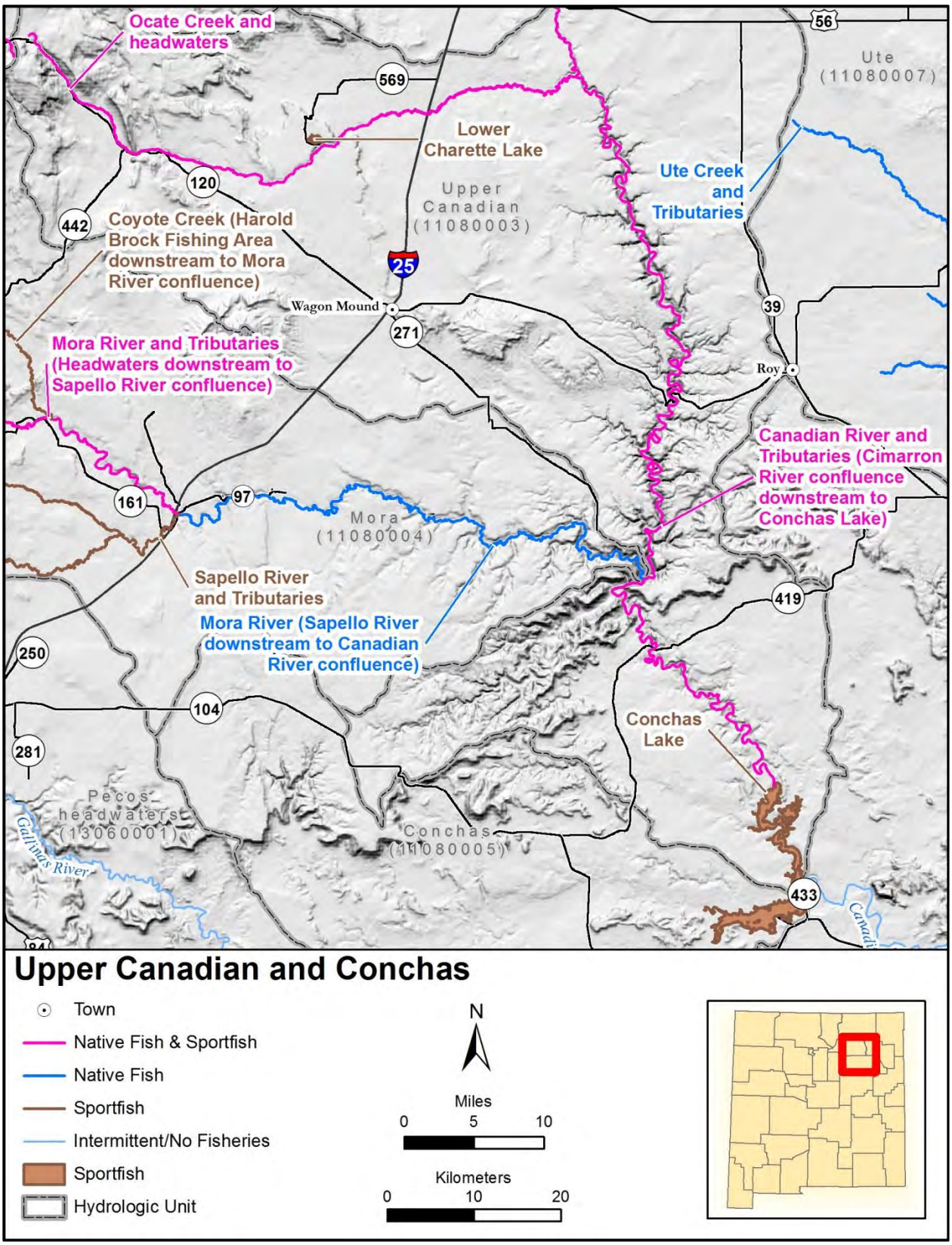


Figure 9. Upper Canadian and Conchas

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HUC 11080004 Mora

Management Direction for HUC 11080004 Mora

Water	Fish Species	Management Type	Management Direction
Luna Creek and Tributaries	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation on West Luna Creek (Red Chile Native Trout Conservation Water)
	Brown Trout	Suppression	Periodically remove Brown Trout to maintain the Rio Grande Cutthroat Trout population. Unlimited angler harvest
Mora River and Tributaries (Headwaters downstream to Sapello River confluence)	Brown Trout	Wild	Predominantly on private land except for extreme headwaters. Maintain regulations to support angling for wild trout
	Central Stoneroller	Native Fish	Maintain distribution
	Creek Chub	Native Fish	Maintain distribution
	Sand Shiner	Native Fish	Maintain distribution
Sapello River and Tributaries	Brown Trout	Wild	Maintain regulations to support angling for wild trout
Mora River and Tributaries (Headwaters downstream to Sapello River confluence)	Sand Shiner	Native Fish	Maintain distribution
	Green Sunfish	Native Fish	Maintain distribution
	White Sucker	Native Fish	Maintain distribution
Santiago Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout
Rito Morphy	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout
Morphy Lake	Triploid Rainbow Trout	Put and Take	Stock triploid Rainbow Trout annually. Investigate methods to control nuisance goldfish population
Pacheco Lake	Trout	Put, Grow, and Take	Investigate suitability for stocking trout
Santiago Lake	Trout	Put, Grow, and Take	Investigate suitability for stocking trout
Enchanted Lake	Trout	Put, Grow, and Take	Investigate suitability for stocking trout

Management Direction for HUC 11080004 Mora			
Water	**Fish Species**	**Management Type**	**Management Direction**
North Fork Lake	Trout	Put, Grow, and Take	Investigate suitability for stocking trout
Middle Fork Lake	Trout	Put, Grow, and Take	Investigate suitability for stocking trout
Coyote Creek and Tributaries (Headwaters downstream to Harold Brock Fishing Area)	Brown Trout	Wild	Entirely on private land. Maintain regulations to support angling for wild trout
	Southern Redbelly Dace	Native Fish	Maintain distribution. Only known distribution of Southern Redbelly Dace in New Mexico
Coyote Creek (Harold Brock Fishing Area downstream to Mora River confluence)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout including Coyote Creek Ponds
	Brown Trout	Wild	Maintain regulations to support angling for wild trout

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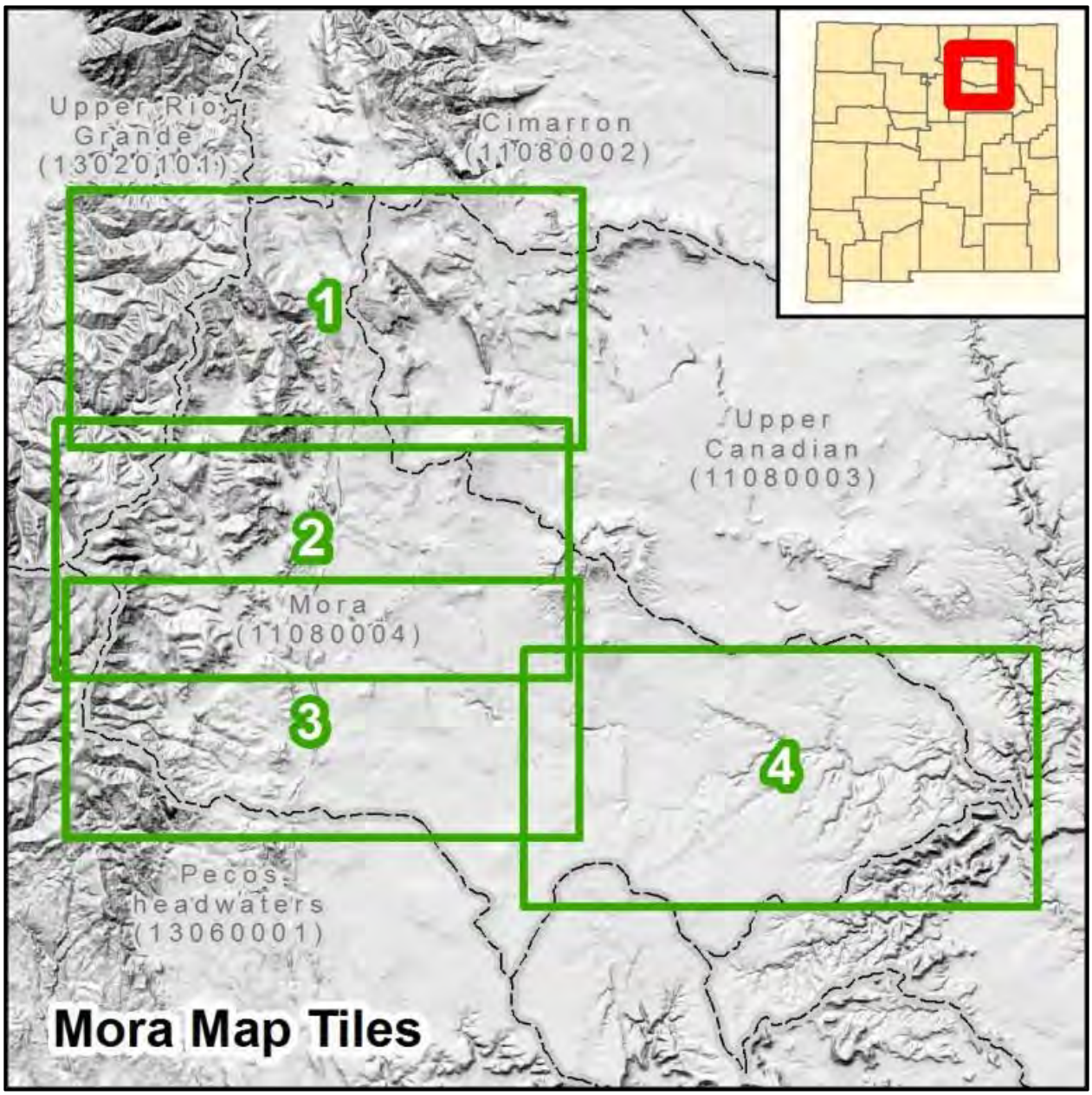


Figure 10. Mora Map Tiles

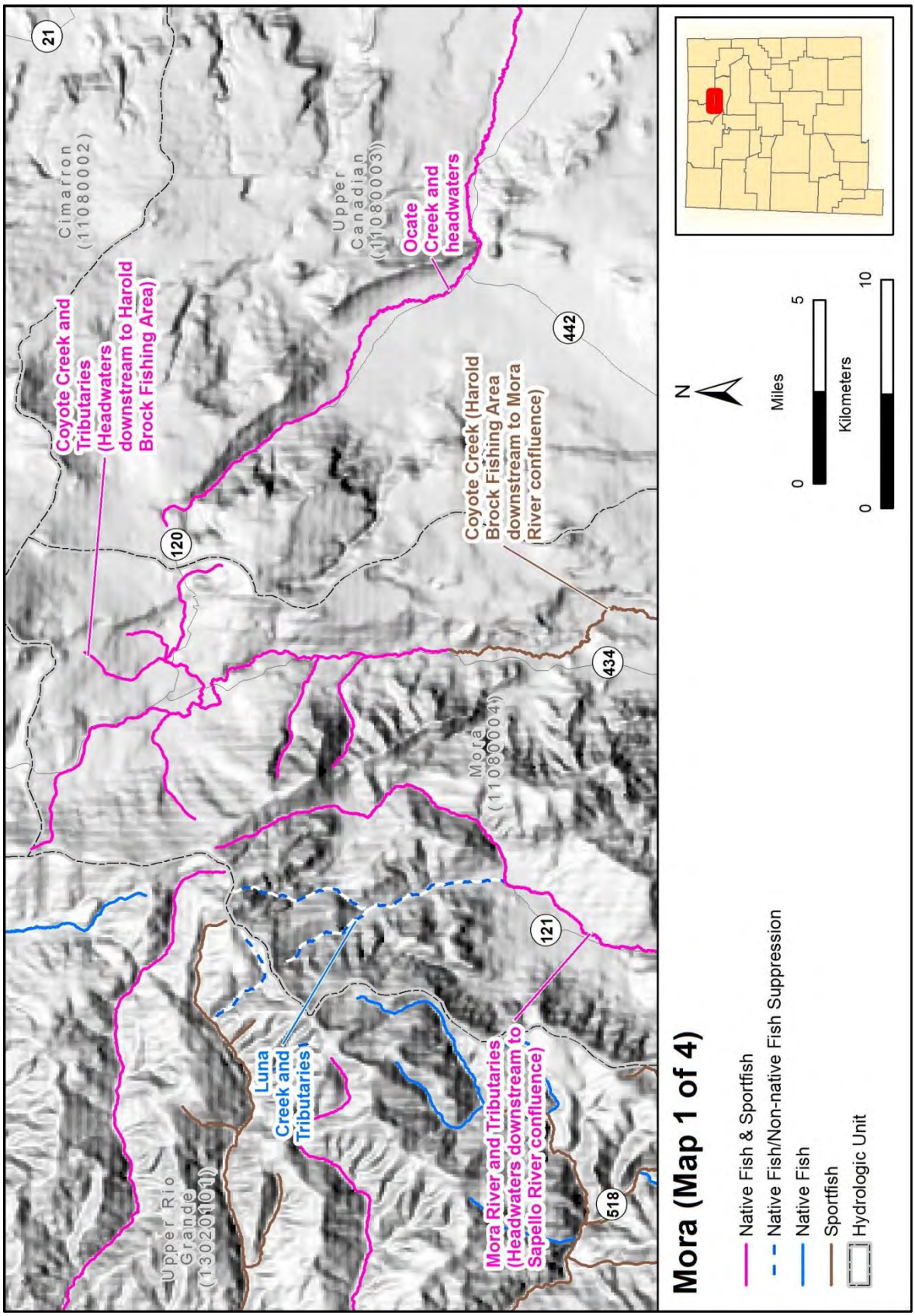


Figure 11. Mora (Map 1 of 4)

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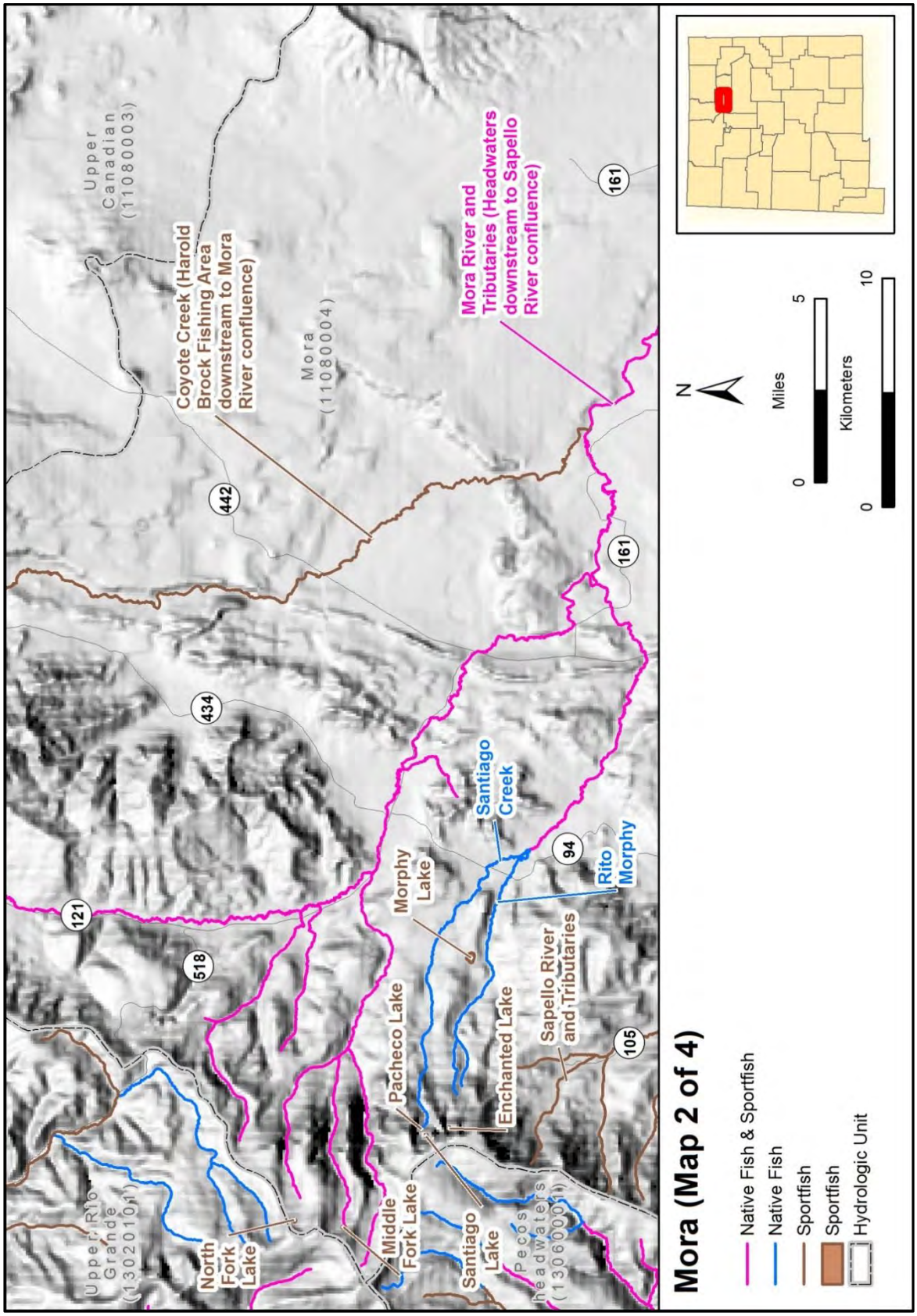


Figure 12. Mora (Map 2 of 4)

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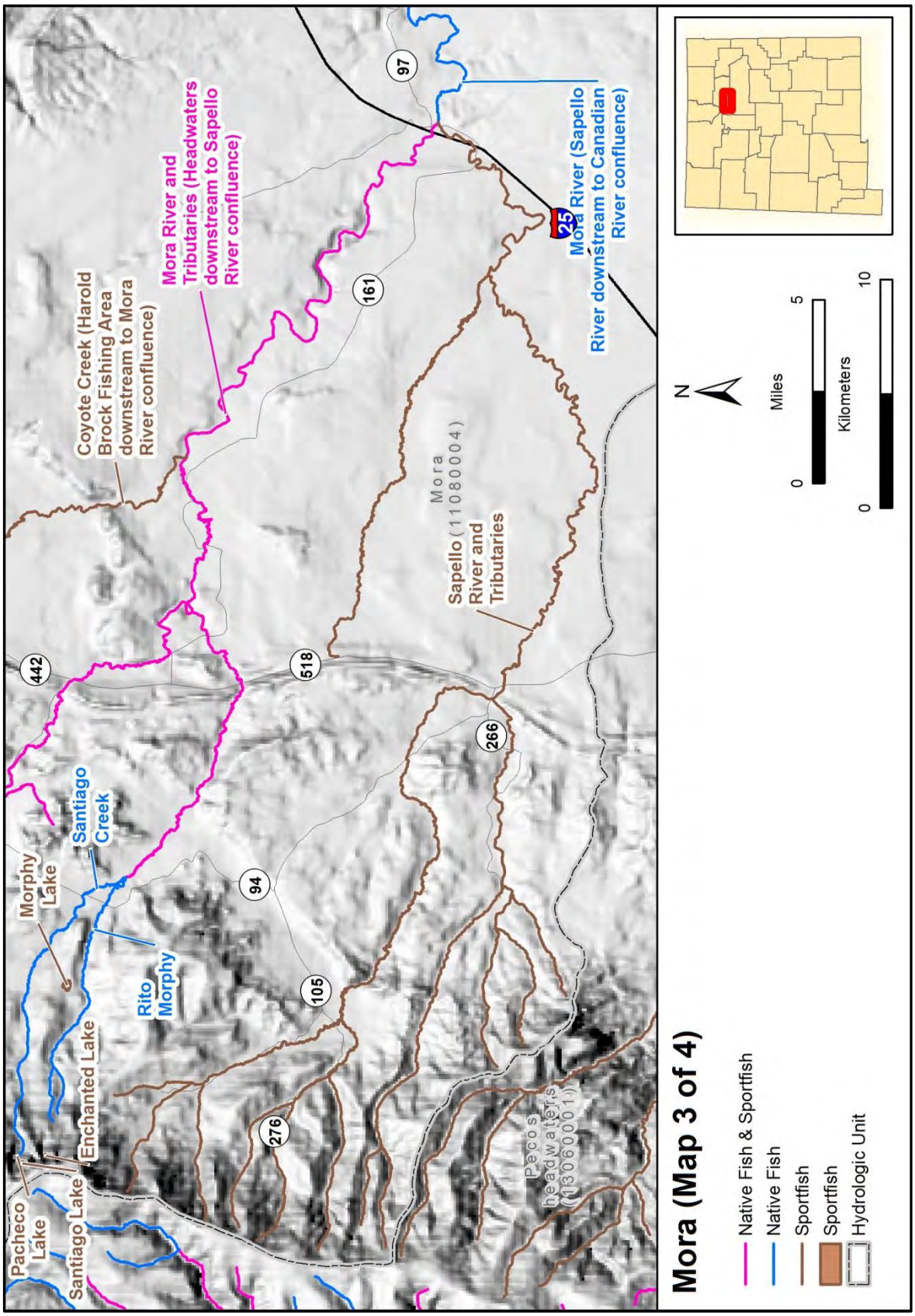


Figure 13. Mora (Map 3 of 4)

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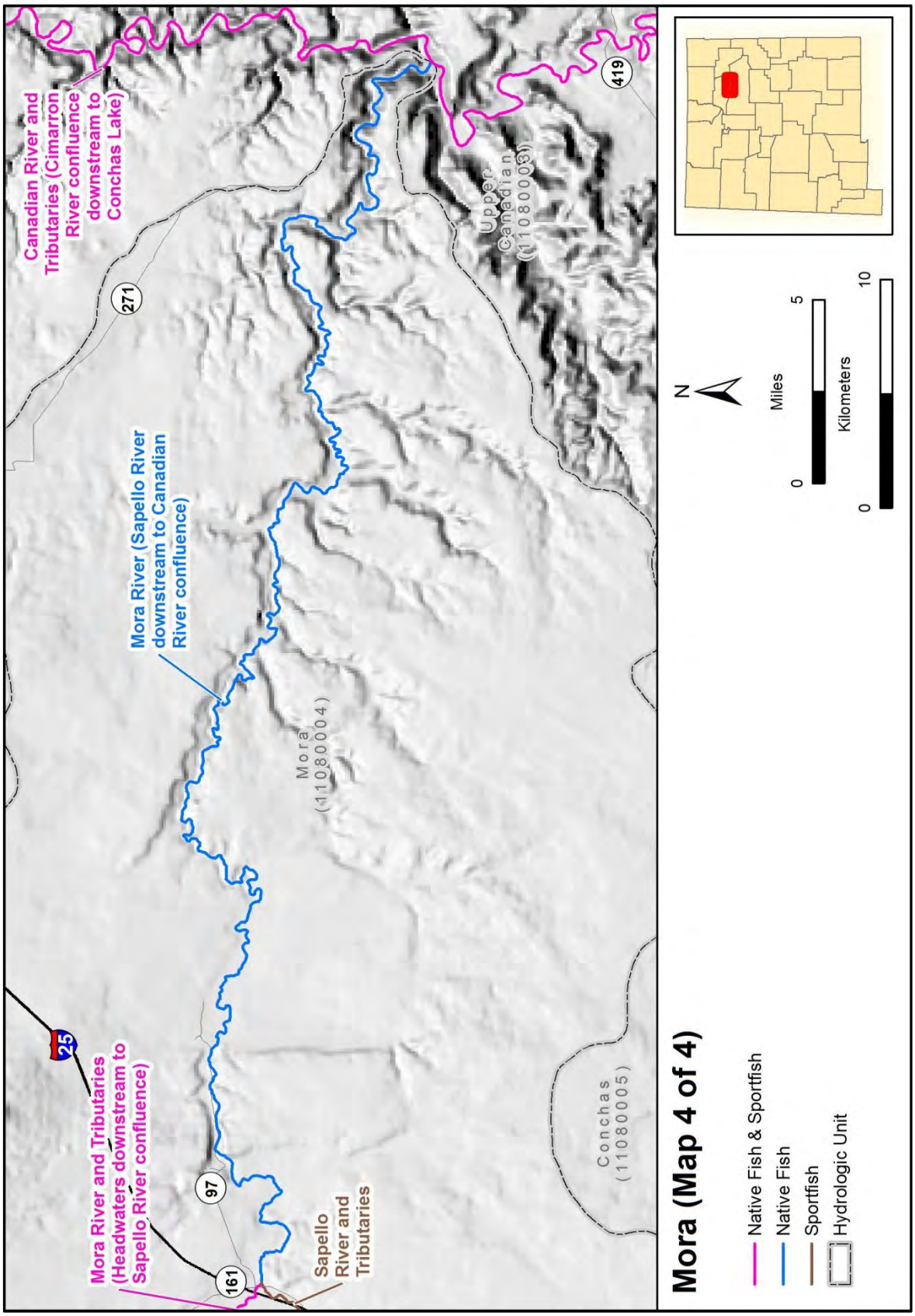


Figure 14. Mora (Map 4 of 4)

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HUC 11080006 Upper Canadian – Ute Reservoir and 11080007 Ute Creek

HUC 11080006 Upper Canadian – Ute Reservoir and 11080007 Ute Creek

Water	Fish Species	Management Type	Management Direction
Ute Creek and Tributaries	Sand Shiner	Native Fish	Maintain distribution
	Suckermouth Minnow	Native Fish	Maintain distribution
Canadian River (Conchas Dam downstream to Ute Lake)	N/A	N/A	Entirely on private land. Status of fishery within this reach unknown due to limited access
Ute Lake	Largemouth Bass	Wild/ Supplemental stocking	Manage as a Low Density Bass Water due to low abundance of Largemouth Bass. Supplement with Largemouth Bass fingerling as available
	Smallmouth Bass	Wild	Manage as a Recreational Bass Water. Special regulation for Smallmouth Bass (14-inch minimum size limit)
	White Bass	Wild	Maintain regulations to support White Bass fishery
	Walleye	Put, Grow, and Take	Stock Walleye at 500 fry/surface acre. Actual stocking varies with reservoir elevation
Canadian River and Tributaries (Ute Dam downstream to stateline)	Arkansas River Shiner	Native Fish	Maintain distribution. Only known occurrence of Arkansas River Shiner in New Mexico
	Peppered Chub	Native Fish	Maintain distribution. Only known occurrence of Peppered Chub in New Mexico
	Plains Minnow	Native Fish	Maintain distribution

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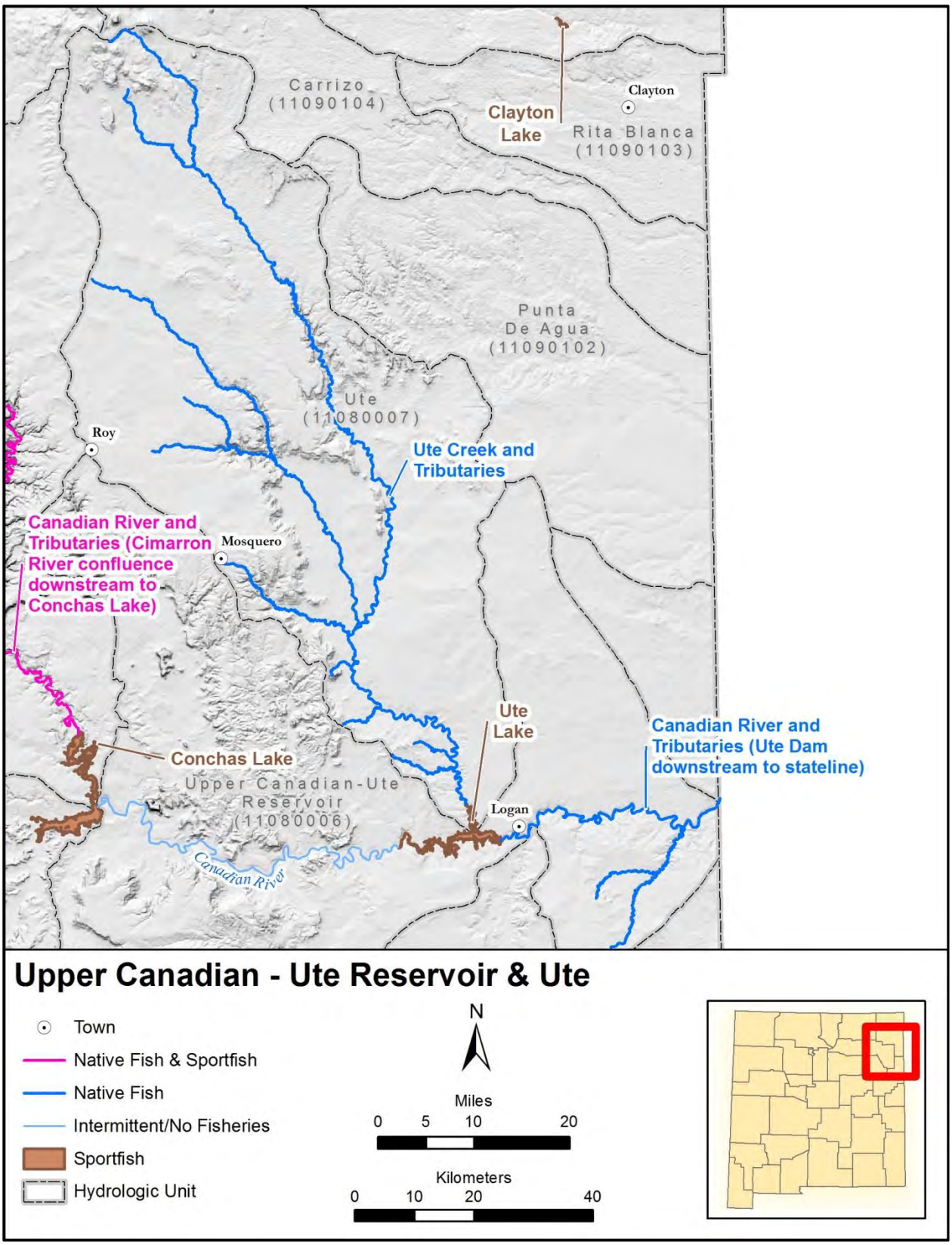


Figure 15. Upper Canadian - Ute Reservoir and Ute

HUC 11040001 Cimarron Headwaters and 11100101 Upper Beaver

Management Direction for HUC 11040001 Dry Cimarron and 11100101 Upper Beaver			
Water	***Fish Species***	***Management Type***	***Management Direction***
Dry Cimarron and headwaters	Central Stoneroller	Native Fish	Maintain distribution
Clayton Lake	Walleye	Put, Grow, and Take	Stock Walleye at 500 fry/surface acre. Actual stocking varies with reservoir elevation
	Largemouth Bass	Wild/ Supplemental stocking	Manage as Trophy Bass Water and maintain regulations to attain trophy potential. Supplement with Largemouth Bass subadults on annual basis
	Channel Catfish	Put and Take	Stock catchable Channel Catfish as available
	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Flathead Catfish	Wild	Continue to transplant Flathead Catfish as necessary to control Black Bullhead population

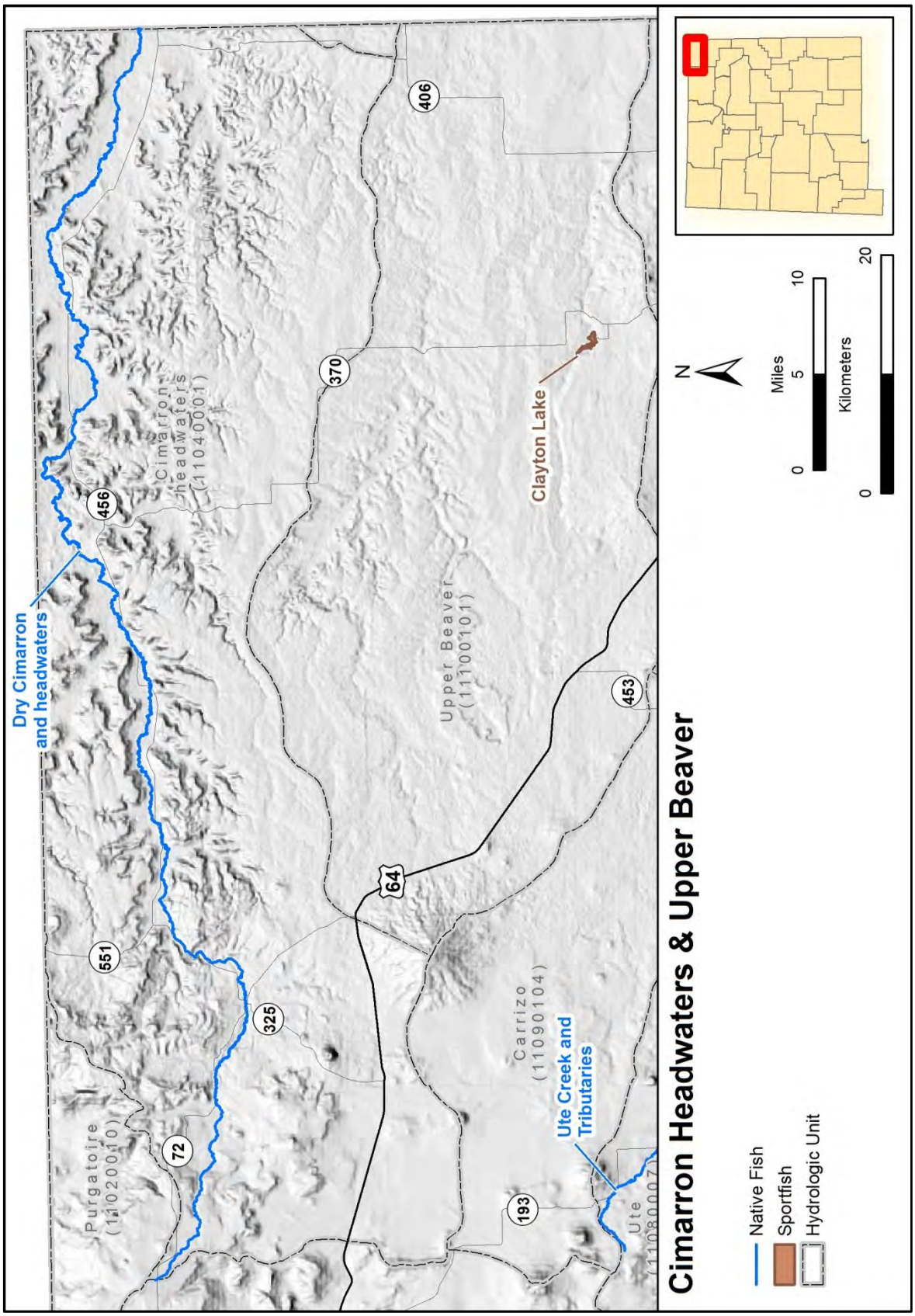


Figure 16. Cimarron Headwaters and Upper Beaver

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HUC 12050001 Yellow House Draw, 12050002 Blackwater Draw, 12050005 Running Water Draw

Management Direction for HUC 12050001 Yellow House Draw, 12050002 Blackwater Draw, and 12050005 Running Water Draw

Water	Fish Species	Management Type	Management Direction
Greene Acres Lake	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Ned Houk Ponds	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Oasis Park Lake	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
	Sunfish	Suppression	Stock and maintain Largemouth Bass to control overpopulated sunfish populations
Dennis Chavez Pond	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
	Sunfish	Suppression	Stock and maintain Largemouth Bass to control overpopulated sunfish populations

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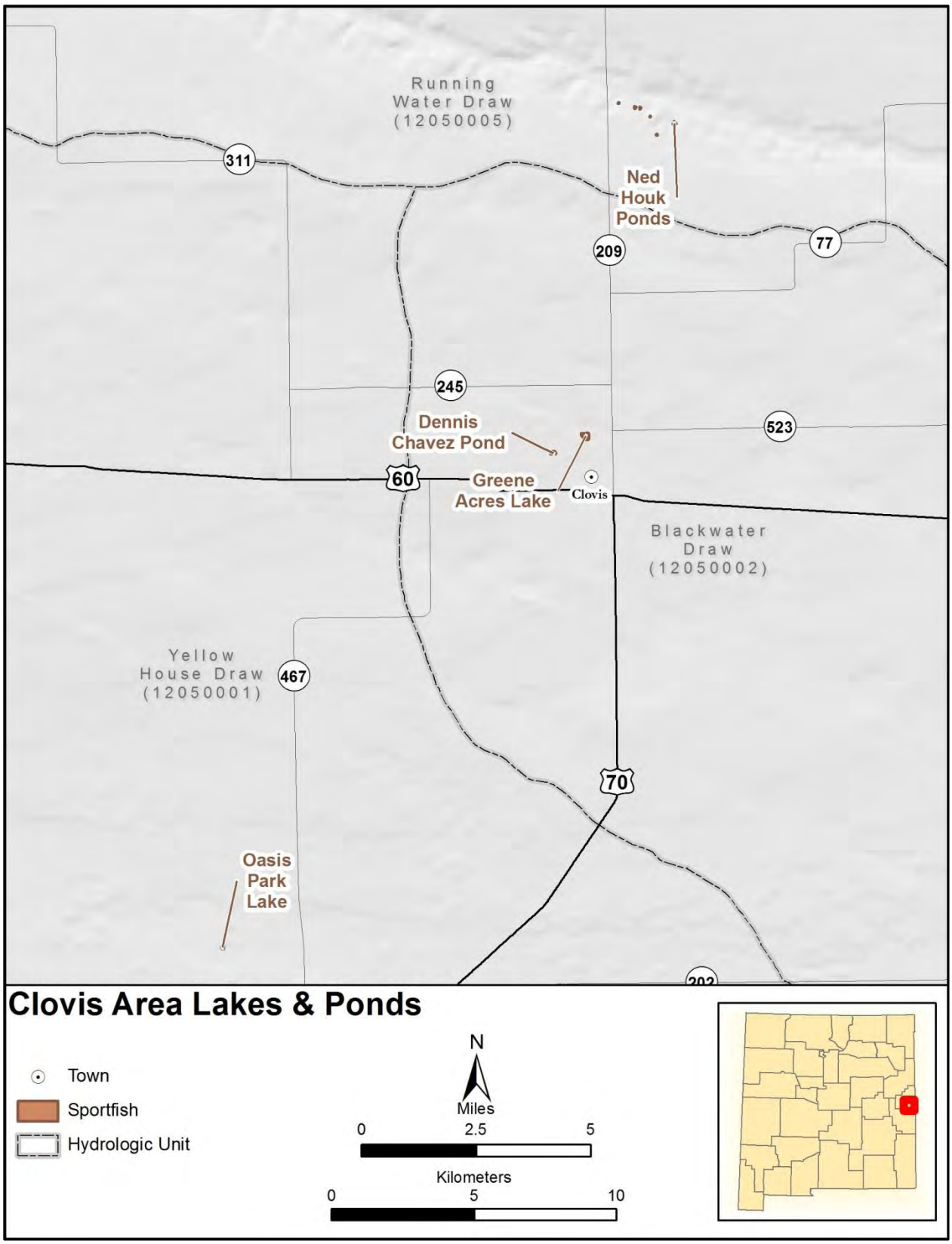


Figure 17. Clovis Area Lakes and Ponds

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Pecos Watershed

The Pecos River arises on the southern slope of the Sangre de Cristo Mountain range in San Miguel County, New Mexico, and runs south through Guadalupe, De Baca, Chaves, and Eddy counties before it enters Texas. The Pecos Watershed encompasses 12.3 million acres in New Mexico. Principal New Mexico cities in the watershed include Las Vegas, Santa Rosa, Fort Sumner, Roswell, Artesia, and Carlsbad. Land use in this watershed is mainly rangeland, with some irrigated cropland and pastureland along the Pecos River. Roughly 10% of the industry in the lower Pecos Valley is agriculture based (De Baca, Chavez, and Eddy Counties). Primary crops include small grains, alfalfa, and other hay crops. Oil and gas development occur within the lower Pecos River valley.

Fisheries management in the Pecos Watershed has focused on trout management in the headwaters and warmwater species in the lower reaches and man-made reservoirs. Popular trout fisheries include the Pecos Canyon and Monastery Lake. Populations of Rio Grande Cutthroat Trout occur in Pecos River tributaries providing unique angling opportunities and significantly contributing to the status of this native trout. In 2012, the Department and other federal and state partners committed to restoring Rio Grande Cutthroat Trout to portions of the Pecos Watershed in the Rio Grande Cutthroat Trout Conservation Strategy. Conservation strategies have also been developed for Rio Grande Chub and Rio Grande Sucker and include waters in the Pecos Watershed. Specific waters are identified below where all or part will be restored to fulfill those commitments.

Several moderate to large reservoirs impound the Pecos River beginning with Santa Rosa Lake and ending with Avalon Dam near the New Mexico/Texas state line. Several urban ponds are intensively managed via seasonal stocking of Channel Catfish or Rainbow Trout. Golden algae blooms have negatively affected fisheries in several reservoirs in the lower Pecos since the early 2000s and continue to negatively affect some fisheries as blooms occur.

Several state or federally protected and sensitive fish species occur within the Pecos River. Designated critical habitat for Pecos Bluntnose Shiner includes significant reaches of the Pecos River between Lake Sumner and Brantley Lake. State threatened Pecos Pupfish inhabit multiple locations in the lower Pecos including waters on the Bottomless Lakes Sate Park. Blue Sucker, Gray Redhorse, and Texas hornshell, a native mussel that was recently declared federally endangered, occupy the Black River. Golden algae has also negatively affected native fish within the Pecos River, particularly downstream of Brantley Lake.

HUC 13060001 Pecos Headwaters – Headwaters to Santa Rosa

Management Direction for HUC 13060001 Pecos Headwaters – Headwaters to Santa Rosa Lake

Water	Fish Species	Management Type	Management Direction
Pecos River (above Pecos Falls)	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Water)
Pecos River and Tributaries (headwaters downstream to Cowles)	Brown Trout	Wild	Maintain regulations to support angling for wild trout
	Rio Grande Cutthroat Trout	Native Fish	Significant portions of this drainage to be considered for Rio Grande Cutthroat Trout restoration in the future
Holy Ghost Creek and Tributaries	Brown Trout	Wild	Maintain regulations to support angling for wild trout
	Rio Grande Cutthroat Trout	Native Fish	Significant portions of this drainage to be considered for Rio Grande Cutthroat Trout restoration in the future
	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout at Holy Ghost Campground downstream to Pecos River confluence
Bear Creek (Upstream of Barrier)	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout
Rito los Esteros	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout
Rio Valdez (Above Barrier)	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Water) from waterfall barrier 0.8 miles below FS Trail 239 upstream to its headwaters
Rio Mora Headwaters	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout
Cave Creek (Above Barrier)	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout
Rito del Padre and Tributaries	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Native Trout Conservation Water) from the fish migration barrier 0.3 miles upstream of confluence with Rito Sebadilloses to its headwaters including Rito de los Chimayosos
	Brown Trout	Suppression	Unlimited angler harvest
Dalton Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout

Management Direction for HUC 13060001 Pecos Headwaters – Headwaters to Santa Rosa Lake

Water	Fish Species	Management Type	Management Direction
Macho Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout
Jack's Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Water) from waterfalls 0.25 miles downstream of Highway 63 crossing to headwaters. Consider barrier improvements to further protect population
Cowles Ponds (Mt. View Ponds)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout. Upper pond open to anglers 11 years old and younger, 65 years old and older, and individuals with disabilities
Panchuela Creek and Tributaries	Brown Trout	Wild	Maintain regulations to support angling for wild trout
	Brook Trout	Wild	Maintain regulations to support angling for wild trout
	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout present in Cave Creek. Significant portions of this drainage to be considered for Rio Grande Cutthroat Trout restoration
Rio Mora (adjacent to Mora Campground)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
Rio Mora and Tributaries (Upstream of Mora Campground)	Trout	Wild	Maintain regulations to support angling for wild trout
	Rio Grande Cutthroat Trout	Native Fish	Significant portions of this drainage to be considered for Rio Grande Cutthroat Trout restoration in the future
Willow Creek	Rio Grande Cutthroat Trout	Native Fish	Active Rio Grande Cutthroat Trout restoration. Anticipated completion 2024
Lake Katherine	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock periodically with Pecos strain Rio Grande Cutthroat Trout, as available
Johnson Lake	Cutthroat Trout	Wild	Maintain regulations to support angling for wild trout. Lake would be part of Panchuela Creek Rio Grande Cutthroat Trout restoration
Pecos Baldy Lake	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock periodically with Pecos strain Rio Grande Cutthroat Trout, as available

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Management Direction for HUC 13060001 Pecos Headwaters – Headwaters to Santa Rosa Lake

Water	Fish Species	Management Type	Management Direction
Stewart Lake	Cutthroat Trout	Wild	Maintain regulations to support angling for wild trout
Truchas Lakes	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock periodically with Pecos strain Rio Grande Cutthroat Trout, as available
Monastery Lake	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
Pecos River and Tributaries (Cowles downstream to Village of Pecos)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Brown Trout	Wild	Special Trout Water regulation (Green Chile Water) in the box canyon 0.5 miles upstream of the confluence with the Mora River to 0.2 miles downstream of the Cowles Bridge. Other species of trout exist in tributaries though the predominant species is Brown Trout. Maintain regulations to support angling for wild trout. Manage habitat improvement reaches within the Pecos Canyon State Park as Quality Trout Waters
Cow Creek and Tributaries	Trout	Wild	Brook, Brown, and Cutthroat trout are present depending upon individual watersheds. Need to investigate fishery status in lower reach of Cow Creek downstream of North San Ysidro
	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout near Cow Creek campground
	Rio Grande Cutthroat Trout	Native Fish	Portions of this drainage to be considered for Rio Grande Cutthroat Trout restoration in the future
Pecos River (Village of Pecos downstream to Interstate 25)	Brown Trout	Wild	Maintain regulations to support angling for wild trout. Collaborate with National Park Service to maintain angler opportunities with the Pecos National Historic Park
	Rio Grande Chub	Native Fish	Maintain distribution
Pecos River (Interstate 25 downstream to Santa Rosa Lake)	Rio Grande Chub	Native Fish	Maintain distribution
	Flathead Chub	Native Fish	Maintain distribution
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout within Villanueva State Park
	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish within Villanueva State Park

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Management Direction for HUC 13060001 Pecos Headwaters – Headwaters to Santa Rosa Lake

Water	Fish Species	Management Type	Management Direction
Gallinas Creek (River) and Tributaries (Headwaters downstream to Interstate 25)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Brown Trout	Wild	Maintain regulations to support angling for wild trout. Limited wild trout potential in lower reaches due to dewatering and increased temperatures
Gallinas River (Downstream of Interstate 25)	N/A	N/A	Limited information is available about the status of this reach
Gallinas Ice Pond	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
El Porvenir Creek (Headwaters downstream to El Porvenir Campground)	Brown Trout	Wild	Maintain regulations to support angling for wild trout. Limited information on the status of this watershed
El Porvenir Creek (El Porvenir Campground downstream to confluence with Gallinas Creek)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
Storrie Lake	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Channel Catfish	Wild	Maintain regulations to support angling for wild Channel Catfish. Stock Channel Catfish as necessary
Harris Lake	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout. Open to anglers 11 years old and younger
	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
Tecolote Creek (Headwaters downstream to confluence with Falls Creek)	Trout	Wild	Brook, Brown, and Cutthroat trout are present in different reaches of this watershed. Maintain regulations to support angling for wild trout
Tecolote Creek (Falls Creek confluence downstream to Pecos River)	Rio Grande Chub	Native Fish	Maintain distribution. Limited information is available about the status of this reach. Primarily on private land

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Management Direction for HUC 13060001 Pecos Headwaters – Headwaters to Santa Rosa Lake

Water	Fish Species	Management Type	Management Direction
El Rito Creek (Santa Rosa)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Roundnose Minnow	Native Fish	Maintain distribution
Santa Rosa Lake	Channel Catfish	Wild	Reservoir subject to significant water level fluctuations both within and between years. Stock Channel Catfish as necessary
	Walleye	Put, Grow, and Take	Stock Walleye at 500 fry/surface acre. Actual stocking varies with reservoir elevation. Brood source for Walleye
	Largemouth Bass	Wild/ Supplemental stocking	Manage as a Recreational Bass Water. Supplement with Largemouth Bass fry as available
	Smallmouth Bass	Wild	Manage as a Recreational Bass Water
Pecos River (Santa Rosa Lake to Lake Sumner)	N/A	N/A	Limited access, limited use and no native species of concern occur in this reach. Located primarily on private land
Lake Sumner	Channel Catfish	Wild	Reservoir subject to significant water level fluctuations both within and between years. Stock Channel Catfish as necessary
	Walleye	Put, Grow, and Take	Stock Walleye at 250 fry/surface acre. Actual stocking varies with reservoir elevation. Brood source for Walleye
	Spotted Bass	Wild	Manage as a Recreational Bass Water. One of two lakes in NM with Spotted Bass fisheries
	Smallmouth Bass	Wild	Manage as a Recreational Bass Water
Perch Lake	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
	Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Rock Lake Kid's Pond	Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout. Open to anglers 11 years old and younger
	Largemouth Bass	Put and Take	Stock occasionally with retired brood bass
	Channel Catfish	Put and Take	Investigate potential as Special Summer Catfish water

Management Direction for HUC 13060001 Pecos Headwaters – Headwaters to Santa Rosa Lake			
Water	**Fish Species**	**Management Type**	**Management Direction**
Blue Hole Park Ponds	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish. Open to anglers 11 years old and younger, 65 years old and older, and individuals with disabilities
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Tres Lagunas	N/A	N/A	Often dry. Some interest from the City of Santa Rosa in stocking but no current plans in place

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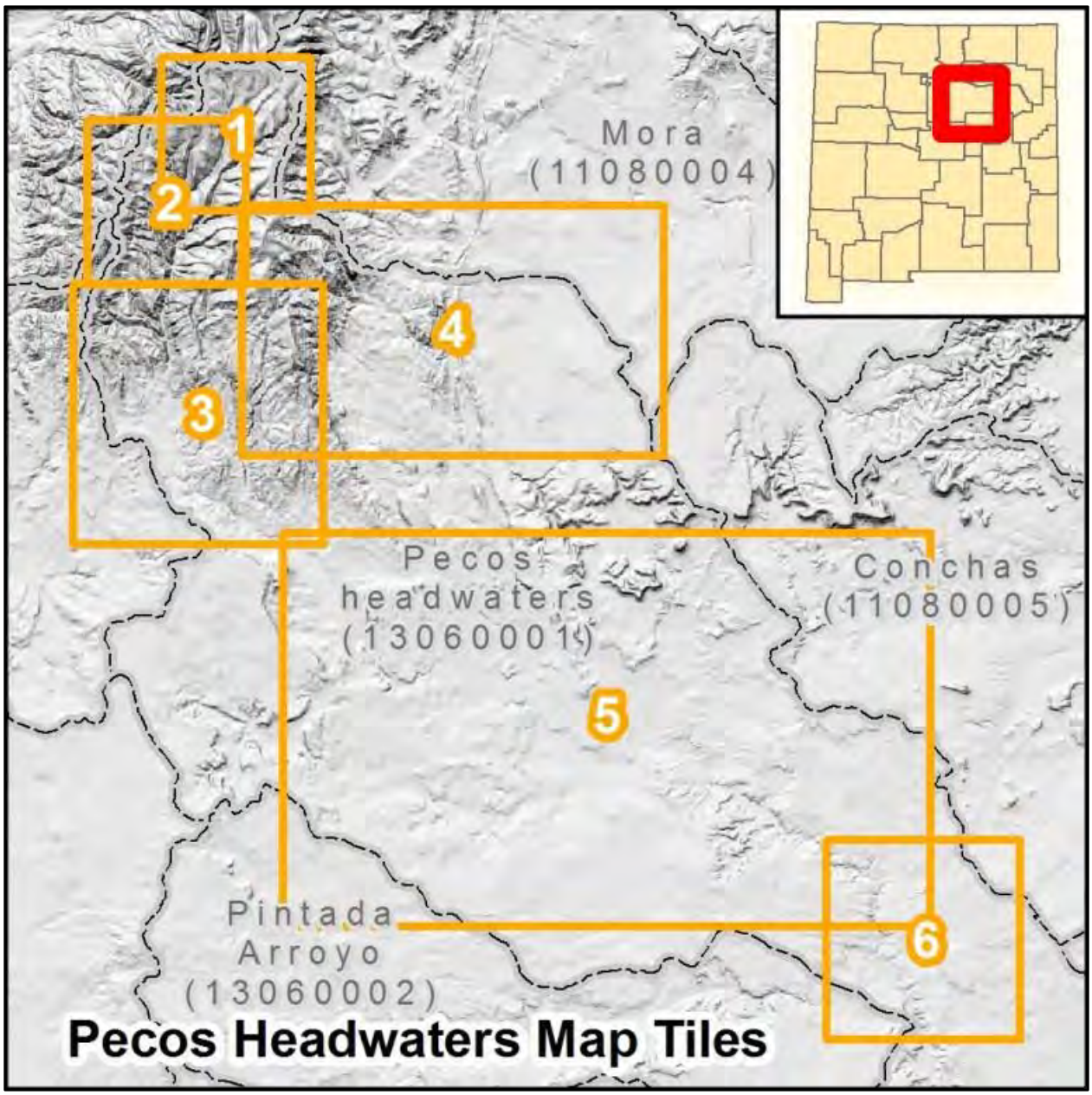


Figure 18. Pecos Headwaters Map Tiles

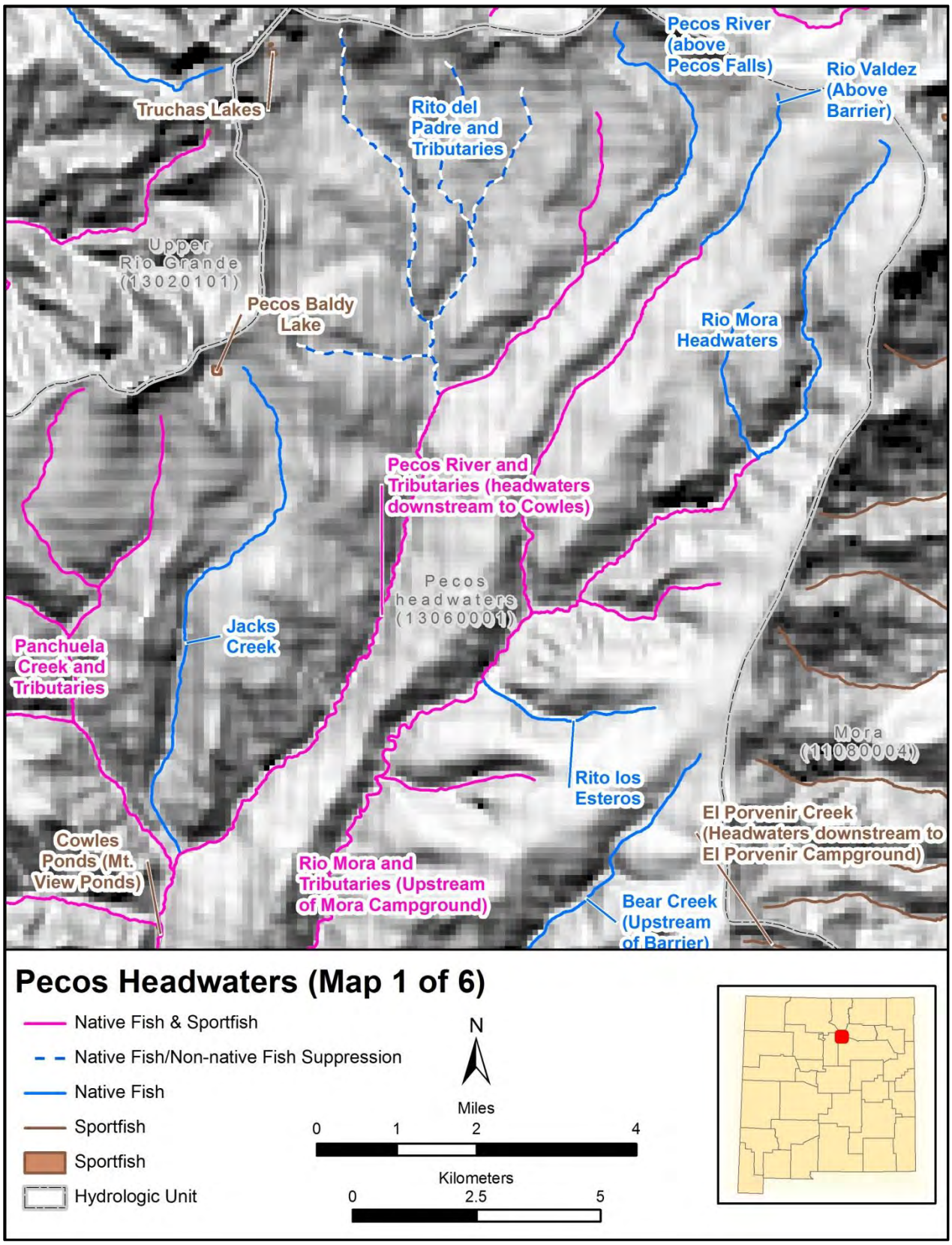


Figure 19. Pecos Headwaters (Map 1 of 6)

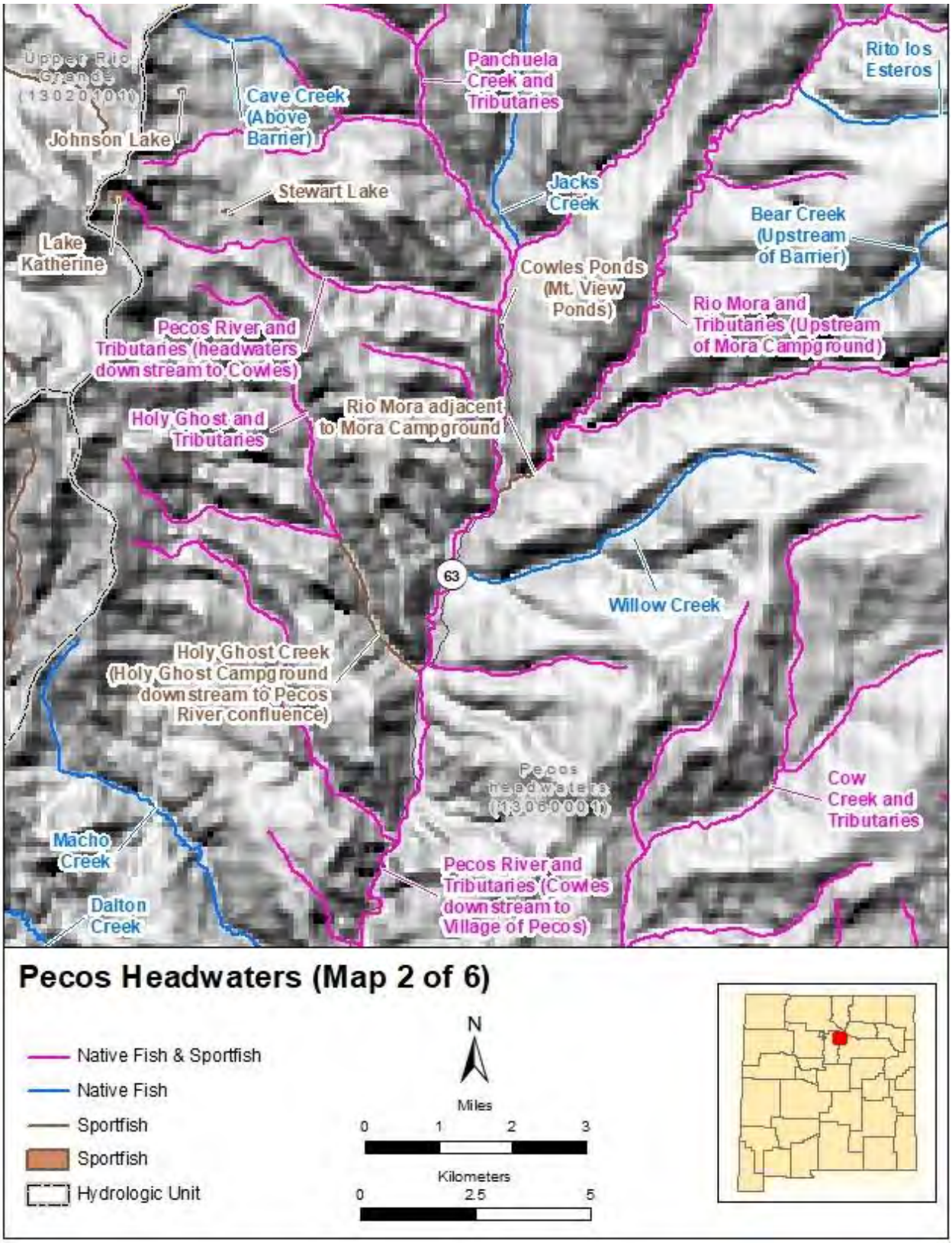


Figure 20. Pecos Headwaters (Map 2 of 6)

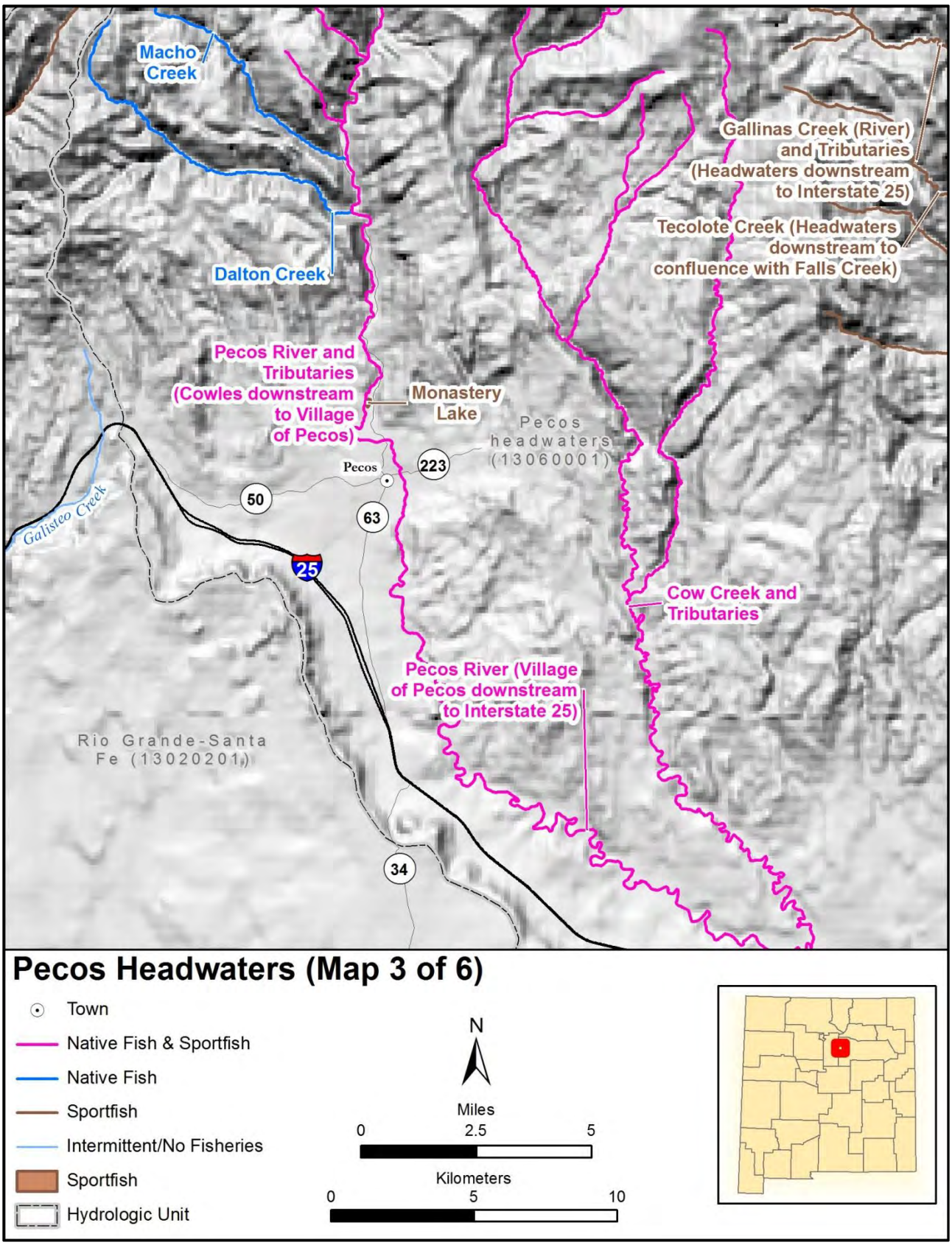


Figure 21. Pecos Headwaters (Map 3 of 6)

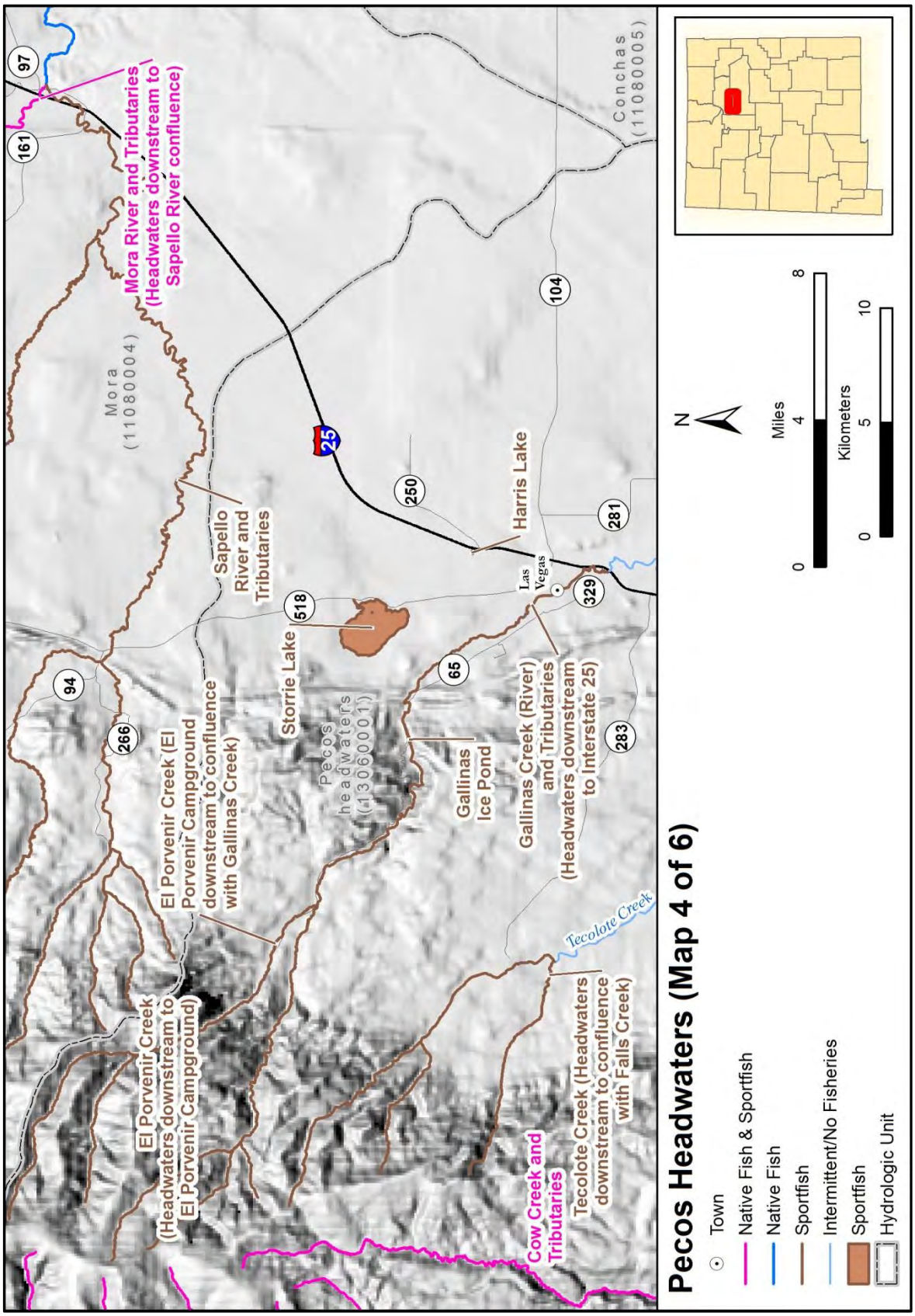


Figure 22. Pecos Headwaters (Map 4 of 6)

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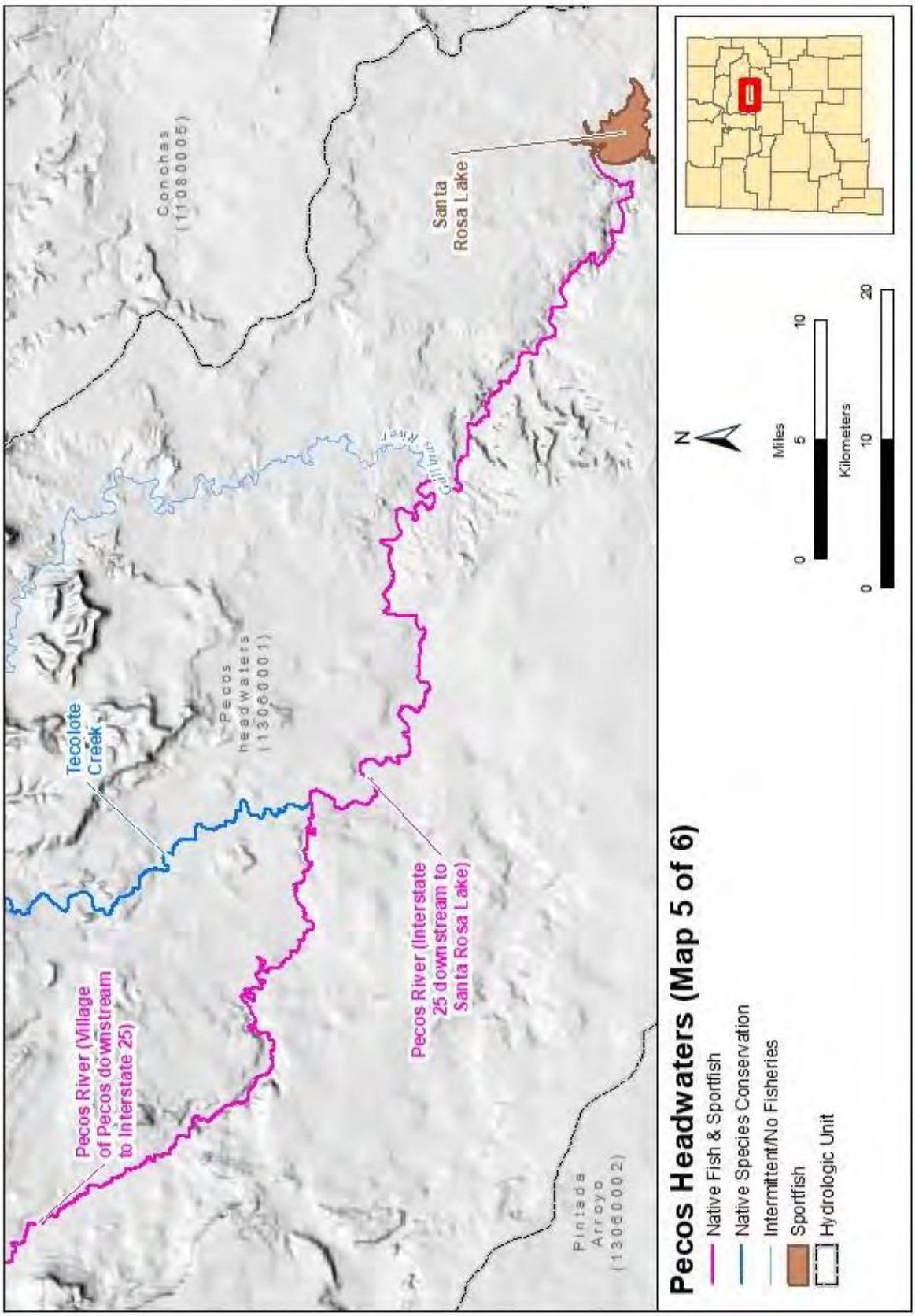


Figure 23. Pecos Headwaters (Map 5 of 6)

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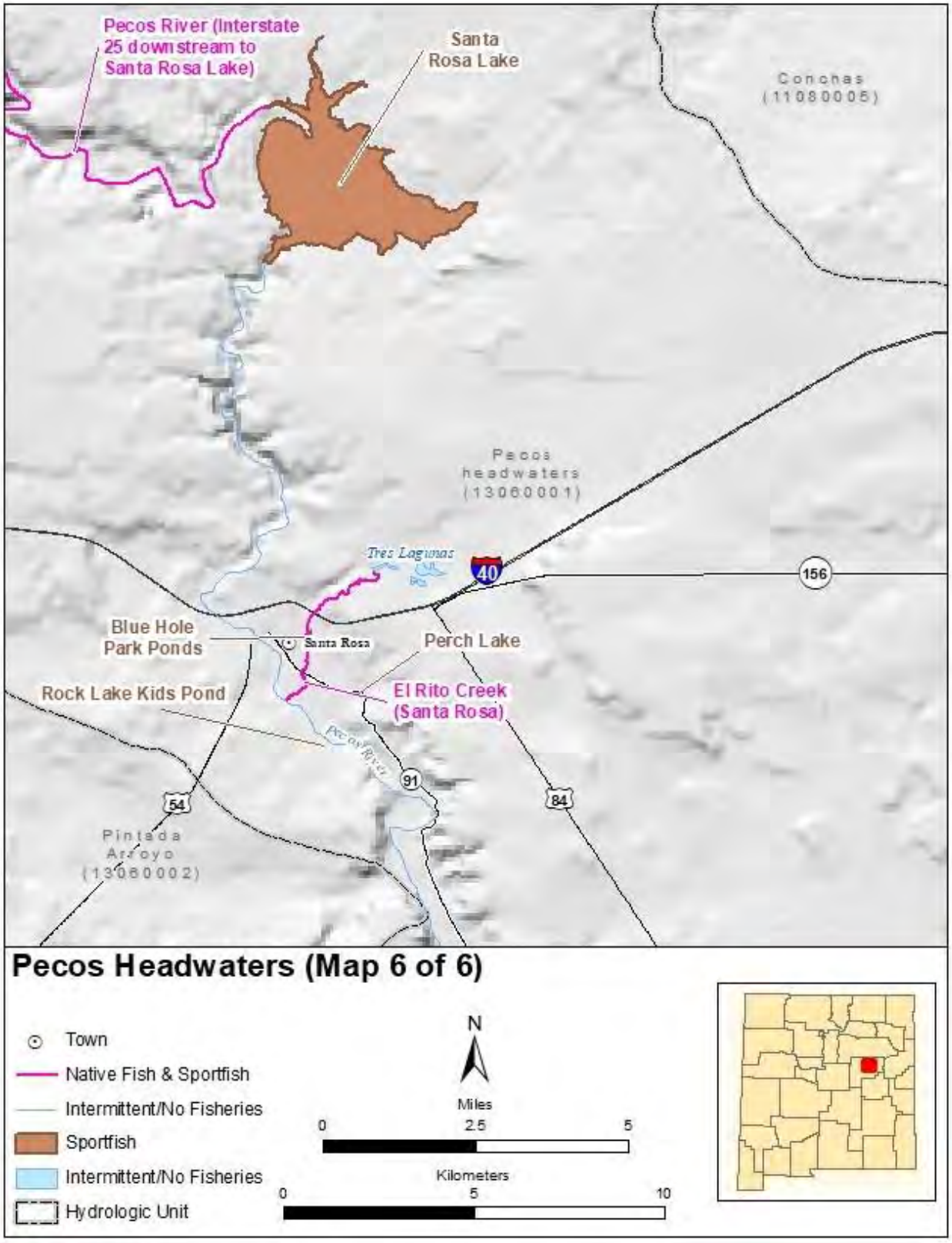


Figure 24. Pecos Headwaters (Map 6 of 6)

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HUC 13060003 Upper Pecos, 13060005 Arroyo del Macho, 13060006 Gallo Arroyo, 13060007 Upper Pecos – Long Arroyo, 13060008 Rio Hondo, 13060010 Rio Peñasco, 13060011 Upper Pecos Black, 13070002 Delaware, 13070007 Landreth-Monument Draws, and 12080003 Monument Seminole Draws

Management Direction for HUC 13060003 Upper Pecos, 13060005 Arroyo del Macho, 13060006 Gallo Arroyo, 13060007 Upper Pecos – Long Arroyo, 13060008 Rio Hondo, 13060010 Rio Peñasco, 13060011 Upper Pecos Black, 13070002 Delaware, 13070007 Landreth-Monument Draws, and 12080003 Monument Seminole Draws

Water	Fish Species	Management Type	Management Direction
Pecos River (Lake Sumner to Fort Sumner)	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout in tailwater reach of Sumner Lake
Pecos River (Fort Sumner to Brantley Reservoir)	Pecos Bluntnose Shiner	Native Fish	Designated critical habitat for Pecos Bluntnose Shiner
	Pecos Pupfish	Native Fish	Pecos Pupfish occupy habitats on Bureau of Land Management, Bitter Lake National Wildlife Refuge, and Bottomless Lakes State Park. Implement actions identified in the Pecos Pupfish Conservation Agreement. All Pecos Pupfish downstream of Brantley Reservoir are Sheepshead Minnow/Pecos Pupfish hybrids
	Rio Grande Shiner	Native Fish	Maintain distribution
	Speckled Chub	Native Fish	Maintain distribution
	Flathead Catfish	Wild	Maintain regulations to support Flathead Catfish
Brantley Lake	Channel Catfish	Wild	Catch-and-release regulations removed in 2018 based on reduced contaminants in fish tissues. Department of Health, NM Environment Department, and NM Department of Game and Fish collaborated on new advisories in 2018. Regular golden algae blooms limit fishery potential and not consistently stocked. Subject to significant water level fluctuation
	White Bass	Wild	Catch-and-release regulations removed in 2018 based on reduced contaminants in fish tissues. Department of Health, NM Environment Department, and NM Department of Game and Fish collaborated on new advisories in 2018
	Largemouth Bass	Wild	Manage as a Recreational Bass Water. Stock Largemouth Bass as necessary

Management Direction for HUC 13060003 Upper Pecos, 13060005 Arroyo del Macho, 13060006 Gallo Arroyo, 13060007 Upper Pecos – Long Arroyo, 13060008 Rio Hondo, 13060010 Rio Peñasco, 13060011 Upper Pecos Black, 13070002 Delaware, 13070007 Landreth-Monument Draws, and 12080003 Monument Seminole Draws

Water	Fish Species	Management Type	Management Direction
Pecos River (Brantley Dam downstream to and including Lake Avalon)	N/A	N/A	Historical stronghold for Blue Sucker, Gray Redhorse and Black Bass. Currently limited potential for any fisheries management due to golden algae. Investigate mitigation measures to reduce the effects of golden algae
Lake Carlsbad	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout. Subject to periodic golden algae blooms
	Spotted Bass	Wild	Manage as a Recreational Bass Water
	Largemouth Bass	Wild	Manage as a Recreational Bass Water. Initiate habitat improvement project to support fishery. Stock Largemouth Bass as necessary Investigate potential as a Trophy Bass Water
	Channel Catfish	Put and Take	Stock with catchable Channel Catfish as available
Bataan Lake	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout. Subject to periodic golden algae blooms. Other sportfish species present but not managed due to limited habitat
	Largemouth Bass	Wild	Manage as a Recreational Bass Water. Initiate habitat improvement project to support fishery. Stock Largemouth Bass as necessary
	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
Pecos River (Lower Tansill Dam downstream to State Line including Six Mile and Ten Mile Dam Lakes)	Largemouth Bass	Wild	Manage Six Mile Dam as a Recreational Bass Water and Ten Mile Dam as a Low Density Bass Water. Subject to periodic golden algae blooms
	Gray Redhorse	Native Fish	Maintain distribution
	Channel Catfish	Wild	Maintain regulations to support Channel Catfish fishery. Consumption advisory for Channel Catfish – updated in 2018 to allow some consumption
	Blue Sucker	Native Fish	Investigate potential for repatriation of Blue Sucker

Management Direction for HUC 13060003 Upper Pecos, 13060005 Arroyo del Macho, 13060006 Gallo Arroyo, 13060007 Upper Pecos – Long Arroyo, 13060008 Rio Hondo, 13060010 Rio Peñasco, 13060011 Upper Pecos Black, 13070002 Delaware, 13070007 Landreth-Monument Draws, and 12080003 Monument Seminole Draws

Water	Fish Species	Management Type	Management Direction
Rio Bonito (Headwaters downstream to Bonito Lake)	Rio Grande Cutthroat Trout	Native Fish	Ongoing YY Brook Trout stocking study to investigate possibility for repatriation of Rio Grande Cutthroat Trout.
Bonito Lake	Triploid Rainbow Trout	Put and Take	Severely impacted by Little Bear Fire. Awaiting completion of dam rehabilitation and resolution of access issues. Stock catchable triploid Rainbow Trout
Rio Bonito (Downstream of Bonito Lake to the Rio Hondo confluence)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Brown Trout	Wild	Limited Brown Trout. Maintain regulations to support wild trout angling. Investigate potential of expanding habitat improvements on lower Rio Bonito
	Rio Grande Chub	Native Fish	Maintain distribution
Copeland Creek	Brook Trout	Wild	Maintain regulations to support wild trout angling
Rio Ruidoso and Tributaries	Brown Trout	Wild	Significant portions of the watershed within the jurisdiction of Mescalero Apache Tribe or on private land. Special Trout Water regulation (X-mas Chile Water) from Mescalero Reservation boundary downstream to Friedenbloom Drive
	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Rio Grande Chub	Native Fish	Maintain distribution
Pine Lodge Creek	Triploid Rainbow Trout	Put and Take	Investigate potential of stocking triploid Rainbow Trout
Grindstone Reservoir	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Channel Catfish	Wild	Maintain regulations to support fishery
	Smallmouth Bass	Wild/ Supplemental stocking	Manage as a Recreational Bass Water

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Management Direction for HUC 13060003 Upper Pecos, 13060005 Arroyo del Macho, 13060006 Gallo Arroyo, 13060007 Upper Pecos – Long Arroyo, 13060008 Rio Hondo, 13060010 Rio Peñasco, 13060011 Upper Pecos Black, 13070002 Delaware, 13070007 Landreth-Monument Draws, and 12080003 Monument Seminole Draws

Water	Fish Species	Management Type	Management Direction
Eagle Creek	Brook Trout	Wild	Headwaters of the watershed within the jurisdiction of Mescalero Apache Tribe. Maintain regulations to support wild trout angling
Alto Lake	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish.
	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Largemouth Bass	Wild/ Supplemental Stocking	Manage as a Recreational Bass Water for Goldfish control. Also continue stocking other species such as Bluegill as necessary to balance bass to sunfish predator/prey ratios
Agua Chiquita	Brook Trout	Wild	Prone to drying. Maintain regulations to support wild trout angling
Rio Peñasco	Brown Trout	Wild	Primarily private property with small section of Forest Service property. Investigate Open Gate properties. Maintain regulations to support wild trout angling
	Triploid Rainbow Trout	Put and Take	Investigate Open Gate opportunities to provide a Rainbow Trout fishery
	Rio Grande Chub	Native Fish	Maintain distribution
	Greenthroat Darter	Native Fish	Maintain distribution
Bosque Redondo Lake	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Bottomless Lakes	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout. Maintain prohibition of fishing with baitfish. Triploid Rainbow Trout stocking locations limited to reduce negative interactions with Pecos Pupfish
	Pecos Pupfish	Native Fish	Implement actions identified in the Pecos Pupfish Conservation Agreement

Management Direction for HUC 13060003 Upper Pecos, 13060005 Arroyo del Macho, 13060006 Gallo Arroyo, 13060007 Upper Pecos – Long Arroyo, 13060008 Rio Hondo, 13060010 Rio Peñasco, 13060011 Upper Pecos Black, 13070002 Delaware, 13070007 Landreth-Monument Draws, and 12080003 Monument Seminole Draws

Water	Fish Species	Management Type	Management Direction
Lake Van	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Roswell Kids Pond	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish. Open to anglers 11 years old and younger
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Corona Pond	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Black River	Blue Sucker	Native Fish	Limited public access. Few Blue Sucker collected over the past several years. Investigate the feasibility of replacing road crossings (2) fragmenting population
	Gray Redhorse	Native Fish	Investigate the feasibility of replacing road crossings (2) fragmenting population
	Largemouth Bass	Wild	Maintain angling regulations to support Recreational Bass Water
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Pecos River (Avalon Dam to Lake Carlsbad)	N/A	N/A	Often dry, limited angling opportunities
Eunice Lake	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Jal Lake	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout

Management Direction for HUC 13060003 Upper Pecos, 13060005 Arroyo del Macho, 13060006 Gallo Arroyo, 13060007 Upper Pecos – Long Arroyo, 13060008 Rio Hondo, 13060010 Rio Peñasco, 13060011 Upper Pecos Black, 13070002 Delaware, 13070007 Landreth-Monument Draws, and 12080003 Monument Seminole Draws

Water	Fish Species	Management Type	Management Direction
Delaware River	Gray Redhorse	Native Fish	Repatriation efforts have ceased due to absence of perennial flows in recent years. Investigate feasibility of restoring perennial flows and if successful repatriate Gray Redhorse
Chaparral Park Lake	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
	Sunfish	Suppression	Stock and maintain Largemouth Bass to control overpopulated sunfish populations
Green Meadow Lake	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Harry McAdams Park Pond	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout. Open to anglers 11 years old and younger, 65 years old and older, and individuals with disabilities

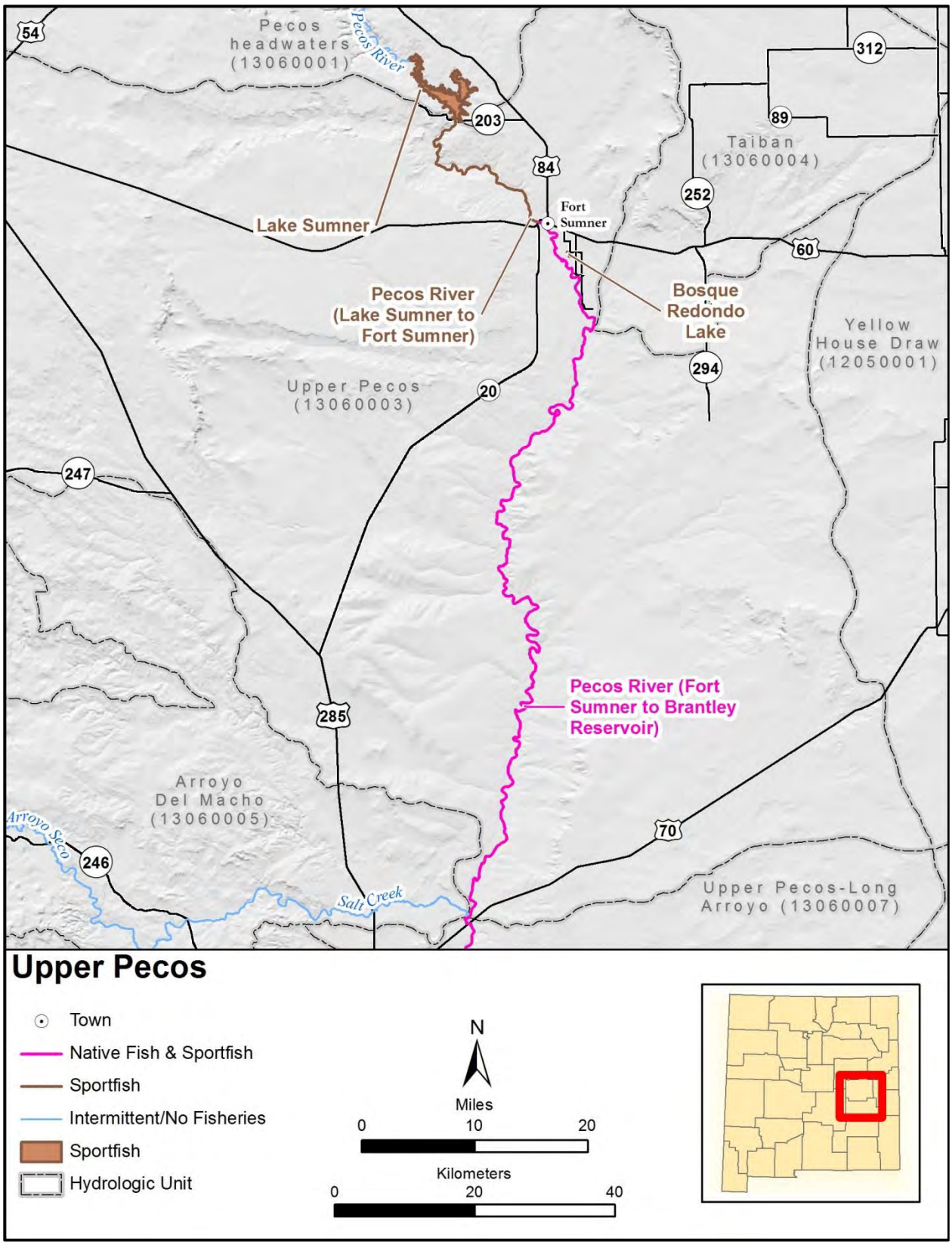


Figure 25. Upper Pecos

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Figure 26. Gallo Arroyo and Arroyo Del Macho

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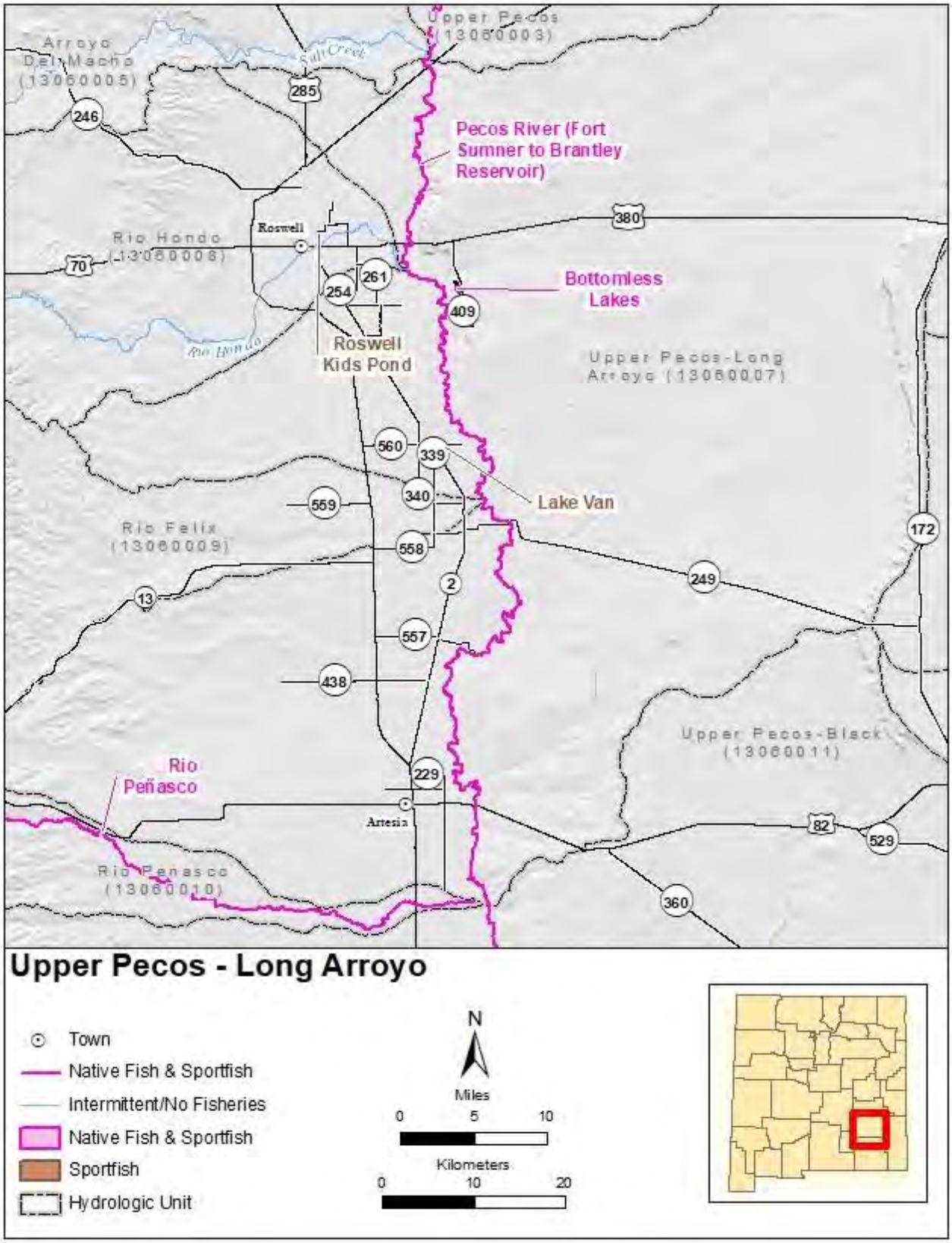


Figure 27. Upper Pecos - Long Arroyo

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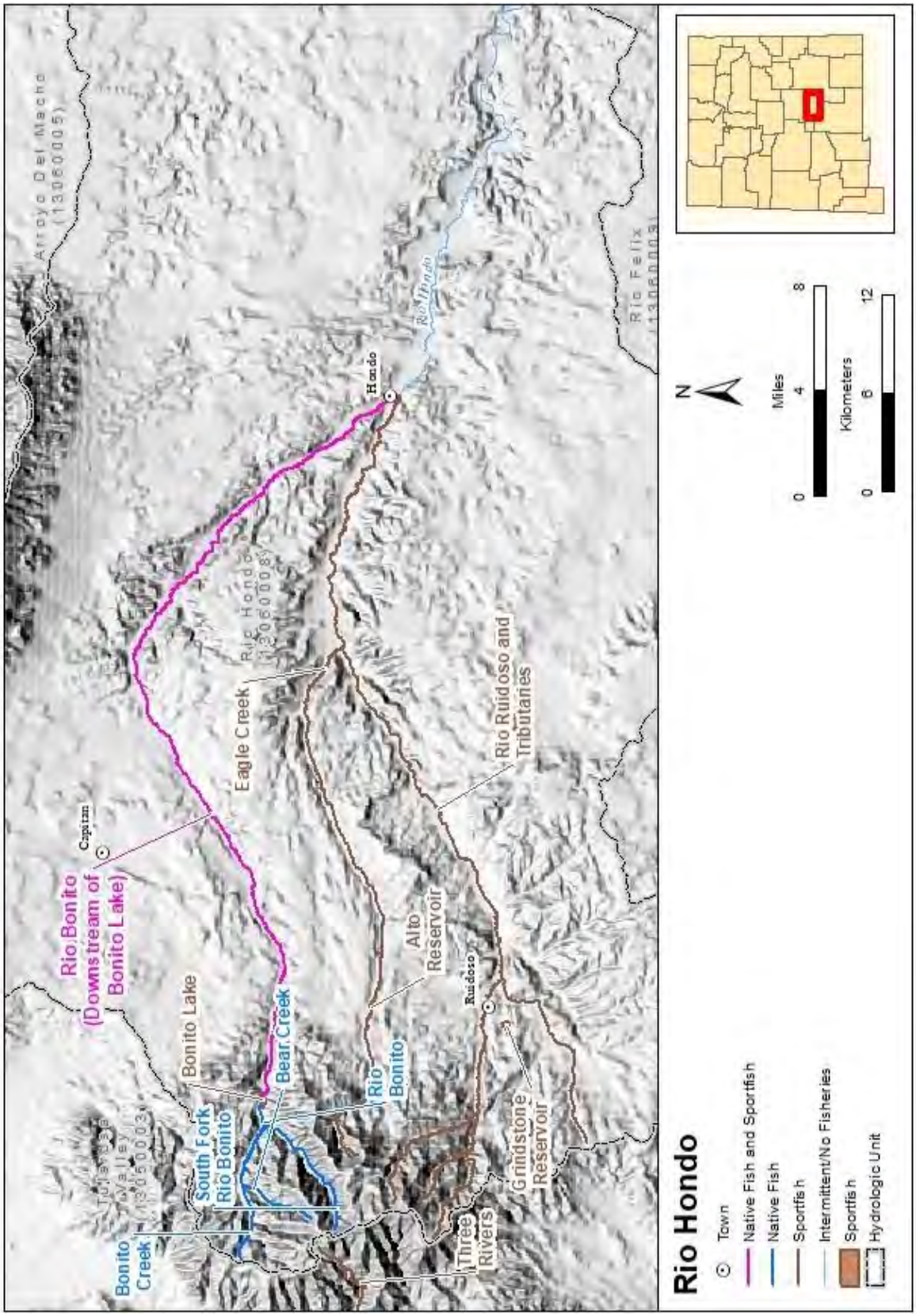


Figure 28. Rio Hondo

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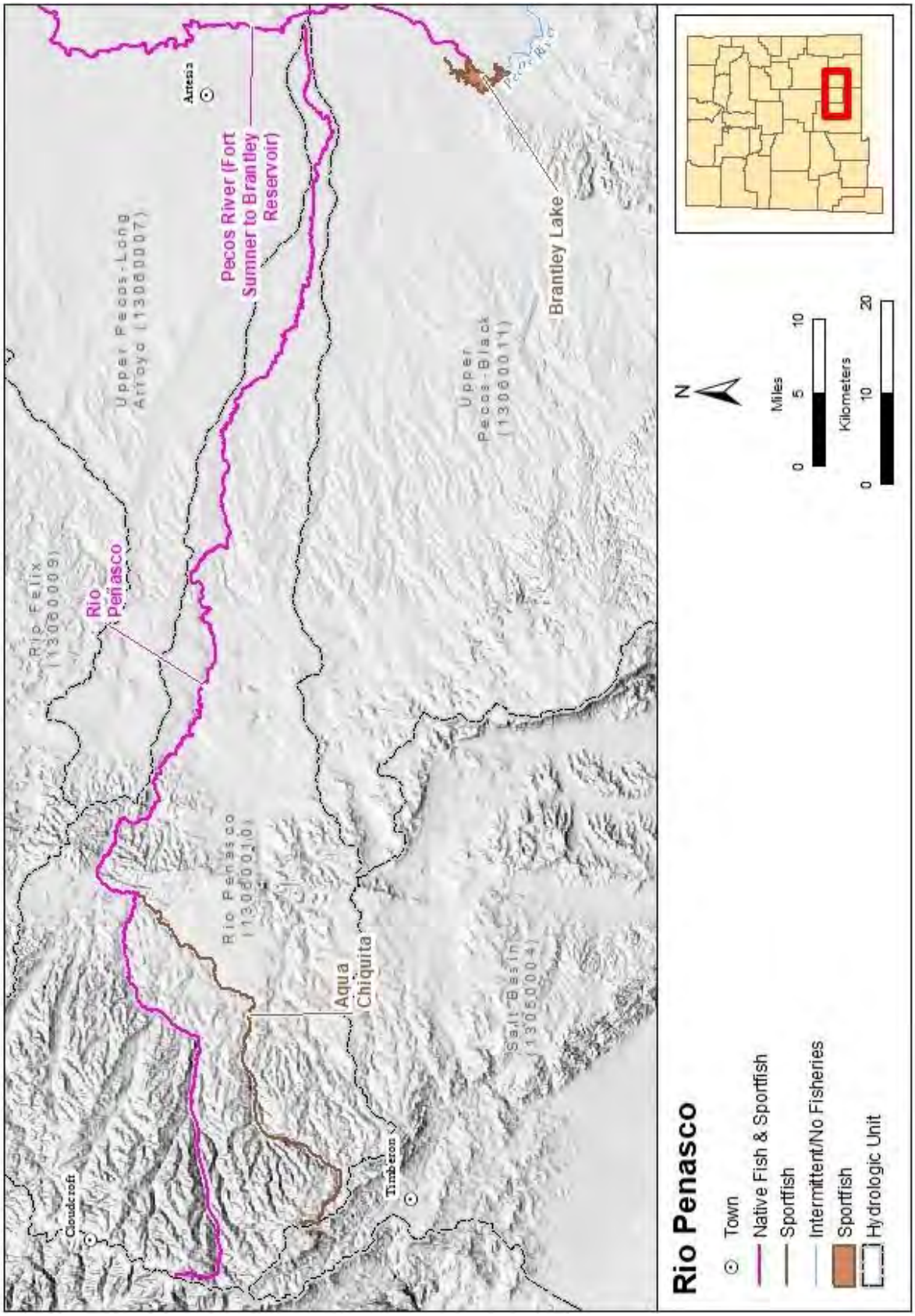


Figure 29. Rio Peñasco

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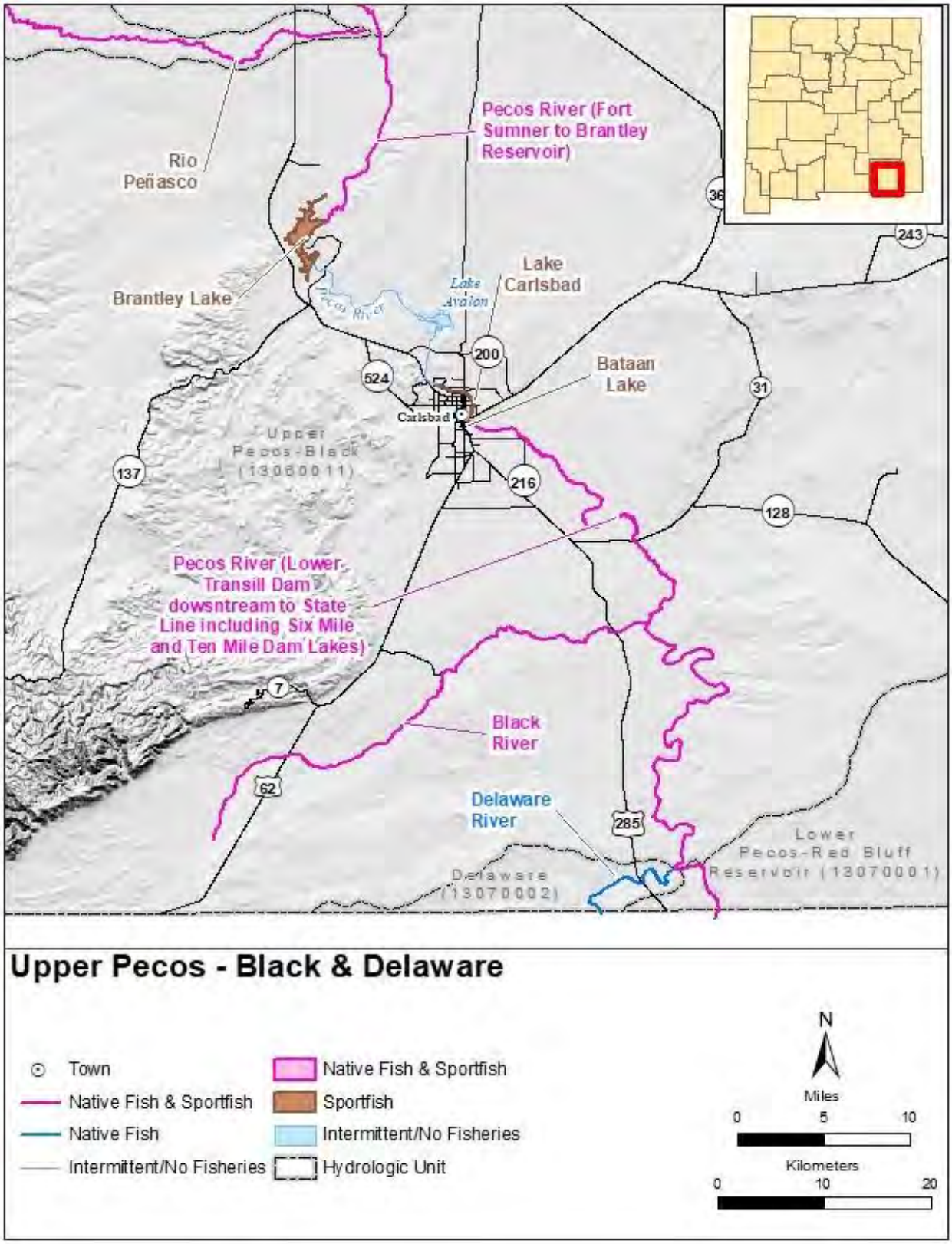


Figure 30. Upper Pecos - Black and Delaware

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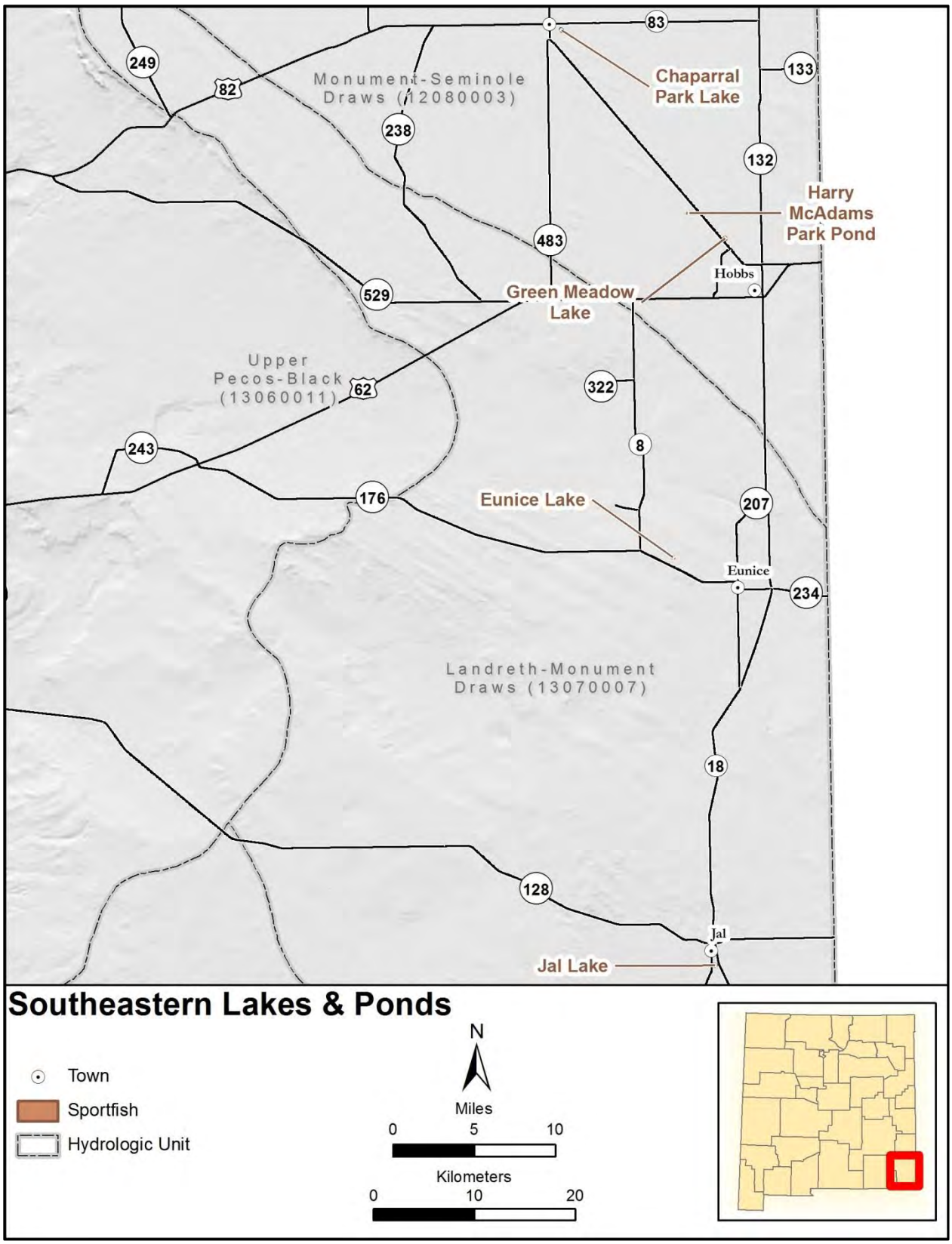


Figure 31. Southeastern Lakes and Ponds

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Tularosa Watershed

The Tularosa Basin encompasses approximately 3.2 million acres in south central New Mexico and is a closed basin. There has been limited development in the watershed because much of the Tularosa Basin is federal government property (White Sands Missile Range, Holloman Air Force Base, White Sands National Monument). Due to limited perennial habitats in the Tularosa Watershed, fisheries management activities are limited to monitoring of White Sands Pupfish in coordination with federal agencies and recreational fisheries in the Three Rivers drainage near Alamogordo and Carrizozo Recreation Lake. The mainstem of the Tularosa River is primarily located on private lands and the status of the fisheries on public reaches are unknown.

HUC 13050003 Tularosa Valley

Management Direction for HUC 13050003 Tularosa Valley

Water	Fish Species	Management Type	Management Direction
Carrizozo Recreation Lake	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Salt Creek and Malpais Spring	White Sands Pupfish	Native Fish	Implement actions identified in the White Sands Pupfish Conservation Agreement
Three Rivers	Brook Trout	Wild	Maintain regulations to support angling for wild trout

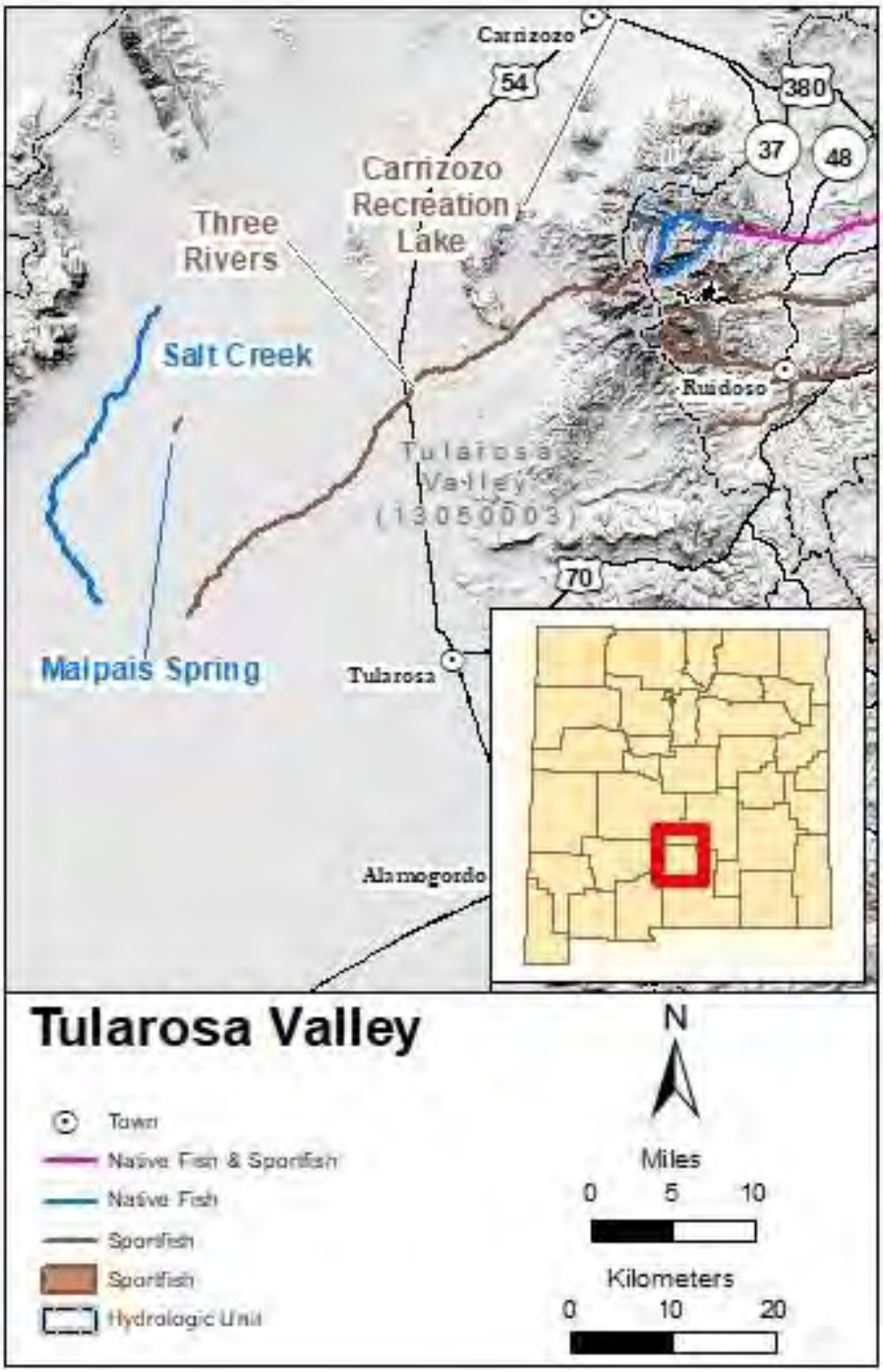


Figure 32. Tularosa Valley

Rio Grande Watershed

The Rio Grande Watershed originates in the San Juan Mountains of southern Colorado and flows south through central New Mexico for the entire length of the State. At El Paso, Texas, the drainage area is approximately 20.1 million acres, including the drainage area in Colorado (US Geological Survey 1996). There are several streams that drain into the Rio Grande include; (1) the Rio Chama, which joins the Rio Grande in north central New Mexico and is the most significant tributary; (2) the Jemez River which joins the Rio Grande near Bernalillo; and (3) the San Jose/Rio Puerco Drainage which also joins the Rio Grande south of San Antonio, NM. Smaller watersheds drain mountains in southern New Mexico. These drainages lack the diversity of those to the north, and many of them are ephemeral. Flow in the Rio Grande, typically low in the winter, is most significantly affected by snowmelt and summer rain events. A spring peak generally occurs between early April and mid-May from snow melt. Low flow returns in June followed by smaller peaks of shorter duration associated with monsoonal rain events. This historical flow regime has been greatly affected by irrigation diversions and agricultural reservoirs in the lower part of the system. Irrigation flows have increased the relative magnitude and duration of summer peaks and reduced the peak associated with snowmelt.

Most lands within the Rio Grande Watershed are under federal and quasi-federal ownership. The headwaters typically occur in National Forests (Carson, Santa Fe, Cibola, and Gila). The Rio Grande flows through large tracts of Bureau of Land Management holdings, the Middle Rio Grande Conservancy District, and the Elephant Butte Irrigation District. Cultivated cropland or orchards occupy about 7% of the basin. This form of agriculture is particularly dense in the Española Valley, Middle Rio Grande Valley, and the Mesilla Valley. Other reaches are used extensively for livestock grazing. Several large reservoirs impound water within the Rio Grande basin for flood control and water storage.

The Rio Grande offers a diversity of angling opportunities in New Mexico. Many high alpine lakes are located within the headwaters and offer exceptional opportunities for catching large Rio Grande Cutthroat Trout. Trout angling opportunities include scores of small streams inhabited by Brook, Brown, Cutthroat, and Rainbow trout as well as trophy angling opportunities in large rivers such as the Rio Grande and Rio Chama. Heron Reservoir offers kokanee angling and is the only Lake Trout fishery in the state. Elephant Butte Reservoir, the state's largest reservoir, receives significant angling pressure for Largemouth Bass, Striped Bass, and White Bass. Current conditions have also increased opportunities for Blue Catfish and Walleye. Popular urban fisheries include Tingley Beach in Albuquerque and Alumni Pond in Las Cruces. Unfortunately, impacts associated with climate change and drought have led to changes in some fisheries. For example, Abiquiu Reservoir has become too warm for the historic

coldwater fisheries it once supported, and Kokanee and Rainbow Trout are no longer being stocked there.

A single federally protected fish, Rio Grande Silvery Minnow, and several state protected or sensitive fish inhabit the Rio Grande Watershed. Active restoration efforts for Rio Grande Cutthroat Trout, Rio Grande Sucker, and Rio Grande Chub are ongoing in the Costilla Creek Watershed. The Department has increased our conservation efforts for Rio Grande Sucker and Rio Grande Chub, which are present in many reaches throughout the drainage. The entire middle Rio Grande is designated for Rio Grande Silvery Minnow recovery, and other than regulation enforcement, the Department has little active management (e.g., stocking) for other species in this reach. Rainbow Trout are seasonally stocked into the drains in this reach. Overall, reach designations for native and sportfish management presents little conflict among the management types.

HUC 13010005 Conejos

Management Direction for HUC 13010005 Conejos

Water	Fish Species	Management Type	Management Direction
Rio de Los Pinos and Tributaries	Triploid Rainbow Trout	Put and Take	Stocked catchable triploid Rainbow Trout in lower sections
	Brown Trout	Wild	Maintain regulations to support angling for wild trout. Special Trout Water regulation (Green Chile Water) from Forest Service Roads 284 and 87A, 2.5 miles upstream to private land. Manage as a Quality Trout Water
	Rio Grande Chub	Native Fish	Maintain Distribution
Beaver Creek and Tributaries	Brook Trout	Wild	Maintain regulations to support angling for wild trout
Laguna Larga	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout in early summer
Lagunitas	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout in early summer
	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock and evaluate fingerling Rio Grande Cutthroat Trout stocking strategies
Rio San Antonio and Tributaries	Brown Trout	Wild	Maintain regulations to support angling for wild trout in lower reaches

Management Direction for HUC 13010005 Conejos			
Water	**Fish Species**	**Management Type**	**Management Direction**
(Headwaters to Rio Nutrias)	Rio Grande Cutthroat Trout	Wild	Consider headwaters for inclusion as Red Chile Native Trout Conservation Water due to recent genetic analysis identifying this population as pure Rio Grande Cutthroat Trout
	Rio Grande Chub	Native Fish	Maintain distribution
	Rio Grande Sucker	Native Fish	Maintain distribution
Rio San Antonio and Tributaries (Rio Nutrias to State Line)	Brown Trout	Wild	Maintain regulations to support angling for wild trout
	Rio Grande Chub	Native Fish	Maintain distribution
	Rio Grande Sucker	Native Fish	Maintain distribution
Tanques Canyon	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Native Trout Conservation Water) from FS Road 93 crossing upstream to its headwaters; support U.S. Forest Service (USFS) in repairing barrier
	Brown Trout	Suppression	Periodically remove Brown Trout to maintain the Rio Grande Cutthroat Trout population. Unlimited angler harvest
Tio Grande Canyon	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Native Trout Conservation Water) within the Carson National Forest excluding private land; support USFS in repairing barrier
	Brown Trout	Suppression	Periodically remove Brown Trout to maintain the Rio Grande Cutthroat Trout population. Unlimited angler harvest

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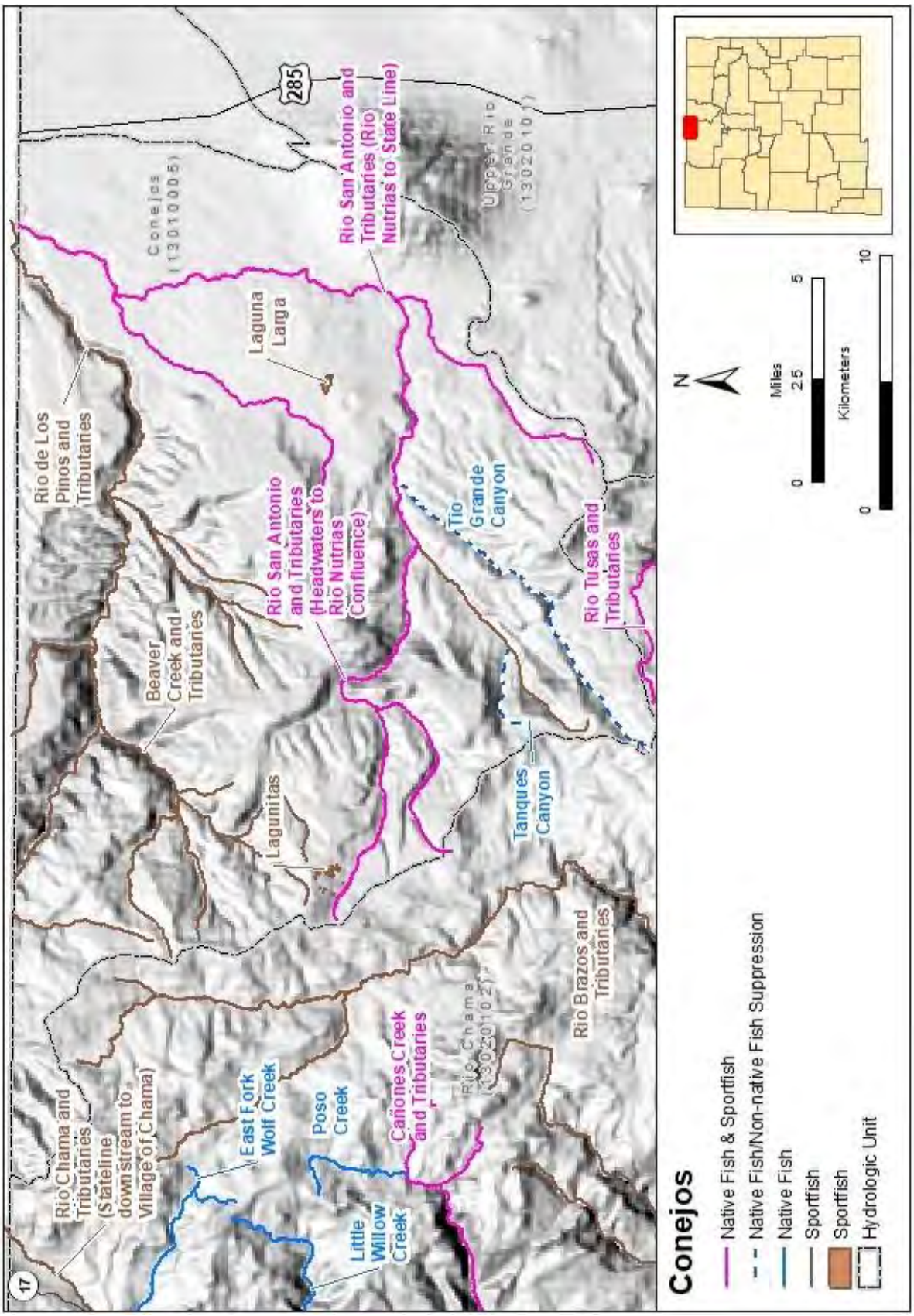


Figure 33. Conejos

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HUC 13020101 Upper Rio Grande

Management Direction for HUC 13020101 Upper Rio Grande

Water	Fish Species	Management Type	Management Direction
Rio Grande (Colorado border downstream to Pilar)	Brown Trout	Wild	Special Trout Water regulation (X-mas Chile Water) from Colorado stateline downstream to Taos Junction Bridge at NM Highway 567. Manage as a Quality Trout Water
	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout between Taos Junction Bridge and Pilar and at John Dunn Bridge near Rio Hondo confluence
	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock fingerling Rio Grande Cutthroat Trout in Rio Grande Gorge and monitor to document recruitment
	Rio Grande Chub	Native Fish	Maintain distribution
Rio Grande (Pilar downstream to confluence of Rio Chama)	Brown Trout	Wild	Maintain regulations to support angling for wild trout
	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout between Pilar and Embudo
	Smallmouth Bass	Wild	Length limit removed in 2022 to encourage harvest of stunted population. Investigate effectiveness of regulation change. Statewide daily bag limit still in place
	Rio Grande Chub	Native Fish	Maintain distribution
Rio Grande (Rio Chama confluence downstream to Cochiti Lake)	Channel Catfish	Wild	Limited public access. Flows through Santa Clara and San Ildelfonso Pueblos before entering White Rock Canyon. Upstream of White Rock Canyon water too warm for year-round trout fishery, dominated by warmwater fish species. In canyon, upstream of Capulin Canyon, Brown Trout are self-sustaining. Downstream of Capulin Canyon fishery is predominantly a warmwater fishery. Channel Catfish are present throughout reach
	Brown Trout	Wild	Maintain regulations to support angling for wild trout
Costilla Creek (Headwaters downstream to Costilla Reservoir Dam)	Rio Grande Cutthroat Trout	Native Fish	Restoration project in this reach has been completed. Core Conservation Population of Rio Grande Cutthroat Trout
	Rio Grande Chub	Native Fish	Repatriate to appropriate habitats
	Rio Grande Sucker	Native Fish	Repatriate to appropriate habitats

Management Direction for HUC 13020101 Upper Rio Grande

Water	Fish Species	Management Type	Management Direction
Costilla Creek and Tributaries (Valle Vidal Unit of Carson National Forest)	Rio Grande Cutthroat Trout	Native Fish	Ongoing Rio Grande Cutthroat Trout restoration project from the Valle Vidal boundary upstream to Costilla Reservoir Dam. Special Trout Water regulation (Red Chile Water). Manage as a Quality Trout Water
	Rio Grande Chub	Native Fish	Repatriate to appropriate habitats including Comanche Creek watershed
	Rio Grande Sucker	Native Fish	Repatriate to appropriate habitats including Comanche Creek watershed
Costilla Creek and Tributaries (Valle Vidal Unit boundary downstream to confluence with Rio Grande)	Cutthroat Trout	Wild	Maintain regulations to support angling for wild trout. Special Trout Water regulation (Red Chile Water) from Valle Vidal boundary downstream to Latir Creek. Manage as a Quality Trout Water
	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout within the Open Gate lease. Investigate long-term transition from Rainbow Trout to Rio Grande Cutthroat Trout catchable stocking
Cabresto Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Native Trout Conservation Water) from Cabresto Canyon to headwaters not including Lake Fork
	Brook Trout	Suppression	Periodically remove Brook Trout to maintain the Rio Grande Cutthroat Trout population. Unlimited angler harvest
	Brown Trout	Suppression	Periodically remove Brown Trout to maintain the Rio Grande Cutthroat Trout population. Unlimited angler harvest
Cabresto Lake	Trout	Wild	Brook, Cutthroat, and Rainbow trout are present in this drainage. Maintain regulations to support angling for wild trout. Investigate need for stocking catchable triploid Rainbow Trout or fingerling Rio Grande Cutthroat Trout
Lake Fork Cabresto	Trout	Wild	Brook and Cutthroat trout are present. Maintain regulations to support angling for wild trout
Red River and Tributaries (Headwaters downstream confluence of Pioneer Creek)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Trout	Wild	Special Trout Water regulation (Green Chile Water) from its confluence with Goose Creek 1.1 miles upstream to the Carson National Forest boundary. Brook, Brown, and Cutthroat trout are present in the reach

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Management Direction for HUC 13020101 Upper Rio Grande

Water	Fish Species	Management Type	Management Direction
Red River and Tributaries (Pioneer Creek confluence downstream to Red River Hatchery)	Triploid Rainbow Trout	Put and Take	Stock triploid Rainbow Trout
	Brown Trout	Wild	Natural thermal scarring as well as molybdenum mine limits wild trout potential
Red River (Red River Hatchery downstream to Rio Grande)	Triploid Rainbow Trout	Put and Take	Stock triploid Rainbow Trout
	Brown Trout	Wild	Special Trout Water regulation (X-mas Chile Water) from the lower walking bridge at Red River Hatchery downstream to confluence with Rio Grande. Manage as a Quality Trout Water
Red River City Ponds	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout from March to November. Middle (smaller) pond open to anglers 11 years old and younger, 65 years old and older, and individuals with disabilities
Red River Hatchery Pond	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout. Open to anglers 11 years old and younger, 65 years old and older, and individuals with disabilities
Eagle Rock Lake	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
Fawn Lakes	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout. Lakes severely impacted by flood damage. Investigate renovation potential with Carson National Forest
Middle Fork Lake	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock fingerling Rio Grande Cutthroat Trout
	Brook Trout	Wild	Maintain regulations to support angling for wild trout
Horseshoe Lake (East Fork Red River)	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock fingerling Rio Grande Cutthroat Trout
Columbine Creek and Tributaries	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Native Trout Conservation Water) from confluence with Red River to headwaters
	Brown Trout	Suppression	Periodically remove Brown Trout to maintain the Rio Grande Cutthroat Trout population. Unlimited angler harvest
San Cristobal Creek and Tributaries	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout

Management Direction for HUC 13020101 Upper Rio Grande

Water	Fish Species	Management Type	Management Direction
Rio Pueblo de Taos	Brown Trout	Wild	Primarily on Pueblo of Taos. Maintain regulations to support angling for wild trout
Rio Hondo Tributaries (Yerba Creek, Italianos Creek, Gavilan Creek, South Fork Rio Hondo)	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Populations of Rio Grande Cutthroat Trout. Special Trout Water Resulations (Red Chile Native Trout Conservation Water) in Yerba, Gavilan, Italianos creeks and South Fork Rio Hondo
	Brown Trout	Suppression	Present in Yerba and Gavilan Creeks, and South Fork Rio Hondo but not Italianos Creek. Periodically remove Brown Trout to maintain the Rio Grande Cutthroat Trout population. Unlimited angler harvest
Rio Hondo (Headwaters downstream to Highway 522)	Trout	Wild	Brown and Cutthroat trout present in this reach. Maintain regulations to support angling for wild trout
Rio Hondo (Highway 522 downstream to Rio Grande)	Triploid Rainbow Trout	Put and Take	Stock triploid Rainbow Trout
	Brown Trout	Wild	Maintain regulations to support angling for wild trout
Williams Lake	N/A	N/A	Habitat is limited and winterkill conditions are likely common. Stocking suspended
Rio Fernando de Taos	Triploid Rainbow Trout	Put and Take	Stock triploid Rainbow Trout during spring and early summer months. Most of this creek is ephemeral which limits angling potential
	Brown Trout	Wild	Maintain regulations to support angling for wild trout
Rio Grande del Rancho (Little Rio Grande) and Tributaries	Brown Trout	Wild	Maintain regulations to support angling for wild trout
	Rio Grande Chub	Native Fish	Maintain distribution
	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout in extreme headwaters of the Little Rio Grande
Rio Chiquito	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Consider headwaters for inclusion as Red Chile Native Trout Conservation Water due to recent genetic analysis identifying this population as pure Rio Grande Cutthroat Trout
	Brown Trout	Wild	Maintain regulations to support angling for wild trout in lower reaches

Management Direction for HUC 13020101 Upper Rio Grande

Water	Fish Species	Management Type	Management Direction
Pot Creek (Rito de la Olla) and Tributaries	Brown Trout	Wild	Maintain regulations to support angling for wild trout
Palociento Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Native Trout Conservation Water) from confluence with Pot Creek to headwaters
	Brown Trout	Suppression	Periodically remove Brown Trout to maintain the Rio Grande Cutthroat Trout population. Unlimited angler harvest
Frijoles Creek (Taos)	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Native Trout Conservation Water) from confluence with Pot Creek to headwaters
	Brown Trout	Suppression	Periodically remove Brown Trout to maintain the Rio Grande Cutthroat Trout population**.** Unlimited angler harvest
Rio Pueblo and Tributaries	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Brown Trout	Wild	Maintain regulations to support angling for wild trout
La Junta Canyon (Rito la Presa)	Brown Trout	Wild	Maintain regulations to support angling for wild trout. Conservation Population of Rio Grande Cutthroat Trout in extreme headwaters of Sardinas and La Presa
Alamitos Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout
Policarpio Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout
Rio Santa Barbara and Tributaries (Headwaters downstream to Middle and West Forks confluence)	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water (Red Chile Native Trout Conservation Water)
	Brown Trout	Suppression	Periodically remove Brown Trout to maintain the Rio Grande Cutthroat Trout population. Unlimited angler harvest
Rio Santa Barbara (Middle and West Forks confluence downstream to Rio Embudo confluence)	Brown Trout	Wild	Maintain regulations to support angling for wild trout

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Management Direction for HUC 13020101 Upper Rio Grande

Water	Fish Species	Management Type	Management Direction
Jicarita Creek and Indian Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Populations of Rio Grande Cutthroat Trout
Rio de las Trampas	Rio Grande Cutthroat Trout	Wild	Conservation Population of Rio Grande Cutthroat Trout suspected of hybridization
Embudo Creek (Rio Embudo) and Tributaries	Brown Trout	Wild	Maintain regulations to support angling for wild trout
	Rio Grande Chub	Native Fish	Maintain Distribution
Rio de Truchas	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout
Rio Medio and Tributaries (Santa Fe)	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout in extreme headwaters
	Brown Trout	Wild	Maintain regulations to support angling for wild trout
Rio Molino	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout
Rio Frijoles (Santa Fe)	Brown Trout	Wild	Maintain regulations to support angling for wild trout
	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout in extreme headwaters
Santa Cruz River	Brown Trout	Wild	Primarily private property below Santa Cruz Reservoir and not managed by the Department. Maintain regulations to support angling for wild trout
Santa Cruz Reservoir	Brown Trout	Wild	Irrigation withdrawals cause lake to drop dramatically through the summer thereby limiting wild trout potential
	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
Rio Quemado	Brown Trout	Wild	Primarily on private land. Maintain regulations to support angling for wild trout
	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout
South Fork Rio Quemado and Tributaries	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout
Guaje Creek	Rio Grande Cutthroat Trout	Native Fish	Severely impacted by Cerro Grande and Las Conchas wildfires. Non-native trout were extirpated. Consider for repatriation of Rio Grande Cutthroat Trout

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Management Direction for HUC 13020101 Upper Rio Grande

Water	Fish Species	Management Type	Management Direction
Los Alamos Reservoir	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout as conditions allow
	Rio Grande Cutthroat Trout	Put, Grow, and Take	Investigate stocking fingerling Rio Grande Cutthroat Trout
Tesuque Creek and Tributaries	Rainbow Trout	Wild	Lower reach almost entirely within Tesuque Pueblo. Maintain regulations to support angling for wild trout in areas under Department jurisdiction
Rio Nambe and Tributaries	Trout	Wild	Lower section entirely within Nambe Pueblo (Rainbow Trout stocked in Nambe Lake by Pueblo). Maintain regulations to support angling for wild trout in areas under Department jurisdiction
Rio en Medio	Rainbow Trout	Wild	Maintain regulations to support angling for wild trout
	Brook Trout	Wild	Maintain regulations to support angling for wild trout
Lost Lake (East Fork Red River)	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock fingerling Rio Grande Cutthroat Trout
Trampas Lakes (Upper)	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock fingerling Rio Grande Cutthroat Trout every other year
Hidden Lake	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock fingerling Rio Grande Cutthroat Trout when possible
Trampas Lakes (Lower)	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock fingerling Rio Grande Cutthroat Trout every other year
San Leonardo Lake	N/A	N/A	Habitat is limited and winterkill conditions are likely common. Stocking suspended
Goose Lake	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock fingerling Rio Grande Cutthroat Trout when possible
Jose Vigil Lake	Rio Grande Cutthroat Trout	Put, Grow, and Take	Investigate stocking with Rio Grande Cutthroat Trout
Osha Canyon	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout
Rito Angostura	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout

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Management Direction for HUC 13020101 Upper Rio Grande

Water	Fish Species	Management Type	Management Direction
La Cueva Canyon	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout
Sardinas Canyon	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout
Rito la Presa Headwaters	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout
Tienditas Creek	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout
Pojoaque River and Tributaries	N/A	N/A	Intermittent throughout reach, no current data. Located across four pueblos (Tesuque, Nambe, Pojoaque, and San Ildefonso)

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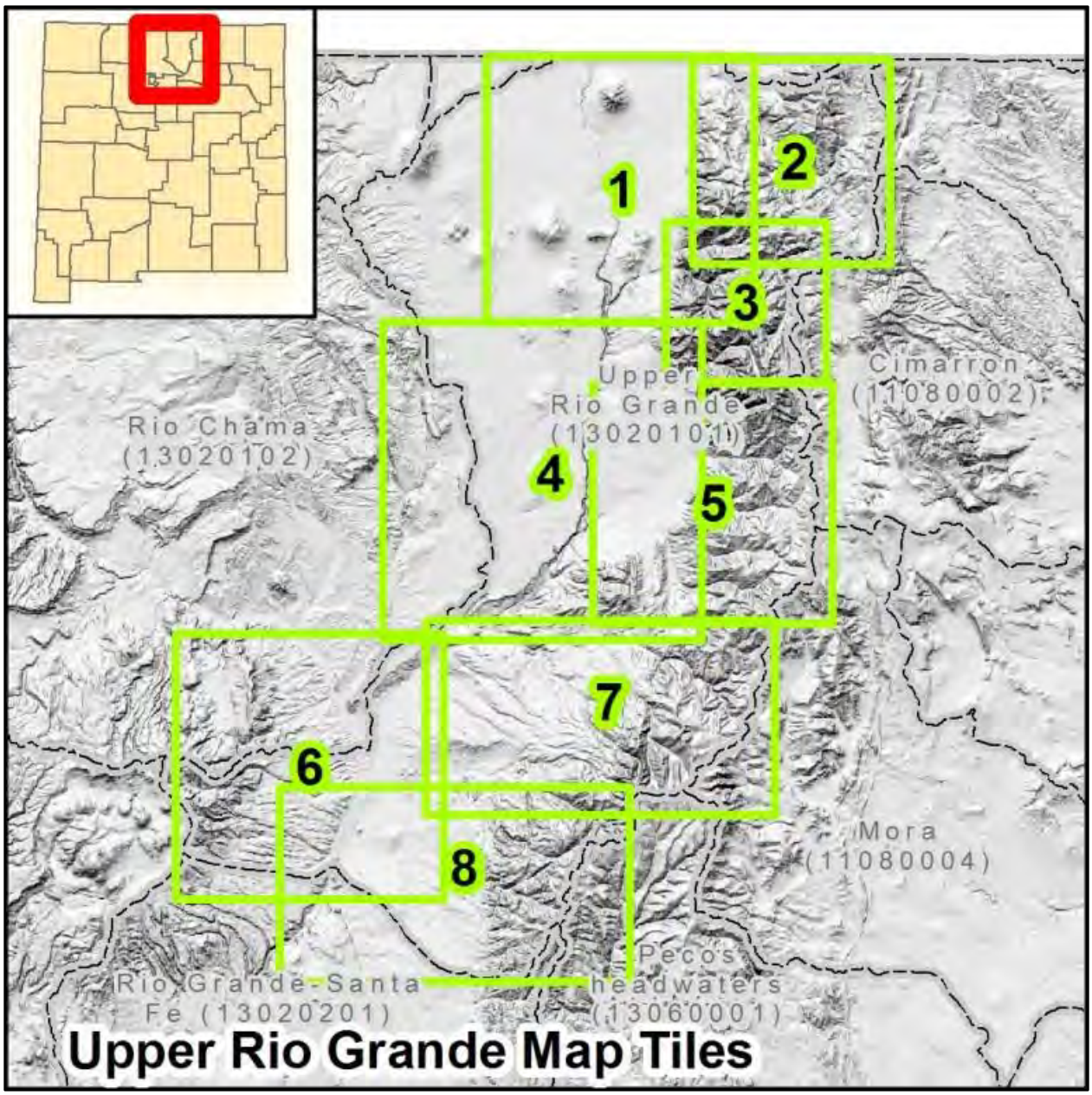


Figure 34. Upper Rio Grande Map Tiles

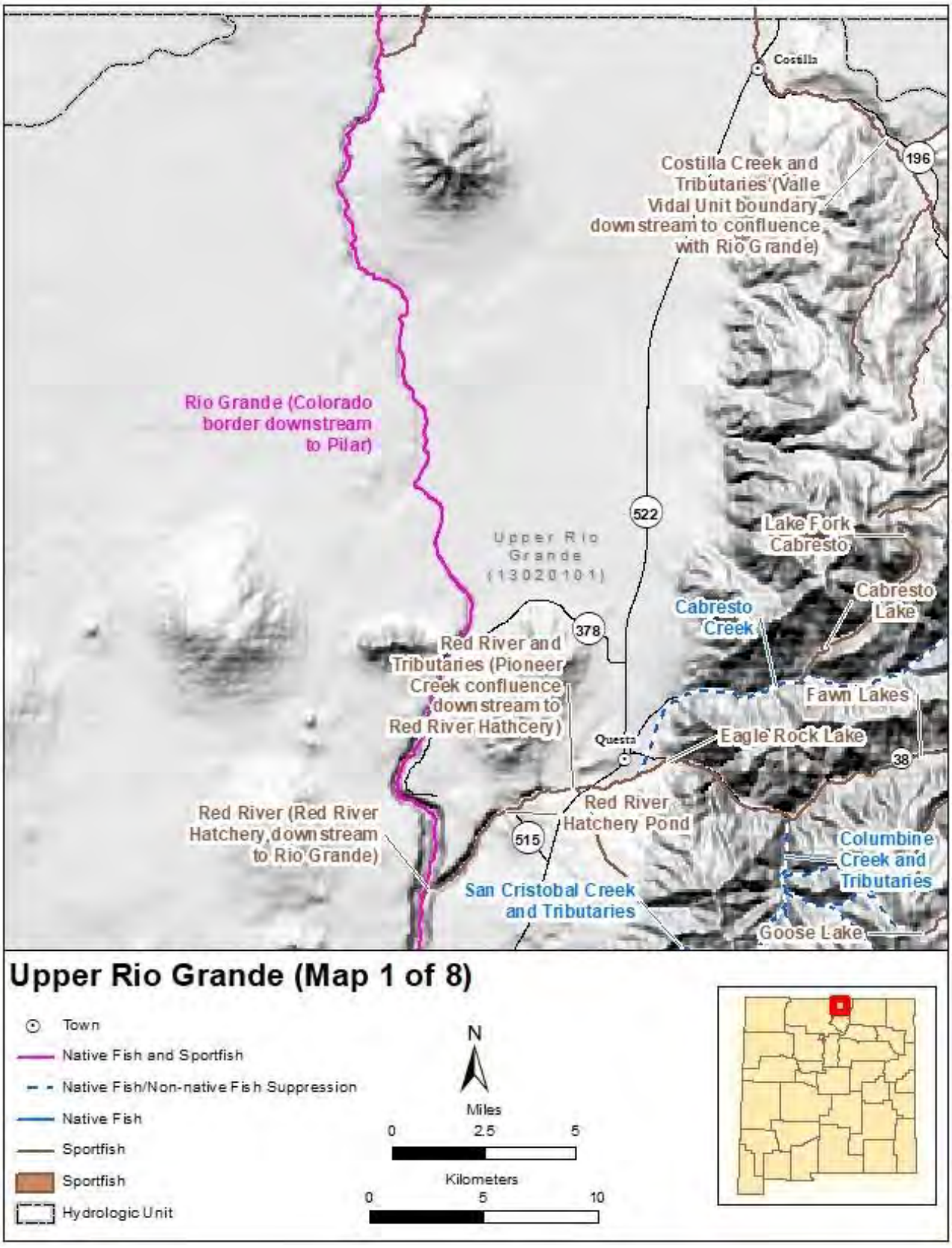


Figure 35. Upper Rio Grande (Map 1 of 8)

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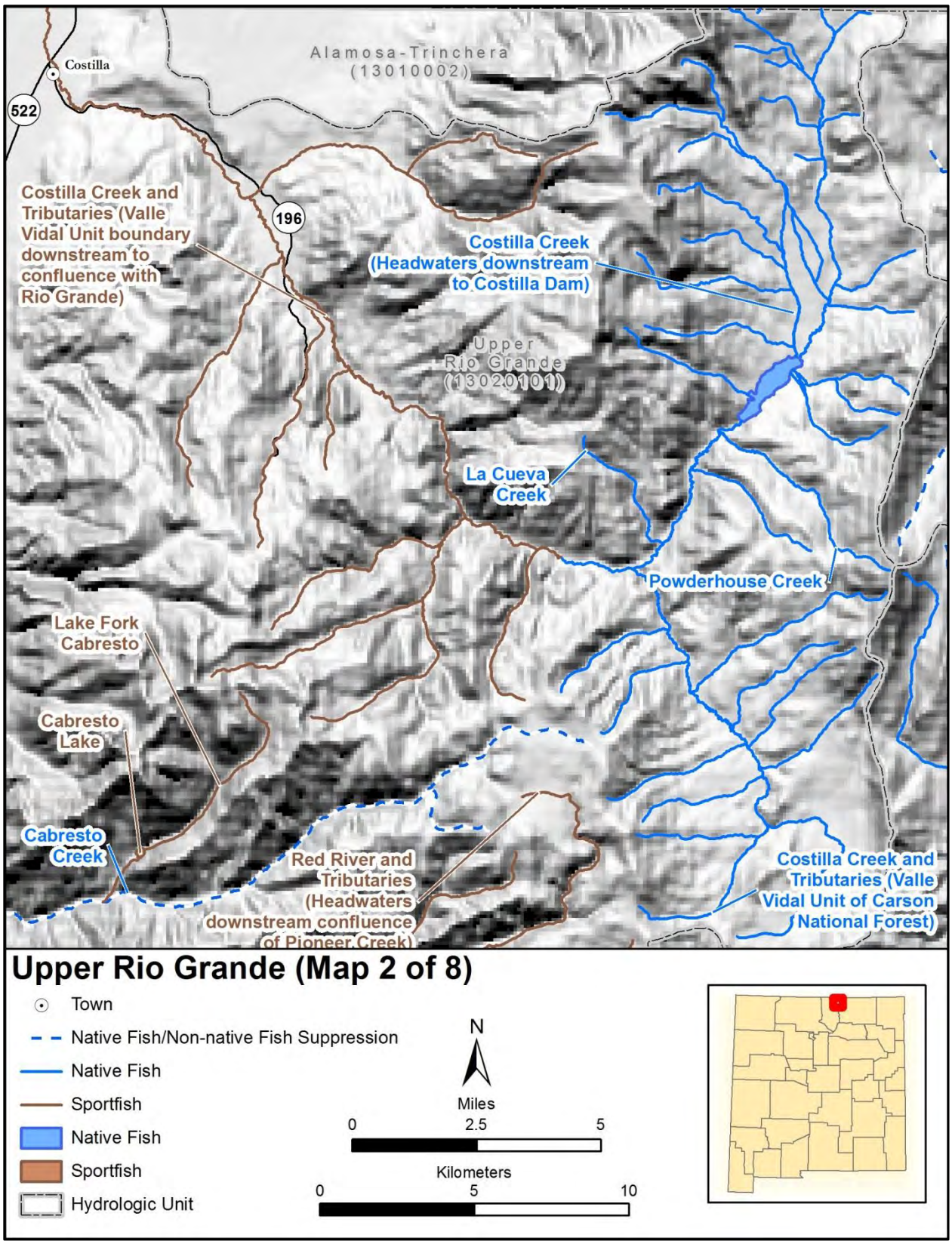


Figure 36. Upper Rio Grande (Map 2 of 8)

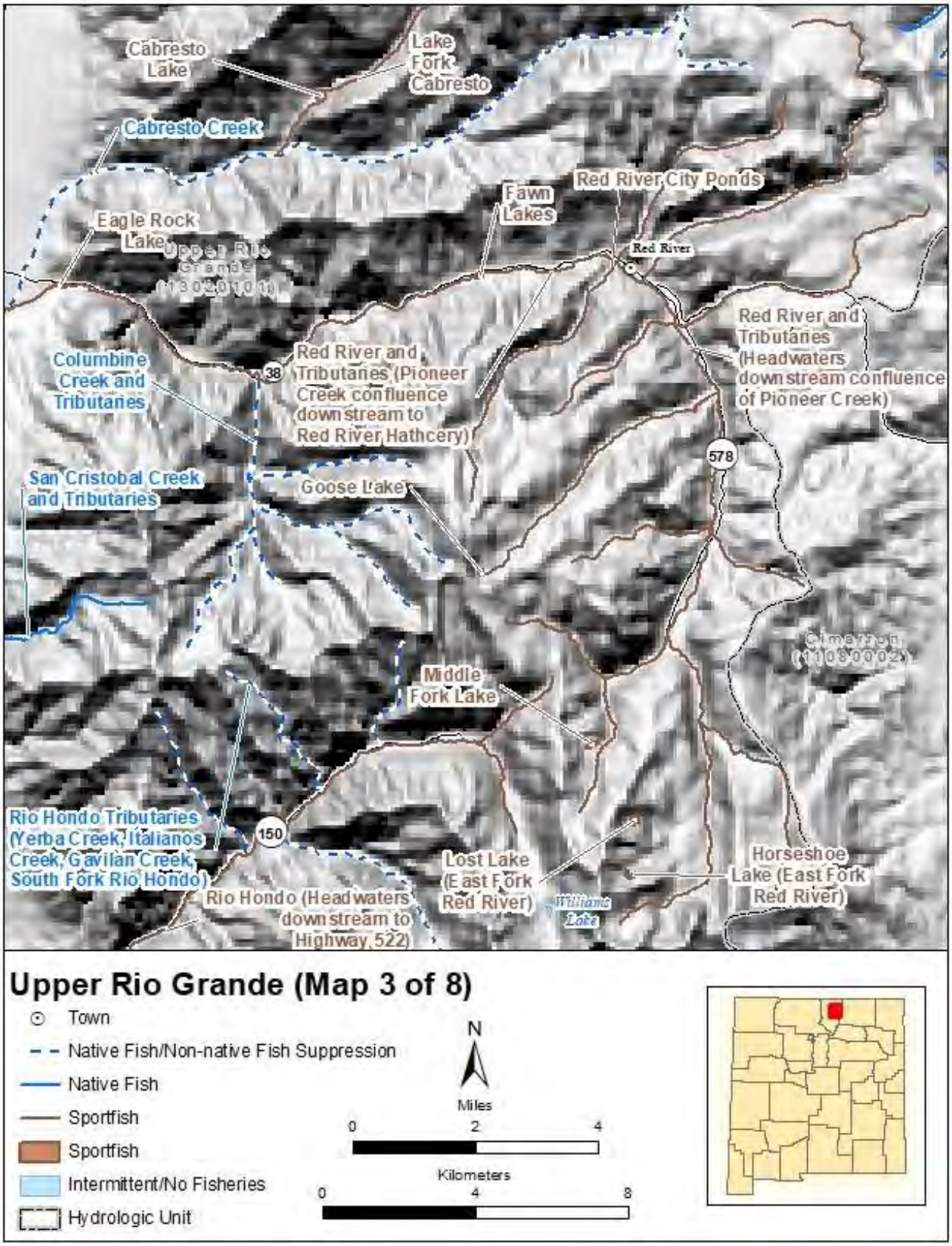


Figure 37. Upper Rio Grande (Map 3 of 8)

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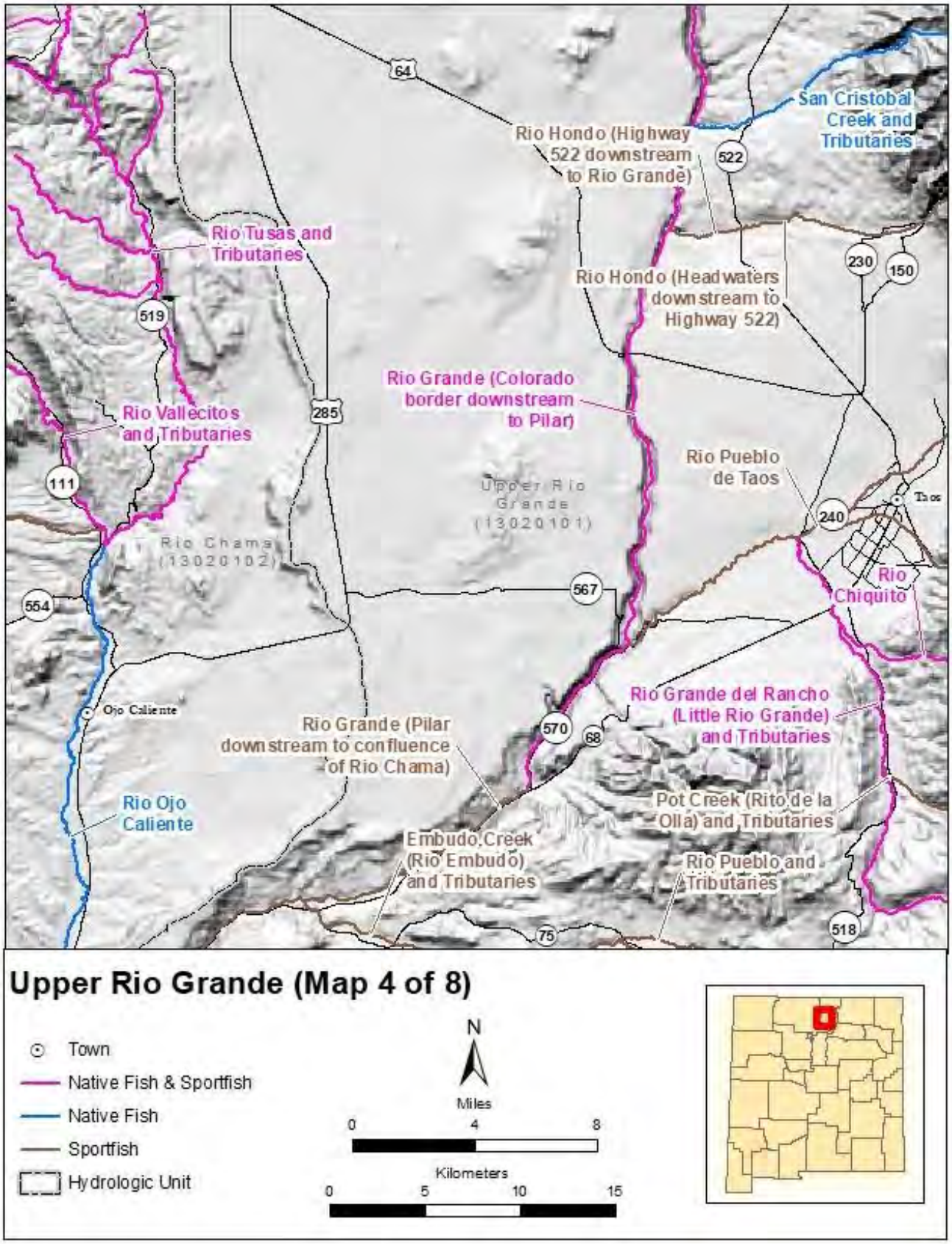


Figure 38. Upper Rio Grande (Map 4 of 8)

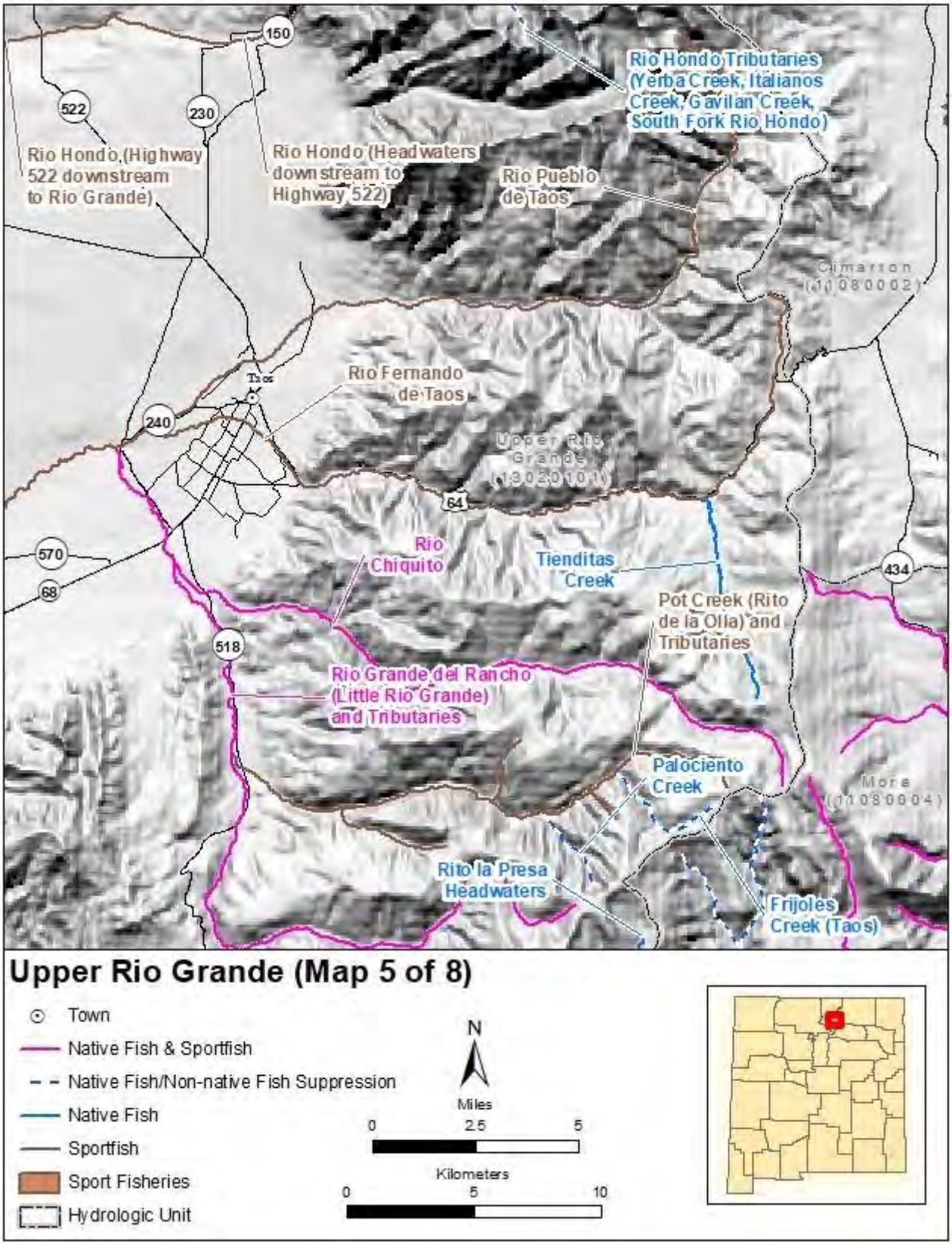


Figure 39. Upper Rio Grande (Map 5 of 8)

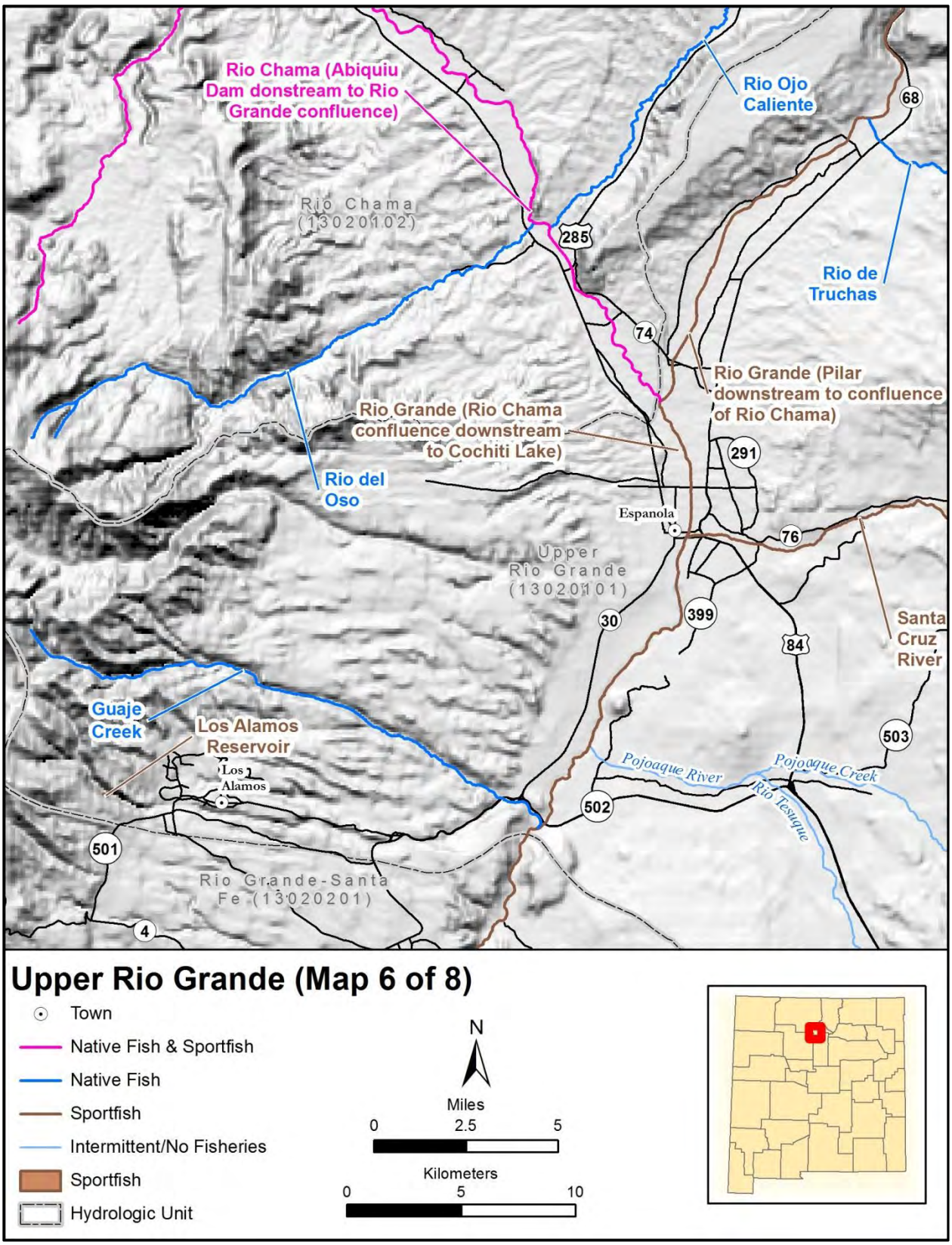


Figure 40. Upper Rio Grande (Map 6 of 8)

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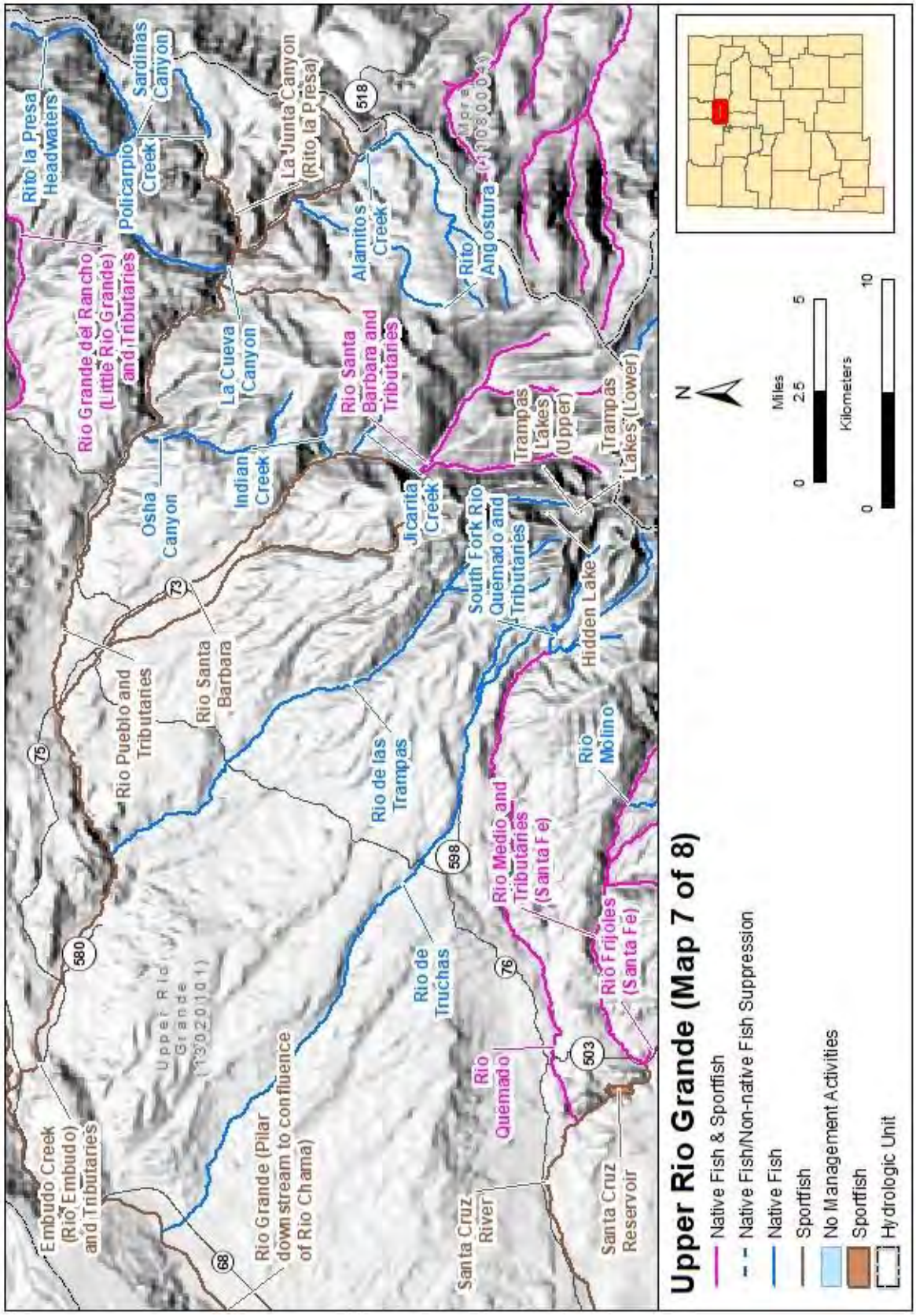


Figure 41. Upper Rio Grande (Map 7 of 8)

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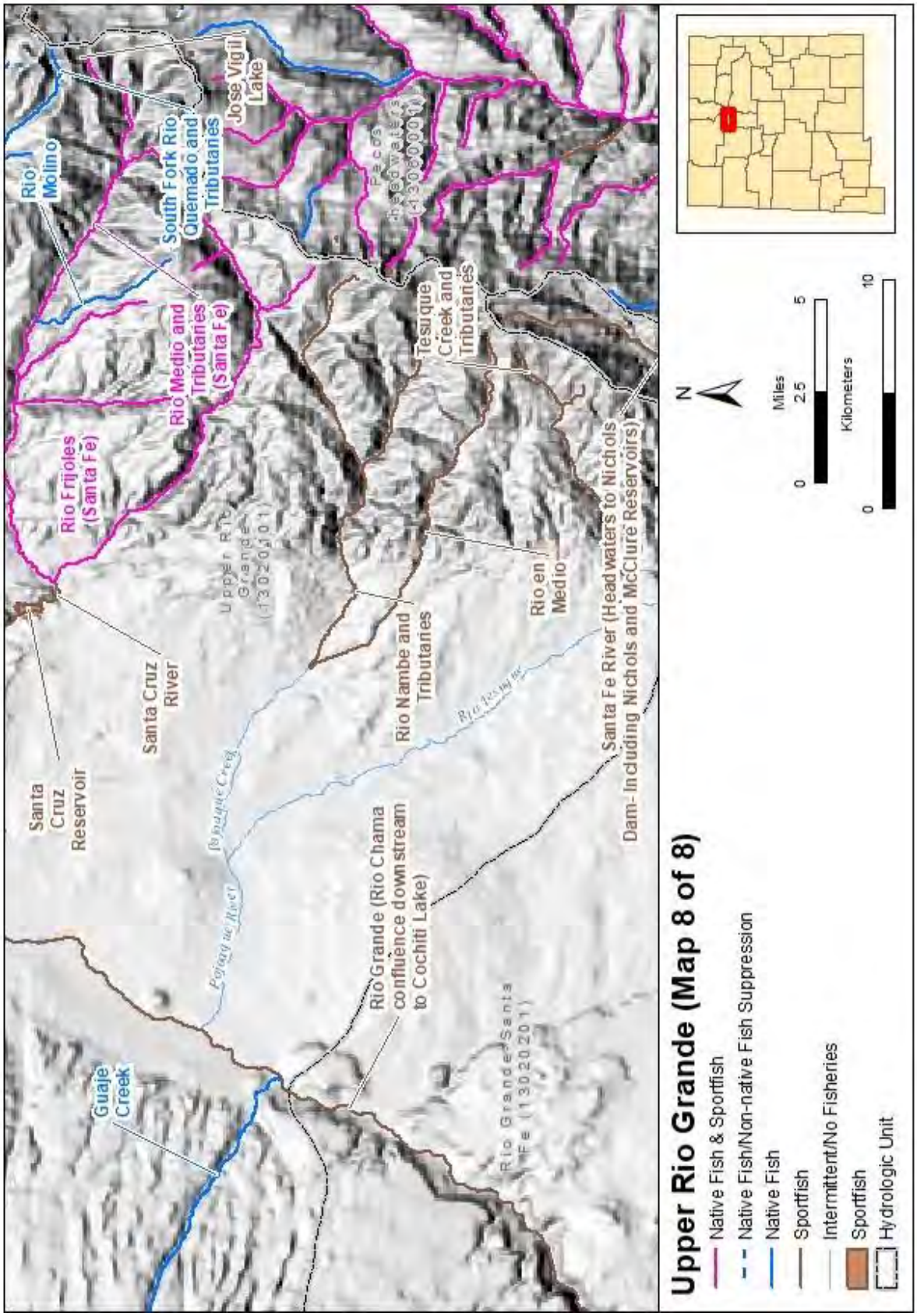


Figure 42. Upper Rio Grande (Map 8 of 8)

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HUC 13020102 Rio Chama

Management Direction for HUC 13020102 Rio Chama

Water	Fish Species	Management Type	Management Direction
Placer Creek	Brook Trout	Suppression/ Wild	Ongoing YY Brook Trout stocking study to investigate possibility for repatriation of Rio Grande Cutthroat Trout upstream of waterfall barrier at FS Road 1893. Maintain regulations to support angling for wild trout downstream of waterfall barrier
Hopewell Lake	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Brook Trout	Wild	Maintain regulations to support angling for wild trout
	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock and evaluate fingerling Rio Grande Cutthroat Trout stocking strategies
Rio Tusas and Tributaries	Rainbow Trout	Wild	Rainbow Trout and Cutthroat Trout population in upper drainage. Maintain regulations to support angling for wild trout
	Rio Grande Chub	Native Fish	Maintain distribution
	Rio Grande Sucker	Native Fish	Maintain distribution
Rio Vallecitos and Tributaries	Brown Trout	Wild	Maintain regulations to support angling for wild trout
	Rio Grande Chub	Native Fish	Maintain distribution
	Rio Grande Sucker	Native Fish	Maintain distribution
Jaroso Creek	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout
El Rito Creek and Tributaries	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout upstream of fish migration barrier near Salvador Canyon. Conservation Population of Rio Grande Cutthroat Trout downstream of barrier. Seasonally stock catchable Rio Grande Cutthroat Trout in lower reach near campground

Management Direction for HUC 13020102 Rio Chama			
Water	**Fish Species**	**Management Type**	**Management Direction**
	Rio Grande Chub	Native Fish	Maintain distribution
Rio Ojo Caliente	Rio Grande Chub	Native Fish	Maintain distribution
	Rio Grande Sucker	Native Fish	Maintain distribution
Rio Chama and Tributaries (Stateline downstream to Village of Chama)	Brown Trout	Wild	No stocking upstream of Village of Chama. No current population data. Maintain regulations to support angling for wild trout
	Rainbow Trout	Wild	Maintain regulations to support angling for wild trout
East Fork Wolf Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout
Rio Chama between Village of Chama and El Vado Lake	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout annually. Leased access in Village of Chama
	Brown Trout	Wild	Special Trout Water regulation (Green Chile Water) within Rio Chama Wildlife and Fishing Area from Heron Reservoir outlet 2.9 miles upstream to Cottonwood Flats. Maintain regulations to support angling for wild trout. Manage Special Trout Water reach as a Quality Trout Water
	Rio Grande Chub	Native Fish	Maintain distribution
Rio Chama (El Vado Dam downstream to Abiquiu Reservoir)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Brown Trout	Wild	Special Trout Water regulation (Red Chile Water) from USGS gaging station located below Cooper's Landing to the Rio Nutrias confluence. Maintain regulations to support angling for wild trout. Manage Special Trout Water reach as Quality Trout Water
	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock fingerling Rio Grande Cutthroat Trout annually and monitor to document recruitment

Management Direction for HUC 13020102 Rio Chama			
Water	**Fish Species**	**Management Type**	**Management Direction**
Rio Chama (Abiquiu Dam downstream to Rio Grande confluence)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout annually in tailwater
	Brown Trout	Wild	Special Trout Water regulation (X-mas Chile Water) from US Highway 84 upstream 7.0 miles to base of Abiquiu Dam. Investigate effectiveness of Special Trout Water regulation. Manage as a Quality Trout Water
	Rio Grande Cutthroat Trout	Put, Grow, and Take	Investigate potential as recreational Rio Grande Cutthroat Trout fishery
	Rio Grande Chub	Native Fish	Maintain distribution
	Flathead Chub	Native Fish	Maintain distribution
Heron Reservoir	Kokanee	Put, Grow, and Take	Primary source for statewide kokanee broodstock. Kokanee season closed October-mid November for kokanee spawn. Stock at 100 fingerlings/surface acre. Annual stocking rate varies by reservoir elevation
	Triploid Rainbow Trout	Put, Grow, and Take	Rainbow Trout stocked by U.S. Fish and Wildlife Service per mitigation measures for the Colorado River Storage Act. Continued stocking uncertain due to Federal reduction in recreational hatchery budget. Fulfill stocking rates with Department raised triploid Rainbow Trout
	Lake Trout	Wild	Lake Trout introduced in the 1980s and is the only Lake Trout fishery in New Mexico. Maintain regulations to support angling for lake trout
El Vado Reservoir	Kokanee	Put, Grow, and Take	Lake experiences large fluctuations due to irrigation demands limiting fishery potential. Stock at 100 fingerlings/surface acre. Annual stocking rate varies by reservoir elevation
	Brown Trout	Wild	Maintain regulations to support angling for wild trout
	Triploid Rainbow Trout	Put, Grow, and Take	Stock fingerling triploid Rainbow Trout

Management Direction for HUC 13020102 Rio Chama			
Water	**Fish Species**	**Management Type**	**Management Direction**
Abiquiu Reservoir	Walleye	Put, Grow, and Take	Stock Walleye at 500 fry/surface acre. Annual stocking varies with reservoir elevation
	Channel Catfish	Wild	Maintain regulations to support angling for Channel Catfish
	Smallmouth Bass	Wild	Manage as a Recreational Bass Water
Rio Chamita and Tributaries	Brown Trout	Wild	Maintain regulations to support angling for wild trout. Investigate riparian restoration opportunities on Sargent Wildlife Management Area to benefit aquatic and terrestrial species and restoration for Rio Grande Cutthroat Trout. Special Trout Water regulation (Green Chile Water) on Sargent Wildlife Management Area
	Rio Grande Chub	Native Fish	Maintain distribution
Nabor Creek to below Nabor Dam (including Nabor Lake)	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Water)
Canones Creek (San Juans) and Tributaries	Brown Trout	Wild	Almost entirely on private and Jicarilla Apache Nation property
	Rio Grande Cutthroat Trout	Native Fish	Almost entirely on private and Jicarilla Apache Nation property. Small population of Rio Grande Cutthroat Trout in headwaters of Poso Creek
Laguna del Campo (Burns Lake)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout. Open to anglers 14 years old and younger, 65 years old and older, individuals with disabilities, and up to two parents supervising youth anglers
Rio Brazos and Tributaries	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout annually at two locations along the Rio Brazos open to angler access granted by landowners. Predominantly privately owned
	Brown Trout	Wild	Maintain regulations to support angling for wild trout
	Rio Grande Chub	Native Fish	Maintain distribution

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Management Direction for HUC 13020102 Rio Chama			
Water	**Fish Species**	**Management Type**	**Management Direction**
	Rio Grande Sucker	Native Fish	Maintain distribution
Brazos Lodge Pond	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout in the early summer
Rito Tierra Amarilla and Tributaries	Cutthroat Trout	Wild	Almost entirely on private property. Maintain regulations to support angling for wild trout
	Rainbow Trout	Wild	Maintain regulations to support angling for wild trout
Nutrias (Trout) Lakes	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout. Reintroduction of boreal toad is ongoing
	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock and evaluate fingerling Rio Grande Cutthroat Trout stocking strategies
Canjilon Lakes	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout. Carson NF working on large-scale dredging/renovation project at these lakes
	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock and evaluate fingerling Rio Grande Cutthroat Trout stocking strategies
Canjilon Creek	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout
	Rio Grande Chub	Native Fish	Maintain distribution
Rio Cebolla (Rio Arriba) and Tributaries	Rio Grande Chub	Native Fish	Maintain distribution
	Trout	Wild	Almost entirely on private land. Maintain regulations to support angling for wild trout
Rio Nutrias (Rio Arriba) and Tributaries	Rio Grande Chub	Native Fish	Maintain distribution
	Trout	Wild	Almost entirely on private land. Maintain regulations to support angling for wild trout

Management Direction for HUC 13020102 Rio Chama			
Water	**Fish Species**	**Management Type**	**Management Direction**
Rio Puerco (East) and Tributaries	Cutthroat Trout	Wild	Hybridized cutthroat trout population in the headwaters. Maintain regulations to support angling for wild trout
	Rainbow Trout	Wild	Rainbow Trout present in lower reaches. Maintain regulations to support angling for wild trout
Coyote Creek (Rio Arriba)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout in the spring
Cañones Creek (Jemez) and Tributaries	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout
Polvadera Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Population lost after the South Fork wildfire. Repatriate Rio Grande Cutthroat Trout if habitat is suitable in the future
Chihuahueños Creek	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout
Rio del Oso	Rio Grande Cutthroat Trout	Native Fish	Severely impacted by the Las Conchas wildfire. Previously inhabited by a small Conservation Population of Rio Grande Cutthroat Trout. Population lost after the wildfire. Repatriate Rio Grande Cutthroat Trout if habitat is suitable in the future
Rio Gallina and Tributaries	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout in the spring. Assess whether stocking is still prudent due to limited access
	Brown Trout	Wild	Maintain regulations to support angling for wild trout
Little Willow Creek	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout almost entirely on Jicarilla Apache Nation property

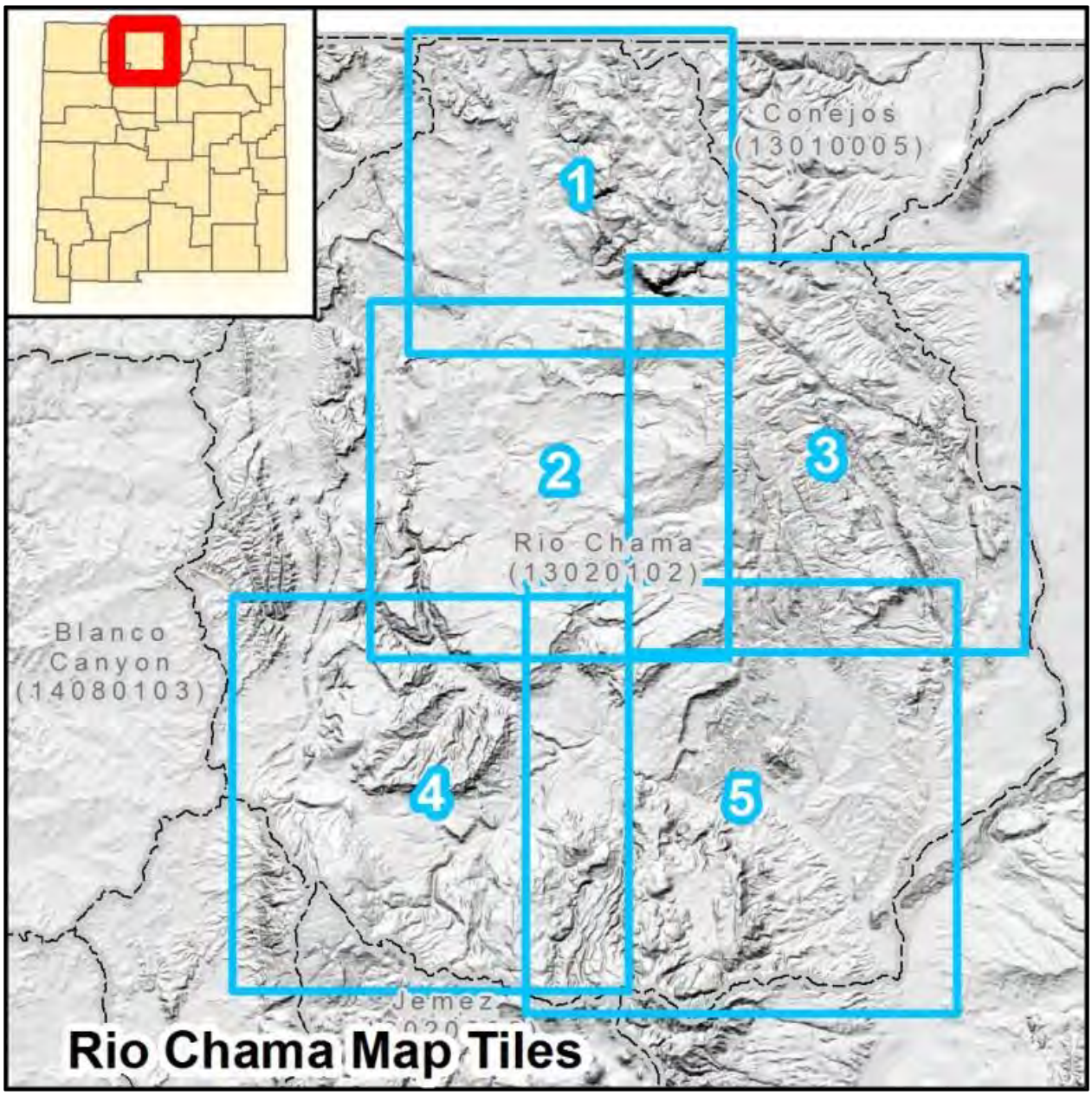


Figure 43. Rio Chama Map Tiles

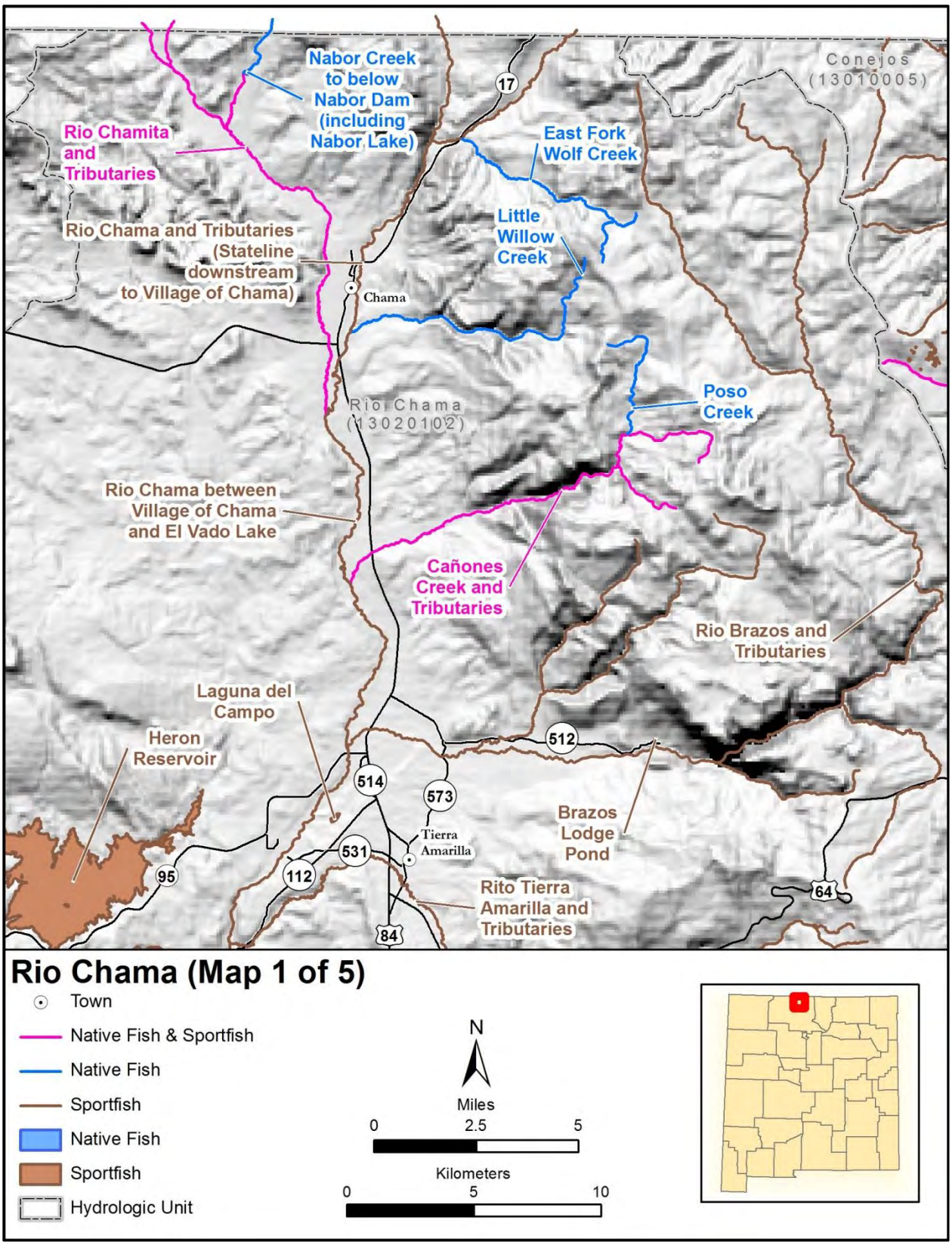


Figure 44. Rio Chama (Map 1 of 5)

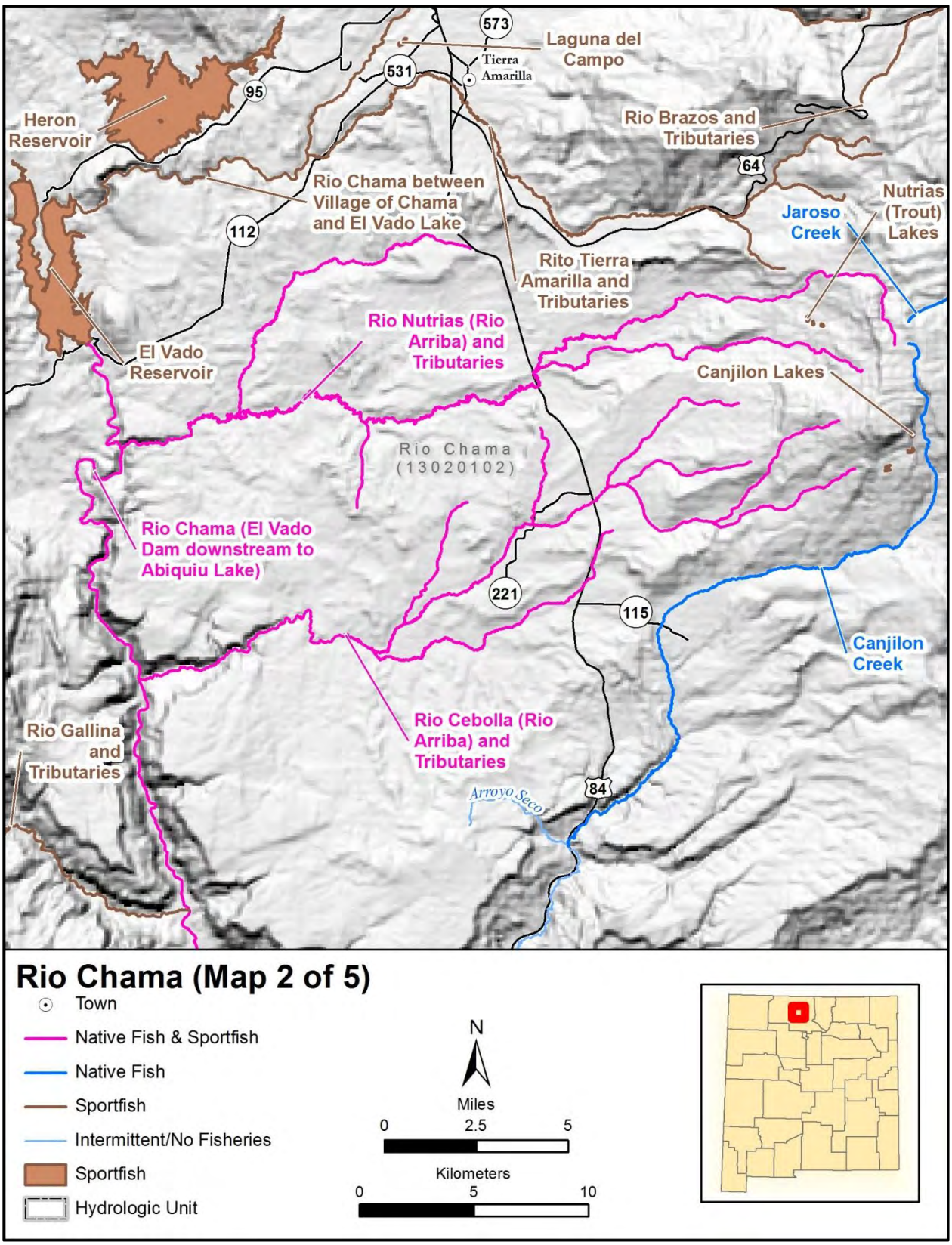


Figure 45. Rio Chama (Map 2 of 5)

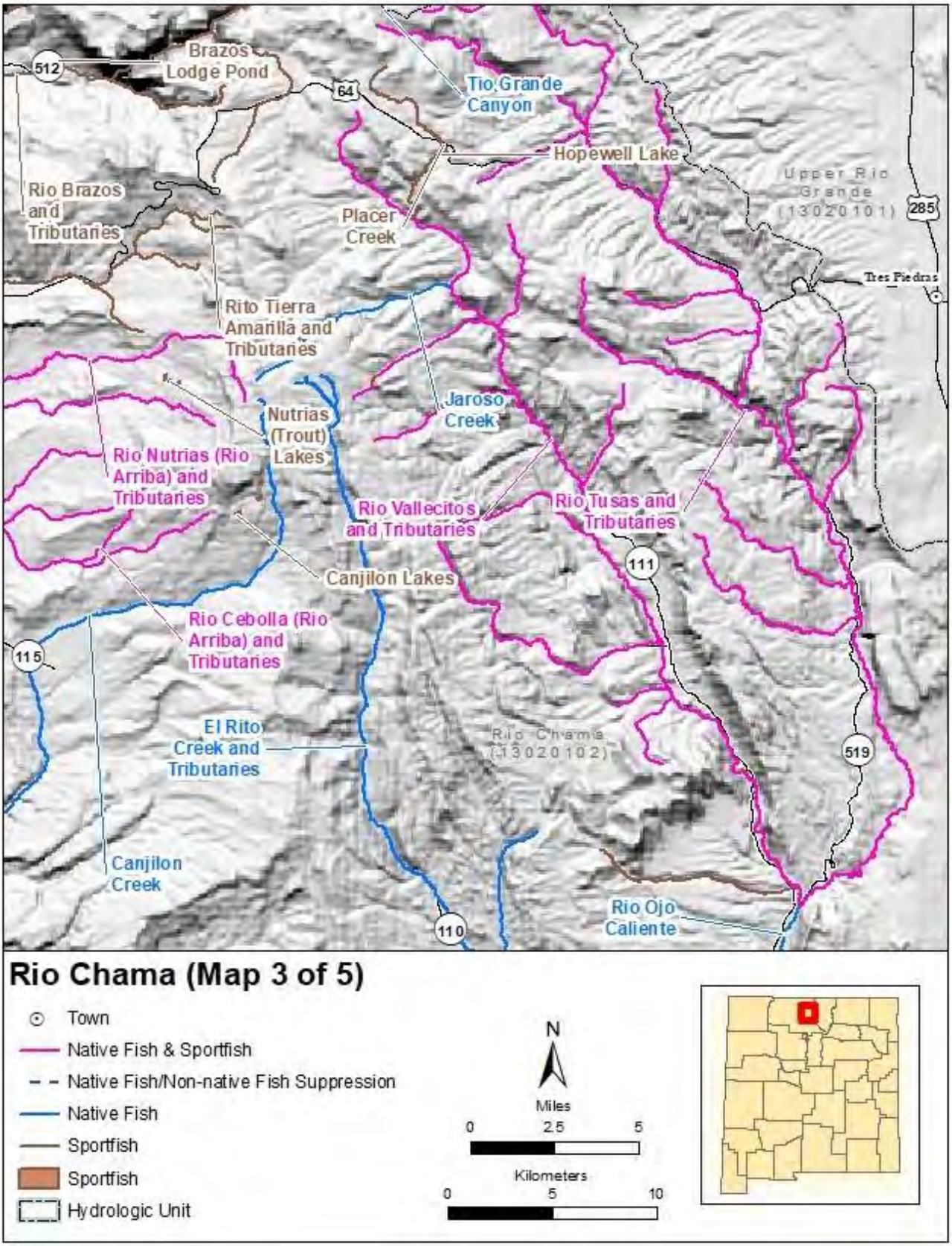


Figure 46. Rio Chama (Map 3 of 5)

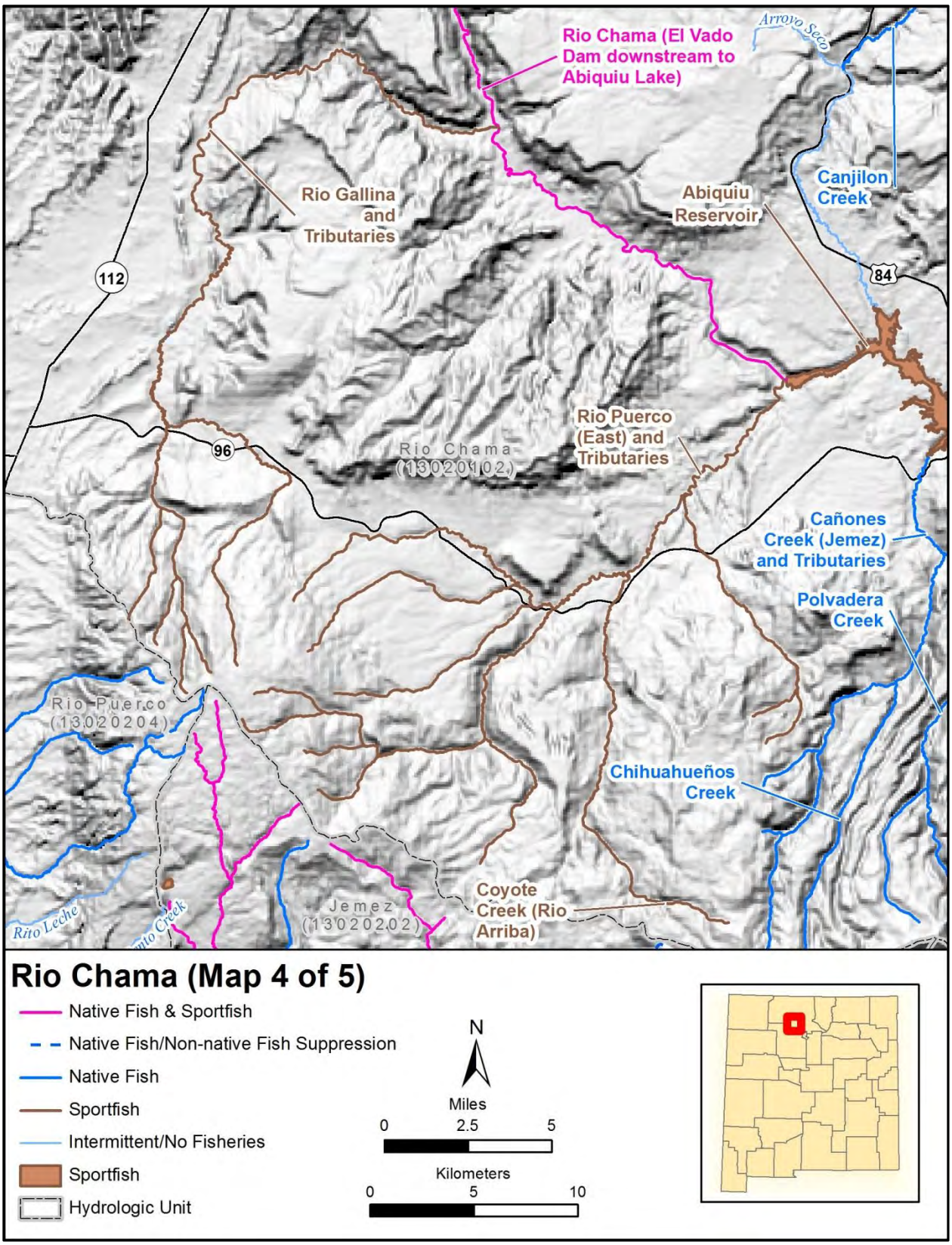


Figure 47. Rio Chama (Map 4 of 5)

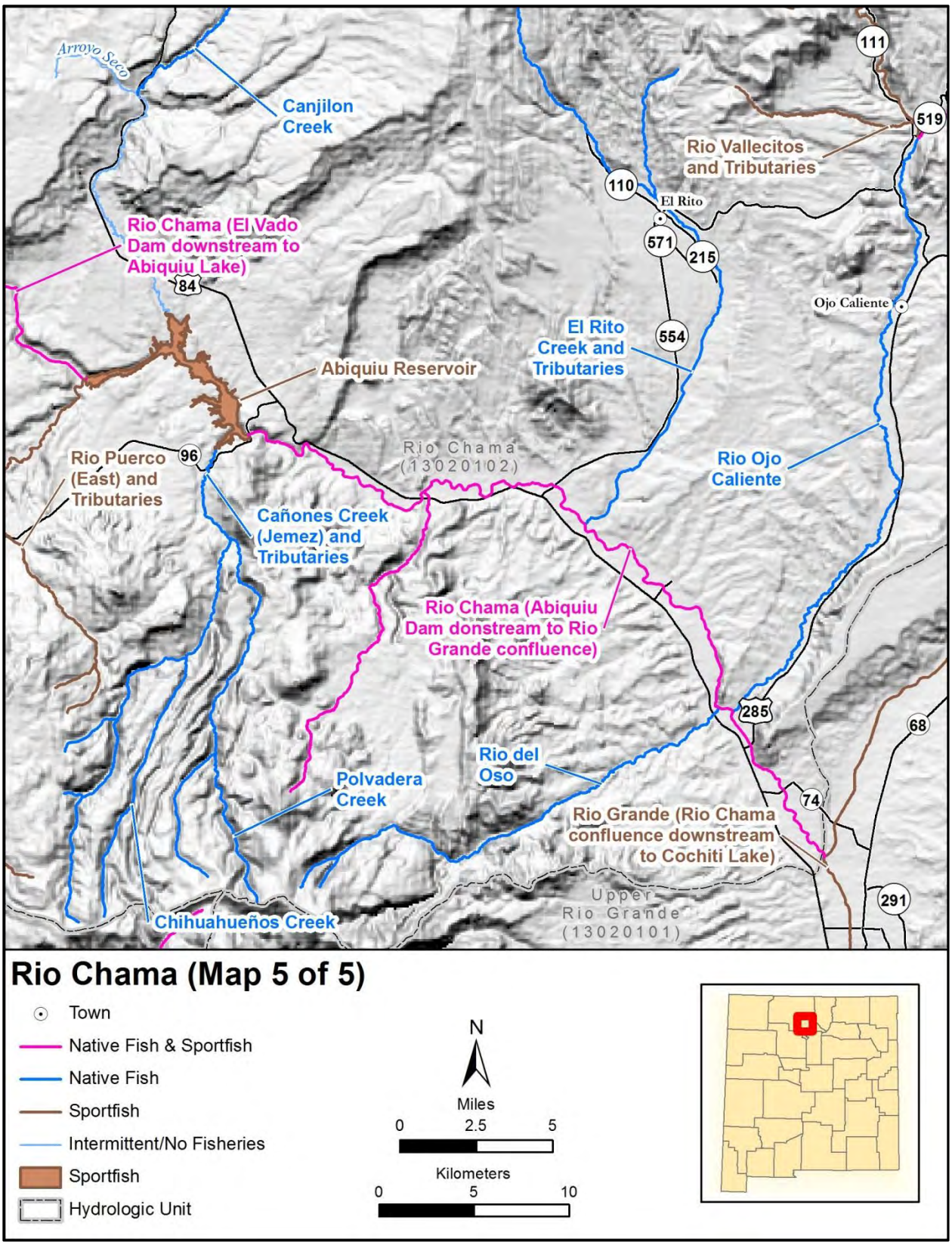


Figure 48. Rio Chama (Map 5 of 5)

HUC 13020201 Rio Grande - Santa Fe

Management Direction for HUC 13020201 Rio Grande-Santa Fe

Water	Fish Species	Management Type	Management Direction
Cochiti Lake	Walleye	Put, Grow, and Take	Collaborate with Cochiti Pueblo and U.S. Army Corps of Engineers to investigate potential for stocking Walleye. If stocked, monitor in the reservoir and in downstream areas to document recruitment and assess reservoir escapement to Rio Grande Silvery Minnow Critical Habitat. Maintain statewide Walleye regulations
	Largemouth Bass	Wild	Manage as a Recreational Bass Water
	Northern Pike	Wild	Maintain regulations to support Northern Pike fishery
Rito de los Frijoles (Frijoles Creek - Los Alamos)	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Located within National Park Service and special angling rules in place
Capulin Creek	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Water) from confluence with Rio Grande to its headwaters
Santa Fe River (Headwaters to Nichols Dam- Including Nichols and McClure Reservoirs)	Rainbow Trout	Wild	Upper Santa Fe River from near Randall Davey Audubon Center upstream to headwaters is closed to the public. Rainbow Trout inhabit this reach including both Nichols and McClure Reservoirs
Santa Fe River (Nichols Dam to wastewater treatment plant)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout in coordination with the City of Santa Fe fishing derby. Stream routinely dries between Nichols Reservoir and wastewater treatment plan
Santa Fe River (Wastewater treatment plant to Rio Grande)	Rio Grande Sucker	Native Fish	Maintain distribution. Rio Grande Sucker are abundant in the reach between wastewater treatment plant and the Rio Grande. Reach is partially within the jurisdiction of Cochiti Pueblo
Peralta Creek	Rio Grande Cutthroat Trout	Native Fish	Severely impacted by the Las Conchas wildfire. Cutthroat Trout population was extirpated. Reintroduction efforts planned for 2022

Management Direction for HUC 13020201 Rio Grande-Santa Fe			
Water	**Fish Species**	**Management Type**	**Management Direction**
Cochiti Creek and Tributaries	Rio Grande Cutthroat Trout	Native Fish	Severely impacted by the Las Conchas wildfire. Brook Trout and Rainbow Trout present prior to Las Conchas wildfire with small Conservation Population of Rio Grande Cutthroat Trout also present in Medio Dia Creek. Will be stocked with Rio Grande Cutthroat Trout when watershed recovers
Las Huertas Creek (Ellis Creek)	N/A	N/A	Formerly stocked once per year with catchable sized Rainbow Trout. Last stocked in 2010 and subject to drying. Stocking suspended
Sanchez Canyon	Rio Grande Cutthroat Trout	Native Fish	Severely impacted by Dome and Las Conchas wildfires. Has existing natural barrier. Evaluate for Rio Grande Cutthroat Trout repatriation

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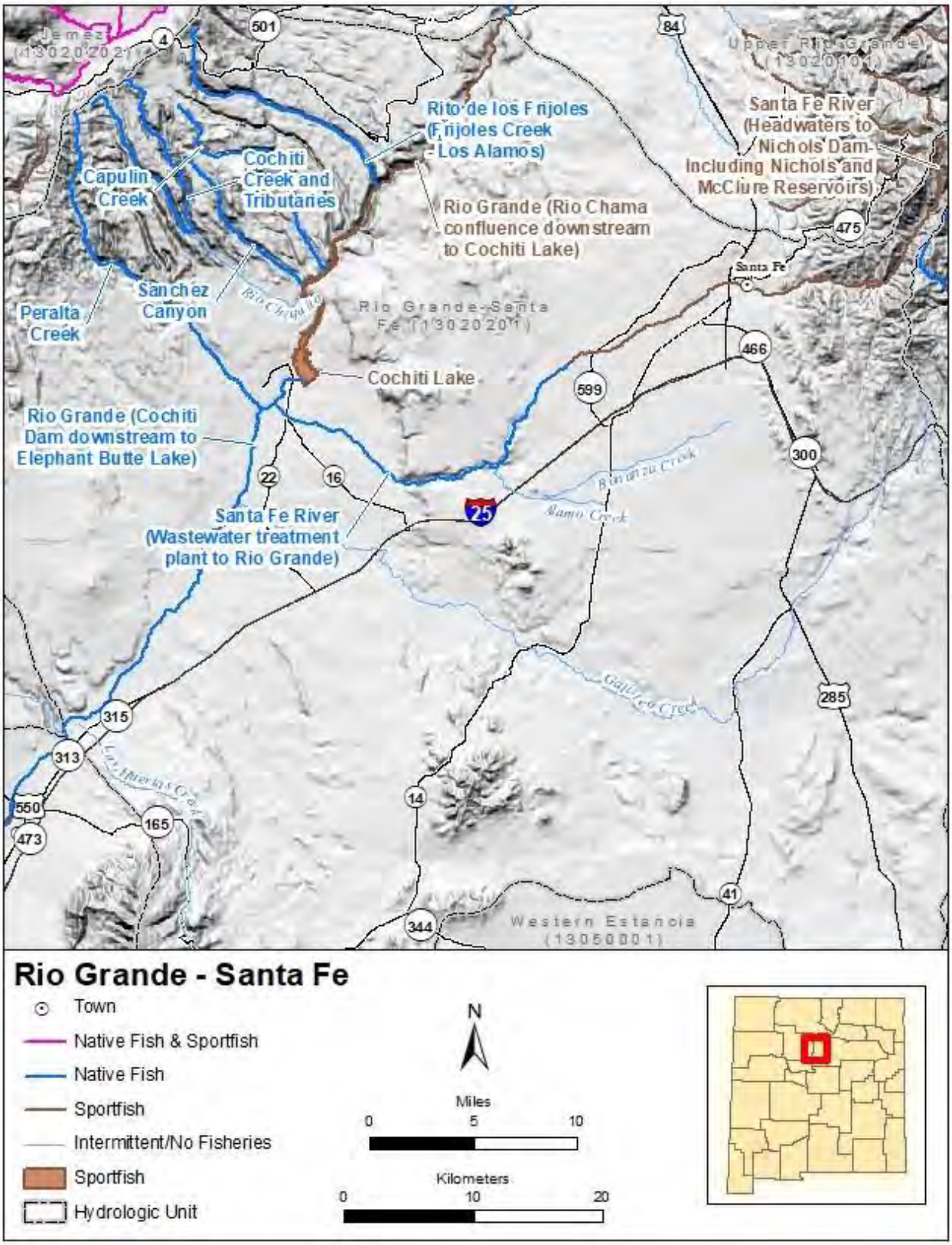


Figure 49. Rio Grande - Santa Fe

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HUC 13020202 Jemez, 13020204 Rio Puerco, 13020207 Rio San Jose

Management Direction for HUC 13020202 Jemez, 13020204 Rio Puerco, 13020207 Rio San Jose

Water	Fish Species	Management Type	Management Direction
San Gregorio Reservoir	Triploid Rainbow Trout	Put and Take	Access for stocking vehicles suspended by Santa Fe National Forest in 2022. Suspend stocking or investigate alternative strategy
	Rio Grande Cutthroat Trout	Put, Grow, and Take	Evaluate stocking fingerling or subadult Rio Grande Cutthroat Trout to replace Rainbow Trout fishery
East Fork Jemez River and Tributaries	Triploid Rainbow Trout	Put and Ta\e	Upper reaches are within the Valles Caldera National Preserve and special use rules may apply. Stock catchable triploid Rainbow Trout downstream of East Fork Trailhead and Preserve boundary
	Brown Trout	Wild	Special Trout Water regulation (Green Chile Water) on Valles Caldera National Preserve and special use rules apply. Maintain regulations to support angling for wild trout
	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock fingerling Rio Grande Cutthroat Trout on Forest Service property as part of recreational stocking study
	Rio Grande Chub	Native Fish	Maintain distribution
	Rio Grande Sucker	Native Fish	Maintain distribution
San Antonio Creek and Tributaries	Triploid Rainbow Trout	Put and Take	Upper reach and tributary (Rio de los Indios) are within Valles Caldera National Preserve. Stock catchable triploid Rainbow Trout downstream of Preserve boundary
	Brown Trout	Wild	Special Trout Water regulation (Green Chile Water) on Valles Caldera National Preserve including 2.0 miles downstream of Preserve boundary and special use rules apply for Preserve reaches. Maintain regulations to support angling for wild trout. Manage as a Quality Trout Water
	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock fingerling Rio Grande Cutthroat Trout as part of recreational stocking study
	Rio Grande Sucker	Native Fish	Maintain distribution
	Rio Grande Chub	Native Fish	Maintain distribution

Management Direction for HUC 13020202 Jemez, 13020204 Rio Puerco, 13020207 Rio San Jose

Water	Fish Species	Management Type	Management Direction
Rio de Las Vacas and Tributaries (Fish Barrier near NM 126 crossing to confluence with Rio Cebolla)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Brown Trout	Wild	Maintain regulations to support angling for wild trout. Turbidity and temperature limit wild trout opportunities
	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock fingerling Rio Grande Cutthroat Trout downstream of the Rio de Las Vacas Campground as part of recreational stocking study
	Rio Grande Sucker	Native Fish	Maintain distribution
	Rio Grande Chub	Native Fish	Maintain distribution
Rio de Las Vacas and Tributaries (Headwaters downstream to Fish Barrier near Highway 126)	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Native Trout Conservation Water)
	Brown Trout	Suppression	Unlimited angler harvest
Rito de Las Palomas	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout
Rio Cebolla (Headwaters downstream to Seven Springs Day Use Area, including McKinney Pond)	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. McKinney Dam needs refurbishment (USFS). Non-native suppression occurred here annually from 2005-2013 and will likely continue. Special Trout Water regulation (Red Chile Native Trout Conservation Water) from Seven Springs Day Use Area upstream to its headwaters
	Brown Trout	Suppression	Periodically remove Brown Trout to maintain the Rio Grande Cutthroat Trout population. Unlimited angler harvest
Rio Cebolla (below Seven Springs Day Use Area to Fenton Lake)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout downstream of Seven Springs Hatchery
	Brown Trout	Wild	Maintain regulations to support angling for wild trout
	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock fingerling Rio Grande Cutthroat Trout annually as part of recreational stocking study
	Rio Grande Sucker	Native Fish	Maintain distribution
	Rio Grande Chub	Native Fish	Maintain distribution

Management Direction for HUC 13020202 Jemez, 13020204 Rio Puerco, 13020207 Rio San Jose

Water	Fish Species	Management Type	Management Direction
Fenton Lake	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout. Excessive sedimentation resulting from the Lake wildfire will require future dredging
	Brown Trout	Wild	Maintain regulations to support angling for wild trout
	Rio Grande Chub	Native Fish	Maintain distribution
Rio Cebolla (Fenton Lake to Rio Guadalupe)	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock fingerling Rio Grande Cutthroat Trout as part of recreational stocking study (Part of Rio Guadalupe stocking)
	Brown Trout	Wild	Maintain regulations to support angling for wild trout
	Rio Grande Sucker	Native Fish	Maintain distribution
	Rio Grande Chub	Native Fish	Maintain distribution
Rio Guadalupe	Brown Trout	Wild	Special Trout Water regulation (Green Chile Water) from Deer Creek Landing upstream 6 miles to Stable Canyon. Manage as a Quality Trout Water
	Rio Grande Cutthroat Trout	Put, Grow, and Take	Stock fingerling Rio Grande Cutthroat Trout as part of recreational stocking study
	Rio Grande Chub	Native Fish	Maintain distribution
	Rio Grande Sucker	Native Fish	Maintain distribution
Jemez River (Battleship Rock downstream to confluence with Rio Guadalupe)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout. Scheduled for stocking year-round though only suitable from September to May
	Brown Trout	Wild	Maintain regulations to support angling for wild trout though water quality (temperature) limits potential downstream of Jemez Springs
	Rio Grande Chub	Native Fish	Maintain distribution
	Rio Grande Sucker	Native Fish	Maintain distribution. Rio Grande sucker are present though White Sucker abundance increasing downstream of Jemez Springs

Management Direction for HUC 13020202 Jemez, 13020204 Rio Puerco, 13020207 Rio San Jose

Water	Fish Species	Management Type	Management Direction
Jemez River (Rio Guadalupe confluence downstream to Rio Grande)	N/A	N/A	Almost entirely within boundaries of Zia, Jemez, and Santa Ana Pueblos. Not actively managed by Department
Seven Springs Kids Pond (Brood Pond)	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout annually. Open to anglers 11 years old and younger
	Rio Grande Cutthroat Trout	Put and Take	Investigate stocking catchable Rio Grande Cutthroat Trout
Paliza Creek	Brown Trout	Wild	Maintain regulations to support angling for wild trout
Rio Puerco (West) and Tributaries (San Pedro Parks Wilderness)	Rio Grande Cutthroat Trout	Native Fish	Conservation Population of Rio Grande Cutthroat Trout in Rio Puerco, Rito de los Pinos, and La Jara Creek
Rito de los Pinos	Brook Trout	Suppression	Ongoing YY Brook Trout stocking study to investigate possibility for repatriation of Rio Grande Cutthroat Trout
Bluewater Lake	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout during winter and spring months
	Channel Catfish	Put and Take	Stock catchable Channel Catfish as available
	Tiger Muskie	Put, Grow, and Take	Maintain target density of 4 fish/acre to maximize growth, suppress unwanted goldfish and white sucker, and provide a quality tiger muskie fishery. Stock fingerling tiger muskie annually (possibly less often) to attain target density
Bluewater Creek (upstream of Bluewater Lake)	Rio Grande Chub	Native Fish	Maintain distribution
	Rio Grande Sucker	Native Fish	Maintain distribution
Grants Riverwalk Pond	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
Rio Puerco (Nacimiento Creek to Rio Grande)	N/A	N/A	No current data and is primarily ephemeral

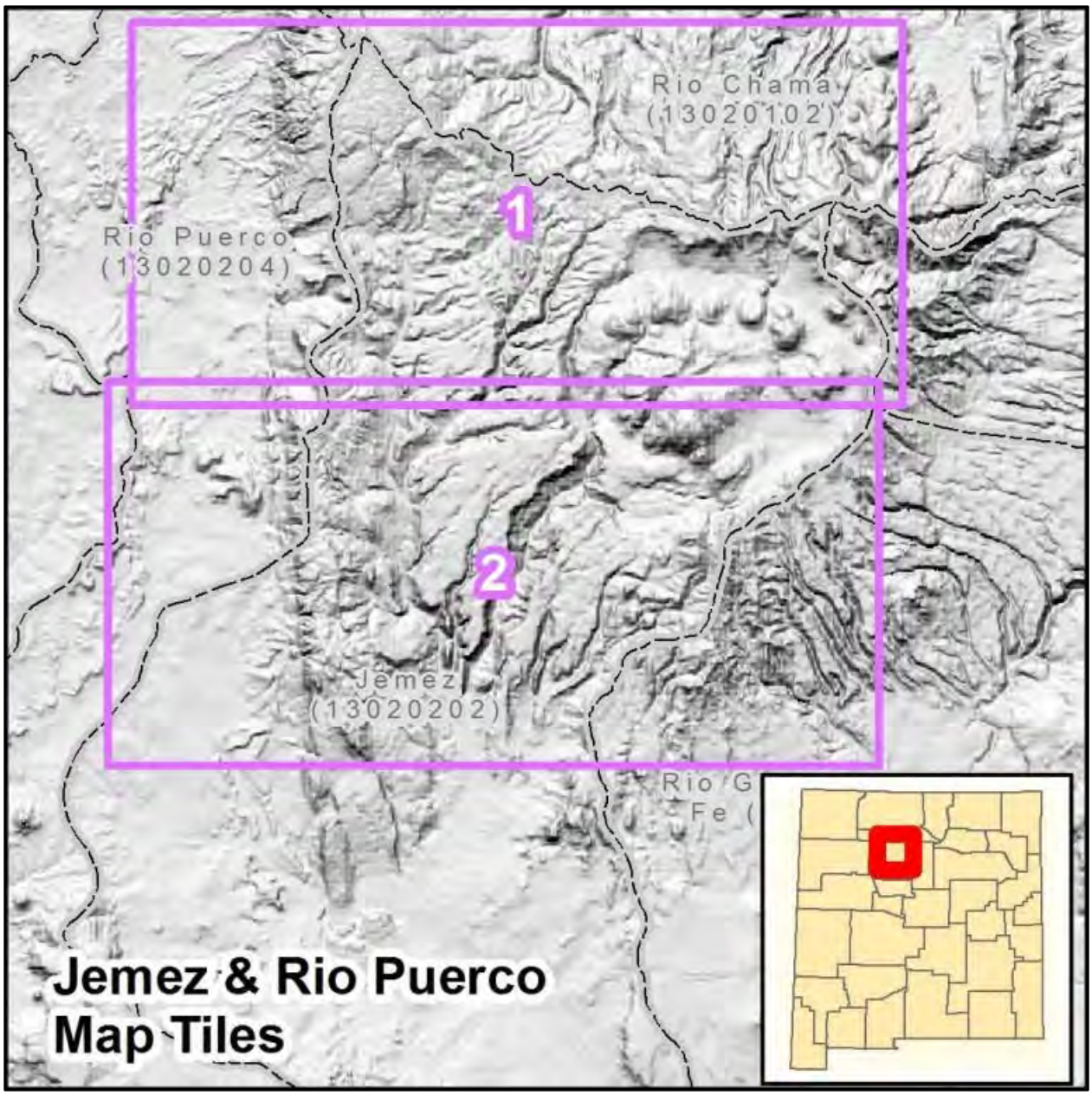


Figure 50. Jemez and Rio Puerco Map Tiles

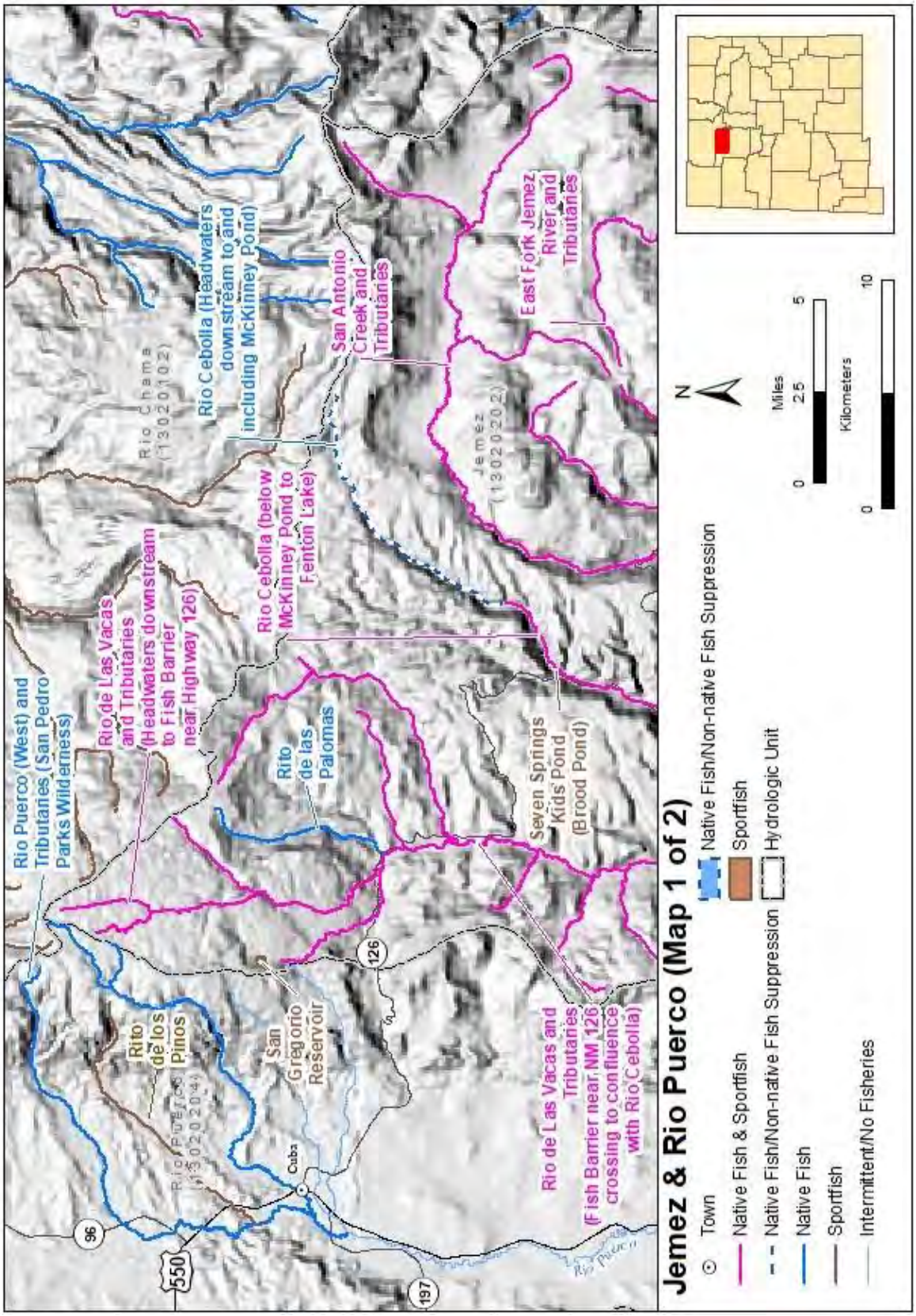


Figure 51. Jemez and Rio Puerco (Map 1 of 2)

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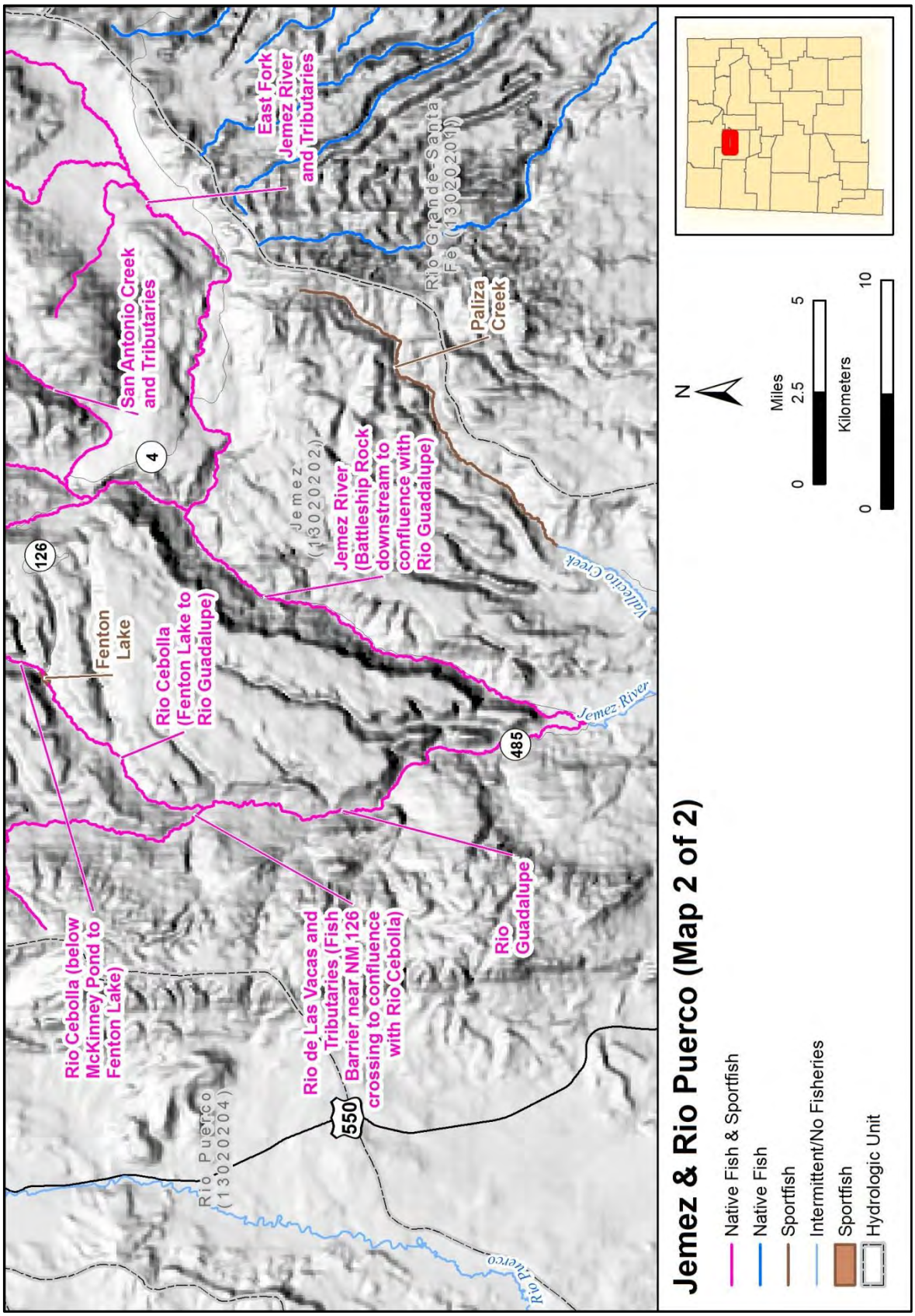


Figure 52. Jemez and Rio Puerco (Map 2 of 2)

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Figure 53. Rio San Jose

HUC 13020203 Rio Grande-Albuquerque, 13020211 Elephant Butte Reservoir, 13030101 Caballo and 13030102 El Paso-Las Cruces

Management Direction for HUC 13020203 Rio Grande-Albuquerque, 13050001 Western Estancia, 13020211 Elephant Butte Reservoir, Rio Grande from Cochiti Dam downstream to Elephant Butte Lake, 13030101 Caballo, and 13030102 El Paso-Las Cruces

Water	Fish Species	Management Type	Management Direction
Rio Grande (Cochiti Dam downstream to Elephant Butte Reservoir)	Rio Grande Silvery Minnow	Native Fish	Designated critical habitat for Rio Grande Silvery Minnow. Intensively managed via the Middle Rio Grande Collaborative Endangered Species Program for Rio Grande Silvery Minnow recovery
Tingley Beach	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout. Special Trout Water regulation (Red Chile Water) southernmost pond. One pond only open to anglers 11 years old and younger
	Largemouth Bass	Wild/ Supplemental stocking	Stock Largemouth Bass as necessary to supplement population
	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
Albuquerque Riverside Drain (Upper and Lower)	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Upper Corrales Riverside Drain	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Bernalillo Riverside Drain	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Belen Riverside Drain	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Peralta Riverside Drain	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
Escondida Lake	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
Manzano Lake	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout. Lease expired and ownership needs confirmation. Investigate Open Gate lease once ownership is confirmed

Management Direction for HUC 13020203 Rio Grande-Albuquerque, 13050001 Western Estancia, 13020211 Elephant Butte Reservoir, Rio Grande from Cochiti Dam downstream to Elephant Butte Lake, 13030101 Caballo, and 13030102 El Paso-Las Cruces

Water	Fish Species	Management Type	Management Direction
Estancia Park Lake	Triploid Rainbow Trout	Put and Take	Winter Trout Water – Stock catchable triploid Rainbow Trout
	Channel Catfish	Put and Take	Special Summer Catfish Water – Stock catchable Channel Catfish
Alamosa Creek	Rio Grande Chub	Native Fish	Maintain distribution
	Rio Grande Sucker	Native Fish	Maintain distribution
Elephant Butte Reservoir	Largemouth Bass	Wild/ Supplemental stocking	Manage as Recreational Bass Water. Supplement Largemouth Bass population when available
	Smallmouth Bass	Wild	Maintain regulations to support Recreational Bass Water
	White Bass	Wild	Maintain regulations to support White Bass fishery
	Catfish (Channel, Blue, Flathead)	Wild	Maintain regulations to support catfish angling
	Striped Bass	Put, Grow, and Take	Stock striped bass at 45 fry/surface acre every other year. Maintain regulations to maintain trophy Striped Bass potential
Rio Grande (Elephant Butte Dam downstream to Caballo Lake)	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable Triploid Rainbow Trout
Caballo Lake	Largemouth Bass	Wild	Manage as a Recreational Bass Water
	White Bass	Wild	Maintain angling regulations to support White Bass fishery
	Walleye	Put, Grow, and Take	Stock Walleye at 500 fry/surface acre annually. Annual stocking varies with reservoir elevation
	Channel Catfish	Wild	Maintain regulations to support catfish angling
	Hybrid Striped Bass	Put, Grow, and Take	Investigate potential as a new recreational angling species in lake

Management Direction for HUC 13020203 Rio Grande-Albuquerque, 13050001 Western Estancia, 13020211 Elephant Butte Reservoir, Rio Grande from Cochiti Dam downstream to Elephant Butte Lake, 13030101 Caballo, and 13030102 El Paso-Las Cruces

Water	Fish Species	Management Type	Management Direction
Ralph Edwards Park Pond	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout for fishing derbies
	Channel Catfish	Put and Take	Stock catchable Channel Catfish for fishing derbies
Las Animas Creek and Tributaries	Rio Grande Cutthroat Trout	Native Fish	Core Conservation Population of Rio Grande Cutthroat Trout. Special Trout Water regulation (Red Chile Water) within Gila National Forest boundary
	Rio Grande Sucker	Native Fish	Maintain distribution
	Rio Grande Chub	Native Fish	Maintain distribution
Palomas Creek	Rio Grande Sucker	Native Fish	Maintain distribution
	Rio Grande Chub	Native Fish	Maintain distribution
Seco Creek	Rio Grande Chub	Native Fish	Maintain distribution
	Rio Grande Sucker	Native Fish	Maintain distribution
Young Pond	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
University Reservoir (Alumni Pond)	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
Burn Lake	N/A	N/A	Lake has been dry for several years and City reallocated land use. Stocking suspended
Rio Grande (Caballo Dam to State Line)	N/A	N/A	Dry most of the year

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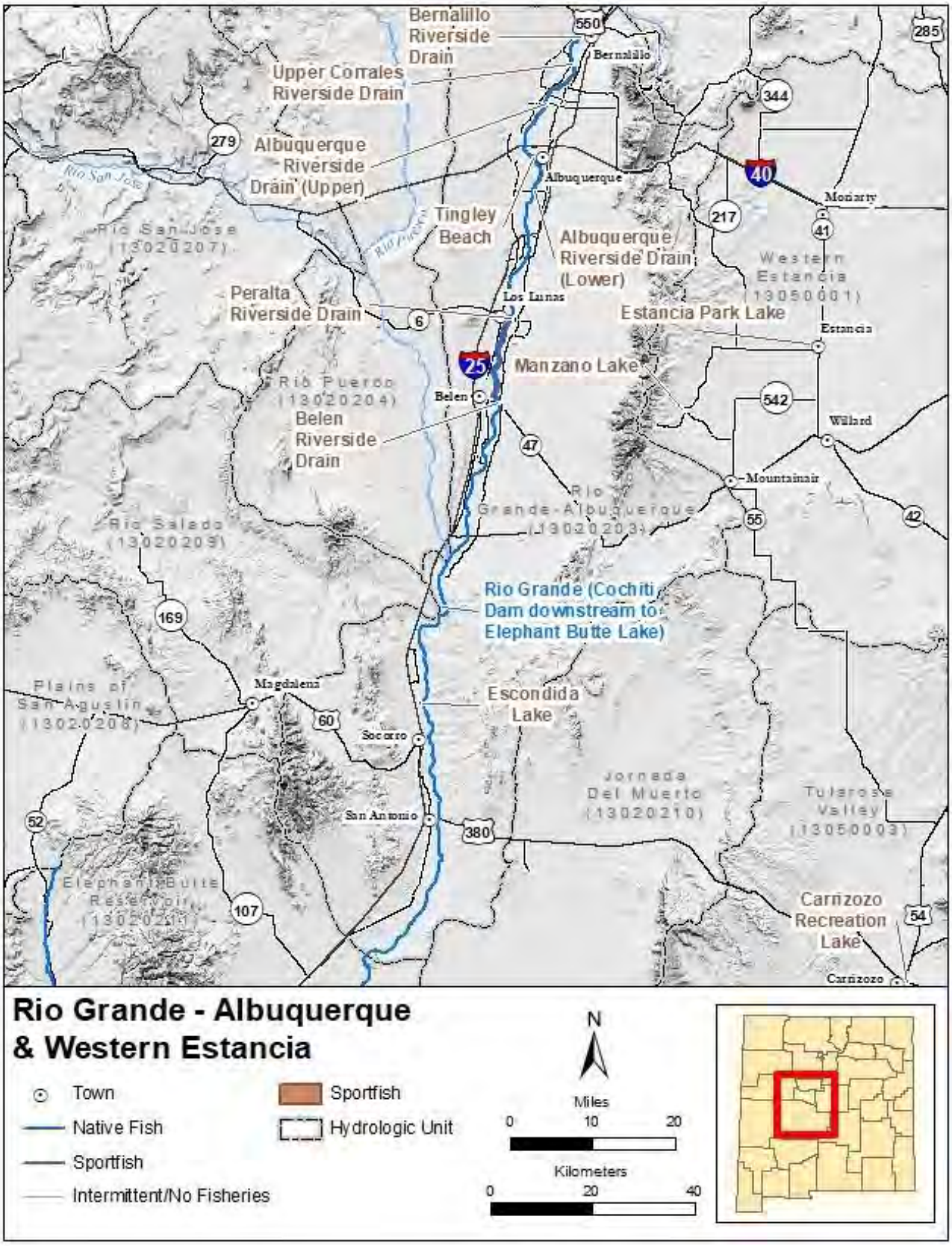


Figure 54. Rio Grande - Albuquerque & Western Estancia

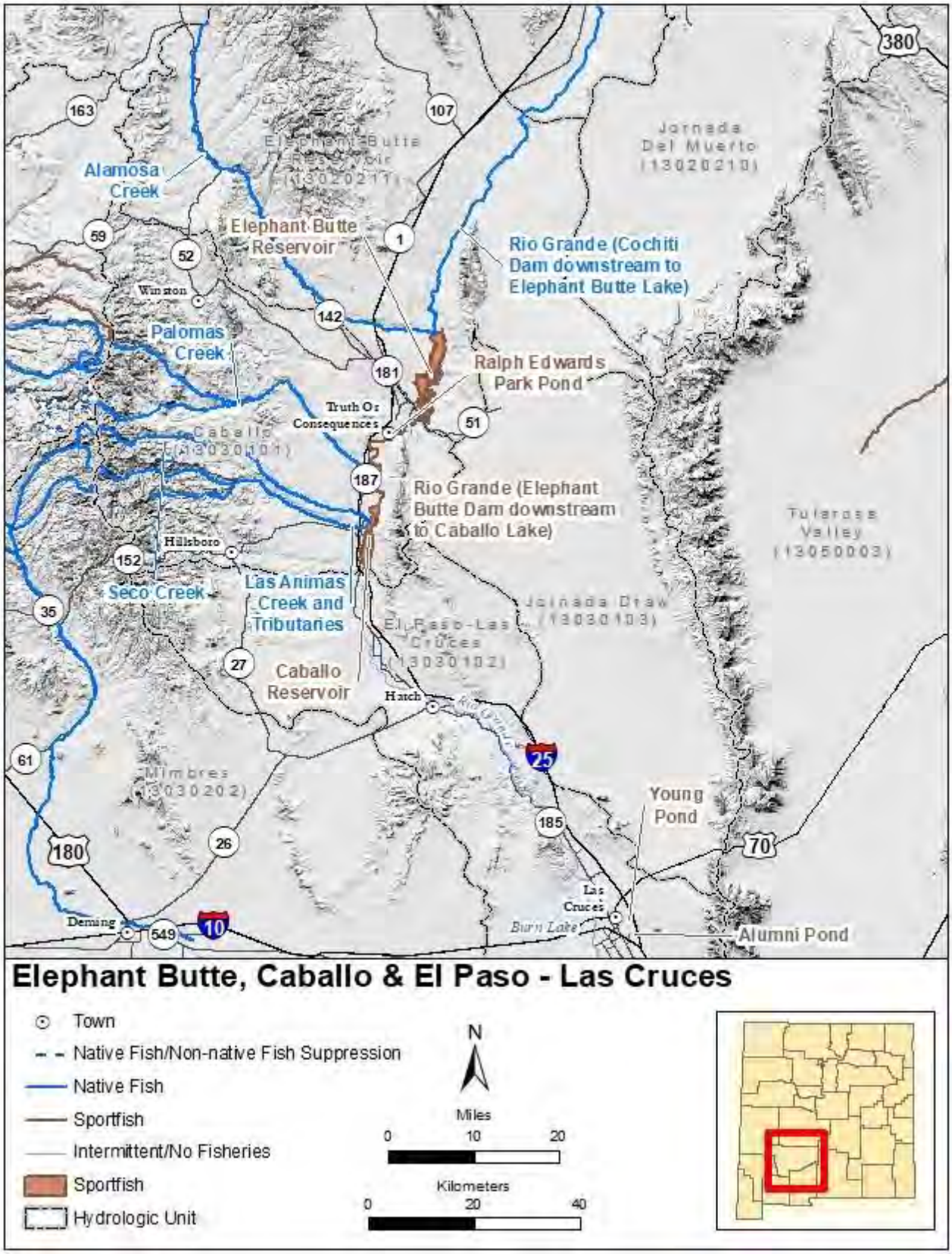


Figure 55. Elephant Butte, Caballo and El Paso - Las Cruces

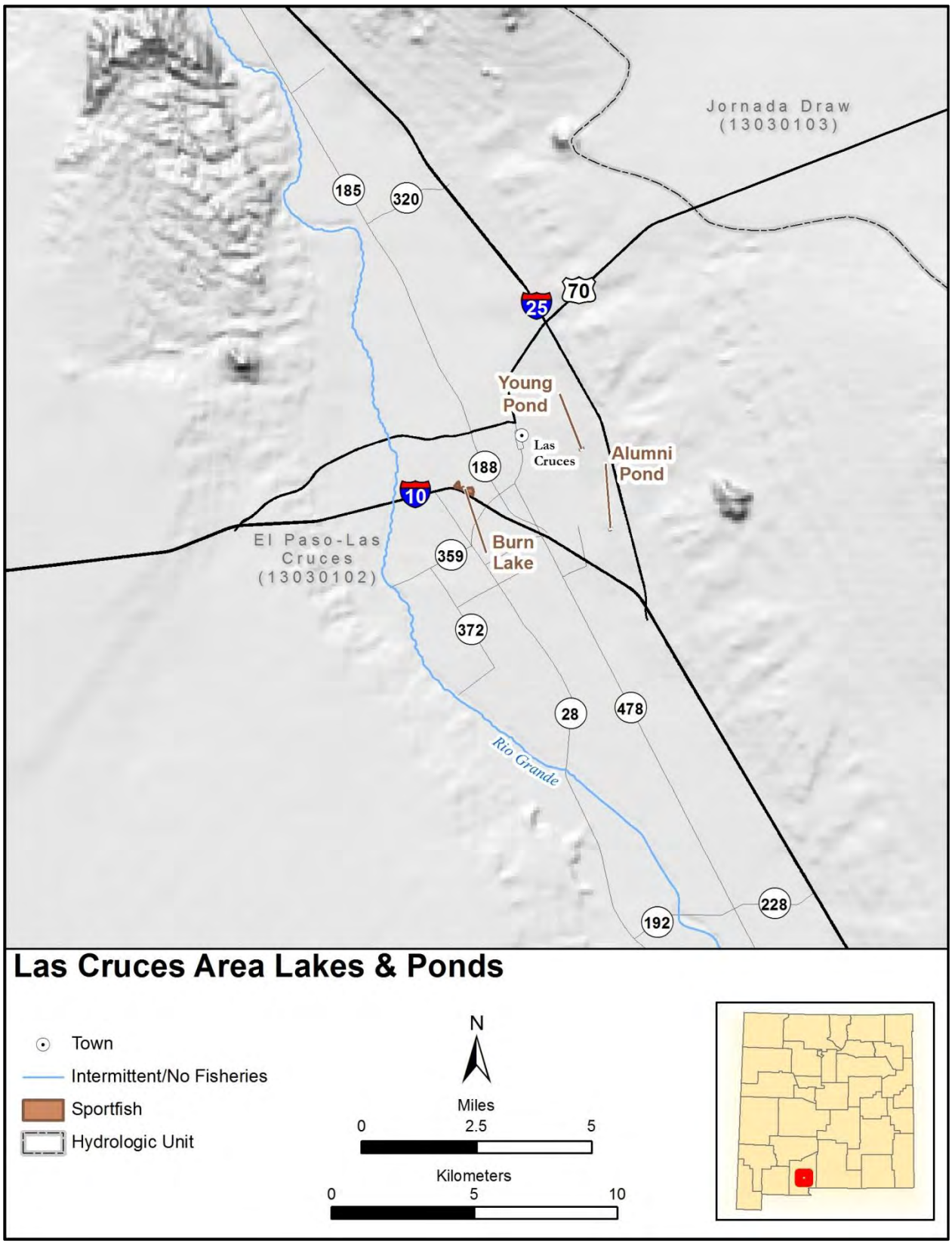


Figure 56. Las Cruces Area Lakes & Ponds

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Mimbres Watershed

The Mimbres River occupies a small endorheic basin in Hidalgo, Luna, and Grant counties in southwest New Mexico. Headwaters are along west- and south-facing slopes of the Black Range, flow southward, and dissipate onto the desert north of Deming. Much of the permanently watered portion of the river is in the Mimbres Valley, where the system is more cienega in character than riverine. Uplands are largely under Forest Service jurisdiction and valley lands are largely privately owned. Although rural, the valley has been subdivided into numerous small tracts, many of which have dwellings with private wells and septic systems. On private lands, the river channel is frequently mechanically realigned and woody riparian vegetation removed. The Nature Conservancy and Department manage small tracts along the river, which provide some protection for aquatic habitats.

Due to the small size of the Mimbres Watershed, fisheries management is limited. Bear Canyon Reservoir and Trees Lake provides recreational fishing opportunities including Largemouth Bass, Channel Catfish, and seasonally stocked Rainbow Trout. The federally threatened Chihuahua Chub inhabits perennial warmwater reaches of the Mimbres River.

HUC 13030202 Mimbres

Management Direction for HUC 13030202 Mimbres

Water	Fish Species	Management Type	Management Direction
Mimbres River and Tributaries	Chihuahua Chub	Native Fish	Proposed Critical Habitat. Stock Chihuahua Chub as needed to maintain population and expand range with intention of creating a self-sustaining population(s)
	Rio Grande Sucker	Native Fish	Maintain distribution
Bear Canyon Reservoir	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
	Channel Catfish	Put and Take	Stock catchable Channel Catfish as available
	Largemouth Bass	Wild	Manage as a Recreational Bass Water. Investigate potential as a Trophy Bass Water
River Ranch Pond	Chihuahua Chub	Native Fish	Recently constructed (2021) pond for Chihuahua Chub refugia
Trees Lake	Triploid Rainbow Trout	Put and Take	Winter Trout Water-Stock catchable triploid Rainbow Trout
	Channel Catfish	Put and Take	Special Summer Catfish Water- Stock catchable Channel Catfish



Figure 57. Mimbres

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Gila Watershed

The Gila River watershed lies within southwestern New Mexico, and is comprised of two major streams, the Gila and San Francisco rivers. Headwater streams of the Gila join to form three forks (West, Middle, and East) in the Mogollon Mountains. From their juncture, the Gila River flows westerly and exits the Mogollon Mountains just east of Gila. Along its mountain course, the river is bordered by Arizona sycamore, Arizona walnut, boxelder, cottonwood, juniper, piñon, and ponderosa.

The primary land uses along the river in the Cliff-Gila Valley are livestock grazing and some irrigated cropland. Water is seasonally diverted from the river. At the western end of the valley, the river is narrowly confined as it flows through the Middle Box. Downstream of the Middle Box, the Gila River flows across desert grasslands and shrublands to exit New Mexico.

Livestock grazing is the primary land use in the lower reaches of Gila River in New Mexico, but some irrigated cropland is present near Virden. The US Forest Service administers mountainous portions of the Gila Watershed. Substantial portions of this watershed are within the Gila and Aldo Leopold wildernesses. The Bureau of Land Management and Forest Service administer portions of the lower watershed, but most lands are privately owned. The Department also owns several properties including the Heart Bar and Red Rock Wildlife Management Areas. The Gila River is the last mainstem river in New Mexico without a major water development.

Historical fisheries management in the Gila River Basin has focused primarily on traditional sportfish management though significant resources have been expended on Gila Trout recovery efforts. Popular coldwater fisheries have included reaches within the Gila Wilderness and Snow Lake. The Department ceased stocking Rainbow Trout in streams and rivers within the Gila River Basin in the early 2000's due to conflicts with native fish populations but continues to stock Rainbow Trout seasonally in lakes. Five wild Gila Trout populations have been opened to fishing since 2006 and excess Gila trout from the Mora National Fish Hatchery and the Glenwood State Fish Hatchery are stocked in other select waters. Popular warmwater fisheries include Lake Roberts, Bill Evans Lake, East Fork of the Gila River, and the wilderness reach of the Gila River between Grapevine Campground and Turkey Creek. Warmwater fisheries management within river reaches was primarily regulated via angling rules with little active management over the past decade (i.e., no stocking).

Five species of fish are federally protected in the Gila River while seven are state protected. Designated critical habitat for Spikedace and Loach Minnow is widely distributed throughout the Gila River Watershed though the current distribution of these fish is significantly less than the critical habitat designation. Predatory sportfish such as Smallmouth Bass and Flathead and Channel catfish have been partially implicated in the overall decline of rare Gila Basin fishes

such as Spikedace and Loach Minnow. As a result, sportfish and native fish management routinely conflict. While all conflicts cannot be easily resolved, reach designations with focal species management will at least help to identify Departmental priorities. The Department expects to continue with Gila Trout restoration within reaches identified below. The Department also plans to focus conservation efforts in reaches designated as Native Fish which could include active suppression or removal of non-native fishes or regulations intended to encourage suppression of predatory fish via angling.

HUC 15040001 Upper Gila

Management Direction for HUC 15040001 Upper Gila

Water	Fish Species	Management Type	Management Direction
White Creek (Above Barrier)	Gila Trout	Native Fish	Gila Trout recovery stream. Impacted by the Whitewater-Baldy wildfire in 2012 and Johnson wildfire in 2021. Stock with Gila Trout once stream habitat is recovered
Whiskey Creek (Unnamed tributary to West Fork Gila River)	Gila Trout	Native Fish	Prior to the 2012 Whitewater-Baldy wildlife was a Gila Trout recovery stream and contained a relict population. Currently contains Rainbow Trout. Restore Whiskey Creek lineage Gila Trout upon restoration of the West Fork Gila River above waterfall near White Creek cabin
Langstroth Creek (Above Barrier)	Gila Trout	Native Fish	Gila Trout recovery stream. Gila Trout were salvaged from the stream after the Johnson wildfire in 2021. Restock once stream habitat is recovered
West Fork Gila River and Tributaries (Headwaters to waterfalls near White Creek Cabin)	Gila Trout	Native Fish	Potential Gila Trout recovery streams. Waterfall would need to be augmented or barrier constructed prior to renovation
West Fork Gila River (Waterfalls near White Creek Cabin downstream to Hells Hole Canyon)	Gila Trout	Put, Grow, and Take	Gila Trout recreation water. Investigate potential for Gila Trout recovery stream
	Trout	Wild	Brown and Rainbow trout present. Maintain regulations to support angling for wild trout

Management Direction for HUC 15040001 Upper Gila			
Water	**Fish Species**	**Management Type**	**Management Direction**
West Fork Gila River (Hells Hole Canyon downstream to Heart Bar WMA)	Gila Trout	Put, Grow, and Take	Gila Trout recreation water. Investigate potential for Gila Trout recovery stream. A barrier and renovation would be required for repatriation of Gila trout
	Trout	Wild	Brown and Rainbow trout present. Maintain regulations to support angling for wild trout
	Loach Minnow	Native Fish	Designated critical habitat for Loach Minnow and currently occupied
	Spikedace	Native Fish	Designated critical habitat for Spikedace and currently occupied
	Roundtail Chub	Native Fish	Maintain distribution
West Fork Gila River (Heart Bar WMA)	Gila Trout	Put and Take	Gila Trout recreational water. Stock with catchable Gila Trout.
	Non-native Fish	Suppression	Annually conduct non-native removals to maintain native endangered fishes
	Loach Minnow	Native Fish	Designated critical habitat for Loach Minnow and currently occupied
	Spikedace	Native Fish	Designated critical habitat for Spikedace and currently occupied
	Roundtail Chub	Native Fish	Maintain distribution
West Fork Gila River (Heart Bar WMA downstream to East Fork Gila River)	Gila Trout	Put and Take	Stock with catchable Gila Trout
	Loach Minnow	Native Fish	Designated critical habitat for Loach Minnow and currently occupied
	Spikedace	Native Fish	Designated critical habitat for Spikedace and currently occupied
Little Creek (Above Barrier)	Gila Trout	Native Fish	Gila Trout recovery stream
Little Creek (Below Barrier)	Brown Trout	Wild	Maintain regulations to support angling for wild trout

Management Direction for HUC 15040001 Upper Gila			
Water	**Fish Species**	**Management Type**	**Management Direction**
Snow Lake	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout. Dam spillway needs repair, dredging sediment from lake would improve reservoir conditions. Investigate suppression and/or eradication of Green Sunfish and Common Carp. Investigate feasibility for Put, Grow, and Take trout fishery
	Gila Trout	Put and Take	Replace some Rainbow Trout stocking with Gila Trout with long-term goal of switching entirely to Gila Trout, if possible
Gilita Creek (Headwaters downstream to Snow Creek confluence)	Brown Trout	Suppression	Maintain unlimited harvest regulation for Brown Trout to promote recruitment potential for Gila Trout
	Gila Trout	Put and Take	Gila Trout recreational water. Special Trout Water regulation (X-mas Chile Water) for entire reach. Stock catchable Gila Trout
Willow Creek and Tributaries	Gila Trout	Native Fish	Gila Trout recovery stream. Special Trout Water regulation (X-mas Chile Water)
	Brown Trout	Suppression	Maintain unlimited harvest regulation for Brown Trout to promote recruitment potential for Gila Trout. Brown Trout may be extirpated
Iron Creek (Above Barrier)	Gila Trout	Native Fish	Gila Trout recovery stream and relict population. Maintain angling closure
Iron Creek (Below Barrier)	Brown Trout	Wild	Maintain regulations to support wild trout fishery. Investigate potential for incorporating Iron Creek into a native fish restoration effort in the Middle Fork Gila River
Middle Fork Gila River and Tributaries	Gila Trout	Native Fish	Investigate native fish restoration to include both coldwater and warmwater habitats with barrier construction
	Roundtail Chub	Native Fish	Maintain distribution
	Spikedace	Native Fish	Designated critical habitat for Spikedace and currently occupied
	Loach Minnow	Native Fish	Designated critical habitat for Loach Minnow and currently occupied
	Non-native Fish	Suppression	Investigate regulations to promote harvest of non-native predators
Main Diamond Creek	Gila Trout	Native Fish	Gila Trout recovery stream and relict population. Maintain angling closure

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Management Direction for HUC 15040001 Upper Gila			
Water	**Fish Species**	**Management Type**	**Management Direction**
South Diamond Creek	Gila Trout	Native Fish	Gila Trout recovery stream and relict population. Maintain angling closure
Black Canyon (Above Barrier)	Gila Trout	Native Fish	Gila Trout recovery stream. Special Trout Water (Red Chile Native Trout Conservation Water) upstream of waterfall barrier - Open July 1 to October 31. Investigate extending angling season. Investigate Open Gate opportunities for improved angler access
	Brown Trout	Suppression	Brown Trout extirpated by Silver wildfire in 2013. Maintain unlimited angler harvest regulation for Brown Trout to promote recruitment potential for Gila Trout
Black Canyon (Below Barrier)	Gila Trout	Put and Take	Stock catchable Gila Trout
East Fork Gila River and Tributaries	Smallmouth Bass	Wild	Maintain regulations to support Smallmouth Bass angling. Designated critical habitat for Loach Minnow and Spikedace but not currently occupied. Investigate Open Gate opportunities for improved angler access
	Channel Catfish	Wild	Maintain regulations to support catfish angling
Gila River (East Fork confluence downstream to Mogollon Creek)	Smallmouth Bass	Wild	Maintain regulations to support Smallmouth Bass angling. Designated critical habitat for Loach Minnow and Spikedace
	Catfish	Wild	Channel and Flathead catfish present. Maintain regulations to support catfish angling
Lake Roberts	Triploid Rainbow Trout	Put and Take	Winter Trout Water - Stock catchable triploid Rainbow Trout
	Gila Trout	Put and Take	Stock catchable Gila Trout
	Channel Catfish	Put and Take	Stock catchable Channel Catfish as available
	Largemouth Bass	Wild	Manage as a Trophy Bass Water and investigate regulations to attain trophy potential

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Management Direction for HUC 15040001 Upper Gila			
Water	**Fish Species**	**Management Type**	**Management Direction**
Sapillo Creek and Tributaries (Lake Roberts to Gila River)	Gila Trout	Put and Take	Gila Trout recreational water. Stock with catchable and subcatchable Gila Trout. Investigate Open Gate opportunities to increase angler access
	Trout	Wild	Maintain angling regulations to support wild trout angling. Brown and Rainbow trout present
	Rio Grande Sucker	Native Fish	Maintain distribution
Trout Creek	Rainbow Trout	Wild	Potential Gila Trout recovery stream. Habitat assessment needed and renovation would be required to repatriate Gila Trout
Cow Creek	Rainbow Trout	Wild	Potential Gila Trout recovery stream that has perennial water and a barrier at lower end. Renovation would be required to repatriate Gila Trout
Sheep Corral Canyon	Gila Trout	Native Fish	Gila Trout recovery stream
Turkey Creek and Tributaries	Roundtail Chub	Native Fish	Roundtail Chub recovery stream. Barrier construction is needed to inhibit migration of non-native fish from the Gila River
	Gila Trout	Native Fish	Potential for Gila Trout restoration. Currently occupied by Rainbow Trout
Mogollon Creek and Tributaries (Headwaters downstream to West Fork Mogollon)	Gila Trout	Native Fish	Gila Trout recovery stream. Special Trout Water regulation (Red Chile Water) from barrier waterfalls to confluence of Trail Canyon - Open July 1 to October 31. Upstream of Trail Canyon is closed to angling. Investigate potential for opening entire stream to angling or extending season
West Fork Mogollon	Gila Trout	Native Fish	Potential Gila Trout recovery stream. Investigate potential for Gila Trout restoration. Currently occupied by Rainbow Trout
Rain Creek	Gila Trout	Native Fish	Potential Gila Trout recovery stream. Investigate potential for Gila Trout restoration. Currently occupied by Rainbow Trout
Sapillo Creek (Headwaters to Lake Roberts)	N/A	N/A	Intermittent throughout reach. No current data
Rocky Canyon	Rio Grande Sucker	Native Fish	Maintain distribution

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Management Direction for HUC 15040001 Upper Gila			
Water	**Fish Species**	**Management Type**	**Management Direction**
Skates Canyon	Rio Grande Sucker	Native Fish	Maintain distribution
Mogollon Creek (West Fork Mogollon confluence to Gila River)	N/A	N/A	Intermittent throughout reach. No current data

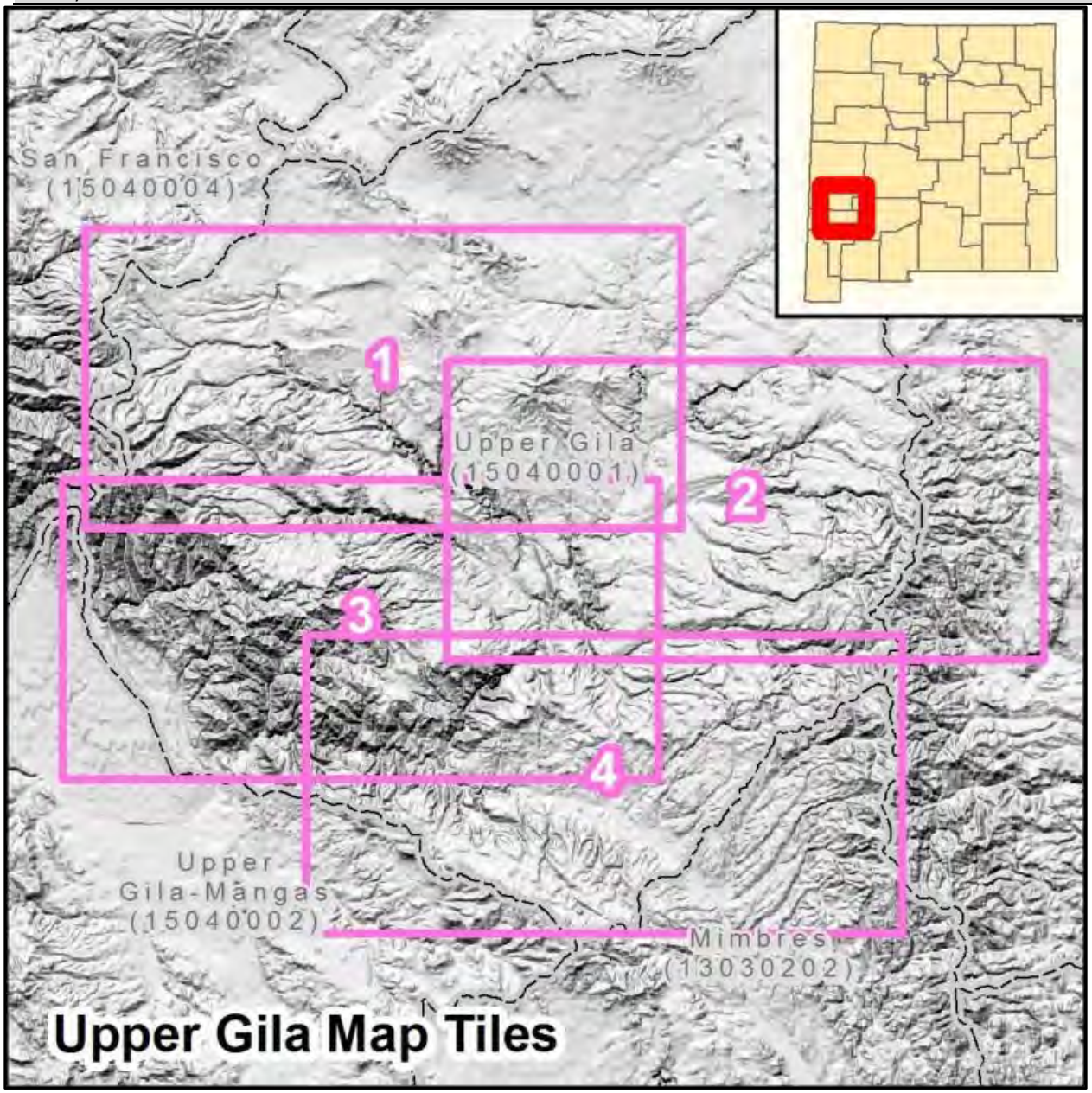


Figure 58. Upper Gila Map Tiles

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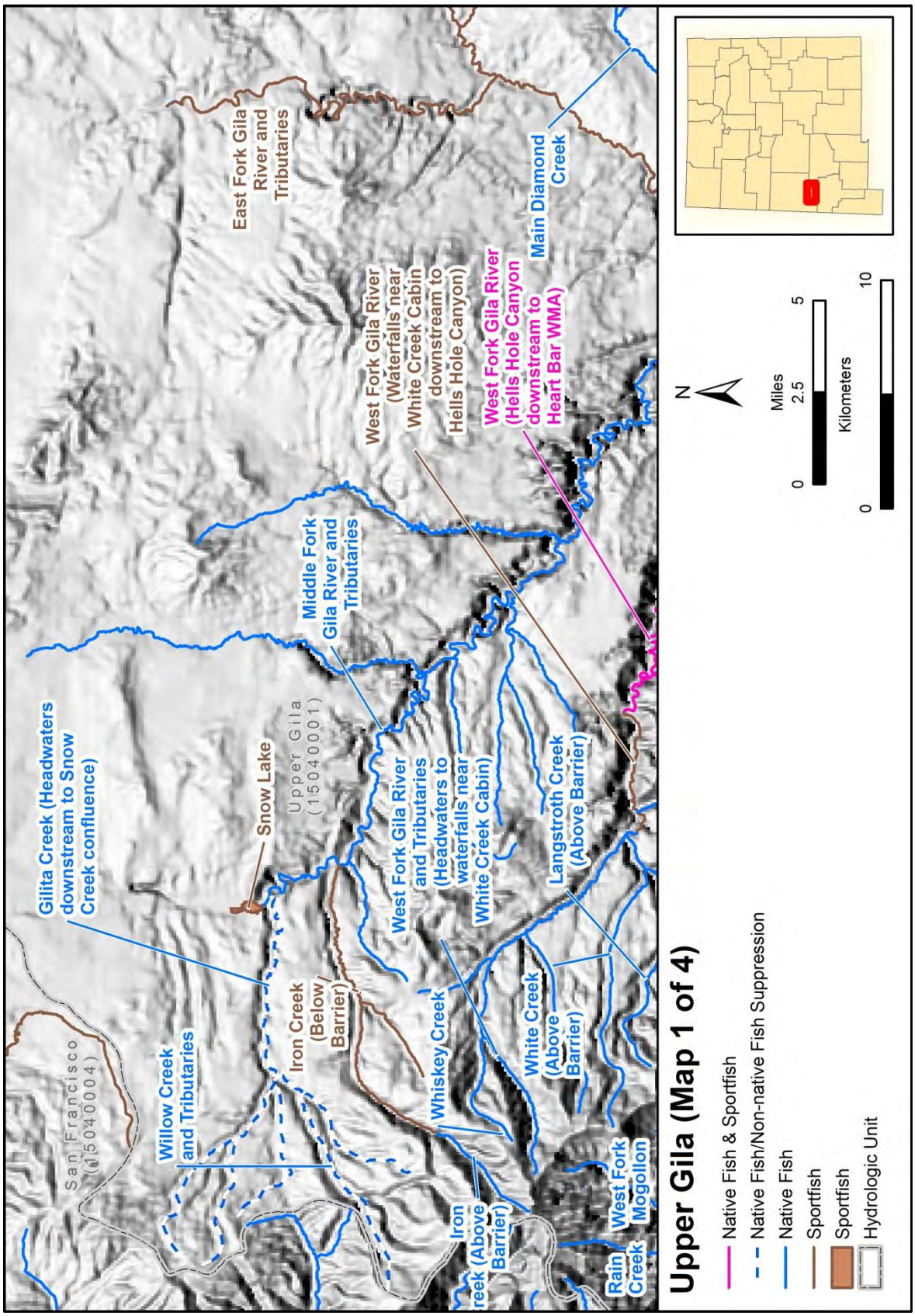


Figure 59. Upper Gila (Map 1 of 4)

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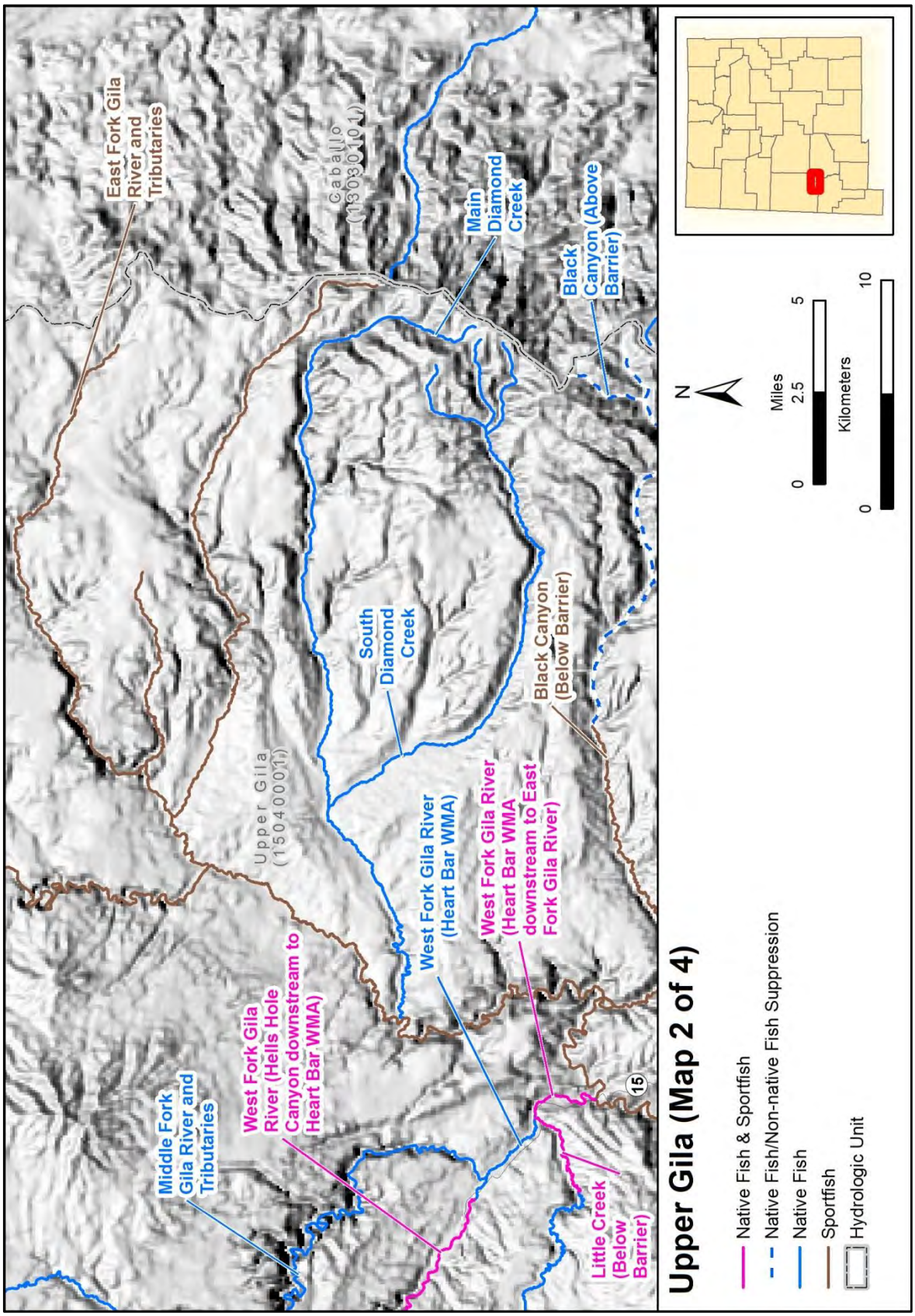


Figure 60. Upper Gila (Map 2 of 4)

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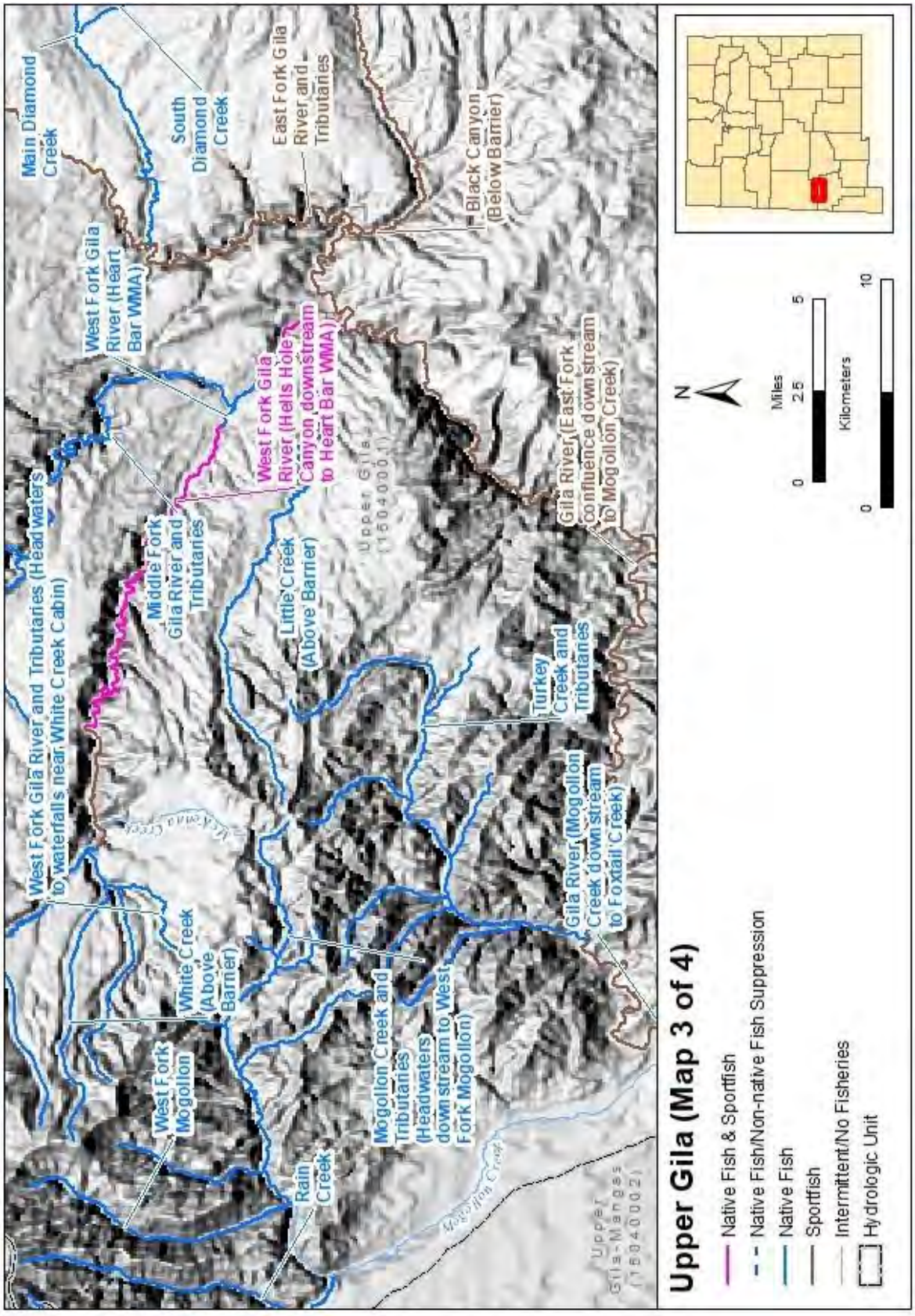


Figure 61. Upper Gila (Map 3 of 4)

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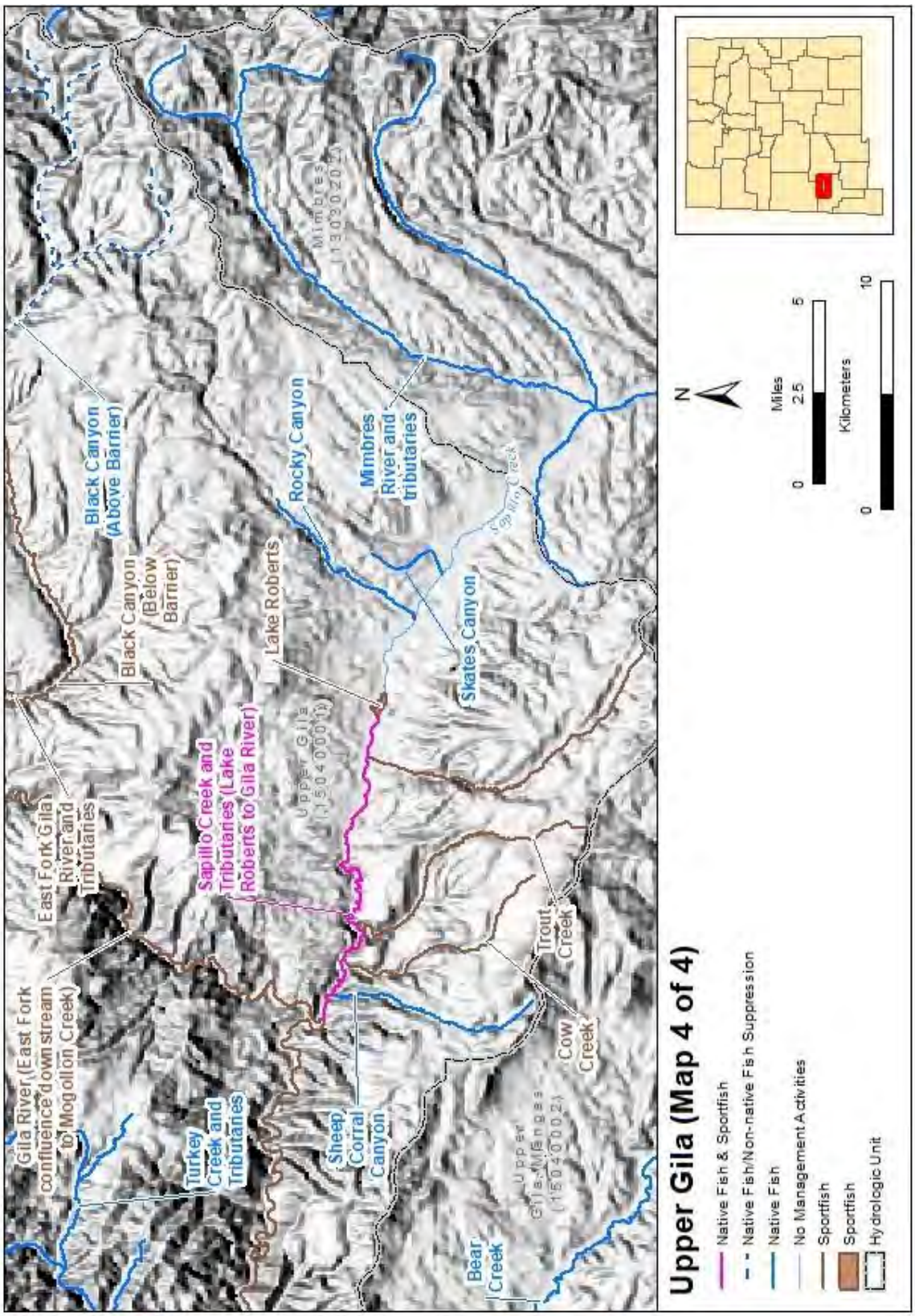


Figure 62. Upper Gila (Map 4 of 4)

HUC 15040002 Upper Gila - Mangas

Management Direction HUC 15040002 Upper Gila - Mangas

Water	Fish Species	Management Type	Management Direction
Gila River (Mogollon Creek downstream to Foxtail Creek)	Loach Minnow	Native Fish	Designated critical habitat for Loach Minnow and currently occupied
	Spikedace	Native Fish	Designated critical habitat for Spikedace and currently occupied
	Non-native fish	Suppression	Investigate regulations to promote harvest of non-native predators up to and including unlimited take
Bear Creek	Loach Minnow	Native Fish	Designated critical habitat for Loach Minnow and currently occupied
Mangas Creek	Loach Minnow	Native Fish	Designated critical habitat for Loach Minnow. Almost entirely on private land
Bill Evans	Channel Catfish	Put and Take	Stock catchable Channel Catfish as available. Investigate Special Summer Catfish program potential
	Largemouth Bass	Wild	Manage as a Trophy Bass Water and investigate regulations to attain trophy potential
	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout between November and March
Gila River and Tributaries (Foxtail Creek downstream to State Line)	Catfish	Wild	Channel and Flathead catfish present. Maintain regulations to support catfish angling
	Spikedace	Native Fish	Designated critical habitat for Spikedace
	Loach Minnow	Native Fish	Designated critical habitat for Loach Minnow
Duck Creek and Tributaries	N/A	N/A	Intermittent throughout reach. No current data
Red Rock Pond	Roundtail Chub	Native Fish	Establish refuge population of Roundtail Chub
	Gila Topminnow	Native Fish	Establish refuge population of Gila Topminnow

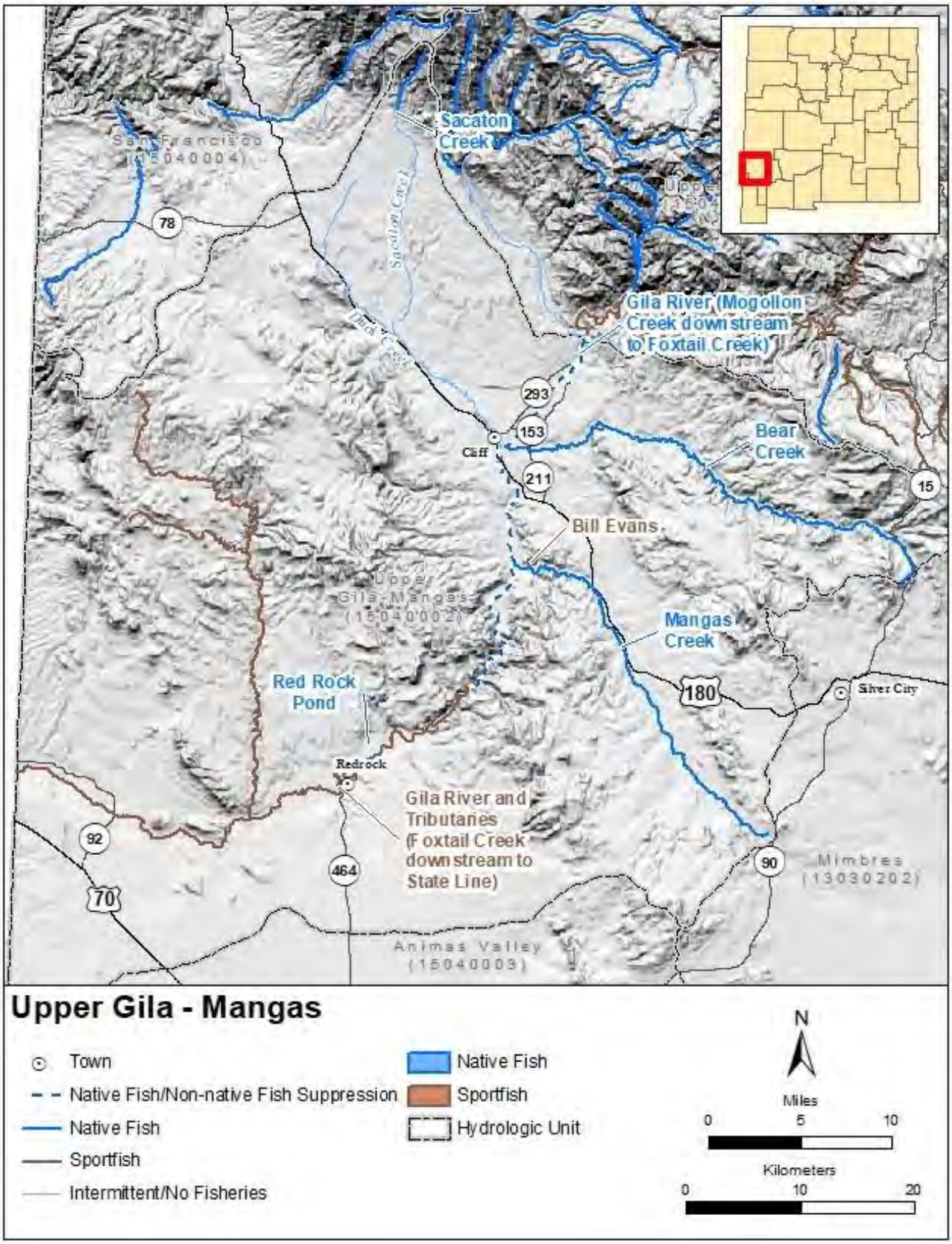


Figure 63. Upper Gila - Mangas

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HUC 15040004 San Francisco

Management Direction for HUC 15040004 San Francisco

Water	Fish Species	Management Type	Management Direction
Tularosa River	Loach Minnow	Native Fish	Designated critical habitat for Loach Minnow and currently occupied in some reaches
Lower Negrito Creek	Loach Minnow	Native Fish	Designated critical habitat for Loach Minnow and currently occupied
Upper Negrito Creek	Triploid Rainbow Trout	Put and Take	Stocking ceased in 2003 due to low water conditions. Resume spring stocking as conditions permit
Saliz Canyon	Loach Minnow	Native Fish	Maintain distribution
San Francisco and Tributaries (Headwaters downstream to Pleasanton Diversion)	Loach Minnow	Native Fish	Designated critical habitat for Loach Minnow and currently occupied
	Spikedace	Native Fish	Designated critical habitat for Spikedace and currently occupied
	Rio Grande Sucker	Native Fish	Maintain distribution
Mineral Creek	Gila Trout	Native Fish	Gila Trout recovery stream. Special Trout Water regulation (Green Chile Water) for entire reach
Whitewater Creek and Tributaries (Headwaters to Catwalk)	Gila Trout	Native Fish	Gila Trout recovery stream. Special Trout Water regulation (X-mas Chile Water) for entire reach
Glenwood Pond	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout annually. Initiate stocking Gila Trout in Glenwood Pond
Big Dry Creek	Gila Trout	Native Fish	Gila Trout recovery stream
Spruce Creek	Gila Trout	Native Fish	Gila Trout recovery stream and relict population. Maintain angling closure
Mule Creek	Roundtail Chub	Native Fish	Roundtail Chub recovery stream
San Francisco River and Tributaries (Pleasanton Diversion downstream to Stateline)	Catfish	Wild	Channel and Flathead catfish present. Maintain regulations to support catfish fishery. Includes designated critical habitat for Loach Minnow and currently occupied. Designated critical habitat for Spikedace and currently occupied
	Smallmouth Bass	Wild	Maintain regulations to support Smallmouth Bass fishery

Management Direction for HUC 15040004 San Francisco			
Water	**Fish Species**	**Management Type**	**Management Direction**
Blue River and Tributaries	Loach Minnow	Native Fish	Designated critical habitat for Loach Minnow
	Spikedace	Native Fish	Designated critical habitat for Spikedace

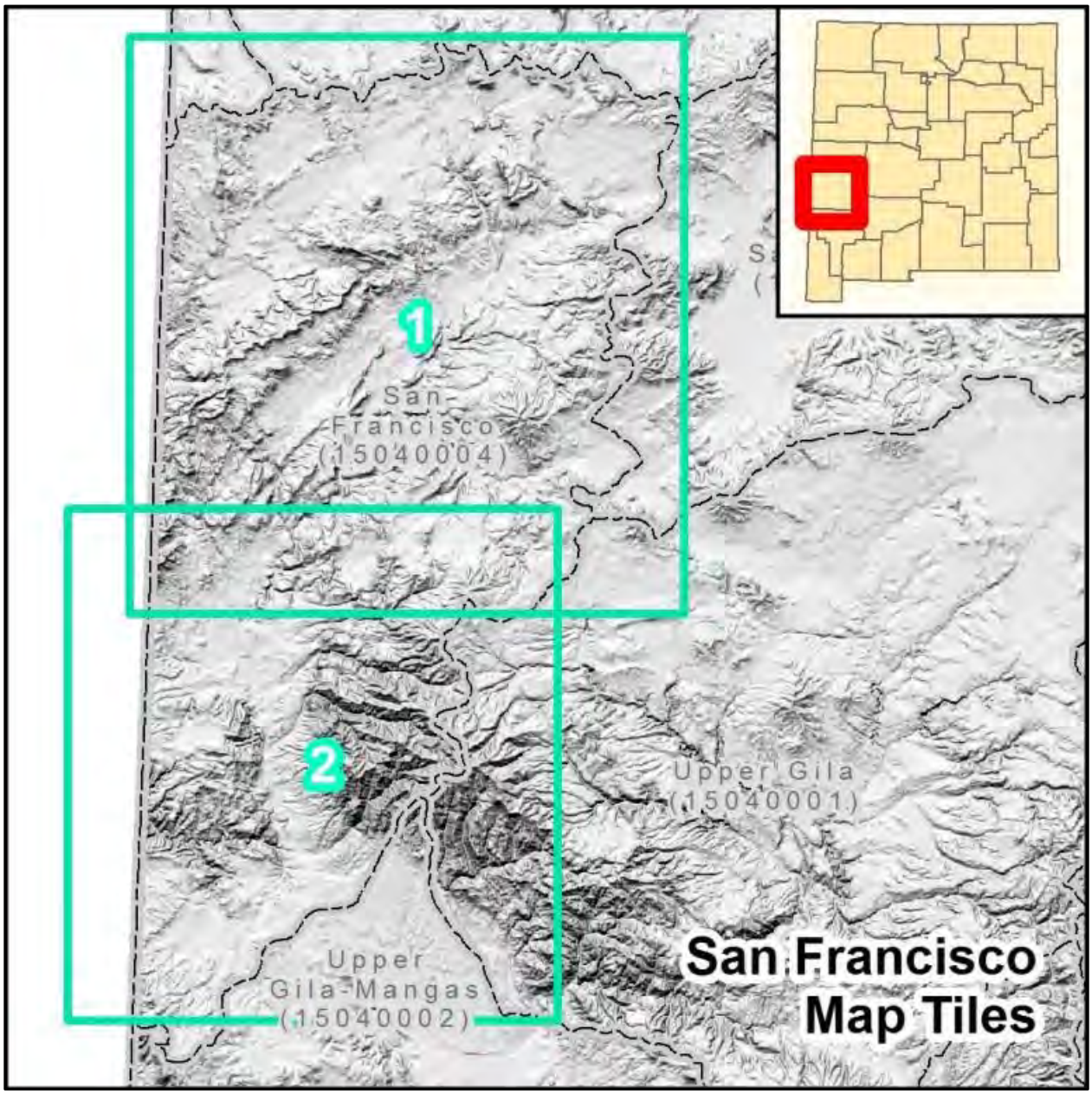


Figure 64. San Francisco Map Tiles

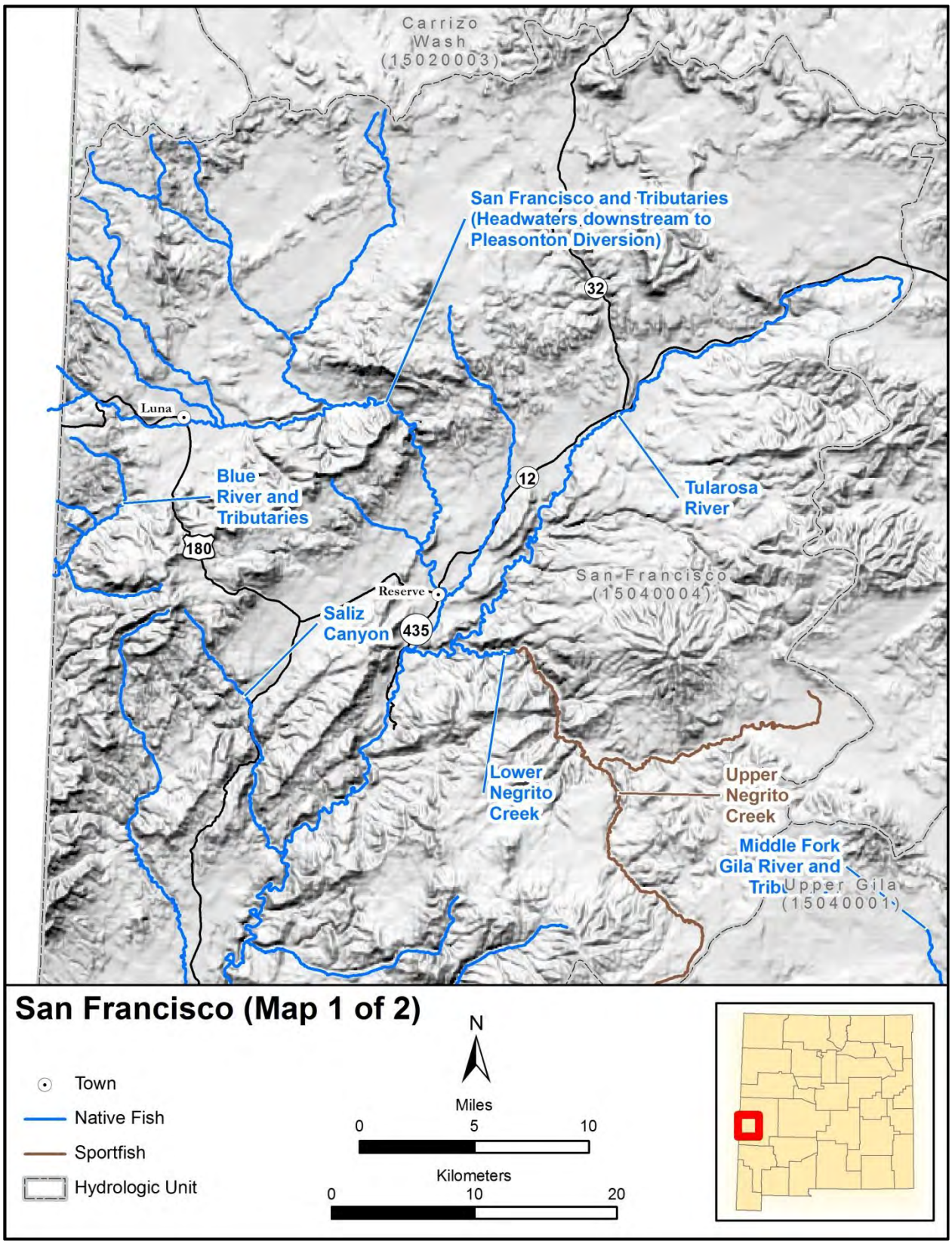


Figure 65. San Francisco (Map 1 of 2)

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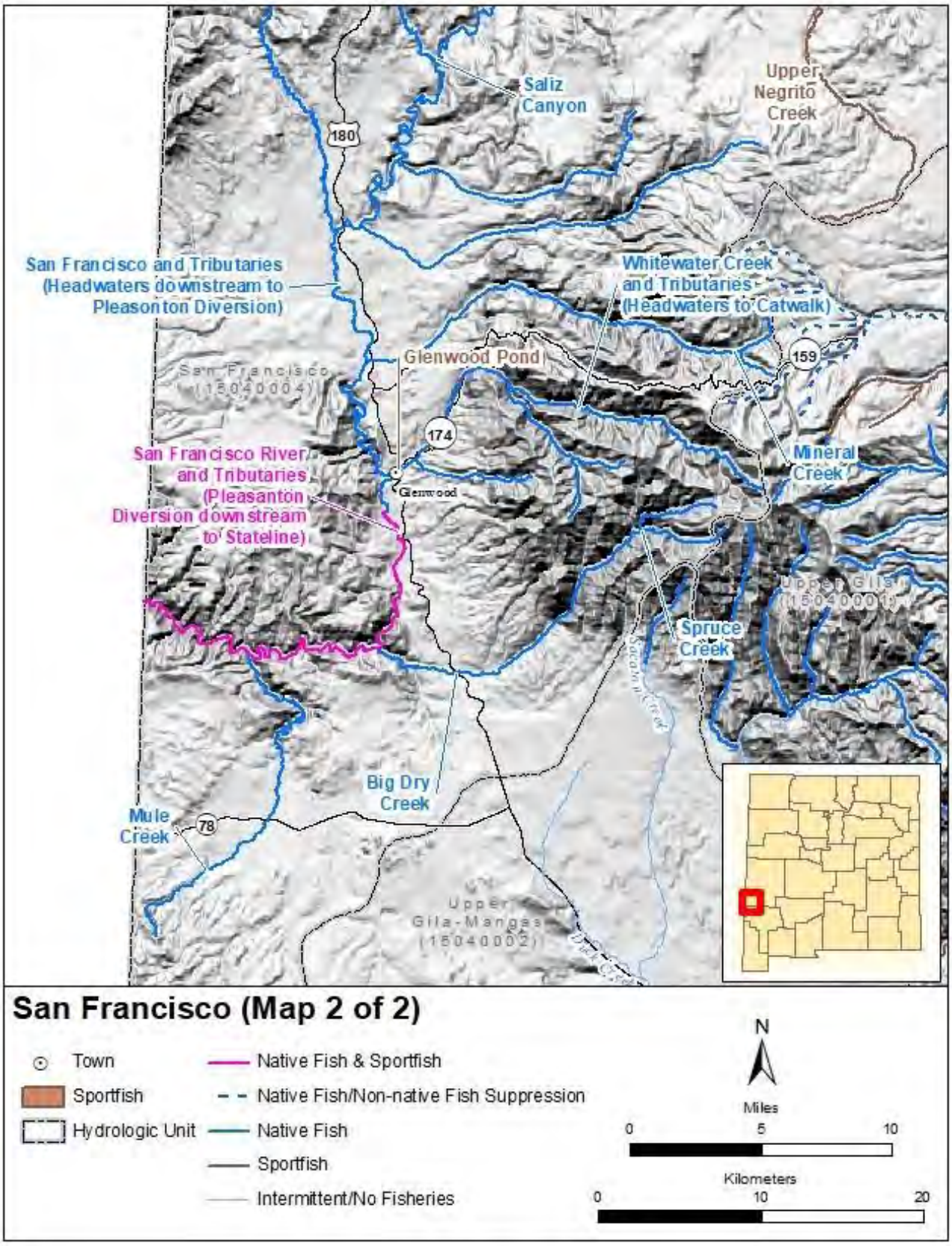


Figure 66. San Francisco (Map 2 of 2)

San Juan Watershed

In New Mexico the San Juan River Watershed occurs almost entirely within San Juan County. The San Juan River originates in the San Juan Mountains of southwestern Colorado, enters New Mexico northeast of Farmington, and flows westward for about 93 miles to exit the state near the Four Corners area. Navajo Dam impounds the upper 19 miles of the river in New Mexico. From Navajo Dam downstream to Farmington the river is restricted to a single, moderately incised channel and habitats are mainly cobbled riffles, moderately deep runs, and large pools. Gradient diminishes as the river progresses downstream from Farmington to Shiprock, but flow remains mostly in a single channel. Downstream of Shiprock the channel is frequently divided among two, three, or four courses. Habitat diversity increases with channel complexity. In addition to habitats common in upstream reaches, backwaters, embayments, shoals, and secondary channels (having their own mix of habitats) are present. The San Juan River within New Mexico is permanently-watered, but permanently flowing tributaries are currently limited to the Navajo, Animas, and Mancos rivers. The San Juan River upstream of Four Corners drains about 6.9 million acres including portions of the system in Colorado. The Bureau of Land Management administers much of the watershed upstream of Farmington and large portions of the watershed are within Navajo Nation and Jicarilla Apache jurisdiction.

Aquatic habitats of the San Juan Watershed are influenced by regulated flows, channelization, water diversion, runoff from municipalities, roads, row-cropped agricultural lands, and petroleum-extraction activities. Currently, Navajo Reservoir is operated to balance the needs of sensitive fish with water development per conditions of a Biological Opinion issued to Bureau of Reclamation by the US Fish and Wildlife Service. Considerable data on water quality and habitats of the main stem of the San Juan River are available in various reports produced by the San Juan River Basin Recovery Implementation Program. Hypolimnetic releases from Navajo Dam maintain coldwater habitats downstream until approximately the Hammond Diversion upstream of Bloomfield.

Two major sport fisheries exist within the San Juan watershed, Navajo Reservoir and the San Juan tailwater trout fishery. Navajo Reservoir provides opportunities for a variety of warmwater and coldwater fish species. The Special Trout Water reach of the San Juan River is world-renowned for both the density and size of both Brown and Rainbow trout.

Critical habitat for the federally endangered Colorado Pikeminnow (also state endangered) and Razorback Sucker includes currently occupied reaches between Farmington and the Navajo Nation boundary. The Department actively participates in recovery program activities for both endangered species including annual monitoring activities and development of research projects that could assist with their recovery. The Department is also a signatory to the Rangewide Conservation Agreement for Roundtail Chub, Bluehead Sucker, and Flannelmouth Sucker.

Activities under this agreement primarily include sharing of data and coordination among signatory agencies.

HUC 14080101 Upper San Juan, 14080104 Animas, 14080105 Middle San Juan

Management Direction HUC 15040001 Upper San Juan, 15040002 Animas, 15040004 Middle San Juan

Water	Fish Species	Management Type	Management Direction
Los Pinos River /Pine River	Kokanee	Put, Grow, and Take	Kokanee run out of Navajo Reservoir into the Pine River. Historical kokanee broodstock water
	Brown Trout	Wild	Maintain regulations to support wild trout fishery
Navajo Reservoir	Triploid Rainbow Trout	Put, Grow, and Take	Stock subcatchable triploid Rainbow Trout. An additional 80,000 fingerling triploid Rainbow Trout stocked by USFWS as mitigation, annually. Due to USFWS hatchery priority shifts, future of mitigation stocking uncertain. Fulfill stocking rates with Department raised triploid Rainbow Trout
	Smallmouth Bass	Wild	Manage as a Recreational Bass Water
	Kokanee	Put, Grow, and Take	Stock fingerling kokanee. Historical kokanee broodstock water. Whirling disease detected in 2020 which may affect brood potential
San Juan River (Navajo Dam downstream 3.5 miles to end of Special Trout Water)	Triploid Rainbow Trout	Put, Grow, and Take	Stock subcatchable triploid Rainbow Trout annually. Managed as a Trophy Trout Water. Special Trout Water (Red Chile Water)
	Brown Trout	Wild	Manage as a Trophy Trout Water
San Juan River (Downstream Boundary of Special Trout Water downstream to Hammond Diversion)	Triploid Rainbow Trout	Put, Grow, and Take	Stock catchable and fingerling triploid Rainbow Trout annually
	Brown Trout	Wild	Maintain regulations to support Wild Trout Water
San Juan River (Hammond Diversion downstream to Animas River confluence)	Roundtail Chub	Native Fish	Investigate the potential for restoring Roundtail Chub as identified in the Colorado River Basin Chubs Recovery Plan
	Mottled Sculpin	Native Fish	Investigate the status of Mottled Sculpin in this reach
Jackson Lake	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout

Management Direction HUC 15040001 Upper San Juan, 15040002 Animas, 15040004 Middle San Juan			
Water	**Fish Species**	**Management Type**	**Management Direction**
Lake Farmington	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Smallmouth Bass	Wild	Manage as a Low Density Bass Water
	White Bass	Wild	Maintain regulations to support White Bass fishery
Aztec Pond	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
Tiger Park Pond	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
La Plata River	Roundtail Chub	Native Fish	Investigate the potential for restoring Roundtail Chub as identified in the Colorado River Basin Chubs Recovery Plan
	Bluehead and Flannelmouth sucker	Native Fish	Investigate potential for restoring habitat to benefit native fishes in the San Juan Basin on Department owned Wildlife Management Areas
Animas River	Mottled Sculpin	Native Fish	Investigate the status of Mottled Sculpin in this reach
	Roundtail Chub	Native Fish	Investigate the potential for restoring Roundtail Chub as identified in the Colorado River Basin Chubs Recovery Plan
	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
San Juan River (Animas River downstream to State Line)- Reaches below Hogback Diversion within jurisdiction of Navajo Nation	Colorado Pikeminnow	Native Fish	Designated critical habitat for Colorado Pikeminnow and currently occupied. Participate in the San Juan River Basin Implementation Program (SJRIP) activities
	Razorback Sucker	Native Fish	Designated critical habitat for Razorback Sucker and currently occupied
	Roundtail Chub	Native Fish	Investigate the potential for restoring Roundtail Chub as identified in the Colorado River Basin Chubs Recovery Plan
	Non-native Fish	Suppression	Participate in non-native fish removal efforts in collaboration with the SJRIP program. Target species are primarily Channel Catfish and Common Carp though all non-native species are removed in this reach. Maintain regulations to suppress non-native fish

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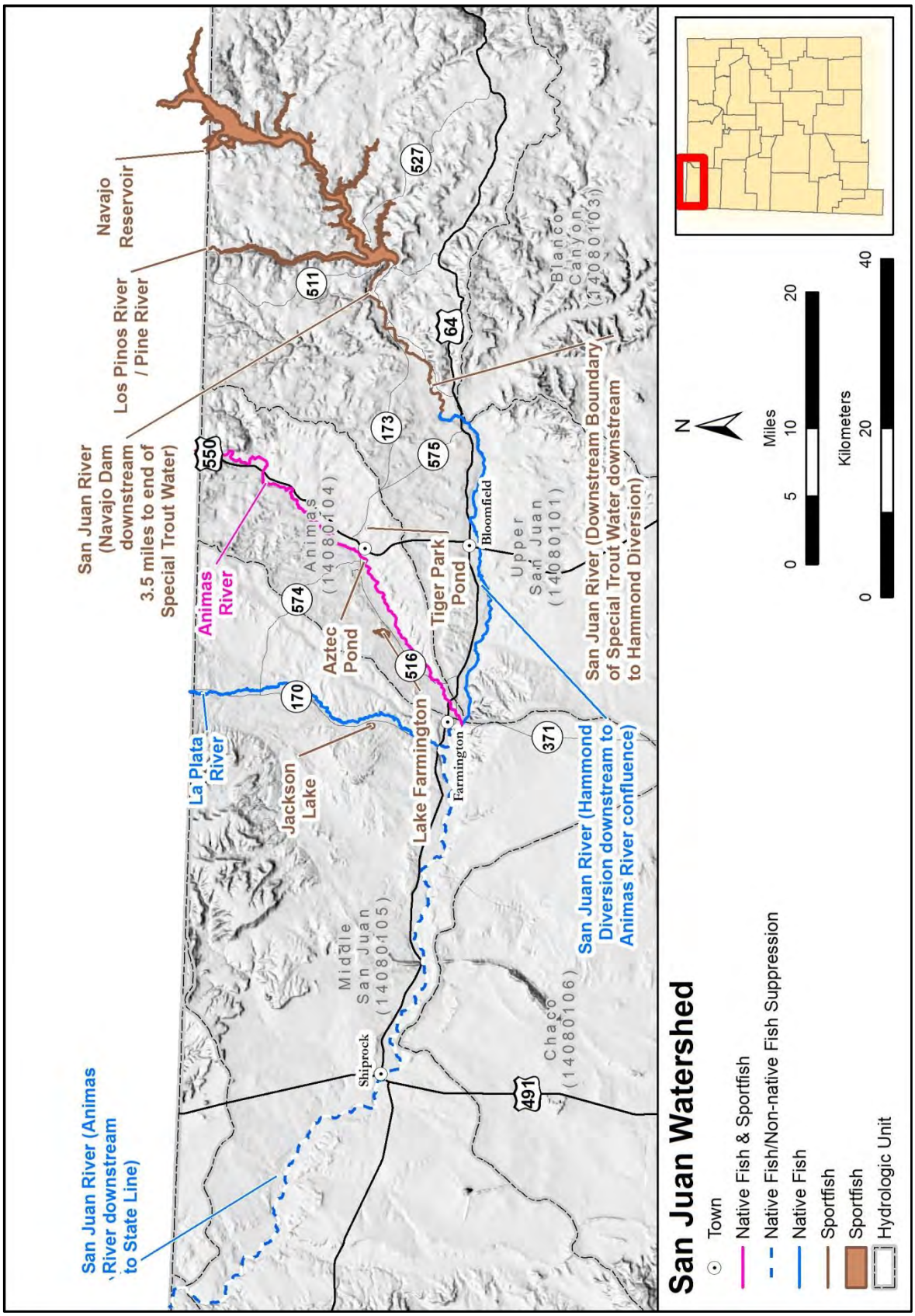


Figure 67. San Juan Watershed

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Zuni Watershed

The Zuni River drains about 800,000 acres as it flows from its headwaters in west-central New Mexico to the Little Colorado River in Arizona. Continuous flow is absent from the headwaters downstream to the Arizona/New Mexico border and surface flow is generally only continuous during heavy spring run-off. Many stream reaches are dry except near perennial springs. Headwaters of the Zuni River watershed include 1st and 2nd order streams such as Rio Nutria and Tampico Draw. Lower areas of the watershed include the main stem of the Zuni River, a 3rd and 4th order system, and associated impoundments such as Black Rock Reservoir. Landownership is primarily private and Forest Service in the upper watershed and tribal in the lower areas. Limited water within the watershed has resulted in minimal fisheries activity within the drainage. The federally and state endangered Zuni Bluehead Sucker inhabits perennial reaches in the upper watershed. The only sport fishery within the drainage is McGaffey Lake. Quemado Lake is located in the Carrizo Wash HUC and provides exceptional trout and tiger muskie angling opportunities.

HUC 15020003 Carrizo Wash, 15020004 Zuni

Management Direction for HUC 15020003 Carrizo Wash, 15020004 Zuni

Water	Fish Species	Management Type	Management Direction
Zuni River and Tributaries	Zuni Bluehead Sucker	Native Fish	Maintain distribution. Rio Nutria, Tampico Draw, and a private property reach are occupied by Zuni Bluehead Sucker. Significant portions of the watershed are on private and Zuni Pueblo land
	Green Sunfish	Suppression	Periodically remove Green Sunfish to reduce predation on Zuni Bluehead Sucker. Investigate other means to remove Green Sunfish from the drainage
McGaffey Lake	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Channel Catfish	Put and Take	Special Summer Catfish Water - Stock catchable Channel Catfish
Quemado Lake	Triploid Rainbow Trout	Put and Take	Stock catchable triploid Rainbow Trout
	Tiger Muskie	Put, Grow, and Take	Maintain target density of 4 fish/acre to maximize growth, suppress unwanted Goldfish, and provide a quality tiger muskie fishery. Stock fingerling tiger muskie annually (possibly less often) to attain target density

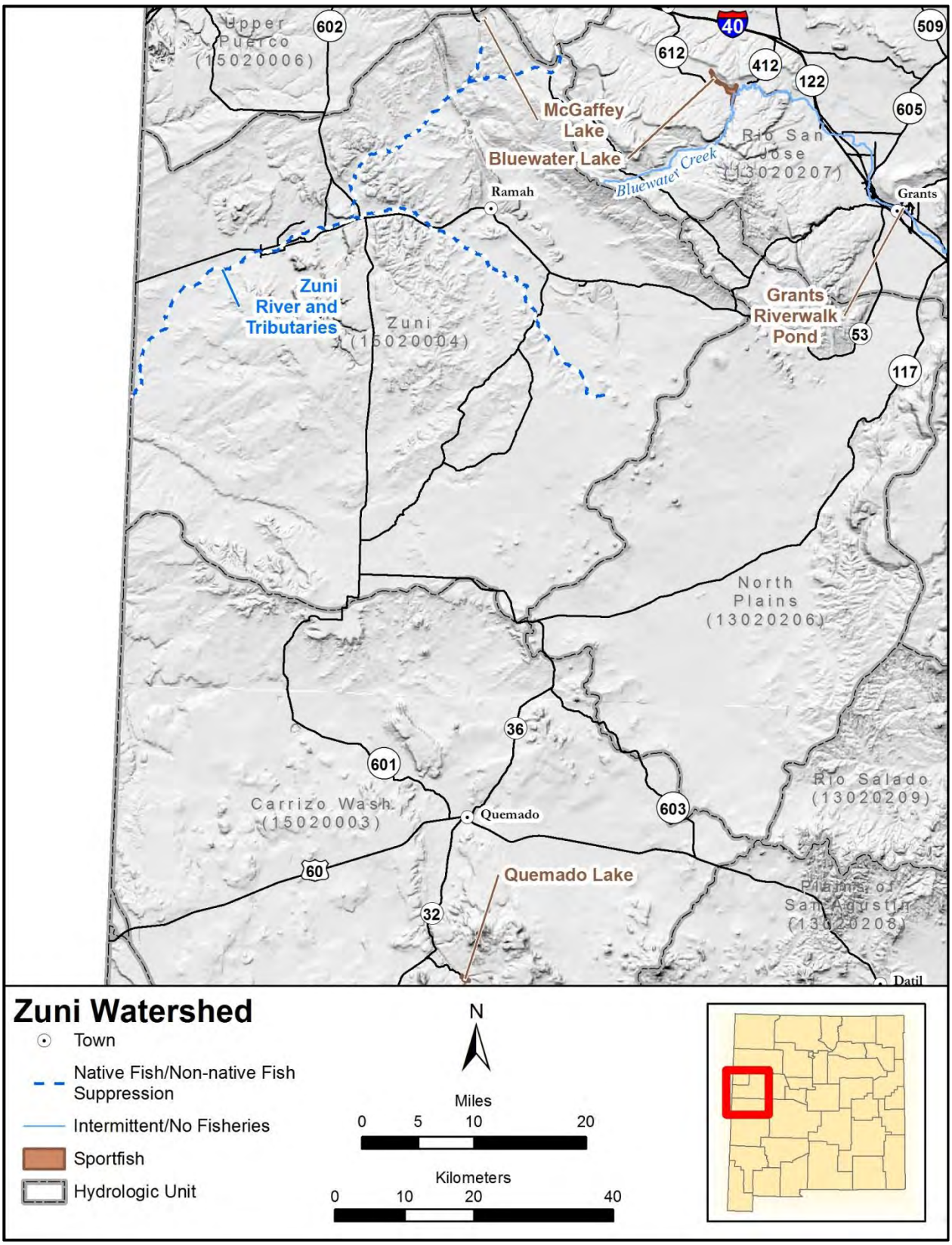


Figure 68. Zuni Watershed

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Appendix A- Fish Parameter Updates from the 2016 Plan

The 2016 Statewide Fisheries Management Plan identified numerous objective parameters for a range of fisheries. After five years of implementation those parameters were reviewed for the 2022 update. Many parameters remain unchanged between the versions but some warranted updates and a few were removed entirely. This appendix identifies the changes and explains the reasons for them.

The parameters below that have been updated are displayed with a ~~strikethrough~~ for deletions, additions in *italics,* and accompanying justification in blue font following each change.

Catfish Parameters

~~Big Cat Waters and Put and Take~~

Put and Take and Summer Catfish Waters

- Average ~~angler catch~~ *Harvest* rate of ~~0.5~~ *1* fish/angler ~~hour~~ *day* during stocking season (late May to early September)
  - Average angler catch rate of .5 fish/ angler hour changed to Angler Harvest Rate: 1 fish/angler day during stocking season to maintain consistency with catchable trout goals, provide a goal that is easier to measure and more realistic
  - Big Cat Waters were changed to Summer Catfish Waters. Parameters are the same as those listed under Big Cat Waters

~~*Put, Grow, and Take*~~

  - Parameters for Put, Grow, and Take Catfish Waters were removed. Stocking juvenile catfish proved this strategy unsuccessful in providing a Channel Catfish fishery in most waters tested. The Put, Grow, and Take stocking strategy will likely only be used on a limited or experimental basis in the future and specific parameters will not be needed

- ~~Catch Per Unit Effort: 7 fish/set night (i.e. number of nets set for a night)~~
- ~~Mean length of 11 inches by Age 3~~
- ~~Multiple size classes of adults~~

Black Bass Parameters

Trophy Bass Waters (Largemouth Bass only)

- Catch Per Unit Effort: > 5 fish/hour of electrofishing that are > than 20 inches in length

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- Recruitment: ~~> 20 Age-1~~ *>10 Age-2 bass*/hour of electrofishing
  - This parameter was amended to replace Age-1 with Age-2 bass. Age-1 bass are not as susceptible to our capture methods and are often underrepresented in our surveys. Age-1 bass generally occupy shallow habitat areas, different from where we survey, and due to their small size they are not as susceptible to electric frequencies used to survey adult bass. Age-2 bass are generally captured in our surveys and will be a better representation of recruitment
- Size Structure: Proportional Stock Density between 50 and 70
- Growth: Mean length of ~~Age-3~~ *Age 4* bass > 14 inches
  - This parameter was amended to a more reasonable growth goal for New Mexico waters. The original growth goal was based upon Florida strain largemouth bass in their native range and is not feasible for New Mexico's reservoirs
- *Body condition: Average relative weight of at least 90*
  - This new parameter was added since body condition reflects available prey base and can be used as indicator of appropriate stocking rates

Recreational Bass Waters

- Catch Per Unit Effort: 20 to 40 fish/hour of electrofishing (minimum size=7 inches for Smallmouth Bass, 8 inches for Largemouth Bass)
- Recruitment: ~~10 to 20 Age-1~~ *>5 Age-2 bass*/hour of electrofishing
  - This parameter was amended to replace Age-1 with Age-2 bass. Age-1 bass are not as susceptible to our capture methods and are often underrepresented in our surveys. Age-1 bass generally occupy shallow habitat areas, different from where we survey, and due to their small size, they are not as susceptible to electric frequencies used to survey adult bass. Age-2 bass are generally captured in our surveys and will be a better representation of recruitment
- Size Structure: Proportional Stock Density between 40 and 60
- *Body Condition: Average relative weight of at least 80*
  - This new parameter was added since body condition reflects available prey base and can be used as indicator of appropriate stocking rates

Low Density Bass Waters

- Catch Per Unit Effort: 0 to 20 fish/hour electrofishing (minimum size= 7 inches for Smallmouth Bass, 8 inches for Largemouth Bass)
- *Body Condition: Average relative weight of at least 80*
  - This new parameter was added since body condition reflects available prey base and can be used as indicator of appropriate stocking rates

Striped Bass Parameters at Elephant Butte Reservoir

- Catch Per Unit Effort: 1 fish/net night
- Size Structure: Proportional Stock Density between 50 and 70
- *Body Condition: Average relative weight of at least 85*
  - This new parameter was added since body condition reflects available prey base and can be used as indicator of appropriate stocking rates

Walleye Parameters

- Catch Per Unit Effort: minimum of 4 fish/net night
  - This parameter was amended by adding "minimum of" in front of "4 fish/net night". The old parameter suggested that if the catch per unit effort was greater than 4 fish/net night the population would not be meeting goals. This parameter is meant as a minimum abundance and not as a cap
- ~~Size Structure: Proportional Stock Density between 40 and 60~~
  - This parameter was removed since walleye populations have consistently been above the Proportional Stock Density (PSD) range which normally means the smaller size classes are missing. The high PSD in New Mexico Walleye populations is not a reflection of an out of balance population but a result of rapid growth
- *Body Condition: Average relative weight of at least 80*
  - This new parameter was added since body condition reflects available prey base for adult fish and can be used as indicator of appropriate stocking rates

Tiger Muskie Parameters

- Density: ~~Minimum of~~ 4 fish/surface acre (*10-year average of surface area*) ~~of habitat~~
  - This parameter was amended by removing "minimum" since 4 fish/surface acre is the actual goal and densities above this goal are too high to sustain a healthy population. Also, the area is now based on a 10-year rolling average since water levels fluctuate significantly changing densities without changes to the actual total population number

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- Unwanted Fish ~~Density~~ *Catch Per Unit* of effort: ~~Maintain low abundance of unwanted Goldfish and White Suckers~~ *<20 fish/ hour electrofishing of goldfish and white suckers in target waters.*
  - This parameter was amended by adding a measurable goal for abundance of unwanted fish species. This abundance will ensure these species are controlled and still provide ample prey base for tiger muskie
- *Average body condition (relative weight) of at least 90 for fish ≥30 inches*
  - This new parameter was added since body condition reflects available prey base and can be used as indicator of appropriate stocking rates

Trout Parameters

Put and Take:

- Angler ~~Catch~~ *Harvest* Rate: ~~0.5~~ *1* fish/angler day during stocking season
  - This parameter was amended by replacing "catch" with "harvest" since our actual goal is 100 percent utilization in Put and Take waters and harvest more accurately reflects utilization
- Stocking Rate: Stock *at least* 1 fish/angler day
  - This parameter was amended by adding "at least" since, based on creel surveys, some waters need to be stocked with more than 1 fish/angler day to meet angler expectations

Put, Grow, and Take:

Kokanee

- Catch Per Unit Effort: 20 fish/net night with *pelagic set nets*
  - This parameter was amended by adding the capture technique for clarification

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Appendix B- Progress Towards 2016 Identified Priority Projects and Needs for Further Investigation and Research

The 2016 Plan identified a number of programmatic fisheries priorities including evaluation of hatchery stocking, habitat restoration, AIS monitoring and prevention, species recovery efforts, and statewide fisheries management. Substantial progress has been made on many of those priorities in the intervening years. Below are the priorities listed in the 2016 version of the plan with progress made and accomplishments in italics.

Evaluation of Hatchery Stocking

Trout

- Continue to evaluate allocation of catchable and subcatchable trout
    - *In 2020 the Department engaged New Mexico State University in a collaborative research project to analyze stocking efficacy of fingerling and subcatchable trout in Eagle Nest Lake to develop stocking strategies for mitigating Northern Pike predation. Results are anticipated in 2022*
    - *Since 2016 the Department has conducted angler utilization and harvest surveys on twelve individual waterbodies stocked with catchable trout to ensure proper and equitable distribution of stocking among Winter Trout Waters*

- Investigate potential for reducing or eliminating stocking of catchable trout from some river systems which support wild trout and reallocate to higher use systems
    - *Since 2016 some discussions and considerations have occurred, however at this time no specific waters have formally been identified to reduce or eliminate catchable trout stocking*

- Continue to investigate areas where native trout, surplus to recovery efforts, can be used to increase angling opportunities for native trout
    - *Since 2016 the Department has evaluated 10 waterbodies stocked with surplus Rio Grande Cutthroat Trout (e.g., Clear Creek, East Fork Jemez River, Horseshoe Lake, Middle Fork Lake, Rio Cebolla, Rio Chama below El Vado, Rio Guadalupe, Rio Grande Gorge, San Antonio Creek, and Trampas Lakes) and adjusted stocking strategies including adding several waterbodies (e.g., Canjilon Lakes, El Rito, Fenton Lake, Goose Lake, Hopewell Lake, Lagunitas Lakes, Nutrias Lakes, and San Gregorio Lake)*
- Monitor and adjust kokanee stocking strategies in accordance with varying reservoir levels and differing spawning success

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- *Since 2016 the Department has conducted annual population surveys on Heron and Navajo reservoirs to evaluate population status and adjust stocking strategies appropriate to current water levels. Water levels, especially at Heron Reservoir, have receded significantly since 2016 and stocking rates have been reduced to accommodate reduced habitat*

Catfish

- Investigate use of subcatchable and fingerling Channel Catfish instead of catchable catfish, where appropriate
    - *Since 2016 the Department has evaluated 10 waterbodies stocked with fingerling and/or subcatchable Channel Catfish and determined stocking subcatchable Channel Catfish can provide marginal angling opportunity in very few waters. Stocking fingerling Channel Catfish in waters was not successful. Stocking of subcatchable and fingerling Channel Catfish has been discontinued*

Walleye

- Evaluate the benefit of utilizing fingerling (advanced fry) Walleye in certain lakes to improve Walleye fisheries
    - *This priority was discontinued due to change in Rock Lake State Fish Hatchery focus to Largemouth Bass. Preliminary research showed fingerling Walleye survive better than fry but increased survival does not outweigh cost of raising Walleye to fingerling size compared to stocking additional fry*

Habitat Restoration

- Working with partners and volunteers, design and implement instream and riparian habitat restoration efforts on Commission owned Wildlife Management Areas including properties in the Rio de Los Pinos, Pecos, Red River, Rio Chama, Chamita, Gila and Mimbres watersheds
    - *Since 2016 the Department has made great strides restoring instream, riparian, and reservoir habitat on Commission owned Wildlife Management Areas including projects in the Rio de Los Pinos (2.0 miles), Pecos River (2.1 miles), Rio Chamita (0.5 miles), Mimbres River (0.8 miles and a 0.2-acre pond), and Bill Evans Lake (60.0 acres)*

- Working with partners and volunteers, design and implement instream, riparian, and reservoir habitat restoration efforts on non-Commission owned properties

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- *Since 2016 the Department has partnered with several federal, state, and non-government organizations restoring instream and riparian habitat including projects in the San Juan River (1.5 miles), Rio Chama (2.0 miles), Mimbres River (1.6 miles) and the Costilla Creek (4.0 miles)*

Aquatic Invasive Species

- Coordinate and conduct intervention efforts to prevent the introduction of zebra and quagga mussels into New Mexico waters.
  - *Continued with education/outreach, early detection monitoring and prevention activities; to date over 243,955 conveyances have been inspected of which 1,147 have received a hot water decontamination*
  - *In July 2017 the State Game Commission amended AIS rules to include mandatory watercraft inspections for out of state conveyances; removal of hull plugs and advanced notice of arrival for conveyances 26 ft. or more in length*
  - *276 samples collected for early detection of zebra and quagga mussels using quantitative polymerase chain reaction analysis*
  - *Responded to an alert of zebra mussels detected in moss balls being sold in pet stores in 2021. Implemented a rapid response including detection, removal from pet stores, and a disinfection and disposal protocols that were distributed directly to pet stores and to the public through social media*

- Improve the current understanding of fish pathogen distribution in waters and hatcheries in New Mexico
  - *Fish health inspections were conducted annually at all Department Hatchery facilities in order to maintain fish health certifications*
  - *Conducted health inspections of wild fish populations used for spawning activities including Rio Grande Cutthroat Trout, Walleye, and kokanee*

Species Recovery Efforts

Native Trout Restoration

- Rio Grande Cutthroat Trout restoration in the Costilla Creek and Rio las Animas watersheds (ongoing) as well as the Pecos River watershed (future)
  - *The Costilla Creek Rio Grande Cutthroat Trout Restoration Project entered its final phase, treatment of lower Comanche Creek and the Costilla Creek downstream to the terminal fish barrier, in 2020. Non-native fish removal is expected to conclude in 2022 and restocking will commence thereafter. Rio Grande Cutthroat Trout have been restored to the Rio las Animas and a project to*

restore them to Willow Creek in the Pecos River drainage began in 2020 and will be completed in 2022

- *The restoration activities above have also created opportunities to restore Rio Grande Chub and Rio Grande Sucker. The Department plans to stock both species into Costilla Creek in 2022*
- *Rio Grande Cutthroat Trout were also restored to Rito de Los Frijoles and Capulin Creek post fire due to habitat recovery*

- Gila Trout restoration in the Gila River Basin (ongoing)
  - *Gila Trout have been stocked and self-sustaining populations have become established in Willow, Mineral, White, and Langstroth creeks. A piscicide treatment in Whitewater Creek was completed in fall 2019 and Gila trout were stocked into the creek in 2020. Gila Trout will continue to be stocked annually until at least 2022 after which self-sustaining population is expected to become established*

- Install, enhance, and maintain fish migration barriers used to protect restored and existing populations of native trout
  - *In order to protect a newly established Gila trout population, a fish migration barrier was completed in Willow Creek (Gila Drainage) in summer 2016*
  - *In anticipation of restoration of Rio Grande Cutthroat Trout, fish migration barriers were constructed in Costilla Creek in 2017 and in Willow Creek (Pecos Drainage) in 2020*

- Investigate potential use and effects of supermale trout to aid in native trout restoration efforts
  - *In 2017 the Department engaged New Mexico State University in a collaborative research project to test the efficacy of using YY male (supermale) Brook Trout as a means of controlling non-native trout for native trout restoration. The project is ongoing but initial results are very promising*

- Incorporate other native fishes into restoration efforts including warmwater reaches, where possible. Examples include Rio Grande Sucker, Rio Grande Chub, Spikedace, and Loach Minnow
  - *There has not been an opportunity to incorporate other native fishes into restoration efforts; however, this remains a priority for the Division and we anticipate opportunities in the Rio Grande and Gila River drainages, in particular*

Rio Grande Chub and Rio Grande Sucker in the Costilla Creek drainage, in the coming years

Gila River Basin Warmwater Fishes

- Identify potential restoration and repatriation opportunities for Spikedace, Loach Minnow, and native chubs including the Middle Fork Gila River and possibly others
    - *Spikedace have been stocked and become established in the San Francisco River and Loach Minnow have been stocked and become established in Saliz Canyon*

- Incorporate native trout into restoration efforts to compliment coldwater reaches and other sensitive or listed taxa recovery efforts, where possible
    - *There has not been an opportunity to incorporate native trout restoration efforts in warmwater fish restoration; however, this remains a priority for the Division*

San Juan River Basin Fishes

- Investigate the importance of Roundtail Chub for successful recovery of Colorado Pikeminnow
    - *Investigation of the importance of Roundtail Chub for successful recovery of Colorado Pikeminnow has not been completed; however, planning for Roundtail Chub investigations and possible repatriations is underway*

- Investigate potential use and effects of supermale fish to aid non-native fish removal efforts
    - *The Division conducted preliminary investigations into the potential use and effects of YY male Channel Catfish to aid non-native removal efforts in the San Juan River Basin and this remains a priority*

Lower Pecos Aquatics

- Texas hornshell mussel and gray redhorse repatriation to the Delaware River (ongoing)
    - *Adult mussels were repatriated to the Delaware River in 2016 and streamside inoculations of mussels were conducted in 2016, 2017 and 2018 in order to establish mussel populations. Gray redhorse was repatriated to the Delaware River in 2017. Unfortunately, river drying that exposed mussel beds occurred in 2019 and 2020 and mussels were collected and removed. Until perennial flow can be secured for the Delaware, it is unlikely the river will be a suitable stream for repatriation of Texas hornshell mussel or Gray Redhorse*

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- Protection of Pecos Pupfish from further expansion of Sheepshead Minnow in New Mexico
    - *Two fish migration barriers were completed at the BLM Overflow Wetlands in 2019 to protect Pecos Pupfish populations from invasion by Sheepshead Minnow*

Statewide Fisheries Management

- Investigate amendments to regulations and develop management actions (including consistent stocking sources of Largemouth Bass) to enhance black bass angling opportunities including Trophy waters
    - *Trophy Bass Waters regulations were adopted by the State Game Commission for Clayton Lake, Lake Roberts, and Bill Evans Lake in 2018. Regulations include a reduced harvest limit in Trophy Bass Waters. These waters are stocked annually with subcatchable Largemouth Bass. Regulations and stocking strategies are focused on protecting and managing for larger sized bass*

- Evaluate and consider amendments to Special Trout Water regulations throughout the state
    - *The Special Trout Water system has been simplified to four basic regulation packages with a New Mexico chile theme. These regulations were tailored to improve angler understanding, facilitate native trout restoration, and maximize biotic potential in these trout fisheries*

- Investigate optimal densities of tiger muskie that suppress unwanted fish populations yet provide trophy angling opportunities
    - *About four fish per acre appears to be the ideal density for maintaining a tiger muskie population in concert with a Rainbow Trout fishery. This density was achieved at Bluewater in 2020. This density was sustained at Quemado Lake until a complete fish kill in 2018. Tiger muskie have been restocked at Quemado Lake*

- Work to encourage expanded youth angling opportunities
    - *Since 2016 the Department has spent significant effort supporting and hosting numerous angling educational events by stocking fish, providing fishing equipment (e.g., rods, reels, tackle, etc.), and providing personnel. In addition, angling regulations at age restricted waters were streamlined to reduce confusion and promote angling opportunities for young anglers. New youth angling opportunities were created by opening the ponds at Pecos Watershed*

Education Center, working with City of Ruidoso to create a new Kid's Fishing Pond at Alto Lake, and expanding Rio Grande Cutthroat Trout angling at Seven Springs Kid's Pond

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Appendix C- Summary of Public Involvement and Comments

Public review of the draft Statewide Fisheries Management Plan Update was initiated by presenting the purpose and need of the Plan Update to the State Game Commission at a regular meeting on March 4, 2022. A draft plan was subsequently published on the Department website with the initial comment period running through April 8, 2022. A specific email address was established to send written comment on the plan. Public meetings were held virtually on March 23rd and March 24th. A total of 16 members of the public signed in and provided contact information at these meetings. Department staff took notes on public comments at each of these meetings. Members of the public were encouraged to submit any questions they had during the meeting to the email address provided. The Department received four written comment letters and identified 67 comments within those letters. Substantive comments, a brief response, and how the final plan update was amended to address the comments are summarized below.

Commentor Name/ Organization	Comment	Response
Gila-Rio Grande Trout Unlimited Chapter	Comment 1.1 The updated indexes and active links to specific watersheds throughout the plan enhance the utility of the document, and the summary of the progress towards the priority projects and the list of the division's major accomplishments since 2016 are commendable.	Comment noted
	Comment 1.2 Include a section describing the issues of climate change and drought, how the Department maintains awareness of these threats, and the plans for responding to protect fish populations when these issues occur.	Climate change along with cyclical drought, episodic drought, wildfire, flood, changing land use patterns, aquatic invasive species, and increasing demand for municipal, commercial, and agricultural water are among the many broad-scale threats to the fisheries of New Mexico. In many cases, these threats are linked and can be additive, compounding, or synergistic in their effects on aquatic communities. Climate change, drought, and other threats are addressed in substantial detail in conservation documents for specific species, like The Rio Grande Cutthroat Trout Conservation Agreement and Strategy and the Gila Trout Recovery Plan, as referenced on page 31 of the Plan Update. Specific references to climate change were added on pages 5, 6, 34, and 90 but a section detailing climate change, drought, and other threats would distract from the primary purpose of the Plan Update, to provide details on recent accomplishments and near-term management direction for every fishery in the state, and therefore was not added.

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	Comment 1.3 We strongly support the regulated opportunities to fish for the threatened native Gila trout that were made possible with implementation of the 4(d) rule of the Endangered Species Act.	Comment noted
	Comment 1.4 The addition of more information and details describing the 4(d) rule in Draft Plan (page 28) would be appreciated here, as this is an excellent venue for informing the public and drawing attention to the critical role of the Division in monitoring these populations.	More information regarding monitoring of Gila Trout streams that are open to angling can be found in the Department's Framework for Management of Gila Trout Angling (2015).
	Comment 1.5 The Plan would also be strengthened by more detailed description of the protocols and procedures that are used for monitoring the status of Gila trout populations, and how these results could stimulate changes in existing angling regulations or closures of selected streams.	See response to comment 1.4
	Comment 1.6 The restoration of Gila trout to the ~24 miles of the Whitewater Creek watershed highlighted on page 31 is an incredible accomplishment!	Comment noted
	Comment 1.7 The management directions of "X-mas" and "Green Chile" that allow take are problematic, and we advocate that the Division investigate the potential for managing Mineral Creek, and Whitewater Creek above the natural waterfall barrier entirely as catch and release waters with a change to Red Chile Native trout conservation.	See response to comment 1.8
	Comment 1.8 Include the assessment of the impacts of harvest/take on Gila trout streams under the statewide fisheries priorities and investigate the feasibility of expanding catch & release "Red Chile" designations for native Gila trout waters to ensure healthy self-sustaining populations.	In many cases healthy, self-sustaining populations can and do support harvest through regulated angling. Providing a range of angling opportunity, including multiple gear types and harvest strategies is important for building and maintaining public support for conservation measures like removing non-native trout in support of native trout. The Department places the highest value on self-sustaining populations of Gila Trout in recovery waters and continuously assess the status of these fisheries. Current data indicate that self-sustaining populations are present in all recovery streams open to angling. This plan is not part of the rule making process for fisheries management in New Mexico, however, the specific recommendations made in comments 1.7, 1.8, 1.9, and 1.16 have been added to our list of suggestions for future rule making. We encourage the commentors to submit comments during the next fisheries rule cycle.

	Comment 1.9 The management type “Native Fish” for Willow Creek is appropriate; however, we have concerns that the designation of the “X-mas Chile” management direction that allows take is not sustainable and urge the division to investigate possible changes in regulations.	See response to comment 1.8
	Comment 1.10 Provide more information on the specific role of Glenwood hatchery and the plans for using hatchery-raised Gila trout need to be described in more detail. It is important to clarify the possible role of the Glenwood hatchery in providing Gila trout for streams with designated “Native Trout” Management Types.	See response to comment 4.7
	Comment 1.11 We would like to see a statement citing the scientific evidence that stream-born fish are healthier and more fit than hatchery-raised fish and recognizing that while hatchery-raised Gila trout should be appropriate for stocking waters designated “Put and Take” and “Put, Grow and Take”, the “Native Trout” management model should strive for self-sustaining stream-born populations. The Plan needs to include statement recognizing the superiority of stream-born vs hatchery fish.	The intent of this comment is unclear. The goal for all Gila Trout Recovery Waters is to establish fully self-sustaining populations. In most cases restored populations are established from hatchery sources that have been certified to be free of common pathogens and are descended from relict Gila Trout lineages. When founding populations our goal is to provide sufficient genetic diversity during stocking for the population to persist and adapt to their new environment.
	Comment 1.12 While the hatchery-raised Gila trout should be appropriate for stocking waters designated “Put and Take” and “Put, Grow and Take” and locations such as Snow Lake, Lake Roberts, and Glenwood Pond, etc. that can support allowed take, we encourage the Division to assess streams such as Whitewater Creek, Mineral Creek, and Willow Creek for management of stream-born native fish with catch & release regulations and regularly scheduled monitoring to quantify the health of these Gila trout populations.	Hatchery-produced Gila Trout are used to establish new recovery populations and are typically stocked for three consecutive years to ensure establishment of a self-sustaining population. Thereafter, streams are generally not stocked. If monitoring indicates that a population is not self-sustaining, we will investigate the causes and adjust regulations as warranted. Current data indicate that self-sustaining populations are present in all recovery streams open to angling,
	Comment 1.13 We were not able to determine from the Draft Plan if the Division intends to use the Glenwood hatchery to stock waters designated for “Native Trout” Management Types or not, and we believe that it is important to provide this clarification.	Gila Trout Recovery Waters (e.g., Native Fish management type) are not routinely stocked. Fish from Glenwood Hatchery will be used primarily to stock non-recovery put and take or put, grow, and take management types.
	Comment 1.14 While we recognize that recommendations for fisheries rule making changes to the “Chile” designations occur in a separate process, we encourage the Division to broadly assess the issue of	See response to comment 1.8

	take/harvest on Gila trout streams under the statewide fisheries priorities and investigate expansion of catch & release managed populations of Gila trout.	
	Comment 1.15 We also encourage the Division's interest and investigational efforts towards expanding Gila trout populations into the West Fork of the Gila, Rain Creek, West fork of Mogollon Creek, lower Black Canyon on the East Fork, the Middle Fork and tributaries such as Iron Creek, Gilita Creek and other waters where suppression regulations allowing removal of non-native trout are appropriate.	Comment noted
	Comment 1.16 We would support the Division's investigation of opportunities and prioritization of habitat improvement projects to enhance angling opportunities in places like the Heart Bar WMA, and the Catwalk section of Whitewater Creek that have strong potential as accessible recreational Gila trout fisheries.	Comment noted
Sara Ricklefs	Comment 2.1 It is important to recognize the presence of virile crayfish *F. virilis* (invasive species) in the Pecos watershed and take actions to curb this invasive species.	The Department recognizes that the Virile Crayfish or Northern Crayfish (*Faxonius virilis*) is non-native to New Mexico; however, the species is most widespread crayfish species in New Mexico, and it has occurred in every drainage in the state for decades. In addition, addressing the spread of invasive species is outside of the purview of this Plan, and is included in our New Mexico Aquatic Invasive Species Management Plan.
	Comment 2.2 Update New Mexico law to remove the virile crayfish from bait eligibility. Enacting a public outreach campaign to discourage actions that contribute to further translocations could be delivered similarly to or in conjunction with already successful zebra mussel/quagga mussel outreach efforts.	Currently, state statutes or rules do not restrict the use of crayfish as bait by individual anglers. The standing rule known as 19.31.9 Hunting and Fishing Regulation-Commercial Use of Fish, that defines which crayfish species can be legally sold by licensed bait dealers in New Mexico, includes Virile Crayfish. Virile Crayfish are included as a legal crayfish species to sell due to their widespread distribution in New Mexico. Our annual angler survey show crayfish use as bait by anglers is very low compared to other live bait. Based upon the low use by anglers and widespread distribution of the species, risk of translocations is low.
USDA Forest Service	Comment 3.1 The USFS supports and looks forward to partnering with the Department in its efforts to manage a variety of fisheries throughout the state to both support native fish communities and angling opportunities.	Comment noted

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	Comment 3.2 Arizona has promoted angling for Roundtail Chub, has the Department investigated if there is any demand in NM for this opportunity?	The Department has not specifically investigated the potential development of Roundtail Chub fisheries in New Mexico, in part, due to the ongoing uncertainty over the ESA listing status of specific populations and the species as a whole. The April 2022 USFWS decision that the Lower Colorado Distinct Population Segment of Roundtail Chub as not warranted for listing under ESA may allow further consideration of this topic.
	Comment 3.3 Several non-native Sportfish species such as Catfish and Smallmouth Bass and Non-Native Salmonids are causing declines in the native fish communities and are the main drivers on why some of these species are at risk. We commend the many programs that the Department supports to conserve and protect native species. To further support this in the Management Plan we would support having a management category that describes the areas where these fish may be undesirable to support native fish populations.	The Plan identifies waters where non-native fish are being suppressed or otherwise controlled for the benefit of native species
	Comment 3.4 Barriers on both Tanques and Tio Grande creeks need improvement, in addition there is likely a need for some type of protection for the pure RGCT in San Antonio Creek.	Comment addressed in the table on page 92
	Comment 3.5 The management of non-native sportfish in the warmwater sections of the Gila and San Francisco Rivers is inconsistent with the designation of Critical Habitat especially in the East Fork Gila, Mainstem Gila, and Lower San Francisco River. Management designed to support trophy Smallmouth Bass fisheries is having devastating impacts to native species populations in those areas, especially the East Fork of the Gila which historically supported both Spikedace and Loach Minnow and still maintains a limited population of Roundtail Chub and native suckers. The USFS would support investigating ways to decrease densities of these species in the East Fork, not continuation of management of high densities of Catfish and Smallmouth Bass.	There is no "Trophy Bass Water" designation in the Gila or San Francisco rivers. Both locations are managed under statewide regulations for bass and catfish with bag limits of 5 and 15 fish per day respectively. The Department's aim is to balance angling opportunity with native fish conservation across the state. This is particularly difficult in the Gila River Basin given the limited opportunities for angling and the presence of numerous federally listed native fish. On the Department' Heart Bar Wildlife Management Area nonnative fish are actively suppressed but other factors, like drought, wildfire, and flood, appear to be substantially stronger ecological drivers of both native and nonnative fish populations. Broadscale suppression of Smallmouth Bass and catfish across the Gila and San Francisco rivers would be cost prohibitive and unlikely to achieve significant results for native fish while also alienating anglers. The Department may consider site specific, partner-led native fish conservation projects that include non-native fish suppression on a case-by-case basis.

	Comment 3.6 Is there adequate information to understand the demand for angling for non-native species in those streams to support Trophy designation?	During the development of the 2016 Plan there was significant public interest to develop a Trophy Bass Water for Smallmouth Bass in the Gila River drainage. The Department has not pursued this management nor changed regulations for these river reaches. There continues to be significant interest for fishing opportunities in these river reaches. The Department will maintain regulations and management approaches to support angling opportunity for Smallmouth Bass in these reaches. The tables have been updated in the Plan Update.
	Comment 3.7 Would there be any support to manage for Roundtail Chub and potentially support limited angling opportunities for that species instead of the non-native sportfish.	See response to Comment 3.2
	Comment 3.8 The Forest Service is also supportive of efforts to reintroduce chub into portions of the San Francisco River drainage to support recovery of that species.	Comment noted
	Comment 3.9 The Forest Service is supportive of efforts to improve fisheries habitat in the reservoirs managed by the Department on the Gila National Forest.	Comment noted
	Comment 3.10 Snow Lake and Lake Roberts would benefit from major restoration projects that might include dredging.	Comment noted
	Comment 3.11 The Forest Service is looking forward to partnering with the Department and other partners on upcoming projects to improve Gila Trout habitat in Willow Creek, Whitewater Creek, and Black Canyon.	Comment noted
Trout Unlimited	Comment 4.1 Identify primary threats to statewide fisheries and aquatic habitat. We ask that you include a new section highlighting and briefly describing specific threats to fisheries and aquatic habitat that apply across the state. We are asking for an acknowledgement of the major threats and a brief description of their current and potential impact on fisheries, but we do not expect you to do this specific to individual watersheds or species. Specifically, we ask that you mention climate change, issues related to surface water availability and management, and water quality impairments including temperature.	See response to Comment 1.2

	Where appropriate, inclusion of strategies that Game and Fish can use to address these threats would also be appreciated.	
	Comment 4.2 Account for climate change in fisheries management. The final plan should acknowledge the impacts of a changing climate on native fish conservation and sportfishing opportunities, and the revenue it generates.	See response to Comment 1.2
	Comment 4.3 Address issues related to water management and surface water availability. We believe there is an appetite to see the Department more engaged in water planning processes occurring around the state (e.g., Rio Grande Basin Study, 50-year State Water Plan) and advocating for trout and fisheries in the context of water management discussions. We ask that you mention the importance of maintaining and restoring adequate water levels in New Mexico's streams and reservoirs to benefit native fish conservation and sportfishing opportunities. We are not asking for bold new actions at this time, but we do ask that our state's Fisheries Management Plan both acknowledge this reality and consider how the Department may respond.	The Department recognizes the importance of water availability and quality for fisheries conservation and angling. We routinely engage and share information with state and federal water management entities including the Office of the State Engineer/Interstate Stream Commission, New Mexico Environment Department, Bureau of Reclamation, and US Army Corps of Engineers. We intend to continue this engagement to the extent practical while acknowledging the Department holds no direct jurisdiction over surface or ground water availability or quality.
	Comment 4.4 Identify concrete steps for transitioning fisheries management toward wild and native trout. We encourage the Department to identify concrete steps for managing more fisheries for native and wild trout populations while reducing reliance on hatchery-raised trout. Please elaborate on strategies that could move that state in the direction of sustainable wild trout fisheries and a reduced reliance on hatcheries in the future.	The subject of this comment is in the investigation phase. Addition of concrete steps or strategies at this time would be premature. The Department intends to work with partner agencies, NGO's, and the public to identify potential locations for experimental implementation in the future. Parameters for wild trout populations can be found on page 28 of the Plan Update.
	Comment 4.5 Identify action items related to increased enforcement of existing fishing regulations. Please include an action item(s) specific to the issue of enforcement within the plan, and consider mentioning enforcement challenges as a specific threat to fisheries if you feel it is warranted.	The Department recognizes law enforcement as a cornerstone to fisheries management, however, enforcement is outside the scope and purview of the Plan Update. The enforcement of existing wildlife, fish, and other state and federal statutes and rules is covered within the Department's Strategic Plan. We would encourage the commentors to report specific concerns regarding enforcement issues to the Department.

	Comment 4.6 Fisheries management needs to account for increased angling pressure and recreational impacts. We'd like to better understand Department's plan for managing wild and native fisheries in the face of increased angling pressure, including how this is being monitored on certain stream segments (i.e., not just relying statewide trends).	Tracking angler use on every water in New Mexico would be cost prohibitive. We currently use several tools to monitor changes in angler use including our biannual angler use and harvest survey. These tools detect broad-scale changes in angler use but are limited in their ability to detect change at the reach level. To address this limitation we occasionally implement on-the-ground creel surveys or ask water specific questions in email surveys. As the Department investigates areas where we could reduce use of hatchery fish in favor of wild trout we foresee implementation of direct angler surveys of those locations. We encourage the commentors to communicate specific areas of concern to the Department.
	Comment 4.7 Consider providing a brief, one paragraph description that includes the location, management objectives, and rearing capacity for each of New Mexico's fish hatcheries. While some of these details are provided, a succinct paragraph for each would more clearly distinguish each hatchery, its specific contribution to native fish and sportfish, as well as how those hatcheries can or will be utilized to achieve the objectives described in this plan.	This comment has been addressed by the addition of information on pages 8-9.
	Comment 4.8 Consistent with our overarching native and wild trout focus, Trout Unlimited applauds the Department's use of hatcheries to rear Gila trout and Rio Grande cutthroat trout for conservation and recreational angling purposes. We support and encourage more hatchery resources towards these ends, and specifically would like to see more recreational native fisheries supported by the state's hatcheries.	Comment noted
	Comment 4.9 Consider other metrics in the future (in addition to populations) to assess fishery health more comprehensively, such as age class and fish biomass, and metrics relevant to carrying capacity.	Comment noted
	Comment 4.10 Regarding divisional priority 6, we would appreciate seeing specific resource concerns addressed in this management plan through actions associated with changing conditions. For example: "In response to increasing stream temperatures, DGF may do the following....".	See response to Comment 1.2

	Comment 4.11 We appreciate the discussion on funding and funding sources. This section would benefit from the inclusion of dollar values for the various programs and funding sources. It may also be beneficial to list the annual revenue derived from angling license sales and matching federal funds.	The Division's total budget for Fiscal Year 2021 was $8.8 million. This information was added to the caption for Figure 5 of page 18. Revenue generated from fishing license sales is difficult to accurately estimate because many resident license buyers purchase combination annual Game-hunting & Fishing licenses.
	Comment 4.12 Statewide, funding from outside partners is utilized towards mutually beneficial projects that promote many of the goals and objects listed in the fisheries management plan. We suggest an attempt at quantifying the resources provided by outside sources which go to benefit the state's fisheries.	The Department recognizes and appreciates the significant direct and indirect contributions of our many partners toward the conservation of fish and their habitats across the state. Quantifying the dollar value of those contributions, while a laudable goal, would be extremely challenging and is beyond the scope of the Plan Update. A statement recognizing these contributions was added to the Funding section on page 18.
	Comment 4.13 The plan references New Mexico's *quality and trophy trout waters.* We are interested in seeing a list of these waters if one exists. Please also consider including a list in the plan.	Currently, the San Juan River tailwater reach is the only designated Trophy Trout Water. Since the original Plan's publication several waters have been identified that meet or likely could be improved to meet the Quality Trout Water parameter, including the Cimarron River, Pecos River, Red River, Rio de los Pinos, Rio Chama, Rio Costilla, Rio Guadalupe, Rio Grande gorge, and San Antonio Creek. The Plan Update didn't specifically mention these as Quality Trout Waters and the tables have been updated to reflect this designation for specific river reaches.
	Comment 4.14 We applaud DGF's fish habitat improvement efforts on 14.5 stream miles of trout water. While this may not seem like much, we understand the logistical, funding, and implementation challenges involved, and we are prepared to provide support for your efforts to upscale restoration work in the coming years.	Comment noted
	Comment 4.15 A worthwhile goal would be to increase the pace and scale of restoration over the next five years of the plan. You might also describe barriers to increasing restoration efforts somewhere in the plan so the challenges are clearly stated and can be tackled in partnership with stakeholders. These barriers are becoming more apparent considering recent increases to state and federal funding.	The intent of this comment is unclear. Increasing the pace of restoration efforts would require additional human resources, funding, and budget which are all issues outside of the scope of this Plan Update.

	Comment 4.16 We commend the Department for its research efforts regarding YY technology to reduce non-native impacts to native trout.	Comment noted
	Comment 4.17 Regarding native trout restoration, we suggest including a statement that the Department will remain vigilant and flexible regarding spontaneous opportunities to enhance and restore native trout, per relevant documents such as the RGCT Conservation Strategy and the Gila Trout Recovery Plan.	Comment addressed on page 34 of the plan
	Comment 4.18 In Appendix B, regarding the objective to stock surplus native trout in waterbodies to improve angling opportunities for native trout, please consider listing the 10 waterbodies where this has occurred, as well as the additional waters you reference, unless there is a good reason not to. We support this goal carrying over to the new plan and suggest that it could be improved by a metric by which you measure success.	The 10 waterbodies have been added to Appendix B along with the additional waters stocked with surplus Rio Grande Cutthroat Trout. The Plan Update has a parameter for measuring success of stocking Rio Grande Cutthroat Trout for recreational purposes page 28
	Comment 4.19 The plan carries over an objective to "*Investigate potential for reducing or eliminating stocking of catchable trout from some river systems which support wild trout and reallocate to higher use systems*." We strongly support this objective, but suggest modifying it to include a metric of success – set a goal of *identifying a minimum number of river systems and/or specific stream segments where this could occur*. Trout Unlimited is committed to helping DGF achieve this priority.	See response to comment 4.4
	Comment 4.20 As written, the plan includes a priority to stock native trout, surplus to recovery efforts, for angling opportunities. Consider a complementary objective where DGF will identify how to increase rearing capacity of native fish specifically for recreational stocking, not just utilizing fish surplus to recovery efforts. This could include an investigation of put and take fisheries that will transition to native trout in the future, or better yet, identifying such streams.	A priority has been added on page 34 to address this comment
	Comment 4.21 We appreciate the Department's intention to work with partners to achieve restoration objectives. In addition to the priorities laid out, we ask that you also work with partners to develop shared priorities to identify and plan future habitat restoration projects,	Comment noted

	and to work with partners to leverage additional funding and resources for fisheries focused projects.	
	Comment 4.22 Aside from geomorphic habitat considerations, water quantity and quality should be habitat metrics. Regarding habitat restoration, we encourage the Department to investigate opportunities to improve water quantity and quality for the betterment of New Mexico's fisheries.	Water quality impairments are outside of the Department's jurisdiction, however, many of the Department's fish habitat improvement projects are founded in approaches to reduce stream temperatures, improve sediment transportation, increase riparian vegetation/shading, and reduce unstable stream banks.
	Comment 4.23 Identify priority areas for targeted mechanical suppression of non-native trout that currently threaten populations of Rio Grande cutthroat and Gila trout. We believe, based on evidence, that mechanical removal can benefit native trout populations and we encourage more of this tactic, especially in partnership with groups like Trout Unlimited.	Suppression of non-native species is identified in the plan with the management type "Suppression". Additional specific management actions are identified in conservation planning documents for Gila and Rio Grande Cutthroat trout.
	Comment 4.24 We suggest investigating the use of electronic fish barriers in addition to the traditional constructed barriers.	Electric fish barriers have been repeatedly considered by the Department for use in native fish conservation projects, however, concerns over logistic constrains, reliability, and safety have precluded their use to date.
	Comment 4.25 We encourage the Department to investigate tools and strategies that can be utilized to maintain or enhance stream flows in priority streams. This should include an assessment of existing authorities under which Game and Fish could lease or acquire water to benefit native fish conservation and sportfishing opportunities.	Comment noted
	Comment 4.26 Explore opportunities to work with water managers to enhance reservoir and river management procedures to benefit or minimize impacts to fish and aquatic habitat.	Department staff continually work with water managers to make recommendations on reservoir and river management procedures to benefit fish populations.
	Comment 4.27 Explore how Game and Fish can help address water quality impairments, including temperature impairments, in priority streams in the coming years.	See response to comment 4.22
	Comment 4.28 We appreciate the priority to work with NGOs on conservation projects with direct volunteer involvement. As mentioned elsewhere, it would also be helpful to identify statewide barriers to increasing	See response to comment 4.15

	the pace and scale of restoration projects by state agencies and partner organizations.	
	Comment 4.29 We suggest a general statement pertaining to stream access acknowledging that the Department is prepared to monitor impacts to fisheries for rivers and streams running through private land that may become publicly accessible pending the written opinion by the State Supreme Court. While this is a controversial issue, many are looking to the Department to ensure the health of our fisheries under any legal scenario.	The Department's 2022-23 Fishing Rules and Information Booklet states "In March 2022, the New Mexico Supreme Court ruled that the Landowner Certification of Non-Navigable Water Rule (19.31.22 NMAC) was unconstitutional. By means of this Court order, all watercourses in the state, that can be legally accessed, are open for public recreational use. Public recreationists are reminded that private property damage remains illegal." The Department is awaiting issuance of the Supreme Court's written opinion in the case in order to formulate future management approaches. We encourage the commentors to identify specific areas of concern and communicate them with the Department.
	Comment 4.30 Consider changing regulations for Xmas Chile Special Trout Waters to include tackle restrictions to lessen harm to fish that are not kept. With a two trout bag limit, the expectation is many smaller fish are being caught and released, so changing tackle restrictions could reduce fish mortality. Because there is already a reduced bag limit, tackle should be managed to cause less harm to fish, thereby improving the overall health of the fishery.	The Xmas Chile Water designation offers additional protection, with a reduce bag limit, while still allowing the use of all legal fishing tackle to avoid alienating any angling group.
	Comment 4.31 We suggest the Department address any necessary barrier issues on Jack's Creek as soon as possible.	Comment noted
	Comment 4.32 We suggest the Department consider genetic sampling in Pecos Wilderness lakes where RGCT purity may be uncertain. For example, Trampas Lakes are reputed to be RGCT fisheries but are inhabited by Snake River cutthroats as well.	Comment noted. The Department began stocking these lakes with Rio Grande Cutthroat Trout to continue recreational angling opportunities yet also align with wilderness values desired by the Forest Service. We do not consider the populations within wilderness lakes as Conservation Populations.
	Comment 4.33 We suggest brown trout suppression action on Rio Chiquito above Borrego Crossing.	Comment noted
	Comment 4.34 To improve the quality of fishing and move toward managing for wild trout, investigate designating the Rio Grande from Taos Junction Bridge to Velarde as special trout water – Xmas Chile.	Proposing and adopting new Special Trout Waters is an independent process from the Plan Update. Currently, the Department isn't considering adding or removing any waters from Special Trout Water designation. We encourage anglers to engage the Department during the next four-year Fisheries Rule review with suggestions on regulation changes.

	Comment 4.35 Investigate upgrading the Special Trout Water designation on the Chama River below Abiquiu Dam for approximately two miles. This stretch of river has experienced significant increases in fishing pressure in recent years, yet regulations remain unchanged. Modifying regulations to reduce the bag limit and restrict bait fishing could improve fishing given the increased angling pressure.	This reach of the Chama River is currently designated as Xmas Chile Water. This designation already offers a reduced bag limit of two trout per day. "Upgrading" the designation would make this reach catch-and-release only. The trout fishery in this reach is primarily supported by a Put and Take Rainbow Trout stocking strategy. The current regulation ensures equitable distribution of stocked fish without alienating any angling group. Also, similar to response to comment 4.34, proposing and adopting Fishing Rule changes is an independent process from the Plan Update.
	Comment 4.36 We share previously expressed concerns over allowing take on portions of Whitewater and Mineral Creeks where Gila trout recovery is still underway. Please investigate changing regulations to limit take where appropriate until recovery populations are secured.	See response to comment 1.8
	Comment 4.37 We are concerned for the negative impacts of drought, temperature, and management strategies on native trout, and recognize that changes in angling regulations or short-term stream closures may be necessary responses when monitoring reveals decreasing populations. We would appreciate a better understanding of how Gila trout populations are being monitored, and how the results of monitoring inform management decisions and regulations.	See response to comment 1.4
	Comment 4.38 We suggest a statement that the Department is prepared monitor conditions and to develop a management strategy for the San Juan River below the town of Navajo Dam to the downstream bridge on Highway 64, which is a quality wild trout fishery running through private land that may become publicly accessible pending legal opinions.	The Department monitors trout populations throughout the San Juan tailwater reach, including downstream of the town of Navajo Dam. Our monitoring allows the Department to detect any significant impacts or changes and make necessary management changes.

STATE OF NEW MEXICO
BEFORE THE WATER QUALITY CONTROL COMMISSION



IN THE MATTER OF PETITION TO AMEND USE FOR LOWER DRY CIMARRON RIVER AND TO ESTABLISH WATER QUALITY STANDARDS FOR LAKES, 20.6.4 NMAC

WQCC 11-05 (R)

ORDER AND STATEMENT OF REASONS

This matter comes before the New Mexico Water Quality Control Commission ("WQCC") upon a petition filed by the New Mexico Environment Department ("NMED") proposing amendments to the State of New Mexico's Standards for Interstate and Intrastate Surface Waters ("Standards"), which are codified as Title 20, Chapter 6, Part 4 of the New Mexico Administrative Code (20.6.4 NMAC). A public hearing was held in Santa Fe, New Mexico on April 10, 2012. The WQCC heard technical testimony from NMED; no other party entered an appearance in this matter. Public comments were heard from one other interested party, a rancher who voiced concerns over water quantity on the Dry Cimarron. On April 10, 2012, the Commission, having familiarized itself with the record and heard technical testimony from NMED's witnesses, deliberated and decided to grant NMED's petition to amend the Standards by an affirmative vote of 13 to 0 for the reasons that follow:

PROCEDURAL HISTORY

1. A public meeting was held in Folsom, New Mexico on August 12, 2010 to discuss the portion of the petition related to the lower Dry Cimarron River. Bearzi at 9; NMED Exhibit 10.

2. A public meeting was held in Roswell, New Mexico on August 30, 2011, to discuss the portion of the petition related to establishing water quality standards for 62 lakes in the Rio Grande, Pecos, Canadian, Gila, San Juan and Little Colorado river basins. NMED Exhibit 12.

3. A public meeting was held in Santa Fe, New Mexico on August 24, 2011, to discuss the portion of the petition related to establishing water quality standards for 62 lakes in the Rio Grande, Pecos, Canadian, Gila, San Juan and Little Colorado river basins. NMED Exhibit 14.

4. Notice of the public meetings in Santa Fe and Roswell was sent to the New Mexico Environment Department's Surface Water Quality Bureau's (SWQB) e-mail distribution list, posted on the SWQB's website and distributed to media outlets via press releases. NMED Exhibit 12.

5. On August 10, 2011, NMED released a discussion draft of the proposal and opened a 30-day comment period. Bearzi at 10; NMED Exhibit 11.

6. On September 26, 2011, NMED filed its Petition to with the WQCC.

7. On November 16, 2011, the WQCC granted NMED's request for a hearing and appointed Ms. Felicia Orth as Hearing Officer in this proceeding.

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8. Public notice of the hearing was published in the New Mexico Register, the Albuquerque Journal (a newspaper of general circulation in the state) and in six newspapers of general circulation located in areas affected by NMED's proposal. NMED Exhibit 16. Notice of the hearing was also sent to the WQCC's mailing list and the SWQB's mailing list. Notice was also published on the SWQB's website.

9. On Marcy 14, 2012, NMED provided a copy of the proposed amendments to the Small Business Regulatory Advisory Commission.

10. On April 10, 2012, a public hearing on NMED's Petition was held in Santa Fe, New Mexico. The WQCC heard technical testimony from NMED; no other party entered an appearance in this matter.

11. On April 10, 2012, the WQCC, having familiarized itself with the record and heard technical testimony from NMED's witnesses, deliberated and decided to grant NMED's Petition by an affirmative vote of 13 to 0.

LEGAL AUTHORITY

1. Under the New Mexico Water Quality Act ("WQA"), any person (including NMED) may at any time petition the Commission to adopt, amend or repeal a water quality standard. NMSA 1978, § 74-6-6.B. Water quality standards must be based on "credible scientific data and other evidence [and] shall include narrative standards and as appropriate, the designated uses of the waters and the water quality criteria necessary to protect such uses." NMSA 1978, § 74-6-4.D. "The standards shall at a minimum protect the public health or welfare, enhance the quality of water and serve the purposes of the Water Quality Act." *Id.*

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2. "In making standards, the commission shall give weight it deems appropriate to all facts and circumstances, including the use and value of the water for water supplies, propagation of fish and wildlife, recreational purposes and agricultural, industrial and other purposes." *Id.*

3. Federal Clean Water Act regulations provide similar direction: "States adopt water quality standards to protect public health or welfare, enhance the quality of water and serve the purposes of the Clean Water Act." 40 CFR § 131.2. Serving the purposes of the CWA means that "water quality standards should, wherever attainable, provide water quality for the protection and propagation of fish, shellfish and wildlife, recreation in and on the water, and agricultural, industrial, and other purposes including navigation." *Id.* A water quality standard "defines the goals for a water body, or portion thereof, by designating the use or uses to be made of the water and by setting criteria necessary to protect the uses." *Id.*

4. Water quality standards also establish water quality criteria that will protect the designated uses of a water body. These criteria must be based on robust scientific rationale and must contain sufficient parameters or constituents to protect the designated use. 40 CFR § 131.11(a).

5. Federal law requires that designated uses reflect the uses actually being attained. 40 CFR § 131.10(i). New Mexico and federal law prohibit the removal of designated uses if they are "existing uses." 20.6.4.15.A(2) NMAC; 40 CFR § 131.10(h). An existing use is "a use actually attained in a surface water of the state on or after November 28, 1975, whether or not it is a designated use." 20.6.4.7.E(3) NMAC. New Mexico's Water Quality Standards also mandate protection of existing uses.

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The general and use-specific criteria apply to existing uses [20.6.4.13 20.6.4.900 NMAC] and the anti-degradation policy requires that the level of water quality necessary to protect existing uses must be maintained. 20.6.4.8.A(1) NMAC.

6. New Mexico's Water Quality Standards and federal regulation prohibit the removal of a designated use that is a CWA Section 101(a)(2) use unless a "Use Attainability Analysis" demonstrates that attaining the use is not feasible. 20.6.4.15.A(1) NMAC; 40 CFR § 131.10(j). Section 101(a)(2) of the Clean Water Act establishes as a national goal the achievement of a level of water quality that "provides for the protection and propagation of fish, shellfish and wildlife, and provides for recreation in and on the water." The corresponding designated uses in New Mexico are the primary contact use, the wildlife habitat use, and all aquatic life use subcategories except the limited aquatic life use. 20.6.4.7.P(5) NMAC (primary contact); 20.6.4.7.W(5) NMAC (wildlife habitat); 20.6.4.7.A(6) NMAC (aquatic life); 20.6.4.7.L(2) NMAC (limited aquatic life).

7. Federal law requires that water quality criteria must be sufficient to support the designated use. "Such criteria must be based on sound scientific rationale and must contain sufficient parameters or constituents to protect the designated use." 40 CFR § 131.11(a).

SUMMARY OF PROPOSED AMENDMENTS

I. Lower Dry Cimarron Proposal

NMED proposes changing the designated aquatic life use for the lower Dry Cimarron River, which is listed in the Water Quality Standards as 20.6.4.702 or Segment 702, from

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coldwater aquatic life with a segment-specific maximum temperature criterion of 25°C (77°F) to coolwater. The coolwater aquatic life use has a 29°C (84°F) maximum temperature criterion. The lower Dry Cimarron River is located in Union County in northeastern New Mexico.

II. Lakes Proposal

NMED proposes to create new classified segments in the Water Quality Standards, exclusively for lakes. The proposed amendments create 19 new classified segments for 62 lakes that are currently either classified with streams or are unclassified. Each proposed segment contains one or more lakes. The proposal includes classifying for the first time many of the unique natural lakes of New Mexico. Small and large reservoirs, high-elevation natural lakes, and natural sinkhole lakes are represented in the proposal.

The lakes are located throughout the state in 6 different basins: the Rio Grande, Pecos, Canadian, Gila, San Juan and Little Colorado river basins.

STATEMENT OF REASONS

The WQCC hereby makes the following findings:

I. Lower Dry Cimarron Proposal

For the reasons set forth more fully below, the WQCC finds that NMED's proposal to change the designated aquatic life use for the lower Dry Cimarron River from coldwater aquatic life with a segment-specific maximum temperature criterion of 25°C (77°F) to coolwater aquatic life with a 29°C (84°F) maximum temperature criterion is well-taken and should be granted.

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A. Description of the portion of the lower Dry Cimarron River subject to this proposal

The portion of the lower Dry Cimarron River at issue in this proposal is located in Union County in northeastern New Mexico. NMED Ex. 20. The segment is referred to in the Standards for Interstate and Intrastate Surface Waters ("Standards") as 20.6.4.702 NMAC, or Segment 702. It is described as: "Perennial portions of the Dry Cimarron river below Oak creek, and perennial portions of Long canyon and Carrizozo creeks. Total length for the Dry Cimarron River below Oak Creek, Long Canyon and Carrizozo Creeks is approximately 130 miles. The streams flow from an elevation of 6,000 feet at the Dry Cimarron and Oak Creek confluence to 4,300 feet at the eastern New Mexico border. They are located in the Southwestern Tablelands Ecoregion, which stretches from Kansas and eastern Colorado to southeastern New Mexico and western Texas. For the ecoregion, the land cover is mostly woodland and grassland; maximum July daily mean temperatures are in the middle to upper 30°C (80°F) range. NMED Ex. 18.

B. NMED's UAA demonstrates the coldwater aquatic life designation for the lower Dry Cimarron River is not appropriate because it is not an existing use, nor is it an attainable use.

In order to change a designated use or use subcategory to one with less stringent criteria, both the New Mexico and federal regulations require the change to be supported by a use attainability analysis ("UAA"). 20.6.4.15.A(1) NMAC; 40 CFR § 131.10(j). SWQB's UAA for Segment 702 is attached as NMED Ex. 26.

The UAA concludes that coolwater is the highest attainable aquatic life use, and that attainment of the coldwater aquatic life use is not feasible because of the first factor listed in 40 CFR § 131.10(g): Naturally occurring pollutant concentrations prevent the

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attainment of the use. The pollutant is heat resulting from naturally occurring ambient air temperatures.

In reaching this conclusion, the UAA considered the following factors: (1) the native fish – both historically and presently – are warmwater and coolwater species; (2) the air-water temperature correlation for the lower Dry Cimarron watershed indicated that average July air temperatures result in attainable maximum stream temperatures in the range of 28 to 30°C, consistent with the coolwater aquatic life temperature criterion of 29°C (84°F), but significantly higher than the currently applicable criterion of 25°C (77°F); and, (3) modeling of stream shading and width-to-depth ratio and flow, which demonstrated that site-specific conditions could not be improved to attain the designated coldwater use and that such as use was therefore not attainable. In addition, UAA makes shows that the coldwater use is not an existing use because neither the existing nor the native fish are coldwater species, and the coldwater use is not attainable due to natural conditions.

Because the coldwater aquatic life designation for the lower Dry Cimarron River is not an existing use, nor is it an attainable use, the WQCC therefore grants NMED's proposal to change the designated aquatic life use for the lower Dry Cimarron River from coldwater aquatic life with a segment-specific maximum temperature criterion of 25°C (77°F) to coolwater aquatic life with a 29°C (84°F) maximum temperature criterion.

II. Lakes Proposal

For the reasons set forth more fully below, the WQCC finds NMED's proposal to create new classified segments in the Water Quality Standards, exclusively for lakes, is well-taken and should be granted.

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A. Lake-specific water quality standards, as opposed to grouping lakes and streams together, are appropriate in light of the unique hydrological characteristics of lakes

Water quality standards apply to all surface waters of the state, including lakes and reservoirs. However, compared to rivers and streams, relatively few lakes - only 28 - are currently identified by name as classified waters in 20.6.4.101-899 NMAC. Instead, many lakes are included in broad geographic groups, such as "all perennial tributaries to the Rio Grande in Santa Fe County," while others are included in the description of a stream system. Still other lakes are covered only as "unclassified perennial waters" in 20.6.4.99 NMAC. The WQCC finds the inclusion of lakes in these groupings occurred without consideration of the characteristics of lakes in general or of specific lakes in particular. Accordingly, in light of the different hydrological characteristics of lakes and streams, the WQCC will grant NMED's proposal to create new classified segments in the Water Quality Standards exclusively for lakes.

NMED proposes to create three new segments exclusively for 36 high-elevation natural lakes: segment 133 for 23 lakes in the Rio Grande Basin, segment 222 for 8 lakes in the Pecos River Basin, and segment 313 for 5 lakes in the Canadian River Basin. All these lakes have similar ecological and physical characteristics. All are contained within Ecoregion 21, the Southern Rockies of the Xeric West. NMED Ex. 28. The lakes are located in the Sangre de Cristo mountains of northern New Mexico, and most are situated above 11,000 feet in elevation. *Id.* They are relatively small; the largest, Lake Katherine, is less than 12 acres in size. *Id.* The lakes are open to the public and most are accessible only on foot or horseback, and are minimally impacted by human activities. *Id.* Some of the lakes are in congressionally designated wilderness areas and have been designated as

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Outstanding National Resource Waters ("ONRWs") by the Commission pursuant to 20.6.4.9 NMAC.

B. Lakes in the Rio Grande Basin

NMED proposes to create a new segment, "Segment 133," exclusively for 23 high elevation natural lakes in the Rio Grande Basin. The lakes are listed in Table 1 (below):

Table 1. Lakes in proposed segment 133

LAKE NAME	CURRENT WQS*	ELEVATION feet	SIZE acres
Bull Creek Lake	99	11460	0.8
Cow Lake	99	11290	0.6
Elk Lake	99	11835	0.7
Goose Lake	123	11640	6.0
Heart Lake	123	11490	4.3
Hidden Lake (Lake Hazel)	123	11280	3.6
Horseshoe Lake	123	11920	6.9
Horseshoe Lake (Alamitos)	123	11760	7.9
Jose Vigil Lake	121	11720	1.9
Lost Lake	99	11495	8.4
Middle Fork Lake	123	11500	8.3
Nambe Lake	121	11380	1.6
Nat Lake II	99	11500	0.7
Nat Lake IV	99	11700	0.6
No Fish Lake	123	11424	1.0
Pioneer Lake	123	11260	1.1
San Leonardo Lake	123	11340	3.5
Santa Fe Lake	121	11620	4.9
Serpent Lake	99	11740	1.0
South Fork Lake	123	11115	0.6
Trampas Lake (east)	123	11255	2.6
Trampas Lake (west)	123	11335	2.7
Williams Lake	123	11220	7.9

* "CURRENT WQS" refers to the currently applicable section of the water quality standards at 20.6.4.97-899 NMAC.

NMED proposes to adopt the same designated uses and criteria for all of the lakes in Segment 133. The proposed uses are high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, except for the following

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segment-specific criteria: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less. The primary contact, livestock watering and wildlife habitat uses already apply to all 23 lakes. The high quality coldwater aquatic life, irrigation and domestic water supply uses; and the protective *E. coli* criteria, already apply to most of the lakes. The proposed specific conductance criterion already applies to six of the lakes.

In light of the similar ecological and physical characteristics of these lakes, the WQCC agrees with NMED's proposal to adopt the same designated uses and criteria for these similar lakes.

NMED proposes to create a new segment, "Segment 134," to contain nine small reservoirs in the Rio Grande basin. These reservoirs are currently classified, but not specifically named, in segment 108 (San Gregorio lake), segment 115 (Hopewell Lake), segment 119 (Canjilon lakes a, c, e and f) and segment 123 (Fawn Lakes). NMED proposes amendments to segments 108, 115 and 119 to exclude these reservoirs. Segment 123 does not need to be amended, because the segment description specifically excludes waters "included in other segments." The reservoirs are listed in Table 2 (below):

Table 2. Reservoirs in proposed segment 134

LAKE NAME	CURRENT WQS	ELEVATION feet	LAKE SIZE acres
Cabresto Lake	123	9340	15.7
Canjilon Lake a	119	10100	5.9
Canjilon Lake c	119	9800	3.0
Canjilon Lake e	119	9800	4.1
Canjilon Lake f	119	9780	2.3
Fawn Lake (east)	123	9000	1.3
Fawn Lake (west)	123	9000	0.8
Hopewell Lake	115	9765	16.1
San Gregorio Lake	108	9410	35.7

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All nine reservoirs are contained within Ecoregion 21, the Southern Rockies of the Xeric West. NMED Ex. 28. They are located in the Jemez and Sangre de Cristo mountains and are situated at or above 9000 feet in elevation. *Id.* The lakes are in the Carson National Forest and open to the public for recreation. *Id.* San Gregorio Lake, the largest lake in the proposed segment, is a designated ONRW pursuant to 20.6.4.9 NMAC.

NMED proposes retaining the high quality coldwater aquatic life use. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, except for the following segment-specific criteria: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less. NMED proposes retaining domestic water supply, irrigation, primary contact, livestock watering and wildlife habitat as designated uses. These uses already apply to all nine reservoirs. Fish culture is not a proposed designated use for segment 134.

In light of the similar ecological and physical characteristics of these lakes, the WQCC agrees with NMED's proposal to adopt the same designated uses and criteria for these similar lakes.

NMED proposes to create a new segment, "Segment 135," to contain Bluewater Lake. The lake is currently classified, but not specifically named, under segment 109. NMED proposes an amendment to segment 109 to exclude this lake. Bluewater Lake is a 610 acre reservoir located at an elevation of 7375 feet in Bluewater Lake State Park. NMED Ex. 28. It was created as an irrigation water supply, and the state park is a popular site for camping, fishing, boating and water skiing. *Id.*

NMED proposes retaining all designated uses currently applicable to segment 109, with the exception of fish culture. These uses are coldwater aquatic life, irrigation,

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domestic water supply, primary contact, livestock watering and wildlife habitat. There is no fish culture on Bluewater Lake to support this designated use. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, except for the following segment-specific criteria: phosphorus 0.1 mg/L or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less. The proposed phosphorus and *E. coli* criteria already apply under segment 109.

In light of Bluewater Lake's designated uses, the WQCC agrees with NMED's proposal to create a new segment with the above designated uses and criteria for Bluewater Lake.

C. Lakes in the Pecos River Basin

NMED proposes to create a new segment, "Segment 222," to include eight hig-elevation natural lakes in the Pecos River Basin. Lake Katherine is the largest at nearly 12 acres, and all are situated above 10,000 feet in elevation. NMED Ex. 28. They are currently either unclassified under section 99 or classified with other perennial waters in segment 217. The lakes are listed in Table 3 (below):

Table 3. Lakes in proposed segment 222

LAKE NAME	CURRENT WQS	ELEVATION feet	LAKE SIZE acres
Johnson Lake	217	11090	2.5
Lake Katherine	217	11742	11.8
Lost Bear Lake	99	11220	0.5
Pecos Baldy Lake	99	11480	5.6
Spirit Lake	99	10809	2.9
Stewart Lake	217	10232	4.2
Truchas Lake (north/upper)	99	11920	0.7
Truchas Lake (south/lower)	99	11870	2.6

The proposed designated uses and criteria are the same as those currently applicable to segment 217, with the exception of fish culture. These designated uses are coldwater aquatic life, domestic water supply, irrigation, primary contact, livestock

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watering and wildlife habitat. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, except for the following segment-specific criteria: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less. Fish culture is not an existing use on the lakes.

In light of the similar ecological and physical characteristics of these lakes, the WQCC agrees with NMED's proposal to adopt the same designated uses and criteria for these similar lakes.

NMED proposes to create a new segment, "Segment 223," to include Bonito Lake. The lake is currently classified, but not specifically named, in segment 209. NMED proposes an amendment to segment 209 to exclude Bonito Lake. The 39 acre lake is located on land owned by the city of Alamogordo and is adjacent to the Lincoln National Forest at 7377 feet in elevation. NMED Ex. 28. It was created by impounding the Rio Bonito. *Id.*

NMED proposes retaining the same designated uses as currently apply to segment 209. These designated uses are coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering, wildlife habitat and public water supply. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, except for the following segment-specific criteria: the specific conductance criterion of 1100 µS/cm; phosphorus 0.1 mg/L or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less to protect public health and the public water supply in accordance with 20.6.4.900.A NMAC.

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In light of the specific uses and physical characters of Bonito Lake, the WQCC agrees to NMED's proposal to adopt the above designated uses and numeric criteria for Bonito Lake.

NMED proposes to create a segment, "Segment 224," for Monastery Lake. The lake is currently an unclassified perennial water under section 99. It is located near the village of Pecos at 7040 feet in elevation. NMED Ex. 28.

NMED proposes changing the aquatic life use from warmwater to coolwater. Measured summer temperatures are consistent with the coolwater criterion of 29°C. The proposed designated uses are coolwater aquatic life, primary contact, livestock watering and wildlife habitat. Monastery Lake is managed as a put-and-take trout fishery. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, except for the following segment-specific criteria: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less. The lake is open to the public, but swimming, boating and camping are not allowed.

In light of the specific use of the lake, the WQCC agrees to NMED's proposal to adopt the above designated uses and criteria for Monastery Lake.

NMED proposes to create a new segment, "Segment 225," for the Santa Rosa Reservoir. The 1500 acre lake is located in Santa Rosa State Park at 4710 feet in elevation. NMED Ex. 28. The dam is used for flood control, irrigation storage and sediment control. *Id.* The State Park manages camping, fishing and boating at the lake. *Id.* The reservoir is currently classified, but not specifically named, in segment 211, a section of the Pecos River that was classified before the reservoir existed. NMED

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proposes an amendment to segment 211 to exclude the reservoir and designated uses better suited to lake conditions.

The proposed designated uses are coolwater aquatic life, irrigation, primary contact, livestock watering and wildlife habitat. NMED proposes changing aquatic life use from marginal warmwater to coolwater, because summer temperatures are consistent with the coolwater criterion of 29°C. There is no fish hatchery to support fish culture as a designated use. NMED also proposes eliminating the flow-quality salinity criteria because they do not apply to lake conditions. The proposed numeric criteria are set forth in 20.6.4.900 NMAC.

In light of the need for designated uses and criteria better suited for lake conditions, the WQCC agrees with NMED's proposal to adopt the above designated uses and criteria for the Santa Rosa Reservoir.

NMED proposes to create a segment, "Segment 226," for Perch Lake. The lake is the first of four segments for natural sinkhole lakes. NMED Ex. 28. It is a 2.8 acre sinkhole lake at 4595 feet in elevation. *Id.* The lake is used for recreation, including swimming and scuba diving. *Id.* It is currently an unclassified water covered under section 99.

NMED proposes changing the aquatic life use from warmwater to coolwater. Measured summer temperatures are consistent with the coolwater criterion of 29°C. The proposed retained designated uses are primary contact, livestock watering and wildlife habitat. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, except for the following segment-specific criteria: the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less to protect public health.

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NMED proposes to create a segment, "Segment 227," for Lea Lake. The lake is also a sinkhole lake, located in Bottomless Lakes State Park at 3450 feet in elevation. NMED Ex. 28. Lea Lake is the only sinkhole lake in the state park where swimming is allowed. *Id.* It is currently an unclassified water covered under section 99.

NMED proposes to retain the following designated uses: warmwater aquatic life, primary contact and wildlife habitat. Salinity is too high to support a recreational fishery or livestock watering. NMED proposes to remove the livestock watering use. It is not an existing use because livestock are not allowed in the state park. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, except for the following segment-specific criteria: the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

NMED proposes to create a new segment, "Segment 228," for Cottonwood Lake and Devil's Inkwell. The lakes are two small sinkhole lakes in Bottomless Lakes State Park. NMED Ex. 28. Both are currently unclassified waters under section 99.

NMED proposes the coolwater aquatic life use because natural conditions allow recreational fishing and summer temperatures are consistent with the coolwater criterion of 29°C. Primary contact and wildlife habitat are also proposed designated uses. NMED also proposes removing the livestock watering use due to salinity and because livestock are not allowed in the state park. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, except for the following segment-specific criteria: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less. NMED proposes retaining the current *E. coli* primary contact criteria because swimming is not permitted in either lake.

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NMED proposes to create a new segment, "Segment 229," for Mirror Lake. The 3.4 acre lake is located in Bottomless Lakes State Park. NMED Ex. 28. Mirror Lake is currently an unclassified water covered under section 99.

NMED proposes retaining the warmwater aquatic life, primary contact and wildlife habitat designated uses. Summer temperatures are consistent with the warmwater criterion of 32.2°C. NMED proposes to remove the livestock watering use due to salinity and because livestock are not allowed in the state park. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, except for the following segment-specific criteria: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less. NMED proposes retaining the current *E. coli* primary contact criteria because swimming is not permitted in either lake.

In light of the ecological and physical characteristics of these sinkhole lakes, the WQCC agrees with NMED's proposal to adopt the above designated uses and criteria for these four sinkhole lakes.

D. <u>Lakes in the Canadian River Basin</u>

NMED proposes to create a new segment, "Segment 313," to include five high-elevation natural lakes in the Canadian River Basin. Two of the lakes are in the Pecos wilderness and are ONRWs pursuant to 20.6.4.9 NMAC. NMED Ex. 28. The lakes are currently either unclassified perennial waters covered under section 99 or classified with other perennial waters in segments 307 or 309. NMED proposes amendments to segments 307 and 309 to exclude the lakes in proposed segment 313. The lakes are listed in Table 4 (below):

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Table 4. Lakes in proposed segment 313

LAKE NAME	CURRENT WQS	ELEVATION feet	LAKE SIZE acres
Encantada Lake	99	10750	2.4
Maestas Lake	307	9951	3.0
Middle Fork Lake of Rio de la Casa	309	12000	1.5
North Fork Lake of Rio de la Casa	99	11810	2.0
Pacheco Lake	307	10865	5.0

NMED proposes retaining the designated uses from segment 309. The proposed designated uses are coldwater aquatic life, domestic water supply, irrigation, primary contact, livestock watering and wildlife habitat. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, except for the following segment-specific criteria: the specific conductance criterion of 300 µS/cm; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

In light of the ecological and physical characteristics of the waters as high elevation natural lakes, the WQCC agrees with NMED's proposal to adopt the same designated uses and criteria for the lakes.

NMED proposes creating a new segment, "Segment 314," including north and south Shuree Ponds. The lakes are located within Carson National Forest at 9330 feet in elevation and are ONRWs pursuant to 20.6.4.9 NMAC. NMED Ex. 28. These reservoirs are currently classified, but not specifically named, in segment 309. NMED proposes an amendment to segment 309 to specifically exclude north and south Shuree Ponds.

The proposed designated uses and specific criteria are the same as those currently applicable to segment 309. These uses are coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat. The temperature criterion for the high quality coldwater aquatic use is consistent with measured

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temperatures. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, except for the following segment-specific criteria: the specific conductance criterion of 500 µS/cm; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less to protect human health. The lakes are located on Forest Service land and are easily accessible to the public with two campgrounds located nearby.

In light of the above reasoning, the WQCC agrees with NMED's proposal to create a new segment for Shuree Ponds and adopt these designated uses and criteria.

NMED proposes to create a new segment, "Segment 315," for Eagle Nest Lake. The 1334 acre reservoir is located in Eagle Nest Lake State Park at 8200 feet in elevation. NMED Ex. 28. It supplies water to the Springer public water system. *Id.* Eagle Nest Lake is currently classified in segment 309 and specifically named as a public water supply. NMED proposes an amendment to segment 309 to exclude Eagle Nest Lake.

NMED proposes retaining the high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering, wildlife habitat and public water supply designated uses. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, except for the following segment-specific criteria: the specific conductance criterion of 500 µS/cm; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less to protect public health and the public water supply pursuant to 20.6.4.900.A NMAC. Eagle Nest Lake is a long-established fishery with resident coldwater species of trout and salmon. The proposed designated uses and specific criteria are the same as those currently applicable to segment 309.

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In light of the above reasoning, the WQCC agrees with NMED's proposal to create a new segment for Eagle Nest Lake and adopt these designated uses and criteria.

NMED proposes to create a new segment, "Segment 316," for Clayton Lake. The 148 acre lake is located in Clayton Lake State Park at 5200 feet in elevation. NMED Ex. 28. It was created as habitat for migratory waterfowl. *Id.* The National Audubon Society recognizes Clayton Lake as an Important Bird Area. *Id.* Clayton Lake is currently covered as an unclassified perennial water under section 99.

NMED proposes changing the aquatic life use from warmwater to coolwater. Measured summer water temperatures are consistent with the coolwater criterion of 29°C. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, except for the following segment-specific criteria: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less. NMED proposes retaining the *E. coli* criteria associated with low-frequency primary contact use, as more stringent criteria may not be attainable given the lake's importance as waterfowl habitat. In addition to the coolwater aquatic life use, NMED proposes retaining the primary contact, livestock watering and wildlife habitat designated uses.

In light of the lake's ecological and physical characteristics, the WQCC agrees with NMED's proposal to adopt these designated uses and criteria.

NMED proposes to create a new segment, "Segment 317," for Springer Lake. The 459 acre lake is located in northeastern New Mexico at 5900 feet in elevation. NMED Ex. 28. The lake was created to provide reliable water to farms and ranchers. *Id.* Springer Lake is currently covered as an unclassified perennial water under section 99.

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NMED proposes changing the aquatic life use from warmwater to coolwater. Springer Lake contains a number of fish species. Measured summer water temperatures are consistent with the coolwater criterion of 29°C. NMED also proposes adding the irrigation use, which is an existing use by the Antelope Valley and Springer Ditch associations. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, including the default *E. coli* criteria identified in section 900.D. Swimming is a common activity in Springer Lake. The proposed designated uses are coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

In light of the lake's ecological and physical characteristics, the WQCC agrees with NMED's proposal to adopt these designated uses and criteria.

E. Lakes in the San Juan River Basin

NMED proposes to create a new segment, "Segment 410," for Jackson Lake. The 60 acre lake is located in northwestern New Mexico at 5488 feet in elevation. NMED Ex. 28. Jackson Lake was first created for irrigation, and the State later purchased the land area and lake. *Id.* The lake is currently covered as an unclassified perennial water under section 99.

NMED proposes changing the aquatic life use from warmwater to coolwater. Measured summer water temperatures are consistent with the coolwater criterion of 29°C, and the lake is home to a number of fish species. The proposed numeric criteria are set forth in 20.6.4.900 NMAC, except for the following segment-specific criteria: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less. The designated purposes of the area are fishing and wildlife viewing.

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Camping and swimming are not allowed. The proposed designated uses are coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

In light of the lake's ecological characteristics, the WQCC agrees with NMED's proposal to adopt the above designated uses and criteria.

F. Lakes in the Little Colorado River Basin

NMED proposes to create a new segment, "Segment 453," for Quemado Lake. The 130 acre lake is located at 7630 feet in elevation. NMED Ex. 28. Recreational activities include camping, boating, picnicking and fishing. *Id.* It is currently covered as an unclassified perennial water under section 99.

NMED proposes changing the aquatic life use from warmwater to coolwater. Summer temperatures are consistent with the coolwater criterion of 29°C. The proposed designated uses are coolwater aquatic life, primary contact, livestock watering and wildlife habitat. NMED proposes increasing the protection for the primary contact use by applying the *E. coli* criteria identified in section 900.D. The proposed use-specific numeric criteria are set forth in 20.6.4.900 NMAC.

In light of the ecological characteristics of Quemado Lake, the WQCC agrees with NMED's proposal to adopt the above designated uses and criteria.

G. Lakes in the Gila River Basin

NMED proposes to create a new segment, "Segment 505," for Bill Evans Lakes. The 62 acre lake is located in southwestern New Mexico at 4800 feet in elevation. NMED Ex. 28. It was originally created to provide water for the Phelps Dodge Mining Company's Tyrone copper refining facility. *Id.* Water is pumped from the Gila River

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300 feet below. *Id.* The lake is currently covered as an unclassified perennial water under section 99.

NMED proposes changing the aquatic life use to coolwater. Measured water temperatures are consistent with the coolwater criterion of 29°C. The lake currently has a designated use of warmwater aquatic life, but was assessed as marginal coldwater aquatic life, based on the presence of seasonally stocked trout. However, the measured summer temperature slightly exceeds the marginal coldwater criterion. NMED proposes that coolwater aquatic life use is the appropriate existing use. The proposed numeric criteria are set forth in 20.6.4.900 NMAC. NMED proposes increasing the protection for the primary contact use by applying the *E. coli* criteria identified in section 900.D. Recreational activities include fishing, boating, camping and hiking.

In light of the lake's ecological characteristics, the WQCC agrees with NMED's proposal to adopt the above designated uses and criteria.

ORDER

By an affirmative vote of 13 to 0, the proposed amendments to the Standards were approved by the WQCC. Title 20, Chapter 6, Part 4 of the New Mexico Administrative Code (20.6.4 NMAC) are to be amended as indicated in Exhibit B, with any appropriate corrections of formatting or other changes necessary to file these regulations with the New Mexico State Records Center. The regulatory change as described in this Order is hereby adopted, to be effective 30 days after filing with the State Records Center.

Butch Tongate

Butch Tongate, Commission Chair

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This is an amendment to 20.6.4 NMAC, Sections 108, 109, 115, 119, 133-135, 209, 211, 217, 222-229, 307, 309, 313-317, 410, 453, 505 and 702, effective July 1, 2012.

20.6.4.108 RIO GRANDE BASIN - Perennial reaches of the Jemez river and all its tributaries above Soda dam near the town of Jemez Springs, except San Gregorio lake and Sulphur creek above its confluence with Redondo creek, and perennial reaches of the Guadalupe river and all its tributaries.

A. Designated Uses: domestic water supply, fish culture, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 400 µS/cm or less (800 µS/cm or less on Sulphur creek); the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less; and pH within the range of 2.0 to 8.8 on Sulphur creek.

[20.6.4.108 NMAC - Rp 20 NMAC 6.1.2106, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-01-12]

[**NOTE:** The segment covered by this section was divided effective 05-23-05. The standards for the additional segment are under 20.6.4.124 NMAC. The standards for San Gregorio lake are in 20.6.4.134 NMAC, effective 07-01-12]

20.6.4.109 RIO GRANDE BASIN - Perennial reaches of Bluewater creek excluding Bluewater lake and waters on tribal lands, Rio Moquino upstream of Laguna pueblo, Seboyeta creek, Rio Paguate upstream of Laguna pueblo, the Rio Puerco upstream of the northern boundary of Cuba, and all other perennial reaches of tributaries to the Rio Puerco, including the Rio San Jose in Cibola county from the USGS gaging station at Correo upstream to Horace springs excluding waters on tribal lands.

A. Designated Uses: coldwater aquatic life, domestic water supply, fish culture, irrigation, livestock watering, wildlife habitat and primary contact; and public water supply on La Jara creek.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: phosphorus (unfiltered sample) 0.1 mg/L or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.109 NMAC - Rp 20 NMAC 6.1.2107, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-01-12]

[**NOTE:** The standards for Bluewater lake are in 20.6.4.135 NMAC, effective 07-01-12]

20.6.4.115 RIO GRANDE BASIN - The perennial reaches of Rio Vallecitos and its tributaries except Hopewell lake, and perennial reaches of Rio del Oso and perennial reaches of El Rito creek above the town of El Rito.

A. Designated Uses: domestic water supply, irrigation, high quality coldwater aquatic life, livestock watering, wildlife habitat and primary contact; public water supply on the Rio Vallecitos and El Rito creek.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.115 NMAC - Rp 20 NMAC 6.1.2112, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-01-12]

[**NOTE:** The standards for Hopewell lake are in 20.6.4.134 NMAC, effective 07-01-12]

20.6.4.119 RIO GRANDE BASIN - All perennial reaches of tributaries to the Rio Chama above Abiquiu dam, except Canjilon lakes a, c, e and f and the Rio Gallina and Rio Puerco de Chama north of state highway 96 and excluding waters on Jicarilla Apache reservation, and the main stem of the Rio Chama from the headwaters of El Vado reservoir upstream to the New Mexico-Colorado line. Some Cañones creek and Rio Chama waters in this segment are under the joint jurisdiction of the state and the Jicarilla Apache tribe.

A. Designated Uses: domestic water supply, fish culture, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact; and public water supply on the Rio Brazos and Rio Chama.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less (1,000 µS or less for Coyote creek); the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.119 NMAC - Rp 20 NMAC 6.1.2116, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-01-12]

[**NOTE:** The standards for Canjilon lakes a, c, e and f are in 20.6.4.134 NMAC, effective 07-01-12]

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20.6.4.133 RIO GRANDE BASIN - Bull Creek lake, Cow lake, Elk lake, Goose lake, Heart lake, Hidden lake (Lake Hazel), Horseshoe lake, Horseshoe (Alamitos) lake, Jose Vigil lake, Lost lake, Middle Fork lake, Nambe lake, Nat II lake, Nat IV lake, No Fish lake, Pioneer lake, San Leonardo lake, Santa Fe lake, Serpent lake, South Fork lake, Trampas lakes (east and west) and Williams lake.

A. Designated Uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.133 NMAC - N, 07-01-12]

20.6.4.134 RIO GRANDE BASIN - Cabresto lake, Canjilon lakes a, c, e and f, Fawn lakes (east and west), Hopewell lake and San Gregorio lake.

A. Designated Uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.134 NMAC - N, 07-01-12]

20.6.4.135 RIO GRANDE BASIN - Bluewater lake.

A. Designated Uses: coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: phosphorus (unfiltered sample) 0.1 mg/L or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.135 NMAC - N, 07-01-12]

[~~20.6.4.133~~] 20.6.4.136 - 20.6.4.200: [RESERVED]

20.6.4.209 PECOS RIVER BASIN - Perennial reaches of Eagle creek upstream of Alto dam to the Mescalero Apache boundary, perennial reaches of the Rio Bonito and its tributaries upstream of state highway 48 (near Angus) excluding Bonito lake, and perennial reaches of the Rio Ruidoso and its tributaries upstream of the U.S. highway 70 bridge near Seeping Springs lakes, above and below the Mescalero Apache boundary.

A. Designated Uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 600 µS/cm or less in Eagle creek, 1,100 µS/cm or less in Bonito creek and 1,500 µS/cm or less in the Rio Ruidoso; phosphorus (unfiltered sample) less than 0.1 mg/L; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.209 NMAC - Rp 20 NMAC 6.1.2209, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-01-12]

[**NOTE:** The standards for Bonito lake are in 20.6.4.223 NMAC, effective 07-01-12]

20.6.4.211 PECOS RIVER BASIN - The main stem of the Pecos river from the headwaters of Sumner reservoir upstream to Tecolote creek excluding Santa Rosa reservoir.

A. Designated Uses: fish culture, irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 3,000 mg/L or less, sulfate 2,000 mg/L or less and chloride 400 mg/L or less.

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[20.6.4.211 NMAC - Rp 20 NMAC 6.1.2211, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-01-12]
[**NOTE:** The standards for Santa Rosa reservoir are in 20.6.4.225 NMAC, effective 07-01-12]

20.6.4.217 PECOS RIVER BASIN - Perennial reaches of Cow creek and all perennial reaches of its tributaries and the main stem of the Pecos river from Cañon de Manzanita upstream to its headwaters, including perennial reaches of all tributaries thereto except lakes identified in 20.6.4.222 NMAC.

A. Designated Uses: domestic water supply, fish culture, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact; and public water supply on the main stem of the Pecos river.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.217 NMAC - Rp 20 NMAC 6.1.2214, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-01-12]
[**NOTE:** The segment covered by this section was divided effective 05-23-05. The standards for the additional segments are under 20.6.4.220 and 20.6.4.221 NMAC.]

20.6.4.222 PECOS RIVER BASIN - Johnson lake, Katherine lake, Lost Bear lake, Pecos Baldy lake, Spirit lake, Stewart lake and Truchas lakes (north and south).

A. Designated Uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.222 NMAC - N, 07-01-12]

20.6.4.223 PECOS RIVER BASIN - Bonito lake.

A. Designated Uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering, wildlife habitat and public water supply.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: specific conductance 1100 µS/cm or less; phosphorus (unfiltered sample) less than 0.1 mg/L; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.223 NMAC - N, 07-01-12]

20.6.4.224 PECOS RIVER BASIN - Monastery lake.

A. Designated Uses: coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.
[20.6.4.224 NMAC - N, 07-01-12]

20.6.4.225 PECOS RIVER BASIN - Santa Rosa reservoir.

A. Designated Uses: coolwater aquatic life, irrigation, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
[20.6.4.225 NMAC - N, 07-01-12]

20.6.4.226 PECOS RIVER BASIN - Perch lake.

A. Designated Uses: coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.226 NMAC - N, 07-01-12]

20.6.4.227 PECOS RIVER BASIN - Lea lake.

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A. **Designated Uses:** warmwater aquatic life, primary contact and wildlife habitat.

B. **Criteria:** The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.227 NMAC - N, 07-01-12]

20.6.4.228 PECOS RIVER BASIN - Cottonwood lake and Devil's Inkwell.

A. **Designated Uses:** coolwater aquatic life, primary contact and wildlife habitat.

B. **Criteria:** The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.228 NMAC - N, 07-01-12]

20.6.4.229 PECOS RIVER BASIN - Mirror lake.

A. **Designated Uses:** warmwater aquatic life, primary contact and wildlife habitat.

B. **Criteria:** The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.229 NMAC - N, 07-01-12]

[~~20.6.4.222~~] 20.6.4.230 - 20.6.4.300: [RESERVED]

20.6.4.307 CANADIAN RIVER BASIN - Perennial reaches of the Mora river from the USGS gaging station near Shoemaker upstream to the state highway 434 bridge in Mora, all perennial reaches of tributaries to the Mora river downstream from the USGS gaging station at La Cueva in San Miguel and Mora counties except lakes identified in 20.6.4.313 NMAC, perennial reaches of Ocate creek and its tributaries downstream of Ocate, and perennial reaches of Rayado creek downstream of Miami lake diversion in Colfax county.

A. **Designated Uses:** marginal coldwater aquatic life, warmwater aquatic life, primary contact, irrigation, livestock watering and wildlife habitat.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.307 NMAC - Rp 20 NMAC 6.1.2305.3, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-01-12]

20.6.4.309 CANADIAN RIVER BASIN - The Mora river and perennial reaches of its tributaries upstream from the state highway 434 bridge in Mora except lakes identified in 20.6.4.313 NMAC, all perennial reaches of tributaries to the Mora river upstream from the USGS gaging station at La Cueva, perennial reaches of Coyote creek and its tributaries, the Cimarron river and its perennial tributaries above state highway 21 in Cimarron except Eagle Nest lake, all perennial reaches of tributaries to the Cimarron river north and northwest of highway 64 except north and south Shuree ponds, perennial reaches of Rayado creek and its tributaries above Miami lake diversion, Ocate creek and perennial reaches of its tributaries upstream of Ocate, perennial reaches of the Vermejo river upstream from Rail canyon and all other perennial reaches of tributaries to the Canadian river northwest and north of U.S. highway 64 in Colfax county unless included in other segments.

A. **Designated Uses:** domestic water supply, irrigation, high quality coldwater aquatic life, livestock watering, wildlife habitat, and primary contact; and public water supply on the Cimarron river upstream from Cimarron[~~, on Eagle Nest lake~~] and on perennial reaches of Rayado creek and its tributaries.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.309 NMAC - Rp 20 NMAC 6.1.2306, 10-12-00; A, 7-19-01; A, 05-23-05; A, 12-01-10; A, 07-01-12]

[**NOTE:** The segment covered by this section was divided effective 05-23-05. The standards for the additional segment are under 20.6.4.310 NMAC. The standards for Shuree ponds are in 20.6.4.314 NMAC and the standards for Eagle Nest lake are in 20.6.4.315 NMAC, effective 07-01-12]

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20.6.4.313 CANADIAN RIVER BASIN - Encantada lake, Maestas lake, Middle Fork lake of Rio de la Casa, North Fork lake of Rio de la Casa and Pacheco lake.

A. Designated Uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.313 NMAC - N, 07-01-12]

20.6.4.314 CANADIAN RIVER BASIN - Shuree ponds (north and south).

A. Designated Uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.314 NMAC - N, 07-01-12]

20.6.4.315 CANADIAN RIVER BASIN - Eagle Nest lake.

A. Designated Uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering, wildlife habitat and public water supply.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.315 NMAC - N, 07-01-12]

20.6.4.316 CANADIAN RIVER BASIN - Clayton lake.

A. Designated Uses: coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.316 NMAC - N, 07-01-12]

20.6.4.317 CANADIAN RIVER BASIN - Springer lake.

A. Designated Uses: coolwater aquatic life, irrigation, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.317 NMAC - N, 07-01-12]

[~~20.6.4.313~~] 20.6.4.318 - 20.6.4.400: [RESERVED]

20.6.4.410 SAN JUAN RIVER BASIN - Jackson lake.

A. Designated Uses: coolwater aquatic life, irrigation, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the monthly geometric mean of *E. coli* bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.410 NMAC - N, 07-01-12]

[~~20.6.4.410 - 20.6.450~~] 20.6.4.411 - 20.6.4.450: [RESERVED]

20.6.4.453 LITTLE COLORADO RIVER BASIN - Quemado lake.

A. Designated Uses: coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.453 NMAC - N, 07-01-12]

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[~~20.6.4.453~~] 20.6.4.454 - 20.6.4.500: [RESERVED]

20.6.4.505 GILA RIVER BASIN - Bill Evans lake.

A. Designated Uses: coolwater aquatic life, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.505 NMAC - N, 07-01-12]

[~~20.6.4.505~~] 20.6.4.506 - 20.6.4.600: [RESERVED]

20.6.4.702 DRY CIMARRON RIVER - Perennial portions of the Dry Cimarron river below Oak creek, and perennial portions of Long canyon and Carrizozo creeks.

A. Designated Uses: [~~coldwater~~] coolwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: [~~temperature 25°C (77°F) or less;~~] the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

(2) TDS 1,200 mg/L or less, sulfate 600 mg/L or less and chloride 40 mg/L or less.

[20.6.4.702 NMAC - N, 05-23-05; A, 12-01-10; A, 07-01-12]

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Appendix A

E.coli data from sampling stations in Santa Cruz Lake

AU ID	AU NAME	STATION_ID	SAMPLE DATE	PARAMETER	VALUE	UNIT
NM-2118.B_00	Santa Cruz Lake	28SantaCruzDp	03/30/17	E. coli	3.1	MPN/100ml
NM-2118.B_00	Santa Cruz Lake	28SantaCruzDp	04/11/18	E. coli	<1	MPN/100ml
NM-2118.B_00	Santa Cruz Lake	28SantaCruzDp	07/24/18	E. coli	4.1	MPN/100ml
NM-2118.B_00	Santa Cruz Lake	28SantaCruzDp	08/03/17	E. coli	4.1	MPN/100ml
NM-2118.B_00	Santa Cruz Lake	28SantaCruzDp	10/16/17	E. coli	4.1	MPN/100ml

EPA Approved

TOTAL MAXIMUM DAILY LOADS

FOR THE

CANADIAN AND UPPER RIO GRANDE BASIN LAKES



AUGUST 20, 2024

NMED Exhibit 41

Prepared by

New Mexico Environment Department, Surface Water Quality Bureau

Monitoring, Assessments, and Standards Section

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_____

For Additional Information please visit:

https://www.env.nm.gov/surface-water-quality/

~or~

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Photo: SWQB staff

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List of Abbreviations

4Q3	4-Day, 3-year low-flow frequency
4T3	Temperature not to be exceeded for 4 or more consecutive hours on more than 3 consecutive days
6T3	Temperature not to be exceeded for 6 or more consecutive hours on more than 3 consecutive days
AU	Assessment Unit
BMP	Best management practices
CALM	Comprehensive Assessment and Listing Methodology
CFR	Code of Federal Regulations
cfs	Cubic feet per second
cfu	Colony forming units
CGP	Construction general permit, storm water
CoolWAL	Cool Water Aquatic Life
CWA	Clean Water Act
^{o}C	Degrees Celsius
DMR	Discharge Monitoring Report
HQCWAL	High Quality Coldwater Aquatic Life
^{o}F	Degrees Fahrenheit
HUC	Hydrologic Unit Code
IR	303(d)/305(b) Integrated List
$j/m^2/s$	Joules per square meter per second
km^2	Square kilometers
LA	Load allocation
lb/day	Pounds per day
mgd	Million gallons per day
mg/L	Milligrams per Liter
mi^2	Square miles
mL	Milliliters
MOS	Margin of safety
MOU	Memorandum of Understanding
MS4	Municipal separate storm sewer system, storm water
MSGP	Multi-sector general permit, storm water
NM	New Mexico
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint source
QAPP	Quality Assurance Project Plan
SSTEMP	Stream Segment Temperature Model
SWPPP	Storm water pollution prevention plan
SWQB	Surface Water Quality Bureau
TMDL	Total Maximum Daily Load
UAA	Use Attainability Analysis
USEPA	U.S. Environmental Protection Agency

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USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WBP	Watershed-based plan
WLA	Waste load allocation
WQCC	Water Quality Control Commission
WQS	Water quality standards (20.6.4 NMAC as amended through 2/8/2023)

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Executive Summary

Section 303(d) of the Federal Clean Water Act, 33 U.S.C. § 1313(CWA), requires states to develop Total Maximum Daily Load (TMDL) management plans for water bodies determined to be water quality limited. A TMDL is defined as "a written plan and analysis established to ensure that a water body will attain and maintain water quality standards including consideration of existing pollutant loads and reasonably foreseeable increases in pollutant loads" (USEPA, 1999). A TMDL defines the amount of a pollutant a water body can assimilate without violating a state's water quality standards. It also allocates that load capacity to known point sources and nonpoint sources at a given flow. It further identifies potential methods, actions, or limitations that could be implemented to achieve water quality standards. TMDLs are defined in 40 Code of Federal Regulations Part 130 (40 C.F.R. § 130.2(i)) as the sum of individual Waste Load Allocations (WLAs) for point sources, and Load Allocations (LAs) for nonpoint source and background conditions, and a Margin of Safety (MOS) in acknowledgement of various sources of uncertainty in the analysis. While a TMDL itself is not a regulatory document, the implementation of TMDLs by federal, state, and local land management and regulatory agencies; landowners; and stakeholders in the contributing watershed utilizing available resources such as Watershed Based Planning documents and National Pollutant Discharge Elimination System (NPDES) permit revisions can lead to the attainment of water quality standards in a waterbody.

The New Mexico Environment Department (NMED) Surface Water Quality Bureau (SWQB) conducted water quality surveys on the Dry Cimarron River and Canadian River watersheds in 2015-2016, and on the Upper Rio Grande watershed in 2017-2018, including the lakes addressed in this TMDL. Eagle Nest Lake was previously sampled in 1999 and 2005, Santa Cruz Lake in 2000 and 2009, and Shuree Pond North and Lake Maloya in 2006. Each lake discussed in this TMDL has water quality monitoring stations located upstream, downstream and in the lake to evaluate the impact of tributary streams and ambient water quality conditions. Assessment of data generated during the Dry Cimarron River and Canadian River watersheds 2015-2016 monitoring efforts was conducted according to the 2017 Comprehensive Assessment and Listing Methodology (CALM) (NMED/SWQB 2017), while assessment of data generated during the Upper Rio Grande watershed 2017-2018 monitoring efforts was conducted according to the 2019 CALM (NMED/SWQB 2019). This TMDL document addresses the documented impairments as summarized in Table ES-1 below. These impairments are also documented in the 2024-2026 CWA §303(d)/305(b) Integrated Report (IR), which list the assessed waters of New Mexico and the corresponding impairments. The IR is meant to serve as a source of basic information on water quality and water pollution control programs in New Mexico (NMED/SWQB 2024). Additional information regarding these impairments can also be reviewed in the 2024-2026 Assessment Rationale, previously known as the Reason of Decision (ROD) (NMED/SWQB 2024).

During the next scheduled Canadian and Dry Cimarron, and Upper Rio Grande water quality surveys, TMDL targets will be re-examined and potentially revised, as this document is an evolving management plan. If new data indicates that the targets used in this analysis are not appropriate and/or if new standards are adopted, the load capacity will be adjusted accordingly. When water quality standards have been achieved, the waterbody will be moved to the appropriate category in the Integrated Report (IR).

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Table ES-1: TMDL Assessment Units by USGS 8-digit Hydrologic Unit Code

Assessment Unit Name	AU_ID	TMDL(s)
HUC 13020101 - Upper Rio Grande		
Santa Cruz Lake	NM-2118.B_00	Aluminum, Nutrients, Temperature
HUC 11080002 - Cimarron		
Eagle Nest Lake	NM-2306.B_00	Nutrients
Lake Maloya	NM-2305.B_20	Nutrients
Shuree Pond North	NM-2306.B_30	Nutrients

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Table ES-2: TMDL for Eagle Nest Lake

New Mexico Standards Segment	20.6.4.315 NMAC and 20.6.4.13(E) NMAC
Assessment Unit Identifier	NM-2306.B_00
NPDES Permit(s)	None
Segment Area	1817.29 acres
Parameters of Concern	Plant Nutrients (Total Nitrogen and Total Phosphorous)
Designated Uses Affected	High Quality Coldwater Aquatic Life
USGS Hydrologic Unit Codes (8)	11080002: Cimarron
Size of Watershed	184.45 square miles
Land Type	Ecoregion 21a: Alpine Zone (0.1%) Ecoregion 21b: Crystalline Subalpine Forests (13.9%) Ecoregion 21c: Crystalline Mid-Elevation Forests (20.0%) Ecoregion 21e: Sedimentary Subalpine Forests (6.3%) Ecoregion 21f: Sedimentary Mid-Elevation Forests (20.0%) Ecoregion 21g: Volcanic Subalpine Forests (7.6%) Ecoregion 21h: Volcanic Mid-Elevation Forests (1.2%) Ecoregion 21j: Grassland Parks (30.9%)
Land Use/Cover	60.2% forest, 29.3% shrubland, 3.2% developed, 2.9% herbaceous, 2.3% wetlands, 1.6% water, less than 1.0% each – planted/cultivated and barren
Geology	32.8% purely sedimentary, 25.7% purely unconsolidated, 15.9% purely igneous, 15.5% igneous and metamorphic, 8.3% purely metamorphic, 1.4% water, 0.4% sedimentary and unconsolidated
Land Ownership/Management	90.8 % Private, 6.9% State Game and Fish, 1.6% Forest Service, less than 1.0% of each – Tribal and State
Probable Sources	Abandoned Mines (Inactive/Tailings); Active Mines (Gravel); Angling Pressure; Bridges/Culverts/RR Crossings; Campgrounds (Defined); Channelization; Crop Production (Cropland or Dry Land); Dams/Diversions; Dirt or Gravel Roads; Flow Alteration (from Water Diversions); Highway/Road/Bridge Runoff; Hiking Trails; Logging Ops – Legacy; Low Water Crossing; Municipal Point Source Discharge; On-Site Treatment Systems (Septic, etc.); Residences/Buildings; Rangeland Grazing (Dispersed); Site Clearance (Land Development); Storm Water Runoff due to Construction; Urban Runoff/Sewers; Waterfowl; Wildlife other than Waterfowl
IR Category	5/5A
Priority Ranking	High
WLA + LA + MOS = TMDL	
Total Nitrogen	0 mg/L + 0.81 mg/L + 0.09 mg/L = 0.9 mg/L
Total Phosphorous	0 mg/L + 0.027 mg/L + 0.003 mg/L = 0.03 mg/L

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Table ES-3: TMDL for Lake Maloya

New Mexico Standards Segment	20.6.4.312 NMAC and 20.6.4.13(E) NMAC
Assessment Unit Identifier	NM-2305.B_20
NPDES Permit(s)	None
Segment Area	115.54 acres
Parameters of Concern	Plant Nutrients (Total Nitrogen and Total Phosphorous)
Designated Uses Affected	Coldwater Aquatic Life
USGS Hydrologic Unit Codes (8)	11080001: Canadian Headwaters
Size of Watershed	20.80 square miles
Land Type	Ecoregion 21f: Sedimentary Mid-elevation Forests (25.2%) Ecoregion 21j: Grassland Parks (64.8%)
Land Use/Cover	41.4% herbaceous, 41.0% shrubland, 13.6% forest, 2.9% wetlands, 1.1% water, less than 1.0% each – developed and planted/cultivated
Geology	36.9% purely igneous, 55.1% purely sedimentary, 8.0% unconsolidated
Land Ownership/Management	51.1% BLM, 48.9% Private
Probable Sources	Grazing in Riparian or Shoreline Zones; Highway/Road/Bridge Runoff (Non-Construction Related); Impervious Surface/Parking Lot Runoff; Off-Road Vehicles; Other Recreational Pollution Sources; Rangeland Grazing; Drought-Related Impacts; Unspecified unpaved road or trail; Waterfowl; Watershed Runoff Following Forest Fire; Wildlife other than Waterfowl
IR Category	5/5A
Priority Ranking	High
WLA + LA + MOS = TMDL	
Total Nitrogen	0 mg/L + 0.81 mg/L + 0.09 mg/L = 0.9 mg/L
Total Phosphorous	0 mg/L + 0.027 mg/L + 0.003 mg/L = 0.03 mg/L

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Table ES-4: TMDL for Santa Cruz Lake

New Mexico Standards Segment	20.6.4.121 NMAC and 20.6.4.13(E) NMAC
Assessment Unit Identifier	NM-2118.B_00
NPDES Permit(s)	None
Segment Area	92.95 acres
Parameters of Concern	Plant Nutrients (Total Nitrogen and Total Phosphorous), Temperature, Aluminum (Total)
Designated Uses Affected	High Quality Coldwater Aquatic Life
USGS Hydrologic Unit Codes (8)	13020101: Upper Rio Grande
Size of Watershed	98.40 square miles
Land Type	Ecoregion 21a: Alpine Zone (4.8%) Ecoregion 21b: Crystalline Subalpine Forests (33.2%) Ecoregion 21c: Crystalline Mid-Elevation Forests (40.2%) Ecoregion 21d: Foothill Shrublands (13.0%) Ecoregion 22h: North Central New Mexico Valleys and Mesas (8.8%)
Land Use/Cover	75.0% forest, 19.6% shrubland, 4.5% herbaceous, less than 1.0% each – water, planted/cultivated, developed, and wetlands
Geology	47.2% purely metamorphic, 29.1% mixed igneous and metamorphic, 16.1 % purely igneous, 7.4% sedimentary
Land Ownership/Management	83.3% Forest Service, 8.3% Bureau of Land Management, 8.2% Private, less than 1.0% each – Tribal and State
Probable Sources	Angling Pressure; Bridges/Culverts/RR Crossings; Dumping/Garbage/Trash/Litter; Fire Suppression (Thinning/Chemicals); Highway/Road/Bridge Runoff; Hiking Trails; Logging Ops – Legacy; On-Site Treatment Systems (Septic, etc.); Paved/Gravel/Dirt Roads; Pavement/Impervious Surfaces; Inappropriate Waste Disposal; Rangeland Grazing (dispersed); Residences/Buildings; Site Clearance (Land Development); Waste from Pets (high concentration); Wildlife other than Waterfowl
IR Category	5/5A
Priority Ranking	High
WLA + LA + MOS = TMDL	
Total Nitrogen	0 mg/L + 0.81 mg/L + 0.09 mg/L = 0.9 mg/L
Total Phosphorous	0 mg/L + 0.027 mg/L + 0.003 mg/L = 0.03 mg/L
Aluminum (total)	0 mg/L + 0.315 mg/L + 0.035 mg/L = 0.35 mg/L
Temperature	0 kJ/day + 2.64×10^{10} kJ/day + 4.65×10^{9} kJ/day = 3.10×10^{10} kJ/day

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Table ES-5: TMDL for Shuree Pond North

New Mexico Standards Segment	20.6.4.314 NMAC and 20.6.4.13(E) NMAC
Assessment Unit Identifier	NM-2306.B_30
NPDES Permit(s)	None
Segment Area	6.19 acres
Parameters of Concern	Plant Nutrients (Total Nitrogen and Total Phosphorous),
Designated Uses Affected	High Quality Coldwater Aquatic Life
USGS Hydrologic Unit Codes (8)	11080002: Cimarron
Size of Watershed	1.97 square miles
Land Type	Ecoregion 21e: Sedimentary Subalpine Forests (13.9%) Ecoregion 21f: Sedimentary Mid-Elevation Forests (86.1%)
Land Use/Cover	54.9% forest, 22.8% shrubland, 21.4% herbaceous, less than 1.0% each – wetlands and water
Geology	51.5% sedimentary, 44.3% unconsolidated, 4.2% igneous
Land Ownership/Management	100% Forest Service
Probable Sources	Drought-Related Impacts; Forest Roads (Road Construction and Use); Grazing in Riparian or Shoreline Zones; Highway/Road/Bridge Runoff; Off-Road Vehicles; Other Recreational Pollution Sources; Rangeland Grazing; Unspecified Unpaved Road or Trail; Waterfowl; Wildlife other than Waterfowl
IR Category	5/5A
Priority Ranking	High
WLA + LA + MOS = TMDL	
Total Nitrogen	0 mg/L + 0.81 mg/L + 0.09 mg/L = 0.9 mg/L
Total Phosphorous	0 mg/L + 0.027 mg/L + 0.003 mg/L = 0.03 mg/L

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1.0 Background

The New Mexico Environmental Department (NMED) Surface Water Quality Bureau (SWQB) establishes TMDLs in this document for Santa Cruz Lake in the Upper Rio Grande watershed, and for Eagle Nest Lake, Lake Maloya and Shuree Pond North in the Canadian River watershed. The SWQB based impairment determinations on data collected during previous lake water quality surveys and during the Canadian River and Dry Cimarron 2015-2016 water quality survey and the Upper Rio Grande 2017-2018 water quality survey.

1.1 Lake and Watershed Description

1.1.1 Eagle Nest Lake

Eagle Nest Lake is a large alpine reservoir located in the Moreno Valley of the Sangre de Cristo Mountains. The lake has a surface area of 1817.28 acres and a maximum storage capacity of 81,360 acre-feet (NMED/SWQB, 2005). The United States Geologic Survey (USGS) maintains a monitoring gage (USGS 07205500) in Eagle Nest Lake that records lake storage and lake surface elevation. Since 2020 lake storage has varied from 48,000 acre-feet to 35,000 acre-feet (USGS, 2022). The reservoir was created in 1918 with the construction of a 140-foot-tall concrete dam that impounded the Cieneguilla, Six Mile and Moreno Creeks. Eagle Nest Lake provides water for recreation and irrigation and the dam outflow forms the Cimarron River. This reservoir is the main feature of Eagle Nest Lake State Park, which has been maintained by the New Mexico State Parks since 2004, while the lake itself is owned by the New Mexico Department of Game and Fish (NMDGF). The area is a popular fishing and camping area, with the NMDGF stocking populations of rainbow trout and kokanee salmon (NMDGF, 2022). Designated uses for Eagle Nest Lake include domestic water supply, public water supply, high quality coldwater aquatic life, irrigation, livestock watering, primary contact and wildlife habitat, with all uses being met except for high quality coldwater aquatic life (NMED/SWQB, 2024).

1.1.2 Eagle Nest Lake Watershed

The Eagle Nest Lake watershed is made up of five HUC 12 watersheds (110800020101-110800020105) and covers 184.46 square miles of the high elevation Moreno Valley and surrounding Sangre de Cristo Mountains within the Canadian River basin. The watershed is located entirely in Colfax County. The elevation ranges from 8,083 feet at the lake outlet to 12,424 feet at the peak of Baldy Mountain, with an average elevation of 9,206 feet. The slope ranges from 0 degrees to 85 degrees, with an average slope of 13 degrees. The watershed receives approximately 22 inches of precipitation a year, with an average annual air temperature of approximately 41 degrees Fahrenheit. Runoff from stormwater and snowmelt is more consistent than most New Mexico watersheds given the watersheds high elevation and wetter climate, resulting in regular surface inputs to the lake from three main streams; Moreno Creek on the north shore, Sixmile Creek on the west shore, and Cieneguilla Creek on the south shore.

Cieneguilla Creek (AU ID: NM-2306.A_065), Moreno Creek (AU ID: NM-2306.A_060) and Sixmile Creek (AU ID: NM-2306.A_064) from Eagle Nest Lake to their headwaters and Eagle Nest Lake (AU ID: NM-2306.B_00) itself have been extensively monitored by the NMED SWQB.

- Cieneguilla Creek was first listed as impaired for sedimentation/siltation and turbidity in 1998 and in 2008 was first listed as impaired for nutrients, temperature, and *E. coli*. TMDL's were prepared

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by the NMED SWQB for the sedimentation/siltation and turbidity impairments in 2004, and for nutrients, temperature, and *E. coli* in 2010. The current 303(d) Integrated Reporting (IR) category for these impairments is 4A, meaning a TMDL has been developed by NMED SWQB and approved by the EPA.

- TMDLs for fecal coliform and turbidity were developed for Moreno Creek in 2000. Fecal coliform was removed as a cause of impairment in 2008 because the criterion was changed to *E. coli* during the 2005 triennial review of water quality standards and data from the 2006 Canadian watershed survey indicated a full support conclusion for *E. coli*. Turbidity was removed as a cause of impairment in 2010 after low exceedance values were observed. The turbidity TMDL remains as a protective TMDL. Moreno Creek was listed as impaired for temperature and nutrients following the 2006 Canadian watershed survey. TMDLs for temperature and nutrients were developed for Moreno Creek in 2010. During the 2015-2016 Canadian/Dry Cimarron watershed survey, new data showed that Moreno Creek was no longer impaired for nutrients but still impaired for temperature. During the 2018 assessment period the nutrient impairment was removed for Moreno Creek, with the current 303(d) IR category for temperature listed as 4A. The nutrient TMDL remains as a protective TMDL.
- TMDLs were developed for Sixmile Creek in 2000 to address fecal coliform and turbidity impairments. Nutrients and temperature were added as impairments for Sixmile Creek in 2008 after the 2006 Canadian watershed survey. In 2018, nutrients were removed as an impairment for Sixmile Creek, while temperature, *E. coli* and turbidity remained as causes of impairment. Temperature and *E. coli* TMDLs were developed in 2010, and a turbidity TMDL was developed in 2004. The current 303(d) IR category for temperature, *E. coli* and turbidity in Sixmile Creek is 4A.
- Eagle Nest Lake was listed as impaired for mercury in fish tissue in 1996 because of fish consumption advisories issued for the lake. After sampling in 2005, arsenic and dissolved oxygen were added to the list of impairments. Changes to the mercury in fish tissue criterion were adopted after the 2005 triennial review and the mercury in fish tissue impairment for Eagle Nest Lake was removed, however a fish consumption advisory remained in place. Following the 2015-2016 Canadian and Dry Cimarron water quality survey, sample data revealed a new impairment for nutrients (replacing dissolved oxygen as the cause of non-support) and no exceedances in arsenic samples warranted the delisting of that impairment for Eagle Nest Lake. The lake is currently impaired for nutrients.

The Moreno Valley is a fault-edged valley situated between the Taos Range and the Cimarron Range of the Sangre de Cristo Mountains. Rocks range in age from Precambrian to Quaternary, and significant folding and faulting have disrupted all geologic units located in the Moreno Valley. (Colpitts, 1990). The eastern portion of the valley is lower in elevation compared to the western portion. Alluvial fans cover much of the valley floor, predominantly from stream deposits of the ample gravel and sand in the surrounding mountains (Chronic 1987). Sedimentary rocks underlie approximately 32.8% of the watershed, unconsolidated rocks approximately 25.7%, igneous rocks approximately 15.9%, igneous and metamorphic rocks approximately 15.5%, metamorphic rocks approximately 8.3%, sedimentary and unconsolidated rocks approximately 0.4%, and 1.4% of the watershed is water (**Figure 1.3**). Soils in the watershed are typically well-drained within the Moreno Valley, while surface outcroppings along the surrounding mountain ranges inhibit infiltration rates. Hydrologic Group A soils (high infiltration rate) make up approximately 7.1% of the watershed, Group B soils (moderate infiltration rate) 49.5% of the watershed, Group C soils (slow infiltration rate) 8.2% of the watershed, Group D soils (very slow infiltration

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rate) 34.4% of the watershed, while the remaining hydrologic soil groups are unknown (0.8% of watershed) (**Figure 1.6**).

As of 2019, land cover for the watershed is approximately 60.2% forest (an increase of 0.9% since 2001), 29.3% shrubland (a decrease of 1.4% since 2001), 3.2% developed, 2.9% herbaceous, 2.3% wetlands, 1.5% water, and <1.0% each planted/cultivated and barren (**Figure 1.4**). Approximately 29.0% of the watershed is situated in Level IV Ecoregion 21c (Crystalline Mid-Elevation Forests), 28.9% is situated in Ecoregion 21f (Sedimentary Mid-Elevation Forests), 20.2% is situated in Ecoregion 21b (Crystalline Subalpine Forests), 10.9% is situated in Ecoregion 21g (Volcanic Subalpine Forests), 9.2% is situated in Ecoregion 21e (Sedimentary Subalpine Forests), 1.7% is situated in Ecoregion 21h (Volcanic Mid-Elevation Forests) and 0.1% is situated in Ecoregion 21a (Alpine) (**Figure 1.2**). A small portion of the south-west watershed is located within the Camino Real Ranger District of the Carson National Forest. Major land uses in the area include private land ownership and recreation, such as camping, hunting, hiking, boating and fishing. Within Colfax County (includes entire Eagle Nest Lake watershed) the Bald Eagle (*Haliaeetus leucocephalus*), Mexican Spotted Owl (*Strix occidentalis lucida*), New Mexican Meadow Jumping Mouse (*Zapus hudsonius luteus*), Organ Mountains Colorado Chipmunk (*Neotamias quadrivittatus australis*), Pacific Marten (*Martes caurina*), Piping Plover (*Charadrius melodus*), Southern Redbelly Dace (*Chrosomus erythrogaster*), Star Gyro (*Gyraulus crista*), Suckermouth Minnow (*Phenacobius mirabilis*), White-Tailed Ptarmigan (*Lagopus leucura*), and the Yellow-Billed Cuckoo (*Coccyzus americanus*) are listed as either Threatened or Endangered by state and/or federal agencies (NHNM Species Information, *https://nhnm.unm.edu/*, accessed 03/17/2022).

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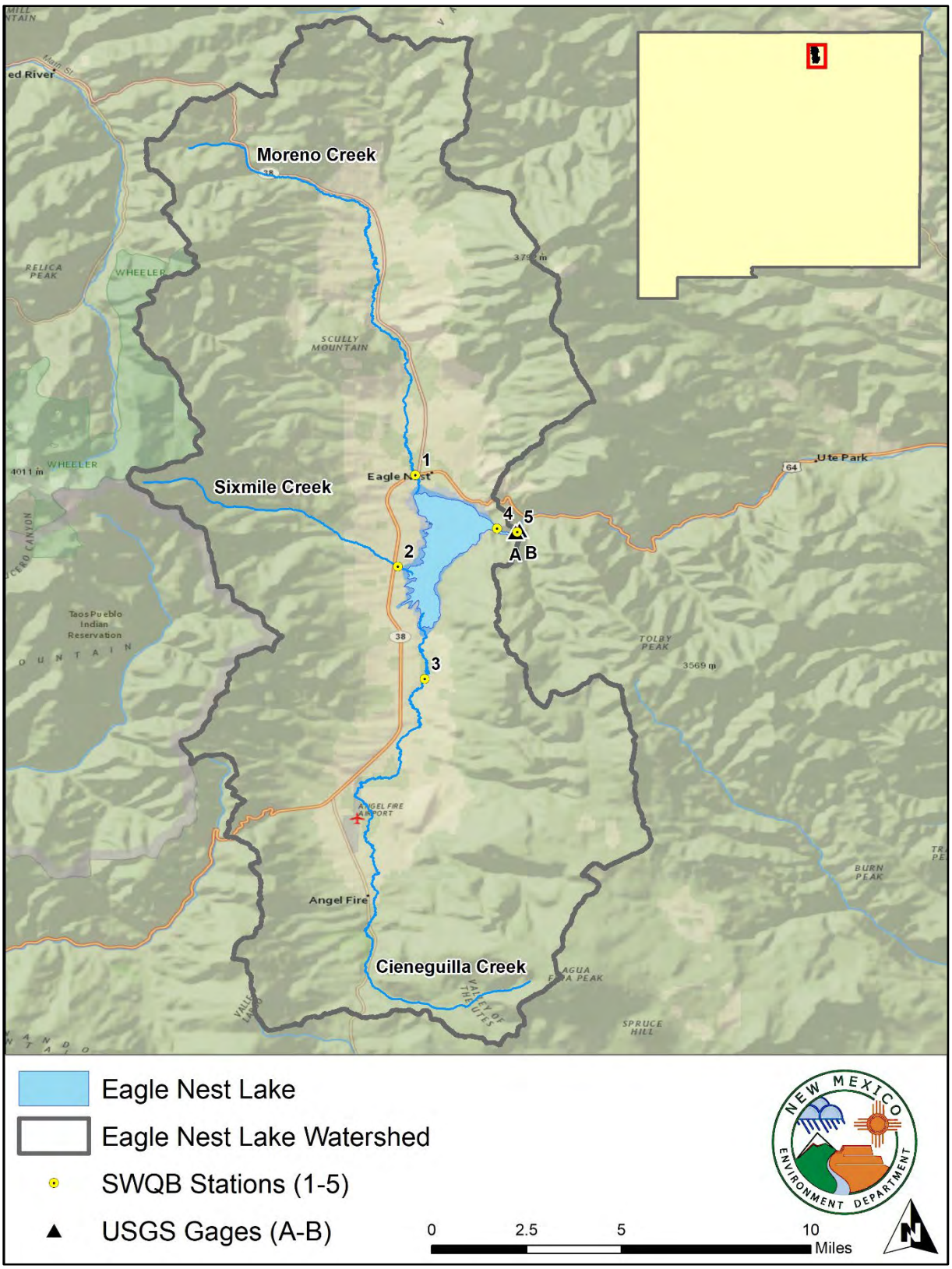


Figure 1.1 Overview map of the Eagle Nest Lake watershed. SWQB Stations (1-5) and USGS Gages (A-B) are identified in Table 1.1.

Table 1.1 Relevant SWQB Stations and USGS Gages shown in Figure 1.1.

Map Label	AU ID/Name	Station ID/Name
1	NM-2306.A_060, Moreno Creek (Eagle Nest Lake to headwaters)	05Moreno003.7, Moreno Creek at US 64
2	NM-2306.A_064, Sixmile Creek (Eagle Nest Lake to headwaters)	05Sixmil001.4, Sixmile Creek at US 64
3	NM-2306.A_065, Cieneguilla Creek (Eagle Nest Lake to headwaters)	05Cieneg006.3, Cieneguilla Creek above Eagle Nest Lake
4	NM-2306.B_00, Eagle Nest Lake	05EagleNestDP, Eagle Nest Lake (Deep)
5	NM-2306.A_130, Cimarron River (Turkey Creek to Eagle Nest Lake)	05Cimarr078.1, Cimarron River at Eagle Nest Outlet
A	NM-2306.B_00, Eagle Nest Lake	USGS Gage 07205500, Eagle Nest Lake near Eagle Nest, NM
B	NM-2306.A_130, Cimarron River (Turkey Creek to Eagle Nest Lake)	USGS Gage 07206000, Cimarron River Below Eagle Nest Dam, NM

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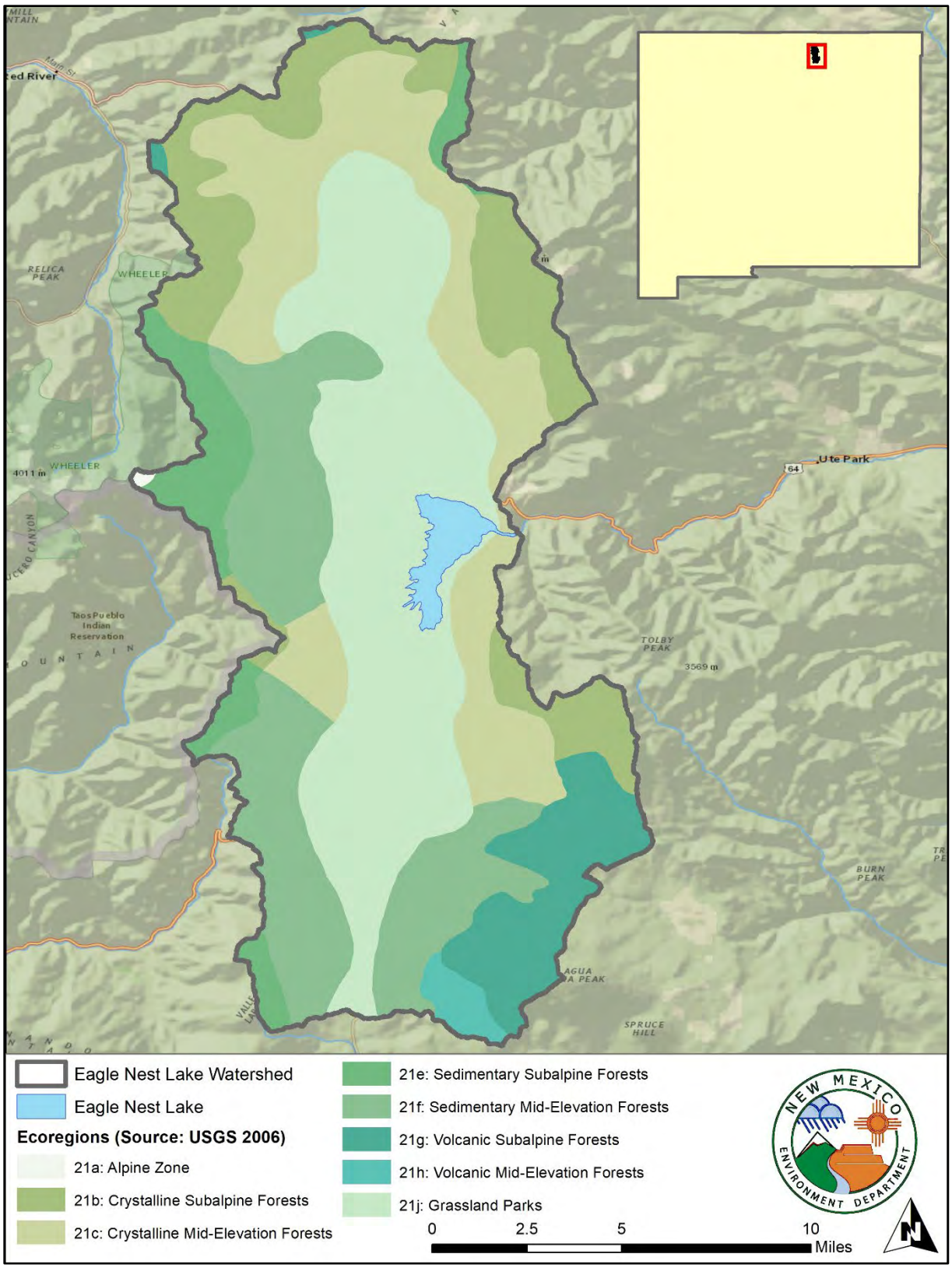


Figure 1.2 Ecoregions of the Eagle Nest watershed.

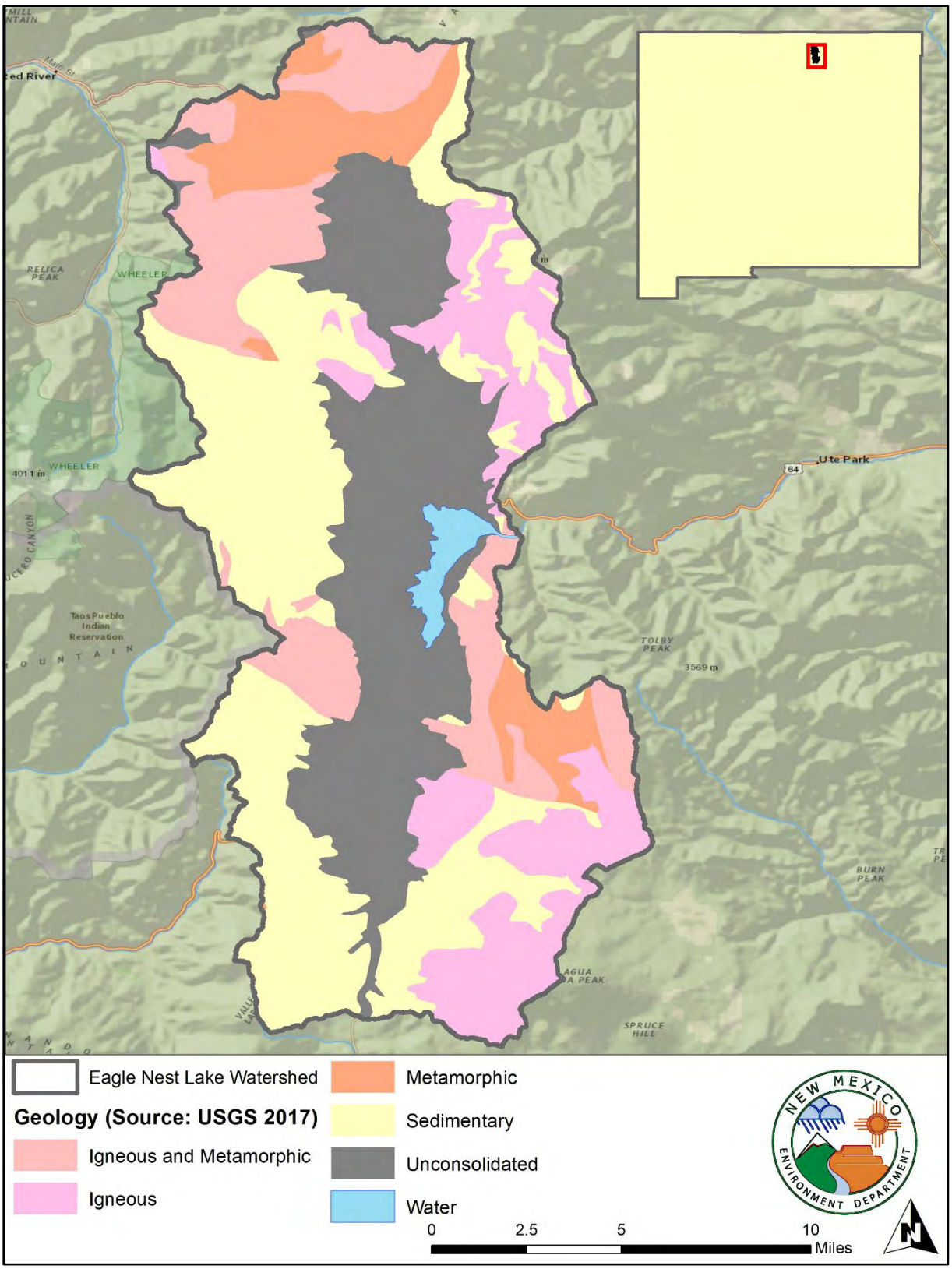


Figure 1.3: Surface geology of the Eagle Nest Lake watershed.

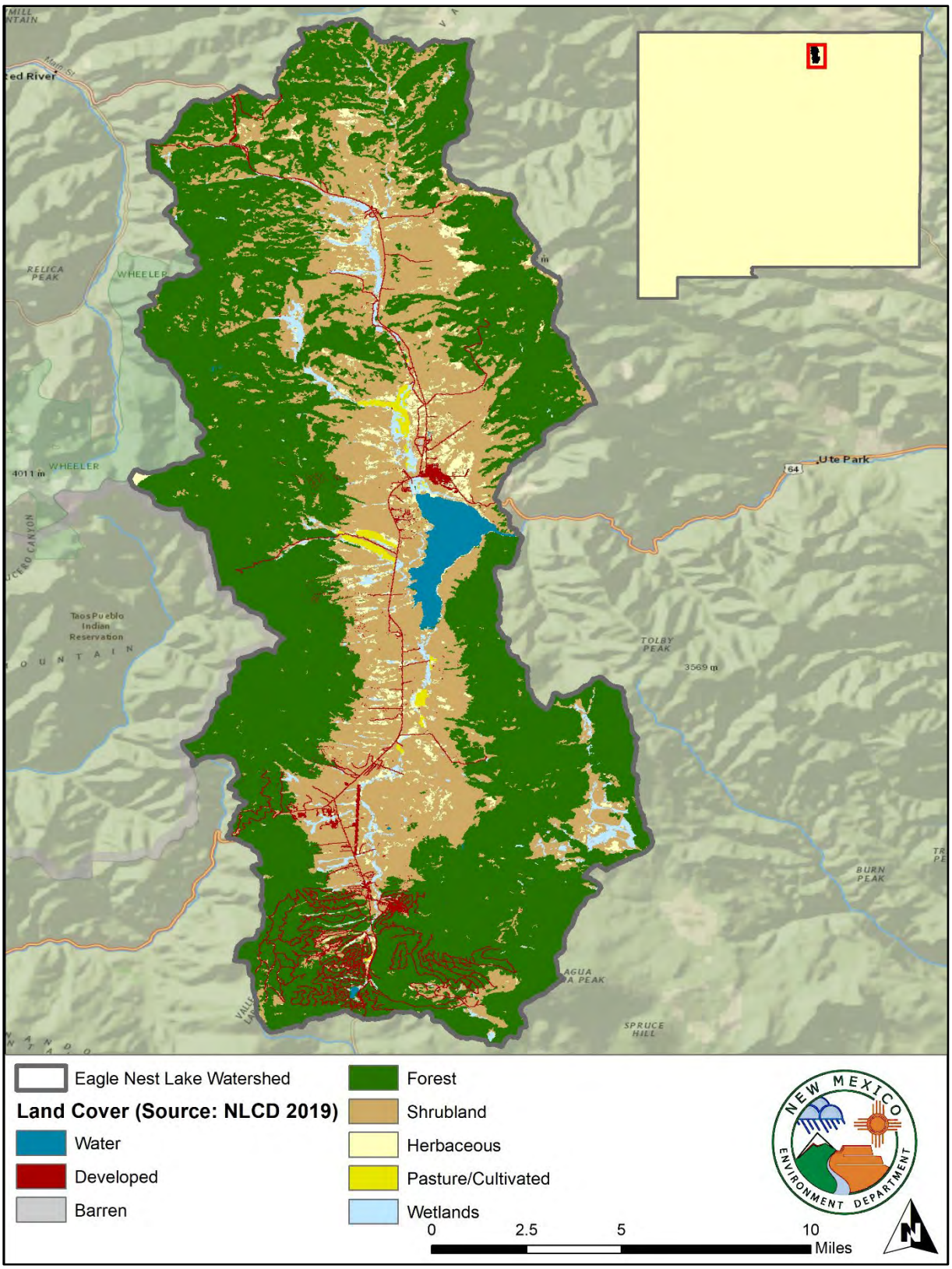


Figure 1.4: Land Cover of the Eagle Nest Lake watershed.

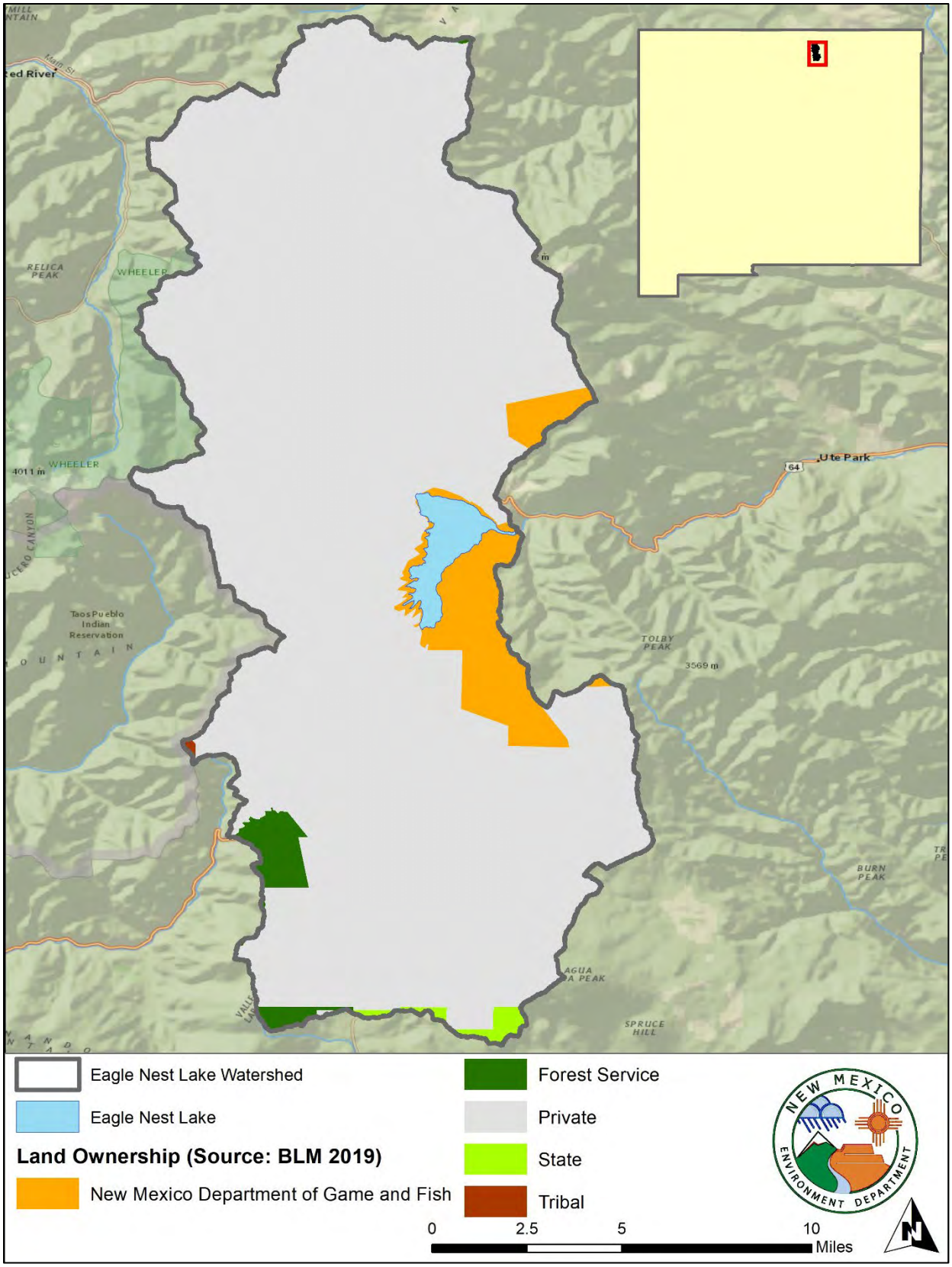


Figure 1.5: Land Ownership of the Eagle Nest Lake watershed.

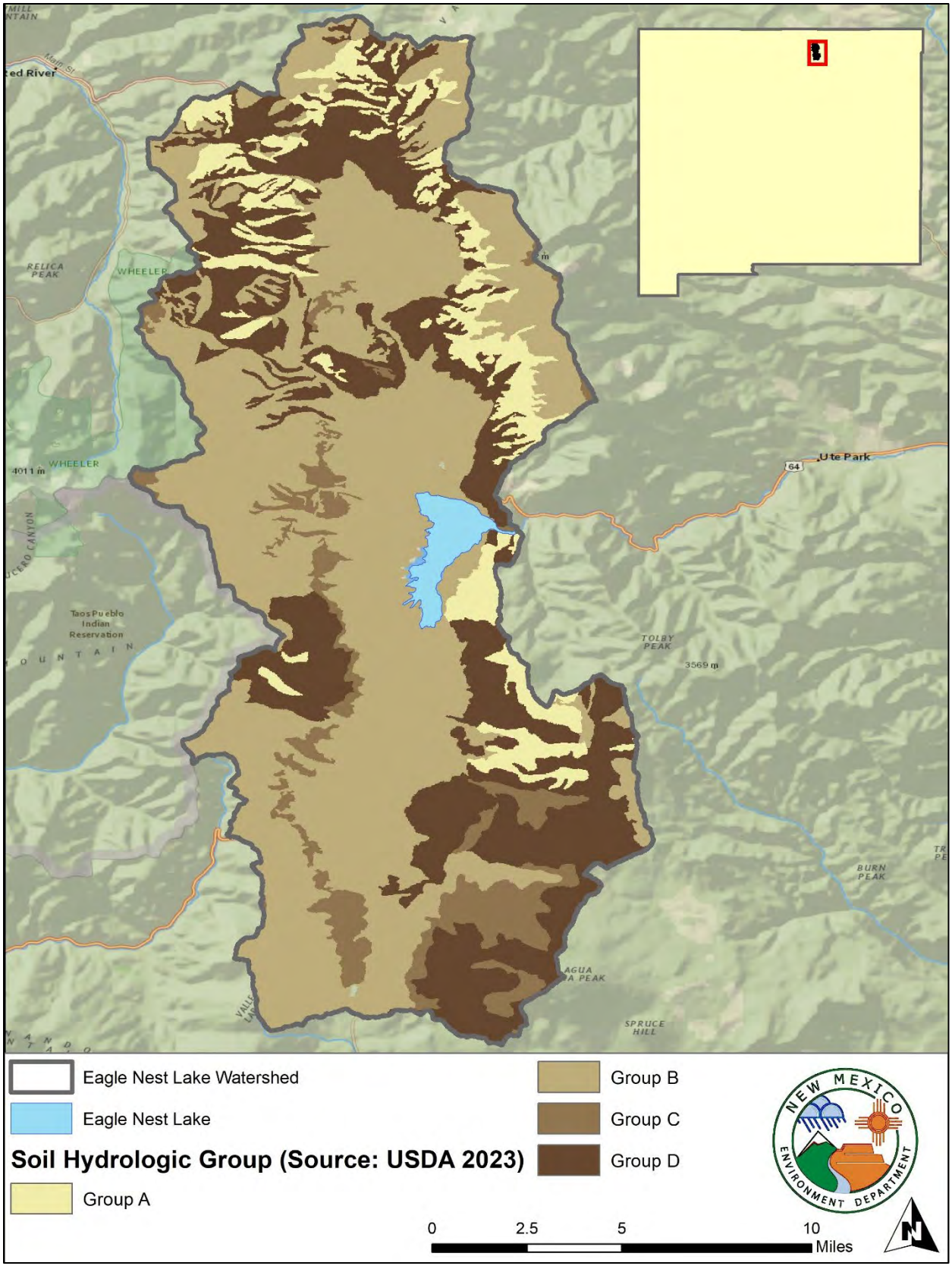


Figure 1.6: Soil Hydrologic Group classification of the Eagle Nest Lake watershed.

1.1.3 Lake Maloya

Lake Maloya is a reservoir located in north-eastern New Mexico on the border with Colorado. The lake has a surface area of 115.54 acres and a capacity of 3690 acre-ft (NMED/SWQB, 2006). The United States Geologic Survey maintains a monitoring station (USGS 07199450) on Lake Maloya to measure lake elevation and capacity. Since 2020 lake storage has varied from 3756 acre-ft to 3044 acre-ft (USGS, 2022). The City of Raton owns the 110-foot-tall earthen dam that creates Lake Maloya and uses the reservoir as a municipal water source. The original Lake Maloya dam was constructed in 1907 and was enlarged in 1949 to increase water storage of the reservoir (City of Raton, 2020). Lake Maloya is also the main feature of the Sugarite Canyon State Park, a popular fishing and camping area. The New Mexico Department of Game and Fish (NMDGF) stocks Lake Maloya with catchable rainbow trout (NMDGF, 2022). Designated uses for Lake Maloya include coldwater aquatic life, irrigation, livestock watering, primary contact, public water supply, and wildlife habitat, with all uses being met except for coldwater aquatic life (NMED/SWQB, 2024).

1.1.4 Lake Maloya Watershed

The Lake Maloya watershed is located within one HUC 12 watershed (110800010101) and covers 20.80 square miles of the Raton Mesas region in the upper reaches of the Canadian River basin. Approximately 85% of the watershed lies in Las Animas County, Colorado, while 15% of the watershed lies in Colfax County, New Mexico. The elevation ranges from 7,454 feet at the lake outlet to 9,537 feet along Raton Mesa, with an average elevation of 8,425 feet. Slopes range from 0 degrees to 84 degrees, with an average slope of 13 degrees. The watershed receives approximately 23 inches of precipitation a year, with an average annual air temperature of approximately 45 degrees Fahrenheit. The Lake Maloya watershed is in the higher elevation region of the Raton Mesas with a cooler and wetter climate than the surrounding lower elevation plains, meaning runoff from stormwater and snowmelt is more consistent than lower elevation watersheds in New Mexico. Lake Maloya is fed by three streams, Schwachheim Creek and Chicorica Creek on the lake's northern shore and Segerstorm Creek on the lake's western shore.

Chicorica and Schwachheim Creek are both located entirely in Colorado, so there is very limited assessment data on these streams for New Mexico. Each stream does have one NMED SWQB monitoring station located at the lake inlet, but sampling has been limited at those locations. Segerstrom Creek is located mostly in Colorado and does not have a NMED SWQB monitoring station located along it. Until further sampling and assessment are completed, the impairment status of these three streams is unknown. Lake Maloya (AU ID: NM-2305.B_20) was first listed as impaired for temperature following a 2006 lake survey which found lake temperature exceedances in two of the six samples collected. Data collected during the 2015-2016 Canadian and Dry Cimarron water quality survey showed new impairments for nutrients and mercury, while temperature was removed as an impairment. Mercury was also removed as an impairment in 2020 because of mercury criterion changes that occurred in 2010, and the lake is currently listed as impaired for nutrients.

The Raton mesas area is located just east of the Sangre de Cristo mountains along the Colorado/New Mexico border. This area consists of many table-top mesas, the product of continuous erosion and geologic makeup. The mesas are capped by a layer of hard basalt from ancient volcanic activity, while soft shale from the Cretaceous period and sandstone mainly from the Tertiary period lie underneath (Lee 1921). Igneous rocks underlie approximately 36.9% of the watershed, sedimentary rocks approximately

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55.1% and unconsolidated approximately 8.0% (**Figure 1.9**). Soils in the watershed typically have low infiltration rates, with the lowest infiltration rates found atop the many mesas throughout the watershed. Hydrologic Group B soils (moderate infiltration rate) make up approximately 1.8% of the watershed, Group C soils (slow infiltration rate) 28.4% of the watershed, Group D soils (very slow infiltration rate) 67.6% of the watershed, and 2.2% of the watershed does not have hydrologic soil group data (**Figure 1.12**).

The 2011 Track Fire greatly altered the land cover of the Lake Maloya watershed. 27,792 acres in total were burned across the Raton Mesas region, including 19,970 acres in New Mexico and 7,822 acres in Colorado (Southwest Fire Science Consortium 2012). Forest coverage across the watershed was reduced by a large percentage, replaced with herbaceous land cover. As of 2019, land cover for the watershed is approximately 41.4% herbaceous (an increase of 37.5% since 2001), 41.0% shrubland (a decrease of 3.7% since 2001), 13.6% forests (a decrease of 33.6% since 2001), 2.9% wetlands, 1.0% water and <1.0% each developed and planted/cultivated (**Figure 1.10**). Approximately 64.8% of the watershed is situated in Level IV Ecoregion 21j (Grassland Parks) and 25.2% is situated in Ecoregion 21f (Sedimentary Mid-elevation Forests) (**Figure 1.8**). Land ownership is approximately 51.1% Bureau of Land Management and 48.9% Private (**Figure 1.11**). Much of the watershed is in the Rocky Mountain District of the Bureau of Land Management. Major land uses in the area include livestock grazing and recreation, such as camping, hunting, hiking, boating, and fishing. Within Colfax County, NM and Las Animas County, CO the Bald Eagle (*Haliaeetus leucocephalus*), Canada Lynx (*Lynx canadensis*), Mexican Spotted Owl (*Strix occidentalis lucida*), New Mexican Meadow Jumping Mouse (*Zapus hudsonius luteus*), Organ Mountains Colorado Chipmunk (*Neotamias quadrivittatus australis*), Pacific Marten (*Martes caurina*), Piping Plover (*Charadrius melodus*), Southern Redbelly Dace (*Chrosomus erythrogaster*), Star Gyro (*Gyraulus crista*), Suckermouth Minnow (*Phenacobius mirabilis*), White-Tailed Ptarmigan (*Lagopus leucura*), and the Yellow-Billed Cuckoo (*Coccyzus americanus*) are listed as either Threatened or Endangered by state and/or federal agencies (NHNM Species Information, *https://nhnm.unm.edu/*, accessed 07/26/2022).

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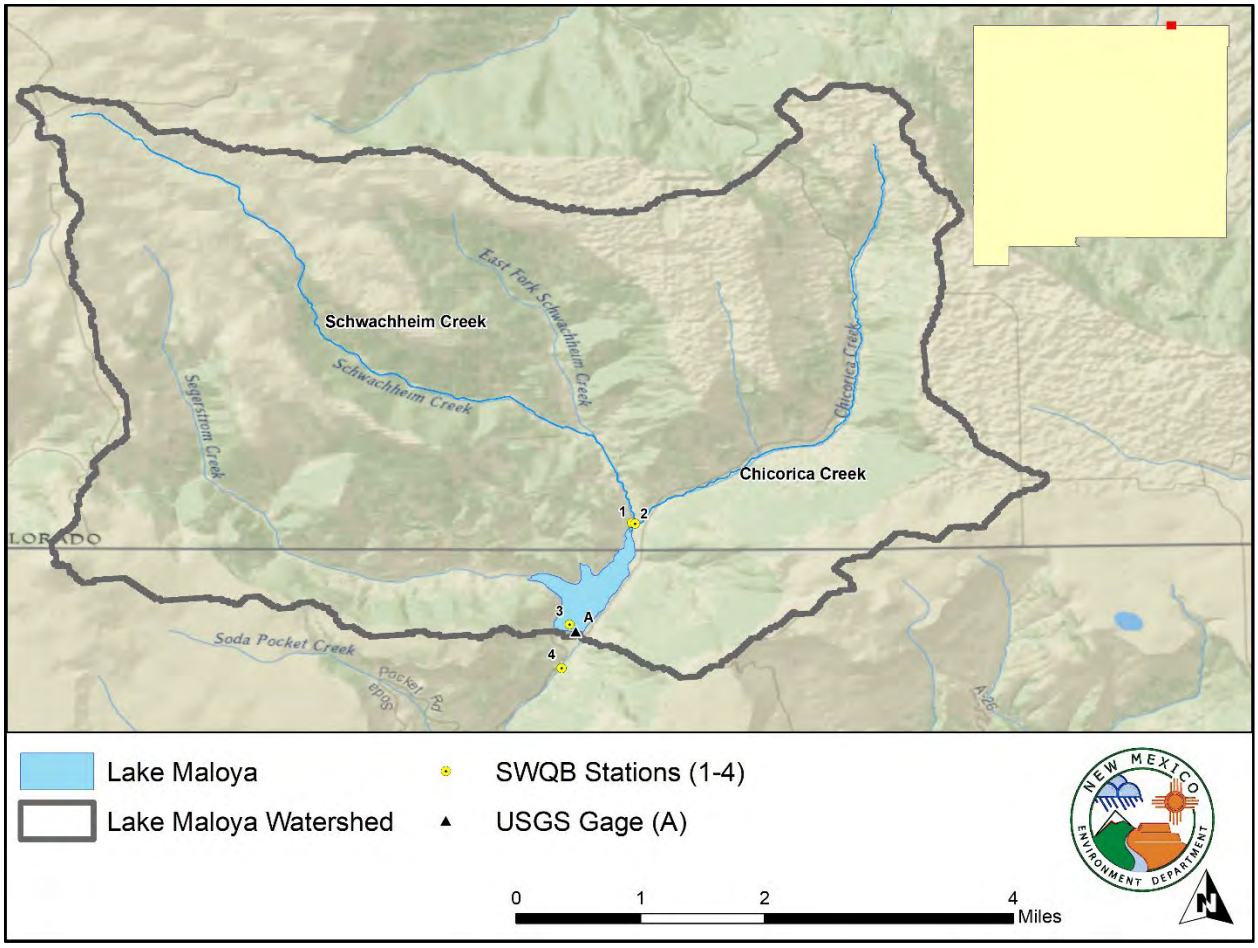


Figure 1.7: Overview map of the Lake Maloya watershed. SWQB Stations (1-4) and USGS Gage (A) are identified in Table 1.2.

Table 1.2: Relevant SWQB Stations and USGS Gage shown in Figure 1.6.

Map Label	AU ID/Name	Station ID/Name
1	NM-9000.A_02x, Canadian r basin inlet/outlets, drains, canals, conveyances	04LMaloSchwIn, Lake Maloya Inlet at Schwachheim Creek
2	NM-9000.A_02x, Canadian r basin inlet/outlets, drains, canals, conveyances	04LMaloChicIn, Lake Maloya Inlet at Chicorica Creek
3	NM-2305.B_20, Lake Maloya	04LMaloyaDeep, Lake Maloya (Deep)
4	NM-2305.A_251, Chicorica Creek (East Fork Chicorica to Lake Maloya)	04Chicor037.3, Chicorica Creek below Maloya
A	NM-2305.B_20, Lake Maloya	USGS Gage 07199450, Lake Maloya near Raton, NM

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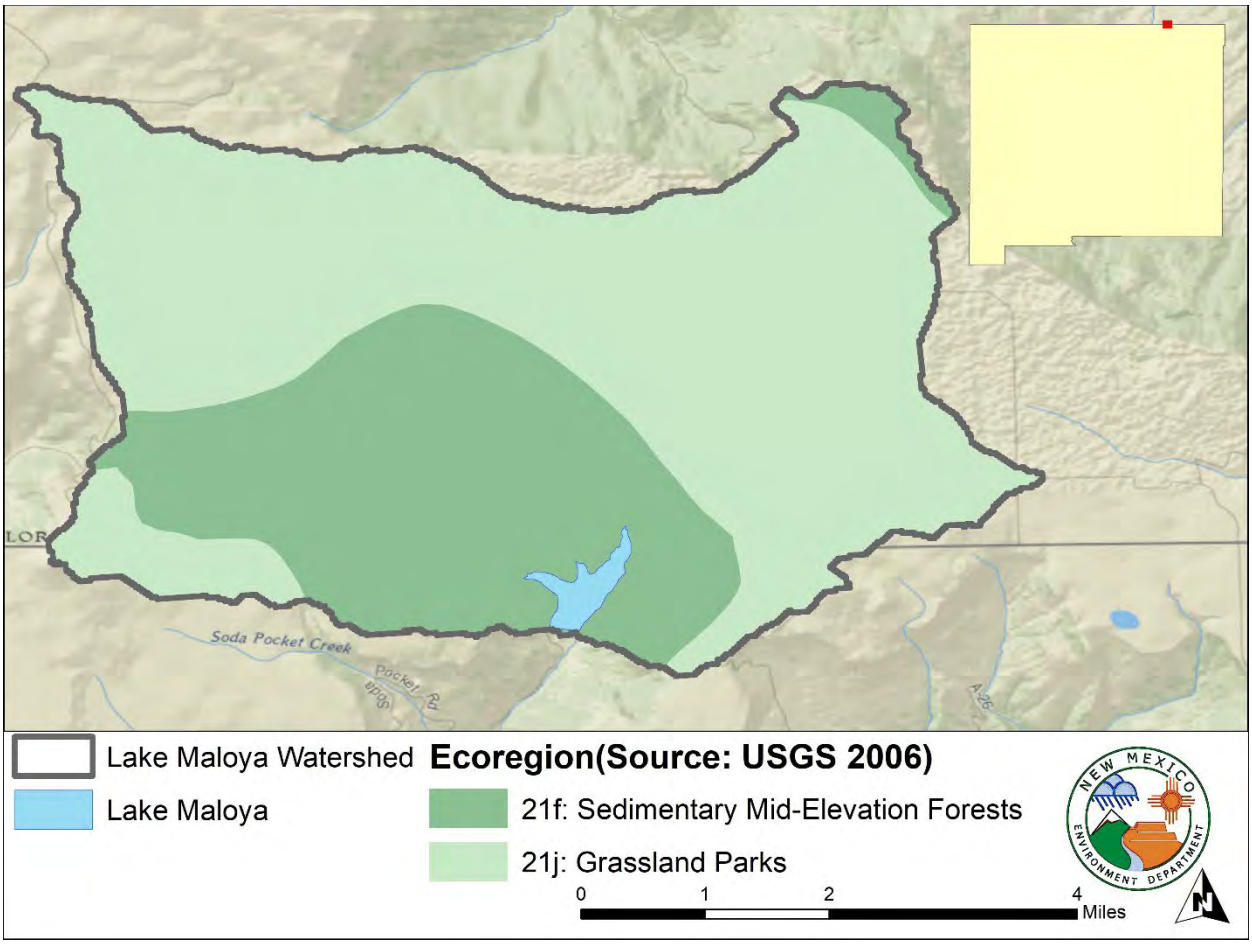


Figure 1.8: Ecoregions of the Lake Maloya watershed.

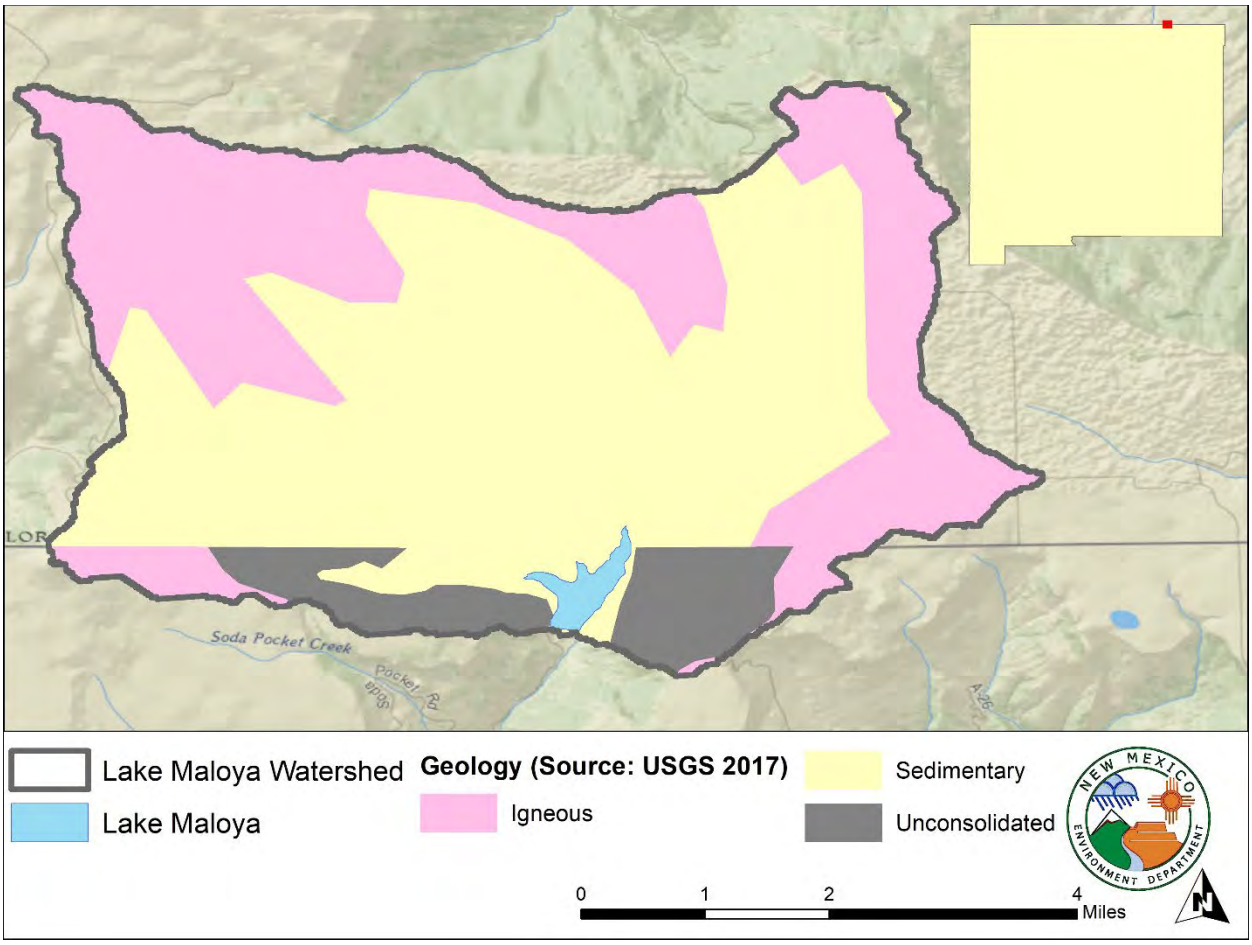


Figure 1.9: Surface geology of the Lake Maloya watershed.

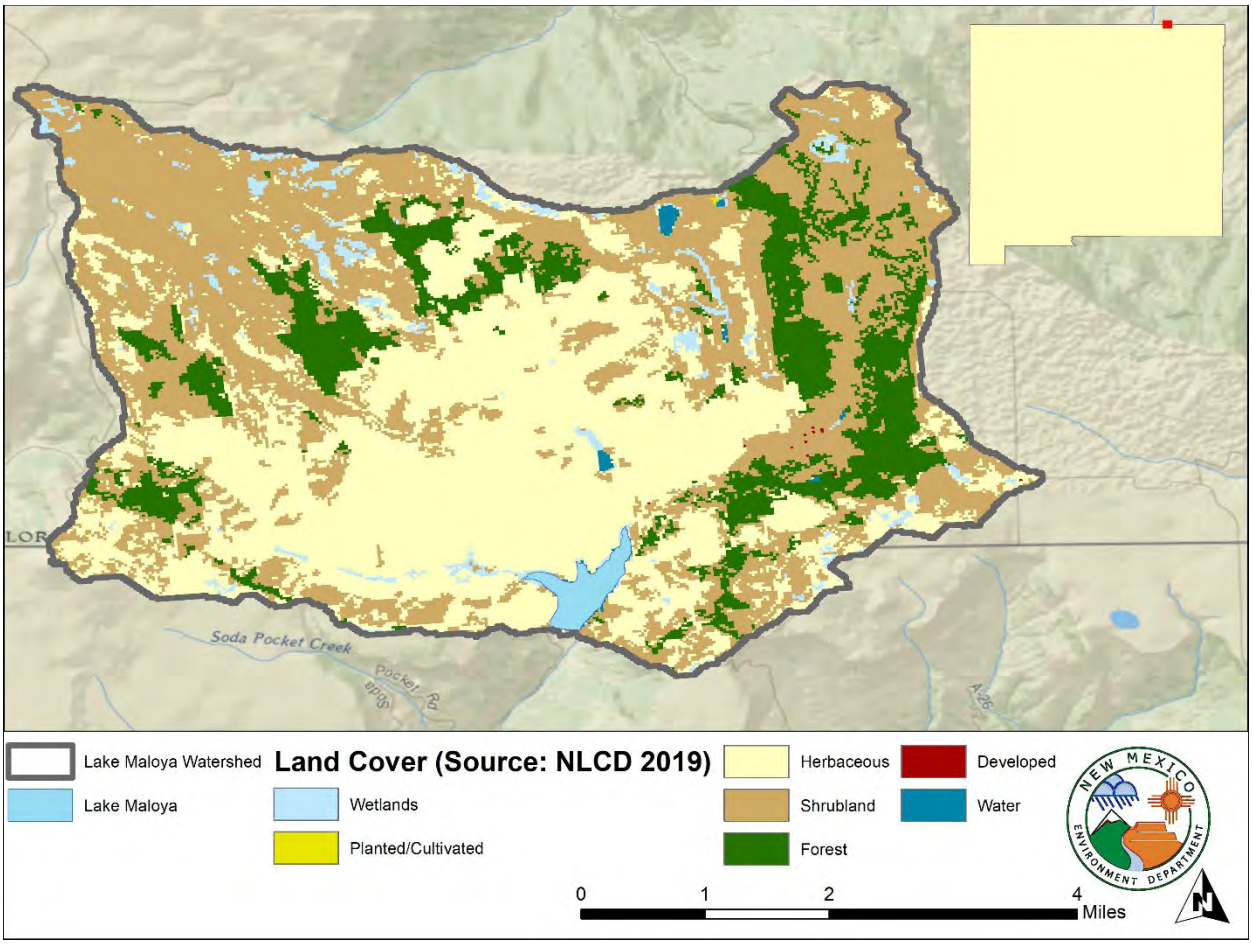


Figure 1.10: Land Cover of the Lake Maloya watershed.

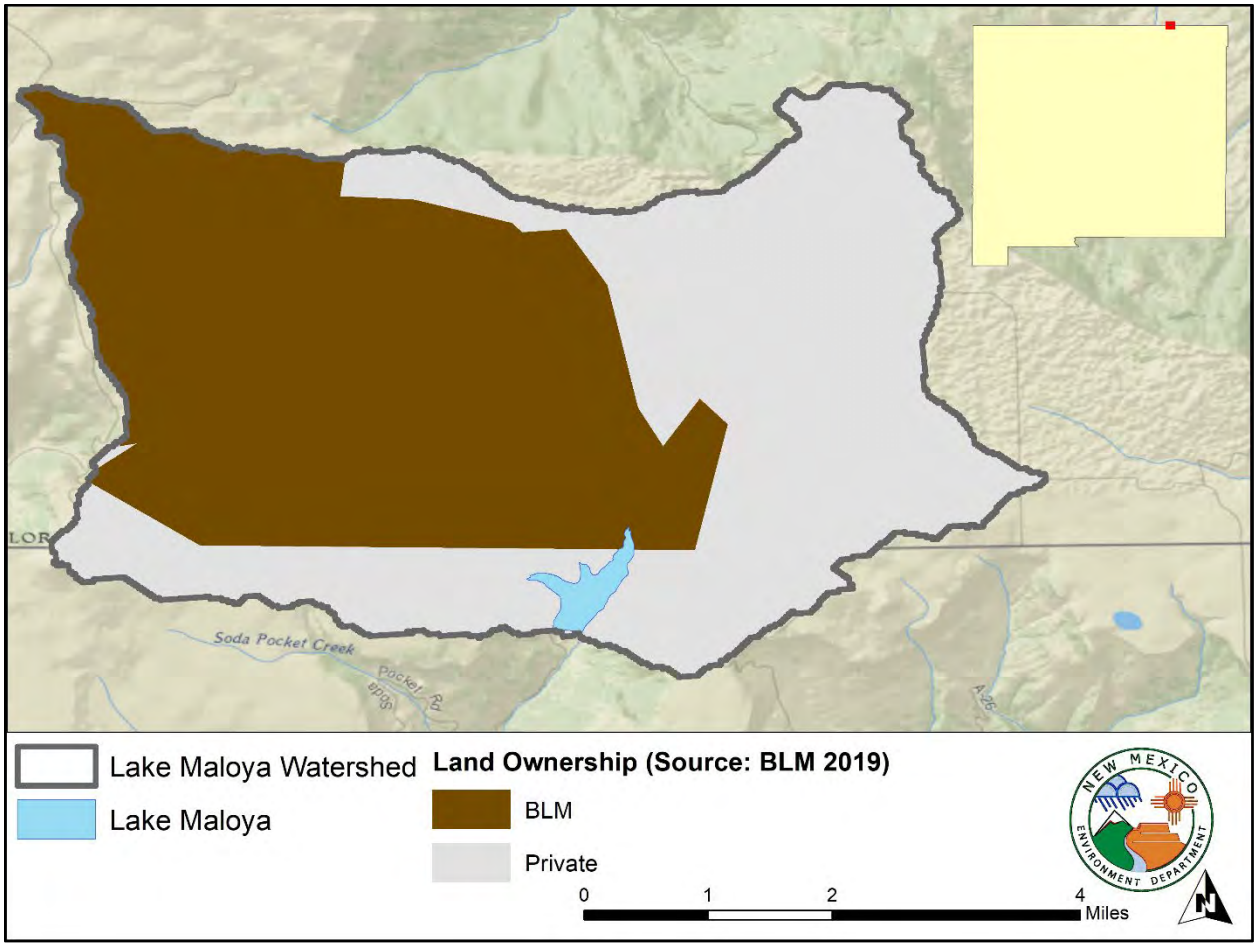


Figure 1.11: Land Ownership of the Lake Maloya watershed.

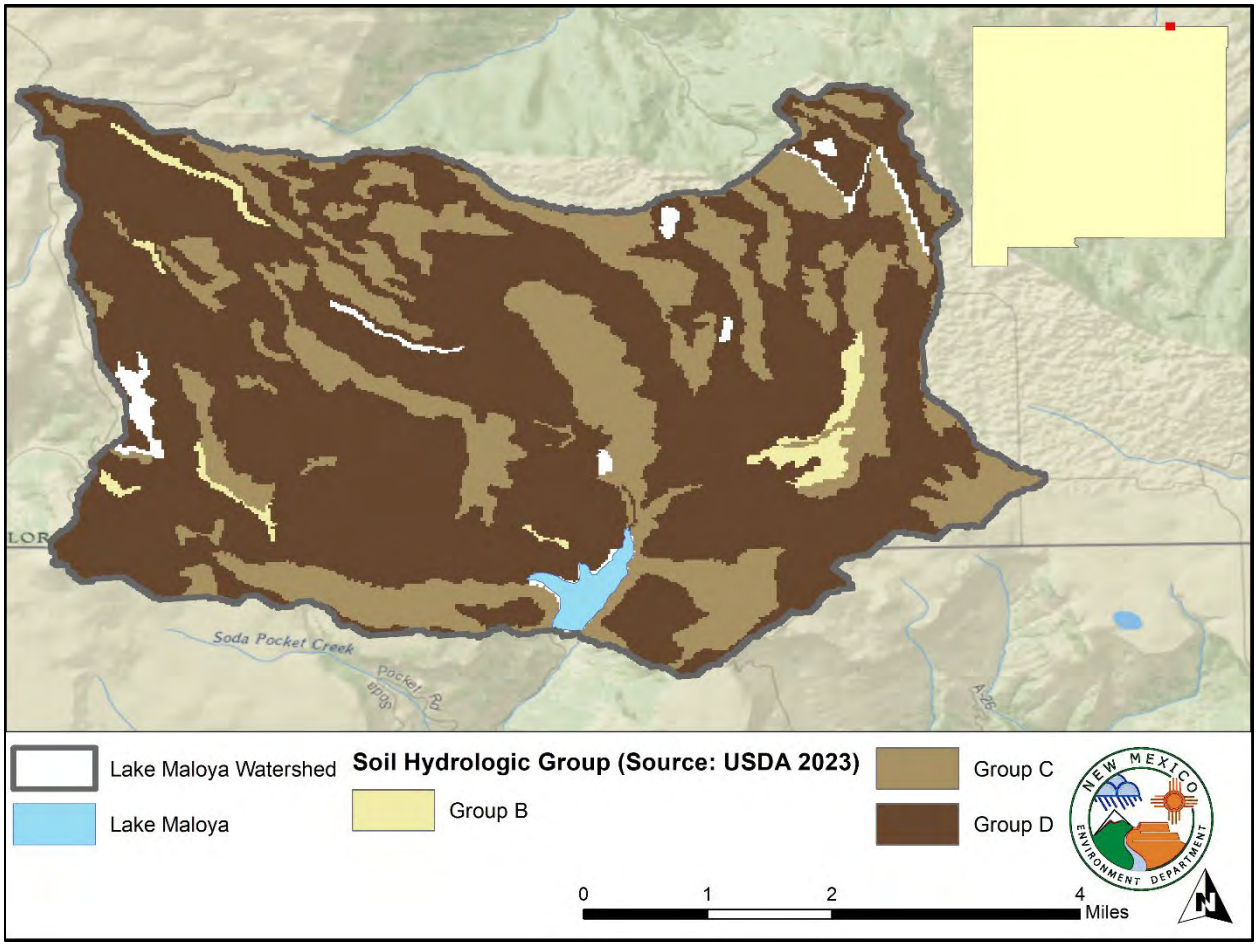


Figure 1.12: Soil Hydrologic Group classification of the Lake Maloya watershed.

1.1.5 Santa Cruz Lake

Santa Cruz Lake is a reservoir located in north-central New Mexico in the Sangre de Cristo foothills near the town of Chimayo. The reservoir is the main feature of the Santa Cruz Recreational Area, managed and maintained by the Bureau of Land Management (BLM), providing hiking, fishing, camping and boating opportunities for the public. The New Mexico Department of Game and Fish (NMDGF) lists rainbow trout, brown trout and bluegills as present in the lake (NMDGF 2006). The largest recorded rainbow trout caught in New Mexico was fished from Santa Cruz Lake on March 13, 1999, weighing 31lb., 12.5 oz. (NMDGF 2020). The Santa Cruz Irrigation District constructed a 125ft tall concrete dam in 1929 to create Santa Cruz Lake for the purposes of flood control, irrigation and recreation (NMED/SWQB 2009). The Santa Cruz Irrigation District manages releases from Santa Cruz Lake for irrigation, and lake levels can drop significantly during times of high irrigation needs (NMED/SWQB 2009). Santa Cruz Lake is fed by the Rio Medio and the Rio Frijoles, which converge just upstream of the lake to form the Santa Cruz River. The reservoir has a surface area of 100 acres, with an estimated capacity of about 3,000 acre-feet (NMED/SWQB 2009), while the National Inventory of Dams (NID) lists the reservoir maximum capacity at 5,948 acre-feet (NID 2021). Designated uses for Santa Cruz Lake include domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, primary contact and wildlife habitat, with all uses being met except for high quality coldwater aquatic life (NMED/SWQB 2024).

1.1.6 Santa Cruz Lake Watershed

The Santa Cruz Lake watershed is made up of three HUC 12 watersheds (130201011001, 130201011002, 130201011104) and covers 98.40 square miles of the western Sangre de Cristo Mountains in the Upper Rio Grande basin. Approximately 83% of the watershed lies in Santa Fe County, while 17% of the watershed lies in Mora County. The elevation ranges from 6,190 feet at the lake outlet to 13,067 feet at Truchas Peak, with an average elevation of 9,041 feet. Slopes range from 0 degrees to 86 degrees, with an average slope of 22 degrees. The watershed receives approximately 25 inches of precipitation a year, with an average annual air temperature of approximately 43 degrees Fahrenheit. Runoff from stormwater and snowmelt is more consistent than many New Mexico watersheds given the eastern portion of the watershed's higher elevation and wetter climate, resulting in regular surface input from the Santa Cruz River.

The Santa Cruz River (AU ID: NM-2118.A_51) was included in the 2017-2018 Upper Rio Grande survey. Exceedances were observed for aluminum and thermograph data showed impairment for temperature. During the 2020 assessment period, the Santa Cruz River was listed as impaired for aluminum and temperature, and lead was noted as a parameter of concern. TMDLs were written for total recoverable aluminum and temperature for this AU and included in the Upper Rio Grande TMDL document. They are pending WQCC approval and the outcome of the Court of Appeals Case Number A-1-CA-40799, NM Environment Department v. Water Quality Control Commission. Santa Cruz Lake (AU ID: NM-218.B_00) was sampled during 2009 and again during the 2017-2018 Upper Rio Grande survey. Temperature impairment was noted during the 2009 survey. Aluminum, nutrients, and temperature were all noted as impairments during the 2017-2018 survey and are the current impairments for Santa Cruz Lake.

The western portion of the Santa Cruz Lake watershed is in the Espanola Badlands, which consists of coalesced alluvial fans formed in the Tertiary time. These alluvial fans have been eroded into the present-day ridges, valleys and badlands that make up the lower elevation western portion of the Santa Cruz Lake

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watershed (Chronic 1987). The Santa Fe Mountains, a subrange of the Sangre de Cristo Mountains, occupy the eastern portion of the Santa Cruz Lake watershed. These mountains are fault-block mountains and fault lines run along the west and east sides of the mountains. The Santa Fe mountains are comprised of mainly Precambrian rock (Clark 1966). Metamorphic rocks underlie approximately 47.2% of the watershed, mixed igneous and metamorphic rocks approximately 29.1%, 16.1% purely igneous rocks, and 7.4% purely sedimentary rocks. (**Figure 1.15**) (USGS 2017). Soils in the watershed are typically well draining, however sporadic surface outcroppings inhibit infiltration rates in the high elevation mountain peaks on the eastern side of the watershed and in the badlands closer to the lake on the western side of the watershed. Hydrologic Group A (high infiltration rate) make up approximately 19.1% of the watershed, Group B soils (moderate infiltration rate) 31.3% of the watershed, Group C soils (low infiltration rate) 34.5% of the watershed, Group C/D soils (low/very low infiltration rate) 0.7% of the watershed, Group D soils (very low infiltration rate) 8.4% of the watershed, and 6% of the watershed does not have hydrologic group soil data (**Figure 1.18**).

As of 2019, land cover for the watershed is approximately 75.0% forest (a decrease of 9.5% since 2001), 19.6% shrubland (an increase of 7.3% since 2001), 4.5% herbaceous (an increase of 2.1% since 2001), and <1.0% each water, planted/cultivated, wetlands, and water (**Figure 1.16**). Approximately 40.2% of the watershed is situated in Level IV Ecoregion 21c (Crystalline Mid-Elevation Forests), 33.2% is situated in Ecoregion 21b (Crystalline Subalpine Forests), 13.0% is situated in Ecoregion 21d (Foothill Shrublands), 8.8% is situated in Ecoregion 22h (North Central New Mexico Valleys and Mesas), and 4.8% is situated in Ecoregion 21a (Alpine) (**Figure 1.14**). Land ownership is approximately 83.3% Forest Service, 8.3% Bureau of Land Management, 8.2% Private and <1.0% each Tribal and State (**Figure 1.17**). Much of the watershed is within the Espanola Ranger District of the Santa Fe National Forest. Major land uses in the area include livestock grazing and recreation, such as camping, hunting, hiking, boating, and fishing. Within Mora and Santa Fe counties, including the Santa Cruz Lake watershed, the Bairds Sparrow (*Ammodramus bairdii*), Bald Eagle (*Haliaeetus leucocephalus*), Boreal Owl (*Aegolius funereus*), Broad-Billed Hummingbird (*Cynanthus latirostris*), Gray Vireo (*Vireo vicinior*), Great Plains Lady's Tresses (*Spiranthes magnicamporum*), Lilljeborg's Pea-Clam (*Pisidium lilljeborgi*), Mexican Spotted Owl (*Strix occidentalis lucida*), Mountain Lily (*Lilium philadelphicum var. adninum*), New Mexican Meadow Jumping Mouse (*Zapus hudsonius luteus*), Northern Beardless-Tyrannulet (*Camptostoma imberbe*), Pacific Marten (*Martes caurina*), Rio Grande Silvery Minnow (*Hydognathus amarus*), Santa Fe Cholla (*Cylindroputia viridiflora*), Southern Pocket Gopher (*Thomomys umbrinus*), Southwestern Willow Flycatcher (*Empidonax traillii extimus*), Spotted Bat (*Euderma maculatum*), Suckermouth Minnow (*Phenacobius mirabilis*), White-Tailed Ptarmigan (*Lagopus leucura*), Yellow Lady's-Slipper (*Cypripedium parviflorum var. pubescens*), and Yellow-Billed Cuckoo (*Coccyzus americanus*) are listed as either Threatened or Endangered by state and/or federal agencies (NHNM Species Information, *https://nhnm.unm.edu/*, accessed 03/17/2022).

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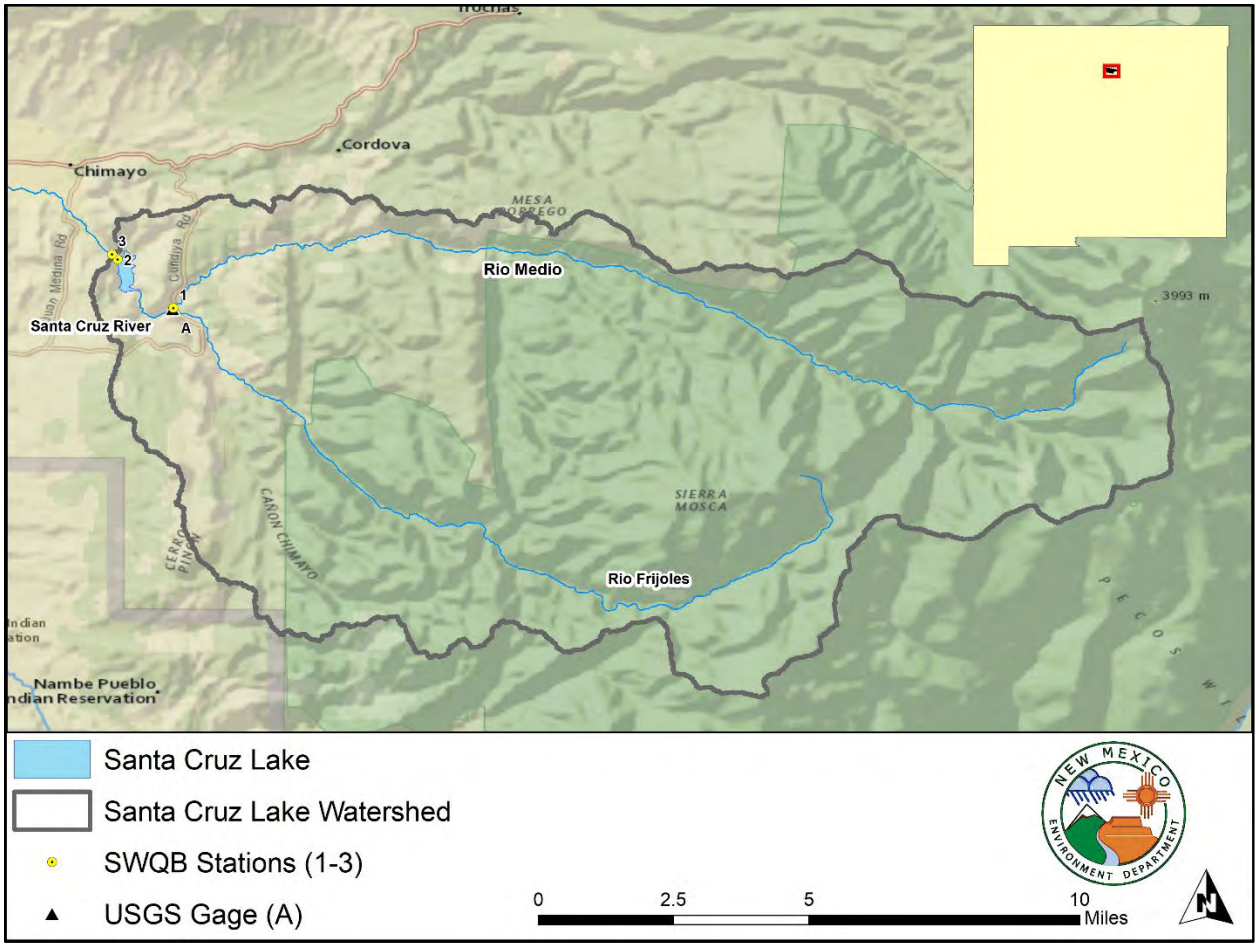


Figure 1.13: Overview map of the Santa Cruz Lake watershed. SWQB Stations (1-3) and USGS Gage (A) are identified in Table 4.1.

Table 1.3: Relevant SWQB Stations and USGS Gage show in Figure 1.11.

Map Label	AU ID/Name	Station ID/Name
1	NM-2118.A_51, Santa Cruz River (Santa Cruz Reservoir to Rio Medio)	28SanCruz019.1, Santa Cruz River at USGS Gage 08291000
2	NM-2118.B_00, Santa Cruz Lake	28SantaCruzDp, Santa Cruz Lake (deep)
3	NM-2111_50, Santa Cruz River (Santa Clara Pueblo bnd to Santa Cruz Dam)	28SanCru016.0, Santa Cruz River below Santa Cruz Lake
A	NM-2118.A_51, Santa Cruz River (Santa Cruz Reservoir to Rio Medio)	USGS Gage 08291000, Santa Cruz River near Cundiyo, NM

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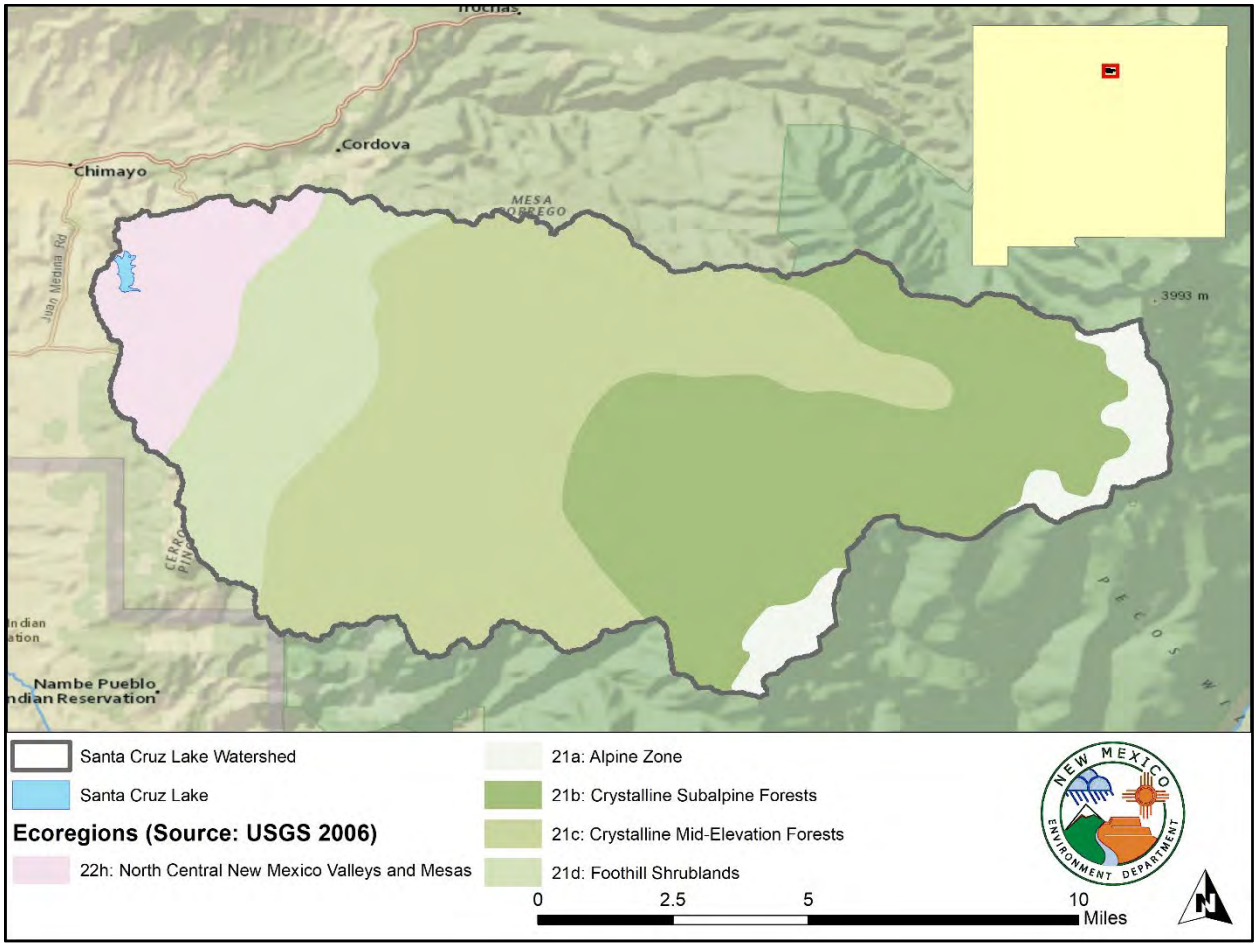


Figure 1.14: Ecoregions of the Santa Cruz Lake watershed.

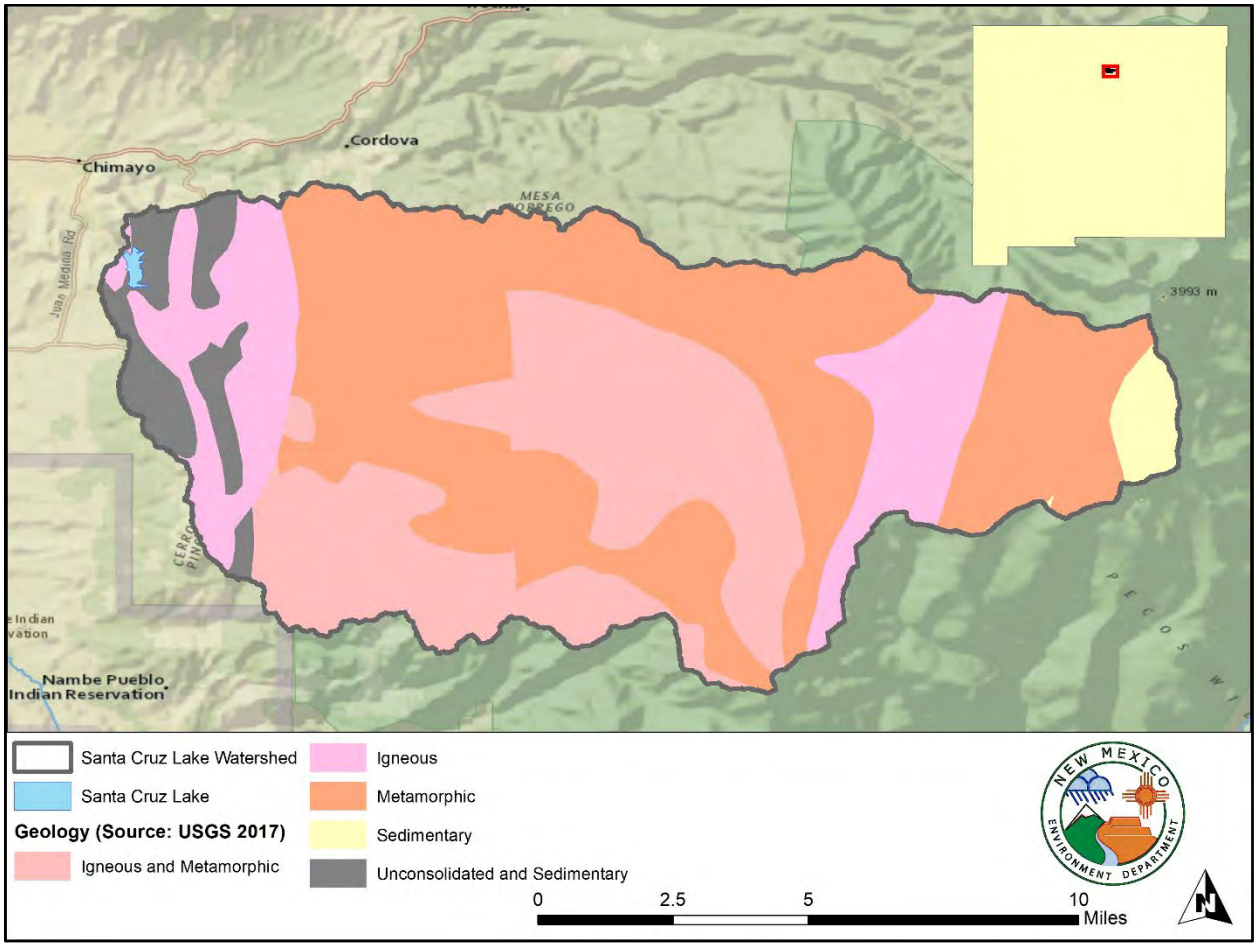


Figure 1.15: Surface geology of the Santa Cruz Lake watershed.

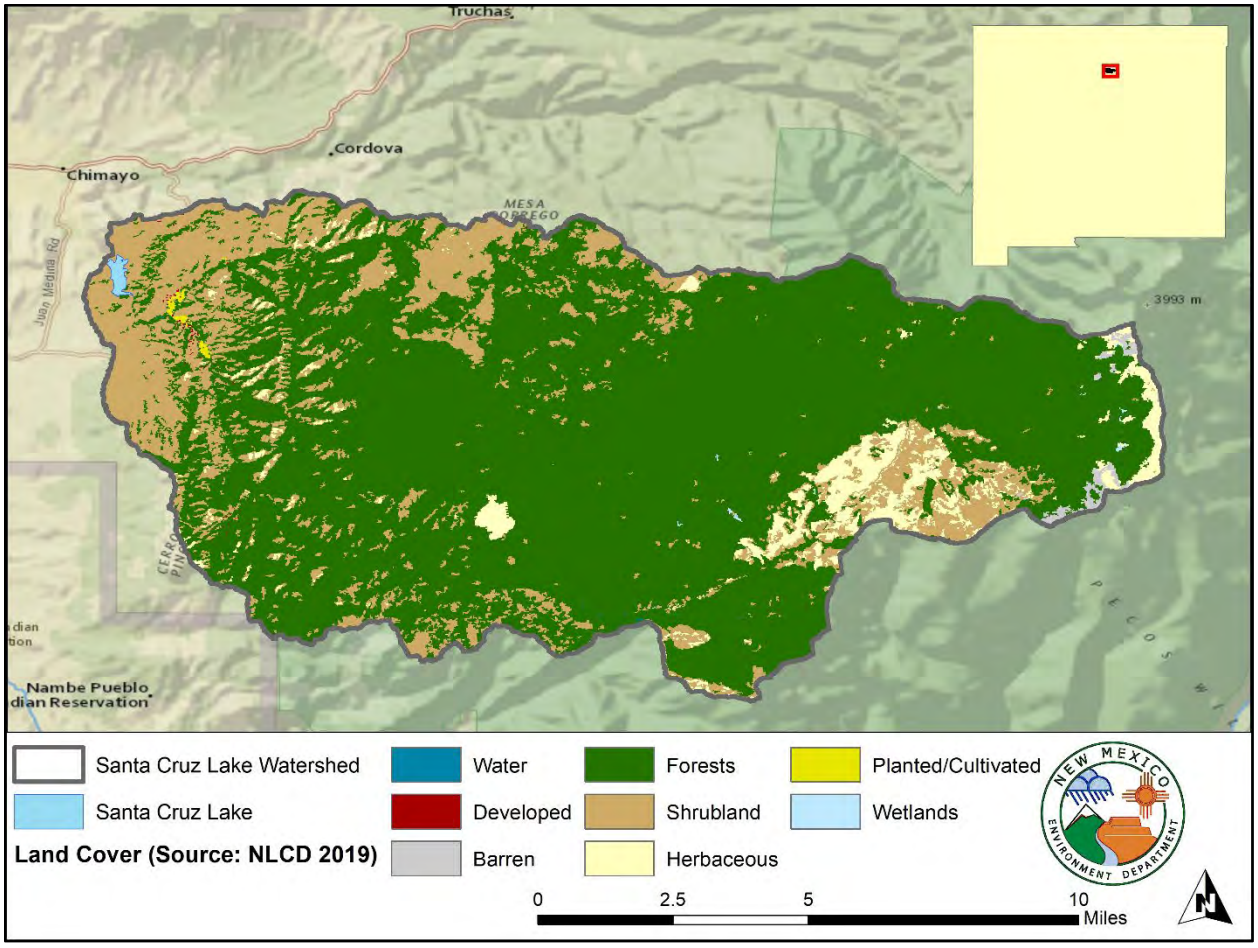


Figure 1.16: Land Cover of the Santa Cruz Lake watershed.

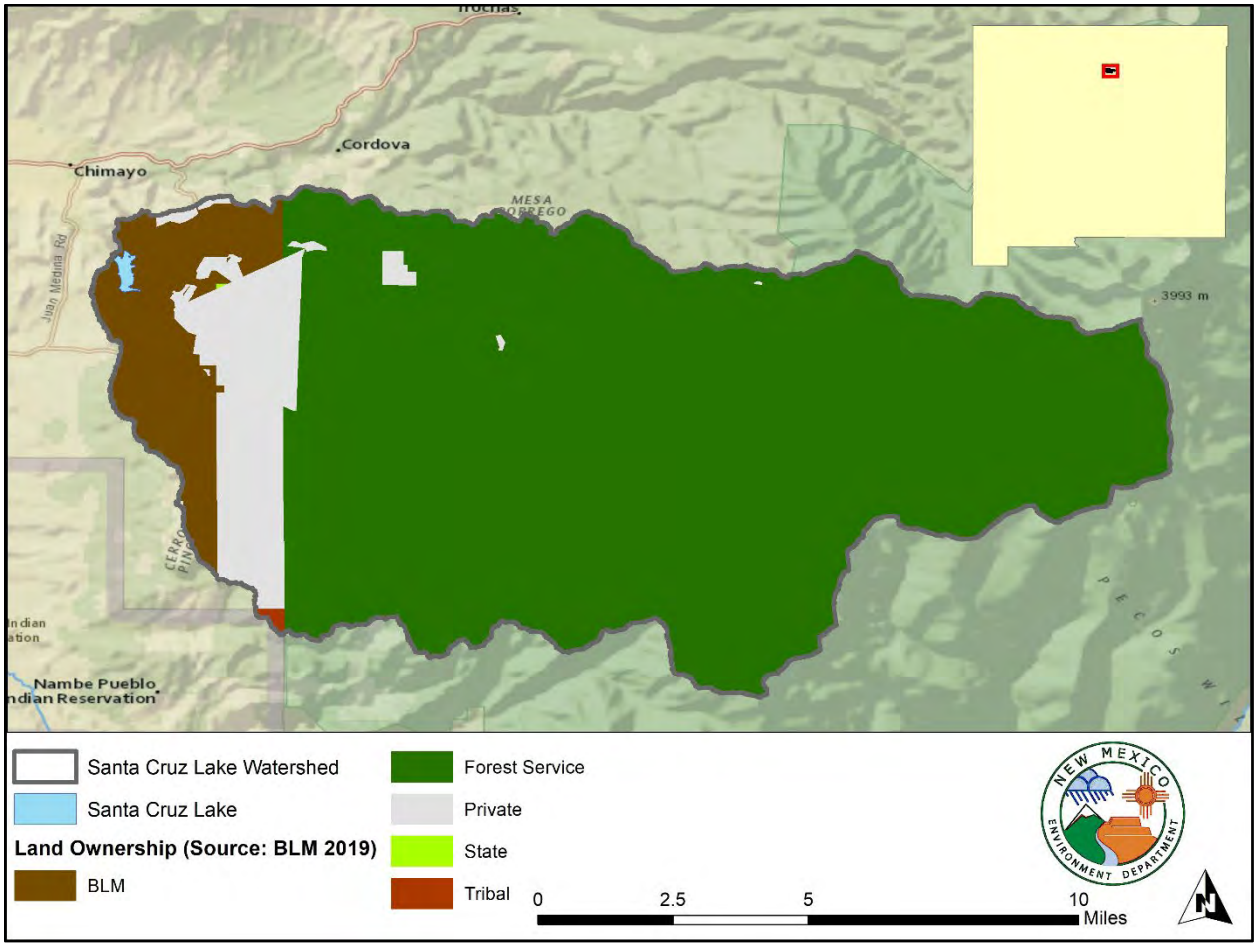


Figure 1.17: Land Ownership of the Santa Cruz Lake watershed.

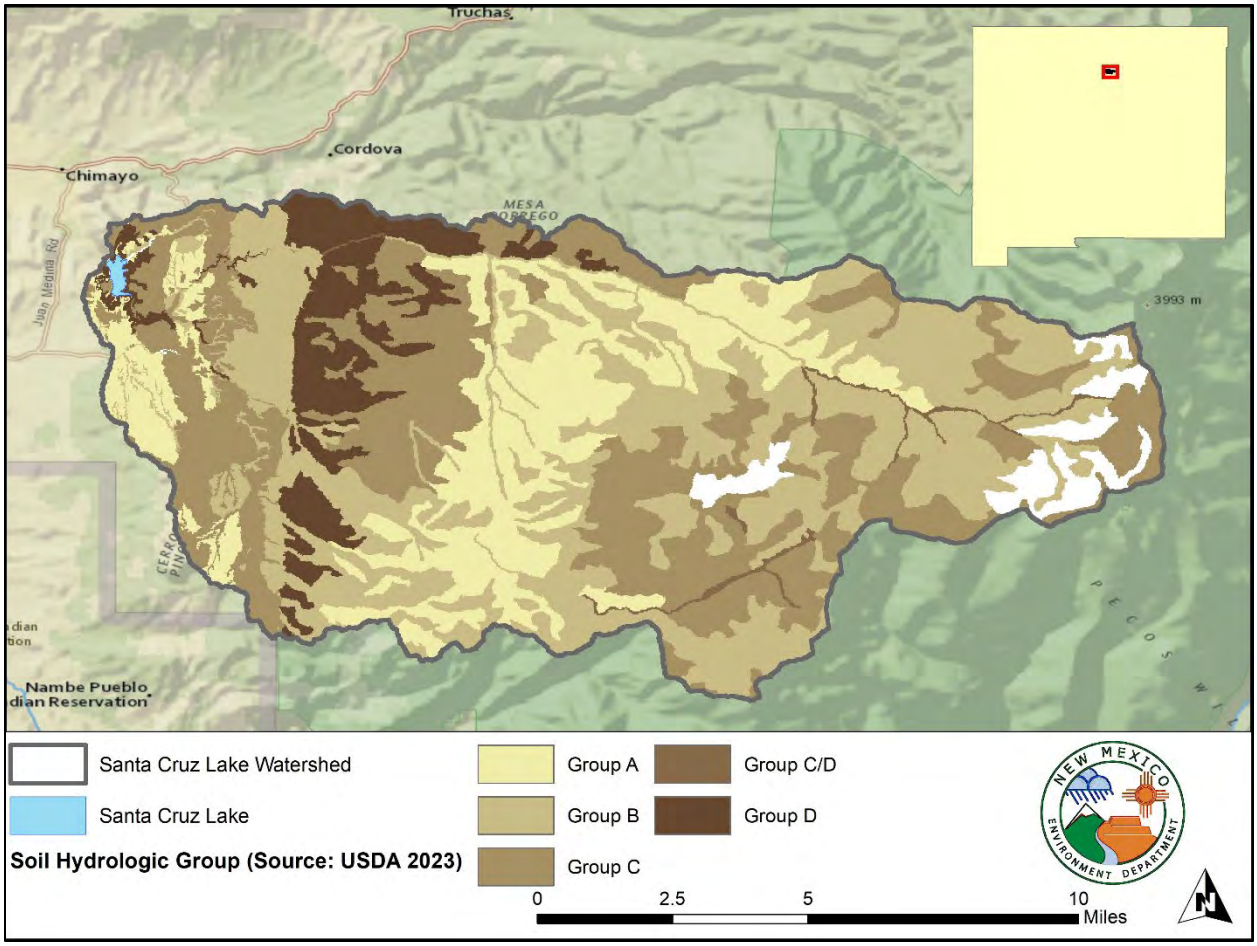


Figure 1.18: Soil Hydrologic Group classification of the Santa Cruz Lake watershed.

1.1.7 Shuree Pond North

Shuree Pond North is a small impoundment along Shuree Creek located near other small ponds. Shuree Pond North is the most significant impoundment in the cluster. The reservoir has a surface area of 6.19 acres (NMED/SWQB, 2024) and a storage capacity of 54 acre-ft. Shuree Pond North is impounded by a 42-foot-tall earthen dam, completed in 1971, that is owned by the United States Forest Service (USFS). The reservoir is in the Valle Vidal Unit of the Carson National Forest. The USFS manages the Shuree Lakes Fishing area, which includes Shuree Pond North. A small population of rainbow trout is stocked and maintained by the NMDGF (NMED/SWQB, 2006). Designated uses for Shuree Pond North include domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, primary contact and wildlife habitat, with all uses being met except for high quality coldwater aquatic life (NMED/SWQB, 2024).

1.1.8 Shuree Pond North Watershed

The Shuree Pond North watershed is located within one HUC 12 watershed (110800020202) and covers 1.98 square miles of the Sangre de Cristo Mountains in the upper reaches of the Canadian River basin. The watershed is located entirely in Colfax County. The elevation ranges from 9,284 feet at the lake outlet to 11,122 feet at an unnamed mountain peak, with an average elevation of 9,839 feet. Slopes range from 0 degrees to 70 degrees, with an average slope of 11 degrees. The watershed receives approximately 22 inches of precipitation a year, with an average annual air temperature of approximately 43 degrees Fahrenheit. Surface input to Shuree Pond North is limited and occurs mainly during the annual snowmelt, otherwise flow from Shuree Creek is intermittent and often dry.

Sampling was attempted at Shuree Creek just above Shuree Pond North during the 2015-2016 Canadian and Dry Cimarron, however during each sampling event the stream was dry. Therefore, no data has been collected at Shuree Creek, the creek remains unassessed, and it is unknown if the stream is impaired. Shuree Pond North (AU ID: NM-2306.B_30) was sampled during the 2015-2016 Canadian and Dry Cimarron water quality survey and during the 2018 assessment was found to be impaired for nutrients.

Sedimentary rocks underlie approximately 51.5% of the watershed, unconsolidated approximately 44.3%, and 4.2% purely igneous rock (**Figure 1.21**) (USGS 2017). Soils in the watershed are typically not well-drained, except for the ridges along the north and east edges of the watershed. Hydrologic Group A soils (high infiltration rate) make up approximately 15.3% of the watershed, Group B soils (moderate infiltration rate) 21.3% of the watershed, Group C soils (low infiltration rate) 50% of the watershed, Group D soils (very low infiltration rate) 12.9% of the watershed, and there is no hydrologic soil group data for 0.5% of the watershed (**Figure 1.24**).

As of 2019, land cover for the watershed is approximately 54.9% forest, 22.8% shrubland, 21.4% herbaceous, and <1.0% each wetland and water (**Figure 1.22**). There were no changes in land cover from 2001 to 2019. Approximately 86.1% of the watershed is situated in Level IV Ecoregion 21f (Sedimentary Mid-Elevation Forests) and 13.9% is situated in Ecoregion 21e (Sedimentary Subalpine Forests) (**Figure 1.20).** Land ownership is 100% Forest Service (**Figure 1.23**). The entire watershed is within the Questa Ranger District of the Carson National Forest. Major land uses in the area include recreation, such as camping, hunting, hiking, boating and fishing. Within Colfax County, including the Shuree Pond North watershed, the Bald Eagle (*Haliaeetus leucocephalus*), Mexican Spotted Owl (*Strix occidentalis lucida*),

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New Mexican Meadow Jumping Mouse (*Zapus hudsonius luteus*), Organ Mountains Colorado Chipmunk (*Neotamias quadrivittatus australis*), Pacific Marten (*Martes caurina*), Piping Plover (*Charadrius melodus*), Southern Redbelly Dace (*Chrosomus erythrogaster*), Star Gyro (*Gyraulus crista*), Suckermouth Minnow (*Phenacobius mirabilis*), White-Tailed Ptarmigan (*Lagopus leucura*), and the Yellow-Billed Cuckoo (*Coccyzus americanus*) are listed as either Threatened or Endangered by state and/or federal agencies (NHNM Species Information, *https://nhnm.unm.edu/*, accessed 03/17/2022).

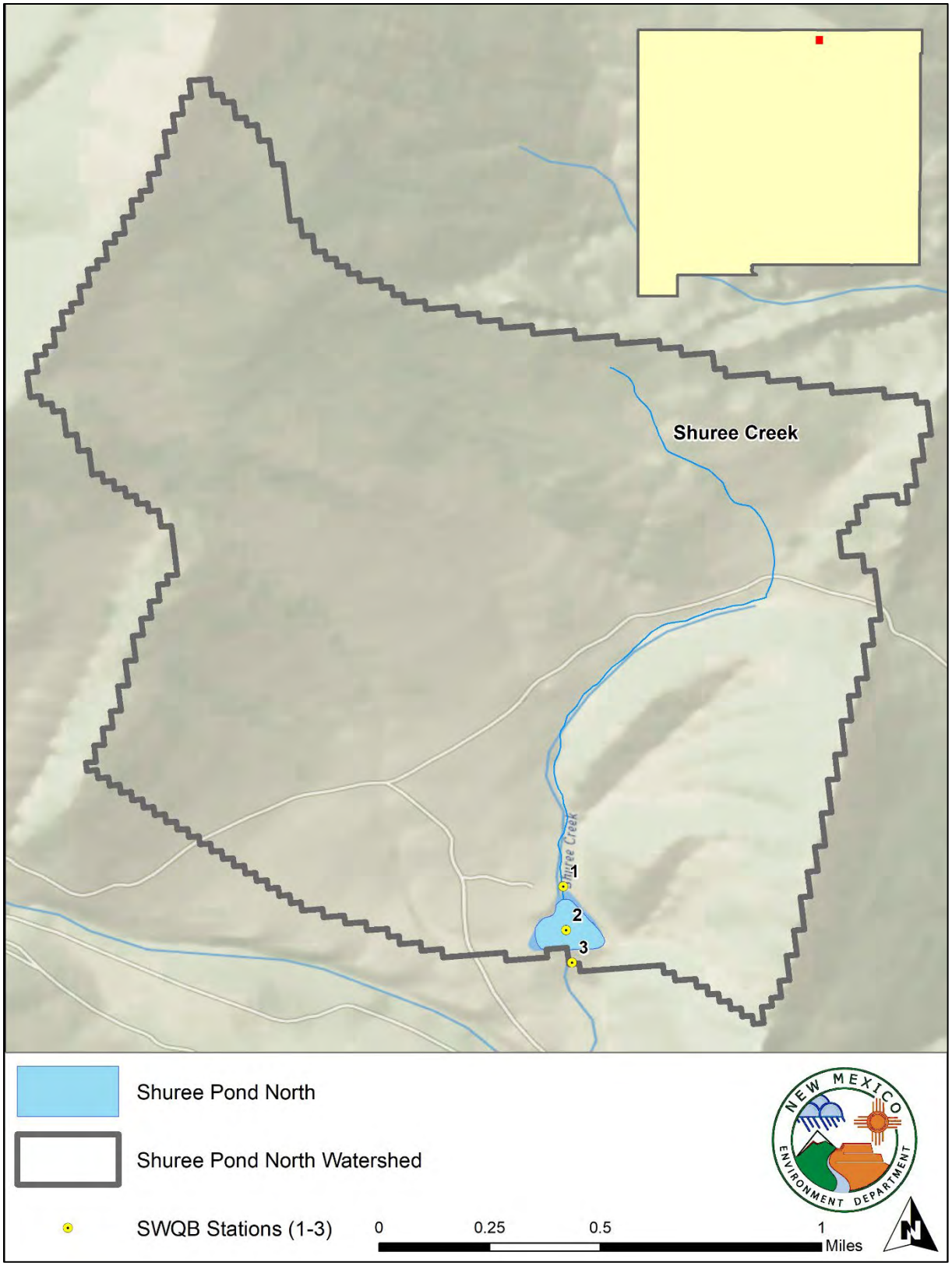


Figure 1.19: Overview map of the Shuree Pond North watershed. SWQB Stations (1-3) are identified in Table 5.1.

Table 1.4: Relevant SWQB Stations shown in Figure 1.16.

Map Label	AU ID/Name	Station ID/Name
1	NM-2306.B_30, Shuree Pond (North)	05ShurCr000.8, Shuree Creek above Shuree Pond
2	NM-2306.B_30, Shuree Pond (North)	05NShureeDeep, North Shuree Pond (Deep)
3	NM-2306.B_30, Shuree Pond (North)	05ShurCr000.6, Shuree Creek blw Shuree Pond

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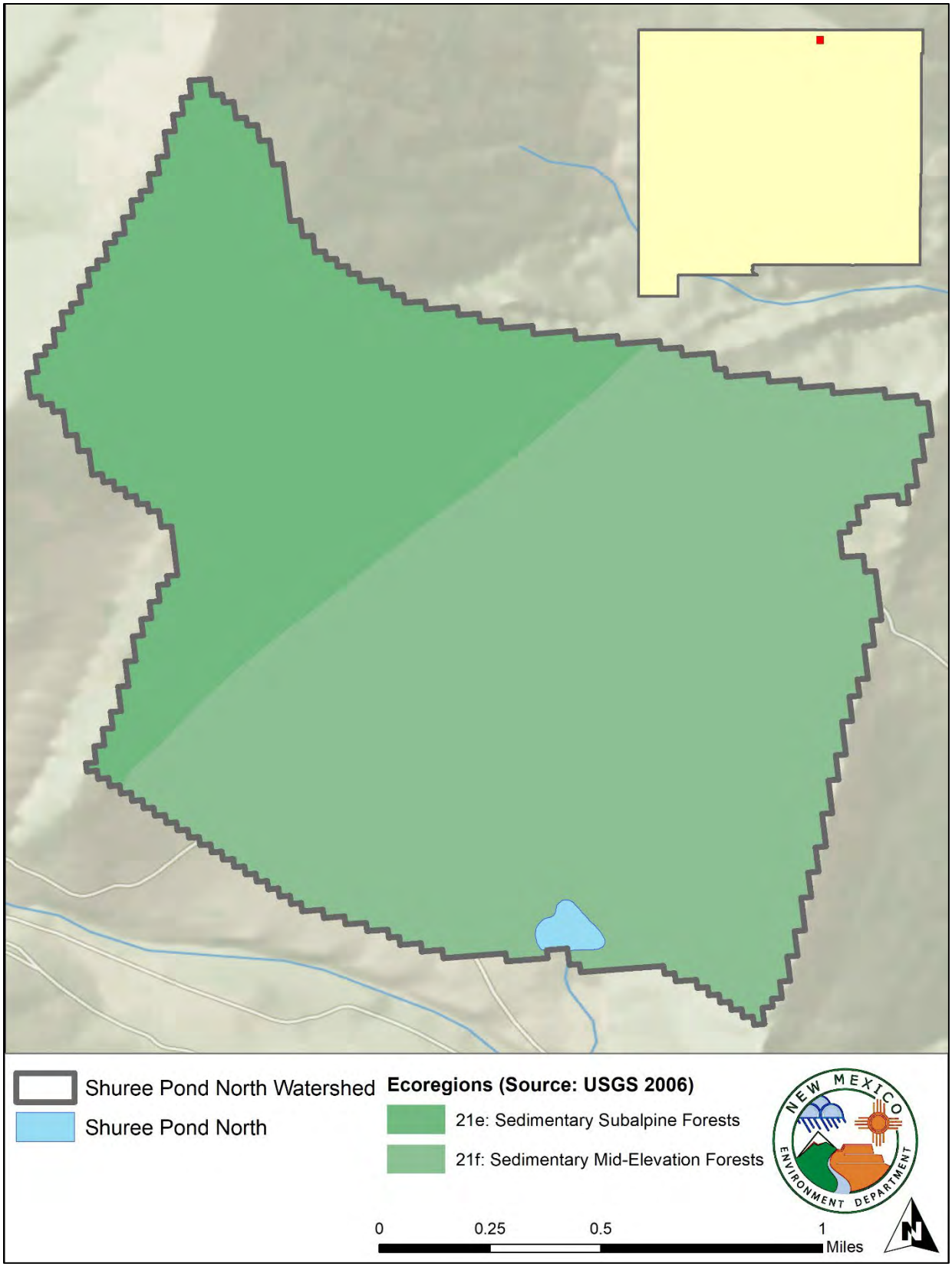


Figure 1.20: Ecoregions of the Shuree Pond North watershed.

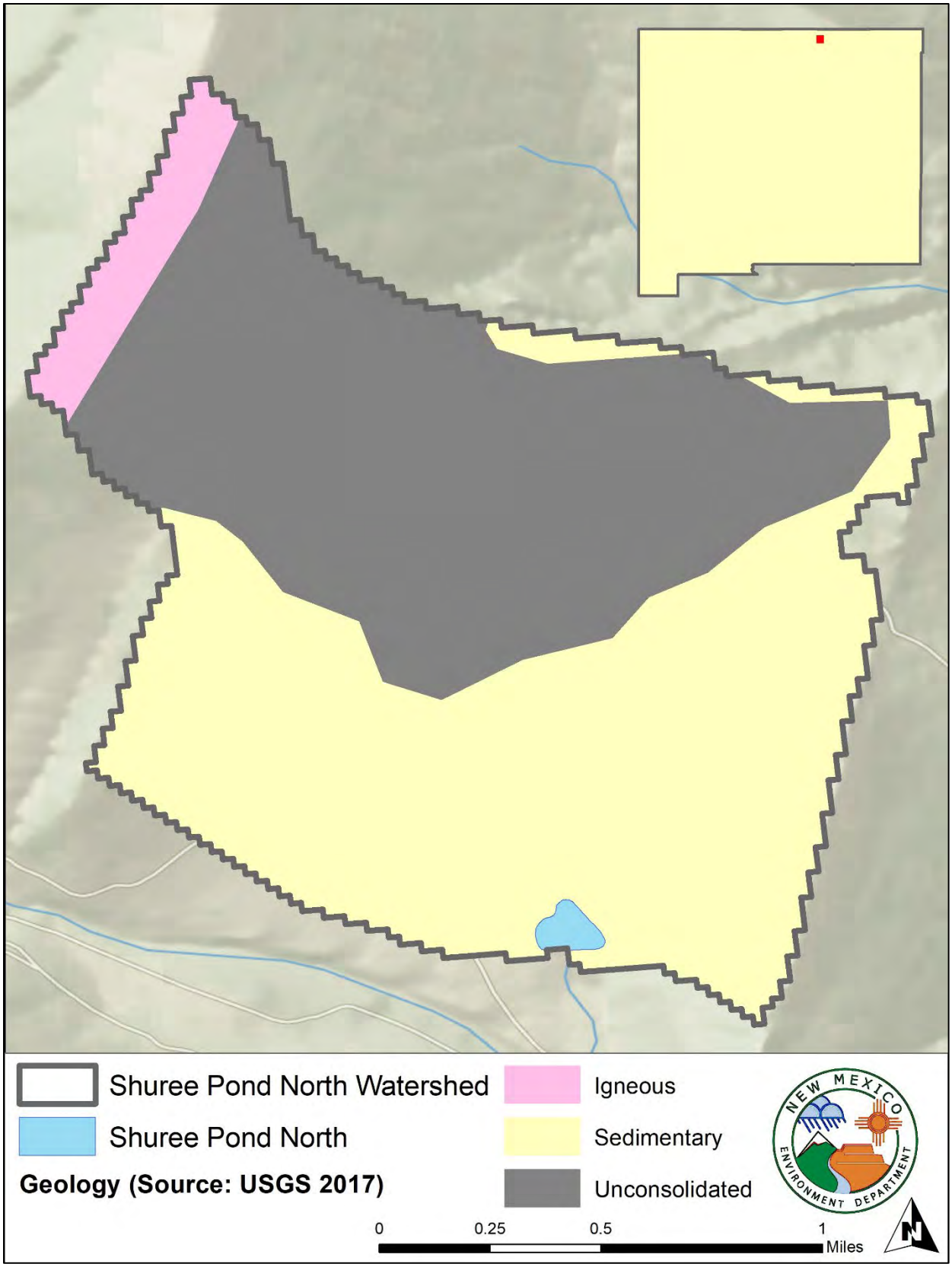


Figure 1.21: Surface geology of the Shuree Pond North watershed.

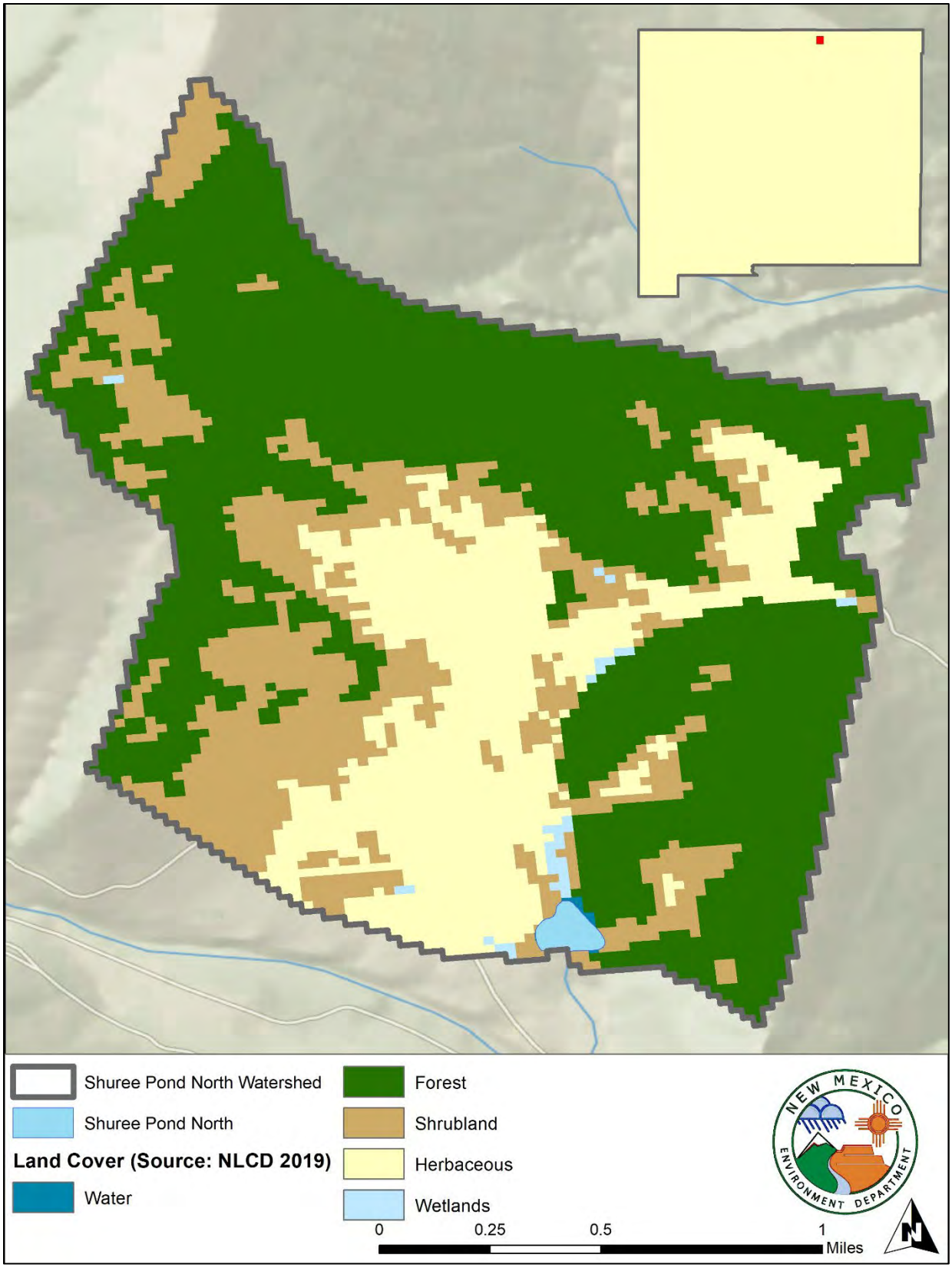


Figure 1.22: Land Cover of the Shuree Pond North watershed.

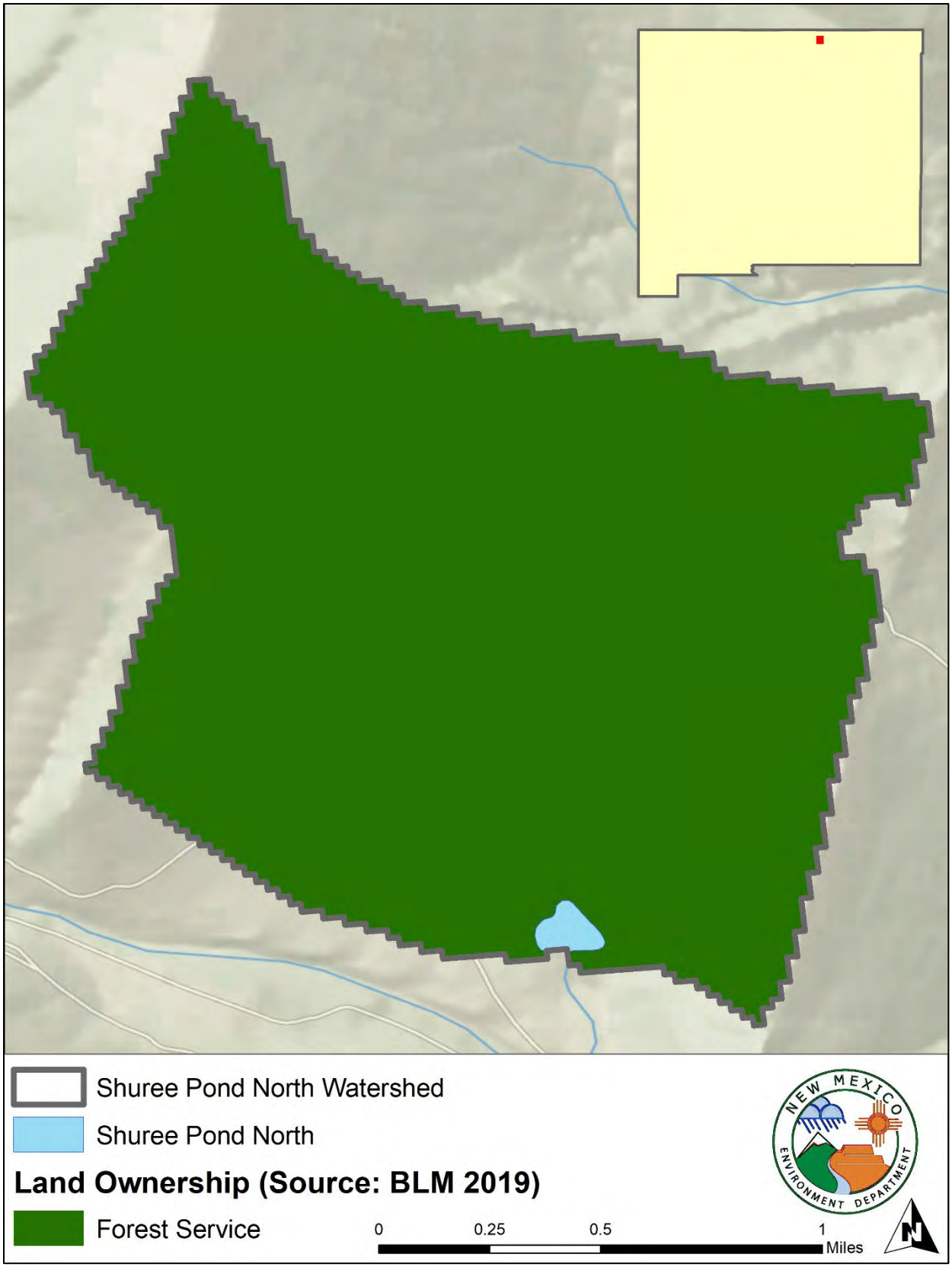


Figure 1.23: Land Ownership of the Shuree Pond North watershed.

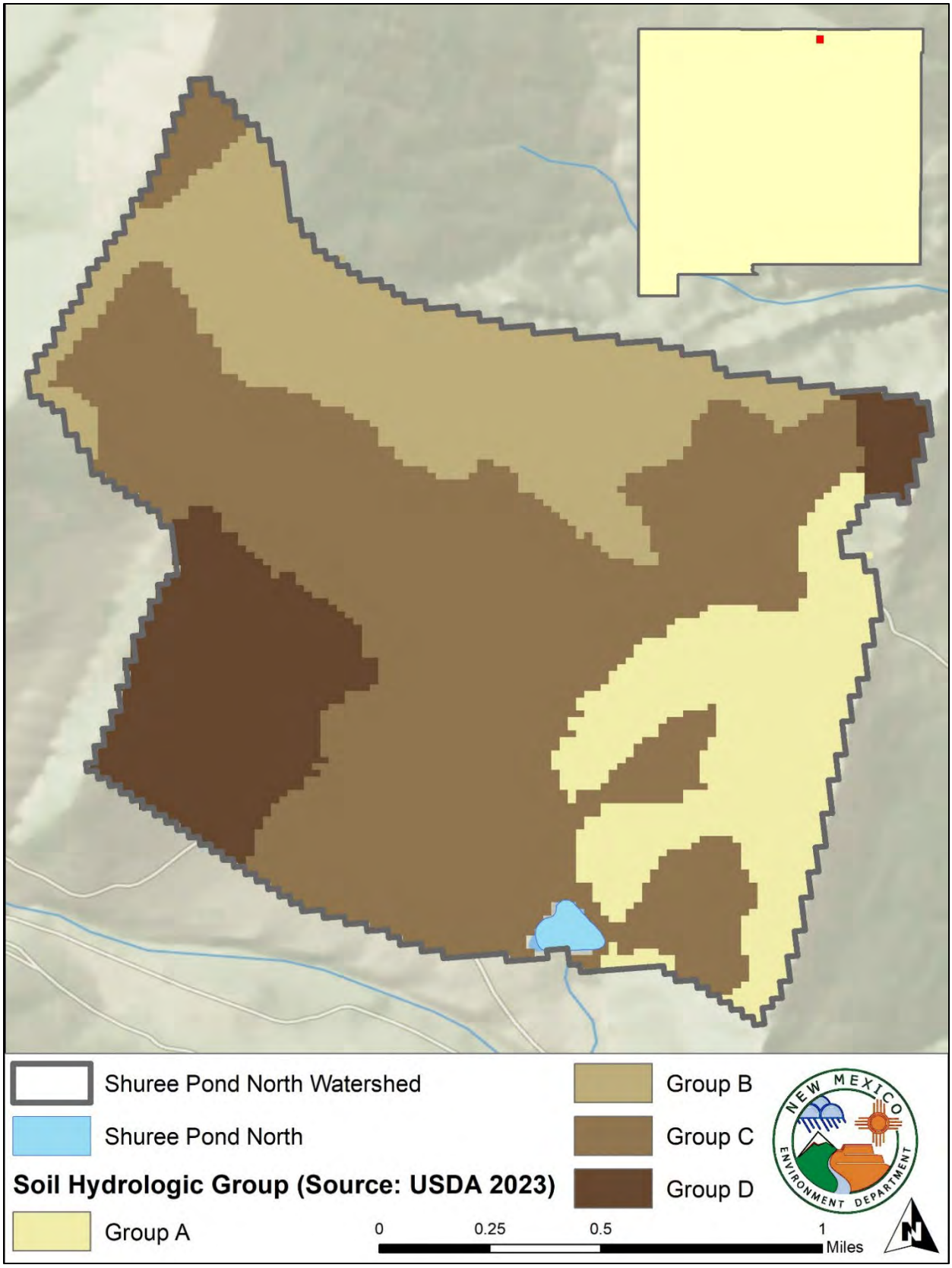


Figure 1.24: Soil Hydrologic Group classification of the Shuree Pond North watershed.

1.2 Water Quality Standards

Water quality standards for Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, and Shuree Pond North are set forth in the following sections of 20.6.4 NMAC:

20.6.4.315 CANADIAN RIVER BASIN: Eagle Nest lake.

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering, wildlife habitat and public water supply.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less. [20.6.4.315 NMAC – N, 7/10/2012]

20.6.4.312 Lake Maloya.

A. Designated uses: coldwater aquatic life, irrigation, livestock watering, wildlife habitat, primary contact and public water supply.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.313 NMAC – N, 12/1/2010; A, 4/23/2022]

20.6.4.121 RIO GRANDE BASIN - Perennial tributaries to the Rio Grande in Bandelier national monument and their headwaters in Sandoval county and all perennial reaches of tributaries to the Rio Grande in Santa Fe county unless included in other segments and excluding waters on tribal lands.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact; and public water supply on Little Tesuque creek, the Rio en Medio, and the Santa Fe river.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less. [20.6.4.121 NMAC - Rp 20 NMAC 6.1.2118, 10/12/2000; A. 5/23/2005; A, 12/1/2010; A, 2/14/2013] [NOTE: The segment covered by this section was divided effective 5/23/2005. The standards for the additional segments are under 20.6.4.126, 20.6.4.127 and 20.6.4.128 NMAC.]

20.6.4.314 CANADIAN RIVER BASIN - Shuree ponds (north and south).

A. Designated uses: high quality coldwater aquatic life, irrigation, domestic water supply, primary contact, livestock watering and wildlife habitat.

B. Criteria: The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less. [20.6.4.314 NMAC - N, 7/10/2012]

Additionally, general criteria applicable to all surface waters of New Mexico are outlined in 20.6.4.13 NMAC. With respect to nutrients, the following narrative criterion guidance is set forth in 20.6.4.13(E) NMAC:

20.6.4.13 GENERAL CRITERIA

E. Plant Nutrients: Plant nutrients from other than natural causes shall not be present in concentrations which will produce undesirable aquatic life or result in the dominance of nuisance species in surface waters of the state.

This narrative criterion can be challenging to assess because the relationships between nutrient levels and impairment of designated uses are not defined, and distinguishing nutrients from "other than natural

causes" is difficult. Numeric thresholds are necessary to establish targets for TMDLs, to develop water quality-based permit limits and source control plans, and to support designated uses within the watershed. Therefore, SWQB, with the assistance from USEPA and the University of Arkansas (Scott and Haggard 2011), developed nutrient-related thresholds, or *narrative translators*, to address both cause (TN and TP) and response variables (dissolved oxygen [DO], pH, chlorophyll-*a*, and percent cyanobacteria). Water quality assessments for nutrients are based on quantitative measurements of these causal and response indicators. If these measurements exceed the numeric nutrient threshold values, indicate excessive primary production, and/or demonstrate an unhealthy biological community, the waterbody is considered impaired. Narrative translators applicable to lakes for the narrative criteria outlined in 20.6.4.13 NMAC are outlined in Appendix D of the 2023 CALM (NMED/SWQB 2023[1]). Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, and Shuree Pond North are all designated coldwater lakes, meaning total nitrogen is considered a nutrient impairment at levels above 0.9 mg/L and total phosphorous is considered a nutrient impairment at levels above 0.03 mg/L.

1.3 Antidegradation and TMDLs

New Mexico's antidegradation policy, which is based on the requirements of 40 C.F.R. § 131.12, describes how waters are to be protected from degradation (20.6.4.8(A) NMAC). At a minimum, the policy mandates that "the level of water quality necessary to protect the existing uses shall be maintained and protected in all surface waters of the state." Furthermore, the policy's requirements must be met whether or not a segment is impaired. TMDLs are consistent with this policy because implementation of a TMDL restores water quality so that existing uses (defined at 20.6.4.7(E)(3) NMAC at the highest quality of water that has been attained since 1975) are protected and water quality criteria are achieved.

The Antidegradation Policy Implementation Procedure establishes the process for implementing the antidegradation policy (Appendix A of NMED/SWQB 2020b[2]). However, certain specific requirements in the Antidegradation Policy Implementation Procedure do not apply to the Water Quality Control Commission's (WQCC) establishment of TMDLs because these types of water quality-related actions already are subject to extensive requirements for review and public participation, as well as various limitations on degradation imposed by state and federal law (NMED/SWQB 2020b).

1.4 Water Quality Monitoring Surveys

Monitoring of surface waters across the State typically occurs using a rotational watershed approach, meaning a given waterbody is generally surveyed intensively, on average, every eight to ten years. Monitoring occurs during the non-winter months (March through November), focuses on physical, chemical, and biological conditions in perennial waters, and includes sampling for most pollutants that have numeric and/or narrative criteria in the WQS. Each assessment unit (i.e., stream reach or lake/reservoir) is typically represented by one monitoring station, each of which receives 4–8 site visits during the survey. Larger lakes/reservoirs typically have both a deep and a shallow station.

The SWQB introduced a new strategy during the 2015-2016 seasons where a larger area is monitored over a two-year period, with 2-6 water chemistry samples collected at each AU per year (4-12 total samples over the entire survey). This two-year monitoring approach is intended to allow more data to be collected

[1] https://www.env.nm.gov/surface-water-quality/calm/
[2] https://www.env.nm.gov/surface-waterquality/wqmp-cpp/

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from the highest priority waters to better capture inter-annual variability primarily due to hydrologic conditions during the sampling events.

Through public outreach, inter-agency coordination, and a scoring system considering a variety of factors, a three-tier monitoring system – primary, secondary, and tertiary – was developed to prioritize AUs. High ranking priority waters (primary AUs) receive the greatest amount of monitoring, whereas low ranking waters (i.e., tertiary AUs) receive the least.

1.5 Hydrologic Conditions

1.5.1 Eagle Nest Lake

The only active USGS gage in the Eagle Nest Lake watershed is at the dam (USGS 07205500: Eagle Nest Lake near Eagle Nest, NM), which records reservoir storage and elevation. An active USGS gage is located just downstream of the Eagle Nest Lake watershed at the outlet of the lake's dam (USGS 07206000: Cimarron River below Eagle Nest Dam, NM). The period of record for reservoir storage (USGS Gage 07205500) is from 1986 to present. Despite the New Mexico Dam Inventory listing the normal storage of Eagle Nest Lake at 81,000 acre-feet, that value is rarely met. Since the year 1986, the reservoir storage has only been above 81,000 acre-feet ten times, less than 1% of observations since the gage became active. The average reservoir storage from November 1986 to June 2022 is 49,244 acre-feet, with a high of 81,360 acre-feet in May 1994 and a low of 16,860 acre-feet in November 2014 (**Figure 1.25**). Data for this TMDL was collected during 2015-2016, when the reservoir had an average storage of 28,933 acre-feet, with a high of 35,510 acre-feet in June 2016 and a low of 17,210 acre-feet in May 2015 (**Figure 1.26**).

Based on the Koppen-Geiger climate classification system, the Eagle Nest Lake watershed exhibits a warm-summer humid continental climate in the lower elevations of the watershed and a subarctic climate in the higher elevations of the watershed (Beck, 2018). Precipitation patterns are heavily influenced by the North American Monsoon season, which typically lasts from early July through September. An automated weather observing system (AWOS) weather station is located within the Eagle Nest Lake watershed at the Angle Fire Airport (KAXX, Elevation: 8330ft, (36.422, -105.2899)), however this single weather station is not representative of the entire watershed. Better estimates of area-weighted average climatic parameters, like precipitation, temperature, etc., can be extracted from the PRISM Climate Group recent years modeled data (PRISM 2022), which integrate and interpolate weather station data from the AWOS weather station as well as many others. Considering the 40-year period from 1981 to 2020 (the most recent complete year available from PRISM at the time of this writing), annual precipitation ranged from a low of 14.54 inches in 1981 and 2020 to a high of 30.34 inches in 1994 (**Figure 1.28**). Considering monthly precipitation, July and August are the wettest months, accounting for nearly 30% of annual precipitation on average (**Figure 1.27**). Average annual air temperatures have ranged from a low of 38.66 °F in 1992 to a high of 43.32 °F in 2017 (**Figure 1.29**). Monthly average air temperatures ranged between 23.6 °F in January to 58.6 °F in July (**Figure 1.27**). Annual dew point temperature values are fairly stable and monthly dew point temperatures tend to follow air temperature. Average annual dew point temperatures have ranged from a low of 18.77 °F in 2011 to a high of 25.14 °F in 1986 (**Figure 1.30**). Monthly average dew point temperatures are between 8.81 °F in January and 40.91 °F in August (**Figure 1.27**).

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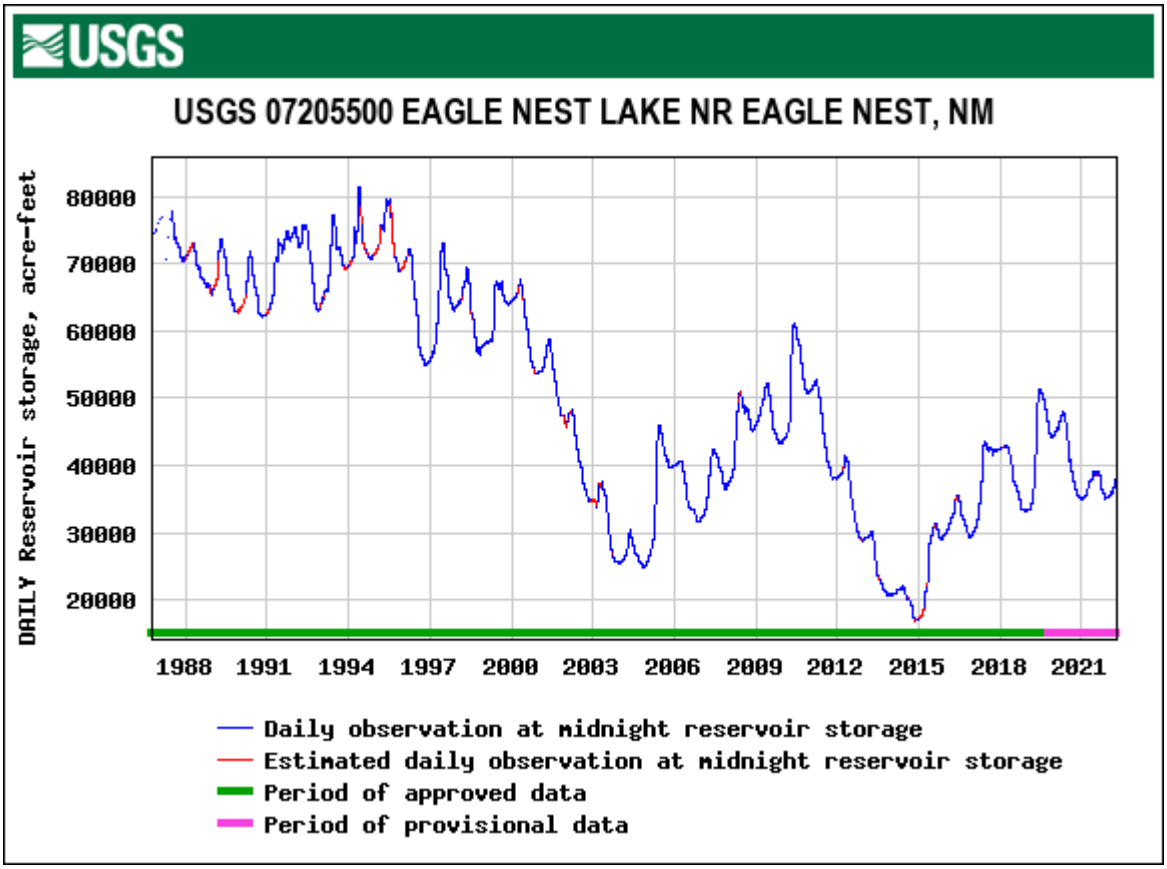


Figure 1.25: Lake Storage (acre-feet) for Eagle Nest Lake from 1986 to present.

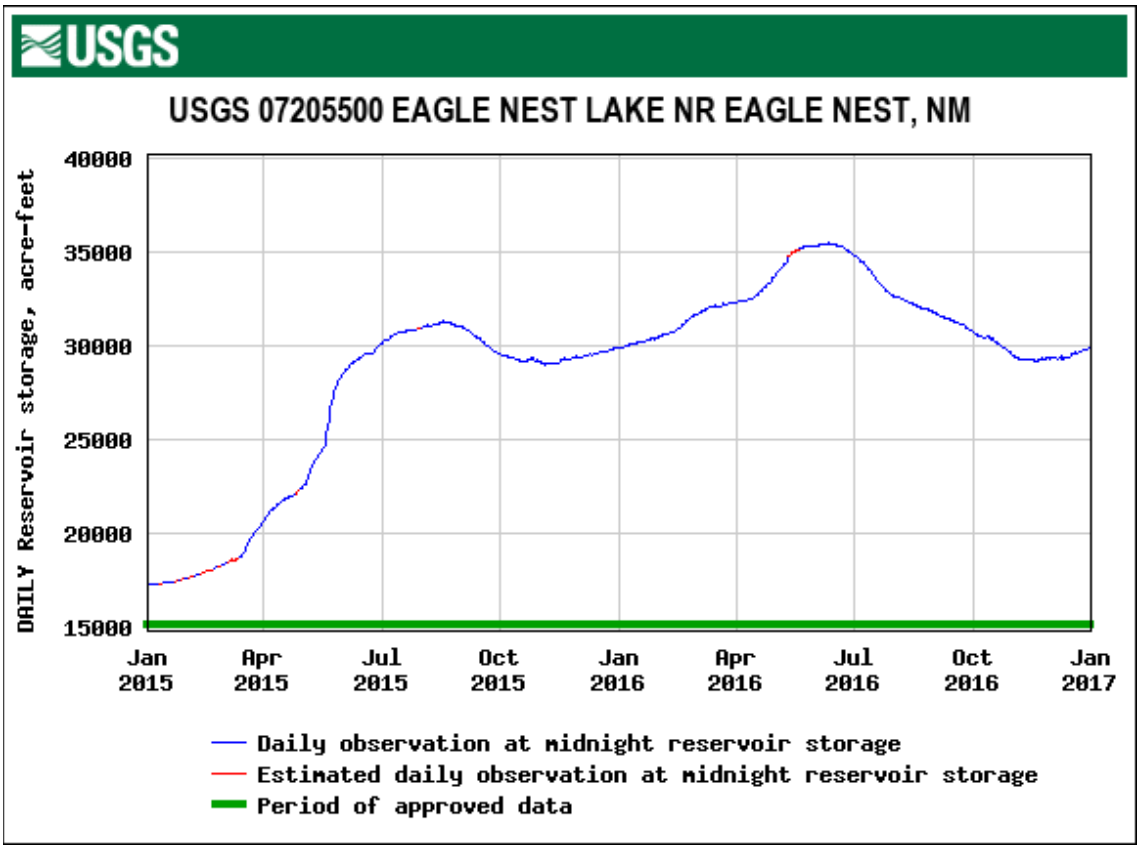


Figure 1.26: Lake storage (acre-feet) for Eagle Nest Lake during the 2015-2016 water quality survey.

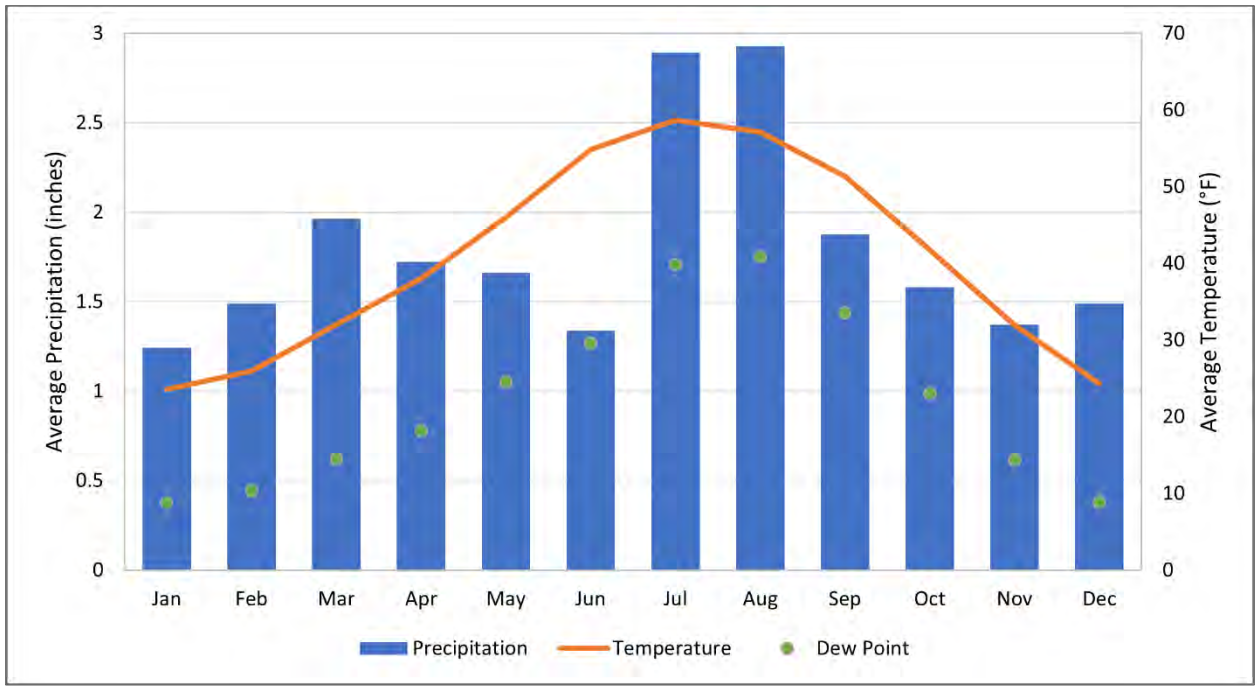


Figure 1.27: Climate overview for Eagle Nest Lake watershed.

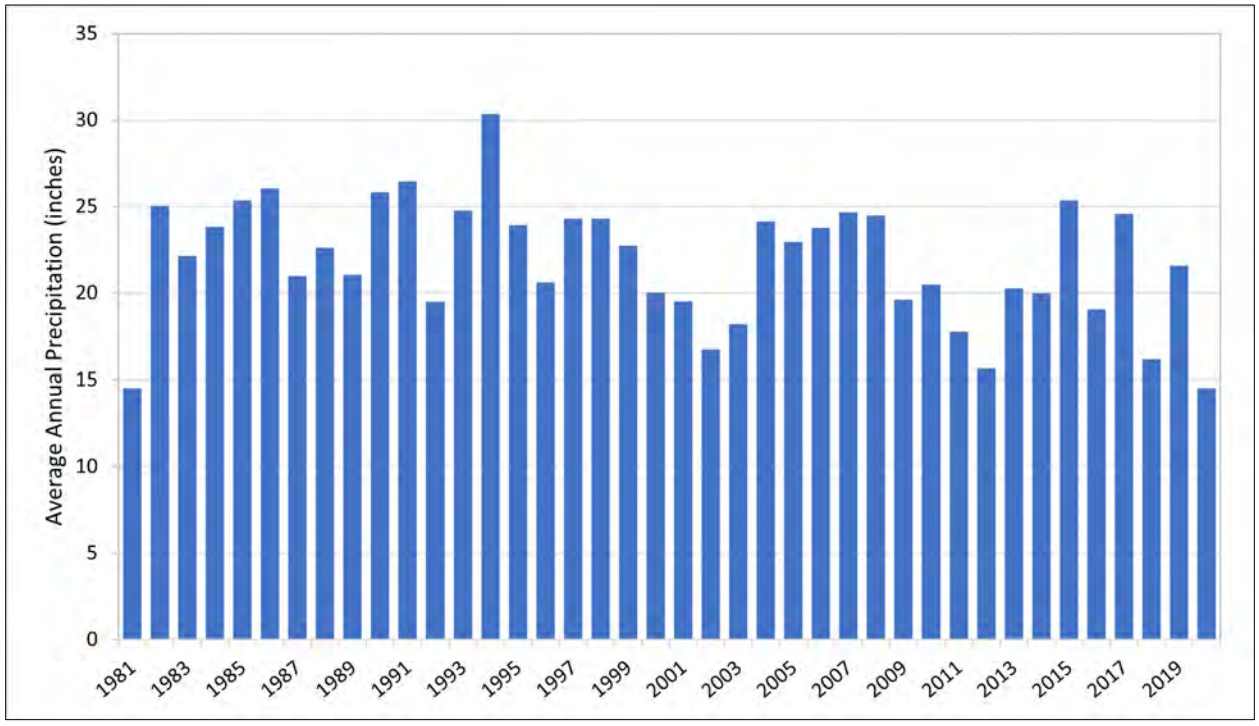


Figure 1.28: Average annual precipitation for Eagle Nest Lake watershed from 1981 to 2020.

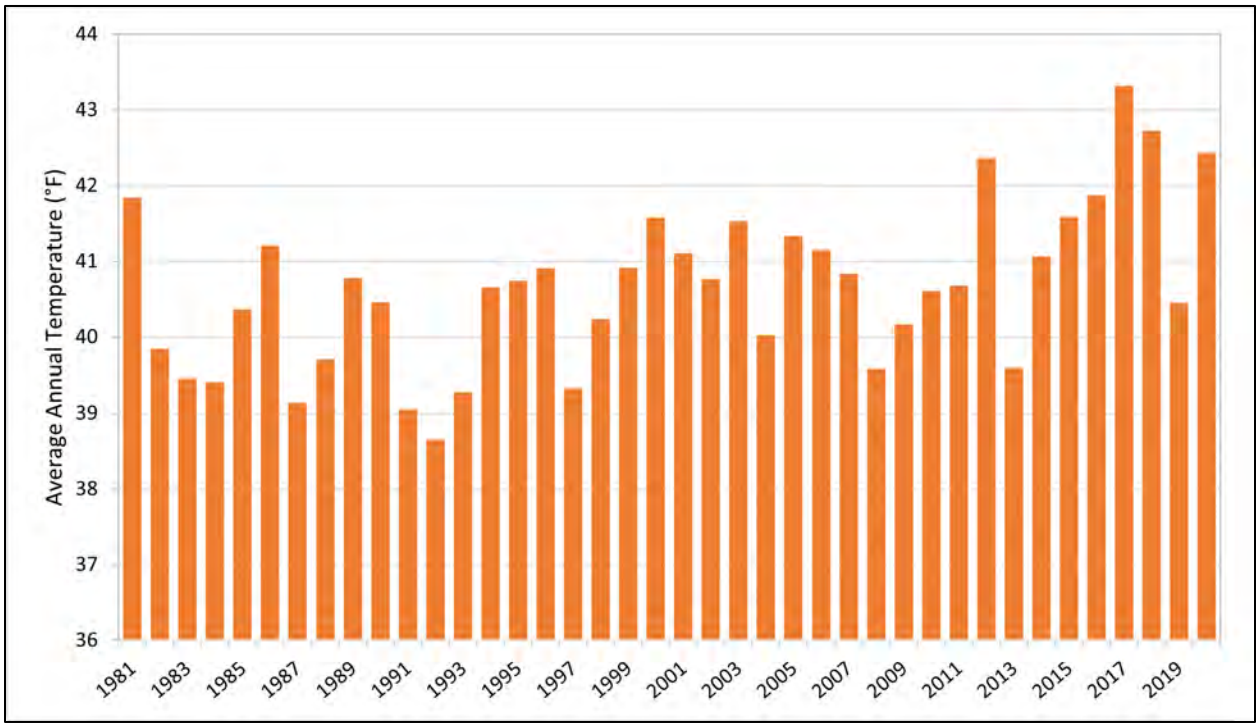


Figure 1.29: Average annual air temperature for Eagle Nest Lake watershed from 1981 to 2020.

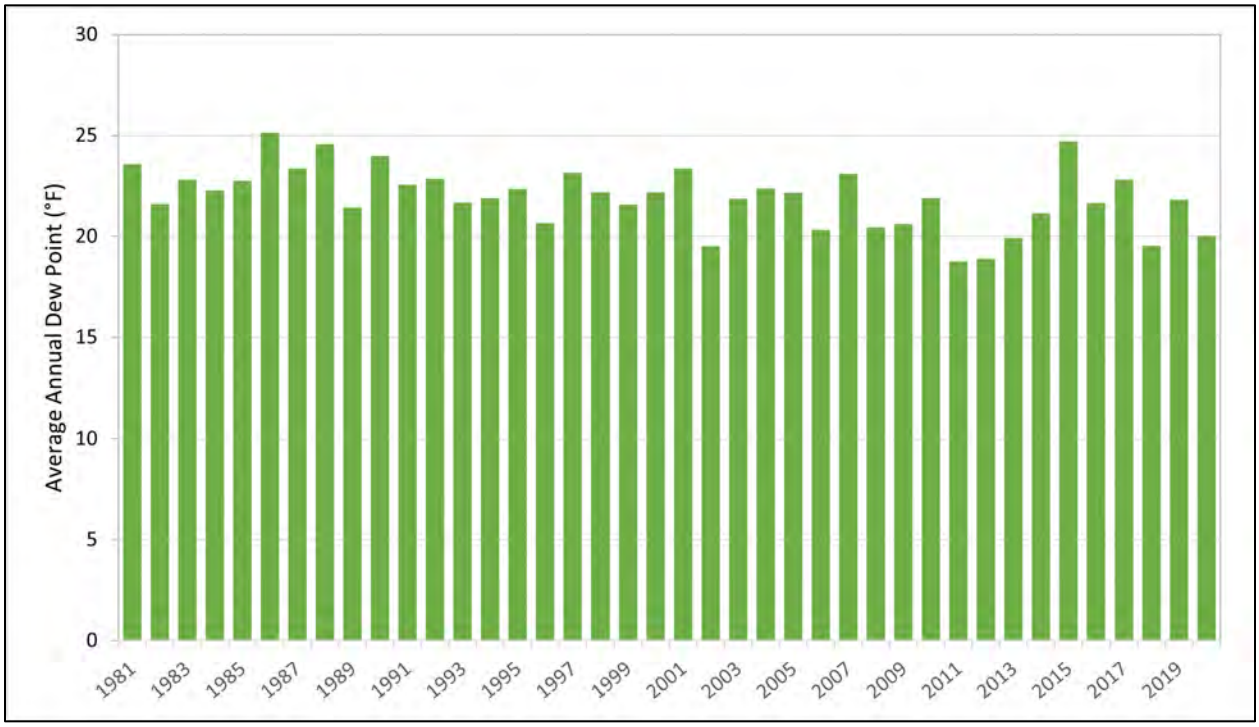


Figure 1.30: Average annual dew point temperature for Eagle Nest Lake watershed from 1981 to 2020.

1.5.2 Lake Maloya

The only active USGS gage in the Lake Maloya watershed is at the Lake Maloya dam (USGS 07199450: Lake Maloya near Raton, NM), which records reservoir storage and elevation. The period of record for reservoir storage is from October 1987 to present. Despite the New Mexico Dam Inventory listing the normal storage of Lake Maloya at 3690 acre-feet, the reservoir was only at or above that level around 24% during the period of record (**Figure 1.31**). Lake storage for the period of record has ranged from a low of 2220 acre-feet during January and February of 1991 to a high of 3949 acre-feet in April 2010. The NHD High Resolution Lake Maloya polygon is 115.54 acres, corresponding with an estimated storage of approximately 3237 acre-feet (Tetra Tech, 2011). During the 2015-2016 water quality survey the average storage was 3620 acre-feet with a low of 3280 acre-feet in January 2015 to a high of 3856 acre-feet in May 2015 (**Figure 1.32**).

Based on the Koppen-Geiger climate classification system, the Lake Maloya watershed exhibits a warm-summer humid continental climate (Beck, 2018). Precipitation patterns are heavily influenced by the North American Monsoon season, which typically lasts from early July through September. No weather stations exist within the Lake Maloya watershed, but there is a weather station at the nearby Raton Municipal Crews Field Airport (KRTN, Elevation: 6353 ft, (36.741, -104.508)). This single weather station is not representative of the entire watershed. Better estimates of area-weighted average climatic parameters, like precipitation, temperature, etc., can be extracted from the PRISM Climate Group's recent years modeled data (PRISM, 2022), which integrates and interpolates weather station data from the AWOS weather station has well as many others. Considering the 40-year period from 1981 to 2020 (the most recent complete year available from PRISM at the time of this writing), annual precipitation ranged from a low of 12.09 inches in 2012 to a high of 32.54 inches in 2017 (**Figure 1.34**). Considering monthly precipitation, July and August are the wettest months, accounting for just over 30% of annual precipitation on average (**Figure 1.33**). Average annual air temperatures have ranged from a low of 43.14 °F in 1993 to a high of 47.78 °F in 2017 (**Figure 1.35**). Average monthly air temperatures range between 29.3 °F in December to 62.51 °F in July (**Figure 1.33**). Annual dew point temperatures have smaller variations when compared to precipitation and temperature, and average monthly dew point temperature values tend to follow air temperatures. Average annual dew point temperatures have ranged from a low of 21.13 °F to a high of 27.61 °F in 2017 (**Figure 1.36**). Monthly average dew point temperatures range from 8.98 °F in January to 44.80 °F in August (**Figure 1.33**).

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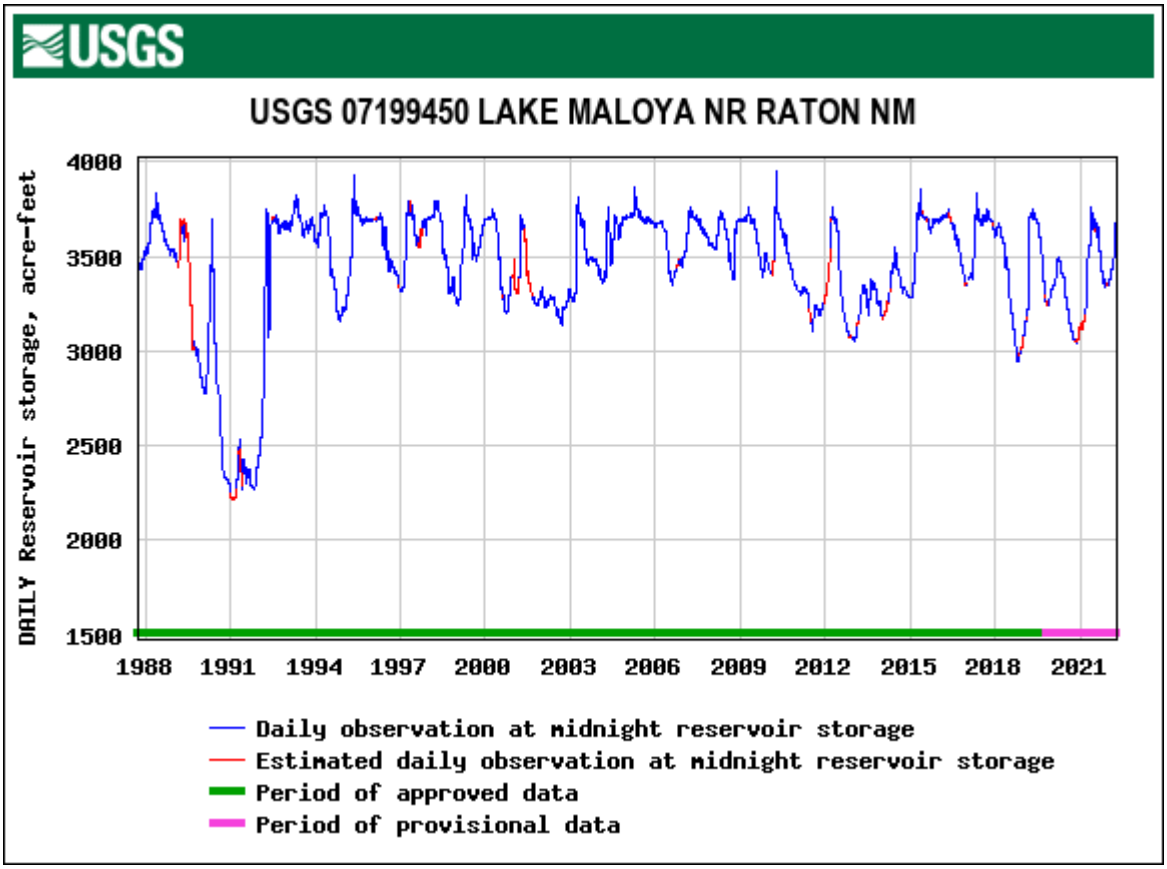


Figure 1.31: Lake Maloya storage (acre-feet) from 1987 to present.

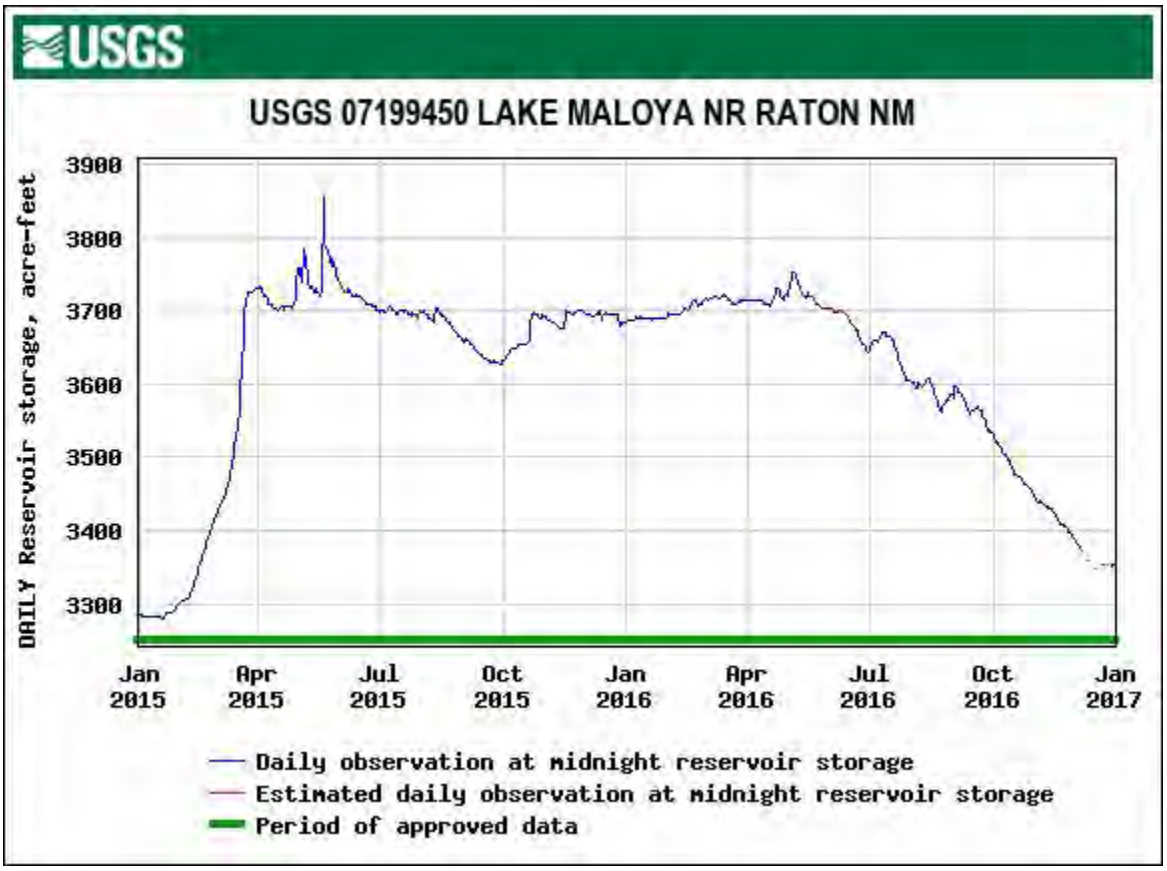


Figure 1.32: Lake storage (acre-feet) for Lake Maloya during the 2015-2016 water quality survey.

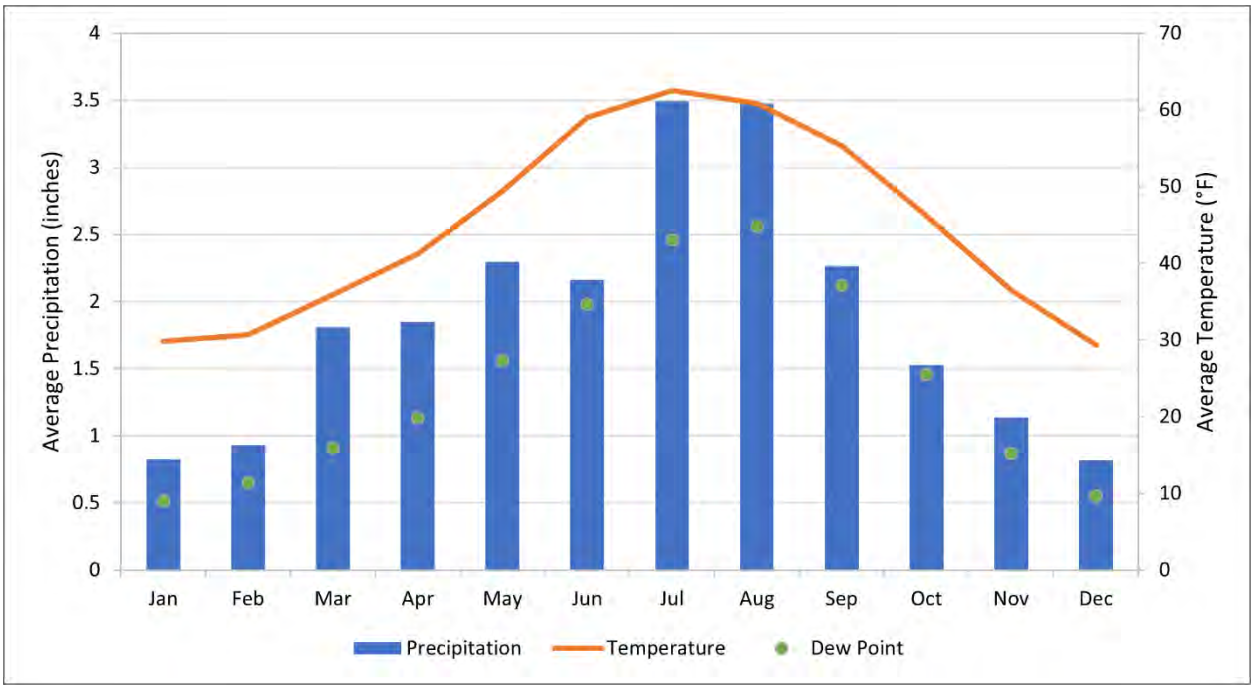


Figure 1.33: Climate overview for Lake Maloya watershed.

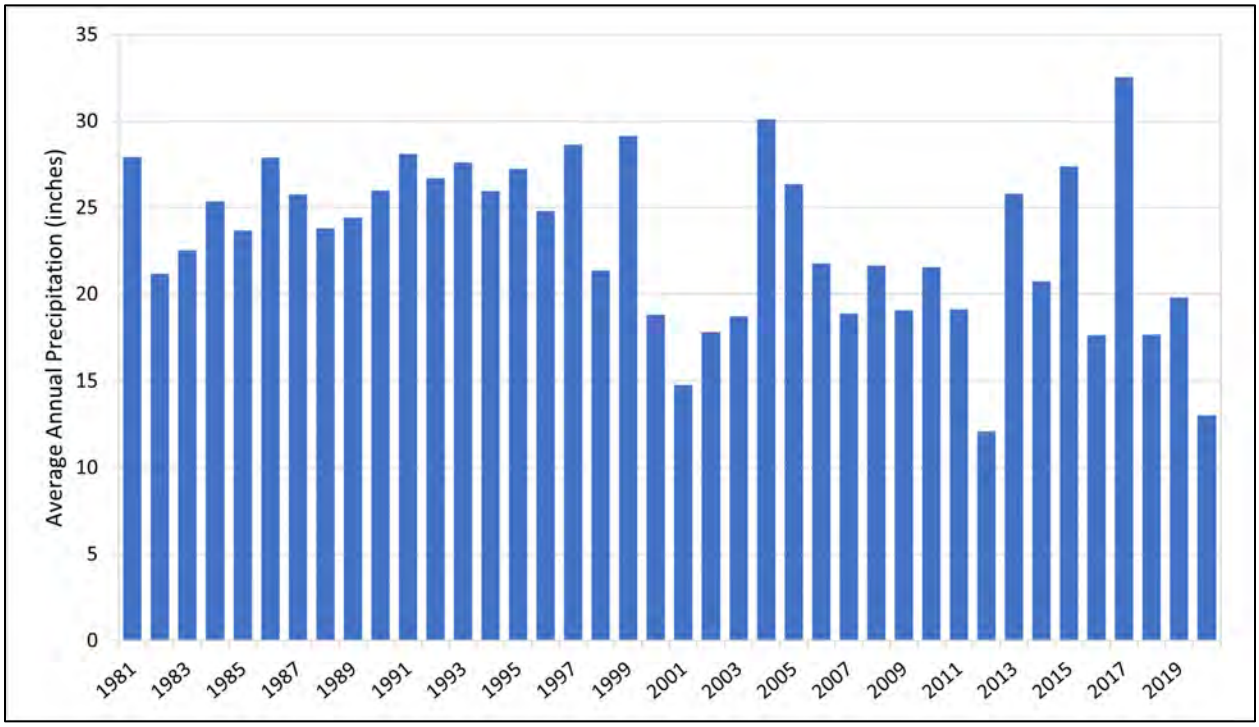


Figure 1.34: Average annual precipitation for the Lake Maloya watershed from 1981 to 2020.

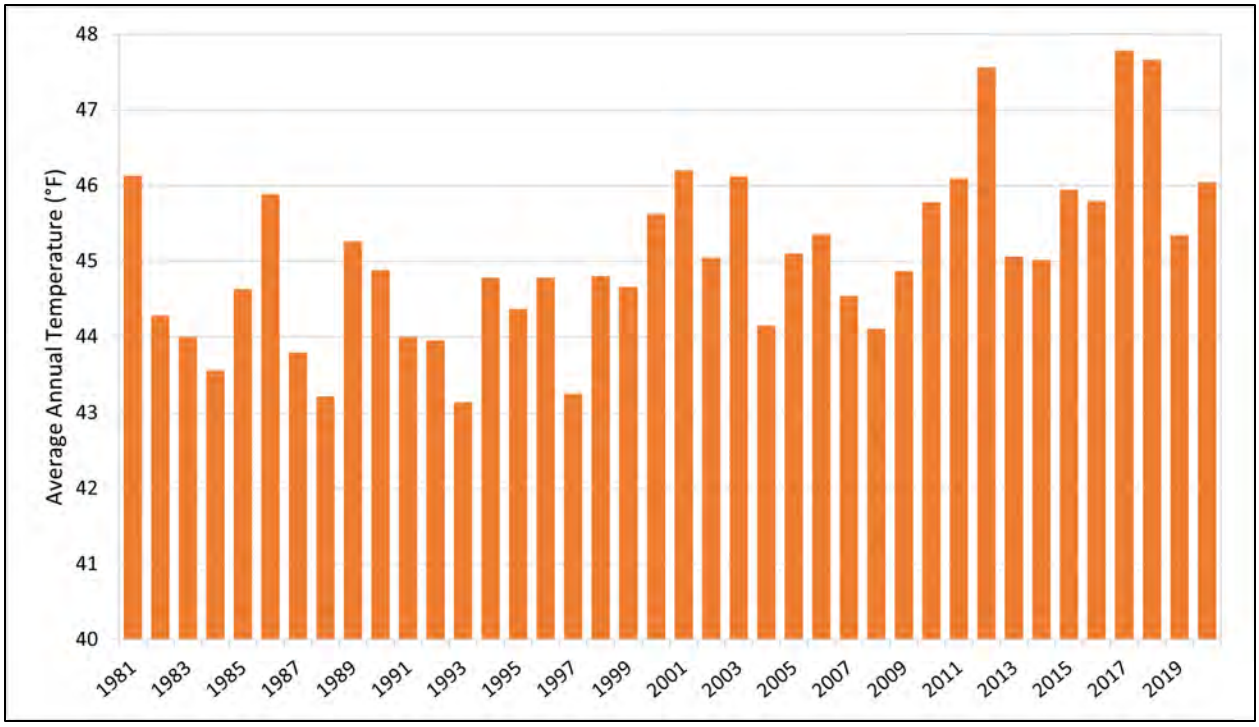


Figure 1.35: Average annual temperature for the Lake Maloya watershed from 1981 to 2020.

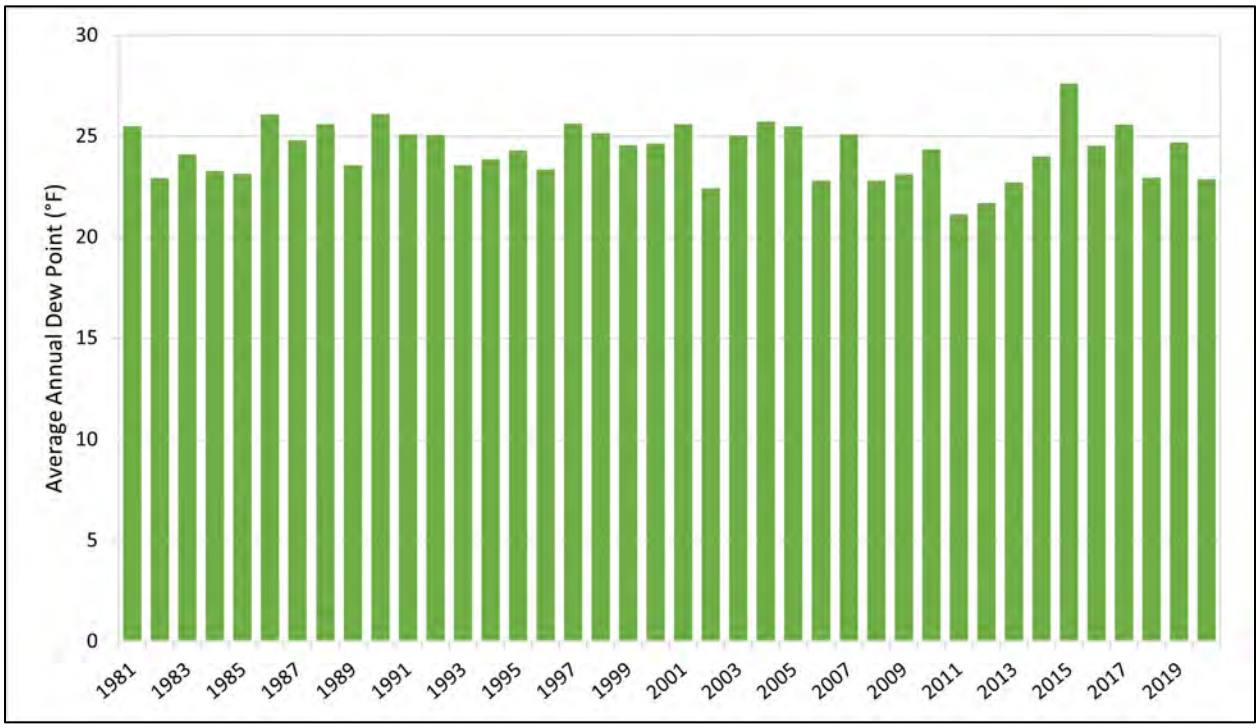


Figure 1.36: Average annual dew point temperature for the Lake Maloya watershed from 1981 to 2020.

1.5.3 Santa Cruz Lake

The only active USGS gage in the Santa Cruz Lake watershed is located about one mile upstream from the lake inlet on the Santa Cruz River (USGS 08291000: Santa Cruz River near Cundiyo, NM), situated just below the confluence of the Rio Medio and the Rio Frijoles. This gage measures mean daily discharge and has a period of record from October 1932 to present (**Figure 1.37**). The New Mexico Dam Inventory list the normal storage (also the spillway storage) at 3546.4 acre-feet, which corresponds to a surface area of 99.8 acres. The NHD High Resolution Santa Cruz Lake polygon is 92.95 acres, corresponding to an approximate storage capacity of 3005 acre-feet (URS, 2010).

Based on the Koppen-Geiger climate classification system, the Santa Cruz Lake watershed exhibits a semi-arid cold climate in the lower elevations, a warm-summer humid continental climate in the middle elevations, and a subarctic climate in the highest elevations of the watershed (Beck, 2018). Precipitation patterns are heavily influenced by the North American Monsoon season, which typically lasts from early July Through September. No weather stations exist within the Santa Cruz Lake watershed, but there is a RAWS weather station maintained by the US Forest Service in the nearby town of Truchas (Elevation: 8340 ft, (36.059, -105.769)). This single weather station is not representative of the entire watershed. Better estimates of area-weighted average climatic parameters, like precipitation, temperature, etc., can be extracted from the PRISM Climate Group's recent years modeled data (PRISM, 2022), which integrates and interpolates weather station data from the RAWS weather stations as well as many others. Considering the 40-year period from 1981 to 2020 (the most recent complete year available from PRISM at the time of this writing), annual precipitation ranged from a low of 13.03 inches in 2020 to a high of 34.87 inches in 1994 (**Figure 1.39**). Considering monthly precipitation, July and August are the wettest months, accounting for nearly 30% of the annual precipitation on average (**Figure 1.38**). Average annual air temperatures have ranged from a low of 40.87 °F in 1992 to a high of 46.44 °F in 2017 (**Figure 1.40**). Average monthly air temperatures range between 26.08 °F in January to 61.54 °F in July (**Figure 1.38**). Annual dew point temperatures have smaller variations when compared to precipitation and temperature, and average monthly dew point temperature values tend to follow air temperatures. Average annual dew point temperatures have ranged from a low of 20.01 °F in 2011 to a high of 26.47 °F in 2015 (**Figure 1.41**). Monthly average dew point temperatures range from 10.62 °F in December to 42.84 °F in August (**Figure 1.38**).

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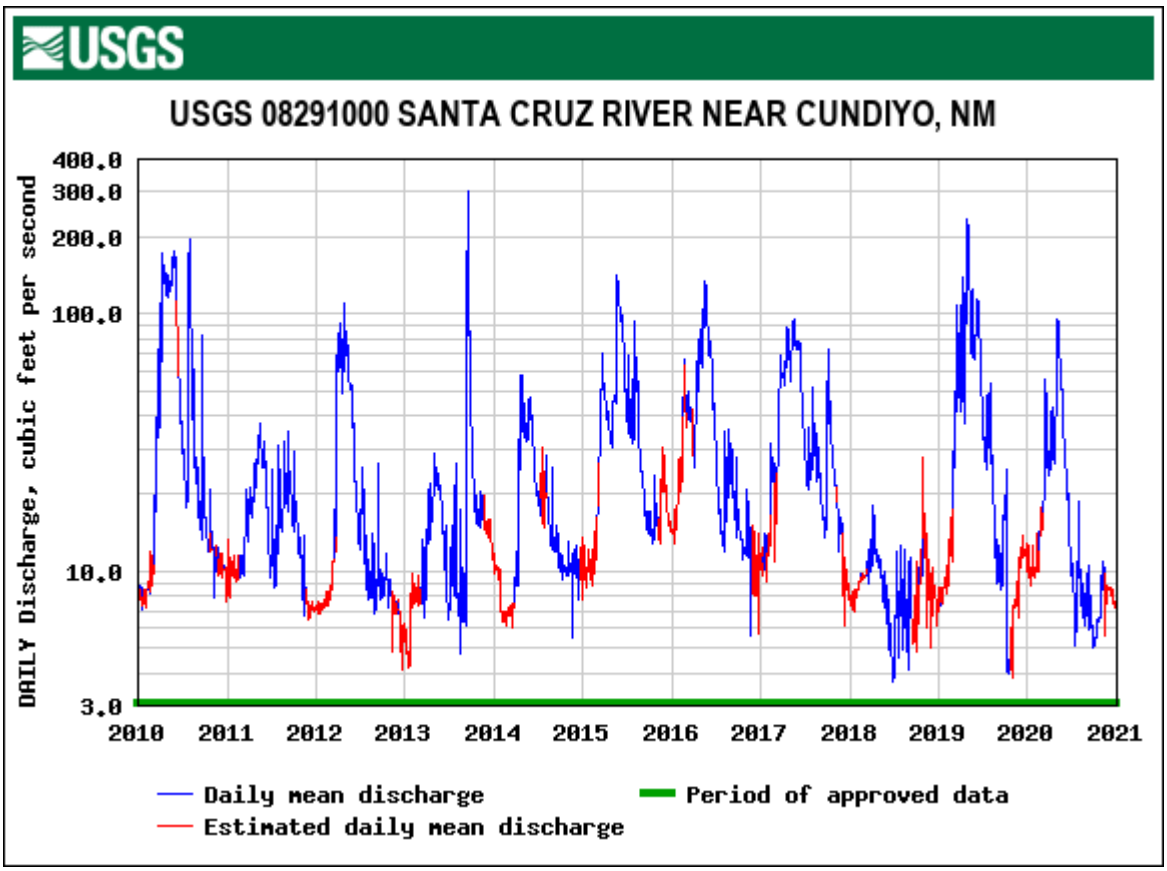


Figure 1.37: Average daily flow at USGS gage 08291000: Santa Cruz River near Cundiyo, NM from 2010 to 2021.

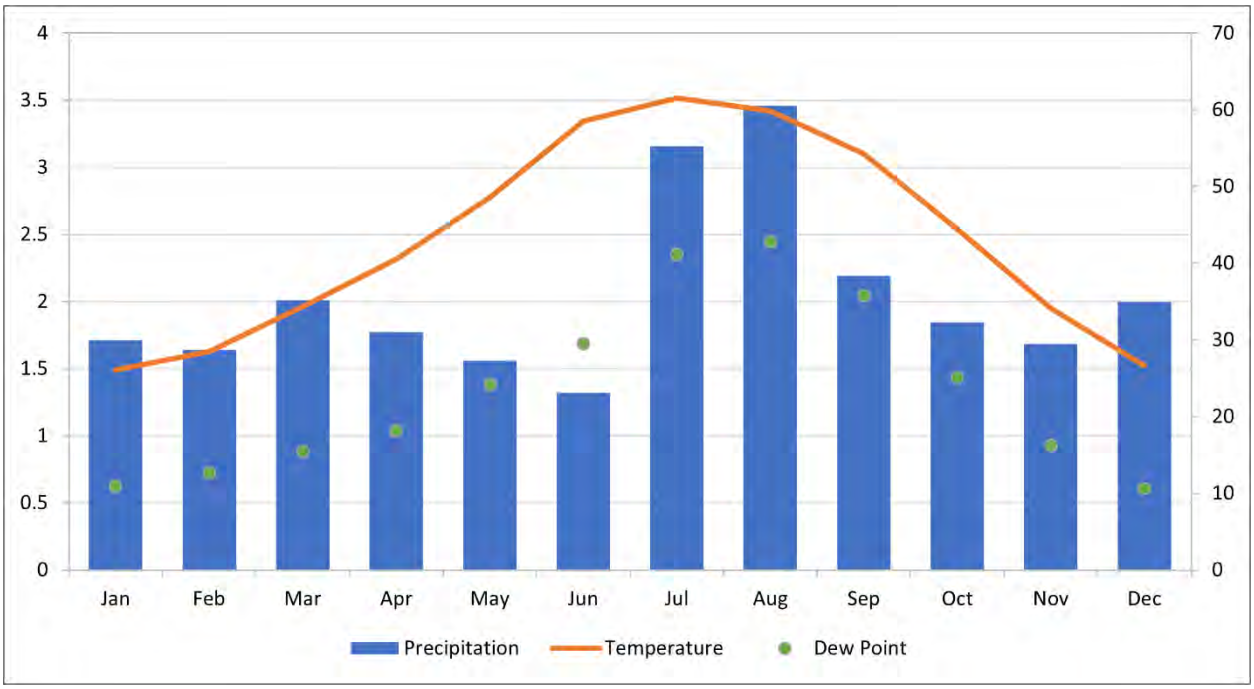


Figure 1.38: Climate overview of the Santa Cruz Lake watershed.

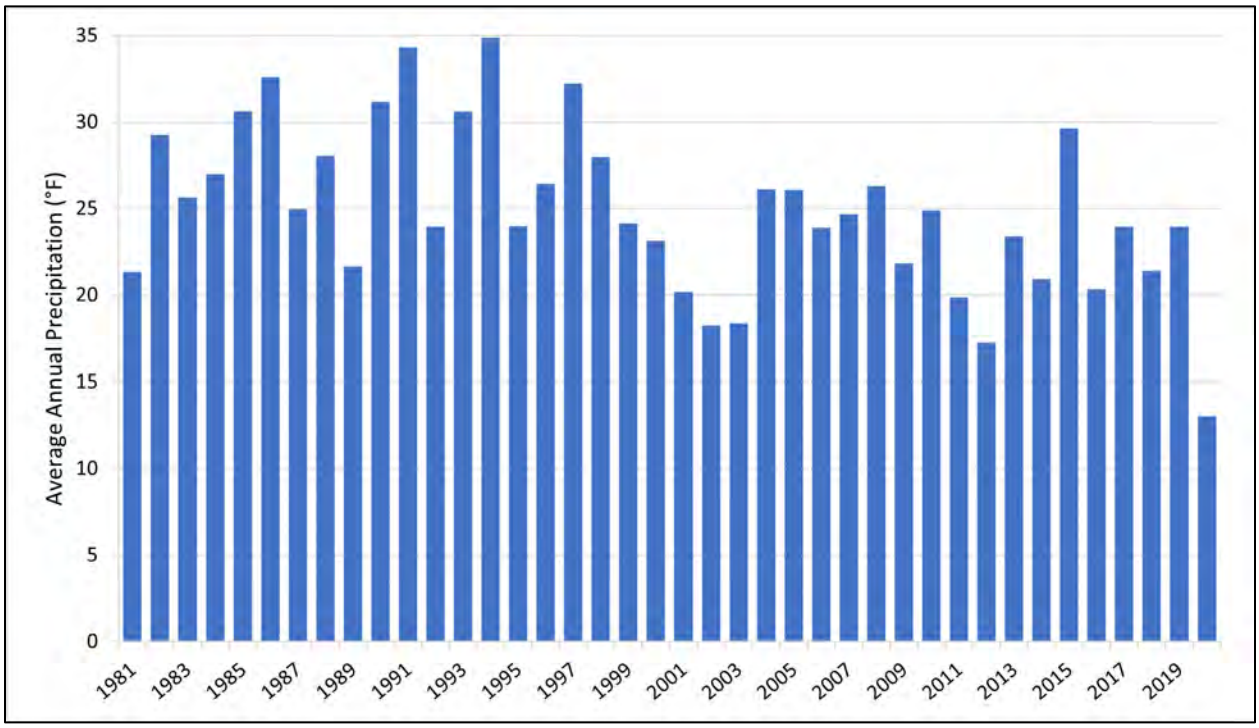


Figure 1.39: Average annual precipitation for the Santa Cruz Lake watershed from 1981 to 2020.

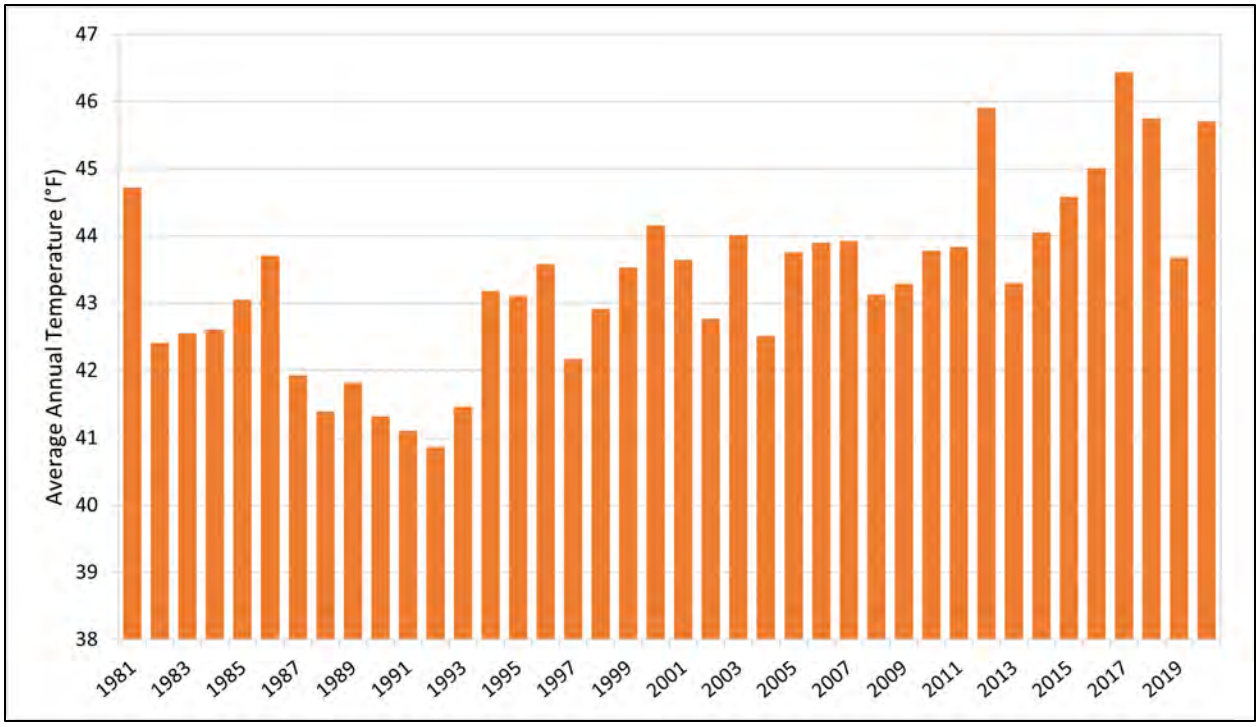


Figure 1.40: Average annual temperature for the Santa Cruz Lake watershed from 1981 to 2020.

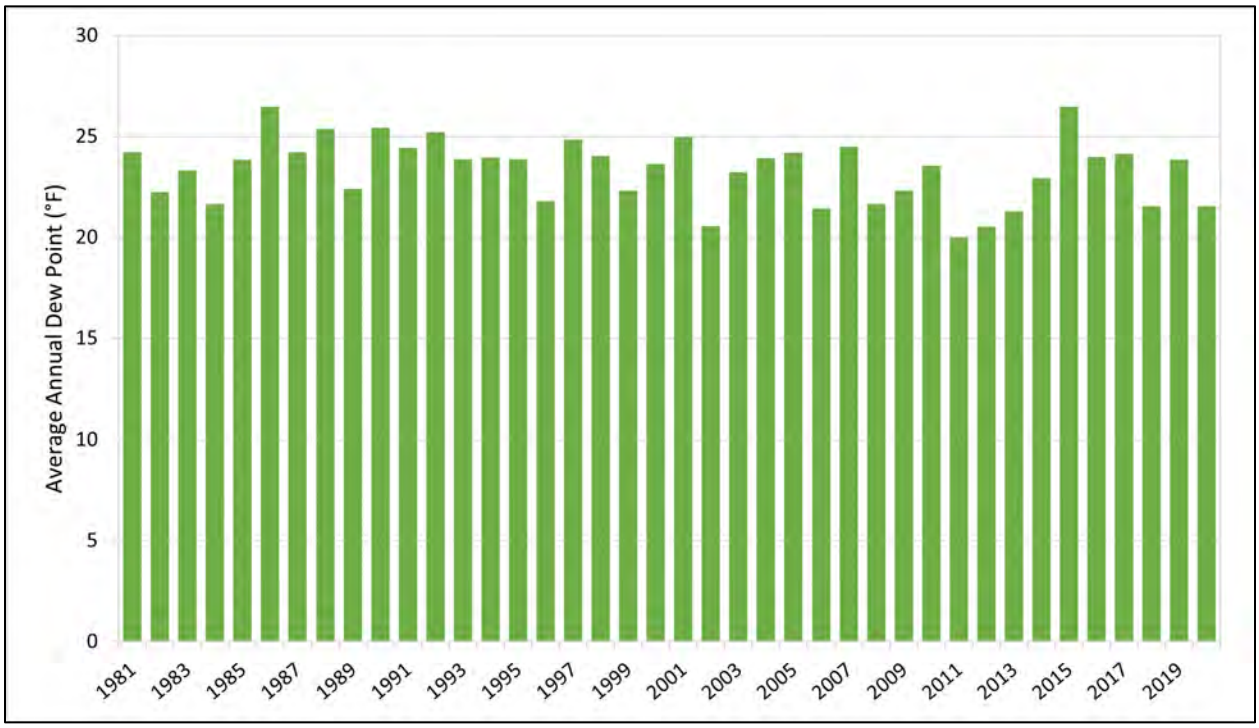


Figure 1.41: Average annual dew point temperature for the Santa Cruz Lake watershed from 1981 to 2020.

1.5.4 Shuree Pond North

There are no active USGS monitoring gages within the Shuree Pond North watershed, however reservoir storage data is available at the National Inventory of Dams (NID) website. Shuree Pond North is owned and operated by the US Forest Service, which lists the normal reservoir storage at 40 acre-feet and the maximum reservoir storage at 54 acre-feet (NID, 2021). These values are not actual observations, rather values based off the construction of the reservoir.

Based on the Koppen-Geiger climate classification system, the Shuree Pond North watershed exhibits a subarctic climate (Beck, 2018). Precipitation patterns are heavily influenced by the North American Monsoon season, which typically lasts from early July through September. Due to its remote location, there are no weather stations in the Shuree Pond North watershed. Better estimates of area-weighted average climatic parameters, like precipitation, temperature, etc., can be extracted from the PRISM Climate Group's recent years modeled data (PRISM, 2022), which integrates and interpolates weather station data from nearby weather stations. Considering the 40-year period from 1981 to 2020 (the most recent complete year available from PRISM at the time of this writing), annual precipitation ranged from a low of 14.24 inches in 2020 to a high of 27.98 inches in 1994 (**Figure 1.43**). Considering monthly precipitation, July and August are the wettest months, accounting for just over 30% of the annual precipitation on average (**Figure 1.42**). Average annual air temperatures have ranged from a low of 40.94 °F to a high of 45.10 °F in 2017 (**Figure 1.44**). Average annual dew point temperatures don't exhibit the same annual variations of precipitation and temperature, while average monthly dew point temperatures tend to follow air temperature values. Average annual dew point temperatures have ranged from a low of 18.69 °F in 2012 to a high of 25.16 °F in 1986 (**Figure 1.45**). Monthly average dew point temperatures range between 8.87 °F in January to 41.47 °F in August (**Figure 1.42**).

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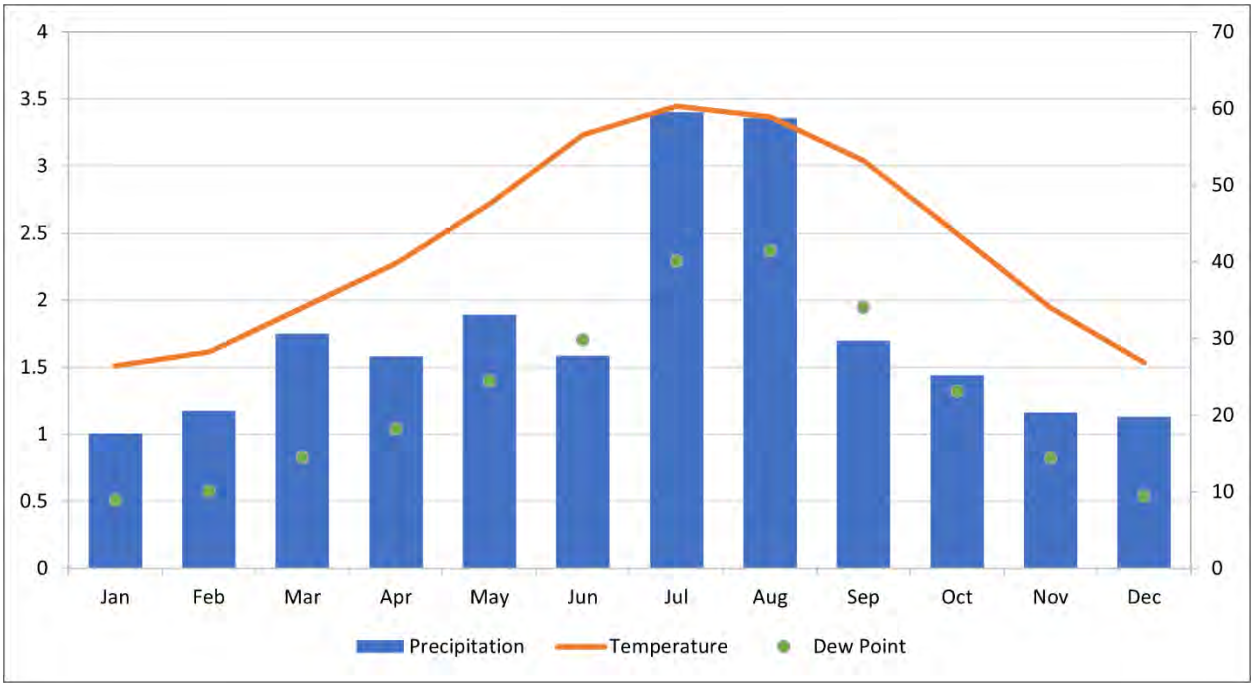


Figure 1.42: Climate overview of the Shuree Pond North watershed.

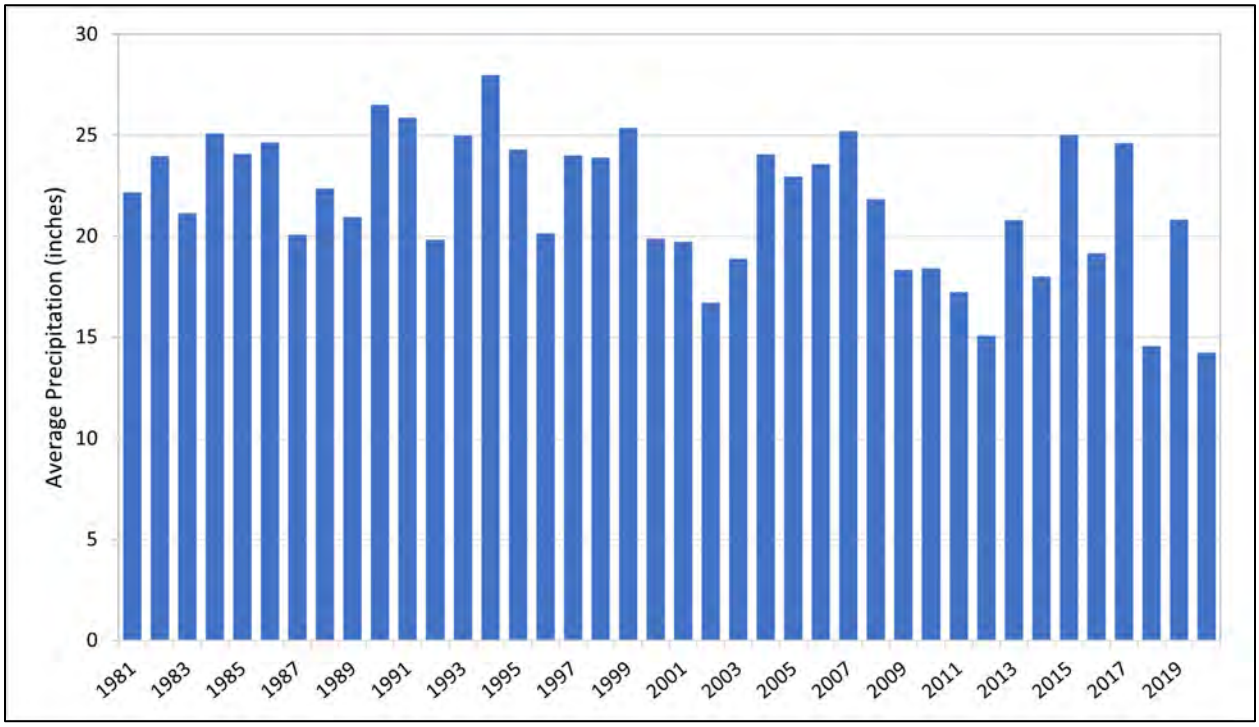


Figure 1.43: Average annual precipitation for the Shuree Pond North watershed from 1981 to 2020.

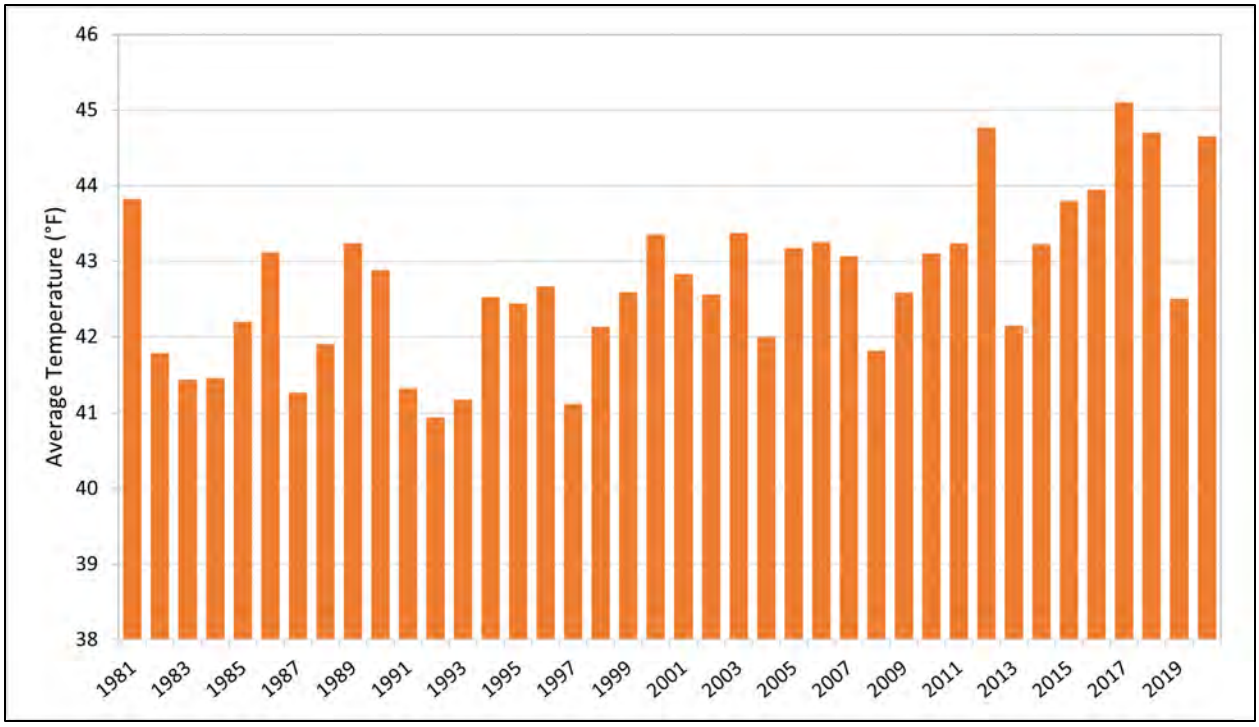


Figure 1.44: Average annual temperature for the Shuree Pond North watershed from 1981 to 2020.

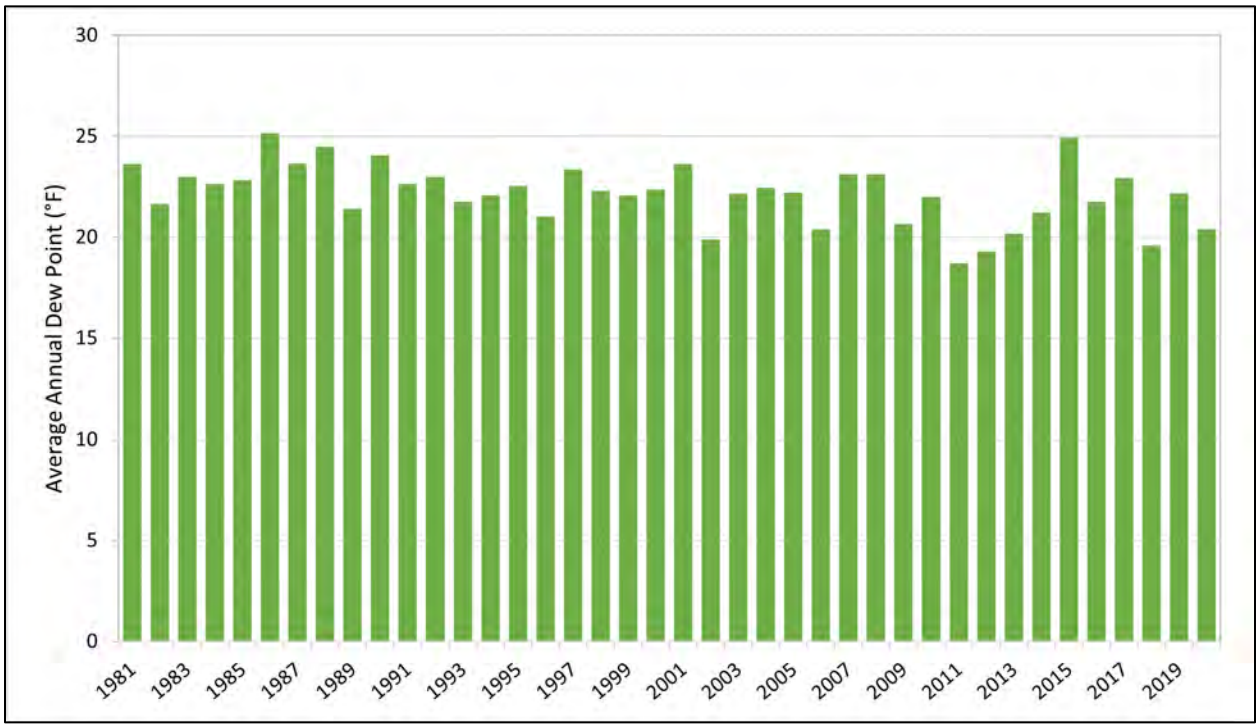


Figure 1.45: Average annual dew point temperature for the Shuree Pond North watershed from 1981 to 2020.

2.0 Aluminum

Chronic high levels of aluminum (Al) can be toxic to fish, benthic invertebrates, and some single-celled plants. Aluminum concentrations from 0.1 to 0.3 mg/L (100 to 300 ug/L) increase mortality and retard growth, gonadal development, and egg production of fish. Information on the toxic forms of aluminum in natural waters suggest that soluble trivalent aluminum (Al_{3+}) exerts a toxic effect on fish by binding to the negative charge of gill tissues, thereby disrupting ionoregulatory and respiratory balance (Exley et al. 1991; Gensemer and Playle 1999). This charge interaction is complicated by subsequent polymerization of insoluble, positive-charged Al oxyhydroxides to fish gill tissues and thus both soluble and insoluble forms are implicated in the toxic response of fish to Al (Gensemer and Playle 1999).

In 2010, the WQCC updated the aquatic life use (ALU) criteria for aluminum from dissolved aluminum to hardness-dependent total recoverable aluminum (TR Al). In 2012, USEPA approved the change for use in waters where the pH is above 6.5. Aluminum-impaired waters of the Upper Rio Grande basin were within the applicable pH range during the 2017-2018 sampling events. The term "total recoverable" refers to the analytical method used in laboratory analysis and is essentially interchangeable with the term "total". "Total recoverable" is used here to reflect the language in 20.6.4.900.I NMAC, specifically, "For aluminum, the criteria are based on analysis of total recoverable aluminum in a sample that is filtered to minimize the mineral phase as specified by the department." Based on recommendations from an aluminum filtration study conducted by SWQB staff (NMED/SWQB 2012), if the turbidity exceeds 30 NTU, samples that will be analyzed for TR Al are filtered using a filter of 10 µm pore size that minimizes mineral-phase aluminum without restricting amorphous or colloidal phases. To be conservative, the TMDLs are calculated to protect against exceedance of the chronic criterion, which is more stringent than the acute criterion.

2.1 Target Loading Capacity

To meet aquatic life designated uses, the SWQB Comprehensive Assessment and Listing Methodology (NMED/SWQB, 2023) says that for any one chemical/physical pollutant, there shall be no more than one exceedance of the acute criterion, and no more than one exceedance of the chronic criterion in three years. Exceedances of the WQS were identified by assessment of the data from the 2017-2018 SWQB Upper Rio Grande intensive water quality survey, as shown in **Table 2.1**. Consequently, Santa Cruz Lake was listed on the 2020-2022 Integrated CWA §303(d)/§305(b) List (NMED/SWQB, 2020) for aluminum. Results of laboratory analyses of the samples are shown in **Appendix A.**

Santa Cruz Lake was listed as impaired for TR Al in 2020, along with the Santa Cruz River AU upstream of the lake (NM-2118.A_51) and the Santa Cruz River AU downstream of the lake (NM-2111_50). A stream TMDL including the Santa Cruz River was written in 2022.

Table 2.1 Exceedances of the Hardness-based Total Recoverable Al WQS.

TMDL Watershed	Parameter	Exceedances (chronic)	Exceedances (acute)
Santa Cruz Lake	**Aluminum, Total Recoverable**	**2/4**	**1/4**

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2.2 Flow

40 CFR 130.7(c)(1) requires states to calculate a TMDL using the critical conditions for stream flow, with TMDLs generally described in mass units per time (USEPA 2007). Given historic variability of reservoir levels, however, a single-value mass-based TMDL based on daily loading would only offer appropriate protections for a single reservoir level. A concentration-based TMDL would offer appropriate protections at all lake levels, therefore TMDLs for the impaired lakes included in this document are described first in concentrations per volume (**Table 2.3**) and second as mass-based values for average reservoir storage and the corresponding critical reservoir storage (**Table 2.4**).

Determining the critical flow conditions for a lake is more complex than simply considering low-flow conditions of a stream. Available data on reservoir storage varies greatly for the reservoirs and lakes across New Mexico. A review of USGS data from multiple reservoirs located across northern New Mexico and southern Colorado was used to determine critical conditions for reservoirs in this TMDL. The USGS average capacity was compared to the minimum observed capacity for the reservoirs included in the review. The average minimum observed capacity of the reservoirs was 9.86% of the USGS average capacity. For this TMDL, the critical conditions of the reservoirs will be listed as 10% of the average storage. **Table 2.2** describes the reservoir storage data available for Santa Cruz Lake. For ease of implementation, estimated surface water inputs of TR Al necessary to achieve concentration-based TMDL values are described in mass-based units for average reservoir storage values and critical conditions.

Table 2.2 Normal and critical reservoir storage for Santa Cruz Lake.

Reservoir/Lake	Data Source	Reservoir/Lake Volume (acre-feet)
Santa Cruz Lake (Average Storage)	Calculated based on ratio of surface area to storage volume (NHD and URS 2010)	3,005 acre-feet
Santa Cruz Lake (Critical Storage)	10% of calculated volume based on ratio of surface area to storage volume (NHD and URS 2010)	300.5 acre-feet

2.3 TMDL Calculations

The TMDL was calculated as a concentration based TMDL and a mass based TMDL. As described above, a concentration based TMDL will offer protection at all lake storage levels. For a concentration based TMDL, the water quality standard criteria as defined in 20.6.4 NMAC, will be the TMDL value. In **Equation 2.1,** the TMDL value would be the water quality standard criteria for TR Al and would be used to calculate the other remaining variables in the equation. Calculations of those variables are described below. Once concentration values have been determined for each part of **Equation 2.1**, conversions must be used to calculate the mass based TMDL. Detailed conversion tables are available in **Appendix B.**

This subsection describes the relationship between the numeric TR Al targets and the allowable pollutant-level by determining the total assimilative capacity of the waterbody, or loading capacity, for the pollutant. The loading capacity is the maximum amount of pollutant loading that a waterbody can receive

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while meeting its water quality objectives. The TMDLs for Santa Cruz Lake are as follows: first the Margin of Safety (MOS) is subtracted as described in Section 2.4, then the Waste Load Allocation (WLA) is subtracted as described in Section 2.5.1, and the remainder is the Load Allocation (LA) as described in Section 2.5.2 and **Equation 2.1**.

$$WLA + LA + MOS = TMDL \qquad \textbf{(Eq. 2.1)}$$

TMDLs are presented below in **Table 2.3** as concentration-based values and in **Tables 2.4** as mass-based values for the average and critical reservoir storage. Chronic aluminum criteria were calculated at the average hardness value that was measured during the survey sampling events that resulted in exceedances of the WQS (data show in **Appendix A**). More information on this calculation is available in 20.6.4.900 NMAC, subsection I.

Table 2.3 Concentration-based TR Al TMDLs.

TMDL Watershed	MOS (mg/L)	LA (mg/L)	WLA (mg/L)	TMDL (mg/L)
Santa Cruz Lake	0.035	0.315	0	0.35

Table 2.4 Concentration-based TR Al TMDLs, expressed as masses for the average and critical reservoir storage values.

Reservoir Storage Volume	MOS (lbs/day)	LA (lbs/day)	WLA (lbs/day)	TMDL (lbs/day)
Santa Cruz Lake Average Storage (3005 acre-feet)	285.90	2573.07	0	2858.97
Santa Cruz Lake Critical Storage (300.5 acre-feet)	28.58	257.31	0	285.89

2.4 Margin of Safety

TMDLs should reflect a MOS based on the uncertainty or variability in the data, the point and nonpoint source load estimates, and the modeling analysis. The MOS can be expressed either implicitly or explicitly. An implicit MOS is incorporated by making conservative assumptions in the TMDL analysis, such as allocating a conservative load to background sources. An explicit MOS is applied by reserving a portion of the TMDL and not allocating it to any other sources.

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For these TR Al TMDLs, the 10% MOS was developed using a combination of conservative assumptions and explicit recognition of potential errors. Therefore, this margin of safety is the sum of the following two elements:

- Conservative Assumptions
    - Treating TR Al as a pollutant that does not readily degrade in the environment.

- Explicit Recognition of Potential Errors
    - Uncertainty exists in sampling nonpoint sources of pollution. A conservative MOS for this element is therefore **5%**.
    - There is inherent variability in lake volumes, both measured and estimated. A conservative MOS for this element in lakes is **5%**.

2.5 Waste Load Allocations and Load Allocations

2.5.1 Waste Load Allocation

There are no active individual National Pollutant Discharge Elimination System (NPDES) permits that discharge to the aluminum impaired AUs, therefore the WLA for these TMDLs is zero.

Sediment and associated contaminants are considered components of industrial storm water discharges covered under NPDES General Permits. Stormwater discharges from construction activities are transient, occurring mainly during construction activity, and during storm events. Coverage under the NPDES Construction General Permit (CGP) for construction sites greater than one (1) acre, or less than one (1) acre if they are part of a common plan of development that will be equal to or greater than one (1) acre, requires preparation of a Storm Water Pollution Prevention Plan (SWPPP) that includes identification and control of all pollutants associated with the construction activities to minimize impacts to water quality. The 2022 CGP also includes state-specific requirements for SWPPPs. The SWPPP must include site-specific interim and permanent stabilization, managerial, and structural solids, erosion and sediment control best management practices (BMPs) and/or other controls that are designed to prevent to the maximum extent practicable an increase in the sediment yield and flow velocity from pre-construction, pre-development conditions to assure that applicable standards in 20.6.4 NMAC, including the antidegradation policy, and TMDL WLAs are met. This requirement applies to discharges both during construction and after construction operations have been completed. Currently in the 2022 CGP, EPA defines "sediment-related parameter" as a pollutant parameter that is closely related to sediment such as turbidity, total suspended solids (TSS), total suspended sediment, transparency, sedimentation, and siltation. For discharge covered under the CGP to a water that is impaired for a parameter other than a sediment-related parameter or nutrients, EPA will inform the operator if any additional controls are necessary to meet water quality standards.

Stormwater discharges from industrial activities and facilities, based on industrial classification codes, may be eligible for coverage under the 2021 NPDES Multi-Sector General Permit (MSGP). The MSGP also requires preparation of a SWPPP. Based on the industrial sector, some of the industrial facilities and activities covered under the MSGP have technology based effluent limitation and/or benchmark monitoring for pollutants. The current MSGP includes state-specific requirements that the benchmark values reflect State of New Mexico WQS.

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It is not possible to calculate individual WLAs for facilities covered by the General Permits at this time using the available tools. While these sources are not given individual allocations, they are addressed through other means, including BMPs, and other stormwater pollution prevention conditions. Implementation of a SWPPP that meets the requirements of a General Permit is generally assumed to be consistent with this TMDL. Loads that are in compliance with the General Permits are therefore currently included as part of the LA.

2.5.2 Load Allocations

The load allocation (LA) accounts for the non-point sources (NPS) of pollution in the respective watersheds. Nonpoint sources include all other categories not classified as point sources (i.e., WLAs). In order to calculate the LA, the WLAs and the MOS were subtracted from the TMDL using **Equation 2.2**.

$$\mathbf{TMDL = WLA + LA + MOS} \qquad \textbf{(Eq. 2.2)}$$

therefore,

$$\mathbf{LA = TMDL - MOS - WLA}$$

2.5.3 Load Reductions

The load reductions necessary to meet target loads were calculated as the difference between the calculated daily target load and the mean measured load. Load reductions necessary are given as both concentrations (**Table 2.5**) and masses (**Table 2.6**).

Table 2.5: Calculation of load reduction for TR Al necessary to achieve target concentrations.

TMDL Watershed	Parameter	Target Concentration (mg/L)[(a)]	Mean Measured Concentration (mg/L)[(b)]	Concentration Reduction Necessary (mg/L)[(c)]	Percent Reduction Necessary[(d)]
Santa Cruz Lake	TR Al	0.315	0.87	0.555	64%

Notes:
(a) Target Concentration = TMDL – MOS. The MOS is not included in the concentration reduction calculations because it is a set aside value, which accounts for any uncertainty or variability in TMDL calculations and therefore should not be subtracted from the measured concentration.
(b) The measured concentration is the magnitude of point and nonpoint sources. It is calculated using mean measured exceedance values (Appendix A).
(c) Concentration reduction necessary is the concentration by which the existing measured concentration must be reduced to achieve the target concentration and is calculated as follows: Measured Concentration – Target Concentration.
(d) Percent reduction necessary is the percent the existing measured concentration must be reduced to achieve the target concentration and is calculated as follows: (Measured Concentration – Target Concentration) / Measured Concentration x 100.

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Table 2.6: Calculation of surface runoff load reduction for TR Al necessary to achieve target concentrations, expressed as masses.

TMDL Watershed	Hardness (mg/L)	Target Load (lbs/day)[(a)]	Mean Measured Load (lbs/day)[(b)]	Load Reduction Necessary (lbs/day)[(c)]	Percent Reduction Necessary[(d)]
Santa Cruz Lake Average Storage (3005 acre-feet)	37	2573.07	7106.59	4533.52	64%
Santa Cruz Lake Critical Storage (300.5 acre-feet)	37	257.31	710.65	453.34	64%

Notes: *(a)* Target Concentration Mass = TMDL – MOS, expressed as mass based on lake storage volume. The MOS is not included in the load reduction calculations because it is a set aside value, which accounts for any uncertainty or variability in TMDL calculations and therefore should not be subtracted from the measured load.
(b) The measured concentration mass is the magnitude of point and nonpoint sources, expressed as mass based on lake storage volume. It is calculated using mean measured exceedance values (Appendix A).
(c) Load reduction necessary as mass is the mass by which the existing measured concentration must be reduced to achieve the target concentration as mass and is calculated as follows: Measured Concentration as Mass – Target Concentration as Mass.
(d) Percent reduction necessary is the percent the existing measured load must be reduced to achieve the target load and is calculated as follows: (Measured Concentration Mass – Target Concentration Mass) / Measured Concentration Mass x 100.

2.6 Probable Pollutant Sources

SWQB conducted an assessment of the probable sources of impairment of the AUs draining into the nutrient impaired lakes according to Standard Operating Procedure 4.1, Revision 2, Probable Source(s) Determination (https://www.env.nm.gov/surface-water-quality/sop/; see also Appendix B). Probable Source Sheets are filled out by SWQB monitoring staff during watershed surveys. The sheets are then reviewed by watershed protection staff familiar with the location, and the TMDL writer conducts a search of aerial imagery, GIS files, and other available resources. The list of probable sources is not intended to single out any particular landowner or land management activity and generally includes several sources per pollutant.

Table 2.7 displays probable pollutant sources for all causes of impairment, including aluminum within each AU in the TMDL study areas, as determined by the field reconnaissance and knowledge of watershed activities. The draft probable source list will be reviewed and modified as necessary, with watershed group/stakeholder input during the TMDL public meeting and comment period. Probable sources of impairment will be further evaluated, refined, and changed as necessary through the Watershed-Based Plan (WBP).

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Table 2.7 Probable Sources for Non-Point pollution in the Santa Cruz Lake watershed.

Lake Watershed	Probable Sources
Santa Cruz Lake	Angling Pressure; Dumping/Garbage/Trash/Litter; Fire Suppression (Thinning/Chemicals); Rangeland Grazing (dispersed); Bridges/Culverts/RR Crossings; Highway/Road/Bridge Runoff; Hiking Trails; Inappropriate Waste Disposal; Residences/Buildings; Logging Ops – Legacy; On-Site Treatment Systems (Septic, etc.); Paved/Gravel/Dirt Roads; Pavement/Impervious Surfaces; Site Clearance (Land Development); Waste from Pets (high concentration); Wildlife other than Waterfowl

2.7 Consideration of Seasonal Variation

Section 303(d)(1) of the CWA requires TMDLs to be "established at a level necessary to implement the applicable WQS with seasonal variation." Data used in the calculation of this TMDL were collected during the spring, summer, and fall to ensure coverage of any potential seasonal variation in the system. Exceedances were observed during spring and fall seasons, which captured lake storage level alterations related to the growing season and early monsoonal rains. The critical condition used for calculating the TMDL is considered to be conservative and protective of the water quality standard under all lake storage levels. Calculations made under average lake storage levels during the specific watershed monitoring survey, in addition to using other conservative assumptions as described in the previous section on MOS, should be protective of the water quality standards designed to preserve aquatic life in the lake. It was assumed that if critical conditions were met during this period, coverage of any potential seasonal variation would also be met.

2.8 Future Growth

Growth estimates for counties in New Mexico are available from the University of New Mexico (https://gps.unm.edu/pop/population-projections.html, accessed 02/14/2024). These estimates project growth to the year 2040. The county included in this TMDL are Santa Fe County and Mora County (including the Santa Cruz Lake watershed).

Table 2.8: Future growth estimates for Mora and Santa Fe counties.

County	Watershed	2020	2025	2030	2035	2040	% Increase (2020-2040)
Mora	Santa Cruz Lake	4,470	4,256	4,024	3,772	3,509	-21.50%
Santa Fe	Santa Cruz Lake	150,488	153,311	155,641	157,291	158,420	5.27%

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Estimates of future growth are not anticipated to lead to a significant increase in nutrients that cannot be controlled with BMPs. However, it is imperative that BMPs continue to be utilized to improve road conditions and grazing allotments and adhere to SWPPP requirements related to construction and industrial activities covered under the general permit. Any future growth would be considered part of the existing load allocation, assuming persistence of the hydrologic conditions used to develop these TMDLs.

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3.0 Plant Nutrients

Nutrient assessments for Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, and Shuree Pond North were included in the 2020-2022 CWA Integrated §303(d)/§305(b) List of Assessed Waters (NMED/SWQB 2020). Assessment of water quality data indicated impairments of total nitrogen (TN) of the CALM coldwater lake threshold of 0.9 mg/L in Eagle Nest Lake, Lake Maloya, and Shuree Pond North, impairments of total phosphorus (TP) of the CALM coldwater lake threshold of 0.03 mg/L in Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, and Shuree Pond North (NMED/SWQB 2023).

Nitrogen and phosphorus are essential for proper functioning of aquatic ecosystems. However, nuisance levels of algae and other aquatic vegetation can develop rapidly in response to nutrient enrichment when other factors (e.g., light, temperature, substrate) are not limiting.

3.1 Target Loading Capacity

There are two potential causes of nutrient enrichment in any given water body: excessive phosphorus and/or nitrogen. Phosphorous is found in water primarily as orthophosphate. In contrast nitrogen may be found as several species, all of which must be considered in nutrient loading. Total nitrogen is defined as the sum of Nitrate + Nitrite (N+N) and Total Kjeldahl Nitrogen (TKN). Presently, there is no USEPA-approved method to test for total nitrogen, however adding the results of USEPA methods 351.2 (TKN) and 353.2 (N+N) is appropriate for estimating total nitrogen (APHA 1989). While not a USEPA-approved method, Method SM4500-N for Total Nitrogen using a persulfate digest, is an approved method in the SWQB QAPP (NMED/SWQB 2021) and is used in cases where a lower detection limit is needed.

The applicable threshold values for causal variables for lakes included in this nutrient TMDL are 0.9 mg/L for total nitrogen and 0.03 mg/L for total phosphorus based on the value identified for cold lakes in Appendix D of the 2023 CALM (NMED/SWQB 2023). Lakes included in the cold lake group are lakes with a designated use of High Quality Coldwater Aquatic Life and Coldwater Aquatic Life, which includes every lake in this TMDL (NMED/SWQB 2023). The nutrient threshold values were used for water quality assessments and as a starting point for TMDL development. For New Mexico lakes, potential numeric nutrient targets were collated from the water quality standards, SWQB analyses of existing data, other state agency examples or published literature. Colorado and Montana are two Mountain West states that have recently adopted numeric TN and TP standards. Colorado adopted interim nutrient limits which have a TN:TP ratio of 11.4 and 11.8 for warm and cold-water streams and rivers, respectively (Colorado Department of Public Health and Environment 2013). Montana's nutrient standards have TN:TP ratios that range from 2.4 to 13.3, with an average ratio of 7.6 (Montana Department of Environmental Quality 2014). Target values were selected for the CALM based on ecoregional considerations and best professional judgement. The target TN values is derived from change point and regression tree analyses of existing water quality data from New Mexico (Scott and Haggard 2011). The target TP value is derived from the boundary between mesotrophic and eutrophic lakes identified by Nurnberg (1996).

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Table 3.1: Applicable nutrient-related thresholds for Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, and Shuree Pond North.

Ecoregion	21 – Southern Rockies (Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, Shuree Pond North) & 22 – Arizona/New Mexico Plateau (Santa Cruz Lake)
Aquatic Life Use	High Quality Coldwater (Eagle Nest Lake, Santa Cruz Lake, Shuree Pond North) & Coldwater (Lake Maloya)
Chlorophyll-*a*	≤ 7.5 µg/L[(a)]
Cyanobacteria	≤ 38%[(a)]
Dissolved Oxygen	6.0 mg/L[(a)]
Total Nitrogen	≤ 0.9 mg/L[(a)]
Total Phosphorus	≤ 0.03 mg/L[(a)]

Notes: (a) Threshold value identified for coldwater lakes in 2021 CALM.

During the 2015-2016 Canadian River watershed survey, including Eagle Nest Lake, Lake Maloya and Shuree Pond North, exceedances were observed in both the causal variables (total nitrogen and total phosphorus) and response variables (chlorophyll-*a*, cyanobacteria, dissolved oxygen, and pH). Eagle Nest Lake observed two exceedances (40%) of the total nitrogen threshold and six exceedances (100%) of the total phosphorus threshold (**Table 3.2**). In addition to the nutrient measurements, the response variables chlorophyll-*a*, cyanobacteria, and dissolved oxygen all also exceeded applicable thresholds (**Table 3.3**). pH measurements did not exceed the applicable threshold. Lake Maloya observed two exceedances (40%) of the total nitrogen threshold and two exceedances (40%) of the total phosphorus threshold (**Table 3.2**). In addition to the nutrient measurements, the response variables chlorophyll-a, cyanobacteria, dissolved oxygen, and pH all also exceeded applicable thresholds (**Table 3.3**). Shuree Pond North observed one exceedance (33%) of the total nitrogen threshold and two exceedances (66%) of the total phosphorus threshold (**Table 3.2**). In addition to the nutrient measurements, the response variables chlorophyll-a and pH both also exceeded applicable thresholds (**Table 3.3**). Cyanobacteria and dissolved oxygen concentration measurements did not exceed the applicable thresholds.

During the 2017-2018 Upper Rio Grande watershed survey, including Santa Cruz Lake, exceedances were observed for both the causal and response variables. Santa Cruz Lake observed no exceedances of the total nitrogen threshold and three exceedances (60%) of the total phosphorus threshold (**Table 3.2**). In addition to the nutrient measurements, the response variables chlorophyll-a, cyanobacteria, and dissolved oxygen all exceeded applicable thresholds (**Table 3.3**).

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Table 3.2 Causal variable exceedance ratios[(a)] of applicable water quality criteria.

TMDL Watershed	Parameter	Associated Criterion/Threshold	Exceedance Ratio[(a)]
Eagle Nest Lake	Total Nitrogen	0.90 mg/L	2/5
	Total Phosphorus	0.03 mg/L	6/6
Lake Maloya	Total Nitrogen	0.90 mg/L	2/5
	Total Phosphorus	0.03 mg/L	2/5
Santa Cruz Lake	Total Nitrogen	0.90 mg/L	0/5
	Total Phosphorus	0.03 mg/L	3/5
Shuree Pond North	Total Nitrogen	0.90 mg/L	1/3
	Total Phosphorus	0.03 mg/L	2/3

Notes: (a) Exceedance ratio is the number of exceedances observed in the total number of samples.

Table 3.3 Response variable exceedance ratios[(a)] of applicable water quality criteria.

Parameter	Eagle Nest Lake	Lake Maloya	Santa Cruz Lake	Shuree Pond North
Chlorophyll-a	3/4	3/5	3/5	1/2
Cyanobacteria	4/6	1/4	3/5	0/2
Dissolved Oxygen (DO)	1/6	1/5	2/5	0/3
pH	0/5	1/5	0/4	2/3

Notes: (a) Exceedance ratio is the number of exceedances observed in the total number of samples.

3.2 Flow

40 CFR 130.7(c)(1) requires states to calculate a TMDL using the critical conditions for stream flow, with TMDLs generally described in mass units per time (USEPA 2007). Given historic variability of reservoir levels, however, a single-value mass-based TMDL based on daily loading would only offer appropriate protections for a single reservoir level. A concentration-based TMDL would offer appropriate protections at all lake levels, therefore TMDLs for the impaired lakes included in this document are described first in concentrations per volume (**Table 3.5a**) and second as mass-based values for average reservoir and the corresponding critical conditions (**Table 3.5b**).

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Determining the critical flow conditions for a lake is more complex than simply considering low-flow conditions of a stream. Available data on reservoir storage varies greatly for the reservoirs and lakes across New Mexico. A review of USGS data for multiple reservoirs located across northern New Mexico and southern Colorado was used to determine critical conditions for reservoirs in this TMDL. The USGS average capacity was compared to the minimum observed capacity for the reservoirs included in the review. The average minimum observed capacity of the reservoirs was 9.86% of the USGS average capacity. For this TMDL, the critical conditions of the reservoirs will be listed as 10% of the average storage. **Table 3.4** describes the reservoir storage data available for Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, and Shuree Pond North. For ease of implementation, estimated surface water inputs of both TN and TP necessary to achieve concentration-based TMDL values are described in mass-based units for average reservoir storage values and critical conditions.

Table 3.4: Reservoir storage capacities.

Reservoir/Lake	Data Source	Reservoir/Lake Volume (acre-feet)
Eagle Nest Lake	2015-2016 Average Storage (USGS Gage: 07205500)	28,933 acre-feet
Eagle Nest Lake	10% of 2015-2016 Average Storage (USGS Gage: 07205500)	2,893.3 acre-feet
Lake Maloya	2015-2016 Average Storage (USGS Gage: 07199450)	3,620 acre-feet
Lake Maloya	10% of 2015-2016 Average Storage (USGS Gage: 07199450)	369 acre-feet
Santa Cruz Lake	Calculated based on ratio of surface area to storage volume (NHD and URS 2010)	3,005 acre-feet
Santa Cruz Lake	10% of calculated volume based on ratio of surface area to storage volume (NHD and URS 2010)	300.5 acre-feet
Shuree Pond North	Normal Storage (National Inventory of Dams)	40 acre-feet
Shuree Pond North	10% of Normal Storage (National Inventory of Dams)	4 acre-feet

3.3 TMDL Calculation

The TMDL was calculated as a concentration based TMDL and a mass based TMDL. As described above, a concentration based TMDL will offer protection at all lake storage levels. For a concentration-based lake nutrient TMDL, the water quality standard numeric criteria as defined in Appendix D of the NMED SWQB

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CALM or segment specific numeric criteria in 20.6.4 NMAC, will be the TMDL value (NMED/SWQB, 2023). In **Equation 3.1,** the TMDL value would be the water quality standard criteria for TN or TP and would be used to calculate the other remaining variables in the equation. Calculations of those variables are described below. Once concentration values have been determined for each part of **Equation 3.1**, conversions must be used to calculate the mass based TMDL. Detailed conversion tables are available in **Appendix B.**

This subsection describes the relationship between the numeric nutrient targets and the allowable pollutant-level by determining the total assimilative capacity of the waterbody, or loading capacity, for the pollutant. The loading capacity is the maximum amount of pollutant loading that a waterbody can receive while meeting its water quality objectives. The TMDLs for Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, and Shuree Pond North are allocated as follows: first the Margin of Safety (MOS) is subtracted as described in Section 3.4, then the Waste Load Allocation (WLA) is subtracted as described in Section 3.5.1, and the remainder is the Load Allocation (LA) as described in Section 3.5.2 and **Equation 3.1**.

$$WLA + LA + MOS = TMDL \qquad \textbf{(Eq. 3.1)}$$

Every lake has a specific carrying capacity for nutrients based on applicable WQS. This carrying capacity, or TMDL, is defined as the concentration of pollutant that can be carried without violating the target concentration for that constituent. These TMDLs were developed based on observed concentrations using lake storage values from **Table 3.4** and the numeric targets. The specific carrying capacity of a receiving water for a given pollutant was estimated using **Equation 3.1**. The calculated carrying concentrations (i.e., TMDLs) for TN and TP are summarized in **Table 3.7a**. The same calculated concentrations, expressed as masses for the lake storage values in **Table 3.4** are also summarized in **Table 3.7b.**

Table 3.5a: Concentration-based Plant Nutrient TMDLs.

TMDL Watershed	Parameter	MOS (mg/L)	LA (mg/L)	WLA (mg/L)	TMDL (mg/L)
Eagle Nest Lake	Total Nitrogen	0.090	0.810	0.000	0.900
	Total Phosphorus	0.003	0.027	0.000	0.030
Lake Maloya	Total Nitrogen	0.090	0.810	0.000	0.900
	Total Phosphorus	0.003	0.027	0.000	0.030
Santa Cruz Lake	Total Nitrogen	0.090	0.810	0.000	0.900
	Total Phosphorus	0.003	0.027	0.000	0.030
Shuree Pond North	Total Nitrogen	0.090	0.810	0.000	0.900
	Total Phosphorus	0.003	0.027	0.000	0.030

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Table 3.5b: Concentration-based Plant Nutrient TMDLs, expressed as masses for average storage and critical storage.

Reservoir Storage Volume[(a)]	Parameter	MOS (lbs/day)	LA (lbs/day)	WLA (lbs/day)	TMDL (lbs/day)
Eagle Nest Lake 2015-2016 Average (28,933 acre-feet)	Total Nitrogen	7,078.37	63,705.34	0.00	70,783.71
	Total Phosphorus	235.95	2,123.51	0.00	2,359.46
Eagle Nest Lake 10% of 2015-2016 Average (2,893 acre-feet)	Total Nitrogen	707.83	6370.53	0.00	7078.36
	Total Phosphorus	23.59	212.35	0.00	235.94
Lake Maloya 2015-2016 Average (3620 acre-feet)	Total Nitrogen	885.62	7,970.60	0.00	8,856.22
	Total Phosphorus	29.52	265.69	0.00	295.21
Lake Maloya 10% of 2015-2016 Average (362 acre-feet)	Total Nitrogen	88.56	797.06	0.00	885.62
	Total Phosphorus	2.95	26.57	0.00	29.52
Santa Cruz Lake Normal Storage (3005 acre-feet)	Total Nitrogen	735.16	6,616.48	0.00	7,351.64
	Total Phosphorus	24.51	220.55	0.00	245.05
Santa Cruz Lake 10% of Normal Storage (300 acre-feet)	Total Nitrogen	73.51	661.65	0.00	735.16
	Total Phosphorus	2.45	22.05	0.00	24.50
Shuree Pond North Normal Storage (40 acre-feet)	Total Nitrogen	9.79	88.07	0.00	97.86
	Total Phosphorus	0.33	0.94	0.00	1.27
Shuree Pond North 10% of Normal Storage (4 acre-feet)	Total Nitrogen	0.979	8.807	0.00	9.786
	Total Phosphorus	0.033	0.094	0.00	0.127

Notes: *(a)* Reservoir Storage Volume is listed as the average reservoir storage (acre-feet) during the watershed surveys for Eagle Nest Lake, and Lake Maloya. Normal reservoir storage (acre-feet) for Santa Cruz Lake and Shuree Pond North were obtained from the National Inventory of Dams and represent the most accurate value for average reservoir storage. Critical conditions are 10% of either the average reservoir storage or the normal reservoir storage.

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3.4 Margin of Safety

TMDLs should reflect a MOS based on the uncertainty or variability in the data, the point and nonpoint source load estimates, and the modeling analysis. The MOS can be expressed either implicitly or explicitly. An implicit MOS is incorporated by making conservative assumptions in the TMDL analysis, such as allocating a conservative load to background sources. An explicit MOS is applied by reserving a portion of the TMDL and not allocating it to any other sources.

For these nutrient TMDLs, the 10% MOS was developed using a combination of conservative assumptions and explicit recognition of potential errors. Therefore, this margin of safety is the sum of the following two elements:

- Conservative Assumptions
    - Treating phosphorus and nitrogen as pollutants that do not readily degrade in the environment.

- Explicit Recognition of Potential Errors
    - Uncertainty exists in sampling nonpoint sources of pollution. A conservative MOS for this element is therefore **5%.**
    - There is inherent variability in lake volumes, both measured and estimated. A conservative MOS for this element in lakes is **5%.**

3.5 Waste Load Allocations and Load Allocations

3.5.1 Waste Load Allocation

There are no National Pollutant Discharge Elimination System (NPDES) individual permits in the Lake Maloya, Santa Cruz Lake, and Shuree Pond North watersheds. There is one NPDES individual permit in the Eagle Nest Lake watershed (NPDES Permit: NM0060503) addressing total nitrogen and total phosphorus for the city of Angel Fire and its wastewater treatment plant effluent discharge. This permit and the associated WLA are included in the 2010 Cimarron River Watershed (Canadian River to Headwaters) TMDL for Cieneguilla Creek (NMED/SWQB 2010). Therefore, the WLA for this permit will not be included in the Eagle Nest Lake TMDL.

There are no Municipal Separate Storm Sewer System (MS4) permits in any of the lake watersheds included in this document. However, excess nutrient loading may be a component of some store water discharges covered under general NPDES permits. There may be storm water discharges from construction activities covered under the NPDES Construction General Permit (CGP). Permitted sites require preparation of a Stormwater Pollution Prevention Plan (SWPPP) that includes identification and control of all pollutants associated with the construction activities to minimize impacts to water quality. The current CGP also includes state-specific requirements to implement site-specific interim and permanent stabilization, managerial, and structural solids, erosion, and sediment control Best Management Practices (BMPs) and/or other controls. BMPs are designed to prevent to the maximum extent practicable an increase in sediment load to the water body or an increase in a sediment-related parameter, such as total suspended solids, turbidity, siltation, stream bottom deposits, etc. BMPs also include measures to reduce flow velocity during and after construction compared to pre-construction conditions to assure that WLAs or applicable water quality standards, including the antidegradation policy,

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are met. Compliance with a SWPPP that meets the requirements of the CGP is generally assumed to be consistent with this TMDL.

Stormwater discharges from active industrial facilities are generally covered under the current NPDES Multi-Sector General Permit (MSGP). This permit also requires preparation of an SWPPP, which includes specific requirements to limit (or eliminate) pollutant loading associated with the industrial activities in order to minimize impacts to water quality. Compliance with a SWPPP that meets the requirements of the MSGP is generally assumed to be consistent with these TMDLs.

It is not possible to calculate individual WLAs for facilities covered by these General Permits at this time using available tools. Loads that are in compliance with the General Permits are therefore currently included as part of the LA.

3.5.2 Load Allocation

The load allocation (LA) accounts for the non-point sources (NPS) of pollution in the respective watersheds. Nonpoint sources include all other categories not classified as point sources (i.e., WLAs). In order to calculate the LA, the WLAs and the MOS were subtracted from the TMDL using **Equation 3.2.**

$$\mathbf{TMDL = WLA + LA + MOS} \qquad \textbf{(Eq. 3.2)}$$

therefore,

$$\mathbf{LA = TMDL - MOS - WLA}$$

3.5.3 Load Reductions

The load reductions necessary to meet target loads were calculated as the difference between the calculated daily target load and the measured load. Load reductions necessary are given as both concentrations (**Table 3.7a**) and masses (**Table 3.7b**).

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Table 3.7a: Calculation of load reductions for TN and TP necessary to achieve target concentrations.

TMDL Watershed	Parameter	Target Concentration (mg/L)[(a)]	Mean Measured Concentration (mg/L)[(b)]	Concentration Reduction Necessary (mg/L)[(c)]	Percent Reduction Necessary[(d)]
Eagle Nest Lake	Total Nitrogen	0.810	0.900	0.090	10.0%
	Total Phosphorus	0.027	0.090	0.063	70.0%
Lake Maloya	Total Nitrogen	0.810	1.480	0.670	45.3%
	Total Phosphorus	0.027	0.051	0.024	47.1%
Santa Cruz Lake	Total Nitrogen	0.810	0.400	0.000	0.0%
	Total Phosphorus	0.027	0.031	0.004	12.9%
Shuree Pond North	Total Nitrogen	0.810	0.880	0.070	8.0%
	Total Phosphorus	0.027	0.049	0.022	44.9%

Notes: *(a)* Target Concentration = TMDL – MOS. The MOS is not included in the concentration reduction calculations because it is a set aside value, which accounts for any uncertainty or variability in TMDL calculations and therefore should not be subtracted from the measured concentration.
(b) The measured concentration is the magnitude of point and nonpoint sources. It is calculated using mean measured exceedance values (Appendix A).
(c) Concentration reduction necessary is the concentration by which the existing measured concentration must be reduced to achieve the target concentration and is calculated as follows: Measured Concentration – Target Concentration.
(d) Percent reduction necessary is the percent the existing measured concentration must be reduced to achieve the target concentration and is calculated as follows: (Measured Concentration – Target Concentration) / Measured Concentration x 100.

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Table 3.7b: Calculation of surface runoff load reductions for TN and TP necessary to achieve target concentrations, expressed as masses.

TMDL Watershed	Parameter	Target Load (lbs/day)[(a)]	Mean Measured Load (lbs/day)[(b)]	Load Reduction Necessary (lbs/day)[(c)]	Percent Reduction Necessary[(d)]
Eagle Nest Lake (2015-2016 Average Storage: 28,933 acre-feet)	Total Nitrogen	63,705	70,783	7,078	10.0%
	Total Phosphorus	2,123	7,078	4,954	70.0%
Lake Maloya (2015-2016 Average Storage: 3,620 acre-feet)	Total Nitrogen	7,970	14,563	6,592	45.3%
	Total Phosphorus	265	501	236	47.1%
Santa Cruz Lake (Calculated from NHD polygon and corresponding storage: 3005 acre-feet)	Total Nitrogen	6,616	3,267	0	0.0%
	Total Phosphorus	221	253	32	12.9%
Shuree Pond North (NID normal storage: 40 acre-feet)	Total Nitrogen	88.07	95.68	7.61	8.0%
	Total Phosphorus	2.93	5.33	2.39	44.9%

Notes: *(a)* Target Concentration Mass = TMDL – MOS, expressed as mass based on lake storage volume. The MOS is not included in the load reduction calculations because it is a set aside value, which accounts for any uncertainty or variability in TMDL calculations and therefore should not be subtracted from the measured load.

(b) The measured concentration mass is the magnitude of point and nonpoint sources, expressed as mass based on lake storage volume. It is calculated using mean measured exceedance values (Appendix A).

(c) Load reduction necessary as mass is the mass by which the existing measured concentration must be reduced to achieve the target concentration as mass and is calculated as follows: Measured Concentration as Mass – Target Concentration as Mass.

(d) Percent reduction necessary is the percent the existing measured load must be reduced to achieve the target load and is calculated as follows: (Measured Concentration Mass – Target Concentration Mass) / Measured Concentration Mass x 100.

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3.6 Probable Pollutant Sources

SWQB conducted an assessment of the probable sources of impairment of the AUs draining into the nutrient impaired lakes according to Standard Operating Procedure 4.1, Revision 2, Probable Source(s) Determination (https://www.env.nm.gov/surface-water-quality/sop/; see also **Appendix C**). Probable Source Sheets are filled out by SWQB monitoring staff during watershed surveys. The sheets are then reviewed by watershed protection staff familiar with the location, and the TMDL writer conducts a search of aerial imagery, GIS files, and other available resources. The list of probable sources is not intended to single out any particular landowner or land management activity and generally includes several sources per pollutant.

Table 3.6 displays probable pollutant sources for all causes of impairment, including plant nutrients within each AU in the TMDL study areas, as determined by the field reconnaissance and knowledge of watershed activities. The draft probable source list will be reviewed and modified as necessary, with watershed group/stakeholder input during the TMDL public meeting and comment period. Probable sources of impairment will be further evaluated, refined, and changed as necessary through the Watershed-Based Plan (WBP).

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Table 3.6: Probable Sources for the Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, and Shuree Pond North watersheds.

Lake Watershed	Probable Sources
Eagle Nest Lake	Abandoned Mines (Inactive/Tailings); Active Mines (Gravel); Angling Pressure; Bridges/Culverts/RR Crossings; Campgrounds (Defined); Channelization; Crop Production (Cropland or Dry Land); Dams/Diversions; Dirt or Gravel Roads; Flow Alteration (from Water Diversions); Highway/Road/Bridge Runoff; Hiking Trails; Logging Ops – Legacy; Low Water Crossing; Municipal Point Source Discharge; On-Site Treatment Systems (Septic, etc.); Residences/Buildings; Rangeland Grazing (Dispersed); Site Clearance (Land Development); Storm Water Runoff due to Construction; Urban Runoff/Sewers; Waterfowl; Wildlife other than Waterfowl
Lake Maloya	Grazing in Riparian or Shoreline Zones; Highway/Road/Bridge Runoff (Non-Construction Related); Impervious Surface/Parking Lot Runoff; Off-Road Vehicles; Other Recreational Pollution Sources; Rangeland Grazing; Drought-Related Impacts; Unspecified unpaved road or trail; Waterfowl; Watershed Runoff Following Forest Fire; Wildlife other than Waterfowl
Santa Cruz Lake	Angling Pressure; Bridges/Culverts/RR Crossings; Dumping/Garbage/Trash/Litter; Hiking Trails; Fire Suppression (Thinning/Chemicals); Highway/Road/Bridge Runoff; Inappropriate Waste Disposal; Logging Ops – Legacy; On-Site Treatment Systems (Septic, etc.); Paved/Gravel/Dirt Roads; Pavement/Impervious Surfaces; Rangeland Grazing (dispersed); Residences/Buildings; Site Clearance (Land Development); Waste from Pets (high concentration); Wildlife other than Waterfowl
Shuree Pond North	Drought-Related Impacts; Forest Roads (Road Construction and Use); Grazing in Riparian or Shoreline Zones; Highway/Road/Bridge Runoff; Off-Road Vehicles; Other Recreational Pollution Sources; Rangeland Grazing; Unspecified Unpaved Road or Trail; Waterfowl; Wildlife other than Waterfowl

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3.7 Linkage between Water Quality and Pollutant Sources

The source assessment phase of TMDL development identifies sources of nutrients that may contribute to both elevated nutrient concentrations and the stimulation of algal growth in a waterbody (**Figure 2.1**). Where data gaps exist or the level of uncertainty in the characterization of sources is large, the recommended approach to TMDL assignments requires the development of allocations based on estimates utilizing the best available information.

Phosphorus and nitrogen generally drive the productivity of algae and macrophytes in aquatic ecosystems, therefore they are regarded as the primary limiting nutrients in freshwaters. The main reservoirs of natural phosphorus are rocks and natural phosphate deposits. Weathering, leaching, and erosion are all processes that breakdown rock and mineral deposits allowing phosphorus to be transported to aquatic systems via water or wind. The breakdown of mineral phosphorus produces inorganic phosphate ions ($H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-}) that can be absorbed by plants from soil or water (USEPA 1999). Phosphorus primarily moves through the food web as organic phosphorus (after it has been incorporated into plant or algal tissue) where it may be released as phosphate in urine or other waste by heterotrophic consumers and reabsorbed by plants or algae to start another cycle (Nebel and Wright 2000).

The largest reservoir of nitrogen is the atmosphere. About 80% of the atmosphere by volume consists of nitrogen gas (N_2). Although nitrogen is plentiful in the environment, it is not readily available for biological uptake. Nitrogen gas must be converted to other forms, such as ammonia (NH_3 and NH_4^+), nitrate (NO_3^-), or nitrite (NO_2^-) before plants and animals can use it. Conversion of gaseous nitrogen into usable mineral forms occurs through three biologically mediated processes of the nitrogen cycle: nitrogen fixation, nitrification, and ammonification (USEPA 1999). Mineral forms of nitrogen can be taken up by plants and algae and incorporated into their tissue. Nitrogen follows the same pattern of food web incorporation as phosphorus and is released in waste primarily as ammonium compounds. The ammonium compounds are usually converted to nitrates by nitrifying bacteria, making it available again for uptake, starting the cycle anew (Nebel and Wright 2000).

Rain, overland runoff, groundwater, drainage networks, and industrial and residential waste effluents transport nutrients to receiving waterbodies. Once nutrients have been transported into a waterbody they can be taken up by algae, macrophytes, and microorganisms either in the water column or in the benthos; they can sorb to organic or inorganic particles in the water column and/or sediment; they can accumulate or be recycled in the sediment; or they can be transformed and released as a gas from the waterbody (**Figure 2.1**).

As noted above, phosphorus and nitrogen are essential for proper functioning of ecosystems. However, excess nutrients cause conditions unfavorable for the proper functioning of aquatic ecosystems. Nuisance levels of algae and other aquatic vegetation (macrophytes) can develop rapidly in response to nutrient enrichment when other factors (e.g., light, temperature, substrate) are not limiting (**Figure 2.1**). The relationship between nuisance algal growth and nutrient enrichment in aquatic systems has been well documented in the literature (Welch 1992; Van Nieuwenhuyse and Jones 1996; Dodds et al. 1997; Chetelat et al. 1999). Unfortunately, the magnitude of nutrient concentration that constitutes an “excess” is difficult to determine and varies by ecoregion. The recommended level of total phosphorus to avoid algal blooms in nitrogen-limited ecosystems is 0.01 to 0.1 mg/L and 0.1 mg/L to 1 mg/L of total nitrogen. The upper end of these ranges also supports less biological diversity.

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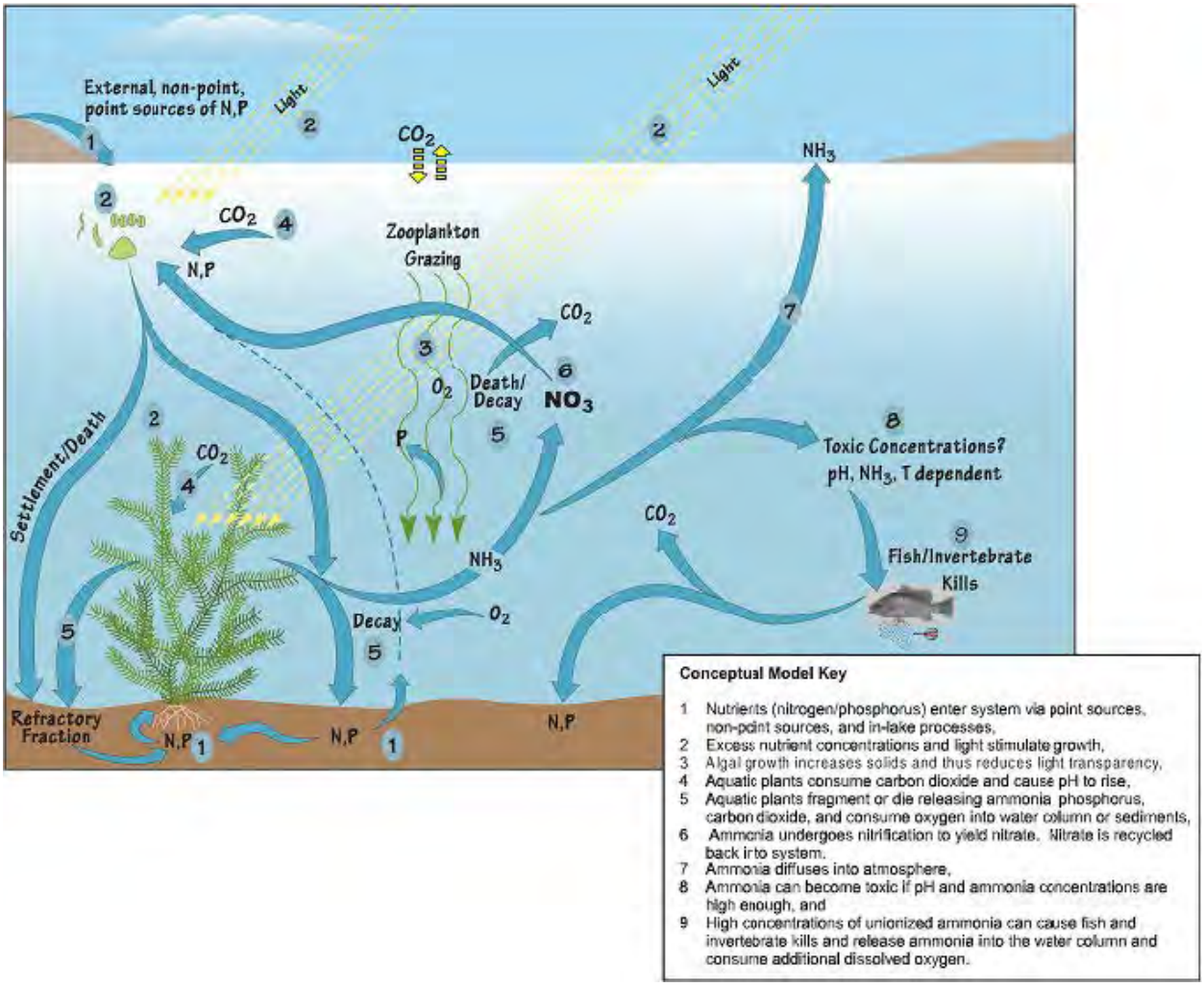


Figure 2.1: Nutrient conceptual model (USEPA 1999)

The presence of plant nutrients in a lake often varies primarily as a function of surface runoff nutrient concentrations, surface runoff volume, and the hydrologic residence time of the lake. As surface runoff nutrient concentrations increase and surface runoff volume decreases through water diversions and/or drought-related stressors, the lake cannot effectively dilute its constituents, causing the concentration of plant nutrients to increase. These in-lake nutrient increases can be further exacerbated if the hydrologic residence time of the lake increases due to impoundments and/or the lake volume drops due to drought-related stressors. Nutrients more readily reach a lake from land uses in close proximity to the lake because the hydrological pathways are shorter and have fewer obstacles than land uses located farther away from the lake. During periods of intense precipitation, such as that common to the monsoonal precipitation dynamics that define New Mexico's climate, distant land uses can become directly hydrologically connected to the lake, thus transporting nutrients to the lake from distant parts of the lake watershed. Additionally, any land cover transitions that reduce vegetation, especially near riparian corridors (e.g.,

ongoing and legacy grazing effects), and increase runoff ratios effectively serve to increase the nutrient transport capacity of surface runoff in both magnitude and distance.

3.8 Consideration of Seasonal Variability

Section 303(d)(1) of the CWA requires TMDLs to be "established at a level necessary to implement the applicable WQS with seasonal variation." Data used in the calculation of this TMDL were collected during the spring, summer, and fall to ensure coverage of any potential seasonal variation in the system. Exceedances were observed during summer and fall seasons, which captured lake storage level alterations related to the growing season and summer monsoonal rains. The critical condition used for calculating the TMDL is considered to be conservative and protective of the water quality standard under all lake storage levels. Calculations made under average lake storage levels during the specific watershed monitoring survey, in addition to using other conservative assumptions as described in the previous section on MOS, should be protective of the water quality standards designed to preserve aquatic life in the lake. It was assumed that if critical conditions were met during this time period, coverage of any potential seasonal variation would also be met.

3.9 Future Growth

Growth estimates for counties in New Mexico are available from the University of New Mexico (https://gps.unm.edu/pop/population-projections.html, accessed 02/14/2024). Growth estimates for counties in Colorado area available from the State Demography Office (https://data.colorado.gov/Demographics/Total-Population-by-County-by-Year/9dd2-kw29, accessed 02/14/2024). These estimates project growth to the year 2040. Counties included in this TMDL are Colfax County (including Eagle Nest Lake, Shuree Pond North, and Lake Maloya watersheds), Santa Fe County and Mora County (including Santa Cruz Lake watershed), and Las Animas County (including the Colorado potion of the Lake Maloya watershed).

Table 3.7: Future growth estimates for Colfax, Mora, Santa Fe and Las Animas (CO) counties.

County	Watershed	2020	2025	2030	2035	2040	% Increase (2020-2040)
Colfax	Eagle Nest Lake, Lake Maloya, Shuree Pond North	11,752	10,712	9,621	8,480	7,313	-20.75%
Mora	Santa Cruz Lake	4,470	4,256	4,024	3,772	3,509	-21.50%
Santa Fe	Santa Cruz Lake	150,488	153,311	155,641	157,291	158,420	5.27%
Las Animas (CO)	Lake Maloya	14,479	14,256	13,962	13,403	12,653	-12.61%

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Estimates of future growth are not anticipated to lead to a significant increase in nutrients that cannot be controlled with BMPs. However, it is imperative that BMPs continue to be utilized to improve road conditions and grazing allotments and adhere to SWPPP requirements related to construction and industrial activities covered under the general permit. Any future growth would be considered part of the existing load allocation, assuming persistence of the hydrologic conditions used to develop these TMDLs.

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4.0 Temperature

Water temperature influences the metabolism, behavior, and mortality of fish and other aquatic organisms. Natural temperatures of a water body fluctuate daily and seasonally. These natural fluctuations do not eliminate indigenous populations but may affect existing community structure and geographical distribution of species. Anthropogenic impacts such as thermal pollution, deforestation, flow modification and climate change can modify these natural temperature cycles, often leading to deleterious impacts on aquatic life communities. Such modifications may contribute to changes in geographic distribution of species and their ability to persist in the presence of additional stressors such as introduced species. One mechanism by which temperature affects fish is that warmer water has a lower capacity for dissolved oxygen. In addition to direct effects, the toxicity of many chemical contaminants increases with temperature (Caissie 2006).

4.1 Target Loading Capacity

Fish and other aquatic organisms have specific ranges of temperature tolerance and preference. Cold water fish such as salmonids (salmon and trout) are especially vulnerable to increased water temperature. For that reason, coldwater criteria are typically designed primarily to support reproducing populations of salmonids. A coolwater Aquatic Life Use (ALU) was approved by the WQCC in October 2010, to support aquatic life whose physiologic tolerances are intermediate between those of warmwater and coldwater aquatic life (NMED/SWQB 2009). Acute temperature criteria (such as New Mexico's T_{MAX}) are intended to protect aquatic life from lethal exposures, whereas chronic criteria (the 4T3 or 6T3) protect from sub-lethal exposures sufficient to cause long-term detrimental effects (Todd *et al*. 2008). The acute and chronic criteria are established to protect the most sensitive members of fish communities, based on laboratory studies of the upper thermal limits of individual species.

ALU temperature water criteria differ for rivers or streams and lakes or reservoirs. When collecting river or stream temperature data, a thermograph is typically deployed to continuously measure temperature. When collecting lake or reservoir temperature data, a temperature reading is captured at every meter of the water column from the surface of the waterbody to the lakebed. The temperature profile is then examined for the presence of a thermocline (greater than 1°C change per meter). If a thermocline is present, then temperature measurements within the epilimnion (above the thermocline) are averaged. If no thermocline is detected (i.e., the lake is well mixed), measurements taken from the upper one-third of the water column are averaged (NMED/SWQB CALM 2023). The averaged temperature values are considered a "grab" sample, and this sample is used as an equivalent to the typical 4T3/6T3 criterion and is used to determine lake temperature impairments.

When assessing continuous temperature data, the 4T3 criterion means the threshold temperature not to be exceeded for four or more consecutive hours in a 24-hour period on more than three consecutive days, and the 6T3 criterion means the threshold temperature not to be exceeded for six or more consecutive hours in a 24-hour period on more than three consecutive days.

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Table 4.1 Aquatic Life Use Temperature (°C) Water Quality Criteria for Lakes or Reservoirs

Criterion	High Quality Coldwater (HQCWL)	Coldwater (CWAL)	Marginal Coldwater (MCWAL)	Coolwater (CoolWAL)	Warmwater (WWAL)	Marginal Warmwater (MWWAL)
4T3 Equivalent[(a)]	20	---	---	---	---	---
6T3 Equivalent[(a)]	---	20	25	29	32.2	32.2

Notes: *(a)* The average temperature of the epilimnion or the upper 1/3 of the water column is used as a 4T3/6T3 equivalent when sampling lakes and reservoirs.

Assessment of the 2017-2018 Upper Rio Grande watershed lake temperature data determined that Santa Cruz Lake (HQCWL) was impaired for temperature. Temperature data are presented in **Appendix A.**

Table 4.2 Temperature criterion and exceedances for Santa Cruz Lake.

Lake	Designated ALU	Temperature Criterion (°C)	Exceedances
Santa Cruz Lake	High Quality Coldwater	20	2/5

4.2 Flow

40 CFR 130.7(c)(1) requires states to calculate a TMDL using the critical conditions for stream flow, with TMDLs generally described in mass units per time (USEPA 2007). Given historic variability of reservoir levels, however, a single-value mass-based TMDL based on daily loading would only offer appropriate protections for a single reservoir level. A concentration-based TMDL would offer appropriate protections at all lake levels, therefore the temperature TMDL for Santa Cruz Lake included in this document is described in concentrations per volume (**Table 4.4**).

Determining the critical flow conditions for a lake is more complex than simply considering low-flow conditions of a stream. Available data on reservoir storage varies greatly for the reservoirs and lakes across New Mexico. A review of USGS data for multiple reservoirs located across northern New Mexico and southern Colorado was used to determine critical conditions for reservoirs in this TMDL. The USGS average capacity was compared to the minimum observed capacity for the reservoirs included in the review. The average minimum observed capacity of the reservoirs was 9.86% of the USGS average capacity. For this TMDL, the critical conditions of the reservoirs will be listed as 10% of the average storage. **Table 4.3** describes the reservoir storage data available for Santa Cruz Lake. For ease of implementation, estimated surface water inputs of both TN and TP necessary to achieve concentration-based TMDL values are described in mass-based units for average reservoir storage values and critical conditions.

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Table 4.3 Normal and critical reservoir storage for Santa Cruz Lake.

Reservoir/Lake	Data Source	Reservoir/Lake Volume (acre-feet)
Santa Cruz Lake (Average Storage)	Calculated based on ratio of surface area to storage volume (NHD and URS 2010)	3,005 acre-feet
Santa Cruz Lake (Critical Storage)	10% of calculated volume based on ratio of surface area to storage volume (NHD and URS 2010)	300.5 acre-feet

4.3 TMDL Calculations

The calculation for a temperature TMDL is expressed in **Equation 4.1**:

$$WQS(°C) \times Flow\ (cfs) \times (1.023 \times 10^{7}) = TMDL\ (kJ/day) \qquad \textbf{Eq. (4.1)}$$

For temperature TMDLs, the WQS criterion is the temperature specified either by the designated ALU or segment-specific criteria. For this lake TMDL, the critical flow is represented as 10% of the normal reservoir storage during the time temperature samples were taken. Reservoir storage is measured in acre-feet/day and must be converted to cubic feet/second (cfs) to be used in the temperature TMDL equation. **Appendix B** shows the conversion from acre-feet/day to cfs for Santa Cruz Lake. The conversion factor is the variable needed to correct the TMDL units to kJ/day. Details of the derivation of the temperature TMDL equation are presented in **Appendix E. Table 4.4** shows the TMDL calculation value for Santa Cruz Lake.

Table 4.4 Temperature TMDL calculation

Lake	Temperature Criterion (°C)	Critical Storage (cfs)	Conversion Factor	TMDL (kJ/day)
Santa Cruz Lake	20	151.61	1.023×10^{7}	3.10×10^{10}

The TMDL is further allocated to a Margin of Safety (MOS), Waste Load Allocation (WLA; permitted point sources), and Load Allocation (LA; nonpoint sources), according to **Equation 4.2**:

$$\textbf{WLA + LA + MOS = TMDL} \qquad \textbf{(Eq. 4.2)}$$

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4.3.1 Margin of Safety

The CWA requires that each TMDL be calculated with a MOS, intended to account for uncertainty in available data or in the actual effect controls will have on loading reductions and receiving water quality. A MOS may be expressed as unallocated assimilative capacity or conservative analytical assumptions used in establishing the TMDL (e.g., derivation of numeric targets, modeling assumptions or effectiveness of proposed management actions). The MOS may be implicit, utilizing conservative assumptions for calculation of the loading capacity, WLAs, and LAs. The MOS may also be explicitly stated as an added separate quantity in the TMDL calculation.

Because of the uncertainty in determining the critical storage value of Santa Cruz Lake, an **explicit MOS of 5%** is being assigned. In recognition of the likelihood of future increases in air temperature and evaporative demand, an **additional explicit 10% MOS** is also being assigned to Santa Cruz Lake.

Table 4.5: MOS value for Santa Cruz Lake temperature TMDL

Lake	MOS (15%) (kJ/day)
Santa Cruz Lake	4.65×10^9

4.3.2 Waste Load Allocation

There are no active individual National Pollutant Discharge Elimination System (NPDES) individual permits that discharge to or upstream of Santa Cruz Lake. There are also no Municipal Separate Storm Sewer System (MS4) permits in this watershed. Therefore, no WLA is assigned.

There may be storm water discharges from industrial, including construction, activities covered under the National Pollutant Discharge Elimination System (NPDES) Construction General Permit (CGP) or Multi-Sector General Permit (MSGP). Excess temperature loading may be a component of some storm water discharges covered under general NPDES permits. Stormwater discharges from industrial, including construction, activities are generally considered transient because they occur mainly during the construction itself and/or only during storm events.

Coverage under the USEPA NPDES CGP for construction sites one (1) acre or greater or smaller if part of a common plan of development require preparation of a Storm Water Pollution Prevention Plan (SWPPP) that includes identification and control of pollutants associated with the construction activities to minimize impacts to water quality. The current CGP also includes state-specific requirements to implement site-specific interim and permanent stabilization, managerial, and structural solids, erosion, and sediment control Best Management Practices (BMPs), and/or other controls. BMPs are designed to prevent to the maximum extent practicable an increase in sediment load to the water body or an increase in a sediment-related parameter, such as total suspended solids, turbidity, siltation, stream bottom deposits, etc. BMPs also include measures to reduce flow velocity during and after construction compared to pre-construction conditions. Stormwater discharges from industrial activities and facilities, based on industrial classification codes, may be eligible for coverage under the current NPDES MSGP. The MSGP also requires preparation of a SWPPP. Some of the industrial facilities and activities covered under the MSGP have technology based effluent limitation and/or benchmark monitoring for pollutants. The current MSGP includes state-specific requirements that the benchmark values reflect State of New Mexico WQS.

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It is not possible to calculate individual WLAs for facilities covered by the General Permits at this time using the available tools. Loads that are in compliance with the General Permits are therefore currently included as part of the Load Allocation (LA). While these sources are not given individual allocations, they are addressed through other means, including BMPs, stormwater pollution prevention conditions, and other requirements. State certification of federal permits ensure that applicable water quality standards, including the antidegradation policy, are met. Compliance with a CGP or MSGP SWPPP that meets the requirements of the general permits is generally assumed to be consistent with this TMDL. Loads that are in compliance with the General Permits are therefore currently included as part of the LA.

4.3.3 Load Allocation

Load Allocation is pollution from any nonpoint source(s) or natural background and is addressed through Best Management Practices (BMPs). Since there are no WLAs in the Santa Cruz Lake watershed, the LA is equal to the TMDL value minus the MOS.

Table 4.5 Temperature TMDL load allocations. Units are kilojoules per day.

Lake	MOS	WLA	LA	TMDL
Santa Cruz Lake	4.65×10^{9}	0	2.64×10^{10}	3.10×10^{10}

4.4 Probable Pollutant Sources

SWQB conducted an assessment of the probable sources of impairment of the AUs draining into the nutrient impaired lakes according to Standard Operating Procedure 4.1, Revision 2, Probable Source(s) Determination (https://www.env.nm.gov/surface-water-quality/sop/; see also **Appendix C**). Probable Source Sheets are filled out by SWQB monitoring staff during watershed surveys. The sheets are then reviewed by watershed protection staff familiar with the location, and the TMDL writer conducts a search of aerial imagery, GIS files, and other available resources. The list of probable sources is not intended to single out any particular landowner or land management activity and generally includes several sources per pollutant.

Table 4.6 displays probable pollutant sources for all causes of impairment, including temperature within each AU in the TMDL study areas, as determined by the field reconnaissance and knowledge of watershed activities. The draft probable source list will be reviewed and modified as necessary, with watershed group/stakeholder input during the TMDL public meeting and comment period. Probable sources of impairment will be further evaluated, refined, and changed as necessary through the Watershed-Based Plan (WBP).

Table 4.6: Probable Sources for the Santa Cruz Lake watershed.

Lake Watershed	Probable Sources
Santa Cruz Lake	Angling Pressure; Bridges/Culverts/RR Crossings; Dumping/Garbage/Trash/Litter; Fire Suppression (Thinning/Chemicals); Highway/Road/Bridge

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	Runoff; Hiking Trails; Inappropriate Waste Disposal; Logging Ops – Legacy; On-Site Treatment Systems (Septic, etc.); Paved/Gravel/Dirt Roads; Pavement/Impervious Surfaces; Rangeland Grazing (dispersed); Residences/Buildings; Site Clearance (Land Development); Waste from Pets (high concentration); Wildlife other than Waterfowl

4.5 Consideration of Seasonal Variation

Section 303(d)(1) of the CWA requires TMDLs to be "established at a level necessary to implement the applicable WQS with seasonal variation." Data used in the calculation of this TMDL were collected during the spring, summer, and fall to ensure coverage of any potential seasonal variation in the system. Exceedances were observed during the summer season, which captured lake storage level alterations related to the growing season and summer monsoonal rains. The critical condition used for calculating the TMDL is considered to be conservative and protective of the water quality standard under all lake storage levels. Calculations made under average lake storage levels during the specific watershed monitoring survey, in addition to using other conservative assumptions as described in the previous section on MOS, should be protective of the water quality standards designed to preserve aquatic life in the lake. It was assumed that if critical conditions were met during this time period, coverage of any potential seasonal variation would also be met.

4.6 Future Growth

Growth estimates for counties in New Mexico are available from the University of New Mexico (https://gps.unm.edu/pop/population-projections.html, accessed 02/14/2024). These estimates project growth to the year 2040. The county included in this TMDL are Santa Fe County and Mora County (including the Santa Cruz Lake watershed).

Table 4.7: Future growth estimates for Mora and Santa Fe counties.

County	Watershed	2020	2025	2030	2035	2040	% Increase (2020-2040)
Mora	Santa Cruz Lake	4,470	4,256	4,024	3,772	3,509	-21.50%
Santa Fe	Santa Cruz Lake	150,488	153,311	155,641	157,291	158,420	5.27%

Estimates of future growth are not anticipated to lead to a significant increase in nutrients that cannot be controlled with BMPs. However, it is imperative that BMPs continue to be utilized to improve road conditions and grazing allotments and adhere to SWPPP requirements related to construction and industrial activities covered under the general permit. Any future growth would be considered part of the existing load allocation, assuming persistence of the hydrologic conditions used to develop these TMDLs.

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5.0 Monitoring

Pursuant to CWA Section 106(e)(1), 33 U.S.C. Section 1251, the SWQB has established appropriate monitoring methods, systems and procedures in order to compile and analyze data on the quality of the surface waters of New Mexico. In accordance with the New Mexico Water Quality Act, NMSA 1978, Sections 74-6-1 to -17, the SWQB has developed and implemented a comprehensive water quality monitoring strategy for the surface waters of the State.

The monitoring strategy establishes the methods of identifying and prioritizing water quality data needs, specifies procedures for acquiring and managing water quality data, and describes how these data are used to progress toward three basic monitoring objectives: to develop water quality-based controls, to evaluate the effectiveness of such controls, and to conduct water quality assessments. SWQB revised its 10-year monitoring and assessment strategy (NMED/SWQB, 2016) and submitted it to USEPA Region 6 for review in June 2016. The strategy details both the extent of monitoring that can be accomplished with existing resources plus expanded monitoring strategies that could be implemented given additional resources. The SWQB utilizes a rotating basin approach to water quality monitoring. In this approach, a select number of watersheds are intensively monitored each year with an established return frequency of approximately every eight to ten years.

The SWQB maintains current quality assurance and quality control plans to cover all monitoring activities. This document, called the Quality Assurance Project Plan, is updated regularly, and approved by USEPA Region 6. In addition, the SWQB identifies the data quality objectives required to provide information of sufficient quality to meet the established goals of the program. Current priorities for monitoring in the SWQB are driven by the CWA Section 303(d) list of streams requiring TMDLs or TMDL alternatives; water bodies identified as needing ALU verification; the need to monitor unassessed perennial waters; and water bodies receiving point source discharge(s). Once assessment monitoring is completed, those reaches showing impacts and requiring a TMDL will be targeted for more intensive monitoring. The methods of data acquisition include fixed-station monitoring, intensive surveys of priority assessment units (including biological assessments), and monitoring of industrial, federal, and municipal dischargers, as specified in the SWQB Standard Operating Procedures.

Long-term monitoring for assessments will be accomplished through the establishment of sampling sites that are representative of the water body and which can be revisited in accordance with the current monitoring strategy. This information will provide time relevant information for use in CWA Section 303(d) listing and 305(b) report assessments and to support the need for developing TMDLs. The approach provides:

- systematic, detailed review of water quality data which allows for a more efficient use of valuable monitoring resources;
- information at a scale where implementation of corrective activities is feasible;
- an established order of rotation and predictable sampling in each basin which allows for enhanced coordinated efforts with other programs; and
- program efficiency and improvements in the basis for management decisions.

It should be noted that a watershed would not be ignored during the years in between water quality surveys. The rotating basin program will be supplemented with other data collection efforts such as on-going studies being performed by the USGS and USEPA. Data will be analyzed, and field studies will be

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conducted to further characterize acknowledged problems and TMDLs will be developed and implemented accordingly. Both long-term and intensive field studies can contribute to the State's Integrated 303(d)/§305(b) listing process for waters requiring TMDLs.

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6.0 Implementation of TMDLs

When approving TMDL documents, USEPA takes action on the TMDL, LA, WLA, and other components of the TMDL as needed (e.g., MOS and future growth). USEPA does not take action on the implementation section of the TMDL, and USEPA is not bound to implement any recommendations found in this section, in particular if they are found to be inconsistent with CWA and NPDES regulations, guidance or policy.

6.1 Point Sources – NPDES Permitting

There are no NPDES individual permits in the Lake Maloya, Santa Cruz Lake, or Shuree Pond North watersheds. There is one NPDES individual permit in the Eagle Nest Lake watershed: NPDES permit NM0030503 for the Village of Angel Fire wastewater treatment plant, permit effective date July 1, 2023 through June 30, 2028. NPDES permit NM0060503 includes phased effluent limits for total nitrogen and total phosphorus and a Total Phosphorous/Total Nitrogen Reduction Plan for the Village of Angel Fire Wastewater Treatment Plant effluent discharge. This permit and the associated WLA are included in the 2010 Cimarron River Watershed (Canadian River to Headwaters) TMDL for Cieneguilla Creek (NMED/SWQB 2010). Therefore, the WLA for this permit will not be included in this TMDL.

6.2 Nonpoint Sources

6.2.1 WBP and BMP Coordination

Public awareness and involvement will be crucial to the successful implementation of these plans and improved water quality. A WBP is a written plan intended to provide a long-range vision for various activities and management of resources in a watershed. It includes opportunities for private landowners and public agencies to reduce and prevent nonpoint source impacts to water quality. This long-range strategy will become instrumental in coordinating efforts to achieve water quality standards in the watershed. The WBP is essentially the Implementation Plan, or Phase Two, of the TMDL process. The completion of the TMDLs and WBPs leads directly to the development of on-the-ground projects to address surface water impairments in the watershed. BMPs to be considered as part of on-the ground-projects to address nutrients and other impairments include establishment of additional riparian vegetation and/or stream channel restoration work, grazing exclusions, and rangeland restoration aimed at slowing/reducing surface runoff to stream channels. Additional information about the reduction of nonpoint source pollution can be found online at: https://www.epa.gov/polluted-runoff-nonpoint-source-pollution.

6.2.2 Clean Water Act 319(h) Funding

The Watershed Protection Section of the SWQB can provide USEPA Section 319(h) funding to assist in implementation of BMPs to address water quality problems on reaches listed as category 4 or 5 waters on the Integrated 303(d)/§305(b) list where WBPs have been developed or to complete BMP demonstration projects in areas without WBPs to encourage further planning and implementations in the watershed. These monies are available to all private, for-profit, and nonprofit organizations that are authenticated legal entities, or governmental jurisdictions including: cities, counties, tribal entities, federal agencies, or agencies of the state. Proposals are submitted through a Request for Proposal (RFP) process. Selected projects typically require a non-federal match, ranging between 10-40% of the total project cost consisting of funds and/or in-kind services. Funding is available, generally annually, for both watershed-based planning and on-the-ground projects to improve surface water quality and associated habitat. Further information on funding from the CWA Section 319(h) and announcements of funding

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opportunities can be found at the SWQB website: https://www.env.nm.gov/surface-water-quality/watershed-protection-section/.

6.2.3 Other Funding Opportunities and Restoration Efforts

Several other sources of funding exist to address impairments discussed in this TMDL document. NMED's Construction Programs Bureau assists communities in need of funding for WWTP upgrades and improvements to septic tank configurations. They can also provide matching funds for appropriate CWA Section 319(h) projects using state revolving fund monies. The U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Environmental Quality Incentive Program (EQIP) program can provide assistance to private landowners in the basin for water quality and other natural resource improvement projects. The USDA Forest Service aligns their mission to protect lands they manage with the TMDL process and are another source of assistance. The US Bureau of Land Management (BLM) has several programs in place to provide assistance to improve unpaved roads and grazing allotments.

The SWQB annually makes available CWA Section 604(b) funds through a Request for Quotes (RFQ) process. The SWQB requests quotes from regional public comprehensive planning organizations to conduct water quality management planning as defined under Sections 205(j) and 303(e) and the CWA. The SWQB seeks proposals to conduct water quality management planning with a focus on projects that clearly address the State's water quality goals to preserve, protect and improve the water quality in New Mexico. The SWQB encourages proposals focused on TMDLs and UAAs or other water quality management planning activities that will directly address identified water quality impairments. The SWQB 604(b) RFQ is released annually in September.

In addition to CWA Section 319(h) grant funding, the Watershed Protection Section of the SWQB administers the state-funded River Stewardship Program as another source of funding for improving surface water quality and river habitat in New Mexico. The New Mexico Legislature appropriated $1,250,000 in state funds for the River Stewardship Program during the 2020 Legislative Session. The River Stewardship Program has the overall goal of addressing the root causes of poor water quality and stream habitat. Objectives of the River Stewardship Program include: "restoring or maintaining hydrology of streams and rivers to better handle overbank flows and thus reduce flooding downstream; enhancing economic benefits of healthy river systems such as improved opportunities to hunt, fish, float or view wildlife; and providing state matching funds required for federal CWA grants." Funding for the River Stewardship Program varies and ranges from $1,250,000 annually to over $10,000,000 appropriations to the program from various State sources, including capital outlay funds ($1,250,000 - $2,300,000 annually), Land of Enchantment Conservation Legacy funds ($1,250,000+ annually), and one-time special appropriations such as American Rescue Plan Act Coronavirus State and Local Fiscal Recovery Funds ($10,000,000 appropriation in 2022). A competitive Request for Proposals process is conducted annually or biannually to select projects for funding. Additional funding sources for watershed protection and improvement projects are listed in Appendix C of the New Mexico Nonpoint Source Management Plan, available at https://www.env.nm.gov/surface-water-quality/nps-plan.

Information on additional watershed restoration funding resources is available on the SWQB website at https://www.env.nm.gov/surface-water-quality/watershed-protection-section/.

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6.3 QWET Modeling Concept Overview

These TMDLs were developed with the support of the Watershed Ecosystems Tool (WET), a graphical user interface (GUI) for the coupled one-dimensional hydrodynamic-ecosystems model GOTM-FABM-PCLake, which was developed by Aarhus University in Denmark to model a multitude of ecosystem parameters in lakes and reservoirs (Anders, 2017). WET can be accessed through the QGIS plugin QWET, which allows model creators to build the WET model within QGIS. Data needed to create a WET model range from simple loading estimates to continuous time series datasets. The Soil and Water Assessment Tool (SWAT) can also be used as input data for the WET model. The lakes included in this TMDL have a range of data availability ranging from detailed USGS gage stations to just a few hand measurements collected by NMED SWQB staff. Detailed information on specific input data for each lake model is available in **Appendix D**.

QWET models were created for Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, and Shuree Pond North to address impairment for nutrients and a QWET model was developed for Santa Cruz Lake to address impairment for temperature.

6.3.1.1 QWET Nutrient Modeling

The QWET nutrient models for Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, and Shuree Pond North were created using various physical, chemical, and meteorological input data that is described in depth in **Appendix D**. The models were manually calibrated using grab sample measurements collected during two water quality surveys, the 2015-2016 Dry Cimarron and Canadian River survey and the 2017-2018 Upper Rio Grande survey. Details on calibrated data can be found in **Appendix D**. The models were run from 1995 to 2020 to predict average daily total phosphorus and total nitrogen levels for the lakes named above. Numerous inputs are used to calculate the lake nutrient concentration in the WET model, including nutrient loading values, model coefficients, lake volume and area, and meteorological conditions. QWET allows the model user to create different nutrient loading scenarios to evaluate the impacts non-point source nutrient increases or decreases will have to the overall total nitrogen (TN) and total phosphorus (TP) concentration values. Five nutrient parameters can be manipulated, organic phosphorus, phosphate, organic nitrogen, nitrate, and ammonia.

Nutrient reduction scenarios were created for each lake and for each TMDL and target concentration value specified in Chapter 3 of this document. To reach desired TN concentrations, organic nitrogen, nitrate, and ammonia values were reduced and to reach desired TP concentrations, organic phosphorus, and phosphate were reduced. A reduction scenario for Santa Cruz Lake's TN concentration was not created because sampled data did not exceed the nutrient threshold.

6.3.1.1.1 Nutrient Results

Eagle Nest Lake

Multiple nutrient reduction scenarios were explored until modeled lake nutrient concentrations met both the TMDL and target concentration values. At the lakes current state, a 65% reduction in TN nutrient loading will result in Eagle Nest Lake achieving the TMDL of 0.90 mg/L and a 73% reduction in TN nutrient loading will result in Eagle Nest Lake achieving the target concentration of 0.81 mg/L. At the lakes current state, a 60% reduction in TP nutrient loading will result in Eagle Nest Lake achieving the TMDL of 0.03 mg/L and a 63% reduction in TP nutrient loading will result in Eagle Nest Lake achieving the target concentration of 0.027 mg/L.

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Lake Maloya

Multiple nutrient reduction scenarios were explored until modeled lake nutrient concentrations met both the TMDL and target concentration values. At the lakes current state, a 72% reduction in TN nutrient loading will result in Lake Maloya achieving the TMDL of 0.90 mg/L and a 78% reduction in TN nutrient loading will result in Lake Maloya achieving the target concentration of 0.81 mg/L. At the lakes current state, a 32% reduction in TP nutrient loading will result in Lake Maloya achieving the TMDL of 0.03 mg/L and a 34% reduction in TP nutrient loading will result in Lake Maloya achieving the target concentration of 0.027 mg/L.

Santa Cruz Lake

Multiple nutrient reduction scenarios were explored until modeled lake nutrient concentrations met both the TMDL and target concentration values. At the lakes current state, a 55% reduction in TP nutrient loading will result in Santa Cruz Lake achieving the TMDL of 0.03 mg/L and a 60% reduction in TP nutrient loading will result in Santa Cruz Lake achieving the target concentration of 0.027 mg/L. Currently, Santa Cruz Lake does not exceed the 0.90 mg/L concentration threshold for TN. No modeling was needed to find nutrient reduction values for TN in Santa Cruz Lake.

Shuree Pond North

Multiple nutrient reduction scenarios were explored until modeled lake nutrient concentrations met both the TMDL and target concentration values. At the lakes current state, a 23% reduction in TN nutrient loading will result in Shuree Pond North achieving the TMDL of 0.90 mg/L and a 31% reduction in TN nutrient loading will result in Shuree Pond North achieving the target concentration of 0.81 mg/L. At the lakes current state, a 62% reduction in TP nutrient loading will result in Shuree Pond North achieving the TMDL of 0.03 mg/L and a 66% reduction in TP nutrient loading will result in Shuree Pond North achieving the target concentration of 0.027 mg/L.

6.3.1.2 QWET Temperature Modeling

Lake temperature is heavily influenced by solar radiation, air temperature, lake volume, and lake surface area, with limited influence from shoreline shading (Sharma et al., 2015). Lake temperature mitigation techniques are not as straight forward as stream temperature mitigation techniques. Forced mixing and dredging are examples of more immediate lake temperature mitigation strategies, however these mitigation strategies and their associated costs may be unrealistic for communities in New Mexico. Reducing lake temperatures needs to be approached at a watershed level or even larger. Multiple lake temperature studies have found that freshwater lakes are warming as global temperatures warm, especially alpine lakes because most alpine areas are experiencing higher rates of air temperature increases (Indicators of Climate Change in California, 2022). Actions that can be taken at the watershed level include reducing the temperature of inflowing water, improving riparian habitats, and controlling bank erosion (EPA, 2014).

The Santa Cruz Lake QWET temperature model was created using various physical, chemical, and meteorological input data that is described in depth in **Appendix D.** The model was manually calibrated using sonde measurements of lake temperature during the Upper Rio Grande 2017-2018 water quality survey. Detailed calibration data can be found in **Appendix D.** The model was run from 1995 to 2020 to predict average daily lake temperatures for Santa Cruz Lake. Cloud cover, air temperature, wind speed,

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and lake volume all contribute to lake temperature calculation in QWET, with air temperature being the most influential. QWET allows the model user to create different climate scenarios to the evaluate the impact of decreasing or increasing air temperatures on lake temperatures. There is no option to alter shoreline shading of the lakes because it would have minimal impact on the lake temperature.

6.3.1.2.1 Temperature Results

With a calibrated temperature model, different climate scenarios can be run within QWET to change the predicted lake temperature. Changes to temperature are determined monthly, so different temperature increases or decreases can be applied per month or season. The temperature model shows Santa Cruz Lake summer water temperatures typically peak around 25 degrees C. This is five degrees higher than the 20 degree C threshold for high quality coldwater aquatic life lakes (HQCWAL) in New Mexico (NMED/SWQB 2023). The goal of creating the QWET temperature model for Santa Cruz Lake is to find out what decrease in air temperature needs to be achieved for Santa Cruz Lake to meet the 20 degree C water temperature threshold.

A decrease in summer air temperature was emphasized because that is when the lake exceeds the designated water temperature threshold. Many different climate scenarios were created, but the scenario that produced the best results was air temperature decreases of 2 degrees C from October through April and 8 degrees C from May through September. These are large air temperature decreases needed to obtain the HQCWAL temperature threshold and highlights the magnitude of the temperature impairment of Santa Cruz Lake. There is also initial work being done to study the attainability of Santa Cruz Lake as a HQCWAL designated lake, as it is the lowest elevation and furthest south HQCWAL lake in New Mexico.

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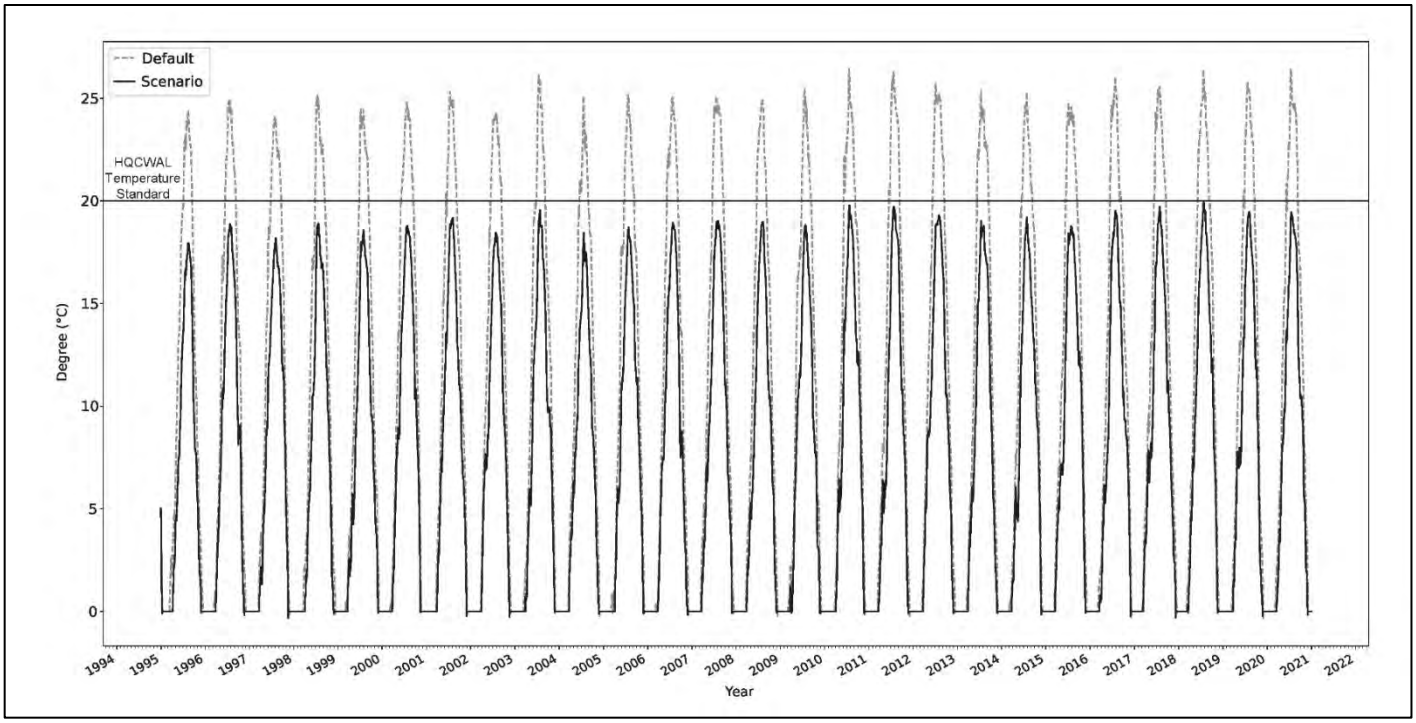


Figure 6.1: Comparison between the default (current) water temperature output and the water temperature output for the climate scenario of a decrease in air temperature of 2 degrees C from October through April and a decrease in air temperature of 8 degrees C from May to September. The black line at 20 degrees C shows the HQCWAL water temperature threshold.

7.0 Applicable Regulations and Reasonable Assurances

New Mexico's Water Quality Act, New Mexico Statutes Annotates (NMSA) 1978 Sections 74-6-1 to -17 (Act), authorizes the WQCC to "promulgate and publish regulation to prevent or abate water pollution in the state" and to require permits. The Act authorizes a constituent agency to take enforcement action against any person who violates a water quality standard. Several statutory provisions on nuisance law could also be applied to NPS water pollution. The Act also states in Section 74-6-12(A):

> *The Water Quality Act (this article) does not grant to the commission or to any other entity the power to take away or modify the property rights in water, nor is it the intention of the Water Quality Act to take away or modify such rights.*

In addition, the State of New Mexico Surface Water Quality Standards (20.6.4.6(C) NMAC) states:

> *Pursuant to Subsection A of Section 74-6-12 NMSA 1978, this part does not grant to the water quality control commission or to any other entity the power to take away or modify property rights in water.*

New Mexico policies are in accordance with the federal CWA Section 101(g):

> *It is the policy of Congress that the authority of each State to allocate quantities of water within its jurisdiction shall not be superseded, abrogated or otherwise impaired by this Act. It is the further policy of Congress that nothing in this Act shall be construed to supersede or abrogate rights to quantities of water which have been established by any State. Federal agencies shall co-operate with State and local agencies to develop comprehensive solutions to prevent, reduce and eliminate pollution in concert with programs for managing water resources.*

New Mexico's CWA Section 319 Program has been developed in a coordinated manner with the State's CWA Section 303(d) process. All watersheds that are targeted in the annual §319 request for proposal process coincide with the State's biennial impaired waters list as approved by USEPA. The State has given a high priority for funding, assessment, and restoration activities to these watersheds.

As a constituent agency, NMED has the authority under NMSA 1978, Section 74-6-10 to issue a compliance order or commence civil action in district court for appropriate relief if NMED determines that actions of a "person" (as defined in the Act) have resulted in a violation of a water quality standard including a violation caused by a NPS. The NMED NPS water quality management program has historically strived for and will continue to promote voluntary compliance to NPS water pollution concerns by utilizing a voluntary, cooperative approach. The State provides technical support and grant monies for implementation of BMPs and other NPS prevention mechanisms through Section 319 of the CWA. Since portions of this TMDL will be implemented through NPS control mechanisms, the New Mexico Watershed Protection Program will target efforts to this and other watersheds with TMDLs.

In order to obtain reasonable assurances for implementation in watersheds with multiple land owners, including federal, state, and private land, NMED has established Memoranda of Understanding (MOUs) with various federal agencies, in particular the U.S. Forest Service and the BLM. MOUs have also been developed with other state agencies, such as the New Mexico Department of Transportation. These MOUs provide for coordination and consistency in dealing with NPS issues.

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The time required to attain standards for all reaches is estimated to be approximately 10-20 years. This estimate is based on a five-year time frame implementing several watershed projects that may not be starting immediately or may be in response to earlier projects. Stakeholders in this process will include the SWQB, and other parties identified in the WBP. The cooperation of watershed stakeholders will be pivotal in the implementation of these TMDLs as well.

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8.0 Public Participation

Public participation was solicited in development of this TMDL, pursuant to CWA §303(d) and Section XIV of the New Mexico Statewide Water Quality Management Plan and Continuing Planning Process. The draft TMDL was made available for a 30-day comment period beginning April 15th and ending May 15th at 5:00 pm. The draft document Notice of Availability was advertised via email distribution lists and webpage postings. Two virtual public meetings were attended by 5 stakeholders on May 1st.

A response to public comments is included as **Appendix F**.

The NM WQCC approved the TMDL on July 9, 2024 and EPA Region 6 approved the TMDL on August 20, 2024. Following EPA approval, the next step for public participation will be development of WBPs and water quality restoration projects, including those that may be funded by CWA Section 319(h) grants managed by SWQB.

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Appendix A: Water Quality Data

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Total recoverable aluminum data:

Exceedances of the applicable criteria are shown in bold red font.

Santa Cruz Lake (AU: NM-2118.B_00)

Date	Hardness (mg/L)	Acute criterion (mg/L)	Chronic criterion (mg/L)	TR Al (mg/L)
3/30/17	32	0.718	0.288	**0.98**
10/16/17	43	1.08	0.431	**0.76**
4/11/18	42	1.04	0.418	0.04
7/24/18	82	2.61	1.04	0.38

Mean hardness of samples with WQS exceedance = 37 mg/L

Plant nutrients data:

Exceedances of the applicable criteria are shown in bold red font.

Eagle Nest Lake (AU: NM-2306.B_00)

Applicable Thresholds: TN (0.9 mg/L) , TP (0.03 mg/L)

Date	TN (mg/L)	TP (mg/L)
4/9/15	**1.07**	**0.066**
10/29/15	**1.17**	**0.137**
5/16/16	0.61	**0.049**
7/20/16	0.79	**0.055**
9/27/16	0.68	**0.116**
11/1/16	MDP	**0.142**

Lake Maloya (AU: NM-2305.B_20)

Applicable Thresholds: TN (0.9 mg/L), TP (0.03 mg/L)

Date	TN (mg/L)	TP (mg/L)
4/8/15	0.71	0.029
10/28/15	**4.08**	0.03
5/5/16	**0.95**	0.03
8/12/16	0.79	**0.048**
10/19/16	0.89	**0.12**

Santa Cruz Lake (AU: NM-2118.B_00)

Applicable Thresholds: TN (0.9 mg/L), TP (0.03 mg/L)

Date	TN (mg/L)	TP (mg/L)
3/30/17	0.49	**0.039**
8/3/17	0.37	0.018
10/16/17	0.424	**0.04**
4/11/18	0.25	0.011
7/24/18	0.45	**0.047**

Shuree Pond North (AU: NM-2306.B_30)
Applicable Thresholds: TN (0.9 mg/L), TP (0.03 mg/L)

Date	TN (mg/L)	TP (mg/L)
10/14/15	**1.18**	0.018
8/22/16	0.75	**0.05**
10/25/16	0.71	**0.078**

Temperature data:

Exceedances of the applicable criteria are shown in bold red font.
Santa Cruz Lake (AU: NM-2118.B_00)
Designated ALU: High Quality Coldwater
Temperature Criterion[(a)] (°C): 20

Date	Measured Temperature (°C)
3/30/17	7.58
8/3/17	**21.34**
10/16/17	13.72
4/11/18	12.09
7/24/18	**23.77**

Appendix B : Conversion Tables

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Conversion calculations for converting nutrient TMDL values from concentration based to mass based.

Watershed	Parameter	TMDL (mg/L)	mg/L to lbs/L	lbs/L	lbs/L to lbs/acre-feet	lbs/acre-feet	lbs/acre-feet to lbs	TMDL (lbs/day)
Eagle Nest Lake (28,933 acre-feet)	TN	0.9	0.9 / 453592.33[a]	1.98416E-06	1.98416E-08 * 1233000[b]	2.446469939	2.446469939 * 28933[c]	70783.71
	TP	0.03	0.03 / 453592.33[a]	6.61387E-08	6.61387E-08 * 1233000[b]	0.081548998	0.081548998 * 28933[c]	2359.46
Lake Maloya (3,620 acre-feet)	TN	0.9	0.9 / 453592.33[a]	1.98416E-06	1.98416E-08 * 1233000[b]	2.446469939	2.446469939 * 3620[c]	8856.22
	TP	0.03	0.03 / 453592.33[a]	6.61387E-08	6.61387E-08 * 1233000[b]	0.081548998	0.081548998 * 3620[c]	295.21
Santa Cruz Lake (3,005 acre-feet)	TN	0.9	0.9 / 453592.33[a]	1.98416E-06	1.98416E-08 * 1233000[b]	2.446469939	2.446469939 * 3005 [c]	7351.64
	TP	0.03	0.03 / 453592.33[a]	6.61387E-08	6.61387E-08 * 1233000[b]	0.081548998	0.081548998 * 3005[c]	245.05
Shuree Pond North (40 acre-feet)	TN	0.9	0.9 / 453592.33[a]	1.98416E-06	1.98416E-08 * 1233000[b]	2.446469939	2.446469939 * 40 [c]	97.86
	TP	0.03	0.03 / 453592.33[a]	6.61387E-08	6.61387E-08 * 1233000[b]	0.081548998	0.081548998 * 40[c]	3.26

Notes: *(a)* 453592.33 is the conversion factor used to convert mg/L to lbs/L. The concentration based TMDL values (mg/L) are divided by the conversion factor (453592.33). The new value is the concentration based TMDL but expressed as lbs/L.
(b) 1233000 is the conversion factor used to convert lbs/L to lbs/acre-feet. The concentration based TMDL values (lbs/L) are multiplied by the conversion factor (1233000). The new value is the concentration based TMDL but expressed as lbs/acre-feet.
(c) To convert the TMDL values from concentration based to a mass, the lbs/acre-feet value must be multiplied by the volume of the lake (acre-feet). This equation gives the TMDL value as a mass, expressed in pounds per day in relation to the volume of the lake.

Conversion of lake volume from acre-feet/day to cubic feet/sec for lake temperature TMDL.

Santa Cruz Lake Critical Storage (acre-feet/day)	Conversion Factor (acre-feet/day to cubic-feet/second)	Santa Cruz Lake Critical Storage (cubic-feet/second)
300.5	0.50451	151.61

Notes: (a) To convert a lake volume from acre-feet/day to cubic-feet/second, multiply the lake volume (acft/day) by the conversion factor (0.50451). This equals the lake volume in cubic-feet/second.

Appendix C: Source Documentation

The approach for identifying probable sources of impairment is documented in SWQB Standard Operating Procedure (SOP) 4.1, Probable Source(s) Determination (https://www.env.nm.gov/surface-waterquality/sop/). “Sources” are defined as activities that may contribute pollutants or stressors to a water body (USEPA, 1997). The list of “Probable Sources of Impairment” in the Integrated 303(d)/305(b) List, Total Maximum Daily Load documents (TMDLs), and Watershed-Based Plans (WBPs) is intended to include any and all activities that could be contributing to the identified cause of impairment, which are supported by evidence strong enough to establish presumption but not proof. Probable Source categories are selected from Appendix A of SOP 4.1, which was adapted from the EPA ATTAINS database.

USEPA, through guidance documents, strongly encourages states to include a list of Probable Sources for each listed impairment. According to the 1998 Section 305(b) report guidance, “…, states must always provide aggregate source category totals…” in the biennial submittal that fulfills CWA section 305(b)(1)(C) through (E) (USEPA, 1997). The list of “Probable Sources” is not intended to single out any particular landowner or single land management activity and has therefore been labeled “Probable” and generally includes several sources for each known impairment.

Any new impairment listing will be assigned a Probable Source of “Source Unknown.” During sampling events, Monitoring Team staff select applicable Probable Sources from a drop-down menu on the Stream/River Field Data Form. Information gathered by the Monitoring Team is used to generate a draft Probable Source list in consequent TMDL planning documents. The TMDL writer then revises the list using aerial imagery, Geographic Information System data, and other available records. The list is also reviewed by Watershed Protection Section staff with knowledge of the AU and watershed. These draft Probable Source lists will be finalized with watershed group/stakeholder input during the pre-survey public meeting, TMDL public meeting, WBP development, and various public comment periods. The Probable Source list in the approved TMDL will be used to update the subsequent Integrated List.

Data on Probable Sources gathered by Monitoring and Assessment Section staff and Watershed Protection Section staff during water quality surveys and watershed restoration projects is housed in the NMED Surface Water Quality Information Database (SQUID). More specific information on Probable Sources of Impairment is provided in individual watershed planning documents (e.g., TMDLs, WBPs, etc.) as they are prepared to address individual impairments by AU.

Literature Cited:

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Appendix D: Modeling Input Data and Calibration

D 1.0 Introduction

This appendix provides lake specific physical, flow and nutrient loading, and meteorological data for input into the QWET model. Physical input data includes lake surface area, coordinates of the lake center, bathymetric data if available, and maximum lake depth. QWET requires either continuous flow and nutrient loading data or estimated constant loading values. Nutrient loading parameters needed are organic phosphorus, phosphate, organic nitrogen, nitrate, and ammonia. Meteorological inputs for the QWET model are formatted at a daily timestep and include air pressure, cloud cover fraction, dew point, temperature, and wind speed. Observation data can also be used for calibration purposes. In the following sections, data sources for these parameters are discussed for each lake to be modeled using QWET.

D 2.0 Physical Input Data

D 2.1 Surface Area

The surface area of the lakes was obtained from the USGS NHD+ GIS geodatabase. Within the geodatabase, the polygons of the lakes have their surface area stated in the attribute table. The surface area is in acres in the geodatabase and must be converted to meters squared for the QWET model.

D 2.2 Bathymetric Data

If there is bathymetric data available, then that is the preferred method for the QWET physical configuration. However, it is very unlikely that lakes and reservoirs in New Mexico will have bathymetric data. There was no bathymetric data available for the lakes included in this TMDL, so a different method using only the lake's max depth was used.

D 2.3 Coordinates

The longitude and latitude of the center of the lake are required. To obtain these values, polygons of the lakes from the USGS NHD+ GIS geodatabase were projected to the WQS84 geographic projection. Then, the coordinates at the polygon's centroid were calculated within the layer's attribute table. QWET requires the polygons to be projected into WQS84 before determining the coordinates.

D 2.4 Maximum Depth

The maximum depth of lakes in this document were calculated from lake depth profiles collected during water quality surveys conducted by the NMED SWQB monitoring team. All recorded maximum depths taken during relevant monitoring surveys were averaged for one lake depth value per lake. This depth value is used as the maximum depth in QWET. The value must be converted from feet to meters.

D 3.0 Flow and Nutrient Loading Data

D 3.1 Flow Data

Continuous flow data is preferred for the QWET model, however if that method is chosen there must also be continuous nutrient loading data. Most lakes in New Mexico do not have continuous nutrient loading data, so a constant flow rate method was established. A variety of methods were used to calculate a constant flow rate for each lake in the TMDL. The constant flow rate for a lake is the average daily water inflow in cubic feet per second.

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The New Mexico Office of the State Engineer (OSE) operates and maintains a stream gage network throughout the state. Three OSE stream gages (Cieneguilla Creek, Moreno Creek, and Sixmile Creek) monitor the inflow to Eagle Nest Lake. The average daily flow from March 13th, 2013, to December 21st, 2020, for each gage was used to calculate an average daily flow for Eagle Nest Lake. QWET only needs one constant flow value, so each stream gages average flow was added together for one constant flow value.

The USGS also operates and maintains a stream gage network, with USGS Gage 08291000 Santa Cruz River near Cundiyo, NM located just upstream from Santa Cruz Lake. Average annual daily flow was downloaded from 1995 to 2020 and a constant flow value for Santa Cruz Lake was calculated. The Santa Cruz River is the only inlet to Santa Cruz Lake.

Lake Maloya and Shuree Pond North do not have OSE or USGS stream gages located at their lake inlets. The NMED SWQB monitoring team has collected flow data at the lake inlets during water quality surveys, but there isn't enough data to create a constant flow value. To circumvent this, the Thomas Equation (**Equation D 3.1**) was used to calculate a constant flow value for Lake Maloya and Shuree Pond North. The Thomas Equation requires the user to find a nearby gaged watershed within 50% to 150% of the original ungagged watershed. The equation then calculates an estimated daily average flow based on the gaged watershed's size and stream gage readings (Thomas et al, 1997).

$$Q_u = Q_g (A_u / A_g)^{0.5} \qquad \textbf{Equation D 3.1}$$

Q_u = Flow (cubic feet per second) at ungagged station/watershed
Q_g = Flow (cubic feet per second) at gaged station/watershed
A_u = Area (square miles) of ungagged watershed
A_g = Area (square miles) of gaged watershed

The ungagged watershed size for Lake Maloya is 20.7 square miles. The gaged watershed must be between 50% (10.35 square miles) and 150% (31.05 square miles) of the ungagged watershed. USGS gage 08252500 Costilla Creek above Costilla Dam, NM and its watershed were used for the Thomas Equation because of the similar geography and environment to the Lake Maloya watershed and the appropriate size (25.01 square miles).

The ungagged watershed size for Shuree Pond North is 1.97 square miles. The gaged watershed must be between 50% (0.96 square miles) and 150% (2.96 square miles) of the ungagged watershed. USGS gage 08253500 Santistevan Creek near Costilla, NM and its watershed were used for the Thomas Equation because of the similar geography and environment to the Shuree Pond North watershed and the appropriate size (2.15 square miles).

D 3.2 Nutrient Loading Data

There is limited nutrient loading data for most lakes in New Mexico, and for the lakes included in this TMDL there are only a handful of samples collected by the NMED SWQB monitoring team. For this reason, a constant value approach was taken. The Water Quality Portal (WQP) was used to create average loading values for organic phosphorus, phosphate, organic nitrogen, nitrate, and ammonia to Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, and Shuree Pond North. The WQP collates publicly available water-quality data from the USGS, EPA and over 400 state, federal, tribal, and local agencies.

Water quality data can be downloaded from the WQP based on a radius from a given point. For this project, a radius of 20 miles around Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, and Shuree Pond North

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was used. This radius was used because it coincides with the Level III EPA Ecoregion(s) that are encompassed by the lake watersheds. The 20-mile radius for Eagle Nest Lake, Lake Maloya and Shuree Pond North include water quality data from other nearby lakes within the Southern Rockies Ecoregion, while the 20-mile radius for Santa Cruz Lake includes water quality data from other nearby lakes within the Southern Rockies Ecoregion and the AZ/NM Plateau Ecoregion. The water quality data within the 20-mile radius was used to create the average nutrient loading values for the lakes. The water quality data ranges from the 1980's to the present day.

D 4.0 Meteorological Data

QWET requires meteorological data at a daily time step. The model creator can use pre-defined meteorological time series data from the European Center for Medium-Range Weather Forecasts (ECMWF) as a minimum requirement or meteorological time series data can be created from more detailed sources for more accurate modeling. The later method was chosen for the models used in this TMDL. Data sources include the PRISM climate dataset, ASOS (automated surface observing systems) and AWOS weather stations, and long-term average monthly data from the Nation Center for Environmental Information and the Western Regional Climate Center.

D 4.1 Air Pressure

Air pressure (hPa) is required for the QWET model. For Eagle Nest Lake, Lake Maloya, Santa Cruz Lake and Shuree Pond North an average monthly value was used. The average monthly value was calculated from the Santa Fe Airport ASOS weather station. An average monthly value was used because of significant data gaps from the weather station. No other nearby weather stations have reliable air pressure data for the time period needed.

D 4.2 Cloud Cover Fraction

Cloud cover fraction (0-1) is required for the QWET model. For Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, and Shuree Pond North an average monthly value was used. For Lake Maloya, the average monthly precent of possible sunshine from the Pueblo, CO weather station was used as cloud cover fraction data. The period of record for this weather station is 1965 to 1983. This data is available from the National Center for Environmental Information (NCEI). For Santa Cruz Lake, the average monthly percent of possible sunshine from the Albuquerque, NM weather station was used as cloud cover fraction data. The period of record for this weather station is 1965 to 1983. This data is also available from NCEI. For Eagle Nest Lake and Shuree Pond North, the average monthly percent of possible sunshine from the Albuquerque, NM weather was used as cloud cover fraction data. However, the average monthly values were lowered by 10% to account for higher cloud cover in the mountainous areas of the Eagle Nest Lake and Shuree Pond North watersheds.

D 4.3 Dew Point

Dew point (°C) data is required for the QWET model. Daily dew point data was created using the PRISM Climate Group GIS raster data layers. Daily dew point rasters were downloaded from January 1st, 1995, to December 31st, 2020, covering the Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, and Shuree Pond North watersheds. These GIS rasters were then reprojected and clipped to the watershed boundaries. Then a python script is used to run zonal statistics on the rasters to create an average daily dew point value for each watershed.

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D 4.4 Temperature

Temperature (°C) is required for the QWET model. Daily temperature data was created using the PRISM Climate Group GIS raster data layers. Daily temperature rasters were downloaded from January 1st, 1995, to December 31st, 2020, covering the Eagle Nest Lake, Lake Maloya, Santa Cruz Lake, and Shuree Pond North watersheds. These GIS rasters were then reprojected and clipped to the watershed boundaries. Then a python script was used to run zonal statistics on the rasters to create an average daily temperature value for each watershed.

D 4.5 Wind Speed

Wind speed (meter/second) is required for the QWET model. Daily wind speed data was created using nearby AWOS and ASOS weather stations with average monthly wind speed data. Average monthly wind speed data was used because there are no weather stations recording wind speed located within the lake watersheds included in this TMDL. Eagle Nest Lake and Shuree Pond North wind speed data was obtained from the Taos Airport AWOS, Lake Maloya wind speed data was obtained from the Raton Airport ASOS, and Santa Cruz Lake wind speed data was obtained from the Santa Fe Airport ASOS.

D 5.0 Observation Data

Model calibration was conducted for each QWET model using water quality data collected by the NMED SWQB monitoring team. Lake sampling procedures are described in depth in SOP 12.1 (Lake Sampling). NMED SWQB SOPs can be found here. Measured data used to calibrate the QWET models are temperature, total nitrogen, and total phosphorus. The observation data was collected during the most recent water quality surveys in the lake watersheds; 2015-2016 for Eagle Nest Lake, Lake Maloya and Shuree Pond North and 2017-2018 for Santa Cruz Lake. The tables below contain detailed information on the observation data used to calibrate the QWET models.

D 6.0 Calibration

Manual calibrations were conducted on the temperature and nutrient models used in this TMDL. QWET does not specify the amount of data points needed for a successful calibration, however there is strong evidence that three or more years of continuous or regular data samples are needed to conduct a thorough calibration of a hydrologic model (Shen et al., 2022; Moriasi et al., 2015). The calibration data used for the QWET temperature and nutrient models was collected by the NMED SWQB monitoring team during the lake watershed's respective water quality survey. The number of available calibration data points is significantly below the standard recommendation of three or more years. There are three to six nutrient calibration data points per lake and 112 temperature calibration data points for Santa Cruz Lake. This lack of data complicated the calibration process and adds significant levels of uncertainty to the model output. However, only general trends of the model output are being analyzed, not specific model output values. Therefore, the models are still being used to discuss reductions needed in air temperature and nutrient inputs for the lakes to meet their designated uses. Additionally, the averaged constant nutrient loading values used for the QWET nutrient models were used as calibration parameters. These values were adjusted in some models to match the calibration data available.

The performance measure used to evaluate these calibrations was Pearson's coefficient of determination (R^2). R^2 values can range from 0 to 1, with values closer to 1 generally indicating a better preforming model and R^2 values above 0.60 considered satisfactory for most hydrologic models (Moriasi *et al*. 2015).

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Performance measures can be skewed by lack of data, so in addition to R^2 these models are also evaluated by visually comparing the model output and the calibration data points. For example, the Shuree Pond North nutrient model has three calibration data points and the R^2 value could be skewed lower or higher than expected because of this lack of data. By visually evaluating plots of the calibration data and model output, the model user could infer that the model is accurate enough to be used to analyze general trends. This process was used to evaluate the calibration of the nutrient QWET models. The Santa Cruz Lake temperature model had enough data to calculate a reasonable R^2 value.

D6.1 Temperature Calibration

Five temperature sampling events were conducted by the NMED SWQB monitoring team at Santa Cruz Lake during the 2017 – 2018 water quality survey. Each temperature sampling event collects multiple temperature readings at different lake depths. Overall, a total of 112 temperature data points were used to calibrate the Santa Cruz Lake QWET temperature model. An R^2 value of 0.89 was achieved during the manual calibration, however a lack of calibration data could be skewing this value.

D6.2 Nutrient Calibration

Total nitrogen (TN) and total phosphorus (TP) samples were collected by the NMED SWQB monitoring team during the 2015-2016 and 2017-2018 water quality surveys. Three samples of TN and TP were used for the Shuree Pond North manual calibration, five samples of TN and TP were used for the Lake Maloya, and Santa Cruz Lake manual calibrations, and six samples of TN and TP were used for the Eagle Nest Lake manual calibration. Because of the extremely limited number of nutrient calibration data points, a performance measure and visually comparing the calibration data points and model output were both employed to evaluate the effectiveness of the nutrient models. The nutrient models were calibrated to produce the best fitting output data according to the few calibration points available.

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Model input data used for QWET nutrient and temperature modeling.

Variable	Eagle Nest Lake	Lake Maloya	Santa Cruz Lake	Shuree Pond North
Physical Variables				
Surface Area (m^2)	7354098.3	467575.7	376156.8	25050.0
Latitude (deg)	36.529	36.988	35.975	36.755
Longitude (deg)	-105.254	-104.373	-105.917	-105.194
Maximum Depth (m)	5.59	6.25	6.51	1.52
Flow and Nutrient Loading Variables				
Flow (m^3/s)	0.38	0.25	0.73	0.07
Organic Phosphorus (mg/L)	0.12	0.12	0.12	0.12
Phosphate (mg/L)	0.12	0.11	0.17	0.12
Organic Nitrogen (mg/L)	0.44	0.52	0.52	0.40
Nitrate (mg/L)	0.97	2.35	0.25	0.57
Ammonia (mg/L)	0.17	0.11	0.14	0.14

Calibration Data used for QWET nutrient models.

Eagle Nest Lake Nutrient Observation Data		
Date	Total Nitrogen (mg/L)	Total Phosphorus (TP)
04/09/2015	1.07	0.066
10/29/2015	1.17	0.137
05/16/2016	0.61	0.049
07/20/2016	0.79	0.055
09/27/2016	0.68	0.116
11/01/2016	1.05	0.142
Lake Maloya Nutrient Observation Data		
Date	Total Nitrogen (mg/L)	Total Phosphorus (TP)
04/08/2015	0.71	0.029
10/28/2015	4.08	0.03
05/05/2016	0.95	0.03
08/12/2016	0.79	0.048
10/19/2016	0.89	0.12
Santa Cruz Lake Observation Data		
Date	Total Nitrogen (mg/L)	Total Phosphorus (TP)
03/30/2017	0.49	0.039
08/03/2017	0.37	0.018
10/16/2017	0.35	0.04
04/11/2018	0.26	0.011
07/24/2018	0.36	0.047
Shuree Pond North Observation Data		
Date	Total Nitrogen (mg/L)	Total Phosphorus (TP)
10/14/2015	1.18	0.018
08/22/2016	0.75	0.05
10/25/2016	0.71	0.078

Appendix E: Calculation of Temperature TMDL

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Calculation of Temperature TMDL

Problem Statement: Convert Temperature Criteria into a Daily Load

Background

The temperature of water is essential for proper metabolic regulation in the aquatic community. Water at a given temperature has a thermal mass that can be represented in units of energy (thermal energy). There are a variety of sources of temperature loading to a waterbody, including air temperature, solar radiation and point source discharge (if present). In addition, how the temperature loading to a stream is translated to the thermal mass of the stream is dependent on its hydrologic characteristics and condition of riparian area (i.e., shading).

The calculation of a TMDL target is governed by the basic equation,

Eq1. *WQS criterion * flow * conversion factor = TMDL target capacity*

For Temperature TMDLs, the WQS criterion is a temperature specified either by the designated Aquatic Life Use (ALU) or site-specific criteria and can be either a maximum temperature or time-duration temperature such as the 4T3 or 6T3.

Flow will generally use the 4Q3 low-flow for the critical flow unless another flow statistic or multiple flow conditions are more appropriate for the situation.

The conversion factor is a variable needed to 1) convert units used by SWQB for flow (in cfs) to cubic meters (m^3) and 2) convert change in water temperature (C) to a volumetric heat capacity (kJ/(m^3*C).

Calculation of Thermal Energy

The thermal loading capacity of a volume is governed by the following equation,

Eq2. *thermal energy = specific heat capacity * mass * change in temperature*

Specific heat capacity is the amount of energy needed to raise the temperature of one kilogram of a substance by 1 degree Celsius.

Mass can be replaced by volume via density.

Accepted Scientific Units for the variables above are:

thermal energy = kilojoule (kJ) (calories are less common and considered archaic)

specific heat capacity = kJ/(kg*C)

mass = kilograms (kg)

change in temperature = Celsius (C)

The specific heat capacity of water at 25^{o}C = 4.182 kJ/(kg*C). This is the isobaric (under constant pressure) value for heat capacity at an absolute atmospheric pressure of 585 mmHg. Note: varying water temperature and absolute pressure to minimum and maximum ambient values has a negligible effect on the resulting heat capacity.

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Calculation of Conversion Factor

Flow (cfs) to (m3/day)

Eq3. 1 cf/s * 86,400 s/day * 0.0283 m3/cf = 2445.12 m3/day

Heat Capacity to Volumetric Heat Capacity

Eq4. 4.182 kJ/(kg*C) * 1000 kg/m3 = 4,182 kJ/(m3*C)

Note: water density varies with temperature but only at a fraction of a percent.

Conversion Factor = 2445.12 m3/day * 4,182 kJ/(m3*C) = 1.023E+07 kJ/(day*C)

Form of TMDL Equation

Eq5. Δ [**°C**] x [**cfs]** x 1.023E+07 = TMDL (kJ/day)

Input variables in **bold**, Δ**°C** = (WQC - 0**°C)** and **cfs** = critical flow

The resulting value is the increase in kJ/day above 0° Celsius.

Appendix F: Response to Comments

SWQB hosted two virtual public meetings on May 1, 2024, from 1:00 to 2:30 pm and from 5:00 to 6:30 pm. Notes from the public meetings are available in the SWQB TMDL files in Santa Fe.

SWQB received the following public comments on the Canadian and Upper Rio Grande Lakes TMDL:

1. New Mexico Department of Game and Fish
2. Dan Campbell
3. Christopher Tingle
4. Doug Eib

Changes made to the TMDL based on public or additional staff comment include:

1. Including more information regarding the impacts of the 2011 Track Fire in the Lake Maloya watershed. This information was added to the Lake Maloya Watershed Description section of the TMDL (Section 1.1.4).
2. All lake description sections (1.1.1, 1.1.3, 1.1.5, and 1.1.7) were updated with more accurate fish stocking information from the New Mexico Department of Game and Fish.
3. A more detailed definition of a TMDL was added to the first paragraph of the Executive Summary.
4. A definition for the Integrated Report (IR) was added to the second paragraph of the Executive Summary.
5. Minor grammatical and spelling errors in TMDL.

PLEASE NOTE: When feasible, original typed letters that were not received electronically were scanned and converted to MSWord. Likewise, when feasible, letters received electronically were also converted to MSWord. All text was converted to Calibri 11 font with standard page margins for ease of collation. Contact information such as phone number, street addresses, and e-mail addresses from private citizens were removed for privacy reasons. All original letters of comment are on file at the SWQB office in Santa Fe, NM.

COMMENT SET 1

From: Marchetti, Jack, DGF

To: Graunke, Lucas, ENV
Cc: Trujillo, Jane, DGF; Frey, Eric, DGF; DGF-EEP-TG
Subject: RE: Canadian and Upper Rio Grande Lakes TMDL public comment; NMDGF response
Date: Tuesday, April 23, 2024 11:03:27 AM

Dear Mr. Graunke,

The New Mexico Department of Game and Fish (Department) would like to submit a formal comment in response to the New Mexico Environment Department (NMED) Surface Water Quality Bureau's (SWQB) draft TMDL document for the Canadian and Upper Rio Grande lakes.

Page 12, Section 1.1.1 (Eagle Nest Lake) of the TMDL document currently states "The area is a popular fishing and camping area, with the NMDGF stocking and maintaining populations of rainbow and cutthroat trout, yellow perch, white sucker, and kokanee salmon (NMDGF 2020)." The Department does not currently stock cutthroat trout in Eagle Nest Lake, nor is there a population of cutthroat trout in the lake. Therefore, the Department requests that this statement be removed from the TMDL document to accurately reflect the Department's current stocking efforts in Eagle Nest Lake. If the NMED SWQB wishes to reference the Department's fish management in the Canadian and Upper Rio Grande lakes, please refer to the Department's 2022 Statewide Fisheries Management Plan. Additionally, the Department's interactive fisheries map can be used by the SWQB or the public to search for fishing locations and available fish species at various locations.

Thank you for the opportunity to submit comments in response to the TMDL document for the Canadian and Upper Rio Grande lakes. Please contact me with any questions.

Sincerely,
Jack Marchetti (he/him)
Aquatic/Riparian Habitat Specialist
Ecological and Environmental Planning Division
New Mexico Department of Game and Fish
Cell: 505-479-1269
jack.marchetti@dgf.nm.gov

SWQB Response: *Thank you for your comments. SWQB acknowledges the need to update the fish stocking information for Eagle Nest Lake and the other lakes discussed in this TMDL. SWQB updated Sections 1.1.1, 1.1.3, 1.1.5, and 1.1.7 to reflect this new information.*

COMMENT SET 2

Public Comment (Phone Call) with Dan Campbell on 5/1/2024:

Summary: After the first public meeting for the Canadian and URG Lakes TMDL on 5/1/2024 from 12:30 to 1:30, Lucas Graunke received a phone call from Dan Campbell who used to work at the WWTP for the City of Raton. Mr. Campbell asked about the source of the land ownership data that was used in the TMDL, and provided information about land owned by the City of Raton and how it is leased out to other government agencies like the New Mexico State Parks. Mr. Campbell also provided information on a new possible state park in the upper watershed of Lake Maloya. Mr. Graunke and Mr. Campbell also discussed the 2011 Track Fire and extensive impact the burn scar had and still has on the watershed. Mr. Campbell also provided information on the amount of water the City of Raton receives from Eagle Nest Lake and from Lake Maloya, with more water being pulled from Eagle Nest Lake than in the past.

SWQB Response: *Thank you for your comments. The land ownership data used to create the land ownership maps and the percentages of laship in the executive summaries of this TMDL are from the Bureau of Land Management (BLM), published in 2019. SWQB acknowledges that the City of Raton leases private land to the New Mexico State Parks for Sugarite Canyon State Park. Since the BLM land ownership data does not consider leased land, Sugarite Canyon State Park displays as private land on the maps created for the TMDL. Information regarding the 2011 Track Fire was added to the Lake Maloya Watershed Description section of this TMDL (Section 1.1.4). The probable source "Watershed Runoff Following Forest Fire" was already included in the probable source list for nutrient impairment of Lake Maloya. SWQB updated Section 1.1.4 to reflect this new information.*

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COMMENT SET 3

Christopher Tingle: Submitted via NMED public comment portal on 5/13/2024

Given the TMDL listed is majority plant nutrients which could be caused by a variety of sources (storm water, surface water, erosion, fertilizer, animal waste, etc.) addressing the concerns from multiple angles can benefit these water source and surrounding populations. All four water sources are commonly known for fishing, boating, and local recreation areas. Given the TMDLS listed, and issues aluminum sulfate should not be the approach to cleaning up the plant nutrients given the harm it could cause additionally. My recommendations would be to address the stormwater and erosion sources known to flow into the bodies of water. Another By addressing this can result in a reduction of animal feces from wildlife and local domestic animals that are running off into the water source. Another beneficial source would be introducing more zooplankton to the lakes. This could have a multi beneficial front in addressing the excess of plant nutrients. Plankton eat the algae, bacteria, and even parasites. By eating these types of things, the plankton promotes a better-quality water. On top of this excess plankton can result in a better fish production given all fours bodies of water mentions are commonly used for fishing. Using a filer in these areas upon the water can allow for absorbent of excess nutrients and minerals that are causing the plant nutrients to grow and building the water sources. Another approach that may be recommended given the size of each water source could be Phoslock. This could allow for absorption of the excess run offs causing the concerns in question to be reduces as well as a prevention method. This has had studies and affects upon both fish and humans. Fish can avoid the sentiment as its being introduced into the water, however the plankton cannot, and this could cause harm and or elimination of plankton in parts of the water which can unintentionally reduce food sources for fish. In general applications of this to water sources it doesn't have any affect upon the human population, however, if someone is relying on this as a source of drinking water or food (eating and drinking on a daily basis) it could cause a approach to minimum lanthanum levels.

SWQB Response: *Thank you for your comments. These possible water quality improvement strategies would be appropriate to expand upon in a future Watershed Based Plan (WBP). WBPs are written for watersheds with impaired waterbodies to discuss restoration strategies to address the water quality impairments. More information on WBPs can be accessed https://www.env.nm.gov/surface-water-quality/wbp/.*

COMMENT SET 4

From: Doug Eib and Lyndsay Remerowski <remereibski@windstream.net>
Sent: Tuesday, May 14, 2024 1:00 PM
To: Graunke, Lucas, ENV <Lucas.Graunke@env.nm.gov>
Subject: [EXTERNAL] Canadian and Upper Rio Grande Basin Draft TMDL Comments

Lucas,

Please find attached my comments on the Canadian and Upper Rio Grande Basin Draft TMDL attached to this e-mail.

Thanks.

Doug Eib

Canadian and Upper Rio Grande Basin Lakes Draft TMDL Comments

Executive Summary

First Paragraph: In the second sentence a TMDL is defined as, "a written plan and analysis established to ensure that a water body will attain and maintain water quality standards including consideration of existing pollutant loads and reasonably foreseeable increases in pollutant loads" (USEPA 1999).

The definition of ensure is "to make certain something will happen". A plan, like a TMDL, without the will and means to execute it, ensures nothing. To imply that a TMDL will "ensure that a water body will attain and maintain water quality standards" is disingenuous and leads the reader to believe that a TMDL by itself has the power to improve water quality. The statement should be removed.

SWQB Response*: This definition is provided by the EPA and referenced accordingly. While a TMDL itself is not a regulatory document, federal, state, and local agencies; regulated permittees; landowners; and stakeholders in the contributing watershed implement TMDLs by applying available resources such as Watershed Based Planning documents and NPDES permits, which can lead to the attainment of water quality standards in a waterbody. This expanded explanation has been added to the first paragraph of the executive summary.*

Third Paragraph: IR is not defined.

SWQB Response: *A definition for the Integrated Report (IR) was added to the second paragraph of the executive summary.*

Paragraph 1.1.3: SWQ should be SWQB.

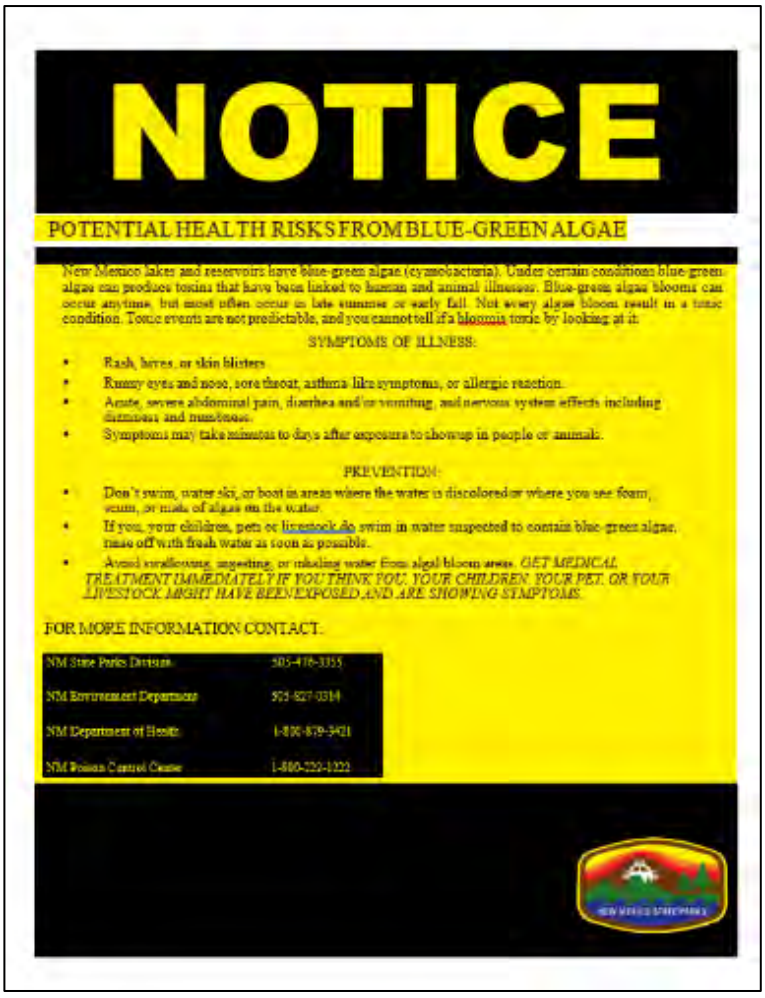
SWQB Response: *Typo has been corrected.*

Background

Paragraph 1.1.1: NMDGF does not stock Yellow Perch, and does not stock or maintain populations of white sucker.

SWQB Response: *Correct. SWQB received a public comment from the New Mexico Department of Game and Fish (NMDGF) requesting that SWQB update the stocked fish information for the lakes in this TMDL (see comment #1). SWQB updated this information in Sections 1.1.1, 1.1.3, 1.1.5, and 1.1.7 reflecting the most current NMDGF fishing stocking information obtained from the NMDGF 2022 Statewide Fisheries Management Plan.*

Eagle Nest Lake is definitely **NOT** meeting its designated use of primary contact. The abject failure of NMED/SWQB and EPA to adequately control nutrient pollution entering Eagle Nest Lake for at least the last 25 years has resulted in harmful algal blooms that now cause closures of at least sections of the lake for primary contact uses. The Eagle Nest Lake State Park website (1) warns visitors that blue-green algae are active in the lake, and posted flyers (see below) advise visitors to avoid swimming, water skiing and boating in areas with blue-green algal blooms. In addition, the notice states that "Toxic events are not predictable, and you cannot tell if a bloom is toxic by looking at it." Jordan Mitchell, the superintendant of Eagle Nest Lake State Park, reports that "…we try to keep algae bloom signs posted year round."



NOTICE

POTENTIAL HEALTH RISKS FROM BLUE-GREEN ALGAE

New Mexico lakes and reservoirs have blue-green algae (cyanobacteria). Under certain conditions blue-green algae can produce toxins that have been linked to human and animal illnesses. Blue-green algae blooms can occur anytime, but most often occur in late summer or early fall. Not every algae bloom result in a toxic condition. Toxic events are not predictable, and you cannot tell if a bloom is toxic by looking at it.

SYMPTOMS OF ILLNESS:

- Rash, hives, or skin blisters.
- Runny eyes and nose, sore throat, asthma like symptoms, or allergic reaction.
- Acute, severe abdominal pain, diarrhea and/or vomiting, and nervous system effects including dizziness and numbness.
- Symptoms may take minutes to days after exposure to show up in people or animals.

PREVENTION:

- Don't swim, water ski, or boat in areas where the water is discolored or where you see foam, scum, or mats of algae on the water.
- If you, your children, pets or livestock do swim in water suspected to contain blue-green algae, rinse off with fresh water as soon as possible.
- Avoid swallowing, ingesting, or inhaling water from algal bloom areas. *GET MEDICAL TREATMENT IMMEDIATELY IF YOU THINK YOU, YOUR CHILDREN, YOUR PET, OR YOUR LIVESTOCK MIGHT HAVE BEEN EXPOSED AND ARE SHOWING SYMPTOMS.*

FOR MORE INFORMATION CONTACT:

NM State Parks Division	505-476-3355
NM Environment Department	505-827-0314
NM Department of Health	1-800-879-3421
NM Poison Control Center	1-800-222-1222

***SWQB Response**: SWQB has not assessed Eagle Nest Lake using harmful algal bloom (HABs) indicators because no numeric criteria (or impairment thresholds) existed to assess primary contact use attainment when the bureau collected water quality data used in this TMDL. However, the Water Quality Control Commission adopted new primary contact criteria for microcystins and cylindrospermopsin in the last Triennial Review, which became effective for state purposes on 4/23/2022. It is unknown at this time whether Eagle Nest Lake is meeting its primary contact use based on algal blooms that may or may not be toxic. SWQB plans to monitor the Canadian Watershed, including Eagle Nest Lake, in 2025.*

SWQB recognizes the importance of monitoring and reporting the occurrence of HABs in New Mexico and identifies HABs as a priority due to public and environmental health risks. In late 2023, SWQB started developing and implementing a HABs program. The SWQB created a dedicated website at: https://www.env.nm.gov/surface-water-quality/habs/. SWQB convened the New Mexico HABs Collaborative Working Group to address the problem of HABs in New Mexico. Through the workgroup, SWQB is striving to increase the state's capacity for monitoring, education, communication and response to the public and environmental health risks posed by HABs. Organizations participating in the workgroup to date include the University of New Mexico, Sandia National Laboratories, Los Alamos National Laboratories, Pueblo de Cochiti, Department of Natural Resources, NMED Drinking Water Bureau, New Mexico Department of Health, New Mexico Department of Game and Fish, New Mexico State Parks, U.S. Army Corps of Engineers, U.S. Bureau of Land Management, and U.S.

Environmental Protection Agency (EPA).

SWQB is developing a sampling and analysis plan to increase monitoring of HABs and their correlated conditions throughout New Mexico. SWQB will use these data to develop a response strategy in partnership with the Department of Health and lake managers as well as provide data to state and national researchers working to further our knowledge of HABs. SWQB is in full partnership with EPA Region 6 who will assist with lab analysis of cyanobacteria and cyanotoxin samples. SWQB is also searching for dedicated funding sources to fund the harmful algal blooms program on a permanent basis.

The section of the NMED/SWQB website that addresses harmful algal blooms (2) advises that blooms may create issues for drinking water supplies and agriculture, and that "Boiling, filtration and/or other treatments will not remove toxins." This statement strongly indicates that, in addition to primary contact, the designated uses of public water supply, domestic water supply and livestock watering are also not being met in Eagle Nest Lake.

Further, the failure of Eagle Nest Lake to meet its existing designated uses due to harmful algal blooms since at least 2018, and probably decades earlier, is a violation of the antidegradation policy of New Mexico Water Quality Standards:

20.6.4.8 ANTIDEGRADATION POLICY AND IMPLEMENTATION PLAN:
A. Antidegradation Policy: This antidegradation policy applies to all surface waters of the state.
(1) Existing uses, as defined in Paragraph (4) of Subsection E of 20.6.4.7 NMAC, and the level of water quality necessary to protect the existing uses shall be maintained and protected in all surface waters of the state.

Eagle Nest Lake nutrient pollution and harmful algal blooms also violate the General Criteria of the New Mexico Water Quality Standards:

20.6.4.13 GENERAL CRITERIA:
General criteria are established to sustain and protect existing or attainable uses of surface waters of the state. These general criteria apply to all surface waters of the state at all times, unless a specified criterion is provided elsewhere in this part. Surface waters of the state shall be free of any water contaminant in such quantity and of such duration as may with reasonable probability injure human health, animal or plant life or property, or unreasonably interfere with the public welfare or the use of property.
M. Biological integrity: Surface waters of the state shall support and maintain a balanced and integrated community of aquatic organisms with species composition, diversity and functional organization comparable to those of natural or minimally impacted water bodies of a similar type and region.
E. Plant nutrients: Plant nutrients from other than natural causes shall not be present in concentrations that will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the state.

***SWQB Response**: The NMED/SWQB website that addresses HABs advises that blooms may (emphasis added) create problems for drinking water supplies and agriculture, but they also may not cause problems. The webpage simply advises the public to be cautious of blooms.*

The nutrient-related numeric criteria associated with domestic water supply and livestock watering are Nitrate as N (10 mg/L) and Nitrite + Nitrate (132 mg/L), respectively. (20.6.4.900(J)(1) NMAC). Based on these criteria and the water quality data collected by the Bureau, Eagle Nest Lake meets both its domestic water supply use and livestock watering use.

The Comprehensive Assessment and Listing Methodology (CALM) describes how SWQB assesses water quality data to make designated use attainment determinations. "Percent cyanobacteria" is included in the CALM as a response variable for the assessment of the Plant Nutrients general criterion. SWQB last sampled Eagle Nest Lake during our 2015-2016 water quality survey. Based on data collected during that survey and assessed using the CALM, SWQB determined that Eagle Nest Lake is impaired due to plant nutrients. This TMDL addresses the Plant Nutrients impairment and establishes goals to achieve water quality standards.

As part of the SWQB HABs program, the Bureau is also researching other states approaches to HABs monitoring, assessment and listing for potential expansion of our assessment approach.

The New Mexico State Parks blue-green algae flyer indicates that direct exposure to algal blooms may result in "nervous system effects including dizziness and numbness", but these symptoms can be prevented by avoiding contact with discolored water, foam scum or algal mats. The NMED/SWQB harmful algal bloom advisory instructs the public to "avoid water and spray from the bloom".

Tumerogenic hepatotoxins (microcystin) and neurotoxins such as β-Methylamino-L-alanine (BMAA) from blue-green algal blooms are known to be concentrated in aerosolized particles, too small to be seen (3), and these particles can travel up to 25 km from algal blooms (4). Both of these advisories fail to acknowledge that simply avoiding contact with waters and water spray containing harmful algal blooms is not sufficient to prevent inhalation of algal toxins.

SWQB Response: *The advisory signs are informational for the public to take appropriate actions to protect their health if they encounter suspicious looking water. The signs err heavily on the side of caution due to the wide variety of blooms that may be encountered. SWQB is working to improve communication, including signage, through the New Mexico HABs Collaborative Working Group and appreciate this feedback regarding exposure routes and public messaging.*

Paragraph 1.3: A TMDL does not restore or protect water quallity. The Eagle Nest Lake watershed, specifiically Cieneguilla Creek, the primary source of influent for Eagle Nest Lake, has had TMDLs for plant nutrients in place since 2004, but 20 years later it remains impaired for plant nutrients. Thanks to the recent extension of the NPDES permit for the Angel Fire WWTP which allows , Cieneguilla Creek, and Eagle Nest Lake are ensured of remaining impaired for the forseeable future.

SWQB Response: *See response #1 above. A TMDL document provides allocations for both nonpoint and point sources but is itself not a regulatory document. The point source loading allocations in the 2004 and 2010 Cieneguilla Creek TMDLs are implemented through the EPA Region 6 NPDES permitting program. The NPDES permit establishes limitations based on the goals established in the TMDL. As the permitting authority, EPA Region 6 is responsible for enforcement of the permit if the WWTP fails to meet those limitations.*

3.2 Flow

The TMDLs are described in mg/L; mg/L is the concentration, so what is concentration per volume?

SWQB Response: *The TMDLs in this document are expressed as concentration values in mg/L and as mass based TMDLs at the average and critical reservoir storage levels expressed as lbs/day as discussed in Sections 2.2, 3.2 and 4.2.*

Plant Nutrients

3.5.3 Load Reductions

Tables 3.7 a and b: Calculation of load reductions for TN and TP necessary to achieve target concentrations:

Because no waste load alocation is given to the Angel Fire WWTP in the Eagle Nest Lake TMDL (as well as the other three lakes in this TMDL), all reductions in nutrient loading are assigned to non-point souces. This means the 70% reduction in phosphorus loading, and 10% reduction in nitrogen loading necessary to achieve target loading must come entirely from unregulated, non-point sources. This is pure fantasy. TMDLs are required to comply with the principle of federal law called reasonable assurance. If NMED SWQB seriously believes they are going to achieve the astronomical reductions to the load allocatons for phosphorus and nitrogen given in this table (as well as the load reductions table for Santa Cruz, and Maloya Lakes, and Shuree Pond North) through 319 grants and the activities of its Watershed Protection Section, they need to provide assurance in the form of data from previous work that shows they are capable of producing results of this magnitude, or anywhere near it, in place of the palaver provided in the current document. Under the assurances section of the 2004 TMDL for plant nutrients in Cienegulla, Moreno and Sixmile Creeks, the time required to attain standards for all reaches was estimated to be approximately 10-20 years. In the 2010 TMDL for plant nutrients in these same creeks the time required to attain standards for all reaches was still estimated to be approximately 10-20 years. This is far from assuring.

SWQB Response*: SWQB calculated the Angel Fire WWTP WLA in the 2010 Cienguilla Creek TMDL. EPA Region 6 NPDES Permitting Program implements the wasteload allocation under NPDES Permit No. NM0030503, which was reissued in July 2023. The other three lakes addressed in this TMDL document are not receiving waters for NPDES permits and therefore do not need a WLA assigned. Reasonable assurances are addressed in Section 7.0 of the TMDL. As your comments address the permit and not the TMDL, the SWQB TMDL Team provided your comments to the SWQB Point Source Regulation Section to be used in future coordination with EPA on the NM0030503 permit.*

The 2010 TMDLs for plant nutrients in Moreno, Cieneguilla and Sixmile Creeks gave the following concentration targets and critical low flows:

	TP (mg/L)	TN (mg/L)	4Q3 (cfs)	4Q3 (L/s)
Moreno	0.02	0.25	0.18	5.097
Sixmile	0.02	0.23	0.17	4.814
Cieneguilla	0.06	0.56	0.31	8.778

The 2010 TMDLs for TN and TP for the Canadian River headwaters also provided for a phased approach to deal with the discharge of plant nutrients from the Angel Fire WWTP into Cieneguilla Creek, the primary inlet to Eagle Nest Lake. Parameters were taken from the NPDES fact sheet from 4/14/22, phase 1, and phase n, and are shown in the following table:

Phase	Flow (MGD)	Flow (L/s)	TP (lbs/day)	TP (mg/L)	TN (lbs/day)	TN (mg/L)
4/14/22	0.206	9.0	1.48	0.86	16.54	9.6
Phase 1	0.5	21.9	0.42	0.1	0.56	3.0
Phase n	0.5	21.9	0.25	0.06	2.3	0.56

The concentrations of TP and TP after mixing, calculated as the sum of (flows x concentrations)/sum of flows, of WWTP effluent under the three phases with Cieneguilla Creek at 2010 TMDL target loads and critical flow appear in the following table:

Phase	TP (mg/L)	TN (mg/L)
4/14/22	0.46	5.135
Phase 1	0.1	3.0
Phase n	0.06	0.56

Finally, the table below shows the total concentrations of TN and TP entering Eagle Nest Lake from Cienega Creek after mixing with WWTP effluent, Moreno Creek and Sixmile Creek, under 2010 TMDL target loading and critical flows.

Phase	TP (mg/L)	Target TP loading	TN (mg/L)	Target TN (mg/L)
4/14/22	0.153	0.027	3.38	0.810
Phase 1	0.063	0.027	1.797	0.810
Phase n	0.050	0.027	0.483	0.810

Even at phase n in the WWTP permit process, target TP concentrations for Eagle Nest Lake will not be met. And, assuming TP in-stream load allocations from Cieneguilla, Moreno and Sixmile Creeks are reduced to zero through the miracle of 319 grants and NMED Watershed Protection Section activities, the concentration of TP flowing into Eagle Nest Lake from the WWTP discharging .06 mg/L TP via Cieneguilla Creek is only reduced to 0.032 mg/L at phase n.

In addition, nutrients from lake sediments have long been known to cycle back into the water where they are available to support biological processes such as algal growth (5). There is no acknowlegdement in this document of the existence of this process, much less an attempt to incorporate it into load allocations. The result is that this TMDL very likely overestimates the nutrient load Eagle Nest Lake can receive without futher impairment.

The health risks that current levels of nutrient loading to Eagle Nest Lake and the concommitant algal blooms are creating are too great to be allowed to continue. The phased approach to dealing with Angel Fire WWTP effluent will allow nutrient loading at over twice the target loading presenteded in the Eagle Nest Lake TMDL for at least five more years, and probably longer due to the moving targets of the phased permitting approach at the WWTP, and sediment nutrient cycling.

SWQB Response: *Thank you for your comments. Since your comments do not address this TMDL but the 2010 TMDL and Angel Fire WWTP NPDES permit, the SWQB TMDL Team provided your comments to the SWQB Point Source Regulation Section to be used in future coordination with EPA on the NM0030503 permit.*

BMAA, linked to neurodegenerative disorders such as Lou Gehrig's Disease (ALS) and Alzheimers, has been found in the nasal passages and olfactory lobes of of people living near waters impacted by blue-green algal blooms (6,7). The EPA website (8) states that, "The evidence for a significant role of BMAA in human disease is lacking and this may impact the initiation of further research efforts with this chemical", relying on a single publication from 2017 (9). This publication has been thoroughly rebutted (10) and there is a large and growing body of evidence suppoting the link of BMAA to neurological disease. Neither NMED SWQB, the New Mexico Department of Health or EPA has a program to monitor airborne algal toxins and EPA has promulgated criteria only for waterborne microcystin. Individuals who visit or live near waters that experience harmful algal blooms are at risk of both outdoor and indoor exposure to aerosolized algal toxins (11). Even without federal or state standards for airborne algal toxins, the public has a right to know the potential human health impacts of harmful algal blooms (12) so they can choose for themselves the level of risk they are willing to accept.

in 2020, Dr. Walter Bradley, former chairman of the University of Miami Department of Neurology and an expert in ALS wrote,

"It may take 20-plus years for a chronic neurotoxin like BMAA to produce Lou Gehrig's or Alzheimer's disease in humans. Does that put us where we were with smoking in the 1950s? Though people long suspected that smoking was harmful to health, it took decades to prove that smoking caused lung cancer -- and to persuade people to quit. But we didn't wait until "all the data was in" before the first surgeon general warnings were issued in 1964. Of course, more research on HABs and BMAA is needed. For example, we need to know how much exposure to HAB-infested water is too dangerous? But there are enough studies to warrant taking action now, including warning the public that exposure to HABs is to be avoided and for lawmakers to enact policies to stem the flow of nutrients that cause algae blooms" (13).

SWQB Response: *The SWQB shares these concerns regarding exposure routes and will discuss them with the New Mexico HABs Working Group. We will also discuss these concerns with the NMED Air Quality Bureau and invite them to the Workgroup.*

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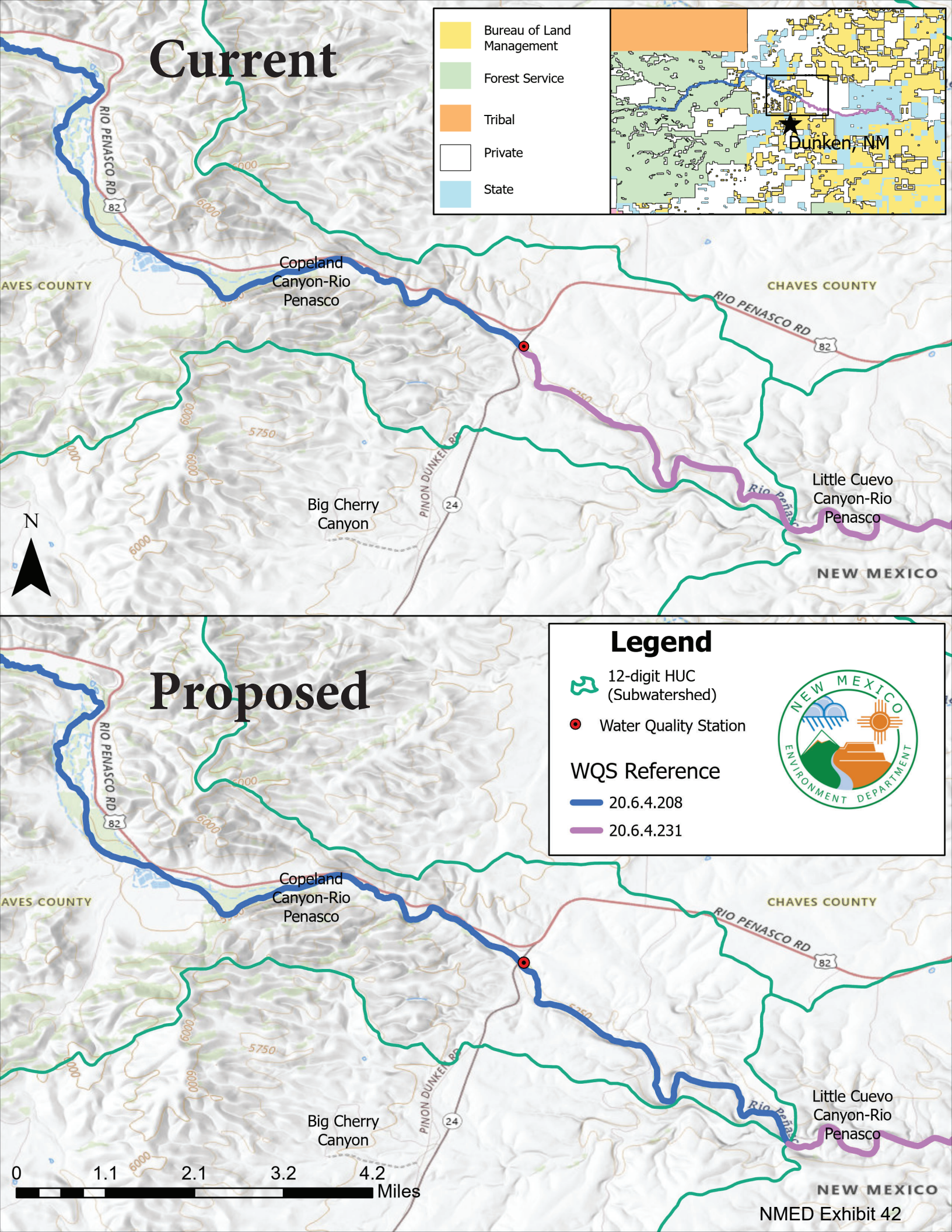
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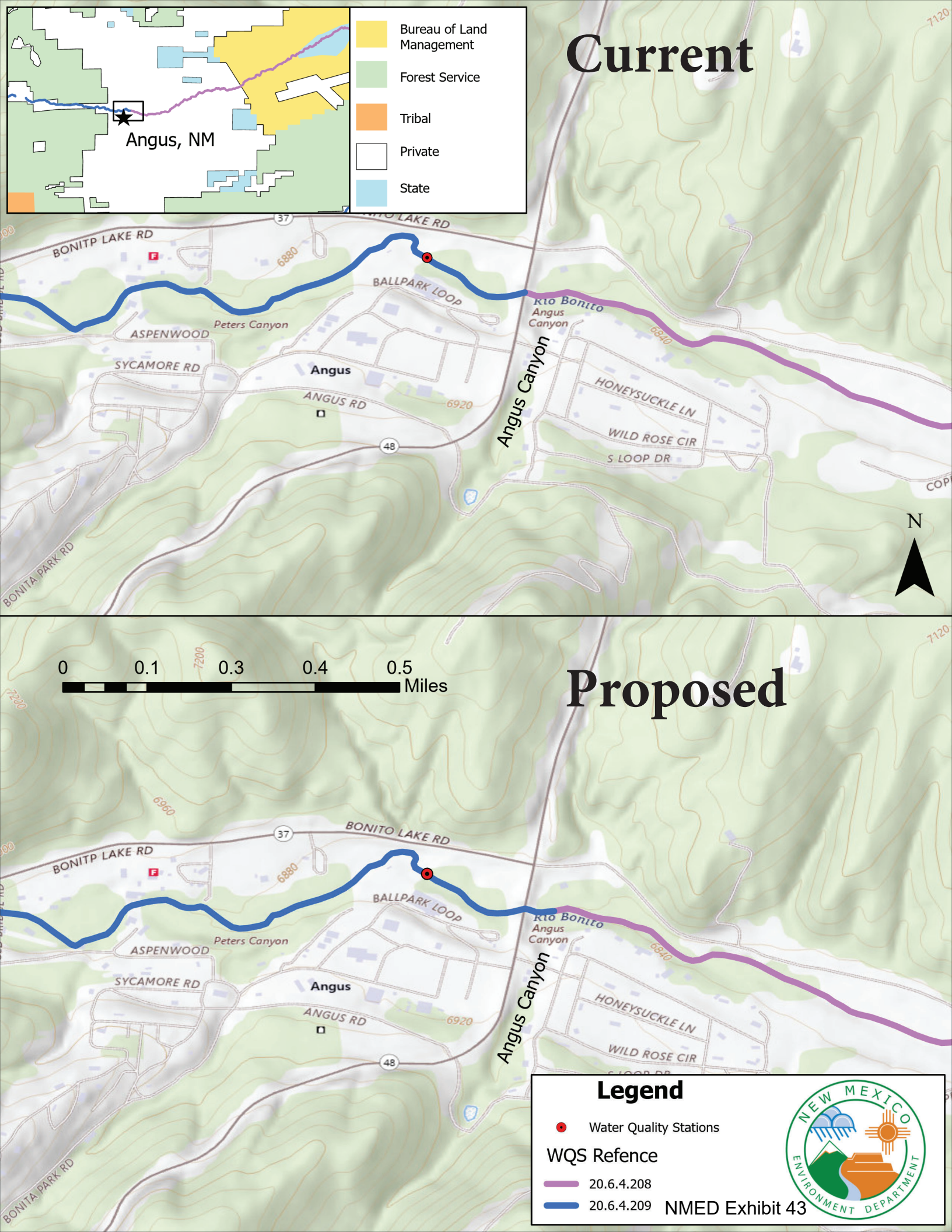
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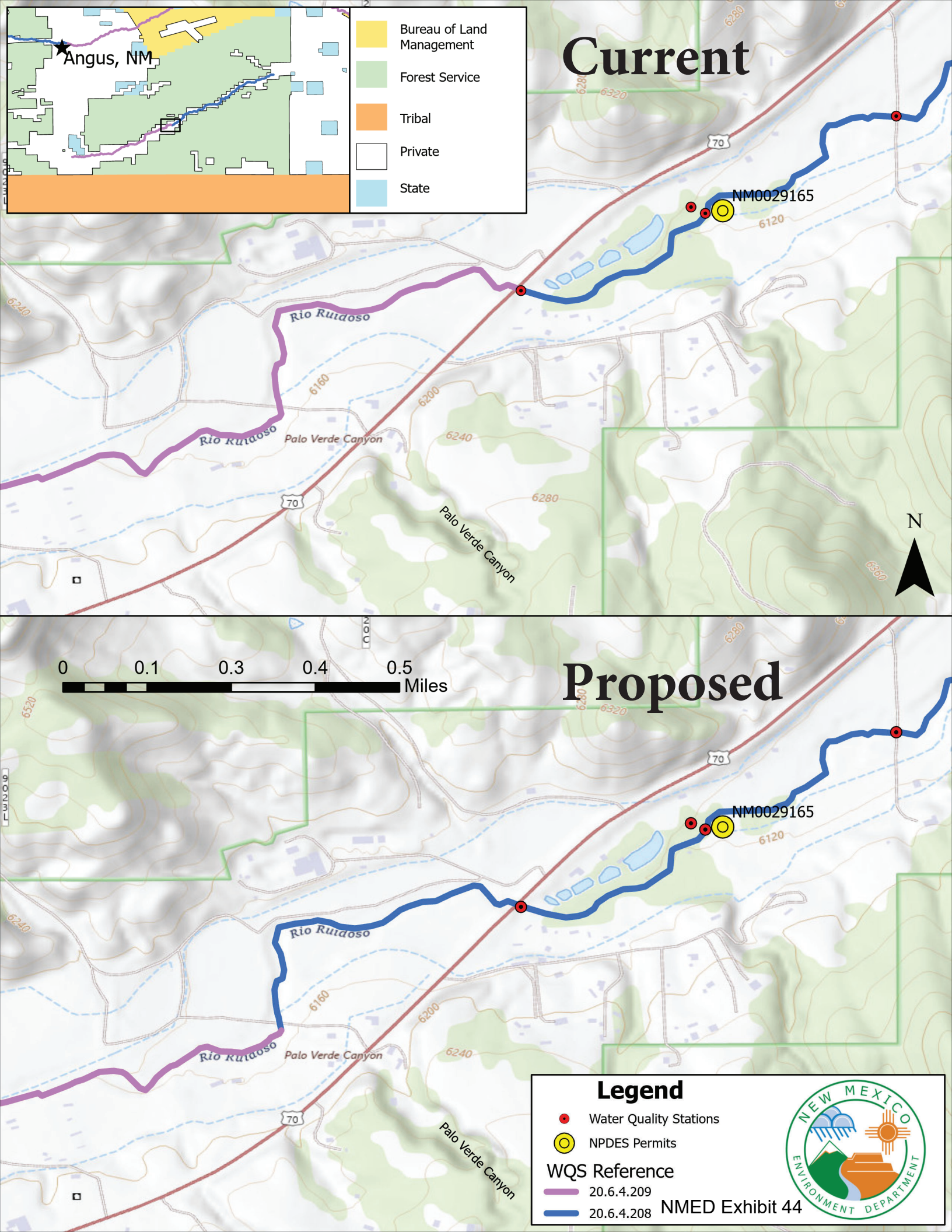
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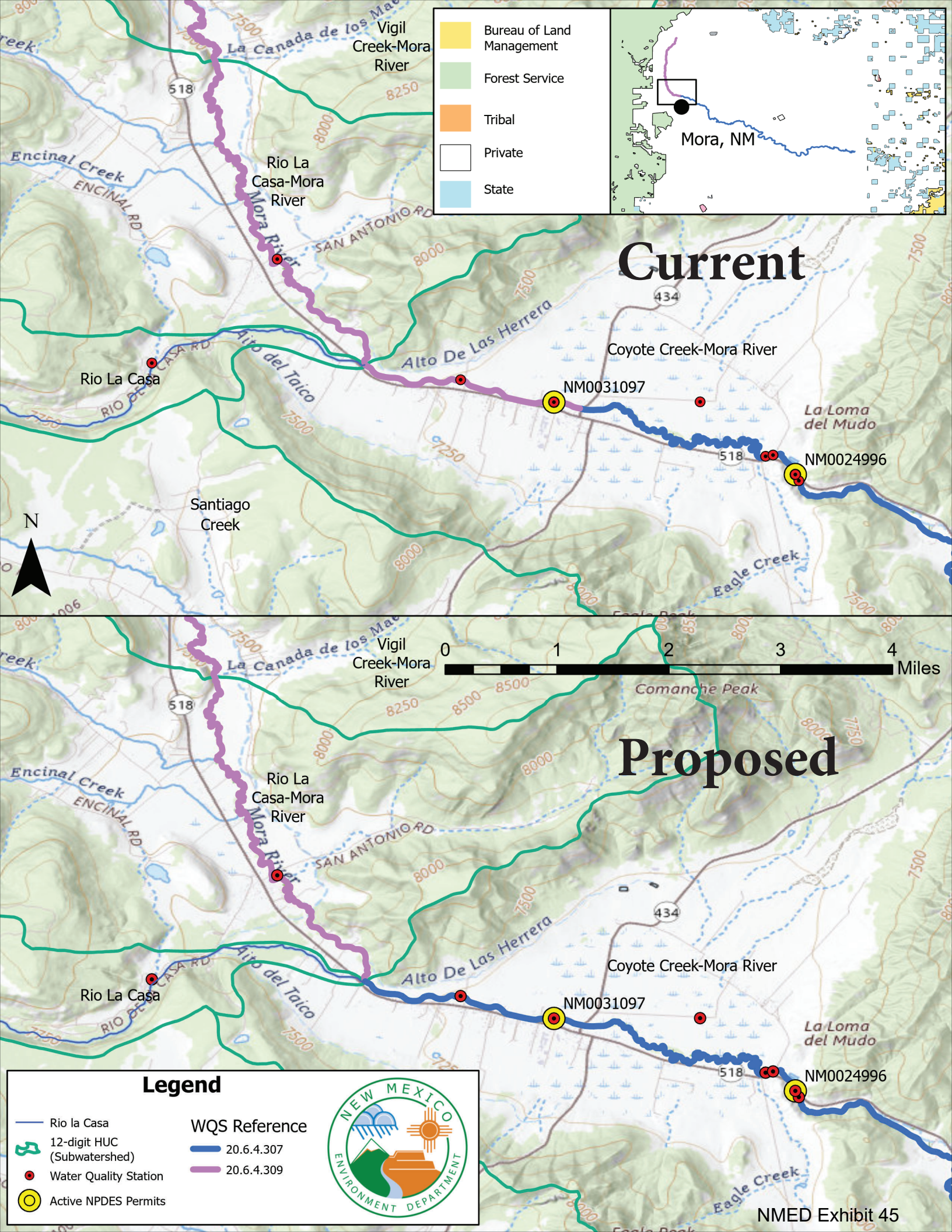
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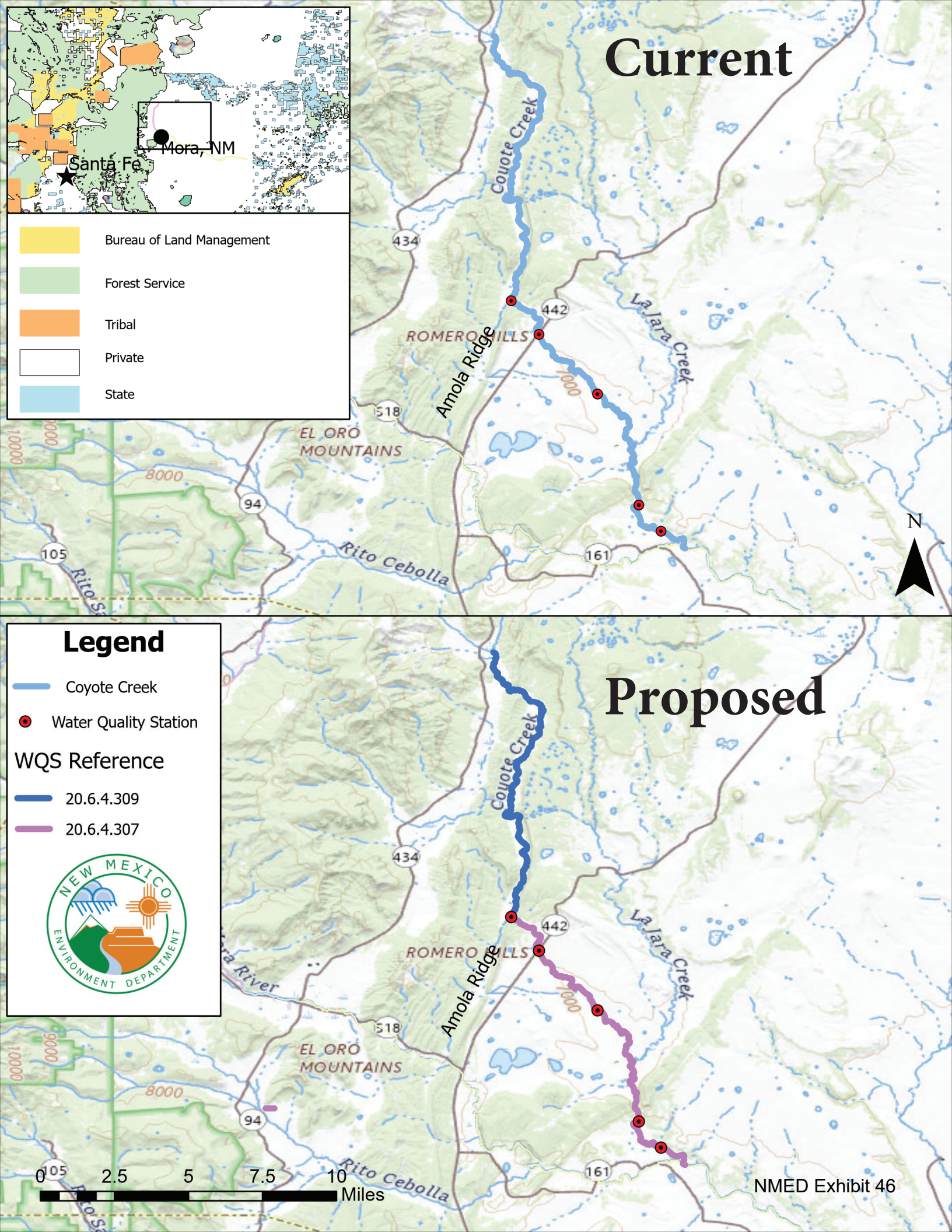


NMED Exhibit 42


Current
Bureau of Land Management
Forest Service
Tribal
Private
State
Angus, NM
BONITP LAKE RD
BONITO LAKE RD
BALLPARK LOOP
Peters Canyon
ASPENWOOD
SYCAMORE RD
Angus
ANGUS RD
Rio Bonito
Angus
Canyon
Angus Canyon
HONEYSUCKLE LN
WILD ROSE CIR
S LOOP DR
BONITA PARK RD
6880
6920
6840
7120
7200
6960
37
48
N
0
0.1
0.3
0.4
0.5
Miles
Proposed
Legend
Water Quality Stations
WQS Refence
20.6.4.208
20.6.4.209
NEW MEXICO
ENVIRONMENT DEPARTMENT
NMED Exhibit 43


Angus, NM
Bureau of Land Management
Forest Service
Tribal
Private
State
Current
NM0029165
Rio Ruidoso
Palo Verde Canyon
70
6120
6160
6200
6240
6280
6320
N
0
0.1
0.3
0.4
0.5
Miles
Proposed
NM0029165
Rio Ruidoso
Palo Verde Canyon
70
Legend
Water Quality Stations
NPDES Permits
WQS Reference
20.6.4.209
20.6.4.208
NEW MEXICO ENVIRONMENT DEPARTMENT
NMED Exhibit 44


Bureau of Land Management
Forest Service
Tribal
Private
State
Mora, NM
Current
Vigil Creek-Mora River
La Canada de los Ma
Rio La Casa-Mora River
Mora River
Encinal Creek
ENCINAL RD
SAN ANTONIO RD
Alto De Las Herrera
Coyote Creek-Mora River
NM0031097
La Loma del Mudo
NM0024996
Rio La Casa
RIO DE CASA RD
Alto del Taico
Santiago Creek
Eagle Creek
Comanche Peak
434
518
N
0 1 2 3 4 Miles
Proposed
Legend
Rio la Casa
12-digit HUC (Subwatershed)
Water Quality Station
Active NPDES Permits
WQS Reference
20.6.4.307
20.6.4.309
NEW MEXICO ENVIRONMENT DEPARTMENT
NMED Exhibit 45


Current
Mora, NM
Santa Fe
Bureau of Land Management
Forest Service
Tribal
Private
State
Coyote Creek
434
442
ROMERO HILLS
La Jara Creek
Amola Ridge
518
EL ORO MOUNTAINS
8000
94
105
Rito Cebolla
161
N
Proposed
Legend
Coyote Creek
Water Quality Station
WQS Reference
20.6.4.309
20.6.4.307
NEW MEXICO ENVIRONMENT DEPARTMENT
0 2.5 5 7.5 10
Miles
NMED Exhibit 46

APPENDIX G

SEDIMENTATION/SILTATION LISTING METHODOLOGY FOR STREAMS AND RIVERS



NEW MEXICO ENVIRONMENT DEPARTMENT
SURFACE WATER QUALITY BUREAU

AUGUST 15, 2025

NMED Exhibit 47

Purpose and Applicability

This document establishes a listing methodology for determining impairment due to excessive sedimentation/siltation (otherwise referred to as stream bottom deposits or SBD) in wadeable, perennial streams. This assessment is only conducted in wadeable, perennial streams at this time because the research used to develop this listing methodology is based upon data and information collected in perennial streams. The Surface Water Quality Bureau (SWQB) will include other waterbody types as additional information becomes available and applicable assessment thresholds are developed.

This protocol was developed to support an interpretation of the *State of New Mexico Standards for Interstate and Intrastate Surface Waters* narrative standard for bottom deposits found at 20.6.4.13 NMAC (https://www.env.nm.gov/surface-water-quality/wqs/):

> ***A. Bottom Deposits and Suspended or Settleable Solids:***
> *(1) Surface waters of the state shall be free of water contaminants including fine sediment particles (less than two millimeters in diameter), precipitates or organic or inorganic solids from other than natural causes that have settled to form layers on or fill the interstices of the natural or dominant substrate in quantities that damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.*

In 2008, the SWQB Sediment Workgroup was formed to review the previous sedimentation/siltation listing methodology and recommend an approach for revision. As a result of workgroup discussions, the SWQB and the U.S. Environmental Protection Agency (EPA) Region 6 contracted with Tetra Tech, Inc. to develop sediment translators or thresholds. Tetra Tech, Inc. generally followed the steps provided in EPA's Framework for developing suspended and bedded sediment (SABS) water quality criteria (EPA 2006). To address the "*from other than natural causes*" portion of the criterion, Level IV ecoregions were used to classify and group sites to examine distributions and define reference conditions that account for New Mexico's varied associated geological and physiographic characteristics around the state. Several staff from Tetra Tech, Inc., EPA Region 6, and the SWQB worked as a team to complete this effort.

This effort included the identification of sediment characteristics that can be expected under the range of environmental settings in New Mexico, especially in undisturbed or best available reference streams. The goal of this characterization was to enable the SWQB to identify situations where sedimentation/siltation expectations are not met, using sediment indicators that show responsiveness to disturbance. Examining the relationships between biological measures and sediment indicators helped to identify where disturbance caused sediment imbalance and biologically-relevant habitat degradation. The results of these analyses led to quantitative sedimentation indicator threshold recommendations for New Mexico perennial streams.

The 100+ page report (Jessup et al. 2010) detailing this effort, plus information on additional bedded sediment indictors as well as suspended sediment indicators, is available at https://www.env.nm.gov/surface-water-quality/sedimentation/. The SWQB also generated a Sedimentation/ Siltation Thresholds Development Plan (NMED/SWQB 2011), which summarizes the seven steps taken to develop recommended bedded sediment thresholds, available at the same web site. For historical purposes, this plan includes an abbreviated description of the previous sedimentation listing methodology utilized during the 1998 – 2010 listing cycles as Attachment A.

Exclusions

This protocol is not applicable to the following water body types because the necessary research and assessment methods are not yet developed for New Mexico:

- Lakes or reservoirs
- Large rivers (non-wadeable)
- Intermittent streams which include water bodies under 20.6.4.98 or 20.6.4.128 NMAC
- Ephemeral streams which include water bodies under 20.6.4.97 or 20.6.4.128 NMAC
- Wetlands or playas

The SWQB is distinguishing rivers from streams by defining systems that cannot be monitored effectively with the biological and habitat methods developed for wadeable streams. These rivers also generally meet the Simon and Lyons (1995) definition of great rivers as those having drainage areas greater than 2,300 square miles (mi^2). There are many systems is in New Mexico that meet the great river definition but are usually suitable to wadeable stream monitoring methods due to the arid nature of the region. For sedimentation monitoring and assessment purposes, the systems included in the "Large Rivers" water body type, and consequently exempt from this protocol, are the non-wadeable portions of the:

1. San Juan River from below Navajo Reservoir to the Navajo Nation boundary near Four Corners,
2. Animas River from the Colorado border to the San Juan River,
3. Rio Grande in New Mexico,
4. Pecos River from below Sumner Reservoir to the Texas border,
5. Rio Chama from below El Vado Reservoir to the Rio Grande,
6. Canadian River below the Cimarron River, and
7. Gila River below Mogollon Creek.

Fine sediment benchmarks in representative riffle areas were previously developed for the San Juan and Animas Rivers. In 2002, the SWQB received a grant to develop a protocol for the determination of sedimentation impairment in these rivers. The SWQB contracted with the U.S. Department of Agriculture (USDA) National Sedimentation Lab (NSL) to provide technical support on the project (Heins et al. 2004). The SWQB used the results of this study to develop a repeatable, quantitative assessment procedure for determining whether New Mexico's current narrative sedimentation standard is being attained in the San Juan and Animas rivers. The NSL study resulted in the determination of fine sediment benchmarks for representative riffles areas in Ecoregion 22 as well as various river reaches in the San Juan River basin. The SWQB used these benchmarks to establish one fine sediment threshold for the San Juan and Animas Rivers and compared the measured bed material characteristics of the stream reach of concern to this fine sediment threshold. This procedure was used to assess the San Juan and Animas rivers for development of the 2004-2006 Integrated List and was applied to subsequent data collected during non-wadeable conditions with comparable sampling methods to determine potential sedimentation impairment in these rivers. This document and the entire NSL report is available at: https://www.env.nm.gov/surface-water-quality/sedimentation/. A hybrid approach was used to assess the San Juan and Animas Rivers for sedimentation on the 2012-2014 Integrated Report following the 2010 watershed survey (see the Assessment Rationale for these assessment units for details). The SWQB hopes to develop a sedimentation listing methodology applicable to all non-wadeable river reaches listed above in the future. However, the hybrid approach will continue to be used until a non-wadeable rivers methodology is developed and listings resulting from the hybrid approach will be placed in IR category 5C with a note that further data collection is needed.

NMED Exhibit 47

1.0 Introduction/Background

Excessive fine sediment filling the interstitial spaces in stream bottom substrate provides sub-optimum habitat for many fish and aquatic insect communities. Excessive fine sediment occurs when biologically-important habitat components, such as spawning gravels and cobble surfaces, are physically covered by fine particles (Chapman and McLeod 1987). Excessive fine sediment can result in decreased inter-gravel oxygen, as well as reduced or eliminated quality and quantity of habitat for fish, macroinvertebrates, and algae (Lisle 1989, Waters 1995). Chapman and McLeod (1987) found that bed material size is related to habitat suitability for fish and macroinvertebrates and that excess sediment decreased both density and diversity of aquatic insects. Specific aspects of sediment-invertebrate relationships can be described as follows: 1) abundance of certain invertebrate taxa is correlated with substrate particle size; 2) fine sediment reduces the abundance of sediment intolerant taxa by reducing interstitial habitat normally available in large-particle substrate (e.g., gravel or cobbles); and 3) community composition changes as substrate particle size changes from large to small (e.g., sand, silt, or clay) (Waters 1995).

Sediment loads that exceed a stream's sediment transport capacity can trigger changes in stream morphology (Leopold et al. 1964). Streams that become overwhelmed with sediment often go through a period of accelerated channel widening and streambank erosion before returning to a stable form (Rosgen 1994). These morphological changes can accelerate erosion, reduce habitat diversity (e.g., pools, riffles, etc.), and place additional stress on the designated aquatic life use.

Substrate characteristics may be considered impacted at a site if they are: 1) not similar to expectations for undisturbed sites in the same environmental setting; or 2) measurably affecting the biota. In the first case, substrate may be more fine, more coarse, more unstable, or more stable than expected under broadly recognized, undisturbed conditions (i.e., reference or best available conditions) for that particular environmental setting. In the second case, biotic responses to disturbed substrates can be variable, but sub-optimal biotic conditions are often associated with unbalanced sediment loads.

Bedded sediments cannot be treated as introduced pollutants such as pesticides because they are not uniquely generated through human input or disturbance. Rather, bedded sediments are components of natural systems that are present even in pristine settings and to which stream organisms have evolved and adapted. Therefore, the detection of a sediment imbalance is more complicated than detecting an absolute concentration or percentage that represents a clear biological impact (Jessup et al. 2010).

The approach used to identify sedimentation/siltation thresholds for wadeable, perennial streams in New Mexico followed seven basic steps:

1. Review background information
2. Assemble datasets
3. Establish reference sites
4. Classify sites
5. Characterize sediments
6. Describe stressor-response relationships
7. Recommend thresholds or benchmarks

These steps are generally based on the EPA Framework for developing SABS water quality criteria (EPA 2006). The details of each step are available in summary form or in entirety in separate documents available on the SWQB web site (NMED/SWQB 2011 and Jessup et al. 2010): https://www.env.nm.gov/surface-water-quality/sedimentation/.

NMED Exhibit 47

Multiple sediment indicators were analyzed for their responsiveness to site disturbance and effects on benthic macroinvertebrates. The analysis used reference distributions, quantile regression, and change-point analysis, and resulted in the threshold recommendations for two bedded sediment indicators (Table 1) – % Sand and Fines (%SaFN) and log Relative Bed Stability calculated without bedrock (LRBS_NOR) – in three sediment site classes, Mountains, Foothills, and Xeric areas (Table 2, Figure 1). The site classes are defined by Level III and IV ecoregions (Griffith et al. 2006) and distinguish bedded sediment expectations across New Mexico. Site classes were identified through a principal component analysis (PCA) of environmental conditions and the bedded sediment indicators. The Foothills and Xeric site class definitions were modified slightly from Jessup et al. 2010 to further divide ecoregion 22 based on site characteristics used in the PCA (see NMED/SWQB 2011 for additional details). Site locations near sediment site class boundaries warrant additional scrutiny. Any study site within approximately twenty kilometers of a boundary should be compared to the adjacent ecoregion definition to determine the appropriate ecoregion and associated bedded sediment site class designation for that particular site. Assessment conclusions for these sites will be reviewed on a case-by-case basis. Sediment site class assignments that deviate from Table 2 will be documented in the SWQB's in-house database (SQUID).

Table 1. Bedded sediment indicators

Sediment Indicator	Description
Percent Sand & Fines (%SaFN)	**The percentage of systematically selected streambed substrate particles that are ≤2.0 mm in diameter from reach-wide pebble count.**
Log Relative Bed Stability (LRBS)	**A measure of the relationship of the median particle size in a stream reach compared to the critical particle size calculated to be mobilized by standardized fluvial stresses in the reach.** Median particle size is determined using a reach-wide pebble count (Peck et al. 2006). Critical particle size is calculated from channel dimensions, flow characteristics, and channel roughness factors (Kaufmann et al. 2008). The measure is expressed as a logarithm of the ratio of geometric mean to critical particle size.
LRBS_NOR	**RBS without bedrock or hardpan (log10).** This measure regards only the potentially mobile streambed particles in determining the geometric mean particle size, and improved associations between the bedded sediment measure and biological responses in the TetraTech analyses (see Jessup et al. 2010 for additional discussion of LRBS_NOR).

Table 2. Definition of bedded sediment site classes

Site Class	Definition
Mountains	Ecoregions 21 and 23, ***except*** *21d, 23a, 23b and 23e*
Foothills	Ecoregions 21d, 22a, 22b, 22f, 23a, 23b, 23e and 79
Xeric	Ecoregions 20, 22, 24, 25, and 26, ***except*** *22a, 22b, 22f*
Ecoregion number	**Ecoregion Name***
20	Colorado Plateaus
21	Southern Rockies
21d	Foothill Woodlands and Shrublands
22a	San Luis Shrublands and Hills
22b	San Luis Alluvial Flats and Wetlands
22f	Taos Plateau
23	Arizona/New Mexico Mountains
23a	Chihuahuan Desert Slopes
23b	Madrean Lower Montane Woodlands
23e	Conifer Woodlands and Savannas
24	Chihuahuan Deserts
25	High Plains
26	Southwestern Tablelands
79	Madrean Archipelago

NOTES: * Additional written descriptions of level 4 ecoregions in New Mexico are available at: https://gaftp.epa.gov/EPADataCommons/ORD/Ecoregions/nm/nm_back.pdf

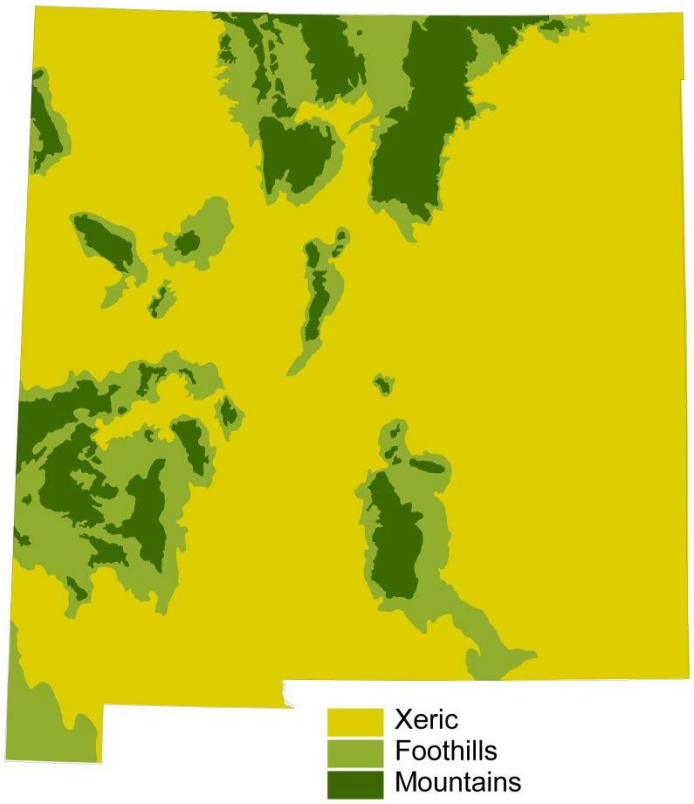


Figure 1. New Mexico Mountain, Foothills, and Xeric site class map

The recommended thresholds by site class resulted from a weight-of-evidence approach that considered multiple analytical approaches and the strength of each analysis. Corroborating evidence for selection of thresholds from reference conditions was found in the analysis of relationships between sediment and biological indicators. Biological effects are indirect indicators of required sediment conditions because biota is affected by other environmental conditions besides sediment conditions (Jessup et al. 2010).

2.0 Assessment Procedure

To determine if there is excessive sedimentation/siltation in the study stream reach, two levels of assessment are performed in sequential order (Figure 2). The first level ("Level 1") considers the simpler indicator of biological impairment, and the second level ("Level 2") considers geomorphic impairment if the Level 1 threshold is exceeded. If the %SaFN site class thresholds are not exceeded in a Level 1 assessment, the assessment is complete, and it is unnecessary to proceed to a Level 2 assessment. Delisting requirements are the same as the those required for listing.

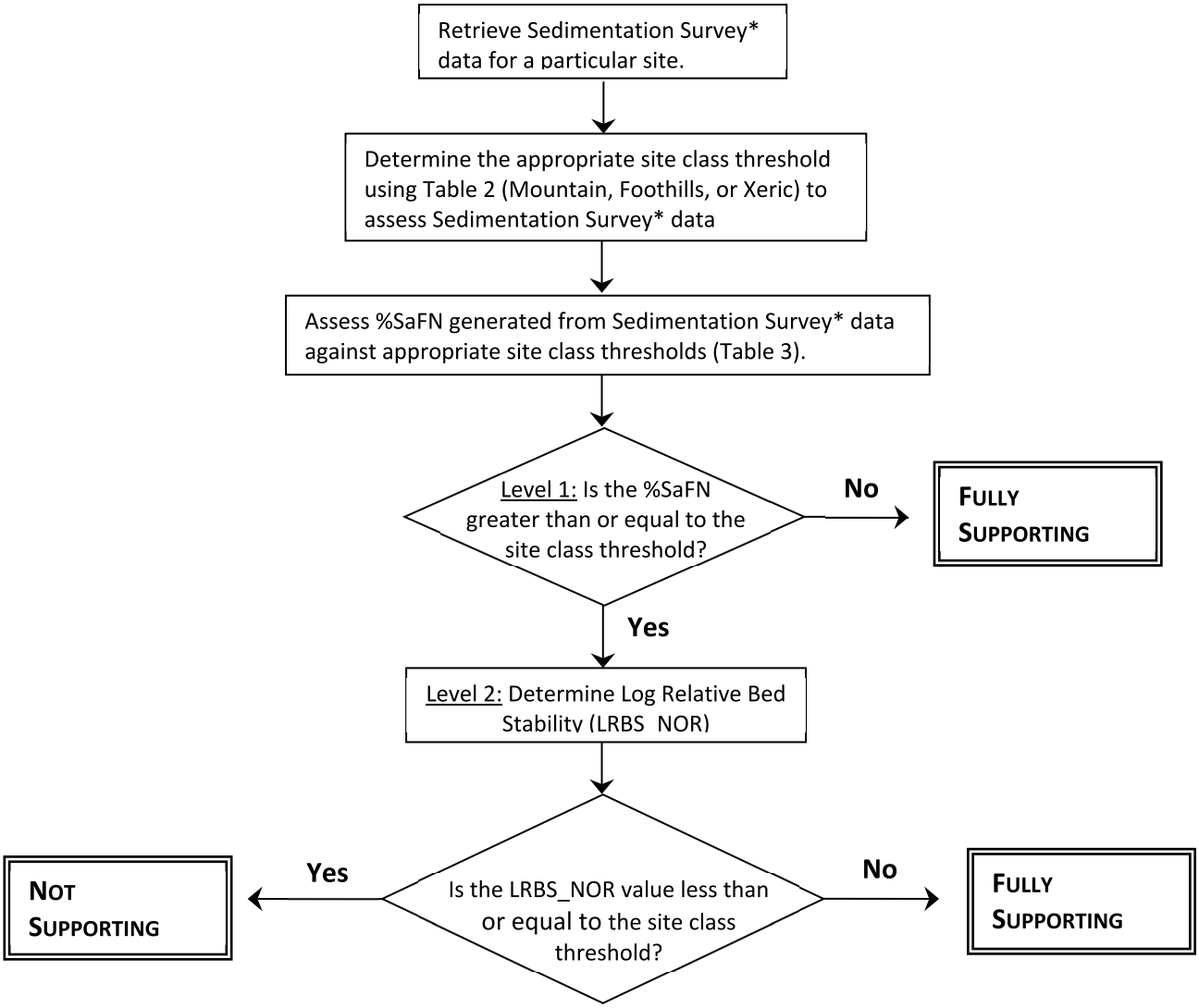


Figure 2. Two-tiered assessment approach for determining sedimentation/siltation impairment
NOTES: * As described in the SWQB's Physical Habitat SOP (https://www.env.nm.gov/surface-water-quality/sop/) or equivalent.

The %SaFN sediment indicator is used in the Level 1 assessment because it is easily measured and correlates strongly with biological metrics. If the %SaFN indicates excessive fine sediment in the stream bed by exceeding thresholds, a Level 2 sedimentation assessment is performed. Level 2 assessments require the collation of Sedimentation Survey data to calculate the log Relative Bed Stability without bedrock (LRBS_NOR) value for a specific site. The LRBS_NOR indicator is an equation that considers site-specific hydraulic potential for moving bed sediments, so that the observed amounts of sand and fine sediments are considered impaired when the streambed is more easily mobilized and transported than expected. The LRBS_NOR measure is appropriate as a second-tier indicator because it is scaled to hydro-geomorphic factors of the individual sites, as well as to the broader site classes, thus allowing evaluation of the potential of the specific site in terms of retaining or flushing fine sediments. When used as a second-tier sediment indicator, LRBS_NOR helps explain whether high %SaFN were expected for a given site or are a result of disturbed conditions (Jessup et al. 2010). Sediment condition relative to the fluvial potential is a better estimate of system stability and imbalance than absolute measures of fine sediment concentration alone, because they intrinsically account for site-specific natural settings. In contrast to LRBS_NOR, the %SaFN measure is an absolute quantity, which is more susceptible to spatial and temporal variations (Jessup et al. 2010) exceeding the natural variability captured by site classification.

Another way to present how the two indicators are applied in a tiered approach is to consider the quadrants when the two indicators are graphed against one another (Figure 3).

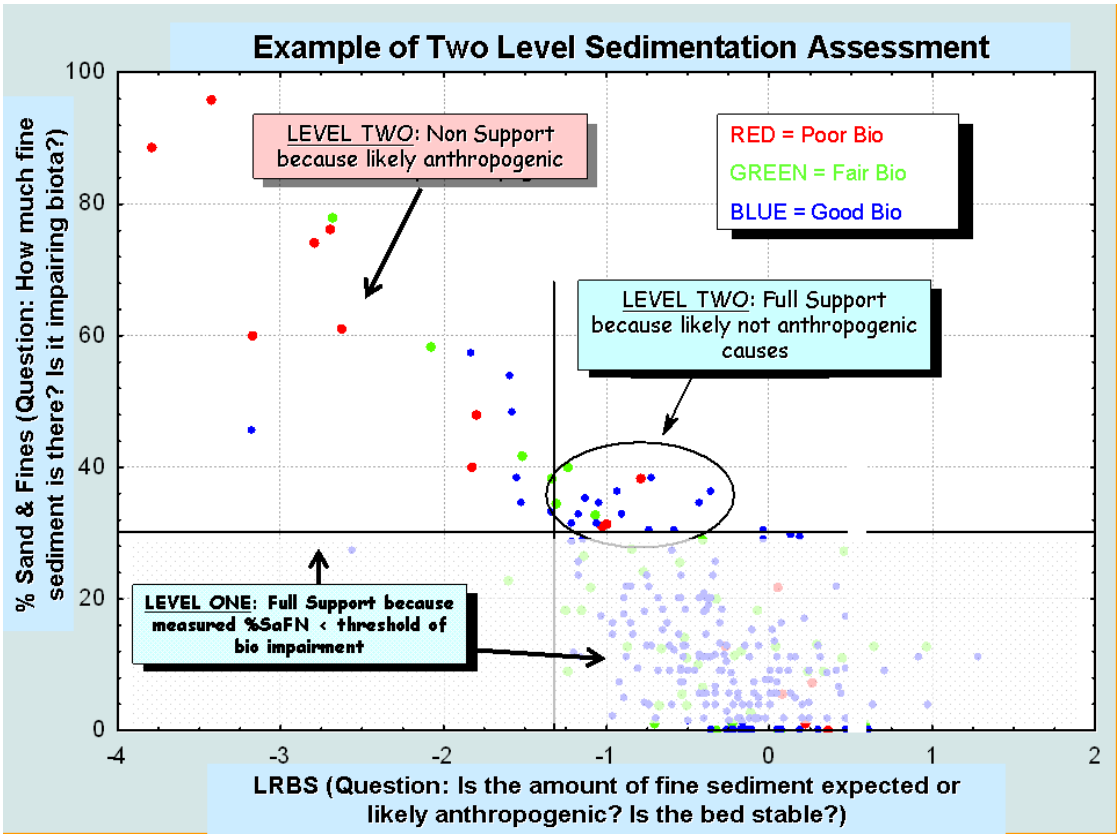


Figure 3. Graphical example of two indicator tiered assessment approach

In Figure 3, sites falling in the upper left quadrant represent **Non Support** (impaired) for sedimentation/siltation because they fail both the Level 1 and Level 2 thresholds (i.e., have both high %SaFN and low LRBS_NOR values). Sites in the other three quadrants are considered **Full Support** (unimpaired). Specifically, sites that fall in the lower quadrants are considered unimpaired because they have low %SaFN (passing the Level 1 threshold). These sites are considered unimpaired because the measured %SaFN values are below the threshold for biological impairment. Observations in the upper right quadrant indicate potential impairment using the Level 1 (%SaFN) threshold but are considered unimpaired based on the Level 2 (LRBS_NOR) threshold because LRBS_NOR values greater than the threshold suggest that the higher %SaFN values may be natural and therefore expected for those sites.

2.1 Level 1 Sedimentation Assessment

Sedimentation surveys are conducted during regular SWQB watershed surveys according to the SWQB's Standard Operating Procedure (SOP) 5.0 Physical Habitat (https://www.env.nm.gov/surface-water-quality/sop) or equivalent. The SWQB's physical habitat surveys are completed during stable low flow conditions between August 15 and November 15 if concurrent biological monitoring is planned, because this is the SWQB's historic biomonitoring index period. If no biological monitoring is planned or needed at a particular site, physical habitat surveys may be conducted during baseflow conditions after snowmelt runoff and prior to the monsoon season (generally mid-May through early-July), or late- fall to early-winter depending on location and weather patterns. However, physical habitat surveys that include canopy cover measurements and have deciduous trees present should be performed before leaves fall which further restricts the survey season. Excessive sedimentation noted following wildfire will be documented in assessment comments and may be assessed for a sedimentation impairment on a case-by-case basis. Data collected during or immediately after fires, floods, extreme drought, or other catastrophic events are generally not used to make attainment decisions because such data are not representative of ambient conditions, however, data collected after the initial impacts of the event have passed (>4 weeks) may be assessed because it can be considered indicative of ambient conditions thereafter. See Main CALM section 2.1.8 "Non-representative data" for more information.

The %SaFN is calculated onsite based on the 105-particle count and recorded on the appropriate field sampling sheet. The %SaFN is an appropriate sediment indicator because it is essentially equivalent to New Mexico's definition of "…fine sediment particles (less than two millimeters in diameter) …" found at 20.6.4.13 NMAC. In a slight deviation from 20.6.4.13 NMAC, this listing methodology includes particles that are less than or equal to 2mm in diameter (Table 3), to be conservative and to match EPA's definition and TetraTech, Inc.'s analyses (Peck et al. 2006, Jessup et al. 2010).

Table 3. Percent Sand & Fines (Level 1) thresholds

Site Class	Measured % Sand & Fines	Number of particles ≤ 2mm diameter based on a 105-particle count
Mountain	< 20% Sand & Fines	< 21 particles
Foothill	< 37% Sand & Fines	< 39 particles
Xeric	< 74% Sand & Fines	< 78 particles

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Level 1 Analysis & Interpretation

If the measured %SaFN is less than the applicable site class threshold in Table 3, the sediment assessment is complete, and the assessment unit is considered to be **Full Support** with respect to New Mexico's narrative sedimentation/siltation standard found at 20.6.4.13 NMAC. If the measured %SaFN is greater than or equal to the applicable site class threshold in Table 3, the assessment is inconclusive and the assessment proceeds to Level 2.

2.2 Level 2 Sedimentation Assessment

Data collected from the sedimentation survey or equivalent (e.g., cross section profile, thalweg profile, large woody debris, slope, and sediment size) are used to calculate LRBS_NOR. Because fluvial conditions are major determinants of the substrate conditions in stream channels, the critical particle size calculated from fluvial characteristics is a predictor of dominant and stable substrate conditions. In essence, the LRBS_NOR calculation is used to predict the expected sediment particle size that would be moved during a bankfull flow event. This expected or "critical" particle size is calculated from channel dimensions, roughness factors, and shear stresses (Kaufmann et al. 2008). The logarithm ratio of the measured particle size to the expected particle size is a measure of the relative stability of the stream bed.

In minimally disturbed streams, the measured geometric mean stream bottom particle size should trend towards the expected particle size (i.e., the size a stream is capable of moving as bedload at bankfull flows). Thus, LRBS_NOR values near zero indicate a stable stream bed, whereas increasingly negative values indicate excess fine sediment. For example, a LRBS_NOR value of -1 means that the measured geometric mean bedded sediment particle size is ten times (10X) finer than the expected particle size that would be moved during bankfull flow events. Calculated LRBS values less than -3 indicate that the bed substrate may be moving even during low flow events.

LRBS_NOR was selected as a sediment impairment indicator because this measure considers only the potentially mobile streambed particles in determining the geometric mean particle size and produces improved associations between the bedded sediment measure and biological responses when compared to the LRBS calculated with bedrock (Jessup et al. 2010). LRBS_NOR threshold values by site class are listed in Table 4.

Table 4. LRBS_NOR (Level 2) thresholds

Site Class	LRBS_NOR Units
Mountain	> -1.1
Foothill	> -1.3
Xeric	> -2.5

Level 2 Analysis & Interpretation

If the calculated LRBS_NOR is greater than the applicable site class threshold in Table 4, the assessment unit is regarded as **Full Support** with respect to New Mexico's narrative sedimentation/siltation standard found at 20.6.4.13 NMAC. If the calculated LRBS_NOR is less than or equal to the applicable site class threshold, the assessment unit is considered **Non Support**.

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REVISION HISTORY:

2012 listing cycle – Protocol was substantially revised based on Jessup et al. (2010).

2014 listing cycle – Minor clarifications and re-formatting.

2016 listing cycle – Minor clarifications.

2018 listing cycle – "Assessment Protocol" changed to "Listing Methodology." Clarified application of Heins et al. 2004 study to waters in the San Juan River basin. Clarified potential re-assignment and documentation of sediment site class for a particular site.

2020 listing cycle – Minor clarifications.

2022 listing cycle – **Pre-Public Comment:** Removed reference to Level 1 and 2 sedimentation surveys (to align with current SOP) and added clarification that Level 1 and 2 are still steps in the assessment procedure; Updated figure 2 to reflect this. Note about delisting added. Minor clarifications and rewording throughout. **Post-Public Comment:** No changes.

2024 listing cycle – Pre-Public Comment: Added a note about sedimentation assessment following wildfires in section 2.1. **Post-Public Comment:** No changes.

2026 listing cycle – Pre-Public Comment: Provided clarification on hybrid approach to assessing sedimentation in non-wadeable rivers. Revised the note about sedimentation assessment following wildfires in section 2.1. **Post-Public Comment:** No changes.

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Recreational Use Analysis

for

Classified Waters 20.6.4.101-20.6.4.899 NMAC

with Secondary Contact

Prepared by:

Surface Water Quality Bureau

New Mexico Environment Department

July 21, 2026

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I. Introduction

The objective of the Clean Water Act (CWA) is to restore and maintain the chemical, physical and biological integrity of the Nation's waters. One of the goals established under the CWA to achieve this objective is to ensure that wherever attainable, water quality provides for 1) the protection and propagation of fish, shellfish and wildlife (aquatic life) and 2) the ability to recreate in and on the water. This Recreational Use Analysis focuses on the second part of this goal.

II. Regulatory Authority and Framework

The CWA implements the measures necessary to achieve this goal through 40 Code of Federal Regulations (CFR) which, in part, requires states to uphold these goals through the adoption of surface Water Quality Standards (WQS). In accordance with 40 C.F.R. § 131.6, these WQS contain, at a minimum, the designated uses for waterbodies, the surface water quality criteria to protect those uses, and an antidegradation policy to ensure the water quality is maintained. The State of New Mexico has codified its WQS under *Standards for Interstate and Intrastate Surface Waters* (20.6.4 NMAC) but recognizes that water quality protection is ongoing and protections for waters may change over time.

The goals and objectives of the CWA, as established in Section 101(a), are to restore and maintain the chemical, physical and biological integrity of the Nations waters; and wherever attainable, to protect for the propagation of fish, shellfish and wildlife, and provide for recreation in and on the water. The CWA requires states to adopt WQS under 40 C.F.R. § 131.4 to achieve these goals and objectives.

The basic authority for water quality management in New Mexico is provided through the Water Quality Act (NMSA 1978, §§ 74-6-1 to 74-6-17). This law establishes the Water Quality Control Commission (WQCC) and specifies its duties and powers. The WQCC is the State's water pollution control agency for all purposes of the federal Clean Water Act (NMSA 1978, § 74-6-3(E)). Under Section 74-6-4(D), the Water Quality Act requires the WQCC to adopt WQS based on credible scientific data and reliable evidence. New Mexico's *Standards for Interstate and Intrastate Surface Waters* (20.6.4 NMAC) establish surface WQS that consist of designated uses for surface waters of the State, the water quality criteria necessary to protect the designated uses, and an antidegradation policy.

Water quality standards must contain three key elements that are intricate to their regulatory function. These include establishing designated uses, criteria to protect those uses and an antidegradation policy. These requirements uphold the objective of the CWA (Section 101 of the CWA) to "restore and maintain the chemical, physical and biological integrity of the Nation's waters."

40 C.F.R. § 131.20 State review and revision of water quality standards.
***(a)* State review.** *The State shall from time to time, but at least once every 3 years, hold public hearings for the purpose of reviewing applicable water quality standards... The State shall also re-examine any waterbody segment with water quality standards that do not include the uses specified in section 101(a)(2) of the Act every 3 years to determine if any new information has become available. If such new information indicates that the uses specified in section 101(a)(2) of the Act are attainable, the State shall revise its standards accordingly…*

Unlike the requirements for removing or lowering a designated use under 40 C.F.R. § 131.10(g), a Use Attainability Analysis (UAA) is not required for revising standards to reflect the highest attainable use. Therefore, this analysis intends to provide the supporting evidence needed to determine if a designated use change from Secondary Contact to Primary Contact is warranted based on available data and supporting information for the eleven classified segments currently designated as Secondary Contact in 20.6.4.101- 20.6.4.899 NMAC.

III. Analysis Framework

A. Reasoning for Analysis

There are two subcategories for designated recreational uses in 20.6.4 NMAC: primary contact and secondary contact as defined under 20.6.4.7(P)(5) NMAC and 20.6.4.7(S)(1) NMAC, respectively. The numeric criteria for primary and secondary contact recreational uses are established in 20.6.4.900(D) NMAC and 20.6.4.900(E) NMAC, respectively. Both primary and secondary contact have criteria for *Escherichia coli* (*E. coli*). In addition, primary contact has pH, microcystin, and cylindrospermopsin criteria.

B. Waterbodies Evaluated

There are currently eleven classified standards segments under 20.6.4 NMAC with secondary contact designated uses (specifically in Sections 103, 124, 126, 128, 140, 141, 206, 213, 219, 308, and 809). Eight of these segments remain classified under secondary contact for the following reasons along with additional information that has been presented and debated during previous triennial reviews and related use attainability analyses:

- NMED does not have and could not locate any readily available *E. coli* and pH data for waterbodies covered by segment 103 to propose a Recreational Use change from secondary to primary contact.

- Segment 124 contains site-specific criteria where the naturally occurring pH range of 2.0 to 9.0 is outside the primary contact criteria range of 6.6 to 9.0.
- Segments 126, 128, 140, and 141 cover waters with restricted human access within the Los Alamos National Laboratory boundary where there is no risk of considerable ingestion, immersion, or ceremonial use.
- Segment 213 covers McAllister Lake. This natural playa lake was McAllister Lake was purchased in 1962 to provide fishing access and winter habitat for waterfowl. The New Mexico Department of Wildlife (NMDOW) manages these lakes as part of the Charette Lakes Wildlife Area. It was filled and maintain as a fishery prior to 2007. Per the) has not stocked McAllister Lake since 2007 due to lack of water and reoccurring issues with golden algae. In recent years, the lake has no longer been irrigated due to an issue with the water source and related pumps and only held water temporarily in response to precipitation events. In early 2026, the pumps were fixed and the NMDOW requested refilling and with the intention of investigating stocking scenarios if the lake conditions and water quality remain suitable. If NMDOW determines that water quality can remain suitable throughout the year, they may investigate warmwater species that could provide a year-round fishery. If water quality is unstable and water supply uncertain, stocking may be limited to trout in winter. The future of McAllister Lake's ability to meet CWA fishable/swimmable goals remains uncertain as NMDOW will not have any 10-year plan for the lake until they complete their study.
- Sections 809 covers ephemeral waters with restricted human access within Chino mines property where there is no risk of considerable ingestion, immersion, or ceremonial use.

IV. Recreational Use Evaluation

A. Designated Use and Criteria Evaluated

Both primary and secondary contact recreational uses have *E. coli* criteria, expressed as cfu or MPN per 100 mL. Either cfu or MPN may be used for purposes of evaluation of recreational uses, as described in 20.6.4.900(D) and 20.6.4.900(E) NMAC. Per 20.6.4.900(D) NMAC, to attain primary contact criteria, the pH must be within a range of 6.6 to 9.0 and *E. coli* must not exceed the monthly geometric mean criteron of 126 cfu/100 mL or exceed the single sample criterion of 410 cfu/100 mL. Although NMAC now also contains water quality criteria for microcystins and cylindrospermopsin for primary contact use, data for these parameters remains very limited and is only available for a small number of lakes currently. According to 20.6.4.900(E) NMAC, to attain secondary contact *E. coli* must not exceed the geometric mean criterion of 548 cfu/100 mL or exceed the single sample criterion of 2507 cfu/100 mL.

SWQB collated and evaluated available *E. coli* and pH data and supporting information for waterbodies with a secondary contact designation for waters under 20.6.4.206, 20.6.4.219, and 20.6.4.308 NMAC to determine whether a change to the designated use is warranted.

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B. Data Used for Evaluation

A search for historical data older than 2009 was conducted by querying validated SWQB datasets in archived folders on the Department's shared server. SWQB collects water quality data pursuant to the most recent, EPA-approved *Quality Assurance Project Plan for Water Quality Management Programs* (QAPP) and Standard Operating Procedures (SOPs)[1], which are incorporated into the QAPP by reference.[2] In addition, SWQB has a Quality Management Plan (QMP) that is updated annually and describes SWQB's quality system for planning, implementing, documenting, and assessing the effectiveness of activities supporting environmental data operations. Accordingly, relevant and applicable *E. coli* and pH data collected by SWQB are defensible and appropriate for purposes of this review.

Any data collected since 2010 were acquired through the SWQB's Surface water Quality Information Database (SQUID). Archived and SQUID *E.coli* and pH data were collated for the WQS segments under review. Each WQS segment may contain one or several Assessment Units (AU), or stream reaches. Each AU generally contains at least one sampling station that is associated with both an AU ID and a sampling station ID. Accordingly, a waterbody segment as described under NMAC, may have one or more AUs with one or more sampling stations. available *E. coli* and pH water quality data for the three AUs reviewed can be found in Appendix A.

SWQB does not specifically monitor or gather information on recreational use demonstrating full immersion, such as swimming and wading. However, any available visitor brochures and recreational websites encouraging popular recreational activities, such as swimming, kayaking, paddleboarding, and wading were evaluated as part of this review.

A. Methods and initial evaluation

Historical datasets were acquired for each WQS segment under review with associated *E. coli* and pH data. Any waterbodies that did not contain both pH and *E. coli* data were excluded from the analysis and are not included in the proposed recreational use amendment. The listings of each waterbody with its associated WQS, AU ID, name of the AU and whether pH and *E.coli* data were available for each waterbody is summarized under Table 1.

[1] Available at https://www.env.nm.gov/surface-water-quality/sop/.
[2] Available at https://www.env.nm.gov/surface-water-quality/protocols-and-planning/.

Table 1. *Summary of Segments and Assessment Units (AU) with available E.coli and pH data.*

Current WQS	Proposed WQS	AU ID	AU NAME	pH and *E. coli* data available?
20.6.4.206		NM-2206.A_33	Rio Felix (Perennial prt abv Old School rd to Lincoln Cyn)	No data
20.6.4.206		NM-2206.A_31	Rio Felix (Intermittent reaches abv Hagerman Canal)	No data
20.6.4.206	20.6.4.231	NM-2208_11	Berrendo Creek (Rio Hondo to Middle Berrendo Creek)	Yes
20.6.4.219		NM-2204.B_00	Avalon Reservoir	Yes
20.6.4.308		NM-2305.5_10	Charette Lake (Lower)	Yes
20.6.4.308		NM-2305.5_20	Charette Lake (Upper)	No data

NMED evaluated the dataset to determine which of the waterbodies meet the primary contact pH range of 6.6 to 9.0. NMED also reviewed the *E. coli* data, focusing on the single grab criterion because the number of samples necessary to calculate a monthly geometric mean were not available. NMED compared the dataset to the primary contact single sample *E. coli* criterion of 410 cfu/100mL. If a segment under review achieves the primary contact criterion, then the waterbody should be able to support primary contact recreation. Alternatively, if the *E. coli* single sample results for a waterbody segment are all greater than 410 cfu/100 mL, then NMED determined that the waterbody's existing use is appropriately designated under secondary contact.

D. Data Review Summary

Table 2 is a summary of findings, which confirms that the AUs with available data achieve the pH and *E. coli* criteria for primary contact. It should be noted that exceedances are not an indication that the primary contact recreation use is not attainable. The data clearly show that water quality in these AUs attain *E. coli* criterion designated to protect primary contact recreation.

Table 2. *Summary of Assessment Unit ("AU") as it pertains to attaining primary contact.*

WQS Segment	AU Name	pH range within 6.6 to 9.0?	# samples ≤ 410 cfu/100 mL over total samples	Primary contact criteria attained?	% > 410 cfu/ 100 mL
20.6.4.206	Berrendo Creek (Rio Hondo to Middle Berrendo Creek)	YES	5/6	YES	16%
20.6.4.219	Avalon Reservoir	YES	8/8	YES	0%
20.6.4.308	Charette Lake (Lower)	YES	6/6	YES	0%

V. Conclusions

NMED conducted a Recreational Use Analysis to determine if a recreational use change was warranted for WQS segments with Secondary Contact. Three WQS segments were analyzed that had least one sampling event with both pH and *E. coli* data were analyzed and recommended for a designated use change. SWQB determined that for the appropriate waterbodies all pH data values ranged from 6.6 to 9.0, thus meeting the criterion for primary contact. In addition, all available *E. coli* data contained more than one sample event that fell at or below 410 cfu/100 mL, thus meeting the single sample criterion for primary contact.

As a result of this analysis, SWQB recommends the following amendments the segment descriptions below and associated recreational designated uses in 20.6.4 NMAC:

20.6.4.206 PECOS RIVER BASIN: Perennial reaches of the Rio Felix[~~ and perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon, excluding North Spring river~~].

A. Designated uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

20.6.4.219 PECOS RIVER BASIN: Avalon reservoir.

A. Designated uses: irrigation storage, livestock watering, wildlife habitat, [~~secondary~~] primary contact and warmwater aquatic life.

20.6.4.231 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from [~~state highway 24 near Dunken~~]Big Cherry Canyon, [~~perennial reaches of North Spring river and~~]perennial reaches of the Rio Hondo and perennial reaches of its tributaries downstream of Bonney canyon.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

20.6.4.308 CANADIAN RIVER BASIN: Charette lakes.

A. Designated uses: coldwater aquatic life, warmwater aquatic life, secondary contact, livestock watering~~, [and]~~ wildlife habitat; and primary contact on Lower Charette lake.

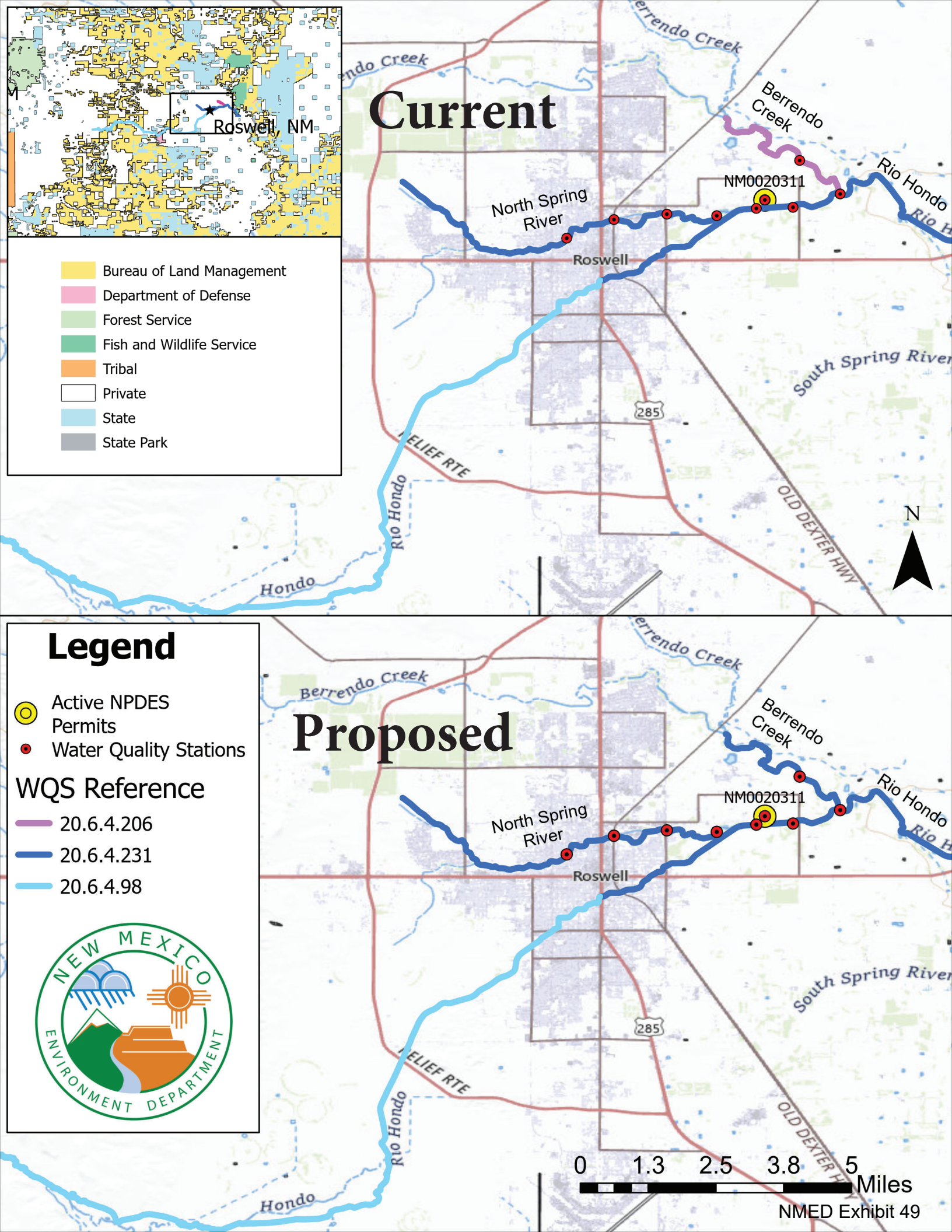
Appendix A

E.coli and pH data from sampling stations relevant to Berrendo Creek (20.6.4.206), Avalon Reservoir (20.6.4.219 NMAC), and Charette Lakes (20.6.4.308 NMAC)

AU ID	AU NAME	STATION_ID	SAMPLE DATE	PARAMETER	VALUE	UNIT
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	3/4/2026	E. coli	75.9	MPN/100ml
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	3/4/2026	E. coli	29.9	MPN/100ml
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	8/5/2025	E. coli	1.0	MPN/100ml
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	8/5/2025	E. coli	3.1	MPN/100ml
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	9/2/2025	E. coli	13.4	MPN/100ml
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	9/2/2025	E. coli	26.5	MPN/100ml
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	10/7/2025	E. coli	8.6	MPN/100ml
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	10/7/2025	E. coli	4.1	MPN/100ml
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	3/4/2026	pH	8.1	None
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	3/4/2026	pH	8.1	None
NM-2204.B_00	Avalon Reservoir	60AvalonBRrec	7/14/2026	pH	8.4	None
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	8/5/2025	pH	8.1	None
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	8/5/2025	pH	8.0	None
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	9/2/2025	pH	8.3	None
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	9/2/2025	pH	7.5	None
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	10/7/2025	pH	8.1	None
NM-2204.B_00	Avalon Reservoir	60AvalonInlet	10/7/2025	pH	8.2	None
NM-2208_11	Berrendo Creek (Rio Hondo to Middle Berrendo Creek)	57Berren001.7	3/16/2022	E. coli	6.3	MPN/100ml
NM-2208_11	Berrendo Creek (Rio Hondo to Middle Berrendo Creek)	57Berren001.7	5/5/2022	E. coli	12.0	MPN/100ml

AU ID	AU NAME	STATION_ID	SAMPLE DATE	PARAMETER	VALUE	UNIT
NM-2208_11	Berrendo Creek (Rio Hondo to Middle Berrendo Creek)	57Berren001.7	5/11/2021	E. coli	5.2	MPN/100ml
NM-2208_11	Berrendo Creek (Rio Hondo to Middle Berrendo Creek)	57Berren001.7	7/20/2021	E. coli	13.4	MPN/100ml
NM-2208_11	Berrendo Creek (Rio Hondo to Middle Berrendo Creek)	57Berren001.7	9/14/2022	E. coli	866.4	MPN/100ml
NM-2208_11	Berrendo Creek (Rio Hondo to Middle Berrendo Creek)	57Berren001.7	10/27/2022	E. coli	17.3	MPN/100ml
NM-2208_11	Berrendo Creek (Rio Hondo to Middle Berrendo Creek)	57Berren001.7	3/16/2022	pH	7.8	None
NM-2208_11	Berrendo Creek (Rio Hondo to Middle Berrendo Creek)	57Berren001.7	5/5/2022	pH	7.9	None
NM-2208_11	Berrendo Creek (Rio Hondo to Middle Berrendo Creek)	57Berren001.7	5/11/2021	pH	8.0	None
NM-2208_11	Berrendo Creek (Rio Hondo to Middle Berrendo Creek)	57Berren001.7	7/20/2021	pH	7.8	None
NM-2208_11	Berrendo Creek (Rio Hondo to Middle Berrendo Creek)	57Berren001.7	9/14/2022	pH	8.2	None
NM-2208_11	Berrendo Creek (Rio Hondo to Middle Berrendo Creek)	57Berren001.7	10/27/2022	pH	8.0	None
NM-2305.5_10	Charette Lake (Lower)	06LoCharetteD	6/17/2025	E. coli	1.0	MPN/100ml
NM-2305.5_10	Charette Lake (Lower)	06LoCharInlet	6/17/2025	E. coli	3.1	MPN/100ml
NM-2305.5_10	Charette Lake (Lower)	06LoCharInlet	7/17/2025	E. coli	6.2	MPN/100ml
NM-2305.5_10	Charette Lake (Lower)	06LoCharInlet	8/27/2025	E. coli	34.1	MPN/100ml
NM-2305.5_10	Charette Lake (Lower)	06LoCharetteD	8/27/2025	E. coli	12.2	MPN/100ml
NM-2305.5_10	Charette Lake (Lower)	06LoCharInlet	9/9/2025	E. coli	1.0	MPN/100ml
NM-2305.5_10	Charette Lake (Lower)	06LoCharInlet	6/17/2025	pH	8.4	None
NM-2305.5_10	Charette Lake (Lower)	06LoCharetteD	6/17/2025	pH	8.9	None
NM-2305.5_10	Charette Lake (Lower)	06LoCharInlet	7/17/2025	pH	8.7	None

AU ID	AU NAME	STATION_ID	SAMPLE DATE	PARAMETER	VALUE	UNIT
NM-2305.5_10	Charette Lake (Lower)	06LoCharInlet	8/27/2025	pH	8.2	None
NM-2305.5_10	Charette Lake (Lower)	06LoCharetteD	8/27/2025	pH	8.8	None
NM-2305.5_10	Charette Lake (Lower)	06LoCharInlet	9/9/2025	pH	8.5	None



NMED Exhibit 49

STATE OF NEW MEXICO
WATER QUALITY CONTROL COMMISSION

IN THE MATTER OF:

PETITION FOR REGULATORY CHANGE TO
ADOPT AMENDMENTS TO 20.6.4 NMAC –
Standards For Interstate and Intrastate Surface Waters **WQCC 25-75 (R)**

DIRECT TECHNICAL TESTIMONY OF EMILY E. MILLER

I. INTRODUCTION

My name is Emily Miller, and I am presenting this written testimony (**NMED Exhibit 50**) on behalf of the New Mexico Environment Department (Department or NMED) Surface Water Quality Bureau (SWQB) concerning the Department's proposed amendments to the State of New Mexico's *Standards for Interstate and Intrastate Surface Waters* (Standards), codified as Title 20, Chapter 6, Part 4 of the New Mexico Administrative Code (20.6.4 NMAC). The Department is proposing these amendments in accordance with NMSA 1978, Section 74-6-6, 20.1.6 NMAC, and 40 Code of Federal Regulations (C.F.R.) Section 131.20, in what is referred to as the State's "Triennial Review." My testimony describes the rationale and provides supporting evidence for the following proposed changes:

- Amend 20.6.4.502 and 503 NMAC in the Gila River Basin,
- Amend 20.6.4.601 NMAC to in the San Francisco River Basin, and
- Amend 20.6.4.601 and 20.6.4.602 NMAC to describe the water quality segment breaks by hydrologic feature rather than road crossing and remove unnecessary language.

II. QUALIFICATIONS

I am currently employed by the NMED SWQB Monitoring and Standards Section (MASS) as a Quality Assurance Officer and have held this position since June 2024. I am responsible for

implementing the Quality Assurance (QA) program within the SWQB. In this position I ensure that data collection activities conducted or managed by the Bureau are planned, reviewed, operated, and managed in a manner consistent with defined QA requirements in order for the resulting environmental information to be fit for purpose. I often review QA plans and resulting data to assess against these requirements, our state water quality standards, and federal guidance and work with internal staff and external cooperators to produce high quality products and services. I also periodically assist with water quality monitoring surveys and developing or revising water quality standards.

I hold a Bachelor of Science degree in Marine Sciences from the University of Maine with a concentration in Oceanography. I defended an undergraduate thesis focusing on estimating Antarctic iceberg melt rate through remote sensing techniques and the relationship between melt rate and modeled ocean temperatures.

Prior to working at NMED, I worked for the Maine Department of Marine Resources as a shellfish and biotoxin specialist conducting intertidal surveys along the coast of Maine. Most recently, I worked at Columbia University's Lamont-Doherty Earth Observatory as a Senior Research Assistant from January 2020 to May 2024. While at LDEO I worked closely with the University-National Oceanographic Laboratory System research vessels managing their underway data systems. This included collection, manipulation, and documentation of their data and metadata collected at sea, as well as collaborating with the greater oceanographic community to improve data accessibility. An accurate and up-to-date copy of my resume is included as **NMED Exhibit 51**.

III. AMENDMENTS ASSOCIATED WITH DESIGNATED USES

A. Amendments to 20.6.4.502 and 503 NMAC in the Gila River Basin

The Department proposes the removal of the warmwater aquatic life use (WWAL) from 20.6.4.502 NMAC and to lower the segment-specific temperature criterion for 20.6.4.503 NMAC from 32.2°C (90°F) to 29°C (84°F). This proposal is based on a comprehensive evaluation that included analysis of existing fisheries data, thermograph records, air-water temperature correlation (AWTC) modeling, and recreational fishing information.

1. Background on Aquatic Life Designated Use, subcategories, and criteria

The federal Clean Water Act (CWA) requires states and tribal nations to adopt Water Quality Standards (WQS) to protect aquatic life, wildlife, and primary contact uses (i.e., swimmable/fishable) where attainable for waters under their jurisdiction. The CWA and its WQS implementing regulations at 40 C.F.R. § 131 allow states flexibility when assigning designated uses to waterbodies, including the ability to create subcategories of designated uses to further define uses and refine criteria to protect those uses. The WQS at 20.6.4.900 NMAC provides seven subcategories of designated uses and associated criteria for the protection of aquatic life including high quality coldwater, coldwater, marginal coldwater, coolwater, warmwater, marginal warmwater, and limited aquatic life.

Surface waters of the state with a designated, existing, or attainable aquatic life use must remain free of substances at concentrations capable of impairing biological communities or the broader ecological integrity of those waters. Except where otherwise specified, the acute and chronic aquatic life criteria in Subsections I, J, K, and L, as well as the human health organism only criteria in Subsection J, apply universally to all aquatic life subcategories. These aquatic life uses encompass a range of thermal and habitat conditions, from minimally disturbed, high value

coldwater systems to waters where natural constraints limit the ability to support aquatic populations on a continuous basis.

In reference to aquatic life per the definitions in 20.6.4.7 NMAC, high quality coldwater aquatic life (HQCWAL) means a perennial water characterized by minimally disturbed conditions, exceptional aesthetic value, and superior habitat capable of supporting and maintaining a propagating coldwater aquatic life community. Coldwater aquatic life (CWAL) means a surface water where temperature and associated chemical and physical attributes are suitable to support, or support and propagate, coldwater organisms. Marginal coldwater aquatic life (MCWAL) is assigned to waters where natural habitat conditions substantially limit coldwater populations during at least part of the year, or where historical information shows that temperatures may periodically exceed levels required to continuously support coldwater species. These distinctions ensure that the designated use reflects the inherent capacity of the system rather than hydrologic condition alone.

All aquatic life use subcategories have a maximum temperature criterion with the exception of limited aquatic life in 20.6.4.900(H) NMAC. The "maximum temperature" is defined in 20.6.4.7 NMAC as the maximum instantaneous temperature unless otherwise identified in a segment-specific temperature criterion. The Department has also established chronic temperature criteria expressed as 4T3 for the protection of HQCWAL, and 6T3 for the protection of HQCWAL, CWAL, and MCWAL uses. The values were developed as sublethal criteria and are intended to protect fish from temperatures that may impact long-term survival, growth, and reproduction. The 4T3 temperature represents the level not to be exceeded for four or more consecutive hours within a 24-hour period on more than three consecutive days, and the 6T3 temperature applies the same

concept using a six-hour duration. Continuous temperature records are required to calculate measured 4T3 or 6T3 values. Where a single segment-specific temperature criterion is indicated in 20.6.4.101-.899 NMAC, it is the maximum temperature and no 4T3 or 6T3 temperature applies.

HQCWAL criteria are defined by strict temperature limits, including a maximum of 23°C and a 4T3 temperature of 20°C. CWAL criteria follow similar thresholds, with a maximum of 24°C and a 6T3 temperature of 20°C. Marginal coldwater uses apply where conditions allow slightly higher temperatures, with a maximum of 29°C and a 6T3 limit of 25°C. Coolwater uses apply to waters that support species with thermal tolerances between those of coldwater and warmwater organisms and must stay below a maximum temperature of 29°C. Warmwater uses apply where temperatures support warmwater communities, with an upper limit of 32.2°C. Marginal warmwater uses apply where natural conditions—such as intermittent or low flows—limit year-round aquatic life, and temperatures may regularly exceed 32.2°C.

2. Designated Use Verifications

Designated Use Verifications (DUVs) were conducted in response to concerns that certain aquatic life use designations in the Greater Gila River Basin may not reflect actual, attainable conditions. Following a comprehensive review of historic and contemporary water temperature data, air water temperature correlation modeling outputs, and fisheries assemblage data, the Department has determined that only two categories of changes are warranted based on available data: reduced segment-specific temperature and removal of the less protective aquatic life use where there are dual designations.

Several surface waters in 20.6.4 NMAC are assigned more than one aquatic life designated use. When a waterbody has dual aquatic life uses —such as both MCWAL and WWAL—the Department is required under 20.6.4.11(F) NMAC and 40 C.F.R. § 131.11(a)(1) to apply the most

protective criteria among those uses. In practice, this only impacts parameters in 20.6.4.900(H) NMAC, such as temperature, dissolved oxygen, and pH, and narrative parameters with numeric assessment thresholds because the criteria in 20.6.4.900(I)-(L) NMAC universally apply to all aquatic life uses except for the Limited Aquatic Life exceptions noted in 20.6.4.900(H) NMAC. A waterbody cannot be considered fully supporting its aquatic life use unless it meets the highest level of protection associated with its assigned designated uses. This approach ensures that more sensitive aquatic communities—particularly those dependent on cooler temperatures or higher dissolved oxygen—are protected. A Use Attainability Analysis (UAA) is not required for the removal of a less stringent dual designated aquatic life use because retention of the higher aquatic life use retains the more stringent criteria, but amendments to WQS must be based on credible scientific data and other evidence. NMSA 1978, § 74-6-4(D).

The Department proposes to remove the less stringent dual aquatic life use designations in 20.6.4.502 NMAC and 20.6.4.601 NMAC to improve regulatory clarity. Because the most protective use and criterion is applied in all cases, the less stringent criteria associated with a lower aquatic life use is not used to determine compliance with the WQS or aquatic life use attainment. Therefore, eliminating the dual aquatic life use designations will not reduce environmental protection.

3. Data sources, modeling tools, and methods

The datasets utilized to support these determinations include water temperature records collected by the SWQB, air water temperature correlation outputs generated using the Parameter elevation Regressions on Independent Slopes Model (PRISM), and long-term annual fish monitoring data compiled by the New Mexico Department of Wildlife (NMDOW) for the Gila

River Basin. While analyzing the available data, the Department focused on those WQS segments that had fisheries data present to accurately evaluate the aquatic assemblage of these reaches.

The term "segment" is formally defined in 20.6.4.7(S)(2) NMAC as "a classified water of the state described in 20.6.4.101 through 20.6.4.899 NMAC. The water within a segment should have the same uses, similar hydrologic characteristics or flow regimes, and natural physical, chemical and biological characteristics and exhibit similar reactions to external stresses, such as the discharge of pollutants." SWQB generally organizes water quality monitoring and CWA § 303(d)/§ 305(b) reporting in streams and rivers by defining several assessment units (i.e., stream reaches) within each segment. Water temperature data collected by the SWQB are obtained in accordance with the Bureau's established Standard Operating Procedures (SOPs) and are subjected to internal Quality Assurance/Quality Control review, followed by formal verification and validation, to ensure the data are appropriate, reliable, defensible, and of sufficient quality for their intended regulatory and scientific applications. SWQB assesses verified and validated data to determine designated use attainment that is reported biannually in the CWA § 303(d)/§ 305(b) Integrated Report. Assessment methodologies, along with the SOPs, which describe the Bureau's standardized methods and quality assurance framework, are publicly available through the SWQB website[1].

The *Air–Water Temperature Correlation* analysis developed by the SWQB provides a defensible basis for supporting the determination of naturally attainable stream temperatures across the state (**NMED Exhibit 52**). Drawing on long-term thermograph records between 1981-2010 from approximately 300 monitoring locations, coupled with validated July average air temperature

[1] https://www.env.nm.gov/surface-water-quality/monitoring-assessment-and-standards-section/

data from the PRISM model, the study demonstrates a consistent 1:1 relationship between maximum weekly average water temperature and ambient air temperature for streams not significantly influenced by groundwater or microclimate effects. This data source has been suitable for supporting DUVs and related testimony and exhibits on attainable temperature-based criteria and has been utilized as supporting evidence in previous rulemakings. However, it is important to note that the input PRISM data is at 800m resolution which would be defined as coarse given that the cross section of most streams and rivers in New Mexico is sub-grid scale. Because of this, it was considered in the overall data review of available data for the proposed changes but not necessarily relied upon as a primary piece of evidence. The resulting data are stored as a GIS layer, which can be found on the SWQB's OpenEnviroMap[2]. The layer is made of individual polylines that store the modeled July Average Air Temperatures (ATEMP), Maximum Instantaneous Temperature (TMAX), 4T3, and 6T3. There are many individual polylines that comprise a stream reach, therefore the values for those polylines were averaged to get values that are representative of the entire reach.

The NMDOW's Gila River Basin Annual Fall Monitoring fisheries dataset represents a robust, long term scientific record suitable for use as a defensible data source in regulatory and ecological assessments. NMDOW and their partners have conducted annual standardized sampling at nine permanent sites across the basin and beyond since 1988, employing consistent multimethod fish collection and habitat characterization protocols to ensure comparability over time. The monitoring effort documents species presence, density, and population trends for both native and nonnative fishes and incorporates detailed habitat measurements and repeated surveys conducted

[2] https://gis.web.env.nm.gov/oem/?map=swqb

even through major disturbance events such as wildfire, flooding, ash flows, and hydrologic disruption. These data reveal biologically meaningful patterns—including species recolonization, density shifts, and recruitment signals. Because the dataset spans more than three decades, encompasses multiple hydrologic and ecological regimes, and integrates consistent methodologies across diverse sites, it provides a rigorous, credible, and scientifically comprehensive foundation for evaluating long term population trajectories, informing management actions, and supporting technical testimony related to aquatic life conditions in the Gila River Basin. This dataset includes 88,791 fish from 22 unique species collected between 1988 and 2024 by NMDOW and partners. The data are stored in the Department of Wildlife's internal database.

New Mexico's aquatic life uses, and associated criteria protect the aquatic community, including fish, based on habitat requirements that include temperature. Fish community data are a critical line of evidence for determining whether a designated aquatic life use is attainable under natural thermal conditions. The Department classified species into thermal guilds, i.e., coldwater, warmwater, or transitional (warm/coldwater transition), using designations provided by the State of New Mexico's Biota Information System of New Mexico (BISON) database (**NMED Exhibit 53**). Because BISON classifications are derived directly from New Mexico's WQS by NMDOW, they provide a regulatorily aligned and methodologically consistent basis for thermal categorization. Although the median lethal temperature (LT_{50}) values were initially reviewed to assess thermal tolerance, substantial variability in experimental design—including differences in acclimation periods and genetic lineages—precluded their use for reliable cross-species comparison. Accordingly, the BISON classifications were determined to be the most scientifically defensible and appropriate method for assigning thermal categories in this context. The

Department evaluated the relative proportions of thermal guilds to determine the dominant guild in each segment.

To evaluate whether segments are supporting propagation of fish, as required by CWA Section 101(a)(2) and necessary to determine the applicable aquatic life use as defined in 20.6.4.7 NMAC, the Department assessed recruitment using length-frequency distributions. Recruitment is the process by which larvae are produced and survive to enter the reproducing population. When a population is reproducing and successfully recruiting, histograms of total lengths show individuals across size bins, including smaller size-classes representing young-of-year fish.

4. Data Review for 20.6.4.502 NMAC

This WQS segment includes reaches of the Gila River, Bear Creek, Mangas Creek, and Blue Creek within the Upper Gila and Upper Gila-Mangas basins (**NMED Exhibit 54**). This segment currently has both MCWAL and WWAL designated uses with a segment-specific temperature criterion of 28°C (82.4°F) or less.

The Department analyzed three NMDOW fish collection stations throughout the segment for this DUV, along with recreational fishing information, and museum records of species presence obtained from the Arctos database[3], an online management information system and provider of research-grade data from natural and cultural history collections. An assessment of fish assemblage data from the three NMDOW collection sites within this WQS segment (Iron Bridge, Cherokee Canyon, and Ash Canyon) shows a community dominated by transitional species with coldwater species present throughout the study period. Longitudinal comparison of fisheries datasets indicates an increased proportion of coldwater species from the 1980s through the 2020s. Length

[3] https://arctos.database.museum/

frequency data further demonstrate successful propagation of both coldwater and transitional fishes throughout the segment. In addition, propagation of small-bodied nonnative warmwater species was documented in recent decades (**NMED Exhibit 53**). Recreational fishing records indicate that all thermal guilds are represented by sportfish including coldwater (Gila trout, rainbow trout), transitional (smallmouth bass), and warmwater species (channel catfish, flathead catfish).

The Department reviewed AWTC-modeled water temperature data and nine SWQB thermograph datasets collected for this WQS segment by the SWQB in 2007, 2011, 2019, and 2020 at long-term monitoring stations (**NMED Exhibit 55**). These datasets either predicted or recorded water temperatures higher than expected given the fish assemblage results which demonstrate a reproducing population of coldwater and transitional species. This is not unexpected given the model resolution and limitations of thermograph placement which may under or overrepresent stream reach thermal conditions.

Fish community data support the removal of the segment's WWAL use. Removal of the WWAL in 20.6.4.502 NMAC will not alter the application of water quality criteria for Clean Water Act implementation, including assessment, permitting, and TMDL development, because the most stringent criteria remain in effect for regulatory purposes (MCWAL). This amendment is therefore expected to provide a more accurate representation of existing fish communities and biological conditions without diminishing environmental protection.

5. Data Review for 20.6.4.503 NMAC

This WQS segment includes reaches of the East, Middle, and West Forks of the Gila River and all perennial tributaries upstream of and including Mogollon creek within the Upper Gila basin (**NMED Exhibit 54**). This segment currently has a HQCWAL designated use with a segment-

specific temperature criterion of 32.2°C (90°F) or less in the East Fork of the Gila River and Sapillo Creek downstream of Lake Roberts.

The Department reviewed AWTC modeled water temperature data and SWQB thermograph data for all reaches where available. There were two NMDOW fish collection stations within the segment which the Department analyzed for this DUV as well as recreational fishing information.

The East Fork of the Gila River downstream of Taylor Creek is approximately 27.6 miles in length. Water temperature data collected by the SWQB in 2007 and 2019 at a long-term monitoring station located at the downstream extent of the reach. The 2007 dataset documented maximum temperatures near 29°C and the 2019 dataset recorded a maximum temperature just above 28°C and a 6T3 value narrowly above 25°C, demonstrating that thermal conditions in East Fork Gila River are within the ranges necessary to support transitional, marginal cold, and coolwater aquatic life. AWTC model outputs generated using long-term meteorological inputs predicted maximum temperatures near 28°C and 6T3 values near 23°C, aligning with thermal conditions necessary for transitional, marginal coldwater, and coolwater aquatic life (**NMED Exhibit 55**).

Fisheries information provides further context regarding attainable aquatic life uses for this segment. Species composition and size class data collected from the Falls Spring area (1980 to present) reflect a fish community dominated by transitional species throughout the study period. This segment supports reproducing populations of transitional species across the length of the assessment unit and a reproducing population of a coldwater species, Speckled Dace. One warmwater species, Yellow Bullhead, had a reproducing population (**NMED Exhibit 53)**.

Collectively, these hydrological, thermal, and biological data indicate that the East Fork Gila River exhibits a thermal regime capable of supporting predominantly transitional aquatic communities, with limited persistence of coldwater and warmwater species.

Sapillo Creek from Lake Roberts to the Gila River extends approximately 11.9 miles. Water temperature data collected by the SWQB in 2007 at the upper extent of the reach documented a maximum temperature of approximately 22°C, with corresponding 4T3 and 6T3 values also near 20°C. Furthermore, data collected in 2019 and 2020 at a water quality station about halfway down the reach demonstrate maximum temperatures between 20-21°C and 4T3 values near 19°C (**NMED Exhibit 55**). All of these water temperature measurements indicate attainment of the HQCWAL temperature criteria. The relatively low temperatures observed in 2007, 2019, and 2020 datasets are likely influenced by the Lake Roberts dam, resulting in lower temperatures than modeled results which do not capture this regime. Nonetheless, the available datasets demonstrate that thermal conditions in Sapillo Creek are within the ranges necessary to support coldwater aquatic life.

The Gila River Basin Annual Fall Monitoring fisheries dataset does not include data from Sapillo Creek. To support evaluations of the fish community, the Department obtained fish presence data from the Museum of Southwestern Biology Division of Fishes using the Arctos museum database. The dataset represents current and historical species collected between 1975 and 2016. Biological information provides additional corroboration of suitable thermal conditions for coldwater aquatic life. Recreational fishing records indicate the presence of wild brown trout, wild rainbow trout, and stocked Gila trout within this reach. The occurrence of naturally reproducing trout is a strong indicator of coldwater habitat capability and supports the conclusion

that the thermal regime is sufficient to sustain coldwater aquatic life uses. Current and historical museum records indicate a native fish assemblage dominated by transitional and coldwater species further supporting the conclusion that the thermal regime is supportive of coldwater aquatic life (**NMED Exhibit 53**).

Taken together, thermograph data, AWTC modeling results, fisheries assemblage information, and recreational fishing reports suggest that these two reaches have different thermal regimes. Therefore, the Department is now proposing to remove the segment-specific temperature criteria of 32.2°C for both these reaches in 20.6.4.503 NMAC by 1) moving the mainstem of the East Fork Gila River to 20.6.4.502 NMAC which results in lowering the temperature criteria applied to this reach from 32.2°C to 28°C, and 2) lowering the temperature criteria applied to Sapillo Creek downstream of Lake Roberts from 32.2°C to the default HQCWAL criteria in 20.6.4.503 NMAC. The proposed revision reflects current biological and thermal conditions in both waterbodies without reducing environmental protection.

Based on this review, the Department proposes modifying its proposed amendments for these reaches to:

> **20.6.4.502 GILA RIVER BASIN: The main stem of the Gila river from Redrock canyon upstream to the confluence of the West Fork Gila river and East Fork Gila river and perennial reaches of tributaries to the Gila river downstream of Mogollon creek, and the mainstem of the East Fork Gila river.**
>
> **A. Designated uses:** industrial water supply, irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, and primary contact[~~and warmwater aquatic life~~].
>
> **B. Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 28°C (82.4°F) or less.
>
> **20.6.4.503 GILA RIVER BASIN: All perennial tributaries to the Gila river upstream of and including Mogollon creek, including perennial tributaries to the East Fork Gila river.**
>
> **A. Designated uses:** domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance of 400 µS/cm or less for all perennial tributaries except West Fork Gila and tributaries thereto, specific conductance of 300 µS/cm or less; [~~temperature [32.2]29°C ([90]84°F) or less in the east fork of the Gila river and Sapillo creek downstream of Lake Roberts;~~] the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

B. Amendments 20.6.4.601 and 20.6.4.602 NMAC in the San Francisco River Basin

The Department proposes relocating the existing segment boundary currently identified as "state highway 12 at Reserve" approximately 0.65 miles downstream to "the confluence with Largo Canyon" in 20.6.4.601 and 20.6.4.602 NMAC. The Department further proposes removal of the marginal warmwater aquatic life use (MWWAL) for perennial reaches of Mule Creek and the San Francisco River segment in 20.6.4.601 NMAC. This determination is supported by a comprehensive technical review that included analysis of existing fisheries data, thermograph datasets, AWTC modeling, and recreational fishing information consistent with the analysis for the proposed amendments to 20.6.4.502 and 503 NMAC, provided in Section III.A of my testimony.

1. Background and rationale for using hydrological breaks for segment boundaries.

As noted in Lynette Guevara's direct testimony, hydrologic features provide a more stable and scientifically defensible basis for water quality segment delineation than roadway crossings, and the proposed revision aligns the segment description with this principle. For this reason, the Department proposes relocating the existing segment boundary currently identified as "state highway 12 at Reserve" to "the confluence with Largo Canyon" in 20.6.4.601 and 20.6.4.602 NMAC (**NMED Exhibit 56**). The revised segment break moves the break approximately 0.65 miles downstream; and is in the 12-digit HUC watershed (Cienega Canyon-San Francisco River),

EPA Level IV Ecoregion (23e – Conifer Woodlands and Savannas), and land use type (private). There are no point source discharge permits impacted by this proposed change.

2. Data Review for 20.6.4.601 NMAC

This WQS segment includes reaches of the San Francisco River and Mule creek within the San Francisco basin (**NMED Exhibit 54**). AWTC modeled water temperature data, and nine SWQB thermograph datasets were reviewed for all reaches where available (**NMED Exhibit 55**). The Department analyzed NMDOW fish data at one collection station within the segment as well as recreational fishing information.

Nine water temperature datasets collected for this WQS segment by the SWQB in 2011, 2019, and 2020 at long-term monitoring stations. Six of the nine datasets had a maximum temperature below 29°C and 6T3 value below 25°C, consistent with the MCWAL temperature criteria. The other three datasets had maximum temperatures over 29°C, but notably two of those had 6T3 value below 25°C meaning all but one of the thermograph datasets available met the 6T3 criteria for MCWAL use attainment. AWTC model outputs generated using long-term meteorological inputs demonstrate a range of thermal conditions that correspond to multiple aquatic life use subcategories. The model output indicated attainment of the MCWAL temperature criteria in the higher elevation reaches of the WQS segment but mostly estimated maximum temperatures over 29°C which is consistent with the WWAL temperature criteria. In summary, measured thermograph data collected in 2011, 2019 and 2020 demonstrate attainment of the MCWAL default temperature criteria, with a few exceptions to maximum temperature excursions over 29°C. AWTC model outputs indicate temperatures consistent with attainment of both the MCWAL and WWAL criteria, mostly favoring the less stringent criteria.

Fisheries assemblage and size class information from the NMDOW fish collection station in the vicinity of Whitewater Creek, which is lower in the watershed, document a predominantly transitional community accompanied by a smaller proportion of coldwater species. Length frequency data further indicate successful propagation of transitional and coldwater fishes throughout the reach (**NMED Exhibit 53**). No propagation of warmwater species was documented in this segment. Taken together, measured thermograph data and fisheries assemblage and size-class information, demonstrate that this segment has thermal conditions that support transitional and marginal coldwater aquatic life. The Department proposes to remove MWWAL since the segment is shown to meet MCWAL temperature criteria. Removal of MWWAL will not alter the application of criteria for CWA implementation —including assessment, permitting, and TMDL development—because the most stringent applicable criteria remain in effect for regulatory purposes. The proposed amendment better reflects current biological and thermal conditions without reducing water quality protection.

IV. CONCLUSION

The Department urges the Commission to adopt the proposed amendments to the Standards, filed with the Department's First Amended Petition (**NMED Exhibit 27**) and based upon the testimony of the Department's witnesses.

This concludes my direct testimony.

EMILY MILLER

Santa Fe, NM — emily.miller@env.nm.gov

EDUCATION

B.S. Marine Sciences - Oceanography
University of Maine
Degree completion: 2019
Honors Thesis: Variations in Antarctic Iceberg Melt Rates in Relation to Southern Ocean Water Properties
Thesis Advisor: Dr. Ellyn Enderlin

WORK EXPERIENCE

Quality Assurance Officer
June 2024 - Present
New Mexico Environment Department Surface Water Quality Bureau
· Ensure that data collection activities associated with projects managed or conducted under the SWQB are planned, reviewed, conducted, and managed in a manner consistent with federal requirements
· Ensure environmental information, products, and services are of known and documented quality for their intended use(s)
· Support the mission of the SWQB by ensuring 1) quality assurance requirements are met in order to receive federal funds; and 2) decisions and rulemaking are conducted appropriately and defensibly to enhance water quality and protect public health or welfare consistent with state and federal law
· Assist with periodic water quality monitoring surveys and in developing or revising water quality standards

Senior Research Assistant
January 2020 - May 2024
Columbia University Lamont-Doherty Earth Observatory
· Manage vessel-based underway data for 9 University-National Oceanographic Laboratory System vessels
· Collect, document, and ingest data and metadata for all devices installed on research vessels
· Collaborate with vessel operators, marine technicians, national repositories, and scientists to meet community needs and improve data accessibility and discoverability
· Ingest submersible data for Schmidt Ocean Institute's ROV SuBastian and Ocean Exploration Trust's ROV's Hercules and Argus for the Marine Geoscience Data System
· Process ship-based multibeam data for the Global Multi-Resolution Topography synthesis integration through MBSystem and Qimera softwares

Shellfish and Biotoxin Specialist
May 2019 - December 2019
Maine Department of Marine Resources
· Conducted intertidal surveys along the Maine coast as part of a long term ecological record including the collection and measurement of sampled shellfish as well as predator and environmental assessment
· Handled data entry from field surveys and coordinated shellfish relocation efforts with local fishermen
· Performed biotoxin sampling techniques in the field and followed FDA regulated laboratory procedures

Undergraduate Research Assistant
Variations in Antarctic Iceberg Melt Rates in Relation to Southern Ocean Water Properties
September 2017 - May 2019
University of Maine School of Earth and Climate Sciences
· Used repeat very high-resolution satellite images to quantify meltwater fluxes and melt rates for icebergs distributed around Antarctica
· Compared iceberg melt rate patterns to Southern Ocean State Estimate (SOSE) water temperature

and velocity outputs. These were utilized in iceberg thermodynamic equations in an effort to better understand variations in iceberg melt and ocean properties at the marine margins of Antarctic glaciers and ice shelves
· Delineated iceberg outlines in Landsat and WorldView imagery for two fjords in Western Greenland
· Generated digital elevation models (DEMs) from very high resolution WorldView stereo pairs through NASA's Ames Stereo Pipeline. Post-processing performed in QGIS and MATLAB to determine bathymetry estimates

Undergraduate Research Assistant
Surveying Benthic Invertebrate Communities Associated with Oyster Aquaculture Sites in Maine
October 2015 - September 2017
University of Maine School of Marine Sciences
· Performed routine field work using a ponar grab to sample underneath and adjacent to suspended oyster cages from three estuaries in Maine
· Sorted and identified benthic organisms to the species level with tabular and dichotomous keys
· Completed sediment grain size and combustion analyses

PUBLICATIONS

Peer Reviewed Literature

· Enderlin, E.M., C. Moffat, E. E. Miller, A. Dickson, C. Oliver, M. C. Dry´ak-Vallies, R. Aberle. August 2023. Antarctic iceberg melt rate variability and sensitivity to ocean thermal forcing. Journal of Glaciology. https://doi.org/10.1017/jog.2023.54
· Carbotte, S.M., S. O'Hara, K. Stocks, D. Clark, L. Stolp, S. Smith, K. Briggs, R. Hudak, E. E. Miller, C. Olson, N. Shane, R. Uribe, R. Arko, C.L. Chandler, V. Ferrini, S. Miller, A. Doyle, J. Holik. December 2022. Rolling Deck to Repository: Supporting the Marine Science Community with Data Management Services from Academic Research Expeditions. Frontiers in Marine Science. https://doi.org/10.3389/fmars.2022.1012756
· Scheick, J., E. M. Enderlin, E. E. Miller, G. Hamilton. April 2019. First order estimates of coastal bathymetry in Ilulissat and Naajarsuit Fjords, Greenland, from remotely-sensed iceberg observations. Remote Sensing. https://doi.org/10.3390/rs11080935

Conference Proceedings (*when presenting author)

· Miller, E. E.*, S. Carbotte, P. Clark, R. Hudak, S. O'Hara, S. Smith, K. Stocks, L. Stolp, R. Uribe. October 2023. Rolling Deck to Repository Current Status and Developements of Data Management within the Academic Research Fleet. 2023 Research Vessel Technical Enhancement Committee (RVTEC) Annual Meeting.
· Verrini, V.L., J.J. Morton, E. E. Miller*, R. Uribe, C. Haskins, H.C. Drennon. December 2022. Optimizing the Integration of Submersible Data into the Marine Geoscience Data System (MGDS). American Geophysical Union Fall Meeting 2022. Abstract 1170924.
· Miller, E.E.*, R. Uribe. October 2022. All Aboard! Encouraging equity in at-sea experiences and oceanographic data access. 2022 SACNAS National Diversity in STEM (NDiSTEM) Conference.
· Drennon, H.C., E. E. Miller, V.L. Ferrini. February 2022. Exploring the Use of Multibeam Sonar Sound Speed Corrections to Map Water Column Variability. American Geophysical Union Ocean Sciences Spring Meeting 2022. Abstract OT07-6709.
· Miller, E. E.*, E. M. Enderlin, M. C. Dryak, A. C. Thomas. December 2018. Investigating the Relationship Between Southern Ocean Temperature Variability and Iceberg Melting Around Antarctica. American Geophysical Union, Fall Meeting 2018. Abstract C21B-1326.

TECHNICAL STRENGTHS

Working Knowledge: Python, Qimera, ArcGIS/QGIS, MATLAB
Intermediate Knowledge: SQL, Unix/Linus, MB-System

Air-Water Temperature Correlation

New Mexico Environment Department
Surface Water Quality Bureau
August 2011

Summary

This document provides a tool for identifying appropriate stream classifications and attainable aquatic life use subcategories. The investigation described here demonstrates that, based on data for approximately 300 New Mexico streams, air temperature is highly correlated with stream water temperature and subsequently with the attainable aquatic life use subcategory.

The key results presented in this document are these, which are applicable unless there are significant groundwater inputs or microclimate effects:

(1) maximum weekly average (water) temperature is equal to July average air temperature; and
(2) attainable aquatic life use subcategories can be related to July average air temperature, as follows:

- high quality and coldwater uses may be attainable if July average air temperature is ≤18°C;
- marginal coldwater and coolwater uses may be attainable if July average air temperature is ≤23°C;
- uses more restrictive than warmwater are generally not attainable if July average air temperature is >23°C.

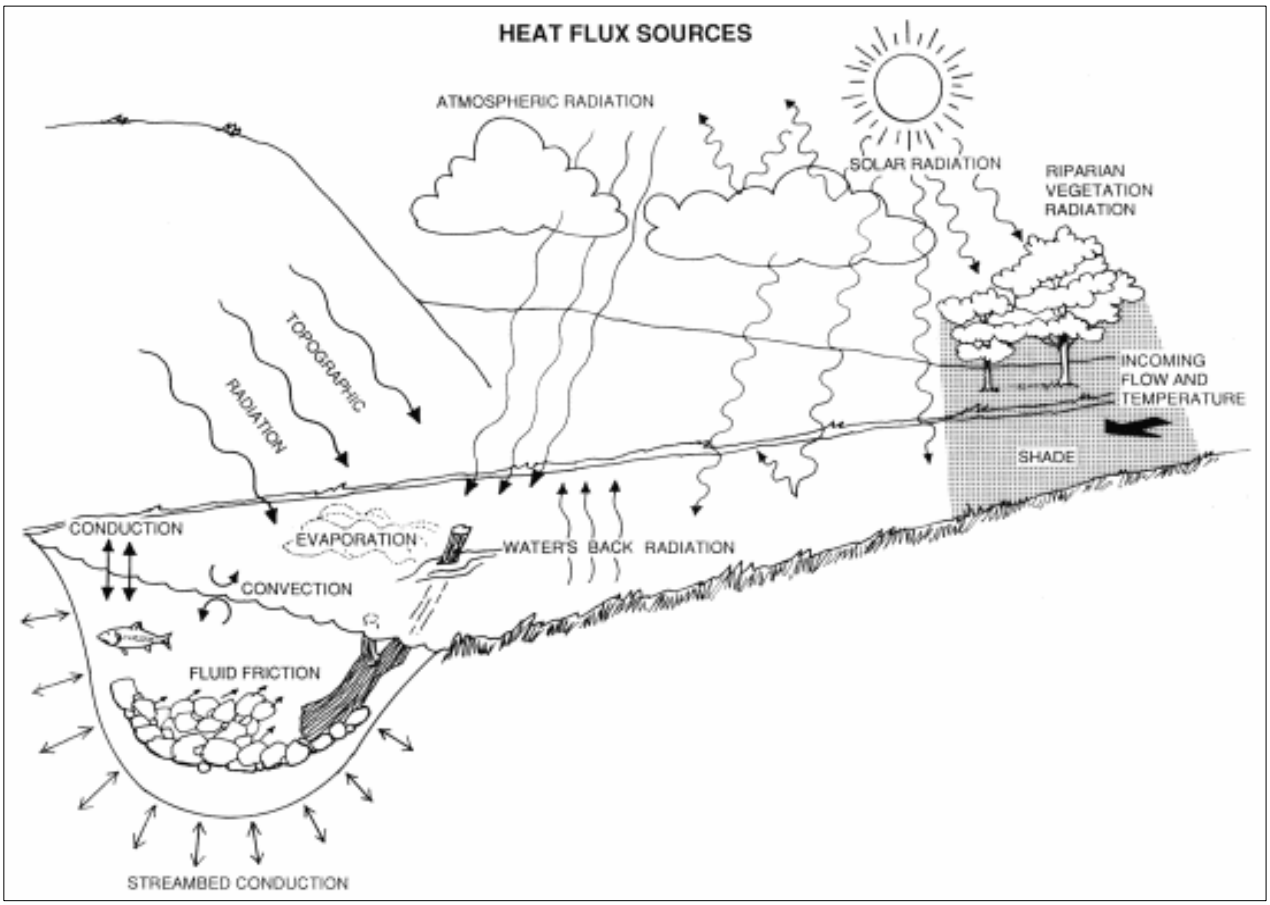
NMED Exhibit 52

Introduction

Temperature has been identified as a leading cause of impairment in rivers and streams in New Mexico (NMED/SWQB 2009). However, the Surface Water Quality Bureau (SWQB) suspects that many of these waters are misclassified; that is, the designated aquatic life use or associated criteria cannot be attained because of naturally limiting conditions.

In the absence of significant groundwater input, stream water temperature is the result of the relationship of eight heat flux components: convection, conduction, fluid friction, evaporation, water back radiation, atmospheric (long wave) radiation, vegetative and topographic (long wave) radiation and solar (short wave) radiation, as illustrated in following figure from the SSTEMP water temperature model (Bartholow, 2002).

Figure 1



Five of the components (evaporation, water back radiation, atmospheric radiation, solar radiation and vegetative-topographic radiation) generally account for more than 90% of the stream heat flux. The significant positive heat fluxes are atmospheric and vegetative-topographic long wave radiation, and short-wave solar radiation.

With the exception of solar radiation, the heat flux components cannot be measured directly, but a number of related factors (and solar radiation) can be. These factors include:

Meteorological Factors

- air temperature
- solar radiation
- relative humidity
- wind speed
- possible sun
- ground temperature

Water or Streamcourse Factors

- inflow temperature
- accretion (groundwater inflow) temperature
- segment inflow (water flow at the top of the segment)
- segment outflow (water flow at the bottom of the segment)
- thermal gradient

Geographical Factors

- latitude
- segment length
- upstream elevation
- downstream elevation

Insolation Factors

- shading
- width-to-depth ratio

Air temperature is highly correlated with the significant positive heat flux components including solar radiation, and consequently with stream water temperature. The correlation is supported by the SSTEMP water temperature model documentation, which asserts: “Air temperature will usually be the single most important factor in determining mean daily water temperature.”

The factors of relative humidity and wind speed are not directly associated with positive heat flux, although they have some influence on water temperature. The remaining meteorological and geographical factors have less influence on water temperature. None of the meteorological or geographical factors are amenable to human intervention.

The water or streamcourse factors are inflow temperature, groundwater inflow, stream segment inflow and outflow, and thermal gradient. With few exceptions, the inflow temperature is correlated to meteorological factors, chiefly air temperature. Although most New Mexico streams are shallow and are not “gaining streams” (not fed by groundwater) for most of their length, there are specific instances where groundwater inflow influences water temperature. Stream flow may influence water temperature, although it may not be amenable to modification. The insolation factors of shading and width-to-depth ratio have some influence on water temperature and are amenable to human intervention through stream restoration activities.

Correlation between Air Temperature and Water Temperature

The SWQB has developed a statewide correlation between July average air temperature and MWAT water temperature (MWAT - maximum weekly average temperature). The MWAT is defined as the seven-day mean of consecutive daily mean temperatures, where daily means are calculated from multiple, equally spaced values per day (Todd et al., 2008). Water quality criteria documents such as EPA (1972) recommend aquatic life temperature limits for prolonged exposure based on the MWAT. Chronic water temperature criteria based on the MWAT have recently been developed in Colorado (Todd et al., 2008).

The analysis provided here verifies a strong correlation between weekly and monthly averages of stream and air temperature. The relationship can be used to estimate the naturally attainable water temperature at any location in the state, absent site-specific mitigating conditions.

Water Temperature Data

Water temperatures were obtained from SWQB water thermograph data. Since 1999, SWQB has deployed long-term temperature data recorders (thermographs) at approximately 300 monitoring stations on New Mexico streams. During the summer season of June through August the thermographs record hourly temperatures, providing approximately 3,000 data points at each station. We reduced the data to summary statistics: the reference date (date of the first maximum temperature); the maximum temperature; the maximum weekly average temperature (MWAT); the 4-hour maximum temperature that occurs for 3 consecutive days (4T3); and the 6-hour maximum temperature that occurs for 3 consecutive days (6T3).

Air Temperature Data

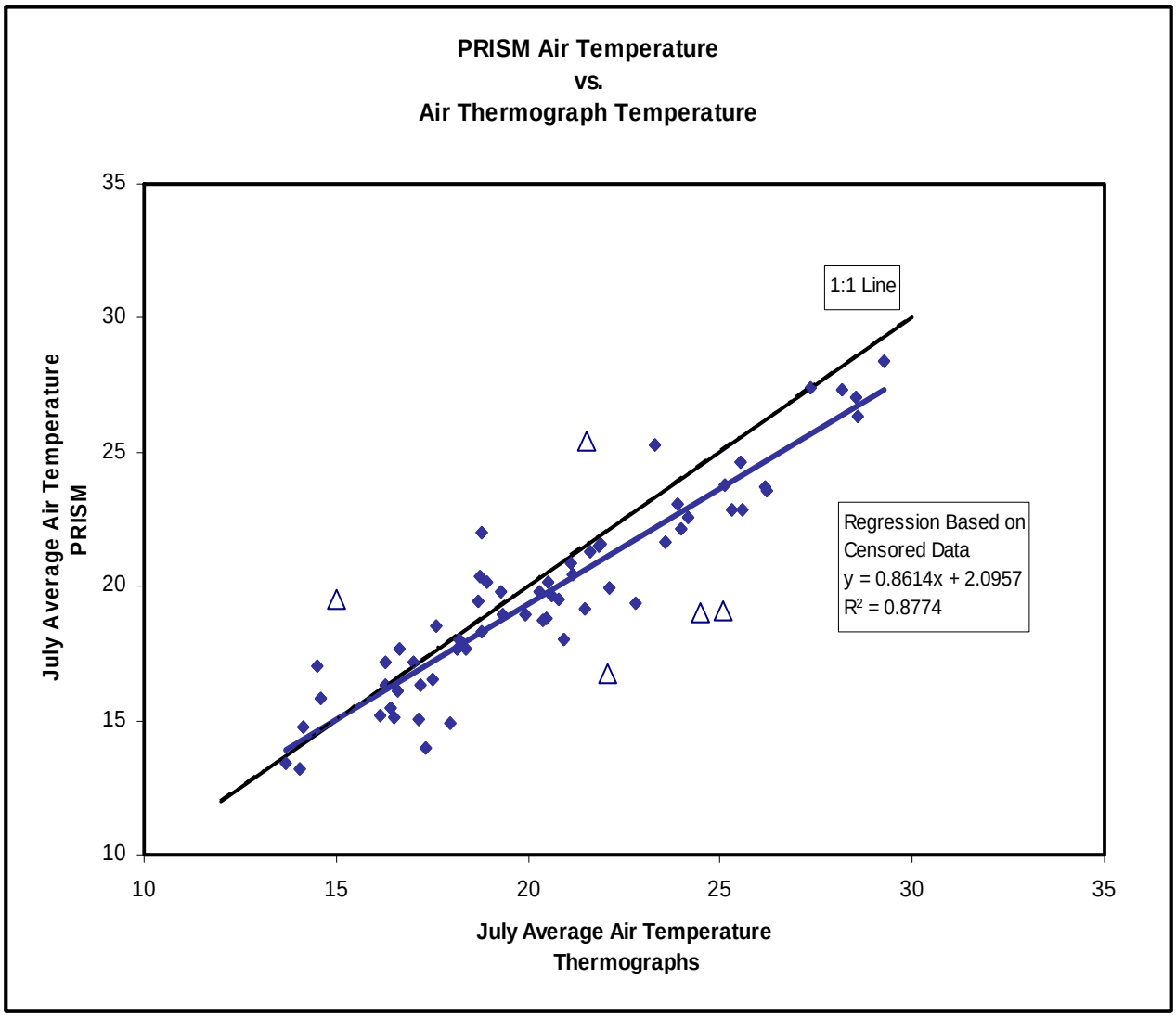
Air temperatures were obtained from two sources: a publically available temperature model known as PRISM (Parameter-elevation Regressions on Independent Slopes Model) and SWQB air thermographs. PRISM, available at http://www.prism.oregonstate.edu/, provides gridded data that can be used to find representative July temperatures for any location in the United States. PRISM can be used to provide July average temperatures that can be associated with any SWQB water monitoring location. The SWQB

co-deployed ambient air thermographs at approximately 70 water thermograph stations. Data provided by these thermographs was also used to calculate July average air temperatures.

PRISM Data Evaluation

Because the PRISM data is potentially more useful than the limited number of SWQB air thermographs, we evaluated the suitability of PRISM data by comparing the SWQB air thermograph data to the PRISM data. The comparison is shown in Figure 2.

Figure 2



The figure shows July average PRISM air temperatures plotted against July average temperatures measured using SWQB air thermographs. If the PRISM model correlated exactly with the air thermographs, the PRISM data would plot on the 1:1 line. The PRISM data may not plot precisely on the line for a number of reasons such as microclimate effects and imprecision of the PRISM model. To adjust for some of this variation, five data points where the thermograph and PRISM values were more than 3.8°C different were not used to develop the regression line. The points that were not used are plotted as triangles in the figure. The cutoff of 3.8°C was chosen because it is two standard deviations from the mean difference between the two datasets.

The regression indicates strong correlation and a slope of nearly 1. Based on this evaluation, we concluded that the PRISM dataset was suitable for use in providing July average temperatures at SWQB water monitoring locations.

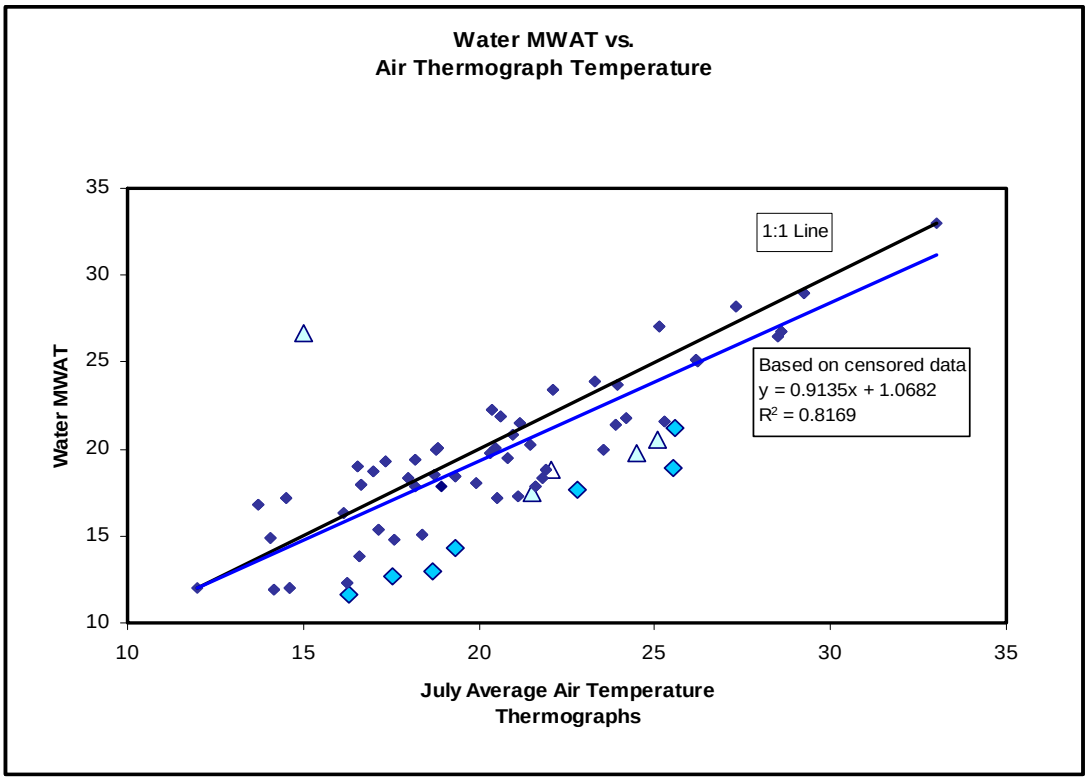
Outlier Analysis

Although other investigators have reported an almost 1:1 relationship between weekly average stream temperature and monthly average air temperature (Morrill et al. 2005), there are a number of reasons why the SWQB dataset may not correlate precisely with the July average air temperatures. These reasons include local conditions that cause the water temperature to be unusually high or low, unrepresentative thermograph locations, inconsistent periods of record and other causes.

To develop a basis for removing data points not well-correlated with July air temperature, particularly where the water temperature is influenced by groundwater, we considered the locations where we had both air and water thermograph data. Based on visual examination of the thermographs, it appeared that at locations where the air – water difference was greater than 4°C, the temperatures were either outliers, influenced by microclimate effects or moderated by groundwater.

To test this, we plotted air thermograph and water MWAT data (Figure 3). Locations identified as outliers in the *PRISM Data Evaluation* (Figure 2) are shown as triangles. Of the five points identified in the *PRISM Data Evaluation*, four also have an air-water difference greater than 4°C. One (15.00°C air, 26.62°C water) appears to be an outlier due to unusually low air thermograph readings, with an air – water difference of negative 11.6°C. The unshaded triangle, identified in the *PRISM Data Evaluation*, had a difference of 3.3°C which is less than the 4-degree cutoff.

Figure 3



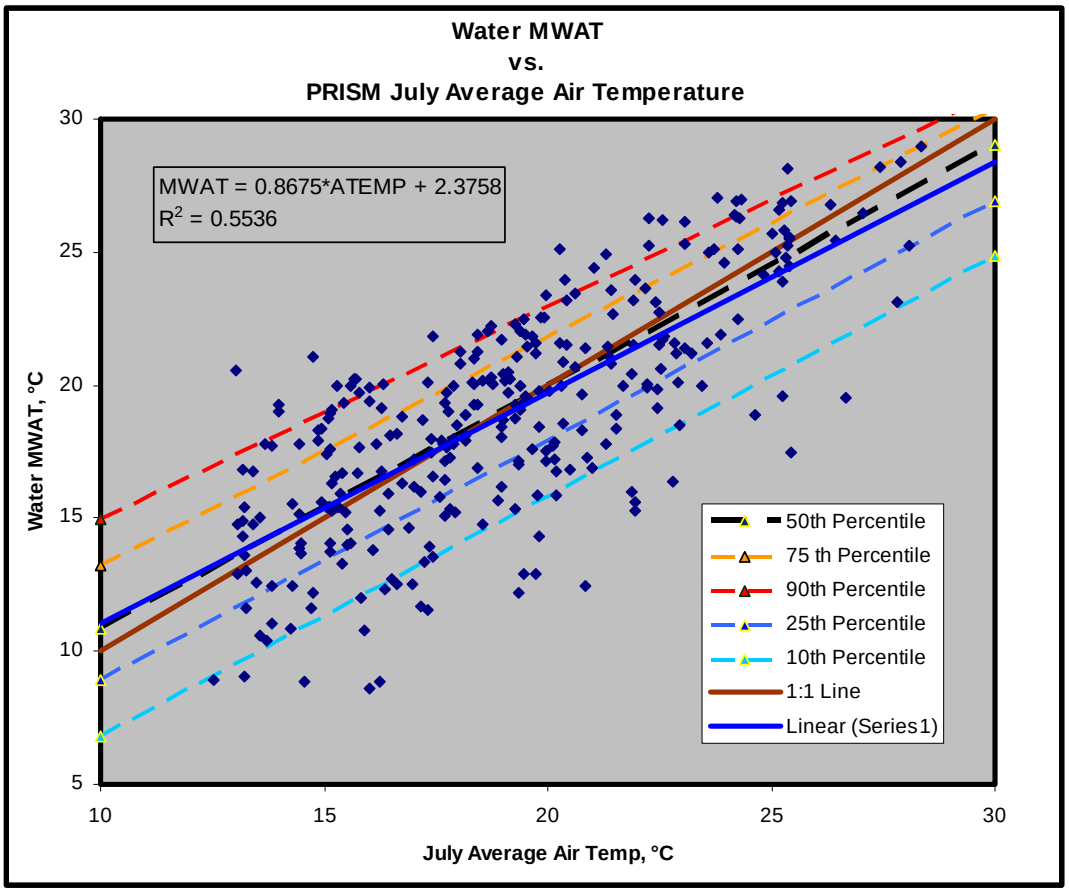
We identified seven additional points (the larger shaded diamonds) based on a positive air – water difference greater than 4°C. At five of the locations, the daily water temperature variation was low (a reference date diel water temperature difference less than 6°C), indicating groundwater influence. Two had a diel difference greater than 12°C. For these, however, the thermograph temperature was about 3°C greater than predicted by PRISM. If the PRISM temperature had been used these points would have been within the 4°C cutoff and would not be shown as shaded diamonds. All seven points, as well as four of those identified by the *PRISM Data Evaluation,* plot in the lower range of the relationship.

Based on this evaluation, we concluded that a July average air – water MWAT difference of 4°C was a reasonable value for use in removing data from locations significantly influenced by groundwater or microclimate effects.

Statewide Correlation

We compared thermograph data from 293 monitoring locations to July average air temperatures from PRISM and plotted the results in Figure 4. No data points were removed. The figure includes the linear least squares regression, the 1:1 line and percentile regression lines.

Figure 4



Regression Coefficients

	m	b
10th percentile	0.9033	-2.2126
25th percentile	0.9015	-0.1133
50th percentile	0.9097	1.7368
75th percentile	0.8571	4.6514
90th percentile	0.8005	6.9644
Linear regression	0.8675	2.3758

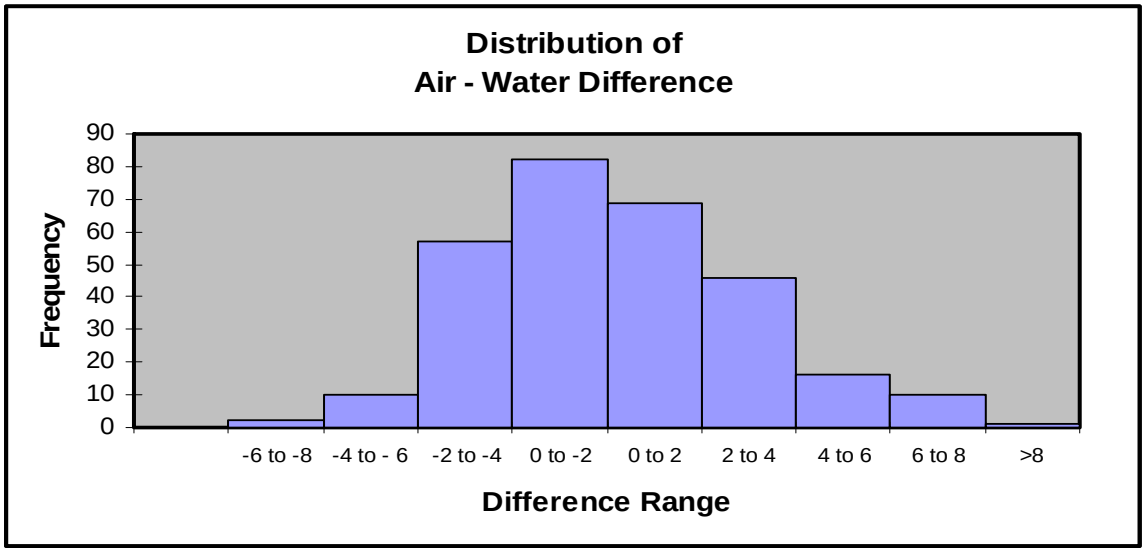
Representative results from the regressions are shown below:

Table 1

July Average Air Temp, °C	Water MWAT based on Regression, °C	Water MWAT 50th Percentile, °C	Water MWAT 25th Percentile, °C	Water MWAT 10th Percentile, °C
15	15.39	15.38	13.41	11.34
20	19.73	19.93	17.92	15.85
25	24.06	24.48	22.43	20.37

Consistent with the *Outlier Analysis*, we calculated the air – water difference. There are 27 locations with an air – water difference greater than 4°C, and 12 with a difference less than 4°C. The distribution is shown in Figure 5.

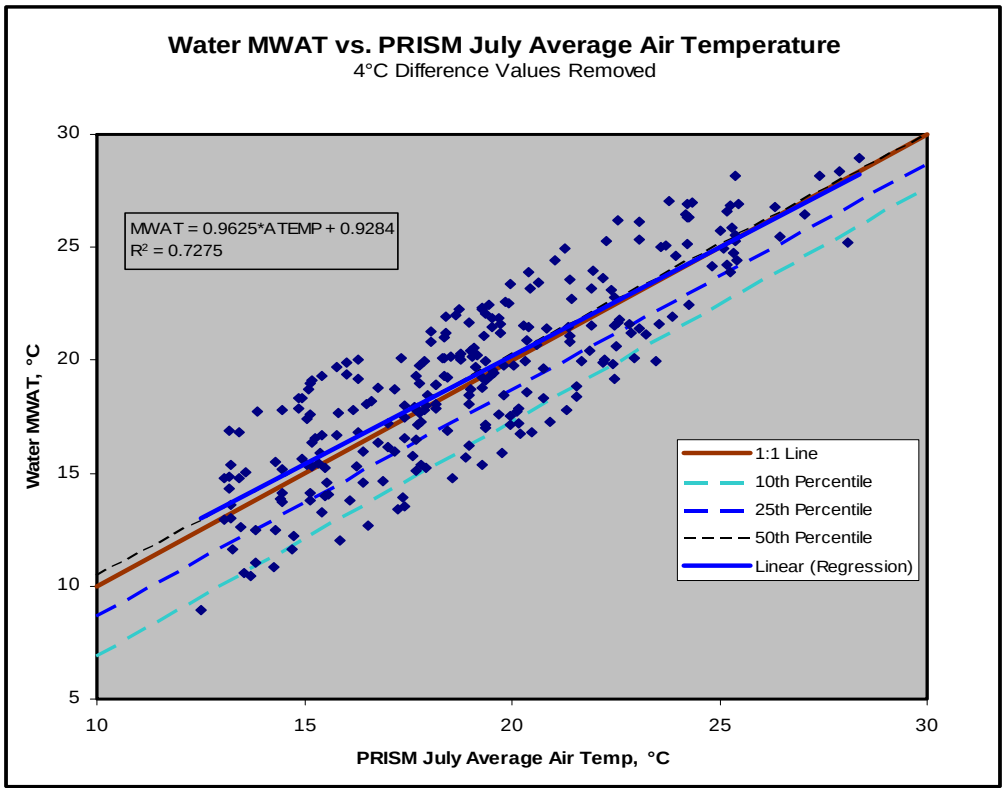
Figure 5



Difference	-6 to -8	-4 to - 6	-2 to -4	0 to -2	0 to 2	2 to 4	4 to 6	6 to 8	>8
Frequency	2	10	57	82	69	46	16	10	1

After removing points with a greater than 4°C difference, we plotted the remaining 254 data points as water MWAT vs. PRISM July average air temperature in Figure 6.

Figure 6



Regression Coefficients

	m	b
10th percentile	1.0353	-3.4280
25th percentile	1.0000	-1.3400
50th percentile	0.9768	0.6900
Linear regression	0.9625	0.9284

Representative results from the regressions are shown below:

Table 2

July Average Air Temp, °C	Water MWAT based on Regression 4°C Δ Removed, °C	Water MWAT 50th Percentile, 4°C Δ Removed, °C	Water MWAT 25th Percentile, 4°C Δ Removed, °C	Water MWAT 10th Percentile, 4°C Δ Removed, °C
15	15.37	15.34	13.66	12.10
20	20.18	20.23	18.66	17.28
25	24.99	25.11	23.66	22.45

Tables 1 and 2 show that in the 15 to 25°C air temperature range, both the 4°C Δ removed and all data regressions predict a temperature within 1°C of the 1:1 line (MWAT = July Average Air Temperature).

Reference Site Evaluation

A list of New Mexico locations considered to be reference sites has recently been developed. *Sediment in New Mexico Streams: Existing Conditions and Potential Benchmarks* (Jessup et al. 2010) includes a file, AppF_NM Datasets2.xlsx, that lists 45 New Mexico locations considered to be reference sites based on characteristics other than temperature. The 45 locations are listed in the file *Bedded Sediment Reference Sites*. SWQB has collected thermograph data at only 13 of these sites. The sites are listed in Table 3.

At the first three sites (Rito Resumidero blw Resumidero Spring, Rio Puerco de Chama @ FR 103 and Bear blw Dorsey Spring), the July average air temperature (PRISM) minus the water MWAT was more than 4°C, and the thermographs did not exhibit the usual diel variation. As with the previous statewide analysis, these characteristics suggest that groundwater inflow are moderating the air temperature influence, so these sites were not used for this analysis.

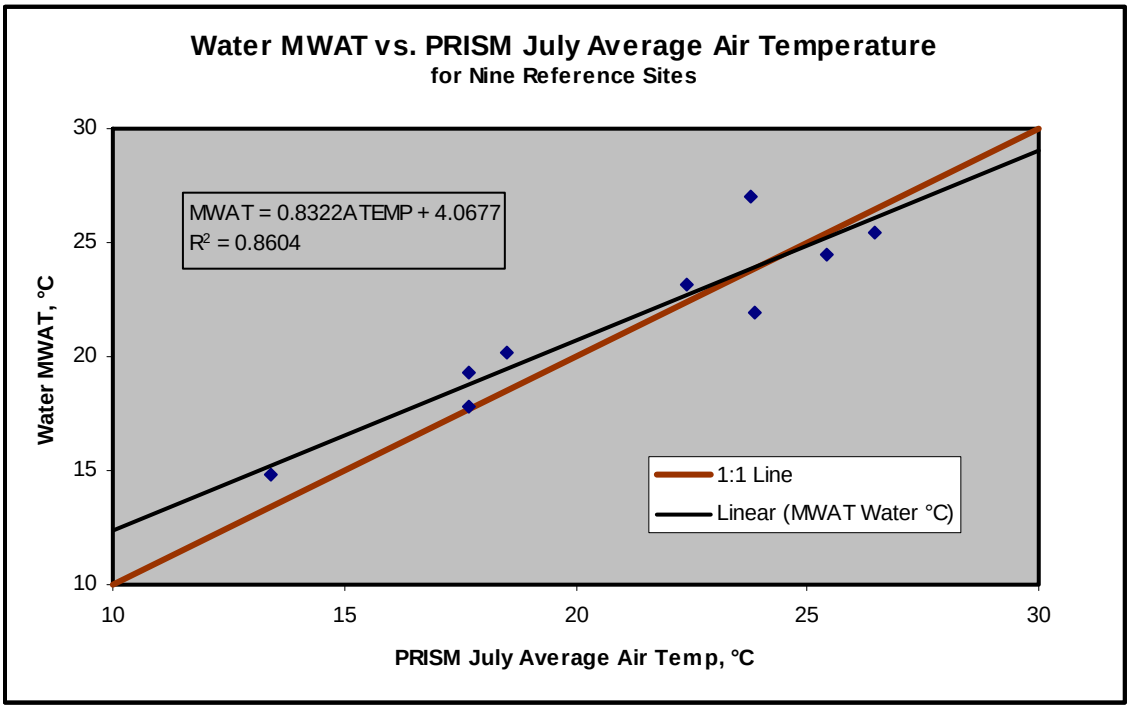
The Dry Cimarron River @ Jesus Mesa site had an air – water difference slightly greater than 4°C, and the air temperature was lower than the water temperature. Although the water temperature exhibited diel variation, the difference between the daily maximum and minimum was less than expected, indicating that factors other than air temperature may be influencing water temperature. The stream at this site is surrounded by exposed bedrock that may elevate the water temperature. Because of this potential microclimate effect, and in order to be consistent with the 4°C cutoff, the Jesus Mesa site was also not used for the reference site correlation.

Table 3

STORET ID	Station	July Average Air Temp (PRISM) °C	MWAT Water °C	Air-Water Difference °C
29RResum001.9	~~Rito Resumidero blw Resumidero Spg~~	~~16.26~~	~~8.87~~	7.39
78BearCr027.0	~~Bear blw Dorsey Spg~~	~~23.45~~	~~18.01~~	5.44
29RPuerc037.5	~~Rio Puerco de Chama @ FR 103~~	~~16.97~~	~~12.54~~	4.43
77Turkey001.8	Turkey Creek	23.87	21.92	1.95
78GilaRi025.5	Gila blw Blue	26.44	25.44	0.99
78GilaRi069.2	Gila blw Mangas	25.41	24.45	0.96
28RGRanc013.1	RG del Rancho @ Talpa-1305269	17.68	17.82	-0.14
77EFkGil000.2	E Fk Gila	22.40	23.14	-0.74
28RCosti032.5	Costilla abv Comanche (blw impoundment)	13.41	14.79	-1.39
05MPonil000.1	M Ponil abv S Ponil	17.70	19.30	-1.60
05NPonil000.1	N Ponil abv S Ponil	18.53	20.19	-1.66
10UteCre104.3	Ute nr Bueyeros	23.79	27.04	-3.26
02DryCim047.2	~~Dry Cim @ Jesus Mesa~~	~~22.27~~	~~26.28~~	-4.02

Figure 7 is a graph of the data from the remaining nine sites.

Figure 7



Representative results are shown below:

Table 4

July Average Air Temp, °C	Water MWAT based on Regression using Reference Data °C
15	16.55
20	20.71
25	24.87

At 15 and 20°C, the predicted MWAT using the reference data is 0.7 to 1.6°C *greater* than the 1:1 line. At 25°C, the reference data regression predicts a water temperature within 0.2°C of the 1:1 line. Despite the limited number of data points, it is clear that the reference sites fall along the same 1:1 air-water temperature relationship found for all sites.

MWAT Prediction Equation

Representative results from the previously discussed regressions are shown below:

Table 5

July Average Air Temp, °C	Water MWAT based on Regression 4°C Δ Removed, °C	Water MWAT based on Regression using All Data, °C	Water MWAT based on Regression using Reference Data °C	Water MWAT 25th Percentile, All Data °C
15	15.37	15.39	16.55	13.41
20	20.18	19.73	20.71	17.92
25	24.99	24.06	24.87	22.43

In the15 to 25°C air temperature range, the 4°C Δ removed and all data regressions predict a temperature within 1°C of the 1:1 line (MWAT = July Average Air Temperature). The reference data regression predicts a water MWAT slightly *greater* than the 1:1 line at 15 and 20°C.

The 1:1 relationship holds for the regression based on all data and also holds when sites expected to be influenced by groundwater are removed. Because of this, and significantly because it also is consistent with the regression based on reference sites, the 1:1 relationship represents the *attainable* water MWAT for locations where water temperature is controlled by ambient air temperature.

We conclude that for New Mexico streams not significantly influenced by groundwater, the *attainable* water MWAT equals the July average air temperature from the PRISM dataset. That is,

MWAT = ATEMP (PRISM July Average Air Temperature)

The regressions based on all of the data, on data without locations suspected of being groundwater dominated, and on reference sites all follow the 1:1 line. Based on this, the 1:1 line appears to represent the physical relationship that exists where the attainable water temperature is correlated to air temperature.

Points that plot below the 1:1 line may represent sites where the water temperature is somewhat influenced by groundwater, or may result from microclimate effects or data collection problems including unrepresentative thermograph locations or inconsistent periods of record. For these reasons, the 25th percentile does not appear to be useful in estimating the naturally attainable water temperature unless there is specific local information to suggest otherwise.

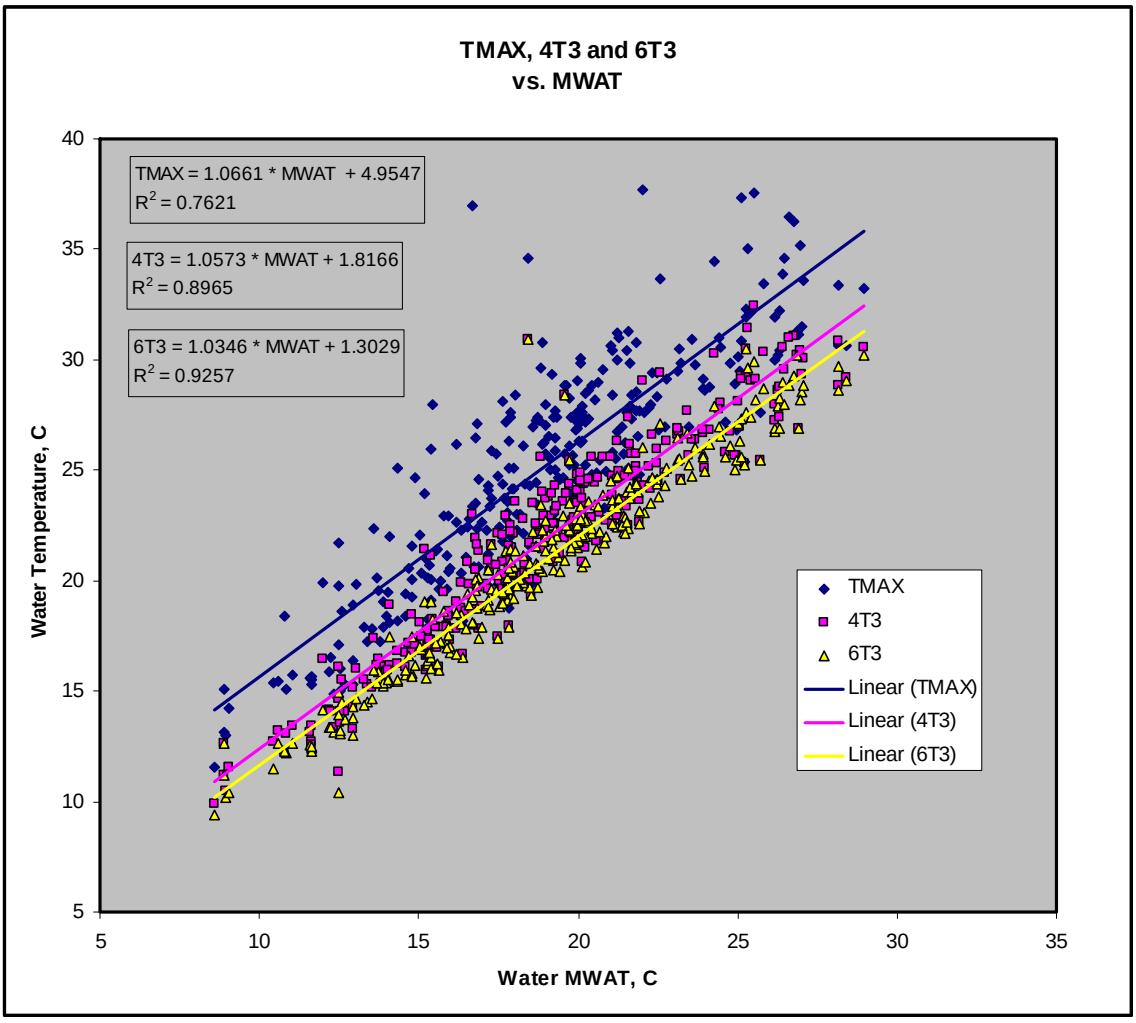
Relationship of MWAT and Air Temperature to NM Criteria

New Mexico aquatic life temperature criteria are not based on the MWAT. As reflected in 2010 amendments to New Mexico's *Standards for Interstate and Intrastate Waters* (20.6.4 NMAC), the criteria are based on maximum, 4T3 and 6T3 temperatures defined as follows: maximum temperature means the instantaneous temperature not to be exceeded at any time; 4T3 temperature means the temperature not to be exceeded for four or more consecutive hours in a 24-hour period on more than three consecutive days; and 6T3 temperature is means the temperature not to be exceeded for six or more consecutive hours in a 24-hour period on more than three consecutive days.

The air-water temperature correlation was developed to predict water MWAT values based on July average temperatures. Because New Mexico criteria are not based on MWAT, predicted MWATs need to be related to New Mexico criteria statistics.

To do this, the dataset that includes the statistics from 293 sites was used to develop a relationship between maximum (TMAX), 4T3 and 6T3 temperature and MWAT. Four TMAX values that were greater than 38°C (100 °F) were removed before doing the correlation, because water temperatures greater than 100°F are usually the result of the thermograph being out of the water. Correlations are in Figure 8.

Figure 8



The air – water temperature correlation indicated that MWAT = ATEMP (PRISM July Average Air Temp). Substituting ATEMP for MWAT yields the following:

6T3 = 1.03 * ATEMP + 1.30
4T3 = 1.06 * ATEMP + 1.82
TMAX = 1.07 * ATEMP + 4.95

Based on these relationships, if the water temperature is not reduced by groundwater input or microclimate effects, the designated use based on water temperature is related to July average air temperature as follows:

- If the air temperature is ≤18, high quality coldwater or coldwater may be attainable;
- If the air temperature is between 18 and 23, marginal coldwater or coolwater may be attainable;
- If the air temperature is >23, uses more restrictive than warmwater are generally not attainable.

Table 7

Temp, °C	High Quality Coldwater	Coldwater	Marginal Coldwater	Coolwater	Warmwater	Marginal Warmwater
Maximum Criterion	23	24	29	29	32.2	32.2
4T3 Criterion	20	-	-	-	-	-
6T3 Criterion	-	20	25	-	-	-
ATEMP (July Average Air Temperature)	≤17	≤18	≤23	≤23	>23	>23
Water Stats @ ATEMP	TMAX 23.1 4T3 19.8	TMAX 24.2 6T3 19.8	TMAX 29.6 6T3 25.0	TMAX 29.6		

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Evaluation of fish assemblage

The Department classified fish species into thermal guilds—coldwater, warmwater, or transitional (warm/coldwater transition)—using the designations provided by the State of New Mexico's Biota Information System of New Mexico (BISON) database. The relative proportions of each thermal guild were then evaluated to identify the dominant thermal guild within each assessment segment (Table 2; Figure 1). Due to the temporal range of the dataset, fish assemblages were evaluated on a decadal timescale. This analysis provides an indication of the fish assemblage currently supported by each segment and whether it is more representative of coldwater, warmwater, or transitional aquatic life.

For Sapillo Creek, fish occurrence records were obtained from the Museum of Southwestern Biology Division of Fishes through the Arctos database (Table 3). Because these records were compiled from multiple collections conducted under varying objectives and sampling methodologies, they are not directly comparable to the Department's standardized survey data and cannot be used to evaluate the relative proportions of thermal guilds. Instead, the Arctos records were used solely as long-term presence data to document the occurrence of fish species within the segments.

Table 1. Fish Fauna of the Gila and San Francisco River Basins. Designations of native status and thermal guild were determined using the State of New Mexico's Biota Information System of New Mexico (BISON) database. Species were determined to be extant if detected in the most recent New Mexico Department of Wildlife (NMDOW) collections.

Scientific name	Common name	Native (Y/N)	Extant	Thermal guild
Agosia chrysogaster	Longfin Dace	Y	Y	Warm/Cold Water Transition
Ameirus melas	Black Bullhead	N	N	Warmwater
Ameiurus natalis	Yellow Bullhead	N	Y	Warmwater
Catostomus clarkii	Desert Sucker	Y	Y	Warm/Cold Water Transition
Catostomus insignis	Sonora Sucker	Y	Y	Warm/Cold Water Transition
Cyprinella lutrensis	Red Shiner	N	Y	Warmwater

Cyprinus carpio	Common Carp	N	Y	Warmwater
Gambusia affinis	Western Mosquitofish	N	Y	Warmwater
Gila robusta	Roundtail Chub	Y	Y	Coldwater
Ictalurus punctatus	Channel Catfish	N	Y	Warmwater
Ictalurus spp.	Catfish species	N	Y	Warmwater
Lepomis cyanellus	Green Sunfish	N	N	Warmwater
Lepomis macrochirus	Bluegill	N	N	Warmwater
Meda fulgida	Spikedace	Y	Y	Warm/Cold Water Transition
Micropterus dolomieu	Smallmouth Bass	N	Y	Warm/Cold Water Transition
Micropterus salmoides	Largemouth Bass	N	Y	Warmwater
Oncorhynchus gilae	Gila Trout	Y	Y	Coldwater
Oncorhynchus mykiss	Rainbow Trout	N	Y	Coldwater
Oncorhynchus spp.	Trout sp. (YoY)	NA	Y	Coldwater
Pimephales promelas	Fathead Minnow	N	Y	Warmwater
Pylodictis olivaris	Flathead Catfish	N	Y	Warmwater
Rhinichthys osculus	Speckled Dace	Y	Y	Coldwater
Salmo trutta	Brown Trout	N	N	Coldwater
Tiaroga cobitis	Loach Minnow	Y	Y	Coldwater

Table 2. Species richness (no. of species observed), abundance (no. of individuals observed), dominant thermal guild, and species richness for segments 20.6.4.502, 503, and 601 in the Gila and San Francisco basins compiled by the SWQB from NMDOW collections. Designations of native status and thermal guild were determined using the State of New Mexico's Biota Information System of New Mexico (BISON) database.

Decade	Segment	Dominant thermal guild	Abundance	Species richness
1980s	20.6.4.502	Warm/cold water transition	856	10
1990s	20.6.4.502	Warm/cold water transition	3260	16
2000s	20.6.4.502	Warm/cold water transition	4373	12
2010s	20.6.4.502	Warm/cold water transition	5034	14
2020s	20.6.4.502	Warm/cold water transition	2840	13
1980s	20.6.4.503	Warm/cold water transition	1788	15
1990s	20.6.4.503	Warm/cold water transition	6422	17
2000s	20.6.4.503	Warm/cold water transition	1933	17
2010s	20.6.4.503	Warm/cold water transition	1811	20
2020s	20.6.4.503	Warm/cold water transition	2753	18
1980s	20.6.4.601	Warm/cold water transition	1184	7
1990s	20.6.4.601	Warm/cold water transition	4402	10
2000s	20.6.4.601	Warm/cold water transition	660	8
2010s	20.6.4.601	Warm/cold water transition	1326	8
2020s	20.6.4.601	Warm/cold water transition	1392	11

Table 3. Historical species detections in Sapillo Creek obtained from Museum of Southwestern Biology Division of Fishes records using Arctos museum database (https://arctos.database.museum/).

Scientific name	Common name	Decade	Native Y/N	Thermal guild
Agosia chrysogaster	Longfin Dace	1980	Y	Warm/cold water transition
Ameiurus melas	Black Bullhead	1980	N	Warmwater
Catostomus insignis	Sonora Sucker	1980	Y	Warm/cold water transition
Gambusia affinis	Western	1980	N	Warmwater
Ictalurus punctatus	Channel Catfish	1980	N	Warmwater
Oncorhynchus mykiss	Rainbow Trout	1980	N	Coldwater
Catostomus clarkii	Desert Sucker	1980	Y	Warm/cold water transition
Catostomus plebeius	Rio Grande Sucker	1980	Y	Coldwater
Pimephales promelas	Fathead Minnow	1980	N	Warmwater
Rhinichthys osculus	Speckled Dace	1980	Y	Coldwater
Salmo trutta	Brown Trout	1980	N	Coldwater
Agosia chrysogaster	Longfin Dace	2000	Y	Warm/cold water transition
Carassius auratus	Goldfish	2000	N	Warmwater
Micropterus salmoides	Largemouth Bass	2000	N	Warmwater
Oncorhynchus mykiss	Rainbow Trout	2000	N	Coldwater
Catostomus plebeius	Rio Grande Sucker	2000	Y	Coldwater
Agosia chrysogaster	Longfin Dace	2010	Y	Warm/cold water transition
Catostomus plebeius	Rio Grande Sucker	2010	Y	Coldwater

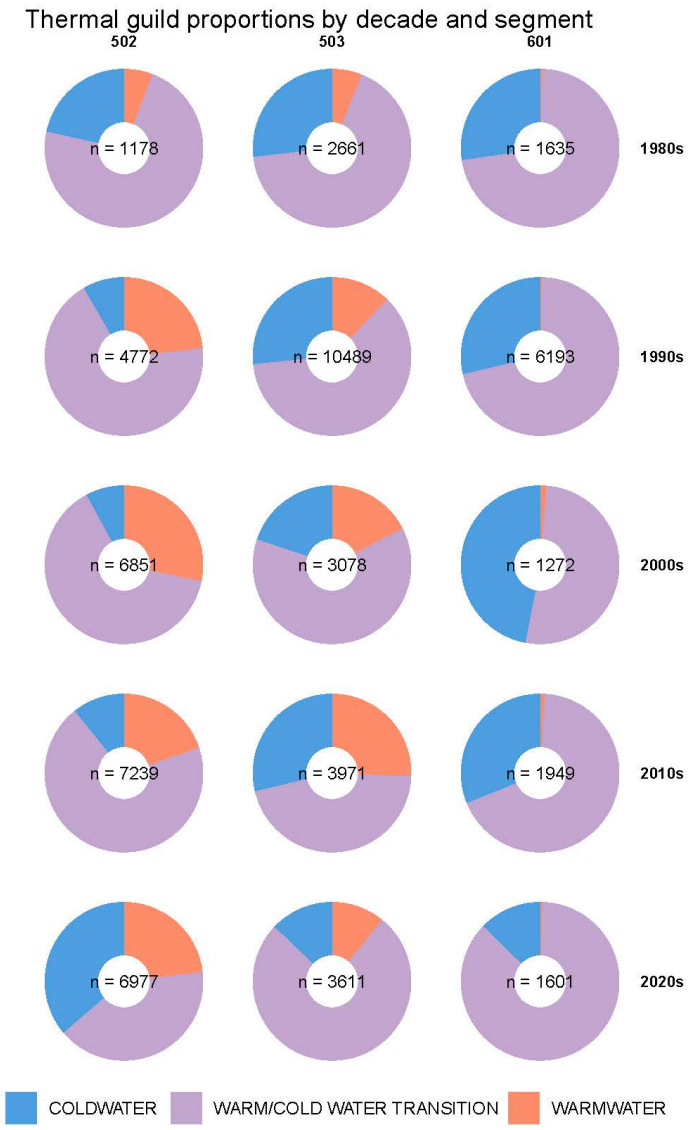


Figure 1. Proportion of each thermal guild, coldwater, transitional, and warmwater, bye decade, in each water quality segment 20.6.4.502,503, and 601.

Propagation evaluation

To evaluate whether segments are supporting propagation of fish, as required by CWA Section 101(a)(2) and necessary to determine the applicable aquatic life use as defined in 20.6.4.7 NMAC, the Department assessed recruitment using length-frequency distributions. Size-

class data were evaluated to assess whether fish species are reproducing and successfully recruiting within assessed segments. Recruitment is defined as the survival of young-of-year individuals to a stage at which they enter the population of reproducing fish. In segments that support both reproduction and recruitment, length-frequency distributions are expected to exhibit individuals across all size classes.

To evaluate this condition, the Department developed length-frequency histograms for fish species with a total sample size greater than 500 individuals. Thermal guild classifications for each species were assigned using the BISON database (Table 1). Due to inherent differences in size structure among taxa, small-bodied and large-bodied species were visualized separately. Due to the temporal range of the dataset, fish assemblages were evaluated on a decadal time-scale.

The Department reviewed each species-specific histogram for the most recent time period (Figure 2– 14). Where size classes were distributed across bins, the population was determined to be reproducing within that segment.

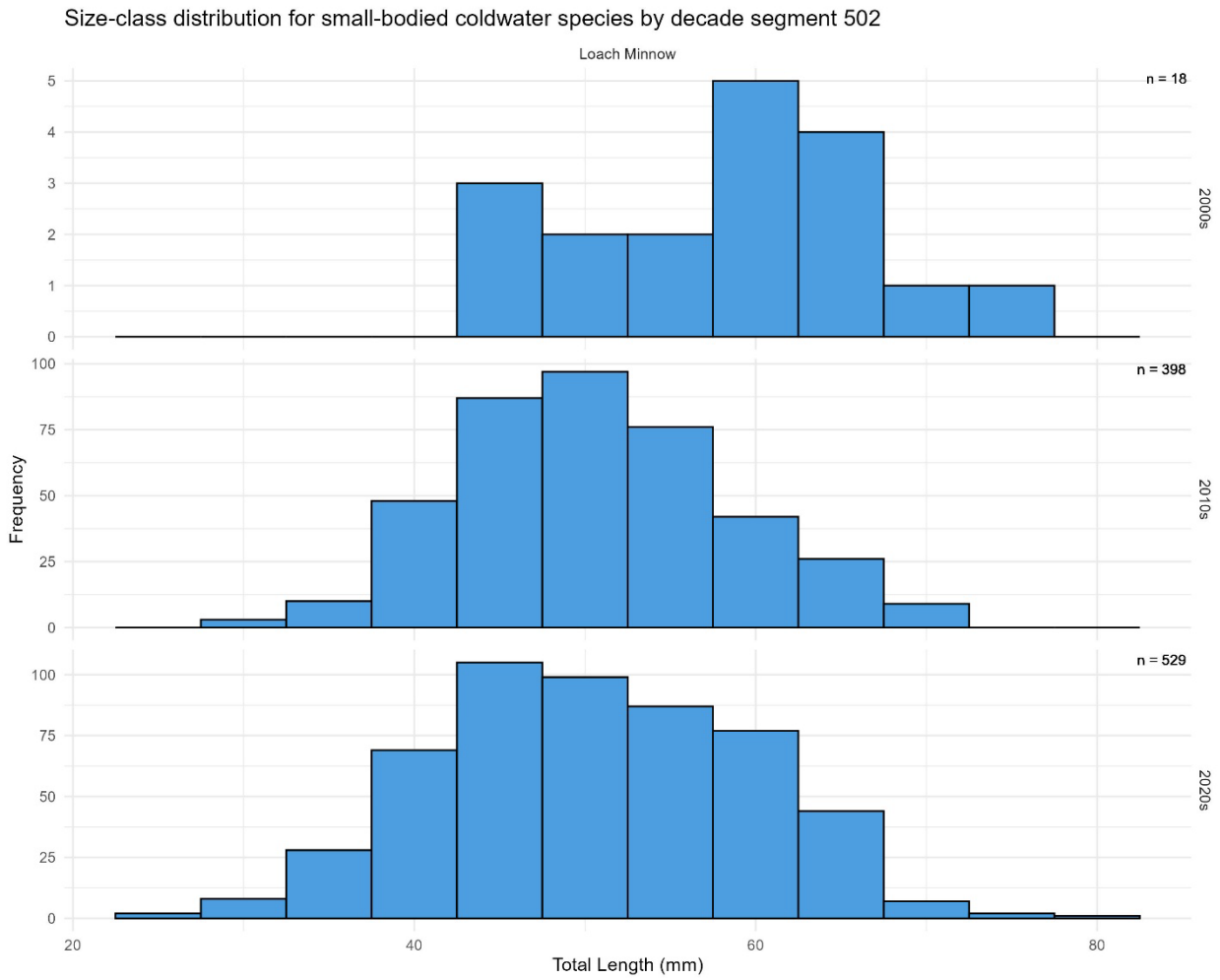


Figure 2 Length-frequency histogram of a small-bodied coldwater species, Loach Minnow, collected in Segment 502 between 2000s and 2020s. The distribution of size classes across bins is indicative of a reproducing and propagating population.

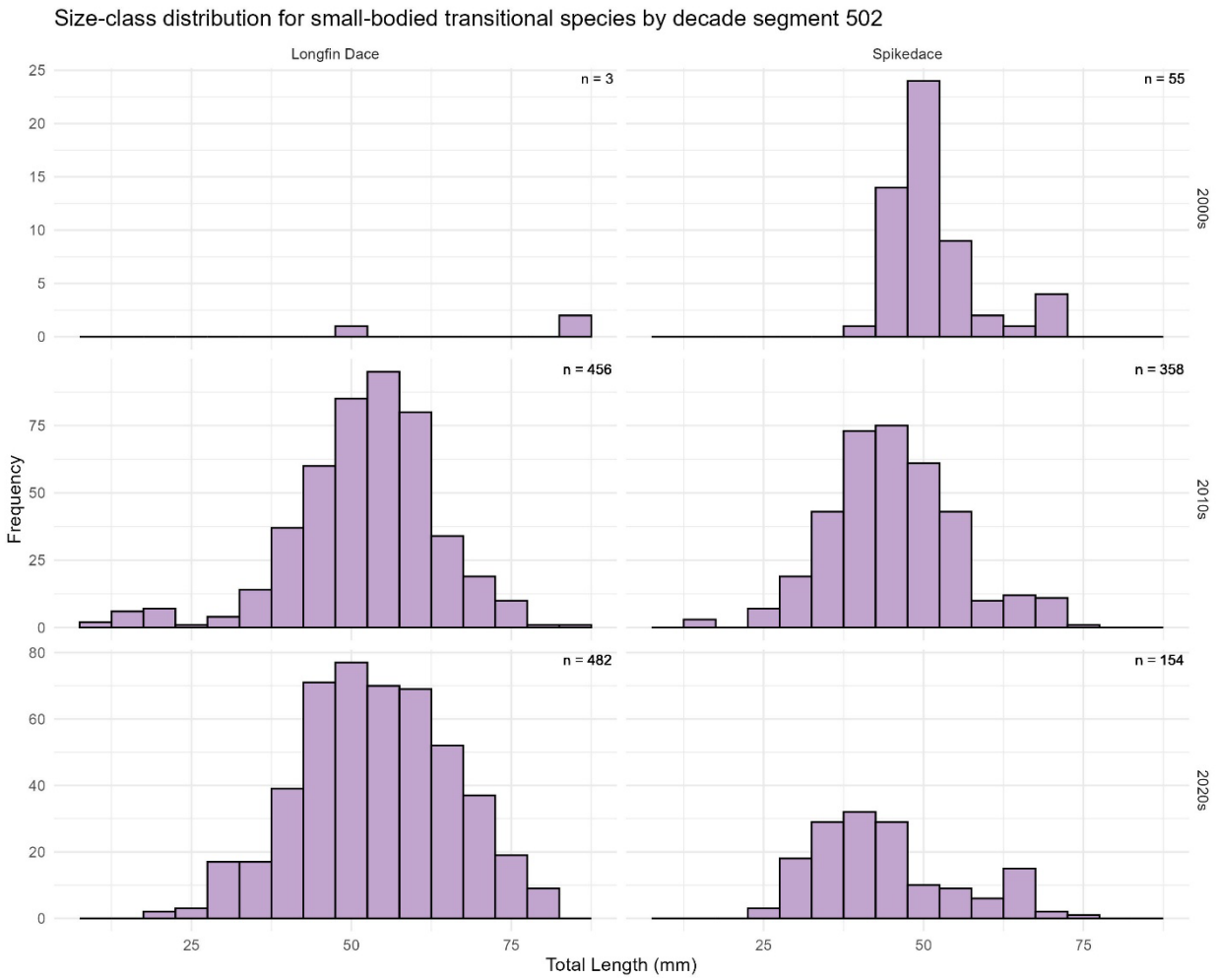


Figure 3 Length-frequency histogram of small-bodied transitional species, Longfin Dace and Spikedace, collected in Segment 502 between 2000s and 2020s. The distribution of size classes across bins is indicative of a reproducing and propagating populations.

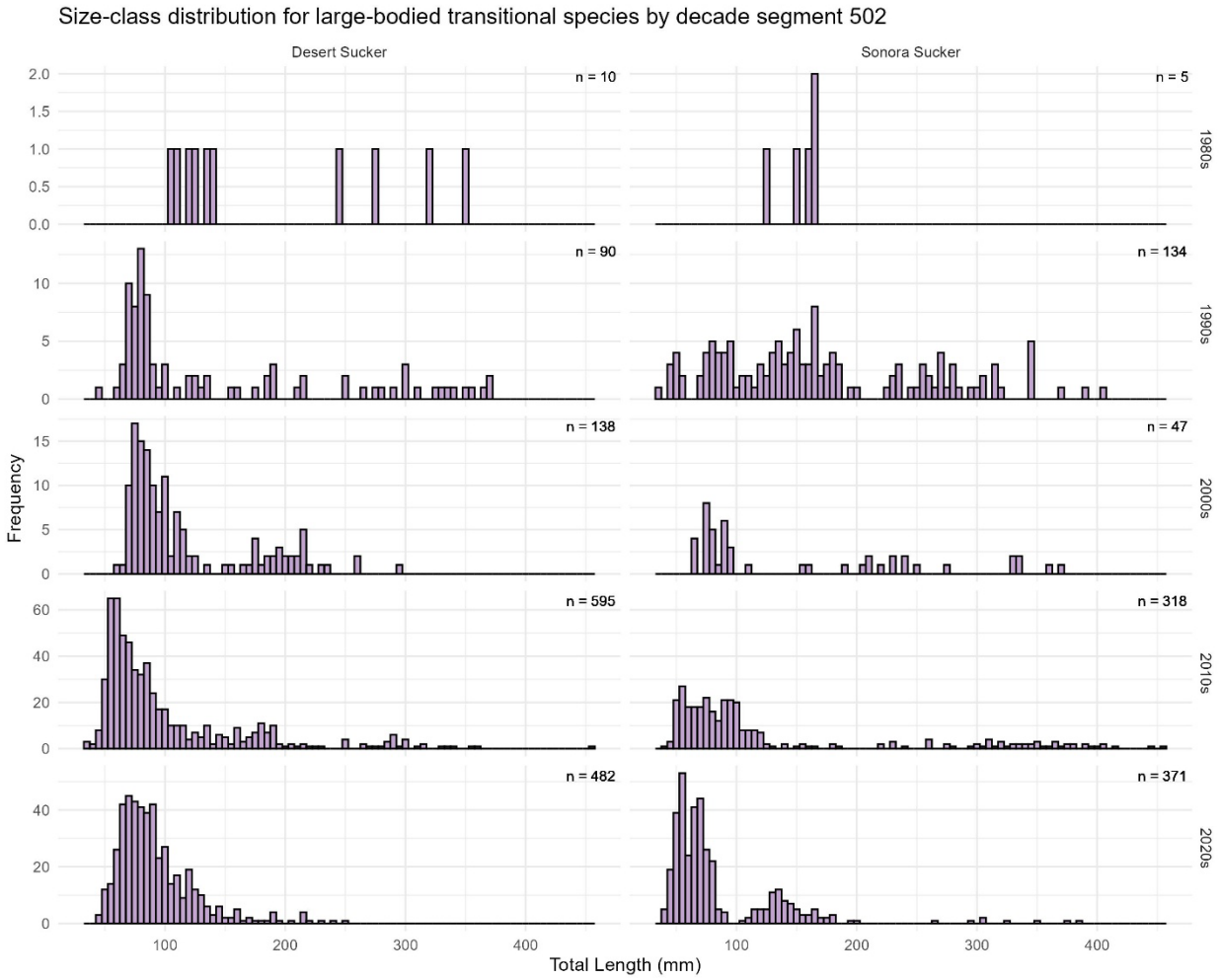


Figure 4 Length-frequency histogram of large-bodied transitional species, Desert Sucker and Sonora Sucker, collected in Segment 502 between 2000s and 2020s. The distribution of size classes across bins is indicative of a reproducing and propagating populations, particularly in later periods.

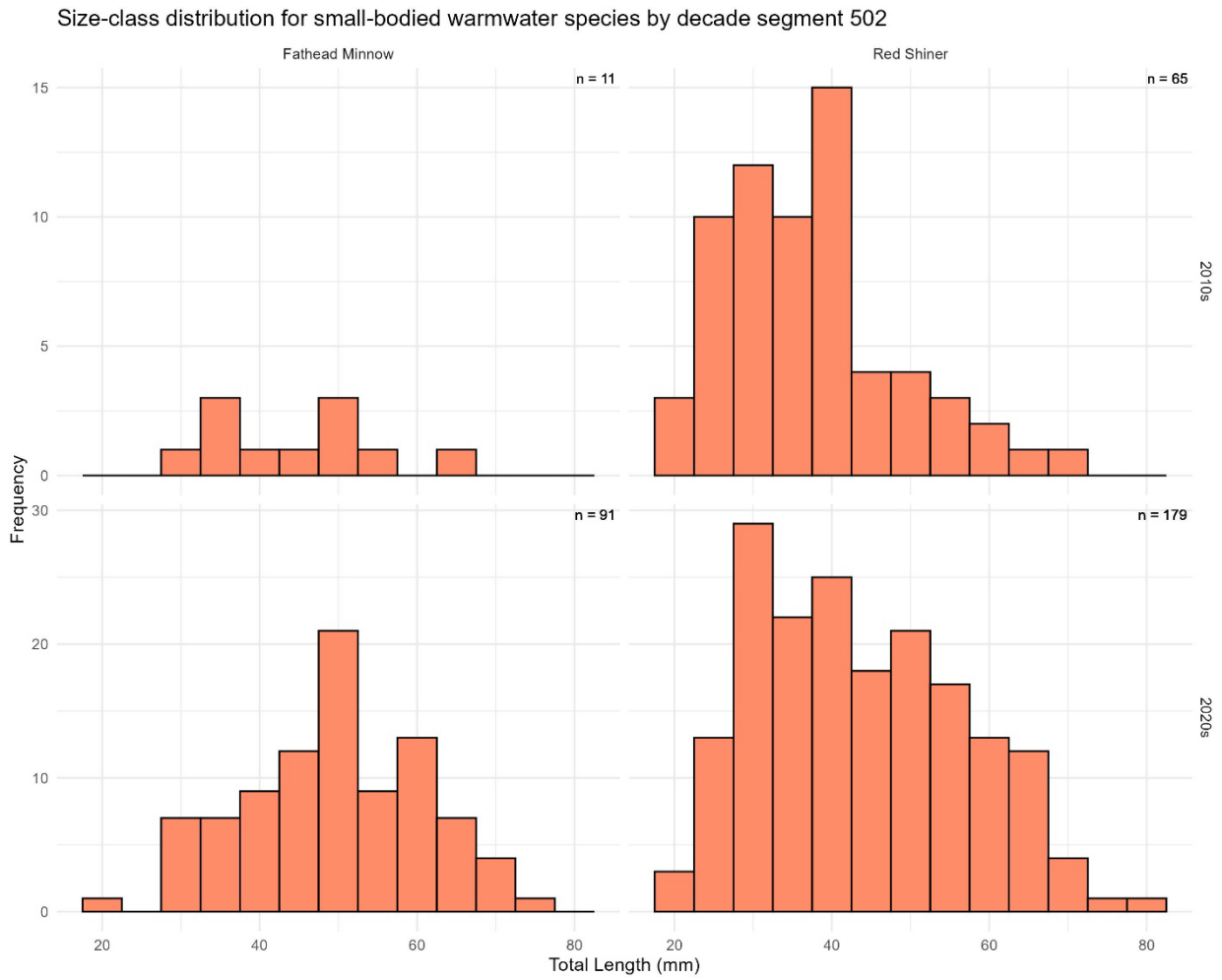


Figure 5 Length-frequency histogram of small-bodied warmwater species, Fathead Minnow and Red Shiner, collected in Segment 502 between 2010s and 2020s. The distribution of size classes across bins is indicative of reproducing and propagating populations.

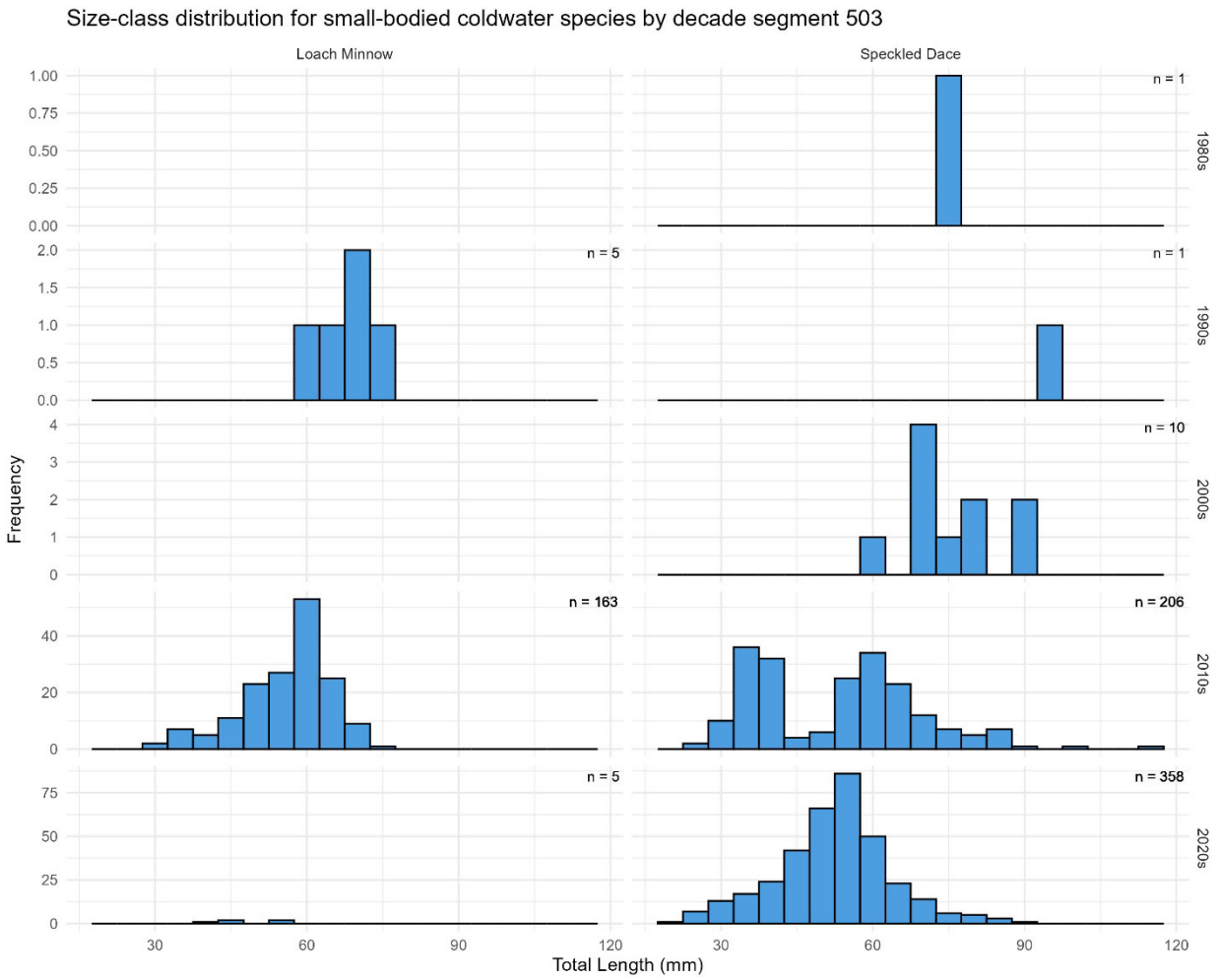


Figure 6 Length-frequency histogram of small-bodied coldwater species, Loach Minnow and Speckled Dace, collected in Segment 503 between 1980s and 2020s. The distribution of size classes across bins is indicative of a reproducing and propagating population of Speckled Dace. The Loach Minnow length-frequency histogram from the 2010s is indicative of a reproducing population, but sample-sizes from other decades were too small to evaluate.

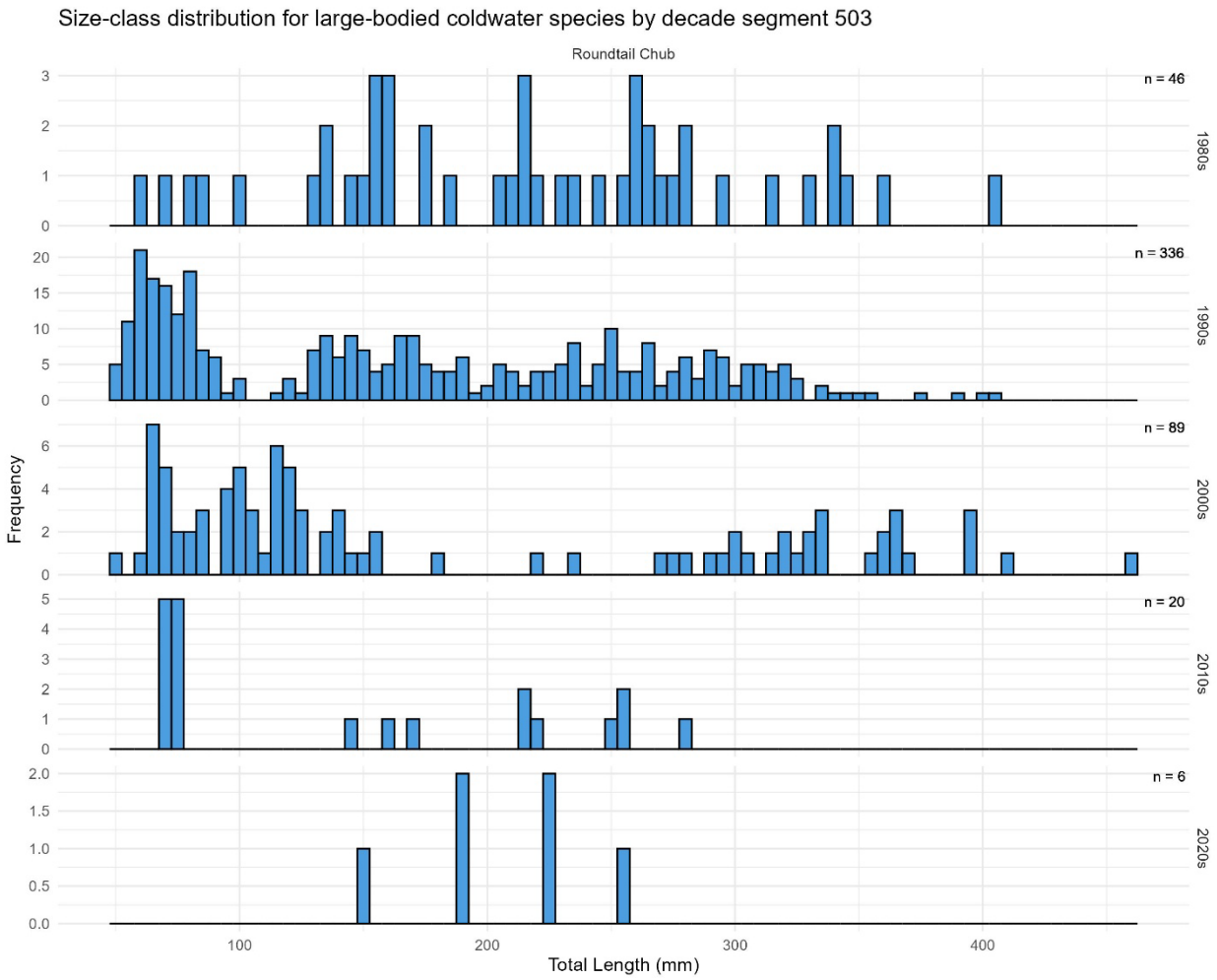


Figure 7 Length-frequency histogram of a large-bodied coldwater species, Roundtail Chub, collected in Segment 503 between 1980s and 2020s. The distribution of size classes across bins was indicative of a reproducing and propagating population in the 1990s. However, recent length-frequency histograms in more recent decades were not indicative of propagation.

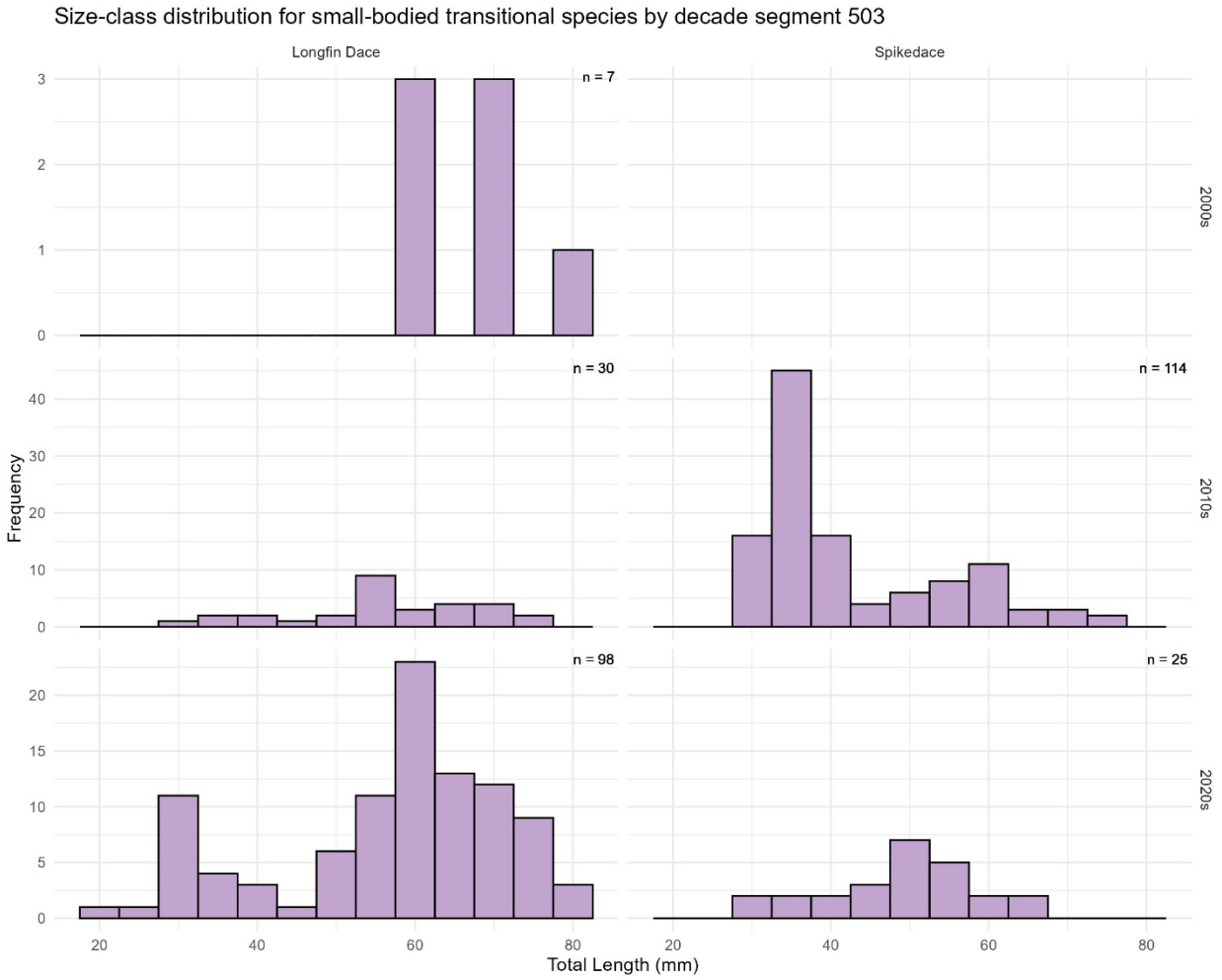


Figure 8 Length-frequency histogram of small-bodied transitional species, Longfin Dace and Spikedace, collected in Segment 503 between 2000s and 2020s. The distribution of size classes across bins was indicative of a reproducing and propagating population of Longfin Dace in the 2020s and of Spikedace in the 2010s.

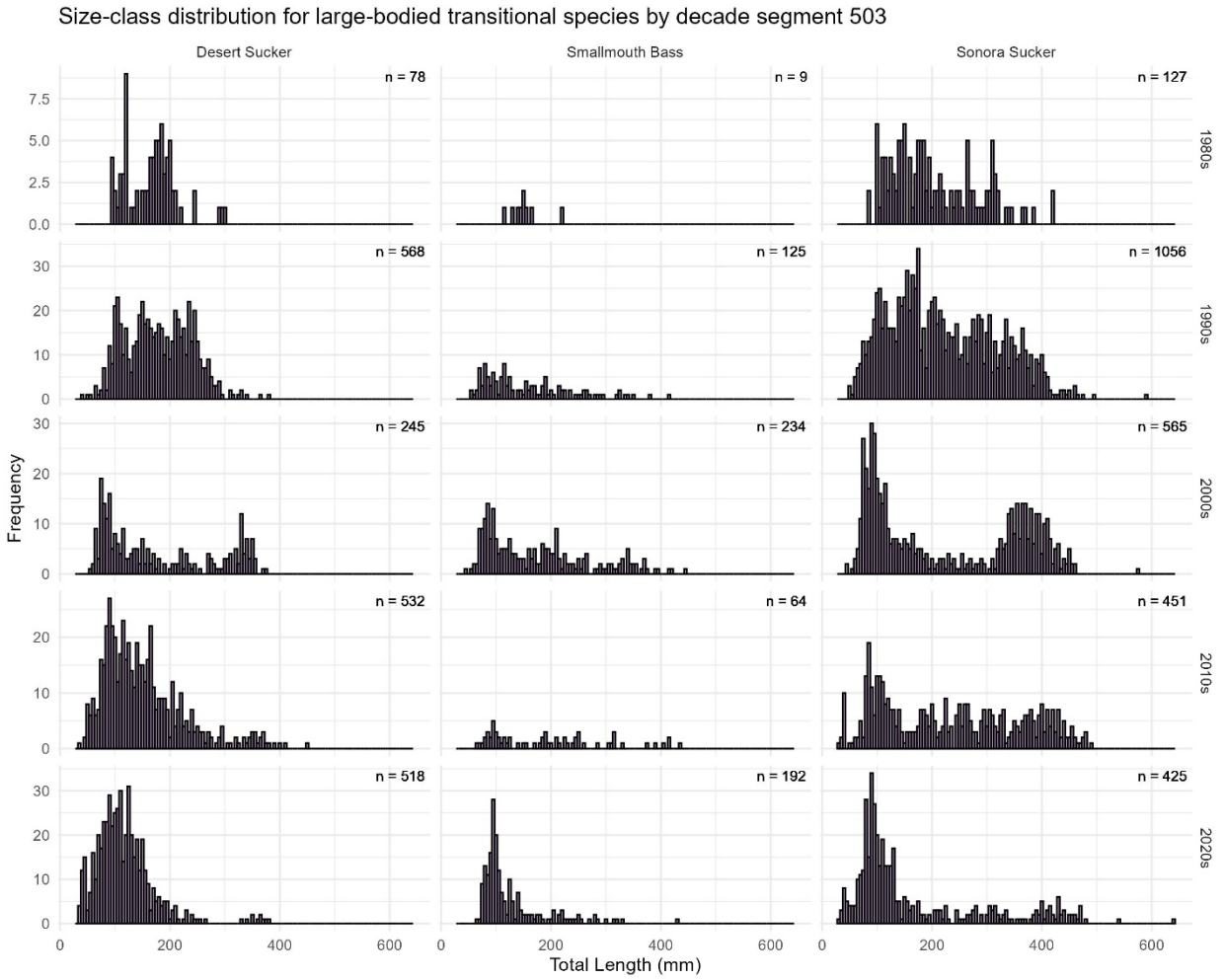


Figure 9 Length-frequency histogram of large-bodied transitional species, Desert Sucker, Smallmouth Bass, and Sonora Sucker, collected in Segment 503 between 1980s and 2020s. The distribution of size classes across bins is indicative of reproducing and propagating populations of all species.

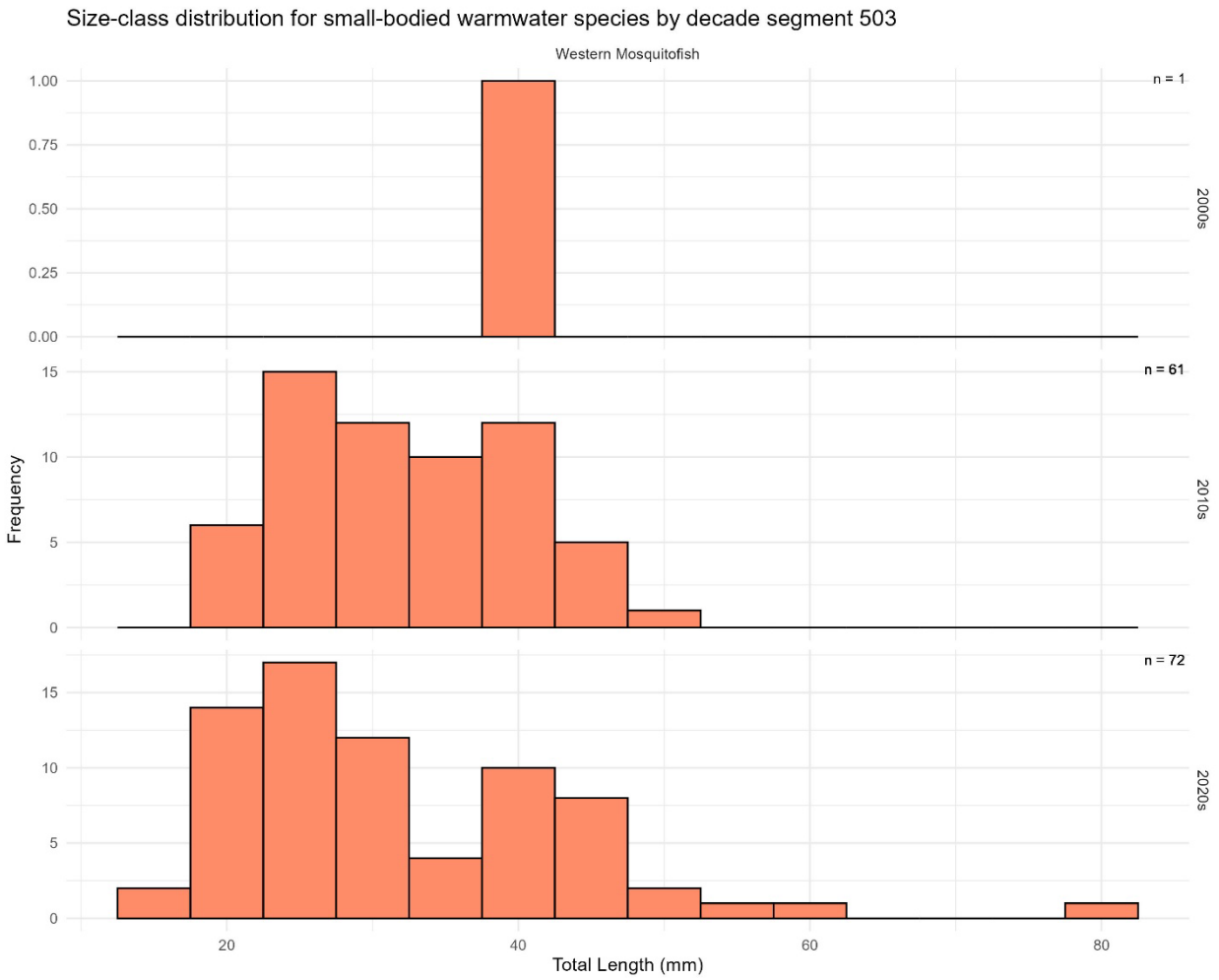


Figure 10 Length-frequency histogram of a small-bodied warmwater species, Western Mosquitofish, collected in Segment 503 between 2000s and 2020s. The distribution of size classes across bins was indicative of a reproducing and propagating population.

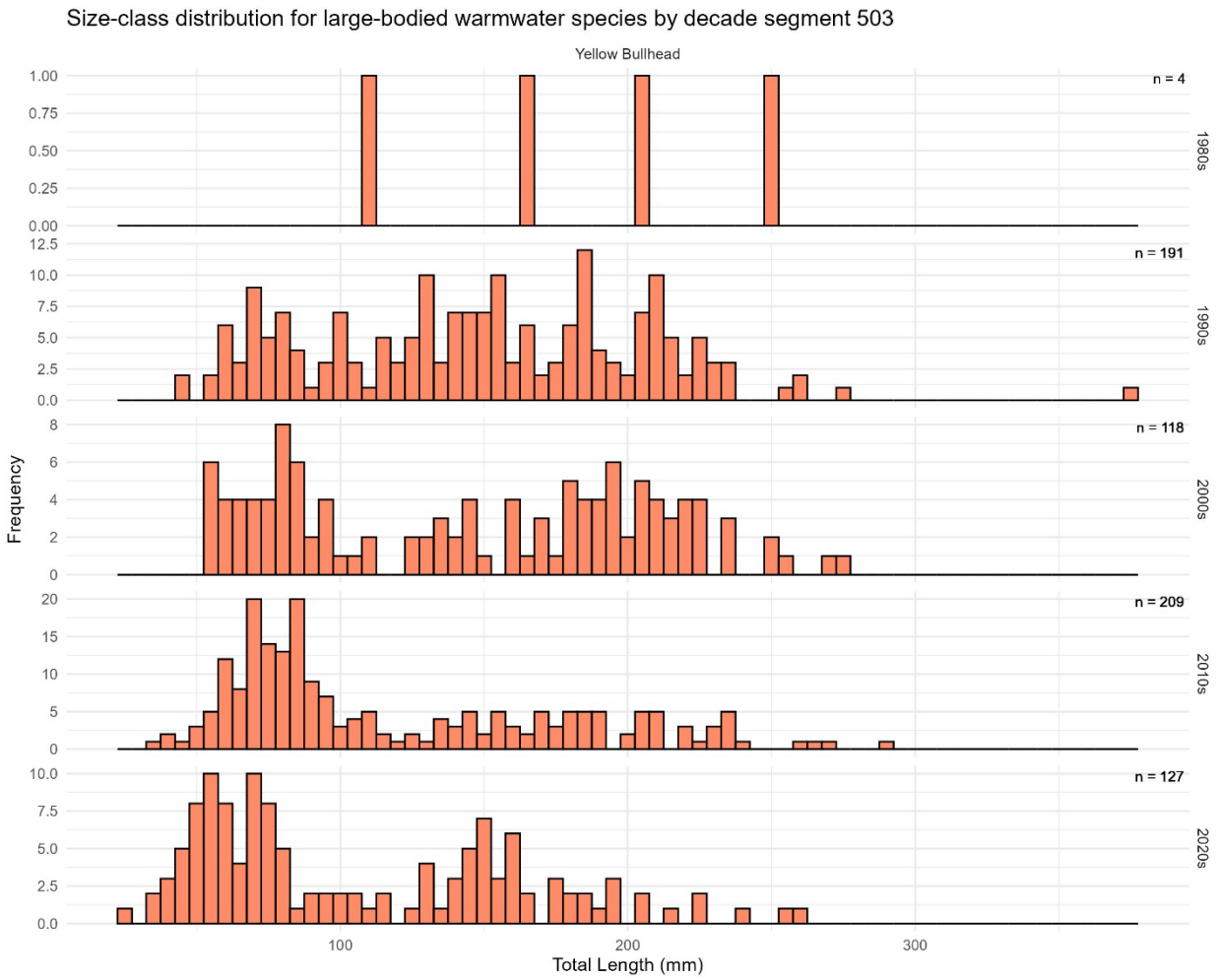


Figure 11 Length-frequency histogram of a large-bodied warmwater species, Yellow Bullhead, collected in Segment 503 between 1980s and 2020s. The distribution of size classes across bins was indicative of a reproducing and propagating population in most timescales.

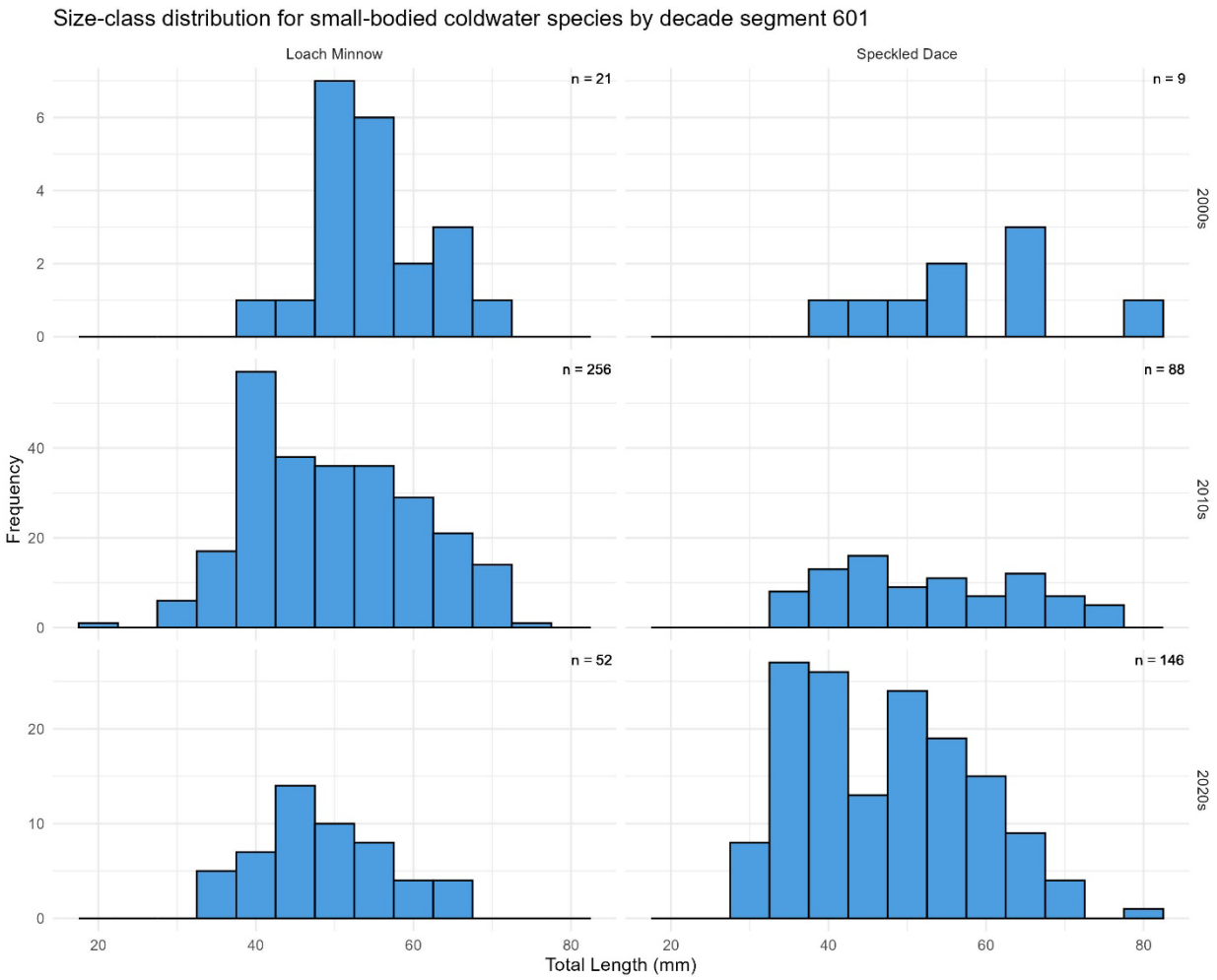


Figure 12 Length-frequency histogram of small-bodied coldwater species, Loach Minnow and Speckled Dace, collected in Segment 601 between 2000s and 2020s. The distribution of size classes across bins is indicative of a reproducing and propagating population of Speckled Dace in the 2010s and 2020s. The Loach Minnow length-frequency histograms across decades are indicative of a reproducing population.

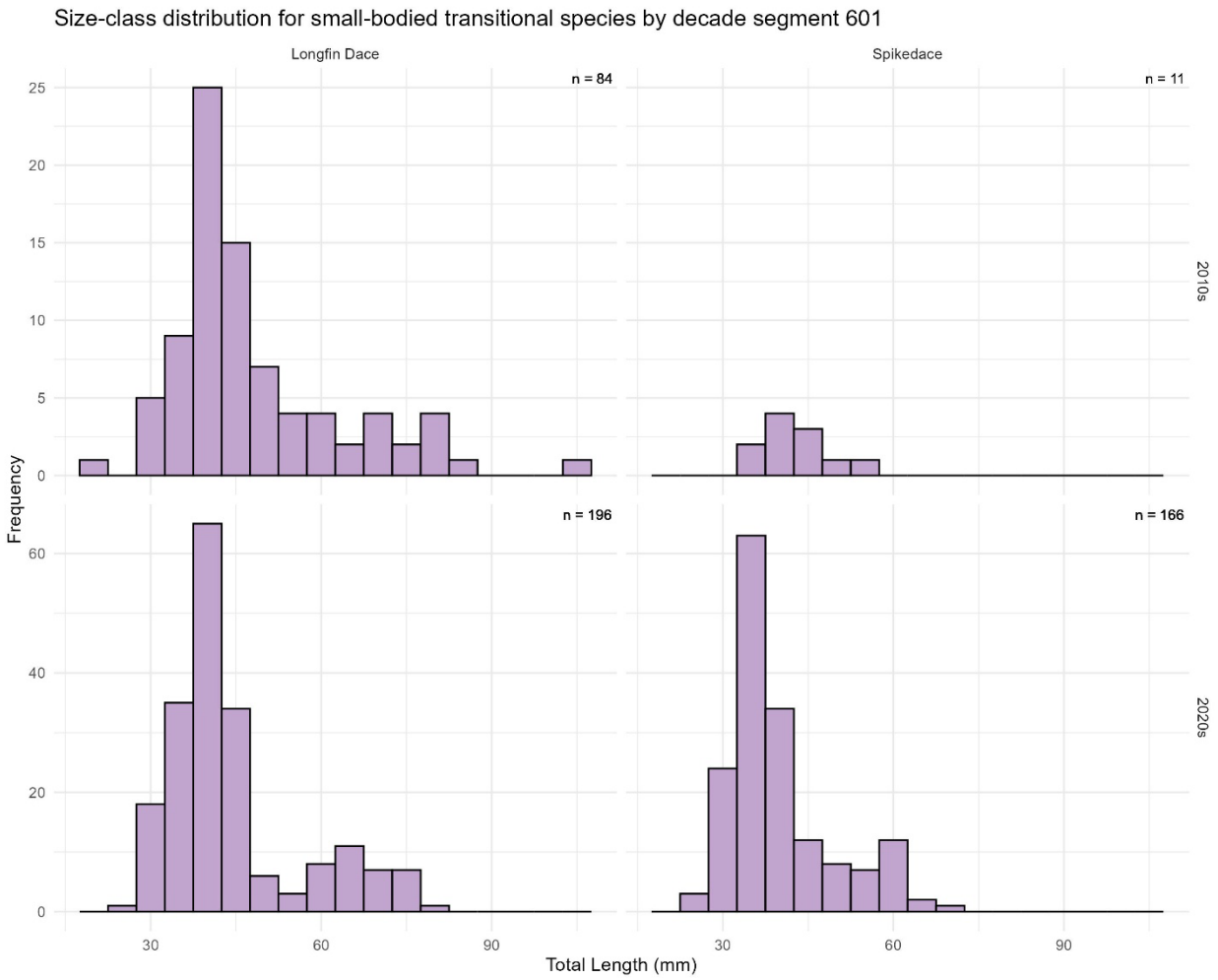


Figure 13 Length-frequency histogram of small-bodied transitional species, Longfin Dace and Spikedace, collected in Segment 601 between the 2010s and 2020s. The distribution of size classes across bins is indicative of reproducing and propagating populations of both species in the 2020s and of Longfin Dace in the 2010s

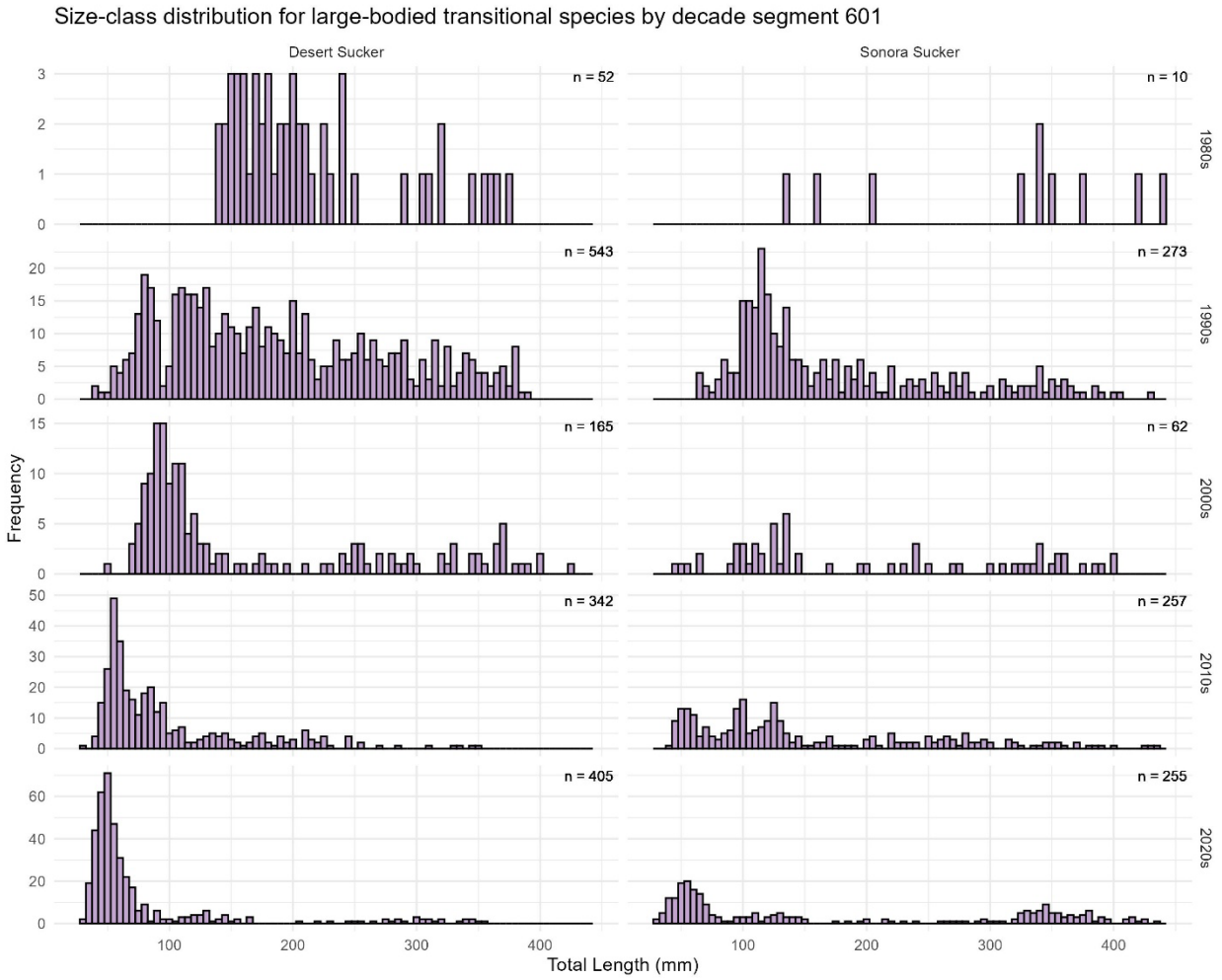
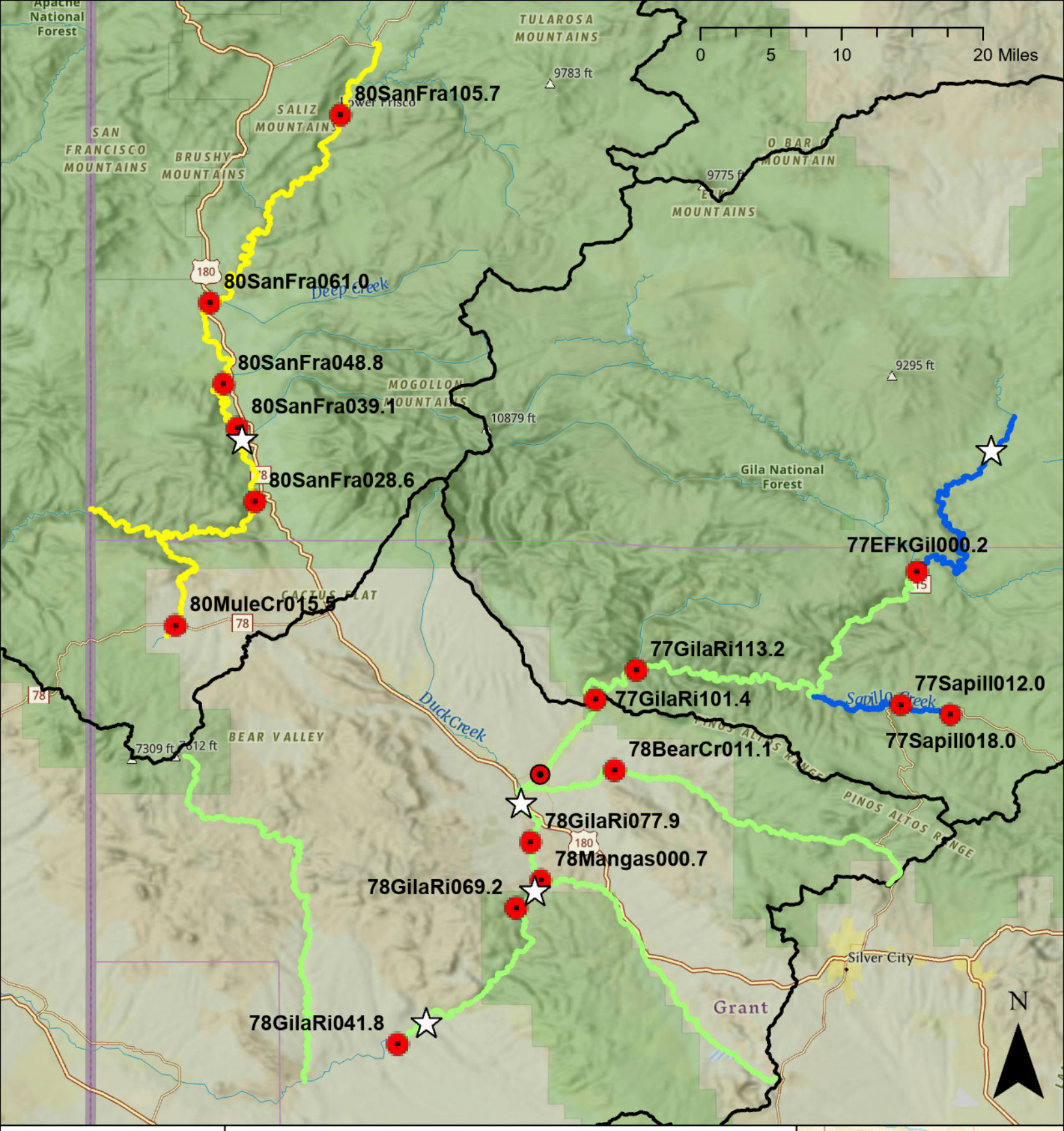


Figure 14 Length-frequency histogram of large-bodied transitional species, Desert Sucker and Sonora Sucker collected in Segment 601 between the 1980s and 2020s. The distribution of size classes across bins is indicative of reproducing and propagating populations of both species across multiple timeframes.



NEW MEXICO ENVIRONMENT DEPARTMENT

WQS segments
- 20.6.4.502
- 20.6.4.503
- 20.6.4.601

HUC 8 boundaries

Water Quality Sampling Stations

Fish collection sites

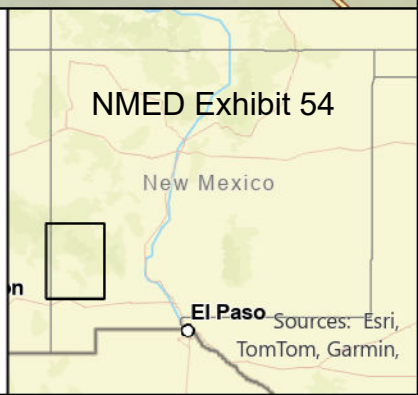
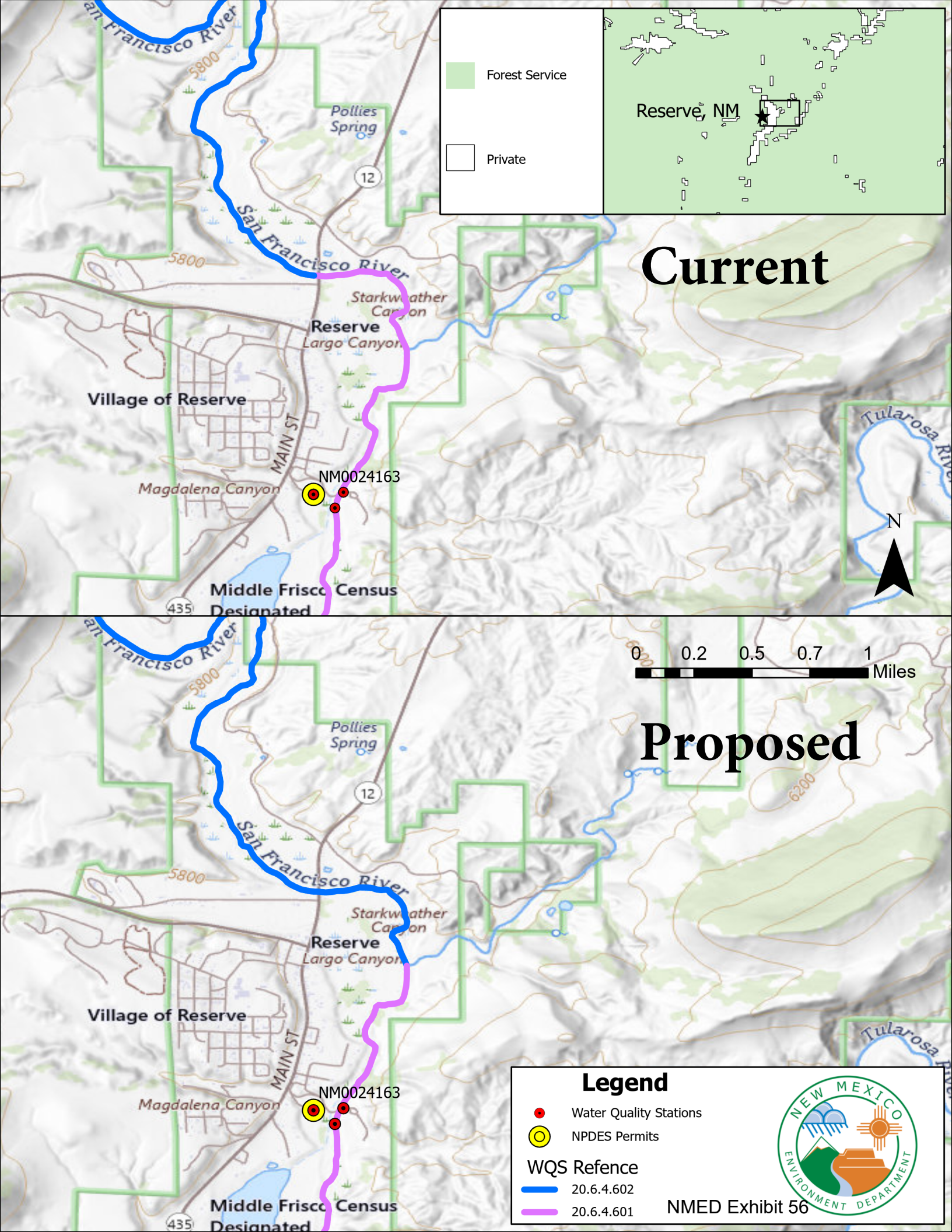


Table 1. SWQB Collected Thermograph Data

WQS segment	Reach name	WQS station ID	Station elevation (ft)	Year	thermograph TMAX (°C)	thermograph 4T3 (°C)	thermograph 6T3 (°C)
20.6.502	Bear Creek (Gila River nr Cliff to headwaters)	78BearCr011.1	4784	2019	30.95	26.37	24.25
20.6.502	Gila River (Mogollon Ck to East and West Forks of Gila R)	77GilaRi113.2	4803	2011	29.12	27.01	26.04
20.6.502	Gila River (Mogollon Ck to East and West Forks of Gila R)	77GilaRi101.4	4626	2019	28.77	26.18	25.40
20.6.502	Mangas Creek (Gila River to Mangas Springs)	78Mangas000.7	4396	2019	33.91	28.62	25.96
20.6.502	Gila River (Mangas Creek to Mogollon Creek)	78GilaRi087.7	4508	2007	28.72	26.87	26.26
20.6.502	Gila River (Mangas Creek to Mogollon Creek)	78GilaRi077.9	4520	2019	30.44	27.92	26.72
20.6.502	Gila River (Mangas Creek to Mogollon Creek)	78GilaRi077.9	4520	2020	30.34	27.92	26.94
20.6.502	Gila River (Red Rock to Mangas Creek)	78GilaRi069.2	4337	2007	30.55	28.94	27.70
20.6.502	Gila River (Red Rock to Mangas Creek)	78GilaRi041.8	4035	2019	31.28	29.46	28.47
20.6.503	Sapillo Creek (Gila River to Lake Roberts)	77Sapill018.0	5997	2007	22.68	20.65	20.58
20.6.503	Sapillo Creek (Gila River to Lake Roberts)	77Sapill012.0	5795	2020	21.53	19.34	18.70
20.6.503	Sapillo Creek (Gila River to Lake Roberts)	77Sapill012.0	5795	2019	20.58	19.15	18.44
20.6.503	East Fork Gila River (Gila River to Taylor Creek)	77EFkGil000.2	5551	2007	29.49	27.55	26.28
20.6.503	East Fork Gila River (Gila River to Taylor Creek)	77EFkGil000.2	5551	2019	28.54	25.70	25.09
20.6.601	San Francisco River (Willow Springs Cyn to NM 12 at Reserve)	80SanFra105.7	5604	2019	27.02	23.20	22.08
20.6.601	San Francisco River (Willow Springs Cyn to NM 12 at Reserve)	80SanFra105.7	5604	2020	31.71	27.11	24.53
20.6.601	San Francisco River (Pueblo Ck to Willow Springs Cyn)	80SanFra061.0	4993	2019	30.09	25.60	23.69
20.6.601	San Francisco River (Whitewater Ck to Pueblo Ck)	80SanFra039.1	4708	2011	25.09	23.28	23.09
20.6.601	San Francisco River (Whitewater Ck to Pueblo Ck)	80SanFra048.8	4882	2019	31.82	29.02	27.24
20.6.601	San Francisco River (Whitewater Ck to Pueblo Ck)	80SanFra048.8	4882	2020	28.67	22.01	21.15
20.6.601	San Francisco River (Box Canyon to Whitewater Creek)	80SanFra028.6	4587	2019	28.37	25.26	23.95
20.6.601	San Francisco River (Box Canyon to Whitewater Creek)	80SanFra028.6	4587	2020	27.36	25.16	23.81
20.6.601	Mule Creek (San Francisco R to Mule Springs)	80MuleCr015.5	5217	2011	26.70	23.95	23.21

Table 2. Air-Water Temperature Correlation (AWTC) Modeled Water Temperature Data

WQS segment	Reach name	AWTC modeled TMAX (°C)	AWTC modeled 4T3 (°C)	AWTC modeled 6T3 (°C)
20.6.4.502	Bear Creek (Gila River nr Cliff to headwaters)	29.688	26.558	25.338
20.6.4.502	Gila River (Mogollon Ck to East and West Forks of Gila R)	29.676	26.546	25.326
20.6.4.502	Mangas Creek (Mangas Springs to headwaters)	30.263	27.133	25.896
20.6.4.502	Mangas Creek (Gila River to Mangas Springs)	31.106	27.976	26.719
20.6.4.502	Gila River (Mangas Creek to Mogollon Creek)	31.640	28.510	27.236
20.6.4.502	Gila River (Red Rock to Mangas Creek)	32.033	28.903	27.615
20.6.4.502	Blue Creek (Gila River to headwaters)	31.192	28.062	26.799
20.6.4.503	Sapillo Creek (Gila River to Lake Roberts)	28.710	25.580	24.387
20.6.4.503	East Fork Gila River (Gila River to Taylor Creek)	27.664	24.534	23.372
20.6.4.601	San Francisco River (Willow Springs Cyn to NM 12 at Reserve)	28.238	25.108	23.930
20.6.4.601	San Francisco River (Pueblo Ck to Willow Springs Cyn)	29.000	25.870	24.671
20.6.4.601	San Francisco River (Whitewater Ck to Pueblo Ck)	30.187	27.057	25.823
20.6.4.601	San Francisco River (Box Canyon to Whitewater Creek)	30.961	27.831	26.574
20.6.4.601	Mule Creek (San Francisco R to Mule Springs)	30.324	27.194	25.956
20.6.4.601	San Francisco River (AZ border to Box Canyon)	31.154	28.024	26.762


Forest Service
Private
Reserve, NM
Current
San Francisco River
Pollies Spring
12
5800
Starkweather Canyon
Reserve
Largo Canyon
Village of Reserve
MAIN ST
Magdalena Canyon
NM0024163
Middle Frisco Census Designated
435
Tularosa River
N
0 0.2 0.5 0.7 1 Miles
Proposed
6200
Legend
Water Quality Stations
NPDES Permits
WQS Refence
20.6.4.602
20.6.4.601
NEW MEXICO ENVIRONMENT DEPARTMENT
NMED Exhibit 56

STATE OF NEW MEXICO
WATER QUALITY CONTROL COMMISSION

IN THE MATTER OF:

PETITION FOR REGULATORY CHANGE TO
ADOPT AMENDMENTS TO 20.6.4 NMAC –
Standards For Interstate and Intrastate Surface Waters **WQCC 25-75 (R)**

DIRECT TECHNICAL TESTIMONY OF STEPHANI CLARK BARKALOW

I. INTRODUCTION

My name is Stephani Clark Barkalow, and I am presenting this written testimony **(NMED Exhibit 57)** on behalf of the New Mexico Environment Department (Department or NMED) concerning proposed changes to numerical Water Quality Standards (WQS) codified at Title 20, Chapter 6, Part 4, of the New Mexico Administrative Code (20.6.4 NMAC).

My testimony will provide the technical basis and reasoning for proposed amendments to water quality criteria in 20.6.4.900 NMAC and updated references in 20.6.4.901 NMAC including:

- Adoption of updated numeric selenium criterion based on U.S. Environmental Protection Agency (EPA) Section 304(a) recommendations;
- Adoption of new numeric criteria for per- and polyfluorylalkyl substances (PFAS), including PFOA and PFOS, based on EPA Section 304(a) recommendations;
- Update to Domestic Water Supply criteria based on EPA Maximum Contaminant Levels (MCLs) and Treatment Techniques;
- Updates to designations of persistent toxic pollutants;
- Establishment of a default pH range for limited aquatic life designated uses;
- Revisiting Clean Water Act Section 304(a) recommended criteria that have been considered but not adopted in previous Triennial Reviews;

- Formatting revisions for Aquatic Life designated uses and their associated criteria;
- Formatting revisions to the criteria table in 20.6.4.900(J) NMAC;
- Correction of a typo in table at 20.6.4.900(L)(1) NMAC; and
- Updated references in Section 901.

My testimony also explains the regulatory framework for water quality standards and how these proposed amendments ensure protection of designated uses in New Mexico.

II. QUALIFICATIONS

I am currently employed by the New Mexico Environment Department (NMED) Surface Water Quality Bureau (SWQB) Monitoring and Standards Section (MASS) as a Senior Water Quality Standards Scientist and have held this position since April 2025. I am responsible for evaluating proposed water quality standards and preparing technical water quality standards demonstrations for New Mexico's surface waters in accordance with the New Mexico Water Quality Act and the federal Clean Water Act.

I hold a Bachelor of Science degree in Biology from the University of New Mexico and a Master of Science degree in Fisheries Conservation and Management from the University of Arizona. My master's work focused on evaluating water quality impacts on sensitive life stages of an endangered fish species, identifying lethal thresholds of suspended sediments, and developing recommendations to mitigate water quality degradation. My findings from this research were published in the *Transactions of the American Fisheries Society* in 2015. This research, and my other peer-reviewed published papers, are referenced in my resume.

Prior to working for SWQB, I worked on water quality issues in various capacities. From March 2014 to October 2024, I worked as a biologist for a fisheries consulting firm where I evaluated impacts of land and water development on aquatic ecosystems, led ecological studies

focusing on sedimentation, entrainment, and aquatic habitat quality, and investigated the influence of geology on concentrations of related elements in water and fish tissues. Most recently, I worked as a biologist with U.S. Fish and Wildlife Service from November 2024 to March 2025 where I administered National Fish and Wildlife Foundation funds in compliance with the Endangered Species Act and Clean Water Act, developed and directed projects related to water quality monitoring, and conducted evaluations of environmental data. An accurate and up-to-date copy of my resume is included as **NMED Exhibit 58**.

III. PROPOSED CRITERIA AMENDMENTS

Water quality standards define "the goals for a waterbody, or portion thereof, by designating the use or uses to be made of the water and by setting criteria necessary to protect the uses." 40 C.F.R. § 131.2. Criteria may be expressed as narrative statements or numeric values that represent the level of water quality necessary to protect a designated use of a waterbody. Under Sections 303(c)(1) and 303(c)(2)(A) of the Clean Water Act (CWA), states are required, when reviewing or revising water quality standards, to adopt water quality criteria necessary to protect designated uses. Consistent with these statutory obligations, 40 C.F.R. § 131.20(a) requires states to review and, when appropriate, modify and adopt applicable water quality standards (i.e., Triennial Review). Pursuant to 40 C.F.R. § 131.11, states are required to adopt criteria that protect designated uses which may be based on numeric criteria based on EPA's CWA Section 304(a) guidance, 304(a) guidance modified to reflect site-specific conditions, or established using other scientifically defensible methods. Although states are not required to adopt EPA's 304(a) criteria verbatim, a state that chooses not to adopt those criteria must provide justification to EPA as part of its Triennial Review under Section 303(c)(1) and 40 C.F.R. § 131.20(c). These requirements guide the review of New Mexico's numeric criteria.

A. CLEAN WATER ACT SECTION 304(a) NUMERIC CRITERIA, 20.6.4.900 NMAC

i. Selenium aquatic life criterion

The Department proposes the adoption of the updated aquatic life selenium criterion based on EPA's recommended chronic criterion published under CWA Section 304(a) in 2016, with a revision in 2021 **(NMED Exhibit 59)**. The Department proposes adoption of the whole-body and muscle tissue-based metrics, as well as the 30day mean water column concentration. The current selenium aquatic life criteria in New Mexico were approved in 2002 and consist of an acute value of 20.0 µg/L and a chronic value of 5.0 µg/L.

EPA's updated selenium criterion is a single chronic aquatic life criterion composed of multiple tissue- and water-based metrics. The criterion was derived from fish egg-ovary selenium concentrations because eggs and ovaries are the most reliable indicators of selenium toxicity. EPA's recommended fish tissue-based metrics include instantaneous whole-body or muscle tissue concentrations, as well as egg-ovary tissue concentrations. Water-based metrics consist of 30-day mean dissolved selenium concentrations for lentic and lotic aquatic systems and a water column intermittent element for evaluating short-term discharges. EPA did not develop an acute criterion because it would not be protective against the primary exposure pathway, which is dietary exposure leading to bioaccumulation. Each medium-specific value is independently applicable, so that an exceedance in any fish tissue or water-based metric is considered an exceedance of the standard.

The Department reviewed the updated selenium criterion during the 2020 Triennial Review and elected not to adopt it due to the complexity of implementing a criterion with multiple metrics and the lack of EPA technical guidance on implementation. In addition, the Department was unable

to devote resources to collection of 30-day water samples or fish tissue samples at a single site. In 2024, EPA published a technical support document for adopting and implementing the 2016 selenium criterion, which clarified sample prioritization and provided guidance on implementation **(NMED Exhibit 60)**. EPA recommends prioritizing fish tissue-based metrics over water column values when there are no new selenium inputs and concentrations of selenium within fish tissue are at steady-state meaning fish uptake and depuration of selenium equilibrate such that selenium concentrations are no longer increasing following a new selenium input to the waterbody. **(NMED Exhibit 60)** Water column values are appropriate when fish are absent or when there are new selenium inputs to a system **(NMED Exhibit 60).**

Based on this updated guidance, the Department proposes adoption of whole-body and muscle tissue-based values, as well as the 30-day mean water column concentration. The Department does not propose adoption of the egg-ovary tissue-based metric because the State does not incorporate egg-ovary tissue collection as part of existing monitoring protocols and due to the potential spatial and temporal challenges related to collection of egg-ovary tissue in gravid female fish. The Department also does not propose adoption of the intermittent water column element because implementation presents challenges by requiring measurement of baseline selenium concentrations in each waterbody and because the metric is essentially a re-expression of the 30-day mean metric.

Selenium is a naturally occurring element found in high concentrations in some sedimentary rocks with high organic content and can enter groundwater and surface waters through natural weathering processes. Anthropogenic sources, including mining, mineral extraction, fossil fuel use, and irrigation of selenium-rich soils, can increase selenium concentrations in aquatic systems. Selenium is a nutritionally essential element; however, at elevated concentrations it can

have deleterious effects due to bioaccumulation through the aquatic food web. Bioaccumulation can result in birth defects and mortality of larvae, particularly in fish, which are the most sensitive taxa. Because the criterion is based on fish tissue, it ensures protection of aquatic life as well as wildlife and terrestrial organisms dependent on aquatic food webs **(NMED Exhibit 59)**. Adoption of EPA's updated selenium criterion, which is based on the best available science and most sensitive species, will provide more stringent protection than the existing criteria, and the Department has determined that it is feasible to implement effectively to ensure continued protection of aquatic life.

The SWQB has established a framework for using fish tissue-based contaminant data during development of the CWA § 303(d)/§ 305(b) Integrated Report **(NMED Exhibit 30)**. Fish tissue monitoring is conducted to support the development of Fish Consumption Advisories in coordination with the NM Department of Wildlife (NMDOW) and the NM Department of Health (NMDOH), which are published in NMDOW's annual New Mexico Fishing Rules and Info proclamation and maintained on SWQB's website to be protective of human health. These data and resultant consumption advisories inform impairment listing of waterbodies for contaminants for which there is a fish consumption advisory. The Department's use of tissue-based data for contaminants like mercury, PCBs, and DDT demonstrates that fish tissue data are already an accepted and regular component of the SWQB monitoring and assessment framework.

The Department has analyzed selenium data in 389 fish muscle samples from 2010 to 2025 using four different EPA methods: 200.9, 200.8, 6020 (ICP-MS) and 6010D (ICP-AE). Selenium concentrations ranged from 0.64 to 8.17 mg/kg, and no selenium concentrations from fish tissue sampled between 2010 and 2025 exceeded the EPA's recommended water quality criterion for muscle tissue of 11.3 mg/kg **(NMED Exhibit 61)**.

Implementation of the proposed selenium criterion is consistent with existing fish tissue monitoring conducted for Fish Consumption Advisories. EPA recommends incorporating selenium sampling into existing tissue monitoring programs, and the addition of selenium is not anticipated to require additional effort for sample acquisition.

ii. PFAS (PFOS and PFOA Aquatic Life Criteria)

The Department proposes to adopt the EPA's CWA Section 304(a) recommended aquatic life criteria for perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA), finalized in September 2024 **(NMED Exhibit 62 and 63)**. These criteria represent the first national criteria developed for these PFAS under Section 304(a) of the CWA. EPA incorporated both water-column and tissue-based components to address bioaccumulation and dietary exposure pathways and established acute and chronic water-column concentrations as well as chronic tissue-based concentrations for fish and aquatic invertebrates. Collectively, these criteria are designed to protect aquatic organisms from adverse effects associated with PFOS and PFOA exposure, including impacts to survival, growth, and reproduction.

PFOS and PFOA are legacy perfluoroalkyl substances (PFAS), a class of synthetic fluorinated chemicals characterized by extreme environmental persistence, resistance to degradation, and bioaccumulative properties. PFAS have been widely used in industrial, consumer, and firefighting applications since the 1950s because their unique chemical and physical properties impart oil-, water-, stain- and soil-repellency, reduce friction, and confer resistance to heat and chemical degradation **(NMED Exhibit 64)**. In the United States, PFOS production ended in 2002 with PFOA production and import eliminated by 2015. Although PFOS and PFOA are no longer manufactured or imported, they remain among the most frequently detected PFAS compounds in aquatic environments due to their persistence and the continued degradation of precursor

compounds **(NMED Exhibits 62 and 63)**. The environmental persistence of PFAS has resulted in widespread detection in surface waters, sediments, groundwater, fish, and wildlife. Sources include wastewater treatment plant discharges, landfill leachate, industrial discharges, aqueous film-forming foam (AFFF), atmospheric deposition, and runoff from contaminated soils.

PFOS bioaccumulates in aquatic organisms and can biomagnify through aquatic food webs **(NMED Exhibit 62)**. Chronic exposure to PFOS has been shown to impair growth, reproduction, and survival in fish and aquatic invertebrates even at low concentrations. Although PFOA generally exhibits lower bioaccumulation potential and toxicity relative to PFOS, it remains toxic to sensitive aquatic species and is associated with developmental, reproductive, and systemic effects in aquatic organisms **(NMED Exhibit 63)**. EPA concluded that tissue-based criteria are necessary to address dietary exposure and trophic transfer, which are important exposure pathways for PFAS in aquatic ecosystems.

The SWQB began sampling PFAS in select surface waters in 2023 to increase the knowledge of PFAS distribution in the State's waterbodies. SWQB completed water quality sampling at 11 sites between 2023 and 2025. PFOS and PFOA were detected at four sites. PFOS ranged from 1.77×10^{-3} to 3.80 µg/L and PFOA ranged from 2.41×10^{-2} to 0.68 µg/L. PFOS and PFOA were not detected at the remaining seven sites as shown in the following table. Except for samples collected in Holloman Lake, all PFOS and PFOA concentrations are below the recommended acute and chronic 304(a) criteria. Holloman Lake PFOS concentrations exceed the chronic 304(a) criterion but not the acute criterion. PFOS and PFOA concentrations reported in the ecological research study **(NMED Exhibit 65)** are within a similar concentration range, but are presented separately in the table due to different collection efforts and methodologies. A value of "ND" in the table indicates that the relevant PFAS compound was not detected in the sample.

		PFOS (µg/L)		PFOA (µg/L)	
Assessment Unit Name	n=	Minimum	Maximum	Minimum	Maximum
Rio Grande (non-pueblo Alameda Bridge to HWY 550 Bridge)	5	ND	ND	ND	ND
Rio Grande (Tijeras Arroyo to Alameda Bridge)	4	ND	ND	ND	ND
Santa Fe River (Cochiti Pueblo bnd to Cienega Creek)	4	4.38×10^{-3}	7.66×10^{-3}	5.48×10^{-3}	9.18×10^{-3}
Cienega Creek (Perennial prt of Santa Fe R to headwaters)	1	2.28×10^{-3}	———	2.66×10^{-3}	———
Rio Grande (Cochiti Reservoir to San Ildefonso bnd)	5	ND	ND	ND	ND
Ute Reservoir	3	1.77×10^{-3}	———	2.41×10^{-3}	2.48×10^{-3}
Mora River (USGS gage east of Shoemaker to HWY 434)	2	ND	ND	ND	ND
Lake Maloya	3	ND	ND	ND	ND
San Juan River (Navajo bnd at Hogback to Animas River)	6	ND	ND	ND	ND
Lake Farmington (Beeline Reservoir)	3	ND	ND	ND	ND
Lake Holloman	8	0.26	3.80	7.10×10^{-2}	0.68
Ecological Research on PFAS at Lake Holloman (NMED 2025)	4	0.15	2.20	2.7×10^{-2}	3.70

Adoption of numeric aquatic life criteria for PFOS and PFOA will establish a scientifically robust foundation for surface water quality assessments, permitting actions, and regulatory decision-making in New Mexico. Adopting EPA's recommended criteria will also ensure that New Mexico's surface water quality standards reflect the best available science regarding the persistence, bioaccumulation, and toxicity of PFOS and PFOA and provide a regulatory framework for the protection of aquatic life from PFOS and PFOA contamination.

B. Non-304(a) NUMERIC CRITERIA, 20.6.4.900 NMAC

i. Domestic Water Supply Criteria

The Department proposes new and updated Domestic Water Supply (DWS) criteria for 2,4-D, methoxychlor, silvex, and lead based on EPA Maximum Contaminant Levels (MCLs) and Treatment Techniques established under National Primary Drinking Water Regulations

(NPDWR) at 40 C.F.R. Part 141.

The DWS designated use is applicable to surface waters that could be used for drinking or culinary purposes after disinfection and is intended to provide protection for individuals who obtain drinking water directly from those waters. DWS criteria are designed to protect long-term users and therefore reflect lifetime exposure assumptions. These criteria are not applicable to waters designated for Public Water Supply, which serve as source waters for public water systems subject to finished drinking water requirements under the federal Safe Drinking Water Act (42 U.S.C. §§ 300f-300j-27). The intent of DWS criteria is to provide a level of protection equivalent to that afforded to individuals served by regulated public water systems.

DWS criteria are derived using chronic exposure parameters consistent with long-term consumption of untreated or minimally treated surface water over a lifetime. These assumptions are appropriate for evaluating household drinking water or culinary use but are not representative of short-term, intermittent, or incidental exposure scenarios. Thus, these criteria do not apply to temporary or incidental consumption of surface waters by recreational users.

EPA utilizes multiple statutory and regulatory mechanisms to protect human health from contaminants in drinking water. Under the Safe Drinking Water Act (42 U.S.C. §§ 300f et seq.), EPA establishes NPDWR, including MCLs and Treatment Techniques, which apply to finished drinking water delivered by public water systems to end users. Although these standards apply to treated drinking water, their underlying health benchmarks provide a scientifically defensible basis for evaluating risks associated with direct consumption of surface water.

In contrast, water quality standards for the protection of designated uses, including human health, are developed pursuant to Section 304(a) of the CWA. Because DWS is not a designated use identified in Section 101(a)(2) of the CWA, there are no mandatory federal numeric criteria

for this use. As a result, states may derive DWS criteria based on EPA Section 304(a) criteria or other scientifically defensible methods.

DWS criteria in 20.6.4.900(J) NMAC are based on MCLs or Treatment Techniques when such values are available. The Water Quality Control Commission (Commission) has previously determined that drinking water-based criteria provide an appropriate and protective basis for establishing DWS criteria, including in the 2010 Triennial Review. The current proposal applies updated NPDWR values where available. The proposed amendments are based on MCLs for 2,4-D, methoxychlor, and silvex, and a Treatment Technique action level for lead **(NMED Exhibit 66)**. In the current rulemaking, no DWS criteria are proposed based on EPA Section 304(a) recommendations using the human health water-only calculations.

ii. Limited Aquatic Life - pH criterion

The Department proposes to include a default pH range of 6.0 to 9.0 for waters designated as limited aquatic life in 20.6.4.900(H)(7) NMAC. pH is a measure of the concentration of hydrogen and hydroxyl ions in water and is expressed on a logarithmic scale from 0 to 14, with 7 being neutral. Water with a pH less than 7 is acidic, and water with a pH greater than 7 is basic.

Both low and high pH can directly affect aquatic biota, decreasing growth, inhibiting reproduction, and causing physical harm and mortality **(NMED Exhibit 67)**. Over time, these direct effects can alter species composition and cause community collapse. pH influences many chemical and biological processes and can alter the chemical form, bioavailability and toxicity of metals, pollutants, and ammonia thus affecting aquatic biota **(NMED Exhibit 68)**. Outside a pH range of 6.0–9.0, toxicity of metals such as aluminum, copper, and zinc increases, and the balance of ammonium–ammonia shifts toward more toxic un-ionized ammonia. Extremes in pH can disrupt osmoregulation and metabolic activity, inhibit egg hatching, and decrease productivity of

aquatic biofilms and periphyton that form the base of aquatic food webs **(NMED Exhibit 69)**.

The limited aquatic life designated use applies to ephemeral waters under 20.6.4.97 NMAC and select classified segments. Unlike other aquatic life designated uses, the current limited aquatic life use designation does not include a default pH range. Ephemeral waters that support short-term assemblages of aquatic biota, including invertebrates and amphibians, rely on appropriate water chemistry for survival, growth, and reproduction.

Establishing a pH range of 6.0 to 9.0 for limited aquatic life waters is necessary to maintain basic chemical and physiological conditions required for aquatic communities during wetted periods. The CWA requires that upstream water quality conditions do not prevent attainment of downstream water quality standards. Because a large proportion of surface waters in New Mexico are non-perennial, establishing a pH range for limited aquatic life waters provides protection for these systems and helps ensure protection of downstream aquatic communities. The proposed pH range is consistent with technology-based effluent limits included in National Pollutant Discharge Elimination System permits **(NMED Exhibit 70)**.

iii. Persistent Toxic Pollutants

The Department proposes to update the designation of persistent toxic pollutants within the numeric criteria table at 20.6.4.900(J)(1) NMAC based on updated scientific information using EPA's Toxics Release Inventory (TRI) Persistent, Bioaccumulative, and Toxic Chemicals **(NMED Exhibit 71)** and the Stockholm Convention on Persistent Organic Pollutants **(NMED Exhibit 73)**.

Persistent chemicals are those that resist environmental degradation and persist in the environment for long periods. Many persistent pollutants are toxic to human health and bioaccumulate in organisms, resulting in increasing concentrations in food webs and elevated risk

to humans and wildlife.

EPA and international bodies, including the Stockholm Convention, define and classify persistent pollutants for regulatory and reporting purposes. EPA's TRI program established criteria to identify chemicals exhibiting persistent or bioaccumulative properties and developed a list of Persistent, Bioaccumulative, and Toxic Chemicals (40 C.F.R. Part 372). Under this program, persistence is evaluated using environmental media-specific half-life thresholds, including a half-life of at least two months in water (**NMED Exhibit 72**).

The TRI program requires reporting for listed chemicals that are currently manufactured, processed, or used in the United States above applicable levels (40 C.F.R. Part 372). Because reporting is activity-based, some legacy chemicals regulated under the CWA are not included because they are banned and no longer used domestically. To address this limitation, the Department also considers the Stockholm Convention on Persistent Organic Pollutants as an appropriate and complementary source for identifying persistent pollutants. Like the TRI Persistent, Bioaccumulative, and Toxic Chemicals, Stockholm Convention pollutants exhibit persistent, bioaccumulative, and toxic properties and are recognized for long-range transport and ecological and human health risks **(NMED Exhibit 73)**.

In the 2002 Triennial Review that adopted criteria for EPA priority pollutants for human health, the Department designated certain pollutants as persistent based on EPA's list of Persistent, Bioaccumulative, and Toxic Chemicals and identified several metals as persistent due to their environmental stability and bioaccumulative behavior. See page 114 of the rulemaking transcript **(NMED Exhibit 74)**. Human health-organism only criteria for persistent toxic pollutants are applied to waters with a limited aquatic life designated use and to tributaries of waters with a designated, existing, or attainable aquatic life use.

Although waters with limited aquatic life designated use do not support fish populations, applying criteria for persistent pollutants to these waters is necessary to protect downstream waters that do support fish that may be consumed by people. Persistent chemicals can bind to soils and may be remobilized during flood events, facilitating downstream transport to waters supporting fish and other wildlife. Long half-lives in soil or water increase the likelihood that chemicals discharged into ephemeral waters will persist and adversely affect downstream intermittent and perennial waters.

IV. 304(a) CRITERIA NOT PROPOSED

As required under CWA 303(c)(1), the Department evaluated EPA's CWA Section 304(a) recommendations relative to the State's numeric criteria in 20.6.4.900(J) NMAC and determined that revisions are not appropriate for several pollutants at this time. In line with past Triennial Reviews, the Department proposes to take no action on EPA's recommended 304(a) criteria for the following pollutants: aluminum, arsenic, copper, manganese, alkalinity, hydrogen sulfide, and zinc. The Department provides its reasoning below.

A. EPA's Recommended Aluminum Criterion

The Department does not propose adopting EPA's recommended acute and chronic aquatic life criteria for aluminum as a replacement for the current hardness-based standard. EPA's updated aluminum criteria utilize a multiple linear regression (MLR) **(NMED Exhibit 75)** to calculate bioavailable aluminum and requires three input parameters: pH, hardness, and dissolved organic carbon (DOC). Although the MLR represents the best available science for calculating aluminum instantaneous water quality criteria, its applicability is limited by uncertainties in EPA's extrapolation beyond the pH range and logistical challenges related to obtaining reliable DOC values across all monitoring locations.

The Department documented its rationale behind retaining the existing hardness-based aluminum criteria and characterized the challenges surrounding DOC collection during the 2020 Triennial Review **(NMED Exhibit 76)**. Since that review, the New Mexico Scientific Laboratory Division (SLD) has begun analyzing DOC and the Department has initiated troubleshooting and DOC collection during ambient rotational watershed water quality surveys. However, most watersheds have not yet been sampled, so acquisition of a statewide DOC data set is still several years away given resource constraints and competing sampling priorities.

EPA's technical support document **(NMED Exhibit 77)** suggests states may use default or ecoregional values for missing site-specific parameters, but EPA's recommended DOC values are based on sparse datasets that do not reflect New Mexico's typically low DOC values, complex geology or hydrologic variability, and would risk mischaracterizing site-specific conditions. Because adoption of EPA's MLR-based aluminum criteria would require representative DOC values to support basin-specific default assignments, the Department intends to develop a more complete statewide DOC dataset before proposing the MLR approach on a statewide level in a future rulemaking. Given these scientific, analytical, and implementation challenges, the Department concludes that retaining the current hardness-based aluminum criteria remains the defensible and practicable approach at this time.

B. EPA Section 304(a) Arsenic Criterion

The Department does not propose the adoption of the 2002 EPA recommended human health criterion for arsenic. The State documented the reasoning behind the current human health-organism only criterion of 9.0 µg/L in the Statement of Reasons from the 2005 Triennial Review **(NMED Exhibit 78)**. The State adopted a New Mexico-specific criterion using arsenic water column and fish tissue concentration from the Rio Grande. The Department's analysis of surface

water quality results for arsenic shows that undeveloped areas in New Mexico frequently exceed the EPA recommended concentration of 1.4 µg/L (increased by one order of magnitude to account for New Mexico's lifetime risk of more than one cancer per 100,000 exposed persons (see 20.6.2.3103(A)(2) NMAC)) **(NMED Exhibit 79)**. Since human health-organism only criteria cannot be modified for natural background (20.6.4.10(G) NMAC), adopting the more stringent criterion is not practicable.

C. EPA Section 304(a) Copper Criterion

The Department does not propose adoption of EPA's recommended aquatic life criterion for copper as a replacement of the current hardness-based water quality standard on a statewide basis. In 2007, EPA introduced revised aquatic life water quality criteria for copper using the Biotic Ligand Model (BLM) **(NMED Exhibit 80)** to consider the effects of ambient water quality on the toxicity of copper. Although the BLM provides a more accurate assessment of copper bioavailability than New Mexico's hardness-based criteria calculation, it requires the input of 11 coincident water quality parameters, some of which are not commonly available, for the calculation of an instantaneous water quality criterion. Recognizing the scarcity of data as a limitation of the BLM in its implementation guidance, the EPA recommends adopting the BLM for copper on a targeted basis while retaining hardness-based standards for all other waters **(NMED Exhibit 81)**. During the 2010 Triennial Review, the Commission adopted the provision described in 20.6.4.10(F)(4)(c) NMAC adding the BLM for copper as a scientifically defensible method for site-specific criterion development.

In 2025, the Commission adopted site-specific criteria for copper for surface waters on the Pajarito Plateau. These site-specific criteria were developed by third party petitioners (Petitioners), using an extensive 18-year water chemistry dataset to evaluate parameters influencing copper

bioavailability and to develop a multiple linear regression that was demonstrated to be comparable to EPA's copper BLM. During the rulemaking, Petitioners' technical witness testified that statewide implementation of the BLM would require additional analyses beyond those conducted for the Pajarito Plateau, including using reference values for missing water chemistry parameters, demonstrating that statewide implementation would involve additional data collection and uncertainty **(NMED Exhibit 82)**. Accordingly, the Department will continue to evaluate the implementation of the BLM for copper on a segment-specific basis.

D. EPA Section 304(a) Manganese Criterion

The Department does not propose adoption of EPA's recommended human health-organism only criterion for manganese. Manganese is a naturally occurring element commonly found in food and water and is an essential micronutrient required for normal cellular function. EPA's human health-organism only criterion was developed in 1976 to address risks of consumption of marine shellfish **(NMED Exhibit 83)**, not freshwater fish, and EPA's 1976 criteria did not identify freshwater fish consumption as a pathway requiring a human-health criterion for manganese. The criterion was developed using early methods that predate EPA's 2000 human-health methodology **(NMED Exhibit 84)** and has not been updated to reflect current human-health criteria procedures. Because the criterion is a legacy value derived for marine shellfish consumption and was not developed using a freshwater fish consumption exposure pathway or modern human-health criteria methods, the Department does not recommend its adoption into the State's WQS.

E. EPA Section 304(a) Alkalinity Criterion

The Department does not propose adoption of EPA's recommended CWA 304(a) aquatic-life criterion for alkalinity. Alkalinity is a measure of the buffering capacity of water, expressed as

calcium carbonate ($CaCO_3$) in units of milligrams per liter (mg/L). Although alkalinity is an important water-quality characteristic that contributes to pH buffering and may influence metal bioavailability, the 1976 EPA criteria document **(NMED Exhibit 83)** in which the criterion was recommended does not identify a direct aquatic-life effects threshold or provide toxicity-based support for a statewide numeric criterion. The recommendation predates the stringent modern aquatic-life criteria development methods used by EPA to develop 304(a) criteria **(NMED Exhibit 85)**. The aquatic-life concerns identified by EPA are addressed through existing pH criteria and narrative standards requiring protection of aquatic life and ecological integrity. Therefore, the Department does not recommend adoption of the aquatic-life criterion for alkalinity.

F. EPA Section 304(a) Hydrogen Sulfide Criterion

The Department does not propose adoption of EPA's recommended CWA 304(a) aquatic life criterion for hydrogen sulfide. EPA's hydrogen sulfide criterion was developed in 1976 **(NMED Exhibit 83)**, prior to the current aquatic life criteria guidelines using limited toxicity information that does not meet the minimum data requirements applied to modern Section 304(a) aquatic life criteria **(NMED Exhibit 85)**.

Hydrogen sulfide is a noxious, soluble, gaseous compound primarily produced by anaerobic decomposition. Hydrogen sulfide toxicity is strongly influenced by site-specific factors including pH and temperature. Formation of hydrogen sulfide is influenced by low dissolved oxygen concentrations which can cause anaerobic decomposition of organic material and the subsequent formation of hydrogen sulfide and other gases. EPA recognizes that the risk to aquatic life of hydrogen sulfide is often localized and transient. Existing water quality standards require that surface waters be free from substances at concentrations that impair aquatic life or ecological integrity and include dissolved oxygen, temperature, and pH criteria that address conditions that

influence hydrogen sulfide formation and toxicity. Given the limited scientific basis of the criterion, and the protections afforded by existing narrative and numeric criteria, the Department does not support adoption of the 1976 hydrogen sulfide criterion.

G. EPA Section 304(a) Zinc criteria

The Department proposes to retain the existing acute and chronic hardness-based criteria for zinc which are less stringent than EPA's Section 304(a) criteria. EPA's hardness-based zinc criteria were published in 1987 **(NMED Exhibit 86)** and were previously adopted during the 1991 Triennial Review into the state standards **(NMED Exhibit 87)**. During the 2010 Triennial Review, the Commission adopted alternative criteria based on updated toxicological studies. The changes to the hardness-based equations were informed by a more recent review of the zinc standards adopted by the state of Colorado, a review of EPA's recalculation procedure, and additional data from newer toxicological studies. The zinc criteria were developed using EPA's guidance for the protection of aquatic life **(NMED Exhibit 88)**.

Although EPA's 1995 zinc criteria are more stringent at the same hardness, the criteria adopted in 2010 and currently in the standards remains the most up-to-date and scientifically rigorous values. The rationale used by the Commission in 2010, and subsequently approved by EPA Region 6, still applies. The Department therefore proposes to retain the current hardness-based acute and chronic aquatic life use criteria for zinc.

V. FORMATTING AMENDMENTS

A. ALU section formatting and clarity

The Department proposes to restructure Section 20.6.4.900(D) - Primary Contact, Section 20.6.4.900(E) - Secondary Contact, and Section 20.6.4.900(H) NMAC - Aquatic Life, into table formats consistent with other subsections of 20.6.4.900 NMAC to provide clarity for implementing

and applying standards. References to using cfu/100mL and MPN/100 mL for *E. coli* bacteria were removed from section 20.6.4.900(D) as redundant as their definitions in 20.6.4.7 NMAC state that either standard may apply based on analytical method used. Additionally, the Department proposes to add clarifying language to the Coolwater criteria in Section 20.6.4.900(H) NMAC regarding segment-specific temperature values to ensure consistency with other aquatic life designated uses and to improve clarity.

B. Non-substantive and typographical changes within numeric criteria tables

The Department is proposing several non-substantive formatting changes to more prominently and consistently display units in the table of numeric criteria at 20.6.4.900(J) NMAC. To improve readability, scientific notation was applied to values less than 0.0001 and to values equal to or greater than 100,000. Additionally, changes to lettering in paragraph (2) (Notes applicable to the table of numeric criteria) resulted in moving note 2(c) regarding criteria units to paragraph (1).

The Department is also proposing to correct a typo in the Total Ammonia Nitrogen (TAN) table at 20.6.4.900(L)(1) NMAC. During the 2020 Triennial Review, the Commission adopted EPA's Section 304(a) criteria for TAN based on the equations and values in EPA's *Aquatic Life Ambient Water Quality Criteria for Ammonia- Freshwater 2013* document. EPA later notified the Department that a typo in its published criteria table had been carried into the newly adopted NMAC table. The proposed amendment updates the acute TAN value at pH 7.9 and 17°C from 3.0 mg/L to the correct value of 6.0 mg/L **(NMED Exhibit 89)**.

C. Amendments to Publication References Section

In the Publication References section (20.6.4.901 NMAC), the Department proposes to remove unnecessary language from the introductory paragraph. The Department further proposes

to add a reference to the most recent edition of American Public Health Association's *Standard Methods for the Examination of Water and Wastewater*. This addition results in the re-lettering of the subsequent references to 20.6.4.901(F) through 20.6.4.901(O) NMAC. The Department further proposes to amend the reference to be consistent with the 2023 review of the Water Quality Standards for Salinity for the Colorado River System (**NMED Exhibit 90**). This review did not indicate the need for amendments to 20.6.4.54 NMAC to meet the Colorado River Salinity Forum's goals.

VI. CONCLUSION

The Department recommends that the Commission adopt the proposed amendments to the WQS discussed above, filed with the Department's First Amended Petition (**NMED Exhibit 27**) and based on the testimony of SWQB's witnesses.

This concludes my direct technical testimony.

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- Master's thesis: Effects of suspended sediment on Yaqui chub, *Gila purpurea*

University of New Mexico, Albuquerque, NM (2005-2010)
Bachelor of Science in Biology, Concentration in Conservation Biology, Minor in Environmental Science

WORK EXPERIENCE

Water Quality Standards Scientist, New Mexico Environment Department, Surface Water Quality Bureau, Albuquerque, NM.
April 2025-present

- Evaluate proposed amendments to New Mexico's Surface Water Quality Standards and develop technically and scientifically defensible WQS proposals consistent with the federal Clean Water Act and New Mexico Water Quality Act
- Conduct evaluations of scientific studies, environmental datasets, and technical literature to assess designated uses and criteria updates
- Perform statistical analyses, data assessments, and calculations to support water quality standards revisions
- Support the triennial review of surface water quality standards under the federal Clean Water Act. Responsibilities involve evaluating new scientific findings and regulatory updates, considering public input, and aiding in subsequent rulemaking
- Act as New Mexico Environment Department's project manager for the New Mexico Fish Consumption Advisories program

Four Corners Power Plant Biologist, U.S. Fish and Wildlife Service, New Mexico Ecological Services Field Office, Albuquerque, NM.
November 2024-February 2025: Full time

- Organized partner meetings within the San Juan River Basin and Colorado River Basin
- Collaborated with state and federal agencies, tribal nations, water users, and non-profit organizations to develop adaptive management strategies for aquatic ecosystems
- Developed partnerships with private landowners and management at Four Corners Power Plant
- Administered National Fish and Wildlife Foundation funds in compliance with Endangered Species Act and Clean Water Act
- Developed and directed projects related to water quality monitoring, habitat creation, habitat monitoring, and monitoring of native and nonnative fishes in the Colorado River Basin
- Evaluated research proposals and prioritized funding based on program goals

- Conducted independent evaluations of environmental data
- Assisted principal investigators with project development, data analysis, and field logistics

Senior Fisheries Biologist, American Southwest Ichthyological Researchers, Albuquerque, NM
March 2014-November 2024; March -April 2025: Full time

- Provide federal agencies with compliance information through data and review of projects for compliance with Endangered Species Act and the Clean Water Act especially in relation to use of water resources for irrigation, energy, and urbanization projects
- Conducted ecological studies and implemented projects in support of management goals of San Juan Recovery Implementation Program, June Sucker Recovery Implementation Program, and Rio Grande Chub and Sucker Conservation Team to inform management efforts related to recruitment, habitat use, and impacts of land and water development on aquatic biodiversity
- Provided and reviewed compliance in regard to ESA Section 10 permits
- Served as lead technical writer of scientific reports and manuscripts
- Worked with federal, state, and tribal cooperators to perform nonnative fish removal and monitoring in the San Juan River
- Coordinated with private landowners along the San Juan River to perform ichthyofaunal surveys adjacent to private land
- Monitored projects and modified as needed in response to emerging technologies and scientific methods
- Supervised junior biologists and technicians and acted as mentor for fisheries and technical staff
- Developed proposals and budgets for federal and state recovery programs
- Participate in recovery planning for listed San Juan River species with San Juan River Implementation Program (SJRIP) including providing reports, presenting scientific data and participating in workshops to develop management plans for fishes and habitat in the San Juan River
- Monitored project deadlines to ensure deliverables were submitted in a timely manner.
- Prepared reports on progress and completion of studies for distribution to recovery programs
- Served as in-office point of contact on contracts administered by U.S. Bureau of Reclamation and New Mexico Department of Game and Fish
- Prepared and published results of endangered fish research in peer reviewed journals
- Worked with federal, state and tribal partners and coordinate with private landowners to implement research projects
- Conducted internal reviews of fisheries project proposals

Research Assistant, University of Arizona, Tucson, AZ
August 2011-May 2014: Full time

- Investigated the effects of sedimentation on aquatic ecosystems and developed recommendations to mitigate water quality degradation.
- Assisted in the development of site-specific water quality criteria for federally protected water bodies.

- Assessed impacts of U.S. Border Patrol activities along the U.S./Mexico border on federally endangered Yaqui Chub, protected under the Endangered Species Act
- Utilized principles of conservation and ecology to develop projects to determine the impact of U.S. Border Patrol construction projects and road raking on the aquatic ecosystem of the Rio Yaqui in compliance with the Endangered Species Act
- Designed and conducted field and laboratory study on effects of suspended sediment on diet, growth, and reproduction of federally endangered Yaqui Chub
- Designed and implemented aquatic invertebrate surveys and performed invertebrate identification
- Performed suspended sediment sampling during flood events to evaluate impact of U.S. Border Patrol activities on water quality in the Rio Yaqui and survival of endangered species in the river
- Collaborated with private landowners and scientists in the United States and Mexico.
- Coordinated with refuge managers at San Bernardino national wildlife refuge and private landowners in the U.S. and Mexico to implement research project
- Summarized results and drafted report to San Bernardino National Wildlife Refuge
- Recommended management practices needed to negate deleterious effects of U.S. Border Patrol activities and ensure protection of endangered fishes and their habitat
- Reviewed fish and wildlife project grant proposals for the University of Arizona Graduate and Professional Student Council
- Obtain and report on federal and state collection permits

Curatorial Assistant, Museum of Southwestern Biology Division of Fishes, University of New Mexico, Albuquerque, NM
November 2008-August 2011

- Curated and preserved collections of fishes.
- Catalogued new fish collections to the museum from historic and contemporary sources.
- Worked with and helped maintain museum database.
- Performed reviews of collection filing system and data to ensure accuracy.
- Managed other student employees.

Field and Laboratory Technician, New Mexico Department of Game and Fish, Santa Fe, NM May 2008- October 2008

- Participated in long term mark/recapture study of Texas Hornshell Mussel a New Mexico state endangered species in the Pecos River Drainage.
- Performed fish surveys in the Black River and Pecos River, NM.
- Performed freshwater snail surveys in Gila River Drainage
- Sampled aquatic invertebrates in different settings.
- Perform detail-oriented work sorting and identifying invertebrate samples

VOLUNTEER SERVICE

New Mexico Department of Game and Fish Share with Wildlife Program

- Peer reviewer 2021-2025

U.S. Fish and Wildlife Species Status Assessment

- Peer reviewer Rio Grande Chub and Rio Grande Sucker

Transactions of the American Fisheries Society

- Journal Peer Reviewer

Ecology of Freshwater Fish

- Journal Peer Reviewer

North American Journal of Fisheries Management

- Journal Peer Reviewer

Thalassas: An International Journal of Marine Sciences

- Journal Peer Reviewer

PEER REVIEWED PUBLICATIONS

Clark Barkalow, S.L., A.D. Urioste, S.P. Platania, and J.G. Mortensen. 2026. Elemental composition of fin rays substantiates natural recruitment of threatened catostomid, June Sucker *Chasmistes liorus*, in its native range (Utah, USA). Western North American Naturalist 86:320–331.

Clark Barkalow, S.L., J.G. Mortensen, and S.P. Platania. 2026. Using fin ray microchemistry to discriminate hatchery sources and evaluate natural recruitment of an endangered catostomid, Razorback Sucker, in the San Juan River, Colorado River basin. North American Journal of Fisheries Management 46:621–635.

Gilbert, E.I, T.A. Diver, S.M. Mussman, M.J. Saltzgiver, W.K. Knight, S.L. Durst, M.A. Farrington, **S.L. Clark Barkalow**, M. Tobler, and N.R. Franssen. 2025. Why is it too cold? Towards a mechanistic understand of cold-water pollution effects on recruitment of an imperiled warmwater fish. Molecular Ecology 34: e17588.

Clark Barkalow, S.L., R.K. Dudley, S.P. Platania, W.H. Brandenburg, M.C. McKinstry, and G.C. White. 2024. Assessing entrainment of larval fish in the Hogback Diversion Canal, San Juan River. River Research and Applications 40:612–626.

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Clark Barkalow, S. L., M. A. Brandenburg, and S. P. Platania. 2020. Otoliths reveal spawning ecology and early life history of sympatric catostomids. North American Journal of Fisheries Management 40:415426.

Brandenburg, W.H., T.A. Francis, D.E. Snyder, K.R. Bestgen, B.A. Hines, W.D. Wilson, S. Bohn, A.S. Harrison, and **S.L. Clark Barkalow**. 2019. Discovery of Grass Carp *Ctenopharyngodon idella* larvae in the Colorado River arm of Lake Powell. North American Journal of Fisheries Management 39:166171.

Barkstedt, J.M., **S.L. Clark Barkalow**, M.A. Farrington, J.L. Kennedy, and S.P. Platania. 2018. Frequency of opercular deformities in age-0 catostomids in the San Juan River from 1998 to 2012. Transactions of the American Fisheries Society. DOI: 10.1002/tafs.10107.

Clark Barkalow, S.L. and S.A. Bonar. 2015. The effects of suspended sediment on early-life stage survival of Yaqui Chub, an endangered USA-Mexico Borderlands Cyprinid. Transactions of the American Fisheries Society. 144:2

REPORTS

Grey, R., **S.L. Clark Barkalow**, and T.A. Diver. 2024. Evaluating temporal and spatial spawning patterns of Channel Catfish *Ictalurus punctatus* to provide alternatives for nonnative fish control in the San Juan River-Task 1. Report to the San Juan River Recovery Implementation Program, Albuquerque, NM.

Clark Barkalow, S.L., S.P. Platania, A.L. Barkalow, and M.P. Zeigler. 2024. Using mobile PIT tag antennas to detect Razorback Sucker spawning areas in the San Juan River. Report to the San Juan River Recovery Implementation Program, Albuquerque, NM.

Clark Barkalow, S.L., S.P. Platania, A.L. Barkalow, and M.P. Zeigler. 2023. Using mobile PIT tag antennas to detect Razorback Sucker spawning areas in the San Juan River. Report to the San Juan River Recovery Implementation Program, Albuquerque, NM.

Clark Barkalow, S.L. A.D. Urioste, and A.C. Wedemeyer. 2023. Effects of habitat and nonnative fishes on the presence and relative abundance of Rio Grande Chub and Rio Grande Sucker in New Mexico. New Mexico Department of Game and Fish, Santa Fe, NM.

Clark Barkalow, S.L., A.T. Willis, and S.P. Platania. 2022. Otolith aging of age-0 Colorado River Brown Trout and Rainbow Trout in Grand Canyon National Park. Report to U.S. Geological Survey Grand Canyon Monitoring and Research Center. Flagstaff, AZ.

Clark Barkalow, S.L. and A.D. Urioste. 2022. Investigating origins of unmarked June Sucker using elemental microchemistry. Central Water Conservancy District, Orem, UT.

Farrington, M.A., R.K. Dudley, **S.L. Clark Barkalow**, and G.C. White. 2022. Colorado Pikeminnow and Razorback Sucker larval fish survey in the San Juan River during 2020. San Juan River Basin Recovery Implementation Program, USFWS, Albuquerque, NM.

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Clark Barkalow, S.L. 2017. Determining origin of San Juan River basin Razorback Suckers. Swimming Upstream Field Report 2017. www.coloradoriverrecovery.org

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Clark Barkalow, S.L. and S.P. Platania. 2017. Natal origin Razorback Suckers collected in the San Juan Arm of Lake Powell in 2016. San Juan River Basin Recovery Implementation Program, USFWS, Albuquerque, NM.

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Clark Barkalow, S.L., W. H. Brandenburg, R.K. Dudley, S.P. Platania, and M.C. McKinstry. 2016. Evaluation of larval fish entrainment in the Hogback Diversion Canal- 2015. San Juan River Basin Recovery Implementation Program, USFWS, Albuquerque, NM.

Clark Barkalow, S.L., M.A. Brandenburg, S.P. Platania, and J.L. Kennedy. 2016. Reproductive ecology and early life history of Bluehead and Flannelmouth Suckers in the San Juan River. New Mexico Department of Game and Fish, Santa Fe, NM.

Clark Barkalow, S.L., S.P. Platania, J.L. Kennedy, and M.A. Brandenburg. 2015. Natal origin of San Juan River Razorback Suckers collected in 2014. San Juan River Basin Recovery Implementation Program, USFWS, Albuquerque, NM.

SKILLS

- **Water Quality Analysis:** Experience analyzing water quality data related to fish survival and recruitment
- **Statistical & GIS Analysis:** Skilled in R, JMP, and GIS for data management and spatial and statistical analyses
- **Technical Writing & Communication:** Proven ability to draft technical reports, proposals, and peer-reviewed scientific publications
- **Public Outreach & Stakeholder Engagement:** Experience working with regulatory agencies, tribal governments, and community organizations
- **Scientific Research & Environmental Assessment:** Evaluating hydrological and ecological factors influencing fish populations
- **Fluorescence microscopy:** Evaluating fluorescence of fish hard-tissue marked with oxytetracycline
- **Plasma Mass Spectrometry:** Operating Inductively Coupled Mass Spectrometer and analyze resultant elemental data

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Office of Water 4304T
EPA 822-R-21-006 August 2021

2021 Revision* to:

Aquatic Life Ambient Water Quality Criterion for Selenium – Freshwater 2016

* This 2021 revision entails errata regarding footnotes on pages xv and 99, as described on page vii.

U.S. Environmental Protection Agency
Office of Water
Office of Science and Technology
Washington, D.C.

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ERRATA

In 2021, EPA identified that the following text was missing from the second sentence in footnote 4 in the criterion table: "When selenium inputs are increasing," Corrected footnote 4 now states: "4. Water column values are based on dissolved total selenium in water and are derived from fish tissue values via bioaccumulation modeling. When selenium inputs are increasing, water column values are the applicable criterion element in the absence of steady-state condition fish tissue data." Footnotes 2 and 3 also reflect that footnote 4 was corrected.

NOTICE

This document has undergone a contractor-led external expert peer-review, as well as an EPA review process following publication and public comments received on the May 14, 2014, and July 28, 2015 criteria drafts. Final review by the Health and Ecological Criteria Division, Office of Science and Technology, U.S. Environmental Protection Agency, has been completed, and the document has been approved for publication.

This document provides guidance to States and Tribes authorized to adopt water quality standards under the Clean Water Act (CWA), to protect aquatic life from toxic effects of selenium. Under the CWA, States and Tribes are to adopt water quality criteria to protect designated uses. State and tribal decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance when appropriate. While this document contains EPA's scientific recommendations regarding ambient concentrations of selenium that protect aquatic life, it does not substitute for the CWA or EPA's regulations; nor is it a regulation itself. Thus, it cannot impose legally-binding requirements on EPA, States, Tribes, or the regulated community, and might not apply to a particular situation based upon the circumstances. EPA may change this document in the future. This document has been approved for publication by the Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use. This document can be downloaded from: http://www.epa.gov/waterscience/criteria/aqlife.html

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FOREWORD

Section 304(a)(l) of the Clean Water Act requires the Administrator of the Environmental Protection Agency to publish water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water, including ground water. This document presents EPA's updated chronic ambient water quality criterion (AWQC) for the protection of aquatic life based upon consideration of all available information relating to effects of selenium on aquatic organisms. EPA has incorporated revisions into this final document based on comments from the general public and an external expert peer review panel on an earlier draft published in the Federal Register in May 14, 2014, and comments from the general public on a second draft published in the Federal Register in July 28, 2015.

The term "water quality criteria" is used in two sections of the Clean Water Act, section 304(a)(l) and section 303(c)(2). The term has a different program impact in each section. In section 304, the term represents a non-regulatory, scientific assessment of ecological effects. The criterion presented in this document is such a scientific assessment. If water quality criteria associated with specific designated uses are adopted by a state or authorized tribe as water quality standards under section 303, and approved by EPA, they become applicable Clean Water Act water quality standards in ambient waters within that state or tribe. Water quality criteria adopted in state or tribal water quality standards could have the same numerical values as criteria developed under section 304. However, states and authorized tribes may adopt water quality criteria that reflect adjustments to EPA's recommended section 304 criteria to reflect local environmental conditions and human exposure patterns. Alternatively, states and authorized tribes may derive numeric criteria based on other scientifically defensible methods but the criteria must be protective of designated uses. It is not until their adoption as part of state or tribal water quality standards, and subsequent approval by EPA, that criteria become Clean Water Act applicable water quality standards. Guidelines to assist the states and authorized tribes in modifying the criteria presented in this document are contained in the Water Quality Standards Handbook (U.S. EPA 1994, as updated), which along with additional guidance on the development of water quality standards and other water-related programs of this Agency have been developed by the Office of Water.

This document provides guidance only. It does not establish or affect legal rights or obligations. It does not establish a binding norm and cannot be finally determinative of the issues addressed. Agency decisions in any particular situation will be made by applying the Clean Water Act and EPA regulations on the basis of specific facts presented and scientific information then available.

Elizabeth Southerland
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Technical support was provided by Great Lakes Environmental Center

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ACRONYMS

AE	Assimilation Efficiency
AWQC	Ambient Water Quality Criteria
BAF	Bioaccumulation Factor
CF	Conversion Factor
CV	Chronic Value (expressed in this document as an EC10)
CWA	Clean Water Act
dw	Dry Weight
ECx	Effect Concentration at X Percent Effect Level
EF	Enrichment Factor
EPA	Environmental Protection Agency
EO	Egg Ovary
FCV	Final Chronic Value
GMCV	Genus Mean Chronic Value
HNOEC	Highest No Observed Effect Concentration
IR	Ingestion Rate
k_e	Rate of selenium loss
k_u	Rate of selenium uptake
LOEC	Lowest Observed Effect Concentration
M	Muscle
MATC	Maximum Acceptable Toxicant Concentration (expressed mathematically as the geometric mean of the NOEC and LOEC)
MDR	Minimum Data Recommendations or Requirements
NPDES	National Pollutant Discharge Elimination System
NOEC	No Observed Effect Concentration
SMCV	Species Mean Chronic Value
SSD	Species Sensitivity Distribution
TMDL	Total Maximum Daily Load
TRAP	EPA's Statistical Program: Toxicity Relationship Analysis Program
TTF	Trophic Transfer Factor
WB	Whole body
WQBELS	Water Quality-based Effluent Limitations
WQC	Water Quality Criteria
WQS	Water Quality Standards
ww	Wet Weight

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EXECUTIVE SUMMARY

This document sets forth the basis for and derivation of the Clean Water Act, Section 304(a) water quality criterion for protecting freshwater aquatic life from harmful effects of selenium, a naturally occurring chemical element that is nutritionally essential in small amounts, but toxic at higher concentrations. This assessment provides a critical review of all data identified in EPA's literature search quantifying the toxicity of selenium to freshwater aquatic organisms, and provides a basis for a criterion that will assure protection of populations of fish, amphibians, aquatic invertebrates, and plants, based on available data.

Although selenium may cause acute toxicity at high concentrations, the most deleterious effect on aquatic organisms is due to its bioaccumulative properties; these chronic effects are found at lower concentrations than acute effects. Organisms in aquatic environments exposed to selenium accumulate it primarily through their diets, and not directly through water (Chapman et al. 2010). The best science also indicates that selenium toxicity occurs primarily through transfer to the eggs and subsequent reproductive effects. Consequently, in harmony with the recommendations of expert panels (U.S. EPA 1998; Chapman et al. 2010) and with peer review and public comments on previous U.S. EPA (2004, 2014, 2015) drafts, the Agency developed a chronic criterion reflective of the reproductive effects of selenium concentrations on fish species.

The 2016 "Aquatic Life Ambient Water Quality Criterion for Selenium – Freshwater, 2016," is a chronic criterion that is composed of four elements. All elements are protective against chronic selenium effects. Two elements are based on the concentration of selenium in fish tissue and two elements are based on the concentration of selenium in the water column. The recommended elements are: (1) a fish egg-ovary element; (2) a fish whole-body and/or muscle element; (3) a water column element (one value for lentic and one value for lotic aquatic systems); and (4) a water column intermittent element to account for potential chronic effects from short-term exposures (one value for lentic and one value for lotic aquatic systems). The assessment of the available data for fish, invertebrates, and amphibians indicates that a criterion value derived from fish will protect the aquatic community. All four criterion elements applied together should protect aquatic life from the chronic effects of exposure to total selenium in waters inhabited by fish, as well as "fishless waters."

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Because the factors that determine selenium bioaccumulation vary among aquatic systems, site-specific water column criterion element values may be necessary at aquatic sites with high selenium bioaccumulation to ensure adequate protection of aquatic life (Appendix K). Finally, this freshwater chronic selenium criterion applies only to aquatic life, and is not intended to address selenium toxicity to aquatic-dependent wildlife such as aquatic-dependent birds.

The toxicity studies relevant to the derivation of the fish tissue selenium criterion elements involve (a) extended duration dietary exposure, and (b) measurement of total selenium in the tissue of the target organism. Selenium either in fish whole-body or in muscle is usually measured in non-reproductive studies, and selenium in eggs or ovaries is typically measured in reproductive studies. Selenium accumulation in the eggs of the exposed adult female prior to spawning has been shown to yield the most robust relationship (statistically significant) with occurrence of deformities and reduced survival of the offspring.

The outcome of assessing both reproductive and non-reproductive studies under laboratory and field conditions led EPA to the conclusion, consistent with expert consensus (Chapman et al. 2009, 2010), that reproductive effects, linked to egg-ovary selenium concentrations, provide the most sound basis for the criterion compared to non-reproductive (e.g., survivorship, growth) endpoints. Reproductive effects have been linked to observed reductions in the populations of sensitive fish species in waterbodies having elevated concentrations of selenium (Young et al. 2010). EPA applied the sensitivity distribution concepts from the U.S. EPA *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and their Uses* (Stephan et al. 1985) to derive the national selenium criterion. Based on the available data, expressed as EC_{10} values, the egg-ovary criterion element concentration is 15.1 milligrams selenium per kilogram dry weight (mg Se/kg dw), based primarily on 17 reproductive studies representing 10 fish genera.

EPA recommends states and tribes adopt all four elements of the criterion into their water quality standards. Two elements are based on the concentration of selenium in fish tissue (eggs or ovaries, and whole-body or muscle) and two elements are based on the concentration of selenium in the water column (a 30-day chronic element and an intermittent exposure element). Both water column elements are further refined into values for lentic waters (e.g., lakes and impoundments) and lotic waters (e.g., rivers and streams). The difference between lentic and lotic water column values reflect the observed difference in selenium bioaccumulation in these

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two categories of aquatic systems (ATSDR 2003; Luoma and Rainbow 2005; Orr et al. 2006; Simmons and Wallschlägel 2005). EPA derived the intermittent exposure element based on the chronic 30-day water column element and the fraction of any 30-day period during which elevated selenium concentrations occur. EPA recommends the intermittent element to address short-term exposures that contribute to chronic effects through selenium bioaccumulation (e.g., releases from storage ponds or other intermittent releases). EPA derived the values for the water-column criterion elements from the egg-ovary element by assessing food-chain bioaccumulation based on available data collected at lentic and lotic systems in the continental United States. Thus, all four criterion elements are based on reproductive effects in freshwater fish.

EPA primarily used field studies in freshwater systems to provide quantitative estimates of selenium bioaccumulation in particulate material (algae, detritus, and sediment) from water, and used field observations and laboratory data to quantify and model the trophic transfer of selenium from particulate material into invertebrates, and from invertebrates into fish. EPA additionally used field and laboratory observations to assess species-specific selenium partitioning between different tissues within a fish (whole-body, eggs and/or ovaries, and muscle). EPA developed food web models of fish in aquatic systems with a range of bioaccumulation potentials and used the food web models with the species-specific estimates of trophic transfer (or the most proximate taxonomic surrogate when species-specific data was not available) to develop water column criterion elements from the egg-ovary criterion element for lotic and lentic aquatic systems. EPA validated this approach using selenium measurements from aquatic systems with a range of bioaccumulation potentials. Similar approaches could be used in the derivation of selenium criteria in saltwater or estuarine systems with selenium data and food webs relevant to those systems.

While more than half the available chronic studies were fish studies, available field data and laboratory toxicity studies suggest that a criterion based on fish will protect amphibians, aquatic invertebrates, and plants since these taxa appear to be less sensitive to selenium than fish (see **Sections 3.1.4** and **6.1.4**).

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Table 1. Summary of the Recommended Freshwater Selenium Ambient Chronic Water Quality Criterion for Protection of Aquatic Life.

Media Type	**Fish Tissue**[1]		**Water Column**[4]	
Criterion Element	**Egg/Ovary** [2]	**Fish Whole Body or Muscle** [3]	**Monthly Average Exposure**	**Intermittent Exposure**[5]
Magnitude	15.1 mg/kg dw	8.5 mg/kg dw whole body or 11.3 mg/kg dw muscle (skinless, boneless filet)	1.5 µg/L in lentic aquatic systems 3.1 µg/L in lotic aquatic systems	$WQC_{int} = \frac{WQC_{30-day} - C_{bkgrnd}(1 - f_{int})}{f_{int}}$
Duration	Instantaneous measurement[6]	Instantaneous measurement[6]	30 days	Number of days/month with an elevated concentration
Frequency	Not to be exceeded	Not to be exceeded	Not more than once in three years on average	Not more than once in three years on average

1. Fish tissue elements are expressed as steady-state.
2. Egg/Ovary supersedes any whole-body, muscle, or water column element when fish egg/ovary concentrations are measured, except as noted in footnote 4 below.
3. Fish whole-body or muscle tissue supersedes water column element when both fish tissue and water concentrations are measured, except as noted in footnote 4 below.
4. Water column values are based on dissolved total selenium in water and are derived from fish tissue values via bioaccumulation modeling. When selenium inputs are increasing, water column values are the applicable criterion element in the absence of steady-state condition fish tissue data.
5. Where WQC30-day is the water column monthly element, for either a lentic or lotic waters; C_{bkgrnd} is the average background selenium concentration, and fint is the fraction of any 30-day period during which elevated selenium concentrations occur, with f_{int} assigned a value ≥0.033 (corresponding to 1 day).
6. Fish tissue data provide instantaneous point measurements that reflect integrative accumulation of selenium over time and space in fish population(s) at a given site.

The recommended chronic selenium criterion is expected to protect the entire aquatic community, including fish, amphibians, and invertebrates, based on available data. Because fish are the most sensitive to selenium effects, EPA recommends that selenium water quality criterion elements based on fish tissue (egg-ovary, whole body, and/or muscle) data take precedence over the criterion elements based on water column selenium data due to the fact, noted above, that fish tissue concentrations provide a more robust and direct indication of potential selenium effects in fish. However, because selenium concentrations in fish tissue are a result of selenium

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bioaccumulation via dietary exposure, there are two specific circumstances where the fish tissue concentrations do not fully represent potential effects on fish and the aquatic ecosystem: 1) "fishless" waters, and 2) areas with new selenium inputs.

For purposes of this document, EPA defines "fishless waters" as waters with insufficient instream habitat and/or flow to support a population of any fish species on a continuing basis, or waters that once supported populations of one or more fish species but no longer support fish (e.g., extirpation) due to temporary or permanent changes in water quality (e.g., selenium pollution), flow or instream habitat. Because of the inability to collect sufficient fish tissue to measure selenium concentrations in fish in such waters, water column concentrations will best represent selenium levels required to protect aquatic communities and downstream waters in such areas. Appendix K of this criterion document discusses approaches to develop a site-specific water column criterion element in such situations.

For purposes of this document EPA defines "new inputs" as new activities resulting in the release of selenium into a lentic or lotic aquatic system. New inputs will likely result in a greater concentrations of selenium in the food web and a relatively slow increase in the selenium concentration in fish until the new selenium release achieves a quasi-"steady-state" balance in the aquatic system. EPA estimates that the concentration of selenium in fish tissue will not reach steady state for several months in lotic systems and longer time periods (e.g., 2 to 3 years) in lentic systems. Achievement of steady state in an aquatic system also depends on the hydrodynamics of the aquatic system, (particularly reservoirs with multiple riverine inputs), the location of the selenium input and the particular food web. EPA expects the time needed to achieve steady state with new or increased selenium inputs to be site specific. Thus, EPA recommends that fish tissue criterion elements not take precedence over the water column criterion elements until the aquatic system achieves steady state. In the interim, EPA recommends sampling and using site-specific data to determine steady state in the receiving water to gain a better understanding of the selenium bioaccumulation dynamics in a given system.

EPA recommends states and tribes adopt into their water quality standards a selenium criterion that expresses the four elements as a single criterion composed of multiple parts in a manner that explicitly affirms the primacy of the whole-body or muscle element over the water column elements, and the egg-ovary element over any other element. Adopting the fish whole-

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body or muscle tissue element into water quality standards ensures the protection of aquatic life when measurements from fish eggs or ovary are not available, and adopting the water column element ensures protection when fish tissue measurements are not available.

EPA recommends that when states adopt a four-part criterion for selenium reflecting EPA's recommended criterion, states use the default monthly average exposure water column elements of the criterion, adopted as part of the state's water quality criterion when implementing the criterion under the National Pollutant Discharge Elimination System (NPDES) permits program and to assist with implementation of other Clean Water Act programs. Alternatively, states may want to develop adopt, and submit for EPA approval, either a site-specific water column criterion element (or set of lentic/lotic criterion element values), or a set of procedures to facilitate the translation of the fish tissue criterion concentration elements into site-specific water concentration values. A site-specific water column criterion element or set of lentic/lotic criterion element values can be developed using a mechanistic modeling approach (Presser and Luoma 2010) or using the empirical bioaccumulation factor approach, both described in Appendix K, for the specific waterbody or waterbodies. Any translation procedure must be scientifically defensible, produce repeatable, predictable outcomes, and result in criterion element values that protect the applicable designated use. Examples of such procedures include the mechanistic modeling approach and the empirical BAF approach described in Appendix K.

This recommended selenium criterion applies to freshwater lentic and lotic systems, as it is based on the toxicity of selenium to freshwater organisms. A similar approach may be appropriate for deriving criteria for selenium in estuarine and marine waters if appropriate data are available.

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1 INTRODUCTION AND BACKGROUND

The objective of the Clean Water Act (CWA) is to "restore and maintain the chemical, biological and physical integrity of the Nation's waters." One of the tools that EPA uses to meet this objective is the development of recommended ambient water quality criteria (AWQC) under section 304(a)(1) of the Act. As provided for by the Clean Water Act, EPA reviews and from time to time revises 304(a)(1) AWQC to ensure the criteria are consistent with the latest scientific knowledge. Section 304(a) aquatic life criteria serve as recommendations to states and authorized tribes for defining ambient water concentrations that will protect against adverse ecological effects to aquatic life resulting from exposure to a pollutant found in water from direct contact or, ingestion of contaminated water and/or food. Aquatic life criteria address the Clean Water Act goals of providing for the protection and propagation of fish and shellfish. When adopted into state or tribal water quality standards (WQS), these criteria can become a basis for establishing National Pollutant Discharge Elimination System (NPDES) program permit limits and, the basis for listing impaired waters under Section 303(d) and establishing Total Maximum Daily Loads (TMDLs).

1.1 HISTORY OF THE EPA RECOMMENDED SELENIUM AWQC FOR AQUATIC LIFE

In 1980 EPA first published numeric aquatic life criteria for selenium in freshwater. These criteria were based on water-only exposure (no dietary exposure). In order to address the lack of consideration of bioaccumulation in the 1980 selenium criteria, in 1987 EPA published updated selenium criteria to address field-based toxicity observed in aquatic ecosystems at levels below the existing criteria values. The 1987 criteria were field-based and accounted for both the water column and dietary uptake pathways manifested at Belews Lake, North Carolina (USA), a cooling water reservoir where water quality and fish communities had been affected by selenium loads from a coal-fired power plant. At that time EPA also provided an acute criterion of 20 µg/L derived from a reverse application of an acute-chronic ratio obtained from conventional water-only exposure toxicity tests applied to the 5 µg/L chronic value based on dietary and water column exposure in Belews Lake.

In 1998-1999 EPA published a revised acute criterion, a formula that recognized that the two oxidation states, selenate and selenite, appeared to have substantially different acute

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toxicities. This acute criterion assumed toxicity was based on water-only exposure. Subsequent research has demonstrated that sulfate levels influence selenate toxicity in water-only exposures.

In 1998 EPA held a peer consultation workshop (EPA-822-R-98-007) to evaluate new science available for selenium relevant to the selenium aquatic life criterion. EPA concluded, and the peer reviewers agreed, that fish-tissue values more directly represent chronic adverse effects of selenium than the conventional water concentration approach used by EPA to protect aquatic life, because chronic selenium toxicity is primarily based on the food-chain bioaccumulation route, not on a water column route of exposure.

In 2004 EPA published a draft chronic whole-body fish-tissue criterion with a water-based monitoring trigger in the summer and fall. The critical effect considered at that time was the impact on survivorship based on overwintering stress to bluegill sunfish. An acute criterion was estimated at that time that addressed concerns with the species of selenium present and adjusted for sulfate levels; however, it did not address the dietary uptake pathway.

Further refinement of the fish tissue approach occurred in 2009 based on the findings of a Pellston scientific workshop on the ecological risk assessment of selenium (Chapman et al. 2009, 2010). As presented by Chapman et al. (2009), some key findings resulting from that workshop are:

- Diet is the primary pathway of selenium exposure for both invertebrates and vertebrates.
- Traditional methods for predicting toxicity on the basis of exposure to dissolved [water column] concentrations do not work for selenium because the behavior and toxicity of selenium in aquatic systems are highly dependent upon site-specific factors, including food web structure and hydrology.
- Selenium toxicity is primarily manifested as reproductive impairment due to maternal transfer, resulting in embryotoxicity and teratogenicity in egg-laying vertebrates.

In this 2016 final recommended freshwater chronic criterion for selenium, EPA includes revisions based on the public and external expert peer reviews of the 2014 draft, public comments on the 2015 draft, data and information from additional studies provided by the public and peer reviewers, and additional scientific analyses. EPA also conducted a new literature review and reanalyzed data considered in the 2004 and 2009 draft criteria documents. This final criterion reflects the latest scientific consensus (e.g., Chapman et al. 2010) on the reproductive

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effects of selenium on aquatic life and their measurement in aquatic systems and supersedes all previous national aquatic life water quality criteria for selenium.

EPA is recommending a national selenium criterion expressed as four elements. All elements are protective against chronic selenium effects, and account for both short term and longer term exposure to selenium. Two elements are based on the concentration of selenium in fish tissue (eggs and ovaries, and whole-body or muscle) and two elements are based on the concentration of selenium in the water-column (two 30-day chronic values and an intermittent value). EPA derived the 30-day chronic water column element from the egg-ovary element by modeling selenium bioaccumulation in food webs of lotic and lentic aquatic systems. EPA is recommending the intermittent value to address short-term exposures that could contribute to chronic effects through selenium bioaccumulation in either lotic or lentic systems. EPA derived the intermittent element based on the chronic 30-day water column element and the fraction of any 30-day period during which elevated selenium concentrations occur. These water column criterion elements apply to the total of all oxidation states (selenite, selenate, organic selenium, and any other forms) (See Appendix L for Analytical Methods for Measuring Selenium). Aquatic communities are expected to be protected by this chronic criterion from any potential acute effects of selenium.

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2 PROBLEM FORMULATION

Problem formulation provides a strategic framework for water quality criteria development by focusing the effects assessment on the most relevant chemical properties and endpoints. The structure of this effects assessment is consistent with EPA's Guidelines for Ecological Risk Assessment (U.S. EPA 1998).

This ecological effects assessment defines a scientifically-defensible water quality criterion for selenium under section 304(a)(1) of the Clean Water Act. Clean Water Act Section 304(a)(1) requires EPA to develop criteria for water quality that accurately reflect the latest scientific knowledge. These criteria are based solely on high quality data and best professional scientific judgments on toxicological effects. Criteria are developed following overarching guidance outlined in the Agency's *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (Stephan et al. 1985), hereafter referred to as "EPA Ambient Water Quality Criteria Guidelines." States and authorized tribes may adopt EPA's recommended criteria into their water quality standards to protect designated uses of water bodies, they may modify EPA's criteria to reflect site-specific conditions, or they may derive criteria using other scientifically-defensible methods, all subject to EPA review and approval.

2.1 OVERVIEW OF SELENIUM SOURCES AND OCCURRENCE

Selenium is a naturally occurring element present in sedimentary rocks and soils. It is also present in the aquatic environment as methyl derivatives of selenium, naturally occurring in freshwaters through methylation by bacteria (Ranjard et.al. 2003). Selenium's occurrence in surficial soils and aquatic sediments in the United States is illustrated in **Figure 2.1**. There are around 40 known selenium-containing minerals, some of which can have as much as 30% selenium, but all are rare and generally occur together with sulfides of metals such as copper, zinc and lead (Emsley 2011). Sedimentary rocks, particularly shales, have the highest naturally occurring selenium content (Burau 1985). The distribution of organic-enriched, sedimentary shales, petroleum source rocks, ore deposits, phosphorites, and coals, in which selenium typically co-occurs, is well characterized in the United States (Presser et al. 2004). Natural weathering of selenium-bearing geologic strata containing selenium can lead to selenium leaching into groundwater and surface water. Two major anthropogenic activities are known to

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cause increased selenium mobilization and introduction into aquatic systems. The first is the mining of metals, minerals and refinement and use of fossil fuels; the second is irrigation of selenium-rich soils.

Mining activities bring selenium-enriched deposits to the surface, where they are exposed to physical weathering processes. The release of selenium related to resource extraction activities is most common in the phosphate deposits of southeast Idaho and adjacent areas of Wyoming, Montana, and Utah, and in coal mining areas in portions of West Virginia, Kentucky, Virginia, and Tennessee (Presser et al. 2004). Where selenium-containing minerals, rocks, and coal are mined, selenium can be mobilized when rock overburden and waste materials are crushed, increasing the surface area and exposure of material to weathering processes. Selenium contamination of surface waters can also occur when sulfide deposits of iron, uranium, copper, lead, mercury, silver, and zinc are released during the mining and smelting of these metal ores. Where coal is burned for power production, selenium can enter surface waters as drainage from fly-ash ponds and fly-ash deposits on land (Gillespie and Baumann 1986). Fly ash deposits have a high surface area to volume ratio, resulting in rates of selenium in leachate several times higher than from the parent feed coal (Fernández-Turiel et al. 1994). The refining of crude oil containing high levels of selenium can also be a major source of loading in certain water bodies (Maher et al. 2010).

Irrigation of selenium-rich soils for crop production in arid and semi-arid regions of the country can mobilize selenium and move it off-site in surface water runoff or via leaching into ground water. Where deposits of Cretaceous marine shales occur, they can weather to produce high selenium soils; such soils are present in many areas of the western U.S. (Lemly 1993c). Selenium is abundant in the alkaline soils of the Great Plains, and some ground waters in California, Colorado, Kansas, Oklahoma, South Dakota and Wyoming contain elevated concentrations of selenium due to weathering of and leaching from rocks and soils. In semi-arid areas of the West, irrigation water applied to soils containing soluble selenium can leach selenium. The excess water (in tile drains or irrigation return flow) containing selenium can be discharged into basins, ponds, or streams. For example, elevated selenium levels at the Kesterson Reservoir in California originated from agricultural irrigation return flow collected in tile drains that discharged into the reservoir (Ohlendorf et al. 1986).

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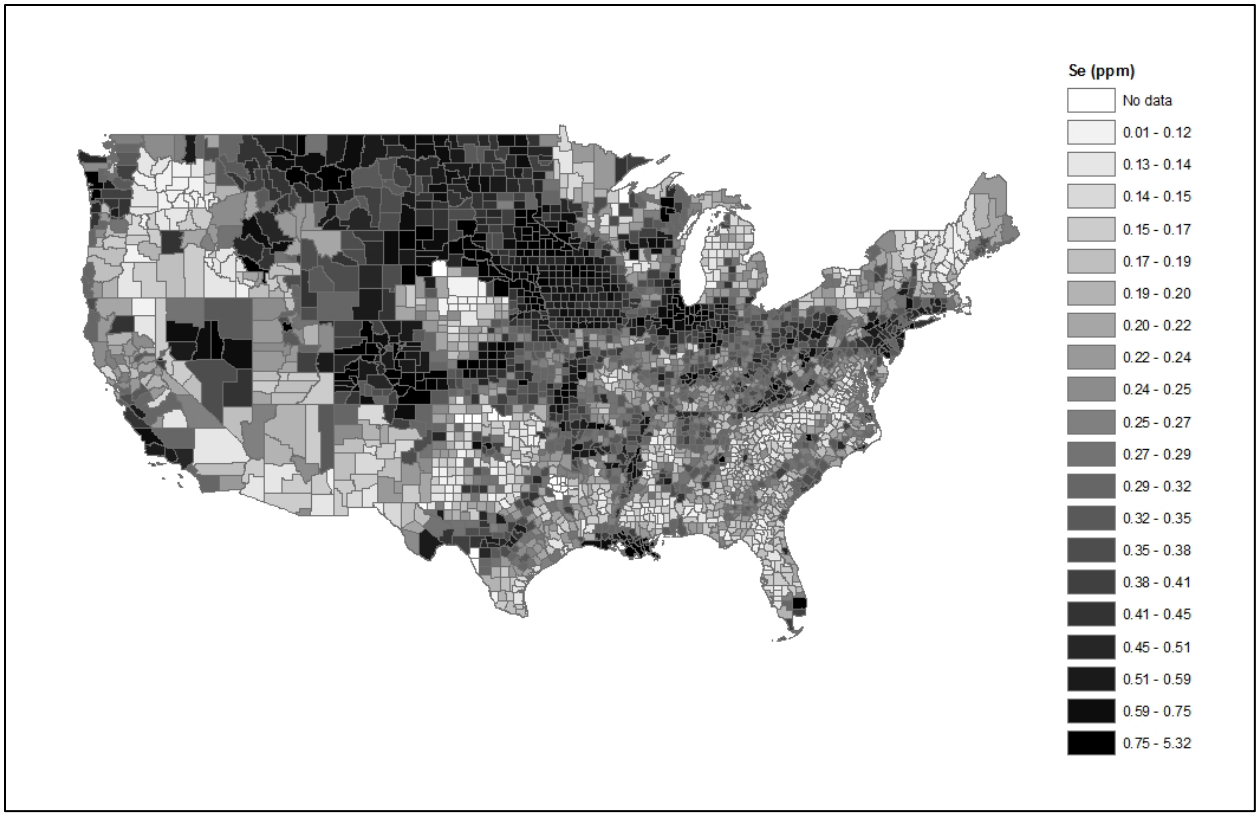


Figure 2.1. Selenium in Surficial Soils and Aquatic Sediments in counties of the Conterminous United States.
U.S. Geological Survey Open-File Report 2004-1001. URL: http://mrdata.usgs.gov/geochem/doc/averages/countydata.htm. Data are available from: http://mrdata.usgs.gov/geochem/doc/groups-cats.htm.

Atmospheric emissions of selenium can originate from several sources including power plants and other facilities that burn coal or oil, selenium refineries that provide selenium to industrial users, base metal smelters and refineries, resource extraction industries, milling operations, and end-product manufacturers (e.g., semiconductor manufacturers) (ATSDR 2003). Airborne selenium particles can settle either on surface waters or on soils from which selenium can be further transported and deposited into water bodies through ground or surface water conveyances or runoff.

The chemical form of selenium that dominates a location is usually dependent on its sources, effluent treatments, and biogeochemical processes in the receiving waters. Irrigation activities in areas with seleniferous soils typically mobilize selenate (SeO_4^{2-}, or Se[VI]) (Seiler et al. 2003). Combustion of coal for power generation creates predominantly selenite (SeO_3^{2-}, or Se[IV]) in the fly ash waste due to the temperatures, pH, and redox conditions involved with the

process (Huggins et al. 2007). Similar conditions during refinement of crude oil can also result in high concentrations of selenite relative to selenate, as was observed in the San Francisco Bay estuary in the 1980s (Cutter 1989). Although selenite is the dominant species in the discharges resulting from crude oil refining and coal burning using conventional technologies, the implementation of alternative treatment technologies can alter the relative concentrations of selenate and selenite. For example, in scrubbers with forced oxidation systems that produce strong oxidizing conditions and high temperatures, the majority of discharged selenium is in the form of selenate (Maher et al. 2010). However for flue gas desulfurization systems that are the inhibited oxidation type, the selenium chemistry is more complex, and selenite may not be the primary form emitted (Petrov et al. 2012). **Table 2.1** shows the predominant form of selenium that is associated with different activities and industries.

EPA's Office of Water and Office of Research and Development conducted the first statistically based survey of contaminants in fish fillets from U.S. rivers from 2008 through 2009. This national fish survey was conducted under the framework of EPA's National Rivers and Streams Assessment (NRSA), a probability-based survey designed to assess the condition of the Nation's streams and rivers (Lazorchak et al. 2014). During June through October of 2008 and 2009, field teams applied consistent methods nationwide to collect samples of fish species commonly consumed by humans at 541 randomly selected river locations ($\geq 5^{th}$ order based on 1:100,000-scale Strahler order) in the lower 48 states. They collected one composite fish sample at every sampling location, with each composite consisting of five similarly sized adult fish of the same species from a list of target species. Largemouth and smallmouth bass were the primary species collected for the study, accounting for 34% and 24% of all fish composites, respectively. Samples were collected from both non-urban (379 sites) and urban locations (162 sites). Each fillet composite sample was homogenized and analyzed using an ICP-MS (Inductively Coupled Plasma- Mass Spectrometry) method for total selenium, and results were reported as wet weight. Three of the 541 samples (approximately 0.6%) exceeded the 2016 criterion for muscle tissue, 11.3 mg/kg dw. The maximum value detected was 17.75 mg Se/kg dw muscle, the median was 1.90 mg Se/kg dw, and the minimum 0.41 mg Se/kg dw.

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Table 2.1. Predominant Chemical Forms of Selenium in Discharges Associated with Different Activities and Industries.

Selenium Form	Sources
Selenate	Agricultural irrigation drainage Treated oil refinery effluent Mountaintop coal mining/ valley fill leachate Copper mining discharge
Selenite	Oil refinery effluent Fly ash disposal effluent Phosphate mining overburden leachate
Organoselenium	Treated agricultural drainage (in ponds or lagoons)

Source: Presser and Ohlendorf 1987; Zhang and Moore 1996; Cutter and Diego-McGlone 1990.

2.2 Environmental Fate and Transport of Selenium in the Aquatic Environment

The fate and transport of selenium in aquatic systems is affected by the distribution of selenium species and their transformations in water, sediment, and biota. These transformations include the assimilation and conversion of inorganic selenium to organic selenium species in plants and microbes that are transferred to higher trophic level consumer species throughout the aquatic food web.

2.2.1 Selenium Species in Aquatic Systems

Aquatic organisms are exposed to a combination of predominantly organic selenium species present in the food web throughout their life history; reproductive effects integrate these exposures to transformed inorganic and organic species of selenium. The bioavailability and toxicity of selenium depend on both its concentration and speciation (Cutter and Cutter 2004; Meseck and Cutter 2006; Reidel et al. 1996). Selenium exists in four oxidation states (VI, IV, 0, -II) and in a wide range of chemical and physical species across these oxidation states (Doblin et al. 2006; Maher et al. 2010; Meseck and Cutter 2006). Therefore, in the effects assessment that follows, we have correlated the adverse effects on aquatic life with total dissolved selenium.

In oxygenated surface waters, the primary dissolved selenium species are selenate (SeO_4^{2-}, or Se[VI]) and selenite (SeO_3^{2-}, or Se[IV]), as well as dissolved organic selenides (-II) formed from fine particulate organic matter (e.g., Doblin et al. 2006; Meseck and Cutter 2006). The relative abundance of selenate and selenite depends on relative contributions from the

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geologic and anthropogenic sources of selenium to the receiving waters, as there is negligible inter-conversion between the two species (e.g., Maher et al. 2010). Aqueous selenite is more abundant than selenate when the majority of selenium originates from discharges from coal fly ash tailings or oil refineries (e.g., Cutter 1989; Huggins et al. 2007). Particulate species in the water column include selenate, selenite, and elemental selenium (Se(0)) bound to resuspended sediments and organic particles, as well as particulate organic selenium species incorporated into suspended detritus (e.g., Cutter and Bruland 1984; Meseck and Cutter 2006).

In sediments, selenate and selenite can be reduced to iron selenides or elemental selenium under abiotic or biotic processes; elemental selenium and selenides can be converted to selenate under oxidizing conditions (Maher et al. 2010). For example, selenate can be reduced to elemental selenium in sediments (e.g., Oremland 1990) in the presence of iron oxides (Chen et al. 2008) and iron sulfides (Breynaert et al. 2008). Elemental selenium and organic selenides are produced by selenate-reducing microbes in sediments. Overall, the reduction of selenate and particularly selenite in sediments increases with increasing sediment organic matter (Tokunaga et al. 1997). Selenite in particular is readily bound to iron and manganese oxy-hydroxides (Maher et al. 2010), and is readily adsorbed to inorganic and organic particles, particularly at a lower pH range (e.g., McLean and Bledsoe 1992; Tokungawa et al. 1997). Microbial reduction of selenite to organic forms (via methylation) increases the solubility and bioavailability of selenium (Simmons and Wallschlägel 2005). Plants and algae produce volatile selenium species by biomethylation of excess selenium, which upon reaching the sediment can be transformed to a more bioavailable species, or deposited in the sediments and effectively removed from the system (Diaz et al. 2009). Depending on environmental conditions, the reduction processes described above are largely reversible, as elemental selenium and selenides in sediments can be oxidized to selenate through microbial or abiotic transformations (e.g., Maher et al. 2010; Tokunaga et al. 1997).

The most important transformation of selenium, with respect to its toxicity to aquatic organisms, is in the uptake of dissolved inorganic selenium into the tissues of primary producers at the base of the food web. The main route of entry of selenium into aquatic foodwebs is from the consumption of particulate selenium of primary producers, and to a lesser degree, from the consumption of sediments (Doblin et al. 2006; Luoma and Presser 2009). For algae, selenite and organic selenides are similarly bioavailable, and both dissolved species are more bioavailable

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than selenate (e.g., Baines et al. 2001; Luoma et al. 1992). In vascular plants, selenate uptake is greater than for the other dissolved species, as the majority of selenium uptake occurs in the roots, and selenate is more easily transported to the shoots and leaves than selenite or organic selenides (Dumont 2006). Following uptake, selenium is metabolized into a variety of organic species that are assimilated into plant tissues. Selenium metabolism in plants is analogous to sulfur metabolism (e.g., Dumont et al. 2006; Ouerdane et al. 2013). Selenate is reduced to selenite, which is then reduced to selenide in a process involving reduced glutathione (Dumont et al. 2006). Selenide is converted to selenocysteine (SeCys), which is then converted to selenomethionine (SeMet) (Dumont et al. 2006). In addition to SeCys and SeMet, a variety of other organic selenium species can be formed; however, SeCys, and particularly SeMet are toxicologically important because these amino acids nonspecifically replace cysteine and methionine in proteins, and are more bioavailable to higher trophic level consumers (Fan et al. 2002; Freeman et al. 2006).

2.2.2 Bioaccumulation of Selenium in Aquatic Systems

Dissolved selenium uptake by animals is slow, whatever the form, such that under environmentally relevant conditions, dissolved selenium in the water column makes little or no direct contribution to bioaccumulation in animals (Lemly 1985a; Ogle and Knight 1996), but does influence the concentration of selenium in particulate matter. Selenium bioaccumulation in aquatic organisms occurs primarily through the ingestion of food (Fan et al. 2002; Luoma et al. 1992; Maher et al. 2010; Ohlendorf et al. 1986; Presser and Ohlendorf 1987; Presser et al. 1994; Saiki and Lowe 1987). However, unlike other bioaccumulative contaminants such as mercury, the single largest step in selenium accumulation in aquatic environments occurs at the base of the food web where algae and other microorganisms accumulate selenium from water by factors ranging from several hundred to tens of thousands (Luoma and Presser 2009; Orr et al. 2012; Stewart et al. 2010). Bioaccumulation and transfer through aquatic food webs are the major biogeochemical pathways of selenium in aquatic ecosystems. Dissolved selenium oxyanions (selenate, selenite) and organic selenides are assimilated into the tissues of aquatic primary producers (trophic level 1 organisms), such as periphyton, phytoplankton, and vascular macrophytes; and subsequently biotransformed into organoselenium. These organisms, together with other particle-bound selenium sources, constitute the particulate selenium fraction in the water column. Selenium from this particulate fraction is then transferred to aquatic primary

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consumers such as zooplankton, insect larvae, larval fish, and bivalves (trophic level 2), and then to predators such as fish and birds (trophic level 3 and above). In addition to the water concentration of selenium, the process of selenium bioaccumulation in aquatic life residing in freshwater systems depends on several factors specific to each aquatic system. These factors include:

Water residence time. Residence time is a measure of the average time a water molecule will spend in a specified region of space. Residence time influences both the proportion of selenium found in particulate and dissolved forms and the predominant form of selenium. Organisms in waters with long residence times such as lakes, ponds, reservoirs, wetlands or estuaries will tend to bioaccumulate more selenium than those living in waters with shorter residence times such as rivers and streams (ATSDR 2003; EPRI 2006; Luoma and Rainbow 2005; Orr et al. 2006; Simmons and Wallschlägel 2005). Several interrelated factors underlie selenium's greater bioaccumulation potential in slow moving systems, such as food web complexity and the organic content and reduction/oxidation potential of sediments. Finally, selenium toxicity in flowing waters with shorter residence times may only be apparent downstream of their selenium sources, whereas waters with longer residence times are more likely to exhibit selenium toxicity near their sources (Presser and Luoma 2006).

Distribution of selenium between particulate and dissolved forms. Selenium is found in both particulate and dissolved forms in water, but direct transfer of selenium from water to animals is only a small proportion of the total exposure. The proportion of selenium found in particulate matter (algae, detritus, and sediment) is important because it is the primary avenue for selenium entering into the aquatic food web (Luoma et al. 1992; Luoma and Rainbow 2005; Ohlendorf et al. 1986; Presser and Ohlendorf 1987; Presser et al. 1994; Presser and Luoma 2006; Saiki and Lowe 1987).

Bioaccumulation in prey. Trophic level 1 organisms such as periphyton and phytoplankton, as well as other forms of particulate material containing selenium, such as detritus and sediment, are ingested by trophic level 2 organisms such as mollusks, planktonic crustaceans, and many insects, increasing the concentration of selenium in the tissues of these higher-level organisms. Differences in the physiological characteristics of these organisms result in different levels of bioaccumulation. Also, selenium effects on invertebrates typically occur at concentrations higher than those that elicit effects on the vertebrates (e.g., fish and birds) that

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prey upon them. Additionally, certain molluscan taxa such as mussels and clams can accumulate selenium to a much greater extent than planktonic crustaceans and insects (although the levels do not seem to be toxic to the mussels) due to higher ingestion rates of both particulate-bound (algae) and dissolved selenium from the water column through filter feeding, as well as the lower rate at which they eliminate selenium (Luoma and Rainbow 2005; Stewart et al. 2013). Because egg-laying (oviparous) vertebrates such as fish and birds are most sensitive to selenium effects, (Janz et al. 2010), these vertebrate consumers are also the most vulnerable groups to selenium poisoning and the focal point of most selenium environmental assessments (Ogle and Knight 1996; Stewart et al. 2010).

Trophic transfer to predators. Bioaccumulation of selenium by higher trophic level organisms, such as trophic level 3 and 4 fish, is highly influenced by the food web of the aquatic environment. For example, fish that primarily consume freshwater mollusks (e.g., redear sunfish) will exhibit greater selenium bioaccumulation than fish that consume primarily insects or crustaceans from waters with the same concentration of dissolved selenium because mollusks tend to accumulate selenium at higher concentrations than other trophic level 2 organisms, as noted above (Luoma and Presser 2009; Stewart et al. 2004).

2.3 Mode of Action and Toxicity of Selenium

Selenium is a naturally occurring chemical element that is also an essential micronutrient. Trace amounts of selenium are required for normal cellular function in almost all animals. However, excessive amounts of selenium can also have toxic effects, with selenium being one of the most toxic of the biologically essential elements (Chapman et al. 2010). Egg-laying vertebrates have a lower tolerance than do mammals, and the transition from levels of selenium that are biologically essential to those that are toxic occurs across a relatively narrow range of exposure concentrations (Luckey and Venugopal 1977; U.S. EPA 1987, 1998; Haygarth 1994; Chapman et al. 2009, 2010). Selenium consumed in the diet of adult female fish is deposited in the eggs, when selenium replaces sulfur in vitellogenin, which is transported to the ovary and incorporated into the developing ovarian follicle (Janz et al. 2010), the primary yolk precursor.

Selenium is a member of the sulfur group of nonmetallic elements, and consequently, the two chemicals share similar characteristics. Selenium can replace sulfur in two amino acids, the seleno-forms being selenomethionine and selenocysteine. It has been a long-standing hypothesis

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that the cause of malformations in egg-laying vertebrates is due to the substitution of selenium for sulfur in these amino acids and their subsequent incorporation into proteins, which causes disruption of the structure and function of the protein. When present in excessive amounts, selenium is erroneously substituted for sulfur, resulting in the formation of a triselenium linkage (Se-Se-Se) or a selenotrisulfide linkage (S-Se-S), either of which was thought to prevent the formation of the normal disulfide chemical bonds (S-S). The end result was thought to be distorted, dysfunctional enzymes and protein molecules that impaired normal cellular biochemistry (Diplock and Hoekstra 1976; Reddy and Massaro 1983; Sunde 1984).

Recent research, however, suggests that selenium's role in oxidative stress plays a role in embryo toxicity, whereas selenium substitution for sulfur does not. The substitution of selenomethionine for methionine does not appear to affect either the structure or function of proteins (Yuan et al. 1998; Mechaly et al. 2000; Egerer-Sieber et al. 2006). The reason is apparently due to selenium not being distally located in selenomethionine, which insulates the protein from an effect on its tertiary structure. Although the incorporation of selenomethionine into proteins is concentration-dependent (Schrauzer 2000), selenocysteine's incorporation into proteins is not (Stadtman 1996). This suggests that neither selenomethionine nor selenocysteine affect protein structure or function. In fact, Se as an essential micronutrient is incorporated into functional and structural proteins as selenocysteine.

The role of selenium-induced oxidative stress in embryo toxicity and teratogenesis appears to be related to glutathione homeostasis. A review of bird studies by Hoffman (2002) showed exposure to selenium altered concentrations and ratios of reduced to oxidized glutathione thereby increasing measurements of oxidative cell damage. Palace et al. (2004) suggested oxidative stress due to elevated selenium levels results in pericardial and yolk sac edema in rainbow trout embryos. Evidence for the role of oxidative stress in selenium toxicity is growing, but mechanistic studies are needed to better understand its effects on egg-laying vertebrates. For a more in depth discussion on the mechanism of toxicity at the cellular level including the evidence against sulfur substitution as a cause and the role of oxidative stress, see Janz et al. (2010).

The most well-documented, overt and severe toxic symptoms in fish are reproductive teratogenesis and larval mortality. Egg-laying vertebrates appear to be the most sensitive taxa, with toxicity resulting from maternal transfer to eggs. In studies involving young organisms

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exposed through transfer of selenium from adult female fish into their eggs, the most sensitive diagnostic indicators of selenium toxicity in vertebrates occur when developing embryos metabolize organic selenium that is present in egg albumen or yolk. It is then further metabolized by larval fish after hatching.

A variety of lethal and sublethal deformities can occur in the developing fish exposed to selenium, affecting both hard and soft tissues (Lemly 1993b). Developmental malformations are among the most conspicuous and diagnostic symptoms of chronic selenium poisoning in fish. Terata are permanent biomarkers of toxicity, and have been used to identify impacts of selenium on fish populations (Maier and Knight1994; Lemly 1997b). Deformities in fish that affect feeding or respiration can be lethal shortly after hatching. Terata that are not directly lethal, but distort the spine and fins, can reduce swimming ability, and overall fitness. Because the rate of survival of deformed young would be less than that for normal young, the percentage of deformed adults observed during biosurveys will likely understate the underlying percentage of deformed young, although quantitation of the difference is ordinarily not possible.

In summary, the most sensitive indicators of selenium toxicity in fish larvae are effects modulated through the reproductive process and exhibited in fish larvae as teratogenic deformities such as skeletal, craniofacial, and fin deformities, and various forms of edema that result in mortality (Lemly 2002). The toxic effect generally evaluated is the reduction in the number of normal healthy offspring compared to the starting number of eggs. In studies of young organisms exposed to selenium solely through their own diet (rather than via maternal transfer), reductions in survival and/or growth are the effects that are generally evaluated.

2.4 Narrow Margin between Sufficiency and Toxicity of Selenium

Selenium has a narrow range encompassing what is beneficial for biota and what is detrimental. Selenium is an essential nutrient that is incorporated into functional and structural proteins as selenocysteine and selenomethionine. Several of these proteins are enzymes that provide cellular antioxidant protection. Selenomethionine is readily oxidized, and its antioxidant activity arises from its ability to deplete reactive oxygen species. Selenomethionine is required as a mineral cofactor in the biosynthesis of glutathione peroxidases. All of the classic glutathione peroxidases contain selenium and are found to be involved in the catalytic reaction of these many enzymes (Allan 1999). The major function of the glutathione peroxidases involves the reduction

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of hydrogen peroxide to water at the expense of the oxidation of glutathione, the enzyme's cofactor, an important antioxidant process at normal dietary levels.

Aquatic and terrestrial organisms require low levels of selenium in their diet to sustain metabolic processes, whereas excess concentrations of selenium that are only an order of magnitude greater than the required level have been shown to be toxic to fish, apparently due to generation of reactive oxidized species, resulting in oxidative stress (Palace et.al. 2004). Dietary requirements in fish have been reported to range from 0.05 to 1.0 mg Se/kg dw (Watanabe et al. 1997). Selenium requirements for optimum growth and liver glutathione peroxidase activity in channel catfish were reported as 0.25 mg Se/kg dw (Gatlin and Wilson 1984). Estimated selenium dietary requirements in hybrids of striped bass, based on selenium retention, were reported as 0.1 mg Se/kg dw (Jaramillo 2006). Selenium deficiency has been found to affect humans (U.S. EPA 1987), sheep and cattle (U.S. EPA 1987), deer (Oliver et al. 1990), fish (Thorarinsson et al. 1994; Wang and Lovell 1997; Wilson et al. 1997; U.S. EPA 1987), aquatic invertebrates (Audas et al. 1995; Caffrey 1989; Cooney et al. 1992; Cowgill 1987; Cowgill and Milazzo 1989; Elendt 1990; Elendt and Bais 1990; Harrison et al. 1988; Hyne et al. 1993; Keating and Caffrey 1989; Larsen and Bjerregaard 1995; Lim and Akiyama 1995; Lindstrom 1991; U.S. EPA 1987; Winner 1989; Winner and Whitford 1987), and algae (Doucette et al. 1987; Keller et al. 1987; Price 1987; Price et al. 1987; Thompson and Hosja 1996; U.S. EPA 1987; Wehr and Brown 1985). The predominance of research on selenium deficiency in invertebrates and algae is related to optimizing the health of test organisms cultured in the laboratory. A summary of several studies that evaluated the deficiency and/or the sufficiency of selenium in the diet of fish is provided in Appendix E.

2.5 INTERACTIONS WITH MERCURY

The most well-known interactions with selenium occur with both inorganic and organic mercury, and are generally antagonistic (Micallef and Tyler 1987; Cuvin and Furness 1988; Paulsson and Lundbergh 1991; Siegel et al. 1991; Southworth et al. 1994; Ralston et al. 2006), with the most likely mechanism being the formation of metabolically inert mercury selenides (Ralston et al. 2006; Peterson et al. 2009). However, other studies have found interactions between mercury and selenium to be additive (Heinz and Hoffman 1998) or synergistic

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(Huckabee and Griffith 1974; Birge et al. 1979). The underlying mechanism for these additive and synergistic interactions between mercury and selenium are unknown.

2.6 ASSESSMENT ENDPOINTS

Assessment endpoints are defined as "explicit expressions of the actual environmental value that is to be protected" and are defined by an ecological entity (species, community, or other entity) and its attribute or characteristics (U.S. EPA 1998). Assessment endpoints may be identified at any level of organization (e.g., individual, population, community). In the context of the Clean Water Act, aquatic life criteria for toxic pollutants are typically determined based on the results of toxicity tests with aquatic organisms in which unacceptable effects on growth, reproduction, or survival occurred. The goal of criteria is to protect the diversity, productivity, and stability of aquatic communities. To achieve this goal, the endpoint of criteria assessment is the survival, growth, and reproduction of a high percentage of species of a diverse assemblage of freshwater aquatic animals (fish, amphibians, and invertebrates) and plants. Toxicity data are aggregated into a sensitivity distribution that indicates the impact of the toxicant under study to a variety of genera representing the broader aquatic community. Criteria are designed to be protective of the vast majority of aquatic animal species in an aquatic community (i.e., approximately 95^{th} percentile of tested aquatic animals representing the aquatic community). As a result, health of the aquatic community may be considered as an assessment endpoint indicated by survival, growth, and reproduction. Assessment endpoints are the ultimate focus in risk characterization and link the measurement endpoints to the risk management process (e.g., policy goals). When an assessment endpoint can be directly measured, the measurement and assessment endpoints are the same. In most cases, however, the assessment endpoint cannot be directly measured, so a measurement endpoint (or a suite of measurement endpoints) is selected that can be related, either qualitatively or quantitatively, to the assessment endpoint. For example, a decline in a sport fish population (the assessment endpoint) may be evaluated using laboratory studies on the mortality of surrogate species, such as the fathead minnow (the measurement endpoint) (EPA/630/R-92/001 February 1992). The assessment endpoint for selenium is the protection of freshwater aquatic life; because we know that fish are the most sensitive aquatic taxon to the toxicological effect of selenium, the criterion is expressed in terms of fish tissue using eggs and ovarian tissue as the most representative element related to selenium toxicity.

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To assess potential effects on the aquatic ecosystem by a particular stressor, and develop 304(a) aquatic life criteria under the CWA, EPA typically requires the following, as outlined in the EPA Ambient Water Quality Criteria Guidelines: acute toxicity test data (mortality, immobility, loss of equilibrium) for aquatic animals from a minimum of eight diverse taxonomic groups; as well as chronic toxicity data (e.g., survival, growth and reproduction) for aquatic animals from 8 eight taxonomic groups (described in more detail below). The diversity of tested species is intended to ensure protection of various components of an aquatic ecosystem. In the case of bioaccumulative compounds like selenium, these acute toxicity studies do not address risks that result from exposure to chemicals via the diet (through the food web). They also do not account for the slow accumulation kinetics of many bioaccumulative compounds such as selenium and may underestimate effects from long-term accumulation in different types of aquatic systems (SAB 2005).

Because the most sensitive adverse effects of selenium are reproductive effects (larval deformities and mortality) on the offspring of exposed fish, chronic effects from long term exposure are the focus of this selenium assessment. In addition to continuous discharges, shorter-term intermittent or pulsed exposures to elevated levels of selenium may also result in bioaccumulation through the aquatic food web and may subsequently adversely affect fish reproduction, and such measures of effect are therefore also estimated from chronic assessment endpoints. Selenium toxicity in the water body could potentially threaten fecundity and recruitment in fishes, resulting in extirpation of sensitive species in a waterbody, and potentially shifting the trophic dynamics of the system. Therefore, the assessment endpoint for selenium is the protection of fish populations. In some waters where ESA-listed fish species occur, a protection goal oriented to protection of individuals may be more appropriate. This should be reflected using site-specific data to derive an SSC for the site.

Chronic toxicity test data (longer-term survival, growth, or reproduction) for aquatic animals are needed from a minimum of eight diverse taxonomic groups (or less generically, [minimum of three taxa] if the derivation is based on an acute to chronic ratio). The diversity of tested species is intended to ensure protection of various components of an aquatic ecosystem. Specific minimum data recommendations or requirements (MDRs) identified for development of criteria in the EPA Ambient Water Quality Criteria Guidelines require aquatic animal toxicity data from:

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1. the family Salmonidae in the class Osteichthyes,
2. a second family in the class Osteichthyes, preferably a commercially or recreationally important warmwater species (e.g., bluegill, channel catfish, etc.),
3. a third family in the phylum Chordata (may be in the class Osteichthyes or may be an amphibian, etc.),
4. a planktonic crustacean (e.g., cladoceran, copepod, etc.),
5. a benthic crustacean (e.g., ostracod, isopod, amphipod, crayfish, etc.),
6. an insect (e.g., mayfly, dragonfly, damselfly, stonefly, caddisfly, mosquito, midge, etc.),
7. a family in a phylum other than Arthropoda or Chordata (e.g., Rotifera, Annelida, Mollusca, etc.), and
8. a family in any order of insect or any phylum not already represented.

Acceptable quantitative chronic values for selenium are available for six of the eight MDRs (requirements 1, 2, 3, 6, 7, and 8). Acceptable chronic values for selenium are not available for two of the MDRs (requirements 4 and 5: planktonic and benthic crustaceans, respectively). Following the approach of U.S. EPA (2008b), which was reviewed by the Science Advisory Board, if information is available to demonstrate that an MDR is not sensitive, then a surrogate value can be used in place of actual toxicity data to represent the missing MDR. Based on the data estimating the sensitivity of insects (*Centroptilum triangulifer*), rotifers (*Brachionus calyciflorus*), and oligochaetes (*Lumbriculus variegatus*), EPA determined that invertebrates (e.g., insects and crustaceans) are generally less sensitive to selenium than fish, based on the characteristics of selenium toxicity to aquatic life. Therefore, the available fish data were used in the genus-level sensitivity distribution to derive the chronic selenium criterion (Note: invertebrate data were included in the sensitivity distribution for the whole body criterion element to demonstrate that the derivation of the criterion element based on the fish egg-ovary to whole body translated values protected invertebrates given the sensitivity range of the available species).

The EPA Ambient Water Quality Criteria Guidelines also require at least one acceptable test with a freshwater alga or vascular plant. If plants are among the aquatic organisms most sensitive to the stressor, results of a plant in another phylum should also be available. A

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relatively large number of tests from acceptable studies of aquatic plants were available for possible derivation of a Final Plant Value. However, the relative sensitivity of freshwater plants to selenium (Appendix F) is less than fish, so plant criterion elements were not developed.

The available scientific evidence indicates that for selenium, critical assessment endpoints for aquatic species are offspring mortality and severe development abnormalities that affect the ability of fish to swim, feed and successfully avoid predation, resulting in impaired recruitment of individuals into fish populations. Selenium enrichment of reservoir environments (e.g., Belews Lake, NC (Lemly 1985), Hyco Reservoir (DeForest 1999), and Kesterson Reservoir, CA (Ohlendorf 1986)) are well documented and demonstrate that adverse effects resulted from bioaccumulative processes at different levels of biological organization, resulting in population-level reductions of resident species.

2.7 Measures of Effect

Each assessment endpoint requires one or more "measures of ecological effect", which are defined as changes in the attributes of an assessment endpoint itself or changes in a surrogate entity or attribute in response to chemical exposure. Ecological effects data are used as measures of direct and indirect effects to growth, reproduction, and survival of aquatic organisms.

The toxicity testing data available for any given pollutant vary significantly, depending primarily on whether any major environmental issues are raised. An in-depth evaluation of available data for selenium has been performed by EPA to determine data acceptability and quality, based on criteria established in the EPA Ambient Water Quality Criteria Guidelines.

In traditional chronic tests used in many EPA aquatic life criteria documents, organisms are exposed to contaminated water but fed a diet grown in uncontaminated media not spiked with the toxicant prior to introduction into the exposure chambers. Such tests are not suitable for deriving a criterion for a bioaccumulative pollutant unless (1) effects are linked to concentrations measured in appropriate tissues, and (2) the route of exposure does not affect the potency of residues in tissue. For selenium, the first condition might be met, but the second condition is not, because the route of selenium exposure appears to influence the potency of a given tissue residue (Cleveland et al. 1993; Gissel-Nielsen and Gissel-Nielsen 1978). Consequently, toxicity tests with water-only exposures (and any tests not relying on dietary exposure) are not included in this assessment.

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Selenium toxicity is primarily manifested as reproductive impairment due to maternal transfer, resulting in embryo mortality and teratogenicity. Measurements of selenium in fish tissue are most closely linked to the chronic adverse effects of selenium (Chapman et al. 2010), since chronic selenium toxicity is based on the food-chain bioaccumulation route, not a direct waterborne route. In this selenium criterion document, water column criterion element concentrations for selenium were derived from fish tissue concentrations by modeling selenium transfer through the food web. The next sections describe approaches used to establish selenium effects concentrations in fish tissue and to relate the concentrations in fish tissue to concentrations in water.

2.7.1 Fish Tissue

Chronic measures of effect concentrations are the $EC_{10,}$ $EC_{20,}$ No Observed Effect Concentration (NOEC), Lowest Observed Effect Concentration (LOEC), and Maximum Acceptable Toxicant Concentration (MATC). The EC_{10} is the concentration of a chemical that is estimated to result in a 10 percent effect in a measured chronic endpoint (e.g., growth, reproduction, or survival); the EC_{20} corresponds to 20 percent effect. The NOEC is the highest chemical concentration at which none of the observed effects are statistically different from the control, as determined by hypothesis testing. The LOEC is the lowest test concentration at which observed effects are found to be statistically different from the control. For selenium, in all cases the effect endpoint used in the estimation of chronic values (e.g., EC_{10}s) is an effect on offspring (with exposure via maternal transfer) from parents exposed to selenium via diet. Selenomethionine was used exclusively in dietary exposures in the lab, whereas field-exposed females would be exposed to a combination of forms of selenium as a function of the selenium in their prey items.

Whenever possible, estimates of selenium concentrations associated with a low level of effect (i.e., EC_{10}) were calculated for each study using the computer program TRAP (version 1.30a), Toxicity Relationship Analysis Program (U.S. EPA 2013). The program is based on a regression approach that models the level of adverse effects as a function of increasing concentrations of the toxic substance. With the fitted model it is possible to estimate the contaminant concentration associated with a small effect. TRAP was used when there are sufficient data for EC_{10} estimation. For studies with binary data, the analysis proceeded by tolerance distribution analyses using the log-triangular distribution, unless there was substantial

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extrabinomial variability, in which case regression analysis was used. For regression analysis, the threshold sigmoidal model was used, exposure variables were log-transformed, and effects variables were weighted appropriately to address their relative uncertainties.

When there were insufficient data for TRAP to fit an effects/exposure curve (no treatments with clear effects near the EC_{10} and/or significant background variability), the EC_{10} was based on interpolation. To ensure that the interpolations were comparable to the TRAP analyses, threshold sigmoidal equation was used. This equation is fitted to two points, and constrained so that 3 equation parameters can be set. The first set-point was treated as the EC_0 with a second associated set-point being the threshold for background effects values, based on the highest NOEC (HNOEC) datum and other NOEC data. The final set-point was the LOEC. If the LOEC is a partial effect, then this point was used to estimate the equation slope. If the LOEC was a 100% effect, it was specified as the EC_{100}; with the EC_0 specified, then this relationship dictated the equation slope. It should be noted that despite the superficial resemblance of these analyses to TRAP they are also subject to the uncertainties associated with the interpolation method.

It should be noted that TRAP involves the assumption that (a) there is a single underlying relationship of the effects variable to the exposure variable which follows the specified equation and (b) the exposure variable is known with negligible error, with uncertainty being predominantly in the effects variable. Some of the reproductive data for selenium involved multiple sources of variability that led to both multiple relationships across different cohorts of offspring and uncertainty in the exposure variable, so that the resulting TRAP curves were more approximate, and TRAP error estimates were generally not useful. These issues can also affect the interpolation protocol. It should also be noted that estimating a concentration associated with a low effects level, such as an EC_{10}, is especially uncertain when treatments yielding partial effects values are lacking in the concentration response data produced by a study. These two issues prevented the use of TRAP in some datasets. When the data are insufficient to provide any meaningful EC_{10} by the first two approaches, the study should either not be used for criteria development or a chronic value should be set by other means than an estimated EC_{10} if possible.

Only studies with a reference site (field surveys) or control treatment(s) (experimental studies) were included in the analysis, because response levels at these low selenium concentrations were the most influential points for calculating the estimated response level at a

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selenium concentration of zero (y_0). When considering the use of the EC_{10} versus the EC_{20}, an EC_{10} was determined to be a more appropriate endpoint for tissue-based criteria given the nature of exposure and effects for this bioaccumulative chemical. EC_{20}s have historically been used in the derivation of EPA criteria applicable to the water medium. While water concentrations may vary rapidly over time, tissue concentrations of bioaccumulative chemicals are expected to vary gradually over time. Thus, where concentrations of selenium in fish tissue are used as an effect threshold, there is potential for sustained impacts on aquatic systems, relative to chemicals that are not as bioaccumulative. Furthermore, it was found that the dose-response curves for selenium across a broad range of fish genera are very steep, such that a small change in selenium tissue concentration yielded a large increase in observed adverse effect. In many cases, the selenium data indicated a change from control effect levels to effects in excess of 50% for larval mortality or deformity over a few mg/kg dry weight increase in selenium detected in fish tissue. These issues call for use of a lower level of effect to attain sufficient protection. The EC_{10} was also preferred over the NOEC or LOEC as these measures of effect are influenced by study design, specifically the concentrations tested, the number of concentrations tested, the number of replicates for each concentration, and the number of organisms in each replicate. As noted by Campbell (2011), EC_{10}s and NOECs are generally of similar magnitude, but EC_{10}s have the advantage of being more reproducible than NOECs (Van der Hoeven et al. 1997; Warne and van Dam 2008). NOECs and MATCs are generally presented if calculated by the original investigators, but were not used where an EC_{10} could be calculated. The four lowest egg-ovary Genus Mean Chronic Values (GMCVs), whose exact values influence the calculation of the egg-ovary criterion element, are all based solely on EC_{10}s. NOECs contribute to some of the GMCVs for less sensitive species.

In this document, chronic values are presented as tissue concentrations of total selenium in units of mg/kg dry weight (dw). Studies of chronic toxicity of selenium to aquatic organisms measure concentrations in distinct tissues (e.g., whole body, ovaries, eggs, muscle, and liver) and report these values as either wet weight (ww) or dw. Studies reporting tissue concentrations only based on wet weight were converted to dry weight using tissue-specific and species-specific conversion factors. When wet to dry weight conversion factors were not available for a given species, conversion factors for a closely related taxon were used. In deriving the egg or ovary tissue criterion element, chronic values are for those tissues directly measured in the study.

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Tissue-to-tissue conversions (e.g., to estimate concentrations in an unmeasured tissue from a study's measured tissue) involve some uncertainty because of variability in tissue concentration ratios (deBruyn et al. 2008; Osmudson et al. 2007). Tissue-to-tissue conversions were needed for calculating the reproductive toxicity-based whole-body and muscle chronic criterion element and water criterion concentration elements.

The overall assessment evaluates both reproductive and non-reproductive studies. Selenium concentrations measured directly in eggs or ovaries from reproductive (maternal transfer) studies are used to derive the egg/ovary criterion element, and corresponding selenium concentrations in whole body or muscle tissue resulting in reproductive effects are estimated using conversion factors. Direct measurements of selenium concentrations in whole-body or muscle from non-reproductive studies are used to examine non-reproductive, chronic effects, such as impairments to growth.

2.7.2 Water

While state monitoring programs may sample ambient waters for selenium, widespread measurements of selenium in fish tissue are relatively rare. Therefore, EPA is providing estimated chronic measures of effect for water column data. The chronic criterion element for the water column is the 30-day average concentration that corresponds to the concentration of selenium in fish tissue estimated to result in a 10 percent effect in fish for a specific water body type (lotic or lentic water bodies as described below in **Section 3.2.4**). The chronic criterion element for the water column is derived by modeling trophic transfer of selenium through the food web resulting in the fish tissue concentration that yields the chronic reproductive effects of concern.

EPA collaborated with the United States Geological Survey (USGS) to develop a model (later published in Presser and Luoma 2010) that relates the concentration of selenium in fish tissue to the water column. The approach is based on bioaccumulation and trophic transfer through aquatic system food-webs. Model parameters are calculated using both field and laboratory measurements of selenium in water, particulate material (algae, detritus and sediment), invertebrates, fish whole-body, and fish egg-ovary. Although EPA and USGS use the same model to relate the concentration of selenium in fish tissue to water, EPA starts with selenium in the egg/ovary (reproductive criterion) whereas USGS starts with selenium in the fish's whole body. The EPA approach therefore has the additional step of converting the

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concentration of selenium in the egg/ovary to whole body. This model (which is a set of equations) is described in more detail in **Section 3.2.1**.

2.7.3 Summary of Assessment Endpoints and Measures of Effect

The typical assessment endpoints for aquatic life criteria are based on effects on growth, reproduction, or survival of the assessed taxa. These measures of effect on toxicological endpoints of consequence to populations are provided by results from toxicity tests with aquatic plants and animals. The toxicity values (i.e., measures of effect expressed as genus means) are used in the genus sensitivity distribution of the aquatic community to derive the aquatic life criteria. Endpoints used in this assessment are listed in **Table 2.2**.

Table 2.2. Summary of Assessment Endpoints and Measures of Effect Used in Criterion Derivation for Selenium.

Assessment Endpoints for the Aquatic Community	**Measures of Effect**
Survival, growth, and reproduction of freshwater fish, other freshwater vertebrates, and invertebrates	For effects from chronic exposure: 1. EC_{10} concentrations in egg and ovary, for offspring mortality and deformity. 2. Measured or estimated reproductive EC_{10} in whole body and muscle. 3. Estimated concentrations (µg/L) in water linked to egg-ovary EC_{10}s by food web-modeling. 4. Intermittent water concentrations yielding exposure equivalent to the above. For acutely lethal effects: Acute toxicity effects based on standard water column-only toxicity testing are not provided here for selenium, due to the dominant significance of chronic effects. Note: Chronic criterion is expected to be protective of acute effects.

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2.7.4 Conceptual Model of Selenium Effects on Aquatic Life

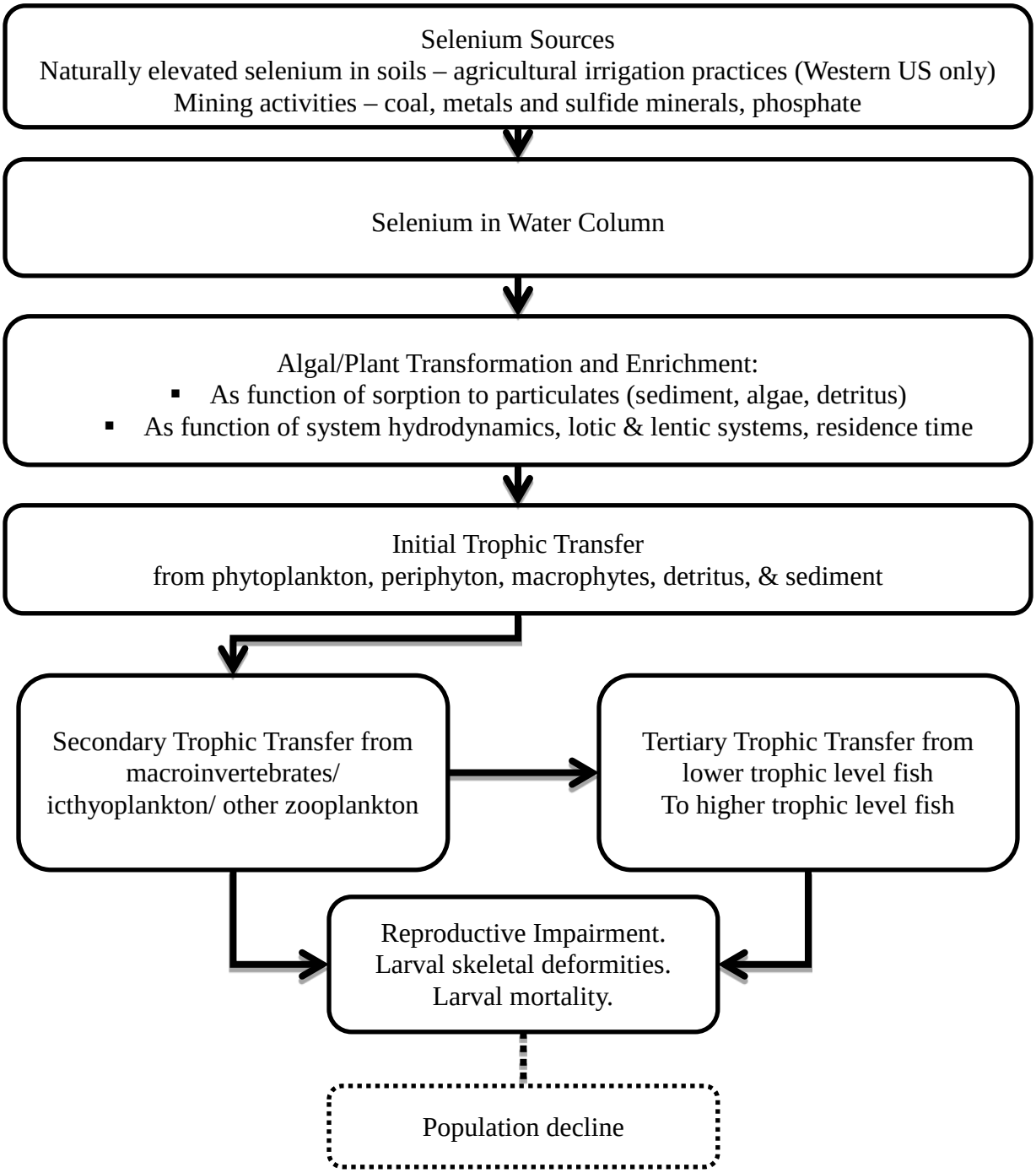


Figure 2.2. Diagram of Selenium Partitioning, Bioaccumulation, and Effects in the Aquatic Environment.

The conceptual model links sources, transformation and uptake through media phases, and consumer transfer and dynamics reflective of the movement of selenium through ecosystems (**Figure 2.2**). Diet is the dominant pathway of selenium exposure for both invertebrates and

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vertebrates. Selenium moves from water to particulates, a collection of biotic and abiotic compartments that includes primary producers, detritus, and sediments, which form the base of aquatic food webs. Transfer from particulates to primary consumers (e.g., macroinvertebrates) to fish is species specific. Knowledge of the food web is one of the keys to determining which biological species or other ecological characteristics will be affected.

During the development of CWA section 304(a) criteria, EPA assembles all available test data and considers all the relevant data that meet acceptable data quality and test acceptability standards. This criterion update document is specific to selenium in fresh water. Chronic criterion elements for selenium are protective concentrations measured in fish tissue and related to protective water concentrations generated using food-web modeling. Further modeling is used to estimate short-term concentrations in water from intermittent or pulsed exposures that are protective against the chronic effect.

2.7.5 Analysis Plan for Derivation of the Chronic Fish Tissue-Based Criterion Elements

Data for possible inclusion in the selenium dataset were obtained primarily by search of published literature using EPA's public ECOTOX database (up to July 2013). These studies were screened for data quality as described in the EPA Ambient Water Quality Criteria Guidelines, and adjusted for factors related to dietary lab or field exposure, which were not considered at the time the Guidelines were written. Additional data were considered and reviewed for inclusion in this criterion based on the public and peer review comments on the 2014 "External Peer Review Draft" criterion document, and public comments on the 2015 draft.

Chronic toxicity studies (both laboratory and field studies) were further screened to ensure they contained the relevant chronic exposure conditions of selenium to aquatic organisms (i.e., dietary, or dietary and waterborne selenium exposure), measurement of chronic effects, and measurement of selenium in tissue(s). The criterion derivation uses only those studies in which test organisms were exposed to selenium in their diet, because such studies most closely replicate real-world exposures (diet and/or diet plus water). This approach accords with findings and recommendations of the 2009 SETAC Pellston Workshop (Chapman et al. 2009, 2010).

EPA grouped studies based on whether the effects were chronic reproductive (e.g., effects on offspring survival or morphology) or chronic non-reproductive (e.g., juvenile growth and survival). At the 2009 Pellston workshop (Chapman et al. 2009, 2010), a group of 46 experts in the area of ecological assessment of selenium in the aquatic environment agreed that the most

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important toxicological effects of selenium in fish arise following maternal transfer of selenium to eggs during vitellogenesis, resulting in selenium exposure when hatched larvae undergo yolk absorption. Such effects include larval mortality or permanent developmental malformations, such as skeletal and craniofacial deformities. Therefore, the chronic fish-tissue-based criterion elements are based on reproductive effects only.

The egg-ovary Species Mean Chronic Values (SMCVs) were calculated from the chronic values (EC_{10}s and occasionally NOECs) obtained from the relevant toxicity tests. Genus Mean Chronic Values (GMCVs) were calculated from the SMCVs and then rank-ordered from least to most sensitive. The four lowest egg-ovary Genus Mean Chronic Values (GMCVs), whose exact values influence the calculation of the egg-ovary criterion element, are all based solely on EC_{10}s. The egg-ovary Final Chronic Value (FCV) was calculated from regression analysis of the four most sensitive GMCVs, in this case extrapolating to the 5^{th} percentile of the distribution represented by the tested genera. The FCV directly serves as the fish tissue egg-ovary criterion concentration element without further adjustment because the underlying EC_{10}s represent a low level of effect (per the EPA Ambient Water Quality Criteria Guidelines).

For the whole-body and muscle criterion element concentrations, CVs were either measured directly using the relevant tissue or the egg-ovary CVs were converted to estimated equivalent whole-body or muscle CVs. The criterion concentration element expressed as whole-body or as muscle concentration was calculated in a manner similar to the egg-ovary criterion element using a combination of directly calculated CVs or CVs that used conversion factors described below.

2.7.6 Analysis Plan for Derivation of the Fish Tissue Criterion Elements Duration

Duration of the averaging periods in national criteria restrict allowable fluctuations in the concentration of the pollutant in the receiving water and restrict the length of time that the concentration in the receiving water can be continuously above a criterion concentration, in order to protect aquatic life. A numerical value for the fish tissue criterion elements averaging period, or duration, is specified as instantaneous, because fish tissue data provide point, or instantaneous, measurements that reflect integrative accumulation of selenium over time and space in the fish population(s) at a given site. Selenium concentrations in fish tissue are generally expected to change only gradually over time (**Section 3.2.6** and Appendix J) in response to environmental fluctuations; thus, there would be relatively little difference in tissue concentrations with

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different averaging period durations if the average selenium concentrations in water are relatively stable over time. Generally fish collected to calculate average tissue concentrations for a site are collected in one sampling event, or over a short time interval due to logistical constraints and costs for obtaining samples incurred by state monitoring programs.

2.7.7 Analysis Plan for Derivation of the Fish Tissue Criterion Elements Return Frequency

Frequency is the number of times an excursion can occur over time without impairing the aquatic community or other use. The current recommendation (1985 Guidelines – EPA PB85-227049) for return frequency of once in 3 years on average is based on the ability of an aquatic ecosystem to recover from a toxic insult when pollutant impacts are associated exclusively with a water column exposure. This recommendation is based on the variability of water concentrations that aquatic life will be exposed to, and is set at a low level such that the water concentrations would mostly be below the criteria concentration. Selenium, however, is a bioaccumulative pollutant, and elevated levels in various ecological compartments (e.g., biota, surficial sediments) require a long period to decrease and the associated aquatic community requires a long time to recover following reduction or removal of an elevated selenium exposure to a given system (e.g., Belews Lake, NC, and Hyco Lake, NC).

Cumbie and Van Horn (1978) first reported young of the year losses in Belews Lake quickly followed by dramatic decreases in standing stocks of many species, and particularly game species like bluegill and largemouth bass. Fish communities were reduced to selenium-tolerant species including cyprinids (e.g., fathead minnow) and green sunfish in both lakes. Selenium reduction in Belews Lake (1985) and Hyco Lake (1990), resulted in rapid decreases in [Se] in the water column, but reductions in fish tissue took much longer. Finley and Garrett (2007) show that concentrations in bluegill and largemouth decreased from 19 and 17 mg/kg dw, respectively in 1992-1994 to ~8.0 mg/kg dw in both species sampled between 2003-2005. In Belews Lake, where Se contamination was higher, [Se] in crappie and redear sunfish averaged 18 and 17 mg/kg dw respectively in 1994-1996, and decreased to ~9-10 mg/kg dw in both species based on sampling in 2004-2006, twenty years later.

Chapman et al. (2010) also reported a similar scenario for Hyco Lake where “fish recruitment failure and the a massive fish kill in 1980 led to a decimated fishery. Selenium concentrations in the reservoir were reduced beginning in 1990 and gradual reductions in Se exposure via the food web led to the reestablishment of a diverse Hyco Lake fish community

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similar to the period prior to Se impact." The Belews and Hyco Lake examples indicate that a protracted period of time (in excess of 10 years) would be necessary for fish communities to recover once a selenium in fish tissue reached concentrations associated with reproductive impacts. Thus, the typical "once-in-three years on average" criteria return frequency is not appropriate for selenium, as this could lead to sustained ecological impacts.

2.7.8 Analysis Plan for Derivation of Chronic Water-based Criterion Element

The relationship between the ambient concentration of selenium in water and the concentration of selenium in the eggs or ovaries of fish is primarily through trophic transfer of selenium, which is greatly affected by site-specific conditions. EPA used a peer-reviewed model to derive water concentrations from the egg-ovary criterion element that explicitly recognizes partitioning of selenium in water and particulate material (algae, detritus, and sediment), and trophic transfer from particulate material to aquatic invertebrates, from invertebrates to fish, and partitioning in fish whole-body and fish eggs and ovaries. The method is composed of five main steps:

1. Formulate a mathematical equation relating the concentration of selenium in the eggs and ovaries of fish to the ambient concentration of selenium in the water column.
2. Develop parameters needed to use the mathematical equation formulated in step 1 from available empirical or laboratory data related to selenium bioaccumulation in aquatic systems and aquatic organisms.
3. Classify categories of aquatic systems where a single water column concentration would be adequately protective by evaluating the bioaccumulation potential at the base of the aquatic food web.
4. Translate the egg-ovary criterion element to an equivalent water column concentration at each aquatic site.
5. Apply a statistical threshold to the distribution of translated water column concentrations for each aquatic system category to yield a water column concentration value that would be protective of each aquatic system category.

EPA worked with USGS to derive a translation equation to estimate the site-specific concentration of selenium in the water column corresponding to the egg-ovary criterion element concentration. This equation utilizes a mechanistic model of bioaccumulation previously

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published in peer-reviewed scientific literature (Luoma et. al. 1992; Wang et. al. 1996; Luoma and Fisher 1997; Wang 2001; Schlekat et al. 2002b; Luoma and Rainbow 2005; Presser and Luoma 2006, 2010; Presser 2013). The equation uses site-specific food web models, species-specific Trophic Transfer Factor (*TTF*) values, egg-ovary to whole-body conversion factor (*CF*) values, and a site-specific enrichment factor (*EF*) values to calculate a site-specific water column concentration element from the egg-ovary criterion element.

Empirical or laboratory data related to selenium bioaccumulation in aquatic organisms are needed to calculate species-specific *TTF* and *CF* parameters and a site-specific *EF* parameter. EPA obtained these data by reviewing its extensive selenium library of published papers and reports, by searching published literature using EPA's public ECOTOX database and other publically available data received through solicitation of public comments on the 2014 "External Peer Review" draft, through the external peer reviewers of the 2014 draft, and through public comments on the 2015 draft criterion document. Studies were screened using the same data quality guidelines described above. Relevant studies contained selenium measurements from field studies (water, particulate material, and aquatic organisms) or contained laboratory data on physiological parameters of selenium bioaccumulation in aquatic organisms. Literature searches for information on selenium associated with particulate matter included searches for data on all forms of algae, detritus, inorganic suspended material, and sediment.

EPA compiled a collection of selenium concentration measurements from acceptable field studies. Measurements were accepted if the study indicated the samples were collected in the field, and the study identified the unit of measure, the media from which the measurement was made, the location from where the sample was taken, and the date the sample was collected. EPA only used data from studies with adequately described field collection protocols and where concentrations were within the bounds of concentrations found using modern, rigorous protocols in similar systems (Sañudo-Wilhelmy et al. 2004). The spatial precision of field data sample collection locations were generally at the site level, although aggregate measurements were also included if exposure conditions were considered similar (e.g., averages of single or composite measurements from several locations in the same aquatic system). The temporal precision of sample collection times were usually at the level of the day they were collected, although some studies only provided enough information to determine the week, month, or year. If the day a series of samples were collected was not reported but the study provided information that

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indicated the samples were taken concurrently, EPA noted sample precision, but assigned a single effective collection date to all the samples.

EPA also compiled a collection of physiological coefficients for food ingestion rate (*IR*), selenium assimilation efficiency (*AE*), and rate of selenium loss (k_e) from published literature. Coefficients were accepted if the studies provided either the actual measurements or sufficient information to derive them, and were reported in standard units (k_e: /d; *AE*: %; *IR*: g/g-d) or could be converted to standard units. Even though IR can be highly variable (Whitledge and Hayward 2000), IR values of surrogate species were occasionally used.

EPA accounted for bioaccumulation variability across aquatic sites by evaluating the parameter *EF* (representing the partitioning of selenium between the dissolved and particulate state) from representative aquatic systems. The parameter *EF* is a measure of bioaccumulation potential because it quantifies the transfer of selenium from the water column to particulate material, which is the single most influential step in selenium bioaccumulation (Chapman et al. 2010). EPA calculated *EF* values for a set of aquatic systems using data from published literature and applied statistical methods to distinguish categories with similar bioaccumulation characteristics. On this basis, a single water column concentration is deemed adequately protective when it is derived using data from aquatic sites in the same category. EPA translated the egg-ovary criterion element into a set of water concentration values and derived a water column criterion element for each aquatic system category using a percentile of the water column concentrations for each category. To ensure adequate protection, EPA selected the 20th percentile of the distribution of median water column values as the statistical cut-off (see **Section 3.2.5**). **Figure 2.3** diagrams the conceptual framework EPA used to derive water column criterion element values from the egg-ovary criterion element.

2.7.9 Analysis Plan for Derivation of the Water Criterion Elements Duration

A numerical value for the lentic and lotic water criterion elements averaging period, or duration, is specified as a 30-day average, because the presence of selenium in water is the initial step in the process of bioaccumulation from the water column to fish tissue. The bioaccumulation process for selenium takes place over a longer term than typically observed for acute and chronic effects on aquatic life based on water concentrations. The derivation of a protective water averaging period from kinetic modeling considerations is described in **Section 3.2.6** and in Appendix J. Because the intermittent criterion element values are based on the water

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criteria chronic magnitudes and duration, the kinetic analysis of Appendix J also controls the intermittent criterion element values.

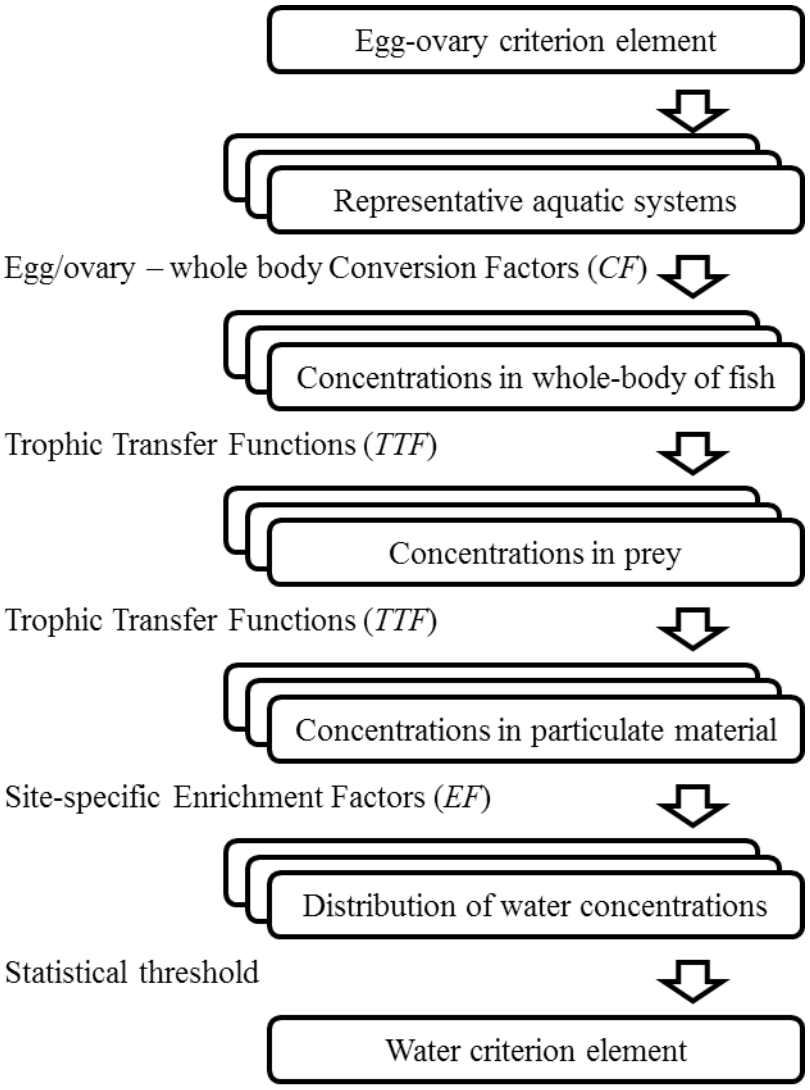


Figure 2.3. Conceptual Model for Translating the Selenium Egg-Ovary Concentration to a Water Column Concentration.

2.7.10 Analysis Plan for Intermittent-Exposure Water-based Criterion Element Derivation

Like the chronic water criterion element, the intermittent-exposure criterion element protects against cumulative exposure of selenium from multiple short-term discharges that may cause an excursion of the fish tissue criterion element. EPA derived the intermittent exposure criterion element directly from the chronic water criterion element by algebraically rearranging

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the chronic water criterion element to establish a limit on an intermittent elevated concentration occurring over a specified percentage of time, while simultaneously accounting for background concentrations (see **Section 3.3**).

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3 EFFECTS ANALYSIS FOR FRESHWATER AQUATIC ORGANISMS

3.1 CHRONIC TISSUE-BASED SELENIUM CRITERION ELEMENT CONCENTRATION

Data were obtained primarily by search of published literature using EPA's public ECOTOX database. The most recent ECOTOX database search extended to July 2013; this document also reflects data either gathered or received by EPA based on information from the 2014 public comment period and 2014 external expert peer review of the "External Peer Review Draft" published in May 2014, as well as information gathered based on public comments on the 2015 draft criterion. All available, relevant, and reliable chronic toxicity values were incorporated into the appropriate selenium AWQC tables and used to recalculate the FCV, as outlined in detail in the EPA Ambient Water Quality Criteria Guidelines.

The chronic values determined from acceptable chronic toxicity studies were separated into reproductive endpoint and non-reproductive endpoint categories. Although both sets of endpoints assess effects due to selenium on embryo/larval or juvenile development and survival and growth, the fundamental difference is exposure route (inherent in test design). That is, the fundamental difference is whether the aquatic organisms (e.g., fish) were directly exposed to selenium in the diet and water column or exposed via maternal transfer of selenium to the eggs/ovaries prior to reproduction. In studies with reproductive endpoints, parental females are exposed to selenium and the contaminant is transferred from the female to her eggs. In the selenium-exposed females, selenium replaces sulfur in vitellogenin, the primary yolk precursor, which is transported to the ovary and incorporated into the developing ovarian follicle (Janz et al. 2010). In most but not all of these studies, progeny from these females were not additionally exposed to aqueous selenium. The chronic values derived for the reproductive effects (survival, deformities, and edema) are based on the concentration of selenium in the eggs or ovary, the tissues most directly associated with the observed effects. In contrast, in studies grouped under non-reproductive effects (usually larval and/or juvenile survival or growth), the tested fish had no maternal pre-exposure to selenium. Chronic values for non-reproductive effects are based on the concentration of selenium in tissues measured in the study: muscle, liver and/or whole body.

The reproductive endpoint studies applied to the derivation of the chronic criterion elements are described below. Less definitive reproductive studies that are not directly applied to

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the criterion derivation are described in **Section 6.1.2** and in Appendix C. Nonreproductive studies are described in **Section 6.1.9**.

3.1.1 Acceptable Studies of Fish Reproductive Effects for the Four Most Sensitive Genera

Below is a brief synopsis of the experimental design, test duration, relevant test endpoints, and other critical information regarding the four sensitive genera that drive the calculation of each specific chronic value. The studies in this section involve effects on the offspring of exposed female fish. Data are summarized in **Table 3.1**. Details of these studies and other chronic studies considered for criterion derivation are contained in Appendix C.

3.1.1.1 Acipenseridae

Acipenser transmontanus (white sturgeon)

Linville (2006) evaluated the effect of elevated dietary selenium on the health and reproduction of white sturgeon. Adult female white sturgeon (approximately 5 years old) were fed either a control diet (no added selenium, 1.4 mg/kg Se) or a diet spiked with selenized yeast (34 mg/kg Se) for six months in a freshwater flow through system. At the end of the dietary exposure, females were induced to spawn and fertilized with non-exposed male milt. Large cohorts of fertilized eggs from individual females (two from control and three from the treatment) were collected and separately hatched. After hatching (stage 36), n=500 sets of larvae were randomly distributed into each of six flowthrough chambers, three for stage 40 assessment and three for stage 45 assessment. Length, weight, mortality, abnormalities (edema, skeletal deformities) and selenium were measured at stages 36, 40 and 45. The mortality and abnormality observations from oldest stage (45) were used for effects analysis because these measurements showed the greatest response.

No selenium effects were observed for length or weight of larvae but effects were observed for both abnormalities (edema and skeletal deformities) and survival. Selenium concentrations in eggs from the control fish were 1.61 and 2.68 mg/kg dry weight (dw), and were 7.61, 11 and 20.5 mg/kg dw in eggs from the treatment fish. As stated above larval survival and abnormality frequency was evaluated at stage 45. Because the mortalities for each cohort were recorded up to the sample collection time for abnormalities, a combined effects variable was derived based on the total proportion of hatched larvae which were both alive and without any abnormalities at stage 45. This can be calculated as PS*(1-PA), where PS is the proportion

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survival in the test chambers and PA is the proportion of the sample of surviving larvae with abnormalities. The larvae hatched from the batches of eggs with selenium concentrations of 1.61, 2.68, 7.61, 11 and 20.5 mg Se/kg dw had 0.3, 0.3, 13.6, 0.3 and 33.8% combined survival and abnormal (edema and deformities) effects, respectively.

Estimation of the EC_{10} was conducted using weighted nonlinear regression analysis with the threshold sigmoid model equation (TRAP version 1.30a). The binary data (i.e., survival and abnormalities) available in this study would normally be analyzed using the tolerance distribution analysis in TRAP; however, the combined survival/abnormalities effects variable in this study precludes its use because of the different sample sizes for survival and abnormality evaluation. When there are insufficient data for TRAP to fit an effects/exposure curve, an interpolation is conducted with the same TRAP equation, but constrained to provide interpolation between two points.

Since the study yielded only one definite partial effect, TRAP cannot be used to estimate a concentration-response curve. Instead, TRAP was used to interpolate between the last two points to estimate the EC_{10} (see Linville summary in Appendix C for detail). The resultant TRAP slope is 2.96 and the interpolated EC_{10} is 15.6 mg/kg.

The white sturgeon EC_{10} of 15.6 mg/kg egg dw is important to include in the criterion analyses because this species a commercially and recreationally important fish species in the Pacific Northwest, and also serves as a surrogate for other sturgeon species in the United States (see **Section 6.4**, Protection of Threatened or Endangered Species), and has a population listed as endangered in the Kootenai River in Idaho and Montana.

3.1.1.2 Salmonidae

Acceptable studies were available for three salmonid genera, *Oncorhynchus*, *Salvelinus* and *Salmo*. All of these studies evaluated the effects of selenium on salmonid embryo/larval survival and deformity and used wild-caught adults taken from selenium contaminated streams and spawned for effects determination. Exposure for all studies was therefore through the parents. Summaries of the studies with *Salvelinus* are discussed in **Section 6.1.2.3**; *Oncorhynchus* and brown trout (*Salmo trutta*) are discussed below.

Oncorhynchus mykiss (rainbow trout) Holm (2002) and Holm et al. (2005) obtained eggs and milt from ripe rainbow trout collected from reference streams and streams containing elevated selenium from an active coal mine in Alberta, Canada. In 2000, 2001 and 2002 eggs

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were fertilized and monitored in the laboratory until swim-up stage, for percent fertilization, deformities (craniofacial, finfold, and spinal malformations), edema, and mortality. No significant differences among sites were observed for percent fertilization and mortality. Percentages of embryonic deformities and edema were significantly different among streams, but rates of deformities at Wampus Creek, one of the reference streams, were often similar to or higher than deformities at streams with elevated concentrations of selenium (see Holm summary in Appendix C). The measurement of selenium in the otolith layers of rainbow trout collected in this watershed showed low selenium exposure in the fish's early life and a higher exposure to selenium during the fish's adult years (Palace et al. 2007), suggesting that individuals that reach adulthood tend not to start their lives in streams with elevated selenium concentrations, even though they may reside there later.

Craniofacial deformities, skeletal deformities and edema in rainbow trout embryo, as a function of selenium in egg wet weight (ww), were fitted to a curve using a weighted regression and a threshold sigmoidal equation (TRAP) from which EC_{10} values were calculated (see Appendix C for tables and figures). EC estimates for finfold deformities, length and weight of rainbow trout embryos could not be made because of inadequate dose-response data. The most sensitive endpoint was edema with an EC_{10} value of 9.5 mg Se/kg egg ww or 24.5 mg Se/kg egg dw. The conversion of ww to dw used the average percent moisture of 61.2% for rainbow trout eggs reported by Seilor and Skorupa (2001).

Oncorhynchus clarkii lewisi (Westslope cutthroat trout)

In a field study similar to those conducted by Holm et al. (2005), Rudolph et al. (2008) collected eggs from Westslope cutthroat trout from Clode Pond (exposed site) and O'Rourke Lake (reference site). Clode Pond is on the property of Fording River Coal Operations in Southeast British Columbia with reported selenium concentrations of 93 µg/L. O'Rourke Lake is an isolated water body into which Westslope cutthroat trout were stocked in 1985, 1989 and 1992 and has selenium levels reported as <1 µg/L. Eggs with the four highest Se concentrations (86.3 to 140 mg/kg dw) collected from Clode Pond fish died before reaching the laboratory. Of those eggs from both ponds that survived, there was no correlation between egg selenium concentration and frequency of deformity or edema in the fry. The percent of alevins (post hatch to swim-up stage) that died was related to the selenium concentration in the eggs; the EC_{10} estimate for alevin survival based on the concentration of selenium in the eggs is 24.7 mg Se/kg

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dw. See Appendix C for details on the statistical analysis and how it differed from the previous draft(s).

As a follow-up to the study by Rudolph et al. (2008), Nautilus Environmental (2011) conducted a more extensive study with Westslope cutthroat trout at the same site. Adult Westslope cutthroat trout were collected from lentic and lotic environments from locations near the mining operations. The lentic fish were primarily captured in Clode Pond, a settling area used to improve water quality of the mining discharge. Lotic fish were collected from the Fording River and its tributaries near the mining operation. Reference females were obtained from Connor Lake which is located within the watershed but not exposed to mining discharges. The researchers reared fertilized eggs from the caught females in the laboratory until they reached swim-up fry stage. A subset of fry surviving at swim-up were reared for an additional 28 days. The most sensitive endpoint was larval survival at swim-up with an EC_{10} of 27.7 mg/kg egg dw determined by interpolation between the one partial effect (20.8% survival at 34.2 mg Se/kg and average NOEC of 87.2% survival at 24.8 mg Se/kg; see Appendix C for detail and how this statistical analysis differed from the previous draft(s)). This result is very similar to the EC_{10} of 24.7 mg/kg egg dw determined for the data generated by Rudolph et al. (2008). See Appendix C for more details on the Nautilus Environmental (2011) study.

The GMCV for *Oncorhynchus* reproductive endpoints is 25.3 mg Se/kg EO. This GMCV is the geometric mean of the *O. mykiss* EC_{10} of 24.5 mg (Holm 2002 and Holm et al. 2005) and the SMCV of 26.2 mg Se/kg EO dw for *O. clarkii.* The *O. clarkii* SMCV was based on the EC_{10} values of 24.7 mg Se/kg EO from Rudolph et al (2008) and 27.7 mg Se/kg EO dw from Nautilus Environmental (2011).

Salmo trutta (brown trout)

Formation Environmental (2011) collected adult female and male brown trout from sites with low and high selenium exposure in the vicinity of a phosphate mine located in Southeastern Idaho in November 2007. Eggs were collected from 26 gravid females across three sampling locations, fertilized with milt collected from several males from the same site and taken to the laboratory for hatching and observation of larval malformations and survival. In addition to the field collected fish, fertilized eggs of 14 females from two separate hatcheries were used in the study.

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The study had two phases, hatch-to-swim up, and swim up-to-15 days post swim-up. There are two experimental complications that affect the interpretation of these data: (a) elevated deformity rates among the offspring that were to serve as hatchery-originated method controls (very low selenium exposure) and among some of the low exposure field-collected organisms, and (b) the accidental loss of a number of individuals from several treatments during the 15-day post swim up portion of the test due to overflow of the tank water. The current criterion document's analysis is still based on the revised count data from AECOM (2012), which built upon and superseded EPA's 2012 analysis (Taulbee et al. 2012), peer reviewed by ERG (2012).

Approximately 600 eggs/female were obtained from the majority of the field and hatchery-collected females; however, the numbers of eggs per female ranged from 20 to 609. Selenium concentrations were measured for a subsample of eggs taken from each field and hatchery-collected female. EPA's primary evaluation in this document is of the survival of larvae from hatch to swim-up. Hatching success and larval survival were monitored to swim-up, at which time the fry were thinned to a maximum of 100 individuals for monitoring survival for 15 days post swim-up. Larvae from 24 field collected and 14 hatchery collected females were assessed for survival, as no larvae hatched from the eggs of two of the 26 field collected females.

Because of uncertainties regarding how best to address the loss of fish during the overflow event during the second phase of the test, and also because of the preferential selection of healthy fish during the thinning process prior to the post-swim-up portion of the test, where only those individuals presumed to be healthy were retained for assessment of deformities, EPA used survival during only the first portion of the test (hatch to swim-up), as it provides a more reliable chronic value.

The dataset of percent survival from hatch to swim-up versus the selenium concentration in eggs is an excellent dataset and provides a good foundation for setting numeric effect concentrations for selenium. There is a narrow range between the NOEC (20.5 mg/kg) and a LOEC with severe effects (26.8 mg/kg, 61% mortality) that leaves little uncertainty in what an appropriately protective effects concentration should be. There are sufficient data for TRAP to estimate a curve, using weighted least-squares nonlinear regression with the threshold sigmoidal model. The weighting factor for the 33 no-effect points is their standard deviation, and the weighting factor for the 5 effect points is their residual standard deviation. The TRAP parameter values are 96.2% for background survival, 1.45 for the logEC_{50} (EC_{50}=28.2 mg/kg), and 4.28 for

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the slope. The EC_{10} is estimated to be 21.0 mg/kg, slightly higher than the NOEC of 20.5 mg/kg. The weighted TRAP model curve fits the 5 higher effects data well, which forces the EC_0 estimate down to 16.4 mg/kg, below two of the points in the background range. In particular, the fitted curve goes through the NOEC data point at 20.5 mg/kg, so that this point is considered to be an EC_8. This is reasonable because the response is so steep at concentrations above this point that some effect at this point is plausible, and also provides further support of an EC_{10} at 21.0 mg/kg. **Section 6.1.6** provides a summary of the analysis that led to the final selection of the EC_{10} for larval survival during the first portion of the test. Appendix C presents details of the study and analysis.

3.1.1.3 Centrarchidae

Lepomis macrochirus (bluegill sunfish)

In a laboratory study, Doroshov et al. (1992a) exposed adult bluegill for 140 days to three dietary treatments of seleno-L-methionine (nominal dietary concentrations of 8, 18 and 28 mg Se/kg) added to trout chow. Near the end of the exposure, ripe females were induced to ovulate and ova were fertilized *in vitro* with milt stripped from males. Fertilized eggs were sampled for fertilization success and selenium content. They were also used in two tests, (a) a larval development study during the first 5 days after hatching, and (b) a 30-day embryo-larval test. In the 30-day larval survival test, statistical difference from the control was only found in the highest test treatment for survival and growth (length and weight) measurements. In the 5-day larval test, the average proportion of larvae with edema was 0% at an egg concentration of 8.33 mg Se/kg (8 mg/kg dietary treatment), 5% at an egg concentration of 19.46 mg Se/kg dw (18 mg/kg dietary treatment), and 95% at an egg concentration of 38.39 mg Se/kg dw (28 mg/kg dietary treatment). The latter two were statistically different from the control (0% edema). All edematous larvae died in the high treatment.

This analysis focuses on the available data for the individual replicates for the 4-day data (5-day were not used because of almost complete mortality at the highest treatment). Of the 33 edema measurements, only 15 could be used because not all the replicate egg concentrations were reported. Table 4 in the Doroshov et al. (1992a) summary in Appendix C shows both individual replicates and the treatment averages, which are only slightly different than the 5-day data (averages) previously used in the selenium document. Individual replicates rather than

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treatment means were used because the exposure concentrations vary substantially and effects are correlated with exposure within the treatment (illustrated by nominal dietary treatments of 18 mg/kg (with corresponding Se concentrations in eggs at that nominal treatment level ranging from 8.55 to 30.20 mg/kg) and 28 mg/kg (with corresponding Se concentrations in eggs ranging from 25.21 to 52.18 mg/kg; see Appendix C for details).

TRAP was fitted to the available data based on the individual replicates and the treatment means using the tolerance distribution option with the log-triangular distribution. In both cases, the TRAP program indicates that the dataset contains inadequate partial responses because the partial responses are less than 10% or greater than 90%, and there are no data (responses) between 10 and 90%. However, for this dataset, these partial responses at both ends of the concentration response curve are sufficiently informative based on multiple lines of evidence (e.g., same response on both days 4 and 5, other endpoints that show effects at dietary treatment of 18 mg/kg, and several instances of edema at dietary treatment 18 mg/kg in contrast to absolutely none for many observations at any lower concentration). Also, because dietary treatment 18 mg/kg does have an effect of several percent or so, estimating the EC_{10} near these points is defensible. Therefore, the EC_{10} estimated using separate replicates is 22.6 mg/kg dw.

A similar study with similar results was done by Coyle et al. (1993) in which two year old pond-reared bluegill sunfish were exposed in the laboratory and fed (twice daily *ad libitum*) Oregon moist™ pellets containing increasing concentrations of seleno-L-methionine. Water concentrations were nominal 10 µg Se/L. The fish were grown under these test conditions for 140 days. Spawning frequency, fecundity, and percentage hatch were monitored for 60 days from the initiation of spawning. There was no effect from the highest dietary selenium concentration (33.3 mg Se/kg dw) on adult growth, condition factor, gonadal somatic index, or other endpoints (Appendix C). The effect of interest in this study was 30-d larval survival after hatch (deformities weren't examined and other reproductive endpoints showed no effect at the highest exposure). For this survival endpoint, there was complete mortality after one week at the highest exposure and no significant differences in survival at lower concentrations.

Previously, the day 5 data were used in the analysis described in Appendix C because this was the only day in which control survival was greater than 90%, with the control and all the treatments showing substantial and increasing toxicity over the next 4 days. However, upon closer analysis, EPA asserts that this is not sufficient cause to base the assessment, because from

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day 6 through day 30, survival at the fifth treatment was greater than survival in the first and third treatments, indicating this is not an effect level. These later data (day 6-30) establish that the highest treatment is best considered an EC_{100} and the fifth treatment an EC_0. Therefore, the TRAP interpolation was redone using 42 mg/kg as an EC_{100} rather than an EC_{93}, resulting in a slope of 7.6 and an EC_{10} of 26.3 mg Se/kg dw in eggs.

Hermanutz et al. (1992), and Hermanutz et al. (1996) exposed bluegill sunfish to sodium selenite spiked into artificial streams (nominal test concentrations: 0, 2.5, 10, and 30 µg Se/L) which entered the food web, thus providing a simulated field exposure (waterborne and dietary selenium exposure). In an effort originally intended to improve the rigor of the statistical analysis of the Hermanutz et al. (1996) data, Tao et al. (1999) re-examined the raw data records and made corrections to the counts. This criterion document considers the Hermanutz et al. (1992) data and the Tao et al. (1999) re-examination of Hermanutz et al. (1996).

These data come from a series of three studies lasting from 8 to 11 months, conducted over a 3-year period. All three studies began with exposure of adult bluegill sunfish in the fall, and with respective studies ending in the summer of the following year. Temperatures averaged 4.6, 4.1 and 4.5°C during the winter months, and averaged 26.4, 23.9 and 22.4°C during the spawning months (June-July) for Studies I, II and III, respectively. Spawning activity was monitored in the stream, and embryo and larval observations were made *in situ* and from fertilized eggs taken from the streams and incubated within egg cups in the laboratory. None of the adult bluegill exposed to the highest concentration of selenium in the water (Study I, mean measured concentration equal to 29.4 µg/L) survived the entire exposure period (although a few did survive to spawn). Reduced survival and increased deformities on offspring were observed in the selenium-dosed streams in both Study I and Study II, but were not found during Study III (recovering from contamination, no active selenium input/treatment). The incidence of edema, lordosis, hemorrhage and larval survival in the one stream concentration common to both Study I and II, 10 µg/L, ranged from 80 to 100 percent, 5 to 18 percent, 27 to 56 percent, and 29 to 58 percent, respectively over the three years (combined egg cup and nest observations). Edema, lordosis, and hemorrhage in the lowest stream concentration in Study II, 2.5 µg/L, ranged from 0 to 4 percent, 0 to 25 percent, and 3.6 to 75 percent, respectively (combined egg cup and nest observations); larval survival was 71.6 percent (72 and 75 percent in the control streams). (See Hermanutz 1996 and 1992 in Appendix C for more detail). The effects were not observed in

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larvae from fish that were not exposed to elevated concentrations of selenium (control treatment). The mean concentrations of selenium in bluegill ovaries, measured at the end of each study, ranged from 2.2 to 5.0 mg/kg dw in controls, 7.6 to 14 mg/kg dw in the 2.5 µg/L treatments, 34 to 52 mg/kg dw in the 10 µg Se/L treatments, and 16 to 55 mg/kg dw in recovering 30 µg/L treatments. Muscle and whole-body measurements were also available. For all three tissue types, concentrations measured during the spring of each exposure period were not used because they were not sufficiently co-occurrent with the observation of effects. It should also be noted that in contrast to more recent field studies, the tissue concentrations cannot be linked from particular adult females to effects on her offspring, but only from an aliquot of females in the treatment to all offspring observed in the treatment.

The egg-cup data for all streams of Studies I, II, and III of this experiment were combined and analyzed in response to measured selenium concentration in the maternal ovaries (mg/kg dw) using TRAP. That is, data for streams receiving water-borne selenium were combined with data for streams recovering from the previous year's contamination. The absence of effects at high tissue levels (55 mg Se/kg ovary dw) in the recovering stream of Study II did not affect the EC_{10} estimate because it was outweighed by three other points showing severe effects at concentrations as low as 16.7 mg Se/kg ovary dw. However, this one observation is suggestive but not definitive corroboration for the field observations of biological recovery in Belews Lake and Hyco Reservoir after selenium loads were reduced, but while tissue concentrations remained relatively high (Lemly 1997a; Crutchfield 2000; Finley and Garrett 2007).

Several egg-cup endpoints were analyzed by TRAP independently (% edema, % lordosis, and % hemorrhage) and in combination (% normal and surviving). The best fit and most sensitive was the combined percent normal and surviving larvae. Due to inadequate partial effects for the ovary analysis, a threshold sigmoidal model was used to interpolate an EC_{10} estimate between the first interpolation point set to the highest no observed effect concentration (HNOEC) of 14.0 mg/kg and the average background survival/normal of 69.1% and the second point set to the LOEC of 16.7 mg/kg and a survival/normal of 5.76%. The resulting EC_{10} is 14.7 mg/kg ovary dw. Chronic values for muscle and whole body based on percentage surviving and free of deformities are 13.4 mg Se/kg muscle dw and 10.6 mg Se/kg whole body dw. (See Appendix C for more discussion of this study).

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The SMCV for bluegill reproductive endpoints based on EC_{10} values is 20.6 mg Se/kg dw in egg/ovary, based on the EC_{10} values of 22.6 mg/kg dw in the Doroshov et al. (1992a) study, 26.3 mg/kg dw in the Coyle et al. (1993) study, and 14.7 mg/kg dw for Hermanutz et al. (1992, and 1996 as corrected by Tao et al. 1999).

3.1.2 Summary of Acceptable Studies of Fish Reproductive Effects

Table 3.1 summarizes the effect concentrations obtained from all acceptable reproductive studies with fish. Summaries of the remainder of the reproductive studies (beyond the four most sensitive genera described above) can be found in **Section 6.1.2** below.

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Table 3.1. Maternal Transfer Reproductive Toxicity Studies.

Species	Reference	Exposure Route	Toxicological Endpoint	Chronic Value mg/kg dw[a]	SMCV mg/kg dw	GMCV mg/kg dw
Salvelinus malma Dolly Varden	Golder 2009	dietary and waterborne (field: Kemess Mine NW British Columbia)	EC_{10} for total deformities	56.2 E	56.2 E	56.2 E
Esox lucius northern pike	Muscatello et al. 2006	dietary and waterborne (field: Saskatoon, Sask.)	EC_{24} larval deformities	34.0 E	34.0 E	34.0 E
Cyprinodon macularius desert pupfish	Besser et al. 2012	dietary and waterborne (lab)	Estimated EC_{10} for offspring survival	27 E	27 E	27 E
Micropterus salmoides largemouth bass	Carolina Power & Light 1997	dietary (lab)	EC_{10} for larval mortality & deformity	26.3 O	26.3 O	26.3 O
Pimephales promelas fathead minnow	Schultz and Hermanutz 1990	dietary and waterborne (mesocosm: Monticello)	LOEC for larval edema and lordosis	<25.6 E[b]	NA[c]	NA
Oncorhynchus mykiss rainbow trout	Holm 2002; Holm et al. 2003, 2005	dietary and waterborne (field: Luscar River, Alberta)	EC_{10} for skeletal deformities	24.5 E[b]	24.5 E	25.3 E
Oncorhynchus clarkii lewisi Westslope cutthroat trout	Rudolph et al. 2008	dietary and waterborne (field: Clode Pond, BC)	EC_{10} for alevin mortality	24.7 E	26.2 E	
Oncorhynchus clarkii lewisi Westslope cutthroat trout	Nautilus Environmental 2011	dietary and waterborne (field: Clode Pond & Fording River, BC)	EC_{10} for survival at swim-up	27.7 E		
Salmo trutta brown trout	Formation Environmental 2011; AECOM 2012	dietary and waterborne (field: Lower Sage Creek & Crow Creek, ID)	EC_{10} for larval survival	21.0 E	21.0 E	21.0 E

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Species	Reference	Exposure Route	Toxicological Endpoint	Chronic Value mg/kg dw[a]	SMCV mg/kg dw	GMCV mg/kg dw
Lepomis macrochirus bluegill	Doroshov et al. 1992a	dietary (lab)	EC_{10} larval edema	22.6 E	20.6 E	20.6 E
Lepomis macrochirus bluegill	Coyle et al. 1993	dietary and waterborne (lab)	EC_{10} for larval survival	26.3 E		
Lepomis macrochirus bluegill	Hermanutz et al. 1992, 1996	dietary and waterborne (mesocosm: Monticello)	EC_{10} for larval edema	14.7 O[b]		
Acipenser transmontanus white sturgeon	Linville 2006	dietary (lab)	EC_{10} for combined edema and deformities	15.6 E	15.6 E	15.6 E

E–Concentration reported in egg; O– concentration reported in ovary

[a] All chronic values reported in this table are based on the measured concentration of selenium in egg/ovary tissues.

[b] Tissue value converted from ww to dw. See Appendix C for conversion factors.

[c] SMCV not calculated due to variability in the observations among replicates in Schultz and Hermanutz (1990). The chronic value is presented in this table to show it is in the range of selenium effect concentrations. See Appendix C for detail. Also, see Appendix E for an additional study with fathead minnow.

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In order of their sensitivity to selenium, **Table 3.2** presents the Genus Mean Chronic Values from acceptable fish reproductive-effect studies that have been measured in terms of egg-ovary concentrations.

Table 3.2. Ranked Genus Mean Chronic Values for Fish Reproductive Effects Measured as Egg or Ovary Concentrations.

Rank	GMCV* (mg Se/kg dw EO)	Species	SMCV (mg Se/kg dw EO)
8	56.2	Dolly Varden, *Salvelinus malma*	56.2
7	34**	Northern pike, *Esox lucius*	34
6	27	Desert pupfish, *Cyprinodon macularius*	27
5	26.3	Largemouth bass, *Micropterus salmoides*	26.3
4	25.3	Cutthroat trout, *Oncorhynchus clarkii*	26.2
		Rainbow trout, *Oncorhynchus mykiss*	24.5
3	21.0	Brown trout, *Salmo trutta*	21.0
2	20.6	Bluegill sunfish, *Lepomis macrochirus*	20.6
1	15.6	White sturgeon, *Acipenser transmontanus*	15.6

* This table excludes *Gambusia*, which has a reproductive chronic value expressed as adult whole-body rather than egg-ovary, because it is a live bearer.
** The Northern Pike SMCV is an EC_{24} based on larval deformities (**Table 3.1**). The EC_{10} is less than 34 mg/kg.
This table excludes GMCV for *Pimephales* due to uncertainty in the chronic value for the Schultz and Hermanutz (1990) study; the estimate of <25.6 mg/kg egg dw in **Table 3.1** shows it is in the range of reproductive effect levels for selenium (See Appendix C for study details).

3.1.3 Derivation of Tissue Criterion Element Concentrations

Data used to derive the final chronic value were differentiated based on the effect (reproductive and non-reproductive effects). Acceptable chronic toxicity data on fish reproductive effects are available for 10 fish genera. Acceptable chronic toxicity data on non-reproductive effects are available for 7 fish genera and 3 invertebrate genera. The fish non-

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reproductive effects data were not used to calculate tissue criterion elements because they were more variable and less reproducible than the data on reproductive effects. The genus sensitivity distribution is predominantly populated with data on fish species because field evidence demonstrated that fish communities were affected in situations having no observable change in the accompanying diverse array of invertebrate communities. As a result, decades of aquatic toxicity research have focused primarily on fish. The studies that have been done with invertebrates (**Table 3.8**, **Section 3.1.4**) have shown them to be more tolerant than most of the tested fish species.

Also, while amphibians are potentially sensitive due to physiologic similarities to fish, effects clearly attributable to selenium are largely unknown (Unrine et al. 2007; Hopkins et al. 2000; Janz et al. 2010). Hopkins et al. (2000) reported that amphibian larvae at sites receiving coal combustion wastes appear to efficiently accumulate selenium in their tissues and possibly due to selenium have exhibited axial malformations. In a recent laboratory exposure, Massé et al. (2015) determined an EC_{10} of 44.9 mg/kg Se for the African clawed frog (*Xenopus laevis*) suggesting that amphibians are similar to the less sensitive fish species (see **Section 6.1.4**).

3.1.3.1 Fish Egg-Ovary Concentration

The lowest four GMCVs from **Table 3.2** are shown below in **Table 3.3**.

Table 3.3. Four Lowest Genus Mean Chronic Values for Fish Reproductive Effects.

Relative Sensitivity Rank	Genus	GMCV (mg Se/kg dw egg-ovary)
4	*Oncorhynchus*	25.3
3	*Salmo*	21.0
2	*Lepomis*	20.6
1	*Acipenser*	15.6

With N=15 GMCVs (see **Section 3.1.6**), the 5th percentile projection yields an egg/ovary criterion element concentration of 15.1 mg Se/kg dw egg/ovary, lower than the most sensitive fish species tested, white sturgeon (*A. transmontanus*). The egg/ovary criterion element concentration is compared to the distribution of egg/ovary chronic values in **Figure 3.1**.

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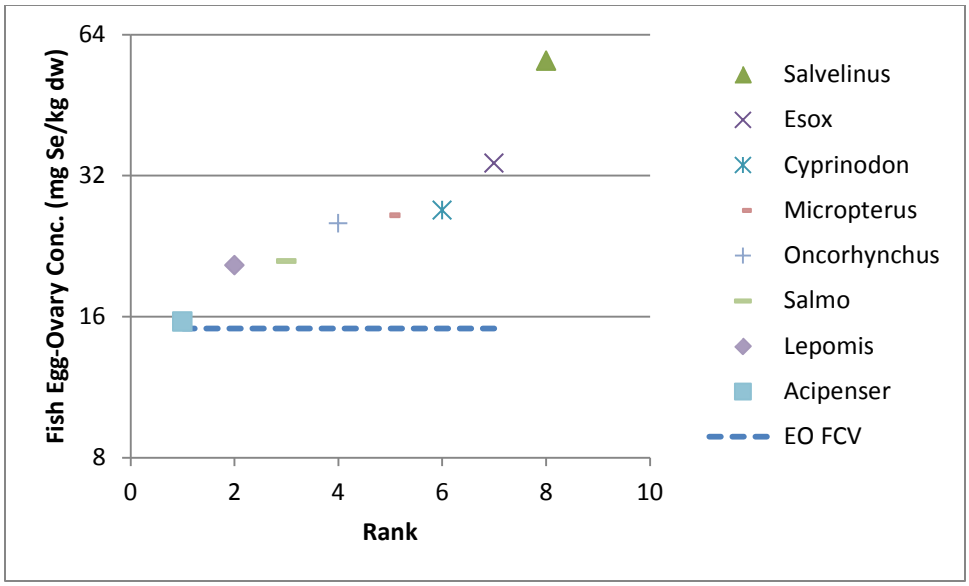


Figure 3.1. Distribution of Reproductive-Effect GMCVs for Fish Measured as Egg-Ovary Concentrations.

3.1.3.2 Fish Whole-Body Criterion Element Concentration

Whole body reproductive chronic values were calculated directly from whole body tissue concentrations measured in the study or by applying an egg-ovary (EO) to whole-body (WB) conversion factor (CF) presented subsequently in **Section 3.2.2.2**. Direct calculations were done when whole body measurements were available in the study and the data were amenable to an effect level determination. **Table 3.4** provides the chronic values for each fish genus and whether it was calculated directly or converted from the reproductive-effect egg-ovary concentrations to whole-body concentrations using a CF. The final EO/WB CF applied to each taxon was determined using a hierarchical approach based on taxonomic relatedness, and is described in **Section 3.2.2**, and in greater detail in Appendix B. The four most sensitive reproductive-effect fish whole-body GMCVs are shown in **Table 3.5**.

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Table 3.4. Tested Reproductive-Effect Whole Body (WB) Concentrations Measured Directly or Converted to WB Concentrations from Egg-Ovary (EO) Concentrations.

Taxon*	EO Chronic Value	EO/WB CF	Direct or Calculated WB Repro Chronic Value	Direct Calculation or Basis for EO/WB CF (from Appendix B)
Salvelinus	56.2	1.61	34.9	Dolly Varden EO/M (1.26) x all fish M/WB (1.27)
Esox	34.0	2.39	14.2	Northern pike EO/M (1.88) x all fish M/WB (1.27)
Cyprinodon	27.0	1.20	22.6	Desert pupfish EO/WB
O. mykiss	24.5	2.44	10.0	Rainbow trout EO/M (1.92) x all fish M/WB (1.27)
Rudolph et al. 2008	24.7	1.96	12.6	*Oncorhynchus* EO/WB
Nautilus 2011	27.7	1.96	14.1	*Oncorhynchus* EO/WB
O. clarkii	26.2	NA	13.3	Geometric mean of two studies
Oncorhynchus	25.3	NA	11.6	Geometric mean of *O. mykiss* and *O. clarkii* WB SMCVs
Micropterus	26.3	1.42	18.5	*Micropterus* EO/WB
Salmo	21.0	NA	13.2	Directly calculated EC_{10}
Coyle et al. 1993	26.3	NA	8.6	Directly calculated EC_{10}
Doroshov et al. 1992a	22.6	2.13	10.6	Bluegill sunfish EO/WB
Hermanutz et al. 1992, 1996	14.7	NA	10.6	Directly calculated EC_{10}
Lepomis	20.6	NA	9.9	Geometric mean of three studies
Acipenser	15.6	1.69	9.2	White sturgeon EO/M (1.33) x all fish M/WB (1.27)

* The GMCV for *Gambusia*, a live bearer, not included in the conversion table, was originally measured as adult WB, not EO, and is >13.38 mg Se/kg dw WB. The "greater than" sign signifies that no effects were found at the highest observed concentrations. This table also excludes *Pimephales* due to uncertainty in the chronic value for the Schultz and Hermanutz (1990) study (See Appendix C for details).

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Table 3.5. The Lowest Four Reproductive-Effect Whole-Body GMCVs.

Relative Sensitivity Rank	Genus	GMCV (mg Se/kg dw whole-body)
4	*Salmo*	13.2
3	*Oncorhynchus*	11.6
2	*Lepomis*	9.9
1	*Acipenser*	9.2

Because the factors used to convert egg-ovary to whole-body concentrations vary across species, the whole-body rankings differ from the egg-ovary rankings. With N=15 GMCVs, the 5th percentile projection yields a whole body criterion element concentration of 8.5 mg Se/kg dw whole-body, slightly lower than the most sensitive fish species tested, white sturgeon (*Acipenser transmontanus*). The fish whole body criterion element is compared to the distribution of fish whole-body reproductive chronic values in **Figure 3.2**.

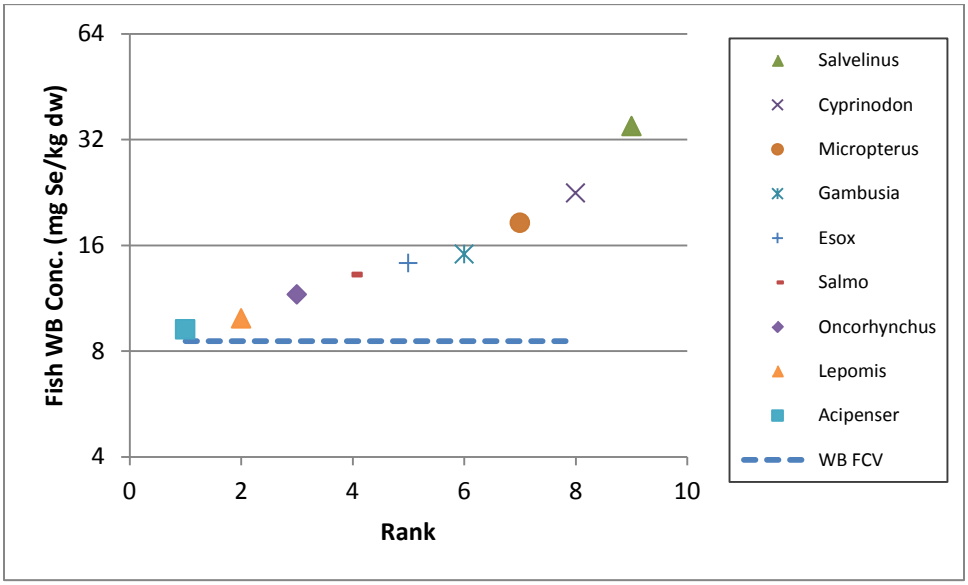


Figure 3.2. Distribution of Reproductive-Effect GMCVs for Fish, either Measured as Whole-Body Concentrations in the Original Tests, or Measured as Egg-Ovary Concentrations but Converted to Whole-Body.
(As shown in **Table 3.4**).

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3.1.3.3 Fish Muscle Criterion Element Concentration

Reproductive chronic values for muscle tissue were calculated directly from muscle tissue concentrations measured in the study or from the egg-ovary to muscle conversion factors of the bioaccumulation modeling approach (presented in **Section 3.2**). Direct calculations were made when muscle measurements were available in the study and the data were amenable to an effect level determination. The final EO/M CF applied to each taxon was determined using a hierarchical approach based on taxonomic relatedness, consistent with the approach used to calculate EO/WB CFs described in **Section 3.2.2**.

Table 3.6 provides the chronic values for each fish taxa and whether it was calculated directly or converted from reproductive-effect egg-ovary concentrations to muscle concentrations. The four most sensitive reproductive-effect fish muscle GMCVs are shown in **Table 3.7**.

Table 3.6. Tested Reproductive-Effect Muscle (M) Concentrations Measured Directly or Converted to M Concentrations from Egg-Ovary (EO) Concentrations.

Taxon	EO Chronic Value	EO/M CF	Direct or Calculated Muscle Repro Chronic Value	Direct Calculation or Basis for EO/M CF (from Appendix B)
Salvelinus	56.2	1.26	44.5	Dolly Varden EO/M
Esox	34.0	NA	21.7	Directly determined EC_{24}
Cyprinodon	27.0	0.94	28.7	Desert pupfish EO/WB (1.20) / all fish M/WB (1.27)
O. mykiss	24.5	1.92	12.8	Rainbow trout EO/M
Rudolph et al. 2008	24.7	NA	16.6	Directly calculated EC_{10}
Nautilus 2011	27.7	1.81	15.3	Cutthroat trout EO/M
O. clarkii	26.2	NA	16.0	Geometric mean of two studies
Oncorhynchus	25.3	NA	14.3	Geometric mean of two SMCVs
Micropterus	26.3	1.19	22.2	*Micropterus* EO/M
Salmo	21.0	1.14	18.5	Brown trout EO/WB (1.45) / all fish M/WB (1.27)

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Taxon	EO Chronic Value	EO/M CF	Direct or Calculated Muscle Repro Chronic Value	Direct Calculation or Basis for EO/M CF (from Appendix B)
Coyle et al. 1993	26.3	1.38	19.1	Bluegill sunfish EO/M
Doroshov et al. 1992a	22.6	NA	15.7	Directly calculated EC_{10}
Hermanutz et al. 1992, 1996	14.7	NA	13.4	Directly calculated EC_{10}
Lepomis	20.6	NA	15.9	Geometric mean of three studies
Acipenser	15.6	NA	11.9	Directly calculated EC_{10}

Table 3.7. The Lowest Four Reproductive-Effect Fish Muscle GMCVs.

Relative Sensitivity Rank	Genus	GMCV (mg Se/kg dw muscle)
4	*Salmo*	18.5
3	*Lepomis*	15.9
2	*Oncorhynchus*	14.3
1	*Acipenser*	11.9

Because the factors used to convert egg-ovary to muscle concentrations vary across species based on empirical data, the whole-body rankings differ from both from the egg-ovary rankings and the muscle rankings. With N=15 GMCVs, the 5th percentile projection yields a muscle criterion element concentration of 11.3 mg Se/kg dw muscle, lower than the muscle value for the most sensitive fish genus tested, *Acipenser*. **Figure 3.3** compares the fish muscle criterion element concentration to the distribution of fish muscle reproductive chronic values in **Table 3.6**.

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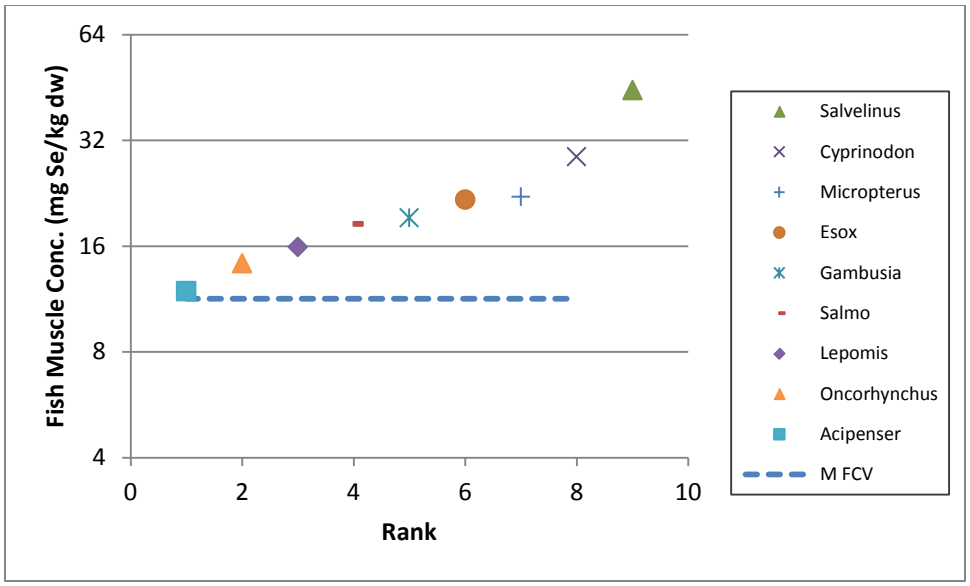


Figure 3.3. Distribution of Reproductive-Effect GMCVs for Fish, either Measured as Muscle in the Original tests, or Measured as Egg-Ovary Concentrations but Converted to Muscle Concentrations.
(As shown in **Table 3.6**). (Live-bearer *Gambusia* was converted from WB to muscle).

3.1.4 Invertebrate Chronic Effects

Below is a brief synopsis of the experimental design of the available invertebrate chronic toxicity tests, and the resulting chronic values.

Brachionus calyciflorus (rotifer)

Dobbs et al. (1996) exposed *Brachionus calyciflorus* to selenate in natural creek water for 25 days in a three-trophic level food chain test system. This is one of two laboratory-based experiments (also see Bennett et al. 1986) that involved exposing algae to selenium (in this case as sodium selenate) in water, and subsequently feeding the algae to rotifers which were in turn fed to fish (fathead minnows). In the Dobbs et al. (1996) study, the rotifers and fish were exposed to the same concentrations of sodium selenate in the water as the algae, but consumed selenium bioaccumulated in the next lower trophic level. Rotifers did not grow well at concentrations exceeding 108.1 µg Se/L in water, and the population survived only 6 days at selenium concentrations equal to or greater than 202.4 µg Se/L in the water (40 µg Se/g dw in the algae). Regression analysis of untransformed growth data (dry weight), determined 4 day post-test initiation, resulted in a calculated EC_{10} of 37.84 µg Se/g dw tissue.

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Lumbriculus variegatus (oligochaete, blackworm)

Although not intended to be a definitive toxicity study for blackworms, Besser et al. (2006) evaluated the bioaccumulation and toxicity of selenized yeast to the oligochaete, *Lumbriculus variegatus,* which was intended to be used for dietary exposure in subsequent studies with the endangered desert pupfish, *Cyprinidon macularius*. Oligochaetes fed selenized-yeast diets diluted with nutritional yeast (54 to 210 mg Se/kg) had stable or increasing biomass and accumulated Se concentrations as high as 140 mg/kg dw. The oligochaetes fed the undiluted selenized-yeast (826 µg/g Se dry wt.) showed reduced biomass. The effect level is considered >140 mg Se/kg dw.

Centroptilum triangulifer (mayfly)

Mayfly larvae (*Centroptilum triangulifer*) were exposed to dietary selenium contained in natural periphyton biofilms to eclosion (emergence) (Conley et al. 2009; Conley et al. 2011; Conley et al. 2013). In Conley et al. (2009), the periphyton fed to the mayfly larvae were exposed to dissolved selenite (radiolabeled ^{75}Se) in November 2008 (12.6 and 13.9 µg/L) and in January 2009 (2.4, 2.4, 4.9, 10.3, and 10.7 µg/L). Periphyton bioconcentrated selenium an average of 1113-fold over the different aqueous selenium concentrations (see Table E-22 in Appendix E). Twenty 4 to 6-day old mayfly larvae were exposed for 4.5 to 6 weeks to each of the periphyton diets until the larvae eclosed to subimagos (final pre-adult winged stage). The subimagos were allowed to emerge to the adult imago stage which deposited their egg masses in Petri dishes. Selenium concentrations were measured in postpartum adults along with their dry weights and clutch size. Selenium increased in concentration from periphyton to the adult mayflies (trophic transfer factor) an average of 2.2-fold. The authors observed a reduction in fecundity with diets containing more than 11 mg Se/kg dw, which is considered the dietary threshold for this study. Using the trophic transfer factor of 2.2, the periphyton selenium concentration of 11 mg/kg dw translates to an adult mayfly selenium concentration of 24.2 mg/kg dw.

Conley et al. (2011) exposed larval *C. triangulifer* larvae similar to Conley et al. (2009) to two different rations of periphyton (1x and 2x) containing low, medium and high selenium levels to evaluate the effect of feeding ration on the bioaccumulation of selenium and life cycle performance of the mayfly. Mayfly larvae were fed either a 1x or 2x ration of periphyton loaded with the three different selenium levels until the larvae eclosed to subimagos after 25-29 days.

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Average periphyton Se concentrations for the three treatments in the 1x ration study were 4.2, 11.9, and 27.2 mg/kg dw, respectively. In the 2x ration study, average periphyton concentrations for the three treatments were 9.5, 19.9, and 40.9 mg/kg dw, respectively (Conley et al. 2011). Subimagos were induced to emerge to adults in petri dishes and their clutch size measured through digital imaging. Mayflies fed the 1x ration had 54% and 72% reductions in survival relative to controls in the medium and high Se treatment levels, respectively, both of which were significant ($p<0.05$). The mayflies fed the 1x ration also had significant reductions in fecundity in the low (44% reduction), medium (63% reduction) and high (77% reduction) Se treatment levels. However, for the mayflies that were fed the 2x ration, there were no significant differences between the controls and any of the three Se treatment levels for any of the endpoints measured including survival and fecundity. The 2x ration mayflies had 60% more biomass than the 1x ration mayflies. This growth difference explains why the 1x ration mayflies had higher concentrations of Se in their tissues (see Table E-23 in Appendix E). The two different rations resulted in vastly different effect levels for Se, <12.8 mg/kg dw in the 1x ration test and >37.3 mg/kg dw in the 2x ration. It is apparent from this study that if the mayflies do not obtain sufficient nutrition, they are more sensitive to selenium. Although reduced feeding levels occur in nature, it is a confounding variable in this study that cannot be used to set a chronic effect level for selenium.

Conley et al. (2013) evaluated the accumulation of selenite and selenate into periphyton with a subsequent feeding exposure to mayfly larvae. As in the previous studies, *C. triangulifer* larvae were fed periphyton previously exposed to different concentrations of selenium. In this study, periphyton plates were first exposed to low (10 µg/L) and high (30 µg/L) concentrations of either selenite or selenate and then fed to mayfly larvae to eclosion and to subimagos. The mean concentrations of selenium in the periphyton fed to the mayflies were 2.2, 12.8 and 37 mg/kg Se dw in the control, low and high treatments, respectively. Mayfly tissue (subimago) concentrations (extrapolated from Figure 4a in Conley et al. 2013) were approximately 4-7, 20-35, and 45-75 mg/kg Se dw, in the control, low and high treatments, respectively. The authors reported significant reductions in survival from the control in the high Se treatment (both pooled data and individual selenite and selenate treatments), but no significant differences were observed in the low Se treatments. Secondary production (mayfly biomass) was significantly reduced relative to the control in the high Se treatment for both selenium species. For the low Se

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exposure treatments, secondary production was not significantly different than the control for the selenite treated periphyton exposure, but was for the selenate and pooled data suggesting an effect level between 20 and 35 mg/kg Se dw. These results as well as those observed in 2x ration exposures in Conley et al. (2011) where no effects were observed at 37.3 mg/kg Se dw generally support the chronic value determined for Conley et al. (2009) of 24.2 mg/kg Se dw. This information included tabulated data from these studies presented in Appendix E.

3.1.5 Summary of Relevant Invertebrate Tests

The available measured invertebrate whole-body effect concentrations are shown in **Table 3.8**. Because the intent of this assessment is to derive a concentration expressed in terms of fish tissue, **Table 3.8** also provides information on how concentrations in invertebrate tissue are translated (in **Section 3.2**) across media to predicted WB fish tissue concentrations (Trophic Level 3, TL3) in a system having invertebrates and fish. That is, consistent with the bioaccumulation modeling approach of **Section 3.2**, the second column of **Table 3.8** uses the median trophic transfer factor of 1.21 from **Table 3.11** to yield expected WB fish tissue concentrations in a system having invertebrates and fish. Whether comparing TL2 (invertebrate) whole-body GMCVs directly to **Table 3.4** TL3 (fish) whole-body GMCVs, or via the trophic transfer adjustment in the second column of **Table 3.8**, it is apparent that invertebrates are not among the most sensitive species.

The relative insensitivity of invertebrates overall when compared with the fish whole-body concentrations demonstrates that invertebrates are expected to be generally protected by selenium criterion values derived from fish. It should be noted that mayflies appear to be the most sensitive invertebrate group tested; their whole-body effects levels just below the *least* sensitive fish genus (*Salvelinus*, Dolly Varden) on whole-body basis. However these mayfly results have some uncertainty due to the indicated effect of feeding ration on selenium toxicity to mayflies that has not been fully defined. The rotifer and lumbriculus tests indicate that these organisms are less sensitive than any tested fish genus on a whole-body basis. Therefore, the invertebrates are considered implicitly in the species sensitivity distribution, and are counted toward the number of values available to calculate the fish tissue criterion elements (as egg-ovary, whole-body, and muscle), and the missing invertebrate MDRs (4 and 5) are considered satisfied by the available invertebrate data.

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Table 3.8. Ranked Invertebrate Whole-Body Chronic Values with Translation to Expected Accompanying Fish Whole-Body Concentrations

SMCV & GMCV as measured (Trophic Level 2) (mg Se/kg dw WB)	Accompanying Trophic Level 3 Median Whole-Body Concentration Predicted by Bioaccumulation Model (Section 3.2) (mg Se/kg dw WB TL3)	Species
> 140	> 169.4	Oligochaete, black, *Lumbriculus variegatus*
37.84	45.8	Rotifer, *Brachionus calyciflorus*
24.2	29.3	Mayfly, *Centroptilum triangulifer*

3.1.6 Selenium Fish Tissue Toxicity Data Fulfilling Minimum Data Needs

The toxicity data currently available for genera and species fulfilling the EPA Ambient Water Quality Criteria Guidelines recommendations for calculation of the freshwater chronic criterion are described in **Sections 3.1.1, 3.1.4, 6.1.2** and Appendix C, and are summarized in **Table 3.9**.

Table 3.9. Minimum Data Requirements Summary Table Reflecting the Number of Species and Genus Level Mean Values Represented in the Chronic Toxicity Dataset for Selenium in Freshwater.

Freshwater Minimum Data Requirement	Genus Mean Chronic Value (GMCV)	Species Mean Chronic Value (SMCV)
1. Family Salmonidae in the class Osteichthyes	3	4
2. Second family in the class Osteichthyes, preferably a commercially or recreationally important warmwater species	2	2
3. Third family in the phylum Chordata (may be in the class Osteichthyes or may be an amphibian, etc.)	5	5
4. Planktonic Crustacean	See text	See text
5. Benthic Crustacean	See text	See text
6. Insect	1	1
7. Family in a phylum other than Arthropoda or Chordata (*e.g.*, Rotifera, Annelida, or Mollusca)	1	1
8. Family in any order of insect or any phylum not already represented	1	1
Total	**15**	**16**

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The first three of these MDRs in **Table 3.9** are easily fulfilled by the fish species represented in **Sections 3.1.1, 6.1.2** and Appendix C. Because the field observations of contaminated sites have found effects on fish and birds in the absence of changes in invertebrate assemblages, scientific studies on the chronic toxicity of dietary selenium for invertebrates has been very limited. The few dietary chronic toxicity studies that are available for invertebrate species (arthropods **,** rotifers, and worms) indicate that they are generally less sensitive than fish, with available data indicating invertebrate whole body mean chronic values ranging from approximately 3 to 12 times higher than the fish whole body criterion element value recommended in this document (**Section 3.1.4**). The above invertebrate data address MDRs 6-8, leaving only MDRs 4 and 5, for the planktonic and benthic crustaceans, to be addressed. Because the 5^{th} percentile calculation methods for the FCV use actual numeric values for the GMCVs of the four most sensitive (fish) genera in the selenium dataset, it is only necessary to know that the more tolerant genera have GMCVs that are greater than those of the lowest four. A recommendation in the draft white paper on Aquatic Life Criteria for Contaminants of Emerging Concern Part I (U.S. EPA 2008b), which was supported by the Science Advisory Board, states "because only the four most sensitive genus mean chronic values (GMCVs) are used in the criterion calculations, chronic testing requirements for a taxon needed to meet an MDR should be waived if there is sufficient information to conclude that this taxon is more tolerant than the four most sensitive genera."

Currently, there are no available data on the chronic toxicity to crustaceans via dietary exposure to selenium. Since there are data available for insects (*Centroptilum spp.* mayfly), EPA used the taxonomic association at the level of phylum (Arthropoda) to allow insects to be a surrogate for crustaceans. There is also associative evidence that macroinvertebrates in general are less sensitive than fish. At sites where there have been documented effects to fish and aquatic-dependent birds from selenium exposure (e.g., Kesterson Reservoir, Belews Lake, Hyco Reservoir), field observations and data indicate that there has been no evidence of effects to macroinvertebrates including crustaceans (Janz et al. 2010). In addition, Janz et al. (2010) notes that the key vector for selenium toxicity via maternal transfer is selenium loading in the egg via vitellogenesis. Crustaceans, and other arthropods are not known to deposit a significant amount of vitellogenin in the egg compared with oviparous vertebrates like fish, therefore, less selenium is likely transferred to the egg via deposition of vitellogenin. These mechanistic considerations

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are thus consistent with the absence of observed field effects on aquatic macroinvertebrates, including crustaceans and other arthropods, and with the Chapman et al. (2009, 2010) expert consensus that it is the egg-laying vertebrates that are most at risk.

Applying this concept to the selenium criterion 5th percentile calculations, GMCVs for MDRs 4 and 5 (the two crustacean MDRs) should be waived and counted in the total number of GMCVs in the dataset, based on (a) the difference in the measured effect values discussed above, and (b) the lack of observed invertebrate field effects linked to selenium (for example, as concluded by Lemly 2002, pages 21-23, and Janz et al. 2010). Thus data are adequate to fulfill the data needs for developing a chronic selenium criterion.

The total number of GMCVs available to derive the chronic criterion is 15. These include ten fish genera from **Sections 3.1.1 and 6.1.2** (*Acipenser, Salmo, Lepomis, Micropterus, Oncorhynchus, Pimephales, Gambusia, Esox, Cyprinodon,* and *Salvelinus*) [Added to these are the tested invertebrate genera *Centroptilum, Brachionus,* and *Lumbriculus* from **Section 3.1.4**, and lastly the two waived genera for MDRs 4 and 5 (crustaceans).

3.2 Chronic Water Column-based Selenium Criterion Element

3.2.1 Translation from Fish Tissue Concentration to Water Column Concentration

EPA derived the chronic water column selenium criterion element by translating the egg-ovary concentration to an equivalent water concentration. EPA worked with USGS to derive a translation equation that utilizes a mechanistic model of bioaccumulation previously published in peer-reviewed scientific literature (Luoma et. al. 1992; Wang et. al. 1996; Luoma and Fisher 1997; Wang 2001; Schlekat et al. 2002b; Luoma and Rainbow 2005; Presser and Luoma 2006, 2010; Presser 2013). This model quantifies bioaccumulation in animal tissues by assuming that net bioaccumulation is a balance between assimilation efficiency from diet, ingestion rate, rate of direct uptake in dissolved forms, loss rate, and growth rate. The basic model is given as:

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$$C_{tissue} = \frac{\left[\left(k_u \times C_{water}\right) + \left(AE \times IR \times C_{food}\right)\right]}{\left(k_e + g\right)} \qquad \text{(Equation 1)}$$

Where:

C_{water}	=	Concentration of chemical in water (µg/L)
C_{tissue}	=	Average concentration of chemical in all tissues at steady-state (µg/g)
k_e	=	Efflux rate (/d)
g	=	Growth rate (/d)
k_u	=	Uptake rate (L/g-d)
AE	=	Assimilation efficiency (%)
IR	=	Ingestion rate (g/g-d)
C_{food}	=	Concentration in food (µg/g)

3.2.1.1 Simplifying the Bioaccumulation Model

Specific application to selenium bioaccumulation permits the simplification of Equation 1 in two ways. One simplification is removing the parameter representing growth rate (*g*), and the other simplification is removing the parameter representing direct aqueous uptake (k_u).

Growth Rate

The growth rate constant *g* is included in Equation 1 because the addition of body tissue has the potential to dilute the concentration of bioaccumulative chemicals when expressed as chemical mass per tissue mass. For very hydrophobic chemicals with low excretion rates such as polychlorinated biphenyls, growth can be an important factor in bioaccumulation estimates (Connolly and Pedersen 1988). However, Luoma and Rainbow (2005) suggest that for selenium, growth rate is a relatively inconsequential parameter under most circumstances. Food consumption is typically high during periods of high growth rate. Because food consumption is the primary route of selenium uptake in aquatic organisms (Ohlendorf et al. 1986a, b; Saiki and Lowe 1987; Presser and Ohlendorf 1987; Lemly 1985a; Luoma et al. 1992; Presser et al. 1994; Chapman et al. 2010), high consumption rates of selenium-contaminated food may counteract the selenium dilution that occurs with the addition of body tissue during periods of fast growth.

EPA evaluated the effect of removing the parameter *g* in the Equation 1 by performing a sensitivity analysis. EPA analyzed a series of hypothetical tissue concentration estimates using Equation 1 with *g* ranging between 0 (no growth) and 0.2/day (a relatively high rate of growth).

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In one analysis, tissue concentrations of selenium were estimated using static values of *IR*. In a second analysis, tissue concentrations of selenium were estimated using values of *IR* that were adjusted for growth rate using a method similar to the approach used in a model of organic chemical accumulation in aquatic food webs (Thomann et al. 1992). As expected, estimates of selenium tissue concentrations were significantly reduced at progressively higher growth rates when *IR* remained constant. However, selenium concentrations remained fairly steady or slightly increased with progressively higher growth rates when *IR* was adjusted for the bioenergetics of growth. This analysis supports the hypothesis that a higher *IR* (and consequently greater rate of selenium ingestion) associated with the higher bioenergetic requirements of rapidly growing young fish tends to oppose the dilution of selenium in their tissues due to growth, whereas a lower *IR* (and consequently lower rate of selenium ingestion) associated with the lower bioenergetic requirements of slower growing older fish tends to oppose the bioconcentration of selenium in their tissues. EPA concludes from this analysis that omitting the growth rate parameter *g* is an appropriate simplification of Equation 1. A more detailed description of this sensitivity analysis is provided in Appendix J.

Uptake Rate

The uptake rate constant k_u is included in Equation 1 to account for direct absorption of bioaccumulative chemicals in the dissolved phase. However, dietary intake of selenium is the dominant source of exposure, suggesting that k_u may also be relatively inconsequential for selenium accumulation (Luoma and Rainbow 2005). Because aqueous uptake of selenium makes up a small percentage of bioaccumulated selenium (Fowler and Benayoun 1976; Luoma et. al. 1992; Roditi and Fisher 1999; Wang and Fisher 1999; Wang 2002; Schlekat et. al. 2004; Lee et. al. 2006), Presser and Luoma (2010a, b, 2013) deemed removal of k_u from Equation 1 as an acceptable simplification.

EPA evaluated the effect of removing the parameter k_u in the Equation 1 by performing a sensitivity analysis. EPA analyzed a series of tissue concentration estimates using Equation 1 and a realistic range of k_u values for trophic level 2 and trophic level 3 organisms. The analysis suggests that approximately 75% of selenium exposure in trophic level 2 organisms (invertebrates) and over 90% of selenium exposure in trophic level 3 organisms occurs through consumption of selenium-contaminated food. EPA concluded that omitting the aqueous uptake

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rate constant k_u is an appropriate simplification of Equation 1. A more detailed description of this sensitivity analysis is provided in Appendix J.

Derivation of the Translation Equation

Disregarding growth (g) and uptake of selenium dissolved in water ($k_u \times C_{water}$), Equation 1 becomes Equation 2 (Reinfelder et al. 1998):

$$C_{tissue} = \frac{AE \times IR \times C_{food}}{k_e}$$

or:

$$C_{tissue} = \frac{AE \times IR}{k_e} \times C_{food} \qquad \text{(Equation 2)}$$

Because application of the bioaccumulation model applies to a single species, the combination of species-specific physiological parameters expressed as $\frac{AE \times IR}{k_e}$ remains constant for the species. Thus the EPA defines the expression $\frac{AE \times IR}{k_e}$ as a single species-specific Trophic Transfer Factor (*TTF*) given as Equation 3 (Reinfelder et al. 1998):

$$TTF = \frac{AE \times IR}{k_e} \qquad \text{(Equation 3)}$$

Substituting *TTF* for $\frac{AE \times IR}{k_e}$ in Equation 2 yields:

$$C_{tissue} = TTF \times C_{food} \qquad \text{(Equation 4)}$$

The trophic level of the organisms considered can be denoted by superscripts given as:

$$C_{tissue}^{TL2} = TTF^{TL2} \times C_{food}^{TL2} \qquad \text{(Equation 5)}$$

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C_{tissue}^{TL2} as defined here represents the steady-state proportional concentration of selenium in the tissue of trophic level 2 organisms relative to the concentration of selenium in their food source.

Using the same rationale, the average concentration of selenium in the tissues of trophic level 3 organisms can be expressed as the concentration of selenium in its food multiplied by a *TTF* which is given as:

$$C_{tissue}^{TL3} = TTF^{TL3} \times C_{food}^{TL3} \qquad \text{(Equation 6)}$$

For trophic level 3 organisms that consume trophic level 2 organisms, $C_{food}^{TL3} = C_{tissue}^{TL2}$. Thus:

$$C_{tissue}^{TL3} = TTF^{TL3} \times C_{tissue}^{TL2} \qquad \text{(Equation 7)}$$

Substituting C_{tissue}^{TL2} in Equation 7 with $TTF^{TL2} \times C_{food}$ in Equation 5 yields:

$$C_{tissue}^{TL3} = TTF^{TL3} \times TTF^{TL2} \times C_{food}^{TL2} \qquad \text{(Equation 8)}$$

Defining the term C_{tissue}^{TL3} as the concentration of selenium in fish tissue, defining the term C_{tissue}^{TL2} as the concentration of selenium in living and nonliving particulate material ingested by invertebrates, and expressing the product of all *TTF* values as a single term results in the equation:

$$C_{whole-body} = TTF^{composite} \times C_{particulate} \qquad \text{(Equation 9)}$$

where:

$C_{particulate}$	=	the concentration of selenium in particulate material
$C_{whole\text{-}body}$	=	the concentration of selenium in the whole body of fish
$TTF^{composite}$	=	the product of all trophic transfer factor values

Equation 9 quantitatively expresses selenium bioaccumulation in fish ($C_{whole\text{-}body}$) as the product of the concentration of selenium at the base of the food web ($C_{particulate}$) and a parameter representing the trophic transfer of selenium through all dietary pathways ($TTF^{composite}$). This model of bioaccumulation is conceptually similar to the model of bioaccumulation utilizing a bioaccumulation factor (BAF). A BAF is the ratio of the concentration of a chemical in the tissue

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of an aquatic organism to the concentration of the chemical dissolved in ambient water at the site of sampling (U.S. EPA 2001c). Similar to the term $TTF^{composite}$, a BAF quantitatively represents the relationship between the chemical concentrations in multiple environmental compartments. However, a BAF is empirically derived from site-specific measurements, whereas $TTF^{composite}$ is derived from knowledge of the ecological system. Because each *TTF* is associated with a particular taxon, $TTF^{composite}$ can be inferred for an aquatic system using existing knowledge and reasonable assumptions, without the considerable time and cost of collecting and analyzing tissue and water samples.

Equation 9 characterizes the bioaccumulation of selenium as a combination of *TTF* parameters from all steps in the dietary pathway of the predator species of interest. Thus it is possible to differentiate bioaccumulative potential for different predator species and food webs by modeling different exposure scenarios. For example, where the fish species of interest is a trophic level 4 predator that primarily consumes trophic level 3 fish, the term $TTF^{composite}$ can be represented as the product of all *TTF* parameters that includes the additional trophic level given as:

$$TTF^{composite} = TTF^{TL4} \times TTF^{TL3} \times TTF^{TL2} \qquad \text{(Equation 10)}$$

where:

TTF^{TL2} = the trophic transfer factor of trophic level 2 species

TTF^{TL3} = the trophic transfer factor of the trophic level 3 species

TTF^{TL4} = the trophic transfer factor of the trophic level 4 species

$TTF^{composite}$ = the product of all trophic transfer factors

Similarly, the consumption of more than one species of organism at the same trophic level can also be modeled by expressing the *TTF* at a particular trophic level as the weighted average of the *TTF*s of all species consumed given as:

$$\overline{TTF}^{TLx} = \sum_i \left(TTF_i^{TLx} \times w_i \right) \qquad \text{(Equation 11)}$$

where:

TTF_i^{TLx} = the trophic transfer factor of the i^{th} species at a particular trophic level

w_i = the proportion of the i^{th} species consumed

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These concepts can be used to formulate an expression of $TTF^{composite}$ to model selenium bioaccumulation in ecosystems with different consumer species and food webs. **Figure 3.4** describes four example food web scenarios and the formulation of $TTF^{composite}$ to model selenium bioaccumulation in each of them.

The parameter $TTF^{composite}$ quantitatively represents all dietary pathways of selenium exposure for a particular fish species within an aquatic system. The parameter is derived from species-specific *TTF* values representing the food web characteristics of the aquatic system, w_i, the proportion of species consumed. See text for further explanation.

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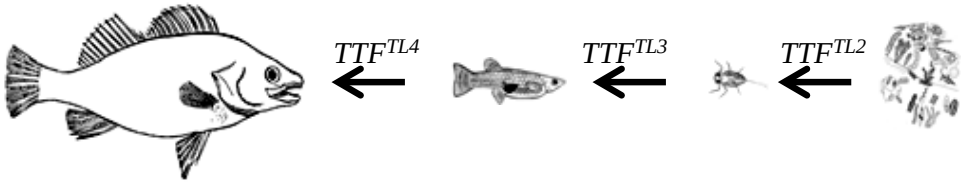
A) Three trophic levels (simple):

$$TTF^{composite} = TTF^{TL3} \times TTF^{TL2}$$



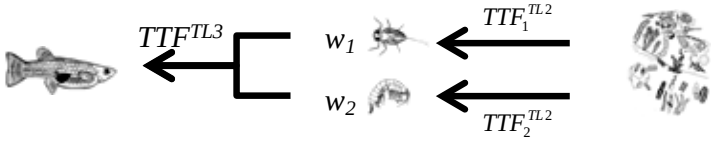
B) Four trophic levels (simple):

$$TTF^{composite} = TTF^{TL4} \times TTF^{TL3} \times TTF^{TL2}$$



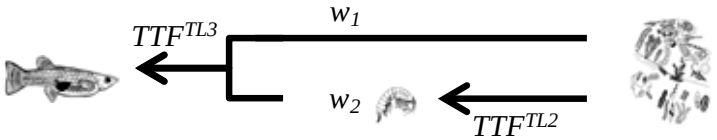
C) Three trophic levels (mix within trophic levels):

$$TTF^{composite} = TTF^{TL3} \times \left[\left(TTF_1^{TL2} \times w_1\right) + \left(TTF_2^{TL2} \times w_2\right)\right]$$



D) Three trophic levels (mix across trophic levels):

$$TTF^{composite} = \left(TTF^{TL3} \times w_1\right) + \left(TTF^{TL3} \times TTF^{TL2} \times w_2\right)$$



E) Four trophic levels (mix across trophic levels):

$$TTF^{composite} = \left[\left(TTF^{TL4} \times TTF^{TL3} \times w_1\right) + \left(TTF^{TL4} \times w_2\right)\right] \times TTF^{TL2}$$

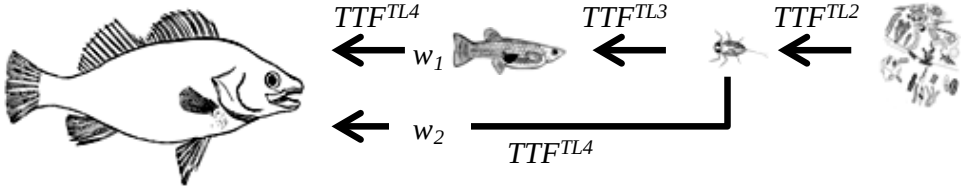


Figure 3.4. Example Aquatic System Scenarios and the Derivation of the Equation Parameter $TTF^{composite}$.

Because EPA's objective is to derive an equation that translates a fish tissue concentration of selenium to a water column concentration, the term C_{water} is reintroduced into

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Equation 9 by defining the enrichment function EF representing the steady state proportional bioconcentration of dissolved selenium at the base of the aquatic food web given as:

$$EF = \frac{C_{particulate}}{C_{water}} \qquad \text{(Equation 12)}$$

Where:

$C_{particulate}$ = Selenium concentration in particulate material (µg/g)
C_{water} = Concentration of selenium dissolved in water (µg/L)
EF = Enrichment function (L/g)

Rearranging the terms of Equation 12:

$$C_{particulate} = EF \times C_{water} \qquad \text{(Equation 13)}$$

Substituting $EF \times C_{water}$ for $C_{particulate}$ in Equation 9 results in:

$$C_{whole-body} = TTF^{composite} \times EF \times C_{water} \qquad \text{(Equation 14)}$$

Solving for the concentration of selenium in water in Equation 14 results in:

$$C_{water} = \frac{C_{whole-body}}{TTF^{composite} \times EF} \qquad \text{(Equation 15)}$$

Because Equation 15 relates a concentration of selenium in water to the concentration of selenium throughout all tissues of the body, $C_{whole\text{-}body}$ must be converted to an equivalent concentration in eggs or ovaries. EPA achieved this conversion by incorporating a species-specific conversion factor (*CF*) into Equation 15. *CF* represents the species-specific proportion of selenium in egg or ovary tissue relative to the concentration of selenium in all body tissues and is given as:

$$CF = \frac{C_{egg-ovary}}{C_{whole-body}} \qquad \text{(Equation 16)}$$

Where:

CF = Whole-body to egg-ovary conversion factor (dimensionless ratio).

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$C_{egg\text{-}ovary}$ = Selenium concentration in the eggs or ovaries of fish (µg/g)

$C_{whole\text{-}body}$ = Selenium concentration in the whole body of fish (µg/g).

Rearranging the terms of Equation 16 yields:

$$C_{whole-body} = \frac{C_{egg-ovary}}{CF} \qquad \text{(Equation 17)}$$

Substituting $C_{whole\text{-}body}$ in Equation 15 with $\frac{C_{egg-ovary}}{CF}$ yields the translation equation:

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite} \times EF \times CF} \qquad \text{(Equation 18)}$$

where $TTF^{composite}$ equals the product of all trophic transfer factors from trophic level 2 through the target fish species.

Equation 18 describes an ecosystem-dependent relationship between the concentration of selenium in the eggs and ovaries of fish with the concentration of selenium in the water column. This approach explicitly recognizes the sequential transfer of selenium between environmental compartments (water, particulate material, invertebrate tissue, fish tissue, and eggs and/or ovary tissue) by incorporating quantitative expressions of selenium transfer from one compartment to the other. Because this approach uses food web modeling along with species-specific *TTF* and *CF* parameters to quantify most of the transfer between compartments, the only field measurements needed to relate selenium in egg-ovary and water are measurements from the water column and particulate material sufficient to calculate *EF*.

3.2.2 Equation Parameters

Empirical or laboratory data related to selenium bioaccumulation in aquatic organisms are needed to derive the equation parameters *EF*, *TTF*, and *CF*. EPA obtained data from published literature as described above The search resulted in the retrieval of 63 acceptable studies containing a total of 8,707 selenium measurements at 768 aquatic sites (2,927 from water, 373 from algae, 29 from detritus, 821 from sediment, 1,324 from various species of

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invertebrates, and 3,233 from various species of fish) and 34 acceptable studies yielding 139 physiological constants (48 values of k_e, 81 values of *AE*, and 10 values of *IR*). EPA used this collection of selenium measurements to calculate site-specific *EF* values and develop species-specific *TTF* and *CF* values in an unbiased and systematic manner. A more detailed description of how EPA calculated *EF* is described below. How EPA calculated *TTF* and *CF* is described in detail in Appendix B.

3.2.2.1 Derivation of Trophic Transfer Factor (*TTF*) Values

EPA derived *TTF* values for taxonomic groups of invertebrates and fish by either using physiological coefficients found in the literature, or by evaluating the empirical relationship between matched pairs of selenium measurements in organisms and the food they consumed. When physiological coefficients were available, EPA calculated a *TTF* value using Equation 3 (**Section 3.2.1**):

$$TTF = \frac{AE \times IR}{k_e} \qquad \text{(Equation 3)}$$

Where:

k_e = Elimination rate constant (/d)

AE = Assimilation efficiency (%)

IR = Ingestion rate (g/g-d)

EPA also derived *TTF* values using empirical measurements of selenium from field studies. EPA searched its collection of available selenium measurements and identified measurements taken from aquatic organisms. For each measurement from an aquatic organism, EPA searched for additional measurements from other aquatic organisms or particulate material that was collected from the same aquatic site and of a type deemed likely to be ingested as a food source or in conjunction with feeding activity (i.e., a lower trophic level). If multiple lower trophic level measurements were matched to an aquatic organism measurement, the median of the lower trophic level measurements was calculated. Each pair of measurements, one taken from an aquatic organism and the other taken from lower trophic level organisms or particulate material, was designated as a matched pair. EPA limited particulate data used to calculate

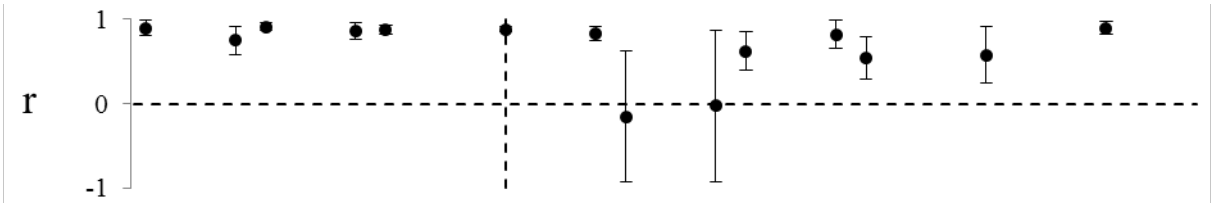
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invertebrate *TTF*s from field data to those aquatic sites with at least two particulate selenium measurements paired with invertebrate selenium measurements, and only used sediment measurements if there was at least one measurement from algae or detritus. If selenium concentrations from more than category of particulate material (algae, detritus, or sediment) were available, EPA used the median Se concentration of the available categories as the particulate concentration for that site.

Because selenium is transferred to aquatic animals primarily through aquatic food webs, the observable concentration of selenium in different environmental compartments may vary over time. To establish an appropriate time period with which to define matched pairs of selenium measurements, the effect of sample collection time on the relationship between selenium concentrations in different media was analyzed. EPA defined matched pairs of selenium measurements as described above using different relative collection time ranges and estimated the strength of the relationship between the two measurements by calculating the Pearson product-moment correlation coefficient (r). **Figure 3.5** shows the correlation coefficients for selenium measurements taken from the same aquatic sites when the measurement collection times were systematically shifted relative to one another. Each correlation coefficient was calculated from a set of data within a specified range of relative collection times with respect to the higher trophic level. For example, the correlation coefficient calculated from invertebrate and fish measurements with a relative sample collection time of 30 to 60 days were from invertebrate and fish samples collected at the same site, with the fish samples collected 30 to 60 days after the invertebrate samples. Similarly, the correlation coefficient calculated from invertebrate and fish measurements with a relative collection time of -60 to -30 days were from invertebrate and fish samples that were collected at the same site, with the fish samples collected 30 to 60 days before the invertebrate samples.

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Particulate versus invertebrate



Invertebrate versus fish

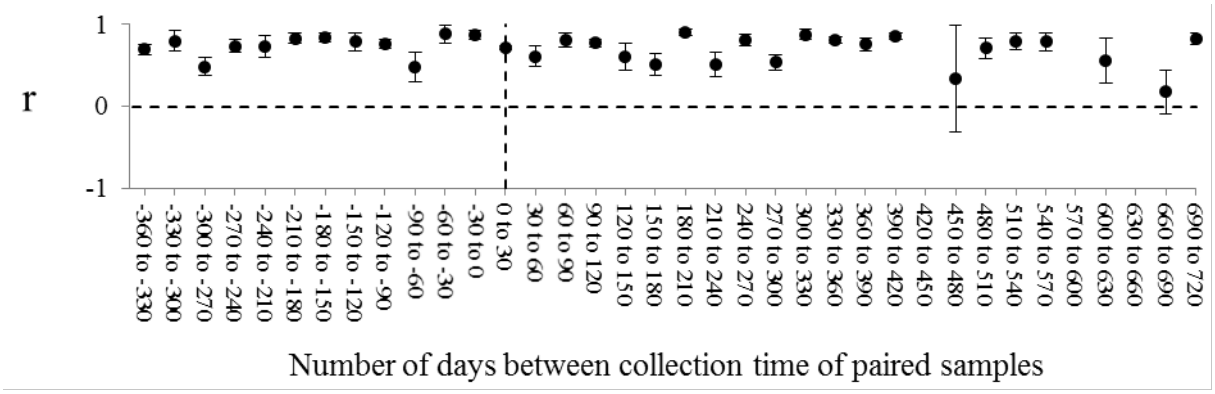


Figure 3.5. Effect of Relative Sample Collection Time on Correlation Coefficients of Selenium Measurements in Particulate Material, and Invertebrate and Fish Tissue. Error bars indicate the 95% confidence interval of r calculated using Fisher's r to z transformation. Horizontal dashed line indicates r = 0; vertical dashed line indicates relative collection time expected to have the highest correlation. The absence of a correlation coefficient indicates an insufficient quantity of data at the specified relative collection time range.

The results of this analysis suggest that the relationship between selenium concentrations in particulate material and invertebrate tissue and between invertebrate tissue and fish tissue is insensitive to relative collection time within a one year time period. These results also suggest that selenium becomes relatively persistent in the aquatic ecosystem once dissolved selenium transforms to particulate selenium and becomes bioavailable. On the basis of these analyses, EPA concludes that selenium measurements from samples collected at the same aquatic site within one year of each other are acceptable to use as matched pairs of measurements from the aquatic sites. Note that EPA chose a relative collection time period of one year on the basis of data taken from many different aquatic sites. Individual aquatic sites may have selenium loads and/or bioaccumulation characteristics that require different relative collection time criteria to accurately characterize selenium relationships.

After matched pairs of selenium measurements from samples collected in the field were identified, EPA evaluated two different analytical approaches to derive species-specific *TTF*

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values from them. *TTF* was previously defined above as the steady state proportion relating the concentration of selenium in the tissue of aquatic organisms to the concentration of selenium in the food they ingest such that:

$$C_{tissue} = TTF \times C_{food} \qquad \text{(Equation 4)}$$

Rearranging the terms of Equation 4 yields Equation 19:

$$TTF = \frac{C_{tissue}}{C_{food}} \qquad \text{(Equation 19)}$$

Because *TTF* can be defined as the ratio of the concentration of selenium observed in the tissue of an aquatic organism to the concentration of selenium observed in the tissue or material the organism ingests, one approach for deriving *TTF* values from field data is to simply use the ratio of the two values. EPA evaluated this approach by calculating the ratios for all matched pairs of selenium measurements, and for each species or taxonomic group, used a statistic of central tendency of the distribution of ratios as the *TTF* value. An advantage of quantifying the relationship between selenium in two environmental compartments using ratios is that it is a simple and straightforward method that is conceptually similar to a bioaccumulation factor (BAF). A disadvantage of this approach is that it presumes that the quality and quantity of data used to derive the ratios adequately represent the relationship being characterized. Furthermore, many aquatic organisms tend to bioaccumulate more metals at low environmental concentrations (McGeer et al. 2003; Borgman et al. 2004; DeForest et al. 2007; U.S. EPA 2007). Thus a distribution of ratios could be biased toward larger values if the data are obtained from aquatic systems with low selenium concentrations.

Another analytical approach for deriving *TTF* values from matched pairs of selenium measurements is to model the species-specific relationships using linear regression. One possibility is to regress the concentration of selenium in the food of a particular species or taxonomic group with the concentration of selenium in the organism's tissue, and use the regression coefficient as the *TTF*. EPA evaluated this approach by applying ordinary least

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squares (OLS) linear regression on the matched pairs of data. The regression coefficient (slope of the fitted line) was then taken as the *TTF* value for that species or taxonomic group. An advantage of this regression approach is that it estimates the quantitative relationship of selenium across a range of environmental concentrations in a manner that allows statistical assessment. Disadvantages of this regression approach include the assumption that the underlying data are normally distributed; one or a few very high values can have a disproportionate influence on the slope of the fitted line; and the bioaccumulation model does not account for a non-zero y-intercept. Constraining the y-intercept to zero (also known as regression through the origin or RTO) eliminates the added complexity of a non-zero y-intercept. However, RTO further increases the disproportionate influence of one or a few high values on the slope of the fitted line. Furthermore, RTO does not provide a straightforward way of evaluating goodness of fit (Gordon 1981).

After evaluating both approaches, EPA decided to use a hybrid approach by designating the median of the ratio of matched pairs of selenium measurements as the *TTF* value, but only if OLS linear regression of those data resulted in a significant ($P \leq 0.05$) fit and positive regression coefficient. Requiring a significant positive OLS linear regression coefficient confirms the relationship between selenium in organisms and the food they ingest is adequately represented by the available data. Using the median of the individual ratios provides an estimate of central tendency for that relationship that is less sensitive to potential bias from measurements taken from aquatic systems with very high or very low selenium concentrations. Some aquatic organisms exhibit selenium bioaccumulation inversely related to water concentration (McGeer et al. 2003; Borgman et al. 2004; DeForest et al. 2007). This inverse relationship is likely due to saturation uptake kinetics of specific transport mechanisms that regulate metals bioaccumulation within certain ranges (U.S. EPA 2007). EPA evaluated the effect of very high and very low selenium concentrations on the calculation of *TTF* values using the hybrid approach described above by calculating TTF values excluding selenium measurements above 10, 25, 50, and 100 μg/g and below 0.1, 0.5, 1.0, and 2.0 μ/g. EPA found that excluding very high or very low selenium measurements had minor effects on *TTF* values. EPA concludes that using the median ratio effectively attenuates effects of selenium concentration on the calculation of *TTF* values using the hybrid approach described above and allows the use of all available data without the need to introduce additional arbitrary exclusion criteria.

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EPA calculated *TTF* values for 13 invertebrate species and 32 fish species that live in freshwater aquatic environments in North America. The data used to derive these *TTF* values are provided in Appendix B. The final *TTF* values are listed in **Table 3.10** and **Table 3.11**. The presence of physiological coefficients for a taxon in **Table 3.10** and **Table 3.11** indicates that the *TTF* values were calculated using those parameters. The absence of physiological coefficients for a taxon indicates that EPA derived the *TTF* value using field data. If a *TTF* value could be calculated from both physiological coefficients and field data, EPA used the *TTF* value calculated from the substantially larger number of field measurements to minimize statistical uncertainty.

Table 3.10. EPA-Derived Trophic Transfer Factor (*TTF*) Values for Freshwater Aquatic Invertebrates.

Common name	Scientific name	AE	IR	k_e	TTF
Crustaceans					
amphipod	*Hyalella azteca*	-	-	-	1.22
copepod	copepods	0.520	0.420	0.155	1.41
crayfish	*Astacidae*	-	-	-	1.46
water flea	*Daphnia magna*	0.406	0.210	0.116	0.74
Insects					
dragonfly	*Anisoptera*	-	-	-	1.97
damselfly	*Coenagrionidae*	-	-	-	2.88
mayfly	*Centroptilum triangulifer*	-	-	-	2.38
midge	*Chironimidae*	-	-	-	1.90
water boatman	*Corixidae*	-	-	-	1.48
Mollusks					
asian clam[a]	*Corbicula fluminea*	0.550	0.050	0.006	4.58
zebra mussel	*Dreissena polymorpha*	0.260	0.400	0.026	4.00
Annelids					
blackworm	*Lumbriculus variegatus*	0.165	0.067	0.009	1.29
Other					
zooplankton	zooplankton	-	-	-	1.89

[a] Not to be confused with *Potamocorbula amurensis*

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Table 3.11. EPA-Derived Trophic Transfer Factor (*TTF*) Values for Freshwater Fish.

Common name	Scientific name	AE	IR	k_e	TTF
Cypriniformes					
blacknose dace	*Rhinichthys atratulus*	-	-	-	0.71
bluehead sucker	*Catostomus discobolus*	-	-	-	1.04
longnose sucker	*Catostomus catostomus*	-	-	-	0.90
white sucker	*Catostomus commersonii*	-	-	-	1.11
flannelmouth sucker	*Catostomus latipinnis*	-	-	-	0.98
common carp	*Cyprinus carpio*	-	-	-	1.20
creek chub	*Semotilus atromaculatus*	-	-	-	1.06
fathead minnow	*Pimephales promelas*	-	-	-	1.57
red shiner	*Cyprinella lutrensis*	-	-	-	1.31
redside shiner	*Richardsonius balteatus*	-	-	-	1.08
sand shiner	*Notropis stramineus*	-	-	-	1.56
Cyprinodontiformes					
western mosquitofish	*Gambusia affinis*	-	-	-	1.21
northern plains killifish	*Fundulus kansae*	-	-	-	1.27
Esociformes					
northern pike	*Esox lucius*	-	-	-	1.78
Gasterosteiformes					
brook stickleback	*Culaea inconstans*	-	-	-	1.79
Perciformes					
black crappie	*Pomoxis nigromaculatus*	-	-	-	2.67
bluegill	*Lepomis macrochirus*	-	-	-	1.03
green sunfish	*Lepomis cyanellus*	-	-	-	1.12
largemouth bass	*Micropterus salmoides*	-	-	-	1.39
smallmouth bass	*Micropterus dolomieu*	-	-	-	0.86
striped bass	*Morone saxatilis*	0.375	0.335	0.085	1.48
walleye	*Sander vitreus*	-	-	-	1.60
yellow perch	*Perca flavescens*	-	-	-	1.42
Salmoniformes					
brook trout	*Salvelinus fontinalis*	-	-	-	0.88
brown trout	*Salmo trutta*	-	-	-	1.38
mountain whitefish	*Prosopium williamsoni*	-	-	-	1.38
cutthroat trout	*Oncorhynchus clarkii*	-	-	-	1.12
rainbow trout	*Oncorhynchus mykiss*	-	-	-	1.07
Scorpaeniformes					
mottled sculpin	*Cottus bairdi*	-	-	-	1.38
sculpin	*Cottus sp.*	-	-	-	1.29
Siluriformes					
black bullhead	*Ameiurus melas*	-	-	-	0.85
channel catfish	*Ictalurus punctatus*	-	-	-	0.68

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For fish species without sufficient data to directly calculate a *TTF* value, EPA estimated the *TTF* value by sequentially considering higher taxonomic classifications until one or more taxa for which a calculated *TTF* value was available matched the taxon being considered. If the lowest matching taxon was common to more than one species with a *TTF* value available, EPA used the median *TTF* from the matching species. For example, although data to directly calculate *TTF* for *Chrosomus eos* (northern redbelly dace) were not available, this species is in the family Cyprinidae, which also includes *Rhinichthys atratulus* (blacknose dace), *Cyprinus carpio* (common carp), *Semotilus atromaculatus* (creek chub), *Pimephales promelas* (fathead minnow), *Cyprinella lutrensis* (red shiner), *Richardsonius balteatus* (redside shiner), and *Notropis stramineus* (sand shiner). Because Cyprinidae is the lowest taxonomic classification where *Chrosomus eos* matches a species with an available *TTF* value, the median of the blacknose dace, common carp, creek chub, fathead minnow, red shiner, redside shiner, and sand shiner *TTF* values was used as the *TTF* value for northern redbelly dace. The data and analyses used to calculate all *TTF* values including those estimated by taxonomic classification are provided in Table B-8 of Appendix B.

3.2.2.2 Derivation of Whole-Body to Egg-Ovary Conversion Factor (*CF*) Values

The parameter *CF* (conversion factor) in Equation 18 (**Section 3.2.1**) represents the species-specific partitioning of selenium as measured in the whole-body and in egg-ovary tissue. EPA derived species-specific *CF* values by applying the same method used to derive species-specific *TTF* values using empirical measurements of selenium concentrations in different tissues of the same fish. To derive whole-body to egg-ovary *CF* values, EPA defined matched pairs of selenium measurements from the whole-body and from the eggs or ovaries measured from the same individual fish or from matched composite samples. Egg-ovary concentration was defined as a measurement from either the eggs or the ovaries. If multiple measurements from both eggs and ovaries of the same individual or matched composite sample were available, the average value was used. For example, both egg and ovary measurements were available for five of the 27 egg-ovary concentrations used to calculate the bluegill egg-ovary to whole body *CF* (Coyle et al. 1993), and 16 of the 69 measurements used to calculate the cutthroat trout egg-ovary to muscle *CF* (Kennedy et al. 2000).

Similar to the procedure used to derive *TTF* values, EPA first confirmed a statistical relationship between egg-ovary and whole body selenium for each species using OLS linear

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regression of the matched pairs of measurements. If the regression resulted in a significant fit ($P \leq 0.05$) with a positive regression coefficient, EPA calculated the ratio of the egg-ovary to whole body selenium concentration of each matched pair and used the median ratio as the *CF* value for the species**.** A detailed comparison of the advantages and disadvantages of the median ratio and least squares regression approaches to calculating *CF*s, along with a comparison of *CF*s calculated from median ratios, OLS regression following log transformation, and total least squares (TLS) regression following log transformation is included in Appendix N.

EPA had sufficient egg-ovary and whole-body selenium measurements to directly derive egg-ovary to whole body *CF* values for 13 species of fish. However, matched pairs of selenium measurements in eggs and/or ovaries and muscle tissue, and matched pairs of selenium measurements in muscle and whole body were also available. To derive *CF* values for additional fish species, EPA used either the additional data or a taxonomic classification approach to estimate *CF*.

For those species of fish with neither sufficient data to directly calculate an egg-ovary to whole body *CF*, nor data to calculate a conversion factor for egg-ovary to muscle or whole body to muscle, EPA first estimated *CF* following the approach described above for the estimation of *TTF* values. In this first approach, EPA sequentially considered higher taxonomic classifications until one or more taxa for which a calculated *CF* value was available matched the taxon being considered, and if the lowest matching taxon was common to more than one species with a *CF* value available, EPA used the median *CF* from the matching species. For example, *CF* data are not available to directly calculate *CF* for *Lepomis microlophus* (redear sunfish); however, genus-level *CF*s for *Lepomis cyanellus* (green sunfish) and *Lepomis macrochirus* (bluegill) are available. Thus, EPA used the median *CF* values of *Lepomis cyanellus* and *Lepomis macrochirus* for redear sunfish.

For fish species without sufficient data to directly calculate an egg-ovary to whole body *CF*, but which had sufficient data to calculate a conversion factor for either egg-ovary to muscle or whole body to muscle, EPA followed a two stage approach based on taxonomic similarity. If a fish species had a species specific egg-ovary to muscle conversion factor, but no whole body data with which to calculate an egg to whole body *CF*, available data for other species would be used to estimate a muscle to whole body conversion factor for that species based on taxonomic relatedness. The estimated muscle to whole body factor would be multiplied by the directly

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measured egg-ovary to muscle factor to estimate an egg-ovary to whole body *CF* for that species. For example, rainbow trout has a species specific egg-ovary to muscle conversion factor of 1.92, but does not have a species specific egg-ovary to whole body *CF*. Using the taxonomic approach described above, the most closely related taxa to rainbow trout with muscle to whole body conversion factors are in the class Actinopterygii. The median conversion factor for the eight species within that class is 1.27. The final egg-ovary to whole body *CF* for rainbow trout is 2.44 (**Table 3.12**), or 1.92 x 1.27.

EPA derived 13 *CF* values directly from matched pairs of egg-ovary and whole-body selenium measurements and an additional seven *CF* values by multiplying EO/M and M/WB conversion factors. Variability in the *CF* values for 19 of the 20 fish species was low (**Table 3.12**). Excluding mountain whitefish, *CF*s ranged from 1.20 to 3.11, a 2.6-fold difference. *CF* variability within each species was also low for 7 of 13 species for which egg-ovary to whole-body *CF*s were calculated. The two species with relatively high standard deviations for their *CF* values (brown trout and cutthroat trout) contained potentially anomalous hatchery data that contributed to the variability (see **Table 3.12** footnote). These species specific *CF* values are listed below in **Table 3.12** and in Table B-5 of Appendix B. All *CF* values including those estimated using the taxonomic classification approach are provided in Table B-6 in Appendix B.

Table 3.12. EPA-Derived Egg-Ovary to Whole-Body Conversion Factor (*CF*) Values.

Common name	Scientific name	CF	Std. Dev.[a]
Acipenseriformes			
white sturgeon	*Acipenser transmontanus*	1.69	
Cypriniformes			
bluehead sucker	*Catostomus discobolus*	1.82	0.19
flannelmouth sucker	*Catostomus latipinnis*	1.41	0.20
white sucker	*Catostomus commersonii*	1.38	0.36
desert pupfish	*Cyprinodon macularius*	1.20	0.10
common carp	*Cyprinus carpio*	1.92	0.49
roundtail chub	*Gila robusta*	2.07	0.29
fathead minnow	*Pimephales promelas*	1.40	0.75
creek chub	*Semotilus atromaculatus*	1.99	1.00
razorback sucker	*Xyrauchen texanus*	3.11	
Esociformes			
northern pike	*Esox lucius*	2.39	
Perciformes			
bluegill	*Lepomis macrochirus*	2.13	0.68

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Common name	Scientific name	CF	Std. Dev.[a]
green sunfish	*Lepomis cyanellus*	1.45	0.23
smallmouth bass	*Micropterus dolomieu*	1.42	0.19
Salmoniformes			
brook trout	*Salvelinus fontinalis*	1.38	
Dolly Varden	*Salvelinus malma*	1.61	
brown trout	*Salmo trutta*	1.45	1.81[b]
rainbow trout	*Oncorhynchus mykiss*	2.44	
cutthroat trout	*Oncorhynchus clarkii*	1.96	2.03[b]
mountain whitefish	*Prosopium williamsoni*	7.39	

[a] Standard deviation for *CF* values for those species that had egg-ovary and whole body selenium concentrations.

[b] The brown trout and cutthroat trout standard deviations for *CF* values of 1.81 and 2.03 are considerably higher than the other standard deviations in this table. The brown trout data were taken from two studies, NewFields (2009) and Osmundson et al. (2007). *CF* values for three of the four fish samples from Osmundson et al. were four to six times greater than the median. Also, the NewFields data consisted of samples collected from natural streams and samples collected from a fish hatchery. The *CF* values for the fish hatchery samples were four to seven times lower than the median value. Although collectively, the data set meets the criteria for including the brown trout *CF*, the *CF* values for Osmundson et al. and NewFields hatchery samples may be anomalously high and low, respectively. Excluding these potentially anomalous data reduces the brown trout standard deviation to 0.47. The cutthroat trout *CF* values are from two sources (Formation 2012 and Hardy 2005). The reason for the higher variability in the cutthroat trout *CF* values is due to the relatively higher *CF* values in the hatchery fish from the Formation study. The standard deviation for cutthroat trout drops to 0.62 if the hatchery fish are excluded. See Appendix B for a presentation of the data for both of these species.

3.2.2.3 Calculation of Site-Specific Enrichment Factor (EF) Values

The most influential step in selenium bioaccumulation occurs at the base of aquatic food webs (Chapman et al. 2010). The parameter *EF* characterizes this step by quantifying the partitioning of selenium between the dissolved and particulate state. *EF* can vary by at least two orders of magnitude across aquatic systems (Presser and Luoma 2010). The greatest reduction in uncertainty when translating a fish tissue concentration of selenium to a water column concentration using Equation 18 is achieved when spatially and temporally coincident site-specific empirical observations of dissolved and particulate selenium of sufficient quality and quantity are used to accurately characterize *EF*. Thus, EPA only used aquatic sites with sufficient data to calculate a reasonably reliable *EF* value.

To calculate the *EF* of aquatic systems, EPA searched its collection of selenium concentration measurements from field studies (see **Section 2.7.8** for a description of data

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sources and acceptability criteria) and identified aquatic sites with measurements from both particulate material and the water column. EPA first identified all selenium measurements from algae, detritus, or sediment, and then searched for corresponding water column measurements from samples collected at the same aquatic site within one year of the particulate sample. If more than one water measurement was available for any given particulate measurement, the median was used. For each of these matched pairs of particulate and water measurements, EPA calculated the ratio of particulate concentration to water concentration. If more than one ratio for any given category of particulate material (algae, detritus, or sediment) was calculated at an aquatic site, EPA used the median ratio. The geometric mean of the algae, detritus, and sediment ratios was used as the site *EF*. Because there were at most only three possible values (one for algae, one for detritus, and one for sediment), EPA used the geometric mean in order to reduce the potential for one of the values to have excessive influence on the final site *EF* value.

The availability of selenium measurements from particulate material was limited. In addition, the majority of particulate measurements were from sediment samples with a significantly lower correlation to selenium in water ($r = 0.34$) compared to algae ($r = 0.68$; Fisher r-to-z transformation, $P < 0.001$) and detritus ($r = 0.94$; Fisher r-to-z transformation, $P < 0.001$). Therefore, to reduce uncertainty in estimating site-specific *EF* values, EPA limited its analysis to those aquatic sites with at least two particulate selenium measurements with corresponding water column measurements, and only used sediment measurements if there was at least one other measurement from either algae or detritus. On the basis of these requirements, *EF* values were calculated for 96 individual aquatic sites.

3.2.3 Food-Web Models

For the aquatic sites with a calculated *EF* value, EPA modeled the food webs for the fish species the studies indicated were present. Some of those studies provided information about the species and proportions of organisms ingested by fish, either through direct analysis of stomach contents, or examination of the presence and prevalence of invertebrate species. For those studies, that site-specific information in the food web models was used. Most studies, however, did not provide site-specific food web information. In those cases, the food webs of fish species present were modeled using information about their typical diet and/or eating habits obtained from the NatureServe database (http://www.natureserve.org).

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After EPA developed food web models, EPA identified the appropriate species-specific *TTF* values for each model and calculated $TTF^{composite}$. Although individual *TTF* values were derived for several different taxa of invertebrates and fish (**Table 3.10** and **Table 3.11**), some of the food web models included one or more taxa for which no *TTF* value was available. EPA estimated *TTF* values for these taxa using the same taxonomic approach used to estimate egg-ovary to whole body, egg-ovary to muscle, and muscle to whole body conversion factors for taxa without sufficient data. In brief, for taxa with insufficient data to calculate a *TTF* value, EPA sequentially considered higher taxonomic classifications until one or more taxa for which a *TTF* value was available matched the taxon being considered. If the lowest matching taxon was common to more than one species with a *TTF* value available, EPA used the median *TTF* from the matching species. EPA used site-specific food-web models to translate the egg-ovary criterion element to a set of water column concentrations in order to derive the water column concentration element of the selenium criterion. Details of these food web models are shown in Table B-8 of Appendix B.

3.2.4 Classifying Categories of Aquatic Systems

Transformation reactions that convert dissolved selenium to particulate forms are the primary route of entry into aquatic food webs, and are critical steps in selenium bioaccumulation and toxicity (Chapman et al. 2010). Site-specific characteristics can result in substantial bioaccumulation variability and consequently different risks of selenium toxicity for a given dissolved selenium concentration. Freshwater systems fall into two distinct categories: lotic systems such as rivers and streams, characterized by flowing water, and lentic systems, such as lakes and ponds, characterized by largely standing water (e.g., Jones 1997). Water residence time is generally shorter in lotic systems than in lentic systems, and subsequently, aquatic organisms living in lentic systems tend to bioaccumulate more selenium than organisms living in lotic systems for a given dissolved selenium concentration (ATSDR 2003; EPRI 2006; Luoma and Rainbow 2005; Orr et al. 2006; Simmons and Wallschlägel 2005).

Although the distinction between lotic and lentic aquatic systems is often straightforward, some aquatic systems possess both lotic and lentic characteristics. For example, flow rate can vary greatly among lotic systems, with slow flowing low gradient systems (such as sloughs) having longer residence times relative to fast flowing high gradient systems. Lotic systems can also become more lentic during dry periods as hydrologic connectivity between deeper pools

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decrease or cease with decreasing flow (Buffagni et al. 2009). Downstream reaches of some low gradient coastal rivers can also be influenced by tides (Riedel and Sanders 1998). Some lentic systems can exhibit some degree of flow, such as lakes fed and drained by one or more streams; however, the magnitude of flow is generally small compared to a lotic system. Even after accounting for flow, the majority of water movement in a lentic system is driven typically by wind or convection rather than gravity (e.g., Jones 1997). Finally, human-made reservoirs have some features that are intermediate between typical lotic and lentic systems. For example, reservoirs tend to be longer and narrower than natural lakes, and they have somewhat shorter water retention time than a natural lake of comparable volume (Thornton et al. 1990). Overall, however, reservoirs as a general class are considered more lentic than lotic, and have historically been classified as a type of lake (Thornton et al. 1990).

To verify the suitability of lentic and lotic aquatic system categories as the basis for independent water column criterion element values, EPA evaluated the aquatic systems that provided data for the 96 *EF* values. EPA utilized the description provided by the study authors to categorize each aquatic system as either lotic or lentic. Of the 39 lentic sites, the authors identified them as ponds (n = 18), lakes (n = 13), reservoirs (n = 4), or marshes (n = 4). Of the 57 lotic sites, the authors identified them as creeks (n = 31), rivers (n = 16), artificial channels (drains and wasteways, n = 3), springs (n = 2), sloughs (n = 2), or ephemeral systems (draws and washes, n = 3). The three ephemeral aquatic sites (two washes and one draw) were categorized as lotic because there was flowing water at the time they were sampled (Butler et al. 1995; Presser and Luoma 2009). *EF* values for these aquatic systems are shown in **Figure 3.6**.

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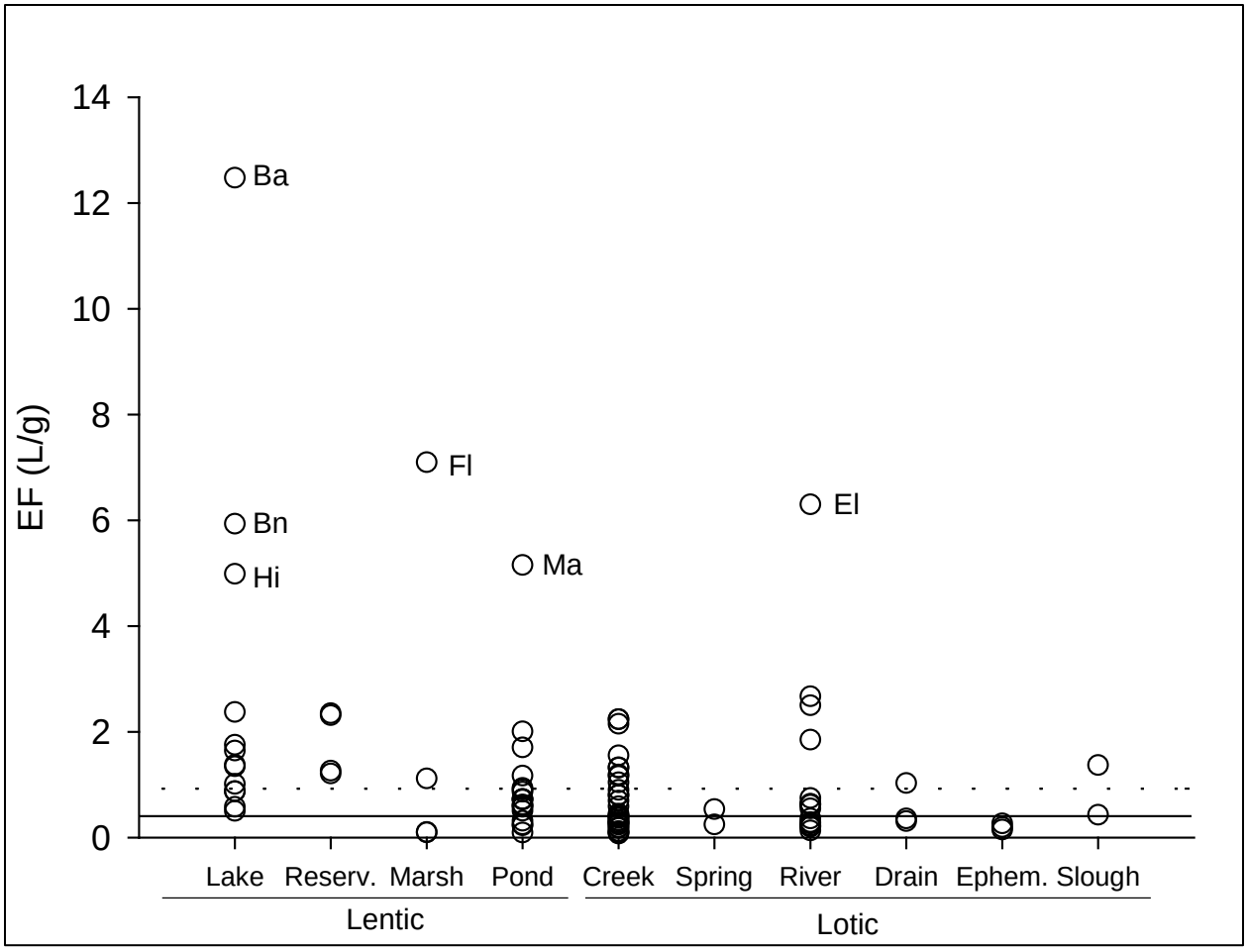


Figure 3.6. Enrichment Factors (*EF*) for 96 Aquatic Sites Derived from Published Studies and Organized by Waterbody Type.
The dashed line represents the median *EF* for the 39 lentic sites (0.9 L/g), and the solid line represents the median *EF* for the 57 lotic sites (0.4 L/g). See text for information on labeled data points.

Because the six labeled aquatic sites in **Figure 3.6** (Ma, Ba, Bn, Hi, El and Fl) appear as outliers, EPA selected them for further scrutiny. Data from site "Ma" result in an *EF* value of 5.2 L/g. Site "Ma" was a small irrigation pond within the Mancos River Valley watershed in southwestern Colorado (Butler et al. 1997). This watershed drains the Mancos Shale, a region that is naturally high in selenium. Data from sites "Hi," "Bn," and "Ba" resulted in *EF* values of 5.0, 5.9, and 12.5 L/g, respectively. Data from site "Hi" were from High Rock Lake, NC, data from site "Bn" were from Barnes Lake, British Columbia (Orr et al. 2006), and data from site "Ba" was from Badin Lake, NC (Lemly 1985). The high *EF* values at these three lakes were the result of a relatively high selenium concentration in particulate matter coupled with low aqueous

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selenium concentrations. Data from site “El” result in an *EF* value of 6.3 L/g. Site “El” is an upstream site in the Elk River watershed in southeastern British Columbia, and the relatively large *EF* is the primarily the result of a low aqueous selenium concentration (McDonald and Strosher 1998). Data from “Fl” result in an *EF* value of 7.1 L/g. Site “Fl” is within Flathead wetland in southeastern British Columbia, and the relatively large *EF* is primarily the result of a low aqueous selenium concentration (Orr et al. 2012).

Figure 3.7 illustrates the variability in *EF* values across aquatic systems and substantial overlap between lotic and lentic categories. Some of this variability can be attributed to differences in the ambient concentration of selenium in the water column at these aquatic sites. *EF* is the ratio of selenium in particulate material ($C_{particulate}$) to selenium in the water column (C_{water}). As expected, the selenium concentrations in particulate material are positively correlated with the selenium concentrations in the water column (**Figure 3.7A**). The plot of $C_{particulate}$ versus C_{water} shows a significant ($P<0.001$) positive relationship for both lentic (slope = 0.65, 95% confidence interval = [0.50, 0.80]) and lotic (slope = 0.55, 95% confidence interval = [0.43, 0.68]) aquatic systems. However, selenium accrual in particulate matter is lower at aquatic sites with a higher water concentration of selenium compared to aquatic sites with a lower water concentration of selenium (**Figure 3.7B**). The plot of C_{water} versus *EF* shows a significant ($P<0.001$) negative relationship for both lentic (slope = -0.36, 95% confidence interval = [-0.51, -0.22]) and lotic (slope = -0.42, 95% confidence interval = [-0.55, -0.30]) aquatic systems. Consistent with other studies (e.g., Hamilton and Palace 2001; Brix et al. 2005; Orr et al. 2006), these results illustrate that the overall longer residence times of lentic systems result in increased bioaccumulation of selenium compared to lotic systems.

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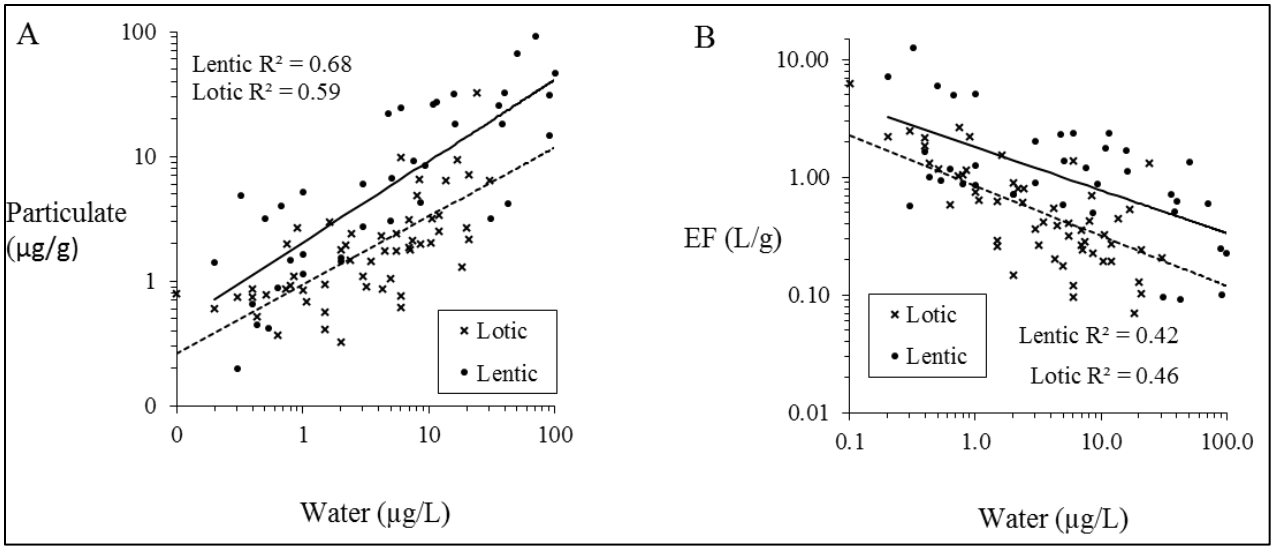


Figure 3.7. The Relationship between C_{water} and $C_{particulate}$, and C_{water} and *EF* for the 39 Lentic and 57 Lotic Aquatic Systems.
A: Relationship between C_{water} and $C_{particulate}$ by site category.
B: Relationship between C_{water} and *EF* by site category.
Solid line, ordinary least squares linear regression of logged data from lentic aquatic systems.
Dashed line, ordinary least squares linear regression of logged data from lotic aquatic systems.

Figure 3.8 shows the distribution of *EF* values grouped by lotic and lentic aquatic system categories. Although EPA derived the lentic and lotic *EF* values from aquatic sites with a similar range of water concentrations, the relative proportion of *EF* values collected at sites with higher water concentrations is larger for lentic sites than lotic sites. In particular, 6 of the 39 lentic *EF* values were from ponds in the Kesterson National Wildlife Refuge where C_{water} ranged from 38.6-196 µg/L (Saiki and Lowe 1987; Schuler et al. 1990). Despite the influence of selenium water concentration on *EF*, the median of *EF* values from lentic and lotic aquatic systems are significantly different from each other (Mann-Whitney U, P = 0.002). EPA concludes from these analyses that lentic and lotic aquatic system categories are appropriate categories for differentiating Se bioaccumulation. A listing of all aquatic-sites from which *EF*s were calculated is provided in Appendix H.

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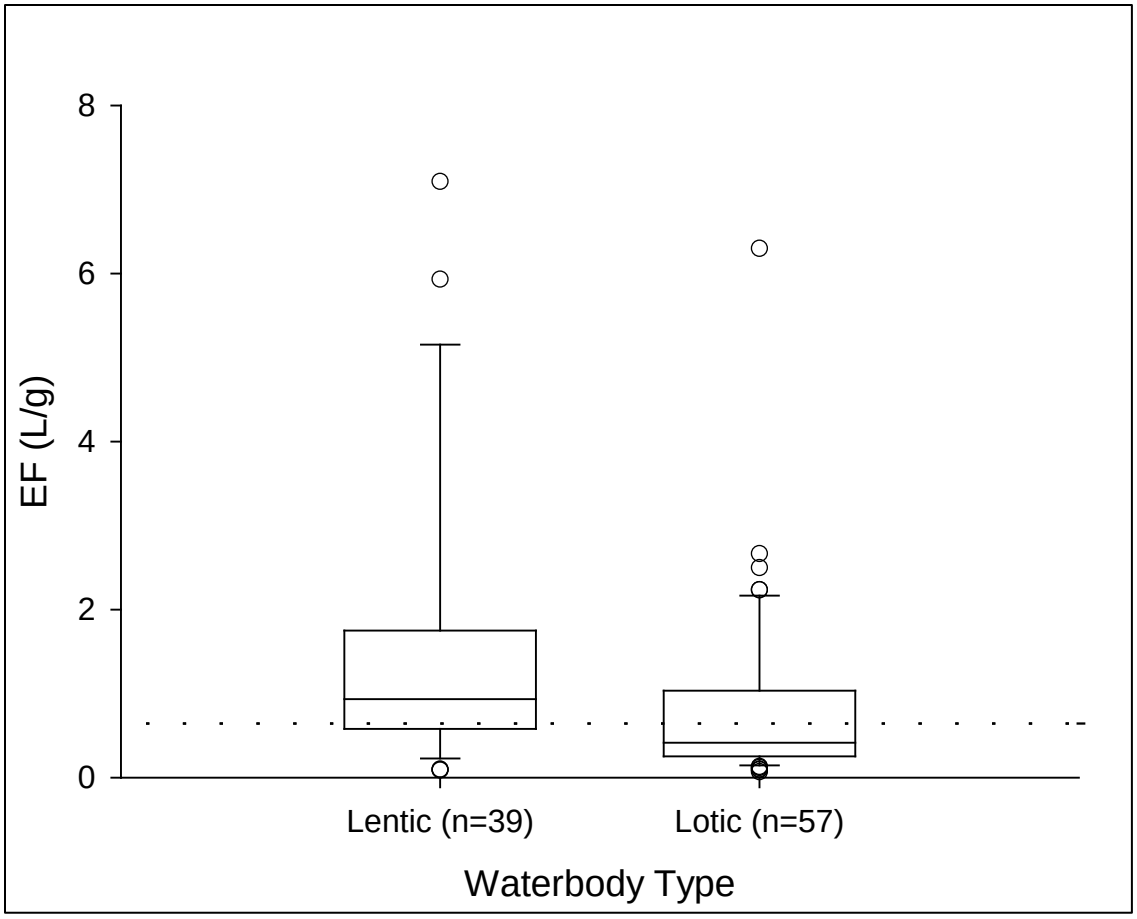


Figure 3.8. Distribution of *EF* Values for the Same 96 Aquatic Systems.
(As shown in **Figure 3.6** and **Figure 3.7** grouped by lentic and lotic aquatic system categories). Boxes show the 25th centile, median, and 75th centile *EF* values; whiskers show the 10th and 90th centiles. Circles represent *EF* values greater than 1.5 times the interquartile (25th-50th – lower circles; 50th-75th –upper circles) range. Dashed line represents the median *EF* of all 96 sites (0.63 L/g). The *EF* value of 12.48 L/g from Badin Lake (Lemly 1985) is off scale.

3.2.5 Deriving Protective Water Column Concentrations for Lentic and Lotic System Categories

To derive the water column element of the selenium criterion, EPA translated the egg-ovary criterion element to a distribution of water column concentration values for lentic and lotic aquatic systems. EPA uses the *EF* values calculated for 96 aquatic sites, available information about the fish species present at those sites, and food web models of those fish species. Because translation of the egg-ovary criterion element is site- and species-specific, several studies identifying more than one species of fish could potentially provide more than one translated water column concentration (one translated water value for each species). EPA considered using

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all water column values for all species present to generate distributions of translated water column values from lentic and lotic aquatic sites. However, the number of reported fish species at aquatic sites with an *EF* value varied from one to six fish species. Furthermore, the studies providing data for 31 of the 96 sites with *EF* values do not provide information on the species of fish that may have been present at the aquatic site. Because the number of fish species at an aquatic site was not consistently reported, and because the number of reported fish species does not necessarily indicate the number of species present at a site, EPA calculated one translated egg-ovary criterion element to water column value for each aquatic site with both an *EF* value and at least one reported fish species. When more than one species was reported at a site, the EPA used the lowest translated water value for that site. Using this methodology, EPA translated the egg-ovary FCV into water column concentrations at 26 lentic and 39 lotic aquatic sites. EPA used these distributions of water concentration values translated from the egg-ovary criterion element to derive chronic water column criterion element values for lentic and lotic aquatic systems. **Table 3.13** shows the model parameter values used to translate the egg-ovary criterion element to site-specific water concentrations, and **Figure 3.9** shows the distribution of the translated values.

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Table 3.13. Data for the 65 Site Minimum Translations of the Egg-Ovary Criterion Concentration Element to a Water Column Concentration.

Identification				Model Parameters			Translation
Reference	**Site**	**Species**	**Type**	***EF*[a]**	***CF*[b]**	***TTF*[composite-c]**	**C_{water}[d]**
Birkner 1978	East Allen Reservoir, Medicine Bow WY	Iowa darter	Lentic	2.31	1.45	2.87	1.57
Birkner 1978	Galett Lake, Laramie WY	Iowa darter	Lentic	0.88	1.45	2.87	4.15
Birkner 1978	Larimer Highway 9 Pond, Fort Collins CO	northern plains killifish	Lentic	1.70	1.20	2.44	3.04
Birkner 1978	Meeboer Lake, Laramie WY	northern plains killifish	Lentic	0.58	1.20	2.44	8.96
Birkner 1978	Miller's Lake, Wellington CO	Iowa darter	Lentic	2.37	1.45	2.87	1.53
Birkner 1978	Sweitzer Lake, Delta CO	fathead minnow	Lentic	0.87	1.40	2.78	4.45
Birkner 1978	Twin Buttes Reservoir, Laramie WY	Iowa darter	Lentic	1.21	1.45	2.87	3.01
Bowie et al. 1996	Hyco Reservoir	bluegill	Lentic	2.35	2.13	2.00	1.51
Butler et al. 1993	Navajo Reservoir, Piedra River Arm, near La Boca	brown trout	Lentic	1.26	1.45	2.78	2.98
Butler et al. 1997	Large pond south of G Road, southern Mancos Valley	fathead minnow	Lentic	2.00	1.40	2.78	1.94
Butler et al. 1997	Pond downstream from site MNP2, southern Mancos Valley	smallmouth bass	Lentic	5.15	1.42	1.93	1.07
Butler et al. 1997	Pond on Woods Canyon at 15 Road	fathead minnow	Lentic	0.90	1.40	2.78	4.29
Grasso et al. 1995	Arapahoe Wetlands Pond	fathead minnow	Lentic	0.86	1.40	2.78	4.49
Lemly 1985	Badin Lake	red shiner	Lentic	12.48	1.95	2.27	0.27
Lemly 1985	Belews Lake	red shiner	Lentic	1.75	1.95	2.27	1.94
Lemly 1985	High Rock Lake	red shiner	Lentic	4.99	1.95	2.27	0.68
Muscatello and Janz 2009	Vulture Lake	northern pike	Lentic	1.01	2.39	4.02	1.56
Orr et al. 2012	Clode Pond 11	cutthroat trout	Lentic	0.71	1.96	2.29	4.70
Orr et al. 2012	Elk Lakes 14	cutthroat trout	Lentic	1.64	1.96	2.29	2.05
Orr et al. 2012	Fording River Oxbow 10	cutthroat trout	Lentic	1.34	1.96	2.29	2.50
Orr et al. 2012	Henretta Lake 27	cutthroat trout	Lentic	0.50	1.96	2.29	6.72
Saiki and Lowe 1987	Kesterson Pond 11	western mosquitofish	Lentic	0.51	1.20	2.37	10.52
Saiki and Lowe 1987	Kesterson Pond 2	western mosquitofish	Lentic	0.32	1.20	2.37	16.83
Saiki and Lowe 1987	Kesterson Pond 8	western mosquitofish	Lentic	0.60	1.20	2.37	8.84
Saiki and Lowe 1987	Volta Pond 26	western mosquitofish	Lentic	0.93	1.20	2.37	5.69

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Identification				Model Parameters			Translation
Reference	**Site**	**Species**	**Type**	***EF*[a]**	***CF*[b]**	***TTF*[composite-c]**	**C_{water}[d]**
Stephens et al. 1988	Marsh 4720	common carp	Lentic	0.10	1.92	1.58	52.02
Butler et al. 1991	Uncompahgre River at Colona	rainbow trout	Lotic	0.63	2.44	2.33	4.21
Butler et al. 1993	Spring Cr. at La Boca	brown trout	Lotic	0.18	1.45	2.78	20.97
Butler et al. 1995	Hartman Draw near mouth, at Cortez	fathead minnow	Lotic	0.15	1.40	2.78	26.04
Butler et al. 1995	McElmo Cr. at Hwy. 160, near Cortez	fathead minnow	Lotic	0.90	1.40	2.78	4.32
Butler et al. 1995	McElmo Cr. downstream from Alkali Cyn.	fathead minnow	Lotic	0.37	1.40	2.78	10.57
Butler et al. 1995	McElmo Cr. downstream from Yellow Jacket Cyn.	red shiner	Lotic	0.12	1.95	2.27	28.34
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	red shiner	Lotic	0.10	1.95	2.27	35.60
Butler et al. 1995	Navajo Wash near Towaoc	speckled dace	Lotic	0.20	1.95	1.36	29.07
Butler et al. 1995	San Juan River at Four Comers	red shiner	Lotic	0.26	1.95	2.27	12.97
Butler et al. 1995	San Juan River at Mexican Hat Utah	common carp	Lotic	0.29	1.92	1.58	17.24
Butler et al. 1995	Woods Cyn. Near Yellow Jacket	fathead minnow	Lotic	0.40	1.40	2.78	9.60
Butler et al. 1997	Cahone Canyon at Highway 666	green sunfish	Lotic	0.20	1.45	2.29	23.22
Butler et al. 1997	Mud Creek at Highway 32, near Cortez	fathead minnow	Lotic	0.07	1.40	2.78	55.27
Casey 2005	Deerlick Creek	rainbow trout	Lotic	2.24	2.44	2.33	1.18
Casey 2005	Luscar Creek	rainbow trout	Lotic	0.33	2.44	2.33	8.14
Formation 2012	Crow Creek - 1A	brown trout	Lotic	0.80	1.45	2.96	4.42
Formation 2012	Crow Creek - 3A	brown trout	Lotic	0.81	1.45	2.97	4.37
Formation 2012	Crow Creek - CC150	brown trout	Lotic	1.04	1.45	2.91	3.44
Formation 2012	Crow Creek - CC350	brown trout	Lotic	1.16	1.45	2.97	3.02
Formation 2012	Crow Creek - CC75	brown trout	Lotic	1.19	1.45	2.87	3.07
Formation 2012	Deer Creek	brown trout	Lotic	1.55	1.45	3.00	2.25
Formation 2012	Hoopes Spring - HS	brown trout	Lotic	0.24	1.45	3.86	11.06
Formation 2012	Hoopes Spring - HS3	brown trout	Lotic	0.54	1.45	2.63	7.40
Formation 2012	Sage Creek - LSV2C	brown trout	Lotic	0.45	1.45	3.01	7.76
Formation 2012	Sage Creek - LSV4	brown trout	Lotic	0.69	1.45	2.88	5.22
Formation 2012	South Fork Tincup Cr.	brown trout	Lotic	1.32	1.45	3.05	2.58
Hamilton and Buhl 2004	Lower East Mill Creek	cutthroat trout	Lotic	1.32	1.96	2.29	2.55
McDonald and Strosher 1998	Elk R. above Cadorna Cr. (745)	mountain whitefish	Lotic	6.30	7.39	2.97	0.11
McDonald and Strosher 1998	Fording R. above Swift Cr. (746)	cutthroat trout	Lotic	0.23	1.96	2.29	14.91
Orr et al. 2012	Elk River 1	cutthroat trout	Lotic	0.55	1.96	2.29	6.14

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Identification				Model Parameters			Translation
Reference	**Site**	**Species**	**Type**	***EF*[a]**	***CF*[b]**	***TTF*[composite-c]**	**C_{water}[d]**
Orr et al. 2012	Elk River 12	cutthroat trout	Lotic	2.67	1.96	2.29	1.26
Orr et al. 2012	Fording River 23	cutthroat trout	Lotic	0.21	1.96	2.29	16.20
Orr et al. 2012	Michel Creek 2	cutthroat trout	Lotic	0.28	1.96	2.29	11.85
Saiki and Lowe 1987	San Luis Drain	western mosquitofish	Lotic	0.36	1.20	2.37	14.81
Saiki and Lowe 1987	Volta Wasteway	western mosquitofish	Lotic	1.03	1.20	2.37	5.17
Saiki et al. 1993	Mud Slough at Gun Club Road	bluegill	Lotic	1.37	2.13	1.47	3.53
Saiki et al. 1993	Salt Slough at the San Luis National Wildlife Refuge	bluegill	Lotic	0.43	2.13	1.47	11.29
Saiki et al. 1993	San Joaquin R. above Hills Ferry Road	bluegill	Lotic	0.36	2.13	1.47	13.50
Saiki et al. 1993	San Joaquin R. at Durham Ferry State Recereation Area	bluegill	Lotic	0.75	2.13	1.47	6.46

a - Geometric mean of the median enrichments functions (*EF*) for all available food types (algae, detritus, and sediment). *EF* (L/g) = C_{food}/C_{water}.
b - Taxa-specific conversion whole-body to egg ovary conversion factor (*CF*; dimensionless ratio).
c - Composite trophic transfer factor ($TTF^{composite}$). Product of *TTF* values for all trophic levels.
d - Translated water concentration corresponding to an egg-ovary criterion element of 15.1 mg Se/kg dw, calculated by Equation 18.

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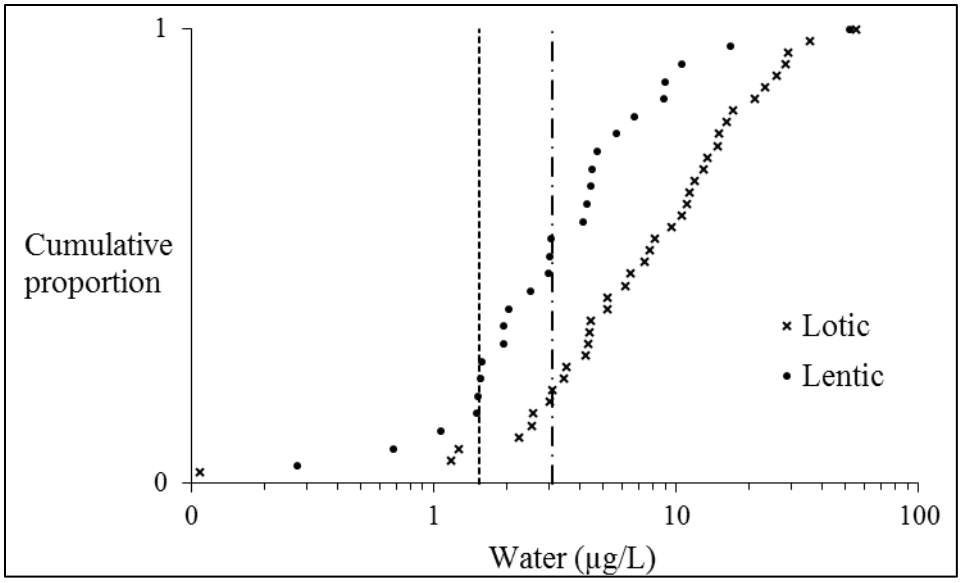


Figure 3.9. Probability Distribution of the Water Column Concentrations Translated from the Egg-Ovary Criterion Element at 26 Lentic and 39 Lotic Aquatic Sites.
Dashed and dash-dot lines show the 20th percentiles of the lentic and lotic distributions, respectively.

EPA selected the 20th percentile from the distribution of translated water column values of each category as the final national water column criterion element concentrations (3.1 µg/L for lotic waters and 1.5 µg/L for lentic waters) because the 20th percentile is consistent with past practice as it provides a high probability of protection for most aquatic systems in both lentic and lotic categories. **Table 3.14** provides the 20th percentile of the water concentration values translated from the egg-ovary criterion element value.

Table 3.14. Water Column Criterion Element Concentration Values Translated from the Egg-Ovary Criterion Element.

	Lentic	**Lotic**
20th percentile (final EPA-recommended water column criterion element)	**1.5 µg/L**	**3.1 µg/L**

As discussed in **Section 2.2.2**, selenium bioaccumulation potential depends on several biogeochemical factors that characterize a particular aquatic system. Uncertainty in the translation of the egg-ovary criterion element to the water column element can be reduced by deriving a site-specific criterion that uses site-specific selenium data and information on food-web dynamics from a biological assessment of the aquatic system. The general considerations are provided in Appendix K. The derivation of water column criterion element values described

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above is constrained by the need to apply a national criterion value to a large number of aquatic systems for lentic and lotic systems.

3.2.6 Derivation of Averaging Period for Chronic Water Criterion Element

In the context of selenium bioaccumulation in a single trophic level, k would be the first-order depuration coefficient, and 1/k would equal the time needed to depurate to a concentration of 1/e times the initial concentration (where e=2.718). For depuration of two trophic levels sequentially, invertebrates and fish, the characteristic time is likewise the time needed for c/c_o to reach a value of 1/e. This differs from typical criteria averaging periods based on U.S. EPA (1995), where the concept that the criterion averaging period should be less than or equal to the "characteristic time" describing the toxic speed of action due to direct waterborne toxicity of metals (i.e., where characteristic time = 1/k, where k is the first-order kinetic coefficient in a toxicokinetic model fitted to the relationship between LC_{50} and exposure duration). For the first trophic level, the kinetics for algal bioaccumulation and depuration were assumed to be rapid compared to the kinetics for larger organisms at higher trophic levels; that is, the characteristic time for algae was assumed to be negligible.

For the second trophic level, invertebrates, values for k_{TL2} are tabulated elsewhere in the document. A value of 0.1/day appears to be environmentally conservative, considerably higher than those for *Lumbriculus*, Asian clam, and zebra mussel, but slightly lower than copepods, which are very small in size. This corresponds to a characteristic time of 10 days.

For fish, the median depuration coefficient measured by Bertram and Brooks (1986) for 6-9 month-old (early adult) fathead minnows is applied, providing a k_{TL3} value of 0.02/day. This corresponds to a characteristic time of 50 days. Because of the small size of adults of this species, this represents faster kinetics than would likely be applicable to the salmonids and centrarchids of greatest concern for selenium toxicity, consonant with the Newman and Mitz (1988) inverse relationship between depuration rate and organism size. The striped bass k value of Baines et al. (2002) is inapplicable here because it was measured in the early juvenile life stage, a size that is too small to be relevant to reproductive impairment stemming from exposure of adult females.

As shown in Appendix J, the characteristic time for the combined second and third trophic levels (invertebrates and fish) is the approximate sum of the above two characteristic times, or 60 days. The analysis of the protectiveness of a 30-day averaging period, shorter than

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the characteristic time, was performed and is shown in Appendix J. That analysis demonstrated that a 30-day averaging period for the chronic water criterion element affords protection under all conditions, and is therefore the duration recommended for the chronic water column criterion element.

3.3 Intermittent-Exposure Water Criterion Element: Derivation from the Chronic Water Criterion Element

Chapman et al. (2009) noted that selenium acute toxicity has been reported rarely in the aquatic environment and that traditional methods for predicting effects based on direct exposure to dissolved concentrations do not work well for selenium. As demonstrated in Appendix J, the kinetics of selenium accumulation and depuration are sufficiently slow that attainment of the water criterion element concentration by ambient 30-day averages will protect sensitive aquatic life species even where concentrations exhibit a high degree of variability.

To address situations where pulsed exposures of selenium could result in bioaccumulation in the ecosystem and potential chronic effects in fish, EPA is providing an intermittent exposure water criterion element concentration intended to limit cumulative exposure to selenium, derived from the chronic 30-day water criterion element magnitude and from its duration, which was obtained from the kinetic analysis of Appendix J. That is, the intermittent criterion element is based on the same kinetic analysis used to derive the water chronic averaging period (30 days).

To illustrate the concept of the intermittent criterion element and its dependence on the 30-day criterion element magnitude and duration, **Figure 3.10** shows a possible sequence of exposures over a 30-day period.

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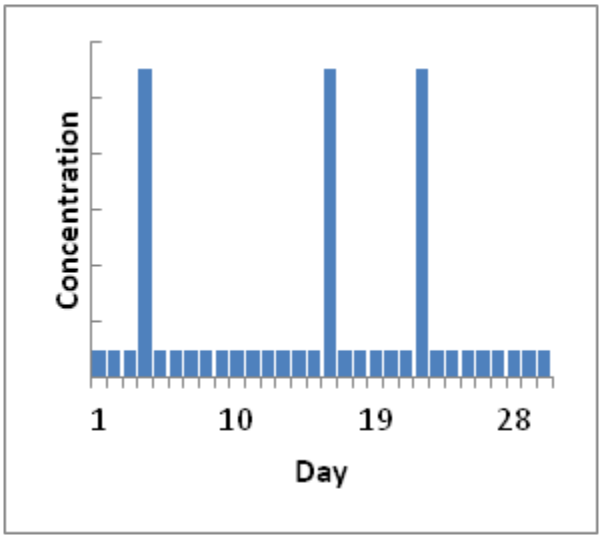


Figure 3.10. Illustration of Intermittent Spike Exposure Occurring for a Certain Percentage of Time (e.g., 10%) Over a 30-Day Period, and Background Exposure Occurring for the Remaining Percentage of Time (e.g., 90%).

The 30-day average concentration, $C_{30\,day}$, is given by Equation 20:

$$C_{30-day} = C_{int} f_{int} + C_{bkgrnd}(1 - f_{int}) \qquad \text{(Equation 20)}$$

Where:

C_{int} = the intermittent spike concentration (µg/L)

f_{int} = the fraction of any 30-day period during which elevated selenium concentrations occur

C_{bkgrnd} = the average daily background concentration occurring during the remaining time, integrated over 30 days.

$C_{30\text{-}day}$ is not to exceed the chronic criterion element, $WQC_{30\text{-}day}$. If the intent is to apply a criterion element, WQC_{int}, to the intermittent spike concentrations, then replacing C_{int} with WQC_{int} and $C_{30\text{-}day}$ with $WQC_{30\text{-}day}$ in the above equation, and then solving for WQC_{int} yields Equation 21:

$$WQC_{int} = \frac{WQC_{30\,day} - C_{bkgrnd}(1-f_{int})}{f_{int}} \qquad \text{(Equation 21)}$$

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The equation expresses the intermittent exposure water criterion element in terms of the 30-day average chronic water criterion element, for a lentic or lotic system, as appropriate, while accounting for the fraction in days of any 30-day period the intermittent spikes occur and for the concentration background occurring during the remaining time. The reasonable worst-case assumption inherent in this approach is that selenium bioaccumulation is linear over a very wide range of concentrations, that is, *EF* and *TTF* values do not decrease significantly as concentrations increase.

If the heights of three spikes in **Figure 3.10** were to differ somewhat among each other, the intermittent element would apply to the arithmetic mean of the three. If the background concentrations were to vary somewhat, then the arithmetic mean background would be entered into the equation. Where concentrations vary smoothly over time, it does not matter where the line is drawn defining elevated versus background concentrations. The intermittent element will yield the same level of protection as the 30-day average element, provided that the equation uses (a) the average of the concentrations occurring for the fraction of time defined as being intermittently elevated, and (b) the average of the concentrations occurring for the remaining time, defined as being background. The intermittent element will only be exceeded under conditions that would have caused the 30-day element to be exceeded, had it been applied.

Table 3.15 illustrates example values for the intermittent element. The bottom row of the lotic and lentic values and the right column are to emphasize that WQC_{int} is not an independent element but a re-expression of the 30-day average water criterion element concentration. WQC_{int} converges to $WQC_{30\text{-}day}$ when the background concentration is already at $WQC_{30\text{-}day}$ or when the intermittent exposure is said to occur throughout the 30-day period.

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Table 3.15. Representative Values of the Intermittent Water Criterion Element Concentration.

Bkgrnd Conc, C_{bkgrnd} (µg/L)		Fraction of Time, f_{int} in a 30-day period				
	0.03333 (1 day)	0.05 (1.5 days)	0.1 (3 days)	0.2 (6 days)	0.5 (15 days)	1 (30 days)
	Lotic Intermittent Criterion Element, WQC_{int} (µg/L)					
0	93	62	31	15.5	6.2	3.1
1	64	43	22	11.5	5.2	3.1
2	35	24	13	7.5	4.2	3.1
2.5	20.5	14.5	8.5	5.5	3.7	3.1
3.1	3.1	3.1	3.1	3.1	3.1	3.1
	Lentic Intermittent Criterion Element, WQC_{int} (µg/L)					
0	45	30	15	7.5	3	1.5
0.5	30.5	20.5	10.5	5.5	2.5	1.5
1	16	11	6	3.5	2	1.5
1.25	8.8	6.3	3.8	2.5	1.8	1.5
1.5	1.5	1.5	1.5	1.5	1.5	1.5

If the value of f_{int}, the intermittent exposure fraction of the month, is assigned a value less than one day, the intermittent criterion element value could exceed water concentrations that have been shown to be acutely toxic to sensitive species in 2- or 4-day toxicity tests (compiled in U.S. EPA 2004). Because the concentrations that would be acutely toxic in exposures of less than one day might not be much greater than those observed to be toxic in 2-4 day exposures, the intermittent fraction of the month must *not* be assigned a value less than 0.033, corresponding to one day.

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4 NATIONAL CRITERION FOR SELENIUM IN FRESH WATERS

The available data indicate that freshwater aquatic life would be protected from the toxic effects of selenium by applying the following four-part criterion, recognizing that fish tissue elements supersede the water elements (except in special situations, see footnotes 3 and 4, Table 4.1) and that the egg-ovary tissue element supersedes all other tissue elements:

1. The concentration of selenium in the eggs or ovaries of fish does not exceed 15.1 mg/kg, dry weight; [1]
2. The concentration of selenium (a) in whole-body of fish does not exceed 8.5 mg/kg dry weight, or (b) in muscle tissue of fish (skinless, boneless fillet) does not exceed 11.3 mg/kg dry weight; [2]
3. The 30-day average concentration of selenium in water does not exceed 3.1 µg/L in lotic (flowing) waters and 1.5 µg/L in lentic (standing) waters more than once in three years on average;
4. The intermittent concentration of selenium in either a lentic or lotic water, as appropriate, does not exceed $WQC_{int} = \frac{WQC_{30-day} - C_{bkgrnd}(1-f_{int})}{f_{int}}$ more than once in three years on average.[3]

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Table 4.1. Summary of the Recommended Freshwater Selenium Ambient Chronic Water Quality Criterion for Protection of Aquatic Life.

Media Type	Fish Tissue[1]		Water Column[4]	
Criterion Element	**Egg/Ovary [2]**	**Fish Whole Body or Muscle [3]**	**Monthly Average Exposure**	**Intermittent Exposure[5]**
Magnitude	15.1 mg/kg dw	8.5 mg/kg dw whole body or 11.3 mg/kg dw muscle (skinless, boneless filet)	1.5 µg/L in lentic aquatic systems 3.1 µg/L in lotic aquatic systems	$WQC_{int} = \frac{WQC_{30-day} - C_{bkgrnd}(1 - f_{int})}{f_{int}}$
Duration	Instantaneous measurement[6]	Instantaneous measurement[6]	30 days	Number of days/month with an elevated concentration
Frequency	Not to be exceeded	Not to be exceeded	Not more than once in three years on average	Not more than once in three years on average

1. Fish tissue elements are expressed as steady-state.
2. Egg/Ovary supersedes any whole-body, muscle, or water column element when fish egg/ovary concentrations are measured, except as noted in footnote 4 below.
3. Fish whole-body or muscle tissue supersedes water column element when both fish tissue and water concentrations are measured, except as noted in footnote 4 below.
4. Water column values are based on dissolved total selenium in water and are derived from fish tissue values via bioaccumulation modeling. When selenium inputs are increasing, water column values are the applicable criterion element in the absence of steady-state condition fish tissue data.
5. Where WQC30-day is the water column monthly element, for either a lentic or lotic waters; C_{bkgrnd} is the average background selenium concentration, and f_{int} is the fraction of any 30-day period during which elevated selenium concentrations occur, with fint assigned a value ≥0.033 (corresponding to 1 day).
6. Fish tissue data provide instantaneous point measurements that reflect integrative accumulation of selenium over time and space in fish population(s) at a given site.

EPA recommends that states and tribes adopt into their water quality standards a selenium criterion that includes all four elements, and express the four elements as a single criterion composed of multiple parts, in a manner that explicitly affirms that the whole-body or muscle elements supersede the water column element, and the egg-ovary element supersedes any other element. The magnitude of the fish egg-ovary element is derived from analysis of the

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available toxicity data. The magnitudes of the fish whole-body element and fish muscle elements are derived from the egg-ovary element coupled with data on concentration ratios among tissues. The magnitudes of the water column elements are derived from the egg-ovary element coupled with bioaccumulation considerations. Inclusion of the fish whole-body or fish muscle element into the selenium criterion ensures the protection of aquatic life when fish egg or ovary tissue measurements are not available, and inclusion of the water column elements into the selenium criterion ensures protection when neither fish egg-ovary nor fish whole-body nor muscle tissue measurements are available. To ensure that the contribution of short-term exposures to the bioaccumulation risks is accounted for in all situations, EPA is also recommending that the intermittent exposure element be included in the selenium criterion, as noted above. EPA is not recommending a separate acute criterion derived from the results of toxicity tests having water-only exposure because selenium is bioaccumulative and toxicity primarily occurs through dietary exposure. Application of the intermittent exposure criterion element values to single day, high exposure events will provide protection from the most important selenium toxicity effect, reproductive toxicity, by protecting against selenium bioaccumulation in the aquatic ecosystem resulting from short-term, high exposure events. It is unnecessary to have an additional acute water column criterion element because the intermittent exposure criterion element will be more stringent than an acute criterion element. Further, as noted in this document, there have been few if any acute exposure, water column-only selenium aquatic toxicity events documented in the literature.

In implementing the water quality criterion for selenium under the NPDES permits program, states may need to establish additional procedures due to the unique components of the selenium criterion. Where states use the selenium water column concentration criterion element values only (as opposed to using both the water column and fish tissue elements) for conducting reasonable potential (RP) determinations and establishing water quality-based effluent limitations (WQBELS) per 40 CFR 122.44(d), existing implementation procedures used for other acute and chronic aquatic life protection criteria may be appropriate. However, if states also decide to use the selenium fish tissue criterion element values for NPDES permitting purposes, additional state WQS implementation procedures (IPs) will be needed to determine the need for and development of WQBELs necessary to ensure that the fish tissue criterion element(s) are met.

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EPA recommends that states use the default monthly average exposure water column elements of the criterion, adopted as part of the state's water quality criterion. Alternatively, states may want to develop and adopt, and submit for EPA approval, either a site-specific water column criterion (see Appendix K for details), or a procedure to facilitate the translation of a fish tissue criterion element concentration into site-specific water concentration values. A site-specific water column criterion element or set of lentic/lotic criterion element values may be developed using a mechanistic modeling approach (Presser and Luoma 2010) or using the empirical bioaccumulation factor approach, both described in Appendix K, for the specific waterbody or waterbodies, or a on a state-wide basis. A translation procedure must be scientifically defensible and able to produce repeatable and predictable outcomes, and must be consistent with either the mechanistic modeling approach or the empirical bioaccumulation factor approach described in Appendix K. The chronic selenium criterion is derived to be protective of the entire aquatic community, including fish, amphibians, and invertebrates. Fish are the most sensitive to selenium effects. Selenium water quality criterion elements based on fish tissue (egg-ovary, whole body, and/or muscle) sample data override the criterion elements based on water column selenium data due to the fact, noted above, that fish tissue concentrations provide the most robust and direct information on potential selenium effects in fish. However, because selenium concentrations in fish tissue are a result of selenium bioaccumulation via dietary exposure, there are two specific circumstances where the fish tissue concentrations do not fully represent potential effects on fish and the aquatic ecosystem: 1) in “fishless” waters, and 2) in areas with new selenium inputs.

Fishless waters are defined as waters with insufficient instream habitat and/or flow to support a population of any fish species on a continuing basis, or waters that once supported populations of one or more fish species but no longer support fish (i.e., extirpation) due to temporary or permanent changes in water quality (e.g., due to selenium pollution), flow or instream habitat. Because of the inability to collect sufficient fish tissue to measure selenium concentrations in fish in such waters, water column concentrations will best represent selenium levels required to protect aquatic communities and downstream waters in such areas.

New inputs are defined as new activities resulting in selenium being released into a lentic or lotic waterbody. New inputs will likely result in increased selenium in the food web, likely resulting in increased bioaccumulation of selenium in fish over a period of time until the new or

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increased selenium release achieves a quasi-"steady state" balance within the food web. EPA estimates that concentrations of selenium fish tissue will not represent a "steady state" for several months in lotic systems, and longer time periods (e.g., two to three years) in lentic systems, depending upon the hydrodynamics of a given system such as the location of the selenium input related to the shape and internal circulation of the waterbody, particularly in reservoirs with multiple riverine inputs, hydraulic residence time, and the particular food web. Estimates of steady state under new or increased selenium input situations are expected to be site dependent, so local information should be used to better refine these estimates for a particular waterbody. Thus, EPA recommends that fish tissue concentration not override water column concentration in these situations until these periods of time have passed in lotic and lentic systems, respectively, or steady state conditions can be estimated.

4.1 Protection of Downstream Waters

EPA regulations at 40 CFR 131.10(b) provide that "[i]n designating uses of a waterbody and the appropriate criteria for those uses, the state shall take into consideration the water quality standards of downstream waters and ensure that its water quality standards provide for the attainment and maintenance of the water quality standards of downstream waters." Especially in cases where downstream waters are lentic waterbody types (e.g., lakes, impoundments), or harbor more sensitive species, a selenium criterion more stringent than that required to protect in-stream uses may be necessary to ensure that water quality standards provide for the attainment and maintenance of the water quality standards of downstream waters.

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5 SITE-SPECIFIC CRITERIA

All four elements of the freshwater selenium criterion may be modified to reflect site-specific conditions where the scientific evidence indicates that different values will be protective of aquatic life and provide for the attainment of designated uses.

Since the fish egg-ovary criterion element is based on toxicity data, a state may modify that element by applying the Recalculation Procedure (U.S. EPA 2013b) to edit the species toxicity database to reflect taxonomic relatedness to the site assemblage, while including tested surrogates for untested resident species.

It is important to note that species in the national data set that are not present at a site should not be deleted from the data set because those species serve as surrogate(s) for other species known or expected to be present at a site. Confidence in the applied tissue criterion element can be improved by further testing of fish species resident at the site. The most relevant testing would measure the survival and occurrence of deformities in offspring of wild-caught female fish to determine an EC_{10} for selenium in the eggs or ovaries (e.g., following Janz and Muscatello 2008).

Using either the EPA national recommended egg-ovary, whole-body, or muscle criterion concentration element or a site-specific egg-ovary, whole-body, or muscle criterion element, translation of the fish tissue criterion to a protective water concentration can be performed in a manner that accounts for site-specific conditions. Appendix K provides a step-wise process for deriving each parameter used in Equation 18 to perform a site-specific translation. These steps include:

1. selecting a target fish species for the waterbody,
2. determining the primary food source for the target species
3. determining the appropriate *TTF* values,
4. determining the appropriate *EF* value, and
5. determining the appropriate *CF* value.

Appendix K also provides information on the data necessary to derive a site-specific criterion, as well as scientifically defensible methods, including the use of traditional Bioaccumulation Factors (BAFs), in addition to the more comprehensive mechanistic modeling.

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6 EFFECTS CHARACTERIZATION

6.1 FISH AND AMPHIBIANS

6.1.1 Principles for Using Studies for which EC_{10}s Cannot Be Calculated

When the data from an acceptable chronic test met the conditions for logistic regression analysis, the EC_{10} was used. When data did not allow calculation of ECs but did allow calculation of closely spaced NOECs and LOECs, the NOEC was used to approximate the EC_{10}. No NOEC values were used in calculating the tissue criterion element values.

When significant effects were observed at all treatment concentrations, such that no treatment concentration was classified as a NOEC, then the chronic value was assigned as "less than" (<) the lowest tested concentration. When no significant effects were observed at any concentration, such that no treatment concentration was defined as an LOEC, then the chronic value was assigned as "greater than" (>) the highest tested concentration.

A number of the chronic values in **Sections 3.1.1** and **6.1.2** (reproductive effects) and in **Section 6.1.9** (nonreproductive effects) include a "greater than" (>) or "less than" (<) sign because of an inability to resolve an exact value when all exposure concentrations of a study yielded either too little or too much effect to provide a point estimate of a chronic value. The decision to use chronic values with a "greater than" or "less than" sign in calculating an SMCV followed a rule based on whether these values add relevant information to the mean, as described below. None of these values were used in this assessment to derive the tissue criterion element values.

6.1.1.1 Evaluation Approach

- Neither a low "greater than" value nor a high "less than" value were used to calculate the SMCV;
- Both a low "less than" value and a high "greater than" value were included in the SMCV calculation. However, none of these values were used in this assessment to calculate the numeric criterion values for fish tissue.

For example, a chronic value reported here as ">15 mg Se/kg" is ignored if the tentative SMCV is 20 mg Se/kg. The ">15 mg Se/kg" value indicates that no significant effects were

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observed at the study's highest tested concentration of 15 mg Se/kg. As this is consistent with what would be expected if the SMCV were 20 mg Se/kg, it provides no information to support modifying the SMCV. However, a different study showing no effects at its highest tested concentration and yielding the value ">25 mg Se/kg" is not consistent with an SMCV of 20 mg Se/kg, and indicates that the ">25 mg Se/kg" value provides information for modifying the mean upwards. Conversely, a chronic value reported here as "<15 mg Se/kg" indicates that significant effects were observed even at the study's lowest tested concentration of 15 mg Se/kg. As this is not consistent with a 20 mg Se/kg SMCV, it indicates the utility of the "<15 mg Se/kg" information for modifying the SMCV downwards. On the other hand, a value reported here as "<25 mg Se/kg" would not be used to recalculate a 20 mg Se/kg SMCV. The intent of the approach is to use all quality information that is relevant and appropriate for calculating the SMCVs.

6.1.2 Acceptable Studies of Fish Reproductive Effects of Genera that were not among the Four Most Sensitive Genera

The following is a brief synopsis of the experimental design, test duration, relevant test endpoints, and other critical information regarding the genera that were not the four most sensitive but were included in the number of GMCVs in the dataset (see **Section 3.1.3**). The studies in this section involve effects on the offspring of exposed female fish. Data are summarized in **Table 3.1**. Details of these studies are contained in Appendix C.

6.1.2.1 Cyprinidae

Pimephales promelas (fathead minnow)

Schultz and Hermanutz (1990) examined the effects of selenium transferred from parental fish (females) on fathead minnow larvae. The parental fathead minnows were first exposed to selenite (10 µg/L) that was added directly to the water in artificial streams in a mesocosm study. The selenite entered the food web and contributed to exposure via diet. Spawning platforms were submerged into treated and control streams. Embryos were collected from the spawning platforms and transferred to a proportional diluter where they were reared in incubation cups for observation. Treated embryos in the egg cups were exposed to 10 µg/L selenium. Edema and lordosis were observed in approximately 25 percent of the larvae spawned and reared in natural water spiked with 10 µg Se/L and in ≤ 6 percent of control larvae. Although

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a case can be made that the selenium treatment had a higher rate of edema and lordosis, there are some issues that add uncertainty to the estimation of an effect concentration (R. Erickson, personal communication). Heavy mortality/loss of embryo/larvae during monitoring and the erratic occurrence of the abnormalities (e.g., significant incidence of edema in only 3 of 10 replicates for the Se treatment) led to the conclusion that results should not be used for criterion derivation. The data from this study support the range of reproductive effect levels determined in other fish studies. The Se concentration in embryos from the 10 µg/L treatment stream of 3.91 mg/kg ww converts to 25.6 mg/kg dw using 15.3% dw (N=3 range 14.7 – 15.6%) for fathead minnow eggs (R. Erickson, personal communication).

Two other studies suggest fathead minnows are less sensitive to selenium than other fish. Young et al. (2010) observed that fathead minnow populations remained after selenium contamination of Belews Lake had eliminated most other fish species, including bluegill and largemouth bass. In a maternal transfer laboratory study with fathead minnows, GEI (2008) estimated EC_{10}s for larval survival and deformities that ranged from 35 – 65 mg Se/kg dw expressed as maternal whole body, as noted in Appendix E, Figures E-2 and E-3.

6.1.2.2 Esocidae

Esox lucius (northern pike)

Muscatello et al. (2006) collected spawning northern pike from four sites near a uranium milling operation in north-central Saskatoon, Canada, with egg concentrations ranging from 2.7 to 48 mg Se/kg dw. The four sites included a reference site and three sites 2, 10 and 15 km downstream of the effluent discharge, representing a gradient of selenium exposure. Milt and ova were stripped from gravid fish. Eggs were then fertilized in the field and incubated in the laboratory for observations and measurements. The test was terminated when the majority of the fry exhibited swim-up and had absorbed the yolk.

Mean egg diameter, fertilization success and cumulative embryo mortality were not significantly different among the sites. Significant increases in percent total deformities including edema, skeletal deformities, craniofacial deformities and fin deformities were observed in fry originating from pike collected at the medium exposure site. The concentrations of selenium in the northern pike eggs collected at the reference and low exposure site were very similar, as were the percent total deformities in embryos/fry. The geometric mean of selenium in

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the eggs of the adult females at the reference and low exposure sites was 3.462 mg Se/kg dw and the corresponding arithmetic mean of the percent total deformities was 13.20%. There were only 4 adult females from exposed sites, and all had relatively similar concentrations in their eggs, all close to the geometric mean concentration of 34.00 mg Se/kg dw. Likewise, all four exposed females had relatively similar percent total deformities, not far from their arithmetic mean of 33.40%. This is not a sufficient level of effect for applying TRAP to determine an EC_{10}. Furthermore, the relatively large spread between the two clusters of exposure concentrations (3.462 and 34.00 mg Se/kg dw) would render a NOEC and LOEC unreliable and unsuitable for defining a threshold. That is, the NOEC and LOEC would be "greater than" and "less than" values, >3.462 and <34.00 mg Se/kg dw respectively, providing little information on the sensitivity of northern pike compared to other species.

Instead, making use of the clustering of data at low exposure and effects and at elevated exposure and effects, the effect level for the elevated exposure eggs was normalized to the low exposure condition and rescaled to a 0-100% range. The rescaled (i.e., Abbott-adjusted) percent of total deformities for the elevated exposure eggs was 24% (relative to the low exposure eggs). Thus the concentration of selenium in the elevated exposure eggs (34 mg Se/kg dw) was equivalent to an EC_{24}, and is *the only effects concentration that can be calculated for this test*, given the limitations in the range of concentrations tested and effects observed. Although the EC_{24} is not directly translatable to an EC_{10} for use in determining the criterion, it is useful for comparison with the EC_{24} in other species in order to determine species sensitivity rank. The EC_{24} for skeletal deformities from the Holm et al. (2005) study of rainbow trout, calculated to be 30.9 mg Se/kg dw in eggs, is slightly lower than the northern pike value, indicating these two species may be similar in tolerance, with the northern pike being slightly more tolerant (see Appendix C for more details.)

6.1.2.3 Salmonidae

Seven publications provide quantitative data on the effects of selenium on salmonid embryo/larval survival and deformity that were used in calculating criterion values. All involve wild-caught adults taken from selenium contaminated streams and spawned for effects determination. Exposure for all studies was therefore through the parents. Data are available for rainbow trout (*Oncorhynchus mykiss*), cutthroat trout (*Oncorhynchus clarkii*), Dolly Varden

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(*Salvelinus malma*) and brown trout (*Salmo trutta*). The studies with *Salvelinus* are discussed below; *Oncorhynchus* and *Salmo* were previously discussed in **Section 3.1.2**.

Salvelinus fontinalis (brook trout)

These data were not used directly in the criterion calculations. See **Section 6.1.5** for discussion of the available data.

Salvelinus malma (Dolly Varden)

Golder (2009) collected adult Dolly Varden from a reference site and two sites downstream from the Kemess Mine in northern British Columbia, one with a high and one with a moderate selenium exposure in the fall of 2008. Fertilized eggs were taken to the laboratory where they were monitored for survival and deformities until 90% of the larvae reached swim-up, approximately five months after fertilization. Alevin mortality was <1% in the treatments collected from the exposed sites and not considered an effect. The prevalence of deformities increased sharply after the selenium egg concentration exceeded 50 mg/kg dw (Appendix C). The proportion of Dolly Varden larvae without any type of deformity (skeletal, craniofacial, and finfold as well as edema), as a function of the log of the selenium concentration in the eggs using TRAP, produced an EC_{10} value of 56.22 mg Se/kg dw and an EC_{20} value of 60.12 mg Se/kg dw.

6.1.2.4 Salmonidae SMCV and GMCV Summary

As given in **Section 3.1.2**, the SMCV for cutthroat trout, *Oncorhynchus clarkii*, is 26.2 mg Se/kg dw in eggs derived from Rudolph et al. (2008), and Nautilus Environmental (2011), (24.7, and 27.7 mg Se/kg dw respectively). The GMCV for the genus *Oncorhynchus* is 25.3 mg Se/kg dw in eggs, derived from the 24.5 mg Se/kg dw EC_{10} from the combined Holm (2002) and Holm et al. (2005) rainbow trout data, the above mean of the Rudolph et al. (2008) and Nautilus Environmental (2011) Westslope cutthroat trout studies. The GMCV for the genus *Salvelinus* is the EC_{10} value of 56.22 mg Se/kg dw for Dolly Varden (*S. malma*) from the Golder (2009) study.

6.1.2.5 Poeciliidae

Data are available for two species in this family. These studies are not represented in **Table 3.1** because they are live-bearing rather than egg-laying, but the relative tolerance of these species is accounted for in derivation of the criterion.

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Gambusia holbrooki (eastern mosquitofish)

Staub et al. (2004) collected male and gravid female eastern mosquitofish from a contaminated ash basin and a reference pond in July 1999. Male fish were used for measuring standard metabolic rate and the reproductive endpoints. Brood size and percent viability of live offspring at parturition were measured using the live-bearing females. Standard metabolic rates of males, brood size of females, and offspring viability were not significantly different between sites. Average concentrations of selenium in females were 11.85 and 0.61 mg/kg dw in the contaminated ash basin and reference sites, respectively. The chronic value in whole body tissue is >11.85 mg Se/kg dw whole-body (Appendix C). In a community of equally exposed fish taxa (fish taxa having whole body tissue concentrations >11.85 mg Se/kg dw), the median egg-ovary concentration among egg-laying fish would be expected to be 1.71 higher, or >20.26 mg Se/kg dw.

Gambusia affinis (western mosquitofish)

Western mosquitofish were collected in June and July 2001 from sites in the grassland water district in Merced County, California. Mosquitofish were collected from two sites that were contaminated with selenium and from two reference sites in the same area with relatively low selenium water concentrations (Saiki et al. 2004). Seventeen to 20 gravid females (mosquitofish are live-bearers) from each site were held in the laboratory for two weeks to quantify live and dead births and to make other measurements. Live and dead fry were visually examined under low magnification with a binocular microscope for evidence of external abnormalities (teratogenic symptoms such as spinal curvature, missing or deformed fins, eyes and mouths and edema). The percentage of live births was high at both selenium-contaminated sites (96.6 to 99.9%) and reference sites (98.8 to 99.2%). There were no obvious anomalies (e.g., deformities, edema) observed during the study. The concentration of selenium in four postpartum females from the site with the highest selenium concentration ranged from 13.0 to 17.5 mg Se/kg dw (geometric mean of the high and low is 15.1 mg Se/kg dw). The chronic value in whole body tissue is >15.1 mg Se/kg dw (Appendix C). Similar to Staub et al. (2004), this value can be converted to egg-ovary concentrations that would be expected in accompanying egg-laying fish, by multiplying by the median fish egg-ovary to whole-body concentration ratio, 1.71. This yields a >25.82 mg Se/kg dw equivalent egg-ovary concentration.

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Gambusia, which have been reported to be tolerant to selenium contamination, are often one of the few remaining species at sites with high levels of selenium contamination (Cherry et al. 1976; Lemly 1985a; Saiki et al. 2004; Young et al. 2010; Janz et al. 2010). The two studies discussed above support this observation with a GMCV of >13.4 mg Se/kg dw in whole body tissue, combining these "greater than" values as described in **Section 6.1.1**. It may be concluded that this genus is not among the most sensitive to selenium.

6.1.2.6 Cyprinodontidae

Cyprinodon macularius (desert pupfish)

Besser et al. (2012), using a diet of oligochaete *Lumbriculus* that had fed on selenized yeast, exposed desert pupfish to six levels of dietary and waterborne selenium. Five-week old juveniles (F_0) were exposed for 85 days, during which time survival and growth were measured. Upon reaching maturity at the end of this exposure period, the 60-day reproductive study was begun, during which F_1 eggs were collected, counted, and further tested for percent hatch, survival, growth, and deformities. The authors observed no significant differences in pupfish survival, growth, total egg production, hatch, or deformities among treatments. Although the authors noted a potential interaction between the timing of egg production and treatment, a comprehensive re-analysis of this data, described in Appendix C, indicated that the phenomenon was neither statistically nor biologically significant. It is concluded that the egg concentration, 27 mg Se/kg (dw), for the test's highest treatment was not sufficiently high to define a concentration-response curve. Although desert pupfish is thus not among the most sensitive species, the slightly reduced survival observed at 27 mg Se/kg egg dw egg suggests that the EC_{10} may be close to that concentration, as also noted by the authors.

6.1.2.7 Centrarchidae

Micropterus salmoides (largemouth bass)

A laboratory study was conducted by Carolina Power & Light (1997) in which adult largemouth bass obtained from a commercial supplier were fed an artificial diet spiked with a gradient of selenomethionine concentrations for several months. Approximately 100 eggs from each spawn were monitored for mortality and deformities up to the larval swim-up stage. The authors combined survival and deformities into a single metric (i.e., survival as normal

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offspring). The average concentration of selenium in the ovaries ranged from 3.1 mg/kg dw in the control to 77.6 mg/kg dw in the high dietary treatment (53.1 mg/kg dw). A plot of the percent survival of larval largemouth bass as a function of the selenium concentration in the parental female ovary shows two groups of data; one at background survival with considerable variability (mean 90.3%, standard deviation 10.9%) and one with <10% survival, with most of the data being at 0% survival (see *Micropterus* summary in Appendix C, Figure 1). Due to inadequate partial effects, a TRAP interpolation was used to estimate an EC_{10} value. Based on a risk management decision that the LOEC cannot be any higher than the lowest concentration with 0% survival (32.9 mg/kg) and that any ECx should be below this, this establishes the higher concentration point for the interpolation (an EC_{100} of 32.9 mg/kg) and requires that the highest 4 NOECs not be considered in setting the EC_0. The lower concentration point for the interpolation is therefore set here to 24.6, the next highest NOEC with greater than the average 90.3% background survival. This results in an EC_{10} of 26.3 mg/kg (and a steep slope of 16). Please see Appendix C for more detailed information.

6.1.3 Reproductive Effects in Catfish (Ictaluridae)

Some important families of fish are not represented in the effects assessment, such as the catfish family (Ictaluridae). In their compilation of egg-ovary versus whole-body ratios, Osmundson et al. (2007) found comparatively high concentrations of selenium in egg-ovary compared to whole body in black bullhead, *Ameiurus melas*, which are related to the Ictaluridae. This raises a question about the potential risks of reproductive effects in this species and possibly in related Ictaluridae. In addition to this concern about how much selenium such species may accumulate in their eggs, U.S. Fish and Wildlife Service (2005) has suggested that offspring of channel catfish (*Ictalurus punctatus*) and related species might be affected at unusually low egg concentrations. This is based on results of a study in which adult female catfish were injected with seleno-L-methionine (Doroshov et al. 1992b). Effects were found in the offspring at egg concentrations between 3.2 mg/kg (NOEC) and 6.3 mg/kg (LOEC), below levels observed in the studies summarized in **Section 3.1.2** and documented in Appendix C. These data were not included in derivation of the criterion because the injection route of exposure is not an acceptable experimental protocol for studies used in criterion derivation due to its difference from exposure routes in the environment (water column and diet).

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In the absence of valid tests yielding an Ictaluridae EC_{10} or chronic value, EPA evaluated the potential vulnerability of the taxonomic group that includes catfish by examining comparative fisheries observations of Ictaluridae and Centrarchidae sharing the same selenium-contaminated water body. Crutchfield (2000) reports results of annual cove rotenone sampling performed from 1982 to 1997 in Hyco Reservoir, North Carolina. The sampling was begun after centrarchid populations in this reservoir had collapsed due to the release of ash pond selenium from a coal-fired power plant. The plant began operating a dry fly ash handling system in January 1990, thereby eliminating the aquatic discharge of selenium; the sampling continued through the recovery period.

Crutchfield (2000) reports abundance data (kg/ha) for 20 fish taxa, including four Ictaluridae and three Centrarchidae. These data were examined to determine the relationship between the Ictaluridae and the selenium-affected Centrarchidae populations. The correlation matrix between annual measured abundance of the seven taxa is shown below in **Table 6.1**. Correlation with the reciprocal of measured average concentrations of selenium in invertebrates is also shown. Because the reciprocal of the selenium concentration is used, a positive correlation means that abundance decreases as selenium concentration increases. Conversely, a negative correlation means abundance decreases as selenium concentration decreases.

Table 6.1. Correlation Matrix (Values of r) for Ictaluridae and Centrarchidae Abundance and for Selenium Food Chain Contamination for the Hyco Reservoir.
(Data Reported by Crutchfield 2000).

	Ictaluridae				**Centrarchidae**			
	Channel catfish	White catfish	Flat bullhead	*Ameiurus* spp.	Bluegill	Large-mouth bass	*Pomoxis* spp. (crappie)	1 ÷ Inverteb. Se Conc
Channel catfish	1.00	-0.36	0.18	0.68	0.08	-0.33	-0.08	-0.44
White catfish	-0.36	1.00	0.02	-0.32	-0.31	-0.24	-0.15	-0.06
Black bullhead	0.18	0.02	1.00	0.40	0.32	-0.08	0.08	-0.03
Ameiurus spp.	0.68	-0.32	0.40	1.00	0.22	-0.24	-0.05	-0.31
Bluegill	0.08	-0.31	0.32	0.22	1.00	0.78	0.76	0.80
Largemouth bass	-0.33	-0.24	-0.08	-0.24	0.78	1.00	0.78	0.92
Pomoxis spp. (crappie)	-0.08	-0.15	0.08	-0.05	0.76	0.78	1.00	0.69
1 ÷ Inverteb. Se Conc.	-0.44	-0.06	-0.03	-0.31	0.80	0.92	0.69	1.00

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The centrarchid abundances are well correlated with each other and are closely related to selenium concentrations in the food chain, with fish abundance decreasing as selenium concentrations increase. Ictaluridae abundances, however, are unrelated either to the selenium-sensitive centrarchid abundances or to the selenium concentrations in the food chain.

Figure 6.1 shows abundance as both mass and numbers of individuals of channel catfish (CCF) and largemouth bass (LMB) observed by Crutchfield (2000) during the period 1982-1997. Both species are long lived. Crutchfield (2000) notes that the decline of reproductive success and abundance of Hyco's largemouth bass (and bluegill) was first documented in the mid-1970s. Because this study was initiated after the largemouth bass recreational fishery had collapsed, **Figure 6.1** does not show the largemouth bass decline, only the period of its depression and subsequent recovery.

Numbers of largemouth bass were very low at the beginning of the study period; their numbers and mass do not begin to recover until invertebrate selenium drops below 30 mg Se/kg dw. In the later portion of the study period, 1989-1997, largemouth bass numbers and mass increase 100-fold. These observations are fully consistent with the premise that the earlier observations of elevated selenium concentrations had been impairing reproduction of largemouth bass.

In contrast, the ups and downs of channel catfish numbers, mass, and size seem to vary randomly throughout the period of study. In 1984 catfish numbers reached their third highest value while their average size was at its minimum: that is, there were many young individuals. Simultaneously, largemouth bass was near its minimum for both numbers and mass. The next year (1985) catfish numbers jumped to their maximum for the study period, and mass reached near maximum. Such observations are easily explained if reproduction is taking place. But they seem inexplicable under a premise that channel catfish reproduction was even more impaired than largemouth bass reproduction, and its population merely a senescent non-reproducing remnant of the pre-contamination population. Rather the observations indicate that *if* selenium was having *any* effect on catfish reproduction, it was far less than on largemouth bass reproduction and was no hindrance to rapid population increases.

Observations of selenium-contaminated Belews Lake accord with the above observations of Hyco Reservoir. Young et al. (2010) indicate that as many as 29 resident fish species were documented prior to contamination, but only common carp, catfish, and fathead minnows

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remained after contamination. The Doroshov et al. (1992b) injection study results suggesting that channel catfish is sensitive at egg concentrations of 5 mg Se/kg dw, four-fold below the largemouth bass Chronic Value, thus conflict with field observations. As demonstrated in the Appendix C discussion of the Cleveland et al. (1993) toxicity tests with juvenile bluegill, the exposure route by which selenium was accumulated can have a dramatic influence on the potency of a given tissue concentration. That is, to accord with the Cleveland et al. (1993) data, the whole-body EC_{50} would be expected to be at least four-fold higher when accumulated via diet than when accumulated via water. For this reason, the criterion is derived only from tests using the environmentally relevant exposure route of diet.

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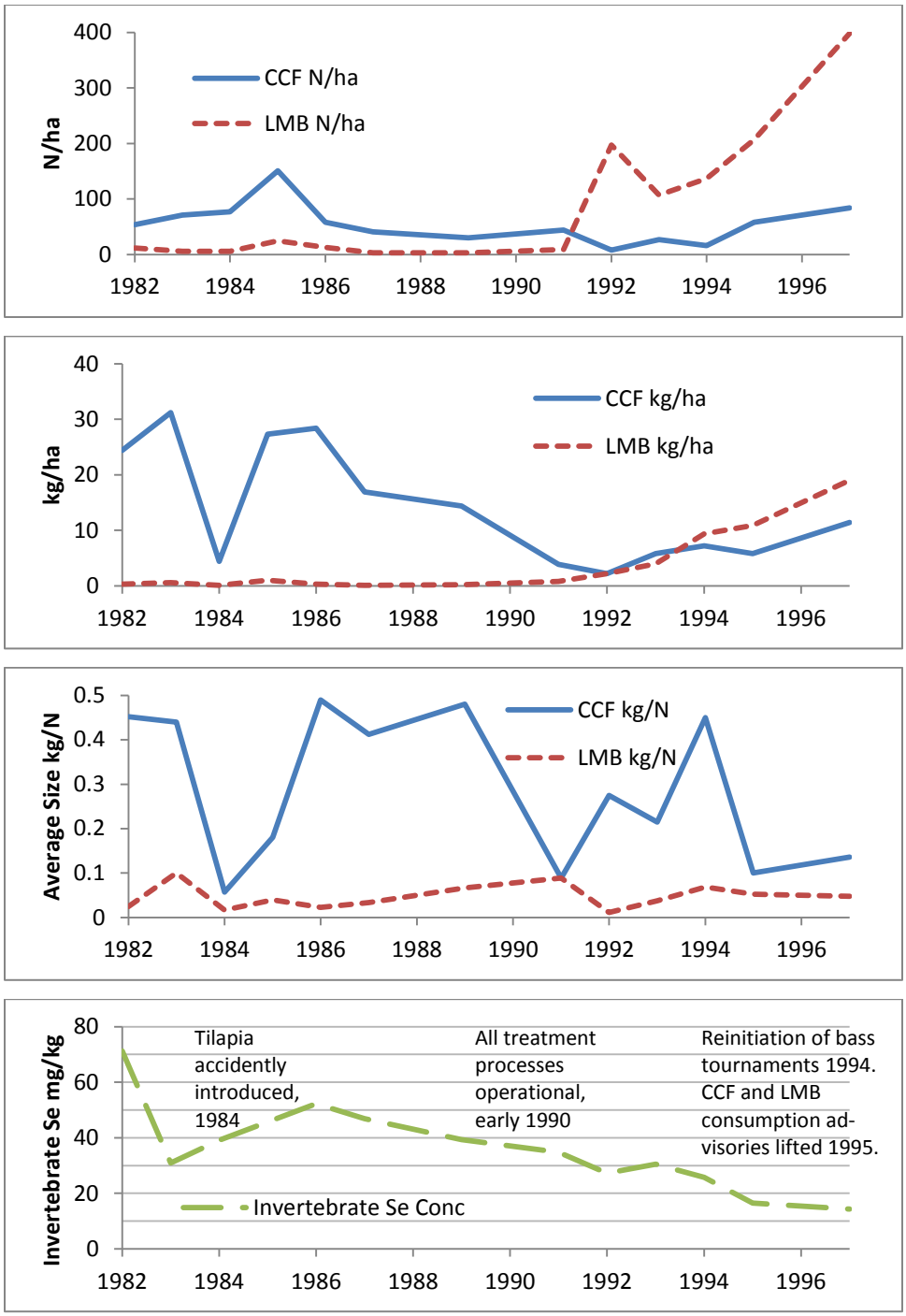


Figure 6.1. Crutchfield (2000) Observations of Channel Catfish (CCF) and Largemouth Bass (LMB) in Hyco Reservoir Beginning a Few Years after Populations of Largemouth Bass had been Reduced by Se Contamination.
(A) number of individuals/ha, (B) mass/ha, (C) mass/ha divided by number/ha, yielding average weight per individual, and (D) invertebrate Se concentration (mg Se/kg dw), and noting other events relevant to management of the fishery.

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6.1.4 Reproductive Effects in Amphibians (*Xenopus laevis*)

Massé et al. (2015) has conducted the only maternal transfer study conducted with an amphibian under controlled laboratory conditions. The African clawed frog (*Xenopus laevis*) was fed a control diet (0.73 mg/kg Se dw) and three spiked diets containing selenium concentrations of 10.92, 30.4 and 94.2 mg/kg dw. Trophic transfer to the frog's eggs was approximately 1:1 with measured selenium concentrations in the control and three spiked diets of 1.6, 10.82, 28.13, and 81.66 mg/kg egg dw, respectively. Deformities were assessed in 200 tadpoles per female (1800 – 2000 tadpoles per treatment group). EC_{10} values determined by the authors for abnormal spinal curvature, abnormal craniofacial structure and abnormal lens structure were 57.3, 38.4, and 34.5 mg/kg Se egg dw, respectively. The EC_{10} value for total deformities of 44.9 mg/kg Se egg dw is in the upper-range of EC_{10} values for fish (see **Table 3.2**). Although *X. laevis* is a non-native amphibian with a different reproductive strategy, their upper-range sensitivity suggests amphibians are protected by the fish chronic criterion elements.

6.1.5 Reproductive Studies Not Used in the Numeric Criterion Derivation

Danio rerio (zebrafish)

Two studies (Penglase et al. 2014; and Thomas and Janz 2014) have shown the zebrafish, *Danio rerio* (family Cyprinidae), to be sensitive to selenium. Penglase et al. (2014) assessed the interaction of selenium with mercury through a maternal transfer study but did have two treatments with selenium exposures resulting in 1.17 mg/kg egg dw (control) and 6.24 mg/kg egg dw. The higher Se egg concentration had significantly reduced embryo survival and fecundity relative to the control, however embryo survival in the controls was low at 54%. With only one selenium treatment exposure, the data were not amenable to TRAP analysis. Thomas and Janz (2014) conducted a maternal transfer study using adult zebrafish that were fed a control diet and three levels of selenomethionine, 3.7, 9.6, and 26.6 mg/kg Se dw for 90 days before breeding the exposed fish and collecting the fertilized embryos for assessment. TRAP analysis of larval survival and larval deformities of 2-6 days post fertilization fish produced very low EC_{10} values. The lowest EC_{10} was for deformities at 7.0 mg/kg egg dw. This value is markedly lower than any of the EC_{10}'s in the current data set. The slope of the concentration-response curve for both deformities and larval survival was very shallow, which was different than the selenium responses for all other fish species for which data were available (see Figure E-6 in Appendix E). Further, the control mortality in the experiment continuing over 160 days was high, over 40%.

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This zebrafish EC_{10} for deformities contrasts with the absence of deformities in the related species, fathead minnow, observed by GEI (2008) at concentrations up 40 mg/kg in adult whole body (dw) as presented in Figure E-3 in Appendix E. The GEI (2008) fathead minnow study was not directly used for criterion derivation because the offspring survival data for Sand Creek appeared to be confounded by multiple stressors in this industrial waterway. However, its deformity data appear unequivocal, indicating that the fathead minnow deformity endpoint is relatively insensitive to selenium.

Since the zebrafish is a non-native cyprinid species, EPA assessed the information available on zebrafish sensitivity to selenium compared to the sensitivity of native cyprinid (minnow) species across the U.S. (Appendix E in the 2016 criterion document), including several studies where native cyprinids were investigated in selenium-impacted waters (NAMC 2008). Data from these studies suggest that native cyprinids are likely less sensitive to selenium than the non-native zebrafish.

The anomalous nature of the concentration-response curve, with the very low value coupled with field and other laboratory data suggesting that cyprinids are not particularly sensitive to selenium was the basis for not including the zebrafish EC_{10} in the data for deriving the criterion. A detailed write up of this study and a summary of field and laboratory studies indicating native cyprinids are not one of the more sensitive families are provided in Appendix E.

Oncorhynchus clarkii (cutthroat trout)

Kennedy et al. (2000) reported no significant differences in mortality and deformity in eggs, larvae, and fry from wild-caught cutthroat trout between a reference and an exposed site (Fording River, British Columbia, Canada). The observations were made on eggs reared in well water from spawning age females collected from the two locations (N = 17 and 20, respectively) and fertilized by one male collected at each site. The mean selenium content in eggs from fish collected from the reference site was 4.6 mg/kg dw and from fish collected from the Fording River was 21.2 mg/kg dw. The chronic value for eggs is >21.2 mg Se/kg dw. These values were not used in the criterion derivation because they represent high “greater than” values, as discussed above, and provide no additional important quantitative data for the analyses.

Hardy (2005) fed cutthroat trout experimental diets containing a range of selenomethionine (0-10 mg/kg dw) for 124 weeks. No significant growth or survival effects were

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observed in the adult fish over the 124 weeks. The whole body concentration reached 12.5 mg/kg dw selenium after 44 weeks. Embryo-larval observations (percent hatch and percent deformed) were not related to whole body selenium concentrations in the spawning females (9.37 mg/kg dw) fed the selenium-laden diet for 124 weeks. The concentration of selenium in eggs from these females was 16.04 mg/kg dw. For this study the chronic value, an unbounded NOEC, is thus >16.04 mg Se/kg dw in eggs. This value was not used in the criterion derivation.

Salvelinus fontinalis (brook trout)

Holm et al. (2005) collected spawning brook trout from streams with elevated selenium contaminated by coal mining activity and from reference streams in 2000, 2001 and 2002. Similar to procedures described by these authors for rainbow trout, above, fertilized eggs were monitored in the laboratory for percent fertilization, deformities (craniofacial, finfold, and spinal malformations), edema, and mortality. Embryos from the contaminated stream had on average a higher frequency of craniofacial deformities than fry from the reference stream (7.9% for the contaminated stream compared to 2.1% in the reference stream). Although this increased rate of craniofacial deformities was calculated to be statistically significant when compared across sites, the Abbott-adjusted effect is only 6% and is thus below the 10% effect represented by an EC_{10}. But more important, when comparing across adult females (the more reliable analysis for selenium reproductive toxicity studies of this type, and the one used to obtain the related rainbow trout EC_{10} for these authors' studies), there is no apparent relationship between brook trout craniofacial deformities and exposure across a broad range of concentrations, as illustrated in Appendix C. An environmentally conservative estimate of the NOEC might be considered to be the average concentration of selenium in eggs from the high exposure site (Luscar Creek), >7.78 mg Se/kg ww or >20.5 mg Se/kg dw using the 61.2% moisture content for rainbow trout eggs cited above. However, the effect threshold appears to be substantially higher based on the absence of any consistent concentration-response relationship up to the maximum observed egg concentration of 18.9 mg Se/kg ww or 48.7 mg Se/kg dw, as shown in the Appendix C graphs. Given the point estimate EC_{10} available for the related species, *Salvelinus malma* (Dolly Varden, **Section 6.1.2.3**), the "greater than" chronic value for brook trout is not used to obtain the GMCV, in accordance with the principles listed in **Section 6.1.1**.

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Lepomis macrochirus (bluegill)

Applicable chronic reproductive data for bluegill can be grouped by exposure type: field and laboratory. In some field studies, chronic value estimates were "less than" fairly high selenium concentrations (Bryson et al. 1984, 1985a; Gillespie and Baumann 1986). This low resolution is due to the observed effect occurring at a single observed high exposure concentration relative to a reference condition. In the Bryson et al. (1984, 1985a) and Gillespie and Baumann (1986) studies, the artificially crossed progeny of females collected from a selenium contaminated reservoir (Hyco Reservoir, Person County, NC) did not survive to swim-up stage, irrespective of the origin of milt used for fertilization. Measured waterborne selenium concentrations prior to the experiments ranged from 35 to 80 µg/L. The ovary tissue selenium concentration associated with this high occurrence of mortality of hatched larvae was <30 mg/kg dw tissue, as reported by Bryson et al. (1985a), and <46.30 mg/kg dw tissue, as reported by Gillespie and Baumann (1986). In the case of the latter, nearly all swim-up larvae from the Hyco Reservoir females were edematous, none of which survived to swim-up.

Bryson et al. (1985b) examined percent hatch and percent swim-up larvae from spawns using bluegills collected from Hyco Reservoir and a control site. There were no differences in the Hyco measurements relative to the control. The concentration of selenium in the liver of the parental Hyco bluegill was 18.6 mg/kg dw. The chronic values for this embryo-larval development test was >18.6 mg Se/kg dw liver. The high "less than" and low "greater than" chronic values obtained from Bryson et al. (1984, 1985a, b) and Gillespie and Baumann (1986) were not used in the SMCV calculation because these values are consistent with and yet provide no numeric basis for modifying the SMCV obtained from the EC_{10}s.

6.1.6 *Salmo* GMCV: EPA Re-analysis of a Key Study Used in Criterion Derivation

Previously, in the draft selenium criterion document submitted for external peer review in May 2014, the lowest GMCV in the reproductive effects dataset was for *Salmo* (15.91 mg/kg dw) based on larval deformities. Subsequently, in 2015, EPA conducted a careful re-analysis in response to stakeholder comments to confirm the validity of the approach used in 2014, resulting in the calculation of an EC_{10} at 18.09 mg/kg dw based on larval mortality from hatch through swim up, prior to a lab overflow accident during the post swim up feeding portion of the test. The dataset was constrained to hatch through swim up information due to uncertainty introduced by the loss of larvae from an overflow event caused by clogged drains during the post swim-up

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portion of the test (Formation 2011). The hatch through swim up deformity endpoint was not considered because of the preferential selection of visibly non-deformed fish for the post swim up portion of the test (Response letter to EPA, J.R. Simplot Company 2014). This is important because the primary endpoint of interest during the post-swim up phase is deformity rate. Random selection of living fish would have been more appropriate since visibly healthy fish may be less likely to express deformities in this later stage of the test.

Following the release of the 2015 draft selenium criterion document, the larval survival from hatch through swim up dataset was reanalyzed, and it was determined that the TRAP model resulting in an EC_{10} of 18.09 mg/kg was not appropriate, because the EC_{10} was lower than one of the treatment levels within the background no-effect range. In order to calculate an EC_{10} that would not fall below the highest background concentration, a weighted least squares nonlinear regression was calculated in TRAP, resulting in an EC_{10} of 21.0 mg/kg. Additional details describing this weighted nonlinear regression approach are described in Appendix C.

6.1.7 Impact of Number of Tested Species on Criterion Derivation

Many of the species used for testing the toxicity of selenium are those observed to be affected at contaminated sites or otherwise suspected to be particularly sensitive. Six of the eight minimum data requirements were met, and the other two (for planktonic and benthic crustaceans) were waived (see **Section 2.6**). Of the N=15 genera used for the calculation of the criterion, ten are fish, which are more sensitive than invertebrates, based on the available data. Of the ten fish genera, five are either salmonids or centrarchids. Had a broader array of expected insensitive taxa been included, the four most sensitive genera would not likely change, but N would increase. The criterion calculation for selenium is relatively insensitive to the effect of increasing the value of N by adding more tests with different genera than those already represented. Setting N=20 (leaving the four most sensitive the same) would only raise the egg-ovary criterion element from 15.1 mg Se/kg to 16.0 mg Se/kg. This insensitivity occurs because the four lowest GMCVs are closely spaced, such that the calculated egg-ovary criterion element is never distant from the lowest GMCV.

6.1.8 Comparisons between Concentrations in Different Tissues

Researchers often report concentrations of selenium in fish eggs or ovaries (e.g., Formation Environmental 2011, 2012; Holm et al. 2005; Osmundson et al. 2007). Osmundson et

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al. (2007) found reduced levels of selenium in ovaries after spawning, presumably due to the loss of selenium through spawning and release of eggs with relatively high concentrations of selenium. Of the 14 chronic values determined from the maternal transfer reproductive studies, 12 values represent selenium measured in eggs. Two values represent selenium measured in the ovaries: Hermanutz et al. (1992, 1996) and Carolina Power & Light (1997). Hermanutz et al. (1992, 1996) sampled adult female bluegill just prior to spawning and at the end of the test (post spawning) and found no decreases in the concentration of selenium in the post-spawned fish. In the Carolina Power & Light (1997) study, selenium in ovaries of largemouth bass was measured from fish sampled just after spawning. No comparison to prespawning fish or selenium in eggs can be made for the largemouth bass study, however, the EC_{10} of 26.3 mg Se/kg ovary dw was mid-range in the SSD indicating this test was not overly conservative due to lower selenium measurements in post spawning ovaries. Based on the observations stated above, egg selenium and ovary selenium were considered equal for the toxicity data set. Any potential error resulting from this assumption would be conservative since the effect of spawning only lowers the selenium concentration in the ovary. EPA recognizes selenium ovary concentrations may vary in field collected samples due to fish reproductive cycles and will address such concerns in the implementation information.

6.1.9 Studies of Non-Reproductive Effects

Non-reproductive effect studies do *not* involve effects on the offspring of exposed female adults, and their results are *not* expressed as selenium concentrations in egg or ovary tissue. Because selenium concentrations in whole body and muscle are generally lower than in egg and ovary, with observed egg-ovary to whole-body ratios ranging from 1.3 to 7.4, and egg-ovary to muscle ratios ranging from 1.0 to 5.8, *whole-body, muscle, and egg-ovary effect concentrations can only be compared after accounting for the inherent differences in the selenium concentrations in these different media*. Non-reproductive effects were determined to provide a less reliable basis for a criterion, in part because comparatively few of such studies provided sigmoidal concentration-response curves. Non-reproductive SMCVs and GMCVs are shown in **Table 6.2** below and summaries of the acceptable non-reproductive studies are included in Appendix D.

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Table 6.2. Freshwater Chronic Values from Acceptable Tests - Non-Reproductive Endpoints.
(Parental Females Not Exposed).

Species	Reference	Exposure route and duration	Selenium form	Toxicological endpoint	Chronic Value mg/kg dw[a]	SMCV mg/kg dw	GMCV mg/kg dw
Acipenser transmontanus white sturgeon	Tashjian et al. 2006	dietary (lab) 8 weeks	seleno-L-methionine in artificial diet	EC_{10} juvenile growth	15.08 WB 27.76 M	EC_{10} 15.1 WB 27.8 M	15.1 WB 27.8 M
			seleno-L-methionine in artificial diet	EC_{20} juvenile growth	17.82 WB 32.53 M	EC_{20} 17.8 WB 32.5 M	
Pogonichthys macrolepidotus Sacramento splittail	Teh et al. 2004	dietary (lab) 9 months	selenized-yeast	NOEC	10.1 M	10.1 M 15.1 M 12.3 M	10.1 M 15.1 M 12.3 M
				LOEC	15.1 M		
				MATC juvenile deformities (juvenile exposure only)	12.34 M		
Pimephales promelas fathead minnow	Bennett et al. 1986	dietary (lab) 9 to 19 days	algae exposed to selenite then fed to rotifers which were fed to fish	Chronic value for larval growth	51.40 WB	51.40 WB 69.83 M	51.40 WB 69.83 M
Pimephales promelas fathead minnow	Dobbs et al. 1996	dietary and waterborne (lab) 8 days	algae exposed to selenate in water then fed to rotifers which were fed to fish	LOEC for larval fish dry weight after 8 d	<73 WBb		
Xyrauchen texanus razorback sucker	Beyers and Sodegren 2001a	dietary and waterborne (lab) 28 days	water: selenate; diet: algae exposed to selenate in water then fed to rotifers which were fed to fish	NOEC for survival and growth	>12.9 WBb	see text	see text
Xyrauchen texanus razorback sucker	Beyers and Sodegren 2001b	dietary and waterborne (lab) 28 days	water: site waters; diet: algae exposed to site water then fed to rotifers which were fed to fish	NOEC for survival and growth	>42 WBb		
Catostomus latipinnis flannelmouth sucker	Beyers and Sodegren 2001a	dietary and waterborne (lab) 28 days	water: selenate; diet: algae exposed to selenate in water then fed to rotifers which were fed to fish	NOEC for survival and growth	>10.2 WB	>10.2 WB	>10.2 WB
Oncorhynchus tshawytscha	Hamilton et al. 1990	dietary (lab) 60 days	mosquitofish spiked with seleno-DL-methionine	EC_{10} for juvenile growth	7.355 WB	EC_{10} 9.052 WB	EC_{10} 9.052 WB

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Species	Reference	Exposure route and duration	Selenium form	Toxicological endpoint	Chronic Value mg/kg dw[a]	SMCV mg/kg dw	GMCV mg/kg dw
chinook salmon				EC_{20} for juvenile growth	10.47 WB	EC_{20} 12.83 WB	
			mosquitofish spiked with SLD diet	EC_{10} for juvenile growth	11.14 WB		
				EC_{20} for juvenile growth	15.73 WB		
Oncorhynchus mykiss rainbow trout	Hilton and Hodson 1983; Hicks et al. 1984	dietary (lab) 16 weeks	sodium selenite in food preparation	juvenile growth NOEC	21 Liver	NOAEC 28.98 L	
				LOEC	71.7 Liver		
				MATC	38.80 Liver	LOAEC 84.68 L	
Oncorhynchus mykiss rainbow trout	Hilton et al. 1980	dietary (lab) 20 weeks	sodium selenite in food preparation	juvenile survival and growth NOEC	40 Liver		
				LOEC	100 Liver	MATC 49.52 L	
				MATC	63.25 Liver		
Morone saxitilis striped bass	Coughlan and Velte 1989	dietary (lab) 80 days	Se-laden shiners from Belews Lake, NC	LOEC for survival of yearling bass	<16.2 M[c]	<16.2 M	<16.2 M
Lepomis macrochirus bluegill	Lemly 1993a	dietary and waterborne (lab) 180 days 20 to 4°C	diet: seleno-L-methionine water: 1:1 selenate:selenite	LOEC for juvenile mortality at 4°C	<7.91 WB	4°C EC_{10}-NOAEC 8.15 WB	4°C & 9°C 9.33 WB
				Threshold prior to "winter stress"	5.85 WB		
		dietary and waterborne (lab) 180 days 20°C	diet: seleno-L-methionine water: 1:1 selenate:selenite	NOEC for juvenile mortality at 20°C	>6.0 WB		
Lepomis macrochirus bluegill	McIntyre et al. 2008	dietary and waterborne (lab) 182 days 20 to 4°C (ES1)	diet: Lumbriculus fed selenized-yeast water: 1:1 selenate:selenite	EC_{10} juv. survival ES1	9.27 WB	4°C EC_{20}-LOAEC 8.80 WB	
				EC_{20} juv. survival ES1	9.78 WB		
		dietary and waterborne (lab) 182 days 20 to 9°C (ES3)	diet: Lumbriculus fed selenized-yeast water: 1:1 selenate:selenite	EC_{10} juv. survival ES3	14.00 WB	9°C EC_{10} 14.0 WB	
				EC_{20} juv. survival ES3	14.64 WB	9°C EC_{20} 14.6 WB	
		dietary and waterborne (lab) 182 days 20 to 4°C (ES2)	diet: seleno-L-methionine water: 1:1 selenate:selenite	NOEC juv. surv. ES2	>9.992 WB		

Species	Reference	Exposure route and duration	Selenium form	Toxicological endpoint	Chronic Value mg/kg dw[a]	SMCV mg/kg dw	GMCV mg/kg dw
Lepomis macrochirus bluegill	Bryson et al. 1985b	dietary (lab) 60 days	seleno-DL-cysteine	NOEC for juvenile growth	>3.74 WB[b]		
Lepomis macrochirus bluegill	Cleveland et al. 1993	dietary (lab) 90 days	seleno-L-methionine	NOEC for juvenile survival	>13.4 WB[b]		

[a] All chronic values reported in this table are based on the measured concentration of selenium in whole body (WB), muscle (M) or liver (L) tissues.

[b] Chronic value not used in SMCV calculation (see text).

[c] Tissue value converted from ww to dw. See Appendix C for conversion.

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6.1.9.1 Comparison of Fish Chronic Reproductive Effects and Chronic Non-Reproductive Effects

A chronic criterion element concentration of 15.1 mg/kg dw in the egg/ovary addresses the toxic effect identified by the Chapman et al. (2009, 2010) expert workshop to be of greatest concern, reproductive effects, and is expected to be protective of non-reproductive endpoints such as juvenile survival and growth.

If the information in the reproductive-effect GMCV **Table 3.2** (expressed as whole-body) were combined with the information in the nonreproductive-effect **Table 6.2**, and the lower of the reproductive or nonreproductive GMCVs for each taxon were used to construct a combined distribution of whole-body chronic values, the resulting criterion element (corresponding to N=18, accounting for three additional fish genera only having nonreproductive-effect GMCVs), the FCV would be calculated to be 9.1 mg Se/kg WB dw, similar to the 8.5 mg Se/kg WB dw FCV for reproductive effects expressed as whole-body **Figure 6.2**.

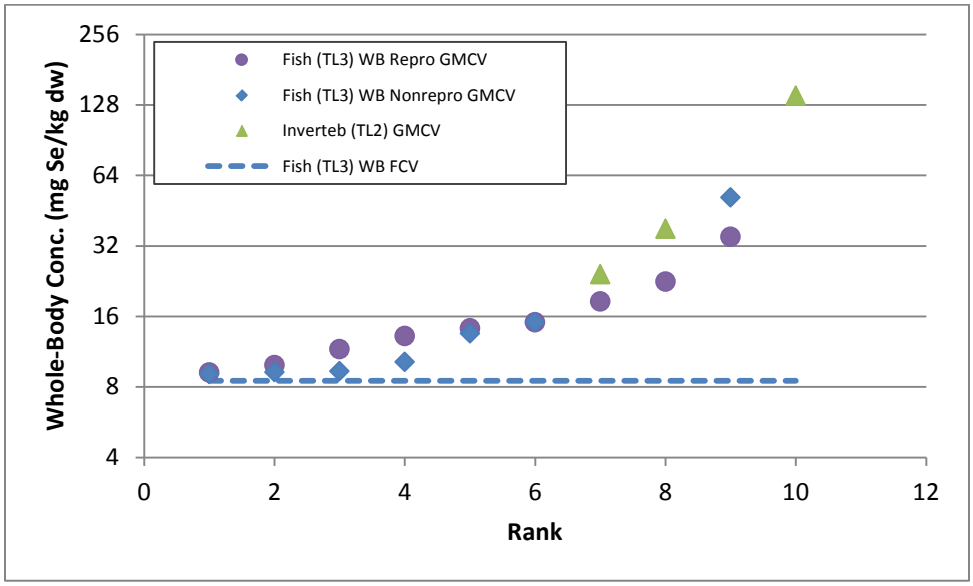


Figure 6.2. Distribution of Fish Reproductive Effect GMCVs from Figure 3.2 and Distribution of Fish Nonreproductive Effect GMCVs and Invertebrate GMCVs.

For establishing a reliable criterion, the sufficiency of and consistency among the data underlying the reproductive-endpoint GMCVs favor their use over any non-reproductive endpoint data (see **Section 3.1.1** and Appendix C). Most of the reproductive studies involved

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examining the offspring of wild-caught females, exposed under real-world conditions. Most had concentration-response curves that supported EC_{10} estimates.

In contrast, the non-reproductive endpoint studies provide fewer data for supporting a criterion, and fewer of these studies yielded the type of concentration-response data that could support EC_{10} estimates. Furthermore, the non-reproductive data are not as consistent, as noted by Janz et al. (2010). The reproductive effect data also show more clear-cut concentration-response relationships than the non-reproductive effect data (11 of the reproductive chronic values are specific ECs, compared to only five of the non-reproductive chronic values), are more readily reproducible, and are better corroborated by field observations. Reproductive effects represent the endpoint of greatest concern (Chapman et al. 2009, 2010); all non-reproductive GMCVs are protected by a criterion derived from the reproductive GMCVs. The reproductive endpoint data, expressed relative to selenium concentrations in fish eggs and ovaries, thus provide a more reliable and protective basis for the criterion. Because the data set used to derive the criterion is comprised primarily of the aquatic species considered most sensitive to selenium (salmonids and centrarchids) and because the criterion is designed to protect 95% of the genera, the egg-ovary criterion element concentration of 15.1 mg/kg dw ovary/egg should be protective of aquatic populations of fish and invertebrates.

6.1.10 Special conditions for consideration of primacy of water column criterion elements over fish tissue criterion elements

The chronic selenium criterion is derived to be protective of the entire aquatic community, including fish, amphibians, and invertebrates. Fish are the most sensitive taxa to selenium effects. Selenium water quality criterion elements based on fish tissue (egg-ovary, whole body, and/or muscle) sample data supersede the criterion elements based on water column selenium data, when measured in the same approximate time frame (approximately one year) and site. This is due to the fact, noted above, that fish tissue concentrations provide the most robust and direct information on potential selenium effects in fish. However, because selenium concentrations in fish tissue are a result of selenium bioaccumulation via dietary exposure, there are two specific circumstances where the fish tissue concentrations do not fully represent potential effects on fish and the aquatic ecosystem: 1) In “fishless” waters, and 2) new selenium inputs. *Fishless waters* are defined as waters with insufficient instream habitat and/or flow to support a population of any fish species on a continuing basis, or waters that once supported

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populations of one or more fish species but no longer support fish (i.e., extirpation) due to temporary or permanent changes in water quality (e.g., due to selenium pollution), flow or instream habitat. Because of the inability to collect sufficient fish tissue to measure selenium concentrations in fish within such waters, water column concentrations will best represent selenium levels required to protect aquatic communities and downstream waters in such areas. *New inputs* are defined as new activities resulting in selenium being released into a lentic or lotic waterbody. New inputs will likely result in increased selenium in the food web, resulting in increased bioaccumulation of selenium in fish over a period of time until the new selenium release achieves a quasi-"steady state" balance within the food web. EPA estimates that concentrations of selenium fish tissue will not represent a "steady state" for several months in lotic systems, and longer time periods (e.g., 2 to 3 years) in lentic systems, dependent upon the hydrodynamics of a given system; the location of the selenium input related to the shape and internal circulation of the waterbody, particularly in reservoirs with multiple riverine inputs; and the particular food web. Estimates of time to achieve steady state under new selenium input situations are expected to be site dependent, so local information should be used to better refine these estimates for a particular waterbody. Thus, EPA recommends that fish tissue concentration not supersede water column concentration until these periods of time have passed in lotic and lentic systems, respectively, or until steady state concentrations can be determined.

6.2 WATER

6.2.1 Validation of Translation Equation for Developing Water Column Concentrations

EPA evaluated the efficacy of the equation used to translate the egg-ovary criterion element to a water column concentration. EPA's translation equation is given as:

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite} \times EF \times CF} \qquad \text{(Equation 18)}$$

Because selenium levels in fish are relatively stable over a long time period if the ecosystem is at steady state with respect to selenium concentration, single measurements of selenium in fish tissue are likely to be less variable and a better representation of selenium loads to the aquatic system than single measurements of selenium in the water column. Thus, EPA used a validation approach based on fish tissue measurements rather than single water measurements.

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Rearranging Equation 18 to solve for egg-ovary concentration yields:

$$C_{egg-ovary} = C_{water} \times TTF^{composite} \times EF \times CF \qquad \text{(Equation 22)}$$

EPA used Equation 22 to calculate the predicted concentration of selenium in the eggs and ovaries of fish from all spatially and temporally relevant measurements in the water column. EPA then compared those predicted values to the measured concentration in the fish.

EPA searched its collection of selenium measurements in fish tissue taken from aquatic sites with a previously calculated *EF* value. Identified tissue measurements from other than eggs or ovaries were converted to equivalent egg-ovary concentrations using species-specific conversion factors as described previously. For each tissue measurement, EPA searched its collection of selenium measurements again for water column measurements that were taken from the same aquatic site and within one year of the tissue measurement. If more than one water column measurement was matched to a tissue measurement, the median water column measurement was used. For each matched pair of tissue and water measurements, appropriate species-specific *TTF* and *CF* values were identified as described previously, and the *EF* value from the site samples were taken. EPA then used Equation 22 to calculate the predicted egg-ovary concentration from the observed water column concentration. Finally, EPA compared the predicted egg-ovary concentrations with the observed egg-ovary concentrations.

EPA identified 317 tissue measurements associated with one or more water column measurements. A predicted egg-ovary concentration was calculated for each water column concentration as described above. **Figure 6.3** shows all 317 predicted egg-ovary concentrations plotted against the measured egg-ovary concentrations. Because both the predicted and observed selenium concentrations exhibited substantial heteroscedasticity (the variability of one variable is unequal across the range of values of a second variable that predicts it), they are plotted and analyzed on a log scale. The predicted and measured concentrations are highly correlated ($r=0.82$, $t_{(315)}=25.30$, $P<0.001$). Data used to generate **Figure 6.3** can be found in Appendix I.

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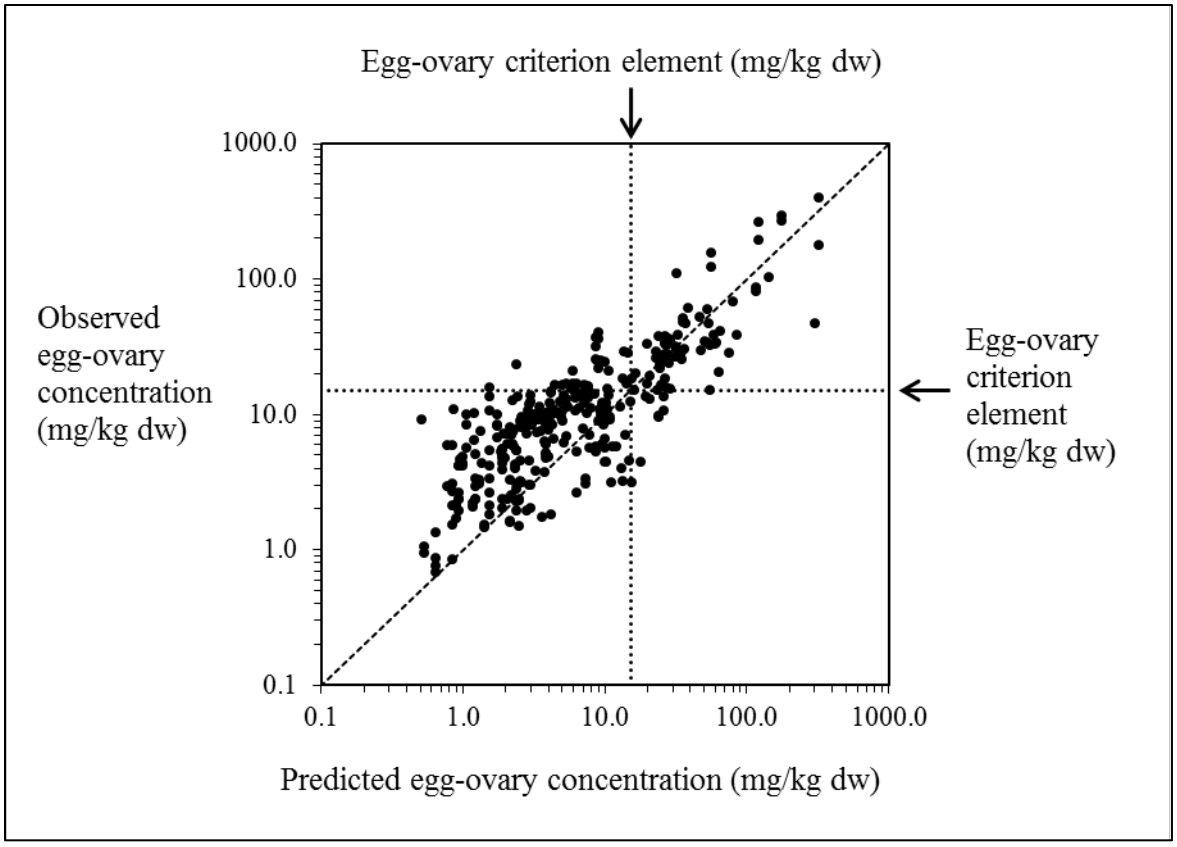


Figure 6.3. Scatter Plot of Predicted Versus Measured Concentrations of Selenium in Fish. Solid line shows unity y = x line; dashed lines show the egg-ovary criterion element value.

Although there is a strong correlation between predicted and observed egg-ovary concentration values, **Figure 6.3** shows more data points above the y = x line at low selenium concentrations. This result suggests the model underestimates bioaccumulation at low selenium concentrations. Such behavior is likely the result of the inherent model assumption of constant bioaccumulation rates regardless of selenium concentration, whereas selenium bioaccumulation has been shown to be inversely related to water concentration (see **Sections 3.2.2** and **3.2.4** for further discussion). Within the range of concentrations near the egg-ovary criterion element value, however, the relationship between predicted and observed selenium concentrations are evenly dispersed around the y = x line. Thus the model is unlikely to result in biased estimates near egg-ovary concentrations that may require regulatory action.

Dispersion around the unity line is likely attributable to several sources of uncertainty including small sample sizes, temporal or spatial variability in selenium exposure, and local variability in aquatic food webs. EPA limited this analysis to only those aquatic sites with at least

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two particulate measurements available to calculate an *EF* value and with at least one of them from algae or detritus. The requirement of at least two particulate measurements was made because a single measurement was considered insufficient. The requirement that at least one of the measurements be for algae and/or detritus was made because selenium within these particulate types was more highly correlated to water (**Section 3.2.2.3**). Nevertheless, only one or two measurements of algae and/or detritus were available for 62 of the 96 aquatic sites evaluated. Although the minimum data requirements described above reduce uncertainty when applying Equation 22 to available data, EPA believes that two particulate measurements are only marginally sufficient. Another potential source of uncertainty is the frequent absence of site-specific information about the types and proportions of organisms ingested by fish. In most cases, EPA estimated the type and proportion of prey organisms using general knowledge of the fish species and aquatic system location. Notwithstanding the limitations in available data, the EPA concludes from this analysis that Equation 18 provides a reasonable translation of the egg-ovary criterion element to a site-specific water concentration.

6.2.2 Sulfate-Selenium Interactions

Several investigators (Brix et al. 2001; Ogle and Knight 1996; Williams et al. 1994) have previously evaluated the role of sulfate on the bioavailability and toxicity of selenium in freshwater organisms. A report from DeForest et al. (2014) notes that a sulfate-dependent selenium criteria would apply only to selenate-dominated, well-oxygenated streams, a subset of freshwater systems in the U.S. The DeForest publication discussed experiments to assess influence of sulfate on selenate uptake on one species of macrophyte (*Lemna minor*) and one algal species (*Pseudokirchnella subcapitata*), a limited data set of primary producers. The authors note that, "It does need to be emphasized here, however, the analysis currently does not include Se data for periphyton and benthic diatoms, as these data are not available." The authors also note that, "due to methodological challenges and high costs, it is difficult to comprehensively evaluate the influence of sulphate on bioconcentration and transfer up the food chain."

Including any type of sulfate relationship in the national criterion derivation would necessitate having sulfate measurements to accompany all observed selenium water concentrations included in the derivation database. That is, the absence of an accompanying sulfate observation would necessitate excluding the water observation. The resulting reduction in

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the number of sites included in the database would reduce the confidence in its ability to represent the nation's waters. For the above reasons, EPA has not included a sulfate relationship in the 2016 selenium criterion.

6.3 UNCERTAINTY

This section examines several areas where EPA addressed uncertainty in the development of the selenium water quality criterion. This section represents a qualitative treatment of specific parts of the derivation process for the selenium freshwater chronic criterion where EPA has identified the potential for uncertainty, and also describes the approaches that the Agency used to reduce uncertainty.

EPA developed a tissue-based water quality criterion designed to be protective of aquatic life from the chronic effects of selenium. In general, EPA followed the procedure detailed in the document, Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses (hereafter referred to as the "Guidelines") (Stephan et al. 1985). The Guidelines sets forth a methodology for deriving ambient water quality criteria for the protection of aquatic life that includes a rigorous list of data quality requirements. Because selenium is a bioaccumulative chemical with maternal diet and transfer as the primary route of exposure for chronic toxicity, EPA included additional data quality requirements such as the requirement of a dietary exposure. See **Section 2.7.5** Analysis Plan for Derivation of the Chronic Fish Tissue-Based Criterion Elements for how chronic effect levels were determined for selenium. The Guidelines provide several recommended approaches that reduce uncertainty in the derivation of criterion. It provides a strict set of guidelines for the acceptance of data to be used in criteria derivation. It provides a minimum set of data requirements (MDRs) that define an assemblage of aquatic organisms that can be used in a genus sensitivity distribution to derive a criterion that is protective of 95% of aquatic species. The requirements in the Guidelines reduce the uncertainty in the ability of a criterion to be protective of aquatic life.

6.3.1 Tissue Criterion Element

The tissue criterion element is based on reproductive effects caused by selenium and is expressed in three different tissue types, egg/ovary, muscle and whole body. Non-reproductive effects were also determined but not used in the derivation of the criterion because of less certainty in the endpoints and effect levels (**Section 6.1.9** and **Table 6.2**). A comparison of fish

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reproductive and non-reproductive effects and the conclusion that the reproductive criterion is protective of the non-reproductive effects is given in **Section 6.1.9.1**.

The dataset used to derive the tissue-based criterion consists primarily of fish species: 12 fish species representing 10 genera and 7 families. Although this might be viewed as a small number of the nearly 800 native freshwater fish species (36 families) of fish in the United States, it is a large number of species relative to chronic criteria derivations for other pollutants. Furthermore, the fish species that have been the focus of some of the research have been the species observed to be those first affected (most sensitive) at selenium-contaminated sites such as Belews Lake and Hyco Reservoir, i.e., bluegill sunfish and largemouth bass. The data set contains three acceptable chronic toxicity studies with bluegill sunfish, the second most sensitive genus in the dataset and one with largemouth bass, the fifth most sensitive genus. The three replicate chronic values for bluegill are 14.7, 22.6, and 26.3 mg Se/kg egg-ovary dw. Of these three values, 14.7 mg Se/kg ovary dw is likely the least certain because the study (Hermanutz et al. 1992, 1996) was not designed to minimize uncertainty in characterizing the tissue concentrations associated with its observed levels of effect.

Three genera representing five species from Salmonidae, a family considered to be generally sensitive to contaminants, are in the data set. Two salmonid genera, *Salmo* and *Oncorhynchus* are the third and fourth most sensitive taxa in the data set. *Salmo* is represented by a single study, but because the study included a large number of individuals across a broad spectrum of exposure, the uncertainty associated with its 21 mg Se/kg egg dw might not be viewed as particularly large. The chronic values for the three studies with *Oncorhynchus* are confined to the narrow range 24.5 – 27.7 mg Se/kg egg dw, and on that basis may be considered to have low uncertainty. Although the numbers of species and families of fish in the data set are a fraction of what are native to the United States, the fish species contained in the data set are known to be those most sensitive to selenium based on field observations or known to be sensitive in general to contaminants. With the lowest six chronic values falling in the relatively narrow range 15.6 – 27 mg Se/kg egg-ovary dw, the selenium tissue criterion element should probably be considered to have the smallest amount of uncertainty among the existing aquatic life criteria.

As stated in the previous paragraph, the data set primarily consists of fish species and contains only three invertebrate species. The cases in the field where adverse effects have been

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observed to fish and water birds (e.g., Belews Lake, Hyco Reservoir, Kesterson Reservoir) have not documented any adverse effects on macroinvertebrates either on a species or community level (Janz et al. 2010). The effect levels determined for the three invertebrate species contained in the data set are consistent with the field observations that macroinvertebrates are in general less sensitive to selenium than fish species. EPA recognizes that there may be more sensitive oviparous taxa (fish and amphibians), as well as macroinvertebrate taxa than those in the current data set and supports the testing of different species.

6.3.1.1 Reproductive Endpoints

Reproductive endpoints were determined from studies in which adults were exposed to selenium either in the laboratory or field. Effects were measured in the offspring which received selenium exposure via maternal transfer. Larval mortality and teratogenic deformities such as skeletal, craniofacial, and fin deformities, and various forms of edema that result in mortality are the most sensitive indicators of selenium toxicity in fish larvae. Recent research suggests the mode of action of selenium-induced toxicity in fish larvae is due to oxidative stress and appears to be related to glutathione homeostasis (See **Section 2.3** for more detail on this subject.). Linking the mode of action directly to the assessment endpoint used in the derivation of the tissue-based criterion provides a consistent concentration-response relationship among the studies used in the data set. Using the most sensitive assessment endpoint (based on the state of the science) reduces uncertainty in the ability of the criterion to protect aquatic life.

6.3.1.2 Egg Ovary Chronic Values

Chronic Values (CV) were based on the most direct representation of exposure to the effect in the offspring, that is, the concentration of selenium in the egg/ovary. One way to assess the precision of the chronic values used in the derivation of the criterion is to look at the reproducibility of tests used to calculate the CV for a taxon. This precision assessment can be done with two tests conducted with cutthroat trout and three tests conducted with bluegill sunfish. The two cutthroat trout studies (Rudolph et al. 2008 and Nautilus Environmental 2011) had very similar EC_{10} values (24.7 and 27.7 mg Se/kg egg dw, respectively) for the same endpoint (larval survival) using fish collected at the same site. Two of the three bluegill tests (Coyle et al. 1993 and Doroshov et al. 1992a) also had very similar EC_{10} values (26.3 and 22.6 mg Se/kg egg dw, respectively) for larval endpoints determined in laboratory exposures. An

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EC_{10} of 14.7 mg Se/kg ovary dw was determined in the third bluegill test, a mesocosm exposure study reported by Hermanutz et al. (1992, 1996). Although the mesocosm study had a lower EC_{10} value when compared with Coyle et al. (1993) and Doroshov et al. (1992a), it was within a factor of 1.8 and 1.5, respectively. Delos (2001) found such differences to be typical when equivalent toxicity tests of the same species are compared. The relatively low variability between chronic toxicity tests conducted with the same species indicates precision in the CV estimates, which reduces the uncertainty the tissue-based criterion.

Most of the CVs were determined using an EC_{10} value and a few were estimated using the NOEC. EC_{10} values were considered more appropriate than EC_{20}, because selenium is a tissue-based criterion due to its nature of exposure and effects for this bioaccumulative chemical. See **Section 2.7.1** for a discussion of why EC_{10}s were favored over EC_{20}s. The use of EC_{10}s and NOECs increases the certainty that the criterion will be protective of aquatic life.

6.3.1.3 Whole Body and Muscle Chronic Values

Effect levels (EC_{10} or NOECs) were determined directly for whole body or muscle tissues when the selenium concentrations for these tissues were measured and reported in the tests. Effect levels were calculated directly using muscle tissue for five of the chronic toxicity tests: northern pike, cutthroat trout (Rudolph), bluegill (Doroshov and Hermanutz) and white sturgeon, while effect levels for three tests were calculated directly using whole body selenium concentrations: bluegill (Coyle and Hermanutz) and brown trout. For the other tests that did not have muscle or whole body selenium measurements, conversion factors (*CF*s) were used to convert the egg/ovary CV to a muscle or whole body CV. The direct calculation of the muscle and whole body CVs (when data were available) reduced uncertainty in these effect level estimates.

6.3.1.4 Conversion Factors

When muscle or whole body chronic values could not be determined directly using selenium concentrations measured and reported for the respective tissue, conversion factors (*CF*) were used to convert the egg/ovary chronic value to either a muscle or whole body chronic value.

To derive egg-ovary to whole-body *CF* values, EPA defined matched pairs of selenium measurements from the eggs or ovaries and from the whole-body measured from the same individual fish or from matched composite samples. If multiple measurements from both eggs

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and ovaries of the same individual or matched composite sample were available, the average value was used. Similar pairings were done for egg-ovary to muscle *CF* values.

After the data sets of the pairings were compiled, EPA first confirmed a statistical relationship between egg-ovary and whole body selenium for each species using ordinary least squares (OLS) linear regression of the matched pairs of measurements. If the regression resulted in a significant fit ($P \leq 0.05$) with a positive slope, EPA calculated the ratio of the egg-ovary to whole body (or muscle) selenium concentration of each matched pair and used the median ratio as the *CF* value for the species. A detailed comparison of the advantages and disadvantages of the median ratio and least squares regression approaches to calculating *CF*s, along with a comparison of *CF*s calculated from median ratios, OLS regression following log transformation, and total least squares (TLS) regression following log transformation is in Appendix N. Table N-3 provides a comparison of the median-based and regression-based *CF*s when they are used to convert an egg-ovary selenium concentration to muscle or whole body. Generally, the median-based and TLS-based *CF*s were similar for both tissue types and this similarity resulted in similar criterion element values (bottom row of Table N-3). The muscle criterion element value for the data set that contained directly calculated CVs and converted CVs was similar whether median or TLS *CF*s were used, 11.3 and 10.2, respectively. The whole body criterion element value was also similar using these two approaches, 8.5 and 9.4, respectively. The median-based *CF* approach was considered to be better than the regression-based *CF* approaches at reducing uncertainty. A detailed comparison and rationale for the median approach is discussed in appendix N.

EPA had sufficient egg-ovary and whole-body selenium measurements to directly calculate egg-ovary to whole body *CF* values for 13 species of fish. Similarly, there were sufficient egg-ovary and muscle selenium measurements to directly calculate egg-ovary to whole body *CF* values for 16 species of fish. To derive *CF* values for additional fish species, EPA used a taxonomic-relatedness approach (most similar taxon) approach to estimate *CF*. This approach is consistent to that done for TTF estimates, and is described in **Section 3.2.2**, and in greater detail in Appendix B.

The variability of *CF*s between fish species and within fish species was fairly low. EPA derived 13 *CF* values directly from matched pairs of egg-ovary and whole-body selenium measurements and an additional seven *CF* values by multiplying EO/M and M/WB conversion

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factors (**Table 3.12**). Excluding mountain whitefish (*CF* = 7.4), *CF*s for 19 of the 20 species ranged from 1.20 to 3.11, a 2.6-fold difference. CF variability within each species was also low for 11 of the 13 species for which egg-ovary to whole-body CFs were determined directly and a standard deviation calculated (**Table 3.12**). The two species with relatively high standard deviations contained data that were potentially anomalous. When the potentially anomalous data were removed the standard deviations for these two species were reduced considerably (see footnote to **Table 3.12**).

6.3.2 Trophic Transfer Factors

A Trophic Transfer Factor (*TTF*) represents the transfer of selenium from one trophic level to the next higher trophic level. *TTF*s are used in the translation of the tissue criterion element concentration to a water element value. For a description of how *TTF*s are used in translation, see **Section 3.2.1**, Translation from Fish Tissue Concentration to Water Column Concentration.

Similar to CFs, EPA calculated *TTF*s from field data using the median-ratio approach after first performing OLS regression of matched pairs of selenium measurements for the two taxa representing successive trophic levels to determine if the relationship is significant ($P \leq 0.05$) and has a positive slope. EPA also evaluated using only OLS regression results to calculate *TTF* values. OLS regression was performed using matched concentrations of selenium in the food of a particular species or taxonomic group with the concentration of selenium in the organism's tissue, and then the slope of the regression was used as the *TTF* for that species or taxonomic group. An advantage of the regression approach is that it estimates the quantitative relationship of selenium across a range of environmental concentrations in a manner that allows statistical assessment. Disadvantages of this regression approach include the assumption that the underlying data are normally distributed; the possibility that one or a few very high or low values can have a disproportionate influence on the slope of the fitted line; and the fact that the bioaccumulation model does not account for a non-zero y-intercept. Constraining the y-intercept to zero (also known as regression through the origin or RTO) eliminates the added complexity of a non-zero y-intercept. However, RTO further increases the disproportionate influence of one or a few high values on the slope of the fitted line. Furthermore, RTO does not provide a straightforward way of evaluating goodness of fit (Gordon 1981).

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The median-ratio approach, following confirmation of a significant ($P \leq 0.05$) relationship and positive slope, was considered to be more appropriate for deriving *TTF*s from field data that the OLS regression approach. Requiring a significant positive OLS linear regression coefficient confirms the relationship between selenium in organisms and the food they ingest is adequately represented by the available data. Using the median of the individual ratios provides an estimate of central tendency for that relationship that is less sensitive to potential bias from measurements taken from aquatic systems with very high or very low selenium concentrations. Some aquatic organisms exhibit selenium bioaccumulation inversely related to water concentration (McGeer et al. 2003; Borgman et al. 2004; DeForest et al. 2007). This inverse relationship is likely due to saturation uptake kinetics of specific transport mechanisms that regulate metals bioaccumulation within certain ranges (U.S. EPA 2007). EPA evaluated the effect of very high and very low selenium concentrations on the calculation of *TTF* values using the hybrid approach (use of median ratios for matched data with significant relationship and positive slope) described above by excluding selenium measurements above various minimum and/or below various maximum selenium concentrations. EPA found that using the median ratio effectively attenuates any effects of selenium concentration on the calculation of *TTF* values using the hybrid approach described above without the need to introduce additional arbitrary exclusion criteria.

*TTF*s were also determined using physiological coefficients (see **Section 3.2.2.1**, Derivation of Trophic Transfer Factors (TFF) Values. However, if a *TTF* value could be calculated from both physiological coefficients and field data, EPA used the *TTF* value calculated from the substantially larger number of field measurements to minimize statistical uncertainty.

*TTF*s were calculated for 32 fish species, and ranged from 0.68 to 2.67 (**Table 3.11**). The majority of fish *TTF*s fell within a relatively narrow range, with an interquartile range ($25^{th} – 75^{th}$ centile) of 1.03 to 1.42. Variability of *TTF*s among the 13 invertebrate taxa was higher, ranging from 0.74 to 4.58 (**Table 3.10**). Much of the variability among invertebrate *TTF*s was related to taxonomic groups. The two bivalve *TTF*s ranged from 4.00 to 4.58. The five insect *TTF*s ranged from 1.48 to 2.88, the five crustacean *TTF*s ranged from 0.74 to 1.89, and the *TTF* for blackworms was 1.29.

EPA translated the tissue criterion element concentration to water element values at field sites that had selenium measurements in the required water, particulates, invertebrates, and fish.

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For species without sufficient data to directly calculate a *TTF* value at these sites, EPA estimated the *TTF* value by sequentially considering higher taxonomic classifications until one or more taxa for which a calculated *TTF* value was available matched the taxon being considered. If the lowest matching taxon was common to more than one species with a *TTF* value available, EPA used the median *TTF* from the matching species.

6.3.3 Enrichment Factors

Enrichment factors are discussed in **Section 3.2.2.3** and Appendix H. This factor, describing how the bottom of the food chain takes up selenium, is the most variable between sites. Variability among *EF*s is the main reason that fish BAFs vary so much between sites, and this variability is the reason the national criterion for selenium needed to be tiered, with tissue having priority over water, to increase certainty that the criterion is protective as intended. The range of site *EF* values shown in Appendix H spans more than a 100-fold range.

The *EF* value measured at a particular site is also likely to be the site's most uncertain parameter, being a ratio of measurements of algae, detritus, and sediment, which may vary within a site in uncertain ways, and measurements of water, which vary over time. The approach for setting site *EF*s was designed to reduce uncertainty. As described in Appendix H, EPA calculated *EF* values by searching its database of selenium measurements and identifying all the selenium measurements from algae, detritus, or sediment. EPA then searched for corresponding water column measurements from samples collected at the same aquatic site within one year of the particulate sample. If more than one water concentration was available for any given particulate measurement, the median water concentration was used. For each of these matched pairs of particulate and water measurements, EPA calculated the ratio of particulate concentration to water concentration. If more than one ratio for any given category of particulate material (algae, detritus, or sediment) was calculated at an aquatic site, EPA used the median of those ratios. Selenium concentrations between particulate and water concentrations were higher for algae and detritus than for sediment. To reduce uncertainty in *EF* values associated with sediments, at least two particulate selenium measurements with corresponding water column measurements were required, and sediment measurements were used only if there was at least one other measurement from either algae or detritus. The geometric mean of the algae, detritus, and sediment ratios was then calculated and used as the site *EF*. Because there were at most only 3 possible values (one for algae, one for detritus, and one for sediment), EPA used the geometric

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mean in order to reduce the potential for one of the values to have excessive influence on the final site EF value. Sites with insufficient data to fulfill these data requirements were not used.

Had EPA increased the data requirements for setting a site *EF*, then the database would be restricted to a smaller number of sites. Because the variability between sites is high, reducing the number of sites in the database would decrease the confidence in the representativeness of the few sites retained (that is, it would increase the potential for sampling error in attempting to characterize the nation's waters). The *EF* determination process thus involved a balance between having enough information to reasonably characterize each site, and having enough sites to represent the range of the nation's waters.

Inclusion of selenium speciation information (such as selenate and selenite concentrations) was infeasible. Very few sites would have the requisite information, thereby increasing the uncertainty in the representativeness of any possible derived national criterion. Likewise, inclusion of a sulfate relationship was not feasible on a national basis at this time, for lack of sulfate data at many sites in the database.

Because *EF* is the BAF component that varies the most between sites, it is the most important in determining what the water concentration would be for a site if its fish tissue concentrations were hypothesized to be at the level of the fish tissue criterion element value. That is, sites with higher *EF*s tabulated in Appendix H have lower translated water concentrations in **Table 3.13**. Despite uncertainties in this parameter, model-predicted versus observed fish-tissue concentrations in the vicinity of the water element criterion concentrations are relatively unbiased, as shown in the figures of Appendix I.

For particular sites, the appropriateness of the national criterion can be resolved by site specific criteria when necessary (e.g., when a permit limit for water is required), as recommended in Appendix K. When taking measurements of a site, uncertainty in particulate measurements (the numerator of the *EF*) can be bypassed by using site-specific fish BAFs, since they only consider water and fish tissue selenium measurements. On the other hand, uncertainty in characterizing time-variable water concentrations is a problem shared by *EF*s and BAFs. However, this uncertainty can be reduced by sampling in a spatially and temporally robust manner, appropriate for the site in question, and then using the mathematical modeling approach to derive a site specific criterion.

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6.3.4 Water Values

Derivation of the water criterion element from the egg-ovary criterion element is described in **Sections 2.7.8** and **3.2**, and involves *EF*s, *TTF*s, and *CF*s. Uncertainties in predicted tissue-to-water ratios combine the uncertainties in the parameters from which they are predicted. The prediction model is linear in all respects. Potential nonlinearities are therefore an uncertainty. **Section 6.2.1** and Appendix I assesses the accuracy of the predictions. As shown in the figures of Appendix I, the predicted values perform reasonably well in the vicinity of the water criterion element concentrations.

Although an earlier published draft document weighted sites by the number of fish species sampled (between 1 to 6 species per site), that overweighting of sites with several measured species was removed from this draft by using only the most bioaccumulative fish species per site, thereby reducing uncertainty that the fish tissue criterion element will be exceeded when using only water column concentration data. Lentic and lotic sites were assessed separately, per **Section 3.2.4**. This increases the likelihood that the water criterion element concentration will be appropriate for the site of application.

To reduce the likelihood that the water criterion element concentration will be under-protective for any particular site of application, the 20th percentiles of translated water concentrations for all lentic and lotic sites, respectively, were used as the water criterion element concentrations. As described previously, these distributions represented the translated water concentrations for the most bioaccumulative fish species at each site, which further reduces the likelihood that the fish tissue criterion element would be exceeded if the water criterion element was being met. These water criterion elements should not be interpreted to be potentially under-protective in 20 percent of sites, because when applied to a site's 30-day once-in-three-year maximum concentration (which is higher than its median), the 20th percentile site would not attain. The actual percentage of sites protected would thus be greater than 80 percent, but the exact percentage is uncertain.

6.4 Protection of Threatened or Endangered Species

The chronic toxicity dataset for selenium contains toxicity data for two Federally-listed endangered species, *Cyprinodon macularius* (desert pupfish) and *Oncorhynchus mykiss* (listed as steelhead, indicating anadromous individuals, but herein called rainbow trout, implying non-anadromous individuals). The dataset also contains toxicity data for *Acipenser transmontanus*

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(white sturgeon), which is listed as endangered in specific locations, such as the Kootenai River white sturgeon in Idaho and Montana. The white sturgeon also serves as a surrogate for other sturgeon listed as threatened or endangered (e.g., pallid and shovelnose sturgeon). The *Acipenser* GMCV of 15.6 mg/kg dw egg is the lowest value in the dataset and therefore provides protection for other potentially sensitive sturgeon. The white sturgeon chronic value is greater than the chronic egg-ovary criterion element value.

Desert pupfish, *Cyprinodon macularius*, with a chronic value estimated to be ≥27 mg Se/kg dw egg, is not among the most sensitive species. Its chronic value of ≥27 mg Se/kg dw egg is substantially above the chronic egg-ovary criterion element value of 15.1 mg Se/kg dw.

Oncorhynchus mykiss has an SMCV of 24.5 mg Se/kg dw egg, whose genus is the fourth most sensitive species in the dataset. The dataset contains multiple studies with cutthroat trout (*Oncorhynchus clarkii*) some subspecies of which are Federally listed as threatened. The SMCV for cutthroat trout is 26.2 mg Se/kg dw egg. Both of these chronic values for *Oncorhynchus* species are greater than the chronic egg-ovary criterion element.

The dataset also contains toxicity information for *Salvelinus malma* (Dolly Varden) which is not threatened or endangered, but is so closely related to the threatened *Salvelinus confluentus* (bull trout) that it can hybridize with that species, producing fertile offspring (Baxter et al. 1997). Dolly Varden is the least sensitive fish species for which information is available, with an SMCV of 56 mg Se/kg dw egg. *Salvelinus fontinalis*, brook trout, can also hybridize with bull trout, but the offspring are sterile, suggesting that it is less closely related. With the available study of brook trout, although in **Section 6.1.5** the NOEC is conservatively set to >20.5 mg Se/kg dw egg, which was the average concentration at the Holm et al. (2005) high-exposure site. The concentration-response information for the offspring of individual females, presented in Appendix C, suggests that its EC_{10} could be substantially higher, possibly as high as that for Dolly Varden.

The egg-ovary criterion element value of 15.1 mg Se/kg (dw) is below all of the above mentioned chronic egg-ovary values for threatened and endangered (or closely related) species. However, because other threatened or endangered species could be more sensitive, if relevant new information becomes available in the future, it should be considered in state- or site-specific criterion calculations.

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The protectiveness of the whole body criterion element concertation of 8.5 mg/kg dw to threatened and endangered species is also supported by a recent non-reproductive study with two sturgeon species. De Riu et al. (2014) fed juvenile green and white sturgeon (~30 g body weight) diets containing a range of selenium concentrations (selenomethionine added to diet formulation; 2.2 mg/kg Se in control diet (no added Se) and 19.7, 40.1 and 77.7 mg/kg Se in the three treatment diets). Several endpoints were monitored over the 8-week exposure period including survival and percent body weight increase (% BWI). White sturgeon had no mortalities through the highest dietary treatment. Green sturgeon juveniles had 0%, 7.7% and 23.1% mortality with the three dietary treatments. TRAP analysis (threshold sigmoid nonlinear regression) of the green sturgeon survival data resulted in a whole body EC_{10} value of 28.93 mg/kg dw. EC_{10} values were lower for % BWI using TRAP. For % BWI, the whole body EC_{10} value for green sturgeon was 16.36 mg/kg dw, and 23.94 mg/kg dw for white sturgeon.

Also notable, the background concentrations of selenium in the juvenile green and white sturgeon were also elevated at 7.2, 6.5 and 7.1 mg/kg dw (green sturgeon whole body), and 4.8 7.3 and 5.6 mg/kg dw (white sturgeon whole body) at test initiation, and after four and eight weeks of exposure, respectively.

The De Riu et al. (2014) study suggests that green sturgeon may be more sensitive to selenium than white sturgeon and also that the EPA whole body concentration of 8.5 mg/kg dw will be protective, based on the survival and growth data and the observation in De Riu 2014 that the control whole body tissue concentrations (up to 7.2 mg/kg dw) are approaching the proposed criterion. This is important because white sturgeon, as well as juvenile green sturgeon (up to three to four years), spend most of their time in the coastal rivers and estuaries. All species in the Acipenseriformes (sturgeon and paddlefish) spawn in freshwaters (Bemis and Kynard 1997) or spend their entire life in freshwater. The white sturgeon's EC_{10} in the dataset provides surrogacy for the threatened and endangered species from this group. For more information on the De Riu et al. (2014) study, see Appendix E.

6.4.1 Special Consideration for Pacific Salmonid Juveniles

The current criterion is based on reproductive effects (larval mortality and/or deformities) for offspring of selenium-exposed adults, and the whole-body criterion element is derived from the egg-ovary element, with an implicit assumption of adult exposure to selenium. One peer-reviewer of the 2014 EPA External Peer Review Draft criterion document raised concerns

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regarding the protection of anadromous salmonids, since there is at least some evidence (e.g., Hamilton et al. 1990) that juvenile growth may be comparable in sensitivity to reproductive effects endpoints used by EPA. Anadromous salmon species (e.g., Chinook salmon) in the Pacific Northwest are unique in that reproductively mature adults are not exposed to selenium in the freshwater environment due to their life history; young juvenile salmon leave freshwater streams and rivers as smolts and mature to adulthood in the marine environment until migration for spawning begins. Furthermore, they are semelparous, breeding only once in their lifetime and subsequently dying, so there is no potential selenium exposure following spawning in freshwater.

Juvenile salmon have evolved different strategies for growth and maturation to the smolt stage, and may spend from three months to two years in freshwater (depending on timing of egg hatching and other factors) before migrating to estuarine areas as smolts and into the ocean to feed and mature. Salmon remain in the ocean for one to six years (more commonly two to four years), with the exception of a small proportion of yearling males (called jack salmon), which mature in freshwater or return after two or three months in salt water (NOAA 2011).

The physiological and morphological changes that allow these species to adapt to marine conditions as juveniles are reversed in returning adults preparing to migrate up natal streams to spawn. One key change is the cessation of feeding prior to re-entry into freshwater. Since mature females are not feeding after returning to freshwater, it is not representative to predict reproductive effects for anadromous salmonid species based on egg-ovary selenium concentrations, because the exposure is wholly from selenium sources in the marine environment (Groot and Margolis 1991).

6.4.1.1 Selenium Toxicity to Juvenile Salmonids

Hamilton et al. (1990) assessed the toxicity of two organoselenium diets in 90-day partial life cycle tests in freshwater with two life stages of Chinook salmon (*Oncorhynchus tshawytscha*). The first diet consisted of fish meal made from low-selenium mosquitofish (collected from a reference site) fortified with selenomethionine (here termed the SeMet diet). The second diet contained fish meal made from high-selenium mosquitofish (*Gambusia affinis*) collected from the San Luis Drain (SLD), California (here termed the SLD diet). This waterbody is known to have high concentrations of selenium. A 90-day partial life cycle study was conducted with swim-up stage salmon larvae in a standardized fresh water that simulated dilution of San Luis Drain water.

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Survival and growth (length and weight) were measured at 30, 60, and 90 days. Unexplained control mortality (33%) between day 60 and day 90 introduced an unacceptable level of uncertainty into the overall health of the fish. The 1985 Aquatic Life Guidelines (Stephan et al. 1985) and the Manual of Instructions for Preparing Aquatic Life Water Quality Criteria Documents (Stephan 1987) require that excessive control mortality be treated as an exclusionary threshold in data quality assessments for regulatory purposes such as deriving water quality criteria. Therefore the 90-day survival data from this study was not used quantitatively. At 60 days, larval control mortality was acceptable (1%), and 60-day larval survival was > 90% in all SLD and SeMet treatments (3.2 ppm – 18.2 ppm) except for the high Se treatment (35.4 ppm). Whole body selenium concentrations were measured at 60 days, were 10.4 and 13.3 mg/kg dw, respectively, for larvae fed the SeMet and SLD diets of 18.2 mg/kg dw (Hamilton et al. 1990).

Although survival was similar in response to the two diets, larval growth responses differed between the SLD and SeMet diets. The salmon fed the SeMet mosquitofish diet had significant reductions in both length and weight at 30, 60, and 90 days; but only at the two highest concentrations (18.2 and 35.4 ppm). The average length and weight of the larvae fed the SLD mosquitofish diet were significantly lower at all concentrations at 30, 60, and 90 days. The greater effect on growth parameters fed the SLD mosquitofish meal diet could have been caused by one or more of several factors: 1) additional forms of organic selenium (e.g., selenocysteine) present in the SLD mosquitofish, 2) additional toxic elements (e.g., heavy metals) that were accumulated by the SLD mosquitofish, and not present in the reference site mosquitofish, and 3) differential metabolic processing of the organoselenium contained in the proteins of the SLD mosquitofish and fed to the larval salmon, versus the larvae fed the diet containing the free amino acid selenomethionine (Hamilton et.al. 1990).

EPA performed a regression on the 60-day weight and whole body concentrations, and derived a whole body EC_{10} value of 7.355 mg/kg dw for the SeMet diet for reduced growth, and a whole body EC_{10} value of 11.14 µg/g dw for the SLD diet for reduced growth. These values are the only two available EC_{10} Species Mean Chronic Values (SMCVs) for non-reproductive endpoints for the genus *Oncorhynchus*, and the Genus Mean Chronic Value (GMCV) is 9.052 mg/kg dw. This is greater than the national whole body criterion element concentration of 8.5 mg/kg dw, which will thus be protective of this genus.

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EPA recommends that states and tribes consider use of the whole-body criterion element for juvenile (smolt) anadromous Pacific salmon species as the primary criterion element over the other elements due to the unique life history of these species, specifically, the lack of exposure to adult salmonids from selenium in freshwater prior to reproduction. The hierarchal structure of the egg-ovary tissue over the other tissue criterion elements applies to all other species in the family Salmonidae. The egg-ovary criterion element, as well as the other fish tissue criterion elements and the water column criterion elements still apply, as applicable, to protect the remainder of the aquatic community in these waters.

6.5 Aquatic-Dependent Wildlife is Beyond the Scope of this Aquatic Criterion Derivation

AWQC that are developed by EPA typically focus directly on aquatic life, not aquatic-dependent wildlife such as birds. As presented by Campbell (2011), EPA recognizes that selenium effects on aquatic-dependent wildlife are also of concern but considers them beyond the scope of this national criterion update. In the interest of providing updated guidance to protect against the known risks of selenium exposure to fish, EPA decided to focus its analyses on updating the existing selenium criterion for freshwater aquatic life based on the latest scientific evidence.

In the future, EPA plans to consider the effects of selenium on aquatic-dependent wildlife, potentially in the form of criteria expanded to address aquatic-dependent wildlife. When translated to a water concentration, a criterion protective of aquatic-dependent wildlife may be more stringent or less stringent than the values provided for aquatic life in this criterion document. This is because data indicate that for most ecosystems, selenium concentrations are generally conserved or increase incrementally at each trophic level in a food web (after a substantial increase from water to trophic level 1 (e.g., algae). Certain specific ecosystems (e.g., estuarine and marine systems more commonly) with mollusk-based food-webs may create a pathway for more selenium to bioaccumulate, particularly in molluscivorous predators (certain fish and aquatic bird species), since the available data indicate that mollusks generally have a higher trophic transfer factor than other invertebrate taxa. This level of bioaccumulation is typically lower, and in contrast to other bioaccumulative chemicals such as mercury, which have much greater biomagnification.

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As stated previously, the single largest step in tissue selenium accumulation in aquatic environments occurs at the base of the food web where algae and other microorganisms accumulate selenium from water (Orr et al. 2012; Stewart et al. 2010). Mollusks such as mussels and clams accumulate selenium to a much greater extent than planktonic crustaceans and insects due to higher ingestion rates of both particulate-bound (algae) and dissolved selenium from the water column through filter feeding, and these organisms have a lower selenium elimination rate (Luoma and Rainbow 2005). Thus, aquatic-dependent wildlife criteria for species that are primarily molluscivores may have concentrations of concern that are not protected by the 2016 selenium criterion elements found in this document. The criteria values for aquatic-dependent wildlife would be expected to depend on the aquatic systems, species, and food webs considered, as well as spatial and temporal considerations related to selenium exposure and breeding and nesting seasons. Where sensitive aquatic-dependent (e.g., bird) species are known to exist, states should consider developing site-specific criteria based on data for such species.

6.6 SUMMARY

EPA developed the 2016 national 304(a) Aquatic Life Ambient Water Quality Criterion for Selenium in Freshwater to be protective of most aquatic life genera in most waters of the United States, with an intended goal of protecting approximately 95% of aquatic genera in an ecosystem. This freshwater chronic selenium criterion applies only to aquatic life, and is not intended to address selenium toxicity to aquatic-dependent wildlife such as aquatic-dependent birds. This document provides guidance to States and Tribes authorized to adopt water quality standards under the Clean Water Act (CWA), to protect aquatic life from toxic effects of selenium.

The 2016 selenium criterion is a chronic criterion that is composed of four elements. All elements are protective against chronic selenium effects. Two elements are based on the concentration of selenium in fish tissue and two elements are based on the concentration of selenium in the water-column. The recommended elements are: (1) a fish egg-ovary element; (2) a fish whole-body and/or muscle element; (3) a water column - element (one value for lentic and one value for lotic aquatic systems); and (4) a water column intermittent element to account for potential chronic effects from short-term exposures (one value for lentic and one value for lotic aquatic systems). The assessment of the available data for fish, invertebrates, and amphibians

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indicates that a criterion value derived from fish is expected to be protective of the aquatic community, based on available data.

EPA recommends that states and tribes adopt into their water quality standards a selenium criterion that includes all four elements, and express the four elements as a single criterion composed of multiple parts, in a manner that explicitly affirms that the whole-body or muscle elements supersede the water column element, and the egg-ovary element supersedes any other element. The magnitude of the fish egg-ovary element is derived from analysis of the available toxicity data. The magnitudes of the fish whole-body element and fish muscle elements are derived from the egg-ovary element coupled with data on concentration ratios among tissues. The magnitudes of the water column elements are derived from the egg-ovary element coupled with bioaccumulation considerations. Inclusion of the fish whole-body or fish muscle element into the selenium criterion ensures the protection of aquatic life when fish egg or ovary tissue measurements are not available, and inclusion of the water column elements into the selenium criterion ensures protection when neither fish egg-ovary nor fish whole-body nor muscle tissue measurements are available. There are two specific circumstances where the fish tissue concentrations do not fully represent potential adverse effects on fish and the aquatic ecosystem: 1) “fishless” waters, because of the inability to collect sufficient fish tissue to measure selenium concentrations in fish in such waters, and 2) areas with new selenium inputs, because the fish tissue concentrations in such systems would not yet represent steady state conditions upon which the criterion is based.

To ensure that the contribution of short-term exposures to the bioaccumulation risks is accounted for in all situations, EPA is recommending that the intermittent exposure element be included in the selenium criterion, as noted above. EPA is not recommending a separate acute criterion element derived from the results of toxicity tests having water-only exposure because selenium is bioaccumulative and toxicity primarily occurs through dietary exposure. Application of the intermittent exposure criterion element values to single day, high exposure events will provide protection from the most important selenium toxicity effect, reproductive toxicity, by protecting against selenium bioaccumulation in the aquatic ecosystem resulting from short-term, high exposure events.

The egg/ovary-based tissue criterion element of 15.1 mg Se/kg dw is based on a genus sensitivity distribution that used the most sensitive assessment endpoint observed in toxicity

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tests, reproductive effects, and included fish species known to be sensitive to selenium (i.e., species from Salmonidae and Centrarchidae), as well as three endangered species (desert pupfish, rainbow trout and white sturgeon).

With respect to the chronic water column criterion elements, EPA intends the lentic and lotic values of 1.5 and 3.1 µg/L, respectively, to be protective of most surface waters in the U.S. These water concentrations represent the 20^{th} percentile of the distribution of translated water column values from sites across the U.S. The intermittent exposure water column criterion element is derived from the chronic water column criterion element, which was derived from the tissue-based criterion.

EPA recognizes selenium bioaccumulation potential depends on the structure of the food web and several biogeochemical factors that characterize a particular aquatic system. Uncertainty in the translation of the egg-ovary criterion element to the water column element can be reduced by deriving a site-specific criterion that uses site-specific selenium data and information on food-web dynamics from a biological assessment of the aquatic system. Appendix K provides recommendations and examples for developing site-specific selenium criteria.

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Aquatic Life Ambient Water Quality Criterion for Selenium – Freshwater 2016 (Appendices A-N)

U.S. Environmental Protection Agency
Office of Water
Office of Science and Technology
Washington, D.C.

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APPENDIX A: SELENIUM CHEMISTRY

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Selenium in aquatic ecosystems exists in a broad range of oxidation states: (+ VI) in selenates ($HSeO_4^-$, SeO_4^{2-}) and selenic acid (H_2SeO_4), (+ IV) in selenites ($HSeO_3^-$, SeO_3^{2-}) and selenous acid (H_2SeO_3), 0 in elemental selenium, and (-II) in selenides (Se^{2-}, HSe^-), hydrogen selenide (H_2Se), and organic selenides (R_2Se). Selenium also shows some tendency to form catenated species like organic diselenides (RseSeR). Within the normal physiological pH range and the reduction potential range permitted by water, only Se, SeO_3^{2-}, $HSeO_3^-$, and SeO_4^{2-} can exist at thermodynamic equilibrium (Milne 1998). While ionic reactions are expected to be rapid in water, oxidation-reduction reactions may be slow, and the possibility exists for the formation of HSe^- in living systems and some environments where anoxic conditions arise. The parallel behavior of comparable species of sulfur and selenium in living systems has often been observed, but it is important to recognize that their chemical characteristics are different in many ways. For instance, selenate is comparable to chromate in oxidizing strength and far stronger than sulfate [$E^0(SeO_4^{2-}/H_2SeO_3)$ = 1.15 V; $E^0(Cr_2O_7^{2-}/Cr^{3+})$ = 1.33V; $E^0(SO_4^{2-}/H_2SO_3)$ = 0.200V (standard potentials in acid solution: Weast 1969)], whereas selenide is a much stronger reducing agent than sulfide [$E^0(Se/H_2Se)$ = -0.36 V; $E^0[S/H_2S$]= 0.14V)].

1.0 INORGANIC SELENIUM

Selenate usually predominates in well-aerated surface waters, especially those with alkaline conditions. In spite of its oxidizing strength, selenate (SeO_4^{2-}) exhibits considerable kinetic stability in the presence of reducing agents (Cotton and Wilkinson 1988). The radius of SeO_4^{2-} is comparable to that of SO_4^{2-} (Frausto da Silva and Williams 1991), and uptake by cells is expected to take place via the same ion channels or permeases for both anions. Competition between sulfate and selenate uptake has been observed in many species: algae (Riedel and Sanders 1996), aquatic plants (Bailey et al. 1995), crustaceans (Ogle and Knight 1996), fungi (Gharieb et al. 1995), HeLa cells (Yan and Frenkel 1994), and wheat (Richter and Bergmann 1993). Reduced selenate bioconcentration with increasing sulfate concentration has been demonstrated in *Daphnia magna* (Hansen et al. 1993). A significant inverse relationship was shown to exist between acute selenate toxicity to aquatic organisms and ambient sulfate concentrations (Brix et al. 2001a). Competition with selenate has also been observed for phosphate in green algae (Riedel and Sanders 1996), and with chromate and tungstate in anaerobic bacteria (Oremland et al. 1989).

Selenous acid species ($HSeO_3^-$ and SeO_3^{2-}) can predominate in solution under the moderately oxidizing conditions encountered in oxygenated waters. Between pH 3.5 and 9.0 biselenite ion is the predominant ion in water, and at pH values below 7.0, selenites are rapidly reduced to elemental selenium under mildly reducing conditions (Faust 1981), situations that are common in bottom sediments.

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Most selenite salts are less soluble than the corresponding selenates. The extremely low solubility of ferric selenite $Fe_2(SeO_3)_3$ ($K_s = 2.0 \pm 1.7 \times 10^{-31}$), and of the basic ferric selenite $Fe_2(OH)_4SeO_3$ ($K_s = 10^{-61.7}$), is important to the environmental cycling of selenium. Selenites also form stable adsorption complexes with ferric oxides, forming complexes of even lower solubility than the ferric selenites. Under certain conditions, selenite (in contrast to selenate) seems to be completely adsorbed in high amounts by ferric hydroxide and, to a lesser extent, by aluminum hydroxide (Faust 1981). Coprecipitation techniques have been applied for preconcentration of selenium in natural waters, using iron (III) hydroxides, which coprecipitates selectively the selenite, but not the selenate, species in river and sea waters (Yoshii et al. 1977). Alum and iron coagulation precipitation can be used in water treatment processes to remove selenite (Clifford et al. 1986). The low levels of selenium in ocean waters have been attributed to the adsorption of selenite by the oxides of metals, such as iron and manganese (National Academy of Sciences 1976).

Relative to selenate, selenite is more reactive because of its polar character, resulting from the asymmetric electron density of the ion, its basicity (attraction to bond with proton), and its nucleophilicity (attraction to bond to a nucleus using the lone pair electrons of the ion). No evidence has yet been presented to show that $HSeO_3^-$ or SeO_3^{2-} is taken up intact into the cell interior. Evidence indicates that selenite is reduced rapidly, even before uptake in some cases, making it difficult to distinguish between uptake and metabolic processes (Milne 1998). Freshwater phytoplankton process selenate and selenite by different mechanisms, leading to different concentrations within the cell, and the concentrations attained are affected by various chemical and biological factors in the environment (Riedel et al. 1991). These authors suggested that selenate is transported into the cell by a biological process with low affinity, whereas selenite appears to be largely physically adsorbed. Contradictory evidence suggesting that selenite uptake is enzymatically mediated was found with marine phytoplankton (Baines and Fisher 2001). Experimental results supporting the hypothesis that separate accumulation mechanisms for selenate and selenite are present in *D. magna* have been published (Maier et al. 1993). However, while some organisms appear to absorb selenite nonspecifically, specific transport systems exist in other species. Sulfate competition is insignificant in the aquatic plant *Ruppia maritima* (Bailey et al. 1995), and specific uptake systems have been demonstrated in some soft line microorganisms (Heider and Boeck 1993). Selenite uptake in green algae, unlike selenate, is increased substantially at lower pH values, a property that represents another difference between these two anions (Riedel and Sanders 1996). The uptake of inorganic selenium species, selenate and selenite, by the green alga *Chlamydomonas reinhardtii* (Dang) was examined as a function of pH over the range 5 to 9, and in media with varying concentrations of major ions and nutrients using ^{75}Se as a radiotracer. Little difference was noted in the uptake of selenate as a function of pH, with the maximum uptake found at pH 8; however, selenite uptake increased

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substantially at the lower pH values. Differences in speciation are suggested to be the cause of these differences. Selenate exists as the divalent ion SeO_4^{2-} over the range of pH tested; whereas monovalent biselenite ion $HSeO_3^-$ is prevalent at these pH values. At the low end of the pH range, neutral selenous acid may also play a role.

Elemental selenium is not measurably soluble in water. It has been reported that elemental selenium is slowly metabolized by several bacteria (Bacon and Ingledew 1989), and the translocation of elemental selenium into the soft tissue of the marine mollusk *Macoma balthica* has been reported (Luoma et al. 1992). The bioavailability of elemental selenium to *M. balthica* was assessed by feeding the organisms ^{75}Se-labeled sediments in which the elemental selenium was precipitated by microbial dissimilatory reduction. A 22% absorption efficiency of particulate elemental selenium was observed. In view of the insolubility of elemental selenium, uptake may be preceded by air oxidation, or in reducing environments thiols may facilitate the solubilization (Amaratunga and Milne 1994). Elemental selenium can be the dominant fraction in sediments (Zawislanski and McGrath 1998).

Selenium is reduced to hydrogen selenide, H_2Se, or other selenides at relatively low redox potentials. Hydrogen selenide by itself is not expected to exist in the aquatic environment since the Se^0/H_2Se couple falls even below the H^+/H_2 couple. Aqueous solutions of H_2Se are actually unstable in air due to its decomposition into elemental selenium and water. Under moderately reducing conditions, heavy metals are precipitated as the selenides, which have extremely low solubilities. The following are log K_s values of some heavy metal selenides of environmental interest: -11.5 (Mn^{2+}), -26.0 (Fe^{2+}), -60.8 (Cu^+), -48.1 (Cu^{2+}), -29.4 (Zn^{2+}), -35.2 (Cd^{2+}), and -64.5 (Hg^{2+}). The precipitation of selenium as heavy metal selenides can be an important factor affecting the cycling of the element in soils and natural waters.

2.0 ORGANOSELENIUM

Organic selenides (conventionally treated as Se(-II) species) in variable concentrations, usually in the form of free and combined selenomethionine and selenocysteine, are also present in natural surface waters (Fisher and Reinfelder 1991). Dissolved organic selenides may be an important source of selenium for phytoplankton cells, because they can account for ~80% of the dissolved selenium in open ocean surface waters, and for a significant fraction in many other environments as well (Cutter 1989; Cutter and Cutter 1995). Dissolved organoselenium levels of 14.2%, 65% and 66% were measured in samples (one meter depth) from Hyco Reservoir, NC; Robinson Impoundment, SC; and Catfish Lake, NC; respectively (Cutter 1986). The Hyco Reservoir organoselenium was identified as being protein bound.

Organoselenium concentrations were found to range from 10.4% (58.7 μg/L) to 53.7% (1.02 μg/L) of the total selenium present in Lake Creek and Benton Lake, MT surface waters (Zhang and Moore 1996). Organoselenium quite often is measured as the difference between total dissolved selenium

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and the sum of selenite plus selenate, and is therefore not typically characterized. Much more work is needed in the area of specific identification and characterization of the nature of the organic selenides present in aquatic ecosystems. Organoselenium form(s) are much more bioavailable and probably play a very important role in selenium ecotoxic effects (e.g. Besser et al., 1993; Rosetta and Knight 1995).

3.0 DEPARTURE FROM THERMODYNAMIC EQUILIBRIUM

In the highly dynamic natural waters, there is often a departure from thermodynamic equilibrium. In the thermodynamic models, kinetic barriers to equilibrium and biological processes are not adequately considered, and the speciation of selenium in oxidized natural waters is not accurately predicted. Selenate is usually the predominate form in solution; however, selenite and organoselenium can both exist at concentrations higher than predicted (Faust 1981; Luoma et al. 1997). Bioaccumulation by microorganisms, bioproduction and release of organoselenium, and mineralization of particulate selenium forms contribute to the disequilibrium.

4.0 PHYSICAL DISTRIBUTION OF SPECIES IN SURFACE WATER

The physical distribution of various selenium species in surface waters is regulated by:

- sorption to or incorporation in suspended particulate matter (SPM), and
- complexation with inorganic and/or organic colloidal material, such as $(FeO\ OH)_n$ and humic substances (dissolved organic matter, DOM).

Both sorption to SPM and complexation with colloidal matter reduces the bioavailability of the selenium species. The average fraction of selenium associated with the suspended particulate phase (0.45μm filtration) as determined from eleven different studies of various surface waters was found to be 16% (0-39% range) of the total selenium, i.e., an average operationally defined dissolved selenium level of 84% (Table A-1). In the James River, VA, the dissolved inorganic and organic selenium was found to be 77% and 70% associated with colloidal matter, respectively (Takayangi and Wong 1984). A study of lake ecosystems in Finland (Wang et al. 1995) found that 52% of the dissolved selenium was associated with humic substances, and in a similar speciation study of Finnish stream waters, Lahermo et al. (1998) determined that 36% of the selenium was complexed with humic matter. Hence, in various waterbodies physical distribution as well as chemical speciation of selenium must be considered in relationship to bioavailability and aquatic toxicity.

Until recently, the organic selenium fraction has been routinely measured as the difference between total dissolved selenium and the sum of selenite and selenate. Unfortunately, the calculation of this important selenium fraction in water as the difference between the total and measurable inorganic fractions has not permitted this fraction to be fully characterized. New techniques are currently being

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developed which should help the specific identification and characterization of the nature of the organic selenides present in aquatic systems. This work is particularly important because portions of the organic selenium fraction (e.g., selenomethionine) of total dissolved selenium in water have been shown to be much more bioavailable than the other forms of selenium, and therefore this work is also important for understanding the manifestation of selenium ecotoxic effects.

Table A-1. Suspended particulate and dissolved selenium as a function of total selenium in freshwater and marine aquatic ecosystems.

Reference	Waterbody	Particulate Se (% of Total)	Fraction dissolved, fd
Cutter 1989	Carquinez, CA	20 - 40	0.6 - 0.8
Cutter 1986	Hyco Reservoir, NC	0	1
Tanizaki et al. 1992	Japanese Rivers	16	0.84
Luoma et al. 1992	San Francisco Bay, CA	22 - 31	0.69-0.78
Cumbie and VanHorn, 1978	Belews Lake, NC	8	0.92
GLEC 1997	Unnamed Stream, Albright, WV	4	0.96
Wang et al. 1995	Finnish Lakes	10	0.9
Lahermo et al. 1998	Finnish Streams	8	0.92
Hamilton et al. 2001a,b	Adobe Creek, Fruita, CO	18	0.82
Hamilton et al. 2001a,b	North Pond, Fruita, CO	0	1
Hamilton et al. 2001a,b	Fish Ponds, Fruita, CO	7	0.93
Nakamoto and Hassler 1992	Merced River, CA	0	1
Nakamoto and Hassler 1992	Salt Slough, CA	4	0.96
Welsh and Maughan 1994	Cibola Lake, CA	39	0.62
Welsh and Maughan 1994	Hart Mine Marsh, Blythe, CA	6	0.94
Welsh and Maughan 1994	Colorado River, Blythe, CA	11	0.89
Welsh and Maughan 1994	Palo Verda Oxbow Lake, CA	33	0.67
Welsh and Maughan 1994	Palo Verda Outfall Drain, CA	0	1
Welsh and Maughan 1994	Pretty Water Lake, CA	21	0.79

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APPENDIX B: CONVERSIONS

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1.0 CONVERSION OF WET TO DRY TISSUE WEIGHT

1.1 Methodology

Conversion factors (*CF*) derived from selenium measurements were calculated using concentrations expressed as dry weights (µg/g dry weight). The majority of tissue and whole-body selenium concentrations were reported as dry weights. Measurements reported as wet weight were converted to equivalent dry weights using available percent moisture data for the relevant species and tissue type.

Species-specific percent moisture data for muscle tissue were available for bluegill (Gillespie and Baumann 1986; Nakamoto and Hassler 1992), rainbow trout (Seiler and Skorupa 2001), and for a composite average of nine fish species (May et al. 2000). Species specific percent moisture data for ovaries were available for bluegill (Gillespie and Baumann 1986; Nakamoto and Hassler 1992), fathead minnow (GEI Associates 2008; Rickwood et al. 2008), and rainbow trout (Seiler and Skorupa 2001). Species-specific % moisture data for whole-body tissues were available for bluegill (USGS NCBP).

Measurements reported as wet weight were converted to equivalent dry weights using available percent moisture data for the relevant species and tissue type. If percent moisture data were unavailable for a fish species, percent moisture data for a similar species (i.e., same genus or, if unavailable, same family) were used. Table B-1a lists percent moisture by tissue type, species, data source, and the target species and study for which the % moisture data were used to convert from wet to dry weight. Table B-1b is a list of 38 freshwater fish species and their percent solids and moisture. Although these data were not needed for wet to dry weight conversion in any of the studies in this document, they are provided here as a potential resource.

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Table B-1a. Percent moisture, by species and tissue type.

% Moisture Data Source		% Moisture by Tissue			Conversion Applied to	
Species	**Study**	**Whole-body**	**Muscle**	**Ovary**	**Species**	**Study**
Used in derivation of FCV						
Rainbow trout	Seiler & Skorupa 2001			61.20	Rainbow trout	Holm et al. 2005
Rainbow trout	Seiler & Skorupa 2001			61.20	Brook trout	Holm et al. 2005
Fathead minnow	Average of GEI Assoc. 2008; Rickwood et al. 2008			75.30	Fathead minnow	Schultz and Hermanutz 1990
Bluegill	Average of Gillespie & Baumann 1986 and Nakamoto & Hassler 1992			76.00	Bluegill	Hermanutz et al. 1996
Avg of 9 spp	May et al. 2000		78.4		Striped bass	Coughlan and Velte 1989
Used in conversion of FCV in egg/ovary to whole-body Se concentrations						
Bluegill	USGS NCBP	74.80			Bluegill	Hermanutz et al. 1996
Bluegill	May et al. 2000		80.09		Bluegill	Hermanutz et al. 1996
Bluegill	Average of Gillespie & Baumann 1986 and Nakamoto & Hassler 1992			76.00	Bluegill	Hermanutz et al. 1996
Rainbow trout	May et al. 2000		77.54		Brook Trout	Holm et al. 2005
Rainbow trout	Seiler & Skorupa 2001			61.20	Brook Trout	Holm et al. 2005
Rainbow trout	May et al. 2000		77.54		Rainbow Trout	Holm et al. 2005
Rainbow trout	Seiler & Skorupa 2001			61.20	Rainbow Trout	Holm et al. 2005
Rainbow trout	May et al. 2000		77.54		Rainbow Trout	Casey & Siwik 2000
Rainbow trout	Seiler & Skorupa 2001			61.20	Rainbow Trout	Casey & Siwik 2000

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Table B-1b. Percent solids and moisture for whole body fish tissues by species.
Data provided by GEI Consultants (GEI 2014).

Species	Average % solids	Count	Min	Max	Avg % moisture
Black bullhead	23.18	6	18.4	27	76.82
Blacknose dace	26.25	44	21.3	31.2	73.75
Bluntnose minnow	25.2	3	23.8	25.9	74.8
Brook stickleback	24.18	57	19.3	27.8	75.82
Carp	21.8	6	21.1	22.8	78.2
Central Stoneroller	25.38	174	17.2	33.7	74.62
Common carp	24.54	62	17.4	43	75.64
Creek chub	23.29	306	16.5	29.3	76.71
Fantail darter	27.71	15	19.5	72.3	72.29
Fathead minnow	23.36	298	15.3	100	76.64
Green sunfish	23.87	150	7.9	29	76.13
Greenside darter	25.55	11	21.7	27	74.45
Johnny darter	28.3	1	--	--	71.7
Largemouth bass	24.26	64	20.6	28.8	75.74
Log perch	23.05	2	22.3	23.8	76.95
Longnose dace	26.75	17	23.4	31.3	73.25
Mimic shiner	24.9	2	24	25.8	75.1
Mosquitofish	23.96	8	22.5	24	76.04
Northern hogsucker	23.93	113	17	39	76.07
Plains killifish	24.5	9	23.3	26.1	75.5
Rainbow darter	27.17	85	12	33.3	72.83
Red shiner	26.93	46	20.9	34.8	73.07
Redside shiner	24.44	8	21.8	26.9	75.56
River chub	24.8	4	22.9	27.3	75.2
River redhorse	20.8	1	--	--	79.2
Rock bass	25.05	24	21.2	29.3	74.95
Rosyface shiner	30.25	2	27.6	32.9	69.75
Rosyside shiner	24.54	5	23.1	25.7	75.46
Sand shiner	26.03	83	20.7	30.7	73.97
Sauger	23	1	--	--	77
Silver shiner	23.4	7	22.3	24.6	76.6
Smallmouth bass	25.78	12	22.7	28.1	74.22
Speckled dace	26.04	35	21	31.2	73.96
Striped shiner	22.9	64	18.2	28.8	77.1
Sunfish	23.2	1	-	-	76.8
Variegated darter	27.45	13	21.7	30.3	72.55
White sucker	22.63	246	16.5	28.4	77.37
Yellow perch	26.02	5	24	28.4	73.98
Grand total	24.85	1990			75.15

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2.0 DERIVATION OF TISSUE CONVERSION FACTORS

2.1 Methodology

EPA used a mechanistic bioaccumulation modeling approach to derive a mathematical relationship between the concentration of selenium in water to the concentration of selenium in the eggs and ovaries of fish. This approach characterizes selenium bioaccumulation as a series of steps representing the phase transformation of selenium from dissolved to particulate form, and then the trophic transfer of selenium through aquatic food webs to invertebrates and fish. The final step in this process is the transfer of selenium into eggs and ovary tissue.

Equation 1 quantitatively models the transfer of selenium through each environmental compartment as a series of site-specific and species-specific parameters. The parameter *CF* in Equation 1 represents the species-specific proportion of selenium in egg or ovary tissue relative to the average concentration of selenium in all body tissues and is given as:

$$CF = \frac{C_{egg-ovary}}{C_{whole-body}} \qquad \text{(Equation 1)}$$

Where:

CF	=	Whole-body to egg-ovary conversion factor (dimensionless ratio).
$C_{egg\text{-}ovary}$	=	Selenium concentration in the eggs or ovaries of fish (µg/g dw)
$C_{whole\text{-}body}$	=	Selenium concentration in the whole body of fish (µg/g dw).

EPA derived species-specific conversion factor (*CF*) values using the same methods that were used to derive species-specific *TTF* values from field data. To derive whole-body to egg-ovary *CF* values, the EPA defined matched pairs of selenium measurements from the whole-body and from the eggs or ovaries measured from the same individual fish or from matched composite samples. Egg-ovary concentration was defined as a measurement from either the eggs or the ovaries. If multiple measurements from both eggs and ovaries of the same individual or matched composite sample were available, the average value was used. EPA first confirmed a statistical relationship between egg-ovary and whole body selenium for each species using ordinary least squares (OLS) linear regression. If the regression resulted in a statistically significant ($P<0.05$) positive slope, EPA calculated the ratio of the egg-ovary to whole body selenium concentration for each matched pair of measurements and used the median as the *CF* value for that species.

EPA derived *CF* values from selenium measurements in units of µg/g dry weight. The majority of tissue and whole body selenium concentrations were reported as dry weights. Measurements reported as

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wet weight were converted to equivalent dry weights using available percent moisture data for the relevant species and tissue type. If percent moisture data were unavailable for a fish species, percent moisture data for a similar species (i.e., same genus or, if unavailable, same family) were used. A listing of percent moisture concentrations by species and target tissue are provided in Table B-1a.

For those species without sufficient data to directly calculate an egg-ovary to whole body *CF*, but which had sufficient data to calculate a conversion factor for either egg-ovary to muscle or whole body to muscle, EPA followed a two stage approach based on taxonomic similarity, similar to that described above. If a fish species had species specific egg-ovary to muscle conversion factor, but no whole body data with which to calculate an egg to whole body *CF*, then available data would be used to estimate a muscle to whole body conversion factor for that species based on taxonomic relatedness. The estimated muscle to whole body factor would be multiplied by the directly measured egg-ovary to muscle factor to estimate an egg-ovary to whole body *CF* for that species. For example, rainbow trout has a species specific egg-ovary to muscle conversion factor of 1.92, but does not have a species specific egg-ovary to whole body *CF*. Using the taxonomic approach described above, the most closely related taxa to rainbow trout with muscle to whole body conversion factors are in the class Actinopterygii. The median conversion factor for the 8 species within that class is 1.27. The final egg-ovary to whole body *CF* for rainbow trout is 2.44 (Table B-6), or 1.92 x 1.27.

The EPA developed species-specific egg-ovary to muscle and muscle to whole-body correction factors following the procedure described for whole-body to egg-ovary conversion factors. The EPA obtained matched pairs of selenium measurements in the whole-body and muscle filets and matched pairs of selenium measurements in muscle filets and whole-body from published scientific literature. EPA first confirmed a statistical relationship between the two tissue types for each species using OLS linear regression. If the regression resulted in a significant fit with a positive slope, the EPA calculated the ratio of each matched pair of measurements and then calculated the median ratio.

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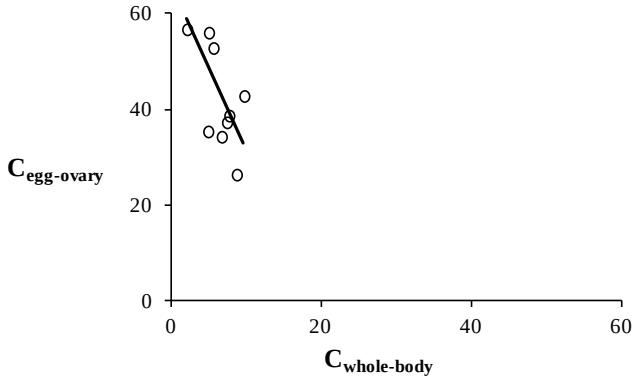
2.2 CF values calculated directly from whole-body and egg-ovary selenium measurements

$C_{whole\text{-}body}$ = Selenium concentration in all tissues (µg/g dw)
C_{egg} = Selenium concentration in eggs (µg/g dw)
C_{ovary} = Selenium concentration in ovary tissue (µg/g dw)
$C_{egg\text{-}ovary}$ = Average selenium concentration in eggs and ovaries $\left(\frac{C_{egg} + C_{ovary}}{2}\right)$

Ratio = $\frac{C_{egg-ovary}}{C_{whole-body}}$

Black bullhead (*Ameiurus melas*)

Study	$C_{whole\text{-}body}$	C_{egg}	C_{ovary}	$C_{egg\text{-}ovary}$	Ratio
Osmundson et al. 2007	5.30	-	64.30	64.30	12.13
Osmundson et al. 2007	4.80	-	35.40	35.40	7.38
Osmundson et al. 2007	5.50	-	52.80	52.80	9.60
Osmundson et al. 2007	4.90	-	56.00	56.00	11.43
Osmundson et al. 2007	9.60	-	42.80	42.80	4.46
Osmundson et al. 2007	7.60	-	38.70	38.70	5.09
Osmundson et al. 2007	7.30	-	37.30	37.30	5.11
Osmundson et al. 2007	6.60	-	34.30	34.30	5.20
Osmundson et al. 2007	8.60	-	26.40	26.40	3.07
Osmundson et al. 2007	2.00	-	56.70	56.70	28.35
Osmundson et al. 2007	5.30	-	64.30	64.30	12.13



Median ratio: 6.29

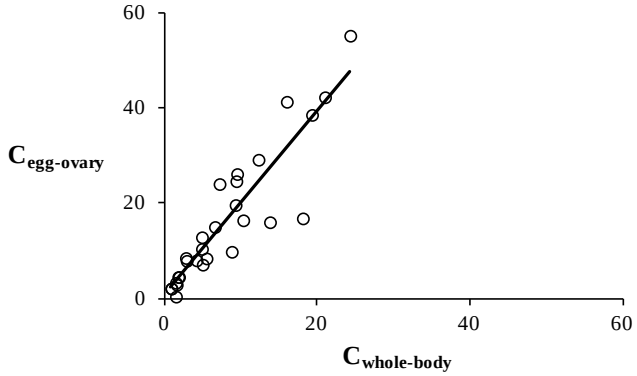
R^2: 0.37
F: 4.67
df: 8
P: 0.046

Not used because negative slope.

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Bluegill (*Lepomis macrochirus*)

Study	$C_{whole-body}$	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Coyle et al. 1993	0.90	1.90	2.10	2.00	2.22
Coyle et al. 1993	2.90	7.30	8.30	7.80	2.69
Coyle et al. 1993	4.90	13.00	12.50	12.75	2.60
Coyle et al. 1993	7.20	22.80	25.00	23.90	3.32
Coyle et al. 1993	16.00	41.30	41.00	41.15	2.57
Doroshov et al. 1992	1.60	2.80	-	2.80	1.75
Doroshov et al. 1992	5.50	8.30	-	8.30	1.51
Doroshov et al. 1992	9.30	19.50	-	19.50	2.10
Doroshov et al. 1992	19.30	38.40	-	38.40	1.99
Hermanutz et al. 1996	1.50	-	0.30	0.30	0.20
Hermanutz et al. 1996	18.10	-	16.70	16.70	0.92
Hermanutz et al. 1996	1.90	-	4.40	4.40	2.32
Hermanutz et al. 1996	2.80	-	8.40	8.40	3.00
Hermanutz et al. 1996	12.30	-	29.00	29.00	2.36
Hermanutz et al. 1996	9.40	-	24.50	24.50	2.61
Hermanutz et al. 1996	1.50	-	3.20	3.20	2.13
Hermanutz et al. 1996	4.90	-	10.30	10.30	2.10
Hermanutz et al. 1996	21.00	-	42.10	42.10	2.00
Hermanutz et al. 1996	24.30	-	55.00	55.00	2.26
Hermanutz et al. 1996	5.00	-	7.00	7.00	1.40
Hermanutz et al. 1996	9.50	-	26.00	26.00	2.74
Hermanutz et al. 1996	6.60	-	14.90	14.90	2.26
Hermanutz et al. 1996	1.80	-	4.40	4.40	2.44
Hermanutz et al. 1996	4.20	-	7.90	7.90	1.88
Hermanutz et al. 1996	10.30	-	16.30	16.30	1.58
Hermanutz et al. 1996	13.80	-	15.90	15.90	1.15
Osmundson et al. 2007	8.80	-	9.70	9.70	1.10

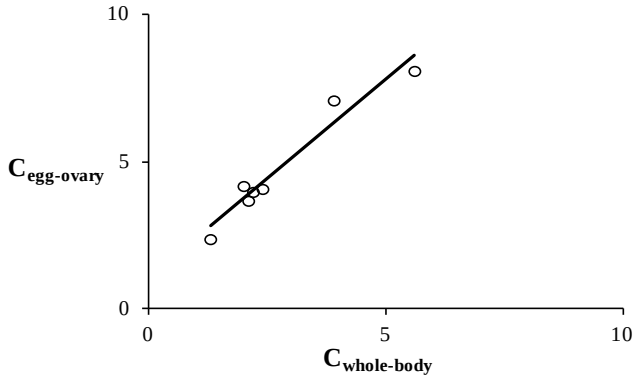


Median ratio: 2.13

R^2: 0.82
F: 110.9
df: 25
P: < 0.001

Bluehead sucker (*Catostomus discobolus*)

Study	$C_{whole-body}$	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Osmundson et al. 2007	1.30	-	2.40	2.40	1.85
Osmundson et al. 2007	2.00	-	4.20	4.20	2.10
Osmundson et al. 2007	2.10	-	3.70	3.70	1.76
Osmundson et al. 2007	2.20	-	4.00	4.00	1.82
Osmundson et al. 2007	2.40	-	4.10	4.10	1.71
Osmundson et al. 2007	3.90	-	7.10	7.10	1.82
Osmundson et al. 2007	5.60	-	8.10	8.10	1.45



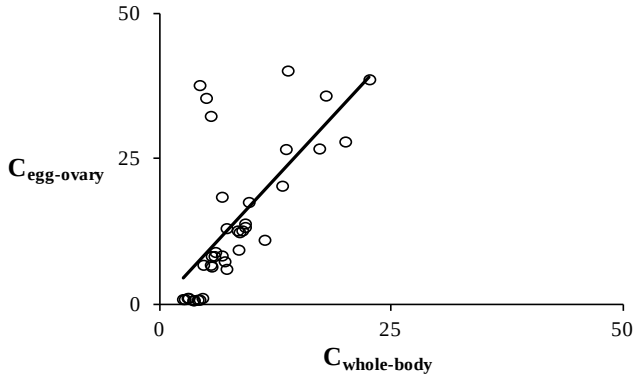
Median ratio: 1.82

R^2: 0.95
F: 88.9
df: 5
P: <0.001

Brown trout (*Salmo trutta*)

Study	$C_{whole-body}$	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Formation 2011 Saratoga fish hatchery	3.60	0.80	-	0.80	0.22
Formation 2011 Saratoga fish hatchery	4.10	0.90	-	0.90	0.22
Formation 2011 Saratoga fish hatchery	3.70	0.80	-	0.80	0.22
Formation 2011 Saratoga fish hatchery	4.30	0.90	-	0.90	0.21
Formation 2011 Saratoga fish hatchery	3.00	1.20	-	1.20	0.40
Formation 2011 Saratoga fish hatchery	3.10	1.20	-	1.20	0.39
Formation 2011 Saratoga fish hatchery	2.70	1.00	-	1.00	0.37
Formation 2011 Saratoga fish hatchery	2.50	1.00	-	1.00	0.40
Formation 2011 Saratoga fish hatchery	8.90	12.80	-	12.80	1.44
Formation 2011	13.80	40.30	-	40.30	2.92
Formation 2011	17.90	36.00	-	36.00	2.01
Formation 2011	13.60	26.80	-	26.80	1.97
Formation 2011	17.20	26.90	-	26.90	1.56
Formation 2011	6.70	18.60	-	18.60	2.78
Formation 2011	9.60	17.70	-	17.70	1.84
Formation 2011	22.60	38.80	-	38.80	1.72
Formation 2011	7.20	13.20	-	13.20	1.83
Formation 2011	9.20	13.40	-	13.40	1.46

Brown trout (*Salmo trutta*)					
Formation 2011	13.20	20.50	-	20.50	1.55
Formation 2011	8.60	12.50	-	12.50	1.45
Formation 2011	11.30	11.20	-	11.20	0.99
Formation 2011	20.00	28.10	-	28.10	1.41
Formation 2011	8.40	12.80	-	12.80	1.52
Formation 2011	5.60	8.40	-	8.40	1.50
Formation 2011	6.70	8.50	-	8.50	1.27
Formation 2011	5.90	8.40	-	8.40	1.42
Formation 2011	6.00	9.10	-	9.10	1.52
Formation 2011	7.00	7.50	-	7.50	1.07
Formation 2011	5.60	6.60	-	6.60	1.18
Formation 2011	4.70	6.90	-	6.90	1.47
Formation 2011	7.20	6.20	-	6.20	0.86
Formation 2011	9.20	14.00	-	14.00	1.52
Formation 2011	5.50	6.90	-	6.90	1.25
Formation 2011	8.50	9.50	-	9.50	1.12
Osmundson et al. 2007	4.60	-	1.20	1.20	0.26
Osmundson et al. 2007	4.30	-	37.80	37.80	8.79
Osmundson et al. 2007	5.00	-	35.60	35.60	7.12
Osmundson et al. 2007	5.50	-	32.50	32.50	5.91

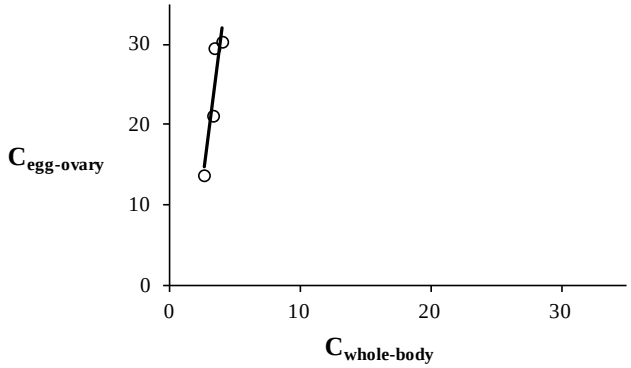


Median ratio: 1.45

R^2: 0.47
F: 31.3
df: 36
P: <0.001

Channel catfish (*Ictalurus punctatus*)

Study	$C_{whole-body}$	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Osmundson et al. 2007	3.40	-	29.50	29.50	8.68
Osmundson et al. 2007	3.30	-	21.10	21.10	6.39
Osmundson et al. 2007	2.60	-	13.70	13.70	5.27
Osmundson et al. 2007	4.00	-	30.30	30.30	7.58



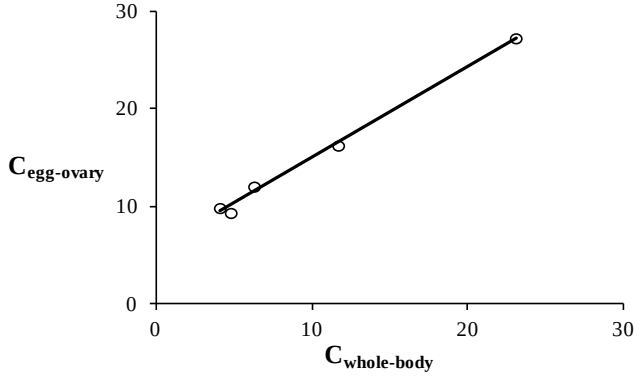
Median ratio: 6.98

R^2: 0.82
F: 9.1
df: 2
P: 0.099

Not used because P > 0.05.

Common carp (*Cyprinus carpio*)

Study	$C_{whole-body}$	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Osmundson et al. 2007	6.30	-	12.10	12.10	1.92
Osmundson et al. 2007	4.80	-	9.40	9.40	1.96
Osmundson et al. 2007	11.70	-	16.30	16.30	1.39
Osmundson et al. 2007	23.10	-	27.30	27.30	1.18
Osmundson et al. 2007	4.10	-	9.90	9.90	2.41

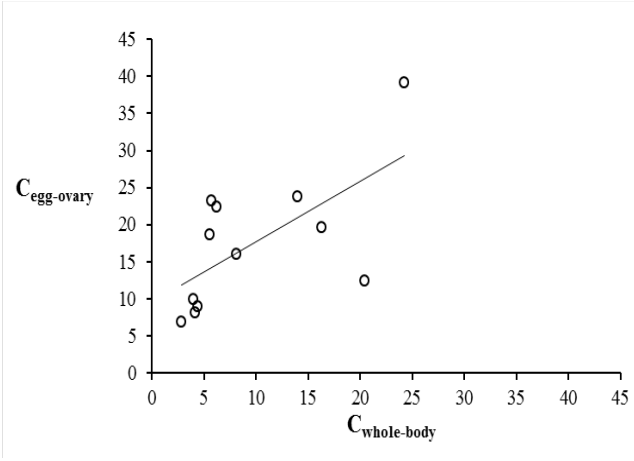


Median ratio: 1.92

R^2: 0.96
F: 584.8
df: 3
P: <0.001

Creek chub (*Semotilus atromaculatus*)

Study	$C_{whole-body}$	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
GEI 2014	2.89	6.86	-	6.86	2.37
GEI 2014	4	9.94	-	9.94	2.49
GEI 2014	4.14	8.1	-	8.1	1.96
GEI 2014	4.46	8.98	-	8.98	2.01
GEI 2014	5.57	18.63	-	18.63	3.34
GEI 2014	6.23	22.35	-	22.35	3.59
GEI 2014	24.26	39.07	-	39.07	1.61
GEI 2014	20.49	12.38	-	12.38	0.60
GEI 2014	16.33	19.59	-	19.59	1.20
GEI 2014	14.03	23.78	-	23.78	1.69
GEI 2014	5.71	23.21	-	23.21	4.06
GEI 2014	8.17	16.03	-	16.03	1.96



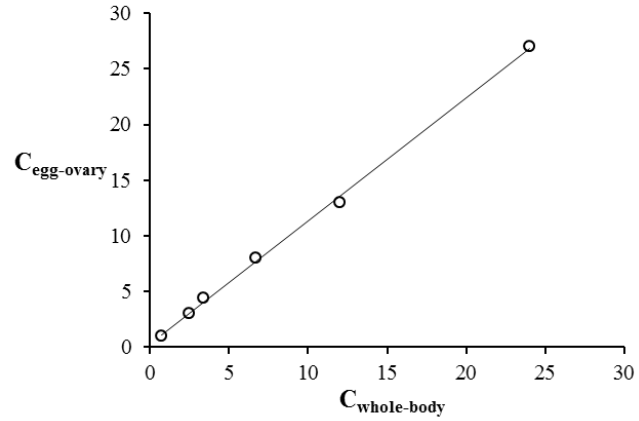
Median ratio: 1.99

R^2: 0.82
F: 7.09
df: 10
P: 0.012

Desert pupfish (*Cyprinodon macularius*)

Study	$C_{whole-body}$	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Besser et al. 2012	0.75	1	-	1	1.33
Besser et al. 2012	2.5	3	-	3	1.20
Besser et al. 2012	3.4	4.4	-	4.4	1.29
Besser et al. 2012	6.7	8	-	8	1.19
Besser et al. 2012	12	13	-	13	1.08
Besser et al. 2012	24	27	-	27	1.13

Desert pupfish (*Cyprinodon macularius*)



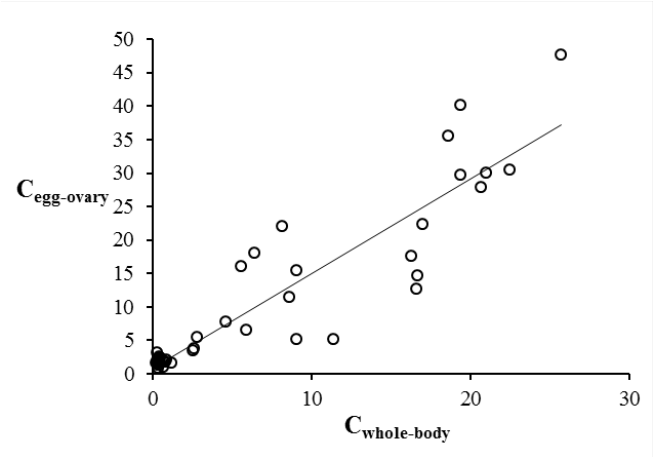
Median ratio: 1.20

R^2: 1.00
F: 194.3
df: 4
P: <0.001

Cutthroat trout (*Oncorhynchus clarkii*)

Study	$C_{whole-body}$	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Hardy 2005	0.70	1.00	-	1.00	1.43
Hardy 2005	2.60	3.80	-	3.80	1.46
Hardy 2005	2.80	5.50	-	5.50	1.96
Hardy 2005	6.40	18.00	-	18.00	2.81
Hardy 2005	1.20	1.60	-	1.60	1.33
Hardy 2005	4.60	7.80	-	7.80	1.70
Hardy 2005	5.90	6.60	-	6.60	1.12
Hardy 2005	9.10	5.10	-	5.10	0.56
Hardy 2005	11.40	5.20	-	5.20	0.46
Hardy 2005	5.60	16.00	-	16.00	2.86
Formation 2012	2.56	3.43	-	3.43	1.34
Formation 2012	16.3	17.6	-	17.6	1.08
Formation 2012	20.7	27.9	-	27.9	1.35
Formation 2012	19.4	29.7	-	29.7	1.53
Formation 2012	17	22.3	-	22.3	1.31
Formation 2012	16.7	14.6	-	14.6	0.87
Formation 2012	25.7	47.6	-	47.6	1.85
Formation 2012	8.17	22	-	22	2.69
Formation 2012	9.07	15.4	-	15.4	1.70
Formation 2012	8.63	11.4	-	11.4	1.32
Formation 2012	16.6	12.7	-	12.7	0.77
Formation 2012	19.4	40.1	-	40.1	2.07
Formation 2012	21	30	-	30	1.43
Formation 2012	18.6	35.6	-	35.6	1.91
Formation 2012	22.5	30.5	-	30.5	1.36
Formation 2012 Henry Lake fish hatchery	0.4	1.65	-	1.65	4.13

Cutthroat trout (*Oncorhynchus clarkii*)					
Formation 2012 Henry Lake fish hatchery	0.45	2.03	-	2.03	4.51
Formation 2012 Henry Lake fish hatchery	0.44	2.48	-	2.48	5.64
Formation 2012 Henry Lake fish hatchery	0.36	1.36	-	1.36	3.78
Formation 2012 Henry Lake fish hatchery	0.5	2.33	-	2.33	4.66
Formation 2012 Henry Lake fish hatchery	0.36	0.83	-	0.83	2.31
Formation 2012 Henry Lake fish hatchery	0.44	2.26	-	2.26	5.14
Formation 2012 Henry Lake fish hatchery	0.28	1.87	-	1.87	6.68
Formation 2012 Henry Lake fish hatchery	0.44	1.98	-	1.98	4.50
Formation 2012 Henry Lake fish hatchery	0.43	1.34	-	1.34	3.12
Formation 2012 Henry Lake fish hatchery	0.31	3.23	-	3.23	10.42
Formation 2012 Henry Lake fish hatchery	0.23	1.58	-	1.58	6.87
Formation 2012 Henry Lake fish hatchery	0.72	1.93	-	1.93	2.68
Formation 2012 Henry Lake fish hatchery	0.73	1.79	-	1.79	2.45
Formation 2012 Henry Lake fish hatchery	0.91	2.06	-	2.06	2.26
Formation 2012 Henry Lake fish hatchery	0.85	1.74	-	1.74	2.05



Median ratio: 1.96

R^2: 0.83
F: 194.3
df: 39
P: <0.001

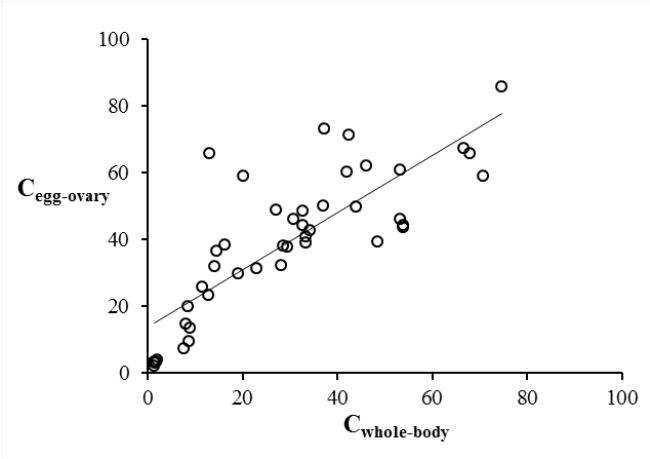
Fathead minnow (*Pimephales promelas*)					
Study	**$C_{whole\text{-}body}$**	**C_{egg}**	**C_{ovary}**	**$C_{egg\text{-}ovary}$**	**Ratio**
GEI 2014	2.04	3.81	-	3.81	1.87
GEI 2014	1.39	2.23	-	2.23	1.60
GEI 2014	1.85	3.31	-	3.31	1.79
GEI 2014	1.32	3.43	-	3.43	2.60
GEI 2014	1.55	3.08	-	3.08	1.99
GEI 2014	37.13	50.06	-	50.06	1.35
GEI 2014	29.54	37.77	-	37.77	1.28
GEI 2014	33.32	40.82	-	40.82	1.23
GEI 2014	28.26	32.23	-	32.23	1.14
GEI 2014	30.74	46.21	-	46.21	1.50

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Fathead minnow (*Pimephales promelas*)					
GEI 2014	53.17	60.84	-	60.84	1.14
GEI 2014	48.52	39.28	-	39.28	0.81
GEI 2014	53.81	44.28	-	44.28	0.82
GEI 2014	53.2	46.21	-	46.21	0.87
GEI 2014	54.01	43.51	-	43.51	0.81
GEI 2014	12.93	23.18	-	23.18	1.79
GEI 2014	8.19	14.67	-	14.67	1.79
GEI 2014	14.25	32.04	-	32.04	2.25
GEI 2014	8.65	19.95	-	19.95	2.31
GEI 2014	16.33	38.51	-	38.51	2.36
GEI 2014	7.69	7.39	-	7.39	0.96
GEI 2014	19.05	29.69	-	29.69	1.56
GEI 2014	8.78	9.55	-	9.55	1.09
GEI 2014	14.68	36.58	-	36.58	2.49
GEI 2014	9.02	13.63	-	13.63	1.51
GEI 2014	46.17	61.99	-	61.99	1.34
GEI 2014	41.97	60.07	-	60.07	1.43
GEI 2014	34.33	42.74	-	42.74	1.24
GEI 2014	33.4	38.89	-	38.89	1.16
GEI 2014	42.53	71.24	-	71.24	1.68
GEI 2014	74.56	85.87	-	85.87	1.15
GEI 2014	67.94	65.85	-	65.85	0.97
GEI 2014	70.85	58.91	-	58.91	0.83
GEI 2014	43.93	49.67	-	49.67	1.13
GEI 2014	66.57	67.39	-	67.39	1.01
GEI 2014	20.21	58.91	-	58.91	2.91
GEI 2014	13.08	65.85	-	65.85	5.03
GEI 2014	23.02	31.38	-	31.38	1.36
GEI 2014	11.55	25.72	-	25.72	2.23
GEI 2014	32.8	48.52	-	48.52	1.48
GEI 2014	27.17	48.9	-	48.9	1.80
GEI 2014	28.54	38.04	-	38.04	1.33
GEI 2014	37.2	73.16	-	73.16	1.97
GEI 2014	32.79	44.28	-	44.28	1.35
GEI 2014	46.17	61.99	-	61.99	1.87

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Fathead minnow (*Pimephales promelas*)

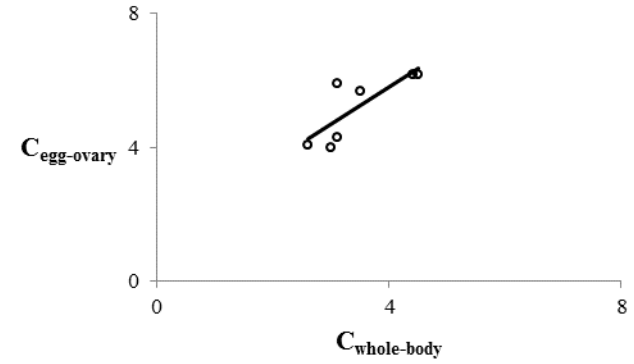


Median ratio: 1.40

R^2: 0.86
F: 81.4
df: 42
P: <0.001

Flannelmouth sucker (*Catostomus latipinnis*)

Study	$C_{whole\text{-}body}$	C_{egg}	C_{ovary}	$C_{egg\text{-}ovary}$	Ratio
Osmundson et al. 2007	3.00	-	4.00	4.00	1.33
Osmundson et al. 2007	2.60	-	4.10	4.10	1.58
Osmundson et al. 2007	3.10	-	5.90	5.90	1.90
Osmundson et al. 2007	3.10	-	4.30	4.30	1.39
Osmundson et al. 2007	3.50	-	5.70	5.70	1.63
Osmundson et al. 2007	4.40	-	6.20	6.20	1.41
Osmundson et al. 2007	4.50	-	6.20	6.20	1.38



Median ratio: 1.41

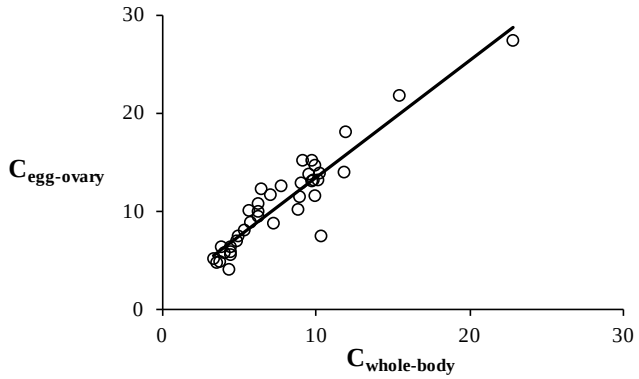
R^2: 0.65
F: 9.2
df: 5
P: 0.021

Green sunfish (*Lepomis cyanellus*)

Study	$C_{whole-body}$	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Osmundson et al. 2007	22.80	-	27.40	27.40	1.20
Osmundson et al. 2007	8.80	-	10.20	10.20	1.16
Osmundson et al. 2007	15.40	-	21.80	21.80	1.42
Osmundson et al. 2007	4.80	-	7.00	7.00	1.46
Osmundson et al. 2007	5.70	-	8.90	8.90	1.56
Osmundson et al. 2007	4.40	-	6.40	6.40	1.45
Osmundson et al. 2007	3.80	-	6.40	6.40	1.68
Osmundson et al. 2007	11.90	-	18.10	18.10	1.52
Osmundson et al. 2007	6.40	-	12.30	12.30	1.92
Osmundson et al. 2007	9.50	-	13.80	13.80	1.45
Osmundson et al. 2007	9.10	-	15.20	15.20	1.67
Osmundson et al. 2007	6.20	-	10.80	10.80	1.74
Osmundson et al. 2007	7.00	-	11.70	11.70	1.67
Osmundson et al. 2007	7.70	-	12.60	12.60	1.64
Osmundson et al. 2007	6.20	-	10.00	10.00	1.61
Osmundson et al. 2007	10.20	-	13.90	13.90	1.36
Osmundson et al. 2007	9.70	-	15.20	15.20	1.57
Osmundson et al. 2007	9.90	-	14.70	14.70	1.48
Osmundson et al. 2007	7.20	-	8.80	8.80	1.22
Osmundson et al. 2007	9.00	-	12.90	12.90	1.43
Osmundson et al. 2007	9.70	-	13.10	13.10	1.35
Osmundson et al. 2007	8.90	-	11.50	11.50	1.29
Osmundson et al. 2007	9.80	-	13.20	13.20	1.35
Osmundson et al. 2007	9.90	-	11.60	11.60	1.17
Osmundson et al. 2007	10.30	-	7.50	7.50	0.73
Osmundson et al. 2007	5.30	-	8.10	8.10	1.53
Osmundson et al. 2007	10.10	-	13.20	13.20	1.31
Osmundson et al. 2007	11.80	-	14.00	14.00	1.19
Osmundson et al. 2007	3.30	-	5.20	5.20	1.58
Osmundson et al. 2007	4.00	-	5.80	5.80	1.45
Osmundson et al. 2007	4.30	-	4.10	4.10	0.95
Osmundson et al. 2007	3.70	-	4.90	4.90	1.32
Osmundson et al. 2007	6.20	-	9.50	9.50	1.53
Osmundson et al. 2007	3.50	-	4.80	4.80	1.37
Osmundson et al. 2007	4.40	-	5.60	5.60	1.27
Osmundson et al. 2007	5.60	-	10.10	10.10	1.80
Osmundson et al. 2007	4.90	-	7.50	7.50	1.53
Osmundson et al. 2007	4.40	-	5.90	5.90	1.34

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Green sunfish (*Lepomis cyanellus*)

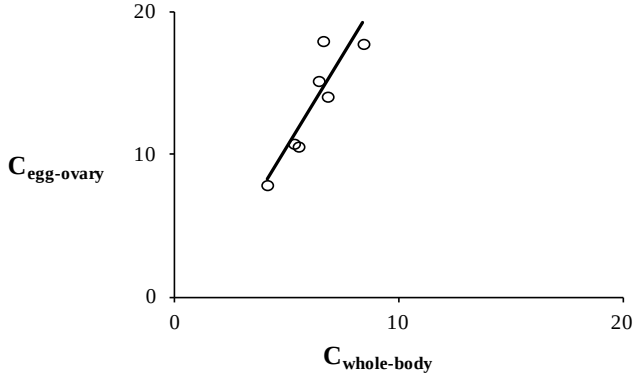


Median ratio: 1.45

R^2: 0.87
F: 240.0
df: 36
P: < 0.001

Roundtail chub (*Gila robusta*)

Study	$C_{whole\text{-}body}$	C_{egg}	C_{ovary}	$C_{egg\text{-}ovary}$	Ratio
Osmundson et al. 2007	4.10	-	7.90	7.90	1.93
Osmundson et al. 2007	5.30	-	10.80	10.80	2.04
Osmundson et al. 2007	6.40	-	15.20	15.20	2.38
Osmundson et al. 2007	6.80	-	14.10	14.10	2.07
Osmundson et al. 2007	5.50	-	10.60	10.60	1.93
Osmundson et al. 2007	6.60	-	18.00	18.00	2.73
Osmundson et al. 2007	8.40	-	17.80	17.80	2.12

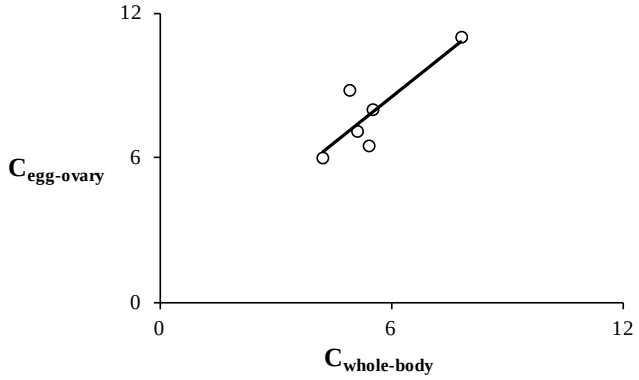


Median ratio: 2.07

R^2: 0.80
F: 20.4
df: 5
P: 0.004

Smallmouth bass (*Micropterus dolomieu*)

Study	$C_{whole-body}$	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Osmundson et al. 2007	4.20	-	6.00	6.00	1.43
Osmundson et al. 2007	5.50	-	8.00	8.00	1.45
Osmundson et al. 2007	5.40	-	6.50	6.50	1.20
Osmundson et al. 2007	7.80	-	11.00	11.00	1.41
Osmundson et al. 2007	5.10	-	7.10	7.10	1.39
Osmundson et al. 2007	4.90	-	8.80	8.80	1.80



Median ratio: 1.42

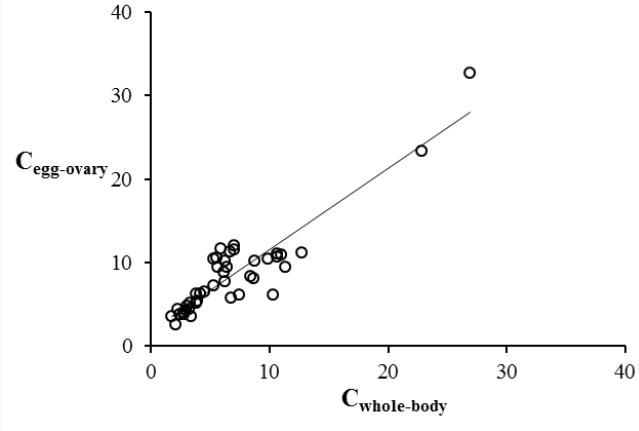
R2: 0.73
F: 10.6
df: 4
P: 0.026

White sucker (*Catostomus commersonii*)

Study	$C_{whole-body}$	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Osmundson et al. 2007	3.80	-	6.20	6.20	1.63
Osmundson et al. 2007	4.20	-	6.20	6.20	1.48
Osmundson et al. 2007	3.30	-	5.20	5.20	1.58
Osmundson et al. 2007	4.50	-	6.50	6.50	1.44
Osmundson et al. 2007	6.30	-	7.70	7.70	1.22
Osmundson et al. 2007	6.80	-	5.80	5.80	0.85
Osmundson et al. 2007	11.00	-	10.90	10.90	0.99
Osmundson et al. 2007	12.70	-	11.20	11.20	0.88
Osmundson et al. 2007	5.70	-	9.40	9.40	1.65
Osmundson et al. 2007	3.90	-	5.40	5.40	1.38
Osmundson et al. 2007	3.80	-	5.10	5.10	1.34
Osmundson et al. 2007	9.90	-	10.40	10.40	1.05
Osmundson et al. 2007	5.30	-	10.40	10.40	1.96
Osmundson et al. 2007	10.70	-	11.00	11.00	1.03
Osmundson et al. 2007	5.90	-	11.70	11.70	1.98
Osmundson et al. 2007	7.00	-	11.60	11.60	1.66
Osmundson et al. 2007	6.40	-	9.40	9.40	1.47
Osmundson et al. 2007	6.30	-	10.20	10.20	1.62
Osmundson et al. 2007	5.30	-	7.30	7.30	1.38
Osmundson et al. 2007	6.20	-	8.90	8.90	1.44

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White sucker (*Catostomus commersonii*)					
Osmundson et al. 2007	5.60	-	10.50	10.50	1.88
Osmundson et al. 2007	8.80	-	10.20	10.20	1.16
Osmundson et al. 2007	8.70	-	8.10	8.10	0.93
Osmundson et al. 2007	11.40	-	9.50	9.50	0.83
Osmundson et al. 2007	10.70	-	10.70	10.70	1.00
Osmundson et al. 2007	8.40	-	8.30	8.30	0.99
Osmundson et al. 2007	7.00	-	12.00	12.00	1.71
Osmundson et al. 2007	7.50	-	6.10	6.10	0.81
Osmundson et al. 2007	10.30	-	6.10	6.10	0.59
Osmundson et al. 2007	6.70	-	11.30	11.30	1.69
Osmundson et al. 2007	2.10	-	2.60	2.60	1.24
Osmundson et al. 2007	1.80	-	3.60	3.60	2.00
Osmundson et al. 2007	3.20	-	4.40	4.40	1.38
Osmundson et al. 2007	2.30	-	4.40	4.40	1.91
Osmundson et al. 2007	3.10	-	4.80	4.80	1.55
Osmundson et al. 2007	3.00	-	4.30	4.30	1.43
Osmundson et al. 2007	2.80	-	4.10	4.10	1.46
Osmundson et al. 2007	2.50	-	3.80	3.80	1.52
Osmundson et al. 2007	3.40	-	3.60	3.60	1.06
Osmundson et al. 2007	2.80	-	3.80	3.80	1.36
GEI 2014	26.9	-	32.7	32.7	1.22
GEI 2014	22.9	-	23.3	23.3	1.02



Median ratio: 1.38

R^2: 0.83
F: 200.4
df: 40
P: < 0.001

Table B-2. Summary of egg-ovary to whole body conversion factors (*CF*) from matched pairs of whole-body and egg-ovary measurements.

Common name	Scientific name	Median ratio (*CF*)
Bluegill	*Lepomis macrochirus*	2.13
Bluehead sucker	*Catostomus discobolus*	1.82
Brown trout	*Salmo trutta*	1.45
Common carp	*Cyprinus carpio*	1.92
Creek chub	*Semotilus atromaculatus*	1.99
Cutthroat trout	*Oncorhynchus clarkii*	1.96
Desert pupfish	*Cyprinodon macularius*	1.20
Fathead minnow	*Pimephales promelas*	1.40
Flannelmouth sucker	*Catostomus latipinnis*	1.41
Green sunfish	*Lepomis cyanellus*	1.45
Roundtail chub	*Gila robusta*	2.07
Smallmouth bass	*Micropterus dolomieu*	1.42
White sucker	*Catostomus commersonii*	1.38

NMED Exhibit 59

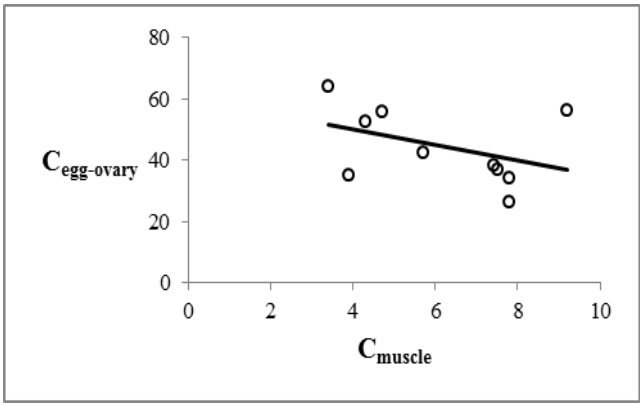
2.3 Muscle to egg-ovary conversion factors

C_{muscle} = Selenium concentration in muscle tissue only (µg/g dw)
C_{egg} = Selenium concentration in eggs (µg/g dw)
C_{ovary} = Selenium concentration in ovary tissue (µg/g dw)
$C_{egg\text{-}ovary}$ = Average selenium concentration in eggs and ovaries $\left(\frac{C_{egg} + C_{o\,var\,y}}{2}\right)$

Ratio = $\frac{C_{egg-o\,var\,y}}{C_{muscle}}$

Black bullhead (*Ameiurus melas*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg\text{-}ovary}$	Ratio
Osmundson et al. 2007	3.40	-	64.30	64.30	18.91
Osmundson et al. 2007	3.90	-	35.40	35.40	9.08
Osmundson et al. 2007	4.30	-	52.80	52.80	12.28
Osmundson et al. 2007	4.70	-	56.00	56.00	11.91
Osmundson et al. 2007	5.70	-	42.80	42.80	7.51
Osmundson et al. 2007	7.40	-	38.70	38.70	5.23
Osmundson et al. 2007	7.50	-	37.30	37.30	4.97
Osmundson et al. 2007	7.80	-	34.30	34.30	4.40
Osmundson et al. 2007	7.80	-	26.40	26.40	3.38
Osmundson et al. 2007	9.20	-	56.70	56.70	6.16



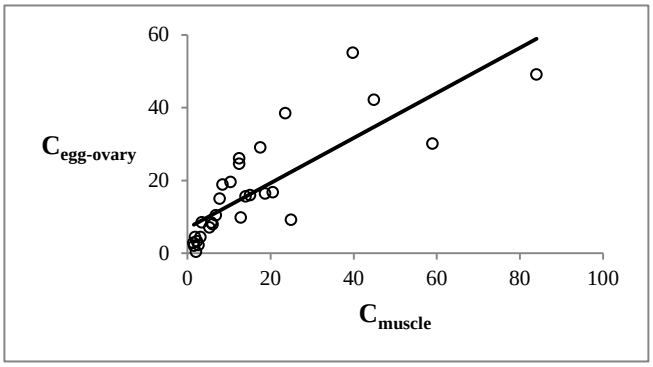
Median ratio: 6.84

R^2: 0.17
F: 1.65
df: 8
P: 0.250

Not used because P > 0.05 and negative slope.

Bluegill (*Lepomis macrochirus*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg\text{-}ovary}$	Ratio
Bryson et al. 1984	84.0	-	49.0	49.0	0.58
Bryson et al. 1985a (pt. 1)	59.0	-	30.0	30.0	0.51
Bryson et al. 1985a (pt. 1)	2.7	-	2.2	2.2	0.81
Bryson et al. 1985a (pt. 2)	25.0	-	9.1	9.1	0.36
Doroshov et al. 1992	1.5	2.8	-	2.8	1.87
Doroshov et al. 1992	5.8	8.3	-	8.3	1.43
Doroshov et al. 1992	10.4	19.5	-	19.5	1.88
Doroshov et al. 1992	23.6	38.4	-	38.4	1.63
Hermanutz et al. 1996	1.6	-	2.0	2.0	1.25
Hermanutz et al. 1996	8.5	-	18.8	18.8	2.21
Hermanutz et al. 1996	14	-	15.5	15.5	1.11
Hermanutz et al. 1996	2.1	-	0.3	0.3	0.14
Hermanutz et al. 1996	20.6	-	16.7	16.7	0.81
Hermanutz et al. 1996	1.9	-	4.4	4.4	2.32
Hermanutz et al. 1996	3.5	-	8.4	8.4	2.40
Hermanutz et al. 1996	17.6	-	29.0	29.0	1.65
Hermanutz et al. 1996	12.5	-	24.5	24.5	1.96
Hermanutz et al. 1996	2.3	-	3.2	3.2	1.39
Hermanutz et al. 1996	6.9	-	10.3	10.3	1.49
Hermanutz et al. 1996	44.9	-	42.1	42.1	0.94
Hermanutz et al. 1996	39.8	-	55.0	55.0	1.38
Hermanutz et al. 1996	5.3	-	7.0	7.0	1.32
Hermanutz et al. 1996	12.5	-	26.0	26.0	2.08
Hermanutz et al. 1996	7.8	-	14.9	14.9	1.91
Hermanutz et al. 1996	3.2	-	4.4	4.4	1.38
Hermanutz et al. 1996	6.1	-	7.9	7.9	1.30
Hermanutz et al. 1996	18.7	-	16.3	16.3	0.87
Hermanutz et al. 1996	15.1	-	15.9	15.9	1.05
Osmundson et al. 2007	12.9	-	9.7	9.7	0.75

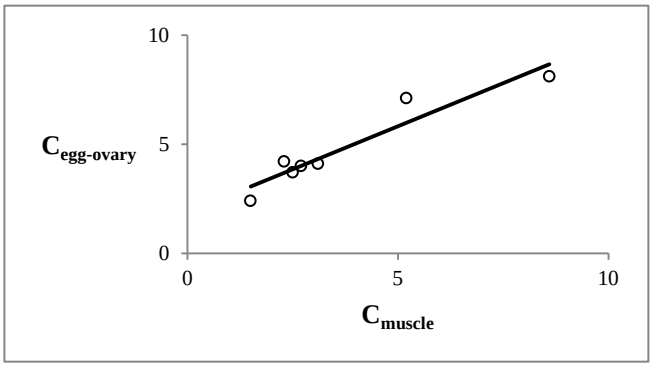


Median ratio: 1.38

R^2: 0.65
F: 50.37
df: 27
P: <0.001

Bluehead sucker (*Catostomus discobolus*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Osmundson et al. 2007	1.5	-	2.4	2.4	1.60
Osmundson et al. 2007	2.3	-	4.2	4.2	1.83
Osmundson et al. 2007	2.5	-	3.7	3.7	1.48
Osmundson et al. 2007	2.7	-	4	4	1.48
Osmundson et al. 2007	3.1	-	4.1	4.1	1.32
Osmundson et al. 2007	5.2	-	7.1	7.1	1.37
Osmundson et al. 2007	8.6	-	8.1	8.1	0.94



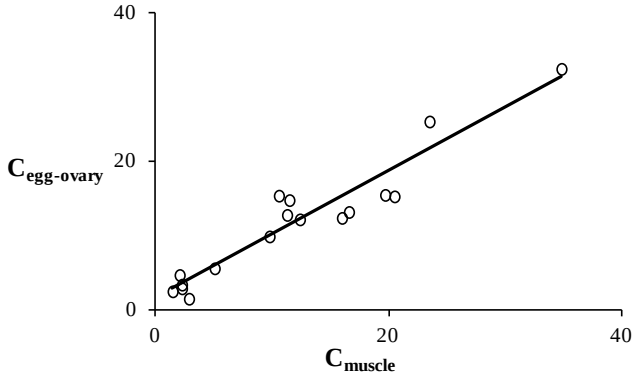
Median ratio: 1.48

R^2: 0.91
F: 47.70
df: 5
P: <0.001

Brook trout (*Salvelinus fontinalis*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Holm et al. 2005	2.80	1.50	-	1.50	0.54
Holm et al. 2005	1.40	2.50	-	2.50	1.79
Holm et al. 2005	2.20	3.40	-	3.40	1.55
Holm et al. 2005	2.00	4.70	-	4.70	2.35
Holm et al. 2005	2.20	2.90	-	2.90	1.32
Holm et al. 2005	5.00	5.60	-	5.60	1.12
Holm et al. 2005	9.70	9.90	-	9.90	1.02
Holm et al. 2005	10.50	15.40	-	15.40	1.47
Holm et al. 2005	11.20	12.80	-	12.80	1.14
Holm et al. 2005	11.40	14.80	-	14.80	1.30
Holm et al. 2005	12.30	12.20	-	12.20	0.99
Holm et al. 2005	15.90	12.40	-	12.40	0.78
Holm et al. 2005	16.50	13.20	-	13.20	0.80
Holm et al. 2005	19.60	15.50	-	15.50	0.79
Holm et al. 2005	20.40	15.30	-	15.30	0.75
Holm et al. 2005	23.40	25.40	-	25.40	1.09
Holm et al. 2005	34.70	32.50	-	32.50	0.94

Brook trout (*Salvelinus fontinalis*)

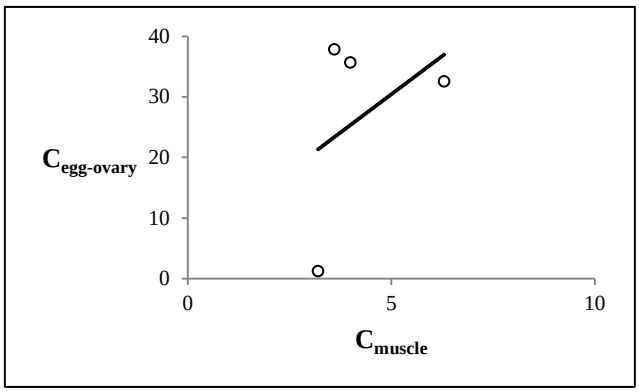


Median ratio: 1.09

R^2: 0.91
F: 152.3
df: 15
P: < 0.001

Brown trout (*Salmo trutta*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Osmundson et al. 2007	3.2	-	1.2	1.2	0.38
Osmundson et al. 2007	3.6	-	37.8	37.8	10.50
Osmundson et al. 2007	4	-	35.6	35.6	8.90
Osmundson et al. 2007	6.3	-	32.5	32.5	5.16



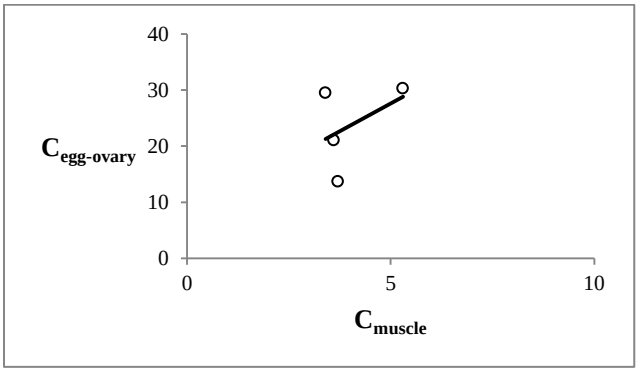
Median ratio: 7.03

R^2: 0.17
F: 0.40
df: 2
P: 0.71

Not used because P > 0.05.

Channel catfish (*Ictaluris punctatus*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg\text{-}ovary}$	Ratio
Osmundson et al. 2007	3.4	-	29.5	29.5	8.68
Osmundson et al. 2007	3.6	-	21.1	21.1	5.86
Osmundson et al. 2007	3.7	-	13.7	13.7	3.70
Osmundson et al. 2007	5.3	-	30.3	30.3	5.72



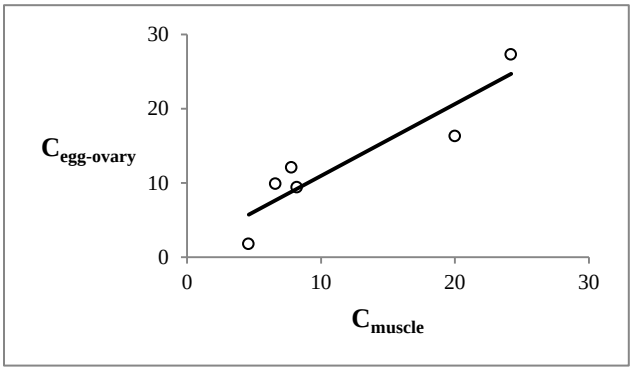
Median ratio: 5.79

R^2: 0.20
F: 0.49
df: 2
P: 0.67

Not used because P > 0.05.

Common carp (*Cyprinus carpio*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg\text{-}ovary}$	Ratio
Garcia-Hernandez 2000	4.6	-	1.8	1.8	0.39
Osmundson et al. 2007	7.8	-	12.1	12.1	1.55
Osmundson et al. 2007	8.2	-	9.4	9.4	1.15
Osmundson et al. 2007	20	-	16.3	16.3	0.82
Osmundson et al. 2007	24.2	-	27.3	27.3	1.13
Osmundson et al. 2007	6.6	-	9.9	9.9	1.50



Median ratio: 1.14

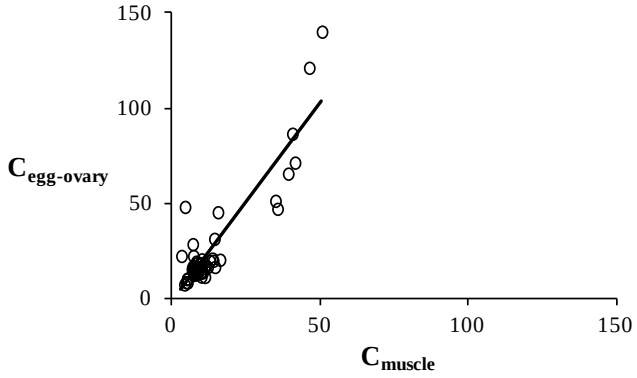
R^2: 0.84
F: 21.7
df: 4
P: 0.007

Cutthroat trout (*Oncorhynchus clarkii*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg\text{-}ovary}$	Ratio
Golder 2005	6.80	-	28.20	28.20	4.15
Golder 2005	4.20	-	47.80	47.80	11.38
Golder 2005	3.00	-	22.00	22.00	7.33
Golder 2005	4.90	-	9.80	9.80	2.00
Golder 2005	4.50	-	8.20	8.20	1.82
Golder 2005	4.00	-	7.00	7.00	1.75
Golder 2005	5.00	-	10.00	10.00	2.00
Golder 2005	5.00	-	10.00	10.00	2.00
Golder 2005	5.00	-	8.00	8.00	1.60
Golder 2005	8.40	-	16.20	16.20	1.93
Golder 2005	8.30	-	18.30	18.30	2.20
Golder 2005	7.00	-	14.30	14.30	2.04
Golder 2005	6.60	-	14.30	14.30	2.17
Golder 2005	8.40	-	14.70	14.70	1.75
Golder 2005	9.80	-	16.40	16.40	1.67
Golder 2005	8.50	-	15.90	15.90	1.87
Golder 2005	16.00	-	20.00	20.00	1.25
Golder 2005	7.00	-	14.00	14.00	2.00
Golder 2005	8.00	-	19.00	19.00	2.38
Golder 2005	7.00	-	14.00	14.00	2.00
Golder 2005	7.00	-	14.00	14.00	2.00
Golder 2005	9.00	-	16.00	16.00	1.78
Golder 2005	7.00	-	13.00	13.00	1.86
Golder 2005	7.00	-	14.00	14.00	2.00
Golder 2005	8.00	-	14.00	14.00	1.75
Golder 2005	9.80	-	20.20	20.20	2.06
Golder 2005	7.00	-	22.00	22.00	3.14
Golder 2005	9.00	-	16.00	16.00	1.78
Golder 2005	7.00	-	12.00	12.00	1.71
Golder 2005	8.00	-	13.00	13.00	1.63
Golder 2005	10.00	-	14.00	14.00	1.40
Kennedy et al. 2000	41.30	75.40	66.80	71.10	1.72
Kennedy et al. 2000	15.30	58.40	31.60	45.00	2.94
Kennedy et al. 2000	14.10	30.60	31.40	31.00	2.20
Kennedy et al. 2000	12.50	20.20	18.50	19.35	1.55
Kennedy et al. 2000	13.70	19.40	19.50	19.45	1.42
Kennedy et al. 2000	14.30	16.20	16.20	16.20	1.13
Kennedy et al. 2000	9.50	16.10	19.30	17.70	1.86
Kennedy et al. 2000	9.40	14.40	22.00	18.20	1.94
Kennedy et al. 2000	8.70	13.20	17.00	15.10	1.74
Kennedy et al. 2000	9.50	12.60	13.60	13.10	1.38
Kennedy et al. 2000	10.20	12.30	14.50	13.40	1.31

Cutthroat trout (*Oncorhynchus clarkii*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Kennedy et al. 2000	10.70	10.50	20.60	15.55	1.45
Kennedy et al. 2000	6.60	9.90	21.50	15.70	2.38
Kennedy et al. 2000	9.70	9.10	13.20	11.15	1.15
Kennedy et al. 2000	10.90	8.50	13.40	10.95	1.00
Kennedy et al. 2000	6.90	13.20	20.30	16.75	2.43
Rudolph et al. 2007	7.70	13.90	-	13.90	1.81
Rudolph et al. 2007	8.20	12.50	-	12.50	1.52
Rudolph et al. 2007	8.00	15.00	-	15.00	1.88
Rudolph et al. 2007	8.10	14.90	-	14.90	1.84
Rudolph et al. 2007	6.60	15.20	-	15.20	2.30
Rudolph et al. 2007	8.50	12.90	-	12.90	1.52
Rudolph et al. 2007	7.20	12.30	-	12.30	1.71
Rudolph et al. 2007	7.30	16.70	-	16.70	2.29
Rudolph et al. 2007	7.60	13.10	-	13.10	1.72
Rudolph et al. 2007	8.70	15.60	-	15.60	1.79
Rudolph et al. 2007	8.20	13.90	-	13.90	1.70
Rudolph et al. 2007	7.90	15.10	-	15.10	1.91
Rudolph et al. 2007	7.60	12.30	-	12.30	1.62
Rudolph et al. 2007	11.80	16.10	-	16.10	1.36
Rudolph et al. 2007	40.40	86.30	-	86.30	2.14
Rudolph et al. 2007	46.10	121.00	-	121.00	2.62
Rudolph et al. 2007	50.40	140.00	-	140.00	2.78
Rudolph et al. 2007	34.70	51.00	-	51.00	1.47
Rudolph et al. 2007	39.00	65.30	-	65.30	1.67
Rudolph et al. 2007	35.40	46.80	-	46.80	1.32
Rudolph et al. 2007	11.30	16.90	-	16.90	1.50
Rudolph et al. 2007	13.40	20.60	-	20.60	1.54

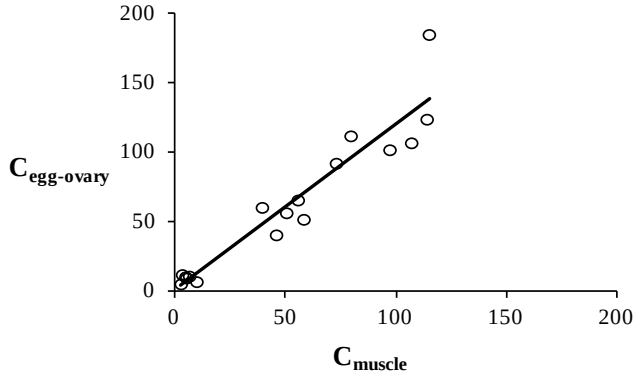


Median ratio: 1.81

R^2: 0.82
F: 308.3
df: 67
P: < 0.001

Dolly Varden (*Salvelinus malma*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Golder 2009	73.00	92.30	-	92.30	1.26
Golder 2009	45.90	40.70	-	40.70	0.89
Golder 2009	107.00	107.00	-	107.00	1.00
Golder 2009	97.20	102.00	-	102.00	1.05
Golder 2009	114.00	124.00	-	124.00	1.09
Golder 2009	115.00	185.00	-	185.00	1.61
Golder 2009	79.60	112.00	-	112.00	1.41
Golder 2009	9.90	7.00	-	7.00	0.71
Golder 2009	3.40	12.10	-	12.10	3.56
Golder 2009	5.30	9.60	-	9.60	1.81
Golder 2009	2.80	5.40	-	5.40	1.93
Golder 2009	4.90	10.50	-	10.50	2.14
Golder 2009	6.60	11.00	-	11.00	1.67
Golder 2009	55.70	65.80	-	65.80	1.18
Golder 2009	58.30	51.90	-	51.90	0.89
Golder 2009	39.50	60.50	-	60.50	1.53
Golder 2009	50.50	56.60	-	56.60	1.12

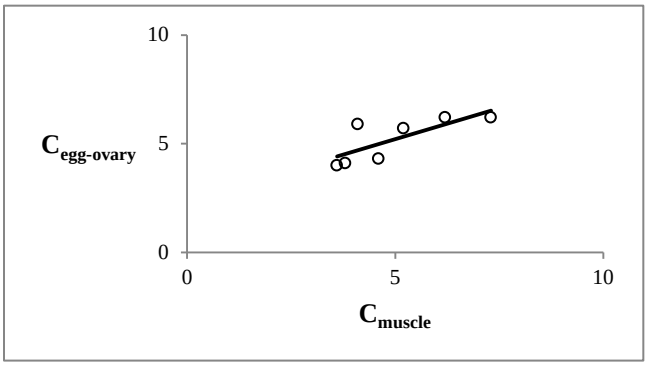


Median ratio: 1.26

R^2: 0.90
F: 140.3
df: 15
P: < 0. 001

Flannelmouth sucker (*Catostomus latipinnis*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg\text{-}ovary}$	Ratio
Osmundson et al. 2007	3.6	-	4.0	4.0	1.11
Osmundson et al. 2007	3.8	-	4.1	4.1	1.08
Osmundson et al. 2007	4.1	-	5.9	5.9	1.44
Osmundson et al. 2007	4.6	-	4.3	4.3	0.93
Osmundson et al. 2007	5.2	-	5.7	5.7	1.10
Osmundson et al. 2007	6.2	-	6.2	6.2	1.00
Osmundson et al. 2007	7.3	-	6.2	6.2	0.85



Median ratio: 1.08

R^2: 0.58
F: 6.92
df: 5
P: 0.036

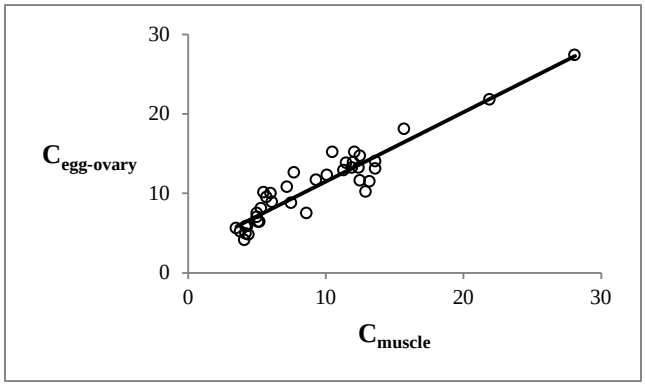
Green sunfish (*Lepomis cyanellus*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg\text{-}ovary}$	Ratio
Osmundson et al. 2007	28.1	-	27.4	27.4	0.98
Osmundson et al. 2007	12.9	-	10.2	10.2	0.79
Osmundson et al. 2007	21.9	-	21.8	21.8	1.00
Osmundson et al. 2007	5	-	7	7	1.40
Osmundson et al. 2007	6.1	-	8.9	8.9	1.46
Osmundson et al. 2007	5.2	-	6.4	6.4	1.23
Osmundson et al. 2007	5.1	-	6.4	6.4	1.25
Osmundson et al. 2007	15.7	-	18.1	18.1	1.15
Osmundson et al. 2007	10.1	-	12.3	12.3	1.22
Osmundson et al. 2007	11.5	-	13.8	13.8	1.20
Osmundson et al. 2007	10.5	-	15.2	15.2	1.45
Osmundson et al. 2007	7.2	-	10.8	10.8	1.50
Osmundson et al. 2007	9.3	-	11.7	11.7	1.26
Osmundson et al. 2007	7.7	-	12.6	12.6	1.64
Osmundson et al. 2007	6	-	10	10	1.67
Osmundson et al. 2007	12	-	13.9	13.9	1.16
Osmundson et al. 2007	12.1	-	15.2	15.2	1.26
Osmundson et al. 2007	12.5	-	14.7	14.7	1.18
Osmundson et al. 2007	7.5	-	8.8	8.8	1.17
Osmundson et al. 2007	11.3	-	12.9	12.9	1.14

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Green sunfish (*Lepomis cyanellus*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg\text{-}ovary}$	Ratio
Osmundson et al. 2007	13.6	-	13.1	13.1	0.96
Osmundson et al. 2007	13.2	-	11.5	11.5	0.87
Osmundson et al. 2007	12.4	-	13.2	13.2	1.06
Osmundson et al. 2007	12.5	-	11.6	11.6	0.93
Osmundson et al. 2007	8.6	-	7.5	7.5	0.87
Osmundson et al. 2007	5.3	-	8.1	8.1	1.53
Osmundson et al. 2007	11.9	-	13.2	13.2	1.11
Osmundson et al. 2007	13.6	-	14	14	1.03
Osmundson et al. 2007	3.8	-	5.2	5.2	1.37
Osmundson et al. 2007	4.2	-	5.8	5.8	1.38
Osmundson et al. 2007	4.1	-	4.1	4.1	1.00
Osmundson et al. 2007	4.2	-	4.9	4.9	1.17
Osmundson et al. 2007	5.7	-	9.5	9.5	1.67
Osmundson et al. 2007	4.4	-	4.8	4.8	1.09
Osmundson et al. 2007	3.5	-	5.6	5.6	1.60
Osmundson et al. 2007	5.5	-	10.1	10.1	1.84
Osmundson et al. 2007	5	-	7.5	7.5	1.50
Osmundson et al. 2007	4.3	-	5.9	5.9	1.37

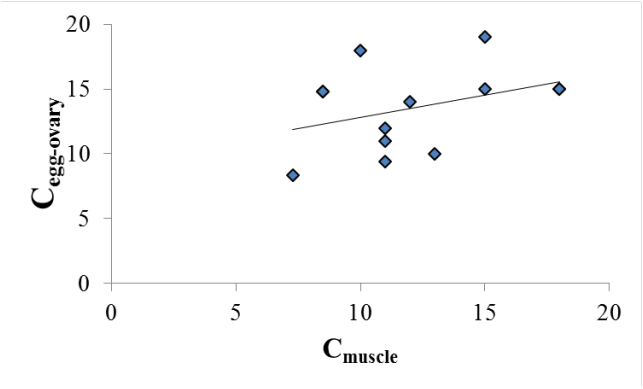


Median ratio: 1.21

R^2: 0.89
F: 281.4
df: 36
P: <0.001

Largemouth bass (*Micropterus salmoides*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Carolina Power & Light 1997	8.48	-	14.79	14.79	1.74
Carolina Power & Light 1997	8.48	-	14.79	14.79	1.74
Carolina Power & Light 1997	7.29	-	8.35	8.35	1.15
Carolina Power & Light 1997	15	-	19	19	1.27
Carolina Power & Light 1997	15	-	15	15	1.00
Carolina Power & Light 1997	12	-	14	14	1.17
Carolina Power & Light 1997	10	-	18	18	1.80
Carolina Power & Light 1997	18	-	15	15	0.83
Carolina Power & Light 1997	18	-	15	15	0.83
Carolina Power & Light 1997	11	-	12	12	1.09
Carolina Power & Light 1997	11	-	9.4	9.4	0.85
Carolina Power & Light 1997	13	-	10	10	0.77
Carolina Power & Light 1997	11	-	11	11	1.00

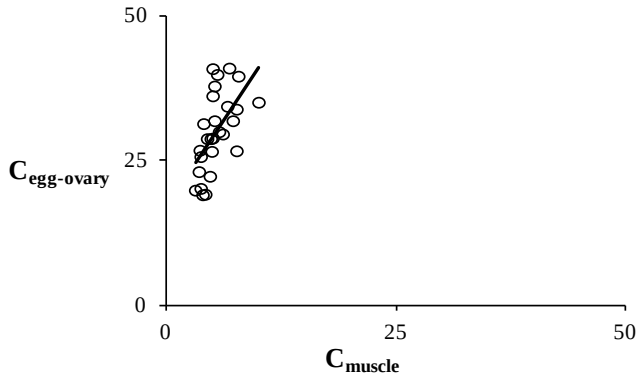


Median ratio: 1.09

R^2: 0.14
F: 1.74
df: 11
P: 0.22
Not used because P>0.05

Mountain whitefish (*Prosopium williamsoni*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Golder 2005	3.60	-	26.90	26.90	7.47
Golder 2005	3.70	-	25.80	25.80	6.97
Golder 2005	3.10	-	20.00	20.00	6.45
Golder 2005	4.20	-	19.30	19.30	4.60
Golder 2005	3.90	-	19.20	19.20	4.92
Golder 2005	3.50	-	23.20	23.20	6.63
Golder 2005	5.20	-	38.00	38.00	7.31
Golder 2005	5.00	-	41.00	41.00	8.20
Golder 2005	5.20	-	32.00	32.00	6.15
Golder 2005	7.60	-	34.00	34.00	4.47
Golder 2005	7.20	-	32.00	32.00	4.44
Golder 2005	5.50	-	40.00	40.00	7.27
Golder 2005	7.80	-	39.70	39.70	5.09
Golder 2005	3.70	-	20.30	20.30	5.49
Golder 2005	4.70	-	22.40	22.40	4.77
Golder 2005	4.40	-	28.90	28.90	6.57
Golder 2005	5.70	-	30.10	30.10	5.28
Golder 2005	4.00	-	31.50	31.50	7.88
Golder 2005	10.00	-	35.20	35.20	3.52
Golder 2005	4.90	-	26.70	26.70	5.45
Golder 2005	7.60	-	26.80	26.80	3.53
Golder 2005	6.10	-	29.70	29.70	4.87
Golder 2005	6.80	-	41.10	41.10	6.04
Golder 2005	5.00	-	29.00	29.00	5.80
Golder 2005	6.60	-	34.50	34.50	5.23
Golder 2005	5.00	-	36.30	36.30	7.26
Golder 2005	4.80	-	28.90	28.90	6.02

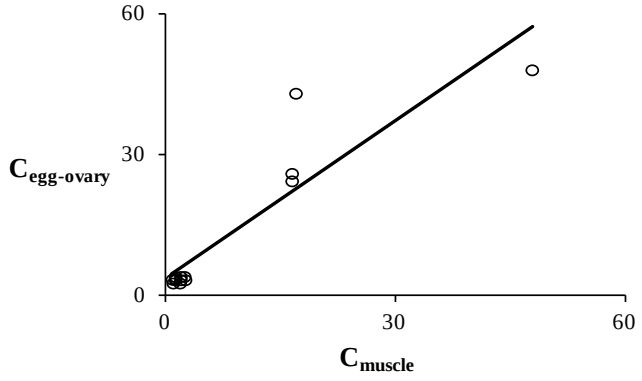


Median ratio: 5.80

R^2: 0.33
F: 12.4
df: 25
P: <0.001

Northern pike (*Esox lucius*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Muscatello et al. 2006	0.90	3.50	-	3.50	3.89
Muscatello et al. 2006	1.90	2.70	-	2.70	1.42
Muscatello et al. 2006	2.60	3.40	-	3.40	1.31
Muscatello et al. 2006	1.30	3.70	-	3.70	2.85
Muscatello et al. 2006	1.00	2.70	-	2.70	2.70
Muscatello et al. 2006	17.00	43.20	-	43.20	2.54
Muscatello et al. 2006	16.50	24.50	-	24.50	1.48
Muscatello et al. 2006	16.50	26.10	-	26.10	1.58
Muscatello et al. 2006	2.00	3.40	-	3.40	1.70
Muscatello et al. 2006	2.00	4.10	-	4.10	2.05
Muscatello et al. 2006	1.30	4.10	-	4.10	3.15
Muscatello et al. 2006	2.50	4.10	-	4.10	1.64
Muscatello et al. 2006	1.30	3.40	-	3.40	2.62
Muscatello et al. 2006	47.80	48.20	-	48.20	1.01



Median ratio: 1.88

R^2: 0.83
F: 58.9
df: 12
P: <0.001

Rainbow trout (*Oncorhynchus mykiss*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Casey and Siwik 2000	4.10	11.60	-	11.60	2.83
Casey and Siwik 2000	3.80	10.10	-	10.10	2.66
Casey and Siwik 2000	2.60	0.10	-	0.10	0.04
Casey and Siwik 2000	3.30	4.90	-	4.90	1.48
Casey and Siwik 2000	2.30	3.60	-	3.60	1.57
Casey and Siwik 2000	2.80	5.30	-	5.30	1.89
Casey and Siwik 2000	2.30	3.70	-	3.70	1.61
Casey and Siwik 2000	2.80	6.40	-	6.40	2.29
Casey and Siwik 2000	3.00	5.20	-	5.20	1.73
Casey and Siwik 2000	4.90	6.80	-	6.80	1.39
Casey and Siwik 2000	1.50	3.60	-	3.60	2.40
Casey and Siwik 2000	2.60	6.90	-	6.90	2.65

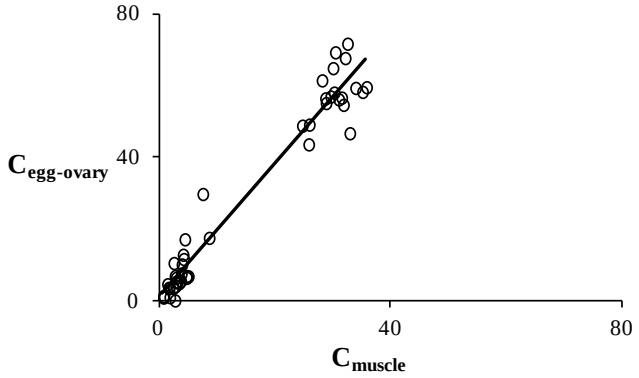
Rainbow trout (*Oncorhynchus mykiss*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Casey and Siwik 2000	4.60	6.90	-	6.90	1.50
Casey and Siwik 2000	4.60	6.40	-	6.40	1.39
Casey and Siwik 2000	3.60	5.50	-	5.50	1.53
Casey and Siwik 2000	2.40	10.50	-	10.50	4.38
Casey and Siwik 2000	3.70	7.60	-	7.60	2.05
Casey and Siwik 2000	2.70	4.10	-	4.10	1.52
Casey and Siwik 2000	0.70	1.10	-	1.10	1.57
Casey and Siwik 2000	0.60	0.90	-	0.90	1.50
Casey and Siwik 2000	0.60	1.30	-	1.30	2.17
Casey and Siwik 2000	28.60	56.30	-	56.30	1.97
Casey and Siwik 2000	30.90	56.00	-	56.00	1.81
Casey and Siwik 2000	32.40	71.50	-	71.50	2.21
Casey and Siwik 2000	28.00	61.30	-	61.30	2.19
Casey and Siwik 2000	31.70	54.50	-	54.50	1.72
Casey and Siwik 2000	29.50	56.80	-	56.80	1.93
Casey and Siwik 2000	30.10	57.90	-	57.90	1.92
Casey and Siwik 2000	29.90	64.70	-	64.70	2.16
Casey and Siwik 2000	32.80	46.60	-	46.60	1.42
Casey and Siwik 2000	31.40	56.50	-	56.50	1.80
Casey and Siwik 2000	32.00	67.50	-	67.50	2.11
Casey and Siwik 2000	35.70	59.40	-	59.40	1.66
Casey and Siwik 2000	24.60	48.70	-	48.70	1.98
Casey and Siwik 2000	30.30	69.10	-	69.10	2.28
Casey and Siwik 2000	25.70	43.50	-	43.50	1.69
Casey and Siwik 2000	35.00	58.10	-	58.10	1.66
Casey and Siwik 2000	33.80	59.20	-	59.20	1.75
Casey and Siwik 2000	28.70	55.00	-	55.00	1.92
Casey and Siwik 2000	25.80	49.00	-	49.00	1.90
Holm et al. 2005	1.70	1.00	-	1.00	0.59
Holm et al. 2005	1.60	3.50	-	3.50	2.19
Holm et al. 2005	1.30	4.60	-	4.60	3.54
Holm et al. 2005	4.00	12.80	-	12.80	3.20
Holm et al. 2005	4.30	17.10	-	17.10	3.98
Holm et al. 2005	8.50	17.50	-	17.50	2.06
Holm et al. 2005	7.40	29.70	-	29.70	4.01

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Rainbow trout (*Oncorhynchus mykiss*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio



Median ratio: 1.92

R^2: 0.96
F: 990.0
df: 45
P: <0. 001

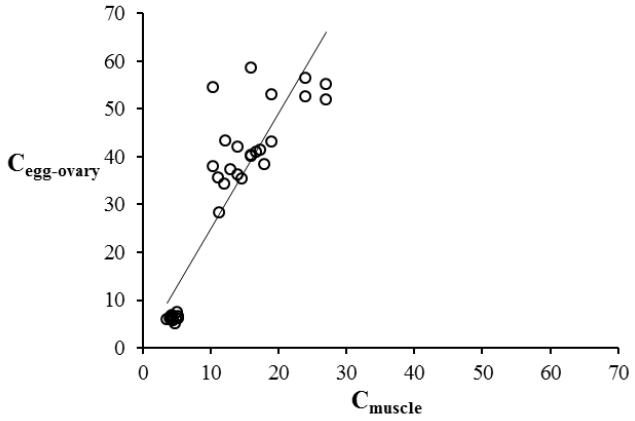
Razorback sucker (*Xyrauchen texanus*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Hamilton et al. 2001a	5	7.5	-	7.5	1.50
Hamilton et al. 2001a	4	6.1	-	6.1	1.53
Hamilton et al. 2001a	4.2	6.6	-	6.6	1.57
Hamilton et al. 2001a	4.4	6.2	-	6.2	1.41
Hamilton et al. 2001a	4.5	5.8	-	5.8	1.29
Hamilton et al. 2001a	4.3	6.8	-	6.8	1.58
Hamilton et al. 2001a	11.1	35.5	-	35.5	3.20
Hamilton et al. 2001a	12.2	43.4	-	43.4	3.56
Hamilton et al. 2001a	10.4	54.5	-	54.5	5.24
Hamilton et al. 2001a	11.3	28.2	-	28.2	2.50
Hamilton et al. 2001a	10.4	38	-	38	3.65
Hamilton et al. 2001a	17.3	41.3	-	41.3	2.39
Hamilton et al. 2001a	13	37.2	-	37.2	2.86
Hamilton et al. 2001a	16.7	40.9	-	40.9	2.45
Hamilton et al. 2001a	14.6	35.3	-	35.3	2.42
Hamilton et al. 2001a	12.1	34.3	-	34.3	2.83
Hamilton et al. 2001b	4.7	5	-	5	1.06
Hamilton et al. 2001b	5.3	6.2	-	6.2	1.17
Hamilton et al. 2001b	3.6	5.9	-	5.9	1.64
Hamilton et al. 2001b	5.3	6.5	-	6.5	1.23
Hamilton et al. 2001b	4.1	6.35	-	6.35	1.55
Hamilton et al. 2001b	4.9	6.1	-	6.1	1.24
Hamilton et al. 2001b	16	40.1	-	40.1	2.51
Hamilton et al. 2001b	18	38.4	-	38.4	2.13
Hamilton et al. 2001b	16	40.2	-	40.2	2.51
Hamilton et al. 2001b	19	43.1	-	43.1	2.27

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Razorback sucker (*Xyrauchen texanus*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Hamilton et al. 2001b	14	41.9	-	41.9	2.99
Hamilton et al. 2001b	14	36.2	-	36.2	2.59
Hamilton et al. 2001b	24	56.5	-	56.5	2.35
Hamilton et al. 2001b	27	51.8	-	51.8	1.92
Hamilton et al. 2001b	24	52.6	-	52.6	2.19
Hamilton et al. 2001b	27	55.1	-	55.1	2.04
Hamilton et al. 2001b	19	53	-	53	2.79
Hamilton et al. 2001b	16	58.5	-	58.5	3.66
Waddell and May 1995 [a]	4.40	3.70	-	3.70	×
Waddell and May 1995 [a]	7.10	4.70	-	4.70	×
Waddell and May 1995 [a]	32.00	10.60	-	10.60	×



Median ratio: 2.31

R^2: 0.80
F: 125.6
df: 32
P: <0.001

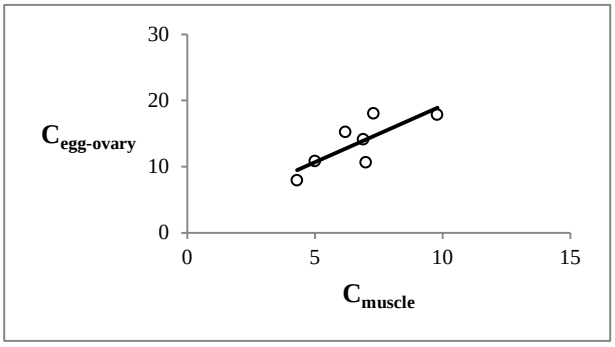
[a] Data from this study were excluded because results were atypical.

Roundtail chub (*Gila robusta*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Osmundson et al. 2007	4.3	-	7.9	7.9	1.84
Osmundson et al. 2007	5	-	10.8	10.8	2.16
Osmundson et al. 2007	6.2	-	15.2	15.2	2.45
Osmundson et al. 2007	6.9	-		14.1	2.04
Osmundson et al. 2007	7	-	10.6	10.6	1.51
Osmundson et al. 2007	7.3	-	18	18	2.47
Osmundson et al. 2007	9.8	-	17.8	17.8	1.82

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Roundtail chub (*Gila robusta*)

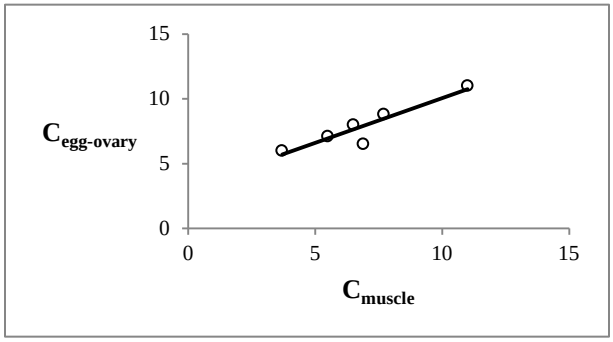


Median ratio: 2.04

R^2: 0.62
F: 8.27
df: 5
P: 0.026

Smallmouth bass (*Micropterus dolomieu*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg\text{-}ovary}$	Ratio
Osmundson et al. 2007	3.7	-	6.0	6.0	1.62
Osmundson et al. 2007	6.5	-	8.0	8.0	1.23
Osmundson et al. 2007	6.9	-	6.5	6.5	0.94
Osmundson et al. 2007	11			11	1.00
Osmundson et al. 2007	5.5	-	7.1	7.1	1.29
Osmundson et al. 2007	7.7	-	8.8	8.8	1.14

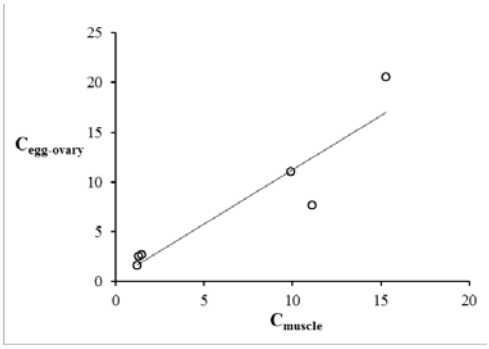


Median ratio: 1.19

R^2: 0.85
F: 23.5
df: 4
P: 0.006

White Sturgeon (*Acipenser transmontanus*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Linville 2006	1.28	2.46	-	2.46	2.46
Linville 2006	1.22	1.61	-	1.61	1.61
Linville 2006	1.48	2.68	-	2.68	2.68
Linville 2006	9.93	11	-	11	11
Linville 2006	15.3	20.5	-	20.5	20.5
Linville 2006	11.1	7.61	-	7.61	7.61



Median ratio: 1.33

R^2: 0.86
F: 24.96
df: 4
P: 0.006

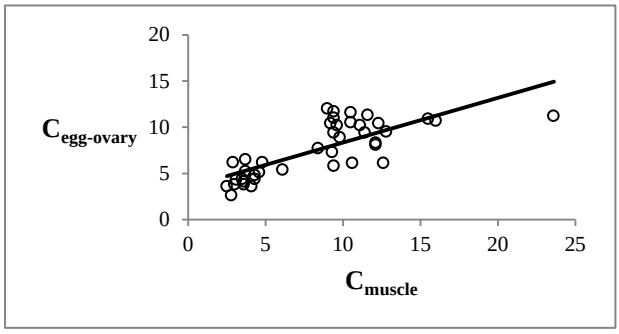
White Sucker (*Catostomus commersonii*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg-ovary}$	Ratio
Osmundson et al. 2007	2.9	-	6.2	6.2	2.14
Osmundson et al. 2007	4.8	-	6.2	6.2	1.29
Osmundson et al. 2007	3.7	-	5.2	5.2	1.41
Osmundson et al. 2007	3.7	-	6.5	6.5	1.76
Osmundson et al. 2007	8.4	-	7.7	7.7	0.92
Osmundson et al. 2007	9.4	-	5.8	5.8	0.62
Osmundson et al. 2007	15.5	-	10.9	10.9	0.70
Osmundson et al. 2007	23.6	-	11.2	11.2	0.47
Osmundson et al. 2007	9.4	-	9.4	9.4	1.00
Osmundson et al. 2007	6.1	-	5.4	5.4	0.89
Osmundson et al. 2007	4.6	-	5.1	5.1	1.11
Osmundson et al. 2007	12.3	-	10.4	10.4	0.85
Osmundson et al. 2007	9.2	-	10.4	10.4	1.13
Osmundson et al. 2007	9.4	-	11	11	1.17
Osmundson et al. 2007	9.4	-	11.7	11.7	1.24
Osmundson et al. 2007	10.5	-	11.6	11.6	1.10
Osmundson et al. 2007	11.4	-	9.4	9.4	0.82
Osmundson et al. 2007	9.6	-	10.2	10.2	1.06
Osmundson et al. 2007	9.3	-	7.3	7.3	0.78
Osmundson et al. 2007	9.8	-	8.9	8.9	0.91
Osmundson et al. 2007	10.5	-	10.5	10.5	1.00

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White Sucker (*Catostomus commersonii*)

Study	C_{muscle}	C_{egg}	C_{ovary}	$C_{egg\text{-}ovary}$	Ratio
Osmundson et al. 2007	11.1	-	10.2	10.2	0.92
Osmundson et al. 2007	12.1	-	8.1	8.1	0.67
Osmundson et al. 2007	12.8	-	9.5	9.5	0.74
Osmundson et al. 2007	16.0	-	10.7	10.7	0.67
Osmundson et al. 2007	12.1	-	8.3	8.3	0.69
Osmundson et al. 2007	9.0	-	12	12	1.33
Osmundson et al. 2007	10.6	-	6.1	6.1	0.58
Osmundson et al. 2007	12.6	-	6.1	6.1	0.48
Osmundson et al. 2007	11.6	-	11.3	11.3	0.97
Osmundson et al. 2007	2.8	-	2.6	2.6	0.93
Osmundson et al. 2007	2.5	-	3.6	3.6	1.44
Osmundson et al. 2007	4.3	-	4.4	4.4	1.02
Osmundson et al. 2007	3.5	-	4.4	4.4	1.26
Osmundson et al. 2007	4.3	-	4.8	4.8	1.12
Osmundson et al. 2007	3.1	-	4.3	4.3	1.39
Osmundson et al. 2007	3.6	-	4.1	4.1	1.14
Osmundson et al. 2007	3.0	-	3.8	3.8	1.27
Osmundson et al. 2007	4.1	-	3.6	3.6	0.88
Osmundson et al. 2007	3.6	-	3.8	3.8	1.06



Median ratio: 1.00

R^2: 0.59
F: 53.92
df: 38
P: < 0.001

Table B-3. Summary of egg-ovary to muscle conversion factors.

Common name	Scientific name	Median ratio
Bluegill	*Lepomis macrochirus*	1.38
Bluehead sucker	*Catostomus discobolus*	1.48
Brook trout	*Salvelinus fontinalis*	1.09
Common carp	*Cyprinus carpio*	1.14
Cutthroat trout	*Oncorhynchus clarkii*	1.81
Dolly Varden	*Salvelinus malma*	1.26
Flannelmouth sucker	*Catostomus latipinnis*	1.08
Green sunfish	*Lepomis cyanellus*	1.21
Mountain whitefish	*Prosopium williamsoni*	5.80
Northern pike	*Esox lucius*	1.88
Rainbow trout	*Oncorhynchus mykiss*	1.92
Razorback sucker	*Xyrauchen texanus*	2.31
Roundtail chub	*Gila robusta*	2.04
Smallmouth bass	*Micropterus dolomieu*	1.19
White sturgeon	*Acipenser transmontanus*	1.33
White sucker	*Catostomus commersonii*	1.00

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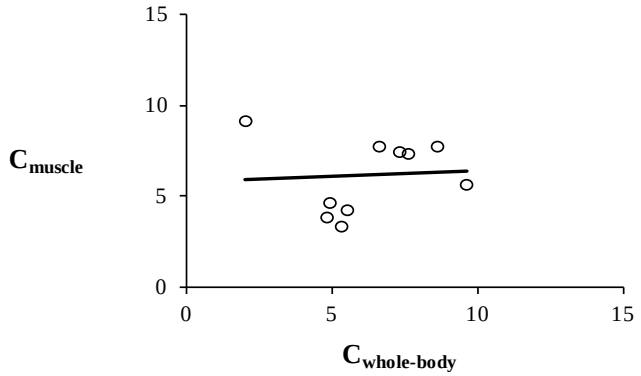
2.4 Muscle to whole-body conversion factors

$C_{whole\text{-}body}$ = Selenium concentration in all tissues (µg/g dw)
C_{muscle} = Selenium concentration in muscle tissue only (µg/g dw)

$$\text{Ratio} = \frac{C_{muscle}}{C_{whole-body}}$$

Black bullhead (*Ameiurus melas*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio
Osmundson et al. 2007	5.30	3.40	0.64
Osmundson et al. 2007	4.80	3.90	0.81
Osmundson et al. 2007	5.50	4.30	0.78
Osmundson et al. 2007	4.90	4.70	0.96
Osmundson et al. 2007	9.60	5.70	0.59
Osmundson et al. 2007	7.60	7.40	0.97
Osmundson et al. 2007	7.30	7.50	1.03
Osmundson et al. 2007	6.60	7.80	1.18
Osmundson et al. 2007	8.60	7.80	0.91
Osmundson et al. 2007	2.00	9.20	4.60



Median ratio: 0.93

R^2: 0.00
F: 0.03
df: 8
P: 0.973

Not used because P > 0.05.

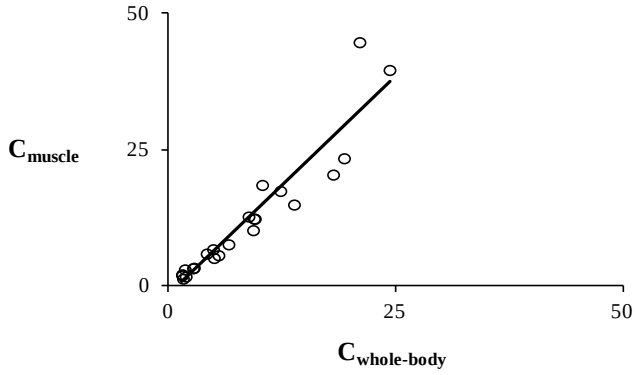
Bluegill (*Lepomis macrochirus*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio
Doroshov et al. 1992	1.60	1.50	0.94
Doroshov et al. 1992	5.50	5.80	1.05
Doroshov et al. 1992	9.30	10.40	1.12
Doroshov et al. 1992	19.30	23.60	1.22
Hermanutz et al. 1996	1.50	2.10	1.40
Hermanutz et al. 1996	18.10	20.60	1.14
Hermanutz et al. 1996	1.90	1.90	1.00
Hermanutz et al. 1996	2.80	3.50	1.25

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Bluegill (*Lepomis macrochirus*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio
Hermanutz et al. 1996	12.30	17.60	1.43
Hermanutz et al. 1996	9.40	12.50	1.33
Hermanutz et al. 1996	1.50	2.30	1.53
Hermanutz et al. 1996	4.90	6.90	1.41
Hermanutz et al. 1996	21.00	44.90	2.14
Hermanutz et al. 1996	24.30	39.80	1.64
Hermanutz et al. 1996	2.70	3.40	1.26
Hermanutz et al. 1996	5.00	5.30	1.06
Hermanutz et al. 1996	9.50	12.50	1.32
Hermanutz et al. 1996	6.60	7.80	1.18
Hermanutz et al. 1996	1.80	3.20	1.78
Hermanutz et al. 1996	4.20	6.10	1.45
Hermanutz et al. 1996	10.30	18.70	1.82
Hermanutz et al. 1996	13.80	15.10	1.09
Osmundson et al. 2007	8.80	12.90	1.47

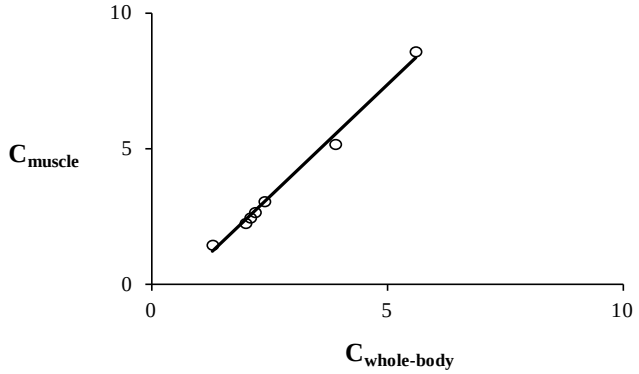


Median ratio: 1.32

R^2: 0.89
F: 172.2
df: 21
P: < 0.001

Bluehead sucker (*Catostomus discobolus*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio
Osmundson et al. 2007	1.30	1.50	1.15
Osmundson et al. 2007	2.00	2.30	1.15
Osmundson et al. 2007	2.10	2.50	1.19
Osmundson et al. 2007	2.20	2.70	1.23
Osmundson et al. 2007	2.40	3.10	1.29
Osmundson et al. 2007	3.90	5.20	1.33
Osmundson et al. 2007	5.60	8.60	1.54

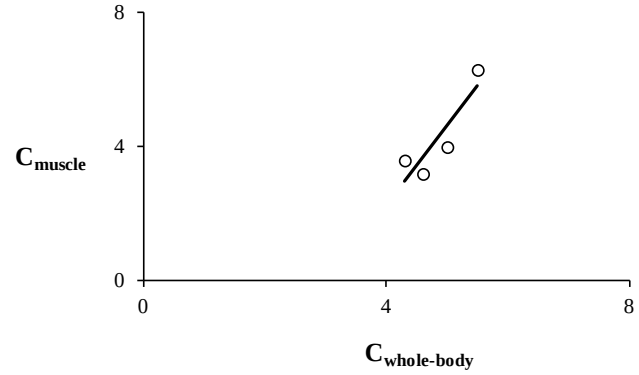


Median ratio: 1.23

R^2: 0.99
F: 682.9
df: 5
P: <0.001

Brown trout (*Salmo trutta*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio
Osmundson et al. 2007	4.60	3.20	0.70
Osmundson et al. 2007	4.30	3.60	0.84
Osmundson et al. 2007	5.00	4.00	0.80
Osmundson et al. 2007	5.50	6.30	1.15



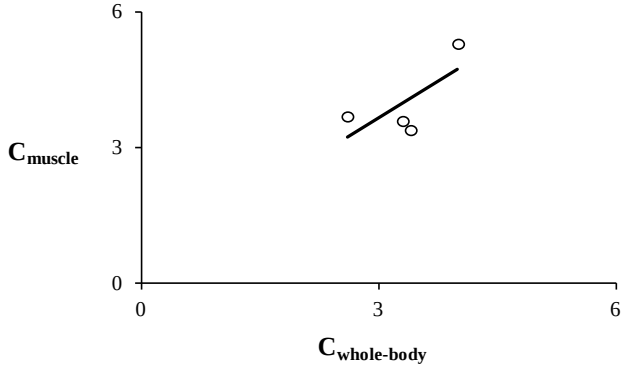
Median ratio: 0.82

R^2: 0.78
F: 7.2
df: 2
P: 0.122

Not used because P > 0.05.

Channel catfish (*Ictalurus punctatus*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio
Osmundson et al. 2007	3.40	3.40	1.00
Osmundson et al. 2007	3.30	3.60	1.09
Osmundson et al. 2007	2.60	3.70	1.42
Osmundson et al. 2007	4.00	5.30	1.33



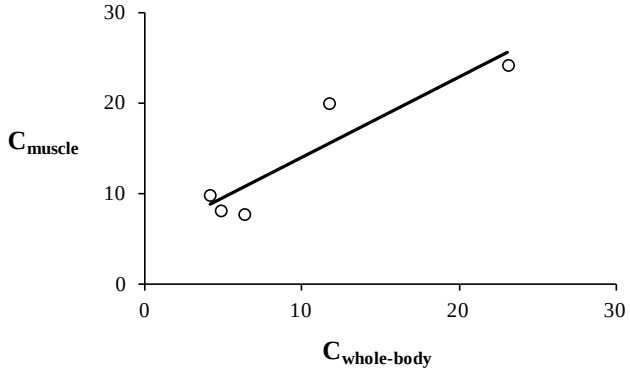
Median ratio: 1.21

R^2: 0.49
F: 2.0
df: 2
P: 0.338

Not used because P > 0.05.

Common carp (*Cyprinus carpio*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio
Osmundson et al. 2007	6.30	7.80	1.24
Osmundson et al. 2007	4.80	8.20	1.71
Osmundson et al. 2007	11.70	20.00	1.71
Osmundson et al. 2007	23.10	24.20	1.05
Osmundson et al. 2007	4.10	6.60	1.61



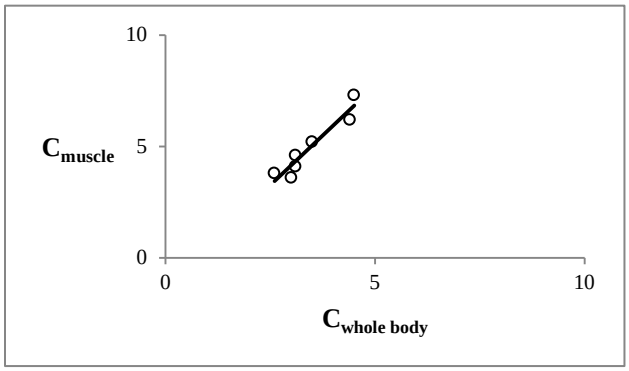
Median ratio: 1.61

R^2: 0.85
F: 17.6
df: 3
P: 0.017

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Flannelmouth sucker (*Catostomus latipinnis*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio
Osmundson et al. 2007	3.0	3.6	1.20
Osmundson et al. 2007	2.6	3.8	1.46
Osmundson et al. 2007	3.1	4.1	1.32
Osmundson et al. 2007	3.1	4.6	1.48
Osmundson et al. 2007	3.5	5.2	1.49
Osmundson et al. 2007	4.4	6.2	1.41
Osmundson et al. 2007	4.5	7.3	1.62



Median ratio: 1.46

R^2: 0.91
F: 50.1
df: 5
P: <0.001

Green sunfish (*Lepomis cyanellus*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio
Osmundson et al. 2007	22.80	28.10	1.23
Osmundson et al. 2007	8.80	12.90	1.47
Osmundson et al. 2007	15.40	21.90	1.42
Osmundson et al. 2007	4.80	5.00	1.04
Osmundson et al. 2007	5.70	6.10	1.07
Osmundson et al. 2007	4.40	5.20	1.18
Osmundson et al. 2007	3.80	5.10	1.34
Osmundson et al. 2007	11.90	15.70	1.32
Osmundson et al. 2007	6.40	10.10	1.58
Osmundson et al. 2007	9.50	11.50	1.21
Osmundson et al. 2007	9.10	10.50	1.15
Osmundson et al. 2007	6.20	7.20	1.16
Osmundson et al. 2007	7.00	9.30	1.33
Osmundson et al. 2007	7.70	7.70	1.00
Osmundson et al. 2007	6.20	6.00	0.97
Osmundson et al. 2007	10.20	12.00	1.18
Osmundson et al. 2007	9.70	12.10	1.25
Osmundson et al. 2007	9.90	12.50	1.26
Osmundson et al. 2007	7.20	7.50	1.04
Osmundson et al. 2007	9.00	11.30	1.26

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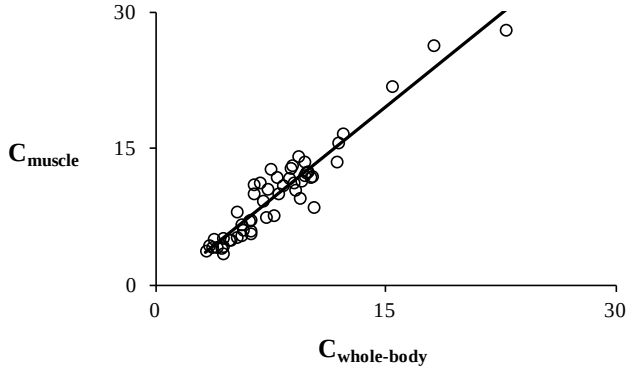
Green sunfish (*Lepomis cyanellus*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio
Osmundson et al. 2007	9.70	13.60	1.40
Osmundson et al. 2007	8.90	13.20	1.48
Osmundson et al. 2007	9.80	12.40	1.27
Osmundson et al. 2007	9.90	12.50	1.26
Osmundson et al. 2007	10.30	8.60	0.83
Osmundson et al. 2007	5.30	5.30	1.00
Osmundson et al. 2007	10.10	11.90	1.18
Osmundson et al. 2007	11.80	13.60	1.15
Osmundson et al. 2007	3.30	3.80	1.15
Osmundson et al. 2007	4.00	4.20	1.05
Osmundson et al. 2007	4.30	4.10	0.95
Osmundson et al. 2007	3.70	4.20	1.14
Osmundson et al. 2007	6.20	5.70	0.92
Osmundson et al. 2007	3.50	4.40	1.26
Osmundson et al. 2007	4.40	3.50	0.80
Osmundson et al. 2007	5.60	5.50	0.98
Osmundson et al. 2007	4.90	5.00	1.02
Osmundson et al. 2007	4.40	4.30	0.98
Osmundson et al. 2007	8.00	10.10	1.26
Osmundson et al. 2007	7.90	11.90	1.51
Osmundson et al. 2007	6.40	11.10	1.73
Osmundson et al. 2007	8.70	11.80	1.36
Osmundson et al. 2007	8.30	11.00	1.33
Osmundson et al. 2007	6.10	7.10	1.16
Osmundson et al. 2007	5.60	6.70	1.20
Osmundson et al. 2007	18.10	26.40	1.46
Osmundson et al. 2007	9.40	9.60	1.02
Osmundson et al. 2007	12.20	16.70	1.37
Osmundson et al. 2007	5.30	8.10	1.53
Osmundson et al. 2007	7.30	10.60	1.45
Osmundson et al. 2007	9.30	14.20	1.53
Osmundson et al. 2007	6.80	11.30	1.66
Osmundson et al. 2007	7.50	12.80	1.71

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Green sunfish (*Lepomis cyanellus*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio

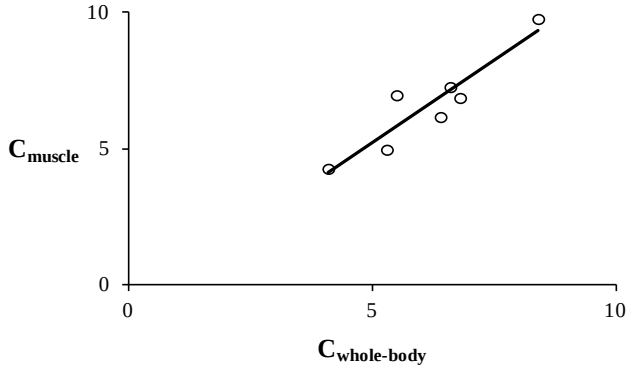


Median ratio: 1.23

R^2: 0.91
F: 501.6
df: 51
P: < 0.001

Roundtail chub (*Gila robusta*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio
Osmundson et al. 2007	4.10	4.30	1.05
Osmundson et al. 2007	5.30	5.00	0.94
Osmundson et al. 2007	6.40	6.20	0.97
Osmundson et al. 2007	6.80	6.90	1.01
Osmundson et al. 2007	5.50	7.00	1.27
Osmundson et al. 2007	6.60	7.30	1.11
Osmundson et al. 2007	8.40	9.80	1.17



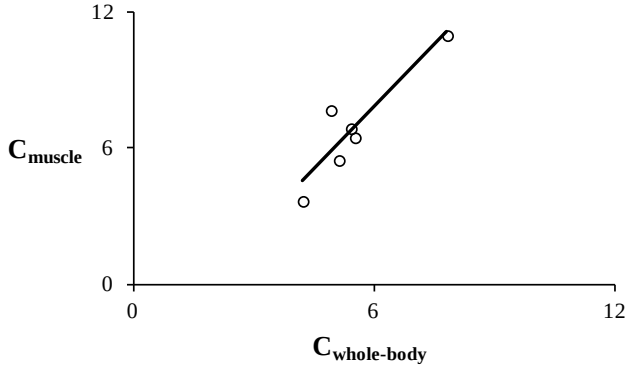
Median ratio: 1.05

R^2: 0.86
F: 29.6
df: 5
P: 0.002

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Smallmouth bass (*Micropterus dolomieu*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio
Osmundson et al. 2007	4.20	3.70	0.88
Osmundson et al. 2007	5.50	6.50	1.18
Osmundson et al. 2007	5.40	6.90	1.28
Osmundson et al. 2007	7.80	11.0	1.41
Osmundson et al. 2007	5.10	7.10	1.08
Osmundson et al. 2007	4.90	8.80	1.57



Median ratio: 1.23

R^2: 0.83
F: 20.2
df: 4
P: 0.008

White sucker (*Catostomus commersonii*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio
Osmundson et al. 2007	3.80	2.90	0.76
Osmundson et al. 2007	4.20	4.80	1.14
Osmundson et al. 2007	3.30	3.70	1.12
Osmundson et al. 2007	4.50	3.70	0.82
Osmundson et al. 2007	6.30	8.40	1.33
Osmundson et al. 2007	6.80	9.40	1.38
Osmundson et al. 2007	11.00	15.50	1.41
Osmundson et al. 2007	12.70	23.60	1.86
Osmundson et al. 2007	5.70	9.40	1.65
Osmundson et al. 2007	3.90	6.10	1.56
Osmundson et al. 2007	3.80	4.60	1.21
Osmundson et al. 2007	9.90	12.30	1.24
Osmundson et al. 2007	5.30	9.20	1.74
Osmundson et al. 2007	10.70	9.40	0.88
Osmundson et al. 2007	5.90	9.40	1.59
Osmundson et al. 2007	7.00	10.50	1.50
Osmundson et al. 2007	6.40	11.40	1.78
Osmundson et al. 2007	6.30	9.60	1.52
Osmundson et al. 2007	5.30	9.30	1.75
Osmundson et al. 2007	6.20	9.80	1.58

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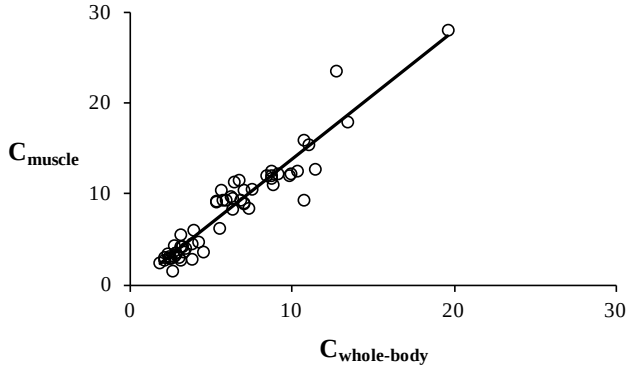
White sucker (*Catostomus commersonii*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio
Osmundson et al. 2007	5.60	10.50	1.88
Osmundson et al. 2007	8.80	11.10	1.26
Osmundson et al. 2007	8.70	12.10	1.39
Osmundson et al. 2007	11.40	12.80	1.12
Osmundson et al. 2007	10.70	16.00	1.50
Osmundson et al. 2007	8.40	12.10	1.44
Osmundson et al. 2007	7.00	9.00	1.29
Osmundson et al. 2007	7.50	10.60	1.41
Osmundson et al. 2007	10.30	12.60	1.22
Osmundson et al. 2007	6.70	11.60	1.73
Osmundson et al. 2007	2.10	2.80	1.33
Osmundson et al. 2007	1.80	2.50	1.39
Osmundson et al. 2007	3.20	4.30	1.34
Osmundson et al. 2007	2.30	3.50	1.52
Osmundson et al. 2007	3.10	4.30	1.39
Osmundson et al. 2007	3.00	3.10	1.03
Osmundson et al. 2007	2.80	3.60	1.29
Osmundson et al. 2007	2.50	3.00	1.20
Osmundson et al. 2007	3.40	4.10	1.21
Osmundson et al. 2007	2.80	3.60	1.29
Osmundson et al. 2007	3.10	5.60	1.81
Osmundson et al. 2007	5.50	6.30	1.15
Osmundson et al. 2007	7.00	9.10	1.30
Osmundson et al. 2007	7.30	8.50	1.16
Osmundson et al. 2007	2.40	3.00	1.25
Osmundson et al. 2007	2.70	4.40	1.63
Osmundson et al. 2007	2.70	3.20	1.19
Osmundson et al. 2007	2.60	1.60	0.62
Osmundson et al. 2007	19.60	28.10	1.43
Osmundson et al. 2007	9.80	12.10	1.23
Osmundson et al. 2007	8.70	11.80	1.36
Osmundson et al. 2007	8.70	12.60	1.45
Osmundson et al. 2007	9.10	12.30	1.35
Osmundson et al. 2007	13.40	18.00	1.34
Osmundson et al. 2007	3.10	2.80	0.90
Osmundson et al. 2007	2.40	3.20	1.33
Osmundson et al. 2007	2.10	3.10	1.48
Osmundson et al. 2007	3.20	4.30	1.34
Osmundson et al. 2007	2.80	3.40	1.21

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White sucker (*Catostomus commersonii*)

Study	$C_{whole\text{-}body}$	C_{muscle}	Ratio



Median ratio: 1.34

R^2: 0.91
F: 561.3
df: 57
P: < 0.001

Table B-4. Muscle to whole-body correction factor.

Common name	Scientific name	Median ratio
Bluegill	*Lepomis macrochirus*	1.32
Bluehead sucker	*Catostomus discobolus*	1.23
Common carp	*Cyprinus carpio*	1.61
Flannelmouth sucker	*Catostomus latipinnis*	1.46
Green sunfish	*Lepomis cyanellus*	1.23
Roundtail chub	*Gila robusta*	1.05
Smallmouth bass	*Micropterus dolomieu*	1.23
White sucker	*Catostomus commersonii*	1.34

Table B-5. Directly calculated final egg-ovary to whole body conversion factors (*CF*).

Common name	Median ratio ($C_{egg\text{-}ovary}$/ $C_{whole\text{-}body}$)	Median ratio ($C_{egg\text{-}ovary}$/ C_{muscle})	Muscle to whole-body correction factor	Final *CF* values
Species				
Bluegill	2.13			2.13
Bluehead sucker	1.82			1.82
Brook trout		1.09	1.27	1.38
Brown trout	1.45			1.45
Common carp	1.92			1.92
Creek chub	1.99			1.99
Cutthroat trout	1.96			1.96

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Common name	Median ratio ($C_{egg\text{-}ovary}$/ $C_{whole\text{-}body}$)	Median ratio ($C_{egg\text{-}ovary}$/ C_{muscle})	Muscle to whole-body correction factor	Final *CF* values
Desert pupfish	1.20			1.20
Dolly Varden		1.26	1.27	1.61
Fathead minnow	1.40			1.40
Flannelmouth sucker	1.41			1.41
Green sunfish	1.45			1.45
Mountain whitefish		5.80	1.27	7.39
Northern pike		1.88	1.27	2.39
Rainbow trout		1.92	1.27	2.44
Razorback sucker		2.31	1.34	3.11
Roundtail chub	2.07			2.07
Smallmouth bass	1.42			1.42
White sturgeon		1.33	1.27	1.69
White sucker	1.38			1.38
Genus				
Catostomus				1.41
Gila				2.07
Lepomis				1.79
Micropterus				1.42
Oncorhynchus				1.96
Family				
Catostomidae				1.41
Centrarchidae				1.45
Cyprinidae				1.95
Salmonidae				1.71
Order				
Cyprinodontiformes				1.20
Perciformes				1.45

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Common name	Median ratio ($C_{egg\text{-}ovary}$/ $C_{whole\text{-}body}$)	Median ratio ($C_{egg\text{-}ovary}$/ C_{muscle})	Muscle to whole-body correction factor	Final *CF* values
Class				
Actinopterygii				1.45

Table B-6. All EPA-derived egg-ovary to whole body (CF), egg-ovary to muscle, and muscle to whole body conversion factors directly calculated or estimated using taxonomic classification. (See main text for explanation of the taxonomic classification approach).

		Direct calculation			Values based on taxonomic classification								Final E-O / WB	
Common name	**Scientific name**	**E-O / WB**	**E-O / M**	**M / WB**	**Order**	**Family**	**Genus**	**E-O / WB**	**E-O / WB source**	**E-O / M**	**E-O / M source**	**M / WB**	**M / WB source**	**Final E-O / WB**	**Final E-O / WB source**
alligator gar	Atractosteus spatula				Lepistosteiformes	Lepisosteidae	Atractosteus	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
bigmouth buffalo	Ictiobus cyprinellus				Cypriniformes	Catostomidae	Ictiobus	1.41	Family Catostomidae	1.28	Family Catostomidae	1.34	Family Catostomidae	1.41	Family Catostomidae
black bullhead	Ameiurus melas				Siluriformes	Ictaluridae	Ameiurus	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
black crappie	Pomoxis nigromaculatus				Perciformes	Centrarchidae	Pomoxis	1.45	Family Centrarchidae	1.21	Family Centrarchidae	1.23	Family Centrarchidae	1.45	Family Centrarchidae
black redhorse	Moxostoma duquesnei				Cypriniformes	Catostomidae	Moxostoma	1.41	Family Catostomidae	1.28	Family Catostomidae	1.34	Family Catostomidae	1.41	Family Catostomidae
blacknose dace	Rhinichthys atratulus				Cypriniformes	Cyprinidae	Rhinichthys	1.95	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.95	Family Cyprinidae
blue catfish	Ictalurus furcatus				Siluriformes	Ictaluridae	Ictalurus	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
bluegill	Lepomis macrochirus	2.13	1.38	1.32	Perciformes	Centrarchidae	Lepomis	2.13	Exact match	1.38	Exact match	1.32	Exact match	2.13	Exact match
bluehead sucker	Catostomus discobolus	1.82	1.48	1.23	Cypriniformes	Catostomidae	Catostomus	1.82	Exact match	1.48	Exact match	1.23	Exact match	1.82	Exact match
brassy minnow	Hybognathus hankinsoni				Cypriniformes	Cyprinidae	Hybognathus	1.95	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.95	Family Cyprinidae
brook stickleback	Culaea inconstans				Gasterosteiformes	Gasterosteidae	Culaea	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
brook trout	Salvelinus fontinalis		1.09		Salmoniformes	Salmonidae	Salvelinus	1.71	Family Salmonidae	1.09	Exact match	1.27	All fish	1.38	E-O/WB * M/WB
brown bullhead	Ameiurus nebulosus				Siluriformes	Ictaluridae	Ameiurus	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
brown trout	Salmo trutta	1.45			Salmoniformes	Salmonidae	Salmo	1.45	Exact match	1.81	Family Salmonidae	1.27	All fish	1.45	Exact match
burbot	Lota lota				Gadiformes	Lotidae	Lota	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
bullhead					Siluriformes	Ictaluridae		1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
chain pickerel	Esox				Esociformes	Esocidae	Esox	1.45	All fish	1.88	Genus Esox	1.27	All fish	2.39	E-O/WB * M/WB
channel catfish	Ictalurus punctatus				Siluriformes	Ictaluridae	Ictalurus	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
common carp	Cyprinus carpio	1.92	1.14	1.61	Cypriniformes	Cyprinidae	Cyprinus	1.92	Exact match	1.14	Exact match	1.61	Exact match	1.92	Exact match
common snook	Centropomus undecimalis				Perciformes	Centropomidae	Centropomus	1.45	Order Perciformes	1.21	Order Perciformes	1.23	Order Perciformes	1.45	Order Perciformes
crappie	Pomoxis sp.				Perciformes	Centrarchidae	Pomoxis	1.45	Family Centrarchidae	1.21	Family Centrarchidae	1.23	Family Centrarchidae	1.45	Family Centrarchidae
creek chub	Semotilus atromaculatus	1.99			Cypriniformes	Cyprinidae	Semotilus	1.99	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.99	Family Cyprinidae
cutthroat trout	Oncorhynchus clarkii	1.96	1.81		Salmoniformes	Salmonidae	Oncorhynchus	1.96	Exact match	1.81	Exact match	1.27	All fish	1.96	Exact match

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Common name	Scientific name	Direct calculation			Values based on taxonomic classification									Final E-O / WB	
		E-O / WB	E-O / M	M / WB	Order	Family	Genus	E-O / WB	E-O / WB source	E-O / M	E-O / M source	M / WB	M / WB source	Final E-O / WB	Final E-O / WB source
desert pupfish	Cyprinodon macularius	1.20			Cyprinodontiformes	Cyprinodontidae	Cyprinodon	1.20	Exact match	1.35	All fish	1.27	All fish	1.20	Exact match
Dolly Varden	Salvelinus malma		1.26		Salmoniformes	Salmonidae	Salvelinus	1.71	Family Salmonidae	1.26	Exact match	1.27	All fish	1.61	E-O/WB * M/WB
fathead minnow	Pimephales promelas	1.40			Cypriniformes	Cyprinidae	Pimephales	1.40	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.40	Family Cyprinidae
flannelmouth sucker	Catostomus latipinnis	1.41	1.08	1.46	Cypriniformes	Catostomidae	Catostomus	1.41	Exact match	1.08	Exact match	1.46	Exact match	1.41	Exact match
flathead catfish	Pylodictis				Siluriformes	Ictaluridae	Pylodictus	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
flathead chub	Platygobio gracilis				Cypriniformes	Cyprinidae	Platygobio	1.95	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.95	Family Cyprinidae
freshwater drum	Aplodinotus grunniens				Perciformes	Sciaenidae	Aplodinotus	1.45	Order Perciformes	1.21	Order Perciformes	1.23	Order Perciformes	1.45	Order Perciformes
goldeye	Hiodon alosoides				Hiodontiformes	Hiodontidae	Hiodon	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
gizzard shad	Dorosoma cepedianum				Clupeiformes	Clupeidae	Dorosoma	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
green sunfish	Lepomis cyanellus	1.45	1.21	1.23	Perciformes	Centrarchidae	Lepomis	1.45	Exact match	1.21	Exact match	1.23	Exact match	1.45	Exact match
iowa darter	Etheostoma exile				Perciformes	Percidae	Etheostoma	1.45	Order Perciformes	1.21	Order Perciformes	1.23	Order Perciformes	1.45	Order Perciformes
Japanese medaka	Oryzias latipes				Beloniformes	Adrianichthyidae	Oryzias	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
kokanee salmon	Oncorhynchus nerka				Salmoniformes	Salmonidae	Oncorhynchus	1.96	Genus Oncorhynchus	1.86	Genus Oncorhynchus	1.27	All fish	1.96	Genus Oncorhynchus
largemouth bass	Micropterus salmoides				Perciformes	Centrarchidae	Micropterus	1.42	Genus Micropterus	1.19	Genus Micropterus	1.23	Genus Micropterus	1.42	Genus Micropterus
largescale sucker	Catostomus macrocheilus				Cypriniformes	Catostomidae	Catostomus	1.41	Genus Catostomus	1.08	Genus Catostomus	1.34	Genus Catostomus	1.41	Genus Catostomus
longnose dace	Rhinichthys cataractae				Cypriniformes	Cyprinidae	Rhinichthys	1.95	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.95	Family Cyprinidae
longnose sucker	Catostomus catostomus				Cypriniformes	Catostomidae	Catostomus	1.41	Genus Catostomus	1.08	Genus Catostomus	1.34	Genus Catostomus	1.41	Genus Catostomus
mosquitofish	Gambusia sp.				Cyprinodontiformes	Poeciliidae	Gambusia	1.20	Order Cyprinodontiformes	1.35	All fish	1.27	All fish	1.20	Order Cyprinodontiformes
mottled sculpin	Cottus bairdi				Scorpaeniformes	Cottidae	Cottus	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
mountain whitefish	Prosopium williamsoni		5.80		Salmoniformes	Salmonidae	Prosopium	1.71	Family Salmonidae	5.80	Exact match	1.27	All fish	7.39	E-O/WB * M/WB
ninespine stickleback	Pungitius pungitius				Gasterosteiformes	Gasterosteidae	Pungitius	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
northern pike	Esox lucius		1.88		Esociformes	Esocidae	Esox	1.45	All fish	1.88	Exact match	1.27	All fish	2.39	E-O/WB * M/WB

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Common name	Scientific name	Direct calculation			Values based on taxonomic classification									Final E-O / WB	
		E-O / WB	E-O / M	M / WB	Order	Family	Genus	E-O / WB	E-O / WB source	E-O / M	E-O / M source	M / WB	M / WB source	Final E-O / WB	Final E-O / WB source
northern pikeminnow	Ptychocheilus oregonensis				Cypriniformes	Cyprinidae	Ptychocheilus	1.95	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.95	Family Cyprinidae
northern plains killifish	Fundulus kansae				Cyprinodontiformes	Fundulidae	Fundulus	1.20	Order Cyprinodontiformes	1.35	All fish	1.27	All fish	1.20	Order Cyprinodontiformes
northern redbelly dace	Chrosomus eos				Cypriniformes	Cyprinidae	Chrosomus	1.95	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.95	Family Cyprinidae
northern squawfish	Ptychocheilus oregonensis				Cypriniformes	Cyprinidae	Ptychocheilus	1.95	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.95	Family Cyprinidae
quillback	Carpiodes cyprinus				Cypriniformes	Catostomidae	Carpiodes	1.41	Family Catostomidae	1.28	Family Catostomidae	1.34	Family Catostomidae	1.41	Family Catostomidae
rainbow trout	Oncorhynchus mykiss		1.92		Salmoniformes	Salmonidae	Oncorhynchus	1.96	Genus Oncorhynchus	1.92	Exact match	1.27	All fish	2.44	E-O/WB * M/WB
razorback sucker	Xyrauchen texanus		2.31		Cypriniformes	Catostomidae	Xyrauchen	1.41	Family Catostomidae	2.31	Exact match	1.34	Family Catostomidae	3.11	E-O/WB * M/WB
red shiner	Cyprinella lutrensis				Cypriniformes	Cyprinidae	Cyprinella	1.95	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.95	Family Cyprinidae
redbreast sunfish	Lepomis auritus				Perciformes	Centrarchidae	Lepomis	1.79	Genus Lepomis	1.29	Genus Lepomis	1.27	Genus Lepomis	1.79	Genus Lepomis
redear sunfish	Lepomis microlophus				Perciformes	Centrarchidae	Lepomis	1.79	Genus Lepomis	1.29	Genus Lepomis	1.27	Genus Lepomis	1.79	Genus Lepomis
redside shiner	Richardsonius balteatus				Cypriniformes	Cyprinidae	Richardsonius	1.95	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.95	Family Cyprinidae
river carpsucker	Carpiodes carpio				Cypriniformes	Catostomidae	Carpiodes	1.41	Family Catostomidae	1.28	Family Catostomidae	1.34	Family Catostomidae	1.41	Family Catostomidae
river redhorse	Moxostoma carinatum				Cypriniformes	Catostomidae	Moxostoma	1.41	Family Catostomidae	1.28	Family Catostomidae	1.34	Family Catostomidae	1.41	Family Catostomidae
rock bass	Ambloplites rupestris				Perciformes	Centrarchidae	Ambloplites	1.45	Family Centrarchidae	1.21	Family Centrarchidae	1.23	Family Centrarchidae	1.45	Family Centrarchidae
roundtail chub	Gila robusta	2.07	2.04	1.05	Cypriniformes	Cyprinidae	Gila	2.07	Exact match	2.04	Exact match	1.05	Exact match	2.07	Exact match
sacramento perch	Archoplites interruptus				Perciformes	Centrarchidae	Archoplites	1.45	Family Centrarchidae	1.21	Family Centrarchidae	1.23	Family Centrarchidae	1.45	Family Centrarchidae
sacramento pikeminnow	Ptychocheilus grandis				Cypriniformes	Cyprinidae	Ptychocheilus	1.95	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.95	Family Cyprinidae
sailfin molly	Poecilia latipinna				Cyprinodontiformes	Poeciliidae	Poecilia	1.20	Order Cyprinodontiformes	1.35	All fish	1.27	All fish	1.20	Order Cyprinodontiformes
sand shiner	Notropis stramineus				Cypriniformes	Cyprinidae	Notropis	1.95	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.95	Family Cyprinidae
sauger	Sander canadensis				Perciformes	Percidae	Sander	1.45	Order Perciformes	1.21	Order Perciformes	1.23	Order Perciformes	1.45	Order Perciformes
sculpin	Cottus sp.				Scorpaeniformes	Cottidae	Cottus	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish

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Common name	Scientific name	Direct calculation			Values based on taxonomic classification									Final E-O / WB	
		E-O / WB	E-O / M	M / WB	Order	Family	Genus	E-O / WB	E-O / WB source	E-O / M	E-O / M source	M / WB	M / WB source	Final E-O / WB	Final E-O / WB source
shadow bass	Ambloplites ariommus				Perciformes	Centrarchidae	Ambloplites	1.45	Family Centrarchidae	1.21	Family Centrarchidae	1.23	Family Centrarchidae	1.45	Family Centrarchidae
shorthead redhorse	Moxostoma macrolepidotum				Cypriniformes	Catostomidae	Moxostoma	1.41	Family Catostomidae	1.28	Family Catostomidae	1.34	Family Catostomidae	1.41	Family Catostomidae
silver carp	Hypophthalmichthys molitrix				Cypriniformes	Cyprinidae	Hypophthalmichthys	1.95	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.95	Family Cyprinidae
smallmouth bass	Micropterus dolomieu	1.42	1.19	1.23	Perciformes	Centrarchidae	Micropterus	1.42	Exact match	1.19	Exact match	1.23	Exact match	1.42	Exact match
smallmouth buffalo	Ictiobus bubalus				Cypriniformes	Catostomidae	Ictiobus	1.41	Family Catostomidae	1.28	Family Catostomidae	1.34	Family Catostomidae	1.41	Family Catostomidae
speckled dace	Rhinichthys osculus				Cypriniformes	Cyprinidae	Rhinichthys	1.95	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.95	Family Cyprinidae
spottail shiner	Notropis hudsonius				Cypriniformes	Cyprinidae	Notropis	1.95	Family Cyprinidae	1.59	Family Cyprinidae	1.33	Family Cyprinidae	1.95	Family Cyprinidae
spotted bass	Micropterus punctulatus				Perciformes	Centrarchidae	Micropterus	1.42	Genus Micropterus	1.19	Genus Micropterus	1.23	Genus Micropterus	1.42	Genus Micropterus
spotted gar	Lepisosteus oculatus				Lepistosteiformes	Lepisosteidae	Lepisosteus	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
stonecat	Noturus flavus				Siluriformes	Ictaluridae	Noturus	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
striped bass	Morone saxatilis				Perciformes	Moronidae	Morone	1.45	Order Perciformes	1.21	Order Perciformes	1.23	Order Perciformes	1.45	Order Perciformes
striped mullet	Mugil cephalus				Mugiliformes	Mugilidae	Mugil	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
sucker					Cypriniformes	Catostomidae		1.41	Family Catostomidae	1.28	Family Catostomidae	1.34	Family Catostomidae	1.41	Family Catostomidae
tilapia					Perciformes	Cichlidae		1.45	Order Perciformes	1.21	Order Perciformes	1.23	Order Perciformes	1.45	Order Perciformes
trout species	Oncorhynchus sp.				Salmoniformes	Salmonidae	Oncorhynchus	1.96	Genus Oncorhynchus	1.86	Genus Oncorhynchus	1.27	All fish	1.96	Genus Oncorhynchus
tui chub	Gila bicolor				Cypriniformes	Cyprinidae	Gila	2.07	Genus Gila	2.04	Genus Gila	1.05	Genus Gila	2.07	Genus Gila
utah sucker	Catostomus ardens				Cypriniformes	Catostomidae	Catostomus	1.41	Genus Catostomus	1.08	Genus Catostomus	1.34	Genus Catostomus	1.41	Genus Catostomus
walleye	Sander vitreus				Perciformes	Percidae	Sander	1.45	Order Perciformes	1.21	Order Perciformes	1.23	Order Perciformes	1.45	Order Perciformes
western mosquitofish	Gambusia affinis				Cyprinodontiformes	Poeciliidae	Gambusia	1.20	Order Cyprinodontiformes	1.35	All fish	1.27	All fish	1.20	Order Cyprinodontiformes
white bass	Morone chrysops				Perciformes	Moronidae	Morone	1.45	Order Perciformes	1.21	Order Perciformes	1.23	Order Perciformes	1.45	Order Perciformes
white crappie	Pomoxis annularis				Perciformes	Centrarchidae	Pomoxis	1.45	Family Centrarchidae	1.21	Family Centrarchidae	1.23	Family Centrarchidae	1.45	Family Centrarchidae
white sturgeon	Acipenser transmontanus		1.33		Acipenseriformes	Acipenseridae	Acipenser	1.45	All fish	1.33	Exact match	1.27	All fish	1.69	E-O/WB * M/WB

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Common name	Scientific name	Direct calculation			Values based on taxonomic classification									Final E-O / WB	
		E-O / WB	E-O / M	M / WB	Order	Family	Genus	E-O / WB	E-O / WB source	E-O / M	E-O / M source	M / WB	M / WB source	Final E-O / WB	Final E-O / WB source
white sucker	Catostomus commersonii	1.38	1.00	1.34	Cypriniformes	Catostomidae	Catostomus	1.38	Exact match	1.00	Exact match	1.34	Exact match	1.38	Exact match
wiper	Morone chrysops x Moron saxatilis				Perciformes	Moronidae	Morone	1.45	Order Perciformes	1.21	Order Perciformes	1.23	Order Perciformes	1.45	Order Perciformes
yellow bullhead	Ameiurus natalis				Siluriformes	Ictaluridae	Ameiurus	1.45	All fish	1.35	All fish	1.27	All fish	1.45	All fish
yellow perch	Perca flavescens				Perciformes	Percidae	Perca	1.45	Order Perciformes	1.21	Order Perciformes	1.23	Order Perciformes	1.45	Order Perciformes

3.0 DERIVATION OF TROPHIC TRANSFER FACTOR VALUES

3.1 Methodology

Taxa specific trophic transfer factors (TTF) to quantify the degree of biomagnification across a given trophic level were calculated from either physiological parameters measured in laboratory studies or from field measurements of paired selenium concentrations in consumer species and their food. TTFs from both approaches were used to calculate translated water concentrations; however, when TTF data of similar quality are available from both approached, as was the case with bluegill, field-derived TTF data are used.

Physiological data consisted of assimilation efficiencies (AE), measured as either a percentage or a proportion, ingestion rates (IR), measured as grams of Se per grams of food consumed per day, and efflux rate constant (k_e), measured as 1/day. All available data were collected for a particular species, and then the TTF for that species was calculated using the equation:

$$\text{TTF} = \frac{AE\ x\ IR}{k_e}$$

Where AE, IR, and K_e were estimated as the median value of all available data for that parameter for that species.

The majority of TTF were calculated using paired whole-body Se measurements from organisms collected at the same site in the field. TTFs for trophic level 2 organisms were determined using the equation:

$$TTF^{TL2} = \frac{C_{tissue}^{TL2}}{C_{food}^{TL2}}$$

Where C_{food}^{TL2} equals the average Se concentration in particulate matter, defined as the average of C_{algae}, $C_{detritus}$, and $C_{sediment}$. Of the three types of particulate matter potentially assumed by TL2 organisms (e.g., the majority of invertebrates), $C_{sediment}$ correlated relatively poorly to C_{tissue}^{TL2}, when compared to C_{algae} and $C_{detritus}$. In order to minimize potentially erroneous TTF calculations based solely on sediment Se concentrations, while note completely discounting the importance of organic matter in sediments as a potential food source, $C_{sediment}$ was included in $C_{particulate}$ calculations only when either C_{algae} or $C_{detritus}$ data were also available.

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TTFs for trophic level 3 organisms were determined using the equation:

$$TTF^{TL3} = \frac{C_{tissue}^{TL3}}{C_{food}^{TL3}}$$

Where C_{food}^{TL3} equals the average whole-body Se concentration in invertebrates collected at the same site as their potential predator species. The majority of trophic level 3 organisms are fish species, but damselflies and dragonflies of the order Odonata are also trophic level 3 organisms, and TTF^{TL3} values were calculated for those species as well.

For all field derived data used to determine TTFs, EPA first confirmed a statistical relationship between whole-body selenium concentrations for each species and its food using OLS linear regression. If the regression resulted in a statistically significant ($P<0.05$) positive slope, EPA calculated the TTF as the median ratio of the paired concentration data.

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3.2 TTF values from physiological coefficients

AE (%) = Assimilation efficiency
IR ($g\ g^{-1}\ d^{-1}$) = Ingestion rate
k_e (d^{-1}) = Efflux rate constant
TTF = $\frac{AE\ x\ IR}{K_e}$

3.2.1 Invertebrates

Baltic macoma (*Macoma balthica*)

Physiological Parameters				
AE (%)	**IR($g\ g^{-1}\ d^{-1}$)**	**k_e (d^{-1})**	**TTF**	**Study**
22.5				Luoma et al. 1992
91.0				Luoma et al. 1992
84.0				Luoma et al. 1992
95.0				Luoma et al. 1992
78.0		0.03		Reinfelder et al. 1997
74.0		0.03		Reinfelder et al. 1997
92.3				Schleckat et al. 2002
58.0				Schleckat et al. 2002
85.8				Schleckat et al. 2002
64.9				Schleckat et al. 2002
90.4				Schleckat et al. 2002
Median Values and TTF				
84.0	0.27[a]	0.03	7.56	

[a] Value taken from *Mytilus edulis*

Short-necked clam (*Ruditapes philippinarum*)

Physiological Parameters				
AE (%)	**IR($g\ g^{-1}\ d^{-1}$)**	**k_e (d^{-1})**	**TTF**	**Study**
70.0		0.013		Zhang et al. 1990
52.0		0.013		Zhang et al. 1990
Median Values and TTF				
61.0	0.27[a]	0.013	12.67	

[a] Value taken from *Mytilus edulis*

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Quahog (*Mercenaria mercenaria*)

Physiological Parameters				
AE (%)	**IR(g g^{-1} d^{-1})**	**k_e (d^{-1})**	**TTF**	**Study**
100.1				Reinfelder and Fisher 1994
92.0		0.01		Reinfelder et al. 1997
Median Values and TTF				
96.1	0.27[a]	0.01	25.93	

[a] Value taken from *Mytilus edulis*

Eastern Oyster (*Crassostrea virginica*)

Physiological Parameters				
AE (%)	**IR(g g^{-1} d^{-1})**	**k_e (d^{-1})**	**TTF**	**Study**
		0.005		Okazaki and Panietz 1981
105.4				Reinfelder and Fisher 1994
70.0		0.070		Reinfelder et al. 1997
Median Values and TTF				
87.7	0.27a	0.038	6.31	

[a] Value taken from *Mytilus edulis*

Common mussel (*Mytilus edulis*)

Physiological Parameters				
AE (%)	**IR(g g^{-1} d^{-1})**	**k_e (d^{-1})**	**TTF**	**Study**
86.0		0.02		Reinfelder et al. 1997
75.0		0.05		Reinfelder et al. 1997
60.7				Wang and Fisher 1996
48.0				Wang and Fisher 1996
13.7				Wang and Fisher 1996
55.1				Wang and Fisher 1996
55.8				Wang and Fisher 1996
71.9				Wang and Fisher 1996
71.5				Wang and Fisher 1996
27.9				Wang and Fisher 1996
84.4				Wang and Fisher 1996
81.0				Wang and Fisher 1996
79.4				Wang and Fisher 1996

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Physiological Parameters				
AE (%)	**IR(g g^{-1} d^{-1})**	**k_e (d^{-1})**	**TTF**	**Study**
63.0		0.037		Wang and Fisher 1996
61.5		0.05		Wang and Fisher 1996
69.0		0.027		Wang and Fisher 1996
81.0		0.022		Wang and Fisher 1997
82.0		0.020		Wang and Fisher 1997
72.0		0.018		Wang and Fisher 1997
78.0		0.055		Wang et al. 1995
76.0		0.065		Wang et al. 1995
71.0		0.058		Wang et al. 1995
33.9				Wang et al. 1996
27.5				Wang et al. 1996
				Wang et al. 1996
				Wang et al. 1996
	0.27	0.022		Wang et al. 1996
		0.026		Wang et al. 1996
		0.019		Wang et al. 1996
Median Values and TTF				
71.3	0.27	0.026	7.30	

Asian clam (*Corbicula fluminea*)

Physiological Parameters				
AE (%)	**IR(g g^{-1} d^{-1})**	**k_e (d^{-1})**	**TTF**	**Study**
55.0	0.05	0.006		Lee et al. 2006
Median Values and TTF				
55.0	0.05	0.006	4.58	

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Zebra mussel (*Dreissena polymorpha*)

Physiological Parameters				
AE (%)	**IR(g g^{-1} d^{-1})**	**k_e (d^{-1})**	**TTF**	**Study**
18.0				Roditi and Fisher 1999
24.0				Roditi and Fisher 1999
46.0				Roditi and Fisher 1999
40.0				Roditi and Fisher 1999
41.0				Roditi and Fisher 1999
7.7				Roditi and Fisher 1999
23.0				Roditi and Fisher 1999
28.0				Roditi and Fisher 1999
	0.40			Roditi and Fisher 1999
		0.026		Roditi and Fisher 1999
Median Values and TTF				
26.0	0.40	0.026	4.00	

Water flea (*Daphnia magna*)

Physiological Parameters				
AE (%)	**IR(g g^{-1} d^{-1})**	**k_e (d^{-1})**	**TTF**	**Study**
	0.08			Goulet et al. 2007
	0.34			Goulet et al. 2007
57.9				Yu and Wang 2002b
43.0				Yu and Wang 2002b
39.8				Yu and Wang 2002b
33.0				Yu and Wang 2002b
41.4				Yu and Wang 2002b
41.5				Yu and Wang 2002b
38.0				Yu and Wang 2002b
24.5				Yu and Wang 2002b
		0.101		Yu and Wang 2002b
		0.12		Yu and Wang 2002b
		0.131		Yu and Wang 2002b
		0.134		Yu and Wang 2002b
		0.108		Yu and Wang 2002b
		0.112		Yu and Wang 2002b
Median Values and TTF				
40.6	0.21	0.12	0.74	

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Copepod (*Temora longicornis*)

Physiological Parameters				
AE (%)	**IR(g g^{-1} d^{-1})**	**k_e (d^{-1})**	**TTF**	**Study**
55.0	0.42	0.115		Wang and Fisher 1998
Median Values and TTF				
55.0	0.42	0.115	2.01	

Copepod (Small, unidentified)

Physiological Parameters				
AE (%)	**IR(g g^{-1} d^{-1})**	**k_e (d^{-1})**	**TTF**	**Study**
50.0	0.42	0.155		Schlekat et al. 2004
Median Values and TTF				
50.0	0.42	0.155	1.35	

Copepod (Large, unidentified)

Physiological Parameters				
AE (%)	**IR(g g^{-1} d^{-1})**	**k_e (d^{-1})**	**TTF**	**Study**
52.0	0.42	0.155		Schlekat et al. 2004
Median Values and TTF				
50.0	0.42	0.155	1.41	

Blackworm (*Lumbriculus variegatus*)

Physiological Parameters				
AE (%)	**IR(g g^{-1} d^{-1})**	**k_e (d^{-1})**	**TTF**	**Study**
		0.009		Riedel and Cole 2001
		0.006		Riedel and Cole 2001
24.0	0.067	0.013		Riedel and Cole 2001
9.0	0.067	0.009		Riedel and Cole 2001
Median Values and TTF				
16.5	0.067	0.0086	1.29	

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Mayfly (*Centroptilum triangulifer*)[a]

Physiological Parameters				
AE (%)	**IR(g g^{-1} d^{-1})**	**k_e (d^{-1})**	**TTF**	**Study**
38.0	0.72	0.25		Riedel and Cole 2001
40.0	0.72	0.19		Riedel and Cole 2001
Median Values and TTF				
39.0	0.72	0.22	1.28	

a – not used because field TTF data available

3.2.2 Vertebrates

Bluegill (*Lepomis macrochirus*)[a]

Physiological Parameters				
AE (%)	**IR(g g^{-1} d^{-1})**	**k_e (d^{-1})**	**TTF**	**Study**
34.0				Besser et al. 1993
22.0				Besser et al. 1993
24.0				Besser et al. 1993
36.0				Besser et al. 1993
30.0				Besser et al. 1993
32.0				Besser et al. 1993
43.0				Besser et al. 1993
40.0				Besser et al. 1993
37.0		0.041		Besser et al. 1993
		0.031		Besser et al. 1993
		0.034		Besser et al. 1993
36.0		0.031		Besser et al. 1993
		0.038		Besser et al. 1993
		0.038		Besser et al. 1993
	0.008			Whitledge and Haywood 2000
	0.042			Whitledge and Haywood 2000
Median Values and TTF				
35.0	0.025	0.036	1.156[a]	

[a] Not used because of availability of acceptable field-based TTF data

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Fathead Minnow (*Pimephales promelas*)

Physiological Parameters				
AE (%)	**IR(g g^{-1} d^{-1})**	**k_e (d^{-1})**	**TTF**	**Study**
50.0				Presser and Luoma 2010
	0.050			Bertram and Brooks 1986
		0.029		Bertram and Brooks 1986
		0.019		Bertram and Brooks 1986
		0.3		Bertram and Brooks 1986
		0.014		Bertram and Brooks 1986
		0.013		Bertram and Brooks 1986
		0.016		Bertram and Brooks 1986
		0.012		Bertram and Brooks 1986
		0.026		Bertram and Brooks 1986
		0.018		Bertram and Brooks 1986
		0.025		Bertram and Brooks 1986
Median Values and TTF				
50.0	0.050	0.0185	1.35	

Striped Bass (*Morone saxatilis*)

Physiological Parameters				
AE (%)	**IR(g g^{-1} d^{-1})**	**k_e (d^{-1})**	**TTF**	**Study**
33	0.17	0.09		Baines et al. 2002
42	0.5	0.08		Baines et al. 2002
	0.12			Buckel and Stoner 2004
	0.16			Buckel and Stoner 2004
	0.11			Buckel and Stoner 2004
	0.08			Buckel and Stoner 2004
Median Values and TTF				
37.5	0.335	0.085	1.48	

TTF calculated from only Baines et al. (2002) because it had complete data.

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3.3 TTF values from field data

3.3.1 Invertebrates

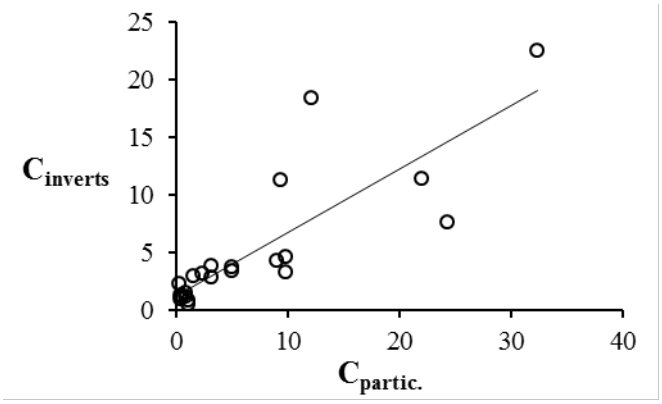
C_{alg} = Selenium concentration in algae (mg/kg)
C_{det} = Selenium concentration in detritus (mg/kg)
C_{sed} = Selenium concentration in sediment (mg/kg)
C_{invert} = Selenium concentration in invertebrate tissue (mg/kg)
C_{part} = Average selenium concentration in particulate material $\left(\frac{C_{alg}+C_{det}+C_{sed}}{3}\right)$
Ratio = $\frac{C_{invert}}{C_{part}}$

Scuds (Amphipoda)

Study	Site	C_{alg}	C_{det}	C_{sed}	C_{part}	C_{invert}	Ratio
Birkner 1978	29	8.80		15.40	12.10	18.40	1.52
Birkner 1978	20	3.00		41.00	22.00	11.40	0.52
Birkner 1978	7	0.18		2.80	1.49	2.90	1.95
Birkner 1978	19	16.80		1.20	9.00	4.30	0.48
Birkner 1978	30	17.30		47.30	32.30	22.50	0.70
Birkner 1978	3	0.10		0.30	0.20	2.30	11.50
Birkner 1978	22	4.60		44.00	24.30	7.60	0.31
Birkner 1978	23	7.80		10.80	9.30	11.30	1.22
Lambing et al. 1994	S46	2.30			2.30	3.20	1.39
Saiki et al. 1993	ET6	1.03	1.15		1.09	0.44	0.40
Saiki et al. 1993	ET6	1.03	1.15		1.09	0.86	0.79
Saiki et al. 1993	GT5	4.50	14.95		9.73	4.60	0.47
Saiki et al. 1993	GT5	4.50	14.95		9.73	3.30	0.34
Saiki et al. 1993	GT4	1.39	8.40		4.90	3.40	0.69
Saiki et al. 1993	GT4	1.39	8.40		4.90	3.70	0.76
Saiki et al. 1993	SJR2	1.25	5.00		3.13	3.80	1.22
Saiki et al. 1993	SJR2	1.25	5.00		3.13	2.80	0.90
Saiki et al. 1993	SJR3	0.45	1.25		0.85	1.50	1.77
Saiki et al. 1993	SJR3	0.45	1.25		0.85	1.10	1.30
Saiki et al. 1993	SJR1	0.22	0.50		0.36	0.89	2.47
Saiki et al. 1993	SJR1	0.22	0.50		0.36	1.30	3.61
Saiki et al. 1993	ET7	0.16	0.76		0.46	1.10	2.42
Saiki et al. 1993	ET7	0.16	0.76		0.46	1.10	2.42

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Scuds (Amphipoda)

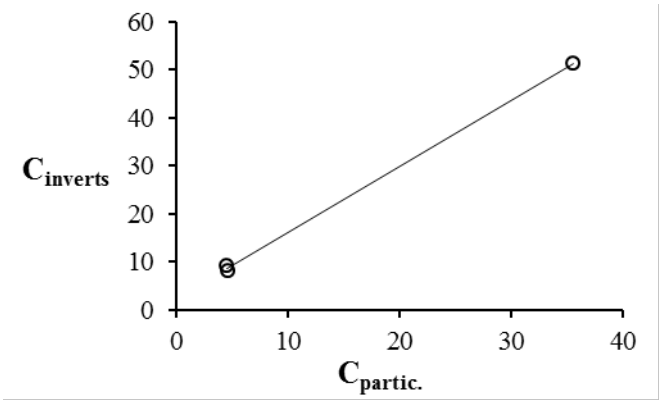


Median ratio: 1.22

R^2: 0.69
F: 46.9
df: 21
P: < 0.001

Earthworms and Leeches (Annelida)

Study	Site	C_{alg}	C_{det}	C_{sed}	C_{part}	C_{invert}	Ratio
Lemly 1985	Badin Lake	8.20		0.91	4.56	8.10	1.78
Lemly 1985	Belews Lake	62.70		8.27	35.49	51.15	1.44
Lemly 1985	High Rock Lake	8.25		0.79	4.52	9.05	2.00



Median ratio: 1.78

R^2: 1.00
F: 2426
df: 1
P: < 0.001

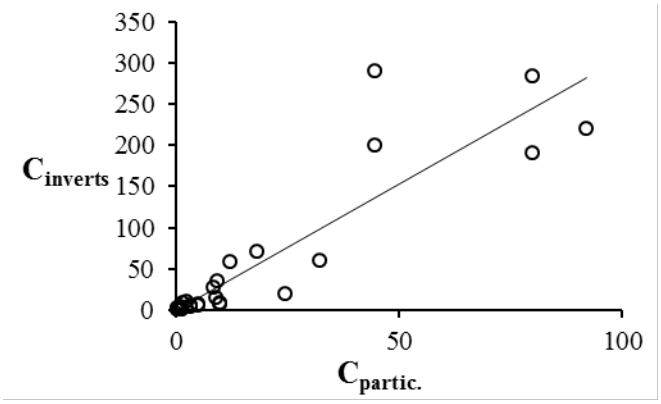
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Midges (Chironomidae)

Study	Site	C_{alg}	C_{det}	C_{sed}	C_{part}	C_{invert}	Ratio
Birkner 1978	29	8.80		15.40	12.10	58.20	4.81
Birkner 1978	19	16.80		1.20	9.00	15.30	1.70
Birkner 1978	30	17.30		47.30	32.30	59.30	1.84
Birkner 1978	3	0.10		0.30	0.20	2.50	12.50
Birkner 1978	22	4.60		44.00	24.30	18.80	0.77
Birkner 1978	27	10.35		6.50	8.43	26.70	3.17
Birkner 1978	12	2.30		0.30	1.30	7.70	5.92
Birkner 1978	23	7.80		10.80	9.30	34.20	3.68
Grasso et al. 1995	17	1.87		0.40	1.14	2.07	1.82
Lambing et al. 1994	S46	2.30			2.30	9.70	4.22
Saiki and Lowe 1987	Kesterson Pond 11	18.15	47.95	8.56	18.15	71.00	3.91
Saiki and Lowe 1987	Kesterson Pond 2	152.7	44.65	34.82	44.65	200.0	4.48
Saiki and Lowe 1987	Kesterson Pond 2	152.7	44.65	34.82	44.65	290.0	6.49
Saiki and Lowe 1987	Kesterson Pond 8	136.5	92.00	6.05	92.00	220.0	2.39
Saiki and Lowe 1987	San Luis Drain	67.00	275.0	79.90	79.90	190.0	2.38
Saiki and Lowe 1987	San Luis Drain	67.00	275.0	79.90	79.90	284.0	3.55
Saiki and Lowe 1987	Volta Pond 26	0.42	1.01	0.29	0.42	1.74	4.18
Saiki and Lowe 1987	Volta Pond 26	0.42	1.01	0.29	0.42	1.30	3.13
Saiki and Lowe 1987	Volta Pond 7		1.39	0.39	0.89	3.00	3.37
Saiki and Lowe 1987	Volta Pond 7		1.39	0.39	0.89	1.30	1.46
Saiki et al. 1993	ET6	1.03	1.15		1.09	0.58	0.53
Saiki et al. 1993	ET6	1.03	1.15		1.09	1.00	0.92
Saiki et al. 1993	GT5	4.50	14.95		9.73	8.90	0.92
Saiki et al. 1993	GT5	4.50	14.95		9.73	7.20	0.74
Saiki et al. 1993	GT4	1.39	8.40		4.90	5.40	1.10
Saiki et al. 1993	GT4	1.39	8.40		4.90	6.90	1.41
Saiki et al. 1993	SJR2	1.25	5.00		3.13	6.00	1.92
Saiki et al. 1993	SJR2	1.25	5.00		3.13	4.10	1.31
Saiki et al. 1993	SJR3	0.45	1.25		0.85	1.50	1.77
Saiki et al. 1993	SJR3	0.45	1.25		0.85	1.60	1.89
Saiki et al. 1993	SJR1	0.22	0.50		0.36	0.47	1.31
Saiki et al. 1993	SJR1	0.22	0.50		0.36	1.00	2.78
Saiki et al. 1993	ET7	0.16	0.76		0.46	0.53	1.16
Saiki et al. 1993	ET7	0.16	0.76		0.46	0.84	1.85

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Midges (Chironomidae)

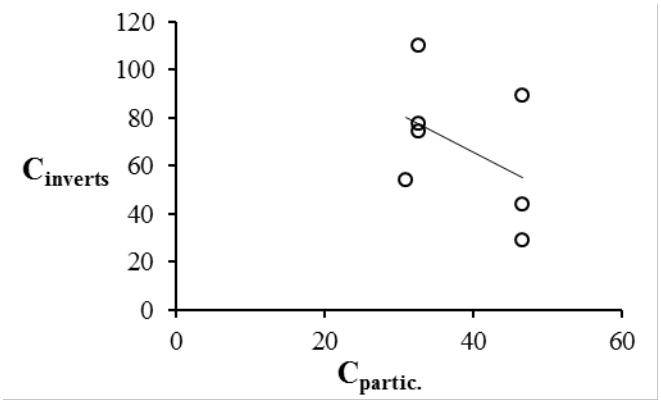


Median ratio: 1.90

R^2: 0.82
F: 144.0
df: 32
P: < 0.001

Beetles (Coleoptera)

Study	Site	C_{alg}	C_{det}	C_{sed}	C_{part}	C_{invert}	Ratio
Schuler et al. 1990	Kesterson Pond 11	53.70		11.50	32.60	77.60	2.38
Schuler et al. 1990	Kesterson Pond 11	53.70		11.50	32.60	74.10	2.27
Schuler et al. 1990	Kesterson Pond 11	53.70		11.50	32.60	110.00	3.37
Schuler et al. 1990	Kesterson Pond 2	52.50		9.30	30.90	54.00	1.75
Schuler et al. 1990	Kesterson Pond 7	87.10		5.90	46.50	89.10	1.92
Schuler et al. 1990	Kesterson Pond 7	87.10		5.90	46.50	28.80	0.62
Schuler et al. 1990	Kesterson Pond 7	87.10		5.90	46.50	43.70	0.94



Median ratio: 1.92

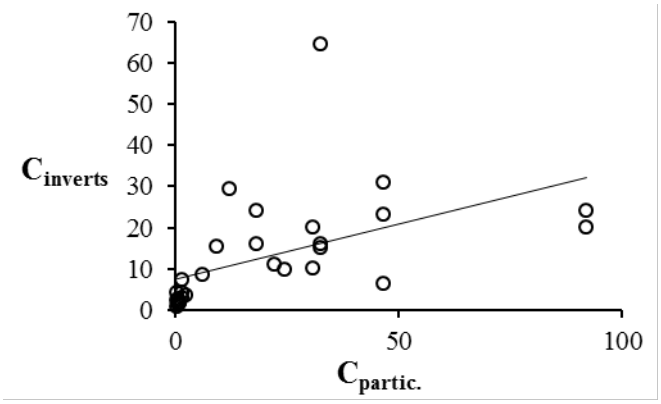
R^2: 0.20
F: 1.24
df: 5
P: 0.36
Not used because P > 0.05 and negative slope.

Water boatmen (Corixidae)

Study	Site	C_{alg}	C_{det}	C_{sed}	C_{part}	C_{invert}	Ratio
Birkner 1978	18	7.60		4.30	5.95	8.40	1.41
Birkner 1978	29	8.80		15.40	12.10	29.40	2.43

Water boatmen (Corixidae)

Study	Site	C_{alg}	C_{det}	C_{sed}	C_{part}	C_{invert}	Ratio
Birkner 1978	20	3.00		41.00	22.00	11.00	0.50
Birkner 1978	7	0.18		2.80	1.49	4.20	2.82
Birkner 1978	3	0.10		0.30	0.20	4.20	21.00
Birkner 1978	22	4.60		44.00	24.30	9.90	0.41
Birkner 1978	12	2.30		0.30	1.30	7.30	5.62
Birkner 1978	23	7.80		10.80	9.30	15.50	1.67
Lambing et al. 1994	S46	2.30			2.30	3.40	1.48
Rinella et al. 1994	G	0.84		0.50	0.67	1.38	2.06
Rinella et al. 1994	A	2.21		0.40	1.31	2.98	2.28
Rinella et al. 1994	Q	1.42		0.50	0.96	2.00	2.08
Saiki and Lowe 1987	Kesterson Pond 11	18.15	47.95	8.56	18.15	24.00	1.32
Saiki and Lowe 1987	Kesterson Pond 11	18.15	47.95	8.56	18.15	16.00	0.88
Saiki and Lowe 1987	Kesterson Pond 8	136.50	92.00	6.05	92.00	20.00	0.22
Saiki and Lowe 1987	Kesterson Pond 8	136.50	92.00	6.05	92.00	24.00	0.26
Saiki and Lowe 1987	Volta Pond 26	0.42	1.01	0.29	0.42	2.15	5.17
Saiki and Lowe 1987	Volta Pond 26	0.42	1.01	0.29	0.42	0.87	2.10
Saiki and Lowe 1987	Volta Pond 7		1.39	0.39	0.89	1.76	1.98
Saiki and Lowe 1987	Volta Pond 7		1.39	0.39	0.89	1.53	1.72
Schuler et al. 1990	Kesterson Pond 11	53.70		11.50	32.60	15.90	0.49
Schuler et al. 1990	Kesterson Pond 11	53.70		11.50	32.60	64.60	1.98
Schuler et al. 1990	Kesterson Pond 11	53.70		11.50	32.60	15.10	0.46
Schuler et al. 1990	Kesterson Pond 2	52.50		9.30	30.90	20.00	0.65
Schuler et al. 1990	Kesterson Pond 2	52.50		9.30	30.90	10.00	0.32
Schuler et al. 1990	Kesterson Pond 7	87.10		5.90	46.50	23.00	0.49
Schuler et al. 1990	Kesterson Pond 7	87.10		5.90	46.50	30.90	0.66
Schuler et al. 1990	Kesterson Pond 7	87.10		5.90	46.50	6.46	0.14
Rinella and Schuler 1992	18	0.59			0.59	2.70	4.58



Median ratio: 1.48

R^2: 0.25
F: 9.17
df: 27
P: < 0.001

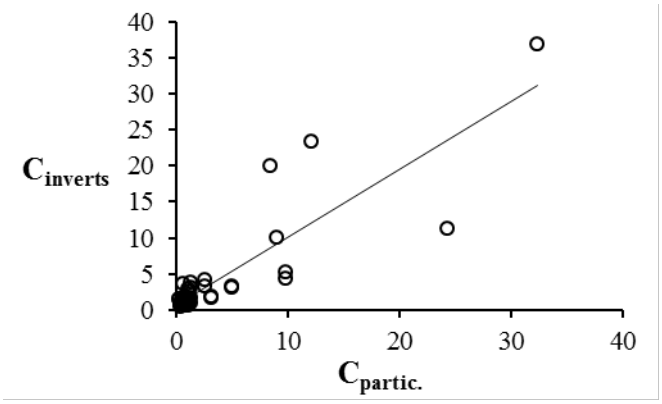
Crayfish (Astacidae)

Study	Site	C_{alg}	C_{det}	C_{sed}	C_{part}	C_{invert}	Ratio
Birkner 1978	29	8.80		15.40	12.10	23.30	1.93
Birkner 1978	19	16.80		1.20	9.00	10.10	1.12
Birkner 1978	30	17.30		47.30	32.30	36.80	1.14
Birkner 1978	22	4.60		44.00	24.30	11.30	0.47
Birkner 1978	27	10.35		6.50	8.43	20.00	2.37
Butler et al. 1993	SP2	1.60		0.50	1.05	2.60	2.48
Butler et al. 1993	SP2	1.60		0.50	1.05	2.90	2.76
Butler et al. 1995	AK	0.45		0.20	0.33	0.76	2.34
Butler et al. 1995	AK	0.45		0.20	0.33	0.79	2.43
Butler et al. 1995	DD	0.88		0.70	0.79	0.62	0.78
Butler et al. 1995	DD	0.88		0.70	0.79	1.10	1.39
Butler et al. 1995	HD1	0.59			0.59	0.86	1.46
Butler et al. 1995	HD1	0.59			0.59	0.79	1.34
Butler et al. 1995	HD2	0.45		0.20	0.32	0.96	2.98
Butler et al. 1995	HD2	0.45		0.20	0.32	1.00	3.10
Butler et al. 1995	ME2	1.11		1.10	1.10	1.10	1.00
Butler et al. 1995	ME2	1.11		1.10	1.10	1.40	1.27
Butler et al. 1995	ME4	1.04		0.50	0.77	1.30	1.69
Butler et al. 1995	ME4	1.04		0.50	0.77	1.80	2.35
Butler et al. 1995	ME3	0.82		0.40	0.61	1.40	2.30
Butler et al. 1995	ME3	0.82		0.40	0.61	3.70	6.07
Butler et al. 1995	NW	3.45		1.60	2.53	4.20	1.66
Butler et al. 1995	NW	3.45		1.60	2.53	3.30	1.31
Butler et al. 1995	SD	0.77		0.50	0.64	1.40	2.20
Butler et al. 1995	SD	0.77		0.50	0.64	1.40	2.20
Butler et al. 1995	YJ2	0.31		0.10	0.21	1.40	6.83
Butler et al. 1995	YJ2	0.31		0.10	0.21	1.50	7.32
Butler et al. 1997	CHK	1.19			1.19	0.90	0.76
Butler et al. 1997	MN2	0.79			0.79	0.83	1.06
Butler et al. 1997	MUD2	1.30			1.30	3.10	2.38
Butler et al. 1997	MUD2	1.30			1.30	3.80	2.92
Butler et al. 1997	TRH	1.25			1.25	0.98	0.78
Butler et al. 1997	TRH	1.25			1.25	1.60	1.28
Saiki et al. 1993	ET6	1.03	1.15		1.09	0.67	0.62
Saiki et al. 1993	ET6	1.03	1.15		1.09	0.83	0.76
Saiki et al. 1993	GT5	4.50	14.95		9.73	5.20	0.53
Saiki et al. 1993	GT5	4.50	14.95		9.73	4.40	0.45
Saiki et al. 1993	GT4	1.39	8.40		4.90	3.10	0.63
Saiki et al. 1993	GT4	1.39	8.40		4.90	3.20	0.65
Saiki et al. 1993	SJR2	1.25	5.00		3.13	1.70	0.54
Saiki et al. 1993	SJR2	1.25	5.00		3.13	1.90	0.61

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Crayfish (Astacidae)

Study	Site	C_{alg}	C_{det}	C_{sed}	C_{part}	C_{invert}	Ratio
Saiki et al. 1993	SJR3	0.45	1.25		0.85	0.77	0.91
Saiki et al. 1993	SJR3	0.45	1.25		0.85	1.30	1.53
Saiki et al. 1993	SJR1	0.22	0.50		0.36	0.50	1.39
Saiki et al. 1993	SJR1	0.22	0.50		0.36	0.74	2.06
Saiki et al. 1993	ET7	0.16	0.76		0.46	0.87	1.91
Saiki et al. 1993	ET7	0.16	0.76		0.46	0.85	1.87

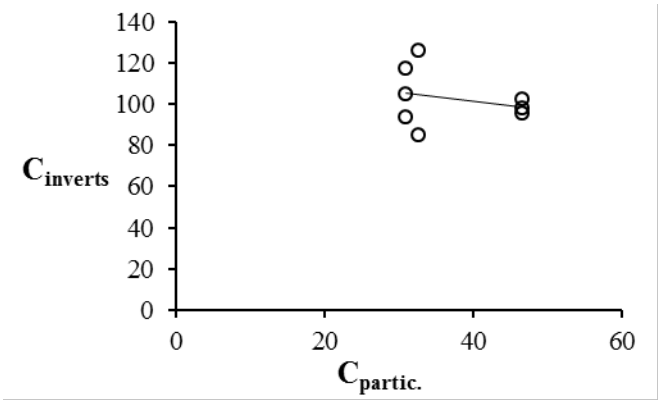


Median ratio: 1.46

R^2: 0.74
F: 130.8
df: 45
P: < 0.001

True flies (Diptera)

Study	Site	C_{alg}	C_{det}	C_{sed}	C_{part}	C_{invert}	Ratio
Schuler et al. 1990	Kesterson Pond 11	53.70		11.50	32.60	126.00	3.87
Schuler et al. 1990	Kesterson Pond 11	53.70		11.50	32.60	85.10	2.61
Schuler et al. 1990	Kesterson Pond 2	52.50		9.30	30.90	117.00	3.79
Schuler et al. 1990	Kesterson Pond 2	52.50		9.30	30.90	93.30	3.02
Schuler et al. 1990	Kesterson Pond 2	52.50		9.30	30.90	105.00	3.40
Schuler et al. 1990	Kesterson Pond 7	87.10		5.90	46.50	95.50	2.05
Schuler et al. 1990	Kesterson Pond 7	87.10		5.90	46.50	97.70	2.10
Schuler et al. 1990	Kesterson Pond 7	87.10		5.90	46.50	102.00	2.19

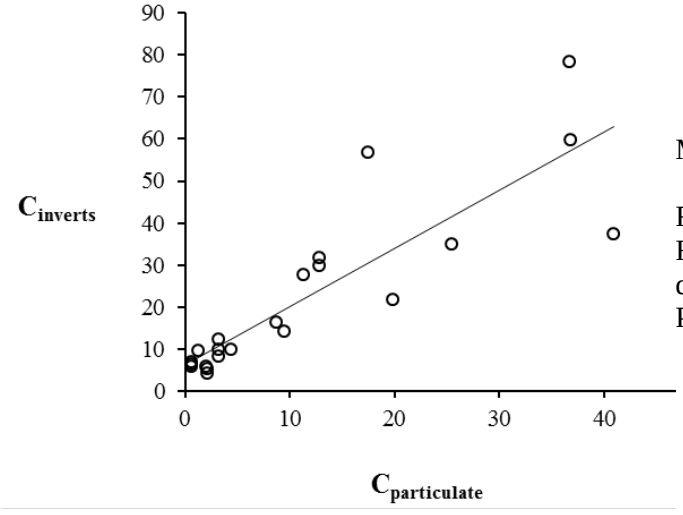


Median ratio: 2.81

R^2: 0.07
F: 0.46
df: 6
P: 0.65
Not used because P > 0.05 and negative slope.

Mayflies (Ephemeroptera)

Study	Site	C_{alg}	C_{det}	C_{sed}	C_{part}	C_{invert}	Ratio
Rinella et al. 1994	A	2.21		0.40	1.31	9.65	7.39
Casey 2005	Deerlick Creek		1.00	0.20	0.60	6.40	10.67
Casey 2005	Luscar Creek	5.50	3.20	2.40	3.20	8.20	2.56
Casey 2005	Deerlick Creek		1.00	0.20	0.60	5.70	9.50
Casey 2005	Luscar Creek	5.50	3.20	2.40	3.20	9.70	3.03
Casey 2005	Deerlick Creek		1.00	0.20	0.60	6.80	11.33
Casey 2005	Luscar Creek	5.50	3.20	2.40	3.20	12.30	3.84
Conley et al. 2009	Plate 10A	4.40			4.40	9.70	2.20
Conley et al. 2009	Plate 20A	25.50			25.50	34.80	1.36
Conley et al. 2009	Plate 20B	17.50			17.50	56.70	3.24
Conley et al. 2009	Plate 20C	8.70			8.70	16.20	1.86
Conley et al. 2009	Plate 20D	11.30			11.30	27.50	2.43
Conley et al. 2009	Plate 5A	2.20			2.20	4.20	1.91
Conley et al. 2009	Plate 5B	2.00			2.00	5.70	2.85
Conley et al. 2011	2x-High	40.90			40.90	37.30	0.91
Conley et al. 2011	2x-Low	9.50			9.50	14.10	1.48
Conley et al. 2011	2x-Medium	19.90			19.90	21.60	1.09
Conley et al. 2013	Control	2.20			2.20	5.10	2.32
Conley et al. 2013	Selenate-high	36.80			36.80	59.80	1.63
Conley et al. 2013	Selenate-low	12.80			12.80	31.70	2.48
Conley et al. 2013	Selenite-high	36.70			36.70	78.40	2.14
Conley et al. 2013	Selenite-low	12.80			12.80	29.80	2.33

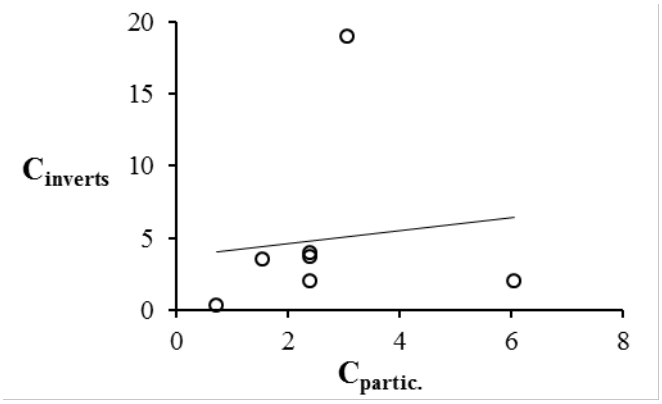


Median ratio: 2.38

R^2: 0.75
F: 59.19
df: 20
P: <0.001

Snails (Gastropoda)

Study	Site	C_{alg}	C_{det}	C_{sed}	C_{part}	C_{invert}	Ratio
Butler et al. 1995	WC	3.30		1.50	2.40	3.70	1.54
Butler et al. 1995	WC	3.30		1.50	2.40	3.90	1.63
Butler et al. 1995	WC	3.30		1.50	2.40	2.00	0.83
Butler et al. 1997	DCP1	1.00		2.10	1.55	3.50	2.26
Butler et al. 1997	MNP2	5.40		6.70	6.05	2.00	0.33
Butler et al. 1997	CHP	4.00		2.10	3.05	19.00	6.23
Butler et al. 1997	LCHP1	0.33		1.10	0.72	0.32	0.45



Median ratio: 1.54

R^2: 0.01
F: 0.07
df: 5
P: 0.93
Not used because P > 0.05.

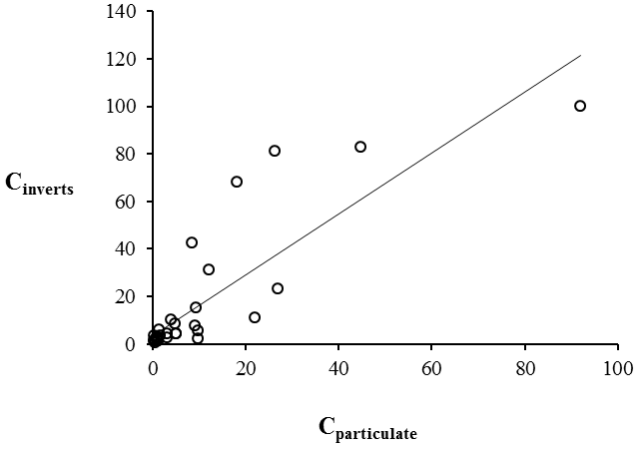
Zooplankton

Study	Site	C_{alg}	C_{det}	C_{sed}	C_{part}	C_{invert}	Ratio
Birkner 1978	29	8.80		15.40	12.10	31.30	2.59
Birkner 1978	20	3.00		41.00	22.00	11.00	0.50
Birkner 1978	7	0.18		2.80	1.49	3.30	2.22
Birkner 1978	19	16.80		1.20	9.00	7.70	0.86
Birkner 1978	3	0.10		0.30	0.20	3.40	17.00
Birkner 1978	27	10.35		6.50	8.43	42.50	5.04
Birkner 1978	12	2.30		0.30	1.30	5.80	4.46
Birkner 1978	23	7.80		10.80	9.30	15.40	1.66
Bowie et al. 1996	Hyco Reservoir	27.0			27.0	23.0	0.85
Lambing et al. 1988	12	1.40		0.30	0.85	2.60	3.06
Saiki and Lowe 1987	Kesterson Pond 11	18.15	47.95	8.56	18.15	68.30	3.76
Saiki and Lowe 1987	Kesterson Pond 2	152.70	44.65	34.82	44.65	83.00	1.86
Saiki and Lowe 1987	Kesterson Pond 8	136.50	92.00	6.05	92.00	100.00	1.09
Saiki and Lowe 1987	Volta Pond 26	0.42	1.01	0.29	0.42	1.46	3.51
Saiki and Lowe 1987	Volta Pond 7		1.39	0.39	0.89	2.90	3.26
Saiki and Lowe 1987	Volta Wasteway	0.87	2.03	0.24	0.87	2.80	3.21
Saiki et al. 1993	ET6	1.03	1.15		1.09	1.20	1.10
Saiki et al. 1993	ET6	1.03	1.15		1.09	1.50	1.38

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Zooplankton

Study	Site	C_{alg}	C_{det}	C_{sed}	C_{part}	C_{invert}	Ratio
Saiki et al. 1993	GT5	4.50	14.95		9.73	2.40	0.25
Saiki et al. 1993	GT5	4.50	14.95		9.73	5.40	0.56
Saiki et al. 1993	GT4	1.39	8.40		4.90	4.50	0.92
Saiki et al. 1993	GT4	1.39	8.40		4.90	4.40	0.90
Saiki et al. 1993	SJR2	1.25	5.00		3.13	2.60	0.83
Saiki et al. 1993	SJR2	1.25	5.00		3.13	4.30	1.38
Saiki et al. 1993	SJR3	0.45	1.25		0.85	1.60	1.89
Saiki et al. 1993	SJR3	0.45	1.25		0.85	1.80	2.12
Saiki et al. 1993	SJR1	0.22	0.50		0.36	1.40	3.89
Saiki et al. 1993	SJR1	0.22	0.50		0.36	1.30	3.61
Saiki et al. 1993	ET7	0.16	0.76		0.46	0.63	1.38
Saiki et al. 1993	ET7	0.16	0.76		0.46	1.40	3.08



Median ratio: 1.89

R^2: 0.71
F: 76.3
df: 31
P: < 0.001

Special case of Odonates (Damselflies and Dragonflies) consuming invertebrates

n = Number of invertebrate food species co-occurring with an Odonate species.

C_{part} = Average selenium concentration in particulate material (mg/kg): $\left(\frac{C_{alg}+C_{det}+C_{sed}}{3}\right)$

C_{food} = Median selenium concentration in all invertebrate tissues that co-occur with an Odonate species (mg/kg)

C_{damsel} = Selenium concentration in damselfly tissue (mg/kg)

C_{dragon} = Selenium concentration in dragonfly tissue (mg/kg)

Ratio = $\frac{C_{food}}{C_{part}}$, $\frac{C_{damsel}}{C_{food}}$, or $\frac{C_{dragon}}{C_{food}}$

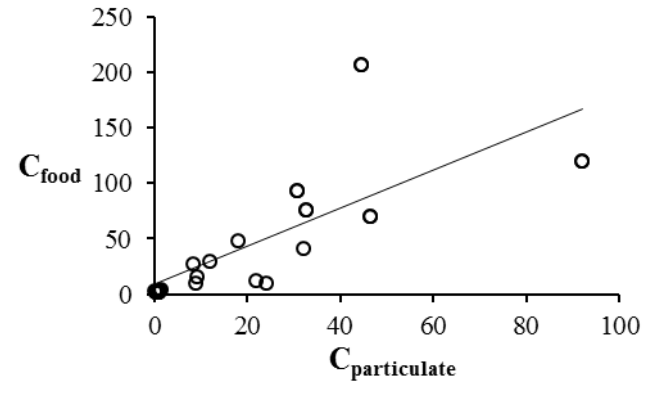
Co-occurring potential food species of damselflies and dragonflies (Odonata)

Study	Site	Co-occurs with:	n	C_{part}	C_{food}	Ratio
Saiki and Lowe 1987	Kesterson Pond 11	dragonflies	4	18.15	47.5	2.62
Saiki and Lowe 1987	Kesterson Pond 2	dragonflies	4	44.65	206.5	4.62
Saiki and Lowe 1987	Kesterson Pond 2	dragonflies	4	44.65	206.5	4.62
Saiki and Lowe 1987	Kesterson Pond 8	dragonflies	5	92.00	120	1.30
Saiki and Lowe 1987	Kesterson Pond 8	dragonflies	5	92.00	120	1.30
Saiki and Lowe 1987	Volta Pond 26	dragonflies	4	0.42	1.52	3.65
Saiki and Lowe 1987	Volta Pond 26	dragonflies	4	0.42	1.52	3.65
Saiki and Lowe 1987	Volta Pond 7	dragonflies	5	0.89	1.53	1.72
Saiki and Lowe 1987	Volta Pond 7	dragonflies	5	0.89	1.53	1.72
Saiki and Lowe 1987	Volta Wasteway	dragonflies	2	0.87	1.83	2.10
Schuler et al. 1990	Kesterson Pond 11	dragonflies	10	32.60	75.85	2.33
Schuler et al. 1990	Kesterson Pond 11	dragonflies	10	32.60	75.85	2.33
Schuler et al. 1990	Kesterson Pond 2	dragonflies	8	30.90	93.3	3.02
Schuler et al. 1990	Kesterson Pond 2	dragonflies	8	30.90	93.3	3.02

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Co-occurring potential food species of damselflies and dragonflies (Odonata)

Study	Site	Co-occurs with:	n	C_{part}	C_{food}	Ratio
Schuler et al. 1990	Kesterson Pond 7	dragonflies	11	46.50	69.2	1.49
Schuler et al. 1990	Kesterson Pond 7	dragonflies	11	46.50	69.2	1.49
Birkner 1978	29	damselflies	3	12.10	29.4	2.43
Birkner 1978	20	damselflies	2	22.00	11.2	0.51
Birkner 1978	7	damselflies	2	1.49	3.55	2.39
Birkner 1978	19	damselflies	2	9.00	9.8	1.09
Birkner 1978	30	damselflies	2	32.30	40.9	1.27
Birkner 1978	3	damselflies	3	0.20	2.5	12.50
Birkner 1978	22	damselflies	3	24.30	9.9	0.41
Birkner 1978	27	damselflies	1	8.43	26.7	3.17
Birkner 1978	23	damselflies	3	9.30	15.5	1.67
Grasso et al. 1995	17	damselflies	1	1.14	2.07	1.82



Median ratio: 2.21

R^2: 0.54
F: 28.7
df: 24
P: < 0.001

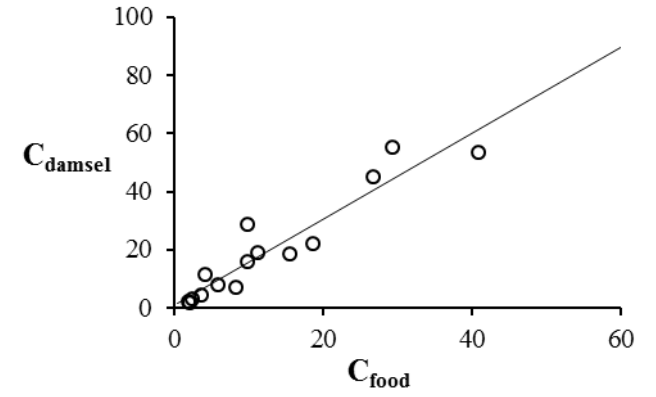
Damselflies (Anisoptera)

Study	Site	C_{food}	C_{damsel}	Ratio
Birkner 1978	29	29.4	55	1.87
Birkner 1978	4	1.95	1.8	0.92
Birkner 1978	25	18.7	21.9	1.17
Birkner 1978	20	11.2	18.7	1.67
Birkner 1978	7	3.55	4.4	1.24
Birkner 1978	19	9.8	28.4	2.90
Birkner 1978	6	4.2	11.1	2.64
Birkner 1978	30	40.9	53.3	1.30
Birkner 1978	3	2.5	3.1	1.24
Birkner 1978	22	9.9	15.8	1.60

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Damselflies (Anisoptera)

Study	Site	C_{food}	C_{damsel}	Ratio
Birkner 1978	27	26.7	45.1	1.69
Birkner 1978	23	15.5	18.4	1.19
Birkner 1978	11	5.9	7.7	1.31
Grasso et al. 1995	17	2.07	1.75	0.85
Grasso et al. 1995	9	8.2	6.98	0.85



Median ratio: 1.30 x 2.21
(damselfly food to particulate) = 2.88

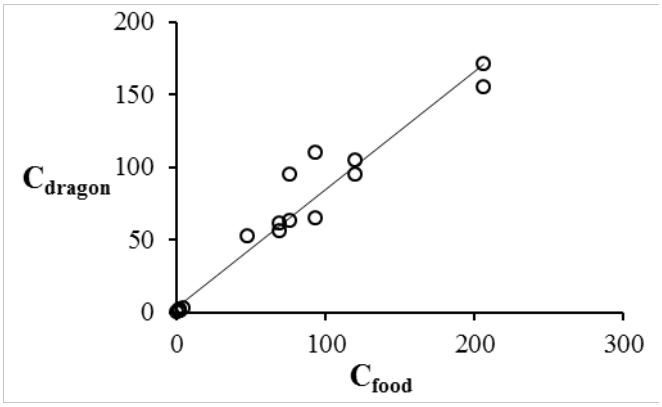
R^2: 0.89
F: 104.4
df: 13
P: <0.001

Dragonflies (Zygoptera)

Study	Site	C_{food}	C_{dragon}	Ratio
Mason et al. 2000	BK	1.845	1.665	0.90
Mason et al. 2000	HCRT	4.305	2.81	0.65
Saiki and Lowe 1987	Kesterson Pond 11	47.5	53	1.12
Saiki and Lowe 1987	Kesterson Pond 2	206.5	155	0.75
Saiki and Lowe 1987	Kesterson Pond 2	206.5	171	0.83
Saiki and Lowe 1987	Kesterson Pond 8	120	95.5	0.80
Saiki and Lowe 1987	Kesterson Pond 8	120	105	0.88
Saiki and Lowe 1987	Volta Pond 26	1.52	1.4	0.92
Saiki and Lowe 1987	Volta Pond 26	1.52	1.42	0.93
Saiki and Lowe 1987	Volta Pond 7	1.53	1.2	0.78
Saiki and Lowe 1987	Volta Pond 7	1.53	1.4	0.92
Saiki and Lowe 1987	Volta Wasteway	1.83	2.5	1.37
Schuler et al. 1990	Kesterson Pond 11	75.85	63.1	0.83
Schuler et al. 1990	Kesterson Pond 11	75.85	95.5	1.26
Schuler et al. 1990	Kesterson Pond 2	93.3	110	1.18
Schuler et al. 1990	Kesterson Pond 2	93.3	65	0.70
Schuler et al. 1990	Kesterson Pond 7	69.2	61.7	0.89
Schuler et al. 1990	Kesterson Pond 7	69.2	56.2	0.81
Sorenson & Schwarzbach 1991	5	0.42	0.49	1.17

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Dragonflies (Zygoptera)



Median ratio: 0.89 x 2.21
(damselfly food to particulate) = 1.97

R^2: 0.95
F: 343.5
df: 17
P: <0.001

3.3.2 Vertebrates

C_{invert} = Selenium concentration in invertebrate tissue (µg/g)
C_{fish} = Average selenium concentration in the whole-body of fish (µg/g)

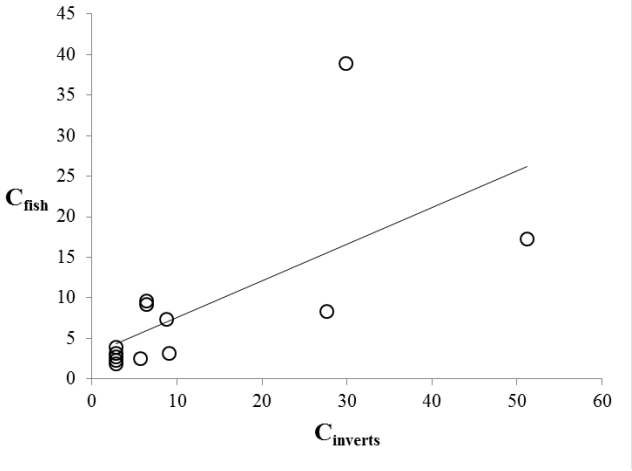
Ratio = $\frac{C_{fish}}{C_{invert}}$

Black bullhead (*Ameiurus melas*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1991	7	29.80	39.00	1.31
GEI 2013	SWA1	2.81	2.37	0.84
GEI 2013	SWA1	2.81	2.73	0.97
GEI 2013	SWA1	2.81	3.96	1.41
GEI 2013	SWA1	2.81	1.95	0.70
GEI 2013	SWA1	2.81	3.21	1.14
Mueller et al. 1991	R2	6.40	9.70	1.52
Mueller et al. 1991	R2	6.40	9.20	1.44
Mueller et al. 1991	R1	8.70	7.40	0.85
Lemly 1985	Badin Lake	5.70	2.58	0.45
Lemly 1985	Belews Lake	51.15	17.32	0.34
Lemly 1985	High Rock Lake	9.05	3.24	0.36
GEI 2014	SC-6	27.54	8.42	0.31

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Black bullhead (*Ameiurus melas*)



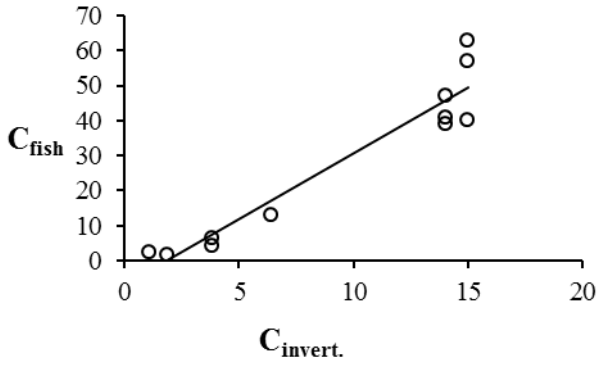
Median ratio: 0.85

R^2: 0.44
F: 8.52
df: 11
P: 0.006

Black crappie (*Pomoxis nigromaculatus*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1995	Totten Reservoir	1.07	2.50	2.35
Butler et al. 1995	Summit Reservoir	1.85	1.70	0.92
Peterson et al. 1991	Ocean Lake, west side	3.83	4.20	1.10
Peterson et al. 1991	Ocean Lake, west side	3.83	6.32	1.65
Mueller et al. 1991	Lake Meredith near Ordway, CO	6.40	13.00	2.03
Lambing et al. 1994	Priest Butte Lakes near Choteau	14.00	39.00	2.79
Lambing et al. 1994	Priest Butte Lakes near Choteau	14.00	41.00	2.93
Lambing et al. 1994	Priest Butte Lakes near Choteau	14.00	47.00	3.36
Lambing et al. 1994	Priest Butte Lakes near Choteau	15.00	40.00	2.67
Lambing et al. 1994	Priest Butte Lakes near Choteau	15.00	57.00	3.80
Lambing et al. 1994	Priest Butte Lakes near Choteau	15.00	63.00	4.20

Black crappie (*Pomoxis nigromaculatus*)



Median ratio: 2.67

R^2: 0.92
F: 97.9
df: 9
P: < 0.001

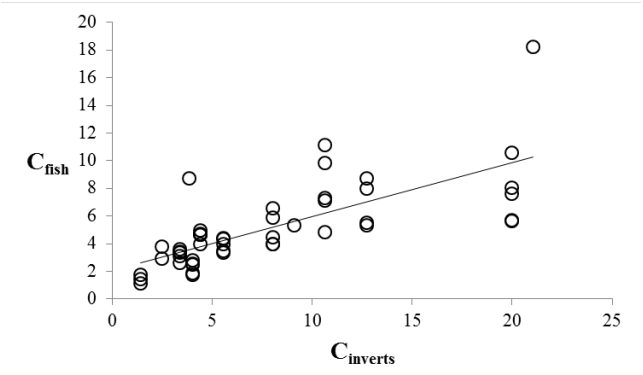
Blacknose dace (*Rhinichthys atratulus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	Cabin Creek, C-CC1	4.40	4.65	1.06
GEI 2014	Cabin Creek, C-CC1	4.40	4.74	1.08
GEI 2014	Cabin Creek, C-CC1	4.40	4.95	1.12
GEI 2014	Cabin Creek, C-CC1	4.40	4.69	1.06
GEI 2014	Cabin Creek, C-CC1	4.40	3.98	0.90
GEI 2014	Cabin Creek, C-CC2	5.56	3.46	0.62
GEI 2014	Cabin Creek, C-CC2	5.56	3.38	0.61
GEI 2014	Cabin Creek, C-CC2	5.56	3.95	0.71
GEI 2014	Cabin Creek, C-CC2	5.56	4.36	0.78
GEI 2014	Cabin Creek, C-CC2	5.56	4.39	0.79
GEI 2014	Coal Fork, C-CF1	3.39	3.58	1.06
GEI 2014	Coal Fork, C-CF1	3.39	3.09	0.91
GEI 2014	Coal Fork, C-CF1	3.39	3.37	0.99
GEI 2014	Coal Fork, C-CF1	3.39	2.64	0.78
GEI 2014	Coal Fork, C-CF1	3.39	3.42	1.01
GEI 2014	Hazy Creek, C-HC1	8.03	3.99	0.50
GEI 2014	Hazy Creek, C-HC1	8.03	5.88	0.73
GEI 2014	Hazy Creek, C-HC1	8.03	4.46	0.56
GEI 2014	Hazy Creek, C-HC1	8.03	6.55	0.82
GEI 2014	Hazy Creek, C-HC1	8.03	3.98	0.50
GEI 2014	Laurel Fork, C-LF1	12.73	5.36	0.42
GEI 2014	Laurel Fork, C-LF1	12.73	7.99	0.63
GEI 2014	Laurel Fork, C-LF1	12.73	8.72	0.68
GEI 2014	Laurel Fork, C-LF1	12.73	5.49	0.43
GEI 2014	Tenmile Fork, C-TF1	20.00	7.62	0.38
GEI 2014	Tenmile Fork, C-TF1	20.00	10.56	0.53

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Blacknose dace (*Rhinichthys atratulus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	Tenmile Fork, C-TF1	20.00	8.02	0.40
GEI 2014	Tenmile Fork, C-TF1	20.00	5.63	0.28
GEI 2014	Tenmile Fork, C-TF1	20.00	5.68	0.28
GEI 2014	Jack Smith (Bear) Branch, H-JSB1	4.03	2.81	0.70
GEI 2014	Jack Smith (Bear) Branch, H-JSB1	4.03	1.86	0.46
GEI 2014	Jack Smith (Bear) Branch, H-JSB1	4.03	1.78	0.44
GEI 2014	Jack Smith (Bear) Branch, H-JSB1	4.03	2.47	0.61
GEI 2014	Jack Smith (Bear) Branch, H-JSB1	4.03	2.55	0.63
GEI 2014	Lukey Fork, H-LF1	9.09	5.32	0.59
GEI 2014	Mud River, H-MR3	3.86	8.72	2.26
GEI 2014	Mud River, H-MR6	2.49	3.80	1.53
GEI 2014	Mud River, H-MR6	2.49	2.93	1.18
GEI 2014	Sugartree Branch, H-SB1	10.62	9.82	0.92
GEI 2014	Sugartree Branch, H-SB1	10.62	7.29	0.69
GEI 2014	Sugartree Branch, H-SB1	10.62	11.14	1.05
GEI 2014	Sugartree Branch, H-SB1	10.62	4.85	0.46
GEI 2014	Sugartree Branch, H-SB1	10.62	7.16	0.67
GEI 2014	Stanley Fork, H-SF1	21.05	18.21	0.87



Median ratio: 0.71

R^2: 0.52
F: 48.97
df: 45
P: < 0.001

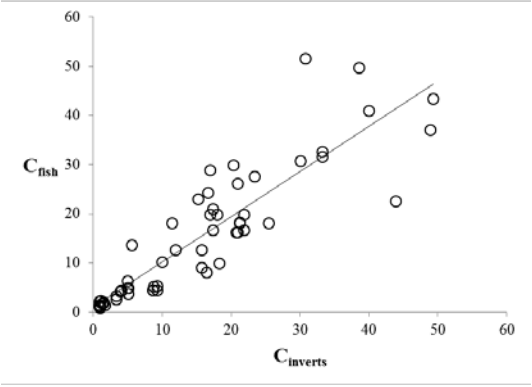
Bluegill (*Lepomis macrochirus*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1995	TT	1.07	2.30	2.16
Hermanutz et al. 1996	MSO II	16.63	24.29	1.46
Hermanutz et al. 1996	MSO III	5.55	13.77	2.48
Hermanutz et al. 1996	MSO I	21.19	18.28	0.86
Hermanutz et al. 1996	MSO I	21.19	18.13	0.86
Hermanutz et al. 1996	MSO II	17.30	20.99	1.21
Hermanutz et al. 1996	MSO II	5.05	4.88	0.97
Hermanutz et al. 1996	MSO I	0.87	1.55	1.78
Hermanutz et al. 1996	MSO II	1.70	1.55	0.91
Hermanutz et al. 1996	MSO III	1.20	1.83	1.52
Hermanutz et al. 1996	MSO III	10.00	10.32	1.03
Hermanutz et al. 1996	MSO III	3.95	4.21	1.06
Hermanutz et al. 1996	MSO II	17.30	16.76	0.97
Hermanutz et al. 1996	MSO II	5.05	3.86	0.76
Mueller et al. 1991	R1	8.70	5.20	0.60
Saiki et al. 1993	ET6	0.85	2.20	2.60
Saiki et al. 1993	ET6	0.85	1.40	1.66
Saiki et al. 1993	GT5	4.90	6.40	1.31
Saiki et al. 1993	GT5	4.90	5.00	1.02
Saiki et al. 1993	GT4	4.05	4.50	1.11
Saiki et al. 1993	GT4	4.05	4.30	1.06
Saiki et al. 1993	SJR2	3.30	3.30	1.00
Saiki et al. 1993	SJR2	3.30	2.70	0.82
Saiki et al. 1993	SJR3	1.50	2.00	1.33
Saiki et al. 1993	SJR3	1.50	1.90	1.27
Saiki et al. 1993	SJR1	0.95	0.87	0.92
Saiki et al. 1993	SJR1	0.95	1.40	1.48
Saiki et al. 1993	ET7	0.86	1.20	1.40
Saiki et al. 1993	ET7	0.86	1.20	1.40
Crutchfield 2000	transect 3	21.80	19.91	0.91
Crutchfield 2000	transect 3	21.80	16.72	0.77
Crutchfield 2000	transect 3	17.90	19.91	1.11
Crutchfield 2000	transect 3	20.70	16.26	0.79
Crutchfield 2000	transect 3	20.35	29.87	1.47
Crutchfield 2000	transect 3	23.40	27.59	1.18
Crutchfield 2000	transect 3	15.20	23.10	1.52
Crutchfield 2000	transect 3	16.95	28.96	1.71
Crutchfield 2000	transect 3	16.95	19.91	1.17
Crutchfield 2000	transect 3	11.95	12.69	1.06
Crutchfield 2000	transect 3	11.40	18.09	1.59
Crutchfield 2000	transect 3	9.25	4.56	0.49
Crutchfield 2000	transect 3	9.25	5.40	0.58

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Bluegill (*Lepomis macrochirus*)

Study	Site	C_{invert}	C_{fish}	Ratio
Crutchfield 2000	transect 3	8.60	4.56	0.53
Crutchfield 2000	transect 3	8.60	4.56	0.53
Crutchfield 2000	transect 4	30.70	51.60	1.68
Crutchfield 2000	transect 4	30.00	30.78	1.03
Crutchfield 2000	transect 4	33.20	31.69	0.95
Crutchfield 2000	transect 4	48.90	37.09	0.76
Crutchfield 2000	transect 4	38.55	49.78	1.29
Crutchfield 2000	transect 4	49.30	43.40	0.88
Crutchfield 2000	transect 4	43.90	22.65	0.52
Crutchfield 2000	transect 4	33.25	32.60	0.98
Crutchfield 2000	transect 4	25.40	18.09	0.71
Crutchfield 2000	transect 4	20.90	16.26	0.78
Crutchfield 2000	transect 4	20.90	26.22	1.25
Crutchfield 2000	transect 4	15.70	12.69	0.81
Crutchfield 2000	transect 4	15.70	9.04	0.58
Crutchfield 2000	transect 4	16.45	8.13	0.49
Crutchfield 2000	transect 4	18.25	9.96	0.55
Bowie et al. 1996	Hyco Reservoir	40.00	41.00	1.03



Median ratio: 1.03

R^2: 0.80
F: 226.0
df: 58
P: < 0.001

Bluehead sucker (*Catostomus discobolus*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1995	AK	0.78	0.94	1.21
Butler et al. 1995	HD1	0.83	0.83	1.01
Butler et al. 1995	HD1	0.83	0.86	1.04
Butler et al. 1995	HD1	0.83	1.20	1.45
Butler et al. 1995	HD1	0.83	1.40	1.70
Butler et al. 1995	DD	0.86	0.64	0.74
Butler et al. 1995	DD	0.86	0.88	1.02
Butler et al. 1995	DD	0.86	1.30	1.51

NMED Exhibit 59

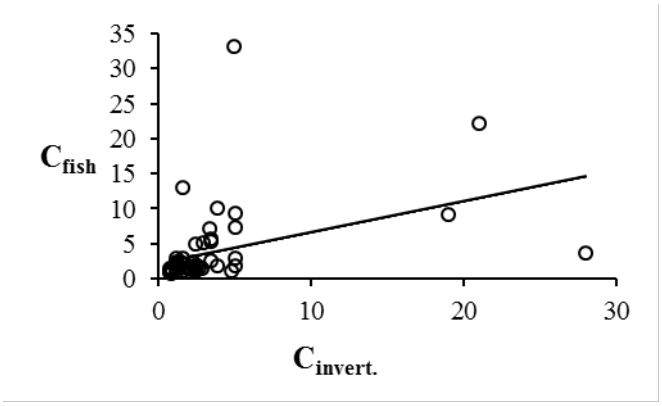
Bluehead sucker (*Catostomus discobolus*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1993	D1	1.20	2.80	2.33
Butler et al. 1993	B1	1.25	1.90	1.52
Butler et al. 1993	B1	1.25	2.20	1.76
Butler et al. 1995	ME2	1.25	0.83	0.66
Butler et al. 1995	ME2	1.25	1.30	1.04
Butler et al. 1993	B2	1.35	1.80	1.33
Butler et al. 1995	SD	1.40	1.50	1.07
Butler et al. 1995	SD	1.40	1.80	1.29
Butler et al. 1993	D2	1.45	1.60	1.10
Butler et al. 1993	D2	1.45	2.30	1.59
Butler et al. 1993	P1	1.50	2.20	1.47
Butler et al. 1994	COL1	1.50	1.60	1.07
Butler et al. 1994	RB3	1.60	13.00	8.13
Butler et al. 1995	YJ2	1.65	0.96	0.58
Butler et al. 1995	YJ2	1.65	2.80	1.70
Butler et al. 1994	NFK3	2.00	1.40	0.70
Butler et al. 1997	MN2	2.20	1.20	0.55
Butler et al. 1997	MUD	2.30	1.80	0.78
Butler et al. 1997	MUD	2.30	2.30	1.00
Butler et al. 1997	CHK	2.40	1.20	0.50
Butler et al. 1997	CHK	2.40	1.60	0.67
Butler et al. 1993	U1	2.45	4.80	1.96
Butler et al. 1995	SJ1	2.50	0.94	0.38
Butler et al. 1995	SJ1	2.50	1.20	0.48
Butler et al. 1995	SJ1	2.50	1.20	0.48
Butler et al. 1995	ME3	2.55	1.70	0.67
Butler et al. 1995	ME3	2.55	1.80	0.71
Butler et al. 1997	MN3	2.70	1.50	0.56
Butler et al. 1997	MN1	2.90	1.40	0.48
Butler et al. 1993	SP1	2.95	5.10	1.73
Butler et al. 1993	SP2	3.40	7.10	2.09
Butler et al. 1997	MUD2	3.45	2.50	0.72
Butler et al. 1997	MUD2	3.45	5.20	1.51
Butler et al. 1997	MUD2	3.45	5.60	1.62
Butler et al. 1993	F2	3.90	10.00	2.56
Butler et al. 1991	4	3.90	1.80	0.46
Butler et al. 1993	F2	4.80	0.94	0.20
Butler et al. 1994	BSW1	5.00	33.00	6.60
Butler et al. 1997	WBR	5.05	1.80	0.36
Butler et al. 1997	WBR	5.05	2.80	0.55
Butler et al. 1995	NW	5.10	7.20	1.41
Butler et al. 1995	NW	5.10	9.30	1.82

NMED Exhibit 59

Bluehead sucker (*Catostomus discobolus*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1994	LZA1	19.00	9.00	0.47
Butler et al. 1994	RB1	21.00	22.00	1.05
Butler et al. 1994	GUN2	28.00	3.60	0.13



Median ratio: 1.04

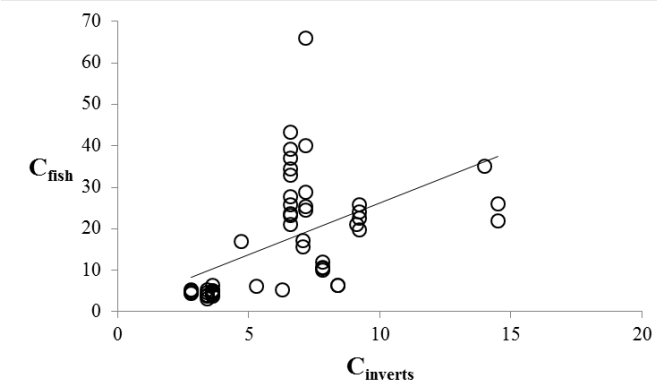
R^2: 0.16
F: 9.6
df: 51
P: < 0.001

Brook stickleback (*Culaea inconstans*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2013	SWA1	2.81	4.40	1.57
GEI 2013	SWA1	2.81	4.59	1.64
GEI 2013	SWA1	2.81	4.66	1.66
GEI 2013	SWA1	2.81	5.00	1.78
GEI 2013	SWA1	2.81	5.21	1.86
GEI 2013	SWA1	3.64	3.69	1.02
GEI 2013	SWA1	3.64	4.16	1.14
GEI 2013	SWA1	3.64	4.21	1.16
GEI 2013	SWA1	3.64	4.62	1.27
GEI 2013	SWA1	3.64	4.78	1.31
GEI 2013	SWA1	3.64	4.98	1.37
GEI 2013	SWA1	3.64	5.06	1.39
GEI 2013	SWA1	3.64	6.28	1.73
Lambing et al. 1994	S38	4.70	17.00	3.62
Lambing et al. 1994	S37	5.30	6.10	1.15
Lambing et al. 1994	S36	6.30	5.30	0.84
GEI 2014	Dry Creek, DC-2	3	3.14	0.92
GEI 2014	Dry Creek, DC-2	3	4.03	1.18
GEI 2014	Dry Creek, DC-2	3	3.76	1.10
GEI 2014	Dry Creek, DC-2	3	5.31	1.55
GEI 2014	Dry Creek, DC-2	3	4.59	1.34
GEI 2014	Dry Creek, DC-3	7	28.89	4.02
GEI 2014	Dry Creek, DC-3	7	66.07	9.20

Brook stickleback (*Culaea inconstans*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	Dry Creek, DC-3	7	24.43	3.40
GEI 2014	Dry Creek, DC-3	7	25.36	3.53
GEI 2014	Dry Creek, DC-3	7	40.17	5.59
GEI 2014	Dry Creek, DC-3	9	25.80	2.80
GEI 2014	Dry Creek, DC-3	9	24.14	2.62
GEI 2014	Dry Creek, DC-3	9	22.46	2.43
GEI 2014	Dry Creek, DC-3	9	19.86	2.15
GEI 2013	SW2-1	6.60	21.14	3.21
GEI 2013	SW2-1	6.60	23.21	3.52
GEI 2013	SW2-1	6.60	23.64	3.58
GEI 2013	SW2-1	6.60	25.89	3.93
GEI 2013	SW2-1	6.60	27.71	4.20
GEI 2013	SW2-1	6.60	32.97	5.00
GEI 2013	SW2-1	6.60	34.54	5.24
GEI 2013	SW2-1	6.60	37.05	5.62
GEI 2013	SW2-1	6.60	39.26	5.95
GEI 2013	SW2-1	6.60	43.38	6.58
GEI 2013	SWB	7.06	15.74	2.23
GEI 2013	SWB	7.06	17.15	2.43
GEI 2013	SW1	7.82	9.96	1.27
GEI 2013	SW1	7.82	10.38	1.33
GEI 2013	SW1	7.82	10.58	1.35
GEI 2013	SW1	7.82	11.98	1.53
GEI 2013	SW11	8.41	6.36	0.76
GEI 2013	SW11	8.41	6.45	0.77
GEI 2013	SW2-1	9.14	21.09	2.31
Lambing et al. 1994	S34	14.00	35.00	2.50
Lambing et al. 1994	S11	14.50	22.00	1.52
Lambing et al. 1994	S11	14.50	26.00	1.79

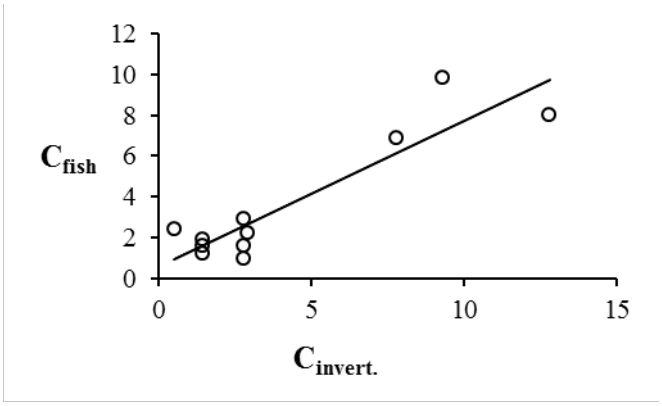


Median ratio: 1.79

R^2: 0.27
F: 18.48
df: 50
P: < 0.001

Brook trout (*Salvelinus fontinalis*)

Study	Site	C_{invert}	C_{fish}	Ratio
Hamilton and Buhl 2004	USC	0.50	2.40	4.80
Mason et al. 2000	BK	1.43	1.21	0.84
Mason et al. 2000	BK	1.43	1.57	1.10
Mason et al. 2000	BK	1.43	1.90	1.33
Mason et al. 2000	HCRT	2.81	0.99	0.35
Mason et al. 2000	HCRT	2.81	1.59	0.57
Mason et al. 2000	HCRT	2.81	2.95	1.05
Butler et al. 1997	MN1	2.90	2.20	0.76
Hamilton and Buhl 2005	LGC	7.80	6.90	0.88
Hamilton and Buhl 2005	UGC	9.30	9.80	1.05
Hamilton and Buhl 2004	DVC	12.80	8.00	0.63
Hamilton and Buhl 2004	USC	0.50	2.40	4.80

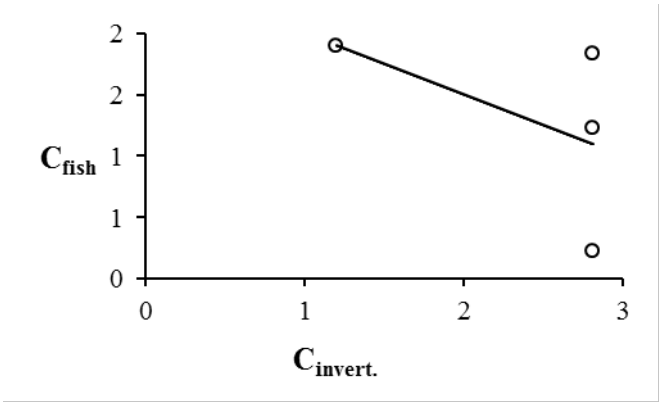


Median ratio: 0.88

R^2: 0.83
F: 43.6
df: 9
P: < 0.001

Brown bullhead (*Ameiurus nebulosus*)

Study	Site	C_{invert}	C_{fish}	Ratio
Rinella and Schuler 1992		1.20	1.90	1.58
Mason et al. 2000	HCRT	2.81	0.22	0.08
Mason et al. 2000	HCRT	2.81	1.23	0.44
Mason et al. 2000	HCRT	2.81	1.83	0.65



Median ratio: 0.55

R^2: 0.27
F: 0.73
df: 2
P: 0.58
Not used because P > 0.05 and negative slope

Brown trout (*Salmo trutta*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1991	10	4.80	2.00	0.42
Butler et al. 1991	12	2.80	5.40	1.93
Butler et al. 1991	4	3.90	3.30	0.85
Butler et al. 1991	4	3.90	3.50	0.90
Butler et al. 1991	3	6.20	3.50	0.56
Butler et al. 1993	SP2	3.40	3.40	1.00
Butler et al. 1993	SP2	2.75	1.20	0.44
Butler et al. 1993	B2	1.35	2.40	1.78
Butler et al. 1993	B2	1.35	2.70	2.00
Butler et al. 1993	B2	1.35	2.70	2.00
Butler et al. 1993	B1	1.25	4.20	3.36
Butler et al. 1993	D2	1.45	3.50	2.41
Butler et al. 1993	D2	1.45	3.50	2.41
Butler et al. 1993	D2	1.45	3.20	2.21
Butler et al. 1993	P1	1.95	3.30	1.69
Butler et al. 1993	LP2	1.00	1.70	1.70
Butler et al. 1993	LP2	1.00	2.10	2.10
Butler et al. 1993	LP2	1.00	1.60	1.60
Butler et al. 1993	LP3	1.12	2.10	1.88
Butler et al. 1993	LP3	1.12	2.80	2.51
Butler et al. 1993	LP4	3.20	1.80	0.56

NMED Exhibit 59

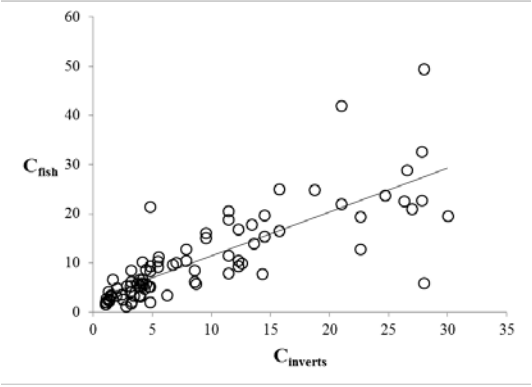
Brown trout (*Salmo trutta*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1993	R2	3.90	5.40	1.38
Butler et al. 1993	R2	3.90	6.70	1.72
Butler et al. 1993	R2	3.70	5.90	1.59
Butler et al. 1993	ST2	4.10	6.00	1.46
Butler et al. 1994	GUN2	28.00	49.45	1.77
Butler et al. 1994	GUN2	28.00	5.90	0.21
Butler et al. 1994	HCC1	21.00	21.98	1.05
Butler et al. 1994	HCC1	21.00	42.00	2.00
Butler et al. 1994	NFK3	2.00	5.00	2.50
Butler et al. 1994	SMF	4.80	21.44	4.47
Butler et al. 1994	SMF	4.80	5.26	1.10
Butler et al. 1994	SMF	4.80	8.40	1.75
Butler et al. 1994	SMF	4.80	9.40	1.96
Formation 2012	CC-1A	12.24	10.51	0.86
Formation 2012	CC-1A	12.24	9.33	0.76
Formation 2012	CC-1A	12.57	9.95	0.79
Formation 2012	CC-1A	12.24	16.85	1.38
Formation 2012	CC-1A	13.55	14.03	1.04
Formation 2012	CC-3A	5.45	10.44	1.92
Formation 2012	CC-3A	5.45	9.20	1.69
Formation 2012	CC-3A	5.48	11.25	2.05
Formation 2012	CC-3A	14.50	15.38	1.06
Formation 2012	CC-3A	14.50	19.68	1.36
Formation 2012	CC-150	4.46	5.83	1.31
Formation 2012	CC-150	4.46	8.67	1.94
Formation 2012	CC-150	4.70	5.20	1.11
Formation 2012	CC-150	7.03	10.14	1.44
Formation 2012	CC-150	14.32	7.83	0.55
Formation 2012	CC-350	3.16	6.28	1.99
Formation 2012	CC-350	3.16	8.53	2.70
Formation 2012	CC-350	4.20	5.78	1.38
Formation 2012	CC-350	11.45	11.50	1.00
Formation 2012	CC-350	11.45	7.95	0.69
Formation 2012	CC-75	3.11	4.05	1.30
Formation 2012	CC-75	3.11	5.35	1.72
Formation 2012	CC-75	3.97	3.18	0.80
Formation 2012	CC-75	4.16	10.32	2.48
Formation 2012	CC-75	4.16	6.60	1.59
Formation 2012	DC-600	8.53	8.54	1.00
Formation 2012	DC-600	8.53	6.20	0.73
Formation 2012	DC-600	8.65	5.85	0.68
Formation 2012	DC-600	7.83	12.83	1.64

NMED Exhibit 59

Brown trout (*Salmo trutta*)

Study	Site	C_{invert}	C_{fish}	Ratio
Formation 2012	DC-600	7.83	10.54	1.35
Formation 2012	HS	15.70	16.52	1.05
Formation 2012	HS	15.70	25.00	1.59
Formation 2012	HS	18.70	24.90	1.33
Formation 2012	HS	27.80	32.63	1.17
Formation 2012	HS	27.80	22.80	0.82
Formation 2012	HS-3	11.40	20.60	1.81
Formation 2012	HS-3	11.40	18.83	1.65
Formation 2012	HS-3	13.41	17.89	1.33
Formation 2012	HS-3	24.70	23.68	0.96
Formation 2012	HS-3	26.55	28.97	1.09
Formation 2012	LSV-2C	22.62	19.45	0.86
Formation 2012	LSV-2C	22.62	12.78	0.56
Formation 2012	LSV-2C	26.31	22.67	0.86
Formation 2012	LSV-2C	30.00	19.53	0.65
Formation 2012	LSV-2C	26.95	20.96	0.78
Formation 2012	LSV-4	9.54	16.20	1.70
Formation 2012	LSV-4	9.54	15.18	1.59
Formation 2012	SFTC-1	2.42	3.68	1.52
Formation 2012	SFTC-1	3.21	2.25	0.70
Formation 2012	SFTC-1	1.63	6.70	4.11
Formation 2012	SFTC-1	2.49	2.64	1.06
Hamilton and Buhl 2005	CC	6.70	9.70	1.45
McDonald and Strosher 1998	ER 747	4.29	4.80	1.12

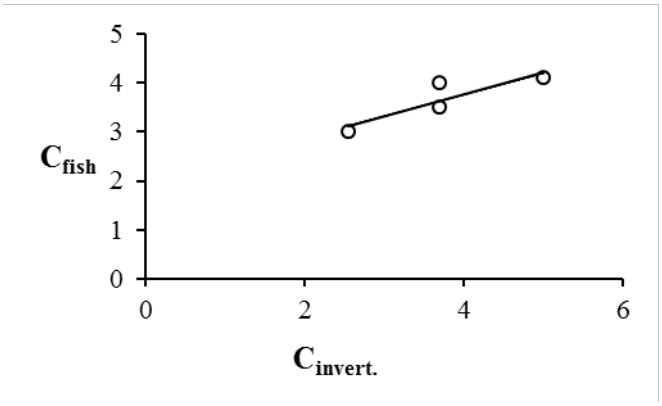


Median ratio: 1.38

R^2: 0.64
F: 151.8
df: 85
P: < 0.001

Bullhead (*Ameiurus sp.*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1995	ME3	2.55	3.00	1.18
Butler et al. 1993	R2	3.70	3.50	0.95
Butler et al. 1993	R2	3.70	4.00	1.08
Butler et al. 1994	BSW1	5.00	4.10	0.82



Median ratio: 1.01

R^2: 0.77
F: 6.58
df: 2
P: 0.13
Not used because P > 0.05

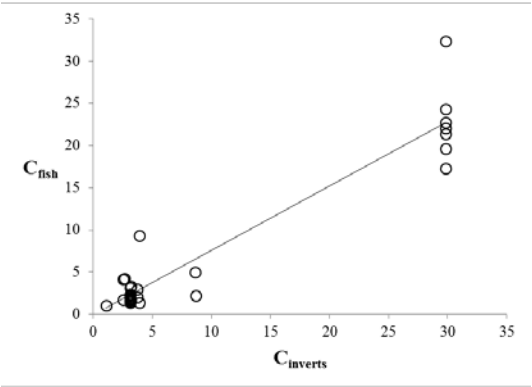
Channel catfish (*Ictalurus punctatus*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1991	7	29.80	21.36	0.72
Butler et al. 1991	7	29.80	22.05	0.74
Butler et al. 1991	7	29.80	17.27	0.58
Butler et al. 1991	7	29.80	19.62	0.66
Butler et al. 1991	7	29.80	22.76	0.76
Butler et al. 1991	7	29.80	24.33	0.82
Butler et al. 1991	7	29.80	32.40	1.09
Butler et al. 1993	LP4	3.20	1.65	0.52
Butler et al. 1993	LP4	3.20	3.30	1.03
Butler et al. 1993	R2	3.90	9.30	2.39
Butler et al. 1993	R2	3.90	1.33	0.34
Butler et al. 1993	R2	3.70	2.04	0.55
Butler et al. 1993	R2	3.70	3.00	0.81
Butler et al. 1995	SJ1	2.50	1.73	0.69
Butler et al. 1995	SJ1	2.50	4.10	1.64
Butler et al. 1995	TT	1.07	1.00	0.94
Butler et al. 1997	MN4	2.65	4.20	1.58
Butler et al. 1997	MN5	8.60	5.00	0.58
Mueller et al. 1991	R1	8.70	2.20	0.25
Roddy et al. 1991	18	3.10	1.40	0.45
Roddy et al. 1991	18	3.10	1.60	0.52
Roddy et al. 1991	18	3.10	1.70	0.55

NMED Exhibit 59

Channel catfish (*Ictalurus punctatus*)

Study	Site	C_{invert}	C_{fish}	Ratio
Roddy et al. 1991	18	3.10	1.80	0.58
Roddy et al. 1991	18	3.10	1.90	0.61
Roddy et al. 1991	18	3.10	2.20	0.71
Roddy et al. 1991	18	3.10	1.50	0.48
Roddy et al. 1991	18	3.10	1.70	0.55
Roddy et al. 1991	18	3.10	1.80	0.58
Roddy et al. 1991	18	3.10	2.00	0.65
Roddy et al. 1991	18	3.10	2.10	0.68
Roddy et al. 1991	18	3.10	2.20	0.71
Roddy et al. 1991	18	3.10	2.30	0.74
Roddy et al. 1991	18	3.10	2.40	0.77
Roddy et al. 1991	18	3.10	3.10	1.00



Median ratio: 0.74

R^2: 0.91
F: 332.8
df: 32
P: < 0.001

Common carp (*Cyprinus carpio*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1991	10	4.80	10.30	2.15
Butler et al. 1991	7	29.80	25.80	0.87
Butler et al. 1991	7	29.80	31.00	1.04
Butler et al. 1991	7	29.80	40.00	1.34
Butler et al. 1991	7	29.80	50.00	1.68
Butler et al. 1991	9	4.10	3.90	0.95
Butler et al. 1991	3	6.20	2.20	0.35
Butler et al. 1993	D2	1.45	3.70	2.55
Butler et al. 1993	F2	7.50	5.80	0.77
Butler et al. 1993	R2	4.30	5.00	1.16
Butler et al. 1993	R2	3.90	4.80	1.23
Butler et al. 1993	R2	3.70	3.30	0.89
Butler et al. 1994	GUN2	28.00	63.00	2.25
Butler et al. 1994	NFK2	3.10	4.90	1.58

Common carp (*Cyprinus carpio*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1994	BSW1	5.00	12.00	2.40
Butler et al. 1994	RB1	21.00	5.10	0.24
Butler et al. 1995	ME4	1.55	3.90	2.52
Butler et al. 1995	ME4	1.55	3.70	2.39
Butler et al. 1995	ME4	1.55	3.80	2.45
Butler et al. 1995	ME3	2.55	4.40	1.73
Butler et al. 1995	ME3	2.55	5.20	2.04
Butler et al. 1995	SJ1	2.50	5.30	2.12
Butler et al. 1995	SJ1	2.50	3.40	1.36
Butler et al. 1995	MN1	2.70	5.80	2.15
Butler et al. 1995	MN1	2.70	9.80	3.63
Butler et al. 1995	MN1	2.70	5.40	2.00
Butler et al. 1997	MN5	8.60	16.00	1.86
Garcia-Hernandez et al. 2000	Cienega de Santa Clara Wetland	3.00	3.30	1.10
GEI 2013	SWB	7.06	12.50	1.77
GEI 2013	SWB	7.06	15.61	2.21
GEI 2013	SW11	8.41	3.14	0.37
GEI 2013	SW11	8.41	3.52	0.42
GEI 2013	SW11	8.41	3.66	0.44
GEI 2013	SW11	8.41	3.85	0.46
GEI 2013	SW11	8.41	5.77	0.69
GEI 2013	SW11	8.41	3.60	0.43
GEI 2013	SW11	8.41	3.79	0.45
GEI 2013	SW11	8.41	3.95	0.47
GEI 2013	SW11	8.41	4.14	0.49
GEI 2013	SW11	8.41	4.34	0.52
GEI 2013	SW11	8.41	3.56	0.42
GEI 2013	SW2-1	6.60	26.73	4.05
GEI 2013	SW2-1	6.60	26.74	4.05
GEI 2013	SW2-1	6.60	28.74	4.36
GEI 2013	SW2-1	6.60	29.73	4.51
GEI 2013	SW2-1	6.60	41.57	6.30
GEI 2013	SW2-1	6.60	22.96	3.48
GEI 2013	SW2-1	6.60	24.27	3.68
GEI 2013	SW2-1	6.60	25.09	3.80
GEI 2013	SW2-1	6.60	31.74	4.81
GEI 2013	SW2-1	6.60	36.81	5.58
GEI 2013	SW2-1	9.14	13.29	1.45
GEI 2013	SW2-1	9.14	13.77	1.51
GEI 2013	SW2-1	9.14	20.49	2.24
GEI 2013	SW2-1	9.14	24.84	2.72

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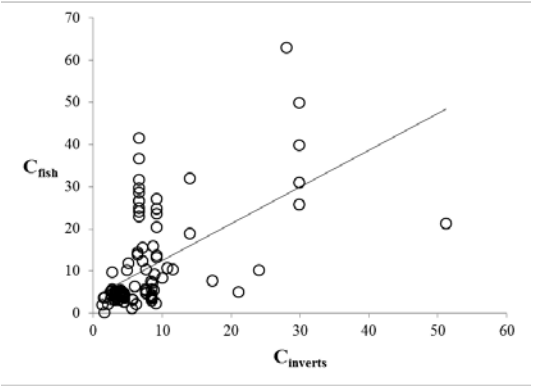
Common carp (*Cyprinus carpio*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2013	SW2-1	9.14	23.65	2.59
GEI 2013	SW2-1	9.14	27.27	2.99
GEI 2013	SW4-1	3.33	3.55	1.07
GEI 2013	SW4-1	3.33	4.68	1.41
GEI 2013	SW4-1	3.33	3.91	1.18
GEI 2013	SW4-1	3.33	4.36	1.31
GEI 2013	SW4-1	3.33	4.48	1.35
GEI 2013	SW4-1	3.33	4.60	1.38
GEI 2013	SW4-1	3.33	4.78	1.44
GEI 2013	SW9	4.45	2.73	0.61
GEI 2013	SW9	4.45	2.99	0.67
GEI 2013	SW9	4.45	3.64	0.82
GEI 2013	SW9	4.45	3.80	0.85
GEI 2013	SW9	4.45	3.90	0.88
GEI 2013	SW9	4.45	4.26	0.96
GEI 2013	SW9	4.45	4.53	1.02
GEI 2013	SW9	4.45	3.70	0.83
GEI 2013	SW9	4.45	3.77	0.85
GEI 2013	SW9	4.45	4.14	0.93
GEI 2013	SW9	4.45	4.41	0.99
GEI 2013	SW9	4.45	4.50	1.01
GEI 2013	SW9	4.45	4.69	1.05
GEI 2013	SW88	3.96	3.88	0.98
GEI 2013	SW88	3.96	5.33	1.35
GEI 2013	SW88	3.96	5.49	1.39
GEI 2013	SW88	3.96	5.66	1.43
Grasso et al. 1995	9	7.59	4.70	0.62
Grasso et al. 1995	9	7.59	4.93	0.65
Grasso et al. 1995	9	7.59	5.51	0.73
Lambing et al. 1994	S34	14.00	19.00	1.36
Lambing et al. 1994	S34	14.00	32.00	2.29
Low and Mullins 1990	5	5.60	1.20	0.21
Low and Mullins 1990	7	1.60	0.30	0.19
May et al. 2008	KR	17.20	7.78	0.45
May et al. 2008	NSCL	10.70	10.80	1.01
May et al. 2008	NSK	8.81	9.33	1.06
May et al. 2008	NSP	24.00	10.30	0.43
May et al. 2008	SSAL	11.50	10.50	0.91
May et al. 2008	SSAU	8.35	7.59	0.91
May et al. 2008	SSO	10.00	8.48	0.85
May et al. 2008	SSW	7.60	10.40	1.37
Mueller et al. 1991	R2	6.40	14.40	2.25

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Common carp (*Cyprinus carpio*)

Study	Site	C_{invert}	C_{fish}	Ratio
Mueller et al. 1991	R2	6.40	14.00	2.19
Mueller et al. 1991	R1	8.70	5.60	0.64
Mueller et al. 1991	A3	6.00	6.50	1.08
Mueller et al. 1991	A6	5.60	3.40	0.61
Mueller et al. 1991	A2	8.50	7.30	0.86
Peterson et al. 1991	7	3.83	4.24	1.11
Peterson et al. 1991	7	3.83	4.41	1.15
Peterson et al. 1991	7	3.83	4.73	1.23
Peterson et al. 1991	7	3.83	5.16	1.35
Peterson et al. 1991	7	3.83	5.21	1.36
Roddy et al. 1991	18	3.10	3.20	1.03
Roddy et al. 1991	18	3.10	3.90	1.26
Roddy et al. 1991	18	3.10	4.60	1.48
Roddy et al. 1991	18	3.10	4.70	1.52
Roddy et al. 1991	18	3.10	4.80	1.55
Roddy et al. 1991	18	3.10	5.30	1.71
Lemly 1985	Badin Lake	5.70	3.17	0.56
Lemly 1985	Belews Lake	51.15	21.29	0.42
Lemly 1985	High Rock Lake	9.05	2.45	0.27
Rinella and Schuler 1992	Harney Lake	2.05	2.20	1.07
Rinella and Schuler 1992	S. Malheur Lake	1.20	2.00	1.67



Median ratio: 1.20

R^2: 0.32
F: 54.27
df: 116
P: < 0.001

Creek chub (*Semotilus atromaculatus*)

Study	Site	C_{invert}	C_{fish}	Ratio
Mason et al. 2000	HCRT	2.81	0.49	0.18
Mason et al. 2000	HCRT	2.81	1.18	0.42
Mason et al. 2000	HCRT	2.81	1.97	0.70
GEI 2013	SW4-1	3.33	4.65	1.40
GEI 2013	SW4-1	3.33	4.96	1.49

Creek chub (*Semotilus atromaculatus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2013	SW4-1	3.33	5.52	1.66
GEI 2013	SW4-1	3.33	6.11	1.84
GEI 2013	SW4-1	3.33	6.31	1.90
GEI 2013	SW4-1	3.33	6.53	1.96
GEI 2013	SW4-1	3.33	6.67	2.01
GEI 2013	LG1	3.37	3.41	1.01
GEI 2013	LG1	3.37	3.58	1.06
GEI 2013	LG1	3.37	3.75	1.11
GEI 2013	LG1	3.37	3.78	1.12
GEI 2013	LG1	3.37	4.10	1.22
GEI 2013	LG1	3.39	3.23	0.95
GEI 2013	LG1	3.39	3.72	1.10
GEI 2013	LG1	3.39	3.74	1.10
GEI 2013	LG1	3.39	3.78	1.12
GEI 2013	LG1	3.39	3.89	1.15
GEI 2013	LG1	3.39	4.03	1.19
GEI 2013	LG1	3.39	4.12	1.22
GEI 2013	LG1	3.39	5.11	1.51
GEI 2013	LG1	3.39	5.21	1.54
GEI 2013	LG1	3.39	5.34	1.58
GEI 2013	LG1	3.56	3.28	0.92
GEI 2013	LG1	3.56	3.37	0.95
GEI 2013	LG1	3.56	3.82	1.07
GEI 2013	LG1	3.56	3.86	1.09
GEI 2013	LG1	3.56	4.02	1.13
GEI 2013	LG1	3.56	4.16	1.17
GEI 2013	LG1	3.56	4.49	1.26
GEI 2013	LG1	3.56	4.53	1.27
GEI 2013	LG1	3.56	4.63	1.30
GEI 2013	LG1	3.56	4.77	1.34
GEI 2013	CC1	3.76	5.43	1.44
GEI 2013	CC1	3.76	5.57	1.48
GEI 2013	CC1	3.76	6.51	1.73
GEI 2013	CC1	3.76	6.71	1.78
GEI 2013	CC1	3.76	7.12	1.89
GEI 2013	CC1	4.69	3.99	0.85
GEI 2013	CC1	4.69	4.06	0.87
GEI 2013	CC1	4.69	4.08	0.87
GEI 2013	CC1	4.69	4.25	0.91
GEI 2013	CC1	4.69	4.44	0.95
GEI 2013	CC1	4.69	4.48	0.96
GEI 2013	CC1	4.69	4.50	0.96

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Creek chub (*Semotilus atromaculatus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2013	CC1	4.69	4.72	1.01
GEI 2013	CC1	4.69	5.24	1.12
GEI 2013	CC1	4.69	5.44	1.16
GEI 2013	CC1	5.86	4.98	0.85
GEI 2013	CC1	5.86	5.39	0.92
GEI 2013	CC1	5.86	5.77	0.99
GEI 2013	CC1	5.86	6.39	1.09
GEI 2013	CC1	5.86	6.43	1.10
GEI 2013	CC1	5.86	6.50	1.11
GEI 2013	CC1	5.86	6.57	1.12
GEI 2013	CC1	5.86	7.42	1.27
GEI 2013	CC1	5.86	7.42	1.27
GEI 2013	CC1	5.86	7.47	1.28
GEI 2014	Bond Creek, BC-2	2.96	2.46	0.83
GEI 2014	Bond Creek, BC-2	2.96	3.22	1.09
GEI 2014	Bond Creek, BC-2	2.96	2.64	0.89
GEI 2014	Bond Creek, BC-2	2.96	2.96	1.00
GEI 2014	Bond Creek, BC-2	2.96	4.47	1.51
GEI 2014	Bond Creek, BC-3	3.02	3.09	1.02
GEI 2014	Bond Creek, BC-3	3.02	2.91	0.96
GEI 2014	Bond Creek, BC-3	3.02	3.45	1.14
GEI 2014	Bond Creek, BC-3	3.02	2.69	0.89
GEI 2014	Bond Creek, BC-3	3.02	3.30	1.09
GEI 2014	Bond Creek, BC-3	5.87	3.44	0.59
GEI 2014	Bond Creek, BC-3	5.87	2.62	0.45
GEI 2014	Bond Creek, BC-3	5.87	3.23	0.55
GEI 2014	Cow Camp Creek, CC-2	5.65	3.05	0.54
GEI 2014	Cow Camp Creek, CC-2	5.65	3.69	0.65
GEI 2014	Cow Camp Creek, CC-2	5.65	3.84	0.68
GEI 2014	Cow Camp Creek, CC-2	5.65	4.44	0.79
GEI 2014	Cow Camp Creek, CC-2	5.65	3.98	0.70
GEI 2014	Hazy Creek, C-HC1	8.03	6.84	0.85
GEI 2014	Hazy Creek, C-HC1	8.03	3.78	0.47
GEI 2014	Hazy Creek, C-HC1	8.03	5.81	0.72
GEI 2014	Hazy Creek, C-HC1	8.03	4.29	0.53
GEI 2014	Hazy Creek, C-HC1	8.03	3.59	0.45
GEI 2014	Laurel Fork, C-LF1	12.73	6.52	0.51
GEI 2014	Laurel Fork, C-LF1	12.73	6.81	0.54
GEI 2014	Laurel Fork, C-LF1	12.73	5.11	0.40
GEI 2014	Laurel Fork, C-LF1	12.73	5.16	0.41
GEI 2014	Laurel Fork, C-LF1	12.73	5.46	0.43
GEI 2014	Little Marsh Fork, C-LMF1	6.02	3.81	0.63

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Creek chub (*Semotilus atromaculatus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	Little Marsh Fork, C-LMF1	6.02	4.89	0.81
GEI 2014	Little Marsh Fork, C-LMF1	6.02	3.58	0.60
GEI 2014	Little Marsh Fork, C-LMF1	6.02	4.81	0.80
GEI 2014	Little Marsh Fork, C-LMF1	6.02	5.82	0.97
GEI 2014	Dry Creek, DC-1	3.37	4.62	1.37
GEI 2014	Dry Creek, DC-1	3.37	5.15	1.53
GEI 2014	Dry Creek, DC-1	3.37	6.46	1.92
GEI 2014	Dry Creek, DC-1	3.37	5.73	1.70
GEI 2014	Dry Creek, DC-1	3.37	4.59	1.36
GEI 2014	Dry Creek, DC-1	2.29	4.94	2.16
GEI 2014	Dry Creek, DC-1	2.29	4.04	1.76
GEI 2014	Dry Creek, DC-1	2.29	3.62	1.58
GEI 2014	Dry Creek, DC-1	2.29	3.84	1.68
GEI 2014	Dry Creek, DC-1	2.15	4.02	1.87
GEI 2014	Dry Creek, DC-1	2.15	3.60	1.67
GEI 2014	Dry Creek, DC-1	2.15	3.28	1.52
GEI 2014	Dry Creek, DC-1	2.15	3.03	1.41
GEI 2014	Dry Creek, DC-1	2.15	4.01	1.86
GEI 2014	Dry Creek, DC-1	1.97	3.51	1.78
GEI 2014	Dry Creek, DC-2	3.42	5.32	1.56
GEI 2014	Dry Creek, DC-2	3.42	4.62	1.35
GEI 2014	Dry Creek, DC-2	3.42	4.43	1.30
GEI 2014	Dry Creek, DC-2	3.42	4.56	1.34
GEI 2014	Dry Creek, DC-2	3.42	6.38	1.87
GEI 2014	Dry Creek, DC-2	3.42	2.96	0.87
GEI 2014	Dry Creek, DC-2	3.42	3.58	1.05
GEI 2014	Dry Creek, DC-2	3.42	3.22	0.94
GEI 2014	Dry Creek, DC-2	3.42	4.07	1.19
GEI 2014	Dry Creek, DC-2	3.42	3.28	0.96
GEI 2014	Dry Creek, DC-2	3.16	6.52	2.07
GEI 2014	Dry Creek, DC-2	3.16	4.92	1.56
GEI 2014	Dry Creek, DC-2	3.16	3.10	0.98
GEI 2014	Dry Creek, DC-2	3.16	3.14	1.00
GEI 2014	Dry Creek, DC-2	3.16	4.36	1.38
GEI 2014	Dry Creek, DC-2	3.16	3.12	0.99
GEI 2014	Dry Creek, DC-2	3.16	5.40	1.71
GEI 2014	Dry Creek, DC-2	2.93	2.85	0.97
GEI 2014	Dry Creek, DC-2	2.93	4.94	1.69
GEI 2014	Dry Creek, DC-2	2.93	5.17	1.76
GEI 2014	Dry Creek, DC-2	2.93	3.47	1.18
GEI 2014	Dry Creek, DC-2	2.93	2.49	0.85
GEI 2014	Dry Creek, DC-3	7.18	23.79	3.31

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Creek chub (*Semotilus atromaculatus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	Dry Creek, DC-3	7.18	16.06	2.24
GEI 2014	Dry Creek, DC-3	7.18	24.43	3.40
GEI 2014	Dry Creek, DC-3	7.18	22.20	3.09
GEI 2014	Dry Creek, DC-3	7.18	26.28	3.66
GEI 2014	Dry Creek, DC-3	9.23	21.48	2.33
GEI 2014	Dry Creek, DC-3	9.23	21.24	2.30
GEI 2014	Dry Creek, DC-3	9.23	21.46	2.33
GEI 2014	Dry Creek, DC-3	9.23	22.48	2.44
GEI 2014	Dry Creek, DC-3	9.23	18.80	2.04
GEI 2014	Dry Creek, DC-3	9.23	16.87	1.83
GEI 2014	Dry Creek, DC-4	19.42	15.86	0.82
GEI 2014	Dry Creek, DC-4	19.42	12.76	0.66
GEI 2014	Dry Creek, DC-4	19.42	28.50	1.47
GEI 2014	Dry Creek, DC-4	19.42	18.14	0.93
GEI 2014	Dry Creek, DC-4	19.42	17.55	0.90
GEI 2014	Dry Creek, DC-4	18.10	34.60	1.91
GEI 2014	Dry Creek, DC-4	18.10	23.70	1.31
GEI 2014	Foidel Creek, FOC-1	3.06	8.00	2.61
GEI 2014	Foidel Creek, FOC-1	3.06	9.68	3.16
GEI 2014	Foidel Creek, FOC-1	3.06	8.86	2.89
GEI 2014	Foidel Creek, FOC-1	3.06	2.51	0.82
GEI 2014	Foidel Creek, FOC-1	3.06	2.86	0.93
GEI 2014	Foidel Creek, FOC-1	3.06	4.24	1.39
GEI 2014	Foidel Creek, FOC-1	3.06	3.27	1.07
GEI 2014	Foidel Creek, FOC-1	3.06	5.03	1.64
GEI 2014	Foidel Creek, FOC-2	2.18	2.07	0.95
GEI 2014	Foidel Creek, FOC-2	2.18	3.06	1.41
GEI 2014	Foidel Creek, FOC-2	2.18	3.82	1.76
GEI 2014	Foidel Creek, FOC-2	2.18	2.26	1.04
GEI 2014	Foidel Creek, FOC-2	2.18	2.02	0.93
GEI 2014	Foidel Creek, FOC-2	2.18	2.28	1.05
GEI 2014	Foidel Creek, FOC-2	2.18	2.44	1.12
GEI 2014	Foidel Creek, FOC-2	2.18	2.62	1.21
GEI 2014	Grassy Creek, GC-2	4.20	5.28	1.26
GEI 2014	Grassy Creek, GC-2	4.20	6.13	1.46
GEI 2014	Grassy Creek, GC-2	4.20	6.29	1.50
GEI 2014	Grassy Creek, GC-2	4.20	4.80	1.15
GEI 2014	Grassy Creek, GC-2	4.20	4.59	1.09
GEI 2014	Grassy Creek, GC-2	4.58	3.27	0.71
GEI 2014	Grassy Creek, GC-2	4.58	5.50	1.20
GEI 2014	Grassy Creek, GC-2	4.58	3.64	0.80
GEI 2014	Grassy Creek, GC-2	4.58	4.29	0.94

NMED Exhibit 59

Creek chub (*Semotilus atromaculatus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	Grassy Creek, GC-2	4.58	3.01	0.66
GEI 2014	Grassy Creek, GC-2	3.96	7.48	1.89
GEI 2014	Grassy Creek, GC-2	3.96	6.12	1.55
GEI 2014	Grassy Creek, GC-2	3.96	8.61	2.18
GEI 2014	Grassy Creek, GC-2	3.96	7.09	1.79
GEI 2014	Grassy Creek, GC-2	3.96	5.06	1.28
GEI 2014	Grassy Creek, GC-2	3.96	4.95	1.25
GEI 2014	Grassy Creek, GC-2	3.96	3.85	0.97
GEI 2014	Grassy Creek, GC-2	3.96	5.32	1.34
GEI 2014	Grassy Creek, GC-2	3.96	4.04	1.02
GEI 2014	Grassy Creek, GC-2	3.96	4.25	1.08
GEI 2014	Grassy Creek, GC-2	3.97	3.48	0.88
GEI 2014	Grassy Creek, GC-2	3.97	3.86	0.97
GEI 2014	Grassy Creek, GC-2	3.97	4.08	1.03
GEI 2014	Grassy Creek, GC-2	3.97	4.58	1.15
GEI 2014	Grassy Creek, GC-2	3.97	3.53	0.89
GEI 2014	Grassy Creek, GC-3	4.54	6.07	1.34
GEI 2014	Grassy Creek, GC-3	4.54	7.25	1.60
GEI 2014	Grassy Creek, GC-3	4.54	5.25	1.16
GEI 2014	Grassy Creek, GC-3	4.54	5.65	1.25
GEI 2014	Grassy Creek, GC-3	4.54	10.75	2.37
GEI 2014	Grassy Creek, GC-3	4.55	3.30	0.73
GEI 2014	Grassy Creek, GC-3	4.55	3.98	0.88
GEI 2014	Grassy Creek, GC-3	4.55	3.46	0.76
GEI 2014	Grassy Creek, GC-3	4.55	4.14	0.91
GEI 2014	Grassy Creek, GC-3	4.55	3.81	0.84
GEI 2014	Grassy Creek, GC-3	4.34	11.05	2.55
GEI 2014	Grassy Creek, GC-3	4.34	7.22	1.66
GEI 2014	Grassy Creek, GC-3	4.34	9.61	2.22
GEI 2014	Grassy Creek, GC-3	4.34	6.03	1.39
GEI 2014	Grassy Creek, GC-3	4.34	3.95	0.91
GEI 2014	Grassy Creek, GC-3	4.34	4.82	1.11
GEI 2014	Grassy Creek, GC-3	4.34	5.18	1.19
GEI 2014	Grassy Creek, GC-3	4.34	4.46	1.03
GEI 2014	Grassy Creek, GC-3	4.34	4.21	0.97
GEI 2014	Grassy Creek, GC-3	4.35	2.97	0.68
GEI 2014	Grassy Creek, GC-3	4.35	4.16	0.96
GEI 2014	Grassy Creek, GC-3	4.35	4.29	0.99
GEI 2014	Grassy Creek, GC-3	4.35	3.69	0.85
GEI 2014	Grassy Creek, GC-3	4.35	4.73	1.09
GEI 2014	Grassy Creek, GC-4	5.10	4.30	0.84
GEI 2014	Grassy Creek, GC-4	5.10	5.17	1.01

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Creek chub (*Semotilus atromaculatus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	Grassy Creek, GC-4	5.10	5.46	1.07
GEI 2014	Grassy Creek, GC-4	5.10	5.63	1.10
GEI 2014	Grassy Creek, GC-4	5.10	5.15	1.01
GEI 2014	Grassy Creek, GC-4	5.76	7.72	1.34
GEI 2014	Grassy Creek, GC-4	5.76	6.04	1.05
GEI 2014	Grassy Creek, GC-4	5.76	7.88	1.37
GEI 2014	Grassy Creek, GC-4	5.76	9.77	1.70
GEI 2014	Grassy Creek, GC-4	5.76	7.35	1.28
GEI 2014	Grassy Creek, GC-4	5.76	4.17	0.72
GEI 2014	Grassy Creek, GC-4	5.76	4.86	0.84
GEI 2014	Grassy Creek, GC-4	5.76	5.02	0.87
GEI 2014	Grassy Creek, GC-4	5.76	4.79	0.83
GEI 2014	Grassy Creek, GC-4	5.76	6.56	1.14
GEI 2014	Grassy Creek, GC-4	5.76	5.31	0.92
GEI 2014	Grassy Creek, GC-4 US	13.16	4.05	0.31
GEI 2014	Grassy Creek, GC-4 US	13.16	4.80	0.36
GEI 2014	Grassy Creek, GC-4 US	13.16	5.41	0.41
GEI 2014	Grassy Creek, GC-4 US	13.16	6.05	0.46
GEI 2014	Big Horse Creek, H-BHC3	5.78	3.96	0.69
GEI 2014	Big Horse Creek, H-BHC3	5.78	2.97	0.51
GEI 2014	Big Horse Creek, H-BHC3	5.78	3.84	0.66
GEI 2014	Sally Fork, H-BLB2	1.64	2.42	1.48
GEI 2014	Sally Fork, H-BLB2	1.64	1.65	1.01
GEI 2014	Sally Fork, H-BLB2	1.64	1.68	1.03
GEI 2014	Sally Fork, H-BLB2	1.64	2.02	1.23
GEI 2014	Sally Fork, H-BLB2	1.64	1.46	0.89
GEI 2014	Hubberson Gulch, HG-2	3.44	4.41	1.28
GEI 2014	Hubberson Gulch, HG-2	3.44	3.56	1.04
GEI 2014	Hubberson Gulch, HG-2	3.44	4.48	1.30
GEI 2014	Hubberson Gulch, HG-2	1.46	2.95	2.03
GEI 2014	Hubberson Gulch, HG-2	1.46	2.66	1.83
GEI 2014	Hubberson Gulch, HG-2	1.46	2.87	1.97
GEI 2014	Jack Smith (Bear) Branch, H-JSB1	4.03	3.04	0.75
GEI 2014	Jack Smith (Bear) Branch, H-JSB1	4.03	1.81	0.45
GEI 2014	Jack Smith (Bear) Branch, H-JSB1	4.03	2.35	0.58
GEI 2014	Jack Smith (Bear) Branch, H-JSB1	4.03	1.91	0.47
GEI 2014	Jack Smith (Bear) Branch, H-JSB1	4.03	2.83	0.70
GEI 2014	Laurel Creek, H-LC1	4.57	1.29	0.28

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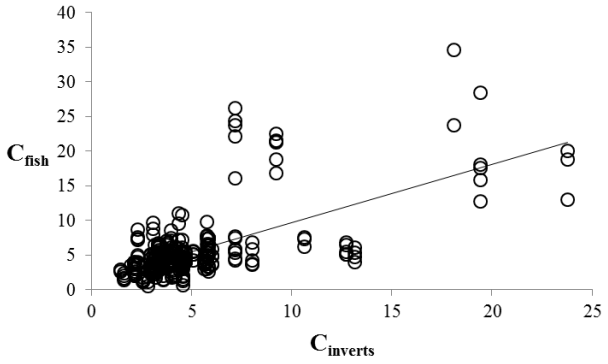
Creek chub (*Semotilus atromaculatus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	Laurel Creek, H-LC1	4.57	2.04	0.45
GEI 2014	Laurel Creek, H-LC1	4.57	1.49	0.33
GEI 2014	Laurel Creek, H-LC1	4.57	1.85	0.41
GEI 2014	Laurel Creek, H-LC1	4.57	0.67	0.15
GEI 2014	Lick Creek, H-LKC1	2.59	1.83	0.71
GEI 2014	Lick Creek, H-LKC1	2.59	1.40	0.54
GEI 2014	Lick Creek, H-LKC1	2.59	1.41	0.54
GEI 2014	Lick Creek, H-LKC1	2.59	1.19	0.46
GEI 2014	Lick Creek, H-LKC1	2.59	1.22	0.47
GEI 2014	Mud River, H-MR3	3.86	4.75	1.23
GEI 2014	Mud River, H-MR3	3.86	4.60	1.19
GEI 2014	Mud River, H-MR3	3.86	5.06	1.31
GEI 2014	Mud River, H-MR3	3.86	3.32	0.86
GEI 2014	Mud River, H-MR3	3.86	4.19	1.08
GEI 2014	Mud River, H-MR5	3.58	1.51	0.42
GEI 2014	Mud River, H-MR5	3.58	1.43	0.40
GEI 2014	Mud River, H-MR5	3.58	1.98	0.55
GEI 2014	Mud River, H-MR5	3.58	3.80	1.06
GEI 2014	Mud River, H-MR5	3.58	3.44	0.96
GEI 2014	Sugartree Branch, H-SB1	10.62	7.29	0.69
GEI 2014	Sugartree Branch, H-SB1	10.62	7.56	0.71
GEI 2014	Sugartree Branch, H-SB1	10.62	6.20	0.58
GEI 2014	Middle Creek, MC-1	3.21	2.75	0.86
GEI 2014	Middle Creek, MC-1	3.21	4.74	1.48
GEI 2014	Middle Creek, MC-1	3.21	4.01	1.25
GEI 2014	Middle Creek, MC-1	3.21	3.94	1.23
GEI 2014	Middle Creek, MC-1	3.21	3.63	1.13
GEI 2014	Middle Creek, MC-1	3.21	1.83	0.57
GEI 2014	Middle Creek, MC-1	3.21	1.85	0.57
GEI 2014	Middle Creek, MC-1	3.21	2.50	0.78
GEI 2014	Middle Creek, MC-1	3.21	2.33	0.73
GEI 2014	Middle Creek, MC-1	3.21	2.56	0.80
GEI 2014	Middle Creek, MC-2	4.19	1.93	0.46
GEI 2014	Middle Creek, MC-2	4.19	1.89	0.45
GEI 2014	Middle Creek, MC-2	4.19	2.51	0.60
GEI 2014	Middle Creek, MC-2	4.19	1.87	0.45
GEI 2014	Middle Creek, MC-2	4.19	2.13	0.51
GEI 2014	Sage Creek, SC-3	2.29	7.33	3.20
GEI 2014	Sage Creek, SC-3	2.29	7.23	3.16
GEI 2014	Sage Creek, SC-3	2.29	7.60	3.32
GEI 2014	Sage Creek, SC-3	2.29	4.77	2.08
GEI 2014	Sage Creek, SC-3	2.29	8.70	3.80

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Creek chub (*Semotilus atromaculatus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	Sage Creek, SC-4	23.79	18.77	0.79
GEI 2014	Sage Creek, SC-4	23.79	20.08	0.84
GEI 2014	Sage Creek, SC-4	23.79	13.05	0.55
GEI 2014	Scotchmans Gulch, SG-1A	7.16	7.41	1.04
GEI 2014	Scotchmans Gulch, SG-1A	7.16	7.65	1.07
GEI 2014	Scotchmans Gulch, SG-1A	7.16	4.47	0.62
GEI 2014	Scotchmans Gulch, SG-1A	7.16	5.83	0.81
GEI 2014	Scotchmans Gulch, SG-1A	7.16	5.37	0.75
GEI 2014	Scotchmans Gulch, SG-1A	7.16	5.69	0.80
GEI 2014	Scotchmans Gulch, SG-1A	7.16	4.31	0.60



Median ratio: 1.06

R^2: 0.41
F: 214.7
df: 303
P: < 0.001

Cutthroat trout (*Oncorhynchus clarkii*)

Study	Site	C_{invert}	C_{fish}	Ratio
Hamilton and Buhl 2004	ShpC	1.90	1.80	0.95
McDonald and Strosher 1998	ER 745	2.74	5.40	1.97
Hamilton and Buhl 2005	SC	4.10	3.50	0.85
McDonald and Strosher 1998	ER 747	4.29	6.57	1.53
Hamilton and Buhl 2005	UAC	5.00	6.60	1.32
Hamilton and Buhl 2004	ACM	6.70	6.30	0.94
Hamilton and Buhl 2005	DC	8.70	11.00	1.26
McDonald and Strosher 1998	ER 746	10.70	12.71	1.19
Hamilton and Buhl 2005	BGS	10.80	12.20	1.13
Hamilton and Buhl 2004	DVC	12.80	10.20	0.80
Hamilton and Buhl 2004	UEMC	26.90	27.00	1.00
Hamilton and Buhl 2004	LEMC	75.20	52.30	0.70
Minnow 2007	BA6	3.27	6.98	2.13
Minnow 2007	AL4	3.92	4.44	1.13
Minnow 2007	MI5	4.00	5.12	1.28

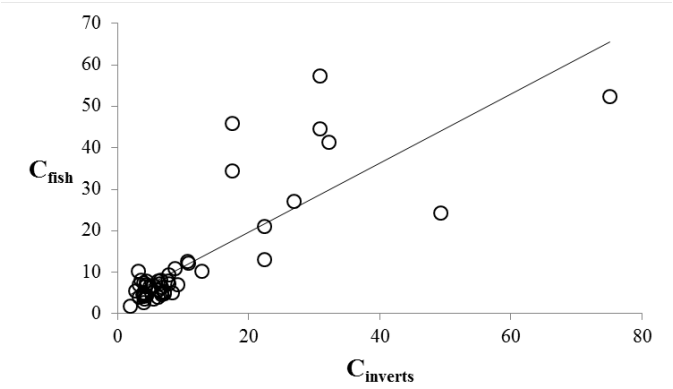
Cutthroat trout (*Oncorhynchus clarkii*)

Study	Site	C_{invert}	C_{fish}	Ratio
Minnow 2007	EL12	4.01	7.42	1.85
Minnow 2007	EL14	4.41	4.52	1.02
Minnow 2007	FO9	4.44	7.80	1.76
Minnow 2007	MI3	6.21	5.65	0.91
Minnow 2007	MI2	6.69	5.16	0.77
Minnow 2007	EL1	7.08	4.82	0.68
Minnow 2007	LI8	7.81	9.36	1.20
Minnow 2007	FO10	17.51	45.94	2.62
Minnow 2007	HA7	22.41	21.10	0.94
Minnow 2007	CL11	30.87	57.27	1.86
Orr et al. 2012	Alexander Creek	3.92	2.71	0.69
Orr et al. 2012	Elk River 1	6.23	5.61	0.90
Orr et al. 2012	Elk River 1	6.23	7.94	1.27
Orr et al. 2012	Elk River 1	7.08	5.35	0.76
Orr et al. 2012	Elk River 12	3.81	4.58	1.20
Orr et al. 2012	Elk River 12	4.01	4.89	1.22
Orr et al. 2012	Fording River 22	3.10	10.28	3.32
Orr et al. 2012	Fording River 23	7.72	7.92	1.03
Orr et al. 2012	Fording River 9	4.44	6.92	1.56
Orr et al. 2012	Line Creek 8	6.61	7.99	1.21
Orr et al. 2012	Line Creek 8	7.81	7.13	0.91
Orr et al. 2012	Michel Creek 2	8.38	5.13	0.61
Orr et al. 2012	Michel Creek 2	6.69	4.63	0.69
Orr et al. 2012	Michel Creek 3	5.42	3.51	0.65
Orr et al. 2012	Michel Creek 3	6.21	4.02	0.65
Orr et al. 2012	Michel Creek 5	4.00	4.12	1.03
Orr et al. 2012	Fording River MP1	5.49	6.84	1.25
Orr et al. 2012	Barnes Lake Wetland 6	3.27	3.92	1.20
Orr et al. 2012	Clode Pond 11	32.22	41.27	1.28
Orr et al. 2012	Clode Pond 11	30.87	44.70	1.45
Orr et al. 2012	Elk Lakes 14	6.40	7.14	1.12
Orr et al. 2012	Elk Lakes 14	4.41	4.35	0.99
Orr et al. 2012	Fording River Oxbow 10	49.26	24.34	0.49
Orr et al. 2012	Fording River Oxbow 10	17.51	34.41	1.97
Orr et al. 2012	Henretta Lake 27	9.16	6.90	0.75
Orr et al. 2012	O'Rourke Lake 1	3.63	8.05	2.22
Orr et al. 2012	Harmer Pond 7	22.41	13.08	0.58

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Cutthroat trout (*Oncorhynchus clarkii*)

Study	Site	C_{invert}	C_{fish}	Ratio



Median ratio: 1.12

R^2: 0.66
F: 95.81
df: 50
P: < 0.001

Fathead minnow (*Pimephales promelas*)

Study	Site	C_{invert}	C_{fish}	Ratio
Birkner 1978	4	1.80	2.10	1.17
Birkner 1978	22	11.30	11.00	0.97
Birkner 1978	27	34.60	79.00	2.28
Birkner 1978	23	15.50	34.50	2.23
Birkner 1978	1	1.75	2.10	1.20
Butler et al. 1991	10	4.80	8.10	1.69
Butler et al. 1991	3	6.20	9.50	1.53
Butler et al. 1993	SP2	3.40	6.00	1.76
Butler et al. 1993	SP2	3.15	8.20	2.60
Butler et al. 1993	D1	1.20	3.70	3.08
Butler et al. 1993	D1	1.20	3.80	3.17
Butler et al. 1993	U1	2.45	6.40	2.61
Butler et al. 1993	R2	3.90	6.60	1.69
Butler et al. 1993	R2	3.70	6.60	1.78
Butler et al. 1993	ST2	4.50	12.80	2.84
Butler et al. 1993	ST2	4.10	7.60	1.85
Butler et al. 1993	ST2	4.10	16.00	3.90
Butler et al. 1993	R1	4.00	11.00	2.75
Butler et al. 1993	R1	4.00	11.00	2.75
Butler et al. 1993	SB2	3.75	5.70	1.52
Butler et al. 1993	SB2	3.75	8.60	2.29
Butler et al. 1993	SB2	3.65	9.90	2.71
Butler et al. 1993	WSB2	4.75	17.10	3.60
Butler et al. 1993	WSB2	3.60	4.20	1.17
Butler et al. 1993	WSB2	3.60	10.00	2.78

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Fathead minnow (*Pimephales promelas*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1993	WSB2	3.00	8.10	2.70
Butler et al. 1994	CRC	7.50	20.40	2.72
Butler et al. 1994	CF1	3.60	7.90	2.19
Butler et al. 1994	GUN2	28.00	7.50	0.27
Butler et al. 1994	IW	8.35	10.00	1.20
Butler et al. 1994	TGC	4.90	11.00	2.24
Butler et al. 1994	AD	2.70	9.60	3.56
Butler et al. 1994	LSW1	3.90	73.00	18.72
Butler et al. 1994	OMD	73.00	13.00	0.18
Butler et al. 1994	PSW1	3.70	22.00	5.95
Butler et al. 1994	MKP	32.00	51.00	1.59
Butler et al. 1995	AK	0.78	2.60	3.35
Butler et al. 1995	AK	0.78	2.90	3.74
Butler et al. 1995	AK	0.78	2.80	3.61
Butler et al. 1995	DD	0.86	3.40	3.95
Butler et al. 1995	DD	0.86	3.90	4.53
Butler et al. 1995	DD	0.86	3.60	4.19
Butler et al. 1995	HD1	0.83	3.90	4.73
Butler et al. 1995	HD1	0.83	2.50	3.03
Butler et al. 1995	HD1	0.83	2.60	3.15
Butler et al. 1995	HD2	0.98	1.50	1.53
Butler et al. 1995	HD2	0.98	1.60	1.63
Butler et al. 1995	ME1	3.40	5.60	1.65
Butler et al. 1995	ME2	1.25	4.80	3.84
Butler et al. 1995	ME4	1.55	1.40	0.90
Butler et al. 1995	ME4	1.55	5.90	3.81
Butler et al. 1995	ME3	2.55	4.30	1.69
Butler et al. 1995	ME3	2.55	5.30	2.08
Butler et al. 1995	ME3	2.55	4.40	1.73
Butler et al. 1995	SD	1.40	4.90	3.50
Butler et al. 1995	SD	1.40	3.00	2.14
Butler et al. 1995	SD	1.40	4.00	2.86
Butler et al. 1995	WC	6.75	18.40	2.73
Butler et al. 1995	WC	6.75	22.90	3.39
Butler et al. 1995	WC	6.75	26.40	3.91
Butler et al. 1995	YJ2	1.65	11.00	6.67
Butler et al. 1995	YJ2	1.65	4.00	2.42
Butler et al. 1997	MNP2	4.40	11.00	2.50
Butler et al. 1997	MUD2	3.45	7.70	2.23
Butler et al. 1997	MUD2	3.45	12.00	3.48
Butler et al. 1997	MUD2	3.45	6.50	1.88
Butler et al. 1997	WCP	9.70	10.00	1.03

NMED Exhibit 59

Fathead minnow (*Pimephales promelas*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1997	WCP	9.70	15.00	1.55
Butler et al. 1997	TR25	1.80	4.00	2.22
Butler et al. 1997	TR25	1.80	5.20	2.89
Butler et al. 1997	TR25	1.80	6.00	3.33
Butler et al. 1997	TRH	1.60	4.20	2.63
Butler et al. 1997	TRH	1.60	4.30	2.69
Butler et al. 1997	TRH	1.60	2.20	1.38
Butler et al. 1997	TRH	1.60	3.00	1.88
Butler et al. 1997	MN5	8.60	7.30	0.85
Butler et al. 1997	MNP1	0.70	1.70	2.43
Butler et al. 1997	MNP1	0.70	1.80	2.57
GEI 2013	SWA1	3.64	4.07	1.12
GEI 2013	SWA1	3.64	4.68	1.29
GEI 2013	SWA1	3.64	4.76	1.31
GEI 2013	SWA1	3.64	5.45	1.50
GEI 2013	SWA1	3.64	5.71	1.57
GEI 2013	SWA1	3.64	3.62	1.00
GEI 2013	SWA1	3.64	3.72	1.02
GEI 2013	SWA1	3.64	4.43	1.22
GEI 2013	SWA1	3.64	4.52	1.24
GEI 2013	SWA1	3.64	4.66	1.28
GEI 2013	SWA1	2.81	4.48	1.60
GEI 2013	SWA1	2.81	4.53	1.61
GEI 2013	SWA1	2.81	5.00	1.78
GEI 2013	SWA1	2.81	5.24	1.87
GEI 2013	SWA1	2.81	5.76	2.05
GEI 2013	SWA1	2.81	3.89	1.39
GEI 2013	SWA1	2.81	3.98	1.42
GEI 2013	SWA1	2.81	4.04	1.44
GEI 2013	SWA1	2.81	4.33	1.54
GEI 2013	SWA1	2.81	4.81	1.71
GEI 2013	SWB	7.06	7.38	1.05
GEI 2013	SWB	7.06	8.49	1.20
GEI 2013	SWB	7.06	8.72	1.24
GEI 2013	SWB	7.06	9.80	1.39
GEI 2013	SWB	7.06	8.61	1.22
GEI 2013	SWB	7.06	9.02	1.28
GEI 2013	SWB	7.06	9.11	1.29
GEI 2013	SWB	7.06	9.30	1.32
GEI 2013	SWB	7.06	9.53	1.35
GEI 2013	SWB	7.44	10.97	1.48
GEI 2013	SWB	7.44	11.22	1.51

NMED Exhibit 59

Fathead minnow (*Pimephales promelas*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2013	SWB	7.44	12.25	1.65
GEI 2013	SWB	7.44	12.43	1.67
GEI 2013	SWB	7.44	12.46	1.68
GEI 2013	SWB	7.44	9.36	1.26
GEI 2013	SWB	7.44	9.46	1.27
GEI 2013	SWB	7.44	9.78	1.32
GEI 2013	SWB	7.44	9.87	1.33
GEI 2013	SWB	7.44	10.66	1.43
GEI 2013	SW11	8.41	5.70	0.68
GEI 2013	SW11	8.41	7.05	0.84
GEI 2013	SW11	8.41	5.38	0.64
GEI 2013	SW11	8.41	4.68	0.56
GEI 2013	SW11	8.41	5.29	0.63
GEI 2013	SW11	8.41	5.34	0.63
GEI 2013	SW11	8.41	5.38	0.64
GEI 2013	SW2-1	6.60	12.83	1.95
GEI 2013	SW2-1	6.60	14.80	2.24
GEI 2013	SW2-1	6.60	20.13	3.05
GEI 2013	SW2-1	6.60	26.75	4.06
GEI 2013	SW2-1	6.60	30.48	4.62
GEI 2013	SW2-1	6.60	12.51	1.90
GEI 2013	SW2-1	6.60	16.70	2.53
GEI 2013	SW2-1	6.60	17.21	2.61
GEI 2013	SW2-1	6.60	18.27	2.77
GEI 2013	SW2-1	6.60	20.66	3.13
GEI 2013	SW2-1	9.14	13.31	1.46
GEI 2013	SW2-1	9.14	15.63	1.71
GEI 2013	SW2-1	9.14	15.77	1.73
GEI 2013	SW2-1	9.14	16.79	1.84
GEI 2013	SW2-1	9.14	17.00	1.86
GEI 2013	SW2-1	9.14	18.21	1.99
GEI 2013	SW2-1	9.14	19.39	2.12
GEI 2013	SW2-1	9.14	22.50	2.46
GEI 2013	SW1	7.82	9.11	1.16
GEI 2013	SW1	7.82	9.15	1.17
GEI 2013	SW1	7.82	11.15	1.43
GEI 2013	SW1	7.82	11.23	1.44
GEI 2013	SW1	7.82	13.76	1.76
GEI 2013	SW1	7.82	9.82	1.26
GEI 2013	SW1	7.82	8.45	1.08
GEI 2013	SW1	7.82	8.88	1.14
GEI 2013	SW1	7.82	9.41	1.20

NMED Exhibit 59

Fathead minnow (*Pimephales promelas*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2013	SW1	7.82	11.07	1.42
GEI 2013	SW1	6.54	7.01	1.07
GEI 2013	SW1	6.54	7.86	1.20
GEI 2013	SW1	6.54	7.98	1.22
GEI 2013	SW1	6.54	8.23	1.26
GEI 2013	SW1	6.54	8.50	1.30
GEI 2013	SW1	6.54	9.48	1.45
GEI 2013	SW1	6.54	9.95	1.52
GEI 2013	SW1	6.54	10.09	1.54
GEI 2013	SW1	6.54	10.19	1.56
GEI 2013	SW4-1	3.33	5.88	1.77
GEI 2013	SW4-1	3.33	5.89	1.77
GEI 2013	SW4-1	3.33	6.07	1.83
GEI 2013	SW4-1	3.33	6.61	1.99
GEI 2013	SW4-1	3.33	6.87	2.07
GEI 2013	SW4-1	3.33	4.85	1.46
GEI 2013	SW4-1	3.33	5.25	1.58
GEI 2013	SW4-1	3.33	5.39	1.62
GEI 2013	SW4-1	3.33	6.11	1.84
GEI 2013	SW4-1	3.33	6.67	2.01
GEI 2013	SW9	4.45	5.57	1.25
GEI 2013	SW9	4.45	5.93	1.33
GEI 2013	SW9	4.45	6.14	1.38
GEI 2013	SW9	4.45	6.20	1.39
GEI 2013	SW9	4.45	6.56	1.47
GEI 2013	SW9	4.45	7.57	1.70
GEI 2013	SW88	3.96	4.73	1.20
GEI 2013	SW88	3.96	4.96	1.25
GEI 2013	SW88	3.96	5.55	1.40
GEI 2013	SW88	3.96	5.56	1.41
GEI 2013	SW88	3.96	6.32	1.60
GEI 2013	SW88	3.96	5.13	1.30
GEI 2013	SW88	3.96	5.86	1.48
GEI 2013	SW88	3.96	6.07	1.53
GEI 2013	CC1	3.76	3.79	1.01
GEI 2013	CC1	3.76	5.23	1.39
GEI 2013	CC1	3.76	7.36	1.96
GEI 2013	CC1	3.76	8.69	2.31
GEI 2013	CC1	3.76	9.07	2.41
GEI 2013	CC1	4.69	5.92	1.26
GEI 2013	CC1	4.69	7.68	1.64
GEI 2013	CC1	4.69	7.59	1.62

NMED Exhibit 59

Fathead minnow (*Pimephales promelas*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2013	CC1	4.69	6.49	1.39
GEI 2013	CC1	4.69	7.14	1.52
GEI 2013	CC1	5.86	6.68	1.14
GEI 2013	CC1	5.86	7.73	1.32
GEI 2013	CC1	5.86	7.88	1.35
GEI 2013	CC1	5.86	8.45	1.44
GEI 2013	CC1	5.86	11.69	2.00
GEI 2013	CC1	5.86	9.21	1.57
GEI 2013	CC1	5.86	9.70	1.66
GEI 2013	LG1	3.56	4.81	1.35
GEI 2013	LG1	3.56	4.86	1.37
GEI 2013	LG1	3.56	5.05	1.42
GEI 2013	LG1	3.56	5.47	1.54
GEI 2013	LG1	3.56	5.56	1.56
GEI 2013	LG1	3.56	3.72	1.05
GEI 2013	LG1	3.56	4.09	1.15
GEI 2013	LG1	3.56	3.26	0.92
GEI 2013	LG1	3.56	3.35	0.94
GEI 2013	LG1	3.56	4.20	1.18
GEI 2013	LG1	3.39	3.60	1.06
GEI 2013	LG1	3.39	3.89	1.15
GEI 2013	LG1	3.39	4.27	1.26
GEI 2013	LG1	3.39	4.45	1.31
GEI 2013	LG1	3.39	5.18	1.53
GEI 2013	LG1	3.39	5.51	1.63
Grasso et al. 1995	17	1.91	6.59	3.45
Grasso et al. 1995	17	1.91	6.60	3.46
Grasso et al. 1995	17	1.91	7.30	3.82
Grasso et al. 1995	10	1.85	2.74	1.48
Grasso et al. 1995	10	1.85	2.79	1.51
Grasso et al. 1995	10	1.85	2.90	1.57
Lambing et al. 1994	S46	6.20	5.10	0.82
Lambing et al. 1994	S48	3.05	2.50	0.82
Lambing et al. 1994	S11	14.50	11.00	0.76
Lambing et al. 1994	S11	14.50	33.00	2.28
Lambing et al. 1994	S34	14.00	25.00	1.79
Lambing et al. 1994	S39	5.85	7.90	1.35
Lambing et al. 1994	S39	5.85	21.00	3.59
Lemly 1985	Badin Lake	5.70	1.50	0.26
Lemly 1985	Belews Lake	51.15	13.60	0.27
Lemly 1985	High Rock Lake	9.05	1.89	0.21
GEI 2014	DC-4	19.42	27.69	1.43

NMED Exhibit 59

Fathead minnow (*Pimephales promelas*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	DC-4	19.42	27.88	1.44
GEI 2014	DC-4	19.42	23.05	1.19
GEI 2014	DC-4	19.42	30.61	1.58
GEI 2014	DC-4	18.10	19.32	1.07
GEI 2014	DC-4	18.10	14.48	0.80
GEI 2014	DC-4	18.10	25.42	1.40
GEI 2014	FOC-2	2.18	4.13	1.90
GEI 2014	FOC-2	2.18	4.10	1.89
GEI 2014	FOC-2	2.18	5.50	2.53
GEI 2014	FOC-2	2.18	4.85	2.23
GEI 2014	FOC-2	2.18	4.65	2.14
GEI 2014	SC-1	5.85	7.95	1.36
GEI 2014	SC-1	5.85	7.62	1.30
GEI 2014	SC-1	5.85	7.88	1.35
GEI 2014	SC-1	5.85	8.46	1.45
GEI 2014	SC-1	5.85	7.29	1.25
GEI 2014	SC-1	5.85	8.94	1.53
GEI 2014	SC-1	5.85	8.28	1.42
GEI 2014	SC-1	5.85	8.62	1.47
GEI 2014	SC-1	5.85	6.17	1.05
GEI 2014	SC-1	5.85	6.09	1.04
GEI 2014	SC-1	5.85	9.23	1.58
GEI 2014	SC-1	5.85	10.00	1.71
GEI 2014	SC-1	5.85	8.12	1.39
GEI 2014	SC-1	5.85	6.71	1.15
GEI 2014	SC-1	5.85	8.34	1.43
GEI 2014	SC-1	4.94	10.22	2.07
GEI 2014	SC-1	4.94	10.86	2.20
GEI 2014	SC-1	4.94	9.82	1.99
GEI 2014	SC-1	4.94	9.45	1.91
GEI 2014	SC-1	4.94	10.30	2.09
GEI 2014	SC-2	14.33	15.86	1.11
GEI 2014	SC-2	14.33	15.08	1.05
GEI 2014	SC-2	14.33	13.33	0.93
GEI 2014	SC-2	14.33	12.04	0.84
GEI 2014	SC-2	14.33	13.82	0.96
GEI 2014	SC-2	11.44	9.64	0.84
GEI 2014	SC-2	11.44	14.94	1.31
GEI 2014	SC-2	11.44	10.91	0.95
GEI 2014	SC-2	11.44	16.06	1.40
GEI 2014	SC-2	11.44	14.60	1.28
GEI 2014	SC-2	12.75	13.81	1.08

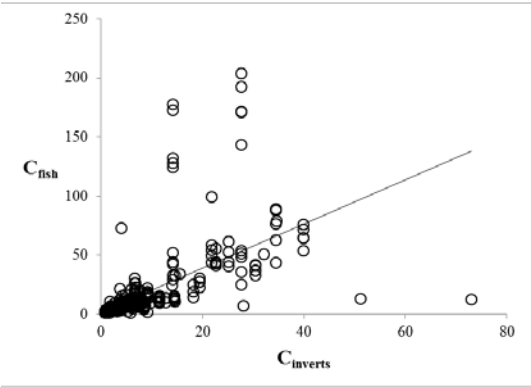
Fathead minnow (*Pimephales promelas*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	SC-2	12.75	14.10	1.11
GEI 2014	SC-2	12.75	10.68	0.84
GEI 2014	SC-3	11.41	11.65	1.02
GEI 2014	SC-3	11.41	10.95	0.96
GEI 2014	SC-3	11.41	10.84	0.95
GEI 2014	SC-3	11.41	13.48	1.18
GEI 2014	SC-3	8.58	7.70	0.90
GEI 2014	SC-3	8.58	6.46	0.75
GEI 2014	SC-3	8.58	6.97	0.81
GEI 2014	SC-3	8.58	10.64	1.24
GEI 2014	SC-3	8.58	7.85	0.91
GEI 2014	SC-3	5.75	13.75	2.39
GEI 2014	SC-3	5.75	11.19	1.95
GEI 2014	SC-3	5.75	12.68	2.20
GEI 2014	SC-4	7.39	6.33	0.86
GEI 2014	SC-4	7.39	14.39	1.95
GEI 2014	SC-4	5.18	2.72	0.53
GEI 2014	SC-4	5.18	11.95	2.31
GEI 2014	SC-4	5.18	7.98	1.54
GEI 2014	SC-4	5.18	6.75	1.30
GEI 2014	SC-6	39.87	72.33	1.81
GEI 2014	SC-6	39.87	76.00	1.91
GEI 2014	SC-6	39.87	64.73	1.62
GEI 2014	SC-6	39.87	54.09	1.36
GEI 2014	SC-6	39.87	64.64	1.62
GEI 2014	SC-6	34.35	76.89	2.24
GEI 2014	SC-6	34.35	89.67	2.61
GEI 2014	SC-6	34.35	63.32	1.84
GEI 2014	SC-6	34.35	88.44	2.57
GEI 2014	SC-6	34.35	44.15	1.29
GEI 2014	SC-6	27.54	51.65	1.88
GEI 2014	SC-6	27.54	35.92	1.30
GEI 2014	SC-6	27.54	25.55	0.93
GEI 2014	SC-6	27.54	54.25	1.97
GEI 2014	SC-6	27.54	48.94	1.78
GEI 2014	SC-6	27.54	204.26	7.42
GEI 2014	SC-6	27.54	143.62	5.22
GEI 2014	SC-6	27.54	192.93	7.01
GEI 2014	SC-6	27.54	171.89	6.24
GEI 2014	SC-6	27.54	171.36	6.22
GEI 2014	SC-8	22.62	43.12	1.91
GEI 2014	SC-8	22.62	43.36	1.92

NMED Exhibit 59

Fathead minnow (*Pimephales promelas*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	SC-8	22.62	55.81	2.47
GEI 2014	SC-8	22.62	44.60	1.97
GEI 2014	SC-8	22.62	41.67	1.84
GEI 2014	SC-9	30.36	37.18	1.22
GEI 2014	SC-9	30.36	41.32	1.36
GEI 2014	SC-9	30.36	37.20	1.23
GEI 2014	SC-9	30.36	33.25	1.10
GEI 2014	SC-9	30.36	41.94	1.38
GEI 2014	SC-8	21.77	99.40	4.57
GEI 2014	SC-8	21.77	54.47	2.50
GEI 2014	SC-8	21.77	59.07	2.71
GEI 2014	SC-8	21.77	43.70	2.01
GEI 2014	SC-8	21.77	50.18	2.31
GEI 2014	SC-9	25.06	40.82	1.63
GEI 2014	SC-9	25.06	61.80	2.47
GEI 2014	SC-9	25.06	44.74	1.79
GEI 2014	SC-9	25.06	52.97	2.11
GEI 2014	SC-8	14.15	52.46	3.71
GEI 2014	SC-8	14.15	29.43	2.08
GEI 2014	SC-8	14.15	44.58	3.15
GEI 2014	SC-8	14.15	33.44	2.36
GEI 2014	SC-8	14.15	42.86	3.03
GEI 2014	SC-8	14.15	128.33	9.07
GEI 2014	SC-8	14.15	173.33	12.25
GEI 2014	SC-8	14.15	132.34	9.35
GEI 2014	SC-8	14.15	124.90	8.83
GEI 2014	SC-8	14.15	177.97	12.58



Median ratio: 1.57

R^2: 0.35
F: 185.7
df: 344
P: < 0.001

Flannelmouth sucker (*Catostomus latipinnis*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1991	10	4.80	2.50	0.52
Butler et al. 1991	7	29.80	22.00	0.74
Butler et al. 1991	4	3.90	1.70	0.44
Butler et al. 1991	9	4.10	1.50	0.37
Butler et al. 1991	9	4.10	6.00	1.46
Butler et al. 1993	P1	1.95	1.50	0.77
Butler et al. 1993	P1	1.50	2.40	1.60
Butler et al. 1993	LP3	1.12	0.92	0.83
Butler et al. 1993	LP3	1.12	1.40	1.26
Butler et al. 1993	LP4	3.20	2.40	0.75
Butler et al. 1993	LP4	3.20	2.60	0.81
Butler et al. 1994	CRC	7.50	12.00	1.60
Butler et al. 1994	LZA1	19.00	17.00	0.89
Butler et al. 1994	BSW1	5.00	9.60	1.92
Butler et al. 1994	COL1	1.50	1.90	1.27
Butler et al. 1994	COL1	1.50	0.50	0.33
Butler et al. 1994	COL1	1.50	0.60	0.40
Butler et al. 1994	COL1	1.50	0.63	0.42
Butler et al. 1994	COL1	1.50	0.92	0.61
Butler et al. 1994	COL1	1.50	1.00	0.67
Butler et al. 1994	COL1	1.50	1.60	1.07
Butler et al. 1994	COL1	1.50	1.70	1.13
Butler et al. 1994	COL1	1.50	1.80	1.20
Butler et al. 1994	COL1	1.50	1.90	1.27
Butler et al. 1994	RB3	1.60	29.00	18.13
Butler et al. 1994	RB1	21.00	4.60	0.22
Butler et al. 1994	LSW1	3.90	6.70	1.72
Butler et al. 1994	PSW1	3.70	9.40	2.54
Butler et al. 1995	AK	0.78	1.10	1.42
Butler et al. 1995	AK	0.78	0.90	1.16
Butler et al. 1995	AK	0.78	0.82	1.06
Butler et al. 1995	AK	0.78	1.10	1.42
Butler et al. 1995	HD1	0.83	2.90	3.52
Butler et al. 1995	HD2	0.98	0.49	0.50
Butler et al. 1995	HD2	0.98	0.54	0.55
Butler et al. 1995	HD2	0.98	0.62	0.63
Butler et al. 1995	HD2	0.98	0.96	0.98
Butler et al. 1995	ME2	1.25	1.60	1.28
Butler et al. 1995	ME2	1.25	1.40	1.12
Butler et al. 1995	ME2	1.25	2.00	1.60
Butler et al. 1995	ME2	1.25	2.20	1.76
Butler et al. 1995	ME4	1.55	1.50	0.97

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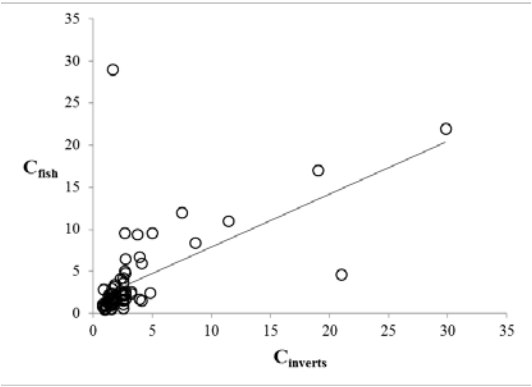
Flannelmouth sucker (*Catostomus latipinnis*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1995	ME4	1.55	1.30	0.84
Butler et al. 1995	ME4	1.55	1.90	1.23
Butler et al. 1995	ME4	1.55	2.40	1.55
Butler et al. 1995	ME4	1.55	3.00	1.94
Butler et al. 1995	ME3	2.55	1.70	0.67
Butler et al. 1995	ME3	2.55	1.70	0.67
Butler et al. 1995	ME3	2.55	2.10	0.82
Butler et al. 1995	ME3	2.55	2.40	0.94
Butler et al. 1995	ME3	2.55	3.60	1.41
Butler et al. 1995	SJ1	2.50	1.71	0.68
Butler et al. 1995	SJ1	2.50	1.50	0.60
Butler et al. 1995	SJ1	2.50	2.20	0.88
Butler et al. 1995	SJ1	2.50	0.61	0.24
Butler et al. 1995	SJ1	2.50	1.10	0.44
Butler et al. 1995	SJ1	2.50	4.20	1.68
Butler et al. 1995	YJ2	1.65	1.60	0.97
Butler et al. 1995	YJ2	1.65	2.40	1.45
Butler et al. 1995	MN1	2.70	6.50	2.41
Butler et al. 1995	MN1	2.70	1.70	0.63
Butler et al. 1995	MN1	2.70	4.80	1.78
Butler et al. 1995	MP	1.60	1.20	0.75
Butler et al. 1995	MP	1.60	1.40	0.88
Butler et al. 1997	MN3	2.70	2.30	0.85
Butler et al. 1997	MN3	2.70	2.60	0.96
Butler et al. 1997	MUD	2.30	4.10	1.78
Butler et al. 1997	MUD	2.30	2.70	1.17
Butler et al. 1997	NW2	11.40	11.00	0.96
Butler et al. 1997	MN4	2.65	5.10	1.92
Butler et al. 1997	MN4	2.65	9.60	3.62
Butler et al. 1997	MN5	8.60	8.40	0.98
Butler et al. 1997	MNQ	1.80	2.10	1.17
Butler et al. 1997	MNQ	1.80	3.20	1.78
Butler et al. 1997	MNQ	1.80	3.50	1.94

NMED Exhibit 59

Flannelmouth sucker (*Catostomus latipinnis*)

Study	Site	C_{invert}	C_{fish}	Ratio

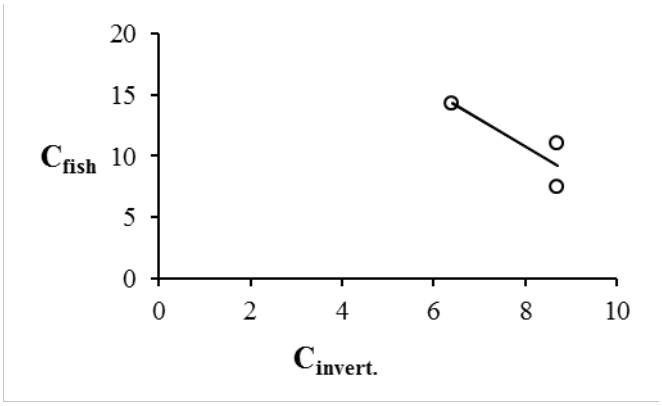


Median ratio: 0.98

R^2: 0.36
F: 41.6
df: 73
P: < 0.001

Gizzard shad (*Dorosoma cepedianum*)

Study	Site	C_{invert}	C_{fish}	Ratio
Mueller et al. 1991	R2	6.40	14.30	2.23
Mueller et al. 1991	R1	8.70	7.50	0.86
Mueller et al. 1991	R1	8.70	11.00	1.26



Median ratio: 1.26

R^2: 0.74
F: 2.78
df: 1
P: 0.39
Not used because P > 0.05 and negative slope.

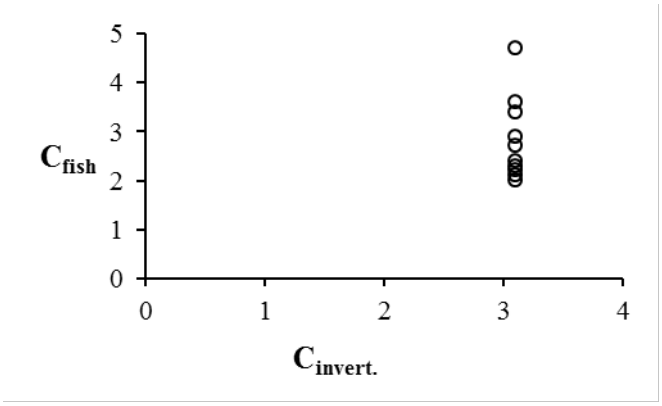
Goldeye (*Hiodon alosoides*)

Study	Site	C_{invert}	C_{fish}	Ratio
Roddy et al. 1991	18	3.10	2.00	0.65
Roddy et al. 1991	18	3.10	2.10	0.68
Roddy et al. 1991	18	3.10	2.20	0.71
Roddy et al. 1991	18	3.10	2.30	0.74
Roddy et al. 1991	18	3.10	2.40	0.77
Roddy et al. 1991	18	3.10	2.70	0.87

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Goldeye (*Hiodon alosoides*)

Study	Site	C_{invert}	C_{fish}	Ratio
Roddy et al. 1991	18	3.10	2.90	0.94
Roddy et al. 1991	18	3.10	3.40	1.10
Roddy et al. 1991	18	3.10	3.60	1.16
Roddy et al. 1991	18	3.10	4.70	1.52



Median ratio: 0.82

R^2: 0.0
F: 0.0
df: 8
P: 1.0

Not used because no slope and P>0.05.

Green sunfish (*Lepomis cyanellus*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1991	10	4.80	7.90	1.65
Butler et al. 1991	7	29.80	15.20	0.51
Butler et al. 1991	7	29.80	25.10	0.84
Butler et al. 1991	3	6.20	6.40	1.03
Butler et al. 1994	LZA1	19.00	37.00	1.95
Butler et al. 1995	HD1	0.83	1.30	1.58
Butler et al. 1995	HD1	0.83	1.30	1.58
Butler et al. 1995	ME3	2.55	5.00	1.96
Butler et al. 1995	MP	1.60	1.90	1.19
Butler et al. 1997	CH1	7.50	9.50	1.27
Butler et al. 1997	MUD2	3.45	7.60	2.20
Butler et al. 1997	MUD2	3.45	7.00	2.03
Butler et al. 1997	TR25	1.80	4.40	2.44
Butler et al. 1997	TRH	1.60	3.30	2.06
GEI 2013	SWA1	2.81	2.96	1.06
GEI 2013	SWA1	2.81	3.21	1.14
GEI 2013	SWA1	2.81	3.24	1.16
GEI 2013	SWA1	2.81	3.69	1.32
GEI 2013	SWA1	2.81	3.88	1.38
GEI 2013	SWB	7.44	11.94	1.61
GEI 2013	SW11	8.41	4.54	0.54

Green sunfish (*Lepomis cyanellus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2013	SW11	8.41	4.84	0.58
GEI 2013	SW11	8.41	5.34	0.63
GEI 2013	SW11	8.41	7.00	0.83
GEI 2013	SW11	8.41	7.13	0.85
GEI 2013	SW9	4.45	4.38	0.98
GEI 2013	SW9	4.45	5.06	1.14
GEI 2013	SW9	4.45	5.53	1.24
GEI 2013	SW9	4.45	5.80	1.30
GEI 2013	SW9	4.45	7.29	1.64
GEI 2013	SW88	3.96	7.14	1.81
GEI 2013	SW88	3.96	7.41	1.87
GEI 2013	LG1	3.39	4.11	1.21
GEI 2013	LG1	3.39	4.33	1.28
GEI 2013	LG1	3.39	5.71	1.68
Roddy et al. 1991	18	3.10	2.80	0.90
Roddy et al. 1991	18	3.10	3.80	1.23
Roddy et al. 1991	18	3.10	4.00	1.29
Roddy et al. 1991	18	3.10	5.20	1.68
Roddy et al. 1991	18	3.10	5.70	1.84
Lemly 1985	Badin Lake	5.70	2.18	0.38
Lemly 1985	Belews Lake	51.15	13.99	0.27
Lemly 1985	High Rock Lake	9.05	2.10	0.23
GEI 2014	C-BCR2	6.81	9.47	1.39
GEI 2014	C-BCR2	6.81	9.29	1.37
GEI 2014	C-BCR2	6.81	8.04	1.18
GEI 2014	C-CC1	4.40	7.23	1.64
GEI 2014	C-CC1	4.40	11.76	2.67
GEI 2014	C-CC2	5.56	4.59	0.83
GEI 2014	C-CC2	5.56	3.04	0.55
GEI 2014	C-CC2	5.56	5.34	0.96
GEI 2014	C-CF1	3.39	3.62	1.07
GEI 2014	C-CF1	3.39	2.95	0.87
GEI 2014	C-CF1	3.39	3.23	0.95
GEI 2014	C-CF1	3.39	5.55	1.64
GEI 2014	C-CLF1	9.30	3.99	0.43
GEI 2014	C-CLF1	9.30	5.23	0.56
GEI 2014	C-CLF1	9.30	4.75	0.51
GEI 2014	C-CLF1	9.30	4.87	0.52
GEI 2014	C-CLF1	9.30	3.58	0.39
GEI 2014	C-CLF2	6.85	5.76	0.84
GEI 2014	C-CLF2	6.85	5.89	0.86
GEI 2014	C-CLF2	6.85	4.78	0.70

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Green sunfish (*Lepomis cyanellus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	C-CLF2	6.85	5.11	0.75
GEI 2014	C-CLF2	6.85	4.10	0.60
GEI 2014	C-LFWOC1	9.32	10.10	1.08
GEI 2014	C-TF1	20.00	4.15	0.21
GEI 2014	C-TF1	20.00	3.47	0.17
GEI 2014	C-TF1	20.00	4.14	0.21
GEI 2014	C-TF1	20.00	4.11	0.21
GEI 2014	C-TF1	20.00	3.41	0.17
GEI 2014	C-WOC1	6.65	12.05	1.81
GEI 2014	C-WOC1	6.65	9.60	1.44
GEI 2014	C-WOC1	6.65	8.66	1.30
GEI 2014	C-WOC1	6.65	5.81	0.87
GEI 2014	C-WOC1	6.65	7.54	1.13
GEI 2014	H-BB1	16.29	9.55	0.59
GEI 2014	H-BB1	16.29	18.27	1.12
GEI 2014	H-BB1	16.29	7.08	0.43
GEI 2014	H-BHC1	5.08	3.69	0.73
GEI 2014	H-BHC1	5.08	2.48	0.49
GEI 2014	H-BHC1	5.08	3.29	0.65
GEI 2014	H-BHC1	5.08	3.49	0.69
GEI 2014	H-BHC1	5.08	3.70	0.73
GEI 2014	H-JSB1	4.03	4.83	1.20
GEI 2014	H-JSB1	4.03	2.57	0.64
GEI 2014	H-JSB1	4.03	3.73	0.93
GEI 2014	H-LF1	9.09	3.12	0.34
GEI 2014	H-LF1	9.09	5.96	0.66
GEI 2014	H-LF1	9.09	4.30	0.47
GEI 2014	H-LF1	9.09	4.02	0.44
GEI 2014	H-LF1	9.09	5.29	0.58
GEI 2014	H-MR2	2.14	9.57	4.47
GEI 2014	H-MR2	2.14	5.55	2.59
GEI 2014	H-MR2	2.14	5.80	2.71
GEI 2014	H-MR2	2.14	5.55	2.59
GEI 2014	H-MR2	2.14	6.88	3.22
GEI 2014	H-MR3	3.86	8.09	2.10
GEI 2014	H-MR3	3.86	16.98	4.40
GEI 2014	H-MR3	3.86	6.80	1.76
GEI 2014	H-MR3	3.86	8.52	2.21
GEI 2014	H-MR3	3.86	6.62	1.72
GEI 2014	H-MR4	9.26	9.01	0.97
GEI 2014	H-MR4	9.26	8.78	0.95
GEI 2014	H-MR4	9.26	18.33	1.98

NMED Exhibit 59

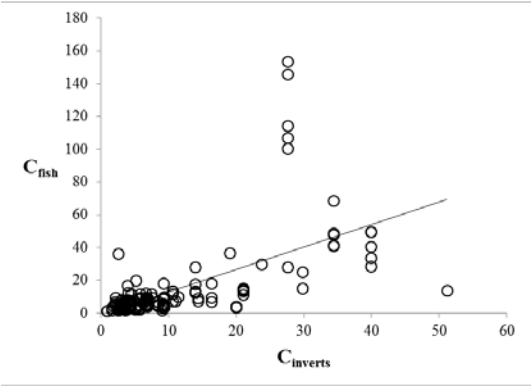
Green sunfish (*Lepomis cyanellus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	H-MR4	9.26	9.84	1.06
GEI 2014	H-MR4	9.26	5.94	0.64
GEI 2014	H-MR5	3.58	5.50	1.54
GEI 2014	H-MR5	3.58	3.52	0.98
GEI 2014	H-MR5	3.58	2.41	0.67
GEI 2014	H-MR5	3.58	3.09	0.86
GEI 2014	H-MR5	3.58	1.94	0.54
GEI 2014	H-MR6	2.49	36.20	14.54
GEI 2014	H-MR6	2.49	2.58	1.04
GEI 2014	H-MR6	2.49	1.94	0.78
GEI 2014	H-MR6	2.49	1.74	0.70
GEI 2014	H-MR6	2.49	2.69	1.08
GEI 2014	H-SB1	10.62	11.90	1.12
GEI 2014	H-SB1	10.62	13.39	1.26
GEI 2014	H-SB1	10.62	7.64	0.72
GEI 2014	H-SB1	10.62	13.45	1.27
GEI 2014	H-SF1	21.05	13.59	0.65
GEI 2014	H-SF1	21.05	14.22	0.68
GEI 2014	H-SF1	21.05	15.27	0.73
GEI 2014	H-SF1	21.05	14.58	0.69
GEI 2014	H-SF1	21.05	11.25	0.53
GEI 2014	H-SF2	13.95	17.74	1.27
GEI 2014	H-SF2	13.95	12.86	0.92
GEI 2014	H-SF2	13.95	12.76	0.91
GEI 2014	H-SF2	13.95	13.41	0.96
GEI 2014	H-SF2	13.95	28.23	2.02
GEI 2014	H-UB1	3.02	4.43	1.47
GEI 2014	H-UB1	3.02	4.91	1.63
GEI 2014	H-UB1	3.02	3.73	1.23
GEI 2014	H-UB1	3.02	8.00	2.65
GEI 2014	H-UB1	3.02	8.36	2.77
GEI 2014	SC-1-25	4.00	12.78	3.19
GEI 2014	SC-2	14.33	9.31	0.65
GEI 2014	SC-2	14.33	7.59	0.53
GEI 2014	SC-2	11.44	10.23	0.89
GEI 2014	SC-2-27	23.76	30.00	1.26
GEI 2014	SC-3	5.75	8.66	1.51
GEI 2014	SC-3	5.75	11.72	2.04
GEI 2014	SC-3	5.75	9.59	1.67
GEI 2014	SC-4	5.18	19.86	3.83
GEI 2014	SC-6	39.87	49.55	1.24
GEI 2014	SC-6	39.87	49.56	1.24

NMED Exhibit 59

Green sunfish (*Lepomis cyanellus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	SC-6	39.87	33.71	0.85
GEI 2014	SC-6	39.87	28.73	0.72
GEI 2014	SC-6	39.87	40.64	1.02
GEI 2014	SC-6	34.35	41.51	1.21
GEI 2014	SC-6	34.35	48.02	1.40
GEI 2014	SC-6	34.35	68.66	2.00
GEI 2014	SC-6	34.35	41.27	1.20
GEI 2014	SC-6	34.35	48.76	1.42
GEI 2014	SC-6	27.54	28.17	1.02
GEI 2014	SC-6	27.54	106.88	3.88
GEI 2014	SC-6	27.54	114.55	4.16
GEI 2014	SC-6	27.54	100.41	3.65
GEI 2014	SC-6	27.54	153.64	5.58
GEI 2014	SC-6	27.54	145.62	5.29
GEI 2014	S-SC1	11.01	7.47	0.68



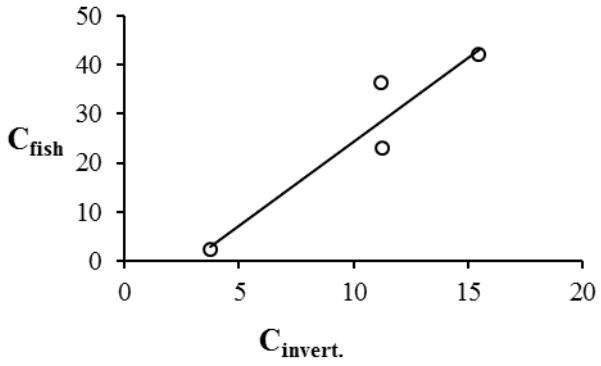
Median ratio: 1.12

R^2: 0.37
F: 93.17
df: 160
P: < 0.001

Iowa darter (*Etheostoma exile*)

Study	Site	C_{invert}	C_{fish}	Ratio
Birkner 1978	7	3.75	2.10	0.56
Birkner 1978	20	11.20	36.30	3.24
Birkner 1978	22	11.30	23.00	2.04
Birkner 1978	23	15.50	41.90	2.70

Iowa darter (*Etheostoma exile*)



Median ratio: 2.37

R^2: 0.90
F: 17.3
df: 2
P: 0.055
Not used because P > 0.05

Largemouth bass (*Micropterus salmoides*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1995	MP	1.60	1.40	0.88
Garcia-Hernandez et al. 2000	Cienega de Santa Clara Wetland	3.00	5.10	1.70
GEI 2013	SWA1	2.81	3.17	1.13
GEI 2013	SW11	8.41	5.02	0.60
GEI 2013	SW11	8.41	5.77	0.69
GEI 2013	SW11	8.41	5.19	0.62
GEI 2013	SW11	8.41	6.26	0.74
GEI 2013	SW11	8.41	6.48	0.77
GEI 2013	SW11	8.41	7.22	0.86
GEI 2013	SW4-1	3.33	5.53	1.66
GEI 2013	SW4-1	3.33	5.65	1.70
GEI 2013	SW4-1	3.33	5.72	1.72
GEI 2013	SW4-1	3.33	5.80	1.74
GEI 2013	SW4-1	3.33	6.34	1.91
GEI 2013	SW4-1	3.33	7.14	2.15
GEI 2013	SW9	4.45	5.78	1.30
GEI 2013	SW9	4.45	5.79	1.30
GEI 2013	SW9	4.45	6.19	1.39
GEI 2013	SW9	4.45	6.87	1.54
GEI 2013	SW9	4.45	7.27	1.63
GEI 2013	SW9	4.45	7.36	1.65
GEI 2013	SW88	3.96	4.87	1.23
GEI 2013	SW88	3.96	5.73	1.45
GEI 2013	SW88	3.96	5.77	1.46
GEI 2013	SW88	3.96	5.93	1.50
GEI 2013	SW88	3.96	6.62	1.67
GEI 2013	SW88	3.96	6.84	1.73

NMED Exhibit 59

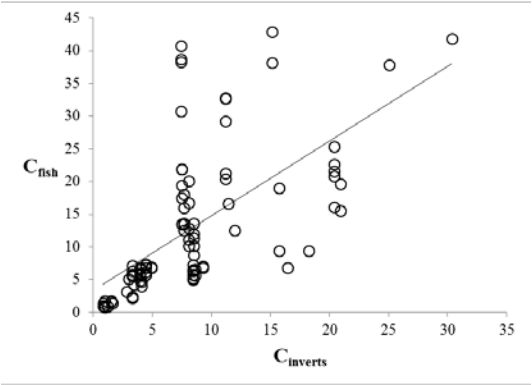
Largemouth bass (*Micropterus salmoides*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2013	LG1	3.39	4.29	1.27
Saiki et al. 1993	ET6	0.85	1.00	1.18
Saiki et al. 1993	ET6	0.85	1.40	1.66
Saiki et al. 1993	GT5	4.90	6.80	1.39
Saiki et al. 1993	GT5	4.90	6.90	1.41
Saiki et al. 1993	GT4	4.05	4.70	1.16
Saiki et al. 1993	GT4	4.05	4.00	0.99
Saiki et al. 1993	SJR2	3.30	2.20	0.67
Saiki et al. 1993	SJR2	3.30	2.40	0.73
Saiki et al. 1993	SJR3	1.50	1.80	1.20
Saiki et al. 1993	SJR3	1.50	1.70	1.13
Saiki et al. 1993	SJR1	0.95	0.80	0.85
Saiki et al. 1993	SJR1	0.95	1.80	1.90
Saiki et al. 1993	ET7	0.86	0.86	1.00
Saiki et al. 1993	ET7	0.86	1.00	1.16
Rinella and Schuler 1992	S. Malheur Lake	1.20	0.92	0.77
Crutchfield 2000	transect 3	11.95	12.52	1.05
Crutchfield 2000	transect 3	11.40	16.67	1.46
Crutchfield 2000	transect 3	9.25	6.83	0.74
Crutchfield 2000	transect 3	9.25	6.99	0.76
Crutchfield 2000	transect 3	8.60	6.59	0.77
Crutchfield 2000	transect 3	8.60	5.69	0.66
Crutchfield 2000	transect 4	20.90	15.53	0.74
Crutchfield 2000	transect 4	20.90	19.68	0.94
Crutchfield 2000	transect 4	15.70	18.95	1.21
Crutchfield 2000	transect 4	15.70	9.43	0.60
Crutchfield 2000	transect 4	16.45	6.83	0.42
Crutchfield 2000	transect 4	18.25	9.43	0.52
GEI 2014	ARB	11.21	20.41	1.82
GEI 2014	ARB	11.21	32.75	2.92
GEI 2014	ARB	11.21	32.73	2.92
GEI 2014	ARB	11.21	29.23	2.61
GEI 2014	ARB	11.21	21.26	1.90
GEI 2014	ARE	20.40	25.35	1.24
GEI 2014	ARE	20.40	20.80	1.02
GEI 2014	ARE	20.40	22.67	1.11
GEI 2014	ARE	20.40	21.57	1.06
GEI 2014	ARE	20.40	16.05	0.79
GEI 2014	ARM	8.51	13.62	1.60
GEI 2014	ARM	8.51	10.13	1.19
GEI 2014	ARM	8.51	12.00	1.41
GEI 2014	ARM	8.51	11.40	1.34

NMED Exhibit 59

Largemouth bass (*Micropterus salmoides*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	ARM	8.51	8.71	1.02
GEI 2014	ARM	7.68	12.52	1.63
GEI 2014	ARM	7.68	13.59	1.77
GEI 2014	ARM	7.68	17.99	2.34
GEI 2014	ARM	7.68	13.49	1.76
GEI 2014	ARM	7.68	15.98	2.08
GEI 2014	ARN	8.06	11.16	1.39
GEI 2014	ARN	8.06	12.89	1.60
GEI 2014	ARN	8.06	16.74	2.08
GEI 2014	ARN	8.06	10.12	1.26
GEI 2014	ARN	8.06	20.08	2.49
GEI 2014	ARN	7.49	17.47	2.33
GEI 2014	ARN	7.49	13.48	1.80
GEI 2014	ARN	7.49	19.44	2.60
GEI 2014	ARN	7.49	21.87	2.92
GEI 2014	ARN	7.49	21.91	2.92
GEI 2014	ARN	7.44	30.73	4.13
GEI 2014	ARN	7.44	40.71	5.47
GEI 2014	ARN	7.44	38.75	5.21
GEI 2014	ARN	7.44	38.24	5.14
GEI 2014	SC-5	15.13	38.13	2.52
GEI 2014	SC-5	15.13	42.86	2.83
GEI 2014	SC-9	30.36	41.87	1.38
GEI 2014	SC-9	25.06	37.84	1.51

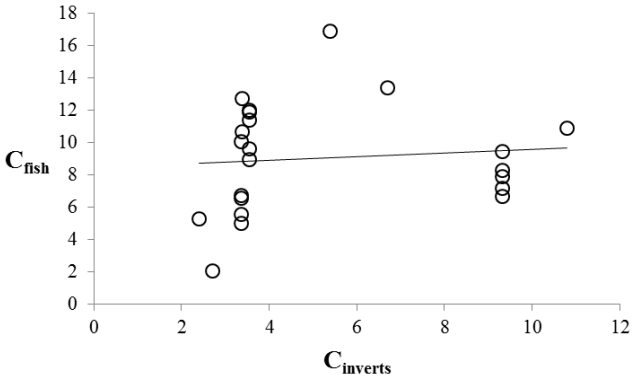


Median ratio: 1.39

R^2: 0.40
F: 61.45
df: 91
P: < 0.001

Longnose dace (*Rhinichthys cataractae*)

Study	Site	C_{invert}	C_{fish}	Ratio
Lambing et al. 1994	S33	2.40	5.30	2.21
Mueller et al. 1991	A1	2.70	2.10	0.78
GEI 2013	LG1	3.37	5.05	1.50
GEI 2013	LG1	3.37	5.57	1.65
GEI 2013	LG1	3.37	6.57	1.95
GEI 2013	LG1	3.37	6.75	2.00
GEI 2013	LG1	3.37	10.08	2.99
GEI 2013	LG1	3.39	10.69	3.15
GEI 2013	LG1	3.39	12.77	3.77
GEI 2013	LG1	3.56	8.95	2.52
GEI 2013	LG1	3.56	9.63	2.71
GEI 2013	LG1	3.56	11.41	3.21
GEI 2013	LG1	3.56	11.94	3.36
GEI 2013	LG1	3.56	12.04	3.39
GEI 2014	Left Fork White Oak Creek, C-LFWOC1	9.32	8.32	0.89
GEI 2014	Left Fork White Oak Creek, C-LFWOC1	9.32	9.47	1.02
GEI 2014	Left Fork White Oak Creek, C-LFWOC1	9.32	7.94	0.85
GEI 2014	Left Fork White Oak Creek, C-LFWOC1	9.32	6.67	0.72
GEI 2014	Left Fork White Oak Creek, C-LFWOC1	9.32	7.19	0.77
Mueller et al. 1991	T1	5.40	16.90	3.13
Hamilton and Buhl 2005	CC	6.70	13.40	2.00
Hamilton and Buhl 2005	BGS	10.80	10.90	1.01

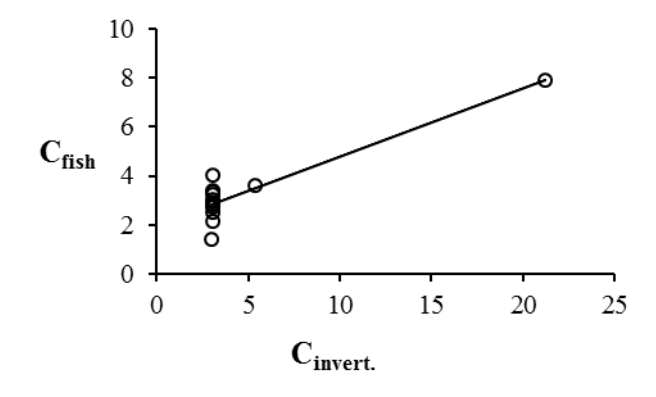


Median ratio: 2.00

R^2: 0.01
F: 0.19
df: 20
P: 0.83
Not used because P > 0.05

Longnose sucker (*Catostomus catostomus*)

Study	Site	C_{invert}	C_{fish}	Ratio
Minnow 2007	FL17	3.03	1.40	0.46
Butler et al. 1994	NFK2	3.10	2.10	0.68
Butler et al. 1994	NFK2	3.10	2.50	0.81
Butler et al. 1994	NFK2	3.10	2.70	0.87
Butler et al. 1994	NFK2	3.10	2.80	0.90
Butler et al. 1994	NFK2	3.10	2.90	0.94
Butler et al. 1994	NFK2	3.10	3.00	0.97
Butler et al. 1994	NFK2	3.10	3.20	1.03
Butler et al. 1994	NFK2	3.10	3.30	1.06
Butler et al. 1994	NFK2	3.10	3.40	1.10
Butler et al. 1994	NFK2	3.10	4.00	1.29
Mueller et al. 1991	T1	5.40	3.60	0.67
Minnow 2007	FL17	21.22	7.90	0.37



Median ratio: 0.90

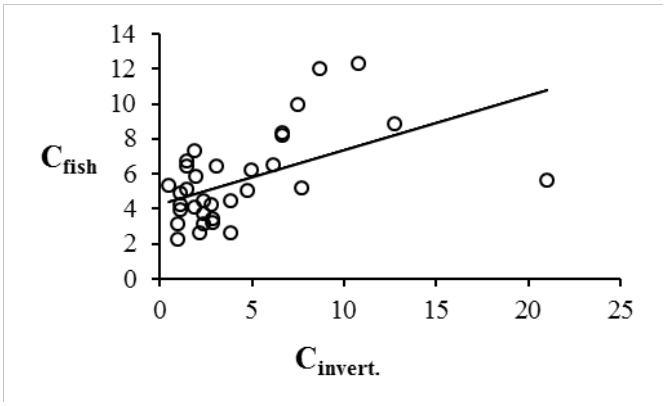
R^2: 0.83
F: 54.66
df: 11
P: <0.001

Mottled sculpin (*Cottus bairdii*)

Study	Site	C_{invert}	C_{fish}	Ratio
Hamilton and Buhl 2004	USC	0.50	5.30	10.60
Butler et al. 1993	LP2	1.00	2.20	2.20
Butler et al. 1993	LP2	1.00	3.10	3.10
Butler et al. 1993	LP3	1.12	3.90	3.50
Butler et al. 1993	LP3	1.12	4.20	3.77
Butler et al. 1993	LP3	1.12	4.90	4.39
Butler et al. 1993	P1	1.50	5.10	3.40
Butler et al. 1993	P1	1.50	6.40	4.27
Butler et al. 1993	P1	1.50	6.70	4.47
Hamilton and Buhl 2004	ShpC	1.90	4.10	2.16
Butler et al. 1993	P1	1.95	7.30	3.74
Butler et al. 1994	NFK3	2.00	5.80	2.90

Mottled sculpin (*Cottus bairdii*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1997	MN2	2.20	2.60	1.18
Butler et al. 1997	CHK	2.40	3.10	1.29
Butler et al. 1997	CHK	2.40	4.40	1.83
Lambing et al. 1994	S33	2.40	3.70	1.54
Butler et al. 1991	12	2.80	4.20	1.50
Butler et al. 1997	MN1	2.90	3.20	1.10
Butler et al. 1997	MN1	2.90	3.40	1.17
Butler et al. 1994	NFK2	3.10	6.40	2.06
Butler et al. 1991	4	3.90	2.60	0.67
Butler et al. 1991	4	3.90	4.40	1.13
Butler et al. 1991	10	4.80	5.00	1.04
Hamilton and Buhl 2005	UAC	5.00	6.20	1.24
Butler et al. 1991	3	6.20	6.50	1.05
Hamilton and Buhl 2004	ACM	6.70	8.30	1.24
Hamilton and Buhl 2005	CC	6.70	8.20	1.22
Butler et al. 1993	F2	7.50	9.90	1.32
Hamilton and Buhl 2004	LBR	7.70	5.20	0.68
Hamilton and Buhl 2005	DC	8.70	12.00	1.38
Hamilton and Buhl 2005	BGS	10.80	12.30	1.14
Hamilton and Buhl 2004	DVC	12.80	8.80	0.69
Butler et al. 1994	HCC1	21.00	5.60	0.27



Median ratio: 1.38

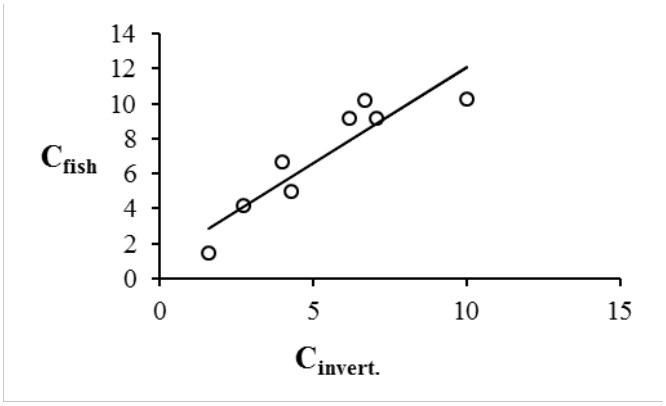
R^2: 0.27
F: 11.62
df: 31
P: < 0.001

Mountain whitefish (*Prosopium williamsoni*)

Study	Site	C_{invert}	C_{fish}	Ratio
Low and Mullins 1990	7	1.60	1.40	0.88
McDonald and Strosher 1998	ER 745	2.74	4.17	1.52
Minnow 2007	EL12	4.01	6.60	1.65
McDonald and Strosher 1998	ER 747	4.29	4.93	1.15

Mountain whitefish (*Prosopium williamsoni*)

Study	Site	C_{invert}	C_{fish}	Ratio
Minnow 2007	MI3	6.21	9.12	1.47
Minnow 2007	MI2	6.69	10.16	1.52
Minnow 2007	EL1	7.08	9.12	1.29
Minnow 2007	FO23	10.00	10.20	1.02



Median ratio: 1.38

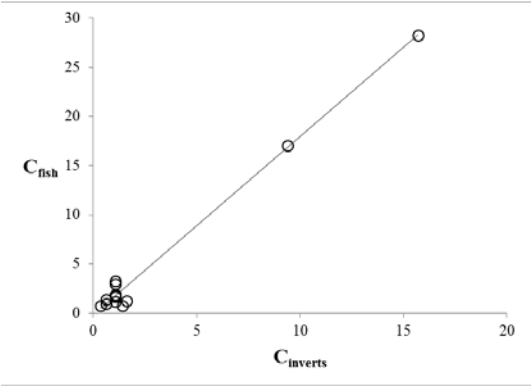
R^2: 0.83
F: 30.27
df: 6
P: <0.001

Northern pike (*Esox lucius*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1995	TT	1.07	2.96	2.78
Butler et al. 1995	TT	1.07	3.24	3.04
Butler et al. 1995	TT	1.07	1.65	1.55
Butler et al. 1995	TT	1.07	1.18	1.11
Butler et al. 1995	TT	1.07	1.90	1.78
Butler et al. 1995	TT	1.07	1.80	1.69
Butler et al. 1995	PU	0.61	0.93	1.52
Butler et al. 1995	PU	0.61	1.40	2.30
Muscatello et al. 2008	David Lake	1.39	0.78	0.56
Muscatello et al. 2008	Delta Lake	9.38	17.02	1.81
Muscatello et al. 2008	Unknown Lake	15.71	28.28	1.80
Muscatello and Janz 2009	Indigo Lake	0.36	0.75	2.08
Muscatello and Janz 2009	Vulture Lake	1.62	1.26	0.78

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Northern pike (*Esox lucius*)

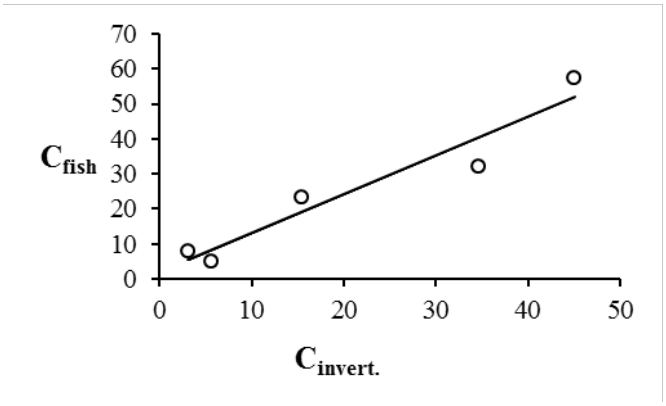


Median ratio: 1.78

R^2: 0.99
F: 982.9
df: 11
P: <0.001

Northern plains killfish (*Fundulus kansae*)

Study	Site	C_{invert}	C_{fish}	Ratio
Birkner 1978	3	3.10	7.70	2.48
Birkner 1978	11	5.65	5.00	0.88
Birkner 1978	23	15.50	23.10	1.49
Birkner 1978	27	34.60	31.90	0.92
Birkner 1978	30	45.05	57.40	1.27



Median ratio: 1.27

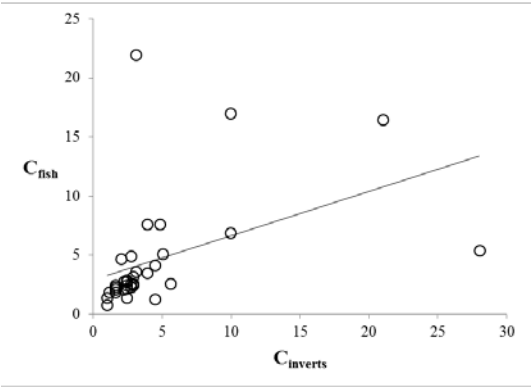
R^2: 0.93
F: 37.8
df: 3
P: 0.008

Rainbow trout (*Oncorhynchus mykiss*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1991	4	3.90	3.50	0.90
Butler et al. 1993	F2	4.80	7.60	1.58
Butler et al. 1993	F2	3.90	7.60	1.95
Butler et al. 1993	LP2	1.00	0.78	0.78
Butler et al. 1993	LP2	1.00	1.40	1.40
Butler et al. 1993	LP3	1.12	1.90	1.70
Butler et al. 1994	GUN2	28.00	5.40	0.19
Butler et al. 1994	HCC1	21.00	16.48	0.78
Butler et al. 1994	NFK3	2.00	4.70	2.35
Butler et al. 1994	NFK2	3.10	21.98	7.09
Butler et al. 1994	NFK2	3.10	3.60	1.16
Butler et al. 1995	MP	1.60	1.88	1.18
Butler et al. 1995	MP	1.60	2.30	1.44
Butler et al. 1995	MP	1.60	2.50	1.56
Butler et al. 1995	MP	1.60	2.10	1.31
Butler et al. 1997	CHK	2.40	1.41	0.59
Butler et al. 1997	CHK	2.40	2.20	0.92
Butler et al. 1997	CHK	2.40	2.50	1.04
Butler et al. 1997	CHK	2.40	2.80	1.17
Butler et al. 1997	CHK	2.40	2.90	1.21
Butler et al. 1997	MN3	2.70	2.28	0.84
Butler et al. 1997	MN3	2.70	2.60	0.96
Butler et al. 1997	MN3	2.70	4.90	1.81
Butler et al. 1997	MN2	2.20	2.10	0.95
Butler et al. 1997	MN2	2.20	2.80	1.27
Butler et al. 1997	MN1	2.90	2.50	0.86
Butler et al. 1997	MN1	2.90	2.60	0.90
Butler et al. 1997	MN1	2.90	3.20	1.10
Butler et al. 1997	WBR	5.05	5.10	1.01
Low and Mullins 1990	5	5.60	2.60	0.46
Casey 2005	Deerlick Creek	4.45	1.29	0.29
Casey 2005	Deerlick Creek	4.45	4.15	0.93
Casey 2005	Luscar Creek	9.95	6.88	0.69
Casey 2005	Luscar Creek	9.95	17.04	1.71

NMED Exhibit 59

Rainbow trout (*Oncorhynchus mykiss*)



Median ratio: 1.07

R^2: 0.19
F: 7.52
df: 32
P: 0.002

Red shiner (*Cyprinella lutrensis*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1991	3	6.20	7.70	1.24
Butler et al. 1994	IW	8.35	83.00	9.94
Butler et al. 1994	AD	2.70	7.30	2.70
Butler et al. 1994	LW	3.00	19.00	6.33
Butler et al. 1994	LSW1	3.90	14.00	3.59
Butler et al. 1995	ME4	1.55	5.10	3.29
Butler et al. 1995	ME3	2.55	4.60	1.80
Butler et al. 1995	ME3	2.55	4.20	1.65
Butler et al. 1995	SJ1	2.50	3.50	1.40
Butler et al. 1995	YJ2	1.65	4.50	2.73
Butler et al. 1997	MN4	2.65	4.20	1.58
Butler et al. 1997	MN5	8.60	4.40	0.51
May et al. 2008	KR	17.20	7.03	0.41
May et al. 2008	NSCL	10.70	7.36	0.69
May et al. 2008	NSCU	10.50	7.24	0.69
May et al. 2008	NSK	8.81	5.81	0.66
May et al. 2008	NSP	24.00	8.62	0.36
May et al. 2008	SSAL	11.50	9.00	0.78
May et al. 2008	SSAU	8.35	11.20	1.34
May et al. 2008	SSO	10.00	7.16	0.72
May et al. 2008	SSW	7.60	10.00	1.32
Mueller et al. 1991	A3	6.00	8.10	1.35
Mueller et al. 1991	A2	8.50	7.90	0.93
Lemly 1985	Badin Lake	5.70	2.10	0.37
Lemly 1985	Belews Lake	51.15	18.25	0.36
Lemly 1985	High Rock Lake	9.05	2.18	0.24
GEI 2014	ARE	20.40	49.84	2.44

NMED Exhibit 59

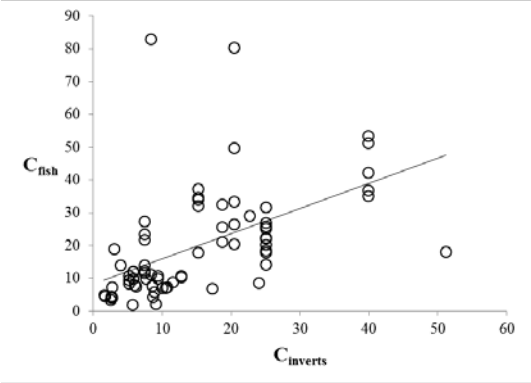
Red shiner (*Cyprinella lutrensis*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	ARE	20.40	80.50	3.95
GEI 2014	ARE	20.40	20.57	1.01
GEI 2014	ARE	20.40	33.37	1.64
GEI 2014	ARE	20.40	26.50	1.30
GEI 2014	ARN	7.44	27.50	3.70
GEI 2014	ARN	7.44	23.58	3.17
GEI 2014	ARN	7.44	21.74	2.92
GEI 2014	FC-4	18.65	21.20	1.14
GEI 2014	FC-4	18.65	32.68	1.75
GEI 2014	FC-4	18.65	25.73	1.38
GEI 2014	GC-1	9.33	10.78	1.16
GEI 2014	GC-1	9.33	9.97	1.07
GEI 2014	SC-2	12.75	10.44	0.82
GEI 2014	SC-2	12.75	10.87	0.85
GEI 2014	SC-3	5.75	12.05	2.10
GEI 2014	SC-3	5.75	12.17	2.12
GEI 2014	SC-3	5.75	9.93	1.73
GEI 2014	SC-3	5.75	9.93	1.73
GEI 2014	SC-4	7.39	12.26	1.66
GEI 2014	SC-4	7.39	11.68	1.58
GEI 2014	SC-4	7.39	14.15	1.92
GEI 2014	SC-4	5.18	9.58	1.85
GEI 2014	SC-4	5.18	8.43	1.63
GEI 2014	SC-4	5.18	10.83	2.09
GEI 2014	SC-5	15.13	17.96	1.19
GEI 2014	SC-5	15.13	34.71	2.29
GEI 2014	SC-5	15.13	34.05	2.25
GEI 2014	SC-5	15.13	37.28	2.46
GEI 2014	SC-5	15.13	32.18	2.13
GEI 2014	SC-6	39.87	53.60	1.34
GEI 2014	SC-6	39.87	37.00	0.93
GEI 2014	SC-6	39.87	35.11	0.88
GEI 2014	SC-6	39.87	51.39	1.29
GEI 2014	SC-6	39.87	42.31	1.06
GEI 2014	SC-8	22.62	29.20	1.29
GEI 2014	SC-9	25.06	22.55	0.90
GEI 2014	SC-9	25.06	18.02	0.72
GEI 2014	SC-9	25.06	25.94	1.04
GEI 2014	SC-9	25.06	18.68	0.75
GEI 2014	SC-9	25.06	14.28	0.57
GEI 2014	SC-9	25.06	31.67	1.26
GEI 2014	SC-9	25.06	20.43	0.82

NMED Exhibit 59

Red shiner (*Cyprinella lutrensis*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	SC-9	25.06	22.27	0.89
GEI 2014	SC-9	25.06	27.05	1.08
GEI 2014	SC-9	25.06	25.28	1.01



Median ratio: 1.31

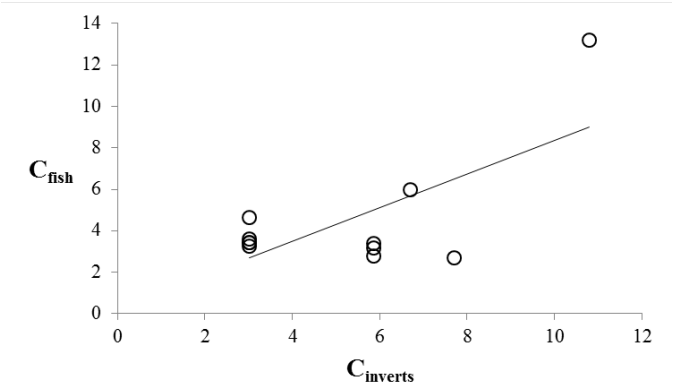
R^2: 0.28
F: 26.57
df: 70
P: <0.001

Redside shiner (*Richardsonius balteatus*)

Study	Site	C_{invert}	C_{fish}	Ratio
Hamilton and Buhl 2004	ACM	6.70	6.00	0.90
Hamilton and Buhl 2004	LBR	7.70	2.70	0.35
Hamilton and Buhl 2005	BGS	10.80	13.20	1.22
GEI 2014	Bond Creek, BC-3	3.02	3.58	1.19
GEI 2014	Bond Creek, BC-3	3.02	3.44	1.14
GEI 2014	Bond Creek, BC-3	3.02	3.44	1.14
GEI 2014	Bond Creek, BC-3	3.02	4.64	1.54
GEI 2014	Bond Creek, BC-3	3.02	3.26	1.08
GEI 2014	Bond Creek, BC-3	5.87	3.18	0.54
GEI 2014	Bond Creek, BC-3	5.87	3.37	0.57
GEI 2014	Bond Creek, BC-3	5.87	2.79	0.47
GEI 2014	Bond Creek, BC-3	3.02	3.58	1.19

NMED Exhibit 59

Redside shiner (*Richardsonius balteatus*)



Median ratio: 1.08

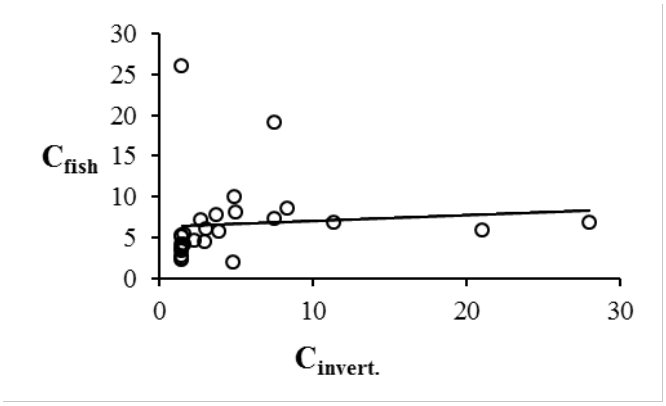
R^2: 0.47
F: 7.84
df: 9
P: 0.011

Roundtail chub (*Gila robusta*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1994	COL1	1.50	2.20	1.47
Butler et al. 1994	COL1	1.50	2.50	1.67
Butler et al. 1994	COL1	1.50	2.70	1.80
Butler et al. 1994	COL1	1.50	3.30	2.20
Butler et al. 1994	COL1	1.50	3.70	2.47
Butler et al. 1994	COL1	1.50	4.10	2.73
Butler et al. 1994	COL1	1.50	5.10	3.40
Butler et al. 1994	COL1	1.50	5.30	3.53
Butler et al. 1994	COL1	1.50	26.00	17.33
Butler et al. 1994	RB3	1.60	5.40	3.38
Butler et al. 1995	MP	1.60	4.20	2.63
Butler et al. 1997	MUD	2.30	4.60	2.00
Butler et al. 1994	AD	2.70	7.10	2.63
Butler et al. 1994	LW	3.00	4.50	1.50
Butler et al. 1994	NFK2	3.10	6.10	1.97
Butler et al. 1994	PSW1	3.70	7.70	2.08
Butler et al. 1994	LSW1	3.90	5.80	1.49
Butler et al. 1991	10	4.80	1.90	0.40
Butler et al. 1994	TGC	4.90	10.00	2.04
Butler et al. 1994	BSW1	5.00	8.10	1.62
Butler et al. 1993	F2	7.50	7.30	0.97
Butler et al. 1994	CRC	7.50	19.00	2.53
Butler et al. 1994	IW	8.35	8.50	1.02
Butler et al. 1997	NW2	11.40	6.90	0.61
Butler et al. 1994	RB1	21.00	5.90	0.28
Butler et al. 1994	GUN2	28.00	6.80	0.24

NMED Exhibit 59

Roundtail chub (*Gila robusta*)



Median ratio: 1.98

R^2: 0.01
F: 0.18
df: 24
P: 0.834
Not used because P > 0.05

Sand shiner (*Notropis stramineus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2013	SW1	6.54	8.43	1.29
GEI 2013	SW1	6.54	9.02	1.38
GEI 2013	SW1	6.54	9.66	1.48
GEI 2013	SW1	6.54	11.21	1.71
GEI 2013	SW1	6.54	11.85	1.81
GEI 2013	SW1	6.54	11.94	1.83
GEI 2013	SW1	6.54	13.50	2.06
GEI 2013	SW1	6.54	14.05	2.15
GEI 2013	SW1	6.54	14.14	2.16
GEI 2013	SW2-1	6.60	18.70	2.84
GEI 2013	SW2-1	6.60	19.33	2.93
GEI 2013	SW2-1	6.60	19.77	3.00
GEI 2013	SW2-1	6.60	20.39	3.09
GEI 2013	SW2-1	6.60	23.70	3.59
GEI 2013	SWB	7.06	8.27	1.17
GEI 2013	SWB	7.06	9.01	1.28
GEI 2013	SWB	7.06	9.81	1.39
GEI 2013	SWB	7.06	10.22	1.45
GEI 2013	SW1	7.82	11.33	1.45
GEI 2013	SW1	7.82	12.05	1.54
GEI 2013	SW1	7.82	12.22	1.56
GEI 2013	SW1	7.82	12.55	1.60
GEI 2013	SW1	7.82	12.65	1.62
GEI 2013	SW1	7.82	12.68	1.62
GEI 2013	SW1	7.82	14.13	1.81
GEI 2013	SW1	7.82	14.43	1.85
GEI 2013	SW1	7.82	15.87	2.03

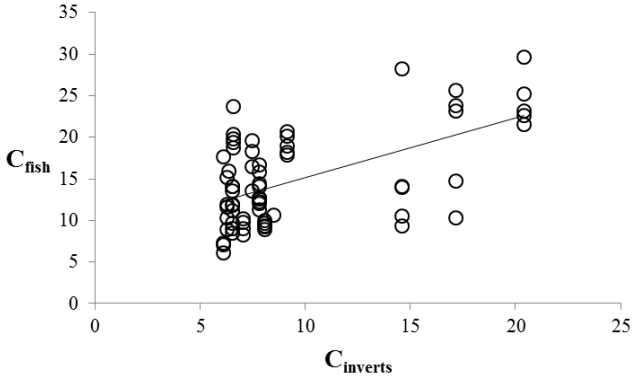
Sand shiner (*Notropis stramineus*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2013	SW1	7.82	16.63	2.13
GEI 2013	SW2-1	9.14	17.84	1.95
GEI 2013	SW2-1	9.14	18.21	1.99
GEI 2013	SW2-1	9.14	18.98	2.08
GEI 2013	SW2-1	9.14	20.12	2.20
GEI 2013	SW2-1	9.14	20.73	2.27
GEI 2014	Arkansas River, ARE	20.40	21.50	1.05
GEI 2014	Arkansas River, ARE	20.40	23.20	1.14
GEI 2014	Arkansas River, ARE	20.40	22.64	1.11
GEI 2014	Arkansas River, ARE	20.40	25.24	1.24
GEI 2014	Arkansas River, ARE	20.40	29.70	1.46
GEI 2014	Arkansas River, ARM	8.51	10.67	1.25
GEI 2014	Arkansas River, ARN	8.06	9.69	1.20
GEI 2014	Arkansas River, ARN	8.06	9.27	1.15
GEI 2014	Arkansas River, ARN	8.06	9.96	1.24
GEI 2014	Arkansas River, ARN	8.06	9.29	1.15
GEI 2014	Arkansas River, ARN	8.06	8.86	1.10
GEI 2014	Arkansas River, ARN	7.49	13.60	1.82
GEI 2014	Arkansas River, ARN	7.49	18.34	2.45
GEI 2014	Arkansas River, ARN	7.49	16.46	2.20
GEI 2014	Arkansas River, ARN	7.49	19.64	2.62
GEI 2014	Fountain Creek, FC-4	14.59	13.95	0.96
GEI 2014	Fountain Creek, FC-4	14.59	9.34	0.64
GEI 2014	Fountain Creek, FC-4	14.59	14.06	0.96
GEI 2014	Fountain Creek, FC-4	14.59	28.26	1.94
GEI 2014	Fountain Creek, FC-4	14.59	10.53	0.72
GEI 2014	Fountain Creek, FC-4	17.15	10.28	0.60
GEI 2014	Fountain Creek, FC-4	17.15	23.76	1.39
GEI 2014	Fountain Creek, FC-4	17.15	14.77	0.86
GEI 2014	Fountain Creek, FC-4	17.15	23.13	1.35
GEI 2014	Fountain Creek, FC-4	17.15	25.62	1.49
GEI 2014	Fountain Creek, FCP	6.13	17.62	2.88
GEI 2014	Fountain Creek, FCP	6.13	7.32	1.19
GEI 2014	Fountain Creek, FCP	6.13	7.14	1.17
GEI 2014	Fountain Creek, FCP	6.13	6.05	0.99
GEI 2014	Fountain Creek, FCP	6.13	7.11	1.16
GEI 2014	Fountain Creek, FCP	6.35	15.93	2.51
GEI 2014	St. Charles River, SC-4	6.29	11.92	1.90
GEI 2014	St. Charles River, SC-4	6.29	15.14	2.41
GEI 2014	St. Charles River, SC-4	6.29	8.94	1.42
GEI 2014	St. Charles River, SC-4	6.29	10.33	1.64
GEI 2014	St. Charles River, SC-4	6.29	11.58	1.84

NMED Exhibit 59

Sand shiner (*Notropis stramineus*)

Study	Site	C_{invert}	C_{fish}	Ratio



Median ratio: 1.56

R^2: 0.32
F: 32.15
df: 67
P: <0.001

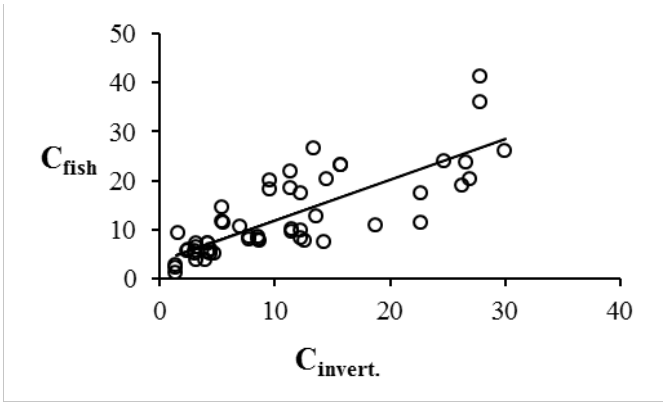
Sculpin (*Cottoidea*)

Study	Site	C_{invert}	C_{fish}	Ratio
Mason et al. 2000	BK	1.43	1.16	0.81
Mason et al. 2000	BK	1.43	2.35	1.64
Mason et al. 2000	BK	1.43	2.64	1.84
Formation 2012	SFTC-1	1.63	9.31	5.71
Formation 2012	SFTC-1	2.42	5.68	2.35
Formation 2012	SFTC-1	2.49	5.87	2.36
Formation 2012	CC-75	3.11	5.03	1.62
Formation 2012	CC-75	3.11	5.58	1.79
Formation 2012	CC-350	3.16	6.47	2.05
Formation 2012	CC-350	3.16	7.12	2.26
Formation 2012	SFTC-1	3.21	3.75	1.17
Formation 2012	CC-75	3.97	3.77	0.95
Formation 2012	CC-75	4.16	7.08	1.70
Formation 2012	CC-75	4.16	7.19	1.73
Formation 2012	CC-350	4.20	5.28	1.26
Formation 2012	CC-150	4.46	5.04	1.13
Formation 2012	CC-150	4.46	6.01	1.35
Formation 2012	CC-150	4.70	5.14	1.09
Formation 2012	CC-3A	5.45	11.65	2.14
Formation 2012	CC-3A	5.45	14.45	2.65
Formation 2012	CC-3A	5.48	11.47	2.09
Formation 2012	CC-150	7.03	10.73	1.53
Formation 2012	DC-600	7.83	7.96	1.02
Formation 2012	DC-600	7.83	8.62	1.10

NMED Exhibit 59

Sculpin (*Cottoidea*)

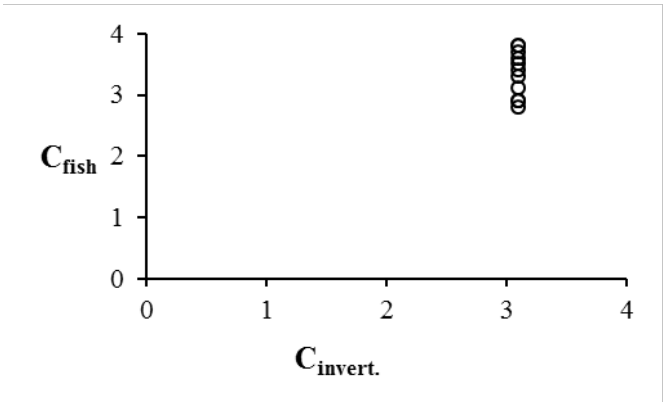
Study	Site	C_{invert}	C_{fish}	Ratio
Formation 2012	DC-600	8.53	7.87	0.92
Formation 2012	DC-600	8.53	8.50	1.00
Formation 2012	DC-600	8.65	7.63	0.88
Formation 2012	LSV-4	9.54	18.28	1.92
Formation 2012	LSV-4	9.54	20.01	2.10
Formation 2012	HS-3	11.40	18.57	1.63
Formation 2012	HS-3	11.40	21.85	1.92
Formation 2012	CC-350	11.45	9.53	0.83
Formation 2012	CC-350	11.45	10.03	0.88
Formation 2012	CC-1A	12.24	8.34	0.68
Formation 2012	CC-1A	12.24	9.94	0.81
Formation 2012	CC-1A	12.24	17.47	1.43
Formation 2012	CC-1A	12.57	7.78	0.62
Formation 2012	HS-3	13.41	26.63	1.99
Formation 2012	CC-1A	13.55	12.63	0.93
Formation 2012	CC-150	14.32	7.35	0.51
Formation 2012	CC-3A	14.50	20.20	1.39
Formation 2012	HS	15.70	23.23	1.48
Formation 2012	HS	15.70	23.25	1.48
Formation 2012	HS	18.70	10.95	0.59
Formation 2012	LSV-2C	22.62	11.38	0.50
Formation 2012	LSV-2C	22.62	17.47	0.77
Formation 2012	HS-3	24.70	23.93	0.97
Formation 2012	LSV-2C	26.31	18.85	0.72
Formation 2012	HS-3	26.55	23.68	0.89
Formation 2012	LSV-2C	26.95	20.32	0.75
Formation 2012	HS	27.80	35.93	1.29
Formation 2012	HS	27.80	41.30	1.49
Formation 2012	LSV-2C	30.00	25.95	0.87



Median ratio: 1.29

R^2: 0.63
F: 87.0
df: 51
P: <0.001

Shorthead redhorse (*Moxostoma macrolepidotum*)				
Study	**Site**	**C_{invert}**	**C_{fish}**	**Ratio**
Roddy et al. 1991	18	3.10	2.80	0.90
Roddy et al. 1991	18	3.10	2.90	0.94
Roddy et al. 1991	18	3.10	2.90	0.94
Roddy et al. 1991	18	3.10	3.10	1.00
Roddy et al. 1991	18	3.10	3.30	1.06
Roddy et al. 1991	18	3.10	3.40	1.10
Roddy et al. 1991	18	3.10	3.50	1.13
Roddy et al. 1991	18	3.10	3.60	1.16
Roddy et al. 1991	18	3.10	3.70	1.19
Roddy et al. 1991	18	3.10	3.80	1.23
Roddy et al. 1991	18	3.10	3.80	1.23



Median ratio: 1.10

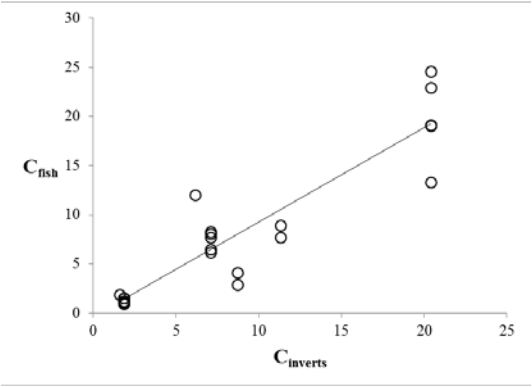
R^2: 0.00
F: 0.00
df: 9
P: 1.0
Not used because P > 0.05

Smallmouth bass (*Micropterus dolomieu*)				
Study	**Site**	**C_{invert}**	**C_{fish}**	**Ratio**
Butler et al. 1995	SU	1.85	1.55	0.84
Butler et al. 1995	SU	1.85	1.22	0.66
Butler et al. 1995	SU	1.85	0.98	0.53
Butler et al. 1995	SU	1.85	1.14	0.62
Butler et al. 1995	SU	1.85	1.50	0.81
Butler et al. 1995	SU	1.85	1.50	0.81
Butler et al. 1995	MP	1.60	1.90	1.19
Butler et al. 1997	MNP3	6.15	12.00	1.95
Mueller et al. 1991	R1	8.70	2.90	0.33
Mueller et al. 1991	R1	8.70	4.10	0.47
GEI 2014	ARE	20.40	24.61	1.21
GEI 2014	ARE	20.40	22.97	1.13
GEI 2014	ARE	20.40	13.28	0.65

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Smallmouth bass (*Micropterus dolomieu*)

Study	Site	C_{invert}	C_{fish}	Ratio
GEI 2014	ARE	20.40	19.06	0.93
GEI 2014	ARE	20.40	19.11	0.94
GEI 2014	ARM	7.10	8.25	1.16
GEI 2014	ARM	7.10	8.04	1.13
GEI 2014	ARM	7.10	7.72	1.09
GEI 2014	ARM	7.10	6.21	0.87
GEI 2014	ARM	7.10	6.51	0.92
GEI 2014	C-SC1	11.30	8.94	0.79
GEI 2014	C-SC1	11.30	7.68	0.68



Median ratio: 0.86

R^2: 0.84
F: 107.1
df: 20
P: <0.001

Speckled dace (*Rhinichthys osculus*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1991	10	4.80	4.80	1.00
Butler et al. 1991	9	4.10	5.70	1.39
Butler et al. 1991	3	6.20	6.50	1.05
Butler et al. 1993	SP2	2.75	12.00	4.36
Butler et al. 1993	B2	1.35	5.80	4.30
Butler et al. 1993	B1	1.25	4.40	3.52
Butler et al. 1993	B1	1.25	4.40	3.52
Butler et al. 1993	D1	1.20	3.50	2.92
Butler et al. 1993	D1	1.20	3.70	3.08
Butler et al. 1993	D1	1.20	3.40	2.83
Butler et al. 1993	D2	1.45	4.90	3.38
Butler et al. 1993	D2	1.45	6.80	4.69
Butler et al. 1993	D2	1.45	6.50	4.48
Butler et al. 1993	F2	3.90	8.90	2.28
Butler et al. 1993	P1	1.95	5.50	2.82
Butler et al. 1993	SP1	2.95	7.30	2.47

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Speckled dace (*Rhinichthys osculus*)				
Study	**Site**	**C_{invert}**	**C_{fish}**	**Ratio**
Butler et al. 1993	SP1	2.95	8.90	3.02
Butler et al. 1993	SP1	2.95	7.00	2.37
Butler et al. 1993	U1	2.45	3.60	1.47
Butler et al. 1993	U1	2.45	6.90	2.82
Butler et al. 1993	U1	2.45	7.30	2.98
Butler et al. 1993	U1	2.45	9.20	3.76
Butler et al. 1993	U1	2.45	9.40	3.84
Butler et al. 1993	U1	2.45	9.80	4.00
Butler et al. 1993	LP3	1.12	6.00	5.38
Butler et al. 1993	LP4	3.20	8.70	2.72
Butler et al. 1993	R2	4.30	17.10	3.98
Butler et al. 1993	R2	3.90	6.00	1.54
Butler et al. 1993	ST2	4.50	15.70	3.49
Butler et al. 1993	ST2	4.10	8.50	2.07
Butler et al. 1993	ST2	4.10	10.70	2.61
Butler et al. 1993	ST2	3.35	9.30	2.78
Butler et al. 1993	R1	4.00	8.50	2.13
Butler et al. 1993	ST1	2.25	6.80	3.02
Butler et al. 1993	SB2	3.60	12.10	3.36
Butler et al. 1993	SB2	3.75	7.80	2.08
Butler et al. 1993	SB2	3.75	10.80	2.88
Butler et al. 1993	SB1	2.15	10.00	4.65
Butler et al. 1993	SB1	2.15	9.50	4.42
Butler et al. 1993	SB1	2.15	7.80	3.63
Butler et al. 1993	WSB2	4.75	15.60	3.28
Butler et al. 1993	WSB2	3.60	11.70	3.25
Butler et al. 1993	WSB2	3.00	6.20	2.07
Butler et al. 1993	WSB2	3.00	7.60	2.53
Butler et al. 1994	CRC	7.50	13.00	1.73
Butler et al. 1994	CF1	3.60	6.10	1.69
Butler et al. 1994	GUN2	28.00	8.90	0.32
Butler et al. 1994	IW	8.35	10.00	1.20
Butler et al. 1994	LZA1	19.00	28.00	1.47
Butler et al. 1994	NFK3	2.00	7.10	3.55
Butler et al. 1994	NFK2	3.10	6.90	2.23
Butler et al. 1994	NFK2	3.10	4.80	1.55
Butler et al. 1994	NFK2	3.10	5.40	1.74
Butler et al. 1994	NFK2	3.10	5.70	1.84
Butler et al. 1994	NFK2	3.10	6.10	1.97
Butler et al. 1994	NFK2	3.10	6.20	2.00
Butler et al. 1994	NFK2	3.10	6.30	2.03
Butler et al. 1994	NFK2	3.10	6.40	2.06

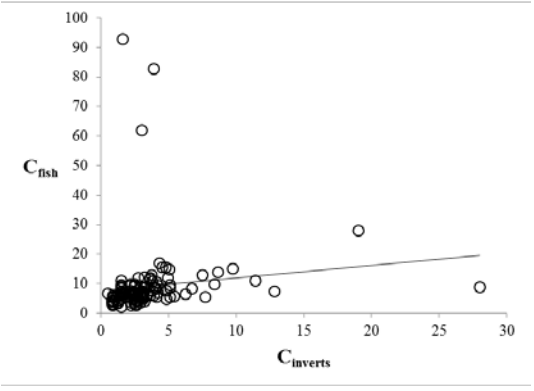
NMED Exhibit 59

Speckled dace (*Rhinichthys osculus*)				
Study	**Site**	**C_{invert}**	**C_{fish}**	**Ratio**
Butler et al. 1994	NFK2	3.10	6.70	2.16
Butler et al. 1994	NFK2	3.10	7.40	2.39
Butler et al. 1994	NFK2	3.10	8.70	2.81
Butler et al. 1994	TGC	4.90	12.00	2.45
Butler et al. 1994	BSW1	5.00	15.00	3.00
Butler et al. 1994	COL1	1.50	2.30	1.53
Butler et al. 1994	COL1	1.50	5.00	3.33
Butler et al. 1994	COL1	1.50	7.30	4.87
Butler et al. 1994	COL1	1.50	7.40	4.93
Butler et al. 1994	COL1	1.50	8.40	5.60
Butler et al. 1994	COL1	1.50	8.60	5.73
Butler et al. 1994	COL1	1.50	9.30	6.20
Butler et al. 1994	COL1	1.50	9.60	6.40
Butler et al. 1994	COL1	1.50	11.00	7.33
Butler et al. 1994	RB3	1.60	93.00	58.13
Butler et al. 1994	SMF	4.80	7.80	1.63
Butler et al. 1994	LW	3.00	62.00	20.67
Butler et al. 1994	LSW1	3.90	83.00	21.28
Butler et al. 1994	PSW1	3.70	13.00	3.51
Butler et al. 1995	AK	0.78	4.30	5.55
Butler et al. 1995	AK	0.78	3.10	4.00
Butler et al. 1995	AK	0.78	4.00	5.16
Butler et al. 1995	DD	0.86	5.60	6.51
Butler et al. 1995	DD	0.86	4.40	5.12
Butler et al. 1995	DD	0.86	6.00	6.98
Butler et al. 1995	HD1	0.83	2.80	3.39
Butler et al. 1995	HD1	0.83	3.20	3.88
Butler et al. 1995	HD1	0.83	5.30	6.42
Butler et al. 1995	ME1	3.40	6.40	1.88
Butler et al. 1995	ME2	1.25	6.10	4.88
Butler et al. 1995	ME3	2.55	2.80	1.10
Butler et al. 1995	ME3	2.55	7.00	2.75
Butler et al. 1995	ME3	2.55	5.50	2.16
Butler et al. 1995	NW	5.10	8.70	1.71
Butler et al. 1995	SJ1	2.50	4.30	1.72
Butler et al. 1995	SJ1	2.50	5.10	2.04
Butler et al. 1995	SJ1	2.50	2.90	1.16
Butler et al. 1995	YJ2	1.65	6.50	3.94
Butler et al. 1995	YJ2	1.65	6.30	3.82
Butler et al. 1995	YJ2	1.65	7.10	4.30
Butler et al. 1995	MN1	2.70	5.50	2.04
Butler et al. 1997	CHK	2.40	5.20	2.17

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Speckled dace (*Rhinichthys osculus*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1997	CHK	2.40	3.80	1.58
Butler et al. 1997	MN3	2.70	6.00	2.22
Butler et al. 1997	MN3	2.70	4.30	1.59
Butler et al. 1997	MN2	2.20	2.70	1.23
Butler et al. 1997	MN2	2.20	3.60	1.64
Butler et al. 1997	MN1	2.90	3.70	1.28
Butler et al. 1997	MUD	2.30	7.20	3.13
Butler et al. 1997	MUD	2.30	6.10	2.65
Butler et al. 1997	NW2	11.40	11.00	0.96
Butler et al. 1997	WBR	5.05	9.70	1.92
Butler et al. 1997	WBR	5.05	5.50	1.09
Butler et al. 1997	MN4	2.65	7.90	2.98
Butler et al. 1997	MN5	8.60	14.00	1.63
Butler et al. 1997	MNQ	1.80	5.90	3.28
Hamilton and Buhl 2004	DVC	12.80	7.50	0.59
Hamilton and Buhl 2004	USC	0.50	6.90	13.80
Hamilton and Buhl 2004	ACM	6.70	8.50	1.27
Hamilton and Buhl 2004	LBR	7.70	5.60	0.73
Hamilton and Buhl 2005	LiB	5.40	5.80	1.07
Hamilton and Buhl 2005	SLC	9.70	15.20	1.57



Median ratio: 2.76

R^2: 0.01
F: 1.76
df: 118
P: 0.177
Not used because P > 0.05

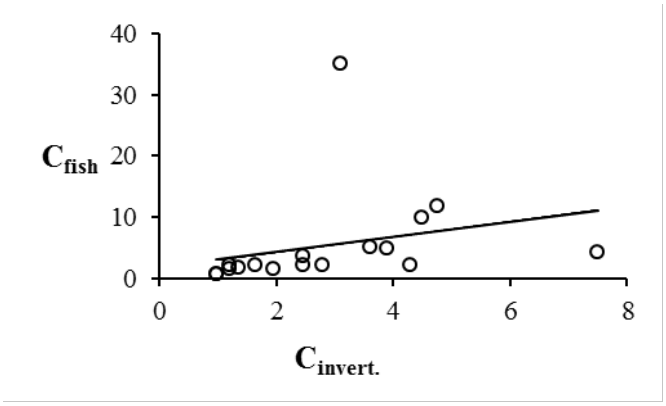
Sucker (Catostomidae)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1995	HD2	0.98	0.68	0.69
Butler et al. 1995	HD2	0.98	0.76	0.78
Butler et al. 1993	D1	1.20	2.30	1.92
Rinella and Schuler 1992	Malheur Lake	1.20	1.60	1.33

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Sucker (Catostomidae)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1993	B2	1.35	1.80	1.33
Butler et al. 1995	YJ2	1.65	2.20	1.33
Butler et al. 1993	P1	1.95	1.50	0.77
Butler et al. 1993	U1	2.45	2.30	0.94
Butler et al. 1993	U1	2.45	3.60	1.47
Butler et al. 1991	12	2.80	2.10	0.75
Butler et al. 1994	NFK2	3.10	35.00	11.29
Butler et al. 1993	SB2	3.60	5.10	1.42
Butler et al. 1993	R2	3.90	5.00	1.28
Butler et al. 1993	R2	4.30	2.20	0.51
Butler et al. 1993	ST2	4.50	10.00	2.22
Butler et al. 1993	WSB2	4.75	11.80	2.48
Butler et al. 1993	F2	7.50	4.20	0.56



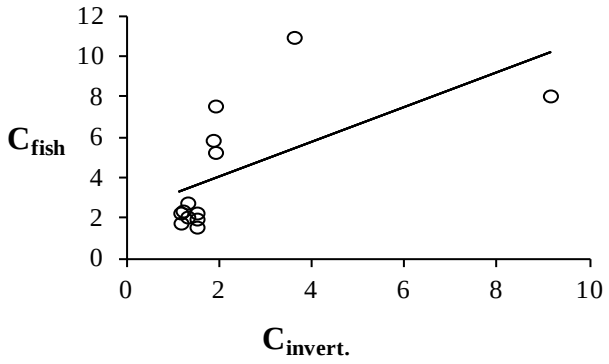
Median ratio: 1.33

R^2: 0.07
F: 1.10
df: 15
P: 0.360
Not used because P > 0.05

Sunfish (Centrarchidae)

Study	Site	C_{invert}	C_{fish}	Ratio
Welsh and Maughan 1994	outfall drain	1.15	2.30	2.00
Welsh and Maughan 1994	Pretty Water	1.16	1.80	1.56
Welsh and Maughan 1994	Hart Mine Marsh	1.20	2.40	2.00
Welsh and Maughan 1994	outfall drain	1.30	2.10	1.62
Welsh and Maughan 1994	outfall drain	1.30	2.80	2.15
Welsh and Maughan 1994	Pretty Water	1.50	1.60	1.07
Welsh and Maughan 1994	Old Channel	1.50	2.00	1.33
Welsh and Maughan 1994	Pretty Water	1.50	2.30	1.53
Welsh and Maughan 1994	Cibola Lake	1.85	5.90	3.19
Welsh and Maughan 1994	Cibola Lake	1.90	5.30	2.79
Welsh and Maughan 1994	Cibola Lake	1.90	7.60	4.00
Welsh and Maughan 1994	Oxbow Lake	3.60	11.00	3.06

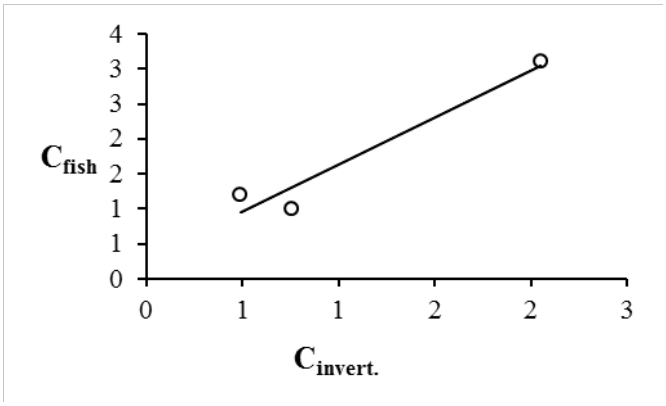
Sunfish (Centrarchidae)				
GEI 2013	SW2-1	9.14	8.10	0.89



Median ratio: 2.00

R^2: 0.38
F: 6.66
df: 11
P: 0.013

Tui chub (*Gila bicolor*)				
Study	**Site**	**C_{invert}**	**C_{fish}**	**Ratio**
Sorenson & Schwarzbach 1991	5	0.49	1.20	2.45
Sorenson & Schwarzbach 1991	4	0.76	1.00	1.32
Rinella and Schuler 1992	Harney Lake	2.05	3.10	1.51

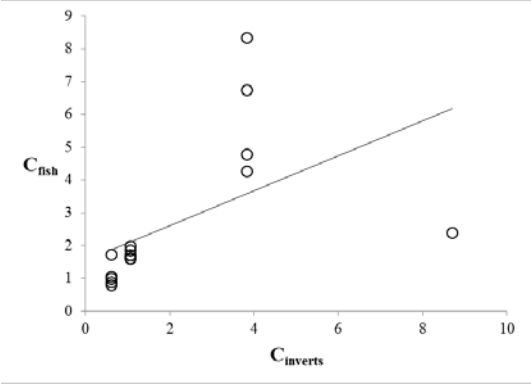


Median ratio: 1.51

R^2: 0.94
F: 15.9
df: 1
P: 0.175
Not used because P > 0.05

Walleye (*Sander vitreus*)				
Study	**Site**	**C_{invert}**	**C_{fish}**	**Ratio**
Butler et al. 1995	TT	1.07	1.86	1.75
Butler et al. 1995	TT	1.07	1.62	1.52
Butler et al. 1995	TT	1.07	1.70	1.60
Butler et al. 1995	TT	1.07	1.70	1.60
Butler et al. 1995	TT	1.07	2.00	1.88

Walleye (*Sander vitreus*)				
Study	**Site**	**C_{invert}**	**C_{fish}**	**Ratio**
Butler et al. 1995	TT	1.07	1.60	1.50
Butler et al. 1995	PU	0.61	1.72	2.82
Butler et al. 1995	PU	0.61	1.05	1.73
Butler et al. 1995	PU	0.61	0.81	1.33
Butler et al. 1995	PU	0.61	1.00	1.64
Butler et al. 1995	PU	0.61	0.89	1.46
Mueller et al. 1991	R1	8.70	2.40	0.28
Peterson et al. 1991	7	3.83	4.27	1.11
Peterson et al. 1991	7	3.83	4.79	1.25
Peterson et al. 1991	7	3.83	6.76	1.77
Peterson et al. 1991	7	3.83	8.35	2.18



Median ratio: 1.60

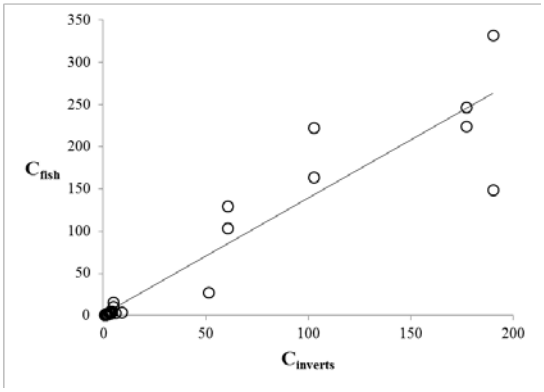
R^2: 0.28
F: 5.46
df: 14
P: 0.018

Western mosquitofish (*Gambusia affinis*)				
Study	**Site**	**C_{invert}**	**C_{fish}**	**Ratio**
GEI 2013	SWA1	3.64	2.91	0.80
GEI 2013	SWA1	2.81	3.01	1.07
GEI 2013	SWA1	2.81	3.49	1.24
GEI 2013	SWA1	2.81	3.66	1.30
GEI 2013	SWA1	2.81	3.89	1.39
GEI 2013	SWA1	2.81	4.27	1.52
Lemly 1985	Badin Lake	5.70	3.35	0.59
Lemly 1985	Belews Lake	51.15	27.20	0.53
Lemly 1985	High Rock Lake	9.05	3.54	0.39
Saiki and Lowe 1987	Kesterson Pond 11	60.65	130.00	2.14
Saiki and Lowe 1987	Kesterson Pond 11	60.65	104.00	1.71
Saiki and Lowe 1987	Kesterson Pond 2	177.00	224.00	1.27
Saiki and Lowe 1987	Kesterson Pond 2	177.00	247.00	1.40
Saiki and Lowe 1987	Kesterson Pond 8	102.50	164.00	1.60

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Western mosquitofish (*Gambusia affinis*)

Study	Site	C_{invert}	C_{fish}	Ratio
Saiki and Lowe 1987	Kesterson Pond 8	102.50	223.00	2.18
Saiki and Lowe 1987	San Luis Drain	190.00	149.00	0.78
Saiki and Lowe 1987	San Luis Drain	190.00	332.00	1.75
Saiki and Lowe 1987	Volta Pond 26	1.42	1.28	0.90
Saiki and Lowe 1987	Volta Pond 26	1.42	1.24	0.87
Saiki and Lowe 1987	Volta Wasteway	2.23	1.35	0.61
Saiki and Lowe 1987	Volta Wasteway	2.23	1.36	0.61
Saiki et al. 1993	ET6	0.85	1.00	1.18
Saiki et al. 1993	ET6	0.85	1.30	1.54
Saiki et al. 1993	GT5	4.90	16.00	3.27
Saiki et al. 1993	GT5	4.90	11.00	2.24
Saiki et al. 1993	GT4	4.05	4.50	1.11
Saiki et al. 1993	GT4	4.05	4.90	1.21
Saiki et al. 1993	SJR2	3.30	4.50	1.36
Saiki et al. 1993	SJR2	3.30	2.20	0.67
Saiki et al. 1993	SJR3	1.50	1.70	1.13
Saiki et al. 1993	SJR3	1.50	2.00	1.33
Saiki et al. 1993	SJR1	0.95	0.95	1.01
Saiki et al. 1993	SJR1	0.95	1.30	1.38
Saiki et al. 1993	ET7	0.86	0.90	1.05
Saiki et al. 1993	ET7	0.86	1.00	1.16



Median ratio: 1.21

R^2: 0.89
F: 263.3
df: 33
P: <0.001

White sucker (*Catostomus commersonii*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1993	LP3	1.12	2.50	2.24
Butler et al. 1993	B1	1.25	2.60	2.08
Butler et al. 1993	D2	1.45	1.90	1.31
Butler et al. 1993	D2	1.45	2.50	1.72

NMED Exhibit 59

White sucker (*Catostomus commersonii*)				
Study	**Site**	**C_{invert}**	**C_{fish}**	**Ratio**
Butler et al. 1993	P1	1.50	1.70	1.13
Butler et al. 1993	P1	1.50	1.80	1.20
Butler et al. 1995	MP	1.60	1.40	0.88
Butler et al. 1995	SU	1.85	1.20	0.65
GEI 2014	Arkansas River, ARB	11.21	14.90	1.33
GEI 2014	Arkansas River, ARB	11.21	20.39	1.82
GEI 2014	Arkansas River, ARB	11.21	13.82	1.23
GEI 2014	Arkansas River, ARB	11.21	8.36	0.75
GEI 2014	Arkansas River, ARB	11.21	10.88	0.97
GEI 2014	Arkansas River, ARB	11.21	21.55	1.92
GEI 2014	Arkansas River, ARB	11.21	18.70	1.67
GEI 2014	Arkansas River, ARB	11.21	24.53	2.19
GEI 2014	Arkansas River, ARB	11.21	15.02	1.34
GEI 2014	Arkansas River, ARB	11.21	28.29	2.52
GEI 2014	Arkansas River, ARE	20.4	18.21	0.89
GEI 2014	Arkansas River, ARE	20.4	19.54	0.96
GEI 2014	Arkansas River, ARE	20.4	15.27	0.75
GEI 2014	Arkansas River, ARE	20.4	11.37	0.56
GEI 2014	Arkansas River, ARE	20.4	17.86	0.88
GEI 2014	Arkansas River, ARE	20.4	10.62	0.52
GEI 2014	Arkansas River, ARE	20.4	17.51	0.86
GEI 2014	Arkansas River, ARE	20.4	24.66	1.21
GEI 2014	Arkansas River, ARE	20.4	18.92	0.93
GEI 2014	Arkansas River, ARE	20.4	21.70	1.06
GEI 2014	Arkansas River, ARM	8.51	10.13	1.19
GEI 2014	Arkansas River, ARM	8.51	9.24	1.09
GEI 2014	Arkansas River, ARM	8.51	8.30	0.97
GEI 2014	Arkansas River, ARM	8.51	10.09	1.19
GEI 2014	Arkansas River, ARM	7.68	16.18	2.11
GEI 2014	Arkansas River, ARM	7.68	13.21	1.72
GEI 2014	Arkansas River, ARM	7.68	11.96	1.56
GEI 2014	Arkansas River, ARM	7.68	8.58	1.12
GEI 2014	Arkansas River, ARM	7.68	9.73	1.27
GEI 2014	Arkansas River, ARM	7.1	8.19	1.15
GEI 2014	Arkansas River, ARM	7.1	7.96	1.12
GEI 2014	Arkansas River, ARN	7.49	9.15	1.22
GEI 2014	Arkansas River, ARN	7.49	8.61	1.15
GEI 2014	Arkansas River, ARN	7.49	7.06	0.94
GEI 2014	Arkansas River, ARN	7.49	11.57	1.54
GEI 2014	Arkansas River, ARN	7.49	11.56	1.54
GEI 2014	Arkansas River, ARN	7.44	21.20	2.85
GEI 2014	Arkansas River, ARN	7.44	23.28	3.13

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White sucker (*Catostomus commersonii*)				
Study	**Site**	**C_{invert}**	**C_{fish}**	**Ratio**
GEI 2014	Arkansas River, ARN	7.44	20.85	2.80
GEI 2014	Arkansas River, ARN	7.44	25.91	3.48
GEI 2014	Bond Creek, BC-2	2.96	3.06	1.03
GEI 2014	Bond Creek, BC-2	2.96	3.54	1.19
GEI 2014	Bond Creek, BC-2	2.96	3.04	1.03
GEI 2014	Bond Creek, BC-3	3.02	2.76	0.91
GEI 2014	Bond Creek, BC-3	3.02	2.85	0.94
GEI 2014	Bond Creek, BC-3	3.02	2.47	0.82
GEI 2014	Bond Creek, BC-3	3.02	2.03	0.67
GEI 2014	Bond Creek, BC-3	3.02	2.23	0.74
GEI 2014	Cow Camp Creek, CC-2	5.65	4.46	0.79
GEI 2014	Cow Camp Creek, CC-2	5.65	4.45	0.79
GEI 2014	Cow Camp Creek, CC-2	5.65	6.19	1.09
GEI 2014	Cow Camp Creek, CC-2	5.65	4.71	0.83
GEI 2014	Cow Camp Creek, CC-2	5.65	5.38	0.95
GEI 2014	Seng Creek, C-SC1	11.302	20.32	1.80
GEI 2014	Dry Creek, DC-4	19.42	26.07	1.34
GEI 2014	Dry Creek, DC-4	19.42	22.55	1.16
GEI 2014	Dry Creek, DC-4	19.42	14.29	0.74
GEI 2014	Dry Creek, DC-4	19.42	14.25	0.73
GEI 2014	Dry Creek, DC-4	19.42	14.67	0.76
GEI 2014	Dry Creek, DC-4	18.1	29.83	1.65
GEI 2014	Dry Creek, DC-4	18.1	30.65	1.69
GEI 2014	Dry Creek, DC-4	18.1	20.87	1.15
GEI 2014	Dry Creek, DC-4	18.1	12.06	0.67
GEI 2014	Fountain Creek, FC-4	18.65	24.54	1.32
GEI 2014	Fountain Creek, FCP	6.13	5.33	0.87
GEI 2014	Fountain Creek, FCP	6.13	5.88	0.96
GEI 2014	Fountain Creek, FCP	6.13	5.88	0.96
GEI 2014	Fountain Creek, FCP	6.13	5.75	0.94
GEI 2014	Fountain Creek, FCP	6.13	4.37	0.71
GEI 2014	Fountain Creek, FCP	5.38	8.50	1.58
GEI 2014	Fountain Creek, FCP	5.38	5.94	1.10
GEI 2014	Fountain Creek, FCP	5.38	5.97	1.11
GEI 2014	Fountain Creek, FCP	5.38	5.76	1.07
GEI 2014	Fountain Creek, FCP	5.38	5.61	1.04
GEI 2014	Fountain Creek, FCP	6.35	15.82	2.49
GEI 2014	Fountain Creek, FCP	6.35	5.68	0.90
GEI 2014	Fountain Creek, FCP	6.35	10.17	1.60
GEI 2014	Fountain Creek, FCP	6.35	12.34	1.94
GEI 2014	Fountain Creek, FCP	6.35	10.64	1.68
GEI 2014	Foidel Creek, FOC-2	2.175	1.74	0.80

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White sucker (*Catostomus commersonii*)				
Study	**Site**	**C_{invert}**	**C_{fish}**	**Ratio**
GEI 2014	Foidel Creek, FOC-2	2.175	1.25	0.57
GEI 2014	Foidel Creek, FOC-2	2.175	1.76	0.81
GEI 2014	Foidel Creek, FOC-2	2.175	2.11	0.97
GEI 2014	Foidel Creek, FOC-2	2.175	1.64	0.76
GEI 2014	Foidel Creek, FOC-2	2.175	2.11	0.97
GEI 2014	Foidel Creek, FOC-2	2.175	2.29	1.05
GEI 2014	Grassy Creek, GC-2	4.195	4.45	1.06
GEI 2014	Grassy Creek, GC-2	4.195	4.42	1.05
GEI 2014	Grassy Creek, GC-2	4.195	2.51	0.60
GEI 2014	Grassy Creek, GC-3	4.535	2.78	0.61
GEI 2014	Grassy Creek, GC-3	4.535	2.76	0.61
GEI 2014	Grassy Creek, GC-3	4.535	2.84	0.63
GEI 2014	Grassy Creek, GC-3	4.535	4.37	0.96
GEI 2014	Grassy Creek, GC-3	4.535	2.89	0.64
GEI 2014	Grassy Creek, GC-3	4.545	4.29	0.94
GEI 2014	Grassy Creek, GC-3	4.545	3.16	0.69
GEI 2014	Grassy Creek, GC-3	4.545	2.76	0.61
GEI 2014	Grassy Creek, GC-3	4.34	4.12	0.95
GEI 2014	Grassy Creek, GC-3	4.35	3.96	0.91
GEI 2014	Grassy Creek, GC-4	5.1	0.93	0.18
GEI 2014	Grassy Creek, GC-4	5.1	1.40	0.27
GEI 2014	Grassy Creek, GC-4	5.1	4.12	0.81
GEI 2014	Grassy Creek, GC-4	5.76	7.04	1.22
GEI 2014	Grassy Creek, GC-4	5.76	7.42	1.29
GEI 2014	Grassy Creek, GC-4	5.76	4.22	0.73
GEI 2014	Grassy Creek, GC-4	5.76	4.75	0.82
GEI 2014	Grassy Creek, GC-4 US	13.16	6.32	0.48
GEI 2014	Grassy Creek, GC-4 US	13.16	4.74	0.36
GEI 2014	Grassy Creek, GC-4 US	13.16	4.98	0.38
GEI 2014	Grassy Creek, GC-4 US	13.16	4.75	0.36
GEI 2014	Grassy Creek, GC-4 US	13.16	4.88	0.37
GEI 2014	Middle Creek, MC-1	3.21	2.03	0.63
GEI 2014	Middle Creek, MC-1	3.21	2.18	0.68
GEI 2014	Middle Creek, MC-1	3.21	1.79	0.56
GEI 2014	Middle Creek, MC-1	3.21	2.28	0.71
GEI 2014	Middle Creek, MC-1	3.21	2.54	0.79
GEI 2014	Middle Creek, MC-2	4.19	2.58	0.62
GEI 2014	Middle Creek, MC-2	4.19	1.90	0.45
GEI 2014	Middle Creek, MC-2	4.19	1.86	0.44
GEI 2014	Middle Creek, MC-2	4.19	1.90	0.45
GEI 2014	Middle Creek, MC-2	4.19	2.10	0.50
GEI 2014	St. Charles River, SC-3	5.75	7.74	1.35

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White sucker (*Catostomus commersonii*)				
Study	**Site**	**C_{invert}**	**C_{fish}**	**Ratio**
GEI 2014	St. Charles River, SC-3	5.75	12.34	2.15
GEI 2014	St. Charles River at US Hwy 50, SC-5	15.13	46.76	3.09
GEI 2014	St. Charles River at US Hwy 50, SC-5	15.13	38.23	2.53
GEI 2014	St. Charles River at US Hwy 50, SC-5	15.13	46.59	3.08
GEI 2014	St. Charles River at US Hwy 50, SC-5	15.13	60.66	4.01
GEI 2014	St. Charles River at US Hwy 50, SC-5	15.13	43.70	2.89
GEI 2014	St. Charles River, SC-9	25.06	35.97	1.44
GEI 2014	St. Charles River, SC-9	25.06	38.53	1.54
GEI 2014	St. Charles River at I-25, SC-I	4.335	7.62	1.76
GEI 2014	St. Charles River at I-25, SC-I	4.335	8.20	1.89
GEI 2014	St. Charles River at I-25, SC-I	4.335	6.10	1.41
GEI 2014	St. Charles River at I-25, SC-I	4.335	22.44	5.18
GEI 2014	St. Charles River at I-25, SC-I	4.335	4.29	0.99
GEI 2014	St. Charles River at I-25, SC-I	4.335	4.79	1.11
GEI 2014	St. Charles River at I-25, SC-I	4.335	47.18	10.88
GEI 2014	St. Charles River at I-25, SC-I	4.335	4.88	1.12
GEI 2014	Wildhorse Creek, WHC	56.14	5.43	0.10
GEI 2014	Wildhorse Creek, WHC	34.24	36.23	1.06
GEI 2014	Wildhorse Creek, WHC	34.24	10.22	0.30
GEI 2014	Wildhorse Creek, WHC	34.24	52.16	1.52
GEI 2014	Wildhorse Creek, WHC	34.24	40.81	1.19
GEI 2014	Wildhorse Creek, WHC	34.24	26.45	0.77
GEI 2014	Wildhorse Creek, WHC	62.34	61.90	0.99
GEI 2014	Wildhorse Creek, WHC	62.34	15.88	0.25
GEI 2014	Wildhorse Creek, WHC	62.34	27.40	0.44
GEI 2014	Wildhorse Creek, WHC	62.34	23.10	0.37
Muscatello and Janz 2009	Indigo Lake	0.36	0.99	2.75
Muscatello and Janz 2009	Vulture Lake	1.62	3.37	2.08
Grasso et al. 1995	17	1.91	2.84	1.49
Grasso et al. 1995	17	1.91	3.19	1.67
Grasso et al. 1995	17	1.91	3.44	1.80
Grasso et al. 1995	17	1.91	3.64	1.91

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White sucker (*Catostomus commersonii*)				
Study	**Site**	**C_{invert}**	**C_{fish}**	**Ratio**
Grasso et al. 1995	17	1.91	4.00	2.09
Grasso et al. 1995	17	1.91	4.01	2.10
Butler et al. 1994	NFK3	2.00	3.90	1.95
Butler et al. 1993	ST1	2.25	4.90	2.18
Lambing et al. 1994	S33	2.40	3.50	1.46
Mueller et al. 1991	A1	2.70	4.20	1.56
GEI 2013	SWA1	2.81	2.83	1.01
GEI 2013	SWA1	2.81	3.89	1.39
GEI 2013	SWA1	2.81	4.18	1.49
Mason et al. 2000	HCRT	2.81	0.81	0.29
Mason et al. 2000	HCRT	2.81	1.43	0.51
Mason et al. 2000	HCRT	2.81	1.43	0.51
Butler et al. 1993	WSB2	3.00	3.90	1.30
Butler et al. 1993	SP2	3.15	3.50	1.11
Butler et al. 1993	LP4	3.20	2.80	0.88
GEI 2013	SW4-1	3.33	3.01	0.91
GEI 2013	SW4-1	3.33	3.45	1.04
GEI 2013	SW4-1	3.33	3.50	1.05
GEI 2013	SW4-1	3.33	3.62	1.09
GEI 2013	SW4-1	3.33	4.04	1.22
GEI 2013	SW4-1	3.33	4.08	1.23
GEI 2013	SW4-1	3.33	4.13	1.24
GEI 2013	SW4-1	3.33	4.17	1.25
GEI 2013	SW4-1	3.33	4.34	1.31
GEI 2013	SW4-1	3.33	4.78	1.44
Butler et al. 1993	ST2	3.35	7.00	2.09
GEI 2013	LG1	3.37	3.54	1.05
GEI 2013	LG1	3.37	3.55	1.05
GEI 2013	LG1	3.37	3.90	1.16
GEI 2013	LG1	3.37	3.95	1.17
GEI 2013	LG1	3.37	4.48	1.33
GEI 2013	LG1	3.39	3.00	0.88
GEI 2013	LG1	3.56	2.72	0.77
GEI 2013	LG1	3.56	2.80	0.79
GEI 2013	LG1	3.56	2.89	0.81
GEI 2013	LG1	3.56	2.99	0.84
GEI 2013	LG1	3.56	3.04	0.86
GEI 2013	LG1	3.56	3.08	0.87
GEI 2013	LG1	3.56	3.13	0.88
GEI 2013	LG1	3.56	3.18	0.89
GEI 2013	LG1	3.56	3.25	0.91
GEI 2013	LG1	3.56	3.27	0.92

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White sucker (*Catostomus commersonii*)				
Study	**Site**	**C_{invert}**	**C_{fish}**	**Ratio**
Butler et al. 1993	WSB2	3.60	4.30	1.19
Butler et al. 1993	WSB2	3.60	6.30	1.75
GEI 2013	SWA1	3.64	2.83	0.78
GEI 2013	SWA1	3.64	3.39	0.93
GEI 2013	SWA1	3.64	3.47	0.95
GEI 2013	SWA1	3.64	3.55	0.98
GEI 2013	SWA1	3.64	3.63	1.00
GEI 2013	SWA1	3.64	3.75	1.03
Butler et al. 1993	SB2	3.65	4.30	1.18
Butler et al. 1993	R2	3.70	4.20	1.14
Butler et al. 1993	SB2	3.75	4.80	1.28
GEI 2013	CC1	3.76	5.99	1.59
GEI 2013	CC1	3.76	6.56	1.74
GEI 2013	CC1	3.76	7.21	1.92
GEI 2013	CC1	3.76	7.42	1.97
GEI 2013	CC1	3.76	7.62	2.03
Peterson et al. 1991	7	3.83	3.30	0.86
Peterson et al. 1991	7	3.83	4.64	1.21
Butler et al. 1993	R2	3.90	5.40	1.38
Butler et al. 1991	4	3.90	5.30	1.36
GEI 2013	SW88	3.96	4.63	1.17
GEI 2013	SW88	3.96	4.75	1.20
Butler et al. 1993	R1	4.00	9.50	2.38
Butler et al. 1993	ST2	4.10	8.30	2.02
GEI 2013	SW9	4.45	4.07	0.91
GEI 2013	SW9	4.45	4.18	0.94
GEI 2013	SW9	4.45	4.19	0.94
GEI 2013	SW9	4.45	4.20	0.94
GEI 2013	SW9	4.45	4.40	0.99
GEI 2013	SW9	4.45	5.18	1.16
GEI 2013	CC1	4.69	4.51	0.96
GEI 2013	CC1	4.69	4.57	0.98
GEI 2013	CC1	4.69	4.94	1.05
GEI 2013	CC1	4.69	5.02	1.07
GEI 2013	CC1	4.69	5.81	1.24
GEI 2013	CC1	4.69	6.01	1.28
GEI 2013	CC1	4.69	6.43	1.37
GEI 2013	CC1	4.69	7.25	1.55
GEI 2013	CC1	4.69	8.00	1.71
GEI 2013	CC1	4.69	8.52	1.82
Butler et al. 1993	F2	4.80	5.20	1.08
GEI 2013	CC1	5.86	5.00	0.85

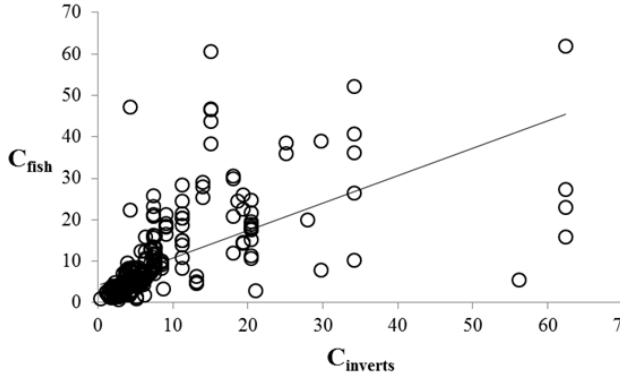
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White sucker (*Catostomus commersonii*)				
Study	**Site**	**C_{invert}**	**C_{fish}**	**Ratio**
GEI 2013	CC1	5.86	5.37	0.92
GEI 2013	CC1	5.86	5.59	0.95
GEI 2013	CC1	5.86	5.71	0.98
GEI 2013	CC1	5.86	5.90	1.01
GEI 2013	CC1	5.86	6.61	1.13
GEI 2013	CC1	5.86	6.79	1.16
GEI 2013	CC1	5.86	6.82	1.16
GEI 2013	CC1	5.86	7.29	1.25
GEI 2013	CC1	5.86	7.48	1.28
Butler et al. 1991	3	6.20	1.80	0.29
GEI 2013	SWB	7.06	7.18	1.02
GEI 2013	SWB	7.06	7.36	1.04
GEI 2013	SWB	7.06	7.98	1.13
GEI 2013	SWB	7.06	8.03	1.14
GEI 2013	SWB	7.06	9.65	1.37
GEI 2013	SWB	7.06	12.76	1.81
GEI 2013	SWB	7.06	12.85	1.82
GEI 2013	SWB	7.06	13.16	1.86
GEI 2013	SWB	7.44	8.21	1.10
GEI 2013	SWB	7.44	8.77	1.18
GEI 2013	SWB	7.44	8.85	1.19
GEI 2013	SWB	7.44	9.87	1.33
GEI 2013	SWB	7.44	10.97	1.48
GEI 2013	SWB	7.44	13.59	1.83
GEI 2013	SWB	7.44	15.75	2.12
GEI 2013	SWB	7.44	16.40	2.21
Butler et al. 1994	IW	8.35	9.70	1.16
Mueller et al. 1991	R1	8.70	3.40	0.39
GEI 2013	SW2-1	9.14	16.54	1.81
GEI 2013	SW2-1	9.14	18.14	1.99
GEI 2013	SW2-1	9.14	18.54	2.03
GEI 2013	SW2-1	9.14	19.16	2.10
GEI 2013	SW2-1	9.14	21.29	2.33
Lambing et al. 1994	S34	14.00	25.30	1.81
Lambing et al. 1994	S34	14.00	28.00	2.00
Lambing et al. 1994	S34	14.00	29.00	2.07
Butler et al. 1994	HCC1	21.00	3.00	0.14
Butler et al. 1994	GUN2	28.00	20.00	0.71
Butler et al. 1991	7	29.80	7.90	0.27

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White sucker (*Catostomus commersonii*)

Study	Site	C_{invert}	C_{fish}	Ratio



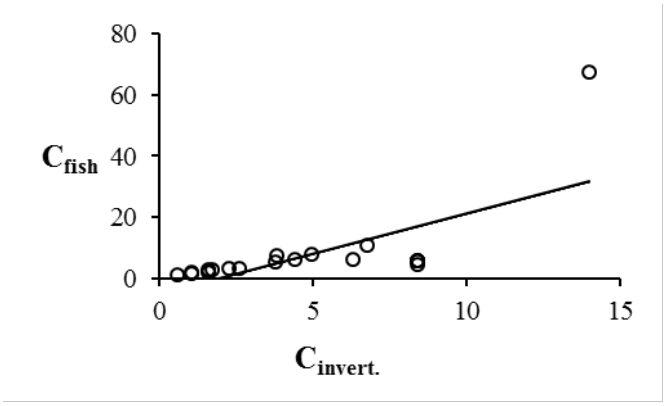
Median ratio: 1.11

R^2: 0.38
F: 174.4
df: 284
P: <0.001

Yellow perch (*Perca flavescens*)

Study	Site	C_{invert}	C_{fish}	Ratio
Butler et al. 1995	PU	0.61	1.10	1.80
Butler et al. 1995	TT	1.07	1.60	1.50
Butler et al. 1995	TT	1.07	1.70	1.60
Butler et al. 1995	MP	1.60	2.00	1.25
Butler et al. 1995	MP	1.60	2.20	1.38
Butler et al. 1995	MP	1.60	2.70	1.69
Belize et al. 2006	Halfway	1.74	2.72	1.56
Belize et al. 2006	Geneva	2.29	3.30	1.44
Belize et al. 2006	Bethel	2.61	3.09	1.19
Belize et al. 2006	McFarlane	3.79	5.40	1.42
Peterson et al. 1991	7	3.83	7.33	1.91
Belize et al. 2006	Long	4.42	6.28	1.42
Belize et al. 2006	Ramsey	4.97	7.64	1.54
Belize et al. 2006	Windy	6.32	6.06	0.96
Belize et al. 2006	Nelson	6.79	10.68	1.57
GEI 2013	SW11	8.41	4.54	0.54
GEI 2013	SW11	8.41	5.49	0.65
GEI 2013	SW11	8.41	5.50	0.65
GEI 2013	SW11	8.41	5.58	0.66
GEI 2013	SW11	8.41	5.68	0.68
Lambing et al. 1994	S34	14.00	67.00	4.79

Yellow perch (*Perca flavescens*)



Median ratio: 1.42

R^2: 0.46
F: 16.24
df: 19
P: <0.001

Table B-7. Final vertebrate Trophic Transfer Factor (TTF) values, including estimated values using taxonomic classification.

Common name	Scientific name	Order	Family	Genus	TTF	TTF source data
alligator gar	*Atractosteus spatula*	Lepistosteiformes	Lepisosteidae	Atractosteus	1.21	All fish
black bullhead	*Ameiurus melas*	Siluriformes	Ictaluridae	Ameiurus	0.85	Exact match
black crappie	*Pomoxis nigromaculatus*	Perciformes	Centrarchidae	Pomoxis	2.67	Exact match
black redhorse	*Moxostoma duquesnei*	Cypriniformes	Catostomidae	Moxostoma	1.01	Family Catostomidae
blacknose dace	*Rhinichthys atratulus*	Cypriniformes	Cyprinidae	Rhinichthys	0.71	Exact match
blue catfish	*Ictalurus furcatus*	Siluriformes	Ictaluridae	Ictalurus	0.68	Genus Ictalurus
bluegill	*Lepomis macrochirus*	Perciformes	Centrarchidae	Lepomis	1.03	Exact match
bluehead sucker	*Catostomus discobolus*	Cypriniformes	Catostomidae	Catostomus	1.04	Exact match
brassy minnow	*Hybognathus hankinsoni*	Cypriniformes	Cyprinidae	Hybognathus	1.20	Family Cyprinidae
brook stickleback	*Culaea inconstans*	Gasterosteiformes	Gasterosteidae	Culaea	1.79	Exact match
brook trout	*Salvelinus fontinalis*	Salmoniformes	Salmonidae	Salvelinus	0.88	Exact match
brown bullhead	*Ameiurus nebulosus*	Siluriformes	Ictaluridae	Ameiurus	0.85	Genus Ameiurus
brown trout	*Salmo trutta*	Salmoniformes	Salmonidae	Salmo	1.38	Exact match
bullhead		Siluriformes	Ictaluridae		0.77	Family Ictaluridae
burbot	*Lota lota*	lota	Gadiformes	Lotidae	1.21	All fish
chain pickerel	*Esox niger*	Esociformes	Esocidae	Esox	1.78	Genus Esox
channel catfish	*Ictalurus punctatus*	Siluriformes	Ictaluridae	Ictalurus	0.68	Exact match
common carp	*Cyprinus carpio*	Cypriniformes	Cyprinidae	Cyprinus	1.20	Exact match
common snook	*Centropomus undecimalis*	Perciformes	Centropomidae	Centropomus	1.41	Order Perciformes
crappie	*Pomoxis sp.*	Perciformes	Centrarchidae	Pomoxis	2.67	Genus Pomoxis
creek chub	*Semotilus atromaculatus*	Cypriniformes	Cyprinidae	Semotilus	1.06	Exact match
cutthroat trout	*Oncorhynchus clarkii*	Salmoniformes	Salmonidae	Oncorhynchus	1.12	Exact match
desert pupfish	*Cyprinodon macularius*	Cyprinodontiformes	Cyprinodontidae	Cyprinodon	1.24	Order Cyprinodontiformes
dolly varden	*Salvelinus malma*	Salmoniformes	Salmonidae	Salvelinus	0.88	Genus Salvelinus
fathead minnow	*Pimephales promelas*	Cypriniformes	Cyprinidae	Pimephales	1.57	Exact match
flannelmouth sucker	*Catostomus latipinnis*	Cypriniformes	Catostomidae	Catostomus	0.98	Exact match
flathead catfish	*Pylodictis olivaris*	Siluriformes	Ictaluridae	Pylodictus	0.77	Family Ictaluridae
flathead chub	*Platygobio gracilis*	Cypriniformes	Cyprinidae	Platygobio	1.20	Family Cyprinidae
freshwater drum	*Aplodinotus grunniens*	Perciformes	Sciaenidae	Aplodinotus	1.41	Order Perciformes
gizzard shad	*Dorosoma cepedianum*	Clupeiformes	Clupeidae	Dorosoma	1.21	All fish
goldeye	*Hiodon alosoides*	Hiodontiformes	Hiodontidae	Hiodon	1.21	All fish
green sunfish	*Lepomis cyanellus*	Perciformes	Centrarchidae	Lepomis	1.12	Exact match
iowa darter	*Etheostoma exile*	Perciformes	Percidae	Etheostoma	1.51	Family Percidae
kokanee salmon	*Oncorhynchus nerka*	Salmoniformes	Salmonidae	Oncorhynchus	1.10	Genus Oncorhynchus
largemouth bass	*Micropterus salmoides*	Perciformes	Centrarchidae	Micropterus	1.39	Exact match
largescale sucker	*Catostomus macrocheilus*	Cypriniformes	Catostomidae	Catostomus	1.01	Genus Catostomus
longnose dace	*Rhinichthys cataractae*	Cypriniformes	Cyprinidae	Rhinichthys	0.71	Genus Rhinichthys

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Common name	Scientific name	Order	Family	Genus	TTF	TTF source data
longnose sucker	*Catostomus catostomus*	Cypriniformes	Catostomidae	Catostomus	0.90	Exact match
mottled sculpin	*Cottus bairdi*	Scorpaeniformes	Cottidae	Cottus	1.38	Exact match
mountain whitefish	*Prosopium williamsoni*	Salmoniformes	Salmonidae	Prosopium	1.38	Exact match
ninespine stickleback	Pungitius pungitius	pungitius	Gasterosteiformes	Gasterosteidae	1.79	Family Gasterosteidae
northern pike	*Esox lucius*	Esociformes	Esocidae	Esox	1.78	Exact match
northern pikeminnow	*Ptychocheilus oregonensis*	Cypriniformes	Cyprinidae	Ptychocheilus	1.20	Family Cyprinidae
northern plains killifish	*Fundulus kansae*	Cyprinodontiformes	Fundulidae	Fundulus	1.27	Exact match
northern redbelly dace	*Chrosomus eos*	Cypriniformes	Cyprinidae	Chrosomus	1.20	Family Cyprinidae
northern squawfish	*Ptychocheilus oregonensis*	Cypriniformes	Cyprinidae	Ptychocheilus	1.20	Family Cyprinidae
quillback	*Carpiodes cyprinus*	Cypriniformes	Catostomidae	Carpiodes	1.01	Family Catostomidae
rainbow trout	*Oncorhynchus mykiss*	Salmoniformes	Salmonidae	Oncorhynchus	1.07	Exact match
razorback sucker	*Xyrauchen texanus*	Cypriniformes	Catostomidae	Xyrauchen	1.01	Family Catostomidae
red shiner	*Cyprinella lutrensis*	Cypriniformes	Cyprinidae	Cyprinella	1.31	Family Cyprinidae
redbreast sunfish	*Lepomis auritus*	Perciformes	Centrarchidae	Lepomis	1.07	Genus Lepomis
redear sunfish	*Lepomis microlophus*	Perciformes	Centrarchidae	Lepomis	1.07	Genus Lepomis
redside shiner	*Richardsonius balteatus*	Cypriniformes	Cyprinidae	Richardsonius	1.08	Exact match
river carpsucker	*Carpiodes carpio*	Cypriniformes	Catostomidae	Carpiodes	1.01	Family Catostomidae
river redhorse	*Moxostoma carinatum*	Cypriniformes	Catostomidae	Moxostoma	1.01	Family Catostomidae
rock bass	*Ambloplites rupestris*	Perciformes	Centrarchidae	Ambloplites	1.12	Family Centrarchidae
roundtail chub	*Gila robusta*	Cypriniformes	Cyprinidae	Gila	1.20	Family Cyprinidae
sacramento perch	*Archoplites interruptus*	Perciformes	Centrarchidae	Archoplites	1.12	Family Centrarchidae
sacramento pikeminnow	*Ptychocheilus grandis*	Cypriniformes	Cyprinidae	Ptychocheilus	1.20	Family Cyprinidae
sailfin molly	*Poecilia latipinna*	Cyprinodontiformes	Poeciliidae	Poecilia	1.21	Family Poeciliidae
sand shiner	*Notropis stramineus*	Cypriniformes	Cyprinidae	Notropis	1.56	Exact match
sauger	*Sander canadensis*	Perciformes	Percidae	Sander	1.60	Genus Sander
sculpin	*Cottus sp.*	Scorpaeniformes	Cottidae	Cottus	1.29	Exact match
shadow bass	*Ambloplites ariommus*	Perciformes	Centrarchidae	Ambloplites	1.12	Family Centrarchidae
shorthead redhorse	*Moxostoma macrolepidotum*	Cypriniformes	Catostomidae	Moxostoma	1.01	Family Catostomidae
silver carp	*Hypophthalmichthys molitrix*	Cypriniformes	Cyprinidae	Hypophthalmichthys	1.20	Family Cyprinidae
smallmouth bass	*Micropterus dolomieu*	Perciformes	Centrarchidae	Micropterus	0.86	Exact match
smallmouth buffalo	*Ictiobus bubalus*	Cypriniformes	Catostomidae	Ictiobus	1.01	Family Catostomidae
speckled dace	*Rhinichthys osculus*	Cypriniformes	Cyprinidae	Rhinichthys	0.71	Genus Rhinichthys
spottail shiner	Notropis hudsonius	hudsonius	Cypriniformes	Cyprinidae	1.56	Genus Notropis
spotted bass	*Micropterus punctulatus*	Perciformes	Centrarchidae	Micropterus	1.12	Genus Micropterus
spotted gar	*Lepisosteus oculatus*	Lepistosteiformes	Lepisosteidae	Lepisosteus	1.21	All fish
stonecat	*Noturus flavus*	Siluriformes	Ictaluridae	Noturus	0.77	Family Ictaluridae
striped bass	*Morone saxatilis*	Perciformes	Moronidae	Morone	1.48	Exact match
striped mullet	*Mugil cephalus*	Mugiliformes	Mugilidae	Mugil	1.21	All fish

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Common name	Scientific name	Order	Family	Genus	TTF	TTF source data
sucker		Cypriniformes	Catostomidae		1.01	Family Catostomidae
tilapia		Perciformes	Cichlidae		1.41	Order Perciformes
trout species	*Oncorhynchus sp.*	Salmoniformes	Salmonidae	Oncorhynchus	1.10	Genus Oncorhynchus
tui chub	*Gila bicolor*	Cypriniformes	Cyprinidae	Gila	1.20	Family Cyprinidae
utah sucker	*Catostomus ardens*	Cypriniformes	Catostomidae	Catostomus	1.01	Genus Catostomus
walleye	*Sander vitreus*	Perciformes	Percidae	Sander	1.60	Exact match
western mosquitofish	*Gambusia affinis*	Cyprinodontiformes	Poeciliidae	Gambusia	1.21	Exact match
white bass	*Morone chrysops*	Perciformes	Moronidae	Morone	1.48	Genus Morone
white crappie	*Pomoxis annularis*	Perciformes	Centrarchidae	Pomoxis	2.67	Genus Pomoxis
white sturgeon	*Acipenser transmontanus*	Acipenseriformes	Acipenseridae	Acipenser	1.21	All fish
white sucker	*Catostomus commersonii*	Cypriniformes	Catostomidae	Catostomus	1.11	Exact match
wiper	*Morone chrysops x Moron saxatilis*	Perciformes	Moronidae	Morone	1.48	Genus Morone
yellow perch	*Perca flavescens*	Perciformes	Percidae	Perca	1.42	Exact match

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Table B-8. Food web models used to calculate composite TTFs to translate the egg-ovary FCV to a water-column value at aquatic sites where sufficient data was available to calculate an enrichment factor (EF).

Reference	Site description	Site ID	Target fish species common name	Fish TTF	Fish prey as described in NatureServe	Fish prey spp comment	1° TL2 TTF species used	1° TL2 spp abbrev.	1° TL2 TTF	1° TL2 proportion	2° TL2 spp used	2° TL2 spp abrev.	2° TL2 TTF	2° TL2 proportion	3° TL2 spp used	3° TL2 spp abrev.	3° TL2 TTF	3° TL2 proportion	4° TL2 spp used	4° TL2 spp abrev.	4° TL2 TTF	4° TL2 proportion	1° TL3 spp	1° TL3 spp used	1° TL3 spp abbrev.	1° TL3 TTF	1° TL3 proportion	Effective TTF	Target fish TTF	TTFcomposite
Default			black bullhead	0.85	Omnivorous bottom feeder; often eats aquatic insects, crustaceans, molluscs, occasionally fishes and carrion		Median of all insects	in	2.14	0.45	Median of all crustaceans	crs	1.41	0.45	Median of all bivalves	bvs	4.29	0.10											2.03	0.85	1.72
Default			black crappie	2.67	Primarily a midwater feeder; zooplankton and small Diptera larvae predominate in the diet of individuals to 12 cm SL, while fishes and aquatic insects predominate in the diet of larger individuals		Median of all insects	in	2.14	0.50	Median of planktonic crustaceans	pc	1.41	0.10									Fish	Median all fish eating median all invertebrates	f+a	2.28	0.4	2.12	2.67	5.66
Default			blacknose dace	0.71	Eats immature aquatic insects, amphipods, and various other aquatic invertebrates; also eats algae and diatoms, which may be of little nutritional value (Smith 1979, Becker 1983).		Median of all insects	in	2.14	0.50	Median of all invertebrates except bivalves	all	1.48	0.50														1.81	0.71	1.29
Default			blue catfish	0.68	Bottom feeder. Eats mostly crustaceans and aquatic insects when young. Later, fishes and large invertebrates become most important (Moyle 1976). Also scavenges.		Median of all insects	in	2.14	0.36	Median insects and benthic crustaceans	in,bc	1.74	0.20	Median of all bivalves	bvs	4.29	0.08					Fish	Median all fish eating median all invertebrates	f+a	2.28	0.36	2.28	0.68	1.56
Default			bluegill	1.03	Feeds opportunistically on aquatic insect larvae, planktonic crustaceans, flying insects, snails, and other small invertebrates; small fishes, fish eggs, crayfish, and algae sometimes are eaten. Larvae and juveniles often eat cladocerans and copepod nauplii. Adults eats mainly aquatic insects, crayfishes, and small fishes, or, in some bodies of water, mostly zooplankton. Feeds at all levels of water column.		Median of all insects	in	2.14	0.68	Median of planktonic crustaceans	pc	1.41	0.20	crayfish	cr	1.46	0.08					Fish	Median all fish eating median all invertebrates	f+a	2.28	0.04	1.95	1.03	2.00
Default			bluehead sucker	1.04	Herbivore, Invertivore		TL1	TL1	1.00	0.60	Median of all invertebrates except bivalves	all	1.48	0.40														1.19	1.04	1.24
Default			brassy minnow	1.20	Eats algae, phyto- and zooplankton, benthic invertebrates, surface drift, bottom ooze (Becker 1983).		TL1	TL1	1.00	0.50	Median of planktonic crustacean	pc	1.41	0.40	Median of all insects	in	2.14	0.10										1.28	1.20	1.54

Reference	Site description	Site ID	Target fish species common name	Fish TTF	Fish prey as described in NatureServe	Fish prey spp comment	1° TL2 TTF species used	1° TL2 spp abbrev.	1° TL2 TTF	1° TL2 proportion	2° TL2 spp used	2° TL2 spp abrev.	2° TL2 TTF	2° TL2 proportion	3° TL2 spp used	3° TL2 spp abrev.	3° TL2 TTF	3° TL2 proportion	4° TL2 spp used	4° TL2 spp abrev.	4° TL2 TTF	4° TL2 proportion	1° TL3 spp	1° TL3 spp used	1° TL3 spp abbrev.	1° TL3 TTF	1° TL3 proportion	Effective TTF	Target fish TTF	TTFcomposite
Default			brook stickleback	1.79	Eats various aquatic invertebrates (including eggs and larvae), eggs and larvae of fishes, and algae. In a Manitoba lake, was opportunistic but heavily dependent on arthropods (Moodie 1986).		Median of all invertebrates except bivalves	all	1.48	0.80	TL1	TL1	1.00	0.20															1.38	1.79	2.47
Default			brook trout	0.88	Feeds opportunistically on various invertebrate and vertebrate animals, including primarily terrestrial and aquatic insects and planktonic crustaceans.		Median of all insects	in	2.14	0.60	crayfish	cr	1.46	0.10	Median of all bivalves	bvs	4.29	0.05					Fish	Median all fish eating median all invertebrates	f+a	2.28	0.25	2.22	0.88	1.96
Default			brown bullhead	0.85	Bottom feeder. Young eat chironomid larvae and small crustaceans. Adults eat larger insect larvae and fishes, also fish eggs, mollusks, carrion, and plant material (Becker 1983, Moyle 1976).		Median of all insects	in	2.14	0.68	Median of all invertebrates except bivalves	all	1.48	0.20	Median of all bivalves	bvs	4.29	0.04					Fish	Median all fish eating median all invertebrates	f+a	2.28	0.08	2.11	0.85	1.79
Default			brown trout	1.38	Eats aquatic and terrestrial insects and their larvae, crustaceans (especially crayfish), molluscs, fishes, and other animals. In streams, young feed mainly on aquatic and terrestrial drift invertebrates; in lakes, they feed on zooplankton and benthic invertebrates (Sublette et al. 1990). Large adults feed on fishes, crayfish, and other benthic invertebrates.		Median of planktonic crustaceans	pc	1.41	0.20	Median of all insects	in	2.14	0.12	crayfish	cr	1.46	0.08					Fish	Median all fish eating median all invertebrates	f+a	2.28	0.6	2.02	1.38	2.78
Default			bullhead	0.77	Black (not exotic to CO and NM): Omnivorous bottom feeder; often eats aquatic insects, crustaceans, molluscs, occasionally fishes and carrion. Stomach often contain substantial amounts of plant material of unknown nutritional value (Moyle 1976). Juveniles planktivorous; at about 27 mm TL, feed largely on crustaceans and midge larvae		Median of all insects	in	2.14	0.68	Median of all invertebrates except bivalves	all	1.48	0.20	Median of all bivalves	bvs	4.29	0.04					Fish	Median all fish eating median all invertebrates	f+a	2.28	0.08	2.11	0.77	1.62
Default			burbot	1.21	Young eat mainly immature aquatic insects, crayfish, molluscs, and other deepwater invertebrates. Larger individuals feed mostly on fishes (Becker 1983, Scott and Crossman 1973).		Median of all insects	in	2.14	0.25	Median of all crustaceans	crs	1.41	0.25									Fish	Median all fish eating median all invertebrates	f+a	2.28	0.5	2.03	1.21	2.45
Default			channel catfish	0.68	Bottom feeder. Young eat mainly small invertebrates; as they grow, fishes and crayfish become increasingly important, though individuals of all sizes eat abundant aquatic insects. Large fish are mainly piscivorous (Moyle 1976).		Median of all insects	in	2.14	0.48	Median of planktonic crustaceans	pc	1.41	0.20	crayfish	cr	1.46	0.08					Fish	Median all fish eating median all invertebrates	f+a	2.28	0.24	1.97	0.68	1.35

Reference	Site description	Site ID	Target fish species common name	Fish TTF	Fish prey as described in NatureServe	Fish prey spp comment	1° TL2 TTF species used	1° TL2 spp abbrev.	1° TL2 TTF	1° TL2 proportion	2° TL2 spp used	2° TL2 spp abrev.	2° TL2 TTF	2° TL2 proportion	3° TL2 spp used	3° TL2 spp abrev.	3° TL2 TTF	3° TL2 proportion	4° TL2 spp used	4° TL2 spp abrev.	4° TL2 TTF	4° TL2 proportion	1° TL3 spp	1° TL3 spp used	1° TL3 spp abbrev.	1° TL3 TTF	1° TL3 proportion	Effective TTF	Target fish TTF	TTFcomposite
Default			common carp	1.20	Omnivorous; adults eat mainly invertebrates, detritus, fish eggs, and plant material (Jester 1974, Becker 1983, Sublette et al. 1990).		Median of all invertebrates except bivalves	all	1.48	0.65	TL1	TL1	1.00	0.35															1.31	1.20	1.58
Default			crappie	2.67	Black: Primarily a midwater feeder; zooplankton and small Diptera larvae predominate in the diet of individuals to 12 cm SL, while fishes and aquatic insects predominate in the diet of larger individuals. White: eats fishes, planktonic crustaceans, and aquatic insects; small individuals eat mostly zooplankton, fish tend to predominate in the diet of larger individuals, though zooplankton also consumed (Moyle 1976)		Median of all insects	in	2.14	0.50	Median of planktonic crustaceans	pc	1.41	0.10										Fish	Median all fish eating median all invertebrates	f+a	2.28	0.4	2.12	2.67	5.66
Default			creek chub	1.06	Feeds opportunistically on various plants and animals, from surface drift to benthos; mostly invertivorous but large individuals often picivorous (Becker 1983). Chironomid larvae and other larval insects important in diet of young.		Median of all invertebrates except bivalves	all	1.48	0.70	TL1	TL1	1.00	0.20										Fish	Median all fish eating median all invertebrates	f+a	2.28	0.1	1.46	1.06	1.55
Default			cutthroat trout	1.12	Opportunistic. Inland cutthroats feed primarily on insects (aquatic and terrestrial); often feeds in and especially downstream from riffle areas; some large individuals feed mostly on fishes; also eats zooplankton and crustaceans.		Median of all insects	in	2.14	0.50	Median of all crustaceans	crs	1.41	0.20										Fish	Median all fish eating median all invertebrates	f+a	2.28	0.3	2.04	1.12	2.29
Default			fathead minnow	1.57	Feeds opportunistically in soft bottom mud; eats algae and other plants, insects, small crustaceans, and other invertebrates (Becker 1983, Sublette et al. 1990).	expected diet of small invertebrates	Median of all insects	in	2.14	0.60	Median of all crustaceans	crs	1.41	0.20	TL1	TL1	1.00	0.20											1.77	1.57	2.78
Default			flannel mouth sucker	0.98	Herbivore, Invertivore Bottom feeder. Reported to feed on diatoms, algae, fragments of higher plants, seeds, and benthic invertebrates (Sigler and Miller 1963; Lee et al. 1980). See Tyus and Minckley 1988 for possible importance of Mormon cricket as food source.		Median insects and benthic crustaceans	in,bc	1.74	0.75	TL1	TL1	1.00	0.25															1.55	0.98	1.52
Default			flathead chub	1.20	Opportunistic; eats aquatic and terrestrial insects and some algae (Olund and Cross 1961)		Median of all insects	in	2.14	0.80	TL1	TL1	1.00	0.20															1.91	1.20	2.30
Default			freshwater drum	1.41	Young feed mainly on minute crustaceans; adults mostly are bottom feeders, eat insect larvae, crustaceans, fishes, and (mostly in rivers) clams and		Median of all crustaceans	crs	1.41	0.44	Median of all insects	in	2.14	0.40	Median of all bivalves	bvs	4.29	0.04						Fish	Median all fish eating median all invertebrat	f+a	2.28	0.12	1.92	1.41	2.71

Reference	Site description	Site ID	Target fish species common name	Fish TTF	Fish prey as described in NatureServe	Fish prey spp comment	1° TL2 TTF species used	1° TL2 spp abbrev.	1° TL2 TTF	1° TL2 proportion	2° TL2 spp used	2° TL2 spp abrev.	2° TL2 TTF	2° TL2 proportion	3° TL2 spp used	3° TL2 spp abrev.	3° TL2 TTF	3° TL2 proportion	4° TL2 spp used	4° TL2 spp abrev.	4° TL2 TTF	4° TL2 proportion	1° TL3 spp	1° TL3 spp used	1° TL3 spp abbrev.	1° TL3 TTF	1° TL3 proportion	Effective TTF	Target fish TTF	TTFcomposite
					snails (Becker 1983, Scott and Crossman 1973, Lee et al. 1980).																			es						
Default			gizzard shad	1.21	Adults primarily bottom filter-feeding detritivores		TL1	TL1	1.00	1.00																		1.00	1.21	1.21
Default			goldeye	1.21	Young-of-year eat mainly microcrustaceans, also other invertebrates. Older individuals eat mainly aquatic insects obtained at surface but also various other animals, including frogs, fishes, and small mammals.		Median insects and benthic crustaceans	in,bc	1.74	1.00																		1.74	1.21	2.10
Default			green sunfish	1.12	Feeds opportunistically on the larger, more active invertebrates that occur with them, and on small fishes. Young feed mostly on crustaceans (zooplankton) and aquatic insect larvae. Adults eat more large aquatic and terrestrial insects, crayfish, and fishes		Median of all insects	in	2.14	0.58	Median of planktonic crustaceans	pc	1.41	0.10	crayfish	cr	1.46	0.08					Fish	Median all fish eating median all invertebrates	f+a	2.28	0.24	2.05	1.12	2.29
Default			Iowa darter	1.51	Eats mainly various invertebrates; commonly ingested food items of adults are midge larvae, mayfly naiads, and amphipods, and of the young, copepods and cladocerans. Apparently feeds on swimming organisms and those on bottom.	expected diet of small invertebrates	Median of all insects	in	2.14	0.70	amphipods	am	1.22	0.16	crayfish	cr	1.46	0.08	Median of planktonic crustaceans	pc	1.41	0.06						1.90	1.51	2.87
Default			kokanee salmon	1.10	Zooplankton, insects.		Median of planktonic crustaceans	pc	1.41	0.80	Median of all insects	in	2.14	0.20														1.56	1.10	1.71
Default			largemouth bass	1.39	Fry feed mainly on zooplankton. Larger young eat insects, crustaceans, and fish fry. Adults eat mainly fishes, though sometimes prefer crayfish or amphibians (Moyle 1976, Smith 1979).		Median of all insects	in	2.14	0.10	crayfish	cr	1.46	0.10									Fish	Median all fish eating median all invertebrates	f+a	2.28	0.8	2.18	1.39	3.04
Default			longnose dace	0.71	Eats mainly benthic insects, especially Diptera and mayflies (Becker 1983, Scott and Crossman 1973); also eats algae and plant material (Sublette et al. 1990). Terrestrial insects and fish eggs common in diet of adults from Lake Michigan (see Sublette et al. 1990).		Median of all insects	in	2.14	0.80	TL1	TL1	1.00	0.20														1.91	0.71	1.36
Default			longnose sucker	0.90	Eats mostly bottom invertebrates (Scott and Crossman 1973).		Median of all invertebrates except bivalves	all	1.48	1.00																		1.48	0.90	1.34

Reference	Site description	Site ID	Target fish species common name	Fish TTF	Fish prey as described in NatureServe	Fish prey spp comment	1° TL2 TTF species used	1° TL2 spp abbrev.	1° TL2 TTF	1° TL2 proportion	2° TL2 spp used	2° TL2 spp abrev.	2° TL2 TTF	2° TL2 proportion	3° TL2 spp used	3° TL2 spp abrev.	3° TL2 TTF	3° TL2 proportion	4° TL2 spp used	4° TL2 spp abrev.	4° TL2 TTF	4° TL2 proportion	1° TL3 spp	1° TL3 spp used	1° TL3 spp abbrev.	1° TL3 TTF	1° TL3 proportion	Effective TTF	Target fish TTF	TTFcomposite
Default			mottled sculpin	1.38	Benthic feeder; forages among rocks, mainly on immature aquatic insect larvae, especially mayflies, chironomid midges, and stoneflies; larger individuals also eat caddisflies and crayfish; crustaceans, annelids, fishes (including fish eggs) and plant material also may be eaten; may take swimming prey from water column (Scott and Crossman 1973, Becker 1983).		Median of all insects	in	2.14	0.70	Median of all crustaceans	crs	1.41	0.10	TL1	TL1	1.00	0.10					Fish	Median all fish eating median all invertebrates	f+a	2.28	0.1	1.97	1.38	2.72
Default			mountain whitefish	1.38	Feeds actively on aquatic and terrestrial insects. Also feeds on some fish eggs and occasionally on fishes. Bottom-oriented predator (Moyle 1976), occasionally feeds at surface (Sigler and Sigler 1987).		Median of all insects	in	2.14	0.90													Fish	Median all fish eating median all invertebrates	f+a	2.28	0.1	2.16	1.38	2.97
Default			ninespine stickleback	1.79	Eats mainly small crustaceans and aquatic insects; sometimes also fish eggs and fry (Becker 1983).		Median of all crustaceans	crs	1.41	0.48	Median of all insects	in	2.14	0.44									Fish	Median all fish eating median all invertebrates	f+a	2.28	0.08	1.80	1.79	3.22
Default			northern pike	1.78	Young initially eat large zooplankton and immature aquatic insects. After 7-10 days fishes begin to enter diet and eventually dominate. Adults feed opportunistically on vertebrates small enough to be engulfed. (Scott and Crossman 1973). Sight feeder.		Median insects and benthic crustaceans	in,bc	1.74	0.05													Fish	Median all fish eating median all invertebrates	f+a	2.28	0.95	2.25	1.78	4.02
Default			northern plains killifish	1.27	Feed effectively at all levels and food habits are generalized. Prefer aquatic insects but also feed on plants.	Montana field guide (http://fieldguide.mt.gov/detail_AFCNB04600.aspx)	Median of all insects	in	2.14	0.80	TL1	TL1	1.00	0.20															1.91	1.27	2.44
Default			northern redbelly dace	1.20	Eats mainly diatoms and filamentous algae, also zooplankton and aquatic insects.		TL1	TL1	1.00	0.70	Median of all insects	in	2.14	0.15	Median insects and benthic crustaceans	in,bc	1.74	0.15											1.28	1.20	1.54
Default			northern squawfish	1.20	Small individuals feed primarily on aquatic and terrestrial insects. Adults feed on fish, insects, insect larvae, crustaceans and some plankton during spring and summer. Fishes are the major component		Median of all insects	in	2.14	0.32	Median of all crustaceans	crs	1.41	0.08									Fish	Median all fish eating median all invertebrates	f+a	2.28	0.6	2.17	1.20	2.61

Reference	Site description	Site ID	Target fish species common name	Fish TTF	Fish prey as described in NatureServe	Fish prey spp comment	1° TL2 TTF species used	1° TL2 spp abbrev.	1° TL2 TTF	1° TL2 proportion	2° TL2 spp used	2° TL2 spp abrev.	2° TL2 TTF	2° TL2 proportion	3° TL2 spp used	3° TL2 spp abrev.	3° TL2 TTF	3° TL2 proportion	4° TL2 spp used	4° TL2 spp abrev.	4° TL2 TTF	4° TL2 proportion	1° TL3 spp	1° TL3 spp used	1° TL3 spp abbrev.	1° TL3 TTF	1° TL3 proportion	Effective TTF	Target fish TTF	TTF composite
					of the diet in winter.																									
Default			rainbow trout	1.07	In lakes, feeds mostly on bottom-dwelling invertebrates (e.g., aquatic insects, amphipods, worms, fish eggs, sometimes small fish) and plankton. In streams, feeds primarily on drift organisms. May ingest aquatic vegetation (probably for attached invertebrates).		Median of all insects	in	2.14	0.75													Fish	Median all fish eating median all invertebrates	f+a	2.28	0.25	2.18	1.07	2.33
Default			red shiner	1.31	Eats various small invertebrates (insects, crustaceans), plant material (digestibility may be low), and microorganisms (Becker 1983). In Virgin River, diet dominated by Ceratopongidae, Simuliidae, and Chironomidae (Greger and Deacon 1988).		Median insects and benthic crustaceans	in,bc	1.74	1.00																		1.74	1.31	2.27
Default			redside shiner	1.08	Feeds mainly on aquatic and terrestrial insects; also eats molluscs, plankton, and some small fish and fish eggs. Fry eat zooplankton and algae.		Median of all insects	in	2.14	0.70	Median of planktonic crustaceans	pc	1.41	0.10	Median of all bivalves	bvs	4.29	0.10					Fish	Median all fish eating median all invertebrates	f+a	2.28	0.1	2.30	1.08	2.48
Default			river carpsucker	1.01	Mostly a bottom feeder, browses on periphyton associated with submerged rocks and debris, ingests various small planktonic plants and animals.		TL1	TL1	1.00	0.75	Median of planktonic crustaceans	pc	1.41	0.25														1.10	1.01	1.11
Default			roundtail chub	1.20	Opportunistic; eats available aquatic and terrestrial insects, gastropods, crustaceans, fishes, and sometimes filamentous algae (Sublette et al. 1990).		Median of all insects	in	2.14	0.55	Median of all crustaceans	crs	1.41	0.15	Median of all bivalves	bvs	4.29	0.15					Fish	Median all fish eating median all invertebrates	f+a	2.28	0.15	2.38	1.20	2.86
Default			Sacramento perch	1.12	Opportunistic; diet mainly benthic insect larvae, snails, mid-water insects, zooplankton, and fishes (Moyle et al. 1989). Young feed mainly on small crustaceans, but as they grow Sacramento perch consume more aquatic insect larvae and pupae. Large adults feed mainly on other fishes when available.		TL1	TL1	1.00	0.75	Median of all insects	in	2.14	0.25														1.29	1.12	1.44
Default			sailfin molly	1.21	Eats mainly algae, vascular plants, organic detritus, and mosquito larvae (and other small invertebrates).		TL1	TL1	1.00	0.75	Median of all insects	in	2.14	0.25														1.29	1.21	1.56

Reference	Site description	Site ID	Target fish species common name	Fish TTF	Fish prey as described in NatureServe	Fish prey spp comment	1° TL2 TTF species used	1° TL2 spp abbrev.	1° TL2 TTF	1° TL2 proportion	2° TL2 spp used	2° TL2 spp abrev.	2° TL2 TTF	2° TL2 proportion	3° TL2 spp used	3° TL2 spp abrev.	3° TL2 TTF	3° TL2 proportion	4° TL2 spp used	4° TL2 spp abrev.	4° TL2 TTF	4° TL2 proportion	1° TL3 spp	1° TL3 spp used	1° TL3 spp abbrev.	1° TL3 TTF	1° TL3 proportion	Effective TTF	Target fish TTF	TTF composite
Default			sand shiner	1.56	Eats various aquatic and terrestrial invertebrates (especially chironomids), algae, and (mainly) bottom particulate matter (Becker 1983). Winter diet mostly chironomids larvae and mayfly and stonefly naiads (Ohio, see Sublette et al. 1990)		Median insects and benthic crustaceans	in,bc	1.74	0.75	TL1	TL1	1.00	0.25															1.55	1.56	2.43
Default			sauger	1.60	Larvae eat microcrustaceans. Young eat zooplankton, immature and adult aquatic insects, and fish fry; adults eat small fishes and various invertebrates (Scott and Crossman 1973), or are almost exclusively piscivorous (Burkhead and Jenkins 1991). Sight feeder, adapted to low light.		Median insects and benthic crustaceans	in,bc	1.74	0.36	Median of planktonic crustaceans	pc	1.41	0.10										Fish	Median all fish eating median all invertebrates	f+a	2.28	0.54	2.00	1.60	3.20
Default			sculpin	1.29	Benthic feeder; forages among rocks, mainly on immature aquatic insect larvae, especially mayflies, chironomid midges, and stoneflies; larger individuals also eat caddisflies and crayfish; crustaceans, annelids, fishes (including fish eggs) and plant material also may be eaten; may take swimming prey from water column (Scott and Crossman 1973, Becker 1983).		Median of all insects	in	2.14	0.70	crayfish	cr	1.46	0.15										Fish	Median all fish eating median all invertebrates	f+a	2.28	0.15	2.06	1.29	2.66
Default			shorthead redhorse	1.01	Invertivore		Median of all invertebrates except bivalves	all	1.48	1.00																		1.48	1.01	1.49
Default			smallmouth bass	0.86	Adults almost entirely piscivorous if sufficient prey available		Median of all insects	in	2.14	0.20													Fish	Median all fish eating median all invertebrates	f+a	2.28	0.8	2.25	0.86	1.93
Default			speckled dace	0.71	An omnivorous benthic feeder, at times feeding on drift in mid-water or rarely at the surface (Schreiber and Minckley 1981). The diet consists mostly of benthic insects, also includes other invertebrates, algae, and detritus (little or no plant material or detritus in some areas) (Sublette et al. 1990, Woodbury 1933, Greger and Deacon 1988). Young feed mainly on zooplankton.		Median of all insects	in	2.14	0.70	Median insects and benthic crustaceans	in,bc	1.74	0.15	TL1	TL1	1.00	0.15										1.91	0.71	1.36

Reference	Site description	Site ID	Target fish species common name	Fish TTF	Fish prey as described in NatureServe	Fish prey spp comment	1° TL2 TTF species used	1° TL2 spp abbrev.	1° TL2 TTF	1° TL2 proportion	2° TL2 spp used	2° TL2 spp abrev.	2° TL2 TTF	2° TL2 proportion	3° TL2 spp used	3° TL2 spp abrev.	3° TL2 TTF	3° TL2 proportion	4° TL2 spp used	4° TL2 spp abrev.	4° TL2 TTF	4° TL2 proportion	1° TL3 spp	1° TL3 spp used	1° TL3 spp abbrev.	1° TL3 TTF	1° TL3 proportion	Effective TTF	Target fish TTF	TTFcomposite
Default			stonecat	0.77	Eats mainly bottom invertebrates (insects, crayfish); sometimes also plant material and fishes (Becker 1983, Scott and Crossman 1973).		Median insects and benthic crustaceans	in,bc	1.74	0.70	TL1	TL1	1.00	0.20									Fish	Median all fish eating median all invertebrates	f+a	2.28	0.1	1.65	0.77	1.26
Default			sucker	1.01	White: Larvae feed near surface on protozoans, diatoms, small crustaceans, and bloodworms. Adults feed opportunistically on bottom organisms, both plant and animal (e.g., chironomid larvae, zooplankton, small crayfishes) (Becker 1983, Sublette et al. 1990). Bluehead: A bottom feeder. Scrapes algae and other organisms from rocks with chisel-like ridges inside each lip; ingests fine organism-laden sediments. May feed in stream riffles, or deeper rocky pools; in lakes it may feed over rocks near shore. May eat aquatic insect larvae. Flannelmouth: Bottom feeder. Reported to feed on diatoms, algae, fragments of higher plants, seeds, and benthic invertebrates (Sigler and Miller 1963; Lee et al. 1980). See Tyus and Minckley 1988 for possible importance of Mormon cricket as food source.		Median of all invertebrates except bivalves	all	1.48	0.50	TL1	TL1	1.00	0.50														1.24	1.01	1.25
Default			tilapia	1.41	aureus: Eats mainly phytoplankton. mossambicus: Nonselective omnivore; eats planktonic algae, aquatic plants, invertebrates, and small fishes (Moyle 1976). zilli: Feeds on algae and higher plants, invertebrates, and occasionally eats dead or dying fish.		Median of all invertebrates except bivalves	all	1.48	0.50	TL1	TL1	1.00	0.50														1.24	1.41	1.74
Default			tui chub	1.20	Adults opportunistic. They feed on plant material, plankton, insect larvae, crustaceans, fish fry and fish eggs, etc. Young feed on zooplankton. Coarse-rakered form eats more plant material, fine-rakered form more zooplankton.		TL1	TL1	1.00	0.40	Median of planktonic crustaceans	pc	1.41	0.28	Median of all insects	in	2.14	0.28	crayfish	cr	1.46	0.04						1.45	1.20	1.75
Default			Utah sucker	1.01	Bottom feeder. Varied diet; feeds freely on both animal and plant organisms, at all depths throughout the year. Grazes on filamentous algae.		Median of all invertebrates except bivalves	all	1.48	0.50	TL1	TL1	1.00	0.50														1.24	1.01	1.25

Reference	Site description	Site ID	Target fish species common name	Fish TTF	Fish prey as described in NatureServe	Fish prey spp comment	1° TL2 TTF species used	1° TL2 spp abbrev.	1° TL2 TTF	1° TL2 proportion	2° TL2 spp used	2° TL2 spp abrev.	2° TL2 TTF	2° TL2 proportion	3° TL2 spp used	3° TL2 spp abrev.	3° TL2 TTF	3° TL2 proportion	4° TL2 spp used	4° TL2 spp abrev.	4° TL2 TTF	4° TL2 proportion	1° TL3 spp	1° TL3 spp used	1° TL3 spp abbrev.	1° TL3 TTF	1° TL3 proportion	Effective TTF	Target fish TTF	TTFcomposite
Default			walleye	1.60	Adults feed opportunistically on various fishes and larger invertebrates.		Median insects and benthic crustaceans	in,bc	1.74	0.50													Fish	Median all fish eating median all invertebrates	f+a	2.28	0.5	2.01	1.60	3.21
Default			western mosquitofish	1.21	Opportunistic omnivore; eats mainly small invertebrates, often taken near water surface. Also eats small fishes and, in the absence of abundant animal food, algae and diatoms (Moyle 1976). Mosquitofish are principally carnivorous, and have strong, conical teeth and short guts (Meffe et al. 1983, Turner and Snelson 1984). They are reported to feed on rotifers, snails, spiders, insect larvae, crustaceans, algae, and fish fry, including their own progeny (Barnickol 1941, Minckley 1973, Meffe and Crump 1987). Cannibalism has been documented by several authors (Seale 1917, Krumholz 1948, Walters and Legner 1980, Harrington and Harrington 1982). Plant material is taken occasionally (Barnickol 1941) and may make up a significant portion of the diet during periods of scarcity of animal prey (Harrington and Harrington 1982). Grubb (1972) showed that anuran eggs from temporary ponds were preferentially selected over those breeding in permanent systems.		Median of all insects	in	2.14	0.75	Median of all crustaceans	crs	1.41	0.25																	1.96	1.21	2.37
Default			white bass	1.48	Eats fishes, zooplankton, aquatic insects, oligochaetes, and crayfish; fishes often dominate diet of adults; diet may vary from place to place (Moyle 1976, Sublette et al. 1990).		Median of all insects	in	2.14	0.30	Median of planktonic crustaceans	pc	1.41	0.05	crayfish	cr	1.46	0.05					Fish	Median all fish eating median all invertebrates	f+a	2.28	0.6	2.15	1.48	3.19
Default			white crappie	2.67	Eats fishes, planktonic crustaceans, and aquatic insects; small individuals eat mostly zooplankton, fish tend to predominate in the diet of larger individuals, though zooplankton also consumed (Moyle 1976)		Median of all insects	in	2.14	0.50	Median of planktonic crustaceans	pc	1.41	0.10									Fish	Median all fish eating median all invertebrates	f+a	2.28	0.4	2.12	2.67	5.66
Default			white sturgeon	1.21	A bottom feeder. Young feed mostly on the larvae of aquatic insects, crustaceans, and molluscs. A significant portion of the		Median insects and benthic	in,bc	1.74	0.31	Median of all bivalves	bvs	4.29	0.09									Fish	Median all fish eating median all	f+a	2.28	0.6	2.29	1.21	2.77

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Reference	Site description	Site ID	Target fish species common name	Fish TTF	Fish prey as described in NatureServe	Fish prey spp comment	1° TL2 TTF species used	1° TL2 spp abbrev.	1° TL2 TTF	1° TL2 proportion	2° TL2 spp used	2° TL2 spp abrev.	2° TL2 TTF	2° TL2 proportion	3° TL2 spp used	3° TL2 spp abrev.	3° TL2 TTF	3° TL2 proportion	4° TL2 spp used	4° TL2 spp abrev.	4° TL2 TTF	4° TL2 proportion	1° TL3 spp	1° TL3 spp used	1° TL3 spp abbrev.	1° TL3 TTF	1° TL3 proportion	Effective TTF	Target fish TTF	TTFcomposite
					diet of larger sturgeon consists of fish.		crustaceans																	invertebrates						
Default			white sucker	1.11	Adults feed opportunistically on bottom organisms, both plant and animal (e.g., chironomid larvae, zooplankton, small crayfishes) (Becker 1983, Sublette et al. 1990).	expected common spp in benthos	TL1	TL1	1.00	0.50	Median of all insects	in	2.14	0.30	Median of planktonic crustaceans	pc	1.41	0.10	crayfish	cr	1.46	0.10						1.43	1.11	1.58
Default			wiper	1.48	Adults are predatory on fishes and larger crustaceans (Hassler 1988).		crayfish	cr	1.46	0.20													Fish	Median all fish eating median all invertebrates	f+a	2.28	0.8	2.11	1.48	3.13
Default			yellow perch	1.42	Larvae and young primarily zooplankton feeders; older young eat mostly invertebrates associated with bottom and with aquatic plants; adults feed among plants and along bottom on larger invertebrates and small fishes (Moyle 1976).		Median insects and benthic crustaceans	in,bc	1.74	0.64	Median of planktonic crustaceans	pc	1.41	0.13	TL1	TL1	1.00	0.07					Fish	Median all fish eating median all invertebrates	f+a	2.28	0.16	1.73	1.42	2.47
Saiki et al. 1993			bluegill	1.03	site-specific: 0.23 chironomid; 0.3 microcrustacea; 0.47 amphipod	stomach analysis	amphipods	am	1.22	0.47	Median of planktonic crustaceans	pc	1.41	0.30	midges	mg	1.90	0.23										1.43	1.03	1.47
Saiki et al. 1993			largemouth bass	1.39	site-specific: 0.73 fish; 0.27 crayfish	stomach analysis	crayfish	cr	1.46	0.27	Saiki bluegill TTFcomp.	BG	1.47	0.73														1.47	1.39	2.04
Saiki et al. 1993			western mosquitofish	1.21	site-specific: 0.89 molluscs, and insects; 0.065 chironomid; 0.045 microcrustacea	stomach contents show a large terrestrial component	Median insects and benthic crustaceans	in,bc	1.74	0.89	midges	mg	1.90	0.07	Median of planktonic crustaceans	pc	1.41	0.05										1.74	1.21	2.10
Formation 2012	Crow Creek - CC150	CC-150	brown trout	1.38	Proportions as described in table B-10		Median of all insects	in	2.14	0.57	midges	mg	1.90	0.27	mayflies	mf	2.38	0.16										2.12	1.38	2.91
Formation 2012	Crow Creek - CC150	CC-150	sculpin	1.29	Proportions as described in table B-10		Median of all insects	in	2.14	0.57	midges	mg	1.90	0.27	mayflies	mf	2.38	0.16										2.12	1.29	2.74

Reference	Site description	Site ID	Target fish species common name	Fish TTF	Fish prey as described in NatureServe	Fish prey spp comment	1° TL2 TTF species used	1° TL2 spp abbrev.	1° TL2 TTF	1° TL2 proportion	2° TL2 spp used	2° TL2 spp abrev.	2° TL2 TTF	2° TL2 proportion	3° TL2 spp used	3° TL2 spp abrev.	3° TL2 TTF	3° TL2 proportion	4° TL2 spp used	4° TL2 spp abrev.	4° TL2 TTF	4° TL2 proportion	1° TL3 spp	1° TL3 spp used	1° TL3 spp abbrev.	1° TL3 TTF	1° TL3 proportion	Effective TTF	Target fish TTF	TTFcomposite
Formation 2012	Crow Creek - 1A	CC-1A	brown trout	1.38	Proportions as described in table B-10		Median of all insects	in	2.14	0.79	midges	mg	1.90	0.09	mayflies	mf	2.38	0.12										2.15	1.38	2.96
Formation 2012	Crow Creek - 1A	CC-1A	sculpin	1.29	Proportions as described in table B-10		Median of all insects	in	2.14	0.79	midges	mg	1.90	0.09	mayflies	mf	2.38	0.12										2.15	1.29	2.78
Formation 2012	Crow Creek - CC350	CC-350	brown trout	1.38	Proportions as described in table B-10		Median of all insects	in	2.14	0.80	midges	mg	1.90	0.07	mayflies	mf	2.38	0.13										2.16	1.38	2.97
Formation 2012	Crow Creek - CC350	CC-350	sculpin	1.29	Proportions as described in table B-10		Median of all insects	in	2.14	0.80	midges	mg	1.90	0.07	mayflies	mf	2.38	0.13										2.16	1.29	2.79
Formation 2012	Crow Creek - 3A	CC-3A	brown trout	1.38	Proportions as described in table B-10		Median of all insects	in	2.14	0.85	midges	mg	1.90	0.05	mayflies	mf	2.38	0.10										2.15	1.38	2.97
Formation 2012	Crow Creek - 3A	CC-3A	sculpin	1.29	Proportions as described in table B-10		Median of all insects	in	2.14	0.85	midges	mg	1.90	0.05	mayflies	mf	2.38	0.10										2.15	1.29	2.78
Formation 2012	Crow Creek - CC75	CC-75	brown trout	1.38	Proportions as described in table B-10		Median of all insects	in	2.14	0.49	midges	mg	1.90	0.38	mayflies	mf	2.38	0.13										2.08	1.38	2.87
Formation 2012	Crow Creek - CC75	CC-75	sculpin	1.29	Proportions as described in table B-10		Median of all insects	in	2.14	0.49	midges	mg	1.90	0.38	mayflies	mf	2.38	0.13										2.08	1.29	2.69
Formation 2012	Deer Creek	DC-600	brown trout	1.38	Proportions as described in table B-10		Median of all insects	in	2.14	0.44	midges	mg	1.90	0.21	mayflies	mf	2.38	0.35										2.18	1.38	3.00
Formation 2012	Deer Creek	DC-600	sculpin	1.29	Proportions as described in table B-10		Median of all insects	in	2.14	0.44	midges	mg	1.90	0.21	mayflies	mf	2.38	0.35										2.18	1.29	2.81
Formation 2012	Hoopes Spring - HS	HS	brown trout	1.38	Proportions as described in table B-10		Median of all bivalves	bvs	4.29	0.44	midges	mg	1.90	0.32	blackworms	bw	1.29	0.24										2.81	1.38	3.86
Formation 2012	Hoopes Spring - HS	HS	sculpin	1.29	Proportions as described in table B-10		Median of all bivalves	bvs	4.29	0.44	midges	mg	1.90	0.32	blackworms	bw	1.29	0.24										2.81	1.29	3.63
Formation 2012	Hoopes Spring - HS3	HS-3	brown trout	1.38	Proportions as described in table B-10		Median of all crustaceans	crs	1.41	0.40	Median of all insects	in	2.14	0.33	mayflies	mf	2.38	0.27										1.91	1.38	2.63
Formation 2012	Hoopes Spring - HS3	HS-3	sculpin	1.29	Proportions as described in table B-10		Median of all crustaceans	crs	1.41	0.40	Median of all insects	in	2.14	0.33	mayflies	mf	2.38	0.27										1.91	1.29	2.47

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Reference	Site description	Site ID	Target fish species common name	Fish TTF	Fish prey as described in NatureServe	Fish prey spp comment	1° TL2 TTF species used	1° TL2 spp abbrev.	1° TL2 TTF	1° TL2 proportion	2° TL2 spp used	2° TL2 spp abrev.	2° TL2 TTF	2° TL2 proportion	3° TL2 spp used	3° TL2 spp abrev.	3° TL2 TTF	3° TL2 proportion	4° TL2 spp used	4° TL2 spp abrev.	4° TL2 TTF	4° TL2 proportion	1° TL3 spp	1° TL3 spp used	1° TL3 spp abbrev.	1° TL3 TTF	1° TL3 proportion	Effective TTF	Target fish TTF	TTFcomposite
Formation 2012	Sage Creek - LSV2C	LSV-2C	brown trout	1.38	Proportions as described in table B-10		Median of all insects	in	2.14	0.57	midges	mg	1.90	0.12	mayflies	mf	2.38	0.31										2.19	1.38	3.01
Formation 2012	Sage Creek - LSV2C	LSV-2C	sculpin	1.29	Proportions as described in table B-10		Median of all insects	in	2.14	0.57	midges	mg	1.90	0.12	mayflies	mf	2.38	0.31										2.19	1.29	2.83
Formation 2012	Sage Creek - LSV4	LSV-4	brown trout	1.38	Proportions as described in table B-10		Median of all insects	in	2.14	0.53	midges	mg	1.90	0.34	mayflies	mf	2.38	0.13										2.09	1.38	2.88
Formation 2012	Sage Creek - LSV4	LSV-4	sculpin	1.29	Proportions as described in table B-10		Median of all insects	in	2.14	0.53	midges	mg	1.90	0.34	mayflies	mf	2.38	0.13										2.09	1.29	2.70
Formation 2012	South Fork Tincup Cr.	SFTC-1	brown trout	1.38	Proportions as described in table B-10		Median of all insects	in	2.14	0.93	Median of all bivalves	bvs	4.29	0.03	mayflies	mf	2.38	0.04										2.22	1.38	3.05
Formation 2012	South Fork Tincup Cr.	SFTC-1	sculpin	1.29	Proportions as described in table B-10		Median of all insects	in	2.14	0.93	Median of all bivalves	bvs	4.29	0.03	mayflies	mf	2.38	0.04										2.22	1.29	2.86

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Table B-9. Calculation of site-specific invertebrate proportions using invertebrate counts in Formation 2012

| Order | Genus | Habitat / Behavior | Functional Feeding | Tolerance | Stream | SF Tincup Creek | | Crow Creek | | |

Order	Genus	Habitat / Behavior	Functional Feeding	Tolerance	Stream	SF Tincup Creek			Crow Creek								Deer Creek								Hoopes Spring								Sage Creek								Crow Creek								
					Location	SFTC1			CC75			CC150			CC350			DC600			HS			HS3				LSV2C			LSV4			CC1A				CC3A				Total
			Groups		Date	8/29/2007	9/9/2008	9/2/2006	8/23/2007	9/3/2008	9/1/2006	8/24/2007	9/3/2008	9/1/2006	8/23/2007	9/4/2008	9/7/2006	8/27/2007	9/8/2008	9/8/2006	8/24/2007	9/4/2008	9/6/2006	8/28/2007	9/5/2008	9/8/2006	8/28/2007	9/5/2008	9/5/2006	9/1/2006	8/25/2007	9/6/2008	9/4/2006	8/26/2007	9/7/2008	
	sp.																																													
Trichoptera	Glossoma sp.	CN	SC	0														4																											4
Trichoptera	Helicopsyche sp.	CN	SC	3					3			5	4		5	93								2			2										19	81			214
Trichoptera	Hesperophylax sp.	CN	SH	5																			3	1	48		14	4														70
Trichoptera	Hydropsyche sp.	CN	F	4				5	47	50	23	29	17	11	74	97	41	1	14		2				2		8	9	11	53	63	91	29	105	79	151					1012
Trichoptera	Hydroptila sp.	CN	SC	6					8	9	1	1											1			16					1			2						39
Trichoptera	Lepidostoma spp.	SP/CB	SH	1		1	3			7		6	8			67	6		16																						141
Trichoptera	Micrasema sp.	CN	SH	1					8		9	65	1	18	14			3			28					4			76	3	3		36							273
Trichoptera	Neothremma sp.	CN	SC	0															4																							4
Trichoptera	Oecetis disjuncta	CN	P	8		2									2	3																						3		7		17
Trichoptera	Onocosmoecus sp.	CB	SH	1		1																																				1
Trichoptera	Oligophlebodes sp.	CN	SC	1					11																														2			13
Trichoptera	Parapsyche sp.	CN	P	1					16			5						7					1			2			1												32
Trichoptera	Psychoglypha sp.	SP/CB	CG	1						3																																3
Trichoptera	Rhyacophila spp.	CN	P	0		7	3	4	5	5	9	17	16	3	5	9	16	23	83					11	13		7														236
Trichoptera	Wormaldia spp.	CN	F	3			3				1	8	15	2	5	6	7							3	9				1								3	1	2	11	77
Coleoptera	Ametor sp.	SW	P	5																		1																			1
Coleoptera	Brychius sp.	CB	SC	7		2				1	3															10															16
Coleoptera	Cleptelmis sp.	CN	CG/SC	4		3	26										4											5		1				1			6		46
Coleoptera	Dubiraphia sp.	CN	CG/SC	4		3																																		3
Coleoptera	Heterlimnius corpulentus	CN/BU	CG/SC	4														30	32			5																			67
Coleoptera	Optioservus quadrimaculatus	CN	CG/SC	4		97	267	43	109	68	40	205	153	78	162	167	7	2	5	12			5	21	33	18	132	151	27	153	74	246	69	83	129					2556
Coleoptera	Oreodytes sp.	SW/DV	P	5		6		1																																	7
Coleoptera	Paracymus sp.	CN	P/OM	5								1																													1
Coleoptera	Zaitzevia parvula	CN/BU	CG/SC	4		170	57	5	4		1	1	7	23	5	18							3	3		2	2	7	2	6	16	11	8	2	13					366
Megaloptera	Sialis sp.	BU/CB	P	4		1			1	3		1																													6

Order	Genus	Habitat / Behavior	Functional Feeding Groups	Tolerance	Stream	SF Tincup Creek					Crow Creek								Deer Creek										Hoopes Spring								Sage Creek								Crow Creek												Total
					Location	SFTC1			CC75			CC150			CC350				DC600				HS					HS3					LSV2C				LSV4				CC1A					CC3A								
					Date	8/29/2007	9/9/2008	9/2/2006	8/23/2007	9/3/2008	9/1/2006	8/24/2007	9/3/2008	9/1/2006	8/23/2007	9/4/2008	9/7/2006	8/27/2007	9/8/2008	9/8/2006	8/24/2007	9/4/2008	9/6/2006	8/28/2007	9/5/2008	9/8/2006	8/28/2007	9/5/2008	9/5/2006	9/1/2006	8/25/2007	9/6/2008	9/4/2006	8/26/2007	9/7/2008	
Odonata	Ophiogomphus sp.	BU	P	1																																					2		7		9
Hemiptera	Sigara sp.	SW	P	10		5																																							5
Diptera	Anopheles sp.	SW	F	8									1																																	1
Diptera	Antocha sp.	BU	CG	3			5	1				4			6																							18		2		1		37
Diptera	Atherix sp.	BU	P	2																																				26	22	24	3	44	119
Diptera	Chelifera sp.	SP/BU	CG	6				2				1						7			4																	1				5			20
Diptera	Dixa sp.	BU	CG	1																		13																							13
Diptera	Empididae	SP/BU	P	6									1						5				2																						8
Diptera	Ephydridae	BU	CG	6								1							1				1																						3
Diptera	Glutops sp.	BU	P	3				1	2									1																											4
Diptera	Hexatoma	BU	P	2		19				9		1			5	4		1								9			4				5								16	1	74
Diptera	Limnophila sp.	BU	P	4							1			3			3					5								5	3			9									29
Diptera	Muscidae	BU	P	6																					1		3																4
Diptera	Pericoma sp.							2			1																																		3
Diptera	Probezzia sp.	BU	P	6						3					2		1	1							2																2			11
Diptera	Ptychoptera sp.		CG	7																																					1			1
Diptera	Simulium sp.	CN	F	6			18	78	5	30	26	49	17	17	5	102	9	15	8		5	4	13	21	38	24	25	24	12	114	35	8	1	26	31	760
Diptera	Tipula sp.	BU	SH	4					7	3				1					3					3			2			2		3	3			27
Chironomidae (family)	Chironomidae	BU/SP	CG/SH/P	6				188	195	173	143	99	143	68	10	30	33	88	151	92	124	25	23	83		20	43	91	149	36	56	35	41	21	8	2168
Hirudinea (class)	Helobdella sp.		PA/P	6								1																														1
Collembola	Collembola										2																																2
Oligochaeta (class)	Oligochaeta		CG	5			5	15	7	2	6	4	7	8	3	5	3	5	19	72	101	5	3			34		9	8	9			19	56		405
Bivalvia (class)	Pisidium sp.	BU	F	8		2		2	4		2						2	6		2	5	2	2			12					3	1	1	23		69
Gastropoda (class)	Fossaria sp.	CN	SC	8			2			1					2					52	57	27	4	4			8				15		1	1		174
Gastropoda (class)	Amnicola sp.	CN	SC	5										2	2	1	1													3		1			10
Gastropoda (class)	Gyraulus sp.	CN	SC																											1					1
Gastropoda (class)	Mentus sp.	CN	SC																	6																6
Gastropoda (class)	Physella sp.	CN	SC	8		19		3	2	1					3	1				114	55	7	2	6		14	32		1	2			3	23		288

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Order	Genus	Habitat / Behavior	Functional Feeding	Tolerance	Stream	SF Tincup Creek				Crow Creek				Deer Creek				Hoopes Spring				Sage Creek				Crow Creek								
					Location	SFTC1		CC75		CC150		CC350		DC600		HS		HS3		LSV2C		LSV4		CC1A		CC3A								Total
			Groups		Date	8/29/2007	9/9/2008	9/2/2006	8/23/2007	9/3/2008	9/1/2006	8/24/2007	9/3/2008	9/1/2006	8/23/2007	9/4/2008	9/7/2006	8/27/2007	9/8/2008	9/8/2006	8/24/2007	9/4/2008	9/6/2006	8/28/2007	9/5/2008	9/8/2006	8/28/2007	9/5/2008	9/5/2006	9/1/2006	8/25/2007	9/6/2008	9/4/2006	8/26/2007	9/7/2008	
Gastropoda (class)	Valvata sp.	CN	SC																		1													1
Amphipoda	Gammarus sp.	SW/BU	OM	6														2			2	4	13	8	1	12				2					44
Ostracoda	Ostracoda	SW	CG	8						1											460	2	9	30	13	8	1	1							525
Tricladida	Polycelis coronata		OM	1									4																					4
Acari (subclass)	Acari		P	8				2		2	3	4		2	6	7													2	2	5			35
					% Subsampled	50	50	12.5	12.5	66.6	12.5	25	50	25	12.5	50	100	33.3	75	50	33.3	100	12.5	33.3	100	25	25	75	12.5	25	25	50	25	25	50	13872
					Total abundance	394	486	516	506	494	465	482	534	477	536	492	420	478	409	498	415	91	596	470	280	541	532	445	445	487	452	463	465	503	500	
					Total taxa	24	19	27	25	22	26	24	16	23	24	21	23	23	16	15	13	14	21	22	14	23	21	17	21	20	18	22	30	20	15	
					Total Counts	788	972	4128	4048	741.7417	3720	1928	1068	1908	4288	984	420	1435.435	545.3333	996	1246.246	91	4768	1411.411	280	2164	2128	593.3333	3560	1948	1808	926	1860	2012	1000	
					Density (#/1m2)	2835	3496	14849	14561	2668	13381	6935	3842	6863	15424	3540	1511	5163	1962	3583	4483	327	17151	5077	1007	7784	7655	2134	12806	7007	6504	3331	6691	7237	3597	
						394	486	516	506	494	465	482	534	477	536	492	420	478	409	498	415	91	596	470	280	541	532	445	445	487	452	463	465	503	500	
							880			1516			1481			1505			1307			1004			1346			1518	445			1402			1468	13872

Functional Feeding Groups (FFG): CG = Collector-Gatherer, SC = Scraper, F = Filterer, P = Predator, SH = Shredder, OM = Omnivore, Habitat/Behavior (Hab/Beh): BU = Burrower, SW = Swimmer, CN = Clinger, CB = Climber, SP = Sprawler, DV = Diver

Table B-10. Summary of Formation 2012 invertebrate data.

Phylum	Subphylum	Class	Subclass	Infraclass	Superorder	Order	Lookup ID	Common name	SFTC1		CC75		CC150		CC350		DC600		HS		HS3		LSV2C		LSV4		CC1A		CC3A	
									Count	Proportion	Count	Proportion	Count	Proportion	Count	Proportion	Count	Proportion	Count	Proportion	Count	Proportion	Count	Proportion	Count	Proportion	Count	Proportion	Count	Proportion
Arthropoda		Insecta	Pterygota		Ephemeropteroidea	Ephemeroptera	Ephemeroptera	Mayflies	36	0.04	185	0.12	231	0.16	192	0.13	444	0.34	115	0.11	325	0.24	421	0.28	56	0.13	168	0.12	136	0.09
Arthropoda		Insecta	Pterygota		Exopterygota	Plecoptera	Plecoptera	Stoneflies	107	0.12	85	0.06	40	0.03	18	0.01	195	0.15	59	0.06	20	0.01	26	0.02	30	0.07	11	0.01	22	0.01
Arthropoda		Insecta			Amphiesmenoptera	Trichoptera	Trichoptera	Caddisflies	30	0.03	268	0.18	283	0.19	539	0.36	229	0.18	34	0.03	230	0.17	324	0.21	135	0.30	325	0.23	623	0.42
Arthropoda		Insecta	Pterygota	Neoptera	Endopterygota	Coleoptera	Coleoptera	Beetles	631	0.72	234	0.15	408	0.28	457	0.30	76	0.06	18	0.02	65	0.05	327	0.22	29	0.07	507	0.36	311	0.21
Arthropoda		Insecta		Neoptera		Megaloptera	Megaloptera	Alderflies, dobsonflies and fishflies	1	0.00	4	0.00	1	0.00																
Arthropoda		Insecta	Pterygota		Odonatoptera	Odonata	Odonata	Dragonflies and damselflies																			2	0.00	7	0.00
Arthropoda		Insecta		Neoptera	Paraneoptera	Hemiptera	Hemiptera	True bugs (cicadas, aphids, planthoppers, leafhoppers, shield bugs)	5	0.01																				
Arthropoda		Insecta			Panorpida	Diptera	Diptera	True flies	42	0.05	143	0.09	103	0.07	145	0.10	55	0.04	29	0.03	89	0.07	85	0.06	36	0.08	221	0.16	166	0.11
Arthropoda		Insecta				Chironomidae (family)	Chironomidae (family)	Midges			556	0.37	385	0.26	108	0.07	272	0.21	241	0.24	106	0.08	154	0.10	149	0.33	127	0.09	70	0.05
Annelida		Clitellata	Hirudinea				Hirudinea (class)	Leeches					1	0.00																
Arthropoda		Entognatha				Collembola	Collembola	Springtails (not insects!)					2	0.00																
Annelida		Clitellata	Oligochaeta				Oligochaeta (class)	Worms	5	0.01	24	0.02	17	0.01	16	0.01	27	0.02	178	0.18	3	0.00	43	0.03	8	0.02	9	0.01	75	0.05
Mollusca		Bivalvia					Bivalvia (class)	Clams	2	0.00	6	0.00	2	0.00			8	0.01	9	0.01	2	0.00	12	0.01			4	0.00	24	0.02
Mollusca		Gastropoda					Gastropoda (class)	Snails and slugs	21	0.02	7	0.00			11	0.01	1	0.00	319	0.32	16	0.01	54	0.04	1	0.00	21	0.01	29	0.02
Arthropoda	Crustacea	Malacostraca				Amphipoda	Amphipoda	Crustaceans											2	0.00	19	0.01	21	0.01			2	0.00		
Arthropoda	Crustacea	Ostracoda					Ostracoda	Sea shrimp					1	0.00							471	0.35	51	0.03	1	0.00	1	0.00		
Platyhelminthes		Turbellaria				Tricladida	Tricladida	Flatworms							4	0.00														
Arthropoda	Chelicerata	Arachnida	Acari				Acari (subclass)	Mites and ticks			4	0.00	7	0.00	15	0.01											4	0.00	5	0.00
							Total		880		1516		1481		1505		1307		1004		1346		1518		445		1402		1468	
								Midge		0.00		0.37		0.26		0.07		0.21		0.24		0.08		0.10		0.33		0.09		0.05
								Mayfly		0.04		0.12		0.16		0.13		0.34		0.11		0.24		0.28		0.13		0.12		0.09
								Other insects		0.93		0.48		0.56		0.77		0.42		0.14		0.30		0.50		0.52		0.76		0.77
								Molluscs		0.03		0.01		0.00		0.01		0.01		0.33		0.01		0.04		0.00		0.02		0.04
								Crustaceans		0.00		0.00		0.00		0.00		0.00		0.00		0.36		0.05		0.00		0.00		0.00
								Annelids		0.01		0.02		0.01		0.01		0.02		0.18		0.00		0.03		0.02		0.01		0.05
								Other		0.00		0.00		0.01		0.01		0.00		0.00		0.00		0.00		0.00		0.00		0.00

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	Total		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00
Take the top 3 that are above 1%		Insects	0.93	Insects	0.50	Insects	0.58	Insects	0.79	Insects	0.44	Midge	0.32	Insects	0.33	Insects	0.57	Insects	0.53	Insects	0.78	Insects	0.85
		Molluscs	0.03	Midge	0.38	Midge	0.27	Midge	0.07	Midge	0.21	Molluscs	0.44	Crustaceans	0.40	Midge	0.12	Midge	0.34	Midge	0.09	Midge	0.05
		Mayfly	0.04	Mayfly	0.13	Mayfly	0.16	Mayfly	0.13	Mayfly	0.35	Worms and leeches	0.24	Mayfly	0.27	Mayfly	0.31	Mayfly	0.13	Mayfly	0.12	Mayfly	0.10
			1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00

APPENDIX C: SUMMARIES OF CHRONIC STUDIES CONSIDERED FOR CRITERIA DERIVATION

White sturgeon C-2
Sacramento splittail C-12
Fathead minnow C-15
Flannelmouth & razorback suckers C-22
Northern pike C-24
Chinook salmon C-27
Rainbow trout & brook trout C-32
Cutthroat trout C-51
Dolly Varden C-65
Brown trout C-68
Desert pupfish C-86
Eastern and western mosquitofish C-103
Striped bass C-105
Bluegill sunfish C-106
Largemouth bass C-147

See Appendix E for descriptions of other, less conclusive studies with:
Rainbow trout
Fathead minnow
Sacramento splittail
White sucker

See Appendix E for descriptions of invertebrate studies.

NMED Exhibit 59

Tashjian, D.H., S.J. The, A. Sogomoyan and S.S.O. Hung. 2006. Bioaccumulation and chronic toxicity of dietary L-selenomethionine in juvenile white sturgeon *(Acipenser transmontanus*). Aquatic Toxicol.79:401-409.

Test Organism: White sturgeon (*Acipenser transmontanus*)

Exposure Route: Dietary only
Seleno-L-methionine was added to an artificial diet consisting of vitamin-free casein, wheat gluten, egg albumin, dextrin, vitamin mix, BTM-mineral mix, cellulose, corn oil, cod liver oil, choline chloride and santoquin; the measured dietary concentrations were 0.4, 9.6, 20.5, 41.7, 89.8, 191.1 mg Se/kg dw.

Test Duration: 8 weeks

Study Design: 25 juvenile white sturgeon were placed in each of 24 90-L tanks. Treatments were randomly assigned to the 24 tanks resulting in 4 replicates per dietary treatment. Four fish from each tank were sampled after 0, 4 and 8 weeks for weight, length, liver weight, condition factors, hepatosomatic indices, hemocrit, histopathology, and selenium measurement in liver, kidney, muscle and gill tissues. 8 fish after 0 and 8 weeks were sampled for whole body selenium measurement.

Effects Data: Sturgeon survival did not differ significantly among treatment groups after the 8-week exposure with a mean survival rate of 99 across all groups. Fish fed 41.7 to 191.1 mg Se/kg dw exhibited significant declines in body weight (see table). All other endpoints measured were as sensitive or less sensitive to selenium in the diet as body weight.

Mean (SE) white sturgeon moisture, lipid and whole body Se after 8-week exposure

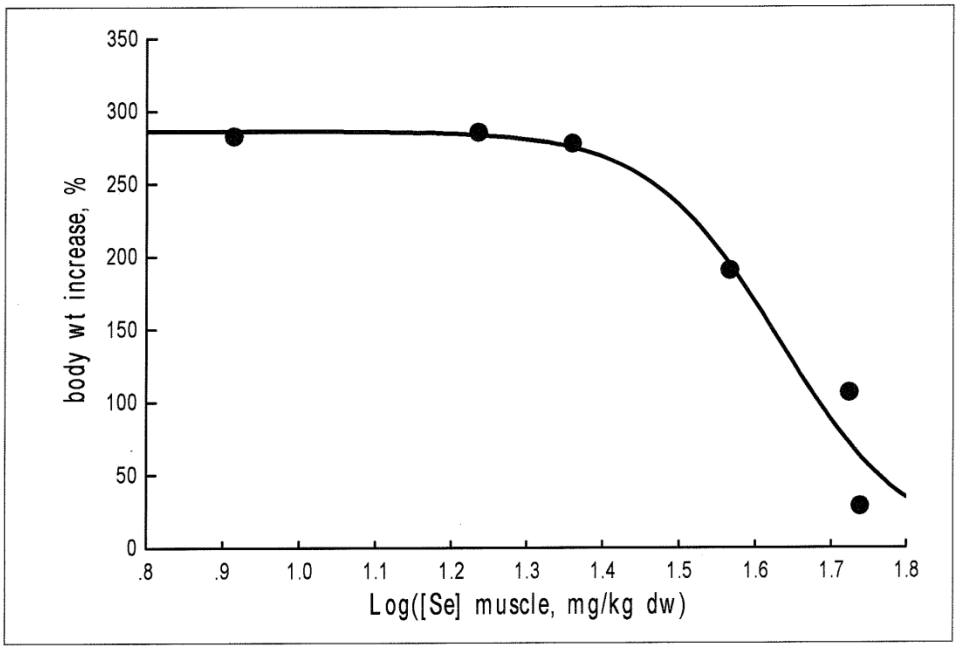
Treatment group	Moisture, % ww	Lipid, % ww	muscle Se, mg/kg dw	whole body Se, mg/kg dw
0.4	76.8 (0.5) b	9.5 (4) abc	8.2 (0.6) e	5.2 (0.4) c
9.6	77.0 (0.7) b	9.5 (0.9) abc	17.2 (0.7) d	11.8 (0.9) b
20.5	76.8 (0.3) b	10.1 (0.4) ab	22.9 (1.5) c	14.7 (0.8) b
41.7	77.3 (0.5) b	9.6 (0.7) abc	36.8 (1.8) b	22.5 (1.4) a
89.8	78.5 (0.3) ab	7.6 (0.4) bcd	52.9 (3.2) a	34.4 (2.3) a
191.1	80.0 (0.4) a	6.1 (0.4) cd	54.8 (2.8) a	27.5 (4.4) a

Mean (SE) white sturgeon body weight increase after 8-week exposure			
Treatment group	Body weight increase (%)	muscle Se, mg/kg dw	whole body Se, mg/kg dw
0.4	282.9 (4.6) a	8.2 (0.6) e	5.2 (0.4) c
9.6	285.5 (9.9) a	17.2 (0.7) d	11.8 (0.9) b
20.5	277.7 (6.1) a	22.9 (1.5) c	14.7 (0.8) b
41.7	191.0 (12.6) b	36.8 (1.8) b	22.5 (1.4) a
89.8	106.5 (5.8) c	52.9 (3.2) a	34.4 (2.3) a
191.1	28.6 (3.6) d	54.8 (2.8) a	27.5 (4.4) a

Letters denote statistical groupings among treatments within each exposure period ($p<0.05$).

Chronic Value: Using the logistic equation with a log transformation of the exposure concentrations (TRAP program), the EC_{10} and EC_{20} values for reduction in body weight are 15.08 and 17.82 mg Se/kg dw whole body and 27.76 and 32.53 mg Se/kg dw muscle tissue.

White sturgeon (Tashjian et al 2006)



Parameter Summary (Logistic Equation Regression Analysis)

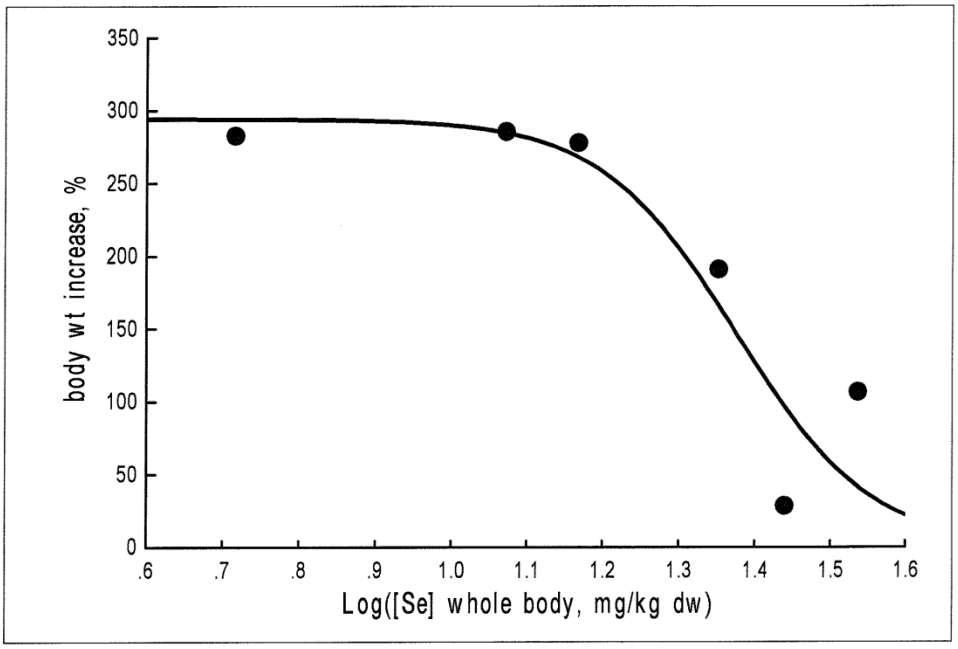
Parameter	Guess	FinalEst	StdError	95%LCL	95%UCL
LogX50	1.6006	1.6303	0.0314	1.5304	1.7301
S	1.6574	2.938	0.925	-0.005	5.882
Y0	284.2	286.3	18.9	226.1	346.5

Effect Concentration Summary

%Effect	Xp Est	95%LCL	95%UCL
50.0	42.69	33.92	53.72
20.0	32.53	21.17	49.99
10.0	27.76	15.63	49.30
5.0	23.98	11.75	48.93

06/19/2009 10:32 MED Toxic Response Analysis Model, Version 1.03

White sturgeon (Tashjian et al 2006)



Parameter Summary (Logistic Equation Regression Analysis)

Parameter	Guess	FinalEst	StdError	95%LCL	95%UCL
LogX50	1.3403	1.3750	0.0643	1.1702	1.5797
S	2.283	2.794	1.908	-3.277	8.865
Y0	284.2	294.2	45.0	151.0	437.3

Effect Concentration Summary

%Effect	Xp Est	95%LCL	95%UCL
50.0	23.71	14.80	37.99
20.0	17.820	6.890	46.090
10.0	15.078	4.160	54.655
5.0	12.926	2.587	64.584

06/19/2009 10:42 MED Toxic Response Analysis Model, Version 1.03

NMED Exhibit 59

Linville, R.G. 2006. Effects of Excess Selenium on the Health and Reproduction of White Sturgeon (*Acipenser transmontanus*): Implications for San Francisco Bay-Delta. Dissertation. University of California at Davis.

Test Organism: White Sturgeon (*Acipenser transmontanus*)

Exposure Route: Dietary only
Selenium was added to the treatment in the form of selenized yeast. Selenized yeast (2.2%; Selenomax®, Ambi Inc.) was added to a commercial salmonid diet and pelleted with fish oil. For the control diet, the selenized yeast mixture contained 1.3% selenized yeast and 98.7 tortula yeast. Only selenized yeast was added to the treatment diet. After pelleting, the diet was allowed to air dry on drying racks.

Test Duration: Females were fed 0.3% body weight/day the experimental diet for 6 months.

Study Design: 16 adult female white sturgeon (approximately 5 years old, mean weight and fork length: 22.71 kg and 134.59 cm) were exposed in a freshwater flow through system to either the control diet (8 females in one tank fed 1.4 mg/kg Se) or treatment (8 females in a separate tank fed 34 mg/kg Se, Se from selenized yeast) for 6 months. After the 6 month dietary exposure, females were induced to spawn and fertilized with non-exposed male milt. Eggs were hatched in jars keeping eggs from each female separate. For each progeny cohort, 3000 larvae were randomly distributed into 3 reps for stage 40 (intestinal portion is void of yolk material, but stomach is not differentiated and is filled with yolk) sampling and 3 reps for stage 45 (yolk sac absorbed, start exogenous feeding) sampling. Se and biological measurements were made in each replicate.

Effects Data: No Se effects were observed for length or weight of larvae. Effects were determined for edema (Table 1), skeletal deformities (Table 2) and larval survival (Table 4). Because the mortalities for each cohort were recorded up to the time the sample was collected for abnormalities, a combined effects variable can be the total proportion of hatched larvae which were both alive and without any abnormalities at stage 45 (Table 4). This was calculated as PS·(1-PA), where PS is the proportion survival in the test chambers prior to sampling and PA is the proportion of the sample of surviving larvae with abnormalities. Binomial confidence limits are included in Table 4 for percent survival and percent abnormalities for each cohort to visualize significant differences among data points and between data points and fitted curves. Such confidence limits cannot be directly calculated for the combined effects variable, for which confidence limits were estimated by combining the lower and upper confidence limits of the individual effects variables using the same equation as above (this slightly overestimates the confidence limit range).

In Table 4, only cohort T2 is significantly different from the controls, based both on larval survival and abnormalities. That this selenium effect is also supported by the microinjection studies of Linville, which showed large abnormality frequencies for egg Se injected with >15 mg/kg, but little or no effect at lower concentrations (this is only supporting information because direct injection of a

specific form of Se is not a complete surrogate for setting effect concentrations for maternally transferred Se). For cohort T3, the data for abnormalities indicate some effects, but cannot be considered a definite effect concentration due to a combination of considerations – overlapping confidence limits with controls, no increase in mortality, limited information on within-cohort variability, and, based on egg concentrations, no effects for cohort T1 at a higher concentration.

EC_{10} Calculations: The combined effects variable is plotted versus Se concentration in the eggs in Figure 1. With only one definite partial effect, TRAP cannot be used to estimate a curve. Instead, the interpolation protocol is applied between the last two points based on specifying the highest no-effect concentration (HNOEC), 11.0 mg/kg, to be the EC_0 in the interpolation equation and specifying the upper control plateau (Y_0 in TRAP) to be average survival of the lower four points. The resultant TRAP slope is 3.0 and the interpolated EC_{10} is 15.6 mg/kg.

The egg EC_{10} of 15.6 mg/kg is slightly lower than the value of 16.3 mg/kg in the previous draft (Figure 3). The lower value was due to the inclusion of larval survival with abnormalities in the endpoint and using interpolation between the last two points rather than a TRAP model of the dataset.

Linville (2006) similarly calculated a 10% effective dose (ED_{10}) of the combined skeletal and edema data of 15.3 mg Se egg/kg dw using a logit regression. Linville (2006) also noted statistically significant differences using a Tukey Honest Significant Difference (HSD) test between Se and control treatments with respect to both the incidence of Stage 45 skeletal and total deformities, respectively, for the maternal transfer study. These author-reported results support the evidence of an effect of selenium in white sturgeon similar to the EC_{10} of 15.6 mg Se/kg egg dw interpolated by TRAP.

The combined effects variable is plotted versus Se concentration in muscle in Figure 2. Unlike for the egg concentration, the muscle concentration for cohort T3, with a small but not significant effect, is greater than that for cohort T1, with no effect, so that TRAP can be used to estimate a curve, although only barely so. This analysis was by tolerance distribution analysis with the log-triangular model. The resultant TRAP estimates are 100% for the control value and 8.8 for the EC_0 (about 11% below the T1 concentration); the standard deviation is 0.14 log units, equivalent to a slope of 3.7. The EC_{10} estimate is 11.9 mg/kg.

Chronic Value: The chronic value for combined deformities and larval survival using egg Se is an EC_{10} of 15.6 mg egg/kg dw. The chronic value for this same endpoint in muscle tissue is an EC_{10} of 11.9 mg muscle/kg dw.

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Table 1. Edema deformities.

	Control			Treatment		
	Cohort	**Edema (%)**	**Larval Se (mg/kg dw)**	**Cohort**	**Edema (%)**	**Larval Se (mg/kg dw)**
	C3	0.00 (1)	2.43	T1	0.00 (1)	11.6
Stage 36	C4	0.00 (1)	1.69	T2	0.00 (1)	18.4
	C5	0.00 (1)	2.67	T3	6.67 (1)	7.75
Stage 40	C4	0.00 (3)	1.8	T1	0.00 (3)	11.6
	C5	0.00 (3)	2.88	T2	4.44 ± 2.22 (3)	20.4
				T3	1.67 ± 1.67 (2)	7.22
Stage 45	C4	0.00 (3)	1.96	T1	0.00 (3)	12
	C5	0.00 (3)	2.59	T2	15.56 ± 1.11 (3)	19.4
				T3	0.00 (2)	7.61

Table 2. Skeletal deformities.

	Control			Treatment		
	Cohort	**Skeletal (%)**	**Larval Se (mg/kg dw)**	**Cohort**	**Skeletal (%)**	**Larval Se (mg/kg dw)**
	C3	0.00 (1)	2.43	T1	0.00 (1)	11.6
Stage 36	C4	0.00 (1)	1.69	T2	0.00 (1)	18.4
	C5	0.00 (1)	2.67	T3	10.00 (1)	7.75
Stage 40	C4	1.11 ± 1.11 (3)	1.8	T1	0.00 (3)	11.6
	C5	1.11 ± 1.11 (3)	2.88	T2	14.44 ± 1.11 (3)	20.4
				T3	8.33 ± 1.67 (2)	7.22
Stage 45	C4	0.00 (3)	1.96	T1	0.00 (3)	12
	C5	0.00 (3)	2.59	T2	21.11 ± 1.11 (3)	19.4
				T3	13.33 ± 3.33 (2)	7.61

Table 3. Combined edema and skeletal deformities.

Control					Treatment			
	Cohort	Affected (%)	Egg Se (mg/kg)	Larval Se (mg/kg)	Cohort	Abnormal (%)	Egg Se (mg/kg)	Larval Se (mg/kg)
Stage 36	C3	0.00 (1)	2.46	2.43	T1	0.00 (1)	11	11.6
	C4	0.00 (1)	1.61	1.69	T2	0.00 (1)	20.5	18.4
	C5	0.00 (1)	2.68	2.67	T3	16.67 (1)	7.61	7.75
Stage 40	C4	1.11 ± 1.11 (3)	1.61	1.8	T1	0.00 (3)	11	11.6
	C5	1.11 ± 1.11 (3)	2.68	2.88	T2	18.89 ± 1.11 (3)	20.5	20.4
					T3	10.00 ± 0 (2)	7.61	7.22
Stage 45	C4	0.00 (3)	1.61	1.96	T1	0.00 (3)	11	12
	C5	0.00 (3)	2.68	2.59	T2	27.78 ± 2.94 (3)	20.5	19.4
					T3	13.33 ± 3.33 (2)	7.61	7.61

Table 4. Stage 45 data combined abnormalities and percent larval survival.

Cohort	Egg Se (mg/kg)	Muscle Se (mg/kg)	% Survival (95% Binomial CL)	% Abnormal (95% Binomial CL) [# Abnormal][1]	% Alive & w/o Abnormalities (95% Binomial CL)
C4	1.61	1.22	99.7 (98.9-99.9)	0.0 (0.0-4.2) [0,0,0]	99.7 (95.7-99.9)
C5	2.68	1.48	99.7 (98.9-99.9)	0.0 (0.0-4.2) [0,0,0]	99.7 (95.7-99.9)
T3	7.61	11.1	>99.6 (98.7-99.8)	13.3 (3.7-24.6) [3,5]	86.4 (74.4-96.3)
T1	11	9.93	>99.6 (98.7-99.8)	0.0 (0.0-4.2) [0,0,0]	99.7 (95.7-99.9)
T2	20.5	15.3	91.6 (90.1-92.8)	27.8 (18.8-38.3) [7,8,10]	66.2 (55.6-75.4)

[1] Bracketed numbers denote abnormal larvae in each of the 2-3 replicates of n=30.

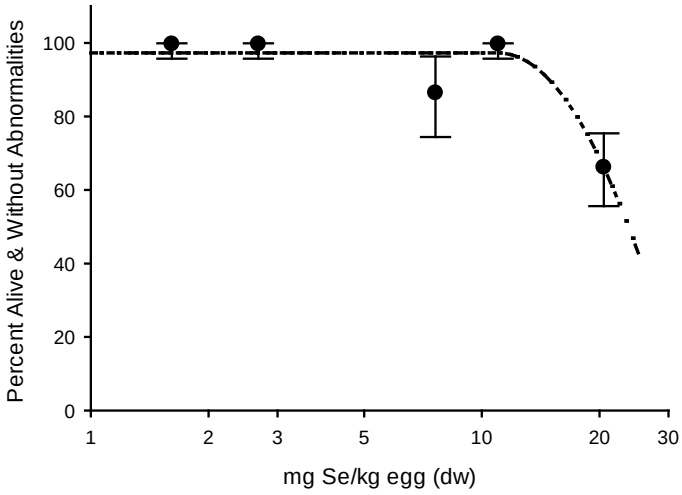


Figure 1. White sturgeon percent alive and without abnormalities as a function of the logarithm of selenium concentrations in eggs. TRAP is used to interpolate between the last two points; EC10 = 15.6 mg Se/kg egg dw.

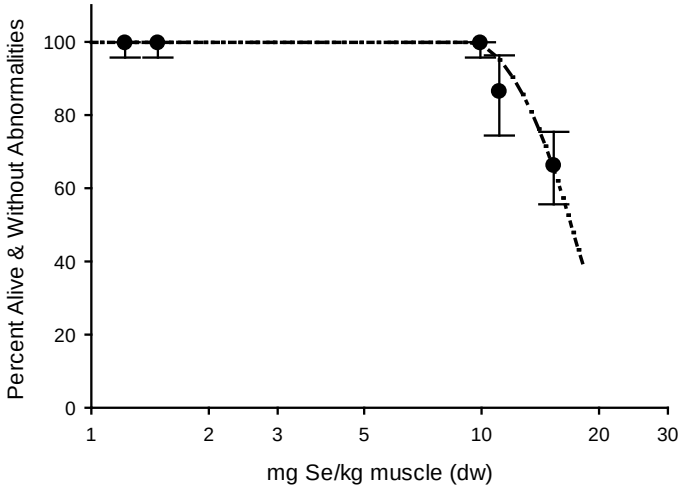
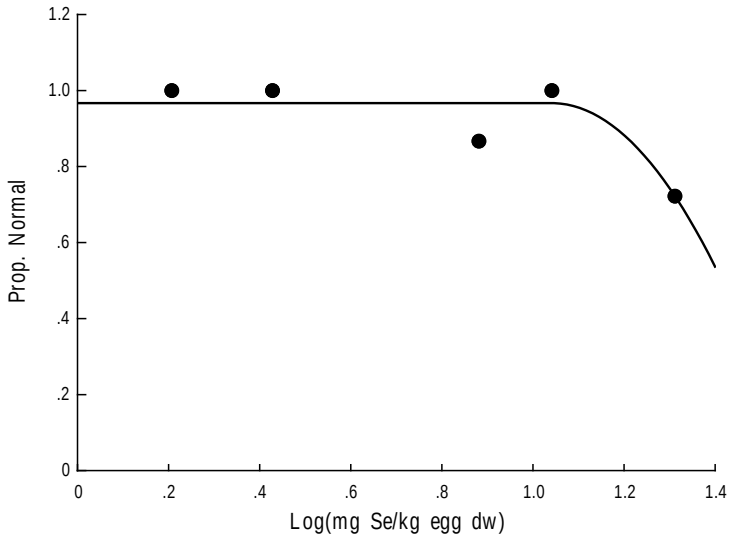


Figure 2. White sturgeon percent alive and without abnormalities as a function of the logarithm of selenium concentrations in female muscle. TRAP tolerance distribution analysis with the log-triangular model; EC10 = 11.9 mg Se/kg muscle dw.



Parameter	Initial	Final
LogX50	1.416	1.4215
S	**2**	**2.6306**
Y0	0.96667	0.96667

Figure 3. TRAP analysis from previous draft. Initial estimate for slope set equal to or less than 2.645 (set to 2 for this figure). EC_{10} = 16.3 mg/kg.

Teh, S.J., X. Deng, D-F Deng, F-C Teh, S.S.O. Hung, T.W. Fan, J. Liu, R.M. Higasi. 2004. Chronic effects of dietary selenium on juvenile Sacramento splittail (*Pogonichthys macrolepidotus*). Environ. Sci. Technol. 38: 6085-6593.

Test Organism: Sacramento splittail (*Pogonichthys macrolepidotus*); juveniles 7-mos.old

Exposure Route: Dietary only

Dietary Treatments: 8 graded levels of dietary Se; dietary levels obtained by combining selenized yeast with Torula (non-active) yeast. Selenized yeast contained approximately 21% of Se as selenomethionine and proteinaceous Se forms. Diet was formulated as pellets by mixing dry ingredients with water and oil, fan-dried, crumbled and sieved. Analyzed levels: 0.4 (no selenized yeast), 0.7, 1.4, 2.7, 6.6, 12.6, and 57.6 mg/kg.

Fish were fed twice daily with a daily feeding rate of 3% BW in first 5 months and then adjusted to 2% BW thereafter.

Test Duration: 9 months

Study Design: A flow-through system with 40 fish/tank (24 total tanks) was used; each tank held 90 L. Flow rate was 4 L/min. Water temperature was maintained at 23°C for 6 months and then 18°C for last 3 months due to failure of water heating system. 5 fish were sampled from each tank at 5 and 9 months and measured for gross deformities, length, weight, Se in liver and muscle. Sections of the liver were kept for histopathology. Condition factor (100 x BW/length), heptatosomatic index (100 x liver weight/BW), BCF (total organ Se/dietary Se) were determined.

Effects Data: Mortality was observed in the two highest dietary treatments: 10 and 34.3%, respectively. No mortalities were observed in fish fed diets # 12.6 mg/kg. No significant difference in growth of fish fed 12.6 mg/kg Se in diet, but there was in the fish fed 26.6 mg/kg Se. See table below for levels of Se in fish at 9 months and associated effects.

Authors determined prevalence of deformities was higher in fish fed 6.6 and 12.6 mg/kg Se in their diet, however a dose-response relationship did not occur (e.g., no deformities in high concentration). Gross pathology was a more sensitive endpoint than growth.

Summary of effects and assoc. dietary and tissue concentrations in Sacramento splittail after 9 month exp.								
Dietary conc'n mg/kg	0.4	0.7	1.4	2.7	6.6	12.6	26.0	57.6
Se in liver, mg/kg dw	20.1	18.6	20.0	23.0	26.8	31.3	40.4	73.7
Se in muscle, mg/kg dw	6.6	6.9	9.2	10.1	15.1	18.9	29.4	38.7
Liver histopathology (mean lesions scores, N=15)								
Macrophage aggregate	0.13	0.07	0.2	0.27	0.40	0.20	0.20	0.85
Glycogen depletion	0	0	0.2	0	0.4	0.2	0	1.38
Single cell necrosis	0	0	0	0.07	0.13	0	0.07	0.46
Fatty vacuolar degeneration	0	0	0	0.2	0.53	0.07	0.2	0.08
Eosinophilic protein droplets	0	0	0	0	0	0	0.07	0.85
Sum of mean lesion scores	0.13	0.07	0.4	0.54	1.46	0.47	0.54	3.62
Gross Pathology (No. of deformities, N=15)								
Facial deformities (eye, jaw, and mouth)	0	1	0	1	5	3	0	0
Body deformities (kyphosis, lordosis, scoliosis)	0	0	4	2	3	1	1	0
Prevalence of deformity (%)	0	6.7	26.7	20	53.3	26.7	6.7	0

Chronic Value: Using gross pathology as the endpoint (prevalence of deformities, %), the NOAEC is 10.1 mg Se/kg dw and the LOAEC is 15.1 mg/kg Se dw in muscle tissue; MATC or CV = 12.34 mg/kg Se in muscle dw.

The above concentrations in juvenile muscle tissue cannot be exactly translated into an equivalent egg-ovary or whole-body concentration in adult splittail. But using the median egg-ovary to muscle ratio of 1.59 for the family Cyprinidae, the NOEC and MATC would represent 16.1 and 19.6 mg Se/kg egg-ovary. Using the median muscle to whole-body ratio of 1.26 for the family Cyprinidae, the NOEC and MATC would represent 8.04 and 9.83 mg Se/kg whole body. However, appropriateness of these conversion estimates rests upon uncertain assumptions that the muscle concentrations in juvenile splittails equal those of adult splittails under the same exposure conditions, and that splittail tissue ratios are those typical of the family Cyprinidae.

Comments: The authors observed deformities including spinal deformities using fish that were 7-months-old at test initiation. This is the only study in which deformities were observed in fish that were not exposed maternally.

Deng et al. (2008) exposed Sacramento splittail juveniles (21-day post hatch) to dietary selenium and dietary methylmercury in a two factorial design for four weeks. No adverse effects (growth, condition factor, lethargy or abnormalities) were observed in the selenium only exposures. The splittail accumulated approximately 3.5 mg Se/kg ww muscle in the highest dietary exposure (35 mg

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Se/kg. Using the average percent moisture in fish muscle of 78.4% (May et al. 2000), the dw Se concentration is 16.2 mg Se/kg muscle indicating the recommended CV does not over-estimate an effect concentration.

Rigby et al. (2010) re-analyzed the juvenile Sacramento splittail data generated in the Teh et al. (2004) study. The authors used logistic regression to estimate EC values for deformities on a culled data set which eliminated the three highest dietary treatments due to their departure from a standard concentration-response relationship. The EC_{10} value for the culled data set was 7.9 mg Se/kg dw muscle which is lower than the recommended CV of 12.3 mg Se/kg dw muscle. Due to the lack of a concentration-response relationship across the entire dietary range and the lack of effects in the Deng et al. (2008) study, an EC_{10} of 7.9 mg Se/kg dw muscle is too uncertain for a recommended CV. Although the recommended CV of 12.3 mg Se/kg dw muscle is based on deformities (an uncertain response), it is considered representative of an effect level for this species because of the significant reductions in growth at the two highest test concentrations.

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Bennett, William N., Arthur S. Brooks, and Martin E. Boraas. 1986. Selenium uptake and transfer in an aquatic food chain and its effects on fathead minnow larvae. Arch. Environ. Contam. Toxicol. 15:513-517.

Test Organism: Fathead minnow (*Pimephales promelas*; 2 to 8 day-old larvae).

Exposure Route: Dietary only
Green alga, *Chlorella pyrenoidosa* were exposed to Se ($H_2{}^{75}SeO_4$) in culture water for 3 days. Rotifers, *Brachionus calyciflorus*, were cultured in chambers with selenium containing green algae at the ratio of 25 μg algae/ml to 50 μg rotifer/ml for 5 hr. The rotifers were filtered to separate them from the algae and immediately heat-killed. The Se concentration in the rotifers was measured for ^{75}Se activity.

Test Duration: 9 to 30 days

Study Design: Selenium uptake by larval fathead minnows was measured in three experiments. Se-contaminated and control rotifers for feeding to larval fish were prepared in advance using the low algae:rotifer ratio. Daily equal volumes of rotifers were divided among five 800 mL polypropylene larval chambers. Three chambers received Se-contaminated rotifers and two received control rotifers. The rotifers were dead at the time of feeding (heat killed).

Larval fish were hatched from eggs spawned in the laboratory. After hatching, active larvae were divided equally among the larval test chambers (daily renewal exposures using dechlorinated Lake Michigan water). Larvae were initially fed rotifers raised on control algae (no selenium). The age of the larvae when first fed Se-contaminated rotifers was 4, 9, and 3 days post-hatch for experiments 1, 2, and 3, respectively. Larval fish were fed Se-contaminated rotifers for 7, 9, and 7 days in the 3 experiments. A post-exposure observation period of 19 and 2 days was used for experiments 1 and 2, respectively. During this time the larvae were fed control rotifers. Daily, larvae from a replicate were removed from the test chamber, washed, placed in a 20 ml vial, and counted for ^{75}Se activity for 20 min. All larvae were then placed in test chambers with fresh food rations. At the end of the study all fish were individually dried and weighed.

	Experiment 1	Experiment 2	Experiment 3
Initial feeding of control diet (days)	3	8	2
Day Se diet first fed	4	9	3
Day Se diet last fed	11	17	9
Observation days on control diet	19	2	0
Age at study termination (days)	30	19	9

Effects Data:

	Experiment 1	Experiment 2	Experiment 3
Mean food Se concentration (mg/kg)	>70	68	55
Food intake (μg rotifers/larva)	50	1330	1190
Initial larvae mean dry wt. at start of Se-laden food (μg)	90	400	100
Final larvae mean dry wt. (μg) at end of test	1470 (Control) 800 (Treatment)[a]	1888 (Control) 1354 (Treatment)[a]	475 (Control) 416 (Treatment)
Final mean larval Se content (μg Se/larva)[b]	0.0062	0.0700	0.0248
Final mean larval Se concentrations (mg Se/kg dw)	43.0	51.7	61.1

[a] Significantly different from the control.
[b] Values when Se-laden feeding was ended.

Selenium was measured in the test water during the feeding exposures, but the concentrations were insignificant (0.84 μg/L). Survival was not affected by the selenium exposures. Preliminary tests showed that fathead minnow larvae would reach plateau concentrations of selenium within the 7- to 9-day exposure periods. The food supply was sufficient to sustain growth of the larvae during the study, according to the authors. The authors state that selenium uptake and higher selenium content in experiment 2 larvae was due to their larger size and ability to consume more rotifers/unit time. Se-exposed larvae were significantly smaller ($p<0.05$) in mass than controls for experiments 1 and 2.

Chronic Value: GM of mean larval Se concentrations measured in the three experiments, i.e., 43.0, 51.7, and 61.1 mg/kg dw WB, respectively, is 51.40 mg Se/kg dw.

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Dobbs, M.G., D.S. Cherry, and J. Cairns, Jr. 1996. Toxicity and bioaccumulation of selenium to a three-trophic level food chain. Environ. Toxicol. Chem. 15:340-347.

Test Organism: Rotifer (*Brachionus calyciflorus*), and fathead minnow (*Pimephales promelas*) 12 to 24 hr-old at start.

Exposure Route: Dietary and waterborne

Water
Filtered and sterilized natural creek water supplemented with nutrients (Modified Guillard's Woods Hole Marine Biological Laboratory algal culture medium) for algal growth. Sodium selenate (Na_2SeO_4) was added to test water to obtain nominal concentrations of 100, 200, or 400 µg Se/L. Concentrations remained stable and equal in each trophic level.

Control Diet
No selenium was added to the water medium for the alga; green alga was free of selenium for the rotifer; and rotifers were free of selenium for the fathead minnow.

Selenium Diet
Sodium selenate was added to the culture medium for the alga; green alga thereby contained a body burden for the rotifer; and rotifers thereby contained a body burden for the fathead minnow.

Dietary Treatments: Each trophic level had a different treatment. The green alga was exposed directly from the water (1, 108.1, 204.9, 397.6 µg total Se/L); rotifers were exposed from the water (1, 108.1, 204.9, 393.0 µg total Se/L) and the green alga as food (2.5, 33, 40, 50 mg Se/kg dry wt.); and the fathead minnow were exposed from water (1, 108.1, 204.9, 393.0 µg total Se/L) and the rotifer as food (2.5, 47, 53, 60 mg Se/kg dry wt.).

Test Duration: 25 days

Study Design: A flow-through system utilizing a stock solution of filtered and sterilized creek water controlled at 25°C was used to expose three trophic levels of organisms. Approximately one liter of media was pumped from the algal chamber into the rotifer chamber each day. A cell density between 3 and 6×10^6 cells/ml was delivered to the rotifer chambers. Rotifers were started at a density of 151.4 ± 7.7 females/ml and one liter/day of rotifers containing culture water was intermittently pumped into the minnow chamber. (*B. calyciflorus* has a life span of about 7 days at 25°C.) The pump was necessary to overcome the swimming ability of rotifers to avoid an overflow tube. Larval fathead minnows (35/chamber) were prevented from escaping by a screened overflow. Chambers were cleaned daily and aeration was provided. All chambers were duplicated for test replication and water was measured for selenium on days 0, 2, 6, 7, 11, 14, 17, 20, and 24. All algal and rotifer biomass and selenium samples were made on these days. Fathead minnow chambers were measured for biomass, dissolved selenium, and tissue selenium concentrations of days 0, 7, 11, 14, 20, and 24.

Additional measurements were made in the 200 µg Se/L test chambers on the fathead minnow on day 16. Selenium concentrations were maintained near the nominal concentrations and the standard deviation of mean concentrations was less than 4 percent.

Effects Data:

Rotifers. Rotifers did not grow well and demonstrated reduced survival at all selenium exposure concentrations during the 25 day test. By test day 7 only the lowest test concentration (108.1 µg/L) had surviving rotifers which showed a decrease in selenium content from test days 18 through 25. A reduction in rotifer biomass was discernable by test day 4 in the selenium treatments and since all test concentrations had viable rotifer populations present, the effect level was calculated using these data.

Effect of Dietary and Waterborne Selenium on Rotifers after 4 Days Exposure

Se in water, µg/L	Se in diet, mg/kg dw	Se in rotifer tissue, mg/kg dw	rotifer biomass, mg/ml dw
1	2.5	2.5	0.028
108.1	33	40	0.025
202.4	40	54	0.011
393	50	75	0.003

Fathead minnows. Due to the reduction of rotifer biomass in the higher test concentrations, fish mortality and reduction in fish growth observed in the latter days of the test was difficult to discern between effects from starvation and selenium toxicity. The data from test day 8 was selected for determining the effect of selenium on fathead minnows because starvation could be excluded as a variable.

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Effect of Dietary and Waterborne Selenium on Larval Fathead Minnows after 8 Days Exposure			
Se in water, µg/L	**Se in diet, mg/kg dw**	**Se in fathead minnow tissue, mg/kg dw**	**Average fish weight, mg dw**
1	2.5	2.5	0.8
108.1	47	45	0.7
202.4	53	75	0.4
393	60	73	0.2

Chronic Value:

Rotifers 42.36 mg Se/kg dw (EC_{20})

Fish < 73 mg Se/kg dw (LOAEC) - not amenable to statistical treatment; the LOAEC was based on the observation that a >50 percent reduction in mean fish weight occurred at this tissue concentration.

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Schultz, R. and R. Hermanutz. 1990. Transfer of toxic concentrations of selenium from parent to progeny in the fathead minnow (*Pimephales promelas*). Bull. Environ. Contam. Toxicol. 45:568-573.

Test Organism: Fathead minnow (*Pimephales promelas*; Adults)

Exposure Route: Dietary and waterborne
Selenite was added to artificial streams which entered the food web; thus, fish were also exposed to selenium in the diet.

Study Design: Four Monticello artificial streams were used for the study which lasted from September 1987 to September 1988. For each study, two streams (treated) were dosed continuously to achieve 10 µg/L and two streams served as controls. Mean selenium concentrations at the head of the treated streams were 9.8 ± 1.2 and 10.3 ± 1.7 µg/L, respectively. The concentrations of selenium measured in the water from controls streams were all less than the detection limit, i.e., 2 µg/L. Spawning platforms were submerged into each stream. One subset of six embryo samples (n = 2000 embryos per sample) were collected from the streams for selenium analysis. Another subset of ten embryo samples were reared in incubation cups receiving the same stream water dosed with sodium selenite via a proportional diluter. The treated embryos in egg cups received an average 9.7 ± 2.6 µg Se/L. Samples of hatched larvae were analyzed for selenium content while others were inspected for occurrence of edema and lordosis. Prior to test termination, female parents were seined. The mean selenium content in the ovaries of seven to eight females from the treated and control streams was reported.

Effects Data: Edema and lordosis occurred in approximately 25 percent of the fish spawned and reared in 10 µg Se/L. Corresponding occurrence in control fish incubated in the egg cups was only 1 and 6 percent, respectively. Table 1 provides the abnormality observations and the selenium residues in the embryos and ovaries from the control and treated streams. Although a case can be made that the Se treatment had a higher rate of edema and lordosis, there are some problems that add uncertainty to the estimation of an effect concentration (R. Erickson, pers. comm.). Heavy mortality/loss of embryo/larvae during monitoring and the erratic occurrence of the abnormalities (e.g., there is a significant incidence of edema in only 3 of 10 replicates for the Se treatment) led to the conclusion that results should not be used for criterion derivation. However, the data from this study support the range of reproductive effect levels determined in other studies. The Se concentration in embryos from the 10 µg/L treatment stream of 3.91 mg/kg ww converts to 25.6 mg/kg dw using 15.3% dw (N=3 range 14.7 – 15.6%) for fathead minnow eggs (R. Erickson, pers. comm). The previous draft used the Se concentrations in the ovaries collected at the end of the study for the effect concentration estimate. However, it was determined that the embryos are a more direct representation of Se exposure and toxicity to the larvae.

Chronic Value: The LOEC for embryos is <25.6 mg Se/kg dw.

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Table 1. Percent Abnormalities in Fathead Minnow Larvae and the Associated Selenium Concentrations in Embryos and Ovaries.

Treatment	[Se] embryos, mg/kg ww (SD)	[Se] ovaries, mg/kg ww (SD)	Edema, % (SD)	Lordosis, % (SD)
Control	0.31 (0.01)	0.77 (0.14)	0.9 (2.2)	5.6 (8.8)
10 µg/L	3.91 (1.87)	5.89 (2.21)	24.6 (36.1)	23.4 (20.8)

SD = standard deviation

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Beyers, D.W. and Sodergren, C. 2001a. Evaluation of interspecific sensitivity to selenium exposure: Larval razorback sucker versus flannelmouth sucker. Larval Fish Laboratory. Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, Colorado.

Test Organism: Larval flannelmouth sucker (*Catostomus latipinnis*) and larval razorback sucker *(Xyrauchen texanus)*

Exposure Route: Dietary and waterborne - laboratory exposure (28-d early life stage) Continuous flow diluter supplied a range of aqueous test concentrations <1, 25.4, 50.6, 98.9, and 190.6 µg/L selenate. Well water was used as the dilution water. Across the range of aqueous exposure concentrations, each test chamber was fed the same daily ration of living rotifers containing selenium at <0.702, 1.35, 2.02, 4.63, and 8.24 mg/kg dw, respectively. Rotifers accumulated selenium from algae (*Chlorella vulgaris*) exposed to 0, 25, 50, 100, and 200 :g/L selenate.

Study Design: Replicated (n=4) exposure beakers using a randomized, balanced 5x2 factorial design (1^{st} factor - selenium; 2^{nd} factor - species). Survival was monitored daily and growth measured at the end of the 28-day exposure. Selenium was measured in the larvae at the end of the 28-day exposure.

Effects Data : No survival effects were observed and there were no decreases in fish weight or length. Fish mass was found to increase as a function of selenium concentration.

Chronic Value: The chronic values for the flannelmouth sucker and razorback sucker were >10.2 and >12.9 mg Se/kg dw, respectively, based on the concentrations of selenium measured in whole-body tissue of larval fish at the highest water and dietary selenium concentrations.

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Beyers, D.W. and Sodergren, C. 2001b. Assessment of exposure of larval razorback sucker to selenium in natural waters and evaluation of laboratory-based predictions. Larval Fish Laboratory. Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, Colorado.

Test Organism: Larval razorback sucker *(Xyrauchen texanus)*

Exposure Route: Dietary and waterborne - laboratory exposure (28-d early life stage)
Larvae were exposed in a daily static-renewal system to control water (reconstituted very hard) and site waters: De Beque, Orchard Mesa, North Pond diluted 50%, and North Pond. Each water type received either a control diet (rotifers) or a diet previously exposed to the site water (site food: rotifers fed algae exposed to respective site water).

Study Design: Replicated (n=4) exposure beakers using a randomized, balanced 5x2 factorial design (1^{st} factor - test water type; 2^{nd} factor - rotifers cultured in control water or in site water). Survival was monitored daily and growth measured at the end of the 28-day exposure. Selenium was measured in the larvae at the end of the 28-day exposure.

Effects Data: No survival effects were observed. There were no significant decreases in growth of fish exposed to both site water and site food compared to fish exposed to control water and control food. There was a significant increase in growth of fish exposed to site water and control food relative to fish exposed to control water and control food ($p<0.0001$). There were reductions in the growth of fish (14%) exposed to site water and site food compared to site water and control food ($p<0.0001$). Due to the lack of a dose-response relationship in both the concentration of selenium in the food (rotifers) and growth, and the concentration of selenium in the fish larvae and growth, the authors did not attribute the effect of site food on the growth of fish to selenium.

Chronic Value: The NOAEC for the razorback sucker larvae in the four site water types based on selenium in whole-body tissue were: De Beque >5.45 mg Se/kg dw; Orchard Mesa >11 mg Se/kg dw; North Pond 50% dilution >41.1 mg Se/kg dw; North Pond >42 mg Se/kg dw. Because no significant effects were observed in larvae exposed to North Pond water at >42 mg Se/kg dw whole-body tissue, this value was selected as the chronic value for the study.

NMED Exhibit 59

Muscatello, J.R., P.M. Bennett, K.T. Himbeault, A.M. Belknap and D.M. Janz. 2006. Larval deformities associated with selenium accumulation in northern pike (*Esox lucius*) exposed to metal mining effluent. Environ. Sci. Technol. 40:6506-6512.

Test Organism: Northern pike (*Esox lucius*)

Exposure Route: Dietary and waterborne - field exposure

Test Duration: Eggs were collected in the field and incubated in the laboratory. The test was terminated when the majority of the fry exhibited swim-up and had absorbed the yolk.

Study Design: The study area was Key Lake uranium milling operation in north-central Saskatoon. Spawning northern pike were collected from four sites, one reference (Davies Creek) and three exposure sites, David Creek near-field (high exposure), Delta Lake (medium exposure), and David Creek far-field (low exposure). The exposure sites were located approximately 2, 10 and 15 km downstream of the effluent discharge. Milt and ova were stripped from ripe fish and eggs were fertilized in the field. Females were saved for metal analysis and age determination. Subsamples of ova (prior to fertilization) were collected for metal analysis.

Although the study sites represent open systems where fish can potentially migrate among sites, radiotelemetry data from tagged adult pike (Muscatello and Janz, unpublished data) indicate high site fidelity at the “high” and “medium” exposure sites (lakes). In contrast, the “low” exposure site likely represents pike that migrated from further downstream sites that were likely of similar Se exposures as the reference site.

Eggs were incubated using a two-way ANOVA experimental design using water collected from reference or exposure sites. So, embryos originating from reference or exposure site females were incubated in either reference or appropriate exposure water. In addition, embryos from reference site females were incubated in water from all four study sites. 50 viable embryos from each individual female were transferred to each of four replicate incubation chambers. Cumulative time to 50% eyed, 50% hatch and 50% swim-up were determined. When the majority of the fry exhibited swim-up and had absorbed the yolk, the remaining fry were preserved and examined for deformities.

Effects Data: Mean egg diameter and fertilization success did not differ among sites. Cumulative embryo mortality throughout incubations was not significantly different among the sites ranging from 45 to 60%. There were no significant differences in the cumulative time to reach 50% eyed embryos, 50% hatch or 50% swim-up among treatments. Differences in the percent total deformities between test waters used during embryo incubation exposures were not significant, so the data were combined for each site (see Table below).

Selenium concentrations in eggs and muscle from female northern pike collected from reference and exposed sites and associated total deformities in embryos					
Site	**Site ID**	**Female**	**[Se] mg/kg dw**		**Total deformities %**
			Egg	**Muscle**	
Davies Creek	Reference	1	3.45	0.86	17
Davies Creek	Reference	2	2.72	1.89	2.5
Davies Creek	Reference	3	3.39	2.56	15.51
Davies Creek	Reference	4	3.72	1.34	7.13
Davies Creek	Reference	5	2.69	1.04	10.41
David Creek (far field)	Low	1	3.39	1.95	20.32
David Creek (far field)	Low	2	4.07	2.04	13.19
David Creek (far field)	Low	3	4.07	1.26	15.33
David Creek (far field)	Low	4	4.07	2.48	18.83
David Creek (far field)	Low	5	3.4	1.26	11.8
Delta Lake	Medium	1	43.19	17	37.8
Delta Lake	Medium	2	24.53	16.52	31.71
Delta Lake	Medium	3	26.14	16.52	26.29
David Creek (near field)	High	1	48.23	47.82	39.5
David Creek (near field)	High	2	N/A*	28.72	N/A*

*female had no eggs

Significant increases in total deformities (edema, skeletal deformities, craniofacial deformities and fin deformities) were observed in fry originating from pike collected at the medium exposure site. Determination of an effect level for the percent total deformities relative to the concentration of selenium in eggs or in female muscle tissue was not amenable to analysis by TRAP. One requirement of TRAP is to have a response greater than 50%, which was not satisfied with the available data.

When data are not amenable to determining an effect level using a software program, such as TRAP, one way to estimate the effect level is to make a direct measurement of effect at an exposure or tissue concentration. For example, if only a control and one exposure concentration, 10 μg/L, were tested in an acute toxicity test and there was 100% survival in the control and 35% in the 10 μg/L, the effect level would be an EC_{35} of 10 **μg**/L. Such an approach was used to estimate effect in the Muscatello et al. data. Because no significant differences were observed in either selenium concentrations in eggs or percent total deformities between the reference and low exposure site, the data from these 10 sites were combined. Similarly, the egg **and muscle** selenium and total deformity data were combined for the 4 medium and high exposure sites. These means, geometric for the selenium concentrations and arithmetic for the percent total deformities, are given in the following table.

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	Mean selenium in northern pike egg and muscle and effect values for reference and exposure sites			
Sites	**[Se] in eggs, mg/kg dw (geometric mean)**	**[Se] in muscle, mg/kg dw (geometric mean)**	**Total deformities, % (arithmetic mean)**	**Total deformities, % (accounting for reference deformities and transformed to new scale)[a]**
Reference sites (includes low exposure)	3.462	1.570	13.20	0
exposure sites	34.00	21.70	33.82	23.76

[a] The % total deformities in the reference and exposed sites were normalized to the reference effect (13.2%) and then transformed to a new scale (100%). i.e, Abbott's formula.

The percent affected becomes 24% or an EC_{24} and the effect level is 34.00 mg Se/kg dw in eggs and 21.70 mg Se/kg in muscle**.**

Chronic Value: EC_{24} = 34.00 mg Se/kg dw in eggs. Note: an EC_{10} cannot be estimated with the data.

NMED Exhibit 59

Hamilton, S.J., K.J. Buhl, N.L. Faerber, R.H. Wiedermeyer and F.A. Bullard. 1990. Toxicity of organic selenium in the diet of chinook salmon. Environ. Toxicol. Chem. 9:347-358.

Test Organism: Chinook salmon (*Oncorhynchus tshawytscha* Walbaum; swim-up larvae)

Exposure Route: Dietary only

Control Diet

Oregon moist pellet diet where over half of the salmon meal was replaced with meal from low-selenium mosquitofish (1.0 mg Se/kg dw) collected from a reference site.

Selenium Diet #1

Oregon moist pellet diet where over half of the salmon meal was replaced with meal from high-selenium mosquitofish (35.4 mg Se/kg dw) collected from the San Luis Drain, CA, termed SLD diet.

Selenium Diet #2

Oregon moist pellet diet where over half of the salmon meal was replaced with meal from low-selenium mosquitofish same as in the control diet, but fortified with seleno-DL-methionine (35.5 mg Se/kg dw), termed SeMet diet.

Dietary Treatments: Each selenium diet was formulated to contain about 36 mg Se/kg dw as the high exposure treatment. The remaining treatments were achieved by thoroughly mixing appropriate amounts of high-exposure treatment diet with control diet to yield the following nominal concentrations (3, 5, 10, and 18 mg Se/kg dw).

Test Duration: 90 days

Study Design: Each dietary treatment was fed twice each day to swim-up larvae (n=100) in each of two replicate aquaria that received 1 L of replacement water (a reconstituted experimental water that simulated in quality a 1:37 dilution of water from the San Luis Drain, CA minus the trace elements) every 15 minutes (flow-through design). Mortality was recorded daily. Growth was evaluated at 30-day intervals by measuring the total lengths and wet weights of two subsets of individual fish (n=10x2) held in separate 11.5 L growth chambers within each replicate aquarium. Tissue samples were collected for whole-body selenium determinations (dw basis) at 30-day intervals throughout the study; 10, 5, and 2 fish were sampled from each duplicate treatment after 30, 60, and 90 days of exposure, respectively. Concentrations of selenium measured in water were below the limit of detection (1.5-3.1 μg/L) in all dietary selenium exposure concentrations.

Effects Data: The magnitude of reduced growth was most evident in the weight of the fish, although total length was significantly reduced in fish fed high Se-laden diets as well. The effect of increasing dietary selenium on mean larval weight was similar in both the SLD and seleno-methionine diets.

Effect of San Luis Drain Diet on Growth and Survival of Chinook Salmon Larvae after 60 Days			
Se in diet, mg/kg dw	**Se in chinook salmon, mg/kg dw**	**Mean larval weight, g**	**Survival, %**
1	0.9	3.35	99
3.2	3.3	2.68	97.3
5.3	4.5	2.76	93
9.6	8.4	2.8	95
18.2	13.3	2.62	92.4
35.4	29.4	1.4	89

Effect of Seleno-methionine Diet on Growth and Survival of Chinook Salmon Larvae after 60 Days			
Se in diet, mg/kg dw	**Se in chinook salmon, mg/kg dw**	**Mean larval weight, g**	**Survival, %**
1	0.9	3.35	99
3.2	2	3.08	100
5.3	3.1	3.22	95
9.6	5.3	3.07	94.1
18.2	10.4	2.61	92.4
35.4	23.4	1.25	62.5

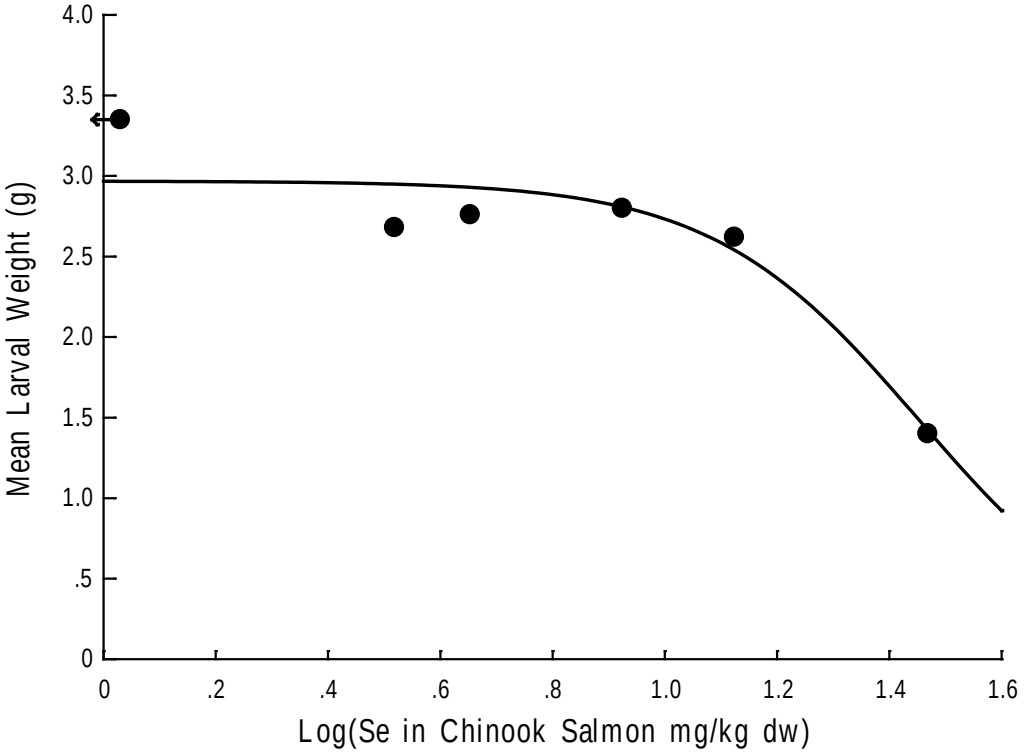
Chronic Value: Due to unacceptable control mortality of swim-up larvae in control treatments after 90 days (33.3 percent - SLD diet; 27.5 percent - SeMet diet), chronic values had to be determined from respective values reported after 60 days (tables above).

Analysis of the elemental composition of the SLD diet indicated that B, Cr, Fe, Mg, Ni and Sr were slightly elevated compared to the control and SeMet diets. No additional analyses were performed to determine the presence of other possible contaminants, i.e., pesticides.

	EC_{20} values		**EC_{10} values**
	Survival (after 60 d of exposure)	**Growth (after 60 d of exposure)**	**Growth (after 60 d of exposure)**
Diet type	**Tissue Se (mg/kg dw)**	**Whole body Tissue Se (mg/kg dw)**	**Whole body Tissue Se (mg/kg dw)**
SLD	NA[a]	15.73	11.14
SeMet	NA[a]	10.47	7.355

[a] The EC_{20} and EC_{10} values for survival of swim-up larvae versus levels of selenium for the SLD and SeMet dietary exposure could not be estimated using non-linear regression.

Hamilton et al (1990) Chinook Salmon fed SLD Diet
Logistic Equation, Three Parameter Model, Se concentrations log_{10} transformed

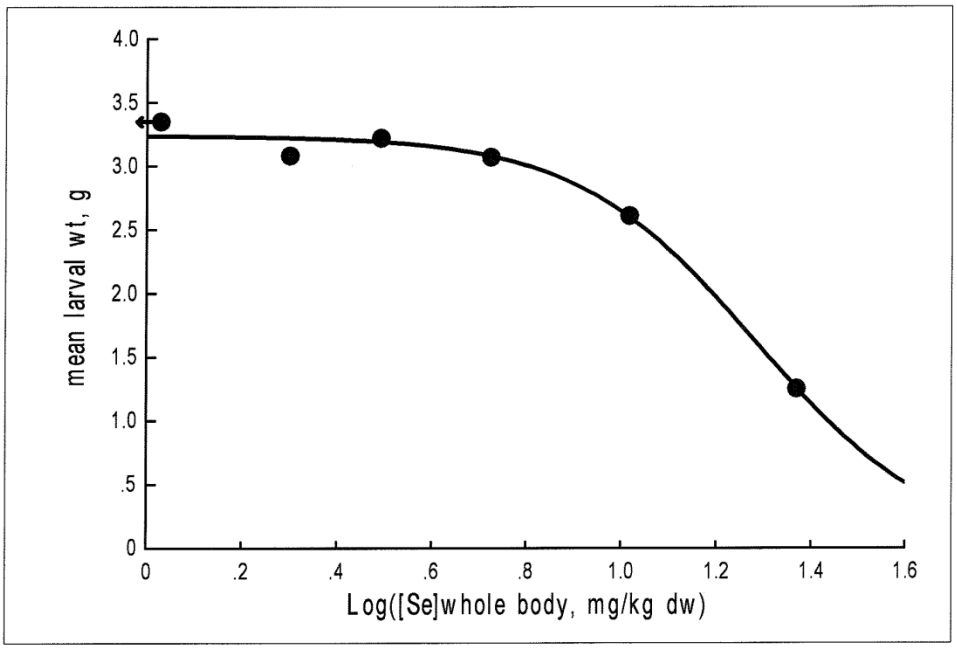


	Guess	FinalEst	SE	95%LCL	95%UCL
LogX50	1.453	1.453	7.30E-02	1.2206	1.6854
StDev	1.353	1.353	6.67E-01	-7.71E-01	3.4769
Y0	2.968	2.968	1.89E-01	2.3651	3.5709

%Effect	Xp Est	95% LCL	95% UCL
50	28.379	16.62	48.458
20	15.734	5.7003	43.431
10	11.143	2.4771	50.127
5	8.1085	1.1213	58.637

	DF	SS	MS	F	P
Total	5	2.0749	0.41498		
Model	2	1.8202	0.91009	10.719	0.95699
Error	3	0.2547	8.49E-02		

Chinook salmon SeMet diet (Hamilton et al. 1990)



Parameter Summary (Logistic Equation Regression Analysis)

Parameter	Guess	FinalEst	StdError	95%LCL	95%UCL
LogX50	1.3148	1.2823	0.0242	1.2053	1.3593
S	0.6971	1.3214	0.1826	0.7404	1.9025
Y0	3.217	3.239	0.067	3.027	3.452

Effect Concentration Summary

%Effect	Xp Est	95%LCL	95%UCL
50.0	19.156	16.045	22.870
20.0	10.472	7.516	14.591
10.0	7.355	4.595	11.775
5.0	5.312	2.899	9.733

06/19/2009 13:52 MED Toxic Response Analysis Model, Version 1.03

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Hilton, J.W. and P.V. Hodson. 1983. Effect of increased dietary carbohydrate on selenium metabolism and toxicity in rainbow trout (*Salmo gairdneri*). J. Nutr. 113:1241-1248.

Test Organism: Rainbow trout (*Oncorhynchus mykiss*; juvenile; approx. 0.6 g each)

Exposure Route: Dietary only

Low carbohydrate diet (LCD)
This diet contained capelin oil at 11 percent of the diet with cellulose as the filler.

High carbohydrate diet (HCD)
This diet contained cerelose at 25 percent of the diet with cellulose as the filler.

For both diets, the selenium was supplemented as sodium selenite which was mixed with cellulose and then added to the diet as a selenium premix.

Test Treatments: The two diets were supplemented with selenium (as sodium selenite) at the rate of 0, 5, or 10 mg/kg dw to make up the six different dietary selenium treatments (n = 3 low carbohydrate diet; n= 3 high carbohydrate diet). The six diets were fed to duplicate groups of 100 fish. The trout were fed to satiation 3-6 times per day. Measured concentrations of selenium in the low carbohydrate diet were: 0.6 (control), 6.6, and 11.4 mg/kg dw, and the measured concentrations of selenium in the high carbohydrate diet were: 0.7 (control), 6.6, and 11.8 mg/kg dw. The tanks received a continuous flow of water with a flow rate of 3-4 liters per minute.

Test Duration: 16 weeks

Study Design: Body weights, feed: gain ratios, and total mortalities were determined after each 28-day interval. After 16 weeks, approximately 20 fish were randomly removed from each tank, weighed, and blood was collected for hemoglobin, hematocrit, and plasma glucose, protein, and calcium determination. The livers and kidneys were then dissected. The livers were assayed for glycogen content, and samples of both liver and kidney were assayed for selenium content. Additional subsamples of fish were sacrificed and assayed for selenium content and for ash, crude protein, and moisture content (n=6 per treatment). Finally, 30 fish were killed, their livers and kidneys dissected, and analyzed for Ca, Cu, Fe, Mg, P, and Zn content.

Effects Data: The only overt sign of selenium toxicity was food avoidance observed in trout fed the highest selenium content in both low and high carbohydrate diets, which led to significantly reduced body weight after 16 weeks. There were no significant differences detected between treatment groups in hematological parameters. Kidney, liver, and carcass selenium levels increased with increasing selenium content of the diet, however, only the liver selenium concentrations were significantly affected by dietary selenium level, dietary carbohydrate level, and the interaction between the two treatments. Mineral analysis of the kidney showed significantly higher levels of calcium and phosphorous in trout reared on the two highest levels of dietary selenium. Concentrations of copper in the liver increased significantly with increasing dietary selenium levels and decreasing dietary carbohydrate levels.

Effect of Selenium in Low carbohydrate Diet to Rainbow Trout		
Se in diet, mg/kg dw	**Se in trout liver, mg/kg dw**	**Trout weight, kg/100 fish**
0.6	0.8	3.3
6.6	38.3	3.3
11.4	49.3	1.8

Effect of Selenium in High carbohydrate Diet to Rainbow Trout		
Se in diet, mg/kg dw	**Se in trout liver, mg/kg dw**	**Trout weight, kg/100 fish**
0.7	0.6	2.7
6.6	21.0	2.3
11.8	71.7	1.4

Chronic Value: The following table lists the NOAEC, LOAEC and MATC for both diets in liver tissue. EC values could not be determined for this study. Data did not meet minimum requirements for analysis.

Diet	**NOAEC, mg Se/kg dw liver**	**LOAEC, mg Se/kg dw liver**	**MATC, mg Se/kg dw liver**
Low carb	38.3	49.3	43.5
high carb	21.0	71.7	38.8

Hicks, B.D., J.W. Hilton, and H.W. Ferguson. 1984. Influence of dietary selenium on the occurrence of nephrocalcinosis in the rainbow trout, *Salmo gairdneri* Richardson. J. Fish Diseases. 7:379-389.

(Note: These data are the exact same as reported for the low carbohydrate diet in **Hilton and Hodson 1983**, with the addition of prevalence of nephrocalcinosis occurring in trout after 16 to 20 weeks of consuming the contaminated test diets).

Test Organism: Rainbow trout (*Oncorhynchus mykiss*; juvenile; approx. 0.6 g each)

Exposure Route: Dietary only
This diet contained capelin oil at 11 percent of the diet with cellulose as the filler. The selenium was supplemented as sodium selenite which was mixed with cellulose and then added to the diet as a selenium premix.

Test Treatments: The test diet was supplemented with selenium (as sodium selenite) at the rate of 0, 5, or 10 mg/kg dw to make up the three different dietary selenium treatments. The three diets were fed to duplicate groups of 100 fish. The trout were fed to satiation 3-6 times per day. Measured concentrations of selenium in the low carbohydrate diet were: 0.6 (control), 6.6, and 11.4 mg/kg dw. The tanks received a continuous flow of water with a flow rate of 3-4 liters per minute.

Test Duration: 16 to 20 weeks

Study Design: See Hilton and Hodson (1983). After 20 weeks on the test diets, ten fish were randomly removed from each treatment. Tissues for histopathological examination included the stomach, intestine and pyloric ceca (including pancreas), spleen, liver, heart, kidney, skin, muscle, and gills.

Effects Data: Only effects of selenium on kidney tissue are included in the article. The kidneys of the 10 trout fed the highest selenium content in the diet exhibited normal appearance. Five of these trout exhibited precipitation of calcium in the tubules with some epithelial necrosis, but no loss of epithelial continuity. Extensive mineralized deposition of Ca within the tubules, tubular dilation and necrosis of tubular epithelium, ulceration of tubules, and intestinal Ca mineralization was observed in four of the ten fish.

Chronic Value: Same as for growth of rainbow trout reported by Hilton and Hodson (1983). The MATC estimated for growth of rainbow trout relative to final concentration of selenium in liver tissue of trout reared on the low carbohydrate diet is the GM of 38.3 (NOAEC) and 49.3 (LOAEC) mg/kg dw, or 43.45 mg/kg dw.

EC values could not be determined for this study. Data did not meet minimum requirements for analysis.

Hilton, J.W., P.V. Hodson, and S.J. Slinger. 1980. The requirements and toxicity of selenium in rainbow trout (*Salmo gairdneri*). J. Nutr. 110:2527-2535.

Test Organism: Rainbow trout (*Oncorhynchus mykiss*; juvenile; approx. 1.28 g each)

Exposure Route: Dietary only
A casien-torula yeast diet was formulated to contain geometrically increasing levels of selenium from 0 to 15 mg/kg dw. The selenium was supplemented as sodium selenite which was mixed with cellulose and then added to the diet as a selenium premix.

Test Duration: 20 weeks

Study Design: Six test diets were fed to triplicate groups of 75 fish. The trout were fed to satiation 3-4 times per day, 6 days per week, with one feeding on the seventh day. Measured concentrations of selenium in the diet were: 0.07 (control), 0.15, 0.38, 1.25, 3.67, and 13.06 mg/kg dw. The tanks received a continuous flow of dechlorinated tap water from the City of Burlington, Ontario municipal water supply. The waterborne selenium content of this water was 0.4µ g/L. During the experiment, the fish were weighed every 2 weeks with the feeding level adjusted accordingly. Mortalities were noted daily and the feed consumption for each treatment was recorded weekly. After 4 and 16 weeks, three to six fish were randomly removed from each tank, sacrificed, and their livers and kidneys removed and weighed. An additional three to six fish were then obtained from each treatment, killed, and prepared for tissue analysis. Organs and carcasses were freeze-dried for determination of selenium concentration. After 16 weeks, three more fish were removed. Kidney, liver, spleen and dorsal muscle tissue was dissected for examination of histopathology. At the end of 8 and 16 weeks, four to five fish were removed, sacrificed, and a blood sample was taken for hematological measurements (hematocrit, red blood cell count, and blood iron concentration). After 20 weeks, three to four more fish were removed, sacrificed, and a blood sample was taken for measurement of glutathione peroxidase activity.

Effects Data: There were no significant differences detected between treatment groups in histopathology, hematology, or plasma glutathione peroxidase activity. Trout raised on the highest dietary level of selenium (13.06 mg/kg dw) had a significantly lower body weight and a higher number of mortalities (10.7; expressed as number per 10,000 fish days) than trout from the other treatments levels after 20 weeks of exposure.

Effects on Juvenile Rainbow Trout			
Se in diet, mg/kg dw	**Se in Liver, mg/kg dw**	**Weight, g/fish**	**Mortality***
0.07	0.6	3.2	0
0.15	0.95	3.5	0
0.38	2.4	3.7	0.6
1.25	11	4.1	0.6
3.67	40[a]	4.1	0
13.06	100[b]	1.4	10.7

* expressed as number per 10,000 fish-days
[a] NOAEC
[b] LOAEC

Chronic Value: NOAEC = 40 mg Se/kg dw
LOAEC = 100 mg Se/kg dw
MATC = 63.25 mg Se/kg dw

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Holm, J. 2002. Sublethal effects of selenium on rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*). Masters Thesis. Department of Zoology, University of Manitoba, Winnipeg, MB.

Holm, J., V.P. Palace, K. Wautier, R.E. Evans, C.L. Baron, C. Podemski, P. Siwik and G. Sterling. 2003. An assessment of the development and survival of rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*) exposed to elevated selenium in an area of active coal mining. Proceedings of the 26th Annual Larval Fish Conference 2003, Bergen, Norway. ISBN 82-7461-059-B.

Holm, J., V.P. Palace, P. Siwik, G. Sterling, R. Evans, C. Baron, J. Werner, and K. Wautier. 2005. Developmental effects of bioaccumulated selenium in eggs and larvae of two salmonid species. Environ. Toxicol. Chem. 24: 2373-2381.

Test Organism: Rainbow trout (*Oncorhynchus mykiss*; spawning adults) and brook trout (*Salvelinus fontinalis*; spawning adults)

Exposure Route: Dietary and waterborne - field exposure
Total selenium concentrations measured at the high selenium site ranged from 6 to 32 μg/L. Selenium was not measured at the reference streams; selenium concentrations at reference locations in the area ranged from <0.5 to 2.2 μg/L.

Study Design: Spawning fish were collected at low selenium or reference streams (Deerlick Creek, Wampus Creek and Cold Creek), a slightly elevated selenium stream (Gregg Creek), and an elevated selenium stream (Luscar Creek) in the Northeastern slopes region of Alberta, Canada. An active coal mine is the source of selenium in the elevated streams. Eggs and milt from the spawning trout were expressed by light pressure from abdomen. Individual clutches of eggs were fertilized from a composite volume of milt derived from 3-5 males. Fertilized eggs from individual females were reared to swim-up stage and examined for a number of parameters including percent fertilization, mortality, edema, and deformities (craniofacial, finfold, and spinal malformations). Similar studies were conducted in 2000, 2001 and 2002. One notable difference is that the embryos were incubated at 8°C in 2000 and at 5°C in 2001. The authors noted that 5°C is a better representation of the actual stream temperature during embryo development.

Effects Data : Other than selenium, there were no significant differences in the concentrations of other elements (Al, As, Sb, Ba, Be, Ni, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Li, Mg, Mn, Hg, Mo, Ag, Sr, Tl, Th, Sn, Ti, U, V, Zn) in trout eggs between the low level and elevated selenium streams. There are two ways to approach determination of effects due to selenium in this study and both are presented here. The first approach determines effects based on a comparison of average conditions between streams (*between streams approach*). For example, if there is a significant difference between the average frequency of deformities in a contaminated stream and reference stream, the effect level for the *between streams approach* would be the average concentration of selenium in the tissue from the contaminated stream. The second approach evaluates individual response variables (e.g., edema, deformities) against the individual selenium tissue concentrations for the combined contaminated and reference stream data set with each year (*within streams approach*). This approach, which results in an

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EC estimate (e.g., EC_{10}) if the data meet the model assumptions, is explained below.

Between streams approach: For each sampling location (stream), data for the three years (Tables 1 and 2) were combined in the between streams analysis of variance (ANOVA). For rainbow trout embryos, there were no significant differences in fertilization, time to hatch and mortality between the streams with elevated selenium and the reference streams. ANOVA indicated significant differences in the frequency of embryonic effects between streams (Table 3). The analysis did not prove useful; however, due to a higher occurrence of effects in some of the reference streams relative to the exposed streams (Tables 3 and 4). The between streams analysis, therefore, was not used to determine effect concentrations for rainbow trout.

ANOVA of brook trout data indicated the only significant difference in embryonic abnormalities among sites was craniofacial deformities (Tables 5 and 6). Significant differences were also found for fertilization and larval weight. The highest average percent fertilization was observed at the site with the greatest concentration of selenium in eggs, which indicates that the differences in fertilization among sites were not caused by variation in selenium concentrations. Because the percent of embryos with craniofacial deformities in Luscar Creek was 7.9% (2.1% in Cold Creek), it was not considered biologically meaningful. Likewise the significantly lower larval weights at the exposed sites was not large (16% lower than Cold Creek larvae) and again coupled with the low occurrence of abnormalities by the brook trout, a signature of selenium effects, the lower larval weights were not considered biologically meaningful.

Within streams approach: As with the *between streams* analysis, data were combined for the three years of study in the *within streams* analysis (Tables 1 and 2). Craniofacial deformities, skeletal deformities and edema in rainbow trout embryo, as a function of selenium in egg ww, were fitted to a curve using a weighted regression and threshold sigmoidal equation from which EC_{10} values were calculated (see Figures 1, 2 and 3). EC estimates for finfold deformities, length and weight of rainbow trout embryos could not be made because of inadequate dose-response. The brook trout data were not suitable for fitting logistic curves (Figure 5).

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Table 1. Rainbow trout embryo-larval parameters collected from a high Se site (Luscar Creek), an intermediate Se site (Gregg River), and reference sites (Deerlick Creek and Wampus Creek) in northeastern Alberta over three consecutive years.

Year	Site	Female #	Se in eggs, mg/kg ww	%craniofacial deformities	%skeletal deformities	%finfold deformities	%edema
2000	Luscar	11	6.84	7.18	13.26	1.66	4.97
2000	Luscar	12	6.66	1.48	4.43	0.74	1.85
2000	Luscar	14	11.6	14.43	23.71	7.22	85.57
2000	Deerlick	16	1.78	0.63	1.9	0.63	0.63
2000	Deerlick	17	1.39	0	0	0	0
2000	Deerlick	18	1.00	0	0.86	0	0
2000	Deerlick	15	5.01	0	0	0	0
2001	Luscar	1	5.39	7.35	6.76	3.53	2.94
2001	Luscar	3	8.39	6.29	4.97	2.98	6.95
2001	Luscar	4	6.48	22.22	22.22	33.33	26.67
2001	Luscar	8	4.47	12	9.33	2.67	10.67
2001	Luscar	14	10.4	34.55	44.85	4.24	43.64
2001	Luscar	32	5.64	8.24	5.97	3.13	9.09
2001	Luscar	33	3.88	5.26	6.58	9.21	3.95
2001	Luscar	39	5.14	1.91	3.18	0	1.27
2001	Luscar	40	3.36	11.62	7.05	5.39	6.64
2001	Luscar	41	11.7	37.67	83.41	3.59	87
2001	Deerlick	8	3.68	9.55	5.45	1.36	5.45
2001	Deerlick	9	3.08	5.39	4.98	0.41	2.07
2001	Deerlick	10	1.62	7.89	7.89	5.26	10.53
2001	Deerlick	16	2.62	24.24	48.48	3.03	12.12
2001	Deerlick	17	2.79	14.13	15.22	4.35	20.65
2001	Deerlick	21	1.96	13.27	35.71	7.14	25.51
2001	Deerlick	22	3.13	1.09	2.17	0	1.09
2001	Deerlick	23	3.03	9.65	14.04	3.51	7.89
2001	Deerlick	25	3.32	9.25	13.29	7.51	8.09
2001	Deerlick	39	2.43	11.89	9.09	7.69	14.69
2001	Gregg	2	4.57	11.97	7.75	15.49	7.04
2001	Gregg	3	4.49	5.58	9.3	2.33	4.65
2001	Gregg	5	4.05	4.95	5.45	2.48	5.94
2001	Gregg	9	5.09	20	13.85	15.38	16.15
2001	Gregg	18	5.97	16.13	19.35	41.94	35.48
2001	Wampus	9	2.66	16.07	0	1.79	7.14
2001	Wampus	13	2.04	7.84	9.8	1.31	7.84
2002	Luscar	3	5.4	60.47	27.9	93	14
2002	Luscar	8	18.3	94.12	23.5	4.4	97.1
2002	Luscar	10	22	100	64.3	3.6	100
2002	Luscar	12	15.7	82.35	47.1	66.7	52.9

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Year	Site	Female #	Se in eggs, mg/kg ww	%craniofacial deformities	%skeletal deformities	%finfold deformities	%edema
2002	Luscar	22	20.5	100	42.1	2.1	100
2002	Luscar	23	6.3	5.59	6.6	1.6	2.7
2002	Luscar	24	26.8	100	100	0	100
2002	Luscar	26	6.5	1.72	1.7	4.3	0.9
2002	Deerlick	10	5.9	5.65	7.26	7.26	3.23
2002	Deerlick	18	7.8	10.77	1.54	9.23	3.08
2002	Deerlick	21	5	6.9	6.9	20.69	1.72
2002	Deerlick	24	4.3	2.88	2.88	21.58	0.72
2002	Deerlick	25	4.4	5.3	5.3	6.82	3.03
2002	Deerlick	26	6.6	2.95	1.85	1.11	1.85
2002	Gregg	1	5.8	4.76	3.81	3.81	3.81
2002	Wampus	1	3	18.84	14.49	72.46	11.59
2002	Wampus	2	4	0	0	100	100
2002	Wampus	3	4.6	4.1	3.28	7.58	0.61
2002	Wampus	4	4.7	25	20	70	12.5
2002	Luscar	28	7	19.23	0	76.9	0

Table 2. Brook trout embryo-larval parameters collected from a high Se site (Luscar Creek), an intermediate Se site (Gregg River), and reference site (Cold Creek) in northeastern Alberta over three consecutive years.

Year	Location	Female #	Se in egg, mg/kg	%craniofaci	%skeletal	%finfold	%edema
2000	Luscar	1	4.78	15.38	0	0	15.38
2000	Luscar	2	4.83	38.06	1.49	3.73	1.49
2000	Luscar	3	5.98	7.39	3.03	0.34	0.5
2000	Luscar	5	3.86	25	5.7	8.77	4.82
2000	Luscar	12	6.06	16.77	1.83	0.7	0
2000	Luscar	13	5.8	4.06	1.42	0.2	0
2000	Luscar	14	5.17	4.13	0.49	0.36	0.12
2000	Luscar	15	9.92	16.22	0.54	0.54	0
2000	Luscar	16	5.03	5.61	0	0.27	0.27
2000	Luscar	17	6.01	9.44	5.83	0.83	1.11
2000	Luscar	18	12.7	14.34	0.72	0	0.36
2000	Cold	21	1.15	3.26	1.48	0.89	0
2000	Cold	22	1.83	4.83	1.38	1.38	0.69
2000	Cold	24	0.97	1.67	0	0.72	0
2000	Cold	25	No data	3.31	1.1	1.66	1.1
2000	Cold	26	0.59	3.45	4.83	6.9	0.69
2000	Cold	33	1.35	6.15	0	1.54	0
2000	Cold	34	2.18	6.45	0	0.81	0
2001	Cold	6	1.79	0	0	0	0
2001	Cold	7	1.36	1.61	0.69	0.46	1.38
2001	Cold	8	0.94	1.36	0	0.27	0.54
2001	Cold	21	1.07	0.43	0	0	0
2001	Cold	51	1.09	0	2.13	0	6.38
2001	Luscar	3	8.4	0	0.93	0	0.46
2001	Luscar	7	7.26	1.35	1.62	0.81	0.27
2001	Luscar	17	14.6	2.22	0.63	0.32	0
2001	Luscar	19	9.79	7.55	2.11	2.42	0.3
2001	Luscar	59	5.8	2.28	0.46	0.91	0.46
2001	Luscar	60	9.03	3.16	0	1.05	1.05
2001	Luscar	61	7.29	0	0	9.09	0
2001	Luscar	64	7.08	1.54	2.19	0	0
2001	Luscar	76	7.1	36.71	13.29	19.65	1.16
2001	Luscar	82	6.06	1.11	0.22	0.88	0.44
2001	Luscar	83	5.82	6	2	5.6	0.8
2001	Gregg	3	7.08	6.32	1.58	20.53	1.58
2001	Gregg	22	7.95	0	0	1.08	0
2001	Gregg	23	9.23	0.5	0.5	2.51	0
2001	Gregg	25	6.46	0.56	0	0.56	0

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Year	Location	Female #	Se in egg, mg/kg	%craniofaci	%skeletal	%finfold	%edema
2001	Gregg	31	7.35	0.51	1.7	0.17	0
2001	Gregg	32	4.91	7.21	0.48	3.37	0.48
2001	Gregg	33	7.02	1.88	1.88	4.38	0
2001	Gregg	34	5.01	0	0.37	0	0
2002	Luscar	17	6.28	1.7	12.74	0.85	0.21
2002	Luscar	23	5.27	7.34	0.46	0	0.46
2002	Luscar	26	6.36	1.81	0.52	0.26	0.26
2002	Luscar	38	18.9	0.9	0.54	0	0.18
2002	Luscar	42	4.95	2.79	0.44	0.15	0.15
2002	Luscar	44	6.47	0	0.25	0	0
2002	Luscar	54	7.96	0.33	0.33	0	0
2002	Luscar	56	18.8	3.99	0.75	0.5	0.75
2002	Gregg	25	6.27	1.23	1.23	0	0
2002	Gregg	37	4.58	2.99	0	0	0
2002	Gregg	39	6.67	3.57	1.19	1.19	1.19
2002	Cold	32	0.42	0	0.6	0	0
2002	Cold	26	0.89	0	0	0	0.29
2002	Cold	2	0.94	0.96	0.32	0	0
2002	Cold	5	1	0.25	0.5	0.25	0
2002	Cold	29	1.02	0.72	1.09	0.36	0.72
2002	Cold	23	1.2	0.35	0.35	0.35	0.35
2002	Cold	48	1.25	9.52	4.76	2.38	0
2002	Cold	42	1.6	0	0	0	0
2002	Cold	22	1.74	0	0	1.09	1.09
2002	Cold	51	2.11	2.17	2.17	0	2.17

Table 3. Results of ANOVA comparing rainbow trout endpoints among sites

% fertilization

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Site	3	77.60	25.8653	0.06336703	0.978935
Residuals	51	20817.33	408.1829		

% mortality

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Site	3	3751.51	1250.504	1.848008	0.1502207
Residuals	51	34510.50	676.676		

% craniofacial deformities

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Site	3	8093.97	2697.989	4.430272	0.007732133
Residuals	50	30449.48	608.990		

% skeletal deformities

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Site	3	3279.30	1093.101	2.773923	0.05094422
Residuals	50	19703.16	394.063		

% finfold deformities

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Site	3	6273.17	2091.056	3.888612	0.01417887
Residuals	50	26886.93	537.739		

% edema

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Site	3	8902.51	2967.502	3.449597	0.0233558
Residuals	50	43012.30	860.246		

Table 3. Results of ANOVA comparing rainbow trout endpoints among sites (continued)

Fry length

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Site	3	5.0847	1.694896	0.5694271	0.6377436
Residuals	50	148.8246	2.976493		

Fry weight

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Site	3	1721.104	573.7012	3.563888	0.02080915
Residuals	48	7726.859	160.9762		

Table 4. Rainbow trout means (standard deviation) for measurements made in eggs, embryos and larvae spawned from fish collected at exposed sites (Luscar and Gregg Creeks) and reference sites (Deerlick and Wampus Creeks).

Parameter	Site			
	Luscar Cr.	Gregg Cr.	Deerlick Cr.	Wampus Cr.
egg Se, mg/kg ww	9.93 (6.77)	6.52 (4.11)	3.49 (1.90)	3.5 (1.09)
fertilization, %	77.8 (20.3)	81.2 (12.7)	77.5 (20.9)	77.5 (24.1)
mortality, %	35.0 (29.5)	34.2 (32.5)	18.1 (14.6)	37.3 (34.5)
craniofacial, %	33.3 (37.2)	10.6 (6.5)	7.1 (6.1)	12.0 (9.6)
skeletal, %	25.0 (27.9)	9.9 (5.8)	9.2 (12.3)	7.9 (8.2)
finfold, %	15.0 (27.1)	13.6 (15.2)	5.4 (6.2)	42.2 (43.7)
edema, %	34.5 (40.3)	12.2 (12.3)	6.1 (7.3)	23.3 (37.8)
larval length, mm	18.5 (2.0)	19.4 (1.6)	19.0 (1.5)	19.2 (0.9)
larval weight, mg	53.3 (16.3)	44.6 (10.4)	41.2 (9.3)	40.6 (8.4)

Table 5. Brook trout means (standard deviation) for measurements made in eggs, embryos and larva spawned from fish collected at exposed sites (Luscar and Gregg Creeks) and reference site (Cold Creek).

Parameter	Site		
	Luscar Cr.	**Gregg Cr.**	**Cold Cr.**
egg Se, mg/kg ww	7.78 (3.80)	6.59 (1.39)	1.26 (0.47)
fertilization, %	92.8 (7.2)	78.4 (18.2)	89.1 (19.6)
mortality, %	6.5 (8.9)	2.9 (2.3)	6.9 (12.1)
craniofacial, %	7.9 (10.1)	2.3 (2.5)	2.1 (2.6)
skeletal, %	2.0 (3.3)	0.8 (0.7)	1.0 (1.4)
finfold, %	1.9 (4.1)	3.1 (6.0)	0.9 (1.5)
edema, %	1.0 (2.9)	0.3 (0.6)	0.7 (1.4)
larval length, mm	17.4 (1.1)	17.9 (0.9)	18.5 (1.2)
larval weight, mg	31.7 (8.6)	31.3 (5.4)	37.8 (7.2)

Table 6. Results of ANOVA comparing brook trout endpoints among sites

% fertilization					
	df	**Sum of Sq**	**Mean Sq**	**F Value**	**Pr(F)**
site	2	1683.3	841.67	3.9128	0.0253
Residuals	60	12906.4	215.11		
% mortality					
	df	**Sum of Sq**	**Mean Sq**	**F Value**	**Pr(F)**
site	2	131.4	65.72	0.7257	0.4882
Residuals	60	5433.6	90.56		
% craniofacial deformities					
	df	**Sum of Sq**	**Mean Sq**	**F Value**	**Pr(F)**
site	2	519.1	259.54	4.9427	0.0103
Residuals	60	3150.6	52.51		

Table 6. Results of ANOVA comparing brook trout endpoints among sites (continued)

% skeletal deformities					
	df	Sum of Sq	Mean Sq	F Value	Pr(F)
site	2	19.2	9.58	1.5631	0.2179
Residuals	60	367.6	6.13		
% finfold deformities					
	df	Sum of Sq	Mean Sq	F Value	Pr(F)
site	2	37.5	18.74	1.2562	0.2921
Residuals	60	895.1	14.92		
% edema					
	df	Sum of Sq	Mean Sq	F Value	Pr(F)
site	2	4.6	2.32	0.4966	0.6110
Residuals	60	280.6	4.68		
Fry length					
	df	Sum of Sq	Mean Sq	F Value	Pr(F)
site	2	16.1	8.04	6.5265	0.0027
Residuals	60	73.9	1.23		
Fry weight					
	df	Sum of Sq	Mean Sq	F Value	Pr(F)
site	2	546.2	273.10	4.6644	0.0131
Residuals	60	3512.9	58.55		

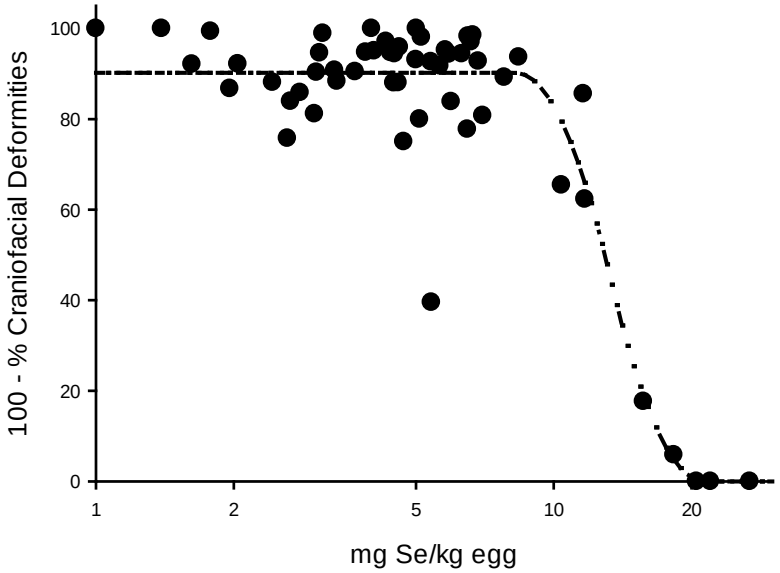


Figure 1. Rainbow trout percent normal (100 - % craniofacial deformities) as a function of the logarithm of selenium concentration in eggs wet weight (Exposure Variable). TRAP weighted regression analysis using a threshold sigmoid equation. The background value was estimated to be 90.2%, the slope 4.8%, and the EC_{10} 10.2 mg Se/kg egg ww.

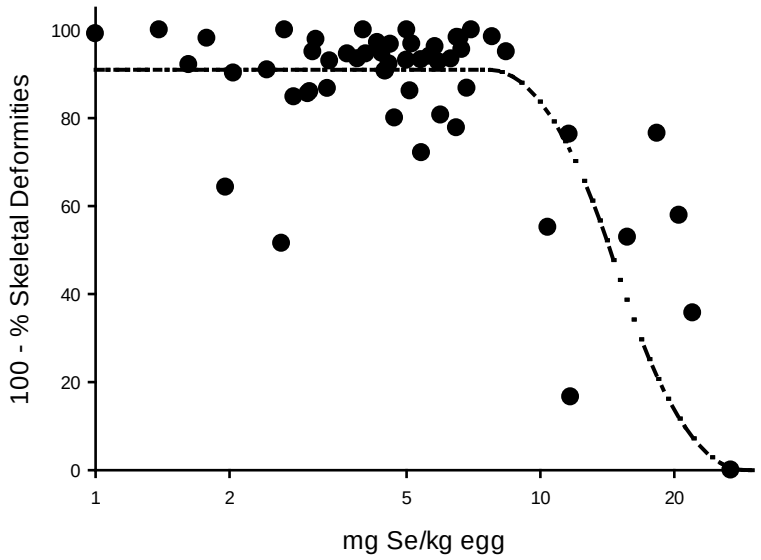


Figure 2. Rainbow trout percent normal (100 - % skeletal deformities) as a function of the logarithm of selenium concentration in eggs wet weight (Exposure Variable). TRAP weighted regression analysis using a threshold sigmoid equation. The background value was estimated to be 91%, the slope3.5%, and the EC_{10} 10.3 mg Se/kg egg ww.

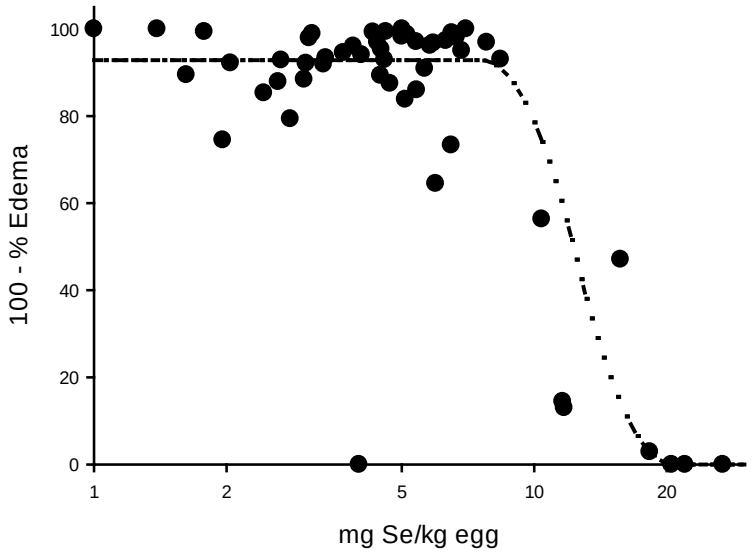


Figure 3. Rainbow trout percent normal (100 - % edema) as a function of the logarithm of selenium concentration in eggs wet weight (Exposure Variable). TRAP weighted regression analysis using a threshold sigmoidal equation excluding the one outlier with 100% edema at 4 mg/kg. The background value was estimated to be 92.8%, the slope 4.6%, and the EC_{10} 9.5 mg Se/kg egg ww.

The previous draft used a TRAP logistic regression (Figure 4). A weighted regression using a threshold sigmoidal equation (Figures 1-3) is a better application of these data.

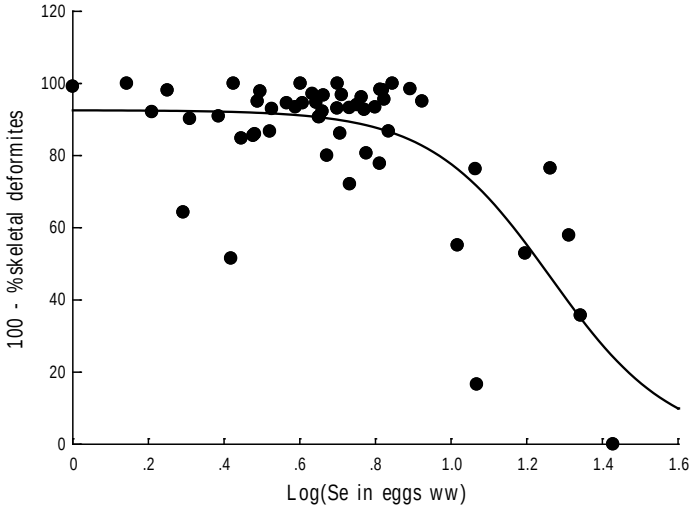
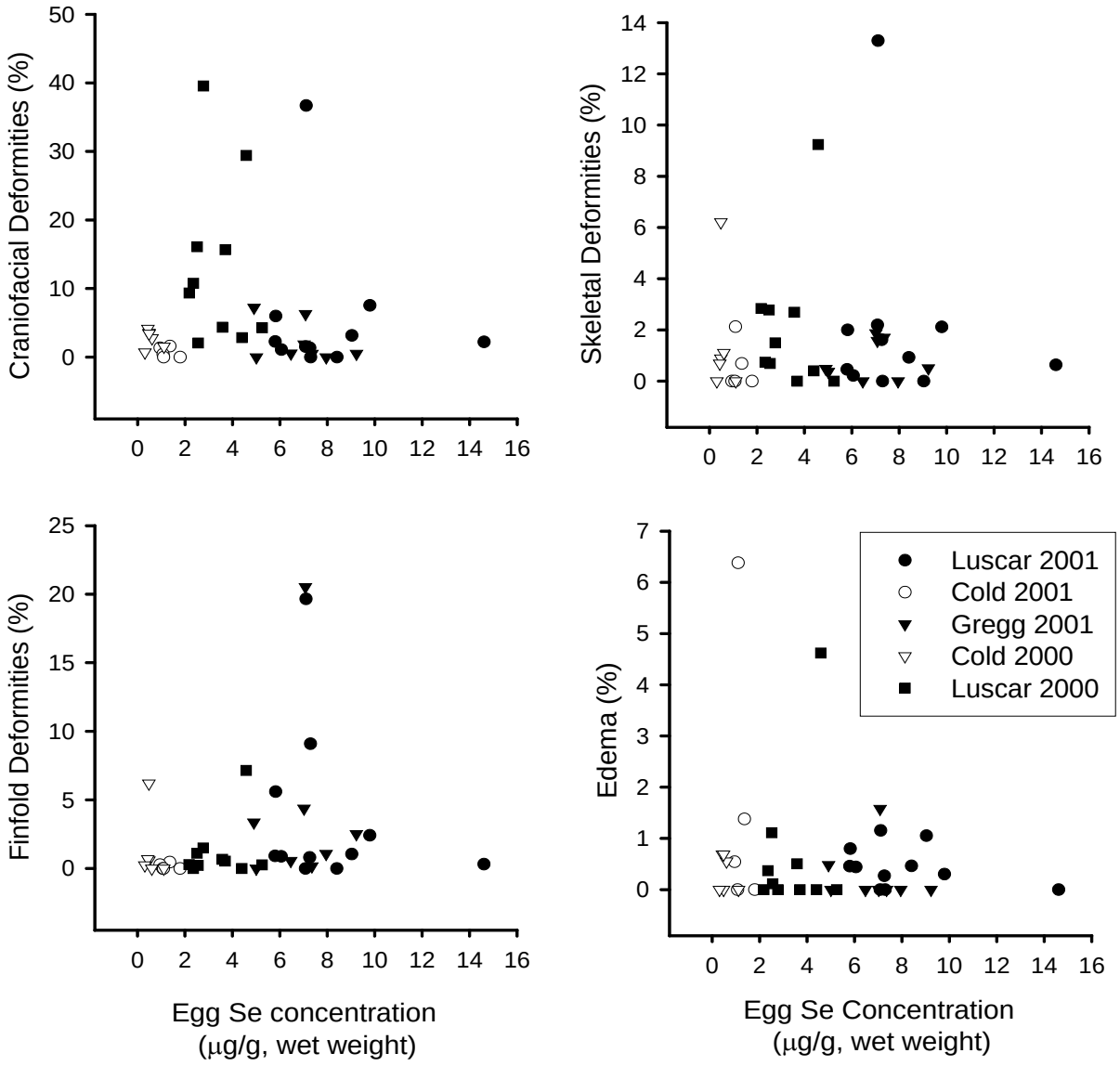


Figure 4. (From Previous Draft) Rainbow trout percent normal (100 - % skeletal deformities) as a function of the logarithm of selenium concentration in eggs wet weight (Exposure Variable). EC_{10} = 8.2 mg/kg ww.

Figure 5. Plot of percent abnormal for craniofacial, skeletal and finfold deformities and edema against selenium concentration in brook trout eggs ww, 2000 and 2001 data.



The effect levels determined using the *within streams* approach resulted in values based on ww in eggs. The primary tissue for which the reproductive effect levels were based, eggs, was converted from ww to dw using the average percent moisture of 61.2% for rainbow trout eggs reported by Seilor and Skorupa (2001).

Chronic Values:

Brook trout: *Between streams approach*
No effects at EC_{10} level at 7.78 mg Se/kg eggs ww or 20.05 mg Se/kg eggs dw; egg. **Chronic value is >20.05 mg Se/kg eggs dw.** Table 3 data, converted to dry weight, suggest no effects at least up to 25-35 mg Se/kg eggs dw.

Rainbow trout: *Within streams approach*
EC_{10} value (edema) at 9.5 mg Se/kg egg ww or 24.5 mg Se/kg egg dw. **Chronic value is 24.5 mg Se/kg eggs dw.**

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Kennedy, C.J., L.E. McDonald, R. Loveridge, M.M. Strosher. 2000. The effect of bioaccumulated selenium on mortalities and deformities in the eggs, larvae, and fry of a wild population of cutthroat trout (*Oncorhynchus clarkii lewisi*). Arch. Environ. Contam. Toxicol. 39:46-52.

Test Organism: Cutthroat trout (*Oncorhynchus clarkii lewisi*; spawning adults, 3-6 years)

Exposure Route: Dietary and waterborne - field exposure
Total selenium concentrations measured at the time the eggs were taken were <0.1 μg/L from the reference site and 13.3 to 14.5 μg/L at the exposed site.

Study Design: At reference and exposed site (Fording River, BC, Canada which receives drainage from open-pit coal mining), eggs were stripped from females (n=20 from reference site; n=17 from exposed site) and fertilized from milt from one male collected at each site. Fertilized eggs were reared in well water and examined for time to hatch, deformities (craniofacial, finfold, skeletal and yolk sac malformations), and mortalities. Inspection of deformities in eggs was performed using 40X magnification.

Effects Data : No significant correlations between the selenium concentrations in the eggs from either site and: hatching time (reference, 25.5-26.5 days; exposed, 22-25.5 days); percent deformities preponding (reference, 0-2.4%; exposed, 0-0.34%); percent deformities after ponding (reference, 0-0.26%; exposed, 0-0.09%); percent mortalities preponding (reference, 1.5-70.3%; exposed, 1-100%); percent mortalities after ponding (reference, 0.3-4.3%; exposed, 1.5-43.7%); total percent mortalities (reference, 2.8-55.8%; exposed, 3.7-100%). The average selenium residues in tissues were as follows:

Site	Adult fish liver, mg Se/kg dw	Adult fish muscle, mg Se/kg dw	eggs, mg Se/kg dw
Reference	8.2; Range: 3.4-14.6	2.4; 1.4-3.8	4.6
Exposed	36.6; Range:18.3-114	12.5; Range: 6.7-41	21.2

Chronic Value: >21.2 mg Se/kg dw in eggs
>12.5 mg Se/kg dw in muscle

Hardy, R.W. 2005. Effects of dietary selenium on cutthroat trout (*Oncorhynchus clarkii*) growth and reproductive performance. Report for Montgomery Watson Harza. December 14, 2005.

Test Organism: Cutthroat trout (*Oncorhynchus clarkii*, 0.9 g)

Exposure Route: Dietary only
Six experimental dietary treatments were produced by cold extrusion. The formulation of the diet was designed to be similar to commercial trout diets and had a proximate composition of 45% protein and 16% lipid. Seleno-methionine diluted in distilled water (100 µg/L) was added in appropriate volumes to each batch of feed to facilitate pelleting. Measured dietary selenium concentrations were 1.2 (control), 3.8, 6.4, 9.0, 11.5, and 12 mg Se/kg dw. Fry were fed initially at a rate of 10 times per day 6 days each week to apparent satiation. Feeding frequency decreased as fish grew.

Test Duration: 124 weeks (865 days, 2.5 yrs)

Study Design: Groups of 50 fish were placed into triplicate tanks (145 L) receiving 4-15 L/min of hatchery water at 14.5EC and fed one of the six experimental diets. The fish in each tank were bulk-weighed and counted every 14 days for the first 12 weeks of the experiment, and then every 4 weeks until 48 weeks. Samples of fish for whole-body selenium analysis were taken at each sampling date for the first 12 weeks followed by every 3 months thereafter. After six months of feeding, the fish were transferred to 575 L tanks and the number of replicate tanks per dietary treatment was reduced to two. After 80 weeks of feeding, the fish were transferred to 1050 L outdoor tanks each supplied with 70 L/min of constant temperature (14.5°C) spring (hatchery) water. After 2.5 years of the feeding trial, fish were spawned and whole body selenium level , egg selenium level, % eyed eggs, % hatched eggs, and % deformed larvae were examined.

Effects Data: No signs of toxicity (reduced growth or survival relative to controls) were observed in fish fed the highest dietary selenium treatment (12 mg Se/kg dw) after the first 80 weeks of exposure just prior to transfer outdoors. No signs of clinical disease were evident, and no relationship was found between feed conversion ratios and the level of selenium added to the feed. Average whole body selenium levels of female Henry's Lake cutthroat trout at spawning at 2.5 to 3 years of age were 5.87, 9.10, 11.37 and 5.61 mg Se/kg dw in the four highest dietary treatments. Average egg selenium levels in the same four dietary treatments were 6.61, 5.05, 5.18, and 16.04 mg Se/kg dw. Percent survival from the eyed stage to hatching varied among treatment groups, with the control and the highest Se dietary treatment having the second highest survival (85%) and the fifth dietary treatment group the highest (93%). Percent deformed larvae ranged from a low of 5.6% in controls to a high of 20.2% in the 6.4 mg Se/kg dw dietary treatment group; larvae in the two highest dietary treatment groups only exhibited 7 and 6.8 %, respectively.

Chronic Value: The chronic value for embryo/larval deformity is a NOAEC of >11.37 mg Se/kg dw whole-body parent tissue and >16.04 mg Se/kg dw egg.

Rudolph, B-L, I. Andreller, CJ. Kennedy. 2008. Reproductive success, early life stage development, and survival of Westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) exposed to elevated selenium in an area of active coal mining. Environ. Sci. Technol. 42: 3109-3114.

Test Organism: Westslope cutthroat trout (*Oncorhynchus clarkii lewisi*)

Exposure Route: Field collected.
In June, 2005, eggs were collected from 12 females from Clode Pond (exposed site) and 16 females from O'Rourke Lake (reference site). Milt was obtained from 3-5 males at each site. Clode Pond is on the property of Fording River Coal Operations in Southeast British Columbia with reported selenium concentrations of 93 µg/L. O'Rourke Lake is an isolated water body into which Westslope cutthroat trout were stocked in 1985, 1989 and 1992 and has selenium levels reported <1 µg/L.

Test duration: Through the end of yolk sac absorption (at swim-up) by the alevins.

Study Design: Individual batches of eggs were fertilized in the field with 2 ml composites of milt. Water-hardened eggs were transported to the rearing laboratory. Eggs and alevins were monitored daily for fertilization, hatching and mortality. After the yolk sacs were absorbed, alevins were sacrificed and preserved in Davidson's solution.

All viable fry (n = 4,922) after yolk absorption were observed for the frequency and severity of skeletal (lordosis, kyphosis, and scoliosis), craniofacial (head, eyes or jaw), and fin malformations as well as edema. The authors used a graduated severity index (GSI) for deformities in which fry were scored 0 (normal) to 3 (severe) based on the level of defect.

Effects Data: Eggs with the four highest Se concentrations (86.3 to 140 mg/kg dw) collected from Clode Pond fish died before reaching the laboratory (Table 1). Excluding the eggs that died from females CP1, CP3, CP4 and CP5, fertilization (total eggs reaching the eyed stage/total eggs x 100) was not related to Se concentrations in the eggs. The percent of alevins (post hatch to swim-up stage) that died was related to the selenium concentration in the eggs (Table 1). Note: The data used to estimate the EC_{10} value excluded the variable from OL1 and OL2 (shaded areas in Table 1). These are data from the reference lake in which only 57% of the larvae survived (OL1) or where the % dead eggs plus % hatch did not add up to %100. Alevin survival was meaningfully higher in the other 15 clutches of eggs from the reference site (85.1 to 99.8%). Because there were insufficient partial effects, a TRAP model was not used to estimate the EC_{10} value. The data consist of a cluster background data and a cluster of 100% mortality (Figure 1). With no way to fit a credible curve, the interpolation method is applied here with the EC_0 set to 20.6 mg/kg with background % survival of 95.75% (not including the one low outlier) and the second extrapolation point being 46.8 mg/kg with 0.3% survival. The resultant slope is 5.6 (similar to slopes in other datasets where it was estimated) and the EC_{10} is 24.7 mg/kg. Note: TRAP was used in the previous draft to derive a similar EC_{10} of 24.1 mg/kg, however as stated above, it

was determined that the data are not amenable to a TRAP model because of insufficient partial effects.

An EC_{10} based on Se in maternal muscle was estimated using the same approach as was used for Se in eggs, that is, by interpolation between an EC_0 and a high EC_P. An EC_{10} of 16.6 mg Se/kg muscle dw was interpolated from an EC_0 (HNOEC) of 13.4 mg/kg and the average background survival of 95.75 and the EC_{100} set to 34.7 mg/kg muscle (Figure 2).

Deformity analysis was not performed on the alevins that died prior to the swim-up stage. Therefore, due either to dead eggs or dead alevins, the occurrence and severity of deformities were assessed on four clutches of eggs from Clode Pond (CP2, CP6, CP11 and CP12) with a range of 11.8 to 20.6 :g Se/g dw and 15 of the 16 clutches (all eggs died in OL8) from O'Rourke Lake (Table 1). There was no correlation between egg Se concentration and frequency of deformity or edema. Statistical differences between sites were observed ($p < 0.05$) for skeletal deformities and edema for both the frequency of the occurrence and the severity score (Table 2). Note: the percent and severity score of skeletal deformities were greater in the reference site than in the exposed site.

The effect level for this study was based on the alevin mortality data and not the deformity measurements. Although edema occurred statistically more often at the exposed site (87.7% at Clode Pond, 61.2% at O'Rourke Lake), it was not correlated with selenium levels in the eggs. Also the greater occurrence of skeletal malformations in the reference site confounded the use of statistical differences between sites to determine effect levels for this study.

Effect Concentration: 24.7 mg Se/kg dw in eggs; 16.6 mg Se/kg dw in muscle.

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Table 1. Fertilization, egg mortality and alevin mortality for offspring from individual fish collected in Clode Pond and O'Rourke Lake.

Fish ID	Muscle [Se] mg/kg dw	Egg [Se] mg/kg dw	Hatch %	Dead eggs, %	Dead alevins, %	% Survival[1]
Clode Pond (exposed site)						
CP1	38.8	88.3	0	100	NA	
CP2	11.8	16.1	98.2	1.8	0.9	99.1
CP3	40.4	86.3	0	100	NA	
CP4	46.1	121	0	100	NA	
CP5	50.4	140	0	100	NA	
CP6	34.7	51	92.6	7.4	92.6	0.0
CP7	39	65.3	91.1	8.9	91.1	0.0
CP8	7	11.8	63.9	36.1	0.8	98.7
CP9	35.4	46.8	63.4	36.6	63.2	0.3
CP10	35.5	75.4	82.4	17.6	82.4	0.0
CP11	11.3	16.9	77.9	22.1	1.3	98.3
CP12	13.4	20.6	97	3	5.1	94.7
avg	30.3	61.6	55.5	44	42	20.0
SD	15.1	42.4	42.5	42	44	0.0
O'Rourke Lake (reference site)						
OL1	8.28	12.9	71.4	28.6	42.9	39.9
OL2	7.7	13.9	27.7	53.1	6.9	75.1
OL3	8.16	12.5	96.1	3.9	2.4	97.5
OL4	8.03	15	85.5	14.5	12.7	85.1
OL5	8.12	14.9	80.7	19.3	5.3	93.4
OL6	6.61	15.2	68	32	4	94.1
OL7	8.52	12.9	97.9	2.1	0.2	99.8
OL8	7.22	12.3	0	100	NA	
OL9	7.25	16.7	87.2	12.8	4.5	94.8
OL10	7.64	13.1	79.6	2.5	5.5	93.1
OL11	8.74	15.6	89.2	10.8	2.4	97.3
OL12	8.2	13.9	83.6	16.4	3	96.4
OL13	7.86	15.1	74.1	25.9	2.8	96.2
OL14	8.5	13.1	77.8	22.2	0.5	99.4
OL15	7.62	12.3	88.2	11.8	2.6	97.1
OL16	8.13	12.7	54.8	45.2	4.8	91.2
avg	7.9	13.9	72.6	25	7	
SD	0.6	1.4	25.8	25	10	

[1] % Survival based on % hatch

Table 2. Deformity results (frequency and severity) for offspring from O'Rourke Lake and Clode Pond. Values are presented as mean ± SE. * indicates a significant difference ($p < 0.05$) between means from the two sites.

Frequency of deformity, %	**O'Rourke Lake**	**Clode Pond**
Skeletal*	37.4 ± 3.6	16.5 ± 2.2
Craniofacial	10.2 ± 2.0	5.7 ± 1.0
Finfold	10.6 ±3.1	7.5 ± 3.84
Edema*	61.2 ± 4.9	87.7 ± 2.0
Severity of deformity, score		
Skeletal*	0.47 ± 0.07	0.18 ± 0.02
Craniofacial	0.12 ± 0.03	0.06 ± 0.01
Finfold	0.15 ± 0.05	0.09 ± 0.05
Edema*	0.61 ± 0.05	0.88 ± 0.02

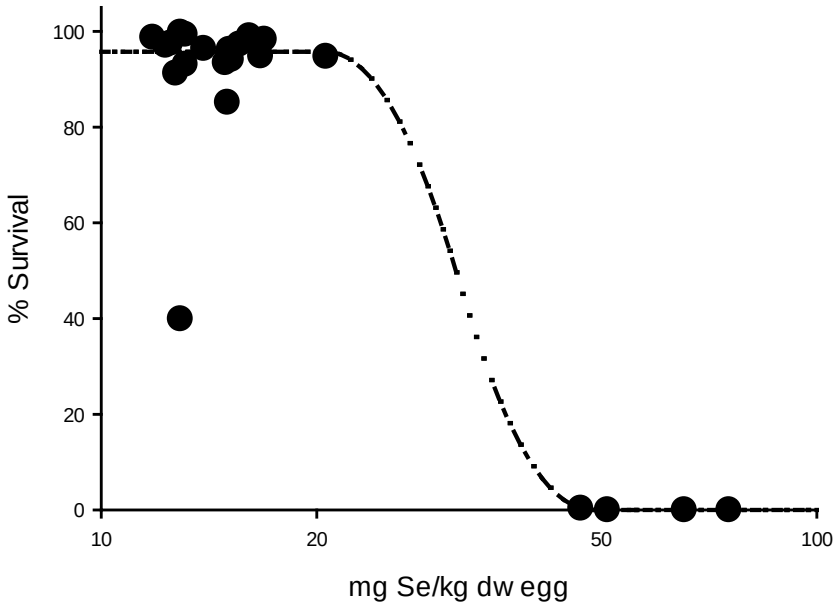


Figure 1. Post-hatch survival of Westslope cutthroat trout alevin as a function of the logarithm of the selenium concentration in eggs.

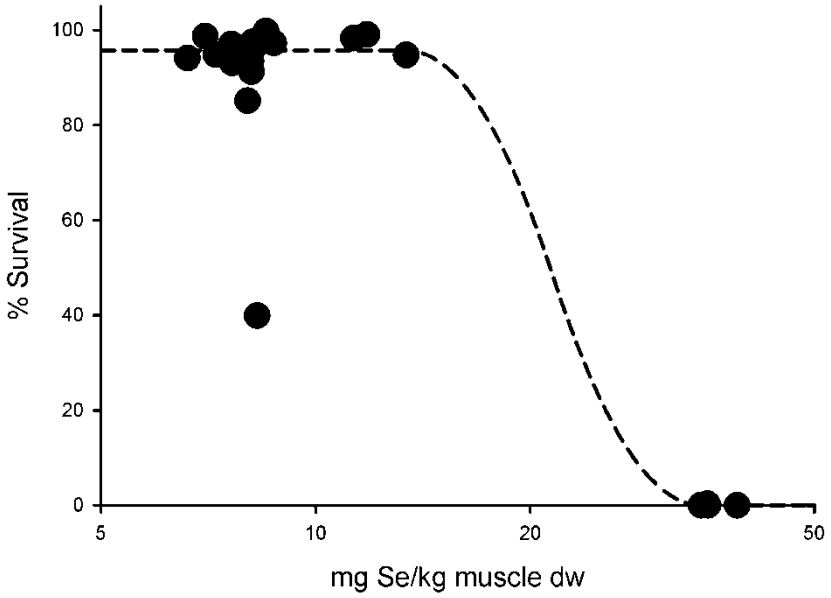


Figure 2. Post-hatch survival of Westslope cutthroat trout alevin as a function of the logarithm of the selenium concentration in maternal muscle.

Nautilus Environmental. 2011. Evaluation of the Effects of Selenium on Early Life Stage Development of Westslope Cutthroat Trout from the Elk Valley, BC. Report to Elk Valley Selenium Task Force, November 24, 2011.

Test Organism: Westslope cutthroat trout (*Oncorhynchus clarkii lewisi)*

Exposure Route: Field collected. Adult fish were collected and spawned from lentic and lotic environments in areas proximate to Teck Coal's Fording River Operations. Eggs were also obtained from fish collected from Connor Lake, a lake located within the Elk valley watershed not exposed to mine discharges and considered a reference site and a methodological control.

Test Duration: Fertilized eggs were reared in the laboratory until they reached swim-up fry stage. A subset of fry surviving at swim-up were reared for an additional 28 days.

Study Design: Gametes were stripped from the ripe adults in the field during June and July 2008 and transported immediately to the laboratory in coolers containing wet ice. Eggs were fertilized in the laboratory. After stripping the eggs, female fish were sacrificed and the whole body stored on ice for later Se analysis. For a given female, approximately 240 fertilized eggs were divided into four replicates of 60 eggs. In cases when fewer eggs were available three replicates of 60 eggs were used. If less than 180 eggs were available, either 3 or 4 replicates of 30 were used. Females with less than 90 eggs were not used. The fertilized eggs were maintained in the laboratory until the fry reached swim-up at which point deformities were assessed. Survival was also assessed up to swim-up. In test chambers in which there were at least 40 surviving fish at swim-up, one-half of the surviving fish were maintained for an additional 28 days. Survival, length, weight and deformities were assessed in the 28-day post swim-up test.

The number, type and severity of deformities were measured at swim-up and at the end of the 28-day post swim-up test. Deformity assessments were conducted on recently killed fresh fish to avoid artifacts caused by preservation. A graduated severity index (GSI) was assigned to each of four types of deformity/abnormality: skeletal, craniofacial, finfold and edema. Graduated Severity Index (GSI) methods followed those described in Holm et al. (2003) and Rudolph et al (2006; 2008).

Effects Data: Survival of the larvae from hatch through swim-up spawned from the four fish collected from the reference site, Connor Lake, ranged from 73 to 92% (egg Se 4.32 to 7.31 mg/kg dw) (Table 1). Larval survival at swim-up was also generally high for fish collected in the Se exposed sites up to egg Se concentration 29.6 mg/kg dw (Table 1, Figure 1). Larvae exposed above this egg Se concentration had poor to no survival. Larvae from one fish (P00811) below this threshold did have poor survival (11.7%). The authors noted that the many of the eggs from this fish displayed an unusual distribution of lipid vesicles which resulted in greater than 50% mortality in the first 24 hours due to egg breakage. The remaining eggs may have been compromised due to the organic material released during the egg breakage.

The rate of deformities in larvae at swim-up showed no relationship with Se in egg through 29.6 mg/kg dw (Table 2).

The results of the 28-day post swim-up test showed no relationships between larval survival or deformities and egg Se (Table 3). The authors also measured the length and weight of larvae at the end of the 28 day test; neither of which showed a relationship with egg Se concentration.

Se Tissue Concentrations. Two analytical laboratories (A and B) measured Se in the eggs. The mean difference in egg Se concentrations between the two laboratories was 34.2%. To better understand the difference between the two laboratories, five egg samples (i.e., from five different fish) from this study were sent to both laboratories in 2010. Both laboratories digested the eggs using the methods they used in their own 2008 original analysis. The respective digestates were split and then shared between laboratories. Both labs then measured selenium in their own digestates and the digestate received from the other lab. The results of this follow-up study showed that when each lab used their own digestion procedures Laboratory A had on average 43% higher measurements in the 2008 analysis and 23% higher in the follow-up 2010 analysis. When each lab measured selenium using the same digestate the difference in the Se measurements between labs was on average only 1 to 8%. The authors concluded that although both laboratories employed acceptable and approved practices, Laboratory A used a more efficient digestion process resulting in higher Se measurements. To compensate for the reduced Se measurements in Laboratory B, its values were increased by 34.2%. The measurements made by Laboratory A are marked in Table 1; unmarked values are Laboratory B measurements increased by 34.2%.

Effect Concentration: The most sensitive endpoint determined by TRAP was larval survival at swim-up. Interpolation was used to estimate an effect concentration for larval survival with the entire egg Se dataset that included egg Se measurements from Laboratory A and adjusted measurements from Laboratory B (EC_{10} = 31.1 mg/kg egg dw; Figure 1) and using only the egg Se measurements from Laboratory A (Figure 2). Because the Laboratory A dataset estimated slightly lower EC values, the EC_{10} of 27.7 mg/kg egg dw is the selected effect concentration for this study. Note: In the previous draft, a TRAP model was used to estimate the EC_{10}. However, because of insufficient partial effects, TRAP was determined not appropriate so the EC_{10} was estimated using an interpolation between the HNOEC and the LOEC (see Figure 3 for the TRAP analysis used in the previous draft).

Table 1. Summary of westslope cutthroat trout larvae surviving to swim-up per parent female (fish ID) including location of collection of parent female and concentration of selenium in the eggs.

				Proportion surviving				
Fish ID	Location	Se egg, mg/kg dw	Replicates	Replicate mean	Replicate min	Replicate max	Number survivors	Total number
YO93	Lentic	3.88*	4	0.8125	0.6667	0.9167	195	240
CL1	Reference	4.32	4	0.9167	0.8833	1	220	240
R082	Lotic	5.21	3	0.9056	0.8333	0.95	163	180
CL4	Reference	5.96*	4	0.7333	0.6	0.8	176	240
CL2	Reference	6.82	4	0.8333	0.7	0.9167	200	240
CL3	Reference	7.31	4	0.8542	0.8167	0.8833	205	240
P00815	Lotic	7.6	3	0.8222	0.7167	0.95	148	180
R026	Lotic	12.53	4	0.5792	0.5	0.65	139	240
P00823	Lotic	12.71	4	0.8875	0.85	0.95	213	240
R039	Lotic	12.9	4	0.6042	0.55	0.65	145	240
R086	Lotic	13.4*	4	0.9417	0.85	0.9833	226	240
R077	Lotic	14.29	3	0.6444	0.6167	0.6667	116	180
R042	Lotic	16.44	3	0.8	0.7	0.9	72	90
R055	Lotic	16.5	4	0.8792	0.7833	0.9667	211	240
R043	Lotic	16.85	4	0.8667	0.7667	0.9667	104	120
R074	Lotic	17.8*	4	0.9375	0.8833	0.9833	225	240
P00811	Lotic	19.25	1	0.1167	0.1167	0.1167	7	60
P00809	Lotic	19.72	4	0.7667	0.65	0.8833	184	240
P00803	Lotic	24.8*	4	0.9375	0.9333	0.95	225	240
R078	Lotic	29.61	4	0.8825	0.8333	0.9333	105	119
GO99	Lotic	34.2*	4	0.2083	0.1667	0.2667	50	240
O087	Lentic	54.7*	4	0.07083	0.01667	0.2	17	240
O085	Lentic	56.8*	4	0	0	0	0	240
WO52	Lentic	61.1*	4	0	0	0	0	240
R069	Lotic	65.61	4	0	0	0	0	240
R071	Lotic	72.9	4	0	0	0	0	240
WO94	Lentic	73.1	4	0	0	0	0	240
UT101	Lentic	74.67	4	0	0	0	0	240

*Laboratory A dataset

Table 2. Summary of westslope cutthroat trout larval deformities to swim-up per parent female (fish ID) including location of collection of parent female and concentration of selenium in the eggs.

Fish ID	Location	Se egg, mg/kg dw	Skeletal combined	Craniofacial combined	Finfold combined	Edema combined	Deformities combined
YO93	Lentic	3.88*	4.5%	0.9%	4.4%	1.9%	7.7%
CL1	Lentic	4.32	7.6%	1.9%	1.0%	1.0%	9.5%
R082	Lotic	5.21	1.2%	1.3%	2.5%	0.0%	3.7%
CL4	Lentic	5.96*	4.3%	7.3%	1.7%	0.7%	12.6%
CL2	Lentic	6.82	11.1%	3.7%	0.8%	3.0%	15.9%
CL3	Lentic	7.31	5.0%	2.0%	1.0%	0.0%	7.0%
P00815	Lotic	7.6	0.0%	2.7%	0.0%	2.9%	5.6%
R026	Lotic	12.53	2.1%	2.1%	0.7%	1.4%	2.1%
P00823	Lotic	12.71	1.9%	2.9%	1.8%	5.6%	7.4%
R039	Lotic	12.9	2.1%	1.9%	2.9%	4.9%	9.9%
R086	Lotic	13.4*	2.7%	1.0%	0.0%	0.0%	2.7%
R077	Lotic	14.29	1.7%	10.4%	0.9%	12.2%	15.5%
R042	Lotic	16.44	1.2%	0.0%	0.0%	2.6%	2.6%
R055	Lotic	16.5	0.0%	2.8%	1.0%	2.9%	4.7%
R043	Lotic	16.85	0.9%	2.6%	1.8%	1.7%	4.4%
R074	Lotic	17.8*	2.7%	1.8%	0.9%	0.9%	3.6%
P00809	Lotic	19.72	3.9%	2.8%	3.3%	4.7%	9.0%
P00803	Lotic	24.8*	2.7%	0.9%	0.0%	0.9%	4.5%
GO92	Lotic	26.1	0.0%	1.9%	1.9%	4.4%	4.4%
R078	Lotic	29.61	1.8%	0.0%	1.0%	2.9%	5.7%
GO99	Lotic	34.2*	14.5%	53.9%	6.8%	28.2%	64.7%

*Laboratory A dataset

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Table 3. Summary of larval survival and rates deformities after the 28-day post swim-up test per parent female (fish ID) including location of collection of parent female and concentration of selenium in the eggs.

Fish ID	Location	Sample size (n)	Egg Se (mg/kg dw)	Survival (%)	Skeletal (%)	Craniofacial (%)	Finfold (%)	Total (%)
CL1	Reference	112	4.3	99.1	0	0	0	0
CL2	Reference	93	6.8	99	0	0	0	0
CL3	Reference	96	7.3	91.7	0	1	1	2
CL4	Reference	68	6	98.6	0	0	4.3	4.3
Y093	Lentic	93	3.9	95.6	0	0	2	2
R082	Lotic	71	5.2	87.4	0	2.9	0	2.9
P00815	Lotic	69	7.6	91.1	0	1.2	1.4	2
P00823	Lotic	105	12.7	96.3	0	0	0	0
R086	Lotic	112	13.4	97.2	0	0.9	0	0.9
R077	Lotic	36	14.3	92.4	2.8	2.8	2.8	4.2
R055	Lotic	101	16.5	95.9	0	4.6	0	4.6
R074	Lotic	106	17.8	93.1	0	0	0	0
P00809	Lotic	65	19.7	91.7	0	0	0	0
P00803	Lotic	108	24.8	95.7	0	0	1	1

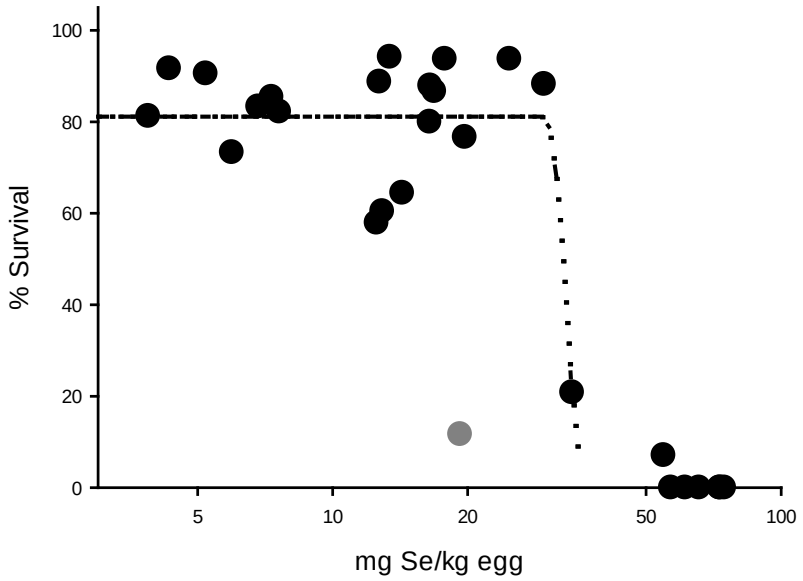


Figure 1. Labs A and B datasets. EC10 based on interpolation between the one partial effect (34.2 mg/kg, 20.8%) and an EC0 set at the HNOEC and the average % survival for all the NOECs (29.6 mg/kg and 81.1%). The slope is 20.5 and the EC10 is 31.1 mg/kg. Note: the gray point denotes egg batch with quality problems noted by authors and was not used in the analysis.

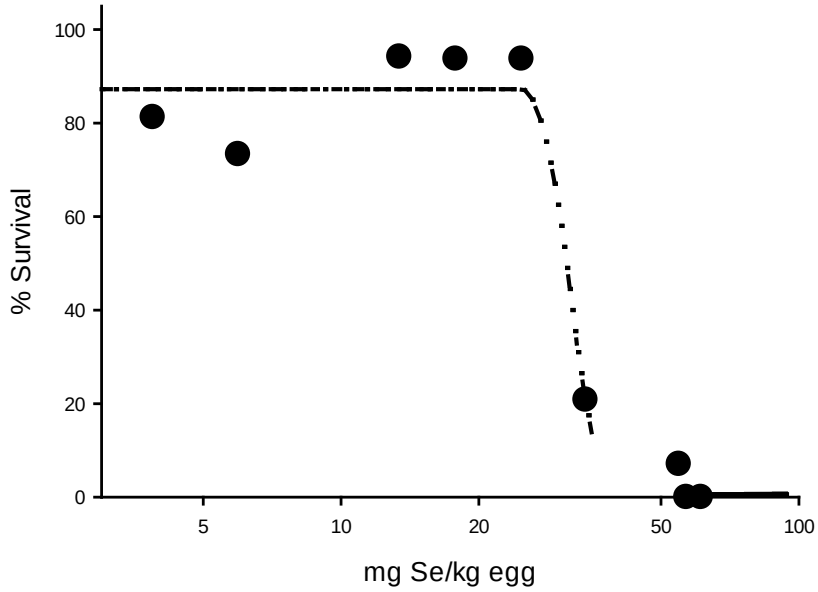


Figure 2. Lab A dataset.* EC10 based on interpolation between the one partial effect (34.2 mg/kg, 20.8%) and an EC0 set at the HNOEC and the average % survival for all the NOECs (24.8 mg/kg and 87.25%). The slope is 9.4 and the EC10 is 27.7 mg/kg.

*Although some scientists have attempted to explain certain occurrences of improved response with increasing concentration in terms of nutrient selenium sufficiency-deficiency, the concentrations involved in this study are too high to for selenium deficiency to be an explanation. The figure's apparent bi-phasic measured response is thus best explained as being a chance outcome of noise.

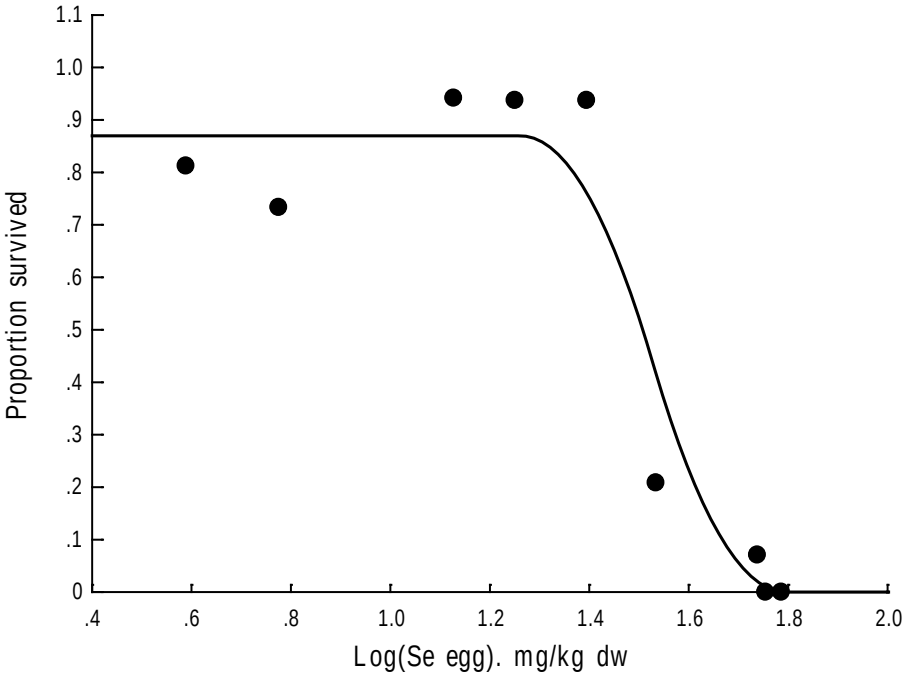


Figure 3. (From previous draft) Tolerance distribution; Model option – Triangular distribution (3 parameter). Includes Laboratory "A" dataset only TRAP EC_{10} estimate = 24.0 mg/kg.

Golder Associates. 2009. Development of a Site-specific Selenium Toxicity Threshold for Dolly Varden Char. Report to Northgate Minerals Corporation, PO Box 3519, Smithers, British Columbia. Report Number 04-1421-101/2000.

Test Organism: Dolly Varden (*Salvelinus malma*)

Exposure Route: Field collected.

Adult Dolly Varden char were collected from reference (North Kemess Creek), high Se exposure (Upper Waste Rock Ponds and Creek) and moderate Se exposure (lower Waste Rock Creek) sites during September 22 to 24, 2008. Eggs were stripped from females and fertilized with milt from males collected from the reference site. Fertilized eggs were taken to the laboratory for testing.

Test duration: The test was terminated when 90% of the larvae reached swim-up, approximately 5 months after fertilization.

Study Design: Approximately 30 fertilized eggs were added to each replicate rearing container. The number of replicates per female parent ranged from one to four depending on the number of eggs available. Embryos were maintained in 4 L containers with 3.5 L dechlorinated tap water in a static-renewal system (3 renewals times/week) at 5°C. The condition of the embryos and alevins were observed daily and any dead individuals were counted and removed. Test termination occurred over a 3-day period during February 11 to 13, 2009. The hatched larvae were sacrificed using an overdose of the anesthetic, clove oil. Individual length and weight were measured on each fry, and deformity analysis was performed on fresh unpreserved larval fish using 40X magnification.

A graduated severity index (GSI) was used for deformity assessment (skeletal, craniofacial, and finfold as well as edema). The narrative criteria were the same as used by Holm et al. (2005) and Rudolph et al. (2008).

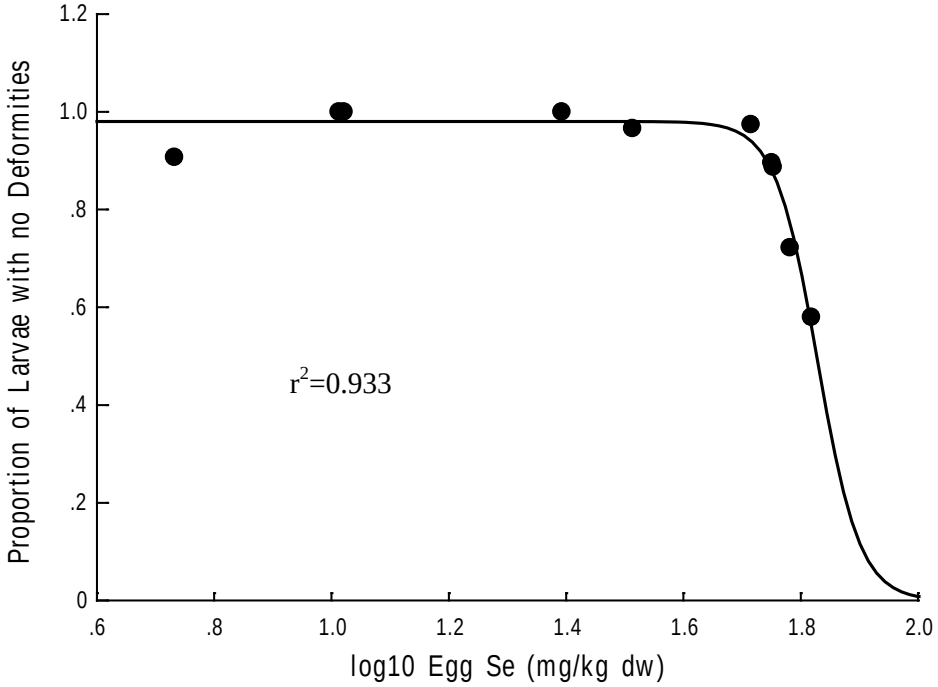
Effects Data: Alevin survival was not related to Se concentration in the eggs (Table 1). Almost all of the mortality occurred during the egg stage. Only 4 alevins died during the study, 1 from Fish #19 and 3 from Fish #2, both females collected at an exposed site. The prevalence of deformities increased sharply after the selenium egg concentration exceeded 50 mg/kg dw (Table 1, Figure 1). The proportion of Dolly Varden larvae with any type of deformity (skeletal, craniofacial, and finfold as well as edema) as a function of the log of the selenium concentration in the eggs using TRAP (logistic equation) produced an EC_{10} value of 56.22 mg/kg dw eggs (Figure 1).

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Table 1. Selenium concentration in the eggs of Dolly Varden char and the survival of alevins to the swim-up stage and the proportion of larvae without any type of deformity.

Fish #	Sample ID	Location	[Se] eggs mg/kg dw	Survival of eggs to swim-up			Proportion of larvae without any type of deformity
				Initial	End	%	
1	WRC-F105	Waste Rock Creek	56.6	120	71	59	0.89
2	WRC-F61	Waste Rock Creek	65.8	120	81	68	0.58
5	WRC-F103	Waste Rock Creek	32.6	29	29	100	0.97
6	WRC-F83	Waste Rock Creek	51.9	120	115	96	0.97
15	WRC-F104	Waste Rock Creek	56.3	60	48	80	0.90
19	WRC-F86	Waste Rock Creek	60.5	120	115	96	0.72
9	NK-F30	North Kemess Creek	11	30	1	3	a
12	NK-F29	North Kemess Creek	10.5	46	15	33	1.00
17	NK-F21	North Kemess Creek	5.4	90	86	96	0.91
SCD1	Redd #1	Southern Collection Ditch	10.3	30	18	60	1.00
SCD2	Redd #2	Southern Collection Ditch	24.7	40	32	80	1.00

Figure C-1. Proportion of Dolly Varden alevin without any type of deformity as a logistic function of the logarithm of the selenium concentration in eggs (TRAP).



	Guess	Final	SE	95% LCL	95% UCL
LogX50	1.844	1.829	0.007	1.812	1.845
Slope	4.152	6.963	1.252	4.003	9.924
Y0	0.975	0.980	0.017	0.939	1.021

ECx	EC	95% LCL	95% UCL
50	67.42	64.92	70.01
20	60.12	57.96	62.35
10	56.22	53.00	59.64
5	52.85	48.64	57.43
1	46.11	40.13	52.99

	DF	SS	MS	F	P
Total	9	1.74E-01	1.93E-02		
Model	2	1.63E-01	8.13E-02	51.429	0.99993
Error	7	1.11E-02	1.58E-03		

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AECOM. 2012. Reproductive success study with brown trout (*Salmo trutta*). Data quality assurance report. Final. December 2012.

Formation Environmental. 2011. Brown Trout Laboratory Reproduction Studies Conducted in Support of Development of a Site-Specific Selenium Criterion. Prepared for J.R. Simplot Company by Formation Environmental. Revised October 2011.

Test Organism: Brown trout (*Salmo trutta*)

Exposure Route: Field collected.

Adult female and male brown trout were collected at three field sites from two streams downstream of the Smokey Canyon mine. In addition, brown trout eggs were obtained from two hatcheries as method controls.

Test duration: Embryo-larval monitoring to 15 days post swim-up.

Study Design: Eggs were collected from 26 ripe female brown trout at three field sites downstream of the Smokey Canyon mine. These included one site on the highly impacted Sage Creek (LSV2C) as well as two sites along Crow Creek (CC-150 and CC-350) downstream of the conflux with Sage Creek. The downstream – most station along Crow Creek (CC-150) was intended to be a field control. Eggs were fertilized in the field with milt collected from males collected at the same site as females. Fertilized eggs were water hardened at the site using stream water, then placed in oxygenated plastic bags and stored on ice in the dark (cooler) for transportation to laboratory. Selenium was measured in adult fish (whole body) and in eggs of field collected females. In addition, eggs were collected from 8 ripe females obtained from the Saratoga National Fish Hatchery (SC) to serve as method controls. Similar to field-caught fish, SC hatchery females were stripped of eggs and fertilized by milt from males obtained from the same hatchery. As a result of lower than expected hatch rates and fungal contamination in some SC hatchery samples, additional hatchery fish were obtained (as already fertilized eyed embryos) from the Spring Creek Trout Hatchery (SPC), which were divided into four treatments.

Approximately 600 fertilized eggs from each female (or 600 eyed embryos for SPC treatments) were placed in egg cups for hatching and monitoring. After swim up, remaining fry were thinned to a target of 100 fry/treatment and monitored for an additional 15-day post swim up feeding trial. Test termination ranged from 83 to 88 days after hatch for all but the Spring Creek Hatchery egg treatments, which occurred 50 days after the arrival of fertilized, eyed embryos from that hatchery.

Endpoints measured in the laboratory study were fecundity, hatch, growth, survival/mortality, and feeding success (growth) post swim up. Larval brown trout were also evaluated for deformities (craniofacial, vertebral, fin) and edema. For this study, deformities were combined and assessed as having at least one deformity, or being fully free of deformities (i.e., normal).

Effects Data: Se concentrations in eggs ranged from 6.2-12.8 mg Se/kg dw at CC150, 6.9-14.0 mg Se/kg dw at CC350, and 11.2-40.3 mg Se/kg dw at LSV2C. Se concentrations in hatchery eggs ranged from 0.76-1.2 mg Se/kg dw at the SC hatchery, and were 0.73 mg Se/kg dw at the SPC hatchery. The Se whole body concentration in field collected fish ranged from 7.2-22.6 mg/kg dw at LSV2C, 4.7-8.4 mg/kg dw at CC150, and 5.5-9.2 mg/kg dw at CC350. Se whole body concentrations in SC hatchery fish ranged from 2.5-4.3 mg/kg dw. Hatchery data were combined with field data and included in all analyses.

Three endpoints were considered for purposes of calculating an EC_{10}. These were percent survival, percent fully free from deformities, and percent surviving and normal. Initially, data for these endpoints were combined and analyzed for both portions of the test: hatch through swim up and the 15-day post swim feeding trial. Data for these endpoints over both portions of the test are shown in Tables 1-3.

A U.S. Fish and Wildlife (2012) review of the Formation Environmental (2011) report suggested that fish lost due to an overflow even resulting from a drain the became clogged with food during the 15-day post swim up portion of the test were more likely to have been dead or deformed, and proposed that all treatments that lost fish to the overflow event should be excluded from the EC_{10} calculation. In the 2014 and 2015 draft Se documents, endpoints assessed for the hatch through 15-day post swim up test were analyzed using two scenarios. In the "worst-case" scenarios, the hypothesis from the USFWS review was examined, by treating all fish lost to overflow as either dead or deformed, rather than excluding those treatments altogether. In the "optimistic" scenario, the overflow event was treated as a random technician error unrelated to selenium toxicity, and any lost fish were removed from the calculation. In other words, fish lost to overflow were assumed to be equally likely to have been dead or deformed compared to fish that were not lost.

Because of the importance of these data for the numeric criterion calculation, and because of several experimental factors that resulted in the calculation of several reasonable EC_{10}s, such as the loss of fish due to an overflow event described above, EPA conducted a careful and thorough reanalysis of the study data and subjected the reanalysis to independent, external peer review (ERG 2012) to confirm the validity and scientific robustness of the approach taken by EPA in the reanalysis and use of the reanalyzed data. Those assessments were then superseded by a reanalysis of a more complete enumeration of the deformity counts provided by AECOM (2012). All analyses reported in the 2014 and 2015 draft Se documents and the current Se document used values from the updated dataset provided by AECOM (2012).

Hatch Through 15-Day Post Swim Up Combined Data

In the 2014 and 2015 draft Se documents, data for three endpoints, survival, deformities, and combined survival+deformities were considered for both portions of the test. The first portion of the test was from hatch through swim up, lasting 88 days (on average). The second portion was the 15-day post-swim up

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feeding trial. None of the fry from the five treatments with Se concentrations of 26.8 mg/kg and higher reached swim-up. However, surviving fry from those treatments were included in the post-swim up feeding trial.

Combined Survival and Deformity Endpoint

Selenium concentrations and counts of total larvae, and counts of proportions of fully normal larvae (alive and normal) are included in Table 1. Background percentages of live and normal individuals were extremely variable and often low (Figure 1). In the 2014 draft document, EC_{10}s for the optimistic (21.16 mg/kg) and worst case (20.65 mg/kg) scenarios were calculated, and these were also reported in the 2015 draft document. Although there is a clear demarcation between treatments equal to or less than 20.5 µg/L and treatments equal to or greater than 26.8 µg/L, suggesting an effect level between these concentrations, a careful reanalysis of these data following the release of the 2015 draft Se document determined that a meaningful EC_{10} cannot be calculated because of the high background variability.

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Table 1. Brown trout selenium concentrations and survival + deformity data (combined endpoint) from hatch to test end (15 days post swim up).

Sample ID[a]	Whole body Se, mg/kg dw	Egg Se mg/kg dw	# Normal	# Normal that were dead at assessment	# Normal and alive	# Live fish assessed for deformities	# Fish died during test	# Fish lost to overflow during post swim up test	# Live fish assessed + # died during test.	Prop. Live fish assessed + # died during test.
SC-001	3.6	0.76	63		63	115	8		123	0.512
SC-002	4.1	0.94	72		72	113	4		117	0.615
SC-003	3.7	0.83	131		131	302	7	9	309	0.424
SC-004	4.3	0.92	46		46	140	28		168	0.274
SC-005	3	1.2	23		23	42	6		48	0.479
SC-006	3.1	1.2	457		457	535	8		543	0.842
SC-007	2.7	1	93		93	137	30		167	0.557
SC-008	2.5	0.96	283		283	359	6	10	365	0.775
SPC-001[c]		0.73	427		427	570	8		578	0.739
SPC-002[c]		0.73	371		371	545	20		565	0.657
SPC-005[c]		0.73	400		400	561	8		569	0.703
SPC-006[c]		0.73	427		427	556	17		573	0.745
CC-150-009	8.4	12.8	106		106	142	11		153	0.693
CC-150-011	5.6	8.4	87		87	266	2		268	0.325
CC-150-012	6.7	8.5	156		156	282	12		294	0.531
CC-150-013	5.9	8.4	137		137	310	46	26	356	0.385
CC-150-015	6	9.1	210		210	445	14		459	0.458
CC-150-016	7	7.5	13		13	23	3	43	26	0.500
CC-150-017	5.6	6.6	99		99	163	7	33	170	0.582
CC-150-018	4.7	6.9	195		195	486	16		502	0.388
CC-150-020	7.2	6.2	453		453	558	6		564	0.803
CC-350-006	9.2	14	120		120	386	26		412	0.291
CC-350-007	5.5	6.9	68		68	131	10	20	141	0.482
CC-350-008	8.5	9.5	269		269	338	21	28	359	0.749
LSV2C-002	8.9	12.8	483		483	544	4	16	548	0.881
LSV2C-003	13.8	40.3	2	2	0	0	395		395	0.000
LSV2C-004	17.9	36	16	16	0	0	289		289	0.000
LSV2C-005	13.6	26.8	8	8	0	0	267		267	0.000
LSV2C-008	9.6	17.7	147		147	194	4	45	198	0.742

Sample ID[a]	Whole body Se, mg/kg dw	Egg Se mg/kg dw	# Normal	# Normal that were dead at assessment	# Normal and alive	# Live fish assessed for deformities	# Fish died during test	# Fish lost to overflow during post swim up test	# Live fish assessed + # died during test.	Prop. Live fish assessed + # died during test.
LSV2C-010	22.6	38.8	5	5	0	0	97		97	0.000
LSV2C-012	7.2	13.2	217		217	554	17		571	0.380
LSV2C-016	9.2	13.4	440		440	530	20		550	0.800
LSV2C-017	13.2	20.5	110		110	150	28	19	178	0.618
LSV2C-019	8.6	12.5	267		267	390	22	39	412	0.648
LSV2C-020	11.3	11.2	240		240	296	5	36	301	0.797
LSV2C-021	20	28.1	8	8	0	0	404		404	0.000

[a] SC – Saratoga National Fish Hatchery; SPC – Spring Creek Trout Hatchery; CC – Crow Creek; LSV – Sage Creek

[b] Test end was 15 days after swim up.

[c] Arrived as fertilized, eyed-eggs. No whole body Se measurement possible.

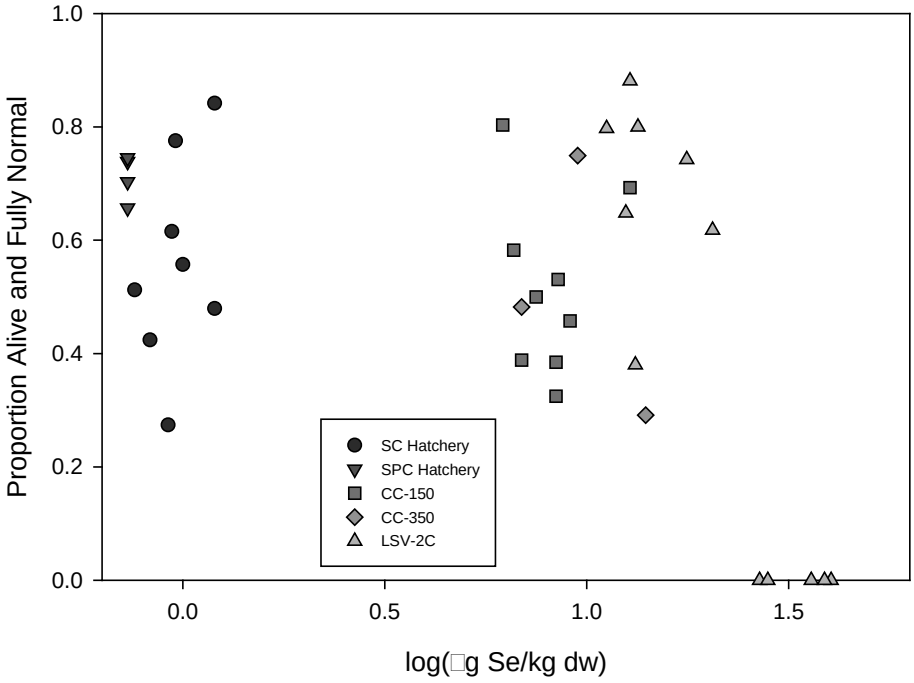


Figure 1. Proportion of alive and normal larvae plotted against Se concentrations in eggs. Effects were highly variable across the entire background concentration range (20.5 mg/kg and lower), such that a meaningful EC_{10} could not be calculated for this endpoint.

Deformity Endpoint

Selenium concentrations, counts of larvae assessed for deformities, and counts and proportions of normal larvae are included in Table 2. As with the combined endpoint, background (at or below 20.5 mg/kg) proportions of deformities were highly variable (Figure 2). In the 2014 draft document, EC_{10}s were calculated for both the optimistic and worst case scenarios, and the EC_{10} of 15.91 mg/kg for the worst case scenario was used as the EC_{10} for Salmo. During the review phase following the release of the 2014 draft Se document, several public commenters noted that because of the high variability, more than one EC_{10} could be calculated by TRAP for both the optimistic and the worst case scenarios depending on the initial model conditions, in particular the slope of the falling limb of the concentration-response curve. For the optimistic scenario, EC_{10}s based on initial conditions ranged from 16.36-21.95 mg/kg, and for the worst case scenario, EC_{10}s based on initial conditions ranged from 15.91-21.58 mg/kg. In order to evaluate the most appropriate EC_{10} for the deformity endpoints, models were evaluated based on residual sum of squares, and the EC_{10} for the model with the lowest residual sum of squares was selected as the most appropriate. For the worst case scenario deformity endpoint, the model with the lowest residual sum

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of squares was the EC_{10}=21.58 mg/kg model, and for the optimistic deformity endpoint, the model with the lowest residual sum of squares was the EC_{10}=21.94 mg/kg model.

These variable EC_{10}s were the result of large variability in background concentration, with several treatments at low Se concentrations experiencing greater than 60% deformities (Figure 2). Although there is clear evidence of an effect between the 20.5 and 26.8 mg/kg concentrations, because of this high background variability, a careful re-analysis of these data following the release of the 2015 draft Se document determined that a meaningful EC_{10} could be calculated for the deformity endpoint.

Some of the background variability in deformities appears to be the result of differences among field sites. For example, deformity rates among field samples appear to be greater for fish hatched from eggs collected in the two Crow Creek sites (CC-150, CC-350) compared to Sage Creek (LSV-2C) (Figure 2). If the result of higher background deformities among Crow Creek sites is not a random artifact, it suggests a confounding factor, unrelated to selenium exposure. Whether the higher deformity rates represent random variation, population differences, other environmental quality differences (unrelated to Se), or methodological issues is unclear**.**

Table 2. Brown trout selenium concentrations and deformity data from hatch to test end (15 days post swim up).

Sample ID[a]	Whole body Se, mg/kg dw	Egg Se mg/kg dw	# Normal	# Assessed for deformities. "Optimistic Case"	# Lost to overflow during post swim up test	Prop. Assessed for deformities plus # lost.
SC-001	3.6	0.76	63	115		0.548
SC-002	4.1	0.94	72	113		0.637
SC-003	3.7	0.83	131	302	9	0.434
SC-004	4.3	0.92	46	140		0.329
SC-005	3	1.2	23	42		0.548
SC-006	3.1	1.2	457	535		0.854
SC-007	2.7	1	93	137		0.679
SC-008	2.5	0.96	283	359	10	0.788
SPC-001[c]		0.73	427	570		0.749
SPC-002[c]		0.73	371	545		0.681
SPC-005[c]		0.73	400	561		0.713
SPC-006[c]		0.73	427	556		0.768
CC-150-009	8.4	12.8	106	142		0.746
CC-150-011	5.6	8.4	87	266		0.327
CC-150-012	6.7	8.5	156	282		0.553
CC-150-013	5.9	8.4	137	310	26	0.442
CC-150-	6	9.1	210	445		0.472

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Sample ID[a]	Whole body Se, mg/kg dw	Egg Se mg/kg dw	# Normal	# Assessed for deformities. "Optimistic Case"	# Lost to overflow during post swim up test	Prop. Assessed for deformities plus # lost.
015						
CC-150-016	7	7.5	13	23	43	0.565
CC-150-017	5.6	6.6	99	163	33	0.607
CC-150-018	4.7	6.9	195	486		0.401
CC-150-020	7.2	6.2	453	558		0.812
CC-350-006	9.2	14	120	386		0.311
CC-350-007	5.5	6.9	68	131	20	0.519
CC-350-008	8.5	9.5	269	338	28	0.796
LSV2C-002	8.9	12.8	483	544	16	0.888
LSV2C-003	13.8	40.3	2	100		0.020
LSV2C-004	17.9	36	16	142		0.113
LSV2C-005	13.6	26.8	8	149		0.054
LSV2C-008	9.6	17.7	147	194	45	0.758
LSV2C-010	22.6	38.8	5	80		0.063
LSV2C-012	7.2	13.2	217	554		0.392
LSV2C-016	9.2	13.4	440	530		0.830
LSV2C-017	13.2	20.5	110	150	19	0.733
LSV2C-019	8.6	12.5	267	390	39	0.685
LSV2C-020	11.3	11.2	240	296	36	0.811
LSV2C-021	20	28.1	8	172		0.047

[a] SC – Saratoga National Fish Hatchery; SPC – Spring Creek Trout Hatchery; CC – Crow Creek; LSV – Sage Creek

[b] Test end was 15 days after swim up.

[c] Arrived as fertilized, eyed-eggs. No whole body Se measurement possible.

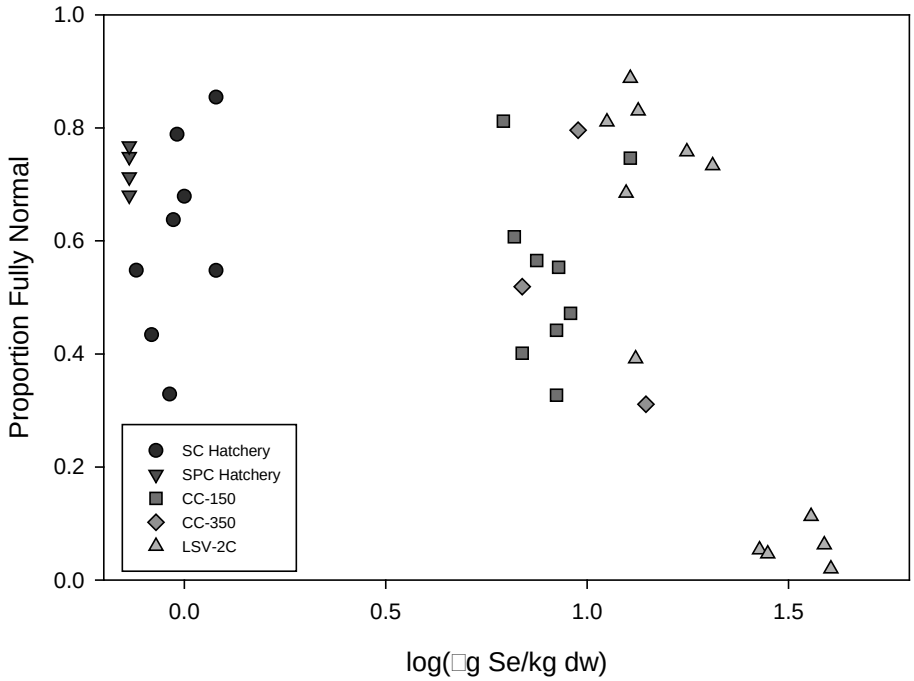


Figure 2. Proportion of normal (free from deformities) larvae plotted against Se concentrations in eggs, hatch through 15-days post swim up. Effects were highly variable across the entire background concentration range (20.5 mg/kg and lower), such that a meaningful EC_{10} could not be calculated for this endpoint.

Survival Endpoint

Selenium concentrations and estimated counts and proportions of larvae surviving from hatch through 15 days post swim up are included in Table 3. Estimated counts and proportions were reported for survival through the 15-day post swim up test because larvae were thinned to a target of 100 individuals/treatment prior to the onset of the post swim up test, and final full test survival is calculated as the product of survival from hatch to swim up and survival during the 15-day post swim up test. In the 2014 draft document, EC_{10}s were calculated for the worst case (16.78 mg/kg) and optimistic (20.40 mg/kg) survival scenarios, and these were also reported in the 2015 draft document. For both scenarios, the assumption was made that fry that failed to swim up would not have survived, and so the survival for the post swim up portion of the test in the 5 treatments with the highest selenium concentrations (26.8 mg/kg and above) was set to zero. The EC_{10} of 16.78 mg/kg for the optimistic is nearly identical to the EC_{10} for the worst case survival scenario of 16.76 mg/kg presented in the response to the FWS review of the Formation Environmental study (Taulbee et al. 2012), peer reviewed by ERG (2012).

In contrast to the deformity and combined deformity+survival endpoints, background survival (concentrations up to and including 20.5 mg/kg) was much less variable. Despite the lower variability among background effect levels, a careful re-examination of these data following the release of the 2015 draft Se

document determined that a meaningful EC_{10} cannot be calculated by TRAP so long as the assumption is made that fry failing to reach swim up are assumed to be dead. This is because TRAP requires at least 2 partial effects to calculate an EC_{10}, and this dataset has no partial effects, but rather, a background range with high and relatively stable survival through 20.5 mg/kg, and then no survival at concentrations of 26.8 mg/kg and above (Figure 3). In order to calculate an EC_{10} for survival, the assumption regarding fry that failed to swim up was removed. In addition, in order to remove the uncertainty introduced by the clogged drain leading to the overflow and loss of fish from some of the treatments in the post swim up test, the EC_{10} for larval survival was calculated for the much longer hatch through swim up portion of the test, as described below.

Table 3. Brown trout selenium concentrations and survival data from hatch to test end (15 days post swim up).

Sample ID[a]	Whole body Se, mg/kg dw	Egg Se mg/kg dw	# Eggs Hatched	Prop. Survival. Hatch to swim up	Prop survival. Post swim up."	Prop survival. Hatch to end[b].
SC-001	3.6	0.76	144	0.951	0.990	0.942
SC-002	4.1	0.94	138	0.978	0.990	0.968
SC-003	3.7	0.83	340	0.982	0.989	0.971
SC-004	4.3	0.92	189	0.868	0.971	0.842
SC-005	3	1.2	70	0.914	1.000	0.914
SC-006	3.1	1.2	564	0.988	0.990	0.978
SC-007	2.7	1	188	0.856	0.970	0.830
SC-008	2.5	0.96	396	0.985	1.000	0.985
SPC-001[c]		0.73	598	0.987	1.000	0.987
SPC-002[c]		0.73	20	1.000	1.000	1.000
SPC-003[c]		0.73	585	0.966	1.000	0.966
SPC-004[c]		0.73	21	1.000	1.000	1.000
SPC-005[c]		0.73	589	0.986	1.000	0.986
SPC-006[c]		0.73	593	0.971	1.000	0.971
CC-150-009	8.4	12.8	173	0.942	0.990	0.933
CC-150-011	5.6	8.4	288	0.993	1.000	0.993
CC-150-012	6.7	8.5	314	0.965	0.990	0.955
CC-150-013	5.9	8.4	402	0.891	0.973	0.866
CC-150-015	6	9.1	479	0.971	1.000	0.971
CC-150-016	7	7.5	89	0.966	1.000	0.966
CC-150-017	5.6	6.6	223	0.969	1.000	0.969
CC-150-018	4.7	6.9	522	0.969	1.000	0.969
CC-150-020	7.2	6.2	584	0.990	1.000	0.990
CC-350-006	9.2	14	432	0.944	0.980	0.926
CC-350-007	5.5	6.9	181	0.950	0.988	0.938
CC-350-008	8.5	9.5	407	0.951	0.986	0.938
LSV2C-002	8.9	12.8	584	0.993	1.000	0.993
LSV2C-003[d]	13.8	40.3	404	0.079	0.281	0.022
LSV2C-004[d]	17.9	36	309	0.414	0.477	0.197
LSV2C-005[d]	13.6	26.8	287	0.387	0.622	0.240
LSV2C-008	9.6	17.7	263	0.989	0.982	0.971
LSV2C-010[d]	22.6	38.8	108	0.231	0.440	0.102
LSV2C-012	7.2	13.2	591	0.971	1.000	0.971

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Sample ID[a]	Whole body Se, mg/kg dw	Egg Se mg/kg dw	# Eggs Hatched	Prop. Survival. Hatch to swim up	Prop survival. Post swim up."	Prop survival. Hatch to end[b].
LSV2C-016	9.2	13.4	570	0.965	1.000	0.965
LSV2C-017	13.2	20.5	217	0.885	0.963	0.852
LSV2C-019	8.6	12.5	471	0.953	1.000	0.953
LSV2C-020	11.3	11.2	357	0.986	1.000	0.986
LSV2C-021[d]	20	28.1	424	0.288	0.730	0.210

[a] SC – Saratoga National Fish Hatchery; SPC – Spring Creek Trout Hatchery; CC – Crow Creek; LSV – Sage Creek

[b] Test end was 15 days after swim up.

[c] Arrived as fertilized, eyed-eggs. No whole body Se measurement possible.[d] Survived but failed to reach swim up. Assumed dead in all hatch to 15-day post swim up analysis.

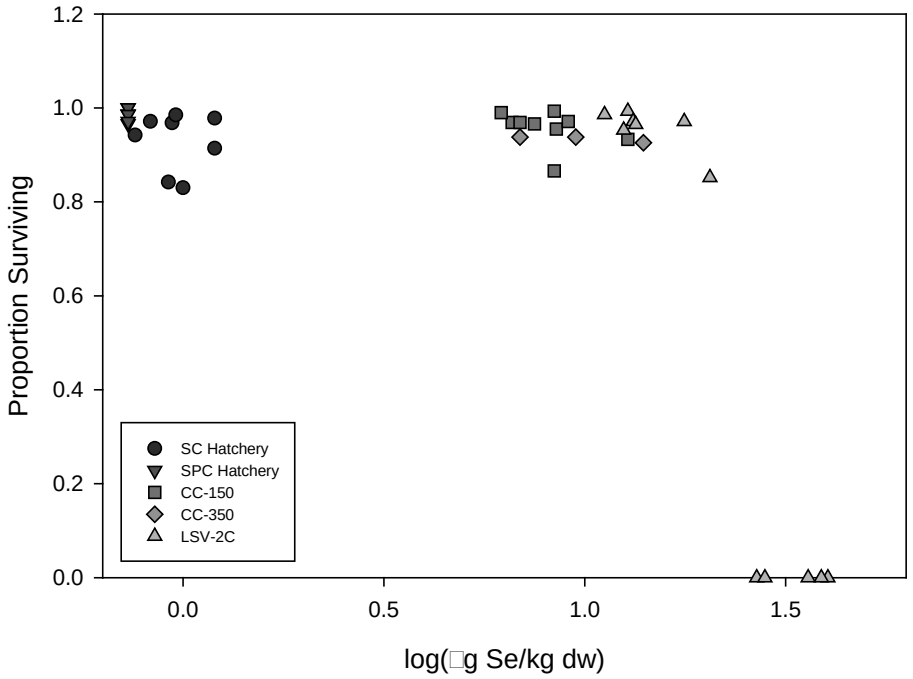


Figure 3. Proportion of larval survival plotted against log transformed Se concentrations in eggs, hatch through 15-day post swim up. Larvae from the five highest Se concentration treatments failed to reach swim up and were assumed to not have survived in the wild.

<u>Assessment of Overflow Loss During 15-day Post Swim Up Feeding Trial</u>

In the 2015 draft Se document, an assessment was made to determine whether the loss of fish from the overflow event during the 15-day post swim up portion of the test was related to survival or to Se treatment concentration measured during the first portion of the test. In this assessment, data were examined from the perspective of whether the overflow loss of brown trout during the second stage of the test could reflect dead, dying, or weak organisms. This was done to examine the hypothesis proposed in the U.S. FWS review that fish lost to overflow were either dead or dying.

First, the relationship between larval survival in the first and second stages of the test (hatch to swim up, 15 days post swim up) were compared for all treatments where larvae successfully reached the swim up stage (Figure 4). Overall, survival in the second stage tracks survival in the first stage (r^2=0.6), but survival in the second stage was noticeably higher in than in the first stage. This result is consistent with the following statement made by the principle scientist of the brown trout study in the public comments to the 2014 selenium draft document submitted for external peer review: "escaped fry were observed swimming in the water bath where the treatment containers were being held. These fry congregated near the treatment cells. Dead or dying fish were not observed."

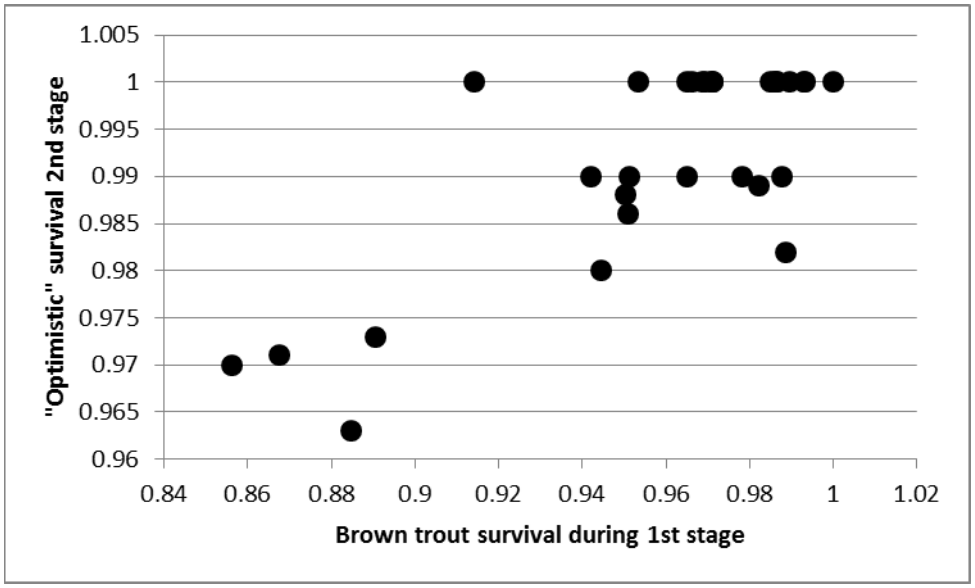


Figure 4. Relationship between survival during the first and second portions of the test. All treatments where larvae successfully reached swim up (Se concentrations of 20.5 mg/kg and lower).

Second, the relationship between larval mortality in the first stage and overflow loss in the second stages of the test (hatch to swim up, 15 days post swim up) were compared separately for all treatments (field and hatchery) and for all field collected treatments (Figure 5). As with figure 4, these correlations were made for treatments where larvae successfully reached the swim up stage. In these instances, there is no apparent relationship between health, as reflected by mortality in the first stage, and overflow loss in the second stage, whether considering all individuals or wild-only: r^2 for both graphs is 0.0. The lack of a relationship in these correlations suggests that overflow loss has a likelihood of being a random noise variable.



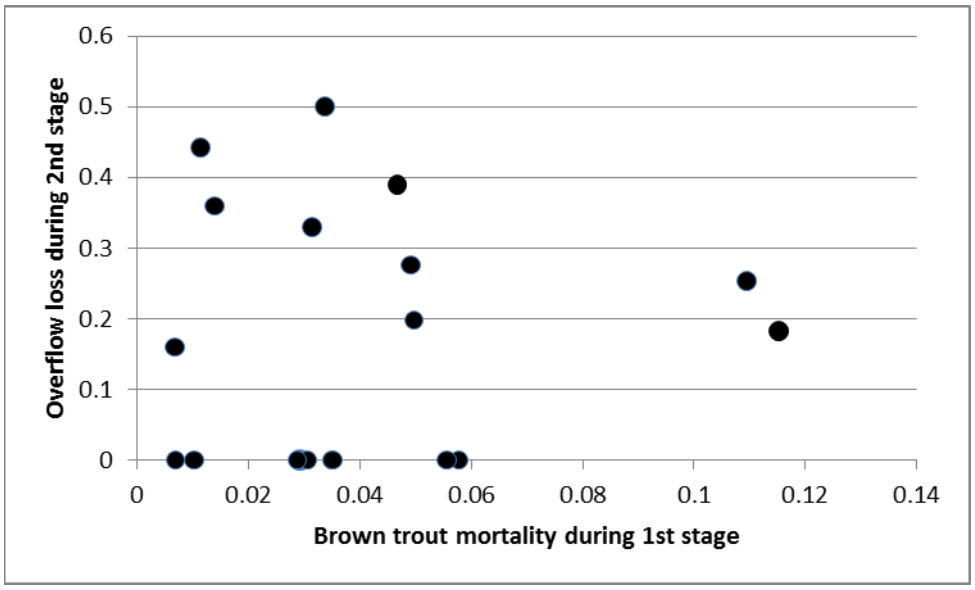


Figure 5. Relationship between mortality during the first stage of the test and overflow loss during the second stage of the test. Upper figure – all hatchery and field treatments. Lower figure – field treatments only. Larvae from treatment levels 26.8 mg/kg and higher, which failed to swim up, were excluded.

Finally, the relationship between overflow loss and selenium concentrations in eggs was examined (Figure 6). As with previous correlations, only larvae from treatments where individuals reached swim up were considered.

Figure 6 shows a clear difference between hatchery (far left) and field treatments, but across the concentration range for the offspring of field collected fish there is no apparent relationship between overflow loss and Se concentration. Within the field treatments, the r^2 of the correlation between Se concentration and overflow loss is 0.01. Although there are no known genetic differences between hatchery

and wild fish, if leaving the aquarium required swimming over the rim, one might speculate that previous generations of hatchery fish might have developed a tolerance to remaining in conditions that might seem crowded to wild organisms. (That is, however, purely speculative.) Otherwise, the difference between hatchery and wild fish would seem only to reflect a random artifact, since the Se concentrations at which the wild fish displayed high overflow losses are low.

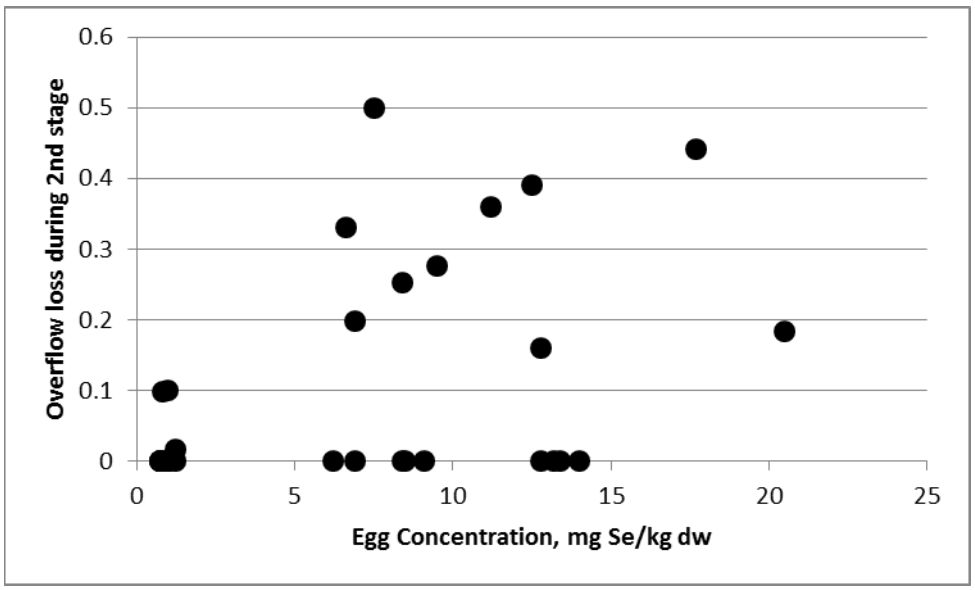


Figure 6. Relationship between egg Se concentration and overflow loss during the second stage of the test. Larvae from treatment levels 26.8 mg/kg and higher, which failed to swim up, were excluded.

In summary, the positive correlation between survival during the hatch to swim up portion of the test and survival during the 15-day post swim up portion of the test, combined with the lack of a correlation between mortality during the hatch to swim up portion of the test and overflow loss during the second stage of the test, suggests that the overflow loss likely represents a random technician error not related to the health of the individuals lost. The relationship between selenium egg concentrations and overflow loss was lower for the larvae hatched from hatchery fish compared to the larvae hatched from field collected fish; however, among field treatments ranging from 6.0-20.5 mg/kg there was no correlation, further supporting the hypothesis that the overflow event was a random occurrence unrelated to the health of larval fish.

The results of the above assessment of the overflow event strongly suggest that the overflow event was a random technician error unrelated to selenium toxicity, and that the "optimistic" scenario is also likely more realistic.

Survival Endpoint – EC_{10} for the first portion of the test

Because larval survival was measured at the end of the first portion of the test (hatch to swim up), an alternative approach to measuring survival would be to

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calculate the brown trout EC_{10} for survival for only the first portion of the test. Selenium concentrations and counts of total larvae and larvae that survived the first portion of the test are included in Table 4. The hatch to swim up portion of the test was much longer than the second portion (88 days on average compared to 15 days), and more importantly, it avoids the experimental confound introduced by the loss of fish during the overflow event. With this approach, the second portion of the test would be rejected as inconclusive due to the laboratory accident.

Unlike survival, deformities could not be analyzed for the first portion of the test because of a bias introduced during the thinning process prior to the initiation of the 15-day post swim up portion of the test. During the thinning process, visibly deformed larvae were selectively removed, so that the fish used in the 15-day post swim up test were less likely to have been deformed. Because of this selection bias, only survival could be evaluated from hatch to swim up. Nevertheless, survival appears to be as sensitive an endpoint as deformities or survival+deformities, as all endpoints exhibit background effects (with differing levels of variability) through 20.5 mg/kg, and severe effects at concentrations between 26.8-40.3 mg/kg.

In contrast to survival endpoints measured from hatch through 15 days post swim up, survival for all treatments were included, including larvae from the five treatments of 26.8 mg/kg and higher, where larvae failed to reach swim up. This avoids any potential inconsistency stemming from not knowing whether small percentages of individuals did not swim up in other treatments. In contrast to the previous EC_{10} calculations, this approach is free from all assumptions about individuals lost in the lab accident. In the 2015 draft document, an EC_{10} of 18.09 mg/kg was calculated for this endpoint in TRAP, and this EC_{10} was used as the GMCV for Salmo. During a subsequent review, this EC_{10} was determined to be inappropriate, because it is lower than the 20.5 mg/kg concentration, which with 88.5% survival falls within the variability of the 32 data points at lower concentrations. Compared to the average survival for all 33 background concentration treatments, the survival at 20.5 mg/kg represents an approximately 8% effect.

In order to calculate an EC_{10} that would not fall below the background concentration of 20.5 mg/kg, a weighted least squares linear regression was calculated in TRAP, using a threshold sigmoid model (Figure 7). The model was weighted using the standard deviation of the 33 background concentrations (all concentrations between 0.73-20.5 mg/kg), and the residual standard deviation of the five concentrations between 26.8-40.3 mg/kg. This was done to provide less weight to the more variable, and more uncertain, high Se treatments relative to the less variable background treatments. The EC_{10} for survival using the weighted regression model is 21.0 mg/kg.

One issue with the above TRAP analysis is that to fit the 5 higher effects data well, the EC_0 estimate is pushed down to 16.4 mg/kg, below two of the points in the background range. Also, the fitted curve goes through the data point at 20.5 mg/kg, so that this point is considered to be an EC_8. This is not unreasonable because the response is so steep at concentrations above this point that some effect at this point is plausible. Nevertheless, this point is within the range of the

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background and there are insufficient data to say that this concentration is an effect level. Thus, to accept this analysis and use the EC_{10} from this curve requires making a slightly conservative risk management decision that the point at 20.5 mg/kg should be treated as having some effect.

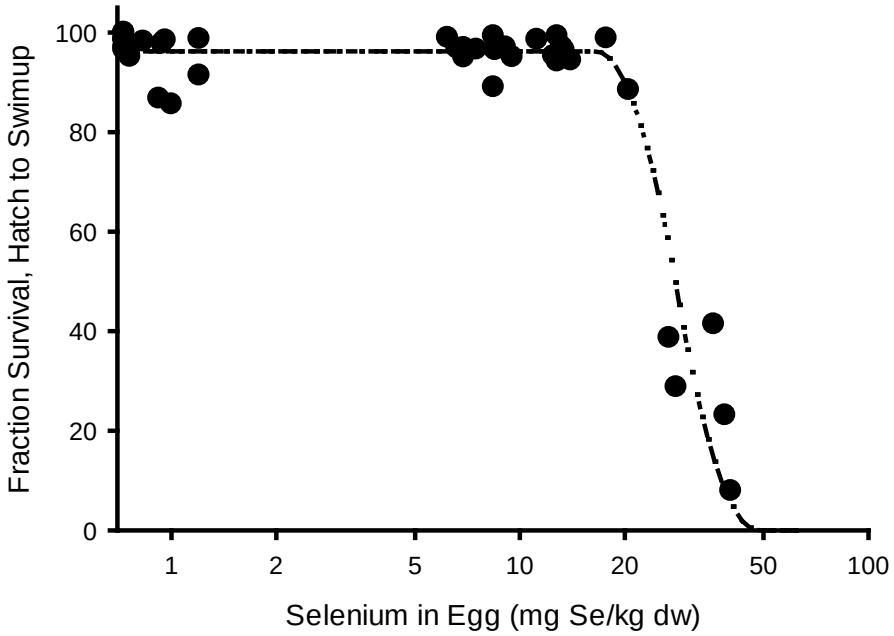


Figure 7. Brown trout survival, hatch to swim up. EC_{10} of 21.0 mg/kg calculated using a weighted nonlinear regression model.

Table 4. Brown trout selenium concentrations and survival data from hatch to swim up (first portion of the test).

Sample ID[a]	Whole body Se, mg/kg dw	Egg Se mg/kg dw	# Larvae Hatched	# Larvae Survived – Hatch to Swim Up	% Larvae Survived – Hatch to Swim Up
SC-001	3.6	0.76	144	137	95.1
SC-002	4.1	0.94	138	135	97.8
SC-003	3.7	0.83	340	334	98.2
SC-004	4.3	0.92	189	164	86.8
SC-005	3	1.2	70	64	91.4
SC-006	3.1	1.2	564	557	98.8
SC-007	2.7	1	188	161	85.6
SC-008	2.5	0.96	396	390	98.5
SPC-001[b]		0.73	598	590	98.7
SPC-002[b]		0.73	20	20	100
SPC-003[b]		0.73	585	565	96.6
SPC-004[b]		0.73	21	21	100
SPC-005[b]		0.73	589	581	98.6

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Sample ID[a]	Whole body Se, mg/kg dw	Egg Se mg/kg dw	# Larvae Hatched	# Larvae Survived – Hatch to Swim Up	% Larvae Survived – Hatch to Swim Up
SPC-006[b]		0.73	593	576	97.1
CC-150-009	8.4	12.8	173	163	94.2
CC-150-011	5.6	8.4	288	286	99.3
CC-150-012	6.7	8.5	314	303	96.5
CC-150-013	5.9	8.4	402	358	89.1
CC-150-015	6	9.1	479	465	97.1
CC-150-016	7	7.5	89	86	96.6
CC-150-017	5.6	6.6	223	216	96.9
CC-150-018	4.7	6.9	522	506	96.9
CC-150-020	7.2	6.2	584	578	99
CC-350-006	9.2	14	432	408	94.4
CC-350-007	5.5	6.9	181	172	95
CC-350-008	8.5	9.5	407	387	95.1
LSV2C-002	8.9	12.8	584	580	99.3
LSV2C-003	13.8	40.3	404	32[c]	7.9
LSV2C-004	17.9	36	309	128[c]	41.4
LSV2C-005	13.6	26.8	287	111[c]	38.7
LSV2C-008	9.6	17.7	263	260	98.9
LSV2C-010	22.6	38.8	108	25[c]	23.1
LSV2C-012	7.2	13.2	591	574	97.1
LSV2C-016	9.2	13.4	570	550	96.5
LSV2C-017	13.2	20.5	217	192	88.5
LSV2C-019	8.6	12.5	471	449	95.3
LSV2C-020	11.3	11.2	357	352	98.6
LSV2C-021	20	28.1	424	122[c]	28.8

[a] SC – Saratoga National Fish Hatchery; SPC – Spring Creek Trout Hatchery; CC – Crow Creek; LSV – Sage Creek

[b] Arrived as fertilized, eyed-eggs. No whole body Se measurement possible.

[c] Survived, but failed to reach swim up.

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Whole Body Concentration

The whole-body concentration response curve for survival, hatch to swim up is shown in Figure 8. These data are not amenable to TRAP modeling, and Figure 8 shows the interpolation procedure, the first interpolation point being an EC_0 at 13.2 mg/kg and 96% survival and the second point an LOEC at 13.6 mg/kg and 39% survival. Because the HNOEC (13.2 mg/kg) and LOEC (13.6 mg/kg) are so close, the chronic value for whole body selenium is the HNOEC of 13.2 mg/kg dw.

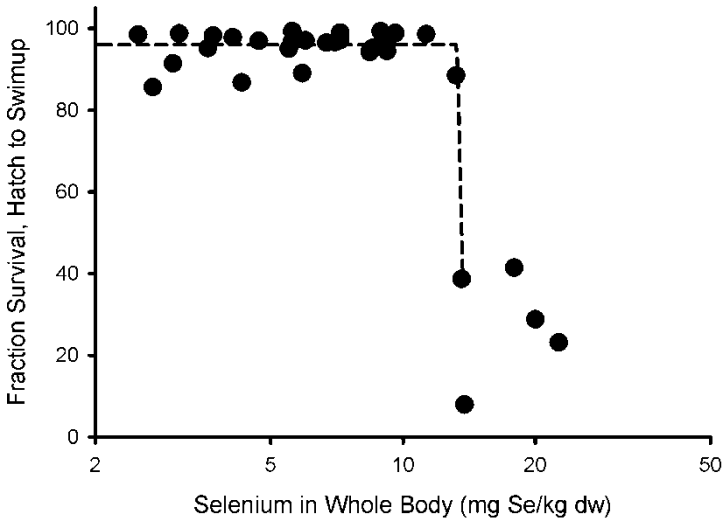


Figure 8. Fraction survival of brown trout larvae as a function of selenium in eggs.

Effect Concentration: For this study the most appropriate, least confounded endpoint is survival, hatch to swim up. For egg selenium, EC_{10} is 21.0 mg Se/kg egg dw, calculated for survival from hatch to swim up using a weighted nonlinear regression model. Expressed as whole body, the chronic value is 13.2 mg Se/kg WB dw.

Besser, J.M., W.G. Brumbaugh, D.M. Papoulias, C.D. Ivey, J.L. Kunz, M. Annis, and C.G. Ingersoll. 2012. Bioaccumulation and toxicity of selenium during a life-cycle exposure with desert pupfish (*Cyprinodon macularius*): U.S. Geological Survey Scientific Investigations Report 2012–5033, 30 p. with appendixes.

Test Organism: Desert pupfish (*Cyprinodon macularius*)

Exposure Route: Dietary and waterborne. Pupfish were fed the oligochaete, *Lumbriculus variegatus*, which had been grown on a diet of selenized yeast.

Test Duration: 180 days life cycle, 21 days F1 larvae, 58 days F1 juveniles and adults.

Study Design: Desert pupfish (*Cyprinodon macularius*), a federally-listed endangered species, were exposed simultaneously to waterborne and dietary selenium at six exposure levels (controls and five selenium treatments) in a three-phase life cycle exposure study. Aqueous exposures were prepared using sodium selenate and sodium selenite salts at an 85%-15% proportion, respectively. Pupfish were fed the oligochaete, *Lumbriculus variegatus*, daily to satiation (25 to 30% rations based on wet weights). Prior to being fed to the pupfish, the oligochaetes were exposed to aqueous selenium and fed selenized yeast at appropriate concentrations to attain the target dietary tissue concentrations. The measured concentrations in water, oligochaetes (pupfish diet), and pupfish tissues for the control and five treatments during the life cycle exposures.

Treatment	water µg/L	oligochaetes mg/kg dw	pupfish, mg/kg dw		
			F_0 WB	eggs	F_1 WB
Control	nd	1.6	0.75	1	1.2
Se–1	3.4	5.1	2.5	3	3.4
Se–2	6.2	7.3	3.4	4.4	3.7
Se–3	14	14	6.7	8	6.7
Se–4	26	24	12	13	12
Se–5	53	52	24	27	31

The 85-day Phase 1 exposure was initiated with approximately five week old juvenile pupfish (F_0). Phase 1 consisted of two separate groups with one group (started two weeks prior to the second group) used for determining survival, growth and whole body selenium concentrations, and the other group used for survival assessment and to provide adults for the main reproduction exposure. Both groups in Phase 1 were similarly exposed to all six treatments, with each treatment having 8 replicates and 10 fish in each replicate.

At the end of the 85-day Phase 1 exposure, the pupfish were reproductively mature and were used for the Phase 2 exposure, the main reproduction study. A preliminary reproduction study was conducted with adults from the first exposure group of F_0 pupfish. These fish were divided into two spawning groups and eggs were collected on four dates during a 9-day period. The main purpose of the preliminary study was to confirm the reproductive maturity of the pupfish, but samples of larvae from this study were used for assessment of deformities. The main reproduction study in Phase 2 was started with adults from the second F_0 exposure. These fish were sorted into spawning groups (1 male and 3 females) in

7-L exposure chambers, with eight replicate spawning groups per selenium treatment. Spawning activity was monitored by removing (and replacing) spawning substrates from each chamber three times a week (Monday-Wednesday-Friday). There were 23 egg collection dates during a 60-day period. All eggs were counted and eggs collected from eight Wednesdays were used for hatching success, deformities and F_1 larval and juvenile growth and survival in the 58-day Phase 3 exposure. Larvae were examined for developmental endpoints including edema, delayed development, and skeletal, eye, craniofacial, and fin deformities.

Effects Data: A summary of the endpoints by each treatment level is shown below.

Table 1. Summary of pupfish toxicity endpoints by exposure treatment (average across all replicates). There were no statistically significant differences across controls and selenium amendment treatments for any of the endpoints shown here (1-way ANOVA, α=0.05).

Endpoint[a]	Control	Se-1	Se-2	Se-3	Se-4	Se-5
F0 survival, day 28	100	100	100	100	100	98
F0 survival, day 56	100	100	100	100	100	100
F0 survival, day 85	100	100	100	100	100	100
F0 survival, day 150	91	94	94	94	91	97
F0 growth, day 28	213	206	204	198	213	203
F0 growth, day 56	535	526	486	469	509	447
F0 growth, day 85	935	998	941	934	914	1053
F0 growth, day 150	1718	1763	1776	1755	1673	1606
F1 survival, day 30	100	100	100	100	98	98
F1 survival, day 58	100	100	93	90	95	88
F1 growth, day 30	73	73	76	78	77	58
F1 growth, day 58	260	264	286	286	288	255
total number eggs	6845	6331	4143	4386	3337	5225
% reduction eggs	NA	8	39	36	51	24
avg % deformities, main	5.3	2.7	4.9	2.4	11.4	8.1
avg % deformities, preliminary	4.4	8.8	11.6	14.3	10.7	21

[a] Endpoint units: survival, %; growth, mg wet weight; % reduction eggs is relative to the control.

The authors observed no significant differences in pupfish survival or growth among treatments. The authors hypothesized the lack of statistically significant acute effects was because the pupfish in this study were near their chronic toxicity threshold, as suggested by the (non-significant) mean reductions in growth (7% in F_0 day 150) and survival (12% in F_1 day 58) in the highest selenium treatment (Se-5), relative to controls (Table 1).

Egg hatching and larval survival in all selenium treatments (not listed in Table 2) were within 10 percent of control means, and differences among treatments were

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not related to selenium exposure. The authors noted that the highest selenium treatment, Se-5, did have the lowest larval survival (84%) and lowest combined egg hatching and larval survival (76 percent). The means frequencies of deformities were higher in the two highest Se treatments (Se-4 and Se-5, Table 1); however % deformities across treatment levels were not statistically significant (1-way ANOVA, p=0.13; Beckon et al. (2012). However, overall deformity rates were statistically significantly higher in a preliminary reproduction than in the main reproduction test. Beckon et al. (2012) hypothesized that the reason for the difference in deformity rates between the two tests was related to the time the eggs were collected relative to the time the respective spawning groups were isolated. Eggs were collected in the preliminary reproductive study 1 - 9 days after the spawning groups were isolated, whereas spawns used to characterize deformities in the main reproduction test were collected at least 14 days after the onset of spawning. The larvae produced from the earlier collected eggs may have been exposed to higher selenium concentrations in the egg. The pattern of a gradual decrease in egg selenium concentration over time was observed in the life cycle study.

Egg production varied considerably over the 23 collection dates (Table 2 and Figure 1). Although each of the selenium treatments had a lower total number of eggs relative to the control, one-way ANOVAs of cumulative egg production did not indicate significant differences among treatments on either a per-replicate basis (p=0.34) or on a per-female basis (p=0.20). Similarly, repeated measures ANOVA indicated no differences between treatments, but the authors indicated significant differences among sampling dates and significant interactions of treatment and date. Because of the lower number of eggs in the selenium treatments and the significance of the interaction of treatment and time, the authors concluded that pupfish egg production was adversely affected by elevated selenium exposure and reported significant reductions in egg production at treatment levels Se-2 through Se-5 (4.4 to 27 mg/kg dw Se in eggs). The authors recognized that typically larval survival and deformities are the most sensitive reproductive endpoint for selenium toxicity and not egg production and suggested more study is needed to confirm the unusual sensitivity of pupfish egg production to selenium.

Table 2. Number of pupfish collected on each sampling date throughout the study, by treatment level. Values represent the sum of all eggs collected on a given date for a given Se treatment.

Day	Control	Se-1	Se-2	Se-3	Se-4	Se-5
2	136	112	90	67	122	94
4	275	173	123	142	188	162
7	307	273	301	283	160	432
9	265	252	226	169	271	283
11	401	136	424	319	265	380
14	417	359	333	246	198	401
17	448	456	206	163	145	232
21	303	664	404	204	163	400
23	287	205	141	143	177	175
25	340	308	94	143	150	228
28	366	273	103	101	95	181
30	130	164	104	52	82	132
32	323	304	271	78	75	151
35	320	427	81	150	74	223
37	236	176	41	113	38	38
39	326	151	159	184	113	140
42	507	140	55	193	101	140
44	251	133	66	152	69	137
51	380	359	227	338	305	370
53	278	63	38	197	56	188
56	199	478	138	195	238	222
58	202	329	331	410	143	320
60	148	396	187	344	109	196

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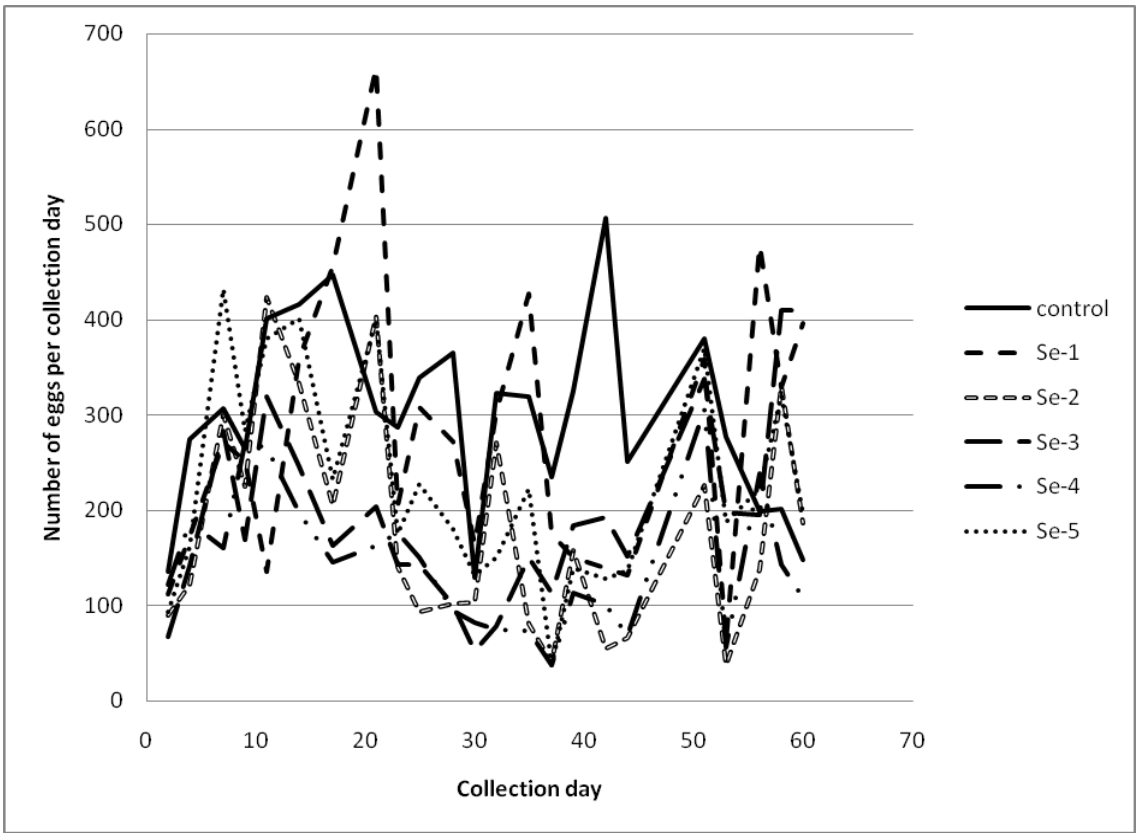


Figure 1. Pupfish egg production by sampling date

Several findings from the pupfish study put a clear demonstration of effect due to selenium in question. The fact that the typical sensitive endpoints for selenium, larval survival and deformities, were not demonstratively responsive to selenium through the highest treatment level, the fact that the egg production data did not show significance among treatments alone, and the fact that egg production increased at the highest selenium treatment level provide sufficient doubt of a clear effect due to selenium. These issues are discussed below.

Examination of the Repeated Measures Analysis:

Analysis Using the Full Dataset: The effects of selenium treatment and sampling date on pupfish egg production (eggs per female per day) were reanalyzed. First, the data were reanalyzed using repeated measures ANOVA. Results of the repeated measures ANOVA analysis were qualitatively similar to those reported in Besser et al. (2012) and are shown in the following table.

Between Subjects

Source	Sum of Sq.	df	Mean Sq.	F-rat.	p-value
Se treatment	2,202.6	5	440,5	1.755	0.143
Error	10,543.5	42	251.0		

Within Subjects

Source	Sum of Sq.	df	Mean Sq.	F-rat.	p-value
Sampling Date	1,867.5	22	84.89	4.973	<0.001
Se Treatment x Sampling Date	2,566.3	110	23.33	1.367	0.010
Error	15,771.8	924	17.07		

As with the results reported in Table 7 of Besser et al. (2012), there was no main effect of Se treatment (note – for purposes of these analyses and associated text, "Se treatment" is defined as the control plus the 5 treatments that received Se amendments), but there was a statistically significant ($p \leq 0.05$) effect of sampling date and a significant date by Se treatment interaction. Results were qualitatively similar because the p-values for Se treatment and sampling day were identical in both analyses, yet the p-values for the day by Se treatment interaction term were nearly identical.

A statistically significant sampling date effect means that there were significant differences in overall egg production on different sampling dates. Daily egg production per female ranged from 2.176 on day 2 to a high of 7.294 on day 11, and was variable throughout the study. Of greater interest is the statistically significant day x Se treatment interaction. What this means is, although there was not an overall significant effect of Se treatment on egg production per female, there was a significant Se treatment effect ($p<0.05$) on egg production per female on at least one of the 23 sampling dates.

Analysis after Removal of Control Replicate Outlier: Repeated measures ANOVA analysis confirmed the results reported in Besser et al. (2012). However, as shown on Figure 8b of Besser et al. (2012), one replicate chamber (replicate g) within the control treatment had only one surviving female pupfish from day 7 through the end of the test (day 60), and that replicate also had the highest overall egg production per female of any test chamber. All replicate chambers in all treatments began with three female pupfish, and the replicate described above was the only one with only one surviving female. All three females survived the 60 day test in the majority of the replicate chambers. In order to determine whether the significant date by Se treatment interaction was an artifact of this one test chamber, data were reanalyzed after removing this replicate.

One requirement of repeated measures ANOVA is that the model cannot contain any missing values. An alternative to repeated measures ANOVA when data are missing, and the most commonly followed procedure under these circumstances, is to analyze the data using a mixed model. This was the procedure followed here.

The results of a fully balanced mixed model (no missing data) should be identical to repeated measures ANOVA. As an initial check, the full dataset was reanalyzed as a mixed model. Sample chamber was the random effect parameter, and Se treatment, sampling date, and Se treatment by sampling date were the fixed effect parameters. As expected, the F-ratios for the effects of selenium treatment, sampling date, and the sampling date by Se treatment interaction were identical. Next, the data were reanalyzed after removing data from control replicate g from all sampling dates. Results of this analysis are reported in the table below.

Mixed Model – Fixed Effect

Effect	Numerator df	Denominator df	F-ratio	p-Value
Se Treatment	5	902	1.087	0.366
Sampling Date	22	902	6.042	<0.001
Se Treatment x Sampling Date	110	902	1.310	0.023

T

The statistically significant interaction between Se Treatment and Sampling Date persisted after removal of the potentially anomalous control treatment chamber with one female pupfish. In other words, even after removing the one potentially anomalous control replicate, there were still some individual sampling dates where the effects of Se treatment were statistically significant ($p<0.05$).

Se Treatment x Sampling Date Interaction: When a significant interaction is observed in a repeated measures ANOVA, the next recommended step in the process is to examine each of the repeated measures (sampling dates) separately to identify those dates where the significant difference in Se treatment level occurred. When individual dates for the full dataset (including the replicate with one surviving female) were analyzed separately, there were significant ($p<0.05$) effects of Se treatment level on egg production on days 28, 35, 37, 42, and 53 (1-way ANOVA, $df_{5,42}$). There were no significant Se treatment effects on the remaining 18 sampling dates. ANOVA results are summarized in the table below.

Sampling Date	F-ratio	p-value
28	2.501	0.045
35	2.704	0.033
37	3.351	0.012
42	4.294	0.003
53	3.352	0.012

Because of the large number of comparisons (23 individual ANOVA models for each sampling date), an alpha of 0.05 is inappropriate for this particular analysis. This is because an alpha of $p<0.05$ means that a statistically significant result will be observed 5% of the time due to chance alone (Type I error). In order to control for the increased likelihood of a Type I error when making multiple comparisons, the alpha level of 0.05 was adjusted using Sidak's correction (Abdi 2007). For 23 comparisons and an alpha of 0.05 for one comparison, the adjusted alpha using Sidak's correction is as follows:

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$$1 - (1 - 0.05)^{\frac{1}{23}} = 0.0027$$

After adjusting alpha to account for the 23 separate sampling dates, there were no sampling dates with a significant Se treatment effect ($p \leq 0.0027$). As a result, it was not necessary to perform *post hoc* means comparisons tests for any of the individual sampling dates to determine which Se treatment levels were significantly different from each other.

Each of the 23 sampling dates for the dataset where the replicate chamber from the control treatment with one surviving female pupfish was excluded were also analyzed using one-way ANOVA to determine which sampling dates had significant Se treatment effects. Significant differences among Se treatment levels at alpha 0.05 are shown in the table below.

Sampling Date	F-ratio	p-value
35	2.839	0.027
42	3.164	0.017
53	2.549	0.042

After adjusting alpha to account for the 23 separate sampling dates, there were no sampling dates with a significant Se treatment effect ($p \leq 0.0027$). As with the full dataset, it was not necessary to perform *post hoc* means comparisons tests for any of the individual sampling dates to determine which Se treatment levels were significantly different from each other.

Summary of Repeated Measures Analysis: This analysis demonstrated that although there was a significant Se treatment by sampling date interaction, regardless of whether or not the control treatment chamber with one female pupfish was excluded, differences among Se treatment levels were only observed for a small subset of the 23 sampling dates. Furthermore, after adjusting alpha to account for multiple comparisons, one-way ANOVA analyses conducted separately for each sampling date to locate the source of the Se Treatment x Sampling Date interaction determined that there were no statistically significant differences among Se treatment levels on any sampling date, precluding the need to perform *post hoc* comparison of means tests to identify significant differences among individual Se treatments.

Combining Effect Metrics Using a Population Model: To improve the certainty of any conclusions to be made about the sensitivity of pupfish to selenium, it is also worthwhile to consider the biological (as opposed to statistical) significance of the observations. But for total egg production, survival, and deformities, the concentration-response curves did not show a sufficient concentration-related effect to calculate an EC10. Nevertheless, because Besser et al. (2012) raised the issue of an interaction of egg production with time, there is a particular concern that there could be a delay in egg production that would reduce population growth rate, even while total numbers of eggs were not significantly affected. This question was evaluated by constructing a population model corresponding to data available from the test.

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This modeling approach allows for combining and properly weighting effects on egg production, timing of egg production, and survival. Percent hatch and percent deformities were also considered in alternate calculations. Because the model is only intended for combining the lab data into a unified concentration-response curve, it cannot be interpreted as making real-world population predictions. The relevant data were taken from spreadsheets Besser et al. (2012b and 2012c), which were provided by Besser.

The reproduction and larval endpoints spreadsheet, Besser et al. (2012b), presents egg production at 23 time points. This information thus allows for 23 adult life stages, each assigned its own fecundity. Another page of this spreadsheet provides larval survival data, thus defining survival of the early life stage. The juvenile and adult survival spreadsheet, Besser et al. (2012b), defines a survival rate shared by these life stages.

For each treatment, the data from the test thus provide *all* the needed input for 25 life stages: (1) an embryo-larval stage with its own daily survival probability (along with hatching and deformity percentages, when considered in alternative calculations), (2) a non-reproducing juvenile stage sharing its treatment's daily survival probability with the adult stages, and (3 – 25) 23 short-duration adult stages each with its own egg production, but sharing its treatment's daily survival probability with the treatment's other adult stages. Use of the data is detailed below.

Egg Production: Egg production at the test's 23 observation time points is from the spreadsheet Besser et al. (2012b), expressed as eggs per female per day. The intent of Besser et al. (2012) was for each treatment to have eight replicates, and each replicate was to have one male and three females. Only replicates matching that design were used. Early in the test Control Replicate "g" ended up with only one female, and was therefore not used here. Se-1 Replicate "h" and Se-3 Replicates "d" and "h" had been inadvertently stocked with two males and two females, and were likewise not used here. Table 3 shows the time course of egg production incorporated into the population model. For each treatment, model fecundity, m_i, for life stages i = 3 – 25, is the observed egg production *divided by 2*, in order to provide *female eggs* per female per day.

Percent Hatch: The spreadsheet Besser et al. (2012b) presents percent hatch for eggs collected at selected time points. Within each treatment these were averaged. In selenium reproductive studies percent hatch is often treated as a noise variable unrelated to selenium exposure. Consequently, the population growth calculations were run with and without including percent hatch. When hatch was incorporated into the calculation, daily fecundity was reduced by multiplying by percent hatch.

Deformities: The Besser et al. (2012b) spreadsheet also provides deformity counts for the study's preliminary test and for its main test. Only the main test results were used here. Counts were totaled for each treatment, and a percentage calculated. Population growth calculations were performed both with and without consideration of deformity percentage. For simplicity when considered, a worst case assumption was made that deformed individuals do not contribute to the

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population. Percent deformity was thereby handled in manner parallel to percent hatch, by multiplying daily fecundity by percent free of deformity.

Table 3. Life stage durations, and observed eggs per female per day at observation time points for control and selenium treatments, *only with replicates having the design three females and one male*. Model fecundity, m, is set at one-half the observed, to yield female eggs per female.

Repro Study Observation Day	Assigned Life Stage Number	Life Stage Duration	Observed Eggs/Female/Day					
			Control	Se-1	Se-2	Se-3	Se-4	Se-5
-	1	35	-	-	-	-	-	-
-	2	85	-	-	-	-	-	-
2	3	2	2.690	2.571	1.875	1.319	2.542	1.958
4	4	2	5.548	4.048	2.563	2.153	3.917	3.375
7	5	3	4.333	4.302	4.181	3.185	2.222	6.000
9	6	2	5.762	5.524	4.708	3.639	5.646	5.896
11	7	2	8.024	3.238	8.833	4.528	5.521	7.917
14	8	3	6.540	4.905	4.625	2.296	2.750	5.569
17	9	3	6.429	7.143	2.861	1.481	2.014	3.222
21	10	4	3.345	7.881	4.208	1.764	1.698	4.167
23	11	2	5.786	4.643	2.938	3.806	3.688	3.646
25	12	2	6.905	7.286	1.958	2.792	3.125	4.750
28	13	3	4.794	4.317	1.431	1.306	1.319	2.514
30	14	2	1.881	3.881	2.167	1.403	1.708	2.750
32	15	2	5.464	7.286	5.646	1.444	1.563	3.146
35	16	3	4.373	7.310	1.132	2.880	1.028	3.097
37	17	2	5.631	4.417	0.927	1.556	0.792	0.792
39	18	2	6.119	3.917	4.240	3.556	2.354	2.917
42	19	3	7.349	2.222	1.056	2.500	1.403	1.944
44	20	2	4.798	3.274	1.719	3.194	1.438	2.854
51	21	7	1.847	2.139	1.571	2.532	2.060	2.202
53	22	2	6.310	1.512	0.823	5.403	1.333	3.917
56	23	3	3.183	7.317	2.076	2.491	3.528	3.083
58	24	2	3.405	7.810	8.469	9.597	3.104	7.656
60	25	2	3.810	8.226	4.115	6.347	2.271	4.271
Total as $\sum$ (duration · eggs/f/d) =			281.6	294.3	181.9	174.7	142.0	220.1

Larval Survival: The Besser et al. (2012b) spreadsheet also has data for larval survival after 14 and 21 days for eggs collected at three time points. The fraction surviving 21 days was used here. For each treatment, the probability of the early life stage (i=1) surviving each day equals the fraction surviving for 21 days, raised to the 1/21 power: $\sigma_1 = \sigma_L = (21\text{-d Surv})^{1/21}$, shown in Table 4.

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Juvenile and Adult Survival: A second spreadsheet, Besser et al. (2012c), has data on juvenile and adult survival after 30 and 58 days. The fraction surviving 58 days was used (Table 4). Parallel to the handling of larval survival, for each treatment the juvenile-adult daily survival probability, σ_{JA} = (58-d Surv)$^{1/58}$, as shown in the table. This value applies to life stages i=2-25 (σ_2 through σ_{25}).

Table 4. Pupfish observed survival and modeled daily survival; fraction hatching and fraction free of deformity.

Treat-ment	Conc	21-d Larval Surv	Larval Daily Surv (σ_L)	58-d Juv+Adlt Surv	Juv+Adlt Daily Surv (σ_{JA})	Fraction Hatch	Fraction Free of Deformity
Control	1	0.9038	0.9952	1.0000	1.0000	0.9023	0.9489
Se-1	3	0.9770	0.9989	1.0000	1.0000	0.9026	0.9727
Se-2	4.4	0.9109	0.9956	0.9250	0.9987	0.8197	0.9563
Se-3	8	0.9600	0.9981	0.9000	0.9982	0.8922	0.9750
Se-4	13	0.9586	0.9980	0.9500	0.9991	0.8988	0.9048
Se-5	27	0.8396	0.9917	0.8750	0.9977	0.9104	0.9174

Formulation of the Population Model: The population growth equation is shown below, in abbreviated form.

$$\begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ \vdots \\ N_{25} \end{bmatrix}_t = \begin{bmatrix} \sigma_1(1-\gamma_1) & 0 & \sigma_3 m_3 & \cdots & \sigma_{25} m_{25} \\ \sigma_1\gamma_1 & \sigma_2(1-\gamma_2) & 0 & \cdots & 0 \\ 0 & \sigma_2\gamma_2 & \sigma_3(1-\gamma_3) & \cdots & 0 \\ \vdots & \vdots & \vdots & \cdots & 0 \\ 0 & 0 & 0 & \cdots & \sigma_{25}(1-\gamma_{25}) \end{bmatrix} \begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ \vdots \\ N_{25} \end{bmatrix}_{t-1}$$

The diagonal of the 25x25 projection matrix has $\sigma_i(1-\gamma_i)$, the sub-diagonal has $\sigma_i\gamma_i$, and the top row has $\sigma_i m_i$. All other elements are 0. For life stage i, σ_i is the daily survival probability, γ_i is the daily probability of graduating to the next life stage, and m_i is the fecundity expressed as number of female eggs produced per female per day, set at one-half the observed eggs/female/day.

The graduation probability, γ_i, for individuals in each life stage was calculated as follows:

$$\gamma_i = \frac{\left(\frac{\sigma_i}{\lambda}\right)^{Dur_i} - \left(\frac{\sigma_i}{\lambda}\right)^{(Dur_i - 1)}}{\left(\frac{\sigma_i}{\lambda}\right)^{Dur_i} - 1}$$

where λ is the population growth rate and Dur_i is the duration of the life stage. In a 2-day duration life stage, were survival 100% (σ=1) and were the population not growing (λ=1), exactly one half (1/*Dur*) would graduate each day from the 2-day life stage. However, with σ<1 and λ>1, there would be a slight youthful bias

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within the life stage, such that slightly more than half would be only 1 day into the life stage and not ready to graduate, and slightly less than half would be in their second day and ready to graduate. The above function adjusts for that.[1] The projected population growth rate for each treatment was calculated as follows. The 25x25 projection matrix was placed on an Excel spreadsheet. Each cell in the diagonal was then modified to subtract the eigenvalue, λ, which represents the population growth rate. That is, each cell in the diagonal was rewritten as $\sigma_i(1-\gamma_i) - \lambda$. The determinant of the 25x25 matrix was then calculated by function MDETERM. To obtain the population growth rate, Excel's Solver was then tasked with finding a value for λ that yielded a value of zero for the matrix determinant. In this case,-10^{-18} < MDETERM < $+10^{-18}$ was deemed sufficiently close to zero. Introducing the constraint to look for λ values between 1.01 and 1.04 was found helpful for Solver to find the dominant eigenvalue. When Solver occasionally could not get the determinant within 10^{-18} of zero, probably due to a solution oscillation that can occur because the input values γ_i are expressed as a function of the solution output λ, digits were removed from Solver's best estimate for λ, to provide a new starting value with which Solver could complete the solution.

Effects on Projected Population Growth Rates: Table 5 and Figure 2 show the model results. Figures 2-B, -C, and -D are almost indistinguishable from Figure 2-A, because hatch and deformity rates varied so little across treatments. Although population growth rates at 4.4 – 27 mg Se/kg are less than at 1 – 3 mg Se/kg, the 6-fold increase in concentration from 4.4 – 27 mg Se/kg yields no change in response. Consequently, the results do not suggest a selenium-related effect, and no EC_{10} can be calculated. Based on the combined influences of egg production and timing, and survival (with or without percentage hatch and deformities), pupfish does not appear to be among the most sensitive species.

[1] The formula for γ is undefined (0/0) under the condition σ=1 and λ=1, so it is not obvious from inspection how it behaves. This function addresses a model artifact that is called numerical dispersion when it occurs in pollutant transport models. It prevents overoptimistic rates of moving through the life stages, particularly in the 35-day and 85-day larval and juvenile stages, and allows a 25-stage model of life duration 180 days to yield precisely the same growth rate as a 180-stage (one day per stage) model, which was also constructed and checked for comparison. However, in this application where absolute growth rates have no particular meaning and only relative differences between treatments are of interest, the function does not change the overall perspective.

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Table 5. Model output: daily population growth rates as λ (factor increase) and r (=ln λ), for models that account for survival, fecundity and its timing, and optionally also hatch and/or deformities. Because λ is responding to all the treatment parameters included in the model, its treatment-to-treatment variations do not exactly track the variations in any single input.

Treat-ment	Conc	Factors included in model: All account for survival (σ_L , σ_{JA}) and fecundity (m) and its timing -		Hatch		deformity		hatch & deform.	
		λ	r	λ	R	λ	r	λ	r
Control	1	1.0337	0.0332	1.0330	0.0324	1.0334	0.0328	1.0326	0.0321
Se-1	3	1.0346	0.0340	1.0338	0.0333	1.0344	0.0338	1.0336	0.0331
Se-2	4.4	1.0299	0.0294	1.0284	0.0280	1.0295	0.0291	1.0281	0.0277
Se-3	8	1.0285	0.0281	1.0277	0.0273	1.0283	0.0279	1.0275	0.0271
Se-4	13	1.0291	0.0287	1.0283	0.0279	1.0283	0.0279	1.0276	0.0272
Se-5	27	1.0294	0.0290	1.0288	0.0283	1.0288	0.0284	1.0281	0.0277

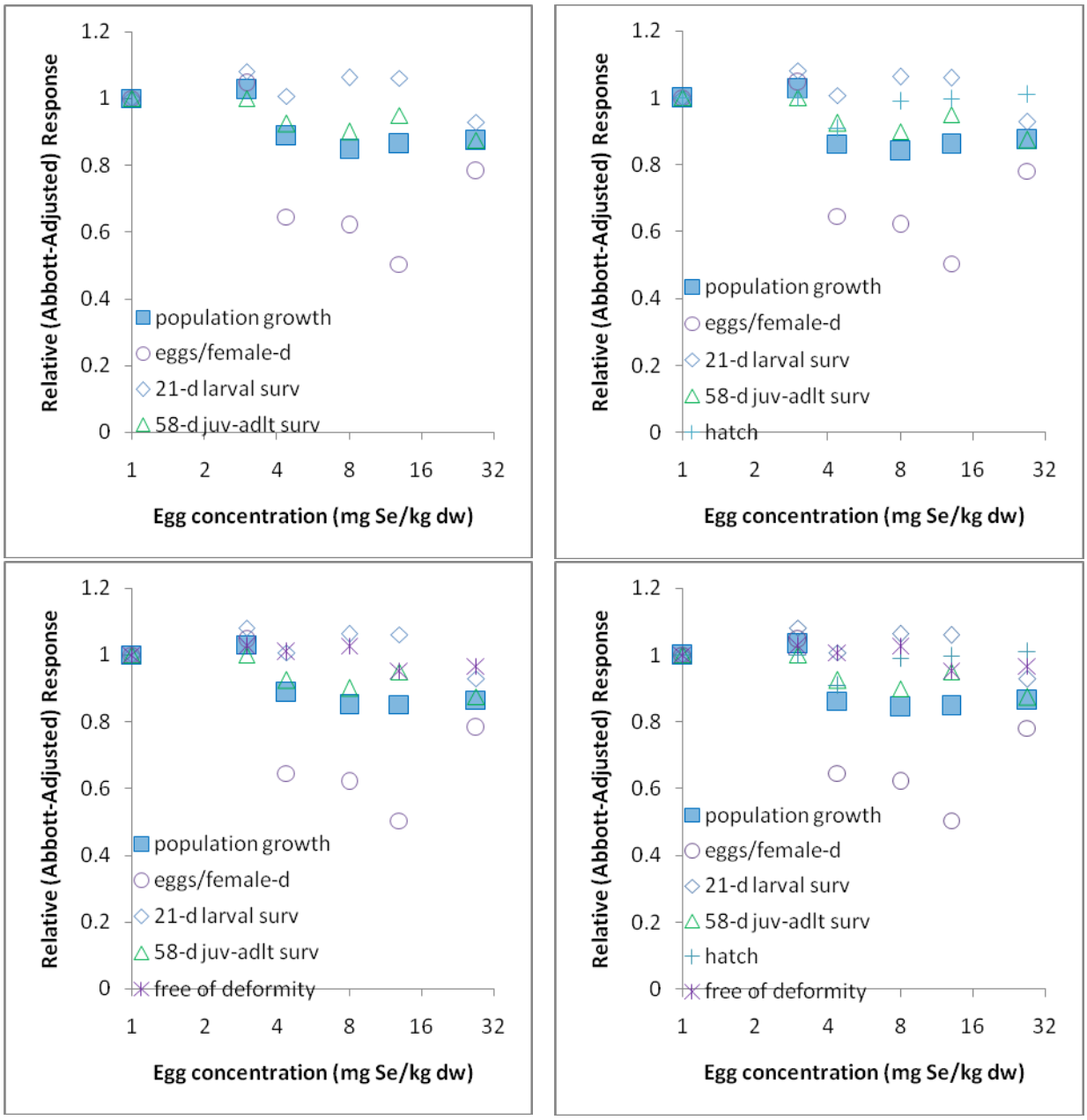


Figure 2. Abbott-adjusted pupfish response as modeled population growth rate (solid-filled symbols) and observed eggs per female per day, larval survival, and juvenile and adult survival (open symbols). Where used in the population model (to modify fecundity), hatch and deformity are shown as open symbols. Some open-symbol points are obscured beneath solid-symbol points. (A) Upper left, egg production and survival only, (B) upper right, adds in influence of percent hatch, (C) lower left, adds in influence of deformities, and (D) lower right, adds in influence of percent hatch and deformities.

Isolating the Influence of Timing of Egg Production: By combining survival with egg production and its timing in the above analysis, the assessment obscures the influence of timing: the issue that was the main reason for undertaking population modeling in the first place. The concern is whether selenium exposure could delay reproduction, thereby yielding reduced population growth. To help isolate the influence on the timing of egg production, two population model runs were performed where all treatments were assigned one of two daily survival rates (0.99 or 0.999) spanning the full range of daily survival rates observed in the 21 and 58 day survival calculations. That is, with survival held constant, the only factors varying across treatments were egg production and timing.

The results are shown in the table below. The Abbott-adjusted results are plotted in Figure 3. Although the relative differences in Figure 3 population growth rates are subdued compared to the wider variation in egg production, this is merely a consequence of the predicted population growth rate being more responsive to survival than to reproduction. It is still apparent that the variations in total egg production are affecting growth rate. The question to be addressed here is whether increasing selenium concentration yields a decline in growth rate beyond the pattern reflecting total egg production.

Population growth rates, as influenced only by differences in egg production and timing					
		With only egg production (*m*) and its timing variable across treatments			
		σ=0.999		**σ=0.99**	
Treat-ment	**Conc**	**λ**	**r**	**λ**	**r**
Control	1	1.0339	0.0334	1.0246	0.0243
Se-1	3	1.0338	0.0333	1.0245	0.0242
Se-2	4.4	1.0310	0.0306	1.0217	0.0215
Se-3	8	1.0293	0.0289	1.0201	0.0199
Se-4	13	1.0293	0.0288	1.0200	0.0198
Se-5	27	1.0324	0.0318	1.0231	0.0228

Inspection of Figure 3 indicates that when survival is assigned a constant value across treatments, the pattern of population growth differences across treatments does not suggest an additional selenium-accentuated factor depressing population growth rate. Population growth at 13 and 27 mg Se/kg is slightly higher than might be expected from total egg production, when compared to lower concentrations. The lack of influence of selenium exposure on timing of egg production is also illustrated by comparing each treatment's cumulative proportion of egg production over the course of the test, as shown in Figure 4. Although the treatments differ somewhat in the temporal pattern of their egg production, there is no consistent relationship with selenium exposure.

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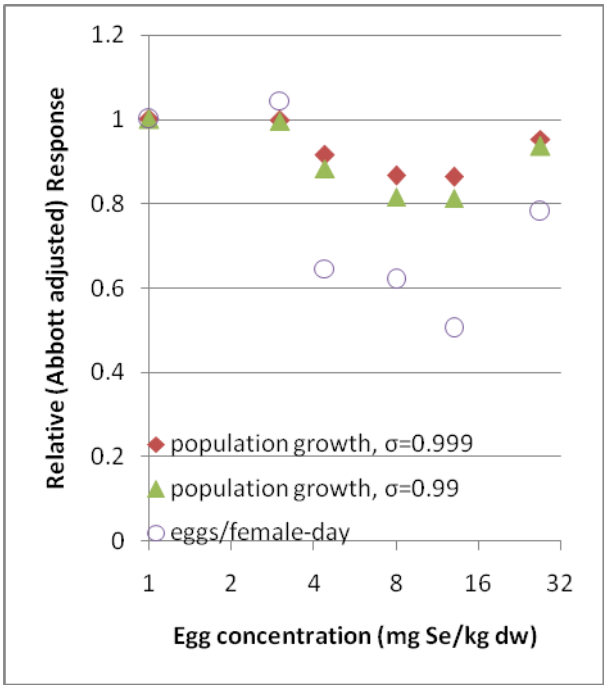


Figure 3. Predicted population growth rate calculated considering differences only in egg production and timing (having assigned uniform survival rates across treatments).

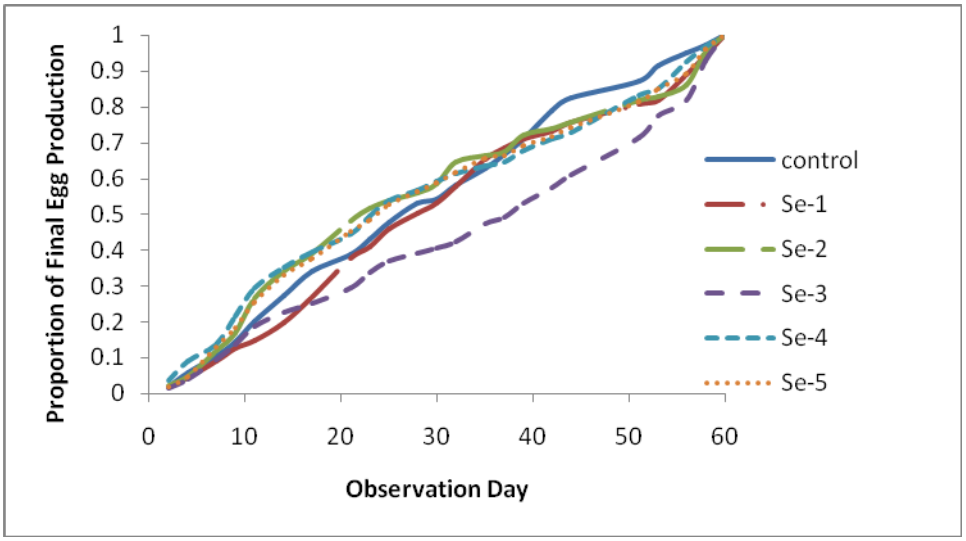


Figure 4. Cumulative pattern of egg production over time. (Control: continuous line. Se-1: dot, dot, long dash. Se-2: long dashes. Se-3: medium dashes. Se-4: short dashes. Se-5: dots.)

Chronic Value: In other selenium studies, egg production and percent hatch have not generally been thought to be related to selenium exposure. Although Besser et al. (2012) noted that repeated measures ANOVA indicated a potential interaction between selenium treatment and egg production on particular sampling dates, a thorough examination of the study data from multiple perspectives indicates no statistically significant or biologically apparent effect of selenium on egg production, timing of egg production, or percent hatch at or below the highest tested concentration of 27 mg Se/kg (dw). Likewise there was no discernible effect on deformity rates.

In the separate tests of F1 larval survival at 21 days and of F1 juvenile-adult survival at 58 days, the highest treatment, 27 mg Se/kg (dw), displayed lower survival than any other treatment. Although the reduction was not sufficient to be statistically significant, Besser et al. (2012) suggest that this is indicative of a threshold. Note that among toxicity tests in general, the 10% effect level of the EC_{10} might or might not be statistically significant from the perspective of hypothesis testing.

Shown below are the survival rates for the 27 mg Se/kg treatment adjusted to the control (Abbott-adjusted), or similarly adjusted to the average survival at all lower treatments (some of which had better survival than the controls). Either way the adjustment is done, results are similar. (These survival data, Abbott-adjusted, are included in Figure 2.)

27 mg Se/kg treatment:	**Larval Surv at 21 days**	**Juv-Adlt Surv at 58 days**
adjusted to control	92.9%	87.5%
adjusted to all lower treatments	89.1%	91.6%

The effect level at 27 mg Se/kg was thus 7% – 13% in the above comparisons. While the concentration response curve is not sufficiently defined to allow confident assignment of an EC_{10}, the data suggest a chronic value in the general neighborhood of 27 mg Se/kg.

An effect level of 27 mg Se/kg egg for the pupfish in this study is consistent with the findings of Saiki et al. (2012a) who evaluated selenium in two related species in the Salton Sea, California. These authors measured 3.09 to 30.4 mg/kg whole body Se levels in mosquitofish and sailfin mollies and based on a lack of a negative relationship with the catch-per-unit-effort deduced these species were not adversely affected by selenium. They extrapolated the finding of selenium tolerance to the pupfish based on the results of another study (Saiki et al 2012b) in which mosquitofish and sailfin mollies accumulated similar levels of selenium to the pupfish. Note: the ratio of selenium in whole body to egg tissues in the pupfish was approximately 1:1 in the Besser study (see first table in the pupfish study summary above).

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Staub, B.P. W.A. Hopkins, J. Novak, J.D. Congdon. 2004. Respiratory and reproductive characteristics of eastern mosquitofish (*Gambusia holbrooki*) inhabiting a coal ash settling basin. Arch. Environ. Contamin. Toxicol. 46:96-101.

Test Organism: Eastern mosquitofish (*Gambusia holbrooki*)

Exposure Route: Waterborne and Dietary - field exposed
Fish were collected from a contaminated ash basin (ASH) and a reference pond (REF)

Study Design: In July 1999, male eastern mosquitofish were collected from ASH and REF (n=26, n=20, respectively) for measurement of standard metabolic rate (SMR). In July 1999, gravid female eastern mosquitofish were collected from ASH and REF and transported to a laboratory for testing. To ensure all females were fertilized in the field, all offspring used in testing were limited to three weeks after collection. (Eastern mosquitofish are live-bearers with a four week gestation period.) Response variables compared between ASH and REF were (1) SMR of males, (2) brood size of females, (3) percent of live offspring at parturition, and (4) trace element concentration in females and offspring.

Effects Data: SMRs of males, brood size of females, and offspring viability were not significantly different between sites. Average (n=5) concentrations of selenium in females were 11.85 and 0.61 mg/kg dw in ASH and REF sites respectively. The average concentrations of selenium in offspring were 15.87 mg/kg dw and below detection in ASH and REF sites, respectively. The authors point out that the selenium concentrations are an under-estimate of the field levels since the females were allowed to depurate during their time in the laboratory prior to parturition.

Chronic Value: >11.85 mg Se/kg dw whole body

Saiki, M.K., B.A. Martin, and T.M. May. 2004. Reproductive status of western mosquitofish inhabiting selenium-contaminated waters in the grassland water district, Merced County, California. Arch. Environ. Contamin. Toxicol. 47:363-369.

Test Organism: Western mosquitofish (*Gambusia affinis*)

Exposure Route: Waterborne and Dietary - field exposed
Fish were collected from selenium-contaminated sites and reference sites in the San Joaquin River watershed.

Study Design: Western mosquitofish were collected in June and July 2001 from San Luis Drain (SLD) at Gun Club Road (Se-contaminated site), North Mud Slough at Gun Club Road (MSN1; reference site); North Mud Slough at State Highway 140 (MSNs; Se-contaminated site); San Joaquin River at Lander Avenue (SJR; reference site). 20 gravid females from each site were held in the laboratory for two weeks to quantify live and dead births and to make other measurements. Only 17 females from SLD were collected. Live and dead fry were visually examined under low magnification with a binocular microscope for evidence of external abnormalities (teratogenic symptoms such as spinal curvature, missing or deformed fins, eyes and mouths and edema).

Effects Data: The percentage of live births was high at both Se-contaminated sites (96.6 to 99.9%) and reference sites (98.8 to 99.2%). There were no obvious anomalies (e.g., deformities, edema) observed during the study. The concentration of selenium in 4 postpartum females from the site with the highest selenium concentration, SLD, ranged from 13.0 to 17.5 mg Se/kg dw (geometric mean of the high and low is 15.1 mg Se/kg dw. The concentration of selenium of western mosquitofish collected at each site is in Table D-8.

Chronic Value: >15.1 mg Se/kg dw whole body

Table D-8. Selenium in whole body samples of western mosquitofish from study sites

Site	N	[Se], mg/kg dw
SLD	8	18.1
MSN2	24	9.31
MSN1	20	2.72
SJR	22	0.907

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Coughlan, D.J. and J.S. Velte. 1989. Dietary toxicity of selenium-contaminated red shiners to striped bass. Trans. Am. Fish Soc. 118:400-408.

Test Organism: Striped bass (*Morone saxitilis*; adults from Lake Norman, NC, approximately 250 g each)

Exposure Route: dietary only
Treated fish were fed selenium contaminated red shiners (1 g) from Belews Lake, NC (9.6 mg Se/kg ww or 38.6 mg Se/kg dw based on a mean reported moisture content of 75.1 percent). Control fish were fed golden shiners from a local bait dealer (0.3 mg Se/kg ww or 1.3 mg Se/kg dw based on a mean reported moisture content of 76.3 percent).

Test Treatments: Test treatments were as described above. Two tanks contained treated fish (n = 20 fish total), and one tank of fish served as the control (n = 10 fish). Each tank received a continuous flow of soft well water (hardness and alkalinity approx. 30 mg/L as $CaCO_3$) throughout the exposure.

Test Duration: 80 days

Study Design: During the experiment, all striped bass (n = 10 per tank) were fed to satiation three times per day. Pre-weighed rations of live red shiners (treated fish) and golden shiners (controls) were added to the tanks and allowed 5 hours to feed. Uneaten prey was removed and weighed. Composite whole-body samples of each prey fish were collected at regular intervals throughout the study for whole-body tissue selenium analysis. The final selenium concentration in epaxial white muscle was determined for surviving striped bass at the end of the test. Moribund striped bass were sacrificed so as to obtain muscle tissue samples for selenium analysis. Samples of liver and trunk kidney of these and the surviving striped bass were dissected for observations of histopathology.

Effects Data: Striped bass fed selenium-laden red shiners exhibited changes in behavior (lethargy, reduced appetite), negligible weight gain, elevated selenium concentrations in muscle, histological damage, and death. Control fish ate and grew well, and behaved normally. Average selenium ingestion was between 60 and 140 Φg Se/fish per day until day 30. Appetite of the treated fish appeared to be significantly reduced beyond this point compared to the appetite of the control group. By day 78, all striped bass fed the Se-laden red shiners either had died or were moribund and sacrificed for analysis. The final selenium concentration in muscle of treated striped bass averaged from 3.5 (tank 1) and 4.0 (tank 2) mg/kg ww, or 16.2 and 18.5 mg/kg dw, respectively, assuming 78.4 percent moisture content in muscle tissue; default May et al (2000) value for all species. The final selenium concentration in muscle of control striped bass fed uncontaminated golden shiners averaged 1.1 mg/kg ww, or 5.09 mg/kg dw (assuming 78.4 percent moisture content in muscle tissue; default May et al (2000) value for all species).

Chronic Value: The chronic value for percent survival of striped bass relative to final selenium in muscle tissue after being fed Se-laden red shiners is <16.2 mg/kg dw.
An EC_{20} value could not be calculated for this data set because the data did not meet the assumptions required for analysis.

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Bryson, W.T., W.R.Garrett, M.A. Mallin, K.A. MacPherson, W.E. Partin, and S.E. Woock. 1984. Roxboro Steam Electric Plant 1982 Environmental Monitoring Studies, Volume II, Hyco Reservoir Bioassay Studies. Environmental Technology Section. Carolina Power & Light Company.

28-day Embryo/Larval Study

Test Organism: Bluegill sunfish (*Lepomis macrochirus;* embryos and larvae)

Exposure Route: dietary and waterborne - field exposure
Native adult bluegill were collected from Hyco Reservoir in Person County, North Carolina and from a nearby control lake (Roxboro City Lake). Hyco Reservoir is a cooling lake for Carolina Power & Light and receives the discharge from the ash storage pond. No selenium values were given for Hyco Reservoir, total selenium was not detected in the control lake (<1 µg/L). A mean selenium for the ash pond effluent from a previous study was 53 µg/L (N=59; range 35-80 µg/L).

Study Design: All combinations of crosses between the Hyco and control fish were made using gametes from the collected fish. Fertilized eggs were exposed in egg cups to 0, 20 and 50 percent ash pond effluent under flow-through conditions. Percent hatch and swim-up successes were measured. Swim-up larvae were released to exposure tanks where there were fed zooplankton collected from Hyco and the control lake. Larvae were observed for 28 days at which time survival and weight were measured.

Effects Data: Survival to the swim-up stage was different between larvae from Hyco females fertilized with either male type and those larvae from control females fertilized with either male type. All crosses involving a Hyco female resulted in larvae exhibiting 100 percent mortality prior to reaching swim-up. Percent survival from hatch to 28 days for larvae from control females exposed to control water and fed control lake zooplankton was only 5 and 12 percent for the two replicates so no meaningful comparisons can be made to the different dilution exposures or diet exposure. The mean concentrations of selenium in the ovaries, female liver and female muscle were 49, 130, and 84 mg/kg dw, respectively.

Effect level: <49, <130 and <84 mg Se/kg dw in adult ovaries, liver and muscle, respectively

Chronic Value: <49.65 mg Se/kg dw in whole body using the muscle to whole body equation
<84 mg Se/kg dw maternal muscle
<49 mg Se/kg dw ovary

Ingestion Study

Test Organism: Bluegill sunfish (*Lepomis macrochirus*; 30-day old larvae)

Exposure Route: Dietary and waterborne - field exposed adults
Juvenile bluegill from crosses with females in 0, 20 and 50 percent ash pond effluent were transferred to control water and fed zooplankton from either Hyco or the control lake. Selenium in Hyco and control zooplankton was 45 and 1.9 mg/kg dw, respectively. Duration was not given.

Study Design: Survival and observations on pathology and morphology were made in the two diet treatments.

Effects Data: Mortality in larvae fed control zooplankton was 23.7 percent, whereas mortality in larvae fed Hyco zooplankton was 97.3 percent. There were no differences in survival (for two diet treatments) in larvae that were raised for the 30 days prior to the test in different effluent concentrations (0, 20 50 percent). The average selenium concentrations in the larvae fed control and Hyco zooplankton were 1.9 and 24.7 mg/kg dw, respectively.

Effect level for larval survival: <24.7 mg Se/kg dw in larvae

Chronic Value: None recommended for larval tissue.

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Bryson, W.T., W.R.Garrett, M.A. Mallin, K.A. MacPherson, W.E. Partin, and S.E. Woock. 1985a. Roxboro Steam Electric Plant Hyco Reservoir 1983 Bioassay Report. Environmental Services Section. Carolina Power & Light Company. September 1985.

28-day Embryo/Larval Study

Test Organism: Bluegill sunfish (*Lepomis macrochirus*; embryos and larvae)

Exposure Route: dietary and waterborne - field exposed
Resident adult bluegill were collected from Hyco Reservoir in Person County, North Carolina and from a nearby control lake (Roxboro City Lake). Hyco Reservoir is a cooling lake for Carolina Power & Light and receives the discharge from the ash storage pond. For embryo/larval study up to swim-up stage, control fish were collected from the unaffected portion of Hyco.

Study Design: Repeat of 1982 28-day Embryo/Larval Study. Three crosses between: Hyco female and Hyco male; control female with Hyco male; and control female with control male. Gametes were fertilized and maintained for the 28-day test in ash pond effluent dilutions of 0, 20 and 50 percent. Percent hatch, percent swim-up success and survival were measured to 28 days post hatch. Two treatments were replicated and fed zooplankton collected from Hyco-affected and Hyco-unaffected (control). Larvae were observed for 28 days at which time survival and weight were measured.

Embryo/Larval Study up to Swim-up Stage. Five crosses were made between fish collected from the affected and unaffected areas. Percent hatch, percent swim-up and survival were measured until swim-up (approximately 3-4 days after hatch).

Effects Data: 28-day Embryo/Larval Study. All larvae that hatched from eggs obtained from Hyco females died prior to completing swim-up (see table below).

Effect level (larval survival): <30, <33 and <59 mg Se/kg dw for adult female bluegill in ovaries, liver and muscle, respectively

Summary of 28-day embryo larval study										
% effluent	Parent source in cross M X F	% hatch	% swim-up	% survival, 28-days	Adult tissue, mg Se/kg dw					
					Gonad		Liver		Muscle	
					M	F	M	F	M	F
0	H X H	92	0	0	33	30	43	33	62	59
20	H X H	98	0	0	33	30	43	33	62	59
20	H X H	92	0	0	33	30	43	33	62	59
50	H X H	97	0	0	33	30	43	33	62	59
0	H X C	89	87	18	33	2.2	43	4.4	62	2.7
20	H X C	96	96	34	33	2.2	43	4.4	62	2.7
50	H X C	60	84	58	33	2.2	43	4.4	62	2.7
0	C X C	79	95	40	nd	2.2	37	4.4	27	2.7
20	C X C	90	96	36	nd	2.2	37	4.4	27	2.7
20	C X C	88	97	25	nd	2.2	37	4.4	27	2.7
50	C X C	72	92	42	nd	2.2	37	4.4	27	2.7

Chronic Value: <36.49 mg Se/kg dw in whole-body using the muscle to whole body equation.
<59 mg Se/kg dw muscle
<30 mg Se/kg dw ovary

Embryo/larval study to swim-up. Percent swim-up of larvae from parents collected in non-affected Hyco averaged 93 percent, whereas percent swim-up from larvae collected from affected Hyco was 12 percent. Effect levels were determined for adult female and larval tissues. Larval tissues were averaged across effluent concentrations (geometric mean).

Effect level (percent swim-up):
Adult female ovaries: >9.1 mg/kg dw; <30 mg/kg dw
Adult female liver: >26 mg/kg dw, <33 mg/kg dw
Adult female muscle: >25 mg/kg dw, <59 mg/kg dw
Larvae: >12.8 mg/kg dw; < 165 mg/kg dw

Summary of Embryo/Larval Study up to Swim-up - Affected vs Unaffected Hyco											
date of fert.	Parents' capture location in Hyco	Percent hatch			Percent swim-up			Selenium in tissue, mg/kg dw			
		at % effluent			at % effluent			Adult female			
		0	20	50	0	20	50	Ovary	Liver	Musc	Larvae
6-24	affected	93	98	94	0	0	0	30	33	59	0: 130 20: 120
6-27	affected	99	88	77	0	0	0	30	33	59	0: 130 20: 120
6-28	affected	29	34	35	25	14	3	30	33	59	0: 130 20: 120
6-28	affected	98	86	91	5	0	0	30	33	59	0: 130 20: 120
6-29	affected	88	93	85	59	42	25	30	33	59	0: 130 20: 120
7-14	unaffected	92	80	84	79	92	89	9.1	26	25	0: 19 20: 11 50: 10
7-26	unaffected	99	94	93	100	98	98	9.1	26	25	0: 19 20: 11 50: 10
7-27	unaffected	76	84	86	100	89	91	9.1	26	25	0: 19 20: 11 50: 10

Chronic Value: The chronic value estimated for the percentage larvae reaching the swim-up stage is presented as a range:
>25 mg Se/kg dw (unaffected area) and <59 mg Se/kg dw muscle (affected area)
>30 mg Se/kg dw (unaffected area) and <9.1 mg Se/kg dw ovary (affected area)

Bryson, W.T., K.A. MacPherson, M.A. Mallin, W.E. Partin, and S.E. Woock. 1985b. Roxboro Steam Electric Plant Hyco Reservoir 1984 Bioassay Report. Environmental Services Section. Carolina Power & Light Company

Ingestion Study

Test Organism: Bluegill sunfish (*Lepomis macrochirus;* juvenile- hatchery raised)

Exposure Route: Dietary only

Test Treatments: 5 diets: Se form (nominal selenium concentration in base diet)
seleno-DL-cystine (5 mg/kg)
seleno-DL-cystine (10 mg/kg)
seleno-DL-methionine (5 mg/kg)
sodium selenite (5 mg/kg)
Hyco zooplankton (5 mg/kg)

Test Duration: 60 days

Study Design: Each treatment contained 40 fish which were maintained in a flow-through system. Fish were fed at 3 percent of their body weight. Length and weight were measured on days 30 and 60. Total selenium was measured in liver and whole-body.

Effects Data: No decreased length or weight in any of the Se-diets relative to the control.

Chronic Value: all values are whole-body
seleno-DL-cysteine: >2.16 mg Se/kg dw
seleno-DL-cysteine-2X: >3.74 mg Se/kg dw
seleno-DL-methionine: >2.46 mg Se/kg dw
sodium selenite : >1.21 mg Se/kg dw
Hyco zooplankton: >2.35 mg Se/kg dw

Because none of the selenium-spiked diet formulations affected growth of juvenile fish at the concentrations tested, the chronic value selected for this study is >3.74 mg Se/kg dw for the seleno-DL-cysteine-2X formulation.

Source and Exposure Embryo-Larval Study

Test Organism: Bluegill sunfish (*Lepomis macrochirus;* Adults from Hyco and a control lake)

Exposure Route: Dietary and waterborne - field exposure

Test Treatments: Four treatments:
Hyco–collected fish exposed to Hyco water in flow through spawning tanks.
Hyco-collected fish in control water in flow through spawning tanks.
Control fish exposed to Hyco water in flow through spawning tanks.
Hyco-collected fish in control water in flow through spawning tanks.

Test Duration: Adult fish were in spawning tanks 4-7 months

Study Design: Eggs from each treatment were observed for percent hatch and percent swim-up.

Effects Data: Fish collected from the control lake did not spawn. Percent hatch and percent swim-up from Hyco fish in Hyco and control water are given in the table below. The percent hatch and percent swim-up were >83 and >83 for all the Hyco fish suggesting no effect for these endpoints.

Source of parents	Se in parental liver tissue, mg/kg dw	Water type for eggs and larvae	N	Percent hatch	Percent swim-up
Hyco	18.6	Hyco	16	86.6	91.1
Hyco	18.6	well water	10	83.8	95.5
Control	13.8	Hyco	a	a	83.3
Control	13.8	well water	12	86.0	97.4

[a] percent hatch unknown.

Chronic Value: The chronic value for this study is >18.6 mg Se/kg dw liver tissue.

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Gillespie, R.B. and P.C. Baumann. 1986. Effects of high tissue concentrations of selenium on reproduction by bluegills. Trans. Am. Fish. Soc. 115:208-213.

Test Organism: Bluegill sunfish, wild-caught (*Lepomis macrochirus*; adults; embryos and larvae)

Exposure Route: dietary and waterborne - field exposure

Test Treatments: High selenium adult fish were collected (electrofishing and with Fyke nets) from Hyco Reservoir. Low selenium adult fish were collected from Roxboro City Lake, Roxboro, NC.

Study Design: All possible combinations of bluegill parents from Hyco Reservoir and Roxboro City Lake were artificially crossed in June and July, 1982 and 1983, respectively. Fertilization success was assessed by stripping subsamples of 100 to 500 eggs per female and combining them with 2 ml of sperm. All zygotes were reared in Roxboro City Lake water and percent fertilization was estimated 2-3 hours later as the proportion of mitotically active zygotes. To estimate hatching success, gametes were combined as before and subsamples of 100 to 300 embryos per cross were transferred to egg cups and maintained in closed aquaria receiving re-circulated Roxboro City Lake water. Percent hatch (approx. 2d at 22 to 25^{o}C) was based on the number of yolk-sac larvae. In 1982, about 200 embryos from 8 crosses were observed and preserved at intervals up to 40 h after fertilization, and about 450 larvae were preserved at intervals of 40 to 180 h after fertilization. In 1983, about 1,800 larvae were observed and preserved from 40 to 150 hr from crosses involving females from Hyco Reservoir, and about 40-300 hr for crosses involving females from Roxboro City Lake (10 crosses total).

Effects Data: No significant differences were found in percent fertilization or in percent hatch among parent combinations from the 18 crosses made in June 1982 and July 1983. In contrast, larvae from all crosses involving a Hyco female were edematous; 100 percent of the larvae were abnormal in 7 of 8 crosses. Note: This outcome was observed when the same female from Hyco Reservoir was crossed with males from either Hyco Reservoir or Roxboro City Lake. The range of selenium concentrations in the ovaries of Hyco Reservoir females used for the cross experiments was from 5.79 to 8.00 (GM = 6.945 mg/kg ww; n=7). The reported concentrations of selenium in ovaries and carcasses of females collected from Hyco Reservoir in 1982 and 1983 were 6.96 and 5.91 mg/kg ww (n=22 and 28, respectively). The reported concentrations of selenium in ovaries and carcasses of females collected from Roxboro City Lake in 1982 and 1983 were 0.66 and 0.37 mg/kg ww (n=14 and 19, respectively). The mean selenium concentration in bluegill larvae (n=222) from artificial crosses of parents from Hyco Reservoir was 28.20 mg Se/kg dw.

Chronic Value: <46.30 mg Se/kg dw ovary using 85 percent moisture for ovaries measured in study.

Doroshov, S., J. Van Eenennaam, C. Alexander, E. Hallen, H. Bailey, K. Kroll, and C. Restrepo. 1992. Development of Water Quality Criteria for Resident Aquatic Species of the San Joaquin River; Part II, Bioaccumulation of Dietary Selenium and its Effects on Growth and Reproduction in Bluegill (*Lepomis macrochirus*). Final Report to State Water Resources Control Board, State of California. Contract Number 7-197-250-0.

Test Organism: Bluegill sunfish (*Lepomis macrochirus*); Population A: selenium bioaccumulation observations used 113 g (range 30-220 g) obtained from Rainbow Ranch Fish Farm, California. Population B: spawning performance observations used 106 g (range 65-220 g) females and 164 g (range 80-289 g) males obtained from Chico Game Fish Farm.

Exposure Route: Dietary only
Dietary
Seleno-L-methionine added to trout chow; the three nominal dietary concentrations of 8, 18 and 28 mg/kg seleno-L-methionine were measured at 5.5, 13.9, and 21.4 mg/kg Se (moisture content 13 to 16%).

Test Duration: 140 days

Study Design: Population A fish and Population B females were fed nominal dietary treatments 8, 18 and 28 mg/kg seleno-L-methionine; Population B males were fed untreated diets until the start of spawning. Population A fish were sampled on days 0, 30, 58, 86 and 114 for Se measurement. At least 3 females were sampled each event. Fish remaining after day 114 were transferred to an outdoor pond fed untreated diet and sampled on day 144 for depuration analysis.

On day 120 Population B males and females were paired for natural spawning which had limited success. Fish were maintained in treatment tanks and females were monitored for egg ripeness. When ripe, females were induced to ovulate and ova were fertilized *in vitro* with semen stripped from males. Fertilized eggs were sampled for fertilization success, Se content, and two live sub-samples for bioassay, one a 30-day embryo-larval test and another for larval development during first 5 days after hatching.

Larval development: after hatching, 100 larvae were transferred to beakers and samples were examined daily for normal, abnormal and dead were recorded.

Larval bioassay: 90 fertilized eggs from each female were placed in groups of approximately 30 eggs. Larvae and fry were fed rotifers and brine shrimp nauplii through the 30 day observation.

Effects Data: Selenium concentrations in parental tissues for Populations A and B are given in Tables 1 and 2, respectively. Treatment effects were only observed on early development bioassays. In the 5-day larval bioassay, systemic edema and underdeveloped lower jaw were apparent in all larvae in the 28 mg/kg dietary treatment by day 3 and complete mortality by day 5, except for two progenies where 10% of the larvae appeared normal. No abnormalities were observed in control and 8 mg/kg treatment. 3 of the 6 progenies in the 18 mg/kg treatment exhibited 10 to 20% larvae with similar abnormalities (Table 3). The average proportion of larvae with edema were 5% in 18 and 95% in 28 mg/kg, both of

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these were statistically different from the control (0% edema).

For analysis of the effect level determination, 4-day edema observations were used (Table 4) rather the 5-day data because the latter were difficult to interpret relative to edema because of almost complete mortality at the highest concentration (although the 4-day and 5-day edema observations were almost identical). Of the 33 edema measurements, only 15 could be used because not all the individual-replicate egg concentrations were reported. Table 4 also shows the treatment averages, which are only slightly different than the 5-day edema data. These averages do not match the average of the individual replicates in this table because they are for all the replicates, not just those with which concentrations could be paired.

The Se egg and edema data from Table 4 are plotted on Figure 1. The individual replicates are analyzed using TRAP. TRAP warns about inadequate partial responses because the partial responses are less than 10% or greater than 90%, and there are no data between 10 and 90%. However, for this dataset, these partial responses at both ends, albeit small, are sufficiently informative based on multiple lines of evidence (e.g., same response on both days 4 and 5, other endpoints that show effects at treatment 18, and several instances of edema at treatment 18 in contrast to absolutely none for many observations at any lower concentration). And because treatment 18 does have an effect of several percent or so, estimating the EC_{10} near these points is defensible; the EC_{10} is 22.6 mg/kg egg. The EC_{10} of 22.6 mg Se/kg egg dw was selected for the chronic value because it was determined using the individual replicates rather than treatment averages as was done in the previous draft document. The EC_{10} of 22.6 mg Se/kg egg is slightly higher than that in the previous draft which used means rather than replicate data (Figure 3).

In the 30-day larval survival bioassay, statistical difference was only in the highest test treatment for survival and growth measurements, length and weight (Table 5). The proportion of abnormal larvae was higher in the selenium-treated diets but was not significantly different from the control. The percent of abnormal larvae in the 18 mg/kg treatment (7.2%) was only slightly higher than the control (6.3%).

Authors present the effect level for bluegill at the 18 mg/kg dietary treatment (NOEC 8 mg/kg) based on proportions of edema and delayed resorption of the yolk sac. The latter endpoint is based on significantly greater yolk area and oil globule area in the 18 and 28 mg/kg treatments.

The most sensitive endpoint, percent edema, as a function of selenium in maternal muscle dw, was fitted to a TRAP tolerance distribution analysis using the individual replicates (Figure 2). The response is steep and the EC_{10} estimate is 15.7 mg/kg. This basically is setting the EC_{10} to the average of the two replicates with nominally 10% edema (15.4 and 16.6 mg/kg), with 90% edema occurring at only a slightly higher concentration (17.3 mg/kg).

Chronic Value: EC_{10} value (edema) at 22.6 mg Se/kg egg dw or 15.7 mg Se/kg muscle dw Chronic Value is 22.6 mg Se/kg eggs dw.

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Table 1. Selenium Concentrations (mg/kg dw) in Bluegills from Population A Day 113 of				
Dietary treatment	**Control**	**8 mg/kg dw**	**18 mg/kg dw**	**28 mg/kg dw**
Ovary	2.17 (0.05)	10.89 (1.83)	26.17 (0.07)	40.32 (2.44)
Female liver	2.51 (0.32)	NA	22.75 (2.96)	40.68 (2.14)
Testis	2.65 (0.21)	9.87	16.38 (0.71)	29.70 (5.02)
Male liver	4.10 (0.37)	14.32	24.28 (4.54)	52.47 (5.23)

Table 2. Selenium Concentrations (mg/kg dw) in Bluegill Parents (Population B) Used in Larval Toxicity Tests				
Dietary treatment	**Control**	**8 mg/kg dw**	**18 mg/kg dw**	**28 mg/kg dw**
Male liver	4.07 (0.23)	6.94 (1.58)	20.46 (3.46)	31.63 (1.75)
Testis	1.87 (0.11)	3.64 (0.47)	9.96 (0.45)	15.25 (0.45)
Female liver	4.00 (0.26)	12.33 (1.09)	25.98 (4.28)	47.60 (4.11)
Female muscle	**1.47 (0.14)**	**5.80 (0.79)**	**10.41 (2.02)**	**23.64 (2.04)**
Ovary	2.23 (0.11)	6.34 (0.47)	14.10 (2.62)	30.63 (3.23)
Eggs	**2.81 (0.14)**	**8.33 (0.63)**	**19.46 (3.83)**	**38.39 (3.14)**
Larvae	NA	NA	NA	35.30 (4.16)
Fry	1.48 (0.11)	1.25 (0.02)	1.37 (0.06)	1.46 (0.03)

Table 3. 5-day Larval Development Toxicity Test, average (SD)				
Dietary treatment	**Control**	**8 mg/kg dw**	**18 mg/kg dw**	**28 mg/kg dw**
Free of Edema, %	100	100	95 (2)*	4.3(2.7)*

Table 4. 4-day Edema Observations by Replicate from 5-day Larval Toxicity Test			
Treatment/Replicate ID	**Se egg, mg/kg dw**	**Se muscle, mg/kg dw**	**Percent edema (n=10)**
08-2C	3.54	2.25	0
18-4C	3.25	0.95	0
8-1S	11.49	7.07	0
8-2S	8.31	5.80	0
8-6S	6.18	1.41	0
18-1S	8.55	2.75	0
18-3S	22.06	15.44	10
18-6S	30.20	16.58	10
28-1S	44.02	NA	100
28-2S	36.31	31.10	100
28-3S	25.21	17.28	90
28-4S	52.18	27.40	100
28-5S	42.40	24.00	100
28-6S	38.47	24.66	100
28-7S	30.12	17.42	90
Treatment	**Se egg, mg/kg dw treatment avg**		**Percent edema treatment avg**
C	2.81	--	0 (n=140)
8	8.33	--	0 (n=50)
18	19.5	--	6.67 (n=60)
28	38.4	--	97.1 (n=70)

Table 5. Results from 30-day Embryo-larval Toxicity Test, average (SD)				
Dietary treatment	**Control**	**8 mg/kg dw**	**18 mg/kg dw**	**28 mg/kg dw**
Larval survival, %	71 (8.5)	51.9 (26.5)	64.4 (3.4)	2.5 (3.5)*
Larval length, mm	19.1 (1.2)	19.9 (1.2)	19.3 (0.8)	16.6 (2.5)*
Larval weight, mg	114 (24)	133 (27)	119 (16)	81 (37)*
Abnormalities in larvae, %	6.3 (7.9)	15.0 (5.8)	7.2 (3.1)	25.0 (43.3)

* Statistically significantly different from control

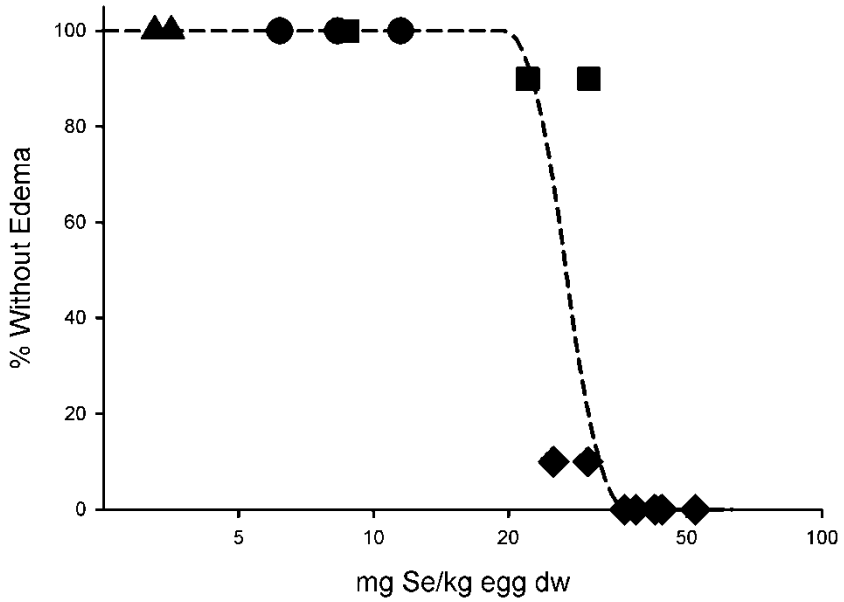


Figure 1. Bluegill larvae without edema (percent) as a function of the logarithm of selenium concentrations in eggs. Triangles denote control, circles treatment 8, squares treatment 18, diamonds treatment 28. The line denotes TRAP fits based on the individual replicates using the tolerance distribution option with the log-triangular distribution. EC_{10} for replicate data is 22.6 mg Se/kg egg dw.

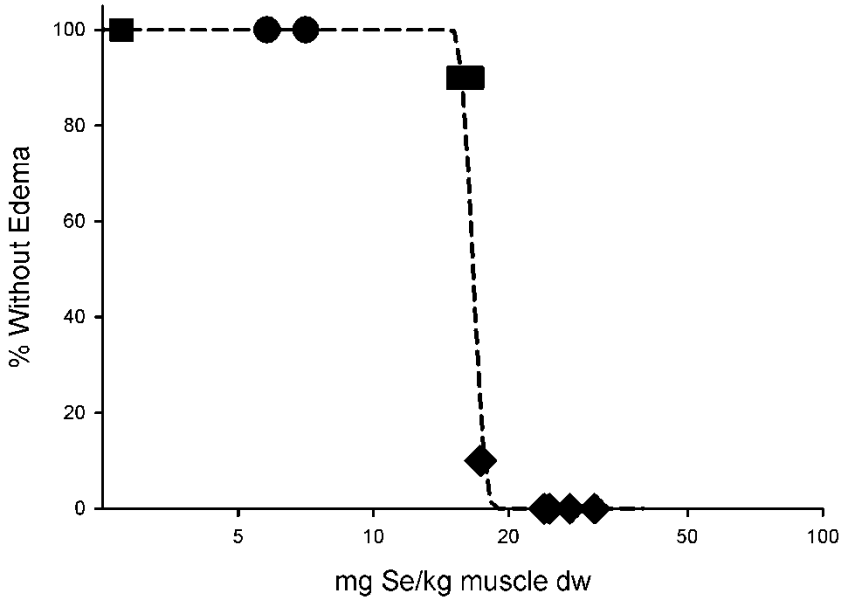
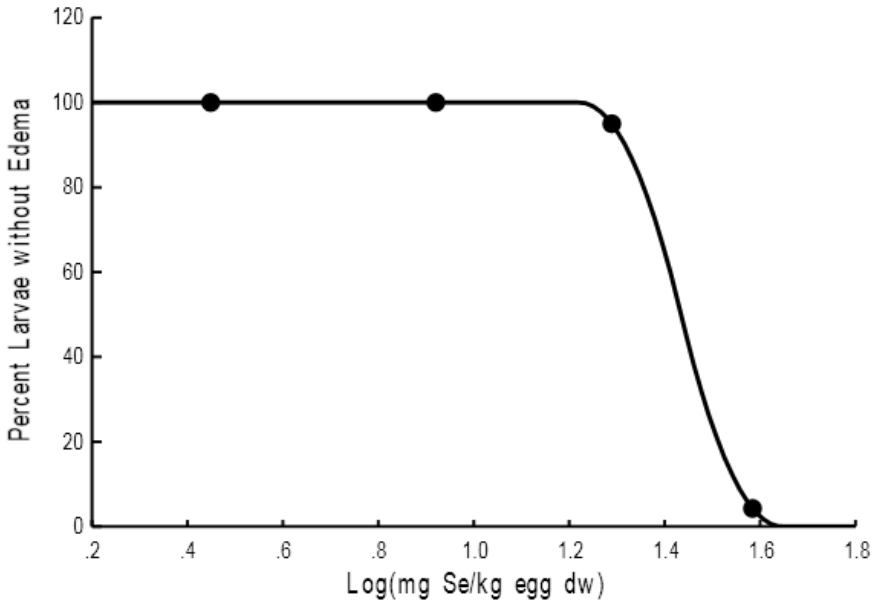


Figure 2. Bluegill larvae without edema (percent) as a function of the logarithm of selenium concentrations in maternal muscle. Triangles denote control, circles treatment 8, squares treatment 18, diamonds treatment 28. The line denotes TRAP fits based on the individual replicates using the tolerance distribution option with the log-triangular distribution. EC_{10} for replicate data is 22.6 mg Se/kg egg dw.

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MED Toxic Response Analysis Model 01/07/2015 18:10



Parameter Summary (Threshold Sigmoid Regression Analysis)

Parameter	Guess	FinalEst	StdError	95%LCL	95%UCL
LogX50	1.4428	1.4342	0.0000	1.4342	1.4342
S	5.452	4.712	0.000	4.712	4.712
Y0	98.33	100.00	0.00	100.00	100.00

Effect Concentration Summary

%Effect	Xp Est	95%LCL	95%UCL
50.0	27.18		
20.0	22.71		
10.0	20.75		
5.0	19.460		

01/07/2015 18:10 MED Toxicity Relationship Analysis Model, Version 1.21

Figure 3. (From previous draft document) TRAP analysis of bluegill larvae without edema (percent) as a function of the logarithm of selenium concentrations in eggs.

Hermanutz et al. 1992. Effects of elevated selenium concentrations on bluegills (*Lepomis macrochirus*) in outdoor experimental streams. Environ. Tox. & Chem. 11: 217-224

Hermanutz et al. 1996. Exposure of bluegill (*Lepomis macrochirus*) to selenium in outdoor experimental streams. U.S. EPA Report. Mid-Continent Ecology Division. Duluth, MN.

Tao, J., P. Kellar and W. Warren-Hicks. 1999. Statistical Analysis of Selenium Toxicity Data. Report submitted for U.S. EPA, Health and Ecological Criteria Div. The Cadmus Group.

Test Organism: Bluegill (*Lepomis macrochirus*; 3 to 4-year old adults)

Exposure Route: Dietary and waterborne followed by dietary only

Dietary and waterborne

Selenite was added to artificial streams which entered the food web; thus, fish were also exposed to selenium in the diet.

Dietary only

Recovering streams exposed bluegill to selenium in prey organisms. Selenite addition to water was ceased (selenium in water was below detection level).

Study Design: Eight Monticello artificial streams were used for three separate studies between 1987 and 1990.

Table 1. Study Design.

Stream	**Study I**	**Study II**	**Study III**
Dates **BG[a] put in station 0-2** **BG transferred to sta. 6 End of study**	**9-1-87** **5-16-88** **8-22-88**	**10-88** **5-89** **8-89**	**11-89** **5-90** **7-90**
1	Unused	Control	Control
2	Unused	2.5 µg/L	Recovering
3	10 µg/L	10 µg/L	Recovering
4	30 µg/L	Recovering	Recovering
5	Control	Control	Control
6	30 µg/L	Recovering	Recovering
7	Control	2.5 µg/L	Recovering
8	10 µg/L	10 µg/L	Recovering

[a] BG = Bluegill

The design of the three Hermanutz et al. studies is included in Table 1 and a schematic diagram of an artificial stream is provided below (Figure 1). For each study, a random sample of 22-50 adult bluegill were transferred from stations 0-2 (provided temperatures above 4°C during winter) to station 6 (most suitable for nests) during mid-May for spawning. Spawning activity was monitored in the streams. Embryo and larval observations were made *in situ* and in the laboratory from fertilized eggs taken from the streams and incubated in the lab.

Figure 1. Schematic Design of One of the Artificial Streams in the Monticello Study

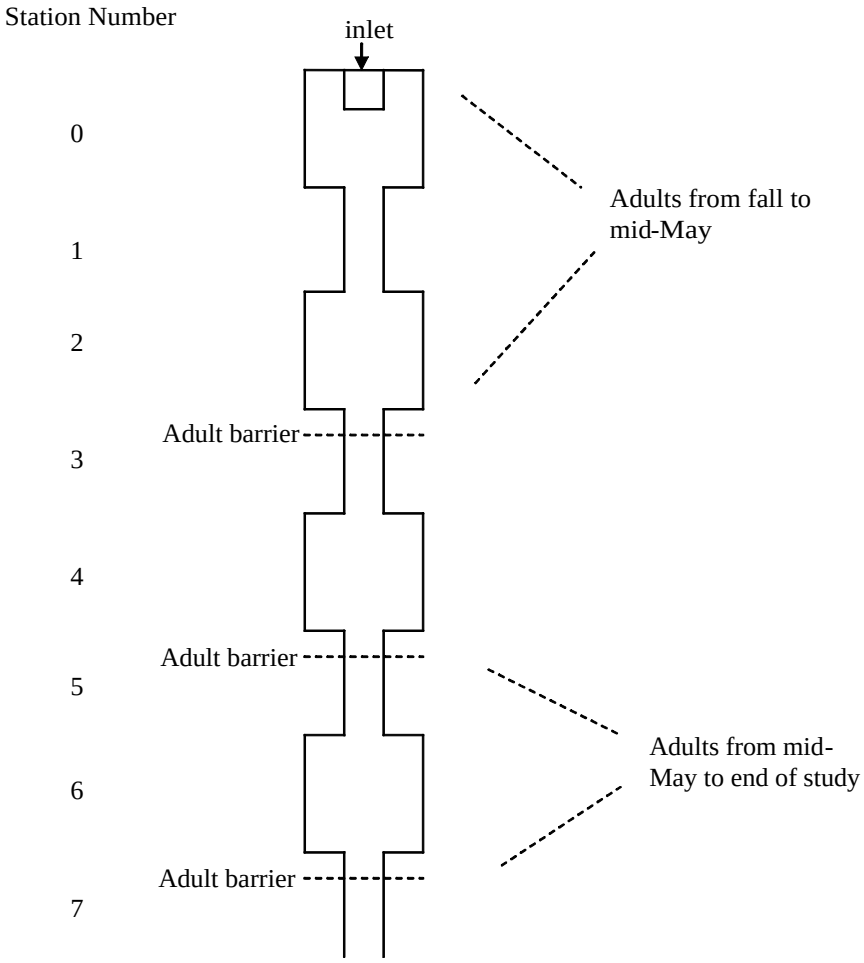


Table 2. Effects on Progeny - Study I[a]

Egg cup observations											
treatment	stream	ovary Se (mg/kg ww)			ovary Se (mg/kg dw)[b]	Geomean ovary Se (mg/kg dw)	% hatch mean ± SD	% survival to 4th day mean ± SD	% edema mean ± SD	% lordosis mean ± SD	% hemorr mean ± SD
		Early	Final	Geometric Mean							
control	5	NA	0.53	0.53	2.21	0.79	93.3 ± 9.1	69.7 ± 13.9	0.1 ± 0.2	1.8 ± 2.6	0.1 ± 0.3
control	7	0.47	0.01	0.07	0.29						
10 µg/L	3	4.29	2.53	3.29	13.73	17.71	71.5 ± 22.5	28.8 ± 23.1	80 ± 1.0	11.6 ± 15.9	28.5 ± 40.6
10 µg/L	8	4.72	6.37	5.48	22.85						
30 µg/L	4	3.71	NA	3.71	15.46	15.46	60.3 ± 25.8	9.1 ± 12.9	50.3 ± 64.1	6.3 ± 1.8	26.8 ± 20.2

Nest observations											
treatment	stream	ovary Se (mg/kg ww)			ovary Se (mg/kg dw)[b]	Geomean ovary Se (mg/kg dw)	# active nests mean ± SD	# embryos Collected mean ± SD	% dead Embryos mean ± SD	# larvae Collected mean ± SD	% dead Larvae mean ± SD
		Early	Final	Geometric Mean							
control	5	NA	0.53	0.53	2.21	0.79	6.5 ± 2.1	1441 ± 205	0.9 ± 0.03	3947 ± 1888	3.0 ± 1.1
control	7	0.47	**NA**	**0.47**	0.29						
10 µg/L	3	4.29	2.53	3.29	13.73	17.71	5.0 ± 4.2	1282 ± 457	3.2 ± 2.9	1169 ± 1093	17.0 ± 21.3
10 µg/L	8	4.72	6.37	5.48	22.85						
30 µg/L [c]	4	3.71	NA	3.71	15.46	15.46	1.0 ± 1.4	361 ± 510	0.4	157 ± 222	12.1

[a] Selenium concentrations in table were taken from Hermanutz et al. (1996); effect values were taken from Hermanutz et al (1992).

[b] used 76% moisture for egg/ovary in bluegill (average of Gillespie and Bauman 1986 and Nakamoto and Hassler 1992) to convert egg/ovary ww to dw

[c] No active nests, embryos, or larvae found in one of the 30 µg/L streams. Therefore, N = 1 for % dead embryos and dead larvae in the 30 µg/L treatment

Table 3. Effects on Progeny - Study II[a]

Egg cup observations												
treatment	stream	No. of trials	% hatch	% survival to 3rd day	% edema	% lordosis	% hemorr	% healthy[b]	ovary Se (mg/kg ww)			ovary Se (mg/kg dw)[c]
									Early	Final	Geometric Mean	
control	1	6	93.0	75.2	0	0	0	97.8	1.02	0.78	0.89	3.72
control	5	5	96.4	71.5	0	0	0	97.9	1.09	0.76	0.91	3.79
2.5 µg/L	2	0	NA	NA	NA	NA	NA	NA		1.82	1.82	7.58
2.5 µg/L	7	4	81.4	71.6	0	0	3.6	92.2	2.02	3.36	2.61	10.86
10 µg/L	3	3	83.3	57.7	100	11.1	49.3	0		8.1	8.10	33.75
10 µg/L	8	2	91.1	57.1	100	18.2	41.1	0	6.96	12.6	9.36	39.02
rec 30 µg/L	4	0	NA	NA	NA	NA	NA	NA				
rec 30 µg/L	6	6	92.9	73.0	17.4	0	11.5	70.7	5.87	13.2	8.80	36.68

Nest Observations														
Treatment	Stream	# active Nests	# embryos Collected	% dead embryos	# larvae collected	% dead larvae	#samples w larvae	% edema	% lordosis	% hemorr	ovary Se (mg/kg ww)			ovary Se (mg/kg dw)[c]
											Early	Final	Geometric Mean	
control	1	6	2458	0.94	3252	0.03	7	0	0	0	1.02	0.78	0.89	3.72
control	5	9	1329	0	3435	1.05	13	0	0	0	1.09	0.76	0.91	3.79
2.5 µg/L	2	1	0		2497	0.20	3	4.1	25	77.6		1.82	1.82	7.58
2.5 µg/L	7	5	1462	0	4717	0.08	8	0	0	52	2.02	3.36	2.61	10.86
10 µg/L	3	2	672	0	5376	0.50	9	81.4	5.0	55.5		8.1	8.10	33.75
10 µg/L	8	3	931	0.32	750	0.40	4	50	14.7	26.7	6.96	12.6	9.36	39.02
R 30 µg/L	4	0	NA	NA	NA	NA	NA	NA	NA	NA				
R 30 µg/L	6	8	646	0	6782	7.8	16	27.3	0	17.1	5.87	13.2	8.80	36.68

[a] Selenium concentrations in table were taken from Hermanutz et al. (1996); effect values were taken from Tao et al. (1999).

[b] Among live larvae that survived up to third day after first larvae hatched; assumes the observations of multiple abnormality types always co-occurred in the same organism. This may overestimate the actual % healthy when this assumption is violated.

[c] used 76% moisture for egg/ovary in bluegill (average of Gillespie and Bauman 1986 and Nakamoto and Hassler 1992) to convert egg/ovary ww to dw

R = recovering stream

Table 4. Effects on Progeny - Study III[a]

Egg cup observations									
treatment	**Stream**	**number of trials**	**% hatch**	**% survival to 3rd day**	**% edema**	**% lordosis**	**% hemorr**	**ovary Se (mg/kg ww)**	**ovary Se (mg/kg dw)[b]**
control	1	2	92	58.6	0	0	0	1.2	5.0
control	5	3	76.7	69.2	0	0.9	0.8	0.93	3.88
R 2.5 µg/L	2	3	87.3	66	0	0	0	1.84	7.67
R 2.5 µg/L	7	6	87.2	76.5	0	0	0	1.97	8.21
R 10 µg/L	3							6.25	26.04
R 10 µg/L	8	3	75.3	74.5	0	0	0	2.44	10.17
R 30 µg/L	4	5	92	78				3.82	15.92
R 30 µg/L	6								

Nest observations								
treatment	**stream**	**# active nests**	**# samples with larvae**	**% edema**	**% lordosis**	**% hemorr**	**ovary Se (mg/kg ww)**	**ovary Se (mg/kg dw)[b]**
control	1	2	5	0	0	0	1.2	5.0
control	5	2	3	0	0	0	0.93	3.88
R 2.5 µg/L	2	5	5	0	0	0	1.84	7.67
R 2.5 µg/L	7	5	2	0	0	0	1.97	8.21
R 10 µg/L	3	2	4	0	0	0	6.25	26.04
R 10 µg/L	8	4	4	0	0	0	2.44	10.17
R 30 µg/L	4	9	13	0	0	0	3.82	15.92
R 30 µg/L	6							

[a] The NOAEC for the study are from recovering 30 µg Se/L treatment.

[b] used 76% moisture for egg/ovary in bluegill (average of Gillespie and Bauman 1986 and Nakamoto and Hassler 1992) to convert egg/ovary ww to dw

R = recovering stream

Effects Data: Tables 2 through 4 include exposure and effects data for Study I, II, and III, respectively. Study I & II deformity and survival data reported in the tables above from the nest and egg in response to Se concentrations in parental ovaries (mg/kg dw) were compiled in Table 5 for TRAP analysis. Study I effects data were obtained from Hermanutz et al. (1992), and corresponding Study I ovary Se concentrations were obtained from Hermanutz et al. (1996). Study II and III exposure data were obtained from Hermanutz et al. (1996) and effects data from Tao et al. (1999).

In this study ovary concentrations were measured in an aliquot of females taken from each treatment. The exposure and effects data are thus not as directly linked as they would be in field studies of more recent design – where offspring health can be directly linked to measured tissue concentrations of their female parent.

In a change from the analyses published in drafts of this criterion document, ovary, muscle, and whole-body concentrations measured too early in the exposure period (that is, during the month of May, and labeled "early" in Tables 2 and 3) have not been used because they were not sufficiently co-occurrent with the effects measurements. On the other hand, the data for the Study II recovering stream and all Study III recovering streams *are* included in the analyses. For this analysis, the nest data continue not to be used, because they were less consistent than the egg-cup data.

EC_{10}s are based on the combined effects on survival and deformities: that is, reduction in the percentage of individuals surviving and normal. Table 5 shows the exposure and effects data used. Figures 2 and 3 show the ovary, and whole-body concentration-response curves and an explanation of how the EC_{10} values were derived. The same approach was used for the muscle data, that is, an interpolation using a nonlinear regression threshold sigmoid equation. The interpolation is based on the threshold sigmoidal model, with the first interpolation point set to the HNOEC of 11.2 mg/kg muscle and the average background survival/normal of 69.1% and the second point set to the LOEC of 21.0 mg/kg and a survival/normal of 5.8%. The resulting EC_{10} is 13.4 mg/kg muscle dw. The EC_{10} estimates for the three tissues (below) are slightly different than the EC_{10} values in the previous draft document. The reason for the difference is the use of the interpolation method in the current version rather than an inappropriate usage of a TRAP model in the previous document.

Chronic Value: This study's chronic values for bluegill based on percentage surviving and free of deformities are the following EC_{10} values:
Ovary: 14.7 mg Se/kg ovary dw
Muscle: 13.4 mg Se/kg muscle dw
Whole body: 10.6 mg Se/kg WB dw.

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Table 5. Final Exposure Concentrations and Egg Cup Survival and Deformity Rates Used for TRAP Analysis (Studies I, II, & III). The percent deformity is the maximum percentage of the individual deformity types for each treatment.

		Tissue concentration at end of exposure (dw)			Effects data from Hermanutz et al. (1996) and Tao et al. (1999)		
Study	**Treatment (µg/L)**	**Se ovary (mg/kg)**	**Se muscle (mg/kg)**	**Se WB (mg/kg)**	**% Survival**	**% Deformity**	**%Normal +Surviving**
I	Control	2.21	2.05	1.546	69.7	1.8	68.4
I	10	16.73	21.03	18.131	28.8	80	5.76
I	30	>25[1]	No data	No data	9.1	50.3	4.52
II	Control	3.25	1.96	1.63	75.2	0	75.2
II	Control	3.17	2.61	1.47	71.5	0	71.5
II	2.5	7.58	6.73	5.40	No data	No data	No data
II	2.5	14	7.13	4.40	71.6	3.6	69
II	10	33.75	36.51	16.47	57.7	100	0
II	10	52.5	55.25	26.79	57.1	100	0
II	R-30	55	39.78	24.29	79	17.4	65.3
III	Control	5.0	3.37	1.27	62.9	0	62.9
III	Control	3.88	3.11	2.66	68	0	68
III	R-2.5	7.67	5.78	4.17	71.3	0	71.3
III	R-2.5	8.21	6.48	4.25	72.2	0	72.2
III	R-10	10.17	11.20	9.29	63.4	0	63.4
III	R-30	15.92	15.12	13.77	81.1	No data	No data

[1] No data were recorded for this treatment, but a value 50% higher than the 10 µg/L treatment was added for inclusion in the analysis.

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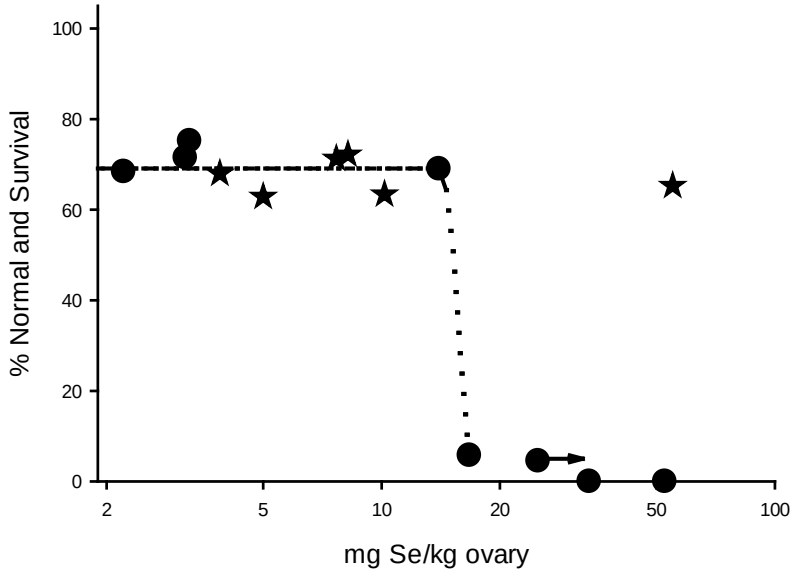


Figure 2. TRAP interpolation curve for the Table 5 ovary data. Circles denote active aqueous exposures and stars denote recovery periods. The interpolation is based on the threshold sigmoidal model, with the first interpolation point set to the HNOEC of 14.0 mg/kg and the average background survival/normal of 69.1% and the second point set to the LOEC of 16.7 mg/kg and a survival/normal of 5.76%. The resulting EC_{10} is 14.7 mg/kg ovary dw.

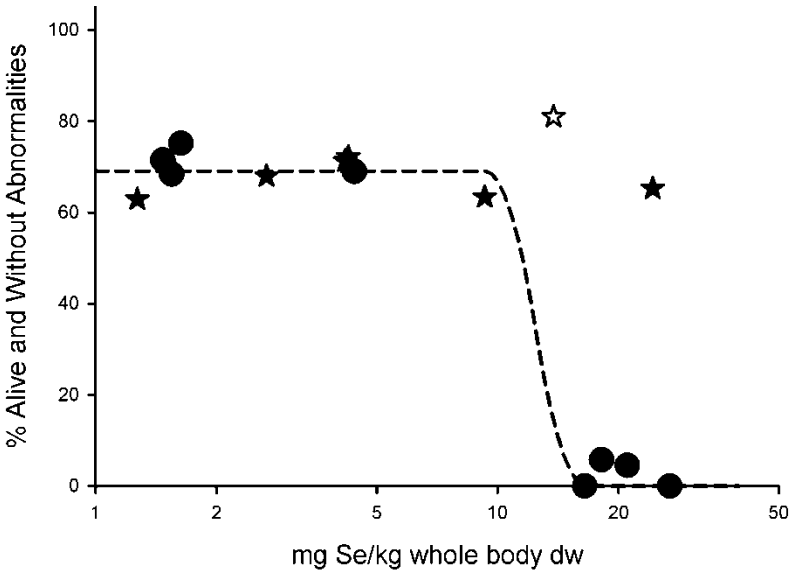


Figure 3. TRAP interpolation curve for the Table 5 whole body data. Circles denote active aqueous exposures and stars denote recovery periods. The interpolation is based on the threshold sigmoidal model, with the first interpolation point set to the HNOEC of 9.3 mg/kg whole body and the average background survival/normal of 69.1% and the second point set to the LOEC of 16.5 mg/kg and a survival/normal of 0%. The resulting EC_{10} is 10.6 mg Se/kg whole body dw.

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Coyle, J.J., D.R. Buckler and C.G. Ingersoll. 1993. Effect of dietary selenium on the reproductive success of bluegills (*Lepomis macrochirus*). Environ. Toxicol. Chem. 12:551-565.

Test Organism: Bluegill sunfish (*Lepomis macrochirus*; two-year old pond-reared adult fish and resultant fry)

Exposure Route: Dietary and waterborne
Dietary
Seleno-L-methionine added in an aqueous solution to Oregon moist pellets; moisture content of diet was 25 percent.
Waterborne
Flow through 10 µg Se/L nominal, 6:1 ratio of selenate:selenite, 98 percent purity, adjusted to pH 2 with HCl to prevent bacterial growth and change in oxidation states of Se(IV) and Se(VI).

Test Duration: 140 days

Study Design: The experiment consisted of a test control and food control (see Test Treatment table below) with fish (n=28 initially) in the four remaining treatments fed one of the four seleno-methionine diets in combination with 10 µg Se/L in water. Spawning frequency, fecundity, and percentage hatch were monitored during the last 80 days of the exposure period. Survival of resulting fry (n=20) was monitored for 30 days after hatch. Adults and fry were exposed in separate, modified proportional flow-through diluters. Fry were exposed to the same waterborne selenium concentrations as their parents. Adults were fed twice daily *ad libitum*. Whole-body selenium concentrations in adult fish were measured at days 0, 60, and were calculated from individually analyzed carcass and gonadal tissue (ovaries and testes) at day 140. Eggs not used in percentage of hatch determinations were frozen and analyzed for total selenium.

Measured Se in:	**Test Treatments**					
	1 (test control)	2 (food control)	3	4	5	6
water (µg Se/L)	0.56	8.4	10.5	10.5	10.1	11.0
diet (mg Se/kg dw)	0.76	0.76	4.63	8.45	16.8	33.3

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Effects Data: There was no effect of the combination of highest dietary selenium concentration (33.3 mg/kg dw) in conjunction with exposure to a waterborne selenium concentration of 11.0 µg/L on adult growth (length and weight), condition factor, gonad weight, gonadal somatic index, or reproductive endpoints (i.e., spawning frequency, number of eggs per spawn, percentage hatch) during the 140-day exposure (Table 1). The mean corresponding whole-body selenium concentration in adults exposed to this waterborne and dietary selenium combination was 19 mg/kg dw. Survival of fry from the exposed adults was affected by 5 days post-hatch. Concentrations of whole-body selenium in adult tissue at day 60 were used to determine effects in the fry because eggs were taken for the larval tests beginning at day 60 of the adult exposure.

Table 1. Effects on Adults

Se in diet, mg/kg dw	Se in water, µg/L	whole-body Se (140 d), mg/kg dw	replicate	total no. spawns	eggs/spawn	hatchability, %
0.8	0.5	0.8	A	15	14,099	94.5
			B	10	5,961	90.5
0.8	7.9	1.0	A	12	9,267	89.5
			B	11	9,255	84.5
4.6	10.5	3.4	A	20	9,782	86.5
			B	12	13,032	96.5
8.4	10.5	6.0	A	2	10,614	96.5
			B	9	7,995	90
16.8	10.1	10	A	13	10,797	83
			B	13	9,147	91.5
33.3	10.1	19	A	14	8,850	80
			B	4	8,850	80

In the 30-d survival after hatch test, there was complete mortality after one week at the highest exposure and no significant differences in survival at lower concentrations. Table 2 provides the survival data at 5 days post hatch used in the analysis of the effect concentration. The day 5 data are given in Table 2 because this was the only day in which control survival was over 90%, with the control and all the treatments showing substantial and increasing toxicity over the next 4 days.

Because the survival in the fifth treatment was about 5% below the average of the lowest four and because the highest treatment still had some survivors, this

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provided two partial effects for TRAP to fit a curve. However, the legitimacy of this depends on the lower survival in the fifth treatment actually being a significant Se effect, rather than reflecting random variation of background survival. Because there were multiple spawns with 200-500 total larvae tested for each survival value above, this might be expected to be a real effect, but there is insufficient data reported to test this. However, from day 6 through day 30, survival at the fifth treatment was above that in the first and third treatments, indicating this is not an effect level. These later data establish that the highest treatment is best considered an EC_{100} and the fifth treatment an EC_0. So an interpolation was done using 42 mg/kg as an EC_{100}, resulting in a slope of 7.6 and an EC_{10} of 26.3 mg/kg. The interpolation between the EC_0 and EC_{100} resulted in a slightly higher EC_{10} in the previous draft document (24.15 mg/kg) which used a TRAP model to estimate the EC_{10}. A figure is not provided here because this interpolation represents a synthesis of the data not tied to the data for a specific day.

As for the analysis with egg concentrations, the whole-body analysis recognizes the highest treatment as an EC_{100} (16 mg Se/kg dry wt whole body) and the second highest treatment as an EC_0 (7.2 mg Se/kg dry wt whole body). The interpolation method then results in an EC_{10} of 8.6 mg/kg. As for the egg concentration analysis, no plot is given because the EC_0 is not for a specific day or survival value.

Table 2. Survival of Larvae at Day 5 in the 30-day Post-hatch Test

Se in diet, mg/kg dw	Se in water, µg/L	egg, mg/kg dw	adult whole-body (60 d), mg/kg dw	mean survival, %
0.8	0.5	1.8	0.9	92
0.8	7.9	1.8	0.9	93
4.6	10.5	7.3	2.9	90
8.4	10.5	13	4.9	95
16.8	10.1	23	7.2	87
33.3	10.1	42	16	7

Chronic Value:

effect level	egg, mg Se/kg dw	whole body, mg Se/kg dw
EC_{10}	**26.3**	**8.6**

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Cleveland, L. et al. 1993. Toxicity and bioaccumulation of waterborne and dietary selenium in juvenile bluegill sunfish (*Lepomis macrochirus*). Aquatic Toxicol. 27:265-280.

Test Organism: Bluegill sunfish (*Lepomis macrochirus*)

Life Stage: juvenile (5 months - waterborne exposure; 3 months - dietary exposure)

Exposure Route: waterborne (60-d) and dietary (90-d) - separate exposures
waterborne - 6:1 selenate:selenite at 0.17, 0.34, 0.68, 1.38, 2.73 mg/L; dietary - seleno-L-methionine in Oregon moist at 1.63, 3.25, 6.5, 13, 26 mg Se/kg dw)

Study Design: Fish were exposed using a flow-through diluter. Each test consisted of an exposure and a depuration phase. Whole body tissue measurements were made at 31 and 60 days of waterborne exposure and at 31, 59 and 90 days of dietary exposure. Mortality and condition factor, K (weight x 10^5/length^3), were reported at selected intervals.

Effects Data: The waterborne exposure (see table below) was determined to have an EC_{20} = 4.07 mg Se/kg dw (1.96-8.44 mg/kg 95% CL). However, because it was a water-only exposure, it was not considered in the derivation of the FCV. These data nevertheless provide evidence that exposure route influences the tissue concentration toxicity threshold, although the mechanistic explanation for this phenomenon is lacking.

A mortality effect level for the dietary exposure could not be calculated because the highest selenium whole body concentration (13.4 mg Se/kg dw) only had 17.5% mortality. The middle selenium concentration did have 22.5% mortality. Cleveland et al. reported a significant decrease in K between 4.7 and 7.7 mg/kg dw (see table below).

Waterborne Exposure Study

Measured selenium in water (:g/L)	**60-d measured selenium in whole body (mg/kg dw)**	**60-d mortality (%)**	**Condition factor (K)**
20 (control)	1.1	10	1.5
160	2.8	12.5	1.5
330	4	22.5	1.6
640	5.3	52.5	1.5
1120	9.8	70	1.6
2800	14.7*	97.5	NA

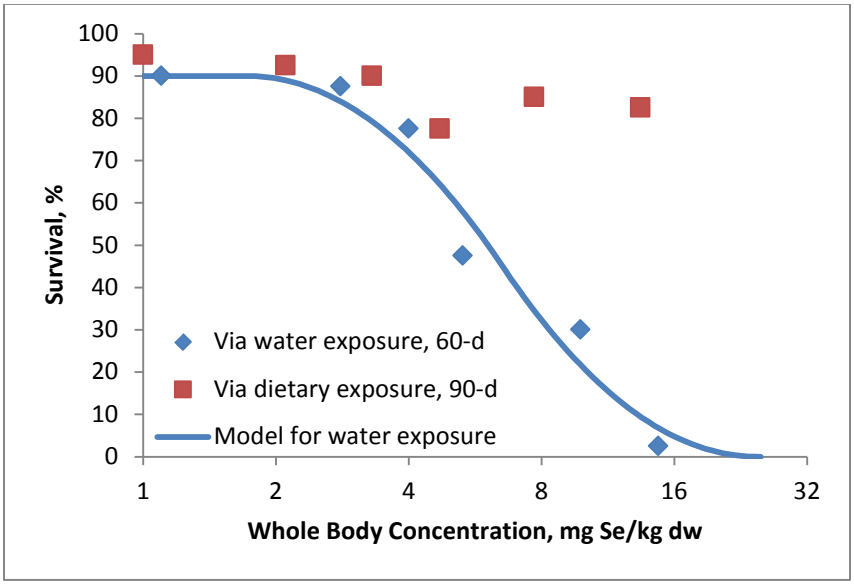
*[a] 30-d measurement because all fish were dead at 60 days in this concentration.

Dietary Exposure Study

Measured selenium in food (mg/kg ww)	90-d measured selenium in whole body (mg/kg dw)	90-d mortality (%)	Condition factor (K)
0.68 (control)	1	5	1.3
2.3	2.1	7.5	1.3
3.5	3.3	10	1.3
6.6	4.7	22.5	1.3
12.7	7.7	15	1.2
25	13.4	17.5	1.2

Discussion

The study demonstrates the influence of exposure route on the potency of a given tissue concentration, as shown in the figure. The TRAP threshold sigmoid concentration-response curve for the water-only exposure yields an EC50 of 6.5 mg Se/kg dw WB. In contrast, higher whole-body concentrations acquired via diet did not yield significant effects and cannot support a TRAP-fitted concentration-response curve or EC estimate. Examination of the graph indicates that the water-only concentration-response curve would need to be shifted to the right a minimum of 4-fold (or possibly more) to be able to fit the (lack of) effects observed in the dietary study. This supports the decision to derive the criteria only from studies relying on the environmentally relevant exposure route, diet.



Survival at 60-days (for water exposure) or 90-days (for dietary exposure) versus whole-body concentration.

Chronic Value: Given (a) the very slight reduction in K (1.3 to 1.2 between 4.7 and 7.7 mg Se/kg dw WB, with no further reduction at 13.4 mg Se/kg dw WB) and uncertain relevance of growth data, and (b) no apparent concentration-related effect on mortality between 4.7 and 13.4 mg Se/kg dw WB, the NOAEC is interpreted to be 13.4 mg Se/kg dw for this study; and the chronic value is >13.4 mg Se/kg dw whole body.

NMED Exhibit 59

Lemly, A.D. 1993a. Metabolic stress during winter increases the toxicity of selenium to fish. Aquatic Toxicol. 27:133-158.

Test Organism: Bluegill sunfish (*Lepomis macrochirus;* juvenile 50-70 mm)

Exposure Route: Waterborne and dietary
Water
1:1 selenite:selenate in stock at pH 2; metered in to reach 5 :g/L
Diet
seleno-L-methionine in TetraMin (5 mg/kg dw)

Test Duration: 180 days

Study Design: Fish were exposed (treatment and control) under intermittent flow-through conditions for 180 days. Tests were run at 4° and 20°C with biological (histological, hematological, metabolic and survival) and selenium measurements made at 0, 60, 120 and 180 days. Fish were fed at a rate of 3% body weight per day. All treatments were initiated at 20°C and then decreased in the cold treatment at a rate of 2°C per week for 8 weeks to reach 4°C and then maintained at that temperature for the remainder of the 180 days.

Effects Data : In the 20°C test, fish accumulated 6 mg/kg dw selenium (whole-body) with no significant effect on survival (4.3% and 7.4% mortality in control and treatment, respectively). In the 4°C test, fish exposed to selenium accumulated 7.9 mg/kg dw (whole-body) selenium and had significant mortality after 120 (33.6%) and 180 days (40.4%) relative to control (3.9%). Several hematological measurements were significantly different in both the warm and cold selenium exposures relative to controls. Both warm and cold selenium treatments also had greater O_2 consumption than controls. Fish lipid content in the cold Se treatment decreased more than the cold control; lipid content did not decrease in either the warm control or the warm Se treatment (see summary tables below). The results suggest significant mortality occurs in juvenile bluegill during winter months when tissue concentrations reach 7.91 mg/kg dw and lipid levels decrease to 6 percent.

Chronic Value: 20°C, >6 mg Se/kg whole-body; 4°C, <7.91 mg Se/kg dw whole body

Comments: See “Comparison of the Cold-Temperature Bluegill Juvenile-Survival Studies” in this appendix after presentation of the McIntyre et al. (2008) study.

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Mean Concentration of Selenium in Tissues, Cumulative Survival*, Percent Lipid Content and Oxygen Consumption in Juvenile Bluegill

day	cold - Se control				cold + Se				warm - Se control				warm + Se			
	Se[a]	Surv. %	lipid, %	O_2[b]	Se[a]	Surv. %	lipid, %	O_2[b]	Se[a]	Surv. %	lipid, %	O_2[b]	Se[a]	Surv. %	lipid, %	O_2[b]
0	1	100	13.2	98	1	100	13.2	98	1	100	13.2	98	1	100	13.2	98
60	1	97.1	12.5	58	5.8	92.9	10	63	1.2	95.7	13.3	98	5.8	100	13.3	103
120	1.1	97.1	11.5	57	7.9	66.4	6	81	1.1	95.7	13.4	100	6	96.7	13.4	120
180	1.4	97.1	10.5	57	7.9	59.6	6	78	1.2	95.7	13.6	100	6	92.6	13.5	120

[a] whole body Se tissue concentration, mg/kg dw
[b] oxygen consumption, mg/kg/hr

* Cumulative Survival: In this experiment, 240 juvenile bluegill were placed in three 400-L fiberglass tanks, 80 in each, and exposed to each control and treatment for a period of 180 days. Ten fish were removed at random from each treatment replicate on days 0, 60, 120, and 180 for selenium, histological, hematological, and metabolic measurements.

Replicate and Average Whole-body concentrations (mg/kg dry weight) of selenium in juvenile bluegill*

	day 0				day 60				day 120				day 180			
replicate	1	2	3	mean	1	2	3	mean	1	2	3	mean	1	2	3	mean
c+Se	0.87	1.21	0.95	1.01	6.30	5.49	5.76	5.85	8.36	7.31	7.85	7.84	7.53	8.01	8.19	7.91
w+Se	1.17	0.96	0.90	1.01	5.61	6.19	5.43	5.74	6.37	5.92	5.50	5.93	5.48	5.72	6.02	5.74
c-Se	0.89			0.89	0.97			0.97	1.01			1.01	1.10			1.10
w-Se	0.99			0.99	1.12			1.12	0.99			0.99	0.96			0.96

* Each value is for a composite sample made from 5 fish.

The Kaplan-Meier estimator was used to calculate survival at time *t*

$$\hat{S}(t) = \frac{\prod r(t_i) - d_i}{r(t_i)}$$

where $r(t_i)$ is the number of fish alive just before time t_i, i.e. the number at risk, and d_i is the number of deaths in the interval $I_i = [t_i, t_{i+1}]$. The 95% confidence interval for such estimate (Venables and Ripley 2002) was computed as

$$\exp\left\{-\hat{H}(t)\exp\left[\pm k_\alpha \frac{\text{s.e.}\left(\hat{H}(t)\right)}{\hat{H}(t)}\right]\right\}$$

where

$$\hat{H}(t) = \sum \frac{d_j}{r(t_j)} \qquad \text{and } j \# i$$

The following table lists the estimates of survival in the cold + Se treatment at 60, 120 and 180 days. The term n.event is the number of deaths at a given interval; n.risk is the number of organisms alive at the beginning of the interval; survival is computed by the Kaplan-Meier estimator.

Time	n.risk	n.event	survival	std.err	lower 95% CI	upper 95% CI
60	210	15	0.929	0.0178	0.884	0.956
120	165	47	0.664	0.0350	0.590	0.728
180	88	9	0.596	0.0381	0.517	0.666

Hematological Measurements in Juvenile Bluegill Sunfish (*indicates significantly different from control)

Warm Exposure	day 0		day 60		day 120		day 180	
blood parameter	warm-Se	warm+Se	warm-Se	warm+Se	warm-Se	warm+Se	warm-Se	warm+Se
total erythrocyte, 10^6/ml	2.95	2.92	2.96	2.93	2.99	2.95	2.96	2.89
% mature	85	86	86	93*	86	94*	85	94*
nuclear shadows, 10^4/ml	0.95	0.86	0.97	2.05*	0.83	2.38*	0.91	2.30*
total leucocytes, 10^4/ml	17.22	17.41	16.90	17.55	16.73	17.62	17.05	17.36
% lymphocytes	23	25	20	23	19	26	21	22
% neutrophils	15	13	14	15	17	19	17	16
hematocrit, %	37	36	37	29*	36	29*	38	28*
MCHC (mean corpuscular hemoglobin conc.)	23	25	25	19*	25	18*	25	17*
Cold Exposure	day 0		day 60		day 120		day 180	
blood parameter	cold-Se	cold+Se	cold-Se	cold+Se	cold-Se	cold+Se	cold-Se	cold+Se
total erythrocyte, 10^6/ml	2.91	2.93	2.97	2.90	3.01	2.95	3.00	2.99

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% mature	84	82	87	95*	85	96*	85	97*
nuclear shadows, 10^4/ml	0.86	0.84	0.83	2.30*	0.89	2.49*	0.90	2.36
total leucocytes, 10^4/ml	16.48	16.88	16.79	16.91	16.80	16.74	16.96	16.63
% lymphocytes	17	16	16	17	19	15	19	18
% neutrophils	13	12	15	11	15	12	12	14
hematocrit, %	39	37	40	30*	41	28*	39	27*
MCHC (mean corpuscular hemoglobin conc.)	26	25	25	18*	22	17*	23	17*
MCV (mean corpuscular volume)	182	171	188	146*	180	135*	185	130*

McIntyre et al. 2008. Effect of Selenium on Juvenile Bluegill Sunfish at Reduced Temperatures. US EPA, Health and Ecological Criteria Division. EPA-822-R-08-020

Test Organism: Bluegill sunfish (*Lepomis macrochirus*); juvenile; average length 47 mm, average weight 1 g

Exposure Route: Waterborne and dietary

Water

1:1 selenite:selenate; For exposure systems (ES) 1 and 3, fish were exposed to a control and a series of 6 nominal concentrations, 1.25, 2.5, 5, 10, 20 and 40 µg Se/L. For ES2, fish were exposed to a control and one nominal concentration, 5 µg Se/L.

Diet

For ES1 and ES3, fish were fed a series of six concentrations of selenium and a background control in *Lumbriculus variegatus*. The measured selenium concentrations in the *L. variegatus* treatments in ES1 were: 2.3 (control), 4.5, 5.3, 7.5, 14.2, 25.7 and 34.9 mg Se/kg dw; in ES3: 2.2 (control), 4.2, 5.0, 7.2, 15.2, 25.4 and 46.7 mg Se/kg dw. Fish were fed worms at a rate of 4% of the current biomass in each fish tank. Selenium was accumulated in *L. variegatus* by feeding the worms in separate tanks a series of six concentrations of selenized-yeast diluted with nutritional yeast: 1.7, 3.3, 6.7, 13.3, 26.7 and 53.5 mg Se/kg dw. Control worms were fed nutritional yeast only. Each tank was additionally exposed to the associated aqueous concentration selenium, e.g., the worms fed the 1.7 mg Se/kg dw selenized yeast were exposed to 1.25 :g Se/L, the worms fed the 3.3 mg Se/kg dw selenized yeast were exposed to 2.5 :g Se/L, and so on. For ES2, fish were fed TetraMin spiked with seleno-L-methionine at a nominal concentration of 5 mg/kg dw and at a rate of 3% of the current biomass in each tank.

Test Duration: 182 days

Study Design: Juvenile bluegill were exposed concurrently to selenium using three separate exposure systems, ES1, ES2 and ES3. In ES1 and ES3, 100 fish were exposed to each of 6 selenium treatments (low through high treatments are referred to as Treatments 1 through 6) and two controls in 200 L carboys under flow-through conditions. Each treatment consisted of an aqueous selenium concentration and an associated dietary selenium concentration, e.g., the fish in the lowest ES1 treatment were exposed to 1.25 :g Se/L and fed worms containing 4.5 mg Se/kg dw (see Exposure Route for other treatment concentrations). Temperature was controlled in each system through the immersion of the carboys in a temperature-controlled water bath and by controlling the temperature of the dilution water being added to the carboys. The temperature in ES1 was maintained at 20°C for the first 30 days of exposure, and then decreased 2°C/week until it reached 4°C (test day 79) at which point temperature was maintained until test termination (test day 182). The only difference between ES1 and ES3 was temperature was decreased 2°C/week until it reached 9°C (test day 65) at which point temperature was maintained until test termination (test day 182).

The exposure of ES2 was similar to ES1 and ES3 in that 100 juvenile bluegill were exposed to treatment in 200 L carboys under flow-through conditions. The

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ES2 selenium treatment consisted of two replicates of 5 µg Se/L waterborne and 5 mg Se/kg dw diet (Tetramin). Two controls were maintained with ES2. The temperature regime for ES2 was identical to ES1.

Observations on fish behavior and mortality were checked daily. Total selenium was measured in each fish tank weekly and selenium speciation was measured monthly in each fish tank. Whole body total selenium was measured in the worms from each tank (2 replicate 5 g samples) on test days 0, 30, 60, 112 and 182 and in the bluegill from each tank (3 replicates of 3-fish composites - total 9 fish) on test days 0, 7, 30, 60, 112 and 182. The standard length and weight of each fish was measured on each sample day. Lipid content was measured in fish at day 0 and from each treatment at test termination.

Effects Data:

Selenium increased in bluegill as the exposure concentrations increased (see following table). No meaningful mortality was observed in ES2. The number of fish that died in ES2 during the 182 day test was two fish in one treatment replicate and none in the other treatment replicate; no deaths were reported in ES2 controls. Significant mortality of juvenile bluegill was observed in ES1 and ES3. After 182 days, a total of 24 and 68 fish died in Treatments 5 and 6, respectively in ES1; and a total of 38 and 61 fish died in Treatments 5 and 6, respectively in ES3. See table below for mortalities in all treatments. Estimates of bluegill survival were adjusted for the removal of individuals from the test population. Individuals were removed from the experiments before test completion, for sampling tissue concentrations or because they suffered accidental deaths unrelated to selenium toxicity. For such data, it was necessary to account for the reduction in number of individuals at risk of death due to selenium over time. If $r(t_i)$ is the number of individuals at risk just before time t_i and d_i is the number of deaths in the interval, $I_i = [t_i, t_{i+1})$, then survival (S) at time t can be estimated as

$$\hat{S}(t) = \prod \frac{r(t_i) - d_i}{r(t_i)}$$

The product (P) was calculated for each period in which one or more deaths occur. The equation is the Kaplan-Meier estimator (Venables and Ripley 2002). This correction was applied to calculate the proportion of survival in treatments with ten or more deaths (10% mortality). The table below provides the adjusted proportion and surviving bluegill in each treatment along with the concentration of selenium in bluegill at test termination. The values in this table were used to calculate the EC_{20} and EC_{10} values using the TEAM software. Growth and lipid content of the bluegill was not negatively affected by the selenium exposures.

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Measured total selenium concentrations in bluegill sunfish for all treatments and controls in Exposure System 1, 2 and 3.

Total Selenium in Whole Body Bluegill Tissue, mg/kg dw

ES1	Control	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6
Test Day	Average (SD)	Average (SD)	Average (SD)	Average (SD)	Average (SD)	Average (SD)	Average (SD)
0	1.93 (0.21)	1.93 (0.21)	1.93 (0.21)	1.93 (0.21)	1.93 (0.21)	1.93 (0.21)	1.93 (0.21)
7	2.43 (0.31)	2.48 (0.11)	2.43 (0.18)	2.64 (0.06)	2.72 (0.07)	3.27 (0.27)	4.27 (0.44)
30	2.10 (0.21)	2.85 (0.10)	3.10 (0.04)	2.94 (0.13)	4.24 (0.22)	6.62 (0.23)	10.21 (0.36)
60	2.11 (0.02)	2.70 (0.20)	3.07 (0.05)	3.69 (0.25)	5.21 (0.30)	8.62 (0.45)	12.66 (0.45)
112	1.98 (0.04)	3.16 (0.11)	3.41 (0.08)	3.99 (0.26)	6.42 (0.05)	11.60 (0.43)	
182	2.08 (0.10)	2.56 (0.21)	3.15 (0.25)	4.02 (0.21)	6.72 (0.09)	10.71 (0.55)	

ES3	Control	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6
Test Day	Average (SD)	Average (SD)	Average (SD)	Average (SD)	Average (SD)	Average (SD)	Average (SD)
0	1.93 (0.21)	1.93 (0.21)	1.93 (0.21)	1.93 (0.21)	1.93 (0.21)	1.93 (0.21)	1.93 (0.21)
7	2.50 (0.10)	2.60 (0.29)	2.38 (0.10)	2.82 (0.20)	3.19 (0.33)	4.29 (0.20)	6.13 (0.62)
30	2.24 (0.41)	2.44 (0.26)	2.70 (0.16)	3.13 (0.10)	3.95 (0.16)	6.06 (0.36)	11.07 (0.92)
60	2.70 (0.22)	2.88 (0.08)	3.04 (0.39)	3.79 (0.24)	5.54 (0.21)	9.50 (0.91)	15.14 (0.96)
112	2.16 (0.14)	2.49 (0.10)	3.10 (0.12)	3.64 (0.16)	6.54 (0.21)	11.50 (0.25)	17.24 (0.30)
182	1.67 (0.21)	3.20 (0.27)	3.83 (0.47)	5.48 (0.24)	9.38 (0.63)	16.01 (0.30)	

ES2	Control	5A	5B
Test Day	Average (SD)	Average (SD)	Average (SD)
0	1.93 (0.21)	1.93 (0.21)	1.93 (0.21)
7	2.19 (0.19)	3.55 (0.25)	3.08 (0.50)
30	2.49 (0.15)	7.05 (0.76)	7.51 (1.18)
60	1.53 (0.03)	8.23 (1.55)	8.09 (0.67)
112	1.57 (0.01)	8.97 (1.28)	9.45 (1.73)
182	1.38 (0.06)	9.41 (1.63)	10.61 (0.38)

Total number of deaths in ES1 and ES3 Treatments throughout the experiment's duration (182 days). Both ES1 and ES3 had two control tanks.

Treatment	ES1	ES3
Control (#1, #2)	0, 7	1, 1
1	5	0
2	1	1
3	0	0
4	3	3
5	24	38
6	68	61

The concentration of selenium in bluegill and the adjusted proportion of surviving fish at the end of the 182 day exposure.

	ES1		ES3	
Treatment	$[Se]_{tissue}$, mg/kg dw	surv	$[Se]_{tissue}$, mg/kg dw	surv
control	2.08	0.962	1.67	0.988
1	2.56	0.988	3.20	1.000
2	3.15	0.984	3.83	0.988
3	4.02	1.000	5.48	1.000
4	6.72	0.962	9.38	0.960
5	10.71	0.497	16.01	0.435
6	12.66	0.075	17.24	0.168

Chronic Value: The NOAEC for bluegill in ES2 was calculated as the geometric mean of the concentration of bluegill in the two replicates at the end of the exposure period, 9.992 mg Se/kg dw whole body. The chronic value for ES2 is therefore >9.992 mg Se/kg dw whole body. The EC_{20} and EC_{10} values for ES1 and ES3 are given in the following table.

	ES1 (4°C)	ES3 (9°C)
	Whole body	Whole body
EC_{20} mg Se/kg dw	9.78	14.64
EC_{10} mg Se/kg dw	9.27	14.00

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Comparison of the Cold-Temperature Bluegill Juvenile-Survival Studies of Lemly (1993a) and McIntyre et al. (2008)

The Lemly (1993a) and McIntyre et al. (2008) cold-temperature juvenile bluegill studies are summarized on the previous pages. This discussion compares and contrasts these studies.

Both studies indicated that juvenile bluegill are more sensitive to selenium at lower temperature than at higher temperature. For a 4°C temperature regime, the EC_{10} of 9.27 mg Se/kg dw WB obtained with McIntyre's selenized yeast-worm-fish dietary bioaccumulation system is somewhat similar to the threshold of 5.85 mg Se/kg dw WB estimated from the time course of bioaccumulation and mortality in Lemly's single treatment with seleno-L-methionine in TetraMin. These chronic values differ by a factor of 1.58.

The difference in diet does not appear to explain the modest difference in results; however, since McIntyre's other 4°C experiment (Exposure System ES2), which used Lemly's seleno-L-methionine in TetraMin diet, experienced no significant toxicity, whereas Lemly's similarly exposed fish experienced 40 percent mortality by the end of the test. In addition to the difference in observed mortalities, Lemly's bluegill in the 4°C selenium exposure decreased in both lipid content and body condition over the 180 days whereas no decreases in these measurements were observed in the McIntyre et al. study, although the fish used in both studies were of comparable size and body condition at test initiation: 47 mm average standard length (range 44 to 54 mm) and a body condition index (100 x fish weight/standard length) of 3.2 in ES2 compared to 50 to 70 mm total length and a body condition factor of 3.9 in Lemly.

There are several possible reasons why such results could differ between studies. (1) ES2 maintained exposure at 20°C for the first 30 days of exposure before decreasing the temperature compared to 7 days in the Lemly study. (2) Lemly measured O_2 consumption by removing and reintroducing test fish to the test tanks, which was not done by McIntyre et al. (3) The two studies differed in photoperiod – Lemly "began with a 16:10 h light/dark photoperiod which was gradually reversed to 10:16" (sic) whereas McIntyre et al. used a fixed photoperiod of 16:8. (4) Some genetic differences between the tested batches of organisms may be expected, reflecting different origins, despite the similarities in their starting size and condition.

The modification to maintain 20°C for 30 days was to allow a longer period of time for the fish to accumulate selenium during a warmer condition prior to decreasing the temperature. This did result in shortening the exposure in ES2 at 4°C by 19 days (103 days at 4°C) compared to 122 days at 4°C in Lemly's study. However, as the majority of deaths in Lemly's study occurred between in the middle 60 days of the 180-day test, the slightly shorter cold period in the McIntyre study would not explain the differences in mortalities.

As stated above, Lemly removed fish (N = 15) from each treatment for oxygen consumption measurement and then returned these fish to the exposure tanks. There is the possibility that the fish removed from the cold plus selenium treatment were sufficiently stressed by the exposure conditions that the additional handling stress contributed to the mortality observed in this treatment. Between test days 60 and 180, 56 fish died Lemly's cold plus selenium treatment. Even if stress due to handling affected all the fish used in the oxygen consumption measurements (up to 30 fish), it does not explain all the mortality that was observed and therefore does not explain the difference between the two studies.

Both Lemly (1993) and McIntyre et al. (2008) showed reduced survival of juvenile bluegill exposed to elevated selenium under lab-simulated winter conditions, albeit at somewhat different concentrations. But only Lemly, not McIntyre et al., found the decreased survival to be accompanied by loss of lipid and body

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condition. It was hypothesized that the decrease in EC_{10} observed by Lemly (1993) in the cold water treatment between 60-180 days was attributed to "winter stress syndrome" (WSS). WSS is hypothesized to occur in warmwater fish species because the presence of a stressor places additional metabolic costs on exposed organisms. These stresses can be better tolerated during periods of warm weather and active feeding. However, during the winter months, feeding and activity levels decrease but the metabolic costs of the stressor remain. As a result, fishes deplete their lipid stores, resulting in lower condition factors and increased susceptibility to mortality (Lemly 1996). Lemly noted three conditions that must be met simultaneously in order for WSS to occur: 1) a significant metabolic stressor must be present, 2) cold water temperatures must be present, and 3) fish must respond by reducing activity and feeding (Lemly 1996).

Several other studies have reported decreased feeding and activity levels for several fish species. McCollum et al. (2003) observed decreased overwinter feeding, and subsequent weight loss, of white crappie. Parrish et al. (2004) observed overwinter weight loss among mature, but not juvenile, salmon in a laboratory study in experimental raceways. Current speed, and by extension prey delivery rate, was the most important factor regulating overwinter feeding and growth. Eckmann (2004) observed overwinter reductions in feeding, weight, and lipid levels in yellow perch, but not in ruffe. Sogard and Olla (2000) observed walleye pollock could mitigate the effects of overwinter lipid depletion by moving to colder waters, where reduced metabolism allowed them to conserve energy. In all of these studies, fish continued to feed during the winter, but feeding rates decreased. The increase in weight among ruffe was attributed to its ability to feed on benthos in the dark during the winter months, suggesting that feeding reduction during winter may be more pronounced for species dependent on vision to feed. This was supported by Bennett and Janz (2007a), who observed that burbot, which rely primarily on smell while feeding on benthic invertebrates, experienced significant overwinter increases in weight and lipids in all sites, while northern pike, which rely primarily on vision while feeding on zooplankton, experienced slight but non-significant increases in weight and length.

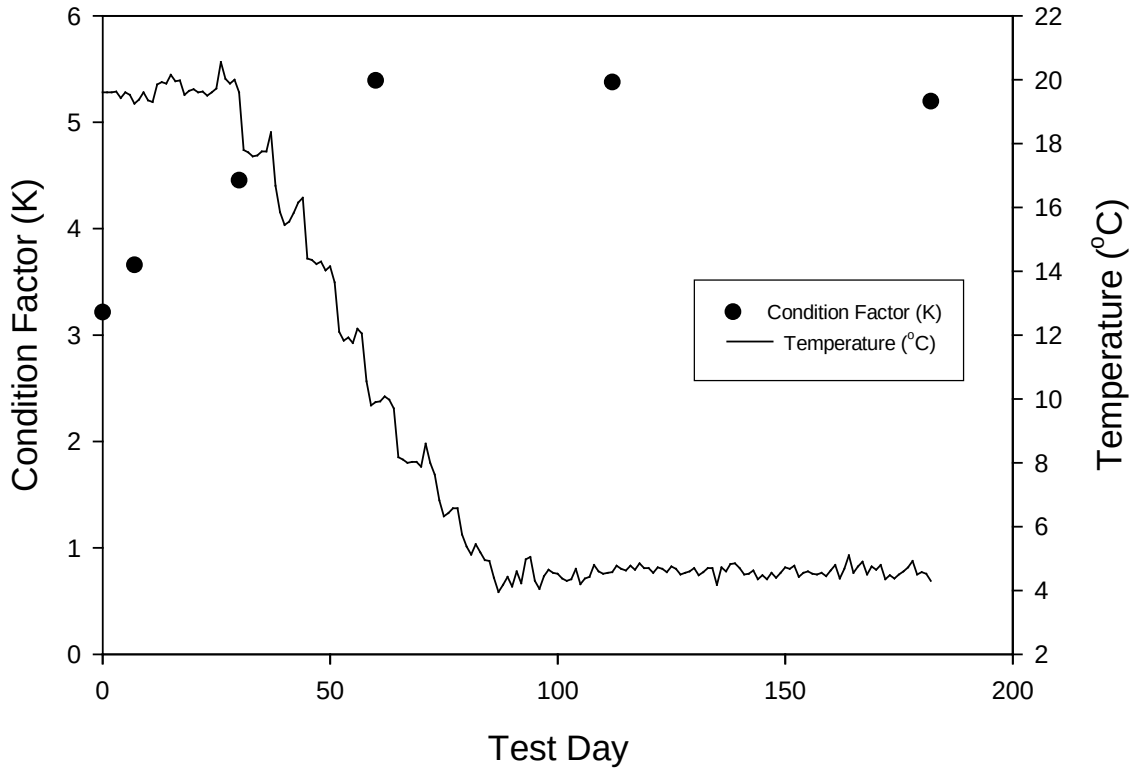
WSS has not been definitively confirmed or refuted, although it has been investigated in the field. Bennett and Janz (2007a) observed no evidence of WSS for juvenile northern pike or burbot. Lengths, weights, and lipids increased for both species, particularly the olfactory feeding burbots, in the spring compared to the previous fall. Overall weights and lipids were higher in the low and high exposure lakes than the reference lake, possibly because of nitrogen limitation in the reference lake coupled with relatively low stressor concentrations in the exposed lakes. In a separate study, overwinter weights and lipids remained similar or increased in northern pike and burbot at both reference and exposure sites, while overwinter weights and lipids decreased at the exposure site for slimy sculpin (Bennett and Janz 2007b). However, this study neither supports nor refutes the WSS hypothesis, because stressor concentrations at the exposure site were not significantly different than at the reference sites, and the weight decrease in sculpin was attributed to higher turbidity at the exposure site, which inhibited food acquisition. In a final field test of WSS fathead minnow, creek chub, and white suckers were collected from reference and exposure sites (Driedger et al. 2009). Stressor levels at exposure sites were high, as whole body Se concentrations in fathead minnow ranged from 11-42 mg/kg dw. All three species either gained or maintained weight overwinter at all sites, indicating that active feeding occurred overwinter. Overall weights at exposure sites were higher, likely because of nutrient limitation at the reference sites, which confounded the ability to fully test the WSS hypothesis.

These results suggest that fish species responses to cold temperatures vary by species and environment. Many species lose weight, but this can be partially explained by the impact of low light levels on consumption levels, especially in northern latitudes where overwinter light limitation is pronounced. Field tests found no evidence of WSS, but were confounded by low stressor levels, nutrient limitation at reference sites, or both.

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It may then be questioned whether the fixed photoperiod alone could account for the differences in the results of the two studies. More explicitly, did the longer light period in McIntyre et al. photoperiod allow the fish to feed more than the fish exposed to the shorter light period in the Lemly study, such that lipid and body condition in the McIntyre et al. fish were maintained and therefore not susceptible to "winter stress syndrome." The effects of photoperiod on fish and other ectotherms are well-documented. Temperature-independent seasonal changes in fish have been reported for growth and food conversion efficiency (Biswas and Takeuchi 2003; Jonassen et al. 2000; Simensen et al. 2000), feeding behavior (Volkoff and Peter 2006), metabolic rate (Evans 1984), and reproduction (Koger et al. 1999; Scott 1979). Some of these studies have found conflicting results on the effect of photoperiod on growth (Fuchs 1978; Jonassen et al. 2000; Simensen et al. 2000). Coupled with temperature being a dominant factor in controlling physiological functions in temperate-zone fish as indicated by a 3 to 4-fold fluctuation in metabolic activities over 10°C (Brett 1970; Fry 1971), it is difficult to use literature findings to explain the difference in the two bluegill studies. In field studies of fish at northern latitudes (Eckmann 2004), reduced light resulted in weight loss not though a bioenergetics interaction with cold temperatures, but by inhibiting feeding ability of visual, but not non-visual predators. If this mechanism applies to bluegill, then photoperiod is less likely to play a major role in the difference in results, as the overwinter light:dark cycle (8:16) should have been sufficiently long for the bluegill in Lemly (1993) to feed.

Observational recordings of the feeding behavior in McIntyre et al. noted that in both control replicates and in both treatment replicates the feeding of the juvenile bluegill went from active to not active on test day 78 when temperatures were decreased from 6.6 to 5.8°C. The feeding observations are reflected in a gradual slight decrease in the body condition factor (K) after test day 60 in the figure below. Although food intake was not quantified during the study, the lack of growth indicated in K suggests feeding markedly decreased as the temperature declined, as shown in the figure. Body condition decreased much more in the Lemly's cold plus selenium exposed fish after test day 60 (approximately 50%) but K in his cold-without-selenium exposure decreased only slightly, similar to McIntyre et al. Therefore it is not possible to determine if the greater decrease in K and in lipid content in Lemly's cold plus selenium treatment was due to decreased feeding because of a shorter photoperiod or because the bluegill fish population used in his study were more sensitive to selenium in cold conditions. McIntyre et al. obtained bluegill from Osage Catfisheries in Missouri whereas Lemly collected fish from ponds (assumed to be near Blacksburg, Virginia, not stated in paper). The fish obtained from Missouri, a location with colder winters than Virginia, may have been better adapted for withstanding colder winter temperatures than Lemly's fish and therefore were less sensitive to "winter stress syndrome" as induced by selenium exposure. Similarly, different populations of a species can have varying sensitivities to stressors. Furthermore, the relative difference in the Lemly and McIntyre et al. results is slightly **less** than Delos (2001) found to be typical when equivalent toxicity tests of the same species are compared. There should thus be no expectation that the two study results should agree more closely than they do.



Relationship between body condition factor (K) and temperature in juvenile bluegill fed a diet of Se-enriched TetraMin in the McIntyre et al. (2008) study.

Carolina Power & Light. 1997. Largemouth Bass Selenium Bioassay- Report. Carolina Power & Light Company, Environmental Services Section, 3932 New Hill, North Carolina. December 1997

Test Organism: Largemouth bass (*Micropterus salmoides*)

Exposure Route: Laboratory; dietary exposure only; DL-selenomethionine added to an artificial diet. Adult largemouth bass obtained from a commercial supplier were fed several months prior to spawning a series of selenium concentrations in the artificial diet.

Test duration: Embryo-larval monitoring through swim-up stage.

Study Design: Dietary exposure studies were conducted in 1995 and in 1996. In 1995, the measured dietary Se concentrations were 0.9 (control), 2.9, 7.5 and 11.2 mg Se/kg dw: in 1996, they were 26.7, 53.1 and 78.4 mg Se/kg dw. Parent fish were fed to satiation twice per day. Approximately 100 eggs from each spawn were transferred to each of 2 to 4 incubation cups. Eggs and larvae were monitored for mortality and deformities up to the larval swim-up stage. Selenium was measured in the liver, muscle and gonad tissues of the parent fish. All live deformed larvae at swim-up stage were considered as mortalities in the analyses.

Effects Data: Over the two year period, 56 successful spawns were obtained across all dietary treatments. Live larval fish with deformities (kyphosis, scoliosis, jaw gap, and lordosis) and edema at swim-up stage were considered mortalities for data analysis. The average concentration of selenium in ovaries ranged from 3.1 mg/kg dw in the control to 77.6 mg/kg dw in the high dietary treatment (Table 1). Larval survival generally decreased as the selenium concentration in the ovary increased (Table 1; Figure 1). A plot of the percent survival of larval largemouth bass as a function of the selenium concentration in the parental female ovary shows two groups of data; one at background survival with considerable variability (mean 90.3%, standard deviation 10.9%) and one with <10% survival, with most of the data being at 0% survival. Due to inadequate partial effects, a TRAP interpolation was used to estimate an EC_{10} value. Based on a risk management decision that the LOEC cannot be any higher than the lowest concentration with 0% survival (32.9 mg/kg) and that any ECx should be below this, this establishes the higher concentration point for the interpolation (an EC_{100} of 32.9 mg/kg) and requires that the highest 4 NOECs not be considered in setting the EC_0. The lower concentration point for the interpolation is therefore set here to 24.6, the next highest NOEC with greater than the average 90.3% background survival. This results in an EC_{10} of 26.3 mg/kg (and a steep slope of 16).

An EC_{10} for the muscle tissue in Table 1 was not determined due to uncertainty in the values. The authors of this report also measured selenium in the ovaries and muscle tissues of largemouth bass collected from Mayo Reservoir (Table 2). There was a considerable difference in the proportion of selenium in the ovaries to the muscle tissues between the largemouth bass collected from the bioassay study and the field collected largemouth bass. The ratio of Se in ovaries to muscle in the laboratory fish was approximately 3.3 whereas it was 1.1 in the field collected fish. With the exception of mountain whitefish, the ovary to muscle ratio observed in the laboratory fish is also considerably higher than other

species (see Appendix B Table B-3). Based on this uncertainty in the muscle concentrations in the laboratory fish, an EC_{10} for this tissue was not calculated. The effect concentration based on the ovary selenium concentrations are not considered uncertain because these concentrations represent the direct exposure of selenium to the larvae from which the effect was observed.

Effect Concentration: **26.3** mg/kg dw in ovaries

Table 1. Selenium concentrations in the diet, ovary and muscle tissues and the percent mortality and deformities.

Measured Se in diet fed to parents, mg/kg dw[a]	Spawn No.	Se in parent **tissues**, mg/kg dw			Larval survival, %	
		Muscle	**Ovary**	Average	Individual	Average
0.9 ± 0.1 (0.7 – 1.3)	6	1.62	5.38	3.1	75.5	95.3
	12	1.77	7.34		99.7	
	13	2.01	3.51		96.2	
	26	2.27	5.74		88.9	
	34	1.18	1.58		99.5	
	35	1.28	1.36		96.8	
	3	1.534	2.09		98.8	
	4	1.583	1.85		100	
	10 (2F)	1.15	2.11		97	
	13	1.181	1.86		97.1	
	14	1.341	1.40		98.4	
2.9 ± 0.5 (2.1 – 3.8)	9	2.075	9.59	8.8	84.9	94.8
	12	1.853	8.03		100	
	15	2.026	9.73		98.5	
	18	3.134	7.66		95.9	
7.5 ± 0.6 (6.3 – 8.4)	1	2.741	8.43	10.8	75	85.8
	2	3.737	25.15		63.9	
	5	5.709	15.31		90.6	
	7	3.468	1.20		79.1	
	8	2.545	6.78		95	
	16	7.302	8.25		96.8	
	19	4.776	10.20		100	
11.2 ± 1.4 (9.3 – 14.1)	6	4.521	35.44	25.0	91.5	88.7
	11	6.044	15.08		77.9	
	17	4.882	24.59		96.7	
26.7 ± 1.7 (23.6 – 29.5)	2	7.52	37.14	40.0	91.2	18.3
	5	12.42	44.67		0	
	11	9.73	34.26		75.9	
	16	10.1	35.58		0	
	17	5.74	33.48		9.9	
	19	11.74	48.24		0	
	36	10.21	35.81		6.3	
	37	14.12	37.88		0	
	51	11.68	32.95		0	

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Measured Se in diet fed to parents, mg/kg dw[a]	Spawn No.	Se in parent **tissues**, mg/kg dw			Larval survival, %	
		Muscle	**Ovary**	Average	Individual	Average
	52	11.16	59.89		0	
53.1 ± 4.8 (45.5 – 61.9)	22	18.15	46.22	61.0	0	0
	25	21.07	70.45		0	
	30	25.02	81.62		0	
	31	16.63	54.99		0	
	32	14.3	53.96		0	
	41	17.73	51.48		0	
	48 (2F)	26.25	84.31		0	
	50 (2F)	11.66	32.87		0	
	55	18.36	73.33		0	
78.4 ± 4.3 (73.2 – 87.0)	4 (2F)	12.6	66.81	77.6	66	5.5
	7	17.24	56.98		0	
	8	20.36	86.49		0	
	10	19.59	65.99		0	
	18	22.52	72.35		0	
	21	18.58	71.89		0	
	24	22.08	62.44		0	
	28	29.15	99.02		0	
	38	58.2	52.37		0	
	44	17.7	102.82		0	
	47	24.14	88.15		0	
	49	18.94	105.29		0	

[a] ± standard error; range of concentrations in parentheses.

Table 2. Se concentrations in muscle and ovary of field-collected (Mayo Reservoir) female largemouth bass.

Date	Se Muscle (mg/kg dw)	Se Ovary (mg/kg dw)	Ovary to Muscle Ratio
05/10/95	8.48	14.79	1.74
05/10/95	8.48	14.79	1.74
05/09/95	7.29	8.35	1.15
04/21/94	15	19	1.27
04/20/94	15	15	1.00
04/22/94	12	14	1.17
04/22/94	10	18	1.80
04/25/94	18	15	0.83
04/25/94	18	15	0.83
04/27/94	11	12	1.09
04/27/94	11	9.4	0.85
04/27/94	13	10	0.77
05/04/94	11	11	1.00
			Median Ratio 1.09

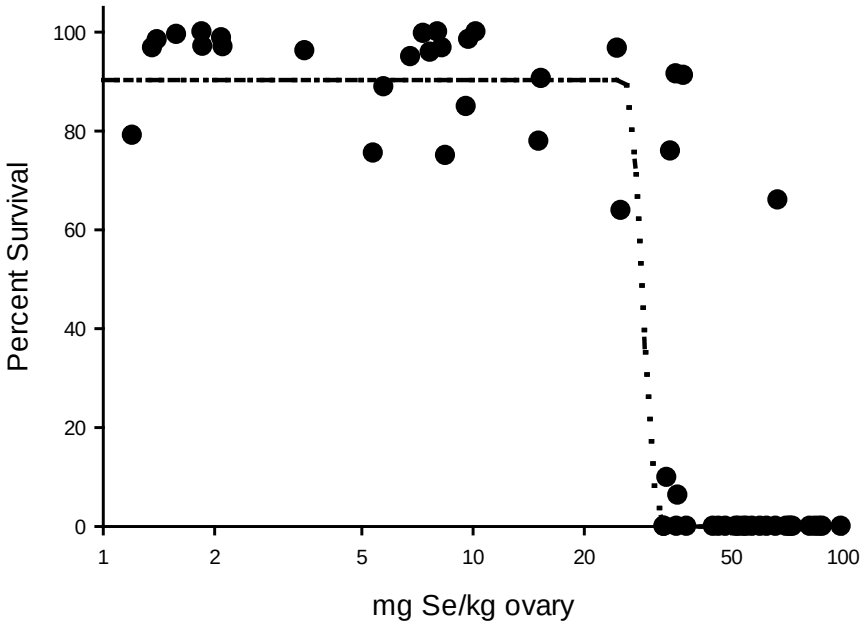


Figure 1. Largemouth bass larval survival relative to Se in ovary. TRAP interpolation was used to estimate the EC_{10} value. The higher concentration point for the interpolation was set at 32.9 mg/kg (EC_{100}) and the lower concentration point for the interpolation was set at 24.6 (NOEC) with greater than the average 90.3% background survival. This results in an EC_{10} of 26.3 mg/kg and a steep slope of 16.

APPENDIX D: SUMMARY STUDIES OF NON-REPRODUCTIVE EFFECTS

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1.0 STUDIES OF NON-REPRODUCTIVE EFFECTS

1.1 Acipenseridae

1.1.1 Acipenser transmontanus (white sturgeon)

Juvenile white sturgeon were exposed for 8 weeks to a series of 5 concentrations of seleno-L-methionine added to an artificial diet (Tashjian et al. 2006). Survival was not affected by selenium treatment with a mean survival rate of 99% across all groups. Fish fed the highest three dietary treatments of selenium, 41.7, 89.8 and 191.1 mg Se/kg dw, exhibited significant declines in growth assessed by body weight measurements. The EC_{10} for reduction in body weight is 15.08 mg Se/kg dw in whole body or 27.76 mg Se/kg dw muscle; the EC_{20} is 17.82 mg Se/kg dw in whole body or 32.53 mg Se/kg dw muscle tissue. The criterion values derived in this document that are based on reproductive endpoints are protective of the endpoint measured in this non-reproductive study.

1.2 Cyprinidae

1.2.1 Pogonichthys macrolepidotus (Sacramento splittail)

Teh et al. (2004) exposed juvenile Sacramento splittail (7 months-old) to 8 levels of dietary selenium, 0.4 (no added selenium), 0.7, 1.4, 2.7, 6.6, 12.6, 26.0, and 57.6 mg/kg. Selenium was added to the diet via selenized yeast which was diluted with Torula yeast (inactive) to attain the target levels. Mortality, growth, histopathology, deformities and selenium content in muscle and liver were observed or measured after 5 and 9 months of exposure. The appearance of deformities was the most sensitive endpoint. The authors determined the occurrence of deformities was higher in fish fed 6.6 and 12.6 mg Se/kg in their diet; however, such pathology was examined for only 15 of the 120 individuals per treatment, and a consistent concentration-response relationship did not occur (i.e., no deformities in the high concentration). The lack of a concentration-response relationship for the incidence of deformities has also been observed in another study. Crane et al. (1992) exposed a European species of perch, *Perca fluviatilis* to three aqueous and dietary selenium treatments in experimental ponds for 288 days up through spawning. Crane et al. (1992) found an increased occurrence of deformities in embryos and larvae in the lowest selenium treatment relative to the control, but a decrease in the middle treatment. No hatching occurred in the high treatment. Teh et al. (2004) proposed several physiological mechanisms to explain the lack of a dose-response relationship, but it appears that the underlying mechanism is not understood at this time. Toxicity tests with unusual dose-response relationships are typically not considered for criteria derivation, but since another assay (Crane et al. 1992) observed a similar relationship, the Teh et al. (2004) study with *P. macrolepidotus* is included. Using prevalence of deformities as the endpoint, the NOEC, LOEC and MATC (chronic value) in *muscle tissue* are 10.1, 15.1 and 12.34 mg Se/kg dw, respectively. The critieron value in muscle tissue, based on the reproductive EC_{10}, is 11.8 mg Se/kg dw. Appendix C provides further details on the study results and an approximate estimate of their relationship to egg-ovary and whole-body concentrations. Teh et al. (2004) is the only study in which deformities developed in fish that were not exposed to selenium from their mothers' ovaries. The selenium criterion values derived based on reproductive endpoints are protective of the endpoint measured in this non-reproductive study, considering the non-reproductive muscle MATC of 12.3 mg Se/kg dw is greater than the reproductive muscle criterion of 11.8 mg Se/kg dw.

1.2.2 Pimephales promelas (fathead minnows)

Non-reproductive chronic values for fathead minnows were derived from two laboratory-based studies. These studies (Bennett et al. 1986 and Dobbs et al. 1996) involved exposing algae to selenium (either as

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sodium selenite or sodium selenate) in water, and subsequently feeding the algae to rotifers which were in turn fed to fathead minnows. In the Bennett et al. (1986) study, larval fathead minnows were fed control rotifers (cultured in chambers without selenium containing algae) or selenium-contaminated rotifers (cultured in chambers with selenium containing algae previously exposed to sodium selenite in the water) in three separate experiments lasting 9 to 30 days. The different experiments were distinguished by 1) the day selenium-laden rotifers were first fed; 2) the day selenium-laden rotifers were last fed; and 3) the age of larvae at experiment termination. The results from the three experiments reported by Bennett et al. (1986) were conflicting. Larval growth was significantly reduced at larval whole-body selenium concentrations of 43.0 mg Se/kg dw in the first experiment and 51.7 mg Se/kg dw in the second experiment, but was slightly but not significantly reduced at 61.1 mg Se/kg dw in the third experiment (see Appendix C). Following the approach of Section 7.1.1, the geometric mean of these three values, 51.40 mg Se/kg dw, is the chronic value for this study.

Dobbs et al. (1996) used a test system similar to that of Bennett et al (1986) (described above). Larval fathead minnows were exposed to the same concentrations of sodium selenate in the water as their prey (rotifers), but also received additional selenium from the consumption of the selenium-contaminated rotifers. In this study, the fathead minnows did not grow well at concentrations exceeding 108.1 µg Se/L in water, and they survived only to 11 days at selenium concentrations equal to or greater than 393.0 µg/L in the water (75 mg Se/kg dw in the diet, i.e., rotifers). The LOEC for retarded growth (larval fish dry weight) in this study was <73 mg Se/kg dw tissue.

A third laboratory study, by Ogle and Knight (1989), examined the chronic effects of elevated foodborne selenium on growth and reproduction of fathead minnows. Juvenile fathead minnows were fed a purified diet mix spiked with inorganic and organic selenium in the following percentages: 25 percent selenate, 50 percent selenite, and 25 percent seleno-L-methionine. The pre-spawning exposure lasted 105 days using progeny of adult fathead minnows originally obtained from the Columbia National Fishery Research Laboratory, as well as those obtained from a commercial fish supplier. After the 105 day exposure period, a single male and female pair from each of the respective treatment replicates were isolated and inspected for spawning activity for 30 days following the first spawning event of that pair. There was no effect from selenium on any of the reproductive parameters measured, including larval survival, at the dietary concentrations tested (5.2 to 29.5 mg Se/kg dw food). Sub-samples of larvae from each brood were maintained for 14 days post-hatch and exhibited >87.4 percent survival. The pre-spawning adult fish fed a mean dietary level of 20.3 mg Se/kg dw exhibited a significant reduction in growth compared to controls (16 percent reduction), whereas a nonsignificant reduction in growth (7 percent) occurred in the fish fed 15.2 mg Se/kg dw. The chronic value, as determined by the geometric mean of the NOEC and the LOEC measured at 98 days post-test initiation, was 17.57 mg Se/kg expressed as the above dietary concentrations, and 5.961 mg Se/kg dw as fathead minnow whole-body tissue. The concentration-response relationship, as indicated by the study data presented in Appendix E, was uniformly shallow; not resembling the sharp sigmoidal function characteristic of most selenium response curves.

Since Ogle and Knight reported that food in the higher selenium concentrations remained uneaten and fish were observed to reject the food containing the higher selenium concentrations, the authors suggested that the decreased growth was caused by a reduced palatability of the seleniferous food items, which contained unnatural percentages of inorganic selenium (Fan et al. 2002). This is a common observation also noted by Hilton and Hodson (1983) and Hilton et al. (1980) and apparent in Coughlan and Velte (1989). It is here interpreted to be an artifact of unrealistic spiking of the diet with inorganic selenium in this early experimental protocol. That is, in the real world it is not expected that avoidance of food items that were unpalatable because of excessive selenium would be either a mechanism by which selenium causes effects or a mechanism by which organisms can avoid exposure. (See Janz et al. (2010) for a more complete discussion of selenium's mechanism of toxicity.) Given the no observed effect on larval

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survival and the apparent non-toxicological effect on growth in the Ogle and Knight study, a chronic value for this study is not included.

1.3 Catostomidae

1.3.1 Xyrauchen texanus (razorback sucker)

Two non-reproductive endpoint studies have been done with the endangered razorback sucker. In the first study, Beyers and Sodergren (2001a) exposed larval razorback suckers for 28 days to a range of aqueous selenate concentrations (6.12, 25.4, 50.6, 98.9, and 190.6 µg/L) and respectively fed them a range of selenium in their diet (rotifers containing <0.702, 1.35, 2.02, 4.63, and 8.24 mg/kg dw). Reflecting the lack of effects on survival and growth in any exposure, the chronic value for this study, based on selenium measured in the larvae at the end of the test, is >12.9 mg Se/kg dw.

In a second study, Beyers and Sodergren (2001b) exposed larval razorback suckers to a control water and three different site waters containing varying concentrations of selenium for 28 days. Two treatments were tested within each water type: fish fed rotifers cultured in the same water type (site diet) and fish fed rotifers cultured in control water. There were no reductions in survival or growth in fish exposed to both the site water and site diet compared to fish exposed to control water and control diet. There were, however, reductions in growth of fish exposed to site water/site food compared to the same site water and control food. The authors did not attribute the effect on larval growth by the diet to selenium and cited several lines of evidence, including: (1) there was not a dose-response relationship in the concentration of selenium in the food (rotifers) and growth, nor in the concentration of selenium in the fish larvae and growth across the three water types; and (2) water from the De Beque site promoted a significant reduction in the growth of fish exposed to site water/site food relative to site water/control food, but contained low levels of selenium in the water (<1 µg/L) and in food (2.10 mg/kg dw) typically lower than those that have been found to elicit effects. The chronic value for this study is >42 mg Se/kg dw based on the whole body concentration of selenium in the larval razorback suckers exposed to North Pond site water.

Two similar studies were conducted in 1996 and 1997 to determine effects of site water and site food, both contaminated with selenium, on the razorback sucker (Hamilton et al. 2001a,b; published later in a peer-reviewed journal in 2005, see Hamilton et al. 2005 a,b,c). Both studies show marked effects of selenium on survival of razorback sucker larvae exposed to contaminated food and to a lesser extent, contaminated water. Although the data convincingly demonstrate effects to larval survival from exposure to contaminated food, interpretation of the results, of chronic criterion derivation is complex because of inconsistencies between: 1) levels of selenium in the food and larvae relative to larval survival; 2) the time to larval mortality relative to selenium in the diet and selenium in the larvae; and 3) levels of other inorganic contaminants in food and water (possible organic contaminants were not measured). Summaries of each of these two studies as well as a third study with razorback suckers (Hamilton et al. 2005d) are presented in Appendix E.

Due to the confounding results, lack of dose-response within and among related studies, and the uncertainty of the effect of other inorganic contaminants on larval response to the various dietary and waterborne treatments, the data from these three studies for razorback sucker (Hamilton et al. 2001a,b; Hamilton et al. 2005d) have not been included. A more detailed explanation of why these studies were not included is given in Appendix E. Because of the vastly different results between the Beyers and Sodergren studies and Hamilton et al. studies and the inability to resolve the differences, SMCV and GMCV were not calculated for the razorback sucker.

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1.3.2 Catostomus latipinnis (flannelmouth sucker)

Beyers and Sodergren (2001a) exposed flannelmouth sucker larvae to a range of aqueous selenate concentrations (<1, 25.4, 50.6, 98.9, and 190.6 µg/L) and fed them a range of selenium in their diet (rotifers containing <0.702, 1.35, 2.02, 4.63, and 8.24 mg/kg dw, respectively). There were no survival or growth effects observed after the 28 day exposure. The chronic value based on the concentration of selenium measured in the larvae exposed to the highest test concentration was >10.2 mg Se/kg dw.

1.4 Salmonidae

1.4.1 Oncorhynchus tshawytscha (Chinook salmon)

Hamilton et al. (1990) conducted a 90-day growth and survival study with swim-up larvae fed one of two different diets. The first diet consisted of Oregon moist™ pellets where over half of the salmon meal was replaced with meal from selenium-laden mosquitofish (*Gambusia affinis*) collected from the San Luis Drain, CA (SLD diet). The second diet was prepared by replacing half the salmon meal in the Oregon moist™ pellets with meal from low-selenium mosquitofish (i.e., the same relatively uncontaminated mosquitofish that were used in the control diet) and spiked with seleno-DL-methionine (SeMe diet). Analysis of the trace element composition in the two different diets indicated that while selenium was the most toxic element in the SLD diet, concentrations of boron, chromium, iron and strontium in the high-selenium mosquitofish replacement diet (SLD diet type) were slightly elevated compared to the replacement diet. These trace elements were, however, only 1.2 (e.g., iron) to 2.0 times (e.g., chromium) higher in the SLD diet than the SeMe diet, which contained the following measured concentrations (dry weight basis) in the food: 10 mg boron/kg, 2.8 mg chromium/kg, 776 mg iron/kg, and 48.9 mg strontium/kg.

During the test, survival of control Chinook salmon larvae (consuming food at approximately 3 mg Se/kg dw) was 99 percent up to 60 days post-test initiation. Between 60 and 90 days of exposure, however, the control survival declined to 66.7% in the SLD test and to 72.5% in the test using the SeMe diet, indicating compromised health. Therefore, only data collected up to 60 days post-test initiation were considered for analysis. Nevertheless, there remains the possibility that even at 60 days, the control organisms were not healthy, although overt signs of stress did not appear until later.

For the SeMe diet, regression analysis of the 60-day growth data yielded a whole-body EC_{10} of 7.355 mg Se/kg dw and an EC_{20} of 10.47 mg Se/kg dw. For the SLD diet, regression analysis of the 60-day growth data yielded a whole-body EC_{10} of 11.14 mg Se/kg dw and an EC_{20} of 15.73 mg Se/kg dw. Note: The San Luis Drain mosquitofish (comprising the Chinook salmon's SLD diet) were not tested for contaminants other than certain key elements. Because the San Luis Drain receives irrigation drainage from the greater San Joaquin Valley, there is a possibility that the SLD diet might have contained elevated levels of pesticides, possibly a confounding factor, although the SLD diet was less toxic than the SeMe diet.

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1.4.2 Oncorhynchus mykiss (rainbow trout)

Hilton and Hodson (1983) reared juvenile rainbow trout on either a high (25 percent) or low (11 percent) available carbohydrate diet supplemented with sodium selenite for 16 weeks. Body weights, feed: gain ratios, and total mortalities were followed throughout the exposure every 28 days. Tissues (livers and kidneys) were extracted for selenium analysis after 16 weeks. By the end of the exposure, fish fed diets (low carbohydrate and high carbohydrate) with the highest selenium concentrations (11.4 and 11.8 mg Se/kg dw food, respectively) exhibited a 45 to 48 percent reduction in body weight (expressed as kg per 100 fish) compared to control fish. The authors attributed such results to food avoidance. With only two dietary exposure concentrations and a control, these data were not amenable to regression analysis. The MATC for growth of juvenile rainbow trout relative to the concentrations of selenium in liver tissue of trout reared on the high carbohydrate seleniferous dietary type is the geometric mean (GM) of 21.00 mg Se/kg dw liver (NOEC) and 71.7 mg Se/kg dw liver (LOEC), or 38.80 mg Se/kg dw liver. The calculated MATC for the same group of experimental fish exposed to selenium in the low carbohydrate diet is 43.5 mg Se/kg dw liver tissue, which is the same MATC for trout exposed for an additional 4 weeks based on the occurrence of nephrocalcinosis in kidneys (see Hicks et al. 1984; Appendix C).

Hilton et al. (1980) employed a similar test design to that of Hilton and Hodson (1983) to examine the narrow window at which selenium changes from an essential nutrient to a toxicant affecting juvenile rainbow trout. The food consisted of a casein-Torula yeast diet supplemented with selenium as sodium selenite. As discussed previously for the Ogle and Knight (1989) study with fathead minnow, this represents an unrealistic fraction of inorganic selenium in the diet. The experiment lasted for 20 weeks. During this time, the trout were fed to satiation 3 to 4 times per day, 6 days per week, with one feeding on the seventh day. Organs (liver and kidney) and carcasses were analyzed for selenium from fish sacrificed at 4 and 16 weeks. No gross histopathological or physiological effects were detected in the fish, although trout raised on the highest dietary level of selenium (13.06 mg Se/kg dw food) had a significantly lower body weight (wet basis), a higher feed:gain ratio, and higher number of mortalities (10.7; expressed as number per 10,000 fish days). The MATC for growth and survival of juvenile rainbow trout relative to the final concentrations of selenium in liver tissue is the geometric mean of the NOEC (40 mg Se/kg dw liver) and the LOEC (100 mg Se/kg dw liver), or 63.25 mg Se/kg dw, both of which hinge on accepting dietary spiking entirely with inorganic selenium as an acceptable experimental protocol.

The non-reproductive GMCV for *Oncorhynchus* (both rainbow trout and Chinook salmon) is 9.052 mg Se/kg dw whole body based on the EC_{10} value derived from the Hamilton et al. (1990) study with Chinook salmon. The NOEC values for the rainbow trout studies conducted by Hilton and Hodson (1983), Hilton et al. (1980), and Hicks et al. (1984) were not used in the GMCV calculation because of the large difference between the NOEC and the LOEC values. If adult fish contained whole-body selenium concentrations equal to 9.052 mg Se/kg dw, their egg-ovary concentrations would be estimated to be 21.5 mg Se/kg dw when translated using the factor 2.37. The criterion values derived based on reproductive endpoints are protective of the endpoint measured.

1.5 Moronidae

1.5.1 Morone saxitilis (striped bass)

A non-reproductive chronic value for selenium was determined from a laboratory dietary exposure conducted using yearling striped bass (Coughlan and Velte 1989). During the experiment, the bass were fed contaminated red shiners (38.6 mg Se/kg dw whole body) from Belews Lake, NC (treated fish) or golden shiners with low levels of selenium (1.3 mg/kg dw whole body) purchased from a commercial supplier (control fish). The test was conducted in soft well water and lasted up to 80 days. During the experiment, all fish were fed to satiation 3 times per day. Control fish grew well and behaved normally.

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Treated fish behaved lethargically, grew poorly due to a significant reduction in appetite, and showed histological damage, all eventually leading to the death of animals. The final selenium concentration in muscle of treated striped bass averaged from 16.2 to 18.5 mg/kg dw tissue (assuming 78.4 percent moisture content), which was 3.4 to 3.6 times higher than the final selenium concentrations in control striped bass, which averaged 5.10 mg/kg dw tissue. The chronic value for this species was determined to be <16.2 mg Se/kg dw in muscle tissue.

1.6 Centrarchidae

1.6.1 Lepomis macrochirus (bluegill)

Bryson et al. (1985b) conducted juvenile survival toxicity tests using hatchery bluegill and various forms of selenium spiked to an artificial diet as well as a diet consisting of zooplankton collected from Hyco Reservoir. There was no effect on length or weight of the juvenile bluegill after 60 days of exposure. The highest concentration of selenium measured in whole body of the juveniles in these tests was in the seleno-DL-cysteine-2X treatment (3.74 mg Se/kg dw).

Cleveland et al. (1993) performed a 90-day diet-only laboratory exposure in which juvenile bluegill were fed a range of selenomethionine concentrations added to Oregon moist™ pellets. The authors observed no significant effects on survival, but did report a very small but apparently statistically significant decrease in the condition factor, K, from 1.3 at four concentrations between 1.0 and 4.7 mg Se/kg dw whole body, to 1.2 at the two concentrations 7.7 and 13.4 mg Se/kg dw whole body. The condition factor (weight x 10^5/length^3) is intended to reflect a fish's reserves. In contrast to the studies of Ogle and Knight (1989), Hilton and Hodson (1983), and Hilton et al. (1989), which appear to have involved an inorganic selenium food palatability problem, this study did not use inorganic selenium in the diet. Nevertheless, given that the reduction in K (1.3 to 1.2) is slight and shows no increasing effect between 7.7 and 13.4 mg Se/kg dw, thus not yielding a sigmoidal concentration-response curve to support an EC_{10} calculation, the chronic value for this study was estimated at >13.4 mg Se/kg dw in whole body tissue.

Data from Lemly (1993a) indicate that over-wintering fish may be more susceptible to the effects of waterborne and dietary selenium due to increased sensitivity at low temperature. The author exposed juvenile bluegill in the laboratory to a single elevated exposure level, waterborne (1:1 selenite:selenate; nominal 5 µg Se/L) and foodborne (seleno-L-methionine in TetraMin; nominal 5 mg Se/kg dw food) selenium for 180 days. Tests with a control and the treated fish were run at 4°C and 20°C with biological and selenium measurements made every 60 days. Survival and whole-body lipid content were unaffected at 20°C (whole-body selenium concentrations equal to 6 mg/kg dw, the sole treatment exposure) when compared to control fish. Thus, at 20°C the chronic value for juvenile bluegill exposed to waterborne and dietary selenium based on survival was >6 mg/kg dw in whole-body tissue. Fish exposed to the combination low-level waterborne and dietary selenium at 4°C exhibited significantly elevated mortality (40.4 percent) relative to controls (2.9 percent), and exhibited significantly greater oxygen consumption and reduced lipid content, which are indicative of stress. At 4°C the chronic value for juvenile bluegill exposed to waterborne and dietary selenium was <7.91 mg Se/kg dw in whole body based on mortality and tissue measurements at the end of the test (180 days), and 5.85 mg Se/kg dw in whole body based on mortality at 180 days and tissue measurements at 60 days. The increase in the concentration of whole-body selenium between Day 60 and 180 at 4°C was apparently due to reductions in body weight caused by loss of lipid (comparatively low in selenium) while body burden in other tissues remained relatively constant. If this concentration of selenium in tissues occurs in sensitive overwintering fish in nature, a concentration of 5.85 mg/kg dw (the selenium tissue concentration in the 4ºC exposure after 60 days) in fish collected during the summer or fall months could be considered a threshold concentration for the selenium-sensitive fish during the winter months. Therefore, this study's chronic value for the threshold concentration prior to winter stress is 5.85 mg Se/kg dw in whole body tissue.

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McIntyre et al. (2008) also investigated the toxicity of selenium to juvenile bluegill under cold temperature conditions in the laboratory. Whereas relative to the control, Lemly (1993a) tested only one exposure level, 5 mg Se/kg in the diet and 5 µg Se/L and one low temperature regime, 4°C, McIntyre et al. (2008) evaluated a range of diet and water concentrations, two types of diet, and two low-temperature regimes. The goal of the study was to determine EC_{10} and EC_{20} values for selenium exposure to juvenile bluegill in 4°C and 9°C low-temperature regimes. Three separate exposure systems were run concurrently for 182 days. Two systems exposed juvenile bluegill to a series of six aqueous and dietary selenium treatments and a control; one exposure system (ES1) with a cold temperature regime (4°C), and one (ES3) with a cool temperature regime (9°C), both using a yeast-worm-fish food chain bioaccumulation system. That is, graded levels of selenized-yeast in ES1 and ES3 were fed to the oligochaete, *Lumbriculus variegatus*, which in turn was fed to bluegill. The third exposure system (ES2) used diet and exposure conditions similar to Lemly's 4°C treatment, i.e., nominal 5 µg Se/L in the water and nominal 5 mg Se/kg dw food (seleno-L-methionine in TetraMin). The cold temperature regime for ES1 and ES2 was 20°C for the first 30 days of exposure, and then decreased 2°C/week until it reached 4°C (test day 79) at which point temperature was maintained until test termination (test day 182). The cool temperature regime (ES3) was similar except when the temperature reached 9°C (test day 65), it was maintained until test termination (test day 182).

At the end of the 182 day exposure in the ES2 (with Lemly's diet and temperature), the bluegill accumulated an average (geometric mean) whole body concentration of 9.99 mg/kg dw with no meaningful mortality in the treatment or control. Significant mortality of juvenile bluegill was observed in the two highest treatments in the cold (ES1) and cool (ES3) *Lumbriculus*-fed tests. No effects on body weight or condition factor were observed. The EC_{10} and EC_{20} values for the cold treatment (ES1) are 9.27 and 9.78 mg Se/kg dw in whole body, respectively. The EC_{10} and EC_{20} values for the cool treatment (ES3) are slightly higher at 14.00 and 14.64 mg Se/kg dw in whole body, respectively.

The design and the results of the McIntyre et al. (2008) study have similarities and differences with Lemly (1993a), as presented in detail with comparisons and contrasts in Appendix C. Both studies found juvenile bluegill were more sensitive in a cold-temperature regime than in a cool (McIntyre et al.) or a warm regime (Lemly). The effect levels determined for the cold temperature regime differed by a factor of 1.58 (ES1 of McIntyre et al., 9.27 mg Se/kg; Lemly, 5.85 mg Se/kg), a difference rather typical of chronic studies conducted in different laboratories using different fish populations (Delos 2001) and similar to the 1.51 factor difference between two EC_{10}s of Hamilton et al. (1990) for chinook salmon.

The difference in the effect levels of the McIntyre ES2 exposure (>9.99 mg/kg) and the Lemly study (5.85 mg/kg) could have been due to the fitness of the fish entering the cold regime. The condition factor, K, in the ES2 selenium-exposed bluegill increased from 3.2 at the start of the exposure to 5.2 at day 60 (approximately 10°C at day 60) and decreased only slightly through over 100 days of 4°C exposure (see figure in bluegill summary in Appendix C). In contrast, K in the Lemly selenium-exposed fish decreased approximately 50% after 120 days of exposure. Shoup and Wahl (2011) conducted an overwinter exposure study with bluegill in which they fed and starved young of year bluegill (the larger size similar to the McIntyre and Lemly fish) under two temperature regimes, 4°C (harsh winter) and 9°C (mild winter) for 140 days and a 10 h light:14 h dark photoperiod. The juvenile bluegill in the Shoup and Wahl study ate in both temperature regimes. The 4°C exposed fish consumed 0.4-0.8% of their body weight/day and their K was not significantly different at the end of the test compared to the start. The Shoup and Wahl results only provide an indication that cold-exposed fish under a winter photoperiod feed and can maintain K.

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The mortality observed in the Lemly laboratory study does not appear to be consistent with field observations. The occurrence of mortality in the field at the concentrations Lemly (1993a) reported to cause mortality in his lab was not observed in the Lemly (1993b) field study of centrarchid deformities in Belews Lake. In that field study, Lemly (1993b) found larval centrarchid deformities at concentrations ranging from 12-80 mg Se/kg dw WB. If juvenile mortality occurred at concentrations lower than those found to induce larval deformities and at concentrations as low as Lemly (1993a) reported in the lab (EC_{40} = 7.91 mg Se/kg WB), then centrarchids would likely not have been present in Belews Lake. The observations of Lemly (1993b) are evidence that larval deformity, not juvenile mortality, is the more sensitive endpoint.

The Crutchfield and Ferson (2000) predictions and field observations of recovery of bluegill at Hyco Reservoir likewise suggest that significant mortality was unlikely to be occurring at the concentrations Lemly (1993a) reported to cause substantial mortality. During a time period over which Crutchfield (2000) indicated dietary invertebrate concentrations exceeded 20 mg Se/kg dw, Crutchfield and Ferson (2000) indicated that bluegill population growth occurred at rates predicted to be natural for the unimpaired species. In contrast, if the Lemly (1993a) lab EC_{40} of 7.91 mg Se/kg dw whole-body were applicable to this field situation, the mortality associated with the resulting bluegill whole-body concentrations (25 mg Se/kg dw whole-body, assuming a trophic transfer factor of 1.27) would have prevented any recovery.

Selenium-induced cold temperature loss of lipid and body condition, a non-reproductive sublethal effect that Lemly (1993a) observed to accompany juvenile mortality in the laboratory (but which McIntyre et al. (2008) did not observe in a similar study) has also not generally been corroborated by field evidence (Janz 2008). Several studies have measured growth and energy storage indicators in juvenile fish just prior to and just after winter at reference sites and sites with elevated selenium in northern Canada (Bennett and Janz 2007a, b; Kelly and Janz 2008; Driedger et al 2009; Weber et al. 2008). The growth (length, weight, condition factor, muscle RNA:DNA ratio, muscle protein) and energy storage (whole body lipids, whole body triglycerides, liver triglycerides, liver glycogen) indicators for five fish species (northern pike, burbot, fathead minnow, creek chub, white sucker) measured just after winter were similar or greater than those measured just before winter at the selenium exposed sites. The slimy sculpin did show a decrease in whole body triglycerides, but the reduction was similar at exposed and reference sites.

Given the uncertainty in the occurrence of winter stress, the results of all four cold-temperature (4°C and 9°C) juvenile-survival lab studies were combined per the standard procedure described in the U.S.EPA Ambient Water Quality Criteria Guidelines, to determine the non-reproductive SMCV for bluegill. The SMCV for the combined 4°C and 9°C tests is 9.33 mg Se/kg dw whole body, based on the four chronic values: (a) the Lemly (1993a) concentration prior to winter stress (5.85 mg Se/kg dw whole body), (b) the McIntyre et al. (2008) ES1 EC_{10} (9.27 mg Se/kg dw whole body), (c) the McIntyre et al. (2008) ES2 NOEC (>9.992 mg Se/kg dw whole body), and the McIntyre et al. (2008) ES3 EC_{10} of 14.00 mg Se/kg dw whole body. This value is not less than the reproductive endpoint-based whole-body criterion concentration of 8.5 mg Se/kg dw. The studies of Bryson et al (1985b) and Cleveland et al. (1993) were not conducted at cold temperatures and were thus not used for these SMCV calculations.

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Table D-1. Freshwater Chronic Values from Acceptable Tests - Non-Reproductive Endpoints (Parental Females Not Exposed).
(Same as Table 6.2 in the main document).

Species	Reference	Exposure route and duration	Selenium form	Toxicological endpoint	Chronic value, mg/kg dw[a]	SMCV mg/kg dw	GMCV mg/kg dw
Acipenser transmontanus white sturgeon	Tashjian et al. 2006	dietary (lab) 8 weeks	seleno-L-methionine in artificial diet seleno-L-methionine in artificial diet	EC_{10} juvenile growth	15.08 WB 27.76 M	EC_{10} 15.1 WB 27.8 M	15.1 WB 27.8 M
				EC_{20} juvenile growth	17.82 WB 32.53 M	EC_{20} 17.8 WB 32.5 M	
Pogonichthys macrolepidotus Sacramento splittail	Teh et al. 2004	dietary (lab) 9 months	selenized-yeast	NOEC	10.1 M	10.1 M 15.1 M 12.3 M	10.1 M 15.1 M 12.3 M
				LOEC	15.1 M		
				MATC juvenile deformities (juvenile exposure only)	12.34 M		
Pimephales promelas fathead minnow	Bennett et al. 1986	dietary (lab) 9 to 19 days	algae exposed to selenite then fed to rotifers which were fed to fish	Chronic value for larval growth	51.40 WB	51.40 WB 69.83 M	51.40 WB 69.83 M
Pimephales promelas fathead minnow	Dobbs et al. 1996	dietary and waterborne (lab) 8 days	algae exposed to selenate in water then fed to rotifers which were fed to fish	LOEC for larval fish dry weight after 8 d	<73 WBb		
Xyrauchen texanus razorback sucker	Beyers and Sodegren 2001a	dietary and waterborne (lab) 28 days	water: selenate; diet: algae exposed to selenate in water then fed to rotifers which were fed to fish	NOEC for survival and growth	>12.9 WBb	see text	see text
Xyrauchen texanus razorback sucker	Beyers and Sodegren 2001b	dietary and waterborne (lab) 28 days	water: site waters; diet: algae exposed to site water then fed to rotifers which were fed to fish	NOEC for survival and growth	>42 WBb		
Catostomus latipinnis flannelmouth sucker	Beyers and Sodegren 2001a	dietary and waterborne (lab) 28 days	water: selenate; diet: algae exposed to selenate in water then fed to rotifers which were fed to fish	NOEC for survival and growth	>10.2 WB	>10.2 WB	>10.2 WB

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Species	Reference	Exposure route and duration	Selenium form	Toxicological endpoint	Chronic value, mg/kg dw[a]	SMCV mg/kg dw	GMCV mg/kg dw
Oncorhynchus tshawytscha chinook salmon	Hamilton et al. 1990	dietary (lab) 60 days	mosquitofish spiked with seleno-DL-methionine	EC_{10} for juvenile growth	7.355 WB	EC_{10} 9.052 WB	EC_{10} 9.052 WB
				EC_{20} for juvenile growth	10.47 WB		
			mosquitofish spiked with SLD diet	EC_{10} for juvenile growth	11.14 WB	EC_{20} 12.83 WB	
				EC_{20} for juvenile growth	15.73 WB		
Oncorhynchus mykiss rainbow trout	Hilton and Hodson 1983; Hicks et al. 1984	dietary (lab) 16 weeks	sodium selenite in food preparation	juvenile growth NOEC	21 Liver	NOAEC 28.98 L	
				LOEC	71.7 Liver		
				MATC	38.80 Liver	LOAEC 84.68 L	
Oncorhynchus mykiss rainbow trout	Hilton et al. 1980	dietary (lab) 20 weeks	sodium selenite in food preparation	juvenile survival and growth NOEC	40 Liver		
				LOEC	100 Liver	MATC 49.52 L	
				MATC	63.25 Liver		
Morone saxitilis striped bass	Coughlan and Velte 1989	dietary (lab) 80 days	Se-laden shiners from Belews Lake, NC	LOEC for survival of yearling bass	<16.2 M[c]	<16.2 M	<16.2 M
Lepomis macrochirus bluegill	Lemly 1993a	dietary and waterborne (lab) 180 days 20 to 4°C	diet: seleno-L-methionine water: 1:1 selenate:selenite	LOEC for juvenile mortality at 4oC	<7.91 WB	4°C EC_{10}-NOAEC 8.15 WB	4°C & 9°C 9.33 WB
				Threshold prior to "winter stress"	5.85 WB		
		dietary and waterborne (lab) 180 days 20°C	diet: seleno-L-methionine water: 1:1 selenate:selenite	NOEC for juvenile mortality at 20oC	>6.0 WB	4°C EC_{20}-LOAEC 8.80 WB	
Lepomis macrochirus bluegill	McIntyre et al. 2008	dietary and waterborne (lab) 182 days 20 to 4°C (ES1)	diet: Lumbriculus fed selenized-yeast water: 1:1 selenate:selenite	EC_{10} juv. survival ES1	9.27 WB	9°C EC_{10} 14.0 WB	
				EC_{20} juv. survival ES1	9.78 WB		
		dietary and waterborne (lab) 182 days 20 to 9°C (ES3)	diet: Lumbriculus fed selenized-yeast water: 1:1 selenate:selenite	EC_{10} juv. survival ES3	14.00 WB	9°C EC_{20} 14.6 WB	
				EC_{20} juv. survival ES3	14.64 WB		

Species	Reference	Exposure route and duration	Selenium form	Toxicological endpoint	Chronic value, mg/kg dw[a]	SMCV mg/kg dw	GMCV mg/kg dw
		dietary and waterborne (lab) 182 days 20 to 4°C (ES2)	diet: seleno-L-methionine water: 1:1 selenate:selenite	NOEC juv. surv. ES2	>9.992 WB		
Lepomis macrochirus bluegill	Bryson et al. 1985b	dietary (lab) 60 days	seleno-DL-cysteine	NOEC for juvenile growth	>3.74 WBb		
Lepomis macrochirus bluegill	Cleveland et al. 1993	dietary (lab) 90 days	seleno-L-methionine	NOEC for juvenile survival	>13.4 WBb		

[a] All chronic values reported in this table are based on the measured concentration of selenium in whole body (WB), muscle (M) or liver (L) tissues.

[b] Chronic value not used in SMCV calculation (see text).

[c] Tissue value converted from ww to dw. See Appendix C for conversion.

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APPENDIX E: OTHER DATA

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1.0 SELENITE

Additional data on the lethal and sublethal effects of selenium on aquatic species are presented in Table E-1. Bringmann and Kuhn (1959a,b, 1976, 1977a, 1979, 1980b, 1981), Jakubczak et al. (1981), and Patrick et al. (1975) reported the concentrations of selenite that caused incipient inhibition (defined variously, such as the concentration resulting in a 3% reduction in growth) for algae, bacteria, and protozoans (Table E-1). Although incipient inhibition might be statistically significant, its ecological importance is unknown. Albertano and Pinto (1986) found the growth of three red algal species was inhibited at selenite concentrations that ranged from 790 to 3,958 μg/L.

2.0 SELENATE

Dunbar et al. (1983) exposed fed *D. magna* to selenate for seven days and obtained an LC_{50} of 1,870 μg/L. This value is in the range of the 48-hr EC_{50}s in Table E-1.

Watenpaugh and Beitinger (1985a) found that fathead minnows did not avoid 11,200 μg/L selenate during 30-minute exposures (Table E-1). These authors also reported (1985b) a 24-hr LC_{50} of 82,000 μg/L for the same species and they found (1985c) that the thermal tolerance of the species was reduced by 22,200 μg/L. Westerman and Birge (1978) exposed channel catfish embryos and newly hatched fry for 8.5 to 9 days to an unspecified concentration of selenate. Albinism was observed in 12.1 to 36.9% of the fry during the five years of such exposures. Pyron and Beitinger (1989) also investigated fathead minnows, and after a 24-hr exposure, no effect on reproductive behavior was found at 36,000 μg/L, but when adults were exposed to 20,000 μg/L selenate for 24-hr, edema was observed for their larvae.

The respiratory rate of the eastern oyster, *Crassostrea virginica*, was unaffected by exposure to selenate at 400 μg/L for 14 days (Fowler et al. 1981). Embryos of the striped bass were quite tolerant to selenate in dilute salt water (Klauda 1985a, b). There was a 93% successful hatch of embryos at 200,000 μg/L, but 50% of 72-day-old juveniles died after four days at 87,000 μg/L. Exposure of juvenile fish for up to 65 days to concentrations of selenate between 39 and 1,360 μg/L caused developmental anomalies and pathological lesions.

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Table E-1. Other Data on Effects of Selenium on Aquatic Organisms

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
FRESHWATER SPECIES						
Selenium (IV)						
Green alga, *Scenedesmus quadricauda*	Sodium selenite	-	96 hr	Incipient inhibition (river water)	2,500	Bringmann and Kuhn 1959a,b
Green alga, *Selenastrum capricornutum*	Sodium selenite	-	72 hr	Decreased dry weight and chlorophyll a	75	Foe and Knight, Manuscript
Green alga, *Selenastrum capricornutum*	Sodium selenite	-	72 hr	BCF = 12-21[b]	10-100	Foe and Knight, Manuscript
Green alga, *Selenastrum capricornutum*	Sodium selenite	-	72 hr	BCF = 11,164[c]	150	Foe and Knight, Manuscript
Alga, *Chrysochromulina breviturrita*	Selenious acid	-	30 days	Increased growth	320	Wehr and Brown 1985
Red alga, *Cyanidium caldarium*	Selenious acid	-	20 days	Inhibited growth	3,958	Albertano and Pinto 1986
Red alga, *Cyanidioschyzon merolae*	Seleniousacid	-	20 days	Inhibited growth	3,140	Albertano and Pinto 1986
Red alga, *Galdieria sulphuraria*	Seleniousacid	-	20 days	Inhibited growth	790	Albertano and Pinto 1986
Algae (diatoms), Mixed population	Sodium selenite	-	18 days	Inhibited growth	11,000	Patrick et al. 1975
Bacterium, *Escherichia coli*	Sodium selenite	-	-	Incipient inhibition	90,000	Bringmann and Kuhn 1959a
Bacterium, *Pseudomonus putida*	Sodium selenite	-	16 hr	Incipient inhibition	11,400 (11,200)	Bringmann and Kuhn 1976; 1977a; 1979; 1980b
Protozoan, *Entosiphon sulcatum*	Sodium selenite	-	72 hr	Incipient inhibition	1.8 (1.9)	Bringmann 1978; Bringmann and Kuhn 1979; 1980b; 1981
Protozoan, *Microreqma heterostoma*	Sodium selenite	-	28 hr	Incipient inhibition	183,000	Bringmann and Kuhn 1959b
Protozoan, *Chilomonas paramecium*	Sodium selenite	-	48 hr	Incipient inhibition	62	Bringmann and Kuhn 1981; Bringmann et al. 1980

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Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
Protozoan, *Uronema parduezi*	Sodium selenite	-	20 hr	Incipient inhibition	118	Bringmann and Kuhn 1980a; 1981
Snail, *Lymnaea stagnalis*	Sodium selenite	-	7.5 days	LT50	3,000	Van Puymbroeck et al. 1982
Cladoceran, *Daphnia magna*	Sodium selenite	-	48 hr	EC50 (river water)	2,500	Bringmann and Kuhn 1959a,b
Cladoceran, *Daphnia magna*	Sodium selenite	214	24 hr	LC50	16,000	Bringmann and Kuhn 1977a
Cladoceran, *Daphnia magna*	Sodium selenite	214	24 hr	EC50 (swimming)	9.9	Bringmann and Kuhn 1977b
Cladoceran, *Daphnia magna*	Sodium selenite	329	48 hr 96 hr 14 days	EC50 (fed)	710 430 430	Halter et al. 1980
Cladoceran (<24 hr), *Daphnia magna*	Sodium selenite	-	48 hr 21 days	EC50 (fed)	685 160	Adams and Heidolph 1985
Cladoceran (5th instar), *Daphnia magna*	Sodium selenite	-	48 hr	LC50 (fed)	680	Johnston 1987
Cladoceran, *Daphnia magna*	Selenious acid	220[d]	48 hr	LC50 (fed)	1,200	Kimball, Manuscript
Cladoceran (preadult), *Daphnia pulex*	Sodium selenite	42	24 hr	Did not reduce oxygen consumption or filtering rate	>498	Reading and Buikema 1980
Ostracod, *Cyclocypris* sp.	Sodium selenite	100.8	48 hr	LC50	130,000	Owsley 1984
Amphipod, *Hyalella azteca*	Sodium selenite	329	14 days	LC50 (fed)	70	Halter et al. 1980
Amphipod (2 mm length), *Hyalella azteca*	Sodium selenite	133	48 hr	LC50	623	Brasher and Ogle 1993
Amphipod (2 mm length), *Hyalella azteca*	Sodiumselenite	133	10 days	LC50 (fed)	312	Brasher and Ogle 1993
Amphipod (2 mm length), *Hyalella azteca*	Sodium selenite	133	24 days	LOEC reproduction (static-renewal)	200	Brasher and Ogle 1993
Midge (first instar), *Chironomus riparius*	Sodium selenite	134	48 h	LC50	7,950	Ingersoll et al. 1990
Midge (first instar), *Chironomus riparius*	Sodium selenite	40-48	48 h	LC50	14,600	Ingersoll et al. 1990
Coho salmon (fry), *Oncorhynchus kisutch*	Sodium selenite	325	43 days	LC50	160	Adams 1976
Rainbow trout (fry), *Oncorhynchus mykiss*	Sodium selenite	334	21 days	LC50	460	Adams 1976

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Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
Rainbow trout (fry), *Oncorhynchus mykiss*	Sodium selenite	334	21 days	Reduced growth	250	Adams 1976
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	330	5 days	LC50	2,700 2,750	Adams 1976
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	325	48 days	LC50	500	Adams 1976
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	325	96 days	LC50	280	Adams 1976
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Sodium selenite	-	4 wk	MATC survival	200	Gissel-Nielsen and Gissel-Nielsen 1978
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Sodium selenite	-	4 wk	MATC survival	4.7 µg/g dw (whole-body)	Gissel-Nielsen and Gissel-Nielsen 1978
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Sodium selenite	-	4 wk	BCF = 23	100	Gissel-Nielsen and Gissel-Nielsen 1978
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Sodium selenite	-	42 wk	MATC growth (dietary only exposure)	>9.96 µg Se/g dw (food)	Goettl and Davies 1978
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Sodium selenite	-	42 wk	MATC survival (dietary only exposure)	5.34 µg Se/g dw (food)	Goettl and Davies 1978
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	135	9 days	LC50	7,020	Hodson et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	135	96 hr 9 days	LC50 (fed)	7,200 5,410	Hodson et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	135	96 hr 9 days	LC50 (fed)	8,200 6,920	Hodson et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	135	41 days	LOAEC (Reduced hatch of eyed embryos)	26	Hodson et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	135	50 wk	Decreased iron in blood and red cell volume	53	Hodson et al. 1980
Rainbow trout (fertilized egg), *Oncorhynchus mykiss*	Sodium selenite	135	44 wk	BCF = 33.2 BCF = 21.1	53	Hodson et al. 1980
Rainbow trout (embryo), *Oncorhynchus mykiss*	Sodium selenite	-	120 hr	Did not reduce survival or time to hatch	10,000	Klaverkamp et al. 1983b

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Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	-	90 days	Chronic value for survival	14	Mayer et al. 1986
Rainbow trout (sac fry), *Oncorhynchus mykiss*	Sodium selenite	272	90 days	LC50	55.2[e]	Hunn et al. 1987
Rainbow trout (sac fry), *Oncorhynchus mykiss*	Sodium selenite	272	90 days	MATC survival	31.48	Hunn et al. 1987
Rainbow trout (egg), *Oncorhynchus mykiss*	Sodium selenite	-	96 hr	BCF = 17.5 BCF = 3.5	0.4 45.6	Hodson et al. 1986
Rainbow trout (embryo), *Oncorhynchus mykiss*	Sodium selenite	-	96 hr	BCF = 3.1 BCF = 3.0	0.4 45.6	Hodson et al. 1986
Rainbow trout (sac-fry), *Oncorhynchus mykiss*	Sodium selenite	-	96 hr	BCF = 13.1 BCF = 1.6	0.4 45.6	Hodson et al. 1986
Rainbow trout (swim-up fry) *Oncorhynchus mykiss*	Sodium selenite	-	96 hr	BCF = 80.3 BCF = 20.2	0.4 45.6	Hodson et al. 1986
Northern pike, *Esox lucius*	Sodium selenite	10.2	76 hr	LC50	11,100	Klaverkamp et al. 1983a
Goldfish, *Carassius auratus*	Selenium dioxide	157	14 days	LC50	6,300	Cardwell et al. 1976a,b
Goldfish, *Carassius auratus*	Sodium selenite	-	10 days	Mortality	5,000	Ellis 1937; Ellis et al. 1937
Goldfish, *Carassius auratus*	Sodium selenite	-	46 days	Gradual anorexia and mortality	2,000	Ellis et al. 1937
Goldfish, *Carassius auratus*	Selenium dioxide	-	7 days	LC50	12,000	Weir and Hine 1970
Goldfish, *Carassius auratus*	Selenium dioxide	-	48 hr	Conditional avoidance	250	Weir and Hine 1970
Fathead minnow, *Pimephales promelas*	Selenium dioxide	157	9 days	LC50	2,100	Cardwell et al. 1976a,b
Fathead minnow, *Pimephales promelas*	Sodium selenite	329	96 hr	LC50 (fed)	1,000	Halter et al. 1980
Fathead minnow, *Pimephales promelas*	Sodium selenite	329	14 days	LC50 (fed)	600	Halter et al. 1980
Fathead minnow, *Pimephales promelas*	Selenious acid	220[d]	8 days	LC50 (fed)	420	Kimball, Manuscript
Creek chub, *Semotilus atromaculatus*	Selenium dioxide	-	48 hr	Mortality	∃12,000	Kim et al. 1977
Bluegill, *Lepomis macrochirus*	Sodium selenite	318	48 days	LC50	400	Adams 1976
Bluegill, *Lepomis macrochirus*	Selenium dioxide	157	14 days	LC50	12,500	Cardwell et al. 1976a,b

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
Bluegill (juvenile), *Lepomis macrochirus*	Sodium selenite	16	323 days	MATC larval survival (dietary only exposure)	19.75 µg Se/g dw (food)	Woock et al. 1987
Bluegill (juvenile), *Lepomis macrochirus*	Sodium selenite	25 and 200	120 days	No mortality	>10	Lemly 1982
Largemouth bass (juvenile), *Micropterus salmoides*	Sodium selenite	25 and 200	120 days	No mortality	10	Lemly 1982
Yellow perch, *Perca flavescens*	Sodium selenite	10.2	10 days	LC50	4,800	Klaverkamp et al. 1983a,b
African clawed frog, *Xenopus laevis*	Sodium selenite	-	7 days	LC50	1,520	Browne and Dumont 1980
African clawed frog, *Xenopus laevis*	Sodium selenite	-	1-7 days	Cellular damage	2,000	Browne and Dumont 1980
Selenium (VI)						
Alga, *Chrysochromulina breviturrita*	-	-	30 days	Increased growth	50	Wehr and Brown 1985
Rotifer, *Brachionus calyciflorus*	Sodium selenate	120	96 hr	EC20 Growth (dry weight)	42.36 (µg/g dw)	Dobbs et al. 1996
Snail, *Lymnaea stagnalis*	Sodium selenate	-	6 days	LT50	15,000	Van Puymbroeck et al. 1982
Cladoceran, *Daphnia magna*	Sodium selenate	129.5	7 days	LC50 (fed)	1,870	Dunbar et al. 1983
Cladoceran (juvenile), *Daphnia magna*	Sodium selenate	-	48 hr	LC50 (fed)	550	Johnston 1987
Cladoceran (5th instar), *Daphnia magna*	Sodium selenate	-	48 hr	LC50 (fed)	750	Johnston 1987
Cladoceran (5th instar), *Daphnia magna*	Sodium selenate	-	90 hr	42% of organisms had visible changes in gut morphology	250	Johnston 1989
Amphipod (2 mm length), *Hyalella azteca*	Sodium selenate	133	48 hr	LC50	2378	Brasher and Ogle 1993
Amphipod (2 mm length), *Hyalella azteca*	Sodium selenate	133	10 days	LC50 (fed)	627	Brasher and Ogle 1993
Amphipod (2 mm length), *Hyalella azteca*	Sodium selenate	133	24 days	LOEC reproduction (static renewal)	>700	Brasher and Ogle 1993

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Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
Amphipod (1-11 days old), *Hyalella azteca*	Sodium selenate	18 (SO_4=3.4)	10 days	LC50 (fed)	43	Borgmann et al. 2005
Amphipod (1-11 days old), *Hyalella azteca*	Sodium selenate	124 (SO_4=32)	10 days	LC50 (fed)	371	Borgmann et al. 2005
Midge (first instar), *Chironomus riparius*	Sodium selenate	134	48 h	LC50	16,200	Ingersoll et al. 1990
Midge (first instar), *Chironomus riparius*	Sodium selenate	40-48	48 h	LC50	10,500	Ingersoll et al. 1990
Rainbow trout (embryo, larva), *Oncorhynchus mykiss*	Sodium selenate	104 (92-110)	28 days	EC50 (death and deformity)	5,000 (4,180) (5,170)	Birge 1978; Birge and Black 1977; Birge et al. 1980
Goldfish (embryo, larva), *Carrassius auratus*	Sodium selenate	195	7 days	EC50 (death and deformity)	8,780	Birge 1978
Goldfish, *Carassius auratus*	Sodium selenate	-	24 hr	BCF = 1.42 BCF = 1.15 BCF = 1.47 BCF = 0.88 BCF = 1.54	0.45 0.9 1.35 2.25 4.5	Sharma and Davis 1980
Fathead minnow, *Pimephales promelas*	Sodium selenate	337.9	48 days	LC50	2,000	Adams 1976
Fathead minnow, *Pimephales promelas*	Sodium selenate	338	48 days	LC50	1,100	Adams 1976
Fathead minnow, *Pimephales promelas*	-	51	30 min	No avoidance	11,200	Watenpaugh and Beitinger 1985a
Fathead minnow, *Pimephales promelas*	-	-	24 hr	LC50	82,000	Watenpaugh and Beitinger 1985b
Fathead minnow, *Pimephales promelas*	-	-	24 hr	Reduced thermal tolerance	22,200	Watenpaugh and Beitinger 1985c
Fathead minnow, *Pimephales promelas*	Sodium selenate	44-49	7 days	Chronic value - growth Chronic value-growth Chronic value-survival	1,739 561 2,000	Norberg-King 1989
Fathead minnow, *Pimephales promelas*	Sodium selenate	160-180	24 hr	No effect on reproductive behavior	36,000	Pyron and Beitinger 1989
Fathead minnow, *Pimephales promelas*	Sodium selenate	160-180	24 hr	Edema in larvae produced from adults exposed to Selenium VI	20,000	Pyron and Beitinger 1989

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Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
Channel catfish (embryo, fry), *Ictalurus punctatus*	Sodium selenate	90	8.5-9 days	Induced albinism	-	Westerman and Birge 1978
Narrow-mouthed toad (embryo, larva), *Gastrophryne carolinensis*	Sodium selenate	195	7 days	EC50 (death and deformity)	90	Birge 1978; Birge and Black 1977; Birge et al. 1979a
Organo-selenium						
Bluegill (juvenile), *Lepomis macrochirus*	Seleno-L-methionine	16	323 days	MATC larval survival (dietary only exposure)	20.83 µg Se/g dw (food)	Woock et al. 1987
Bluegill (juvenile), *Lepomis macrochirus*	Seleno-L-methionine	283	90 days	EC20 survival (dietary only exposure)	>13.4 µg/g dw (food)	Cleveland et al. 1993
Bluegill (2 yr and adult), *Lepomis macrochirus*	Selenium	-	field	NOEC deformities	53.83 µg Se/g dw (liver)	Reash et al. 1999
Bluegill (2 yr and adult), *Lepomis macrochirus*	Selenium	-	field	NOEC deformities	23.38 µg Se/g dw (ovaries)	Reash et al. 1999
Redear sunfish (adult), *Lepomis microlophus*	Selenium	-	field	LOEC Adverse histopathological alterations	<38.15 µg Se/g dw	Sorensen 1988
Selenium Mixtures						
Phytoplankton, Mixed population	Selenium	-	field	Reduced growth rates	18	Riedel et al. 1991
Cladoceran (<24 hr), *Daphnia magna*	Selenite-Selenate mixture	138	21 days	MATC growth	115.2 µg Se/L	Ingersoll et al. 1990
Cladoceran (<24 hr), *Daphnia magna*	Selenite-Selenate mixture	138	21 days	MATC productivity	21.59 µg/g dw (whole-body)	Ingersoll et al. 1990
Midge (<24-hr), *Chironomus riparius*	Selenite-Selenate mixture	138	30 days	MATC emergence	503.6	Ingersoll et al. 1990
Bluegill (juvenile), *Lepomis macrochirus*	Selenite-Selenate mixture	283	60 days	NOEC survival	340	Cleveland et al. 1993
Bluegill (juvenile), *Lepomis macrochirus*	Selenite-Selenate mixture	283	60 days	EC20 survival	4.07 µg/g dw (whole body)	Cleveland et al. 1993

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Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[a]	Reference
SALTWATER SPECIES						
Selenium (IV)						
Anaerobic bacterium, *Methanococcus vannielli*	Sodium selenite	-	110 hr	Stimulated growth	79.01	Jones and Stadtman 1977
Bacterium, *Vibrio fisheri*	Sodium selenite	-	5 min	50% decrease in light output (Microtox7)	68,420	Yu et al. 1997
Green alga, *Chlorella* sp.	Sodium selenite	32	14 days	5-12% increase in growth	10-10,000	Wheeler et al. 1982
Green alga, *Platymonas subcordiformis*	Sodium selenite	32	14 days	23% increase in growth	100-10,000	Wheeler et al. 1982
Green alga, *Dunaliella primolecta*	Sodium selenite	32	20 days	Increased growth; induced glutathione peroxidase	4,600	Gennity et al. 1985a,b
Diatom, *Skeletonema costatum*	Selenium dioxide	-	5 days	BCF = 18,000 BCF = 16,000 BCF = 10,000	0.06 0.79 3.6	Zhang et al. 1990
Diatom, *Chaetoceros muelleri*	Selenium dioxide	-	6 days	BCF = 337,000 BCF = 65,000 BCF = 5,000	0.06 0.79 3.6	Zhang et al. 1990
Diatom, *Phaeodactylum tricornutum*	Selenium dioxide	-	8 days	BCF = 109,000 BCF = 27,000 BCF = 7,000	0.06 0.79 3.6	Zhang et al. 1990
Diatom, *Thallassiosira aestivalis*	Selenium oxide	29-30	72 hr	No effect on cell morphology	78.96	Thomas et al. 1980a
Brown alga, *Fucus spiralis*	Sodium selenite	-	60 days	1355% increase in growth of thalli	2.605	Fries 1982
Red alga, *Porphyridium cruentum*	Sodium selenite	32	27 days	Increase growth; induced glutathione peroxidase	4,600	Gennity et al. 1985a,b

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Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[a]	Reference
Selenium (VI)						
Bacterium, *Vibrio fisheri*	Sodium selenate	-	15 min	50% decrease in light output (Microtox7)	3,129,288	Yu et al. 1997
Green alga, *Chlorella* sp.	Sodium selenate	32	14 days	No effect on rate of cell	10-1,000	Wheeler et al. 1982
Green alga, *Chlorella* sp.	Sodium selenate	32	4-5 days	100% mortality	10,000	Wheeler et al. 1982
Green alga, *Dunaliella primolecta*	Sodium selenate	32	14 days	No effect on rate of cell population growth	10-100	Wheeler et al. 1982
Green alga, *Dunaliella primolecta*	Sodium selenate	32	14 days	71% reduction in rate of cell population growth	1,000	Wheeler et al. 1982
Green alga, *Dunaliella primolecta*	Sodium selenate	32	4-5 days	100% mortality	10,000	Wheeler et al. 1982
Green alga, *Platymonas subcordiformis*	Sodium selenate	32	14 days	No effect on rate of cell population growth	10	Wheeler et al. 1982
Green alga, *Platymonas subcordiformis*	Sodium selenate	32	14 days	16% decrease in rate of cell population growth	100	Wheeler et al. 1982
Green alga, *Platymonas subcordiformis*	Sodium selenate	32	14 days	50% decrease in rate of cell population growth	1,000	Wheeler et al. 1982
Green alga, *Platymonas subcordiformis*	Sodium selenate	32	4-5 days	100% mortality	10,000	Wheeler et al. 1982
Brown alga, *Fucus spiralis*	Sodium selenate	-	60 days	160% increase in growth rate of thalli	2.605	Fries 1982
Red alga, *Porphridium cruentum*	Sodium selenate	32	14 days	23-35% reduction in rate of cell population growth	10-1,000	Wheeler et al. 1982
Red alga, *Porphyridium cruentum*	Sodium selenate	32	4-5 days	100% mortality	10,000	Wheeler et al. 1982

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Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[a]	Reference
Eastern oyster (adult), *Crassostrea virginica*	Sodium selenate	34	14 days	No significant effect on respiration rate of gill tissue	400	Fowler et al. 1981
Striped bass (embryo), *Morone saxatilis*	Sodium selenate	7.2-7.5	4 days	93% successful hatch and survive	200,000	Klauda 1985a,b
Striped bass (larva), *Morone saxatilis*	Sodium selenate	4.0-5.0	4 days	LC50 (control survival= 77%)	13,020	Klauda 1985a,b
Striped bass (juvenile), *Morone saxatilis*	Sodium selenate	3.5-5.5	9-65 days	Significant incidence of development anomalies of lower jaw	39-1,360	Klauda 1985a,b
Striped bass (juvenile), *Morone saxatilis*	Sodium selenate	3.5-5.5	45 days	Significant incidence of severe blood cytopathology	1,290	Klauda 1985a,b

[a] Concentration of selenium, not the chemical. Units are µg selenium/L of water unless noted otherwise.
[b] Converted from dry weight to wet weight basis (see Guidelines).
[c] Growth of algae was inhibited.
[d] From Smith et al. (1976).
[e] Calculated from the published data using probit analysis and allowing for 8.9% spontaneous mortality.

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3.0 OTHER DATA - ENDANGERED SPECIES

Two similar studies were conducted in 1996 and 1997 to determine effects of site water and site food, both contaminated with selenium, on the endangered species, razorback sucker, *Xyrauchen texanus* (Hamilton et al. 2001a,b; published later in a peer-reviewed journal in 2005, see Hamilton et al. 2005 a,b,c). Both studies show marked effects of selenium on survival of razorback sucker larvae exposed to contaminated food and to a lesser extent, contaminated water. Although the data convincingly demonstrate effects to larval survival from exposure to contaminated food, interpretation of the results in the context of chronic criterion derivation is complex because of inconsistencies between: 1) levels of selenium in the food and larvae relative to larval survival; 2) the time to larval mortality relative to selenium in the diet and selenium in the larvae; and 3) levels of other inorganic contaminants in food and water (possible organic contaminants were not measured). A summary of each of these two studies is presented below.

Evaluation of Contaminant Impacts on Razorback Sucker held in Flooded Bottomland Sites Near Grand Junction , Colorado - 1996 (Hamilton et al. 2001a; also Hamilton et al. 2005 a,b,c)

This study was initiated with 5-day old razorback sucker larvae spawned from adults (first time spawners) which were previously held (9 months) in three different locations along the Colorado River that contained varying levels of selenium: Horsethief (the designated reference site which receives water pumped directly from the Colorado River near Fruita, CO, and where dissolved selenium concentrations in water ranged from <1.6 to 3.9 µg/L during the period of exposure), Adobe Creek (low level selenium contamination - dissolved selenium concentrations in water ranged from 1.5 to 11.6 µg/L; avg. = 3.8 µg/L), and North Pond (high level selenium contamination - dissolved selenium concentrations in water ranged from 3.8 to 19.6 µg/L; avg. = 9.5 µg/L). The selenium content in eggs from three Horsethief females ranged from 5.8 to 6.6 mg Se/kg dw, and the selenium content in adult muscle plugs at spawning was from 3.4 to 5.0 mg Se/kg dw. The selenium content in the eggs from three Adobe Creek females ranged from 38.0 to 54.5 mg Se/kg dw, and the selenium content in adult muscle plugs at spawning was from 11.5 to 12.9 mg Se/kg dw. The selenium content in the eggs from three North Pond females ranged from 34.3 to 37.2 mg Se/kg dw, and the selenium content in adult muscle plugs at spawning was from 14.1 to 17.3 mg Se/kg dw. The selenium content in eggs from one of three hatchery brood stock females was 7.1 mg Se/kg dw, and the selenium content in muscle plugs of two of three hatchery brood stock females at spawning ranged from 2.6 to 13.8 mg Se/kg dw. The razorback sucker larvae spawned from fish hatchery brood stock (older, previously spawned females) and held in Colorado River (Horsethief) water were used as an additional reference group of test fish.

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The experimental groups were subdivided into those receiving reference water (hatchery water; 24-Road Fish Hatchery) or site water (Table E-2). They were further subdivided into those receiving a daily ration of reference food (brine shrimp) or zooplankton (predominantly cladocerans and copepods) collected from each site where their parents were exposed for the previous 9 months. A total of 60 larvae from each of the four adult sources (Horsethief, Adobe Creek, North Pond, Brood Stock held in different ponds at Horsethief) were exposed to each treatment (2 replicates x 3 spawns x 10 fish/beaker). The larvae were held in beakers containing 800 ml of test water. Fifty percent of the test water was renewed daily.

Table E-2. Treatment conditions during the 30-day larval study.

Source of Larvae	Treatments	Se in food (mg/kg dw)	Dissolved Se in water (µg/L)
Horsethief Adults	Reference food: Reference water	2.7	< 1.6
	Reference food: Site water	2.7	0.9
	Site food: Reference water	5.6	< 1.6
	Site food: Site water	5.6	0.9
Adobe Creek Adults	Reference food: Reference water	2.7	< 1.6
	Reference food: Site water	2.7	5.5
	Site food: Reference water	20	< 1.6
	Site food: Site water	20	5.5
North Pond Adults	Reference food: Reference water	2.7	< 1.6
	Reference food: Site water	2.7	10.7
	Site food: Reference water	39	<1.6
	Site food: Site water	39	10.7
Hatchery raised Adults	Reference food: Reference water	2.7	< 1.6
	Reference food: Site water	2.7	0.9
	Site food: Reference water	5.6	< 1.6
	Site food: Site water	5.6	0.9

Growth, survival and development were evaluated amongst treatment groups for up to 30 days in the treatment conditions. Each treatment group was fed once daily after renewal. Test waters were collected every day from each site as grab samples for the renewal. A small portion of this water was retained at 3- and 7-day intervals for an analysis of total and dissolved selenium concentrations. At approximately 2-day intervals, aquatic invertebrates and brine shrimp not used for feeding were sieved from the media for selenium analysis. The number of live fish was recorded daily. After the 30-day exposure period, the surviving fish were sacrificed and measured for total length. At this same time,

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approximately four fish from each treatment, when available, were collected as a composite sample and analyzed for total selenium.

After 30 days of exposure in the reference food-reference water treatment, survival of razorback sucker larvae from brood stock and Horsethief adults (89 and 87 percent, respectively) was slightly higher than those from Adobe Creek adults (84 percent) and North Pond adults (75 percent). Corresponding selenium concentrations in larval whole-body tissue were 3.6, 3.3, 7.7 and 9.7 mg Se/kg dw, respectively. Survival was similar or slightly reduced in larvae from all four sources after 30 days of exposure in the reference food-site water treatments; corresponding selenium concentrations in larval whole-body tissue were 5.2, 5.1, 12.7 and 15.2 mg Se/kg dw, respectively. In contrast, none of the larvae spawned from parents from Horsethief, Adobe Creek, or North Pond survived to 30 days when fed zooplankton collected from the three sites, irrespective of the water type they were exposed to (i.e., reference or site). Only the larvae from brood stock adults, which were fed zooplankton from the Horsethief site for this treatment, survived, and even these larvae suffered substantial mortality (40 and 60 percent respectively). The mean selenium concentrations in whole-body tissue of larvae from brood stock adults after the 30-day exposures were 5.4 mg Se/kg dw (site food-reference water treatment) and 6.9 mg Se/kg dw (site food-site water treatment).

Several inconsistencies were observed that indicate selenium may not be solely responsible for the effect on larval survival. Larval survival in the Adobe Creek treatment group exposed to reference water (<1.6 µg/L) and reference food (2.7 mg Se/kg dw) was 84 percent, similar to survival of larvae from brood stock (89 percent). The selenium concentration in the larvae from this Adobe Creek treatment group after 30 days was higher (7.7 mg/kg dw) than that of the brood stock fish (5.4 mg Se/kg dw) in the reference water (<1.6 µg/L) and site food (5.6 mg Se/kg dw) treatment, which had a 30-day survival of 62 percent. Also, the time to 50 percent mortality between the site food treatments, where most mortality occurred, was not related to selenium concentration in the diet or in the larvae.

Although the larvae from brood stock held at Horsethief and the larvae from the first-time spawning adults held at Horsethief that were used for the 9 month exposure received the same site food, no larvae from the latter group survived the 30 day exposure. Concentrations of selenium in the larvae of these two treatment groups were essentially the same between days 6 and 12 of the exposure (8.1 to 8.9 mg Se/kg dw). During this same general time frame (6 to 7 days of exposure), larvae from Adobe Creek and North Pond adults apparently tolerated up to 32 and 39 mg Se/kg dw in tissue, respectively, without any increase in mortality when exposed to reference food and reference water. Larvae grown out under hatchery conditions from adults in the Horsethief and Adobe Creek treatments also did not differ in total deformities compared to larvae from brood stock. There was also no difference between treatments (brood stock, Horsethief, Adobe Creek, and North pond) in percent egg viability, percent hatchability,

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percent embryos with deformities, and percent mortality of deformed embryos and larvae from a separate test initiated with eggs in the same study (Hamilton et al. 2005b).

Evaluation of Contaminant Impacts on Razorback Sucker held in Flooded Bottomland Sites Near Grand Junction , Colorado - 1997 (Hamilton et al. 2001b)

In a similar 30-day larval study conducted by the authors in the following year (1997), razorback sucker larvae from a single hatchery brood stock female (11 mg Se/kg dw muscle) were subjected to the sixteen different combined water and dietary exposure conditions described in the earlier (1996) study. The female parent was held at Horsethief Canyon State Wildlife Area before spawning. The larvae were held in beakers containing 800 ml of test water as before; fifty percent of the test water was renewed daily. Specific treatment conditions for the 1997 30-day larval study are listed in Table E-3.

Table E-3. Treatment conditions during the 30-day larval study.

Water Treatments	Se in food (mg/kg dw)	Se in water (µg/L)
Reference food (brine shrimp): Reference water (24-Road Hatchery)	3.2	< 1
Reference food: Site water (Horsethief)	6.0	1.6
Reference food: Site water (Adobe Creek)	32.4	3.4
Reference food: Site water (North Pond)	52.5	13.3
Horsethief food: Reference water	3.2	< 1
Horsethief food: Site water (Horsethief)	6.0	1.6
Horsethief food: Site water (Adobe Creek)	32.4	3.4
Horsethief food: Site water (North Pond)	52.5	13.3
Adobe Creek food: Reference water	3.2	< 1
Adobe Creek food: Site water (Horsethief)	6.0	1.6
Adobe Creek food: Site water (Adobe Creek)	32.4	3.4
Adobe Creek food: Site water (North Pond)	52.5	13.3
North Pond food: Reference water	3.2	< 1
North Pond food: Site water (Horsethief)	6.0	1.6
North Pond food: Site water (Adobe Creek)	32.4	3.4
North Pond food: Site water (North Pond)	52.5	13.3

After 30 days of exposure in this study, there was also good survival of razorback sucker larvae fed reference food (brine shrimp) and held in reference water or water from Horsethief (83 and 81 percent, respectively). The survival of these larvae was significantly greater than survival of larvae fed brine shrimp and held in water from North Pond (52 percent). Corresponding selenium concentrations in larval whole-body tissue after 10 days were 6.3, 6.7, and 11 mg Se/kg dw, respectively. The average concentrations of selenium in the water for the three treatments were <1, 1.6, and 13.3 µg Se/L. After 30

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days the mean selenium concentrations in these larvae were 5.2, 5.2, and 16 mg Se/kg dw, respectively. Survival was markedly reduced (0 to 30 percent survival) in the remaining treatments where larvae were fed zooplankton from the various sites. Complete mortality was experienced by larvae exposed to Horsethief food and reference water treatment after 30 days.

Similar to the previous study, several inconsistencies in results suggested that selenium may not have been solely responsible for the effect on larval survival. The most notable inconsistency was that the greatest effect on larval survival (percent survival or time to 50 percent mortality) was from exposure to Horsethief food, the food with the lowest selenium contamination.

The authors of the above two studies (Hamilton et al. 2001a,b) make a strong argument that some of the inconsistency in response observed in their studies between larvae fed reference and site diets may be related to the difference in arsenic concentration between the two diets. The arsenic concentration measured in the brine shrimp used in the reference diet was 24 mg total As/kg dw (measured in the second larval study) versus between 6 and 7.5 mg total As/kg dw measured in the zooplankton from the various sites. In their publication (Hamilton et al. 2005c), the authors cite several studies reporting an ameliorating effect of arsenic against the toxicity of a variety of forms of selenium in various animals (Dubois et al. 1940, Hoffman et al. 1992, Klug et al. 1949, Levander 1977, Moxon 1938, Thapar et al. 1969). In terms of the survival of larvae from Horsethief, Adobe Creek and North Pond adults when fed the reference diet, the authors propose that the arsenic concentrations in the brine shrimp diet may have resulted in an antagonistic interaction with selenium and reduced adverse effects in larvae. Such hypothesis is questionable, because their studies included diets spiked with inorganic arsenic salts, whereas the arsenic in brine shrimp (and other natural diets), is most likely predominantly organic arsenic (US EPA 2003). Additionally, in a separate but related study by the same authors (Hamilton et al. 2005d), larval razorback sucker spawned from one female at the Ouray Native Fish Facility were fed zooplankton from six sites (S1, S3, S4, S5, SR, and NR) adjacent to the Green River, Utah at four different initial ages (5, 10, 24, and 28 day old larvae) for 20 to 25 days. The selenium concentrations in zooplankton from the S1 reference site ranged from 2.3 to 3.5 mg Se/kg dw (dissolved Se in water <0.6 to <1.1 µg/L). The concentrations in zooplankton from sites S3 and S4 were slightly higher (range 2.4 to 6.7 mg Se/kg dw; water, 0.3-0.8 µg/L), substantially elevated at S5 (12- 26 mg Se/kg dw; water, 0.6-3.1 µg/L), and highest at SR and NR (44-94 mg Se/kg dw; water, 14-107 µg/L). All larvae in the test initiated when they were 5 days old (study 1) died after 25 days of exposure. Median time to death was shortest in fish fed zooplankton from the reference site (S1) and longest for SR and NR. Interestingly, the concentration of arsenic measured in zooplankton collected from S1 was 12 mg As/kg dw, half that of the brine shrimp used in the above study (Hamilton et al. 2001b), which did not appear to antagonize the toxicity of the

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selenium in the diet in this test. In this and the previous two studies, additional inorganic contaminants such as vanadium and strontium were elevated in the zooplankton fed to the larval razorback sucker.

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De Riu, D., L. Jang-Won, Huang, S., Monielloa, G., and Hung, S. 2014. Effect of dietary selenomethionine on growth performance, tissue burden, and histopathology in green and white sturgeon. Aquat. Toxicol. 148:65-73.

Test Organisms: Green sturgeon (*Acipenser medirostris*)
White sturgeon (*Acipenser transmontanus*)

Exposure Route: Dietary only
Three different concentrations of L-selenomethionine were added to an artificial diet mixture: nominal concentrations of 0 (control), 50, 100, and 200 mg SeMet/kg (measured: 2.2 mg/kg Se in control diet (no added Se) and 19.7, 40.1 and 77.7 mg/kg Se in the three treatment diets).

Test Duration: 8 weeks

Study Design: Daily rations of the treatment diets (3% BW/d for first 4 weeks and 2% BW/d for second 4 weeks) were fed to the juvenile sturgeon (approximately 30 g). Each of the four dietary treatment consisted of 3 replicate 90 L tanks with 25 juveniles in each tank. Several endpoints were monitored over the 8 week exposure period including survival, percent body weight increase (% BWI), and hepatosomatic index (HSI).

Effects Data: White sturgeon had no mortalities through the highest dietary treatment. Green sturgeon juveniles had 0%, 7.7% and 23.1% mortality with the three dietary treatments (see table below). %BWI had a greater response to selenium concentration in juvenile tissues than HSI (see table below). Of note is the relatively high concentration of Se in the whole body and muscle tissues of the juvenile sturgeon in the control treatment (both species). The reason for the relatively high Se control concentrations was not due to accumulation of Se from the artificial diet because the concentration of Se remained relatively constant over the 8 week exposure.

Chronic Value: TRAP analysis (threshold sigmoid nonlinear regression) of the green sturgeon survival data resulted in a whole body EC_{10} value of 28.93 mg/kg dw. EC_{10} values were lower for % BWI and HSI using TRAP. For % BWI, the whole body EC_{10} value for green sturgeon was 16.36 mg/kg dw, and for white sturgeon, 23.94 mg/kg dw. For HSI, the whole body EC_{10} value for green sturgeon was 10.86 mg/kg dw (with a very wide 95% confidence interval, 1.842-64.08 mg/kg dw), and for white sturgeon there were no discernible effects.

Selenium in Juvenile Sturgeon Tissues and Endpoints Measured at end of Eight Week Exposure

Green Sturgeon

Dietary [Se] mg/kg dw	whole body [Se] mg/kg dw	muscle [Se] mg/kg dw	survival %	%BWI	HIS
2.2 (control)	7.1	8.4	100	6.6	2
19.7	22.8	31.1	100	2.6	1.3
40.1	27.8	37	92.3	0.8	0.8
77.7	34.3	36.8	76.9	-1	0.9

White Sturgeon

Dietary [Se] mg/kg dw	whole body [Se] mg/kg dw	muscle [Se] mg/kg dw	survival %	%BWI	HIS
2.2 (control)	5.6	9.2	100	4.2	2.6
19.7	20.1	27	100	4.2	3.6
40.1	31.8	41.3	100	2.8	3
77.7	47.1	57.9	100	1	2.2

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4.0 OTHER DATA – CHRONIC STUDIES WITH FISH SPECIES

Some chronic studies met the requirements of an acceptable chronic test but were excluded from being included in the data set used for criterion derivation for a variety of reasons. Summaries of these studies are provided below.

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Vidal, D., S.M. Bay and D. Schlenk. 2005. Effects of dietary selenomethionine on larval rainbow trout (*Oncorhynchus mykiss*). Arch. Environ. Contam. Toxicol.49:71-75.

Test Organism: Rainbow trout (*Oncorhynchus mykiss*)

Exposure Route: Dietary only
Selenomethionine was added to dry fish food; the measured dietary concentrations were 4.6, 12 and 18 µg Se/g dw. The measured selenium in the control diet was 0.23 µg Se/g dw.

Test Duration: 90 days

Study Design: Each of the three dietary treatments and control had 5 replicates, each replicate contained 12 to 16 larval rainbow trout that were 27 days old at initiation. Each fish was fed an average of 10 mg/d for 30 days; 25 mg/d on days 30-60; and 40 mg/d thereafter. Fish were sampled on days 30, 60 and 90 for length, weight, selenium, hepatic GSH and thiobarbituric acid-reactive substances (TBARS) measurements.

Effects Data: The authors reported significant decreases in weight and length after the 90-day exposure (Table E-4). There were no significant differences in the hepatic lipid peroxidation and hepatic GSH to GSSH ratios among the treatments. The authors found significant differences in weight and length in the 4.6 and 12 µg Se/g dw dietary treatments, but not the 18 µg Se/g dw treatment. Based on larval trout body burden, the authors reported an LOEC of 1.20 µg/g ww, the concentration of Se in fish fed the 12 µg Se/g dw dietary treatment. The Se concentration in larval rainbow trout associated with the lowest dietary treatment that showed significant decreases in larval weight and length was 0.58 µg Se/g ww or 2.06 µg Se/g dw based on 71.8% moisture in whole body rainbow trout (NCBP).

Chronic Value: The data from this study was not used to calculate a chronic value for selenium due to several inconsistencies. The significant decreases in length and weight observed in the two lowest concentrations were not observed in the highest dietary treatment. The Se concentrations in the larval rainbow trout were irregular with the 60-day concentrations being considerably higher than the 90-day concentrations. The authors explain this observation to rapid growth in the fish causing dilution of the Se body burden. However, the increase in fish weight from 30 to 60 days was similar to the 60 to 90 day increase and the 60 day Se concentrations increased from day 30. Also, the Se concentration in the control fish went from below detection on day 0 to 0.46 µg/g ww on day 30; to 1.24 µg/g ww on day 60; and to 0.31 µg/g ww on day 90. The 60-day measured Se in the control fish (1.24 µg/g ww) was more than twice the concentration of Se in the fish with lowest concentration showing effects (0.58 µg/g ww).

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Table E-4. Mean (SD) rainbow trout growth after four SeMet dietary treatments.

test day	Treatment, µg/g dw	weight, g	fork length, cm	[Se] whole body, µg/g ww	[Se] whole body, µg/g dw**
0	control	0.37 (0.30)	3.14 (0.41)	ND	ND
30	control	1.33 (0.92)	4.66 (0.41)	0.46 (0.20)	1.63
	4.6	1.25 (0.21)	4.84 (0.29)	1.05 (0.77)	3.72
	12	1.33 (0.30)	5.09 (0.46)	1.81 (1.04)	6.42
	18	1.31 (0.37)	4.97 (0.50)	1.60 (0.93)	5.67
60	control	2.96 (0.92)	6.91 (0.56)	1.24 (0.54)	4.40
	4.6	2.33 (0.63)	6.69 (0.67)	1.70 (0.72)	6.03
	12	2.52 (0.38)	6.88 (0.35)	1.83 (0.94)	6.49
	18	2.59 (0.24)	6.92 (0.24)	2.62 (1.22)	9.29
90	control	5.17 (1.09)	7.70 (0.33)	0.31 (0.20)	1.09
	4.6	3.45 (0.35)*	6.93 (0.19)*	0.58 (0.21)	2.06
	12	3.45 (0.35)*	6.84 (0.68)*	1.20 (0.21)*	4.25
	18	3.82 (0.62)	7.37 (0.62)	1.41 (0.27)*	5.00

* Significantly different than the control.

** ww converted to dw using 71.8% moisture for whole body rainbow trout (NCBP).

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Pilgrim, N. 2009. Multigenerational Effects of Selenium in Rainbow Trout, Brook Trout, and Cutthroat Trout. Master's Thesis. University of Lethbridge.

Test Organisms: Rainbow trout (*Oncorhynchus mykiss*), cutthroat trout (*Oncorhynchus clarkii*) and brook trout (*Salvelinus fontinalis*)

Exposure Route: Dietary only
Selenomethionine added to trout chow and gelatin. Two dietary treatment levels, nominal Se concentrations, 15 (low) and 40 (high) mg/kg.

Test Duration: Rainbow trout were fed the experimental diets from August - December 2009, brook trout July - November 2010, and cutthroat trout December 2010 - April 2011.

Study Design: Fish were obtained from a fish hatchery brood stock. Mature females and were fed the experimental diets in 710 L tanks. Spawning was stimulated by injecting Ovaprim® into the females. Eggs were fertilized and incubated at the fish hatchery until the eye spots were visible. A portion of the eyed stage larvae from each treatment was shipped to the University of Lethbridge Aquatic Research Facility for the swim-up stage of the experiment conducted in gravel bed flumes. Endpoints measured included percent survival in the first (spawned eggs to eyed eggs) and second (eyed eggs to yolk-absorbed fry) stages of development, swim-up success, and malformations (spinal, craniofacial and finfold deformities and edema).

Effects Data: Selenium affected larval survival, swim-up success and the percent of malformations in larvae in one or more of the three species tested (see table below). Visual inspection of plots of the replicate data in Pilgrim (2009) showed considerable variation between the endpoints and selenium in eggs. The distribution of selenium among the tissues was markedly inconsistent with other studies that have used these species. For example, the amount of selenium in the eggs was 8 and 18 times greater than the concentration in the respective muscle tissues in cutthroat and rainbow trout. Median ratios (egg Se:muscle Se) calculated for rainbow trout (Casey and Siwik 2000; Holm et al. 2005) and cutthroat trout (Golder 2005; Kennedy et al. 2000; Rudolph et al. 2007) were 1.9 and 1.8, respectively. Due to the considerable variation in the concentration response of the replicate data and anomalous selenium distribution, these data were not included in the data set to derive the criterion.

Table E-5. Mean selenium concentrations in the diet and selected tissues and selected endpoints measured in rainbow trout (RN), brook trout (BK) and cutthroat trout (CT).
Adapted from Table 3.1 in Pilgrim (2009).

		Tissue, mg/kg ww			Survival, %			
Species	**Diet ww**	**Muscle**	**Liver**	**Egg**	**Stage 1**	**Stage 2**	**Swim-up success**	**Total malformations, %**
	1.47	0.21	3.77	1.17	82.36	61.56	57.18	10
	12.7	0.51	6.53	4.30	77.86	48.64	73.83	9.86
RBT	35.2	0.74	17.21	13.0	54.72	30.33	27.45	29.63
	1.47	0.23	0.72	0.81	86.3	82.68	84	21.3
	12.7	1.14	7.23	5.01	71.37	88.72	83.42	23.93
BK	35.2	3.41	20.4	8.15	71.37	44.63	50.11	24.23
	1.47	0.31	1.00	2.02	61.41	61.87	55.3	6.13
	12.7	0.93	6.00	9.80	30.65	14.75	21.71	48.06
CT	35.2	2.05	14.4	18.0	21.99	0	0.08	NA

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Formation Environmental. 2012. Appendix E – Yellowstone Cutthroat Trout Adult Laboratory Reproduction Studies. Technical Support Document: Proposed Site-Specific Selenium Criterion, Sage and Crow Creeks, Idaho. Prepared for J.R. Simplot Company. January 2012.

Test Organism: Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*)

Exposure Route: Field collected. Adult female and male Yellowstone cutthroat trout were collected at five field sites from four streams near the Smokey Canyon mine. In addition Yellowstone cutthroat trout eggs were obtained from a hatchery as method controls.

Test Duration: Test duration was from hatch through 15 days post swim up, and averaged 55-56 days for larvae hatched from field collected fish and 64 days for larvae hatched from laboratory collected fish.

Study Design: Eggs were collected from 15 ripe females at five sites from four streams upstream and downstream of the Smokey Canyon mine. This included one selenium impacted stream downstream of the mine, Sage Creek (LSV), one site along Crow Creek upstream of Sage Creek (CC-150) and one site along Crow Creek downstream of Sage Creek (CC-350), and in sites within the reference streams Deer Creek (DC), and South Fork Tincup Creek (SFTC). Eggs were fertilized in the field with milt collected from males collected at the same site as females. Fertilized eggs were water hardened at the site using stream water, then placed in oxygenated plastic bags and stored on ice in the dark (cooler) for transportation to laboratory. In addition, eggs were collected from 16 ripe females obtained from Henry's Lake hatchery (HL) to serve as method controls. Hatchery females were stripped of eggs and fertilized by milt from males obtained from the same hatchery. For field and hatchery fish, Se was measured in adult fish (whole body) and in eggs of field collected females.

A target of approximately 600 fertilized eggs from each female (were placed in egg cups for hatching and monitoring. After swim up, remaining fry were thinned to a target of 100 fry/treatment and monitored for an additional 15 day post swim up feeding trial.

Endpoints measured in the laboratory were hatch, survival (hatch to swim up, and hatch through 15 days post swim up), and deformities. Deformities were combined as assessed as having at least one deformity, or being fully free of deformities (i.e., normal).

Effects Data: Eggs failed to hatch for one of the field treatments (SFTC-1), and six of the hatchery treatments, resulting in a final dataset of eggs fertilized from 14 field collected fish and 10 hatchery fish. Se concentrations in eggs obtained from field collected females ranged from 11.4 mg/kg in Deer Creek through 47.6 mg/kg in Crow Creek downstream of Little Sage Creek (Table E-6). Se concentrations in eggs obtained from Henry's Lake hatchery fish ranged from 0.83 mg/kg – 3.23 mg/kg (Table E-6). Se concentrations in whole body tissue samples obtained from field collected females ranged from 8.17 mg/kg in Deer Creek through 25.7 mg/kg in Crow Creek downstream of Little Sage Creek (Table E-6). Se concentrations in whole body tissue samples obtained from Henry's Lake hatchery fish ranged from 0.23-0.91 mg/kg (Table E-6).

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Table E-6. Yellowstone cutthroat trout selenium concentrations, survival, and deformity data from hatch to test end.

Sample ID[a]	Egg Se mg/kg	WB[b] Se mg/kg	# Free From Deformities	# Assessed For Deformities	# Died	# Survived	# Assessed + # Died
CC-150/001	17.6	16.3	22	182	33	182	215
CC-350/001	27.9	20.7	14	138	120	138	258
CC-350/002	29.7	19.4	143	602	83	602	685
CC-350/003	22.3	17.0	73	330	36	330	366
CC-350/004	14.6	16.7	149	480	19	480	499
CC-350/005	47.6	25.7	91	392	71	392	463
DC/001	22	8.17	95	275	30	275	305
DC/002	15.4	9.07	133	465	26	465	491
DC/003	11.4	8.63	59	380	39	380	419
DC/004	12.7	16.6	7	38	23	38	61
HL/002	2.03	0.45	5	39	10	39	49
HL/003	2.48	0.44	121	302	19	302	321
HL/004	1.36	0.36	154	416	20	416	436
HL/006	0.83	0.36	21	244	103	244	347
HL/007	2.26	0.44	120	404	18	404	422
HL/008	1.87	0.28	147	412	37	412	449
HL/011	3.23	0.31	69	296	22	296	318
HL/012	1.58	0.23	112	454	27	454	481
HL/013	1.93	0.72	148	483	24	483	507
HL/015	2.06	0.91	0	36	6	36	42
LSV2C/001	40.1	19.4	2	200	536	0	536[c]
LSV2C/002	30.0	21.0	40	319	105	319	424
LSV2C/003	35.6	18.6	92	487	138	487	625
LSV2C/004	30.5	22.5	107	476	75	476	551

a – CC – Crow Creek; DC – Deer Creek; LSV2C – Sage Creek; HL – Henry's Lake (Hatchery)
b – whole body
c – does not include the 200 fish assessed that were dead prior to assessment, as all fish for that treatment died during the swim up stage in this sample.

Figure E-1 is a plot of % free from deformities versus egg concentration. The previous draft used TRAP to estimate an effect level for these data but after further review it was concluded these data just do not demonstrate any clear effect of Se and therefore inappropriate for analysis by TRAP. There is no obvious trend, especially one that is substantial relative to the data variability. The correlation coefficient for these data is not significant and a t-test of the two data clusters is likewise not significant. The survival data also do not show a useful trend, especially one suitable for EC10 estimation. Although no effect concentration was determined for this test, the data do not contradict the other cutthroat trout datasets in that there are no effects up to 30 mg/kg and of the three points in excess of 30 mg/kg, one did show 100% mortality. The data are consistent with *Oncorhynchus* not being one of the four most sensitive genera.

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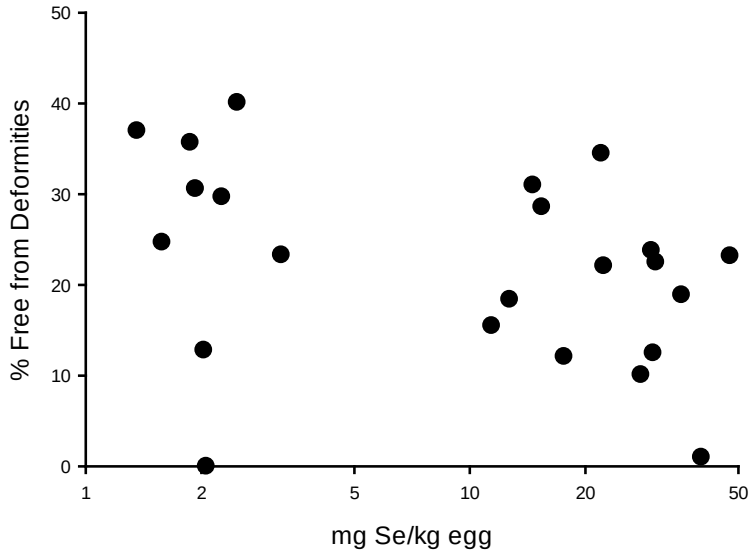


Figure E-1. Plot of percent free from deformities relative to the concentration of selenium in cutthroat trout eggs.

Effect Concentration: NA

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Deng, X. 2005. Early life stages of Sacramento splittail (*Pogonichthys macrolepidotus*) and selenium toxicity to splittail embryos, juveniles and adults. Doctoral dissertation, University of California, Davis.

Test Organism: Sacramento splittail (*Pogonichthys macrolepidotus*)

Exposure Route: Dietary only
Four concentrations of selenium in the fish diet (0.6, 17.3, 33.0, and 70.1 mg/g) were created by mixing different proportions of selenized and Torula yeast. A different batch of selenized yeast was used in the adult exposure.

Test duration: 24 weeks

Study Design: Fourteen adult fishes were placed in each circular tank (92 cm diameter, 33 cm height) and fed one of the four diets. Each diet was provided to fishes in three tanks. The twelve tanks were arranged in three rows. Each row had all four treatment concentrations with randomly assigned positions. Thus, the experiment had a randomized block design. Adult splittail fishes were obtained from the Tracy Pump Station (U.S. Bureau of Reclamation, Tracy, CA). After 12 and 24 weeks of exposure, blood samples were collected, the liver, gonad, kidney and white muscle were dissected, and liver and gonad were weighed to calculate hepatosomatic and gonadosomatic indices. Stages of ovarian and testicular development were determined from histological studies.

Effects Data: No mortality occurred throughout the experiment. Fish in control, 17.3, and 33.0 mg/g treatments exhibited normal behavior. Fish exposed to 70.1 mg/g in did not consume as much food as fishes exposed to lower selenium concentrations, and displayed abnormal behaviors. Splittail adults were less sensitive to dietary selenium than juveniles. Relative to control, no changes in body weight, total length, GSI, and condition factor were observed in fishes exposed to selenium concentrations in food up to 33 mg/g. In general, tissue concentrations in fishes exposed to selenium were higher than in the control, but differences in selenium concentrations among them were often small and not significant (Table E-7). Percentages of ovaries with atretic follicles increased with higher concentrations of selenium in their diet: 30% in control, 45.5% in the 17.3 mg Se/g, and 100% in the 33.0, and 70.1 mg/g treatments. The average concentration of selenium in ovaries of fish exposed to 17.3 mg/g in their diet was 6.5 mg/g. This low effect level, though, is disputable because of the very low number of ovaries analyzed, the occurrence of atresia in 30% of ovaries in control, and the lack of significant differences in concentrations of selenium in ovaries among treatments exposed to elevated levels of this element.

Table E-7. Mean concentration of selenium in ovaries (SE).[‡]

	Diet Concentration (mg Se/g)			
	0.6	17.3	33.0	70.1
[Se] in ovary (mg/g dw)	4.4 (0.57)	6.5 (1.0)	8.3 (0.14)	8.9 (0.46)

[‡] Values estimated from Figure 4 in Deng (2005) (pg. 111)

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de Rosemond, K. Liber and A. Rosaasen. 2005. Relationship between embryo selenium concentration and early life stage development in white sucker. Bull. Environ. Contam. Toxicol. 74: 1134-1142.

Test Organism: White Sucker (*Catostomus commersoni*)

Exposure Route: Field collected.
In June, 2002, eggs were collected from 4 females from Island Lake (exposed site); milt was obtained from 2 males. Island Lake is downstream from Cluff Lake uranium mine located in northern Saskatchewan. Selenium concentrations in Island lake range from 1 to 11 µg/L and in recent years have been typically 4-5 µg/L. No fish/eggs were collected from a reference site.

Test duration: Through the end of yolk absorption by the larvae; 33 days post-fertilization.

Study Design: Individual batches of eggs were fertilized in the field with milt and water-hardened. Eggs were air transported to the laboratory in Saskatoon for testing. 200 eggs were randomly selected from each clutch and then separated into groups of 100 which were placed into individual test chambers (n = 8).

On test day 30 (3 days prior to test termination), all fish larvae that exhibited macroscopic deformities (e.g., kyphosis, lordosis, scoliosis and edema) were removed, photographed and preserved. At test termination, (day 33), 40 larvae from each female whites sucker were evaluated for deformities using a microscope.

Effects Data: Although all four females were collected from the exposed site, selenium concentrations in eggs were grouped into two low (Fish 2 and 3 in Table E-8) and two high (Fish 1 and 4 in Table E-8). Larval mortality and developmental deformities were not related to selenium concentrations in eggs (Table E-8). The data suggest that embryo/larval effects are not observed at concentrations in eggs reaching 40.3 mg/kg dw (geometric mean of the two high selenium concentrations in eggs). However, because a reference condition with low selenium exposure was not established, it is not appropriate to estimate an effect concentration for this study. Note: the average percent moisture for the four clutches of eggs was 92.6%.

Effect Concentration: NA

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Table E-8. Embryo/larval endpoints for eggs from four female white sucker collected from Island Lake in June 2002.

Measurement	Fish 1	Fish 2	Fish 3	Fish 4
Successfully hatched larvae[a]	161	140	176	141
Deformed larvae[b]	21	25	16	13
Dead larvae[c]	6	14	6	4
Macroscopic deformities , %				
Embryological[d]	6.8	6.4	5.7	1.4
Developmental[e]	6.2	11.4	3.4	7.8
Microscopic deformities, %				
Developmental[f]	7.5	5	2.5	7.5
Total developmental deformities, %[g]	13.7	16.4	5.9	15.3
[Se] eggs mg/kg ww[h]	2.7	0.7	0.6	3.2
[Se] eggs mg/kg dw[h]	33.6	9.4	8.4	48.3

[a] Initial number was 200 per fish

[b] Total number of deformed larvae throughout study; includes embryological and macroscopic deformities

[c] Total number of larvae that died throughout study.

[d] Percent of curled deformities that appeared in embryonic fish; deformities were evident immediately after embryos hatched.

[e] Percent of deformities that were designated developmental; deformities became evident as larvae grew and absorbed yolk sac (after experimental day 15).

[f] Percent of microscopic developmental deformities that were evident in the 40 fish examined per female white sucker.

[g] The estimated percentage of offspring that had microscopic and macroscopic developmental deformities combined.

[h] Selenium concentration measured in a subsample of embryos collected on test day 0.

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Ogle, R.S. and A.W. Knight. 1989. Effects of elevated foodborne selenium on growth and reproduction of the fathead minnow (*Pimephales promelas*). Arch. Environ. Contam. Toxicol. 18:795-803.

Test Organism: Fathead minnows (*Pimephales promelas*; juvenile, 59 to 61 d old)

Exposure Route: Dietary only
Purified diet mix spiked with inorganic and organic selenium: 25 percent selenate, 50 percent selenite, and 25 percent seleno-L-methionine, homogenized in dextrin.

Test Treatments: Completely randomized block design (2 blocks); 4 replicates per block (n = 8 replicates total per treatment). Actual mean total selenium levels in each exposure treatment were: 0.4 (control), 5.2, 10.2, 15.2, 20.3, and 29.5 mg/kg dw. Fish used in the first randomized block (F_2 generation fish) were progeny from F_1 generation originally obtained from the Columbia National Fishery Research Laboratory, some of which were used in an initial range-finding experiment. Fish obtained from a commercial supplier were used in the second randomized block. The prepared diet was extruded into 1.5 mm pellets which were air-blown dried to 5 percent moisture content and crushed and sieved so that only particles retained by an 11.8 mesh/cm sieve were used in the study. The amount of selenium in water that leached from the food during the experiment averaged only 0.8 μg/L.

Test Duration: 105 days, F_2 generation (block one) and commercial fish (block two);
14 days F_3 generation

Study Design: Ten fish were randomly placed in each cell per block (n = 8x10, or 80 fish total per treatment). Fish were fed twice daily at 6 percent body weight per day, with wastes and uneaten food removed 30 min. after each feeding. Test tanks were flushed with two tank volumes of fresh test water after each feeding (solution renewal). Growth (as wet weight) was determined every two weeks by bulk weighing, and one fish from two of the cells per treatment in a given block (n = 4 total per treatment) was removed for selenium (whole-body) analysis. After 105 days of exposure, a single male and female fish from each treatment replicate (n = 4 breeding pairs per treatment in a given block, or 8 breeding pairs per treatment total) were placed in 250 ml beakers and inspected for spawning activity for 30 days following the first spawning event for that pair (each pair being one replicate). Gonads and muscle tissue were dissected for selenium analysis from these fish at the end of the 30 days spawning period. The spawning substrates were inspected daily for eggs to determine fertility and viability. Samples of not more than 50 eggs from each spawn were incubated in flowing, aerated water and inspected for percent hatch determination. Ten larvae from each incubated brood were transferred to separate glass test chambers and maintained (48 h renewal; fed brine shrimp twice daily) for 14 days to determine percent larval survival.

Effects Data: There was no effect of selenium on any of the reproductive parameters measured at the dietary concentrations tested. Percent hatch and percent larval survival were very high (>87.4 percent) and essentially equal for all of the treatments. Growth of pre-spawning adults was affected by the selenium exposure (Table E-9).

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Table E-9. Effects on fathead minnow growth after 98 days of exposure to dietary selenium.

Measured mean selenium in diet, mg/kg dw	Whole-body selenium, mg/kg dw	Mean fish weight, g ww
0.4	1.76	1.30
5.2	2.78	1.24
10.2	3.42	1.20
15.2	5.40	1.21
20.3	6.58	1.09
29.5	7.46	0.94

Chronic Value: An EC value could not be calculated for these data because the data did not meet the minimum requirements for analysis.

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GEI Consultants. 2008. Maternal Transfer of Selenium in Fathead Minnows, with Modeling of Ovary Tissue to Whole Body Concentrations.

Test Organism: Fathead Minnow (*Pimephales promelas*)

Exposure Route: Field collected.
Gravid adult fathead minnows were collected from creeks with a wide range of surface water selenium concentrations near the city of Denver, CO during the 2006 summer breeding season.

Sites
Low selenium exposure:

- Sand Creek at Colfax. In 2002, aqueous selenium averaged 0.9 µg/L.

Moderate to high selenium exposure:

- Sand Creek downstream of refinery
- East Tollgate Creek
- Mainstem Tollgate Creek

Control fish – no field exposure

- Laboratory-reared fish from Aquatic BioSystems

Test duration: Embryo-larval test was 48 hours post hatch.

Study Design: Field collected adult fish were either field dissected for selenium measurement in paired tissues or transported live back to the laboratory in coolers with site water. Fish were transported to the laboratory where mating pairs were bred in individual chambers containing spawning substrates. Eggs were removed from the spawning substrate and reared in a standard Falcon dish with lab water. Eggs were screened under a dissecting microscope for viability. Dead eggs were removed and numbers recorded on a datasheet. Three separate breeding experiments were conducted.

Upon hatching, larvae were moved to standard bioassay cups containing lab water and maintained in the laboratory incubator at 25ºC. Larvae were maintained via static conditions in exposure cups for 48 hours post-hatch without food to ensure full absorption of the yolk sac before they were fixed in formalin. Deformity assessment was performed on fixed embryos using a dissection microscope. Test endpoints consisted of egg production, fertilization success, mortality, and deformities (includes edema and skeletal, craniofacial and finfold malformations). The authors used a graduated severity index (GSI) for deformities in which larvae were scored 0 (normal), 1 (slight), 2 (moderate), and 3 (severe) based on the level of defect.

Effects Data: All fish successfully spawned except those collected from Sand Creek downstream from the refinery. These fish had visible parasites and were only used in the ovary-to-whole body selenium analysis. A suite of metal and metalloids were measured in fish samples from each location. Fish collected from East Tollgate Creek had higher concentrations of 9 of the 15 metals that were

measured in fish from at least one site. Aluminum and iron showed the highest difference with an approximate 10-fold increase in the East Tollgate Creek fish.

Only the first brood of each mating pair was used for the analysis because effects appeared to be muted in subsequent broods. The lower response in the second brood was thought to be due to clearing of selenium in the oocytes. There was poor correlation between egg fertilization ($R^2 = 0.13$) and embryo mortality ($R^2 = 0.18$) data with whole body selenium concentrations in the adult fish (see Table E-10 for summary data; see Table E-11 for individual brood data). Neither the fraction of embryos surviving nor fertilization rate as a function of the concentration of selenium in maternal fathead minnows was suitable for estimating EC values. Although there were low survival and fertilization rates at some higher selenium concentrations, these responses were quite varied and did not follow a defined concentration-response relationship (Figure E-2).

Of the 9 broods from fish collected at the three exposed sites only one brood (from East Tollgate Creek) had deformities greater than 10%. The fathead minnow females that produced the brood with the greatest number of deformities and highest GSI also had the second highest concentration of whole body selenium, 46.4 mg/kg dw (Table E-12; Figures E-3 and E-4). Approximately half of the larvae from this brood exhibited some sort of malformation. Similar to the embryo parameters, EC values were not able to be estimated for any of the 4 malformation parameters.

The authors used probit analysis and TRAP to determine effect levels for each of the embryonic and larval endpoints (Table E-13). Although there is an indication of effect due to selenium exposure in both the embryonic and larval endpoints, there is too much variation in the responses observed with the embryos and insufficient response observed with the larvae to derive a reasonable estimate of effect levels. Therefore, no effect level was determined for this study.

Effect Concentration: Unable to determine due to high variability or insufficient response.

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Table E-10. Mean fathead minnow first brood embryo and larval parameters and adult whole-body (WB) selenium concentrations (dw) for each site (± 1SE); CON = control, SCC = Sand Creek at Colfax Avenue bridge, TGC = Tollgate Creek, and ETC = East Tollgate Creek.

Parameter	Site			
	Con	SCC	TGC	ETC
n (number of breeding pairs)	10	3	3	4
WB Se concentration (mg/kg dw)	2.86 ± 0.18	9.17 ± 0.46	35.87 ± 3.73	44.53 ± 2.41
Egg fertilization (%)	84.75 ± 3.32	23.99 ± 22.45	63.42 ± 31.82	59.6 ± 22.26
Embryo mortality (%)	22.03 ± 3.34	89.04 ± 9.70	46.40 ± 26.86	50.76 ± 23.63
Mean spawn size (# of eggs per spawn)	129 ± 23	318 ± 63	162 ± 61	317 ± 158
Total larva evaluated (total # of broods)	957	89	281	254
Mean brood GSI score	4.85 ± 1.22	8.88 ± 8.88	14.88 ± 4.63	21.75 ± 9.53
Larval craniofacial defects (%)	2.64 ± 0.90	4.65 ± 4.65	6.26 ± 3.63	18.48 ± 13.84
Larval skeletal defects (%)	4.74 ± 0.89	9.30 ± 9.30	6.21 ± 1.48	19.62 ± 12.11
Larval finfold defects (%)	2.19 ± 0.78	4.07 ± 4.07	5.71 ± 3.08	17.23 ± 14.48
Larval edema (%)	3.89 ± 1.01	5.23 ± 5.23	6.26 ± 3.63	20.32 ± 12.93
Larval length (mm)	4.90 ± 0.05	4.97 ± 0.12	4.83 ± 0.14	4.90 ± 0.07

Table E-11. Fathead minnow first brood embryo parameters and adult whole-body (WB) selenium concentrations (dw) for each site (± 1SE); for site acronyms see Table E-9.

Brood Code	Treatment	Maternal WB Se Conc dw (mg/kg)	Total eggs (total dead+total hatch+not hatched)	Survival fraction (total dead/total eggs)	Fert. Rate ((Initial Egg Count - 1st day mortalities)/Initial Egg Count)
T-1a-1	CON	2.90	19	0.79	0.96
T-1f-1	CON	3.24	238	0.77	0.88
T-1f-1	CON	1.94	19	0.63	0.73
T-2a-1	CON	2.25	135	0.98	0.98
T-3a-1	CON	2.71	154	0.68	0.72
T-3b-1	CON	2.64	90	0.90	0.95
T-3d-1	CON	3.67	76	0.70	0.71
T-4d-1	CON	3.43	199	0.85	0.91
T-5d-1	CON	3.33	149	0.73	0.87
T-6d-1	CON	2.52	183	0.76	0.78
T-2b-1	SCC	9.92	395	0.00	0.00
T-4a-1	SCC	8.35	193	0.03	0.03
T-6a-1	SCC	9.25	340	0.30	0.69
T-2a-1	TGC	32.29	132	0.83	0.91
T-3a-1	TGC	43.33	79	0.00	0.00
T-4a-1	TGC	31.99	262	0.77	1.00
T-1f-1	ETC	39.76	141	0.52	0.70

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Brood Code	Treatment	Maternal WB Se Conc dw (mg/kg)	Total eggs (total dead+total hatch+not hatched)	Survival fraction (total dead/total eggs)	Fert. Rate ((Initial Egg Count - 1st day mortalities)/Initial Egg Count)
T-3b-1	ETC	47.47	208	0.88	0.92
T-5a-1	ETC	46.37	634	0.07	0.17

Table E-12. Fathead minnow first brood larval malformations and adult whole-body (WB) selenium concentrations (dw) for each site (± 1SE); CON = control, SCC = Sand Creek at Colfax Avenue bridge, TGC = Tollgate Creek, and ETC = East Tollgate Creek.

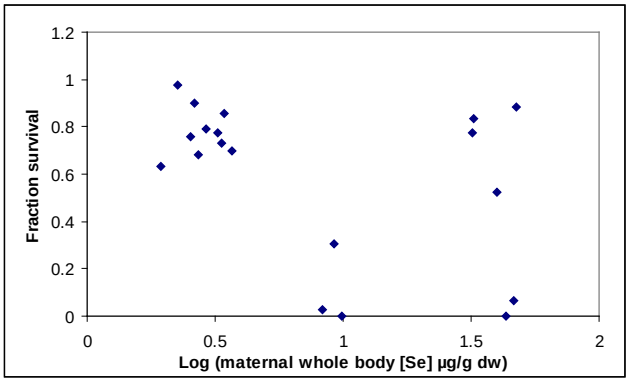
Brood Code	Treatment	Maternal WB Se Conc dw (mg/kg)	Total Larvae	Spinal Incidence	%larvae w/o spinal deformity	%larvae w/o craniofacial deformity	%larvae w/o finfold deformity	%larvae w/o edema	Total GSI Score
T-1f-1	CON	1.94	11	9	91	100	100	100	1
T-2a-1	CON	2.25	141	3	97	99	98	96	24
T-6d-1	CON	2.52	117	2	98	99	99	97	16
T-3b-1	CON	2.64	81	4	96	98	99	98	12
T-3a-1	CON	2.71	96	1	99	100	100	100	1
T-1a-1	CON	2.90	14	7	93	93	93	93	10
T-1f-1	CON	3.24	189	8	92	98	98	94	53
T-5d-1	CON	3.33	95	4	96	97	99	98	20
T-4d-1	CON	3.43	164	3	97	98	99	96	28
T-3d-1	CON	3.67	49	6	94	92	94	90	29
T-4a-1	SCC	8.35	3	0	100	100	100	100	0
T-6a-1	SCC	9.25	86	19	81	91	92	90	71
T-4a-1	TGC	31.99	190	5	95	97	97	97	41
T-2a-1	TGC	32.29	91	8	92	90	91	90	78
T-1f-1	ETC	39.76	65	5	95	95	98	94	20
T-5a-1	ETC	46.37	39	44	56	54	54	54	152
T-3b-1	ETC	47.47	150	11	89	95	96	91	89

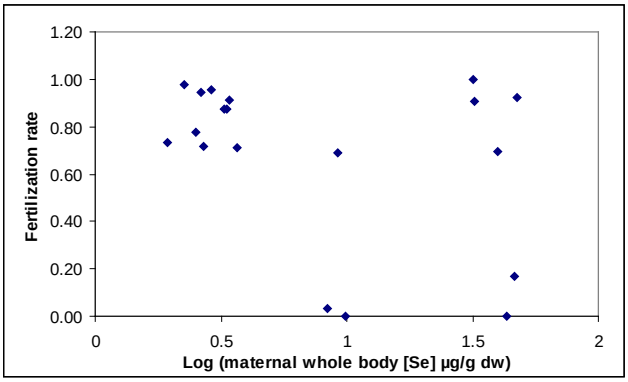
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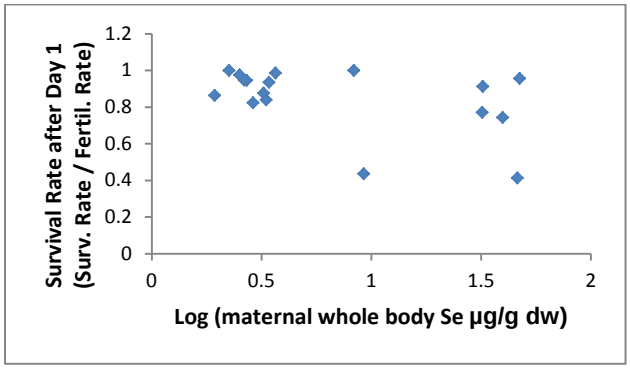
Table E-13. Authors calculation and comparison of fathead minnow larval deformity EC_{10} estimates using probit analysis and TRAP.

Effect	Endpoint	Probit Results WB [Se] mg/kg, dw (±SE)	TRAP Results WB [Se] mg/kg, dw (95% CL)	Probit Results Ovary [Se] mg/kg, dw (±SE)	TRAP Results Ovary [Se] mg/kg, dw (95% CL)
Edema	EC_{10}	39.48 ± 16.21	45.78 (40.95 - 51.20)	52.99 ± 19.99	61.43 (55.04 – 68.55)
Finfold	EC_{10}	68.55 ± 27.26	48.31 (39.41 - 59.21)	87.95 ± 32.16	64.81 (53.01 – 79.24)
Skeletal	EC_{10}	27.80 ± 9.53	46.08 (41.94 - 50.62)	38.67 ± 12.32	61.82 (56.36 – 67.80)
Craniofacial	EC_{10}	53.86 ± 18.77	47.41 (38.92 - 57.76)	70.83 ± 22.84	63.56 (52.37 – 77.16)
All abnormalities	EC_{10}	16.98 ± 5.38	45.50 (41.10 - 50.37)	24.23 ± 7.06	61.06 (55.26 – 67.48)
All abnormalities except edema	EC_{10}	21.35 ± 6.45	45.69 (41.10 - 50.79)	30.32 ± 8.51	61.27 (55.23 – 67.97)

Figure E-2. The fraction total survival of embryos (top left), fraction of embryos successfully fertilized (right), survival adjusted for fertilization (bottom) versus maternal whole body selenium concentration. Bottom figure EC10=35.2 mg/kg Se dw WB.







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Figure E-3. Percent 2-day post-hatch larvae without edema (A), finfold deformity (B), craniofacial deformity (C), and spinal deformity (D) relative to maternal whole body selenium concentration. EC10s: 61.4 – 64.8 mg/kg dw WB.

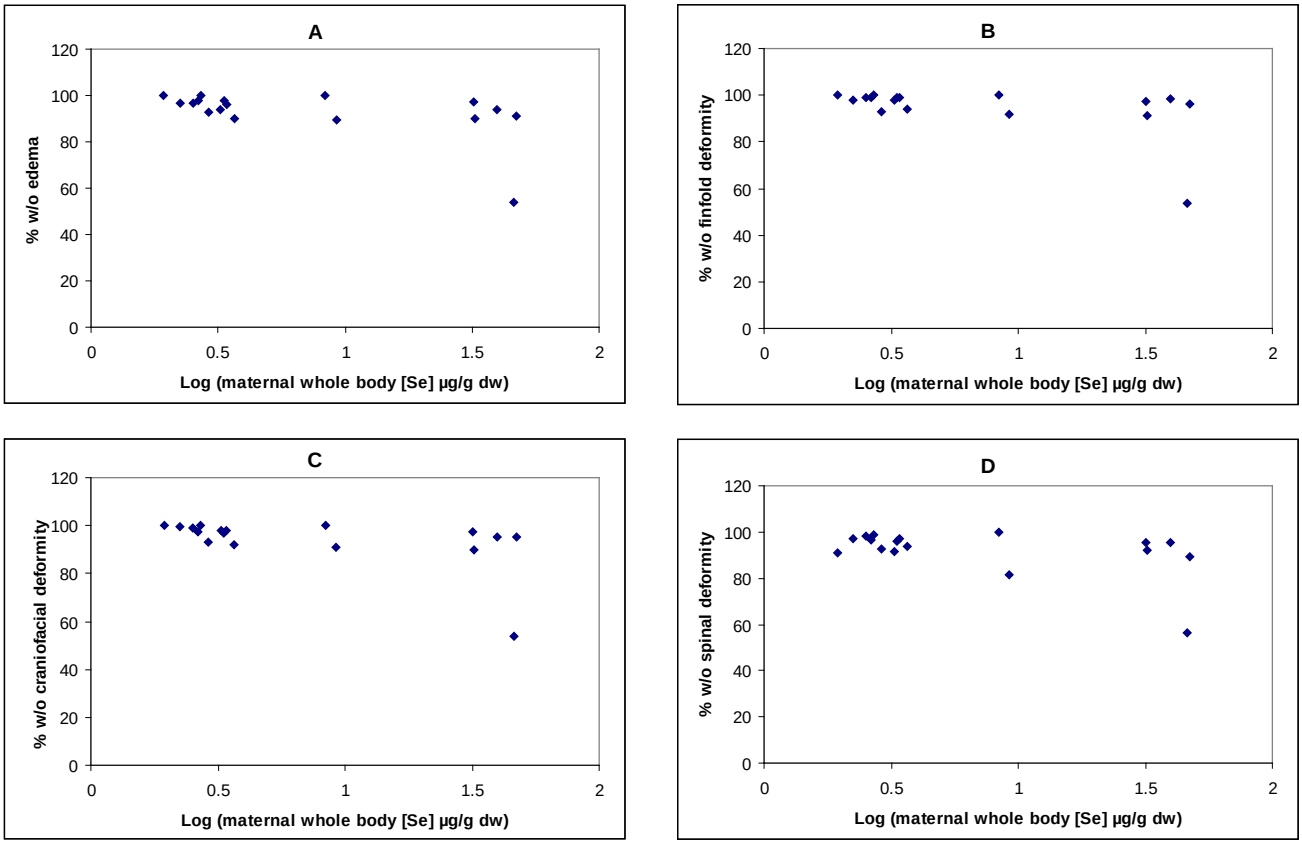
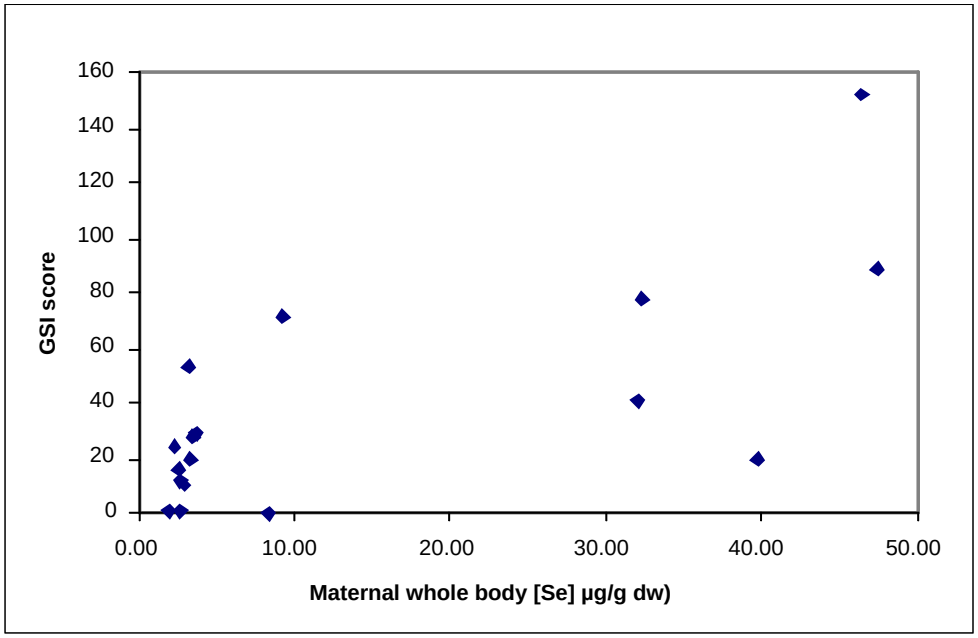


Figure E-4. Percent 2-day post-hatch larvae Graduated Severity Index (GSI) relative to maternal whole body selenium concentration



4.1 Evaluation of zebrafish (Danio rerio) and native cyprinid sensitivity to selenium

Overview:

Two new studies on zebrafish (*Danio rerio*), Thomas and Janz (2014), Thomas (2014), and Penglase et al. (2014), were made available to EPA by David Janz, one of the external peer reviewers. Thomas (2014) and Thomas and Janz (2014) were the original dissertation and peer reviewed paper, respectively, of the same body of work. The apparent sensitivity of the zebrafish to selenium relative to other species in the EPA selenium criteria document was the subject of several public commenters, as well as Dr. Janz in the comments received by EPA.

EPA calculated an EC10 of 7.004 mg Se/kg egg dw, or approximately 3.5 mg/kg whole body) from the Thomas (2014) and Thomas and Janz (2014) study. EPA was not able to calculate an EC10 from Pengalese et al. (2014). The Thomas (2014) and Thomas and Janz (2014) study is summarized in the following section (Part I). Penglase et al. (2014) is summarized in section 7.1.5 of the main document.

EPA noted that the concentration-response curves for both deformities and survival are anomalously shallow, yielding EC10s far below that of any other sensitive species. The shallow slope indicates partial effects across the range of test doses, with some individuals being very sensitive, and others being less sensitive than other test species. A typical test signature of the nutritionally essential element selenium is that above a particular concentration there is a precipitous increase in adverse effects, with most test organisms affected within a narrow dose range. Additional issues discovered during the analysis of available information in the literature and supplied by the investigator raised questions of test quality that introduced uncertainty in the results reported. This uncertainty, and the fact that zebrafish may not represent the sensitivity range for cyprinids native to the US (discussed in Part II), led to the decision to include this study qualitatively in the effects characterization.

The paucity and relative insensitivity of the available data for cyprinids (fathead minnow EC10 = < 23.9 mg/kg dw; based on LOEC in ovary) relative to other fish families like centrarchids (sunfish), and salmonids (trout and salmon) caused additional concern. This led EPA to investigate the field significance of the zebrafish EC10 (7.004 mg/kg egg) compared to what we know about cyprinid occurrence in selenium impacted waters. The available studies with native cyprinids indicate that a variety of native cyprinid genera (e.g. chubs, shiners, dace) have stable, diverse populations and are reproducing successfully (based on length frequency data) in selenium impacted waters at whole body concentrations far exceeding our proposed whole body criterion element of 8.0 mg/kg dw. Taken together, the available studies (Hamilton et al. (1998), NAMC (2008), Presser (2013), USGS (2012)), indicate that native cyprinids as a family are not expected to be overly sensitive to selenium when compared with other families of freshwater fish. This is important because zebrafish are non-native, and have only been recently discovered in U.S. waters due to accidental introduction.

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EPA believes there is significant uncertainty regarding the actual sensitivity to zebrafish, and therefore proposes inclusion of the zebrafish studies in the effects characterization section, as well as inclusion of a comprehensive analysis of the studies as well as the studies on sensitivity of selenium to native cyprinids (below) in its own technical appendix, and issuing an FRN soliciting additional studies or information on zebrafish, as well as native cyprinids.

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4.1.1 Part I. Chronic summary of Thomas (2014) and Thomas and Janz (2014)

Thomas, J.K. 2014. Effects of Dietary and in ovo Selenomethionine Exposure in Zebrafish (*Danio rerio*). Dissertation. University of Saskatchewan, Saskatoon, Canada.

Thomas and Janz, D.M. 2014. *In ovo* exposure to selenomethionine via maternal transfer increases developmental toxicities and impairs swim performance in F1 generation zebrafish (*Danio rerio*). Aquatic Toxicol. 152:20-29.

Test Organism: Zebrafish (*Danio rerio*)

Exposure Route: Dietary only
Selenomethionine spiked into Nutrafin® basic flake food

Test Treatments: Control diet (1.3 mg/kg Se dw) and three selenium-spiked diets (3.7, 9.6, and 26.6 mg/kg Se dw).

Test Duration: 90 days

Study Design: Adult zebrafish were fed a control diet (1.3 mg/kg Se dw) and three selenium-spiked diets (3.7, 9.6, and 26.6 mg/kg Se dw) for 60 days, followed by an additional 30-40 days with equal rations (2.5%) of control or SeMet-spiked diets and clean chironomids. After 90 days of feeding exposure, adult fish from each exposure group were bred 3-4 times and embryos were collected and used to assess a number of different effects including larval survival and deformities. Eggs from each treatment were pooled from which replicate samples were collected for selenium measurement, larval survival and deformity assessment

Effects Data: The authors presented mortality and deformities in the F1 generation graphically for days up to 6 days post fertilization (dpf). The bar graphics were initially converted to numeric values using a length measuring tool in GIMP (GNU Image Manipulation Program). EC10 values for both mortality and deformities were very low with deformities being slightly lower. Upon request, the authors provided a table of the number of deformities in observed in 2-6 days post fertilization (dpf) fish larvae for each replicate pool of eggs (Table E-14) (David Janz, pers. comm.). TRAP analysis of these data produced a very low EC10 of 7.0 mg/kg egg Se dw. The concentration-response curve in Figure E-5 is extremely shallow compared to similar tests on other species, such that the apparent sensitivity of zebrafish relative to other species depends on what level of effect is considered. A comparison of egg-ovary zebrafish concentration-response curves for survival and deformities with well-founded concentration-response curves for other species is presented in Figure E-6. The shallow survival and deformity slopes for the zebrafish stand out as atypical for a selenium response. Note the EC50 values for the zebrafish are very similar to the EC50 values for the majority of other fish species and the zebrafish EC90 is similar to the EC90 of the least sensitive fish, Dolly Varden.

A GMCV based on this test has not been included in the Sensitivity Distribution for several reasons. Although the deformity and survival EC50s are within the range observed for a number of other species, the concentration-response curves

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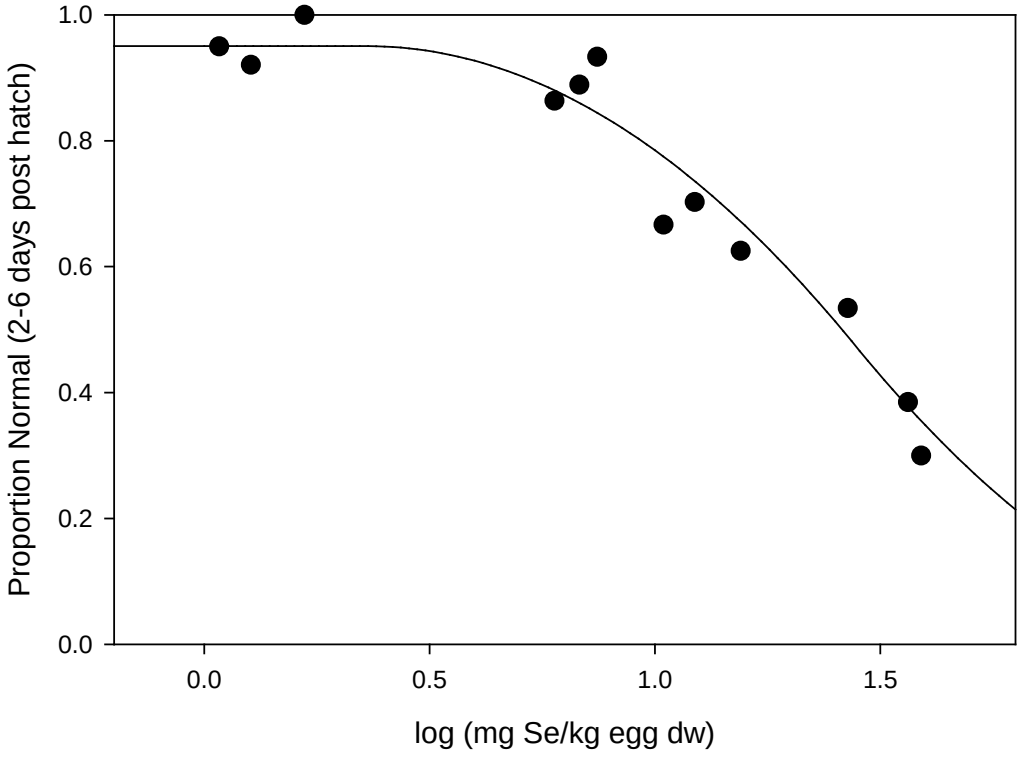
for both deformities and survival are anomalously shallow, yielding EC10s far below that of any other sensitive species (Figure E-6). Furthermore, if the concentration-response curves are log-symmetrical, as generally has been assumed in estimating EC10s, the projected EC90s for zebrafish would place it among the least sensitive known species**,** indicating greater variability among individuals within this one species than among individuals across the entire class of other fishes represented in the figure. The implication of such a shallow concentration-response curve is that this species has exceptional genetic diversity with respect to selenium tolerance, such that populations could adapt to very high or very low selenium concentrations. The field significance of its exceptionally low EC10 is thus uncertain. The low EC10 might or might not have some relationship to the selenium deficiency reported by Hook (2008) in substantial portions of its home range in the Ganges and Brahmaputra basins in India and Bangladesh.

An assessment of the relative sensitivity of cyprinids using both field and laboratory data is provided in the following section (Part II).

Table E-14. Selenium concentrations in zebrafish eggs and deformities in 2-6 dpf larvae.

Se in eggs, mg.kg dw	Total	Deformed	% Deformity
1.67	35	0	0.00
1.27	63	5	7.94
1.08	40	2	5.00
5.99	44	6	13.64
7.45	45	3	6.67
6.80	36	4	11.11
12.26	37	11	29.73
10.46	39	13	33.33
15.51	48	18	37.50
38.98	30	21	70.00
36.44	65	40	61.54
26.81	88	41	46.59

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Parameter Summary:

Parameter	Initial	Final	Std. Error	95%LCL	95%UCL
LogX50	1.45	1.4421	0.0408	1.3632	1.5247
Standard Deviation	0.44	0.4421	0.0586	0.3514	0.5964
Y0	0.95	0.9503	0.0184	0.9	0.9799

Effect Concentration Summary:

%Effect	ECx	95%LCL	95%UCL
90	65.15	45.28	93.73
50	27.79	23.08	33.47
20	11.12	8.647	14.29
10	7.004	4.884	10.04
5	5.053	3.208	7.958

Figure E-5. Tolerance distribution model (triangular distribution model shape) of the proportion of normal zebrafish larvae (1-fraction with deformities) vs. the logarithm of concentration of selenium in zebrafish eggs.

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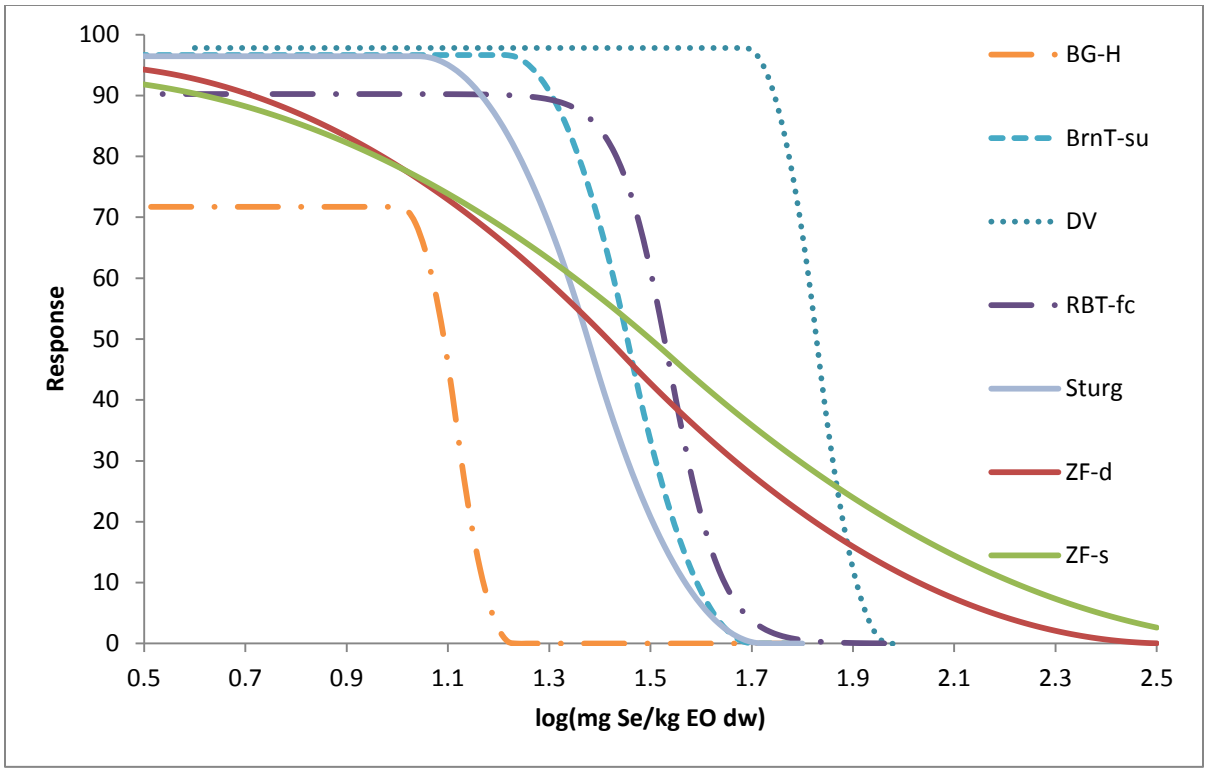


Figure E-6. Thomas and Janz (2014) zebrafish concentration-response curves for deformities and survival, ZF-d and ZF-s, compared with representative concentration-response curves for other species spanning the full range of EC10s.
BG-H: bluegill, Hermanutz et al. (1992, 1996); BrnT-su: brown trout survival to swim-up (Formation 2011); DV: Dolly Varden, Golder (2009; RBT-fc: rainbow trout facial-cranial deformities, Holm (2002) and Holm et al. (2003, 2005); Sturg: sturgeon deformities, Linville (2006).

4.1.2 Part II - Evaluating Sensitivity of Cyprinids (Cyprinidae) to Selenium from Field and Laboratory Data

Background:

The draft selenium criteria document is based on reproductive effects (mortality deformities) to larval fish following maternal exposure. These chronic tests are based primarily on species from the families salmonidae and centrarchidae. There is a paucity of data for a number of fish families used for development of selenium criteria. This limitation in data is particularly notable for the family cyprinidae ("minnows"), because it is comprised of approximately 180 general and is one of the most diverse families in North America. A recent toxicity test with zebrafish (*Danio rerio*), discussed above in Part 1, indicated that some cyprinids may be markedly more sensitive to the effects of selenium than other fish families for which toxicity data are available. This study was very different than all previous studies

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examining larval effects in that the slope was very shallow, whereas the slopes for all other species were steep (see Figure E-6).

This analysis considers the results of the zebrafish laboratory survival study and several field collection studies, which evaluated cyprinid abundance and diversity in watersheds impacted by selenium, to compare the sensitivity of the zebrafish evaluated by Thomas (2014) and Thomas and Janz (2014) to native cyprinid populations. Available water and whole body tissue selenium concentrations (> 8.0 mg/kg dw), were compared to the translated egg-ovary to whole body zebrafish EC10 values (~ 3.5 mg/kg dw) to evaluate the relative sensitivity of native cyprinids to the non-native zebrafish test outcome.

Executive Summary:

The occurrence and effect of selenium on native cyprinids were evaluated based on the results of field studies conducted in four aquatic systems (CO, NC, UT, and WV) having elevated selenium concentrations. The objective of this evaluation was to compare the sensitivity of native cyprinid populations with the results of a recent toxicity test with zebrafish (*Danio rerio*) (Thomas (2014), Thomas and Janz (2014)) that suggests some cyprinids may be markedly more sensitive to the effects of selenium than other fish families for which toxicity data are available. The following set of analyses evaluated studies of widely-distributed native cyprinid species occurring in waters impacted by selenium from various sources and the relationships between whole body tissue levels, (and water concentrations where available) and impacts from selenium via toxicity or population metrics.

Cyprinid genera representing many species native to the US were found to be present in waters with selenium concentrations exceeding the current national criteria value (5µg/L). Cyprinid species present in the four studies examined represent 169 of the approximately 180 species present (at the genus level) in the United States. Abundance and diversity at sites impacted by selenium (water concentrations > 5.0 µg/L) were found to be no different than at sites in the Arkansas River, Colorado with low selenium concentrations (3.0-3.5 µg/L) watershed, with the exception of one location where extremely high selenium concentrations (Wildhorse Creek, CO; approximately 413 µg Se/L) were detected.
Whole body tissue concentrations within several widely distributed cyprinid genera exceeded the proposed whole body tissue element of 8.0 mg/kg dw and had sustainable reproducing populations, as indicated by length frequency analysis and occurrence data for the four studies. When evaluated by itself, the influence of selenium whole-body concentration in reducing family Cyprinidae densities was not statistically significant ($R^2 = 0.02$; $p = 0.51$). Rather, substrate characteristics of the waterbodies sampled had the strongest influence. In contrast, when evaluated by itself, the influence of selenium whole-body concentration in reducing family Centrarchidae densities was significant ($R^2 = 0.53$; $p = 0.02$).

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In spite of the potential for confounding factors, GEI (2008) obtained parallel results at a different location, Dixon Creek and Canadian River in Texas, affected by refiner effluent selenium. Again, selenium whole-body selenium had no relationship to cyprinid density ($R^2 = 0.00$) but was a significant negative factor for centrarchid density ($R^2 = 0.41$, $p = 0.003$). And in the Sand Creek Drainage, CO, GEI found no negative association between fathead minnow densities and selenium concentrations of 3-26 mg Se/kg whole-body dw and 8-45 mg Se/kg ovary dw.

These findings suggest that native cyprinids are less sensitive than centrarchids, and are thus likely to be protected by a national criterion based heavily on centrarchid and salmonid sensitivity. Based on these available data, native cyprinids appear to have a tolerance to selenium that is greater than centrarchid and salmonid species, and much greater than indicated by the non-native zebrafish test outcome. It is therefore expected that the proposed selenium criterion will be protective of native cyprinids occurring throughout the United States.

Laboratory Exposures:

1. Chronic Toxicity and Hazard Assessment of an Inorganic Mixture Simulating Irrigation Drainwater to Razorback Sucker and Bonytail. Hamilton et al. (2000). USGS CERC Laboratory

Toxic effects from inorganics associated with irrigation activities, and possibly contributing to the decline of endangered fish in the middle Green River, Utah were investigated. Two 90-day chronic toxicity studies were conducted with two endangered fish, razorback sucker (*Xyrauchen texanus*) and bonytail chub (*Gila elegans*). Swim-up larvae were exposed in a reconstituted water simulating the middle Green River. The inorganic mixtures were tested at 1X, 2X, 4X, 8X, and 16X the measured environmental concentrations of the evaluated inorganic constituents (2 ug/L arsenic, 630 ug/L boron, 10 ug/L copper, 5 ug/L molybdenum, 51 ug/L selenate, 8 ug/L selenite, 33 mg/L uranium, 2 ug/L vanadium, and 20 ug/L zinc).

Bonytail chub survival was 95% or greater at 30, 60, and 90 days except for the 16X treatment (1232 ug/L Se), whereas growth was reduced after 30, 60, and 90 days at the 8X treatment (532 ug/L Se). Swimming performance of bonytail chub was reduced after 90 days of exposure at the 8X treatment. Whole-body residues of copper, selenium, and zinc increased in a concentration-response manner, but did not increase at 90 days of exposure at the 8X treatment for most species tested, and at lower treatment concentrations for the bonytail chub. Mean whole body selenium residues at the 8X treatment were 23.3, 16.7, and 9.4 mg/kg Se dw at 30, 60 and 90 days respectively. Hamilton et al. (2000) concluded that adverse effects in bonytail chub were associated with whole-body concentrations of 9.4 to 10.8 mg/kg Se dw in this study. One key uncertainty is the effect that the combination of toxic elements, in contrast to selenium alone, had on outcomes measured in this study. However, basing the selenium toxicity

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evaluation on exposure to multiple contaminants is expected to provide a more conservative estimate of effect on the bonytail chub (*Gila elegans*) than if selenium is tested alone.

Field Collection Studies

2. Selenium Tissue Thresholds: Tissue Selection Criteria, Threshold Development Endpoints, and Potential to Predict Population or Community Effects in the Field. Part III: Field Application of Tissue Thresholds: Potential to Predict Population or Community Effects in the Field. NAMC Report (2008).

Field studies were conducted by GEI in the Arkansas River, CO mainstem and selected tributaries between 2005 and 2006 to examine the relationship between selenium concentrations as well as habitat characteristics in surface waters and cyprinid abundance and diversity in the Arkansas River. The data collected for the study included:

1) Seasonal fish and macroinvertebrate (not shown) sampling to determine species composition and the relative abundance of aquatic organisms);
2) Whole-body fish tissue, composite macroinvertebrate tissue (not shown), and water and sediment (not presented) sample collection for the evaluation of Se concentrations in these tissues and the evaluation of bioaccumulation pathways; and
3) Physical habitat measurements (not presented), to determine relationships between the occurrence of biota and their physical environment. Data were collected from fall 2004 to fall 2006 from the Arkansas River, Fountain and Wildhorse Creeks, and the St. Charles River.

Total selenium (dissolved) was measured at 4 sites mainstem and 6 sites on three tributaries of the Arkansas River watershed near Pueblo Colorado (Table E-15). Multiple site visits (6 to 17) to collect water for selenium determination were conducted at the 10 sampling stations between 2005 and 2006.

Table E-15. Selenium water column data: Total Selenium (µg/L, dissolved).

Site	Sampling Duration 2005-06	Sample Size	Mean [Se] (µg/L)	Standard Deviation
AR (Arkansas River)				
AR1 (ARM) Mainstem, in Pueblo below Whitlock WWTP	8 months	15	7.05	3.69
AR2 (ARE) Mainstem below Pueblo WW Reclamation Center and Fountain Creek	12 months	9	10.6	4.06
AR3 (ARB) Mainstem, downstream of Pueblo	10 months	7	8.72	4.0
AR4 (ARN) Mainstem, downstream of St. Charles River	10 months	8	8.81	2.85

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Site	Sampling Duration 2005-06	Sample Size	Mean [Se] (µg/L)	Standard Deviation
Arkansas River Tributaries				
WHC (Wildhorse Creek)	6 months	17	418	115
FC (Fountain Creek)				
FCP (Upstream)	12 months	9	3.43 (4.9)*	1.05
FC4 (Downstream)	6 months	12	12.1	4.34
SC (St. Charles River)				
SC1 (Upstream)	6 months	6	3.09 (4.8)*	1.37
SC2 (Mid-Point)	6 months	11	11.7	6.22
SC5 (Downstream)	8 months	13	20.3	13

* Maximum [Se] in FCP and SC1 < 5.0 ug/L, current selenium criterion

Summary of Selenium Concentrations in Water:

1) Total selenium concentrations exceeded the EPA chronic selenium standard of 5 µg/L in surface water samples collected from most locations, with only the upper reaches of the St. Charles River and Fountain Creek having mean selenium concentrations below the EPA chronic selenium standard.
2) Selenium concentrations in water samples from Wildhorse Creek were more than 20X greater than in water samples collected from all other sample locations, with a mean selenium concentration of 418 ± 115 µg/L.
3) The minimum concentration measured in water samples from Wildhorse Creek (315 µg/L) was approximately 7X greater than the maximum selenium concentration measured at other study sites (43.6 µg/L at St. Charles River, SC5).

Selenium in Fish Tissue:

Selenium concentrations in fish tissue (whole body) were measured for three representative cyprinid species (central stoneroller, sand shiner, red shiner), one catostomid (white sucker), and three centrarchids (green sunfish, smallmouth bass, and largemouth bass) (Table E-16).

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Table E-16. Mean fish tissue concentrations.
[Average whole body mg/kg dw estimated by eye from graphs in NAMC (2008)].

Sample Site	ARM	ARN	ARE	ARB	WHC	FCP	FC4	SC1	SC2	SC5
Mean water [Se] ug/L	7.0	8.8	10.6	8.7	418	3.43	12.1	3.1	11.7	20.3
Cyprinids										
Sand Shiner	10	10-21	25			10-17	15-21			
Red Shiner		23	42				25			30
Central Stoneroller	8	10-20			18-47	12	14	5	45	33
Centrarchids										
Green Sunfish								12	30	
Largemouth Bass	11-15	14-36	22	26						40
Smallmouth Bass	7		20	20						
Catostomids										
White sucker	8-11	10-24	16-18	14-21	32-33	6-10	24	6-14		47

Summary of selenium in fish tissue:

1) The mean concentrations in all cyprinids across all sites was 21.06 mg/kg dwt; SE = 1.38).
2) For comparison, the mean concentration in all centrarchids across all sites was 19.73 mg/kg dw; SE = 1.32; and the mean concentration in white sucker (catostomids) across all sites was 17.52 mg/kg dw; SE = 1.52.
3) Most mean whole-body Se concentrations were well above the U.S. EPA (2014) proposed chronic tissue criterion element for whole body of 8.13 mg/kg dry weight.

Comparison to national draft fish tissue criteria:

Given that these are waters known to be impacted by selenium there were only a few fish samples (Tables E-17, E-18) that were at or below the proposed whole body criteria element of 8.1:

1) The Arkansas River mainstem (mean water [Se] = 7.05 ug/L), had samples from three species that met the criteria in 2006, central stoneroller, smallmouth bass and white sucker.
2) In the tributaries to the Arkansas River that were sampled, white sucker in both Fountain Creek (mean water [Se] = 3.43 ug/L) and St. Charles River met the whole body criteria in 2004 and 2005, whereas the only cyprinid to meet the proposed whole body criterion was the central stoneroller in 2005.

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Cyprinid Abundance and Diversity:

Table E-17. Cyprinid Diversity (native spp. present– excludes carp): NAMC 2008 Study.

Site	[Se] in water ug/L	2005	2006
Arkansas River Mainstem			
ARM	7.05	1/6	3/6
ARB	8.72	6/6	5/6
ARN	8.81	5/6	3/6
ARE	10.6	5/6	4/6
Arkansas River Tributaries			
Fountain Creek			
FCP	3.43	5/6	4/6
FC4	12.1	4/6	6/6
Whitehorse Creek (WHC)	413	1/6	1/6
St. Charles River			
SC1	3.09	5/6	5/6
SC2[1]	11.7	4/6	NS
SC5	20.3	6/6	5/6

[1]SC2 only sampled in 2005

Table E-18. Cyprinid Abundance (native spp. present– excludes carp): NAMC 2008 Study

Site	[Se] in water ug/L	2005	2006
Arkansas River Mainstem			
ARM	7.05	8	460
ARE	8.72	643	950
ARB	8.81	697	521
ARN	10.6	446	116
Arkansas River Tributaries			
Fountain Creek			
FCP	3.43	746	2352
FC4	12.1	1978	1825
Whitehorse Creek (WHC)[1]	413	926	81
St. Charles River			
SC1	3.09	2920	14583
SC2[2]	11.7	2757	NS
SC5	20.3	3102	2568

[1]Whitehorse Creek comprised 1 species, central stoneroller
[2] SC2 not sampled in 2006

Summary of cyprinid abundance and diversity:

1) Diversity as well as abundance of cyprinids in the tributaries vs the Arkansas River mainstem more likely a function of habitat and/or predator density rather than influence of selenium.
2) Several sites on Wildhorse Creek, Fountain Creek, and the St. Charles River, had substantial changes in the populations of some fish species between sample years 2005 and 2006, with fish that were present in one year in high numbers and with a variety of age classes, either

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absent or present in low numbers the other year. These changes are likely to be linked to higher stream flows present in 2006 and significant habitat changes due to beaver activity at some sites. Variable population compositions and numbers of cyprinids are not uncommon in plains streams with highly variable flow regimes and habitat conditions (Schlosser 1987).

3) Based on an evaluation of age class distribution (indicated by length-frequency distribution data), it was concluded that the following sites had viable and reproducing cyprinid populations (NAMC 2008:

> Arkansas River mainstem: The length-frequency data collected for the fish species at these sites indicates multiple age groups present for most of the species at the sites.
> Fountain Creek - Length-frequency analysis of the flathead chubs indicated that the populations are reproducing, with juvenile and older adult fish present in relatively high numbers at both sites and years.
> St. Charles River - Length-frequency analysis of the fish populations indicated that sites had reproducing populations of central stonerollers, fathead minnows, and sand shiners, with juvenile and adult fish collected during both years (GEI 2007a).
> Wildhorse Creek - the age class distribution of central stonerollers was similar between years, indicating a reproducing population that includes both juvenile and adult fish in both years, despite the extremely high [Se] in water.

Relevance/Surrogacy of Arkansas River Cyprinids to all Cyprinid Species in US

Cyprinids captured from the Arkansas River are representative of cyprinid species occurring throughout the US. This conclusion is based on the following lines of evidence:

- Six of the seven cyprinid species (central stoneroller, fathead minnow, flathead chub, longnose dace, red shiner, and sand shiner) captured from the Arkansas River during this investigation are native to the United States;
- Four of the six cyprinid species found in the Arkansas River basin (central stoneroller, fathead minnow, sand shiner and red shiner) are widely distributed throughout the United States (see species specific distribution maps Attachment 1); and,
- Six of the native species present in the Arkansas River Basin are direct surrogates at the genus level for the 142 native cyprinids in North America (Table E-19).

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Table E-19. Cyprinid species surrogacy and occurrence in water for native species inhabiting the Arkansas River and select tributaries.

Species	Cyprinid group	# of species represented by genus	[Se] in waterbodies where species occurred	Average tissue concentration or range
Campostoma anomalum Central stoneroller	stonerollers	5 species	3.1-418 ug/L	5-47 mg/kg dw
Pimephales promelas Fathead minnow	Blunthead minnows	4 species	3.1 - 20.3 ug/L	No tissue
Platygabio gracilis Flathead chub	Flathead chub	1 species	3.1 - 20.3 ug/L	No tissue
Rhynichthys cataractae Longnoise dace	dace	9 species	3.1 - 20.3 ug/L	No tissue
Cyprinella lutrensis Red shiner	Satinfin shiners	32 species	3.1 - 20.3 ug/L	23-42 mg/kg dw
Notropis stramineus Sand shiner	Eastern shiners	91 species	3.1 - 20.3 ug/L	10-25 mg/kg dw

Summary cyprinid surrogacy:

Cyprinid species collected from the Arkansas River watershed are representative (at the genus level) of the 142 cyprinid species native to North America. With the exception of one sample location (Whitehorse Creek), the abundance and diversity of cyprinid species present and the occurrence of multiple age classes indicates that cyprinids are successfully surviving and reproducing in the Arkansas River watershed, even with selenium concentrations exceeding 5ug/L in water and 8 mg/kg bw in whole body fish tissue. North American species not represented at the genera level comprise 54 species (mostly chubs – 40 species), many of which are geographically isolated.

3. Observations of cyprinids in NC Reservoirs (Hyco Reservoir and Belews Lake) – (located at end of NAMC 2008 report).

Crutchfield et al. (2000) evaluated long-term water quality data, selenium chemical concentration data collected for sediment, invertebrate and fish tissues, and invertebrate and fish population data collected from the Hyco Reservoir to document the recovery of the aquatic community following the 1990 installation of a dry fly ash pollution abatement system. Since 1973, data have been collected from six locations in the Hyco Reservoir, with varying fly ash exposure. Gamefish including bluegill sunfish and largemouth bass were reproductively extirpated due to high selenium concentrations prior to installation of the pollution abatement system. The fish community was dominated by green sunfish (*Lepomis cyanellus*), eastern mosquitofish (*Gambusia holbrooki*), gizzard shad (*Dorosoma cepedianum*), and satinfin shiner (*Cyprinella analostana*). Their main observation was that satinfin shiner was a dominant cyprinid in the Se limited fish community prior to selenium reduction.

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Barwick and Harrell (1997) evaluated fish population monitoring and tissue selenium concentration data to document the recovery of fish populations in Belews Lake for the ten years following installation of a dry fly ash pollution abatement system. Fish diversity and biomass data were collected from 1977 to 1994 (with the exception of 1978-1979 and 1982-1983) at two sites on the lake. In 1980 and 1981, fathead minnows (*Pimephales promelas*) dominated the fish community, representing 62 percent and 81 percent of the biomass, respectively (Barwick and Harrell 1997). By 1984, red shiner (*Cyprinella lutrensis*), common carp (*Cyprinius carpio*), and fathead minnows (*Pimephales promelas*) were the dominant cyprinids in the selenium limited fish community prior to selenium reduction. The authors noted that cyprinid abundance started to decrease as green sunfish, a more Se- tolerant sunfish recovered in 1989-1990, followed by further decreases in 1990-1994, as channel catfish, bluegill, and largemouth bass populations increased (Barwick and Harrell 1997).

Young et al. (2010), reviewing the studies of Belews Lake, NC, note that during the period of maximal selenium inputs, egg and ovary concentrations reached 40-159 mg Se/kg dw. Out of as many as 29 resident species prior to contamination, only catfish and the cyprinids common carp and fathead minnows remained during the period of maximum impact.

4. Presser, T.S., 2013, Selenium in ecosystems within the mountaintop coal mining and valley-fill region of southern West Virginia—assessment and ecosystem-scale modeling: U.S. Geological Survey Professional Paper 1803, 86 p. http://dx.doi.org/10.3133/pp1803.

USGS sampled southern West Virginia ecosystems affected by drainage from mountaintop coal mines and valleys filled with waste rock (valley fills) in the Coal, Gauley, and Lower Guyandotte watersheds during 2010 and 2011. Sampling data from earlier studies in these watersheds (for example, Upper Mud River Reservoir) and other mining-affected watersheds in WV are also are included to assess additional hydrologic settings and food webs for comparison.

1) Site-specific fish abundance and richness data documented the occurrence of various species of chub, shiner, dace, minnow, and central stoneroller (*Campostoma anomalum*) in the sampled watersheds.
2) Model species for streams were limited to creek chub (*Semotilus atromaculatus*) and central stoneroller. Creek chub was present at all sites during USGS sampling in 2010-2011. However, both of these species are considered to have high tolerance for environmental stressors based on results of traditional comparative fish community assessments. Concentrations of Se in water and whole body tissues of creek chub, blacknose dace, and stoneroller are shown in Table E-20.
3) The order of abundance for species with greater than 28 individuals was: creek chub, striped shiner, mottled sculpin, green sunfish, central stoneroller, blacknose dace, bluntnose minnow, and northern hog sucker. Shiners and darters were prevalent, but bluegill sunfish were absent during the 2010 survey.

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Table E-20. Se in fish whole body tissue samples: Upper Mud River Basin and Tributaries.
(Compilations of data from different sources presented in (Presser et al. 2013).

Stream Segment	Year	[Se] in water Mean (Range) in ug/L	Creek Chub Mean (Range) in mg/kg dw	Blacknose Dace Mean (Range) in mg/kg dw	Stoneroller Mean (Range) in mg/kg dw
Upper Mud River	2011	10.5, 18.2	9.0 (6.4–11)	Not Sampled	Not Sampled
Upper Mud River 1	2010	Not Sampled	10.3 (9.4–10.9)	Not Sampled	Not Sampled
Lower Mud River	2008	7.9	10.3 (9.4-15.4)	Not Sampled	Not Sampled
	2011	5.2, 7	9 (6.4-11)	Not Sampled	Not Sampled
Upper Mud River 2 (above Upper Mud River 1)	2005	9.8 (4–22)[1]	2.9 (<1-8.7)	Not Sampled	Not Sampled
	2006	Not Sampled	5.6 (2.2-10)	Not Sampled	Not Sampled
	2007	Not Sampled	7.7 (3.7-10)	Not Sampled	Not Sampled
Berry Branch	2009-2010	8.3 (1.7–18)[2]	4.0 (3.3–5.0)	9.6 (7.8–13)	Not Sampled
Stanley Fork	2009-2010	6.0 (3.0–7.4)[3]	10.3 (7.2–13)	Not Sampled	Not Sampled
Lower Kanawha River Watershed					
Little Scary Creek	2006	20	Not Sampled	55	Not Sampled
	2009	31.4 (23-42)	28 (3-80)	Not Sampled	Not Sampled
Connor Run	2009	47.8 (4-90)	(21-36)	Not Sampled	Not Sampled
Upper Kanawha River Watershed					
Jack's Branch Mining Complex					
Bull push fork w/pond	2010	9.0-10.0	Not Sampled	66 (19–113)	Not Sampled
Bull push fork downstream	2010	9.1–10	8.6 (6.2–13)	10.7 (5.5–14)	6.9 (3.1–17)
Hughes Fork	2005 - 2007	5.3 (2–10)	7.8 (4.1–10.9) 2005 7.9 (2.7–12.9) 2007	Not Sampled	12.4 (0.5–34.5) 2005
Hughes Creek	2010-2011	2.1-13	9.9 (3.7–17)	16.9 (6.8–25)	9.0 (3.6–14)
Big Coal River Watershed					
Beech Creek	2005-2007	Not Sampled	(3-18)	Not Sampled	Not Sampled
Seng Creek	2005-2009	27.5 (15–42)	8.2 (4.8–14.7)	Not Sampled	Not Sampled
	2011	23.3	8.1 (5.4-10)	Not Sampled	Not Sampled
White Oak Creek	2005-2007	15.8 (8–27)	5.8 (<1-12.8)	Not Sampled	7.1 (2.5–12.8)

[1] Water samples collected between 2005 and 2008.
[2] Water samples collected in 2009 and 2010.
[3] Water samples collected in 2009 and 2010.

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Study Summary:

Samples in various environmental media (water, sediment, algae, macroinvertebrates, fish) were collected by USGS (2010-2011), and others (e.g. WVDEP, Potesta) between 2005 and 2011. The stream segments presented here represent a subset of the stream segments with available data. Only streams with water [Se] > 5.0 ug/L are presented to facilitate comparison with other studies with Se-impacted streams. Overarching observations include:

1) [Se] in water averaged from 5.3 ug/L – 31.4 ug/L with a high of 90 ug/L (Connor Run, 2009).
2) [Se] in fish tissue: creek chub – averaged from 5.8 mg/kg wb to 28 mg/kg wb, with a maximum whole body concentration of 80 mg/kg wb (Little Scary Creek, 2009).
3) [Se] in fish tissue: blacknose dace – averaged from 10.7 mg/kg wb to 66 mg/kg wb, with a maximum whole body concentration of 113 mg/kg wb (Bull push fork w/pond, 2010)
4) [Se] in fish tissue: central stoneroller – averaged from 6.9 mg/kg wb to 12.4 mg/kg wb, with a maximum whole body concentration of 34.5 mg/kg wb (Hughes Fork, 2005). Note also, that central stoneroller, although common through stream segments samples, were not ubiquitous, as was observed in the study conducted by NAMC in the Arkansas River near Pueblo CO.

5. Selenium concentrations in fish tissue collected from the Gunnison River.
http://pubs.usgs.gov/of/2012/1235/of12-1235.pdf

Approach: In sampling conducted in summer 2010, muscle tissue plugs were collected from common carp (*Cyprinus Linnaeus)*, roundtail chub (*Gila robusta; listed*), and whole body tissue samples were collected from speckled dace (*Rhinichthys osculus)* inhabiting critical habitat in the Gunnison River in Western Colorado (Table E-21). Total selenium in fish muscle plugs (mg/kg dw) for roundtail chub, or in whole body (speckled dace) was calculated for all tissues. In follow-up sampling conducted in the summer of 2011, muscle plugs were collected from common carp (*Cyprinus Linnaeus)*, roundtail chub (*Gila robusta; listed*), and bonytail chub (*Gila elegans, listed*) inhabiting critical habitat in the Gunnison River in Western Colorado.

This study was intended to document any changes in selenium concentration in fish over the last 20 years based on remediation efforts that have been completed to date.

Table E-21. Fish tissue concentrations observed in Cyprinids.

Species	**Year**	**Mean (Range) [Se]**	**# > muscle = 11***	**# > whole body = 8**
Roundtail Chub	2010	9.7 mg/kg dw (5.2-32.4)	2/15	
	2011	7.33 mg/kg dw (5.6-11.2)	1/15	
Speckled Dace	2010	7.46 mg/kg dw (5.7-9.7)		6/15

* Muscle plugs were collected since this species is large enough for non-destructive sampling, and b) a listed species.

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5.0 OTHER DATA – CHRONIC STUDIES WITH INVERTEBRATE SPECIES

A limited number of studies have evaluated the effects of selenite on invertebrate species, an important prey item for fish and birds as summarized by Debruyn and Chapman (2007). The following **studies** with a rotifer, and annelid, and an insect (mayfly) were found suitable for establishing species sensitivity.

5.1 Rotifers

Dobbs et al. (1996) exposed *Brachionus calyciflorus* to selenate in natural creek water for 25 days in a three-trophic level food chain test system. This is one of two laboratory-based experiments (also see Bennett et al. 1986) that involved exposing algae to selenium (in this case as sodium selenate) in water, and subsequently feeding the algae to rotifers which were in turn fed to fish (fathead minnows). In this particular study, the rotifers and fish were exposed to the same concentrations of sodium selenate in the water as the algae, but received additional selenium from their diet (i.e., the algae fed to rotifers and the rotifers fed to fish). The overall exposure lasted for 25 days. Rotifers did not grow well at concentrations exceeding 108.1 µg Se/L in water, and the population survived only 6 days at selenium concentrations equal to or greater than 202.4 µg Se/L in the water (40 µg Se/g dw in the algae). Regression analysis of untransformed growth data (dry weight) determined 4 day post-test initiation resulted in a calculated EC_{10} of 37.84 µg Se/g dw tissue.

5.2 Aquatic Worms

Although not intended to be a definitive toxicity study for this invertebrate, Besser et al. (2006) evaluated the bioaccumulation and toxicity of selenized yeast to the oligochaete, *Lumbriculus variegatus,* which was intended to be used for dietary exposure in subsequent studies with the endangered desert pupfish, *Cyprinidon macularius*. Oligochaetes fed selenized-yeast yeast diets diluted with nutritional yeast (54 to 210 mg Se/kg) had stable or increasing biomass and accumulated Se concentrations as high as 140 mg/kg dw. The oligochaetes fed the undiluted selenized-yeast (826 µg/g Se dry wt.) showed reduced biomass. The effect level is considered >140 mg Se/kg dw.

5.3 Aquatic Insects (Plecoptera: Mayfly)

Conley, J.M., D.H. Funk and D.B. Buchwalter. 2009. Selenium bioaccumulation and maternal transfer in the mayfly *Centroptilum triangulifer* in a life-cycle, periphyton-biofilm trophic assay. Environ. Sci. Technol. 43:7952-7957.

Conley, J.M., D.H. Funk, N.J. Cariello and D.B. Buchwalter. 2011. Food rationing affects dietary selenium bioaccumulation and life cycle performance in the mayfly *Centroptilum triangulifer*. Ecotoxicol. 20:1840-1851.

Conley, J.M., D.H. Funk, D.H. Hesterberg, L-C. Hsu, J. Kan, Y-T. Liu and D.B. Buchwalter. 2013. Bioconcentration and biotransformation of selenite versus selenite exposed to periphyton and subsequent toxicity to the mayfly *Centroptilum triangulifer*. Environ. Sci. Technol. 47:7965-7973.

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Conley et al. (2009) exposed mayfly larvae (*Centroptilum triangulifer*) to dietary selenium contained in natural periphyton biofilms to eclosion. The periphyton fed to the mayfly larvae were exposed to dissolved selenite (radiolabeled ^{75}Se) in November 2008 (12.6 and 13.9 µg/L) and in January 2009 (2.4, 2.4, 4.9, 10.3, and 10.7 µg/L). Periphyton bioconcentrated Se an average of 1113-fold over the different aqueous Se concentrations (Table E-22). Twenty 4 to 6-day old mayfly larvae were exposed for 4.5 to 6 weeks to each of the periphyton diets until the larvae eclosed to subimagos. The subimagos were allowed to emerge to the adult imago stage which deposited their egg masses in Petri dishes. Selenium was measured in postpartum adults along with their dry weights and clutch size.

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Table E-22. Selenium concentrations in water exposed to periphyton, periphyton and mayfly adults.

Treatment	Dissolved [Se] exposed to periphyton, µg/L	[Se] in periphyton, mg/kg dw	[Se] in mayfly adult, mg/kg dw
5A	2.4	2.2	4.2
5B	2.4	2.0	5.7
10A	4.9	4.4	9.7
20C	10.3	8.7	16.2
20D	10.7	11.3	27.5
20A	12.6	25.5	56.7
20B	13.9	17.5	34.8

Selenium increased in concentration from periphyton to the adult mayflies (trophic transfer factor) an average of 2.2-fold (Table E-22). The authors observed a decrease in fecundity as maternal postpartum Se concentrations increased. Fecundity was also related to growth of the mayflies. The authors observed a reduction in fecundity for this mayfly when they were fed diets containing more than 11 mg Se/kg dw. This threshold is considered the effect value for this study. Using the trophic transfer factor of 2.2, the periphyton Se concentration of 11 mg/kg dw translates to an adult mayfly Se concentration of 24.2 mg/kg dw.

Conley et al. (2011) exposed larval *C. triangulifer* similar to Conley et al. (2009) to two different rations of periphyton (1x and 2x) to evaluate the effect of feeding ration on the bioaccumulation and life cycle performance of the mayfly. Periphyton (on plates) was initially exposed to low (1.1 to 3.4 µg/L), medium (5.9 – 8.9 µg/L) and high (19.2 – 23.1 µg/L) selenite. Fifteen 1-2 day-old mayfly larvae were then fed either 1 plate (1x ration) or 2 plates (2x ration) in bottles containing 1.8 L water to eclosion to subimagos (25-29 days). Subimagos were induced to emerge to adults in petri dishes and their clutch size measured through digital imaging. Selenium measurements from this study are given in Table E-23.

Table E-23. Selenium concentrations in water, periphyton and mayfly tissues for two feeding rations.
(Adapted from Table 1 in Conley et al. 2011)

Feeding ration – Se level	Mean dissolved Se exposed to periphyton, µg/L	Mean periphyton, mg Se/kg dw	Mean mayfly tissue, mg Se/kg dw
1x – low	1.1	4.2 ± 0.6 (4)	12.8 ± 3.6 (28)
1x – medium	5.9	11.9 ± 2.1 (4)	31.7 ± 7.5 (15)
1x - high	21.4	27.2 ± 4.2 (4)	68.4 ± 24.0 (9)
2x – low	2.7/3.4[a]	9.5 ± 0.9 (3)	14.1 ± 3.8 (19)
2x – medium	7.1/8.9[a]	19.9 ± 1.6 (3)	21.6 ± 2.8 (22)
2x - high	19.2/23.1[a]	40.9 ± 1.7 (3)	37.3 ± 6.7 (13)

[a] Two values represent two different loading exposures, September and October. The plates were combined for mayfly exposure.

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Mayflies fed the 1x ration had 54% and 72% reductions in survival relative to controls in the medium and high Se treatment levels, respectively, both significant ($p<0.05$). The mayflies fed the 1x ration also had significant reductions in fecundity in the low (44% reduction), medium (63% reduction) and high (77% reduction) Se treatment levels. However, for the mayflies fed the 2x ration, there were no significant differences between the controls and any of the three Se treatment levels for any of the endpoints measured including survival and fecundity. The 2x ration mayflies had 60% more biomass than the 1x ration mayflies. This growth difference explains why the 1x ration mayflies had higher concentrations of Se in their tissues. The two different rations resulted in vastly different effect levels for Se, <12.8 mg/kg dw in the 1x ration test and >37.3 mg/kg dw in the 2x ration. It is apparent from this study that if the mayflies do not obtain sufficient nutrition, they are more sensitive to selenium. Although reduced feeding levels occur in nature, it is a confounding variable in this study that cannot be used to set a chronic effect level for selenium.

Conley et al. (2013) evaluated the accumulation of selenite and selenate into periphyton with subsequent feeding exposure to mayfly larvae. As in his previous studies, *C. triangulifer* larvae were fed periphyton previously exposed to different concentrations of selenium. In this study, periphyton plates were first exposed to low (10 µg/L) and high (30 µg/L) concentrations of either selenite or selenate and then fed to mayfly larvae to ecolsion to subimagos. The selenite and selenate treatment exposures resulted in similar levels of selenium in the subimagos. Since no differences in selenium accumulation was observed, the selenite and selenate treatments could be pooled for measuring the endpoints, survival and secondary production (total mayfly biomass produced). Mean selenium concentrations fed the mayflies were 2.2, 12.8 and 37 mg/kg Se dw in the control, low and high treatments, respectively. Mayfly tissue (subimago) concentrations (extrapolated from Figure 4a in Conley et al. 2013) were approximately 4-7, 20-35, and 45-75 mg/kg Se dw, in the control, low and high treatments, respectively. The authors reported significant reductions in survival from the control in the high Se treatment (both pooled data and individual selenite and selenate treatments) but no significant differences were observed in the low Se treatments. Secondary production was significantly reduced relative to the control in the high Se treatment for both selenium species. For the low Se exposure treatment, secondary production was not significantly different than the control for the selenite treated periphyton exposure, but was for the selenate and pooled data suggesting an effect level between 20 and 35 mg/kg Se dw. These results as well as those observed in 2x ration exposures in Conley et al. (2011) where no effects were observed at 37.3 mg/kg Se dw generally support the chronic value determined for Conley et al. (2009) of 24.2 mg/kg Se dw.

The following invertebrate studies were inconclusive for establishing species sensitivity because of limitations in the experimental designs, as explained for each.

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5.4 Aquatic Insect (Midge: Chironimids)

Malchow et al. (1995) fed fourth instar *Chironomus decorus* midge larvae a diet of seleniferous algae under laboratory conditions for 96 hours. For algae cultured with selenite, a larval tissue concentration of 4.05 µg Se/g dry weight resulted in a 46% reduction in growth relative to the controls. At a larval tissue concentration of 8.6 µg Se/g dry weight, larval growth was reduced by only 39%. Since the study only reported two exposure concentrations, it is unclear if the tissue effect concentration at 4.05 µg Se/g dry weight is real or an anomaly. Additional exposure concentrations and subsequent effect levels are needed to resolve this issue.

Malchow et al. (1995) also fed fourth instar *Chrionomus decorus* midge larvae a diet of algae cultured with selenate, and the midge larvae were exposed under laboratory conditions for 96 hours. A dietary exposure of 2.11 µg Se/g dry weight significantly reduced larval growth (15% reduction) at tissue concentrations of 2.55 µg Se/g dry weight. At a larval tissue concentration of 6.62 µg Se/g dry weight, growth was reduced 20% relative to the controls. The 15-20% reduced growth at larval tissue concentrations 2.55 µg Se/g dry weight may be statistically significant, but not biologically meaningful. In addition, exposure to only two selenium concentrations precludes confirmation of a dose-response.

Alaimo et al. (1994) also exposed *2010* midge larvae to selenite diet, but the selenium source was from field contaminated widgeongrass (*Ruppia maritima*). *Ruppia* stems and leaves were collected from four selenium contaminated evaporation ponds located in the San Joaquin Valley of California. Three-day old larvae were exposed to each of the four treatment diets (*Ruppia* from each pond) plus a Cerophyll control for 14 days (egg to pupation), with the moderately hard reconstituted water renewed at day 7 and every three days thereafter. The growth (weight) of exposed larvae was significantly reduced in all of the selenium treatments when compared to the controls. The lowest effect level was observed for the Westlake pond (primarily selenite), where growth was reduced 40 percent relative to the controls at a larval tissue concentration below the detection level (1.0 ppm dry weight, or 1.0 µg Se/g dry weight). These results are suspect because the field collected *Ruppia* likely contained contaminants other than selenium, the control organisms were fed a different diet (Cerophyll), and the single concentration exposure is difficult to defend.

6.0 OTHER DATA – FIELD STUDY WEST VIRGINIA IMPOUNDMENTS

In response to the USEPA (2004) draft whole fish tissue criterion for selenium, the West Virginia Department of Environmental Protection (2010) initiated a study to assess selenium bioaccumulation among fishes residing in the State's lakes and streams. A focus of the study was the collection and evaluation of bluegill, *Lepomis macrochirus*, larvae (ichthyoplankton) from selected waterbodies since

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2007, based on concerns regarding fish population health at locations subjected to elevated selenium inputs, particularly during the more sensitive developmental life stages of fishes (e.g. yolk-sac larvae). Also, in 2009, WVDEP began acquiring data about selenium concentrations within fish eggs of various species within reference and selenium-impacted waters. WVDEP also conducted deformity surveys of adult fishes in selenium enriched waters as well as at reference locations in 2008-2009.

WVDEP scientists found that larval deformity rates were variable throughout the study duration but were nonetheless correlated with waterborne selenium exposure. Reference locations produced age-based larval bluegill subsamples (24-168 hours) with low deformity rates (0 - 1.27%); whereas, locations with seleniferous inputs exhibited bluegill deformity rates ranging from 0% to 47.56% in developmental stages up to 312 hours. Maximum deformity rates among staged bluegill subsamples as determined through these evaluations were 19.28%, representing specimens collected from selenium-enriched waters. Concentrations of selenium within fish eggs also varied according to study location and ranged from <0.8 mg/kg dry weight among bluegill eggs at the control site to 64.62 mg/kg dry weight among largemouth bass, *Micropterus salmoides,* eggs collected from selenium-enriched waters. Searches for more mature, yet developmentally-deformed fishes revealed increased deformity rates (14%) among largemouth bass residing in a selenium impacted reservoir as compared to deformity rates among largemouth bass found in the reference lake (0%). The data on egg selenium concentrations are not adequate for constructing a concentration-response curve. Nevertheless, the overall deformity rate in the contaminated Upper Mud River Reservoir was 5% among 10,000 individual fish, average egg selenium concentration 9.8 mg/kg dw. The overall deformity rate in the reference Plum Orchard Lake was 0.5% among 13,000 individuals, average egg selenium concentration nondetectable or <0.8 mg/kg dw.

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7.0 OTHER DATA - NUTRITIONAL DEFICIENCY/SUFFICIENCY STUDIES CONTAINING MEASURED SELENIUM IN THE DIET AND WHOLE BODY FISH TISSUE

Ingested dietary dose studies in fish designed to identify nutritionally deficient and/or nutritionally sufficient selenium doses in fish food or prey primarily describe selenium effects on growth, with survival reductions and effects on antioxidant enzyme activity also occasionally reported. A number of the dietary studies have measured a range of dietary doses that maximize fish growth, as opposed to a single dietary dose associated with nutritional sufficiency for growth. Regardless of whether nutritionally sufficient dietary doses are reported as a single concentration or as a range of concentrations, reduced growth or survival is observed at both lower dietary doses (nutritional deficiency) and at higher dietary doses (toxicity).

Although dietary doses are normally presented as selenium concentrations in food, expressed in terms of mg/kg Se in the diet, several studies have also concurrently presented nutritionally deficient/sufficient Se levels in terms of the whole body Se concentration in the fish. These studies permit a comparison of nutritionally deficient/sufficient whole body Se residues in fish to the national criterion for Se in whole bodies of fish. When combined with measured whole body fish tissue residues associated with toxicity, a complete picture of the range of Se residues in whole body fish tissue associated with nutritional deficiency, nutritional sufficiency and toxicity emerges.

Eight fish species have information on both nutritionally deficient dietary doses and whole body concentrations of selenium measured in the same study (Table E-24). Six of the eight species are native to North America. Nutritionally deficient dietary doses of Se range between 0.03 mg/kg dw in Atlantic salmon (*Salmo salar*, Poston et al. 1976) associated with reduced survival to 1.4 mg/kg dw in Atlantic cod (*Gadus morhua,* Hamre et al. 2008), also associated with reduced survival. Whole body Se residues identified as nutritionally deficient range between 0.64 mg/kg dw in Malabar grouper (*Epinephelus malabaricus*) associated with suboptimal weight gain and feed efficiency (Lin and Shiau 2005) and 4.72 mg/kg dw in North African catfish (*Clarias gariepinus*), also associated with suboptimal weight gain (Abdel-Tawwab et al. 2007). The whole body Se residues associated with growth and/or survival reductions due to nutritional deficiency of the six North American species (Prussian carp, Han et al. 2011; common carp, Gaber 2007; Atlantic cod, Hamre et al. 2008; Coho salmon, Felton et al. 1990; cobia, Lin et al. 2010; Atlantic salmon, Poston et al. 1976) all range between 1.0 and 2.7 mg/kg dw.

Ten fish species have information on both nutritionally sufficient dietary doses and whole body concentrations of selenium measured in the same study (Table D-23). Eight of the 10 species are native to North America. Nutritionally sufficient dietary doses of Se for the North American resident species, all but one of which are based on maximum growth of fish, range between 0.1 mg/kg dw in hybrid striped

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bass (Jaramillo 2006) and 6.6 mg/kg dw in rainbow trout (Hilton and Hodson 1983). Several studies have identified a range of dietary doses and associated whole body residues that maximize growth and survival relative to that of fish fed lower dietary doses and which subsequently contain lower whole body selenium residues. Whole body Se residues associated with nutritional sufficiency based on maximal growth and/or survival of all North American species except for hybrid striped bass (Jaramillo 2006) range between 0.2 – 3.63 mg/kg dw (Table D-23). For hybrid striped bass, Jaramillo (2006) observed that maximum weight gain occurred in selenite supplemented diets containing 1.19 mg/kg dw Se, which resulted in whole body Se residues of 5.13 mg/kg dw. Jaramillo (2006) also exposed hybrid striped bass to seleno-DL-methionine supplemented diets containing 0.90 mg/kg dw, which resulted in the maximum weight gain of all seleno-DL-methionine supplemented diets tested, and a whole body Se residue of 7.2 mg/kg dw.

The nutritional sufficiency study of Rider et al. (2009) with rainbow trout is unique in that it determined dietary and whole body selenium requirements for both stressed and unstressed fish. Rider et al. (2009) observed that rainbow trout stressed by a combination of low water levels in holding tanks and twice daily handling of fish by 30 second aerial exposure in dip nets resulted in a higher nutritional requirement for selenium than was observed in fish not subjected to the stress routine. They concluded that trout exposed to physical stressors could benefit from an additional 0.3 – 2.0 mg/kg dw additional selenium supplementation over and above the Se content of nutritionally Se sufficient diets for fish not undergoing stress.

The fish with the highest known nutritional requirement for selenium is the non-North American resident North African catfish (*Clarias gariepinus*). Abdel-Tawwab et al. (2007) determined in a 12 week study with fingerlings that Se dietary doses of 1.04 mg/kg dw and 3.67 mg/kg dw were associated with suboptimal and maximum weight gains of the catfish, respectively. Catfish survival was 100% in both the Se-deficient and Se-sufficient dietary dose exposures during the 12 week study period. The respective whole body selenium tissue residues at the end of the 12 week study were 4.72 mg/kg dw in the Se-deficient fish and 15.43 mg/kg dw in the fish fed the nutritionally sufficient Se diet. North African catfish (Abdel-Tawwab et al. 2007) is the only known fish species with an identified whole body nutritional requirement for Se higher than the national aquatic life criterion for whole body Se in fish.

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Table E-24. Studies with both empirically measured selenium dietary doses and whole body residues associated with nutritional deficiency and sufficiency in fish.

Species	Lifestage / Size Wet wt	Exposure duration	Ingested dietary dose Se mg/kg dry wt.	Se chemical form	Whole body Se mg/kg dry wt	Deficiency or Sufficiency	Deficiency symptoms Basis for sufficiency determination	Reference
Malabar grouper (*Epinephelus malabaricus*)	Juvenile 12.2 g	8 weeks	0.21	Basal diet	0.64	Deficiency	Suboptimal weight gain and feed efficiency	Lin and Shiau 2005
Prussian carp (*Carassius gibelio*)	Juvenile 2.74 g	100 days	0.47	Seleno-methionine	1.0	Deficiency	Suboptimal growth, feeding rate and feed conversion rate	Han et al. 2011
Common carp (*Cyprinus carpio*)	Juvenile 26.9 g	120 days	0.04	Basal diet	1.04	Deficiency	Reduced growth and survival	Gaber 2007
Atlantic cod (*Gadus morhua*)	Larvae 0.16 g (estimated from dry wt of larvae	23 days	1.4	Basal diet	1.1	Deficiency	Larval survival 32% lower compared to larvae fed selenium-enriched diet	Hamre et al. 2008
Cobia (*Rachycentron canadum*)	Juvenile 6.27 g	10 weeks	0.21 - 0.62	0.21 = Basal diet, 0.62 = seleno-DL-methionine	1.13 - 2.11	Deficiency	Statistically significantly reduced specific growth rate and survival	Liu et al. 2010
Coho salmon (*Oncorhynchus kisutch*)	Smolt 22.7 g	Hatchery reared	0.7 - 0.9	Not given	1.974	Deficiency	Survival of hatchery reared smolts 1.5 - 2.0x lower than wild smolts	Felton et al. 1990
Atlantic salmon (*Salmo salar*)	Fry 0.1 g	4 weeks	0.03 - 0.04	Basal diet	2.7	Deficiency	Decreased survival relative to fry fed diet supplemented with 0.1 µg/g Se and 0.5 IU/g vitamin E	Poston et al. 1976
North African catfish (*Clarias gariepinus*)	Fingerling 68.6 g	12 weeks	1.04	Organic Se	4.72	Deficiency	Suboptimal weight gain and specific growth rate	Abdel-Tawwab et al. 2007
Rainbow trout (*Oncorhynchus mykiss*)	Juvenile 0.6 g	16 weeks	0.6 - 6.6	Selenite $Na_2SeO_3 \cdot 5H_2O$	0.2 - 1.0	Sufficiency	No deficiency or toxicity signs on growth	Hilton and Hodson 1983

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Species	Lifestage / Size Wet wt	Exposure duration	Ingested dietary dose Se mg/kg dry wt.	Se chemical form	Whole body Se mg/kg dry wt	Deficiency or Sufficiency	Deficiency symptoms Basis for sufficiency determination	Reference
Atlantic salmon (*Salmo salar*)	Parr 4.5 g	8 weeks	1.2	Basal diet	0.58 - 0.70	Sufficiency	No deficiency signs on growth, survival or glutathione peroxidase activity	Lorentzen et al. 1994
Rainbow trout (*Oncorhynchus mykiss*)	Juvenile 26.3 g	11 weeks	0.77	Basal diet	0.9	Sufficiency	Optimal growth, survival and antioxidant status	Rider et al. 2009
Malabar grouper (*Epinephelus malabaricus*)	Juvenile 12.2 g	8 weeks	0.77	Seleno-methionine	0.92	Sufficiency	Maximal weight gain and feed efficiency	Lin and Shiau 2005
Atlantic salmon (*Salmo salar*)	Parr 4.5 g	8 weeks	3.4	Selenite $Na_2SeO_3 \cdot 5H_2O$	1.13	Sufficiency	No deficiency signs on growth, survival or glutathione peroxidase activity	Lorentzen et al. 1994
Common carp (*Cyprinus carpio*)	Juvenile 26.9 g	120 days	0.24 - 0.32	Selenite $Na_2SeO_3 \cdot 5H_2O$	1.23 - 1.29	Sufficiency	Maximal growth and survival	Gaber 2007
Rainbow trout (*Oncorhynchus mykiss*)	Juvenile 26.3 g	11 weeks	2.3 - 3.9	Selenite $Na_2SeO_3 \cdot 5H_2O$	1.6 - 2.8	Sufficiency	Optimal growth, survival and antioxidant status	Rider et al. 2009
Prussian carp (*Carassius gibelio*)	Juvenile 2.74 g	100 days	1.23 - 2.77	Seleno-methionine	1.7 - 3.4	Sufficiency	Maximal growth, no effect on survival, no increase in oxidative stress	Han et al. 2011
Hybrid striped bass (wiper, *Morone chrysops* x *Morone saxatilis*)	Juvenile 2.94 g	12 weeks	0.10	Basal diet	2.01	Sufficiency	Minimum dietary requirement for acceptable survival and growth	Jaramillo 2006
Atlantic salmon (*Salmo salar*)	Parr 4.5 g	8 weeks	3.1	Seleno-methionine	2.06	Sufficiency	No deficiency signs on growth, survival or glutathione peroxidase activity	Lorentzen et al. 1994
Cobia (*Rachycentron canadum*)	Juvenile 6.27 g	10 weeks	0.85 - 1.36	Seleno-DL-methionine	2.58 - 2.62	Sufficiency	Maximal and statistically identical specific growth rate and survival	Liu et al. 2010

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Species	Lifestage / Size Wet wt	Exposure duration	Ingested dietary dose Se mg/kg dry wt.	Se chemical form	Whole body Se mg/kg dry wt	Deficiency or Sufficiency	Deficiency symptoms Basis for sufficiency determination	Reference
Rainbow trout (*Oncorhynchus mykiss*)	Juvenile 26.3 g	11 weeks	2.4 - 4.1	Organic Se - yeast	2.8 - 4.8	Sufficiency	Optimal growth, survival and antioxidant status	Rider et al. 2009
Atlantic cod (*Gadus morhua*)	Larvae 0.16 g (estimated from dry wt of larvae	23 days	4.8	Selenite $Na_2SeO_3 \cdot 5H_2O$	3.5	Sufficiency	Larval survival increased 32%, growth essentially unchanged relative to survival of larvae fed basal diet	Hamre et al. 2008
Coho salmon (*Oncorhynchus kisutch*)	Smolt 14.28 g	Wild smolts	Se in natural diet unknown	Unknown	3.63	Sufficiency	Survival of wild smolts 1.5 - 2.0x higher than hatchery reared smolts	Felton et al. 1990
Hybrid striped bass (wiper, *Morone chrysops* x *Morone saxatilis*)	Juvenile 2.94 g	12 weeks	1.19	Selenite $Na_2SeO_3 \cdot 5H_2O$	5.13	Sufficiency	Highest weight gain of any selenite diet test, significantly higher than basal diet weight gain	Jaramillo 2006
Hybrid striped bass (wiper, *Morone chrysops* x *Morone saxatilis*)	Juvenile 2.92 g	12 weeks	0.90	Seleno-DL-methionine	7.2	Sufficiency	Highest survival and weight gain of any seleno-DL-methionine diet tested	Jaramillo 2006
North African catfish (*Clarias gariepinus*)	Fingerling 68.6 g	12 weeks	3.67	Organic Se	15.43	Sufficiency	Maximal weight gain, specific growth rate and survival	Abdel-Tawwab et al. 2007

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APPENDIX F: TOXICITY OF SELENIUM TO AQUATIC PLANTS

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1.0 SELENITE

Data are available on the toxicity of selenite to 13 species of freshwater algae and plants (Table F-1). Results ranged from an LC_{50} of 70,000 µg/L for the green alga, *Chlorella ellipsoidea* (Shabana and El-Attar 1995) to 522 µg/L for incipient inhibition of the green alga, *Scenedesmus quadricauda* (Bringmann and Kuhn 1977a, 1978a,b, 1979, 1980b). Foe and Knight (Manuscript) found that 75 µg/L decreased the dry weight of *Selenastrum capricornutum* (Table F-1). Wehr and Brown (1985) reported that 320 µg/L increased the growth of the alga *Chrysochromulina breviturrita*.

The 96-hr EC_{50} for the saltwater diatom, *Skeletonema costatum*, is 7,930 µg/L, based on reduction in chlorophyll *a* (Table F-1). Growth of *Chlorella* sp., *Platymonas subcordiformis*, and *Fucus spiralis* increased at selenite concentrations from 2.6 to 10,000 µg/L (Table F-1). Other marine algae exposed to selenite from 14 to 60 days had no observed effect concentrations (NOAEC) that ranged from 1,076 to 107,606 µg/L. These data suggest that saltwater plants will not be adversely affected by concentrations of selenite that do not affect saltwater animals.

2.0 SELENATE

Growth of several species of green algae was affected by concentrations ranging from 100 to 40,000 µg/L (Table F-1). Blue-green algae appear to be more tolerant to selenate with 1,866 µg/L being the lowest concentration reported to affect growth (Kiffney and Knight 1990). Kumar (1964) found that a blue-green alga developed and lost resistance to selenate. The difference in the sensitivities of green and blue-green algae to selenate might be of ecological significance, particularly in bodies of water susceptible to nuisance algal blooms. For example, Patrick et al. (1975) reported that a concentration of 1,000 µg/L caused a natural assemblage of algae to shift to a community dominated by blue-green algae.

The saltwater coccolithophore, *Cricosphaera elongata*, had reduced growth when exposed to 41,800 µg/L selenate for 14 days (Boisson et al. 1995). Seven other saltwater algal species investigated by Wong and Oliveira (1991a) exhibited NOEC growth values that ranged from 1,043 to 104,328 µg/L. At 10,000 µg/L, selenate is lethal to four species of saltwater phytoplankton and lower concentrations increase or decrease growth (Table F-1). Wheeler et al. (1982) reported that concentrations as low as 10 µg/L reduced growth of *Porphyridium cruentum* (Table F-1).

Although selenite appears to be more acutely toxic than selenate to most aquatic animals, this does not seem to be true for aquatic plants. Selenite and selenate are about equally toxic to the freshwater algae *Anabaena cylindrica*, *Anabaena flos-aquae*, *Anabaena variabilis*, *Anacystis nidulans*, and *Scenedesmus dimorphus* (Kiffney and Knight 1990; Kumar and Prakash 1971; Moede et al. 1980) and the saltwater algae *Agemenellum quadroplicatum*, *Chaetoceros vixvisibilis* and *Amphidinium carterae* (Wong and Oliveira 1991a). The two oxidation states equally stimulated growth of *Chrysochromulina*

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breviturrita (Wehr and Brown 1985). On the other hand, selenate is more toxic than selenite to the freshwater *Selenastrum capricornutum* (Richter 1982; Ibrahim and Spacie 1990) and the saltwater *Chorella* sp., *Platymonas subcordiformis* and *Nannochloropsis oculata* (Wheeler et al. 1982; Wong and Oliveira 1991a). In addition, Fries (1982) found that growth of thalli of the brown macroalga, *Fucus spiralis*, was stimulated more by exposure to selenite at 2.605 μg/L than to the same concentration of selenate.

A Final Plant Value, as defined in the Guidelines, cannot be obtained because no test in which the concentrations of selenite or selenate were measured and the endpoint was biologically relevant has been conducted with an important aquatic plant species.

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Table F-1. Toxicity of selenium to aquatic plants.

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration (days)	Effect	Concentration (µg/L)[a]	Reference
FRESHWATER SPECIES						
Selenium (IV)						
Green alga, *Chlorella vulgaris*	Sodium selenite	-	90-120	Reduced growth	5,480	De Jong 1965
Green alga, *Chlorella ellipsoidea*	Sodium selenite	-	7	EC50	70,000	Shabana and El-Attar 1995
Green alga, *Scenedesmus dimorphus*	Sodium selenite	-	14	Reduced growth	24,000	Moede et al. 1980
Green alga, *Scenedesmus quadricauda*	Sodium selenite	-	8	Incipient inhibition	522	Bringmann and Kuhn 1977a; 1978a,b; 1979; 1980b
Green alga, *Scenedesmus quadricauda*	Sodium selenite	-	8	Incipient inhibition	2,500	Bringmann and Kuhn 1959a
Green alga, *Selenastrum capricornutum*	Sodium selenite	-	4	EC50	2,900	Richter 1982
Green alga, *Selenastrum capricornutum*	Sodium selenite	-	6	EC50	65,000	Ibrahim and Spacie 1990
Blue-green alga, *Anabaena constricta*	Sodium selenite	-	7	EC50	67,000	Shabana and El-Attar 1995
Blue-green alga, *Anabaena cylindrica*	Sodium selenite	-	14	Reduced growth	24,000	Moede et al. 1980
Blue-green alga, *Anabaena flos-aquae*	Sodium selenite	-	10	Reduced chlorophyll a	1,866	Kiffney and Knight 1990
Blue-green alga, *Anabaena variabilis*	Sodium selenite	-	6-18	LC50	15,000[b]	Kumar and Prakash 1971
Blue-green alga, *Anacystis nidulans*	Sodium selenite	-	10-18	LC50	30,000[b]	Kumar and Prakash 1971
Blue-green alga, *Microcystis aeruginisa*	Sodium selenite	-	8	Incipient inhibition	9,400 (9,300)	Bringmann and Kuhn 1976; 1978a,b
Alga, *Euglena gracilis*	-	-	15	Reduced growth	5,920	Bariaud and Mestre 1984
Duckweed, *Lemna minor*	-	-	4	EC50	2,400	Wang 1986
Duckweed, *Lemna minor*	Sodium selenite	-	14	EC50 (mult. rate)	3,500	Jenner and Janssen-Mommen 1993

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Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration (days)	Effect	Concentration (µg/L)[a]	Reference
Duckweed, *Lemna minor*	Sodium selenite	-	14	NOEC (mult. rate)	800	Jenner and Janssen-Mommen 1993
Selenium (VI)						
Green alga, *Ankistrodesmus falcatus*	Sodium selenate	-	14	Did not reduce growth	10	Vocke et al. 1980
Green alga, *Scenedesmus dimorphus*	Sodium selenate	-	14	Reduced growth	22,100	Moede et al. 1980
Green alga, *Scenedesmus obliquus*	Sodium selenate	-	14	Reduced growth	100	Vocke et al. 1980
Green alga, *Selenastrum capricornutum*	Sodium selenate	-	14	Reduced growth	300	Vocke et al. 1980
Green alga, *Selenastrum capricornutum*	Sodium selenate	-	4	EC50	199	Richter 1982
Green alga, *Selenastrum capricornutum*	Sodium selenate	-	6	EC50	<40,000	Ibrahim and Spacie 1990
Blue-green alga, *Anabaena cylindrica*	Sodium selenate	-	14	Reduced growth	22,100	Moede et al. 1980
Blue-green alga, *Anabaena flos-aquae*	Sodium selenate	-	10	Reduced chlorophyll a	1,866	Kiffney and Knight 1990
Blue-green alga, *Anacystis nidulans*	Sodium selenate	-	6-18	EC50	39,000[b]	Kumar and Prakash 1971
Blue-green alga, *Anabaena viriabilis*	Sodium selenate	-	10-18	EC50	17,000[b]	Kumar and Prakash 1971
Blue-green alga, *Microcoleus vaginatus*	Sodium selenate	-	14	Reduced growth	10,000	Vocke et al. 1980
Duckweed, *Lemna minor*	Sodium selenate	-	14	EC50 (mult. rate)	11,500	Jenner and Janssen-Mommen 1993
Duckweed, *Lemna minor*	Sodium selenate	-	14	NOEC (mult. rate)	>2,400	Jenner and Janssen-Mommen 1993

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Species	Chemical	Salinity (g/kg)	Duration (days)	Effect	Concentration (µg/L)[a]	Reference
SALTWATER SPECIES						
Selenium (IV)						
Green alga, *Dunaliella tertiolecta*	Sodium selenite	-	60	NOEC growth	1,076	Wong and Oliveira 1991a
Cyanophyceae alga, *Agemenellum quadruplicatum*	Sodium selenite	-	60	NOEC growth	10,761	Wong and Oliveira 1991a
Diatom, *Chaetoceros vixvisibilis*	Sodium selenite	-	60	NOEC growth	1,076	Wong and Oliveira 1991a
Diatom, *Skeletonema costatum*	Selenious acid[c]	-	4	EC50 (reduction in chlorophyll a)	7,930	U.S. EPA 1978
Coccolithophore, *Cricosphaera elongata*	Sodium selenite	-	14	Reduced growth	4,570	Boisson et al. 1995
Dinoflagellate, *Amphidinium carterae*	Sodium selenite	-	60	NOEC growth	10,761	Wong and Oliveira 1991a
Dinoflagellate, *Peridinopsis borgei*	Selenium oxide	-	70-75	Maximum growth	0.01-0.05	Lindstrom 1985
Eustigmatophyceae alga, *Nannochloropsis oculata*	Sodium selenite	-	60	NOEC growth	107,606	Wong and Oliveira 1991a
Pyrmnesiophyceae alga, *Isochrysis galbana*	Sodium selenite	-	60	NOEC growth	1,076	Wong and Oliveira 1991a
Pyrmnesiophyceae alga, *Pavlova lutheri*	Sodiun selenite	-	60	NOEC growth	1,076	Wong and Oliveira 1991a
Selenium (VI)						
Green alga, *Dunaliella tertiolecta*	Sodium selenate	-	60	NOEC growth	104,328	Wong and Oliveira 1991a
Cyanophyceae alga, *Agemenellum quadruplicatum*	Sodium selenate	-	60	NOEC growth	10,433	Wong and Oliveira 1991a
Diatom, *Chaetoceros vixvisibilis*	Sodium selenate	-	60	NOEC growth	1,043	Wong and Oliveira 1991a
Coccolithophore, *Cricosphaera elongate*	Sodium selenate	-	14	Reduced growth	41,800	Boisson et al. 1995
Dinoflagellate,	Sodium	-	60	NOEC	10,433	Wong and

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Species	Chemical	Salinity (g/kg)	Duration (days)	Effect	Concentration (µg/L)[a]	Reference
Amphidinium carterae	selenate			growth		Oliveira 1991a
Eustigmatophyceae alga, *Nannochloropsis oculata*	Sodium selenate	-	60	NOEC growth	10,433	Wong and Oliveira 1991a
Pyrmnesiophyceae alga, *Isochrysis galbana*	Sodium selenate	-	60	NOEC growth	10,433	Wong and Oliveira 1991a
Pyrmnesiophyceae alga, *Pavlova lutheri*	Sodium selenate	-	60	NOEC growth	104,328	Wong and Oliveira 1991a

[a] Concentration of selenium, not the chemical.
[b] Estimated from published graph.
[c] Reported by Barrows et al. (1980) in work performed under the same contract.

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APPENDIX G: UNUSED DATA

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Based on the requirements set forth in the guidelines (Stephen et al. 1985) the following studies are not acceptable for the following reasons and are classified as unused data. Note the acceptance of chronic toxicity data included diet and field exposures where selenium was the dominant toxicant.

Studies Were Conducted with Species That Are Not Resident in North America

Ahsanullah and Brand (1985)
Ahsanullah and Palmer (1980)
Baker and Davies (1997)
Barghigiani et al. (1993)
Chidambaram and Sastry (1991a,b)
Congiu et al. (1989)
Cuvin and Furness (1988)
Fowler and Benayoun (1976a,b)
Gaikwad (1989)
Gotsis (1982)
Hiraika et al. (1985)
Juhnke and Ludemann (1978)
Kitamura (1990)
Manoharan and Prabakaran (1994)
Minganti et al. (1994, 1995)
Niimi and LaHam (1975, 1976)
Regoli (1998)
Regoli and Principato (1995)
Rhodes et al. (1994)
Ringdal and Julshamn (1985)
Rouleau et al. (1992)
Sastry and Shukla (1994)
Savant and Nilkanth (1991)
Shultz and Ito (1979)
Srivastava and Tyagi (1985)
Takayanagi (2001)
Tomasik et al. (1995b)
Tian and Liu (1993)
Wrench (1978)

Deelstra et al. (1989), Forsythe and Klaine (1994), Okasako and Siegel (1980) and Petrucci et al. (1995) conducted tests with brine shrimp species that are too atypical to be used in derving national criteria.

These Studies or Reviews Contain Relevant Data That Have Been Published Elsewhere

Adams and Johnson (1981)
Biddinger and Gloss (1984)
Bowie et al. (1996)
Brandao et al. (1992)
Brooks (1984)
Burton and Stemmer (1988)
Chapman et al. (1986)
Davies (1978)
Debruyn and Chapman (2007)
Devillers et al. (1988)
Eisler (1985)
Hall and Burton (1982)
Hodson and Hilton (1983)
Hodson et al. (1984)
Jenkins (1980)
Kaiser et al. (1997)
Kay (1984)
LeBlanc (1984)
Lemly (1993c, 1996ab, 1997d)
Lemly and Smith (1987)
McKee and Wolf (1963)
National Research Council (1976) Neuhold (1987)
NCDNR&CD (1986)
Peterson and Nebeker (1992)
Phillips and Russo (1978)
Presser (1994)
Roux et al. (1996)
Swift (2002)
Thompson et al. (1972)
Versar (1975)

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Authors Did Not Specify the Oxidation State of Selenium Used in Study

Greenberg and Kopec (1986)
Hutchinson and Stokes (1975)
Kapu and Schaeffer (1991)
Kramer et al. (1989)
Mahan et al. (1989)
Rauscher (1988)
Snell et al. (1991b)

Not Useful Because of No Effects Observed at Exposure Concentrations or Insufficient Number of Treatments

Muscatello and Janz (2009)
Pyle et al. (2005)
Schlenk et al (2003)

Chronic Study with no Dietary Exposure

Hopkins et al. (2002)
Oti (2005)
Rowe (2003)
Teh et al. (2002)

Selenium Was a Component of an Effluent, Fly Ash, Formulation, Mixture, Sediment or Sludge

Apte et al. (1987)
Baer et al. (1995)
Baker et al. (1991)
Berg et al. (1995)
Besser et al. (1989)
Biedlingmaier and Schmidt (1989)
Bjoernberg (1989)
Bjoernberg et al. (1988)
Bleckmann et al. (1995)
Boisson et al. (1989)
Bondavalli et al. (1996)
Bowmer et al. (1994)
Brieger et al. (1992)
Burton and Pinkney (1984)
Burton et al. (1983, 1987a)
Cherry et al. (1987)
Cieminski and Flake (1995)
Clark et al. (1989)
Cooke and Lee (1993)
Cossu et al. (1997)
Coyle et al. (1993)
Crane et al. (1992)
Crock et al. (1992)
Cushman et al. (1977)
Davies and Russell (1988)
de Peyster et al. (1993)
Dickman and Rygiel (1996)
Dierenfeld et al. (1993)
Doebel et al. (2004)
Drndarski et al. (1990)
Eriksson and Forsberg (1992)
Eriksson and Pedros-Alio (1990)
Fairbrother et al. (1994)
Fava et al. (1985a,b)
Feroci et al. (1997)
Finger and Bulak (1988)
Finley (1985)
Fisher and Wente (1993)
Fjeld and Rognerud (1993)
Fletcher et al. (1994)
Follett (1991)
Gerhardt (1990)
Gerhardt et al. (1991)
Gibbs and Miskiewicz (1995)
Graham et al. (1992)

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Gunderson et al. (1997)
Hall (1988)
Hall et al. (1984, 1987, 1988,1992)
Hamilton et al. (1986, 2000)
Harrison et al. (1990)
Hartwell et al. (1987ab, 1988, 1997)
Hatcher et al. (1992)
Haynes et al. (1997)
Hayward et al. (1996)
Hellou et al. (1996b)
Henebry and Ross (1989)
Henny et al. (1989, 1990, 1995)
Hildebrand et al. (1976)
Hjeltnes and Julshman (1992)
Hockett and Mount (1996)
Hodson (1990)
Hoffman et al. (1988, 1991)
Homziak et al. (1993)
Hopkins et al. (2000)
Hopkins et al. (2004)
Hothem and Welsh (1994a)
Jackson (1988)
Jackson et al. (1990)
Jacquez et al. (1987)
Jay and Muncy (1979)
Jayasekera (1994)
Jayasekera and Rossbach (1996)
Jenner and Bowmer (1990) (1992)
Jin et al. (1997)
Jorgensen and Heisinger (1987)
Karlson and Frankenberger (1990)
Kemble et al. (1994)
Kennedy (1986)
Kersten et al. (1991)
King and Cromartie (1986)
King et al. (1991, 1994)
Klusek et al. (1993)
Koh and Harper (1988)
Koike et al. (1993)
Krishnaja et al. (1987)
Kruuk and Conroy (1991)
Kuehl and Haebler (1995)
Kuehl et al. (1994)
Kuss et al. (1995)
Landau et al. (1985)
Livingston et al. (1991)
Lobel et al. (1990)
Luoma and Phillips (1988)
Lundquist et al. (1994)
Lyle (1986)
MacFarlane et al. (1986)
Mann and Fyfe (1988)
Marcogliese et al. (1987)
Marvin and Howell. (1997)Maurer et al (1999)
McCloskey and Newman (1995)
McCloskey et al. (1995)
McCrea and Fischer (1986)
McLean et al. (1991)
Mehrle et al. (1987)
Metcalf-Smith (1994)
Micallef and Tyler (1989)
Mikac et al. (1985)
Miles and Tome (1997)
Miller et al. (1996)
Misitano and Schiewe (1990)
Moore (1988)
Munawar and Legner (1993)
Muskett et al. (1985)
Naddy et al. (1995)
Nielsen and Bjerregaard (1991)
Norman et al. (1992)
Nuutinen & Kukkonen (1998)
Oberbach and Hartfiel (1987, 1988)
Oberbach et al. (1989)
Ohlendorf et al. (1989, 1990, 1991)
Olson and Welsh (1993)
Peters et al.(1999)
Phillips and Gregory (1980)
Pratt and Bowers (1990)
Presser and Ohlendorf (1987)
Prevot and Sayer-Gobillard (1986)
Pritchard (1997)
Pyle et al. (2001)
Reash et al. (1988, in press)
Rhodes and Burke (1996)

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Ribeyre et al. (1995)
Rice et al. (1995)
Riggs and Esch (1987)
Riggs et al. (1987)
Robertson et al. (1991)
Roper et al. (1997)
Rowe et al. (1996)
Russell et al. (1994)
Ryther et al. (1979)
Saiki and Jenings (1992)
Saiki and Ogle (1995)
Saleh et al. (1988)
Seelye et al. (1982)
Sevareid and Ichikawa (1983)
Skinner (1985)
Somerville et al. (1987)
Sorenson and Bauer (1983)
Specht et al. (1984)
Steele et al. (1992)
Stemmer et al. (1990)
Summers et al. (1995)
Thomas et al. (1980b)
Timothy et al. (2001)
Trieff et al. (1995)
Turgeon and O=Conner (1991)
Twerdok et al. (1997)
Unsal (1987)
Van Metre and Gray (1992)
Wahl et al. (1994)
Wandan and Zabik (1996)
Wang et al. (1992, 1995)
Welsh (1992)
Weres et al. (1990)
White and Geitner (1996)
Wiemeyer et al. (1986)
Wildhaber and Schmitt (1996)
Williams et al. (1989)
Wolfe et al. (1996)
Wolfenberger (1987)
Wong and Chau (1988)
Wong et al. (1982)
Wu et al. (1997)
Yamaoka et al. (1994)
Zagatto et al. (1987)
Zaidi et al. (1995)
Zhang et al. (1996)

Exposed enzymes, excised tissue or tissue extractor

Tripathi and Pandey (1985) and Heinz (1993b) used test organisms that had been previously exposed to pollutants in food or water.

Albers et al. (1996)
Al-Sabti (1994, 1995)
Arvy et al. (1995)
Augier et al. (1993a, b)
Avery et al. (1996)
Baatrup (1989)
Baatrup and Dansher (1987)
Baatrup et al. (1986)
Babich et al. (1986, 1989)
Barrington et al. (1997)
Becker et al. (1995a,b)
Bell et al. (1984, 1985, 1986a,b, 1987ab)
Berges and Harrison (1995)
Blondin et al. (1988)
Boisson et al. (1996)
Bottino et al. (1984)
Braddon (1982)
Braddon-Galloway and Balthrop (1985)
Bradford et al. (1994a,b)
Brandt et al. (1990)
Byl et al. (1994)
Chandy and Patel (1985)
Chen et al. (1997)
Cheng et al. (1993)
Christensen and Tucker (1976)
Dabbert and Powell (1993)
DeQuiroga et al. (1989)
Dierickx (1993)
Dietrich et al. (1987)
DiIlio et al. (1986)

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Doyotte et al. (1997)
Drotar et al. (1987)
Dubois and Callard (1993)
Ebringer et al. (1996)
Engberg and Borsting (1994)
Engberg et al. (1993)
Eun et al. (1993)
Foltinova and Gajdosova (1993)
Foltinova et al. (1994)
Freeman and Sanglang (1977)
Grubor-Lajsic et al. (1995)
Hait and Sinha (1987)
Hanson (1997)
Heisinger and Scott (1985)
Heisinger and Wail (1989)
Henderson et al. (1987)
Henny and Bennett (1990)
Hoffman and Heinz (1988, 1998)
Hoffman et al. (1989, 1998)
Hoglund (1991)
Hontela et al. (1995)
Hsu et al. (1995)
Hsu and Goetz (1992)
Ishikawa et al. (1987)
James et al. (1993)
Jovanovic et al. (1995, 1997)
Kai et al. (1995)
Kedziroski et al. (1996)
Kelly et al. (1987)
Kralj and Stunja (1994)
Lalitha and Rani (1995)
Lan et al. (1995)
Lemaire et al. (1993)
Livingstone et al. (1992)
Low and Sin (1995, 1996)
Micallef and Tyler (1990)
Montagnese et al. (1993)
Murata et al. (1996)
Nakonieczny (1993)
Neuhierl and Boeck (1996)
Nigro (1994)
Nigro et al (1992)
Norheim and Borch-Iohnsen (1990)
Norheim et al. (1991)
O=Brien et al. (1995)
Olson and Christensen (1980)
Overbaugh and Fall (1985)
Palmisano et al. (1995)
Patel et al. (1990)
Patel and Chandy (1987)
Perez Campo et al. (1990)
Perez-Trigo et al. (1995)
Phadnis et al. (1988)
Price and Harrison (1988)
Rady et al. (1992)
Rani and Lalitha (1996)
Regoli et al. (1997)
Schmidt et al. (1985)
Schmitt et al. (1993)
Segner et al. (1994)
Sen et al. (1995)
Shigeoka et al. (1990, 1991)
Siwicki et al. (1994)
Srivastava and Srivastava (1995)
Sun et al. (1995)
Takeda et al. (1992a,b,(1993, 1997)
Treuthardt (1992)
Vazquez et al. (1994)
Veena et al. (1997)
Wise et al. (1993a,b)
Wong and Oliveira (1991b)
Yokota et al. (1988)

Test procedures test material or results were not adequately described by Botsford (1997), Botsford et al. (1997, 1998), Bovee (1978), Gissel-Nielsen and Gissel-Nielsen (1973, 1978), Greenberg and Kopec (1986), Mauk (2001), and Nassos et al. (1980) or when the test media contained an excessive amount (>200 μg/L) of EDTA (Riedel and Sanders (1996).

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Some data obtained from tests conducted with just one exposure concentration to evaluate acute or chronic toxicity were not used (e.g., Bennett 1988; Heinz and Hoffman 1998; Munawar et al. 1987; Pagano et al. 1986; Wolfenberger 1986).

Kaiser (1980) calculated the toxicities of selenium(IV) and selenium(VI) to *Daphnia magna* based on physiochemical parameters. Kumar (1964) did not include a control treatment in the toxicity tests. The daphnids were probably stressed by crowding in the tests reported be Schultz et al. (1980). Siebers and Ehlers (1979) exposed too few test organisms as did Owsley (1984) in some tests.

Selenium Concentrations Reported in Wild Aquatic Organisms Were Insufficient to Calculate BAF

Abdel-Moati and Atta (1991)
Adeloju and Young (1994)
Aguirre et al. (1994)
Akesson and Srikumar (1994)
Aksnes et al. (1983)
Allen and Wilson (1990)
Ambulkar et al. (1995)
Amiard et al. (1991, 1993)
Andersen and Depledge (1997)
Andreev and Simeonov (1992)
Angulo (1996)
Arrula et al. (1996)
Arway (1988)
Ashton (1991)
Augier et al. (1991, 1993, 1995a,b)
Augspurger et al. (1998)
Avery et al. (1996)
Badsha and Goldspink (1988)
Baines and Fisher (2001)
Baldwin and Maher (1997)
Baldwin et al. (1996)
Barghigiani (1993)
Barghigiani et al. (1991)
Baron et al. (1997)
Batley (1987)
Baumann and Gillespie (1986)
Baumann and May (1984)
Beal (1974)
Beck et al. (1997)
Beland et al. (1993)
Beliaeff et al. (1997)
Bell and Cowey (1989)
Benemariya et al. (1991)
Berry et al. (1997)
Bertram et al. (1986)
Besser et al. (1994, 1993)
Birkner (1978)
Boisson and Romeo (1996)
Bowerman et al. (1994)
Braune et a. (1991)
Brezina and Arnold (1977)
Brugmann and Hennings (1994)
Brugmann and Lange (1988)
Brumbaugh and Walther (1991)
Burger (1992, 1994, 1995, 1996, 1997a,b)
Burger and Gochfeld (1992a,b, 1993, 1995 ab, 1996, 1997)
Burger et al. (1992a,b,c,1993, 1994a,b)
Byrne and DeLeon (1986)
Byrne et al. (1985)
Cantillo et al. (1997)
Capar and Yess (1996)
Capelli et al. (1987, 1991)
Cappon (1984)
Cappon and Smith (1981) (1982a,b)
Cardellicchio (1995)
Carell et al. (1987)
Carter and Porter (1997)
Caurant et al. (1994, 1996)
Chau and Riley (1965)
Chiang et al. (1994)

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Chou and Uthe (1991)
Chvojka (1988)
Chvojka et al. (1990)
Clifford and Harrison (1988)
Collins (1992)
Combs et al. (1996)
Cosson et al. (1988)
Courtney et al. (1994)
Cruwys et al. (1994)
Crutchfield (2000)
Cumbie and Van Horn (1978)
Currey et al. (1992)
Custer and Hohman (1994)
Custer and Mitchell (1991, 1993)
Custer et al. (1997)
Dabeka and McKenzie (1991)
Davoren (1986)
Deaker and Maher (1997)
Demon et al. (1988)
Dietz et al. (1995, 1996)
Doherty et al. (1993)
Elliott and Scheuhammer (1997)
Eriksson et al. (1989)
Evans et al. (1993)
Felton rt al. (1990)
Felton et al. (1994)
Fitzsimons et al. (1995)
Focardi et al. (1985, 1988)
Fowler (1986)
Fowler et al. (1975, 1985)
France (1987)
Friberg (1988)
Froslie et al. (1985, 1987)
Gabrashanske and Daskalova (1985)
Gabrashanska and Nedeva (1994)
Galgan and Frank (1995)
Garcia - Hermandez et al. (2000)
Giardina et al. (1997)
Gillespie and Baumann (1986)
Gochfeld (1997)
Goede (1985, 1991, 1993a,b)
Goede et al. (1989, 1993)
Goede and DeBruin (1984, 1985)
Goede and Wolterbeek (1993, 1994a,b)
Gras et al. (1992)
Greig and Jones (1976)
Gutenmann et al. (1988)
Gutierrez-Galindo et al. (1994)
Guven et al. (1992)
Halbrook et al. (1996)
Hall and Fisher (1985)
Hamilton and Waddell (1994)
Hamilton and Wiedmeyer (1990)
Hansen et al. (1990)
Hardiman and Pearson (1995)
Hargrave et al. (1992)
Harrison and Klaverkamp (1990)
Hasunuma et al. (1993)
Haynes et al. (1995)
Hein et al. (1994)
Heiny and Tate (1997)
Heinz (1993a)
Heinz and Fitzgerald (1993a,b)
Heit (1985)
Heit and Klusek (1985)
Heit et al. (1980, 1989)
Hellou et al. (1992a,b) (1996a,b)
Henny and Herron (1989)
Hodge et al. (1996)
Hilton et al. (1982)
Honda et al. (1986)
Hothem and Ohlendorf (1989)
Hothem and Welsh (1994b)
Hothem and Zador (1995)
Hothem et al. (1995)
Houpt et al. (1988)
Hunter et al. (1995, 1997)
Ibrahim and Farrag (1992)
Ibrahim and Mat (1995)
Ishikawa et al. (1993)
Itano et al. (1984, 1985a,b)
Jarman et al. (1996)
Johns et al. (1988)
Johnson (1987)
Jop et al. (1997)

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Jorhem et al. (1994)
Julshamn et al. (1987)
Kai et al. (1986a,b, 1988, 1992a,b, 1996)
Kaiser et al. (1979)
Kalas et al. (1995)
Kidwell et al. (1995)
Koeman et al. (1973)
Kovacs et al. (1984)
Krogh and Scanes (1997)
Krushevska et al. (1996)
Lakshmanan and Stephen (1994)
Lalitha et al. (1994)
LamLeung et al. (1991)
Lan et al. (1994a,b)
Langlois and Langis (1995)
Larsen and Stuerup (1994)
Larsen et al. (1997)
Lauchli (1993)
Law et al. (1996)
Lee and Fisher (1992a,b, 1993)
Leighton and Wobeser (1994)
Leland and Scudder (1990)
Lemly (1985a, 1994)
Leonzio et al. (1986, 1989, 1992)
Leskinen et al. (1986)
Li et al. (1996)
Lie et al. (1994)
Liu et al. (1987)
Lizama et al. (1989)
Lobel et al. (1989, 1991, 1992a,b)
Lonzarich et al. (1992)
Lourdes et al. (1990)
Lowe et al. (1985)
Lucas et al. (1970)
Lytle and Lytle (1982)
Mackey et al. (1996)
Maher (1987)
Maher et al. (1992, 1997)
Mann et al. (1988)
Mason et al. (2000)
Masuzawa et al. (1988)
Matsumoto (1991)
Maven et al. (1995)
May and McKinney (1981)
Mcdowell et al. (1995)
McKenzie-Parnell et al. (1988)
Meador et al. (1993)
Mehrle et al. (1982)
Meltzer et al. (1993)
Metcalfe-Smith et al. (1992, 1996)
Michot et al. (1994)
Mills et al. (1993)
Moharram et al. (1987)
Moller (1996)
Mora and Anderson (1995)
Morera et al. (1997)
Muir et al. (1988)
Mutanen et al. (1986)
Nadkarni and Primack (1993)
Nakamoto and Hassler (1992)
Narasaki and Cao (1996)
Navarrete et al. (1990)
Nettleton et al. (1990)
Nicola et al. (1987)
Nielsen and Dietz (1990)
Norheim (1987)
Norheim et al. (1992)
Norrgren et al. (1993)
Norstrom et al. (1986)
O=Conner (1996)
O=Shea et al. (1984)
Ober et al. (1987)
Oehlenschlager (1997)
Ohlendorf (1986)
Ohlendorf and Harrison (1986)
Ohlendorf and Marois (1990)
Ohlendorf et al. (1986a,b, 1987, 1988a,b)
Okazaki and Panietz (1981)
Ostapczuk et al. (1997)
Pakkala et al. (1972)
Pal et al. (1997) Palawski et al. (1991)
Palmer-Locarnini and Presley (1995)
Paludan-Miller et al. (1993)
Papadopoulou and Andreotis (1985)
Park and Presley (1997)
Park et al. (1994)

Paveglio et al. (1994)
Payer and Runkel (1978)
Payer et al. (1976)
Pennington et al. (1982)
Presley et al. (1990)
Quevauviller et al. (1993a,b)
Ramos et al. (1992)
Rao et al. (1996)
Reinfelder and Fisher (1991)
Reinfelder et al. (1993, 1998)
Renzoni et al. (1986)
Riget et al. (1996)
Risenhoover (1989)
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APPENDIX H: CALCULATION OF EF VALUES

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EPA calculated EF values by searching its database of selenium measurements and identifying all the selenium measurements from algae, detritus, or sediment. EPA then searched for corresponding water column measurements from samples collected at the same aquatic site within one year of the particulate sample. If more than one water measurement was available for any given particulate measurement, the median was used. For each of these matched pairs of particulate and water measurements, EPA calculated the ratio of particulate concentration to water concentration. If more than one ratio for any given category of particulate material (algae, detritus, or sediment) was calculated at an aquatic site, EPA used the median ratio. The geometric mean of the algae, detritus, and sediment ratios was used as the site *EF*. Because there were at most only 3 possible values (one for algae, one for detritus, and one for sediment), EPA used the geometric mean in order to reduce the potential for one of the values to have excessive influence on the final site *EF* value. Sites with insufficient data to fulfill these criteria are left blank.

EPA evaluated differences in bioaccumulation between different categories of aquatic systems by analyzing EF values for different categories. EPA sequentially consolidated categories and examined differences in the distribution of EF values between categories. See text for a complete description of this analysis.

Reference	Site description	Site ID	Specific waterbody type - original	Specific waterbody type - Lentic or Lotic	C_{algae} (mg/kg)	$C_{detritus}$ (mg/kg)	C_{sed} (mg/kg)	$C_{particulate}$ (mg/kg)	C_{water} (µg/L)	Site EF (L/g)
Birkner 1978	East Allen Reservoir, Medicine Bow WY	20	Reservoir	Lentic	3.00		41.00	11.09	4.80	2.31
Birkner 1978	Galett Lake, Laramie WY	7	Lake	Lentic	0.18		2.80	0.70	0.80	0.88
Birkner 1978	Larimer Highway 9 Pond, Fort Collins CO	30	Pond	Lentic	15.50		47.30	27.08	15.90	1.70
Birkner 1978	Meeboer Lake, Laramie WY	3	Lake	Lentic	0.10		0.30	0.17	0.30	0.58
Birkner 1978	Miller's Lake, Wellington CO	22	Lake	Lentic	4.60		44.00	14.23	6.00	2.37
Birkner 1978	Sweitzer Lake, Delta CO	27	Lake	Lentic	10.35		6.50	8.20	9.40	0.87
Birkner 1978	Twin Buttes Reservoir, Laramie WY	23	Reservoir	Lentic	7.80		10.80	9.18	7.60	1.21

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Reference	Site description	Site ID	Specific waterbody type - original	Specific waterbody type - Lentic or Lotic	C_{algae} (mg/kg)	$C_{detritus}$ (mg/kg)	C_{sed} (mg/kg)	$C_{particulate}$ (mg/kg)	C_{water} (µg/L)	Site EF (L/g)
Bowie et al. 1996	Hyco Reservoir		Reservoir	Lentic	27.00			27.00	11.50	2.35
Butler et al. 1993	Navajo Reservoir, Piedra River Arm, near La Boca	N2	Reservoir	Lentic	2.65		0.60	1.26	1.00	1.26
Butler et al. 1997	Large pond on Dove Creek	DCP1	Pond	Lentic	1.00		2.10	1.45	2.00	0.72
Butler et al. 1997	Large pond south of G Road, southern Mancos Valley	MNP2	Pond	Lentic	5.40		6.70	6.01	3.00	2.00
Butler et al. 1997	Pond downstream from site MNP2, southern Mancos Valley	MNP3	Pond	Lentic	4.50		5.90	5.15	1.00	5.15
Butler et al. 1997	Pond on Cahone Canyon, west of 1 5 Road	CHP	Pond	Lentic	4.00		2.10	2.90	5.00	0.58
Butler et al. 1997	Pond on Woods Canyon at 15 Road	WCP	Pond	Lentic	2.30		3.20	2.71	3.00	0.90
Butler et al. 1997	West pond at CC Road	PVP1	Pond	Lentic	1.50		1.40	1.45	2.00	0.72
Grasso et al. 1995	Arapahoe Wetlands Pond	17	Pond	Lentic	1.87		0.40	0.86	1.00	0.86
Lemly 1985	Badin Lake		Lake	Lentic	7.70		2.07	3.99	0.32	12.48
Lemly 1985	Belews Lake		Lake	Lentic	44.10		8.27	19.10	10.91	1.75
Lemly 1985	High Rock Lake		Lake	Lentic	6.20		1.80	3.34	0.67	4.99
Muscatello and Janz 2009	Vulture Lake		Lake	Lentic	0.35		0.54	0.43	0.43	1.01
Orr et al. 2006	Barns Lake Wetland	BLW	Lake	Lentic	4.40		2.00	2.97	0.50	5.93

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Reference	Site description	Site ID	Specific waterbody type - original	Specific waterbody type - Lentic or Lotic	C_{algae} (mg/kg)	$C_{detritus}$ (mg/kg)	C_{sed} (mg/kg)	$C_{particulate}$ (mg/kg)	C_{water} (µg/L)	Site EF (L/g)
Orr et al. 2006	Fording River Oxbow	FRO	Oxbow	Lentic	5.55		7.90	6.62	5.04	1.37
Orr et al. 2006	Fording Settling Pond (Clode Pond)	FSP	Pond	Lentic	5.49		2.80	3.92	42.99	0.09
Orr et al. 2006	Goddard Marsh	GM	Marsh	Lentic	3.21		26.00	9.14	90.95	0.10
Orr et al. 2012	Clode Pond 11	CL11	Pond	Lentic	25.80			25.80	36.10	0.71
Orr et al. 2012	Elk Lakes 14	EL14	Lake	Lentic	0.66			0.66	0.40	1.64
Orr et al. 2012	Flathead Wetland 17	FL17	Marsh	Lentic	1.42			1.42	0.20	7.10
Orr et al. 2012	Fording River Oxbow 10	FO10	Oxbow	Lentic	67.31			67.31	50.10	1.34
Orr et al. 2012	Goddard Marsh 13	GO13	Marsh	Lentic	18.15			18.15	16.30	1.11
Orr et al. 2012	Henretta Lake 27	HE27	Lake	Lentic	4.30			4.30	8.60	0.50
Saiki and Lowe 1987	Kesterson Pond 11		Pond	Lentic	18.15	47.95	8.56	19.53	38.60	0.51
Saiki and Lowe 1987	Kesterson Pond 2		Pond	Lentic	152.70	44.65	34.82	61.92	195.85	0.32
Saiki and Lowe 1987	Kesterson Pond 8		Pond	Lentic	136.50	92.00	6.05	42.34	70.35	0.60
Saiki and Lowe 1987	Volta Pond 26		Pond	Lentic	0.42	1.01	0.29	0.50	0.53	0.93
Saiki and Lowe 1987	Volta Pond 7		Pond	Lentic		1.39	0.39	0.74	0.63	1.17
Schuler et al. 1990	Kesterson National Wildlife Refuge	Kesterson Pond 7	Pond	Lentic	87.10		5.90	22.67	100.00	0.23

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Reference	Site description	Site ID	Specific waterbody type - original	Specific waterbody type - Lentic or Lotic	C_{algae} (mg/kg)	$C_{detritus}$ (mg/kg)	C_{sed} (mg/kg)	$C_{particulate}$ (mg/kg)	C_{water} (µg/L)	Site EF (L/g)
Schuler et al. 1990	Kesterson National Wildlife Refuge	Kesterson Pond 2	Pond	Lentic	52.50		9.30	22.10	90.00	0.25
Schuler et al. 1990	Kesterson National Wildlife Refuge	Kesterson Pond 11	Pond	Lentic	53.70		11.50	24.85	40.00	0.62
Stephens et al. 1988	Marsh 4720	*	Marsh	Lentic	2.10		4.20	2.97	31.00	0.10
Butler et al. 1991	Uncompahgre River at Colona	4	River	Lotic	0.95			0.95	1.50	0.63
Butler et al. 1993	Spring Cr. at La Boca	SP2	Creek	Lotic	1.60		0.50	0.89	5.00	0.18
Butler et al. 1995	Cahone Canyon at Highway 666	CH	Creek	Lotic	2.50		4.30	3.28	12.00	0.27
Butler et al. 1995	Hartman Draw near mouth, at Cortez	HD2	Draw	Lotic	0.45		0.20	0.30	2.00	0.15
Butler et al. 1995	McElmo Cr. at Hwy. 160, near Cortez	ME1	Creek	Lotic	1.80			1.80	2.00	0.90
Butler et al. 1995	McElmo Cr. downstream from Alkali Cyn.	ME2	Creek	Lotic	1.11		1.10	1.10	3.00	0.37
Butler et al. 1995	McElmo Cr. downstream from Yellow Jacket Cyn.	ME4	Creek	Lotic	1.04		0.50	0.72	6.00	0.12
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	ME3	Creek	Lotic	0.82		0.40	0.57	6.00	0.10
Butler et al. 1995	Navajo Wash near Towaoc	NW	Wash	Lotic	3.45		1.60	2.35	12.00	0.20
Butler et al. 1995	San Juan River at Four Comers	SJ1	River	Lotic	0.52		0.30	0.39	1.50	0.26
Butler et al. 1995	San Juan River at Mexican Hat Utah	SJ3	River	Lotic	0.94		0.20	0.43	1.50	0.29
Butler et al. 1995	Woods Cyn. Near Yellow Jacket	WC	Creek	Lotic	3.30		1.50	2.22	5.50	0.40

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Reference	Site description	Site ID	Specific waterbody type - original	Specific waterbody type - Lentic or Lotic	C_{algae} (mg/kg)	$C_{detritus}$ (mg/kg)	C_{sed} (mg/kg)	$C_{particulate}$ (mg/kg)	C_{water} (µg/L)	Site EF (L/g)
Butler et al. 1997	Cahone Canyon at Highway 666	CH1	Creek	Lotic	2.05			2.05	10.50	0.20
Butler et al. 1997	Mud Creek at Highway 32, near Cortez	MUD2	Creek	Lotic	1.30			1.30	18.50	0.07
Butler et al. 1997	Tributary of Cahone Canyon at 13 Road	CH2	Creek	Lotic	1.75			1.75	5.50	0.32
Butler et al. 1997	Tributary of Yellow Jacket Canyon at Highway 666	YJ1	Creek	Lotic	1.85			1.85	7.00	0.26
Butler et al. 1997	Unnamed tributary of Cow Canyon at 8 Road	COW	Creek	Lotic	1.45			1.45	3.50	0.41
Butler et al. 1997	Unnamed tributary of Cross Canyon upstream from Alkali Canyon	CCTR	Creek	Lotic	1.75			1.75	4.50	0.39
Casey 2005	Deerlick Creek		Creek	Lotic		1.00	0.20	0.45	0.20	2.24
Casey 2005	Luscar Creek		Creek	Lotic	5.50	3.20	2.40	3.48	10.70	0.33
Formation 2012	Crow Creek - 1A	CC-1A	Creek	Lotic	3.64		1.20	2.09	2.45	0.80
Formation 2012	Crow Creek - 3A	CC-3A	Creek	Lotic	3.10		0.83	1.60	2.20	0.81
Formation 2012	Crow Creek - CC150	CC-150	Creek	Lotic	1.20		0.63	0.87	0.80	1.04
Formation 2012	Crow Creek - CC350	CC-350	Creek	Lotic	1.50		0.70	1.02	0.86	1.16
Formation 2012	Crow Creek - CC75	CC-75	Creek	Lotic	1.01		0.54	0.74	0.52	1.19
Formation 2012	Deer Creek	DC-600	Creek	Lotic	4.55		1.40	2.52	1.62	1.55

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Reference	Site description	Site ID	Specific waterbody type - original	Specific waterbody type - Lentic or Lotic	C_{algae} (mg/kg)	$C_{detritus}$ (mg/kg)	C_{sed} (mg/kg)	$C_{particulate}$ (mg/kg)	C_{water} (µg/L)	Site EF (L/g)
Formation 2012	Hoopes Spring - HS	HS	Spring	Lotic	12.00		2.30	5.25	20.95	0.24
Formation 2012	Hoopes Spring - HS3	HS-3	Spring	Lotic	12.00		7.00	9.17	17.05	0.54
Formation 2012	Sage Creek - LSV2C	LSV-2C	Creek	Lotic	8.09		4.60	6.10	13.80	0.45
Formation 2012	Sage Creek - LSV4	LSV-4	Creek	Lotic	9.56		3.60	5.87	8.45	0.69
Formation 2012	South Fork Tincup Cr.	SFTC-1	Creek	Lotic	0.73		0.31	0.47	0.44	1.32
Golder 2011; Teck Coal 2013	McLeod River below Cheviot Creek	MR-2	River	Lotic	1.47			1.47	2.38	0.62
Golder 2011; Teck Coal 2013	McLeod River below Luscar Dreek	MR-6	River	Lotic	0.86			0.86	4.29	0.20
Golder 2011; Teck Coal 2013	McLeod River below Whitehorse Creek	MR-4	River	Lotic	0.68			0.68	1.07	0.64
Golder 2011; Teck Coal 2013	McLeod River reference	MR-1	River	Lotic	0.75			0.75	0.30	2.50
Golder 2011; Teck Coal 2013	Prospect Creek far field	PC-3	Creek	Lotic	0.37			0.37	0.63	0.59
Golder 2011; Teck Coal 2013	Prospect Creek reference	PC-1	Creek	Lotic	0.86			0.86	0.40	2.15
Hamilton and Buhl 2004	lower East Mill Creek	LEMC	Creek	Lotic	25.70		38.90	31.62	24.00	1.32

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Reference	Site description	Site ID	Specific waterbody type - original	Specific waterbody type - Lentic or Lotic	C_{algae} (mg/kg)	$C_{detritus}$ (mg/kg)	C_{sed} (mg/kg)	$C_{particulate}$ (mg/kg)	C_{water} (µg/L)	Site EF (L/g)
McDonald and Strosher 1998	Elk R. above Cadorna Cr. (745)	ER 745	River	Lotic	0.31		1.28	0.63	0.10	6.30
McDonald and Strosher 1998	Elk R. above Fording R.	ER 750	River	Lotic	0.78		0.70	0.74	0.40	1.85
McDonald and Strosher 1998	Fording R. above Swift Cr. (746)	ER 746	River	Lotic	1.56		2.41	1.94	8.60	0.23
McDonald and Strosher 1998	Michel Cr. at Highway 3	ER 751	Creek	Lotic	1.26		2.32	1.71	7.10	0.24
Orr et al. 2006	Alexander Creek	AC	Creek	Lotic	4.49		0.90	2.01	0.90	2.23
Orr et al. 2006	Fording River	FR	River	Lotic	3.27		2.10	2.62	20.10	0.13
Orr et al. 2006	Line Creek	LC	Creek	Lotic	2.19		2.10	2.14	20.90	0.10
Orr et al. 2012	Elk River 1	EL1	River	Lotic	2.30			2.30	4.20	0.55
Orr et al. 2012	Elk River 12	EL12	River	Lotic	2.00			2.00	0.75	2.67
Orr et al. 2012	Fording River 23	FO23	River	Lotic	6.35			6.35	30.60	0.21
Orr et al. 2012	Michel Creek 2	MI2	Creek	Lotic	2.10			2.10	7.40	0.28
Presser and Luoma 2009	Upper Peters canyon (dry)	U PCW dry	Wash	Lotic	1.20		0.60	0.85	3.20	0.27
Saiki and Lowe 1987	San Luis Drain		Drain	Lotic	67.00	275.00	79.90	113.76	316.50	0.36
Saiki and Lowe 1987	Volta Wasteway		Wasteway	Lotic	0.87	2.03	0.24	0.76	0.74	1.03
Saiki et al. 1993	Mud Slough at Gun Club Road	GT5	Slough	Lotic	4.50	14.95		8.20	6.00	1.37

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Reference	Site description	Site ID	Specific waterbody type - original	Specific waterbody type - Lentic or Lotic	C_{algae} (mg/kg)	$C_{detritus}$ (mg/kg)	C_{sed} (mg/kg)	$C_{particulate}$ (mg/kg)	C_{water} (µg/L)	Site EF (L/g)
Saiki et al. 1993	Salt Slough at the San Luis National Wildlife Refuge	GT4	Slough	Lotic	1.39	8.40		3.42	8.00	0.43
Saiki et al. 1993	San Joaquin R. above Hills Ferry Road	SJR2	River	Lotic	1.25	5.00		2.50	7.00	0.36
Saiki et al. 1993	San Joaquin R. at Durham Ferry State Recereation Area	SJR3	River	Lotic	0.45	1.25		0.75	1.00	0.75
Stephens et al. 1988	Drain J3	*	Drain	Lotic	24.00		48.00	33.94	110.00	0.31

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APPENDIX I: OBSERVED VERSUS PREDICTED EGG-OVARY CONCENTRATIONS

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The following table includes data for 317 individual fish tissue selenium measurements from the 64 sites where EFs could be calculated. Observed egg-ovary fish tissue measurements were compared to predicted egg-ovary fish tissue measurements calculated using equation 22 of the main text, also shown here for convenience.

$$C_{egg-ovary} = C_{water} \times TTF^{composite} \times EF \times CF \quad \text{(Equation 22)}$$

These data were used to generate the observed to predicted egg-ovary concentration Figure 6.3 of the main text. When the measured tissue type was either muscle or whole body, it was converted to egg-ovary using taxa specific conversion factors. The predicted and measured concentrations are highly correlated ($r = 0.82$, $t_{(315)} = 25.30$, $P < 0.001$).

Study	Site	Species	Site Water (µg/l)	EF (l/g)	TTF^{comp}	CF	Pred. E/O (mg/kg)	Obs. E/O (mg/kg)	Obs. tissue type
Birkner 1978	East Allen Reservoir, Medicine Bow WY	Iowa darter	4.80	2.31	2.87	1.45	46.14	52.68	WB
Birkner 1978	Galett Lake, Laramie WY	Iowa darter	0.80	0.88	2.87	1.45	2.91	3.05	WB
Birkner 1978	Larimer Highway 9 Pond, Fort Collins CO	northern plains killifish	15.90	1.70	2.44	1.20	79.04	68.71	WB
Birkner 1978	Meeboer Lake, Laramie WY	northern plains killifish	0.30	0.58	2.44	1.20	0.51	9.22	WB
Birkner 1978	Miller's Lake, Wellington CO	fathead minnow	6.00	2.37	2.78	1.40	55.31	15.37	WB
Birkner 1978	Miller's Lake, Wellington CO	Iowa darter	6.00	2.37	2.87	1.45	59.18	33.38	WB
Birkner 1978	Sweitzer Lake, Delta CO	northern plains killifish	9.40	0.87	2.44	1.20	23.94	38.18	WB
Birkner 1978	Sweitzer Lake, Delta CO	fathead minnow	9.40	0.87	2.78	1.40	31.89	110.38	WB
Birkner 1978	Twin Buttes Reservoir, Laramie WY	northern plains killifish	7.60	1.21	2.44	1.20	26.79	27.65	WB
Birkner 1978	Twin Buttes Reservoir, Laramie WY	fathead minnow	7.60	1.21	2.78	1.40	35.69	48.20	WB
Birkner 1978	Twin Buttes Reservoir, Laramie WY	Iowa darter	7.60	1.21	2.87	1.45	38.18	60.81	WB
Bowie et al. 1996	Hyco Reservoir	bluegill	11.50	2.35	2.00	2.13	114.97	87.47	WB
Butler et al. 1991	Uncompahgre River at Colona	flannelmouth sucker	1.50	0.63	1.52	1.41	2.03	2.40	WB
Butler et al. 1991	Uncompahgre River at Colona	white sucker	1.50	0.63	1.58	1.38	2.07	7.32	WB
Butler et al. 1991	Uncompahgre River at Colona	bluehead sucker	1.50	0.63	1.24	1.82	2.13	3.27	WB
Butler et al. 1991	Uncompahgre River at Colona	mottled sculpin	1.50	0.63	2.72	1.45	3.72	3.77	WB

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Study	Site	Species	Site Water (µg/l)	EF (l/g)	TTF^{comp}	CF	Pred. E/O (mg/kg)	Obs. E/O (mg/kg)	Obs. tissue type
Butler et al. 1991	Uncompahgre River at Colona	mottled sculpin	1.50	0.63	2.72	1.45	3.72	6.39	WB
Butler et al. 1991	Uncompahgre River at Colona	brown trout	1.50	0.63	2.78	1.45	3.80	4.77	WB
Butler et al. 1991	Uncompahgre River at Colona	brown trout	1.50	0.63	2.78	1.45	3.80	5.06	WB
Butler et al. 1991	Uncompahgre River at Colona	rainbow trout	1.50	0.63	2.33	2.44	5.39	6.88	WB
Butler et al. 1993	Navajo Reservoir, Piedra River Arm, near La Boca	brown trout	1.00	1.26	2.78	1.45	5.08	6.20	E-O
Butler et al. 1993	Navajo Reservoir, Piedra River Arm, near La Boca	channel catfish	1.00	1.26	1.35	1.45	2.47	2.32	WB
Butler et al. 1993	Navajo Reservoir, Piedra River Arm, near La Boca	bullhead	1.00	1.26	1.62	1.45	2.96	2.03	WB
Butler et al. 1993	Navajo Reservoir, Piedra River Arm, near La Boca	bullhead	1.00	1.26	1.62	1.45	2.96	3.05	WB
Butler et al. 1993	Navajo Reservoir, Piedra River Arm, near La Boca	common carp	1.00	1.26	1.58	1.92	3.82	6.15	WB
Butler et al. 1993	Navajo Reservoir, Piedra River Arm, near La Boca	common carp	1.00	1.26	1.58	1.92	3.82	5.19	WB
Butler et al. 1993	Navajo Reservoir, Piedra River Arm, near La Boca	common carp	1.00	1.26	1.58	1.92	3.82	6.15	WB
Butler et al. 1993	Spring Cr. at La Boca	white sucker	5.00	0.18	1.58	1.38	1.96	4.83	WB
Butler et al. 1993	Spring Cr. at La Boca	bluehead sucker	5.50	0.18	1.24	1.82	2.22	12.91	WB
Butler et al. 1993	Spring Cr. at La Boca	speckled dace	5.00	0.18	1.36	1.95	2.37	23.45	WB
Butler et al. 1993	Spring Cr. at La Boca	fathead minnow	5.00	0.18	2.78	1.40	3.48	11.46	WB
Butler et al. 1993	Spring Cr. at La Boca	brown trout	5.00	0.18	2.78	1.45	3.60	1.74	WB
Butler et al. 1993	Spring Cr. at La Boca	fathead minnow	5.50	0.18	2.78	1.40	3.83	8.38	WB
Butler et al. 1993	Spring Cr. at La Boca	brown trout	5.50	0.18	2.78	1.45	3.96	4.92	WB
Butler et al. 1995	Hartman Draw near mouth, at Cortez	sucker	2.00	0.15	1.25	1.41	0.53	1.07	WB
Butler et al. 1995	Hartman Draw near mouth, at Cortez	sucker	2.00	0.15	1.25	1.41	0.53	0.96	WB
Butler et al. 1995	Hartman Draw near mouth, at Cortez	flannelmouth sucker	2.00	0.15	1.52	1.41	0.64	0.69	WB
Butler et al. 1995	Hartman Draw near mouth, at Cortez	flannelmouth sucker	2.00	0.15	1.52	1.41	0.64	0.76	WB
Butler et al. 1995	Hartman Draw near mouth, at Cortez	flannelmouth sucker	2.00	0.15	1.52	1.41	0.64	0.87	WB
Butler et al. 1995	Hartman Draw near mouth, at Cortez	flannelmouth sucker	2.00	0.15	1.52	1.41	0.64	1.35	WB
Butler et al. 1995	Hartman Draw near mouth, at Cortez	fathead minnow	2.00	0.15	2.78	1.40	1.16	2.10	WB

Study	Site	Species	Site Water (µg/l)	EF (l/g)	TTF^{comp}	CF	Pred. E/O (mg/kg)	Obs. E/O (mg/kg)	Obs. tissue type
Butler et al. 1995	Hartman Draw near mouth, at Cortez	fathead minnow	2.00	0.15	2.78	1.40	1.16	2.24	WB
Butler et al. 1995	McElmo Cr. at Hwy. 160, near Cortez	speckled dace	2.00	0.90	1.36	1.95	4.77	12.51	WB
Butler et al. 1995	McElmo Cr. at Hwy. 160, near Cortez	fathead minnow	2.00	0.90	2.78	1.40	7.00	7.82	WB
Butler et al. 1995	McElmo Cr. downstream from Alkali Cyn.	flannelmouth sucker	3.00	0.37	1.52	1.41	2.37	2.25	WB
Butler et al. 1995	McElmo Cr. downstream from Alkali Cyn.	flannelmouth sucker	3.00	0.37	1.52	1.41	2.37	1.97	WB
Butler et al. 1995	McElmo Cr. downstream from Alkali Cyn.	flannelmouth sucker	3.00	0.37	1.52	1.41	2.37	2.82	WB
Butler et al. 1995	McElmo Cr. downstream from Alkali Cyn.	flannelmouth sucker	3.00	0.37	1.52	1.41	2.37	3.10	WB
Butler et al. 1995	McElmo Cr. downstream from Alkali Cyn.	bluehead sucker	3.00	0.37	1.24	1.82	2.49	1.51	WB
Butler et al. 1995	McElmo Cr. downstream from Alkali Cyn.	bluehead sucker	3.00	0.37	1.24	1.82	2.49	2.36	WB
Butler et al. 1995	McElmo Cr. downstream from Alkali Cyn.	speckled dace	3.00	0.37	1.36	1.95	2.92	11.92	WB
Butler et al. 1995	McElmo Cr. downstream from Alkali Cyn.	fathead minnow	3.00	0.37	2.78	1.40	4.29	6.71	WB
Butler et al. 1995	McElmo Cr. downstream from Yellow Jacket Cyn.	flannelmouth sucker	6.00	0.12	1.52	1.41	1.54	2.11	WB
Butler et al. 1995	McElmo Cr. downstream from Yellow Jacket Cyn.	flannelmouth sucker	6.00	0.12	1.52	1.41	1.54	1.83	WB
Butler et al. 1995	McElmo Cr. downstream from Yellow Jacket Cyn.	flannelmouth sucker	6.00	0.12	1.52	1.41	1.54	2.68	WB
Butler et al. 1995	McElmo Cr. downstream from Yellow Jacket Cyn.	flannelmouth sucker	6.00	0.12	1.52	1.41	1.54	3.38	WB
Butler et al. 1995	McElmo Cr. downstream from Yellow Jacket Cyn.	flannelmouth sucker	6.00	0.12	1.52	1.41	1.54	4.23	WB
Butler et al. 1995	McElmo Cr. downstream from Yellow Jacket Cyn.	common carp	6.00	0.12	1.58	1.92	2.18	7.49	WB
Butler et al. 1995	McElmo Cr. downstream from Yellow Jacket Cyn.	common carp	6.00	0.12	1.58	1.92	2.18	7.11	WB

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Study	Site	Species	Site Water (µg/l)	EF (l/g)	TTF^{comp}	CF	Pred. E/O (mg/kg)	Obs. E/O (mg/kg)	Obs. tissue type
Butler et al. 1995	McElmo Cr. downstream from Yellow Jacket Cyn.	common carp	6.00	0.12	1.58	1.92	2.18	7.30	WB
Butler et al. 1995	McElmo Cr. downstream from Yellow Jacket Cyn.	fathead minnow	6.00	0.12	2.78	1.40	2.80	1.96	WB
Butler et al. 1995	McElmo Cr. downstream from Yellow Jacket Cyn.	fathead minnow	6.00	0.12	2.78	1.40	2.80	8.24	WB
Butler et al. 1995	McElmo Cr. downstream from Yellow Jacket Cyn.	red shiner	6.00	0.12	2.27	1.95	3.20	9.97	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	flannelmouth sucker	6.00	0.10	1.52	1.41	1.23	2.40	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	flannelmouth sucker	6.00	0.10	1.52	1.41	1.23	2.40	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	flannelmouth sucker	6.00	0.10	1.52	1.41	1.23	2.96	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	flannelmouth sucker	6.00	0.10	1.52	1.41	1.23	3.38	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	flannelmouth sucker	6.00	0.10	1.52	1.41	1.23	5.07	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	bluehead sucker	6.00	0.10	1.24	1.82	1.29	3.27	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	bluehead sucker	6.00	0.10	1.24	1.82	1.29	3.09	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	bullhead	6.00	0.10	1.62	1.45	1.34	4.35	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	speckled dace	6.00	0.10	1.36	1.95	1.52	5.47	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	speckled dace	6.00	0.10	1.36	1.95	1.52	13.68	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	speckled dace	6.00	0.10	1.36	1.95	1.52	10.75	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	common carp	6.00	0.10	1.58	1.92	1.74	8.45	WB

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Study	Site	Species	Site Water (µg/l)	EF (l/g)	TTF^{comp}	CF	Pred. E/O (mg/kg)	Obs. E/O (mg/kg)	Obs. tissue type
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	common carp	6.00	0.10	1.58	1.92	1.74	9.99	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	green sunfish	6.00	0.10	2.29	1.45	1.91	7.26	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	fathead minnow	6.00	0.10	2.78	1.40	2.23	6.01	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	fathead minnow	6.00	0.10	2.78	1.40	2.23	7.41	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	fathead minnow	6.00	0.10	2.78	1.40	2.23	6.15	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	red shiner	6.00	0.10	2.27	1.95	2.55	8.99	WB
Butler et al. 1995	McElmo Cr.upstream from Yellow Jacket Cyn.	red shiner	6.00	0.10	2.27	1.95	2.55	8.21	WB
Butler et al. 1995	Navajo Wash near Towaoc	bluehead sucker	12.00	0.20	1.24	1.82	5.30	16.91	WB
Butler et al. 1995	Navajo Wash near Towaoc	bluehead sucker	12.00	0.20	1.24	1.82	5.30	13.09	WB
Butler et al. 1995	Navajo Wash near Towaoc	speckled dace	12.00	0.20	1.36	1.95	6.23	17.00	WB
Butler et al. 1995	San Juan River at Four Comers	channel catfish	1.50	0.26	1.35	1.45	0.77	2.98	M
Butler et al. 1995	San Juan River at Four Comers	flannelmouth sucker	1.50	0.26	1.52	1.41	0.84	2.70	M
Butler et al. 1995	San Juan River at Four Comers	channel catfish	1.50	0.26	1.35	1.45	0.77	5.95	WB
Butler et al. 1995	San Juan River at Four Comers	flannelmouth sucker	1.50	0.26	1.52	1.41	0.84	2.11	WB
Butler et al. 1995	San Juan River at Four Comers	flannelmouth sucker	1.50	0.26	1.52	1.41	0.84	3.10	WB
Butler et al. 1995	San Juan River at Four Comers	flannelmouth sucker	1.50	0.26	1.52	1.41	0.84	0.86	WB
Butler et al. 1995	San Juan River at Four Comers	flannelmouth sucker	1.50	0.26	1.52	1.41	0.84	1.55	WB
Butler et al. 1995	San Juan River at Four Comers	flannelmouth sucker	1.50	0.26	1.52	1.41	0.84	5.92	WB
Butler et al. 1995	San Juan River at Four Comers	bluehead sucker	1.50	0.26	1.24	1.82	0.89	2.18	WB
Butler et al. 1995	San Juan River at Four Comers	bluehead sucker	1.50	0.26	1.24	1.82	0.89	1.71	WB
Butler et al. 1995	San Juan River at Four Comers	bluehead sucker	1.50	0.26	1.24	1.82	0.89	2.18	WB
Butler et al. 1995	San Juan River at Four Comers	speckled dace	1.50	0.26	1.36	1.95	1.04	8.40	WB
Butler et al. 1995	San Juan River at Four Comers	speckled dace	1.50	0.26	1.36	1.95	1.04	9.97	WB
Butler et al. 1995	San Juan River at Four Comers	speckled dace	1.50	0.26	1.36	1.95	1.04	5.67	WB
Butler et al. 1995	San Juan River at Four Comers	common carp	1.50	0.26	1.58	1.92	1.19	10.18	WB

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Study	Site	Species	Site Water (µg/l)	EF (l/g)	TTF^{comp}	CF	Pred. E/O (mg/kg)	Obs. E/O (mg/kg)	Obs. tissue type
Butler et al. 1995	San Juan River at Four Comers	common carp	1.50	0.26	1.58	1.92	1.19	6.53	WB
Butler et al. 1995	San Juan River at Four Comers	red shiner	1.50	0.26	2.27	1.95	1.75	6.84	WB
Butler et al. 1995	San Juan River at Mexican Hat Utah	channel catfish	1.50	0.29	1.35	1.45	0.85	10.88	WB
Butler et al. 1995	San Juan River at Mexican Hat Utah	flannelmouth sucker	1.50	0.29	1.52	1.41	0.93	2.40	WB
Butler et al. 1995	San Juan River at Mexican Hat Utah	flannelmouth sucker	1.50	0.29	1.52	1.41	0.93	2.68	WB
Butler et al. 1995	San Juan River at Mexican Hat Utah	flannelmouth sucker	1.50	0.29	1.52	1.41	0.93	4.23	WB
Butler et al. 1995	San Juan River at Mexican Hat Utah	flannelmouth sucker	1.50	0.29	1.52	1.41	0.93	1.97	WB
Butler et al. 1995	San Juan River at Mexican Hat Utah	flannelmouth sucker	1.50	0.29	1.52	1.41	0.93	2.40	WB
Butler et al. 1995	San Juan River at Mexican Hat Utah	flannelmouth sucker	1.50	0.29	1.52	1.41	0.93	4.23	WB
Butler et al. 1995	San Juan River at Mexican Hat Utah	bluehead sucker	1.50	0.29	1.24	1.82	0.98	4.18	WB
Butler et al. 1995	San Juan River at Mexican Hat Utah	bluehead sucker	1.50	0.29	1.24	1.82	0.98	4.36	WB
Butler et al. 1995	San Juan River at Mexican Hat Utah	bluehead sucker	1.50	0.29	1.24	1.82	0.98	4.91	WB
Butler et al. 1995	San Juan River at Mexican Hat Utah	common carp	1.50	0.29	1.58	1.92	1.31	7.49	WB
Butler et al. 1995	Woods Cyn. Near Yellow Jacket	fathead minnow	5.50	0.40	2.78	1.40	8.65	25.71	WB
Butler et al. 1995	Woods Cyn. Near Yellow Jacket	fathead minnow	5.50	0.40	2.78	1.40	8.65	32.00	WB
Butler et al. 1995	Woods Cyn. Near Yellow Jacket	fathead minnow	5.50	0.40	2.78	1.40	8.65	36.89	WB
Butler et al. 1997	Cahone Canyon at Highway 666	green sunfish	10.50	0.20	2.29	1.45	6.83	13.79	WB
Butler et al. 1997	Large pond south of G Road, southern Mancos Valley	fathead minnow	3.00	2.00	2.78	1.40	23.39	15.37	WB
Butler et al. 1997	Mud Creek at Highway 32, near Cortez	bluehead sucker	18.50	0.07	1.24	1.82	2.94	4.55	WB
Butler et al. 1997	Mud Creek at Highway 32, near Cortez	bluehead sucker	18.50	0.07	1.24	1.82	2.94	9.45	WB
Butler et al. 1997	Mud Creek at Highway 32, near Cortez	bluehead sucker	18.50	0.07	1.24	1.82	2.94	10.18	WB
Butler et al. 1997	Mud Creek at Highway 32, near Cortez	green sunfish	18.50	0.07	2.29	1.45	4.33	11.03	WB
Butler et al. 1997	Mud Creek at Highway 32, near Cortez	green sunfish	18.50	0.07	2.29	1.45	4.33	10.16	WB
Butler et al. 1997	Mud Creek at Highway 32, near Cortez	fathead minnow	18.50	0.07	2.78	1.40	5.05	10.76	WB
Butler et al. 1997	Mud Creek at Highway 32, near Cortez	fathead minnow	18.50	0.07	2.78	1.40	5.05	16.77	WB
Butler et al. 1997	Mud Creek at Highway 32, near Cortez	fathead minnow	18.50	0.07	2.78	1.40	5.05	9.08	WB
Butler et al. 1997	Pond downstream from site MNP2, southern Mancos Valley	smallmouth bass	1.00	5.15	1.93	1.42	14.09	17.03	WB
Butler et al. 1997	Pond on Woods Canyon at 15 Road	fathead minnow	3.00	0.90	2.78	1.40	10.55	13.97	WB
Butler et al. 1997	Pond on Woods Canyon at 15 Road	fathead minnow	3.00	0.90	2.78	1.40	10.55	20.96	WB
Casey 2005	Deerlick Creek	rainbow trout	0.20	2.24	2.33	2.44	2.55	3.14	M

Study	Site	Species	Site Water (µg/l)	EF (l/g)	TTF^{comp}	CF	Pred. E/O (mg/kg)	Obs. E/O (mg/kg)	Obs. tissue type
Casey 2005	Deerlick Creek	rainbow trout	0.20	2.24	2.33	2.44	2.55	8.16	E-O
Casey 2005	Luscar Creek	rainbow trout	10.70	0.33	2.33	2.44	19.85	16.79	M
Casey 2005	Luscar Creek	rainbow trout	10.70	0.33	2.33	2.44	19.85	33.48	E-O
Formation 2012	Crow Creek - 1A	sculpin	2.20	0.80	2.78	1.45	7.08	14.43	WB
Formation 2012	Crow Creek - 1A	sculpin	2.20	0.80	2.78	1.45	7.08	12.10	WB
Formation 2012	Crow Creek - 1A	brown trout	2.20	0.80	2.96	1.45	7.52	15.20	WB
Formation 2012	Crow Creek - 1A	brown trout	2.20	0.80	2.96	1.45	7.52	13.49	WB
Formation 2012	Crow Creek - 1A	sculpin	2.45	0.80	2.78	1.45	7.89	11.29	WB
Formation 2012	Crow Creek - 1A	brown trout	2.45	0.80	2.96	1.45	8.37	14.39	WB
Formation 2012	Crow Creek - 1A	sculpin	2.90	0.80	2.78	1.45	9.34	25.35	WB
Formation 2012	Crow Creek - 1A	brown trout	2.90	0.80	2.96	1.45	9.91	24.36	WB
Formation 2012	Crow Creek - 1A	sculpin	4.80	0.80	2.78	1.45	15.45	18.33	WB
Formation 2012	Crow Creek - 1A	brown trout	4.80	0.80	2.96	1.45	16.40	20.29	WB
Formation 2012	Crow Creek - 3A	sculpin	1.80	0.81	2.78	1.45	5.86	20.97	WB
Formation 2012	Crow Creek - 3A	sculpin	1.80	0.81	2.78	1.45	5.86	16.91	WB
Formation 2012	Crow Creek - 3A	brown trout	1.80	0.81	2.97	1.45	6.22	15.09	WB
Formation 2012	Crow Creek - 3A	brown trout	1.80	0.81	2.97	1.45	6.22	13.30	WB
Formation 2012	Crow Creek - 3A	sculpin	2.20	0.81	2.78	1.45	7.17	16.65	WB
Formation 2012	Crow Creek - 3A	brown trout	2.20	0.81	2.97	1.45	7.60	16.27	WB
Formation 2012	Crow Creek - 3A	brown trout	2.60	0.81	2.97	1.45	8.99	22.24	WB
Formation 2012	Crow Creek - 3A	sculpin	4.20	0.81	2.78	1.45	13.68	29.32	WB
Formation 2012	Crow Creek - 3A	brown trout	4.20	0.81	2.97	1.45	14.52	28.45	WB
Formation 2012	Crow Creek - CC150	sculpin	0.68	1.04	2.74	1.45	2.81	8.72	WB
Formation 2012	Crow Creek - CC150	sculpin	0.68	1.04	2.74	1.45	2.81	7.31	WB
Formation 2012	Crow Creek - CC150	brown trout	0.68	1.04	2.91	1.45	2.98	8.43	WB
Formation 2012	Crow Creek - CC150	brown trout	0.68	1.04	2.91	1.45	2.98	12.54	WB
Formation 2012	Crow Creek - CC150	sculpin	0.80	1.04	2.74	1.45	3.31	7.46	WB
Formation 2012	Crow Creek - CC150	brown trout	0.80	1.04	2.91	1.45	3.51	7.52	WB
Formation 2012	Crow Creek - CC150	sculpin	1.40	1.04	2.74	1.45	5.79	15.57	WB
Formation 2012	Crow Creek - CC150	brown trout	1.40	1.04	2.91	1.45	6.14	14.66	WB
Formation 2012	Crow Creek - CC150	sculpin	1.50	1.04	2.74	1.45	6.20	10.67	WB
Formation 2012	Crow Creek - CC150	brown trout	1.50	1.04	2.91	1.45	6.58	11.32	WB

Study	Site	Species	Site Water (µg/l)	EF (l/g)	TTF^{comp}	CF	Pred. E/O (mg/kg)	Obs. E/O (mg/kg)	Obs. tissue type
Formation 2012	Crow Creek - CC350	sculpin	0.82	1.16	2.79	1.45	3.86	9.39	WB
Formation 2012	Crow Creek - CC350	sculpin	0.82	1.16	2.79	1.45	3.86	10.33	WB
Formation 2012	Crow Creek - CC350	sculpin	0.86	1.16	2.79	1.45	4.02	7.66	WB
Formation 2012	Crow Creek - CC350	brown trout	0.82	1.16	2.97	1.45	4.09	9.08	WB
Formation 2012	Crow Creek - CC350	brown trout	0.82	1.16	2.97	1.45	4.09	12.33	WB
Formation 2012	Crow Creek - CC350	sculpin	0.89	1.16	2.79	1.45	4.19	14.56	WB
Formation 2012	Crow Creek - CC350	brown trout	0.86	1.16	2.97	1.45	4.27	8.36	WB
Formation 2012	Crow Creek - CC350	brown trout	0.89	1.16	2.97	1.45	4.44	16.63	WB
Formation 2012	Crow Creek - CC350	sculpin	1.10	1.16	2.79	1.45	5.15	13.83	WB
Formation 2012	Crow Creek - CC350	brown trout	1.10	1.16	2.97	1.45	5.47	11.49	WB
Formation 2012	Crow Creek - CC75	sculpin	0.46	1.19	2.69	1.45	2.13	8.10	WB
Formation 2012	Crow Creek - CC75	sculpin	0.46	1.19	2.69	1.45	2.13	7.30	WB
Formation 2012	Crow Creek - CC75	brown trout	0.46	1.19	2.87	1.45	2.26	5.86	WB
Formation 2012	Crow Creek - CC75	brown trout	0.46	1.19	2.87	1.45	2.26	7.74	WB
Formation 2012	Crow Creek - CC75	sculpin	0.52	1.19	2.69	1.45	2.39	5.47	WB
Formation 2012	Crow Creek - CC75	brown trout	0.52	1.19	2.87	1.45	2.54	4.60	WB
Formation 2012	Crow Creek - CC75	sculpin	0.85	1.19	2.69	1.45	3.94	10.43	WB
Formation 2012	Crow Creek - CC75	brown trout	0.85	1.19	2.87	1.45	4.18	14.92	WB
Formation 2012	Crow Creek - CC75	sculpin	1.00	1.19	2.69	1.45	4.64	10.28	WB
Formation 2012	Crow Creek - CC75	brown trout	1.00	1.19	2.87	1.45	4.92	9.54	WB
Formation 2012	Deer Creek	sculpin	1.45	1.55	2.81	1.45	9.17	11.07	WB
Formation 2012	Deer Creek	sculpin	1.50	1.55	2.81	1.45	9.49	12.34	WB
Formation 2012	Deer Creek	sculpin	1.50	1.55	2.81	1.45	9.49	11.42	WB
Formation 2012	Deer Creek	brown trout	1.45	1.55	3.00	1.45	9.73	8.46	WB
Formation 2012	Deer Creek	brown trout	1.50	1.55	3.00	1.45	10.07	12.35	WB
Formation 2012	Deer Creek	brown trout	1.50	1.55	3.00	1.45	10.07	8.96	WB
Formation 2012	Deer Creek	sculpin	2.00	1.55	2.81	1.45	12.65	11.55	WB
Formation 2012	Deer Creek	brown trout	2.00	1.55	3.00	1.45	13.43	18.55	WB
Formation 2012	Deer Creek	sculpin	2.40	1.55	2.81	1.45	15.18	12.51	WB
Formation 2012	Deer Creek	brown trout	2.40	1.55	3.00	1.45	16.11	15.24	WB
Formation 2012	Hoopes Spring - HS	sculpin	20.50	0.24	3.63	1.45	26.38	33.71	WB
Formation 2012	Hoopes Spring - HS	sculpin	20.50	0.24	3.63	1.45	26.38	33.74	WB

Study	Site	Species	Site Water (µg/l)	EF (l/g)	TTF^{comp}	CF	Pred. E/O (mg/kg)	Obs. E/O (mg/kg)	Obs. tissue type
Formation 2012	Hoopes Spring - HS	sculpin	20.95	0.24	3.63	1.45	26.96	15.89	WB
Formation 2012	Hoopes Spring - HS	brown trout	20.50	0.24	3.86	1.45	27.99	23.89	WB
Formation 2012	Hoopes Spring - HS	brown trout	20.50	0.24	3.86	1.45	27.99	36.15	WB
Formation 2012	Hoopes Spring - HS	brown trout	20.95	0.24	3.86	1.45	28.61	36.00	WB
Formation 2012	Hoopes Spring - HS	sculpin	27.30	0.24	3.63	1.45	35.13	52.15	WB
Formation 2012	Hoopes Spring - HS	brown trout	27.30	0.24	3.86	1.45	37.28	47.18	WB
Formation 2012	Hoopes Spring - HS	sculpin	40.45	0.24	3.63	1.45	52.05	59.94	WB
Formation 2012	Hoopes Spring - HS	brown trout	40.45	0.24	3.86	1.45	55.23	32.97	WB
Formation 2012	Hoopes Spring - HS3	sculpin	16.10	0.54	2.47	1.45	30.96	31.71	WB
Formation 2012	Hoopes Spring - HS3	sculpin	16.10	0.54	2.47	1.45	30.96	26.95	WB
Formation 2012	Hoopes Spring - HS3	sculpin	17.05	0.54	2.47	1.45	32.79	38.65	WB
Formation 2012	Hoopes Spring - HS3	brown trout	16.10	0.54	2.63	1.45	32.85	29.78	WB
Formation 2012	Hoopes Spring - HS3	brown trout	16.10	0.54	2.63	1.45	32.85	27.23	WB
Formation 2012	Hoopes Spring - HS3	brown trout	17.05	0.54	2.63	1.45	34.79	25.87	WB
Formation 2012	Hoopes Spring - HS3	sculpin	26.00	0.54	2.47	1.45	49.99	34.73	WB
Formation 2012	Hoopes Spring - HS3	brown trout	26.00	0.54	2.63	1.45	53.05	34.24	WB
Formation 2012	Hoopes Spring - HS3	sculpin	31.75	0.54	2.47	1.45	61.05	34.37	WB
Formation 2012	Hoopes Spring - HS3	brown trout	31.75	0.54	2.63	1.45	64.78	41.89	WB
Formation 2012	Sage Creek - LSV2C	sculpin	13.50	0.45	2.83	1.45	24.76	25.35	WB
Formation 2012	Sage Creek - LSV2C	sculpin	13.50	0.45	2.83	1.45	24.76	16.52	WB
Formation 2012	Sage Creek - LSV2C	sculpin	13.80	0.45	2.83	1.45	25.31	27.36	WB
Formation 2012	Sage Creek - LSV2C	sculpin	14.30	0.45	2.83	1.45	26.23	37.66	WB
Formation 2012	Sage Creek - LSV2C	brown trout	13.50	0.45	3.01	1.45	26.27	28.12	WB
Formation 2012	Sage Creek - LSV2C	brown trout	13.50	0.45	3.01	1.45	26.27	18.48	WB
Formation 2012	Sage Creek - LSV2C	brown trout	13.80	0.45	3.01	1.45	26.86	32.78	WB
Formation 2012	Sage Creek - LSV2C	brown trout	14.30	0.45	3.01	1.45	27.83	28.24	WB
Formation 2012	Sage Creek - LSV2C	sculpin	18.75	0.45	2.83	1.45	34.39	29.49	WB
Formation 2012	Sage Creek - LSV2C	brown trout	18.75	0.45	3.01	1.45	36.49	30.30	WB
Formation 2012	Sage Creek - LSV4	sculpin	8.45	0.69	2.70	1.45	23.02	29.04	WB
Formation 2012	Sage Creek - LSV4	sculpin	8.45	0.69	2.70	1.45	23.02	26.53	WB
Formation 2012	Sage Creek - LSV4	brown trout	8.45	0.69	2.88	1.45	24.43	23.42	WB
Formation 2012	Sage Creek - LSV4	brown trout	8.45	0.69	2.88	1.45	24.43	21.95	WB

Study	Site	Species	Site Water (µg/l)	EF (l/g)	TTF^{comp}	CF	Pred. E/O (mg/kg)	Obs. E/O (mg/kg)	Obs. tissue type
Formation 2012	South Fork Tincup Cr.	sculpin	0.32	1.32	2.86	1.45	1.73	8.24	WB
Formation 2012	South Fork Tincup Cr.	brown trout	0.32	1.32	3.05	1.45	1.84	5.32	WB
Formation 2012	South Fork Tincup Cr.	sculpin	0.43	1.32	2.86	1.45	2.37	5.44	WB
Formation 2012	South Fork Tincup Cr.	sculpin	0.44	1.32	2.86	1.45	2.42	13.51	WB
Formation 2012	South Fork Tincup Cr.	brown trout	0.43	1.32	3.05	1.45	2.51	3.25	WB
Formation 2012	South Fork Tincup Cr.	brown trout	0.44	1.32	3.05	1.45	2.57	9.69	WB
Formation 2012	South Fork Tincup Cr.	sculpin	0.56	1.32	2.86	1.45	3.06	8.52	WB
Formation 2012	South Fork Tincup Cr.	brown trout	0.56	1.32	3.05	1.45	3.24	3.82	WB
Grasso et al. 1995	Arapahoe Wetlands Pond	white sucker	1.00	0.86	1.58	1.38	1.89	3.92	WB
Grasso et al. 1995	Arapahoe Wetlands Pond	white sucker	1.00	0.86	1.58	1.38	1.89	4.41	WB
Grasso et al. 1995	Arapahoe Wetlands Pond	white sucker	1.00	0.86	1.58	1.38	1.89	4.75	WB
Grasso et al. 1995	Arapahoe Wetlands Pond	white sucker	1.00	0.86	1.58	1.38	1.89	5.03	WB
Grasso et al. 1995	Arapahoe Wetlands Pond	white sucker	1.00	0.86	1.58	1.38	1.89	5.52	WB
Grasso et al. 1995	Arapahoe Wetlands Pond	white sucker	1.00	0.86	1.58	1.38	1.89	5.54	WB
Grasso et al. 1995	Arapahoe Wetlands Pond	fathead minnow	1.00	0.86	2.78	1.40	3.36	9.21	WB
Grasso et al. 1995	Arapahoe Wetlands Pond	fathead minnow	1.00	0.86	2.78	1.40	3.36	9.22	WB
Grasso et al. 1995	Arapahoe Wetlands Pond	fathead minnow	1.00	0.86	2.78	1.40	3.36	10.20	WB
Hamilton and Buhl 2004	lower East Mill Creek	cutthroat trout	24.00	1.32	2.29	1.96	142.01	102.73	WB
Lemly 1985	Badin Lake	black bullhead	0.32	12.48	1.72	1.45	9.99	4.44	M
Lemly 1985	Badin Lake	western mosquitofish	0.32	12.48	2.37	1.20	11.33	5.77	M
Lemly 1985	Badin Lake	common carp	0.32	12.48	1.58	1.92	12.10	5.81	M
Lemly 1985	Badin Lake	green sunfish	0.32	12.48	2.29	1.45	13.30	3.25	M
Lemly 1985	Badin Lake	fathead minnow	0.32	12.48	2.78	1.40	15.52	3.17	M
Lemly 1985	Badin Lake	red shiner	0.32	12.48	2.27	1.95	17.74	4.45	M
Lemly 1985	Belews Lake	black bullhead	10.91	1.75	1.72	1.45	47.79	29.84	M
Lemly 1985	Belews Lake	western mosquitofish	10.91	1.75	2.37	1.20	54.18	46.86	M
Lemly 1985	Belews Lake	common carp	10.91	1.75	1.58	1.92	57.86	38.97	M
Lemly 1985	Belews Lake	green sunfish	10.91	1.75	2.29	1.45	63.60	20.84	M
Lemly 1985	Belews Lake	fathead minnow	10.91	1.75	2.78	1.40	74.25	28.75	M
Lemly 1985	Belews Lake	red shiner	10.91	1.75	2.27	1.95	84.87	38.59	M
Lemly 1985	High Rock Lake	black bullhead	0.67	4.99	1.72	1.45	8.36	5.58	M

Study	Site	Species	Site Water (µg/l)	EF (l/g)	TTF^{comp}	CF	Pred. E/O (mg/kg)	Obs. E/O (mg/kg)	Obs. tissue type
Lemly 1985	High Rock Lake	western mosquitofish	0.67	4.99	2.37	1.20	9.48	6.10	M
Lemly 1985	High Rock Lake	common carp	0.67	4.99	1.58	1.92	10.12	4.49	M
Lemly 1985	High Rock Lake	green sunfish	0.67	4.99	2.29	1.45	11.13	3.13	M
Lemly 1985	High Rock Lake	fathead minnow	0.67	4.99	2.78	1.40	12.99	4.00	M
Lemly 1985	High Rock Lake	red shiner	0.67	4.99	2.27	1.95	14.85	4.62	M
McDonald and Strosher 1998	Elk R. above Cadorna Cr. (745)	cutthroat trout	0.10	6.30	2.29	1.96	2.83	10.61	WB
McDonald and Strosher 1998	Elk R. above Cadorna Cr. (745)	mountain whitefish	0.10	6.30	2.97	7.39	13.83	7.11	WB
McDonald and Strosher 1998	Fording R. above Swift Cr. (746)	cutthroat trout	8.60	0.23	2.29	1.96	8.71	24.96	WB
Muscatello and Janz 2009	Vulture Lake	white sucker	0.43	1.01	1.58	1.38	0.95	4.65	WB
Muscatello and Janz 2009	Vulture Lake	burbot	0.43	1.01	2.45	1.45	1.54	15.91	WB
Muscatello and Janz 2009	Vulture Lake	ninespine stickleback	0.43	1.01	3.22	1.45	2.03	6.02	WB
Muscatello and Janz 2009	Vulture Lake	northern pike	0.43	1.01	4.02	2.39	4.17	1.83	WB
Orr et al. 2012	Clode Pond 11	cutthroat trout	36.10	0.71	2.29	1.96	115.88	81.06	E-O
Orr et al. 2012	Elk Lakes 14	cutthroat trout	0.40	1.64	2.29	1.96	2.95	14.02	E-O
Orr et al. 2012	Elk River 1	cutthroat trout	4.20	0.55	2.29	1.96	10.33	11.02	E-O
Orr et al. 2012	Elk River 1	cutthroat trout	4.20	0.55	2.29	1.96	10.33	15.60	E-O
Orr et al. 2012	Elk River 12	cutthroat trout	0.75	2.67	2.29	1.96	8.98	9.00	E-O
Orr et al. 2012	Fording River 23	cutthroat trout	30.60	0.21	2.29	1.96	28.52	15.56	E-O
Orr et al. 2012	Fording River Oxbow 10	cutthroat trout	50.10	1.34	2.29	1.96	302.30	47.81	E-O
Orr et al. 2012	Henretta Lake 27	cutthroat trout	8.60	0.50	2.29	1.96	19.33	13.56	E-O
Orr et al. 2012	Michel Creek 2	cutthroat trout	7.40	0.28	2.29	1.96	9.43	10.07	E-O
Saiki and Lowe 1987	Kesterson Pond 11	western mosquitofish	38.60	0.51	2.37	1.20	55.41	155.61	WB
Saiki and Lowe 1987	Kesterson Pond 11	western mosquitofish	38.60	0.51	2.37	1.20	55.41	124.49	WB
Saiki and Lowe 1987	Kesterson Pond 2	western mosquitofish	195.85	0.32	2.37	1.20	175.68	268.13	WB
Saiki and Lowe 1987	Kesterson Pond 2	western mosquitofish	195.85	0.32	2.37	1.20	175.68	295.66	WB

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Study	Site	Species	Site Water (µg/l)	EF (l/g)	TTF^{comp}	CF	Pred. E/O (mg/kg)	Obs. E/O (mg/kg)	Obs. tissue type
Saiki and Lowe 1987	Kesterson Pond 8	western mosquitofish	70.35	0.60	2.37	1.20	120.13	196.31	WB
Saiki and Lowe 1987	Kesterson Pond 8	western mosquitofish	70.35	0.60	2.37	1.20	120.13	266.93	WB
Saiki and Lowe 1987	San Luis Drain	western mosquitofish	316.50	0.36	2.37	1.20	322.76	178.36	WB
Saiki and Lowe 1987	San Luis Drain	western mosquitofish	316.50	0.36	2.37	1.20	322.76	397.41	WB
Saiki and Lowe 1987	Volta Pond 26	western mosquitofish	0.53	0.93	2.37	1.20	1.41	1.53	WB
Saiki and Lowe 1987	Volta Pond 26	western mosquitofish	0.53	0.93	2.37	1.20	1.41	1.48	WB
Saiki and Lowe 1987	Volta Wasteway	western mosquitofish	0.74	1.03	2.37	1.20	2.15	1.62	WB
Saiki and Lowe 1987	Volta Wasteway	western mosquitofish	0.74	1.03	2.37	1.20	2.15	1.63	WB
Saiki et al. 1993	Mud Slough at Gun Club Road	bluegill	6.00	1.37	1.47	2.13	25.69	10.67	WB
Saiki et al. 1993	Mud Slough at Gun Club Road	bluegill	6.00	1.37	1.47	2.13	25.69	13.65	WB
Saiki et al. 1993	Mud Slough at Gun Club Road	largemouth bass	6.00	1.37	2.04	1.42	23.73	9.65	WB
Saiki et al. 1993	Mud Slough at Gun Club Road	largemouth bass	6.00	1.37	2.04	1.42	23.73	9.79	WB
Saiki et al. 1993	Mud Slough at Gun Club Road	western mosquitofish	6.00	1.37	2.10	1.20	20.61	13.17	WB
Saiki et al. 1993	Mud Slough at Gun Club Road	western mosquitofish	6.00	1.37	2.10	1.20	20.61	19.15	WB
Saiki et al. 1993	Salt Slough at the San Luis National Wildlife Refuge	bluegill	8.00	0.43	1.47	2.13	10.70	9.17	WB
Saiki et al. 1993	Salt Slough at the San Luis National Wildlife Refuge	bluegill	8.00	0.43	1.47	2.13	10.70	9.60	WB
Saiki et al. 1993	Salt Slough at the San Luis National Wildlife Refuge	largemouth bass	8.00	0.43	2.04	1.42	9.89	5.68	WB
Saiki et al. 1993	Salt Slough at the San Luis National Wildlife Refuge	largemouth bass	8.00	0.43	2.04	1.42	9.89	6.67	WB
Saiki et al. 1993	Salt Slough at the San Luis National Wildlife Refuge	western mosquitofish	8.00	0.43	2.10	1.20	8.59	5.39	WB
Saiki et al. 1993	Salt Slough at the San Luis National Wildlife Refuge	western mosquitofish	8.00	0.43	2.10	1.20	8.59	5.87	WB
Saiki et al. 1993	San Joaquin R. above Hills Ferry Road	bluegill	7.00	0.36	1.47	2.13	7.83	5.76	WB
Saiki et al. 1993	San Joaquin R. above Hills Ferry Road	bluegill	7.00	0.36	1.47	2.13	7.83	7.04	WB
Saiki et al. 1993	San Joaquin R. above Hills Ferry Road	largemouth bass	7.00	0.36	2.04	1.42	7.23	3.12	WB
Saiki et al. 1993	San Joaquin R. above Hills Ferry Road	largemouth bass	7.00	0.36	2.04	1.42	7.23	3.41	WB
Saiki et al. 1993	San Joaquin R. above Hills Ferry Road	western mosquitofish	7.00	0.36	2.10	1.20	6.28	2.63	WB
Saiki et al. 1993	San Joaquin R. above Hills Ferry Road	western mosquitofish	7.00	0.36	2.10	1.20	6.28	5.39	WB

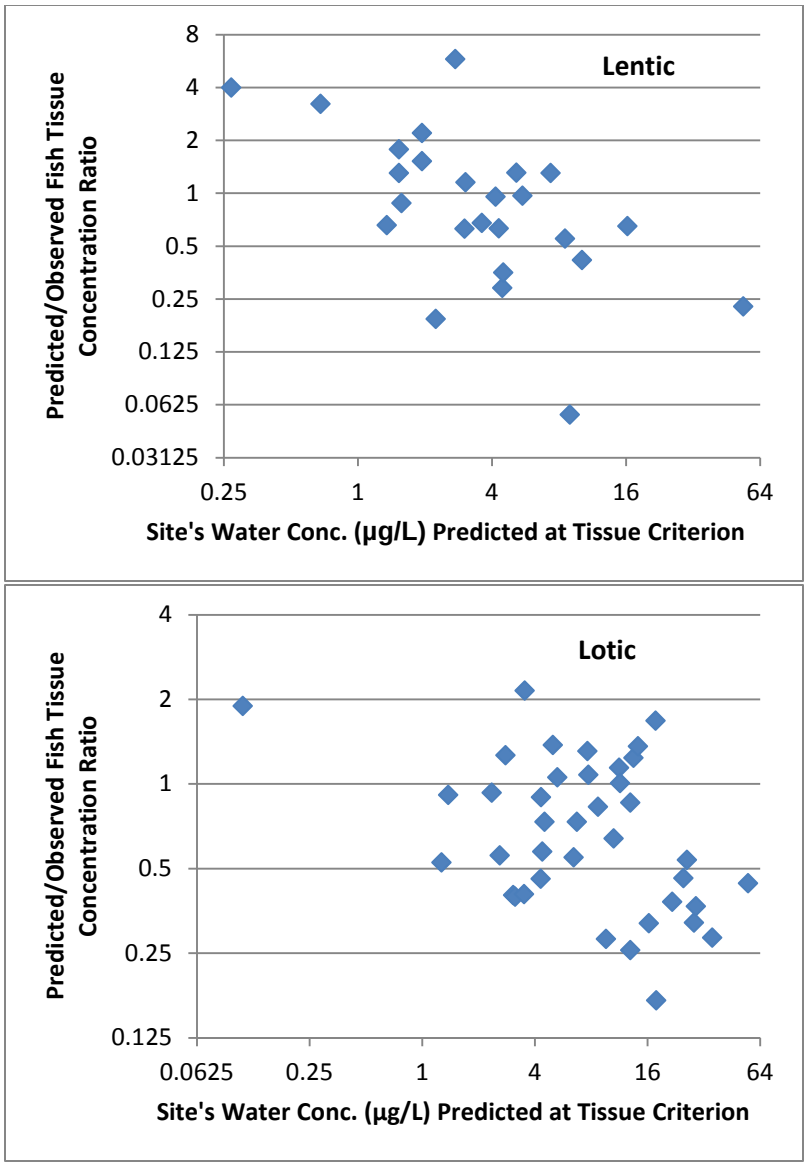
Study	Site	Species	Site Water (µg/l)	EF (l/g)	TTF^{comp}	CF	Pred. E/O (mg/kg)	Obs. E/O (mg/kg)	Obs. tissue type
Saiki et al. 1993	San Joaquin R. at Durham Ferry State Recereation Area	bluegill	1.00	0.75	1.47	2.13	2.34	4.05	WB
Saiki et al. 1993	San Joaquin R. at Durham Ferry State Recereation Area	bluegill	1.00	0.75	1.47	2.13	2.34	4.27	WB
Saiki et al. 1993	San Joaquin R. at Durham Ferry State Recereation Area	largemouth bass	1.00	0.75	2.04	1.42	2.16	2.41	WB
Saiki et al. 1993	San Joaquin R. at Durham Ferry State Recereation Area	largemouth bass	1.00	0.75	2.04	1.42	2.16	2.55	WB
Saiki et al. 1993	San Joaquin R. at Durham Ferry State Recereation Area	western mosquitofish	1.00	0.75	2.10	1.20	1.87	2.03	WB
Saiki et al. 1993	San Joaquin R. at Durham Ferry State Recereation Area	western mosquitofish	1.00	0.75	2.10	1.20	1.87	2.39	WB
Stephens et al. 1988	Marsh 4720	black bullhead	31.00	0.10	1.72	1.45	7.43	10.16	WB
Stephens et al. 1988	Marsh 4720	common carp	31.00	0.10	1.58	1.92	9.00	36.49	WB
Stephens et al. 1988	Marsh 4720	common carp	31.00	0.10	1.58	1.92	9.00	40.33	WB

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The ratio of predicted versus observed tissue concentrations in the above table can be compared against the main text Table 3.13 water concentrations that would be predicted to occur if each site's egg-ovary tissue concentration were at the criterion level. Figure I-1 shows the results. It can be seen that for those sites (in the left portion of each graph) where tissue concentrations equal to the egg-ovary criterion would be predicted to yield water concentrations not far on either side of the water criteria values, the predicted-to-observed tissue concentration ratios are not particularly biased relative to a ratio of 1.0. This indicates that the model is performing reasonably well for those sites strongly influencing the derived values of the water criteria.

The derivation of the water criteria concentrations involves an assumption of linearity in projecting the water concentration that would correspond to a tissue concentration equal to the tissue criterion. Figure I-2 suggests that high BAFs tend to be associated with low water concentrations, and low BAFs with high water concentrations. At the low concentrations associated with the 20^{th} percentile model-predicted BAF, the linearity assumption would appear to be environmentally conservative. At high concentrations, the opposite situation would occur, but overall, because the criterion is based on the 20^{th} percentile, the linearity assumption appears to be protective.

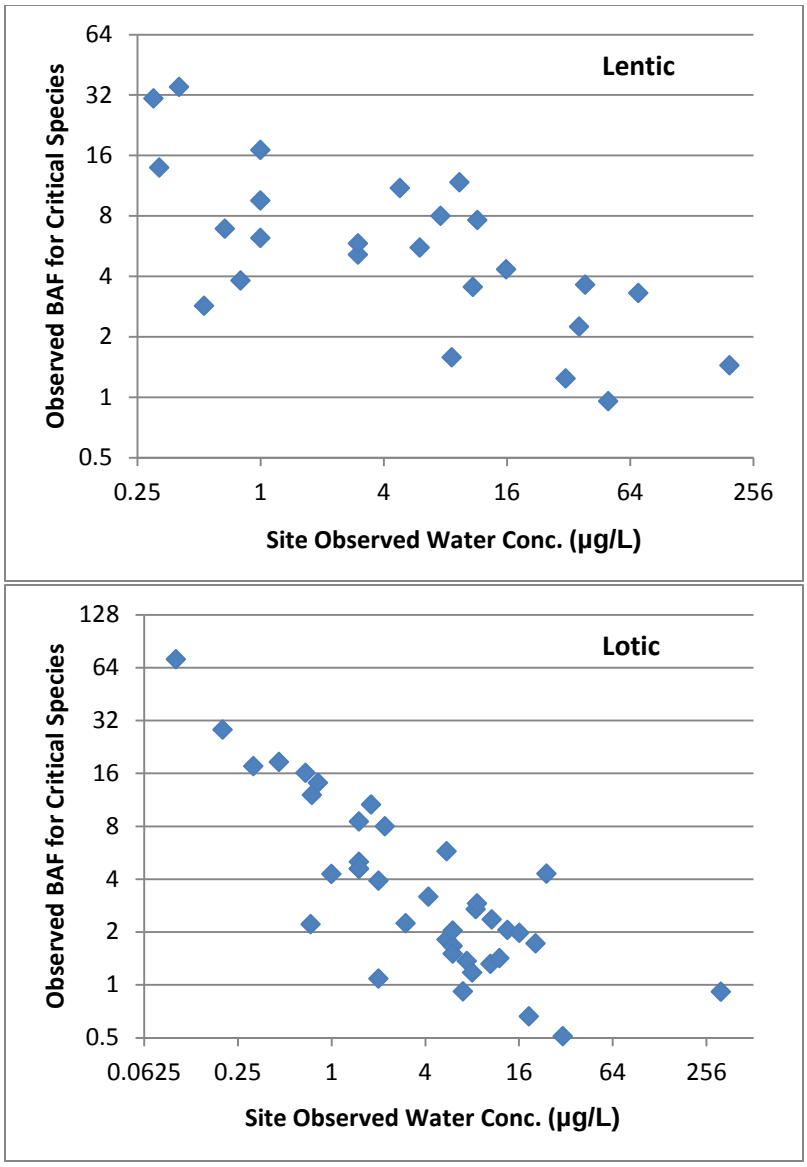
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Figures I-1. For lentic (left panel) and lotic (right panel) waters, predicted-to-observed fish-tissue concentration ratio for each of the 65 sites, plotted versus each site's Table 3.13 water concentration that would be predicted to occur if its tissue levels were at the egg-ovary tissue criterion level.

Corresponding to how the water criteria concentrations were derived, for sites with multiple fish species, the plotted ratio is for the species having the highest predicted tissue-to-water ratio (i.e., highest predicted BAF). For sites having multiple samples of that species, the plotted value is the average predicted-to-observed ratio for that species.

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Figures I-2. For lentic (left panel) and lotic (right panel) waters, observed BAFs (egg-ovary tissue-to-water concentration ratios) versus observed water concentration (both from the above table), for each site's fish species used in Table 3.13 (that is, for the species used in the water criteria calculations).

For sites having multiple samples of such species, tissue concentrations were averaged. Because nearly all samples were either whole body or muscle, the graphed BAFs include application of the CF, to normalize all samples to egg-ovary tissue. Since the CFs have been are assumed to be independent of concentration, the graphs do not reflect any potential CF nonlinearities, if they exist.

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APPENDIX J: SUPPLEMENTARY INFORMATION ON SELENIUM BIOACCUMULATION IN AQUATIC ANIMALS

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1.0 EFFECTS OF GROWTH RATE ON THE ACCUMULATION OF SELENIUM IN FISH

EPA analyzed the effect of the growth rate parameter *g* when estimating selenium bioaccumulation using the mechanistic bioaccumulation modeling described in Equation 1 of the main text. Because the addition of tissue associated with growth could have a dilution effect on the chemicals present in tissue, a parameter representing growth rate is present in the denominator of Equation 1. Indeed, growth can be an important factor in the bioaccumulation of very hydrophobic chemicals with low excretion rates such as polychlorinated biphenyls, (Connolly and Pedersen 1988). However, the effect of growth may not be as important for selenium because of its unique biogeochemical characteristics, route of exposure, and role as a micronutrient.

EPA tested the effect of the growth rate parameter *g* on estimates of selenium bioaccumulation using Equation 1 with different food web scenarios. Increasing growth rates from 0 (no growth) to 0.2/day (a relatively high rate of growth) reduced selenium concentrations in trophic level 2 and 3 organisms by as much as a factor of 10 to 20. Thus incorporating growth rate in Equation 1 could result in significant dilution of selenium and lower estimates of selenium bioaccumulation.

Although increasing the value of the growth parameter g in Equation 1 reduces estimates of selenium bioaccumulation, this simple analysis neglects an important physiological linkage between growth and food consumption. Organisms must consume enough food to support growth and meet their energy requirements for respiration, specific dynamic action, waste loss, and reproduction. These physiological requirements suggest that higher growth rates are associated with greater rates of food consumption. Because food consumption is the primary route of selenium exposure in aquatic organisms, increased selenium exposure associated with higher food consumption could counterbalance the dilution of selenium in tissue associated with higher growth rates.

EPA tested the effects of growth on estimates of selenium bioaccumulation using Equation 1 when increased food consumption was associated with higher growth rates. EPA modified Equation 1 to incorporate a simple relationship for bioenergetics (Thomann et al. 1992) and applied the model to reexamine the sensitivity of selenium bioaccumulation to growth rates in trophic level 2 and 3 organisms. The results of this analysis showed that increasing growth rates over two orders of magnitude increased selenium concentrations in trophic level 2 by a factor of 2, and decreased selenium concentrations in trophic level 3 by 10%. When growth rates were increased simultaneously in trophic levels 2 and 3, the selenium concentrations increased by less than a factor of 2. This analysis suggests that when bioenergetics is considered, selenium bioaccumulation is generally insensitive to organism growth rates. EPA believes that uncertainties in the toxicokinetic parameters of selenium far outweigh the effects on growth rate on selenium bioaccumulation. Thus, the growth rate parameter *g* was removed from Equation

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1 for the purpose of deriving a translation equation that could be used to implement a tissue-based selenium water quality criterion.

2.0 Analysis of the Relative Contribution of Aqueous and Dietary Uptake on the Bioaccumulation of Selenium

EPA analyzed the relative contributions of direct aqueous uptake versus ingestion of selenium in consideration of removing the uptake rate constant k_u from Equation 1 in Section 3.2 of the main text. Because an important exposure route for some chemicals is direct contact with water, an uptake rate constant k_u is present in the numerator of Equation 1. However, fish and invertebrate organisms absorb selenium primarily through the consumption of food rather than from direct aqueous uptake (Forester 2007; Lemly 1985; Luoma et al. 1992). Thus, removing the uptake rate constant k_u could simplify Equation 1 while maintaining the key determinants of selenium bioaccumulation.

EPA tested the relative contribution of aqueous versus dietary uptake of selenium using a version of Equation 1 that incorporates both exposure pathways (Thomann et. al. 1992). For trophic level 2, selenium bioaccumulation was estimated for a range of uptake rates that varied according to the respiration rate and aqueous transfer efficiency of selenium relative to dissolved oxygen. For trophic level 3, uptake rates were varied within a range of values reported in Besser et al. (1993) and Bertram and Brooks (1986).

EPA's analysis showed that diet accounted for 34% - 92% of selenium bioaccumulation at trophic level 2, with a median of 74%. At trophic level 3, diet accounted for 62% - 100% of tissue selenium, with a median of 95%. Thus, disregarding aqueous uptake of selenium only resulted in a small (~5%) reduction in estimated selenium bioaccumulation in trophic level 3 organisms. These results are consistent with previous studies indicating that diet is the primary exposure route of selenium, and suggests that the uptake rate constant for selenium can be removed from Equation 1 with negligible effect for higher trophic levels organisms.

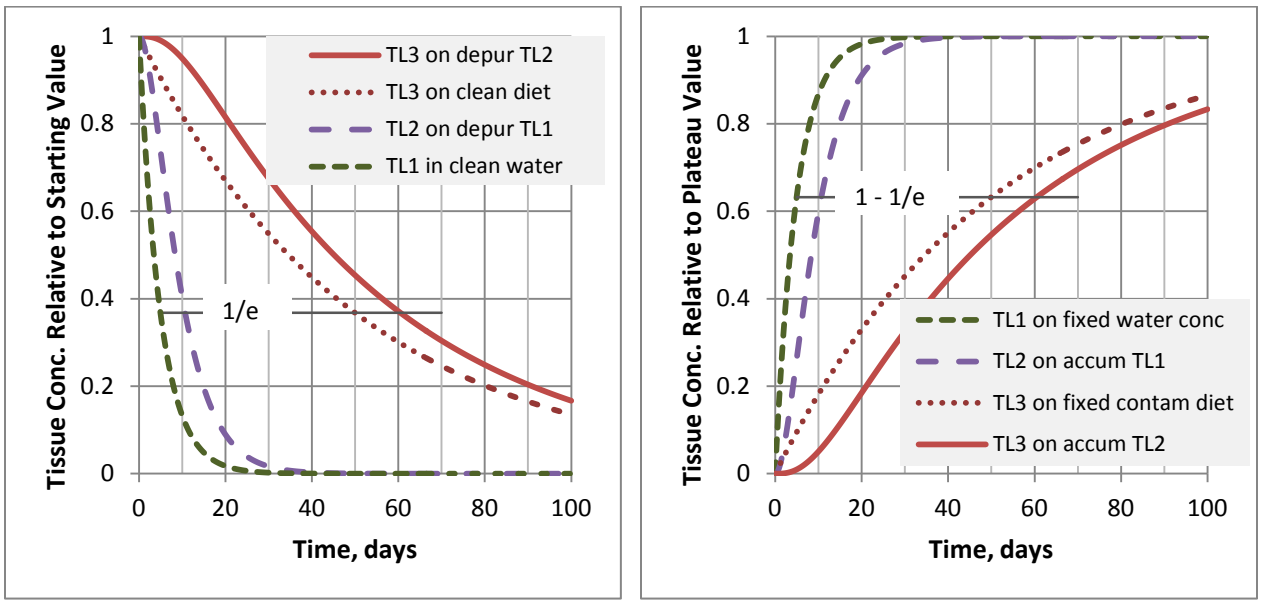
3.0 Kinetics of Accumulation and Depuration: Averaging Period

3.1 Background

For setting averaging periods for aquatic life criteria, U.S. EPA (1995b) used the concept that the criterion averaging period should be less than or equal to the "characteristic time" describing the toxic speed of action. In the context of the water-borne direct toxicity of metals, characteristic time = 1/k, where k is the first-order kinetic coefficient in a toxico-kinetic model fitted to the relationship between LC50 and exposure duration.

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In the context of selenium bioaccumulation in a single trophic level, k would the first-order depuration coefficient, and 1/k would equal the time needed to depurate to a concentration of 1/e times the initial concentration (where e=2.718). For depuration of multiple trophic levels sequentially, the characteristic time is likewise the time needed for c/c_o to reach a value of 1/e, as shown in Figure J-1a. The accumulation curve is the inverted depuration curve, as shown in Figure J-1b.



Figures J-1 a & b. Depuration and accumulation behavior for algae-detritus-sediment k=0.2/day, invertebrate k=0.2/day and fish k=0.02/day, calculated with time step = 0.1 day.
Concentration is expressed as a dimensionless ratio: concentration at time t divided by either starting concentration (J1a) or plateau concentration (J1b).

In the Figures J-1 a & b examples, the characteristic time for algae-detritus-sediment is 5 days, the characteristic time for invertebrates on an invariant diet is 5 days, the characteristic time for fish on an invariant diet is 50 days, and the characteristic time for fish on an invertebrate diet that is itself depurating or accumulating is the approximate sum of the individual characteristic times, or ~60 days.

In contrast to the model depuration rate, k, the model uptake rate (AE, assimilation efficiency, multiplied by IR, intake rate) does not affect the characteristic response time. Rather it affects the magnitude of the accumulation plateau. Uptake rate thus affects the TTF value itself but is not relevant to setting an averaging period.

Because short averaging periods are more environmentally conservative than long averaging periods, selecting parameter values for fast kinetics is more environmentally conservative. Figure J1 reflects environmentally conservative choices for k values.

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3.2 Approach for Modeling Effects of Time-Variable Se Concentrations

Expression of concentrations. None of the concentrations in this analysis are expressed in ordinary units of concentration. All concentrations are modeled as values normalized to their allowable benchmark concentration – that is, concentration = 1 for a particular medium (water, algae-detritus-sediment, invertebrates, or fish) means that the medium is at its criterion concentration or corresponding benchmark. It is assumed that the benchmarks correctly align – water held at its benchmark concentration will ultimately yield Trophic Levels 1, 2, and 3 at their respective benchmark concentrations. The Trophic Level 3 benchmark is the reproductive EC10 for the 5th percentile taxon: i.e., the fish tissue criterion.

Formulation of the bioaccumulation model for kinetic analysis. For algae-detritus-sediment, for invertebrates, and for fish, accumulation at time t equals accumulation at time t-1 plus intake minus depuration, as follows:

Algae-detritus-sediment:

$$C_{TL1}[t] = C_{TL1}[t\text{-}1] + k_{uptake}\, C[t\text{-}1]water - k_{TL1}\, C_{TL1}[t\text{-}1]$$

Invertebrates:

$$C_{TL2}[t] = C_{TL2}[t\text{-}1] + AE_{TL2}\, IR_{TL2}\, C_{TL1}[t\text{-}1] - k_{TL2}\, C_{TL2}[t\text{-}1]$$

Fish:

$$C_{TL3}[t] = C_{TL3}[t\text{-}1] + AE_{TL3}\, IR_{TL3}\, C_{TL2}[t\text{-}1] - k_{TL3}\, C_{TL3}[t\text{-}1]$$

For algae-detritus-sediment, the depuration rate k is assigned a value of 0.2/day, similar to the sum of depuration and growth-dilution rate coefficients used by Brix and DeForest (2008). Because a lentic system would involve the slower kinetics of sediment exchange, the rapid rate used here implies a lotic system.

For invertebrates, a value of 0.2/day was assigned, considerably higher than those for *Lumbriculus*, Asian clam, zebra mussel, but close to those of mayfly and copepods, which are very small in size. As previously mentioned, higher k (more rapid kinetics) is an environmentally conservative assumption in this context.

For fish, the median depuration coefficient measured by Bertram and Brooks (1986) for 6-9 month-old (early adult) fathead minnows was used, providing a k_{TL3} value of 0.02/day. Because of the small size of adults of this species, this represents faster kinetics than would likely be applicable the salmonids and centrarchids of greatest concern for selenium toxicity. The striped bass k value of Baines et al. (2002) is inapplicable here because it was measured in the early juvenile life stage, a size that is too small to be relevant to reproductive impairment stemming from exposure of adult females. The concentration in fish could be equivalently viewed as either whole body or egg-ovary, relative to their

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respective benchmarks. That is, partitioning within body of the fish is assumed not to involve a time delay.

The value of a TTF is given by AE x IR/k (or k_{uptake}/k for algae-detritus-sediment). Concentrations in TL1, TL2, and TL3 are normalized to their benchmarks, meaning that all benchmark concentrations have a value of 1.0. In this normalized context, the TTFs must also equal 1.0, since upon reaching steady state, TL1 at its benchmark will yield TL2 at its benchmark, which in turn will yield TL3 at its benchmark. Again, the analysis is not intended to reflect actual concentrations, merely portray temporal behavior. Since 1 = TTF = AE x IR/k, it follows that AE x IR = k within this normalized framework. Although only the product AE x IR is relevant, they are retained as distinct parameters to maintain parallelism with remainder of the criterion document. AE was assigned a value of 0.5 for fish and invertebrates, and IR = k/AE in the normalized framework.

Time step durations of 0.1-1.0 day were considered. Short time steps increase accuracy by decreasing the numerical dispersion inherent in expressing C[t] = f(C[t-1]). A time step of 0.5 day was found to yield sufficient accuracy, as measured by predicted values at the characteristic time for depuration or accumulation (per Figure J-1).

Prediction of Effects. The effect level associated with the tissue concentration at any time t is calculated via the log probit concentration-response curve, one of the commonly used sigmoid curves. It assumes that the sensitivities in the underlying population are log-normally distributed such that the concentration yielding effects on k percentage of the population is given by:

$$EC_k = EC50 \exp(\sigma z)$$

where σ is the inverse of the concentration-response curve slope and z is the normal deviate corresponding to k percent (e.g., for k=10%, z=NORMSINV(0.1)=−1.28155). Among the reproductive impairment studies presented in Appendix C, an approximate median ratio for EC50/EC10 is 1.5. This translates to σ=0.3164.

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Since the fish tissue criterion concentration equals 1.0 in this normalized framework, at any time t, the fractional level of effect corresponding to any value of C_{TL3} is given by:

Fractional Effect[t] = NORMSDIST(z[t])

where z[t] is given by:

$z[t] = LN(C_{TL3}[t]/1.5)/0.3164$

Exposure Scenarios. Three exposure scenarios were evaluated under which the water criterion was just barely attained. The first two are absolute worst case scenarios, in which the 30-day average water concentration remains continuously at the criterion concentration at all times. The third is a realistic scemario.

1. Steady concentrations at the criterion: this is worst-case continuous exposure. In the real world this could not occur because water concentrations vary substantially over time. For the 30-day average concentration not to exceed more than once in three years, the realistically varying daily concentrations must remain well below the criterion concentration a large majority of the time.

2. Uniform 1-day spikes at 30X the water criterion concentration, occurring at uniform 30-day intervals (i.e., separated by 29 days of zero concentration) such that the 30-day average always equals the criterion. This is the worst-case intermittent scenario, attaining the criterion through a time series that continually maximizes the 30-day average exposure at the water criterion concentration while also imposing the highest variability possible from spikes of 1-day duration. In the real world intermittent runoff sources do not occur at uniform intervals: merely averaging 30-days between discharges would yield an exceedance each time the discharge occurred with less than 30-days spacing. Further, the once-per-month peak concentrations could never be controlled at exactly 30X the chronic water criterion per the above discussion of the first scenario.

   It is because they lack real-world random variability that the above two scenarios are not realistic. They are used as absolute worst cases for purposes of comparison. The following third scenario represents a realistic and indeed typical situation for continuous exposure:

3. Log-normally distributed, smoothly variable concentrations with the 30-day average exceeding the criterion once in three years when counted using the procedure of EPA (1986). The log

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standard deviation of 0.5 applied here represents typical real-world time variability for continuously flowing waters. The log serial correlation coefficient $\rho = 0.8$ represents that typical of smaller streams.

With respect to maximizing toxic effects while attaining the criterion, Scenarios #1 and #2 are absolute worst cases. In contrast, Scenario #3 represents typical time variability in ambient waters. This third scenario requires randomly generated concentrations (having specified target statistical characteristics). Multiple runs of long series are therefore needed to assure some reasonable degree of accuracy. A minimum of 20 runs of random series of 3000 days were used. The concentrations at each half-day time step were generated by the following formula:

*C[t]water = C[t-1]water^(ρ′) * GM^(1-ρ′) * EXP{σ * SQRT(1-ρ′^2)*NORMSINV(RAND)}*

where ρ′ (rho prime) is the desired serial correlation coefficient between half-day time steps: ρ′=SQRT(ρ) [approximation], where ρ (rho) is the desired serial correlation coefficient between daily values; GM is the desired geometric mean or median, and σ is the desired log standard deviation. The above formula allows a time series with the desired statistical characteristics to be generated.

3.2.1 Model Results

3.2.1.1 Steady concentrations at the water criterion concentration.

No graphic is needed to explain this scenario. With water steady at its criterion, algae-detritus-sediment and invertebrates are likewise steady at their benchmark concentrations, and fish tissue is at its criterion concentration. For the 5th percentile taxon, the effect would thus be 10% since the concentration is steady at the EC10.

3.2.1.2 Uniformly spaced spikes at maximum concentrations

Figure J-2. Scenario 2, uniform 1-day spikes at 30X the water criterion concentration, occurring at uniform 30-day intervals such that the 30-day average always equals the criterion. Read invertebrate and fish tissue concentrations on left scale, water concentrations on right scale. Time=0 does not represent the beginning of exposure; prior to Time=0 the same exposure pattern had been going on for a long time (e.g., 10,000 days).

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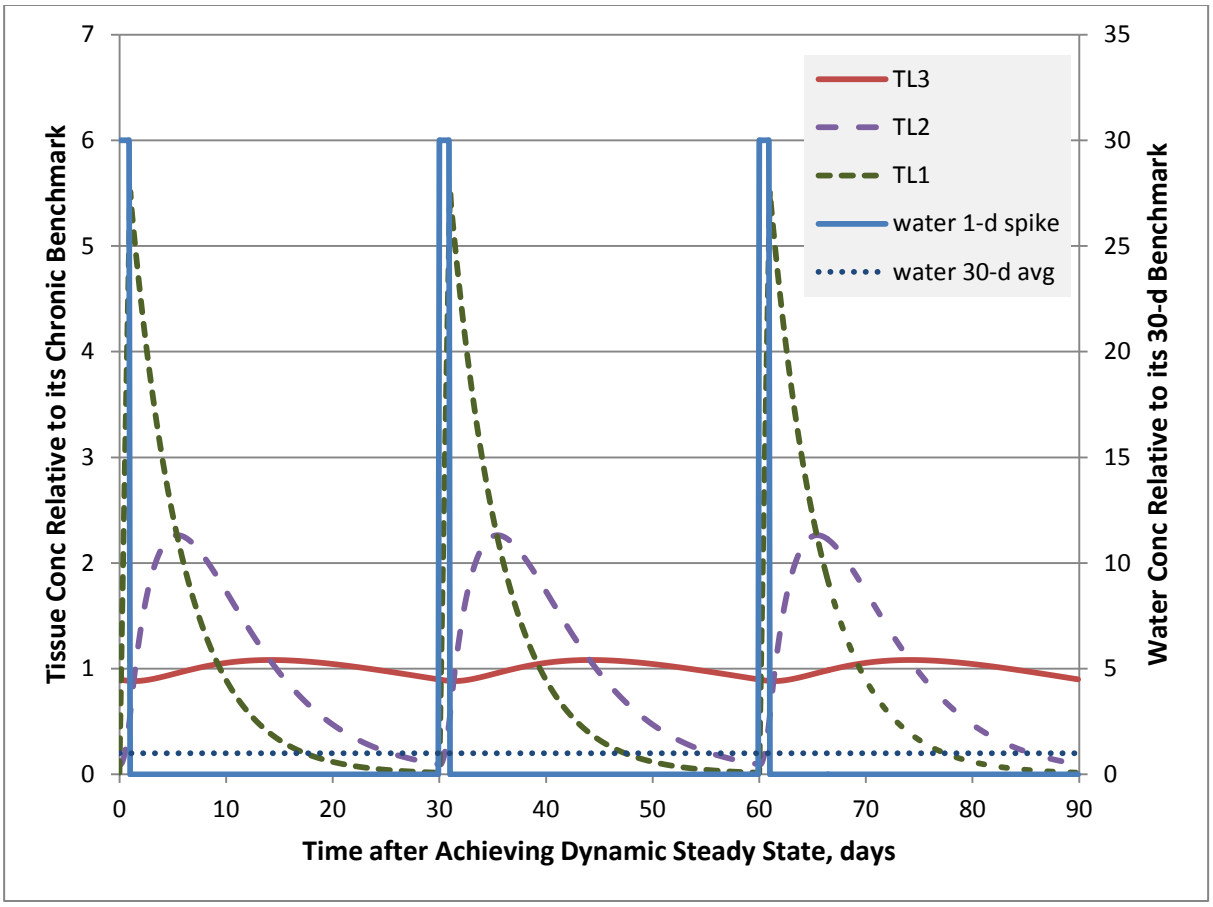


Figure J-2. Uniform 1-day spikes at 30X the water criterion concentration, occurring at uniform 30-day intervals such that the 30-day average always equals the criterion.
Tissue and water concentrations are expressed as dimensionless ratios relative to their respective criteria or benchmarks, as explained in the text.

With their more rapid kinetics, TL1 and TL2 tissue concentration swings are much more drastic than TL3 (fish) tissue concentration swings, but were the spike to continue as a steady exposure 30-fold above the water benchmark, TL1, TL2, and TL3 would all ultimately plateau at 30-fold above their respective benchmarks.

The key point here is that attaining the 30-day average via 1-day spikes spaced 30 days apart generates a small oscillation in fish tissue concentrations. Averaged over the 30-days, the fish tissue concentrations exactly attain their criterion and the predicted effect is 10%.

3.2.1.3 Log-normally distributed, smoothly varying concentrations

This is the most realistic scenarios, corresponding to typical variability observed in streams.

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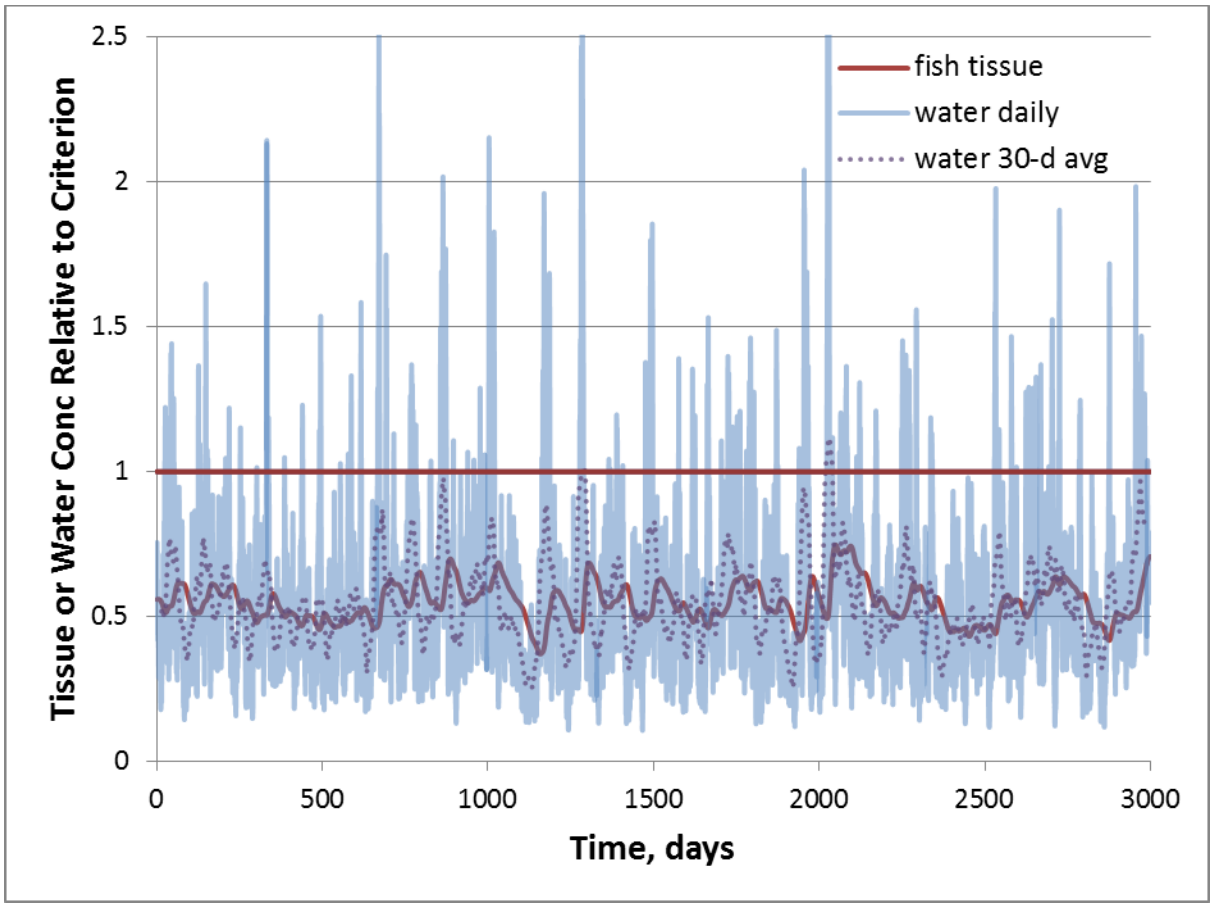


Figure J-3. A typical example of log-normally distributed, smoothly variable concentrations. The standard deviation of natural logs is 0.5 and the serial correlation coefficient of logs is 0.8 for daily values, both typical real-world situations. (The compression of 3000 days into the graph might make it difficult to recognize that the time series is smoothly varying – it has serial correlation.) At time=0, TL1, TL2, and TL3 begin at their average concentrations.

In the Figure J-3 example run, instantaneous water concentrations exceed the 30-day average criterion 7% of the time. The 30-day average concentrations exceed the criterion 1.05 times per 3 year period, counted per the EPA (1986) counting method. Tissue concentrations do not exceed their criterion at any time, and the aggregate effect is 0.12%.

In contrast to the previous scenario, the elevated concentrations here are random in their magnitude, duration, and spacing. This randomness reduces the average exposure (and aggregate effect) compatible with attainment of the 30-day average water target.

3.2.2 Summary of Scenario Results

Because Scenario 3 involves generation of random concentrations, the above graphs show just one run (3000 days) for each. Full results for the 20 runs of that scenario are shown below.

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Scenario	Water: # 30-day avg. exceedances / 3-yr 1	Water: % of time exceeding	Tissue: % of time exceeding	Mean effect for 5th %ile Taxon	Comment
1. Steady	0.00	0.00	0.00	10.0	Steady at water and tissue benchmarks
2. Uniform spikes	0.00	3.33	56.7	10.0	30-d avg water conc. remains steady at benchmark (Fig. J2)
3. Smooth variable	1.01	7.8	0.00	0.18	Median=0.49 x benchmark, log stdev=0.5, rho(daily)=0.8 (e.g., Fig. 5) 2
1. Counting procedure for 30-d avg. exceedances is that of U.S. EPA (1986). 2. Results for Scenario 3 are average of 20 runs of 3000 days, each run with 0.6-1.4 exceedances / 3 yr. Runs not yielding exceedances within these bounds were not used. Among the 20 runs used, the effect CV=0.35.					

It can be concluded that the kinetics of selenium accumulation and depuration are sufficiently slow that applying a 30-day averaging period to the water criterion concentration affords protection even under unrealistic worst case conditions.

3.2.3 Example Responses to Increases in Water Concentrations

The previous Figures J-2 and J-3 illustrate situations after achievement of a dynamic steady state, where daily water concentrations change but longer-term mean water concentrations do not change. Given the same kinetic parameters as used above (i.e., yielding a 60-day characteristic time), this section addresses the rate at which tissue concentrations respond to increases in mean water concentrations, for example as would result from a new source. This is similar to the rising curve previously shown in Figure J-1b. The rapid kinetics used here for the water-TL1 step imply a small lotic system having little involvement of the bed sediments.

3.2.3.1 Step-function example

This example addresses the question: If water concentrations are increased to a level that is slightly too high, ultimately (at Time=∞) yielding fish-tissue concentrations at the EC20 instead of the EC10, how long would it take for those tissue concentrations to rise to a level that exceeds the (EC10-based) criterion?

Prior to Time=0 in this example the concentrations in TL3 had been at a moderate background concentration of 0.406 times the criterion, corresponding to the median West Virginia reference-site egg concentrations tabulated by West Virginia Department of Environmental Protection (2010). The concentrations in TL1 and TL2 are likewise assumed to have been at 0.406 normalized to their corresponding benchmarks. At Time=0 the water concentrations increase such that ultimately they will

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produce an effect 10% higher than the target, thus at the EC20 of the hypothetical 5th percentile sensitive species. For typical selenium concentration-response slopes, this is 1.15-fold above the EC10. Figure J4 illustrates this scenario, which shows that 90 days are needed for TL3 concentrations to rise above the criterion.

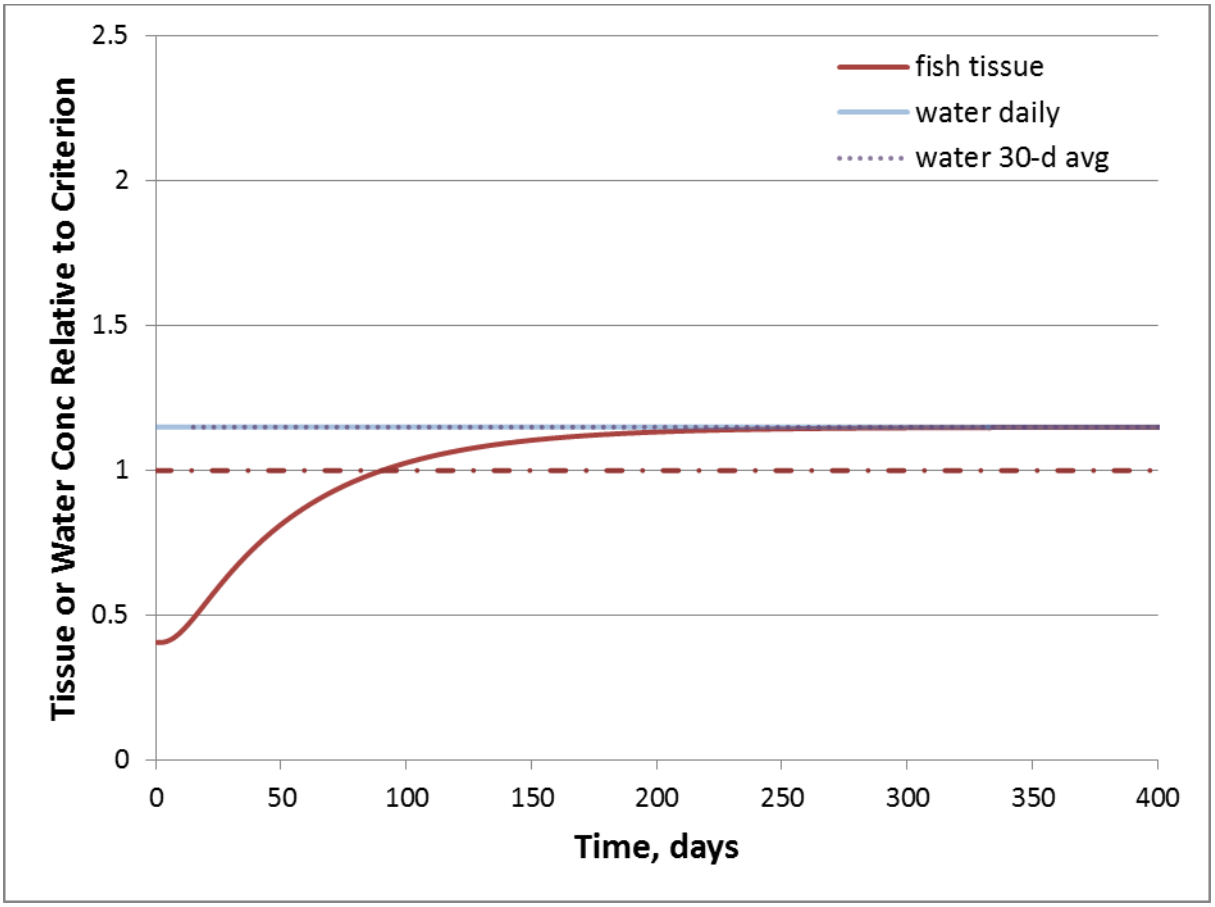


Figure J-4. TL3 concentration responding to a Time=0 step-function increase in water concentration that remains time-invariant thereafter.
Given that the water concentration is too high, ultimately yielding tissue concentrations at the hypothetical sensitive species EC20, 1.15-fold above the criterion, and given the previously presented kinetic parameters, it is calculated to take 90 days for TL3 concentrations to rise above the criterion.

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3.2.3.2 Continuously time-variable example for flowing waters

To provide more realism, this example considers typical time variability, following up on Figure J3. In this example, prior to Time=0, TL1, TL2, and TL3 concentrations were at a low background concentration, 0.1 normalized to their criterion or respective benchmark. At Time=0 begin water concentrations having median = geometric mean = 0.49 normalized as a dimensionless ratio, concentration/criterion. Because the water concentrations are log-normally distributed, with log standard deviation = 0.5, the arithmetic mean is higher than the median and has the normalized value 0.56. If the simulation went on for a very long time, this time series (designed to have geometric mean 0.49 times the criterion, log standard deviation 0.5, and log serial correlation coefficient 0.8) would average one exceedance every three years, when exceedances are counted using the EPA (1986) approach. Figure J-5 shows a typical short series of 400 days.

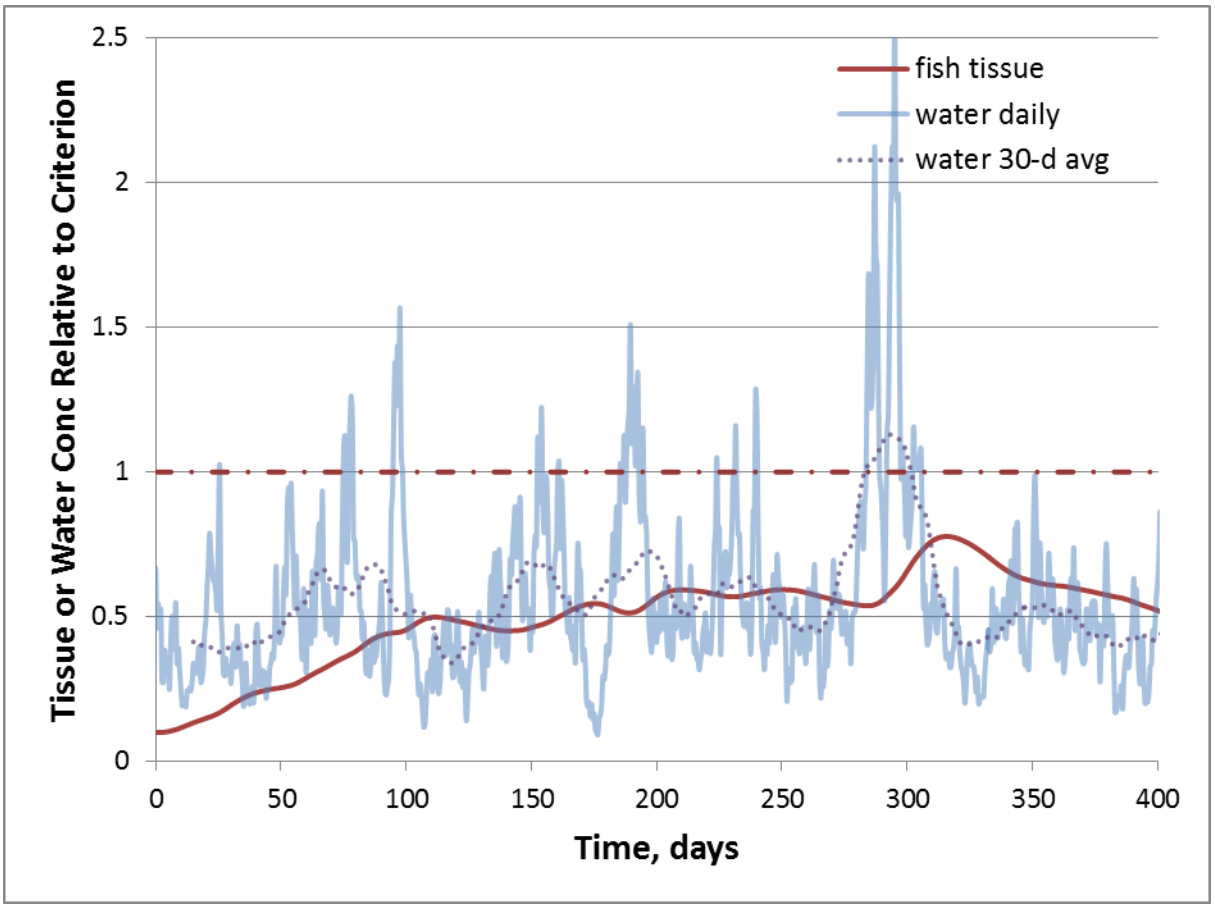


Figure J-5. Flowing water example of TL3 concentration starting at a concentration of 0.1 normalized to the criterion, and responding to randomly varying log-normally distributed water concentrations having median 0.49 (expressed as a dimensionless ratio: concentration/criterion), log standard deviation 0.5, and log serial correlation coefficient 0.8.
Again, all concentrations are as dimensionless ratios relative to the criteria concentrations.

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Several points are worth noting. Because the water concentrations happen (by chance) to be below average for the first 50 days, the TL3 concentrations rise somewhat slowly during that period. Were they to be above average during that period, the TL3 concentrations would more rapidly approach their dynamically varying plateau. In such a short time series it is not graphically apparent what the long-term average TL3 concentration will be; however, because the long-term arithmetic mean water concentration would be 0.56 (normalized the its criterion), the TL3 concentration would likewise end up averaging 0.56 normalized to its criterion, if tracked for many years.

It is also worth noting that most 400-day series of the type shown in Figure J-5 would not have occurrences of 30-day average concentrations above the criterion (as suggested by Figure J-3). This particular random series does have a period of 30-day average exceedances, near Day 300, but it does not persist long enough to cause the TL3 concentration to approach its criterion.

Lastly, it should be noted that when concentrations are randomly varying as in Figure J-5, the water concentrations that one observes are highly dependent on when the samples are taken. The TL3 concentrations observed are far less dependent on when the samples are taken (after the plateau is approached), but time variations, although muted, are still present.

The example scenarios depicted here show lotic time to steady state of approximately 3 months to less than 1 year under different discharge scenarios including both continuous and intermittent discharges. The scenarios also assume that the new selenium input is from one source; multiple new sources particularly with varying discharge patterns, might have a different response time and pattern for various trophic levels.

The example is likely not appropriate for lentic systems, because they would not be expected to have the rapidly varying water concentrations of Figure J-5. In addition, the water-to-TL1 kinetics would likely be slower in lentic systems with new or time-varying sources because of the role of bottom sediments acting as a reservoir in recycling selenium. Ultimately this should yield slower rising and smoother TL3 concentrations compared to those in Figure J-5.

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APPENDIX K: TRANSLATION OF A SELENIUM FISH TISSUE CRITERION ELEMENT TO A SITE-SPECIFIC WATER COLUMN VALUE

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1.0 TRANSLATING THE CONCENTRATION OF SELENIUM IN TISSUE TO A CONCENTRATION IN WATER USING MECHANISTIC BIOACCUMULATION MODELING

Introduction:

EPA recommends fish tissue elements of the selenium criterion supersede water column elements under steady state conditions because the selenium concentration in fish tissue is a more sensitive and reliable indicator of the negative effects of selenium in aquatic life. However, implementation of a fish tissue criterion element can be challenging because many state and tribal Clean Water Act (CWA) programs prefer the expression of water quality criteria as an ambient concentration in the water-column. Therefore, EPA also recommends two monthly average water-column criterion elements, one for lotic (flowing) waters, and the other for lentic (still) waters. EPA derived all water column criterion elements from the egg/ovary criterion element representing a protective selenium concentration for fish species populations. Thus the water column criterion elements also represent protective selenium concentrations for fish species populations. If threatened or endangered fish species are present, states and tribes may need to derive alternative water column elements with a refined protection goal that account for site-specific bioaccumulation characteristics.

EPA derived water-column criterion elements by modeling selenium bioaccumulation in aquatic systems. The EPA worked with the United States Geological Survey to derive a translation equation utilizing a mechanistic model of bioaccumulation previously published in peer-reviewed scientific literature (Luoma et. al., 1992; Wang et. al., 1996; Luoma and Fisher, 1997; Wang, 2001; Schlekat et al. 2002b; Luoma and Rainbow 2005; Presser and Luoma 2006; Presser and Luoma 2010; Presser 2013). EPA translated the selenium egg-ovary criterion element into two set(s) of site-specific water concentration values (lentic and lotic), and used the distribution(s) of those water column values to derive the respective water-column criterion elements. This appendix describes approaches that states and tribes may choose to use regarding application of this same mechanistic modeling approach (or alternatively an empirical bioaccumulation factor (BAF) approach) to translate a fish tissue criterion element (egg-ovary, whole body, or muscle) into site-specific water-column concentrations to more precisely manage selenium in specific aquatic systems.

The relationship between the concentration of selenium in the tissues of fish and the concentration of selenium in the water column can vary substantially among aquatic systems. The species of fish, the species and proportion of prey, and a variety of site-specific biogeochemical factors affect selenium bioaccumulation and thus determine the allowable concentration of selenium in ambient water protective of aquatic life. States and tribes may choose to adopt the results of site-specific water column translations as site-specific criteria (SSC) or adopt a translation procedure into state or tribal water quality

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standards. Under both options, the water quality standards revisions must be approved by EPA under Section 303(c) of the Clean Water Act. If a state or tribe adopts a translation procedure that will be implemented by other CWA programs, it must be scientifically defensible, produce repeatable, predictable outcomes, and result in criteria that protect the applicable designated use. Examples of such approaches include the mechanistic modeling approach and the empirical BAF approach described within this Appendix.

EPA considered both mechanistic and empirical modeling approaches to translate the selenium egg-ovary criterion element into water column concentration elements. A mechanistic modeling approach uses scientific knowledge of the physical and chemical processes underlying bioaccumulation to establish a relationship between the concentrations of selenium in the water column and the concentration of selenium in the tissue of aquatic organisms. The mechanistic modeling approach enables formulation of site-specific models of trophic transfer of selenium through aquatic food webs and translation of the egg-ovary criterion element into an equivalent site-specific water concentration. The empirical modeling approach establishes a relationship between concentrations of selenium in fish tissue and ambient water directly by measuring selenium concentrations in both media and calculating the ratio of the two concentrations. The ratio (BAF) can then be used to estimate the target concentration of selenium in the water column as related to the adopted fish tissue element.

Both the mechanistic and empirical modeling approaches have advantages and disadvantages that should be considered before deciding which approach to use. On the one hand, the mechanistic modeling approach has the advantage of not requiring extensive fish tissue sampling and analysis by using knowledge of aquatic system food webs. However, uncertainty in the selection of model parameters increases uncertainty in the outcome leading to a reduction in defensibility. Of particular concern with respect to the mechanistic model EPA developed is the selection of the value for the enrichment factor parameter *EF* (discussed in more detail below). On the other hand, the empirical BAF approach is conceptually and computationally simpler because it relies only on field measurements and does not require extensive knowledge of the physical, chemical, or biological characteristics of the aquatic system. However, obtaining a sufficient number of measurements in fish tissue and water may be logistically difficult and/or more expensive.

The appropriate modeling approach to use when translating the selenium egg-ovary criterion element to a site-specific water-column concentration depends on individual circumstances and site-specific characteristics. The mechanistic modeling approach may be a useful method in situations where there is little or no data on the amount of selenium in an aquatic system, the empirical BAF approach may be desirable in circumstances where in fish tissue and water data are available. Below is a description of

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methodology than can be used to translate the egg-ovary criterion element to a site-specific water-column concentration for site-specific management of selenium.

1.1 Relating the Concentration of Selenium in Fish Tissue and Water using the Mechanistic Modeling Approach

The relationship between the concentration of selenium in the eggs or ovaries of fish and the concentration of selenium in the water column is given in Equation K-1 (Equation 18 from the main text):

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite} \times EF \times CF} \qquad \textit{(Equation K-1)}$$

Where:

C_{water} = the concentration of selenium in water (µg/L),

$C_{egg\text{-}ovary}$ = the concentration of selenium in the eggs or ovaries of fish (µg/g),

$TTF^{composite}$ = the product of the trophic transfer factor (*TTF*) values of the fish species that is the target of the egg-ovary criterion element and the *TTF* values of all lower trophic levels in its food web (no units of measurement, see explanation below).

EF = the steady state proportional bioconcentration of dissolved selenium at the base of the aquatic food web (L/g),

CF = the species-specific proportion of selenium in eggs or ovaries relative to the average concentration of selenium in all body tissues (no units of measurement).

The basic principles expressed in Equation K-1 are illustrated in the conceptual model shown in Figure K-1.

Selenium dissolved in surface water enters aquatic food webs by becoming associated with trophic level 1 primary producer organisms (e.g., algae) and other biotic (e.g., detritus) and abiotic (e.g., sediment) particulate material. An enrichment function (*EF*) quantifies the bioconcentration of selenium in particulate material and thus its bioavailability in the aquatic system. The parameter *EF* is a single value that represents the steady state proportional concentration of selenium in particulate material relative to the concentration of selenium dissolved in water.

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Organic particulate material is consumed by trophic level 2 organisms (usually aquatic invertebrates, but also some fish species that are herbivores/detritivores) resulting in the accumulation of selenium in the tissues of those organisms. Trophic level 2 invertebrates are consumed by trophic level 3 fishes resulting in further accumulation of selenium in the tissues of those fish. Bioaccumulation of selenium from one trophic level to the next is quantified by a trophic transfer factor (*TTF).* A *TTF* is a single value that represents the steady state proportional concentration of selenium in the tissue of an organism relative to the concentration of selenium in the food it consumes. Different species of organisms metabolize selenium in different ways. Thus each species is associated with a specific *TTF* value. Because the trophic transfer of selenium through all trophic levels is mathematically equal to the product of the individual *TTF* values, all consumer-resource interactions in a particular aquatic ecosystem are simplified in Equation K-1 by representing the product of all the individual *TTF* values as the single parameter $TTF^{composite}$.

Fish accumulate selenium in different tissues of the body in differing amounts. Species physiology, age, diet, sex, and spawning status are some of the factors that affect selenium partitioning in body tissues. Because the primary selenium criterion element is expressed as a concentration in the eggs and/or ovaries, a conversion factor (*CF*) quantifies the relationship between the concentration of selenium in the eggs and/or ovaries and the average concentration of selenium in the whole body or muscle tissues. The parameter *CF* in Equation K-1 is a single value that represents the steady state proportional concentration of selenium in the eggs and/or ovaries relative to the average concentration of selenium in all body tissues. Different species of fish accumulate selenium in their eggs and ovaries to different degrees. Thus each species of fish is associated with a specific *CF* value.

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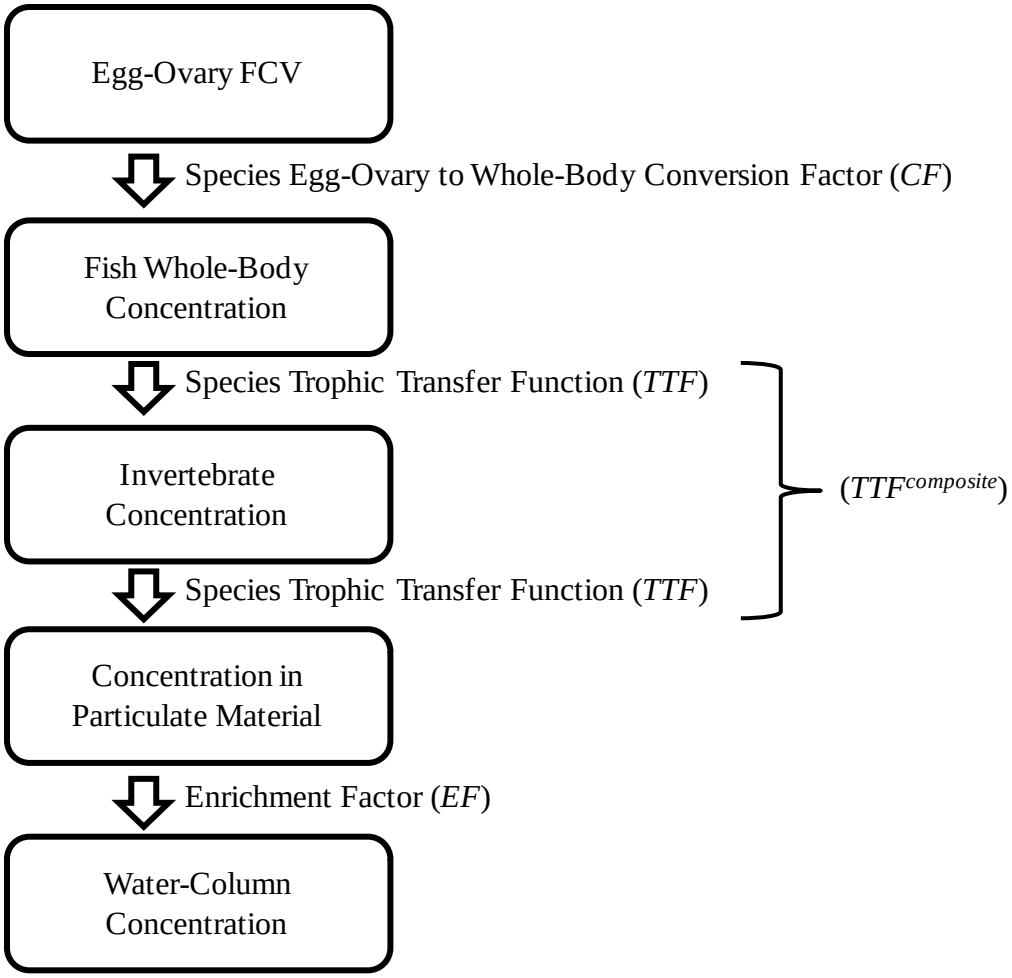


Figure K-1. Conceptual model for translating the egg-ovary FCV to a water-column concentration.
Note: States may want to use the whole body or muscle criterion elements as the starting point for site specific translation to a water column concentration.

Once the parameters that quantify the transfer of selenium through each step in this pathway are identified, they can be used with Equation K-1 to translate the egg-ovary criterion element to a site-specific concentration of selenium in the water column (i.e., target water column concentration).

Because each *TTF* value is species-specific, it is possible to differentiate bioaccumulation in different aquatic systems by modeling the food web of the target fish species. For example, where the food web contains more than 3 trophic levels, $TTF^{composite}$ can be represented as the product of all *TTF* values for each trophic level given in Equation K-2, which is a generalization of Equation 10 from the main text:

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$$TTF^{composite} = TTF^{TL2} \times TTF^{TL3} \times \ldots \times TTF^{TLn} \qquad \textit{(Equation K-2)}$$

Where:

$TTF^{composite}$ = the product of all *TTF* values at all trophic levels.

TTF^{TLn} = the *TTF* value of the highest trophic level.

The consumption of more than one species of organism at the same trophic level can also be modeled by expressing the *TTF* value at a particular trophic level as the average *TTF* values of all species at that trophic level weighted by the proportion of species consumed given as Equation K-3 (Equation 11 in the main text):

$$\overline{TTF}^{TLx} = \sum_i \left(TTF_i^{TLx} \times w_i \right) \qquad \textit{(Equation K-3)}$$

Where:

TTF_i^{TLx} = the trophic transfer factor of the i^{th} species at a particular trophic level

w_i = the proportion of the i^{th} species consumed.

These concepts can be used to formulate a mathematical expression of $TTF^{composite}$ that models selenium bioaccumulation in a variety of aquatic ecosystems. Figure K-2 illustrates five hypothetical food web scenarios and the formulation of $TTF^{composite}$ for each of them. For each scenario, the value of $TTF^{composite}$, the *CF* value associated with the targeted fish species, and the site-specific *EF* value can be used with Equation K-1 to translate the egg-ovary criterion element to a site-specific water concentration value. The hypothetical food web models in Figure K-2 are a few possible examples of food web models for illustrative purposes. It is desirable to derive and use of a food web model that best represents the aquatic system for which the water column translation will apply. The general steps for deriving a site-specific translation of the egg-ovary criterion element to a water concentration value are described below.

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A) Three trophic levels (simple):

$$TTF^{composite} = TTF^{TL3} \times TTF^{TL2}$$



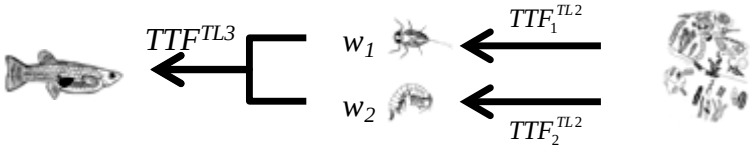
B) Four trophic levels (simple):

$$TTF^{composite} = TTF^{TL4} \times TTF^{TL3} \times TTF^{TL2}$$



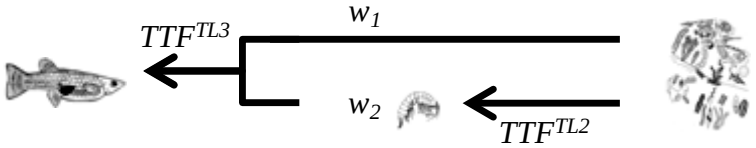
C) Three trophic levels (mix within trophic levels):

$$TTF^{composite} = TTF^{TL3} \times \left[\left(TTF_1^{TL2} \times w_1\right) + \left(TTF_2^{TL2} \times w_2\right)\right]$$



D) Three trophic levels (mix across trophic levels):

$$TTF^{composite} = \left(TTF^{TL3} \times w_1\right) + \left(TTF^{TL3} \times TTF^{TL2} \times w_2\right)$$



E) Four trophic levels (mix across trophic levels):

$$TTF^{composite} = \left[\left(TTF^{TL4} \times TTF^{TL3} \times w_1\right) + \left(TTF^{TL4} \times w_2\right)\right] \times TTF^{TL2}$$

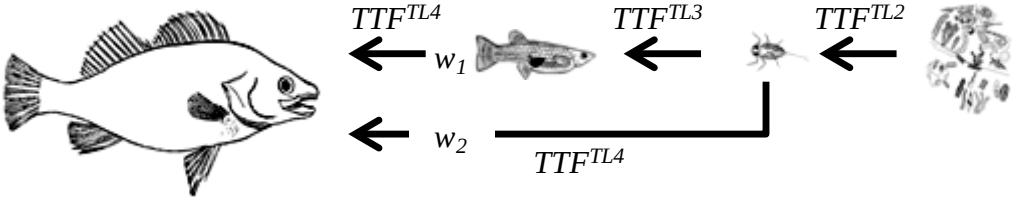


Figure K-2. Example mathematical expressions of $TTF^{composite}$ representing different food-web scenarios.

$TTF^{composite}$ quantitatively represents the trophic transfer of selenium through all dietary pathways of a targeted fish species. The mathematical expression of the food web model is used to calculate a value for $TTF^{composite}$ using appropriate species-specific *TTF* values and the proportions of each species consumed at each trophic level. See text for further explanation.

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1.2 Steps for Deriving a Site-Specific Water Concentration Value from the Egg-Ovary Criterion Element

Below are the steps for deriving a site-specific water concentration value from the selenium egg-ovary criterion element using EPA's mechanistic model approach:

1) Identify the appropriate target fish species.
2) Model the food web of the targeted fish species.
3) Identify appropriate *TTF* values by either:
    a. selecting the appropriate *TTF* values from a list of EPA-derived values, or
    b. deriving *TTF* values from existing data, or
    c. deriving *TTF* values by conducting additional studies, or
    d. extrapolating *TTF* values from existing values.
4) Determine the appropriate value of *EF* by either
    a. deriving a site-specific *EF* value from field measurements, or
    b. deriving an appropriate *EF* value from existing data, or
    c. extrapolating from *EF* values of similar waters.
5) Determine the appropriate *CF* value by either,
    a. selecting the appropriate *CF* value from a list of EPA-derived values, or
    b. deriving a *CF* value from existing data, or
    c. deriving a *CF* value by conducting additional studies, or
    d. extrapolating a *CF* value from existing values.
6) Translate the selenium egg-ovary criterion element into a site-specific water concentration value using Equation K-1.

Below are detailed descriptions of each step followed by example calculations using a variety of hypothetical scenarios. EPA is providing this information to support help states and tribes that choose to develop selenium water column values from the egg-ovary criterion element or develop translation procedures. Successful application of the mechanistic approach described here requires use of particular food web models and parameter values that are appropriate for particular aquatic systems.

1.2.1 Identify the Appropriate Target Fish Species

1.2.1.1 When fish are present

In developing a site-specific translation of the egg-ovary criterion element, the user wshould select whether to use a mechanistic model or empricial (BAF) approach. This decision will in large part

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determine the data and information requirements. A mechanistic model approach will likely require information on the spatial and temporal distribution of aquatic organisms, and may require measurements of selenium in ambient water and particulate material. An empirical model approach will use measurements of selenium is fish tissue and ambient water.

Developing a site-specific translation of the egg-ovary criterion element will also entail selection of which species of fish to target. The concentration of selenium in eggs and ovaries is the most sensitive and consistent indicator of toxicity. However, toxicity and bioaccumulation potential can vary among species. Species in the families Acipenseridae, Centrarchidae, and Salmonidae are particularly sensitive to selenium (Table 3.3 in the main document), whereas species such as stoneroller species, creek chub, blackside dace, and white sucker have documented tolerance to selenium and can be found in selenium contaminated systems (NAMC 2008, Presser 2012). Green sunfish accumulate less selenium than other species with comparable exposures in the same aquatic system (Hitt and Smith 2015). Selection of the fish species in the aquatic system with the greatest selenium sensitivity and bioaccumulation potential is recommended.

Several additional factors should also be considered in deciding which species to target when developing a site-specific translation of the egg-ovary criterion element. Anadromous species (species that migrate from salt water to spawn in fresh water) should generally avoided because selenium exposure and bioaccumulation occurs over a relatively long period through the consumption of locally contaminated aquatic organisms. Additionally considerations include whether the fish species selected typically consume organisms known or suspected to readily bioaccumulate selenium (e.g., mollusks). For example, high concentrations of selenium in San Francisco Bay white sturgeon are associated with their consumption of *Potamocorbula amurensis*, a bivalve in close proximity to selenium-contaminated sediments that rapidly and efficiently accumulates selenium (Stewart et al. 2004). In contrast, striped bass from the same aquatic system have substantially lower concentration of selenium in their tissues because their zooplankton-based food web has substantially lower selenium bioaccumulation characteristics (Schlekat et al. 2004; Stewart et al. 2004). The 2016 selenium criterion was developed for freshwater, but if considering other ecosystems, it may be worth noting that salinity may also affect bioaccumulation of selenium. Freshwater mollusks tend to have relatively higher *TTF* values when compared to other freshwater invertebrate taxa (e.g., aquatic insects), but they are lower than mollusks in marine or brackish systems (and particularly *P. amurensis*, an invasive clam in the San Francisco Bay). In aquatic systems with resident fish species of unknown selenium sensitivity and bioaccumulation potential, other factors such as ecological significance could be considered when choosing a target species.

Data from fisheries or biological surveys or other biological assessments could be considered to determine the fish species that reside in specific surface waters. State and tribal resource agency personnel

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familiar with fish sampling activities could also be a source of information on resident fish species. General information on the fish species present in state and tribal surface waters may also be found at:

- State Fish and Game agencies
- U.S. Fish and Wildlife Service (http://www.fws.gov)
- U.S. Geological Survey (http://www.usgs.gov)
- NatureServe.org (http://www.natureserve.org)
- Fishbase (http://www.fishbase.org)
- State or local sources of biological information (e.g. Biota Information System of New Mexico at http://www.bison-m.org)

Measurements of selenium in fish tissue would most reflect the ecosystem if adult (reproductively mature) fish are sampled. Selenium measurements in fish tissue will likely be more stable in adult fish because they are more likely to have a stable prey base. Reproductively mature (ripe or gravid) females would be needed for measures selenium in eggs and/or ovary tissue for comparison to the the egg-ovary tissue criterion element. It would be prudent to avoid sampling ovary tissue "post-spawn" due to a potential decrease in selenium concentration presumably due to the loss of selenium through spawning and release of eggs with relatively high concentrations of selenium. Consideration of closely related taxonomic surrogates (same genus or family) for threatened or endangered species may be useful.

Figure K-3 shows an example decision tree that may help in selection of the appropriate fish species for deriving a site-specific water concentration value from the selenium egg-ovary, whole-body, or muscle FCV. The use of taxonomic hierarchies for anlysis utilizes evolutionary relationships to infer biological similarities among organisms (Suter 1993). Additional information on fish tissue sampling (e.g., species selection, temporal and spatial considerations) is under development and will be published in the form of a technical support document (TSD) by the EPA in the near future.

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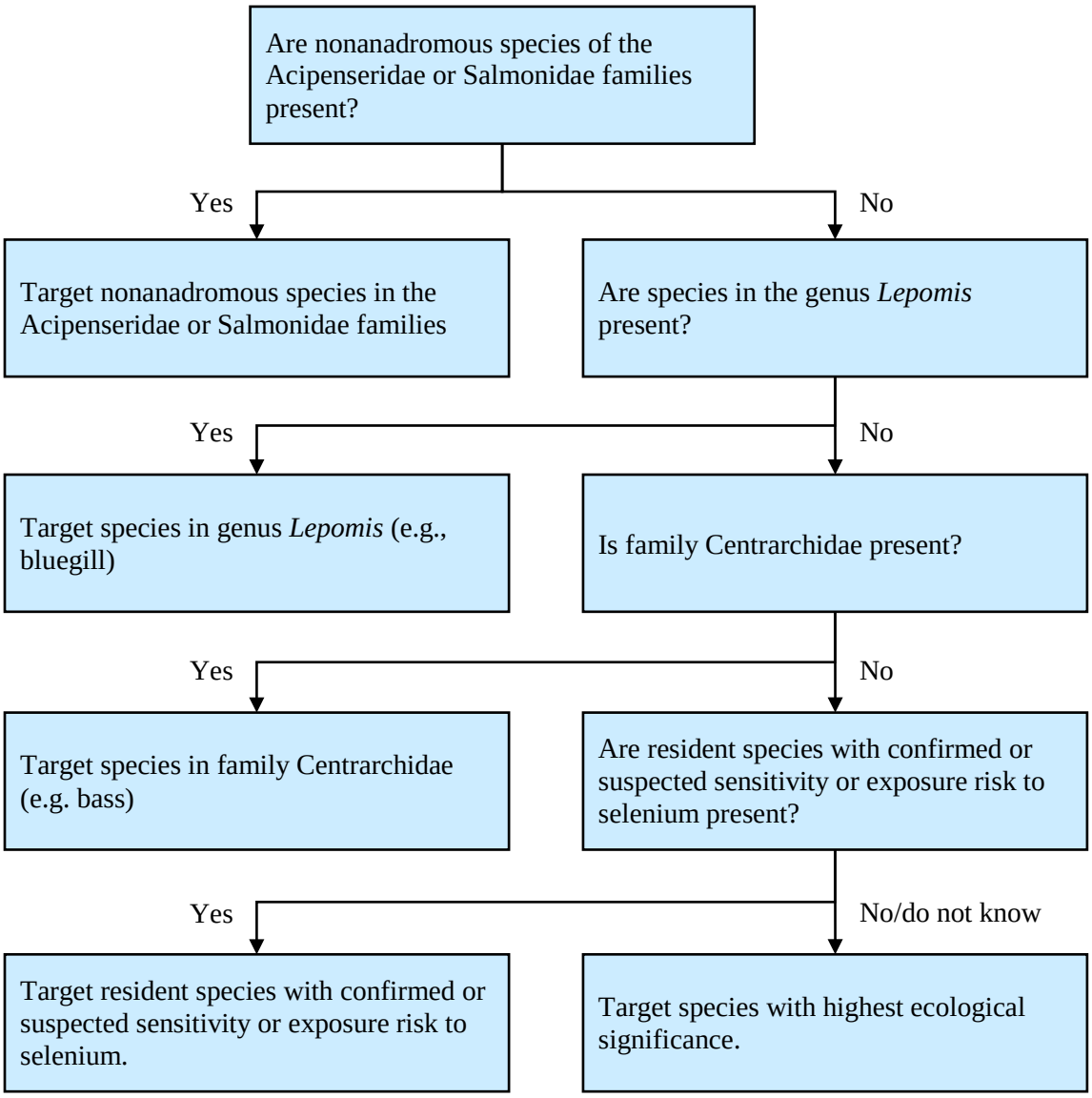


Figure K-3. Recommendeed decision process for selection of the fish species to use when deriving a water concentration from the selenium egg-ovary FCV.
This decision tree is also generally applicable when using the whole body or muscle tissue as the starting point for development of SSC, particularly when using the BAF approach.

1.2.1.2 When fish are absent from a site

Some aquatic systems do not contain resident fish. Fish may be absent from a waterbody because of intermittent or persistent low flows, physical impediments such as waterfalls or impoundments, lack of adequate habitat for feeding and/or spawning, or intolerable aquatic conditions related to pH, turbidity, temperature, salinity, total dissolved solids, chemical contaminants, or pathogens. These conditions could be due to natural or anthropogenic causes. Some streams may be naturally intermittent or ephemeral, or

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they might exhibit low or intermittent flows because of impoundments or water draw-down for agricultural irrigation, industrial uses, drinking water supply, or other uses.

When fish are absent from a waterbody, consideration of sampling the most sensitive fish species inhabiting nearby, most proximate downstream waters may be useful in order to understand selenium bioaccumulation potential in such systems. Although the upper reaches of some aquatic systems may not support fish communities, the invertebrate organisms that reside there may tolerate high concentrations of selenium and pose a selenium risk to predator fish if transported downstream. Users may choose to evaluate upstream waters without fish by measuring the selenium concentration in water, biotic and/or abiotic particulate material, and/or the tissues of invertebrate aquatic organisms that reside there. Because selenium associated with particulate material and invertebrate organisms can be transported downstream during intermittent high flows, elevated concentrations of selenium in the tissues of downstream fish could indicate upstream sources of selenium that require a more detailed evaluation of upstream conditions.

1.2.2 Model the Food-Web of the Targeted Fish Species

After selecting the target fish species, model users should formulate a mathematical expression of the target species food-web that will be used to calculate the value of $TTF^{composite}$. As discussed previously, $TTF^{composite}$ is the product of the *TTF* values across trophic levels of the target fish species food-web. The complexity of the food-web model will depend on the species of fish that is targeted, the diversity of prey species in the aquatic system, and the amount of information that is available. Many of the same information sources used to identify the targeted fish species in a waterbody could also be used to obtain information about its food web. The types and proportions of food organisms the targeted fish species consumes can be directly assessed through studies that examine stomach contents or from information gathered through biological assessments. If site-specific information is not available, model users could estimate the target fish species food-web using publicly available databases such as NatureServe (http://www.natureserve.org). For example, the NatureServe database record for fathead minnow in the HUC watershed #5040004 in Ohio indicates under the heading: “Ecology and Life History - Food Comments,” the fathead minnow “feeds opportunistically in soft bottom mud; eats algae and other plants, insects, small crustaceans, and other invertebrates (Becker 1983, Sublette et al. 1990).”

Additional sources of information include:

- FishBase (http://www.fishbase.org). FishBase is a relational database developed at the World Fish Center in collaboration with the Food and Agriculture Organization of the United Nations (FAO) and many other partners.

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- Carlander, K.D. Handbook of Freshwater Fishery Biology, volumes 1, 2 and 3. Iowa state University Press, Ames, Iowa. 1969-1997.

1.2.3 Identify Appropriate *TTF* Values

The food-web model uses appropriately selected species-specific *TTF* values (and, if appropriate, proportions within the same trophic level). Model users identify the appropriate *TTF* values by using one of the following four procedures, or by using other scientifically defensible methods.

1.2.3.1 Select the appropriate *TTF* values from the provided list of EPA-derived values

Species-specific TTF values represent the steady state proportional concentration of selenium in the tissue of an organism relative to the concentration of selenium in the food it consumes. EPA-derived *TTF* values for aquatic invertebrates and fish are provided in Tables K-1 and K-2 (Tables 3.10 and 3.11 in main text; see also main text for a complete explanation of the procedure EPA used to derive these values).

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Table K-1. EPA-derived Trophic Transfer Factor (TTF) values for freshwater aquatic invertebrates.

AE = Assimilation efficiency (%), IR = Ingestion rate (g/g-d), k_e = Elimination rate constant (/d).

Common name	Scientific name	AE	IR	k_e	TTF
Crustaceans					
amphipod	*Hyalella azteca*	-	-	-	1.22
copepod	copepods	0.520	0.420	0.155	1.41
crayfish	*Astacidae*	-	-	-	1.46
water flea	*Daphnia magna*	0.406	0.210	0.116	0.74
Insects					
dragonfly	*Anisoptera*	-	-	-	1.97
damselfly	*Coenagrionidae*	-	-	-	2.88
mayfly	*Centroptilum triangulifer*	-	-	-	2.38
midge	*Chironimidae*	-	-	-	1.90
water boatman	*Corixidae*	-	-	-	1.48
Mollusks					
asian clam[a]	*Corbicula fluminea*	0.550	0.050	0.006	4.58
zebra mussel	*Dreissena polymorpha*	0.260	0.400	0.026	4.00
Annelids					
blackworm	*Lumbriculus variegatus*	0.165	0.067	0.009	1.29
Other					
zooplankton	zooplankton	-	-	-	1.89

[a] Not to be confused with *Potamocorbula amurensis*

Table K-2. EPA-derived Trophic Transfer Factor (*TTF*) values for freshwater fish.

AE = Assimilation efficiency (%), IR = Ingestion rate (g/g-d), k_e = Elimination rate constant (/d).

Common name	Scientific name	AE	IR	k_e	TTF
Cypriniformes					
blacknose dace	*Rhinichthys atratulus*	-	-	-	0.71
bluehead sucker	*Catostomus discobolus*	-	-	-	1.04
longnose sucker	*Catostomus catostomus*	-	-	-	0.90
white sucker	*Catostomus commersonii*	-	-	-	1.11
flannelmouth sucker	*Catostomus latipinnis*	-	-	-	0.98
common carp	*Cyprinus carpio*	-	-	-	1.20
creek chub	*Semotilus atromaculatus*	-	-	-	1.06
fathead minnow	*Pimephales promelas*	-	-	-	1.57
red shiner	*Cyprinella lutrensis*	-	-	-	1.31
redside shiner	*Richardsonius balteatus*	-	-	-	1.08
sand shiner	*Notropis stramineus*	-	-	-	1.56
Cyprinodontiformes					
western mosquitofish	*Gambusia affinis*	-	-	-	1.21
northern plains killifish	*Fundulus kansae*	-	-	-	1.27
Esociformes					
northern pike	*Esox lucius*	-	-	-	1.78
Gasterosteiformes					
brook stickleback	*Culaea inconstans*	-	-	-	1.79

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Common name	Scientific name	AE	IR	k_e	TTF
Perciformes					
black crappie	*Pomoxis nigromaculatus*	-	-	-	2.67
bluegill	*Lepomis macrochirus*	-	-	-	1.03
green sunfish	*Lepomis cyanellus*	-	-	-	1.12
largemouth bass	*Micropterus salmoides*	-	-	-	1.39
smallmouth bass	*Micropterus dolomieu*	-	-	-	0.86
striped bass	*Morone saxatilis*	0.375	0.335	0.085	1.48
walleye	*Sander vitreus*	-	-	-	1.60
yellow perch	*Perca flavescens*	-	-	-	1.42
Salmoniformes					
brook trout	*Salvelinus fontinalis*	-	-	-	0.88
brown trout	*Salmo trutta*	-	-	-	1.38
mountain whitefish	*Prosopium williamsoni*	-	-	-	1.38
cutthroat trout	*Oncorhynchus clarkii*	-	-	-	1.12
rainbow trout	*Oncorhynchus mykiss*	-	-	-	1.07
Scorpaeniformes					
mottled sculpin	*Cottus bairdi*	-	-	-	1.38
sculpin	*Cottus sp.*	-	-	-	1.29
Siluriformes					
black bullhead	*Ameiurus melas*	-	-	-	0.85
channel catfish	*Ictalurus punctatus*	-	-	-	0.68

The *TTF* values from these lists could be used exclusively, or in conjunction with *TTF* values obtained from other sources (see below). Note that these tables do not represent an exhaustive list of all *TTF* values that may be required to calculate a site-specific water concentration value. If this list does not include a required *TTF* value, another approach could be considered to obtain an appropriate value.

1.2.3.2 Deriving *TTF* values from existing data

If model users cannot obtain one or more required *TTF* values from Tables K-1 and/or K-2, species-specific *TTF* values could be derived using existing data. One approach for deriving species-specific *TTF* values is to use the physiological coefficients representing food ingestion rate (*IR)*, selenium efflux rate (k_e), and selenium assimilation efficiency (*AE*) to calculate a *TTF* value using Equation K-4 (Equation 3 from the main text, Reinfelder et al. 1998**)** given as:

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$$TTF = \frac{AE \times IR}{k_e} \qquad \textit{(Equation K-4)}$$

Where:

TTF = species-specific trophic transfer factor

AE = species-specific assimilation efficiency (%)

IR = species-specific ingestion rate (g/g-d)

k_e = species-specific efflux rate constant (/d)

The physiological coefficients *IR*, *AE* and are species-specific values. Values for AE and k_e can only be derived from laboratory studies. Values for IR may be derived from laboratory studies or obtained from published literature. After the three physiological coefficients are obtained, a *TTF* value can be calculated using Equation K-4.

Another way to derive species-specific *TTF* values is to empirically assess the relationship between the selenium concentration in the tissue of organisms and the selenium concentration in the food they consume using paired measurements from field studies. Species-specific *TTF* values can be derived from such measurements by calculating ratios, using regression techniques, or other scientifically defensible methods.

Model users could choose to use the same approach EPA used to calculate species-specific *TTF* values. EPA derived *TTF* values using a combination median and regression approach. EPA defined the *TTF* value for any trophic level as:

$$TTF^{TLn} = \frac{C_{tissue}^{TLn}}{C_{food}^{TLn}} \qquad \textit{(Equation K-5)}$$

Where:

TTF^{TLn} = The trophic transfer factor of a given trophic level,

C_{tissue}^{TLn} = The selenium concentration (mg/kg dw) in the tissues of the consumer organism,

C_{food}^{TLn} = The selenium concentration (mg/kg dw) in the consumer organism's food.

EPA used the median of the ratios given in Equation K-5 as the species-specific *TTF* value, but only if an empirical relationship between the paired measurements could be confirmed by linear

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regression analysis. EPA considered the relationship acceptable if a linear regression of tissue selenium concentration on food selenium concentration resulted in both a statistically significant fit ($P < 0.05$) and a positive slope (i.e., selenium concentrations in the consumer increases with increasing selenium in food).

1.2.3.3 Deriving *TTF* values by conducting additional studies

Additional studies could be conducted to obtain the data needed to derive *TTF* values for specific needs, or to revise existing *TTF* values, if the existing *TTF* values do not appear to be appropriate for a particular aquatic system.

1.2.3.4 Extrapolating *TTF* values from existing values

If one or more necessary *TTF* values are not available, and the information needed to derive a species-specific *TTF* value is not available or impractical to obtain, model users could consider extrapolating a new *TTF* value from other known *TTF* values. One possible method to extrapolate a *TTF* value is to sequentially consider higher taxonomic classifications until one or more of the organisms with a known *TTF* value matches the taxon being considered. If the lowest matching taxon is common to more than one of the available *TTF* values, the average *TTF* from the matching table entries could be used. The use of taxonomic hierarchies in this way utilizes evolutionary relationships to infer biological similarities among organisms (Suter 1993).

EPA used such an extrapolation approach to derive some of the *TTF* values necessary to develop the water column criterion elements. For example, the *TTF* value for *Chrosomus eos* (northern redbelly dace) was not available. *TTF* values were also not available for other species in the genus *Chrosomus*, but *TTF* values were available for species in the family Cyprinidae, including *Rhinichthys atratulus* (blacknose dace), *Cyprinus carpio* (common carp), *Semotilus atromaculatus* (creek chub), *Pimephales promelas* (fathead minnow), *Cyprinella lutrensis* (red shiner), *Richardsonius balteatus* (redside shiner), and *Notropis stramineus* (sand shiner). Because Cyprinidae is the lowest taxonomic classification where *Chrosomus eos* matches one or more species with an available *TTF* value, EPA used the median *TTF* value of blacknose dace, common carp, creek chub, fathead minnow, red shiner, redside shiner, and sand shiner as the *TTF* value for northern redbelly dace.

1.2.4 Determine the Appropriate *EF* Value

The selenium enrichment function (*EF*) value represents the bioavailability of selenium at the base of the aquatic food web. The base of the aquatic food web includes phytoplankton, periphyton, detritus, inorganic suspended material, biofilm, sediment and/or attached vascular plants (Presser and Luoma, 2010). EPA refers to this mixture of living and non-living entities as particulate material. The parameter *EF* varies more widely across aquatic systems than any other parameter, and is influenced by

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the source and form of selenium, water residence time, the biogeochemical characteristics of the waterbody, and the type of particulate matter collected. Because *EF* can vary greatly across waterbodies, this parameter has the greatest potential to introduce uncertainty in the translation from an egg-ovary selenium concentration to a water column concentration. For this reason, use *EF* values derived from site-specific data is recommended whenever possible in applying the model. One of the following four procedures could be used to derive *EF* values, or other scientifically defensible methods could be used.

1.2.4.1 Deriving a site-specific *EF* value from field measurements

Equation 12 from the main text defines the parameter *EF* as the ratio of the concentration of selenium in particulate material to the concentration of selenium dissolved in water given as:

$$EF = \frac{C_{particulate}}{C_{water}} \qquad \textit{(Equation K-6)}$$

Where:

$C_{particulate}$ = Concentration of selenium in particulate material (µg/g)

C_{water} = Concentration of selenium dissolved in water (µg/L)

EF = Enrichment Function (L/g)

To calculate a site-specific *EF* value, EPA first calculates the ratio of each individual particulate measurement and its associated water measurement (if more than one water measurement is available for any given particulate measurement, the median water measurement is used). If more than one ratio for any given category of particulate material is available (e.g., more than one ratio of algae to water), EPA takes the median of the ratios. EPA then calculates the geometric mean of the median ratios for each category of particular material as the site *EF* value. EPA only uses sediment measurements if there are at least one measurement from either algae or detritus.

Deriving a site-specific *EF* value in this manner is a relatively straightforward procedure. However, consideration of data that appropriately accounts for the spatial and temporal variability of an aquatic system would be useful in the development of any sampling plan. Aquatic system characteristics such as dimension, volume, shape, residence time, velocity, and growing season are a few important factors that should be considered in designing a sampling plan that will adequately account for variability. State and Federal agencies (USGS, ACOE) as well as watershed groups may be useful sources of information that can help characterize the temporal and spatial variability at a particular aquatic system. When developing the selenium criterion, EPA observed a relatively lower correlation between the selenium concentration in water and abiotic (benthic sediments) particulate samples compared to the same analysis between water and biotic (algae and detritus) particulate samples, resulting in EPA's decision

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that calculation of any site-specific *EF* values include information from at least one type of biotic particulate indeveloping its criteiron. Prioritization of sampling of biotic particulate material over abiotic samples should be considered. Regaridng selenium measurements from abiotic particulate material, consideration of utilizing at least one type of biotic particulate material when deriving the *EF* value of an aquatic system is recommended.

Site-specific *EF* values using particulate and water samples that are as spatially and temporally coincident as possible would be considered the most robust. Although EPA's analysis of particulate and water samples from a sample population of aquatic systems found that samples taken within one year of each other, based on data availability, were appropriate in deriving the national criterion (Figure 3.5 in the main document), a site-specific EF value would ideally involve collecting particulate and water samples at the same location and time to ensure their representativeness of sirte-specific conditions. One simple and effective sampling and analysis scenario would be to collect water samples or a combination of particulate and water samples, separate the particulate material from the water in each sample by filtering, measure the concentration of selenium in the separated water and particulate material, compute the ratio of the two measurements from each sample, and then calculate the mean or median of all the ratios.

Selenium bioaccumulation occurs more readily in aquatic systems with longer residence times (such as lakes, reservoirs, oxbows, and wetlands) and with fine particulate sediments high in organic carbon. A well-planned sampling protocol was developed in association with the development of a site-specific water-column criterion for selenium in the San Francisco Bay Delta[2]. States and tribes may also want to consult Doblin et al. (2006) for specific particulate sampling methods. EPA's National Rivers and Streams Assessment[3] also provides methods for quantitative periphyton sampling that commonly represents the base of many aquatic food webs. Analytical methods to measure selenium in particulate material and in water are discussed in Appendix L.

1.2.4.2 Deriving an appropriate *EF* value from existing data

If suitable and sufficient site-specific measurements of selenium in particulate material and water are already available, the model user may be able to use that data to derive an appropriate *EF* value. However, it would be important to ensure that the data represents current conditions, were collected and analyzed using scientifically sound sampling and analytical techniques, and proper quality assurance and quality control protocols were implemented.

1.2.4.3 Extrapolating from *EF* values of similar waters

[2] https://www3.epa.gov/region9/water/ctr/selenium-modeling_admin-report.pdf

[3] https://www.nemi.gov/methods/method_summary/12558/ (EPA-841-B-07-009) and https://www.nemi.gov/methods/method_summary/12565/ (EPA-841-B-12-009)

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In circumstances where a site-specific, field-derived *EF* value is not available or practical to develop, an *EF* value from one or more aquatic systems with similar hydrological, geochemical, and biological characteristics could be used to estimate *EF*. However, there is a possibility of introducing significant uncertainty when using *EF* values extrapolated from other aquatic systems. More information on this topic is contained in Appendix H of this document.

1.2.5 Determine the Appropriate *CF* Value

1.2.5.1 Selecting the appropriate *CF* value from the list of values that were used to derive EPA's recommended water criteria concentration values

The parameter *CF* represents the species-specific proportion of selenium in eggs or ovaries relative to the average concentration of selenium in all body tissues. EPA derived species-specific *CF* values for 20 species of fish from studies that measured selenium concentrations in both eggs and/or ovaries and in whole body and/or muscle. These *CF* values can be found in Appendix B and are reproduced below (Table K-3).

Table K-3. Selenium Whole Body to Egg-Ovary Conversion Factors (*CF*).

Common name	Median ratio (Cegg-ovary/ Cwhole-body)	Median ratio (Cegg-ovary/ Cmuscle)	Muscle to whole-body correction factor	Final CF values
Species				
Bluegill	2.13			2.13
Bluehead sucker	1.82			1.82
Brook trout		1.09	1.27	1.38
Brown trout	1.45			1.45
Creek chub	1.99			1.99
Common carp	1.92			1.92
Cutthroat trout	1.96			1.96
Desert pupfish	1.20			1.20
Dolly Varden		1.26	1.27	1.61
Fathead minnow	1.40			1.40
Flannelmouth sucker	1.41			1.41
Green sunfish	1.45			1.45
Mountain whitefish		5.80	1.27	7.39
Northern pike		1.88	1.27	2.39
Rainbow trout		1.92	1.27	2.44

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Common name	Median ratio (Cegg-ovary/ Cwhole-body)	Median ratio (Cegg-ovary/ Cmuscle)	Muscle to whole-body correction factor	Final CF values
Razorback sucker		2.31	1.34	3.11
Roundtail chub	2.07			2.07
Smallmouth bass	1.42			1.42
White sturgeon		1.33	1.27	1.69
White sucker	1.38			1.38
Genus				
Catostomus				1.41
Gila				2.07
Lepomis				1.79
Micropterus				1.42
Oncorhynchus				1.96
Family				
Catostomidae				1.41
Centrarchidae				1.45
Cyprinidae				1.95
Salmonidae				1.71
Order				
Cyprinodontiformes				1.20
Perciformes				1.45
Class				
Actinopterygii				1.45

The data and methods used to derive the *CF* in this table are described in Appendix B.

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1.2.5.2 Deriving a *CF* value from existing data

The parameter *CF* is mathematically expressed as Equation K-7 (Equation 16 in the main text):

$$CF = \frac{C_{egg-ovary}}{C_{whole-body}} \qquad \textit{(Equation K-7)}$$

Where:

CF = Whole-body to egg-ovary conversion factor (dimensionless ratio).

$C_{egg\text{-}ovary}$ = Selenium concentration in the eggs or ovaries of fish (µg/g)

$C_{whole\text{-}body}$ = Selenium concentration in the whole body of fish (mg/kg).

If suitable and sufficient data are available, a model user could derive a species-specific *CF* value using the same numerical methods described above to calculate the parameter *EF*. The median of the ratios given in Equation K-7 could be used as the species-specific *CF* value, but only if an empirical relationship between the paired measurements could be confirmed by linear regression analysis. IN deriving the national criterion, EPA considered it to be acceptable if a linear regression of egg-ovary selenium concentration on whole body selenium concentration resulted in both a statistically significant fit ($P < 0.05$) and a positive slope. Other scientifically defensible methods could be used. Regardless of the method used, the user should ensure that the data used to derive *CF* values were collected using adequate quality assurance and quality control protocols.

1.2.5.3 Deriving a *CF* value by conducting additional studies

Additional studies could be performed to obtain data needed to derive *CF* values for specific needs or to revise existing *CF* values if there is reason to believe doing so may increase the accuracy of the resulting water concentration value. Analytical methods to measure selenium in tissue are discussed in Appendix L. Where appropriate, additional data could be obtained as part of a NPDES permit application by invoking authority under CWA section 308 (or comparable state or tribal authority) to require NPDES-regulated facilities to collect information necessary to develop permit limits**.**

1.2.5.4 Extrapolating the CF value from the list of values that were used to derive EPA's recommended water criteria concentration values

If one or more necessary *CF* values are not available, and the information needed to derive a species-specific *CF* value is not available or impractical to obtain, a model user could could consider extrapolating a new *CF* value from other known *CF* values. One possible method to extrapolate a *CF* value is to use the same taxonomic approach EPA uses for *TTF* values that are not available for specific

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species (Section 1.2.3.4). Sequentially consider higher taxonomic classifications could be considered until one or more of the fish species with a known *CF* value matches the taxon being considered. If the lowest matching taxon is common to more than one of the available *CF* values, the average *CF* value from the matching table entries could be used.

1.2.6 Translate the Selenium Egg-Ovary Criterion Element into a Site-Specific Water Concentration Value using Equation K-1

Model users could derive a site-specific water concentration value from the egg-ovary criterion element value using Equation K-1 with appropriate values of *CF*, $TTF^{composite}$ (derived from the product of the individual *TTF* values from each trophic level) and *EF*. Note that NPDES permitting regulations at 40 CFR § 122.45(c) requires that a Water Quality-Based Effluent Limit (WQBEL) for metals be expressed as total recoverable metal, unless an exception is met under 40 CFR § 122.45(c)(1)-(3). Equation K-1 assumes selenium concentrations dissolved in water. While states and tribes may express ambient water quality criteria in water quality standards as dissolved selenium, an additional step would be necessary to convert the dissolved selenium concentration to a total recoverable selenium concentration for the purpose of NPDES permitting. Guidance for converting expression of metal concentrations in water from dissolved to total recoverable can be found in *Technical Support Document for Water Quality-based Toxics Control* (U.S. EPA 1991) and *The Metals Translator: Guidance for Calculating a Total Recoverable Permit Limit from a Dissolved Criterion* (U.S. EPA 1996).

1.3 Managing Uncertainty using the Mechanistic Modeling Approach

Uncertainty in the translation of the egg-ovary criterion element to a water column value using the mechanistic bioaccumulation modeling approach (Equation K-1) can arise from several sources. These include:

- Measurement error when deriving input parameters,
- Inaccurate food web models due to misidentification and/or incorrect proportions of prey organisms,
- Inaccurate or inappropriate *EF*, *TTF*, and/or *CF* values,
- Biological variability,
- Unaccounted factors affecting bioaccumulation (e.g. selenium speciation), and
- Other unknown factors.

The most influential step in selenium bioaccumulation occurs at the base of aquatic food webs (Chapman et al. 2010). The parameter *EF* characterizes this step by quantifying the partitioning of

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selenium between the dissolved and particulate state. *EF* can vary by at least two orders of magnitude across aquatic systems (Presser and Luoma 2010). The greatest reduction in uncertainty could be achieved when translating a fish tissue concentration of selenium to a water column concentration using Equation K-1 by using temporally and spatially coincident site-specific empirical observations of dissolved and particulate selenium of sufficient quality and quantity to accurately characterize *EF*.

Presser (2013) provides several recommendation to reduce uncertainty in an ecosystem scale approach to deriving a site-specific selenium water column criterion in a coal mining impacted area of West Virginia. Suggested actions to reduce uncertainty include:

- Obtaining temporally matched pairs of selenium measurements in dissolved and particulate material across a broad range of sites to ensure the samples accurately characterize the aquatic system and to assess sample variability;
- Characterizing particulate material across seasons to better define the base of the food web;
- Evaluating aquatic systems variables such as residence time, watershed dilution, and physical habitat attributes on as fine a scale as possible;
- Refining model assumptions to accurately characterize dietary preferences and composition of fish, and develop additional *TTF* values if necessary;
- Identify and target fish species particularly sensitive to selenium;
- Consider temporal changes in the bioaccumulation potential of the aquatic system and changes in selenium sensitivity over the life cycle of fish; and
- Consider variability in hydrology and selenium discharges.

The suitability of selected equation parameters could be determined by obtaining fish tissue and water column measurements of selenium from small-scale field studies, use of equation K-1 to estimate one measurements using the other, and comparison of the estimated concentration with the actual concentration (see Section 6.2.1 of the main document for a description of EPA's validation approach).

1.4 Example Calculations

Below are six hypothetical examples that demonstrate how to translate the egg-ovary FCV to a site-specific water concentration criterion using Equation K-1. These examples encompass a variety of hypothetical aquatic systems with various fish species and food webs. For these hypothetical examples, species-specific *TTF* values were taken from Tables K-1 and K-2, and *CF* values were taken from Table K-3. To calculate EF in these examples, the EPA used a hypothetical water concentration of 5 µg/L and the hypothetical particulate concentrations of 4.25 µg/g and 8.75 µg/g in lotic and lentic aquatic systems, respectively.

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1.4.1 Example 1

Bluegill (*Lepomis macrochirus*) in a river that consume mostly amphipods:

Current water concentration (µg/L)	5.00
Current particulate concentration (mg/kg)	4.25
Trophic transfer factor for bluegill (TTF^{TL3})	1.03
Trophic transfer factor for amphipods (TTF^{TL2})	1.22
Egg-ovary to whole-body conversion factor for bluegill (CF)	2.13
Selenium egg-ovary FCV (mg/kg)	15.1

$$\mathrm{EF} = \frac{\mathrm{C_{particulate}}}{\mathrm{C_{water}}}$$

$$EF = \frac{4.25}{5.00}$$

= 0.85 L/g

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite}\ x\ EF\ x\ CF}$$

$$TTF^{composite} = TTF^{TL3} \times TTF^{TL2}$$
$$= 1.03 \times 1.22$$
$$= 1.26$$

$$C_{water} = \frac{15.1}{1.26 \times 0.85 \times 2.13}$$

= 6.62 µg/L

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1.4.2 Example 2

Fathead minnow (*Pimephales promelas*) in a river that consume mostly copepods:

Current water concentration (µg/L)	5.00
Current particulate concentration (mg/kg)	4.25
Trophic transfer factor for fathead minnow (TTF^{TL3})	1.57
Trophic transfer factor for copepods (TTF^{TL2})	1.41
Egg-ovary to whole-body conversion factor for fathead minnow (CF)	1.40
Selenium egg-ovary FCV (mg/kg)	15.1

$$EF = \frac{C_{particulate}}{C_{water}}$$

$$EF = \frac{4.25}{5.00}$$

= 0.85 L/g

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite} \; x \; EF \; x \; CF}$$

$TTF^{composite} = TTF^{TL3} \times TTF^{TL2}$

$= 1.57 \times 1.41$

$= 2.21$

$$C_{water} = \frac{15.1}{2.21 \times 0.85 \times 1.40}$$

= 5.74 µg/L

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1.4.3 Example 3

Bluegill (*Lepomis macrochirus*) in a lake that consume mostly aquatic insects:

Current water concentration (µg/L)	5.0
Current particulate concentration (mg/kg)	8.75
Trophic transfer factor for bluegill (TTF^{TL3})	1.03
Trophic transfer factor for aquatic insects (median of Odonates, Water boatman, Midges, and Mayflies) (TTF^{TL2})	2.14
Egg-ovary to whole-body conversion factor for bluegill (CF)	2.13
Selenium egg-ovary FCV (mg/kg)	15.1

$$EF = \frac{C_{particulate}}{C_{water}}$$

$$EF = \frac{8.75}{5.00}$$

= 1.75 L/g

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite} \; x \; EF \; x \; CF}$$

$TTF^{composite}$ = $TTF^{TL3} \times TTF^{TL2}$

= 1.03 x 2.14

= 2.20

$$C_{water} = \frac{15.1}{2.20 \times 1.75 \times 2.13}$$

= 1.84 µg/L

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1.4.4 Example 4

Fathead minnow (*Pimephales promelas*) in a river that consume approximately ⅔ copepods and ⅓ aquatic insects:

Current water concentration (µg/L)	5.0
Current particulate concentration (mg/kg)	4.25
Trophic transfer factor for fathead minnow (TTF^{TL3})	1.57
Trophic transfer factor for copepods and aquatic insects (TTF^{TL2}) Copepods = 1.41 Average of all aquatic insects = 2.14 $TTF^{TL2} = \sum_{i=1}^{n}(TTF_i \times w_i)$ $= (1.41 \times ⅔) + (2.14 \times ⅓)$ $= 1.65$	1.65
Egg-ovary to whole-body conversion factor for fathead minnow (CF)	1.40
Selenium egg-ovary FCV (mg/kg)	15.1

$$EF = \frac{C_{particulate}}{C_{water}}$$

$$EF = \frac{4.25}{5.00}$$

= 0.85 L/g

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite} \; x \; EF \; x \; CF}$$

$TTF^{composite} = TTF^{TL3} \times TTF^{TL2}$

= 1.57 × 1.65

= 2.59

$$C_{water} = \frac{15.1}{2.59 \times 0.85 \times 1.40}$$

= 4.90 µg/L

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1.5.5 Example 5

Flathead chub (*Platygobio gracilis*) in a river with a diet of approximately 80% aquatic insects and 20% algae:

Current water concentration (µg/L)	5.0
Current particulate concentration (mg/kg)	4.25
Trophic transfer factor of flathead chub: Lowest matching taxon is the family Cyprinidae. Therefore, the TTF value of Cyprinidae is used (TTF^{TL3})	1.20
Trophic transfer factor for insects (TTF^{TL2}) Average of all aquatic insects = 2.14	2.14
Egg-ovary to whole-body conversion factor for flathead chub (species-specific value not available, so median CF for family Cyprinidae is used). (CF)	1.95
Selenium egg-ovary FCV (mg/kg)	15.1

$$EF = \frac{C_{particulate}}{C_{water}}$$

$$EF = \frac{4.25}{5.00}$$

= 0.85 L/g

$$TTF^{composite} = [TTF^{TL3} \times TTF^{TL2} \times w_1] + [TTF^{TL3} \times w_2]$$

Where:
w_1 = Proportion of fathead chub diet from insects; and
w_2 = Proportion of fathead chub diet from algae

$$TTF^{comb} = [1.20 \times 2.14 \times 0.8] + [1.20 \times 0.2]$$
= 2.29

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite} \; x \; EF \; x \; CF}$$

$$C_{water} = \frac{15.1}{2.29 \times 0.85 \times 1.95}$$

= 3.98 µg/L

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1.5.6 Example 6

Largemouth bass (*Micropterus salmoides*) in a large river that consume mostly Western mosquitofish (*Gambusia affinis*) that consume approximately ¾ insects and ¼ crustaceans:

Current water concentration (µg/L)	5.0
Current particulate concentration (mg/kg)	4.25
Trophic transfer factor of largemouth bass (TTF^{TL4})	1.39
Trophic transfer factor of Western mosquitofish (TTF^{TL3})	1.21
Trophic transfer factor for insects and crustaceans (TTF^{TL2}) Median all Insects – 2.14 Median all Crustaceans – 1.41 $TTF^{TL2} = \sum_{i=1}^{n}\left(TTF_i^{TL2} w_i\right)$ = (2.14 x 0.75) + (1.41 x 0.25) = 1.96	1.96
Egg-ovary to whole-body conversion factor for largemouth bass (species-specific value not available, so median CF for genus Micropterus is used) (CF)	1.42
Selenium egg-ovary FCV (mg/kg)	15.1

$$EF = \frac{C_{particulate}}{C_{water}}$$

$$EF = \frac{4.25}{5.00}$$

= 0.85 L/g

$TTF^{composite} = TTF^{TL4} \times TTF^{TL3} \times TTF^{TL2}$
$= 1.39 \times 1.21 \times 1.96$
$= 3.30$

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite} \; x \; EF \; x \; CF}$$

$$C_{water} = \frac{15.1}{3.30 \times 0.85 \times 1.42}$$

= 3.79 µg/L

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2.0 TRANSLATING THE CONCENTRATION OF SELENIUM IN TISSUE TO A CONCENTRATION IN WATER USING BIOACCUMULATION FACTORS (BAF)

2.1 Summary of the BAF Approach

A bioaccumulation factor (BAF) is the ratio (in milligrams/kilogram per milligrams/liter, or liters per kilogram) of the concentration of a chemical in the tissue of an aquatic organism to the concentration of the chemical dissolved in ambient water at the site of sampling (U.S. EPA 2001c). BAFs are used to relate chemical concentrations in aquatic organisms to concentrations in the ambient media of aquatic ecosystems where both the organism and its food are exposed and the ratio does not change substantially over time. The BAF is expressed mathematically as:

$$BAF = \frac{C_{tissue}}{C_{water}} \qquad \textit{(Equation K-8)}$$

Where:

BAF	=	bioaccumulation factor derived from site-specific field-collected samples of tissue and water (L/kg)
C_{tissue}	=	concentration of chemical in fish tissue (mg/kg)
C_{water}	=	ambient concentration of chemical in water (mg/L)

The site-specific BAF can then be applied to the tissue criterion to solve for a target site-specific water column criterion (C_{target}):

$$C_{target} \times \frac{C_{egg-ovary\ criterion}}{BAF} \qquad \textit{(Equation K-9)}$$

Where:

C_{target}	=	site-specific water criterion concentration (mg/L)
$C_{egg\text{-}ovary\ criterion}$	=	national egg-ovary tissue criterion (15.1 mg Se/kg dw)
BAF	=	bioaccumulation factor derived from site-specific field-collected samples of tissue and water (L/kg)

To translate a fish tissue criterion to a water concentration value, a site-specific, field-measured BAF for the waterbody could be developed, and then a water concentration criterion could be calculated using Equation K-9. Detailed information about how to derive a site-specific, field-measured BAF is provided in *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000) Technical Support Document Volume 3: Development of Site-specific Bioaccumulation*

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Factors (U.S. EPA 2009). Although this guidance was developed for deriving human health criteria, the methodological approach is also applicable to the derivation of aquatic life criteria. The following example illustrates the calculation of a site specific water column criterion using the BAF approach.

2.1.1 Example: Derivation of a site specific water column criterion for a waterbody impacted by selenium

Available data for a hypothetical site indicate that the average egg/ovary tissue concentration of selenium for the bluegill (*Lepomis macrochirus*) is 22 mg/kg (dw). This concentration exceeds the USEPA proposed egg/ovary criterion of 15.1 mg/kg (dw). The ambient selenium water column concentration at that hypothetical site is 4.0 µg/L. The following calculation shows how to derive a target water column that would achieve a site-specific criterion using the bioaccumulation factor (BAF) approach.

Site specific selenium egg/ovary concentration (bluegill; mg/kg dw)	22.0
Selenium egg/ovary criterion (mg/kg, dw)	15.1
Ambient selenium water column concentration (µg/L)	4.0
Target water column concentration (µg/L)	X

Set up proportional equation to solve for allowable water column concentration:

$$\frac{Site\ specific\ egg/ovary\ conc.\ (\frac{mg\ Se}{kg\ dw})}{Site\ specific\ water\ concentration\ (\frac{\mu g\ Se}{L})} = \frac{Criterion\ egg\ ovary\ conc.\ (\frac{mg\ Se}{kg\ dw})}{Target\ water\ concentration\ (\frac{\mu g\ Se}{L})}$$

Solve for the target water concentration that will achieve a site-specific criterion:

$$\frac{22.0\ (\frac{mg\ Se}{kg\ dw})}{4.0\ (\frac{\mu g\ Se}{L})} = \frac{15.1\ (\frac{mg\ Se}{kg\ dw})}{Target\ water\ concentration\ (\frac{\mu g\ Se}{L})}$$

Target water concentration = 2.75 µg/L.

2.2 Managing Uncertainty using the BAF Approach

Uncertainty can be introduced when using the BAF approach to derive a water concentration value from a fish tissue criterion concentration. Inaccurate water concentration values can result when BAFs are derived from water and fish tissue concentration measurements that are obtained from sources that do not closely represent site characteristics, or from field data collected from large-scale sites that encompass multiple water bodies or ecosystems. Most of this uncertainty results from differences in the

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bioavailability of selenium between the study sites where measurements are made to derive the BAF, and the site(s) to which the BAF is used to derive needed water concentration values.

Because of uncertainties associated with the BAF approach, EPA does not recommend developing BAFs from data extrapolated from different sites or across large spatial scales. EPA's Framework for Metals Risk Assessment (U.S. EPA 2007) outlines key principles about metals and describes how they should be considered in conducting human health and ecological risk assessments due the the effects of water chemistry on bioavilability of such chemicals. The current science does not support the use of a single, generic threshold BAF value as an indicator of metal bioaccumulation. The use of BAFs are appropriate only for site-specific applications where sufficient measurements have been taken from the site of interest and there is little or no extrapolation of BAF values across differing exposure conditions and species.

The preferred approach for using a BAF to implement the selenium fish tissue criterion is to calculate a site-specific, field-measured BAF from data gathered at the site of interest, and to apply that BAF to that site. A site-specific, field-measured BAF is a direct measure of bioaccumulation in an aquatic system because the data are collected from the aquatic ecosystem itself and thus reflects real-world exposure through all relevant exposure routes. A site-specific, field-measured BAF also reflects biotic and abiotic factors that influence the bioavailability, biomagnification, metabolism, and biogeochemical cycling of selenium that might affect bioaccumulation in the aquatic organism or its food web. Appropriately developed site-specific, field-measured BAFs are appropriate for all bioaccumulative chemicals, regardless of the extent of chemical metabolism in biota from a site (U.S. EPA 2000).

Although a site-specific, field-measured BAF is a direct measure of bioaccumulation, its predictive power depends on a number of important factors being properly addressed in the design of the field sampling effort. For example, sampling in areas with relatively long water residence times should be a priority because selenium bioaccumulation occurs more readily in aquatic systems with longer residence times (such as wetlands, oxbows, and estuaries) and with fine particulate sediments high in organic carbon. In addition, migratory species should generally not be used because their exposure to selenium could reflect selenium concentrations in areas other than where the fish were caught. Fish may also need to be sampled and BAF values recalculated if selenium levels significantly change over time because BAFs are known to be affected by the ambient concentration of the metals in the aquatic environment (McGeer et al. 2003; Borgman et al. 2004; DeForest et al. 2007). States and tribes should refer to *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000) Technical Support Document Volume* (U.S. EPA 2009) for guidance on appropriate methods for developing a site-specific, field-derive BAF.

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The advantage of using the BAF approach is its relative simplicity, especially when the data necessary to derive the BAF is already available. Furthermore, the BAF approach is completely empirical and does not require any specific knowledge about the physical, chemical, or biological characteristics of the waterbody. The relationship between the concentration of selenium in fish tissue and water is directly determined by direct measurements in these media. This may be advantageous when there are uncertainties with how to collect a particulate sample that is representative of the base of the food web, or dilution concerns (e.g., sandy streams with little surface area for algae sampling and high potential for sand contamination of a benthic sediment sample).

Limitations of the BAF approach should be considered before deciding if this method is appropriate for translating the selenium FCV to a water concentration value. One disadvantage of the BAF approach is the considerable effort and resources necessary to collect sufficient data to establish the relationship between tissue and water concentrations. Resource use increases as the spatial scale and complexity of the aquatic system increases. Furthermore, the BAF approach does not allow extrapolation across species, space, and large time scales because the site-specific factors that might influence bioaccumulation are integrated within the tissue concentration measurements and thus cannot be individually adjusted to extrapolate to other conditions. Thus, site-specific, field-measured BAFs only provide an accounting of the uptake and accumulation of selenium for an organism at a specific site and point in time. This is more important in lotic habitats, since the kinetics of selenium bioaccumulation may be very different at a site upstream or downstream from the site of interest.

As noted previously, NPDES permitting regulations at 40 CFR § 122.45(c) require WQBELs for metals be expressed as total recoverable metal unless an exception is met under 40 CFR § 122.45(c)(1)-(3). Guidance for converting expression of metals in water from dissolved to total recoverable can be found in *Technical Support Document for Water Quality-based Toxics Control* (U.S. EPA 1991) and *The Metals Translator: Guidance for Calculating a Total Recoverable Permit Limit from a Dissolved Criterion* (U.S. EPA 1996). Whether or not a water concentration value derived from a site-specific, field-derived BAF requires conversion from dissolved to total recoverable selenium depends on how the BAF is developed. Generally, conversion would not be necessary if the BAF is derived from water concentration values that measure total selenium; however, conversion would be necessary if the BAF was derived from water concentration values that measured dissolved selenium. Table K-4 compares some of the principle characteristics of the mechanistic bioaccumulation modeling approach or the BAF approach for translating the selenium FCV to a water concentration.

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3.0 COMPARISON OF MECHANISTIC BIOACCUMULATION MODELING AND BAF APPROACHES

Data from Saiki et al. (1993) are used here to illustrate an example comparison of the two translation approaches, the mechanistic bioaccumulation modeling approach and the bioaccumulation factor (BAF) model approach. Definitive selenium measurements for all ecosystem compartments (e.g., water, algae, etc.) are available for two species, bluegill and largemouth bass, at four sites. Food web pathways were calculated using results of gut content analysis. Although Saiki et al. (1993) satisfies the minimum requirements for a site specific translation, it represents a sparse dataset, with only two measurements per ecosystem compartment, one for the spring and fall of 1987, respectively. For purposes of this exercise, samples from the same site collected at different time periods will be treated as replicate data; however, EPA recommends using larger sample sizes collected during the same time period when calculating a site specific criterion.

Selenium data used to calculate site specific water criteria are included in Table K-4. Median concentrations and coefficients of variation for each ecosystem compartment at each site are included in Table K-5. Because at most only two concentrations were available for each ecosystem, site median are equal to site averages. Site specific translations for both approaches will be calculated using median selenium concentrations.

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Table K-4. Selenium concentrations in ecosystem compartments for four sites described in Saiki et al. (1993).
Water concentrations expressed as µg/L, all other concentrations expressed as mg/kg dw.

Site	Date	Water	Algae	Detritus	Amphipod	Chironomid	Crayfish	Zooplankton	Bluegill	Largemouth Bass
Mud Slough at Gun Club Road	Fall 1987	3	7.40	22	4.6	8.9	5.2	2.4	6.4	6.8
Mud Slough at Gun Club Road	Spring 1987	9	1.60	7.9	3.3	7.2	4.4	5.4	5	6.9
Salt Slough at the San Luis National Wildlife Refuge	Fall 1987	3	0.38	8.9	3.4	5.4	3.1	4.5	4.5	4.7
Salt Slough at the San Luis National Wildlife Refuge	Spring 1987	13	2.40	7.9	3.7	6.9	3.2	4.4	4.3	4
San Joaquin R. above Hills Ferry Road	Fall 1987	3	1.20	6.6	3.8	6	1.7	2.6	3.3	2.2
San Joaquin R. above Hills Ferry Road	Spring 1987	11	1.30	3.4	2.8	4.1	1.9	4.3	2.7	2.4
San Joaquin R. at Durham Ferry State Recreation Area	Fall 1987	1	0.39	1.2	1.5	1.5	0.77	1.6	2	1.8
San Joaquin R. at Durham Ferry State Recreation Area	Spring 1987		0.50	1.3	1.1	1.6	1.3	1.8	1.9	1.7

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Table K-5. Median selenium concentrations in ecosystem compartments for four sites described in Saiki et al. (1993).
For purposes of this exercise, spring and fall samples measured at the same site are treated as replicates. Water concentrations expressed as µg/L, all other concentrations expressed as mg/kg dw. Coefficients of determination included in parentheses.

Site	Water	Algae	Detritus	Amphipod	Chironomid	Crayfish	Zooplankton	Bluegill	Largemouth Bass
Mud Slough at Gun Club Road	6.0 (0.71)	4.50 (0.91)	14.95 (0.67)	3.95 (0.23)	8.05 (0.15)	4.80 (0.12)	3.90 (0.54)	5.70 (0.17)	6.85 (0.01)
Salt Slough at the San Luis National Wildlife Refuge	8.0 (0.88)	1.39 (1.03)	8.40 (0.08)	3.55 (0.06)	6.15 (0.17)	3.15 (0.02)	4.45 (0.02)	4.40 (0.03)	4.35 (0.11)
San Joaquin R. above Hills Ferry Road	7.0 (0.81)	1.25 (0.06)	5.00 (0.45)	3.30 (0.21)	5.05 (0.27)	1.80 (0.08)	3.45 (0.35)	3.00 (0.14)	2.30 (0.06)
San Joaquin R. at Durham Ferry State Recreation Area	1.0 (na)	0.45 (0.17)	1.25 (0.06)	1.30 (0.22)	1.55 (0.05)	1.04 (0.36)	1.70 (0.08)	1.95 (0.04)	1.75 (0.04)

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3.1 Translation using the BAF Approach

Site specific BAFs were calculated for bluegill and largemouth bass at each of the four sites (Table K-6). A site-specific water criterion was calculated for each species at the four sites using equation K-8, which is equivalent to the BAF example shown in the previous section. The site specific criterion calculation for bluegill at site "Salt Slough at the San Luis National Wildlife Refuge" is included below as an example.

$$BAF = \frac{C_{tissue}}{C_{water}} = \frac{4.4\ \mu g/g}{8\ \mu g/L} = 0.55\ L/g$$

$$C_{water\ criterion} = \frac{C_{tissue\ criterion}}{BAF} = \frac{8.5\ mg/kg}{0.55\ L/g} = 15.5\ \mu g/L$$

The whole body tissue criterion of 8.5 mg/kg is used here because whole body fish tissue selenium measurements were made. If site specific egg ovary fish tissue had been measured, then the egg ovary tissue criterion of 15.1 mg/kg would have been used.

Table K-6. Site and species specific translated water concentrations using the BAF translation approach.

		Bluegill:			**Largemouth Bass:**		
Site	**Water (µg/L)**	**WB Se (mg/kg)**	**BAF (L/g)**	**Water SSC[a] (µg/L)**	**WB Se (mg/kg)**	**BAF (L/g)**	**Water SSC[a] (µg/L)**
Mud Slough at Gun Club Road	6.0	5.70	0.95	8.95	6.85	1.14	7.45
Salt Slough at the San Luis National Wildlife Refuge	8.0	4.40	0.55	15.45	4.35	0.54	15.63
San Joaquin R. above Hills Ferry Road	7.0	3.00	0.43	19.83	2.30	0.33	25.87
San Joaquin R. at Durham Ferry State Recreation Area	1.0	1.95	1.95	4.36	1.75	1.75	4.86

a – Site specific criterion based on BAF for respective species.

At each site, the lowest translated water criterion for all species is used as the site specific criterion. At site "Mud Slough at Gun Club Road," the site specific criterion is based on the translated concentration for largemouth bass, and at the other 3 sites, the site specific criterion is based on the translated concentration for bluegill. Site specific water concentrations calculated using the BAF approach range from 4.4 to 19.8 µg/L Table K-6).

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3.2 Translation using the Mechanistic Bioaccumulation Modeling Approach

The first step in the bioaccumulation modeling approach is the calculation of site specific enrichment factors (*EF*s). Because both algae and detritus selenium concentrations were available, the first step was the calculation of separate *EF*s for algae and detritus at each site, following the procedures described in section 1.2.4.1. Algal and detrital *EF*s, respectively, were calculated using the median of all Se concentrations in algae (or detritus) at a site by the median of all Se concentrations in water at the same site. After calculating separate algal and detrital *EF*s, the final *EF* at each site was calculated as the geometric mean of the algal and detrital *EF* at a given site. Algal, detrital, and site *EF*s are shown in Table K-7.

Table K-7. Se concentrations in water, algae, detritus, and site specific *EF*s.

Site	Water (µg/L)	Algae (mg/kg)	Detritus (mg/kg)	EF (L/g)
Mud Slough at Gun Club Road	6.0	4.50	14.95	1.37
Salt Slough at the San Luis National Wildlife Refuge	8.0	1.39	8.40	0.43
San Joaquin R. above Hills Ferry Road	7.0	1.25	5.00	0.36
San Joaquin R. at Durham Ferry State Recreation Area	1.0	0.45	1.25	0.75

As an example, the EF calculation for site "Salt Slough at the San Luis National Wildlife Refuge" is shown below.

$$EF_{algae} = \frac{C_{algae}}{water}\ ;\ EF_{detritus} = \frac{C_{detritus}}{water}$$

$$EF_{site} = \sqrt{\left(EF_{algae} \times EF_{detritus}\right)}$$

$$EF_{algae} = \frac{1.39\ mg/kg}{8.0\ \mu g/L};\ EF_{detritus} = \frac{8.4\ mg/kg}{8.0\ \mu g/L}$$

$$EF_{site} = \sqrt{(0.17 \times 1.05)}$$

$$EF_{site} = 0.43\ L/g$$

The second step in the bioaccumulation modeling approach is the calculation of site specific composite trophic transfer factors ($TTF^{composite}$). Based on gut content analysis, bluegill diets consisted of

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47% amphipods, 23% chironomids, and 30% zooplankton, while largemouth bass diets consisted of 73% bluegill and 27% crayfish.

The composite TTF for bluegill was calculated using the following equation:

$$TTF^{composite} = [TTF^{TL3} \times TTF^{TL2} \times w_1] + [TTF^{TL3} \times TTF^{TL2} \times w_2] + [TTF^{TL3} \times TTF^{TL2} \times w_3]$$

Where:

W_1 = proportion of diet from amphipods,

W_2 = proportion of diet from chironomids, and

W_3 = proportion of diet from zooplankton.

For each of the 3 species in the bluegill diet, site specific TTF^{TL3} and TTF^{TL2} were calculated separately. Using median concentrations from Table K-5, $TTF^{composite}$ were calculated for each of the sites and are included in Table K-8.

Table K-8. Trophic transfer factors (TTFs) for bluegill and bluegill prey.

	TL2 TTFs:			**TL3 TTFs:**			**$TTF^{composite}$:**
Site	**Amphipod**	**Chironomid**	**Zooplankton**	**BG-Amph**	**BG-Chiro**	**BG-Zoo**	**Bluegill**
Mud Slough at Gun Club Road	0.41	0.83	0.40	1.44	0.71	1.46	0.59
Salt Slough at the San Luis National Wildlife Refuge	0.73	1.26	0.91	1.24	0.72	0.99	0.90
San Joaquin R. above Hills Ferry Road	1.06	1.62	1.10	0.91	0.59	0.87	0.96
San Joaquin R. at Durham Ferry State Recreation Area	1.53	1.83	2.01	1.50	1.26	1.15	2.30

As an example, the bluegill $TTF^{composite}$ for site "Salt Slough at the San Luis National Wildlife Refuge" is shown below.

$$TTF^{composite} = [1.24 \times 0.73 \times 0.47] + [0.72 \times 1.26 \times 0.23] + [0.99 \times 0.91 \times 0.30]$$

$$TTF^{composite} = 0.90$$

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The composite TTF for largemouth bass was calculated using the following equation:

$$TTF^{composite} = [TTF^{TL4} \times TTF^{TL3} \times TTF^{TL2} \times w_1] + [TTF^{TL3} \times TTF^{TL2} \times w_2]$$

Where:

W_1 = proportion of diet from bluegill, and

W_2 = proportion of diet from crayfish

For the proportion of the largemouth bass diet consisting of bluegill, TTF^{TL3} x TTF^{TL2} was equal to the $TTF^{composite}$ for bluegill. As was the case for bluegill, site specific TTFs were calculated for each species, and are included in Table K-9.

Table K-9. Trophic transfer factors (TTFs) for largemouth bass and largemouth bass prey.

	Crayfish dietary fraction:		Bluegill dietary fraction:		$TTF^{composite}$:
Site	**Crayfish**	**LMB-Cray**	**Bluegill[a]**	**LMB-BG**	**LMB**
Mud Slough at Gun Club Road	0.49	1.43	0.59	0.70	0.49
Salt Slough at the San Luis National Wildlife Refuge	0.64	1.38	0.90	0.89	0.82
San Joaquin R. above Hills Ferry Road	0.58	1.28	0.96	0.74	0.71
San Joaquin R. at Durham Ferry State Recreation Area	1.22	1.69	2.30	2.06	4.03

a – $TTF^{composite}$ for bluegill.

As an example, the largemouth bass $TTF^{combined}$ for site "Salt Slough at the San Luis National Wildlife Refuge" is shown below.

$$TTF^{composite} = \left[TTF^{TL4} \times TTF_{bluegill}^{composite} \times w_1\right] + [TTF^{TL3} \times TTF^{TL2} \times w_2]$$

$$TTF^{composite} = [0.89 \times 0.90 \times 0.73] + [1.38 \times 0.64 \times 0.27]$$

$$TTF^{composite} = 0.82$$

After calculating site and species specific EF and $TTF^{combined}$, site specific water criterion concentrations were calculated using a modified version of equation K-1, shown below.

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$$C_{water\ criterion} = \frac{C_{tissue\ criterion}}{EF\ x\ TTF^{composite}}$$

The site specific criterion calculation for bluegill at site "Salt Slough at the San Luis National Wildlife Refuge" is included below as an example.

$$C_{water\ criterion} = \frac{8.5\ mg/kg}{0.43\ L/g\ x\ 0.90} = 22.1\ \mu g/L$$

Because the selenium in fish tissue at these sites were measured as whole body concentrations, the whole body criterion of 8.5 µg/L is used, and an egg-ovary to whole body conversion factor is not required. As with the BAF approach, the lowest translated water criterion for all species is used as the site specific criterion. At site "San Joaquin R. at Durham Ferry State Recreation Area," the site specific criterion is based on the translated concentration for largemouth bass, and at the other 3 sites, the site specific criterion is based on the translated concentration for bluegill. Site specific water concentrations calculated using the mechanistic bioaccumulation modeling approach are more variable than concentrations calculated using the BAF approach, and range from 2.8 to 33.3 µg/L Table K-10). At all sites using both methods, the translated site specific water concentration criteria were higher than the measured water concentrations.

Table K-10. Site and species specific translated water concentrations using the mechanistic bioaccumulation modeling approach.

		Bluegill:			Largemouth Bass:		
Site	**EF (L/g)**	**WB Se (mg/kg)**	**TTF**	**Water SSC (µg/L)**	**WB Se (mg/kg)**	**TTF**	**Water SSC (µg/L)**
Mud Slough at Gun Club Road	1.37	5.70	0.59	10.61	6.85	0.49	12.65
Salt Slough at the San Luis National Wildlife Refuge	0.43	4.40	0.90	22.14	4.35	0.82	24.18
San Joaquin R. above Hills Ferry Road	0.36	3.00	0.96	24.79	2.30	0.71	33.31
San Joaquin R. at Durham Ferry State Recreation Area	0.75	1.95	2.30	4.95	1.75	4.03	2.83

3.3 Summary Comparison of the Mechanistic Bioaccumulation and BAF Approaches

A comparison of the mechanistic bioaccumulation and BAF approaches is included in Table K-11.

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Table K-11. Comparison of mechanistic bioaccumulation and BAF approaches.

Mechanistic bioaccumulation modeling	Bioaccumulation Factor (BAF)
Knowledge of the aquatic system needed	No information on aquatic system needed
Choice of input parameters at discretion of state or tribe	No input parameters to choose
Species-specific	Species-specific
Can be applied at different sites if site *EF* can be estimated.	Site-specific
Fish tissue sampling not required for translation	Fish tissue and water sampling required

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APPENDIX L: ANALYTICAL METHODS FOR MEASURING SELENIUM

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The Clean Water Act (CWA) establishes an EPA approval process for certain analytical methods used in the National Pollutant Discharge Elimination System (NPDES) program and for section 401 certifications. EPA has several approved methods for measuring selenium in water under 40 CFR § 136. EPA generally requires the use of EPA-approved methods for the NPDES program and for CWA section 401 certifications issued by states and tribes (40 CFR § 136.1). However, since there are no EPA approved methods for the analysis of selenium in fish tissue, states and tribes may use analytical methods not approved by EPA to evaluate the attainment of water quality standards or to develop or implement Total Maximum Daily Loads provided that these methods are scientifically sound (40 CFR 122.21(g)(7)).

Implementation of a water quality standard for selenium may require the ability to detect and measure the concentration of selenium in effluent, ambient water, tissue, and other media that is below the detection limit or limit of quantitation that some analytical methods can provide. States and tribes should choose an analytical method that is sufficiently sensitive to implement its water quality standard for selenium. Below are descriptions of some of the methods available for measuring selenium concentrations with sufficient sensitivity to implement EPA's recommended selenium criterion. Complete descriptions of analytical methods appropriate for analyzing selenium in different media can be found in the National Environmental Methods Index at http://www.nemi.gov.

1.0 General Considerations when Measuring Concentrations of Selenium

The oxidation states of selenium dissolved in surface water are usually selenate (+6), selenite (+4), and organo-selenium (-2). The presence of selenium in different oxidation states complicates some analytical methods (Presser and Ohlendorf 1987). EPA recommends using standard reference samples to check for the percentage recovery of each species of selenium (selenate, selenite and organo-selenium) during initial testing of selenium methodologies for quality control and assurance.

If water samples are not filtered, particulate species such as elemental selenium and particulate organo-selenium will also be measured. In addition, federal regulations at 40 CFR §122.45(c) generally requires considering total recoverable metals when establishing effluent limits and reporting requirements.

2.0 Analytical Methods Recommended for Measuring Selenium in Water

EPA has several approved analytical methods under 40 CFR § 136 specifically for measuring total selenium in water. These regulations state that measurements for NPDES permit applications and permittee reporting should be made using analytical methods approved by EPA. Because EPA has

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approved methods for analyzing selenium in water, these methods must be used for NPDES permits (40 CFR § 122.21(g)(7), 122.41(j), 136.1, 136.3, and 136.6).

A complete list of EPA-approved analytical methods for selenium can be found at: http://www.epa.gov/waterscience/methods/method/. Three EPA-approved methods that may be sufficiently sensitive[4] for the purposes of implementing a selenium water quality criterion are listed below (Table L-1).

Table L-1. Suggested EPA-Approved Methods for Selenium in Water

Method	Technique	Method detection limit
American Public Health Standard Method 3114 B (2009) or 3114 C (2009)	Hydride generation atomic absorption spectrometry (HG-AAS)	2 µg/L
EPA Method 200.8, Rev 5.4 (1998)	Inductively coupled plasma mass spectrometry (ICP-MS)	7.9 µg/L
EPA Method 200.9, Rev.2.2 (1994)	Stabilized temperature graphite furnace atomic absorption (STGF-AA)	0.6 µg/L

2.1 American Public Health Standard Method 3114 B

For measuring selenium in water, American Public Health Standard Method 3114 B uses the HG-AAS technique. Method 3114 B has a method detection limit (MDL) of 2 µg/L. Samples for dissolved analytes should be filtered on-site through 0.45-micron capsule filters certified free of trace-element contamination or other appropriate filtering equipment (Wilde et al. 1999). Dissolved samples should be preserved with high purity hydrochloric acid or nitric acid to a pH less than 2.

For measuring total selenium, samples should not be filtered. In addition, all selenium in the sample should be in the form of selenite (+4). Thus, the following pre-treatment steps to convert all selenium in the sample to selenite are critical when using the HG-AAS method:

1. Boiling with persulfate to oxidize and digest organic material.
2. Boiling with hydrochloric acid to reduce selenate species to selenite.
3. Reduction by sodium borohydride to hydrogen selenide in the quartz tube of the AAS.

[4]For more information on choosing a sufficiently sensitive method, see the memorandum *Analytical Methods for Mercury in National Pollutant Discharge Elimination System (NPDES) Permits* from James A. Hanlon, Director of the Office of Wastewater Management, dated August 23, 2007, available at http://www.epa.gov/npdes/pubs/mercurymemo_analyticalmethods.pdf.

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Optimal conversion conditions are essential for accurate results because too mild a reduction could lead to incomplete reduction of selenate and too rigorous a reduction could lead to plating out of elemental selenium (Cutter 1987, 1983; Presser and Barnes 1984, 1985).

Method 3114 B has the advantage that it is a fully validated method, is commonly used by many laboratories, is relatively inexpensive, is less susceptible to background interference (Cutter 1987, 1983; Presser and Barnes 1984, 1985), and has sufficient sensitivity to accurately measure what can be expected in many lotic aquatic systems. However, this method may not be sufficiently sensitive for some lentic aquatic systems where relatively lower selenium concentrations may need to be measured. If no selenium is detected in a lentic system using this method, EPA recommends using a more sensitive analytical method.

2.2 EPA Method 200.8

EPA method 200.8 has a MDL of 7.9 µg/L using the ICP-MS analytical technique. This method has the advantage that no pre-treatment steps are necessary. However, this method may not be sufficiently sensitive in many applications of the selenium criterion (Lamothe et al. 1999). If no selenium is detected using this method, EPA recommends monitoring with a more sensitive method.

2.3 EPA Method 200.9

Method 200.9 has a MDL of 0.6 µg/L using the STGF-AA analytical technique. This method has the advantage that it can detect selenium at very low concentrations. However, graphite furnace techniques require careful matrix matching.

Of these three EPA approved methods, Method 3114B using the HG-AAS technique is the most cost-effective, with sufficient sensitivity and relatively low risk of interference in most cases. EPA Method 200.8 may be used where appropriate, such as when selenium concentrations in effluent are known to be higher than 7.9 µg/L. EPA Method 200.9 may be used if a very low MDL is needed. Some additional methods not approved by EPA that states and tribes might consider are:

- Collision/Reaction Cell Inductively Coupled Plasma Mass Spectroscopy (cICP-MS) (Garbarino et al. 2005) - A relatively new technique that is a sensitive and selective detector for metal analysis. However, isobaric interference can cause problems for quantitative determination as well as identification based on the analyte pattern. Collision cells, reaction cells or other interfaces reducing sample matrix effects that might otherwise interfere in the mass selective determinative step are allowed in CWA analyses provided the method performance specifications relevant to ICP-MS measurements are met

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- Fluorometric Analysis - a wet chemistry technique using diaminonapthalene. This method also achieves acceptable precision and accuracy on standard reference samples (Olson 1969; Olson et al. 1975; American Public Health Association Standard Method 3500, on-line version).

Methods for measuring different species of selenium dissolved in water are also available. These methods determine the species of dissolved selenium present in a sample through differential digestion and hydride generation atomic adsorption spectrophotometry (Cutter 1978, 1983; Presser and Barnes, 1984; 1985; May et al. 2007). Selenite can be measured in samples with no pre-treatment. Selenate plus selenite can be measured in samples subjected to boiling with hydrochloric acid. Subtraction of the measured selenite fraction from the measured combined fraction would yield a measure of the selenate fraction. If a sample is analyzed to measure total dissolved selenium as described above, then measurements of the combined fraction can be subtracted to yield measurements of the dissolved organo-selenium fraction.

3.0 ANALYTICAL METHODS AVAILABLE FOR MEASURING SELENIUM IN FISH TISSUE

EPA does not have approved methods under 40 CFR § 136 for measuring selenium in fish tissue. However, states and tribes are not required to use EPA-approved methods for monitoring and assessment of criteria attainment or other activities not related to permit applications or reports.

The techniques described above for analyzing selenium in water (HG-AAS, ICP-MS, and STGF-AA) can be used to measure selenium in fish tissue if the samples are made soluble. Tissue samples are homogenized and digested prior to analysis using strong acid or dry-ashing digestion as described below. A review of sample digestion techniques has been published (Ihnat 1992). Standard reference materials, analytical duplicates, and matrix spike samples are recommended to determine the applicability of a selected digestion procedure.

3.1 Strong acid digestion

Solid samples can be subjected to strong acid digestion to break down mineral and organic matrices. Samples are typically dried and homogenized before digestion. Determination of percent moisture may be part of the drying procedure. Note that some strong acid digestion methods may not be suitable for fish tissue. Strong acid digestion methods are categorized by the type of material or amount of organic material present (e.g., solid waste; biological tissue, plants, soil, sediment, rock, coal) and degrees of tissue solubilization needed (extraction, leachate, or complete destruction). Methods differ in acid mixture and degree and type of heating (EPA Method 3050B, Revision 2, 1996; EPA Method 200.2,

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Revision 2.8, 1994; Briggs and Crock, 1986; Taggart, 2002, chapters I, J, and K). High boiling acids (perchloric and sulfuric) may lead to a loss of selenium if solutions are heated to dryness.

3.2 Dry-ashing digestion

Dry-ashing digestion is applicable to biological samples (Brumbaugh and Walther, 1989; May et al., 2007). Biological samples are normally lyophilized (freeze-dried) and homogenized before digestion. Determination of percent moisture may be part of the drying procedure. Dried solid samples are:

1. Boiled in nitric acid for solubilization and oxidation
2. Ashed at 500º C with magnesium nitrate to complete oxidation and decompose remaining organic material
3. Heated with hydrochloric acid to dissolve the ash and reduce selenium to the selenite (+4) state required for detection by HG-AAS.

3.3 Analytical methods available for measuring selenium in particulate material

There are no 40 CFR § 136 methods for analyzing selenium in particulate material. However, states and tribes are not required to use EPA-approved methods for monitoring and assessment of criteria attainment or other activities not related to permit applications or reports.

The techniques described above for analyzing selenium in water (HG-AAS, ICP-MS, and STGF-AA) can be used to measure selenium in particulate material after the sample has been separated from the water and pre-treated using the same methods used for fish tissue. In order to obtain a particulate material sample, a water column sample should be filtered to separate the particulate material and bed sediment. Various techniques for collection of suspended particulate material using filtration are available from the EPA (e.g. Method 1669) and the U.S. Geological Survey (Moulton et al. 2002; USGS, Britton and Greeson 1987). These techniques include:

- EPA Method 1669 (1996) includes filtration through a 0.45 µm capsule filter at the field site.
- USGS protocols for collection of phytoplankton and seston in rivers and streams as part of their National Water Quality Assessment Program for watershed and habitat assessment (http://water.usgs.gov/nawqa/protocols.html).
- Textbooks such as *Limnological Analyses* address sampling of lakes using traditional techniques including phytoplankton nets. (Wetzel and Likens 1991).
- Sampling of suspended material from estuaries where particulates are a substantial part of the ecosystem is described in Doblin et al. (2005) as part of their work on the San Francisco Bay-Delta Estuary.
- Separating suspended sediment using high-speed centrifugation and decantation when the concentration of particulate material is relatively low (Horowitz et al. 1989).

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APPENDIX M: ABBREVIATIONS

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REFERENCE AND SITE ABBREVIATIONS

Reference	Site		Species	
Bi:	22	Miller's Lake, Wellington CO	FM	Fathead minnow
Birkner 1978	27	Sweitzer Lake, Delta CO	FM	Fathead minnow
	23	Twin Buttes Reservoir, Laramie WY	FM	Fathead minnow
	20	East Allen Reservoir, Medicine Bow WY	ID	Iowa darter
	7	Galett Lake, Laramie WY	ID	Iowa darter
	22	Miller's Lake, Wellington CO	ID	Iowa darter
	23	Twin Buttes Reservoir, Laramie WY	ID	Iowa darter
	30	Larimer Highway 9 Pond, Fort Collins CO	NPK	Northern plains killfish
	3	Meeboer Lake, Laramie WY	NPK	Northern plains killfish
	27	Sweitzer Lake, Delta CO	NPK	Northern plains killfish
	23	Twin Buttes Reservoir, Laramie WY	NPK	Northern plains killfish
Bu91:	4	Uncompahgre River at Colona	BhS	Bluehead sucker
Butler et al. 1991	4	Uncompahgre River at Colona	BnT	Brown trout
	4	Uncompahgre River at Colona	FS	Flannelmouth sucker
	4	Uncompahgre River at Colona	MS	Mottled sculpin
	4	Uncompahgre River at Colona	RT	Rainbow trout
	4	Uncompahgre River at Colona	WS	White sucker
Bu93:	SP2	Spring Creek at La Boca	BhS	Bluehead sucker
Butler et al. 1993	N2	Navajo Reservoir, Piedra R. Arm, near La Boca	BT	Brown trout
	SP2	Spring Creek at La Boca	BT	Brown trout
	N2	Navajo Reservoir, Piedra R. Arm, near La Boca	BB	Black bullhead
	N2	Navajo Reservoir, Piedra R. Arm, near La Boca	ChC	Channel catfish
	N2	Navajo Reservoir, Piedra R. Arm, near La Boca	CC	Common carp

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Reference	Site		Species	
	SP2	Spring Creek at La Boca	FM	Fathead minnow
	SP2	Spring Creek at La Boca	SD	Speckled dace
	SP2	Spring Creek at La Boca	WS	White sucker
Bu95:	ME2	McElmo Cr., downstream from Alkali Canyon	BhS	Bluehead sucker
Butler et al. 1995	ME3	McElmo Cr., upstream from Yellow Jacket Canyon	BhS	Bluehead sucker
	NW	Navajo Wash near Towaoc	BhS	Bluehead sucker
	SJ1	San Juan R. at Four Corners	BhS	Bluehead sucker
	SJ3	San Juan R. at Mexican Hat Utah	BhS	Bluehead sucker
	ME3	McElmo Cr., upstream from Yellow Jacket Canyon	BB	Black bullhead
	SJ1	San Juan R. at Four Corners	ChC	Channel catfish
	SJ3	San Juan R. at Mexican Hat Utah	ChC	Channel catfish
	ME4	McElmo Cr., downstream from Yellow Jacket Canyon	CC	Common carp
	ME3	McElmo Cr., upstream from Yellow Jacket Canyon	CC	Common carp
	SJ1	San Juan R. at Four Corners	CC	Common carp
	SJ3	San Juan R. at Mexican Hat Utah	CC	Common carp
	HD2	Hartman Draw near mouth, at Cortez	FM	Fathead minnow
	ME1	McElmo Cr. at Hwy. 160, near Cortez	FM	Fathead minnow
	ME2	McElmo Cr., downstream from Alkali Canyon	FM	Fathead minnow
	ME4	McElmo Cr., downstream from Yellow Jacket Canyon	FM	Fathead minnow
	ME3	McElmo Cr., upstream from Yellow Jacket Canyon	FM	Fathead minnow
	WC	Woods Canyon near Yellow Jacket	FM	Fathead minnow
	SJ1	San Juan R. at Four Corners	FS	Flannelmouth sucker
	HD2	Hartman Draw near mouth, at Cortez	FS	Flannelmouth sucker
	ME2	McElmo Cr., downstream from Alkali Canyon	FS	Flannelmouth sucker
	ME4	McElmo Cr., downstream from Yellow Jacket Canyon	FS	Flannelmouth sucker
	ME3	McElmo Cr., upstream from Yellow Jacket Canyon	FS	Flannelmouth sucker
	SJ3	San Juan R. at Mexican Hat Utah	FS	Flannelmouth sucker
	ME3	McElmo Cr., upstream from Yellow Jacket Canyon	GnS	Green sunfish
	ME4	McElmo Cr., downstream from Yellow Jacket Canyon	RSh	Red shiner
	ME3	McElmo Cr., upstream from Yellow Jacket Canyon	RSh	Red shiner

Reference	Site		Species	
	SJ1	San Juan R. at Four Corners	RSh	Red shiner
	ME1	McElmo Cr. at Hwy. 160, near Cortez	SD	Speckled dace
	ME2	McElmo Cr., downstream from Alkali Canyon	SD	Speckled dace
	ME3	McElmo Cr., upstream from Yellow Jacket Canyon	SD	Speckled dace
	NW	Navajo Wash near Towaoc	SD	Speckled dace
	SJ1	San Juan R. at Four Corners	SD	Speckled dace
	HD2	Hartman Draw near mouth, at Cortez	Su	Sucker
Bu97:	MUD2	Mud Cr. at Hwy. 32, near Cortez	BhS	Bluehead sucker
Butler et al. 1997	MNP2	Large pond south of G Road, southern Mancos Valley	FM	Fathead minnow
	MUD2	Mud Cr. at Hwy. 32, near Cortez	FM	Fathead minnow
	WCP	Pond on Woods Canyon at 15 Road	FM	Fathead minnow
	CH1	Cahone Canyon at Hwy. 666	GnS	Green sunfish
	MUD2	Mud Cr. at Hwy. 32, near Cortez	GnS	Green sunfish
	MNP3	Pond downstream from site MNP2, southern Mancos Valley	SB	Smallmouth bass
Ca:	DC	Deerlick Creek	RT	Rainbow trout
Casey **2005**	LC	Luscar Creek	RT	Rainbow trout
Fo:	CC-1A	Crow Creek – 1A	BnT	Brown trout
Formation 2012	CC-3A	Crow Creek – 3A	BnT	Brown trout
	CC-150	Crow Creek – 150	BnT	Brown trout
	CC-350	Crow Creek – 350	BnT	Brown trout
	CC-75	Crow Creek – 75	BnT	Brown trout
	DC	Deer Creek	BnT	Brown trout
	HS	Hoopes Spring	BnT	Brown trout
	HS-3	Hoopes Spring – 3	BnT	Brown trout
	LSV-2C	Sage Creek – 2C	BnT	Brown trout
	LSV-4	Sage Creek – 4	BnT	Brown trout
	SFTC	South Fork Tincup Creek	BnT	Brown trout

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Reference	Site		Species	
	CC-1A	Crow Creek – 1A	Sc	Sculpin
	CC-3A	Crow Creek – 3A	Sc	Sculpin
	CC-150	Crow Creek – 150	Sc	Sculpin
	CC-350	Crow Creek – 350	Sc	Sculpin
	CC-75	Crow Creek – 75	Sc	Sculpin
	DC	Deer Creek	Sc	Sculpin
	HS	Hoopes Spring	Sc	Sculpin
	HS-3	Hoopes Spring – 3	Sc	Sculpin
	LSV-2C	Sage Creek – 2C	Sc	Sculpin
	LSV-4	Sage Creek – 4	Sc	Sculpin
	SFTC	South Fork Tincup Creek	Sc	Sculpin
Gr:	17	Arapahoe Wetlands Pond	FM	Fathead minnow
Grasso et al. 1995	17	Arapahoe Wetlands Pond	WS	White sucker
HB:	LEMC	Lower East Mill Creek	CT	Cutthroat trout
Hamilton and				
Buhl 2004				
Le:	BA	Badin Lake	BB	Black bullhead
Lemly 1985	BE	Belews Lake	BB	Black bullhead
	HR	High Rock Lake	BB	Black bullhead
	BA	Badin Lake	CC	Common carp
	BE	Belews Lake	CC	Common carp
	HR	High Rock Lake	CC	Common carp
	BA	Badin Lake	FM	Fathead minnow
	BE	Belews Lake	FM	Fathead minnow
	HR	High Rock Lake	FM	Fathead minnow
	BA	Badin Lake	GnS	Green sunfish
	BE	Belews Lake	GnS	Green sunfish
	HR	High Rock Lake	GnS	Green sunfish

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Reference	Site		Species	
	BA	Badin Lake	WM	Western mosquitofish
	BE	Belews Lake	WM	Western mosquitofish
	HR	High Rock Lake	WM	Western mosquitofish
	BA	Badin Lake	RSh	Red shiner
	BE	Belews Lake	RSh	Red shiner
	HR	High Rock Lake	RSh	Red shiner
Sa87:	KP11	Kesterson Pond 11	WM	Western mosquitofish
Saiki and	KP2	Kesterson Pond 2	WM	Western mosquitofish
Lowe 1987	KP8	Kesterson Pond 8	WM	Western mosquitofish
	SLD	San Luis Drain	WM	Western mosquitofish
	VP26	Volta Pond 26	WM	Western mosquitofish
	VW	Volta Wasteway	WM	Western mosquitofish
Sa93:	GT4	Salt Slough at San Luis Wildlife Refuge	Bg	Bluegill
Saiki et al. 1993	GT5	Mud Slough at San Luis Wildlife Refuge	Bg	Bluegill
	SJR2	San Joaquin R. above Hills Ferry Rd.	Bg	Bluegill
	SJR3	San Joaquin R. at Durham Ferry Recreation Area	Bg	Bluegill
	GT4	Salt Slough at San Luis Wildlife Refuge	LMB	Largemouth bass
	GT5	Mud Slough at San Luis Wildlife Refuge	LMB	Largemouth bass
	SJR2	San Joaquin R. above Hills Ferry Rd.	LMB	Largemouth bass
	SJR3	San Joaquin R. at Durham Ferry Recreation Area	LMB	Largemouth bass
	GT4	Salt Slough at San Luis Wildlife Refuge	WM	Western mosquitofish
	GT5	Mud Slough at San Luis Wildlife Refuge	WM	Western mosquitofish
	SJR2	San Joaquin R. above Hills Ferry Rd.	WM	Western mosquitofish
	SJR3	San Joaquin R. at Durham Ferry Recreation Area	WM	Western mosquitofish
St:	M4720	Marsh 4720	BB	Black bullhead
Stephens et al. 1988	M4720	Marsh 4720	CC	Common carp

APPENDIX N: COMPARISON OF APPROACHES FOR CALCULATING SELENIUM TISSUE CONVERSION FACTORS

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1.0 COMPARISON OF THE MEDIAN RATIO AND REGRESSION APPROACHES

Regression analysis and the application of median ratios are two approaches that can be used to quantify the relationship between two variables, such as the concentration of selenium within two tissue types. When concentrations in the two tissues are plotted, each point represents the ratio of one tissue type to another. A regression analysis calculates the line that best fits those tissue concentrations, which is characterized by both a slope and a y-intercept. In contrast, the median ratio is a single value representing the 50^{th} centile of all ratios. Conversion factors (CFs) are presently calculated as the median ratio of two tissue types. The use of median ratios grew out of the goal of patterning the translation procedure after the Luoma and Presser selenium bioaccumulation model, where field derived factors representing the transfer of selenium from one ecosystem compartment to another were represented as single values calculated using constrained (y-intercept passes through the origin) regression. Median ratios were implemented to produce a single value that was operationally similar to a constrained regression slope, but that was free from the issues associated with constrained regression, particularly cases where the y-intercept was notably different from zero, which would result in slopes that were highly divergent from slopes derived using conventional regression. Both median ratios and conventional regression (with or without log transformation) are far superior to constrained (no y-intercept) regression. The following discussion will compare median ratios and conventional linear regression.

A median is a measure of central tendency that is free from all parametric assumptions associated with linear regression. As the 50^{th} centile of all y/x ratios, it is independent of the effects of outliers or the overall distribution of ratios. As implemented in the criterion document, median ratios were assumed to be representative of the linear relationship between the concentration in tissue y to the concentration in tissue x. This assumption was tested with a pre-screening procedure using conventional linear regression. If the regression model had a positive slope and was statistically significant at $P<0.05$, then the relationship was assumed to be positive and linear, and a median ratio was used as representative of that linear relationship.

A log-log regression includes both a slope and a y-intercept. Because they apply to log space, these parameters mean something different than similar parameters in arithmetic space. Linear relationships in log space translate back to power functions in arithmetic space. That is, the log space straight line function:

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$$\log(EO) = m \cdot \log(WB) + b \qquad (1)$$

translates to:

$$EO = a \cdot WB^{m} \qquad (2)$$

where the coefficient $a=10^{b}$. The log-log plot intercept b represents the value of log EO when WB=1 mg/kg (that is when log(WB)=0).

The key point when comparing log-log regression to the median ratio approach is that when log-log slope m=1, then Equation 2 reduces to a simple direct proportion EO = a·WB in arithmetic space**.** Figure N-1 illustrates the behavior of CF (that is, the ratio EO/WB), depending on whether the log-log slope m of the plot of log(EO) versus log(WB) has a value 1, >1, or <1.

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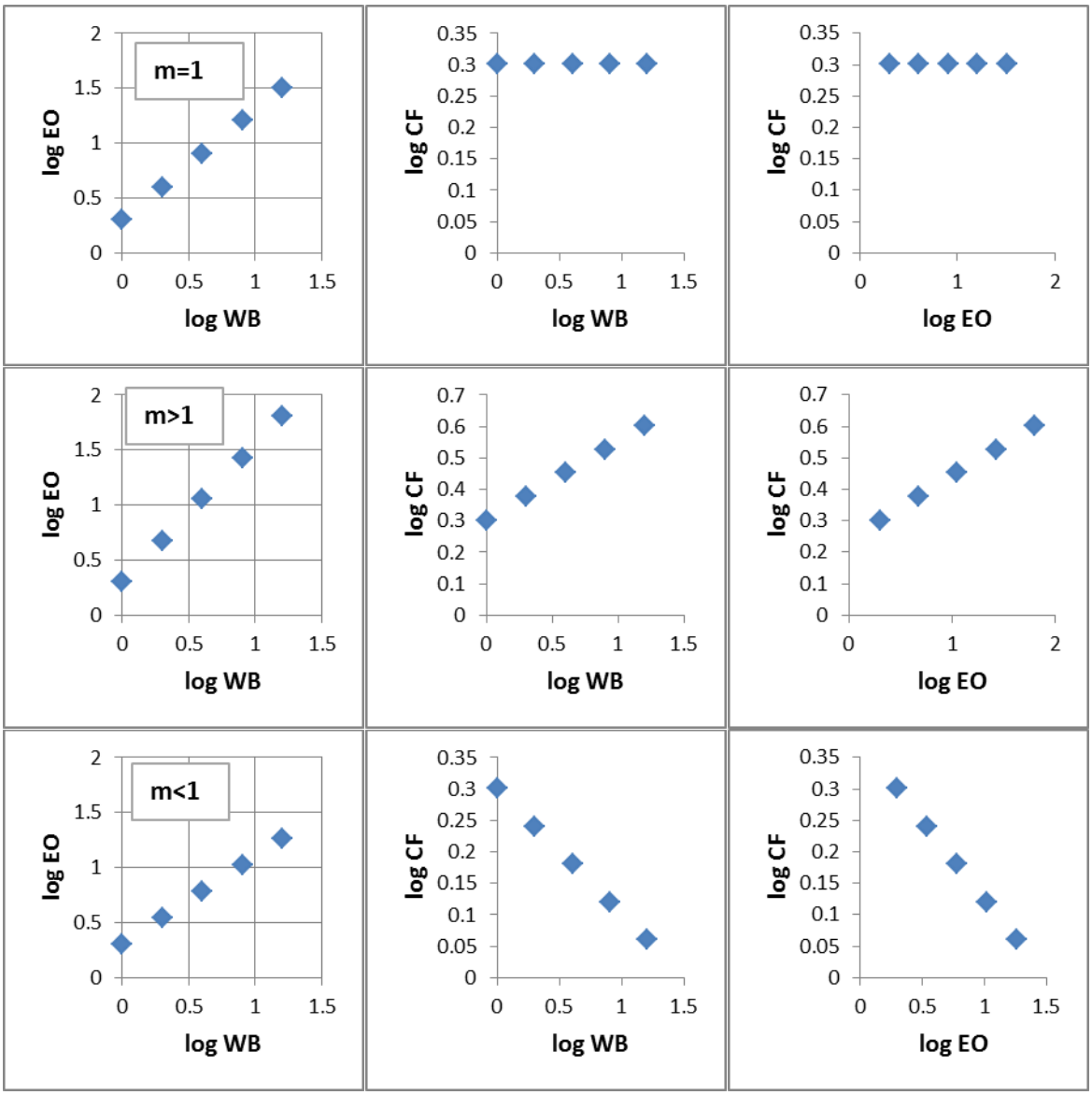


Figure N-1. Idealized illustration (sans scatter) of the effect of log-log slope, m, on whether CF is stable, increases, or decreases with concentration (whether measured as WB in column 2 or EO in column 3).

Top row: m=1. Second row: m=1.25. Bottom row: m=0.8. In all cases, CF=EO/WB, but the three rows were not designed to yield the same median CF. Were the five idealized data points replaced by a large number of well-behaved real-world data points, the straight lines would tend to be replaced by oval clouds of points having the illustrated slopes.

When the log-log slope m≈1, CF does not change with concentration. In that case, CF is the simple proportionality constant as assumed in all previous versions of the criterion document. When m is noticeably different from 1, CF changes with concentration, and we would solve for its value at the EO criterion concentration. If the EO criterion concentration is not near the median EO value in the graphed data, then the regression-calculated CF value may differ somewhat from the median CF.

While both a median ratio and a linear regression account for all of the plotted values within a particular relationship, the regression model is derived from the specific locations of every data point, whereas the median is derived independent of the specific distribution of the data points. In this way, a regression contains more information about the entire data distribution, and as such, is more affected by deviations from linearity. This second point can be an advantage or a disadvantage, depending on the data distribution. For some CF relationships in the database, there is evidence of slight non-proportionality, in which the y/x ratios at higher concentrations are different than the y/x ratios at lower concentrations. In these instances, a log transformation of the tissue concentrations will serve to better linearize the overall relationship, so that the resulting regression model will better capture the y/x relationship across the full concentration range. The median ratio of these models will be the same regardless of whether or not the data are transformed. However, because the use of median ratios is based on the assumption of proportionality, CFs calculated using regression of log transformed values will provide slightly more accurate representations of the relationship across the full concentration range than a median ratio, for those datasets that show some evidence of non-proportionality. An exception would be a case where the midpoint of the data distribution, where the median ratio is more likely to be located, is similar to the criterion concentration. In these instances the median ratio would be expected to be similar the regression based CF regardless of slope. Finally, for those datasets that do not show this effect, selection of either the median ratio or the regression based CF approach are both equally valid approaches.

Another source of uncertainty can occur for species with a CF derived from a narrow concentration range that does not encompass the criterion concentration. In these instances, the slope of the regression model may not be representative of the slope had there been concentrations bracketing the criterion. Similarly, the median of the concentration ratios within this small range may not be representative of the median ratio if there had been concentrations bracketing the criterion. However, it may be preferable, or "safer", to use a non-parametric median rather than the result of an extrapolated regression equation, particularly when the regression is based on few data points (no matter how good r^2 is).

To conclude, CFs calculated from median ratios have the advantages of simplicity, being easier to explain and implement, and they are "safer" in the sense that they are not affected by outliers or the distribution of variance across the data range. CFs calculated from log regression include more

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information about the entire data distribution, but can be sensitive to outliers. CFs calculated from the two approaches can diverge in cases where the data range does not encompass the criterion concentration, particularly in cases those where the log transformed slope is also much greater or less than one. Overall, the median ratio and log regression approaches generate similar CFs for this dataset, and have little effect on the translated water criterion elements.

In general, as indicated by the idealized data in Exhibit A, the median and the TLS regression-predicted CF will be similar under either of the following conditions: (a) log-log EO/WB slope near 1.0, or (b) criterion near the middle of the observed data range of tissue concentrations for the species. They are likely to differ from each other when both of the following conditions simultaneously occur: (c) log-log slope distant from 1.0, and (d) criterion distant from the center of the data range.

2.0 COMPARISON OF THE ORDINARY LEAST SQUARES AND TOTAL LEAST SQUARES REGRESSION APPROACHES

The calculation of conversion factors using linear regression following log transformation addresses the issues associated with non-proportional relationships between Se in different tissues, and is the approach recommended by several public commenters. Conventional ordinary least squares (OLS) regression results can vary depending on which tissue type is assigned to the x and y axis, respectively. This is because OLS regression assumes that the variable on the y axis is dependent on the variable on the x axis, and the resulting regression is the line that minimizes the sum of the squared distances between observed y-values and predicted y-values. OLS regression assumes that the values on the x-axis have no uncertainty. For datasets such as the paired tissue concentrations used to calculate CF, there is no dependency between the selenium concentrations in one tissue type to another tissue type, and concentrations in both tissue types are equally uncertain. Because of this, we could assign either tissue type to either axis, and the resulting CF would be slightly different. By convention, we assign egg-ovary to the y-axis when comparing it to whole-body or muscle, and we assign muscle to the y-axis when comparing it to whole-body, because these are the ratios used in the translation equations. While CFs using median ratios are not affected by axis assignment, CFs using OLS are, for reasons described above.

An alternative regression approach that corrects this issue is total least squares (TLS) regression. TLS regression is preferable to OLS regression in cases where there is error associated with each of the variables, and there is no dependency of one variable on the other. With TLS, the regression is the line that minimizes the sum of the squared distances between observed predicted x- and y-values, and produced the same result regardless of which variable is assigned to which axis. Curves drawn by eye tend to mimic TLS, not OLS. Without thinking about it, the person drawing the line naturally attempts to

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minimize both vertical and horizontal errors. However, a significant disadvantage of TLS regression is that Excel has no built-in function to perform it, and many readers will be unfamiliar with it.

Table N-1 shows the effect of the different calculation procedures (median ratio, log OLS regression - xyOLS, log OLS regression with reversed axes - yxOLS, and log TLS regression) on all directly measured CFs. Median ratio CFs tend to diverge from regression based CFs for datasets where log-log slopes are markedly different than 1 and the criterion is not near the center of the observed concentrations. CFs calculated from TLS regression nearly always fall between CFs calculated from OLS regression with and without the axes reversed, and are not affected by axis order.

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	Directly calculated conversion factors for each tissue ratio, by method											
	EO/WB				M/WB				EO/M			
Species	Ratio	xyOLS	yxOLS	TLS	Ratio	xyOLS	yxOLS	TLS	Ratio	xyOLS	yxOLS	TLS
bluegill	2.13	1.90	2.04	1.98	1.32	1.36	1.37	1.36	1.38	1.11	1.24	1.18
bluehead sucker	1.82	1.41	1.50	1.45	1.23	1.70	1.67	1.59	1.48	0.82	0.91	0.85
brook trout									1.09	0.96		0.99
brown trout	1.45	1.53	1.77	1.74								
common carp	1.92	1.62	1.63	1.62	1.61	1.36	1.41	1.45	1.14	1.06	1.18	1.14
creek chub	1.99	2.05	2.01	2.03								
cutthroat trout	1.96	1.37	1.67	1.48					1.81	1.97	1.83	1.89
desert pupfish	1.20	1.14	1.14	1.14								
dolly varden									1.26	1.64	1.52	1.59
fathead minnow	1.40	1.71	1.56	1.64								
flannelmouth sucker	1.41	1.14	1.84	1.49	1.46	1.94	1.89	1.85	1.08	0.51	1.06	0.69
green sunfish	1.45	1.35	1.45	1.40	1.23	1.28	1.32	1.24	1.21	1.08	1.17	1.12
mountain whitefish									5.80	10.47	4.98	7.35
northern pike									1.88	1.65	1.78	1.70
rainbow trout									1.92	1.82	1.88	1.82
razorback sucker									2.31	1.93	1.89	1.90
roundtail chub	2.07	2.22	2.26	2.24	1.05	1.08	1.10	1.05	2.04	1.99	2.10	2.06
smallmouth bass	1.42	1.31	1.68	1.52	1.23	1.88	1.97	1.68	1.19	0.67	0.88	0.72
white sturgeon									1.33	0.97	1.07	1.01
white sucker	1.38	1.02	1.25	1.12	1.34	1.43	1.54	1.45	1.00	0.59	0.84	0.67

Table N-1. Comparison of all directly calculated conversion factors by method.
Methods include median ratio (Ratio), log ordinary least squares (xyOLS), log ordinary least squares with axes reversed (yxOLS), and log total least squares (logTLS). Regression based CFs were calculated at the egg ovary criterion concentration of 15.1 mg/kg. Muscle to whole body (M/WB) CFs were calculated at the muscle concentration at the egg-ovary criterion.

The following examples illustrate the differences between OLS and TLS regressions, and the effect of axis assignment on CF.

2.1 Example 1 – Flannelmouth Sucker (Egg-ovary/Whole-body)

CF by approach: (1.41 –median ratio, 1.13 – log OLS, 1.86 – log OLS with reversed axes, 1.48 – log TLS)

Model comparison 1a - Regression model results and calculation of CF (Egg-ovary y-axis; Whole-body x-axis):

OLS: log (Egg-ovary) = (0.7966 x (log Whole-body)) + 0.2857

log (Whole-Body) = (log (16 mg/kg) – 0.2857)/0.7966 = 1.153

CF at egg-ovary criterion = 10^((log Egg-ovary) – (log Whole-body)) = 1.13

TLS: log (Egg-ovary) = (0.9877 x (log Whole-body)) + 0.1843

log (Whole-Body) = (log (16 mg/kg) – 0.1843)/0.9877 = 1.033

CF at egg-ovary criterion = 10^((log Egg-ovary) – (log Whole-body)) = 1.48

In Figure N-2, the fitted regression lines do not appear particularly divergent; however, these points cover a relatively narrow (and low), concentration range. At the criterion concentration (log E/O = 1.204), the predictions lines are more divergent, resulting in the differences between the CFs. Also, note that the TLS slope is close to 1. The resulting TLS-derived CF is similar to the median ratio CF (1.48 vs 1.41). In contrast, the OLS slope is lower than 1, resulting in a CF for the OLS model that is notably different than the median ratio CF (1.13 vs 1.41).

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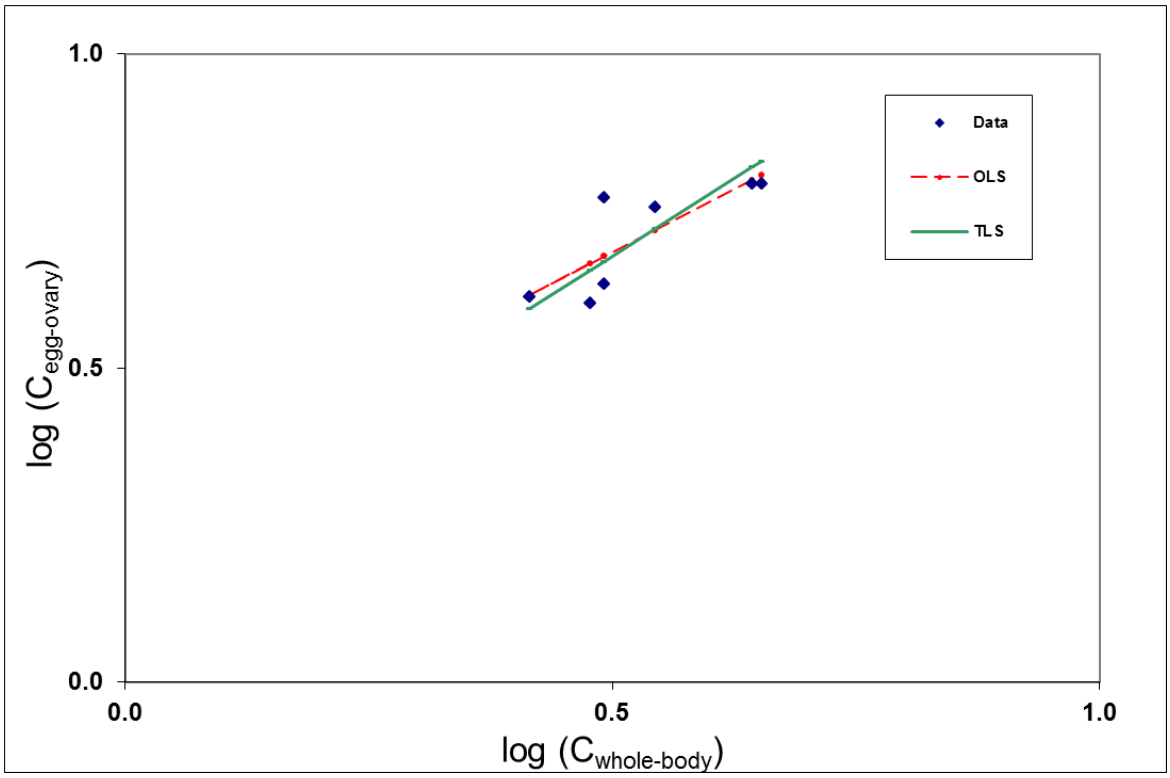


Figure N-2. OLS vs. TLS regression model fits for flannelmouth sucker.
Egg-ovary concentrations are on the y-axis and whole-body concentrations are on the x-axis.

Model comparison 1b - Regression model results and calculation of CF (Egg-ovary x-axis; Whole-body y-axis):

OLS: log(Whole-body) = (0.8126 x (log Egg-ovary)) - 0.0450 = 0.9335

CF at egg-ovary criterion = 10^((log Egg-ovary) – (log Whole-body)) = 1.86

TLS: log(Whole-body) = (1.012 x (log Egg-ovary)) - 0.1866 =1.033

CF at egg-ovary criterion = 10^((log Egg-ovary) – (log Whole-body)) = 1.48

At first glance, Figure N-3 appears very similar to Figure N-2. However, note that the axes are reversed, and because we are now solving for y (whole body concentration at egg-ovary criterion concentration), the shallower slope of the reverse OLS figure results a whole body concentration at the egg-ovary criterion lower than in the upper figures, which in turn results in a larger CF. Also, note that the TLS model is a mirror image of the model in Figure N-3, and as such has the same calculated CF. As above, the TLS slope is close to 1, with a TLS-derived CF that is similar to the median ratio CF (1.48 vs 1.41). In contrast, the OLS slope is lower than 1, resulting in an OLS-derived CF that is notably different than the median ratio CF (1.86 vs 1.41).

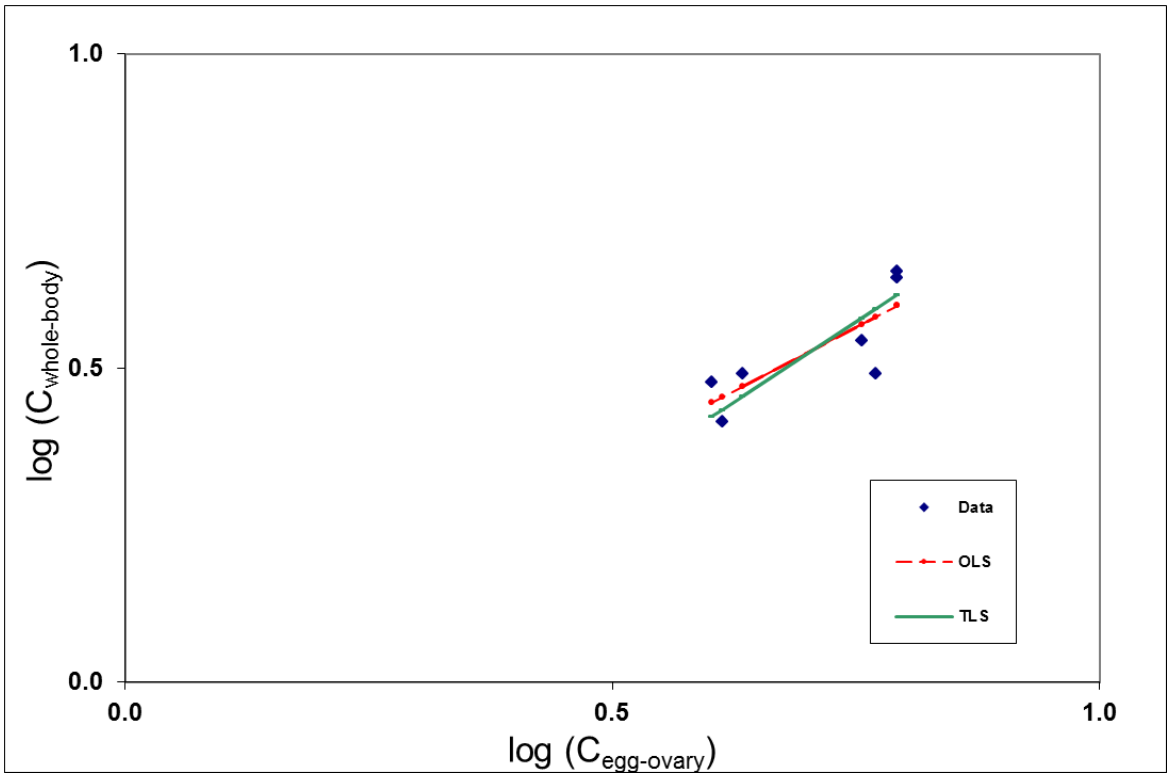


Figure N-3. OLS vs. TLS regression model fits for flannelmouth sucker.
Egg-ovary concentrations are on the x-axis and whole-body concentrations are on the y-axis.

2.2 Example 2 – Bluegill (Egg-ovary/Whole-body)

CF by approach: (2.13 –median ratio, 1.90 – log OLS, 2.07 – log OLS with reversed axes, 2.01 – log TLS)

Model comparison 2a - Regression model results and calculation of CF (Egg-ovary y-axis; Whole-body x-axis):

OLS: log(Egg-ovary) = (1.061 x (log Whole-body)) + 0.2227

log (Whole-Body) = (log (16 mg/kg) – 0.2227)/1.061 = 0.9250

CF at egg-ovary criterion = 10^((log Egg-ovary) – (log Whole-body)) = 1.90

TLS: log(Egg-ovary) = (1.240 x (log Whole-body)) + 0.0.0861

log (Whole-Body) = (log (16 mg/kg) – 0.0861)/1.240 = 0.9018

CF at egg-ovary criterion = 10^((log Egg-ovary) – (log Whole-body)) = 2.01

Compared to the OLS regression line, the slope of the TLS regression line is slightly steeper, resulting in a slightly larger calculated CF (Figure N-4). Even though the slopes are larger than 1, the data range encompasses the criterion concentration, which is close to the middle of the data distribution. As a result, the regression based CFs are similar overall to the median ratio CF.

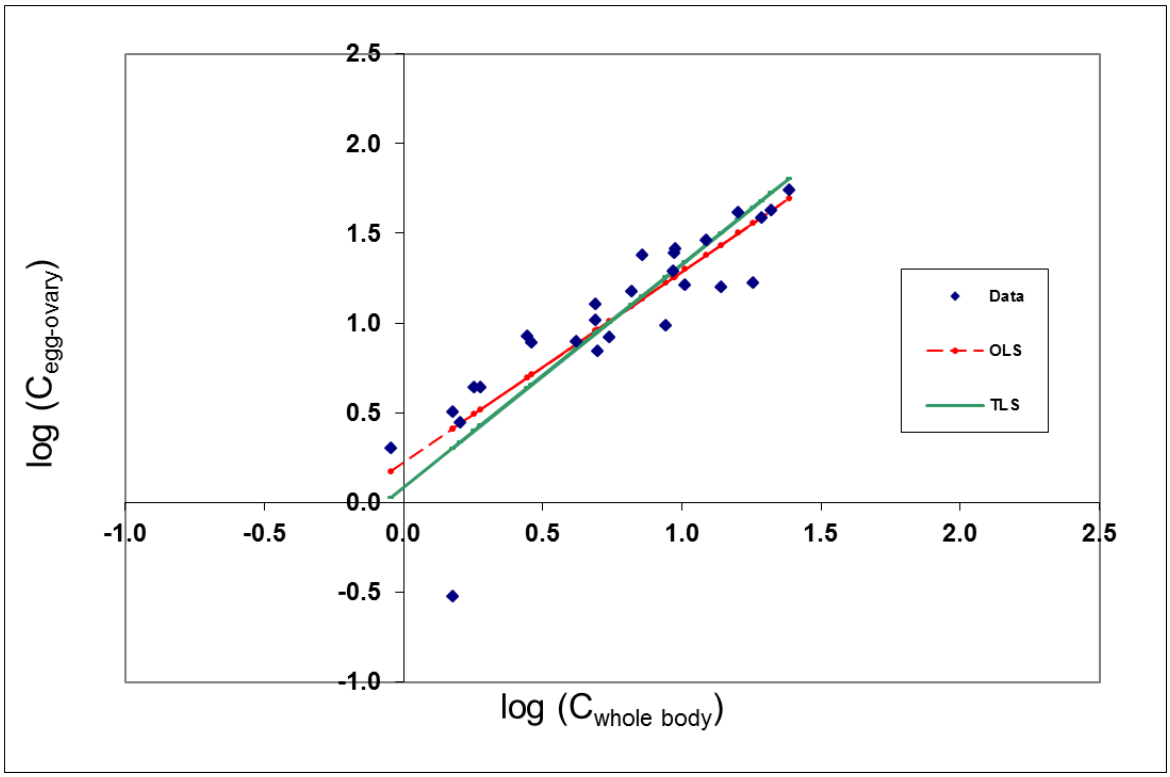


Figure N-4. OLS vs. TLS regression model fits for bluegill. Egg-ovary concentrations are on the y-axis and whole-body concentrations are on the x-axis.

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Model comparison 2b - Regression model results and calculation of CF (Egg-ovary x-axis; Whole-body y-axis):

OLS: log(Whole-body) = (0.7269 x (log Egg-ovary)) + 0.0129 = 0.8883

CF at egg-ovary criterion = 10^((log Egg-ovary) – (log Whole-body)) = 2.07

TLS: log(Whole-body) = (0.8066 x (log Egg-ovary)) - 0.0695 =0.9018

CF at egg-ovary criterion = 10^((log Egg-ovary) – (log Whole-body)) = 2.01

Compared to the OLS regression line, the slope of the TLS regression line is slightly steeper, resulting in a slightly smaller calculated CF (Figure N-5). Even though the slopes are less than 1, the data range encompasses the criterion concentration, which is also close to the middle of the data distribution. As a result, the regression based CFs are similar overall to the median ratio CF.

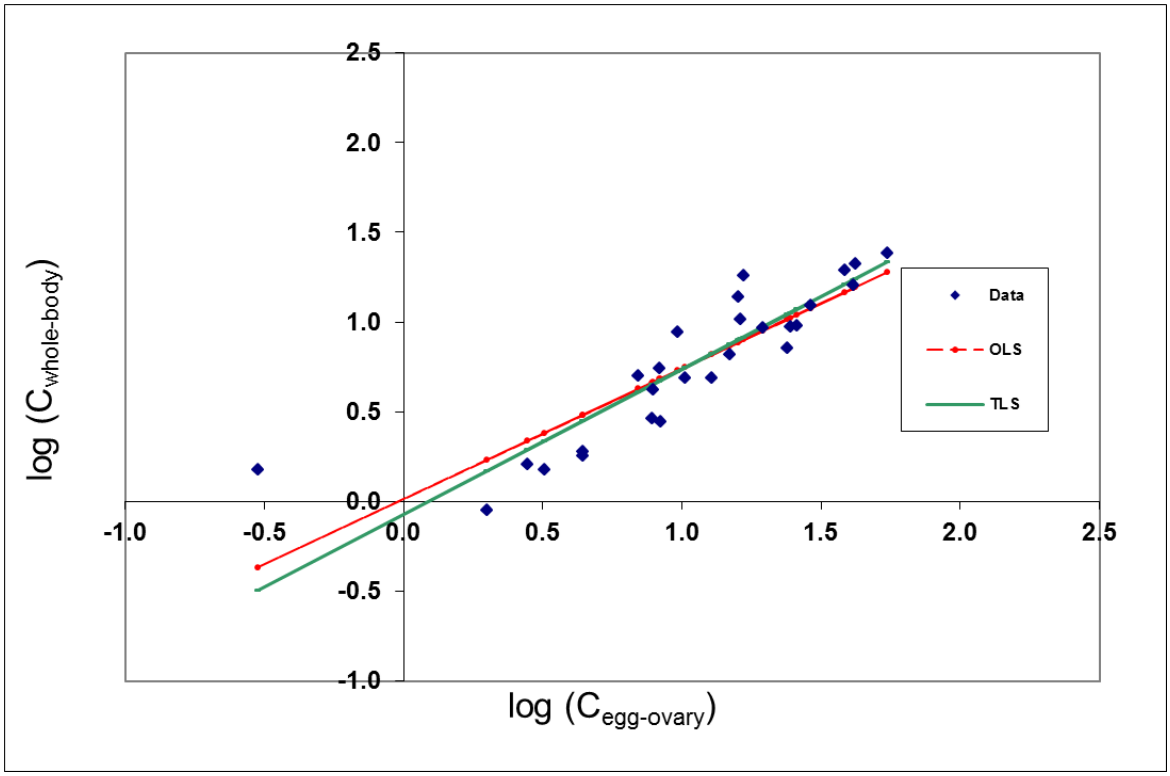


Figure N-5. OLS vs. TLS regression model fits for bluegill.
Egg-ovary concentrations are on the x-axis and whole-body concentrations are on the y-axis.

The effect of the CFs calculated by the different approaches has a minor effect on the final translated water criterion elements. Compared to the median ratio method, translated water criterion element concentrations are slightly higher using CFs calculated from the log OLS regression methods, CFs calculated from the reverse axis log OLS are slightly lower. Lentic translated water criterion element

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concentrations are the same using CFs from median ratios and log TLS regression methods, while lotic concentrations calculated from log TLS CFs are slightly lower compared to those calculated using median ratio CFs (**Table N-2**).

Table N-2. Translated water concentration criterion element criterion concentrations by CF calculation method.

Method	Lentic (µg/L)	Lotic (µg/L)
Median Ratio	1.5	3.1
log OLS regression	1.6	3.3
inverse log OLS regression	1.4	2.9
log TLS regression	1.5	2.9

3.0 COMPARISON OF MEDIAN- AND REGRESSION-BASED CONVERSION FACTORS TO CALCULATE CHRONIC VALUES FOR MUSCLE AND WHOLE BODY TISSUES

Besides being used in the translation of the egg-ovary (EO) tissue criterion to water, conversion factors (CF) were also used to convert egg-ovary (EO) chronic values (CV) to muscle or whole body tissue concentrations. These conversions were done when the data from a reproductive toxicity study did not have muscle or whole body selenium concentrations or if the latter tissue data was not usable to determine a chronic value. Directly calculated CVs using either muscle or whole body selenium measurements from a study was preferred over converted CVs in the determination of the final chronic value (= criterion).

Table N-3 provides a comparison of median-based and regression-based CFs when they are used to convert an EO selenium concentration to muscle or whole body. Regression-based CFs used total least squares (TLS) regression for the reasons stated above. The table lists each taxon in the reproductive toxicity data set and presents CVs that are either directly calculated or converted from the EO CV using either the median or TLS CF. Generally, the median-based and TLS-based CFs were similar for both tissue types and this similarity resulted in similar criteria (bottom row). The muscle criterion for the data set that contained directly calculated CVs and converted CVs was similar whether median or TLS CFs were used, 11.3 and 10.6, respectively. The whole body criterion was also similar using these two approaches, 8.5 and 9.6, respectively. The median-based CFs were selected based on reasons stated in the previous section.

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Table N-3. Comparison of muscle and whole body chronic values when calculated directly and converted from egg-ovary concentrations using median- and TLS regression-based conversion factors.

Taxon	EO CV	Muscle chronic values (CV) and conversion factors (CF)						Whole body chronic values (CV) and conversion factors (CF)					
		Direct + Median	Direct + TLS	Median CF	Median CV	TLS CF	TLS CV	Direct + Median	Direct + TLS	Median CF	Median CV	TLS CF	TLS CV
Salvelinus	56.22	44.48	35.36	1.26	44.48	1.59	35.36	34.92	24.34	1.61	34.92	2.31	24.34
Esox	34	21.70[d]	21.70[d]	1.88	18.13	1.70	20.00	14.23	13.77	2.39	14.23	2.47	13.77
Cyprinodon	27	28.72	34.18	0.94	28.72	0.79	34.18	22.50	23.68	1.20	22.50	1.14	23.68
O. mykiss	24.5	12.79	13.46	1.92	12.79	1.82	13.46	10.04	9.28	2.44	10.04	2.64	9.28
O. clarkii, Rudolph	24.7	16.6[d]	16.6[d]	1.81	13.65	1.89	13.07	12.60	16.69	1.96	12.60	1.48	16.69
O. clarkii, Nautilus	27.7	15.30	14.66	1.81	15.30	1.89	14.66	14.13	18.72	1.96	14.13	1.48	18.72
Oncorhynchus	25.31	14.28	14.49	NA	13.59	NA	13.65	11.58	12.81	NA	11.58	NA	12.81
Micropterus	26.3	22.16	36.53	1.19	22.16	0.72	36.53	18.52	17.30	1.42	18.52	1.52	17.30
L. macrochirus, Coyle	26.3	19.13	22.29	1.38	NA	1.18	NA	8.6[d]	8.6[d]	NA	NA	NA	NA
L. macrochirus, Doroshov	22.6	15.7[d]	15.7[d]	NA	NA	NA	NA	10.61	11.41	2.13	NA	1.98	11.41
L. macrochirus, Hermanutz	14.7	13.4[d]	13.4[d]	NA	NA	NA	NA	10.6[d]	10.6[d]	NA	NA	NA	NA
Lepomis	20.60	15.91	16.74	1.38	14.98	1.18	17.45	9.890	10.13	2.13	9.656	1.98	10.40
Salmo	21	18.50	17.50	1.14	18.50	1.20	17.50	13.2[d]	13.2[d]	1.45	14.48	1.74	12.07
Acipenser	15.6	11.9[d]	11.9[d]	1.33	11.73	1.01	15.45	9.209	10.68	1.69	9.209	1.46	10.68
Criterion	**15.10**	**11.34**	**11.57**	NA	**10.99**	NA	**13.35**	**8.538**	**9.567**	NA	**8.189**	NA	**9.879**

[d] directly calculated from muscle or whole body selenium concentrations

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United States Environmental Protection Agency

Office of Water
EPA 820-R-24-001
April 2024

Technical Support for Adopting and Implementing the EPA's 2016 Selenium Criterion in Water Quality Standards

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Technical Support for Adopting and Implementing the EPA's 2016 Selenium Criterion in Water Quality Standards

While this document cites statutes and regulations that contain requirements applicable to water quality standards, it does not impose legally binding requirements on the EPA, states, authorized Tribes, other regulatory authorities, or the regulated community, and may not apply to a particular situation based upon the circumstances. The EPA, state, Tribal and other decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from those provided in this technical support document as appropriate and consistent with statutory and regulatory requirements. The EPA may update this document as new information becomes available. In addition to this document, the EPA has related documents that provide considerations and recommendations on implementing criteria based on the national Clean Water Act (CWA) section 304(a) recommended selenium criterion for freshwater, which are available at the EPA's selenium website: https://www.epa.gov/wqc/aquatic-life-criterion-selenium.

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List of Acronyms and Abbreviations

BAF	Bioaccumulation factor
CFR	Code of Federal Regulations
CWA	Clean Water Act
FR	Federal Register
GLI	Great Lakes Initiative
HAC	Highest attainable condition
NPDES	National Pollutant Discharge Elimination System
SSD	Species sensitivity distribution
TMDL	Total maximum daily load
UAA	Use attainability analysis
USEPA	U.S. Environmental Protection Agency
WQBELs	Water quality-based effluent limits
WQC	Water quality criteria
WQS	Water quality standards

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Definitions[1]

Bioaccumulation
The uptake and retention of a chemical by an aquatic organism from all surrounding media (e.g., water, food, sediment).[2]

Critical species
In the context of the recalculation procedure, a resident species that (a) is commercially or recreationally important at the site, or (b) is listed as threatened or endangered under section 4 of the Endangered Species Act, or (c) is a species for which there is firm evidence that its loss would yield an unacceptable impact on the site's commercially or recreationally important species, endangered species, abundances of a variety of other species, or structure or function.[3]

Dissolved total selenium
All species of selenium that are dissolved into the water column and that would be measured in a water sample after it has been passed through a 0.45 µm membrane filter.[4]

Performance-based approach
A water quality standard that is a transparent process, rather than a specific outcome (such as the concentration portion of a criterion for a pollutant). This process or methodology is sufficiently detailed and has suitable safeguards that ensure predictable, repeatable outcomes. Approval of this process or methodology by the EPA would also serve for CWA purposes as the approval under CWA section 303(c)[5] of each outcome generated from following that process or method.[6]

Site-specific criterion/site-specific criterion element
Water quality criterion/criterion element that is modified to reflect site-specific conditions. For selenium, a criterion/criterion element that is developed to protect aquatic life at a particular

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[1] This glossary is meant to provide plain language definitions for key terms used in this document. Individuals should consult the Clean Water Act and the EPA's implementing regulations to identify whether there are legal definitions of these terms.
[2] USEPA. 2003. *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000) Volume 2: Development of National Bioaccumulation Factors.* EPA-882-R-03-030. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://nepis.epa.gov/Exe/ZyPDF.cgi/P1005EZQ.PDF?Dockey=P1005EZQ.PDF.
[3] USEPA. 2013. *Revised Deletion Process for the Site-Specific Recalculation Procedure for Aquatic Life Criteria*. EPA 823-R-13-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC, www.epa.gov/sites/production/files/2015-08/documents/revised_deletion_process_for_the_site-specific_recalculation_procedure_for_aquatic_life_criteria.pdf.
[4] Protho, M.G. USEPA. 1993. Memorandum: Office of Water Policy and Technical Guidance on Interpretation and Implementation of Aquatic Life Metals Criteria. Office of Water, Washington DC. https://www.epa.gov/sites/production/files/2019-03/documents/metals-criteria-interpret-aqlife-memo.pdf.
[5] Approval by the EPA includes federal WQS promulgated by the EPA.
[6] *EPA Review and Approval of State and Tribal Water Quality Standards*, 65 Fed. Reg. 24641 (Apr. 27, 2000).

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site, usually by taking into account a site's physical, chemical, and/or biological conditions (i.e., water quality characteristics or species composition).[7]

Steady-state

An organism is in steady-state when the rates of chemical uptake and depuration are equal and tissue concentrations remain constant over time.[8] For the purposes of the national CWA section 304(a) recommended selenium criterion, steady-state refers to conditions where sufficient time has passed after the introduction of a new or increased input of selenium into a waterbody or watershed of a waterbody such that fish tissue selenium concentrations are no longer increasing.

Water quality criterion element

A magnitude, frequency, and duration for a particular media type (e.g., fish tissue, water column), which are individual components of the overall water quality criterion. The water quality criterion elements for selenium are related through a hierarchy, with fish tissue criterion elements having primacy over water column criterion elements, and the egg-ovary fish tissue criterion element having primacy over all other criterion elements.

[7] USEPA. 2017. *Water Quality Standards Handbook. Chapter 3: Water Quality Criteria.* EPA-823-B-17-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/sites/default/files/2014-10/documents/handbook-chapter3.pdf.

[8] USEPA. 2003. *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000) Volume 2: Development of National Bioaccumulation Factors.* EPA-882-R-03-030. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://nepis.epa.gov/Exe/ZyPDF.cgi/P1005EZQ.PDF?Dockey=P1005EZQ.PDF.

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1.0 Introduction

1.1 The EPA's National CWA Section 304(a) Recommended Chronic Aquatic Life Selenium Criterion in Freshwater

In 2016, the U.S. Environmental Protection Agency updated its national Clean Water Act (CWA) section 304(a) recommended chronic aquatic life criterion for selenium in freshwater systems to reflect the latest scientific information and, in 2021, issued an erratum, *2021 Revision to: Final Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016*.[9] The EPA's national CWA section 304(a) recommended selenium criterion still reflects the latest science and the EPA is not aware of any updated scientific information that would change this recommendation. The latest scientific information indicates that selenium toxicity to aquatic life is driven by dietary exposures and that the reproductive life-stages of egg-laying vertebrates are the most sensitive to the toxic effects of selenium. The recommended criterion has four criterion elements: (1) a fish egg-ovary criterion element; (2) a fish whole-body and/or muscle criterion element; (3) a water column criterion element (one value for lentic and one value for lotic aquatic systems); and (4) a water column intermittent criterion element (to account for potential chronic effects from short-term exposures to high concentrations in lentic and lotic aquatic systems) (see Table 1). Under the EPA's 2016 national CWA section 304(a) recommended selenium criterion, the fish tissue criterion elements have primacy over water column elements, except where there are no fish, where fish tissue data are not adequate, or for waterbodies with new or increased discharges where selenium concentrations in fish tissue might not have stabilized and reached steady-state. The EPA also recommends that the egg-ovary tissue criterion element has primacy over whole-body and muscle tissue criterion elements.

Toxicity data indicate that the selenium concentration in fish eggs and ovaries is the most robust and consistent measurement endpoint directly tied to adverse reproductive effects in aquatic organisms. Toxicity to developing embryos and larvae is directly linked to egg selenium concentration.[10] The EPA derived the whole-body, muscle tissue, and water column elements from the egg-ovary element so that states and authorized Tribes could more readily implement their water quality criteria (WQC) based on the EPA's national CWA section 304(a)

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[9] In 2021, the EPA identified that the following text was missing from the second sentence in footnote 4 in the selenium criterion table: "When selenium inputs are increasing" and issued an erratum. The EPA corrected footnote 4 to state: "4. Water column values are based on dissolved total selenium in water and are derived from fish tissue values via bioaccumulation modeling. When selenium inputs are increasing, water column values are the applicable criterion element in the absence of steady-state condition fish tissue data." USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016.* EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

[10] USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016.* EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

recommended selenium criterion. The assessment of the available data on chronic selenium exposure for fish, invertebrates, and amphibians indicates that a criterion element derived from fish is expected to be protective of the aquatic community in a waterbody, since other taxa appear to be less sensitive to selenium than fish. The EPA did not develop an acute criterion for selenium when it updated the chronic criterion. Although selenium may cause acute toxicity at high concentrations, the most deleterious effects on aquatic organisms are due to selenium's bioaccumulative properties.

In the case of bioaccumulative compounds like selenium, acute toxicity studies do not address risks that result from chronic exposure to chemicals via the diet (through the food web pathway). Such studies also do not account for the accumulation kinetics of many bioaccumulative compounds, such as selenium, and may underestimate effects from long-term accumulation in some types of aquatic systems. Therefore, since acute studies do not address the primary exposure pathway for organisms to selenium and because chronic toxicity occurs at lower concentrations, an acute criterion was not included in the national CWA section 304(a) recommended selenium criterion. As described in the EPA's *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016* (hereafter referred to as *Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016*), the EPA also included an intermittent exposure criterion element to provide protection from the most significant chronic effects of selenium toxicity, reproductive toxicity, by protecting against selenium bioaccumulation in the aquatic ecosystem resulting from short-term, high concentration exposure events.[11]

The EPA recommends, as stated in the *Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016*, that states and authorized Tribes[12] adopt into their water quality standards (WQS) a selenium criterion that includes all four criterion elements.[13] For more information see the EPA's *Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016,* which can be found at https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

[11] USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016.* EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

[12] Throughout this document and in the CWA, the term "states" means the fifty states, the District of Columbia, the Commonwealth of Puerto Rico, the United States Virgin Islands, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands. The term "authorized Tribe" means those federally recognized Indian Tribes with authority to administer a CWA WQS program.

[13] USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016.* EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

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Table 1. Summary of the Recommended Freshwater Selenium Ambient Chronic Water Quality Criterion for Protection of Aquatic Life.

Media Type	Fish Tissue[1]		Water Column[4]	
Criterion Element	**Egg-ovary[2]**	**Fish Whole-body or Muscle[3]**	**Monthly Average Exposure**	**Intermittent Exposure[5]**
Magnitude	15.1 mg/kg dry weight	8.5 mg/kg dry weight whole-body or 11.3 mg/kg dry weight muscle (skinless, boneless fillet)	1.5 µg/L in lentic aquatic systems 3.1 µg/L in lotic aquatic systems	$WQC_{int} = \frac{WQC_{30-day} - C_{bkgrnd}(1 - f_{int}}{f_{int}}$
Duration	Instantaneous measurement[6]	Instantaneous measurement[6]	30 days	Number of days/month with an elevated concentration
Frequency	Not to be exceeded	Not to be exceeded	Not more than once in three years on average	Not more than once in three years on average

1. Fish tissue elements are expressed as steady-state.
2. Egg-ovary supersedes any whole-body, muscle, or water column element when fish egg-ovary concentrations are measured, except as noted in footnote 4 below.
3. Fish whole-body or muscle tissue supersedes water column element when both fish tissue and water concentrations are measured, except as noted in footnote 4 below.
4. Water column values are based on dissolved total selenium in water and are derived from fish tissue values via bioaccumulation modeling. When selenium inputs are increasing, water column values are the applicable criterion element in the absence of steady-state condition fish tissue data.
5. Where $WQC_{30\text{-}day}$ is the water column monthly element for either lentic or lotic waters; C_{bkgrnd} is the average background selenium concentration; and f_{int} is the fraction of any 30-day period during which elevated selenium concentrations occur, with f_{int} assigned a value ≥0.033 (corresponding to 1 day).
6. Fish tissue data provide instantaneous point measurements that reflect integrative accumulation of selenium over time and space in fish population(s) at a given site.

1.2 Selenium Technical Support Materials

The EPA has prepared a four-volume set of documents to provide recommendations to states, authorized Tribes, and other agencies for implementing their WQC based on the national CWA section 304(a) recommended selenium criterion for aquatic life.[14] These four documents constitute the Technical Support Materials for the EPA's *Aquatic Life Ambient Water Quality*

[14] USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016.* EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

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Criterion for Selenium–Freshwater 2016.[15] Each document of the set focuses on a specific aspect of implementation of WQC based on the national CWA section 304(a) recommended selenium criterion. Together, these four EPA documents provide information to assist states and authorized Tribes with adopting WQC based on the EPA's national CWA section 304(a) recommended selenium criterion and implementing them in various CWA programs.

1) *Technical Support for Adopting and Implementing the EPA's Selenium 2016 Criterion in Water Quality Standards*: Provides recommendations for the adoption and implementation of criteria based on the national CWA section 304(a) recommended selenium criterion, including the various flexibilities available to states and authorized Tribes using WQS tools.
2) *Technical Support for Fish Tissue Monitoring for Implementing the EPA's 2016 Selenium Criterion*: Provides an overview of how to establish or enhance existing fish tissue monitoring programs to facilitate implementation of fish tissue criterion elements based on the national CWA section 304(a) recommended selenium criterion.
3) *Frequently Asked Questions: Implementing Water Quality Standards Based on the EPA's 2016 Selenium Criterion in Clean Water Act Section 402 National Pollutant Discharge Elimination System Permits*: Provides information to help National Pollutant Discharge Elimination System (NPDES) permit writers understand what permitting guidance (i.e., state or tribal implementation procedures) may be appropriate to implement state and authorized tribal WQS based on the EPA's national CWA section 304(a) recommended selenium criterion. This set of FAQs also provides recommendations on how to establish water quality-based effluent limits (WQBELs) in NPDES permits.
4) *Frequently Asked Questions: Implementing the EPA's 2016 Selenium Criterion in Clean Water Act Sections 303(d) and 305(b) Assessment, Listing, and Total Maximum Daily Load Programs*: Provides information on how to complete assessments, list impaired waters, and develop total maximum daily loads (TMDLs) to implement EPA-approved[16] WQS that are based on the EPA's national CWA section 304(a) recommended selenium criterion.

[15] USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016.* EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

[16] EPA-approved includes both WQS adopted by states, territories or authorized Tribes and approved by the EPA and WQS promulgated by the EPA.

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2.0 Adopting the EPA's National CWA section 304(a) Recommended Selenium Criterion

2.1 The Four-Part Criterion

As described in the EPA's *Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016*,[17] the EPA recommends that states and authorized Tribes adopt into their WQS one selenium criterion composed of four criterion elements: two fish tissue criterion elements (i.e., egg-ovary and whole-body and/or muscle tissue) and two water column criterion elements (i.e., 30-day average and intermittent exposure). The EPA recommends that states and authorized Tribes clearly express all four criterion elements as part of a single criterion. Including all four recommended criterion elements of the selenium criterion in state or Tribal WQS ensures protection from excessive selenium when egg-ovary data are unavailable by allowing application of the criterion using other fish tissue or water column data. Along with the four criterion magnitude elements, the EPA also recommends adopting the corresponding durations and frequencies for each of the criterion elements.

States and authorized Tribes should clearly indicate in their WQS that fish tissue criterion elements supersede the water column criterion elements (except when selenium inputs are increasing and steady-state condition fish tissue data are not available), and that the egg-ovary criterion element supersedes all other criterion elements. Under the EPA's national CWA section 304(a) recommended selenium criterion, this hierarchy applies to all CWA implementation activities. The egg-ovary criterion element supersedes all other criterion elements because it was derived directly from toxicity data and served as the basis for deriving all the other criterion elements. This hierarchy should be described in a state or authorized Tribe's WQS, in footnotes accompanying the criterion. The EPA recommends using the footnotes provided with the national CWA section 304(a) recommended selenium criterion (Table 1) to clearly and accurately describe the hierarchical structure.

The fish tissue criterion elements of this criterion are expressed in dry weight concentrations. This is because many of the toxicity values used to derive the criterion were expressed as dry weights. Instructions for converting between dry weight and wet weight concentrations are provided in Appendix C of *Technical Support for Fish Tissue Monitoring for Implementing the EPA's 2016 Selenium Criterion*.[18]

The two monthly average water column values included in the national CWA section 304(a) recommended selenium criterion were derived for the protection of two different types of

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[17] USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016*. EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

[18] USEPA. 2024. *Technical Support for Fish Tissue Monitoring for Implementing the EPA's 2016 Selenium Criterion*. EPA-820-R-24-003. U.S. Environmental Protection Agency, Office of Water, Washington, DC.https://www.epa.gov/system/files/documents/2024-03/selenium-fishtissue-tsd.pdf

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waterbodies, lentic and lotic waters. Lentic waters are waterbodies that consist of standing water, including waterbody types such as lakes and ponds. Lotic waters are waterbodies that consist of flowing waters, including waterbody types such as rivers and streams. The application of the appropriate water column value is based on best professional judgement of the state or authorized Tribe. Although states and authorized Tribes do not need to classify their waters based on these terms, they may find it useful to consider incorporating these criterion elements into any existing classifications for different types of waterbodies (e.g., lakes). One resource that may be helpful for states and authorized Tribes is a geospatial dataset the United States Geological Survey (USGS) developed on lotic and lentic waters, available at https://www.sciencebase.gov/catalog/item/5d420fbde4b01d82ce8da8e9.

The national CWA section 304(a) recommended selenium criterion is a chronic criterion. The EPA no longer recommends an acute criterion for short-term ambient exposures because aquatic organisms are exposed to selenium primarily through their diet. Since acute studies are conducted as water-only exposures, they do not address this primary exposure pathway for organisms and do not account for the slow accumulation kinetics of selenium. Additionally, chronic toxicity occurs at lower concentrations than acute toxicity, so protection from acute toxicity is provided by the chronic criterion. Given these properties of selenium, an acute criterion was not included in the national CWA section 304(a) recommended selenium criterion.

Selenium has the potential to bioaccumulate in aquatic food webs, where it can continue to pose a risk even after short-term elevations of the selenium concentration in the water column return to ambient levels. Therefore, the EPA's national CWA section 304(a) recommended selenium criterion includes an intermittent exposure water column criterion element to provide protection from long-term chronic effects that may be caused by short-term elevations above ambient background concentrations of selenium water column concentrations in aquatic systems.

If data for a particular criterion element are not available, WQC based on the national CWA section 304(a) recommended selenium criterion should be implemented with one of the other criterion elements, according to the hierarchy of the criterion. For example, if fish tissue data are not available, but water column data are, the criterion should be implemented using the water column criterion element. This situation may occur for fishless waters or when fish tissue data are not available because they were not collected or were not adequate. Fishless waters are defined as waters with insufficient instream habitat and/or flow to support a population of any fish species on a continuing basis, or waters that once supported populations of one or more fish species but no longer support fish (see the executive summary of the EPA's *Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016*).[19]

[19] USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016.* EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

As noted in the introduction of this document, the national CWA section 304(a) recommended selenium criterion is designed for the protection of aquatic life. As a result, when the national CWA section 304(a) recommended selenium criterion is adopted into state or Tribal WQS, it should be applied to all waterbodies with an aquatic life designated use and, by extension, all species within those waterbodies that are protected by that use. The assessment of the available data for fish, invertebrates, and amphibians indicates that fish are the most sensitive taxa to the impacts from selenium. As such, the criterion elements were derived from fish toxicity values to be protective of the entire aquatic community, not solely fish species. When all four criterion elements are applied together according to the hierarchy, they protect aquatic life from the chronic effects of exposure to selenium in waters that are both inhabited by fish and not inhabited by fish (i.e., fishless).

Table 1, reproduced from the USEPA 2021, provides an example of how the four-part criterion could be adopted into a state or authorized Tribe's WQS. The EPA recommends adopting this table, including the frequency and duration components, with all accompanying footnotes.

Footnote 1 in Table 1 indicates that the fish tissue concentrations of the criterion are expressed as steady-state. An organism is in steady-state when the rates of chemical uptake and depuration are equal and tissue concentrations remain generally constant over time.[20]

Footnotes 2 and 3 in Table 1 describe the structure of the criterion. They explain the primacy of the whole-body and/or muscle tissue criterion element over the water column criterion elements, and the egg-ovary criterion element over any other criterion element. This means when assessing a waterbody in steady-state conditions against WQC based on the national CWA section 304(a) recommended selenium criterion, egg-ovary data take precedence for assessment decisions followed by whole-body and/or muscle tissue data, and lastly by water column data (see *Frequently Asked Questions: Implementing the EPA's 2016 Selenium Criterion in Clean Water Act Sections 303(d) and 305(b) Assessment, Listing, and Total Maximum Daily Load Programs*).[21]

Footnote 4 in Table 1 states that the water column criterion elements of the national CWA section 304(a) recommended selenium criterion were derived from the egg-ovary criterion element via mechanistic bioaccumulation modeling.[22]

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[20] USEPA. 2003. *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000) Volume 2: Development of National Bioaccumulation Factors.* EPA-882-R-03-030. U.S. Environmental Protection Agency, Office of Water, Washington, DC. pp. 1-4. https://nepis.epa.gov/Exe/ZyPDF.cgi/P1005EZQ.PDF?Dockey=P1005EZQ.PDF.

[21] USEPA. 2024. *Frequently Asked Questions: Implementing the EPA's 2016 Selenium Criterion in Clean Water Act Sections 303(d) and 305(b) Assessment, Listing, and Total Maximum Daily Load Programs*. EPA-820-R-24-004. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2024-03/selenium-faq-cwa303.pdf

[22] USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016.* EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

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Footnote 4 also indicates that when both steady-state fish tissue data are absent and selenium inputs to the waterbody (e.g., receiving stream) are increasing, the water column criterion element is the applicable criterion element. For the purposes of the EPA's national CWA section 304(a) recommended selenium criterion, steady-state refers to conditions where sufficient time has passed after the introduction of a new or increased input of selenium into a waterbody or watershed of a waterbody such that fish tissue selenium concentrations are no longer increasing.[23] New or increased inputs of selenium will likely result in higher selenium concentrations in the water column and food web; however, the increase in selenium concentrations in fish tissue is likely to occur at a slower rate than in the water column. When fish tissue data are not in steady-state and do not represent the total potential bioaccumulative effects of selenium in the aquatic ecosystem, the water column criterion element is more appropriate to protect the entire aquatic ecosystem. Fish tissue data should not be considered for CWA implementation of the criterion (e.g., NPDES permits program or CWA section 303(d) listing of impaired waters) until after selenium concentrations in fish tissue have stopped increasing due to new or increased selenium inputs to a waterbody or watershed of a waterbody. However, any fish tissue data, whether steady-state or not, that are higher than the fish tissue criterion elements indicate a potential impact on the aquatic community. Therefore, in the situation where the water column criterion element is met, but the fish tissue criterion element is exceeded, the EPA recommends developing a site-specific water column criterion element that more appropriately reflects a protective water column concentration for that site (see section 2.2 for more information on the development of site-specific water column criterion elements).

In the EPA's *Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016*, "new inputs" are defined as new activities resulting in the release of selenium into a lentic or lotic aquatic system. These "new inputs" are both new and increased inputs of selenium and are referring to the release of a substantial amount of additional selenium from either anthropogenic point or nonpoint sources into a waterbody or watershed. New or increased selenium inputs do not refer to seasonal variability of selenium that occurs naturally within a system (e.g., spring run-off events or precipitation-driven pulses) or *de minimis* discharges. Examples of new or increased inputs include releases of additional selenium into the waterbody or watershed from the opening or expansion of petroleum refining facilities, the opening or expansion of mining operations where increased selenium is likely to be discharged, or other anthropogenic activities (such as irrigation of selenium-rich soils) that would substantially increase selenium loadings to a waterbody or watershed of a waterbody over time. Any available appropriate data, including data collected by the state or authorized Tribe, by permittees, and by other entities may be evaluated to determine if there are new or increasing selenium inputs.

[23] This definition of steady-state applies to the national CWA section 304(a) recommended selenium criterion. It does not apply to the discussion of steady-state modeling or conditions in the "Technical Support Document for Water Quality-based Toxics Control" (EPA/505/2-90-001, March 1991).

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A watershed is defined as "an area of land that drains water, sediment, and dissolved materials to a common receiving body or outlet" (i.e., waterbody).[24] For large waterbodies, a state or authorized Tribe may want to evaluate new or increased inputs of selenium within a portion of the watershed that is at or up to a hydrologic unit code level of eight digits in size or consider whether a different watershed size is warranted.

For implementation purposes, states and authorized Tribes may assume that the selenium concentration in fish tissue is in steady-state unless a substantial new or increased input of selenium has recently occurred in the waterbody's watershed. In general, the EPA estimates that once a new or increased input of selenium commences the concentration of selenium in fish tissue will reach steady-state after several months in lotic systems and longer time periods (e.g., two to three years) in lentic systems.[25] These time frames can be used as a general estimate of what is considered a recent input of selenium into a watershed. However, these values are general estimates and the time needed for fish tissue to achieve steady-state after a new or increased input of selenium to a waterbody has occurred is site-specific. Potential factors affecting steady-state conditions in an aquatic system can include: (1) the hydrodynamics of the aquatic system (e.g., particularly reservoirs with multiple riverine inputs and controlled releases of water into downstream waterbodies); (2) the location of the selenium input; and (3) the site-specific food web. Therefore, if states and authorized Tribes make the assumption that fish tissue is in steady-state, the EPA recommends documenting the rationale behind those assumptions to demonstrate that any resulting CWA decisions are protective and have a sound scientific rationale.

Alternatively, fish tissue data can be used to evaluate whether fish tissue concentrations are in steady-state. The EPA recommends monitoring fish tissue in the affected waterbody, starting when new or increased inputs of selenium begin (or before if possible) and continuing until fish tissue data demonstrate that selenium concentrations in fish tissue are no longer increasing. With sufficient and appropriate monitoring data, collected over several sequential sampling periods, the state or authorized Tribe can use appropriate statistical methods (one example is the Mann-Kendall statistical approach, but other statistical approaches may be used) to determine when the fish tissue concentrations are no longer increasing.[26]

When implementing state and Tribal criteria based on the national CWA section 304(a) recommended selenium criterion, if selenium inputs are decreasing in a waterbody, the

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[24] USEPA. *Watershed Academy website*, *Introduction to Watershed Ecology*. https://cfpub.epa.gov/watertrain/moduleFrame.cfm?parent_object_id=518

[25] USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016.* EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

[26] The following documents may be referenced for guidance on statistical analyses: *Statistical Methods in Water Resources* (https://pubs.usgs.gov/tm/04/a03/tm4a3.pdf); *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories: Volume 1, Fish Sampling and Analysis, Third Edition* (https://www.epa.gov/sites/default/files/2015-06/documents/volume1.pdf); *Statistical Analysis for Monotonic Trends* (https://www.epa.gov/sites/default/files/2016-05/documents/tech_notes_6_dec2013_trend.pdf); *Statistical Methods for Environmental Pollution Monitoring* (https://www.osti.gov/servlets/purl/7037501).

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hierarchy of the criterion should apply, and fish tissue criterion elements should take precedence for CWA implementation. Just as the concentration of selenium increases in fish tissue at a slower rate than it does in the water column, selenium concentration also decreases at a slower rate in fish tissue compared to the selenium concentration in the water column. Similarly, selenium can persist in an aquatic ecosystem, and it will take more time to decrease in sediment and biota than in the water column. When water column concentrations of selenium are decreasing, those concentrations may meet the water column criterion element before the fish tissue concentrations meet the fish tissue criterion elements. That is, there is a lag between decreasing water column concentrations of selenium and decreasing selenium concentrations in fish tissue. While the fish tissue selenium concentrations are elevated, effects on aquatic life are still possible. Therefore, the EPA recommends using the fish tissue criterion elements for the CWA implementation of WQC based on the national CWA section 304(a) recommended criterion when selenium inputs to a waterbody or the watershed of a waterbody are decreasing.

In footnote 4, the EPA intends for "dissolved total selenium," to have a defined meaning. Within that term, "total selenium" refers to the combination of all species of selenium that are dissolved into the water column and does not refer to the total recoverable form of selenium. Dissolved total selenium is the selenium that would be measured in a water sample after it has been passed through a 0.45 µm membrane filter.[27] In other words, the criterion is for dissolved selenium in total, not the individual species of selenium (e.g., selenite or selenate, individually).

Footnote 5 of Table 1 describes the equation and input parameters for the intermittent criterion element. The intermittent criterion element is a rearrangement of the 30-day average water column criterion element and was designed to help with permitting where discharges into waterbodies occur only intermittently, rather than continuously. CWA section 303(d) assessments of waterbodies should still be made using the 30-day average water column criterion element, but for waterbodies that have intermittent discharges, this criterion element can be used to determine proper limits for permits. For more information, see section 3.3 of the EPA's *Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016*,[28] questions 11 and 15 of *Frequently Asked Questions: Implementing the EPA's 2016 Selenium Criterion in Clean Water Act Sections 303(d) and 305(b) Assessment, Listing, and Total Maximum Daily Load Programs,*[29] and questions 2-2, 3-1, and 3-4 of *Frequently Asked*

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[27] Protho, M.G. USEPA. 1993. Memorandum: Office of Water Policy and Technical Guidance on Interpretation and Implementation of Aquatic Life Metals Criteria. Office of Water, Washington, DC. https://www.epa.gov/sites/production/files/2019-03/documents/metals-criteria-interpret-aqlife-memo.pdf.

[28] USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016.* EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

[29] USEPA. 2024. *Frequently Asked Questions: Implementing the EPA's 2016 Selenium Criterion in Clean Water Act Sections 303(d) and 305(b) Assessment, Listing, and Total Maximum Daily Load Programs*. EPA-820-R-24-004. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/wqc/aquatic-life-criterion-selenium.

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Questions: Implementing Water Quality Standards Based on the EPA's 2016 Selenium Criterion in Clean Water Act Section 402 National Pollutant Discharge Elimination System Permits.[30]

Footnote 6 of Table 1 explains the duration component of the fish tissue criterion elements. These criterion elements were developed to protect aquatic populations from negative impacts caused by selenium. Fish tissue data provide instantaneous point measurements that reflect integrative accumulation of selenium over time and space in the fish at a given site.[31] Thus, the recommended duration for the selenium criterion is an instantaneous measurement. States and authorized Tribes have flexibility in how they interpret a discrete fish sample to represent a given species' population at a site at a given time. Generally, fish tissue samples collected to calculate the central tendency of tissue concentrations for a species at a site are collected either in one sampling event, as a composite, or over a short time interval (less than a week) due to the logistical constraints and costs for obtaining samples. The EPA recommends defining a single sampling event as a week or less and does not recommend averaging fish concentrations across sampling events, but instead evaluating each sampling event separately for implementation purposes. The *Technical Support for Fish Tissue Monitoring for Implementing the EPA's 2016 Selenium Criterion* contains additional information on sampling fish populations.[32]

The frequency component of the fish tissue criterion elements of the national CWA section 304(a) recommended selenium criterion differs from the "once-in-three years on average" frequency of most other national CWA section 304(a) recommended aquatic life water column criteria. Selenium is a bioaccumulative pollutant; therefore, elevated levels of selenium in various ecological compartments (e.g., biota, surficial sediments) require a long period of time to decrease. As a result, the associated aquatic community requires a long time to recover following the reduction or removal of an elevated selenium exposure to a given system. The time frame to recover is variable and will depend on the biogeochemical processes of the system, including residence time and food web dynamics. Thus, the "once-in-three years on average" frequency component is not appropriate for selenium in fish tissue, as this could lead to sustained ecological impacts. Therefore, the recommended frequency for the fish tissue criterion elements of the national CWA section 304(a) recommended selenium criterion is "not

[30] USEPA. 2024. *Frequently Asked Questions: Implementing Water Quality Standards Based on the EPA's 2016 Selenium Criterion in Clean Water Act Section 402 National Pollutant Discharge Elimination Systems Permits.* EPA-820-R-24-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/wqc/aquatic-life-criterion-selenium.

[31] See the *Technical Support for Fish Tissue Monitoring for Implementing the EPA's 2016 Selenium Criterion* for information on selection of sampling location and target species to assure appropriate representation of the waterbody. Mobility and home range of a species should be considered when selecting a target species to assure fish tissue is representative of selenium exposure at the sampling location.

[32] USEPA. 2024. *Technical Support for Fish Tissue Monitoring for Implementing EPA's 2016 Selenium Criterion*. EPA-820-R-24-003. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2024-03/selenium-fishtissue-tsd.pdf.

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to be exceeded." For additional information regarding duration and frequency, see sections 2.7.6 and 2.7.7 of *Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016*.[33]

In addition to the four-part criterion, states and authorized Tribes have the option of adopting a method to derive site-specific water column criterion elements, referred to by the EPA as a "performance-based approach." The EPA discusses a performance-based approach for a WQS in the preamble of the rule *EPA Review and Approval of State and Tribal Water Quality Standards*.[34] Here the EPA considers a performance-based approach to be a WQS that is a transparent process rather than a specific outcome. [35] The state or authorized Tribe can adopt a process, such as a criterion derivation methodology, rather than a specific outcome, such as a concentration of a pollutant. If a state or authorized Tribe adopts a process or methodology that is sufficiently detailed and has suitable safeguards that ensure predictable, repeatable outcomes, the EPA can approve that process as a WQS. Approval of this process or methodology would also serve for CWA purposes as the approval of each outcome generated from following that process or method. More information about this approach and what information should be included in the method can be found in section 2.2.1 of this document.

The EPA recommends the adoption of the entire national CWA section 304(a) recommended selenium criterion, including all of the criterion elements, footnotes, frequency, and duration. In addition, states and authorized Tribes have the option to develop, adopt, and submit for the EPA approval, site-specific criteria or criterion elements for individual sites (see sections 2.2 and 3.1 for information on options for developing and adopting site-specific criteria). While the EPA presents some methods for developing site-specific criteria in this document and in the national CWA section 304(a) recommended selenium criterion document, any method that is scientifically defensible and protective of the designated uses may be used to develop site-specific criteria. States and authorized Tribes also have the option of developing a methodology for deriving site-specific water column criterion elements for individual sites, which can be adopted as part of a WQS in addition to the four-part criterion and submitted to the EPA for review. If approved by the EPA, this process can be used to develop site-specific water column criterion elements for state and Tribal waters (see section 2.2.1 of this document).

2.2 Options for Site-specific Water Column Criterion Elements

The EPA recommends that when states and authorized Tribes adopt the national CWA section 304(a) recommended selenium criterion, they adopt all four criterion elements, including the 30-day average water column criterion element. States and authorized Tribes also have the

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[33] USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016.* EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

[34] *EPA Review and Approval of State and Tribal Water Quality Standards.* 65 Fed. Reg. 24641 (Apr. 27, 2000). A performance-based approach can be included in state or tribal WQS or as a part of a federal WQS promulgated by the EPA in accordance with the CWA section 303(c) and the EPA's implementing regulations.

[35] *EPA Review and Approval of State and Tribal Water Quality Standards* 65 Fed. Reg. 24641 (Apr. 27, 2000).

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additional option of adopting site-specific water column criterion elements, if desired (either through individual adoption or a performance-based approach). The relationship between the concentration of selenium in the tissues of fish and the concentration of selenium in the water column can differ substantially between different aquatic systems. The chemical form of selenium, species of fish, the species and proportion of prey, and a variety of site-specific biogeochemical factors affect selenium bioaccumulation and thus determine the allowable concentration of selenium in ambient water that is protective of aquatic life. Because of the site-specific nature of this relationship, the EPA provides two methodologies for deriving site-specific water column criterion elements:

1) The mechanistic modeling approach; and
2) The empirical bioaccumulation factor (BAF) approach.

The mechanistic modeling approach uses scientific knowledge of the physical and chemical processes underlying bioaccumulation to specifically model bioaccumulation and trophic transfer through the food web to establish a relationship between the concentrations of selenium in the water column and the concentration of selenium in the tissue of aquatic organisms. The EPA used this approach to derive the default water column criterion elements.[36] This approach generally requires the collection of particulate material and water samples and knowledge of the site's food web. The empirical bioaccumulation factor approach, on the other hand, establishes a site-specific relationship between water column selenium concentrations and fish tissue selenium concentrations by measuring both matrices directly and using the ratio between them to determine a site-specific water column criterion element. Both approaches are described in detail in Appendix K of *Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016*.[37] Both methodologies provide acceptable approaches for translating the recommended fish tissue criterion elements into site-specific water column criterion elements. States and authorized Tribes may use either approach to develop a site-specific water column criterion element. The decision of which approach to use will likely be driven by which data is easiest to collect for a particular site.

In addition, a state or authorized Tribe can develop site-specific criteria using other methodologies if the methodologies are scientifically defensible and the criteria are based on a sound scientific rationale and protective of the applicable designated uses, pursuant to the CWA section 303(c) and the EPA's implementing regulations, including 40 Code of Federal Regulations (CFR) section 131.11. Where a state or authorized Tribe adopts the 304(a) recommended fish tissue criterion elements and the hierarchy of the criterion, and then adopts a site-specific water column criterion element, the hierarchy of the criterion still applies; fish tissue criterion elements take precedence over the site-specific water column criterion

[36] Presser, T.S. and S.N. Luoma. 2010. A methodology for ecosystem-scale modeling of selenium. *Integrated Environmental Assessment and Management* 6:685-710; Presser, T.S. and S.N. Luoma. 2010. *Ecosystem-Scale Selenium Modeling in Support of Fish and Wildlife Criteria Development for the San Francisco Bay-Delta Estuary, California*. U.S. Geological Survey, Reston, Virginia.
[37] Ibid.

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elements in the implementation of the criterion, unless selenium inputs are increasing in a waterbody.

One instance where a state or authorized Tribe may want to develop a site-specific water column criterion element for selenium is for fishless waters. Fishless waters are defined as waters with insufficient instream habitat and/or flow to support a population of any fish species on a continuing basis, or waters that once supported populations of one or more fish species but no longer support fish (see the executive summary of the EPA's *Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016*).[38] Even though the national CWA section 304(a) recommended selenium criterion tissue elements are for fish tissue, the criterion is intended to protect an aquatic life designated use that would include other aquatic life, including invertebrates. In this instance, a site-specific water column criterion element for a fishless waterbody would need to be protective of the entire aquatic community present in that water and potentially downstream waters (40 CFR 131.10(b)). When deriving a site-specific water column criterion element for fishless waters, it may be appropriate to use the mechanistic model[39] to translate from either a fish tissue criterion element or an invertebrate toxicity threshold. Fish tissue criterion elements should be used to protect the whole aquatic community if fish populations were once supported in that waterbody or for protection of fish downstream, depending on the type of waterbody downstream and the fish present in that downstream waterbody. Invertebrate toxicity thresholds may be appropriate if fish currently and historically have not used the waterbody. Currently (April 2024), the EPA is not aware of sufficient toxicity data on invertebrates for an invertebrate toxicity threshold for selenium. However, as new toxicity data become available, this may be an appropriate taxa to use for deriving site-specific water column criterion elements for fishless waters. The appropriateness of that toxicity data will be evaluated on a case-by-case basis but should generally account for dietary exposure and evaluate survival, growth, and potentially reproductive effects. Potential downstream impacts should also be accounted for by evaluating trophic transfer factors and evaluating what impacts the selenium concentrations of the invertebrates may have on downstream fish species.

There is also one instance where the EPA specifically recommends developing a site-specific water column criterion element. This is when the ambient water column selenium concentrations in a waterbody/waterbody segment are meeting the national CWA section 304(a) recommended water column criterion elements, but the fish tissue concentrations are greater than the national recommended fish tissue criterion elements. In this situation, the elevated fish tissue concentrations may indicate an impact on the aquatic system and indicate

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[38] USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016.* EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

[39] See Appendix K of USEPA 2021 for a description of the mechanistic model. USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016.* EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

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that a water column criterion element lower than the national CWA section 304(a) recommended water column criterion element is needed to protect aquatic life.

There are two approaches to adopting and submitting site-specific selenium water column criterion elements to the EPA for review under section 303(c) of the CWA: 1) states and authorized Tribes may adopt and submit individual water column criterion elements each time they are derived; or 2) they may adopt and submit a performance-based approach for deriving site-specific water column criterion elements (see section 2.2.1). States and authorized Tribes should carefully consider the relative tradeoffs of each approach. The adoption and the EPA approval of individual site-specific water column criterion elements could potentially be simpler to apply in assessment, CWA section 303(d) listing and TMDL development, as well as in NPDES permit development since the implementation can immediately proceed with the established criterion element value rather than having the additional step of calculating the criterion element value using the criterion derivation methodology. On the other hand, the performance-based approach could provide states and authorized Tribes the flexibility to adaptively derive site-specific water column criterion elements to account for the most up-to-date data and information for the site without making it necessary for them to submit the site-specific water column criterion element to the EPA for review each time those criterion elements are derived. Under the performance-based approach, stakeholders would have the opportunity to provide comments on the derivation process (e.g., translation mechanisms and associated sampling plans, input parameters, and data analysis methods) during the WQS adoption process under CWA section 303(c) and the EPA's implementing regulations at 40 CFR Part 131. However, comments on the resulting site-specific water column criterion elements derived through the performance-based approach would be submitted as part of individual actions through each of the implementing programs, such as during a public notice for an NPDES permit. The performance-based approach could involve more coordination among the implementation programs to ensure that they are aiming to achieve the same desired condition in the waterbody. For more information on the performance-based approach, see *EPA Review and Approval of State and Tribal Water Quality Standards*.[40]

When developing site-specific water column criterion elements either through the adoption of individual site-specific water column criterion elements or a performance-based approach, states and authorized Tribes must ensure that the site-specific water column criterion elements are protective of the designated use and based on a sound scientific rationale (40 CFR 131.11(a)) and developed using scientifically defensible methods (40 CFR 131.11(b)(1)(iii)). To help ensure that the designated uses are protected, states and authorized Tribes may want to engage with local community stakeholders to evaluate how the waterbody is used and what species are present in the waterbody. If threatened or endangered fish species are present, states and authorized Tribes may need to derive alternative water column elements with a refined protection goal that account for site-specific bioaccumulation characteristics (both when individually adopting a site-specific water column criterion element or using a performance-based approach). The EPA recommends consulting with its regional offices early

[40] *EPA Review and Approval of State and Tribal Water Quality Standards*. 65 Fed. Reg. 24641 (Apr. 27, 2000).

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and often during the process. The EPA also recommends states and authorized Tribes periodically review the adopted criterion elements, including during the triennial WQS review process (33 USC 1313(c)(1); 40 CFR 131.20), to ensure that those water column criterion elements continue to protect the designated use over time.

2.2.1 Adoption of Site-specific Water Column Criterion Elements through a Performance-Based Approach

As previously mentioned, states and authorized Tribes can choose to adopt into their WQS and submit to the EPA a set of procedures to translate the fish tissue criterion elements into site-specific water column criterion elements. The EPA considers this a performance-based approach to developing site-specific water column criterion elements. Any translation procedure should be transparent, sufficiently detailed, and include suitable safeguards to ensure repeatable, predictable outcomes. In addition, the resulting water column criterion elements must protect the applicable designated use (including federally listed species, if present). If the EPA approves the procedures of the performance-based approach consistent with CWA section 303(c) and the EPA's implementing regulations at 40 CFR Part 131, each resulting site-specific water column criterion element generated consistent with that approach does not need to be individually adopted into the state or authorized Tribe's WQS or individually approved by the EPA under CWA section 303(c).

Importantly, for public transparency, the EPA strongly recommends states and authorized Tribes maintain a list of the resulting site-specific water column criterion elements and underlying data used for their respective derivations on their publicly accessible website. The EPA also strongly encourages states and authorized Tribes to coordinate closely with the EPA when developing a performance-based approach and when conducting the first few studies to develop site-specific water column criterion elements.

In *Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016,* the EPA provides recommendations for site-specific water column translation procedures in Appendix K.[41] States and authorized Tribes may consider the procedures described in this appendix as a starting point for developing a performance-based approach to derive site-specific water column criterion elements. Appendix K presents the general methods for conducting a site-specific water column translation by either the mechanistic model approach or the BAF approach. In addition, it presents a number of options for determining the values to use as input parameters in both of these methods. Interested states or authorized Tribes should decide which of those options they will use for their performance-based approach or describe in their WQS under which circumstances each option will be used.

[41] USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016.* EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf.

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In addition to the general methods provided in Appendix K, states and authorized Tribes should include additional methods in a performance-based approach that can help to make the procedure more transparent and repeatable. These could include methods for: 1) selecting sites and sampling locations within a site; 2) determining what aquatic species (including threatened and endangered species) are present at the site; 3) selecting target species; 4) selecting tissue type for sampling; 5) sampling plans, including spatial and temporal considerations at a site, whether individual or composite samples will be collected, the total number of samples that will be collected per replicate, and the number of replicates that will be collected; 6) extrapolating trophic transfer factors or conversion factors from existing data; and 7) specifying how data will be processed and analyzed. States and authorized Tribes should consider what level of protection will appropriately protect the designated aquatic life use of the waterbody, which will influence what percentile of the resulting data set should be used for the final criterion value. States and authorized Tribes should also account for spatial and temporal variability and assure that the resulting criterion element is protective of the entire site.

States and authorized Tribes' methods for their performance-based approaches should be clear and definitively state which methods will be followed in particular situations. For example, a state or authorized Tribe's performance-based approach should specifically address fishless waters by either including a method specifically designed to derive a site-specific water column criterion element for a fishless water (potentially translating from an invertebrate threshold when data for that are available) or specifying that the performance-based approach cannot be used to derive a site-specific water column criterion element for a fishless water. An example of a detailed performance-based approach is the *Draft Translation of Selenium Tissue Criterion Elements to Site-specific Water Column Criterion Elements for California Version 1, August 8, 2018*.[42]

If a state or authorized Tribe chooses to adopt a performance-based approach as part of a WQS, one method for incorporating the performance-based approach could be to adopt the national CWA section 304(a) recommended selenium criterion table (Table 1) into its WQS with the addition of a footnote that references the document that describes the state or authorized Tribe's translation methodology, sampling plans, and data analysis. By adopting such a footnote into the WQS, the state or authorized Tribe will have incorporated by reference their translation procedure that is scientifically defensible, produces repeatable, predictable outcomes and results in criterion elements that protect the applicable designated use. Any revisions to this document that has been incorporated by reference would be a revision to a WQS that would be subject to the EPA review under CWA section 303(c) and the EPA's implementing regulations at 40 CFR Part 131.

[42] USEPA. 2018. *Draft Translation of Selenium Tissue Criterion Elements to Site-specific Water Column Criterion Elements for California Version 1, August 8, 2018.* U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/sites/production/files/2018-12/documents/california_selenium_2040-af79_pba_20181121_508c_.pdf.

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2.2.2 Adoption of Site-specific Water Column Criterion Elements Individually

States and authorized Tribes can choose to adopt and submit to the EPA for review site-specific water column criterion elements each time they are derived and adopted. These site-specific water column criterion elements can be derived using one of the methodologies described in Appendix K or another scientifically defensible approach. These site-specific water column criterion elements must protect the designated use and must be reviewed and approved by the EPA under CWA section 303(c) and the EPA's implementing regulations at 40 CFR Part 131 before they are applicable for CWA purposes, such as NPDES permitting, waterbody assessment and listing, and TMDL development.

2.3 Relationship of the EPA's National CWA section 304(a) Recommended Selenium Criterion to the Great Lakes Initiative

The EPA's national CWA section 304(a) recommended selenium criterion does not supersede the requirements applicable to the Great Lakes at 40 CFR Part 132. Those requirements, known as the *Great Lakes Water Quality Guidance* (also known as the *Great Lakes Initiative* or *GLI*), apply to all streams, rivers, lakes, and other bodies of water within the U.S. portion of the Great Lakes drainage basin. For those waters, states and authorized Tribes must adopt WQS, including criteria, that are *consistent with (as protective as)* the WQS regulations the EPA promulgated on March 23, 1995 (see 60 FR 15366, March 23, 1995, and 40 CFR 132.1(b) and 132.4).

Under the Great Lakes system-specific regulations, if a state or authorized Tribe adopts a revised criterion for selenium, the EPA in its review must determine if the new criterion is as protective as the selenium chronic criterion (5 µg/L) promulgated in 40 CFR 132.6, Table 2, and whether all binding implementation procedures are as protective as the GLI procedures (see 40 CFR 132.5(g)). The EPA makes its approval/disapproval decisions about new and revised WQS on a case-by-case basis depending upon the supporting information. For waters within the Great Lakes Basin, states and authorized Tribes should evaluate whether the national CWA section 304(a) recommended selenium criterion meets the requirements at 40 CFR Part 132. The EPA would evaluate any proposed revised selenium criterion submitted as part of a state or authorized Tribe's new or revised WQS on a case-by-case basis, in accordance with the CWA and the EPA's implementing regulations at 40 CFR Parts 131 and 132.

3.0 Options for Implementing the EPA's Selenium Criterion

States and authorized Tribes have some flexibility when adopting the national CWA section 304(a) recommended selenium criterion. Options include, but are not limited to, deriving site-specific fish tissue criterion elements, deriving site-specific water column criterion elements (see section 2.2 of this document), adopting WQS variances, revising designated uses, and using

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compliance schedules. This section describes how each option could fit within a state or authorized Tribe's WQS adoption and implementation processes.

3.1 Site-specific Fish Tissue Criterion Elements

3.1.1 Site-specific Fish Tissue Criterion Elements Using the Species Recalculation Procedure[43]

The EPA's WQS regulation at 40 CFR 131.11(b)(1)(ii) provides states and authorized Tribes with the opportunity to adopt criteria that are "…modified to reflect site-specific conditions." As with any criterion, a site-specific criterion must protect the designated use, must be based on a sound scientific rationale, and is subject to the EPA review and approval or disapproval (40 CFR 131.11(a)).

One process that can be used to modify a criterion to reflect site-specific conditions is the recalculation procedure. The recalculation procedure is a process used to modify the taxonomic composition of the toxicity data set used for the species sensitivity distribution (SSD)[44] upon which a site-specific criterion is based, in order to better match the species assemblage that is expected to occur at the site. The recalculation procedure creates a site-specific toxicity data set (and corresponding SSD) that is appropriate for deriving a site-specific aquatic life criterion by correcting, adding, and/or deleting test results from the national toxicity data set for the pollutant of concern based on the resident species of the site. For site-specific recalculations at sites with limited diversity, "the underlying concept of having tests for a diversity of species is more fundamental than having tests for particular taxonomic groups that may be irrelevant to the site."[45] Therefore, recalculations can be performed, even if all of the minimum data requirements are not met. This procedure is intended to provide flexibility to states and authorized Tribes to derive site-specific criteria that best reflect the expected resident species at a site. The species recalculation procedure may result in site-specific criteria that differ from national CWA section 304(a) criteria recommendations (i.e., concentrations that are higher or lower than national recommendations) when there are demonstrated differences in sensitivity

[43] USEPA. 2013. *Revised Deletion Process for the Site-Specific Recalculation Procedure for Aquatic Life Criteria*. EPA 823-R-13-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. www.epa.gov/sites/production/files/2015-08/documents/revised_deletion_process_for_the_site-specific_recalculation_procedure_for_aquatic_life_criteria.pdf.

[44] For additional description of the derivation of the fish tissue criterion elements and the distribution of species sensitivities, see section 3.1.3 of USEPA 2021. USEPA. 2021. *2021 Revision to: Aquatic Life Ambient Water Quality Criterion for Selenium–Freshwater 2016.* EPA 822-R-21-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2021-08/selenium-freshwater2016-2021-revision.pdf

[45] USEPA. 2013. *Revised Deletion Process for the Site-Specific Recalculation Procedure for Aquatic Life Criteria*. EPA 823-R-13-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. www.epa.gov/sites/production/files/2015-08/documents/revised_deletion_process_for_the_site-specific_recalculation_procedure_for_aquatic_life_criteria.pdf.

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between the expected resident aquatic species and those that were used to derive the national criteria recommendations.

Critical species should also be taken into consideration when using the recalculation procedure. A critical species is a resident species that (a) is commercially or recreationally important at the site; or (b) is listed as threatened or endangered under section 4 of the Endangered Species Act (states and authorized Tribes may also want to consider species that are candidates for protection under the Endangered Species Act as critical species); or (c) is a species for which there is firm evidence that its loss would yield an unacceptable impact on the site's commercially or recreationally important species, endangered species, abundances of a variety of other species, or structure or function.[46] The deletion process of the recalculation procedure should not be undertaken unless toxicity data are available for at least one species in each *class* of aquatic plants or animals that contains a *critical species*. For example, if the site has a salmonid that fits the designation of a critical species, the deletion process should not be undertaken unless toxicity data for a species in class teleostei[47] are available (possibly via new testing). It is important to note that species not present at the site, but included in the national criterion database, may be surrogates for other species that are present at the site, but not included in the national criterion database.

The EPA developed the national CWA section 304(a) recommended selenium criterion by first deriving an egg-ovary criterion element from egg-ovary toxicity data then deriving all other criterion elements from that egg-ovary criterion element. A state or authorized Tribe developing site-specific fish tissue criterion elements using the recalculation procedure could similarly start with deriving the egg-ovary criterion element and then deriving other fish-tissue criterion elements. States and authorized Tribes should also consider corresponding changes to the applicable water column criterion elements. See section 2.2 of this document for more information. Note that a state or authorized Tribe that is considering adopting the EPA's national CWA section 304(a) selenium criterion recommendations for the fish tissue criterion elements as recommended but is interested in developing site-specific water column values can proceed as described in section 2.2 of this document.

As with any criteria, states and authorized Tribes using the recalculation procedure should ensure that their site-specific criteria "…provide for the attainment and maintenance of the water quality standards of downstream waters" (40 CFR 131.10(b)). This requirement can be met in a number of ways, including using a combination of water quality standards, such as criteria (numeric criteria and/or narrative criteria) and general policies. Additional information

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[46] USEPA. 2013. *Revised Deletion Process for the Site-Specific Recalculation Procedure for Aquatic Life Criteria*. EPA 823-R-13-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC, www.epa.gov/sites/production/files/2015-08/documents/revised_deletion_process_for_the_site-specific_recalculation_procedure_for_aquatic_life_criteria.pdf.

[47] Teleostei is currently listed as a class by the Integrated Taxonomic Information System (itis.gov). Osteichthyes was previously classified as a superclass that contained the classes Sarcopterygii and Actinopterygii, but those two taxa have now been elevated to superclasses and Teleostei has been elevated to class (https://www.itis.gov/servlet/SingleRpt/SingleRpt).

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about this requirement can be found in *Protection of Downstream Waters in Water Quality Standards: Frequently Asked Questions*.[48] In addition, states and authorized Tribes should consider how they will demonstrate that a species that is contained in the national data set but is being removed from that data set in order to derive the new site-specific criterion is not present at the site (or a surrogate for another species present at the site) before using the recalculation approach. For additional information on the procedure, see the EPA's *Revised Deletion Process for the Site-Specific Recalculation Procedure for Aquatic Life Criteria*.[49] States and authorized Tribes interested in developing site-specific fish tissue criterion elements based on the revised deletion process should engage their EPA Regional office early in the process to ensure the development of sound scientific analyses. The EPA cautions that the deletion process for site-specific criterion development is not appropriate for a performance-based approach because different survey techniques are needed at different sites to determine which species are present.

When developing site-specific criterion elements, consideration should be given to what area is defined as the site. In the general context of site-specific criteria, a "site" may be a state, region, watershed, waterbody, or segment of a waterbody. The site-specific criterion must provide adequate protection for the entire site, however the site is defined. For the recalculation procedure, all species that occur at the site need to be considered when deciding what species, if any, are to be deleted (or added) from (to) the data set. Unique populations or less sensitive uses within sites may justify a designation as a distinct site. If the site contains endangered or threatened species and/or their critical habitat, and the EPA's approval of the state or authorized Tribe's proposed site-specific criterion may affect these species or habitat, the EPA must engage in interagency consultation under the Endangered Species Act section 7(a)(2) with either or both the United States Fish and Wildlife Service and National Marine Fisheries Service, depending on the species, to ensure that the EPA's approval is not likely to jeopardize the continued existence of any threatened or endangered species or result in the destruction or adverse modification of critical habitat. During consultation, the EPA would consider the potential effect of its approval on the species and on the physical and biological features of the critical habitat as well as how the EPA's approval of the site-specific criterion may affect water quality required for the species within the critical habitat.

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[48] USEPA. 2014. *Protection of Downstream Waters in Water Quality Standards: Frequently Asked Questions*. EPA 820-F-14-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. www.epa.gov/sites/production/files/2018-10/documents/protection-downstream-wqs-faqs.pdf.

[49] USEPA. 2013. *Revised Deletion Process for the Site-Specific Recalculation Procedure for Aquatic Life Criteria*. EPA 823-R-13-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. www.epa.gov/sites/production/files/2015-08/documents/revised_deletion_process_for_the_site-specific_recalculation_procedure_for_aquatic_life_criteria.pdf.

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For additional information on site-specific WQC, see chapter 3 of the EPA's *Water Quality Standards Handbook*.[50]

3.1.2 Site-specific Criteria for Sites with Naturally Elevated Selenium Levels

Natural conditions are generally associated with the condition of ecological integrity, defined as the structure, composition, function, or diversity of a habitat in the absence of human disturbance or alteration.[51] For some areas in the U.S., selenium may be elevated in soils and waterbodies under natural conditions. States and authorized Tribes have two options when addressing areas that have naturally elevated selenium concentrations: (1) they may develop site-specific criteria for waterbodies in these locations (e.g., where the current aquatic life designated use is appropriate); or (2) they may refine or subcategorize the aquatic life designated use for waterbodies in these areas and set new criteria to be protective of the modified use (See section 3.3 of this document for more information on revising designated uses). These are two separate pathways for accomplishing the goal of setting appropriate criteria for these waterbodies.

To set a site-specific criterion using a natural conditions justification, states and authorized Tribes should demonstrate that the elevated levels of selenium are due to natural conditions and that no anthropogenic activities (e.g., agriculture, mining, irrigation, coal, or oil combustion) are responsible for elevating selenium concentrations in the waterbody. In many areas where soils are elevated in selenium, anthropogenic activities either release selenium or expose soils or rock to weathering, which results in the release of additional selenium into the water column. When an anthropogenic activity leads to a greater release of selenium than natural weathering, the state or authorized Tribe should not develop a site-specific criterion using the natural conditions justification. However, if the anthropogenic impacts can be separated from the natural impacts in these situations where both occur, then the state or authorized Tribe could develop a site-specific criterion for the portion of the elevated selenium that is due solely to those natural causes.

When developing a site-specific criterion, the state or authorized Tribe should identify the site boundaries and temporal dynamics to which a natural background (concentration of a parameter due only to non-anthropogenic sources) criterion applies (i.e., it is important that such criteria are developed to maintain and protect the spatial and temporal variation in

[50] USEPA. 2017. Chapter 3: Water Quality Criteria in *Water Quality Standards Handbook*. EPA 823-B-17-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/sites/production/files/2014-10/documents/handbook-chapter3.pdf.

[51] Landres, P.B., P. Morgan, and F.J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. *Ecological Applications* 9(4): pp. 1179–1188; Davies, S.P. and S.K. Jackson. 2006. The biological condition gradient: A descriptive model for interpreting change in aquatic ecosystems. *Ecological Applications* 16(4): pp. 1251–1266.

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selenium concentrations under natural conditions[52]). If concentrations vary seasonally, adoption of seasonal criteria may be appropriate. Where concentrations vary spatially, additional waterbody segmentation may be appropriate. In cases where selenium is elevated due to both natural conditions and anthropogenic activities, methods such as modeling (e.g., historical or hydrologic modeling), an examination of past paleolimnological studies, comparison to reference sites with no anthropogenic impacts, or other scientifically defensible techniques may be considered as an option for defining natural conditions.[53] Using these or other tools, a state or authorized Tribe may be able to define what proportion of elevated selenium is due to natural versus anthropogenic impacts. A site-specific criterion could then be derived for the portion of the concentration that is elevated due to natural conditions.

When deriving site-specific fish tissue criterion elements, states and authorized Tribes should consider corresponding changes to the applicable water column criterion elements. If selenium at the site is entirely from natural sources, then the water column criterion element could be set at ambient water column concentrations. However, if some of the selenium is from anthropogenic sources, then the water column concentration should be derived using modeling methods. See section 2.2 for more information on options for adopting site-specific water column criterion elements.

As articulated in the 1997 memorandum *Establishing Site-Specific Aquatic Life Criteria Equal to Natural Background,*[54] the EPA recommends that interested states and authorized Tribes establish site-specific numeric aquatic life criteria by setting the criteria values equal to natural background, where natural background is defined as due *only* to non-anthropogenic sources (i.e., non-human-induced sources). The EPA cautions against using the terminology "ambient" interchangeably with "natural." Ambient conditions refer to current conditions at a site and can include both impacts from anthropogenic and natural sources.

3.2 Water Quality Standards Variances

A state or authorized Tribe could consider a WQS variance if it determines that it is not feasible at present to attain a designated use and an associated criterion, such as a newly adopted

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[52]See the *Technical Support for Fish Tissue Monitoring for Implementing of the EPA's 2016 Selenium Criterion* for information on sampling fish and spatial and temporal variability. https://www.epa.gov/system/files/documents/2024-03/selenium-fishtissue-tsd.pdf.

[53] Swetnam, T.W., C.D. Allen, and J.L. Betancourt. 1999. Applied historical ecology: Using the past to manage for the future. *Ecological Applications* 9(4): pp. 1189–1206; Hughes, R.M., S.G. Paulsen, and J.L. Stoddard. 2000. EMAP-Surface waters: A multiassemblage, probability survey of ecological integrity in the U.S.A. *Hydrobiologia* 422/423: pp. 429–443; Kilgour, B.W., and L.W. Stanfield. 2006. Hindcasting reference conditions in streams. *American Fisheries Society Symposium* 48: pp. 623–639; Herlihy, A.T., S.G. Paulsen, J. Van Sickle, J.L. Stoddard, C.P. Hawkins, and L.L. Yuan. 2008. Striving for consistency in a national assessment: The challenges of applying a reference-condition approach at a continental scale. *Journal of the North American Benthological Society* 27(4): pp. 860–877.

[54] Davies, T. USEPA. 1997. Memorandum: Establishing Site Specific Aquatic Life Criteria Equal to Natural Background. Office of Water, Washington DC. https://www.epa.gov/sites/production/files/2014-08/documents/naturalbackground-memo.pdf.

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selenium criterion, but it may be attainable in the future. A WQS variance may also be considered if there is uncertainty about the feasibility of meeting the designated use and criterion, but progress can be made by implementing known controls and tracking environmental improvements. The WQS regulations at 40 CFR 131.3(o) define a *WQS variance* as "a time-limited designated use and criterion for a specific pollutant(s) or water quality parameter(s) that reflect the highest attainable condition (HAC) during the term of the WQS variance." The WQS variance regulation at 40 CFR 131.14 ensures that incremental progress is made toward attainment of the applicable designated use and associated criterion, while not allowing any lowering of the currently attained ambient water quality. This is accomplished by establishing an HAC, which serves as the basis for deriving less-stringent NPDES permit limits and requirements throughout the term of the WQS variance.[55] Although less stringent than the adopted criterion, the HAC still provides a target for incrementally improving water quality until the applicable designated use and associated criterion become attainable. It is important to note that these permit limits and requirements are applicable only to the discharger(s), pollutant(s)/parameter(s), and waterbody or waterbody segment(s) identified in the WQS variance. All other applicable standards not specifically addressed by the EPA-approved WQS variance would continue to apply for CWA purposes.

A state or authorized Tribe can choose to adopt a WQS variance that is applicable to a single discharger, multiple dischargers, or an entire waterbody/waterbody segment. Because the national CWA section 304(a) recommended selenium criterion is intended to protect aquatic life (CWA section 101(a)(2)), in its WQS variance submission the state or authorized Tribe must provide supporting documentation demonstrating that attaining the designated use and criterion is not feasible throughout the term of the WQS variance due to one of the factors listed at 40 CFR 131.14(b)(2)(i)(A). Such a demonstration, when combined with the other regulatory requirements of 40 CFR 131.14, provides the framework for WQS variances as a water quality improvement tool. The regulations at 40 CFR Part 132 apply to states and authorized Tribes that regulate waters in or contributing to waters of the Great Lakes System. If 40 CFR 131.14 and 40 CFR Part 132 overlap, the more stringent regulation applies. WQS variances are considered new or revised WQS and, therefore, must be reviewed and approved by the EPA in order to be in effect for CWA purposes.

To help states and authorized Tribes in the process of adopting WQS variances, the EPA has developed various resources, including a WQS variances website,[56] the *WQS Variance Building Tool*,[57] *Checklist for Evaluating State Submission of Discharger-Specific Water Quality Standards*

[55] WQS variances with a term greater than five years must be reevaluated at least every five years to determine whether the HAC is more stringent than originally adopted. See 40 CFR 131.14 (b)(1)(v).
[56] USEPA. *Water Quality Standards Variance website.* https://www.epa.gov/wqs-tech/water-quality-standards-variances.
[57] USEPA. *Water Quality Standards Variance Building Tool*. https://www.epa.gov/wqs-tech/water-quality-standards-variance-building-tool.

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Variances,[58] and several other resources available on the "Resources" tab of the *WQS Variance Building Tool*. States and authorized Tribes are encouraged to coordinate with the EPA throughout the WQS variance adoption process to develop their WQS variance submissions.

3.3 Revision to Designated Uses

Prior to adopting a revised selenium criterion, a state or authorized Tribe may want to evaluate potential revisions to the relevant designated uses for certain waterbodies as discussed below. The WQS regulation at 40 CFR 131.10(g) provides that states or authorized Tribes may remove a CWA section 101(a)(2) designated use that is *not* an existing use, as defined in 40 CFR 131.3(e), or establish subcategories of such a use that requires less stringent criteria if the state or authorized Tribe can demonstrate that attaining the designated use is not feasible because of one or more of the six factors listed in 40 CFR 131.10(g). Those factors are:

1) Naturally occurring pollutant concentrations prevent the attainment of the use; or

2) Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation requirements to enable uses to be met; or

3) Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place; or

4) Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate such modification in a way that would result in the attainment of the use; or

5) Physical conditions related to the natural features of the waterbody, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses; or

6) Controls more stringent than those required by sections 301(b) and 306 of the Act would result in substantial and widespread economic and social impact.

Where required under the EPA's WQS regulations, the state or authorized Tribe must make such a demonstration through a *use attainability analysis* (UAA), which is defined under 40 CFR 131.3(g) as "…a structured scientific assessment of the factors affecting the attainment of the use which may include physical, chemical, biological, and economic factors as described in 40 CFR 131.10(g)." A state or authorized Tribe must conduct a UAA whenever (1) the state or

[58] USEPA. 2016. *Checklist for Evaluating State Submission of Discharger-Specific Water Quality Standards Variances*. U.S. Environmental Protection Agency, Office of Water. Washington, DC. https://www.epa.gov/sites/production/files/2016-03/documents/checklist-evaluating-discharger-specific.pdf.

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authorized Tribe designates for the first time, or has previously designated for a waterbody, uses that do not include the uses specified in section 101(a)(2) of the CWA; or (2) the state or authorized Tribe wishes to remove a designated use that is specified in section 101(a)(2) of the Act, to remove a subcategory of such a use, or to designate a subcategory of such a use that requires a criterion less stringent than previously applicable (40 CFR 131.10(j)). If a state or authorized Tribe adopts a new or revised WQS based on a required use attainability analysis, the state or authorized Tribe shall also adopt the highest attainable use, as defined in 40 CFR 131.3(m).[59] The WQS regulations also do not allow states and authorized Tribes to remove any uses that are existing uses. In addition, uses cannot be removed if they can be attained by implementing effluent limits required under sections 301(b) and 306 of the Act and by implementing cost-effective and reasonable best management practices for nonpoint source control (40 CFR 131.10(h)).

For selenium, there are at least two potential circumstances where a use change may be appropriate for a waterbody. The first is fishless waters. States or authorized Tribes may want to recognize the difference in aquatic communities in these waters by creating a subcategory of the aquatic life designated use. When doing so, the state or authorized Tribe should be sure that protections for other forms of aquatic life, such as macroinvertebrates, are protected by the revised designated use and associated criterion. If aquatic-dependent wildlife use the waterbody, then the state or authorized Tribe may also want to set a selenium criterion for the protection of these species as well. The second is waterbodies located in areas where the selenium is naturally elevated in the underlying geology and, as a result, are particularly vulnerable to elevated selenium concentrations in the water. Ambient selenium concentrations in these waterbodies can be exacerbated by anthropogenic activities. If the conditions in this circumstance are precluding attainment of the designated use and cannot be remedied, a limited or modified aquatic life use may be more appropriate for these waterbodies. The EPA's regulations at 40 CFR 131.10(g) provide factors related to natural and anthropogenic conditions for states and authorized Tribes to employ in a UAA to justify revising the aquatic life use (see 40 CFR 131.10(j) for when a UAA is required). If the state or authorized Tribe can demonstrate the full aquatic life use is not feasible for a waterbody using at least one of the factors at 40 CFR 131.10(g), then the designated use the state or authorized Tribe must adopt in place of the full aquatic life use must be the highest attainable use for the waterbody, as required by 40 CFR 131.10(g).

[59] 40 CFR 131.3(m) defines "highest attainable use" as the "…modified aquatic life, wildlife, or recreation use that is both closest to the uses specified in section 101(a)(2) of the Act and attainable, based on the evaluation of the factor(s) in §131.10(g) that preclude(s) attainment of the use and any other information or analyses that were used to evaluate attainability."

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For additional information on use changes and UAAs, see the EPA's *Water Quality Standards Handbook.*[60] Additional information also is available at http://water.epa.gov/scitech/swguidance/standards/uses/uaa/.

3.4 Compliance Schedules

If a state or authorized Tribe's applicable WQS[61] or implementing regulations include a provision authorizing the use of permit compliance schedules, a compliance schedule that is consistent with 40 CFR 122.47 can be included in an NPDES permit with WQBELs for selenium. The NPDES permit regulations at 40 CFR 122.47 allow compliance schedules if (1) the discharger cannot immediately meet the new WQBEL, and requires time to install treatment technology or implement other controls necessary to come into compliance with a new WQBEL; (2) the permitting authority (the state or the EPA) determines that a compliance schedule is *appropriate* in light of all the circumstances; and (3) the discharger can meet its final WQBEL at a date determined to be as-*soon-as-possible*. See section 502(17) of the CWA for a definition of *schedules of compliance* and 40 CFR 122.47 for more information about the schedules. For additional information on compliance schedules, see section 5 in *Frequently Asked Questions: Implementing Water Quality Standards Based on the EPA's 2016 Selenium Criterion in Clean Water Act Section 402 National Pollutant Discharge Elimination System Permits*.[62]

Compliance schedules in NPDES permits can allow additional time to achieve compliance with WQBELs based on WQS adopted after July 1, 1977, if the state or authorized Tribe (i.e., a Tribe with TAS for WQS) has indicated clearly in its WQS or implementing regulations that it intends to allow the use of permit compliance schedules. As defined in the NPDES regulations, "a schedule of compliance" is "a schedule of remedial measures included in a 'permit', including an enforceable sequence of interim requirements (for example, actions, operations, or milestone events) leading to compliance with the CWA and regulations" (40 CFR 122.2). If the schedule is longer than one year, it must include annual interim requirements and dates for their achievement (40 CFR 122.47(a)(3)). Additionally, the permit must include a final WQBEL and a date for its achievement. The decision to include a compliance schedule as well as the dates and interim requirements must be supported by the administrative record. The permit fact sheet should include a justification for the compliance schedule being determined to be *appropriate* and why the chosen time frame was deemed to be *as soon as possible*. For

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[60] USEPA. 2012. Chapter 2: Designation of Uses in *Water Quality Standards Handbook*. EPA 823-B-12-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/sites/production/files/2014-10/documents/handbook-chapter2.pdf.

[61] 40 CFR 131.15 states that: "If a State intends to authorize the use of schedules of compliance for water quality-based effluent limits in NPDES permits, the State must adopt a permit compliance schedule authorizing provision. Such authorizing provision is a water quality standard subject to EPA review and approval under section 303 of the Act and must be consistent with sections 502(17) and 301(b)(1)(C) of the Act."

[62] USEPA. 2024. *Frequently Asked Questions: Implementing Water Quality Standards Based on the EPA's 2016 Selenium Criterion in Clean Water Act Section 402 National Pollutant Discharge Elimination System Permits.* EPA-820-R-24-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/system/files/documents/2024-03/selenium-faq-cwa402.pdf.

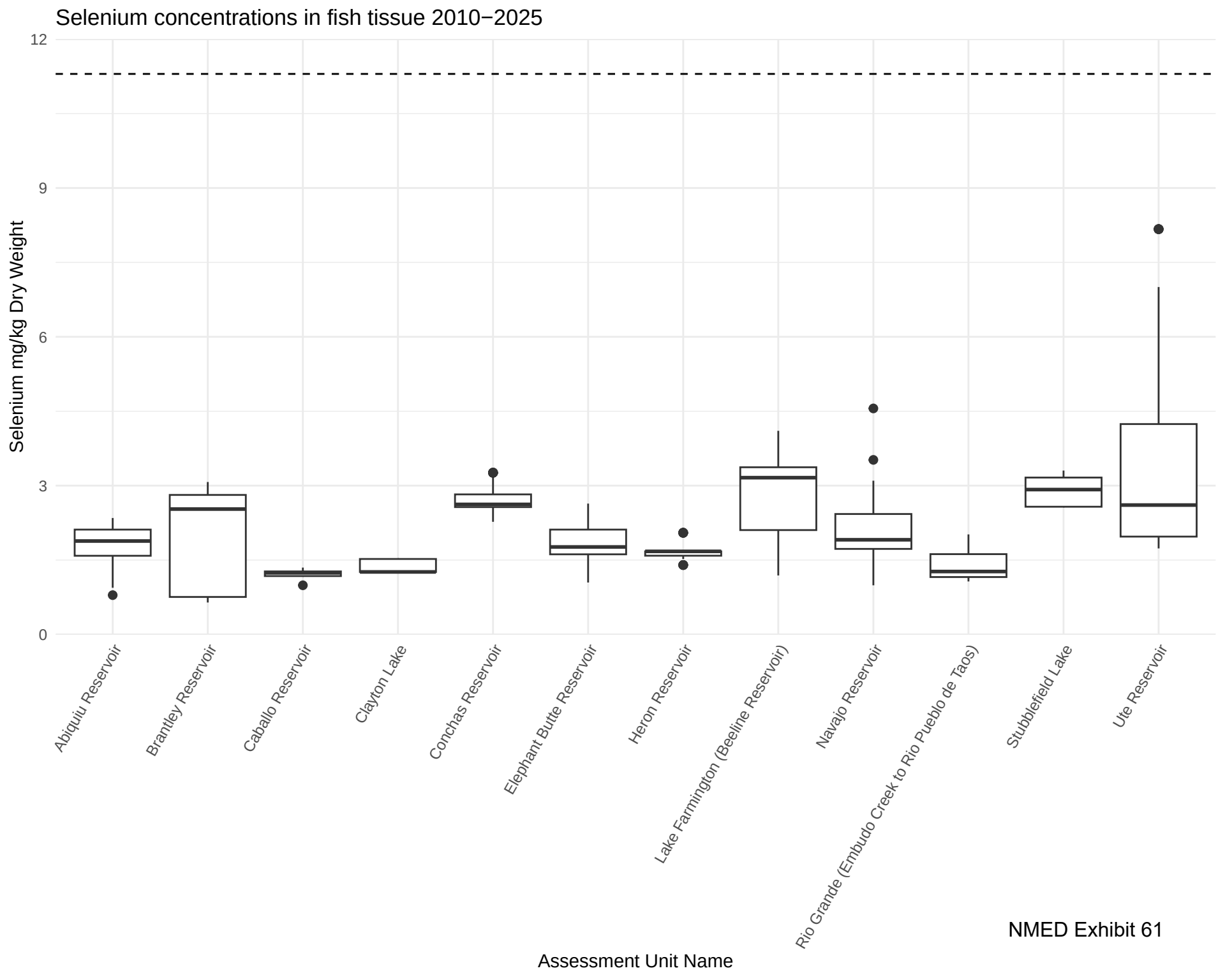
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additional information on compliance schedules, see section 9.1.3 of the EPA's *NPDES Permit Writers' Manual*[63] and the May 10, 2007, memorandum from the EPA's Office of Wastewater Management on compliance schedules for water quality-based effluent limitations in NPDES permits.[64]

[63] USEPA. 2010. *NPDES Permit Writers' Manual*. EPA 833-K-10-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/sites/production/files/2015-09/documents/pwm_2010.pdf.

[64] Hanlon, J.A. USEPA. 2007. Memorandum: Compliance Schedules for Water Quality-Based Effluent Limitations in NPDES Permits. Office of Water, Washington DC. https://www3.epa.gov/npdes/pubs/memo_complianceschedules_may07.pdf.

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Selenium concentrations in fish tissue 2010−2025
Selenium mg/kg Dry Weight
12
9
6
3
0
Abiquiu Reservoir
Brantley Reservoir
Caballo Reservoir
Clayton Lake
Conchas Reservoir
Elephant Butte Reservoir
Heron Reservoir
Lake Farmington (Beeline Reservoir)
Navajo Reservoir
Rio Grande (Embudo Creek to Rio Pueblo de Taos)
Stubblefield Lake
Ute Reservoir
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FINAL

FRESHWATER AQUATIC LIFE AMBIENT WATER QUALITY CRITERIA AND ACUTE SALTWATER BENCHMARK FOR

PERFLUOROOCTANE SULFONATE (PFOS)

September 2024

U.S. Environmental Protection Agency Office of Water, Office of Science and Technology, Health and Ecological Criteria Division

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ACRONYMS

6:2 Cl-PFESA	6:2 chlorinated polyfluorinated ether sulfonate
ACR	Acute-to-Chronic Ratio
AFFF	Aqueous film-forming foams
AIC	Akaike information criteria
AMV	Acute Maximum Value
ASW	artificial sea water
AWQC	National Recommended Ambient Water Quality Criteria
BAF	Bioaccumulation factor
C8-PFPA	Perfluorooctyl phosphonic acid
C8/C8-PFPiA	Bis(perfluorooctyl) phosphinic acid
CAS/CASRN	Chemical Abstracts Service Registry Numbers
CC	Chronic Criterion
CCC	Criterion Continuous Concentration
C-F	carbon-fluorine
CMC	Criterion Maximum Concentration
C-R	concentration-response
C-S	carbon-sulfur
CWA	Clean Water Act
DER	Data Evaluation Record
DMSO	dimethyl sulfoxide
dpf	days post fertilization
drc	dose-response curve
dw	dry weight
ECF	Electrochemical fluorination
ECOTOX	ECOTOXicology database
ELS	Early life-stage
EPA	U.S. Environmental Protection Agency
EtFASAAs	*N*-ethyl perfluoroalkane sulfonamidoacetic acids
EtFASAs	*N*-ethyl perfluoroalkane sulfonamides
EtFOSAA	*N*-ethyl perfluorooctane sulfonamidoacetic acid
EtFOSE	*N*-ethyl perfluorooctane sulfonamidoethanol
FACR	Final Acute-to-Chronic Ratio
FASAAs	Perfluoroalkyl sulfonamidoacetic acids
FASAs	Perfluoroalkane sulfonamids
FASEs	perfluoroalkyl sulfonamidoethanols
FAV	Final Acute Value
FCV	Final Chronic Value
FFTG	Canadian Federal Fish Tissue Guideline
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FOSA	Perfluorooctane sulfonamide
FWQG	Federal Water Quality Guideline
GLI	U.S. EPA Great Lakes Initiative
GMAV	Genus Mean Acute Value
GMCV	Genus Mean Chronic Value

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HC1	1% Hazardous Concentration
GSD	genus sensitivity distribution
hpf	hours post fertilization
ICE	Interspecies Correlation Estimation
K_{ow}	n-octanol-water partition co-efficient
LOD	limit of detection
LOEC	Lowest Observed Effect Concentration
LOQ	limit of quantification
MATC	Maximum Acceptable Toxicant Concentration
MC	Maximum Criterion
MDL	Method Detection Limit or Minimum Detection Limit
MDRs	minimum data requirements
NAMs	New Approach Methods
NCCA	National Coastal Condition Assessment
NOEC	No Observed Effect Concentration
NPDES	National Pollutant Discharge Elimination System
NRSA	National Rivers and Streams Assessment
OCSPP	Office of Chemical Safety and Pollution Prevention
OECD	Organization for Economic Co-operation and Development
ORD	Office of Research and Development
OSF	Octane sulfonyl fluoride
OW	Office of Water
PFAAs	Perfluoroalkyl acids
PFAS	Per- and polyfluorinated substances
PFCA	Perfluoroalkyl carboxylic acids or Perfluoroalkyl carboxylates
PFDA	Perfluorodecanoate or Perfluorodecanoic acid
PFdiCAs	Perfluoroalkyl dicarboxylic acids
PFdiSAs	Perfluoroalkane disulfonic acids
PFECAs	Perfluoroalkylether carboxylic acids
PFESAs	Perfluoroalkylether sulfonic acids
PFDoA	Perfluorododecanoate or Perfluorododecanoic acid
PFOA	Perfluorooctanoic acid or Perfluorooctanoate
PFOS	Perfluorooctane sulfonate or Perfluorooctane sulfonate acid
PFOSI	Perfluorooctane sulfinic acid
PFOS-K	PFOS potassium salt
PFOS-Li	PFOS lithium salt
PFPAs	Perfluoroalkyl phosphonic acids
PFPiAs	Perfluoroalkyl phosphinic acids
PFSAs	Perfluoroalkane sulfonic acids or Perfluoroalkyl sulfonates
PFSiAs	FASA *N*-glucuronides or Perfluoroalkyl sulfinic acids
pKa	Acid dissociation constant
POSF	Perfluorooctanesulfonyl fluoride
PPAR-α	Nuclear peroxisome proliferator activated receptor-alpha
ppt	parts per thousand
SMACR	Species Mean Acute-to-Chronic Ratio
SMAV	Species Mean Acute Value

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SMCV	Species Mean Chronic Value
SNUR	Significant New Use Rules
SOP	Standard Operating Procedure
SSD	Species Sensitivity Distribution
TMDLs	Total Maximum Daily Loads
TSCA	Toxic Substances Control Act
U.S.	United States
UCMR	Unregulated Contaminant Monitoring Rule
web-ICE	Web-based Interspecies Correlation Estimation
WQS	Water Quality Standards
ww	wet weight
WWTPs	Wastewater treatment plants

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NOTICES

This document provides information that states and authorized Tribes may consider when establishing water quality standards under the Clean Water Act (CWA) to protect aquatic life from effects of Perfluorooctane sulfonate (PFOS). Under the CWA, states and authorized Tribes establish water quality criteria to protect designated uses. State and Tribal decision makers retain the discretion to adopt approaches that are scientifically defensible that differ from these recommended criteria or benchmarks, including to reflect site-specific conditions. While this document contains the Environmental Protection Agency's (EPA) scientific recommendations regarding ambient concentrations of PFOS that protect aquatic life, the PFOS Criteria Document does not substitute for the Clean Water Act or the EPA's regulations; nor is this document or the values it contains a regulation itself. This document does not establish or affect legal rights or obligations, or impose legally binding requirements on the EPA, states, Tribes, or the regulated community. It cannot be finally determinative of the issues addressed. This document has been approved for publication by the Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use. This document can be downloaded from: https://www.epa.gov/wqc/aquatic-life-criteria-perfluorooctane-sulfonate-pfos.

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FOREWORD

The Clean Water Act (CWA) Section 304(a)(l) (P.L. 95-217) directs the Administrator of the EPA to develop and publish water quality criteria recommendations that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water, including groundwater. This document includes EPA's recommended ambient water quality criteria (AWQC) for the protection of aquatic life based upon consideration of all available information relating to effects of perfluorooctanoic acid on aquatic organisms in freshwaters, as well as an informational acute saltwater benchmark developed under CWA Section 304(a)(2).

Aquatic life benchmarks, developed by the EPA under 304(a)(2) of the CWA, are informational values that EPA generates when there are limited high quality toxicity data available and data gaps exist for several aquatic organism families. EPA develops aquatic life benchmarks to provide information that states and Tribes may consider in their water quality protection programs, including when developing water quality standards. In developing aquatic life benchmarks, data gaps may be filled using new approach methods (NAMs), such as computer-based toxicity estimation tools (e.g., EPA's Web-ICE) or other new approach methods intended to reduce reliance on additional animal testing (https://www.epa.gov/chemical-research/epa-new-approach-methods-work-plan-reducing-use-vertebrate-animals-chemical), including the use of read-across estimates based on other chemicals with similar structures. Like criteria recommendations developed under Section 304(a)(l), the EPA's aquatic life benchmark values are not regulatory, nor do they automatically become part of a state's water quality standards.

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Under CWA Section 303, states or authorized Tribes adopt water quality standards and submit them to EPA for review and approval. If approved by EPA as water quality standards, they become the CWA water quality standards applicable in ambient waters within that state or authorized Tribe. A state or authorized Tribe may, where appropriate, adopt water quality criteria that have the same numerical values as recommended criteria or benchmarks developed by EPA under CWA Section 304. States and authorized Tribes have discretion to adopt criteria that modify EPA's recommended criteria to reflect site-specific conditions, such as the local water chemistry or ecological conditions, or to develop criteria based on other scientifically defensible methods that are protective of designated uses (40 C.F.R. 131.11[b]). Guidelines to assist the states and authorized Tribes in modifying the criteria presented in this document are contained in the Water Quality Standards Handbook (see Chapter 3 titled "Water Quality Criteria")(U.S. EPA 2023).

Deborah G. Nagle
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Office of Science and Technology

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EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) developed the recommended perfluorooctane sulfonate (PFOS) aquatic life ambient water quality criteria and an acute saltwater benchmark in accordance with the provisions of Section 304(a) of the Clean Water Act. This document provides the EPA's basis for and derivation of the national PFOS ambient water quality criteria recommendations to protect aquatic life. The EPA has derived the recommended PFOS aquatic life criteria and benchmark to be consistent with methods described in the EPA's "*Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*" (i.e., EPA's 1985 Guidelines; U.S. EPA 1985) and EPA's OCSPP's Ecological Effects Test Guidelines (U.S. EPA 2016b).

PFOS is an organic, human-made perfluorinated compound, consisting of an eight-carbon backbone and a sulfonate functional group. PFOS (and other related chemicals that are perfluoroalkane sulfonic acids) is used in a variety of industrial and commercial products, including surface treatments of soil, surface treatments of textiles, paper, and metals, and in specialized applications such as in firefighting foams. This document provides a critical review of all aquatic toxicity data identified in the EPA's literature search for PFOS, including the anionic form (CAS No. 45298-90-6), the acid form (CAS No. 1763-23-1), potassium salt (CAS No. 2795-39-3), an ammonium salt (CAS No. 56773-42-3), sodium salt (CAS No. 4021-47-0), and a lithium salt (CAS No. 29457-72-5). It also quantifies the toxicity of PFOS to aquatic life and provides criteria to protect aquatic life in freshwater from the acute and chronic toxic effects of PFOS.

The Aquatic Life Ambient Water Quality Criteria for PFOS document includes water column-based acute and a water column-based chronic criteria, as well as chronic tissue-based

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criteria for freshwaters. Quantitatively-acceptable estuarine/marine toxicity data only fulfilled five of the eight minimum data requirements (MDRs) for deriving acute estuarine/marine criteria and four of the eight MDRs for deriving chronic estuarine/marine criteria per the 1985 Guidelines. The EPA did, however, include an acute aquatic life benchmark for estuarine/marine environments in Appendix L, using available estuarine/marine species toxicity data and the New Approach Methods (NAMs) application of the EPA Office of Research and Development's (ORD) peer-reviewed web-based Interspecies Correlation Estimate tool (Web-ICE; Version 3.3; https://www.epa.gov/webice/) (Raimondo et al. 2010). The estuarine/marine benchmarks are CWA Section 304(a)(2) information provided for states and authorized Tribes to consider in their state/tribal water quality protection programs. However, the acute estuarine/marine benchmark magnitude is less certain than the freshwater criteria as the benchmark was based on both direct laboratory-based and estimated PFOS acute toxicity data (Appendix L).

The freshwater acute water column-based criterion magnitude is 0.071 mg/L, and the chronic water column-based criterion magnitude is 0.00025 mg/L (250 ng/L). The final chronic freshwater criterion also contains tissue-based criteria with magnitudes of 0.201 mg/kg wet weight (ww) for fish whole-body, 0.087 mg/kg ww for fish muscle tissue, and 0.028 mg/kg ww for invertebrate whole-body tissue. All criteria are intended to be equally protective against adverse PFOS effects and are intended to be independently applicable. The three tissue criteria magnitudes (for fish and invertebrate tissues) are translations of the chronic water column criterion for freshwater using bioaccumulation factors (BAFs) derived from a robust national dataset of BAFs (Burkhard 2021). The assessment of the available data for fish, invertebrates, amphibians, and plants indicates these criteria are expected to protect the freshwater aquatic community.

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Table Ex-1. Recommended Perfluorooctane Sulfonate (PFOS) Ambient Water Quality Criteria for the Protection of Aquatic Life in Freshwaters.

Type/Media	Acute Water Column (CMC)[1,4]	Chronic Water Column (CCC)[1,5]	Chronic Invertebrate Whole-Body[1,2]	Chronic Fish Whole-Body[1,2]	Chronic Fish Muscle[1,2]
Magnitude	0.071 mg/L	0.00025 mg/L	0.028 mg/kg ww	0.201 mg/kg ww	0.087 mg/kg ww
Duration	One-hour average	Four-day average	Instantaneous[3]		
Frequency	Not to be exceeded more than once in three years on average	Not to be exceeded more than once in three years on average	Not to be exceeded[6]		

[1] All five of these water column and tissue criteria are intended to be independently applicable and no one criterion takes primacy. All of the above recommended criteria (acute and chronic water column and tissue criteria) are intended to be protective of aquatic life. These criteria are applicable throughout the year.
[2] Tissue criteria are derived from the chronic water-column criterion magnitude (CCC) with the use of bioaccumulation factors and are expressed as wet weight (ww) concentrations.
[3] Tissue data provide instantaneous point measurements that reflect integrative accumulation of PFOS over time and space in aquatic life population(s) at a given site.
[4] Criterion Maximum Concentration; applicable throughout the water column.
[5] Criterion Continuous Concentration; applicable throughout the water column.
[6] PFOS chronic freshwater tissue-based criteria should not be exceeded, based on measured tissue concentrations representing the central tendency of samples collected at a given site and time.

Table Ex-2. Acute Perfluorooctane Sulfonate (PFOS) Benchmark for the Protection of Aquatic Life in Estuarine/Marine Waters.

Type/Media	Acute Water Column Benchmark
Magnitude	0.55 mg/L
Duration	One hour on average
Frequency	Not to be exceeded more than once in three years on average

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1 INTRODUCTION AND BACKGROUND

National Recommended Ambient Water Quality Criteria (AWQC) are established by the EPA under the CWA. Section 304(a)(1) states that aquatic life criteria serve as recommendations to states and authorized Tribes by defining ambient water concentrations that are expected to protect against unacceptable adverse ecological effects to aquatic life resulting from exposure to pollutants found in water. States and authorized Tribes may adopt these criteria into their water quality standards (WQS) to protect the designated uses of water bodies. States and authorized Tribes may also modify these criteria before adopting these into standards. After adoption, states/authorized Tribes submit new and revised WQS to EPA for review and approval or disapproval. When approved by EPA, the state's/Tribes WQS become the application WQS for CWA purposes. Such purposes include identification of impaired waters and establishment of Total Maximum Daily Loads (TMDLs) under CWA Section 303(d) and derivation of water quality-based effluent limitations in permits issued under the CWA Section 402 National Pollutant Discharge Eliminations System (NPDES) programs. The EPA recommends the adoption of both the acute and chronic water column criteria as well as the chronic-tissue based criteria to ensure the protection of aquatic life through all exposure pathways, including direct aqueous exposure and bioaccumulation. Aquatic life benchmarks, developed by the EPA under 304(a)(2) of the CWA, are informational values that the EPA generates when there are limited high quality toxicity data available and data gaps exist for several aquatic organism families. The EPA provided an acute estuarine/marine benchmark in Appendix L as additional information on protective values that states and tribes may consider in their water quality programs.

This assessment provides a critical review of all aquatic toxicity data identified in the EPA's literature search for PFOS, including the anionic form (CAS No. 45298-90-6), the acid

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form (CAS No. 1763-23-1), a potassium salt (CAS No. 2795-39-3), an ammonium salt (CAS No. 56773-42-3), a sodium salt (CAS No. 4021-47-0), and a lithium salt (CAS No. 29457-72-5). It quantifies the toxicity of PFOS to aquatic life and provides criteria to protect aquatic life in freshwater from the acute and chronic toxic effects of PFOS.

The EPA derived the recommended criteria using the best available data to reflect the latest scientific knowledge on the toxicological effects of PFOS to aquatic life. The EPA developed the criteria following the general approach outlined in the EPA's "*Guidelines for Deriving Numerical Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses"* (U.S. EPA 1985). The PFOS freshwater criteria, if adopted and implemented, are expected to be protective of most aquatic organisms, including species listed as threated and endangered, in the community and are derived to be protective of aquatic life designated uses established by states and Tribes for freshwaters. The estuarine/marine benchmarks are also intended to be protective of aquatic life designated uses, but as they are based on fewer empirical PFOS data have greater inherent uncertainty. The criteria recommendations presented herein are the EPA's best estimate of the concentrations of PFOS, with associated frequency and duration specifications, that would protect sensitive aquatic life from unacceptable acute and chronic effects.

1.1 Previously Derived PFOS Toxicity Values and Thresholds

Within the U.S., no states or Tribes have CWA Section 303(c) approved water quality standards for the protection of aquatic life from the exposure to PFOS. However, several states have published draft/interim acute and chronic ecological screening level values/benchmarks for the protection of aquatic life. As such, previously published PFOS acute and chronic criteria, benchmarks, and thresholds developed by states and international regulatory authorities were

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identified, that included values for both freshwater and marine systems, and are summarized below.

1.1.1 Previously Published Acute Water Protective Values for Direct Aqueous Exposure

Previously published freshwater acute values were available for four states (Florida, Michigan, Minnesota, and Texas) and one geographic region (Europe). These publicly available values for other jurisdictions ranged from 0.021 mg/L in Texas (Giesy et al. 2010; TCEQ 2021) to 0.78 mg/L in Michigan (EGLE 2010). The EPA's freshwater acute PFOS criterion (0.071 mg/L) falls into the middle of the range of state- and European-derived values.

There were two previously derived estuarine/marine acute values, with a benchmark/criterion of 0.0072 mg/L in Europe (RIVM 2010) and 0.21 mg/L in Florida (Stuchal and Roberts 2019) (Table 1-1). These values were derived using safety factors. Consequently, these state values were both lower than the EPA's PFOS acute estuarine/marine benchmark (0.55 mg/L), which used measured and estimated acute toxicity data (Appendix L).

1.1.2 Previously Published Chronic Water Protective Values for Direct Aqueous Exposure

Previously published freshwater chronic values were available for five states (California, Florida, Michigan, Minnesota, and Texas) and three countries or geographic regions (Australia/New Zealand, Canada, and Europe). The publicly available state-derived values ranged from 0.00056 mg/L in California (RWQCB 2020; SERDP 2019; 99% species protection) to 0.14 mg/L in Michigan (EGLE 2010). Overall, the EPA's chronic water column-based PFOS criterion (0.00025 mg/L) is lower than chronic state-derived values because the EPA's chronic PFOS criterion was based on recently published and sensitive insect data.

Internationally, chronic PFOS protective values were 0.000023 mg/L in Europe (RIVM 2010), 0.00013 mg/L in Australia/New Zealand (CRCCare 2017; EPAV 2017) 95% species protection level), and 0.00680 mg/L in Canada (ECCC 2018) (Table 1-1). The EPA's chronic

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water-column based PFOS criterion (0.00025 mg/L) is in the middle of the range of chronic PFOS values used in different international jurisdictions.

Previously published estuarine/marine chronic values were available for three states (California, Florida, and Texas) and two geographic regions (Australia/New Zealand and Europe). These publicly available values for other jurisdictions ranged from 0.000294 mg/L for Texas (CRCCare 2017; TCEQ 2021) to 0.013 mg/L in Florida (Stuchal and Roberts 2019) and were 0.0000046 mg/L in Europe (RIVM 2010) and 0.00013 mg/L in Australia/New Zealand (95% species protection; CRCCare 2017; EPAV 2017). The EPA did not derive a chronic PFOS criterion or benchmark for estuarine/marine water because of data limitations.

1.1.3 Previously Published Chronic Fish Tissue Criteria

There was a single previously derived fish tissue value for other jurisdictions. This value was a Canadian Federal Fish Tissue Guideline (FFTG) of 9.4 mg/kg whole-body wet weight (ww) (ECCC 2018). This value was derived by multiplying Canada's Federal Water Quality Guideline of 6.8 µg/L by a BAF of 1,378 L/kg. Canada's fish whole-body based Federal Water Quality Guideline (9.4 mg/kg ww) is significantly larger than the EPA's PFOS fish whole-body tissue criterion (0.201 mg/kg ww) because the EPA's value considered more recently published and relatively sensitive toxicity data that were not available at the time Canada's fish whole-body Water Quality Guideline was derived.

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Table 1-1. Previously Derived PFOS Toxicity Values and Thresholds.

State / Country of Applicability	Aquatic Life Protective Value (mg/L unless otherwise indicated)	Criteria or Benchmark and Calculation Approach	Source
Freshwater Acute			
Some European Countries	0.036	Maximum Acceptable Concentration calculated using the lowest acute (LC50) value of 3.6 mg/L for mysid (*Americamysis bahia)* ÷ by assessment factor of 100. Dataset includes freshwater and marine aquatic species, combined.	RIVM (2010)
Texas	0.021	Acute surface water benchmark calculated using U.S. EPA Great Lakes Initiative (GLI; (U.S. EPA 1995)) Tier I Methodology as reported in (Giesy et al. 2010). This is an acute surface water benchmark and does not represent a CWA Section 303(c) approved water quality standard for PFOS.	Giesy et al. (2010); TCEQ (2021)
Minnesota	0.085	Maximum Criterion (MC) calculated as the acute curve-fitted and extrapolated 10-d EC50 for midge (*Chironomus tentans*) of 170 µg/L, which serves as the Final Acute Value or FAV followed by ÷ 2. This draft value does not represent a CWA Section 303(c) approved water quality standard for PFOS.	STS/MPCA (2007)
Florida	0.53	Secondary Acute Value (SAV) calculated using U.S. EPA Great Lakes Initiative (GLI; U.S. EPA 1995) Tier II Methodology. FAV calculated as the lowest GMAV (unspecified) divided by a safety factor of 6.1. This value was released in a White Paper sponsored by Florida Department of Environmental Protection and is considered a draft eco-based surface water screening level. It is not a CWA Section 303(c) approved water quality standard.	Stuchal and Roberts (2019)

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State / Country of Applicability	Aquatic Life Protective Value (mg/L unless otherwise indicated)	Criteria or Benchmark and Calculation Approach	Source
Michigan	0.78	FAV of 1,557 µg/L calculated as the lowest Genus Mean Acute Value (GMAV) of 9,500 µg/L for fathead minnow (*Pimephales promelas*) ÷ by a safety factor of 6.1 (following U.S. EPA Great Lakes Initiative [(GLI; U.S. EPA 1995)]. The Acute Maximum Value (AMV) of 0.78 mg/L was then calculated as the FAV ÷ 2. This protective value is a translation of narrative water quality criteria and does not represent a CWA Section 303(c) approved water quality standard for PFOS.	EGLE (2010)
Marine Acute			
Some European Countries	0.0072	Maximum Acceptable Concentration calculated using the lowest acute value (LC_{50}) of 3.6 mg/L for a mysid (*Americamysis bahia*) ÷ by an assessment factor of 500. Dataset includes freshwater and marine aquatic species, combined.	RIVM (2010)
Florida	0.21	Secondary Acute Value (SAV) calculated using U.S. EPA Great Lakes Initiative (GLI; U.S. EPA 1995) Tier II Methodology. FAV calculated as the lowest GMAV (unspecified) divided by a safety factor of 21.9. This value was released in a White Paper sponsored by Florida Department of Environmental Protection and is considered a draft eco-based surface water screening level. It is not a CWA Section 303(c) approved water quality standard.	Stuchal and Roberts (2019)
Freshwater Chronic			
Some European Countries	0.000023	Maximum Permissible Concentration calculated using the lowest value (LOEC) of 0.0023 mg/L for *Chironomus tentans* (MacDonald et al. 2004) ÷ by an assessment factor (100). Dataset includes freshwater and marine aquatic species, combined.	RIVM (2010)

State / Country of Applicability	Aquatic Life Protective Value (mg/L unless otherwise indicated)	Criteria or Benchmark and Calculation Approach	Source
Canada	0.00680	Federal Water Quality Guideline (FWQG) calculated as the fifth percentile value from a Species Sensitivity Distribution (SSD) consisting of 20 species-specific values representing fish (5), amphibians (2), invertebrates (5), and plants and algae (8).	ECCC (2018)
Australia, New Zealand	0.00000023 (99% species protection - high conservation value systems)	Guidelines calculated from Species Sensitivity Distribution (SSD) consisting of 18 species-specific values for fish, amphibians, insects, crustaceans, and algae following the guidance of Warne et al. (2018) and Batley et al. (2014)	CRCCare (2017); EPAV (2017); HEPA (2020)
	0.00013 (95% species protection - slightly to moderately disturbed systems)		
	0.002 (90% species protection - highly disturbed systems)		
	0.031 (80% species protection - highly disturbed systems)		
California	0.00056 (99% species protection)	HC_1 calculated from an acute and chronic NOEC-based SSD as reported in SERDP Project ER18-1614 (SERDP 2019). Acute NOEC values were converted to chronic values using mean acute-to-chronic ratios derived from Giesy et al. (2010). This value represents an "Interim Final Environmental Screening Level" and does not represent a CWA Section 303(c) approved water quality Standard for PFOS.	RWQCB (2020); SERDP (2019)
Texas	0.0051	Acute surface water benchmark calculated using U.S. EPA Great Lakes Initiative (GLI; U.S. EPA 1995) Tier I Methodology as reported in Giesy et al. (2010). This is a chronic surface water benchmark and does not represent a CWA Section 303(c) approved water quality standard for PFOS.	Giesy et al. (2010); TCEQ (2021)

State / Country of Applicability	Aquatic Life Protective Value (mg/L unless otherwise indicated)	Criteria or Benchmark and Calculation Approach	Source
Minnesota	0.019	Chronic Criterion (CC) calculated as the FAV (170 µg/L) ÷ FACR (9.12) per Minnesota Rules Chapter 7050. Two species-specific ACRs and a default ACR were used to calculate the FACR. This draft value does not represent a CWA Section 303(c) approved water quality standard for PFOS.	STS/MPCA (2007)
Florida	0.037	Secondary Chronic Value (SCV) calculated using U.S. EPA Great Lakes Initiative (GLI; U.S. EPA 1995) Tier II Methodology with acute-to-chronic (ACR) of 14.5. SCV = SAV (530 µg/L) ÷ ACR (14.5) = 37 µg/L. This value was released in a White Paper sponsored by Florida Department of Environmental Protection and is considered a draft eco-based surface water screening level. It is not a CWA Section 303(c) approved water quality standard.	Stuchal and Roberts (2019)
Michigan	0.14	Final Chronic Value (FCV) calculated as the FAV (1,557 µg/L) ÷ FACR (11.35) per U.S. EPA Great Lakes Initiative (GLI; U.S. EPA 1995). Two species-specific ACRs and a default ACR were used to calculate the FACR. This protective value is a translation of narrative water quality criteria and does not represent a CWA Section 303(c) approved water quality standard for PFOS.	EGLE (2010)
Marine Chronic			
Australia, New Zealand	0.00000023 (99% species protection - high conservation value systems)	Guidelines calculated from SSD following the guidance of Warne et al. (2018) and Batley et al. (2014) and consisting of nine species-specific values representing fish (2), echinoderms (2), crustaceans (2), mollusc (1), and algae (2). Note: Per HEPA (2020) freshwater values are to be used on an interim basis until final marine guideline values can be set using the nationally agreed process under the Australian and New Zealand Guidelines for Fresh and Marine Water Quality	CRCCare (2017); EPAV (2017); HEPA (2020)
	0.00013 (95% species protection - slightly to moderately disturbed systems)		
	0.002 (90% species protection - highly disturbed systems)		
	0.031 (80% species protection - highly disturbed systems)		

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State / Country of Applicability	Aquatic Life Protective Value (mg/L unless otherwise indicated)	Criteria or Benchmark and Calculation Approach	Source
Some European Countries	0.0000046	Maximum Permissible Concentration calculated using the lowest value (LOEC) of 0.0023 mg/L for *Chironomus tentans* divided by an assessment factor (500). Dataset includes freshwater and marine aquatic species, combined.	RIVM (2010)
Texas	0.000294	Default guidelines calculated from SSD following the guidance of Warne et al. (2018) and Batley et al. (2014) and consisting of nine of 16 species-specific values as reported in CRCCare (2017). This is a chronic surface water benchmark and does not represent a CWA Section 303(c) approved water quality standard for PFOS.	CRCCare (2017); TCEQ (2021)
California	0.0026 (99% species protection)	HC_1 calculated from an acute and chronic NOEC-based SSD as reported in SERDP Project ER18-1614 (2019). Acute NOEC values were converted to chronic values using mean acute-to-chronic ratios derived from Giesy et al. (2010). This value represents an "Interim Final Environmental Screening Level" and does not represent a CWA Section 303(c) approved water quality Standard for PFOS.	RWQCB (2020); SERDP (2019)
Florida	0.013	Secondary Chronic Value (SCV) calculated using U.S. EPA Great Lakes Initiative (GLI; U.S. EPA 1995) Tier II Methodology with acute-to-chronic (ACR) of 15.6. SCV = SAV (210 µg/L) ÷ ACR (15.6) = 13 µg/L. This value was released in a White Paper sponsored by Florida Department of Environmental Protection and is considered a draft eco-based surface water screening level. It is not a CWA Section 303(c) approved water quality standard.	Stuchal and Roberts (2019)
Fish Tissue			
Canada	9.4 mg/kg whole body ww fish tissue	Federal Fish Tissue Guideline (FFTG) where FFTG of 9.4 mg/kg ww = (FWQG of 6.8 µg/L) * (BAFgeomean of 1378 L/kg)	ECCC (2018)

1.2 Overview of Per- and Polyfluorinated Substances (PFAS)

PFOS, and its salts, belong to the per- and polyfluorinated substances (PFAS) group of chemicals. PFAS are a large group of structurally diverse anthropogenic chemicals that include PFOA, PFOS, and thousands of other fully or partially fluorinated chemicals. There are many families or subclasses of PFAS, and each contains many individual structural homologues and can exist as either branched-chain or straight-chain isomers (Buck et al. 2011; U.S. EPA 2021a). These PFAS families can be divided into two primary categories: non-polymers and polymers. The non-polymer PFAS include perfluoroalkyl and polyfluoroalkyl substances. Polymer PFAS include fluoropolymers, perfluoropolyethers, and side-chain fluorinated polymers (Table 1-2). Several U.S. federal, state, and industry stakeholders as well as European entities have posited various definitions of what constitutes a PFAS. OECD, an international organization comprised of 38 countries, recently published practical guidance regarding the terminology of PFAS (U.S. EPA 2021a). The OECD-led "Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance" workgroup provided an updated definition of PFAS, originally posited in part by Buck et al. (2011), as follows: "PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e. with a few noted exceptions, any chemical with at least a perfluorinated methyl group (–CF3) or a perfluorinated methylene group (–CF2–) is a PFAS". It is not within the scope of this framework to compare and contrast the various definitions, or the nuances associated with defining or scoping PFAS; rather the reader of this document is referred to OECD (2021) for review. Generally, the structural definition of PFAS includes chemicals that contain at least one of the following three structures:

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- R-(CF_2)-CF(R′)R″, where both the CF_2 and CF moieties are saturated carbons, and none of the R groups can be hydrogen (TSCA draft definition);
- R-CF_2OCF_2-R′, where both the CF_2 and CF moieties are saturated carbons, and none of the R groups can be hydrogen; and
- $CF_3C(CF_3)$R′R ″, where both the CF_2 and CF moieties are saturated carbons, and none of the R groups can be hydrogen.

It should also be noted that what defines or constitutes a PFAS may change or evolve over time and under different purviews (e.g., federal, state, international).

Table 1-2. Two Primary Categories of PFAS[1].

PFAS Non-polymers	Structural Elements	Example PFAS Families
Perfluoroalkyl acids	Compounds in which all carbon-hydrogen bonds, except those on the functional group, are replaced with carbon-fluorine bonds	Perfluoroalkyl carboxylic and sulfonic acids (e.g., PFOA, PFOS), perfluoroalkyl phosphonic and phosphinic acids, perfluoroalkylether carboxylic and sulfonic acids
Polyfluoroalkyl acids	Compounds in which all carbon-hydrogen bonds on at least one carbon (but not all) are replaced with carbon-fluorine bonds	polyfluoroalkyl carboxylic acids, polyfluoroalkylether carboxylic and sulfonic acids
PFAS Polymers	**Structural Elements**	**Example PFAS Families**
Fluoropolymers	Carbon-only polymer backbone with fluorines directly attached	polytetrafluoroethylene, polyvinylidene fluoride, fluorinated ethylene propylene, perfluoroalkoxyl polymer
Polymeric perfluoropolyethers	Carbon and oxygen polymer backbone with fluorines directly attached to carbon	F-(CmF2mO-)nCF3, where the CmF2mO represents -CF2O, -CF2CF2O, and/or -CF(CF3)CF2O distributed randomly along polymer backbone
Side-chain fluorinated polymers	Non-fluorinated polymer backbone with fluorinated side chains with variable composition	n:1 or n:2 fluorotelomer-based acrylates, urethanes, oxetanes, or silicones; perfluoroalkanoyl fluorides; perfluoroalkane sulfonyl fluorides

1: Amalgamation of information from Figure 9 of OECD (2021) and Buck et al. (2011).

PFOS belongs to the perfluoroalkyl acids (PFAAs) of the non-polymer perfluoroalkyl substances category of PFAS. PFAAs are among the most researched PFAS (Wang et al. 2017).

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The PFAA family includes perfluoroalkyl carboxylic, sulfonic, sulfinic, phosphonic, and phosphinic acids (Table 1-3). PFAAs are highly persistent and are frequently found in the environment (Ahrens 2011; Wang et al. 2017). PFAAs may dissociate to their anions in aqueous environmental media, soils, or sediments depending on their acid strength (pK_a value). The protonated and anionic forms may have different physiochemical properties.

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Table 1-3. Classification and Chemical Structure of Perfluoroalkyl Acids (PFAAs).[1]

Classification	Functional Group	Examples
Perfluoroalkyl carboxylic acids (PFCAs) Or Perfluoroalkyl carboxylates (PFCAs)	-COOH	Perfluorooctanoic acid (PFOA)
	$-COO^-$	Perfluorooctanoate (PFOA)
Perfluoroalkane sulfonic acids (PFSAs) Or Perfluorokane sulfonates (PFSAs)	$-SO_3H$	Perfluorooctane sulfonic acid (PFOS)
	$-SO_3^-$	Perfluorooctane sulfonate (PFOS)[2]
Perfluoroalkyl sulfinic acids (PFSIAs)	$-SO_2H$	Perfluorooctane sulfinic acid (PFOSI)
Perfluoroalkyl phosphonic acids (PFPAs)	$-P(=O)(OH)_2$	Perfluorooctyl phosphonic acid (C8-PFPA)
Perfluoroalkyl phosphinic acids (PFPiAs)	$-P(=O)(OH)(C_mF_{2m+1})$	Bis(perfluorooctyl) phosphinic acid (C8/C8-PFPiA)
Perfluoroalkylether carboxylic acids (PFECAs)	$CF_3(OCF_2)_nCOOH$	Perfluoro (3,5,7-trioxaoctanoic) acid
Perfluoroalkylether sulfonic acids (PFESAs)	$CF_3(OCF_2)_nSO_3H$	6:2 chlorinated polyfluorinated ether sulfonate (6:2 Cl-PFESA)
Perfluoroalkyl dicarboxylic acids (PFdiCAs)	$HOOC-C_nF_{2n}-COOH$	9:3 Fluorotelomer betaine
Perfluoroalkane disulfonic acids (PFdiSAs)	$HO_3S-C_nF_{2n}-SO_3H$	Perfluoro-1,4-disulfonic acid

[1] Modified from Buck et al. (2011); OECD (2021).

[2] The anionic form is most prevalent in the aquatic environment.

Perfluoroalkane (or -alkyl) sulfonic acids (PFSAs), including PFOS, consist of a general chemical structure (of $C_nF_{2n+1}SO_3H$ for PFOS; see Figure 1-1). This chemical structure makes PFOS extremely strong and stable, and resistant to hydrolysis, photolysis, microbial degradation, and metabolism (see Section 2.3) (Ahrens 2011; Beach et al. 2006; Buck et al. 2011). Furthermore, PFOS has been classified as persistent, bioaccumulative, and toxic (Ahrens 2011; Buck et al. 2011; Lindstrom et al. 2011; OECD 2002).

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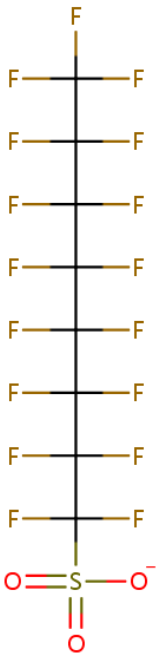


Figure 1-1. Chemical Structure of Linear Perfluorooctane Sulfonate (PFOS).
Source: United States EPA Chemistry Dashboard; https://comptox.epa.gov/dashboard

1.2.1 Physical and Chemical Properties of PFOS

Physical and chemical properties along with other reference information for PFOS are provided in Table 1-4. These physical and chemical properties help to define the environmental fate and transport of PFOS in the aquatic environment.

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Table 1-4. Chemical and Physical Properties of PFOS.

Property	PFOS, acidic form[1]	Source
Chemical Abstracts Service Registry Number (CAS No.)	1763-23-1	
Chemical Abstracts Index Name	1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-1-octanesulfonic acid	
Synonyms	Perfluorooctane sulfonic acid; heptadecafluoro-1-octane sulfonic acid; PFOS acid; perfluorooctane sulfonate	
Chemical Formula	$C_8HF_{17}O_3S$	
Molecular Weight (grams per mole [g/mol])	500.13	Lewis (ed. 2004); HSDB (2012); SRC (2016)
Color/Physical State	White powder (potassium salt)	OECD (2002)
Boiling Point	258–260 °C	SRC (2016)
Melting Point	No data	
Vapor Pressure	2.0×10^{-3} millimeters Mercury (mm Hg) at 25°C (estimate)	HSDB (2012)
Henry's Law Constant	Not measurable; not expected to volatilize from aqueous solution ($< 2.0 \times 10^{-6}$)	ATSDR (2015)
K_{OW}	Not measurable	EFSA (2008); ATSDR (2015)
Organic carbon water partitioning coefficient (K_{OC})	2.57	Higgins and Luthy (2006)
Estimated pKa	3.27 (no empirical measurements available)	Brooke et al. (2004)
Solubility in Water	680 mg/L	OECD (2002)
Half-Life in Water	Stable	UNEP (2006)
Half-Life in Air	Stable	UNEP (2006)

[1] PFOS is commonly produced as a potassium salt (CAS No. 2795-39-3). Properties specific to the salt are not included.

PFOS is moderately water soluble, nonvolatile, and stable (Beach et al. 2006; Young and Mabury 2010). PFOS is solid at room temperature with a low vapor pressure. No direct measurement of the acid dissociation constant (pKa) is available. However, PFOS is considered to have a low pKa, which is based on a calculated pKa of 3.27 provided from Finland in a comment to Brooke et al. (2004). Therefore, PFOS is deemed to be a strong acid (Brooke et al. 2004). PFOS introduced as a salt will dissociate into ionic components when in natural water at a

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neutral pH and is commonly present as a PFOS anion in solution (Beach et al. 2006; Giesy et al. 2010; Young and Mabury 2010). The PFOS anion forms strong ion pairs with many cations, resulting in less solubility in waters that contain great amounts of dissolved solids. Thus, PFOS solubility in saltwater is approximately 12 mg PFOS/L compared to 589 mg PFOS/L in pure water (Beach et al. 2006). PFOS is reported to have a mean solubility of 56 mg PFOS/L in pure octanol (OECD 2002). These solubility data suggest that any form of PFOS discharged into a water source tends to remain dissolved, unless the PFOS was sorbed to particulate matter or assimilated by organisms (which are both discussed further in Sections 2.2 and 2.5, respectively) (OECD 2002).

Due to the surfactant properties of PFOS, it forms three layers when added to octanol and water in a standard test system used to measure an n-octanol-water partition co-efficient (K_{ow}), thus preventing direct measurement (Giesy et al. 2010; OECD 2002). Although a K_{ow} cannot be directly measured, a K_{ow} for PFOS has been estimated from its individual water and octanol solubilities (Giesy et al. 2010); however, the veracity of such estimates is uncertain (OECD 2002). Lacking a reliable K_{ow} for PFOS precludes application of K_{ow}-based models commonly used to estimate various physiochemical properties for organic compounds, including bioconcentration factors and soil adsorption coefficients. Further, the unusual characteristics of PFOS would bring into question the use of K_{ow} as a predictor of environmental behavior. For example, bioaccumulation of PFOS is thought to be mediated via binding to proteins rather than partitioning into lipids (Giesy et al. 2010; OECD 2002), the latter being the theoretical basis for K_{ow}-based prediction of bioaccumulation.

PFOS is not expected to volatilize from aqueous solution based on its vapor pressure and predicted Henry's law constant < 2.0×10^{-6} (Beach et al. 2006). In 2002, OECD classified PFOS

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as a type 2, non-volatile chemical that has a very low or possibly negligible volatility (Beach et al. 2006; Giesy et al. 2010; OECD 2002).

2 PROBLEM FORMULATION

A problem formulation provides a strategic framework for water quality criterion development under the CWA by focusing on the most relevant chemical properties and endpoints. In the problem formulation, the purpose of the assessment is stated, the problem is defined, and a plan for analyzing and characterizing risk is developed. The structure of this problem formulation is consistent with the EPA's Guidelines for Ecological Risk Assessment (U.S. EPA 1998).

2.1 Overview of PFOS Sources

2.1.1 Manufacturing of PFOS

PFOS is used in a variety of products including surface treatments for soil and stain resistance, coating of paper as part of a sizing agent formulation, and in specialized applications such as firefighting foams. PFOS is produced through electrochemical fluorination (ECF) in which an organic raw material, such as octane sulfonyl fluoride (OSF; $C_8H_{17}SO_2F$) in the case of PFOS, undergoes electrolysis in anhydrous hydrogen fluoride solution. This electrolysis leads to the replacement of all the hydrogen atoms by fluorine atoms and results in perfluorooctanesulfonyl fluoride (POSF; $C_8F_{17}SO_2F$), which is the major raw material used to manufacture PFOS (Figure 2-1; Buck et al. 2011). The base-catalyzed hydrolysis of POSF results in PFOS and its salts (Lehmler 2005). ECF results in a mixture of linear and branched chain perfluorinated isomers and homologues, with ratios of linear to branched perfluorinated carbon chains of roughly 70 to 80% linear and 20 to 30% branched for PFOS synthesis depending on how the process is controlled (De Voogt 2010). All compounds produced from POSF and other neutral PFAS with sufficient chain length and a sulfur group have the potential to degrade or transform into PFOS, and therefore have been considered to be "PFOS equivalents" and potential sources of PFOS to the aquatic environment (see Section 2.4)(Ahrens

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2011; Lindstrom et al. 2011). PFOS is used in a variety of products including surface treatments for soil and stain resistance, coating of paper as part of a sizing agent formulation, and in specialized applications such as firefighting foams.

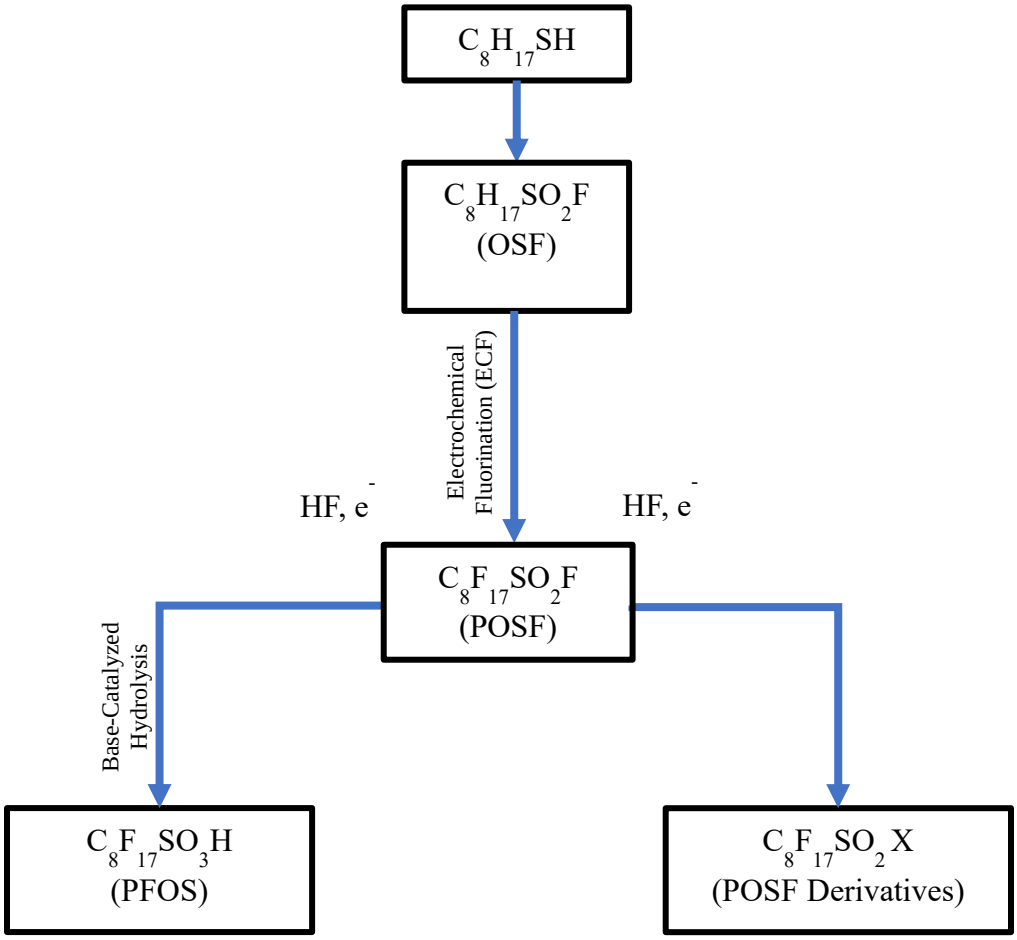


Figure 2-1. Synthesis of PFOS by electrochemical fluorination (ECF).
Modified from Buck et al. (2011).

The manufacture of PFOS started in 1949 with Minnesota Mining and Manufacturing (name changed later to the 3M Company) (3M Company 1999). Prior to 2000, the 3M Company was the major producer of POSF, the raw material used to make PFOS (Figure 2-1), with smaller producers in Europe and Asia (Paul et al. 2009; U.S. EPA 2000a). In 2000, the 3M company manufactured approximately 78% of the estimated global POSF production (approximately

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3,665 tons of the 4,650 tons produced globally; (approximately 3,665 tons of the 4,650 tons produced globally; OECD 2002). The estimated total cumulative production of POSF is between 44,000 and 96,000 tons (Paul et al. 2009; Prevedouros et al. 2006; Smithwick et al. 2006). Information on previous and current production of POSF from Asia and other production sources is limited (Paul et al. 2009; Prevedouros et al. 2006; Smithwick et al. 2006).

In May 2000, following negotiations between the EPA and 3M, the 3M Company agreed to voluntary phase out and find substitutes for PFOS chemistry used to produce all but a few small applications (i.e., aqueous film-forming foams (AFFF), and hard chrome plating mist suppression) across their range of products by 2002 (Lindstrom et al. 2011; U.S. EPA 2000a). Starting around the same time, a series of Significant New Use Rules (SNUR) were also put into place by the EPA to restrict the production and use of materials that contain PFOS and its precursors in the U.S. (Lindstrom et al. 2011). In 2009, PFOS and related compounds were listed under Annex B of the Stockholm Convention on Persistent Organic Pollutants; restricting global manufacturing and use of PFOS (Ahrens 2011; OECD 2002). Homologues, neutral precursor compounds, and new classes of PFAS continue to be produced and therefore, are potential sources of PFOS (Ahrens 2011). Assuming there was no step-up production of PFOS and its precursors to offset the phase-out by the 3M Company, the production is estimated to be approximately 1,000 tons from 2002 and onward (Paul et al. 2009). However, while industrialized countries, like the U.S., phased-out the use of PFOS and its precursors, producers in other countries, such as China and Brazil, have scaled up their production to fill remaining demand (Wang et al. 2013). Despite the wide use in an array of industrial and consumer products globally, information on the sources, volumes, and emission of PFOS and its precursors are limited (Paul et al. 2009; Zhang et al. 2016).

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2.1.2 Sources of PFOS to Aquatic Environments

Aquatic environments and soil are thought to serve as a reservoir of PFOS, with 42,000 tons emitted to aquatic environments compared to 235 tons released into to air between 1980 and 2002 (Paul et al. 2009). Unlike other contaminants commonly found in aquatic ecosystems, such as metals for example, PFAS are synthetic compounds with no natural source. Thus, the occurrence of any PFAS in the environment is an indication of anthropogenic sources (Ahrens 2011). The occurrence of PFOS in aquatic environments can be attributed to both point and non-point sources, entering aquatic environments from industrial and consumer products during manufacturing, along supply chains, and during product use and/or disposal (Ahrens 2011; Ahrens and Bundschuh 2014; Kannan 2011; Paul et al. 2009). However, quantitative assessments of PFOS production, point and non-point source discharges, and environmental measurements are limited compared to other persistent, bioaccumulative pollutants (Ahrens and Bundschuh 2014; Zhang et al. 2016).

Potential point sources of PFOS to the aquatic environment include both industrial facilities and municipal wastewater treatment plants (WWTPs). Additional point sources may include surface water runoff from industrial use sites such as metal plating facilities, areas that have received AFFF applications, landfills, and contaminated soils. Of these, industrial facilities, specifically those for fluorochemical manufacturing and other use facilities, are a primary source of PFOS to aquatic systems (Ahrens et al. 2011a; Houtz et al. 2016; Sedlak et al. 2017). Estimated total global releases to water arising from discharge of PFOS during manufacturing from 1970 to 2002 ranged between 230 and 1,450 tons (Paul et al. 2009).

Potential non-point PFOS sources to aquatic environments include: dry and wet atmospheric deposition, runoff from contaminated soils, runoff from metal plating facilities, the runoff or discharge of contaminated groundwater, particularly from the use of fire-fighting

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foams, and land application of contaminated biosolids (Ahrens 2011; Kannan 2011; OECD 2002; Paul et al. 2009). Identification of non-point PFOS sources and understanding their relative contribution to aquatic ecosystems is difficult due to the lack of sufficient measured environmental data (Ahrens 2011; Paul et al. 2009). Overall, the presence of non-point PFOS sources and their relative contributions are reported to be dependent on the aquatic system, air, groundwater, and soil levels, and nearby land uses. For example, concentrations of PFAS, including PFOS, have been influenced by urban land use (Ahrens 2011; Zhang et al. 2016). Overall, PFOS occurrence in aquatic environments is driven by legacy PFOS sources since PFOS use in the United States was voluntarily phased out by 2002 and SNUR were put into place by the EPA to restrict the production and use of PFOS and its precursors (Lindstrom et al. 2011). However, PFAS concentrations in the environment in general continue to be positively correlated with human population density. For example, PFOS was detected in aquatic systems at elevated concentrations (ranging between 97 and 1,371 ng/L) in densely populated areas of the U.S. and Europe (Zhang et al. (2016) and Loos et al. (2009); respectively), and Paul et al. (2009) estimated the total global PFOS emissions to air and water from 1970 to 2009 resulting from consumer use and disposal to be between 420 and 2,100 tons.

Importantly, PFAS are still produced that can transform or degrade into compounds belonging to the PFSAs family, including PFOS (Ahrens 2011). PFAS precursors such as perfluoroalkyl sulfonamidoacetic acids (FASAAs) and perfluoroalkyl sulfonamidoethanols (FASEs) are known to metabolically transform and degrade to PFOS, respectively (Ahrens and Bundschuh 2014; Benskin et al. 2009; Boulanger et al. 2005b; Buck et al. 2011; Lange 2000; Liu and Mejia Avendano 2013; Plumlee et al. 2008; Rhoads et al. 2008; Wang et al. 2017). However, the understanding of these transformation processes is limited, and additional work is needed to

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fully understand these processes and their role as sources of PFOS to aquatic environments (Buck et al. 2011; Lau et al. 2007; Liu and Mejia Avendano 2013; Wang et al. 2017). Degradation of precursors represents a potentially significant source of PFOS to the aquatic environment, particularly since PFOS production within the U.S. has not occurred since 2002 (Buck et al. 2011; Liu and Mejia Avendano 2013). Nevertheless, PFOS-treated articles, such as fabrics, paper, and other treated materials, are still being imported into the U.S. and are ultimately, at least in part, released into the environment (Allred et al. 2015; Lang et al. 2016; Liu et al. 2014d). The importation of PFOS treated articles is considered as production under the Toxic Substances Control Act (TSCA) (U.S. EPA 2020).

2.2 Environmental Fate and Transport of PFOS in the Aquatic Environment

2.2.1 Environmental Fate of PFOS in the Aquatic Environment

PFOS has low volatility in ionized form but can adsorb to particles in air where it can be transported globally, including remote locations (Benskin et al. 2012; Butt et al. 2010). PFOS is water soluble and has been found in surface water, ground water, and drinking water. Because of the relatively low K_{oc} of PFOS, it does not easily adsorb to sediments and tends to stay in the water column (Ahrens 2011; Beach et al. 2006; Giesy et al. 2010; Higgins and Luthy 2006).

PFOS can be re-emitted to aquatic environments from PFOS contaminated soil, groundwater, ice, and sediment (see Section 2.3). Sediment may be an important sink of PFOS in the aquatic environment (Ahrens 2011). The movement of PFOS between groundwater, surface water, and sediment depends on the chemical properties of PFOS and site-specific physiochemical characteristics (including pH, temperature, organic carbon content, and salinity) of the aquatic environment. In general, PFOS may sorb to sediments (with a Kd greater than 1 mL/g; (with a Kd greater than 1 mL/g; Giesy et al. 2010). However, this sorption to sediments is limited and PFOS has a K_{oc} of 2.57 indicating that PFOS is relatively mobile in water and the

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physicochemical characteristics of the sediment ultimately influence the sorption of PFOS (Ahrens 2011; Higgins and Luthy 2006). While the release of PFOS from the transformation of other PFAS and historical products still in use (e.g., consumer goods manufactured, imported and/or obtained before the PFOS discontinuation and regulations) are expected to continue into the future, the re-emissions of PFOS from existing sinks are assumed to be decreasing since the restrictions and regulations of PFOS have gone into place (Ahrens 2011; Ahrens and Bundschuh 2014; Paul et al. 2009; Washington and Jenkins 2015; Washington et al. 2015).

In the water column, and other environmental compartments, PFOS is stable and resistant to hydrolysis, photolysis, volatilization, and biodegradation (see Appendix M)(Beach et al. 2006; OECD 2002). The persistence of PFOS has been attributed to the strong carbon-fluorine (C-F) bond. Additionally, there are limited indications that naturally occurring defluorinating enzymes exist that can break a C-F bond. Consequently, no biodegradation or abiotic degradation processes for PFOS are known. The physiochemical properties discussed in Table 1-4 result in PFOS being highly persistent in the aquatic environment (Ahrens 2011). In aquatic environments, the only dissipation mechanisms for PFOS are physical mechanisms, such as environmental dilution, offsite transport, plant uptake, and sorption.

2.2.2 Environmental Transport of PFOS in the Aquatic Environment

The environmental fate of PFOS, outlined in the previous section (Section 2.2.1) plays a role in the environmental transport of PFOS (Ahrens 2011). PFOS is either distributed in biota (via bioaccumulation discussed in Section 2.5) or abiotic matrices (such as water and sediment). Sediment in particular can act as a sink for PFOS. However, the role of sediment as a sink or source by resuspension is not well understood (Ahrens 2011).

The distribution of PFOS is widespread, including to remote regions despite the limited number of manufacturing facilities and/or small population sizes typically found in these areas

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(Benskin et al. 2012; Butt et al. 2010). PFOS has been detected in water, sediment, and biota samples from aquatic environments in remote areas (Butt et al. 2010; Giesy and Kannan 2001; Houde et al. 2006b; Yamashita et al. 2008). To date, the dominant transport pathway for PFOS to remote regions has not been conclusively characterized and much of the focus has been on marine systems, with few studies in freshwater environments (Ahrens 2011; Butt et al. 2010; Giesy and Kannan 2002). Additionally, the relative importance of each potential transport pathway is difficult to accurately determine (Butt et al. 2010; Young and Mabury 2010). Many researchers suggest that the dominant mechanism of PFOS transport occurs through water as the anionic form of PFOS, which is the most commonly found form in the aquatic environment, is less volatile (see Section 2.2.1 above) and has a high water solubility. These characteristics make partitioning to and transport through the air less likely (Butt et al. 2010; Giesy and Kannan 2002). However, PFOS transport through water is likely the dominant mechanism on more local scales (e.g., within a waterbody or watershed), and is likely not the prevailing transport pathway of PFOS to remote regions given the considerations of the long distances. Instead, atmospheric transport is likely the main mechanism of PFOS transport to remote regions. Another potential source to remote regions is the indirect formation of PFOS through transformation of other PFAS, particularly volatile precursors (see Section 2.3)(Butt et al. 2010; Wang et al. 2015; Young and Mabury 2010).

Volatile PFOS precursors, which may reach remote locations via atmospheric deposition themselves, may subsequently be metabolized to PFOS in aquatic organisms (Giesy and Kannan 2002). In all likelihood, the continued presence of PFOS in remote areas may be due to multiple exposure pathways, including those caused by direct production and use of PFOS itself as well as degradation and transformation of precursor compounds (Armitage et al. 2009). To better

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comprehend both environmental transport and exposure to PFOS, the following needs to be better understood: 1) the potential transformation, metabolism, and bioaccumulation of PFOS and its precursors (particularly partitioning behavior, such as tissue distribution and lipophilicity); 2) explicit biotransformation pathways and pharmacokinetics; and 3) atmospheric fate and transport of PFOS and its precursors (Armitage et al. 2009).

2.3 Transformation and Degradation of PFOS Precursors in the Aquatic Environment

Transformation and degradation processes of various PFAS are potential sources of PFOS to the aquatic environment (see Section 2.1.2 above). PFAS are still produced that can transform or degrade into compounds belonging to the PFSAs family of PFAS, including PFOS (Ahrens 2011). Thus, transformation and degradation of PFAS should be considered as an ongoing potential source of PFOS to the aquatic environment. Currently, the understanding of these transformation and degradation processes is limited, particularly for PFOS. There is little understanding of which PFAS and how much of each has been or will be released into the aquatic environment (Liu and Mejia Avendano 2013; Wang et al. 2017). Additional work is needed to fully understand the details of these processes and the occurrence of the compounds to better comprehend their role as a source of PFOS to aquatic environments (Lau et al. 2007).

These transformation and degradation pathways are dependent on environmental conditions, degradation kinetics, and the chemical structures and properties of the individual PFAS precursors and volatile PFAS (Buck et al. 2011; Butt et al. 2014; Liu and Mejia Avendano 2013). Of particular importance is the environmental stability of key chemical linkages (such as esters and ethers) as the stability of these chemical linkages determines the stability of the overall PFAS (Liu and Mejia Avendano 2013). The most well studied PFAS precursors are fluorotelomer-based compounds, which are produced through telomerization technology and are

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associated with PFOA as the final product (Buck et al. 2011; Liu and Mejia Avendano 2013). In contrast, perfluoroalkane sulfonamido derivatives and other PFAS, such as side-chain-fluorinated polymers, are not as well studied.

It is essential to understand the biodegradation of volatile PFAS, such as perfluroalkane sulfonamido derivatives as their degradation is directly linked with PFOS generation in the environment (Liu and Mejia Avendano 2013). Most published studies on the degradation of perfluoroalkane sulfonamido derivatives focus on those with eight fluorinated carbons since PFOS is a final product (Buck et al. 2011). *N*-ethyl perfluorooctane sulfonamidoethanol (EtFOSE) in particular is the most commonly studied.

2.3.1 Degradation of perfluoroalkane sulfonamido derivatives

Perfluoroalkane sulfonamido derivatives, including perfluoroalkane sulfonamides, sulfonamidoethanols, sulfonamidoethyl acrylates, and sulfonamidoethyl methacrylates, are final products on their own and are important building blocks for further synthesis (Buck et al. 2011). The various derivatives have been found to degrade into PFSAs, such as PFOS when sufficient chain length is present, and are intermediates along the transformation pathway. These derivatives include members of the *N*-ethyl perfluoroalkane sulfonamidoacetic acids (EtFASAAs), *N*-ethyl perfluoroalkane sulfonamides (EtFASAs), perfluoroalkane sulfonamidoacetic acids (FASAAs), perfluoroalkane sulfonamids (FASAs), FASA *N*-glucuronides, and perfluoroalkane sulfinic acids (PFSiAs; Buck et al. 2011). Additionally, in the environment *N*-alkyl perfluoroalkane sulfonamidoethyl acrylates and methacrylates (and polymers based on them) may undergo hydrolysis of the ester linkages to produce *N*-alkyl perfluoroalkane sulfonamidoethanols (FASEs; Buck et al. 2011).

In particular, several studies have demonstrated that EtFOSE, a member of the *N*-alkyl perfluoroalkane sulfonamidoethanols of the perfluoroalkane sulfonamido substances, degrades

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into PFOS (Benskin et al. 2009; Boulanger et al. 2005b; Hatfield 2001; Lange 2000; Plumlee et al. 2009; Rhoads et al. 2008). EtFOSE was a product of ECF and was a precursor compound for the synthesis of other products such as phosphate esters that were used to manufacture paper protectors (3M Company 1999). Several studies have investigated the degradation of EtFOSE and all found that it is prone to degradation (Benskin et al. 2009; Boulanger et al. 2005b; Hatfield 2001; Lange 2000; Plumlee et al. 2009; Rhoads et al. 2008).

The overall pathway of EtFOSE degradation was determined to be the major difference between these studies (Figure 2-2). Rhoads et al. (2008) determined that EtFOSA could undergo direct dealkylation to form perfluorooctane sulfonamide (FOSA; as shown by the red arrow in Figure 2-2). Lange (2000) suggested that PFOA could be formed as a minor end product through an abiotic one-electron transfer mechanism from perfluorooctane sulfinic acid (PFOSI; demonstrated by the blue arrow in (Figure 2-2). In contrast, the other studies did not find PFOA to be a degradation product (Benskin et al. 2013; Boulanger et al. 2005b; Rhoads et al. 2008). Further, in the aerobic biodegradation studies, the rate limiting step was determined to be the degradation of *N*-ethyl perfluorooctane sulfonamidoacetic acid (EtFOSAA) and consequently EtFOSAA was the major degradation product rather than PFOS (Liu and Mejia Avendano 2013). Nevertheless, the degradation of EtFOSE resulted in the formation of PFOS as one of the final degradation products. In contrast, in the abiotic degradation studies, PFOS and PFOSI were either present at trace concentrations or were not observed (Hatfield 2001; Plumlee et al. 2009). Instead FOSA was considered to be the stable end product (Plumlee et al. 2009). The differences in the degradation pathways observed in the literature can likely be attributed to environmental conditions (Buck et al. 2011; Liu and Mejia Avendano 2013). Nevertheless, these pathways demonstrated that degradation of EtFOSE resulted in the formation of PFOS and should be

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considered a potential source of PFOS to the aquatic environment. However, currently the relative contribution of this potential source to the aquatic environment cannot be quantified (Buck et al. 2011; Liu and Mejia Avendano 2013).

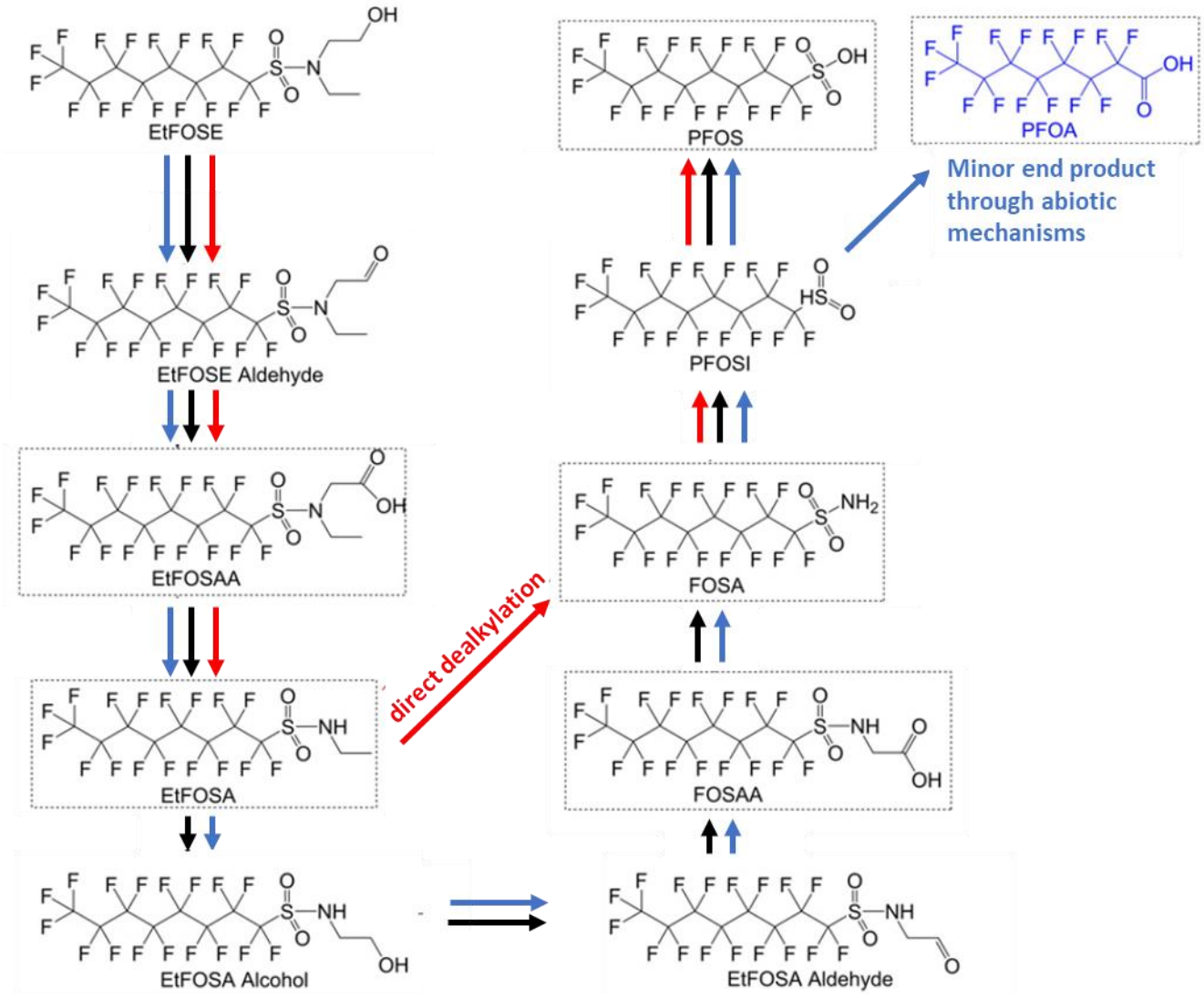


Figure 2-2. Aerobic Biodegradation of EtFOSE in Activated Sludge.
Black arrows show the Aerobic Biodegradation pathway as described by Liu and Mejia Avendano (2013). Blue pathway was observed by Lange (2000). Red pathway was observed by Rhoads et al. (2008). Semi-stable compounds are shown inside boxes.
Modified from: Liu and Mejia Avendano (2013).

2.3.2 Perfluorooctane sulfonamide-based side-chained polymers

In contrast to some other PFAS described in Section 1.2, fluorinated side-chain polymers do not have the per- or polyfluorinated backbone. Instead, fluorinated side-chain polymers consist of a variable composition with per- and polyfluoroalkyl side chains (Buck et al. 2011). The side chains of each of these polymer types may serve to transform into PFAS. Currently, little is known about these transformation processes (Liu and Mejia Avendano 2013). Given the high production volume of perfluorooctane-sulfonamide-based side-chain polymers prior to 2002, these fluorinated side-chain polymers may contribute to the levels of PFAS in the environment. It remains unknown how much these polymers contribute to the PFSAs in the environment (Liu and Mejia Avendano 2013). However, this transformation process is expected to occur over a long period of time (e.g., > 1,000 years) and may be a relatively small contributor of PFAS, including PFOS, in the environment (Buck et al. 2011).

2.3.3 Fluoroalkyl surfactants used in AFFFs

The release of AFFF during firefighting activities has been determined to be a substantial source of PFOS to the aquatic environment (see Section 2.1.2). Since 2002, fluorinated alternatives to PFAAs have been used to manufacture AFFF (Buck et al. 2011; Wang et al. 2013). The ten classes of AFFF chemicals have been identified and show that the new formulations of AFFF include the eight carbon perfluoroalkyl moiety (Place and Field 2012). Some of these fluorinated alternatives may undergo transformation and degradation processes and therefore may contribute to the levels of PFOS occurring in the aquatic environment (Liu and Mejia Avendano 2013). However, additional details about the transformation and degradation processes, including specific transformation pathways, the time to undergo transformation to produce a final product, and the influence of the environmental condition, are lacking at this time (Liu and Mejia Avendano 2013; Wang et al. 2013).

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2.4 Environmental Monitoring of PFOS in Abiotic Media

PFOS has been detected in a variety of environmental abiotic matrices in aquatic environments around the globe. These abiotic media include surface water, soils, sediments, groundwater, air, and ice caps (Butt et al. 2010; Lau et al. 2007). Water is expected to be the primary environmental medium in which PFOS is found (Lau et al. 2007). Occurrence and detection of PFOS in surface waters is described below and occurrence in other abiotic media is described in Appendix N.

2.4.1 PFOS Occurrence and Detection in Ambient Surface Waters

2.4.1.1 Summary of PFOS occurrence and concentrations across the U.S.

PFOS is one of the dominant PFAS detected in aquatic ecosystems, along with PFOA (Ahrens 2011; Benskin et al. 2012; Dinglasan-Panlilio et al. 2014; Nakayama et al. 2007; Remucal 2019; Zareitalabad et al. 2013). Despite its wide use and persistence in the aquatic environment, current information on the distribution of PFOS in surface waters of the U.S. is relatively limited (Jarvis et al. 2021). Available data are largely collected from freshwater systems in eastern states, with most of the current, published PFOS occurrence data focused on a handful of study areas with known manufacturing or industrial uses of PFAS and among areas of known AFFF use, such as fire-training areas on military bases (Figure 2-3 and Appendix N).

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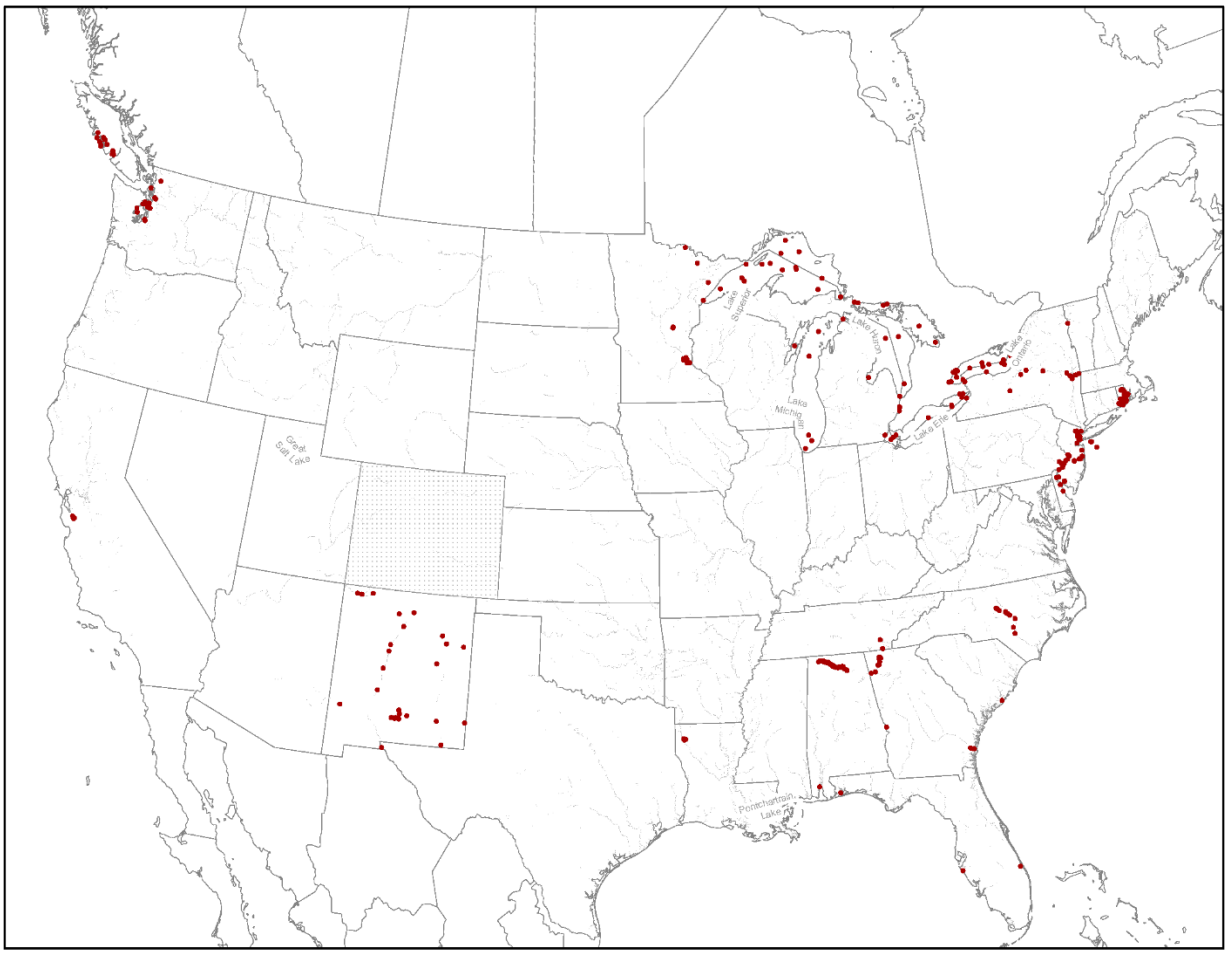


Figure 2-3. Map Indicating Sampling Locations for Perfluorooctane Sulfonate (PFOS) Measured in Surface Waters across the United States (U.S.).

Based on data reported in the current, publicly available literature. Sampling locations for the Colorado data were not available. Therefore, dash marks were used to indicate that measured PFOS surface water concentrations were available for Colorado; however, the exact sampling locations within the state were not publicly available. Detailed information on sampling locations, including references, coordinates (with the exception of Colorado), and sampling site identification numbers and names, are provided in Appendix N.

Modified from: Jarvis et al. (2021).

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Concentrations of PFOS in surface waters across the U.S. appear to vary widely, with observed concentrations ranging over eight orders of magnitude. PFOS is generally detected in the picogram and nanogram per liter range with reported concentrations in microgram per liter (or part-per-trillion) ranges (Ahrens 2011; Zareitalabad et al. 2013). For the purposes of this overview, all concentrations reported here are in nanogram per liter (ng/L). Measured surface water concentrations of PFOS in peer-reviewed journal articles and publicly available industry and government reports range between 0.074 and 8,970,000 ng/L with an arithmetic mean concentration of 786.77 ng/L and a median concentration of 3.6 ng/L (Figure 2-4) (Jarvis et al. 2021). However, it should be noted that the mean and median concentrations reported in Jarvis et al. (2021) were calculated from the reported concentrations for individual samples and therefore, are not fully representative of all the measured PFOS concentrations in U.S. surface waters. Additionally, as demonstrated by the median concentration of 3.6 ng/L, a majority (roughly 91%) of measured PFOS concentrations were found to fall below 300 ng/L (Jarvis et al. 2021).

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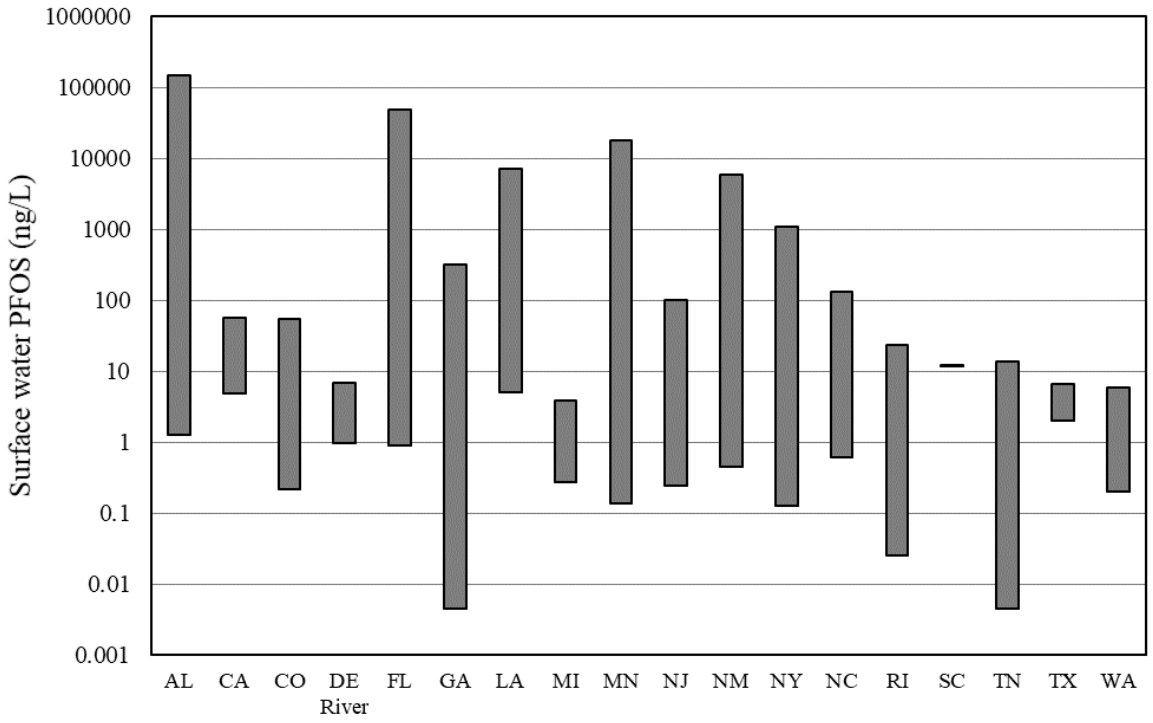


Figure 2-4. Distribution of the Minimum and Maximum Concentrations (ng/L) of Perfluorooctane Sulfonate Measured in Surface Waters for Each State or Waterbody (excluding the Great Lakes) with Reported Data in the Publicly Available Literature.
The distribution is arranged alphabetically by state and waterbody. The measurements in the Delaware River (DE River) could not be contributed to one specific state, and therefore the waterbody is listed.
Modified from: Jarvis et al. (2021).

Numerous available studies report measured PFOS concentrations in surface waters across the U.S. (Appendix N), some of which are summarized in (Jarvis et al. 2021); however, more detailed information on PFOS occurrence in areas not previously sampled and spatial and temporal variability of PFOS remain limited. Prior to the review by Jarvis et al. (2021), there were few analyses of spatial variability of PFOS concentrations in surface water across the U.S (Remucal 2019). Jarvis et al. (2021) indicates that the presence and measured concentrations of PFOS in surface waters are similar between lotic and lentic systems, based on the limited data available (Jarvis et al. 2021)(Appendix N). And as mentioned in the sources of PFOS section above (Section 2.1.2), in contrast with other contaminants commonly found in aquatic ecosystems, PFOS is a synthetic compound with no natural source. Thus, the occurrence of

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PFOS in water is a result of the presence of an anthropogenic source, a transport pathway (air, surface water, or ground water), and the persistence and mobility of the PFOS in the environment. Therefore, PFOS concentrations in surface water tend to be dependent on the presence of a nearby source and generally increase with levels of urbanization.

Further, there are insufficient data to quantitatively evaluate temporal trends of PFOS in surface waters across the U.S. (Remucal 2019). However, recent studies have suggested that PFOS concentrations in surface waters with limited sampling sites in northeastern states appear to have decreased since the voluntary phase out of PFOS in 2002 (Pan et al. 2018; Zhang et al. 2016). While these studies observed lower measured PFOS concentrations in surface waters compared to those reported in earlier reports (Hansen et al. 2002; Nakayama et al. 2007), few studies have measured PFOS concentrations from the same sampling sites over time (Jarvis et al. 2021). Eight studies (six focused on the Great Lakes and two in New York on the Hudson River) measured PFOS in the same waterbody over time (Appendix N). Thus, the observed lower concentrations reported in recent literature could be due to trends of PFOS concentrations decreasing since the 2002 PFOS phaseout, differences in sampling site locations, and/or advances in analytical methods for detecting PFOS that reduced detection limits (Jarvis et al. 2021).

Despite the wide use and persistence of PFOS in aquatic ecosystems and unlike the extensive sampling of PFOS in drinking water sources[1], groundwater, and fish tissue monitoring[2], current information on the environmental distribution of PFOS in ambient surface

[1] EPA's database for the Unregulated Contaminant Monitoring Rule (UCMR) that includes data for treated surface waters (https://www.epa.gov/dwucmr).
[2] EPA's National Rivers and Streams Assessment (NRSA; https://www.epa.gov/national-aquatic-resource-surveys/ncca) and the Great Lakes Human Health Fish Tissue Study component of the EPA National Coastal Condition Assessment (NCCA/GL).

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waters across the U.S. remains very limited. More recent sampling efforts indicate that PFOS occurrence may be more widespread. PFOS was detected in almost all collected surface water samples, which can likely be attributed to improvements in analytical methods that lowered the PFOS detection limit compared to older analytical methods (Gewurtz et al. 2013).

Thus, from the currently available data, which were largely collected from freshwater systems in eastern states and in the Upper Midwest with known manufacturing or industrial uses of PFAS or use of AFFF, PFOS concentrations measured in U.S. surface waters appear to vary widely, across eight orders of magnitude (Jarvis et al. 2021). PFOS concentrations in remote areas (i.e., areas with little to no PFAS manufacturing and/or industrial uses) range between 0.074 to 23.23 ng/L (Jarvis et al. 2021). This contrasts with PFOS concentrations measured in areas with known PFAS manufacturing, industrial use, and/or application of AFFF, which vary widely and reach up to the maximum observed concentration of 8,970,000 ng/L at a site impacted by AFFF (Appendix N). While current PFAS occurrence data illustrate the prevalence and quantify concentrations of PFOS in surface waters across the U.S., additional data, particularly in central, southwestern, and western freshwaters as well as saltwater systems, are needed to better understand PFOS occurrence in aquatic ecosystems across the U.S. (Jarvis et al. 2021). See Appendix N for further discussion of PFOS occurrence in surface waters and other abiotic media such as aquatic sediments, groundwater, air, and ice.

2.5 Bioaccumulation and Biomagnification of PFOS in Aquatic Ecosystems

PFAS, including PFOS, are found in aquatic ecosystems around the globe (e.g., Ankley et al. 2020; Giesy and Kannan 2001; Houde et al. 2008). Although they were used predominantly in more populated areas, these compounds are resistant to hydrolysis, photolysis, and biodegradation (see Section 2.2), facilitating their long-range transport to aquatic ecosystems in

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the remote arctic and mid-oceanic islands (see Section 2.2.2) (Haukas et al. 2007; Houde et al. 2006b). Several physical-chemical properties of PFOS contribute to bioaccumulation within aquatic species once they have entered an ecosystem.

2.5.1 PFOS Bioaccumulation in Aquatic Life

In contrast to many persistent organic pollutants, which tend to partition to fats, PFOS preferentially binds to proteins. Within an organism PFOS tends to bioaccumulate within protein-rich tissues, such as the blood serum proteins, liver, kidney, and gall bladder (De Silva et al. 2009; Jones et al. 2003; Martin et al. 2003a; Martin et al. 2003b). PFOS also binds to ovalbumin, and the transfer of PFOS to such albumin in eggs can be an important mechanism for depuration in female oviparous species, as well as a mechanism for maternal transfer of PFOS to offspring (Jones et al. 2003; Kannan et al. 2005).

The stability of PFOS contributes to its bioaccumulation potential, as it has not been found to undergo biotransformation within the organism (Martin et al. 2003a; Martin et al. 2003b). Within an organism, PFOS undergoes enterohepatic recirculation, in which PFOS is excreted from the liver in bile to the small intestine, then reabsorbed and transported back to the liver (Goecke-Flora and Reo 1996). This process becomes increasingly more efficient the longer the perfluorinated chain length is, resulting in longer biological half-lives for chemicals like PFOS with a relatively long chain length, as they are less readily excreted. PFAS with sulfonate head groups, such as PFOS, are more efficiently resorbed by the small intestine than carboxylate PFAS such as PFOA, resulting in higher bioaccumulation levels (Hassell et al. 2020; Jeon et al. 2010; Martin et al. 2003a).

Sex differences in the elimination rates of PFOS in addition to the transfer of PFOS to albumin in eggs (e.g., Jones et al. 2003; Kannan et al. 2005) have not been well studied. Some research suggests lower PFOS elimination rates in female rats than in male rats (Butenhoff et al.

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2012; Chang et al. 2012; Pizzurro et al. 2019), suggesting potentially longer retention of PFOS in females. However, this difference was not observed in mice, rabbits, monkeys, or humans (Pizzurro et al. 2019). In contrast to PFOS, PFOA elimination rates are higher in females than in males for both female fathead minnows (Lee and Schultz 2010) and rats (Pizzurro et al. 2019), suggesting potential longer retention of PFOA in males. These data indicate further research across species and genders for PFAS elimination rates may be useful.

The structure of PFOS also affects its bioaccumulation potential, with linear forms being more bioaccumulative than branched forms (Fang et al. 2014; Hassell et al. 2020). The preferential accumulation of linear PFOS occurs because the elimination rate of branched isomers of PFOS is higher, particularly across gill surfaces (Hassell et al. 2020). This pattern has also been observed in the field, as the proportion of branched isomers was higher in water and sediment compared to fish tissue in Taihu Lake, China (Fang et al. 2014) and Lake Ontario (Houde et al. 2008).

2.5.2 Factors Influencing PFOS Bioaccumulation and Biomagnification in Aquatic Ecosystems

Because of their affinity for binding to proteins, PFAS can enter the base of the food web through sorption to organic matter in sediments or biofilms (Higgins and Luthy 2006; Jeon et al. 2010; Penland et al. 2020), or can bind to blood proteins at gill surfaces of aquatic organisms through respiration (De Silva et al. 2009; Hassell et al. 2020; Martin et al. 2003a; Martin et al. 2003b).

PFAS binding to the surface of sediment organic matter and biofilms is influenced by both hydrophobic and electrostatic effects, resulting from the hydrophobicity of the perfluorinated chain and the hydrophilicity of the sulfonate or carboxylate head groups (Higgins and Luthy 2006)(see Section 2.2 for further details on the sorption of PFOS). Overall, these results suggest that sorption to sediments should be an important mechanism for PFOS entry into

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an aquatic ecosystem, but that subsequent dietary uptake from benthic feeding organisms will be more important for PFOS than PFOA.

The importance of the sediment pathway for PFOS bioaccumulation in aquatic ecosystems has been demonstrated in laboratory studies with *Chironomus riparius* (Bertin et al. 2014), *C. plumosus* (Wen et al. 2016), *Gammarus fossarum* and *G. pulex* (Bertin et al. 2016), and *Lumbriculus variegatus* (Lasier et al. 2011), where PFOS concentrations were positively correlated between sediments and whole-body tissue samples of benthic feeding organisms. The sediment pathway has also been demonstrated in several field studies, where PFOS was measured in sediments and biofilms, and was higher in benthic-feeding invertebrates relative to pelagic-feeding invertebrates (Lescord et al. 2015; Loi et al. 2011; Martin et al. 2004; Penland et al. 2020). In addition, the distribution of PFAS in sediments was more similar to their distribution in the tissues of benthic invertebrates (Lescord et al. 2015) and fish (Thompson et al. 2011) than they were to their distribution in pelagic organisms.

PFAS can also enter aquatic organisms directly from the water column through respiration. Because of its binding affinity to proteins, PFOS can enter the body of gill-breathing organisms by binding to proteins in the blood at gill surfaces (Jones et al. 2003; Martin et al. 2003a; Martin et al. 2003b). The relative distribution of PFOS in tissues is related to the primary route of exposure (dietary or respiratory). In rainbow trout, the rank order of PFOS concentrations following aqueous exposure was blood > kidney > liver (Martin et al. 2003a). In contrast, their rank order following dietary exposure was liver > blood > kidney (Goeritz et al. 2013). Hong et al. (2015) observed the highest concentrations of PFOS in the intestines of green eel goby, soft tissues, shell, and legs of shore crabs; and gills and intestines of oysters, suggesting

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bioaccumulation through both dietary and aqueous uptake in invertebrates, and primarily dietary uptake in fish.

In addition to being bioaccumulative, PFOS has been shown to biomagnify with increasing trophic level in a variety of freshwater ecosystems (Kannan et al. 2005; Martin et al. 2004; Penland et al. 2020; Xu et al. 2014) and saltwater ecosystems (de Vos et al. 2008; Houde et al. 2006b; Loi et al. 2011; Powley et al. 2008; Tomy et al. 2004) in North America, Europe, and Asia. PFOS is often the most abundant PFAS in aquatic organisms, and this high relative abundance is at least partially explained by the biotransformation of PFOS precursor chemicals into PFOS (see Section 2.3)(Haukas et al. 2007; Kannan et al. 2005; Kelly et al. 2009; Martin et al. 2004; Tomy et al. 2004). Higher trophic level organisms have a greater capacity to metabolize PFOS precursor chemicals, which have been found in lower concentrations in increasing trophic level (Fang et al. 2014; Kannan et al. 2005; Martin et al. 2004). This suggests that in addition to biomagnification, some of the trophic-level increase in PFOS can be explained by the biotransformation of precursor chemicals.

2.5.3 Environmental Monitoring of PFOS in Biotic Media

PFOS is one of the dominant PFAS detected in aquatic ecosystems, along with PFOA (Ahrens 2011; Benskin et al. 2012; Dinglasan-Panlilio et al. 2014; Remucal 2019; Zareitalabad et al. 2013). PFAS were first detected in human serum samples in the late 1960s, and subsequent studies across several continents demonstrated the global distribution of PFAS in humans (Giesy and Kannan 2001; Houde et al. 2006b). Since then, the global distribution of PFAS in tissues of aquatic species has been demonstrated in studies conducted in freshwater and marine environments across every continent, including remote regions far from direct sources, such as the high arctic, Antarctica, and oceanic islands (Giesy and Kannan 2001; Houde et al. 2006b).

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In lentic surface waters of the U.S., one of the most comprehensive studies of PFOS concentrations included fish muscle tissue data from 157 near shore sites across the Great Lakes selected following a probabilistic design as part of the 2010 National Coastal Condition Assessment (Stahl et al. 2014). In this study, PFOS was measured in fish collected at every site, with a median concentration of 15.2 ng/g ww (Stahl et al. 2014). Lake trout (31% of sampled species), smallmouth bass (14%), and walleye (13%) were the most commonly-sampled species from the Great Lakes samples, and the average PFOS concentrations in lake trout muscle were more than twice as high as PFOS concentrations in muscle of smallmouth bass and walleye (Stahl et al. 2014).

Martin et al. (2004) measured PFOS in whole body samples of invertebrates and fish in Lake Ontario, near the town of Niagara-on-the-Lake. PFOS concentrations were much higher in the benthic amphipod *Diporeia hoya* (280 ng/g ww) than in the more pelagic *Mysis relicta* (13 ng/g ww), suggesting sediments are an important source of PFOS in this area (Martin et al. 2004). Among the four fish species sampled, whole body PFOS concentrations were highest in the slimy sculpin (450 ng/g ww), whose preferred food source is *D. hoya* (Martin et al. 2004). Although adult lake trout occupy the highest trophic level at this site, based on nitrogen stable isotope analysis, their PFOS concentrations were less than half (170 ng/g ww) of those measured in sculpin, as their food web is largely pelagic, and not affected by the high sediment PFOS concentrations. Based on stomach content analysis, 90% of the adult lake trout diet consists of alewife, which feed primarily on the more pelagic *M. relicta*, and have the lowest average PFOS concentration (46 ng/g ww) among all fish species (Martin et al. 2004).

Guo et al. (2012) measured PFOS in lake trout muscle tissues in Canadian waters of Lake Superior, Huron, Erie, and Ontario. Average PFOS concentrations correlated with watershed

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urbanization, and were 0.85, 8.3, 27, and 46 ng/g ww, respectively (Guo et al. 2012). Delinsky et al. (2010) measured PFOS in bluegill, black crappie, and pumpkinseed muscle tissue in 59 lakes in Minnesota, including four lakes in the Minneapolis-St. Paul metropolitan area. PFOS was detected in muscle tissues of fish collected in 13 of the 59 lakes, and concentrations ranged from 1.08 to 52.4 ng/g ww in lakes where it was detected. In the four lakes in the Minneapolis-St. Paul metropolitan area, PFOS concentrations in fish muscle tissues ranged from 4.39 to 47.3 ng/g ww (Delinsky et al. 2010).

In flowing surface waters of the U.S., one of the most comprehensive fish PFOS monitoring studies included the collection of fish muscle tissue data from 164 urban river sites (5^{th} order or higher) across the conterminous U.S. selected following a probabilistic design. The study was part of the 2008 - 2009 National Rivers and Streams Assessment and the National Coastal Condition Assessment (Stahl et al. 2014). PFOS was detected in 73% of the urban river sites, with a median concentration of 10.7 ng/g ww (Stahl et al. 2014). Largemouth bass (34% of sampled species), smallmouth bass (25%), and channel catfish (11%) were the most commonly sampled species from the urban stream sites, and PFOS concentrations in the muscles of largemouth bass were approximately twice as high as concentrations in the muscles of smallmouth bass (Stahl et al. 2014).

Ye et al. (2008) reported average PFOS concentrations of 83.1, 84.6, and 147 ng/g ww from whole body composite samples of multiple fish species from the Mississippi River, Missouri River, and Ohio River, respectively. Delinsky et al. (2010) sampled PFOS in bluegill, black crappie, and pumpkinseed muscle tissue at several locations along the upper Mississippi River in 2007, and found concentrations ranging from 3.06 ng/g ww at unimpacted sites to 2,000 ng/g ww at Pool 2, a heavily impacted site in the Minneapolis-St. Paul metropolitan area

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(Delinsky et al. 2010). Malinsky et al. (2011), as reported in Stahl et al. (2014), measured PFOS concentrations ranging from 41.7 to 180 ng/g ww in fish muscle samples collected along the Mississippi River, with the lowest concentration reported for sauger and the highest reported for bluegill.

Kannan et al. (2005) measured PFOS in invertebrates and vertebrates from two rivers in Southern Michigan (Raisin River, St. Claire River), and one in Northern Indiana (Calumet River). PFOS concentrations were similar across sites for the different taxa and suggested trophic biomagnification for PFOS. Among invertebrate taxa, zebra mussel PFOS soft tissue whole body concentrations ranged from below detection to 3.1 ng/g ww, amphipod whole body concentrations ranged from below detection to 2.9 ng/g ww, and crayfish whole body concentrations ranged from 2.4 to 4.3 ng/g ww. Among fish, PFOS concentrations in round goby whole body samples ranged from 6.6 to 21.5 ng/g ww, and smallmouth bass muscle samples ranged from below detection to 41.3 ng/g ww (Kannan et al. 2005).

In a more recent study, Penland et al. (2020) measured PFAS concentrations in invertebrates and vertebrates along the Yadkin – Pee Dee River, in North and South Carolina in 2015. PFOS was measured in whole body tissues of snails (6.47 ng/g ww) but was not detected in whole body tissues of Asian clam, unionid mussels, or crayfish. The highest concentrations in invertebrates were measured in aquatic insect whole body samples (132.8 ng/g ww) and was hypothesized to result from dietary uptake of aquatic biofilms. PFOS was measured in muscle tissue of all 11 sampled fish species and ranged from 11.42 ng/g ww in channel catfish to 37.36 ng/g in whitefin shiner. The highest concentration that Penland et al. (2020) measured was 482.9 ng/g ww, from the eggs of a single robust redhorse sample, underscoring the preferential binding of PFOS to ovalbumin.

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Houde et al. (2006a) measured whole body PFOS in six fish species in Charleston Harbor, South Carolina, and whole body PFOS in zooplankton and five fish species in Sarasota Bay, Florida. Charleston Harbor was the more developed of the two sites and had higher overall PFOS concentrations. Average PFOS concentrations in Charleston Harbor ranged from 19 ng/g ww in pinfish to 92 ng/g in spot. In Sarasota Bay, PFOS concentrations averaged 0.2 ng/g ww in zooplankton and ranged from 3.1 ng/g ww in pigfish to 8.8 ng/g ww in spotted seatrout, suggesting evidence of trophic biomagnification.

Lescord et al. (2015) measured PFOS in chironomids, zooplankton, and juvenile and adult arctic char in six high arctic lakes in Canada. Two of these lakes had been contaminated by PFAS from a nearby airport while the other lakes were free from point source contamination. PFOS in chironomid whole body samples was high at the two contaminated lakes, ranging from 28 to 445 ng/g ww, compared to 5.3 to 14 ng/g ww at the reference lakes (Lescord et al. 2015). Whole body concentrations in pelagic zooplankton were relatively lower, ranging from 49 to 60 ng/g ww, compared to 0.12 to 2.0 ng/g ww at the reference lakes. The higher concentrations of PFOS in the benthic chironomids indicate the importance of sediments as a route of exposure into the base of the food web. PFOS in whole body samples of juvenile char (181 to 224 ng/g ww) and muscle tissue of adult char (24 to 117 ng/g ww) at the two contaminated lakes were lower than whole body PFOS in chironomids, indicating a lack of trophic biomagnification. Additionally, PFOS in whole body samples of juvenile char (0.001 to 15 ng/g ww) and muscle tissues of adult char (below detection to 2 ng/g ww) at the four reference lakes was also lower than whole body PFOS in chironomids at the four reference lakes.

Tomy et al. (2004) measured PFOS in whole body samples of zooplankton (*Calamus hyperboreus*), shrimp (*Pandalus sp.*), clams (*Nya truncata* and *Serripes groenlandica*), and arctic

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cod (*Boreogadus saida*); and liver samples of deepwater redfish (*Sebastes mentella*) collected from unimpacted marine locations in the Canadian Arctic. PFOS concentrations were low for all taxa, with the lowest concentrations measured in shrimp (0.3 ng/g ww) and clams (0.04 ng/g ww). PFOS concentrations were similar in zooplankton (1.8 ng/g ww), arctic cod (1.3 ng/g ww), and redfish (1.4 ng/g ww), indicating little, if any biomagnification from invertebrates to fish (Tomy et al. 2004). Haukas et al. (2007) found the average liver PFOS concentration (2.02 ng/g ww) in arctic cod *B. saida* collected in the Barents Sea off the coast of Svalbard in 2004 to be similar to whole body concentrations for this species reported by Tomy et al. (2004). The average whole body PFOS concentration (3.85 ng/g ww) in ice amphipod (*Gammarus wilkitzkii*) samples was higher than the average liver PFOS concentration in in arctic cod, indicating no biomagnification from invertebrates to fish in this ecosystem (Haukas et al. 2007).

Current data indicate that PFOS concentrations measured in aquatic biota vary widely, approximately across four orders of magnitude for both fish (ranging between 0.85 and 2,000 ng/g ww) and aquatic invertebrates (ranging between 0.04 and 445 ng/g ww). Like ambient surface water concentrations, PFOS concentrations in aquatic biota inhabiting remote areas (i.e., areas with little to no PFAS manufacturing and/or industrial uses) appear to be lower than those in areas with known PFAS manufacturing, industrial use, and/or application of AFFF. While current PFAS monitoring data illustrate the prevalence and quantify concentrations of PFOS in aquatic biota across the U.S., additional data are needed to better understand PFOS occurrence and potential bioaccumulation in aquatic ecosystems across the U.S.

2.6 Exposure Pathways of PFOS in Aquatic Environments

There are multiple exposure pathways of PFOS in the aquatic environment, including: 1) direct (dermal and respiratory) aqueous exposure; 2) direct exposure to contaminated sediment

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(for benthic organisms); 3) dietary and biomagnification; and 4) maternal-transfer (Ankley et al. 2020). Exposure of PFOS through water and sediment occurs through direct contact with the respective media, such as water passing across the gills, or consumption of suspended and deposited sediments (Prosser et al. 2016). Upon entering an organism, PFAS such as PFOS tend to bind to proteins, and concentrate preferentially within the blood and protein rich tissues, such as liver (Haukas et al. 2007; Xia et al. 2013b). The affinity of PFOS to bind to proteins contributes to the bioaccumulation and biomagnification of PFOS (see Section 2.5 above), resulting in increasing concentrations of PFOS in higher trophic level organisms, such as predatory fish and birds (Custer et al. 2019; Haukas et al. 2007; Xu et al. 2014). However, as noted previously in Section 1.2.1, the lack of a meaningful K_{ow} for PFOS due to its binding primarily to protein, not lipids, precludes application of K_{ow}-based models that are commonly used to estimate bioconcentration factors and predict bioaccumulation for many other important, environmental contaminants (e.g., PCBs). Lastly, elevated PFOS concentrations in eggs and young of aquatic life suggests that PFOS may be maternally transferred to offspring. This exposure pathway may be particularly important among egg-laying species because of the preferential binding of PFOS to egg albumin (Kannan et al. 2005). In summary, PFOS exposure has been found to occur through multiple exposure routes, including via water, sediment, diet, and maternal transfer (Jones et al. 2003; Kannan et al. 2005; Sharpe et al. 2010; Wang et al. 2011).

2.7 Effects of PFOS on Biota

The number of PFOS ecotoxicity studies and data are increasing and study designs are evolving to expand the understanding of the effects of PFOS. Currently, PFOS ecotoxicity studies are primarily focused on fish, aquatic invertebrates, plants, and algae. Fewer studies are

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being conducted on aquatic-dependent birds, reptiles, and mammals. Sections 3 and 4 provide study summaries of individual publicly available high quality aquatic life toxicity studies, and Appendix A through Appendix H summarize current PFOS aquatic life ecotoxicity data, both studies used here and unused studies due to quality issues.

2.7.1 Mode of Action and Toxicity of PFOS

The mechanism(s) underpinning the toxicity of PFOS is not well-understood and is an active area of research. Toxicity literature indicate that PFOS causes a wide range of adverse effects in aquatic organisms, including reproductive effects, developmental toxicity, and estrogen, androgen and thyroid hormone disruption (see Sections 3 and 4 and Appendices A.1 through H.1). However, a great deal of research is still needed from a mechanistic perspective to better understand how the different modes of action elicit specific biological responses. Some potential PFOS modes of action in aquatic life appear to include: 1) oxidative stress (Li et al. 2017; Sant et al. 2018; Shi and Zhou 2010); 2) autophagic cell death or apoptosis (Sant et al. 2018; Shi et al. 2008); 3) endocrine modulation of estrogen and thyroid receptors (Benninghoff et al. 2011; Chen et al. 2018; Du et al. 2013; Kim et al. 2011; Shi et al. 2008); 4) interference at the mitochondrial level through the uncoupling of oxidative phosphorylation (ECCC 2018); 5) interference with the homeostasis of DNA metabolism (Hoff et al. 2003); and 6) activation of the nuclear peroxisome proliferator activated receptor-alpha (PPAR-α) pathways (Arukwe and Mortensen 2011; Cheng et al. 2016; Fang et al. 2013; Fang et al. 2012; Yang et al. 2014).

Following exposure to PFOS, molecular level events can perturb estrogen-, androgen- and thyroid-related endocrine systems, as well as neuronal-, lipid-, and carbohydrate-metabolic systems and lead to cellular- and organ-level disturbances and ultimately result in effects on reproduction, growth, and development at the individual organism-level(see Ankley et al. 2020 and Lee et al. 2020 for the latest reviews on the subject) for the latest reviews on the subject).

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The mechanisms of PFOS toxicity to fish in particular appear to be related to oxidative stress, apoptosis, thyroid disruption, and alterations of gene expression during development (Lee et al. 2020). Additionally, published research suggested that many of these molecular pathways interact with each other and could be linked. For example, oxidative stress following exposure to PFOS was correlated with effects on egg hatching and larval formation, linking reproductive toxicity, oxidative stress, and developmental toxicity (Lee et al. 2020). The actual mechanism(s) through which PFOS induced oxidative stress operates still requires additional study, but increased ß-oxidation of fatty acids and mitochondrial toxicity are proposed triggers (Ankley et al. 2020; Lee et al. 2020). Thus, the alteration of multiple biological pathways is a plausible explanation for the diversity of observed effects of PFOS reported in the literature (Lee et al. 2020). However, the available data did not allow for a defined adverse outcome pathway-based understanding of the ultimate reductions to survival, growth, and reproduction in the various aquatic taxa in which these effects have been observed or may be expected to occur. Thus, further mechanistic research is warranted.

Notably, PFOS appeared to be related to the disruption of the sex hormone-related endocrine system at the molecular, tissue, and organ levels, resulting in observed adverse reproductive outcomes in freshwater and saltwater fish and invertebrates alike. Further, these effects have been reported after exposure via multiple exposure routes (i.e., waterborne, dietary, maternal; (i.e., waterborne, dietary, maternal; Lee et al. 2020). And these reproductive effects also appeared to be trans-generational, as observed in a multi-generational zebrafish (*Danio rerio*) study by Wang et al. (2011) (see study summary in Appendix Section C.2.5).

PFOS is one of the most studied PFAS in the ecotoxicity literature, with reported adverse effects on survival, growth, and reproduction. However, a great deal of additional research is

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needed to better understand the modes of action of PFOS. Specifically, additional research from a mechanistic perspective is needed to better understand how the different modes of action elicit specific biological responses in fish, aquatic invertebrates, and amphibians. Potential effects of PFOS involving multiple biological pathways are a research challenge for PFOS and PFAS in general.

2.7.2 Potential for Interactions with Other PFAS

PFAS occur as mixtures in the environment. Occurrence studies document the presence of complex mixtures of PFAS in surface waters in the U.S. and across the globe (see also Section 2.4.1)(Ahrens 2011; Ahrens and Bundschuh 2014; Giesy and Kannan 2002; Houde et al. 2006b; Keiter et al. 2012; Wang et al. 2017). Although the EPA's PFOS recommended aquatic life water quality criteria are based solely on single chemical exposures to aquatic life, it is recognized that PFAS are often introduced into the aquatic environment as end-use formulations comprised of mixtures of PFAS and/or PFAS-precursors. However, the ecological effects of these potential PFAS mixtures are poorly understood (Ankley et al. 2020). It was useful, therefore, to briefly summarize the types of interactions that might be expected based on the few PFAS mixture studies involving PFOS and one or more PFAS to date. It should be noted that for purposes of this document, the reader is referred to Ankley et al. (2020) and elsewhere for more comprehensive reviews of PFAS mixtures in general, and the challenges they are expected to present in ecological risk assessment. Beyond PFOA and PFOS, systematic reviews of chemical mixture studies across various compound classes indicate that departures from dose additivity are uncommon and rarely exceed minor deviations (~2-fold) from predictions based on additivity (Martin et al. 2021).

Findings of the PFAS-specific studies below are as reported by the study authors without any additional interpretation or analysis of uncertainty. At both the organismal and cellular

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levels, studies on zebrafish (*D. rerio*; Ding et al. 2013), a water flea *(D. magna*; Yang et al. 2019), mosquito (*Aedes aegypti*; Olson 2017), a bioluminescent cyanobacteria (*Anabaena sp*.; Rodea-Palomares et al. 2012), or with cultured hepatocytes of the cyprinid (*Gobiocypris rarus*; Wei et al. 2009), demonstrated that the effects observed from *in vivo* and *in vitro* tests on PFAS mixtures vary and can have unpredictable exposure and species-specific effects. PFAS mixture studies on zebrafish reported interactions for combinations of PFOA and PFOS, but departures from additive models were also minor (Ding et al. 2013). Menger et al. (2020) reported zebrafish behavioral effects from a PFAS mixture that were less than individual PFAS, however evaluation of chemical dose response and comparison to mixture models was not conducted. Yang et al. (2019) exposed the water flea, *D. magna*, to single and binary mixtures of PFOS and PFOA. The authors reported synergism in acute and chronic toxic effects. Conversely, Rodea-Palomares et al. (2012) showed a binary PFOS and PFOA mixture as having an antagonistic interaction across the whole range of effect levels tested using the bioluminescent cyanobacterium, *Anabaena.* Olson (2017) exposed larvae of the mosquito, *A. aegypti,* to PFOS and perfluorohexane sulfonate (PFHxS) separately and as a mixture and reported increased toxicity in a manner greater than would be predicted by additivity.

In tests with cultured hepatocytes of the cyprinid, *G. rarus*, co-exposure of PFOS with a mixture of five other PFAS [PFOA, Perfluorononanoate or Perfluorononanoic acid (PFNA), Perfluorodecanoate or Perfluorodecanoic acid (PFDA), Perfluorododecanoate or Perfluorododecanoic acid (PFDoA), and 8:2 FTOH] resulted in highly complex interactions (Wei et al. 2009). A number of genes differentially expressed in the mixture were not differentially expressed in the exposure to the individual chemicals, potentially indicating different modes of action for the mixture compared to the individual chemicals. In this case, the authors reported no

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additive responses for the mixture. Consistent with the possible mechanisms of toxicity of PFOS (see Section 2.7.1), the genes identified in the study are involved in multiple biological functions and processes, including fatty acid metabolism and transport, xenobiotic metabolism, immune response, and oxidative stress (Wei et al. 2009). Finally, U.S. EPA (Conley et al. 2022) observed PFOA and PFOS interacting in an additive manner to reduce pup body weight, pup liver weight, and maternal liver weight in the Sprague-Dawley rat.

2.8 Conceptual Model of PFOS in the Aquatic Environment and Effects

A conceptual model depicts the relationship between a chemical stressor and ecological compartments, linking exposure characteristics to ecological endpoints. The conceptual model provided in Figure 2-5 summarizes sources, potential pathways of PFOS exposure for aquatic life and aquatic-dependent wildlife, and possible toxicological effects.

PFOS initially enters the aquatic environment through point sources, including municipal and industrial dischargers and landfill leachate and non-point sources, including land application of contaminated biosolids (see Section 2.1.2). PFOS enters the aquatic environment in dissolved and particle-bound forms and may sorb to surfaces, such as sediment and particulate matter in the water column (see Section 2.2.2), which is depicted in the conceptual model (Figure 2-5). The conceptual model depicted in Figure 2-5 shows exposure pathways for the biological receptors of concern (i.e., aquatic life) and potential effects (e.g., on survival, growth, and reproduction) in those receptors. Both direct (i.e., exposure from the water column which is represented by **) and indirect (i.e., dietary exposure via the food web *) pathways are represented in the conceptual model.

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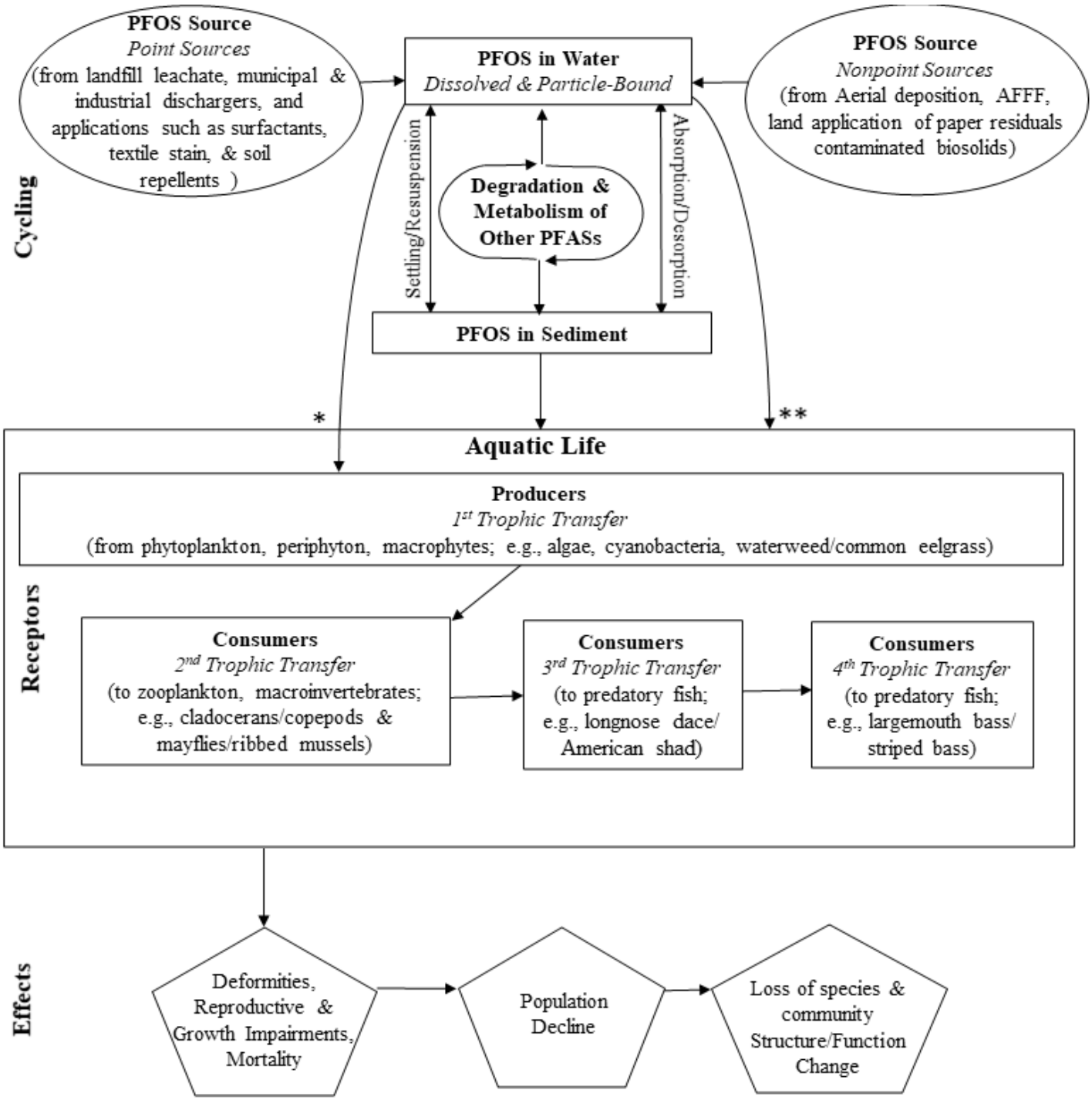


Figure 2-5. Conceptual Model Diagram of Sources, Compartmental Partitioning, and Trophic Transfer Pathways of Perfluorooctane Sulfonate (PFOS) in the Aquatic Environment and its Bioaccumulation and Effects in Aquatic Life.

PFOS sources represented in ovals, compartments within the aquatic ecosystem represented by rectangles, and effects in pentagons. Examples of organisms in each trophic transfer provided as freshwater/marine. Movement of PFOS from water to receptors indicated by two separate pathways: bioconcentration by producers (*) and direct exposure (**) to all trophic levels within box. Relative proportion of PFOS transferred between each trophic level is dependent on life history characteristics of each organism.

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2.9 Assessment Endpoints

Assessment endpoints are defined as "explicit expressions of the actual environmental value that is to be protected" and are defined by an ecological entity (species, community, or other entity) and its attribute or characteristics (U.S. EPA 1998). Assessment endpoints may be identified at any level of organization (e.g., individual, population, community). In the context of the CWA, aquatic life criteria for toxic pollutants are typically determined based on the results of toxicity tests with aquatic organisms in which unacceptable effects on growth, reproduction, or survival occurred. This information is typically compiled into a sensitivity distribution based on genera and representing the impact on taxa across the aquatic community. Criteria are based on the 5^{th} percentile of genera and are thus intended to be protective of approximately 95 percent of aquatic genera.

The use of laboratory toxicity tests to protect aquatic species was based on the concept that effects occurring to a species in appropriate laboratory tests will generally occur to the same species in comparable field situations. Since aquatic ecosystems are complex and diversified, the 1985 Guidelines recommended acceptable data be available for at least eight genera with a specified taxonomic diversity (the standard eight-family minimum data requirements, or MDRs). The intent of the eight-family MDR was to serve as a surrogate sample community representative of the larger and generally much more diverse natural aquatic community, not necessarily the most sensitive species in a given environment. The 1985 Guidelines note that since aquatic ecosystems can tolerate some stress and occasional adverse effects, protection of all species at all times and places are not deemed necessary (the intent is to protect 95 percent of a group of diverse taxa, and any commercially and recreationally important species; (the intent is to protect 95 percent of a group of diverse taxa, and any commercially and recreationally important species; U.S. EPA 1985).

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For more details on aquatic life assessment endpoints for PFOS see Section 3.1 below. This criteria derivation for aquatic life was developed using a genus sensitivity distribution (GSD), which represents the potential for impact to the survival, growth, or reproductive effects on taxa across aquatic communities.

2.10 Measurement Endpoints

2.10.1 Overview of Toxicity Data Requirements

To ensure the protection of various components of an aquatic ecosystem, the EPA compiles acute toxicity test data from a minimum of eight diverse taxonomic groups.

- Acute freshwater criterion require data from the following taxonomic groups:
    a. fish in the family Salmonidae in the class Osteichthyes
    b. a second family of fish in the class Osteichthyes, preferably a commercially or recreationally important warmwater species (e.g., bluegill, channel catfish)
    c. a third family in the phylum Chordata (may be in the class Osteichthyes or may be an amphibian)
    d. a planktonic crustacean (e.g., cladoceran, copepod)
    e. a benthic crustacean (e.g., ostracod, isopod, amphipod, crayfish)
    f. an insect (e.g., mayfly, dragonfly, damselfly, stonefly, caddisfly, mosquito, midge)
    g. a family in a phylum other than Arthropoda or Chordata (e.g., Rotifera, Annelida, Mollusca)
    h. a family in any order of insect or any phylum not already represented

- Acute estuarine/marine criterion require data from the following taxonomic groups:
    a. two families in the phylum Chordata
    b. a family in a phylum other than Arthropoda or Chordata
    c. a family from either Mysidae or Penaeidae
    d. three other families not in the phylum Chordata (may include Mysidae or Penaeidae, whichever was not used above)
    e. any other family

Additionally, to ensure the protection of various animal components of the aquatic ecosystem from long term exposures, chronic toxicity test data are recommended from the same eight diverse taxonomic groups that are recommended for acute criteria. If the eight diverse

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taxonomic groups are not available to support the chronic criterion derivation using a genus distribution approach, the chronic criterion may be derived using an acute-to-chronic ratio (ACR) approach. To apply an ACR approach to derive a chronic criterion, a minimum of three taxa are recommended, with at least one chronic test being from an acutely sensitive species. To calculate ACRs, chronic aquatic life criteria require data from the following taxonomic groups:

a. At least one fish
b. At least one invertebrate
c. At least one acutely sensitive freshwater species, for freshwater chronic criterion (the other two may be saltwater species)
d. At least one acutely sensitive saltwater species for estuarine/marine chronic criterion (the other two may be freshwater species)

The 1985 Guidelines also specified at least one quantitative test with a freshwater alga or vascular plant. If plants are among the most sensitive aquatic organisms, toxicity test data from a plant in another phylum should also be available. Aquatic plant toxicity data were examined to determine whether aquatic plants are likely to be adversely affected by the concentration expected to be protective for other aquatic organisms (see Appendix E for freshwater plant toxicity studies).

2.10.2 Measure of PFOS Exposure Concentrations

This PFOS aquatic life AWQC document provides a critical review of all data identified in the EPA's literature search for PFOS, including all forms of PFOS used in toxicity literature (such as the anionic form and salts) and identified in the ECOTOX database:

- the anionic form (CAS No. 45298-90-6)
- the acid form (CAS No. 1763-23-1)
- potassium salt (CAS No. 2795-39-3)
- an ammonium salt (CAS No. 56773-42-3)
- sodium salt (CAS No. 4021-47-0)
- and a lithium salt (CAS No. 29457-72-5)

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Typically, studies do not complete an analysis or provide enough information regarding isomer delineation to determine if the PFOS tested was purely linear or branched. However, several PFOS toxicity studies stated that the linear PFOS isomer was used for dosing with fewer studies indicating that the branched isomer was used. Studies reported by researchers that conducted PFOS-only exposures were considered for possible inclusion. For most the EPA aquatic life criteria documents with non-bioaccumulative substances, organisms are exposed to contaminated water but fed a diet grown in uncontaminated media (not spiked with the toxicant prior to introduction into the exposure chambers). Such tests were reviewed, and tests of sufficient quality are included in these PFOS criteria. Toxicity tests conducted with PFOS-spiked diet were also reviewed and considered suitable for deriving a criterion for this bioaccumulative pollutant; however, these toxicity tests were limited in the current PFOS toxicity literature. Consequently, toxicity tests with direct aqueous, dietary, and maternal transfer were included in the EPA's derivation of aquatic life criterion for PFOS (see Section 3). Studies not included in the numeric criteria derivation, including some studies with other PFOS exposures (i.e., *in vitro* studies), were considered qualitatively as supporting information if they were deemed to be of sufficient quality, and are described in the Effects Characterization section below (Section 4.3).

This set of published literature was identified using the ECOTOXicology database (ECOTOX; https://cfpub.epa.gov/ecotox/) as meeting data quality standards. ECOTOX is a source of high-quality toxicity data for aquatic life, terrestrial plants, and wildlife. The database was created and is maintained by the EPA, Office of Research and Development, Center for Computational Toxicology and Exposure. The ECOTOX search generally begins with a comprehensive chemical-specific literature search of the open literature conducted according to ECOTOX Standard Operating Procedures (SOPS; Elonen 2020). The search terms are often

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comprised of chemical terms, synonyms, degradates and verified Chemical Abstracts Service (CAS) numbers. After developing the literature search strategy, ECOTOX curators conduct a series of searches, identify potentially applicable studies based on title and abstract, acquire potentially applicable studies, and then apply the applicability criteria for inclusion in ECOTOX. Applicability criteria for inclusion into ECOTOX generally include:

a. The toxic effects are related to single chemical exposure (unless the study is being considered as part of a mixture effects assessment)
b. There is a biological effect on live, whole organisms or *in vitro* preparation including gene chips or omics data on adverse outcome pathways potentially of interest
c. Chemical test concentrations are reported
d. There is an explicit duration of exposure
e. Toxicology information that is relevant to EPA Office of Water (OW) is reported for the chemical of concern
f. The paper is published in the English language
g. The paper is available as a full article (not an abstract)
h. The paper is publicly available
i. The paper is the primary source of the data
j. A calculated endpoint is reported or can be calculated using reported or available information
k. Treatment(s) are compared to an acceptable control
l. The location of the study (*e.g.*, laboratory vs. field) is reported
m. The tested species is reported (with recognized nomenclature)

Following inclusion in the ECOTOX database, toxicity studies were subsequently evaluated by EPA OW. All studies were evaluated for data quality as described by U.S. EPA (1985) and in EPA's Office of Chemical Safety and Pollution Prevention (OCSPP)'s Ecological Effects Test Guidelines (U.S. EPA 2016b), and EPA OW's internal data quality SOP, which is consistent with OCSPP's data quality review approach (U.S. EPA 2018). Office of Water completed a Data Evaluation Record (DER) for each species by chemical combination from the PFOS studies identified by ECOTOX. This in-depth review ensured the studies used to derive the criteria resulted in robust scientifically-defensible criteria. Example DERs are shown in

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Appendix Q with the intent to convey the meticulous level of evaluation, review, and documentation each PFOS study identified by ECOTOX was subject to.

The 1985 Guidelines document indicates that tests used in criteria should be for North American resident species. Due to the EPA's interest in using all available quality data, particularly for data-sparse PFOS (relative to cadmium or ammonia, for example), PFOS toxicity studies were considered for possible inclusion regardless of the test species residential status in North America, as with other published aquatic life criteria. This approach was also based on the relative similarity in sensitivities between resident and non-resident species (see Sections 3 and 4). Moreover, non-North American resident species serve as taxonomically-related surrogate test organisms for the thousands of untested resident species. Supporting analyses to evaluate the influence of including non-resident species on the freshwater criteria magnitudes were conducted by limiting toxicity datasets to North American resident species with established populations in North America (see Section 4.2). These supporting analyses provided an additional line-of-evidence that further suggested it is appropriate to consider non-resident species in PFOS criteria derivation because of their minimal influence of the criteria magnitudes.

Additionally, a substantial number of PFOS toxicity tests reported only nominal, or unmeasured, PFOS concentrations. For PFOS, the EPA has examined the issue of whether nominal (unmeasured) and measured concentrations are in close agreement with each other (Jarvis et al. 2023). While measured PFOS toxicity tests are generally preferred, results of Jarvis et al. (2023) demonstrated that experimental conditions had little influence on observed discrepancies between nominal and measured concentrations for PFOS, with the exception of saltwater tests and freshwater studies that contained substrate. Nominal and measured concentrations in the analysis generally displayed a high degree of linear correlation (>0.95

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freshwater, >0.84 saltwater) and relatively low median percent differences (Jarvis et al. 2023). In freshwater tests, when tests with substrate were removed, 89% of the 527 PFOA and PFOS measured concentrations were within 20% of their nominal counterparts Conversely, 65.50% of measured PFOS saltwater concentrations differed from corresponding nominal concentrations by >20% (EPA's OCSPP's Ecological Effects Test Guidelines (U.S. EPA 2016b) consider tests acceptable when measured concentrations are within 20% of nominal, and Rewerts et al. (2021) suggested that PFAS-specific toxicity tests may even be acceptable if measured and nominal concentrations do not differ by up to 30%). Potential dosing errors, differences in experimental design, and/or the presence of substrate were hypothesized to be the primary contributor to these discrepancies (Jarvis et al. 2023). Therefore, when available, measured PFOS concentrations were used; however, for several studies measured PFOS concentrations were not reported, and nominal concentrations were utilized, especially if a concentration-response relationship was observed in another medium where PFOS was measured from the same study (e.g., diet, blood, or eggs).

Typically, per the 1985 Guidelines, acute toxicity data from all measured flow-through tests would be used to calculate species mean acute values (SMAV), unless data from a measured flow-through test were unavailable, in which case the acute criterion would be calculated as the geometric mean of all the available acute values (i.e., results of unmeasured flow-through tests and results of measured and unmeasured static and renewal tests). Chronic unmeasured flow-through tests, as well as measured and unmeasured static and renewal tests are not typically considered to calculate chronic values (an exception being for renewal tests with cladocerans where test concentrations were measured). In the case of PFOS, static, renewal, and flow-through experiments were considered for possible inclusion for both species mean acute

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and chronic values regardless of whether PFOS concentrations were measured because PFOS is a highly stable compound (see Section 1.2.1), resistant to hydrolysis, photolysis, volatilization, and biodegradation (see Section 2.3)(Giesy et al. 2010).

Additionally, chronic values were based on endpoints and durations of exposure that were appropriate to the species. Thus, both life- and partial life-cycle tests were utilized for the derivation of the chronic criteria. However, it should be noted that typically, per the 1985 Guidelines, life-cycle chronic tests would be preferred for invertebrates. The chronic studies used in the derivation of the PFOS criteria followed taxa-specific exposure duration requirements from various test guidelines (i.e., EPA's 1985 Guidelines and EPA's OCSPP's Ecological Effects Test Guidelines, (i.e., EPA's 1985 Guidelines and EPA's OCSPP's Ecological Effects Test Guidelines, U.S. EPA 2016b) when available. For example, the EPA's 1985 Guidelines states that daphnid tests should begin with young < 24 hours old and last for not less than 21 days; and this chronic test duration was applied to the consideration of all chronic daphnid tests. When taxa-specific exposure duration requirements were not available for a particular test organism in the PFOS toxicity literature, both life- and partial life-cycle tests were considered in the derivation of the chronic criteria.

PFOS toxicity in aquatic life can be manifested as effects on survival, growth, and/or reproduction. Measurements of fish tissue, such as whole-body, muscle, and eggs, were most closely linked to the chronic adverse effects of PFOS, since PFOS is highly persistent and bioaccumulative. The following subsection of this problem formulation describes the approaches used to establish PFOS effect concentrations in aquatic life in relation to the various criteria derived, including for water and tissue.

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2.10.3 Measures of Effect

Each assessment endpoint requires one or more "measures of ecological effect," which are defined as changes in the attributes of an assessment endpoint itself or changes in a surrogate entity or attribute in response to chemical exposure. Ecological effects toxicity test data are used as measures of direct and indirect effects to growth, reproduction, and survival of aquatic organisms.

2.10.3.1 Acute Measures of Effect

The acute measures of effect on aquatic organisms are the lethal concentration (LC_{50}), effect concentration (EC_{50}), or inhibitory concentration (IC_{50}) estimated to produce a specific effect in 50 percent of the test organisms (Table 2-1). LC_{50} is the concentration of a chemical that is estimated to kill 50 percent of the test organisms. EC_{50} is the concentration of a chemical that is estimated to produce a specific effect (e.g., immobilization) in 50 percent of the test organisms. The IC_{50} is the concentration of a chemical that is estimated to inhibit some biological process (e.g., enzyme activity associated with an apical endpoint such as mortality) in 50 percent of the test organisms.

2.10.3.2 Chronic Measures of Effect

The measure of effect for chronic exposures of PFOS was the effect concentration estimated to produce a chronic effect on survival, growth, or reproduction in 10 percent of the test organisms (EC_{10}; Table 2-1). The EPA selected an EC_{10} to estimate a low level of effect that would be both different from controls and not expected to be severe enough to cause severe effects at the population level for a bioaccumulative contaminant, such as PFOS. The use of the EC_{10}, instead of an $EC_{20,}$ is also consistent with the use of this metric for the bioaccumulative pollutant selenium in the recent 2016 Selenium Freshwater Aquatic Life Criteria (U.S. EPA 2016c), and is consistent with the harmonized guidelines from OECD and the generally preferred

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effect level for other countries such as Canada, Australia and New Zealand (CCME 2007; OECD 2001; Warne et al. 2018).

Regression analysis was used preferentially to characterize a concentration-response (C-R) relationship and to estimate concentrations at which chronic effects are expected to occur. Author-reported No Observed Effect Concentrations (NOECs) and Lowest Observed Effect Concentrations (LOECs) were only used for the derivation of chronic criterion when a robust EC_{10} could not be calculated for the genus. A NOEC is the highest test concentration at which none of the observed effects are statistically different from the control. A LOEC is the lowest test concentration at which the observed effects are statistically different from the control. When LOECs and NOECs are used, a Maximum Acceptable Toxicant Concentration (MATC, geometric mean of the NOEC and LOEC) is calculated. For the calculation of the chronic criteria, point estimates were selected for use as the measure of effect in favor of MATCs, as MATCs are highly dependent on the concentrations tested. Point estimates also provided additional information that is difficult to determine with an MATC, such as a measure of effect level across a range of tested concentrations.

In conformity with the 2013 Ammonia Freshwater Aquatic Life Criteria (U.S. EPA 2013), a decision rule was also applied to the PFOS toxicity data when an author-reported NOEC or LOEC was used. The decision rule was not to use "greater than" values for concentrations of low magnitude or "less than" values for concentrations of high magnitude because they added little significant information to the analyses. Conversely, if data from studies with only low concentrations indicated a significant effect (suggesting the test material was highly toxic) or studies with high concentrations only found an incomplete response for a chronic endpoint (indicating low toxicity of the test material), those data did significantly enhance the

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understanding of PFOS toxicity. Thus, the decision rule was applied as follows: "greater than" (>) high toxicity values and "less than" (<) low toxicity values were included (U.S. EPA 2013). Data that met the quality objectives and test requirements were utilized quantitatively in deriving these criteria for aquatic life and are presented in Table 3-3 and Table 3-7.

Table 2-1. Summary of Assessment Endpoints and Measures of Effect Used in the Criteria Derivation for PFOS.

Assessment Endpoints for the Aquatic Community	Measures of Effect
Aquatic Life: Survival, growth, and reproduction of freshwater and estuarine/marine aquatic life (i.e., fish, amphibians, aquatic invertebrates)	For effects from acute exposure: 1. LC_{50}, EC_{50}, or IC_{50} concentrations in water For effects from chronic exposure: 1. EC_{10} concentrations in water 2. NOEC and LOEC concentrations in water. *Only used when an EC_{10} could not be calculated for a genus.* *Note: only chronic exposures were considered for derivation of the tissue-based criteria since PFOS is a bioaccumulative chemical. These chronic tissue-based criteria are expected to be protective of acute effects, because acute effects were observed at much greater concentrations than chronic effects.*

LC_{50} = 50% Lethal Concentration
EC_{50} = 50% Effect Concentration
IC_{50} = 50% Inhibitory Concentration
NOEC = No-observed-effect-concentration
LOEC = Lowest-observed-effect-concentration
EC_{10} = 10% Effect Concentration

2.10.3.3 Summary of Independent Calculation of Toxicity Values

Where data were available, toxicity values, including LC_{50} and EC_{10} values, were independently calculated using data from the toxicity studies meeting the inclusion criteria described above, via independent statistical analysis conducted by the EPA. Occasionally, individual replicate-level data or treatment-level data were acquired from the study authors to independently calculate toxicity values. All data were analyzed using the statistical software

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program R (version 3.6.2) and the associated dose-response curve (drc) package. The R drc package has several models available for modeling a C-R relationship for each toxicity study. The specific model used to calculate toxicity values was selected following the details provided in Appendix K and the models performed well on most or all statistical metrics. The independently-calculated toxicity values used to derive the PFOS aquatic life criteria are included in each quantitative study summary below and were utilized to derive these criteria for aquatic life, where available (for the acute criterion see genus mean values in Table 3-9 and for the chronic criterion, see genus mean values in Table 3-10).

2.11 Analysis Plan

2.11.1 Derivation of Water Column Criteria

During CWA Section 304(a) criteria development, the EPA reviews and considers all relevant toxicity test data. Information available for all relevant species and genera are reviewed to identify: 1) data from acceptable tests that meet data quality standards; and 2) whether the acceptable data meet the minimum data requirements (MDRs) as outlined in the EPA's 1985 Guidelines (U.S. EPA 1985). The MDRs described in Section 2.10.1 were met for acute and chronic freshwater criteria derivation. Acute and chronic MDRs for PFOS estuarine/marine criteria derivation were not met. Consequently, the EPA used the available toxicity data and the EPA's New Approach Methods (NAMs) to generate protective estuarine/marine benchmarks. A minimal number of tests from acceptable studies of aquatic algae and vascular plants were also available. The relative sensitivity of freshwater plants to PFOS exposures indicates plants are less sensitive than aquatic vertebrates and invertebrates so plant criteria were not developed.

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2.11.2 Consideration for the Derivation of Tissue-Based Criteria following Chronic PFOS Exposures

Chronic toxicity studies (both laboratory and field studies) were further screened to ensure that they contained the relevant chronic PFOS exposure routes for aquatic organisms (i.e., dietary, maternal, or dietary and waterborne PFOS exposure), measurement of chronic effects, and measurement of PFOS in tissue(s). The EPA considered deriving tissue-based criteria using empirical toxicity tests with studies that exposed test organisms to PFOS via water, diet, and/or maternal transfer and reported exposure concentrations based on measured tissue concentrations. This approach generally corresponded with the 2016 Selenium Aquatic Life Freshwater Criterion, which is the only other EPA 304(a) recommended aquatic life criterion with tissue-based criteria (U.S. EPA 2016c). However, currently, the freshwater chronic PFOS toxicity dataset with measured tissue concentrations is somewhat limited. There were 14 total chronic aquatic life studies considered, six quantitative (three fish, one invertebrate, and two amphibian studies) and eight qualitative studies (see Section 4.5). The quantitative studies provided data for three of the eight MDRs. The qualitative studies provided supporting information for only one additional MDR. Therefore, it was concluded that there are currently insufficient data to derive a chronic tissue criterion using a GSD approach from empirical tissue data from toxicity studies. Thus, the EPA used a Bioaccumulation Factor (BAF) approach for chronic tissue criteria development.

2.11.3 Translation of Chronic Water Column Criterion to Tissue Criteria

To enable use of fish tissue measurements of PFOS in protecting designated uses, chronic tissue criteria for PFOS were derived by translating the chronic freshwater water column criterion (summarized in Section 2.11.1 above) into tissue criteria using bioaccumulation factors (BAFs) and the following equation:

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$$Tissue\ Criteria = Chronic\ Water\ Column\ Criterion\ \times BAF \qquad (Eq.\ 1)$$

The resulting tissue criteria correspond to the tissue type serving as the basis of the BAF used in the equation.

2.11.3.1 Aquatic Life Bioaccumulation Factors (BAFs)

A BAF is determined from field measurements and is calculated using the equation:

$$BAF = \frac{C_{biota}}{C_{water}} \qquad (Eq.\ 2)$$

Where:
C_{biota} = PFOS concentration in organismal tissue(s)
C_{water} = PFOS concentration in water where the organism was collected

Given that a BAF is determined from field measurements [as opposed to controlled experiments designed to measure bioconcentration of PFOS using specific test guidelines; (OECD 2001; U.S. EPA 2016c)], a BAF is an expression of all exposure routes, i.e., dietary, water, maternal transfer, and contact with water and sediments via skin and ingestion. Depending upon the tissue residue measurement, BAFs can be based upon residues in the whole organisms, muscle, liver, or any other tissue.

The literature search for reporting on PFOS bioaccumulation was implemented by developing a series of chemical-based search terms. These terms included chemical names and Chemical Abstracts Service registry numbers (CASRN or CAS[3]), synonyms, tradenames, and other relevant chemical forms (i.e., related compounds). Databases searched were Current Contents, ProQuest CSA, Dissertation Abstracts, Science Direct, Agricola, TOXNET, and UNIFY (database internal to U.S. EPA's ECOTOX database). The literature search yielded numerous citations and the citation list was further refined by excluding citations on analytical

[3] Chemical Abstracts Service registry number (CASRN or CAS) for PFOS is 1763-23-1.

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methods, human health, terrestrial organisms, bacteria, and where PFOS was not a chemical of study. The citations meeting the search criteria were reviewed for reported BAFs and/or reported concentrations in which BAFs could be calculated. Data from papers with appropriate information were extracted into a PFOS dataset. The studies meeting these inclusion criteria were also screened for data quality.

Four factors were evaluated in the screening of the BAF literature: 1) number of water samples; 2) number of organism samples; 3) water and organism temporal coordination in sample collection; and 4) water and organism spatial coordination in sample collection. Additionally, the general experimental design was evaluated. For further details on BAFs compilation and ranking, see .

Table 2-2 below outlines the screening criteria for study evaluation and ranking. Only BAFs of high and medium quality were used to derive the tissue criteria (Appendix O). For further details on BAFs compilation and ranking, see Burkhard (2021).

Table 2-2. Evaluation Criteria for Screening Bioaccumulation Factors (BAFs) in the Public Literature.

Table modified from Burkhard (2021).

Screening Factor	High Quality	Medium Quality	Low Quality
Number of Water Samples	> 3	2 – 3	1
Number of Organism Samples[1]	> 3	2 – 3	1
Temporal Coordination	Concurrent collection	Within one year	Collection period > 1 year
Spatial Coordination	Co-located collection	Within 1 - 2 km	Significantly different locations (> 2 km)
General Experimental Design			Mixed species tissues samples

[1] Organismal samples from the same species and tissue type.

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3 EFFECTS ANALYSIS FOR AQUATIC LIFE

3.1 Toxicity to Aquatic Life

All available, reliable studies relating to the acute and chronic toxicological effects of PFOS on aquatic life were considered in the derivation of the national recommended PFOS criteria. Data for possible inclusion in the PFOS criteria were obtained from published literature reporting acute and chronic exposures of PFOS that were associated with mortality, survival, growth, and reproduction. This set of published literature was identified by the EPA's public ECOTOX database (ECOTOX: https://cfpub.epa.gov/ecotox/) as meeting data quality standards. ECOTOX is a source of high-quality toxicity data for aquatic life, terrestrial plants, and wildlife. The database was created and is maintained by the EPA, Office of Research and Development, Center for Computational Toxicology and Exposure. Studies were then further reviewed by the EPA OW to determine test acceptability for use in the criteria derivation. Additional literature searches were also conducted to ensure all available toxicity data were captured. The latest search was conducted through March 2024.

3.1.1 Summary of PFOS Toxicity Studies Used to Derive the Aquatic Life Criteria

Quantitative data for acute PFOS toxicity were available for 29 freshwater species, representing 20 genera and 17 families in five phyla, and six estuarine/marine species, representing six genera and five families in four phyla. Chronic PFOS toxicity data were available for 19 freshwater species, representing 17 genera and 15 families in four phyla, and five estuarine/marine species, representing five genera and five families in three phyla (Table 3-1).

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Table 3-1. Summary Table of Minimum Data Requirements per the 1985 Guidelines Reflecting the Number of Acute and Chronic Genus and Species Level Mean Values in the Freshwater and Saltwater Toxicity Datasets for PFOS.

MDR	Freshwater			
	GMAV	**SMAV**	**GMCV**	**SMCV**
Family Salmonidae in the class Osteichthyes	1	1	1	1
Second family in the class Osteichthyes, preferably a commercially or recreationally important warmwater species	2	2	2	2
Third family in the phylum Chordata (may be in the class Osteichthyes or may be an amphibian, etc.)	5	10	3	4
Planktonic Crustacean	2	5	3	4
Benthic Crustacean	3	3	2	2
Insect	1	1	3	3
Family in a phylum other than Arthropoda or Chordata (e.g., Rotifera, Annelida, or Mollusca)	5	6	2	2
Family in any order of insect or any phylum not already represented	1	1	1	1
Total	**20**	**29**	**17**	**19**
MDR	**Saltwater[a]**			
	GMAV	**SMAV**	**GMCV**	**SMCV**
Family in the phylum Chordata	1	1	1	1
Family in the phylum Chordata	0	0	0	0
Either the Mysidae or Penaeidae family	2	2	1	1
Family in a phylum other than Arthropoda or Chordata	1	1	0	0
Family in a phylum other than Chordata	1	1	1	1
Family in a phylum other than Chordata	1	1	1	1
Family in a phylum other than Chordata	0	0	1	1
Any other family	0	0	0	0
Total	**6**	**6**	**5**	**5**

[a] The 1985 Guidelines require that data from a minimum of eight families are needed to calculate an estuarine/marine criterion. Insufficient data exist to fulfill all eight of the taxonomic MDR groups. Consequently, the EPA cannot derive an estuarine/marine acute criterion, based on the 1985 Guidelines. However, the EPA has developed estuarine/marine benchmarks through use of surrogate data to fill in missing MDRs using the EPA's Web-based Inter-species Correlation Estimation (web-ICE) tool. These benchmarks are provided in Appendix L.

Below are the summarized studies that provided key acute and chronic freshwater toxicity data with effect values that were used quantitatively in deriving the acute and chronic freshwater criteria to protect aquatic life from harmful exposure to PFOS. Study summaries are

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also provided for the estuarine/marine toxicity data that could be used quantitatively to derive acute and chronic estuarine/marine criteria if the MDRs were met.

Study summaries for the most sensitive taxa are grouped by acute or chronic exposure and sorted by sensitivity to PFOS. Study data were summarized in tabular form in Appendix A (freshwater acute studies), Appendix B (estuarine/marine acute studies), Appendix C (freshwater chronic studies), and Appendix D (estuarine/marine chronic studies). Key acute and chronic toxicity studies used qualitatively as supporting information are described in the Effects Characterization (Section 4) below and corresponding data are listed in Appendix E, Appendix F, Appendix G and Appendix H while the remaining, unused studies are listed in Appendix J.

Acute and chronic values were presented as reported by the study authors for each individual study. The EPA independently calculated toxicity values if sufficient raw data were available to conduct statistical analyses. All toxicity values, such as LCs, ECs, NOECs, LOECs, and species- and genus-mean values, were given to four significant figures to prevent round-off error in subsequent calculations, not to reflect the precision of the value. The author-reported toxicity values and the EPA's independently-calculated values (where available) were included for each study throughout the document (in the quantitative data study summaries and appendices as applicable), and the specific value utilized to derive the criteria were identified along with a justification. The EPA's independently-calculated toxicity values were used preferentially, where available.

3.1.1.1 Summary of Acute PFOS Toxicity Studies Used to Derive the Freshwater Aquatic Life Criterion

Acute toxicity data were available for all of the freshwater MDRs. Acceptable data on the acute effects of PFOS in freshwater were available for a total of 29 species representing 20 genera and 17 families in five phyla (Appendix A: Acceptable Freshwater Acute PFOS Toxicity

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Studies). More specifically, quantitative data for acute PFOS toxicity were available for three freshwater fish species (two of the eight MDRs), 16 freshwater invertebrate species (five of the eight MDRs), and 10 freshwater amphibian species (one of the eight MDRs). Ranked genus mean acute values (GMAVs) for PFOS in freshwater based on acute toxicity were identified in Table 3-2 (4 most sensitive genera) and Table 3-3 (all genera) and plotted in Figure 3-1.

Table 3-2. The Four Most Sensitive Genera Used in Calculating the Acute Freshwater Criterion (Sensitivity Rank 1-4).
Ranked below from most to least sensitive.

Rank	Genus	Species	GMAV (mg/L)
1	*Neocloeon*	Mayfly, *N. triangulifer*	0.07617
2	*Moina*	Cladoceran, *M. microcopa* and *M. micrura*	3.075
3	*Pimephales*	Fathead minnow, *P. promelas*	6.950
4	*Oncorhynchus*	Rainbow trout, *O. mykiss*	7.515

3.1.1.1.1 Most Sensitive Freshwater Genus for Acute Toxicity: Neocloeon (mayfly)

Soucek et al. (2023) conducted a 96-hour acute toxicity test to determine the effects of PFOS-K (PFOS potassium salt, CAS # 2795-39-3, 98% purity) in water on the parthenogenetic mayfly, *Neocloeon triangulifer*. The test was performed under static, nonrenewal conditions beginning with < 24 hour old nymphs. Mayflies were fed live diatom biofilm scraping beginning on day 0. Feeding only occurred on day 0. The authors indicated test organisms required food to survive the entire 96-hour exposure, with previous studies demonstrating greater than 80% mortality at 48 hours with no food (Soucek and Dickinson 2015). Percent survival in the control treatment after 96 hours was 100%. The EPA was able to independently calculate a 96-hour LC_{50} of 0.07617 mg/L (0.06546 - 0.08688 mg/L; 95% CI) for this study. The EPA's independently-

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calculated LC_{50} is in line with the author-reported LC_{50} of 0.08 mg/L. Therefore, the independently-calculated LC_{50} of 0.07617 mg/L was used quantitatively to derive the freshwater acute water column criterion for PFOS.

3.1.1.1.2 Second Most Sensitive Freshwater Genus for Acute Toxicity: Moina (cladoceran)

Ji et al. (2008) performed a 48-hour static, unmeasured acute test of PFOS (purity unreported) with *Moina macrocopa*. The test followed the EPA's Methods for measuring the acute toxicity of effluents and receiving waters to freshwater and marine organisms [U.S. EPA/600/4-90/027F; (U.S. EPA 2002)]. The test involved four replicates of five neonates each in five nominal test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 6.25, 12.5, 25, 50 and 100 mg/L. Survival of organisms in the negative control was not reported in the paper. However, raw data were obtained by the EPA from the study authors and control survival was 100% in the acute test. The study authors reported a 48-hour EC_{50} value of 17.95 mg/L for *M. macrocopa*. The 48-hour EC_{50} value was independently-calculated by the EPA as 17.20 mg/L. The independently-calculated acute toxicity value was quantitatively used in the derivation of the freshwater acute water column criterion.

Razak et al. (2023) tested the acute toxicity of perfluorooctanesulfonate (PFOS, ≥98% purity) on *Moina micrura* for 48 hours in a measured, static experiment. Testing methods followed OECD 202 (OECD 2004) with nominal testing concentrations of 10, 25, 50, 75, 100, 250, 500, 750, 1,000, 2,500, 5,000, 7,500, and 10,000 µg/L, plus a control, with four replicates per treatment. Test water was filtered lake water. Each replicate consisted of 10 neonates (<48 hours old) in 50 mL of solution in a 100 mL beaker, and organisms were not fed during the study. The lethal effect concentrations (LC) were calculated using Probit analysis, and the 48-

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hour LC_{50} value of 549.6 µg/L, or 0.5496 mg/L was determined to be acceptable for quantitative use.

The geometric mean of the two SMAVs for *Moina macrocopa* (17.20 mg/L) and *Moina micrura* (0.5496 mg/L) were used to calculate the GMAV of 3.075 mg/L for the genus *Moina*. If the EPA excluded the *M. micrura* SMAV on the basis of it being an overly sensitive outlier (relative to *M. macrocopa* and the overall acute data except for *N. triangulifer*) that would result in the final PFOS acute criterion potentially being underprotective of untested sensitive invertebrate or other taxa, considering that the available data serve as surrogate information for the thousands of untested freshwater species. Conversely, excluding the *M. macrocopa* SMAV on the basis of it being a tolerant outlier (relative to *M. micrura*) would result in the Moina GMAV being highly influenced by a single test/species with an LC_{50} that was relatively sensitive (i.e., *M. micrura* SMAV = 0.5496 mg/L) compared to the overall acute data with the exception of *N. triangulifer*. Averaging the *M. micrura* and *M. moina* SMAVs resulted in a GMAV (3.075 mg/L) that was the second most sensitive GMAV, still in the general range of the data overall.

3.1.1.1.3 Third Most Sensitive Freshwater Genus for Acute Toxicity: Pimephales (fathead minnow)

Drottar and Krueger (2000c) evaluated the acute effects of PFOS-K (PFOS potassium salt, CAS# 2795-39-3, Lot # 217 (T-6295) obtained from the 3M Company, 90.49% purity) on juvenile fathead minnows (*Pimephales promelas*) during a 96-hour measured, static study. Researchers followed protocols from U.S. EPA Series 850, OPPTS 850.1075 and OECD Guideline 203. All fish used in the test were from the same source and year class, and the total length of the longest fish was no more than twice the length of the shortest. The authors reported an LC_{50} of 9.5 mg/L PFOS. The EPA's independently-calculated 96-hour LC_{50} was 9.020 mg/L and was used quantitatively to derive the freshwater acute water column criterion for PFOS. 3M

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Company (2000) provides the results of a 96-hour static, unmeasured acute toxicity test with the fathead minnow and PFOS-Li (PFOS lithium salt, CAS # 29457-72-5). Fish were 79 days old at test initiation with an average length of 2.1 cm and weight of 0.069 g. No mortality occurred in the control treatment and 100% mortality was observed in the highest treatment (56 mg/L). The study authors reported that the test sample containing 24.5% PFOS-Li exhibited a 96-hour LC_{50} of 19 mg/L, which equates to 4.655 mg/L as PFOS. The independently-calculated 96-hr LC_{50} value was 21.86 mg/L, which equates to 5.356 mg/L as PFOS, and was used quantitatively to derive the freshwater acute water column criterion for PFOS.

The geometric mean of the two acute toxicity values described above for *P. promelas* (9.020 and 5.356 mg/L) were used to calculate an SMAV and GMAV of 6.950 mg/L, which represents the second most sensitive GMAV in the EPA's freshwater acute dataset for PFOS.

3.1.1.1.4 Fourth Most Sensitive Freshwater Genus for Acute Toxicity: Oncorhynchus (trout)

Sharpe et al. (2010) evaluated the acute effects of PFOS-K (potassium salt, CAS # 2795-39-3, 98% purity) to *Oncorhynchus mykiss*, rainbow trout, via a 96-hour renewal exposure with measured concentrations (renewal was not stated in paper, but assumed based on other information provided, including the test Guideline protocol that the authors cited as the protocol that was used). There were limited details in the publication about the test protocol; however, it was noted that the Organization for Economic Co-operation and Development (OECD) Guideline 203 was followed, and the study authors did not identify any deviations from these test guidelines. The EPA obtained clarification from the study authors on the experimental design regarding the biomass loading rate, which was 1 to 1.5 g/L (based on four fish weighing a total of 2 to 3 g per 2 L tank; personal communication with Greg Goss and Rainie Sharpe, March 2021). This biomass loading rate was slightly higher than that stated in OECD Guidelines of 0.8

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g/L (OECD 1992). The author-reported 96-hour LC_{50} for the study was 2.5 mg/L. The authors do not specify if this concentration was nominal or measured. Given the clarifications regarding the biomass loading, the LC_{50} from this study was used quantitatively to derive the freshwater acute water column criterion for PFOS.

Palmer et al. (2002a) evaluated the acute effects of PFOS-K (potassium salt, identified as FC-95 obtained from 3M Company) to rainbow trout via a 96-hour static exposure with measured concentrations. The study author-reported 96-hour LC_{50} for the study was 22 mg/L. The independently-calculated 96-hour LC_{50} value was 22.59 mg/L. The independently-calculated LC_{50} was used quantitatively to derive the freshwater acute water column criterion for PFOS.

The geometric mean of the two toxicity values described above (2.5 and 22.59 mg/L), was used to calculate the SMAV and GMAV of 7.515 mg/L for rainbow trout, *O. mykiss*. The GMAV of 7.515 mg/L is consistent with the acute rainbow trout studies cited in OECD's 2002 PFOS Hazard Assessment, from which the LC_{50} values for rainbow trout range from 7.8 to 22 mg/L (OECD 2002).

Table 3-3. Ranked Freshwater Genus Mean Acute Values.

Rank[a]	GMAV (mg/L PFOS)	MDR Group[c]	Genus	Species	SMAV[b] (mg/L PFOS)
1	0.07617	F	*Neocloeon*	Mayfly, *Neocloeon triangulifer*	0.07617
2	3.075	D	*Moina*	Cladoceran, *Moina macrocopa*	17.20
				Cladoceran, *Moina micrura*	0.5496
3	6.950	B	*Pimephales*	Fathead minnow, *Pimephales promelas*	6.950
4	7.515	A	*Oncorhynchus*	Rainbow trout, *Oncorhynchus mykiss*	7.515
5	13.50	G	*Ligumia*	Black sandshell, *Ligumia recta*	13.50

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Rank[a]	GMAV (mg/L PFOS)	MDR Group[c]	Genus	Species	SMAV[b] (mg/L PFOS)
6	15.61	E	*Neocaridina*	Japanese swamp shrimp, *Neocaridina denticulata*	15.61
7	15.99	C	*Xenopus*	African clawed frog, *Xenopus laevis*	15.99
8	16.50	G	*Lampsilis*	Fatmucket, *Lampsilis siliquoidea*	16.50
9	19.88	C	*Hyla*	Gray treefrog, *Hyla versicolor*	19.88
10	22.48	G	*Dugesia*	Planaria, *Dugesia japonica*	22.48
11	27.86	B	*Danio*	Zebrafish, *Danio rerio*	27.86
12	43.15	D	*Daphnia*	Cladoceran, *Daphnia carinata*	11.56
				Cladoceran, *Daphnia magna*	51.86
				Cladoceran, *Daphnia pulicaria*	134.0
13	47.40	C	*Ambystoma*	Jefferson salamander, *Ambystoma jeffersonianum*	51.71
				Small-mouthed salamander, *Ambystoma texanum*	30.00
				Eastern tiger salamander, *Ambystoma tigrinum*	68.63
14	48.81	E	*Pontastacus*	Crayfish, *Pontastacus leptodactylus*	48.81
15	56.49	C	*Anaxyrus*	American toad, *Anaxyrus americanus*	56.49
16	59.87	E	*Procambarus*	Crayfish, *Procambarus fallax f. virginalis*	59.87
17	61.80	H	*Brachionus*	Rotifer, *Brachionus calyciflorus*	61.80
18	64.35	G	*Elliptio*	Eastern elliptio, *Elliptio complanata*	64.35
19	109.2	C	*Lithobates*	American bullfrog, *Lithobates catesbeiana*	133.3
				Green frog, *Lithobates clamitans*	113.0
				Northern leopard frog, *Lithobates pipiens*	72.72
				Wood frog, *Lithobates sylvatica*	130.0

Rank[a]	GMAV (mg/L PFOS)	MDR Group[c]	Genus	Species	SMAV[b] (mg/L PFOS)
20	172.1	G	*Physella*	Bladder snail, *Physella acuta*	183.0
				Snail, *Physella heterostropha pomilia*	161.8

[a] Ranked from the most sensitive to the most tolerant based on Genus Mean Acute Value.
[b] From Appendix A: Acceptable Freshwater Acute PFOS Toxicity Studies.
[c] MDR Groups identified by list provided in Section 2.10.1 above.

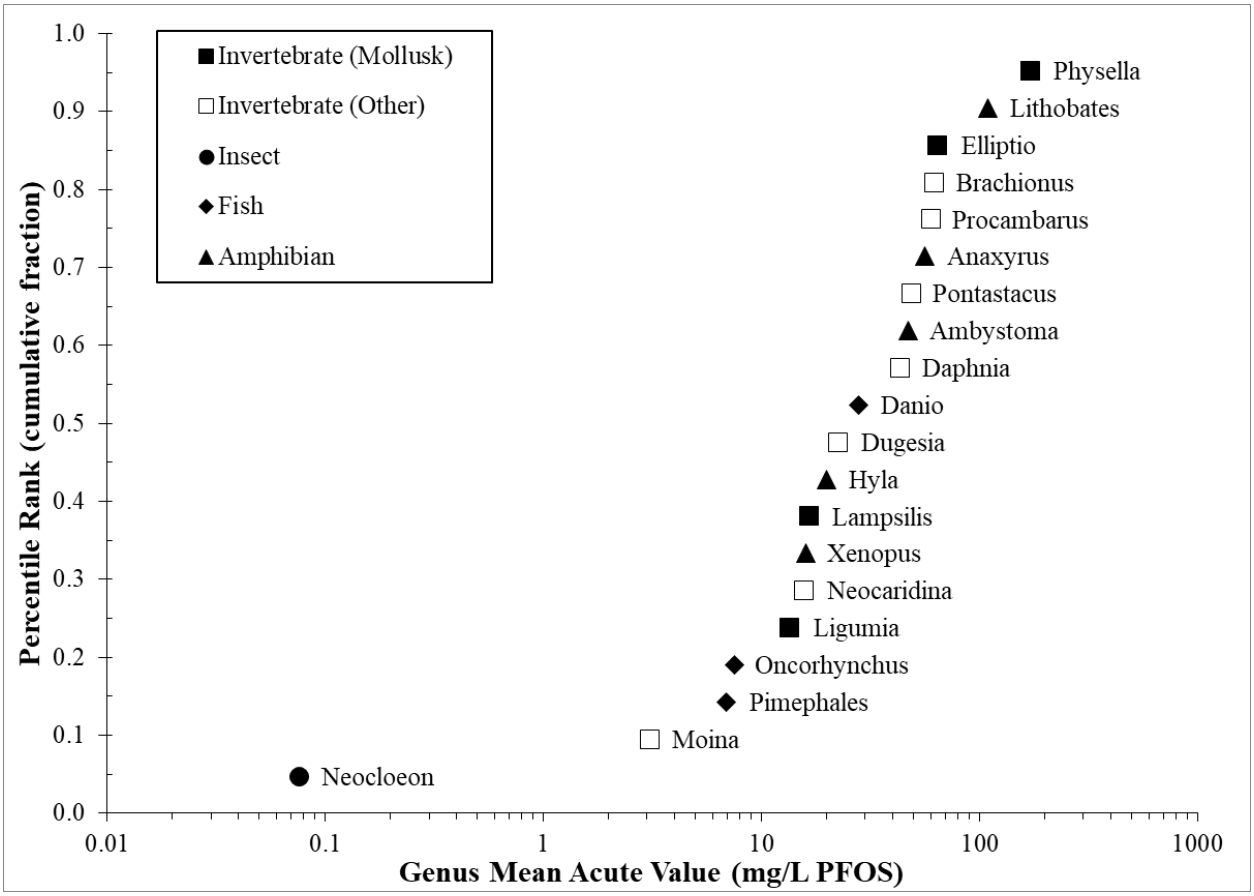


Figure 3-1. Freshwater Acute PFOS GMAVs Fulfilling the Acute MDRs.

3.1.1.2 Summary of Acute PFOS Toxicity Studies Used to Derive the Estuarine/Marine Aquatic Life Criterion

Quantitative empirical data for acute PFOS toxicity were available for six saltwater species, representing six genera and five families. The data available for saltwater species fulfilled only five of the eight MDRs. In the interest of providing information to states/authorized Tribes on protective values, the EPA developed an estuarine/marine acute benchmark using the

available empirical data supplemented with toxicity values generated through the use of NAMs, specifically through the use of the EPA Office of Research and Development's peer-reviewed publicly-available Web-based Interspecies Correlation Estimation (WebICE) tool (Raimondo et al. 2010). These benchmarks are provided in Appendix L. Table 3-4 below shows the four most sensitive acute estuarine/marine genera that could be used quantitatively to derive acute criteria if the MDRs were met. Ranked GMAVs for saltwater organisms based on acceptable acute toxicity values were identified in Table 3-5 and plotted in Figure 3-2.

Table 3-4. The Four Most Sensitive Acute Estuarine/Marine Genera.
Ranked Below from Most to Least Sensitive.

Rank	Genus	Species	GMAV (mg/L PFOS)
1	*Mytilus*	Mediterranean mussel, *M. galloprovincialis*[1]	1.1
2	*Strongylocentrotus*	Purple sea urchin, *S. purpuratus*	1.7
3	*Paracentrotus*	Sea urchin, *P. lividus*[2]	1.795
4	*Americamysis*	Mysid, *A. bahia*	4.914

[1] Not a resident species in North America, but other species in this genus are resident and commercially or ecologically important species.
[2] Not a resident species in North America, but other species in this family (Echinidae) are common ecotoxicity test species that serves as a surrogate for untested urchin species residing in North America.

3.1.1.2.1 Most Sensitive Estuarine/Marine Genus for Acute Toxicity: Mytilus (mussel)

The acute toxicity of perfluorooctane sulfonate (PFOS, purity not provided) on the Mediterranean mussel, *Mytilus galloprovincialis* was evaluated by **Fabbri et al. (2014)**. This species is not resident to North America, but is a surrogate for North American mussel species, including the widespread, commercially and ecologically important blue mussel, *Mytilus edulis.* The test endpoint was the percentage of normal D-larvae in each well, including malformed larvae and pre-D stages, at test termination (48 hours). The acceptability of test results was based

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on controls for a percentage of normal D-shell stage larvae, > 75% (ASTM 2004b). The percentage of normal D-larva decreased with increasing test concentrations. The NOEC and LOEC reported for the study were 0.00001 and 0.0001 mg/L, respectively. However, the test concentrations failed to elicit a 50% reduction in malformations in the highest test concentration (1 mg/L), and an EC_{50} was not determined. Therefore, the EC_{50} for the study was greater than the highest test concentration (1 mg/L). The 48-hour EC_{50} based on malformation of > 1 mg/L was acceptable for quantitative use.

Hayman et al. (2021) report the results of a 48-hour static, measured test on the effects of PFOS-K (PFOS potassium salt, CAS # 2795-39-3, 98% purity) on *M. galloprovincialis*. Authors noted that tests followed U.S. EPA (1995) and ASTM (2004a) protocols. Larvae were enumerated for total number of larvae that were alive at the end of the test as well as number of normally-developed D-shaped larvae. There were no significant differences between solvent control and filtered seawater, suggesting no adverse effects of methanol. The author-reported 48-hr EC_{50}, based on normal development, was 1.1 mg/L. The EPA was not able to independently calculate a 48-hour EC_{50} value as the curve fitted model did not result in a good fit. Therefore, the author-reported EC_{50} of 1.1 mg/L was considered for quantitative use.

The two EC_{50} values from the two studies both indicated sensitivity of the Mediterranean mussel to acute exposure of PFOS is above 1 mg/L. However, the EC_{50} for *M. galloprovincialis* from **Fabbri et al. (2014)** was unbounded while the EC_{50} from **Hayman et al. (2021)** was definitive, and therefore the latter EC_{50} (1.1 mg/L) serves as the basis for the SMAV and GMAV used to derive the acute estuarine/marine benchmark for PFOS.

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3.1.1.2.2 Second Most Sensitive Estuarine/Marine Genus for Acute Toxicity: Strongylocentrotus (sea urchin)

The **Hayman et al. (2021)** study also included the results of a 96-hour static, measured test on the effects of PFOS-K (PFOS potassium salt, CAS # 2795-39-3, 98% purity) on the purple sea urchin, *Strongylocentrotus purpuratus*. Authors noted that tests followed U.S. EPA (1995) and ASTM (2004a) protocols. At test termination (96 hours), the first 100 larvae were enumerated and observed for normal development (4-arm pluteus stage). As with the other tests in the study with different species, there were no significant differences between solvent control and filtered seawater, suggesting no adverse effects of methanol. The author-reported 96-hour EC_{50}, based on normal development, was 1.7 mg/L. The EPA was not able to independently calculate a 96-hour EC_{50} value as the curve fitted model did not result in a good fit. Therefore, the author-reported EC_{50} of 1.7 mg/L mg/L was thus applied for quantitative use and was utilized as the SMAV and GMAV to derive the acute estuarine/marine benchmark for PFOS.

3.1.1.2.3 Third Most Sensitive Estuarine/Marine Genus for Acute Toxicity: Paracentrotus (sea urchin)

A 72-hour static, unmeasured PFOS (purity not provided) toxicity test with the sea urchin, *Paracentrotus lividus* (a non-North American species) was conducted by **Gunduz et al. (2013)**. The 72-hour EC_{50} based on normal development to the pluteus stage was 1.795 mg/L PFOS and was acceptable for quantitative use; however, additional consideration needs to be given to the use of this value in benchmark derivation due to the short test duration.

3.1.1.2.4 Fourth Most Sensitive Estuarine/Marine Genus for Acute Toxicity: Americamysis (mysid)

Along with the Mediterranean mussel and purple sea urchin, **Hayman et al. (2021)** conducted a 96-hour static, measured test to determine the effects of PFOS-K on the mysid, *Americamysis bahia*. Authors noted that tests followed U.S. EPA (1995) and ASTM (2004a)

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protocols. Only two of the sixty organisms (3.3%) were found dead in the controls at test termination. The author-reported 96-hour LC_{50} is 5.1 mg/L PFOS-K. The independently-calculated 96-hr LC_{50} value was 4.914 mg/L and is acceptable for quantitative use in the derivation of the acute estuarine/marine benchmark for PFOS.

Table 3-5. Ranked Estuarine/Marine Water Genus Mean Acute Values.

Rank[1]	GMAV (mg/L PFOS)	MDR Group[3]	Genus	Species	SMAV[2] (mg/L PFOS)
1	1.1	D	*Mytilus*	Mussel, *Mytilus galloprovincialis*	1.1
2	1.7	F	*Strongylocentrotus*	Purple sea urchin, *Strongylocentrotus purpuratus*	1.7
3	1.795	E	*Paracentrotus*	Sea urchin, *Paracentrotus lividus*	1.795
4	4.914	C	*Americamysis*	Mysid, *Americamysis bahia*	4.914
5	6.9	C	*Siriella*	Mysid, *Siriella armata*	6.9
6	>15	A	*Cyprinodon*	Sheepshead minnow, *Cyprinodon variegatus*	>15

[1] Ranked from the most sensitive to the most tolerant based on Genus Mean Acute Value.
[2] From Appendix B: Acceptable Estuarine/Marine Acute PFOS Toxicity Studies.
[3] MDR Groups identified by list provided in Section 2.10.1 above.

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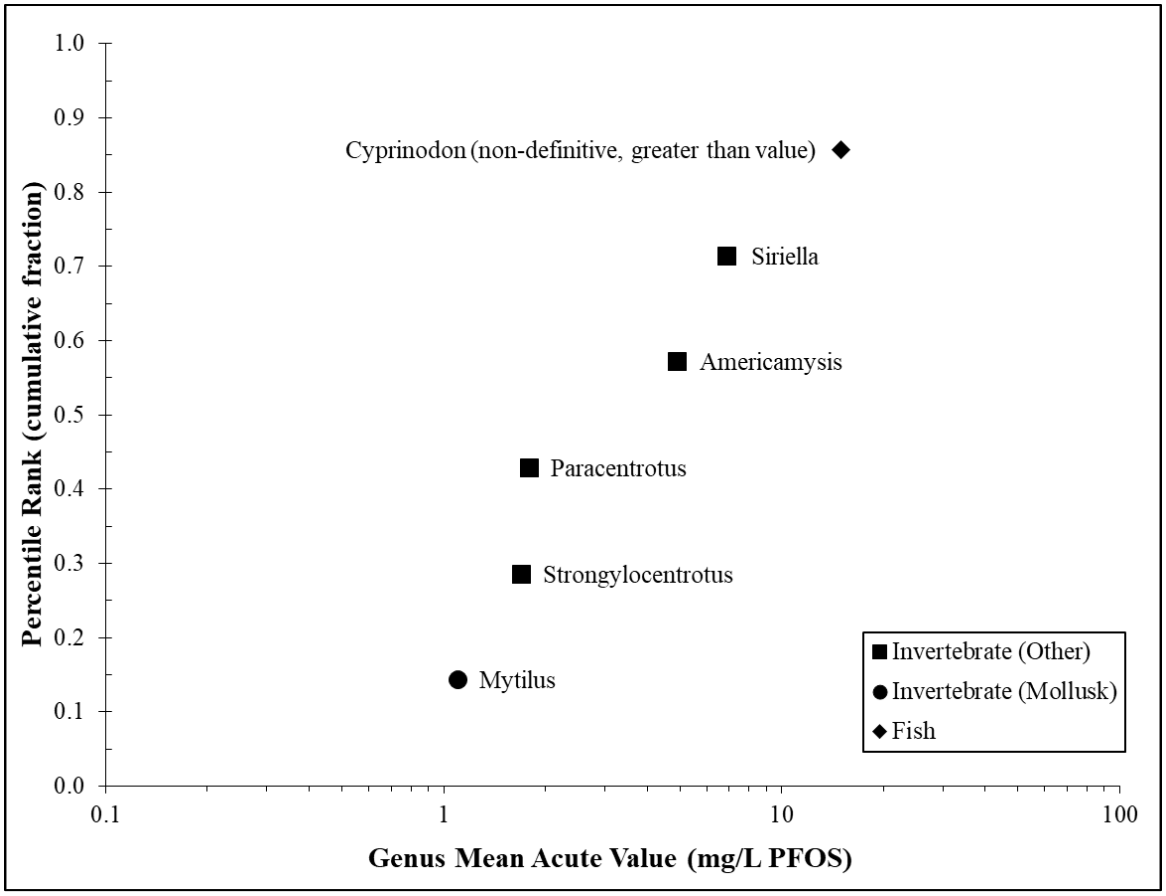


Figure 3-2. Acceptable Estuarine/Marine GMAVs.

3.1.1.3 Summary of Chronic PFOS Toxicity Studies Used to Derive the Freshwater Aquatic Life Criterion

Chronic toxicity data were available for all of the freshwater MDRs. Chronic PFOS toxicity data were available for 19 freshwater species, representing 17 genera and 15 families in four phyla. More specifically, quantitative data for acute PFOS toxicity were available for four freshwater fish species, representing four genera and three families (two of the eight MDRs), 11 freshwater invertebrate species, representing 11 genera and ten families (five of the eight MDRs), and three amphibian species, representing two genera in two families (one of the eight MDRs). Ranked GMCVs for PFOS in freshwater based on chronic toxicity are listed in Table 3-6 (four most sensitive genera) and Table 3-7 (all genera) and plotted in Figure 3-3.

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Table 3-6. The Four Most Sensitive Genera Used in Calculating the Chronic Freshwater Criterion.

Ranked Below from Most to Least Sensitive.

Rank	Genus	Species	GMCV (mg/L PFOS)[1]
1	*Neocloeon*	Mayfly, *Neocloeon triangulifer*	0.000226
2	*Chironomus*	Midge, *Chironomus dilutus*	0.005198
3	*Lampsilis*	Fatmucket, *Lampsilis siliquoidea*	0.01768
4	*Enallagma*	Blue damselfly, *Enallagma cyathigerum*	0.03162

[1]Other values were used in additional analyses supporting the criterion calculation to examine the effects of less certain toxicity studies and non-resident species on the chronic freshwater criterion. See Section 4.1 below for more details.

3.1.1.3.1 Most Sensitive Freshwater Genus for Chronic Toxicity: Neocloeon (mayfly)

Soucek et al. (2023) conducted a chronic life-cycle test to determine the effects of PFOS-K (PFOS potassium salt, CAS # 2795-39-3, 98% purity) on the parthenogenetic mayfly, *Neocloeon triangulifer*. The test was performed under renewal conditions over 27 days beginning with < 24 hour old nymphs. There were sixteen (with one mayfly per replicate) replicates per test concentration and control. Replicates one through eight were destructively sampled on day 14 and replicates nine through sixteen continued until the end of the test (when all mayflies either molted into imago stage or died). The endpoints that were evaluated included survival for all replicates, 14-d length and calculated dry weight (using a previously published body dry weight equation; Besser et al. 2021) for replicates 1 through 8, and percent survival to pre-emergent nymph (PEN) stage, number of days until PEN stage, percent emergence (to imago stage), and pre-egg laying live weight of imago for replicates 9 through 16. Percent survival in the control after 14 days was 100%. Percent survival of mayflies after 14 days in the remaining seven test concentrations ranged from 79 to 100%. The most sensitive endpoint was 14-day dry weight. The study authors reported three different 14-day dry weight EC_{10} values that were

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calculated using various point-estimation approaches. The author-reported 14-day dry weight EC_{10} values produced by the various approaches were relatively similar to one another, ranging from 0.000226 (using TRAP [2 parameter, threshold sigmoidal curve]) to 0.000272 mg/L (using log-linear regression, controls excluded). The EPA was not able to fit a reliable model with significant model parameters to the 14-day dry weight C-R dataset and, therefore, relied on the author-reported EC_{10} of 0.000226 mg/L (based on TRAP) as the primary effect concentration. The EPA selected the TRAP-based EC_{10} preferentially over the EC_{10} values based on the two other point estimation approaches (i.e., log-linear regression with and without controls) because the TRAP-based model (1) considered control responses; (2) was more fundamentally consistent with the maximum likelihood regression approaches used by the EPA to assess C-R datasets throughout this PFOS aquatic life AWQC document, and; (3) relied on replicate-level data, which the EPA used preferentially over treatment-mean data in assessing C-R datasets throughout the PFOS aquatic life criteria derivation process. The author-reported EC_{10} of 0.000226 mg/L (TRAP-based) was used quantitatively to derive the freshwater chronic water column criterion for PFOS.

3.1.1.3.2 Second Most Sensitive Freshwater Genus for Chronic Toxicity: Chironomus (midge)

MacDonald et al. (2004) conducted sub-chronic, partial-life cycle tests on larva and chronic life-cycle tests to determine the effects of PFOS-K (PFOS potassium salt, 95% purity) on the midge, *Chironomus dilutus* (formally known as *Chironomus tentans*). The test was performed under renewal conditions over 10 days for the larval test and greater than 50 days for the life-cycle test. The tests followed the general guidance given by EPA-600-R99-064 (U.S. EPA 2000b) and ASTM E 1706-00 (ASTM 2002).

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The author-reported 10-day growth and survival EC_{10}s for the study were 0.0492 and 0.1079 mg/L, respectively. The study authors also reported NOECs of 0.0491 mg/L, LOECs of 0.0962 mg/L, and MATCs of 0.0687 mg/L for both endpoints. The author-reported 20-day EC_{10}s for growth, survival, and total emergence were 0.0882, 0.0864, and 0.0893 mg/L, respectively. The study authors also reported NOECs of 0.0217 mg/L for growth and survival and < 0.0023 mg/L for emergence, LOECs of 0.0949 mg/L for growth and survival and 0.0271 mg/L for emergence, and MATCs of 0.0454 mg/L for growth and survival and 0.0071 mg/L for emergence. It is noted here that the paper reported contrasting NOECs for 20-day survival. The text in the paper stated that the NOEC was 0.0271 mg/L and Table 2 of the paper provided a value of 0.0949 mg/L. The EPA assumed the NOEC in Table 2 of the paper was not correct and that 0.0217 mg/L was the correct NOEC based on the data presented in Figure 3A of the paper, since the EPA was unable to gain confirmation from the study authors. This assumption was applied to the summary of the study results presented in this PFOS aquatic life AWQC document. The EPA was able to independently calculate an EC_{10} for 10-day growth of 0.05896 mg/L for the study. The independently-calculated 10-day EC_{10} value for growth of the midge was used quantitatively to derive the freshwater chronic water column criterion for PFOS.

McCarthy et al. (2021) conducted two chronic toxicity tests with PFOS (98% purity) on the midge, *C. dilutus*, a 10-day and a 20-day exposure, following standard protocols from U.S. EPA (2000b) and ASTM (2002) with slight modifications. The 10-day exposure was considered a range finding test, with concentrations spaced by ~100x and only mortality measured, whereas the 20-day exposure measured both survival and growth and was termed an "abbreviated full life cycle test" by the study authors. The 20-day exposure is less than the recommended 50 – 65 day full-life cycle method outlined in U.S. EPA (2000b) and used in MacDonald et al. (2004), and

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since exposures of midges started on day two or four, the actual exposure duration is only 16 or 19 days long. The most sensitive endpoint was survival from the "abbreviated full life cycle test" with an author-reported 16-day EC_{10} of 0.00136 mg/L PFOS. Additionally, the study authors reported EC_{10}s of 0.00162 and 0.00323 mg/L PFOS for growth as mean biomass and mean weight, respectively. The EPA was unable to independently calculate EC_{10}s for survival and mean weight. However, the EPA was able to independently calculate an EC_{10} value for mean biomass of 0.001588 mg/L PFOS. The independently-calculated 16-day EC_{10} for mean biomass was used quantitatively to derive the freshwater chronic water column criterion for PFOS.

Krupa et al. (2022) conducted a partial-life cycle chronic toxicity test with the midge, *C. dilutus*, and PFOS-K (perfluorooctanesulfonate potassium salt, > 98% purity, CAS No. 2795-39-3. The larvae were exposed to PFOS for 16 days. The measured exposure concentrations were < the limit of detection (LOD), 0.001, 0.0025, 0.004, 0.0075, 0.016 and 0.03 mg/L. At test termination, larval survival was assessed, and ash-free dry weight (AFDW) was determined following ASTM (2019). The AFDW of five groups of 12 larvae was measured at test initiation to establish a baseline for growth. The author-reported 16-day growth EC_{10} was 0.0015 mg/L PFOS-K. The EPA was unable to fit a reliable model for any of the chronic endpoints from this test. Therefore, the author-reported EC_{10} value of 0.0015 mg/L for growth presented in the paper was used quantitatively to derive the freshwater chronic water column criterion for PFOS.

The most sensitive endpoints from the two toxicity studies with *C. dilutus* that could be independently-calculated (see details in Appendix C.2.2) were for 10-day growth with an EC_{10} of 0.05896 mg/L (MacDonald et al. 2004) and 16-day mean biomass with an EC_{10} of 0.001588 mg/L (McCarthy et al. 2021). The EPA could not independently calculate the 16-day growth EC_{10} of 0.0015 mg/L (Krupa et al. 2022). Although over an order of magnitude difference exists

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between MacDonald et al. (2004) and the other two studies, all three EC_{10}s were used quantitatively to derive the chronic aquatic life criterion with a SMCV and GMCV equal to the geometric mean of the three values or 0.005198 mg/L.

As mentioned in the Bots et al. (2010) summary (Section 3.1.1.3.4), the observed effects of PFOS on aquatic insects appeared to be consistent across the available data for chironomids and odonates. However, Bots et al. (2010) did not measure the effects of PFOS on nymph growth and therefore, the observed effects in that study cannot be compared with the results of MacDonald et al. (2004), McCarthy et al. (2021), and Krupa et al. (2022). The remainder of the toxicity values available for aquatic insects were used as supporting information to corroborate the toxicity value used to derive the freshwater chronic criterion and to better understand the effects of PFOS on aquatic insects in general. No other quantitative toxicity values were available for this species or genus.

3.1.1.3.3 Third Most Sensitive Freshwater Genus for Chronic Toxicity: Lampsilis (mussel)

Hazelton (2013); Hazelton et al. (2012) conducted a test of the long-term effects of PFOS (acid form, > 98% purity) on glochidia and juvenile life stages from the mussel *Lampsilis siliquoidea* using a unique experimental design for which standard methods have not been established. The test exposed brooding glochidia (in marsupia) for 36 days followed by a 24-hour exposure of free glochidia in a factorial design. As such, the free glochidia from the control group of the marsupia exposure were divided between a control and the two PFOS treatments and the PFOS treatments were split into control and the same PFOS treatment group as the marsupia exposure. This factorial design allowed for the comparison of PFOS effects in two different life-stages. See Appendix C.2.3 for additional details on the experimental design and considerations for the utilization of this study in the criterion derivation.

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The data presented in the paper for metamorphosis success were considered for quantitative use in the derivation of the chronic criterion for PFOS (see Appendix C.2.3). The author-reported NOEC was 0.0045 mg/L and LOEC was 0.0695 mg/L. The reduction in metamorphosis success at the LOEC was estimated to be 35.4%. However, this was not a definitive test in that both the study design (which only included two treatment groups) and level of data presented (which are only presented graphically in Figure 2 of the paper) in the publication lack the details needed to fully understand the effects of chronic PFOS exposures to the glochidia and juvenile life stages of *L. siliquoidea.* Additionally, as there were only two PFOS treatment groups and the gap in these exposure concentrations is large (about 15-fold), the EPA was not able to fit a curve to estimate an EC_{10} in a manner similar to the other toxicity studies used to derive this criterion. Instead, both the use of an MATC and an estimated EC_{10} were considered for the chronic value. An EC_{10} was estimated by assuming the 0.0695 mg/L treatment represents an $EC_{35.4}$ and estimating the EC_{10} using the exposure response slope from another PFOS toxicity study focused on another mussel species (*Perna viridis*). Specifically, the chronic exposure of *Perna viridis* reported by Liu et al. (2013), which is summarized in Section 3.1.1.4.1, was used to derive a $EC_{10}/EC_{35.4}$ ratio from that study, which was 0.0033/0.0186, or 0.1770. Applying this ratio to Hazelton et al. (2012) yields an estimated EC_{10} of 0.0123 mg/L. Given the similarity between this EC_{10} and the author-reported MATC for Hazelton et al. (2012), the MATC of 0.01768 mg/L was used to derive the chronic criterion for PFOS. The EPA hopes to further refine the estimated EC_{10} by obtaining the treatment level data from the study authors and exploring additional exposure response slopes from the PFOS dataset. No other quantitative chronic toxicity values were available for this species or genus; therefore, the

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MATC of 0.01768 mg/L was used quantitatively to derive the freshwater chronic water column criterion for PFOS.

3.1.1.3.4 Fourth Most Sensitive Freshwater Genus for Chronic Toxicity: Enallagma (damselfly)

Bots et al. (2010) conducted a 320-day partial life-cycle study under renewal test conditions to examine the effects of PFOS (tetraethylammonium salt, 98% purity) on the damselfly *Enallagma cyathigerum.* Approximately 40% of the nymphs in the control treatment died during the first 60 days and similar mortality levels were observed in the other treatments. However, it appeared that control survival plateaued between 60 and 200 days, with 82.57% of the remaining nymphs in the control treatment surviving during this time, indicating that survival settled out during this phase of the experiment. The initial drop in nymph survival could likely be attributed to the handling of the test organisms between the various phases of the experiment. This would explain the observed plateau between 60 and 200 days, as the nymphs were not handled during this time. The observed control survival in this test was consistent with other odonate tests and excessive mortality of nymphs is typically expected within the first 200 days given the difficulty in maintaining odonates in a lab setting (Abbott and Svensson 2007; Rice 2008). Therefore, the observed control survival for this study was considered within the acceptable range for this species up to the 200-day exposure duration. Further, the control survival observed in this study was largely consistent with the toxicity testing guidelines for chironomids (requiring 70% control survival: ASTM 2002; U.S. EPA 2000b), which are currently the only test guidelines for an emergent aquatic insect as there currently is no test guideline for odonates. Therefore, considerations regarding the use of these data for chronic criterion derivation were based on best scientific judgement and were restricted to the first 200 days of the experiment.

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The observed effects of PFOS on *E. cyathigerum* reported in the paper by the study authors include decreased survival over the exposure duration and decreased metamorphosis success. The MATC based on metamorphic success was less sensitive than for survival. As such, the MATC author-reported value of 0.03162 mg/L for nymph survival was considered quantitatively in the derivation of the aquatic life criteria. The remainder of the toxicity values were used as supporting information to corroborate the toxicity value used to derive the freshwater chronic criterion and to better understand the effects of PFOS on aquatic insects. As no other quantitative toxicity values were available for this species or genus, the author-reported MATC of 0.03162 mg/L served directly as the SMCV/GMCV. Additionally, the EPA ran additional analyses with some of the other toxicity values for *E. cyathigerum* to understand the influence of this study on the overall chronic criterion (see Section 4.1 below).

Table 3-7. Ranked Freshwater Genus Mean Chronic Values.

Rank[a]	GMCV (mg/L PFOS)	MDR Group[c]	Genus	Species	SMCV[b] (mg/L PFOS)
1	0.000226	F	*Neocloeon*	Mayfly, *Neocloeon triangulifer*	0.000226
2	0.005198	F	*Chironomus*	Midge, *Chironomus dilutus*	0.005198
3	0.01768	G	*Lampsilis*	Fatmucket, *Lampsilis siliquoidea*	0.01768
4	0.03162	F	*Enallagma*	Blue damselfly, *Enallagma cyathigerum*	0.03162
5	0.03217	B	*Danio*	Zebrafish, *Danio rerio*	0.03217
6	0.06519	D	*Daphnia*	Cladoceran, *Daphnia carinata*	0.003162
				Cladoceran, *Daphnia magna*	1.344
7	> 0.1	A	*Salmo*	Atlantic salmon, *Salmo salar*	> 0.1
8	0.1098	B	*Pimephales*	Fathead minnow, *Pimephales promelas*	0.1098

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Rank[a]	GMCV (mg/L PFOS)	MDR Group[c]	Genus	Species	SMCV[b] (mg/L PFOS)
9	0.167	E	*Procambarus*	Crayfish, *Procambarus fallax f. virginalis*	0.167
10	0.1789	D	*Moina*	Cladoceran, *Moina macrocopa*	0.1789
11	0.25	H	*Brachionus*	Rotifer, *Brachionus calyciflorus*	0.25
12	0.5997	C	*Xiphophorus*	Swordtail fish, *Xiphophorus helleri*	0.5997
13	0.7507	C	*Xenopus*	African clawed frog, *Xenopus laevis*	> 0.7160
				Clawed frog, *Xenopus tropicalis*	0.7871
14	1.316	C	*Lithobates*	Northern leopard frog, *Lithobates pipiens*	1.316
15	2.899	E	*Hyalella*	Amphipod, *Hyalella azteca*	2.899
16	8.527	G	*Physella*	Snail, *Physella heterostropha pomilia*	8.527
17	8.640	D	*Ceriodaphnia*	Cladoceran, *Ceriodaphnia dubia*	8.640

[a] Ranked from the most sensitive to the most tolerant based on Genus Mean Chronic Value.
[b] From Appendix C: Acceptable Freshwater Chronic PFOS Toxicity Studies
[c] MDR Groups identified by list provided in Section 2.10.1 above.

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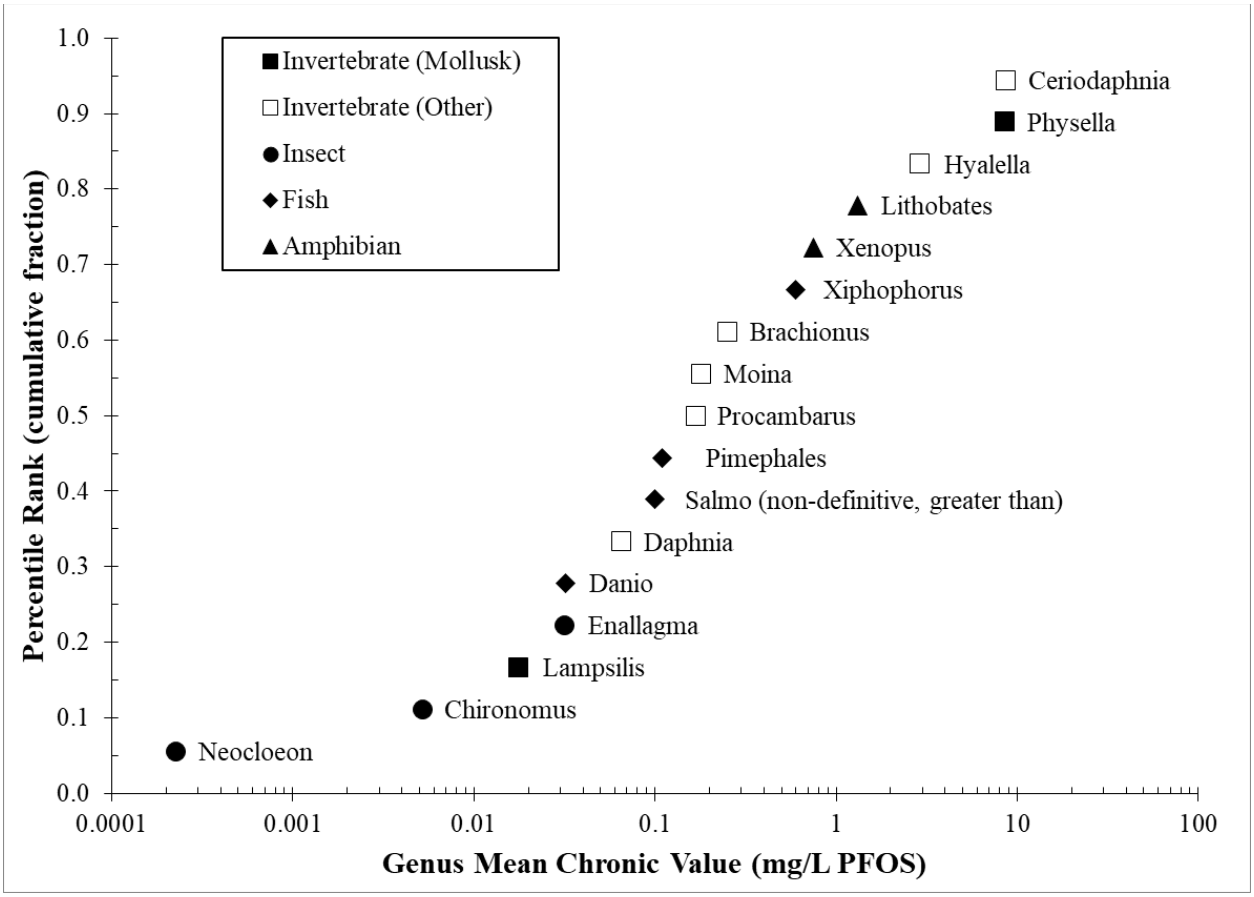


Figure 3-3. Ranked Freshwater Chronic PFOS Used Quantitatively to Derive the Criterion.

3.1.1.4 Summary of Chronic PFOS Toxicity Studies Used to Derive the Saltwater Aquatic Life Criterion

Data for chronic PFOS toxicity were available for five saltwater invertebrate species, representing five genera and five families. The data available for saltwater fish fulfilled only five of the eight MDRs.

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Table 3-8. The Four Ranked Estuarine/Marine Genus Mean Chronic Values.
Ranked Below from Most to Least Sensitive.

Rank	Genus	Species	GMCV (mg/L PFOS)	Comments
1	*Perna*	Asian green mussel, *Perna viridis*	0.0033	Not a resident species in North America
2	*Austrochiltonia*	Amphipod, *Austrochiltonia subtenuis*	0.01118	Not a resident species in North America, but other species in this Order (Amphipoda) are common ecotoxicity test species that serves as a surrogate for untested amphipod species residing in North America.
3	*Americamysis*	Mysid, *Americamysis bahia*	0.3708	North American resident species
4	*Tigriopus*	Copepod, *Tigriopus japonicus*	0.7071	Not a resident species in North America, but other species in this genus (*Tigriopus*) are common ecotoxicity test species that serves as a surrogate for untested copepod species residing in North America.

3.1.1.4.1 Most Sensitive Estuarine/Marine Genus: Perna (mussel)

Liu et al. (2013) evaluated the chronic effects of PFOS-K (PFOS potassium salt, CAS# 2795-39-3, 98% purity) on green mussels, *Perna viridis*, via a 7-day measured, static-renewal study. Mussels were exposed at a salinity of 25 ppt (artificial seawater) and a temperature of 25°C. PFOS concentrations were verified through water and muscle tissue samples via liquid chromatography-tandem mass spectrometry. Weights and lengths were determined on days zero and seven. An author-reported NOEC of 0.0096 mg/L and a LOEC of 0.106 mg/L was determined for the growth condition index. The EPA's independently-calculated EC_{10} for growth condition index is 0.0033 mg/L. This EC_{10} is used quantitatively to represent the chronic sensitivity of this species to PFOS exposure in the marine/estuarine aquatic life dataset.

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3.1.1.4.2 Second Most Sensitive Estuarine/Marine Genus: Austrochiltonia (amphipod)

Sinclair et al. (2022) tested perfluorooctane sulfonic acid (PFOS, purity not reported) on amphipods (*Austrochiltonia subtenuis*) in a 7-day unmeasured, static experiment. The 7-day experiment consisted of five controls, one solvent control (methanol 0.25 mL/L), and five nominal PFOS concentrations (0.04, 0.2, 1.0, 5.0, 25 µg/L). Test vessels were 600 mL beakers with 400 mL of test material and a 2x2 cm gauze substrate. Each test vessel included 20 amphipods, and all test material was dissolved in modified standard artificial media. The NOEC and LOEC for 7-day survival were 0.005 mg/L and 0.025 mg/L, respectively, and the resulting MATC of 0.01118 mg/L was determined to be acceptable for quantitative use.

3.1.1.4.3 Third Most Sensitive Estuarine/Marine Genus: Americamysis (mysid)

Drottar and Krueger (2000h) reported the results of a 35-day flow-through, measured life-cycle test of PFOS-K (potassium salt, 90.49% purity) with *Americamysis bahia* (formerly *Mysidopsis bahia*). The 35-day NOEC (reproduction and growth) was 0.25 mg/L, and the corresponding 35-day LOEC was 0.55 mg/L. An independently-calculated EC_{10} could not be defined at this time given the level of data that was presented in the paper (Appendix D). The calculated MATC for the test was 0.3708 mg/L. This chronic value was considered acceptable for quantitative use despite the control survival of 78% because it was only slightly below the 80% survival threshold, and because there were no other deficiencies in the study design.

3.1.1.4.4 Fourth Most Sensitive Estuarine/Marine Genus: Tigriopus (copepod)

A 20-day renewal, unmeasured full life-cycle test with PFOS (analytical grade) was conducted on the copepod, *Tigriopus japonicus* (non-North American species) by **Han et al. (2015)**. The development of the copepod's growth from nauplii to copepodite and from nauplii to adults was determined daily based on morphological characteristics. Results were presented as

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the number of days needed to reach the normal development stages. The highest test concentration (1 mg/L PFOS) significantly increased the amount of time it took the copepods to reach the development stage. Additionally, the authors assessed the reproduction of the copepods by counting the nauplii produced by eight ovigerous females for 10 days in each well exposed to PFOS. However, it was unclear if this was a subsampling of the organisms used in the 20-day developmental test or if an independent assay with adult females was run. Results are presented graphically as daily nauplii production/individual. There was a statistically significant decrease in production (daily nauplii production/individual) in the 0.25, 0.5 and 1.0 mg/L PFOS concentrations compared to the control. Production was decreased by approximately 50% in the highest concentration (1 mg/L). The 20-day MATC based on time to reach development stage was 0.7071 mg/L and was acceptable for quantitative use in the marine/estuarine chronic aquatic life dataset.

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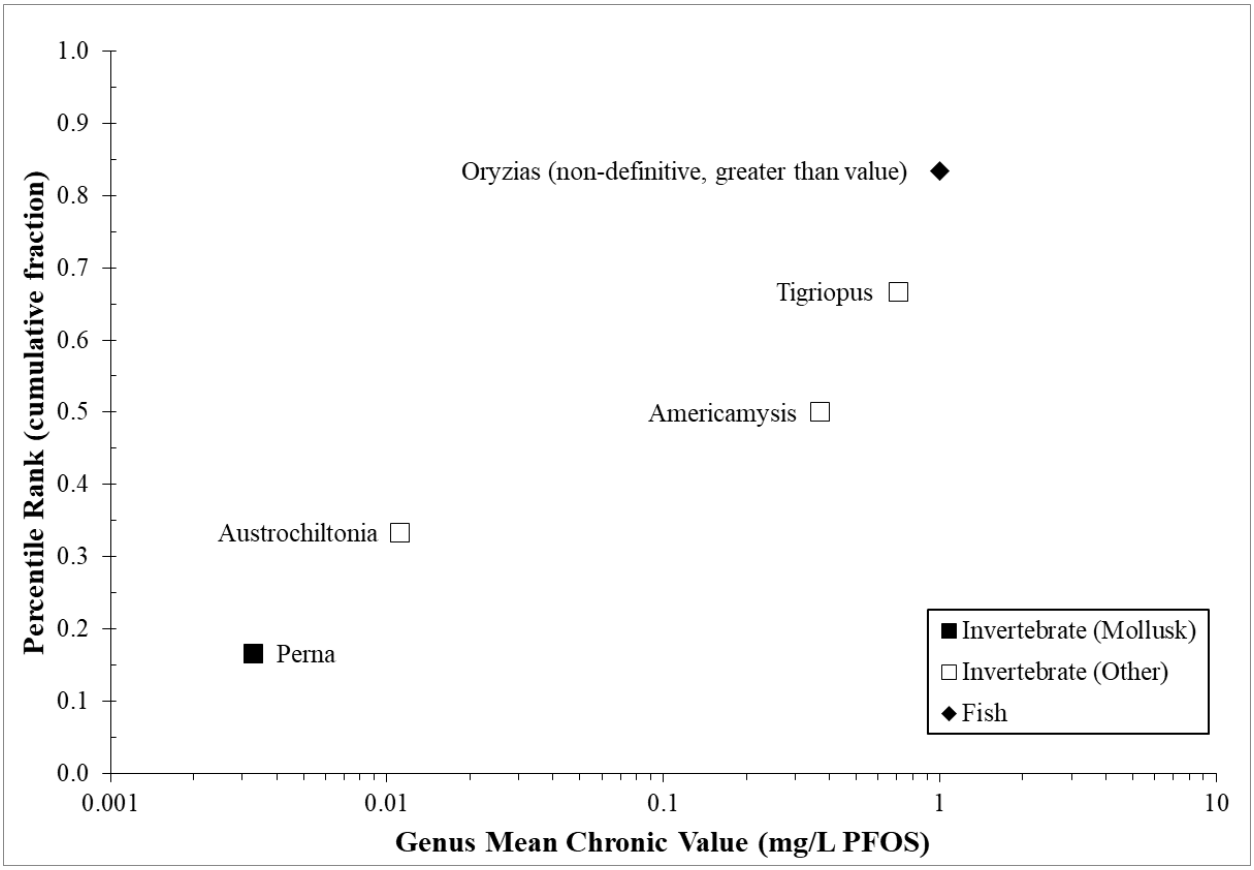


Figure 3-4. Acceptable Estuarine/Marine GMCVs.

3.2 Derivation of the PFOS Aquatic Life Criteria

3.2.1 Derivation of Water Column Criteria for Direct Aqueous Exposure

3.2.1.1 Derivation of Acute Water Column Criterion for Freshwater

The PFOS acute dataset for freshwater based on direct aqueous exposures contained 20 genera representing all eight MDRs. GMAVs for the 20 freshwater genera are provided in Table 3-3, and the four most sensitive genera were within a factor of ~100 of each other. The lowest acute value for the mayfly, *Neocloeon triangulifer*, is 40 times lower than the second most sensitive genus (Figure 3-5). The freshwater FAV, the 5th percentile of the genus sensitivity distribution, for PFOS was 0.1413 mg/L, and was calculated using the procedures described in the 1985 Guidelines (U.S. EPA 1985). The FAV was lower than all of the GMAVs of the tested species, except the mayfly, *Neocloeon triangulifer*. The FAV was then divided by two to obtain a

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concentration yielding minimal effects (see Section 2.9). The FAV/2, which is the acute freshwater criterion (or criterion maximum concentration, CMC), was 0.071 mg/L PFOS (rounded to two significant figures), and is expected to be protective of approximately 95% of freshwater genera potentially exposed to PFOS via direct aqueous exposure, under short-term duration conditions of one-hour, when the criterion magnitude is not exceeded more than once in three years on average (Table 3-9).

Table 3-9. Freshwater Final Acute Value and Criterion Maximum Concentration.

Calculated Freshwater FAV based on 4 lowest values: Total Number of GMAVs in Dataset = 20						
Rank	**Genus**	**GMAV (mg/L)**	**ln(GMAV)**	**ln(GMAV)^2**	**P=R/(N+1)**	**sqrt(P)**
1	*Neocloeon*	0.07617	-2.57	6.63	0.048	0.218
2	*Moina*	3.075	1.12	1.26	0.095	0.309
3	*Pimephales*	6.950	1.94	3.76	0.143	0.378
4	*Oncorhynchus*	7.515	2.02	4.07	0.190	0.436
		Σ (Sum):	**2.50**	**15.72**	**0.48**	**1.34**

S^2 = 534.58 **S = slope**
L = -7.127 **L = X-axis intercept**
A = -1.957 **A = lnFAV**
FAV = 0.1413 **P = cumulative probability**
CMC = 0.071 mg/L PFOS (rounded to two significant figures)

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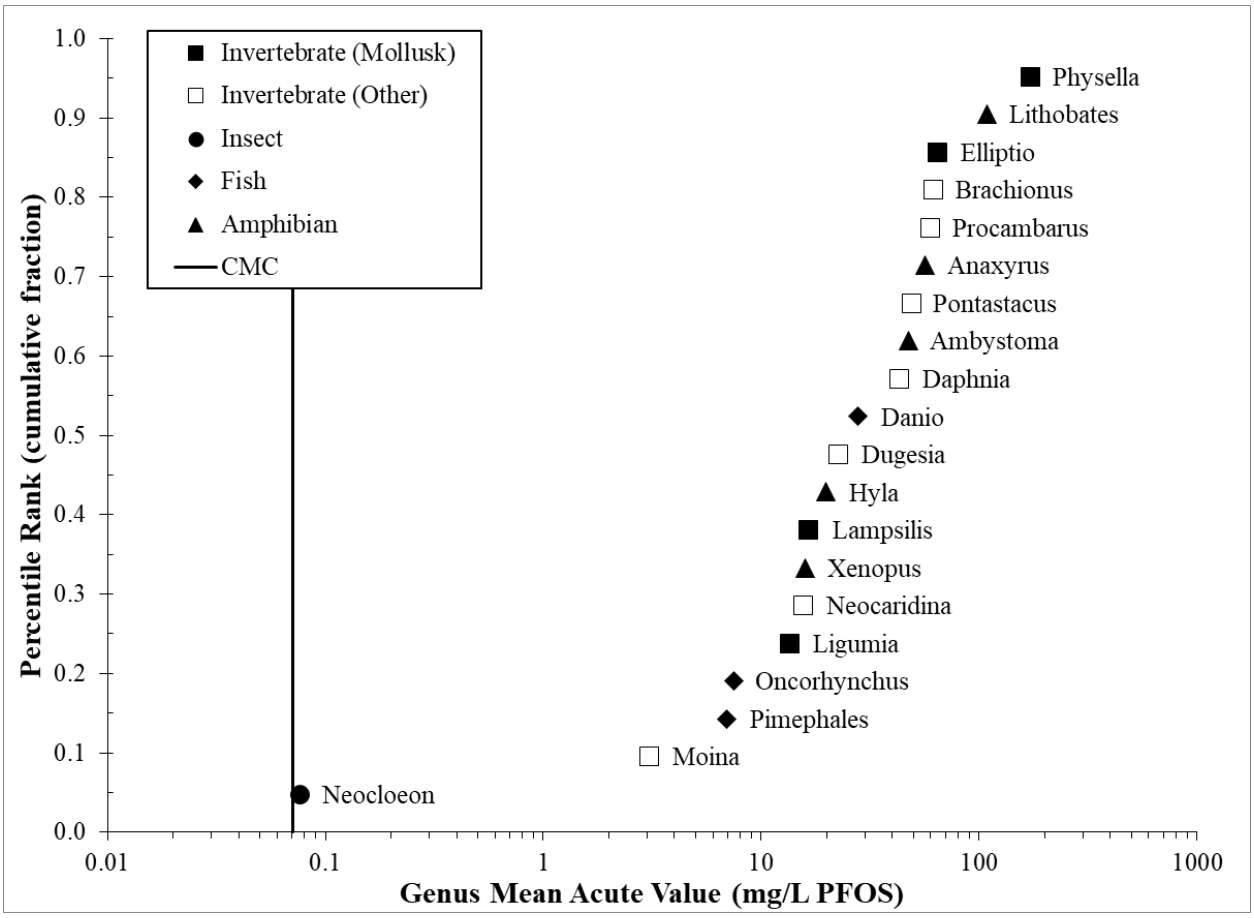


Figure 3-5. Ranked Freshwater Acute PFOS GMAVs Used Quantitatively to Derive the Criterion.

3.2.1.2 Derivation of Acute Water Column Criterion for Estuarine/Marine Water

The estuarine/marine acute dataset for PFOS contained six genera (Table 3-5 and Appendix B) representing only five of the eight taxonomic MDR groups. The missing MDR groups included one family in the phylum Chordata, a family in a phylum other than Chordata, and another family not already represented. The GMAVs of the four most sensitive definitive estuarine/marine genera were within a factor of 4.5 of each other (Table 3-5).

Because data were available for only five of eight MDRs, the EPA developed an estuarine/marine acute benchmark using the available empirical data supplemented with toxicity values generated through the use of NAMs, specifically through the use of the EPA Office of

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Research and Development's peer-reviewed publicly-available web-ICE tool (Raimondo et al. 2010). This benchmark is provided in Appendix L.

3.2.1.3 Derivation of Chronic Water Column Criterion for Freshwater

The PFOS chronic dataset based on direct aqueous exposures contained data for all eight MDRs, thus the Final Chronic Value (FCV) can be calculated directly without the use of an ACR. There were GMCVs for 17 freshwater genera (Table 3-7). The four most sensitive genera were within a factor of 140 of each other. The lowest chronic value for the mayfly, *Neocloeon triangulifer*, is over an order of magnitude lower than the second most sensitive genus (Figure 3-6). The freshwater FCV for PFOS of 0.0002491 mg/L was calculated using the procedures described in the 1985 Guidelines (U.S. EPA 1985). The FCV is the 5th percentile of the genus sensitivity distribution and is intended to be protective of 95 percent of the genera. The FCV was lower than all of the GMCVs of the tested species, except the mayfly, *Neocloeon triangulifer*. Unlike the FAV, the FCV was not divided by two, as it already represents a low effect level, and was equal to the water column chronic criterion (or criterion continuous concentration, CCC; Table 3-10). The freshwater CCC had a magnitude 0.00025 mg/L PFOS (rounded to two significant figures), or 0.25 µg/L, and is expected to be protective of 95% of freshwater genera potentially exposed to PFOS through direct aqueous exposure under long term conditions of four days, if not exceeded more than once every three years on average (Table 3-10).

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Table 3-10. Freshwater Final Chronic Value and Criterion Continuous Concentration.

Calculated Freshwater FCV based on 4 lowest values: Total Number of GMCVs in Dataset = 17						
Rank	**Genus**	**GMCV (mg/L)**	**ln(GMCV)**	**ln(GMCV)^2**	**P=R/(N+1)**	**sqrt(P)**
1	*Neocloeon*	0.000226	-8.39	70.48	0.056	0.236
2	*Chironomus*	0.005198	-5.26	27.66	0.111	0.333
3	*Lampsilis*	0.01768	-4.04	16.28	0.167	0.408
4	*Enallagma*	0.03162	-3.45	11.93	0.222	0.471
		Σ (Sum):	**-21.14**	**126.35**	**0.56**	**1.45**

S^2 = 472.36 **S = slope**
L = -13.157 **L = X-axis intercept**
A = -8.297 **A = lnFCV**
FCV = 0.0002491 **P = cumulative probability**
CCC = 0.00025 mg/L PFOS (rounded to two significant figures)

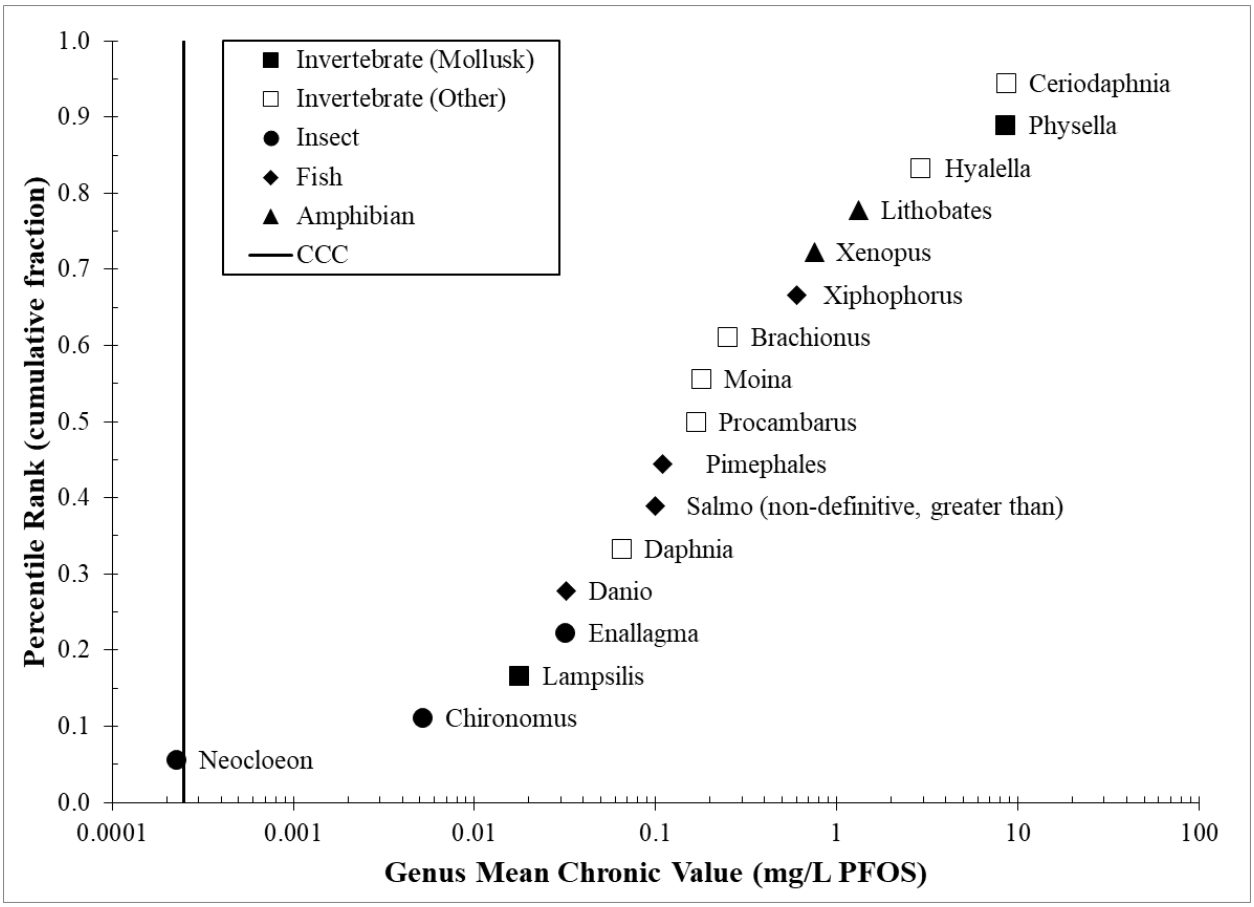


Figure 3-6. Ranked Freshwater Chronic PFOS GMCVs Used Quantitatively to Derive the Criterion.

3.2.1.4 Deriving A Protective Duration Component of the Chronic Water Column-Based Criterion

Effects to sensitive life stages was a primary reason why the 1985 Guidelines (U.S. EPA 1985) recommended a 4-day duration for most water column-based criteria. U.S. EPA (1985) states, "*An averaging period of four days seems appropriate for use with the CCC for two reasons. With one of the two reasons specify being, "for some species it appears that the results of chronic tests are due to the existence of a sensitive life stage at some time during the test*."

The SMCV for *C. dilutus*, representing the *Chironomus* GMCV (second most sensitive genus) is based on the EPA's independently-calculated EC_{10} of 0.05896 mg/L for a 10-day larval growth endpoint by MacDonald et al. (2004), an EC_{10} of 0.001588 mg/L for a 16-day larval mean biomass endpoint by McCarthy et al. (2021), and an EC_{10} of 0.0015 mg/L for a 14-day larval growth endpoint by Krupa et al. (2022). The EC_{10} for a 10-day larval growth by MacDonald et al. (2004) is slightly higher than the author-reported EC_{10} for this effect in the study. The author-reported EC_{10}s for the 20-day test by MacDonald et al. (2004) were higher than those for the 10-day test, which is an atypical outcome, and were not used for criteria derivation. Consequently, there was no clear influence of exposure time on the effects of PFOS on this species.

The SMCV for *L. siliquoidea,* representing the *Lampsilis* GMCV (third most sensitive genus) is based on a 36-day study by Hazelton (2013); Hazelton et al. (2012) using glochidia and juvenile life stages. The test exposed brooding glochidia (in marsupia) for 36 days followed by a 24-hour exposure of free glochidia. The 24-hour free glochidia exposure consisted of a factorial design, such that free glochidia from the control group of the marsupia exposure were divided between a control and the two PFOS treatments and the PFOS treatments were split into control

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and the same PFOS treatment group as the marsupia exposure. This factorial design allowed for the comparison of PFOS effects in two different life-stages.

Given the limitations of time points that could be discerned by the test, it appeared that for reduced viability and or metamorphosis success of free glochidia to occur at concentrations near the chronic value for the test (0.01768 mg/L), the test's 36-day exposure period would also be needed. For example, the study authors determined that the *in-marsupia* (36-day) exposure held the greatest weight of evidence and explained 78% of the variability in the glochidia viability (AIC = 22843, wi = 0.78) and 83% of the metamorphosis success (AIC = 21955, wi = 0.83). As a result, this species appears to be protected by the chronic 4-day duration component of the water column criterion. It should also be noted, brief PFOS exposures at elevated concentrations consistent with the magnitude and four-day duration of the chronic criterion are not expected to cause effects to free swimming glochidia based on the 24-hour acute toxicity data for glochidia.

The SMCV for *Enallagma cyathigerum*, representing the *Enallagma* GMCV (fourth most sensitive genus) are based on a 320-day partial life-cycle test by Bots et al. (2010). Only a single treatment, 0.1 mg/L, showed partial effects. The treatment 10X higher (i.e., 1 mg/L) yielded 100% mortality within 20 days. The treatment 10X lower (0.01 mg/L) showed no effects over the entire test. The authors provided the time course of mortality throughout the entire test. At 0.1 mg/L a marked reduction in survival began at 130 days, and reached zero survival at 250 days, suggesting a relatively long time-to-effect. Because 0.1 mg/L is more than 3-fold higher than the estimated chronic value for the test, 0.03162 mg/L, it is postulated that the time course of mortality observed at 0.1 mg/L would be substantially faster than what would be expected to occur at 0.03162 mg/L. Given the relatively slow manifestation of chronic effects observed in

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this study, this species appears to be protected by the chronic 4-day duration component of the water column criterion.

No chronic PFOS toxicity tests specifically evaluated time-to-effect, reported effect data at time intervals at a high enough resolution to model the speed of toxic action, assessed time variable PFOS exposures, or provided insight into the potential for latent toxicity. However, chronic tests, including life-cycle tests with relatively sensitive species, suggested chronic effects may occur at durations shorter than those of standard chronic toxicity tests (e.g., 28-day ELS tests) and a chronic 4-day duration component of the water column criterion was considered protective for these species/genera. Therefore, the EPA has set the duration component of the PFOS chronic water column criterion at four days to reflect the chronic criterion duration recommended in the 1985 Guidelines. This 4-day duration component of the chronic water column is also consistent with U.S. EPA (1991), which considered the default 4-day chronic averaging period as "*the shortest duration in which chronic effects are sometimes observed for certain species and toxicants*", and concludes that 4-day averaging "*should be fully protective even for the fastest acting toxicants*."

3.2.1.5 Derivation of Chronic Water Column Criterion for Estuarine/Marine Water

The estuarine/marine chronic dataset for PFOS contained GMCVs for five genera. GMCVs for five estuarine/marine genera are summarized in Section 3.1.1.4 and shown in Figure 3-4. The eight-family taxonomic (MDR) requirement was not met by the chronic dataset, as acceptable chronic studies for species representing three MDR groups are not available (one family in the phylum Chordata, a family in a phylum other than Arthropoda or Chordata, and another family not already represented). The 1985 Guidelines allow the use of a Final Acute-Chronic Ratio (FACR) to convert a FAV to an FCV (i.e., FAV/FACR = FCV), which is equivalent to a CCC. However, since an FAV could not be calculated with the available data, an

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FCV also could not be calculated. Consequently, the EPA could not derive estuarine/marine chronic criteria for PFOS (see Appendix L for derivation of acute estuarine/marine benchmarks).

3.2.2 Derivation of Freshwater Chronic Tissue criteria for PFOS

Currently, the freshwater chronic PFOS toxicity data with measured tissue concentrations were somewhat limited. There are 14 total freshwater aquatic life studies considered for either quantitative (six studies – three fish, one invertebrate, and two amphibian studies) or qualitative (eight studies) use in this aquatic life criterion. The quantitative studies only comprised data for three of the eight MDRs. The qualitative studies provided supporting information for only one additional MDR. Therefore, it was concluded that there is currently insufficient data to derive a chronic tissue criterion using a GSD approach from empirical tissue data from toxicity studies. However, these studies provided context to the translation of tissue criteria as described in Section 3.2.3 below. This comparison is provided in the Effects Characterization (Section 4.5).

3.2.3 Translation of Chronic Water Column Criterion to Tissue Criteria

As described in Section 3.2.2 above, there are currently insufficient freshwater chronic toxicity data with measured tissue concentrations to derive a chronic PFOS tissue criterion using a GSD approach. Therefore, the chronic tissue criteria for PFOS were derived by translating the chronic freshwater water column criterion (see Section 3.2.1.3) into tissue criteria using bioaccumulation factors (summarized in Section 3.2.3.1 below) and the following equation:

$$Tissue\ Criteria = Chronic\ Water\ Column\ Criterion\ \times BAF \qquad (Eq.\ 1)$$

The resulting tissue criteria corresponded to the tissue type associated with the BAF used in the equation.

3.2.3.1 PFOS Bioaccumulation Factors (BAFs)

Section 2.11.3.1 above summarizes the literature search, calculation, and evaluation of the PFOS BAFs for aquatic life. These BAFs were compiled by and can be found in Burkhard

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(2021). BAFs used in the derivation of the PFOS tissue criteria consisted of two or more water and organism samples each and were collected within one year and 2 km distance of one another. In order to derive more protective tissue criteria and to limit the effects of site-specific differences in BAFs, the distributions of BAFs used to derive tissue criteria were based on the lowest species-level BAF reported at a site. When more than one BAF was available for the same species within the same waterbody, the species-level BAF was calculated as the geometric mean of all BAFs for that species at that site. Summary statistics for the PFOS BAFs used in the criteria derivation are presented in Table 3-11 and individual BAFs are provided in Appendix O.

Table 3-11. Summary Statistics for PFOS BAFs in Fish and Invertebrates[1].

Category	n	Geometric Mean BAF (L/kg-ww)	Median BAF (L/kg-ww)	20th Centile BAF (L/kg-ww)	Minimum (L/kg-ww)	Maximum (L/kg-ww)
Invertebrates	28	771.6	924	111.5	2.69	100,000
Fish (Whole-Body)	28	3,739	5,905	803.9	4.79	46,098
Fish (Muscle)	21	1,069	1,048	346.4	8.72	50,234

[1] Based on the lowest species-level BAF measured at a site (i.e., when two or more BAFs were available for the same species at the same site, the species-level geometric mean BAF was calculated, and the lowest species-level BAF was used).

The fish tissue criteria were developed for muscle and whole-body to accommodate the most commonly sampled tissue types in monitoring programs. Additional tissue values for various other tissue types (e.g., liver and blood) were also calculated and can be found in Appendix P.

3.2.3.2 Deriving Protective Tissue Concentrations from the Chronic Water-Column Criterion

Invertebrate whole-body and fish muscle and whole-body tissue criteria were derived separately by multiplying the freshwater chronic water-column criterion (see Section 3.2.1.3) by the respective 20th centile of the distribution of BAFs using Equation (Eq. 1) from Section 3.2.3. The 20th centile BAF was used to derive tissue-based criteria as a relatively conservative BAF

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estimate in order to protect species across taxa and across water bodies with variable bioaccumulation conditions. That is, use of the 20th centile BAF protects species and conditions where the bioaccumulation of PFOS and resultant tissue-based exposures is relatively low as well as those conditions with the bioaccumulation potential of PFOS is relatively high.

The invertebrate whole-body tissue criterion was calculated by multiplying the 20th centile BAF of 111.5 L/kg ww by the PFOS freshwater chronic water criterion of 0.00025 mg/L, resulting in an invertebrate whole-body tissue criterion of 0.028 mg/kg ww. The fish whole-body tissue criterion was calculated by multiplying the 20th centile BAF of 803.9 L/kg ww by the PFOS freshwater chronic water criterion of 0.00025 mg/L, resulting in a fish whole-body tissue criterion of 0.201 mg/kg ww. The fish muscle tissue criterion was calculated by multiplying the 20th centile BAF of 346.4 L/kg ww by the PFOS freshwater chronic water criterion of 0.00025 mg/L, resulting in a fish muscle tissue criterion of 0.087 mg/kg ww. The chronic tissue-based criteria are expected to be protective of 95% of freshwater genera potentially exposed to PFOS under long-term exposures if the tissue-based criteria are not exceeded. The duration component of the tissue-based criteria is expressed as an instantaneous duration because the tissue-based criteria are protective of long-term conditions and represent an integrated measure of bioaccumulated PFOS concentrations over time.

The EPA acknowledges that there is uncertainty in deriving protective tissue criteria magnitudes by transforming the chronic water column criterion (which was based on tests that only added PFOS to the water column) into tissue concentrations through field-measured bioaccumulation data of paired water and tissue concentrations in waterbodies. Nevertheless, the chronic water column criterion is based on chronic toxicity tests where test organisms were fed. In these tests, PFOS can directly affect species based on direct water column exposure and/or

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sorb to added food that is consumed by test organisms before eliciting chronic effects from dietary exposure. Therefore, the chronic water column criterion magnitude accounts for water column-based and, to a possible lesser extent, dietary-based effects, while the field-based BAFs account for water column- and dietary-based PFOS exposure and subsequent accumulation in tissues. The chronic tissue criteria will allow states, Tribes, and stakeholders monitoring PFOS in freshwater lentic and lotic systems to evaluate potential effects to aquatic organisms based on the aquatic tissue monitoring data collected. Quantitatively acceptable data on the effects of dietary exposures to aquatic species were relatively limited, thus the EPA chose to develop protective values for freshwater aquatic organisms based on the observed relationship between water column concentrations and tissue concentrations and observed PFOS toxicity in chronic tests where PFOS was only added directly to the water column.

3.2.3.3 Deriving A Protective Duration and Exceedance Frequency for the Tissue-based Chronic Criteria

3.2.3.3.1 Duration: Chronic Tissue-Based Criteria

PFOS concentrations in tissues are generally expected to change only gradually over time in response to environmental fluctuations. The chronic tissue-based criteria averaging period, or duration, was therefore specified as instantaneous, because tissue data provide point, or instantaneous, measurements that reflect integrative accumulation of PFOS over time and space in population(s) at a given site.

3.2.3.3.2 Frequency: Chronic Tissue-Based Criteria

The PFOS tissue-based criteria frequencies are set as “not to be exceeded” to ensure protection of freshwater aquatic organisms. The “not to exceed” condition for frequency is meant to account for the many variables influencing ecological recovery and uncertainty due to the complete lack of PFAS-specific ecological recovery case studies available to inform recovery

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rates following elevated PFOS concentrations in aquatic biota. Ecological recovery times following chemical disturbances in general are situational-specific, being largely dependent on: (1) biological variables such as the presence of nearby source populations or generational time of taxa affected; (2) physical variables such as lentic and lotic habitat considerations where recovery rates in lentic systems may be slower than lotic systems where the pollutant may be quickly flushed downstream, and; (3) chemical variables such as the persistence of the chemical and potential for residual effects.

PFOS-specific case studies are unavailable to directly inform rates of ecological recovery following elevated concentrations in fish and aquatic invertebrates. Metals and other chemical pollutants may be retained in the sediment and biota, where they can result in residual effects over time that further delay recovery. Few studies are available concerning PFOS elimination or depuration half-life in aquatic animals, however the data that exist indicate a short half-life. For example, the elimination half-life for PFOS in adult rainbow trout exposed to PFOS for 28 days via the diet followed by 28 days depuration was estimated to be 8.4 days in muscle tissue (Falk et al. 2015), while the terminal half-life in rainbow trout receiving a one-time intra-arterial injection of PFOS was 86.8 days (Consoer 2017). Additionally, the depuration half-life in northern leopard frog tadpoles via a 40-day aqueous exposure to 0.01 mg/L PFOS was estimated to be 2.2 days (Hoover et al. 2017). It's unclear whether PFOS half-life in aquatic organism tissues is the mechanistic result of rapid depuration or an artifact of these measurements taken during relatively short testing times (e.g., 28 days) where steady state between PFOS and water and tissues has not occurred. Long-term uptake and subsequent excretion rates of PFOS has been extensively studied in humans relative to aquatic life. Li et al. (2018) reported a median PFOS half-life of 3.4 years in human serum following exposure to PFOS in drinking water, which the

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authors stated was in the range of previously published estimates. Due to chemical retention in tissues, ecosystems impacted by discharges of bioaccumulative pollutants (such as selenium) generally recover from chemical disturbances at relatively slow rates. For example, Lemly (1997) concluded that although water quality in Belews Lake in North Carolina (a freshwater reservoir) had recovered significantly in the decade since selenium discharges were halted in 1985, the threat to fish had not been eliminated. The selenium discharges that led to severe reproductive failure and deformities in fish were still measurable (as fish deformities) in 1992 (seven years later) and in 1996 (ten years later). Lemly (1997) estimated based on these data that "*the timeframe necessary for complete recovery from selenium contamination from freshwater reservoirs can be on the order of decades.*"

Beyond bioaccumulation, chemical-specific considerations such as degradation versus persistence may also provide a mechanism influencing ecological recovery rates. The persistence of PFOS in the environment has been attributed to the strong C-F bond, with no known biodegradation or abiotic degradation processes for PFOS (refer to Section 2.3). Somewhat similarly to PFOS, metals do not degrade and may persist in aquatic systems following elevated discharge. The persistence of metals may explain why metals had the second longest median recovery time of any disturbance described in a systematic review of aquatic ecosystem recovery (Gergs et al. 2016). Gergs et al. (2016) showed recovery times following metal disturbances ranged from roughly six months to eight years (median recovery time = 1 year; 75^{th} centile ~ 3 years; n = 20). Unlike metals, however, PFOS is not naturally occurring, and aquatic organisms possess no evolved detoxification mechanisms to aid in recovery at the individual level. Furthermore, the degradation of other PFAS into PFOS may represent an additional source of PFOS in aquatic systems that further delays recovery.

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The persistence and bioaccumulative/human-made nature of PFOS in aquatic systems, in combination with the documented recovery times of pollutants with similar chemical attributes (Gergs et al. 2016; Lemly 1997; Mebane 2022), suggests aquatic systems may recover from PFOS tissue criteria exceedances on the order of 5 to 10 years, if sources were eliminated. However, recovery times could be longer, if the sources of PFOS and other PFAS that degrade into PFOS have not been removed. Specifying a time interval associated with ecological recovery from exceedances of PFOS tissue criteria, then, is highly uncertain given the lack of PFOS-specific examples of ecological recovery and the many situational-specific factors influencing recovery (Mebane 2022). For example, the lack of PFOS degradation in the environment, and the fact that other PFAS in the environment can degrade into PFOS could act as ongoing PFOS sources that further delay recovery. Given these uncertainties, the PFOS tissue-based criteria frequencies are set as "not to be exceeded" to ensure protection of aquatic life populations. Moreover, if tissue-based criteria were exceeded, then PFOS has likely built up through the food web and PFOS source reservoirs are likely to exist, representing a broad level of PFOS contamination throughout the aquatic ecosystem.

The "not to exceed" frequency components of the tissue-based criteria do not suggest aquatic ecosystems could never recover from an exceedance of the PFOS tissue-based criteria under the right conditions. Ecological recovery from such an exceedance could begin once PFOS source reservoirs existing within the ecosystem are eliminated or decreased, including other PFAS that degrade into PFOS; became permanently isolated from possible uptake by the ecosystem (e.g., long-term burial with no benthic disturbances under certain environmental conditions); and, unaffected organisms were able to repopulate the system through immigration and/or reproductive events that yield generations that are no longer exposed to PFOS.

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Evaluation of PFOS concentrations in tissues would likely include evaluating the central tendency of samples for a given species, collected at a specific site and time. Considering a measure of central tendency to assess tissue-based exposures in the field relative to the criteria is appropriate because the criteria are intended to protect aquatic life populations.

3.3 Summary of the PFOS Freshwater Aquatic Life Criteria and Acute Estuarine/Marine Benchmark

The PFOS aquatic life criteria were developed to protect freshwater aquatic life against adverse effects, such as mortality, altered growth, and reproductive impairments, associated with acute and chronic exposure to PFOS. The nationally recommended criteria include water column based acute and chronic criteria for fresh waters. The freshwater acute water column-based criterion magnitude is 0.071 mg/L, and the chronic water column-based criterion magnitude is 0.00025 mg/L (Table 3-12). The chronic freshwater tissue-based criteria magnitudes are 0.201 mg/kg wet weight (ww) for fish whole-body, 0.087 mg/kg ww for fish muscle tissue and 0.028 mg/kg ww for invertebrate whole-body tissue. These PFOS aquatic life criteria are expected to be protective of aquatic life on a national basis (Table 3-12). All of these water column and tissue criteria are intended to be independently applicable and no one criterion takes primacy. All of the recommended criteria (acute and chronic water column and tissue criteria) are intended to be protective of aquatic life. Acute and chronic water column criteria for estuarine/marine waters could not be derived at this time due to data limitations; however, an estuarine/marine acute benchmark protective of aquatic life is provided in Appendix L.

The freshwater chronic water-column criterion is more strongly supported than the chronic tissue-based criteria because the water column-based chronic criterion was derived directly from the results of empirical toxicity tests. The chronic tissue-based criteria are relatively less certain because they were derived by transforming the chronic water-column

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criterion into tissue concentrations through BAFs, with any uncertainty and variability in the underlying BAFs then propagating into the resultant tissue-based criteria magnitudes.

Table 3-12. Recommended Perfluorooctane Sulfonate (PFOS) Ambient Water Quality Criteria for the Protection of Aquatic Life in Freshwaters.

Type/Media	Acute Water Column (CMC)[1,4]	Chronic Water Column (CCC)[1,5]	Chronic Invertebrate Whole-Body[1,2]	Chronic Fish Whole-Body[1,2]	Chronic Fish Muscle[1,2]
Magnitude	0.071 mg/L	0.00025 mg/L	0.028 mg/kg ww	0.201 mg/kg ww	0.087 mg/kg ww
Duration	One-hour average	Four-day average	Instantaneous[3]		
Frequency	Not to be exceeded more than once in three years on average	Not to be exceeded more than once in three years on average	Not to be exceeded[6]		

[1] All five of these water column and tissue criteria are intended to be independently applicable and no one criterion takes primacy. All of the above recommended criteria (acute and chronic water column and tissue criteria) are intended to be protective of aquatic life. These criteria are applicable throughout the year.
[2] Tissue criteria are derived from the chronic water-column criterion magnitude (CCC) with the use of bioaccumulation factors and are expressed as wet weight (ww) concentrations.
[3] Tissue data provide instantaneous point measurements that reflect integrative accumulation of PFOS over time and space in aquatic life population(s) at a given site.
[4] Criterion Maximum Concentration; applicable throughout the water column.
[5] Criterion Continuous Concentration; applicable throughout the water column.
[6] PFOS chronic freshwater tissue-based criteria should not be exceeded, based on measured tissue concentrations representing the central tendency of samples collected at a given site and time.

This Aquatic Life Ambient Water Quality Criteria and Acute Saltwater Benchmark for PFOS document includes a water column based acute benchmark for estuarine/marine waters. The derivation of this benchmark is described in detail in Appendix L. The saltwater acute benchmark 0.55 mg/L (magnitude component), expressed as a one-hour average (duration component), that is not to be exceeded more than once in three years on average (Table 3-13).

Aquatic life benchmarks, developed under 304(a)(2) of the CWA, are informational values that the EPA generates when there are limited high quality toxicity data available and data gaps exist for several aquatic organism families. The EPA develops aquatic life benchmarks to provide information that states and Tribes may consider in their water quality protection

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programs. In developing aquatic life benchmarks, data gaps may be filled using new approach methods (NAMs), such as computer-based toxicity estimation tools (e.g., EPA's Web-ICE) or other new approach methods intended to reduce reliance on additional animal testing (https://www.epa.gov/chemical-research/epa-new-approach-methods-work-plan-reducing-use-vertebrate-animals-chemical), including the use of read-across estimates based on other chemicals with similar structures. The EPA's aquatic life benchmark values are not regulatory, nor do they automatically become part of a state's water quality standards.

Table 3-13. Acute Perfluorooctane Sulfonate (PFOS) Benchmark for the Protection of Aquatic Life in Estuarine/Marine Waters.

Type/Media	Acute Water Column Benchmark
Magnitude	0.55 mg/L
Duration	One hour on average
Frequency	Not to be exceeded more than once in three years on average

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4 EFFECTS CHARACTERIZATION FOR AQUATIC LIFE

The purpose of this section was to describe the supporting information for the derivation of the PFOS aquatic life AWQC that contributed to the weight-of-evidence for the derivation. This section includes: (1) additional analyses supporting the criteria that were used as part of the lines-of-evidence discussion to better understand the influence of using less certain toxicity data (Section 4.1); (2) an assessment of the influence of including non-North American resident species in water column criteria derivation (i.e., species not resident to North America removed from dataset; Section 4.2); (3) summaries of the toxicity studies with apical endpoints (e.g., effects on survival, growth, or reproduction) that were not used directly to derive the water column criteria, but were used qualitatively to support them (Section 4.3); (4) a discussion of acute to chronic ratios (Section 4.4); (5) a comparison of empirical tissue concentrations to translated tissue criteria (Section 4.5); (6) a discussion of the effects of PFOS on aquatic plants (Section 4.6); and (7) a discussion of the effects of PFOS on threatened and endangered species (Section 4.7). The EPA derived the final national recommended PFOS aquatic life AWQC described in the Effects Analysis Section (see Section 3 above). The additional analyses presented here are solely intended to support the PFOS criteria through a weight-of-evidence approach that evaluated the influence of data variation and uncertainties on the PFOS criteria.

4.1 Additional Analyses Supporting the Derivation of the Chronic Water Column Criterion for Freshwater

In addition to the EPA's recommended freshwater chronic water column criterion of 0.00025 mg/L PFOS described above in Section 3.2.1.3, eight additional analyses supporting the derivation of the chronic criterion were examined as part of a line-of-evidence evaluation to consider the effect of including less certain toxicity data (i.e., the chronic toxicity values for damselfly, fatmucket, and mayfly) on the magnitude of the freshwater chronic water column

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criterion. The data considered to be less certain generally centered around two specific areas: (1) the difficultly in reliably estimating a chronic toxicity value given the wide spacing (up to 15-fold difference) of the treatment concentrations (e.g., for fatmucket in Hazelton et al. (2012) and damselfly in Bots et al. (2010) (see Section 3.1.1.3.3 and 3.1.1.3.4, respectively) and (2) the uncertainty in the chronic toxicity values given the level of data presented in the papers associated with the mayfly (*N. triangulifer*), fatmucket (*L. siliquoidea*), and damselfly (*E. cyathigerum*) – see study summaries in Appendices C.2.1, C.2.3, and C.2.4, respectively).

The eight additional analyses presented below involved either changing or excluding toxicity values from the three toxicity studies (Table 4-1). The additional analyses presented here are solely intended to support the PFOS chronic criterion through a weight-of-evidence approach that evaluated the influence of data variation on the criterion derivation process. Based on these additional analyses, the EPA decided to retain the mayfly, fatmucket, and damselfly values as presented in Section 3.1.1.3, to ensure protection of these sensitive taxa as well as the many untested species for which these species may serve as representative taxonomic surrogate species. The availability of additional toxicity data for these particular taxa would reduce the uncertainty in the analysis. The criteria presented in Section 3.3 are the EPA's best estimate of the maximum concentrations of PFOS that will support protection of sensitive aquatic life from unacceptable chronic exposures.

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Table 4-1. Additional Analyses Supporting the Derivation of the Freshwater Chronic Water Column Criterion.

*Presented in the order that is summarized in the text below.**

Order of Additional Analyses	Purpose of Additional Analysis	Details of Additional Analysis	Chronic Water Column Concentration for Additional Analysis (mg/L)	Study
1	To explore the impact of using the various author reported toxicity values for damselfly	Used 10-day MATC of 0.3162 mg/L for damselfly instead of 150-day MATC of 0.03162 mg/L	0.00025	Bots et al. (2010)
2		Used 60-day NOEC of 0.1 mg/L for damselfly instead of 150-day MATC of 0.03162 mg/L	0.00025	
3		Used 320-day NOEC of 0.01 mg/L for damselfly instead of 150-day MATC of 0.03162 mg/L	0.00027	
4	To explore the impact of using the MATC for fatmucket	Removed MATC of 0.01768 mg/L for fatmucket	0.00021	Hazelton et al. (2012)
5	To explore the impact of using both the EC_{10} for fatmucket and the 150-day MATC for damselfly	Removed both MATC of 0.01768 mg/L for fatmucket and 150-day MATC of 0.03162 mg/L for damselfly	0.00016	Hazelton et al. (2012) and Bots et al. (2010), respectively
6	To explore the impact of using the EC_{10} for fatmucket	Use estimated EC_{10} of 0.0123 mg/L for fatmucket instead of MATC of 0.01768 mg/L	0.00025	Hazelton et al. (2012)
7	To explore the impact of using the various author-reported toxicity values for mayfly	Use EC_{10} of 0.000272 mg/L for mayfly calculated with linear regression without control	0.00029	Soucek et al. (2023)
8		Use EC_{10} of 0.000232 mg/L for mayfly calculated with linear regression without control	0.00026	

*Final derived freshwater chronic water column criterion was 0.00025 mg/L PFOS.

In the first additional analysis, instead of using the 150-day MATC of 0.03162 mg/L for *Enallagma cyathigerum* as described in the calculation of the final freshwater chronic water column criterion described above in Section 3.2.1.3, the 10-day MATC of 0.3162 mg/L was used (Table 4-2) (Bots et al. 2010), yielding a freshwater FCV for PFOS of 0.0002486 mg/L. This chronic water column concentration of 0.00025 mg/L (rounded to two significant figures) is the same as the final chronic value of 0.00025 mg/L derived above. This first additional analysis indicated that there is little difference in the calculated chronic criterion based either on the 150-

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day or 10-day MATC for *E. cyathigerum.* However, as the 150-day MATC was more comparable to the other aquatic insect data and more representative of life-cycle effects than the 10-day MATC, the EPA has concluded that the 150-day MATC should be used quantitatively to derive the freshwater chronic criterion.

In the second analysis, instead of using the 150-day MATC of 0.03162 mg/L for *E. cyathigerum*, the 60-day NOEC of 0.1 mg/L from the same test was used (Table 4-2) (Bots et al. 2010), also yielding an FCV of 0.0002486 mg/L. Similar to the first analysis, there is no difference in the calculated chronic criterion based either on the 150-day or 60-day NOEC for *E. cyathigerum.* However, since the 150-day MATC was more comparable to the other aquatic insect data and representative of life-cycle effects than the 10-day MATC, the EPA has concluded that the 150-day MATC should be used quantitatively to derive the freshwater chronic criterion.

In the third analysis, instead of using the 150-day MATC of 0.03162 mg/L for *E. cyathigerum*, the 320-day NOEC of 0.01 mg/L from the same test was used (Table 4-2) (Bots et al. 2010), yielding an FCV of 0.0002661 mg/L, or 0.00027 mg/L (rounded to two significant figures). This analysis indicated that there is a slightly higher FCV (less stringent) in the calculated chronic criterion if the 320-day NOEC for *E. cyathigerum* is used. However, as there were concerns with the control survival of test organisms (reported as roughly 60% in the first 60 days), the EPA has determined that the 150-day MATC should be used quantitatively to derive the freshwater chronic water column criterion since this toxicity value still represents a life-cycle effect and control survival of test organisms was determined to be acceptable at this time point in the test.

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In the fourth analysis, the MATC for fatmucket (*L. siliquoidea)* of 0.01768 mg/L was removed from the chronic dataset to understand the influence of this toxicity value on the criterion magnitude (Table 4-2). This additional analysis placed the GMCV of 0.03217 mg/L for *Danio* among the four most sensitive genera, and yielded an FCV of 0.0002097 mg/L or 0.00021 mg/L (rounded to two significant figures) (Section 3.2.1.3; U.S. EPA 1985). The removal of the chronic toxicity value for *L. siliquoidea* has only a modest influence on the calculated chronic criterion magnitude (criteria became more stringent) but would eliminate mollusks from the chronic PFOS dataset. The EPA decided to retain the fatmucket value to ensure representation and protection of this sensitive taxon.

In the fifth analysis, the 150-day MATC of 0.03162 mg/L for damselfly (*E. cyathigerum*) and MATC for fatmucket (*L. siliquoidea*) of 0.01768 mg/L were removed since these values are less certain compared to other quantitative studies in the chronic criterion dataset (Table 4-2). As noted above, these toxicity values were considered to be less certain due to (1) the difficultly in reliably estimating a chronic toxicity value given the wide spacing (15-fold difference in Hazelton et al. (2012) for *L. siliquoidea* and 10-fold difference in Bots et al. (2010) for *E. cyathigerum*) of the treatment concentrations, and (2) the uncertainty in the chronic toxicity values given the level of data presented in the papers. This fifth analysis yielded a freshwater FCV for PFOS of 0.0001621 mg/L, or 0.00016 mg/L (rounded to two significant figures). The calculated chronic criterion magnitude was reduced 1.6-fold. The EPA decided to retain the damselfly and fatmucket values as presented in Section 3.1.1.3 in the criterion derivation to ensure representation and protection of these sensitive taxa.

In the sixth analysis, the estimated EC_{10} for fatmucket of 0.0123 mg/L was used in the chronic dataset to understand the influence of this estimated toxicity value on the criterion

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derivation (Table 4-2), particularly since the EPA was not able to fit a curve to estimate an EC_{10} given that there were only two PFOS treatment groups and the gap in these exposure concentrations is large (about 15-fold). This additional analysis yielded an FCV of 0.0002476 mg/L, or 0.00025 mg/L. This additional analysis indicated that the estimated toxicity value from *L. siliquoidea* has no influence on the calculated chronic criterion. Since the estimated toxicity value had no influence on the recommended CCC value, the author-reported MATC was used instead.

In the seventh analysis, another author-reported EC_{10} for mayfly of 0.000272 mg/L (based on log-linear regression without controls) was used in the chronic dataset to understand the influence of this alternate toxicity value on the criterion derivation (Table 4-2). This additional analysis yielded a FCV was 0.0002938 mg/L, or 0.00029 mg/L, indicating that this other toxicity value for *N. triangulifer* has little influence on the final calculated chronic criterion. Since this other toxicity value had limited influence on the recommended CCC value, the author-reported EC_{10} (0.000226 mg/L, two parameter, threshold sigmoidal curve) described in Section 3.1.1.3.1 in the criterion derivation was used instead.

Lastly, in the eighth analysis, a second author-reported EC_{10} for mayfly of 0.000232 mg/L (based on log-linear regression with controls) was used in the chronic dataset to understand the influence of this third toxicity value on the chronic criterion derivation (Table 4-2). This additional analysis yielded a FCV was 0.0002550 mg/L, or 0.00026 mg/L, indicating that this third possible toxicity value for *N. triangulifer* has limited influence on the calculated chronic criterion. Since this alternate toxicity value had limited influence on the recommended CCC value, the author-reported EC_{10} (0.000226 mg/L, two parameter, threshold sigmoidal curve) described in Section 3.1.1.3.1 in the criterion derivation was used instead.

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Table 4-2. GMCVs Used in Derivation of Chronic Criterion and Additional Analyses Supporting the Chronic Criterion for Freshwater.

MDR Group[1]	Genus	Species	Chronic Criterion	Additional Analysis							
			GMCV (mg/L PFOS)[2]	First[3]	Second[3]	Third[3]	Fourth[4]	Fifth[5]	Sixth[6]	Seventh[7]	Eighth[7]
F	*Neocloeon*	Mayfly, *Neocloeon triangulifer*	0.000226	0.000226	0.000226	0.000226	0.000226	0.000226	0.000226	**0.000272**	**0.000232**
F	*Chironomus*	Midge, *Chironomus dilutus*	0.005198	0.005198	0.005198	0.005198	0.005198	0.005198	0.005198	0.005198	0.005198
G	*Lampsilis*	Fatmucket, *Lampsilis siliquoidea*	0.01768	0.01768	0.01768	0.01768	-	-	**0.0123**	0.01768	0.01768
F	*Enallagma*	Blue damselfly, *Enallagma cyathigerum*	0.03162	**0.3162**	**0.1**	**0.01**	0.03162	-	0.03162	0.03162	0.03162
B	*Danio*	Zebrafish *Danio rerio*	0.03217	0.03217	0.03217	0.03217	0.03217	0.03217	0.03217	0.03217	0.03217
D	*Daphnia*	Cladoceran, *Daphnia carinata*	0.06519	0.06519	0.06519	0.06519	0.06519	0.06519	0.06519	0.06519	0.06519
		Cladoceran, *Daphnia magna*									
A	*Salmo*	Atlantic salmon, *Salmo salar*	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1
B	*Pimephales*	Fathead minnow, *Pimephales promelas*	0.1098	0.1098	0.1098	0.1098	0.1098	0.1098	0.1098	0.1098	0.1098
E	*Procambarus*	Crayfish, *Procambarus fallax f. virginalis*	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
D	*Moina*	Cladoceran, *Moina macrocopa*	0.1789	0.1789	0.1789	0.1789	0.1789	0.1789	0.1789	0.1789	0.1789
H	*Brachionus*	Rotifer, *Brachionus calyciflorus*	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
C	*Xiphophorus*	Swordtail fish, *Xiphophorus helleri*	0.5997	0.5997	0.5997	0.5997	0.5997	0.5997	0.5997	0.5997	0.5997
C	*Xenopus*	African clawed frog, *Xenopus laevis*	0.7507	0.7507	0.7507	0.7507	0.7507	0.7507	0.7507	0.7507	0.7507
		Clawed frog, *Xenopus tropicalis*									
C	*Lithobates*	Northern leopard frog, *Lithobates pipiens*	1.316	1.316	1.316	1.316	1.316	1.316	1.316	1.316	1.316
E	*Hyalella*	Amphipod, *Hyalella azteca*	2.899	2.899	2.899	2.899	2.899	2.899	2.899	2.899	2.899

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MDR Group[1]	Genus	Species	Chronic Criterion	Additional Analysis							
			GMCV (mg/L PFOS)[2]	First[3]	Second[3]	Third[3]	Fourth[4]	Fifth[5]	Sixth[6]	Seventh[7]	Eighth[7]
G	*Physella*	Snail, *Physella heterostropha pomilia*	8.527	8.527	8.527	8.527	8.527	8.527	8.527	8.527	8.527
D	*Ceriodaphnia*	Cladoceran, *Ceriodaphnia dubia*	10.69	10.69	10.69	10.69	10.69	10.69	10.69	10.69	10.69
Chronic Water Column Concentration			**0.00025**	**0.00025**	**0.00025**	**0.00027**	**0.00021**	**0.00016**	**0.00025**	**0.00029**	**0.00026**

[1] MDR Groups identified according to the list provided in Section 2.10.1 above.
[2] GMCVs as presented in Table 3-7 in Section 3.1.1.3. Genera presented in order of rank according to the chronic criterion derivation. The rank order of GMCVs was not changed for the additional analyses.
[3] Additional analysis with changes to toxicity value for *E. cyathigerum.*
[4] Additional analysis with the exclusion of *L. siliquoidea.*
[5] Additional analysis with the exclusion of *L. siliquoidea* and *E. cyathigerum.*
[6] Additional analysis with the changes to toxicity value for *L. siliquoidea*.
[7] Additional analysis with the changes to toxicity value for *N. triangulifer*.

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4.2 Influence of Using Non-North American Resident Species on PFOS Criteria

The EPA conducted two additional analyses of the freshwater criteria by analyzing the effect of reducing the limited toxicity datasets to only organisms that are resident to, or have been introduced and have established populations in the conterminous U.S. These analyses were conducted for illustrative purposes, to indicate the effects on the criteria magnitude of the inclusion of data for taxa that are not resident species to North America but serve as surrogates for other sensitive organisms. This analysis was conducted for both the acute and chronic freshwater datasets only, since the estuarine/marine datasets are limited even when all species are included.

4.2.1 Freshwater Acute Water Column Criterion with Native and Established Organisms (Species Not Resident to North America removed from dataset)

For the purpose of illustrating the effect of including non-resident species in the acute criterion calculation, additional analyses were made. For this illustrative analysis, four species were removed from the freshwater acute water column criterion calculation to ensure that only native, reproducing, or established organism in the conterminous U.S. were included: Japanese swamp shrimp (*Neocaridina denticulata*), planarian (*Dugesia japonica*), crayfish (*Pontastacus leptodactylus*) and cladoceran (*Daphnia carinata*). Removal of these species truncated the freshwater acute dataset to 25 species (Table 4-3). None of the non-resident species were among the four most sensitive, with the cladoceran (*Daphnia carinata*), being the most sensitive SMAV of the four (Table 3-3). The acute water column concentration was 0.048 mg/L PFOS (Table 4-4) when using the reduced dataset which was slightly lower than the recommended CMC of 0.071 mg/L. This value is lower than all of the GMAVs in Table 3-3. The EPA decided to retain the full acute dataset and associated acute criterion for PFOS of 0.071 mg/L in order to have the

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largest, high-quality dataset to serve as surrogate species for the broad range of the thousands of untested species present in the freshwater environment in the U.S.

Table 4-3. Ranked Freshwater Genus Mean Acute Values with Native and Established Organisms, excluding Species Not Resident to North America.

Rank[a]	GMAV (mg/L PFOS)	MDR Group[c]	Genus	Species	SMAV[b] (mg/L PFOS)
1	0.07617	F	*Neocloeon*	Mayfly, *Neocloeon triangulifer*	0.07617
2	3.075	D	*Moina*	Cladoceran, *Moina macrocopa*	17.20
				Cladoceran, *Moina micrura*	0.5496
3	6.950	B	*Pimephales*	Fathead minnow, *Pimephales promelas*	6.950
4	7.515	A	*Oncorhynchus*	Rainbow trout, *Oncorhynchus mykiss*	7.515
5	13.5	G	*Ligumia*	Black sandshell, *Ligumia recta*	13.5
6	15.99	C	*Xenopus*	African clawed frog, *Xenopus laevis*	15.99
7	16.5	G	*Lampsilis*	Fatmucket, *Lampsilis siliquoidea*	16.5
8	19.88	C	*Hyla*	Gray treefrog, *Hyla versicolor*	19.88
9	27.86	B	*Danio*	Zebrafish, *Danio rerio*	27.86
10	47.40	C	*Ambystoma*	Jefferson salamander, *Ambystoma jeffersonianum*	51.71
				Small-mouthed salamander, *Ambystoma texanum*	30.00
				Eastern tiger salamander, *Ambystoma tigrinum*	68.63
11	56.49	C	*Anaxyrus*	American toad, *Anaxyrus americanus*	56.49
12	59.87	E	*Procambarus*	Crayfish, *Procambarus fallax f. virginalis*	59.87
13	61.8	H	*Brachionus*	Rotifer, *Brachionus calyciflorus*	61.8
14	64.35	G	*Elliptio*	Eastern elliptio, *Elliptio complanata*	64.35

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Rank[a]	GMAV (mg/L PFOS)	MDR Group[c]	Genus	Species	SMAV[b] (mg/L PFOS)
15	83.36	D	*Daphnia*	Cladoceran, *Daphnia magna*	51.86
				Cladoceran, *Daphnia pulicaria*	134
16	109.2	C	*Lithobates*	American bullfrog, *Lithobates catesbeiana*	133.3
				Green frog, *Lithobates clamitans*	113
				Northern leopard frog, *Lithobates pipiens*	72.72
				Wood frog, *Lithobates sylvatica*	130
17	172.1	G	*Physella*	Bladder snail, *Physella acuta*	183.0
				Snail, *Physella heterostropha pomilia*	161.8

[a] Ranked from the most sensitive to the most tolerant based on Genus Mean Acute Value.
[b] From Appendix A: Acceptable Freshwater Acute PFOS Toxicity Studies.
[c] MDR Groups identified by list provided in Section 2.10.1 above.

Table 4-4. Calculation of Freshwater Acute Water Column Concentration with Native and Established Organisms (Species Not Resident to North America Removed from Dataset).

Calculated Freshwater FAV based on 4 lowest values: Total Number of GMAVs in Dataset = 17						
Rank	**Genus**	**GMAV (mg/L)**	**ln(GMAV)**	**ln(GMAV)^2**	**P=R/(N+1)**	**sqrt(P)**
1	*Neocloeon*	0.07617	-2.57	6.63	0.056	0.236
2	*Moina*	3.075	1.12	1.26	0.111	0.333
3	*Pimephales*	6.950	1.94	3.76	0.167	0.408
4	*Oncorhynchus*	7.515	2.02	4.07	0.222	0.471
		Σ (Sum):	**2.50**	**15.72**	**0.56**	**1.45**

S^2 = 458.21
L = -7.127
A = -2.340
FAV = 0.0963

S = slope
L = X-axis intercept
A = lnFAV
P = cumulative probability

Acute Water Column Concentration = 0.048 mg/L PFOS (rounded to two significant figures)

4.2.2 Freshwater Chronic Water Criterion with Native and Established Organisms (Species Not Resident to North America removed from dataset)

For the purpose of illustrating the effect of including non-resident species in the chronic criterion calculation, additional analyses were made. For this illustrative analysis, two species were removed from the chronic freshwater dataset that are not native or established organism in the conterminous U.S.: the cladoceran (*Daphnia carinata*) and the clawed frog (*Xenopus tropicalis*). Removal of these species truncated the freshwater chronic dataset to 17 species representing 17 genera (Table 4-5). The revised freshwater chronic dataset consisted of all eight MDRs. The cladoceran and clawed frog GMCVs were not among the four most chronically sensitive species. Removal of the species that are not resident to North America had no effect on the chronic water column concentration (Table 4-6) because other species were available from the same genera and neither of the non-resident species were from the four most chronically sensitive genera. The chronic water column concentration was 0.0002491 mg/L PFOS when using the reduced dataset, which was the same as the recommended chronic criterion of 0.00025 mg/L. Therefore, the EPA decided to retain the full chronic dataset and associated chronic water column criterion for PFOS of 0.00025 mg/L in order to have the largest, high quality dataset to serve as surrogate species for the broad range of the thousands of untested species present in the freshwater environment in the U.S.

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Table 4-5. Ranked Freshwater Genus Mean Chronic Values with Native and Established Organisms.

Rank[a]	GMCV (mg/L PFOS)	MDR Group[c]	Genus	Species	SMCV[b] (mg/L PFOS)
1	0.000226	F	*Neocloeon*	Mayfly, *Neocloeon triangulifer*	0.000226
2	0.005198	F	*Chironomus*	Midge, *Chironomus dilutus*	0.005198
3	0.01768	G	*Lampsilis*	Fatmucket, *Lampsilis siliquoidea*	0.01768
4	0.03162	F	*Enallagma*	Blue damselfly, *Enallagma cyathigerum*	0.03162
5	0.03217	B	*Danio*	Zebrafish, *Danio rerio*	0.03217
6	>0.1	A	*Salmo*	Atlantic salmon, *Salmo salar*	>0.1
7	0.1098	B	*Pimephales*	Fathead minnow, *Pimephales promelas*	0.1098
8	0.167	E	*Procambarus*	Crayfish, *Procambarus fallax f. virginalis*	0.167
9	0.1789	D	*Moina*	Cladoceran, *Moina macrocopa*	0.1789
10	0.25	H	*Brachionus*	Rotifer, *Brachionus calyciflorus*	0.25
11	0.5997	C	*Xiphophorus*	Swordtail fish, *Xiphophorus helleri*	0.5997
12	> 0.7610	C	*Xenopus*	African clawed frog, *Xenopus laevis*	> 0.7610
13	1.316	C	*Lithobates*	Northern leopard frog, *Lithobates pipiens*	1.316
14	1.344	D	*Daphnia*	Cladoceran, *Daphnia magna*	1.344
15	2.899	E	*Hyalella*	Amphipod, *Hyalella azteca*	2.899
16	8.527	G	*Physella*	Snail, *Physella heterostropha pomilia*	8.527
17	8.640	D	*Ceriodaphnia*	Cladoceran, *Ceriodaphnia dubia*	8.640

[a] Ranked from the most sensitive to the most tolerant based on Genus Mean Chronic Value.
[b] From Appendix C: Acceptable Freshwater Chronic PFOS Toxicity Studies
[c] MDR Groups identified by list provided in Section 2.10.1 above.

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Table 4-6. Calculation of Freshwater Chronic Water Column Concentration with Native and Established Organisms.

Calculated Freshwater FCV based on 4 lowest values: Total Number of GMCVs in Dataset = 17						
Rank	**Genus**	**GMCV (mg/L)**	**ln(GMCV)**	**ln(GMCV)^2**	**P=R/(N+1)**	**sqrt(P)**
1	*Neocloeon*	0.000226	-8.39	70.48	0.056	0.236
2	*Chironomus*	0.005198	-5.26	27.66	0.111	0.333
3	*Lampsilis*	0.01768	-4.04	16.28	0.167	0.408
4	*Enallagma*	0.03162	-3.45	11.93	0.222	0.471
		Σ (Sum):	**-21.14**	**126.35**	**0.56**	**1.45**

S^2 = 472.36 **S = slope**
L = -13.157 **L = X-axis intercept**
A = -8.297 **A = lnFCV**
FCV = 0.0002491 **P = cumulative probability**
Chronic Water Column Concentration = 0.00025 mg/L PFOS (rounded to two significant figures)

4.3 Qualitatively Acceptable Water Column-Based Toxicity Data

Several studies were identified as either not meeting the EPA's data quality guidelines for inclusion in the criteria derivation or did not have data available to support the independent calculation of a toxicity value (e.g., LC_{50} and/or EC_{10}). However, these studies were used qualitatively as supporting information to the PFOS criterion derived to protect aquatic life and provide additional evidence of the observed toxicity and effects of PFOS, including the relative sensitivities of surrogate, untested species. The key studies with apical endpoints (e.g., effects on survival, growth, or reproduction) that were used qualitatively in the derivation of the PFOS water column criteria are summarized below, grouped as either acute or chronic exposures and sorted by relative sensitivity of genera following the previous study summaries included in the Effects Analysis (Section 3). Qualitative study summaries within a factor of two of the final acute and chronic values were also included and arranged according to taxonomic relatedness. NOEC and LOEC values were provided in several of the study summaries for comparison to the toxicity values summarized in the Effects Analysis section. The toxicity values summarized

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below as part of this Effects Characterization were not used quantitatively to derive the acute or chronic PFOS freshwater criteria. Results of each individual study (as well as the rationale why a study was not quantitatively acceptable) were considered relative to the corresponding freshwater acute or chronic criterion magnitude to ensure the water column-based PFOS criteria were not underproductive and to provide additional supporting evidence of the potential toxicity of PFOS to aquatic organisms. Tabulated data for the studies summarized below, as well as additional qualitative studies of less sensitive taxa, were listed in Appendix G.

4.3.1 Consideration of Qualitatively-Acceptable Acute Data

4.3.1.1 Qualitatively Acceptable Acute Data for Species Among the Four Most Sensitive Genera Used to Derive the Acute Water Column Criterion

4.3.1.1.1 Most acutely sensitive genus, Neocloeon

There were no qualitatively-acceptable acute tests with the genus, *Neocloeon*.

4.3.1.1.2 Second most acutely sensitive genus, Moina

There were no qualitatively-acceptable acute tests with the genus, *Moina*.

4.3.1.1.3 Third most acutely sensitive genus, Pimephales

There were no qualitatively-acceptable acute tests with the genus, *Pimephales*.

4.3.1.1.4 Fourth most acutely sensitive genus, Oncorhynchus

Raine et al. (2021) exposed unfertilized rainbow trout (*Oncorhynchus mykiss*) oocytes for three hours to PFOS (perfluorooctanesulfonic acid, > 97% pure, CAS No. 1763-23-1, obtained from SynQuest Laboratories). The authors reported a residue accumulation NOEC of 0.87 mg/L and LOEC of 7.47 mg/L PFOS. This test is considered for qualitative use since the exposure duration was too short for both acute and chronic test exposure according to the test guidelines. Also, no apical endpoints were reported.

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4.3.1.2 Consideration of Relatively Sensitive Tests with Freshwater Species based on Qualitatively-Acceptable Acute Data

4.3.1.2.1 Genus: Danio (zebrafish)

Cormier et al. (2019) evaluated the acute effects of (1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluorooctane-1-sulfonic acid (PFOS, purity ≥ 98%, CAS No. 2785-37-3, purchased from Sigma-Aldrich in St. Louis, MO) on zebrafish (*Danio rerio*) via a 96-hour measured, static-renewal study. Zebrafish embryos were collected and tested according to OECD TG 236. The authors reported a 96 hour NOEC value of 700 ng/L PFOS (or 0.0007 mg/L) for hatching success, embryo mortality, and developmental deformations. Since the value represents a greater than low value (see description of decision rule in Section 2.10.3.2) (U.S. EPA 2013), the study is only used qualitatively in the acute criterion.

Haimbaugh et al. (2022) evaluated the acute toxic effects of low-level (≤2,400 ng/L) PFOS on zebrafish from zero to five days post fertilization. Unmeasured test concentrations (24, 240, or 2,400 ng/L PFOA) were renewed daily. At test termination, the highest test concentration (2,400 ng/L or 0.0024 mg/L) had no effects on mortality or abnormal development. This test was not used quantitatively and retained for qualitative use only because the exposure durations were too long for an acute test and too short for a chronic test with no effects observed. This study also represents a greater than low value.

The noted toxicity values provided above (>0.0007 mg/L and >0.0024 mg/L), indicated that this genus might be more sensitive to acute exposures of PFOS than the quantitative data for the genus (with a GMAV of 27.86 mg/L). However, this non-definitive qualitative value does not provide any clarity on true sensitivity. All eight of the quantitatively-acceptable acute tests for this species reported LC_{50} values (range = 3.502 – 71.12 mg/L; geometric mean = 27.86

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mg/L; n = 8) that were more than an order of magnitude greater than the FAV, leading the EPA to conclude that *D. rerio* is not a sensitive species to acute PFOS exposures.

4.3.2 Consideration of Qualitatively-Acceptable Chronic Data

4.3.2.1 Qualitatively Acceptable Chronic Data for Species Among the Four Most Sensitive Genera Used to Derive the Chronic Water Column Criterion

4.3.2.1.1 Most chronically sensitive genus, Neocloeon

There were no qualitatively-acceptable chronic tests with the genus, *Neocloeon*.

4.3.2.1.2 Second most chronically sensitive genus, Chironomus

Zhai et al. (2016) exposed *Chironomus plumosus* larvae to PFOS (perfluorooctane sulfonate, obtained from Tokyo Chemical Industries, Tokyo, Japan, 98% pure) spiked in sediment for 10.3 days. The sediment was collected from the upstream region of the Yongding River in Beijing, China. Spiking involved adding 1 mL of PFOS methanol solution (20 mg/L) to the sediment to obtain a concentration of 100 ng/g PFOS and thoroughly mixing in a fume hood. The midge larvae used in this study were collected from the uncontaminated upstream area of the Yangliuqing River in the outer suburbs of Tianjin, China. At the end of the experiment, the surviving larvae were counted. The 10-day mortality NOEC was 0.00985 mg/L PFOS, the only concentration tested. This study was considered for qualitative use for the following reasons: (1) the exposure duration was relatively short when comparing to the test guidelines for aquatic invertebrates and considered a sub-chronic exposure, (2) the sediment and test organisms used appear to have been previously exposed to low levels of PFAS (albeit low exposures) based on the measured concentrations reported in the paper, and (3) the apical endpoint for mortality results in a > NOEC that is a low value, which provides little information to the relative sensitivity of midge and was not used to derive the chronic PFOS criterion based on the data use rules established for these criteria (see Section 2.10.3.2).

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Stefani et al. (2014) conducted a chronic (10 generation) test of PFOS (form and purity not reported) with the midge, *Chironomus riparius*. The NOEC and LOEC were 0.0035 and > 0.0035 mg/L (as time-weighted average) as there were no effects on emergence, reproduction, or sex ratio at this concentration. The results from this study were not acceptable for quantitative use because only a single test concentration was used, the chronic value is a greater than low value and not informative for criterion development, and there was a lack of details pertaining to the characteristics of the sediment used in the exposure, including details regarding any differences in measured concentrations over the duration of the exposure. Since this study was focused on the chronic effects of PFOS to a relatively sensitive species, however, consideration of the greater than chronic value from this study (> 0.0035 mg/L) in the context of other values for the midge was prudent. The EC_{10}s for *Chironomus dilutus* of 0.05896 mg/L, 0.001588 mg/L, and 0.0015 mg/L from MacDonald et al. (2004), McCarthy et al. (2021), and Krupa et al. (2022), respectively, that were used quantitatively in the chronic criterion derivation are more robust values than the toxicity value reported in Stefani et al. (2014), and likely a better estimation of the sensitivity of *C. riparius*. The chronic value reported by Stefani et al. (2014), although slightly lower than the *Chironomus* GMCV, is higher than the final recommended chronic criterion, and was expressed as a NOEC, as no effects were observed at 0.0035 mg/L (as time-weighted average).

In a companion paper to Stefani et al. (2014), Marziali et al. (2019) similarly conducted a chronic (10 generation) test of PFOS (form and purity not reported) with *C. riparius*. The LOEC based on F1 developmental time and F1 adult weight was < 0.004 mg/L (time-weighted average). The were no effects on F1 exuvia length at this concentration. The results from this study were not considered for quantitative use because only a single test concentration was used,

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there was a lack of consistent observed effects in both the control and the treatment groups across the generations, and details pertaining to the characteristics of the sediment used in the exposure were lacking, including details regarding any differences in measured concentrations over the duration of the exposure. Again, it is prudent to consider the less than chronic value from this study (< 0.004 mg/L) in the context of the more robust and definitive values for midge. Similar to the determination above, the chronic values established for the related midge, *C. dilutus*, from MacDonald et al. (2004) and McCarthy et al. (2021) are deemed more reliable and definitive values representing the sensitivity of the genus in the freshwater chronic water column criterion dataset.

4.3.2.1.3 Third most chronically sensitive genus, Lampsilis

There were no qualitatively-acceptable chronic tests with the genus, *Lampsilis*.

4.3.2.1.4 Fourth most chronically sensitive genus, Enallagma

Van Gossum et al. (2009) conducted a chronic, approximately 4-month renewal test of PFOS (tetraethylammonium salt, 98% purity) with damselfly, *Enallagma cyathigerum.* The test organisms were larvae that had reached the F2 instar stage. Dilution water was dechlorinated tap water. Photoperiod was 16 hours light and 8 hours dark. Light intensity was not reported. A primary stock solution was prepared and proportionally diluted with dilution water to prepare the test concentrations. Exposure vessels were plastic containers (15 cm x 10 cm x 11 cm) with a 2 cm depth of test solution. The test employed 19-20 larvae each in two test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 0.01, 0.1, 1, and 10 mg/L. All larvae were housed (and presumably tested) in temperature-controlled rooms at 21±1.3°C. No other water quality parameters were reported as having been measured in test solutions. Negative control mortality was said to be much lower than the 100% mortality that occurred at 1

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and 10 mg/L but was not reported. The 4-month NOEC (behavioral – including general activity, swimming performance, foraging success) was 0.010 mg/L. The 4-month LOEC was 0.100 mg/L. The calculated MATC was 0.03163 mg/L. The chronic value was acceptable for qualitative use because only non-apical endpoints were reported.

4.3.2.2 Consideration of Relatively Sensitive Tests with Freshwater Species based on Qualitatively-Acceptable Chronic Data

4.3.2.2.1 Genus: Lithobates (leopard frog)

Flynn et al. (2021) evaluated the chronic effects of perfluorooctane sulfonic acid (PFOS, CAS# 1763-23-1, ≥ 96% purity, purchased from Sigma-Aldrich) on Northern Leopard frogs, *Lithobates pipiens* (formerly, *Rana pipiens*), via a 30-day sediment-spiked measured, static mesocosm study. The study authors reported a 30-day NOEC of 0.016 mg/L for weight, snout-vent length and mortality and a 30-day LOEC of 0.00006 mg/L for developmental stage (measured as Gosner stage). Independently-calculated EC_{10}s could not be calculated as the EPA was unable to fit a model with significant parameters. Therefore, given this was an outdoor mesocosm with spiked sediment that included the addition of algal and zooplankton communities, and the EPA was unable to independently calculate toxicity values based on the replicate level data provided by the study authors, this study was used qualitatively to derive the final recommended chronic water column criterion.

Hoskins et al. (2022) evaluated the chronic effects of PFOS alone and in mixture with PFHxS on northern leopard frogs (*Lithobates pipiens*) from Gosner Stage 25 tadpoles through metamorphosis (Gosner Stage 46) in a static-renewal measured exposure. No effects were observed on survival, mass index and snout-vent length at 0.000934 mg/L PFOS (the highest test concentration at test termination (day 120). The test results in a greater than NOECs (>0.000934 mg/L) and provides little information to the relative sensitivity of the species. Therefore, this

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study was not used to derive the chronic PFOS criterion based on prior data use rules (U.S. EPA 2013).

4.4 Acute-to-Chronic Ratios

The 1985 Guidelines allow the use of a final acute-to-chronic ratio (FACR) to convert the FAV to the FCV as an alternative approach to derive the chronic criterion instead of the direct calculation to determine the FCV (as described in Section 2.10.1) when the eight MDRs are not met (U.S. EPA 1985). While this alternative approach was not needed for the derivation of the chronic PFOS criterion, which was derived from empirical chronic data with all of the eight MDRs met, the possibility of calculating a scientifically-defensible FACR is as follows, for illustrative purposes only. Seventeen ACRs for eight invertebrate species and two fish species can be calculated from the quantitative acute and chronic toxicity data (Appendix A and Appendix C). Appendix I includes the ACRs for freshwater aquatic species with quantitative chronic values for which comparable quantitative acute values were reported from the same study or same investigator and laboratory combination. For each species where more than a single ACR was calculated, species mean acute-to-chronic ratios (SMACRs) were also calculated as the geometric mean value of individual ACRs for a species. In the case of a single ACR within a species, that ACR was the SMACR.

The ACRs ranged from 4.110 to 12,877 across all tests (a factor of 3,133), which occurs within the *Daphnia magna* SMACR. There was little explanation for the extreme range in ACRs among paired tests with *D. magna*. However, the ACR of 12,877 from paired tests conducted by Lu et al. (2015) appears to be an outlier. Excluding the 12,877 outlier ACR from the paired tests with *D. magna* reported by Lu et al. (2015) and from the paired test with *Daphnia carinata* (Logeshwaran et al. 2021) produced an SMACR range of 16.32 to 1,030. This range was greater

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than a factor of 10 with no relationship between SMACR and SMAV apparent. The 1985 Guidelines do not provide for calculation of a FACR under these circumstances.

4.5 Comparison of Empirical Tissue Concentrations to Translated Tissue Criteria

Measured PFOS tissue data were reported in 14 publications focused on freshwater species, six of which were quantitatively acceptable and eight of which were qualitatively acceptable (Table 4-7). The six quantitatively acceptable studies included data for one invertebrate, two fish, and one amphibian species, and the eight qualitatively acceptable studies included data for two invertebrate and four fish species. Results of these studies are summarized in Section 4.5.1 and Section 4.5.2, below.

Tissue concentration data from these toxicity studies were compared to the translated tissue criteria (fish whole body, fish muscle, invertebrate whole body) and supplemental fish tissue values (blood, liver, reproductive tissue) to better understand the protectiveness of the chronic aquatic life tissue criteria. Although tissue concentrations from the toxicity literature were limited, translated tissue criteria and supplemental fish tissue values were lower than tissue-based PFOS concentrations from chronic toxicity studies where toxic effects were observed, suggesting that the tissue criteria (and supplemental fish tissue values) are protective. Finally, while no amphibian tissue criteria are available, tissue concentrations from two amphibian toxicity tests suggest that the fish tissue criteria are protective of amphibians.

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Table 4-7. Comparison of Empirical Tissue Concentrations to Chronic Tissue Criteria and Additional Tissue Values.

Species	Endpoint	Percent Effect Observed	Measured Tissue Concentration (mg/kg ww)[1]	Calculated Chronic Tissue Values[2] (mg/kg ww)	Tissue Type	Reference
Quantitative Studies						
Fatmucket (*Lampsilis siliquoidea*)	Probability of successful metamorphosis of glochidia	33.5%	LOEC: 0.248	0.028	Invertebrate Whole-body (adult)	Hazelton et al. (2012)
Zebrafish (*Danio rerio)*	F1 survival	21%	LOEC: 4.8	0.201	Whole-body (adult female)	Wang et al. (2011)
			LOEC: 6.0	0.201	Whole-body (adult male)	
Fathead minnows (*Pimephales promelas*)	Fecundity	49% (LOEC)	NOEC: 7.1 – LOEC 19.4	0.616	Liver concentrations (adult male)[3]	Ankley et al. (2005)
			NOEC: 31.8 – LOEC 82.9	0.616	Liver concentrations (adult female)	
			NOEC: 8.8 – LOEC 19.9	1.29[3]	Gonad concentrations (adult male)[3]	
			NOEC: 33.1 – LOEC 81.6	1.29	Gonad concentrations (adult female)	
	Growth (weight in F1)	18%	LOEC: 37.9	1.29[3]	Gonad concentrations (adult F0 male)[3]	Suski et al. (2021)
			LOEC: 37.4	1.29	Gonad concentrations (adult F0 female)	
			LOEC: 84.5	0.616	Liver (adult F0 male)	
			LOEC: 68.2	0.616	Liver (adult F0 female)	
Northern leopard frog (*Lithobates pipiens*)	Length at metamorphosis (GS 42[4])	17%	LOEC: 66.6	None Available	Whole-body (before metamorphosis, day 54)	Ankley et al. (2004)
	Gosner stage after 40 days	5%	LOEC: 14.36		Whole-body	Hoover et al. (2017)

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Species	Endpoint	Percent Effect Observed	Measured Tissue Concentration (mg/kg ww)[1]	Calculated Chronic Tissue Values[2] (mg/kg ww)	Tissue Type	Reference
Qualitative Studies						
Red worms (*Limnodrilus hoffmeisteri*)	Reduction in superoxide dismutase[5]	13%	LOEC: 1,757 (dw)	0.028	Invertebrate Whole-body	Liu et al. (2016)
Great pond snails (*Lymnaea stagnalis*)	Survival	31%	LOEC: 2,877	0.028	Invertebrate Whole-body	Olson (2017)
European eels (*Anguilla anguilla*)	Survival	0%	NOEC: > 5.037	0.616	Liver	Roland et al. (2014)
Goldfish (*Carassius auratus*)	Survival	0%	NOEC: > 39.91 (dw)	0.087	Muscle	Feng et al. (2015)
Common carp (*Cyprinus carpio*)	Condition factor	3%	LOEC: 168.4	0.616	Liver	Hagenaars et al. (2008)
Zebrafish (*Danio rerio*)	Swimming distance[5]	18%	LOEC: 21.6	0.201	Whole-body	Spulber et al. (2014)

[1] Measured tissue concentrations are author-reported values. The EPA did not independently calculate toxicity values for tissue concentrations.

[2] Chronic tissue value concentrations represent chronic tissue criteria (invertebrates, fish muscle, fish whole body) or additional tissue values (fish blood, fish liver, fish reproductive tissue) calculated from BAFs for a given tissue type. See Section 3.2.3 and Appendix P for details.

[3] Fish reproductive tissue value based on female reproductive tissue.

[4] Gosner stage (GS) associated with this endpoint is not specifically reported by the study authors. However, the authors define complete metamorphosis as emergence of the forelimbs, which is GS 42 according to Taylor and Kollros (1946).

[5] Non-apical endpoint.

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4.5.1 Comparison of Quantitative Studies and Tissue-Based Criteria

Tissue concentration data from these toxicity studies were compared to the translated tissue values for invertebrates and fish to better understand the protectiveness of the aquatic life tissue criteria. Hazelton et al. (2012) exposed adult fatmucket (*Lampsilis siliquoidea*) to aqueous PFOS for 36 days. Measured PFOS water concentrations in the control and exposure treatments averaged 0.0021, 0.0045, and 0.0695 mg/L, respectively. Corresponding tissue concentrations were 0.009, 0.015 and 0.248 mg/kg wet weight. A statistically significant decrease in the probability of successful metamorphosis of glochidia to the juvenile stage was observed in the highest PFOS exposure concentration.

Wang et al. (2011) exposed larval (8 hpf) zebrafish (*Danio rerio*) to aqueous PFOS for five months. Fish were exposed to three nominal PFOS concentrations (0.005, 0.05, and 0.25 mg/L, respectively). Whole-body PFOS tissue concentrations measured after five months in the two highest exposure concentrations averaged 6.0 and 11.2 mg/kg wet weight, respectively, in males, and 4.8 and 7.8 mg/kg wet weight, respectively, in females. PFOS was also measured in embryos produced from exposed parents and averaged 5.69 and 11.35 ng/embryo wet weight in the two highest exposure concentrations. Weights of embryos were not reported by the study authors, so concentrations could not be calculated to compare embryo tissue concentrations to the translated tissue criteria. However, given the study design included tissue measurements in the parental (F0) generation and the exposure to the offspring generation (F1) was via maternal transfer, the tissue concentration in the F0 generation associated with the F1 survival LOEC of 0.05 mg/L was a whole-body tissue concentration of 6.2 and 4.0 mg/kg wet weight (ww) in male and females, respectively.

Ankley et al. (2005) exposed sexually mature adult fathead minnows (*Pimephales promelas*) to aqueous PFOS for 21 days during which time they were allowed to reproduce, and

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then the resulting offspring were held for an additional 24 days in the same exposure concentrations. Aqueous measured PFOS concentrations in the control and exposure treatments averaged <0.001, 0.0276, 0.101, 0.281, and 0.818 mg/L, respectively. PFOS was measured in the plasma, livers, and gonads of adult males and females after 21 days, in embryos, and in whole-body larval samples after 12 and 24 days. Tissue measurements were not made in organisms from the highest exposure concentration, where exposed adults were either dead or listless after 14 days. Plasma PFOS concentrations in adult organisms exposed to 0.0276, 0.101, and 0.281 mg/L PFOS averaged 26.9, 135, and 354 mg/L in males, and 47.1, 177, and 471 mg/L in females. Liver PFOS concentrations in adults averaged 7.1, 19.4, and 109 mg/kg wet weight in males, and 31.8, 82.9, and 261 mg/kg wet weight in females, respectively. Similarly, gonad PFOS concentrations averaged 8.8, 19.9, and 108 mg/kg wet weight in males, and 33.1, 81.6, and 263 mg/kg wet weight in females. PFOS concentrations in embryos from parents exposed to 0.0276, 0.101, and 0.281 mg/L PFOS were 9.3, 11.5, and 28.6 mg/kg, respectively. Larval PFOS concentrations measured after 12 and 24 days of exposure were similar, with whole-body concentrations corresponding to the 0.0276, 0.101, and 0.281 mg/L exposures were 19.8, 48.0, and 57.5 mg/kg wet weight after 12 days, and 17.8, 49.0, and 83.5 mg/kg wet weight after 24 days. The most sensitive apical endpoint was fecundity, with an aqueous EC_{10} of 0.051 mg/L. No corresponding tissue-based EC_{10} was calculated, but the corresponding liver concentrations would be expected to fall between 7.1 and 19.4 mg/kg in males and 31.8 and 82.9 mg/kg in females, and the corresponding gonad concentrations would be expected to fall between 8.8 and 19.9 mg/kg in males and 33.1 and 81.6 mg/kg in females. No muscle or whole-body measurements in adults are available to perform a direct comparison to the tissue criteria.

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Suski et al. (2021) reported the chronic toxicity of PFOS-K (PFOS potassium salt, CAS# 2795-39-3, ≥ 98%,) on the fathead minnow, *Pimephales promelas*. Measured PFOS concentrations in water were 0.00014 (control), 0.044, 0.088, 0.14, and 0.231 mg/L. The most sensitive endpoint from the study was a significant decrease in the mean mass of individuals in the larval F1 generation with the author-reported NOEC and LOEC, based on growth in the F1 generation, being 0.044 (6% reduction in growth compared to controls) and 0.088 mg/L PFOS (associated with an 18% reduction in growth), respectively. The calculated MATC based on mean mass of individuals in the larval F1 generation is 0.06222 mg/L. The F1 larval LOEC was associated with measured gonad and liver concentrations in F0 male and females of 37.9, 37.4, 84.5, and 68.2 mg/kg ww, respectively. No corresponding tissue-based EC_{10} was calculated, but the corresponding gonad and liver EC_{10} concentrations would be expected to be greater than the translated reproductive tissue concentration of 1.29 mg/kg ww and the translated liver tissue concentration of 0.616 mg/kg ww. No muscle or whole-body measurements in adults are available to perform a direct comparison to the fish tissue criteria.

Ankley et al. (2004) exposed Northern leopard frogs (*Lithobates pipiens*) to PFOS from Gosner stage 8/9 embryos through metamorphosis. The time to metamorphosis ranged from 60-112 days. All frogs in the highest exposure concentration died before metamorphosis. The most sensitive apical endpoint was length at metamorphosis, which was significantly lower ($p < 0.05$) in the second highest exposure relative to the control. The measured aqueous PFOS concentrations in the NOEC and LOEC exposure concentrations averaged 0.957 and 3.42 mg/L over the full exposure duration. PFOS in whole body tissue was analyzed as dry weight but reported by the authors as wet weight normalized. Corresponding whole-body tissue NOEC and LOEC concentrations measured in tadpoles exposed for 54 days (before metamorphosis) were

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16.9 and 66.6 mg/kg wet weight normalized. Whole body concentrations were also measured after 35 days and were higher than the 54-day measurements at the 0.957 mg/L exposure (22.1 mg/kg wet weight normalized) and 3.42 mg/L exposures (117.0 mg/kg wet weight normalized). Tadpole moisture content was not reported.

In a separate study with *L. pipiens*, Hoover et al. (2017), exposed juvenile (Gosner stage 26) northern leopard frogs to three PFOS concentrations (0.008, 0.078, and 0.884 mg/L measured PFOS, respectively) for 40 days. Survival, growth (snout-vent length), and developmental time (Gosner stage after 40 days) were measured, and the most sensitive apical endpoint was developmental time (Gosner stage after 40 days), with a NOEC of 0.008 mg/L and a LOEC of 0.078 mg/L. Whole body PFOS concentrations in frogs exposed to 0.008 mg/L PFOS in solution averaged 10.45 mg/kg dry weight after 40 days, and concentrations in frogs exposed to 0.078 mg/L averaged 51.46 mg/kg dry weight after 40 days. Tadpole moisture content was not reported in this study. In order to convert the reported dry weight concentrations to wet weight concentrations, so that they would be more directly comparable to the whole-body fish tissue criteria, a whole-body moisture content of 72.1% was applied, calculated as the average for all fish collected as part of the USGS National Contaminant Biomonitoring Program (NCBP Fish Database (usgs.gov)). Corresponding 40-day NOEC and LOEC wet weight PFOS tissue concentrations were 2.92 and 14.36 mg/kg wet weight, respectively.

In all of the studies described above, the translated tissue criteria and supplemental fish tissue concentrations were lower than the measured tissue concentrations where toxicity was observed, suggesting that the tissue criteria are protective. As noted above, tissue concentrations associated with the LOEC in both Ankley et al. (2004) and Hoover et al. (2017) are higher than

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the fish whole-body tissue criterion, suggesting that the fish tissue criteria is protective of amphibians.

4.5.2 Comparison of Qualitative Studies and Tissue-Based Criteria

Like the comparison with the quantitative studies, tissue concentration data from these qualitative toxicity studies were compared to the translated tissue values for invertebrates and fish to better understand the protectiveness of the aquatic life tissue criteria. Liu et al. (2016) exposed 4-5 cm body length red worms (*Limnodrilus hoffmeisteri*) to two aqueous concentrations of PFOS for 10 days at pH 8.0 and measured oxidative stress biomarker activity. Measured exposure concentrations were 0.567 and 5.494 mg/L PFOS, and corresponding whole-body tissue PFOS concentrations were 89.5 and 1,757 mg/kg dry weight. Moisture content was not reported. A significant ($P < 0.05$) reduction in superoxide dismutase was observed in the highest treatment concentration after 10 days. Apical endpoints were not reported for this exposure. In a separate study with *L. hoffmeisteri*, Qu et al. (2016) calculated 48-hour EC_{50}s in response to PFOS at three pH values (6.2, 7.0, 8.0). PFOS was not measured in water. However, whole body tissue concentrations were measured after 48-hours in the control, 0.2 mg/L, and 2.0 mg/L nominal PFOS exposures. Whole-body tissue concentrations in the 2.0 mg/L exposure were 23.41 mg/kg dry weight at pH 6.2 and 12.61 mg/kg dry weight at pH 8.0. After 48 hours, a significant ($P < 0.05$) increase in superoxide dismutase was observed in both the 0.2 mg/L and 2.0 mg/L PFOS treatments; however, no significant differences were observed at pH 8.0 for either treatment level.

Olson (2017) exposed adult great pond snails (*Lymnaea stagnalis*) to PFOS for 21 days. The most sensitive apical endpoint was survival, with a NOEC of 3 mg/L PFOS nominal, and a LOEC of 6 mg/L PFOS nominal. Whole-body PFOS tissue concentrations at the NOEC and LOEC after 21 days were 8,969 mg/kg dry weight and 9,820 mg/kg dry weight, respectively.

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Percent moisture was not reported by the study authors, so dry weights were converted to wet weights using the average whole soft body % moisture content of 70.7% for the snail species *Achatina achatina* (Achaglinkame et al. 2020) in order to more directly compare *L. stagnalis* tissue concentrations from this study to the invertebrate chronic whole body tissue criterion. Resulting wet weight PFOS concentrations at the NOEC and LOEC were 2,628 and 2,877 mg/kg, respectively.

Roland et al. (2014) exposed juvenile European eels (*Anguilla anguilla*) to PFOS for 28 days. Measured PFOS water concentrations were 0.00001 mg/L in the control and 0.00081 and 0.011 mg/L in the two aqueous exposure concentrations. Corresponding liver tissue PFOS concentrations after 28 days were 0.0338 and 5.037 mg/kg wet weight, respectively. The study authors noted that during the study, there was no mortality, and no significant differences in growth across either PFOS treatment. Significant ($p < 0.05$) changes in protein expression were reported for both exposure concentrations.

Feng et al. (2015) conducted a 96-hour study with juvenile goldfish (*Carassius auratus*) and measured the effects of PFOS on mortality or antioxidant enzyme activity. Measured PFOS in the two exposure concentrations were 1.04 µmol/L (0.520 mg/L) and 10.18 µmol/L (5.09 mg/L). Liver, gill, and muscle PFOS concentrations were 32.81, 42.13, and 33.08 mg/L dry weight, respectively, at the lower exposure level, and 58.37, 69.02, and 39.91 mg/L dry weight, respectively, at the higher exposure level. No mortality occurred during the test. Among the antioxidant enzyme activity endpoints, glutathione peroxidase activity was significantly ($p < 0.05$) lower in the highest exposure concentration than the control.

Hagenaars et al. (2008) exposed juvenile common carp (*Cyprinus carpio*) to three exposure concentrations of PFOS plus a control for 14 days and measured relative condition

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factor and several non-apical endpoints related to liver function. Nominal PFOS exposure concentrations were control, 0.1, 0.5, and 1 mg/L. Corresponding liver PFOS concentrations after the 14-day exposure were 0.97, 35.97, 168.4, and 283.0 mg/kg wet weight. The most sensitive endpoint was condition factor, which was significantly ($p < 0.0001$) lower than controls at the 0.5 mg/L nominal aqueous exposure concentration. Hepatosomatic index was also significantly ($P < 0.05$) lower at the 0.5 mg/L concentration compared to the control. The corresponding liver tissue PFOS concentration at this effect concentration (LOEC) was 168.4 mg/kg wet weight.

Spulber et al. (2014) exposed *Danio rerio* embryos (2 hpf) to 0.1 mg/L and 1.0 mg/L nominal PFOS concentrations for seven days. Corresponding whole-body PFOS concentrations in 7-day-old larvae were 21.6 and 213.5 mg/kg wet weight, respectively. Spulber et al. (2014) reported no effects of PFOS on viability, time to hatch, or deformities. The most sensitive endpoint was swimming distance, where fish exposed to the 0.1 and 1.0 mg/L PFOS treatments exhibited lower levels of activity ($p < 0.05$) in response to a pulse of darkness.

The translated tissue criteria and supplemental fish tissue concentrations were lower than the measured tissue concentrations where toxicity was observed for all of the qualitative studies. Although tissue concentrations from the toxicity literature were limited, available data suggest that the tissue criteria are protective.

4.6 Effects on Aquatic Plants

Available data for aquatic plants and algae were reviewed to determine if aquatic plants were likely to be more sensitive than aquatic animals to aqueous PFOS exposure (see Appendix E). Toxicity values for freshwater plants were well above the freshwater chronic water column criterion. Effect concentrations for freshwater plants and algae ranged from 0.19 to 252 mg/L

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compared to the range in animal chronic values of 0.000226 to 16.35 mg/L (Appendix C: Acceptable Freshwater Chronic PFOS Toxicity Studies). Therefore, it was not necessary to develop a criterion based on the toxicity of PFOS to aquatic plants. The PFOS freshwater acute and chronic criteria are expected to be protective of freshwater plants.

4.7 Protection of Threatened and Endangered Species

The PFOS acute and chronic datasets are include some data representing species that are listed as threatened or endangered by the U.S. Fish and Wildlife Service and/or National Oceanic and Atmospheric Administration (NOAA) Fisheries. Summaries are provided here describing the available PFOS toxicity data for listed species indicating that the 2024 PFOS criteria are protective of these listed species, based on available scientific data.

4.7.1 Quantitatively Acceptable Acute Toxicity Data for Listed Species

Quantitatively acceptable acute toxicity test data evaluating the effects of PFOS on threatened and endangered freshwater species were available for rainbow trout (*Oncorhynchus mykiss*) with a SMAV of 7.515 mg/L PFOS (Palmer et al. 2002a; Sharpe et al. 2010). The SMAV is over 100 times higher than the recommended acute criterion (CMC) of 0.071 mg/L, indicating the acute criterion is protective of rainbow trout and is expected to be protective of other listed salmonid species.

Quantitatively acceptable acute data were also available for the Eastern tiger salamander (*A. tigrinum*). While the species is not considered to be a federally listed species, it is considered endangered in Delaware, Maryland, New Jersey, New York, and Virginia (Smith 2003), threatened in North Carolina (Smith 2003), and critically imperiled in Louisiana (2024). The Eastern tiger salamander is also closely related to the endangered California tiger salamander (U.S. FWS 2016a; U.S. FWS 2016b; U.S. FWS 2017). The *A. tigrinum* SMAV of 68.63 (Tornabene et al. 2021) is almost an order of magnitude above the recommended acute criterion

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(CMC) of 0.071 mg/L, indicating the acute criterion is protective of the Eastern tiger salamander and the federally-listed California tiger salamander. There were no acceptable acute toxicity data for endangered or threatened estuarine/marine aquatic species.

4.7.2 Quantitatively Acceptable Chronic Toxicity Data for Listed Species

Quantitatively acceptable chronic toxicity test data evaluating the effects of PFOS on threatened and endangered freshwater species were available for the listed Atlantic salmon (*Salmo salar*) with a SMCV of >0.1 mg/L PFOS (Spachmo and Arukwe 2012). The SMCV is 400 times higher than the recommended chronic criterion (CCC) of 0.00025 mg/L, indicating the acute criterion is protective of Atlantic salmon and other listed salmonid species. There were no acceptable chronic toxicity data for endangered or threatened estuarine/marine aquatic species.

4.7.3 Qualitatively Acceptable Toxicity Data for Listed Species

Focusing on qualitatively acceptable tests with apical endpoints and water column exposures, there were toxicity data available for two fish species, rainbow trout and Atlantic salmon. For rainbow trout, the NOEC for mortality was 1 mg/L in a 12-day microcosm exposure and 3 mg/L in a 14-day early life stage static laboratory test (Oakes et al. 2005). For Atlantic salmon (*Salmo salar*), no adverse effects for growth were observed at the highest treatment concentration (0.1 mg/L PFOS) following a 49-day exposure (Arukwe et al. 2013). For both species, the qualitative NOECs were orders of magnitude greater than the recommended acute criterion (CCC) of 0.00025 mg/L, which further indicates that the chronic criteria are protective of listed salmonid species. There were no qualitative acute or chronic toxicity data for endangered or threatened estuarine/marine aquatic species.

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4.8 Summary of the PFOS Aquatic Life Criterion and the Supporting Information

The PFOS aquatic life AWQC were developed to protect aquatic life against adverse effects, such as mortality, altered growth, and reproductive impairments, associated with acute and chronic exposure to PFOS. The national recommended criteria include water column-based acute and chronic criteria for fresh waters. The freshwater acute water column-based criterion magnitude is 0.071 mg/L, and the chronic water column-based criterion magnitude is 0.00025 mg/L (0.25 µg/L). The chronic freshwater criterion also contains tissue-based criteria expressed as 0.201 mg/kg wet weight (ww) for fish whole-body, 0.087 mg/kg ww for fish muscle tissue, and 0.028 mg/kg ww for invertebrate whole-body tissue. These PFOS aquatic life criteria are expected to be protective of all freshwater aquatic life on a national basis. Although empirical PFOS toxicity data for estuarine/marine species were not available to fulfill the eight MDRs directly, the EPA included an acute aquatic life benchmark for estuarine/marine environments using available estuarine/marine species toxicity data and a NAMs application of the EPA ORD's peer-reviewed web-ICE tool (see Appendix L). The estuarine/marine acute water column-based benchmark magnitude is 0.55 mg/L and is expected to protect estuarine/marine aquatic life from acute aqueous PFOS exposures. The EPA conducted additional analyses supporting the derivation of the water column criteria for PFOS (as summarized above in Sections 4.1 and 4.2) and confirmed that the criteria and benchmark calculations presented in this document accurately reflect the latest and best available scientific knowledge.

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Appendix A Acceptable Freshwater Acute PFOS Toxicity Studies

A.1 Summary Table of Acceptable Quantitative Freshwater Acute PFOS Toxicity Studies

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Author Reported Effect Conc. (mg/L)	EPA Calculated Effect Conc. (mg/L)	Final Effect Conc. (mg/L)[e]	Species Mean Acute Value (mg/L)	Reference
Planaria (0.9 cm), *Dugesia japonica*	S, U	96 hr	PFOS-K >98%	-	25	LC50	17	-	**17**	-	Li (2008)
Planaria (0.9 ±0.1 cm), *Dugesia japonica*	S, U	96 hr	PFOS-K >98%	-	25	LC50	23	22.68	**22.68**	-	Li (2009)
Planaria (10-12 mm), *Dugesia japonica*	R, U	96 hr	PFOS-K >99%	-	20	LC50	29.46	-	**29.46**	22.48	Yuan et al. (2014)
Eastern elliptio (76.5 g, 48.7 mm), *Elliptio complanata* (formerly, *Unio complamatus*)	R, M	96 hr	PFOS-K 90.49%	7.9-8.5	21.8-23.7	LC50	59	64.35	**64.35**	64.35	Drottar and Krueger (2000f)
Fatmucket (glochidia, <24 hr), *Lampsilis siliquoidea*	S, M	24 hr	PFOS >98%	8.46	20	EC50 (viability)	16.5	-	**16.5**	-	Hazelton (2013); Hazelton et al. (2012)
Fatmucket (juvenile, 4-6 wks), *Lampsilis siliquoidea*	R, M	96 hr	PFOS >98%	8.46	20	LC50	158.1	-	158.1[d]	16.5	Hazelton (2013); Hazelton et al. (2012)
Black sandshell (glochidia, <24 hr), *Ligumia recta*	S, M	24 hr	PFOS >98%	8.46	20	EC50 (viability)	13.5	-	**13.5**	-	Hazelton (2013); Hazelton et al. (2012)
Black sandshell (juvenile, 4-6 wk), *Ligumia recta*	R, M	96 hr	PFOS >98%	8.46	20	LC50	141.7	-	141.7[d]	13.5	Hazelton (2013); Hazelton et al. (2012)
Bladder snail (mixed age), *Physella acuta* (formerly, *Physa acuta*)	S, U	96 hr	PFOS-K >98%	-	25	LC50	178	183.0	**183.0**	183.0	Li (2009)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Author Reported Effect Conc. (mg/L)	EPA Calculated Effect Conc. (mg/L)	Final Effect Conc. (mg/L)[e]	Species Mean Acute Value (mg/L)	Reference
Snail (adult, 4 mo.), *Physella heterostropha pomilia* (formerly, *Physa pomilia*)	S, M	96 hr	PFOS-K ≥98%	-	25	LC50	161.77	-	**161.8**	161.8	Funkhouser (2014)
Rotifer (<2 hr old neonates), *Brachionus calyciflorus*	S, U[b]	24 hr	PFOS-K ≥98%	-	20	LC50	61.8	-	**61.8**	61.8	Zhang et al. (2013)
Cladoceran (6-12 hr), *Daphnia carinata*	S, U	48 hr	PFOS-K ≥98%	-	21	LC50	8.8	11.56	**11.56**	11.56	Logeshwaran et al. (2021)
Cladoceran (<24 hr), *Daphnia magna*	S, M	48 hr	PFOS-K 90.49%	8.2-8.6	19.3-20.2	EC50	61	58.51	**58.51**	-	Drottar and Krueger (2000g)
Cladoceran (<24 hr), *Daphnia magna*	S, U	48 hr	PFOS-K 95%	-	21	EC50 (immobility)	67.2	-	**67.2**	-	Boudreau (2002); Boudreau et al. (2003a)
Cladoceran (<24 hr), *Daphnia magna*	S, U	48 hr	PFOS Unreported	-	21	EC50 (immobility)	37.36	35.46	**35.46**	-	Ji et al. (2008)
Cladoceran (<24 hr), *Daphnia magna*	S, U	48 hr	PFOS-K >98%	7.82-7.91	25	EC50	63	55.40	**55.40**	-	Li (2009)
Cladoceran (<24 hr), *Daphnia magna*	S, U	48 hr	PFOS-K >98%	7.82-7.91	25	EC50	63	72.70	**72.70**	-	Li (2009)
Cladoceran (<24 hr), *Daphnia magna*	S, U	48 hr	PFOS-K >98%	7.82-7.91	25	EC50	63	64.60	**64.60**	-	Li (2009)
Cladoceran (<24 hr), *Daphnia magna*	S, M	48 hr	PFOS-K 99%	7	22	LC50	78.09	-	**78.09**	-	Yang et al. (2014)
Cladoceran (<24 hr), *Daphnia magna*	S, U	48 hr	PFOS 98%	7.2	20	EC50 (death/immobility)	23.41	-	**23.41**	-	Lu et al. (2015)
Cladoceran (<24 hr), *Daphnia magna*	S, U	48 hr	PFOS-K ≥98%	7	20	EC50 (death/immobility)	79.35	94.58	**94.58**	-	Liang et al. (2017)
Cladoceran (12-24 hr), *Daphnia magna*	S, U	48 hr	PFOS-K 98%	-	-	LC50	22.77	22.43	**22.43**	51.86	Yang et al. (2019)
Cladoceran (<24 hr), *Daphnia pulicaria*	S, U	48 hr	PFOS-K 95%	-	21	EC50 (immobility)	134	-	**134**	134	Boudreau (2002); Boudreau et al. (2003a)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Author Reported Effect Conc. (mg/L)	EPA Calculated Effect Conc. (mg/L)	Final Effect Conc. (mg/L)[e]	Species Mean Acute Value (mg/L)	Reference
Cladoceran (<24 hr), *Moina macrocopa*	S, U	48 hr	PFOS Unreported	-	25	EC50 (immobility)	17.95	17.20	**17.20**	17.20	Ji et al. (2008)
Cladoceran (<48 hr), *Moina micrura*	S, M	48 hr	PFOS ≥98%	-	27	LC50	0.5496	-	**0.5496**	0.5496	Razak et al. (2023)
Crayfish (intermolt), *Pontastacus leptodactylus* (formerly, *Astacus leptodactylus*)	R, M	96 hr	PFOS-K ≥98%	6.79	21	LC50	48.81	-	**48.81**	48.81	Belek et al. (2022)
Crayfish (juvenile, 2 wks, 0.041 g), *Procambarus fallax f. virginalis*	S, M	96 hr	PFOS-K ≥98%	-	25	LC50	59.87	59.87	**59.87**	59.87	Funkhouser (2014)
Japanese swamp shrimp, *Neocaridina denticulata*	S, U	96 hr	PFOS-K >98%	-	25	LC50	10[g]	12.91	**12.91**	-	Li (2009)
Japanese swamp shrimp, *Neocaridina denticulata*	S, U	96 hr	PFOS-K >98%	-	25	LC50	10[g]	28.55	**28.55**	-	Li (2009)
Japanese swamp shrimp, *Neocaridina denticulata*	S, U	96 hr	PFOS-K >98%	-	25	LC50	10[g]	10.32	**10.32**	15.61	Li (2009)
Mayfly (<24 hr larva), *Neocloeon triangulifer*	S, M	96 hr	PFOS-K 98%	-	23	LC50	0.08	0.07617	**0.07617**	0.07617	Soucek et al. (2023)
Rainbow trout (juvenile), *Oncorhynchus mykiss*	S, M	96 hr	PFOS-K 86.9%	-	11.3-12.9	LC50	22	22.59	**22.59**	-	Palmer et al. (2002a)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Author Reported Effect Conc. (mg/L)	EPA Calculated Effect Conc. (mg/L)	Final Effect Conc. (mg/L)[e]	Species Mean Acute Value (mg/L)	Reference
Rainbow trout (parr), *Oncorhynchus mykiss*	R, M	96 hr	PFOS-K 98%	-	10	LC50	2.5	-	**2.5**	7.515	Sharpe et al. (2010)
Zebrafish (embryo), *Danio rerio*	R, U	96 hr	PFOS Unreported	7-8.5	26	LC50	71	-	**71**	-	Ye et al. (2007)
Zebrafish (embryo), *Danio rerio*	S, U	96 hr	PFOS-K ≥97%	7.2-7.5	26	LC50	58.47	-	**58.47**	-	Hagenaars et al. (2011a)
Zebrafish (adult), *Danio rerio*	R, M	96 hr	PFOS-K 98%	-	26	LC50	22.2	-	**22.2**	-	Sharpe et al. (2010)
Zebrafish (3 mo., 2.2 cm), *Danio rerio*	R, U	96 hr	PFOS-K Unreported	-	23	LC50	17.0	-	**17.0**	-	Wang et al. (2013)
Zebrafish (embryo), *Danio rerio*	S, U	96 hr	PFOS-K 98%	8.3	28.5	LC50	68	71.12	**71.12**	-	Li et al. (2015)
Zebrafish (embryo), *Danio rerio*	S, U	96 hr	PFOS-K 98%	-	28	LC50	3.502	-	**3.502**		Du et al. (2016a); Du et al. (2017)
Zebrafish (embryo, 1 hpf), *Danio rerio*	R, U	96 hr	PFOS Unreported	-	26	LC50	34.2	38.82	**38.82**	-	Stengel et al. (2017b)
Zebrafish (embryo), *Danio rerio*	R, M	96 hr	PFOS-K ≥98%	-	26	LC50	23.99[c]	-	**23.99**	27.86	Nilén et al. (2022)
Fathead minnow (juvenile), *Pimephales promelas*	S, M	96 hr	PFOS-K 90.49%	8.2-8.5	22	LC50	9.5	9.020	**9.020**	-	Drottar and Krueger (2000c)
Fathead minnow (79 d), *Pimephales promelas*	S, U	96 hr	PFOS-Li 24.5%	8.0-8.4	19.2-19.5	LC50	4.655[f]	5.356[f]	**5.356**	6.950	3M Company (2000)
American toad (larva, Gosner stage 26), *Anaxyrus americanus*	S, U	96 hr	PFOS Unreported	-	21	LC50	62[g]	63.41	63.41[d]	-	Tornabene et al. (2021)
American toad (larva, Gosner stage 41), *Anaxyrus americanus*	S, U	96 hr	PFOS Unreported	-	21	LC50	62[g]	56.49	**56.49**	56.49	Tornabene et al. (2021)
Gray treefrog (larva, Gosner stage 26), *Hyla versicolor*	S, U	96 hr	PFOS Unreported	-	21	LC50	79	78.33	78.33[d]	-	Tornabene et al. (2021)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Author Reported Effect Conc. (mg/L)	EPA Calculated Effect Conc. (mg/L)	Final Effect Conc. (mg/L)[e]	Species Mean Acute Value (mg/L)	Reference
Gray treefrog (larva, Gosner stage 40), *Hyla versicolor*	S, U	96 hr	PFOS Unreported	-	21	LC50	24	19.88	**19.88**	19.88	Tornabene et al. (2021)
American bullfrog (tadpole, Gosner stage 25), *Lithobates catesbeiana* (formerly, *Rana catesbeiana*)	S, U	96 hr	PFOS Unreported	-	21	LC50	144	154.8	154.8[d]	-	Flynn et al. (2019)
American bullfrog (larva, Gosner stage 26), *Lithobates catesbeiana*	S, U	96 hr	PFOS Unreported	-	21	LC50	163	133.3	**133.3**	133.3	Tornabene et al. (2021)
Green frog (larva, Gosner stage 26), *Lithobates clamitans* (formerly, *Rana clamitans*)	S, U	96 hr	PFOS Unreported	-	21	LC50	113	-	**113**	113	Tornabene et al. (2021)
Northern leopard frog (larva, Gosner stage 26), *Lithobates pipiens* (formerly, *Rana pipiens*)	S, U	96 hr	PFOS Unreported	-	21	LC50	73	72.72	**72.72**	72.72	Tornabene et al. (2021)
Wood frog (larva, Gosner stage 26), *Lithobates sylvatica* (formerly, *Rana sylvatica*)	S, U	96 hr	PFOS Unreported	-	21	LC50	130	-	**130**	130	Tornabene et al. (2021)
African clawed frog (embryos), *Xenopus laevis*	R, M	96 hr	PFOS-K 86.9%	7.3	24	LC50	13.8	15.53	**15.53**	-	Palmer and Krueger (2001)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Author Reported Effect Conc. (mg/L)	EPA Calculated Effect Conc. (mg/L)	Final Effect Conc. (mg/L)[e]	Species Mean Acute Value (mg/L)	Reference
African clawed frog (embryos), *Xenopus laevis*	R, M	96 hr	PFOS-K 86.9%	7.27	24	LC50	17.6	18.04	**18.04**	-	Palmer and Krueger (2001)
African clawed frog (embryos), *Xenopus laevis*	R, M	96 hr	PFOS-K 86.9%	7.26	24	LC50	15.3	14.6	**14.60**	15.99	Palmer and Krueger (2001)
Jefferson salamander (larva, Harrison stage 40), *Ambystoma jeffersonianum*	S, U	96 hr	PFOS Unreported	-	21	LC50	64	51.71	**51.71**	51.71	Tornabene et al. (2021)
Small-mouthed salamander (larva, Harrison stage 40), *Ambystoma texanum*	S, U	96 hr	PFOS Unreported	-	21	LC50	41[g]	46.71	46.71[d]	-	Tornabene et al. (2021)
Small-mouthed salamander (larva, Harrison stage 46), *Ambystoma texanum*	S, U	96 hr	PFOS Unreported	-	21	LC50	41[g]	30.00	**30.00**	30.00	Tornabene et al. (2021)
Eastern tiger salamander (larva, Harrison stage 40), *Ambystoma tigrinum*	S, U	96 hr	PFOS Unreported	-	21	LC50	73	68.63	**68.63**	68.63	Tornabene et al. (2021)

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

[b] Chemical concentrations made in a side-test representative of exposure and verified stability of concentrations of PFOS in the range of concentrations tested under similar conditions. Daily renewal of test solutions.

[c] Reported in moles converted to milligram based on a molecular weight of 500.13 mg/mmol or 538.22 mg/mmol PFOS-K.

[d] Not used in SMAV calculation; only the most sensitive life-stage used.

[e] Values in bold used the in the SMAV calculation.

[f] Author-reported LC_{50} of 19 mg/L x 24.5% PFOS = 4.655 mg/L PFOS; EPA-calculated LC_{50} of 21.86 mg/L x 24.5% PFOS = 5.356 mg/L PFOS.

[g] Author pooled tests or life-stages.

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A.2 Detailed PFOS Acute Freshwater Toxicity Study Summaries and Corresponding Concentration-Response Curves (when calculated for the most sensitive genera)

The purpose of this section was to present detailed study summaries for tests that were considered quantitatively acceptable for criteria derivation, with summaries grouped and ordered by genus sensitivity. Concentration-response (C-R) models developed by the EPA that were used to determine acute toxicity values used for water column criterion derivation are also presented for the most sensitive genera when available. C-R models included here with study summaries were those for the five most sensitive genera (consistent with Section 3.1.1.1). When required, the EPA also included models for non-resident species that were more sensitive than the fourth most sensitive North American resident genus. In many cases, authors did not report C-R data in the publication/supplemental materials and/or did not provide C-R data upon the EPA request. In such cases, the EPA did not independently calculate a toxicity value and the author-reported effect concentrations were used in the derivation of the criterion.

A.2.1 Most Sensitive Freshwater Genus for Acute Toxicity: *Neocloeon* (mayfly)

Soucek et al. (2023) conducted a 96-hour acute toxicity test to determine the effects of PFOS-K (PFOS potassium salt, CAS # 2795-39-3, 98% purity) on the parthenogenetic mayfly, *Neocloeon triangulifer*. The test was performed under static, nonrenewal conditions beginning with < 24-hour old nymphs. Exposures consisted of five mayfly nymphs per 30 mL polypropylene cup filled with 20 mL test solution. The control and each of six PFOS test concentrations were replicated five times for a total of 25 test organisms per treatment. Nominal test concentrations were 0 (control), 0.0156, 0.0313, 0.0625, 0.125, 0.250, and 0.500 mg/L PFOS. Mean measured PFOS concentrations (EPA Analytical Method 1633; LC-MC/MS) were 0.0002 (control), 0.017, 0.046, 0.052, 0.103, 0.253, and 0.358 mg/L PFOS, respectively. Animals were exposed at 23 ± 1°C under a 16:8 hour light (˜110 – 300 lux):dark cycle and fed live diatom

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biofilm scraping beginning on Day 0. Percent survival in the control treatment after 96 hours was 100%. A uniform C-R pattern for percent survival was observed decreasing from 100 and 96% in the lowest treatments to 4 and 0% in the highest test treatments. The EPA was able to independently calculate a 96-hour LC_{50} of 0.07617 mg/L (0.06546 – 0.08688 mg/L; 95% CI) for this study. The EPA's independently-calculated LC_{50} is in line with the author-reported LC_{50} of 0.08 mg/L. Therefore, the independently-calculated LC_{50} of 0.07617 mg/L was acceptable for quantitative use in the derivation of the freshwater acute water column criterion for PFOS.

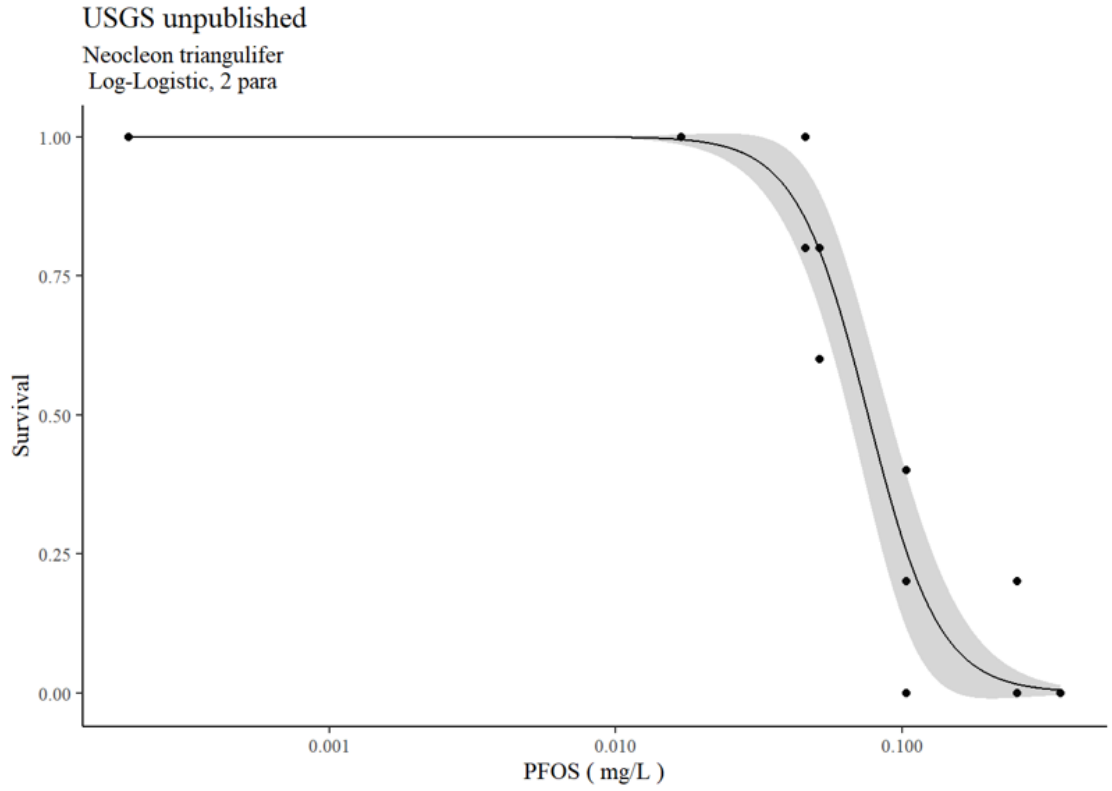
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A.2.1.1 Soucek et al. (2023) Concentration Response Curve – Neocloeon (mayfly)

Publication: Soucek et al. (2023)
Species: Mayfly, *Neocloeon triangulifer*
Genus: *Neocloeon*
EPA-Calculated LC_{50}: 0.07617 (0.06546 – 0.08688) mg/L
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	3.4747	0.5921	58679	$4.414\ e^{-9}$
e	0.07617	0.0063135	12.0644	$< 2.2\ e^{-16}$

Concentration-Response Model Fit:



A.2.2 Second Most Sensitive Freshwater Genus for Acute Toxicity: *Moina* (cladoceran)

Ji et al. (2008) performed a 48-hour static, unmeasured acute test of PFOS (acid form, CAS # 1763-23-1, purity unreported) with *Moina macrocopa*. The test followed the EPA's Methods for measuring the acute toxicity of effluents and receiving waters to freshwater and marine organisms [U.S. EPA/600/4-90/027F; (U.S. EPA 2002)]. *M. macrocopa* used for testing were obtained from brood stock cultured at the Environmental Toxicology Laboratory at Seoul

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National University (South Korea). Test organisms were less than 24 hours old at test initiation. Dilution water was moderately hard reconstituted water (hardness typically 80-100 mg/L as $CaCO_3$). Experiments were conducted in glass jars of unspecified size and fill volume. The photoperiod for the test was assumed by the reviewers to have been 16:8-hours light:dark, as was used for daphnid culture in tests by the same authors. Preparation of test solutions was not described. The test involved four replicates of five neonates each in five nominal test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 6.25, 12.5, 25, 50 and 100 mg/L. Test temperature was maintained at 25 ± 1°C. Authors note water quality parameters (pH, temperature, conductivity, and D.O.) were measured 48 hours after exposure, but the information was not reported. Survival of organisms in the negative control was not reported in the paper. However, raw data were obtained by the EPA from the study authors and control survival was 100% in the acute test, meeting the EPA/600/4-90/027F requirement of at least 90% survival for test acceptability. The study authors reported a 48-hour EC_{50} value of 17.95 mg/L (C.I. 14.72 - 21.18) for *M. macrocopa*. The 48-hour EC_{50} value was independently-calculated by the EPA as 17.20 (13.73 – 20.66) mg/L. The independently-calculated acute toxicity value was quantitatively used in the derivation of the freshwater acute water column criterion.

Razak et al. (2023) tested the acute toxicity of perfluorooctanesulfonate (PFOS) on *Moina micrura* for 48 hours in a measured, static experiment. PFOS (≥98% purity) analytical standards were purchased from Dr. Ehrenstorfer GmbH (Augsburg, Germany), and PFOA and solvents for making test solutions were purchased from Fisher Scientific (New Jersey, USA). Organisms were obtained from the Aquatic Animal Health and Therapeutics Laboratory (Aquahealth) at the Institute of Bioscience, Universiti Putra Malaysia. Culturing procedures

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followed International Organisation for Standardization (ISO) procedure 6341:2012. Cultures were kept under a 12:12 light:dark cycle at 27±1°C. Culture water was renewed every two weeks, and culture organisms were fed green algae (*Chlorella vulgaris*) three times weekly. Both culture and test water was filtered (0.2 µm) surface lake water. A stock solution of 100 mg/L PFOS with filtered surface lake water was made just before testing began. Testing methods followed OECD 202 (OECD 2004) with nominal testing concentrations of 10, 25, 50, 75, 100, 250, 500, 750, 1,000, 2,500, 5,000, 7,500, and 10,000 µg/L, plus a control, with four replicates per treatment. Each replicate consisted of 10 neonates (<48 hours old) in 50 mL of solution in a 100 mL beaker, and organisms were not fed during the study. Nonparametric Kruskal-Wallace tests followed by post-hoc tests were used to calculate significant ($P<0.05$) differences between controls and treatment concentrations for all endpoints. The lethal effect concentrations (LC_{10}, LC_{50}, LC_{75}, LC_{90}) were calculated using Probit analysis, and the 48-hour LC_{50} value of 549.6 µg/L, or 0.5496 mg/L was determined to be acceptable for quantitative use. C-R data could not be obtained for this test (beyond the visual presentation in the Razak et al. (2023), so the EPA was unable to perform independent C-R analysis.

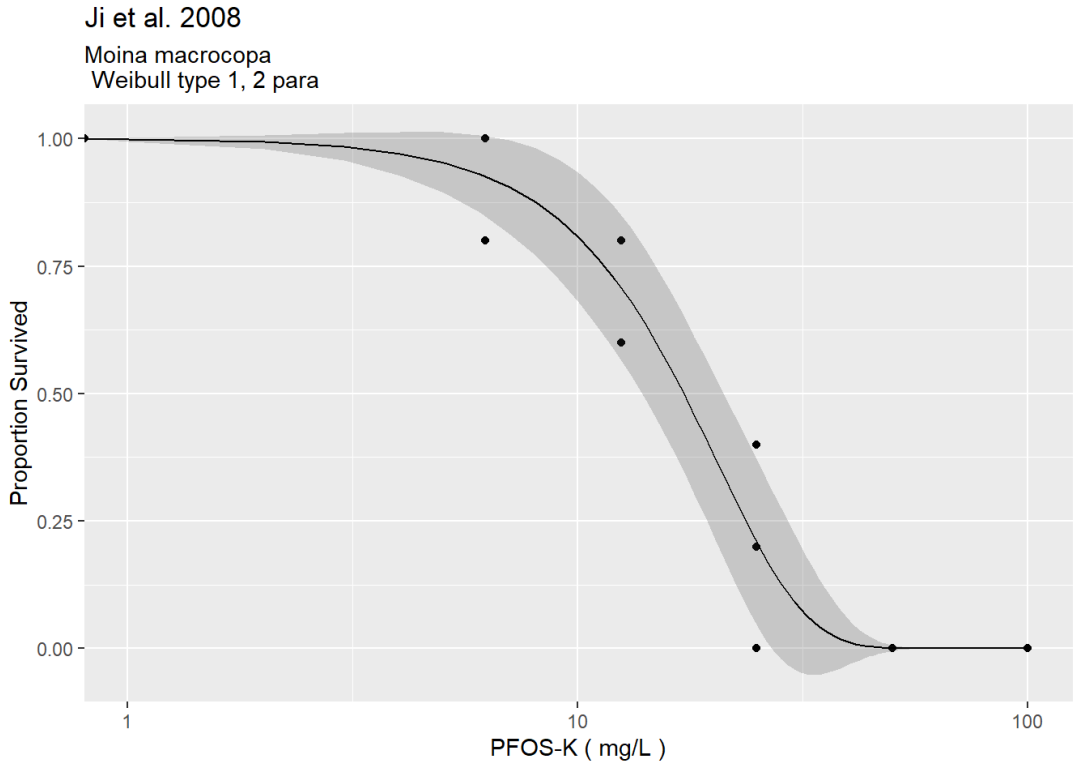
A.2.2.1 Ji et al. (2008) Concentration Response Curve – Moina (cladoceran)

Publication: Ji et al. (2008)
Species: Cladoceran, *Moina macrocropa*
Genus: *Moina*
EPA-Calculated LC_{50}: 17.20 (13.73 – 20.66) mg/L
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	2.18	0.47	4.60	$4.16\ e^{-06}$
e	20.34	2.06	9.87	$<2.2\ e^{-16}$

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Concentration-Response Model Fit:



A.2.3 Third Most Sensitive Freshwater Genus for Acute Toxicity: *Pimephales* (fathead minnow)

3M Company (2000) provides the results of a 96-hour static, unmeasured acute toxicity test with the fathead minnow, *Pimephales promelas*, and PFOS-Li (perfluorooctanesulfonate lithium salt, CAS # 29457-72-5). A stock solution was made with carbon-filtered well water at a test sample concentration of 400 mg/L and where the test sample was reported as a mixture of PFOS-Li (24.5%) in water (75.5%). Fish were obtained from a commercial supplier (Aquatic Biosystems, Fort Collins, CO) and were 79 days old at test initiation with an average length of 2.1 cm and weight of 0.069 g. Exposure vessels were 2 L glass beakers containing 1 L of solution and 10 fish per beaker (0.69 g fish/L). Each test treatment was replicated twice with nominal test concentrations (control, 3.2, 5.6, 10.0, 18.0, 32.0 and 56.0 mg/L test sample). Throughout the experiment the dissolved oxygen (D.O.) ranged from 4.8 - 7.9 mg/L, pH 8.0 - 8.4 and a test temperature of 19.2 - 19.5°C. The low D.O. of 4.8 mg/L was only observed in one

replicate of the highest test concentration at 96 hours; D.O. was ≥6.0 mg/L for all other treatments and replicates. No mortality occurred in the control treatment and 100% was observed in the highest treatment (56 mg/L). The study authors reported that the test sample containing 24.5% PFOS-Li exhibited a 96-hour LC_{50} of 19 mg/L, which equates to 4.655 mg/L as PFOS. The independently-calculated 96-hour LC_{50} value was 21.86 (17.63 – 26.08) mg/L, which equates to 5.356 mg/L as PFOS and is acceptable for quantitative use in the derivation of the acute freshwater criterion for PFOS.

Drottar and Krueger (2000c) evaluated the acute effects of PFOS-K (CAS# 2795-39-3, Lot # 217 (T-6295) obtained from the 3M Company, 90.49% purity, stored at ambient room temperature) on juvenile fathead minnows (*Pimephales promelas*) during a 96-hour measured, static study. Researchers stated they followed protocols by U.S. EPA Series 850 (OPPTS 850.1075), OECD Guideline 203, and ASTM E729-88a. A primary stock solution was prepared at 27 mg/L and mixed with an electric mixer for 22 hours prior to use in testing to ensure solubilization of the test substance. After mixing, the primary stock solution was proportionally diluted with dilution water to prepare the four additional test concentrations. Test fish were obtained from cultures at Wildlife International Ltd. in Easton, Maryland. The minnows were held for approximately 126 days prior to testing and were acclimated to test conditions for 48 hours prior to test initiation. Fish were fed a commercially-prepared diet prior to the 48-hour acclimation period. All fish used in the test were from the same source and year class, and the total length of the longest fish was no more than twice the length of the shortest. Fathead minnows were randomly distributed among mean measured test concentrations of 0 (control), 3.3, 5.6, 9.5, 17 and 28 mg/L, with 10 fish per 25-L polyethylene aquarium provided in duplicate. Aquaria were filled with 15 L of test solution with an observed D.O. of 7.7 - 8.4 mg/L,

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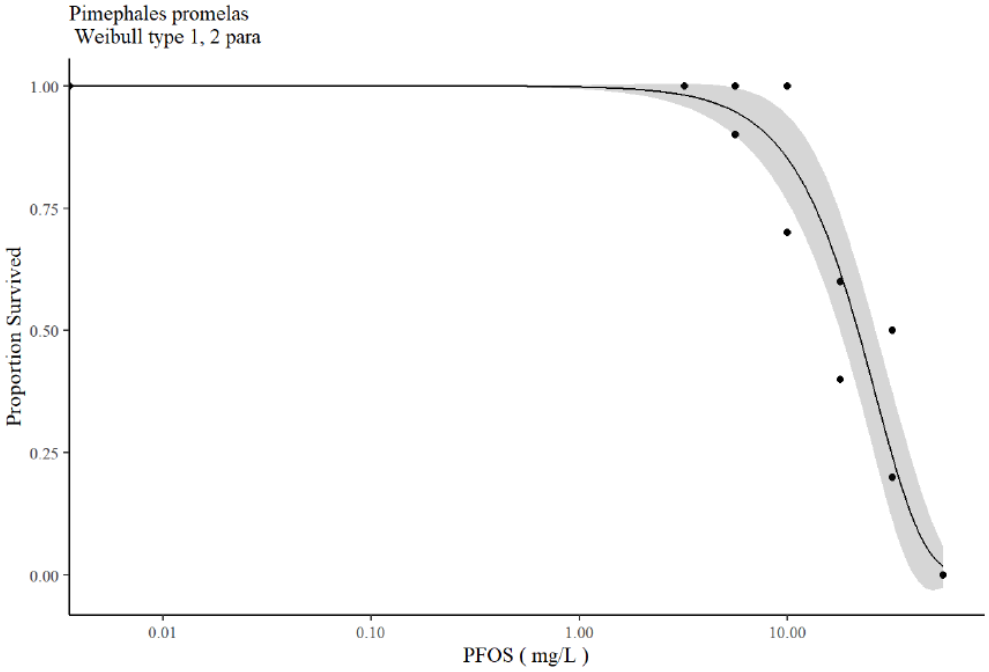
temperature of 22 ± 2ºC, pH of 8.2 - 8.5, and a total hardness of 131 mg/L as $CaCO_3$. Fathead minnows were subjected to a 16:8-hour light:dark photoperiod at 391 lux. Sand and 0.45 um filtered well water from a 40 m deep well on site served as both the culture water and the testing media. The authors reported an LC_{50} of 9.5 mg/L PFOS. The EPA's independently-calculated 96-hour LC_{50} was 9.020 (7.146 - 10.89) mg/L, rounded to four significant figures, and was used quantitatively to derive the freshwater acute water column criterion.

A.2.3.1 3M Company (2000) Concentration Response Curve – Pimephales (fathead minnow)

Publication: 3M Company (2000)
Species: Fathead minnow, *Pimephales promelas*
Genus: *Pimephales*
EPA-Calculated LC_{50}: 21.86 (95% C.I. 17.63 – 26.08) mg/L
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	1.8756	0.3016	6.2191	$4.999\ e^{-10}$
e	26.5720	2.5673	10.3501	$< 2.2\ e^{-16}$

Concentration-Response Model Fit:

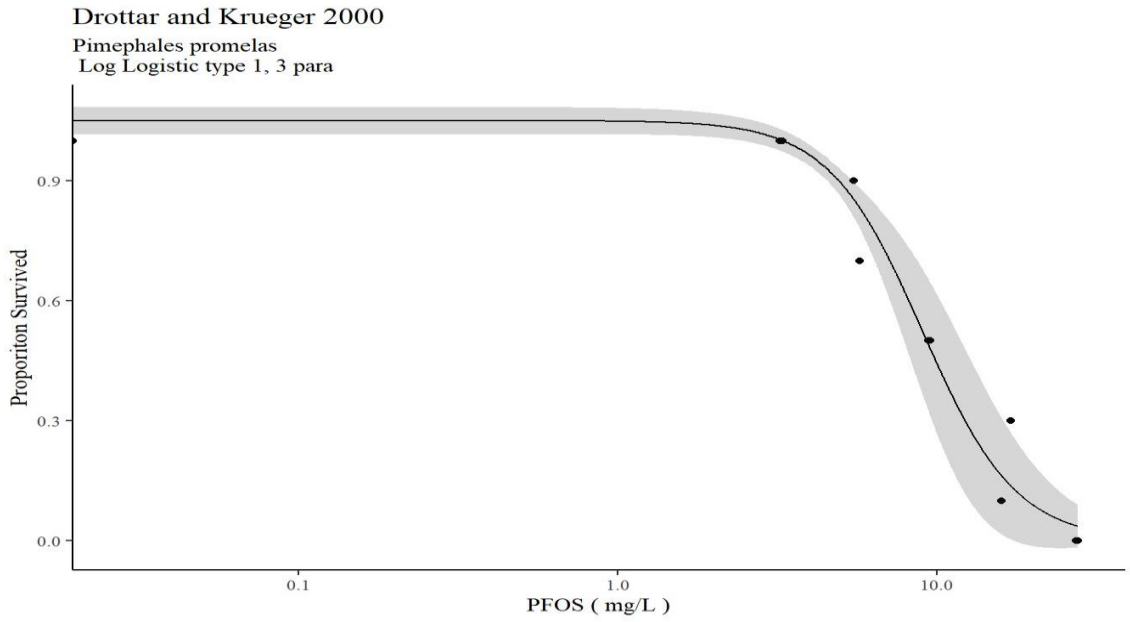


A.2.3.2 Drottar and Krueger (2000c) Concentration Response Curve – Pimephales (fathead minnow)

Publication: Drottar and Krueger (2000c)
Species: Fathead minnow, *Pimephales promelas*
Genus: *Pimephales*
EPA-Calculated LC_{50}: 9.020 (95% C.I. 7.146 - 10.89) mg/L
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	2.9683	0.4433	6.6965	$2.134\ e^{-11}$
d	1.0503	0.0174	60.4403	$< 2.2\ e^{-16}$
e	9.0196	0.8923	10.1084	$< 2.2\ e^{-16}$

Concentration-Response Model Fit:



A.2.4 Fourth Most Sensitive Freshwater Genus for Acute Toxicity: *Oncorhynchus* (trout)

Sharpe et al. (2010) evaluated the acute effects of perfluorooctane sulfonate (PFOS, potassium salt, CAS #2795-39-3, 98% purity) to *Oncorhynchus mykiss*, rainbow trout, via a 96-hour renewal measured exposure (renewal not stated in paper, but assumed based on other information provided, including the test Guideline protocol). Limited details about the test protocol were provided in the publication, but the authors noted they followed OECD Guideline 203, and did not identify any deviations from these test guidelines. Trout eggs were obtained

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from Raven Trout Hatchery, transported immediately postfertilization to the University of Alberta aquatics facility, and kept in dechlorinated City of Edmonton water. The eggs were reared until hatching in Heath trays in a recirculating, temperature-controlled system at 10°C with a 12:12-hour light:dark photoperiod (the same conditions are assumed for the toxicity test). The rainbow trout used in the study were parr (2-3 g, the fourth stage of the salmon life cycle) at test initiation. The dilution water was dechlorinated City of Edmonton water, and dissolved oxygen content and temperature were monitored daily, but physico-chemical results were not reported. PFOS was dissolved in MeOH, and all vehicle controls received a volume of MeOH equal to that present in the highest PFOS dose of that experiment (final MeOH content 0.2% v/v). The concentration of PFOS in any experiment was always well below its reported solubility in water (≈500 mg/L). Trout toxicity tests were performed using food-grade 2 L plastic tanks with four fish per tank, and two tanks per dose. The EPA obtained clarification from the study authors regarding the experimental set-up pertaining to the biomass loading rate, which was 1 to 1.5 g/L (based on four fish weighing a total of 2 to 3 g per 2 L tank (personal communication with Greg Goss and Rainie Sharpe, March 2021). This biomass loading rate was nearly two-fold higher than that stated in OECD Guidelines of 0.8 g/L (OECD 1992). The trout were randomly assigned to doses defined as control (0 mg/L PFOS); vehicle control (0 mg/L PFOS, 0.2% MeOH v/v); and 0.78, 1.56, 3.12, 6.25, and 12.5 mg/L PFOS. The authors indicated that measured PFOS concentrations averaged 88% of nominal but did not indicate whether LC_{50}s were based on measured or nominal concentrations. Given the clarifications regarding the biomass loading, this study was considered for quantitative use in the derivation of the acute PFOS freshwater criterion. The author-reported 96-hour LC_{50} for the study of 2.5 mg/L (authors did not specify if this concentration was nominal or measured) was acceptable for quantitative

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use and was among other toxicity values used for this species to calculate the SMAV/GMAV (see further details at the end of the study summaries in this section) that was utilized to derive the freshwater acute water column criterion.

Palmer et al. (2002a) evaluated the acute effects of PFOS (PFOS, potassium salt, identified as FC-95 obtained from 3M Company) to *Oncorhynchus mykiss*, rainbow trout, via a 96-hour static exposure with measured concentrations. The test organisms were obtained from Thomas Fish Company in Anderson, California and were reported as juveniles with a mean weight of 0.34 g and mean total length of 3.6 cm. All test organisms were from the same source and year class, and the length of the longest fish was no more than twice the length of the shortest. The fish were held for approximately five weeks prior to the initiation of the test. This acclimation was done in water from the same source and at the same temperature as the test. During the acclimatation period, no mortalities or signs of disease were observed. Test organisms were only fed a commercially-prepared diet (reported from Zeigler Brothers Inc.) during a 14-day holding period after which point fish were no longer fed through the acclimation period (at least 48 hours prior to the test) or during the test. The test water was obtained from a well located near the testing facility and was characterized as moderately-hard water. The target test temperature was 12 ± 1°C and a 16:8-hour light:dark photoperiod was maintained through the holding, acclimatation, and testing periods. Dissolved oxygen and pH measurements were made on water samples collected at test initiation followed by 24-hour intervals for each replicate test chamber of each treatment and control. Test chambers were 25-L polyethylene aquaria containing 15 L of test solution. At the initiation of the test, rainbow trout were indiscriminately moved from the acclimation tank and distributed two at a time to the test chambers until each contained ten fish. The resulting biomass loading rate was 0.23 g fish/L of

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test water. A 40-L stock solution was prepared in dilution water at a concentration of 150 mg PFOS/L. Nominal concentrations were 3.1, 6.3, 13, 25, and 50 mg/L. Two replicates of each test solution were prepared at nominal concentrations by adding the appropriate volume of stock solution to dilution water in the test aquaria to achieve the final volume of 15 L. Measured test concentrations at the end of the test ranged from 97 to 100% of nominal with concentrations of 3.0, 6.3, 13, 25, and 50 mg/L. Results from this study were based on measured concentrations. Mortality and other signs of toxicity were observed daily. Trout in the control group appeared normal and healthy throughout the test period. Additionally, test organisms in the lowest treatment groups (3.0 and 6.3 mg/L) appeared healthy with no mortalities or other signs of toxicity. After 96-hours of exposure, mortality in the 13, 25, and 50 mg/L treatment groups was 20, 50, and 100%, respectively. The author-reported 96-hour LC_{50} for the study was 22 mg/L. This study was considered acceptable for quantitative use in the derivation of the acute PFOS freshwater water column criterion. The independently-calculated 96-hour LC_{50} value was 22.59 mg/L.

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A.2.4.1 Sharpe et al. (2010) Concentration Response Curve - Oncorhynchus (trout)

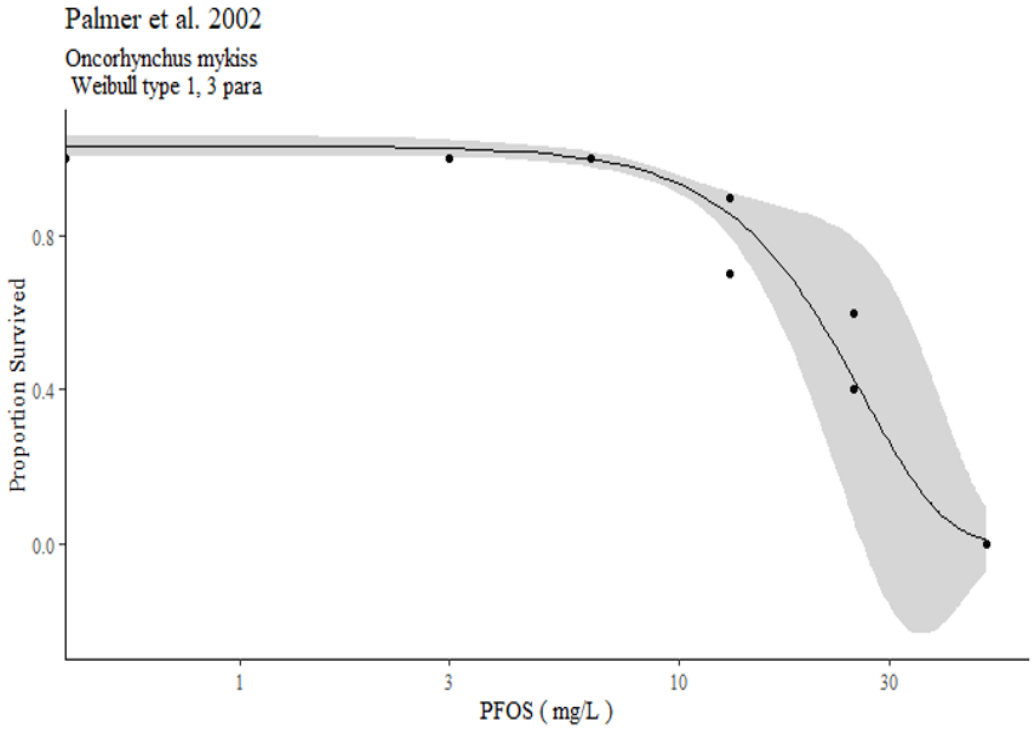
Publication: Sharpe et al. (2010)
Species: Rainbow trout, *Oncorhynchus mykiss*
Genus: *Oncorhynchus*
EPA-Calculated LC_{50}: Not calculable, concentration-response data not available

A.2.4.2 Palmer et al. (2002a) Concentration Response Curve - Oncorhynchus (trout)

Publication: Palmer et al. (2002a)
Species: Rainbow trout, *Oncorhynchus mykiss*
Genus: *Oncorhynchus*
EPA-Calculated LC_{50}: 22.59 (95% C.I. 14.53 – 30.65) mg/L
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	2.3775	0.5634	4.2189	$2.455\ e^{-5}$
d	1.0339	0.0140	73.6910	$< 2.2\ e^{-16}$
e	26.3557	5.7449	4.5877	$4.482\ e^{-6}$

Concentration-Response Model Fit:



A.2.5 Fifth Most Sensitive Freshwater Genus for Acute Toxicity: *Ligumia* (mussel)

Hazelton (2013); Hazelton et al. (2012) evaluated the acute effects of PFOS (acid form, > 98% purity) on two freshwater mussels*: Ligumia recta* and *Lampsilis siliquoidea.* The tests yielded the 4th and 7th most sensitive genera values (respectively) in the PFOS freshwater acute criterion dataset (the *L. siliquoidea* results are reported below). Acute toxicity was observed under either static or renewal conditions over a 24-hour period (< 24-hour old glochidia; static exposure) or a 96-hour period (4–6-week-old juveniles; renewal exposure). The tests followed the (ASTM 2006) test method. Dilution water was hard reconstituted water (total hardness typically 160-180 mg/L as $CaCO_3$). Photoperiod and light intensity were not reported. No details were provided regarding primary stock solution and test solution preparation. Experiments were conducted in 3.8 L glass jars of unspecified fill volume. The test employed three replicates of 150 glochidia or seven juvenile mussels each in six measured test concentrations plus a negative control (10 juveniles for the control treatment). Nominal concentrations were 0 (negative control), 0.005, 0.05, 0.5, 5, 50, and 500 mg/L; respective measured concentrations were < limit of quantitation (LOQ; specifics not provided), 0.0054, 0.0514, 0.456, 4.68, 47.2, and 490 mg/L. Recovery of PFOS standards ranged from 85.3-123% over all experiments. For all acute tests, alkalinity ranged from 97 to 110 mg $CaCO_3$/L with a mean of 104.4 mg $CaCO_3$/L; total hardness ranged from 132 to 162 mg $CaCO_3$/L with a mean of 149.6 mg $CaCO_3$/L; conductivity ranged from 514 to 643 µS/cm with a mean of 556.5 µs/cm; pH ranged from 8.05 to 8.56 with a mean of 8.46; and D.O. ranged from 8.16 to 9.46 mg/L with a mean of 8.62 mg/L (n = 12 for alkalinity and total hardness, n = 55 for all other parameters). Exposures were conducted in environmental chambers set at a temperature of 20°C (glochidia tests), or in dilution water maintained at 20°C (juvenile tests). Survival of mussels in the negative control was > 90% in all exposures. The 24-hour EC_{50} reported by the study authors for glochidia of *L. recta* was 13.5 mg/L (C.I. 5.7-31.8).

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The 96-hour LC_{50} reported by the study authors for juvenile *L. recta* was 141.7 mg/L (C.I. 80.4-249.6). The 24-hour EC_{50} for *L. recta* glochidia represented an acute value acceptable for quantitative use. The juvenile life stage was less sensitive, such that its LC_{50} is not used quantitatively in the SMAV for the species. An independently-calculated toxicity value could not be calculated at this time given the lack of data presented in the paper. The study author reported values are currently used quantitatively to derive the freshwater acute water column criterion.

A.2.5.1 Hazelton et al. (2012) Concentration Response Curve – Ligumia (mussel)

Publication: Hazelton et al. (2012)
Species: Black sandshell, *Ligumia recta*
Genus: *Ligumia*
EPA-Calculated LC_{50}: Not calculable, concentration-response data not available

A.2.6 Sixth Most Sensitive Freshwater Genus for Acute Toxicity: *Neocaridina* (shrimp)

Li (2009) conducted three independent repeats of a 96-hour static test on PFOS (potassium salt, >98% purity) with the freshwater shrimp species, *Neocaridina denticulata* (a non-North American species). Test organisms were obtained from an unspecified local supplier and acclimated in the laboratory for at least seven days prior to the experiments. *N. denticulata* of unspecified age were used at test initiation. Dilution water was dechlorinated tap water. The photoperiod consisted of 12 hours of illumination at an unreported light intensity. A primary stock solution was prepared in dilution water. Exposure vessels were polypropylene beakers of unreported dimensions and 1 L fill volume. The test employed five replicates of six shrimp each in at least five test concentrations (the first repeated experiment had one additional PFOS treatment group at 10 mg/L compared to the other two experimental repeats) plus a negative control. Each treatment was tested three independent times. Nominal test concentrations were in the range of 5-200 mg/L PFOS. The test temperature was maintained at 25±2°C. Water quality parameters including pH, conductivity, and D.O. were reported as having been measured at the

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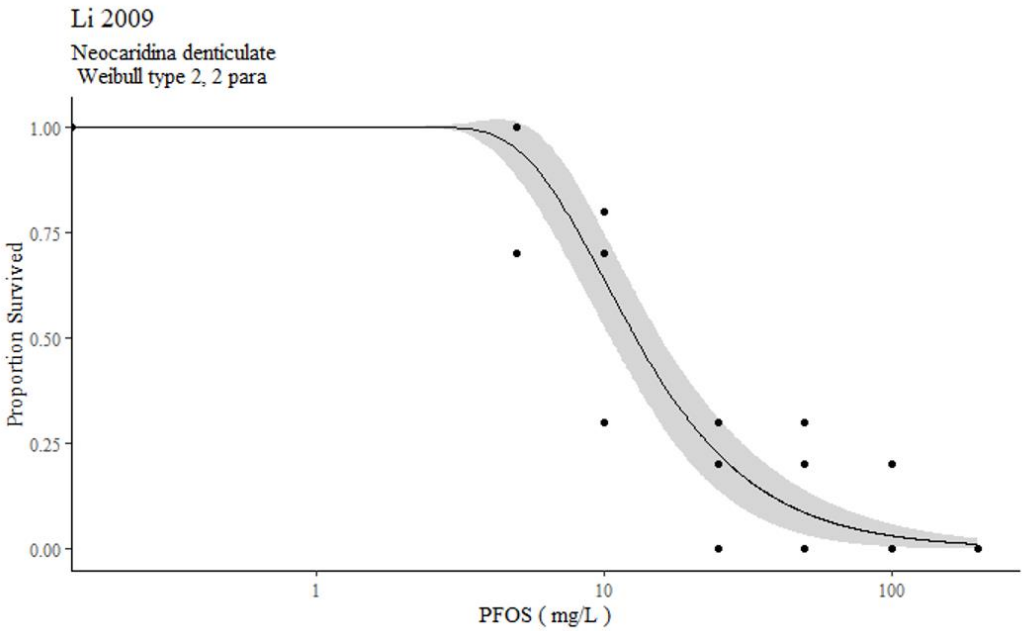
beginning and end of each test, but the information was not reported. Survival of negative control animals was 90%. The study reported 96-hour LC_{50} was 10 mg/L (C.I. 9-12). The toxicity test was acceptable for quantitative use. The independently-calculated LC_{50} values for the three independent experimental repeats were 12.91 (10.29 – 15.53), 28.55 (15.05 – 42.05), 10.32 (7.788 – 12.85) mg/L, respectively. These independently-calculated LC_{50} values were used to calculate the SMAV/GMAV value (as the geometric mean of the three LC_{50} values previously mentioned) of 15.61 mg/L and was used to derive the freshwater acute water column criterion.

A.2.6.1 Li (2009) Concentration Response Curve – Neocaridina (shrimp)

Publication: Li (2009)
Species: Japanese Swamp Shrimp, *Neocaridina denticulata*
Genus: *Neocaridina*
EPA-Calculated LC_{50}s: 12.91 (95% C.I. 10.29 – 15.53), 28.55 (95% C.I. 15.05 – 42.05), 10.32 (95% C.I. 7.788 – 12.85) mg/L
Concentration-Response Model Estimates:

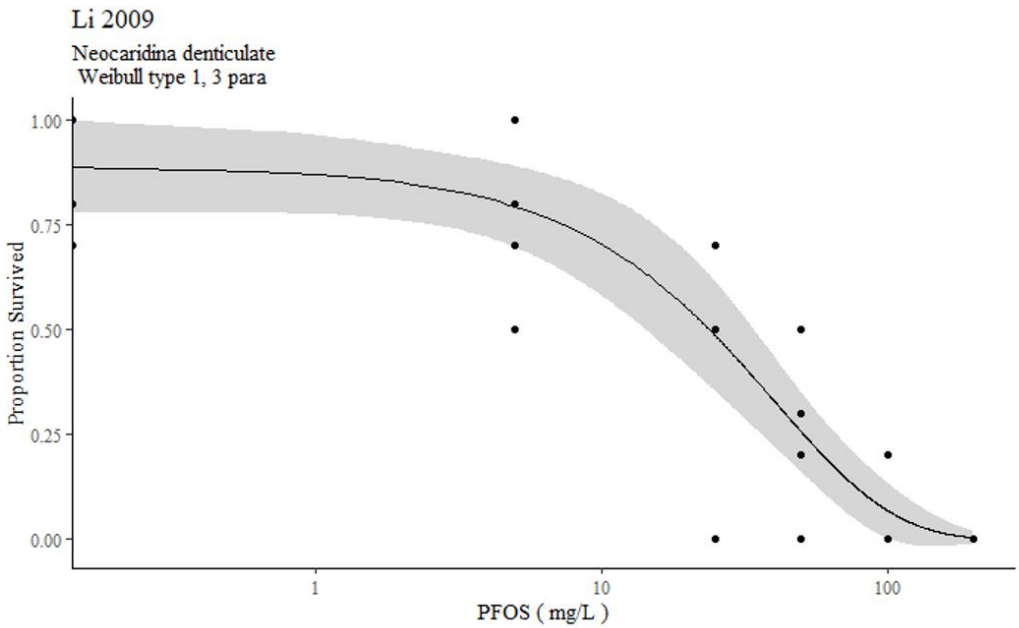
Parameter	Estimate	Std. Error	t-stat	p-value
b	-1.5141	0.1920	-7.8879	$3.091\ e^{-15}$
e	10.1360	1.0252	9.8865	$< 2.2\ e^{-16}$

Concentration-Response Model Fit: *In order of LC_{50}s listed immediately above*



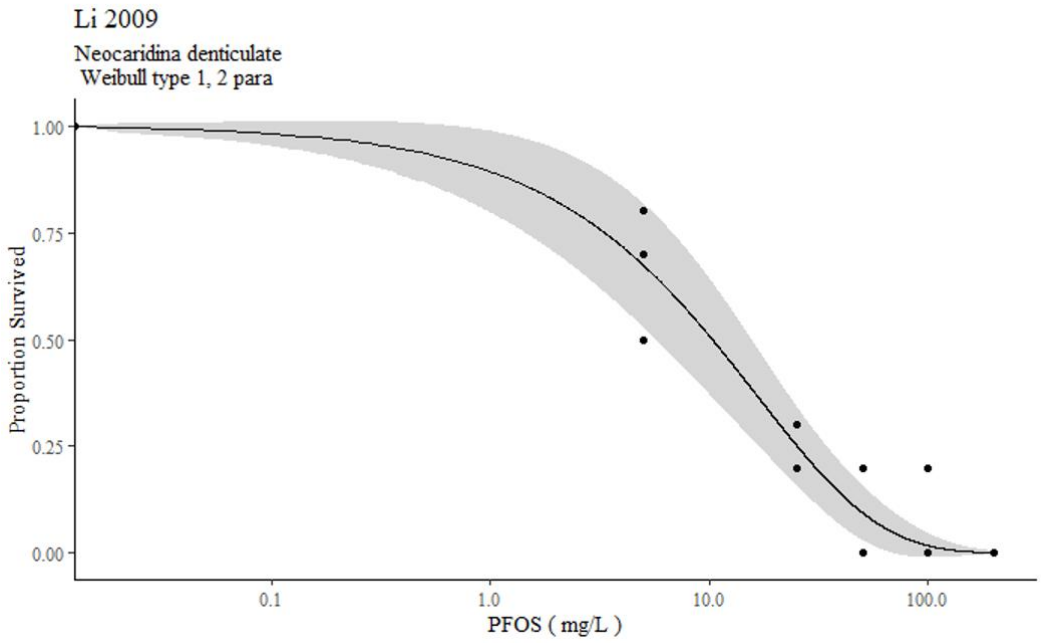
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	1.0404	0.2369	4.3919	$1.124\ e^{-5}$
d	0.8880	0.0571	15.5493	$< 2.2\ e^{-16}$
e	40.6105	7.5714	5.3637	$8.156\ e^{-8}$



Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	0.7749	0.1332	5.8195	5.903 e^{-9}
e	16.5563	3.3654	4.9196	8.672 e^{-7}



A.2.7 Seventh Most Sensitive Freshwater Genus for Acute Toxicity: *Xenopus* (frog)

Palmer and Krueger (2001), associated with Wildlife International, conducted three good laboratory practice (GLP) renewal definitive assays with the potassium salt of PFOS (86.9% purity) using the frog embryo teratogenesis assay - *Xenopus* (FETAX) with *Xenopus laevis.* A primary PFOS stock solution was prepared in FETAX solution at a concentration of 48 mg/L, and subsequently diluted with FETAX solution to prepare the six nominal test concentrations (1.82, 3.07, 5.19, 8.64, 14.4 and 24.0 mg PFOS/L). Eggs were obtained from breeding colonies of *X. laevis* at the University of Maryland Wye Research and Education Center. Adults were held in flow-through polyethylene aquaria with 10 cm of dechlorinated tap water (23.5±0.5°C) and a maximum of 10 adults/chamber and photoperiod of 16:8-hours light:dark. They were bred in the dark following injection of human chorionic gonadotropin to

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dorsal lymph sac of males and females. During each assay, *X. laevis* embryos (between NF stages 8-11) were exposed to PFOS for 96 hours. Two replicate test chambers were maintained in each treatment group and four replicates were maintained in each control group from the three separate assays. Each test chamber contained 25 embryos for a total of 50 embryos per treatment group and 100 embryos per control group. Tests were conducted at 24°C, pH of 7.26-7.30, estimated total hardness of 75 mg/L as $CaCO_3$, D.O. of 7.8-8.1 mg/L and a 12:12-hour light:dark photoperiod (60-85 foot candles). PFOS concentrations were measured at the initiation and termination of all three assays. The authors reported 96-hour LC_{50} values for mortality of 13.8, 17.6 and 15.3 mg/L PFOS, teratogenesis EC_{50}s of 12.1, 17.6 and 16.8 mg/L PFOS, and minimum concentration to inhibit growth values (effectively a LOEC) of >14.7, 7.97 and 8.26 mg/L for the same three tests, respectively. Independently-calculated 96-hour LC_{50} values for mortality were 15.53 (13.86 – 17.21), 18.04 (15.33 – 20.74), and 14.60 (12.65 – 16.55) mg/L for the three assays, respectively. No additional quantitative, acute toxicity data were available for this species. Therefore, these independently-calculated LC_{50} values were used to calculate the SMAV/GMAV value (as the geometric mean of the three LC_{50} values) of 15.99 mg/L that was used to derive the freshwater acute water column criterion.

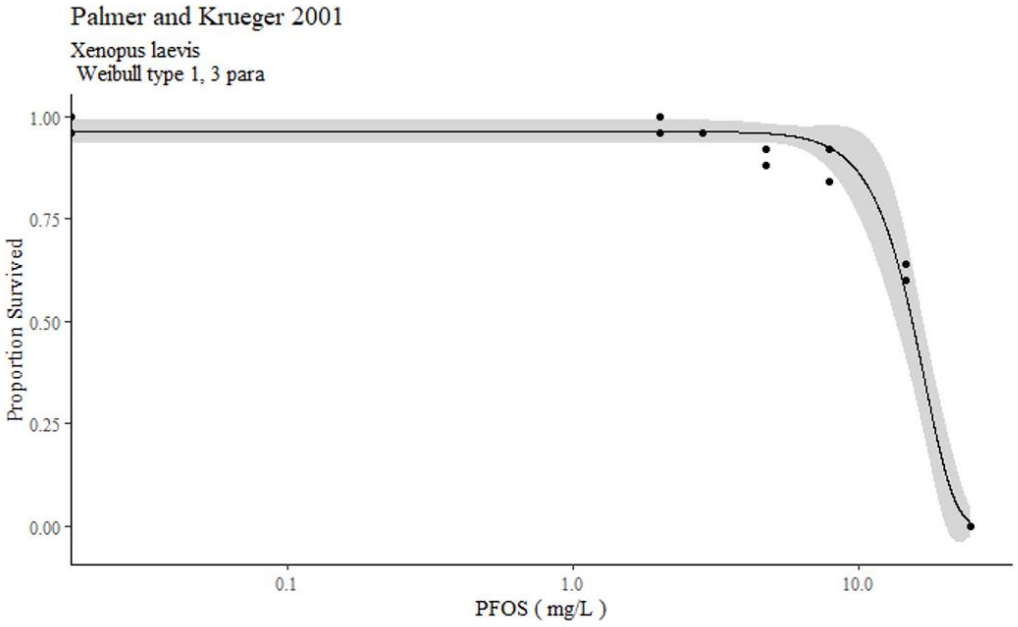
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A.2.7.1 Palmer and Krueger (2001) Concentration Response Curve – Xenopus (frog)

Publication: Palmer and Krueger (2001)
Species: Frog, *Xenopus laevis*
Genus: *Xenopus*
EPA-Calculated LC_{50}: 15.53 (95% C.I. 13.86 – 17.21), 18.04 (95% C.I. 15.33 – 20.74), 14.60 (95% C.I. 12.65 – 16.55) mg/L
Concentration-Response Model Estimates:

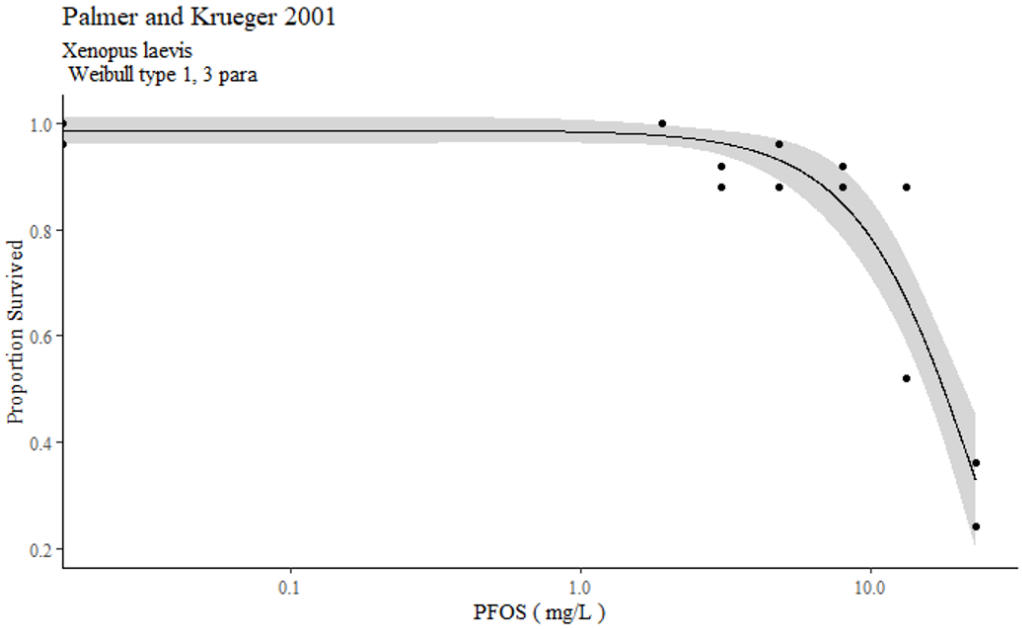
Parameter	Estimate	Std. Error	t-stat	p-value
b	4.1306	1.0464	3.9475	$7.897\ e^{-5}$
d	0.9633	0.0149	64.7242	$< 2.2\ e^{-16}$
e	16.9770	0.7991	21.2452	$< 2.2\ e^{-16}$

Concentration-Response Model Fit: *In order of LC_{50}s listed immediately above*



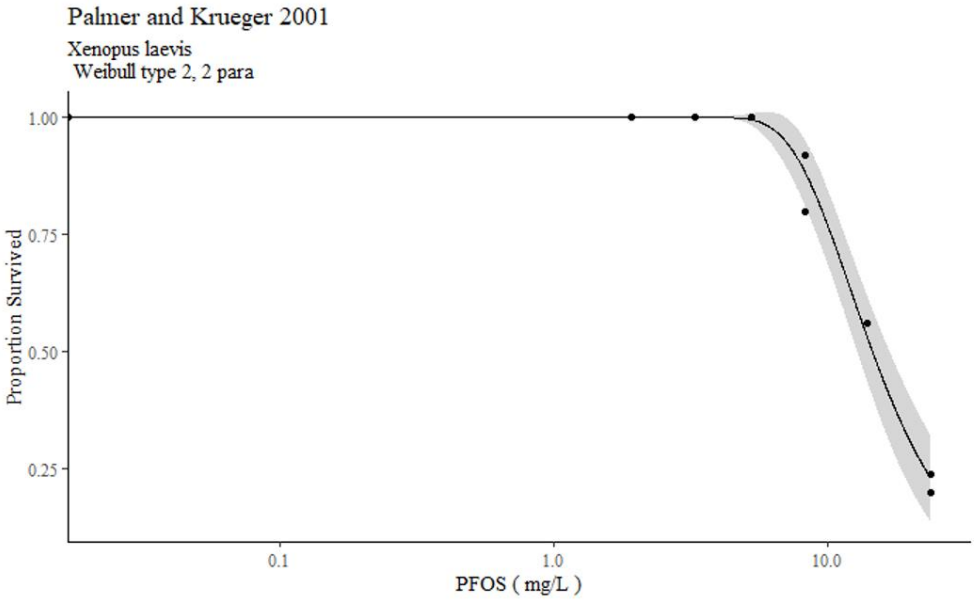
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	1.8800	0.3458	5.4366	$5.431\ e^{-8}$
d	0.9868	0.0127	77.7694	$< 2.2\ e^{-16}$
e	21.9190	1.9259	11.3812	$< 2.2\ e^{-16}$



Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	-1.9934	0.2667	-7.4757	$7.681\ e^{-14}$
e	12.1461	0.7197	16.8763	$< 2.2\ e^{-16}$



A.2.8 Eighth Most Sensitive Freshwater Genus for Acute Toxicity: *Lampsilis* (mussel)

Hazelton (2013); Hazelton et al. (2012) evaluated the acute effects of PFOS (acid form, > 98% purity) on two freshwater mussels, as noted above*: Lampsilis siliquoidea* and *Ligumia recta.* The *L. siliquoidea* studies yielded the 7th most sensitive genus value in the PFOS freshwater acute criterion dataset. Hazelton et al.'s experimental design and study conditions for *L. siliquoidea* were reported above under the description of the fourth most sensitive taxa, *Ligumia*. The 24-hour EC_{50} reported by the study authors for glochidia of *L. siliquoidea* was 16.5 mg/L (C.I. 8.0-33.9). The 96-hour LC_{50} reported by the study authors for juvenile *L. siliquoidea* was 158.1 mg/L (C.I. not calculable). The 24-hour EC_{50} for *L. siliquoidea* glochidia represented an acute value acceptable for quantitative use for the mussel species. Because the juvenile life stage was less sensitive, only the glochidia LC_{50} was used to calculate the SMAV. An

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independently-calculated toxicity value could not be calculated at this time given the data presented in the paper. The study author reported value was used quantitatively to derive the freshwater acute water column criterion.

A.2.9 Ninth most Sensitive Freshwater Genus for Acute Toxicity: *Hyla* (frog)

Tornabene et al. (2021) conducted acute toxicity tests with the gray treefrog, *Hyla versicolor*, and PFOS (purchased from Sigma Aldrich, Catalog # 77282-10G; purity not provided). The acute tests followed standard 96-hour acute toxicity test guidance (ASTM 2017; U.S. EPA 2002). The frog was collected from the field in the wetlands of Indiana near the campus of Purdue University. Collected egg masses were raised outdoors in 200 L polyethylene tanks filled with well water. Experiments began when frogs reached Gosner stage 26, defined as when larvae are free swimming and feeding. An additional acute test with Gosner stage (GS) 40 was run to determine if toxicity varied between life stages. Before test initiation larvae were acclimated to test conditions (21°C and 12:12-hour light:dark photoperiod) for 24 hours. A stock solution of PFOS (500 mg/L) was made in UV-filtered well water and diluted with well water to reach test concentrations (ranged from 0 - 500 mg/L PFOS). Test concentrations were not measured in test solutions, based on previous research that demonstrated limited degradation under similar conditions. Larva were transferred individually to 250 mL plastic cups with 200 mL of test solutions and were not fed during the exposure period. The number of replicates varied by life stage and treatment; 10 replicates for each treatment for GS 26 larva, and five to six replicates for each treatment for GS 40 frogs. No mortality occurred in the controls of the GS 26 test and two of the six frogs died in the controls of the GS 40 test. The author reported 96-hour LC_{50}s were 79 and 24 mg/L PFOS for GS 26 and 40, respectively. The independently-calculated 96-hr LC_{50} values were 78.33 and 19.88 mg/L and are acceptable for quantitative use.

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Given that GS 40 frogs appear to be a more sensitive life-stage the LC_{50} of 19.88 (13.80 – 25.95) mg/L was utilized in the derivation of the freshwater acute water column criterion.

A.2.10 Tenth Most Sensitive Freshwater Genus for Acute Toxicity: *Dugesia* (planarian)

Li (2008) conducted three independent repeats of a 96-hour static, unmeasured acute toxicity test on the potassium salt of PFOS (CAS # 2795-39-3, > 98% purity) with the planarian, *Dugesia japonica* (a non-North American species). The test organisms were originally collected from Nan-shi stream located in Wu-lai, Taipei County, Taiwan in 2004 and maintained in the laboratory in dechlorinated tap water. The planarians had a body length of 0.9 ±0.1 cm at test initiation. Dilution water was dechlorinated tap water. The photoperiod consisted of 12 hours of illumination at an unreported intensity. A primary stock solution was prepared in dilution water. Exposure vessels were polypropylene beakers of unreported dimensions and 50 mL fill volume. The test employed five replicates of five planarians each in at least five test concentrations plus a negative control. Nominal test concentrations were in the range of 10-200 mg/L PFOS. The test temperature was maintained at 25 ±1°C. No other water quality parameters were reported for test solutions. Survival of negative control animals was not reported. The author-reported 96-hour LC_{50} was 17 mg/L (C.I. 16-18). The toxicity value could not be independently calculated at this time given the level of data that was presented in the paper. The author-reported value was used quantitatively to derive the freshwater acute water column criterion.

Li (2009) conducted three independent repeats of a second 96-hour static, unmeasured acute test of PFOS (potassium salt, > 98% purity) with *Dugesia japonica.* The tested individuals were also originally collected from Nan-shi stream located in Wu-lai, Taipei County, Taiwan in 2004 and maintained in the laboratory in dechlorinated tap water. The planarians had a body length of 0.9±0.1 cm at test initiation. Dilution water was dechlorinated tap water. The photoperiod consisted of 12 hours of illumination at an unreported intensity. A primary stock

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solution was prepared in dilution water. Exposure vessels were polypropylene beakers of unreported dimensions and 50 mL fill volume. Each of the three independent repeats employed three replicates of 10 planarians each in at least five test concentrations plus a negative control. Nominal test concentrations were in the range of 5-200 mg/L PFOS. The test temperature was maintained at 25±1°C. Water quality parameters including pH, conductivity, and D.O. were reported as having been measured at the beginning and end of each test, but the information is not reported. Survival of negative control animals was also not reported. The author-reported 96-hour LC_{50} was 23 mg/L (C.I. 20-25). An independently-calculated LC_{50} could not be estimated for the first and second independent tests (as EPA was unable to fit a model with significant parameters), but was estimated for the third independent test as 22.68 (18.27 – 27.10) mg/L. This acute value was acceptable for quantitative use and was used to derive the freshwater acute water column criterion.

Yuan et al. (2014) also conducted a 96-hour unmeasured acute test on PFOS (potassium salt, > 99% purity) with *Dugesia japonica*, under daily renewal conditions. *D. japonica* used for testing were originally collected from a fountain in Quan HetouBoshan, China, and cultivated in the laboratory for an unspecified time period before use. The planarians had a body length of 10-12 mm at test initiation. Dilution water was aerated tap water. No details were provided regarding photoperiod or light intensity. A primary stock solution was prepared by dissolving the salt in DMSO. The control and exposed planarians received 0.005% DMSO (v/v). Exposure vessels were beakers of unreported material type and dimensions with 50 mL fill volume. The test employed three replicates of 10 planarians each in six test concentrations plus a solvent control. Nominal test concentrations were 0 (solvent control), 10, 30, 35, 37.5, 40 and 45 mg/L PFOS. The test temperature was reported as 20°C. No other water quality parameters were

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reported. Survival of solvent control animals was not reported. The author-reported 96-hour LC_{50} was 29.46 mg/L (C.I. 25.80 - 33.12). An independently-calculated toxicity value could not be calculated at this time given the level of data that was presented in the paper. The author-reported value was used quantitatively to derive the freshwater acute water column criterion.

The noted toxicity values provided in each study summary above (17.00, 22.68, and 29.46 mg/L), comprising of both author-reported and independently-calculated LC_{50} values, were used to calculate the SMAV/GMAV value (as the geometric mean of the three LC_{50} values previously mentioned) of 22.48 mg/L, which was used to derive the freshwater acute aquatic life criterion.

A.2.11 Eleventh Most Sensitive Freshwater Genus for Acute Toxicity: *Danio* (zebrafish)

Ye et al. (2007) evaluated the acute effects of perfluorooctanesulfonic acid (PFOS, purity not reported) to *Danio rerio* via a 96-hour static-renewal unmeasured exposure. The PFOS stock solution of 480 mg/L was maintained at a pH of 8.2 with phosphate buffer and test substances were agitated in the reconstituted water by ultrasonification. The solutions were stored at 4 ± 1°C. Each test solution, at the selected concentration, was prepared by diluting the stock solution with reconstituted water. No added solvents were used. The fish (AB strain) used in this experiment were obtained from the School of Life Sciences at Fandan University, Shanghai, China. Breeding fish (1.5 years old) were fed live brine shrimp twice daily and kept with a 14:10-hour light:dark period in aquaria containing aerated natural water. The pH ranged from 7 to 8.5 and water temperature was maintained at 26 ± 1°C. Embryos were obtained from spawning adults, usually 5 male and 3 female. For each toxicant concentration, 48 embryos were randomly distributed into each well of 24-well polystyrene multi-well plates, with four eggs per well. Each well was filled with 2.5 mL test solution which were completely renewed daily by transferring embryos into newly cleaned wells. Nominal exposure concentrations were 0

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(control), 10, 85, 100, 110, 160, 200 and 240 mg/L PFOS. The multi-well plates were kept at 26 ± 1°C, with a photoperiod of 16:8-hour light:dark. The observations of embryos were made at distinct stages, which represent important steps of zebrafish development. The author-reported 96-hour LC_{50} was 71 mg/L PFOS. The EPA was unable to independently calculate a 96-hour LC_{50} value based on the level of data provided by the study authors in the paper. Therefore, the author-reported LC_{50} value was used quantitatively to derive the freshwater acute water column criterion.

Hagenaars et al. (2011b) exposed *D. rerio* embryos to the potassium salt of PFOS (CAS # 2795-39-3, purity ≥97%) under static unmeasured conditions for 96 hours. The PFOS was dissolved in medium-hard reconstituted laboratory water, which was aerated and kept at 26°C until use (no solvent). Adult wild-type zebrafish (breeding stock) were obtained from a commercial supplier (Aqua hobby, Heist-op-den-berg, Belgium) and kept in aerated and biologically filtered medium-hard reconstituted freshwater. Four males and four females were used for egg production. Fertilized eggs were collected in egg traps within 30 minutes of spawning. Eggs were transferred to the test solutions (nominal PFOS concentrations of 0.1, 0.5, 1, 5, 10 mg/L in the definitive ELS test and 1, 5, 10, 25, 50 and 100 mg/L in the 96-hour range-finding test) within 60 minutes after spawning. Eggs with anomalies or damaged membranes were discarded and fertilized eggs were separated from the non-fertilized eggs using a stereomicroscope. Twenty normally shaped fertilized eggs per exposure concentration were divided over a 24-well plastic plate and each egg was placed individually in 2 mL of the test solution. The remaining four wells were filled with clean water and used for the control eggs. Two replicate plates were used for each exposure concentration resulting in 40 embryos per treatment at the beginning of the experiment. The 24-well plates were covered with a self-

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adhesive foil, placed in an incubation chamber at 26 ± 0.3°C and subjected to a 14:10-hour light:dark cycle. A test was considered valid if more than 90% of the controls successfully hatched and showed neither sublethal nor lethal effects. The authors reported a 96-hour LC_{50} of 58.47 mg/L PFOS, based on the results of the range-finding test. The author-reported value was used quantitatively to derive the freshwater acute water column criterion.

Sharpe et al. (2010) examined the toxicity of PFOS-K (potassium salt, CAS # 2795-39-3, 98% purity) and bioaccumulation of PFOS and its isomers on *Danio rerio* through three different tests, a 96-hour renewal toxicity test on adults, a 48-hour renewal toxicity test on embryos, and a chronic exposure test that evaluated maternal transfer and fecundity of PFOS isomers. The 96-hour test is described in this appendix, as these results were used quantitatively to derive the freshwater acute water column criterion. The 48-hour and chronic toxicity tests were used qualitatively (Appendix G). The authors provided little detail about the test protocol, other than following OECD Guideline 203. Adult zebrafish were obtained from a local pet store. They were acclimated and held in 70 L glass aquaria in an environmental chamber set to 26°C under a 14:10-hour light:dark photoperiod for six to 10 months prior to use in experiments. Conditioned zebrafish water (ZF water) was obtained from the Biological Sciences Zebrafish Facility at the University of Alberta, where an automated reverse osmosis system regulated both the salinity and hardness (160 mg/L total hardness and 20 mg/L calcium carbonate hardness) of the water. A stock solution of 25 mg/ml PFOS in MeOH was used for dosing in all experiments. All vehicle controls received a volume of MeOH equal to that present in the highest PFOS treatment of that experiment (final MeOH content 0.65% v/v). The concentration of PFOS in any experiment was always well below its reported solubility in water (approximately 500 mg/L). Zebrafish toxicity tests were performed using food grade 2 L plastic tanks with four fish per

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tank, and two tanks per concentration. Fish were randomly assigned to nominal concentrations defined as control (0 mg/L PFOS); vehicle control (0 mg/L PFOS, 0.4% MeOH v/v); and 6.25, 12.5, 2, 50 and 100 mg/L PFOS. Authors indicated that measured PFOS concentrations averaged 88% of nominal but did not indicate whether the LC_{50} was measured or nominal. The adult 96-hour acute test followed OECD 203 protocol and was acceptable for quantitative use. The author-reported LC_{50} was 22.2 ± 4.6 mg/L for PFOS. The author-reported value was used quantitatively to derive the freshwater acute water column criterion.

Evaluated the acute effects of perfluorooctane sulfonate, potassium salt (PFOS-K, CAS# 2795-39-3 purchased from Wellington Laboratories Inc., Ontario, Canada) on zebrafish (*Danio rerio*) during a 96-hour unmeasured, static-renewal study. Zebrafish were purchased from a local market at approximately three months in age and 2.2 cm in length. Fish were allowed to acclimate for seven days and were fed three times per week until 24 hours before the test was started. Water used for the testing was aerated for 48 hours before testing began, and testing followed OECD Guideline 203. Observed exposure water characteristics were total hardness of 180-220 mg/L as $CaCO_3$, temperature of 23 ± 1ºC, D.O. of 7.0 – 8.6 mg/L and a photoperiod of 12:12-hours light:dark. Each 2-L beaker was filled with 1,500 mL of test solution at nominal concentrations of 0 (control), 2.87, 5, 8.7, 15.14, 26.34, 45.83 and 79.74 mg/L PFOS. There were three replicates per concentration, and seven fish per beaker. Test solutions were renewed at 48 hours. The author-reported 96-hour LC_{50} was 17.0 mg/L PFOS based on a sigmoidal three-parameter regression. The EPA was unable to independently calculate a 96-hour LC_{50} value based on the level data provided in the paper. Therefore, the author-reported LC_{50} value of 17.0 mg/L PFOS was used quantitatively to derive the freshwater acute water column criterion.

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Li et al. (2015) evaluated the acute effects of PFOS (CAS # 2795-39-3, 98% purity) to *Danio rerio* via a 96-hour static unmeasured exposure. Solutions for waterborne exposure were formulated with medium used to rear embryos (reconstituted laboratory water). Adult, wild-type zebrafish were obtained from the Institute of Hydrobiology, at the Chinese Academy of Sciences (Wuhan, China), and kept in treated tap water at 26 – 29°C. Fish were reared with a female/male ratio of 1:2 under 14:10-hour light:dark photoperiod, with 1/3 of the water exchanged daily. Spawning and fertilization took place within 30 minutes after the lights were turned on in the morning, with fertilized embryos collected and cleaned with embryo rearing water. Immediately after fertilization, embryos were examined, and damaged or unfertilized embryos were discarded. Zebrafish embryos were exposed in 24-well cell culture plates (assume plastic) to a series of PFOS concentrations (6.25, 12.5, 25.0, 50.0, 100.0 and 200.0 mg/L). Twenty, normally shaped, fertilized embryos were assigned to each treatment (three replicates) and 2 mL of test solution per well; the four remaining wells were assigned with control embryos. Embryos were exposed in an incubator at 28.5°C, pH of 8.3 and a 14:10-hour light:dark photoperiod. Toxicological endpoints included whether embryos were clear or opaque, exhibited edema at 4, 8, 24, 48, 72, or 96 hpf, or developed structural malformations at 72 or 96 hpf until hatching. Coagulated embryos before hatching are opaque, milky white, and appear dark under the microscope. Coagulation of embryos was recorded and used for the calculation of an LC_{50} value. The author reported 96-hour LC_{50} was 68.0 mg/L PFOS. The independently-calculated LC_{50} value was 71.12 (56.82 – 85.42) mg/L PFOS. This toxicity value is acceptable for quantitative use and was used to derive the freshwater acute water column criterion.

Du et al. (2017); Du et al. (2016b) exposed *Danio rerio* to heptadecafluorooctanesulfonic acid (PFOS, potassium salt, CAS# 2795-39-3, 98% purity) using

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static unmeasured procedures. Although the study focused on the protective effects of zinc nanoparticles (ZnO-NPs) on PFOS toxicity (development and damage to DNA), data were also reported for PFOS-only exposures. Adult AB strain zebrafish were purchased from State Key Laboratory of Freshwater Ecology and Biotechnology, Chinese Academy of Sciences (Wuhan, China). Fish were maintained and tested at 28°C under a 14:10-hour light:dark cycle. Male and female fish were paired in spawning boxes overnight in rearing water and spawning was completed at the beginning of the light cycle. Eggs were collected from the spawn traps and transferred to clean rearing water prior to testing. The embryos were exposed to PFOS (1, 2, 4, 8 and 16 mg/L in a preliminary test to determine the LC_{50}, and at 0.4, 0.8 and 1.6 mg/L in a later test with ZnO-NPs solutions to evaluate mortality (at 96 hours), body length (at 96 hours), hatch rate (at 72 hours), heart rate (at 48 hours), and malformation rate (at 96 hours). Embryos were kept in 24-well multi-plates at two embryos/well, in which 20 wells contained 2 mL reconstituted water test solution and four wells contained 2 mL of culture medium as the control. Each plate contained 40 embryos for exposure testing and eight embryos as internal water controls. For each concentration and water control, three 24-well plates (replicates) were included. The study authors reported a 96-hour LC_{50} of 3.502 mg/L for PFOS. The EPA was unable to independently calculate a 96-hour LC_{50} value based on the level data provided in the paper. Therefore, the author-reported LC_{50} value of 3.502 mg/L PFOS was used quantitatively to derive the freshwater acute water column criterion.

Stengel et al. (2017b) exposed 1 hpf *Danio rerio* embryos to PFOS for 96 hours using renewal unmeasured procedures as specified in (OECD 2013) guidelines. PFOS stock and exposure solutions were prepared in reconstituted laboratory water. All adult zebrafish used for breeding were wild-type descendants of the “Westaquarium” strain and obtained from the

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Aquatic Ecology and Toxicology breeding facilities at the University of Heidelberg. Details of zebrafish maintenance, egg production and embryo rearing were as described previously (Kimmel et al. 1995; Kimmel et al. 1988; Nagel 2002; Spence et al. 2006; Wixon 2000) but included updates for the purpose of the zebrafish embryo toxicity test by Lammer et al. (2009). Embryos no older than 1 hpf were exposed in glass vessels, which had been preincubated (saturated) for at least 24 hours, to a series of PFOS dilutions (0, 3.125, 6.25, 12.5, 25, 50 mg/L). After confirmation of fertilization success, embryos were individually transferred to the wells of 24-well plates, which had been pre-incubated with 2 mL of the test solutions per well for 24 hours prior to the test start and kept in an incubator at 26.0 ±1.0°C under a 14:10-hour light:dark regime. In order to prevent evaporation or cross-contamination between the wells, the plates were sealed with self-adhesive foil. Embryo tests were classified as valid if the mortality in the negative control was ≤ 10%, and if the positive control (3,4-dichloroaniline) showed mortalities between 20 and 80%. All fish embryo tests were run in three independent replicates. Both lethal and sublethal effects were used for the determination of EC values. The author-reported 96-hour LC_{50} and EC_{50} (combination of lethal and sublethal effects) values were 34.2 and 21.4 mg/L PFOS, respectively. The independently-calculated LC_{50} was 38.82 (36.67 – 40.98) mg/L PFOS. The independently-calculated LC_{50} was considered quantitative and used to derive the freshwater acute water column criterion.

Nilén et al. (2022) evaluated the acute effects of perfluorooctanesulfonate, potassium salt (PFOS-K, CAS No. 2795-39-3, ≥ 98% purity, purchased from Sigma-Aldrich, Stockholm, Sweden) on zebrafish (*Danio rerio*) during a 96-hour measured, static-renewal test. PFOS stock solutions (464 mM) were prepared in DMSO. Adult zebrafish (AB strain) were purchased from Karolinska Institute (Stockholm, Sweden). Fish were kept at a 14:10-hour light:dark cycle in a

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recirculating system. Fish embryo toxicity tests were performed following the OECD Technical Guideline No. 236 (OECD 2013). Prior to testing, 96-well plates were pre-incubated for 24 hours with the chemical solutions to limit sorption to the well plates. On the day of exposure, five different exposure concentrations were prepared in glass beakers through a serial dilution (1:2) using ISO water. The DMSO content was adjusted to 0.09% (v/v) in all solutions and all tests included three control groups: negative control (ISO-water), solvent control (0.09 % DMSO in ISO-water) and positive control (4 mg/L DCA). Test concentrations were selected based on previous studies about lethality and sub-lethality. One embryo (64-cell stage) with 250 µL of test solution was added to each well on a 96-well plate. For each concentration, 24 embryos were used, and each test contained a total of 192 embryos. The plates were covered with self-adhesive film and incubated at 26 ± 1°C in a 14:10-hour light:dark cycle. An experiment was considered valid by the study authors if the mortality in the negative control and the solvent control was less than 10%. In addition, the mortality of the positive control had to be ≥ 30%. Each experiment was repeated three to five times representing independent replicates and the embryos were exposed for 96 hpf. The exposure solutions were sampled before the start and at the end of the exposure period. Nominal exposure concentrations were 0 (control), 0 (solvent control), 7, 14, 28, 56 and 111.5 µM PFOS-K. Equivalent PFOS concentrations were 3.768, 7.535, 15.07, 30.14 and 60.01 mg/L PFOS-K, respectively, based on a molecular weight of 538.22 g/mol PFOS-K. Measured concentrations were between 1.3 and 23% of nominal at 96 hours. The author-reported 96-hour LC_{50} was 44.57 µM PFOS-K, or 23.99 mg/L PFOS-K (based on a molecular weight of 538.22 g/mol; 44.57 x 538.22 ÷ 1,000). The EPA was unable to independently calculate a 96-hour LC_{50} value based on the level of data provided in the paper by the study authors. Therefore,

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the author-reported LC_{50} value of 23.99 mg/L PFOS was used quantitatively to derive the freshwater acute water column criterion.

A.2.12 Twelfth Most Sensitive Freshwater Genus for Acute Toxicity: *Daphnia* (cladoceran)

Logeshwaran et al. (2021) conducted acute and chronic toxicity tests with the cladoceran, *Daphnia carinata*, and PFOS-K (perfluorooctanesulfonate potassium salt, ≥ 98% purity, purchased from Sigma-Aldrich Australia). In-house cultures of daphnids were maintained in 2 L glass bottles with 30% natural spring water in deionized water, 21℃ and a 16:8-hour light:dark photoperiod. The acute test protocol followed OECD (2000) with slight modifications. A PFOS stock solution (20 mg/mL) was prepared in dimethylformamide and diluted with deionized water to achieve a concentration of 200 mg/L PFOS. Cladoceran culture medium was used to prepare the PFOS stock and test solutions. Ten daphnids (6-12 hours old) were transferred to polypropylene containers containing one of 14 nominal test concentrations (0, 0.5, 1, 2.5, 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 mg/L PFOS). Each test treatment was replicated three times and held under the same conditions as culturing. At test termination (48 hours) immobility was determined after 15 seconds of gentle stirring. No mortality occurred in the controls. The author-reported 48-hour EC_{50} was 8.8 mg/L PFOS. The independently-calculated 48-hour EC_{50} value was 11.56 (10.06 – 13.07) mg/L and is acceptable for quantitative use in the derivation of the freshwater acute water column criterion.

Drottar and Krueger (2000g) reported the results of a 48-hour static, measured acute toxicity test on PFOS (potassium salt, CAS # 2795-39-3, 90.49% purity) with *Daphnia magna*. The GLP test was conducted at Wildlife International, Ltd. In Easton, MD in February, 1999. The test followed OECD (2004); (U.S. EPA 1996d). The test organisms were less than 24 hours old at test initiation. Dilution water was 0.45 µm filtered well water [hardness: 132 (128-136) mg/L as $CaCO_3$; alkalinity: 178 (176-178) mg/L as $CaCO_3$; pH: 8.3 (8.2-8.3); TOC: < 1.0 mg/L;

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conductivity: 313 (310-315) µmhos/cm]. Photoperiod was 16:8-hours light:dark with a 30 minute transition period. Light was provided at an intensity of approximately 359 lux. A primary stock solution was prepared in dilution water at 91 mg/L. It was mixed for ~19.5 hours prior to use. After mixing, the primary stock was proportionally diluted with dilution water to prepare the four additional test concentrations. Exposure vessels were 250 mL plastic beakers containing 240 mL of test solution. The test employed two replicates of 10 daphnids each in five measured test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 12, 20, 33, 55, 91 mg/L. Mean measured concentrations were <LOQ (4.58 mg/L), 11, 20, 33, 56 and 91 mg/L. Analyses of test solutions were performed at Wildlife International Ltd. Using HPLC/MS. The mean percent recovery of matrix fortifications analyzed concurrently during sample analysis was 96.2%. Samples collected at test initiation had measured values from 85.5 to 112% of nominal. Measured values for samples taken at 24 hours ranged from 92.2 to 115% of nominal, and at 48 hours from 91.6 to 106% of nominal. Dissolved oxygen in control and highest test concentration (91 mg/L) ranged from 8.6-8.9 mg/L and 8.6-9.1 mg/L; pH ranged from 8.2-8.5 and 8.5-8.6, respectively. Test temperature ranged from 19.5-20.2°C and 19.3-20.1°C, respectively. At 24 hours, daphnids in the negative control, and the 11, 20 and 33 mg/L treatments appeared healthy and normal with no mortality, immobility, or overt clinical signs of toxicity. However, five percent mortality was observed at 48 hours in the negative control. The author-reported 48-hour EC_{50} was 61 mg/L (C.I. 33-91). The independently-calculated toxicity value was 58.51 (53.59 – 63.43) mg/L and was used quantitatively to derive the freshwater acute water column criterion.

Boudreau (2002); Boudreau et al. (2003a) performed a 48-hour static test on PFOS (potassium salt, CAS # 2795-39-3, 95% purity) with *Daphnia magna* and *Daphnia pulicaria* as

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part of a Master's thesis at the University of Guelph, Ontario, Canada. The results were subsequently published in the open literature (Boudreau et al. 2003a). The test followed ASTM (1999a). Daphnids used for testing were less than 24 hours old at test initiation. *D. magna* were obtained from a brood stock (Dm99- 23) at ESG International (Guelph, ON, Canada). *D. pulicaria* were acquired from a brood stock maintained in the Department of Zoology at the University of Guelph. Dilution water was clean well water obtained from ESG International. Hardness was softened by addition of distilled deionized water to achieve a range of 200-225 mg/L of $CaCO_3$. Photoperiod was 16:8-hours light:dark under cool-white fluorescent light between 380 and 480 lux. Laboratory-grade distilled water was used for all solutions with maximum concentrations derived from stock solutions no greater than 450 mg/L. Test vessels consisted of 225 mL polypropylene disposable containers filled with 150 mL of test solution. All toxicity testing involved four replicates of 10 daphnids each in five nominal test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 31, 63, 125, 250 and 450 mg/L. Experiments were conducted in environmental chambers at a test temperature of 21 ±1°C. Authors note temperature and pH were measured at beginning and end of study, but the information was not reported. Survival of daphnids in the negative control was also not reported, although ASTM E729-96 requires at least 90% survival for test acceptability. The author-reported 48-hour EC_{50} for *D. magna* was 67.2 mg/L (C.I. 31.3-88.5). The author-reported 48-hour EC_{50} for *D. pulicaria* was 134 mg/L (C.I. 103-175). Independently-calculated toxicity values could not be calculated given the level of data that was presented in the paper. The study author reported values were used quantitatively to derive the freshwater acute water column criterion.

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Ji et al. (2008) performed a 48-hour static, unmeasured acute test of PFOS (acid form, CAS # 1763-23-1, purity unreported) with *Daphnia magna*. The test followed the EPA's Methods for measuring the acute toxicity of effluents and receiving waters to freshwater and marine organisms (U.S. EPA 2002). *D. magna* used for testing were obtained from brood stock cultured at the Environmental Toxicology Laboratory at Seoul National University (South Korea). Test organisms were less than 24 hours old at test initiation. Dilution water was moderately hard reconstituted water (hardness typically 80-100 mg/L as $CaCO_3$). Experiments were conducted in glass jars of unspecified size and fill volume. Photoperiod was assumed by the reviewers to have been 16:8-hours light:dark. Preparation of test solutions was not described. The test involved four replicates of five daphnids each in five nominal test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 6.25, 12.5, 25, 50 and 100 mg/L. Test temperature was maintained at 21 ± 1°C. Authors note water quality parameters (pH, temperature, conductivity, and D.O.) were measured 48 hours after exposure, but the information is not reported. Survival of daphnids in the negative control was not reported in the paper. However, raw data were obtained by the EPA from the study authors and control survival was 100% and therefore meets the EPA/600/4-90/027F requirement of at least 90% survival for test acceptability. The author-reported 48-hour EC_{50} value for the study was 37.36 mg/L (C.I. 30.72-43.99) for *D. magna*. The 48-hour EC_{50} value was independently-calculated as 35.46 (28.26 – 42.66) mg/L. The independently-calculated acute toxicity value was included in the derivation of the freshwater acute water column criterion.

Li (2009) conducted three independent repeats of a 48-hour static acute test on PFOS (potassium salt, > 98% purity) with *Daphnia magna*. The test followed OECD (1984). *D. magna* used for the test were less than 24 hours old at test initiation. Dilution water was dechlorinated

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tap water. The photoperiod consisted of 12 hours of illumination at an unreported light intensity. A primary stock solution was prepared in dilution water and did not exceed 400 mg/L. Exposure vessels were polypropylene of unreported dimensions and 50 mL fill volume. The test employed five replicates of six daphnids each in at least five test concentrations plus a negative control. Each treatment was tested three independent times. Based on water solubility of test chemicals and preliminary toxicity results, nominal test concentrations were in the range of 10 - 400 mg/L for PFOS. Water quality parameters including water pH, conductivity and D.O. were measured at the beginning and at the end of each test. Initial values of pH were 7.82±0.12 and 7.91±0.03 after 48 hours. At the start of the bioassays, D.O. and specific conductivity were 67.7±6.8% and 101.8±6.8 µS/cm. After the 48-hour testing period, D.O. and specific conductivity were 55.6±1.26% and 109.1±3.5 µS/cm. The D.O. after 48-hours of testing was lower than the test guideline recommendation of >60% (ASTM 2002; U.S. EPA 2016a; U.S. EPA 2016b); however, it was not low enough to change the use of the study. The test was conducted in a temperature incubator at 25 ±2°C. None of the control animals became immobile at the end of the test. The author-reported 48-hour EC_{50} was 63 mg/L (C.I. 58-69) which was an average LC_{50} of the three tests. The independently-calculated LC_{50} values for the three independent experimental repeats were 55.40 (45.97), 72.70 (61.63 – 83.77) and 64.60 (49.53 – 79.66) mg/L, respectively. The three independently-calculated LC_{50} values were used to calculate the SMAV for *D. magna* and derive the freshwater acute water column criterion.

Yang et al. (2014) conducted a 48-hour static acute test of PFOS (potassium salt, CAS # 2795-39-3, 99% purity) with *Daphnia magna,* following ASTM (1993). *D. magna* used for the test were donated by the Chinese Research Academy of Environmental Sciences. The daphnids were less than 24 hours old at test initiation. Dilution water was dechlorinated tap water (pH,

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7.0±0.5; D.O., 7.0±0.5 mg/L; total organic carbon, 0.02 mg/L; and hardness, 190.0±0.1 mg/L as $CaCO_3$). Photoperiod was 12:12-hours light:dark at an unreported light intensity. A primary stock solution was prepared by dissolving PFOS in deionized water and cosolvent DMSO. The primary stock was proportionally diluted (0.56x) with dilution water to prepare the test concentrations. Exposure vessels were 200 mL beakers of unreported material type containing 200 mL of test solution. The test employed three replicates of 10 daphnids each in six test concentrations (measured in low and high treatments) plus a negative and solvent control. Nominal concentrations were 0 (negative and solvent controls), 20.00, 36.00, 64.80, 116.64, 209.95 and 377.91 mg/L. Mean measured concentrations before and after renewal were respectively 18.43 and 19.80 and mg/L (lowest concentration) and 341.74 and 372.35 mg/L (highest concentration). Analyses of test solutions were performed using HPLC/MS and negative electrospray ionization. The concentration of PFOS was calculated from standard curves (linear in the concentration range of 1-800 ng/mL), and the average extraction efficiency was in the range of 70-83%. The concentrations and chromatographic peak areas exhibited a significant positive correlation ($r = 0.9987$, $p < 0.01$), and the water sample-spiked recovery was 105%. The temperature, D.O., and pH were reported has having been measured every day during the acute test, but results are not reported. Negative control survival was > 96%. Solvent control survival was 100%. The author reported 48-hour LC_{50} was 78.09 mg/L (C.I. 54.38-112.13) and was used quantitatively to derive the freshwater acute water column criterion.

Lu et al. (2015) conducted a 48-hour static test on PFOS (purity 98%) with *Daphnia magna*, following OECD (2004). *D. magna* used for the test were originally obtained from the Chinese Center for Disease Control and Prevention (Beijing, China) and cultured in the laboratory according to the International Organization for Standardization (ISO 1996). Daphnids

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were less than 24 hours old at test initiation. Dilution water was the same used for daphnid culture and was reconstituted according to OECD (2004) with a hardness of 250 mg/L as $CaCO_3$, as calculated based on the recipe provided, and pH ranging from 7.7 to 8.4. Photoperiod was 16:8-hours light:dark at an unreported light intensity. The test solution was prepared immediately prior to use by diluting the stock solution with a daphnia culture medium. Exposure vessels were 100 mL glass beakers containing 45 mL of test solution. The test employed three replicates of 10 daphnids each in six nominal test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 1, 3, 10, 30, 100 and 300 mg/L. Exposure water quality was checked daily and maintained at a temperature of 20 ± 1°C, pH of 7.2 ± 0.3, and D.O. of 6.5 ± 0.5 mg/L. One hundred percent survival was observed at 48 hours in the negative control. The author-reported 48-hour EC_{50} was 23.41 mg/L (LC_{50} = 49.27) and used quantitatively to derive the freshwater acute water column criterion.

Liang et al. (2017) conducted a 48-hour static test on PFOS (potassium salt, CAS # 2795-39-3, ≥ 98% purity) with *Daphnia magna*. The test followed OECD (2004). *D. magna* used for the test were originally obtained from State Key Laboratory of Environmental Aquatic Chemistry (Eco-Environmental Sciences of Chinese Academy of Sciences, Beijing) and cultured in the laboratory according to Revel et al. (2015). Daphnids were less than 24 hours old at test initiation. Dilution water was artificial medium (M4) at 20°C and pH 7 (Revel et al. 2015). Photoperiod was 16:8-hours light:dark at an unreported light intensity. The test solution was prepared immediately prior to use by diluting the stock solution with M4 medium. Exposure vessels were 80 mL beakers of unreported material type containing an unspecified volume of test solution. The test employed five replicates of five daphnids each in six nominal test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 30, 44,

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66, 100 and 150 mg/L. No mention was made of water quality being checked during the exposure. 100% survival was observed at 48 hours in the negative control. The author reported 48-hour EC_{50} was 79.35 mg/L. The independently-calculated toxicity value was 94.58 (94.20 – 94.96) mg/L and was used quantitatively to derive the freshwater acute water column criterion.

Yang et al. (2019) evaluated the acute effects of perfluorooctane sulfonate, potassium salt (PFOS-K, CAS# 2795-39-3, 98% purity, purchased from Sigma-Aldrich in St. Louis, MO) on *Daphnia magna* via a 48-hour unmeasured, static mortality test. *D. magna* cultures were obtained from the Institute of Hydrobiology of Chinese Academy of Science in Wuhan, China. Organisms were cultured in Daphnia Culture Medium according to the parameters laid out in OECD Guideline 202, and all testing followed the guideline. Cultures were fed green algae daily and were acclimated for two to three weeks before testing. Acute test concentrations included 0 (control), 0.0000156, 0.0000234, 0.0000349, 0.0000788 and 0.000118 mol/L (or 0 (control), 8.396, 12.59, 18.78, 28.31, 42.41, and 63.51 mg/L given the molecular weight of the form of PFOS used in the study, CAS # 2795-39-3, of 538.22 g/mol). Five neonates (12-24 hours old) were placed randomly in 100 mL glass beakers filled with 60 mL test solution, with four replicates per concentration. Organisms were observed for mortality at 48 hours, and the authors reported a LC_{50} of 22.77 mg/L. The EPA's independently-calculated 48-hour LC_{50} was 22.43 (15.74 – 29.12) mg/L PFOS and was used quantitatively to derive the freshwater acute water column criterion.

A.2.13 Thirteenth Most Sensitive Freshwater Genus for Acute Toxicity: *Ambystoma* (salamander)

Tornabene et al. (2021) conducted acute toxicity tests with three species of salamanders in the genus *Ambystoma* and PFOS (purchased from Sigma Aldrich, Catalog # 77282-10G; purity not provided). Acute tests followed standard 96-hour acute toxicity test guidance (ASTM

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2017; U.S. EPA 2002). The three test species (Jefferson salamander, *Ambystoma jeffersonianum*; small-mouthed salamander, *A. texanum*; eastern tiger salamander, *A. tigrinum*) were collected from a field in the wetlands of Indiana near the campus of Purdue University. Collected egg masses were raised outdoors in 200 L polyethylene tanks filled with well water. Experiments began when salamanders reached Harrison stage 40, defined as when larvae are free swimming and feeding. Before test initiation larvae were acclimated to test conditions (21°C and 12:12-hour light:dark photoperiod) for 24 hours. An additional acute test with Harrison stage 46 small-mouthed salamanders was run to determine if toxicity varied between life stages. A stock solution of PFOS (500 mg/L) was made in UV-filtered well water and diluted with well water to reach test concentrations (ranged from 0-500 mg/L PFOS). Test concentrations were not measured in test solutions, based on previous research that demonstrated limited degradation under similar conditions. Larva were transferred individually to 250 mL plastic cups with 200 mL of test solutions and were not fed during the exposure period. The number of replicates varied by species, life stage and treatment; five replicates per treatment for Jefferson salamander and Harrison stage 46 small-mouthed salamander, seven replicates per treatment for Harrison stage 40 small-mouthed salamander, and 20 replicates in the control and 10 replicates in each treatment for eastern tiger salamander. No mortality occurred in any of the control groups. Author-reported 96-hour LC_{50}s were 64, 41 and 73 mg/L PFOS for the Jefferson salamander, small-mouthed salamander and eastern tiger salamander, respectively. The authors did not find a significant difference between the life stages of small-mouthed salamander so results of the two tests were pooled. The independently-calculated 96-hour LC_{50} values were 51.71 (40.84 – 62.58) for Jefferson salamander; 46.71 (34.33 – 59.09) and 30.00 (27.14 – 32.86) for small-mouthed salamander, Harrison stage 40 and 46; and 68.63 (61.90 – 75.37) mg/L for eastern tiger

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salamander, respectively. In general, the independently-calculated toxicity values were acceptable for quantitative use and used to derive the freshwater acute water column criterion for PFOS. However, only the LC_{50} value of 30.00 mg/L for Harrison stage 46 small-mouthed salamander was used for this species as this life stage was determined to be the most sensitive.

A.2.14 Fourteenth Most Sensitive Freshwater Genus for Acute Toxicity: *Pontastacus* (crayfish)

Belek et al. (2022) tested heptadecafluorooctanesulfonic acid potassium salt (PFOS-K) on narrow-clawed crayfish (*Pontastacus leptodactylus*; formerly, *Astacus leptodactylus*) for 96 hours in an unmeasured, static experiment. Heptadecafluorooctanesulfonic acid potassium salt (≥98% purity) was obtained from Sigma-Aldrich (USA). Crayfish were obtained from a local breeder in Lake Egirdir, Turkey during the inter-molt stage, and averaged 29.1±0.39 g weight and 10.27±0.05 cm length. Crayfish were acclimated in the laboratory at the Biology Department of Gazi University for two weeks in glass aquariums filled with aerated, dechlorinated tap water for two weeks at a temperature of 21°C, and were fed a daily ration of raw trout. Testing parameters followed animal care guidance from NRC (1996). A 96-hour acute test was conducted to determine the LC_{50}, and a subsequent 21-day chronic test was conducted with a water only control, a DMSO solvent control, and two treatments set to 0.5 and 5 mg/L, which approximated 1% and 10% of the acute LC_{50}. The chronic test measured biochemical and enzymatic responses to PFOS. Mean water quality parameters for test water were as follows: 21±1°C temperature, 6.79±0.31 pH, 117.38±17.20 µS/cm specific conductivity, 0.01±0.001 mg/L total ammonia nitrogen, and 6.72±0.05 mg/L dissolved oxygen. Organisms were kept under a 16:8 light:dark cycle in 15 L of aerated, dechlorinated tap water during testing. The LC_{50} was calculated using Probit analysis using the U.S. EPA LC_{50} Software Program version 1.00. The author reported 96-hour LC_{50} value of 48.81 mg/L was determined to be acceptable for quantitative use.

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A.2.15 Fifteenth Most Sensitive Freshwater Genus for Acute Toxicity: *Anaxyrus* (toad)

Tornabene et al. (2021) conducted acute toxicity tests with the American toad, *Anaxyrus americanus*, and PFOS (purchased from Sigma Aldrich, Catalog # 77282-10G; purity not provided). The acute tests followed standard 96-hour acute toxicity test guidance (ASTM 2017; U.S. EPA 2002). The frog was collected from a field in the wetlands of Indiana near the campus of Purdue University. Collected egg masses were raised outdoors in 200 L polyethylene tanks filled with well water. Experiments began when toads reached Gosner stage (GS) 26, defined as when larvae are free swimming and feeding. An additional acute test with GS 41 was run to determine if toxicity varied between life stages. Before test initiation larvae were acclimated to test conditions (21°C and 12:12-hour light:dark photoperiod) for 24 hours. A stock solution of PFOS (500 mg/L) was made in UV-filtered well water and diluted with well water to achieve test concentrations ranging from 0 – 500 mg/L PFOS. Test concentrations were not measured in test solutions, based on previous research that demonstrated limited degradation under similar conditions. Larva were transferred individually to 250 mL plastic cups with 200 mL of test solutions and were not fed during the exposure period. The number of replicates varied by life stage, and treatment; 10 replicates for each treatment for GS 26 toads, and six to 10 replicates for each treatment for GS 41 toads. No mortality occurred in any of the control groups. The author-reported 96-hour LC_{50} was 62 mg/L PFOS. The authors did not find a significant difference between the life stages of the American toad, so results of the two tests were pooled. The independently-calculated 96-hour LC_{50} values were 63.41 (62.32 – 64.51) mg/L for the GS 26 toads and 56.49 (49.10 – 63.90) mg/L for GS 41 toads. Given that the GS 41 toads appear to be a more sensitive life-stage the LC_{50} of 56.49 mg/L was considered acceptable for quantitative use and used in the derivation of the freshwater acute water column criterion.

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A.2.16 Sixteenth Most Sensitive Freshwater Genus for Acute Toxicity: *Procambarus* (crayfish)

Funkhouser (2014) conducted a 7-day static acute test on PFOS (potassium salt, ≥98% purity) with the crayfish species, *Procambarus fallax* (f. *virginalis*), as part of a Master's thesis at the Texas Tech University, Lubbock, TX. Juvenile *P. fallax* (2-week old, 0.041 g) used for the test were originally purchased from a private collector. The crayfish reproduced for several generations before being used for experiments. Based on an average reproductive age of 141-255 days, an interclutch period of 50-85 days, and a brooding time of 22-42 days, the author estimated the experimental animals to be stage F4-F6 (Seitz et al. 2005). Dilution water was moderately hard reconstituted laboratory water (3.0 g $CaSO_4$, 3.0 g $MgSO_4$, 0.2 g KCl, and 4.9 g $NaHCO_3$ added to 50 L deionized water). Photoperiod was 14:10-hours light:dark at an unreported light intensity. PFOS was dissolved in dilution water to prepare the test concentrations. Exposure vessels were 1 L polypropylene containers containing 500 mL of test solution. The test employed two replicates of three snails each in five test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 40, 80, 120, 160, and 200 mg/L. Exposure concentrations were reportedly measured, but concentrations were not reported. Analyses of test solutions were performed using LC-MS/MS. Standards were used as part of the analytical method, but details were not reported. The reporting limit was 0.010 mg/L. Experiments were conducted in an incubator at 25 ±1°C and covered with plastic opaque sheeting to limit evaporation. No other water quality parameters were reported as having been measured in test solutions. Negative control survival was 100% after seven days. The author reported 96-hour LC_{50} was reported as 59.87 mg/L. For comparison, the 7-day LC_{50} was 39.71 mg/L. The independently-calculated 96-hour LC_{50} value was also 59.87 mg/L (C.I. 54.29-65.45). This independently-calculated LC_{50} value of 59.7 mg/L was used quantitatively to derive the freshwater acute water column criterion.

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A.2.17 Seventeenth Most Sensitive Freshwater Genus for Acute Toxicity: *Brachionus* (rotifer)

Zhang et al. (2013) performed a 24-hour static test of PFOS (potassium salt, CAS # 2795-39-3, ≥98% purity) with *Brachionus calyciflorus*. Organisms were less than two hours old at test initiation. All animals were parthenogenetically-produced offspring of one individual from a single resting egg collected from a natural lake in Houhai Park (Beijing, China). The rotifers were cultured in an artificial inorganic medium at 20°C (16:8-hours light:dark; 3,000 lux) for more than six months before toxicity testing to acclimate to the experimental conditions. All toxicity tests were carried out in the same medium and under the same conditions as during culture (i.e., pH, temperature, illumination). Solvent-free stock solutions of PFOS (1,000 mg/L) were prepared by dissolving the solid in deionized water via sonication. After mixing, the primary stock was proportionally diluted with dilution water to prepare the test concentrations. Exposures were in 15 mL, 6-well cell culture plates (assumed plastic) each containing at total of 10 mL of test solution. The test employed seven measured test concentrations plus a negative control. Each treatment consisted of one replicate plate of 10 rotifers each in individual cells and repeated six times. Nominal concentrations were 0 (negative control), 40, 50, 60, 70, 80, 90, and 100 mg/L. PFOS concentrations were not measured in the rotifer exposures, but rather, in a side experiment using HPLC/MS. The side experiment showed that the concentration of PFOS measured every eight hours over a 24-hour period in rotifer medium with green algae incurs minimal change in the concentration range 0.25 to 2.0 mg/L. The acute test was conducted without green algae added to the exposure medium. One hundred percent survival was observed at 24 hours in the negative control. The author-reported 24-hour LC_{50} was 61.8 mg/L. The author-reported value was used quantitatively to derive the freshwater acute water column criterion.

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A.2.18 Eighteenth Most Sensitive Freshwater Genus for Acute Toxicity: *Elliptio* (mussel)

Drottar and Krueger (2000f) reported the results of a 96-hour renewal, measured test on the effects of PFOS (potassium salt, CAS # 2795-39-3, 90.49% purity) on *Elliptio complanata* (formerly known as *Unio complanatus)*. The good laboratory practice (GLP) test was conducted at Wildlife International, Ltd. In Easton, MD in August, 1999, using a protocol based on procedures outlined in U.S. EPA (1996b). *E. complanata* (76.5 g and 48.7 mm) used for the test were purchased from Carolina Biological Supply Company in Burlington, NC, after being caught in the wild. They were of an unspecified age at test initiation. Dilution water was 0.45 µm filtered well water [total hardness: 126 (120-132) mg/L as $CaCO_3$; alkalinity: 174 (170-178) mg/L as $CaCO_3$; pH: 8.3 (8.1-8.5); TOC: < 1.0 mg/L; conductivity: 21 (310-330) µmhos/cm]. Photoperiod was 16:8-hours light:dark with a 30-minute transition period. Light was provided at an intensity of approximately 369 lux. A primary stock solution was prepared in dilution water at 91 mg/L. It was mixed for ~24 hours prior to use. After mixing, the primary stock was proportionally diluted with dilution water to prepare the four additional test concentrations. Exposure vessels were 25 L polyethylene aquaria containing 20 L of test solution. The test employed two replicates of 10 mussels each in five measured test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 5.7, 11, 23, 46, and 91 mg/L. Mean measured concentrations were less < 0.115 mg/L, 5.3, 12, 20, 41, and 79 mg/L, respectively. Analyses of test solutions were performed at Wildlife International, Ltd. using high performance liquid chromatography with mass spectrometric detection (HPLC/MS). The mean percent recovery of matrix fortifications analyzed concurrently during sample analysis was 94.7%. Concentrations measured at test initiation averaged 86% of nominal. Concentrations measured prior to renewal at 48 hours averaged 89% of nominal. Concentrations measured at 96 hours averaged 100% of nominal. Dissolved oxygen in control and the high-test concentration (79

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mg/L) respectively ranged from 5.8-8.5 mg/L and 5.0-8.6 mg/L; pH ranged from 8.0-8.4 and 7.9-8.5. Test temperature ranged from 21.4-21.8°C and 21.8-23.7°C. Mussels in the negative control, the 5.3, 12, and 20 mg/L treatments appeared healthy and normal throughout the test with no mortality, immobility or overt clinical signs of toxicity. The author-reported 96-hour LC_{50} was 59 mg/L (C.I. 51-68). The independently-calculated LC_{50} value was 64.35 (56.22 – 72.48) mg/L and used to derive the freshwater acute water column criterion.

A.2.19 Nineteenth Most Sensitive Freshwater Genus for Acute Toxicity: *Lithobates* (frog)

Flynn et al. (2019) evaluated the acute effects of perfluorooctanesulfonic acid (PFOS, CAS# 1763-23-1, purchased from Sigma-Aldrich) on the American bullfrog (*Lithobates catesbeiana*, formerly, *Rana catesbeiana*) during a 96-hour unmeasured, static study. Testing followed Purdue University's Institutional Animal Care and Use Committee Guidelines Protocol #16010013551. American bullfrog eggs were taken from a permanent pond in the Martell Forest outside of West Lafayette, Indiana. The eggs from a single egg mass were acclimated in 100-L outdoor tanks filled with 70 L of aged well water and covered with a 70% shade cloth. Once hatched, tadpoles were fed rabbit chow and TetraMin® *ad libitum* and were acclimated to laboratory conditions for 24 hours before testing. A 500 mg/L PFOS stock solution was prepared with RO water to create nominal test concentrations of 0 (control), 10, 25, 50, 75, 100, 150, 300 and 500 mg/L. Each treatment contained 10 replicates with one Gosner Stage 25 tadpole in each 250 mL plastic tub maintained at 21ºC and a 12:12-hour light:dark photoperiod. Mortality was monitored twice daily. The author-reported LC_{50} value was 144 mg/L PFOS. The EPA's independently-calculated 96-hour LC_{50} was 154.8 (108.7 – 200.9) mg/L PFOS and used quantitatively to derive the freshwater acute water column criterion. However, this value was not used in the SMAV calculation because a more sensitive life stage was available for the species.

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Tornabene et al. (2021) conducted acute toxicity tests with four species of frogs in the genus *Lithobates* (formerly, *Rana*) and PFOS (purchased from Sigma Aldrich, Catalog # 77282-10G; purity not provided). Acute tests followed standard 96-hour guidance (ASTM 2017; U.S. EPA 2002). The four test species (American bullfrog, *Lithobates catesbaeiana*; green frog, *L. clamitans*; northern leopard frog, *L. pipiens*; wood frog, *L. sylvatica*) were collected from a field in the wetlands of Indiana near the campus of Purdue University. Collected egg masses were raised outdoors in 200 L polyethylene tanks filled with well water. Experiments began when frogs reached Gosner stage 26, defined as when larvae are free swimming and feeding. Before test initiation larvae were acclimated to test conditions (21℃ and 12:12-hour light:dark photoperiod) for 24 hours. A stock solution of PFOS (500 mg/L) was made in UV-filtered well water and diluted with well water to reach test concentrations ranging from 0 – 500 mg/L PFOS. Test concentrations were not measured in test solutions, based on previous research that demonstrated limited degradation under similar conditions. Larva were transferred individually to 250 mL plastic cups with 200 mL of test solutions and were not fed during the exposure period. The number of replicates varied by species, and treatment; 20 replicates in the control and five to 10 replicates in each treatment for American bullfrog, 10 replicates for each treatment for green frog, northern leopard frog and wood frog. No mortality occurred in any of the control groups. Author-reported 96-hour LC_{50}s were 163, 113, 73 and 130 mg/L PFOS for the American bullfrog, green frog, northern leopard frog, and wood frog, respectively. The independently-calculated 96-hr LC_{50} values for American bullfrog and northern leopard frog were 133.23 (95.75 – 170.8), and 72.72 (63.88 – 81.55) mg/L, respectively. The EPA was unable to independently calculate LC_{50} values for green frog and wood frog as a curve could not be fit with significant parameters. Therefore, the independently-calculated LC_{50} values for American

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bullfrog (133.3 mg/L) and northern leopard frog (72.72 mg/L) were used quantitatively to derive the freshwater acute water column criterion for PFOS, while the author-reported LC_{50} values for green frog (113 mg/L) and wood frog (130 mg/L) were used. The author-reported toxicity values were consistent with the independently-calculated LC_{50} values for other species included in the study.

A.2.20 Twentieth Most Sensitive Freshwater Genus for Acute Toxicity: *Physella* (snail)

Li (2009) conducted three independent repeats of a 96-hour static acute test on PFOS (potassium salt, > 98% purity) with the bladder snail species, *Physella acuta* (Note: formerly known as *Physa acuta*). The test organisms were collected from a ditch located in Shilin of Taipei City in June 2005. Snails were fed with lettuce and half of the culture medium was changed with dechlorinated water every two weeks, implying a holding time of greater than two weeks. *P. acuta* of mixed ages were used at test initiation. Dilution water was dechlorinated tap water. The photoperiod consisted of 12 hours of illumination at an unreported light intensity. A primary stock solution was prepared in dilution water. Exposure vessels were polypropylene beakers of unreported dimensions and 1 L fill volume. The test employed 5-6 replicates of six snails each in at least five test concentrations plus a negative control. Each treatment was tested three independent times. Nominal test concentrations were in the range of 25-300 mg/L PFOS. The test temperature was maintained at 25±2°C. Water quality parameters including pH, conductivity, and D.O. were reported as having been measured at the beginning and end of each test, but the information was not reported. Survival of negative control animals was also not reported. The author-reported 96-hour LC_{50} was 178 mg/L (C.I. 167-189) and represented an average of the LC_{50}s for each test. Only one of three independent experiments could be fitted. The independently-calculated LC_{50} value was 183.0 (161.4 – 204.7) mg/L and was used quantitatively to derive the freshwater acute water column criterion.

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Funkhouser (2014) conducted a 96-hour static test on PFOS (potassium salt, ≥98% purity) with the physid snail, *Physella heterostropha pomilia* (Note: formerly known as *Physa pomilia*), as part of a Master's thesis at the Texas Tech University, Lubbock, TX. Adult *P. pomilia* (4 month old) used for the test were field collected from two different collections from the North Fork of the Double Mountain Fork of the Brazos River near Lubbock, TX. Offspring from both collections were reared in 12, 10-gallon aquaria with lab water for several generations prior to use in the test. Dilution water was moderately hard reconstituted laboratory water (3.0 g $CaSO_4$, 3.0 g $MgSO_4$, 0.2 g KCl, and 4.9 g $NaHCO_3$ added to 50 L deionized water). Photoperiod was 12:12-hours light:dark at an unreported light intensity. PFOS was dissolved in dilution water to prepare the test concentrations. Exposure vessels were 400 mL polypropylene containers containing 200 mL of test solution. The test employed two replicates of four snails each in six test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 100, 150, 200, 250, 300, and 375 mg/L. Exposure concentrations were reportedly measured, but concentrations were not reported. Analyses of test solutions were performed using liquid chromatography/ tandem mass spectrometry (LC-MS/MS). Standards were used as part of the analytical method, but details were not reported. The reporting limit was 0.010 mg/L. Experiments were conducted in incubators set to 25°C, which did not vary more than 1°C during the course of the test. No other water quality parameters were reported as having been measured in test solutions. Negative control survival was not reported specifically for the test but was reported to be 85-100% across all experiments. The author-reported 96-hour LC_{50} was reported as 161.77 mg/L. An independently-calculated toxicity value could not be calculated given the level of data that was presented in the paper. The study author reported value was used quantitatively to derive the freshwater acute water column criterion.

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Appendix B Acceptable Estuarine/Marine Acute PFOS Toxicity Studies

B.1 Summary Table of Acceptable Quantitative Estuarine/Marine Acute PFOS Toxicity Studies

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp (°C)	Salinity (ppt)	Effect	Author Reported Effect Conc. (mg/L)	EPA Calculated Effect Conc. (mg/L)	Final Effect Conc. (mg/L)[b]	Species Mean Acute Value (mg/L)	Reference
Sea urchin (larvae), *Paracentrotus lividus*	S, U	72 hr	PFOS Unreported	-	18	35	EC50 (malformation)	1.795	-	**1.795**	1.795	Gunduz et al. (2013)
Purple sea urchin (embryo), *Strongylocentrotus purpuratus*	S, M	96 hr	PFOS-K 98%	-	15	30	EC50 (normal development)	1.7	-	**1.7**	1.7	Hayman et al. (2021)
Mediterranean mussel (larva), *Mytilus galloprovincialis*	S, U	48 hr	PFOS Unreported	7.9-8.1	16	36	EC50 (malformation)	>1	-	>1[c]	-	Fabbri et al. (2014)
Mediterranean mussel (embryo), *Mytilus galloprovincialis*	S, M	48 hr	PFOS-K 98%	-	15	30	EC50 (normal development)	1.1	-	**1.1**	1.1	Hayman et al. (2021)
Mysid (3 d), *Americamysis bahia*	S, M	96 hr	PFOS-K 98%	-	20	30	LC50	5.1	4.914	**4.914**	4.914	Hayman et al. (2021)
Mysid (neonate, <24 hr), *Siriella armata*	S, U	96 hr	PFOS 98%	-	20	-	LC50	6.9	-	**6.9**	6.9	Mhadhbi et al. (2012)
Sheepshead minnow (3.0 cm, 0.44 g), *Cyprinodon variegatus*	R, M	96 hr	PFOS-K 86.9%	-	22	20	LC50	>15	-	**>15**	>15	Palmer et al. (2002b)

a S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

[b] Values in bold used the in the SMAV calculation

[c] Not used in SMAV calculations, because a definitive value is available

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B.2 Detailed PFOS Acute Saltwater Toxicity Study Summaries and Corresponding Concentration-Response Curves (when calculated for the most sensitive genera)

The purpose of this section was to present detailed study summaries for acute saltwater tests that were considered quantitatively acceptable for criterion derivation, with summaries grouped and ordered by genus sensitivity. The data available for saltwater invertebrates fulfilled three of the eight MDRs. The EPA could not, therefore, develop acute estuarine/marine criteria following the 1985 Guidelines methods. In the interest of providing informations to states/Tribes on protective values, the EPA developed an estuarine/marine acute benchmark using the available empirical data supplemented with toxicity values generated through the use of New Approach Methods (NAMs), specifically through the use of the EPA Office of Research and Development's peer-reviewed publicly-available web-ICE tool (Raimondo et al. 2010). These benchmarks are provided in Appendix L.

B.2.1 Most Sensitive Estuarine/Marine Genus for Acute Toxicity: *Mytilus* (mussel)

The acute toxicity of perfluorooctane sulfonate (PFOS, purity not provided) on the Mediterranean mussel, *Mytilus galloprovincialis* was evaluated by **Fabbri et al. (2014)**. This species is not resident to North America, but is a surrogate for North American mussel species, including the widespread, commercially and ecologically important blue mussel, *Mytilus edulis.* Sexually mature mussels were purchased from an aquaculture farm in the Ligurian Sea (La Spezia, Italy) and held for two days for gamete collection. Gametes were held in artificial sea water (ASW) made of analytical grade salts and at a constant temperature of 16 ±1°C. It was assumed that the gametes were held at the same environmental conditions as the adults, so test salinity was assumed to be 36 ppt with a pH of 7.9-8.1. Embryos were transferred to 96-well microplates with a minimum of 40 embryos/well. Each treatment had six replicates. Embryos were incubated with a 16:8-hour light:dark photoperiod for 48 hours and exposed to one of six

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nominal PFOS concentrations (0.00001, 0.0001, 0.001, 0.01, 0.1, and 1 mg/L) or control (ASW) water. The PFOS stock was made with ethanol, and ASW control samples run in parallel included ethanol at the maximal final ethanol concentration of 0.01%. Each experiment was repeated four times. At test termination (48 hours), the endpoint was the percentage of normal D-larvae in each well, including malformed larvae and pre-D stages. The acceptability of test results was based on the control group exhibiting >75% of normal D-shell stage larvae (ASTM 2004b). Authors noted that controls had ≥80% normal D-larvae across all tests. PFOS was only measured once in one treatment which was similar to the nominal concentration; that is, 0.000085 mg/L versus the nominal concentration of 0.0001 mg/L. PFOS was below the limit of detection (LOD) in the control ASW (0.06 ng/L or 0.00000006 mg/L). The percentage of normal D-larva decreased with increasing test concentrations. The NOEC and LOEC reported for the study were 0.00001 and 0.0001 mg/L, respectively. However, the test concentrations failed to elicit a 50% reduction in malformations in the highest test concentration, and an EC_{50} was not determined. Therefore, the EC_{50} for the study was greater than the highest test concentration (1 mg/L). The 48-hour EC_{50} based on malformation of >1 mg/L was acceptable for quantitative use.

Hayman et al. (2021) report the results of a 48-hour static, measured test on the effects of PFOS-K (potassium salt, CAS # 2795-39-3, 98% purity, purchased from Sigma-Aldrich, St. Louis, MO) on the Mediterranean mussel, *Mytilus galloprovincialis*. Authors note tests followed U.S. EPA (1995) and ASTM (2004b) protocols. Mussels were collected in the field (San Diego Bay, CA) and conditioned in a flow-through system at 15°C. Mussels were induced to spawn by heat-shock and approximately 250 embryos (2-cell stage) were added to 20 mL borosilicate glass scintillation vials with 10 mL of test solution. There were five replicates per test concentration. Test conditions were 30 ppt, 15°C and a 16:8-hour light:dark photoperiod. Six test solutions were

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made in 0.45 µm filtered seawater (North San Diego Bay, CA) with PFOS-K dissolved in methanol. The highest concentration of methanol was 0.1% (v/v). Measured test concentrations ranged from 0.52 – 2.50 mg/L. Control mussel embryos were exposed to 100% filtered seawater and the acute test also included a solvent control. At test termination (48 hours), larvae were enumerated for total number of larvae that were alive at the end of the test (normally or abnormally developed), as well as number of normally-developed (in the prodissoconch "D-shaped" stage) larvae. There were no significant differences between solvent and negative (100% filtered seawater) control groups, suggesting no adverse effects of methanol. The author-reported 48-hr EC_{50}, based on normal development, was 1.1 mg/L PFOS. The EPA was not able to independently calculate a 48-hour EC_{50} value as the curve fitted model did not result in a good fit. Therefore, the author-reported EC_{50} of 1.1 mg/L mg/L was considered for quantitative use.

B.2.2 Second Most Sensitive Estuarine/Marine Genus for Acute Toxicity: *Strongylocentrotus* (sea urchin)

Hayman et al. (2021) report the results of a 96-hour static, measured test on the effects of PFOS-K (potassium salt, CAS # 2795-39-3, 98% purity, purchased from Sigma-Aldrich, St. Louis, MO) on the purple sea urchin, *Strongylocentrotus purpuratus*. Authors note that tests followed U.S. EPA (1995) and ASTM (2004b) protocols. Sea urchins were collected in the field (San Diego Bay, CA) and conditioned in flow-through system at 15°C. They were induced to spawn by KCl injection and approximately 250 embryos (2-cell stage) were added to 20 mL borosilicate glass scintillation vials with 10 mL of test solution. There were five replicates per test concentration. Test conditions were 30 ppt, 15°C and a 16:8-hour light:dark photoperiod. Seven test solutions were made in 0.45 µm filtered seawater (North San Diego Bay, CA) with PFOS dissolved in methanol. The highest concentration of methanol was 0.1% (v/v). Measured test concentrations ranged from 0.52 – 10.0 mg/L. Control urchin embryos were exposed to

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100% filtered seawater and the acute test also included a solvent control. At test termination (96 hours), the first 100 larvae were enumerated and observed for normal development (4-arm pluteus stage). There were no significant differences between solvent and negative (100% filtered seawater) control groups, suggesting no adverse effects of methanol. The author-reported 96-hour EC_{50}, based on normal development, was 1.7 mg/L PFOS. The EPA was not able to independently calculate a 96-hour EC_{50} value as the curve fitted model did not result in a good fit. Therefore, the author-reported EC_{50} of 1.7 mg/L mg/L was considered for quantitative use.

B.2.3 Third Most Sensitive Estuarine/Marine Genus for Acute Toxicity: *Paracentrotus* (sea urchin)

A 72-hour static, unmeasured PFOS (purity not provided) toxicity test with the sea urchin, *Paracentrotus lividus* (a non-North American species) was conducted by **Gunduz et al. (2013)**. Adult sea urchins were collected from the Aegean coast of Turkey, in an area the authors noted as clean and lacking domestic and industrial wastewater inputs. Filtered natural seawater from the same area was used as the dilution water. Adult sea urchins were cultivated in the same filtered natural sea water with a salinity of 35 ppt and 18°C. Zygote suspensions (1 mL) were added to the controls or 9 mL of the various PFOS treatments. This ensured that there were about 30 fertilized embryos/mL or approximately 300 embryos per treatment. The experiments were conducted in six-well TPP culture plates with six replicates per treatment. PFOS stock solutions were made with dimethyl sulfoxide (DMSO) and diluted with seawater to obtain five nominal treatments (0.5, 1.0, 3.0, 5.0 and 10 mg/L PFOS). In addition to a natural seawater control, experiments also included a DMSO solvent control equal to the amount in the highest test concentration. The embryos were incubated in a growth chamber at 18 ±2°C from 10 minutes after fertilization to up to the 72-hour pluteus larval stage. At test termination, 100 individuals were selected randomly from each treatment and evaluated for normal plutei, retarded plutei,

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pathologic malformed plutei, pathologic embryos unable to differentiate up to the pluteus larval stages, and dead embryos/larvae. There was 97.75% and 91% frequency of normal larvae in the control and solvent control, respectively with no deaths reported in the controls or any PFOS treatments. The 72-hour EC_{50} based on normal development to the pluteus stage was 1.795 mg/L PFOS and is acceptable for quantitative use; however, additional consideration needs to be given to the short test duration.

B.2.4 Fourth Most Sensitive Estuarine/Marine Genus for Acute Toxicity: *Americamysis* (mysid)

Hayman et al. (2021) report the results of a 96-hour static, measured test on the effects of PFOS (potassium salt, CAS # 2795-39-3, 98% purity, purchased from Sigma-Aldrich, St. Louis, MO) on the mysid, *Americamysis bahia*. Authors note that tests followed U.S. EPA (1995); U.S. EPA (2002); and ASTM (2004b) protocols. Mysids were purchased from a commercial supplier (Aquatic Research Organisms, Hampton, NH) and acclimated to test conditions (30 ppt, 20°C and a 16:8-hour light:dark photoperiod). Five test solutions were made in 0.45 µm filtered seawater (North San Diego Bay, CA) with PFOS-K dissolved in methanol. The highest concentration of methanol was 0.1% (v/v). Measured test concentrations ranged from 0.95 – 16 mg/L. Control mysids were exposed to 100% filtered seawater and the acute test also included a solvent control. Five mysids (3 days old, which is older than the typical age of < 24 hours at test initiation) were added to 120 mL polypropylene cups and 100 mL of test solutions with six replicates per treatment. Living mysids were counted and dead organisms were removed daily. There were no significant differences between solvent and negative (100% filtered seawater) control groups, suggesting no adverse effects of methanol. Only two organisms were found dead in the controls at test termination. The author-reported 96-hour LC_{50} was 5.1

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mg/L PFOS. The independently-calculated 96-hr LC_{50} value was 4.914 (3.578 – 6.250) mg/L and is acceptable for quantitative use.

B.2.5 Fifth Most Sensitive Estuarine/Marine Genus for Acute Toxicity: *Siriella* (mysid)

Mhadhbi et al. (2012) performed a 96-hour static, unmeasured acute test with PFOS (98% purity) and the mysid, *Siriella armata*. Mysids were collected from the same source as the dilution water [filtered sea water from the Ria of Vigo (Iberian Peninsula)] and quarantined before use in 100 L plastic tanks with circulating sand-filtered seawater. The adult stock was fed daily and maintained at laboratory conditions (17-18°C, salinity between 34.4-35.9 ppt, and D.O. 6 mg/L). A stock solution of PFOS was made either with filtered sea water from the Ria of Vigo for low exposure concentrations, or with DMSO for high PFOS concentrations (a final maximum DMSO concentration of 0.01% (v/v) in the test medium). However, the authors did not indicate what was considered a high-test concentration. If DMSO was used, a solvent control was also included. Twenty neonates (<24 hours old) were used per each treatment. Mysids were exposed to one of five nominal PFOS treatments (1.25, 2.5, 5, 10 and 20 mg/L). To prevent cannibalism, a single individual was added to each glass vial with 2-4 mL of test solution. Vials were incubated at 20°C with a 16-hour light period. Neonates were fed 10-15 *Artemia salina* nauplii daily and mortality was recorded after 96 hours. The 96-hour LC_{50} was 6.9 mg/L PFOS and was acceptable for quantitative use.

B.2.6 Sixth Most Sensitive Estuarine/Marine Genus for Acute Toxicity: *Cyprinodon* (sheepshead minnow)

Palmer et al. (2002b) conducted a 96-hour static-renewal measured acute test with PFOS-K (perfluorooctanesulfonate potassium salt, 86.9% purity from the 3M Company) on the sheepshead minnow, *Cyprinodon variegatus*. The test followed standard guidance for acute toxicity tests outlined in U.S. EPA (1985) and ASTM (1994). Sheepshead minnows were purchased from a commercial supplier (Aquatic Biosystems, Fort Collins, CO) and held for

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several weeks prior to testing. Fifty-one hours before testing fish were acclimated to test conditions (16:8-hour light:dark photoperiod, salinity of 20 ppt and 22°C). Natural seawater (Indian River Inlet, Delaware) was filtered and diluted with well water to 20 ppt and was used for culturing and testing. A nominal PFOS stock solution (40 mg/L) was made by dissolving PFOS in methanol and diluting it with seawater to achieve the nominal test concentration (20 mg/L). A solvent control (0.5 mL/L methanol) and a sea water control were also included. Ten minnows (3.0 cm, 0.44 g) were added to 25 L polyethylene aquaria with 15 L of test solution (loading was 0.30 g fish/L of test water). Test treatments were replicated three times. PFOS concentrations were measured daily at test solution renewal with averaged measured concentrations in the control and solvent control less than the LOQ (5 mg/L) and PFOS-spiked seawater, 15 mg/L. At test termination (96 hours) none of the minnows died in the controls or single PFOS test treatment, therefore the author-reported LC_{50} was >15 mg/L. The EPA was unable to independently calculate the LC_{50} value as this test only consisted of one treatment group. The author-reported LC_{50} >15 mg/L is being used quantitatively for the acute saltwater benchmark because it is a greater than high value which adds value to the assessment of potential sensitivity of this species to acute PFOS exposure (see Section 2.10.3.2).

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Appendix C Acceptable Freshwater Chronic PFOS Toxicity Studies

C.1 Summary Table of Acceptable Quantitative Freshwater Chronic PFOS Toxicity Studies

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Chronic Value Endpoint	Author Reported Chronic Value (mg/L)	EPA Calculated Chronic Value (mg/L)	Final Chronic Value (mg/L)[c]	Species Mean Chronic Value (mg/L)	Reference
Fatmucket (adult), *Lampsilis siliquoidea*	R, M	36 d	PFOS >98%	7.6-8.5	14.6-16.1	MATC (metamorphosis success)	0.01768	0.0123	**0.01768**	0.01768	Hazelton et al. (2012); Hazelton (2013)
Snail (egg), *Physella heterostropha pomilia* (formerly, *Physa pomilia*)	R, M	44 d	PFOS-K ≥98%	-	25	EC10 (clutch size)	14.14	8.527	**8.527**	8.527	Funkhouser (2014)
Rotifer (<2 hr old neonates), *Brachionus calyciflorus*	R, U[b]	Up to 158 hr	PFOS ≥98%	-	20	LOEC (reduced net reproductive rate)	<0.25	-	0.25	0.2500	Zhang et al. (2013)
Cladoceran (<24 hr), *Ceriodaphnia dubia*	R, M	6 d	PFOS-K 98%	6.91-8.02	24.0-25.9	EC10 (neonates / female)	6.9	10.69	**10.69**	-	Krupa et al. (2022)
Cladoceran (<8 hr), *Ceriodaphnia dubia*	R, M	7 d	PFOS-K 97.5%	7.73 (7.64-7.86)	24.5 (23.8-25.2)	EC10 (neonates / female)	10.0	8.371	**8.371**	-	Kadlec et al. (2024)
Cladoceran (<8 hr), *Ceriodaphnia dubia*	R, M	7 d	PFOS-K 97.5%	7.76 (7.71-7.81)	24.4 (24.1-24.8)	EC10 (neonates / female)	14.5	9.205	**9.205**	-	Kadlec et al. (2024)
Cladoceran (<8 hr), *Ceriodaphnia dubia*	R, M	7 d	PFOS-K 97.5%	7.58 (7.49-7.67)	24.9 (24.3-25.7)	EC10 (neonates / female)	9.8	6.766	**6.766**	8.640	Kadlec et al. (2024)
Cladoceran (6-12 hr), *Daphnia carinata*	R, U	21 d	PFOS-K ≥98%	-	21	MATC (days to first brood)	0.003162	-	**0.003162**	0.003162	Logeshwaran et al. (2021)
Cladoceran (<24 hr), *Daphnia magna*	R, M	21 d	PFOS-K 90.49%	8.1-8.5	19.4-20.1	EC10 (cumulative young)	16.97	11.19	**11.19**	-	Drottar and Krueger (2000e)
Cladoceran (<24 hr), *Daphnia magna*	R, U	21 d	PFOS-K 95%	-	21	EC10 (survival)	35.36	16.35	**16.35**	-	Boudreau (2002);

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Chronic Value Endpoint	Author Reported Chronic Value (mg/L)	EPA Calculated Chronic Value (mg/L)	Final Chronic Value (mg/L)[c]	Species Mean Chronic Value (mg/L)	Reference
											Boudreau et al. (2003a)
Cladoceran (<24 hr), *Daphnia magna*	R, U	21 d	PFOS Unreported	-	21	EC10 (number of young / brood)	1.768	1.051	**1.051**	-	Ji et al. (2008)
Cladoceran (<24 hr), *Daphnia magna*	R, U	21 d	PFOS-K >98%	-	20	EC10 (total neonates/female)	2.236	3.030	**3.030**	-	Li (2010)
Cladoceran (<24 hr), *Daphnia magna*	R, M	21 d	PFOS-K 99%	7	22	EC10 (survival)	4.17	2.610	**2.610**	-	Yang et al. (2014)
Cladoceran (<24 hr), *Daphnia magna*	R, U	21 d	PFOS 98%	7.2	20	EC10 (number of offspring / brood / female)	0.0179	0.001818	**0.001818**	-	Lu et al. (2015)
Cladoceran (<24 hr), *Daphnia magna*	R, U	21 d	PFOS-K ≥98%	7	20	EC10 (survival)	5.657	3.596	**3.596**	-	Liang et al. (2017)
Cladoceran (12-24 hr), *Daphnia magna*	R, U	21 d	PFOS-K 98%	-	20	EC10 (growth-length)	0.8218	0.9093	**0.9093**	-	Yang et al. (2019)
Cladoceran (<24 hr), *Daphnia magna*	R, U	21 d	PFOS >99%	7.5	23	MATC (number of young)	1.581	-	**1.5815**	1.344	Seyoum et al. (2020)
Cladoceran (<24 hr), *Moina macrocopa*	R, U	7 d	PFOS Unreported	-	25	EC10 (number of young / starting adult)	<0.3125	0.1789	**0.1789**	0.1789	Ji et al. (2008)
Amphipod (7-8 d, juvenile), *Hyalella azteca*	R, M	42 d	PFOS-K 98%	7.77-8.10	22.1-22.8	EC10 (survival)	<4.8	**2.899**	**2.899**	2.899	Krupa et al. (2022)
Crayfish (4 wk juvenile, 0.056 g), *Procambarus fallax f. virginalis*	R, M	28 d	PFOS-K ≥98%	-	25	LC20	0.1670	-	**0.1670**	0.1670	Funkhouser (2014)
Blue damselfly (nymph), *Enallagma cyathigerum*	R, U	320 d	Perfluorooctanes ulfonic acid tetraethylammonium >98%	≥7.5	21	MATC (survival at 150 days)	0.03162	-	**0.03162**	0.03162	Bots et al. (2010)
Midge (newly hatched larva), *Chironomus dilutus*	R, M	10 d	PFOS-K 95%	-	21-23	EC10 (growth at 10 days)	0.04920	0.05896	**0.05896**	-	MacDonald et al. (2004)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Chronic Value Endpoint	Author Reported Chronic Value (mg/L)	EPA Calculated Chronic Value (mg/L)	Final Chronic Value (mg/L)[c]	Species Mean Chronic Value (mg/L)	Reference
Midge (4-day old larvae), *Chironomus dilutus*	R, M	16 d	PFOS 98%	6.8-8.7	20.0-23.2	EC10 (mean biomass)	0.001620	0.001588	**0.001588**	-	McCarthy et al. (2021)
Midge (4-day old larvae), *Chironomus dilutus*	R, M	16 d	PFOS-K 98%	7.28-7.75	22.0-22.9	EC10 (growth)	0.0015	-	**0.0015**	0.005198	Krupa et al. (2022)
Mayfly (<24 hr larva), *Neocloeon triangulifer*	R, M	14 d	PFOS-K 98%	-	23	EC10 (dry weight at day 14)	0.000226	-	**0.000226**	0.000226	Soucek et al. (2023)
Atlantic salmon (embryo-larval), *Salmo salar*	F, U	49 d	PFOS 98%	-	5.0-7.0	LOEC (growth – weight and length)	>0.1	-	**>0.1**	>0.1	Spachmo and Arukwe (2012)
Zebrafish (8 hpf), *Danio rerio*	R, U	Life-cycle	PFOS >96%	7.0-7.5	28	EC10 (F1 offspring: % survival)	0.01581[d]	0.01650	**0.01650**	-	Wang et al. (2011)
Zebrafish (male, 3.5 mo), *Danio reio*	R, U	21 d	PFOS Unknown	7.0-7.4	28	EC10 (mean body length)	0.05657	0.06274	**0.06274**	0.03217	Guo et al. (2019)
Fathead minnow (embryo, <24 hpf), *Pimephales promelas*	F, M	47 d	PFOS-K 90.49%	8.2	24.5	EC10 (survival)	0.4243	0.4732	**0.4732**	-	Drottar and Krueger (2000d)
Fathead minnow (adult), *Pimephales promelas*	F, M	21 d	PFOS >98%	7.3	25	EC10 (fecundity)	0.4794	0.05101	**0.05101**	-	Ankley et al. (2005)
Fathead minnow (adult, 5 mo.), *Pimephales promelas*	R, M	42 d	PFOS-K ≥98%	7.9	24.96	EC10 (F1 larval growth – weight)	0.06223	0.0549	**0.0549**	0.1098	Suski et al. (2021)
Swordtail fish (adult female 6-7 mo), *Xiphophorus helleri*	R, U	42 d	PFOS-K >98%	-	27	EC10 (female survival)	1.118	0.5997	**0.5997**	0.5997	Han and Fang (2010)
Northern leopard frog (stage 8/9 embryo), *Lithobates pipiens*	F, M	35 d	PFOS-K 98%	-	20	LC50	6.210	-	6.21		Ankley et al. (2004)
Northern leopard frog (stage 8/9 embryo), *Lithobates pipiens*	F, M	112 d	PFOS-K 98%	-	20	MATC (growth – length)	1.732	-	**1.732**	-	Ankley et al. (2004)

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Chronic Value Endpoint	Author Reported Chronic Value (mg/L)	EPA Calculated Chronic Value (mg/L)	Final Chronic Value (mg/L)[c]	Species Mean Chronic Value (mg/L)	Reference
Northern leopard frog (larva, Gosner stage 26), *Lithobates pipiens*	R, M	40 d	PFOS ≥98%	-	20	MATC (Gosner stage at 40 d)	0.0316	-	0.03162	-	Hoover et al. (2017)
Northern leopard frog (larva, Gosner stage 26), *Lithobates pipiens*	R, M	40 d	PFOS ≥98%	-	20	LOEC (growth – snout-vent length)	>1	-	**>1**	1.3161	Hoover et al. (2017)
African clawed frog (larvae, NF 46/47 – 5 dpf), *Xenopus laevis*	R, M	4 mo.	PFOS 98%	6.5-7.0	22	LOEC (survival, weight, sex ratio/intersex)	> 0.7160	-	> **0.7160**	> 0.7160	Lou et al. (2013)
Clawed frog (embryo, NF 10), *Xenopus tropicalis* (formerly, *Silurana tropicalis*)	F, M	150 d post metamorphosis	PFOS ≥98%	7.5	26	MATC (weight at metamorphosis)	0.7871	-	**0.7871**	0.7871	Fort et al. (2019)

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

[b] Chemical concentrations made in a side-test representative of exposure and verified stability of concentrations of PFOS in the range of concentrations tested under similar conditions. Daily renewal of test solutions.

[c] Values in bold used in SMCV calculation. SMCVs are calculated as the geometric mean of all bold-faced values for a species. See section 2.10.3.2 (Chronic Measures of Effect) for decision rules regarding use of greater (>) and less than (<) values in SMCV calculations.

[d] Author-reported value based on a different test endpoint than the EPA-calculated value.

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C.2 Detailed PFOS Chronic Freshwater Toxicity Study Summaries and Corresponding Concentration-Response Curves (when calculated for the most sensitive genera)

The purpose of this section was to present detailed study summaries for tests that were considered quantitatively acceptable for freshwater chronic water column criterion derivation, with summaries grouped and ordered by genus sensitivity. C-R models developed by the EPA that were used to determine chronic toxicity values used for criterion derivation are also presented for the most sensitive genera when available. The C-R models included with the study summaries were those for the four most sensitive genera (consistent with Section 3.1.1.3). When required, the EPA also included models for non-resident species that were more sensitive than the fourth most sensitive North American resident genus. In many cases, authors did not report C-R data in the publication/supplemental materials and/or did not provide C-R data upon the EPA request. In such cases, the EPA did not independently calculate a toxicity value and the author-reported effect concentrations were used in the derivation of the criterion.

C.2.1 Most Sensitive Freshwater Genus for Chronic Toxicity: *Neocloeon* (mayfly)

Soucek et al. (2023) conducted a chronic life-cycle test to determine the effects of PFOS-K (PFOS potassium salt, CAS # 2795-39-3, 98% purity) on the parthenogenetic mayfly, *Neocloeon triangulifer*. The test was performed under renewal conditions over 27 days beginning with < 24 hour old nymphs. Single mayfly exposures were static without renewal for the first four days due to the small size of starting organisms and then water was renewed three times per week thereafter by transferring organisms to new exposure chambers. From Day 0 to 14, mayflies were exposed in 30 mL polypropylene cups with 20 mL exposure water. Organisms were transferred after 14 days into 250 mL glass beakers with 100 or 150 mL of test water (or control water) and to 300 mL tall form glass beakers for emergence. There were sixteen replicates (with one mayfly per replicate) per test concentration and control. Replicates one

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through eight were destructively sampled on day 14 and replicates nine through sixteen continued until the end of the test (when all mayflies either molted into imago stage or died). The endpoints that were evaluated included survival for all replicates, 14-d length and calculated dry weight (using a previously published body length dry weight equation; Besser et al. 2021) for replicates 1 through 8, and percent survival to pre-emergent nymph (PEN) stage, number of days until PEN stage, percent emergence (to imago stage), and pre-egg laying live weight of imago for replicates 9 through 16. Nominal test concentrations were 0 (control), 0.00016, 0.00031, 0.00063, 0.00125, 0.0025, 0.005, and 0.010 mg/L PFOS. Mean measured PFOS concentrations (EPA Analytical Method 1633; LC-MC/MS) were 0.000056 (control), 0.000205, 0.000418, 0.000764, 0.001143, 0.002057, 0.003892, and 0.006789 mg/L PFOS, respectively. Mayflies were exposed at 23 ± 1°C under a 16:8-hour light:dark cycle and fed 0.2 mL diatom slurry plus small scraping on test Days 0 and 4 followed by live diatom biofilm scraping after Day 4 on solution renewal days. Percent survival in the control after 14 days was 100%. Percent survival of mayflies after 14 days in the remaining seven test concentrations ranged from 79 to 100%. The most sensitive endpoint was 14-day dry weight. The study authors reported three different 14-day dry weight EC_{10} values that were calculated using various point-estimation approaches. The author-reported 14-day dry weight EC_{10} values produced by the various approaches were relatively similar to one another, ranging from 0.000226 (using TRAP [2 parameter, threshold sigmoidal curve]) to 0.000272 mg/L (using log-linear regression, controls excluded). The EPA was not able to fit a reliable model with significant model parameters to the 14-day dry weight C-R dataset and, therefore, relied on the author-reported EC_{10} of 0.000226 mg/L (based on TRAP) as the primary effect concentration. The EPA selected the TRAP-based EC_{10} preferentially over the EC_{10} values based on the two other point estimation approaches (i.e., log-

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linear regression with and without controls) because the TRAP-based model (1) considered control responses; (2) was more fundamentally consistent with the maximum likelihood regression approaches used by the EPA to assess the C-R datasets evaluated in this document, and; (3) relied on replicate-level data, which the EPA used preferentially over treatment-mean data in assessing the C-R datasets. The author-reported EC_{10} of 0.000226 mg/L (TRAP-based) was used in the derivation of the freshwater PFOS chronic water column criterion.

Current toxicity literature indicates that aquatic insects, specifically mayfly, midge, and odonates, are sensitive to PFOS exposures. Further, given that recent research has led to the development of successful culturing methods for mayflies that are now being used in laboratory-based toxicity studies (Soucek and Dickinson 2015; Soucek et al. 2023), new toxicity studies indicate that mayflies (*Neocloeon triangulifer*) are the most sensitive taxa to acute and chronic PFOS exposures. This finding is consistent with other chemical exposures, including major geochemical ions, pesticides, and heavy metals (Johnson et al. 2015; Kim et al. 2012; Raby et al. 2018; Soucek and Dickinson 2015; Soucek et al. 2020; Soucek et al. 2023; Wesner et al. 2014). The high sensitivity of mayflies to contaminant exposures has also been observed in mesocosm-based experiments (Mebane et al. 2020) and field-based surveys (Cormier et al. 2018; U.S. EPA 2011). Many of these laboratory-based toxicity tests used mayflies capable of adapting to laboratory settings, therefore it is hypothesized that mayfly species unable to survive in laboratory settings may also be even more sensitive to contaminant exposures than the relatively hardy mayfly species (e.g., *N. triangulifer*) now commonly being used to toxicity testing. Thus, inclusion of the mayfly toxicity data (Soucek et al. 2023) is important to ensuring the protectiveness of the PFOS aquatic life AWQC.

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Publication: Soucek et al (2023)
Species: Mayfly, *Neocloeon triangulifer*
Genus: *Neocloeon*
EPA-Calculated EC_{10}: unable to fit a reliable model with significant model parameters; author-reported TRAP-based EC_{10} used

C.2.2 Second Most Sensitive Freshwater Genus for Chronic Toxicity: *Chironomus* (midge)

MacDonald et al. (2004) conducted larval sub-chronic partial-life cycle and chronic life-cycle tests to determine the effects of PFOS (potassium salt, 95% purity) on the midge, *Chironomus dilutus* (formally known as *Chironomus tentans*). The test was performed under renewal conditions over 10 days for the larval sub-chronic partial-life cycle test and 60 days for the chronic life-cycle test, with four of the twelve replicates terminated following 20 days of exposure to evaluate survival and growth. The tests followed the general guidance given by EPA-600-R99-064 (U.S. EPA 2000b) and ASTM E 1706-00 (ASTM 2002). These methods are for measuring the toxicity and bioaccumulation of sediment-associated contaminants with freshwater invertebrates and have different exposure durations than those typically considered for invertebrate aqueous exposures, as well as different control survival requirements and recommendations. *C. dilutus* used for the tests were 10-day old larvae for the 10-day exposure (larval sub -chronic partial-life cycle test) and newly-hatched larvae at test initiation for the chronic life-cycle test (both 60-d and 20-day exposures). Dilution water was reconstituted hard water consistent with ASTM (2002) with unspecified total hardness, but typically 160-180 mg/L as $CaCO_3$ (based on ASTM 2002), with alkalinity 110-120 mg/L as $CaCO_3$, and pH 7.6-8.0. The photoperiod was 16:8-hours light:dark. Light intensity was not reported. A primary stock solution was proportionally diluted with dilution water to prepare the test concentrations. Exposure vessels were 250 mL polypropylene beakers containing 240 mL of test solution and a sediment substrate. The 10-day exposure test employed at least two replicates with 10

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individuals all of which were obtained from four large C-shaped egg cases that were distributed among seven test solutions plus a negative control. The life-cycle test (60-day exposure) employed 12 replicates of 12 midges each in five measured test solutions plus a negative control. From these 12 replicates, four were randomly terminated following a 20-day exposure to measured survival and growth endpoints (thereby referred to as the 20-day exposure henceforth) The remaining eight replicates were monitored over the test duration for emergence and reproduction. Nominal test concentrations for the 10-day test were 0 (negative control), 0.001, 0.005, 0.010, 0.020, 0.040, 0.080, and 0.150 mg/L. The nominal test concentrations for the 20-day exposure were 0 (negative control), 0.001, 0.005, 0.010, 0.050, and 0.100 mg/L. Mean measured concentrations for the 10-day test were 0 (LOQ not reported), 0.0008, 0.00460, 0.0115, 0.241, 0.0491, 0.0962, and 0.1501 mg/L, respectively. Mean measured concentrations for the 20-day exposure were 0 (LOQ not reported), 0.0023, 0.0144, 0.0217, 0.0949, and 0.149 mg/L, respectively. Analyses of test solutions were performed using LC-MS. The mean percent recovery and detection limits were not reported. Measured values of test concentrations in the 20-day exposure were 2 to 2.5-fold higher than nominal concentrations. Temperature and D.O. concentrations were measured in at least two replicates per treatment on a daily basis for the 10-day test and up to day 20 in the life-cycle test. Afterwards they were measured every other day (on alternate days from test solution renewal) from days 21 to 60 for the life-cycle test. The frequency of monitoring was reduced during this period, because both parameters consistently remained within acceptable ranges (21.0-23.0°C; D.O. >5.0 mg/L). Survival of negative control animals was >75%, which was considered acceptable for a full life-cycle exposure per ASTM (2002). The study authors reported EC_{10}s and NOECs; however, specific details pertaining to the

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curve fitting process (including statistical output from the models and the curves) were not provided in the paper and therefore, limit independent interpretation of the toxicity values.

The observed effects of PFOS on *C. dilutus* reported in the paper by the study authors include survival and growth as weight (measured as mg of ash-free dry mass per individual) for both the 10-day and 20-day exposure durations and emergence and reproduction over the 60-day exposure duration. Significant reductions in larval weight were observed after 10 days of exposure to PFOS in the 0.0962 and 0.1501 mg/L treatment groups (roughly 0.38 and 0.19 mg, respectively) compared to the control group (roughly 0.88 mg). These differences resulted in roughly a 56.8 and 78.4% decline in midge weight in these treatment groups compared to those observed in the control. In contrast, there were no significant differences reported for survival between any of the PFOS treatments (with percent survival ranging between roughly 69.7% in the highest treatment group and 100% in the lowest) and the control (with roughly 100% survival). However, the authors noted that there was a 30% decline of midge survival in the highest PFOS treatment group with a measured concentration 0.1501 mg/L. The author-reported 10-day growth and survival EC_{10}s for the study were 0.0492 and 0.1079 mg/L, respectively. The study authors also reported NOECs of 0.0491 mg/L, LOECs of 0.0962 mg/L, and MATCs of 0.0687 mg/L for both endpoints.

Similar to the 10-day exposure results summarized above, there was a general decline in growth (as ash-free dry mass per individual) across the PFOS treatment groups (ranging roughly between 29.2 and 47.2% reduction compared to controls) in the 20-day exposure (chronic life-cycle test). However, only the decline in the 0.0949 mg/L treatment group was significantly different (roughly 0.29 mg) compared to the control (roughly 0.89 mg) and there was not a C-R relationship across the PFOS treatment groups. Additionally, midge survival was reduced after

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20 days of exposure to PFOS in the 0.0949 and 0.149 mg/L treatment groups (29.2 and 0% survival, respectively) compared to the control (75% survival). Survival was determined to be not significantly different across the rest of the PFOS treatment groups (ranging roughly between 56.5 and 75% survival) compared to the control. However, it should be noted that there was a 25% decline in survival in the 0.0217 mg/L PFOS treatment group compared to the control that was determined not to be significantly different. The author-reported 20-day EC_{10}s for growth, survival, and total emergence were 0.0882, 0.0864, and 0.0893 mg/L, respectively, and the study authors also reported NOECs of 0.0217 mg/L for growth and survival and < 0.0023 mg/L for emergence, LOECs of 0.0949 mg/L for growth and survival and 0.0217 mg/L for emergence, and MATCs of 0.0454 mg/L for growth and survival and 0.0071 mg/L for emergence. Also, it should be noted, the paper reports contrasting NOECs for 20-day survival. The text in the paper stated that the NOEC was 0.0217 mg/L for growth and survival and Table 2 of the paper stated 0.0949 mg/L. The EPA assumed the NOEC in Table 2 of the paper was not correct and that 0.0217 mg/L was the correct NOEC based on the data presented in Figure 3A of the paper. This assumption was applied to the summary of the study results presented in this document.

Independent statistical analyses were conducted for both the 10-day (larval sub-chronic partial-life cycle test) and 60- and 20-day (chronic life-cycle test) exposure durations using data that were estimated (using Web plot digitizer) from the figures presented in the paper. The EPA could not fit a curve to independently verify the 10-day survival (due to a lack of a specific sample size for this endpoint as the number of replicates was not stated in the paper; however, the number of replicates was between two and four and the EPA sought to obtain clarification and treatment level data from the study authors) or the 20-day growth toxicity values (due to a lack of an observed C-R for this endpoint). However, the EPA-calculated 10-day EC_{10} for

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growth was 0.05896 mg/L, which was slightly higher than the growth-based EC_{10} of 0.0492 mg/L reported in the paper. The chronic life-cycle EC_{10}s for larval survival (following 20 days of exposure) and emergence (with 60 days of exposure) were 0.0171 and 0.0102 mg/L, respectively. These chronic life-cycle EC_{10}s were much lower than those reported in the paper of 0.0864 and 0.0893 mg/L, respectively. The EC_{10}s for survival and emergence endpoints from the chronic life-cycle test were not considered to be reliable endpoints at this time given the disparities in the calculated EC_{10}s and the level of data that was presented in the paper, which made independent verification of the toxicity values less accurate. Specifically, for the 20-day survival endpoint, there appeared to be overdispersion (i.e., observed data display a larger variability than would be expected given an assumed statistical distribution about the mean response) in the data as it was presented in the paper (in Figure 3A of the paper), which adds uncertainty around the independently-calculated EC_{10} of 0.0171 mg/L and may explain the disparity between the reported EC_{10} and the EPA's independently-calculated value. As for the 60-day emergence endpoint, there was a lack of a C-R relationship and there were very similar levels of observed effects (which ranged between 42.6 and 50.1%) despite the more than nine-fold increase in the mid-range treatment concentrations (0.0023, 0.0144, 0.0217 mg/L, respectively). Lastly, the toxicity values from the observed effects from the chronic life-cycle exposure were considered to be less certain given the relatively large difference between the nominal and measured concentrations for this test. The dosing of the chronic life-cycle test (20- and 60-day exposure) was more of a concern than the larval sub-chronic partial-life cycle test (10-day exposure), which had measured concentrations that were much more in line with the expected nominal concentrations. Thus, the survival and emergence endpoints from the chronic life-cycle test were not considered for quantitative use in the derivation of the freshwater chronic

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water column criterion. Instead, these endpoints were considered as supporting information until detailed replicate level data can be obtained from the study authors.

The most sensitive endpoint from the remaining toxicity values that could be independently calculated was for 10-day growth with an EC_{10} of 0.05896 mg/L. As mentioned in the Bots et al. (2010) summary in Section C.2.4 below, the observed effects of PFOS on aquatic insects appears to be consistent across the available data for chironomids and odonates. However, Bots et al. (2010) did not measure the effects of PFOS on nymph growth and therefore, the observed effects in MacDonald et al. (2004) on larval weight cannot be compared across the two studies. The EC_{10} of 0.05896 (0.05769 – 0.06023) mg/L for 10-day growth was used quantitatively to derive the freshwater chronic water column criterion. The remainder of the toxicity values were used as supporting information to corroborate the toxicity value used and to better understand the effects of PFOS on aquatic insects.

McCarthy et al. (2021) conducted a 10-day range-finding toxicity test and a separate 20-day (note, based on age of starting organisms, this test was actually 16 or 19 days of exposure) "abbreviated partial-life cycle" toxicity test with PFOS (98% purity, purchased from Sigma-Aldrich) on the midge, *Chironomus dilutus*. PFOS stock solution was dissolved in reconstituted moderately hard water without the use of a solvent and stored in polyethylene at room temperature until use. Two chronic exposures with PFOS were run, a 10-day and a 20-day exposure, following standard protocols (U.S. EPA 2000b) with slight modifications. The 10-day exposure was considered a range-finding test, with concentrations spaced by ~100x and only mortality measured, whereas the 20-day exposure measured both survival and growth. The 20-day exposure is less than the recommended 65-day full-life cycle method outlined in U.S. EPA (2000b) and since exposures of midges started on day two or four the actual exposure duration is

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only 16 or 19 days long; therefore, the study authors referred to this test as an "abbreviated partial-life cycle test". Exposure vessels for both experiments were 1 L high-density polyethylene beakers containing natural-field collected sediment. The 10-day exposure had 60 mL of sediment and 105 mL of test solution and the 20-day exposure had 100 mL of sediment and 175 mL of test solution. PFOS in test solutions was added via pipette to the beakers with the tip just above the sediment substrate. Nominal test concentrations for the 10-day and 20-day exposure were 0, 0.0004086, 0.33, 33, 100 and 350 mg/L PFOS and 0, 0.001, 0.005, 0.01, 0.05 and 0.1 mg/L PFOS, respectively. Egg cases were obtained from outside suppliers (Aquatic Biosystems or USGS Columbia Environmental Research Center) and held for 10 days in the 10-day test or held for four days before testing in the 20-day exposure (in test vessels). In the 20-day exposure the test organism age (four-day old larvae) was greater than the protocol recommendation (< 24 hour) because earlier experiments had control survival issues (< 70%). In both tests each beaker held 12 organisms with five replicates per exposure treatment. Solutions were renewed every 48 – 72 hours in the 10-day exposure and daily for the 20-day exposure. Water samples of test concentrations were measured on day one and day 10 in the 10-day exposure and day 10, 15 and 20 in the 20-day exposure. In the 10-day exposure measured test concentrations ranged from 7 – 62% of nominal. In the 10-day exposure, the author-reported LOEC, based on mortality, of 0.4086 µg/L (0.0004086 mg/L PFOS) is reported as a nominal concentration. Mean PFOS concentrations in the 20-day exposure were 0 (control), 0.000447, 0.00209, 0.0042, 0.0231 and 0.0463 mg/L PFOS. Results of the *C. tetans* 16- to 19-day "abbreviated full life cycle test" were used preferentially over the results of the 10-day range-finding test to inform the chronic sensitivity of *C. tetans* because: (1) the 10-day range-finding test only measured survival, (2) the 10-day range-finding test had exposure concentrations that

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differed by up to a factor of 100, which make C-R modeling more difficult than the dilution series in the16- to 19-day test, and (3) the 16- to 19-day test was a longer exposure duration that was more akin to a full life-cycle test. Consequently, the results of the 10-day range finding test were not used quantitatively to derive the freshwater chronic water column criterion, but they were retained for qualitative use.

From the 16- to 19-day "abbreviated full life cycle test" percent survival in the control and lowest test concentration were 77% with no survivors reported in the highest two test concentrations. The most sensitive endpoint appeared to be survival with an author-reported 16-day reported EC_{10} of 1.36 µg/L (0.00136 mg/L PFOS). Additionally, the authors reported EC_{10}s of 1.62 µg/L (0.00162 mg/L PFOS) and 3.23 µg/L (0.00323 mg/L PFOS) for growth as mean biomass and mean weight, respectively. The EPA was unable to independently calculate EC_{10}s for survival and mean weight. However, the 16- to 19-day independently-calculated EC_{10} value for mean biomass was 0.001588 (0.00118 – 0.00200) mg/L PFOS. This independently-calculated EC_{10} was acceptable for quantitative use and was used in the derivation of the freshwater chronic water column criterion.

Krupa et al. (2022) conducted a partial-life cycle chronic toxicity test with the midge, *Chironomus dilutus*, and PFOS-K (perfluorooctanesulfonate potassium salt, > 98% purity, CAS No. 2795-39-3, purchased from Sigma-Aldrich). *C. dilutus* egg masses obtained from Aquatic Biosystems (Fort Collins, Colorado, USA) were placed in 12-inch glass culture bowls (2 – 3 egg mases per dish) containing carbon-filtered municipal tap water and examined daily for viability and hatch. Hatching began after 2 days and larvae typically left the egg case 24-hours after the first hatch. The larvae were fed daily finely ground TetraMin® fish food flakes (~150 mg/dish as a slurry) with partial water changes as necessary until the larvae were the appropriate age for

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initiating the test (4-days old). The larvae were exposed to PFOS for 16 days. A 100 mg/L PFOS-K stock solution was prepared by dissolving PFOS-K salt into ultrapure water using a stir bar and stir plate for >20-hours. Controls and PFOS solutions were then prepared using carbon filtered dechlorinated tap water. Each test concentration was individually spiked rather than serially diluted to reduce PFOS waste generated. All test solutions for water renewals were prepared the day before test initiation. The measured exposure concentrations were < LOD, 0.001, 0.0025, 0.004, 0.0075, 0.016 and 0.03 mg/L, with 5 replicates of 12 animals per replicate for each concentration. Tests were conducted in 300 mL polycarbonate beakers containing approximately 200 mL of exposure solution under a 16:8-hour light:dark cycle in an environmental chamber maintained at 22.5 ± 1°C. Each beaker received 50 mL of clean silica sand (250 – 500 µm) as substrate. Aeration was provided and larvae were fed finely ground TetraMin® (6 mg/day, added as a slurry in dechlorinated water). Partial water renewals (150 mL of solution was exchanged) were conducted three times per week, after 48 or 72-hour periods. At test termination, larval survival was assessed, and ash-free dry weight (AFDW) was determined following ASTM (2019). The AFDW of five groups of 12 larvae was measured at test initiation to establish a baseline for growth. The temperature, D.O., pH, and total hardness test values ranged from 22.0 - 22.9°C, 7.29 - 8.05 mg/L, 7.28 - 7.75 SU and 52 - 62 mg/L as $CaCO_3$, respectively. Water samples for verification of PFOS concentrations were collected at test initiation (day 0) and termination (day 16), in addition to before (out-water) and after (in-water) every renewal of test solution. Water samples from days 0, 6, 10, and 16 were analyzed to verify PFOS concentrations. The author-reported 16-day growth EC_{10} was 0.0015 mg/L PFOS-K. The EPA was unable to fit a reliable model for any of the chronic endpoints from this test. Therefore,

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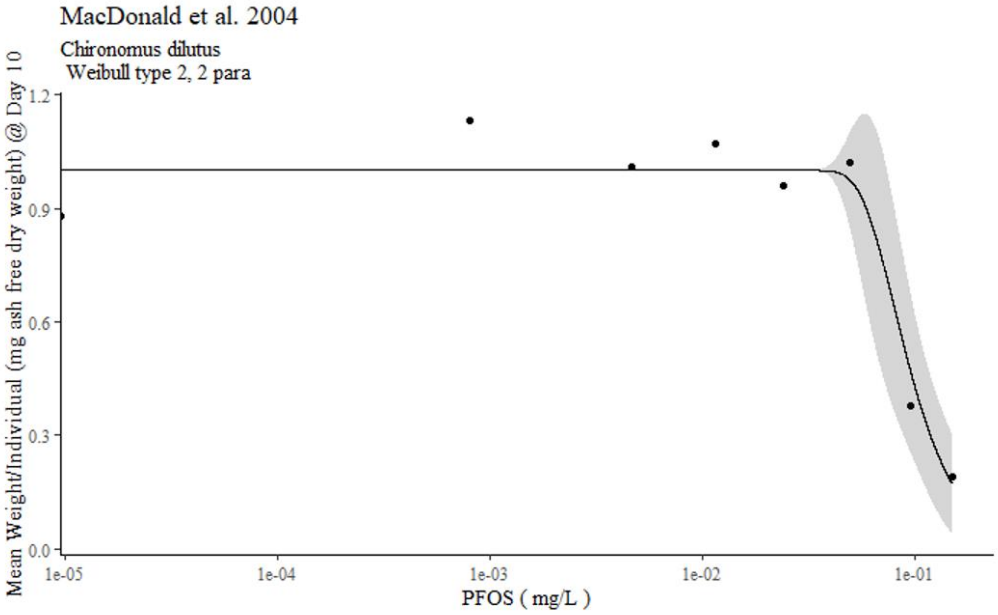
the author-reported EC_{10} value of 0.0015 mg/L for growth was used to derive the freshwater chronic water column criterion.

C.2.2.1 MacDonald et al. (2004) Concentration Response Curve – Chironomus (midge)

Publication: MacDonald et al. (2004)
Species: Midge (*Chironomus dilutus*)
Genus: *Chironomus*
EPA-Calculated EC_{10}: 0.05896 (95% C.I. 0.05769 – 0.06023) mg/L
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	-2.6770	0.6384	-4.1933	0.0057
e	0.0805	0.0090	8.9243	0.0001

Concentration-Response Model Fit:

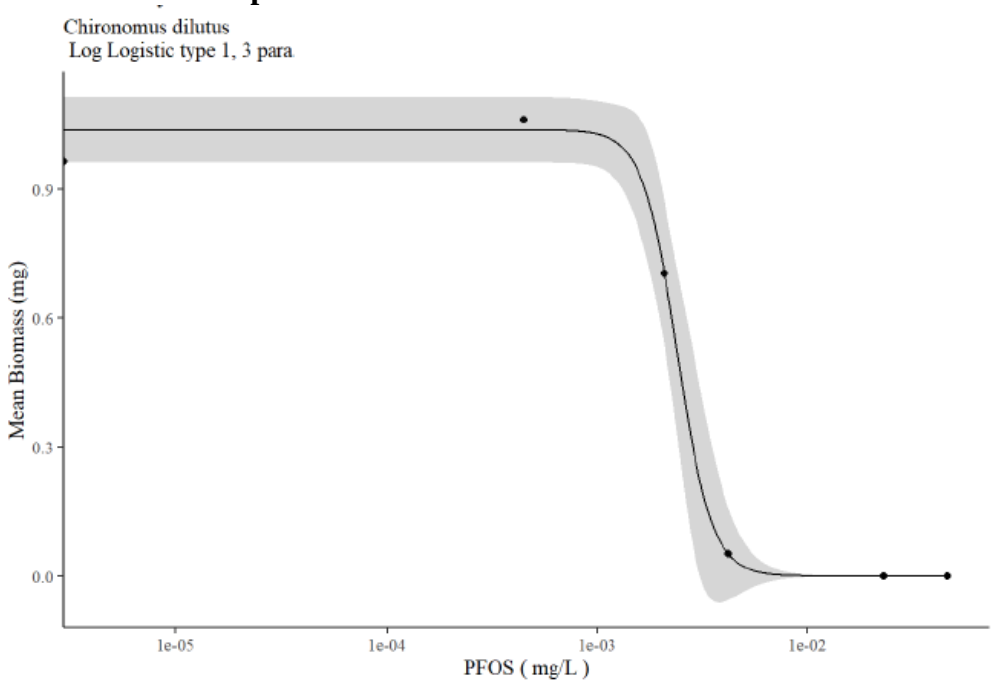


C.2.2.2 McCarthy et al. (2021) Concentration Response Curve – Chironomus (midge)

Publication: McCarthy et al. (2021)
Species: Midge *Chironomus dilutus*
Genus: *Chironomus*
EPA-Calculated EC_{10}: 0.001588 (95% C.I. 0.00118 – 0.00200) mg/L
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	5.2881	1.0432	5.0693	0.0148
d	1.0372	0.0238	43.4942	$2.675\ e^{-5}$
e	0.0024	0.0001	21.9936	0.0002

Concentration-Response Model Fit:



C.2.2.3 Krupa et al. (2022) Concentration Response Curve – Chironomus (midge)

Publication: Krupa et al. (2022)
Species: Midge, *Chironomus dilutus*
Genus: *Chironomu*
EPA-Calculated EC_{10}: unable to fit a reliable model with significant model parameters; author-reported EC_{10} used

C.2.3 Third Most Sensitive Freshwater Genus for Chronic Toxicity: *Lampsilis* (mussel)

Hazelton (2013); Hazelton et al. (2012) conducted a test of the long-term effects of PFOS (acid form, > 98% purity) on glochidia and juvenile life stages from the mussel *Lampsilis siliquoidea*. To initiate the PFOS partial life-cycle test, brooding females were collected from Perche Creek, Missouri and shipped over night to the test laboratory. The length of time between collection from Perche Creek and shipment was not reported, and authors were unable to recall such details (R. Bringolf, personal comm.); however, the EPA did not believe storage, shipping, and handling compromised test results since study authors only relied on those mussels with >70% glochidia viability. Dilution water was dechlorinated tap water. Mean total hardness (47.5 ± 9.2 mg $CaCO_3$/L) and alkalinity (34.8 ± 4.1 mg $CaCO_3$/L) were measured by titration twice weekly (n = 8) prior to water changes. Replicates used for water quality measurements were changed daily to allow measurements from all four replicates every four days. For all treatments, water temperature ranged from 14.6 to 16.1°C, D.O. ranged from 6.1 to 7.3 mg/L, and pH ranged from 7.6 to 8.5, but did not differ across treatments. Photoperiod and light intensity were not reported. No details were provided regarding primary stock solution and test solution preparation. The test exposed brooding glochidia (in marsupia) for 36 days followed by a 24-hour exposure of free glochidia. Experiments were conducted in 3.8 L glass jars of unspecified fill volume. The 36-day *in marsupia* exposure test employed four replicates individually containing single brooding females for each of the two PFOS treatment groups plus the control. The *in marsupia* exposure was followed by a 24-hour free glochidia exposure consisting of a factorial design, such that free glochidia from the control group of the *in marsupia* exposure were divided between a control and the two PFOS treatments and the PFOS treatments were split into control and the same PFOS treatment group as the *in marsupia* exposure. This factorial design allowed for the comparison of PFOS effects in two different life stages. However, it

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should be noted that glochidia were pooled from females within each *in marsupia* treatment group, and thus the influence of parental effects could be a confounding factor that cannot be separated from the PFOS effects. Nevertheless, the influence of the potential parental confounding factor was likely to be minimal compared to the effects of the PFOS exposures.

Nominal concentrations throughout the exposures were 0 (negative control), 0.001 and 0.100 mg/L. Mean measured concentrations were 0.00211 (negative control), 0.00452 and 0.0695 mg/L. Analyses of test solutions were performed at the U.S. EPA National Exposure Research Laboratory in Research Triangle Park, NC using HPLC/MS. Two standard curves were used to quantify PFOS water concentrations during the experiment: low range (0.00005, 0.00025, 0.0005, 0.00075, 0.001, 0.0025, 0.005 mg/L) and high range (0.001, 0.005, 0.010, 0.025, 0.050, 0.100, 0.150 mg/L). Two replicate samples were measured at each standard concentration. Accuracy (recovery) of PFOS in the low-range standard curve ranged from 89.5 to 123% (n = 7) and for the high-range standard curve accuracy was 85.3 to 123% (n = 7). Adult mussel and glochidia survival in the negative control was 100% and > 90%, respectively. The study authors determined that the *in marsupia* exposure held the greatest weight of evidence and explained 78% of the variability in the glochidia viability (AIC = 22843, w_i = 0.78) and 83% of the metamorphosis success (AIC = 21955, w_i = 0.83), and therefore it appeared that the data presented in the study are in terms of the *in marsupia* exposure alone and there are no data presented in terms of the factorial design during the 24-hour free glochidia exposure. Additionally, the specific treatment groups of the data presented in the paper are unclear in terms of the factorial design during the 24-hour free glochidia exposure (e.g., it is unclear if the data presented in Figure 2 of the paper are lumped according to marsupial exposure, reducing seven

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treatments to three, or if only the data in which the *in marsupia* and free glochidia exposures were the same are presented).

The test resulted in an author-reported NOEC of 0.0695 mg/L, which was associated with a 38% reduction in the viability of free glochidia at 24 hours post removal from females, a point when control viability of free glochidia was > 80% (author reported LOEC and MATC > 0.0695 mg/L). While a 38% reduction was observed at the NOEC (0.0695 mg/L) treatment group compared to controls, the authors reported this reduction was not statistically different from the control. Over time, the study authors reported significant reductions in free glochidia survival between three- and seven-days post removal from females, indicating a potential LOEC < 0.0045 mg/L. However, it should be noted that the observed level of effect between the two PFOS treatment groups (0.0045 and 0.0695 mg/L) were extremely similar despite the 15-fold difference between treatment groups. Additionally, in accordance with the decision rule described in Section 2.10.3.2 and a study by Bringolf et al. (2013), only glochidia toxicity data within 24 hours and with survival of at least 80% in the control treatment would be considered (U.S. EPA 2013). These specific data requirements ensured that the related effects of PFOS exposure to the viability of glochidia were consistent with environmental exposures during this short life stage and also take the unique life cycle of mussels into account. Therefore, the chronic toxicity value for viability of free glochidia at 24 hours following removal from females resulted in a NOEC of >0.0695 mg/L, which is an uncertain value and indicated that viability of free glochidia at 24 hours was a less sensitive endpoint.

In contrast, the data presented in the paper for metamorphosis success suggest a NOEC of 0.0045 mg/L and a LOEC of 0.0695 mg/L, or MATC = 0.01768 mg/L. The reduction in metamorphosis success at the LOEC was estimated to be 35.4%. However, as there were only

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two PFOS treatment groups and the gap in these exposure concentrations is large (about 15-fold), the EPA was not able to fit a curve to estimate an EC_{10} in a manner similar to the other toxicity studies used to derive the freshwater chronic water column criterion. Instead, both the use of an MATC and an estimated EC_{10} were considered for the chronic value. An EC_{10} was estimated by assuming the 0.0695 mg/L treatment represents an $EC_{35.4}$ and estimating the EC_{10} using the exposure response slope from another chronic PFOS toxicity study focused on another mussel species (*Perna viridis*). Specifically, the chronic exposure of *Perna viridis* reported by Liu et al. (2013), which is summarized in Section 3.1.1.4.1 and D.2.1, was used to derive a ratio of $EC_{10}/EC_{35.4}$ values from that study equal to: $EC_{10}/EC_{35.4} = 0.0033/0.0186 = 0.1774$. Applying this ratio to Hazelton et al. (2012) yields an estimated EC_{10} of 0.0123 mg/L. Given the similarity between this EC_{10} and the author-reported MATC for metamorphosis success of 0.01768 mg/L, the latter was used to derive the freshwater chronic water column criterion. While this MATC is currently used quantitatively to derive the chronic water column criterion, the EPA hopes to further refine this estimated EC_{10} by obtaining the treatment level data from the study authors and exploring additional exposure response slopes from the study-specific dataset.

C.2.3.1 Hazelton et al. (2012) Concentration Response Curve – Lampsilis (mussel)

Publication: Hazelton et al. (2012)
Species: Fatmucket, *Lampsilis siliquoidea*
Genus: *Lampsilis*
EPA-Calculated EC_{10}: 0.0123 mg/L
Concentration-Response Model Fit: Concentration-response data not available
Value used Quantitatively in Criterion: Author-reported MATC of 0.01768 mg/L

C.2.4 Fourth Most Sensitive Freshwater Genus for Chronic Toxicity: *Enallagma* (damselfly)

Bots et al. (2010) conducted a 320-day partial life-cycle study under renewal test conditions to assess the effects of PFOS (tetraethylammonium salt, 98% purity) on the damselfly

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Enallagma cyathigerum. Test organisms were obtained by collecting mature female *E. cyathigerum* all from the same location near the edge of a fen (a groundwater fed wetland) in northern Belgium. After collection, females were transported to the laboratory in small cages and housed in oviposition chambers for 24 hours before eggs were collected. *E. cyathigerum* used for the test were newly-hatched nymphs at test initiation. Dilution water was dechlorinated tap water that contained only a negligible concentration of PFOS (2.64 ng/L) and no other water quality parameters from the tap water were provided other than pH ≥7.5. Photoperiod was 16:8-hours light:dark in a climate room. Light intensity was not reported. Test solutions were prepared taking purity into account. To start the test, a total of 18,552 eggs were distributed amongst 150 exposure chambers (i.e., petri dishes of unreported size and material type). The distribution of the total number of eggs consisted of the entire clutch from each of the 30 females being divided into five subsamples, which were then randomly allotted to the various test treatments; thereby ensuring that each treatment group consisted of an even distribution of test organisms from the 30 females. After hatching, a total of 7,938 nymphs continued to be exposed (10 individuals per cup of unreported size and material type). After 10 days, seven nymphs for every female and treatment were monitored (resulting in a total of 741 nymphs). Nominal concentrations were 0 (negative control), 0.01, 0.1, 1.0, and 10 mg/L. Actual test concentrations were not measured. All nymphs were housed (and presumably tested) in a climate room at 21°C. Water quality (pH, carbonate and total water hardness, O_2, NO_2, and NO_3 levels) was checked weekly using standard aquarium tests, but values are not reported. Approximately 40% of the nymphs in the control treatment died during the first 60 days and similar mortality levels were observed in the other treatments. Additionally, it appears that control survival plateaued between 60 and 200 days, with 82.57% of the remaining nymphs in the control treatment surviving during this time,

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indicating that survival settled out during this phase of the experiment. The initial drop in nymph survival can likely be attributed to the handling of the test organisms between the various phases of the experiment. This would explain the observed plateau between 60 and 200 days, as the nymphs were not handled during this time. The observed control mortality in this test was consistent with other odonate tests and excessive mortality of nymphs is typically expected within the first 200 days given the difficulty in maintaining odonates in a lab setting (Abbott and Svensson 2007; Rice 2008). Therefore, the observed control survival for this study was considered within the acceptable range for this species up to the 200-day exposure duration. Further, the control survival observed in this study was largely consistent with the toxicity testing guidelines for chironomids (requiring 70% control survival)(ASTM 2002; U.S. EPA 2002), which represent the only test guidelines for an emergent aquatic insect species as similar test guidelines for odonates are not available. Therefore, considerations regarding the use of these data for chronic water column criterion derivation was based on best scientific judgement and were restricted to the first 200 days of the experiment. After 200 days, nymph survival in the control and the PFOS treatments decreased. This drop in survival likely coincided with metamorphosis. However, control survival at the end of the exposure duration was only roughly 40% of the starting nymphs and therefore, survival after 200 days of exposure was not considered a viable test endpoint for this particular study.

The other possible observed effects of PFOS on *E. cyathigerum* reported by the authors included decreased survival over the exposure duration and decreased metamorphosis success. Nymph survival after five days did not differ between the control, 0.01 and 0.100 mg/L treatments and was significantly lower in the 1.0 and the 10.0 mg/L treatments. After 10 days of exposure, 80% of the nymphs in the 1.0 mg/L treatment and all nymphs in the 10 mg/L treatment

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died. After 20 days of exposure, all nymphs in the 1.0 mg/L treatment died. However, there was no observed statistical difference between the control and any of the other treatment groups during this exposure time through 120 days. Between 120 and 250 days of exposure there was not an observed difference in survival between the control and the lowest treatment group (0.01 mg/L). In contrast, nymph survival in the 0.100 mg/L treatment group started to decrease compared to the control and the 0.01 mg/L treatment group, with 60% survival in the control compared to 48.5% survival in the 0.100 mg/L treatment after 150 days of exposure. This decrease was statistically significantly different from controls. All nymphs in the 0.100 mg/L treatment group died within 250 days of exposure. While nymph survival in the control was roughly 40% at the end of the 320-day exposure duration, there was no observed difference between the control and the lowest treatment group of 0.01 mg/L. Lastly, the paper also reported observed effects of PFOS on metamorphosis success stating that metamorphosis success was lower with 75.5% success in the 0.01 mg/L treatment (the only treatment group to have nymphs survive to this life stage) compared to the control with 92.5%. However, data for this observed endpoint was not provided in the paper beyond the percentages observed in the control and 0.01 mg/L PFOS treatment group. The specific sample sizes for this endpoint were difficult to ascertain from the paper as only the total number of test organisms across all test treatments was provided.

As indicated in the summary of the results above, toxicity values through the experiment decline with exposure duration. The EPA took all of the author-reported toxicity values between 10 (which was considered to be the start of the chronic exposure) and 200 days of exposure into account. Independently-calculated EC_{10} values could not be determined given the level of data that were presented in the paper. Author-reported toxicity values after 10 days of exposure were

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a NOEC of 0.1 mg/L and a LOEC of 1.0 mg/L. The LOEC was associated with a 79% decrease in nymph survival compared to the control at this time. This NOEC and LOEC resulted in a MATC of 0.3162 mg/L. Author-reported toxicity values after 150 days of exposure were a NOEC of 0.01 mg/L and a LOEC of 0.1 mg/L. The LOEC was associated with a 19% decrease in nymph survival compared to the control at this time. This NOEC and LOEC resulted in a MATC of 0.03162 mg/L. Lastly, the authors also reported a NOEC of 0.01 mg/L for survival and an LOEC of < 0.01 mg/L for metamorphosis success after 320 days of exposure. Both of these toxicity values fell outside the 200-day exposure duration and were not considered for use in the freshwater chronic criterion calculation since control survival at this point was low (40%) and considered unacceptable for quantitative use. Additionally, there was insufficient data provided in the paper to evaluate the reported results for the endpoints at 320 days of exposure. Therefore, these toxicity values were considered as supporting information and only the toxicity values from 10 to 200 days of exposure range were considered further for chronic water column criterion derivation.

The 150-day MATC of 0.03162 mg/L for nymph survival was similar to the author-reported 10-day and 20-day survival and growth MATCs of 0.0687 and 0.0454 mg/L for chironomid (MacDonald et al. 2004), and these later toxicity values were therefore more comparable than the 10-day MATC of 0.3162 mg/L for nymph survival, which was focused on the effects of PFOS on a much earlier instar of odonate (which has a much longer development time and life span) in relation to the 20-day MATC of 0.0454 mg/L for chironomid. These results indicated that PFOS effects to the two aquatic insects was likely similar; however additional data are needed to fully understand the effects of PFOS to odonates. The MATC for nymph survival at 150-day reported above was used quantitatively to derive the chronic water column criterion.

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Additionally, the EPA ran additional analyses with some of the other toxicity values for *E. cyathigerum* to understand the influence of this study on the overall chronic criterion (see Section 4.1).

C.2.4.1 Bots et al. (2010) Concentration Response Curve – Enallagma (damselfly)

Publication: Bots et al. (2010)
Species: Damselfly, *Enallagma cyathigerum*
Genus: *Enallagma*
EPA-Calculated EC_{10}: Not calculable, concentration-response data not available

C.2.5 Fifth Most Sensitive Freshwater Genus for Chronic Toxicity: *Danio* (zebrafsh)

Wang et al. (2011) evaluated the full life-cycle effects of PFOS (> 96% purity) on *Danio rerio* via a static-renewal study that reported nominal exposure concentrations. This test evaluated the effects of PFOS on a parental (F0) generation and included breeding trials to assess the effects of PFOS on an offspring (F1) generation exposed via maternal transfer. PFOS stock solutions were prepared in 100% dimethylsulfoxide (DMSO). Adult zebrafish (wild-type strain AB) were raised and kept at standard laboratory conditions of 28°C with a 14:10-hour light:dark cycle in a recirculation system according to standard zebrafish culture protocols. Water supplied to the system was filtered by reverse osmosis (pH 7.0-7.5), and Instant Ocean salt was added to the water to raise the conductivity to a range of 450 to 1,000 µS/cm (system water). Zebrafish embryos were obtained from spawning adults in tanks overnight with a sex ratio of 1:1. Embryos were collected within one hour after spawning and rinsed in embryo medium. High-quality 8-hpf embryos were divided into four treatment groups: DMSO vehicle control (0.01% v/v), and PFOS concentrations of 0.005, 0.050, and 0.250 mg/L. Embryos were first exposed to PFOS in a petri dish (100 embryos/treatment) for five days without media change, and all embryos hatched and survived in this stage. After five days, the fish were transferred into 2 L tanks for the period of 5-dpf to 30 dpf, and after that were raised in 9 L tanks (30 fish/tank) until the end of the

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experiment, 150 dpf. Fish were kept in a static system, and 50% water was renewed with freshly prepared solutions every five days. Each tank was checked for morbid fish on a daily basis, and water quality was monitored on a weekly basis. Feeding was initiated at day five. Between five and 14 dpf, fish were fed three times daily with zebrafish larval diet (Aquatic Habitats), and after 14 dpf they were fed twice daily with freshly hatched live *Artemia*. The experiment was repeated three times with embryos derived from different parental stocks. At the end of exposure period (150 dpf or five months), all fish were checked for their sex. However, the method used for determining sex, as either external morphology or genetic testing, was not stated in the paper. The EPA assumed external morphology was used and concluded that the effects on sex ratio may not be reliable since determining sex through external morphology in zebrafish is difficult. A subsample of 10 male and 10 female fish from each batch were also measured for standard body length and wet weight. Condition factor (K) was tabulated to determine their overall fitness, and sperm motility in male F0 fish was also determined after chronic PFOS exposure. The most sensitive endpoint was F0 parental male sperm density with a chronic value of <0.005 mg/L PFOS. However, as sperm density was not typically considered an apical endpoint and the reported effects of PFOS on sperm density did not translate to other reproductive effects (i.e., fertilization), this endpoint was not considered further. Instead, the most sensitive apical endpoint for the F0 generation was considered to be male growth (length and weight) with an author-reported MATC of 0.01581 mg/L PFOS. However, the EPA was unable to fit a C-R curve with significant model parameters for the male growth endpoints; and therefore, was unable to independently verify the reported toxicity value for the F0 generation.

Breeding trials were also carried out to produce F1 offspring. Six different crosses were employed between F0 females and males to incorporate both the exposure of the same treatment

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groups throughout and crosses between the control and highest treatment group. Specifically, for the groups exposed to the same treatment throughout the experiment, females were paired with males in the same treatment group (DMSO control or PFOS-exposed concentrations of 0.005, 0.050, and 0.250 mg/L). For the crosses between the control and the highest treatment group, some females from the 0.250 mg/L PFOS treatment group were paired with males from the DMSO controls, and some females from the controls were paired with males from the 0.250 mg/L PFOS treatment group. For each of these crosses, eight randomly selected female fish were paired with four male fish in two separate spawning tanks with four females and two males per tank. Spawning was induced every other day for five days, and embryos were used for monitoring their developmental progress. All eggs from each spawn were evaluated for fertilization success. Percent fertilization was expressed as the number of fertilized eggs divided by total number of eggs. Fifty fertilized embryos from each spawn were further monitored for continuous development. Percent hatch was calculated at 72 hpf. Larvae were also assessed for their morphological appearance. Percent survival was monitored until 8 dpf. Surviving larvae at 5 dpf with normal morphology were further subjected to behavior assessment (larval swimming speeds were recorded when they responded to a 70-minute dark to light, 10-minute for each period, transition stimulation). Following the receipt of treatment level data from the study authors, the EPA independently calculated an EC_{10} value of 0.0165 (0.01267 – 0.02033) mg/L for F1 survival. While this EC_{10} has some uncertainty given the wide spacing (10x) of the treatment concentrations, this toxicity value was supported by others in the PFOS toxicity literature (see Section 4.3.2.1.1 and Appendix G).The independently-calculated EC_{10} value of 0.01650 mg/L value for F1 survival from this study was used to derive the freshwater chronic water column criterion.

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Guo et al. (2019) evaluated the chronic effects of perfluorooctane sulfonate (PFOS solution of ~40% in water purchased from Sigma-Aldrich) to AB strain zebrafish (*Danio rerio*) males in a 21-day static-renewal, unmeasured study. Use of official test guidelines were not cited by the authors. Approximately 3.5-month-old male adult zebrafish were purchased from Taiyuan fish hatcheries in Shanxi Province, PR China. Prior to exposure, fish were acclimated for 15 days in a flow-through dechlorinated tap water system (<1% mortality during the holding period) with the following water quality characteristics and conditions: pH: 7.0-7.4, temperature: 28 ± 1°C and a 14:10-hour light:dark photoperiod. The fish were fed a commercially available adult zebrafish compound feed during both acclimation and exposure. Nominal concentrations of PFOS dissolved in dechlorinated tap water were reported to be 0 (control), 0.02, 0.04 and 0.08 mg/L. Three replicates were tested at each concentration. A total of 660 fish were divided equally among the four concentration groups. Water quality was maintained the same throughout the experiment as during acclimation, as well as to meet the following conditions: D.O. between 5 - 6 mg/L and total hardness 20.0 mg/L as $CaCO_3$. Exposure media was changed every three days and aquaria were cleaned during testing. On days 7, 14 and 21, 50 fish from each group were sacrificed, with 30 fish measured for length and body weight, while the other 20 dissected on ice to evaluate PFOS concentrations in the liver. The test fish had a mean body weight of 0.19 ± 0.03 g and a mean length of 2.5 ± 0.3 cm at test initiation. On day seven fish lengths ranged from >2 cm to <3 cm for all groups, and weights were >0.3 to <0.4 g for the control and 0.02 mg/L exposure. Mean fish weight measured for the 0.04 and 0.08 mg/L treatment groups were significantly different from the control group after 7 days. At days 14 and 21, the length of fish in the highest concentration (0.08 mg/L PFOS) was significantly different from the control group, and the same effect of PFOS on mean fish weight was observed at 14 and 21 days as

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reported at seven days. Therefore, weight was the most sensitive endpoint at 21 days, with a NOEC and LOEC of 0.02 and 0.04 mg/L PFOS, respectively. No mortality was observed in any treatment. An independently-calculated EC_{10} could not reliably be estimated for mean fish weight as the data were sparse, was inconsistent with the author-reported toxicity values, and the confidence bands were wide. Instead, the EPA's independently-calculated EC_{10} based on mean body length (in cm) at 21 days was 0.06274 (0.06229 – 0.06318) mg/L PFOS and used quantitatively to derive the freshwater chronic water column criterion.

C.2.6 Sixth Most Sensitive Freshwater Genus for Chronic Toxicity: *Daphnia* (cladoceran)

Logeshwaran et al. (2021) conducted acute and chronic toxicity tests with the cladoceran, *Daphnia carinata*, and PFOS-K (perfluorooctancesulfonate potassium salt, ≥ 98% purity, purchased from Sigma-Aldrich Australia). In-house cultures of daphnids were maintained in 2 L glass bottles with 30% natural spring water in deionized water, 21°C and a 16:8-hour light:dark photoperiod. The chronic test protocol followed OECD (2012). A PFOS stock solution (20 mg/mL) was prepared in dimethylformamide and diluted with deionized water to achieve a concentration of 200 mg/L PFOS. Cladoceran culture medium was used to prepare the PFOS stock and test solutions. One daphnid (6-12 hours old) was transferred to 100 mL polypropylene containers containing 50 mL of nominal test solutions (0, 0.001, 0.01, 0.1, 1.0 and 10 mg/L PFOS). Each test treatment was replicated ten times with test solutions renewed and daphnids fed daily. At test termination (21 days) test endpoints included survival, days to first brood, average offspring in each brood and total live offspring. At the higher test concentrations (1 and 10 mg/L) reproduction was completely inhibited. No mortality occurred in the controls and lowest test concentration. However, reproduction was inhibited at the lowest test concentration. The author-reported 21-day NOEC and LOEC, based on average offspring in each brood and total live offspring, was < 0.001 and 0.001 mg/L PFOS, respectively. Additionally, the author-

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reported 21-day NOEC and LOEC based on the days to first brood was 0.001 and 0.01 mg/L, respectively, resulting in an MATC of 0.003162 mg/L. The EPA could not independently calculate 21-day EC_{10} values for any of the endpoints given the level of data provided in the paper by the study authors. And while the endpoints of mean offspring per each brood and total living offspring appear to be more sensitive than the days to first brood, they result in less than LOECs of 0.001 mg/L and are not consistent with other chronic toxicity values for this species. Therefore, the author-reported MATC of 0.003162 mg/L for the days to first brood was used to derive the freshwater chronic water column criterion.

Exclusion of the *D. carinata* SMCV under the basis of being an overly sensitive outlier (relative to *D. magna* and the chronic data overall except for aquatic insects [*N. triangulifer* and *C. dilutus*]) had the possibility that the *Daphnia* GMCV could be underproductive. Conversely, excluding the *D. magna* SMCV under the basis of being a tolerant outlier (relative to *D. carinata*) would result in the *Daphnia* GMCV being highly influenced by a single test/species with a relatively sensitive chronic value. The *D. carinata* chronic value was also an MATC, calculated as the geometric mean of the NOEC (0.001 mg/L) and LOEC (0.01 mg/L) from a 10X dilution series, meaning the MATC was influenced by a relatively low NOEC. However, offspring-based endpoints reported by (Logeshwaran et al. 2021) suggest a LOEC of <0.001 mg/L. Using both the *D. magna* and *D. carinata* SMAVs resulted in protective a *Daphnia* GMCV based on the *Daphnia* data as a whole. Finally, the chronic PFOS freshwater criterion (i.e., 0.00025 mg/L) is four times lower than the offspring-based LOECs (i.e., 0.001 mg/L) reported by (Logeshwaran et al. 2021) and should be protective of *D. carinata* based on all endpoints measured by (Logeshwaran et al. 2021).

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Drottar and Krueger (2000e) reported the results of a life-cycle, 21-day renewal, measured test of PFOS (potassium salt, CAS # 2795-39-3, 90.49% purity) with *Daphnia magna*. The GLP test was conducted at Wildlife International, Ltd. in Easton, MD in February, 1999. The test followed (U.S. EPA 1996c). *D. magna* used for the test were less than 24 hours old at test initiation. Dilution water was 0.45 µm filtered and UV sterilized well water [total hardness: 124 (120-128) mg/L as $CaCO_3$; alkalinity: 169 (164-172) mg/L as $CaCO_3$; pH: 8.2 (8.0-8.3); TOC: <1.0 mg/L; and conductivity: 329 (315-340) µmhos/cm]. Photoperiod was 16:8-hours light:dark with a 30 minute transition period. Light was provided at an intensity of 329-383 lux. A primary stock solution was prepared in dilution water at 46 mg/L. It was mixed until all test substance was dissolved prior to use. After mixing, the primary stock was proportionally diluted with dilution water to prepare the five additional test concentrations. Exposure vessels were 250 mL plastic beakers containing 200 mL of test solution. The test employed 10 replicates of one daphnid each in six measured test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 1.4, 2.9, 5.7, 11, 23, and 46 mg/L. Mean measured concentrations were < 0.458 mg/L (the LOQ), 1.5, 2.9, 5.6, 12, 24, and 48 mg/L, respectively. Analyses of test solutions were performed at Wildlife International Ltd. using HPLC/MS. The mean percent recovery of matrix fortifications analyzed concurrently during sample analysis was 104%. Measured values of new samples ranged from 94 to 121% of nominal. Measured values from the old solutions ranged from 90 to 108% of nominal. PFOS was stable throughout the renewal periods. Dissolved oxygen in new and old test concentrations ranged from 8.3-8.9 mg/L in the negative controls and 8.3-9.0 mg/L at the NOEC of 12 mg/L. Similarly, pH ranged from 8.1-8.4 and 8.2-8.5, respectively, and test temperature from 19.4-20.1°C (negative control and at the NOEC). Cumulative young in the 1.5, 2.9, 5.6, 12, and 24 mg/L treatment groups was 100, 100,

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100, 90, and 0%, respectively. After 48 hours, cumulative young of the second generation in the negative control was 95%. The 21-day NOEC (survival, growth, and reproduction) was 12 mg/L. The 21-day LOEC was 24 mg/L and the calculated MATC is 16.97 mg/L. No second-generation *D. magna* survived the 24 mg/L treatment. The independently-calculated EC_{10} based on cumulative young was 11.19 (10.50 – 11.89) mg/L and used quantitatively to derive the freshwater chronic water column criterion.

Boudreau (2002) also conducted a chronic life-cycle 21-day renewal, unmeasured test of PFOS (potassium salt, CAS # 2795-39-3, 95% purity) with *Daphnia magna* as part of a Master's thesis at the University of Guelph, Ontario, Canada. The results were subsequently published in the open literature **Boudreau et al. (2003a)**. The test followed ASTM (1999a). *D. magna* used for testing were less than 24 hours old at test initiation. *D. magna* were obtained from a brood stock (Dm99-23) at ESG International (Guelph, ON, Canada). Dilution water was clean well water. Hardness was softened by addition of distilled deionized water to achieve a range of 200-225 mg/L of $CaCO_3$. Photoperiod was 16:8-hours light:dark under cool-white fluorescent light between 380 and 480 lux. Laboratory-grade distilled water was used for all solutions with maximum concentrations derived from stock solutions no greater than 450 mg/L. Test vessels consisted of 225 mL polypropylene disposable containers containing 120 mL of test solution. All toxicity testing involved four replicates of three daphnids each in five nominal test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 6, 13, 25, 50, and 100 mg/L. The test was conducted in environmental chambers at 21 ±1°C. Authors noted that temperature and pH were measured at the beginning and end of study, but the information was not reported. Survival of daphnids in the negative control was 100%. The 21-day NOEC (survival and reproduction) was 25 mg/L. The 21-day LOEC was 50 mg/L and the

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calculated MATC is 35.36 mg/L. The independently-calculated EC_{10} based on survival was 16.35 (7.377 – 25.33) mg/L and was used quantitatively to derive the freshwater chronic water column criterion.

Ji et al. (2008) conducted chronic life-cycle tests of the effects of PFOS (acid form, CAS # 1763-23-1, purity unreported) on *Daphnia magna*. Tests were done under renewal conditions over a 21-day period. The test followed OECD (1998). *D. magna* used for testing were obtained from brood stock cultured at the Environmental Toxicology Laboratory at Seoul National University (in South Korea). Organisms were less than 24 hours old at test initiation. Dilution water was moderately-hard reconstituted water (total hardness typically 80-100 mg/L as $CaCO_3$). Experiments were conducted in glass jars of unspecified size and fill volume. Photoperiod was assumed to be 16:8-hours light:dark as was used for daphnid culture. Preparation of test solutions was not described. The test involved 10 replicates of one daphnid each in five nominal test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 0.3125, 0.625, 1.25, 2.5, and 5 mg/L. Test temperature was 21 ±1°C. Authors noted water quality parameters (pH, temperature, conductivity, and D.O.) were measured after changing the medium, but the information was not reported. Survival of daphnids in the negative control was 100%. The author reported *D. magna* 21-day NOEC for the reproductive endpoint of number of young per brood was 1.25 mg/L. The author reported 21-day LOEC for the same endpoint was 2.5 mg/L. The calculated MATC was 1.768 mg/L. In the independent verification of the toxicity values, the EPA recalculated the reproductive endpoint noted to be the number of young per brood. This recalculated reproductive endpoint took the full effects of PFOS into account as it was representative of the full life cycle. The calculated EC_{10} for *D. magna* was 1.051 (0.2680 –

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1.834) mg/L. The independently-calculated EC_{10} of 1.051 mg/L was used quantitatively to derive the freshwater chronic water column criterion.

Li (2010) conducted a chronic life-cycle 21-day test on the effects of PFOS (potassium salt, >98% purity) on *Daphnia magna*. The test followed OECD (1998). *D magna* used for the test were maintained in the laboratory for more than one year and were less than 24 hours old at test initiation. Dilution water was distilled water with ASTM medium (0.12 g/L $CaSO_4.2H_2O$, 0.12 g/L $MgSO_4$, 0.192 g/L $NaHCO_3$, and 0.008 g/L KCl – calculated total hardness 169 mg/L as $CaCO_3$). Photoperiod was 16:8-hours light:dark at an unreported light intensity. A primary stock solution was prepared in dilution water and did not exceed 400 mg/L. Exposure vessels were 50 mL polypropylene culture tubes with 50 mL fill volume. The test involved 10 replicates of one daphnid each in five nominal test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 0.5, 1, 5, 10, and 20 mg/L. Test temperature was maintained at 20 ±1°C. Water quality parameters measured in test solutions were not reported. Survival of daphnids in the negative control was 96.7%. The *D. magna* 21-day NOEC (reproduction – no. young per female) was 1 mg/L. The 21-day LOEC was 5 mg/L and the calculated MATC was 2.236 mg/L. The independently-calculated toxicity value (EC_{10}) based on total neonates per female was 3.030 (-1.280 – 7.340) mg/L and was used quantitatively to derive the freshwater chronic water column criterion.

Yang et al. (2014) evaluated the chronic 21-day renewal, measured test of PFOS (potassium salt, CAS # 2795-39-3, 99% purity) with *Daphnia magna*. The test followed (ASTM 1993). *D. magna* used for the test were donated by the Chinese Research Academy of Environmental Sciences, and less than 24 hours old at test initiation. Dilution water was dechlorinated tap water (pH, 7.0 ± 0.5; D.O., 7.0 ± 0.5 mg/L; total organic carbon, 0.02 mg/L;

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and total hardness, 190.0 ± 0.1 mg/L as $CaCO_3$). Photoperiod was 12:12-hours light:dark at an unreported light intensity. A primary stock solution was prepared by dissolving PFOS in deionized water and cosolvent DMSO. The primary stock was proportionally diluted with dilution water to prepare the test concentrations. Exposure vessels were 200 mL beakers of unreported material type containing 100 mL of test solution. The test employed 10 replicates of one daphnid each in six test concentrations (measured in low and high treatments) plus a negative and solvent control. Nominal concentrations were 0 (negative and solvent controls), 2.00, 2.60, 3.38, 4.39, 5.71 and 7.43 mg/L. Mean measured concentrations before and after renewal were 1.74 and 1.98 mg/L (lowest concentration) and 6.78 and 7.54 mg/L (highest concentration). Analyses of test solutions were performed using HPLC/MS and negative electrospray ionization. The concentration of PFOS was calculated from standard curves (linear in the concentration range of 1-800 ng/mL), and the average extraction efficiency was in the range of 70-83%. The concentrations and chromatographic peak areas exhibited a significant positive correlation ($r=0.9987$, $p<0.01$), and the water sample-spiked recovery was 105%. Test temperature was maintained at 22 ±2°C. The D.O. and pH were reported as having been measured, but results are not reported. Negative and solvent control survival was 100%. The *D. magna* 21-day EC_{10} for reproduction was reported to be 2.26 mg/L from the study authors and 4.17 mg/L for survival. The independently-calculated EC_{10} based on survival was 2.610 (1.291 – 3.929) mg/L and was used quantitatively to derive the freshwater chronic water column criterion.

Lu et al. (2015) conducted a chronic life-cycle 21-day renewal, unmeasured test of PFOS (purity 98%) with *Daphnia magna*. The test followed OECD (2012). *D. magna* used for the test were originally obtained from the Chinese Center for Disease Control and Prevention (Beijing, China) and cultured in the laboratory according to the International Organization for

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Standardization (ISO 1996). Daphnids were less than 24 hours old at test initiation. Dilution water was the same used for daphnid culture and was reconstituted according to OECD (2004) with a total hardness of 250 mg/L as $CaCO_3$, as calculated based on the recipe provided, and pH ranging from 7.7 to 8.4. Photoperiod was 16:8-hours light:dark at an unreported light intensity. The test solution was prepared immediately prior to use by diluting the stock solution with culture medium. Exposure vessels were 100 mL glass beakers containing 45 mL of test solution. The test employed 20 replicates of one daphnid each in six nominal test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 0.008, 0.04, 0.2, 1, and 5 mg/L. Exposure water quality was checked daily and maintained at 20 ±1°C, pH of 7.2 ±0.3, and D.O. of 5.3 mg/L. Negative control survival was 100%. The author reported *D. magna* 21-day NOEC (no. offspring per brood per female) was 0.008 mg/L and the 21-day LOEC was 0.04 mg/L. The calculated MATC was 0.0179 mg/L and the independently-calculated EC_{10} was 0.001818 (-0.0000395 – 0.003675) mg/L for the same endpoint. Other endpoints, including growth and other reproductive endpoints, could not be independently-calculated by the EPA. The independently-calculated EC_{10} from this study was acceptable for quantitative use to derive the freshwater chronic water column criterion.

Liang et al. (2017) conducted a chronic life-cycle 21-day renewal, unmeasured test of PFOS (potassium salt, CAS # 2795-39-3, ≥98% purity) with *Daphnia magna*. The test organisms were originally obtained from State Key Laboratory of Environmental Aquatic Chemistry (Eco-Environmental Sciences of Chinese Academy of Sciences, Beijing) and cultured in the laboratory according to Revel et al. (2015). Daphnids were less than 24 hours old at test initiation. Dilution water was artificial medium "M4 (Elendt)" at 20°C and pH 7. Photoperiod was 16:8-hours light:dark at an unreported light intensity. The test solution was prepared

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immediately prior to use by diluting the stock solution with M4 medium. Exposure vessels were 80 mL glass beakers containing an unspecified volume of test solution. The test employed 10 replicates of one daphnid each in six nominal test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 1, 2, 4, 8, and 16 mg/L. No mention was made of water quality being checked during the exposure. Negative control survival was 100%. The *D. magna* 21-day NOEC (days to 1st brood, intrinsic rate of natural increase, r) was 4 mg/L. The 21-day LOEC was 8 mg/L and the calculated MATC was 5.657 mg/L. The independently-calculated EC_{10} based on survival was 3.596 (2.1207 – 5.0704) mg/L and used quantitatively to derive the freshwater chronic water column criterion.

Yang et al. (2019) evaluated the chronic effects of perfluorooctane sulfonate, potassium salt (PFOS-K, CAS# 2795-39-3, 98% purity, purchased from Sigma-Aldrich in St. Louis, MO) on *Daphnia magna* via a 21-day unmeasured, static-renewal test that evaluated growth and reproductive effects. *D. magna* cultures were obtained from the Institute of Hydrobiology of Chinese Academy of Science in Wuhan, China. Organisms were cultured in Daphnia Culture Medium according to the parameters laid out in OECD Guideline 202 and all testing followed OECD Guideline 211. Cultures were fed green algae daily and were acclimated for two to three weeks before testing. The 21-day chronic study had nominal concentrations of 0 (control), 0.00000124, 0.00000188, 0.0000281 and 0.00000420 mol/L (or 0 (control), 0.6674, 1.012, 1.512, and 2.261 mg/L given the molecular weight of the form of PFOS used in the study, CAS # 2795-39-3, of 538.22 g/mol). Each neonate (12–24 hours old) was placed in a 100 mL glass beaker, in which there were 10 replicates, each filled with 80 mL of test solution maintained at 20 ±1°C and a 16:8-hour light:dark photoperiod with a light intensity maintained at 1000 - 1500 lux. *D. magna* were fed green algae and test solutions were renewed every 72 hours. Test

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organisms were counted daily, with any young also removed. The author-reported NOEC and LOEC for reproduction (measured as mean offspring proportion relative to control at 21 days) was <0.6674 and 0.6674 mg/L PFOS, respectively. The author-reported NOEC and LOEC for growth (measured as length) was 0.6674 and 1.012 mg/L PFOS (MATC = 0.8218 mg/L). The independently-calculated EC_{10} values for reproduction and growth are 0.3773 and 0.9093 mg/L, respectively. However, the reproduction EC_{10} of 0.3773 mg/L was determined to be less statistically robust as the independently-calculated toxicity values were control normalized and could not be weighted given the level of data provided by the study authors in the paper. Therefore, the independently-calculated EC_{10} for growth of 0.9093 (0.7423 – 1.076) mg/L was used quantitatively to derive the freshwater chronic water column criterion freshwater.

Seyoum et al. (2020) evaluated the chronic effects of perfluorooctane sulfonic acid (PFOS, CAS# 1763-23-1, > 99%, purchased from Sigma) on *Daphnia magna* neonates via a 21-day unmeasured, static-renewal study. The study authors did not report following any specific protocol. *D. magna* ephippia were purchased from MicroBioTests Inc. (Belgium) and were activated by rinsing in tap water. Ephippia were hatched by incubating at 20-22 ºC for 72 to 90 hours in standard freshwater under a continuous light intensity (6,000 lux). Newly hatched neonates (<24-hour old) were fed a suspension of Spirulina micro-algae two hours before testing. Nominal concentrations of 0 (control), 1, 10 and 25 µM (or 0 (control), 0.5001, 5.001, and 12.50 mg/L given the molecular weight of the form of PFOS used in the study, CAS # 176-23-1, of 500.13 g/mol) were prepared by mixing the respective amounts of PFOS in dimethyl sulfoxide (DMSO). Ten <24-hour old neonates, exposed in triplicate, were placed into 250 mL crystallization dishes with 100 mL of test solution. A mean temperature of 23°C, D.O. of 8 to 9 mg/L, total hardness of 250 mg/L as $CaCO_3$, pH of 7.5 ±0.25 and salinity of 0.02% were

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reported in the exposure water. *D. magna* were fed a mixture of *Spirulina* microalgae and yeast (*Saccharomyces cerevisiae*) daily during the test, and 50% of the test solution was changed every other day. Neonates were counted daily and removed. At day 21, neonate counts were reported to be highest in the control with >40 to < 60 neonates, and >20 to <40 neonates were reported at the 0.5001 and 5.001 mg/L (or 1 and 10 µM) concentrations, respectively. Neonate counts for the 12.50 mg/L (or 25 µM) concentration were not reported. A reproductive NOEC of 0.5001 mg/L and a LOEC of 5.001 mg/L were reported by the study authors, resulting in an MATC of 1.581 mg/L. This LOEC of 5.001 mg/L was associated with a 42.95% decrease in reproduction (measured as the mean number of daphnids at 21 days) compared to control. An independently-calculated EC_{10} value could not be determined as the EPA was unable to fit a model with significant parameters. Instead, the author-reported MATC of 1.581 mg/L PFOS was used quantitatively to derive the chronic water column criterion for freshwater.

C.2.7 Seventh Most Sensitive Freshwater Genus for Chronic Toxicity: *Salmo* (salmon)

Atlantic salmon, *Salmo salar*, embryos were evaluated by **Spachmo and Arukwe (2012)** via a 56-day unmeasured exposure to PFOS (98% purity). Eggs were obtained from Lundamo Hatcheries, Norway (Aquagen) and transported to the Norwegian University of Science and Technology Centre of Fisheries and Aquaculture in Trondheim, Norway. The eggs were kept in plastic tanks (25 L) at 5-7°C with filtered, re-circulating and aerated water. Approximately one-third of the water volume was changed once per week. The eggs and larvae were exposed to PFOS (100 µg/L) for 49 days representing the developmental period from 404 to 679-degree days. PFOS was dissolved in methanol (carrier solvent: 0.01%) and control group was exposed to the carrier solvent only. Hatching occurred at 20 calendar days after start of exposure, at an effective developmental age of 504-degree days, after which riverbed environment was simulated by tank bed gravel and continuous water flow. Fish sampling was performed at 21, 35,

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49 and 56 calendar days after exposure, or at respective developmental ages of 549, 597, 679 and 721 degree days. The exposure was terminated at 679-degree days, and 712-degree days represents the end of a one-week exposure-free recovery period. Thus, day 49 sampling was performed 24 hours after terminating the exposure and no exposure related differences in hatching rate were observed. The 49-day growth NOEC and LOEC were 0.10 and >0.10 mg/L PFOS, respectively. These data are deemed quantitative and used to derive the freshwater chronic water column criterion.

C.2.8 Eighth Most Sensitive Freshwater Genus for Chronic Toxicity: *Pimephales* (minnow)

Drottar and Krueger (2000d), associated with Wildlife International, conducted a good laboratory practice (GLP) 47-day flow-through measured early life-stage toxicity test with <24-hour old *P. promelas* embryos. A primary stock solution was prepared by dissolving PFOS (90.49% purity) in dilution water at a concentration of 88.4 mg a.i./L, then proportionally diluted with dilution water to prepare five secondary stock solutions at concentrations of 44.2, 22.1, 11.0, 5.52 and 2.76 mg a.i./L. Stock solutions were prepared every three to four days during the test. The five stocks were injected into the diluter mixing chambers (at a rate of 6.0 mL/minute) where they were mixed with dilution water (at a rate of 116 mL/minute) to achieve the desired test concentrations. The water used for culturing and testing was freshwater obtained from a well approximately 40 meters deep located on the Wildlife International Ltd. site. The well water was characterized as moderately-hard water. The well water was passed through a sand filter to remove particles greater than approximately 25 μm and then pumped into a 37,800-L storage tank where the water was aerated with spray nozzles. Prior to delivery to the diluter system, the water again was filtered (0.45 μm), then passed through a UV sterilizer to remove microorganisms and particles. Fathead minnow embryos used in this test originated from cultures maintained by Wildlife International Ltd., Easton, MD. The embryos were removed

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from spawning substrates and examined under the dissecting microscope to select healthy specimens at approximately the same stage of development. Embryos collected for use in the test were from six individual spawns. Embryos were exposed to a geometric series of six test concentrations and a negative (dilution water) control under flow-through conditions at 24.5°C, pH of 8.2, total hardness of 140 mg/L as $CaCO_3$ and a photoperiod of 16:8-hours light:dark. Four replicate test chambers (9 L glass aquaria) were maintained in each treatment and the control group. Each test chamber contained one incubation cup with 20 embryos, resulting in a total of 80 embryos per treatment. The exposure period included a five-day embryo hatching period, and a 42-day post-hatch juvenile growth period. Nominal test concentrations were 0.14, 0.29, 0.57, 1.1, 2.3 and 4.6 mg/L a.i. Mean measured test concentrations (0, 0.15, 0.30, 0.60, 1.2, 2.4 and 4.6 mg/L) were determined from samples of test water collected from each treatment and the control group at the beginning of the test, on day four, at weekly intervals during the test, and at test termination. To start the test, embryos less than 24 hours old were collected from cultures and groups of one and two individuals were impartially distributed among incubation cups until each cup contained 20 embryos. One cup was then placed in each treatment and control test chamber. Twice during the next twenty-four hours and daily thereafter, all dead embryos were counted and removed from the cups to avoid contaminating viable embryos. All eggs that remained were considered viable. Dead embryos continued to be removed daily. After hatching, the larvae were counted and released into the test chambers, where exposure continued until test termination. Observations of mortality and other clinical signs were made daily during the test. Time to hatch, hatching success, growth, and survival were monitored in each treatment and control group. The most sensitive 47-day chronic value (MATC) of 0.4243 mg/L PFOS was based on post-hatch survival as reported by the study authors. The independently-calculated EC_{10} based on survival

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was 0.4732 (0.3308 – 0.6156) mg/L and used quantitatively to derive the freshwater chronic water column criterion.

Ankley et al. (2005) also exposed *Pimephales promelas* to PFOS (potassium salt, > 98% pure) under flow-through measured conditions for 21 days. Stock solutions were prepared by dissolving crystals in Lake Superior control water with stirring (mean measured test conditions: 25°C, pH of 7.3, total hardness of 46 mg/L as $CaCO_3$, alkalinity of 40 mg/L as $CaCO_3$ and D.O. of 6.2 mg/L). Two stock solutions of approximately 9.7 and 97 mg/L were used to span the desired range of target concentrations in test water. Final test concentrations were generated by appropriate dilution of the PFOS stocks with Lake Superior water and were supplied to the test tanks at a flow rate of approximately 45 mL/min. Sexually mature fathead minnows (six to seven months old) obtained from the on-site culture facility were used for the toxicity test. Eight pairs of fish (one male and one female) were exposed at each treatment level, 0 (control), 0.03, 0.1, 0.3, and 1.0 mg PFOS/L. Assays were conducted using glass aquaria containing 10 L of test solution, with two pairs of fish separated by perforated nylon screening in each tank. Reproductive viability of the fish used for the test was documented during a 27-day acclimation phase in the same tanks in which the tests were conducted. The number of eggs spawned by each pair was evaluated daily by inspecting the underside of a polyvinyl chloride spawning tile placed on the bottom of the test chambers. Egg fertility was assessed using an optical microscope. The animals were held at 25 ±1°C under 16:8-hour light:dark photoperiod and fed frozen brine shrimp to satiation twice daily. Conditions during the 21-day reproduction phase of the PFOS exposure were the same as during the acclimation phase. To evaluate possible early developmental toxicity of PFOS, 50 to 75 eggs from single viable spawns were collected during the final 7-day of the reproduction phase of the test. A subset of eggs was reserved for the

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determination of PFOS concentrations. Embryos were held in 300 mL Pyrex beakers in the same aquaria as the parental fish. Embryos hatched within four to five days and thereafter were fed live brine shrimp twice daily. After 12 days, fry were randomly sampled for PFOS analysis and to reduce the number of animals per chamber to ≤30. Remaining fry were maintained in a larger chamber (1 L plastic container) within the original tank. Developing fish were inspected daily to assess survival. After 24 days, they were anesthetized and weighed. A subset of the fry was collected for PFOS measurements, while others were preserved in Bouin's fixative for histological analyses. The authors reported a 21-day EC_{50} (fecundity) of 0.23 mg/L PFOS, and a chronic value of 0.4794 mg/L PFOS for percent hatch (21-day), probability of survival, and larval weight endpoints (21-day (F0) + 24-day (F1)). The independently-calculated EC_{10} was 0.05101 (0.0408 – 0.0613) mg/L based on fecundity and used quantitatively to derive the freshwater chronic water column criterion.

Suski et al. (2021) reported the chronic toxicity of PFOS-K (perfluorooctancesulfonate potassium salt, CAS # 2795-39-3, ≥ 98%, purchased from Sigma-Aldrich) on the fathead minnow, *Pimephales promelas*. Adult (5-month old) fathead minnows were purchased from a commercial supplier (Aquatic Biosystems) and were sexually mature when the test was initiated. Fish were fed twice a day and held in dechlorinated tap water at test conditions (mean conditions: 24.96°C, D.O. of 7.68 mg/L, pH 7.9 and conductivity of 347.3 µS/cm). Stock solutions of PFOS (150 mg/L) were made without a solvent and prepared weekly with stock solutions shaken at 80 rpm for 24 hours to ensure mixing. Test solutions were made by diluting the stock with dechlorinated tap water and shaking the solutions for 10 minutes prior to water exchanges. Half of the total volume (10 L) in each exposure 5-gallon polycarbonate tank was renewed three times per week. Measured PFOS concentrations were 0.14 (control), 44, 88, 140

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and 231 µg/L PFOS (or 0.00014 (control), 0.044, 0.088, 0.14, and 0.231 mg/L PFOS). Each test treatment was replicated six times for each treatment and consisted of two females and one male per tank with exposures lasting 42 days. Tanks were expected daily for eggs and all eggs collected were assumed to be per single female regardless of the number of females per tank. On the last week of testing, eggs were carried through hatching in their respective test treatments, and 20 larval fish per concentration were exposed for an additional 21 days to investigate developmental effects. One liter polypropylene beakers were used for the F1 generation exposure with solutions renewed daily. Survival of adult fathead minnows in the control and two lowest test concentrations was ≥80% at test termination. Survival of male fish in the highest test treatment was significantly less than male control fish, and while female survival was also less compared to control fish, the effects were not significant. The mean number of spawning events per female was also reduced in the two high test treatments, but the effect was only significant in the 140 µg/L (0.14 mg/L) treatment. Larval survival in the F1 generation was significantly reduced in the highest test treatment. The most sensitive endpoint from the study was a significant decrease in the mean mass of individuals in the larval F1 generation with reported values of 3.76, 3.53, 3.09, 2.64 and 2.00 mg for the test treatments of control, 0.044, 0.088, 0.14, and 0.231 mg/L PFOS, respectively. The author-reported NOEC and LOEC, based on growth in the F1 generation, were 0.044 (6% reduction in growth compared to controls) and 0.088 mg/L PFOS (associated with an 18% reduction in growth), respectively, with a MATC of 0.06223 mg/L. The independently-calculated EC_{10} value was 0.0549 (0.0396 – 0.0701) mg/L and used in the derivation of the freshwater chronic column criterion.

C.2.9 Ninth Most Sensitive Freshwater Genus for Chronic Toxicity: *Procambarus* (crayfish)

Funkhouser (2014) conducted a chronic 28-day renewal test of PFOS (potassium salt, ≥98% purity) with a crayfish species, *Procambarus fallax* (f. *virginalis*). The study was

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conducted as part of a Master's thesis at Texas Tech University, Lubbock, TX. Juvenile *P. fallax* (4-weeks old, 0.056 g) used for the test were originally purchased from a private collector. The crayfish reproduced for several generations before being used for experiments. Based on an average reproductive age of 141-255 days, an interclutch period of 50-85 days, and a brooding time of 22-42 days, the author estimated the experimental animals to be stage F4-F6 (Seitz et al. 2005). Dilution water was moderately hard reconstituted laboratory water (3.0 g $CaSO_4$, 3.0 g $MgSO_4$, 0.2 g KCl, and 4.9 g $NaHCO_3$ added to 50 L deionized water). Photoperiod was 14:10-hours light:dark at an unreported light intensity. PFOS was dissolved in dilution water to prepare the test concentrations. Exposure vessels were 1 L polypropylene containers containing 500 mL of test solution. The test employed eight replicates of one crayfish each in five test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 0.2, 0.5, 1.3, 3.2, 8 and 20 mg/L. Exposure concentrations were reportedly measured, but concentrations were not provided. Analyses of test solutions were performed using LC-MS/MS. Standards were used as part of the analytical method, but details were not reported. The reporting limit was 0.010 mg/L. Experiments were conducted in an incubator set at 25 ±1°C and covered with plastic opaque sheeting to limit evaporation. No other water quality parameters were reported as having been measured in test solutions. Negative control survival was 85% after 28 days. The 28-day LC_{20} was reported as 0.167 mg/L. An independently-calculated EC_{10} could not be calculated given the level of data that were presented in the paper. The study author-reported LC_{20} value was used quantitatively to derive the freshwater chronic water column criterion.

C.2.10 Tenth Most Sensitive Freshwater Genus for Chronic Toxicity: *Moina* (cladoceran)

Ji et al. (2008) conducted a chronic life-cycle test of the effects of PFOS (acid form, CAS # 1763-23-1, purity unreported) on *Moina macrocopa*. The test was performed under renewal conditions over a 7-day period. The *M. macrocopa* test followed a protocol developed

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and reported by Sutherland and Krueger (2001) that was similar to OECD (1998), but with slight modification. *M. macrocopa* used for testing were obtained from brood stock cultured at the Environmental Toxicology Laboratory at Seoul National University (in South Korea). Test organisms were less than 24 hours old at test initiation. Dilution water was moderately hard reconstituted water (total hardness typically 80-100 mg/L as $CaCO_3$). Experiments were conducted in glass jars of unspecified size and fill volume. Photoperiod was assumed 16:8-hours light:dark as was used for daphnid culture. Preparation of test solutions was not described. The test involved 10 replicates of one daphnid each in five nominal test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 0.3125, 0.625, 1.25, 2.5, and 5 mg/L. Test temperature was 25 ±1°C. Authors noted that water quality parameters (pH, temperature, conductivity, and D.O.) were measured after changing the medium, but the information was not reported. Survival of daphnids in the negative control was 100%. The author reported *M. macrocopa* 7-day LOEC for the reproductive endpoint of number of young per surviving adult was 0.3125 mg/L. In the independent verification of the toxicity value, the EPA recalculated the reproductive endpoint to be the number of young per starting adult (instead of surviving adult). This recalculated reproductive endpoint took the full effects of PFOS into account as it was representative of the full life cycle. The independently-calculated EC_{10} for *M. macrocopa* was 0.1789 (0.041 – 0.399) mg/L and used to derive the freshwater chronic water column criterion.

C.2.11 Eleventh Most Sensitive Freshwater Genus for Chronic Toxicity: *Brachionus* (rotifer)

Zhang et al. (2013) conducted a chronic life-cycle renewal test of PFOS (potassium salt, CAS # 2795-39-3, ≥98% purity) with *Brachionus calyciflorus*. The test duration was five days in a full-life cycle test (primary emphasis) and 28 days in a multi-generation population growth test (secondary emphasis – only two exposure concentrations plus a control). Test organisms were

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less than two hours old at test initiation. All animals were parthenogenetically-produced offspring of one individual from a single resting egg collected from a natural lake in Houhai Park (Beijing, China). The rotifers were cultured in an artificial inorganic medium at 20°C (16:8-hours light:dark; 3,000 lux) for more than six months before toxicity testing to acclimate to the experimental conditions. Culture medium was an artificial inorganic medium and all toxicity tests were carried out in the same culture medium and under the same conditions as during culture (i.e., pH, temperature, illumination). Solvent-free stock solutions of PFOS (1,000 mg/L) were prepared by dissolving the solid in deionized water via sonication. After mixing, the primary stock was proportionally mixed with dilution water to prepare the test concentrations. Exposures were carried out in 24-well cell culture plates (assumed plastic) containing 2 mL of test solution per cell. The test employed four measured test concentrations plus a negative control. Each treatment consisted of one replicate plate of 15 rotifers each in individual cells. Treatments were repeated six times. Nominal concentrations were 0 (negative control), 0.25, 0.5, 1.0, and 2.0 mg/L. PFOS concentrations were not measured in the rotifer exposures, but rather, in a side experiment using HPLC/MS. The side experiment showed that the concentration of PFOS measured every eight hours over a 24-hour period in rotifer medium with green algae incurs minimal change in the concentration range 0.25 to 2.0 mg/L. One hundred percent survival was observed at 24 hours in the negative control in the corresponding acute test but was not provided for the life-cycle test. The *B. calyciflorus* 5-day LOEC (net reproductive rate and intrinsic rate of natural increase) was 0.25 mg/L. The author-reported value (<0.25 mg/L) was used quantitatively to derive the freshwater chronic water column criterion.

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C.2.12 Twelfth Most Sensitive Freshwater Genus for Chronic Toxicity: *Xiphophorus* (swordtail fish)

The toxicity of PFOS (potassium salt, > 98% purity) to the swordtail fish, *Xiphophorus helleri*, was evaluated by **Han and Fang (2010)**. A PFOS stock solution (250 mg/L) was prepared by dissolving crystals in dechlorinated tap water (from the same water source as that used in fish keeping). Six- to seven-month old adult swordtails were purchased from a local fish farm with no water pollution. The fish were separated by sex into different aquaria. Both the males and females were acclimated for eight weeks under semi-static conditions in charcoal filtered, aerated tap water at 27 ±1°C with a 14:10-hour light:dark photoperiod. The water in each aquarium was completely renewed every 48 hours. The fish were fed once daily in the morning with flake food and once daily at dusk with frozen blood worms. Adult male fish were then randomly distributed into 30 L tanks containing 20 L dechlorinated tap water or a corresponding PFOS solution. Swordtail fish were exposed to 0 (control), 0.1, 0.5 or 2.5 mg/L PFOS for three weeks and then transferred into clean water for one-week recovery. Every day, half of the water in each tank was replaced with fresh water, and the fish were exposed to the appropriate concentrations daily. Exposure conditions were the same as those during the acclimation period. Each aquarium housed 10 swordtails. Three aquaria were used for each exposure concentration and for the controls, resulting in three full biological replicates for each exposure group. Body, liver and testis weights were determined at 7, 14, 21 and 28 days after ice-bath anaesthetization. The livers were weighed immediately, then frozen in liquid nitrogen and stored at -80°C for RNA extraction. The hepatosomatic index (HSI) and gonadal somatic index (GSI) values were also calculated. Nonpregnant adult female fish were housed under the same exposure conditions as the males for the six-week exposure period. At the same time, to ensure impregnation of the females, nine adult females were paired with three adult males and

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kept in each aquarium for one week, after which the males were taken out. There were also three biological replicates for each exposure group. One pregnant female per aquarium was isolated and housed until giving birth. Larvae were maintained in clean water for up to 14 days after birth to calculate their survival rate. At the end of the exposure period, the survival rate, HSI and GSI values of all groups were determined. The total number of puerperal females and females with eggs or embryos in each group was recorded to determine their corresponding ratios. More than 100 adult swordtails (with a male:female ratio of about 1:3) were housed together to obtain at least 240 juveniles (20-30 days old). All of the fry were then randomly separated into two exposure groups (0 and 0.1 mg/L) and kept under the same housing conditions as the males. Each tank contained 40 fry. There were also three biological replicates in each group. After a 90-day exposure period, the HSI, GSI, and condition factor (CF) values and the sex ratio of each group were calculated by sex category. Body length from the snout to the end of the caudal fin and sword length from the distal end of the middle rays of the caudal fin to the tip of the sword were measured for each young male. After an extended period of stable breeding, part of the juveniles became young females and some of them were with eggs, embryos or puerperal. So, just like adult females, the total number of puerperal females and females with eggs or embryos in each group were recorded as a single entity to determine their corresponding ratios. The 4-week (adult male), 6-week (adult female) and 90-day (juvenile female and male) survival chronic values were >2.5, 1.118 and >0.1 mg/L PFOS, respectively. The study-author reported survival chronic value for offspring of females exposed for six weeks was 0.2236 mg/L PFOS, and the 90-day growth and percent females with eggs chronic value was <0.1 mg/L PFOS. The independently-calculated EC_{10} for adult female survival was 0.5997 (0.2336 – 0.9658) mg/L, which was acceptable for quantitative use.

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C.2.13 Thirteenth Most Sensitive Freshwater Genus for Chronic Toxicity: *Xenopus* (frog)

Lou et al. (2013) evaluated the chronic toxicity of PFOS to the African clawed frog, *Xenopus laevis*. PFOS (98% purity) stock solutions (8 mg/mL) were prepared by dissolving in DMSO every four weeks and stored at 4°C. Stock solutions were diluted by charcoal-filtered tap water to prepare test water. DMSO concentrations were 0.001% (v/v) in all tanks including the solvent control group. The same charcoal-filtered tap water (pH 6.5-7.0, D.O. >5 mg/L, and total water hardness, as $CaCO_3$, of approximately 150 mg/L) was used to raise *X. laevis* frogs and tadpoles. Adult female and male *X. laevis* (3 years old, obtained from Nasco, USA.) were raised separately in glass tanks at 22 ±2°C with a 12:12-hour light:dark cycle and fed with chopped pork liver (commercial amphibian diet three times a week). A pair of *X. laevis* was injected by human chorionic gonadotropin to induce breeding. Fertilized eggs were incubated in the same dechlorinated tap water at 22 ±2°C for six days (and were fed live *Artemia* starting on the 5^{th} day). On the fifth day postfertilization, tadpoles at NF stage 46/47 were exposed to PFOS (nominal: 0.0001, 0.001, 0.100 and 1.0 mg/L; measured: 0, 0.00009, 0.001, 0.1117, 0.7160 mg/L) until two months post-metamorphosis. Each exposure group and control group consisted of three replicated tanks. Each tank with 18 L water was assigned randomly 25 tadpoles. The tadpoles were fed with live *Artemia* three times daily. After metamorphosis, the juvenile frogs were fed with live *Artemia* daily and chopped pork liver every other day. The test water (22 ±2°C) was completely replaced every other day. Fluorescent lighting provided a photoperiod of 12 hours and a light intensity ranging from 600 to 1,000 lux at the water surface. During the exposure, the animals were observed for mortality and growth daily and dead tadpoles were removed. At the end of exposure, the survival rate of the frogs in each tank was recorded. After anaesthetization, the frogs were weighted and dissected. The liver tissue of each frog was weighed and hepatosomatic index (HSI) was calculated. The sex or intersex of each frog was

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determined by examining the gross gonadal morphology with a stereo microscope. The survival, weight and sex ratio/intersex chronic value were all > 0.7160 mg/L PFOS (or 1 mg/L PFOS as the nominal concentration). The study-author reported value was used quantitatively to derive the freshwater chronic water column criterion.

Fort et al. (2019) evaluated the chronic effects of perfluorooctane sulfonic acid (PFOS, ≥98% purity, CAS # 1763-23-1, lot # BCBH2834V from Sigma-Aldrich in St. Louis, MO) on clawed frogs (*Xenopus tropicalis*, formerly *Silurana tropicalis*) in a 150-day post-metamorphosis flow-through, measured study. Stock solutions were prepared by dissolving PFOS into filtered, dechlorinated tap water in 18 L glass carboys, which were then pumped into the master mixing cell of the continuous flow diluter. Adult frogs were obtained from Xenopus 1 and fed salmon starter pellets daily for 30 days during acclimation prior to breeding. Temperature during acclimation was maintained at 26 ±0.5ºC. Researchers followed the breeding guidance of Fort et al. (2002), and added human chorionic gonadotropin the day before breeding began. Three pairs of frogs were isolated and allowed to breed, but only a single clutch with a >70% spawn rate was utilized for the experiment. Normal appearing dejellied embryos (Nieuwkoop and Faber Stage 10) were randomly selected, and 20 were placed in each of four aquaria, each 4-L in size, for a total of 80 embryos per concentration. The frogs were subjected to a 12:12-hour light:dark photoperiod with a light intensity of 600 ± 50 lux, and the pH was maintained naturally at 7.5 ±0.3. The diluter system achieved a complete volume change every 6.5 hours, and diluter performance, flow rates, temperature, D.O. and light intensity were measured daily. Test organisms were exposed to mean measured concentrations of <0.03 (control), 0.05, 0.13, 0.31, 0.59 and 1.05 mg/L PFOS until metamorphosis, and liquid chromatography mass-spectrometry was used to verify differences in PFOS concentrations. At metamorphosis (NF Stage 66), weight

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and snout-vent lengths were measured. Frogs were kept an additional 150 days past metamorphosis without PFOS to determine weights, lengths, and sex differences amongst the organisms. Mortality data showed a NOEC value >1.05 mg/L while the pre-metamorphosis portion of the study showed a NOEC of 0.59 mg/L and a LOEC of 1.05 mg/L for both snout-vent length and weight (MATC = 0.7871 mg/L). The LOEC of 1.05 mg/L was associated with 5% (snout-vent length) and 14% (weight) decrease compared to controls, respectively. A significant increase in the median metamorphosis time was observed in the 1.05 mg/L PFOS treatment relative to the control. The post-metamorphosis LOEC was reported as 1.05 mg/L. No LC_{50} value was reported in that only 5.2 percent mortality was observed in the highest exposure concentration (1.05 mg/L) at test termination. Independently-calculated EC_{10}s could not be calculated as the EPA was unable to fit a model with significant parameters. Instead, the author-reported MATC of 0.7871 mg/L PFOS based on growth (measured as mean body weight at metamorphosis) was used quantitatively to derive the freshwater chronic water column criterion.

C.2.14 Fourteenth Most Sensitive Freshwater Genus for Chronic Toxicity: *Lithobates* (frog)

The chronic flow-through measured toxicity of PFOS (potassium salt, 98% purity) to the northern leopard frog, *Lithobates pipiens* (formerly, *Rana pipiens*), was investigated by **Ankley et al. (2004)**. Two PFOS stock solutions (708 and 21.7 mg/L) were prepared by dissolving solid PFOS with one liter of Lake Superior water in a glass carboy for 24 hours and then brought to a volume of 18 L for the final stock solutions. Contents were stirred at room temperature (~20°C) for 24 hours prior to being used. Solutions were pumped from the carboys to the glass aquaria through Teflon® tubing using fluid metering pumps equipped with stainless-steel rotary dispensers. Target concentrations were achieved by diluting the high and low stock solutions with an appropriate volume of the Lake Superior (control) water. The PFOS stock solutions were renewed every seven days. Fertilized eggs were collected from Grand Lake (St. Louis County,

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MN), near a sandy shoreline with no development. Tests were initiated with stage 8/9 embryos; animals were gently separated with a plastic spatula from the egg mass, inspected under a microscope for viability (evidence of cell division), and randomly allocated to treatment groups. Exposures were conducted in glass aquaria in 10 L of water, which was continually renewed at a flow rate of about 50 mL/minute (72 L/day). Duplicate tanks at target (nominal) PFOS concentrations of 0.03, 0.1, 0.3, 1, 3, and 10 mg/L and four replicate control aquaria were used. Embryos (n=120) were placed in each aquarium; in addition, two of the control tanks and the duplicate tanks at 0.1 and 1 mg PFOS/L received an extra 80 organisms (total of 200) at test initiation to provide animals for determination of PFOS concentrations during the early part of the assay. Although biomass varied between the tanks with 120 versus 200 tadpoles, in both situations total loading to the system was more than two orders of magnitude lower than guidance recommended for a test at this flow rate. Water temperature was maintained at 20 ± 0.5°C, and the photoperiod (provided by fluorescent lights) was a constant 16:8-hour light:dark cycle. On hatching (at approximately six days), animals were fed a mixture of live brine shrimp, ground trout chow, and Tetrafin *ad libitum* two times daily. Dead organisms were removed daily and inspected for gross abnormalities. On test day 6, 10 newly-hatched (<24 hours) animals were randomly removed from each tank, preserved in 10% neutral buffered formalin, and subsequently examined for developmental anomalies. Groups of animals were randomly selected from each treatment (excluding the 10 mg/L group, which had been terminated because of high mortality) on test days 35 (10 tadpoles/tank) and 54 (three tadpoles/tank). The animals were weighed, and developmental stage was recorded, before being processed for PFOS tissue analysis. The first tadpoles to undergo complete metamorphosis (defined as emergence of the forelimbs) were observed on test day 60. Metamorphs were removed from the test tanks,

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sacrificed with an overdose of MS-222, weighed, measured (total and snout-vent length), and assessed for gross abnormalities. Metamorphosis of the tadpoles continued over the next 51 days, until the test was terminated, when remaining tadpoles were counted, staged, and weighed. A subset of tadpoles from the control and 3 mg PFOS/L treatments were processed for histological analysis of the thyroid gland when they were sampled at forelimb emergence. The most sensitive apical chronic value was the 112-day growth MATC of 1.732 mg/L PFOS, followed by the 5-week LC_{50} of 6.21 mg/L PFOS. These data are considered quantitative even though the control mortality was >20% at test termination (Note: Excessive mortality of amphibian larvae should be expected within the full duration of this experiment given the life history strategy employed by amphibians. Therefore, the observed control survival for this study was considered within the acceptable range for this species and the toxicity data should be limited to the first 10 weeks of the experiment). The author-reported value (112-d growth MATC of 1.732 mg/L) was used quantitatively to derive the chronic water column criterion.

Hoover et al. (2017) also evaluated the chronic toxicity of PFOS (>98% purity) to *Lithobates pipiens*. Test solutions were renewed every four days and exposure concentrations were measured prior to and after each water change. Stock solutions consisted of 1 g of chemical dissolved in 2 L of Milli-Q water, then vacuum-filtered before storage in polycarbonate bottles. Eight northern leopard frog egg masses were collected during early spring from a temporary pond at the Purdue Wildlife Area in West Lafayette, IN, and randomly assigned to outdoor ~100 L wading pools. After hatching, larvae were checked daily for mortality and fed Purina Rabbit Chow *ad libitum*. Treatments consisting of a control and PFOS at three concentrations (nominally 0.010, 0.100, and 1.0 mg/L) were placed in two replicates on adjacent shelves within an environmental chamber. Experimental units consisted of 15 L plastic aquaria filled with 7.5 L

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of filtered, UV-irradiated well water. Tadpoles (n=35 per aquarium) were randomly assigned to the experimental units. Prior to addition to aquaria, a subset of animals was examined to confirm development at Gosner stage 26, when hind limb buds start to develop. Tadpoles with visible irregularities in morphology, coloration, or behavior were excluded. Animals were maintained at 20 ±2°C with a 12:12-hour light:dark photoperiod for 10 days to acclimate to indoor conditions and were fed a TetraMin® slurry *ad libitum*. Water changes (100%) were conducted every four days. Tadpoles were exposed for 40 days and were monitored daily for mortality and abnormalities. A water sample (~5 mL) was taken immediately prior to and after each water change to monitor concentration of test chemicals. Every 10 days, six animals were randomly collected from each aquarium. The animals were euthanized, measured (total length at 10 days, snout-vent length otherwise), and staged (Gosner) prior to storage at -20°C for chemical analyses. After 40 days, the depuration phase was initiated by removing animals, cleaning each aquarium with a methanol-soaked sponge, and rinsing to remove adsorbed compound. Aquaria were refilled with clean water; animals were returned to the same aquarium and monitored as described above. Water changes were carried out every four days with fresh water, and a water sample was taken prior to each water change. Two tadpoles were sampled every 10 days for an additional 30 days. The 40-day chronic value was 0.0316 mg/L PFOS based on Gosner stage reached at test termination. This study was deemed quantitative, even though PFOS was detected in the control organisms. While the concentrations were much lower than any of the PFOS treatment groups (3 orders of magnitude lower), it indicated that some potential contamination may have occurred in the controls. The author-reported value (a developmental-based MATC of 0.0316 mg/L) was used quantitatively to derive the freshwater chronic water column criterion.

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C.2.15 Fifteenth Most Sensitive Freshwater Genus for Chronic Toxicity: *Hyalella* (amphipod)

Krupa et al. (2022) conducted a 42-day chronic toxicity test with the amphipod, *Hyalella azteca*, and PFOS-K (perfluorooctanesulfonate potassium salt, > 98% purity, CAS No. 2795-39-3, purchased from Sigma-Aldrich). *H. azteca* were obtained from an in-house culture maintained according to U.S. EPA (2000b). Following published methods for conducting water-only testing with *H. azteca* (Bartlett et al. 2021; Ivey et al. 2016), the methods for this chronic 42-d static-renewal test were modified from standard guidance for sediment testing (U.S. EPA 2000b) to a water-only exposure to avoid sorption of PFOS to sediment. Juvenile amphipods approximately 7- to 8-d old were obtained from mixed-age animals passing through a 425 µm sieve and retained on a 355 µm sieve. Animals were then acclimated to test conditions for 2-days before the start of the exposures. Tests were conducted in 300 mL polycarbonate beakers containing 200 mL of test water, a thin layer of clean silica sand (250 – 500 mm diameter, 5 mL per beaker) and ten amphipods under a 16:8-hour light:dark cycle in an environmental chamber maintained at 23 ± 1°C for 42-days. Aeration was provided at a trickle flow rate via glass pipettes. Mean measured exposure concentrations were 0.0093 (control), 4.8, 9.3, 21, and 45 mg/L PFOS, with eight replicates per concentration. Three liters of a 300 mg/L PFOS stock solution was made by dissolving the PFOS salt into dechlorinated tap and mixing the solution on a stir plate for > 20-hours. A total of 10 L of each test concentration was then prepared by mixing the stock solution into carbon filtered dechlorinated tap water containing added sodium bromide (0.052 mg/L). Amphipods were fed 1 mL of YCT food mixture (1.8 g/L mixture) per beaker daily and a ramped (food increased over time) ration of finely ground TetraMin® (0.25 mg/day during week 1, 0.5 mg/day at week 2, 1 mg/day at week 3, and 1.5 mg/day thereafter). For beakers with ≤ 50 % survival, the feeding ration was halved. The YCT and TetraMin® were mixed together as a slurry. The test solution was renewed every 7 days. On Day 7, a partial water

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change removing about 150 mL of solution was performed to avoid disturbing the younger *H. azteca*. Complete renewal of the test solution started on Day 14 and continued weekly for the remainder of the test. For these water changes, the entire content of a beaker was transferred to a 12-inch diameter glass culture bowl. New sand and exposure solution were then placed in the beaker. Surviving adult amphipods were enumerated and transferred back to the beaker. On Day 21, all beakers were replaced with new ones. On days 28, 35 and 42, after the adults were transferred back to the beakers, the former contents of the beaker (all the discarded sand and water) were preserved in 70% ethanol with rose bengal stain for later enumeration of offspring. At test termination, sex and combined replicate dry biomass were determined for each replicate. To determine biomass, animals were loaded onto a pre-weighed pan made of aluminum foil and placed in a 60°C oven for a minimum of 24-hours. The pans were then placed in a desiccator for at least 1-hour before being weighed. Eight pans with ten animals each were loaded with organisms on Day 0 to establish a baseline for growth. Water quality parameters observed during testing ranged from 7.31 - 8.57 mg/L D.O., 7.77 - 8.10 SU pH, 22.1 - 22.8°C and 62 - 72 mg/L as $CaCO_3$ total hardness. Aqueous samples for PFOS concentration verification were collected before test initiation (day 0) and termination (day 42). Analytical samples were also collected during test solution renewals: out-water on days 7, 14, 21, 28 and 35; and in-water on day 21. The author- reported 42-day reproductive EC_{10} was 0.7 mg/L PFOS. The EPA's independently-calculated models for EC_{10} estimation were similar; however, the survival model was the most robust. The EPA's independently-calculated EC_{10}s for the other 2 endpoints (the growth as dry weight and reproduction as neonates per female) were different from the author-reported values of 0.9 and 0.7 mg/L, respectively. The study authors were not able to calculate an EC_{10} for survival and so was reported to be <4.8 mg/L. However, the EC_{50}s for all endpoints were similar

between the author-reported and the EPA's independently-calculated values. Thus, the differences in the EC_{10} values were considered to be a result of the difference in models. Therefore, the EPA's calculated value for the 42-day survival endpoint (EC_{10} = 2.899 mg/L PFOS-K; 1.132 - 4.667, 95% CI) was used to derive the chronic freshwater chronic water column criterion.

C.2.16 Sixteenth Most Sensitive Freshwater Genus for Chronic Toxicity: *Physella* (snail)

Funkhouser (2014) conducted a 44-day renewal test of PFOS (potassium salt, ≥98% purity) with *Physella heterostropha pomilia* as part of a Master's thesis at Texas Tech University, Lubbock, TX. Egg masses from 100 *P. pomilia* adults were collected from Canyon Lake 6, Lubbock Lakes System, Lubbock, TX, in May 2013 and used for testing. Dilution water was moderately hard reconstituted laboratory water (3.0 g $CaSO_4$, 3.0 g $MgSO_4$, 0.2 g KCl, and 4.9 g $NaHCO_3$ added to 50 L deionized water). Photoperiod was 12:12-hours light:dark at an unreported light intensity. PFOS was dissolved in dilution water to prepare the test concentrations. Exposure vessels were 250 mL polypropylene containers containing 200 mL of test solution. The test employed two replicates composed of four egg masses each with an average of 37.25 eggs/egg mass at start, then truncated to just four snails per replicate once snails hatched. The test consisted of seven test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 10, 20, 40, 50, 70, 80, and 90 mg/L. Exposure concentrations were reportedly measured, but concentrations were not provided. Analyses of test solutions were performed using LC-MS/MS. Standards were used as part of the analytical method, but details were not reported. The reporting limit was 0.010 mg/L. Experiments were conducted in incubators set to 25°C, which did not vary more than 1°C during the course of the studies. No other water quality parameters were reported as having been measured in test solutions. Negative control survival was not reported specifically for the test but was reported to

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be 85-100% across all experiments. The 44-day life-cycle MATC was 14.14 mg/L (from the author-reported NOEC and LOEC, 10 and 20 mg/L, respectively) for mean number of eggs per egg mass. The independently-calculated EC_{10} for the same endpoint was 8.527 (6.170 – 10.88) mg/L. The independent statistical analysis was conducted using data that was estimated (using Web plot digitizer) from the figures presented in the paper. This chronic value was acceptable for quantitative use and was used to derive the freshwater chronic water column criterion.

C.2.17 Seventeenth Most Sensitive Freshwater Genus for Chronic Toxicity: *Ceriodaphnia* (cladoceran)

Krupa et al. (2022) conducted a 6-day chronic toxicity test with the cladoceran, *Ceriodaphnia dubia*, and PFOS-K (perfluorooctanesulfonate potassium salt, > 98% purity, purchased from Sigma-Aldrich). In-house cultures of daphnids were reared according to U.S. EPA (2002) and maintained in 100 mL glass beakers filled with 80 mL of moderately hard reconstituted water (MHRW) prior to testing so that organisms used in the test were less than 24 hours old and were all released within an 8-hour period. The chronic toxicity test was conducted as a three-brood (6-d) static-renewal test according to standard protocol (U.S. EPA 2002). The measured exposure concentrations were < LOD-0.0003, 1.7, 3.5, 7.1, 13, 27, and 48 mg/L PFOS. There were 10 replicates per concentration with one organism per each replicate. The highest test concentration was prepared by dissolving the appropriate mass of PFOS into MHRW water. Once the compound was fully dissolved, the highest concentration was then serially diluted to the other, lower target concentrations. The tests were conducted in 20 mL glass scintillation vials containing 15 mL of test water under a 16:8-hour light:dark cycle in an environmental chamber maintained at 25 ± 1°C without aeration. *C. dubia* were fed daily with 0.45 mL of 1:1 *P. subcapitata* and YCT (yeast-cerophyll-trout chow). Survival and reproduction were recorded each day and neonates and any dead animals were removed. Complete renewal of the test

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solution and count of survivors and neonates was performed daily. Water quality parameters were measured at every water renewal for both the in-water and out-water and ranged from 6.1 - 12.4 mg/L D.O., 6.91 - 8.02 SU pH and 24.0 - 25.9°C. Water samples collected at test initiation (day 0), before (out-water) and after (in-water) test solution renewals, and at test termination (day 6) were analyzed to verify PFOS concentrations. The author-reported 6-day reproductive EC_{10} was 6.9 mg/L PFOS-K. The independently-calculated 6-day EC_{10} value based on reproduction was 10.69 (5.839 – 15.54) mg/L and was considered acceptable for quantitative use to the chronic freshwater chronic water column criterion.

Kadlec et al. (2024) tested the chronic toxicity of potassium perfluorooctanesulfonate (PFOS-K) on *Ceriodaphnia dubia* for 7 days in a measured, renewal experiment. Similar chronic tests were also performed with *Chironomus dilutus* and *Hyallela azteca*, but this summary is limited to the results of the *C. dubia* tests. Test chemicals were obtained from Sigma, Alfa Aesar, Synquest, and Toronto Research Chemical (purity 96-99%). Test organisms were obtained from in-house cultures maintained following ASTM and EPA protocols. Test water was UV-treated and sand-filtered Lake Superior water was supplemented with Na_2SO_4, NaCl, KCl, $CaCl_2$ x $2H_2O$, and $MgCl_2$ x $6H_2O$. Testing protocols followed species-specific ASTM methodologies (ASTM 2002). Three separate tests were conducted, each with a 0.5x dilution series of measured PFOS concentrations, with ten replicates of each concentration, and one organism per replicate. Test 1 mean concentrations were 0.23 (control), 2.3, 4.4, 8.8, 18, and 38 mg/L. Test 2 mean concentrations were 0.0049 (control), 0.049, 0.090, 0.25, 0.42, 0.92, 1.9, 3.9, 8.0, 17, and 35 mg/L. Test 3 mean concentrations were 0.27 (control), 2.7, 5.9, 11, 23, and 46 mg/L. *C. dubia* neonates (<8-hour) were placed in 1 oz polystyrene cups filled with 15 mL of solution. Dissolved oxygen and pH were measured twice in each exposure per treatment and twice in stock solutions.

Tests chambers were placed in a water bath to maintain a steady temperature under a 16:8 light:dark cycle. Study authors reported average water quality measurements of 24.7°C, 8.6 mg/L DO, 7.8 pH, 52 mg/L as $CaCO_3$ hardness, 41 mg/L as $CaCO_3$ alkalinity, and 145 µmhos/cm conductivity. Testing solutions were renewed daily, and organisms were fed daily with 100 µg/L YCT and algae. Control survival was 96.8% with a mean reproduction of 26.8. EC_{20}s and EC_{50}s for survival and young per surviving female were calculated following methods described in Mount et al. (2016), using custom software written with Intel Visual Fortran Compiler Xe and Winteracter 13.0. The author reported EC_{20}s for young per surviving female for tests 1, 2, and 3 were 10.0, 14.5 and 9.8, respectively. Concentration-response data were reported for these tests, allowing the EPA to independently model concentration-response curves using the dose-response curve package in R. The EPA-calculated EC_{10}s for tests 1, 2, and 3 were 8.371, 9.205, and 6.766 mg/L, respectively, which were determined to be acceptable for quantitative use.

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Appendix D Acceptable Estuarine/Marine Chronic PFOS Toxicity Studies

D.1 Summary Table of Acceptable Quantitative Estuarine/Marine Chronic PFOS Toxicity Studies

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Salinity (ppt)	Chronic Value Endpoint	Author Reported Chronic Value (mg/L)	EPA Calculated Chronic Value (mg/L)	Final Chronic Value (mg/L)[b]	Species Mean Chronic Value (mg/L)	Reference
Asian green mussel (60-65 mm), *Perna viridis*	R, M	7 d	PFOS-K 98%	-	25	25	EC10 (growth condition index)	0.03190	0.0033	**0.0033**	0.0033	Liu et al. (2013)
Copepod (nauplii), *Tigriopus japonicus*	R, U	20 d	PFOS Unreported	-	25	32	MATC (developmental stage)	0.7071	-	**0.7071**	0.7071	Han et al. (2015)
Amphipod (juvenile, 14 d), *Austrochiltonia subtenuis*	S, U	7 d	PFOS Unreported	8.12-8.3	20.3-21.2	-	MATC (mortality)	**0.01118**	-	**0.01118**	0.01118	Sinclair et al. (2022)
Mysid (< 24 hr) *Americamysis bahia*	F, M	35 d	PFOS-K 90.49%	8.2-8.4	25	19-21	MATC (reproduction, growth)	0.3708	-	**0.3708**	0.3708	Drottar and Krueger (2000h)
Japanese medaka, *Oryzias latipes*	S, U	30 d	PFOS-K 98%	7.87	24.77	34.68	NOEC (growth condition index)	1.0	-	**>1.0**	>1.0	Oh et al. (2013)

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

[b] Values in bold used in SMCV calculation.

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D.2 Detailed PFOS Acute Toxicity Study Summaries and Corresponding Concentration-Response Curves (when calculated for the most sensitive genera)

The purpose of this section was to present detailed study summaries for tests that were considered quantitatively acceptable for estuarine/marine chronic criterion derivation, with summaries grouped and ordered by genus sensitivity. Data for chronic PFOS toxicity were available for three saltwater invertebrate species, representing three genera and three families. Chronic PFOS toxicity data was available for one fish species. The data available fulfilled only four of the eight MDRs, therefore the EPA could not develop a chronic estuarine/marine criterion following the 1985 Guideline methods.

D.2.1 Most Sensitive Estuarine/Marine Genus: *Perna* (mussel)

Liu et al. (2013) evaluated the chronic effects of perfluorooctanesulfonate, potassium salt (PFOS-K, CAS# 2795-39-3, 98% purity, purchased from Sigma-Aldrich) on green mussels, *Perna viridis*) via a 7-day measured, static-renewal study. The mussels were obtained from a local farm in Singapore, and subsequently acclimated to laboratory conditions for seven days before testing. Mussels were kept at a salinity of 25 ppt (artificial seawater) and a temperature of 25ºC. Forty mussels (60-65 mm length) per 50-L polypropylene tank in duplicate were exposed to measured PFOS concentrations of 0 (control), 0.00012, 0.0011, 0.0096, 0.106 and 0.968 mg/L. Mussels were fed a commercial marine micro-alga purchased from Reed Mariculture on renewal days, which occurred every two days, two hours before the solution renewal. PFOS concentrations were verified through water and muscle tissue samples via LC/MS. Weights and lengths were determined on days 0 and 7. A NOEC of 0.0096 mg/L and a LOEC of 0.106 mg/L was determined for the growth condition index resulting in an MATC of 0.03190 mg/L. No LC_{50} value was reported. The EPA's independently-calculated EC_{10} is 0.0033 (0.00330 – 0.00332) mg/L and was acceptable for quantitative use.

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D.2.2 Second Most Sensitive Estuarine/Marine Genus: *Austrochiltonia* (amphipod)

Sinclair et al. (2022) tested perfluorooctane sulfonic acid (PFOS) on amphipods (*Austrochiltonia subtenuis*) in a 7-day unmeasured, static experiment. PFOS (purity not reported) was purchased from Sigma-Aldrich (Melbourne, VIV, Australia). Test organisms were originally field collected from Deep Creek, Victoria, Australia, but had been maintained in a laboratory culture for over five years at RMIT University in Melbourne, Australia. Organisms were cultured in standard artificial media (SAM) modified from Borgmann (1996) at 21±1°C under a 16:8 light:dark cycle, and they were fed powdered Tetramin fish food and YTC every two days. Two days prior to testing, 14-day old amphipods were selected and held in 2 L glass beakers until test initiation. The 7-day experiment consisted of five controls, one solvent control (methanol 0.25 mL/L), and five nominal PFOS concentrations (0.04, 0.2, 1.0, 5.0, 25 µg/L). Test vessels were 600 mL beakers with 400 mL of test material and a 2x2 cm gauze substrate. Each test vessel included 20 amphipods, and all test media was dissolved in SAM. Seven-day survival was assessed using a series of two-sample Student's t-tests (assuming equal variance) comparing survival in each treatment to its corresponding control. After seven days, PFOS in tissues was measured to calculate bioconcentration factors, and a suite of metabolites were also measured. Based on the results of the t-tests, there was a statistically significant ($p<0.05$) decrease in survival (21% mortality) at the highest concentration compared to its control. Setting the highest concentration 0.025 mg/L as the LOEC and the highest concentration with no adverse effect 0.005 mg/L as the NOEC, the resulting MATC was 0.01118 mg/L, which was determined to be acceptable for quantitative use.

D.2.3 Third Most Sensitive Estuarine/Marine Genus: *Americamysis* (mysid)

Drottar and Krueger (2000h) reported the results of a life-cycle, 35-day flow-through, measured test of PFOS-K (potassium salt, 90.49% purity) with *Americamysis bahia* (formerly

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Mysdiopsis bahia). This good laboratory practice (GLP) test was conducted at the Wildlife International, Ltd. toxicology facility in Easton, MD in June, 1999. The test followed U.S. EPA OPPTS 850.1350, and ASTM Standard E 1191-90 test guidelines. Mysids used for the test were neonates less than 24 hours old at test initiation. The dilution water was filtered natural seawater collected at Indian River Inlet, DE diluted to a salinity of approximately 20 ppt with well water [pH: 8.3 (8.2-8.4); TOC: ≥5.8 mg/L; temperature: 25±2°C]. Photoperiod was 16:8-hours, light:dark with a 30-minute transition period. Light was provided at an intensity of 623-815 lux. A primary stock solution was prepared in dilution water at 89.5 mg/L. It was mixed until all of the test substance was dissolved prior to use. After mixing, the primary stock was proportionally diluted with dilution water to prepare the five additional test concentrations. Exposure vessels were glass beakers with nylon mesh screens on each side placed in 9 L glass aquaria with 5 L of test solution. After mysids reached sexual maturity, they were placed in pairs in glass petri dishes to observe reproduction. The test employed four replicates of fifteen mysids each in six measured test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 0.086, 0.17, 0.34, 0.69, 1.4, and 2.7 mg/L. Mean measured concentrations were < 0.0458 (LOQ), 0.057, 0.12, 0.25, 0.55, 1.3, and 2.6 mg/L, respectively. Analyses of test solutions were performed at Wildlife International Ltd. using HPLC/MS. Measured values ranged from 66 to 96% of nominal. Mortality from test initiation to pairing (day 20) in the 0.057, 0.12, 0.25, 0.55, 1.3, and 2.6 mg/L treatment groups was 8, 25, 18, 17, 32 and 100%, respectively, and mean control mortality was 22%. From pairing until test termination (day 20 to day 35) survival was greater than 90% in the control and all but the 1.3 mg/L treatment, which had 57% survival during that period. The 35-day NOEC (reproduction and growth) was 0.25 mg/L and corresponding LOEC was 0.55 mg/L. The EPA-calculated MATC was 0.3708 mg/L. The EC_{10}

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could not be calculated at this time given the level of data that was presented in the paper. The chronic value was considered acceptable for quantitative use despite the control survival of 78% because it was only slightly below the 80% survival threshold, and because there were no other deficiencies in the study design.

D.2.4 Fourth Most Sensitive Estuarine/Marine Genus: *Tigriopus* (copepod)

A 20-day renewal, unmeasured full life-cycle test with PFOS (analytical grade) was conducted on the copepod, *Tigriopus japonicus* (non-North American species) by **Han et al. (2015)**. Copepods were cultured and maintained in 0.2 µm filtered artificial seawater adjusted to 32 psu salinity and 25°C under a 12-hour photoperiod. *T. japonicus* were fed with green algae, *Tetraselmis suecica*. PFOS (100 mg/L in MeOH) was concentrated by evaporation and re-dissolved in DMSO to obtain a maximum stock concentration (1,000 mg/L). The PFOS stock was diluted with artificial seawater to obtain four nominal test concentrations (0, 0.25, 0.5 and 1 mg/L PFOS). The final concentration of DMSO in seawater was 0.001% (v/v) or less for each treatment. Ten newly-hatched nauplii (<12 hour post hatch) were allocated to each well of a 12-well tissue culture plate with 4 mL of test solution. There were three replicates per each treatment. Organisms were fed algae during testing and 50% of test media was replaced daily. Over the next 20 days, the development of the copepod's growth from nauplii to copepodite and from nauplii to adults was determined daily based on morphological characteristics. Results were presented as the number of days needed to reach the normal development stages. The highest test concentration (1 mg/L PFOS) significantly increased the amount of time it took the copepods to reach the development stage. Additionally, the authors assessed the reproduction of the copepods by counting the nauplii produced by eight ovigerous females for 10 days in each well exposed to PFOS. However, it was unclear if this was a subsampling of the organisms used in the 20-day developmental test or if an independent assay with adult females. Results are presented

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graphically as daily nauplii production/individual. There was a statistically significant decrease in production (daily nauplii production/individual) in the 0.25, 0.5 and 1.0 mg/L PFOS concentrations compared to the control. It was decreased by approximately 50% in the highest concentration (1 mg/L). While this endpoint was more sensitive than the growth endpoint, the publication is unclear about the method used for the reproduction test endpoint and whether it was an independently-conducted 10-day test or a subsample of reproducing adults were observed from the 20-day test. The EPA sought but did not receive responses to clarifying questions posed to the authors. Additionally, the authors were asked if control survival for the test was above 80% and if the authors could provide the data. Based on the information presented in the paper without additional information and data provided by the authors to clarify adherence to the EPA data quality objectives and allow independent calculation and verification of point estimates, the developmental stage is considered for quantitative use and the reproductive endpoint for qualitative use. The 20-day MATC (based on time to reach development stage) was 0.7071 mg/L and was acceptable for quantitative use.

D.2.5 Fifth Most Sensitive Estuarine/Marine Genus: *Oryzias* (fish)

Oh et al. (2013) evaluated the 30-day chronic toxicity of PFOS to the Japanese medaka, *Oryzias latipes*, via an unmeasured static exposure. PFOS (98% pure, CAS No. 2795-39-3) was dissolved in filtered seawater with the minimal concentration (< 0.001%) of dimethyl sulfoxide (DMSO) used as a vehicle to prevent cellular damage to the fish. Chemical measurements were not made, and nominal concentrations were used throughout the study. Prior to test initiation, the fish were adapted to a seawater environment by first acclimation in a 50/50 freshwater/saltwater mix, then sequentially increasing the saltwater component by replacing half of the water with the same volume of seawater every day for 15 days. The fish were fed newly-hatched brine shrimp (< 24 hours after hatching) and commercial flake food twice per day. No mortality was observed

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during acclimation to the seawater over one month. The fish were maintained at 25°C under a constant photoperiod of 16:8-hour light:dark, and water quality was monitored by measuring the pH, D.O., and temperature. Fish from the third generation of *O. latipes* (n = 7/group) that had adapted to seawater for over one month were used in the series of exposure experiments. Fish were exposed for 30 days to one PFOS concentration (1 mg/L) plus a 0.22 µm filtered seawater control and a DMSO carrier solvent control to examine biological effects (specifically, the condition factor, K, a growth endpoint). Test conditions were maintained at an average temperature of 24.77 ℃, pH of 7.87 SU, D.O. of 5.90 mg/L, and salinity of 34.68 PSU with fish fed daily.

The 30-day NOEC condition factor of 1.0 mg/L PFOS was selected as the primary endpoint from this study. Authors also stated, "*In our preliminary study, fish mortality was altered 30 days after PFC (perfluorinated compounds) exposure, suggesting that repeated exposure to PFCs for 30 days at 1 µg/mL causes adverse effect on O. latipes*." The statement about results from the preliminary test is in direct conflict with the results of condition factor in the final test. Few details are provided about the preliminary test. Results of the final test were retained as quantitatively acceptable because they provide chronic estuarine/marine data that are limited.

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Appendix E Acceptable Freshwater Plant PFOS Toxicity Studies

E.1 Summary Table of Acceptable Quantitative Freshwater Plant PFOS Toxicity Studies

Species	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Reported Effect Concentration (mg/L)	Reference
Cyanobacteria, *Microcystis aeruginosa*	S, U	72 hr	PFOS-K 98%	7.4	23	MATC (cell density)	0.3162	Muhammad (2023)
Cyanobacteria, *Microcystis aeruginosa*	S, U	96 hr	PFOS-K 98%	-	25	EC30 (population growth rate)	77.39	Zhang et al. (2023b)
Diatom, *Navicula pelliculosa*	S, M	96 hr	PFOS-K 86.9%	7.5-8.9	24	EC50 (area under growth curve)	252	Sutherland and Krueger (2001)
Green alga, *Chlorella vulgaris*	S, U	96 hr	PFOS-K 95%	-	23	IC50 (cell density)	81.6	Boudreau (2002); Boudreau et al. (2003a)
Green alga, *Chlorella vulgaris*	S, U	96 hr	PFOS-K 98%	-	25	EC20 (population growth rate)	13.42	Zhang et al. (2023b)
Green alga, *Raphidocelis subcapitata* (formerly, *Selenastrum capricornutum* and *Pseudokirchneriella subcapitata*)	S, U	96 hr	PFOS-K 24-28%	-	23	EC50 (specific growth rate)	49.28[b]	3M Company (2000)
Green alga, *Raphidocelis subcapitata*	S, U	4 d	PFOS-K Unknown	-	23	EC50 (cell count)	77.19	3M Company (2000)
Green alga, *Raphidocelis subcapitata*	S, U	7 d	PFOS-K Unknown	-	23	EC50 (cell count)	76.68	3M Company (2000)
Green alga, *Raphidocelis subcapitata*	S, U	10 d	PFOS-K Unknown	-	23	EC50 (cell count)	83.92	3M Company (2000)
Green alga, *Raphidocelis subcapitata*	S, U	14 d	PFOS-K Unknown	-	23	EC50 (cell count)	76.78	3M Company (2000)
Green alga, *Raphidocelis subcapitata*	S, M	96 hr	PFOS-K 90.49%	7.4-8.4	24	EC50 (cell density)	71	Drottar and Krueger (2000b)
Green alga, *Raphidocelis subcapitata*	S, U	96 hr	PFOS-K 95%	-	23	IC50 (cell density)	48.2	Boudreau (2002); Boudreau et al. (2003a)
Green alga, *Scenedesmus quadricauda*	S, M	96 hr	PFOS-K 99%	7	22	EC50 (growth inhibition rate)	89.34	Yang et al. (2014)

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Species	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Reported Effect Concentration (mg/L)	Reference
Duckweed, *Lemna gibba*	S, M	7 d	PFOS-K 86.9%	7.5	25	IC10 (frond number)	18.06	Desjardins et al. (2001b)
Duckweed, *Lemna minor*	S. M	96 hr	PFOS ≥95.0%	6.5	25	NOEC (population growth rate)	9.859	Wu et al. (2023)
Water milfoil (5 cm apical shoots), *Myriophyllum sibiricum*	S, M	14 d	PFOS-K Unreported	-	-	EC10 (wet weight)	0.7	Hanson et al. (2005)
Water milfoil (5 cm apical shoots), *Myriophyllum sibiricum*	S, M	28 d	PFOS-K Unreported	-	-	EC10 (wet weight)	0.19	Hanson et al. (2005)
Water milfoil (5 cm apical shoots), *Myriophyllum sibiricum*	S, M	42 d	PFOS-K Unreported	-	-	EC10 (wet weight)	0.6	Hanson et al. (2005)
Water milfoil (5 cm apical shoots), *Myriophyllum spicatum*	S, M	14 d	PFOS-K Unreported	-	-	EC10 (plant length)	4.8	Hanson et al. (2005)
Water milfoil (5 cm apical shoots), *Myriophyllum spicatum*	S, M	28 d	PFOS-K Unreported	-	-	EC10 (dry weight)	3.3	Hanson et al. (2005)
Water milfoil (5 cm apical shoots), *Myriophyllum spicatum*	S, M	42 d	PFOS-K Unreported	-	-	EC10 (wet weight)	3.5	Hanson et al. (2005)

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, NR=not reported

[b] The independently-calculated EC_{50} value was 176.0 mg/L as the test substance, or 49.28 mg/L based on the percentage of PFOS-K (active ingredient 28%) in the test substance.

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E.2 Summary of Plant PFOS Toxicity Studies Considered in the Aquatic Life Criterion Derivation

E.2.1 Cyanobacteria, *Microcystis aeruginosa*

Muhammad (2023) tested perfluorooctane sulfonic acid potassium salt (PFOS-K) on *Microcystis aeruginosa* for seven days in a static, unmeasured experiment. PFOS potassium salt (98% purity) was obtained from Sigma-Aldrich. Algae were obtained from Golder Laboratory, at the State University of New York, USA. Algae were cultured in 500 mL Erlenmeyer flasks containing 200mL of BG11 medium at the Phycology Laboratory of Ahmadu Bello University's Department of Botany in Zaria. Cultures were maintained at 23°C, pH 7.4, under a 16:8 hour light:dark photoperiod at a light intensity of 40 µmol/m^2/s. The BG11 growth medium was sterilized by autoclaving at 121°C 24 hours before use. Cultures were changed and maintained in a manner to insure they were experiencing exponential growth. *M. aeruginosa* in the exponential growth phase were added to test vessels containing test solution at a density of approximately $1.0x10^6$ cells/mL. The experimental design consisted of nominal concentrations of 0 (control), 0.001, 0.01, 0.1, 1 and 10 mg/L PFOS, diluted from a PFOS stock solution prepared in BG-11 medium, with three replicates per treatment level. Cell density was measured on days 1, 3, and 7. Cellular pigment content was measured on days 1 and 7, biochemical composition, antioxidant enzyme composition, and microcystin analysis was measured on day 7. One-way ANOVA and means comparisons tests were used to assess significant differences ($p<0.05$) between treatments, and repeated measures ANOVA was used to assess significant differences between sampling dates. All analyses were conducted using the R statistical analysis program v3.63. By day three, cell density in the 1 mg/L treatment were significantly lower than in controls, and by day seven, cell density in the 0.1 mg/L treatment were significantly lower than in controls. Chlorophyll *a* also decreased with increasing PFOS concentrations, and biochemical and

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enzymatic endpoints also differed among PFOS treatment concentrations. The author-reported 72 hour NOEC and LOEC for cell density were 0.1 and 1 mg/L, and the resulting MATC of 0.3162 mg/L was determined to be acceptable for quantitative use.

Zhang et al. (2023b) tested perfluorooctane sulfonic acid potassium salt (PFOS-K) on *Microcystis aeruginosa* for 12 days in a static, unmeasured experiment. PFOS potassium salt (98% purity) was purchased from Sigma-Aldrich (St. Louis, USA). Algae were obtained from the Freshwater Algae Culture Collection at the Institute of Hydrobiology in Wuhan, China. Algae were cultured in Erlenmeyer flasks within BG-11 media in an illumination incubator at 25±1°C on a 12:12 hour light-dark cycle at a light intensity of 4,000±50 lux. *M. aeruginosa* in the exponential growth phase were added to 100 mL Erlenmeyer flasks containing test solution at a density of approximately $1.0x10^5$ cells/mL. The experimental design consisted of nominal concentrations of 0 (solvent control), 0.01, 1, 20, 50, 100, 250 and 500 mg/L PFOS, diluted from a PFOS stock solution prepared in BG-11 medium and containing 0.05% formaldehyde as a solvent, with three replicates per treatment. Testing methods followed OECD guidelines with modifications (OECD 2006). Algal cell density was measured after 4 and 12 days using a UV-vis spectrophotometer. Algal cell densities were used to calculate growth inhibition at all concentrations relative to controls, and effect concentrations (ECs) were calculated using nonlinear regression modeling. Chlorophyll *a* and optical quantum yield were also measured after 4 and 12 days. ANOVA followed by Tukey's multiple comparison test was used to identify significant ($p<0.05$) differences between treatments and controls, using GraphPad Prism v8.0. EC_{20}s were calculated using a four-parameter nonlinear regression model in GraphPad Prism v8.0. A 96-hour EC_{20} was not reported, so the 96-hour EC_{30} for growth inhibition of 77.39 mg/L was determined to be acceptable for quantitative use.

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E.2.2 Diatom, *Navicula pelliculosa*

Sutherland and Krueger (2001) conducted a 96-hour static acute algal growth inhibition test on PFOS (potassium salt, 86.9% purity) with the freshwater diatom, *Navicula pelliculosa*. The good laboratory practice (GLP) test was conducted at the Wildlife International, Ltd. in Easton, Maryland in February-March, 2000. The test followed U.S. EPA (1996a) and ASTM (1990). The freshwater diatom was provided from in-house cultures that had been actively growing in the culture medium for at least two weeks. The test media was prepared by adding the stock nutrient solution to purified well water according to ASTM 1218 and adjusting pH to 7.5. Seven measured concentrations (0, 62.3, 83.2, 111, 150, 206, 266, 335 mg/L PFOS) were tested from one negative control and six nominal concentrations: 61.5, 81.3, 110, 147, 198, 264 and 347 mg/L based on PSOF-K purity. Solutions were stirred for approximately 24 hours before testing. Exposures were conducted in 250 mL plastic Erlenmeyer flasks containing 100 mL solution and plugged with foam stoppers. Each flask contained $1x10^4$ cells/mL and each test concentration had three replicates. Flasks were incubated in environmental chambers at 24±2°C under constant illumination (4,300 lux) and shaken continuously at ~100 rpm. pH in the test solutions ranged from 7.5-8.9 over the exposure period. Samples were collected daily to determine cell density and to calculate area under the curve and growth rates. The cell density of the control replicates increased by greater than two orders of magnitude during the test. The 96-hour EC_{50}, based on area under the growth curve, was 252 mg/L PFOS (NOEC<62.3 mg/L). The plant value was acceptable for quantitative use.

E.2.3 Green alga, *Chlorella vulgaris*

Boudreau (2002) performed a 96-hour static acute algal growth inhibition test on PFOS (potassium salt, 95% purity) with *Chlorella vulgaris* as part of a Master's thesis at the University of Guelph, Ontario, Canada. The same information was subsequently published in the open

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literature as **Boudreau et al. (2003a)**. The acute algal growth inhibition tests followed protocols found in ASTM (1999b) and Geis et al. (2000). All treatment concentrations were based on the PFOS anion (without K) and solutions were prepared in laboratory-grade distilled water. *C. vulgaris* (UTCC 266 strain) were obtained as slants from the University of Toronto Culture Collection (UTCC; Toronto, Canada). Toxicity testing consisted of initial range-finder tests (0, 28, 56, 113, 225, and 450 mg/L) followed by at least two definitive tests (0, 12.5, 25, 50, 100, 200, and 400 mg/L). Tests were conducted in 20 mL solution in 60 x 15 mm polyethylene disposable petri dishes. Each dish contained $1.5x10^4$ cells/mL and each test concentration had four replicates. Tests were continuously illuminated with cool-white fluorescent light between 3,800 and 4,200 lux and incubated at 23±1°C. Each dish was manually shaken twice a day during testing. Toxicity test endpoints included cell density and chlorophyll *a* content. The most sensitive endpoint, cell density, had a reported NOEC of 8.2 mg/L and an IC_{50} of 81.6 mg/L. The IC_{50} value was considered quantitatively acceptable for use.

Zhang et al. (2023b) tested perfluorooctane sulfonic acid potassium salt (PFOS-K) on *Chlorella vulgaris* for 12 days in a static, unmeasured experiment. PFOS potassium salt (98% purity) was purchased from Sigma-Aldrich (St. Louis, USA). Algae were obtained from the Freshwater Algae Culture Collection at the Institute of Hydrobiology in Wuhan, China. Algae were cultured in Erlenmeyer flasks within BG-11 media in an illumination incubator at 25±1°C on a 12:12 hour light-dark cycle at a light intensity of 4,000±50 lux. *C. vulgaris* in the exponential growth phase were added to 100 mL Erlenmeyer flasks containing test solution at a density of approximately $1.0x10^5$ cells/mL. The experimental design consisted of nominal concentrations of 0 (solvent control), 0.01, 1, 20, 50, 100, 250 and 500 mg/L PFOS, diluted from a PFOS stock solution prepared in BG-11 medium and containing 0.05% formaldehyde as a

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solvent, with three replicates per treatment. Testing methods followed OECD guidelines with modifications (OECD 2006). Algal cell density was measured after 4 and 12 days using a UV-vis spectrophotometer. Algal cell densities were used to calculate growth inhibition at all concentrations relative to controls, and EC_{50}s were calculated using nonlinear regression modeling. Chlorophyll *a* and optical quantum yield were also measured after 4 and 12 days. ANOVA followed by Tukey's multiple comparison test was used to identify significant ($p<0.05$) differences between treatments and controls, using GraphPad Prism v8.0. Effect concentrations (ECs) were calculated using a four-parameter nonlinear regression model in GraphPad Prism v8.0. The 96-hour EC_{20} for growth inhibition was 13.42 mg/L, and was determined to be acceptable for quantitative use.

E.2.4 Green alga, *Raphidocelis subcapitata*

3M Company (2000) provided the results of a 96-hour toxicity test completed in 1991 with the green alga, *Raphidocelis subcapitata* (formerly *Selenastrum capricornutum*), and PFOS-K (perfluorooctancesulfonate potassium salt, CAS # 2795-39-3) in a formulated mixture with diethylene glycol butyl ether and water (mixed product FM-3820, with 24-28% PFOS-K). Based on this purity the author made calculations to adjust test concentrations using 28% active ingredient, but the presence of diethylene glycol could also contribute to toxicity. The toxicity test followed OECD test guidelines with five test concentrations and control in a static unmeasured exposure. A stock culture of the alga was obtained from the Culture Collection of Algae at the University of Texas at Austin. Alga were transferred to 250 mL flasks with an initial density of $1x10^4$ cells/mL and 100 mL of test solution. There were three replicates for each of the five nominal test concentrations (62.5, 125, 250, 500 and 1,000 mg/L) and control. Synthetic nutrient medium was used as the dilution media for all test treatments. Alga were grown at 23°C and continuously shaken. The author-reported EC_{50}, based on average specific growth rate, was

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255 mg/L as the test substance, or 71 mg/L based on the percentage of PFOS-K (active ingredient 28%) in the test substance. The independently-calculated EC_{50} value was 176.0 mg/L as the test substance, or 49.28 mg/L based on the percentage of PFOS-K (active ingredient 28%) in the test substance. The plant value was acceptable for quantitative use.

3M Company (2000) provides the results of four separate toxicity tests completed in 1981 with the green alga, *Raphidocelis subcapitata* (formerly *Selenastrum capricornutum*), and PFOS-K (perfluorooctancesulfonate potassium salt, CAS # 2795-39-3, unknown purity). The toxicity tests followed a protocol modified from OECD (1979). There were four separate exposure regimes: 1) four day exposure + 10 day recovery period; 2) seven day exposure + seven day recovery period; 3) 10 day exposure + four day recovery period; and 4) 14 day continuous exposure. A bacteria-free culture of the alga was obtained from the U.S. EPA (Corvallis, OR) and stored in the dark until testing. Seven-day old stock cultures with an initial density of $1x10^4$ cells/mL were placed in 250 mL flasks with 50 mL of test solution. There were three replicates for each of the six nominal test concentrations (26, 40, 61, 93, 145 and 225 mg/L) and control. Nutrient medium was used as the dilution media for all test treatments and test solutions were not renewed during the exposure. Alga were grown at 23°C and continuously shaken at 100 rpm. The author-reported EC_{50}, based on cell counts, was 82, 99, 98, and 95 mg/L, for the 4-, 7-, 10- and 14-day exposures, respectively. However, it should be noted that the authors do not specify if the EC_{50}s were determined after the exposure period or the post-observation period. The independently-calculated EC_{50} values were 77.19, 76.68, 83.92, 76.78 mg/L and are acceptable for quantitative use.

Drottar and Krueger (2000b) conducted a 96-hour static acute algal growth inhibition test on PFOS (potassium salt, 90.49% purity) with the freshwater alga, *Raphidocelis subcapitata*

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(formerly *Selenastrum capricornutum*). The good laboratory practice (GLP) test was conducted at the Wildlife International, Ltd. in Easton, Maryland in April, 1999. The test followed ASTM (1990); OECD (1984); U.S. EPA (1996a) methodologies. The green alga was originally obtained from the culture collection at University of Texas at Austin (or another supplier) and maintained at Wildlife International Ltd. for a minimum of two weeks in culture medium. Algae used in tests were in exponential growth phase. The test media was prepared by adding the stock nutrient solution to purified well water according to ASTM 1218 and adjusting pH to 7.5. Seven measured concentrations (< 0.115, 5.5, 11, 21, 44, 86, 179 mg/L PFOS) were tested from a negative control and six nominal concentrations: 5.7, 11, 23, 46, 91, 183 mg/L based on PFOS-K purity. Test concentrations were measured at test initiation, at 72 hours, and at test termination by HPLC-MS with a mean recovery of 99.1%. Solutions were stirred for approximately 24 hours before testing. Exposures were conducted in 250 mL polycarbonate flasks containing 100 mL solution and plugged with foam stoppers. Each flask contained $1x10^4$ cells/mL and each test concentration had three replicates. Flasks were incubated in environmental chambers at 24±2°C under constant illumination (4,300 lux) and shaken continuously at ~100 rpm. The pH in test solutions ranged from 7.4-8.4 over the exposure period. Samples were collected daily to determine cell density and to calculate area under the curve and growth rates. The 96-hour EC_{50}, based on cell density and area under the growth curve, was 71 mg/L PFOS (NOEC=44 mg/L). The plant value was acceptable for quantitative use.

Boudreau (2002) performed a 96-hour static acute algal growth inhibition test on PFOS (potassium salt, 95% purity) with *Raphidocelis subcapitata* (formerly *Pseudokirchneriella subcapitata*). The study was part of a Master's thesis at the University of Guelph, Ontario, Canada and subsequently published in the open literature as **Boudreau et al. (2003a)**. The acute

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algal growth inhibition tests followed protocols found in ASTM (1999b); Geis et al. (2000) and Geis et al. (2000). All treatment concentrations were based on the PFOS anion (without K) and solutions were prepared in laboratory-grade distilled water. *R. subcapitata* (UTCC 37 strain) were obtained as slants from the University of Toronto Culture Collection (UTCC; Toronto, Canada). Toxicity testing consisted of initial range-finder tests (0, 28, 56, 113, 225, and 450 mg/L) followed by at least two definitive tests (0, 12.5, 25, 50, 100, 200, and 400 mg/L). Tests were conducted in 20 mL solutions in 60 x 15 mm polyethylene disposable petri dishes. Each dish contained $1.5x10^4$ cells/mL and each test concentration had four replicates. Tests were continuously illuminated with cool-white fluorescent light between 3,800 and 4,200 lux and incubated at 23±1°C. Each dish was manually shaken twice a day during testing. Toxicity test endpoints included cell density and chlorophyll *a* content. The reported NOEC and IC_{50} based on most sensitive endpoint, cell density, were 5.3 mg/L and 48.2 mg/L. The IC_{50} from the study was acceptable for quantitative use.

E.2.5 Green alga, *Scenedesmus quadricauda*

Yang et al. (2014) conducted a 96-hour static, measured test on the growth effects of PFOS (potassium salt, CAS # 2795-39-3, 99% purity) with the green alga, *Scenedesmus quadricauda*. Algae were obtained from in-house cultures from the Chinese Research Academy of Environmental Sciences. The algae used for testing were inoculated at a cell density equal to $2.0x10^4$ cells/mL in 50 mL beakers. PFOS was dissolved in deionized water and DMSO (amount not provided) and then diluted with M4 medium. Alga were exposed to 0 (solvent control), 50.00, 65.00, 84.50, 109.85, 142.81 and 185.65 mg/L PFOS. Each treatment was replicated three times. While the text implied the exposures were static, the supplemental information provided the measured test concentrations in the highest and lowest test treatments both before and after renewal. Measured concentrations ranged from 42.56 mg/L (before renewal) to 49.78 mg/L

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(after renewal) in the lowest treatment, and from 165.61 (before renewal) to 183.90 mg/L (after renewal) in the highest treatment. The experiments were conducted at 22±2°C with a 12:12-hour light:dark cycle. The initial pH of the test solution was 7.0±0.5, total hardness was 190±0.1 mg/L as $CaCO_3$, and total organic carbon was 0.02 mg/L. Algae concentrations in the beakers were measured daily with a microscope. The 96-hour EC_{50} (based on growth inhibition) was 89.34 mg/L and was acceptable for quantitative use.

E.2.6 Duckweed, *Lemna* sp.

Desjardins et al. (2001b) performed a static, measured 7-day growth inhibition study on the duckweed *Lemna gibba* with PFOS-K (perfluorooctanesulfonate potassium salt, 86.9% purity from 3M Corporation). The test protocol from U.S. EPA, OPPTS Number 850.4400 was followed. Duckweed was cultured and tested at Wildlife International Ltd. in 20X AAP medium and were actively growing for at least two weeks prior to testing. The pH of the medium was adjusted to pH 7.5 with HCl and filtered to sterilize before use. Test chambers were covered 250 mL plastic beakers with 100 mL of culture medium or test concentration and held at 25°C under continuous warm-white lighting with a target intensity of 5,000 lux. Fronds of duckweed were exposed to six test concentrations and a control with three replicates for each treatment. PFOS concentrations in the test medium were measured on day 0, 3, 5 and 7 with mean reported concentrations of <4.39 (LOQ), 7.74, 15.1, 31.9, 62.5, 147 and 230 mg/L PFOS active ingredient. Growth was defined as an increase in the total number of fronds in each replicate and measured by direct count on day 3, 5 and 7. Frond numbers on day seven in the 147 and 230 mg/L test treatments were inhibited by 65 and 81% as compared to the control. The reported 5-day IC_{10} based on frond number was 30.7 mg/L PFOS. The independently-calculated 5-day IC_{10} value was 18.06 mg/L and was acceptable for quantitative use.

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Wu et al. (2023) tested perfluorooctane sulfonate (PFOS) on duckweed, *Lemna minor*, for 96 hours in a static, measured experiment. PFOS (≥95.0% purity) was obtained from Dr. Ehrenstorfer GmbH (Augsburg, Germany). DMSO solvent (≥ 99.9% purity) was obtained from Merck (Germany). Duckweed was obtained from in house cultures that had been grown in a modified Swedish Standards Institute (SIS) medium. Duckweed cultures were housed in 150 mm petri dishes with 100 mL SIS medium that was changed every two weeks. SIS medium pH was adjusted to 6.5 by using NaOH or HCl. Plants were cultured at 25±1°C and 60% humidity under a 12:12 light dark cycle at 2,000 lux. Duckweed was precultured for 1 week in clean SIS media for seven days prior to testing. Duckweed experiments were conducted in 6-well polypropylene plates to avoid PFOS sorption to container walls. Each replicate well contained 10mL of test material and two colonies approximately the same size of a 3-frond *L. minor*. Nominal test concentrations were 0 (control), 0.001, 0.1, and 10 mg/L PFOS. All test chambers included DMSO solvent, and each treatment had three duplicates. PFOS concentrations measured on day 0 were 1.00±0.02, 90.0±0.73, and 9,859±2.83 µg/L. PFOS in solvent controls were not reported for day 0 but was below detection levels when measured after 96 hours. The number of fronds in each treatment well were counted after 48 and 96 hours. In addition, Fourier-transform infrared spectroscopy (FTIR) was performed on a subset of fronds from each treatment at the end of the 96-hour exposure to examine responses to PFOS at the biochemical level. Statistically significant ($p<0.05$) differences between treatment groups were assessed with one-way ANOVA followed by Dunnett's tests using SPSS Statistics 26. No statistically significant differences in frond number were observed. However, FTIR analysis revealed structural and functional alterations in response to PFOA at the biochemical level. The reported NOEC of 9.859 mg/L for population growth rate was determined to be acceptable for quantitative use.

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E.2.7 Watermilfoil, *Myriophyllum* sp.

Hanson et al. (2005) conducted a 42-day toxicity study of PFOS (potassium salt, purity not provided) with two species of submergent watermilfoils, *Myriophyllum spicatum* and *M. sibiricum*. The study was conducted in 12,000 L outdoor microcosms at the University of Guelph Microcosm Facility located in Ontario, Canada. Each microcosm was below ground and was flush with the surface. Plastic trays filled with sediment (1:1:1 mixture of sand, loam and organic matter, mostly manure) were placed in the bottom of each microcosm. The total carbon content of the sediment was 16.3%. Ten apical shoots, 5 cm in length, from in-house cultures using the same sediment were transferred to each microcosm, with three separate microcosms used for each treatment (0, 0.3, 10 and 30 mg/L). Endpoints of toxicity that were monitored on days 1, 14, 28 and 42 of the study included growth in plant length, root number, root length, longest root, node number, wet mass, dry mass, and chlorophyll *a* and *b* content. PFOS treatments were dissolved in the same water (well water) used to supply the microcosms. Measured concentrations in the microcosms were reported in a companion publication (Boudreau et al. 2003b). Results from the companion paper showed that measured concentrations remained similar to nominal concentrations throughout the entire exposure period and did not change appreciably over the course of the study. Water quality (i.e., pH, temperature, D.O., hardness, and alkalinity) and light levels were measured regularly, but were not reported. *M. sibiricum* was more sensitive to PFOS than *M. spicatum*. The 42-day EC_{10} (based on wet weight) was 0.6 mg/L for *M. sibiricum* and 3.5 mg/L for *M. spicatum*. The plant values were acceptable for quantitative use.

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Appendix F Acceptable Estuarine/Marine Plant PFOS Toxicity Studies

F.1 Summary Table of Acceptable Quantitative Estuarine/Marine Plant PFOS Toxicity Studies

Species	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Salinity (ppt)	Effect	Reported Effect Concentration (mg/L)	Reference
Green alga, *Chlorella sp.*	S, U	96 hr	PFOS >98%	-	23	30[c]	EC50 (population abundance)	77.62	Mao (2023)

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, NR=not reported

[b] Salinity of Erdschreiber's medium

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F.2 Summary of Plant PFOS Toxicity Studies Considered in the Aquatic Life Criterion Derivation

F.2.1 Green alga, *Chlorella* sp.

Mao (2023) tested perfluorooctane sulfonate (PFOS) on an estuarine/marine *Chlorella sp.* for seven days in a static, unmeasured experiment. PFOS (>98% purity) was obtained from Tokyo Chemical Industry Co. Ltd. Algae were obtained from the Freshwater Algae Culture Collection at the Institute of Hydrobiology in Wuhan, China. Algae were obtained from the Algae Culture Collection at the Institute of Hydrobiology in Wuhan, China. Algae were cultured in Erdschreiber medium within a conical flask inside an illumination incubator at 23±1°C under a 12:12 light:dark cycle at 5,000 lux. Algae were shaken three times per day to prevent sticking to the sides of the flask, and inoculated once every two weeks to maintain optimal growth. *Chlorella sp.* in the exponential growth phase were added to test vessels containing test solution at a density of approximately $5.0x10^4$ cells/mL. The experimental design consisted of nominal concentrations of 0 (control), 5, 10, 20, 40, 80, and 160 mg/L PFOS. Testing protocols followed OECD guidelines, and all experiments were performed in triplicate. Statistical analysis included one-way ANOVA, using SPSS version 26 software. Algal cell density and size were measured daily, and algal growth inhibition was calculated using the equation provided in the OECD guidelines. Chlorophyll *a*, maximum quantal yield, cell membrane integrity, esterase activity relative to control, relative electron transfer rate, and reactive oxygen species were reported after 1, 3, 5, and 7 days, respectively. Algae exhibited maximum growth at 10 mg/L, but growth significantly declined at 40 mg/L and higher concentrations. Increasing PFOS concentrations also inhibited chlorophyll *a*, and increased oxidative stress. The 96-hour EC_{50} for algal growth inhibition was 77.62 mg/L, and was determined to be acceptable for quantitative use.

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Appendix G Other Freshwater PFOS Toxicity Studies

G.1 Summary Table of Acceptable Qualitative Freshwater PFOS Toxicity Studies

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Unicellular protist, *Paramecium caudatum*	S, U	1 hr	Heptadecafluorooctane sulfonic acid potassium salt >98%	7.2	20-24	LC50	-	12.86[e]	Duration too short for an acute test, single-cell organism	Matsubara et al. (2006)
Protozoa, *Tetrahymena pyriformis*	S, U	2 hr	PFOS Unreported	7.2	25	EC50 (population abundance)	-	51.51[e]	Duration too short for an acute test, single-cell organism	Lim (2022)
Protozoa, *Tetrahymena pyriformis*	S, U	96 hr	PFOS Unreported	7.2	25	EC50 (population abundance)	-	13.2	Single-cell organism	Lim (2022)
Cyanobacteria, *Anabaena sp.*	S, M	24 hr	PFOS 98%	-	-	EC50 (bioluminescence)	-	16.29	Duration too short for a plant test, non-apical endpoint	Rodea-Palomares et al. (2012)
Cyanobacteria, *Anabaena sp.*	S, U	24 hr	PFOS-K 98%	7.8	28	EC50 (bioluminescence)	-	83.51	Duration too short for a plant test, non-apical endpoint	Rodea-Palomares et al. (2015)
Green alga (7.0×10^5 cells/ml), *Chlorella vulgaris*	S, M	96 hr	PFOS-K 98%	-	-	LOEC (chlorophyll a)	-	40	Missing exposure details	Xu et al. (2017)
Green alga, *Raphidocelis subcapitata*	S, M	72 hr	PFOS-K 98%	-	21-24	EC50 (growth)	-	35	Duration too short for a plant test, missing some exposure details	Rosal et al. (2010)
Green alga, *Raphidocelis subcapitata*	S, U	72 hr	PFOS-K 98%	-	22	EC50 (growth inhibition)	-	35	Duration too short for a plant test	Boltes et al. (2012)
Green alga, *Scenedesmus obliquus*	S, U	72 hr	PFOS Unreported	7.5	22	IC50 (growth rate reduction)	-	77.8[e]	Duration too short for a plant test	Liu et al. (2008)
Green alga, *Scenedesmus obliquus*	S, U	72 hr	PFOS ≥98%	7.5	22	NOEC (growth)	-	40	Duration too short for a plant test	Liu et al. (2009)
Green alga, *Scenedesmus obliquus*	S, U	7 d	PFOS-K >98%	7.1	25	EC50 (biomass)	-	136.69	Missing exposure details	Xue et al. (2022)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Duckweed, *Lemna gibba*	S, U	7 d	PFOS-K 95%	-	25	IC50 (wet weight)	-	31.1	Culture water not characterized, missing some exposure details	Boudreau et al. (2003a)
Blue green algae, *Scynechocystis sp.*	S, M	2 d	PFOS-K >98%	7.5	30	NOEC (abundance)	1->1	1	Only one exposure concentration	Marchetto et al. (2021)
Blue green algae, *Scynechocystis sp.*	F, M	12-15 d	PFOS-K >98%	7.5	30	NOEC (biomass)	1->1	1	Only one exposure concentration	Marchetto et al. (2021)
Aquatic microcosm (mixed invertebrate and aquatic plant community)	S, M	35-42 d	PFOS-K 86%	8.3-8.6	15.9-20.5	MATC (zooplankton community abundance)	3.0-10	5.478	Mixed species exposure, static chronic exposure	Boudreau (2002); Boudreau et al. (2003b)
Aquatic microcosm (mixed invertebrate and aquatic plant community)	S, M	35 d	PFOS-K Unreported	8.3	18	MATC (zooplankton abundance; *Cyclops diaptomus* abundance)	1.0-10	3.162	Mixed species exposure	Sanderson et al. (2002)
Tubificid worm (0.03g, 0.8cm), *Limnodrilus hoffmeisteri*	S, M	96 hr	PFOS-K 99%	7	22	LC50	-	120.97	Atypical source of organisms	Yang et al. (2014)
Tubificid worm, *Limnodrilus hoffmeisteri*	S, U	24 hr	PFOS >98%	5.0	23	LC50	-	45.26	Duration too short for an acute test, missing some exposure details	Liu et al. (2016)
Tubificid worm, *Limnodrilus hoffmeisteri*	S, U	24 hr	PFOS >98%	6.0	23	LC50	-	46.23	Duration too short for an acute test, missing some exposure details	Liu et al. (2016)
Tubificid worm, *Limnodrilus hoffmeisteri*	S, U	24 hr	PFOS >98%	7.0	23	LC50	-	60.70	Duration too short for an acute test, missing some exposure details	Liu et al. (2016)
Tubificid worm, *Limnodrilus hoffmeisteri*	S, U	24 hr	PFOS >98%	8.0	23	LC50	-	64.48	Duration too short for an acute test, missing some exposure details	Liu et al. (2016)
Tubificid worm, *Limnodrilus hoffmeisteri*	S, U	24 hr	PFOS >98%	9.0	23	LC50	-	65.74	Duration too short for an acute test, missing some exposure details	Liu et al. (2016)
Tubificid worm (3-4 cm), *Limnodrilus hoffmeisteri*	R, U	48 hr	PFOS-K 98%	6.2	22	LC50	-	23.81	Duration too short for an acute test, missing some exposure details	Qu et al. (2016)
Tubificid worm (3-4 cm), *Limnodrilus hoffmeisteri*	R, U	48 hr	PFOS-K 98%	7.0	22	LC50	-	35.89	Duration too short for an acute test, missing some exposure details	Qu et al. (2016)
Tubificid worm (3-4 cm), *Limnodrilus hoffmeisteri*	R, U	48 hr	PFOS-K 98%	8.0	22	LC50	-	39.80	Duration too short for an acute test, missing some exposure details	Qu et al. (2016)

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Planarian (10-12 mm), *Dugesia japonica*	R, U	10 d	PFOS-K >99%	-	20	LOEC (regeneration: decreased appearance of auricles)	< 0.5-0.5	0.5	Duration too long for an acute test and too short for a chronic test	Yuan et al. (2014)
Planarian, *Dugesia japonica*	R, U	10 d	PFOS >99%	-	20	LOEC (enzymatic, gene expression and biochemistry changes)	-	5	Duration too long for an acute exposure and too short for a chronic exposure, atypical endpoints	Zhang et al. (2023a)
Planarian, *Dugesia japonica*	R, U	7 d	PFOS Unreported	-	20	MATC (gene expression)	0.5-1	0.7071	Duration too long for an acute exposure and too short for a chronic exposure, atypical endpoints	Sun et al. (2023a)
Chinese pond mussel (1 year), *Sinanodonta woodiana* (formerly, *Anodonta woodiana*)	S, U	48 hr	PFOS Unreported	7	24	LC50	-	28.39	Duration too short for an acute test	Xia et al. (2018)
Freshwater mussel (6 cm), *Unio ravoisieri*	R, U	96 hr	PFOS-K ≥98%	8	18	LC50	-	65.9	Test species fed from the natural freshwater used	Amraoui et al. (2018)
Asian clam (adult), *Corbicula fluminea*	R, M	28 d	PFOS-K 98%	6.85-7.35	23	LOEC (biochemical, enzyme and genetic markers)	-	0.0005082	Atypical endpoint, only one exposure concentration	Bi et al. (2022)
Mud snail (4.0 g, 2.0 cm) *Cipangopaludina cathayensis*	S, M	96 hr	PFOS-K 99%	7	22	LC50	-	247.14	Source of organisms may be problematic	Yang et al. (2014)
Snail (adult), *Lymnaea stagnalis*	S, M	96 hr	PFOS-K 95%	-	20	LC50	-	196	Test species fed	Olson (2017)
Snail (0-3 week, juvenile), *Lymnaea stagnalis*	S, M	96 hr	PFOS-K 95%	-	20	LC50	-	150	Test species fed	Olson (2017)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Snail (0-3 week, juvenile), *Lymnaea stagnalis*	R, M	21 d	PFOS-K 95%	-	20	NOEC (survival, feeding rate, mass change, length change, carbohydrate concentration)	50->50	>50	Duration too short for a chronic test	Olson (2017)
Snail (3-6 week, juvenile), *Lymnaea stagnalis*	R, M	21 d	PFOS-K 95%	-	20	MATC (mass change, length change)	25-50	35.35	Duration too short for a chronic test	Olson (2017)
Snail (6-9 week, juvenile), *Lymnaea stagnalis*	R, M	21 d	PFOS-K 95%	-	20	NOEC (survival, mass change, length change, carbohydrate and protein concentration)	50->50	>50	Duration too short for a chronic test	Olson (2017)
Snail (9-12 week, juvenile), *Lymnaea stagnalis*	R, M	21 d	PFOS-K 95%	-	20	NOEC (survival, feeding rate, mass change, length change, protein concentration)	50->50	>50	Duration too short for a chronic test	Olson (2017)
Snail (adult), *Lymnaea stagnalis*	R, M	21 d	PFOS-K 95%	-	20	MATC (survival)	3.0-6	4.243	Duration too short for a chronic test	Olson (2017)
Snail (5 mm), *Physella heterostropha pomilia* (formerly, *Physa pomilia)*	S, M	50 hr	PFOS-K ≥98%	-	25	NOEC-LOEC (avoidance)	< 30-30	-	Duration too short for an acute test; atypical endpoint	Funkhouser (2014)
Snail (adult, 4 mo.), *Physella heterostropha pomilia* (formerly, *Physa pomilia*)	R, M	14 d	PFOS-K ≥98%	-	25	LC50	-	94.99	Duration too long for an acute test and too short for a chronic test	Funkhouser (2014)
Rotifer (< 2 hr old neonates), *Brachionus calyciflorus*	R, U[b]	4 d	PFOS-K 98%	-	20	MATC (intrinsic rate of population increase and resting egg production)	0.125-0.25	0.1768	Atypical concentration-response pattern	Zhang et al. (2014)
Cladoceran (<24 hr), *Daphnia magna*	R, U	25 d	PFOS-K 99%	7.8	20	MATC (reproduction F0 generation)	0.01-0.1	0.03162	No consistent concentration-response relationship	Jeong et al. (2016)
Cladoceran (<24 hr), *Daphnia magna*	S, U	48 hr	PFOS-Li 24.5%	8.6	20.1-21.0	EC50 (death/immobility)	-	51.45	Inability to verify author-reported LC50	3M Company (2000)

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Cladoceran (0-24 hr), *Daphnia magna*	S, U	48 hr	PFOS-K Unreported	7.6	22	EC50		27	Another test within the same publication had 24.5% purity and this test purity was unknown, could be of low purity.	3M Company (2000)
Cladoceran (0-12 hr), *Daphnia magna*	R, U	28 d	PFOS-K Unreported	7.6	22	MATC (reproduction)	7.0-18.0	11.22	Inability to calculate an EC10 and comments by authors	3M Company (2000)
Cladoceran (adult, ~ 14 d), *Daphnia magna*	S, M	48 hr	PFOS-K ≥98%	-	21	MATC (biochemistry changes)	13.34-27.33	19.09	Non-apical endpoint	Labine et al. (2022)
Amphipod (7 d), *Hyalella azteca*	R, M	7 d	PFOS-K 97.5%	7.11 (6.85-7.46)	22.8 (22.1-23.3)	EC20 (growth - biomass)	-	7.20	Duration too short for a chronic exposure	Kadlec et al. (2024)
Crayfish (3 wk juvenile, 0.048 g), *Procambarus fallax f. virginalis*	R, M	38 d	PFOS-K ≥98%	-	25	MATC (survival/growth)	0.2->0.2	>0.2	Only two organisms per exposure concentration; invasive species	Funkhouser (2014)
Crayfish (juvenile, 2 wk, 0.041 g), *Procambarus fallax f. virginalis*	R, M	7 d	PFOS-K ≥98%	-	25	LC50	-	39.71	Duration too long for an acute test and too short for a chronic test, only six organisms per exposure concentration, test species fed; invasive species	Funkhouser (2014)
Crayfish (intermolt), *Pontastacus leptodactylus* (formerly, *Astacus leptodactylus*)	R, M	21 d	PFOS-K ≥98%	6.79	21	MATC (oxidative status index)	0.5-5	1.581	Non-apical endpoint	Belek et al. (2022)
Oriental river prawn (0.30 g, 4.0 cm), *Macrobrachium nipponense*	S, M	96 hr	PFOS-K 99%	7	22	LC50	-	19.77	Source of organisms may be problematic	Yang et al. (2014)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Yellow fever mosquito (1st instar), *Aedes aegypti*	S, U	48 hr	PFOS Unreported	-	25	LC50	-	1.18	Duration too short for an acute test, missing some exposure details	Olson (2017)
Yellow fever mosquito (1st instar), *Aedes aegypti*	R, U	~42 d	PFOS Unreported	-	25	MATC (average time to emergence)	0.05-0.125	0.079	Missing some exposure details	Olson (2017)
Blue damselfly (larva, F2 instar stage), *Enallagma cyathigerum*	R, U	4 mo	Perfluorooctanesulfonic acid tetraethylammonium 98%	-	21	MATC (general activity, burst swimming, foraging success)	0.01-0.1	0.03163	Sporadic solution renewal, behavioral endpoints	Van Gossum et al. (2009)
Midge (Instar, 3 d), *Chironomus dilutus*	R, M	7 d	PFOS-K 97.5%	7.01 (6.54-7.33)	22.6 (21.7-23.7)	EC20 (growth - biomass)	-	0.018	Duration too short for a chronic exposure	Kadlec et al. (2024)
Midge (Instar, 3 d), *Chironomus dilutus*	R, M	7 d	PFOS-K 97.5%	7.38 (7.32-7.47)	22.9 (20.5-23.9)	EC20 (growth - biomass)	-	0.016	Duration too short for a chronic exposure	Kadlec et al. (2024)
Midge, *Chironomus dilutus*	R, M	10 d	PFOS 98%			LOEC (mortality)	-	0.0004086	Range-finding test	McCarthy et al. (2021)
Midge (0.05 g, 1.2 cm), *Chironomus plumosus*	S, M	96 hr	PFOS-K 99%	7	22	LC50	-	182.12	Source of organisms may be problematic	Yang et al. (2014)
Midge (larva, 3rd-4th instar), *Chironomus plumosus*	S, M	10.33 d	PFOS 98%	-	25	NOEC (mortality)	-	0.00985	Only one exposure concentration, sediment exposure	Zhai et al. (2016)
Midge (larva, 3rd-4th instar), *Chironomus plumosus*	S, M	10.33 d	PFOS 98%	-	25	NOEC (mortality)	-	0.00987	Only one exposure concentration, sediment exposure	Zhai et al. (2016)
Midge (larva, 3rd-4th instar), *Chironomus plumosus*	S, M	10.33 d	PFOS 98%	-	25	NOEC (mortality)	-	0.00987	Only one exposure concentration, sediment exposure	Zhai et al. (2016)
Midge (larva, 3rd-4th instar), *Chironomus plumosus*	S, M	10.33 d	PFOS 98%	-	25	NOEC (mortality)	-	0.00985	Only one exposure concentration, sediment exposure	Zhai et al. (2016)
Midge (larva, 3rd-4th instar), *Chironomus plumosus*	S, M	10.33 d	PFOS 98%	-	25	NOEC (mortality)	-	0.00985	Only one exposure concentration, sediment exposure	Zhai et al. (2016)

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Midge (larva, 3rd-4th instar), *Chironomus plumosus*	S, M	10.33 d	PFOS 98%	-	25	NOEC (mortality)	-	0.00985	Only one exposure concentration, sediment exposure	Zhai et al. (2016)
Midge (larva, 3rd-4th instar), *Chironomus plumosus*	S, M	10.33 d	PFOS 98%	-	25	NOEC (mortality)	-	0.00987	Only one exposure concentration, sediment exposure	Zhai et al. (2016)
Midge (larva, 3rd-4th instar), *Chironomus plumosus*	S, M	10.33 d	PFOS 98%	-	25	NOEC (mortality)	-	0.00987	Only one exposure concentration, sediment exposure	Zhai et al. (2016)
Midge (multi-generational), *Chironomus riparius*	S, M	10 generations (~20-28 d ea.)	PFOS Unspecified	7.8-8.2	20	NOEC (emergence, reproduction, sex ratio)	-	0.0035	Only one exposure concentration, static chronic test	Stefani et al. (2014)
Midge (multi-generational), *Chironomus riparius*	S, M	10 generations (~20-28 d ea.)	PFOS Unspecified	7.8-8.2	20	LOEC (increased mutation rate)	-	0.0035	Only one exposure concentration, static chronic test	Stefani et al. (2014)
Midge (1st instar larva), *Chironomus riparius*	S, M	~36 d[d] (1st of 10 generations)	PFOS Unreported	7.5-8.2	20.1	LOEC (F1 developmental time, adult weight, exuvia length)	-	0.004	Only one exposure concentration, static chronic test, significant responses not observed in every generation	Marziali et al. (2019)
European eel (juvenile, 138.3 g), *Anguilla anguilla*	R, M	28 d	PFOS-K >98%	-	20	NOEC (survival, growth)	0.011->0.011	0.011	Not true ELS test (28 days beginning with juvenile)	Roland et al. (2014)
European eel (juvenile, 138.3 g), *Anguilla anguilla*	R, M	28 d	PFOS-K >98%	-	20	LOEC (proteomic growth)	< 0.00081-0.00081	0.00081	Not true ELS test (28 days beginning with juvenile), atypical endpoint	Roland et al. (2014)
Rainbow trout (immature, 16.4 cm, 22.7 g), *Oncorhynchus mykiss*	Microcosm	12 d	PFOS 89%	9.2	6.0-16.5	NOEC (mortality)	-	3	Atypical exposure, not a true ELS test	Oakes et al. (2005)
Rainbow trout (immature, 16.4 cm, 22.7 g), *Oncorhynchus mykiss*	Microcosm	12 d	PFOS 89%	9.2	6.0-16.5	LOEC (decrease LSI and condition index (K) in females)	-	3	Atypical exposure, not a true ELS test	Oakes et al. (2005)
Rainbow trout (female, mature, 34.8 cm, 511.1 g), *Oncorhynchus mykiss*	S, U	14 d	PFOS 89%	-	12	NOEC (mortality)	-	1	Atypical exposure, not a true ELS test	Oakes et al. (2005)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Rainbow trout (female, mature, 34.8 cm, 511.1 g), *Oncorhynchus mykiss*	S, U	14 d	PFOS 89%	-	12	LOEC (decrease LSI)	-	1	Atypical exposure, not a true ELS test	Oakes et al. (2005)
Rainbow trout (11 mo), *Oncorhynchus mykiss*	Diet, U	15 d	PFOS-K Unknown	-	12	NOEC (growth - weight)	-	250 mg/kg bw per day	Dietary exposure	Benninghoff et al. (2011)
Rainbow trout (fry, 15 week), *Oncorhynchus mykiss*	Diet, U	8 mo	PFOS-K Unknown	-	12	LOEC (survival, tumor incidence)	-	2.5 mg/kg bw per day	Dietary exposure, mixture exposure	Benninghoff et al. (2012)
Rainbow trout (oocyte, ova), *Oncorhynchus mykiss*	S, M	3 hr	PFOA >97%	-	6	NOEC (accumulation residue)	-	0.87	Duration too short for an acute test	Raine et al. (2021)
Rainbow trout (oocyte, ova), *Oncorhynchus mykiss*	S, M	3 hr	PFOA >97%	8.5	6	LOEC (accumulation residue)	-	7.47	Duration too short for an acute test	Raine et al. (2021)
Rainbow trout (juvenile, ~7 mo), *Oncorhynchus mykiss*	R, M	10 d	PFOS Unreported	-	12	LOEC (enzymatic changes)	-	0.0008	Non-apical endpoint, duration too short for a chronic exposure	Solan et al. (2022)
Atlantic salmon (embryo), *Salmo salar*	R, U	49 d	Sodium perfluoro-1-octanesulfonate Unreported	-	5-7	NOEC (growth - length and weight)	0.1->0.1	0.1	Only one exposure concentration; greater than low value so less informative	Arukwe et al. (2013)
Goldfish (6.91 g, 6.01 cm), *Carassius curatus*	R, U	48 hr	PFOS-K >99%	-	18	NOEC-LOEC (swimming behavior: motion distance and % of actionless time)	2.0-8	-	Atypical endpoint and source of organisms, duration too short for an acute test	Xia et al. (2013a)
Goldfish (6.0 g, 7.0 cm), *Carassius curatus*	S, M	96 hr	PFOS-K 99%	7	22	LC50	-	81.18	Source of organisms may be problematic	Yang et al. (2014)
Goldfish (juvenile, 27.85 g), *Carassius curatus*	S, M	96 hr	PFOS >98%	7.25	23	Antioxidant enzyme activity	-	5.001[e]	Atypical endpoint, no point estimate	Feng et al. (2015)
Common carp (juvenile, 3.72g, 5.18 cm), *Cyprinus carpio*	R, U[c]	14 d	PFOS >98%	-	-	NOEC (liver protein)	1->1	1	Duration too short for a chronic test, atypical endpoint	Hagenaars et al. (2008)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Common carp (juvenile, 3.72g, 5.18 cm), *Cyprinus carpio*	R, U[c]	14 d	PFOS >98%	-	-	MATC (liver glycogen)	0.5-1	0.7071	Duration too short for a chronic test, atypical endpoint	Hagenaars et al. (2008)
Common carp (juvenile, 3.72g, 5.18 cm), *Cyprinus carpio*	R, U[c]	14 d	Perfluorooctanesulfonic PFOS >98%	-	-	NOEC (liver lipid)	1->1	1	Duration too short for a chronic test, atypical endpoint	Hagenaars et al. (2008)
Common carp (juvenile, 3.72g, 5.18 cm), *Cyprinus carpio*	R, U[c]	14 d	PFOS >98%	-	-	LOEC (relative condition factor)	< 0.1-0.1	0.1	Duration too short for a chronic test	Hagenaars et al. (2008)
Common carp (juvenile, 3.72g, 5.18 cm), *Cyprinus carpio*	R, U[c]	14 d	PFOS >98%	-	-	MATC (HSI)	0.1-0.5	0.2236	Duration too short for a chronic test, atypical endpoint	Hagenaars et al. (2008)
Common carp (juvenile, ~12 cm; ~20 g), *Cyprinus carpio*	F, M	96 hr	PFOS 100.3%	6.9	23	LOEC (DNA damage)	-	5.395	Atypical endpoint	Kim et al. (2010)
Common carp (juvenile), *Cyprinus carpio*	R, M	76 d	PFOS 98%	-	-	NOEC (growth - weight)	-	0.00082	Greater than low value	Shan et al. (2022)
Zebrafish (female fry, 14 dpf), *Danio rerio*	R, U	70 d	PFOS-K >99%	-	27	EC10 (male weight)	0.01-0.05	0.001990	Missing some exposure details	Du et al. (2009)
Zebrafish (embryo - blastula stage), *Danio rerio*	R, U	Fert. up to 15 dpf	PFOS-K 99%	-	-	MATC (body length and average weight)	0.200-0.400	0.2828	Duration too short for a chronic test	Shi et al. (2009)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, M	114 hr	PFOS >96%	7.0-7.5	28	LC50	-	2.20	Duration too long for an acute test	Huang et al. (2010)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, M	114 hr	PFOS >96%	7.0-7.5	28	EC50 (malformation)	-	1.12	Duration too long for an acute test, atypical endpoint	Huang et al. (2010)
Zebrafish (embryo), *Danio rerio*	R, M	21 d	PFOS-K 98%	-	26	LOEC (reduce fecundity)	<0.5-0.5	0.5	Only one exposure concentration, control issues	Sharpe et al. (2010)
Zebrafish (embryo), *Danio rerio*	R, M	48 hr	PFOS-K 98%	-	26	LC50 (range of 3 tests)	-	7.7-38.9	Duration too short for an acute test, results are not reproducible	Sharpe et al. (2010)
Zebrafish (embryo, 4 hpf), *Danio rerio*	S, U	96 hr	PFOS-K >99%	-	28.5	NOEC-LOEC (increased ROS formation)	0.2-0.4	-	Atypical endpoint, missing exposure details	Shi and Zhou (2010)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Zebrafish (embryo), *Danio rerio*	R, U	96 hr	PFOS-K 98%	-	26	LC50	-	54.36[e]	Problems with reported data to be used for LC50 analysis	Ding et al. (2012); Ding et al. (2013)
Zebrafish (F2 embryo, 0 hpf), *Danio rerio*	F, M	300-330 d	PFOS-K ≥98%	8.25-8.75	26	MATC (F2 180 d survival)	0.1-0.3	0.1732	Poor concentration-response, test design complications	Keiter et al. (2012)
Zebrafish (embryo, 6-8 hpf), *Danio rerio*	R, U	6 d	PFOS Unreported	-	26	AC50 (toxicity score: includes survival, hatchability, and malformation index)	-	16.44[e]	Duration too long for an acute test and too short for a chronic test, atypical endpoint	Padilla et al. (2012)
Zebrafish (embryo), *Danio rerio*	S, U	72 hr	PFOS 98%	8.3	28.5	LC50	-	68	Duration too short for an acute test, missing some exposure details	Zheng et al. (2012)
Zebrafish (embryo), *Danio rerio*	S, U	72 hr	PFOS 98%	8.3	28.5	EC50 (malformation)	-	37	Duration too short for an acute test, atypical endpoint, missing exposure details	Zheng et al. (2012)
Zebrafish (embryo, F0 generation), *Danio rerio*	R, U	120 dpf	PFOS >96%	6.8-7.6	28	LOEC Increase mortality and malformations in the F1 generation	<0.250-0.250	0.250[e]	Only one exposure concentration	Chen et al. (2013)
Zebrafish (embryo, 4hpf), *Danio rerio*	R, U	120 hr	PFOS ≥98%	-	28	NOEC-LOEC (suppression of steroidogenic enzyme synthesis)	0.1-0.2	-	Duration too long for an acute test, atypical endpoint, missing exposure details	Du et al. (2013)
Zebrafish (embryo, 4 hpf), *Danio rerio*	R, U	116 hr	PFOS-K Unreported	-	-	NOEC (development, hatch, mortality)	5->5	5	Duration too long for an acute test and too short for a chronic test, only one exposure concentration	Liu et al. (2013)
Zebrafish (embryo – 4 cell stage), *Danio rerio*	S, U	Fert. to 144 hpf	PFOS Unreported	7.2-7.6	26	EC50 (lethal and sublethal effects)	-	1.5	Duration too long for an acute test and too short for a chronic test, static chronic exposure	Ulhaq et al. (2013)
Zebrafish (embryo - 4 cell stage), *Danio rerio*	S, U	Fert. to 144 hpf	PFOS Unreported	7.2-7.6	26	LC50	-	>10	Duration too long for an acute test and too short for a chronic test, static chronic exposure	Ulhaq et al. (2013)
Zebrafish (embryo), *Danio rerio*	S, U	48 hr	PFOS >96%	-	-	Malformation (100%)	-	8.002[e]	Duration too short for an acute test, atypical endpoint, no point estimate	Chen et al. (2014)
Zebrafish (embryo), *Danio rerio*	R, U	6 d	PFOS-K 98%	7.5	28.5	LC50	-	6.25	Duration too long for an acute test and too short for a chronic test	Hagenaars et al. (2014)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Zebrafish (embryo), *Danio rerio*	R, U	6 d	PFOS-K 98%	7.5	28.5	EC50 (uninflated swim bladder)	-	2.29	Duration too long for an acute test and too short for a chronic test, atypical endpoint	Hagenaars et al. (2014)
Zebrafish (embryo, 2 hpf), *Danio rerio*	S, U	6 d	PFOS-K >98%	7.4	28	NOEC-LOEC (behavior: spontaneous swimming activity)	0.1-1.0	-	Duration too long for an acute test and too short for a chronic test, atypical endpoint, only two exposure concentrations	Spulber et al. (2014)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS-K Unknown	-	28	LOEC (mortality)	3.307-33.07	33.07[e]	Duration too long for an acute test and too short for a chronic test	Truong et al. (2014)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS Unknown	-	28	LOEC (mortality)	0.32-3.2	3.2[e]	Duration too long for an acute test and too short for a chronic test	Truong et al. (2014)
Zebrafish (embryo, 8 hpf), *Danio rerio*	R, U	42 dpf	PFOS >96%	7.0-7.5	28	LOEC (increased condition index)	-	0.25	Only one exposure concentration	Chen et al. (2016)
Zebrafish (embryo, 8 hpf), *Danio rerio*	R, U	150 dpf	PFOS >96%	7.0-7.5	28	LOEC (increased estradiol in male/females and testosterone in males)	-	0.25	Only one exposure concentration	Chen et al. (2016)
Zebrafish (larva, 120 hpf), *Danio rerio*	S, M	24 hr	PFOS ≥98%	7.0-7.5	28	NOEC (various metabolites)	-	9.700	Duration too short for an acute test, atypical endpoint	Huang et al. (2016)
Zebrafish (embryo), *Danio rerio*	R, U	6 d	PFOS Unknown	-	28	LOEC (liver size and gene expression)	<0.0005-0.0005	0.0005	Duration too long for an acute test and too short for a chronic test, atypical endpoint	Tse et al. (2016)
Zebrafish (embryo, 8 hpf), *Danio rerio*	R, U	180 d	PFOS >96%	7.0-7.5	27	MATC (altered sex ratio: female dominance, F1 offspring survival)	0.05-0.25	0.1118[e]	Non-apical endpoint	Cui et al. (2017)
Zebrafish (3 hpf), *Danio rerio*	S, U	5 d + 9 d observation	PFOS Unreported	7.2-7.7	26-28	MATC (growth - total body length)	0.02-0.2	0.06325[e]	Duration too long for an acute test and too short for a chronic test, static chronic exposure	Jantzen et al. (2017)
Zebrafish (3 hpf), *Danio rerio*	S, U	5 d + 9 d observation	PFOS Unreported	7.2-7.7	26-28	LOEC (interoccular distance)	< 0.02-0.02	0.02[e]	Duration too long for an acute test and too short for a chronic test, static chronic exposure	Jantzen et al. (2017)
Zebrafish (3 hpf), *Danio rerio*	S, U	5 d + 9 d observation	PFOS Unreported	7.2-7.7	26-28	MATC (yolk sac area)	0.02-0.2	0.06325[e]	Duration too long for an acute test and too	Jantzen et al. (2017)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
									short for a chronic test, static chronic exposure	
Zebrafish (3 hpf), *Danio rerio*	S, U	5 d + 9 d observation	PFOS Unreported	7.2-7.7	26-28	LOEC - (swimming activity - crossing frequency)	< 0.02-0.02	0.02[e]	Duration too long for an acute test and too short for a chronic test, static chronic exposure	Jantzen et al. (2017)
Zebrafish (embryo), *Danio rerio*	S, M	48 hr	PFOS Unknown	-	27	LC50	-	107.6	Duration too short for an acute test	Rainieri et al. (2017)
Zebrafish (embryo, 3 hpf), *Danio rerio*	R, U	7 d	PFOS Unreported	-	28.5	MATC (islet morphological anomalies)	8.0-16.0[e]	11.31[e]	Duration too long for an acute test and too short for a chronic test	Sant et al. (2017)
Zebrafish (sperm), *Danio rerio*	S, U	20 sec	PFOS-K ≥98%	8	25	NOEC-LOEC (sperm motility)	0.09-0.9	-	Duration too short for an acute test, atypical endpoint	Xia and Niu (2017)
Zebrafish (sperm/egg), *Danio rerio*	S, U	2 min	PFOS-K ≥98%	8	25	NOEC-LOEC (fertilization success)	0.09-0.9	-	Duration too short for an acute test, atypical endpoint	Xia and Niu (2017)
Zebrafish (embryo, 3 hpf), *Danio rerio*	S, U	5 d	PFOS Unknown	7.2-7.7	27	LOEC (gene expression of Leptin A mRNA)	<0.01-0.01	0.01[e]	Duration too long for an acute test and too short for a chronic test, atypical endpoint	Annunziato (2018)
Zebrafish (embryo, 1-2 hpf), *Danio rerio*	R, U	96 hr	PFOS >99%	-	25	NOEC-LOEC (growth: body length)	<0.050-0.050	-	Atypical endpoint, missing exposure details	Dang et al. (2018)
Zebrafish (embro, 2 hpf), *Danio rerio*	R, U	72 hr	PFOS Unknown	-	28.5	LOEC (malformations)	0.5-1.0	1.0[e]	Duration too short for an acute test	Ortiz-Villanueva et al. (2018)
Zebrafish (embro, 2 hpf), *Danio rerio*	R, U	72 hr	PFOS Unknown	-	28.5	LOEC (survival)	5.0-10	10[e]	Duration too short for an acute test	Ortiz-Villanueva et al. (2018)
Zebrafish (embryo, 1 hpf), *Danio rerio*	R, U	96 hr	PFOS Unreported	7.6	28.5	NOEC-LOEC (pericardial area)	8-16[e]	-	Atypical endpoint, missing exposure details	Sant et al. (2018)
Zebrafish (embryo, 1 hpf), *Danio rerio*	S, U	96 hr	PFOS Unreported	-	26	NOEC (enzymes, olfactory cells)	-	6.650	Atypical endpoint, missing exposure details	Stengel et al. (2017a)
Zebrafish (female, 4 mo), *Danio rerio*	R, U	21 d	PFOS Unknown	7.0-7.5	28	NOEC (growth - length and weight)	0.2->0.2	0.2	Inability to independently verify effect values, partial life cycle test	Bao et al. (2019)
Zebrafish (embryo, maximum of 4 hpf), *Danio rerio*	R, M	96 hr	PFOS Unknown	-	26	NOEC (hatching success, embryo mortality, deformation)	0.0007->0.0007	0.0007	Greater than low value	Cormier et al. (2019)

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Zebrafish (embryo, 2 hpf), *Danio rerio*	R, U	72 hr	PFOS-K ≥98%	-	28	LOEC (growth - total body length)	2.691-5.832	5.382[e]	Duration too short for an acute test	Martinez et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS-K Unreported	-	-	Benchmark Dose Value at 10% extra effect (abnormal development)	-	5.732[e]	Duration too long for an acute test, atypical test endpoint	Thomas et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS-K Unreported	-	-	Benchmark Dose Value at 10% extra effect (mortality)	-	3.014[e]	Duration too long for an acute test, atypical test endpoint	Thomas et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS Unreported	-	-	Benchmark Dose Value at 10% extra effect (abnormal development)	-	2.526[e]	Duration too long for an acute test, atypical test endpoint	Thomas et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS Unreported	-	-	Benchmark Dose Value at 10% extra effect (abnormal development)	-	6.357[e]	Duration too long for an acute test, atypical test endpoint	Thomas et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS Unreported	-	-	Benchmark Dose Value at 10% extra effect (abnormal development)	-	4.181[e]	Duration too long for an acute test, atypical test endpoint	Thomas et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS Unreported	-	-	Benchmark Dose Value at 10% extra effect (abnormal development)	-	6.642[e]	Duration too long for an acute test, atypical test endpoint	Thomas et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS Unreported	-	-	Benchmark Dose Value at 10% extra effect (abnormal development)	-	2.786[e]	Duration too long for an acute test, atypical test endpoint	Thomas et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS Unreported	-	-	Benchmark Dose Value at 10% extra effect (abnormal development)	-	1.180[e]	Duration too long for an acute test, atypical test endpoint	Thomas et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS Unreported	-	-	Benchmark Dose Value at 10% extra effect (abnormal development)	-	5.211[e]	Duration too long for an acute test, atypical test endpoint	Thomas et al. (2019)

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS Unreported	-	-	Benchmark Dose Value at 10% extra effect (abnormal development)	-	1.370[e]	Duration too long for an acute test, atypical test endpoint	Thomas et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS Unreported	-	-	Benchmark Dose Value at 10% extra effect (abnormal development)	-	4.751[e]	Duration too long for an acute test, atypical test endpoint	Thomas et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS Unreported	-	-	Benchmark Dose Value at 10% extra effect (abnormal development)	-	4.641[e]	Duration too long for an acute test, atypical test endpoint	Thomas et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS Unreported	-	-	Benchmark Dose Value at 10% extra effect (abnormal development)	-	4.791[e]	Duration too long for an acute test, atypical test endpoint	Thomas et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS Unreported	-	-	Benchmark Dose Value at 10% extra effect (abnormal development)	-	5.877[g]	Duration too long for an acute test, atypical test endpoint	Thomas et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS Unreported	-	-	Benchmark Dose Value at 10% extra effect (mortality)	-	0.5501[e]	Duration too long for an acute test, atypical test endpoint	Thomas et al. (2019)
Zebrafish (embryo), *Danio rerio*	R, M	6 d	PFOS ≥98%	7.5	28.5	NOEC (growth and survival)	-	1.339	Greater than low value	Tu et al. (2019)
Zebrafish (embryo, 2 hpf), *Danio rerio*	R, M	118 hr	PFOS-K ≥98%	-	28	EC50 (mortality, malformations)	-	2.045[e]	Duration too long for an acute test and too short for a chronic test, mixed test endpoints	Vogs et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	R, M	96 hr	Perfluoroctane sulfonate sodium salt >98%	-	26	NOEC (mortality, hatch)	-	0.4514[e]	Only one exposure concentration	Yi et al. (2019)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	90-94 hr	PFOS-K ≥98%	7-7.5	28	NOEC (mortality, deformity)	-	2.06	Duration too short for an acute test, behavioral focus with secondary reference to no mortality or deformity	Christou et al. (2020)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	66 hr	PFOS 97%	-	28	NOEC (survival)	25->25	25[e]	Duration too short for an acute test	Dasgupta et al. (2020)
Zebrafish (embryo 4-64 stage), *Danio rerio*	S, M	144 hr	PFOS 98%	7.2-7.6	26	MATC (abnormal development)	0.16-2.2	0.5933	Duration too long for an acute test and too short for a chronic test	Menger et al. (2020)
Zebrafish (adult, 4.5 mo), *Danio rerio*	R, U	28 d	PFOS >95%	-	28	LOEC (reproduction - sperm development)	<0.2510-0.2510	0.2501[e]	Atypical endpoint	Xin et al. (2020)
Zebrafish (adult, 4.5 mo), *Danio rerio*	R, U	28 d	PFOS >95%	-	28	NOEC (reproduction - oocyte development)	0.2510->0.2510	0.2501[e]	Atypical endpoint	Xin et al. (2020)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	90 hr exposure + 177 d observation	PFOS-K ≥98%	7.0-7.5	28-28.5	NOEC (mortality)	2.06->2.06	2.06	Atypical exposure duration	Christou et al. (2021)
Zebrafish (embryo, 4 hpf), *Danio rerio*	R, U	92 hr	PFOS ≥98%	-	-	NOEC (mortality)	0.5->0.5	0.5	Only one exposure concentration, duration too short for an acute test	Dong et al. (2021)
Zebrafish (embryo), *Danio rerio*	R, M	120 hr	PFOS-K >95%	-	28.5	NOEC (mortality)	-	>1.803[e]	Duration too long for an acute exposure, too short for a chronic test	Han et al. (2021)
Zebrafish (embryo), *Danio rerio*	R, M	120 hr	PFOS >95%	-	28.5	NOEC (mortality)	-	>1.730[e]	Duration too long for an acute exposure, too short for a chronic test	Han et al. (2021)
Zebrafish (embryo, 6 hpf), *Danio rerio*	R, M	96 hr	PFOS-K ≥98%	-	28.5	LOEC (malformations, locomotive behavior)	<20-20	20	Only one exposure concentration; atypical endpoint	Huang et al. (2021)
Zebrafish (embryo, 6 hpf), *Danio rerio*	R, U	96 hr	PFOS-K ≥98%	-	-	MATC (growth, histology, abnormal development)	10.0-20.0	14.14	Atypical endpoint for an acute test	Huang et al. (2021)
Zebrafish (embryo, 4 hpf), *Danio rerio*	S, U	116.83 hr	PFOS Unreported	-	28.0	NOEC (mortality)	10.00->10.00	10.00[c]	Atypical duration	Lee et al. (2021)
Zebrafish (embryo, 6-8 hpf), *Danio rerio*	S, U	112-114 hr	Potassium perfluoro-1-octanesulfonate >98%	-	28	NOEC (mortality)	-	0.2476[e]	Duration too long for an acute test; only one exposure concentration	Rericha et al. (2021)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Zebrafish (embryo, <1 hpf), *Danio rerio*	R, U	96 hr	PFOS Unreported	-	28.5	LOEC (increase lauric C12:0 and myristic C14:0 fatty acids)	<8.002-8.002	8.002[e]	Atypical endpoint	Sant et al. (2021)
Zebrafish (dechorinated embryo, 1 dpf), *Danio rerio*	R, U	30 d	PFOS Unreported	-	28.5	NOEC (growth - length)	16->16	16[e]	Growth effects not the focus of study rather other non-apical endpoints	Sant et al. (2021)
Zebrafish (adult, 90 dpf), *Danio rerio*	R, U	10 d	PFOS-K >98%	7.21	28.0	LOEC (gene expression)	<0.5-0.5	0.5	Atypical endpoint	Zhu et al. (2021)
Zebrafish (embryo, 2 hpf), *Danio rerio*	R, M	120 hr	PFOS-K Unreported	-	28	MATC (growth - length)	0.050-2.066	0.3214	Duration too long for an acute exposure, too short for a chronic test	Fey et al. (2022)
Zebrafish (embryo, ≤4 hpf), *Danio rerio*	R, U	5 d	PFOS 99.4%	-	27	NOEC (mortality and development)	-	>0.0024	Duration too long for an acute exposure, too short for a chronic test, test represents a greater than low value (followed decision rule; Section 2.10.3.2)	Haimbaugh et al. (2022)
Zebrafish (embryo, ≤4 hpf), *Danio rerio*	R, U	4-6 wk	PFOS 99.4%	-	27	NOEC (reproduction and growth)	-	>0.0024	Test represents a greater than low value (followed decision rule; Section 2.10.3.2)	Haimbaugh et al. (2022)
Zebrafish (embryo, 4 hpf), *Danio rerio*	S, U	116 hr	PFOS Unreported	-	-	NOEC (development, mortality)	-	10.00[e]	Duration too long for an acute exposure, too short for a chronic test, test represents a greater than low value (followed decision rule; Section 2.10.3.2)	Lee et al. (2022)
Zebrafish (embryo, 3 hpf), *Danio rerio*	S, U	117 hr	PFOS-NA >98%	-	-	LC50	-	16.47[e]	Duration too long for an acute exposure, too short for a chronic test	Lindqvist and Wincent (2022)
Zebrafish (embryo, 7 hpf), *Danio rerio*	R, M	30 d	PFOS-K >98%	6.86-7.39	24.9-25.3	EC10 (growth-weight)	0.004-0.140	0.098	Poor control survival (75%)	Krupa et al. (2022)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS Unreported	-	28	Benchmark Dose Value at 10% extra effect (morphology)	-	7.753[e]	Duration too long for an acute exposure, too short for a chronic test	Truong et al. (2022)
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOS-K Unreported	-	28	Benchmark Dose Value at 10% extra	-	5.930[e]	Duration too long for an acute exposure, too short for a chronic test	Truong et al. (2022)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
						effect (morphology)				
Zebrafish (embryo, 2 hpf), *Danio rerio*	R, U	94 hr	PFOS 98.7%	7.2	28.5	NOEC (growth - length)	-	>0.5001[e]	Duration too short for an acute exposure. Greater than low value.	Wang et al. (2022)
Zebrafish (embryo, 2 hpf), *Danio rerio*	R, U	82 hr	PFOS 98.7%	7.2	28.5	NOEC (hatching rate)	-	>0.5001[e]	Duration too short for an acute exposure. Greater than low value.	Wang et al. (2022)
Zebrafish (embryo, 2 hpf), *Danio rerio*	R, M	118 hr	PFOS-K ≥98%	-	28.0	NOEC (mortality)	-	2.418	Duration too long for an acute test	Wu et al. (2022)
Zebrafish (embryo, 0.5 hpf), *Danio rerio*	S, U	119.5 hr	PFOS-K ≥98%	7.2	28	EC50 (abnormal development)	-	6	Duration too long for an acute exposure, too short for a chronic test, atypical endpoint	Gui et al. (2023)
Zebrafish (embryo, 5 hpf), *Danio rerio*	R, U	8 mo	PFOS Unreported	6.8-7.0	28	NOEC (mortality)	-	>0.5001[g]	Greater than low value	Hawkeye et al. (2023)
Zebrafish (embryo, 72 hpf), *Danio rerio*	R, U	48.83 hr	PFOS ≥98%	-	28.5	LOEC (swimming behavior)	-	0.1	Duration too short for an acute exposure, atypical endpoint	Kalyn et al. (2023)
Zebrafish (adult, 3 mo), *Danio rerio*	F, U	14 d	PFOS Unreported	7.0-7.4	28	LOEC (growth - weight)	<0.08-0.08	0.08	Duration too short for a chronic exposure	Lu et al. (2024)
Zebrafish (2 mo), *Danio rerio*	R, U	14 d	PFOS-K Unreported	7	28	LOEC (biochemistry and enzymatic changes)	-	0.03	Non-apical endpoints, duration too short for a chronic exposure	Liu et al. (2023a)
Zebrafish (embryo, 4 hpf), *Danio rerio*	R, U	92 hr	PFOS-K >98%	7.2-7.4	27	MATC (growth - length)	0.100-0.500	0.2236	Non-apical endpoints, duration too short for an acute exposure	Mahapatra et al. (2023)
Zebrafish (embryo, 4 hpf), *Danio rerio*	S, U	116 hr	PFOS-K >98%	-	28.5	LC50	-	24.77[g]	Duration too long for an acute exposure and too short for a chronic exposure	Min et al. (2023)
Zebrafish (embryo, 6 hpf), *Danio rerio*	R, U	90 hr	PFOS-K Unreported	-	28	AC50 (development)	-	1.965[g]	Duration too short for an acute exposure	Phelps et al. (2023)
Zebrafish (embryo, 6 hpf), *Danio rerio*	R, U	90 hr	PFOS-K Unreported	-	28	AC50 (growth length)	-	1.351[g]	Duration too short for an acute exposure	Phelps et al. (2023)

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Zebrafish (embryo, 6 hpf), *Danio rerio*	R, U	90 hr	PFOS-K Unreported	-	28	AC50 (morphology)	-	1.125[g]	Duration too short for an acute exposure	Phelps et al. (2023)
Zebrafish (embryo, 2 hpf), *Danio rerio*	R, U	70 hr	PFOS-K >98%	-	26	LC50	-	2.104[g]	Duration too short for an acute exposure	Zhou et al. (2023)
Spottail shiner (female, mature, 8.9 cm, 6.7 g), *Notropis hudsonius*	Microcosm	14 d	PFOS 89%	-	-	NOEC (mortality)	-	3	Atypical exposure, not a true ELS test	Oakes et al. (2005)
Spottail shiner (female, mature, 8.9 cm, 6.7 g), *Notropis hudsonius*	Microcosm	14 d	PFOS 89%	-	-	LOEC (increase TBARS in liver/ovary and FAO activity in liver)	-	3	Atypical exposure, not a true ELS test	Oakes et al. (2005)
Fathead minnow (embryo, 48 hpf), *Pimephales promelas*	F, M	33 d	PFOS-K Unreported	6.6-7.3	22-26	EC10 (survival)	1.0-1.9	1.378	Another test within the same publication had 24.5% purity and this test purity was unknown, could be of low purity	3M Company (2000)
Fathead minnow (mature, 6.1 cm, 2.0 g), *Pimephales promelas*	Microcosm	28 d	PFOS 89%	9.2	16.6-22.8	LC10	-	3.5	Atypical exposure, not a true ELS test	Oakes et al. (2005)
Fathead minnow (embryo, <2 hpf), *Pimephales promelas*	R, M	14 d	PFOS-K ≥98%	8.4	27	MATC (mortality)	1.25-2.50	1.768	Duration, atypical exposure (5 d in toxicant + 9 d in clean water)	Krzykwa et al. (2021)
Topmouth gudgeon (juvenile female, 0.81 g, 4.03 cm), *Pseudorasbora parva*	R, U	96 hr	PFOS-K >99%	-	15	NOEC-LOEC (spontaneous swim behavior: swim distance)	0.5-2	-	Atypical endpoint and source of organisms	Xia et al. (2014)
Topmouth gudgeon (4.0 g, 4.0 cm), *Pseudorasbora parva*	S, M	96 hr	PFOS-K 99%	7	22	LC50	-	67.74	Source of organisms may be problematic	Yang et al. (2014)
Topmouth gudgeon (4.0 g, 4.0 cm), *Pseudorasbora parva*	R, M	30 d	PFOS-K 99%	7	22	EC10 (survival)	-	2.12	Not a true ELS test (started with older life stage), renewal chronic exposure, source of organisms may be problematic	Yang et al. (2014)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Creek chub (mature, 11.8 cm, 16.3 g), *Semotilus atromaculatus*	Microcosm	14 d	PFOS 89%	-	-	NOEC (mortality)	-	3	Atypical exposure, not a true ELS test	Oakes et al. (2005)
Creek chub (mature, 11.8 cm, 16.3 g), *Semotilus atromaculatus*	Microcosm	14 d	PFOS 89%	-	-	LOEC (increase TBARS in liver/ovary and FAO activity in liver)	-	3	Atypical exposure, not a true ELS test	Oakes et al. (2005)
Quinbo (juvenile, 2.77 g, 5.62 cm), *Spinibarbus sinensis*	R, U	30 d	PFOS-K >99%	6.8-7.5	18	MATC (% mobile, % highly mobile, swim distance, swim speed, freq. highly mobile, % social, resting metabolic rate)	0.32-0.80	0.506	Test was not replicated	Xia et al. (2015b)
Quinbo (juvenile, 2.77 g, 5.62 cm), *Spinibarbus sinensis*	R, U	30 d	PFOS-K >99%	6.8-7.5	18	MATC (decrease maximum linear acceleration)	0.32-0.80	0.506	Atypical endpoint	Xia et al. (2015c); Xia et al. (2015a)
Quinbo (juvenile, 2.77 g, 5.62 cm), *Spinibarbus sinensis*	R, U	30 d	PFOS-K >99%	6.8-7.5	28	MATC (decrease maximum linear acceleration)	0.32-0.80	0.506	Atypical endpoint	Xia et al. (2015a); Xia et al. (2015b)
White sucker (mature, 22.7 cm, 114.5 g), *Catostomus commersonii*	Microcosm	14 d	PFOS 89%	-	-	NOEC (mortality)	-	3	Atypical exposure, not a true ELS test	Oakes et al. (2005)
White sucker (mature, 22.7 cm, 114.5 g), *Catostomus commersonii*	Microcosm	14 d	PFOS 89%	-	-	LOEC (decrease LSI in females)	-	3	Atypical exposure, not a true ELS test	Oakes et al. (2005)
Bluegill (28.6 mm, 0.60 g), *Lepomis macrochirus*	S, U	96 hr	PFOS DEA salt Unreported	8.2-8.3	-	LC50	-	31	Only one replicate per treatment	3M Company (2000)
Nile tilapia, *Oreochromis niloticus*	Diet, U	144 hr	PFOS Unreported	-	22	MATC (weight and survival)	1.0-5.0 (mg/g bw)	2.236 (mg/g bw)	Duration too short for a chronic test, missing exposure details	Han et al. (2011)
Medaka (adult, male), *Oryzias latipes*	R, U	14 d	PFOS Unreported	-	25	NOEC (adult survival, GSI%, HSI%, condition factor)	1->1	1	Duration too long for an acute test and too short for a chronic test	Ji et al. (2008)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Medaka (adult, female), *Oryzias latipes*	R, U	14 d	PFOS Unreported	-	25	NOEC (adult survival, condition factor)	1->1	1	Duration too long for an acute test and too short for a chronic test	Ji et al. (2008)
Medaka (adult, female), *Oryzias latipes*	R, U	14 d	PFOS Unreported	-	25	LOEC (GSI%)	<0.01-0.01	0.01	Duration too long for an acute test and too short for a chronic test	Ji et al. (2008)
Medaka (adult, female), *Oryzias latipes*	R, U	14 d	PFOS Unreported	-	25	MATC (HSI%)	0.1-1	0.3162	Duration too long for an acute test and too short for a chronic test	Ji et al. (2008)
Medaka (F1 generation, <12 hr, embryo), *Oryzias latipes*	R, U	7-14 d (assumed)	PFOS Unreported	-	25	MATC (% hatchability, time to hatch)	0.1-1	0.3162	Duration too long for an acute test and too short for a chronic test	Ji et al. (2008)
Medaka (F1 generation, <12 hr, embryo), *Oryzias latipes*	R, U	~28 d post-hatch (assumed)	PFOS Unreported	-	25	MATC (swim up success)	0.1-1	0.3162	Duration too long for an acute test and too short for a chronic test	Ji et al. (2008)
Medaka (F1 generation, <12 hr, embryo), *Oryzias latipes*	R, U	100 d post-hatch	PFOS Unreported	-	25	EC10 (growth - length)	<0.01-0.01	0.0013	Duration too long for an acute test and too short for a chronic test	Ji et al. (2008)
Medaka (F1 generation, <12 hr, embryo), *Oryzias latipes*	R, U	28 d post-hatch	PFOS Unreported	-	25	LOEC (larval survival)	<0.01-0.01	0.01	Duration too long for an acute test and too short for a chronic test	Ji et al. (2008)
Medaka (adult, 16 week, 0.38g) *Oryzias latipes*	R, U	21 d	PFOS ≥98%	-	25	LOEC (fecundity)	<1.0-1.0	1	Only one exposure concentration	Kang et al. (2019)
African clawed frog (embryos), *Xenopus laevis*	R, M	96 hr	PFOS-K 86.9%	7.3	24	EC50 (teratogenesis)	-	12.1	Atypical acute endpoint	Palmer and Krueger (2001)
African clawed frog (embryos), *Xenopus laevis*	R, M	96 hr	PFOS-K 86.9%	7.27	24	EC50 (teratogenesis)	-	17.6	Atypical acute endpoint	Palmer and Krueger (2001)
African clawed frog (embryos), *Xenopus laevis*	R, M	96 hr	PFOS-K 86.9%	7.26	24	EC50 (teratogenesis)	-	16.8	Atypical acute endpoint	Palmer and Krueger (2001)
African clawed frog (embryos), *Xenopus laevis*	R, M	96 hr	PFOS-K 86.9%	7.3	24	NOEC (growth)	-	14.7	Atypical acute endpoint	Palmer and Krueger (2001)
African clawed frog (embryos), *Xenopus laevis*	R, M	96 hr	PFOS-K 86.9%	7.27	24	LOEC (growth)	-	7.97	Atypical acute endpoint	Palmer and Krueger (2001)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
African clawed frog (embryos), *Xenopus laevis*	R, M	96 hr	PFOS-K 86.9%	7.26	24	LOEC (growth)	-	8.26	Atypical acute endpoint	Palmer and Krueger (2001)
African clawed frog (tadpoles, NF stage 46/47), *Xenopus laevis*	R, U	67 d	PFOS >96%	-	22	NOEC (survival and forelimb emergence)	0.1->0.1	0.1	Control issues	Cheng et al. (2011)
African clawed frog (embryo, NF 10), *Xenopus laevis*	R, M	96 hr	PFOS >99%	-	24	LC50	-	>96	Non-definitive value	San-Segundo et al. (2016)
American toad (larva, Gosner stage 25), *Anaxyrus americanus*	R, M	26-45 d	PFOS ≥98%	-	20	NOEC (mortality, growth, development)	-	0.6162	Lack of dose response	Flynn et al. (2022)
Asiatic toad (tadpole, 1.8 cm, 0.048 g), *Bufo gargarizans*	R, M	96 hr	PFOS-K 99%	7	22	LC50	-	48.21	Source of organisms may be problematic	Yang et al. (2014)
Asiatic toad (tadpole, 1.8 cm, 0.048 g), *Bufo gargarizans*	R, M	30 d	PFOS-K 99%	7	22	EC10 (survival)	-	2.00	Renewal chronic exposure, not a true ELS test, source of organisms may be problematic	Yang et al. (2014)
Bullfrog (tadpole, Gosner stage 25), *Lithobates catesbeiana* (formerly, *Rana catesbeiana*)	R, M	65 d	PFOS-K >98%	-	23	LOEC (growth: snout-vent length)	-	0.002430	Potential mixture effects, missing exposure details (prior exposure)	Lech et al. (2022)
Northern leopard frog (Gosner stage 25), *Lithobates pipiens*	S, M	116 d	PFOS Unknown	7.41-8.54	13.1-29.8	NOEC (survival and growth)	0.0128->0.0128	0.0128	Outdoor mesocosm	Foguth et al. (2020)
Northern leopard frog (Gosner stage 26.5, 0.109 g), *Lithobates pipiens*	R, U	10 d	PFOS-K ≥98%	7.9	22	NOEC (development, growth, survival)	0.1->0.1	0.1	Duration too long for an acute test and too short for a chronic test	Brown et al. (2021)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Northern leopard frog (larva, Gosner stage 25), *Lithobates pipiens*	S, M	30 d	PFOS ≥96%	7.8	26.2	LOEC (developmental stage)	<0.00006-0.00006	0.00006	Duration too long for an acute test and too short for a chronic test	Flynn et al. (2021)
Leopard frog (larva, Gosner stage 25), *Lithobates pipiens*	R, M	30 d	PFOS ≥98%	-	20	MATC (developmental stage, growth-weight)	0.1219-1.437	0.4185	Lack of dose response; PFOS present in controls	Flynn et al. (2022)
Leopard frog (larva, Gosner stage 25), *Lithobates pipiens*	R, M	30 d	PFOS ≥98%	-	20	LOEC (scaled mass index)	-	0.00774	Lack of dose response; PFOS present in controls	Flynn et al. (2022)
Leopard frog (larva, Gosner stage 25), *Lithobates pipiens*	R, M	30 d	PFOS ≥98%	-	20	NOEC (mortality)	-	1.437	Lack of dose response; PFOS present in controls	Flynn et al. (2022)
Leopard frog (tadpole, Gosner stage 25), *Lithobates pipiens*	R, M	120 d	PFOS ≥98%	7.87 (7.40-8.25)	20.3 (19.4-21.0)	NOEC (mortality, growth)	-	>0.000934	Test represents a greater than low value (followed data rule)	Hoskins et al. (2022)
Black spotted frog, *Pelophylax nigromaculatus* (formerly, *Rana nigromaculata*)	R, M	21 d	PFOS >98%	6.5	20	LOEC (biochemistry changes and gene expression)	-	0.01	Non-apical endpoints	Lin et al. (2022a)
Black spotted frog (adult), *Pelophylax nigromaculatus*	R, M	21 d	PFOS-K >98%	6.5	20	LOEC (biochemistry changes and gene expression)	-	0.0009150	Non-apical endpoints	Lin et al. (2022b)
Black spotted frog, *Pelophylax nigromaculatus*	R, M	21 d	PFOS-K >98%	6.5	20	LOEC (gene expression)	-	0.00121	Non-apical endpoints	Liu et al. (2023b)
Black spotted frog (adult), *Pelophylax nigromaculatus*	R, M	21 d	PFOS ≥98%	6.5	20	LOEC (gene expression)	-	0.01114	Non-apical endpoint	Shi et al. (2023)
Tiger salamander (larva, 46 hr), *Ambystoma tigrinum*	R, M	30 d	PFOS ≥98%	-	20	NOEC (growth, survival)		0.6213	Lack of dose response	Flynn et al. (2022)

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

[b] Chemical concentrations made in a side-test representative of exposure and verified stability of concentrations of PFOS in the range of concentrations tested under similar conditions. Daily renewal of test solutions.

[c] Water concentrations were not measured, but PFOS concentrations were measured in the liver.

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[d] 36 days corresponds to the first of ten generations, the one with the most consistent negative response. The value at 36 days is 1/10 of the duration of this year-long 10-generation study.

[e] Reported in moles converted to gram based on a molecular weight of 500.13 g/mol (PFOS); 538.22 g/mol (PFOS-K); 629.4 g/mol (PFOS-TEA); 522.111 g/mol (PFOS-Na).

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Appendix H Other Estuarine/Marine PFOS Toxicity Studies

H.1 Summary Table of Acceptable Qualitative Estuarine/Marine PFOS Toxicity Studies

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Salinity (ppt)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Bacterium, *Vibrio fischeri*	S, M	15 min	PFOS-K 98%	-	18	-	EC50 (bioluminescence inhibition)	-	>500	Duration too short for a plant test, missing some exposure details, non-apical endpoint	Rosal et al. (2010)
Cyanobacterium, *Anabaena sp.*	S, M	24 hr	PFOS-K 98%	-	28	-	EC50 (bioluminescence inhibition)	-	143.27	Duration too short for a plant test, missing some exposure details, non-apical endpoint	Rosal et al. (2010)
Dinoflagellate, *Pyrocystis lunula*	S, M	24 hr	PFOS-K 98%	-	19	-	EC50 (bioluminescence inhibition)	-	4.9	Duration too short for a plant test	Hayman et al. (2021)
Dinoflagellate, *Symbiodiniaceae*	R, M	7 d	L-PFOS Unreported	-	25	-	NOEC (population abundance)	0.0001->0.0001	0.0001	Only one exposure concentration	Bednarz et al. (2022)
Dinoflagellate, *Symbiodiniaceae*	R, M	14 d	L-PFOS Unreported	-	25	-	LOEC (population abundance)	<0.0001-0.0001	0.0001	Only one exposure concentration	Bednarz et al. (2022)
Dinoflagellate, *Symbiodiniaceae*	R, M	7 d	L-PFOS Unreported	-	32	-	NOEC (population abundance)	0.0001->0.0001	0.0001	Only one exposure concentration	Bednarz et al. (2022)
Dinoflagellate, *Symbiodiniaceae*	R, M	14 d	L-PFOS Unreported	-	32	-	LOEC (population abundance)	<0.0001-0.0001	0.0001	Only one exposure concentration	Bednarz et al. (2022)
Dinoflagellate, *Symbiodiniaceae*	R, M	28 d	L-PFOS Unreported	-	32	-	NOEC (population abundance)	0.0001->0.0001	0.0001	Only one exposure concentration	Bednarz et al. (2022)
Golden brown alga, *Isochrysis galbana*	S, U	72 hr	PFOS 98%	-	20	-	EC50 (growth inhibition)	-	37.5	Duration too short for a plant test	Mhadhbi et al. (2012)
Alga, *Ceratoneis closterium*	S, U	72 hr	PFOS-K Unknown	-	-	33	NOEC (growth)	4.16->4.16	4.16	Sediment and other PFAS present in exposure	Simpson et al. (2021)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Salinity (ppt)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Diatom, *Skeletonema costatum*	S, M	96 hr	PFOS-K 86.9%	8.0-8.4	20	~30	EC50 (cell density)	-	>3.20	Only one exposure concentration	Desjardins et al. (2001a)
Sandworm (adult), *Perinereis wilsoni*	R, M	7 d	PFOS-K Unreported	8.1	17.1	36	NOEC (survival)	0.000028->0.000028	0.000028	Only one exposure concentration	Sakurai et al. (2017)
Sea urchin (adult), *Glyptocidaris crenularis*	R, U	21 d + 7 d observation	PFOS-K 98%	8.1	13	30	NOEC (mortality)	1.0->1.0	1.0	Not a true ELS test (started with adults); missing exposure details	Ding et al. (2015)
Sea urchin (adult), *Glyptocidaris crenularis*	R, U	21 d + 7 d observation	PFOS-K 98%	8.1	13	30	LOEC (SOD activity)	<0.01-0.01	0.01	Not a true ELS test (started with adults); missing exposure details; atypical endpoint	Ding et al. (2015)
Purple sea urchin (fertilized eggs), *Paracentrotus lividus*	S, U	48 hr	PFOS 98%	-	20	-	EC50 (growth inhibition)	-	20	Duration too short for an acute test	Mhadhbi et al. (2012)
Purple sea urchin (sperm), *Paracentrotus lividus*	S, U	65 min	PFOS Unreported	7.69	22	-	NOEC (reproduction - egg fertilization)	-	0.0005	Duration too short, greater than low value	Munari et al. (2022)
Sea urchin (embryo), *Psammechinus miliaris*	R, U[b] (tissue)	72 hr	PFOS-K ≥98%	8	19	31	EC50 (morphological abnormality)	-	>0.3999[c]	Interpolated endpoint; missing some exposure details	Anselmo et al. (2011)
Sea urchin (embryo), *Psammechinus miliaris*	R, U[b] (tissue)	16 d	PFOS-K ≥98%	8	19	31	NOEC (morphological abnormalities, hatch success, development)	0.3999->0.3999	0.3999[c]	Duration too short for chronic test and too long for acute test	Anselmo et al. (2011)
Sea urchin (larva), *Psammechinus miliaris*	S, U	85 min.	PFOS-K ≥98%	-	19	-	IC50 (cellular efflux pump inhibition)	-	1.399[c]	Duration too short for a chronic test and too long for an acute test, atypical endpoint	Anselmo et al. (2012)
Eastern oyster (33.8mm), *Crassostrea virginica*	S, M	96 hr	PFOS-K 90.49%	7.5-8.1	22	20-21	EC50 (shell deposition)	-	>3.0	Lack of replication; atypical endpoint	Drottar and Krueger (2000i)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Salinity (ppt)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Eastern oyster (adult, 70-100 mm), *Crassostrea virginica*	S, U	48 hr	PFOS ≥97%	7.5	24.9	20	LOEC (cellular lysosomal damage)	<3-3	3	Atypical endpoint	Aquilina-Beck et al. (2020)
Mediterranean mussel (6.4 cm), *Mytilus galloprovincials*	R, U	30 d	PFOS Analytical grade	8.1	17.5	34.5	LOEC (increase micronuclei nuclear aberrations in gills cells)	<2-2	2	Atypical endpoint; missing some exposure details	Nalbantlar and Arslan (2017)
Green mussel (adult), *Perna viridis*	R, M	7 d + 7 d observation	PFOS-K 98%	-	25	30	EC50 (integrative genotoxicity)	0.00095-0.0097	0.033	Duration too short for a chronic test and too long for an acute test, atypical endpoint	Liu et al. (2014a)
Green mussel (adult), *Perna viridis*	R, M	7 d	PFOS-K 98%	-	25	25	MATC (CAT and SOD activity)	0.106-0.968	0.3203	Duration too short for a chronic test and too long for an acute test, atypical endpoint	Liu et al. (2014b)
Green mussel (60-65 mm), *Perna viridis*	R, M	7 d	PFOS-K 98%	-	25	25	MATC (relative condition factor)	0.0096-0.106	0.0319	Duration too short for a chronic test and too long for an acute test, atypical endpoint	(Liu et al. 2014c)
Green mussel, *Perna viridis*	R, M	7 d + 7 d observation	PFOS-K 98%	8	25	30	MATC (hemocyte cell viability)	0.0096-0.106	0.0319	Duration too short for a chronic test and too long for an acute test, atypical endpoint	Liu and Gin (2018)
Green mussel, *Perna viridis*	R, U	7 d	PFOS >98%	-	25	3.2	MATC (biochemistry changes)	0.01-0.1	0.0316	Non-apical endpoint	Xu et al. (2022)
White sunset shell (15.0-20.3 mm), *Soletellina alba*	S, M	28 d	PFOS-K Unreported	8	19	30	NOEC (survival)	0.85->0.85	0.85	Other PFAS measured in the sediment and water	Simpson et al. (2021)
Bivalve (8.1-18.9 mm), *Tellina deltoidalis*	S, M	28 d	PFOS-K Unreported	8	19	30	MATC (growth - weight)	0.22-0.28	0.2482	Other PFAS measured in the sediment and water	Simpson et al. (2021)
Smooth cauliflower coral, *Stylophora pistillata*	R, U	7 d	L-PFOS Unreported	-	32	-	NOEC (lipid peroxidation)	0.0001->0.0001	0.0001	Atypical endpoint	Bednarz et al. (2022)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Salinity (ppt)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Smooth cauliflower coral, *Stylophora pistillata*	R, U	28 d	L-PFOS Unreported	-	32	-	LOEC (lipid peroxidation)	<0.0001-0.0001	0.0001	Atypical endpoint	Bednarz et al. (2022)
Mysid (juvenile), *Americamysis bahia*	S, M	96 hr	PFOS-K 90.49%	8.1-8.2	23.5-25.3	20	LC50	-	3.6	Percent recovery of test substance is low	Drottar and Krueger (2000a)
Copepod (adult), *Nitocra spinipes*	S, M	10 d	PFOS-K Unreported	8.1	21	30	NOEC (reproduction)	2.0->2.0	2.0	Other PFAS measured in the sediment and water	Simpson et al. (2021)
Copepod (adult), *Nitocra spinipes*	S, M	28 d	PFOS-K Unreported	8.1	21	30	NOEC (survival)	0.48->0.48	0.48	Other PFAS measured in the sediment and water	Simpson et al. (2021)
Copepod (adult, female), *Tigriopus japonicus*	R, U	10 d	PFOS Unreported	-	25	32	MATC (reproduction)	0.1-0.25	0.1581	Difficult to determine test methodology	Han et al. (2015)
Amphipod (adult), *Gammarus insensibilis*	S, U	48 hr	PFOS-K ≥98%	8	19	32.5	LC50	-	9.99	Duration too short for an acute test	Touaylia et al. (2019)
Amphipod (adult), *Melita plumulosa*	S, M	10 d	PFOS-K Unreported	-	21	30	EC10 (reproduction)	-	0.9	Other PFAS measured in the sediment and water	Simpson et al. (2021)
Smooth sentinel crab (6-15 mm carapace), *Macrophthalmus sp.*	S, M	28 d	PFOS-K Unreported	8	19	30	NOEC (survival)	0.85->0.85	0.85	Other PFAS measured in the sediment and water	Simpson et al. (2021)
Chinese mitten crab (11.89 g), *Eriocheir sinensis*	R, U	21 d	PFOS-K >98%	7.6-8.1	18-22	0.3	MATC (total hemocyte count)	0.01-0.1	0.03162	Duration too short for a chronic test and too long for an acute test	Zhang et al. (2015)
Mud crab (3cm), *Macrophthalmus japonicus*	R, U	96 hr	PFOS 98%	-	20	30	LC50	-	>0.03	Only three exposure concentrations, atypical source of organisms	Park et al. (2015)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Salinity (ppt)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Mud crab (3cm), *Macrophthalmus japonicus*	R, U	7 d	PFOS 98%	-	20	30	LOEC (mortality)	<0.001-0.001	0.001	Only three exposure concentrations, atypical source of organisms	Park et al. (2015)
Marine medaka (embryo, 2 dpf), *Oryzias melastigma*	R, U	8 d	PFOS 98%	-	28	30	MATC (sinus venosus–bulbus arteriosus distance)	4.0-16	8	Duration too short for a chronic test and too long for an acute test, only three exposure concentrations	Huang et al. (2011)
Marine medaka (embryo, 2 dpf), *Oryzias melastigma*	R, U	8 d	PFOS 98%	-	28	30	LOEC (decrease heart rate)	<1-1	1	Duration too short for a chronic test and too long for an acute test, only three exposure concentrations	Huang et al. (2011)
Marine medaka (embryo), *Oryzias melastigma*	R, M	8 d	PFOS 98%	-	28	30	NOEC (embryo mortality)	16->16	16	Duration too short for a chronic test and too long for an acute test	Fang et al. (2012)
Marine medaka (embryo), *Oryzias melastigma*	R, M	8 d	PFOS 98%	-	28	30	LOEC (malformation)	<1-1	1	Duration too short for a chronic test and too long for an acute test	Fang et al. (2012)
Marine medaka (embryo), *Oryzias melastigma*	R, U	≤21 d	PFOS 98%	-	28	30	MATC (increase hatching rate, decrease hatching time)	1.0-4	2.00	Duration too short for a chronic test, low control hatch success, only three exposure concentrations	Wu et al. (2012)
Marine medaka (embryo), *Oryzias melastigma*	R, U	≤21 d + 7 d observation	PFOS 98%	-	28	30	MATC (larval survival)	1.0-4	2.00	Duration too short for a chronic test, low control hatch success, only three exposure concentrations	Wu et al. (2012)
Atlantic Cod (juvenile), *Gadus morhua*	F, U[b] (tissue)	5 d (1 hr/day)	PFOS Technical grade	7.7	10	33.8	NOEC (survival, growth)	0.2->0.2	0.20	Duration too short for a chronic test and too long for an acute test, only two exposure concentrations. Pulsed exposure.	Preus-Olsen et al. (2014)
European seabass (juvenile), *Dicentrarchus labrax*	D, U	21 d	PFOS-K ≥98%	-	20	28	LOEC (histology, enzymatic and genetic changes)	-	4.83 µg/kg	Dietary exposure, non-apical endpoints	Espinosa-Ruiz et al. (2023)
Blackrock fish (5 mo. old), *Sebastes schlegelli*	R, U	6 d	PFOS 99%	8.0-8.2	8.0-12	10	NOEC (survival, growth)	1->1	1	Duration too short for a chronic test and too long	Jeon et al. (2010)

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Salinity (ppt)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
										for an acute test, only two exposure concentrations	
Blackrock fish (5 mo. old), *Sebastes schlegelli*	R, U	6 d	PFOS 99%	8.0-8.2	8.0-12	17.5	NOEC (survival, growth)	1->1	1	Duration too short for a chronic test and too long for an acute test, only two exposure concentrations	Jeon et al. (2010)
Blackrock fish (5 mo. old), *Sebastes schlegelli*	R, U	6 d	PFOS 99%	8.0-8.2	8.0-12	25	NOEC (survival, growth)	1->1	1	Duration too short for a chronic test and too long for an acute test, only two exposure concentrations	Jeon et al. (2010)
Blackrock fish (5 mo. old), *Sebastes schlegelli*	R, U	6 d	PFOS 99%	8.0-8.2	8.0-12	34	NOEC (survival, growth)	1->1	1	Duration too short for a chronic test and too long for an acute test, only two exposure concentrations	Jeon et al. (2010)
Turbot (embryo), *Scophthalmus maximus* (formerly, *Psetta maxima*)	R, U	6 d	PFOS 98%	-	18	-	LC50	-	0.11	Duration too short for a chronic test and too long for an acute test	Mhadhbi et al. (2012)

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

[b] Study did not measure water concentrations, but there are measured concentrations from analysis of the tissue of organisms.

[c] Reported in moles converted to gram based on a molecular weight of 500.13 g/mol (PFOS); 538.22 g/mol (PFOS-K); 629.4 g/mol (PFOS-TEA).

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Appendix I Acute to Chronic Ratios

I.1 Acute to Chronic Ratios from Quantitatively Acceptable Toxicity Tests.

Species	Chemical / Purity	Acute Method[a]	Chronic Method[a]	Acute Test Duration	Chronic Test Duration	Chronic Effect	Acute Effect Conc. (mg/L)	Chronic Effect Conc. (mg/L)	ACR[c]	SMACR[c]	Reference
Fatmucket, *Lampsilis siliquoidea*	PFOS >98%	S, M	S, M	24 hour	36 day	MATC (metamorphosis success)	16.5	0.01768	**933.3**	**933.3**	Hazelton (2013); Hazelton et al. (2012)
Snail, *Physella heterostropha pomilia* (formerly, *Physa pomilia)*	PFOS-K ≥98%	S, M	R, M	96 hour	44 day	EC10 (clutch size)	161.8	8.527	**18.98**	**18.98**	Funkhouser (2014)
Rotifer, *Brachionus calyciflorus*	PFOS ≥98%	S, U[b]	R, U[b]	24 hour	Up to 158 hours	LOEC (reduced net reproductive rate)	61.8	0.25	**247.2**	**>247.2**	Zhang et al. (2013)
Cladoceran, *Daphnia carinata*	PFOS-K ≥98%	S, U	R, U	48 hour	21 day	MATC (days to first brood)	11.56	0.003162	3,656	3,656[b]	Logeshwaran et al. (2021)
Cladoceran, *Daphnia magna*	PFOS-K 90.49%	S, M	R, M	48 hour	21 day	EC10 (cumulative young)	58.51	11.19	**5.229**	-	Drottar and Krueger (2000c)
Cladoceran, *Daphnia magna*	PFOS-K 95%	S, U	R, U	48 hour	21 day	EC10 (survival)	67.2	16.35	**4.110**	-	Boudreau et al. (2003a)
Cladoceran, *Daphnia magna*	PFOS Unreported	S, U	R, U	48 hour	21 day	EC10 (# of young/brood)	35.46	1.051	**33.74**	-	Ji et al. (2008)
Cladoceran, *Daphnia magna*	PFOS-K >98%	S, U	R, U	48 hour	21 day	EC10 (total neonates/female)	63.84[d]	3.030	**21.07**	-	Li (2009); Li (2010)
Cladoceran, *Daphnia magna*	PFOS-K 99%	S, M	R, M	48 hour	21 day	EC10 (survival)	78.09	2.610	**29.92**	-	Yang et al. (2014)
Cladoceran, *Daphnia magna*	PFOS 98%	S, U	R, U	48 hour	21 day	EC10 (number of offspring/brood/female)	23.41	0.001818	12,877[b]	-	Lu et al. (2015)
Cladoceran, *Daphnia magna*	PFOS-K ≥98%	S, U	R, U	48 hour	21 day	EC10 (survival)	94.58	3.596	**26.30**	-	Liang et al. (2017)
Cladoceran, *Daphnia magna*	PFOS-K 98%	S, U	R, U	48 hour	21 day	EC10 (growth-length)	22.43	0.9093	**24.67**	**16.23**	Yang et al. (2019)

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Species	Chemical / Purity	Acute Method[a]	Chronic Method[a]	Acute Test Duration	Chronic Test Duration	Chronic Effect	Acute Effect Conc. (mg/L)	Chronic Effect Conc. (mg/L)	ACR[c]	SMACR[c]	Reference
Cladoceran, *Moina macrocopa*	PFOS Unreported	S, U	R, U	48 hour	7 day	EC10 (# of young/starting adult)	17.20	0.1789	**96.14**	**96.14**	Ji et al. (2008)
Crayfish, *Procambarus fallax f. virginalis*	PFOS-K ≥98%	S, M	R, M	96 hour	28 day	LC20	59.87	0.167	**358.5**	**358.5**	Funkhouser (2014)
Mayfly, *Neocloeon triangulifer*	PFOS-K 98%	R, M	R, M	96 hour	23 day	EC10 (dry weight at day 14)	0.07617	0.000226	**337.0**	**337.0**	Soucek et al. (2023)
Zebrafish, *Danio rerio*	PFOS-K unknown/ PFOS 96%	R, U	R, U	96 hour	Life Cycle	EC10 (F1 offspring: % survival)	17	0.01650	**1,030**	**1,030**	Wang et al. (2011); Wang et al. (2013)
Fathead minnow, *Pimephales promelas*	PFOS-K 90.49%	S, M	F, M	96 hour	47 day	EC10 (survival)	9.020	0.4732	**19.06**	**19.06**	Drottar and Krueger (2000c)

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

[b] Value appears to be an outlier and is not used in SMACR calculation.

[c] Values in bold are used in the SMACR and FACR calculations.

[d] Geometric mean of three LC50s.

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I.2 Acute to Chronic Ratios from Qualitatively Acceptable Toxicity Tests.

Species	Acute / Chronic Chemical and Purity	Acute Method[a]	Chronic Method[a]	Acute Test Duration	Chronic Test Duration	Acute Effect	Chronic Effect	Acute Effect Conc. (mg/L)	Chronic Effect Conc. (mg/L)	ACR	References
Planaria, *Dugesia japonica*	PFOS-K >99%	R, U	R, U	96 hours	10 days	LC50	LOEC (regeneration: decreased appearance of auricles)	29.46	0.5	58.92	Yuan et al. (2014)
Snail, *Lymnaea stagnalis*	PFOS Unreported	S, M	R, M	96 hours	21 days	LC50	MATC (survival)	171.5	4.243	40.41	Olson (2017)
Midge, *Chironomus sp.*	PFOS-K (99%) / PFOS Unreported	S, M	S, M	96 hours	~36 days (1st of 10 generations)	LC50	LOEC (F1 developmental time, adult weight, exuvia length)	182.12	0.004	45,530	Marziali et al. (2019); Yang et al. (2014)
Midge, *Chironomus sp.*	PFOS-K (99%) / PFOS-K (95%)	S, M	S, M	96 hours	Life cycle (>50 days)	LC50	EC10 (total emergence)	182.12	0.05896	3,089	MacDonald et al. (2004); Yang et al. (2014)
Yellow fever mosquito, *Aedes aegypti*	PFOS Unreported	S, U	R, U	48 hours	~42 days	LC50	MATC (average time to emergence)	1.18	0.079	14.94	Olson (2017)
Rainbow trout, *Oncorhynchus mykiss*	PFOS-K (98%) / PFOS (89%)	R, M	S, U	96 hours	14 days	LC50	LOEC (decrease LSI)	2.5	1.0	2.500	Oakes et al. (2005); Sharpe et al. (2010)
Zebrafish, *Danio rerio*	PFOS ≥97%	S, U	R, U	96 hours	6 days	LC50	EC50 (uninflated swim bladder)	58.47	2.29	25.53	Hagenaars et al. (2014); Hagenaars et al. (2011b)
Zebrafish, *Danio rerio*	PFOS-K 98%	R, M	R, M	96 hours	21 days	LC50	LOEC (reduced fecundity)	22.2	0.5	44.40	Sharpe et al. (2010)
Zebrafish, *Danio rerio*	PFOS 98%	S, U	R, U	96 hours	70 days	LC50	MATC (increased malformation & decreased survival of F1 fish)	3.502	0.02236	156.6	Du et al. (2016a); Du et al. (2009)

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Species	Acute / Chronic Chemical and Purity	Acute Method[a]	Chronic Method[a]	Acute Test Duration	Chronic Test Duration	Acute Effect	Chronic Effect	Acute Effect Conc. (mg/L)	Chronic Effect Conc. (mg/L)	ACR	References
African clawed frog, *Xenopus laevis*	PFOS-K (86.9%) / PFOS-K (86.9%)	R, M	R, M	96 hours	96 hours	LC50	LOEC (growth)	15.49	8.26	1.875	Palmer and Krueger (2001)

a S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

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Appendix J Unused PFOS Toxicity Studies

J.1 Summary Table of Unused PFOS Toxicity Studies

Author	Citation	Reason Unused
Arukwe, A. and A.S. Mortensen	2011. Lipid peroxidation and oxidative stress responses of salmon fed a diet containing perfluorooctane sulfonic- or perfluorooctane carboxylic acids. Comp. Biochem. Physiol. Part C 154: 288-295.	Force-fed (oral gavage); only one exposure concentration
Arukwe, A., M.V. Cangialosi, R.J. Letcher, E. Rocha and A.S. Mortensen	2013. Changes in morphometry and association between whole-body fatty acids and steroid hormone profiles in relation to bioaccumulation patterns in salmon larvae exposed to perfluorooctane sulfonic or perfluorooctane carboxylic acids. Aquat. Toxicol. 130-131: 219-230.	Only one exposure concentration
Balbi, T., C. Ciacci, E. Grasselli, A. Smerilli, A. Voci and L. Canesi	2017. Utilization of *Mytilus* digestive gland cells for the in vitro screening of potential metabolic disruptors in aquatic invertebrates. Comp. Biochem. Physiol. Part C. 191: 26-35.	In vitro (excised cells)
Bilbao, E., D. Raingeard, O. Diaz de Cerio, M. Ortiz-Zarragoitia, P. Ruiz, U. Izagirre, A. Orbea, I. Marigómez, M.P. Cajaraville and I. Cancio	2010. Effects of exposure to Prestige-like heavy fuel oil and to perfluorooctane sulfonate on conventional biomarkers and target gene transcription in the thicklip grey mullet *Chelon labrosus*. Aquat. Toxicol. 98: 282-296.	Only one exposure concentration; the number of fish was not reported
Blanc, M., A. Karrman, P. Kukucka, N. Scherbak and S. Keiter	2017. Mixture-specific gene expression in zebrafish (*Danio rerio*) embryos exposed to perfluorooctane sulfonic acid (PFOS), perfluorohexanoic acid (PFHxA) and 3,3',4,4',5-pentachlorobiphenyl (PCB126). Sci. Total Environ. 590: 249-257.	Mixture (PFOS, PFHxA and PCB126)
Blanc, M., J. Ruegg, N. Scherbak and S.H. Keiter	2019. Environmental chemicals differentially affect epigenetic-related mechanisms in the zebrafish liver (zf-l) cell line and in zebrafish embryos. Aquat. Toxicol. 215:105272-9999.	Control absent from test
Chen, J., L. Zheng, L. Tian, N. Wang, L. Lei, Y. Wang, Q. Dong, C. Huang and D. Yang	2018. Chronic PFOS exposure disrupts thyroid structure and function in zebrafish. Bull. Environ. Contam. Toxicol. 101: 75-79.	Only one treatment concentration; severe lack of procedural details
Chen, K., N. Iwasaki, X. Qiu, H. Xu, Y. Takai, K. Tashiro, Y. Shimasaki and Y. Oshima	2020. Adipogenesis of perfluorooctanesulfonate (PFOS) on Japanese medaka (*Oryzias latipes*) embryo using ovo-nanoinjection-mRNA seq analysis. J. Fac. Agric. Kyushu Univ. 65(2): 295-303.	Injected toxicant in ova
Cheng, J., S. Lv, S. Nie, J. Liu, S. Tong, N. Kang, Y. Xiao, Q. Dong, C. Huang and D. Yang	2016. Chronic perfluorooctane sulfonate (PFOS) exposure induces hepatic steatosis in zebrafish. Aquat. Toxicol. 176: 45-52.	Only one exposure concentration; unmeasured chronic exposure
Consoer, D.M.	2017. A mechanistic investigation of perfluoroalkyl acid kinetics in rainbow trout (*Oncorhynchus mykiss*). A dissertation submitted to the faculty of the University of Minnesota.	Injected toxicant; only one exposure concentration
Cui, Y., W. Liu, W. Xie, W. Yu, C. Wang and H. Chen	2015. Investigation of the effects of perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) on apoptosis and cell cycle in a zebrafish (*Danio rerio*) liver cell line. Int. J. Environ. Res. Public Health 12(12): 15673-15682.	Excised cells (liver cell line)
Dale, K., F. Yadetie, T. Horvli, X. Zhang, H.G. Froysa, O.A. Karlsen and A. Goksoyr	2022. Single PFAS and PFAS mixtures affect nuclear receptor- and oxidative stress-related pathways in precision-cut liver slices of Atlantic cod (*Gadus morhua*). Sci. Total Environ. 814: 1-12.	In vitro; no apical endpoints

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Author	Citation	Reason Unused
Diaz de Cerio, O., E. Bilbao, M.P. Cajaraville and I. Cancio	2012. Regulation of xenobiotic transporter genes in liver and brain of juvenile thicklip grey mullets (*Chelon labrosus*) after exposure to Prestige-like fuel oil and to perfluorooctane sulfonate. Gene. 498: 50-58.	Only one exposure concentration
Dorts, J., P. Kestemont, P.A. Marchand, W. D'Hollander, M.L. Thezenas, M. Raes and F. Silvestre	2011. Ecotoxicoproteomics in gills of the sentinel fish species, *Cottus gobio*, exposed to perfluorooctane sulfonate (PFOS). Aquat. Toxicol. 103: 1-8.	Only two exposure concentrations, not North American species
Dragojevic, J., P. Maric, J. Loncar, M. Popovic, I. Mihaljevic, and T. Smital	2020. Environmental Contaminants Modulate Transport Activity of Zebrafish Organic Anion Transporters Oat1 and Oat3. Comp. Biochem. Physiol. C Toxicol. Pharmacol.231:8 p.	In vitro; no apical endpoints
Du, J., S. Wang, H. You and Z. Liu	2016b. Effects of ZnO nanoparticles on perfluorooctane sulfonate induced thyroid-disrupting on zebrafish larvae. J. Environ. Sci. 47: 153-164.	Only 72-75% control survival in 14-day test
Du, J., J. Tang, S. Xu, J. Ge, Y. Dong, H. Li and M. Jin	2018. Parental transfer of perfluorooctane sulfonate and ZnO nanoparticles chronic co-exposure and inhibition of growth in F1 offspring. Regul. Toxicol. Pharmacol. 98: 41-49.	Excessive control mortality in the F0 generation
Fang, C., Q. Huang, T. Ye, Y. Chen, L. Liu, M. Kang, Y. Lin, H. Shen and S. Dong	2013. Embryonic exposure to PFOS induces immunosuppression in the fish larvae of marine medaka. Ecotox. Environ. Saf. 92: 104-111.	Excessive control mortality (~60% control survival)
Fernández-Sanjuan, M., M. Faria, S. Lacorte and C. Barata	2013. Bioaccumulation and effects of perfluorinated compounds (PFCs) in zebra mussels (*Dreissena polymorpha*). Environ. Sci. Pollut. Res. 20:2661–2669.	Mixture
Garoche, C., A. Boulahtouf, M. Grimaldi, B. Chiavarina, L. Toporova, M.J. Den Broeder, J. Legler, W. Bourguet and P. Ba	2021. Interspecies differences in activation of peroxisome proliferator-activated receptor gamma by pharmaceutical and environmental chemicals. Environ. Sci. Technol. 55(24): 16489-16501.	In vitro
Gorrochategui, E., S. Lacorte, R. Tucker and F.L. Martin	2016. Perfluoroalkylated substance effects in *Xenopus laevis* A6 kidney epithelial cells determined by ATR-FTIR spectroscopy and chemometric analysis. Chem. Res. Toxicol. 29: 924-932.	The tests were performed on cell cultures obtained from an outside source. Whole organisms were not investigated.
Hagenaars A., I.J. Meyer, D. Herzke, B.G. Pardo, P. Martinez, M. Pabon, W. De Coen and D. Knapen	2011. The search for alternative aqueous film forming foams (AFFF) with a low environmental impact: Physiological and transcriptomic effects of two Forafac® fluorosurfactants in turbot. Aquat. Toxicol. 104: 168-176.	Only one exposure concentration; missing detail (focus is on other chemicals)
Hoff, P.T., W. Van Dongen, E.L. Esmans, R. Blust and W.M. De Coen	2003. Evaluation of the toxicological effects of perfluorooctane sulfonic acid in the common carp (*Cyprinus carpio*). Aquat. Toxicol. 62 (4): 349-359.	Exposure was from a single intra-peritoneal injection
Hoff, P.T., K. Van Campenhout, K. Van de Vijver, A. Covaci, L. Bervoets, L. Moens, G. Huyskens, G. Goemans, C. Belpaire, R. Blust and W. De Coen	2005. Perfluorooctane sulfonic acid and organohalogen pollutants in liver of three freshwater fish species in Flanders (Belgium): relationships with biochemical and organismal effects. Environ. Pollut. 137: 324-333.	Field exposure, but concentrations were not measured so no BAFs could be calculated
Honda, M., A. Muta, T. Akasaka, Y. Inoue, Y. Shimasaki, K. Kanna, N. Okino and Y. Oshima	2014. Identification of perfluorooctane sulfonate binding protein in the plasma of tiger pufferfish *Takifugu rubripes*. Ecotox. Environ. Safety. 104: 409-413.	Injected toxicant; only one exposure concentration
Honda, M., A. Muta, A. Shimazaki, T. Akasaka, M. Yoshikuni, Y. Shimasaki and Y. Oshima	2018. High concentrations of perfluorooctane sulfonate in mucus of tiger puffer fish *Takifugu rubripes*: a laboratory exposure study. Environ. Sci. Pollut. Res. 25: 1551-1558.	Injected toxicant
Huang, T.S., P.A. Olsvik, A. Krovel, H.S. Tung and B.E. Torstensen	2009. Stress-induced expression of protein disulfide isomerase associated 3 (PDIA3) in Atlantic salmon (*Salmo salar* L.). Comp. Biochem. Physiol. Part B Biochem. Mol. Biol. 154(4): 435-442.	In vitro (cultured hepatocytes)

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Author	Citation	Reason Unused
Huang, Q., S. Dong, C. Fang, X. Wu, T. Ye and Y. Lin	2012. Deep sequencing-based transcriptome profiling analysis of *Oryzias melastigma* exposed to PFOS. Aquat. Toxicol. 120-12: 54-58.	Only one or two exposure concentrations
Huang, Q., Y. Chen, Y. Chi, Y. Lin, H. Zhang, C. Fang and S. Dong	2015. Immunotoxic effects of perfluorooctane sulfonate and di(2-ethylhexyl) phthalate on the marine fish *Oryzias melastigma*. Fish Shell. Immunol. 44: 302-306.	Only two exposure concentrations
Huang, J., Q. Wang, S. Liu, H. Lai and W. Tu.	2022. Comparative chronic toxicities of PFOS and its novel alternatives on the immune system associated with intestinal microbiota dysbiosis in adult zebrafish. J. Hazard. Mater. 425: 11 p.	Only on exposure concentration; lack of apical endpoints
Jacobson, T., K. Holmstrom, G. Yang, A.T. Ford, U. Berger and B. Sundelin	2010. Perfluorooctane sulfonate accumulation and parasite infestation in a field population of the amphipod *Monoporeia affinis* after microcosm exposure. Aquat. Toxicol. 98(1): 99-106.	Dilution water not characterized, mixture
Jantzen, C.E.	2016. Toxicological Profiles of Perfluoroctanoic Acid (PFOA), Perfluorooctane Sulfonate (PFOS) and Perfluornonanoic Acid (PFNA) in Zebrafish (*Danio rerio*). Ph.D. Thesis, Rutgers, The State University of New Jersey, New Brunswick, NJ: 177 p.	Thesis publication; separate DERs were completed for individual components of the study
Jantzen, C.E., K.M. Annunziato and K.R. Cooper	2016. Behavioral, morphometric, and gene expression effects in adult zebrafish (Danio rerio) embryonically exposed to PFOA, PFOS, and PFNA. Aquat. Toxicol. 180:123–130.	Single concentration test where exposure to PFOS was of an acute (117 hours) duration but endpoints were measured at 6 months of age.
Keiter S., K. Burkhardt-Medicke, P. Wellner, B. Kais, H. Färber, D. Skutlarek, M. Engwall, T. Braunbeck, S.H. Keiter and T. Luckenbach	2016. Does perfluorooctane sulfonate (PFOS) act as chemosensitizer in zebrafish embryos? Sci. Total Environ. 548-549:317–324.	Mixture
Khan, E.A., X. Zhang, E.M. Hanna, F. Yadetie, I. Jonassen, A. Goksoyr and A. Arukwe	2021. application of quantitative transcriptomics in evaluating the ex vivo effects of per- and polyfluoroalkyl substances on Atlantic cod (Gadus morhua) ovarian physiology. Sci. Total Environ.755(1): 11 p.	In-vitro study
Kim, S., K. Ji, S. Lee, J. Lee, J. Kim, S. Kim, Y. Kho and K. Choi	2011. Perfluorooctane sulfonic acid exposure increases cadmium toxicity in early life stage of zebrafish, *Danio rerio*. Environ. Toxicol. Chem. 30(4): 870-877.	Only one exposure concentration; atypical duration (7 days)
Kovacevic, V., A.J. Simpson and M.J. Simpson	2018. Evaluation of Daphnia magna metabolic responses to organic contaminant exposure with and without dissolved organic matter using 1H nuclear magnetic resonance (NMR)-based metabolomics. Ecotoxicol. Environ. Saf.164:189-200.	Only one exposure concentration; test not focused on the toxicological effects of PFOS but on the effects of dissolved organic matter following exposure to PFOS and other contaminants
Kovacevic, V., A.J. Simpson and M.J. Simpson	2019. The concentration of dissolved organic matter impacts the metabolic response in *Daphnia magna* exposed to 17α-ethynylestradiol and perfluorooctane sulfonate. Ecotoxicol. Environ. Saf. 170: 468-478.	Only one treatment concentration (examined across a gradient of dissolved organic matter concentrations); endpoints measured were a suite of metabolic changes; atypical design for this test organism
Krovel, A.V., L. Softeland, B. Torstensen and P.A. Olsvik	2008. Transcriptional effects of PFOS in isolated hepatocytes from Atlantic salmon *Salmo salar* L. Comp. Biochem. Physiol., Part C. 148: 14-22.	In vitro

Author	Citation	Reason Unused
Lee, W. and Y. Kagami	2010. Effects of perfluorooctanoic acid and perfluorooctane sulfonate on gene expression profiles in medaka (*Oryzias latipes*). Abstracts. Toxicol. Let. 196S: S37-S351.	Abstract only, cannot judge against data quality objectives
Li, M.H.	2011. Changes of cholinesterase and carboxylesterase activities in male guppies, *Poecilia reticulata*, after exposure to ammonium perfluorooctanoate, but not to perfluorooctane sulfonate. Fresenius Environ. Bull. 20(8a): 2065-2070.	Each treatment group was run three times at separate times (not simultaneously) and the sample size for each treatment group was unclear; control mortality not reported
Li, Y., B. Men, Y. He, H. Xu, M. Liu and D. Wang	2017. Effect of single-wall carbon nanotubes on bioconcentration and toxicity of perfluorooctane sulfonate in zebrafish (*Danio rerio*). Sci. Total Environ. 607-608: 509-518.	Bioaccumulation (steady state no documented); only 4 days; static exposure
Li, R., T. Tang, W. Qiao and J. Huang	2020. Toxic effect of perfluorooctane sulfonate on plants in vertical-flow constructed wetlands. J. Environ. Sci. 92: 176-186.	PFOS added to a simulated wastewater (mixture) which was not properly characterized
Liu, C., Y. Dua and B. Zhoua	2007a. Evaluation of estrogenic activities and mechanism of action of perfluorinated chemicals determined by vitellogenin induction in primary cultured tilapia hepatocytes. Aquat. Toxicol. 85: 267-277.	In vitro (cultured hepatocytes)
Liu, C., K. Yu, X. Shi, J. Wang, P.K.S. Lam, R.S.S. Wu and B. Zhou	2007b. Induction of oxidative stress and apoptosis by PFOS and PFOA in primary cultured hepatocytes of freshwater tilapia (*Oreochromis niloticus*). Aquat. Toxicol. 82: 135-143.	Excised cells (cultured hepatocytes)
Martin, J.W., S.A. Mabury, K.R. Solomon and D.C.G. Muir	2003a. Bioconcentration and tissue distribution of perfluorinated acids in rainbow trout (*Oncorhynchus mykiss*). Environ. Toxicol. Chem. 22: 196-204.	Bioaccumulation (steady state no documented); only 12 days
Martin, J.W., S.A. Mabury, K.R. Solomon and D.C.G. Muir	2003b. Dietary accumulation of perfluorinated acids in juvenile rainbow trout (*Oncorhynchus mykiss*). Environ. Toxicol. Chem. 22(1): 189-195.	Mixture
Martin, J.W., S.A. Mabury, K.R. Solomon and D.C.G. Muir	2013. Progress toward understanding the bioaccumulation of perfluorinated alkyl acids. Environ. Toxicol. Chem. 32(11): 2421-2423.	Review paper
Mortensen, A.S., R.J. Letcher, M.V. Cangialosi, S. Chu and A. Arukwe	2011. Tissue bioaccumulation patterns, xenobioticbiotransformation and steroid hormone levels in Atlantic salmon (*Salmo salar*) fed a diet containing perfluoroactane sulfonic or perfluorooctane carboxylic acids. Chemosphere. 83: 1035-1044.	One dietary dosage level provided over a 6-day period; not intended as a toxicity test
Mylroie, J.E., M.S. Wilbanks, A.N. Kimble, K.T. To, C.S. Cox, S.J. Mcleod, K.A. Gust, D.W. Moore, E.J. Perkins and N. Garcia-Reyero	2021. Perfluorooctanesulfonic acid induced toxicity on zebrafish embryos in the presence or absence of the chorion. Environ. Toxicol. Chem. 40(3): 780-791.	Use of dilution medium (estradiol media) to prepare stock solutions inconsistent with EPA test guidelines
Oh, J.H., H.B. Moon and E.S. Choe	2013. Alterations in differentially expressed genes after repeated exposure to perfluorooctanoate and perfluorooctanesulfonate in liver of *Oryzias latipes*. Arch. Environ. Contam. Toxicol. 64(3): 475-483.	Only one exposure concentration, no concentration-response observed, not North American species
Otero-Sabio, C., M. Giacomello, C. Centelleghe, F. Caicci, M. Bonato, A. Venerando, J.M. Graic, S. Mazzariol, L. Finos	2022. Cell Cycle Alterations Due to Perfluoroalkyl Substances PFOS, PFOA, PFBS, PFBA and the New PFAS C6O4 on Bottlenose Dolphin (Tursiops truncatus) Skin Cell. Ecotoxicol. Environ. Saf.244:10 p	In vitro; no apical endpoints
Pablos, M.V., P. García-Hortigüela and C. Fernández	2015. Acute and chronic toxicity of emerging contaminants, alone or in combination, in *Chlorella vulgaris* and *Daphnia magna*. Environ. Sci. Pollut. Res. 22: 5417-5424.	Mixture

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Author	Citation	Reason Unused
Popovic, M, R. Zaja, K. Fent and T. Smital	2014. Interaction of environmental contaminants with zebrafish organic anion transporting polypeptide, Oatp1d1 (Slco1d1). Toxicol. Appl. Pharmacol. 280(1): 149-158.	Excised cells
Prosser, R.S., K. Mahon, P.K. Sibley, D. Poirier and T. Watson-Leung	2016. Bioaccumulation of perfluorinated carboxylates and sulfonates and polychlorinated biphenyls in laboratory-cultured *Hexagenia* spp., *Lumbriculus variegatus* and *Pimephales promelas* from field-collected sediments. Sci. Total Environ. 543: 715-726.	Mixture (filed collected sediment, contained PFAS mixtures and PCBs)
Roland, K., P. Kestemont, L. Henuset, M.A. Pierrard, M. Raes, M. Dieu and F. Silvestre	2013. Proteomic responses of peripheral blood mononuclear cells in the European eel (*Anguilla anguilla*) after perfluorooctane sulfonate exposure. Aquat. Toxicol.128/129: 43-52.	In vitro (excised cells)
Shi, X., Y. Du, P.K.S. Lam, R.S.S. Wu and B. Zhou	2008. Developmental toxicity and alteration of gene expression in zebrafish embryos exposed to PFOS. Toxicol. Appl. Pharmacol. 230(1): 23-32.	Excessive control mortality
Shi, X., L.W.Y. Yeung, P.K.S. Lam, R.S.S. Wu and B. Zhou	2009b. Protein profiles in zebrafish (*Danio rerio*) embryos exposed to perfluorooctane sulfonate. Toxicol. Sci. 110(2): 334-340.	Only one exposure concentration; atypical duration (8 days)
Stanic, B., J. Petrovic, B. Basica, S. Kaisarevic, K. Schirmer and N. Andric	2021. Characterization of the ERK1/2 phosphorylation profile in human and fish liver cells upon exposure to chemicals of environmental concern. Environ. Toxicol. Pharmacol. 88: 9 p.	In vitro
Stevenson, C.N., L.A. MacManus-Spencer, T. Luckenbach, R.G. Luthy and D. Epel	2006. New perspectives on pefluorochemical ecotoxicology: inhibition and induction of an efflux transporter in marine mussel, *Mytilus californianus*. Environ. Sci. Technol. 40: 5580-5585.	Excised cells (mussel gill tissue)
Sun, X., Y. Xie, X. Zhang, J. Song, and Y. Wu	2023b. Estimation of Per- and Polyfluorinated Alkyl Substance Induction Equivalency Factors for Humpback Dolphins by Transactivation Potencies of Peroxisome Proliferator-Activated Receptors. Environ. Sci. Technol.57(9): 3713-3721.	In vitro
Thienpont, B., A. Tingaud-Sequeira, E. Prats, C. Barata, P.J. Babin and D. Raldua	2011. Zebrafish eleutheroembryos provide a suitable vertebrate model for screening chemicals that impair thyroid hormone synthesis. Environ. Sci. Technol. 45(17): 7525-7532.	Only one exposure concentration; atypical duration (3 days)
Qiu, X., N. Iwasaki, K. Chen, Y. Shimasaki and Y. Oshima	2019. Tributyltin and perfluorooctane sulfonate play a synergistic role in promoting excess fat accumulation in Japanese medaka (*Oryzias latipes*) via in ovo exposure. Chemosphere. 220: 687-695.	Injected toxicant into eggs, not North American species
Wagner, N.D., A.J. Simpson and M.J. Simpson	2016. Metabolomic responses to sublethal contaminant exposure in neonate and adult *Daphnia magna*. Environ. Toxicol. Chem. 36(4): 938-946.	Only one exposure concentration
Wagner, N.D., A.J. Simpson and M.J. Simpson	2018. Sublethal metabolic responses to contaminant mixture toxicity in *Daphnia magna*. Environ. Toxicol. Chem. 37(9): 2448-2457.	Only one exposure concentration
Wang, S., C. Zhuang, J. Du, C. Wu and H. You	2017. The presence of MWCNTs reduces developmental toxicity of PFOS in early life stage of zebrafish. Environ. Pollut. 222: 201-209.	The 96-hour LC50 reported in the publication is the same as the value in Du et al. 2016 (no details provided about this test)
Xia, X., X. Chen, X. Zhao, H. Chen and M. Shen	2012. Effects of carbon nanotubes, chars, and ash on bioaccumulation of perfluorochemicals by *Chironomus plumosus* larvae in sediment. Environ. Sci. Technol. 46: 12467-12475.	Mixture (PFCs mixed in sediment)

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Author	Citation	Reason Unused
Xia, X., A.H. Rabearisoa, X. Jiang and Z. Dai	2013. Bioaccumulation of perfluoroalkyl substances by *Daphnia magna* in water with different types and concentrations of protein. Environ. Sci. Technol. 47: 10955-10963.	Bioaccumulation (steady state not documented); only 3 days; test was unmeasured
Xia, X., Z. Dai, A.H. Rabearisoa, P. Zhao and X. Jiang	2015a. Comparing humic substance and protein compound effects on the bioaccumulation of perfluoroalkyl substances by *Daphnia magna* in water. Chemosphere. 119: 978-986.	Bioaccumulation (steady state not documented); only 3 days; test was unmeasured
Xia, X., A.H. Rabaerisoa, Z. Dai, X. Jiang, P. Zhao and H. Wang	2015b. Inhibition effect of Na+ and Ca2+ on the bioaccumulation of perfluoroalkyl substances by Daphnia magna in the presence of protein. Environ. Toxicol. Chem. 34(2): 429-436.	Bioaccumulation (steady state not documented); only 3 days; test was unmeasured
Yang, Z., L. Fu, M. Cao, F. Li, J. Li, Z. Chen, A. Guo, H. Zhong, W. Li, Y. Liang, and Q. Luo	2023. PFAS-Induced Lipidomic Dysregulations and Their Associations with Developmental Toxicity in Zebrafish Embryos. Sci. Total Environ.861:9 p.	Injected toxicant
Zhang, L., Y.Y. Li, T. Chen, W. Xia, Y. Zhou, Y.J. Wan, Z.Q. Lv, G.Q. Li and S.Q. Xu	2011a. Abnormal development of motor neurons in perfluorooctane sulphonate exposed zebrafish embryos. Ecotoxicol. 20: 643-652.	Static, unmeasured exposure to single-concentration (1 mg/L) from 6 hours post-fertilization to 120 days post-fertilization
Zhang, L., Y.Y. Li, H.C. Zeng, J. Wei, Y.J. Wan, J. Chen and S.Q. Xu	2011b. MicroRNA expression changes during zebrafish development induced by perfluorooctane sulfonate. J. Appl. Toxicol. 31: 210-222.	Poor control survival (>80% at 24 hour and increasing)

Appendix K EPA Methodology for Fitting Concentration-Response Data and Calculating Effect Concentrations

Toxicity values, including LC_{50} and EC_{10} values, were independently-calculated from the data presented in the toxicity studies meeting the inclusion criteria described above (see Section 2.10) and when adequate concentrations-response data were published in the study or could be obtained from authors. When concentration-response data were not presented in toxicity studies, concentration-response data were requested from study authors to independently calculate toxicity values. In cases where study authors did not respond to the EPA's request for data or were unable to locate concentration-response data, the toxicity values were not independently-calculated by the EPA, and the reported toxicity values were retained for criteria deviation. The EPA also retained author-reported effect concentrations when data availability did not support effect concentration calculation by the EPA. This retention was done to be consistent with use of author-reported toxicity values in previous criteria documents and retain informative toxicity values (that would have otherwise not been used only on the basis of lacking the underlying C-R data). Where concentration-response data were available, they were analyzed using the statistical software program R (version 3.6.2) and the associated dose-response curve (drc) package.

In some cases, the author reported toxicity values were different than the corresponding effect concentrations calculated by the EPA. Overall, the magnitude of such discrepancies were limited and largely occurred for several potential reasons such as: (1) instances where authors were presumed to calculate effect concentrations using replicate level data, but the EPA only had access to treatment mean data; (2) the model selected to fit a particular set of C-R data, and; (3) the software used to fit a model to C-R data and calculate an effect concentration.

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K.1 Fitting Concentration Response Data in R

Concentration-response data were obtained from quantitatively-acceptable toxicity studies when reported data were available. In many scenarios, toxicity studies report treatment-level mean concentrations and mean organismal responses; however, individual-replicate data may also be reported. When fitting C-R curves, replicate-level data were preferred over treatment-level data, if both types of data were available. Within R, the drc package can fit a variety of mathematical models to each set of C-R data.

K.1.1 Fitting Acute Mortality Data

K.1.1.1 Dichotomous Data

Dichotomous data are binary in nature (e.g., live/dead or 0/1) and are typical of survival experiments. They are usually represented as a proportion survived.

K.1.2 Fitting Chronic Growth, Reproduction, and Survival Data

K.1.2.1 Continuous Data

Continuous data take on any value along the real number line (e.g., biomass).

K.1.2.2 Count Data

Count data take on only integer values (e.g., number of eggs hatched).

K.1.2.3 Dichotomous Data

Dichotomous data are binary in nature (e.g., live/dead or 0/1) and are typical of survival experiments. They are usually represented as a proportion survived.

K.2 Determining Most Robust Model Fit for Each C-R curve

The R drc package was used to fit a variety of models to each individual C-R dataset. A single model was then selected from these candidate models to serve as the representative C-R model. The selected model represented the most statistically-robust model available. To determine the most-statistically-robust model for a C-R dataset, all individual model fits were assessed on a suite of statistical metrics.

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K.2.1 Selecting Candidate Models

Initially, models were ranked according to the Akaike information criteria (AIC). The AIC provides a measure of the amount of information lost for a given model by balancing goodness of fit with model parsimony. The models with the lowest AIC, relative to other models based on the same data, tend to be optimal. In some instances, however, the model with the lowest AIC possessed a questionable characteristic that suggested said model was not the most appropriate. Rather than selecting a model based solely on the lowest AIC, the initial ranking step was only used to identify a subset of candidate models that were more closely examined before selecting a model fit for each C-R dataset.

K.2.2 Assessment of Candidate Models to Determine the Most Appropriate Model

Candidate models (i.e., models with low AIC scores relative to other models produced for a particular C-R dataset) were further evaluated based on additional statistical metrics to determine a single, statistically robust curve for each quantitatively-acceptable toxicity test. These additional statistical metrics were evaluated relative to the other candidate curve fits produced for each C-R dataset. Of these statistical metrics, residual standard errors, confidence intervals relative to effects concentration estimates, and confidence bands carried the most weight in determining the most appropriate model to be representative of an individual C-R dataset. These additional statistical metrics included:

K.2.2.1 Comparison of residual standard errors

As with AIC, smaller values were desirable. Residual standard errors were judged relative to other models.

K.2.2.2 Width of confidence intervals for EC estimates

Confidence intervals were assessed on standard error relative to estimate and confirming that the intervals were non-negative. Judged in absolute and relative to other models.

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K.2.2.3 Width of confidence bands around the fitted model

A general visual inspection of the confidence bands for the fitted model. Wide bands in the area of interest were undesirable. Judged in absolute and relative to other models.

K.2.2.4 P-values of parameters estimates and goodness of fit tests

Hypothesis tests of parameter values to determine whether an estimate is significantly different from zero. Goodness of fit tests were used to judge the overall performance of the model fit. Typically, the level of significance was set at 0.05. There may have been occasional instances where the 0.05 criterion may not be met, but there was little recourse for choosing another model. Judged in absolute terms.

K.2.2.5 Residual plots

Residuals were examined for homoscedasticity and biasedness. Judged in absolute and relative to other models.

K.2.2.6 Overly influential observations

Observations were judged based on Cook's distance and leverage. When an observation was deemed overly influential, it was not reasonable to refit the model and exclude any overly influential observations given the limited data available with typical C-R curves. Judged in absolute terms.

K.3 Determining Curve Acceptability for use in Criteria Derivation

The final curve fits selected for each of the quantitatively-acceptable toxicity tests were further evaluated and classified to determine whether the curves were: 1) quantitatively acceptable for use, 2) qualitatively acceptable for use, or 3) unacceptable. To determine curve acceptability for use in deriving an effect concentration, each individual curve was considered based on the statistical metrics described above and assessed visually to compare how the calculated effect concentration aligned with the underlying raw C-R data. Instead of evaluating

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curves fits relative to other curve fits for the same data (as was previously described to select the most-robust curve for each test), curve fit metrics were used to assign each curve a score:

- **Quantitatively Acceptable Model**. Model performed well on most/all statistical metrics and resultant effect concentrations were typically used in a quantitative manner.
- **Qualitatively Acceptable Model**. Model generally performed well on statistical metrics; however, the model presented some characteristic(s) that called estimates into question. Such models were considered with caution. These problems may have consisted of any number of issues such as a parameter with a high p-value, poor goodness of fit p-value, wide confidence bands for fit or estimate interval, or residuals that indicate model assumptions are not met. Broadly, effect concentrations from models that were deemed qualitatively acceptable were not used numerically in criteria derivation if quantitatively acceptable models for different endpoints or tests from the same publication were available. If quantitatively acceptable models for different endpoints or tests from the same publication were not available, effect concentrations from the qualitatively acceptable model were used numerically in criteria derivation on a case-by-case basis.
- **Unacceptable Model**. Model poorly fit the data. These models were not used for criteria derivation.

No single statistical metric can determine a given model's validity or appropriateness. Metrics should be considered as a whole. As such, there is a slightly subjective component to these evaluations. That said, this assessment scheme was developed to aid in evaluating models as to their quantitative or qualitative attributes in a transparent and relatively repeatable manner.

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Appendix L Derivation of Acute Protective PFOS Benchmarks for Estuarine/Marine Waters through a New Approach Method (NAM): WebICE

The 1985 *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (U.S. EPA 1985) recommend that data for a minimum of eight families be available to fulfill taxonomic minimum data requirements (MDRs) to calculate criteria values, including to calculate estuarine/marine aquatic life criteria. Acute estuarine/marine test data are currently available for only five of the eight family MDRs (the dataset was missing another family in the Phylum Chordata, a family in a phylum other than Chordata, and any other family); thus, the EPA was not able to derive an acute estuarine/marine criterion element for PFOS based on the 1985 Guidelines MDR specifications (Section 3.2.1.2). However, the EPA was able to develop an acute PFOS protective benchmark for aquatic life using a New Approach Methods (NAMs) process, via the application of Interspecies Correlation Estimation (ICE) models (Raimondo et al. 2010). Although not a criterion based on 1985 Guidelines MDR specifications, because of gaps in available data for several of the taxonomic MDRs listed in the 1985 Guidelines for the derivation of aquatic life criteria, this benchmark represents an aquatic life value derived to be protective of aquatic communities. The ICE model predictions supplement the available test dataset to fulfill the missing MDRs and allow the derivation of an acute estuarine/marine benchmark for aquatic life using procedures consistent with those in the 1985 Guidelines. This is important as it provides an approach by which values that are protective of aquatic life communities can be developed, even when MDRs are not fulfilled by PFOS test data. This approach is consistent with both the 1985 Guidelines "good science" clause, the EPA's interest in providing useful information to states and Tribes regarding protective values for aquatic life, and the EPA's intention to reduce the use of animal testing via

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application of NAMs (https://www.epa.gov/chemical-research/epa-new-approach-methods-work-plan-reducing-use-animals-chemical-testing).

L.1 Introduction to Web-ICE

ICE models, developed by the EPA's Office of Research and Development, are log-linear regressions of the acute toxicity (EC_{50}/LC_{50}) of two species across a range of chemicals, thus representing the relationship of inherent sensitivity between those species (Raimondo et al. 2010). Each model is derived from an extensive, standardized database of acute toxicity values by pairing each species with every other species for which acceptable toxicity data are available. Once developed, ICE models can be used to predict the sensitivity of an untested taxon (predicted taxa are represented by the y-axis) from the known, measured sensitivity of a surrogate species (represented by the x-axis) (Figure L-1).

ICE models have been developed for a broad range of different chemicals (e.g., metals and other inorganics, pesticides, solvents, and reactive chemicals) and across a wide range of toxicity values. There are approximately 3,400 significant ICE models for aquatic animal and plant species in the most recent version of web-ICE (v3.3, www3.epa.gov/webice, last updated June 2016; (Raimondo et al. 2015).

Models were validated using leave-one-out cross validation, which formed the basis for the analyses of uncertainty and prediction robustness. For this process, each datapoint within the model (representing the relative sensitivity of two species for a particular chemical) is systematically removed, one at a time. The model is then redeveloped with the remaining data (following each removal) and the removed value of the surrogate species is entered into the model. The estimated value for the predicted species is then compared to the measured value for that species (Raimondo et al. 2010; Willming et al. 2016).

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ICE models have high prediction accuracy when values are derived from models with robust parameters (e.g., mean square error, R^2), that fall within a defined range of acceptability, and with close prediction confidence intervals that facilitate evaluating the fit of the underlying data (Brill et al. 2016; Raimondo et al. 2010; Willming et al. 2016). Results of these analyses provide the basis of the user guidance for selecting ICE predicted toxicity with high confidence (Box 1).

ICE models have undergone extensive peer review and their use has been supported for multiple applications, including direct toxicity estimation for endangered species (NRC 2013) (Willming et al. 2016) and development of Species Sensitivity Distributions (SSDs) (Awkerman et al. 2014; Bejarano et al. 2017; Dyer et al. 2006; Dyer et al. 2008; Raimondo et al. 2010; Raimondo and Barron 2020). The application of ICE-predicted values to develop protective aquatic life values by multiple independent, international groups confirms that values developed from ICE-generated SSDs provide a level of protection that is consistent with using measured laboratory data (Dyer et al. 2008; Feng et al. 2013; Fojut et al. 2012; Palumbo et al. 2012; Wang et al. 2020; Wu et al. 2015; Wu et al. 2016; Zhang et al. 2017). A recent external review of ICE models additionally supports their use in regulatory applications based on the reliability of underlying data, model transparency, statistical robustness, predictive reliability, proof of principle, applicability to probabilistic approaches, and reproducibility of model accuracy by numerous independent research teams (Bejarano and Wheeler 2020).

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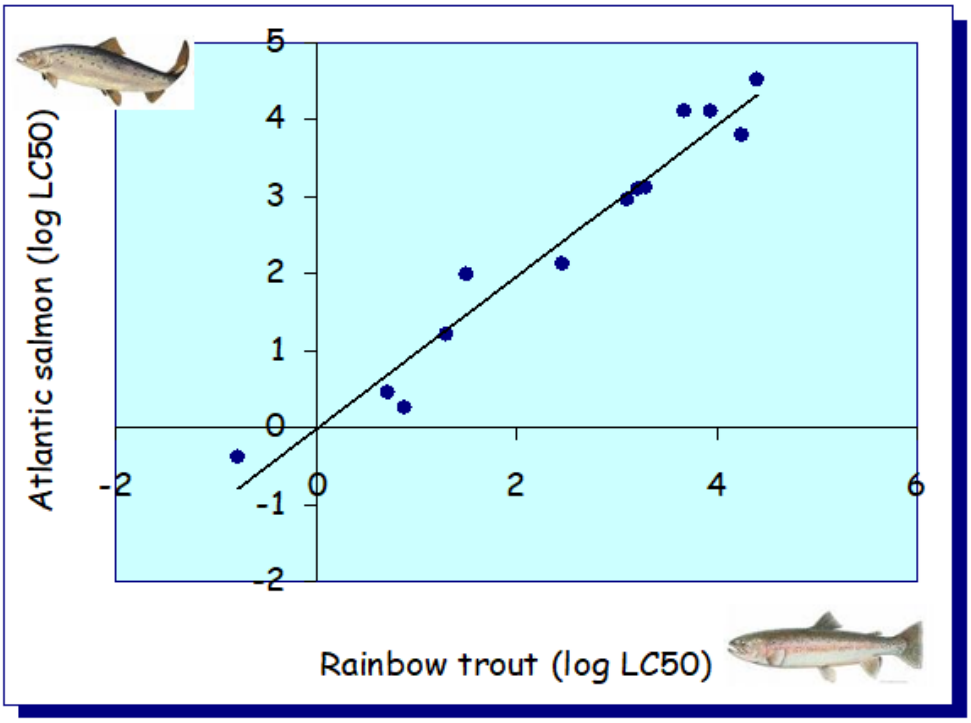


Figure L-1. Example ICE Model for Rainbow Trout (surrogate) and Atlantic Salmon (predicted).
Each model datapoint is a common chemical that was tested in both species to develop a log-linear regression.

Box 1. ICE Model User Guidance Recommended for Listed Species (Willming et al. 2016):

- Close taxonomic distance (within class)
- Low MSE (<~ 0.95)
- High R^2 (>~ 0.6)
- High slope (>~ 0.6)
- Prediction confidence intervals should be used to evaluate the prediction using professional judgement for the application (Raimondo et al. 2024).
- For models between vertebrates and invertebrates, using those with lower MSE or MOA-specific models (not available for PFAS) has been recommended for listed species predictions (Willming et al. 2016).

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L.2 Application of Web-ICE with PFOS

ICE models are developed using a diversity of compounds (e.g., metals and other inorganics, pesticides, solvents, and reactive chemicals) across a wide range of toxicity values; however, PFAS are not included in web-ICE v3.3 due to the lack of available PFAS toxicity data when web-ICE v3.3 was created. PFAS acute values (typically reported as mg/L) can be greater than those used to develop an ICE model (ICE database toxicity range $1E^{-4}$ to $1E^{8}$ µg/L) such that the input PFAS value of the surrogate would be outside the model domain. In these cases, a user can either enter the value as µg/L and allow the model to extrapolate beyond its range or enter the toxicity as a "scaled" value (i.e., enter and estimate the value as mg/L). The principal assumptions of ICE models are: 1) they represent the relationship of inherent sensitivity between two species, which is conserved across chemicals, mechanisms of action, and ranges of toxicity; and 2) the nature of a contaminant that was tested on the surrogate reflects the nature of the contaminant in the predicted species (e.g., effect concentration (EC_{50}) or lethal concentration (LC_{50}), percentage of active ingredient, technical grade; Raimondo et al. (2010)). While neither of these assumptions are violated by either extrapolating beyond the range of the model or using scaled toxicity data, the uncertainty of using ICE models in either manner had not been thoroughly evaluated. Additionally, since PFAS were not included in the database used to develop web-ICE v3.3, the validation of ICE models to accurately and specifically predict to these compounds has not been previously explored. We address both these topics in the sections below.

L.2.1 Prediction Accuracy of Web-ICE for Scaled Toxicity and Values Beyond the Model Domain

The accuracy of using scaled toxicity data as input into ICE models was evaluated using an analysis with the existing ICE models (v3.3) and as described in detail in Raimondo et al.

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(2024). Briefly, ICE models containing a minimum of 10 datapoints and spanning at least five orders of magnitude were separated into two subsets: 1) a lower subset that contained all paired chemical data corresponding to values below the 75th percentile of surrogate species values; and 2) an upper subset containing paired chemical data above the 75th percentile of surrogate values. The Raimondo et al. (2024) lower subset was used to develop "truncated" ICE models. The surrogate values in the upper subset were converted to mg/L and entered into the truncated ICE model. The predicted mg/L value was compared to the respective value of the measured predicted species. Prediction accuracy was determined as the fold difference (maximum of the predicted/measured and measured/predicted) between the predicted and the measured value, consistent with previously published evaluations of ICE models (Raimondo et al. 2010; Willming et al. 2016). Accuracy of using scaled toxicity as input into ICE models was compared to overall ICE prediction accuracy as previously reported and prediction accuracy of the respective upper subset data points that were entered into the models as µg/L (i.e., values beyond the model domain). A total of 3,104 datapoints from 398 models were evaluated. A match-paired comparison showed that the average fold differences of toxicity values predicted using scaled toxicity was not significantly different than the respective average fold differences of all cross-validated data points reported in Willming et al. (2016) (Wilcoxon paired rank sum test, V = 42741, p-value 0.11). Additionally, Raimondo et al. (2010) and Willming et al. (2016) showed a consistent and reproducible relationship between the taxonomic distance of the predicted and surrogate species, which was also reproduced using scaled values; the percentage of datapoints predicted using scaled toxicity was within 5-fold of the measured value for over 94% of all validated datapoints for species pairs within the same order, with a reduction in accuracy coinciding with decreasing taxonomic relatedness Raimondo et al. (2024). Comparison of scaled

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values with those predicted from µg/L values beyond the model domain showed that predicted values varied by a factor of 10 for models with slopes ranging from 0.66 – 1.33. Toxicity values predicted from models with slopes within this range had a median fold difference of 2.4 using mg/L values and 2.8 using µg/L values (Wilcoxon paired rank sum test, V = 1334749, p-value 0.77). These results and a detailed review of ICE model assumptions are provided in Raimondo et al. (2024)[4].

L.2.2 Direct Comparison of Web-ICE and Measured Toxicity Values

Since limited PFOS toxicity test data are available for estuarine/marine species, the ability of ICE models to predict PFOS toxicity was evaluated using direct comparisons of freshwater species sensitivity as reported in the criteria document and predicted by web-ICE. In this comparison, the measured species mean acute values (SMAVs) for PFOS reported in Appendix A.1 and Appendix B.1 were used as values for surrogate species to predict all possible species that also had a measured PFOS SMAV reported. The available SMAVs for PFOS that could be used as ICE surrogate values along with the number of ICE models (i.e., potential predicted species) corresponding to each surrogate are shown in Table L-1.

[4] Use of scaled toxicity values and the use of surrogate toxicity values beyond the bounds of the ICE model that are input as µg/L are two approaches that both make extrapolations beyond the bounds of the underlying data. Actual predictions resulting from the two approaches from the same ICE model begin to deviate from one another the further the slope of the ICE model deviates from 1.0 (which is a primary reason why scaled toxicity data were only employed on ICE models with slopes ranging from 0.66 – 1.33). Overall, use of the scaled approach compared to direct extrapolation results a negligible change in the final estuarine/marine benchmark, primarily because the three of the four most sensitive estuarine/marine GMAVs were based on direct toxicity test results, and secondarily, because only a subset of ICE models required use of scaled toxicity data to account for predicting beyond the bounds of the underlying ICE model. For example, the final acute PFOS estuarine/marine benchmark was 0.55 mg/L (see section L.2.4). Had the values in Table L-4 been predicted using unscaled data that were input as µg/L only (and the model slope requirement of 0.66 -1.33 been retained), the final acute estuarine/marine benchmark would remain unchanged at 0.55 mg/L. Had the values in Table L-4 been predicted using unscaled data input as µg/L only (and the model slope requirement of 0.66 -1.33 was removed), the final acute estuarine/marine benchmark would increase slightly to 0.57 mg/L. While both approaches contain uncertainty, use of the scaled approach resulted in a more protective acute PFOS estuarine/marine benchmark (i.e., CMC = 0.55 mg/L) than an exploratory benchmark that used acute toxicity data estimated through direct extrapolation, with the model slope requirement of 0.66 -1.33 removed (i.e., exploratory CMC = 0.57 mg/L).

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Table L-1. Surrogate Species Measured Values for PFOS and Corresponding Number of ICE Models for Each Surrogate.

For example, there are 53 species for which *Daphnia magna* can predict toxicity.

Broad Taxon	Species		PFOS SMAV (mg/L)	Number of ICE Models
	Common Name	Scientific		
Amphibian	Bullfrog	*Lithobates catesbeiana* [a]	133.3	9
Amphibian	African clawed frog	*Xenopus laevis*	15.99	2
Crustacean	Mysid	*Americamysis bahia*	4.914	28
Crustacean	Cladoceran	*Daphnia magna*	51.86	53
Fish	Zebrafish	*Danio rerio*	27.86	2 (juvenile models) 6 (embryo models)
Fish	Rainbow trout	*Oncorhynchus mykiss*	7.515	77
Fish	Fathead minnow	*Pimephales promelas*	6.95	74
Mollusc	Fatmucket	*Lampsilis siliquoidea*	16.5	29
Mollusc	Black sandshell	*Ligumia recta*	13.5	1

[a] *Lithobates catesbeianus* was used in web-ICE.

Table L-2 shows direct comparisons for PFOS measured and ICE-predicted values. The regressions for these comparisons are provided in the Appendix L.2.6. Comparisons are limited by the number of measured toxicity values and models available. To be included in this comparison, a measured value was needed for both species in an ICE model pair. For direct comparison of predicted and measured PFOS values, the measured SMAV of the surrogate species is entered into a model for which the measured SMAV for the intended predicted species is also known. The PFOS toxicity predicted by this model is then compared to the measured SMAV for the predicted species as listed in Appendix A.1, Appendix B.1 and Table L-1. This allows both species of an ICE model to serve as either the predicted or surrogate species. The exception to this was in cases involving zebrafish embryos, as web-ICE v3.3 only included models for which zebrafish embryos were used as surrogates. Accuracy of ICE predictions are presented as the "fold-difference" between the measured and the predicted species, such that fold

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difference is the maximum of the ratio of the predicted LC_{50}/measured LC_{50} or measured LC_{50}/predicted LC_{50}. Analyses of ICE prediction accuracy have shown that ICE models over- and under-estimate toxicity values randomly, i.e., there is no systematic bias associated with the models (Table L-2) (Raimondo et al. 2010; Raimondo et al. 2024). For accuracy assessments, the fold difference provides a simplified metric to easily see how close predictions are to measured values at a glance. A 5-fold difference has been demonstrated to be the average interlaboratory variability of acute aquatic toxicity tests and represents a conservative amount of variance under standardized test conditions for a given life stage (Fairbrother 2008; Raimondo et al. 2010). This inter-test variation can increase significantly where experimental variables differ between tests; however, all ICE models are based on standardized life stages to minimize extraneous variability (Raimondo et al. 2010).

These comparisons are consistent with web-ICE user guidance (Raimondo et al. 2015), previously published reports on ICE model accuracy (Raimondo et al. 2010; Willming et al. 2016), and the above presented uncertainty analysis of using scaled toxicity as model input. ICE models predict with acceptable accuracy for PFOS when invertebrates were used to predict to invertebrate species and vertebrates were used to predict to vertebrate species in these comparisons. Models validated across a wide range of species, chemicals, and toxicity values show an acceptable level of prediction accuracy (>90% values predicted within 5-fold of measured value) when adhering to the model guidance listed in Box 1 (Raimondo et al. 2010; Willming et al. 2016).

The results summarized in Sections L.2.1 and L.2.2 demonstrate that the relationship of inherent sensitivity represented by ICE models is preserved across taxa, chemicals, and range of toxicity values when using robust ICE models. While the current analysis uses freshwater species

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to predict to estuarine/marine species, previous model validation and uncertainty analyses did not indicate the habitat of the species to be an influential source of ICE model uncertainty (Raimondo et al. 2010; Willming et al. 2016).

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Table L-2. Comparison of ICE-predicted and measured values of PFOS for species using both scaled values (entered as mg/L) and values potentially beyond the model domain (entered as µg/L).

Measured SMAVs are for the predicted species as listed in Appendix A.1, Appendix B.1 and Table L-1. Footnotes indicate where predictions or models do not meet one or more of the user guidance criteria.

Predicted Species	Surrogate Species	Toxicity Values Potentially Beyond Model Domain				Scaled Toxicity Values			
		Measured SMAV (µg/L)	web-ICE Predicted (µg/L)	95% Confidence Intervals (ug/L)	Fold Difference	Measured SMAV (mg/L)	web-ICE Predicted (mg/L)	Confidence Interval (mg/L)	Fold Difference
Bullfrog (*Lithobates catesbeianus*)	Daphnid (*Daphnia magna*)	133,300	59755.54	12281.24 - 290746.24	2.23	133.3	63.35	7.50 - 534.65	2.1[a]
	Fathead minnow (*Pimephales promelas*)		8356.68	3748.61 - 18629.28	15.95		13.26	4.13 - 42.57	10.05
	Rainbow trout (*Oncorhynchus mykiss*)		15140.53	8139.36 - 28163.81	8.8		33.9	13.63 - 84.26	3.93
African clawed frog (*Xenopus laevis*)	Fathead minnow (*Pimephales promelas*)	15,990	7034.49	800.65 - 61804.35	2.27[a]	15.99	18.93	0.306 - 1170.65	1.18[ab]
Mysid (*Americamysis bahia*)	Daphnid (*Daphnia magna*)	4,914	9221.68	5220.28 - 16290.18	1.88	4.914	28.55	19.59 - 41.60	5.81
	Fathead minnow (*Pimephales promelas*)		359.91	135.34 - 957.15	13.65[c]		0.481	0.104 - 2.21	10.22[c]
	Rainbow trout (*Oncorhynchus mykiss*)		1172.37	702.88 - 1955.47	4.19[c]		2.01	1.08 - 3.75	2.44[c]
Daphnid (*Daphnia magna*)	Bullfrog (*Lithobates catesbeianus*)	51,860	81946.04	17394.84 - 386042.67	1.58	51.86	199.47	32.95 - 1207.24	3.85
	Fathead minnow (*Pimephales promelas*)		1697.85	1149.29 - 2508.22	30.54[c]		3.29	1.36 - 7.96	15.76[c]
	Fatmucket (*Lampsilis siliquoidea*)		23122.84	7634.81 - 70030.01	2.24		7.73	1.46 - 40.85	6.71[b]
	Mysid (*Americamysis bahia*)		6096.75	3829.31 - 9706.79	8.51		21.29	13.73 - 33.02	2.44
	Rainbow trout (*Oncorhynchus mykiss*)		2775.45	2007.74 - 3836.72	18.69[c]		8.83	5.26 - 14.80	5.87[c]
	Zebrafish embryo (*Danio rerio*)		4515.51	1042.06 - 19566.76	11.48[c]		2.85	0.171 - 47.42	18.2[abc]
Rainbow trout (*Oncorhynchus mykiss*)	Bullfrog (*Lithobates catesbeianus*)	7,515	82395.25	38247.48 - 177501.32	10.96	7.515	39.73	16.29 - 96.91	5.29
	Daphnid (*Daphnia magna*)		22196.99	15080.46 - 32671.85	2.95[c]		245.99	182.01 - 332.46	32.73[cd]
	Fathead minnow (*Pimephales promelas*)		2771.13	2136.90 - 3593.60	2.71		3.43	2.01 - 5.85	2.19
	Fatmucket (*Lampsilis siliquoidea*)		48028.61	3264.96 - 706515.68	6.39[ac]		13.14	1.03 - 167.64	1.75[abc]

Predicted Species	Surrogate Species	Toxicity Values Potentially Beyond Model Domain				Scaled Toxicity Values			
		Measured SMAV (µg/L)	web-ICE Predicted (µg/L)	95% Confidence Intervals (ug/L)	Fold Difference	Measured SMAV (mg/L)	web-ICE Predicted (mg/L)	Confidence Interval (mg/L)	Fold Difference
	Mysid (*Americamysis bahia*)		6169.68	3855.10 - 9873.91	1.22		68.63	45.85 - 102.73	9.13[d]
	Zebrafish embryo (*Danio rerio*)		11721	4212.88 - 32610.00	1.56		3.46	0.618 - 19.40	2.17[b]
Fathead minnow (*Pimephales promelas*)	African clawed frog (*Xenopus laevis*)	6,950	16080.14	1020.67 - 253332.73	2.31[a]	6.95	7.89	0.071 - 868.40	1.14[ab]
	Bullfrog (*Lithobates catesbeianus*)		121541.51	44334.20 - 333204.08	17.49		91.08	33.84 - 245.08	13.11
	Daphnid (*Daphnia magna*)		46651.96	30060.61 - 72400.58	6.71[c]		712.85	474.15 - 1071.71	102.57[cd]
	Fatmucket (*Lampsilis siliquoidea*)		116669.9	19477.15 - 698863.06	16.79[c]		595.88	48.52 - 7317.09	85.74[abc]
	Mysid (*Americamysis bahia*)		13672.93	5348.62 - 34952.76	1.97[c]		254.88	118.25 - 549.38	36.67[cd]
	Rainbow trout (*Oncorhynchus mykiss*)		14424.97	11028.30 - 18867.80	2.08		36.58	23.89 - 56.02	5.26
	Zebrafish embryo (*Danio rerio*)		31446.57	17390.46 - 56863.77	4.52		56.87	17.21 - 187.92	8.18[b]
Fatmucket (*Lampsilis siliquoidea*)	Black sandshell (*Ligumia recta*)	16,500	11412.52	2418.09 - 53863.02	1.45	16.5	8.15	0.319 - 208.15	2.02[ab]
	Daphnid (*Daphnia magna*)		23821.82	9341.74 - 60746.62	1.44		138.32	48.08 - 397.96	8.38
	Fathead minnow (*Pimephales promelas*)		717.52	149.82 - 3436.35	23[c]		3.21	0.065 - 158.39	5.14[abc]
	Rainbow trout (*Oncorhynchus mykiss*)		1585.37	485.38 - 5178.24	10.41[c]		44.11	9.18 - 211.95	2.67[cd]
Black sandshell (*Ligumia recta*)	Fatmucket (*Lampsilis siliquoidea*)	13,500	19191.22	4438.79 - 82973.68	1.42	13.5	26.59	1.49 - 472.22	1.97[ab]

[a] Confidence interval >1.5 order magnitude
[b] Input data outside model range
[c] Guidance for model mean square error, R^2, and/or slope not met.
[d] Does not meet slope criteria for using scaled toxicity (0.66-1.33).

L.2.3 Prediction of Estuarine/Marine Species Sensitivity to PFOS

A value of PFOS sensitivity was predicted with web-ICE v3.3 for all possible species using all available surrogate species (Table L-1). Predicted values were obtained by entering all available surrogate species into the web-ICE SSD generator, which predicts to all possible species from all available surrogates simultaneously and exports results into an excel spreadsheet. Web-ICE results were generated using both mg/L and µg/L values to evaluate the full set of possible predictions using both units of measure against the model domain, confidence intervals, and model parameters. First, all available models were evaluated based on the parameter (MSE, R^2, slope) guidance in Box 1, which are the same for an ICE species pair regardless of input value (Table L-3). Models that did not meet the parameter criteria in Box 1 were rejected in this first pass. In the next step, values that were predicted using µg/L were evaluated against the model domain and selected for the next tier of evaluation when the surrogate value was within the range of data used to develop the model. If the surrogate value reported as µg/L was beyond the model domain, the mg/L value was evaluated if it was within the model domain and if the model slope was between 0.66-1.33 (Raimondo et al. 2024). Cases in which both units were outside the model domain were not included quantitatively, but the value with the narrowest confidence intervals was included for qualitative considerations. Values (using either µg/L or mg/L input value) were excluded quantitatively from the SMAVs but retained for qualitative consideration if an evaluation of confidence intervals, model parameters, and the model domain indicated the relationship between surrogate and predicted species was not informed by robust underlying data. At this stage, specific predictions should be based on holistic evaluation of all available information provided by the model, confidence interval, and data used to develop the model. Decisions to exclude a prediction from the SMAV are clarified

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in footnotes. Because the sensitivity of a single species can be predicted by multiple surrogates, we calculated the SMAV where multiple robust models were available for a predicted species. Each predicted species was then assigned to the appropriate saltwater MDRs as defined in the 1985 *Guidelines.*

Saltwater MDRs:

a. Family in the phylum Chordata
b. Family in the phylum Chordata
c. Either the Mysidae or Penaeidae family
d. Family in a phylum other than Arthropoda or Chordata
e. Family in a phylum other than Chordata
f. Family in a phylum other than Chordata
g. Family in a phylum other than Chordata
h. Any other family

The acute sensitivity of estuarine/marine species to PFOS is presented in Table L-4. A total of 36 models representing 19 estuarine/marine species were available in web-ICE to predict the toxicity of PFOS to saltwater species (Table L-3). Of these, 12 models were initially rejected based on model parameters not meeting the guidance in Box 1, reducing the number of predicted species to 17 represented by 24 models. Further evaluation of ICE predictions resulted in 12 SMAVs. The range of sensitivity for the predicted taxa is consistent with the range of sensitivity of freshwater species for this compound.

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Table L-3. All ICE Models Available in web-ICE v3.3 for Saltwater Predicted Species Based on Surrogates with Measured PFOS.

Model parameters are used to evaluate prediction robustness. Cross-validation success is the percentage of all model data that were predicted within 5-fold of the measured value through leave-one-out cross-validation (Willming et al. 2016). Taxonomic distance describes the relationship between surrogate and predicted species (e.g., 1 = shared genus, 2 = shared family, 3 = shared order, 4 = shared class, 5 = shared phylum, 6 = shared kingdom).

Predicted Species	Surrogate Species	Slope	Intercept	Degrees of Freedom (N-2)	R^2	p-value	Mean Square Error (MSE)	Surrogate Model Minimum Value (µg/L)	Surrogate Model Maximum Value (µg/L)	Cross-Validation Success (%)	Taxonomic Distance	Use in Criteria
Acartia tonsa	*Daphnia magna*	0.59	1.31	2	0.91	0.0443	0.17	2.24	38514.70	50	5	Rejected
Allorchestes compressa	*Daphnia magna*	0.83	1.59	3	0.8	0.039	0.12	5.00	184.54	100	5	Accepted
Allorchestes compressa	*Pimephales promelas*	0.84	0.15	3	0.96	0.0028	0.02	163.05	26895.72	100	6	Accepted
Americamysis bahia	*Daphnia magna*	0.83	0.02	160	0.68	<0.001	0.93	0.07	840000.00	64	5	Accepted
Americamysis bahia	*Oncorhynchus mykiss*	0.92	-0.5	150	0.6	<0.001	1.08	0.06	1100000.00	57	6	Rejected
Americamysis bahia	*Pimephales promelas*	0.95	-1.12	46	0.55	<0.001	1.75	2.27	70200000.00	35	6	Rejected
Chelon labrosus	*Lampsilis siliquoidea*	1.27	1.5	1	0.99	0.0403	0	19.01	281.00	NA	6	Accepted qualitatively
Chelon macrolepis	*Pimephales promelas*	1.51	-1.04	2	0.97	0.0114	0.05	26.00	2533.38	100	4	Accepted qualitatively
Crassostrea virginica	*Americamysis bahia*	0.44	1.76	114	0.34	<0.001	0.88	0.003	117648.20	55	6	Rejected
Crassostrea virginica	*Daphnia magna*	0.44	1.54	116	0.28	<0.001	1.08	0.08	137171.43	58	6	Rejected
Crassostrea virginica	*Lampsilis siliquoidea*	0.82	-0.28	3	0.95	0.0041	0.06	30.00	22000.00	100	4	Accepted
Crassostrea virginica	*Oncorhynchus mykiss*	0.59	0.97	120	0.5	<0.001	0.68	0.02	570000.00	68	6	Rejected
Crassostrea virginica	*Pimephales promelas*	0.75	0.44	24	0.61	<0.001	0.68	1.24	206300.75	69	6	Accepted
Cyprinodon bovinus	*Oncorhynchus mykiss*	0.72	0.8	2	0.91	0.0427	0.08	4.93	1637.92	100	4	Accepted qualitatively
Cyprinodon bovinus	*Pimephales promelas*	0.67	0.65	2	0.99	0.0043	0	10.49	7847.42	100	4	Accepted
Cyprinodon variegatus	*Americamysis bahia*	0.57	1.88	88	0.56	<0.001	0.67	0.003	182000.00	64	6	Rejected
Cyprinodon variegatus	*Daphnia magna*	0.53	1.79	84	0.49	<0.001	0.72	0.08	304000.00	64	6	Rejected
Cyprinodon variegatus	*Lampsilis siliquoidea*	0.72	0.76	1	0.99	0.0392	0	30.00	22000.00	NA	6	Accepted qualitatively
Cyprinodon variegatus	*Oncorhynchus mykiss*	0.75	0.9	87	0.65	<0.001	0.56	0.82	12700000.00	75	4	Accepted
Cyprinodon variegatus	*Pimephales promelas*	0.69	0.98	24	0.74	<0.001	0.43	2.27	16500000.00	77	4	Accepted
Farfantepenaeus duorarum	*Americamysis bahia*	1.03	0.06	6	0.81	0.0022	0.55	0.01	720.00	50	4	Accepted
Farfantepenaeus duorarum	*Daphnia magna*	1.08	0.14	16	0.76	<0.001	1.32	0.04	65686.02	44	5	Rejected
Farfantepenaeus duorarum	*Oncorhynchus mykiss*	1.2	-1.36	15	0.72	<0.001	1.54	0.57	221000.00	47	6	Rejected
Fenneropenaeus merguiensis	*Daphnia magna*	0.82	1.43	4	0.66	0.0473	0.4	5.00	1251.41	67	5	Accepted
Gasterosteus aculeatus	*Oncorhynchus mykiss*	1.05	0.29	4	0.9	0.0038	0.18	0.61	890.00	83	4	Accepted
Hydroides elegans	*Daphnia magna*	0.49	1.59	2	0.96	0.0182	0.01	5.00	1251.41	100	6	Rejected
Hydroides elegans	*Oncorhynchus mykiss*	0.2	2.3	1	0.99	0.0179	0	1.84	13390.93	NA	6	Rejected
Litopenaeus stylirostris	*Americamysis bahia*	1.04	0.01	5	0.6	0.0401	0.29	0.58	24.09	57	4	Accepted
Menidia menidia	*Oncorhynchus mykiss*	1.28	-1.4	3	0.94	0.005	0.23	11.24	91000.00	60	4	Accepted qualitatively
Menidia peninsulae	*Americamysis bahia*	0.63	0.91	3	0.88	0.0162	0.32	0.01	1160.00	80	6	Accepted qualitatively
Menidia peninsulae	*Oncorhynchus mykiss*	1.01	-0.36	2	0.91	0.0421	0.35	0.82	1600.00	50	4	Accepted qualitatively

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Predicted Species	Surrogate Species	Slope	Intercept	Degrees of Freedom (N-2)	R^2	p-value	Mean Square Error (MSE)	Surrogate Model Minimum Value (µg/L)	Surrogate Model Maximum Value (µg/L)	Cross-Validation Success (%)	Taxonomic Distance	Use in Criteria
Metamysidopsis insularis	*Daphnia magna*	0.86	0.93	3	0.94	0.0057	0.18	6.97	317472.74	80	5	Accepted
Metamysidopsis insularis	*Lampsilis siliquoidea*	1.03	0.62	2	0.99	0.0027	0.02	19.01	87705.88	75	6	Accepted
Mugil cephalus	*Oncorhynchus mykiss*	1.44	-0.37	3	0.89	0.0144	0.12	0.82	29.18	100	4	Accepted qualitatively
Tigriopus japonicus	*Pimephales promelas*	0.81	1.12	5	0.76	0.0103	0.11	195.14	27000.00	86	6	Accepted
Tisbe battagliai	*Daphnia magna*	0.86	1.25	2	0.94	0.0289	0.08	0.61	184.54	100	5	Accepted

NA = Not Available.

Table L-4. ICE-Estimated Species Sensitivity to PFOS.

Values in bold and underlined are used for SMAV.

Common Name	Scientific	Surrogate	Input Unit	Estimated Toxicity (mg/L)	95% Confidence Intervals (mg/L)	SMAV
Calanoid copepod	*Acartia tonsa*	*Daphnia magna*	µg/L	13.12[abc]	(0.66 - 259.64)	NA
Amphipod	*Allorchestes compressa*	*Daphnia magna*	mg/L	**1072.28**	(323.49 - 3554.23)	50.94
		Pimephales promelas	µg/L	**2.42**	(1.29 - 4.54)	
Mysid	*Americamysis bahia*	*Daphnia magna*	µg/L	**9.22**	(5.22 - 16.29)	9.22
		Oncorhynchus mykiss	µg/L	1.17[c]	(0.7 - 1.96)	
		Pimephales promelas	µg/L	0.36[c]	(0.14 - 0.96)	
Thicklip mullet	*Chelon labrosus*	*Lampsilis siliquoidea*	mg/L	1144.93[ab]	(126.12 - 10393.7)	NA
Bigscale mullet	*Chelon macrolepis*	*Pimephales promelas*	µg/L	61.79[ab]	(4.94 - 772.16)	NA
Eastern oyster	*Crassostrea virginica*	*Americamysis bahia*	µg/L	2.52[c]	(1.45 - 4.37)	1.89
		Daphnia magna	µg/L	4.31[c]	(2.02 - 9.2)	
		Lampsilis siliquoidea	µg/L	**1.56**	(0.44 - 5.55)	
		Oncorhynchus mykiss	µg/L	2.01[c]	(1.3 - 3.1)	
		Pimephales promelas	µg/L	**2.28**	(0.78 - 6.67)	
Leon springs pupfish	*Cyprinodon bovinus*	*Oncorhynchus mykiss*	mg/L	27.57[a]	(3.2 - 236.94)	1.82
		Pimephales promelas	µg/L	**1.82**	(0.78 - 4.24)	
Sheepshead minnow	*Cyprinodon variegatus*	*Americamysis bahia*	µg/L	9.87[c]	(5.58 - 17.46)	5.77
		Daphnia magna	µg/L	20.32[c]	(9.75 - 42.39)	
		Lampsilis siliquoidea	µg/L	6.76[a]	(0.56 - 81.92)	
		Oncorhynchus mykiss	µg/L	**7.08**	(4.53 - 11.06)	
		Pimephales promelas	µg/L	**4.7**	(2.32 - 9.52)	
Pink shrimp	*Farfantepenaeus duorarum*	*Americamysis bahia*	mg/L	**6.02**	(1.34 - 26.97)	6.02
		Daphnia magna	µg/L	173.22[ac]	(14.83 - 2023.16)	
		Oncorhynchus mykiss	µg/L	2.12[c]	(0.38 - 11.71)	
Banana prawn	*Fenneropenaeus merguiensis*	*Daphnia magna*	mg/L	**722.81**	(131.83 - 3963)	722.81
Threespine stickleback	*Gasterosteus aculeatus*	*Oncorhynchus mykiss*	mg/L	**16.46**	(5.22 - 51.84)	16.46
Polychaete	*Hydroides elegans*	*Daphnia magna*	µg/L	8.45[bc]	(1.31 - 54.56)	NA
		Oncorhynchus mykiss	µg/L	1.28[c]	(0.89 - 1.83)	
Blue shrimp	*Litopenaeus stylirostris*	*Americamysis bahia*	mg/L	**5.41**	(1.59 - 18.41)	5.41
Atlantic silverside	*Menidia menidia*	*Oncorhynchus mykiss*	µg/L	3.97[a]	(0.52 - 30.32)	NA
Tidewater silverside	*Menidia peninsulae*	*Americamysis bahia*	mg/L	22.65[d]	(3.47 - 147.72)	NA

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Common Name	Scientific	Surrogate	Input Unit	Estimated Toxicity (mg/L)	95% Confidence Intervals (mg/L)	SMAV
		Oncorhynchus mykiss	mg/L	3.35[a]	(0.1 - 118.6)	
Mysid	*Metamysidopsis insularis*	*Daphnia magna*	mg/L	**258.03**	(48.24 - 1380.1)	156.17
		Lampsilis siliquoidea	µg/L	**94.52**	(27.87 - 320.53)	
Striped mullet	*Mugil cephalus*	*Oncorhynchus mykiss*	mg/L	7.66[d]	(2.17 - 27.01)	NA
Harpacticoid copepod	*Tigriopus japonicus*	*Pimephales promelas*	µg/L	**18.04**	(7.2 - 45.24)	18.04
Harpacticoid copepod	*Tisbe battagliai*	*Daphnia magna*	mg/L	**550.44**	(107.35 - 2822.37)	550.44

NA = Not Available

[a] Both confidence intervals >1.5 order magnitude

[b] Input data outside model range

[c] Guidance for model mean square error, R^2, and/or slope not met

[d] Does not meet slope criteria for using scaled toxicity (0.66-1.33)

L.2.4 Derivation of Acute Water Quality Benchmark for Estuarine/Marine Water

The web-ICE predicted acute dataset for PFOS contains 15 genera, representing the eight MDR groups that would be necessary for developing an estuarine/marine criterion. The EPA fulfilled these eight MDRs by integrating the acceptable quantitative study data (discussed in Section 3.1.1.2) with data derived using web-ICE to support calculating a protective benchmark. In scenarios where both empirical LC_{50} values and estimated LC_{50} values were available for the same species, only the empirical data were used to derive the species mean acute value. The ranked GMAVs for these combined data along with the MDR met by each GMAV is summarized in Table L-5. From this dataset, an acute benchmark was calculated using procedures consistent with the 1985 Guidelines and with those used for the derivation of freshwater criteria values for PFOS. GMAVs for the four most sensitive genera were within a factor of 1.7 of each other (Table L-6). The estuarine/marine FAV (the 5^{th} percentile of the genus sensitivity distribution) for PFOS is 1.096 mg/L (Table L-6). The FAV is lower than all of the GMAVs for both the tested species and for values derived using web-ICE. The FAV was then divided by two to obtain a concentration yielding a minimal effects acute benchmark. The FAV/2, which is the estuarine/marine acute water column benchmark magnitude, is 0.55 mg/L PFOS (rounded to two significant figures) and is expected to be protective of 95% of estuarine/marine genera potentially exposed to PFOS under short-term conditions of one-hour of duration, if the one-hour average magnitude is not exceeded more than once in three years (Figure L-2). This acute benchmark for estuarine/marine aquatic life is greater than the recommended acute freshwater criterion (0.071 mg/L), suggesting that estuarine/marine species may be less acutely sensitive to PFOS and emphasizing the importance of having a separate benchmark value for the protection of estuarine/marine aquatic life.

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Table L-5. Ranked Estuarine/Marine Genus Mean Acute Values.

Values in bold were derived from empirical toxicity tests with the species.

MDR Group	Name	Species (lifestage)	SMAV	GMAV	Rank	Percentile
D	**Mediterranean mussel**	***Mytilus galloprovincialis***	**1.1**	**1.1**	1	0.06
F	**Purple sea urchin**	***Strongylocentrotus purpuratus***	**1.7**	**1.7**	2	0.13
E	**Sea urchin**	***Paracentrotus lividus***	**1.795**	**1.795**	3	0.19
D	Eastern oyster	*Crassostrea virginica*	1.89	1.89	4	0.25
C	**Mysid**	***Americamysis bahia***	**4.914**	**4.914**	5	0.31
A	Leon springs pupfish	*Cyprinodon bovinus*	1.82	**5.225**	6	0.38
	Sheepshead minnow	***Cyprinodon variegatus***	**>15**			
F	Blue shrimp	*Litopenaeus stylirostris*	5.41	5.41	7	0.44
F	Pink shrimp	*Farfantepenaeus duorarum*	6.02	6.02	8	0.50
C	**Mysid**	***Siriella armata***	**6.9**	**6.9**	9	0.56
B	Threespine stickleback	*Gasterosteus aculeatus*	16.46	16.46	10	0.63
G	Harpacticoid copepod	*Tigriopus japonicus*	18.04	18.04	11	0.69
E	Amphipod	*Allorchestes compressa*	50.94	50.94	12	0.75
C	Mysid	*Metamysidopsis insularis*	156.2	156.2	13	0.81
H	Harpacticoid copepod	*Tisbe battagliai*	550.4	550.4	14	0.88
F	Banana prawn	*Fenneropenaeus merguiensis*	722.8	722.8	15	0.94

MDR Groups

a. Family in the phylum Chordata
b. Family in the phylum Chordata
c. Either the Mysidae or Panaeidae family
d. Family in a phylum other than Arthropoda or Chordata
e. Family in a phylum other than Chordata
f. Family in a phylum other than Chordata
g. Family in a phylum other than Chordata
h. Any other family

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Table L-6. Estuarine/Marine Final Acute Value and Protective Aquatic Acute Benchmark.
Bold values represent genera for which empirical toxicity data were available.

Calculated Estuarine/Marine FAV based on 4 lowest values; n=15						
Rank	**Genus**	**GMAV (mg/L)**	**ln(GMAV)**	**ln(GMAV)^2**	**P=R/(N+1)**	**sqrt(P)**
1	***Mytilus***	1.1	0.10	0.01	0.063	0.250
2	***Strongylocentrotus***	1.7	0.53	0.28	0.125	0.354
3	***Paracentrotus***	1.795	0.59	0.34	0.188	0.433
4	*Crassostrea*	1.89	0.64	0.41	0.250	0.500
		Σ (Sum):	**1.85**	**1.04**	**0.63**	**1.54**

S^2 =	5.32	S = slope
L =	-0.424	L = X-axis intercept
A =	0.092	A = lnFAV
FAV =	1.096	P = cumulative probability
PVAL=	**0.55 mg/L PFOS** (rounded to two significant figures)	

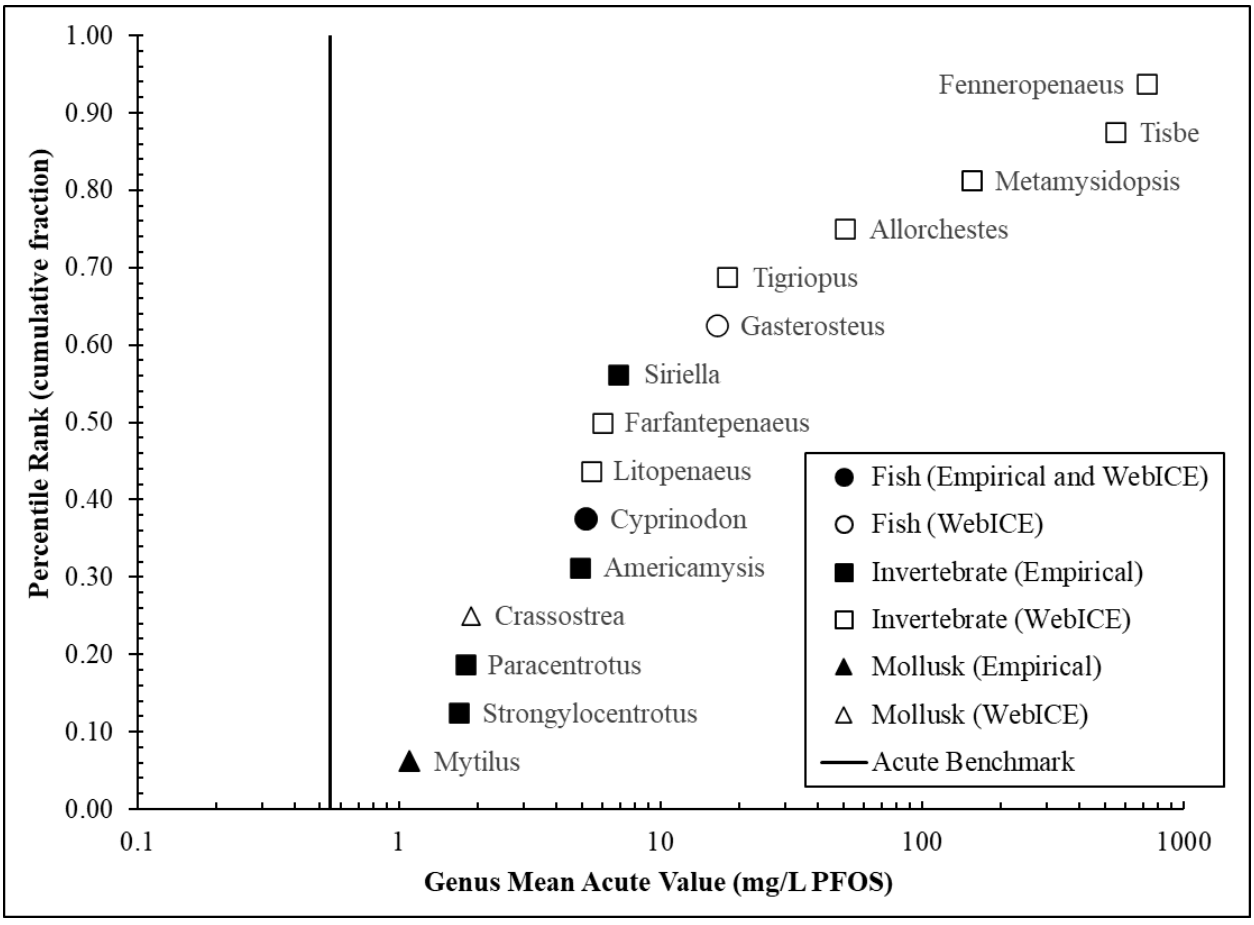


Figure L-2. Ranked Estuarine/Marine Acute PFOS GMAVs used for the Aquatic Life Acute Benchmark Calculation.

L.2.5 Estuarine Marine/Benchmark Uncertainty

Epistemic uncertainty of individual ICE estimates used for SMAV calculation was quantified through the calculation of corresponding 95% confidence intervals for each ICE estimate. Of the individual models and resultant ICE-estimated LC_{50} values estimates from the available and quantitatively acceptable models (see bolded and underlined values in Table L-4; n =16), the range of individual 95% CIs (i.e., 95% CI range = upper 95% CI – lower 95% CI) as a percent of the corresponding LC_{50} estimate (i.e., = [95% CI range/LC50 estimate]*100) ranged from 92.23% to 530.04%. The ICE model with the lowest 95% CI range relative to the LC_{50} estimate (i.e., 92.23%) employed *Oncorhynchus mykiss* as the predictor species and *Cyprinodon variegatus* as the predicted species. The ICE model with the largest 95% CI range relative to the LC_{50} estimate (i.e., 530.04%) employed *Daphnia magna* as the predictor species and *Fenneropenaeus merguiensis* as the predicted species. Fifteen of the 16 ICE-predicted values in Table L-4 that were used for SMAV calculation had 95% CI ranges that were greater than the corresponding LC_{50} estimate (i.e., 95% CI range was >100% of the LC_{50} estimate). The relatively wide ranging 95% CIs demonstrate the underlying uncertainty in the PFOS estuarine/marine benchmark.

Six of the 15 GMAVs used to derive the acute PFOS estuarine/marine benchmark were based on empirical toxicity tests. The six GMAVs based on empirical data were not evenly distributed across the GSD, with all empirical data falling below the 60^{th} percentile of sensitivity (Table L-2). Also, three of the four most sensitive GMAVs in the GSD (Figure L-2) were based on empirical data and five of the six most sensitive GMAVs were based empirical acute values, meaning final estuarine/benchmark magnitude was primarily based on relatively certain empirical toxicity tests and the inherent uncertainty in the ICE models had little influence on the final acute estuarine/marine benchmark magnitude.

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The estuarine/marine benchmark appears adequately protective based on the available high quality empirical data (Appendix B.1). The acute PFOS estuarine/marine benchmark (i.e., 0.55 mg/L) is two times lower than the lowest GMAV (i.e., 1.1 mg/L), which was based on empirical data for *Mytilus*. The EPA further evaluated the appropriateness of the estuarine/marine benchmark by comparing it to empirical, but qualitatively acceptable, data for estuarine/marine species. The EPA specifically focused on qualitatively-acceptable estuarine/marine tests reported in Table H.1 that: (1) tested an animal species; (2) exposed test organisms to PFOS for a continuous exposure duration that was reasonably similar to standard acute exposures (e.g., 48 hours to seven days); (3) reported acute apical effects; and (4) reported effect concentrations that were lower than the acute estuarine/marine benchmark final acute value (i.e., 1.096 mg/L). The EPA identified three individual tests in Table H.1 as meeting the previous criteria:

1. Park et al. (2015) conducted a seven-day test with the mud crab, *Macrophthalmus japonicus*. Exposures lasted seven days, but survival was also recorded at 96 hours. The authors did not calculate an LC_{50}, but at 96 hours there was 36% mortality in the highest test concentration (i.e., 0.03 mg/L). Therefore, the 96-hour LC_{50} was >0.03 mg/L. The test was not used quantitatively because an LC_{50} could not be calculated based on the three exposure concentrations used. Overall, 36% mortality after 96 hours in the 0.03 mg/L treatment suggests this species may be sensitive to acute PFOS exposures relative to the acute estuarine/marine benchmark. However, the source of the organisms (fish market) could be problematic as there is no mention of potential previous exposure or measures of PFOS in test organisms at any point during the experiment.

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2. Mhadhbi et al. (2012) conducted a 6-day test with the turbot, *Schophthalmus maximus*. Endpoints included dead embryos, malformation, hatch success at 48 hours and larval survival (missing heartbeat and a non-detached tail) at six days. The 6-day LC_{50} of 0.11 mg/L PFOS was not acceptable for acute benchmark derivation because of the relatively long exposure duration. Nevertheless, the 6-day LC_{50} is nearly an order of magnitude lower than the acute estuarine/marine benchmark final acute value (i.e., 1.096 mg/L) and five times lower than the acute estuarine/marine benchmark, suggesting *S. maximus* is sensitive to acute PFOS exposures at concentrations below the acute estuarine/marine benchmark.
3. Jeon et al. (2010) performed a 6-day test on blackrock fish, *Sebastes schlegeli*. There were no significant differences in total length, weight and survival (no mortality observed in any of the exposures) over the 6 - day exposure. The NOEC (survival and growth) was 1 mg/L at each test salinity (10, 17.5, 25 and 34 ppt), which is less than the acute estuarine/marine benchmark final acute value (i.e., 1.096 mg/L). The lack of effects observed at 1.0 mg/L preclude this test from providing meaningful information about the protectiveness of the acute estuarine/marine benchmark.

Results from Mhadhbi et al. (2012), which was determined to only be acceptable for qualitative use, suggests *S. maximus* is sensitive to acute PFOS exposures at concentrations below the acute estuarine/marine benchmark, but at an exposure duration that was 50% longer than the standard 96- hour exposure duration from quantitatively acceptable tests. Additionally, results of quantitatively acceptable empirical toxicity studies with estuarine/marine organisms do not provide any evidence that the aquatic estuarine/marine community will experience unacceptable acute effects at the acute estuarine/marine PFOS benchmark.

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L.2.6 ICE Regressions Supporting the Acute Estuarine/Marine Benchmark

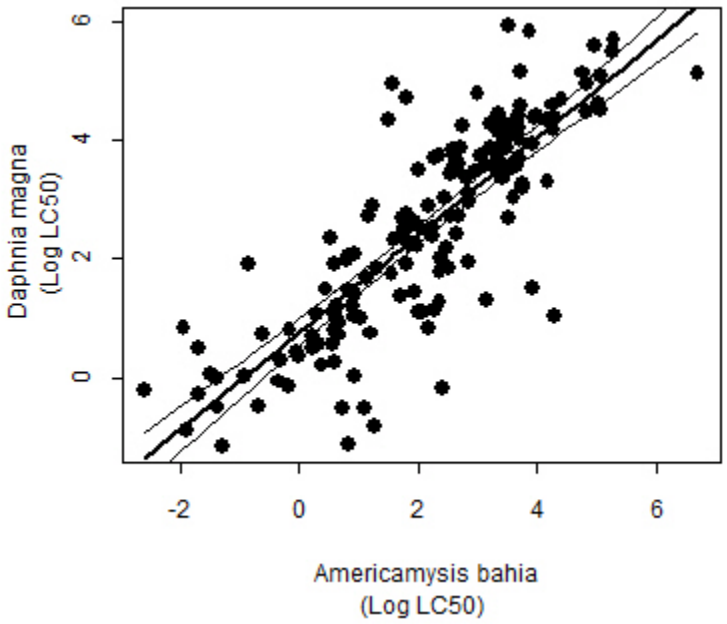


Figure L-3. *Americamysis bahia* (X-axis) and *Daphnia magna* (Y-axis) regression model used for ICE predicted values.

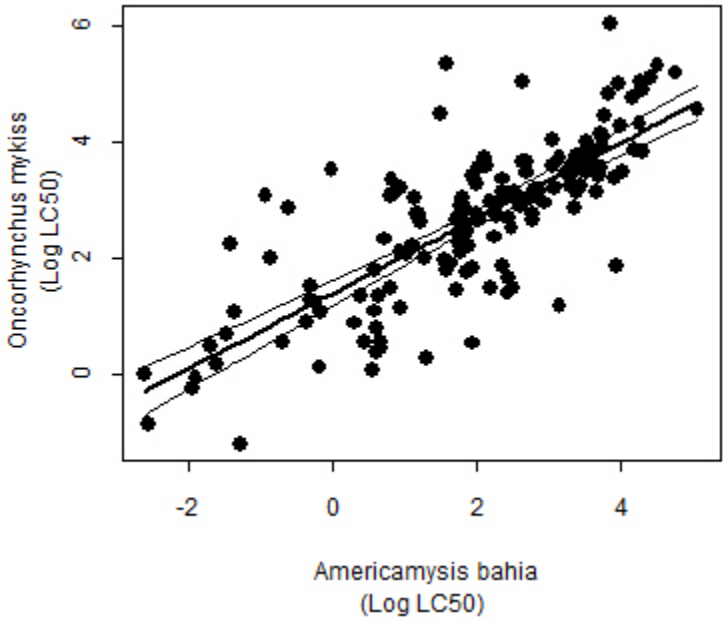


Figure L-4. *Americamysis bahia* (X-axis) and *Oncorhynchus mykiss* (Y-axis) regression model used for ICE predicted values.

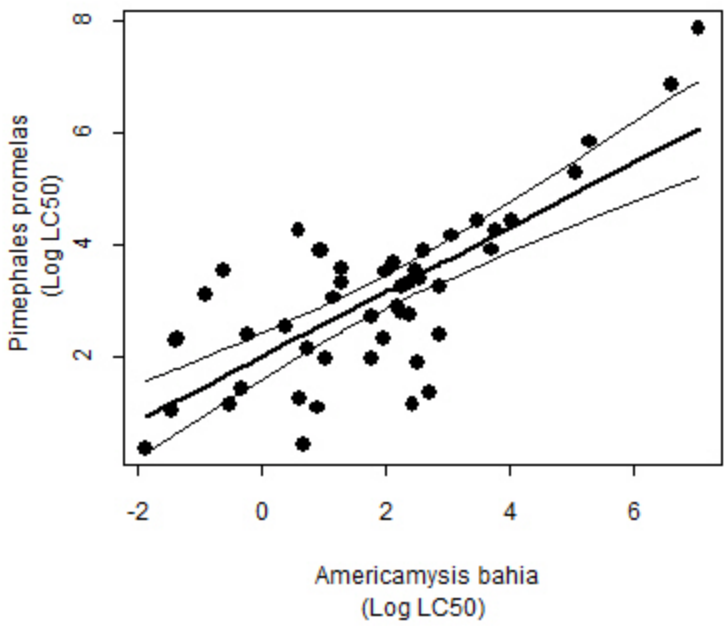


Figure L-5. ***Americamysis bahia*** **(X-axis) and** ***Pimephales promelas*** **(Y-axis) regression model used for ICE predicted values.**

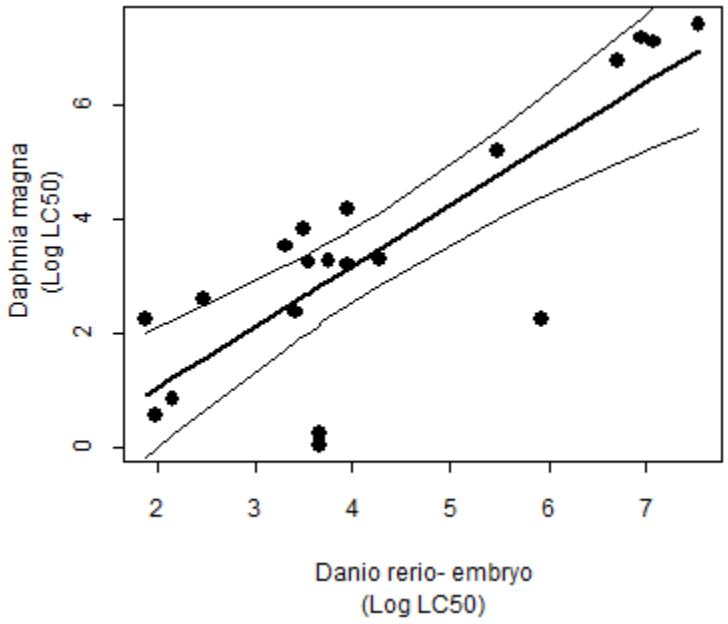


Figure L-6. ***Danio rerio*** **-embryo (X-axis) and** ***Daphnia magna*** **(Y-axis) regression model used for ICE predicted values.**

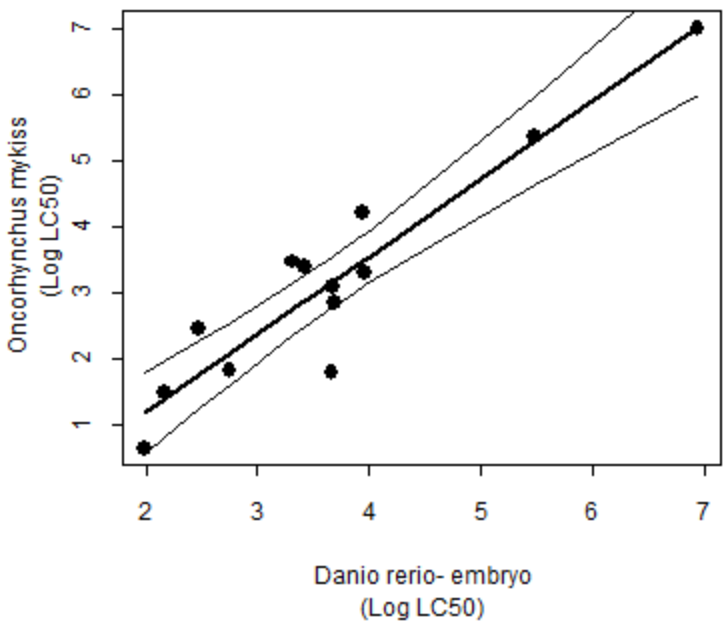


Figure L-7. *Danio rerio* - embryo (X-axis) and *Oncorhynchus mykiss* (Y-axis) regression model used for ICE predicted values.

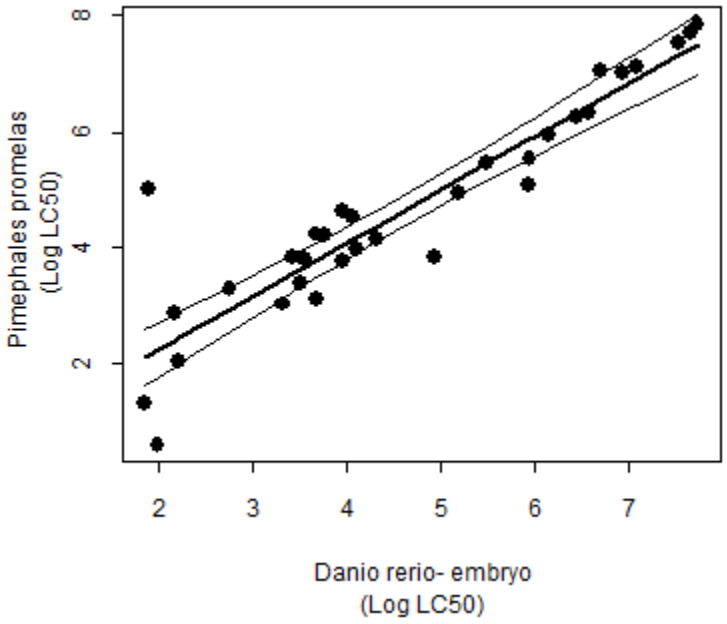


Figure L-8. *Danio rerio* - embryo (X-axis) and *Pimephales promelas* (Y-axis) regression model used for ICE predicted values.

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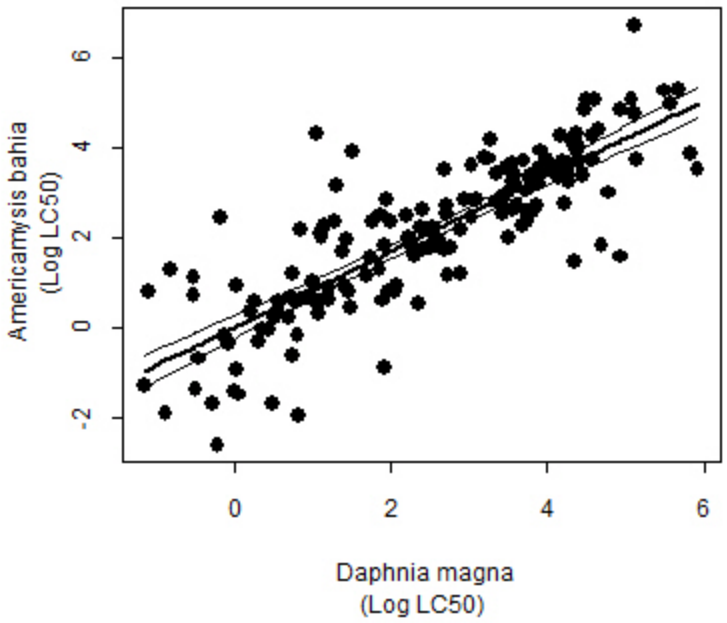


Figure L-9. *Daphnia magna* (X-axis) and *Americamysis bahia* (Y-axis) regression model used for ICE predicted values.

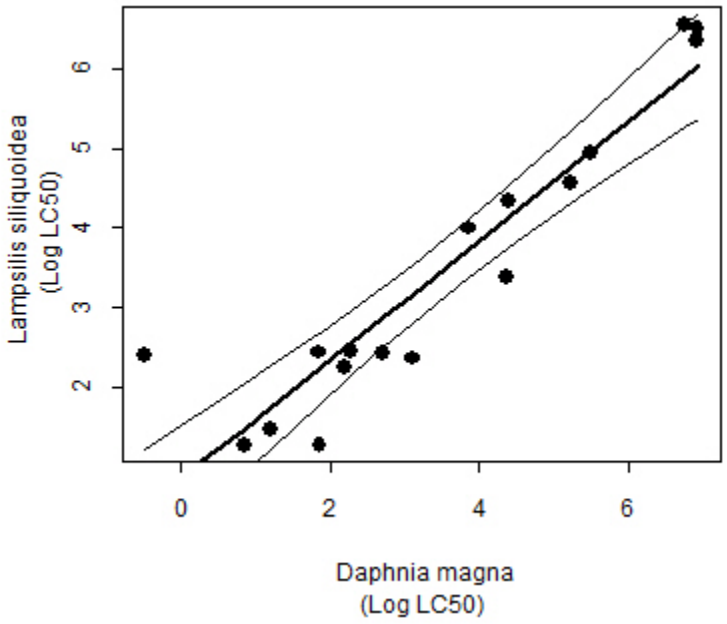


Figure L-10. *Daphnia magna* (X-axis) and *Lampsilis siliquoidea* (Y-axis) regression model used for ICE predicted values.

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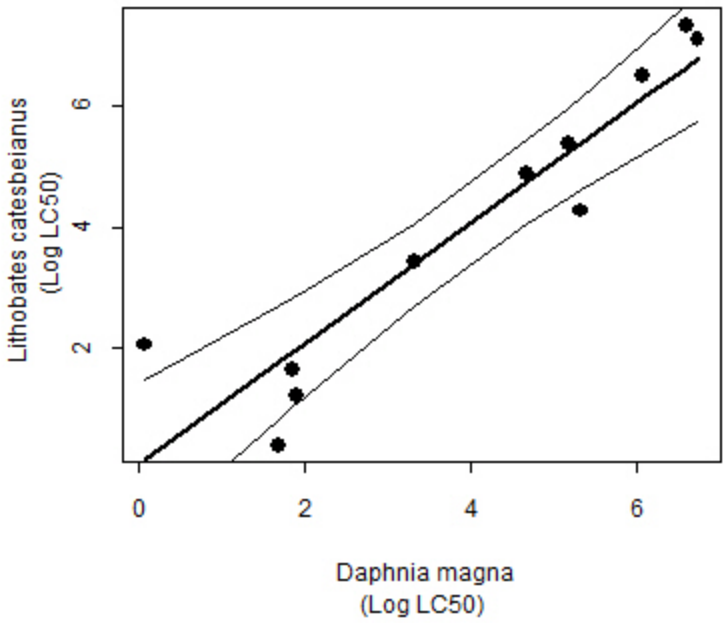


Figure L-11. *Daphnia magna* (X-axis) and *Lithobates catesbeianus* (Y-axis) regression model used for ICE predicted values.

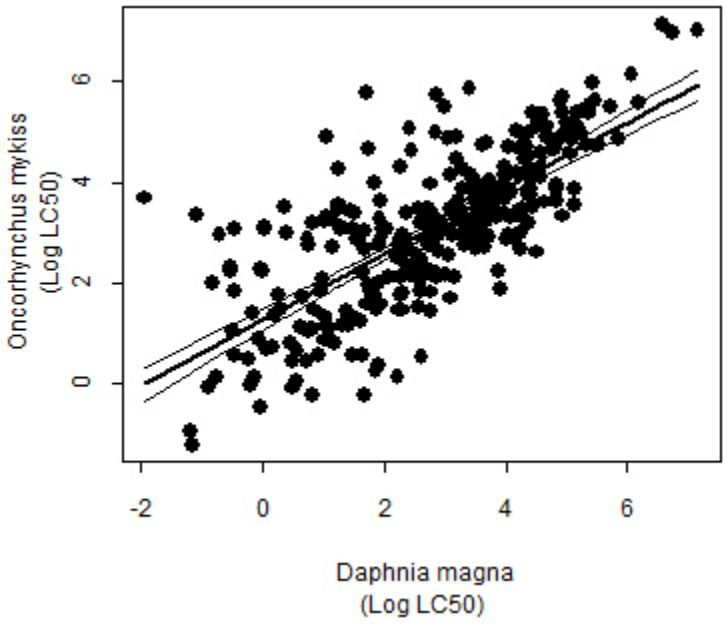


Figure L-12. *Daphnia magna* (X-axis) and *Oncorhynchus mykiss* (Y-axis) regression model used for ICE predicted values.

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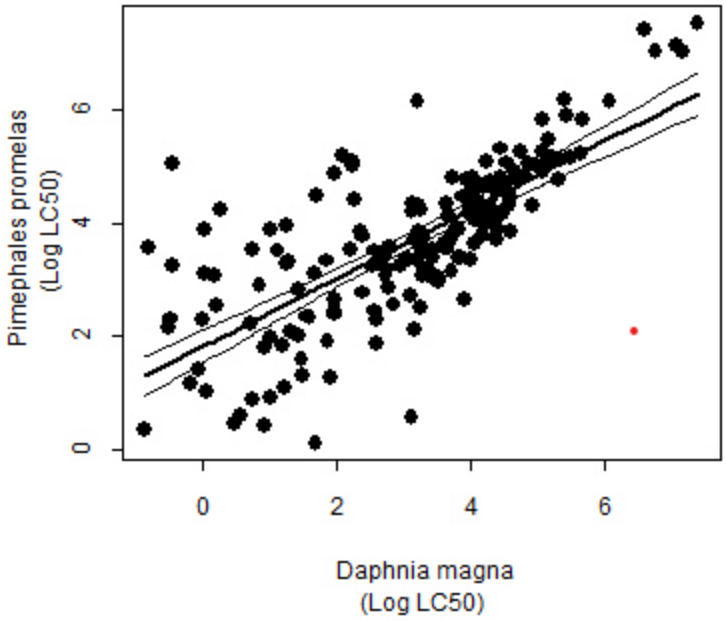


Figure L-13. *Daphnia magna* (X-axis) and *Pimephales promelas* (Y-axis) regression model used for ICE predicted values.

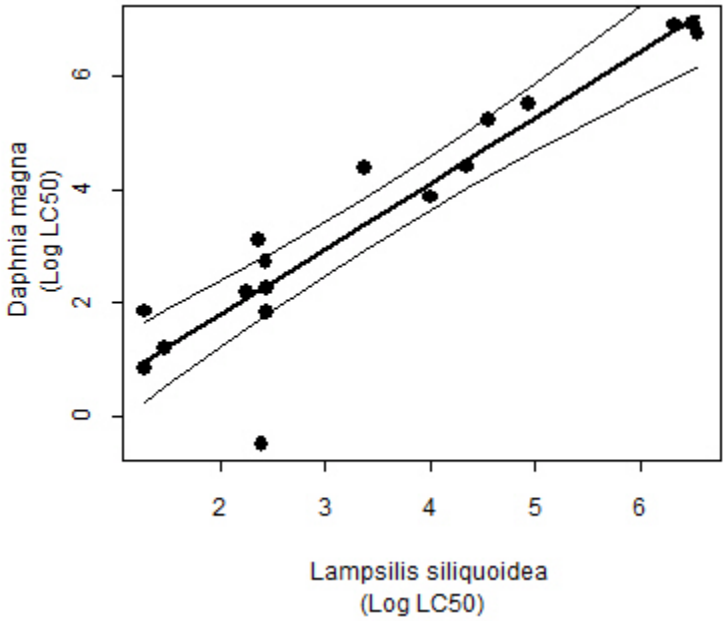


Figure L-14. *Lampsilis siliquoidea* (X-axis) and *Daphnia magna* (Y-axis) regression model used for ICE predicted values.

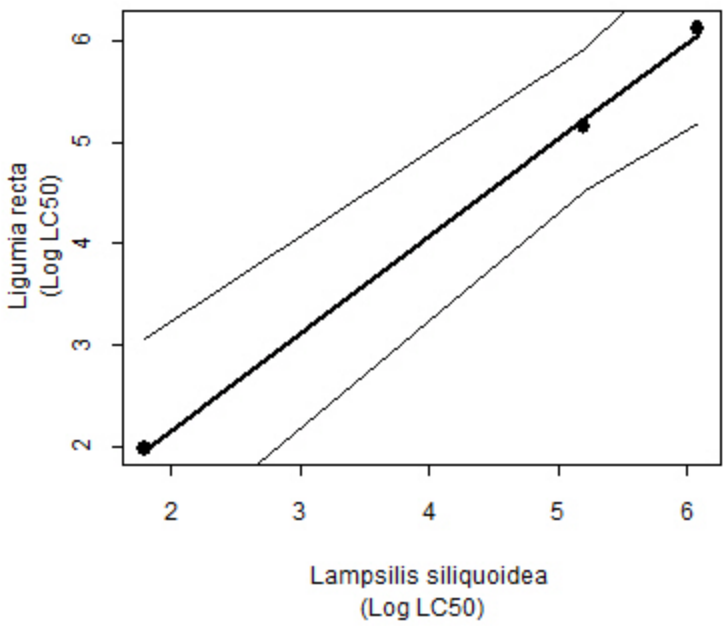


Figure L-15. *Lampsilis siliquoidea* (X-axis) and *Ligumia recta* (Y-axis) regression model used for ICE predicted values.

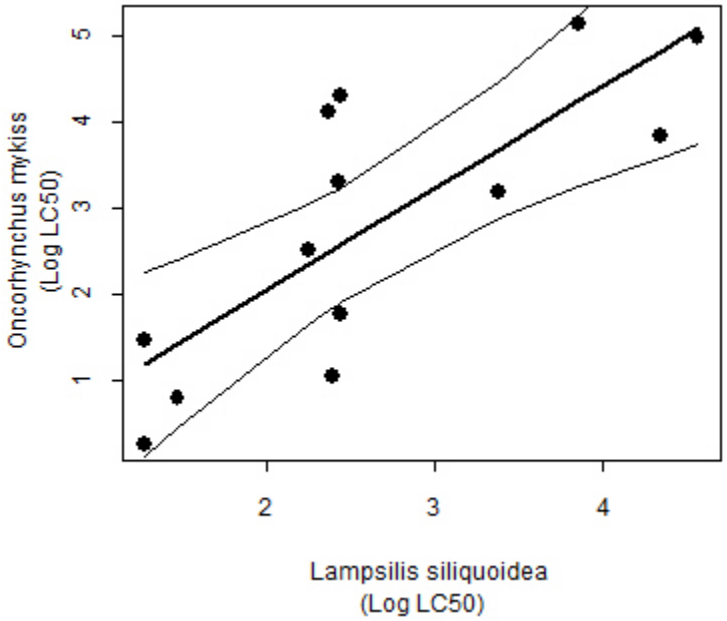


Figure L-16. *Lampsilis siliquoidea* (X-axis) and *Oncorhynchus mykiss* (Y-axis) regression model used for ICE predicted values.

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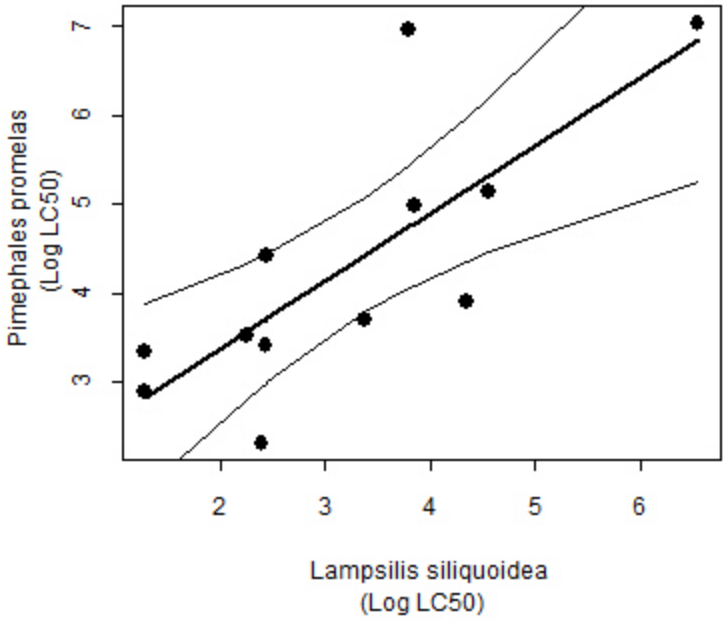


Figure L-17. *Lampsilis siliquoidea* (X-axis) and *Pimephales promelas* (Y-axis) regression model used for ICE predicted values.

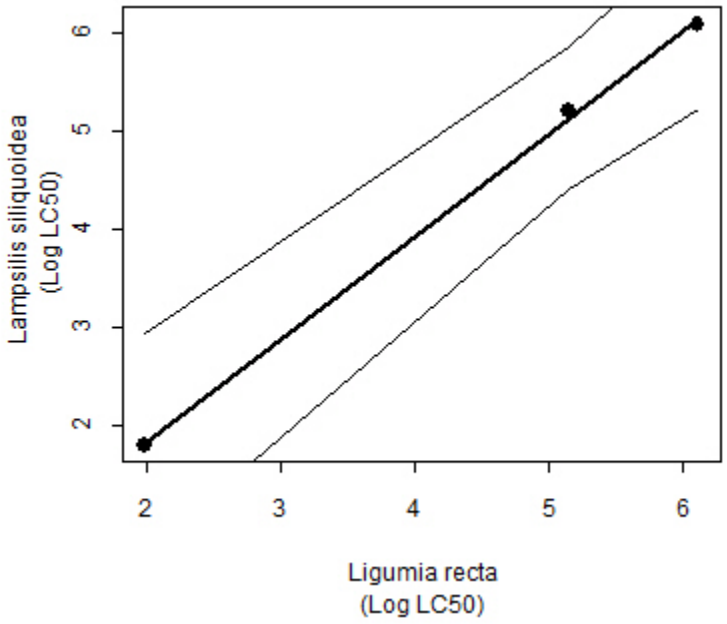


Figure L-18. *Ligumia recta* (X-axis) and *Lampsilis siliquoidea* (Y-axis) regression model used for ICE predicted values.

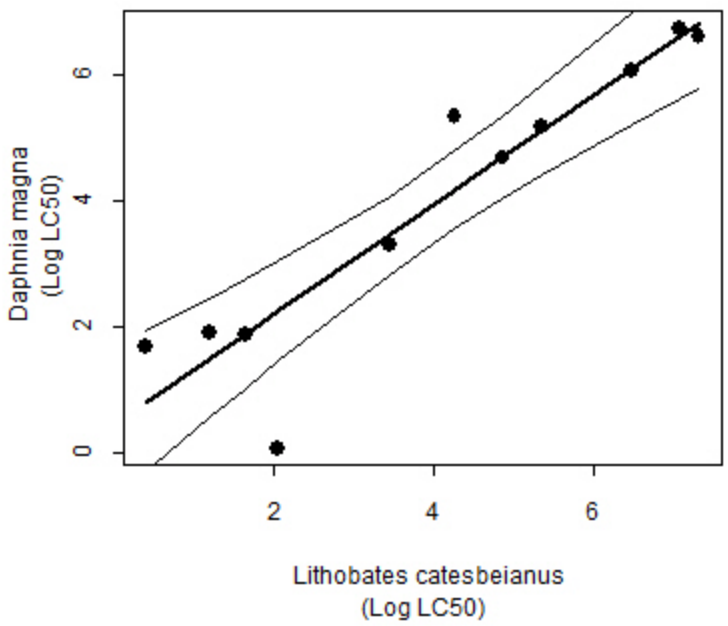


Figure L-19. *Lithobates catesbeianus* (X-axis) and *Daphnia magna* (Y-axis) regression model used for ICE predicted values.

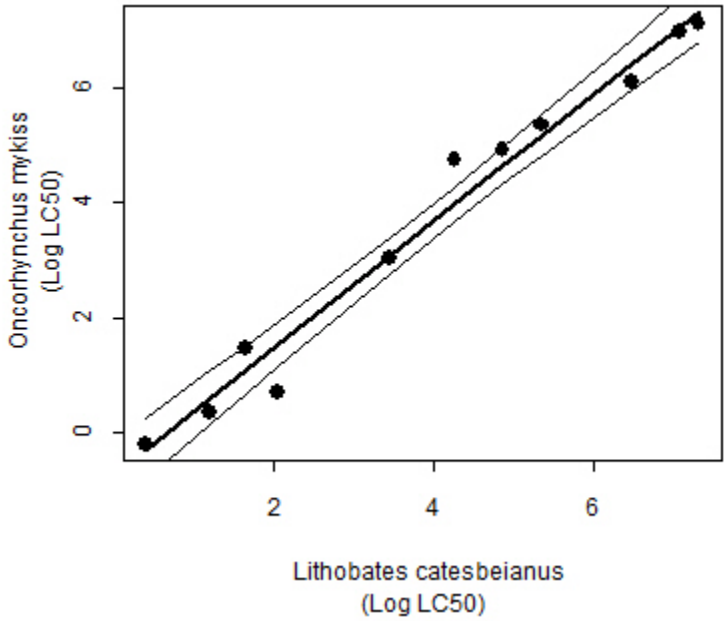


Figure L-20. *Lithobates catesbeianus* (X-axis) and *Oncorhynchus mykiss* (Y-axis) regression model used for ICE predicted values.

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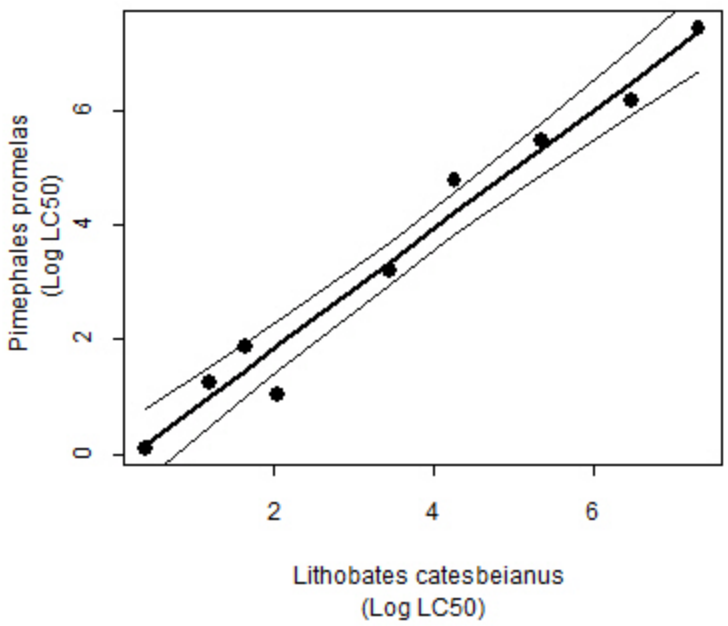


Figure L-21. *Lithobates catesbeianus* (X-axis) and *Pimephales promelas* (Y-axis) regression model used for ICE predicted values.

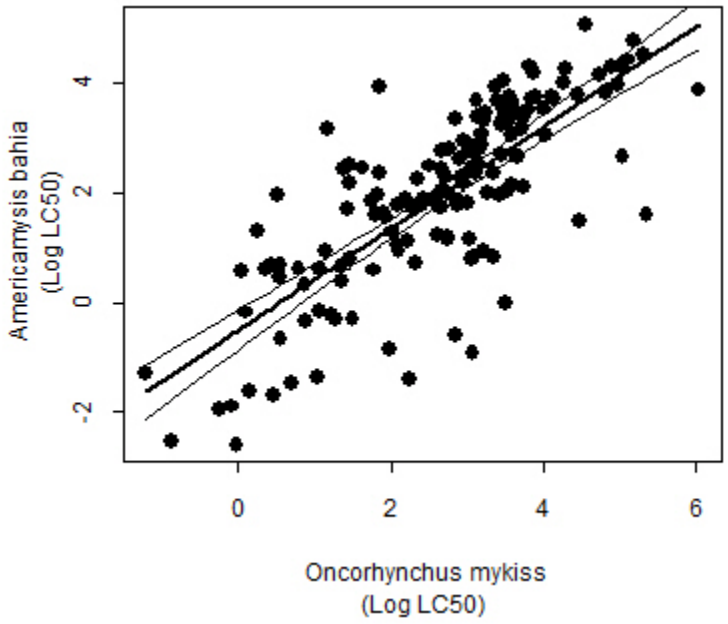


Figure L-22. *Oncorhynchus mykiss* (X-axis) and *Americamysis bahia* (Y-axis) regression model used for ICE predicted values.

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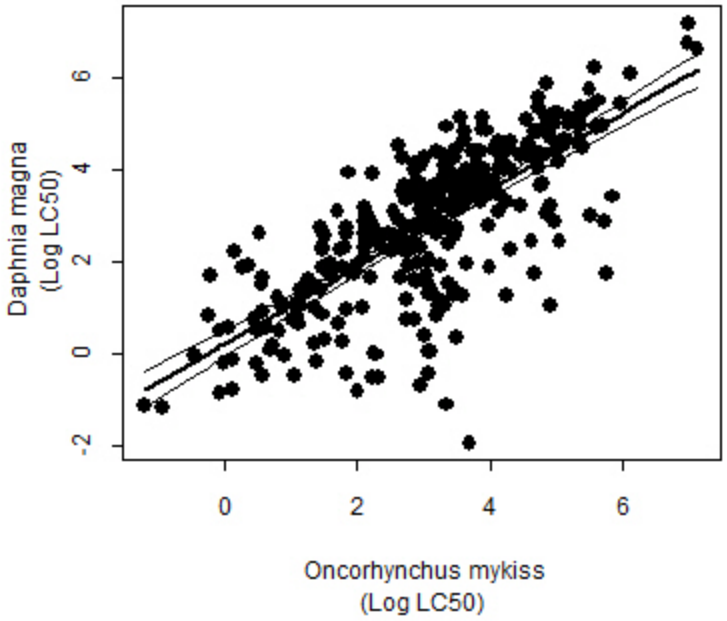


Figure L-23. *Oncorhynchus mykiss* (X-axis) and *Daphnia magna* (Y-axis) regression model used for ICE predicted values.

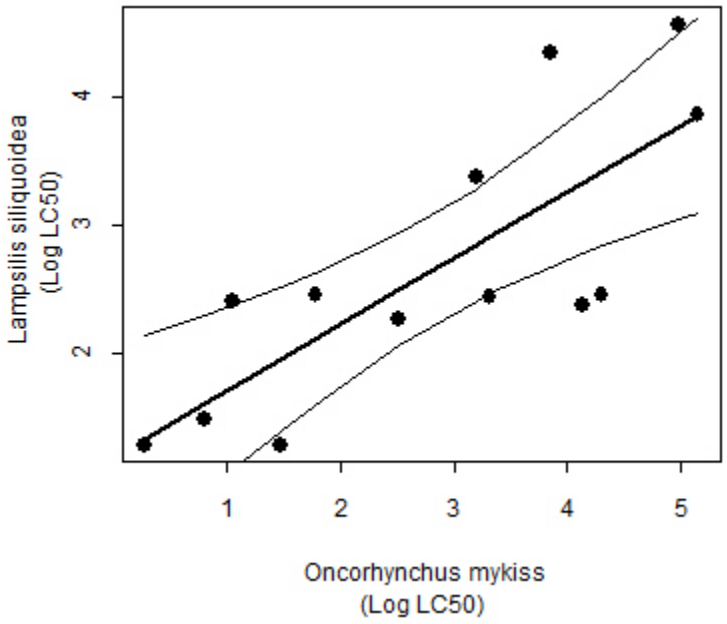


Figure L-24. *Oncorhynchus mykiss* (X-axis) and *Lampsilis siliquoidea* (Y-axis) regression model used for ICE predicted values.

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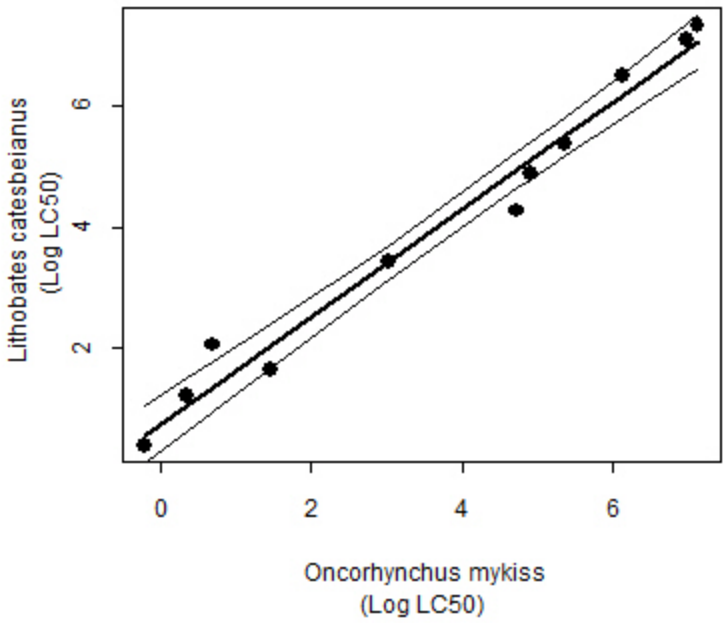


Figure L-25. *Oncorhynchus mykiss* (X-axis) and *Lithobates catesbeianus* (Y-axis) regression model used for ICE predicted values.

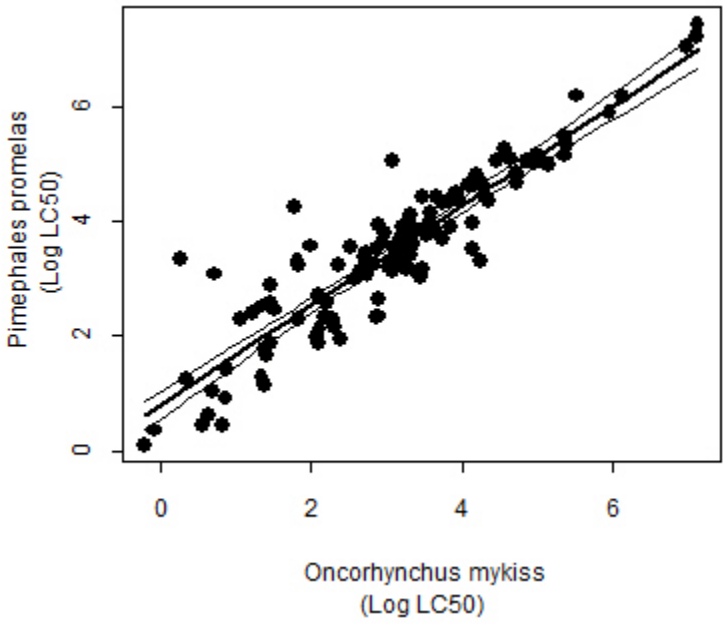


Figure L-26. *Oncorhynchus mykiss* (X-axis) and *Pimephales promelas* (Y-axis) regression model used for ICE predicted values.

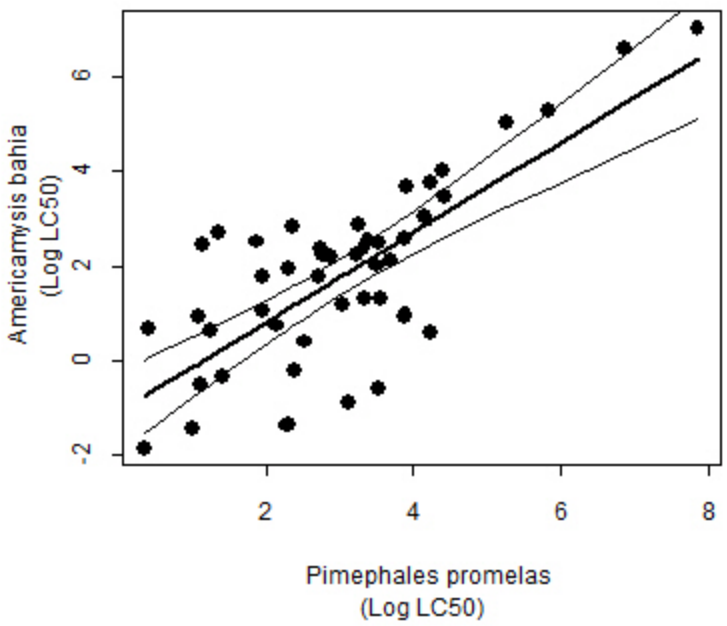


Figure L-27. *Pimephales promelas* (X-axis) and *Americamysis bahia* (Y-axis) regression model used for ICE predicted values.

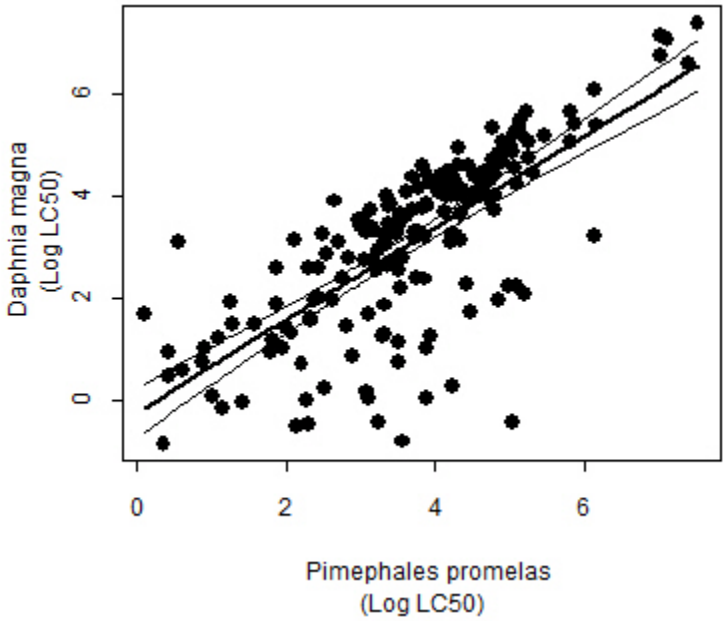


Figure L-28. *Pimephales promelas* (X-axis) and *Daphnia magna* (Y-axis) regression model used for ICE predicted values.

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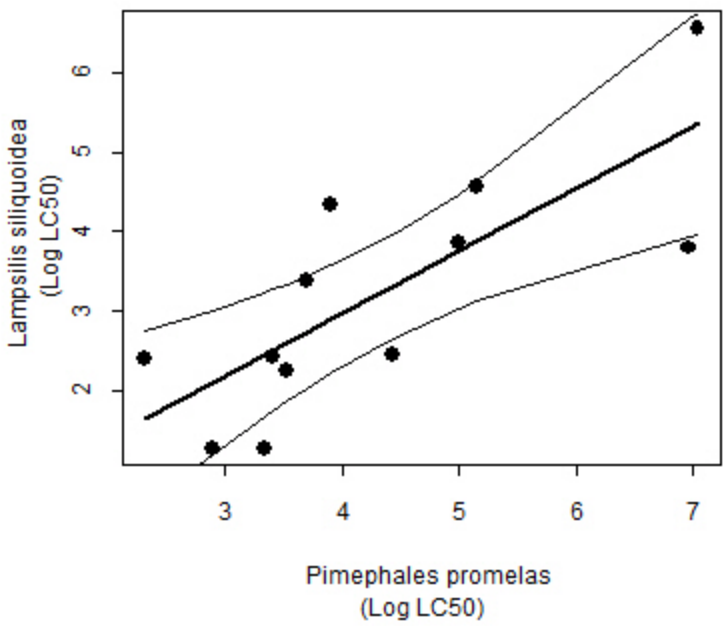


Figure L-29. *Pimephales promelas* (X-axis) and *Lampsilis siliquoidea* (Y-axis) regression model used for ICE predicted values.

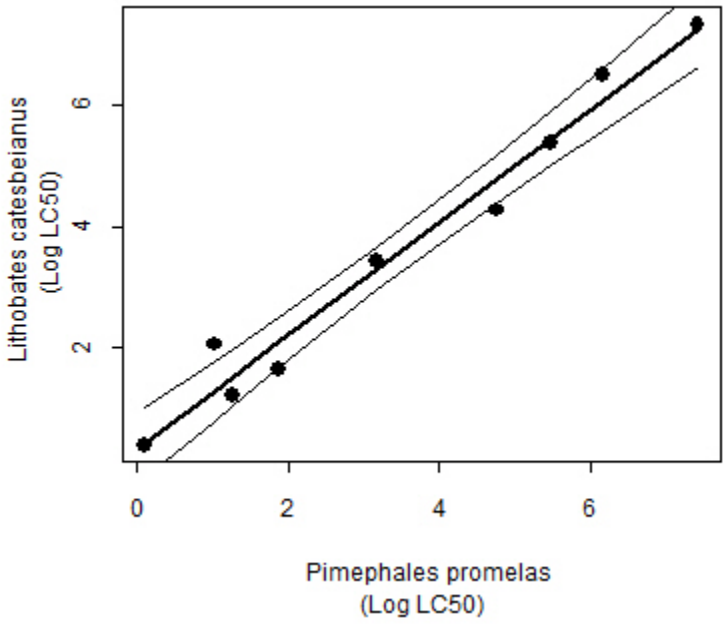


Figure L-30. *Pimephales promelas* (X-axis) and *Lithobates catesbeianus* (Y-axis) regression model used for ICE predicted values.

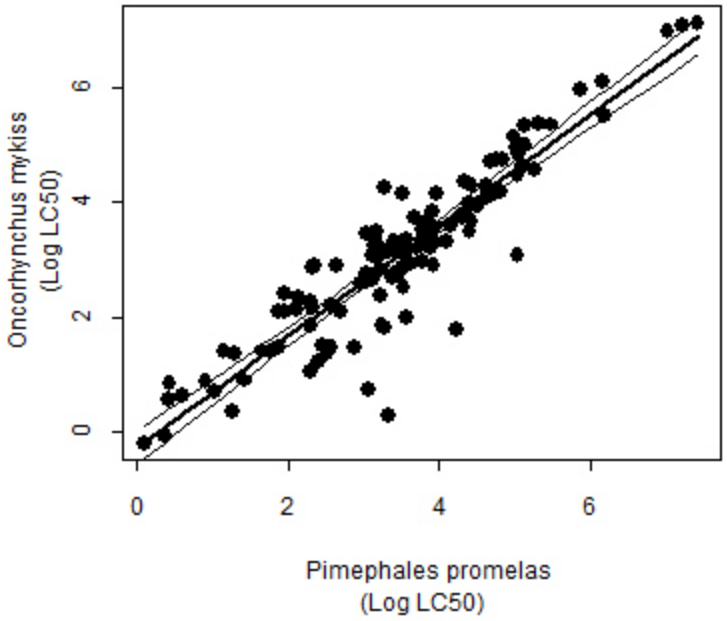


Figure L-31. *Pimephales promelas* (X-axis) and *Oncorhynchus mykiss* (Y-axis) regression model used for ICE predicted values.

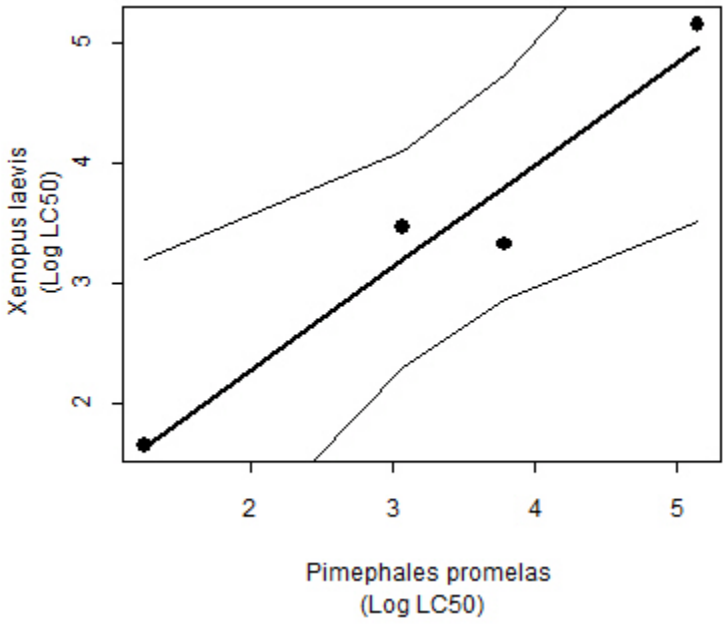


Figure L-32. *Pimephales promelas* (X-axis) and *Xenopus laevis* (Y-axis) regression model used for ICE predicted values.

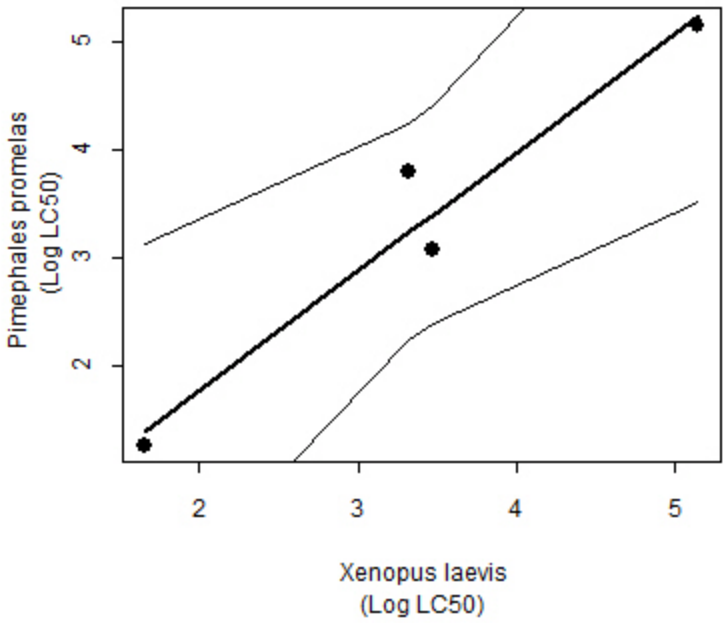


Figure L-33. *Xenopus laevis* (X-axis) and *Pimephales promelas* (Y-axis) regression model used for ICE predicted values.

Appendix M Environmental Fate of PFOS in the Aquatic Environment

Natural degradation of PFOS has not been observed. As described above in Section 2.2 above, under environmental conditions, PFOS does not photolyze, hydrolyze, or biodegrade and is thermally stable. For these reasons, PFOS is considered to be highly persistent in the environment (Beach et al. 2006; OECD 2002).

M.1 Photolysis

PFOS does not appear to photolyze (OECD 2002). No experimental evidence of direct or indirect photolysis was available (Hatfield 2001). The indirect photolytic half-life of PFOS using an iron oxide photo-initiator matrix model was estimated to be ≥ 3.7 years at 25°C. This half-life was based on the analytical method of detection (Giesy et al. 2010).

M.2 Hydrolysis

No hydrolytic loss of PFOS was observed in a 49 day study under experimental conditions of 50°C and pH conditions of 1.5, 5, 7, 9 or 11 (Hatfield 2001). Instead, the half-life of PFOS was estimated to be ≥41 years at 25°C. However, this estimate was influenced by the analytical limit of quantification and that no loss of PFOS was actually detected (Giesy et al. 2010).

M.3 Biodegradation

Several studies have demonstrated that PFOS does not biodegrade under aerobic or anaerobic conditions (Gledhill and Markley 2000c; Gledhill and Markley 2000b; Gledhill and Markley 2000a; Key et al. 1998; Laboratory 2002; Lange 2001; Remde and Debus 1996; Saez et al. 2008). Results from a study conducted by Kurume Laboratory in 2002 showed no biodegradation of PFOS after 28 days as measured by net oxygen demand, loss of total organic carbon, and loss of parent material. Key et al. (1998) demonstrated that even under sulfur-

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limiting conditions, PFOS did not degrade. Similarly, Saez et al. (2008) observed no PFOS degradation under aerobic or anaerobic conditions in municipal sewage sludge. In contrast, Schröder (2003) reported that PFOS was anaerobically degraded; however, the reported results are uncertain as the results could likely be attributed to sorption and there was a lack of increased fluoride concentrations reported (Frömel and Knepper 2010).

The persistence of PFOS has been attributed to the strong C-F bond. Additionally, there have been limited indications that naturally occurring, defluorinating enzymes exist that can break a C-F bond, which is likely due to the rarity of fluorinated molecules in nature (Frömel and Knepper 2010). To date, no laboratory data exist that demonstrates the PFOS undergoes significant biodegradation in environmental conditions (Beach et al. 2006; Giesy et al. 2010; OECD 2002).

M.4 Thermal Stability

Based on carbon-sulfur (C-S) bond energy, which is weaker than the carbon-carbon (C-C) or the C-F bond energies, PFOS is considered to have relatively low thermal stability. Thus, PFOS would more easily breakdown under incineration conditions and would be nearly completely destroyed when incinerated (Beach et al. 2006; Giesy et al. 2010).

M.5 Adsorption/Desorption

In general, PFOS may adsorb to sediments (with a K_d greater than 1 mL/g; (Giesy et al. 2010)). However, this sorption to sediment is limited since PFOS has a K_{oc} of 2.57, indicating that PFOS is relatively mobile in water and the physicochemical characteristics of the sediment ultimately influence the sorption of PFOS (Ahrens et al. 2011b; Beach et al. 2006; Giesy et al. 2010; Higgins and Luthy 2006). Sediment characteristics have a strong influence on the partitioning of PFOS (You et al. 2010). Specifically, organic content was found to have a

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significant influence on the partitioning of PFOS. Density of the sediment was also found to be an important factor influencing partitioning (Ahrens et al. 2011b). PFOS has a high affinity to bind to organic carbon with log K_{oc} values ranging between 2.57 and 3.8 cm^3/g ((Higgins and Luthy 2006) and (Ahrens et al. 2010); respectively). A sorption mechanism could be a salting-out and calcium-bridging effect, as PFOS sorption to sediment increased with increased salinity, pH, and calcium (You et al. 2010). Thus, the sorption of PFOS is a complicated process that is partially dependent on other factors such as metal anion concentrations, pH, temperature, and salinity; however, the strong relationship between PFOS concentrations and organic carbon in soil, sediment, and sludge indicates that these other factors have a minor influence on PFOS sorption (Ahrens et al. 2011b; Chen et al. 2012; Higgins and Luthy 2006; You et al. 2010).

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Appendix N Occurrence of PFOS in Abiotic Media

N.1 Summary of Measured Perfluorooctane Sulfonate Concentrations in Surface Waters Across the United States.

Modified from: Jarvis et al. (2021).

State	Waterbody[1]	Arithmetic Mean PFOS Concentration (ng/L)[2]	Median PFOS Concentration (ng/L)[2]	Range of PFOS Concentration (ng/L)	Reference
	Lake Erie	3.77	3	2.8 - 5.5	Sinclair et al. (2006)
		31.3	32.5	21.5 – 38.5	Boulanger et al. (2004)
		2.84	2.63	2.49 - 3.41	De Silva et al. (2011)
		4.5	4.2	4.0 - 5.3	Furdui et al. (2008)
	Lake Huron	2.25	1.96	0.239 - 5.46	De Silva et al. (2011)
		1.73	1.5	1.2 – 2.7	Furdui et al. (2007)
	Lake Michigan	2.03	2.03	0.93 – 3.13	Simcik and Dorweiler (2005)
		2.00	1.96	1.73 – 2.36	De Silva et al. (2011)
	Lake Ontario	not provided	4.9	2.9 – 30	Sinclair et al. (2006)
		55.4	59.8	16.5 – 85.5	Boulanger et al. (2004)
		5.96	5.63	2.60 – 9.48	De Silva et al. (2011)
		8.69	6.6	3.6 – 37.6	Furdui et al. (2008)
		2.20	not provided	not provided	Houde et al. (2008)
	Lake Superior	0.255	0.236	0.095 – 0.395	De Silva et al. (2011)
		0.233	0.3	0.1 – 0.3	Furdui et al. (2008)
		0.246	0.124	0.074 – 0.996	Scott et al. (2010)
Alabama	Waterbody near Decatur	58,016	41,027	9 – 150,000	OECD (2002)

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State	Waterbody[1]	Arithmetic Mean PFOS Concentration (ng/L)[2]	Median PFOS Concentration (ng/L)[2]	Range of PFOS Concentration (ng/L)	Reference
	Waterbody in Decatur	2.5< x <25	2.5< x <25	2.5< x <25	3M Company (2001)
	Pond in Decatur	111	111	111	
	Waterbody in Mobile	30.3	35.5	< 25 – 41.5	3M Company (2001)
	Pond in Mobile	32.5	32.5	32.5	
	Tennessee River (upstream of Baker's Creek)	30.85	29.80	16.0 – 52.6	Hansen et al. (2002)
	Tennessee River (downstream of Baker's Creek)	103.9	107.0	30.3 – 144	Hansen et al. (2002)
California	Upper Silver Creek	not provided	not provided	27 – 56	Plumlee et al. (2008)
	Coyote Creek	not provided	not provided	4.8 – 25	
Colorado	Animas River	<0.48	<0.48	<0.48	CDPHE (2020)
	Arkansas River	1.96	0.62	0.23 - 5.00	
	Arvada Blunn Reservoir	0.77	0.77	0.77	
	Barker Reservoir	<0.49	<0.49	<0.49	
	Bessemer Ditch	14.0	14.0	14.0	
	Big Thompson River	3.90	3.90	3.90	
	Blue River	1.20	1.20	1.20	
	Boulder Feeder Canal	<0.45	<0.45	<0.45	
	Boyd Lake	1.00	1.00	1.00	
	Cache la Poudre River	5.61	5.61	<0.45 - 11.0	
	Clear Creek	7.95	7.95	7.20 - 8.70	

State	Waterbody[1]	Arithmetic Mean PFOS Concentration (ng/L)[2]	Median PFOS Concentration (ng/L)[2]	Range of PFOS Concentration (ng/L)	Reference
	Colorado River	0.67	0.66	0.65 - 0.69	
	Coon Creek	<0.48	<0.48	<0.48	
	Eagle River	0.68	0.68	0.68	
	East Plum Creek	<0.43	<0.43	<0.43	
	Erie Lake	3.70	3.70	3.70	
	Fairmount Reservoir	<2.50	<2.50	<2.50	
	Fountain Creek	16.9	20.0	3.50 -24.0	
	Fraser River	1.00	1.00	1.00	
	Gore Creek	0.98	0.98	0.98	
	Gunnison River	0.71	0.71	0.71	
	Horsetooth Reservoir	0.51	0.51	0.51	
	Jackson Creek	<0.44	<0.44	<0.44	
	Jerry Creek	<0.485	<0.485	<0.48 – <0.49	
	Kannah Creek Flowline	<0.49	<0.49	<0.49	
	Lakewood Reservoir	<0.45	<0.45	<0.45	
	Little Fountain Creek	<0.46	<0.46	<0.46	
	Maple Grove Reservoir	10.0	10.0	10.0	
	Marstron Reservoir	0.48	0.48	0.48	
	McBroom Ditch	4.90	4.90	4.90	
	Mclellen Reservoir	1.30	1.30	1.30	
	Mesa Creek	<0.49	<0.49	<0.49	
	Michigan River	<0.46	<0.46	<0.46	

State	Waterbody[1]	Arithmetic Mean PFOS Concentration (ng/L)[2]	Median PFOS Concentration (ng/L)[2]	Range of PFOS Concentration (ng/L)	Reference
	Molina Power Plant Tail	<0.50	<0.50	<0.50	
	North Fork Gunnison River	<0.47	<0.47	<0.47	
	Purdy Mesa Flowline	<0.49	<0.49	<0.49	
	Purgatoire River	0.47	0.47	0.47	
	Ralston Reservoir	<0.46	<0.46	<0.46	
	Rio Grande	<0.47	<0.47	<0.47	
	Roaring Fork River	<0.50	<0.50	<0.50	
	San Juan River	<0.44	<0.44	<0.44	
	Sand Creek	30.3	30.3	6.50 - 54.0	
	Severy Creek	<0.47	<0.47	<0.47	
	Somerville Flowline	<0.48	<0.48	<0.48	
	South Boulder Creek	0.50	0.50	0.50	
	South Platte River	10.5	11.5	3.80 - 16.0	
	St. Vrain River	3.90	3.90	3.90	
	Strontia Springs	<0.51	<0.51	<0.51	
	Taylor River	<0.45	<0.45	<0.45	
	Uncompahgre River (delta)	0.54	0.54	0.54	
	Welton Reservoir	2.60	2.60	2.60	
	White River	<0.46	<0.46	<0.46	
	Yampa River	<0.47	<0.47	<0.47	
Delaware, New Jersey, Pennsylvania	Delaware River	3.98	3.5	0.97 - 6.92	Pan et al. (2018)

State	Waterbody[1]	Arithmetic Mean PFOS Concentration (ng/L)[2]	Median PFOS Concentration (ng/L)[2]	Range of PFOS Concentration (ng/L)	Reference
Florida	Waterbody in Pensacola	16.29	2.5< x <25	<25 – 29	3M Company (2001)
	Pond in Pensacola	2.5< x <25	2.5< x <25	2.5< x <25	
	Waterbody in Port St. Lucie	50.83	2.5< x <25	<2.5 – 137.5	
	Small pond in Port St. Lucie[3]	9,784	1,945	1,830 – 48,200	
	Sarasota Bay	0.90	not provided	not provided	Houde et al. (2006a)
Georgia	Waterbody in Columbus	59.9	55	44.6 – 80	3M Company (2001)
	Pond in Columbus	<2.5	<2.5	<2.5	
	Conasauga River	162.1	192	<1.5 - 321	Konwick et al. (2008)
	Altamaha River	2.63	2.6	2.6 – 2.7	
	Streams and ponds in Dalton	70.36	70.73	10.5-119.5	
	Oostanaula River	150.3	151	148 - 152	Lasier et al. (2011)
Louisiana	Waterbodies (locations of concern) near Barksdale A.F.B.	776.7	195.0	<10 – 7,070	Cochran (2015); Lanza et al. (2017)
	Reference waterbodies near Barksdale A.F.B.	<10	<10	<10	
Michigan	Raisin River	3.5	3.5	3.5	Kannan et al. (2005)
	St Clair River	2.6	2	1.9 – 3.9	
	Siskiwit Lake	0.283	0.283	0.277 – 0.289	Scott et al. (2010)
Minnesota	Upper Mississippi River	528.9	<2	<2 – 18,200	Newsted et al. (2017)

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State	Waterbody[1]	Arithmetic Mean PFOS Concentration (ng/L)[2]	Median PFOS Concentration (ng/L)[2]	Range of PFOS Concentration (ng/L)	Reference
	Lake of the Isles	2.47	2.47	2.47	Simcik and Dorweiler (2005)
	Lake Calhoun	50.4	50.4	50.4	
	Lake Harriet	22.1	22.1	22.1	
	Minnesota River	9.21	9.21	9.21	
	Lake Tettegouche	0.23	0.23	0.23	
	Lake Nipisiquit	<0.27	<0.27	<0.27	
	Lake Loiten	<0.27	<0.27	<0.27	
	Little Trout Lake	1.2	1.2	1.2	
New Jersey	Echo Lake Reservoir	<2	<2	<2	NJDEP (2019)
	Passaic River	13.1	13.1	13.0 – 13.2	
	Raritan River	6.9	6.9	6.9	
	Metedeconk River	1.65	1.65	<2 – 2.8	
	Pine Lake	102	102	102	
	Horicon Lake	10	10	10	
	Little Pine Lake	100	100	100	
	Mirror Lake	72.9	72.9	72.9	
	Woodbury Creek	6.4	6.4	6.4	
	Fenwick Creek	3.1	3.1	3.1	
	Cohansey River	<2	<2	<2	
	Harbortown Road	1.93	1.93	1.93	Zhang et al. (2016)
	Passaic River	4.59	4.07	0.244 – 9.99	
New Mexico	Alamogordo Domestic Water Sys.	<	<1	<1	NMED (2020)
	Animas River	0.799	0.625	< 0.89 - 1.5	
	Canadian River	0.848	0.9	< 0.89 - 1.2	

State	Waterbody[1]	Arithmetic Mean PFOS Concentration (ng/L)[2]	Median PFOS Concentration (ng/L)[2]	Range of PFOS Concentration (ng/L)	Reference
	Cloud Country Estates WUA	<0.93	<0.93	<0.93	
	Gila River	<0.93	<0.93	<0.93	
	Holloman AFB Golf Course Pond 1	1,220	1,220	1,220	
	Holloman AFB Golf Course Pond 2	878	878	878	
	Holloman AFB Lagoon G	310	310	310	
	Holloman AFB Outfall	951	951	951	
	Holloman AFB Sewage Lagoon	2,200	2,200	2,200	
	Karr Canyon Estates	<0.93	< 0.93	< 0.93	
	La Luz MDWCA	<1.3	<1.3	<1.3	
	Lake Holloman	4,033	4,500	1,700 - 5,900	
	Mountain Orchard MDWCA	< 0.93	< 0.93	< 0.93	
	Pecos River	1.223	1.50	<0.94 - 1.70	
	Rio Chama	<0.98	<0.98	<0.96 - <1	
	Rio Grande	1.052	0.474	<0.465 - 2.90	
	Rio Puerco	4.35	4.35	3.10 - 5.60	
	San Juan River	<1.15	<1.15	<1.06 – <1.24	
	Tularosa Water System	0.723	0.723	<0.89 - 1.0	
New York	Washington Park Lake	1.67	1.77	<0.25 – 2.88	Kim and Kannan (2007)
	Rensselaer Lake	7.11	6.58	5.85 – 9.3	

State	Waterbody[1]	Arithmetic Mean PFOS Concentration (ng/L)[2]	Median PFOS Concentration (ng/L)[2]	Range of PFOS Concentration (ng/L)	Reference
	Iroquois Lake	not provided	not provided	not provided	
	Unnamed lake 1 outside Albany, NY	not provided	not provided	not provided	
	Unnamed lake 2 outside Albany, NY	not provided	not provided	not provided	
	Niagara River	5.17	5.5	3.3 – 6.7	Sinclair et al. (2006)
	Finger Lakes	not provided	1.6	1.3 – 2.6	
	Lake Onondaga	681	756	198 – 1,090	
	Lake Oneida	3.5	3.5	3.5	
	Erie Canal	8.37	6.4	5.7 - 13	
	Hudson River	not provided	1.7	1.5 – 3.4	
	Lake Champlain	not provided	2.7	0.8 – 7.7	
	Lower NY Harbor	0.755	0.755	0.755	Zhang et al. (2016)
	Staten Island	1.66	1.66	1.66	
	Hudson River	1.81	1.81	0.79 – 2.84	
North Carolina	Cape Fear River	31.2	28.9	<1 - 132	Nakayama et al. (2007)
Rhode Island	Narragansett Bay	2.2	2.2	2.2	Benskin et al. (2012)
	Allen Cove Inflow	1.20	1.20	1.20	Zhang et al. (2016)
	Bristol Harbor	0.508	0.46	0.437 – 0.626	
	Brook at Mill Cove	9.80	9.80	9.80	
	Buckeye Brook	4.13	4.13	4.13	
	Chickasheen Brook	< 0.05	< 0.05	< 0.05	
	EG Town Dock	0.735	0.735	0.735	
	Fall River	0.238	0.238	0.238	
	Green Falls River	0.291	0.291	0.29 – 0.292	
	Hunt River	1.48	1.48	1.48	

State	Waterbody[1]	Arithmetic Mean PFOS Concentration (ng/L)[2]	Median PFOS Concentration (ng/L)[2]	Range of PFOS Concentration (ng/L)	Reference
	Mill Brook	3.94	3.94	3.94	
	Narrow River	0.298	0.264	0.176 – 0.488	
	Pawcatuck River	0.561	0.561	0.509 – 0.612	
	Pawtuxet River	2.19	2.19	2.19	
	Queens River	0.334	0.334	0.334	
	Sand Hill Brook	1.82	1.82	1.82	
	Secret Lake – Oak Hill Brook	<0.05	<0.05	<0.05	
	Slack's Tributary	0.777	0.777	0.777	
	South Ferry Road Pier	0.161	0.161	0.161	
	Southern Creek	3.74	3.74	3.74	
	Woonasquatucket River	14.6	14.6	5.87 – 23.2	
South Carolina	Charleston Harbor	12.0	not provided	not provided	Houde et al. (2006a)
Tennessee	Waterbody near Cleveland	2.5 < x <25	2.5 < x <25	<2.5 - <25	3M Company (2001)
	Conasauga River	<0.009[4]	<0.009[4]	<0.009[4]	Lasier et al. (2011)
Texas	Rio Grande	4.17	4.1	2.0 - 6.5	NMED (2020)
Washington	Puget Sound	2.3	1.45	0.2 – 5.9	Dinglasan-Panlilio et al. (2014)
	Clayoquot Sound	0.32	0.3	0.25 – 0.4	
	Barkley Sound	0.7	0.7	0.7	
Multiple States (10 Air Force Bases across the continental U.S.)	Surface waters impacted by aqueous film forming foam use	not provided	2,170	8,970,000 (maximum)	Anderson et al. (2016)

Less than (<) values based on study specific LOD and LOQ values that the study authors reported, LOD = limit of detection and LOQ = limit of quantitation

[1] Name of Waterbody Sampled for PFOS. Name or description of waterbody above is consistent with that provided in cited reference.
[2]Calculation of arithmetic mean and median includes lower of ½ LOD or ½ LOQ, depending on information provided. See full occurrence table in Appendix N for waterbody-specific details.
[3] Study authors conducted additional sampling of this waterbody but were unable to detect the initial high PFOS concentrations in any of the additional samples.
[4] Reported as ng/g by the study authors.

N.2 PFOS occurrence and concentrations in the Great Lakes region

The Great Lakes are among the most widely studied waterbodies in the U.S. for PFOS occurrence. However, occurrence data are still relatively limited for this system. Comparisons across the Great Lake system indicate PFOS concentrations are higher in Lakes Erie and Ontario, ranging between 2.8 and 38.5 ng/L and 2.6 and 85.5 ng/L, respectively (Figure 2-3) (Boulanger et al. 2004; De Silva et al. 2011; Furdui et al. 2008; Sinclair et al. 2006), compared to the more northern Great Lakes. These northern Great Lakes (i.e., Lakes Huron, Michigan, and Superior) have a maximum observed concentration of 5.46 ng/L, which was observed in Lake Huron (Remucal 2019). However, current measured PFOS concentrations were not from sampling sites around urbanized areas (such as Chicago and Detroit) and may not be representative of the potential sources of PFOS related to these areas. The measured concentrations of PFOS in the surface waters of Lakes Huron and Michigan range between 0.24 and 5.46 ng/L (De Silva et al. 2011; Furdui et al. 2008) and 0.93 and 3.13 ng/L (De Silva et al. 2011; Simcik and Dorweiler 2005), respectively. In contrast, measured PFOS concentrations observed in Lake Superior were considerably lower and range between 0.074 and 0.996 ng/L (De Silva et al. 2011; Furdui et al. 2008; Scott et al. 2010). The higher PFOS concentrations in Lakes Erie and Ontario are likely due to higher levels of industrial activities and urbanization around these lakes (Boulanger et al. 2004; Remucal 2019) and could also be associated with the sampling locations. A mass balance constructed for Lake Ontario by Boulanger et al. (2004) indicated wastewater effluent was the

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major source of PFOS to the lake. In contrast, inputs from Canadian tributaries and atmospheric deposition of PFOS, and other PFAS that may be transformed into PFOS, were the major contributing sources of PFOS to Lake Superior. Inputs from Canadian tributaries and atmospheric deposition were estimated to contribute 57 and 32% of PFOS inputs into Lake Superior, respectively (Scott et al. 2010).

N.3 PFOS occurrence and concentrations in the southeastern U.S.

Measured PFOS concentrations in southeastern U.S. surface waters were similar to those measured in Lakes Erie and Ontario, with some of the highest observed concentrations occurring in waterbodies near areas with PFOS manufacturing. In 2001, the 3M Company conducted a multi-city study measuring PFOS concentrations across waterbodies with known manufacturing and/or industrial uses of PFOS (3M Company 2001). In the 3M Company's 2001 report, PFOS concentrations from sites with known PFOS discharges were compared to PFOS concentrations measured in waterbodies with no known sources of any PFAS (3M Company 2001). In this comparison study, cities with known PFOS exposure were Mobile and Decatur, Alabama, Columbus, Georgia, and Pensacola, Florida. Measured PFOS concentrations ranged from not detected (reported detection limit of 2.5 ng/L; 3M Company 2001) to 80 ng/L in the cities with known PFOS discharges. These PFOS concentrations were compared to those measured in control cities. These control cities were Cleveland, Tennessee and Port St. Lucie, Florida and PFOS concentrations ranged from not detected to 137.5 ng/L (3M Company 2001). The PFOS concentrations measured in Cleveland, Tennessee were below the limit of quantification (25 ng/L) and were lower than the PFOS concentrations observed in the cities with known PFOS exposure, as was expected in the report for the control cities. However, PFOS concentrations around Port St. Lucie, Florida, the other control city, were unexplainably similar to, and at times

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higher than, the waterbodies with known PFOS discharges. The sources of PFOS near Port St. Lucie, Florida remain unknown; however, observed PFOS concentration suggest the presence of a potential manufacturing/industrial source or the use of AFFF in this area (3M Company 2001).

Water samples were collected from ponds near all of the sampling sites except those in Cleveland, Tennessee. PFOS concentrations in these additional pond sites were similar to those measured in Mobile, Alabama (ranging between 32 and 33 ng/L), lower than those observed in Columbus, Georgia (as PFOS was not detected with a detection limit of 2.5 ng/L), and higher than those measured in Decatur, Alabama (ranging between 108 and 111 ng/L) and in Port St. Lucie, Florida (ranging between 1,830 and 48,200 ng/L). Samples collected from the pond site near Port St. Lucie, Florida had some of the highest measured PFOS concentrations in publicly available literature with the maximum concentration of 48,200 ng/L. In the report, the 3M Company conducted additional sampling at the pond site in Port St. Lucie, Florida and determined that the measured PFOS concentrations at this site were more variable than the initial measurements indicated and were lower than the previous measurements, ranging between below detection (i.e., <2.5 ng/L) and 2,340 ng/L. Aside from the samples collected in Port St. Lucie, Florida, this report demonstrated that measured PFOS concentrations in surface waters tend to be higher in areas with PFOS manufacturing and/or industrial use (3M Company 2001).

In separate studies, PFOS and PFOA concentrations were measured in surface waters by Hansen et al. (2002) near Decatur, Alabama, and Konwick et al. (2008) in Georgia. Hansen et al. (2001) studied a stretch of the Tennessee River near Decatur, Alabama, and Konwick et al. (2008) focused on the Conasauga River in Georgia, both areas with known PFOS discharge and use. In Hansen et al. (2002), discharge from a fluorochemical manufacturing facility entered the Tennessee River towards the middle of the study area. In contrast, Konwick et al. (2008)

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compared the PFOS concentrations measured in the Conasauga River with those from sites with no known exposure along the Altamaha River. In both studies, mean PFOS concentrations were higher in the study areas with PFOS sources. Specifically, Hansen et al. (2002) observed mean PFOS concentrations upstream of the fluorochemical manufacturing facility were 30.85 ng/L (ranging between 16.0 and 52.6 ng/L) and were 103.9 ng/L (ranging between 30.3 and 144 ng/L) downstream of the fluorochemical manufacturing facility. Similarly, Konwick et al. (2008) observed higher measured PFOS concentrations in the Conasauga River, which ranged from below the limit of detection (i.e., 1.5 ng/L) to 321 ng/L, compared to those in the Altamaha River, ranging between 2.6 and 2.7 ng/L. Consistent with the report from the 3M Company summarized above, effluents from manufacturing facilities, WWTP, and carpet mill effluents were determined to be the source of increased PFOS concentrations in both the Tennessee and Conasauga Rivers (Hansen et al. 2002; Konwick et al. 2008; respectively). These PFOS concentrations are relatively consistent with those measured in Alabama and Georgia as reported by the 3M Company (3M Company 2001).

Nakayama et al. (2007) and Cochran (2015) measured PFAS, including PFOS, in the Cape Fear Drainage Basin in North Carolina and waterbodies on Barksdale Air Force Base in Bossier City, Louisiana, respectively. PFOA and PFOS were found to be the dominant PFAS detected in both studies. Nakayama et al. (2007) detected PFOS in 97.5% of all samples above the limit of quantification of 1 ng/L. PFOS concentrations in the Cape Fear Drainage Basin ranged between <1 (the lower limit of quantification) and 132 ng/L with a mean concentration of 31.2 ng/L. As in other studies summarized above, lower PFAS concentrations, including PFOS, were found in the upland tributaries and concentrations were highest in the middle reaches of the Cape Fear Drainage Basin, nearer expected sources. Wastewater treatment plant effluents were

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identified as the source of PFAS to the study area. AFFF usage at the Department of Defense base in Fayetteville, North Carolina and the land application of contaminated biosolids likely contributed as well (Nakayama et al. 2007). Cochran (2015) detected PFOS in 79% of all water samples collected and concentrations ranged between below the limit of quantification (i.e., 10 ng/L) and 7,070 ng/L, with an average concentration of 776.7 ng/L. PFOS concentrations collected in Barksdale Air Force Base varied based on proximity to fire training areas. Cochran (2015) attributed the evaluated PFOS concentrations to runoff and ground infiltration of AFFF formerly used on the base during firefighting and/or training.

N.4 PFOS occurrence and concentrations in the midwestern U.S.

Similar PFOS concentrations were reported in the publicly available literature for waterbodies in urban areas across the midwestern U.S., with lower PFOS concentrations reported in remote areas in the same states (Newsted et al. 2017; Simcik and Dorweiler 2005). In Minnesota, Simcik and Dorweiler (2005) observed PFOS concentrations ranged between 2.4 and 50.4 ng/L in urban areas near Minneapolis and between less than the limit of quantification (i.e., 0.27 ng/L) and 1.2 ng/L in remote areas in northern Minnesota. Additionally, Newsted et al. (2007) reported an average PFOS concentration of 528.9 ng/L (ranging between below limit of quantification and 18,200 ng/L; limit of quantification not provided) in surface waters collected from the Upper Mississippi River near the Minneapolis/St. Paul, Minnesota metropolitan area. The source of PFOS at these urban sites was attributed to manufacturing (3M plant), runoff, and wastewater discharge (Newsted et al. 2017; Simcik and Dorweiler 2005).

N.5 PFOS occurrence and concentrations in the northeastern U.S.

Several studies measured PFOS concentrations in surface waters in the northeastern U.S. that are comparable to those reported in Minnesota (NJDEP 2019; Sinclair et al. 2006). Sinclair

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et al. (2006) measured PFOS in various waterbodies across New York state and observed a median concentration of 756 ng/L in surface waters collected from the Superfund site at Lake Onondaga (ranging between 198 and 1,090 ng/L; Table N.1) and attributed these elevated concentrations to several industries located along Lake Onondaga. All other observed concentrations of PFOS in New York, including sites along the Niagara River, the Finger Lakes, Lakes Oneida and Champlain, the Erie Canal, and the Hudson River, had lower median PFOS concentrations ranging between 0.8 and 13 (Table N.1)(Sinclair et al. 2006).

The New Jersey Department of Environmental Protection (NJDEP) measured PFOS in surface water samples collected from 14 different sites across New Jersey. PFOS concentrations ranged from below the detection limit of 2.0 ng/L and 102 ng/L (NJDEP 2019). Individual samples collected along Pine, Little Pine, and Mirror Lakes had measured PFOS concentrations of 102, 100, and 72.9 ng/L, respectively. All other observed concentrations of PFOS in New Jersey freshwaters were below 15 ng/L. NJDEP attributed the elevated concentrations of PFOS observed at Pine, Little Pine, and Mirror Lakes to the use of AFFF in training and/or fire-fighting on the Department of Defense (DoD) Joint Base McGuire-Lix-Lakehurst (NJDEP 2019).

N.6 PFOS occurrence and concentrations in the western U.S.

PFOS concentrations in surface waters of western U.S. states are consistent with the lower-end concentrations (less than 100 ng/L) measured in eastern states; however, the monitoring data for PFOS was limited in the western U.S. Plumlee et al. (2008) measured PFOS concentrations in Coyote Creek and a tributary of Upper Silver Creek in San Jose, California and found concentrations to be similar to those measured in eastern states. Concentrations of PFOS in Coyote Creek ranged from 4.8 to 25 ng/L and concentrations in Upper Silver Creek ranged from 27 to 56 ng/L. The source of PFOS to these aquatic systems was unknown, however,

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Plumlee et al. (2008) stated that a combination of atmospheric deposition of volatile precursors and surface runoff were likely sources of PFOS to both Coyote and Upper Silver Creeks.

Lastly, Dinglasan-Panlilio et al. (2014) measured PFOS concentrations in surface waters along the Puget Sound in Washington, as well as Clayoquot and Barkley Sounds in British Columbia, Canada. PFOS concentrations measured by Dinglasan-Panlilio et al. (2014) were lower than those observed from sites in eastern states (such as those summarized above for Alabama, Florida, and North Carolina with known manufacturing and/or industrial use of PFOS). Concentrations ranged from 0.2 to 5.9 ng/L in Puget Sound and 0.25 to 0.7 ng/L in Clayoquot and Barkley Sound, British Columbia. These concentrations are consistent with those reported in the publicly available literature for remote areas, such as in Minnesota (Simcik and Dorweiler 2005) and in New York (Sinclair et al. 2006), as summarized above. The study authors indicated specific regional sources and atmospheric deposition were likely PFOS sources to these remote areas (Dinglasan-Panlilio et al. 2014).

N.7 Comparison of PFOS occurrence in the U.S. to global surface waters

Similar to surface waters in the U.S., generally PFOS and PFOA were the most commonly detected PFAS in surface waters around the world (Ahrens 2011). On a global scale, PFOS concentrations in surface waters generally range between picogram/liter and nanogram/liter with some concentrations in the milligram/liter range. However, PFOS occurrence data were limited for surface waters in Africa and South America. Based on the currently available data, PFOS concentrations in the U.S. were relatively similar to those reported in studies with sampling sites in other countries. Global surface water PFOS concentrations reported in the public literature ranged between not detected and 2,100,000 ng/L

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(Jarvis et al. 2021). These global surface water concentrations are summarized in Jarvis et al. (2021) to provide a comparison with those observed in the U.S.

Overall, the currently available data on PFOS occurrence in ambient surface waters show the widespread distribution and variability of PFOS concentrations in surface waters around the world and that surrounding land use has a large influence on PFOS concentrations in surface waters. In general, urbanized areas with high population densities tended to have elevated PFOS concentrations in surface waters (Jarvis et al. 2021). Like in the U.S., PFOS concentrations in surface waters around the world vary widely and current information on the environmental distribution of PFOS in surface waters around the world is relatively limited.

N.8 PFOS Occurrence and Detection in Aquatic Sediments

PFOS has been detected in sediments of aquatic environments across various countries (Lau et al. 2007). Typically, in the U.S., soil and sediment measurements of PFOS occur in the µg/kg dry weight (dw) range with measured concentrations in the public literature ranging from not detected (with a detection limit of 0.08 µg/kg dw) to 31.38 µg/kg dw (3M Company 2001; Cochran 2015). Anderson et al. (2016), measured concentrations of PFAS in sediment across ten U.S. Air Force bases where there is a known history of use of AFFF use and found that PFOS concentrations were detected in 94% of samples. The median concentration of PFOS across all sample sites was 31.0 µg/kg, with a maximum concentration of 190,000 µg/kg (Anderson et al. 2016). Arias et al. (2015) measured PFOS in sediment from an evaporation pond used to collect the wastewater arising from fire-fighting exercises at an Australian military air base. Despite the discontinued use of PFOS/PFOA-based foams six years earlier, the PFOS sediment concentration was 38,000,000 µg/kg, a million times higher than the average global values for sediments (0.28 - 3.8 µg/kg PFOS) reported by the authors (Arias et al. 2015).

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These observed concentrations were similar to other sediment concentrations in areas with known perfluorinated chemical discharges and manufacturing. Lasier et al. (2011) measured PFOS in sediment from the Coosa River, Georgia watershed, upstream, and downstream of a land-application site of municipal/industrial wastewater with sediment concentrations ranging from less than the method detection limit (MDL) to 1.73 µg/kg dw upstream of the land-application and 1.66 - 20.18 µg/kg dw PFOS downstream. Giesy and Kannan (2001), as presented in OECD (2002), measured PFOS in sediments collected from locations upstream and downstream of the 3M facility in Decatur, Alabama. The two closest sites downstream of the 3M facility had significantly greater concentrations (1,299 and 5,930 µg/kg ww) than the two upstream sites (~0.18 and 0.98 µg/kg ww; OECD 2002).

Other sediment concentrations across the U.S. were much lower: <4 µg/kg across sites in Puget Sound, Washington, San Francisco and Monterey Bay California, the Niagara River in New York, and Lake Michigan. These concentrations appeared to be similar to other sediment concentrations across the globe (Table N-1).

Table N-1. Global Sediment Concentration of PFOS.

Location	PFOS concentration	Reference
Tokyo Bay, Japan	0.29-0.36 µg/kg dw	Ahrens et al. (2010)
Ariake Sea, Japan	0.11 µg/kg ww	Nakata et al. (2006)
Toronto, Canada	<0.1-2.2 µg/kg ww	Vedagiri et al. (2018)
Lake Ontario, Canada	10 µg/kg dw	ECCC (2018)
Lake Ontario, Niagara Basin	27-47 µg/kg	Meyers et al. (2012)
Lake Ontario, Mississauga Basin	4.4-19 µg/kg	Meyers et al. (2012)
Lake Ontario, Rochester Basin	8.1-49 µg/kg	Meyers et al. (2012)
Resolute Lake, Canada	24-85 µg/kg ww	Butt et al. (2010)
Gufunes Bay, Iceland	< 50 µg/kg ww	Butt et al. (2010); Kallenborn (2004)
Faroe Islands	< 50 - 0.11 µg/kg	Butt et al. (2010); Kallenborn (2004)
Urban reservoir, Singapore	2.8-3.6 µg/kg dw	Nguyen et al. (2016)

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N.9 PFOS Occurrence and Detection in Air and Rain

Air concentrations of PFOS in the atmosphere varied widely across the globe. In an urban area in Albany, NY, perfluorinated acids were measured in air samples in both the gas and particulate phase in May and July of 2006 (Kim and Kannan 2007). PFOS in the gas phase had a mean concentration of 1.70 pg/m^3 (range: 0.94-3.0) and the particulate phase had a mean concentration of 0.64 pg/m^3 (range: 0.35-1.16) (Kim and Kannan 2007). Kim and Kannan (2007) also reported mean PFOS concentrations of 0.36 ng/L and 0.62 ng/L in rain and snow, respectively.

Above Lake Ontario, concentrations of PFOS in the particulate phase measured in air samples over the lake were higher than those observed by Kim and Kannan (2007) near Albany, NY. The mean concentration of PFOS at Lake Ontario was 6.4 ± 3.3 pg/m^3 (Boulanger et al. 2005a), with a range of concentrations from not detected to 8.1 pg/m^3 (Martin et al. 2010). In an urban area in Minneapolis, Minnesota, PFOS was measured in both the particulate and gas phase. PFOS in the particulate phase ranged from 2.1 - 7.9 pg/m^3 and the gas phase ranged from 1.8 - 5.0 pg/m^3 in across the five samples (MPCA/STS 2007).

In Canada, PFOS air concentrations measured in 2009 showed widespread distribution with remote sites having similar concentrations as urban sites (ECCC 2018). Using passive samplers, PFOS concentrations were detected in Toronto, Ontario (8 pg/m^3), an agricultural site in Saskatchewan (5 pg/m^3), Whistler, British Columbia (4 pg/m^3), and Alert, N Nunavut (2 pg/m^3) (ECCC 2013).

Other reported concentrations of PFOS in air samples included Sydney, Florida (3.4 pg/m^3), Tudor Hill, Bermuda (6.1 pg/m^3), Malin Head, Ireland (3.3 pg/m^3), and Hilo, Hawaii (6.6 pg/m^3) are similar to the concentrations reported in Canada (ECCC 2018) and Japan (Sasaki et al. 2003). The annual geometric mean concentration of PFOS in air samples collected monthly

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from 2001-2002 in the town of Oyamazaki and Fukuchiyama City were 5.3 and 0.6 pg/m^3, respectively (Sasaki et al. 2003).

Across Europe, PFOS air concentrations were reported to be variable. In the particulate phase PFOS concentrations ranged from < 1.8 - 46 pg/m^3. Most locations had low (~1-2 pg/m^3) to less than the reported Minimum Detection Limit (MDL) and included Hazelrigg, United Kingdom, Kjeller Norway, and Mace Head, Ireland (Barber et al. 2007). The highest concentrations were reported in Manchester, United Kingdom. Similarly, high concentrations were reported for another urban area, 150 pg/m^3 for Paris, France (ECCC 2018).

Even in the Arctic, PFOS, its precursors, and degradation products, have been detected in air samples in Resolute Bay, Nunavut, Canada, during the summer of 2004 (Stock et al. 2007). PFOS in the filter samples were 1-2 orders of magnitude greater than other compounds, with a mean concentration of 5.9 pg/m^3 (Butt et al. 2010). These concentrations are greater than PFOS concentrations measured in the particle phase of air samples measured in Zeppelinstasjonen, Svalbard, Norway (Butt et al. 2010). PFOS was measured in September and December, 2006 and August and December, 2007, with mean concentrations of 0.11 pg/m^3 (range: 0.03 - 0.50 pg/m^3) and 0.18 pg/m^3 (range: 0.02 - 0.97 pg/m^3), respectively (NILU 2007).

N.10 PFOS Occurrence and Detection in Groundwater

Similar to surface water, PFOS and PFOA are the dominant PFAS detected in groundwater. Generally, PFOS concentrations tend to occur in the ng/L range, with some elevated detections in the µg/L range (Ahrens 2011; Xiao 2017). Concentrations of PFOS were detected in groundwater samples across Minnesota in 2006 and 2007, approximately five years after the 3M Corporation phased out PFOS production in Minnesota in 2002 (MPCA/STS 2007). Data collected from shallow aquifers across Minnesota in both urban and agricultural areas were

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likely affected by a variety of different contamination sources (i.e., industrial and municipal stormwater, pesticides, land application of contaminated biosolids and atmospheric deposition) and indicated that perfluorinated chemicals are present in areas beyond the disposal sites and aquifers associated with these disposal sites (MPCA/STS 2007). Groundwater samples of PFOS ranged from < 0.00222 - 0.037 µg/L across urban areas, with most of the perfluorinated compound detections in the Twin Cities metro area (MPCA/STS 2007). Concentrations in rural areas of Minnesota were all less than the analytical method reporting limit (0.025 µg/L).

Detections of PFOS in groundwater have been associated with the use of AFFF and fire-training locations (Ahrens 2011; Xiao 2017). The use of AFFF to suppress fires resulted in the release of various PFAS into the environment as AFFF contains high levels of PFAS (Ahrens 2011; Moody and Field 2000). The use of AFFF in particular has been identified as an important source of groundwater contamination with PFAS (Moody and Field 2000). This contamination is often persistent, lasting for many years after the release (Moody and Field 2000; Xiao 2017). The transformation of PFOS precursor compounds (see Section 2.3) by soil micro-organisms may be a contributing source of PFOS in groundwater (Xiao 2017).

Groundwater samples from wells in the area of a known plume were measured in 1998 and 1999. Samples were taken at the Wurtsmith Air Force Base in northeastern Michigan, a base where fire-training exercises were conducted from the 1950's until the base was decommissioned in 1993. PFOS concentrations ranged from 4.0 to 110 µg/L depending on the proximity to the training pad, demonstrating that PFOS is still present in measurable quantities for at least five or more years after the use of AFFF (Moody et al. 2003). These values are consistent with ten other U.S. Air Force bases where there is a known historic use of AFFF to extinguish hydrocarbon-based fires but were not active fire-training areas. Anderson et al. (2016) measured groundwater

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samples between March and September 2014 at the ten locations with PFOS concentrations detected in 96% of samples. The median groundwater concentration of PFOS across all sites was 2.17 µg/L, with a maximum concentration of 8,970 µg/L (Anderson et al. 2016). Other reported groundwater concentrations at other U.S. military installations summarized by Cousins et al. (2016) include: Tyndall Air Force Base (147 - 2,300 µg/L; Schultz et al. 2004), Fallon Naval Air station (< LOD - 380 µg/L; Schultz et al. 2004) and Ellsworth Air Base (5 - 75 µg/L; McGuire et al. 2014). Similar concentrations are reported at other airports and bases globally, including at a fire training area in Cologne, Germany (0.02 - 8.35 µg/L; Weiß et al. 2012); air force base F18 in Sweden (< 0.001 - 42.2 µg/L; Filipovic et al. 2015) and the Jersey airport in the United Kingdom (10 - 98 µg/L; Rumsby et al. 2009).

N.11 PFOS Occurrence and Detection in Ice

Very little information was provided about PFOS concentrations in ice. Saez et al. (2008) found PFOS in a Russian Artic ice core sampled in 2007. The PFOS concentration reported was 0.0053 ng/L.

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Appendix O Bioaccumulation Factors (BAFs) Used to Calculate PFOS Tissue Values

O.1 Summary Table of PFOS BAFs used to calculate tissue criteria and supplemental fish tissue values

Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
common carp	*Carassius auratus*	Blood	11167	**11167**	high	17 Sites in six major rivers, Korea	Lam et al. (2014)
mandarin	*Siniperca scherzeri*	Blood	73612	73612	high	17 Sites in six major rivers, Korea	Lam et al. (2014)
lefteye flounder	*Paralichthys olivaceus*	Blood	5625	**5625**	medium	Ariake Bay	Taniyasu et al. (2003)
crucian carp	*Carassius carassius*	Blood	80168	**80168**	high	Beijing Airport, China	Wang et al. (2016)
crucian carp	*Carassius carassius*	Blood	22484	**22484**	high	Gaobeidian Lake, China	Shi et al. (2020)
carp	*Cyprinus carpio*	Blood	84211	84211	medium	Lake Biwa	Taniyasu et al. (2003)
bluegill	*Lepomis macrochirus*	Blood	11053	**11053**	medium	Lake Biwa	Taniyasu et al. (2003)
largemouth bass	*Micropterus salmoides*	Blood	169737	169737	medium	Lake Biwa	Taniyasu et al. (2003)
European perch	*Perca fluviatilis*	Blood	58000	**58000**	medium	Lake Halmsjön, near Stockholm, Sweden	Wang et al. (2016)
black seabream	*Acanthopagrus schlegeli*	Blood	14138	**14138**	medium	Osaka Bay	Taniyasu et al. (2003)
white croaker	*Argyrosomus argentatus*	Blood	19540	19540	medium	Osaka Bay	Taniyasu et al. (2003)
Japanese scad	*Trachurus japonicus*	Blood	14138	**14138**	medium	Osaka Bay	Taniyasu et al. (2003)
crucian carp	*Carassius carassius*	Blood	9638	**9638**	high	Tangxum Lake, China	Shi et al. (2015)
conger eel	*Conger myriaster*	Blood	3500	**3500**	medium	Tokyo Bay	Taniyasu et al. (2003)
rockfish	*Sebastes inermis*	Blood	9423	9423	medium	Tokyo Bay	Taniyasu et al. (2003)
Japanese stingfish	*Sebastiscus marmoratus*	Blood	5154	5154	medium	Tokyo Bay	Taniyasu et al. (2003)
crucian carp	*Carassius carassius*	Blood	19999	19999	high	Xiaoqing River, China	Shi et al. (2015)
common carp	*Cyprinus carpio*	Blood	7244	**7244**	high	Xiaoqing River, China	Pan et al. (2017)

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Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
crucian carp	*Carassius carassius*	Blood	21275	**21275**	high	Yubei River, China	Shi et al. (2020)
crucian carp	*Carassius carassius*	Gonad	25645	**25645**	high	Beijing Airport, China	Wang et al. (2016)
crucian carp	*Carassius carassius*	Gonad	8012	**8012**	high	Gaobeidian Lake, China	Shi et al. (2020)
European perch	*Perca fluviatilis*	Gonad	16000	**16000**	medium	Lake Halmsjön, near Stockholm, Sweden	Ahrens et al. (2015)
European chub	*Leuciscus cephalus*	Gonad	10000	**10000**	high	Orge River, near Paris, France	Labadie and Chevreuil (2011)
chub	*Leuciscus cephalus*	Gonad	2222	**2222**	medium	Roter Main, Upper Franconia, Germany	Becker et al. (2010)
crucian carp	*Carassius carassius*	Gonad	5888	**5888**	high	Tangxum Lake, China	Shi et al. (2015)
crucian carp	*Carassius carassius*	Gonad	11482	**11482**	high	Xiaoqing River, China	Shi et al. (2015)
crucian carp	*Carassius carassius*	Gonad	7990	**7990**	high	Yubei River, China	Shi et al. (2020)
common carp	*Carassius auratus*	Liver	4572	**4572**	high	17 Sites in six major rivers, Korea	Lam et al. (2014)
mandarin	*Siniperca scherzeri*	Liver	24718	24718	high	17 Sites in six major rivers, Korea	Lam et al. (2014)
Mozambique tilapia	*Oreochromis mossambicus*	Liver	436.8	436.8	medium	Matikulu, N2 Bridge	Fauconier et al. (2020)
cape stumpnose	*Rhabdosargus holubi*	Liver	111.2	**111.2**	medium	Matikulu, N2 Bridge	Fauconier et al. (2020)
lefteye flounder	*Paralichthys olivaceus*	Liver	23958	**23958**	medium	Ariake Bay	Taniyasu et al. (2003)
crucian carp	*Carassius carassius*	Liver	83753	**83753**	high	Beijing Airport, China	Wang et al. (2016)
crucian carp	*Carassius carassius*	Liver	11180	**11180**	high	Gaobeidian Lake, China	Shi et al. (2020)
tilapia	tilapia	Liver	5108	**4176**	medium	Key River, Taiwan	Lin et al. (2014)
tilapia	tilapia	Liver	4181		medium	Key River, Taiwan	Lin et al. (2014)
tilapia	tilapia	Liver	3409		medium	Key River, Taiwan	Lin et al. (2014)
carp	*Cyprinus carpio*	Liver	1053	**1053**	medium	Lake Biwa	Taniyasu et al. (2003)
bluegill	*Lepomis macrochirus*	Liver	74211	74211	medium	Lake Biwa	Taniyasu et al. (2003)
largemouth bass	*Micropterus salmoides*	Liver	61579	61579	medium	Lake Biwa	Taniyasu et al. (2003)

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Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
European perch	*Perca fluviatilis*	Liver	39000	**39000**	medium	Lake Halmsjön, near Stockholm, Sweden	Ahrens et al. (2015)
European chub	*Leuciscus cephalus*	Liver	19953	**19953**	high	Orge River, near Paris, France	Labadie and Chevreuil (2011)
white croaker	*Argyrosomus argentatus*	Liver	1609	1609	medium	Osaka Bay	Taniyasu et al. (2003)
common seabass	*Lateolabrax japonicus*	Liver	459.8	**459.8**	medium	Osaka Bay	Taniyasu et al. (2003)
Japanese scad	*Trachurus japonicus*	Liver	1034	1034	medium	Osaka Bay	Taniyasu et al. (2003)
crucian carp	*Carassius auratus*	Liver	19953	19953	high	Pearl River Delta, China	Pan et al. (2014)
mud_carp	*Cirrhinus molitorella*	Liver	25119	25119	medium	Pearl River Delta, China	Pan et al. (2014)
leather_catfish	*Clarias fuscus*	Liver	5012	5012	high	Pearl River Delta, China	Pan et al. (2014)
grass carp	*Ctenopharyngodon idellus*	Liver	39811	39811	high	Pearl River Delta, China	Pan et al. (2014)
common_carp	*Cyprinus carpio*	Liver	25119	25119	high	Pearl River Delta, China	Pan et al. (2014)
chub	*Hypophthalmichthys molitrix*	Liver	7943	7943	high	Pearl River Delta, China	Pan et al. (2014)
snakehead	*Ophicephalus argus*	Liver	15849	15849	high	Pearl River Delta, China	Pan et al. (2014)
bream	*Parabramis pekinensis*	Liver	3162	**3162**[c]	high	Pearl River Delta, China	Pan et al. (2014)
tilapia	*Tilapia aurea*	Liver	3162	**3162**[c]	high	Pearl River Delta, China	Pan et al. (2014)
chub	*Leuciscus cephalus*	Liver	4556	**4556**	medium	Roter Main, Upper Franconia, Germany	Becker et al. (2010)
silver perch	*Bidyanus bidyanus*	Liver	26000	**26000**	high	Shoalhaven region, Australia	Terechovs et al. (2019)
common shiner	*Notropis cornutus*	Liver	12589	**12589**	high	Spring/Etobicoke Creek, Toronto, Canada	Awad et al. (2011)
sea mullet	*Mugil cephalus*	Liver	5000	**5000**	medium	Sydney Harbour, Australia	Thompson et al. (2011)
crucian carp	*Carassius carassius*	Liver	4426	**4426**	high	Tangxum Lake, China	Shi et al. (2015)
common seabass	*Lateolabrax japonicus*	Liver	3269	3269	medium	Tokyo Bay	Taniyasu et al. (2003)
flatfish	*Pleuronectidae*	Liver	6846	6846	medium	Tokyo Bay	Taniyasu et al. (2003)

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Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
rockfish	*Sebastes inermis*	Liver	2462	**2462**	medium	Tokyo Bay	Taniyasu et al. (2003)
Japanese stingfish	*Sebastiscus marmoratus*	Liver	4423	4423	medium	Tokyo Bay	Taniyasu et al. (2003)
crucian carp	*Carassius carassius*	Liver	9226	9226	high	Xiaoqing River, China	Shi et al. (2015)
common carp	*Cyprinus carpio*	Liver	4467	**4467**	high	Xiaoqing River, China	Pan et al. (2017)
crucian carp	*Carassius carassius*	Liver	10735	**10735**	high	Yubei River, China	Shi et al. (2020)
Mozambique tilapia	*Oreochromis mossambicus*	Muscle	17.44	17.44	medium	Matikulu, N2 Bridge	Fauconier et al. (2020)
cape stumpnose	*Rhabdosargus holubi*	Muscle	8.718	**8.718**	medium	Matikulu, N2 Bridge	Fauconier et al. (2020)
crucian carp	*Carassius carassius*	Muscle	50234	**50234**	high	Beijing Airport, China	Wang et al. (2016)
juvenile char (muscle)	*Salvelinus alpinus*	Muscle	10800	**20785**	high	Char Lake, Canadian High Arctic	Lescord et al. (2015)
adult char (muscle)	*Salvelinus alpinus*	Muscle	40000		high	Char Lake, Canadian High Arctic	Lescord et al. (2015)
crucian carp	*Carassius carassius*	Muscle	1130	**1130**	high	Gaobeidian Lake, China	Shi et al. (2020)
meagre	*Argyrosomus regius*	Muscle	2496	2496	high	Gironde estuary, SW France	Munoz et al. (2017)
common seabass	*Dicentrarchus labrax*	Muscle	3257	3257	high	Gironde estuary, SW France	Munoz et al. (2017)
spotted seabass	*Dicentrarchus punctatus*	Muscle	2535	3844	high	Gironde estuary, SW France	Munoz et al. (2017)
spotted seabass	*Dicentrarchus punctatus*	Muscle	5830		high	Gironde estuary, SW France	Munoz et al. (2017)
anchovy	*Engraulis encrasicolus*	Muscle	1761	1761	high	Gironde estuary, SW France	Munoz et al. (2017)
mullet	*Liza ramada*	Muscle	1226	1226	high	Gironde estuary, SW France	Munoz et al. (2017)
sprat	*Sprattus sprattus*	Muscle	808.7	**808.7**	medium	Gironde estuary, SW France	Munoz et al. (2017)
tilapia	tilapia	Muscle	245.0	**256.4**	medium	Key River, Taiwan	Lin et al. (2014)
tilapia	tilapia	Muscle	323.0		medium	Key River, Taiwan	Lin et al. (2014)
tilapia	tilapia	Muscle	213.0		medium	Key River, Taiwan	Lin et al. (2014)
European perch	*Perca fluviatilis*	Muscle	3400	**3400**	high	Lake Halmsjön, near Stockholm, Sweden	Ahrens et al. (2015)
brown bullhead	*Ameiurus nebulosus*	Muscle	794.3	794.3	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. (2016)
common carp	*Cyprinus carpio*	Muscle	7943	7943	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. (2016)

Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
northern pike	*Esox lucius*	Muscle	1000	1000	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. (2016)
channel catfish	*Ictalurus punctatus*	Muscle	3162	3162	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. (2016)
pumpkinseed	*Lepomis gibbosus*	Muscle	631.0	**631.0**	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. (2016)
smallmouth bass	*Micropterus dolomieu*	Muscle	6310	6310	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. (2016)
largemouth bass	*Micropterus salmoides*	Muscle	5012	5012	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. (2016)
yellow perch	*Perca flavescens*	Muscle	794.3	794.3	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. (2016)
white crappie	*Pomoxis annularis*	Muscle	1000	1000	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. (2016)
black crappie	*Pomoxis nigromaculatus*	Muscle	1585	1585	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. (2016)
juvenile char (muscle)	*Salvelinus alpinus*	Muscle	1878	**1048**	high	Meretta Lake, Canadian High Arctic	Lescord et al. (2015)
adult char (muscle)	*Salvelinus alpinus*	Muscle	585.4		high	Meretta Lake, Canadian High Arctic	Lescord et al. (2015)
eel	*Anguilla anguilla*	Muscle	3236	**3236**	high	Netherlands	Kwadijk et al. (2010)
European chub	*Leuciscus cephalus*	Muscle	2512	**2512**	high	Orge River, near Paris, France	Labadie and Chevreuil (2011)
crucian carp	*Carassius auratus*	Muscle	1585	1585	high	Pearl River Delta, China	Pan et al. (2014)
mud_carp	*Cirrhinus molitorella*	Muscle	2512	2512	medium	Pearl River Delta, China	Pan et al. (2014)
leather_catfish	*Clarias fuscus*	Muscle	251.2	**251.2**[c]	high	Pearl River Delta, China	Pan et al. (2014)
grass carp	*Ctenopharyngodon idellus*	Muscle	2512	2512	high	Pearl River Delta, China	Pan et al. (2014)
common_carp	*Cyprinus carpio*	Muscle	1585	1585	high	Pearl River Delta, China	Pan et al. (2014)
chub	*Hypophthalmichthys molitrix*	Muscle	631.0	631.0	high	Pearl River Delta, China	Pan et al. (2014)
snakehead	*Ophicephalus argus*	Muscle	398.1	398.1	high	Pearl River Delta, China	Pan et al. (2014)
bream	*Parabramis pekinensis*	Muscle	398.1	398.1	high	Pearl River Delta, China	Pan et al. (2014)

Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
tilapia	*Tilapia aurea*	Muscle	251.2	**251.2**[c]	high	Pearl River Delta, China	Pan et al. (2014)
juvenile char (muscle)	*Salvelinus alpinus*	Muscle	1038	**2162**	high	Resolute Lake, Canadian High Arctic	Lescord et al. (2015)
adult char (muscle)	*Salvelinus alpinus*	Muscle	4500		high	Resolute Lake, Canadian High Arctic	Lescord et al. (2015)
goby	*Gobio gobio*	Muscle	2963	2963	medium	Roter Main, Upper Franconia, Germany	Becker et al. (2010)
chub	*Leuciscus cephalus*	Muscle	481.5	**481.5**	medium	Roter Main, Upper Franconia, Germany	Becker et al. (2010)
eel	*Anguilla anguilla*	Muscle	1148	**518.8**	medium	Schiphol Amsterdam Airport	Kwadijk et al. (2014)
eel	*Anguilla anguilla*	Muscle	234.4		medium	Schiphol Amsterdam Airport	Kwadijk et al. (2014)
silver perch	*Bidyanus bidyanus*	Muscle	6000	**6000**	high	Shoalhaven region, Australia	Terechovs et al. (2019)
sea mullet	*Mugil cephalus*	Muscle	157.1	**157.1**	medium	Sydney Harbour, Australia	Thompson et al. (2011)
crucian	*Carassius cuvieri*	Muscle	15599	15599	high	Taihu Lake, China	Fang et al. (2014)
lake saury	*Coilia mystus*	Muscle	9190	9190	high	Taihu Lake, China	Fang et al. (2014)
gobies	*Ctenogobius giurinus*	Muscle	6144	6144	high	Taihu Lake, China	Fang et al. (2014)
Mongolian culter	*Culter mongolicus*	Muscle	15088	15088	high	Taihu Lake, China	Fang et al. (2014)
common carp	*Cyprinus carpio*	Muscle	7623	7623	high	Taihu Lake, China	Fang et al. (2014)
minnow	*Hemiculter leucisculus*	Muscle	6092	6092	high	Taihu Lake, China	Fang et al. (2014)
silver carp	*Hypophthalmichthys molitrix*	Muscle	1761	**1761**	high	Taihu Lake, China	Fang et al. (2014)
mudfish (Oriental weatherfish)	*Misgurnus anguillicaudatus*	Muscle	10810	10810	high	Taihu Lake, China	Fang et al. (2014)
white bait	*Reganisalanx brachyrostralis*	Muscle	2835	2835	high	Taihu Lake, China	Fang et al. (2014)
Chinese bitterling	*Rhodeus sinensis Gunther*	Muscle	6444	6444	high	Taihu Lake, China	Fang et al. (2014)
Crucian carp	*Carassius carassius*	Muscle	741.3	**741.3**	high	Tangxum Lake, China	Shi et al. (2015)
Crucian carp	*Carassius carassius*	Muscle	1567	1567	high	Xiaoqing River, China	Shi et al. (2015)
common carp	*Cyprinus carpio*	Muscle	537.0	**537.0**	high	Xiaoqing River, China	Pan et al. (2014)

Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
crucian carp	*Carassius carassius*	Muscle	1167	**1167**	high	Yubei River, China	Shi et al. (2020)
grass goby	*Zosterisessor ophiocephalus*	WB	863.7	**863.7**	medium	AC Site, Orbetell lagoon, Italy	Renzi et al. (2013)
ommon carp	*Cyprinus carpio*	WB	11749	**11749**	high	Baiyangdian Lake, China	Zhou et al. (2012)
herring	*Clupea harengus membras*	WB	20893	**20893**	medium	Baltic Sea	Gebbink et al. (2016)
spat	*Sprattus sprattus*	WB	22387	22387	medium	Baltic Sea	Gebbink et al. (2016)
grass carp	*Ctenopharyngodon idellus*	WB	7960	**7960**	medium	Bantou Reservoir - Xiamen Sea, China	Dai and Zheng (2019)
crucian carp	*Carassius carassius*	WB	43954	**43954**	high	Beijing Airport, China	Wang et al. (2016)
juvenile char (whole body)	*Salvelinus alpinus*	WB	30000	**30000**	high	Char Lake, Canadian High Arctic	Lescord et al. (2015)
grass goby	*Zosterisessor ophiocephalus*	WB	332.0	**332.0**	medium	FC Site, Orbetell lagoon, Italy	Renzi et al. (2013)
goby	*Pomatoschistus*	WB	2400	**2400**	medium	Gironde estuary, SW France	Munoz et al. (2017)
chameleon goby	*Tridentiger trigonocephalus*	WB	8086	**8086**	medium	Gulf Park - Xiamen Sea, China	Dai and Zheng (2019)
Chinese icefish	*Neosalanx tangkahkeii taihuensis*	WB	2267	**2267**	medium	Lake Chaohu, China	Pan et al. (2019)
lake trout	*Salvelinus namaycush*	WB	84598	**46098**	high	Lake Erie	De Silva et al. (2011)
lake trout	*Salvelinus namaycush*	WB	25119		medium	Lake Erie	Furdui et al. (2007)
walleye	*Sander vitreus*	WB	47659	47659	high	Lake Erie	De Silva et al. (2011)
European perch	*Perca fluviatilis*	WB	6400	**6400**	medium	Lake Halmsjön, near Stockholm, Sweden	Ahrens et al. (2015)
lake trout	*Salvelinus namaycush*	WB	21142	**18305**	high	Lake Huron	De Silva et al. (2011)
lake trout	*Salvelinus namaycush*	WB	15849		medium	Lake Huron	Furdui et al. (2007)
lake trout	*Salvelinus namaycush*	WB	6310	**6310**	medium	Lake Michigan	Furdui et al. (2007)
alewife	*Alosa pseudoharengus*	WB	24000	24000	medium	Lake Ontario	Houde et al. (2008)
slimy sculpin	*Cottus cognatus*	WB	234000	234000	medium	Lake Ontario	Houde et al. (2008)

Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
rainbow smelt	*Osmerus mordax*	WB	45000	45000	medium	Lake Ontario	Houde et al. (2008)
lake trout	*Salvelinus namaycush*	WB	17293	**16715**	high	Lake Ontario	De Silva et al. (2011)
lake trout	*Salvelinus namaycush*	WB	7943		medium	Lake Ontario	Furdui et al. (2007)
lake trout	*Salvelinus namaycush*	WB	34000		medium	Lake Ontario	Houde et al. (2008)
lake trout	*Salvelinus namaycush*	WB	14453	**16982**	high	Lake Superior	De Silva et al. (2011)
lake trout	*Salvelinus namaycush*	WB	19953		medium	Lake Superior	Furdui et al. (2007)
flag-tailed glass perchlet	*Ambassis miops*	WB	774.6	774.6	medium	Mai Po Marshes, Hong Kong	Loi et al. (2011)
small snakehead	*Channa asiatica*	WB	1283	1283	medium	Mai Po Marshes, Hong Kong	Loi et al. (2011)
ladyfish	*Elops saurus*	WB	550.9	550.9	high	Mai Po Marshes, Hong Kong	Loi et al. (2011)
grey mullet	*Mugil cephalus*	WB	821.6	821.6	high	Mai Po Marshes, Hong Kong	Loi et al. (2011)
Mozambique tilapia	*Oreochromis mossambicus*	WB	422.5	**422.5**	high	Mai Po Marshes, Hong Kong	Loi et al. (2011)
juvenile char (whole body)	*Salvelinus alpinus*	WB	4415	**4415**	high	Meretta Lake, Canadian High Arctic	Lescord et al. (2015)
grass goby	*Zosterisessor ophiocephalus*	WB	565.0	**565.0**	medium	NC Site, Orbetell lagoon, Italy	Renzi et al. (2013)
yellowfin goby	*Acanthogobius flavimanus*	WB	576.9	576.9	medium	Omuta River mouth and estuary, Japan	Kobayashi et al (2018)
sea bass	*Lateolabrax sp.*	WB	384.6	**384.6**	medium	Omuta River mouth and estuary, Japan	Kobayashi et al (2018)
grey mullet	*Mugil cephalus*	WB	1038	1038	medium	Omuta River mouth and estuary, Japan	Kobayashi et al (2018)
juvenile char (whole body)	*Salvelinus alpinus*	WB	8615	**8615**	high	Resolute Lake, Canadian High Arctic	Lescord et al. (2015)
perch	*Esox lucius*	WB	2344	**3846**	medium	Schiphol Amsterdam Airport	Kwadijk et al. (2014)
perch	*Esox lucius*	WB	6310		medium	Schiphol Amsterdam Airport	Kwadijk et al. (2014)
medaka	*Oryzias latipes*	WB	5500	**5500**	high	Seven locations across Japan	Iwabuchi et al. (2015)

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Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
juvenile char (whole body)	*Salvelinus alpinus*	WB	8889	**8889**	high	Small Lake, Canadian High Arctic	Lescord et al. (2015)
common shiner	*Notropis cornutus*	WB	1995	**1995**	high	Spring/Etobicoke Creek, Toronto, Canada	Awad et al. (2011)
crucian carp	*Carassius carassius*	WB	1963	**1963**	high	Tangxum Lake, China	Shi et al. (2015)
bleak	*Alburnus alburnus*	WB	251.2	251.2	medium	Xerta, Ebro Delta, Spain	Pignotti et al. (2017)
common carp	*Cyprinus carpio*	WB	1000	1000	medium	Xerta, Ebro Delta, Spain	Pignotti et al. (2017)
mullet	*Liza sp.*	WB	4.786	**4.786**	medium	Xerta, Ebro Delta, Spain	Pignotti et al. (2017)
roach	*Rutilus rutilus*	WB	199.5	199.5	medium	Xerta, Ebro Delta, Spain	Pignotti et al. (2017)
rudd	*Scardinius erythrophtalmus*	WB	79.43	79.43	medium	Xerta, Ebro Delta, Spain	Pignotti et al. (2017)
European catfish	*Silurus glanis*	WB	100.0	100.0	medium	Xerta, Ebro Delta, Spain	Pignotti et al. (2017)
ebro chub	*Squalius laietanus*	WB	100.0	100.0	medium	Xerta, Ebro Delta, Spain	Pignotti et al. (2017)
crucian carp	*Carassius carassius*	WB	2818	**2818**	high	Xiaoqing River, China	Shi et al. (2015)
mesozooplankton	Mesozooplankton	Invert	3450	3450	high	17 Sites in six major rivers, Korea	Lam et al. (2014)
microzooplankton	Microzooplankton	Invert	3017	**3017**	high	17 Sites in six major rivers, Korea	Lam et al. (2014)
chironomids	Diptera	Invert	550000	550000	high	9-Mile Lake, Canadian High Arctic	Lescord et al. (2015)
zooplankton	zooplankton	Invert	100000	**100000**	high	9-Mile Lake, Canadian High Arctic	Lescord et al. (2015)
snail	Gastropoda	Invert	15.26	**15.26**	medium	aMatikulu N2 Bridge	Fauconier et al. (2020)
zooplankton	zooplankton	Invert	295.1	**295.1**	medium	Baltic Sea	Gebbink et al. (2016)
chironomids	Diptera	Invert	280000	280000	high	Char Lake, Canadian High Arctic	Lescord et al. (2015)

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Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
zooplankton	zooplankton	Invert	2400	**2400**	high	Char Lake, Canadian High Arctic	Lescord et al. (2015)
ghost crab	*Ocypode stimpsoni*	Invert	3270	**3270**	medium	Fenglin - Xiamen Sea, China	Dai and Zheng (2019)
copepods	Copepoda	Invert	3.400	**68.50**	high	Gironde Estuary, SW France	Munoz et al. (2019)
copepods	Copepoda	Invert	1380		medium	Gironde Estuary, SW France	Munoz et al. (2017)
brown shrimp	*Crangon crangon*	Invert	3.900	166.5	high	Gironde Estuary, SW France	Munoz et al. (2019)
brown shrimp	*Crangon crangon*	Invert	7110		medium	Gironde Estuary, SW France	Munoz et al. (2017)
oyster	*Crassostrea gigas*	Invert	122.0	122.0	high	Gironde Estuary, SW France	Munoz et al. (2017)
gammarids	*Gammarus sp.*	Invert	2380	2380	medium	Gironde Estuary, SW France	Munoz et al. (2017)
mysids	Mysidacea	Invert	3.900	117.8	high	Gironde Estuary, SW France	Munoz et al. (2017)
mysids	Mysidacea	Invert	3560		medium	Gironde Estuary, SW France	Munoz et al. (2017)
white shrimp	*Palaemon longirostris*	Invert	3.400	97.62	high	Gironde Estuary, SW France	Munoz et al. (2019)
white shrimp	*Palaemon longirostris*	Invert	2803		medium	Gironde Estuary, SW France	Munoz et al. (2017)
Pacific oyster	*Crassostrea gigas*	Invert	6430	**6430**	medium	Gulf Park - Xiamen Sea, China	Dai and Zheng (2019)
snails	*Bithynia tentaculata*	Invert	128.4	128.4	high	Hogsmill River, Chertsey Bourne River, Blackwater River	Wilkinson et al. (2018)
amphipod	*Gammarus pulex*	Invert	118.0	**118.0**	high	Hogsmill River, Chertsey Bourne River, Blackwater River	Wilkinson et al. (2018)
Manila clam	*Ruditapes philippinarum*	Invert	3991	**3991**	high	Jiaozhou Bay, China	Cui et al. (2019)
orange-striped hermit crab	*Clibanarius infraspinatus*	Invert	3879	**3879**	medium	Jimei Bridge - Xiamen Sea, China	Dai and Zheng (2019)
Pacific oyster	*Crassostrea gigas*	Invert	4180	4180	medium	Jimei Bridge - Xiamen Sea, China	Dai and Zheng (2019)
ghost crab	*Ocypode stimpsoni*	Invert	4240	4240	medium	Jimei Bridge - Xiamen Sea, China	Dai and Zheng (2019)
diporeia	*Diporeia hoyi*	Invert	32000	32000	medium	Lake Ontario	Houde et al. (2008)
mysis	*Mysis relicta*	Invert	3000	3000	medium	Lake Ontario	Houde et al. (2008)
zooplankton	zooplankton	Invert	650.0	**650.0**	high	Lake Ontario	Houde et al. (2008)
worms	Capitellidae	Invert	913.93	913.93	high	Mai Po Marshes, Hong Kong	Loi et al. (2011)
gastropoda	Gastropoda	Invert	92.33	92.33	medium	Mai Po Marshes, Hong Kong	Loi et al. (2011)
sand prawn	*Metapenaeus ensis*	Invert	286.4	286.4	medium	Mai Po Marshes, Hong Kong	Loi et al. (2011)

Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
worms	Nereidae	Invert	78.25	**78.25**	medium	Mai Po Marshes, Hong Kong	Loi et al. (2011)
black tiger prawn	*Penaeus monodon*	Invert	220.7	220.7	medium	Mai Po Marshes, Hong Kong	Loi et al. (2011)
worms	*Sabellidae*	Invert	364.6	364.6	medium	Mai Po Marshes, Hong Kong	Loi et al. (2011)
zooplankton	zooplankton	Invert	266.0	266.0	medium	Mai Po Marshes, Hong Kong	Loi et al. (2011)
chironomids	Diptera	Invert	7000	7000	high	Meretta Lake, Canadian High Arctic	Lescord et al. (2015)
zooplankton	zooplankton	Invert	1195	**1195**	high	Meretta Lake, Canadian High Arctic	Lescord et al. (2015)
chironomids	Diptera	Invert	243333	243333	high	North Lake, Canadian High Arctic	Lescord et al. (2015)
zooplankton	zooplankton	Invert	36667	**36667**	high	North Lake, Canadian High Arctic	Lescord et al. (2015)
Snail	*Cerithidea rhizophorarum*	Invert	2.692	**2.692**	medium	Omuta River mouth and estuary, Japan	Kobayashi et al. (2018)
crab	*Carcinus aestuarii*	Invert	1623	1623	medium	Orbetell lagoon, AC Site, Italy	Renzi et al. (2013)
bivalve	*Mytilus galloprovincialis*	Invert	5029	5029	medium	Orbetell lagoon, AC Site, Italy	Renzi et al. (2013)
prawn	*Palaemon serratus*	Invert	451.4	**451.4**	medium	Orbetell lagoon, AC Site, Italy	Renzi et al. (2013)
bivalve	*Ruditapes decussatus*	Invert	1150	1150	medium	Orbetell lagoon, AC Site, Italy	Renzi et al. (2013)
crab	*Carcinus aestuarii*	Invert	551.5	551.5	medium	Orbetell lagoon, FC Site, Italy	Renzi et al. (2013)
bivalve	*Mytilus galloprovincialis*	Invert	1137	1137	medium	Orbetell lagoon, FC Site, Italy	Renzi et al. (2013)
prawn	*Palaemon serratus*	Invert	187.5	**187.5**	medium	Orbetell lagoon, FC Site, Italy	Renzi et al. (2013)
bivalve	*Ruditapes decussatus*	Invert	392.2	392.2	medium	Orbetell lagoon, FC Site, Italy	Renzi et al. (2013)
bivalve	*Ruditapes decussatus*	Invert	1059	**1059**	medium	Orbetell lagoon, M Site, Italy	Renzi et al. (2013)
crab	*Carcinus aestuarii*	Invert	1140	1140	medium	Orbetell lagoon, NC Site, Italy	Renzi et al. (2013)
bivalve	*Mytilus galloprovincialis*	Invert	2728	2728	medium	Orbetell lagoon, NC Site, Italy	Renzi et al. (2013)
prawn	*Palaemon serratus*	Invert	302.6	**302.6**	medium	Orbetell lagoon, NC Site, Italy	Renzi et al. (2013)
bivalve	*Ruditapes decussatus*	Invert	577.2	577.2	medium	Orbetell lagoon, NC Site, Italy	Renzi et al. (2013)
chironomids	Diptera	Invert	17115	17115	high	Resolute Lake, Canadian High Arctic	Lescord et al. (2015)
zooplankton	zooplankton	Invert	2308	**2308**	high	Resolute Lake, Canadian High Arctic	Lescord et al. (2015)
waterlouse, water boatmen,	Isopoda, Hemiptera, amphipoda, nematoda	Invert	942.0	**942.0**	medium	site A Stockholm Arlanda Airport	Koch et al. (2019)

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Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
amphipods, roundworm							
mayflies, caddisflies, dragonflies, water boatmen, waterlouse, fresh water amphipods	Ephemeroptera, Trichoptera, Odonata, Hemiptera, Isopoda, Amphipoda	Invert	534.0	**534.0**	medium	site K the Kvarntorp area	Koch et al. (2019)
fresh water amphipods	Amphipoda	Invert	905.0	**905.0**	medium	site R Ronneby Airport	Koch et al. (2019)
chironomids	Diptera	Invert	58889	58889	high	Small Lake, Canadian High Arctic	Lescord et al. (2015)
zooplankton	zooplankton	Invert	2444	**2444**	high	Small Lake, Canadian High Arctic	Lescord et al. (2015)
rock oyster	*Saccostrea commercialis*	Invert	85.71	**85.71**	medium	Sydney Harbour, Australia	Thompson et al. (2011)
freshwater mussel	Unionidae	Invert	572.2	572.2	high	Taihu Lake, China	Fang et al. (2014)
pearl mussel	Unionidae	Invert	1011	1011	high	Taihu Lake, China	Fang et al. (2014)
zooplankton	zooplankton	Invert	380.3	**380.3**	high	Taihu Lake, China	Fang et al. (2014)
amphipod	*Gammarus sp., Hyalella sp.*	Invert	6015	**6015**	high	Welland River, Hamilton, Ontario, Canada	De Solla et al. (2012)

a – WB (Fish whole body); Invert (Invertebrate whole body)
b – Lowest species level BAF (highlighted in bold) at each site represents the site-level BAF
c – One site level BAF represented by two species tied for lowest species level BAF

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O.2 Summary of PFOS BAFs used to calculate tissue criteria and supplemental fish tissue values

Field measured BAFs used to calculate fish and invertebrate PFOS tissue criteria (fish muscle, fish whole body, and invertebrate whole body) and supplemental fish tissue values (blood, reproductive tissue, liver) are shown in Appendix O.1. Summary statistics for the BAFs from this table used to derive tissue criteria and additional tissue values (i.e., lowest species-level BAF from each site) are reported in Table 3-11 and Table P-2, respectively. Rankings for individual BAFs were determined by Burkhard (2021), who devised a ranking system based on five characteristics: 1) number of water samples; 2) number of tissue samples; 3) spatial coordination of water and tissue samples; 4) temporal coordination of water and tissue samples; and 5) general experimental design. For the first four characteristics, a score of one to three was assigned, based on number of samples or how closely the water and tissue measurements were paired. For the experimental design characteristic, a default value of zero was assigned; unless the measured tissues were composites of mixed species, in which case it was assigned a three (Burkhard 2021). These sub-scores were then summed and assigned a rank based on the final score. Studies with high quality rankings had scores of four or five, studies with medium quality rankings had scores of five or six, and studies with low quality rankings had scores of seven or higher (Burkhard 2021). Parameters for the scores assigned to the five characteristics are listed in Table 2-2, and additional details can be found in Burkhard (2021). Only BAFs from studies with high or medium quality rankings were included for the final BAF geometric mean calculations used to derive tissue criteria (Table 3-12) and supplemental tissue values (Table P-3).

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O.3 PFOS BAFs References

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Appendix P Translation of Chronic Water Column Criterion into Other Fish Tissue Types (liver, blood, reproductive tissues)

The PFOS aquatic life criteria (summarized in Section 3.3) include chronic tissue criteria for fish whole body, fish muscle, and invertebrate whole-body. Additional values for fish liver, fish blood, and fish reproductive tissues were also calculated by transforming the chronic water column criterion (i.e., 0.00025 mg/L) into representative tissue concentrations using tissue-specific bioaccumulation factors (BAFs). Fish BAFs for liver, blood, and reproductive tissues were identified following the same approaches used to identify fish whole body, muscle, and inverterbrate whole body BAFs, which are described in detail in Section 2.11.3.1. Briefly, BAFs were determined from field measurements and calculated using the equation:

$$BAF = \frac{C_{biota}}{C_{water}} \qquad (Eq.\ P\text{-}1)$$

Where:
C_{biota} = PFOS concentration in organismal tissue(s)
C_{water} = PFOS concentration in water

For further details on BAFs compilation and ranking, see Section 2.11.3.1 and Burkhard (2021). BAFs based on reproductive tissues identified by Burkhard (2021) were further screened to evaluate characteristics that influence reproductive tissue BAFs. These characteristics included timing of sample collection and organism sex, age, length and weight. However, since the data were limited, the influence of these characteristics could not be fully evaluated to determine their potential influence on PFOS BAFs for reproductive tissues. Therefore, characteristics of timing of sample collection and organism age, length or weight were currently not considered to be influential given available data. Reproductive tissue BAFs were additionally screened to ensure only BAFs based on adult females were considered, because female

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reproductive tissues are most relevant to potential maternal transfer to offspring. This subset of reproductive-based BAFs and corresponding species and sampling locations are described in Table P-1.

Table P-1. Characteristics of adult fish sampled for the calculation of PFOS reproductive tissue BAFs.

All sampled fish were adults, and all reproductive tissues identified as gonad. Weights, lengths, and BAFs are averages.

Author	Species	Collection Date	n	Sex	Age (yr.)	Weight (g-ww)	Length (cm)	BAF (L/kg)
Ahrens et al. (2015)	European perch (*Perca fluviatilis*)	10/12/2012	3	F	7, 8, 9	N.R.	N.R.	16,000
Becker et al. (2010)	European chub (*Leuciscus cephalus*)	8/28/2007	6	N.R.	4	178.5	25.5	2,222
Labadie and Chevreuil (2011)	European chub (*Leuciscus cephalus*)	April 2010	5	3 M 2 F	N.R.	228.0 (M) 258.2 (F)	28.5 (M) 27.8 (F)	10,000
Shi et al. (2015, 2018)	Crucian carp (*Carassius carassius*)	July 2014[1]	30	24 F 6 M	N.R.	79.4 (F) 60.5 (M)	15.0 (F) 13.7 (M)	11,482
Shi et al. (2015, 2018)	Crucian carp (*Carassius carassius*)	July 2014[2]	13	9 F 4 M	N.R.	352.3 (F) 320.7 (M)	24.6 (F) 24.8 (M)	5,888
Shi et al. (2020)	Crucian carp (*Carassius carassius*)	N.R.	30[3]	N.R.	N.R.	N.R.	N.R.	7,990
Shi et al. (2020)	Crucian carp (*Carassius carassius*)	N.R.	20[3]	N.R.	N.R.	N.R.	N.R.	8,012
Wang et al. (2016)	Crucian carp (*Carassius carassius*)	April 2014	8	N.R.	N.R.	(16.8 - 65.1)[5]	(10.0 - 14.7)[5]	25,645

N.R.= Not Reported
[1]Xiaoqing River, China
[2]Tangxun Lake, China
[3]Yubei River, China
[4]Gaobeidian Lake, China
[5]Range

The distributions of fish liver, fish blood, and fish reproductive BAFs identified in the literature used to calculate tissue-specific BAFs were determined in the same manner as invertebrate, fish muscle, and fish whole body BAFs (Section 3.2.3.1). Briefly, distributions of BAFs used to derive additional tissue values were based on the lowest species-level BAF

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reported at a site. When more than one BAF was available for the same species at the same site, the species-level BAF was calculated as the geometric mean of all BAFs for that species at that site. Summary statistics for the PFOA BAFs used in the derivation of the additional tissue-based values are presented below (Table P-2) and individual BAFs are provided in Appendix O.

Table P-2. Summary Statistics for PFOS BAFs in Additional Fish Tissues[1].

Category	n	Geometric Mean BAF (L/kg-wet weight)	Median BAF (L/kg-wet weight)	20th Centile BAF (L/kg-wet weight)	Minimum (L/kg-wet weight)	Maximum (L/kg-wet weight)
Liver	19	5,688	4,572	2,462	111	83,753
Blood	11	14,355	11,167	6,273	3,500	80,168
Reproductive Tissue	8	8,903	9,006	5,155	2,222	25,645

1- Based on the lowest species-level BAF measured at a site (i.e., when two or more BAFs were available for the same species at the same site, the species-level geometric mean BAF was calculated, and the lowest species-level BAF was used).

The chronic freshwater column criterion (see Section 3.2.1.3) was then translated into tissue values using the 20th centile BAFs from the distributions of BAFs summarized in Table P-2 using the following equation:

$$Tissue\ Value = Chronic\ Water\ Column\ Criterion \times 20th\ \ Centile\ BAF \qquad (Eq.\ Q\text{-}2)$$

The resulting tissue values that correspond to the 20th centile tissue-specific BAF used in equation Q-2 are reported in Table P-3. The values reported in Table P-3 represent tissue-based concentrations that offer a level of protection that is equal to the magnitude components of the chronic water column criterion as well as the fish whole body, fish muscle, and invertebrate whole-body tissue-based criteria; however, the tissue-based values reported in Table P-3 are only presented for comparative purposes and are not recommended criteria.

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Table P-3. PFOS Concentrations for Additional Fish Tissue.[1, 2]

Category	PFOS Concentration (mg/kg ww)
Liver	0.616
Blood	1.57
Reproductive Tissue	1.29

[1] These PFOS concentrations are provided as supplemental information and are not intended to replace the PFOS fish tissue criteria provided in Table .

[2] Tissue criteria derived from the chronic water column concentration (CCC) with the use of bioaccumulation factors and are expressed as wet weight (ww) concentrations.

Appendix Q Example Data Evaluation Records (DERs)

The PFOS toxicity literature evaluated and used to derive the PFOS aquatic life criteria was identified using the ECOTOXicology database (ECOTOX; https://cfpub.epa.gov/ecotox/) as meeting data quality standards. ECOTOX is a source of high-quality toxicity data for aquatic life, terrestrial plants, and wildlife. The database was created and is maintained by the EPA, Office of Research and Development, Center for Computational Toxicology and Exposure. The ECOTOX search generally begins with a comprehensive chemical-specific literature search of the open literature conducted according to ECOTOX Standard Operating Procedures (SOPs). The search terms are often comprised of chemical terms, synonyms, degradates and verified Chemical Abstracts Service (CAS) numbers. After developing the literature search strategy, ECOTOX curators conduct a series of searches, identify potentially applicable studies based on title and abstract, acquire potentially applicable studies, and then apply the applicability criteria for inclusion in ECOTOX. Applicability criteria for inclusion into ECOTOX generally include:

1. The toxic effects are related to single chemical exposure (unless the study is being considered as part of a mixture effects assessment);
2. There is a biological effect on live, whole organisms or *in vitro* preparation including gene chips or omics data on adverse outcome pathways potentially of interest;
3. Chemical test concentrations are reported;
4. There is an explicit duration of exposure;
5. Toxicology information that is relevant to OW is reported for the chemical of concern;
6. The paper is published in the English language;
7. The paper is available as a full article (not an abstract);
8. The paper is publicly available;
9. The paper is the primary source of the data;
10. A calculated endpoint is reported or can be calculated using reported or available information;
11. Treatment(s) are compared to an acceptable control;
12. The location of the study (*e.g.*, laboratory vs. field) is reported; and
13. The tested species is reported (with recognized nomenclature).

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Following inclusion in the ECOTOX database, toxicity studies are subsequently evaluated by the Office of Water. All studies were evaluated for data quality generally as described by U.S. EPA (1985) in the 1985 Guidelines and in the EPA's Office of Chemical Safety and Pollution Prevention (OCSPP)'s Ecological Effects Test Guidelines (U.S. EPA 2016b), and the EPA OW's internal data quality SOP, which is consistent with OCSPP's data quality review approach (U.S. EPA 2018). These toxicity data were further screened to ensure that the observed effects could be primarily attributed to PFOS exposure. Office of Water completed a DER for each species by chemical combination from the PFOS studies identified by ECOTOX. Example DERs are presented here to convey the meticulous level of evaluation, review, and documentation each PFOS study identified by ECOTOX was subject to. Appendix Q.1 shows an example fish DER and Appendix Q.2 shows an example aquatic invertebrate DER.

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Q.1 Example Fish DER

Part A: Overview

I. Test Information

Chemical name:

CAS name: CAS Number:
Purity: Storage conditions:
Solubility in Water (units):

____ **Controlled Experiment** (*manipulated*) ____ **Field Study/Observation** (*not manipulated*) (*Place X by One*)

Primary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)

Secondary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)
(*At least one reviewer should be from EPA for sensitive taxa*)

Citation: *Indicate: author(s), year, study title, journal, volume, and pages*.
(e.g., Slonim, A.R. 1973. Acute toxicity of beryllium sulfate to the common guppy. J. Wat. Pollut. Contr. Fed. 45(10): 2110-2122)

Companion Papers: *Identify any companion papers associated with this paper using the citation format above.*

Were other DERs completed for Companion Papers? ____ **Yes** ____ **No** (*If yes, list file names of DERs below*)

Study Classification for Aquatic Life Criteria Development: *Place X by One Based on Highest Use*

_____ Acceptable for Quantitative Use
_____ Acceptable for Qualitative Use
_____ Not Acceptable for Use/Unused

General Notes: *Provide any necessary details regarding the study's use classification for all pertinent endpoints, including non-apical endpoints within the study (e.g., note all study classifications for each endpoint if the use varies)*

Major Deficiencies (note any stated exclusions): *Check all that apply. Checking any of these items make the study "**Not Acceptable for Use**"*

_____ Mixture (for controlled experiments only)
_____ No Controls (for controlled experiments only)
_____ Excessive Control Mortality (> 10% for acute and > 20% for chronic)
_____ Dilution water not adequately characterized
_____ Bioaccumulation: steady state not reached
_____ Dermal or Injection Exposure Pathway
_____ Review paper or previously published without modification

_____ Other: *(if any, list here*)

POTENTIAL CHEMICAL MIXTURES: *Describe any potential chemicals mixtures as characterized by study authors (including any confirmation of chemical mixtures).*

DESCRIPTION OF DILUTION WATER: *Describe concerns with characterization of and/or major deficiencies with dilution water.*

General Notes:

Minor Deficiencies: *List and describe any minor deficiencies or other concerns with test. These items may make the study "**Acceptable for Qualitative Use**"* **(exceptions may apply as noted)**

***For Field Studies/Observations**: A field study/observation may be considered "**Acceptable for Quantitative Use**" if it consisted of a range of exposure concentrations and the observed effects are justifiably contributed to a single chemical exposure*

_____ Mixture (observed effects not justifiably contributed to single chemical exposure)
_____ Uncharacterized Reference Sites/Conditions

POTENTIAL CHEMICAL MIXTURES PRESENT AT SITE: *Describe any potential chemicals mixtures present at the site as characterized by study authors (including any confirmation of chemicals present at study site).*

EXPOSURE VARIABILITY ACROSS STUDY SITE(S): *Describe any exposure variability across study site(s) as characterized by study authors (i.e., description of study design with reference and contaminated sites).*

General Notes:

Reviewer's Comments: *Provide additional comments that do not appear under other sections of the DER*.

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ABSTRACT: *Copy and paste abstract from publication.*

SUMMARY*: Fill out and modify as needed.*

Acute:

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Hardness (mg/L as $CaCO_3$) or Salinity (ppt)	DOC (mg/L)	Effect	Reported Effect Concentration (mg/L)	Verified Effect Concentration (mg/L)	Classification
											Quantitative / Qualitative / Unused

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

Chronic:

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Hardness (mg/L as $CaCO_3$) or Salinity (ppt)	DOC (mg/L)	Chronic Limits	Reported Chronic Value (mg/L or µg/g)	Verified Chronic Value (mg/L or µg/g)	Chronic Value Endpoint	Classification
												Quantitative / Qualitative / Unused

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

II. Results *Provide results as reported in the publication (including supplemental materials). Include screen shots of tables and/or figures reporting results from the article following tabulated data table in each associated results section for all studies. Complete tabulated data tables for all studies for studies marked "**Acceptable for Quantitative Use"** and **"Acceptable for Qualitative Use**".*

Water Quality Parameters: *If only general summary data of water quality parameters is provided by study authors (i.e., no specific details of water quality parameters on a treatment level is provided), summarize any information regarding water quality parameters under General Notes below and indicate data not provided in* Table A.II.1.

General Notes: *For aquatic life criteria development, measured water quality parameters in the treatments nearest the toxicity test endpoint(s), e.g., LC_{50}, EC_{20}, etc., are most relevant.*

Table A.II.1. Measured Water Quality Parameters in Test Solutions.

Dissolved oxygen, temperature, pH and [other parameters (hardness, salinity, DOC)] in test solutions during the *[X]*-day exposure of *[test organism]* to *[concentration of treatment(s)]* of *[test substance]* under *[static renewal/flow-through]* conditions.

Parameter	Treatment	Mean	Range
Dissolved Oxygen (% saturation or mg/L)	*[1]*		
	[2]		
	j		
	j		
Temperature (°C)	*[1]*		
	[2]		
	j		
	j		
pH	*[1]*		
	[2]		
	j		
	j		
Other (e.g., hardness, salinity, DOC)	*[1]*		
	[2]		
	j		
	j		

Chemical Concentrations: *Summarize the concentration verification data from test solutions/media. Expand table to include measured concentration data for each media type (i.e., water, diet, muscle, liver, blood, etc.).*

General Notes: *Provide any necessary detail regarding the measured concentrations, including any identified cause for substantial differences between nominal and measured concentrations, if samples were collected on separate days (and if so provide details), and any potential cross contamination.*

Table A.II.2. Measured (and Nominal) Chemical Concentrations in Test Solutions/Media.

[Analytical Method] verification of test and control concentrations during an [X]-day exposure of [test organism] to [test substance] under [static renewal/flow-through] conditions.

Treatment	Nominal Concentration (units)	[Mean] Measured Concentration (units)	Number of Samples	Non-Detect[a]	Number of Samples Below Non-Detect	[Standard Deviation or Standard Error]	Range
Control							
[1]							
[2]							
[3]							
[4]							
[5]							
[6]							
j							

[a]Non-Detect: 0 = measured and detected; 1= measured and not detected; if not measured or reported enter as such

Mortality: *Briefly summarize mortality results (if any).*

General Notes: *Comment on concentrations response relationship and slope of response if provided. Compare mortality in treatments with control group and/or the reference chemical.*

Table A.II.3. Mean Percent [Mortality or Survival].

Mean percent mortality [or number of immobilized, survival] of [test organism] exposed to [test substance] for [test duration] under [static/renewal/flow-through] conditions.

Treatment	[Mean % Mortality]	[Standard Deviation or Standard Error]
Control		
[1]		
[2]		
[3]		
[4]		
[5]		
[6]		
[LCx]		
NOEC		
LOEC		

[a] Use superscript to identify the values reported to be significantly different from control.

Growth: *Briefly summarize growth results (if any).*

General Notes: *Comment on concentrations response relationship and slope of response if provided. Compare growth endpoints in treatments with control group and/or the reference chemical.*

Table A.II.4. Mean [Growth].

Mean growth [length and/or weight] of [test organism] exposed to [test substance] for [test duration] under [static/renewal/flow-through] conditions.

Treatment	Mean Growth [Length/Weight] (units)	[Standard Deviation or Standard Error]	Mean Percent Change in [Length/ Biomass]	[Standard Deviation or Standard Error]
Control				
[1]				
[2]				
[3]				
[4]				
[5]				
[6]				
j				
[ECx]				
NOEC				
LOEC				

[a] Use superscript to identify the values reported to be significantly different from control.

Reproductive: *Briefly summarize reproduction endpoint results (if any). For multi-generational studies, copy and paste* Table A.II.5 *below for each generation with reproductive effects data.*

General Notes: *Comment on concentrations response relationship and slope of response if provided. Compare reproductive endpoints in treatments with control group and/or the reference chemical.*

Table A.II.5. Mean [Reproductive] Effect.

Mean [reproductive] effects for [generation] of [test organism] exposed to [test substance] for [test duration] under [static/renewal/flow-through] conditions.

Treatment (units)	[Mean Number of Spawns]	[Standard Deviation or Standard Error]	[Mean Number of Eggs]	[Standard Deviation or Standard Error]	[Mean Percent Hatch]	[Standard Deviation or Standard Error]	[Mean Hatch Percent Survival Post]	[Standard Deviation or Standard Error]
Control								
[1]								
[2]								
[3]								
[4]								
[5]								
[6]								
j								
[ECx]								
NOEC								
LOEC								

[a] Use superscript to identify the values reported to be significantly different from control.

Sublethal Toxicity Endpoints: *Include other sublethal effect(s), including behavioral abnormalities or other signs of toxicity, if any. Copy* Table A.II.6 *as needed to provide details for each sublethal effect observed.*

General Notes: *Briefly summarize observed sublethal effects otherwise not captured in the results table(s) below.*

Table A.II.6. Mean [Sublethal] Effect.

*Mean [*Sublethal effect*, (e.g., behavioral abnormalities, etc.)]* in *[test organism]* during [test duration (*acute/chronic*)] exposure to *[test substance]* under *[static/renewal/flow-through]* conditions.

Treatment	[Mean Sublethal Response] (units)	[Standard Deviation or Standard Error]
Control		
[1]		
[2]		
[3]		
[4]		
[5]		
[6]		
j		
[ECx]		
NOEC		
LOEC		

[a] Use superscript to identify the values reported to be significantly different from control

Reported Statistics: *Copy and paste statistical section from publication.*

Part B: Detailed Review
I. Materials and Methods

Protocol/Guidance Followed: *Indicate if provided by authors.*

Deviations from Protocol: *If authors report any deviations from the protocol noted above indicate here.*

Study Design and Methods: *Copy and paste methods section from publication.*

TEST ORGANISM: *Provide information under Details and any relevant or related information or clarifications in Remarks.*

Parameter	Details	Remarks
Species:	Common Name: Scientific Name:	North American species? ____ Surrogate for North American Taxon? ____ *(Place X if applicable)*

Strain/Source:
• Wild caught from unpolluted areas [1]
  o Quarantine for at least 14 days or until they are disease free, before acclimation [1]
• Must originate from same source and population [1]
• Should not be used:
  o If appeared stressed, such as discoloration or unusual behavior [1]
  o If more than 5% die during the 48 hours before test initiation [1]
  o If they were used in previous test treatments or controls [2]
• No treatments of diseases may be administered:
  o Within 16 hour of field collection [1]
  o Within 10 days or testing or during testing [1]		

Age at Study Initiation:
Acute:
• Juvenile stages preferred [1]
Chronic:
• Life-cycle test:
  o Embryos or newly hatched young < 48 hours old [2]
• Partial life-cycle test:
  o Immature juveniles at least 2 months prior to active gonad development [2]
• Early life-stage test:
  o Shortly after fertilization [2]		

Was body weight or length recorded at test initiation?	____ Yes ____ No	
Was body weight or length recorded at regular intervals?	____ Yes ____ No *If yes, describe regular intervals:*	

STUDY PARAMETERS: *Provide information under Details and any relevant information of deficiencies in Remarks. Complete for <u>both Controlled Experiments and Field Studies/Observations.</u>*

	Parameter	Details	Remarks
For Both Controlled Experiments and Field Observations	**Number of Replicates per Treatment Group:** • At least 2 replicates/treatment recommended for acute tests [1] • At least 2 replicates/treatment recommended for chronic tests [3]	Control(s): Treatment(s):	
	Number of Organisms per Replicate/ Treatment Group: • At least 10 organisms/treatment recommended [3] • At least 7 organisms/treatment acceptable [4]	Control(s): Treatment(s):	
	Exposure Pathway: *(i.e., water, sediment, gavage, or diet).* *Note: all other pathways (e.g., dermal, single dose via gavage, and injection) are unacceptable.*		
	Exposure Duration: **Acute** • Should be 96 hours [2] **Chronic** • Life-cycle tests: o Ensure that all life stages and life processes are exposed [2] o Begin with embryos (or newly hatched young), continue through maturation and reproduction, and should end not less than 24 days (90 days for salmonids) after the hatching of the next generation [2] • Partial life-cycle tests: o Allowed with species that require >1 year to reach sexual maturity, so that all major life stages can be exposed to the test material in <15 months [2] o Begin with immature juveniles at least 2 months prior to active gonad development, continue through maturation and reproduction, and end not less than 24 days (90 days for salmonids) after the hatching of the next generation [2] • Early life-cycle tests: o 28 to 32 day (60 day post hatch for salmonids) exposures from shortly after fertilization through embryonic, larval, and early juvenile development [2]	____ Acute ____ Partial Life Cycle ____ Early Life Stage ____ Full Life Cycle ____ Other *(please remark):*	
	Test Concentrations (remember units): *Recommended test concentrations include at least three concentrations other than the control; four or more will provide a better statistical analysis* [3]	Nominal: Measured: Media measured in:	
	Observation Intervals: • Should be an appropriate number of observations over the study to ensure water quality is being properly maintained [4]		

CONTROLLED EXPERIMENT STUDY PARAMETERS: *Provide information under Details and any relevant information of deficiencies in Remarks. Complete for Controlled Experiments only.*

For Controlled Experiments Only

Parameter	Details	Remarks

Acclimation/Holding:
• Should be placed in a tank along with the water in which they were transported
  o Water should be changed gradually to 100% dilution water (usually 2 or more days) [1]
  o For wild-caught animals, test water temperature should be within 5°C of collection water temperature [1]
  o Temperature change rate should not exceed 3°C within 72 hours [1]
• To avoid unnecessary stress and promote good health:
  o Organisms should not be crowded [1]
  o Water temperature variation should be limited [1]
  o Dissolved oxygen:
  ▪ Maintain between 60 - 100% saturation [1]
  ▪ Continuous gentle aeration if needed [1]
  o Unionized ammonia concentration in holding and acclimation waters should be < 35 µg/L [1]
	Duration:
	Feeding:
	Water type:
	Temperature (°C):
	Dissolved Oxygen (mg/L):
	Health (*any mortality observed?*):
		Identify number of individuals excluded from testing and/or analysis (if any):

Acclimation followed published guidance? *Describe, if any*	____ Yes ____ No *If yes, indicate which guidance:*	

Test Vessel:
• Test chambers should be loosely covered [1]
• Test chamber material:
  o Should minimize sorption of test chemical from water [1]
  o Should not contain substances that can be leached or dissolved in solution and are free of substances that could react with exposure chemical [1]
  o Glass, No. 316 stainless steel, nylon screen and perfluorocarbon (e.g. Teflon) are acceptable [1]
  o Rubber, copper, brass, galvanized metal, epoxy glues, lead and flexible tubing should not come into contact with test solution, dil. water, or stock [1]
• Size/volume should maintain acceptable biomass loading rates (see Biomass Loading Rate below) [1]
	Material:
	Size:
	Fill Volume:
		Briefly describe the test vessel:

Test Solution Delivery System/Method:
• Flow-through preferred for some highly volatile, hydrolysable or degradable materials [2]
  o Concentrations should be measured often enough using acceptable analytical methods [2]
• Chronic exposures:
  o Flow-through, measured tests required [2]
	Test Concentrations Measured
	____ Yes ____ No
	
	Test Solution Delivery System:
	____ Static
	____ Renewal
	Indicate Interval:
	
	____ Flow-through
	Indicate Type of Diluter:	

Source of Dilution Water:
• Freshwater hardness range should be < 5 mg/L or < 10% of the average (whichever is greater) [1]
• Saltwater salinity range should be < 2 g/kg or < 20% of the average (whichever is greater) [1]
• Dilution water must be characterized (natural surface water, well water, etc.) [3]
  o Distilled/deionized water without the addition of appropriate salts should not be used [2]
• Dilution water in which total organic carbon or particulate matter >5 mg/L should not be used [2]
  o Unless data show that organic carbon or particulate matter do not affect toxicity [2]		

Dilution Series (*e.g., 0.5x, 0.6x, etc.*):		

	Parameter	Details	Remarks
For Controlled Experiments Only	**Dilution Water Parameters:** *Measured at the beginning of the experiment or averaged over the duration of the experiment (details of water quality parameters measured in test solutions should be included under the results section)*	Dissolved Oxygen (mg/L): pH: Temperature (°C): Hardness (mg/L as $CaCO_3$): Salinity (ppt): Total Organic Carbon (mg/L): Dissolved Organic Carbon (mg/L):	
	Aeration: • Acceptable to maintain dissolved oxygen at 60 - 100% saturation at all times [1] • Avoid aeration when testing highly oxidizable, reducible and volatile materials [1] • Turbulence should be minimized to prevent stress on test organisms and/or re-suspend fecal matter [1] • Aeration should be the same in all test chambers at all times [1]	____ Yes ____ No	
	Describe Preparation of Test Concentrations (e.g., water exposure, diet):		
	Test Chemical Solubility in Water: *List units and conditions (e.g., 0.01% at 20ºC)*		
	Were concentrations in water or diet verified by chemical analysis? *Measured test concentrations should be reported in* Table A.II.2 *above.*	__Yes __No *Indicate media:*	
	Were test concentrations verified by chemical analysis in tissue? *Measured test concentrations can be verified in test organism tissue (e.g., blood, liver, muscle) alone if a dose-response relationship is observed.* *Measured test concentrations should be reported in* Table A.II.2 *above.*	__Yes __No *Indicate tissue type:*	*If test concentrations were verified in test organism tissue, was a dose-response relationship observed?*
	Were stability and homogeneity of test material in water/diet determined?	__Yes __No	
	Was test material regurgitated/avoided?	__Yes __No	
	Solvent/Vehicle Type (Water or Dietary): • When used, a carrier solvent should be kept to a minimum concentration [1] • Should not affect either survival or growth of test organisms [1] • Should be reagent grade or better [1] • Should not exceed 0.5 ml/L (static) or 0.1 ml/L (flow through) unless it was shown that higher concentrations do not affect toxicity [3]		
	Negative Control:	____ Yes ____ No	
	Reference Toxicant Testing:	____ Yes ____ No	*If Yes, identify substance:*
	Other Control: *If any (e.g. solvent control)*		

	Biomass Loading Rate:
	• Loading should be limited so as not to affect test results. Loading will vary depending on temperature, type of test (static vs. flow-through), species, food/feeding regime, chamber size, test solution volume, etc. [1]
	• This maximum number would have to be determined for the species, test duration, temperature, flow rate, test solution volume, chamber size, food, feeding regime, etc.
	• Loading should be sufficiently low to ensure:
	  ○ Dissolved oxygen is at least 60% of saturation (40% for warm-water species) [1,5]
	  ○ Unionized ammonia does not exceed 35 µg/L [1]
	  ○ Uptake by test organisms does not lower test material concentration by > 20% [1]
	  ○ Growth of organisms is not reduced by crowding
	• Generally, at the end of the test, the loading (grams of organisms; wet weight; blotted dry) in each test chamber should not exceed the following:
	  ○ Static tests: > 0.8 g/L (lower temperatures); > 0.5 g/L (higher temperatures) [1]
	  ○ Flow through tests: > 1 g/L/day or > 10 g/L at any time (lower temperatures); > 0.5 g/L/day or > 5 g/L at any time (higher temperatures) [1]
	• Lower temperatures are defined as the lower of 17˚C or the optimal test temperature for that species [1]		

	Parameter	Details	Remarks

For Controlled Experiments Only	**Feeding:**
	• Unacceptable for acute tests [2]
	  o Exceptions:
	  ▪ Data indicate that the food did not affect the toxicity of the test material [2]
	  ▪ Test organisms will be severely stressed if they are unfed for 96 hours [2]
	  ▪ Test material is very soluble and does not sorb or complex readily (e.g., ammonia) [2]
		____ Yes ____ No	

	Lighting:
	• Depends on the type of test (acute or chronic) and endpoint (e.g., reproduction) of interest.
	  o Embryos should be incubated under dim incandescent lighting (≤ 20 fc) or total darkness during early life-stage toxicity testing
	  o Embryos must not be subjected to prolonged exposure to direct sunlight, fluorescent lighting, or high intensity incandescent lighting
	• Generally, ambient laboratory levels (50-100 fc) or natural lighting should be acceptable, as well as a diurnal cycle consisting of 50% daylight or other natural seasonal diurnal cycle.
	• Artificial light cycles should have a 15 – 30-minute transition period to avoid stress due to rapid increases in light intensity [1]		

Study Design/Methods Classification: *(Place X by One Based on Overall Study Design/Methods Classification)*
Provide details of Major or Minor Deficiencies/Concerns with Study Design in Associated Sections of Part A: Overview
This classification should be taken into consideration for the overall study classification for aquatic life criteria development in Part A.

_____ Study Design Acceptable for Quantitative Use
_____ Study Design Acceptable for Qualitative Use
_____ Study Design Not Acceptable for Use

Additional Notes: *Provide additional considerations for the classification of study use based on the study design.*

OBSERVATIONS: *Provide information under Details and any relevant information in Remarks. This information should be consistent with the Results Section in Part A.*

Parameter	Details	Remarks

Parameters measured including sublethal effects/toxicity symptoms:
Common Apical Parameters Include:
Acute
• EC_{50} based on percentage of organisms exhibiting loss of equilibrium plus the percentage of organisms immobilized plus percentage of organisms killed [2]
  ○ If not available, the 96-hr LC_{50} should be used [2]
Chronic
• Life-cycle/Partial Life-cycle test:
  ○ Survival and growth of adults and young, maturation of males and females, eggs spawned per female, embryo viability (salmonids only), and hatchability [2]
• Early life-cycle test:
  ○ Survival and growth [2]
	List parameters:	

Was control survival acceptable? **Acute** • > 90% control survival at test termination [2] **Chronic** • > 80% control survival at test termination [2]	____ Yes ____ No Control survival (%):	
Were individuals excluded from the analysis?	____ Yes ____ No *If yes, describe justification provided:*	
Was water quality in test chambers acceptable? • If appropriate, describe any water quality issues (e.g., dissolved oxygen level below 60% of saturation)	____ Yes ____ No	
Availability of concentration-response data: • Were treatment level concentration-response data included in study publication (can be from tables, graphs, or supplemental materials)? *specify endpoints in remarks* • Were replicate level concentration-response data included in study publication (can be from tables, graphs, or supplemental materials)? *specify endpoints in remarks* • If treatment and/or replicate level concentration-response data were included, how was data presented? *(check all that apply)* • Were concentration-response data estimated from graphs study publication or supplemental materials? • Should additional concentration-response data be requested from study authors? *If concentration-response data are available, complete **Verification of Statistical Results (Part C)** for sensitive species.*	____ Yes ____ No ____ Yes ____ No ____ Tables ____ Graphs ____ Supplemental Files ____ Yes ____ No *If yes, indicate software used:* ____ Yes ____ No Requested by: Request date: Date additional data received:	

Part C: Statistical Verification of Results

I. Statistical Verification Information: *Report the statistical methods (e.g., EPA TRAP, BMDS, R, other) used to verify the reported study or test results for the five (5) most sensitive genera and sensitive apical endpoints (including for tests where such estimates were not provided). If values for the LC_{50}, LT_{50} and NOEC are greater than the highest test concentration, use the ">" symbol.*

Primary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)

Secondary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)
(*At least one reviewer should be from EPA for sensitive taxa*)

Endpoint(s) Verified:

Additional Calculated Endpoint(s):

Statistical Method (e.g., TRAP, BMDS, R, other):

II. Toxicity Values: *Include confidence intervals if applicable*

NOEC:
LOEC:
MATC:

EC_5:
EC_{10}:
EC_{20}:
EC_{50} or LC_{50}

Dose-Response Curve Classification: *(Place X by One)*
This classification should be taken into consideration for the overall study classification for aquatic life criteria development in Part A

_____ Dose-Response Curve Acceptable for Quantitative Use
_____ Dose-Response Curve Acceptable for Qualitative Use
_____ Dose-Response Curve Not Acceptable for Use

Summary of Statistical Verification: *Provide summary of methods used in statistical verification.*

Additional Notes:

Attachments:

1. *Provide attachments to ensure all data used in Part C are captured, whether from study results reported in the publication and/or from additional data requested from study authors*
    - *Data from study results of the publication should be reported in Results section of Part A*
    - *Additional data provided upon request from study authors should be reported in Table C.II.1 below and original correspondence with study authors should be included as attachments*
2. *Model assessment output (including all model figures, tables, and fit metrics)*
3. *Statistical code used for curve fitting*

III. Attachments: *Include all attachments listed above after the table below.*

Additional Data Used in Response-Curve: *Provide all data used to fit dose-response curve not captured in Results section of DER above in Part A. Add rows as needed. First row in italicized text is an example.*

Table C.II.1 Additional Data Used in Dose-Response Curve.

Curve ID	Species	Endpoint	Treatment	Replicate	[Standard Deviation or Standard Error]	# of Survivors	N[a]	k[a]	n[a]	Response	Response Unit	Conc	Conc units
Alchronic1	*Ceriodaphnia dubia*	*# of young/female*	*0*	*6*			*10*	*10*	*1*	*18*	*count*	*0.03*	*mg/L*

[a] N = number of individuals per treatment; k = number of replicates per treatment level; n = number of individuals per replicate

Part D: References to Test Guidance

1. ASTM Standard E 739, 1980. 2002. Standard guide for conducting acute toxicity tests on test materials with fishes, macroinvertebrates, and amphibians. ASTM International, West Conshohocken, PA.
2. Stephan, C.E., D.I. Mount, D.J. Hansen, J.H. Gentile, G.A. Chapman and W.A. Brungs. 1985. Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and their Uses. PB85-227049. National Technical Information Service, Springfield, VA.
3. Stephan, C.E. 1995. Review of results of toxicity tests with aquatic organisms. Draft. U.S. EPA, MED. Duluth, MN. 13 pp.
4. OECD 203. 1992. Test No. 203: Fish, Acute Toxicity Test. OECD Guidelines for the Testing of Chemicals, Section 2, OECD Publishing, Paris, https://doi.org/10.1787/9789264069961-en.
5. American Public Health Association (APHA). 2012. Standard methods for the examination of water and wastewater. Part 8000 - Toxicity. APHA. Washington, DC.

Q.2 Example Aquatic Invertebrate DER

Part A: Overview

I. Test Information

Chemical name:

CAS name: CAS Number:
Purity: Storage conditions:
Solubility in Water (units):

____ **Controlled Experiment** (*manipulated*) ____ **Field Study/Observation** (*not manipulated*) (*Place X by One*)

Primary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)

Secondary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)
(*At least one reviewer should be from EPA for sensitive taxa*)

Citation: *Indicate: author(s), year, study title, journal, volume, and pages.*
(e.g., Keller, A.E and S.G. Zam. 1991. The acute toxicity of selected metals to the freshwater mussel, *Anodonta imbecilis*. Environ. Toxicol. Chem. 10(4): 539-546.)

Companion Papers: *Identify any companion papers associated with this paper using the citation format above.*

Were other DERs completed for Companion Papers? ____ **Yes** ____ **No** (*If yes, list file names of DERs below*)

Study Classification for Aquatic Life Criteria Development:

_____ Acceptable for Quantitative Use
_____ Acceptable for Qualitative Use
_____ Not Acceptable for Use/Unused

General Notes: *Provide any necessary details regarding the study's use classification for all pertinent endpoints, including non-apical endpoints within the study (e.g., note all study classifications for each endpoint if the use varies)*

Major Deficiencies (note any stated exclusions): *Check all that apply. Checking any of these items make the study "**Not Acceptable for Use**"*

_____ Mixture (for controlled experiments only)
_____ No Controls (for controlled experiments only)
_____ Excessive Control Mortality (> 10% for acute and > 20% for chronic)
_____ Dilution water not adequately characterized
_____ Bioaccumulation: steady state not reached
_____ Dermal or Injection Exposure Pathway
_____ Review paper or previously published without modification

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_____ Other: *(if any, list here)*

POTENTIAL CHEMICAL MIXTURES: *Describe any potential chemicals mixtures as characterized by study authors (including any confirmation of chemical mixtures).*

DESCRIPTION OF DILUTION WATER: *Describe concerns with characterization of and/or major deficiencies with dilution water.*

General Notes:

Minor Deficiencies: *List and describe any minor deficiencies or other concerns with test. These items may make the study "**Acceptable for Qualitative Use**"* **(exceptions may apply as noted)**

***For Field Studies/Observations**: A field study/observation may be considered "**Acceptable for Quantitative Use**" if it consisted of a range of exposure concentrations and the observed effects are justifiably contributed to a single chemical exposure*

_____ Mixture (observed effects not justifiably contributed to single chemical exposure)
_____ Uncharacterized Reference Sites/Conditions

POTENTIAL CHEMICAL MIXTURES PRESENT AT SITE: *Describe any potential chemicals mixtures present at the site as characterized by study authors (including any confirmation of chemicals present at study site).*

EXPOSURE VARIABILITY ACROSS STUDY SITE(S): *Describe any exposure variability across study site(s) as characterized by study authors (i.e., description of study design with reference and contaminated sites).*

General Notes:

Reviewer's Comments: *Provide additional comments that do not appear under other sections of the template*.

ABSTRACT: *Copy and paste abstract from publication.*

SUMMARY*: Fill out and modify as needed.*

Acute:

Species (lifestage)	Method[a]	Test duration	Chemical / Purity	pH	Temp. (°C)	Hardness (mg/L as $CaCO_3$) or Salinity (ppt)	DOC (mg/L)	Effect	Reported Effect Concentration (mg/L)	Verified Effect Concentration (mg/L)	Classification
											Quantitative / Qualitative / Unused

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

Chronic:

Species (lifestage)	Method[a]	Test duration	Chemical / Purity	pH	Temp. (°C)	Hardness (mg/L as $CaCO_3$) or Salinity (ppt)	DOC (mg/L)	Chronic Limits	Reported Chronic Value (mg/L or µg/g)	Verified Chronic Value (mg/L or µg/g)	Chronic Value Endpoint	Classification
												Quantitative / Qualitative / Unused

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

II. Results *Provide results as reported in the publication (including supplemental materials). Include screen shots of tables and/or figures reporting results from the article following tabulated data table in each associated results section for all studies. Complete tabulated data tables for all studies for studies marked "**Acceptable for Quantitative Use"** and **"Acceptable for Qualitative Use**".*

Water Quality Parameters: *If only general summary data of water quality parameters is provided by study authors (i.e., no specific details of water quality parameters on a treatment level is provided), summarize any information regarding water quality parameters under General Notes below and include data not provided in* Table A.II.1.

General Notes: *For aquatic life criteria development, measured water quality parameters in the treatments nearest the toxicity test endpoint(s), e.g., LC_{50}, EC_{20}, etc., are most relevant.*

Table A.II.1. Measured Water Quality Parameters in Test Solutions.

Dissolved oxygen, temperature, pH and [other parameters (hardness, salinity, DOC)] in test solutions during the *[X]*-day exposure of *[test organism]* to *[concentration of treatment(s)]* of *[test substance]* under *[static renewal/flow-through]* conditions.

Parameter	Treatment	Mean	Range
Dissolved oxygen (% saturation or mg/L)	*[1]*		
	[2]		
	j		
	j		
Temperature (°C)	*[1]*		
	[2]		
	j		
	j		
pH	*[1]*		
	[2]		
	j		
	j		
Other (e.g., hardness, salinity, DOC)	*[1]*		
	[2]		
	j		
	j		

Chemical Concentrations: *Summarize the concentration verification data from test solutions/media. Expand table to include each measured concentration data for each media type (i.e., muscle, liver, blood, etc.).*

General Notes: *Provide any necessary detail regarding the measured concentrations, including any identified cause for substantial differences between nominal and measured concentrations, if samples were collected on separate days (and if so provide details), and any potential cross contamination.*

Table A.II.2. Measured (and Nominal) Chemical Concentrations in Test Solutions/Media.

[Analytical Method] verification of test and control concentrations during an [X]-day exposure of [test organism] to [test substance] under [static renewal/flow-through] conditions.

Treatment	Nominal Concentration (units)	[Mean] Measured Concentration (units)	Number of Samples	Non-Detect[a]	Number of Samples Below Non-Detect	[Standard Deviation or Standard Error]	Range
Control							
[1]							
[2]							
[3]							
[4]							
[5]							
[6]							
j							

[a]Non-Detect: 0 = measured and detected; 1=measured and not detected; if not measured or reported enter as such

Mortality: *Briefly summarize mortality results (if any).*

General Notes: *Comment on concentrations response relations and slope of response if provided. Compare mortality with control treatment and/or the reference chemical.*

Table A.II.3. Mean Percent [Mortality or Survival].

Mean percent mortality [or number of immobilized] or survival of [test organism] exposed to [test substance] for [test duration] under [static/renewal/flow-through] conditions.

Treatment	[Mean % Mortality]	[Standard Deviation or Standard Error]
Control		
[1]		
[2]		
[3]		
[4]		
[5]		
[6]		
[LC_x]		
NOEC		
LOEC		

[a] Use superscript to identify the values reported to be significantly different from control.

Growth: *Briefly summarize growth results (if any).*

General Notes: *Comment on concentrations response relations and slope of response if provided. Compare growth endpoints with control treatment and/or the reference chemical.*

Table A.II.4. Mean [Growth].

Mean growth [length and/or weight] of [test organism] exposed to [test substance] for [test duration] under [static/renewal/flow-through] conditions.

Treatment	Mean Growth [Length/Weight] (units)	[Standard Deviation or Standard Error]	Mean Percent Change in [Length/ Biomass]	[Standard Deviation or Standard Error]
Control				
[1]				
[2]				
[3]				
[4]				
[5]				
[6]				
j				
[EC_x]				
NOEC				
LOEC				

[a] Use superscript to identify the values reported to be significantly different from control.

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Reproductive: *Briefly summarize reproduction endpoint results (if any). For multi-generational studies, copy and paste* Table A.II.5 *below for each generation with reproductive effects data.*

General Notes: *Comment on concentrations response relations and slope of response if provided. Compare reproduction endpoints with control treatment and/or the reference chemical.*

Table A.II.5. Mean [Reproductive] Effect.

Mean [reproductive] effects for [generation] of [test organism] exposed to [test substance] for [test duration] under [static/renewal/flow-through] conditions.

Treatment (units)	[Mean Number of Spawns]	[Standard Deviation or Standard Error]	[Mean Number of Eggs]	[Standard Deviation or Standard Error]	[Mean Number of Offspring]	[Standard Deviation or Standard Error]
Control						
[1]						
[2]						
[3]						
[4]						
[5]						
[6]						
j						
[ECx]						
NOEC						
LOEC						

[a] Use superscript to identify the values reported to be significantly different from control.

Sublethal Toxicity Endpoints: *Include other sublethal effect(s), including behavioral abnormalities or other signs of toxicity, if any. Copy Table A.II.6 as needed to provide details for each sublethal effect observed.*

General Notes: *Briefly summarize observed sublethal effects otherwise not captured in the results table(s) below.*

Table A.II.6. Mean [Sublethal] Effect.

*Mean [*Sublethal effect, *(e.g., behavioral abnormalities, etc.)]* in *[test organism]* during [test duration (*acute/chronic*)] exposure to *[test substance]* under *[static/renewal/flow-through]* conditions.

Treatment	[Mean Sublethal Response] (units)	[Standard Deviation or Standard Error]
Control		
[1]		
[2]		
[3]		
[4]		
[5]		
[6]		
j		
[ECx]		
NOEC		
LOEC		

[a] Use superscript to identify the values reported to be significantly different from control

Reported Statistics: *Copy and paste statistical section from publication.*

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Part B: Detailed Review

I. Materials and Methods

PROTOCOL/GUIDANCE FOLLOWED: *Indicate if provided by authors.*

DEVIATIONS FROM PROTOCOL: *If authors report any deviations from the protocol noted above indicate here.*

Study Design and Methods: *Copy and paste methods section from publication.*

TEST ORGANISM: *Provide information under Details and any relevant or related information or clarifications in Remarks.*

Parameter	Details	Remarks
Species:	Common Name: Scientific Name:	North American species? ____ Surrogate for North American Taxon? ____ *(Place X if applicable)*

Strain/Source:
• Wild caught from unpolluted areas [1]
  o Quarantine for at least 7 days or until they are disease free, before acclimation [1]
• Must originate from same source and population [1]
• Should not be used:
  o If appeared stressed, such as discoloration or unusual behavior [1]
  o If more than 5% die during the 48 hours before test initiation [1]
  o If they were used in previous test treatments or controls [2]
• No treatments of diseases may be administered:
  o Within 16 hours of field collection [1]
  o Within 10 days of testing or during testing [1]		

Age at Study Initiation:
Acute:
• Larval stages preferred [1]
• Mayflies and Stoneflies
  o Early instar [1]
• Daphnids/cladocerans:
  o < 24-hr old [1]
• Midges:
  o 2nd or 3rd instar larva [1]
• *Hyalella azteca* (chronic exposure)
  o Generally, 7 - 8 days old [3]
• Freshwater mussels (chronic exposure)
  o Generally, 2 month old juveniles [4]
• Mysids (chronic exposure)
  o < 24-hr old [1]		

Was body weight or length recorded at test initiation and/or at regular intervals?	____ Yes ____ No	
Was body weight or length recorded at regular intervals?	____ Yes ____ No *If yes, describe regular intervals:*	

STUDY PARAMETERS: *Provide information under Details and any relevant information of deficiencies in Remarks. Complete for both Controlled Experiments and Field Studies/Observations.*

For Both Controlled Experiments and Field Observations

Parameter	Details	Remarks
Number of Replicates per Treatment Group: • At least 2 replicates/treatment recommended for acute tests [1] • At least 2 replicates/treatment recommended for chronic tests [5]	Control(s):	
	Treatment(s):	
Number of Organisms per Replicate/ Treatment Group: • At least 10 organisms/treatment recommended.	Control(s):	
	Treatment(s):	
Exposure Pathway: *(i.e., water, sediment, or diet). Note: all other pathways (e.g., dermal, injection) are unacceptable.*		
Exposure Duration: **Acute** • Cladocerans and midges should be 48 hours [2] o Longer durations acceptable if test species not fed and had acceptable controls [2] • Freshwater mussel glochidia should be a maximum of 24 hours [4] o Shorter durations (6, 12, 18 hours) acceptable so long as 90% survival of control animals achieved (see below) [4] • Embryo/larva (bivalve mollusks, sea urchins, lobsters, crabs, shrimp and abalones) should be 96 hours, but at least 48 hours [2] • Other invertebrate species should be 96 hours **Chronic** • Daphnids/cladocerans should be 21 days (3-brood test) [2] o Exception 7 days acceptable for *Ceriodaphnia dubia* [2] • Freshwater juvenile mussels should be at least 28 days [4] • *Hyalella azteca* should be at least 42 days o Beginning with 7 - 8 day old animals [3] • Mysids should continue until 7 days past the median time of first brood release in the controls [4]	____ Acute ____ Chronic ____ Other *(please remark):*	
Test Concentrations (remember units): *Recommended test concentrations include at least three concentrations other than the control; four or more will provide a better statistical analysis.*	Nominal:	
	Measured:	
	Media measured in:	
Observation Intervals: • Should be an appropriate number of observations over the study to ensure water quality is being properly maintained [1]		

CONTROLLED EXPERIMENT STUDY PARAMETERS: *Provide information under Details and any relevant information of deficiencies in Remarks. Complete for Controlled Experiments only.*

For Controlled Experiments Only

Parameter	Details	Remarks

Acclimation/Holding:
• Should be placed in a tank along with the water in which they were transported [1]
  o Water should be changed gradually to 100% dilution water (usually 2 or more days) [1]
  o For wild-caught animals, test water temperature should be within 5°C of collection water temperature [1]
  o Temperature change rate should not exceed 3°C within 72 hours [1]
• To avoid unnecessary stress and promote good health:
  o Organisms should not be crowded [1]
  o Water temperature variation should be limited
  o Dissolved oxygen:
  ▪ Maintain between 60 - 100% saturation [1]
  ▪ Continuous gentle aeration if needed [1]
  o Unionized ammonia concentration in holding and acclimation waters should be < 35 µg/L [1]
	Duration:
	Feeding:
	Water:
	Temperature (°C):
	Dissolved Oxygen (mg/L):
	Health (*any mortality observed?*):
		Identify number of individuals excluded from testing and/or analysis (if any):

Acclimation followed published guidance? *Describe, if any*	____ Yes ____ No *If yes, indicate which guidance:*	

Test Vessel:
• Test chambers should be loosely covered [1]
• Test chamber material:
  o Should minimize sorption of test chemical from water [1]
  o Should not contain substances that can be leached or dissolved in solution and free of substances that could react with exposure chemical [1]
  o Glass, No. 316 stainless steel, nylon screen and perfluorocarbon (e.g. Teflon) are acceptable [1]
  o Rubber, copper, brass, galvanized metal, epoxy glues, lead and flexible tubing should not come into contact with test solution, dilution water or stock [1]
• Size/volume should maintain acceptable biomass loading rates (see below) [1]
• Substrate:
  o Required for some species (e.g., *Hyalella azteca*) [3]
  o Common types: stainless steel screen, nylon screen, quartz sand, cotton gauze and maple leaves [3]
  o More inert substances preferred over plant material, since plants may break down during testing and promote bacterial growth [3]
  o Consideration should be given between substrate and toxicant [3]
  ▪ Hydrophobic organic compounds in particular can bind strongly to Nitex® screen, reducing exposure concentrations, especially for studies using static or intermittent renewal exposure methods [3]
	Material:
	Size:
	Fill Volume:
	Substrate Used *(if applicable)*:
		Briefly describe the test vessel here

	Parameter	Details	Remarks

For Controlled Experiments Only	**Test Solution Delivery System/Method:**
	• Flow-through preferred for some highly volatile, hydrolyzable or degradable materials [2]
	  o Concentrations should be measured often enough using acceptable analytical methods [2]
	• Chronic exposures:
	  o Flow-through, measured tests required [2]
	  o Exception: renewal is acceptable for daphnids [2]
		Test Concentrations Measured
		____ Yes ____ No
		
		Test Solution Delivery System:
		____ Static
		____ Renewal
		Indicate Interval:
		
		____ Flow-through
		Indicate Type of Diluter:	

	Source of Dilution Water:
	• Freshwater hardness range should be < 5 mg/L or < 10% of the average (whichever is greater) [1]
	• Saltwater salinity range should be < 2 g/kg or < 20% of the average (whichever is greater) [1]
	• Dilution water must be characterized (natural surface water, well water, etc.) [2]
	  o Distilled/deionized water without the addition of appropriate salts should not be used [2]
	• Dilution water in which total organic carbon or particulate matter exceed 5 mg/L should not be used
	  o Unless data show that organic carbon or particulate matter do not affect toxicity [2]
	• Dilution water for tests with *Hyalella azteca*
	  o Reconstituted waters should have at least 0.02 mg bromide/L; natural ground or surface water presumed to have sufficient bromide [3]
	  o Recommended that control/dilution waters have chloride concentrations at or above 15 mg/L [3]		

	Dilution Series (*e.g., 0.5x, 0.6x, etc.*):		
	Dilution Water Parameters: *Measured at the beginning of the experiment or averaged over the duration of the experiment (details of water quality parameters measured in test solutions should be included under the results section)*	Dissolved Oxygen (mg/L): pH: Temperature (°C): Hardness (mg/L as $CaCO_3$): Salinity (ppt): Total Organic Carbon (mg/L): Dissolved Organic Carbon (mg/L):	
	Aeration: • Acceptable to maintain dissolved oxygen at 60 - 100% saturation at all times [1] • Avoid aeration when testing highly oxidizable, reducible and volatile materials • Turbulence should be minimized to prevent stress on test organisms and/or re-suspend fecal matter [1] • Aeration should be the same in all test chambers at all times [1]	____ Yes ____ No	
	Describe Preparation of Test Concentrations (e.g., water exposure, diet):		

	Parameter	Details	Remarks
For Controlled Experiments Only	**Test Chemical Solubility in Water:** • List units and conditions (e.g., 0.01% at 20ºC)		
	Were concentrations in water or diet verified by chemical analysis? *Measured test concentrations should be reported in* Table A.II.2 *above.*	____ Yes ____ No *Indicate media:*	
	Were test concentrations verified by chemical analysis in tissue? *Measured test concentrations can be verified in test organism tissue (e.g., blood, liver, muscle) alone if a dose-response relationship is observed.* *Measured test concentrations should be reported in* Table A.II.2 *above.*	____ Yes ____ No *Indicate tissue type:*	*If test concentrations were verified in test organism tissue, was a dose-response relationship observed?*
	Were stability and homogeneity of test material in water/diet determined?	____ Yes ____ No	
	Was test material regurgitated/avoided?	____ Yes ____ No	
	Solvent/Vehicle Type: • When used, a carrier solvent should be kept to a minimum concentration [1] • Should not affect either survival or growth of test organisms [1] • Should be reagent grade or better [1] • Should not exceed 0.5 ml/L (static), or 0.1 ml/L (flow through) unless it was shown that higher concentrations do not affect toxicity [5]		
	Negative Control:	____ Yes ____ No	
	Reference Toxicant Testing:	____ Yes ____ No *If yes, identify substance:*	
	Other Control: *If any (e.g. solvent control)*		
	Biomass Loading Rate: • Loading should be limited so as not to affect test results. Loading will vary depending on temperature, type of test (static vs. flow-through), species, food/feeding regime, chamber size, test solution volume, etc. [1] • This maximum number would have to be determined for the species, test duration, temperature, flow rate, test solution volume, chamber size, food, feeding regime, etc. • Loading should be sufficiently low to ensure: o Dissolved oxygen is at least 60% of saturation (40% for warm-water species) [1,6] o Unionized ammonia does not exceed 35 µg/L [1] o Uptake by test organisms does not lower test material concentration by > 20% [1] o Growth of organisms is not reduced by crowding • Generally, at the end of the test, the loading (grams of organisms; wet weight; blotted dry) in each test chamber should not exceed the following: o Static tests: > 0.8 g/L (lower temperatures); > 0.5 g/L (higher temperatures) [1] o Flow through tests: > 1 g/L/day or > 10 g/L at any time (lower temperatures); > 0.5 g/L/day or > 5 g/L at any time (higher temperatures) [1] o Lower temperatures are defined as the lower of 17˚C or the optimal test temperature for that species. [1]		

For Controlled Experiments Only	**Feeding:**
	• Unacceptable for acute tests [2]
	  o Exceptions:
	  ▪ Data indicate that the food did not affect the toxicity of the test material [2]
	  ▪ Test organisms will be severely stressed if they are unfed for 96 hours [2]
	  ▪ Test material is very soluble and does not sorb or complex readily (e.g., ammonia) [2]
		____ Yes ____ No	

	Lighting: • No specific requirements for lighting • Generally, ambient laboratory levels (50 - 100 fc) or natural lighting should be acceptable, as well as a diurnal cycle consisting of 50% daylight or other natural seasonal diurnal cycle • Artificial light cycles should have a 15 - 30 minute transition period to avoid stress due to rapid increases in light intensity [1] • Depends on the type of test (acute or chronic) and endpoint (e.g., reproduction) of interest.		

Study Design/Methods Classification: *(Place X by One Based on Overall Study Design/Methods Classification)*
Provide details of Major or Minor Deficiencies/Concerns with Study Design in Associated Sections of Part A: Overview
This classification should be taken into consideration for the overall study classification for aquatic life criteria development in Part A.

_____ Study Design Acceptable for Quantitative Use
_____ Study Design Acceptable for Qualitative Use
_____ Study Design Not Acceptable for Use

Additional Notes: *Provide additional considerations for the classification of study use based on the study design.*

OBSERVATIONS: *Provide information under Details and any relevant information in Remarks. This information should be consistent with the Results Section in Part A.*

Parameter	Details	Remarks

Parameters measured including sublethal effects/toxicity symptoms:
Common Apical Parameters Include:
Acute
• Daphnids/cladocerans:
  ○ EC_{50} based on percentage of organisms immobilized plus percentage of organisms killed [2]
• Embryo/larva (bivalve molluscs, sea urchins, lobsters, crabs, shrimp, and abalones):
  ○ EC_{50} based on the percentage of organisms with incompletely developed shells plus the percentage of organisms killed [2]
  ▪ If not available, the lower of the 96 hour EC_{50} based on the percentage of organisms with incompletely developed shells and the 96-hr LC_{50} should be used [2]
• Freshwater mussel (glochidia and juveniles):
  ○ Glochidia: EC_{50} based on 100 x number closed glochidia after adding NaCl solution - number closed glochidia before adding NaCl solution) / Total number open and closed glochidia after adding NaCl solution [4]
  ○ Juvenile: EC_{50} based on percentage exhibiting foot movement within a 5-min observation period [4]
• All other species and older life stages:
  ○ EC_{50} based on the percentage of organisms exhibiting loss of equilibrium plus the percentage of organisms immobilized plus the percentage of organisms killed [2]
  ▪ If not available, the 96 hour LC_{50} should be used [2]
Chronic
• Daphnid:
  ○ Survival and young per female [2]
• Mysids:
  ○ Survival, growth and young per female [2]
	List parameters:	

Was control survival acceptable?
Acute
• > 90% control survival at test termination [2]
  ○ Glochidia 90% after 24 hours, or, the next longest duration less than 24 hours that had at least 90% survival [4]
Chronic
• > 80% control survival at test termination [2]
  ○ 80% in 42 day test with *Hyalella azteca*, slightly lower in tests substantially longer than 42 days [3]
	____ Yes ____ No
	Control survival (%):	

Parameter	Details	Remarks
Were individuals excluded from the analysis?	____ Yes ____ No *If yes, describe justification provided:*	
Was water quality in test chambers acceptable? • If appropriate, describe any water quality issues (e.g., dissolved oxygen level below 60% of saturation)	____ Yes ____ No	
Availability of concentration-response data: • Were treatment level concentration-response data included in study publication (can be from tables, graphs, or supplemental materials)? *specify endpoints in remarks* • Were replicate level concentration-response data included in study publication (can be from tables, graphs, or supplemental materials)? *specify endpoints in remarks* • • If treatment and/or replicate level concentration-response data were included, how was data presented? *(check all that apply)* • Were concentration-response data estimated from graphs study publication or supplemental materials? Should additional concentration-response data be requested from study authors? *If concentration-response data are available, complete **Verification of Statistical Results (Part C)** for sensitive species*.	____ Yes ____ No ____ Yes ____ No ____ Tables ____ Graphs ____ Supplemental Files ____ Yes ____ No *If yes, indicate software used:* ____ Yes ____ No Requested by: Request date: Date additional data received:	

Part C: Statistical Verification of Results

I. Statistical Verification Information: *Report the statistical methods (e.g., EPA TRAP, BMDS, R, other) used to verify the reported study or test results for the five (5) most sensitive genera and sensitive apical endpoints (including for tests where such estimates were not provided). If values for the LC_{50}, LT_{50} and NOEC are greater than the highest test concentration, use the ">" symbol.*

Primary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)

Secondary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)
(*At least one reviewer should be from EPA for sensitive taxa*)

Endpoint(s) Verified:

Additional Calculated Endpoint(s):

Statistical Method (e.g., TRAP, BMDS, R, other):

II. Toxicity Values: *Include confidence intervals if applicable*

NOEC:
LOEC:
MATC:

EC_5:
EC_{10}:
EC_{20}:
EC_{50} or LC_{50}

Dose-Response Curve Classification: *(Place X by One)*
This classification should be taken into consideration for the overall study classification for aquatic life criteria development in Part A

_____ Dose-Response Curve Acceptable for Quantitative Use
_____ Dose-Response Curve Acceptable for Qualitative Use
_____ Dose-Response Curve Not Acceptable for Use

Summary of Statistical Verification: *Provide summary of methods used in statistical verification.*

Additional Notes:

Attachments:

1. *Provide attachments to ensure all data used in Part C is captured, whether from study results reported in the publication and/or from additional data requested from study authors*
    - *Data from study results of the publication should be reported in Results section of Part A*
    - *Additional data provided upon request from study authors should be reported in Table C.II.1 below and original correspondence with study authors should be included as attachments*
2. *Model assessment output (including all model figures, tables, and fit metrics)*
3. *Statistical code used for curve fitting*

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III. Attachments: *Include all attachments listed above after the table below.*

Additional Data Used in Response-Curve: *Provide all data used to fit dose-response curve not captured in Results section of DER above in Part A, rows as needed. First row in italicized text is an example.*

Table C.II.1 Additional Data Used in Dose-Response Curve.

Curve ID	Species	Endpoint	Treatment	Replicate	[Standard Deviation or Standard Error]	# of Survivors	N[a]	k[a]	n[a]	Response	Response Unit	Conc	Conc units
Alchronic1	*Ceriodaphnia dubia*	*# of young/female*	*0*	*6*			*10*	*10*	*1*	*18*	*count*	*0.03*	*mg/L*

[a] N = number of individuals per treatment; k = number of replicates per treatment level; n = number of individuals per replicate

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Part D: References to Test Guidance

6. ASTM Standard E 739, 1980. 2002. Standard guide for conducting acute toxicity tests on test materials with fishes, macroinvertebrates, and amphibians. ASTM International, West Conshohocken, PA.
7. Stephan, C.E., D.I. Mount, D.J. Hansen, J.H. Gentile, G.A. Chapman and W.A. Brungs. 1985. Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and their Uses. PB85-227049. National Technical Information Service, Springfield, VA.
8. Mount, D.R. and J.R. Hockett. 2015. Issue summary regarding test conditions and methods for water only toxicity testing with *Hyalella azteca*. Memorandum to Kathryn Gallagher, U.S. EPA Office of Water. U.S. EPA Office of Research and Development. MED. Duluth, MN. 9 pp.
9. Bringolf, R.B., M.C. Barnhart, and W.G. Cope. 2013. Determining the appropriate duration of toxicity tests with glochidia of native freshwater mussels. Submitted to Edward Hammer. U.S. EPA. Chicago, IL, May 8, 2013. 39 pp.
10. Stephan, C.E. 1995. Review of results of toxicity tests with aquatic organisms. Draft. U.S. EPA, MED. Duluth, MN. 13 pp.
11. American Public Health Association (APHA). 2012. Standard methods for the examination of water and wastewater. Part 8000 - Toxicity. APHA. Washington, DC.

United States Environmental Protection Agency
Office of Water 4304T
EPA-842-R-24-002 September 2024

FINAL

FRESHWATER AQUATIC LIFE AMBIENT WATER QUALITY CRITERIA AND ACUTE SALTWATER AQUATIC LIFE BENCHMARK

for

PERFLUOROOCTANOIC ACID

(PFOA)

September 2024

U.S. Environmental Protection Agency Office of Water, Office of Science and Technology, Health and Ecological Criteria Division

Washington, D.C.

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ACKNOWLEDGEMENTS

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ACRONYMS

8:2 FTAC	fluorotelomer acrylate
8:2 FTMAC	fluorotelomer methacrylate
8:2 FTOH	fluorotelomer alcohol
8:2 FTS	fluorotelomer stearate
8:2 HMU	aliphatic diurethane ester
ACR	Acute-to-Chronic Ratio
ADP	Action Development Process
AFFF	aqueous film-forming foam
AIC	Akaike information criteria
ASTM	American Society for Testing and Materials
AWQC	National Recommended Ambient Water Quality Criteria
BAF	bioaccumulation factor
BMF	biomagnification factors
C8/C8-PFPIA	Bis(perfluorooctyl) phosphinic acid
C8-PFPA	Perfluorooctyl phosphonic acid
CAS	Chemical Abstracts Service
CASRN	Chemical Abstracts Service Registry Number
C-F	carbon fluorine
C-R	concentration-response
CC	Chronic Criterion
CCC	Criterion Continuous Concentration
CMC	Criterion Maximum Concentration
CWA	Clean Water Act
DER	Data Evaluation Record
dpf	days post fertilization
diPAPs	polyfluoroalkyl phosphoric acid diesters
drc	dose-response curve
dw	dry weight
ECF	Electrochemical fluorination
ECOTOX	ECOTOXicology database
EC_x	Effect concentration at x percent level
EPA	U.S. Environmental Protection Agency
EU	European Union
FACR	Final Acute-to-Chronic Ratio
FAV	Final Acute Value
FCV	Final Chronic Value
FTEOs	fluorotelomer ethoxylates
FTCAs	fluorotelomer carboxylates
FTOH	fluorotelomer alcohol
GLI	Great Lakes Initiative
GMAV	genus mean acute value
GMCV	genus mean chronic value
GSD	genus sensitivity distribution
GSI	gonadal somatic index
hpf	hours post fertilization

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HSI	hepatic somatic index
ICE	Interspecies Correlation Estimation
IC_x	Inhibitory concentration at x percent level
K_d	partitioning coefficients
K_{OC}	Organic carbon water partitioning coefficient
K_{OW}	n-octanol-water partition coefficient
LC_x	Lethal concentration at x percent level
LOECs	Lowest Observed Effect Concentrations
LOQ	limit of quantification
MATC	Maximum Acceptable Toxicant Concentration
MC	Maximum Criterion
MDRs	minimum data requirements
NAMs	New Approach Methods
NOECs	No Observed Effect Concentrations
NPDES	National Pollutant Discharge Elimination System
OECD	Organization for Economic Cooperation and Development
OCSPP	Office of Chemical Safety and Pollution Prevention
ORD	Office of Research and Development
OW	Office of Water
ppt	parts per thousand
PFAAs	perfluoroalkyl acids
PFAS	per- and polyfluorinated substances
PFCAs	Perfluorocarboxylic acids, perfluoroalkyl carboxylates or perfluoroalkyl carboxylic acids
PFdiCAs	Perfluoroalkyl dicarboxylic acids
PFdiSAs	Perfluoroalkane disulfonic acids
PFECAs	Perfluoroalkylether carboxylic acids
PFESAs	Perfluoroalkylether sulfonic acids
PFO	Perfluorooctanoate
PFOA	Perfluorooctanoic acid, pentadecafluoro-1-octanoic acid, pentadecafluoro-n-octanoic acid, octanoic acid, pentadecafluoro-, perfluorocaprylic acid, pentadecafluorooctanoic acid, perfluoroalkyl carboxylic acid or perfluoroheptanecarboxylic acid
PFOAAms	perfluorooctaneamido quaternary ammonium salt
PFOS	Perfluorooctane sulfonic acid or perfluorooctane sulfonate
PFOSI	Perfluorooctane sulfinic acid
PFPAs	Perfluoroalkyl phosphonic acids
PFPIAs	Perfluoroalkyl phosphinic acids
PFSAs	Perfluoroalkane sulfonic acids or perfluorokane sulfonates
PFSIAs	Perfluoroalkyl sulfinic acids
pKa	acid dissociation constant
QACs	quaternary ammonium polyfluoroalkyl surfactants
SMACR	species mean acute-to-chronic ratio
SMAV	species mean acute value
SMCV	species mean chronic value
SOP	standard operating procedure

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SSD	species sensitivity distribution
TMDLs	Total Maximum Daily Loads
TSCA	Toxic Substances Control Act
U.S.	United States
web-ICE	Web-based Interspecies Correlation Estimation
WQS	water quality standards
ww	wet weight
WWTPs	wastewater treatment plants

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NOTICES

This document provides information that states and authorized Tribes may consider when establishing water quality standards under the Clean Water Act (CWA) to protect aquatic life from effects of Perfluorooctanoic acid (PFOA). Under the CWA, states and authorized Tribes establish water quality criteria to protect designated uses. State and Tribal decision makers retain the discretion to adopt approaches that are scientifically defensible that differ from these recommended criteria or benchmarks, including to reflect site-specific conditions. While this document contains the Environmental Protection Agency's (EPA) scientific recommendations regarding ambient concentrations of PFOA that protect aquatic life, the PFOA Criteria Document does not substitute for the Clean Water Act or the EPA's regulations; nor is this document or the values it contains a regulation itself. This document does not establish or affect legal rights or obligations, or impose legally binding requirements on the EPA, states, Tribes, or the regulated community. It cannot be finally determinative of the issues addressed. This document has been approved for publication by the Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use. This document can be downloaded from: https://www.epa.gov/wqc/aquatic-life-criteria-perfluorooctanoic-acid-pfoa.

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FOREWORD

The Clean Water Act (CWA) Section 304(a)(l) (P.L. 95-217) directs the Administrator of the EPA to develop and publish water quality criteria recommendations that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water, including groundwater. This document includes EPA's recommended ambient water quality criteria (AWQC) for the protection of aquatic life based upon consideration of all available information relating to effects of perfluorooctanoic acid on aquatic organisms in freshwaters, as well as an informational acute saltwater benchmark developed under CWA Section 304(a)(2).

Aquatic life benchmarks, developed by the EPA under 304(a)(2) of the CWA, are informational values that EPA generates when there are limited high quality toxicity data available and data gaps exist for several aquatic organism families. EPA develops aquatic life benchmarks to provide information that states and Tribes may consider in their water quality protection programs, including when developing water quality standards. In developing aquatic life benchmarks, data gaps may be filled using new approach methods (NAMs), such as computer-based toxicity estimation tools (e.g., EPA's Web-ICE) or other new approach methods intended to reduce reliance on additional animal testing (https://www.epa.gov/chemical-research/epa-new-approach-methods-work-plan-reducing-use-vertebrate-animals-chemical), including the use of read-across estimates based on other chemicals with similar structures. Like criteria recommendations developed under Section 304(a)(l), the EPA's aquatic life benchmark values are not regulatory, nor do they automatically become part of a state's water quality standards.

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Under CWA Section 303, states or authorized Tribes adopt water quality standards and submit them to EPA for review and approval. If approved by EPA as water quality standards, they become the CWA water quality standards applicable in ambient waters within that state or authorized Tribe. A state or authorized Tribe may, where appropriate, adopt water quality criteria that have the same numerical values as recommended criteria or benchmarks developed by EPA under CWA Section 304. States and authorized Tribes have discretion to adopt criteria that modify EPA's recommended criteria to reflect site-specific conditions, such as the local water chemistry or ecological conditions, or to develop criteria based on other scientifically defensible methods that are protective of designated uses (40 C.F.R. 131.11[b]). Guidelines to assist the states and authorized Tribes in modifying the criteria presented in this document are contained in the Water Quality Standards Handbook (see Chapter 3 titled "Water Quality Criteria"; U.S. EPA 2023).

Deborah G. Nagle
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Office of Science and Technology

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EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) developed the recommended perfluorooctanoic acid (PFOA) freshwater aquatic life ambient water quality criteria and an acute saltwater benchmark in accordance with the provisions of Section 304(a) of the Clean Water Act. This document provides the EPA's basis for and derivation of the national PFOA ambient water quality criteria recommendations to protect aquatic life. The EPA has derived the recommended PFOA aquatic life criteria and benchmark to be consistent with methods described in the EPA's "*Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*" (U.S. EPA 1985).

PFOA is an organic, human-made perfluorinated compound, consisting of a seven-carbon backbone and a carboxylate functional group. PFOA (and other related chemicals in the perfluorocarboxylic acids, PFCAs) is used primarily in specialized applications associated with surface coatings in a variety of industrial and commercial products. This document provides a critical review of toxicity data for aquatic life identified in the EPA's literature search for PFOA, including the anionic form (CAS No. 45285-51-6), the acid form (CAS No. 335-67-1), and the ammonium salt (CAS No. 3825-26-1). It also quantifies the toxicity of PFOA to aquatic life and provides final criteria recommendations to protect aquatic life in freshwater from the acute and chronic toxic effects of PFOA.

The Aquatic Life Ambient Water Quality Criteria for PFOA document includes water column-based acute and water column-based chronic criteria, as well as chronic tissue-based criteria for freshwaters. Quantitatively-acceptable estuarine/marine toxicity data only fulfilled three of the eight minimum data requirements (MDRs) for deriving an acute estuarine/marine criterion, and one of the eight MDRs for deriving a chronic estuarine/marine criterion per the 1985 Guidelines. The EPA did, however, include an acute aquatic life benchmark for

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estuarine/marine environments in Appendix L, using available estuarine/marine species toxicity data and the New Approach Methods (NAMs) application of the EPA Office of Research and Development's (ORD) peer-reviewed web-based Interspecies Correlation Estimate tool (Web-ICE; Version 3.3; https://www.epa.gov/webice/). The estuarine/marine benchmarks are CWA Section 304(a)(2) information provided for states and authorized Tribes to consider in their state/tribal water quality protection programs. However, the acute estuarine/marine benchmark magnitude is less certain than the freshwater criteria as the benchmark was based on both direct laboratory-based and estimated PFOA acute toxicity data (Appendix L).

The final freshwater acute water column-based criterion magnitude is 3.1 mg/L, and the final chronic water column-based chronic criterion magnitude is 0.10 mg/L. The final chronic freshwater criterion also contains tissue-based criteria with magnitudes of 6.49 mg/kg wet weight (ww) for fish whole-body, 0.133 mg/kg ww for fish muscle tissue, and 1.18 mg/kg ww for invertebrate whole-body tissue. All criteria are intended to be equally protective against adverse PFOA effects and are intended to be independently applicable. The three tissue criteria magnitudes (for fish and invertebrate tissues) are translations of the chronic water column criterion for freshwater using bioaccumulation factors (BAFs) derived from a robust national dataset of BAFs (Burkhard 2021). The assessment of the available data for fish, invertebrates, amphibians, and plants indicates these criteria recommendations are expected to protect the freshwater aquatic community.

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Table Ex-1. Recommended Perfluorooctanoic acid (PFOA) Ambient Water Quality Criteria for the Protection of Aquatic Life in Freshwater.

Type/Media	Acute Water Column (CMC)[1,4]	Chronic Water Column (CCC)[1,5]	Chronic Invertebrate Whole-Body[1,2]	Chronic Fish Whole-Body[1,2]	Chronic Fish Muscle[1,2]
Magnitude	3.1 mg/L	0.10 mg/L	1.18 mg/kg ww	6.49 mg/kg ww	0.133 mg/kg ww
Duration	One-hour average	Four-day average	Instantaneous[3]		
Frequency	Not to be exceeded more than once in three years on average	Not to be exceeded more than once in three years on average	Not to be exceeded[6]		

[1] All five of these water column and tissue criteria are intended to be independently applicable and no one criterion takes primacy. All of the above recommended criteria (acute and chronic water column and tissue criteria) are intended to be protective of aquatic life. These criteria are applicable throughout the year.
[2] Tissue criteria derived from the chronic water column concentration (CCC) with the use of bioaccumulation factors and are expressed as wet weight (ww) concentrations.
[3] Tissue data provide instantaneous point measurements that reflect integrative accumulation of PFOA over time and space in aquatic life population(s) at a given site.
[4] Criterion Maximum Concentration; applicable throughout the water column.
[5] Criterion Continuous Concentration; applicable throughout the water column.
[6] PFOA chronic freshwater tissue-based criteria should not be exceeded, based on measured tissue concentrations representing the central tendency of samples collected at a given site and time.

Table Ex-2. Acute Perfluorooctanoic Acid (PFOA) Benchmark for the Protection of Aquatic Life in Estuarine/Marine Waters.

Type/Media	Acute Water Column Benchmark
Magnitude	7.0 mg/L
Duration	One hour average
Frequency	Not to be exceeded more than once in three years on average

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1 INTRODUCTION AND BACKGROUND

National Recommended Ambient Water Quality Criteria (AWQC) are established by the EPA under the CWA. Section 304(a)(1) states that aquatic life criteria serve as recommendations to states and authorized Tribes by defining ambient water concentrations that are expected to protect against unacceptable adverse ecological effects to aquatic life resulting from exposure to pollutants found in water. States and authorized Tribes may adopt these criteria into their water quality standards (WQS) to protect the designated uses of water bodies. States and authorized Tribes may also modify these criteria to reflect site-specific conditions or use other scientifically defensible methods to develop criteria before adopting these into standards. After adoption, states/authorized Tribes submit new and revised WQS to the EPA for review and approval or disapproval. When approved by the EPA, the state's/Tribe's WQS become the applicable WQS for CWA purposes. Such purposes include identification of impaired waters and establishment of Total Maximum Daily Loads (TMDLs) under CWA Section 303(d) and derivation of water quality-based effluent limitations in permits issued under the CWA Section 402 National Pollutant Discharge Elimination System (NPDES) program. The EPA recommends the adoption of both the acute and chronic water column criteria as well as the chronic tissue-based criteria to ensure the protection of aquatic life through all exposure pathways, including direct aqueous exposure and bioaccumulation. Aquatic life benchmarks, developed by EPA under 304(a)(2) of the CWA, are informational values that EPA generates when there are limited high quality toxicity data available and data gaps exist for several aquatic organism families. EPA provided an acute estuarine/marine benchmark in Appendix L as additional information on protective values that states and tribes may consider in their water quality programs.

This document provides a critical review of toxicity data identified in the EPA's literature search for PFOA, including the anionic form (CAS No. 45285-51-6), the acid form (CAS No.

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335-67-1), and the ammonium salt (CAS No. 3825-26-1). It also quantifies the toxicity of PFOA to aquatic life and provides criteria to protect aquatic life in freshwater from the acute and chronic toxic effects of PFOA.

The EPA derived the recommended criteria using the best available data to reflect the latest scientific knowledge on the toxicological effects of PFOA on aquatic life. The EPA developed the criteria following the general approach outlined in the EPA's "*Guidelines for Deriving Numerical Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses"* (U.S. EPA 1985). The PFOA criteria, if adopted and implemented, are expected to be protective of most aquatic organisms, including species listed as threated or endangered, in the community (i.e., approximately 95 percent of tested aquatic organisms representing the aquatic community) and are derived to be protective of aquatic life designated uses established by states and authorized Tribes for freshwaters. The estuarine/marine benchmarks are also intended to be protective of aquatic life designated uses, but they are based on fewer empirical PFOA toxicity data and, therefore, have greater inherent uncertainty. The criteria recommendations presented herein are the EPA's best estimate of the concentrations of PFOA, with associated frequency and duration specifications, that would protect sensitive aquatic life from unacceptable acute and chronic effects of PFOA.

1.1 Previously Derived PFOA Toxicity Values and Thresholds

Other jurisdictions (e.g., states, countries, etc.) have previously published PFOA acute and chronic criteria, benchmarks, or thresholds, including values for both freshwater and marine systems. These values focus exclusively on water column-based values only; no other jurisdiction has previously derived tissue-based values. Within the United States, no states or Tribes have CWA Section 303(c) approved PFOA water quality standards for the protection of

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aquatic life. However, several states have published draft/interim acute and chronic ecological screening level values/benchmarks for the protection of aquatic life (e.g., Michigan, Minnesota, Texas, Florida, California).

These publicly available freshwater acute values range from 4.47 mg/L in Texas (TCEQ 2021) to 20 mg/L in Florida (Stuchal and Roberts 2019) (Table 1-1). The EPA's freshwater acute PFOA criterion (3.1 mg/L) is slightly lower than the range of state-derived values. No acute estuarine/marine criteria, benchmarks, or protective values have been established for PFOA, other than the benchmark provided herein.

Publicly available freshwater chronic values for other jurisdictions range from 0.22 mg/L in Australia/New Zealand (95% species protection level; CRC CARE 2017; EPAV 2016; HEPA 2020; Table 1-1) to 2.27 mg/L in Texas (TCEQ 2021), which are all higher than the EPA's freshwater chronic criterion of 0.10 mg/L, which includes more recently published data not accounted for in other previously published values.

Previously published estuarine/marine chronic values are available for Australia/New Zealand with a chronic protective value of 0.22 mg/L (95% species protection level) and California with a chronic "interim final screening level value" of 0.54 mg/L (Table 1-1).

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Table 1-1. Previously Derived PFOA Toxicity Values and Thresholds.

State/Country of Applicability	Aquatic Life Protective Value (mg/L)	Criteria or Benchmark and Calculation Approach	Source
Freshwater Acute			
Texas	4.47	Based on NOAELs, LOAELs, or similar values from specific toxicological studies. Contact the TCEQ for more information. This is an acute surface water benchmark and does not represent a CWA Section 303(c) approved water quality standard for PFOA.	TCEQ 2021
Michigan	7.7	Calculated from a species sensitivity distribution (SSD) consisting of two species-specific values. The Final Acute Value (FAV) was based on the lowest EC_{50} divided by a safety factor of 13 (following the U.S. EPA Great Lakes Initiative [GLI; U.S. EPA 1995a]). This protective value is a translation of narrative water quality criteria and does not represent a CWA Section 303(c) approved water quality standard for PFOA.	EGLE 2010
Minnesota	15	Calculated from a species sensitivity distribution (SSD) consisting of three species-specific values. The Maximum Criterion (MC) was based on the lowest EC_{50} divided by a safety factor of 13 (following the U.S. EPA Great Lakes Initiative [GLI; U.S. EPA 1995a]). This draft value is does not represent a CWA Section 303(c) approved water quality standard for PFOA.	STS/MPCA 2007
Florida	20	Secondary Acute Value (SAV) calculated using the U.S. EPA Great Lakes Initiative (GLI; U.S. EPA 1995a) Tier II Methodology. FAV calculated as the lowest GMAV (unspecified) divided by a safety factor of 5.2. This value was released in a White Paper sponsored by Florida Department of Environmental Protection and is considered a draft eco-based surface water screening level, it is not a CWA Section 303(c) approved water quality standard.	Stuchal and Roberts 2019

State/Country of Applicability	Aquatic Life Protective Value (mg/L)	Criteria or Benchmark and Calculation Approach	Source
Freshwater Chronic			
Australia, New Zealand	0.019 (99% species protection – high conservation value systems)	Guidelines calculated from a species sensitivity distribution (SSD) consisting of 12 species-specific values for fish, insects, crustaceans, rotifers, algae, and plants following the guidance of Warne et al. (2018) and Batley et al. (2014)	CRC CARE 2017, EPAV 2016, HEPA 2020
	0.22 (95% species protection – slightly to moderately disturbed systems)		
	0.632 (90% species protection – highly disturbed systems)		
	1.824 (80% species protection – highly disturbed systems)		
California	0.54 (99% species protection)	HC1 calculated from an acute and chronic NOEC-based SSD as reported in DoD-SERDP Project ER18-1614 (DoD-SERDP 2019). Acute NOEC values were converted to chronic values using mean acute-to-chronic ratios derived from Giesy et al. (2010). This value represents an "Interim Final Environmental Screening Level" and does not represent a CWA Section 303(c) approved water quality Standard for PFOA.	San Francisco Bay RWQCB 2020; DoD-SERDP 2019
Michigan	0.88	Final Chronic Value (FCV) was calculated as the FAV ÷ Final Acute: Chronic ratio (ACR) (following the GLI; U.S. EPA 1995a). This protective value is a translation of narrative water quality criteria and does not represent a CWA Section 303(c) approved water quality standard for PFOA.	EGLE 2010

State/Country of Applicability	Aquatic Life Protective Value (mg/L)	Criteria or Benchmark and Calculation Approach	Source
Florida	1.3	Secondary Chronic Value (SCV) calculated using the U.S. EPA Great Lakes Initiative (GLI; U.S. EPA 1995a) Tier II Methodology with acute-to-chronic ratio (ACR) of 15.3. SCV = SAV (20,000 µg/L) ÷ ACR (15.3) = 1,300 µg/L or 1.3 mg/L. This value was released in a White Paper sponsored by Florida Department of Environmental Protection and is considered a draft eco-based surface water screening level, it is not a CWA Section 303(c) approved water quality standard.	Stuchal and Roberts 2019
Minnesota	1.7	Chronic Criterion (CC) calculated as the FAV ÷ a generic ACR following Minnesota Rules Chapter 7050. No species-specific ACRs were available at the time to calculate the FACR. This draft value idoes not represent a CWA Section 303(c) approved water quality standard for PFOA.	STS/MPCA 2007
Texas	2.77	Based on NOAELs, LOAELs, or similar values from specific toxicological studies. Contact the TCEQ for more information. This is a chronic surface water benchmark and does not represent a CWA Section 303(c) approved water quality standard for PFOA.	TCEQ 2021
Marine Chronic			
California	0.54 (99% species protection)	HC1 calculated from an acute and chronic NOEC-based SSD as reported in DoD-SERDP Project ER18-1614 (DoD-SERDP 2019). Acute NOEC values were converted to chronic values using mean acute-to-chronic ratios derived from Giesy et al. (2010). This value represents an "Interim Final Environmental Screening Level" and does not represent a CWA Section 303(c) approved water quality Standard for PFOA.	San Francisco Bay RWQCB 2020; DoD-SERDP 2019
Australia, New Zealand	0.019 (99% species protection – high conservation value systems) 0.22 (95% species protection – slightly to moderately disturbed systems)	Freshwater values are to be used on an interim basis until final marine guideline values can be set using the nationally agreed process under the Australian and New Zealand Guidelines for Fresh and Marine Water Quality.	HEPA 2020

State/Country of Applicability	Aquatic Life Protective Value (mg/L)	Criteria or Benchmark and Calculation Approach	Source
	0.632 (90% species protection – highly disturbed systems)		
	1.824 (80% species protection – highly disturbed systems)		

1.2 Overview of Per- and Polyfluorinated Substances (PFAS)

Perfluorooctanoic acid (PFOA), and its salts, belong to the per- and polyfluorinated substances (PFAS) group of chemicals. PFAS are a large group of structurally diverse anthropogenic chemicals that include PFOA, PFOS, and thousands of other fully or partially fluorinated chemicals. There are many families or subclasses of PFAS, and each contains many individual structural homologues and can exist as either branched-chain or straight-chain isomers (Buck et al. 2011; U.S. EPA 2021). These PFAS families can be divided into two primary categories: non-polymers and polymers. The non-polymer PFAS include perfluoroalkyl and polyfluoroalkyl substances. Polymer PFAS include fluoropolymers, perfluoropolyethers, and side-chain fluorinated polymers (Table 1-2). Several U.S. federal, state, and industry stakeholders as well as European entities have posited various definitions of what constitutes a PFAS. OECD, an international organization comprised of 38 countries, recently published a practical guidance regarding the terminology of PFAS (OECD 2021). The OECD-led "Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance" workgroup provided an updated definition of PFAS, originally posited in part by Buck et al. (2011), as follows: "PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e. with a few noted exceptions, any chemical with at least a perfluorinated methyl group (–CF3) or a perfluorinated methylene group (–CF2–) is a PFAS". It is not within the scope of this framework to compare and contrast the various definitions, or the nuances associated with defining or scoping PFAS; rather the reader of this document is referred to OECD (2021) for review. Generally, the structural definition of PFAS includes chemicals that contain at least one of the following three structures:

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- R-(CF_2)-CF(R′)R″, where both the CF_2 and CF moieties are saturated carbons, and none of the R groups can be hydrogen (TSCA draft definition);
- R-CF_2OCF_2-R′, where both the CF_2 and CF moieties are saturated carbons, and none of the R groups can be hydrogen; and
- $CF_3C(CF_3)$R′R ″, where both the CF_2 and CF moieties are saturated carbons, and none of the R groups can be hydrogen.

It should also be noted that what defines or constitutes a PFAS may change or evolve over time and under different purviews (e.g., federal, state, international).

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Table 1-2. Two Primary Categories of PFAS[1].

PFAS Non-polymers	Structural Elements	Example PFAS Families
Perfluoroalkyl acids	Compounds in which all carbon-hydrogen bonds, except those on the functional group, are replaced with carbon-fluorine bonds	Perfluoroalkyl carboxylic and sulfonic acids (e.g., PFOA, PFOS), perfluoroalkyl phosphonic and phosphinic acids, perfluoroalkylether carboxylic and sulfonic acids
Polyfluoroalkyl acids	Compounds in which all carbon-hydrogen bonds on at least one carbon (but not all) are replaced with carbon-fluorine bonds	polyfluoroalkyl carboxylic acids, polyfluoroalkylether carboxylic and sulfonic acids
PFAS Polymers	**Structural Elements**	**Example PFAS Families**
Fluoropolymers	Carbon-only polymer backbone with fluorines directly attached	polytetrafluoroethylene, polyvinylidene fluoride, fluorinated ethylene propylene, perfluoroalkoxyl polymer
Polymeric perfluoropolyethers	Carbon and oxygen polymer backbone with fluorines directly attached to carbon	F-(CmF2mO-)nCF3, where the CmF2mO represents -CF2O, -CF2CF2O, and/or -CF(CF3)CF2O distributed randomly along polymer backbone
Side-chain fluorinated polymers	Non-fluorinated polymer backbone with fluorinated side chains with variable composition	n:1 or n:2 fluorotelomer-based acrylates, urethanes, oxetanes, or silicones; perfluoroalkanoyl fluorides; perfluoroalkane sulfonyl fluorides

[1:] Amalgamation of information from Figure 9 of OECD (2021) and Buck et al. (2011).

PFOA belongs to the perfluoroalkyl acids (PFAAs) of the non-polymer perfluoroalkyl substances category of PFAS (Table 1-2). PFAAs are among the most researched PFAS (Wang et al. 2017). The family PFAAs includes perfluoroalkyl carboxylic, sulfonic, sulfinic, phosphonic, and phosphinic acids (Table 1-3). PFAAs are highly persistent and are frequently found in the environment (Ahrens 2011; Wang et al. 2017). PFAAs may dissociate to their anions in aqueous environmental media, soils, or sediments depending on their acid strength (pK_a value). Although the protonated and anionic forms may have different physiochemical

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properties, the anionic form is the dominant form in the aquatic environment, including in the toxicity tests used to derive the PFOA criteria.

Table 1-3. Classification and Chemical Structure of Perfluoroalkyl Acids (PFAAs).[1]

Classification	Functional Group	Example
Perfluoroalkyl carboxylic acids (PFCAs)	-COOH	Perfluorooctanoic acid (PFOA)[2]
Or Perfluoroalkyl carboxylates (PFCAs)	$-COO^-$	Perfluorooctanoate (PFO)
Perfluoroalkane sulfonic acids (PFSAs)	$-SO_3H$	Perfluorooctane sulfonic acid (PFOS)
Or Perfluorokane sulfonates (PFSAs)	$-SO_3^-$	Perfluorooctane sulfonate (PFOS)
Perfluoroalkyl sulfinic acids (PFSIAs)	$-SO_2H$	Perfluorooctane sulfinic acid (PFOSI)
Perfluoroalkyl phosphonic acids (PFPAs)	$-P(=O)(OH)_2$	Perfluorooctyl phosphonic acid (C8-PFPA)
Perfluoroalkyl phosphinic acids (PFPIAs)	$-P(=O)(OH)(C_mF_{2m+1})$	Bis(perfluorooctyl) phosphinic acid (C8/C8-PFPIA)
Perfluoroalkylether carboxylic acids (PFECAs)	$CF_3(OCF_2)_nCOO^-$	perfluoro (3,5,7-trioxaoctanoic) acid
Perfluoroalkylether sulfonic acids (PFESAs)	$CF_3(OCF_2)_nSO_3H$	6:2 Cl-PFESA
Perfluoroalkyl dicarboxylic acids (PFdiCAs)	$HOOC\text{-}C_nF_{2n}\text{-}COOH$	9:3 Fluorotelomer betaine
Perfluoroalkane disulfonic acids (PFdiSAs)	$HO_3S\text{-}C_nF_{2n}\text{-}SO_3H$	Perfluoro-1,4-disulfonic acid

[1]: Modified from Buck et al. (2011) and OECD (2021).
[2]: At most environmentally relevant pH conditions, PFOA occurs in the anionic form.

Perfluoroalkyl carboxylic acids (PFCAs), including PFOA, consist of a general chemical structure of $C_nF_{2n+1}COOH$. This chemical structure makes PFOA (see Figure 1-1) extremely strong and stable, and resistant to hydrolysis, photolysis, microbial degradation, and metabolism (Ahrens 2011; Beach et al. 2006; Buck et al. 2011).

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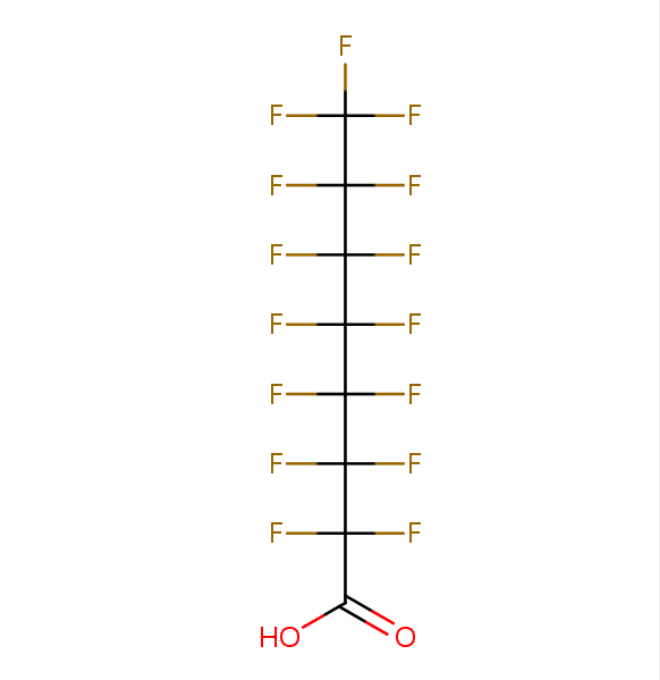


Figure 1-1. Chemical Structure of the Linear Isomer of Perfluorooctanoic acid (PFOA).
(Source: United States EPA Chemistry Dashboard; https://comptox.epa.gov/dashboard).

1.2.1 Physical and Chemical Properties of PFOA

Physical and chemical properties along with other reference information for PFOA are provided in Table 1-4. These physical and chemical properties helped to define the environmental fate and transport of PFOA in the aquatic environment. In the environment, PFOA rapidly ionizes in water to its anionic form (perfluorooctanoate, PFO). PFOA is highly stable and is resistant to hydrolysis, photolysis, volatilization, and biodegradation (UNEP 2015).

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Table 1-4. Chemical and Physical Properties of PFOA.

Property	PFOA, acidic form[1]	Source
Chemical Abstracts Service Registry Number (CASRN)	335-67-1	
Chemical Abstracts Index Name	2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-pentadecafluorooctanoic acid	
Synonyms	PFOA; Pentadecafluoro-1-octanoic acid; Pentadecafluoro-n-octanoic acid; Octanoic acid, pentadecafluoro-; Perfluorocaprylic acid; Pentadecafluorooctanoic acid; Perfluoroheptanecarboxylic acid;	
Chemical Formula	$C_8HF_{15}O_2$	
Molecular Weight (grams per mole [g/mol])	414.07	PubChem Identifier (CID 9554) (URL: https://pubchem.ncbi.nlm.nih.gov/compound/9554); Lide (2007)
Color/Physical State	White powder (ammonium salt)	PubChem Identifier (CID 9554) (URL: https://pubchem.ncbi.nlm.nih.gov/compound/9554)
Boiling Point	192.4 ºC	HSDB (2012); Lide (2007); SRC (2016)
Melting Point	54.3 ºC	HSDB (2012); Lide (2007); SRC (2016)
Vapor Pressure	0.525 mm Hg at 25 °C (measured) 0.962 mm Hg at 59.25 °C (measured)	Hekster et al. (2003); HSDB (2012); SRC (2016) ATSDR (2015); Kaiser et al. (2005)
K_{AW}	0.00102 (experimentally determined; equivalent to Henry's Law Constant of 0.000028 Pa-m^3/mol at 25 °C)	Li et al. (2007)
K_{OW}	Not measurable	UNEP (2015)
Organic carbon water partitioning coefficient (K_{OC})	2.06	Higgins and Luthy (2006)
pKa	3.15 (mean measured)	Burns et al. (2008) and 3M Company (2003) as reported in EPA Chemistry Dashboard (URL: https://comptox.epa.gov/dashboard/dsstoxdb/results?search=DTXSID8031865#properties)
Solubility in Water	9,500 mg/L (estimated); 3,300 mg/L at 25 ºC (measured)	Hekster et al. (2003); Inoue et al. (2012)

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Property	PFOA, acidic form[1]	Source
Half-Life in Water	Stable	UNEP (2015)
Half-Life in Air	Stable	UNEP (2015)

[1]: PFOA is most commonly produced as an ammonium salt (CASRN 3825-26-1). Properties specific to the salt are not included.

PFOA is water soluble, nonvolatile, and stable, with a low vapor pressure and is a solid at room temperature (UNEP 2015). The EPA's chemistry dashboard reported a mean experimental acid dissociation constant (pKa) for PFOA of 3.15 calculated from pKa values determined from Burns et al. (2008) and 3M Company (2003). Burns et al. (2008) measured an acid dissociation constant (pKa) for PFOA of 3.8 using a standard water-methanol mixed solvent approach, which indicates PFOA is a moderate acid, while 3M Company (2003) reported a measured PFOA pKa of 2.5.

Due to the surfactant properties of PFOA, it forms three layers when added to octanol and water in a standard test system used to measure a n-octanol-water partition co-efficient (K_{OW}), thus preventing direct measurement (EFSA 2008; Giesy et al. 2010). Although a K_{OW} cannot be directly measured, a K_{OW} for PFOA has been estimated from its individual water and octanol solubilities (estimated PFOA K_{OW} range = 2.69 – 6.3; UNEP 2015); however, the veracity of such estimates is uncertain (UNEP 2015). Lacking a reliable K_{OW} for PFOA precludes application of K_{OW}-based models commonly used to estimate various physiochemical properties for organic compounds, including bioconcentration factors and soil adsorption coefficients. Further, the unusual characteristics of PFOA would bring into question the use of K_{OW} as a predictor of environmental behavior; for example, bioaccumulation of PFOA is thought to be mediated via binding to proteins rather than partitioning into lipids (EFSA 2008; Giesy et al. 2010), the latter being the theoretical basis for K_{OW}-based prediction of bioaccumulation.

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2 PROBLEM FORMULATION

A problem formulation provides a strategic framework for water quality criteria development under the CWA by focusing on the most relevant chemical properties and endpoints. In the problem formulation, the purpose of the assessment is stated, the problem is defined, and a plan for analyzing and characterizing risk is developed. The structure of this problem formulation was consistent with the EPA's Guidelines for Ecological Risk Assessment (U.S. EPA 1998).

2.1 Overview of PFOA Sources

2.1.1 Manufacturing of PFOA

PFOA is primarily produced through Electrochemical Fluorination (ECF) in which an organic raw material, in the case of PFOA as octanoyl fluoride ($C_7H_{15}COF$), undergoes electrolysis in anhydrous hydrogen fluoride solution. This electrolysis leads to the replacement of all the hydrogen atoms by fluorine atoms and results in perfluorooctanoyl fluoride ($C_7F_{15}COF$), which is the major raw material used to manufacture PFOA and PFOA salts (Figure 2-1; Buck et al. 2011). Electrochemical Fluorination typically results in a mixture of branched and linear isomers.

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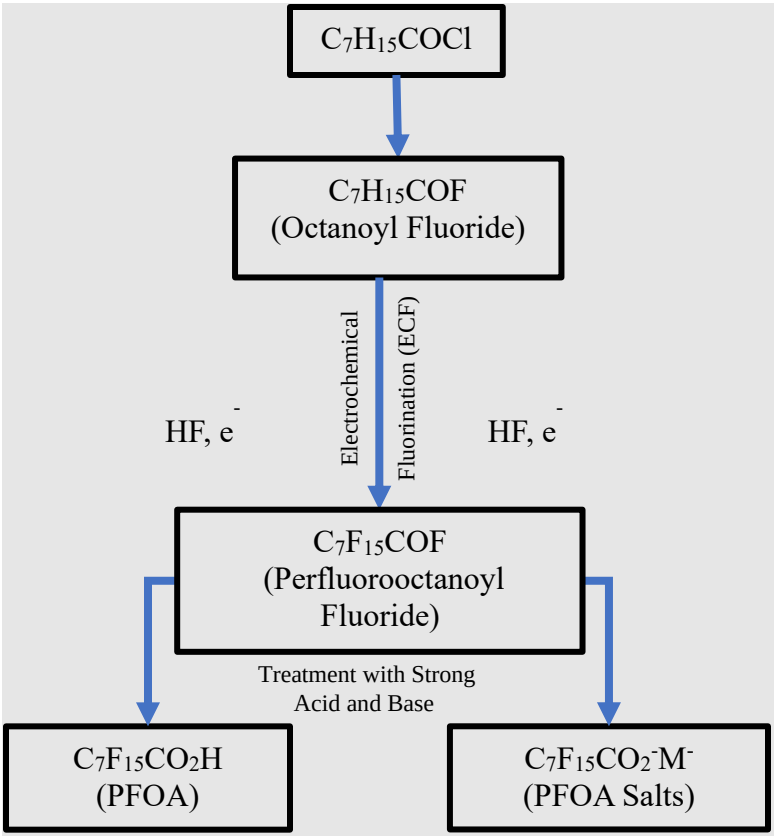


Figure 2-1. Synthesis of Perfluorooctanoic acid (PFOA) by Electrochemical Fluorination (ECF).
Modified from Buck et al. (2011).

Initial production of PFOA started in the 1940s and commercial production and use as protective coatings starting in the mid-1950s. From 1951 – 2004 the total global historic industry wide emission of PFCAs (including PFOA) from all sources (i.e., direct and indirect sources such as manufacture, use, consumer products, and PFCA precursors) ranged from 3,200 tons to 7,300 tons (Prevedouros et al. 2006). In 2006, the EPA initiated the 2010/2015 PFOA Stewardship Program, resulting in major PFOA producers committing to a 95% reduction in PFOA facility emissions and product contents across the globe by 2010. The 2010/2015 PFOA Stewardship Program further aimed to eliminate PFOA emissions and product content by 2015 (U.S. EPA 2006).

2.1.2 Sources of PFOA to Aquatic Environments

PFCAs, including PFOA are primarily released into water (95% of PFCAs are emitted to water; 3M Company 2000b) and can enter the aquatic environment from both industrial and consumer products during manufacturing, along the supply chains, during product use and/or disposal (Ahrens and Bundschuh 2014; Kannan 2011). Occurrence of PFOA in the aquatic environment arises from both direct and indirect sources (Ahrens et al. 2011a). However, the quantitative assessments of their production, direct and indirect emissions, and environmental measurements are lacking (Ahrens and Bundschuh 2014; Prevedouros et al. 2006).

The direct sources of PFOA to the aquatic environment include both municipal and industrial wastewater treatment plants (WWTPs), landfill leachate, and runoff from contaminated biosolids (Renner 2009). WWTPs in particular are an important source of PFOA to aquatic systems (Ahrens et al. 2009).

Indirect sources of PFOA to aquatic environments include dry and wet atmospheric deposition, runoff from contaminated soils, and consumer product use and disposal (Kannan 2011). Identification of indirect sources of PFOA and understanding their relative contribution to aquatic ecosystems is difficult. Overall, the presence of indirect sources of PFOA and their contributions are dependent on the system and the nearby land uses. Overall PFAS concentrations, including PFOA, in the environment are positively correlated with population density. Overall, PFOA occurrence in aquatic environments is driven by legacy PFOA sources because use of PFOA in the United States was largely phased out by 2010, and completely phased out by 2015 in accordance with the EPA's 2010/2015 PFOA Stewardship Program.

In addition to direct discharge, environmental breakdown of precursor compounds containing a seven-member perfluoro moiety can provide an additional source of PFOA. Metabolic transformation of PFAS precursors, such as PAPs, FTCAs, FTUCAs, FTSAs, and

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FASAAs, and the degradation of volatile PFAS, such as FTOHs, FASAs, and FASEs, can be potential sources of PFOA as these compounds can transform into more persistent PFAS, including PFCAs and PFOA (Ahrens and Bundschuh 2014). For example, fluoroacrylate polymers can breakdown in soil and release fluorotelomer alcohol (FTOH) which can further degrade into PFOA (Russell et al. 2008). Similarly, polyfluoroalkyl phosphoric acid diesters (diPAPs) are used in commercial applications, such as food packaging, and can be found in WWTP sludge and contaminated biosolids. In environmental media, diPAPs can release FTOH that further degrades into PFOA (Lee et al. 2010; Sinclair and Kannan 2006; Washington et al. 2009). Current understanding of these transformation processes remains limited, and additional work is needed to fully understand these processes and their role in generation of sources of PFOA to aquatic environments (Lau et al. 2007).

PFOA can also be re-emitted to the aquatic environment from ice melt and sediment transport. Release of PFOA will continue into the future from the transformation of other PFAS and the historical products still in use (e.g., consumer goods manufactured and/or obtained before the PFOA discontinuation).

2.2 Environmental Fate and Transport of PFOA in the Aquatic Environment

2.2.1 Environmental Fate of PFOA in the Aquatic Environment

In natural waters near neutral pH, PFOA rapidly dissociates into ionic components. In aquatic environments, PFOA has an affinity to remain in the water column rather than sediments, but can also adsorb to sediments in the presence of organic carbon, with the partitioning coefficients (K_d) increasing with salinity (Canada 2012; Hekster et al. 2003). Because of its water solubility and preferential binding to proteins, once PFOA enters a waterbody it tends to remain dissolved in the water column, where it is mobile, unless it adsorbs to organic particulate matter or is assimilated by organisms.

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PFOA has low volatility in the ionized form but can adsorb to particles in air where it can be transported globally, including remote locations (Del Vento et al. 2012; Shoeib et al. 2006). PFOA is water soluble and has been found in surface water, ground water, and drinking water. Because of the relatively low log K_{OC} of PFOA, it does not easily adsorb to sediments and tends to stay in the water column.

In the water column, and other environmental compartments, PFOA is stable and resistant to hydrolysis, photolysis, volatilization, and biodegradation (Higgins and Luthy 2006; UNEP 2015). The persistence of PFOA has been attributed to the strong carbon-fluorine (C-F) bond. Additionally, there are limited indications that naturally occurring defluorinating enzymes exist that can break a C-F bond. Consequently, no biodegradation or abiotic degradation processes for PFOA are known. In aquatic environments, the only dissipation mechanisms for PFOA are physical mechanisms, such as environmental dilution and sorption.

2.2.2 Environmental Transport of PFOA in the Aquatic Environment

The physiochemical properties discussed in Section 1.2.1 above enable PFOA to be highly persistent in the aquatic environment. PFOA tends to be distributed in waters and in the atmosphere (Ahrens 2011; Yamashita et al. 2008). PFOA concentrations in seawater are typically greater than PFOS, which has been attributed to the relatively lower bioaccumulation potential, lower sorption to sediments, and greater water solubility (Ahrens 2011; Ahrens et al. 2009).

Numerous uncertainties exist in the understanding of environmental transport of PFOA in aquatic systems. Both point and non-point sources contribute PFOA to the aquatic environment. PFOA can be transported from these sources into rivers, streams, lakes, and marine environments. There is a general decrease in PFOA concentrations along a transport pathway resulting from dilution in the water column. For example, measured PFOA concentrations in

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WWTP effluents were generally an order of magnitude greater than riverine concentrations, with the upper end of riverine concentrations being similar to WWTP effluents. Although minimum and maximum PFOA concentrations in coastal waters (ranging from hundreds of pg/L to several ng/L) were below corresponding measurements in riverine systems, coastal PFOA concentrations in general were largely similar to riverine concentrations. Open oceans contained the lowest PFOA concentrations resulting from immense dilution. Overall, open ocean concentrations of PFOA were roughly 2.5 orders of magnitude lower than those reported in WWTP effluents (Ahrens 2011).

PFOA has been found in a diversity of environments, including in the arctic and Antarctic, despite the limited number of manufacturing facilities and/or small population sizes typically found in these areas (Del Vento et al. 2012; Shoeib et al. 2006). Although PFOA has low volatility, particularly in the ionized form, it can absorb to air particles before being deposited via atmospheric deposition to these remote regions. For example, Kim and Kannan (2007) reported PFOA in snow in the United States ranging from below the limit of quantification to 20 ng/L. Similarly, Young et al. (2007) reported mean PFOA concentrations in snow in Canada ranging from 0.01 ng/L to 0.15 ng/L.

The continued presence of PFOA in open oceans and in remote polar areas may be due to multiple exposure pathways, including those caused by direct production, use, and discharge of PFOA itself, degradation and transformation of precursor compounds, and via long range aqueous and atmospheric transport (Armitage et al. 2009).

2.3 Transformation and Degradation of PFOA Precursors in the Aquatic Environment

Included among major sources of PFOA to the environment is from the abiotic and biotic transformation and degradation of polyfluoroalkyl precursor substances (see Section 2.2.2

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above). Polyfluoroalkyl substances are one type of precursor substance that have the potential to be transformed abiotically or biotically into PFCAs such as PFOA (Buck et al. 2011). On a global scale, production volumes of polyfluoroalkyl substances, many of which are likely polyfluoroalkyl precursor substances that ultimately degrade or transform to PFOA, greatly exceed direct emissions of PFOA through its manufacture, use and disposal (Butt et al. 2014; Liu and Mejia Avendaño 2013). According to the OECD (2006), there were approximately one thousand polyfluorylalkyl chemicals commercially produced at the time that could conceivably degrade to PFCAs such as PFOA. For example, Buck et al. (2011) identified 42 families of compounds and numerous individual PFAS detected in environmental and human matrices, many of which have not been evaluated for their biodegradability (Liu and Mejia Avendaño 2013). Any or all members of these PFAS have the ability to be transformed or degraded to PFAAs such as PFCAs or perfluoroalkane sulfonic acids (PFSAs).

Critical reviews by Butt et al. (2014) and Liu and Mejia Avendaño (2013) provided a comprehensive summary of the qualitative and quantitative relationships between biodegradation and transformation of polyfluoroalkyl precursors and generation of PFOA and other PFCAs. The most well-studied polyfluoroalkyl precursor substances are fluorotelomer-based compounds, which are produced through telomerization technology and are associated with PFOA as the final product (Buck et al. 2011).

2.3.1 Biodegradation of fluorotelomer-based precursors

The aerobic biodegradation pathway of fluorotelomer alcohols (8:2 and 6:2 FTOH) have been thoroughly studied. Dinglasan et al. (2004) was among the first to investigate the biotransformation of 8:2 FTOH in a mixed microbial culture. Additional studies of the aerobic microbial degradation of 8:2 FTOH by Liu et al. (2010) and Wang et al. (2005, 2009, and 2012) have since confirmed the formation of PFOA via this pathway. The observed half-lives of 8:2

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FTOH ranged from <2 days to 30 days in these laboratory studies. Molar yield of PFOA ranged anywhere from 0.5 to 40% depending on type of microbes or microcosm used in the study, with Wang et al. (2009) observing relatively higher PFOA yield in aerobic soils relative to PFOA yield in pure bacterial culture (Liu et al. 2010). Thus, aerobic microbial degradation of 8:2 FTOH can be a significant source of PFOA in some environmental compartments. Anaerobic microbial degradation of 8:2 FTOH, on the other hand, is inefficient and likely an insignificant source of PFOA to the environment (Zhang et al. 2013b). Additional studies are needed, however, to understand anaerobic biodegradability of FTOHs and related compounds in general (Liu and Mejia Avendaño 2013).

Aerobic biodegradation of several other types of fluorotelomer-based, polyfluoroalkyl precursor substances definitively linked to PFOA formation include: fluorotelomer stearate (8:2 FTS) with observed half-life in aerobic soils of 5-28 days and molar yield of about 01.7-4% (Dasu et al. 2012, 2013); fluorotelomer acrylate (8:2 FTAC) and fluorotelomer methacrylate (8:2 FTMAC) monomers with observed half-life in aerobic soils of 3-5 days and 15 days and molar yields of 7.8 and 10%, respectively (Royer 2011); fluorotelomer ethoxylates (FTEOs) with observed half-life in unfiltered WWTP effluent of approximately one day and molar yield of about 0.3% (Frömel and Knepper 2010); and fluorotelomer urethanes, specifically, aliphatic diurethane ester (8:2 HMU), with an half-life in aerobic soils of >180 days and molar yield of 0.9% (Dasu 2011).

2.3.2 Biodegradation of side-chain polymers

At present, a crucial need exists to understand the potential degradation of side-chain fluorinated polymers in natural environments because they currently represent a high percentage of all commercial and industrial PFAS sales products (Liu and Mejia Avendaño 2013). Side-chain polymers are those with polyfluoroalkyl or perfluoroalkyl chains attached to non-

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fluorinated backbones (Buck et al. 2011). Russell et al. (2008) investigated the biodegradation of a high molecular weight (~40,000 amu, 100–300 nm in diameter) polyacrylate polymer aqueous dispersion product in four aerobic soils over two years. Two approaches (molar mass balance and kinetic modeling) gave conflicting results. The molar mass balance approach indicated no evidence of biodegradation because the PFOA generated was mostly accounted for by impurity (residual non-polymerized PFAS) degradation. Conversely, using the kinetic modeling approach half-lives of PFOA were estimated to be around 1,200-1,700 years among the four soils tested. Upon further investigation using a low molecular weight (~3,500 amu) polyurethane polymer product and a similar approach, Russell et al. (2010) clearly demonstrated biodegradability of the low molecular weight polyurethane polymer product compared to the polyacrylate polymer, as the levels of PFOA produced were several orders of magnitude greater than what the impurities could account for. Applying a similar kinetic modeling approach, the half-lives of the polyurethane polymer were estimated to range from 28 to 241 years among the four test soils. Given the large disparity in half-life prediction between the two studies, however, additional research is needed to clarify the contributions of polyfluoroalkyl polymers to PFOA formation due to the high percentage of side-chain fluorinated polymers that exist in commercial and industrial sales products.

2.3.3 Biodegradation of other polyfluoroalkyl substances

Recently, Mejia-Avendaño et al. (2016) examined the formation of PFOA from aerobic biotransformation of quaternary ammonium polyfluoroalkyl surfactants (QACs). Capitalizing on several recent studies focused on identifying specific PFAS in major PFAS-based aqueous film-forming foam (AFFF) formulations, all the newly identified PFAS were polyfluoroalkyl compounds. These compounds have perfluoroalkyl carbon chain lengths varying from four to 12 and possess functionalities such as sulfonyl, thioether, tertiary amine, quaternary ammonium,

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carboxylate, sulfonate, amine oxide, and betaine, etc. (Mejia-Avendaño et al. 2016). Importantly, the identified cationic PFAS in these studies contain either tertiary amine or quaternary ammonium groups. In this first study of the fate of polyfluoroalkyl cationic surfactants used in aqueous AFFF formulations, the biotransformation of perfluorooctaneamido quaternary ammonium salt (PFOAAmS) was characterized by a DT50 value (time necessary to consume half of the initial mass) of 142 days and significant generation of perfluoroalkyl carboxylic acid (PFOA) at a yield of 30% (mol) by day 180. Three novel biotransformation intermediates were identified for PFOAAmS, and it was demonstrated that despite overall high stability of QACs and their biocide nature, the ones with perfluoroalkyl chains can be substantially biotransformed into perfluoroalkyl acids in aerobic soil.

The above microbial biotransformation and degradation pathways are all dependent on environmental conditions, degradation kinetics, and the chemical structures and properties of the individual polyfluoroalkyl precursors (Buck et al. 2011; Butt et al. 2014; Liu and Mejia Avendaño 2013). Of particular importance is the environmental stability of key chemical linkages (such as esters and ethers) as the stability of these chemical linkages determines the stability of the overall PFAS (Liu and Mejia Avendaño 2013). It is evident through these studies that the biotransformation and biodegradability of polyfluoroalkyl precursor substances is due to the breakdown of the non-fluorinated functionality of the precursor substances, which precedes the breakdown of the perfluorinated carbons. In contrast, perfluoroalkyl chemicals in general resist biotransformation and defluorination under natural conditions. Using ^{14}C-labeled PFOA to examine five different microbial communities, a range of electron donors for reductive defluorination processes, and the possibility of co-metabolism during reductive dechlorination of

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trichloroethene, Liou et al. (2010) was able to confirm that PFOA is highly resistant to microbial degradation in natural environments.

2.3.4 Non-microbial biodegradation of other polyfluoroalkyl substances

Butt et al. (2014) reviewed the current state of knowledge regarding the biotransformation of fluorotelomer-based, polyfluoroalkyl precursor substances that degrade to form PFCAs (PFOA) in microbial systems, rats, mice, and fish. Consistent with information presented above, the majority of biotransformation studies thus far used 8:2 FTOH (a fluorotelomer alcohol) as the substrate; only a few studies of non-FTOH biotransformation exist. The biotransformation studies of 8:2 FTOH metabolism universally show the formation of PFOA. As above, the overall yield of PFOA is low, presumably because of the multiple branches in the biotransformation pathways, including conjugation reactions in animal systems which are capable of phase II metabolism and results in the formation of conjugated metabolites such as glucuronide, sulfate, and glutathione metabolites. Butt et al. (2014) also showed that fluorotelomer carboxylates (FTCAs) appear to be more stable in animal models, whereas they are relatively labile in microbial systems. In contrast, the unsaturated form of FTCAs – FTUCAs appear to be readily degraded in animal models.

2.4 Environmental Monitoring of PFOA in Abiotic Media

PFOA has been detected in a variety of environmental abiotic matrices in aquatic environments around the globe. These abiotic media include surface water, soils, sediments, groundwater, air, and ice caps (Butt et al. 2010; Lau et al. 2007). Water is expected to be the primary environmental media that PFOA is found (Lau et al. 2007). Occurrence and detection of PFOA in other aquatic abiotic media found in the aquatic environment are summarized below.

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2.4.1 PFOA Occurrence and Detection in Ambient Surface Waters

PFOA is one of the dominant PFAS detected in ambient surface waters, along with PFOS (Ahrens 2011; Benskin et al. 2012; Dinglasan-Panlilio et al. 2014; Nakayama et al. 2007; Remucal 2019; Zareitalabad et al. 2013). Most of the current, published PFOA occurrence studies have focused on a handful of broad geographic regions, many times targeting sites with known manufacturing or industrial uses of PFAS, such as the Great Lakes, the Cape Fear River and waterbodies near Decatur, Alabama (Figure 2-2; Boulanger et al. 2004; Cochran 2015; Hansen et al. 2002; Konwick et al. 2008; Nakayama et al. 2007; 3M Company 2001).

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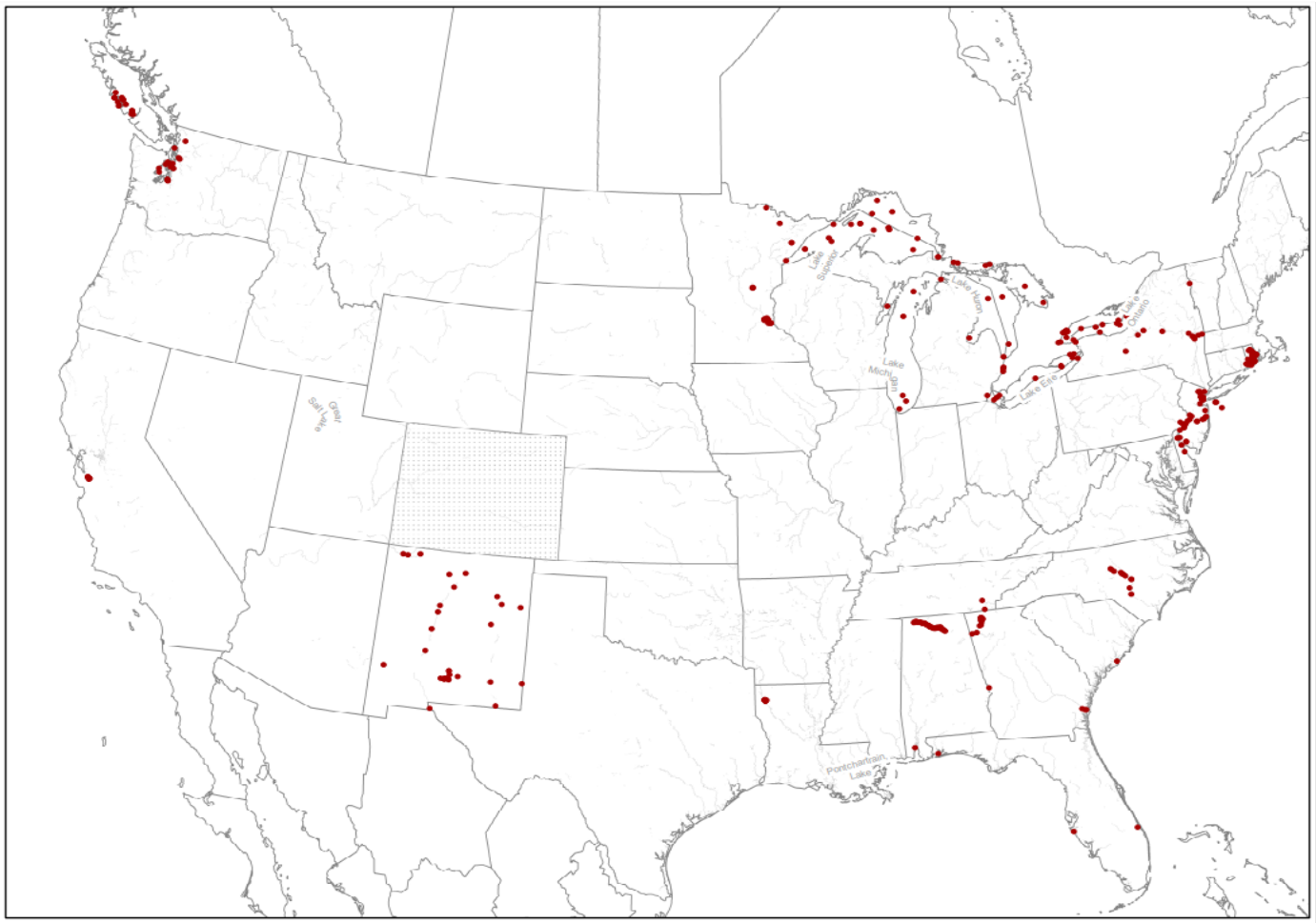


Figure 2-2. Map Indicating Sampling Locations for Perfluorooctanoic acid (PFOA) Measured in Surface Waters Across the United States (U.S.) Based on Data Reported in the Publicly Available Literature.
Colorado sampling coordinates were not available, these data are represented by the dash marks to indicate measured PFOA surface water concentrations are available in Colorado.

Concentrations of PFOA in surface waters vary widely (Figure 2-3), with observed concentrations ranging over seven orders of magnitude and detected generally between pg and ng per liter with some sites with reported concentrations in µg/L (Zareitalabad et al. 2013). For the purposes of this overview and comparison, all concentrations reported here are in ng per liter (ng/L). Unlike other contaminants commonly found in aquatic ecosystems, PFAS are synthetic compounds and therefore have no natural source. Thus, the occurrence of any PFAS in the environment is an indication of anthropogenic sources, including consumer and industrial use,

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long-range transport, atmospheric deposition, surface water runoff, and general persistence in the environment.

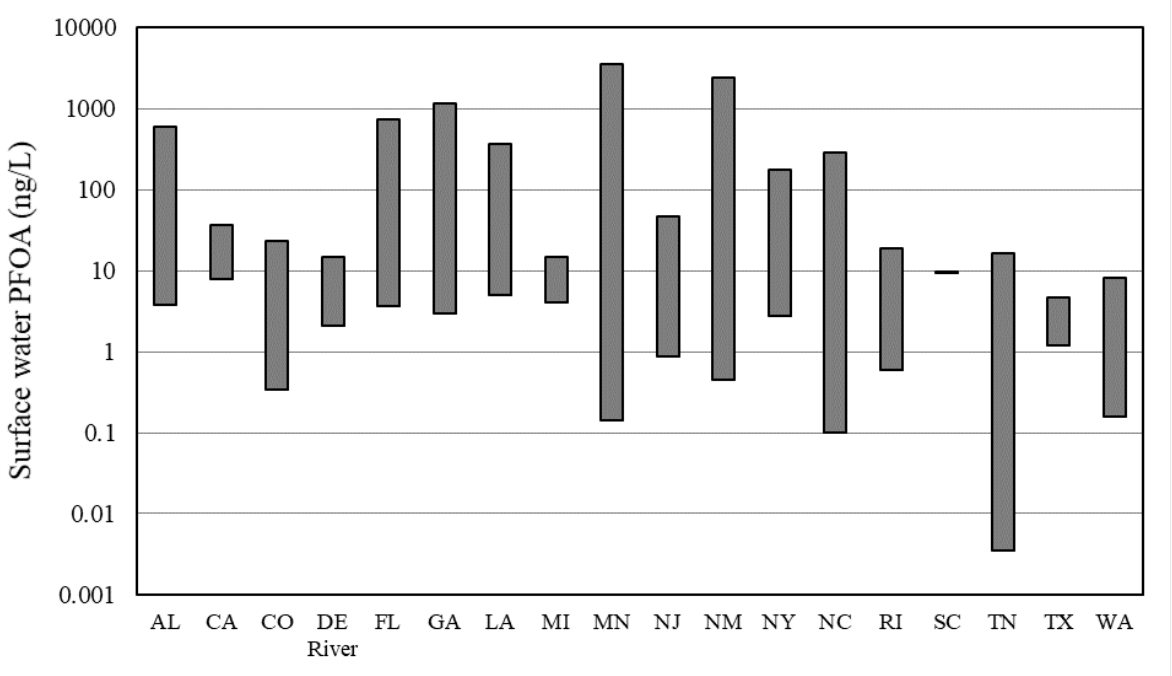


Figure 2-3. Distribution of the minimum and maximum concentrations (ng/L) of Perfluorooctanoic acid (PFOA) measured in surface waters for each state or waterbody (excluding the Great Lakes) with reported data in the publicly available literature.
The distribution is arranged alphabetically by state and waterbody.

PFOA concentrations in surface water tend to increase with levels of urbanization. Across the Great Lakes region, PFOA was higher in the downstream lakes of Erie and Ontario and lower in the upstream lakes of Superior, Michigan, and Huron (Remucal 2019). Similarly, Zhang et al. (2016) observed measured PFOA concentrations in urban areas (urban average PFOA concentration = 10.17 ng/L; n = 20) to be more than three time greater than concentrations in rural areas (rural average PFOA concentration = 2.95 ng/L; n = 17) within New Jersey, New York, and Rhode Island. Temporal variation of PFOA in surface waters remains largely unknown due to data limitations. See Appendix M for further discussion of PFOA occurrence in surface waters and other abiotic media such as aquatic sediments, groundwater, air, and ice.

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2.5 Bioaccumulation and Biomagnification of PFOA in Aquatic Ecosystems

PFOA is found in aquatic ecosystems around the globe (e.g., Ankley et al. 2020; Giesy and Kannan 2001; Houde et al. 2008). Although they were used predominantly in more populated areas, these compounds are resistant to hydrolysis, photolysis, and biodegradation, which facilitates their long-range transport to aquatic ecosystems in the remote arctic and mid-oceanic islands (Haukås et al. 2007; Houde et al. 2006a). Several physical-chemical properties of PFAS contribute to their bioaccumulation within aquatic and aquatic-dependent species once they have entered an aquatic ecosystem.

2.5.1 PFOA Bioaccumulation in Aquatic Life

In contrast to many persistent organic pollutants which tend to partition to fats, PFOA preferentially binds to proteins (Martin et al. 2003a, 2003b). Within the body, PFOA tends to bioaccumulate within protein-rich tissues, such as the blood serum proteins, liver, kidney, and gall bladder (De Silva et al. 2009; Jones et al. 2003; Martin et al. 2003a, 2003b). PFOA may also bind to ovalbumin, and the transfer of PFOA to such albumin in eggs can be an important mechanism for depuration in female oviparous species, as well as a mechanism for maternal transfer (Jones et al. 2003; Kannan et al. 2005).

The stability of PFOA contributes to its bioaccumulation potential, as PFOA has not been found to undergo biotransformation within the organism and is primarily depurated through excretion in urine or across gill surfaces (De Silva et al. 2009; Martin et al. 2003b). Within an organism, PFOA may undergo enterohepatic recirculation, in which PFOA is excreted from the liver in bile to the small intestine, then reabsorbed and transported back to the liver (Goecke-Flora and Reo 1996). Among PFAS, this process becomes increasingly more efficient the longer the perfluorinated chain length, resulting in longer half-lives for chemicals like PFOA with a relatively long chain length, as they are less readily excreted. PFAS with carboxylate head

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groups, such as PFOA, are less efficiently resorbed by the small intestine and transported back to the liver than sulfonate PFAS, resulting in lower bioaccumulation levels (Hassell et al. 2020; Martin et al. 2003a).

Sex differences in the elimination rate of PFOA chemicals have been observed in some species. Lee and Schultz (2010) observed that the elimination rate of PFOA from blood plasma was ten times faster in female fathead minnows compared to males. The faster elimination rate may be related to sex hormones (i.e., androgen and estrogen) levels, as the elimination rate in females decreased four-fold following exposure to the androgen trenbolone (Lee and Schultz 2010). This pattern has also been observed in rats, where the elimination of PFOA was 70 times faster in females than males and was attributed to sex-related differences in the expression of organic anion transporters in kidneys resulting in higher excretion rates (Kudo et al. 2002). The mechanism for the higher elimination rate in female fathead minnows has not been determined, and the degree to which gender-related differences in elimination rate apply to other fish species, or other taxonomic groups, is unknown. However, it does suggest that the sex of the organism should be considered when assessing ecosystem level bioaccumulation, and that there may be another mechanism in addition to egg production that can result in lower concentration of PFAS in females.

The structure of PFOA also contributes to its bioaccumulation potential, with linear forms being more bioaccumulative than branched forms (De Silva et al. 2009; Hassell et al. 2020). The preferential accumulation of linear PFOA occurs because the elimination rate, of branched isomers of PFOA is higher, particularly across gill surfaces (De Silva et al. 2009). This pattern has also been observed in the field, as the proportion of branched isomers was higher in

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water and sediment compared to fish tissue in Taihu Lake, China (Fang et al. 2014) and Lake Ontario (Houde et al. 2008).

2.5.2 Factors Influencing Potential for PFOA Bioaccumulation and Biomagnification in Aquatic Ecosystems

PFOA binding to the surface of sediment organic matter and biofilms is influenced by both hydrophobic and electrostatic effects, resulting from the hydrophobicity of the perfluorinated chain and the hydrophilicity of the carboxylate head groups (Higgins and Luthy 2006). In a series of laboratory studies, Higgins and Luthy (2006) demonstrated that PFOA sorption to sediments increased with increasing organic content, increasing calcium ions, and decreasing pH. The strongest effect was observed in response to increasing organic content, demonstrating the importance of hydrophobic effects, while the increased sorption in response to calcium ions and decreasing pH demonstrated the role of electrostatic effects (Higgins and Luthy 2006). Across all PFAS, sorption to sediments increased with increasing perfluorinated chain length, and for a given chain length, PFAS such as PFOS, had approximately 1.7 times the sorption capacity as perfluoroalkyl carboxylic acids (PFCA) such as PFOA (Higgins and Luthy 2006). The capacity of PFOA to bind to particulate matter increases with increasing salinity. Jeon et al. (2010) observed that water column PFOA partitioned more readily to particulate organic matter as salinity increased from 10 to 34 ppt, resulting in increased uptake of PFOA in Pacific oysters (*Crassostrea gigas*). In a recent review, Li et al. (2018a) found no single parameter strongly predicted PFOA sorption to sediments and Li et al. (2019) reported that the protein content of soil was a better predictor of sorption than organic carbon. Overall, these results suggest that sorption to sediments should be an important mechanism for PFOA entry into an aquatic ecosystem.

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Evidence of the PFOA sediment pathway in aquatic ecosystems, although mixed, overall demonstrates the importance of bioaccumulation from sediments and biofilms via diet into aquatic invertebrates. In laboratory studies, PFOA concentrations in sediment were positively correlated to PFOA tissue concentrations in *Lumbriculus variegatus* (Lasier et al. 2011), but not for *Chironomus plumosus* (Wen et al. 2016) or the amphipods *Gammarus fossarum* and *G. pulex* (Bertin et al. 2016). In field studies PFOA concentrations were positively correlated between sediments and biofilms and benthic feeding organisms (Lescord et al. 2015; Loi et al. 2011; Martin et al. 2004; Penland et al. 2020). In addition, the distribution of PFAS in sediments was more similar to their distribution in the tissues of benthic invertebrates (Lescord et al. 2015) and benthic-feeding fish (Thompson et al. 2011) than they were to their distribution in pelagic organisms.

PFOA can also enter aquatic organisms directly from the water column through respiration. Because of its binding affinity to proteins, PFOA can enter the body of gill-breathing organisms by binding to proteins in the blood at gill surfaces (De Silva et al. 2009; Jones et al. 2003; Martin et al. 2003a, 2003b).

The relative distribution of PFOA in tissues is related to the primary route of exposure (dietary or respiratory). In rainbow trout, the rank order of PFOA concentrations following aqueous exposure was blood>kidney>liver (Martin et al. 2003a). In contrast, their rank order following dietary exposure was liver>blood>kidney (Goeritz et al. 2013). Hong et al. (2015) observed the highest concentrations of PFAS in the intestines of green eel goby; soft tissues, shell, and legs of shore crabs; and gills and intestines of oysters, suggesting bioaccumulation through both dietary and aqueous uptake in invertebrates, and primarily dietary uptake in fish.

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Data from multiple field studies suggest trophic biomagnification potential of PFOA is low, and is often not observed, particularly with respect to aquatic organisms. In a review of PFOA and PFOS concentration data across major taxonomic groups, Ahrens and Bundschuh (2014) found that maximum PFOA and PFOS concentrations were similar for invertebrates, but that maximum PFOS concentrations in fish were nearly an order of magnitude greater than PFOA, and several orders of magnitude greater for aquatic-dependent birds and mammals.

When individual aquatic species pairs were considered, biomagnification factors (BMF) greater than one, indicating biomagnification, have been observed for PFOA (e.g., Fang et al. 2014; Penland et al. 2020; Tomy et al. 2009), suggesting trophic biomagnification. However, when ecosystem-level biomagnification is assessed using trophic biomagnification factors (TMF), which measures the change in the concentration of a chemical per trophic level within a food web, PFOA is nearly always shown not to biomagnify (Loi et al. 2011; Martin et al. 2004; Tomy et al. 2004; Xu et al. 2014; Zhou et al. 2012), unless aquatic-dependent species, such as aquatic-dependent birds, are included in the food web model (Houde et al. 2006a; Kelly et al. 2009; Tomy et al. 2009). The overall lack of biomagnification in PFOA relative to PFOS is attributed to its physical-chemical properties, including a shorter perfluorinated chain length and the carboxylate head group, both of which are associated with less efficient assimilation into tissues and faster excretion rates (e.g., Martin et al. 2003a, 2003b).

2.5.3 Environmental Monitoring of PFOA in Biotic Media

Generally, PFOA is one of the dominant PFAS detected in aquatic ecosystems, along with PFOS (Ahrens 2011; Benskin et al. 2012; Dinglasan-Panlilio et al. 2014; Nakayama et al. 2007; Remucal 2019; Zareitalabad et al. 2013). PFAS were first detected in human serum samples in the late 1960s, and subsequent studies across several continents demonstrated the global distribution of PFAS in humans (Giesy and Kannan 2001; Houde et al. 2006b). Since

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then, the global distribution of PFAS in tissues of aquatic and aquatic-dependent species has been demonstrated in studies conducted in freshwater and marine environments across every continent, including remote regions far from direct sources, such as the high arctic, Antarctica, and oceanic islands (Giesy and Kannan 2001; Houde et al. 2006b).

In lentic surface waters of the United States, one of the most comprehensive studies of PFOA concentrations included fish muscle tissue data from 157 near shore sites across the Great Lakes selected following a probabilistic design as part of the 2010 National Coastal Condition Assessment (Stahl et al. 2014). In this study, PFOA was measured in fish collected at 12% of the sites, with a 90th centile concentration of 0.16 ng/g wet weight (ww), and a maximum concentration of 0.97 ng/g ww (Stahl et al. 2014). Lake trout (31% of samples), smallmouth bass (14%), and walleye (13%) were the most commonly sampled species from the Great Lakes samples.

Martin et al. (2004) measured PFOA in whole body samples of invertebrates and fish in Lake Ontario, near the town of Niagara-on-the-Lake. PFOA concentrations were much higher in the benthic amphipod *Diporeia hoya* (90 ng/g ww) than in the more pelagic *Mysis relicta* (2.5 ng/g ww), suggesting sediments are an important source of PFOA in this area (Martin et al. 2004). Among the four fish species sampled, PFOA concentrations were highest in the slimy sculpin (44 ng/g ww), which feeds on *M. relicta* and *D. hoya*. Although lake trout occupy the highest trophic level at this site, their PFOA concentrations were the lowest of all sampled fish species (1.0 ng/g ww) (Martin et al. 2004). PFOA concentrations were lower in lake trout than in alewife (1.6 ng/g ww), which comprise 90% of the lake trout diet, suggesting a lack of PFOA biomagnification in this system (Martin et al. 2004).

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Guo et al. (2012) measured PFOA in lake trout muscle tissues in Canadian waters of Lakes Ontario, Erie, Huron, and Superior, as well as Lake Nipigon, Ontario. The average PFOA concentration across all sites was 0.045 ng/g ww and was not significantly different ($P<0.1$) across the different lakes (Guo et al. 2012). Finally, Delinsky et al. (2010) sampled bluegill, black crappie, and pumpkinseed muscle tissues in 59 lakes in Minnesota, including four lakes in the Minneapolis-St. Paul metropolitan area, and did not detect PFOA in any of the samples (limit of quantification = 0.77 ng/g ww; see Table 2 of Delinsky et al. 2009).

In flowing surface waters of the United States, one of the most comprehensive studies of PFOA concentrations included fish muscle tissue data from 164 urban river sites (5^{th} order or higher) across the coterminous U.S. selected following a probabilistic design as part of the 2008-2009 National Rivers and Streams Assessment and the National Coastal Condition Assessment (Stahl et al. 2014). Largemouth bass (34% of samples), smallmouth bass (25%), and channel catfish (11%) were the most commonly sampled species from the urban stream sites (Stahl et al. 2014). PFOA was not detected in any of the urban river sites (Stahl et al. 2014). The lack of detection may have been related to the method detection limit of 2.37 ng/g ww, which was higher than the highest PFOA concentration measured in the Great Lakes coastal survey described above, which also followed a probabilistic sampling design (Stahl et al. 2014).

In 2005, Ye et al. (2008) detected average PFOA concentrations of 0.17 ng/g ww and 0.2 ng/g ww from whole body composite samples of multiple fish species from the Ohio River and Mississippi River, respectively. PFOA was not detected (<1.0 ng/g ww) in whole body composite fish samples collected from the Missouri River (Ye et al. 2008). Delinsky et al. (2010) sampled PFOA in bluegill, black crappie, and pumpkinseed muscle tissues at eleven locations

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along the upper Mississippi River in 2007, and did not detect it at any location, including the heavily impacted Pool Two site in the Minneapolis-St. Paul metropolitan area.

In a more recent study, Penland et al. (2020) measured PFAS concentrations in invertebrates and vertebrates along the Yadkin – Pee Dee River, in North and South Carolina in 2015. PFOA was detected in whole body tissues of unionid mussels (7.41 ng/g ww) and aquatic insects (10.68 ng/g ww), but was not detected in Asian clam, snails, or crayfish. PFOA was measured in muscle tissue of two of the 11 sampled fish species, the channel catfish (21.19 ng/g ww) and notchlip redhorse (45.66 ng/g ww). PFOA was not detected in the eggs of a robust redhorse sample, which had the highest measured PFOS concentration (482.9 ng/g ww) of any sample from the Penland et al. (2020) study.

Houde et al. (2006a) measured whole body PFOA in six fish species in Charleston Harbor, South Carolina, and whole body PFOA of zooplankton and five fish species in Sarasota Bay, Florida. Charleston Harbor was the more developed of the two sites and had higher overall PFOA concentrations. PFOA was detected in four of the six fish species in Charleston Harbor and ranged from 0.5 ng/g ww in spot to 1.8 ng/g ww in spotted seatrout. In Sarasota Bay, PFOA concentrations averaged 0.3 ng/g ww in zooplankton and was not detected in any of the fish species (Houde et al. 2006a).

Overall, these results illustrate the distribution of PFOA in biotic media collected from invertebrate and fish samples. In contrast to PFOS, PFOA concentrations in biotic media are often low, or below detection levels, highlighting the lower overall bioaccumulation potential for this chemical, based on its physical-chemical properties, including a shorter perfluorinated chain length, and a carboxylate head group. In addition, trophic biomagnification is rarely observed with PFOA, as concentrations in invertebrates are often similar to concentrations in fish.

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2.6 Exposure Pathways of PFOA in Aquatic Environments

There are multiple potential exposure pathways of PFOA in the aquatic environment, including: (1) direct aqueous (dermal and respiratory) exposure, (2) direct exposure from contaminated sediment (for benthic organisms), (3) diet (e.g., bioaccumulation and biomagnification), and (4) maternal transfer (Ankley et al. 2020). Exposure of PFOA through water and sediment occurs through direct contact with the respective media, such as water passing across the gills, or consumption of suspended and deposited sediments (Prosser et al. 2016). Elevated PFOA concentrations in eggs of fish and piscivorous birds suggests that PFOA may maternally transfer to offspring. Given these exposure pathways, aquatic organisms, such as fish and aquatic invertebrates, are exposed to PFOA when it is present in the environment. This exposure occurs through multiple exposure routes including water, sediment, diet, and maternal transfer.

2.7 Effects of PFOA on Biota

Currently, PFOA aquatic ecotoxicity data are primarily available for freshwater fish, aquatic invertebrates, plants, and algae. Section 3 and Section 4 provide study summaries of individual publicly available ecotoxicity studies, Appendix A through Appendix F summarize the current quantitatively acceptable PFOA aquatic life ecotoxicity data, and Appendix G and Appendix H list current qualitatively acceptable PFOA aquatic life ecotoxicity data.

2.7.1 Mechanisms of PFOA Toxicity

The mechanisms underpinning the toxicity of PFOA to aquatic organisms, like other PFAS, is an active and on-going area of research. Much work is still needed from a mechanistic perspective to better understand how the different modes of action elicit specific biological responses. Molecular disturbance at the cellular- and organ-level resulting in effects on reproduction, growth and development at the individual-level are associated with the sex-related

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endocrine system, thyroid-related endocrine system, and neuronal-, lipid-, and carbohydrate-metabolic systems (see Ankley et al. 2020 and Lee et al. 2020 for the latest reviews on the subject). The underlying mechanisms of PFOA toxicity to aquatic animals, and fish in particular, appear to be related to oxidative stress, apoptosis, thyroid disruption, and development-related gene expression (Lee et al. 2020). The published research suggests that many of these molecular pathways interact with each other and could be linked. For example, for several PFAS including PFOA, oxidative stress appears correlated with effects on egg hatching and larval formation, linking reproductive toxicity, oxidative stress, and developmental toxicity (Lee et al. 2020). The actual mechanism(s) through which PFAS induce oxidative stress require additional study, but increased ß-oxidation of fatty acids and mitochondrial toxicity are proposed triggers (Ankley et al. 2020).

Of particular importance to this document is that PFOA exposure-related disruption of the sex-related endocrine system (e.g., androgen and estrogen) at the molecular, tissue and organ levels appears to have adverse reproductive outcomes in fish and invertebrates, and likely in both freshwater and saltwater and via multiple exposure routes, i.e., waterborne and dietary (Lee at al. 2020). The reproductive effects were observed in the F_0, F_1 and F_2 generations of zebrafish, *Danio rerio*, in the multi-generational PFOA exposure reported by Lee et al. (2017).

It is clear that PFOA, and many other PFAS, cause a wide range of adverse effects in aquatic organisms, including: reproductive failure, developmental toxicity; androgen, estrogen and thyroid hormone disruption; immune system disruption; and, neuronal and developmental damage. Study of the systematic interactions among the relevant biological pathways in fish is a research need, as well as a better understanding of several knowledge gaps in non-fish aquatic organisms where mechanistic-based investigations need to be prioritized.

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2.7.2 Potential Interactions with Other PFAS

PFAS may occur as mixtures in the environment. Occurrence studies document the presence of complex mixtures of PFAS in surface waters in the U.S. and across the globe (Ahrens 2011; Ahrens and Bundschuh 2014; Giesy and Kannan 2002; Houde et al. 2006a, 2006b; Keiter et al. 2012; Wang et al. 2017; see Section 2.4.1). Although the EPA's PFOA criteria are based solely on single chemical exposure aquatic toxicity tests, it is recognized that PFAS are often introduced into the environment as end-use formulations comprised of mixtures of PFAS and or PFAS-precursors, the ecological effects of which are poorly understood (Ankley et al. 2020). It is useful, therefore, to briefly summarize the types of interactions that might be expected based on the few PFAS mixtures studies involving PFOA and one or more PFAS to date. Note that for purposes of this document, the reader is referred to Ankley et al. (2020) and elsewhere for more comprehensive reviews of PFAS mixtures in general, and the challenges they are expected to present in ecological risk assessment. Beyond PFOA and PFOS, systematic reviews of chemical mixture studies across various compound classes indicate that departures from dose additivity are uncommon and rarely exceed minor deviations (~2-fold) from predictions based on additivity (Martin et al. 2021).

Findings of the PFAS-specific studies described below are as reported by the study authors without any additional interpretation or analysis of uncertainty. At both the organismal and cellular levels, studies on zebrafish (*Danio rerio*; Ding et al. 2013), a water flea (*Daphnia magna*; Yang et al. 2019), a bioluminescent cyanobacterium (*Anabaena sp.*; Rodea-Palomares et al. 2012), or with cultured hepatocytes of the cyprinid, *Gobiocypris rarus* (Wei et al. 2009), demonstrate that the effects observed from *in vivo* and *in vitro* tests on PFAS mixtures vary. PFAS mixture studies on zebrafish reported interactions for combinations of PFOA and PFOS, but departures from additive models were also minor (Ding et al. 2013). Menger et al. (2020)

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reported zebrafish behavioral effects from a PFAS mixture that were less than individual PFAS, however evaluation of chemical dose response and comparison to mixture models was not conducted. Yang et al. (2019) exposed the water flea, *Daphnia magna,* to single and binary mixtures of PFOA and PFOS. The authors reported synergism in acute and chronic toxic effects. Conversely, Rodea-Palomares et al. (2012) showed binary PFOA and PFOS mixture as having an antagonistic interaction at the whole range of effect levels tested using the bioluminescent cyanobacterium, *Anabaena.*

In tests with cultured hepatocytes of the cyprinid *G. rarus,* co-exposure of PFOA with a mixture of five other PFAS [PFNA, PFDA, PFDoA, PFOS, 8:2 FTOH] altered genes involved in multiple biological functions and processes, including fatty acid metabolism and transport, xenobiotic metabolism, immune response, and oxidative stress. Additionally, greater than 80% of the altered genes in both the PFOA- and PFOS-dominant mixture groups were of the same gene set (Wei et al. 2009). Finally, Conley et. al. (2022) observed PFOA and PFOS interacting in an additive manner to reduce pup body weight, pup liver weight, and maternal liver weight in the Sprague-Dawley rat.

2.8 Conceptual Model of PFOA in the Aquatic Environment and Effects

A conceptual model depicts the relationship between a chemical stressor and ecological compartments, linking exposure characteristics to ecological endpoints. The conceptual model provided in Figure 2-4 summarizes sources, potential pathways of PFOA exposure for aquatic life and aquatic-dependent wildlife and possible toxicological effects.

PFOA initially enters the aquatic environment through direct discharge from wastewater treatment facilities, atmospheric deposition, and runoff from contaminant surfaces such as PFAS disposal sites or contaminated biosolids. PFOA enters the aquatic environment primarily in the

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dissolved form and to a lesser extent, particle-bound forms. Exposure pathways for the biological receptors of concern (i.e., aquatic organisms) and potential effects (e.g., impaired survival, growth, and reproduction) in those receptors are represented in the conceptual model (Figure 2-4). Both direct (i.e., exposure from the water column which is represented by *) and indirect (i.e., bioconcentrated by producers and bioaccumulated by consumers in higher trophic levels represented by **) pathways are represented in the conceptual model.

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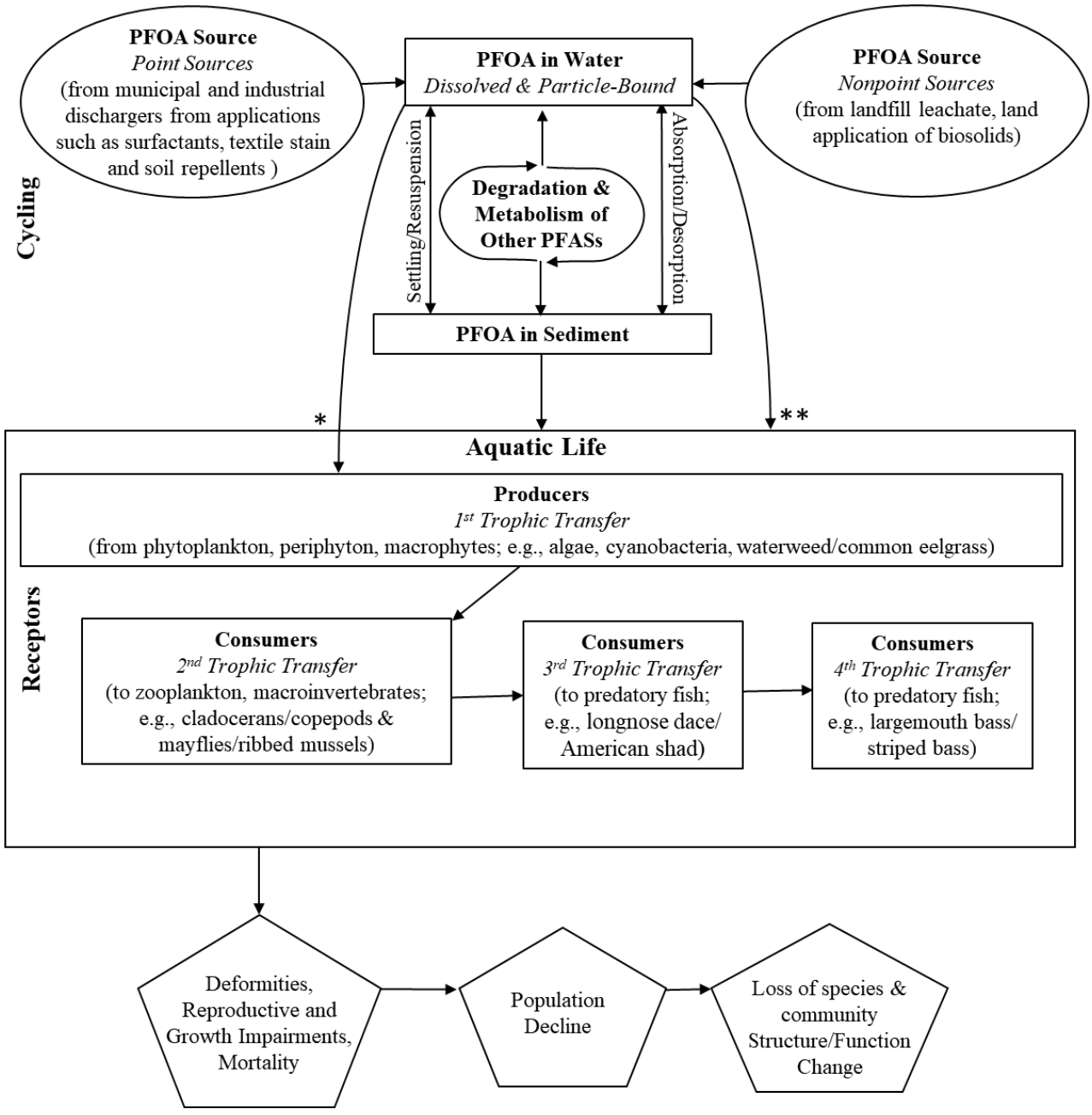


Figure 2-4. Conceptual Model Diagram of Sources, Compartmental Partitioning, and Trophic Transfer Pathways of Perfluorooctanoic acid (PFOA) in the Aquatic Environment and its Bioaccumulation and Effects in Aquatic Life and Aquatic-dependent Wildlife.

PFOA sources represented in ovals, compartments within the aquatic ecosystem represented by rectangles, and effects (on trophic levels of aquatic-dependent wildlife, represented by shaded box) in pentagons. Examples of organisms in each trophic transfer provided as freshwater/marine. Movement of PFOA from water to receptors indicated by two separate pathways: direct exposure to all trophic levels within box (*) and bioconcentration by producers (**). Relative proportion of PFOA transferred between each trophic level is dependent on life history characteristics of each organism.

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2.9 Assessment Endpoints

Assessment endpoints are defined as the explicit expressions of the environmental values to be protected and are comprised of both the ecological entity (e.g., a species, community, or other entity) and the attributes or characteristics of the entity to be protected (U.S. EPA 1998). Assessment endpoints may be identified at any level of organization (e.g., individual, population, community). In context of the CWA, aquatic life criteria for toxic substances are typically determined based on the results of toxicity tests with aquatic organisms, for which adverse effects on growth, reproduction, or survival are measured. This information is typically compiled into a sensitivity distribution based on genera and representing the impact on taxa across the aquatic community. Criteria are based on the 5^{th} percentile of genera and are, thus intended to be protective of approximately 95 percent of aquatic genera to ensure aquatic communities are protected. Assessment endpoints consistent with the criteria developed in this document are summarized in Table 2-1.

The use of laboratory toxicity tests to protect bodies of water and resident aquatic species was based on the theory that effects occurring to a species in appropriate laboratory tests will generally occur to the same species in comparable field situations. Since aquatic ecosystems are complex and diverse, the 1985 Guidelines recommend that acceptable data be available for at least eight genera with a specified taxonomic diversity (the standard eight minimum data requirements, or MDRs). The intent of the eight MDRs is to serve as a typical surrogate sample community representative of the larger and generally much more diverse natural aquatic community, not necessarily the most sensitive species in a given environment. The 1985 Guidelines note that since aquatic ecosystems can tolerate some stress and occasional adverse effects, protection of all species at all times and places are not deemed necessary (the intent is to

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protect 95 percent of a group of diverse taxa, and any commercially and recreationally important species).

2.10 Measurement Endpoints

2.10.1 Overview of Toxicity Data Requirements

To ensure the protection of various components of an aquatic ecosystem, the EPA collects acute toxicity test data from a minimum of eight diverse taxonomic groups.

- Acute freshwater criteria require data from the following eight taxonomic groups:
    a) the family Salmonidae in the class Osteichthyes
    b) a second family in the class Osteichthyes, preferably a commercially or recreationally important warmwater species (e.g., bluegill, channel catfish)
    c) a third family in the phylum Chordata (may be in the class Osteichthyes or may be an amphibian)
    d) a planktonic crustacean (e.g., cladoceran, copepod)
    e) a benthic crustacean (e.g., ostracod, isopod, amphipod, crayfish)
    f) an insect (e.g., mayfly, dragonfly, damselfly, stonefly, caddisfly, mosquito, midge)
    g) a family in a phylum other than Arthropoda or Chordata (e.g., Rotifera, Annelida, Mollusca)
    h) a family in any order of insect or any phylum not already represented

- Acute estuarine/marine criteria require data from the following taxonomic groups:
    a) two families in the phylum Chordata
    b) a family in a phylum other than Arthropoda or Chordata
    c) a family from either Mysidae or Penaeidae
    d) three other families not in the phylum Chordata (may include Mysidae or Penaeidae, whichever was not used above)
    e) any other family

Additionally, to ensure the protection of various components of the aquatic ecosystem from long term exposures, chronic toxicity test data are recommended for the same minimum of eight diverse taxonomic groups that are recommended for freshwater acute criterion derivation. If the eight diverse taxonomic groups are not available to support chronic criterion derivation using a genus distribution approach, the chronic criterion may be derived using an acute-to-

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chronic ratio (ACR) approach. To apply an ACR approach to derive a chronic freshwater criterion a minimum of three taxa are recommended, with at least one chronic test being from an acutely sensitive species. Acute-to-chronic ratios (ACRs) can be calculated with data for aquatic organisms.

- Chronic aquatic life criteria require data from the following taxonomic groups:
    a) At least one is a fish
    b) At least one is an invertebrate
    c) At least one is an acutely sensitive freshwater species, for freshwater chronic criterion (the other two may be saltwater species)
    d) At least one is acutely sensitive saltwater species for estuarine/marine chronic criterion (the other two may be freshwater species)

The 1985 Guidelines also specified at least one quantitative test with a freshwater alga or vascular plant. If plants are among the most sensitive aquatic organisms, toxicity test data from a plant in another phylum should also be available. Aquatic plant toxicity data are examined to determine whether aquatic plants are likely to be adversely affected by the concentration expected to be protective for other aquatic organisms.

2.10.2 Measure of PFOA Exposure Concentrations

These PFOA ambient water quality criteria are for the protection of aquatic life. This criteria document provides a critical review of all data identified in the EPA's literature search for PFOA, including:

- the anionic form (CAS No. 45285-51-6),
- the acid form (CAS No. 335-67-1), and;
- the ammonium salt (CAS No. 3825-26-1).

PFOA toxicity studies typically do not conduct an analysis or separation sufficient to determine if the test compound is purely linear or branched. Data for possible inclusion in the PFOA criteria were obtained from published literature reporting acute and chronic exposures of PFOA that were associated with mortality, growth, and reproduction. This set of published

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literature was identified using the ECOTOXicology database (ECOTOX; https://cfpub.epa.gov/ecotox/) as meeting data quality standards. ECOTOX is a source of high-quality toxicity data for aquatic life, terrestrial plants, and wildlife. The database was created and is maintained by the EPA, Office of Research and Development, Center for Computational Toxicology and Exposure. The ECOTOX search generally begins with a comprehensive chemical-specific literature search of the open literature conducted according to ECOTOX Standard Operating Procedures (SOPs; Elonen 2020). The search terms are often comprised of chemical terms, synonyms, degradates and verified Chemical Abstracts Service (CAS) numbers. After developing the literature search strategy, ECOTOX curators conduct a series of searches, identify potentially applicable studies based on title and abstract, acquire potentially applicable studies, and then apply the applicability criteria for inclusion in ECOTOX. Applicability criteria for inclusion into ECOTOX generally include:

1. The toxic effects are related to single chemical exposure (unless the study is being considered as part of a mixture effects assessment);
2. There is a biological effect on live, whole organisms or *in vitro* preparation including gene chips or omics data on adverse outcome pathways potentially of interest;
3. Chemical test concentrations are reported;
4. There is an explicit duration of exposure;
5. Toxicology information that is relevant to OW is reported for the chemical of concern;
6. The paper is published in the English language;
7. The paper is available as a full article (not an abstract);
8. The paper is publicly available;
9. The paper is the primary source of the data;
10. A calculated endpoint is reported or can be calculated using reported or available information;
11. Treatment(s) are compared to an acceptable control;
12. The location of the study (*e.g.*, laboratory vs. field) is reported; and
13. The tested species is reported (with recognized nomenclature).

Following inclusion in the ECOTOX database, toxicity studies were subsequently evaluated by the Office of Water. All studies were evaluated for data quality as described by U.S. EPA (1985), the EPA's Office of Chemical Safety and Pollution Prevention (OPP)'s

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Ecological Effects Test Guidelines (U.S. EPA 2016b), and the EPA OW's internal data quality standard operating procedure (SOP), which is consistent with OPP's data quality review approach (U.S. EPA 2016b). Office of Water completed a Data Evaluation Record (DER) for each species by chemical combination from the PFOA studies identified by ECOTOX. This in-depth review ensured the studies used to derive the criteria resulted in robust scientifically defensible criteria. Example DERs are shown in Appendix P with the intent to convey the meticulous level of evaluation, review, and documentation each PFOA study identified by ECOTOX was subject to.

Studies that did not fully meet the data quality objectives outlined by the EPA SOP were not considered for inclusion in the criteria derivation, including some studies with other PFAS exposures, but were considered qualitatively as supporting information and are characterized in the Effects Characterization. These studies are listed in Appendix G and Appendix H. Furthermore, only single chemical toxicity tests with PFOA were considered for possible inclusion in criteria derivation, studies that tested chemical mixtures, including mixtures with PFAS were excluded from criteria derivation. Both controlled laboratory experiments and field observations/studies were included.

The 1985 Guidelines recommend only toxicity tests focused on North American resident species be considered. Due to the EPA's interest in using all available quality data, particularly for a data-sparse chemical like PFOA (relative to chemicals such as cadmium or ammonia), toxicity studies were considered for possible inclusion regardless of the test species residential status in North America. Use of non-North American residential species is also consistent with other published aquatic life criteria (U.S. EPA 2018). Non-North American resident species also serve as taxonomically-related surrogate test organisms for the thousands of untested resident

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species. Supporting analyses to evaluate the influence of including non-resident species on the freshwater criteria magnitudes were conducted by limiting toxicity datasets to North American resident species with established populations in North America (see Section 4.1). These analyses provided an additional line-of-evidence that supports inclusion of non-resident species in PFOA criteria derivation.

Toxicity tests used in many previous aquatic life criteria documents are typically based on measured chemical concentrations only. For PFOA, the EPA has examined the issue of whether nominal (unmeasured) and measured concentrations are in close agreement with each other (Jarvis et al. 2023). While measured PFOA toxicity tests are generally preferred, results of Jarvis et al. (2023) demonstrated that experimental conditions had little influence on observed discrepancies between nominal and measured concentrations for PFOA, with the exception of freshwater studies that contained substrate. Nominal and measured concentrations in the analysis generally displayed a high degree of linear correlation (>0.98 freshwater, >0.84 saltwater) and relatively low median percent differences (Jarvis et al. 2023). In freshwater tests, when tests with substrate were removed, 89% of the 527 PFOA and PFOS measured concentrations were within 20% of their nominal counterparts (Note: the EPA's OCSPP's Ecological Effects Test Guidelines (2016b) consider tests acceptable when measured concentrations are within 20% of nominal, and Rewerts et al. (2021) suggested that PFAS-specific toxicity tests may even be acceptable if measured and nominal concentrations do not differ by up to 30%.). Of the observed disparities between measured and nominal concentrations in the PFOA freshwater data sets, those with substrate (McCarthy et al. 2021; Oakes et al. 2004) were concluded to be the primary contributor to observed differences with measured PFOA concentrations systematically lower than corresponding nominal concentrations, indicating that added PFOA may have sorbed to

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substrate, reducing PFOA in the water column (Jarvis et al. 2023). PFOA concentrations in test waters are expected to remain relatively constant over the course of acute and chronic exposures given its ability to resist breakdown and transformation (Ahrens 2011). Since toxicity tests with substrate and nominal concentrations only were not used quantitatively in PFOA criteria derivation, the EPA determined nominal test concentrations adequately represent actual PFOA exposures in standard acute and chronic laboratory-based toxicity tests. Consequently, PFOA toxicity tests were not excluded from quantitative use in criteria derivation on the basis of unmeasured test concentrations alone.

Typically, per the 1985 Guidelines acute toxicity data from all measured flow-through tests would be used to calculate species mean acute values (SMAVs), unless data from a measured flow-through test were unavailable, in which case the acute criterion would be calculated as the geometric mean of all the available acute values (i.e., results of unmeasured flow-through tests and results of measured and unmeasured static and renewal tests). Chronic unmeasured flow-through tests, as well as measured and unmeasured static and renewal tests are not typically considered to calculate chronic values. In the case of the PFOA, static, renewal, and flow-through experiments were considered for possible inclusion for both species mean acute and chronic values regardless of whether PFOA concentrations were measured because PFOA is a highly stable compound, resistant to hydrolysis, photolysis, volatilization, and biodegradation (Section 1.2.1) and, therefore, expected to vary only minimally in the course of a toxicity test.

Additionally, chronic values were based on endpoints and exposure durations that were appropriate to the species. Thus, both life- and partial life-cycle tests were utilized for the derivation of the chronic criterion. However, it should be noted that the 1985 Guidelines specify life-cycle chronic tests are typically used for invertebrates. The chronic studies used in the

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derivation of the chronic water column-based PFOA criterion followed taxon-specific exposure duration requirements from various test guidelines (i.e., the EPA's 1985 Guidelines and the EPA's OCSPP's Ecological Effects Test Guidelines) when available. For example, only chronic daphnid studies of 21 days were considered in the chronic criterion derivation because the EPA 1985 Guidelines states daphnid tests should begin with young < 24-hours old and last at least 21 days. When taxon-specific exposure duration requirements were not available for a particular test organism in the PFOA toxicity literature, both life- and partial life-cycle tests were considered in the derivation of the chronic criterion.

PFOA toxicity in aquatic life is manifested as effects on survival, growth, and reproduction. Measurements of fish tissue may be linked to the chronic adverse effects of PFOA, since PFOA is highly persistent and potentially bioaccumulative.

2.10.3 Measures of Effect

Each assessment endpoint requires one or more "measures of ecological effect," which are defined as changes in the attributes of an assessment endpoint itself or changes in a surrogate entity or attribute in response to chemical exposure. Ecological effects data were used as measures of direct and indirect effects to growth, reproduction, and survival of aquatic organisms.

2.10.3.1 Acute Measures of Effect

The acute measures of effect on aquatic organisms are the lethal concentration (LC_{50}), effect concentration (EC_{50}), or inhibitory concentration (IC_{50}) estimated to produce a specific effect in 50 percent of the test organisms. LC_{50} is the concentration of a chemical that is estimated to kill 50 percent of the test organisms. EC_{50} is the concentration of a chemical that is estimated to produce a specific effect in 50 percent of the test organisms. And the IC_{50} is the concentration of a chemical that is estimated to inhibit some biological process (e.g., enzyme

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inhibition associated with an apical endpoint such as mortality) in 50 percent of the test organisms.

2.10.3.2 Chronic Measures of Effect

The endpoint for chronic exposures is the effect concentration estimated to produce a chronic effect on survival, growth, or reproduction in 10 percent of the test organisms (EC_{10}). The EPA selected an EC_{10} to estimate a low level of effect that would be both different from controls and not expected to be severe enough to cause effects at the population level for a potentially bioaccumulative contaminant, such as PFOA. The use of the EC_{10}, instead of an EC_{20}, is also consistent with the use of this metric for the bioaccumulative pollutant selenium in the recent 2016 Selenium Freshwater Aquatic Life Criteria (U.S. EPA 2016a). Use of a 10% effect concentration for deriving chronic criteria magnitudes is also consistent with the harmonized guidelines from OECD and the generally preferred effect level for countries such as Canada, Australia, and New Zealand (CCME 2007; Warne et al. 2018).

Regression analysis was used preferentially to characterize a concentration-effect relationship and to estimate concentrations at which chronic effects are expected to occur (i.e., point estimate). Reported No Observed Effect Concentrations (NOECs) and Lowest Observed Effect Concentrations (LOECs) were only used for the derivation of a chronic criterion when a robust EC_{10} could not be calculated for the genus. A NOEC is the highest test concentration at which none of the observed effects are statistically different from the control. A LOEC is the lowest test concentration at which the observed effects are statistically different from the control. When LOECs and NOECs were used, a Maximum Acceptable Toxicant Concentration (MATC) was calculated, which is the geometric mean of the NOEC and LOEC. For the calculation of a chronic criterion, point estimates were selected for use as the measure of effect in favor of MATCs, as MATCs are highly dependent on the concentrations tested. Point estimates also

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provide additional information that is difficult to determine with an MATC, such as a measure of effect level across a range of tested concentrations. A decision rule was also applied to the PFOA toxicity data when an author-reported NOEC or LOEC was used in conformity with the 2013 Ammonia Freshwater Aquatic Life Criteria (U.S. EPA 2013) such that "greater than" values for concentrations of a relatively low magnitude compared to the other available toxicity data, and "less than" values for concentrations of relatively high magnitude were considered to add little significant information to the analyses and were not used quantitatively. Conversely, if data from studies with relatively low "less than" values indicated a significant effect or studies with relatively high "greater than" values only found an incomplete response for a chronic endpoint (indicating low toxicity of the test material), those data significantly enhanced the understanding of PFOA toxicity. Thus, the decision rule was applied as follows: "greater than" (>) high toxicity values and "less than" (<) low toxicity values were used quantitatively to derive the chronic water column-based PFOA criterion (U.S. EPA 2013). Data that met the quality objectives and test requirements were utilized quantitatively in deriving freshwater criteria for aquatic life and are presented in Table 3-3 and Table 3-7.

Table 2-1. Summary of Assessment Endpoints and Measures of Effect Used in the Criteria Derivation for PFOA.

Assessment Endpoints for the Aquatic Community	Measures of Effect
Aquatic Life: Survival, growth, and reproduction of freshwater and estuarine/marine aquatic life (i.e., fish, amphibians, aquatic invertebrates)	For effects from acute exposure: 1. LC_{50}, EC_{50}, or IC_{50} concentrations in water For effects from chronic exposure: 1. EC_{10} concentrations in water 2. NOEC and LOEC concentrations in water; Only used when an EC_{10} could not be calculated for a genus.

NOEC = No observed effect concentration
LOEC = Lowest observed effect concentration
EC_{10} = 10% Effect Concentration

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2.10.3.3 Summary of Independent Calculation of Toxicity Values

Toxicity values, including LC_{50} and EC_{10} values, were independently calculated from the data presented in the toxicity studies meeting the inclusion criteria described above when adequate concentrations-response data were published in the study or could be obtained from authors. When concentration-response data were not presented in toxicity studies, concentration-response data were requested from study authors to independently calculate toxicity values. In cases where study authors did not respond to the EPA's request for data or were unable to locate concentration-response data, the toxicity values were not independently calculated by the EPA, and the reported toxicity values were retained for criteria deviation. Where concentration-response data were available, they were analyzed using the statistical software program R (version 3.6.2) and the associated dose-response curve (drc) package. The R drc package has various models available for modeling a concentration-response relationship for each toxicity study. The specific model used to calculate toxicity values was selected following the details provided in Appendix K, and the models performed well on most or all statistical metrics. The independently calculated toxicity values used to derive the PFOA aquatic life criteria were included in each study summary below and were used to derive criteria for aquatic life, where available. Details relating to the independent verification of toxicity values for each toxicity study used to derive the criteria were included in Appendix A.2 and Appendix C.2.

2.11 Analysis Plan

2.11.1 Derivation of Water Column Criteria

During CWA Section 304(a) criteria development, the EPA reviews and considers all relevant toxicity test data. Information available for all relevant species and genera were reviewed to identify: 1) data from acceptable tests that meet data quality standards, and 2)

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whether the acceptable data meet the MDRs as outlined in the EPA's 1985 Guidelines (U.S. EPA 1985). The taxa represented by the different MDR groups represent taxa with different ecological, trophic, taxonomic and functional characteristics in aquatic ecosystems, and are intended to be a representative subset of the diversity within a typical aquatic community. MDRs for derivation of acute and chronic freshwater criteria were met for all the eight MDRs.

Acute and chronic MDRs for PFOA estuarine/marine criteria derivation were not met and, consequently, acute and chronic estuarine/marine criteria were not derived. The EPA is, however, including an acute aquatic life benchmark for estuarine/marine environments (see Appendix L), using available estuarine/marine species toxicity data and application of ORD's peer-reviewed web-ICE tool. A minimal number of tests from acceptable studies of aquatic algae and vascular plants were also available for possible derivation of a Final Plant Value. However, the relative sensitivity of freshwater plants to PFOA exposures indicated plants are less sensitive than aquatic vertebrates and invertebrates so plant criteria were not developed.

2.11.2 Derivation of Tissue-Based Criteria

Chronic toxicity studies (both laboratory and field studies) were further screened to ensure they contained the relevant chronic PFOA exposure conditions to aquatic organisms (i.e., dietary, or dietary and waterborne PFOA exposure), measurement of chronic effects, and measurement of PFOA in tissue(s). The EPA considered deriving tissue-based criteria using empirical toxicity tests with studies that exposed organisms to PFOA in water and/or diet and reported exposure concentrations based on measured tissue concentrations. This approach would also correspond with the 2016 Selenium Aquatic Life Freshwater Criterion, which is the only 304(a) aquatic life criterion with tissue-based criterion elements. However, the freshwater chronic PFOA toxicity data with measured tissue concentrations were limited, with no quantitatively acceptable tissue-based tests. Qualitatively acceptable tissue-based tests were

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reported for four species (three fish species and one amphibian) across five publications. Therefore, there were insufficient data to derive tissue-based criteria using a GSD approach from empirical tissue data from toxicity studies. The EPA thus developed protective tissue-based criteria through a bioaccumulation factor approach (Burkhard 2021).

2.11.3 Translation of Chronic Water Column Criterion to Tissue Criteria

Because there were insufficient chronic toxicity data with measured tissue concentrations to derive chronic PFOA tissue criteria using a GSD approach, the EPA derived PFOA chronic tissue-based criteria by translating the chronic freshwater water column criterion (see Section 3.2.1.3) into tissue-based criteria magnitudes using bioaccumulation factors and the following equation:

$$Tissue\ Criteria = Chronic\ Water\ Column\ Criterion \times BAF \quad \textit{(Equation 1)}$$

The resulting tissue-based criteria magnitudes correspond to the tissue type from the BAF used in the equation (see Section 2.11.3.1).

2.11.3.1 Aquatic Life Bioaccumulation Factors

A bioaccumulation factor (BAF) is determined from field measurements and is calculated using the equation:

$$BAF = \frac{C_{biota}}{C_{water}} \quad \textit{(Equation 2)}$$

Where:
C_{biota} = PFOA concentration in the organismal tissue(s)
C_{water} = PFOA concentration in water where the organism was collected

The EPA considered BAF data from field measurements to capture all PFOA exposure routes, *i.e.*, dietary, water, contact with sediments via dermal exposure and ingestion, and

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maternal transfer. Depending on the tissue residue measurement, BAFs can be based upon residues in the whole organism, muscle, liver, or any other tissue.

Searching for literature reporting on PFOA was implemented by developing a series of chemical-based search terms. These terms included chemical names and Chemical Abstracts Service registry numbers (CASRN or CAS), synonyms, tradenames, and other relevant chemical forms (i.e., related compounds). Databases searched were Current Contents, ProQuest CSA, Dissertation Abstracts, Science Direct, Agricola, TOXNET, and UNIFY (database internal to the U.S. EPA's ECOTOX database). The literature search yielded numerous citations and the citation list was further refined by excluding citations on analytical methods, human health, terrestrial organisms, bacteria, and where PFOA was not a chemical of study. The citations meeting the search criteria were reviewed for reported BAFs and/or reported concentrations in which BAFs could be calculated for freshwater and estuarine/marine species. BAFs from both freshwater and estuarine/marine species were considered because: (1) inclusion of estuarine/marine BAFs expanded the relatively limited PFOA BAF dataset, and (2) Burkhard (2021) did not specifically observe notable differences in PFAS BAFs between freshwater and estuarine/marine systems, instead stating additional research is needed to formulate conclusions.

Data from papers with appropriate BAF information were further screened for data quality. Four factors were evaluated in the screening of the BAF literature: (1) number of water samples, (2) number of organism samples, (3) water and organism temporal coordination in sample collection, and (4) water and organism spatial coordination in sample collection. Additionally, the general experimental design was evaluated. Table 2-2 below outlines the screening criteria for study evaluation and ranking. Only BAFs of high and medium quality were

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used to derive the tissue criteria (Appendix O). For further details on BAFs compilation and ranking, see Burkhard (2021).

Table 2-2. Evaluation Criteria for Screening Bioaccumulation Factors (BAFs) in the Public Literature.

Screening Factor	High Quality	Medium Quality	Low Quality
Number of Water Samples	>3	2 – 3	1
Number of Organism Samples	>3	2 – 3	1
Temporal Coordination	Concurrent collection	Within one year	Collection period >1 year
Spatial Coordination	Collocated collection	Within 1 - 2 km	Significantly different locations (>2 km)
General Experimental Design			Mixed species tissues samples

Modified from Burkhard (2021).

PFOA bioaccumulation potential in aquatic life is expected to be relatively low compared to PFOS bioaccumulation, or PFOA bioaccumulation in aquatic-dependent birds and mammals The high water solubility of PFOA may allow aquatic organisms to excrete PFOA through the gills. Conversely, aquatic dependent birds and mammals lack such an excretion mechanism, as the low vapor pressure of PFOA limits its ability to be transferred across the alveolar membrane from lungs to air (Canada 2012; Kelly et al. 2004). The tissue criteria for fish and invertebrates presented here protect aquatic life populations from PFOA exposure accumulating in tissues and provide U.S. states and Tribes greater context to their fish-tissue monitoring programs, which are actively measuring PFAS, including PFOA.

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3 EFFECTS ANALYSIS FOR AQUATIC LIFE

3.1 Toxicity to Aquatic Life

All available studies relating to the acute and chronic toxicological effects of PFOA on aquatic life were considered in the derivation of these national recommended PFOA criteria. Data for possible inclusion in these PFOA criteria were obtained from published literature reporting acute and chronic exposures of PFOA that were associated with mortality, survival, growth, and reproduction. The latest search was conducted through the March 2024 ECOTOX database update. Acute and chronic data meeting the quality objectives and test requirements were utilized quantitatively in deriving these criteria for aquatic life and are presented in Appendix A: Acceptable Freshwater Acute PFOA Toxicity Studies; Appendix B: Acceptable Estuarine/Marine Acute PFOA Toxicity Studies; Appendix C: Acceptable Freshwater Chronic PFOA Toxicity Studies, and; Appendix D: Acceptable Estuarine/Marine Chronic PFOA Toxicity Studies.

3.1.1 Summary of PFOA Toxicity Studies Used to Derive the Aquatic Life Criteria

Quantitatively acceptable acute PFOA toxicity data were available for 27 freshwater species, representing 19 genera and 17 families in five phyla, and four estuarine/marine species, representing four genera and three families in three phyla (Table 3-1). Quantitatively acceptable chronic PFOA toxicity data were available for 13 freshwater species, representing 12 genera and ten families in three phyla and two estuarine/marine species, representing two genera and two families in two phyla. The following study summaries present the key acute and chronic freshwater toxicity data with effect values that were used quantitatively to derive the acute and chronic freshwater and estuarine/marine criteria to protect aquatic life. Study summaries for the most sensitive taxa are presented below and are grouped by acute or chronic exposure and sorted by sensitivity to PFOA.

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Acute and chronic values were presented as reported by the study authors for each individual study, unless stated otherwise. The EPA independently calculated these toxicity values if sufficient raw data were available for the EPA to conduct statistical analyses. The EPA's independently-calculated toxicity values were used preferentially, where available. Author-reported toxicity values and the EPA's independently calculated values (where available) were included in each study summary and in appendices, as applicable. The results of all toxicity values, such as LC values, EC values, NOECs, LOECs, and species- and genus-mean values, are given to four significant figures to prevent round-off error in subsequent calculations, not to reflect the precision of the value. The specific toxicity value utilized in the derivation of the corresponding PFOA criteria is stated for each study at the end of the summaries below and in the respective appendices.

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Table 3-1. Summary Table of Minimum Data Requirements per the 1985 Guidelines Reflecting the Number of Acute and Chronic Genus and Species Level Mean Values in the Freshwater and Saltwater Toxicity Datasets for PFOA.

MDR[a, b]	Freshwater			
	GMAV	**SMAV**	**GMCV**	**SMCV**
Family Salmonidae in the class Osteichthyes	1	1	1	1
Second family in the class Osteichthyes, preferably a commercially or recreationally important warmwater species	3	3	2	2
Third family in the phylum Chordata (may be in the class Osteichthyes or may be an amphibian, etc.)	5	10	2	2
Planktonic Crustacean	3	6	3	4
Benthic Crustacean	1	1	1	1
Insect	1	1	1	1
Family in a phylum other than Arthropoda or Chordata (e.g., Rotifera, Annelida, or Mollusca)	4	4	1	1
Family in any order of insect or any phylum not already represented	1	1	1	1
Total	**19**	**27**	**12**	**13**
MDR	**Saltwater[a]**			
	GMAV	**SMAV**	**GMCV**	**SMCV**
Family in the phylum Chordata	0	0	1	1
Family in the phylum Chordata	0	0	0	0
Either the Mysidae or Penaeidae family	2	2	0	0
Family in a phylum other than Arthropoda or Chordata	1	1	0	0
Family in a phylum other than Chordata	1	1	1	1
Family in a phylum other than Chordata			0	0
Family in a phylum other than Chordata			0	0
Any other family			0	0
Total	**4**	**4**	**2**	**2**

[a] The 1985 Guidelines require that data from a minimum of eight families are needed to calculate an estuarine/marine criterion. Insufficient data exist to fulfill all eight of the taxonomic MDR groups. Consequently, the EPA cannot derive an estuarine/marine acute criterion, based on the 1985 Guidelines. However, the EPA has developed estuarine/marine benchmarks through use of surrogate data to fill in missing MDRs using the EPA's WebICE tool and other New Approach Methods. These benchmarks are provided in Appendix L.

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3.1.1.1 Summary of Acute PFOA Toxicity Studies Used to Derive the Freshwater Aquatic Life Criterion

The acute data set for PFOA contains 19 genera representing all eight taxonomic MDR groups (Table 3-3). Quantitatively-acceptable data for acute PFOA toxicity were available for four freshwater fish species, representing four genera and three families and fulfilled two of the eight MDRs. Quantitatively acceptable data for acute PFOA toxicity were also available for 13 freshwater invertebrate species, representing ten genera and nine families, and fulfilled five of the eight MDRs. Quantitatively acceptable acute data were available for 10 freshwater amphibian species, representing five genera and five families fulfilling one of the MDRs. Summaries of studies for the most sensitive acute genera are described below, with the four most sensitive genera provided in Table 3-2.

Table 3-2. The Four Most Sensitive Genera Used in Calculating the Acute Freshwater Criterion (Sensitivity Rank 1-4).
Ranked Below from Most to Least Sensitive

Rank	Genus	GMAV (mg/L)	Species
1	*Moina*	8.885	Cladoceran (*Moina macrocropa*)
			Cladoceran (*Moina micrura*)
2	*Neocloeon*	13.05	Mayfly (*Neocloeon triangulifer*)
3	*Chydorus*	93.17	Cladoceran (*Chydorus sphaericus*)
4	*Daphnia*	142.8	Cladoceran (*Daphnia carinata*)[a]
			Cladoceran (*Daphnia magna*)
			Cladoceran (*Daphnia pulicaria*)

[a] Not a North American resident but in same genus as resident species.

3.1.1.1.1 Most acutely sensitive genus: Moina (cladoceran)

Ji et al. (2008) performed a 48-hour static, unmeasured acute test of PFOA (CAS # 335-67-1, purity unreported) with *Moina macrocopa*. Testing method followed U.S. EPA/600/4-

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90/027F (2002). The test involved four replicates of five daphnids (<24 hours old) each in five unmeasured test concentrations (62.5, 125, 250, 500 and 1,000 mg/L) plus a negative control. Dilution water was moderately hard reconstituted water. Survival of daphnids in the negative control was not reported, although EPA/600/4-90/027F requires at least 90% survival for test acceptability. The author-reported 48-hour EC_{50} for the study was 199.51 mg/L. The EPA performed C-R analysis for the test. The EPA-calculated EC_{50} (166.3 mg/L PFOA) was acceptable for quantitative use in deriving the acute freshwater PFOA criterion and served directly as the *Moina macrocopa* Species Mean Acute Value (SMAV).

Razak et al. (2023) tested the acute toxicity of perfluorooctanoic acid (PFOA, ≥98% purity) to *Moina micrura* in a 48-hour static measured experiment. Testing methods followed OECD 202 (OECD 2004) with nominal testing concentrations of 10, 25, 50, 75, 100, 250, 500, 750, 1,000, 2,500, 5,000, 7,500, and 10,000 µg/L, plus a control, with four replicates per treatment. Filtered surface lake water was used as test water. Measured concentrations were not reported, but the authors noted they were 94.3±6.1% of nominal on average. Each replicate consisted of 10 neonates (<48 hours old) in 50 mL of solution in a 100 mL beaker, and organisms were not fed during the study. Lethal effect concentrations (LC) were calculated using Probit analysis, and the 48-hour LC_{50} value of 474.7 µg/L, or 0.4747 mg/L was determined to be acceptable for quantitative use. The 48-hr LC_{50} was acceptable for quantitative use in deriving the acute freshwater PFOA criterion and served directly as the *Moina micrura* SMAV.

Moina macrocopa (SMAV of 166.3 mg/L) is much more tolerant to acute freshwater PFOA exposures than *M. micrura* (SMAV of 0.4747 mg/L) but both species were used to determine the *Moina* Genus Mean Acute Value (GMAV) of 8.885 mg/L. If the EPA were to exclude the *M. micrura* SMAV on the basis of it being an overly sensitive outlier (relative to *M.*

macrocopa and the overall quantitatively acceptable acute data), that would result in the final PFOA acute criterion potentially being underprotective of untested sensitive invertebrate species or other taxa, considering that the available data serve as surrogate information for the thousands of untested freshwater species. Conversely, excluding the *M. macrocopa* SMAV on the basis of it being a tolerant outlier (relative to *M. micrura*) would result in the final PFOA acute criterion being highly influenced by a single test/species with an LC_{50} that was uniquely sensitive (i.e., *M. micrura* SMAV = 0.4747 mg/L) compared to the overall acute data. Averaging the *M. micrura* and *M. moina* SMAVs resulted in a GMAV (8.885 mg/L) that was the most sensitive GMAV, yet still in the general range of the data overall.

3.1.1.1.2 Second most acutely sensitive genus: Neocloeon (mayfly)

Soucek et al. (2023) exposed the parthenogenetic mayfly, *Neocloeon triangulifer*, to PFOA (CAS # 335-67-1, 95% purity) in water in a 96-hour acute toxicity test. The test was performed under static, non-renewal conditions beginning with <24-hour old larvae. Mayflies were fed live diatom biofilm scraping beginning on day 0. Feeding only occurred on day 0, and the authors indicated test organisms required food to survive the entire 96-hour exposure, with previous studies demonstrating greater than 80% mortality at 48 hours with no food (Soucek and Dickinson 2015). Percent survival in the control treatment after 96 hours was 100%. The EPA-calculated acute LC_{50} (i.e., 13.045 mg/L) was similar to the author-reported LC_{50} of 13.451 mg/L. The EPA-calculated LC_{50} value (i.e., 13.045 mg/L) was acceptable for quantitative use in deriving the acute freshwater PFOA criterion and served directly as the *Neocloeon* GMAV.

3.1.1.1.3 Third most acutely sensitive genus: Chydorus (cladoceran)

Le and Peijnenburg (2013) performed a 48-hour static unmeasured acute PFOA toxicity test with the cladoceran, *Chydorus sphaericus*. The authors reported the 48-hour EC_{50} was 0.22 mM PFOA (91.10 mg/L). The EPA performed concentration-response (C-R) analysis for the test

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and calculated a LC_{50} of 93.17 mg/L PFOA that is acceptable for quantitative use. No other quantitatively acceptable acute toxicity data were available for *Chydorus sphaericus* or other members of the genus *Chydorus*. Therefore, the LC_{50} (i.e., 93.17 mg/L) from this test served directly as the *Chydorus sphaericus* SMAV and the *Chydorus* GMAV.

3.1.1.1.4 Fourth most acutely sensitive genus: Daphnia (cladoceran)

Logeshwaran et al. (2021) conducted an acute PFOA test with the cladoceran, *Daphnia carinata*, and PFOA (95% purity, purchased from Sigma-Aldrich Australia) following OECD guidelines (2000) with slight modifications. Authors used nominal test concentrations (0, 0.5, 1, 2.5, 5, 10, 20, 30, 40, 50, 100, 150, 200 and 250 mg/L PFOA) with three replicates per treatment. No mortality occurred in the controls. The author-reported 48-hour EC_{50} was 78.2 mg/L PFOA. The EPA-calculated 48-hour EC_{50} value was 66.80 mg/L, which was acceptable for quantitative use. No other quantitatively acceptable acute tests were available for this species and the EC_{50} of 66.80 mg/L from Logeshwaran et al. (2021) served directly as the *Daphnia carinata* SMAV.

Boudreau (2002) performed a 48-hour static PFOA (CAS # 335-67-1, ≥97% purity) acute test with *Daphnia pulicaria*, following ASTM E729-96 (1999). Five unmeasured test concentrations plus a negative control were used with 3-4 replicates per treatment and 10 daphnids per replicate. Nominal concentrations were 0 (negative control), 26.3, 52.6, 105, 210 and 420 mg/L. Mortality of daphnids in the negative control was not reported, but the protocol followed by the authors (i.e., ASTM E729-96) required ≥ 90% survival in negative controls. The 48-hour *D. pulicaria* EC_{50} reported in the publication was 203.7 mg/L, which was acceptable for quantitative use. No other quantitatively acceptable acute tests were available for this species and the EC_{50} of 203.7 mg/L from Boudreau (2002) served directly as the *D. pulicaria* SMAV.

Boudreau (2002) also performed a 48-hour static PFOA (CAS # 335-67-1, ≥97% purity) acute test with *Daphnia magna* following the same methods used in the *D. pulicaria* acute test.

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The 48-hour *D. magna* EC_{50} reported in the publication was 223.6 mg/L, which was acceptable for quantitative use.

Colombo et al. (2008) conducted a 48-hour static PFOA (ammonium salt, CAS # 3825-26-1, 99.7% purity) acute test on *Daphnia magna*. Authors stated the test followed OECD test guideline 202 (1992). The nominal test concentrations included control, 100, 178, 316, 562 and 1,000 mg/L, with four replicates/treatment and five animals/replicate. No mortality was observed in the controls, and the 48-hour EC_{50} reported in the study was 480 mg/L, which was acceptable for quantitative use.

Ji et al. (2008) performed a 48-hour static acute test of PFOA (CAS # 335-67-1, purity unreported; obtained from Sigma Aldrich, St. Louis, MO) on *D. magna*. Authors stated the test followed U.S. EPA/600/4-90/027F (2002). The test involved four replicates of five daphnids each in five unmeasured test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 62.5, 125, 250, 500 and 1,000 mg/L. Mortality of daphnids in the negative control was not reported, although EPA/600/4-90/027F requires at least 90% survival for test acceptability. The author-reported 48-hour EC_{50} for the study was 476.52 mg/L (95% C.I. = 375.3 – 577.7 mg/L). The EPA performed C-R analysis for the test. The EPA-calculated EC_{50} was 542.5 mg/L PFOA and was acceptable for quantitative use.

Li (2009) conducted a 48-hour static PFOA (ammonium salt, >98% purity) acute test with *Daphnia magna*. Authors stated the test generally followed OECD 202 (1984). The test employed five replicates of six daphnids each in five test concentrations (nominal range = 31 – 250 mg/L) plus a negative control. No control daphnids were immobile at the end of the test. The author-reported 48-hour EC_{50} for the study was 181 mg/L (95% C.I.: 166-198 mg/L) which was averaged across three tests. The EPA performed C-R analysis for each individual test. All three

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tests had acceptable curves with the EPA-calculated EC_{50} values of 220.8 mg/L, 157.9 mg/L, and 207.3 mg/L, which were acceptable for quantitative use.

Yang et al. (2014) conducted a 48-hour acute test of PFOA (CAS # 335-67-1, 99% purity) with *Daphnia magna*, following ASTM E729 (1993). The test employed three replicates of 10 daphnids each in six test concentrations plus a negative and solvent control. Nominal concentrations were 0 (negative and solvent controls), 50, 80, 128, 204.8, 327.68 and 524.29 mg/L. Test concentrations were measured in low and high treatments only. Negative control and solvent control mortality were 0% each. The author-reported 48-hour LC_{50} was 201.85 mg/L (95% C.I. = 134.68 – 302.5 mg/L). The EPA performed C-R analysis for the test and fit an acceptable curve with an EPA-calculated LC_{50} of 222.0 mg/L PFOA, which was acceptable for quantitative use.

Barmentlo et al. (2015) performed a 48-hour static, measured acute test of PFOA (CAS # 335-67-1, >96% purity) with *Daphnia magna* following OECD 202 (2004) test guidelines. The test involved four to six replicates of five daphnids each in five test concentrations plus a negative control. Nominal concentrations were not provided, but PFOA was measured in the control, lowest, and highest test concentrations. Based on these measurements, the authors interpolated all test concentrations to be: 0.053 (negative control), 81, 128, 202, 318 and 503 mg/L. The author-reported 48-hour EC_{50} was 239 mg/L (95% C.I. = 190-287 mg/L). The EPA performed C-R analysis for the test and fit an acceptable curve with an EPA-calculated EC_{50} of 215.6 mg/L PFOA, which was acceptable for quantitative use.

Ding et al. (2012a) conducted a 48-hour static, partially measured acute test on PFOA (CAS # 335-67-1; 96% purity from Sigma Aldrich) with *D. magna*. The test generally followed OECD test guideline 202 (2004). Authors employed four replicates of five daphnids each in six

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test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 144.9, 165.6, 186.3, 207.0, 227.7, and 248.4 mg/L. Concentrations of PFOA were confirmed in the highest and lowest concentrations, though only nominal concentrations were reported. It was stated that the verified concentrations were "well in line with nominal concentrations". The 48-hour EC_{50} was reported as 211.6 mg/L (95% C.I. = 184.7 – 255.5 mg/L). The EPA performed C-R analysis for the test. The EPA-calculated EC_{50} was 216.1 mg/L PFOA, which was acceptable for quantitative use.

Lu et al. (2016) evaluated the acute toxicity of PFOA (CAS# 335-67-1, 98% purity, purchased from Tokyo Chemical Industry Co., Ltd., Tokyo, Japan) on *Daphnia magna* immobilization. The test was conducted following modified OECD standard test procedure 202, whereby five concentration treatments (3, 10, 30, 100 and 300 mg/L) plus a blank control were employed with three replicates per treatment. Authors reported immobility/survival to be a more sensitive endpoint than survival alone. The author-reported 48-hour EC_{50} for immobility/survival was 110.7 mg/L and the EPA-calculated 48-hour EC_{50} was 114.6 mg/L, which was acceptable for quantitative use.

Yang et al. (2019) evaluated the acute effects of PFOA (CAS# 335-67-1, purchased from Sigma-Aldrich in St. Louis, MO) on *Daphnia magna* in a 48-hour unmeasured static exposure. Authors stated the protocol for all testing followed OECD Guideline 202. Nominal acute test concentrations included 0 (control), 66.67, 79.92, 96.06, 115.1, 138.3, and 166.0 mg/L PFOA, with four replicates per treatment. Authors reported an LC_{50} of 120.9 mg/L PFOA. The EPA-calculated 48-hour LC_{50} was 117.2 mg/L, which was acceptable for quantitative use.

Chen et al. (2022) tested the acute toxicity of ammonium perfluorooctanoic acid (APFO, $\geq$98% purity) to *Daphnia magna* in a 48-hour unmeasured, static experiment. The acute APFO

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exposure generally followed test method OECD 202 (OECD 2004). For each replicate, 10 neonates were exposed to 50 mL of test solutions with nominal concentrations of 0, 10, 50, 100, 200, and 500 mg/L APFO, made by diluting the stock solution with culture medium. There were three replicates per treatment and test organisms were not fed during the experiment. Control mortality was less than 10% in the AFPO and reference toxicity tests. The 48-hour EC_{50} for immobility was 156.9 mg/L, which was acceptable for quantitative use.

Quantitatively acceptable *D. magna* acute values from Boudreau (2002; EC_{50} = 223.6 mg/L), Colombo et al. (2008; EC_{50} = 480 mg/L), Ji et al. (2008; EC_{50} = 542.5 mg/L), Li (2009; EC_{50} = 220.8, 157.9, and 207.3 mg/L), Yang et al. (2014; LC_{50} = 222.0 mg/L), Barmentlo et al. (2015; EC_{50} = 215.6 mg/L), Ding et al. (2012a; EC_{50} = 216.1 mg/L), Lu et al. (2016; EC_{50} = 114.6 mg/L), Yang et al. (2019; LC_{50} = 117.2 mg/L), and Chen et al. (2022; EC_{50} = 156.9 mg/L) were taken together as a geometric mean value to calculate the *D. magna* SMAV of 213.9 mg/L. The *D. carinata* SMAV (i.e., 66.80 mg/L), *D. pulicaria* SMAV (i.e., 203.7 mg/L), and *D. magna* SMAV (i.e., 213.9 mg/L) were used to determine the *Daphnia* GMAV of 142.8 mg/L.

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Table 3-3. Ranked Freshwater Genus Mean Acute Values.

Rank[a]	GMAV (mg/L PFOA)	MDR Group[c]	Genus	Species	SMAV[b] (mg/L PFOA)
1	8.885	D	*Moina*	Cladoceran, *Moina macrocopa*	166.3
				Cladoceran, *Moina micrura*	0.4747
2	13.05	F	*Neocloeon*	Mayfly, *Neocloeon triangulifer*	13.05
3	93.17	D	*Chydorus*	Cladoceran, *Chydorus sphaericus*	93.17
4	142.8	D	*Daphnia*	Cladoceran, *Daphnia carinata*	66.80
				Cladoceran, *Daphnia magna*	213.9
				Cladoceran, *Daphnia pulicaria*	203.7
5	150.0	H	*Brachionus*	Rotifer, *Brachionus calyciflorus*	150.0
6	161.0	G	*Ligumia*	Black sandshell, *Ligumia recta*	161.0
7	164.4	G	*Lampsilis*	Fatmucket, *Lampsilis siliquoidea*	164.4
8	377.0	C	*Xenopus*	Frog, *Xenopus sp.*	377.0
9	383.6	H	*Dugesia*	Planaria, *Dugesia japonica*	383.6
10	431.5	E	*Neocaridina*	Green neon shrimp, *Neocaridina denticulata*	431.5
11	450.4	B	*Danio*	Zebrafish, *Danio rerio*	450.4
12	593.6	B	*Pimephales*	Fathead minnow, *Pimephales promelas*	593.6
13	646.2	C	*Hyla*	Gray treefrog, *Hyla versicolor*	646.2
14	664.0	B	*Lepomis*	Bluegill, *Lepomis macrochirus*	664.0
15	681.1	G	*Physella*	Bladder snail, *Physella acuta*	681.1
16	689.4	C	*Ambystoma*	Jefferson salamander, *Ambystoma jeffersonianum*	1,070
				Small-mouthed salamander, *Ambystoma texanum*	407.3

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Rank[a]	GMAV (mg/L PFOA)	MDR Group[c]	Genus	Species	SMAV[b] (mg/L PFOA)
				Eastern tiger salamander, *Ambystoma tigrinum*	752.0
17	793.9	C	*Anaxyrus*	American toad, *Anaxyrus americanus*	793.9
18	951.5	C	*Lithobates*	American bullfrog, *Lithobates catesbeiana*	1,020
				Green frog, *Lithobates clamitans*	1,070
				Northern leopard frog, *Lithobates pipiens*	751.7
				Wood frog, *Lithobates sylvatica*	999
19	4,001	A	*Oncorhynchus*	Rainbow trout, *Oncorhynchus mykiss*	4,001

a Ranked from the most sensitive to the most resistant based on Genus Mean Acute Value.
b From Appendix A: Acceptable Freshwater Acute PFOA Toxicity Studies.
c MDR Groups – Freshwater:

A. the family Salmonidae in the class Osteichthyes
B. a second family in the class Osteichthyes, preferably a commercially or recreationally important warmwater species (e.g., bluegill, channel catfish, etc.)
C. a third family in the phylum Chordata (may be in the class Osteichthyes or may be an amphibian, etc.)
D. a planktonic crustacean (e.g., cladoceran, copepod, etc.)
E. a benthic crustacean (e.g., ostracod, isopod, amphipod, crayfish, etc.)
F. an insect (e.g., mayfly, dragonfly, damselfly, stonefly, caddisfly, mosquito, midge, etc.)
G. a family in a phylum other than Arthropoda or Chordata (e.g., Rotifera, Annelida, Mollusca, etc.)
H. a family in any order of insect or any phylum not already represented.

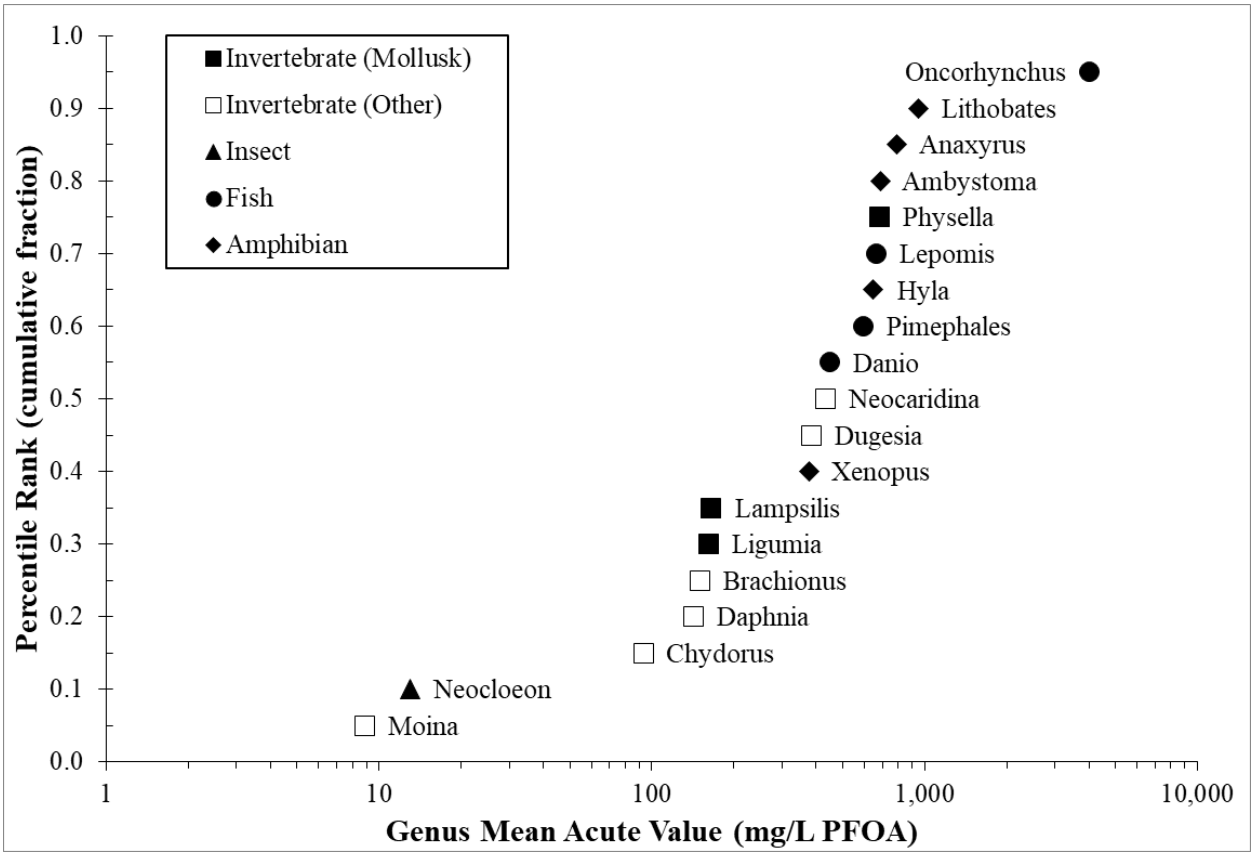


Figure 3-1. Ranked Freshwater Acute PFOA GMAVs Fulfilling the Acute Family MDR.

3.1.1.2 Summary of Quantitatively Acceptable Acute PFOA Toxicity Studies for Estuarine/Marine Species

Quantitatively-acceptable empirical data for acute PFOA toxicity were available for four estuarine/marine species, representing four genera and three families in three phyla. The data available for estuarine/marine invertebrates fulfilled three of the eight MDRs. In the interest of providing information to states/authorized Tribes on protective values, the EPA developed an estuarine/marine acute benchmark using the available empirical data supplemented with toxicity values generated through the use of new approach methods, specifically through the use of the EPA Office of Research and Development's peer-reviewed publicly-available Web-based Interspecies Correlation Estimation (web-ICE) tool (Raimondo et al. 2010). These benchmarks are provided in Appendix L.

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The following section provides information and summaries of studies for the sensitive estuarine/marine taxa, based on the limited available data (Table 3-4). Study summaries for the 4 most sensitive genera are provided below.

Table 3-4. Estuarine/Marine Acute PFOA Genera.
Ranked Below from Most to Least Sensitive

Rank	Genus	GMAV (mg/L)	Species
1	*Siriella*	15.5	Mysid (*Siriella armata*)[a]
2	*Mytilus*	17.58	Mediterranean mussel (*Mytilus galloprovincialis*)
3	*Strongylocentrotus*	20.63	Purple sea urchin (*Strongylocentrotus purpuratus*)
4	*Americamysis*	24	Mysid (*Americamysis bahia*)

[a] Not a North American resident species, but a member of the *Siriella* genus and serves as a surrogate for untested *Siriella* species residing in North America (Heard et al. 2006).

3.1.1.2.1 Most sensitive estuarine/marine genus: Siriella (mysid)

Mhadhbi et al. (2012) performed a 96-hour static, unmeasured acute test with PFOA (96% purity) on the mysid, *Siriella armata*. Mysids were exposed to one of ten nominal PFOA treatments (0.1, 0.5, 1, 2, 5, 10, 20, 30, 40 and 80 mg/L). Neonates were fed 10-15 *Artemia salina* nauplii daily and mortality was recorded after 96 hours. The 96-hour LC_{50} reported in the study was 15.5 mg/L PFOA and was acceptable for quantitative use. No other quantitatively acceptable acute toxicity data were available for *Siriella armata* or other members of the genus *Siriella*. Therefore, the LC_{50} (i.e., 15.5 mg/L) from this test served directly as the *Siriella* GMAV. Although *S. armata* is not a North American resident species, it is a member of the Mysidae Family and serves as a surrogate for untested mysid species, including members of the genus *Siriella*, residing in North America (Heard et al. 2006).

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3.1.1.2.2 Second most sensitive estuarine/marine genus: Mytilus (mussel)

The acute toxicity of PFOA (purity not provided) on the Mediterranean mussel, *Mytilus galloprovincialis*, which occurs in California and other parts of the Pacific Northwest (Green 2014), was evaluated by **Fabbri et al. (2014)**. The endpoint was the percent reduction of normal D-larvae in each well. Authors noted that controls had ≥80% normal D-larvae across all tests, meeting the >75% acceptability threshold outlined by ASTM (2004). PFOA was only measured once in one treatment which was similar to the nominal concentration. The percentage of normal D-larva decreased with increasing test concentrations. The NOEC and LOEC reported for the study were 0.00001 and 0.0001 mg/L, respectively. Although authors report ~27% effect at the LOEC (i.e., 0.0001 mg/L), the test concentrations failed to elicit 50% malformations in the highest test concentration, and an EC_{50} was not determined. Therefore, the EC_{50} for the study was greater than the highest test concentration (1 mg/L). The 48-hour EC_{50} based on malformation of >1 mg/L was quantitatively acceptable.

Hayman et al. (2021) reported the results of a 48-hour static, measured acute PFOA (CAS # 335-67-1, 95% purity, purchased from Sigma-Aldrich, St. Louis, MO) test on the Mediterranean mussel, *Mytilus galloprovincialis*. Authors note that tests followed U.S. EPA (1995b) and ASTM (2004) protocols. Six test solutions were made in 0.45 µm filtered seawater (North San Diego Bay, CA) with PFOA dissolved in methanol. The highest concentration of methanol was 0.02% (v/v) and each treatment solution contained five replicates. At test termination (48 hours), larvae were enumerated for total number of larvae that were alive at the end of the test (normally or abnormally developed) as well as number of normally-developed (in the prodissoconch "D-shaped" stage) larvae. There were no significant differences between solvent control and filtered seawater, suggesting no adverse effects of methanol. The author

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reported 48-hour EC_{50}, based on normal larvae survival was 9.98 mg/L PFOA. The EPA-calculated 48-hour EC_{50} value was 17.58 mg/L, which was acceptable for quantitative use.

Although the 48-hour EC_{50} based on malformation of >1 mg/L from Fabbri et el. (2014) met the EPA's data quantitatively objectives, it was not used directly in the calculation of the *M. galloprovincialis* SMAV because it was a "greater than LC_{50}" value and a definitive LC_{50} was available for the same species as reported by Hayman et al. (2021). The definitive LC_{50} value from Hayman et al. (2021) of 17.58 mg/L served directly as the *Mytilus galloprovincialis* SMAV and as the *Mytilus* GMAV.

3.1.1.2.3 Third most sensitive estuarine/marine genus: Strongylocentrotus (urchin)

Hayman et al. (2021) reported the results of a 96-hour static, measured PFOA (CAS # 335-67-1, 95% purity, purchased from Sigma-Aldrich, St. Louis, MO) test with the purple sea urchin, *Strongylocentrotus purpuratus*. Authors note that tests followed U.S. EPA (1995b) and ASTM (2004) protocols. Six test solutions were made in 0.45 µm filtered seawater (North San Diego Bay, CA) with PFOA dissolved in methanol and each treatment was replicated five times. The highest concentration of methanol was 0.02% (v/v). At test termination (96 hours), the first 100 larvae were enumerated and observed for normal development (organisms distinguished as being in the four arm pluteus stage). There were no significant differences between solvent control and filtered seawater, suggesting no adverse effects of methanol. The author reported 96-hour EC_{50}, based on normal development, was 19 mg/L PFOA. The EPA-calculated 96-hour EC_{50} value was 20.63 mg/L, which was acceptable for quantitative use. The EC_{50} value of 20.63 mg/L was the only acceptable acute value for *Strongylocentrotus purpuratus* or any members of the genus *Strongylocentrotus*. Therefore, it served directly as the *Strongylocentrotus purpuratus* SMAV and the *Strongylocentrotus* GMAV.

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3.1.1.2.4 Fourth most sensitive estuarine/marine genus: Americamysis (mysid)

Hayman et al. (2021) conducted a 96-hour static, measured test to assess effects of PFOA (CAS # 335-67-1, 95% purity, purchased from Sigma-Aldrich, St. Louis, MO) on the mysid, *Americamysis bahia*. Authors note that tests followed U.S. EPA (2002) protocols. Six test solutions were made in 0.45 µm filtered seawater (North San Diego Bay, CA) with PFOA dissolved in methanol. The highest concentration of methanol was 0.02% (v/v) and each test solution was replicated six times with five mysids per replicate. There were no significant differences between solvent control and filtered seawater, suggesting no adverse effects of methanol. No organisms were found dead in the controls at test termination. The EPA was unable to fit a concentration-response model with significant parameters and relied on the author-reported 96-hour LC_{50} of 24 mg/L PFOA as the quantitatively acceptable acute value. The LC_{50} value of 24 mg/L was the only acceptable acute value for *Americamysis bahia* or any members of the genus *Americamysis.* Therefore, it served directly as the *Americamysis bahia* SMAV and the *Americamysis* GMAV.

The estuarine/marine acute data set for PFOA contained four genera (Figure 3-2) representing only three of the eight taxonomic MDR groups. The missing MDR groups included two families in the phylum Chordata, two families in a phylum other than Chordata, and any other family not already represented (Table 3-5). As noted above, the EPA used the available acute toxicity data and ORD's peer-reviewed web-ICE tool to develop aquatic life benchmarks for consideration by states and Tribes (see Appendix L).

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Table 3-5. Ranked Estuarine/Marine Genus Mean Acute Values.

Rank[a]	GMAV (mg/L PFOA)	MDR Group[c]	Genus	Species	SMAV[b] (mg/L PFOA)
1	15.5	C	*Siriella*	Mysid, *Siriella armata*	15.5
2	17.58	D	*Mytilus*	Mediterranean mussel, *Mytilus galloprovincialis*	17.58
3	20.63	F	*Strongylocentrotus*	Purple sea urchin, *Strongylocentrotus purpuratus*	20.63
4	24	C	*Americamysis*	Mysid, *Americamysis bahia*	24

a Ranked from the most sensitive to the most resistant based on Genus Mean Acute Value.
B From Appendix B: Acceptable Estuarine/Marine Acute PFOA Toxicity Studies
c MDR Groups identified in Footnote C of Table 3-1.

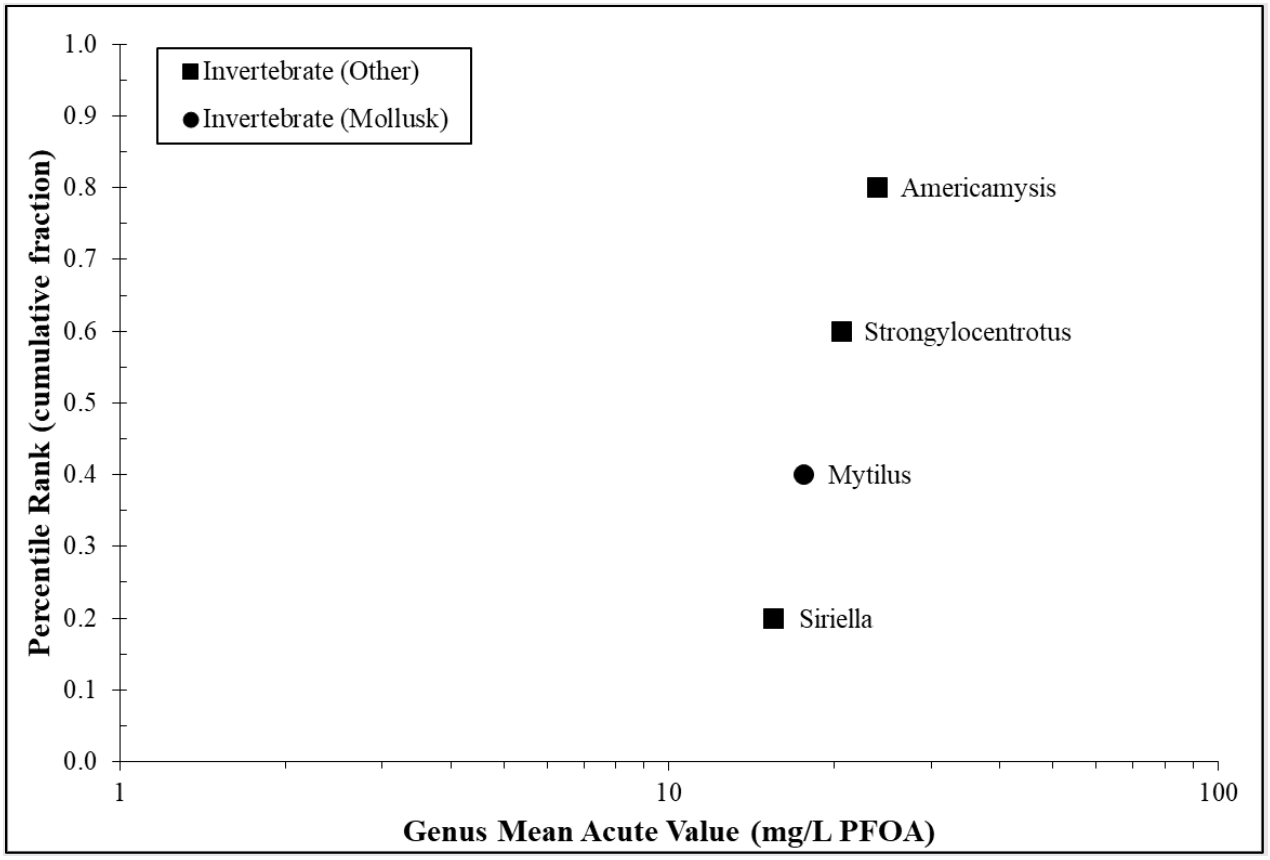


Figure 3-2. Acceptable Estuarine/Marine GMAVs.

3.1.1.3 Summary of Chronic PFOA Toxicity Studies Used to Derive the Freshwater Aquatic Life Criterion

Acceptable chronic PFOA toxicity data in freshwater were available for a total of 13 species representing 12 genera and ten families in three phyla. All eight of the required MDRs were fulfilled. The following section provides information and summaries of studies for the sensitive taxa with effect values used in the quantitative calculation of the chronic freshwater PFOA criterion (Table 3-6). The chronic data set for PFOA based on quantitatively acceptable data contains 12 genera representing all eight taxonomic MDR groups (Table 3-7).

Table 3-6. The Most Sensitive Genera Used in Calculating the Chronic Freshwater Water Column Criterion (Sensitivity Rank 1-4).

Ranked Below from Most to Least Sensitive

Rank	Genus	GMCV (mg/L)	Species
1	*Hyalella*	0.147	Amphipod (*Hyalella azteca*)
2	*Lithobates*	0.288	American bullfrog (*Lithobates catesbeiana*)
3	*Daphnia*	0.3695	Cladoceran (*Daphnia carinata*)[a]
			Cladoceran (*Daphnia magna*)
4	*Brachionus*	0.7647	Rotifer (*Brachionus calyciflorus*)

[a] Not a North American resident but in same genus as resident species.

3.1.1.3.1 Most chronically sensitive genus: Hyalella (amphipod)

Bartlett et al. (2021) evaluated the chronic effects of PFOA (CAS# 335-67-1, 96% purity, solubility in water at 20,000 mg/L, purchased from Sigma-Aldrich) on *Hyalella azteca* via a 42-day static-renewal, measured study. Methods for this study were adapted from Borgmann et al. (2007), and organisms were two to nine days old at the test initiation. A 100 mg/L stock solution was prepared to yield measured test concentrations of 0 (control), 0.84, 3.3,

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8.9, 29 and 97 mg/L PFOA. Two separate tests were performed with five replicates per concentration and 20 amphipods per replicate. At test termination (day 42), adults were sexed and weighed, as well as their young counted. The 42-day author-reported LC_{10} value for survival was 23.2 mg/L PFOA. The author-reported EC_{10} values for growth and reproduction were 0.160 mg/L and 0.0265 mg/L, respectively. The EPA only performed C-R analysis for the growth and reproduction-based endpoints for this test, given the apparent tolerance of the survival-based endpoint. The EPA calculated EC_{10} values for the 42-day growth endpoint (i.e., control normalized wet weight/amphipod) and the 42-day reproduction endpoint (i.e., number of juveniles per female). The 42-day growth-based EC_{10} of 0.488 mg/L was not selected as the primary endpoint from this test because it was more tolerant than the reproduction-based EC_{10} of 0.147 mg/L, which was acceptable for qualitative use. The EC_{10} value of 0.147 mg/L was the only acceptable chronic value for *Hyalella azteca* or any members of the genus *Hyalella.* Therefore, it served directly as the *Hyalella azteca* Species Mean Chronic Value (SMCV) and the *Hyalella* Genus Mean Chronic Value (GMCV).

3.1.1.3.2 Second most chronically sensitive genus: Lithobates (frog)

Flynn et al. (2019) evaluated the chronic effects of PFOA (CAS# 335-67-1, purchased from Sigma-Aldrich) on the American bullfrog (*Lithobates catesbeiana,* formerly, *Rana catesbeiana*) during a 72-day static-renewal unmeasured exposure. The authors tested a negative control and two treatment concentrations (i.e., 0.144 and 0.288 mg/L), which were the only three PFOA-only treatments within the larger factorially-designed experiment. Each treatment contained 10 tadpoles (Gosner stage 25) and treatments were replicated four times. On day 72 of the experiment, all tadpoles were euthanized and measured (snout vent length and mass). The most sensitive chronic endpoint was growth (snout-vent length), with a 72-day NOEC and LOEC of 0.144 mg/L and 0.288 mg/L, respectively. The EPA could not independently calculate an EC_{10}

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value because there were minimal effects observed across the limited number of treatment concentrations tested. Consequently, the EPA used the LOEC of 0.288 mg/L as the chronic value from this chronic test. The LOEC was used preferentially to the MATC from this test because a ~7% reduction in snout-vent length relative to control responses was observed at the LOEC (i.e., 0.288 mg/L), which is a similar effect level to the chronic 10% effect level (i.e., EC_{10}) used preferentially to derive the chronic criterion. The LOEC value of 0.288 mg/L was the only acceptable chronic value for *Lithobates catesbeiana* or any members of the genus *Lithobates.* Therefore, it served directly as the *Lithobates catesbeiana* SMCV and the *Lithobates* GMCV.

3.1.1.3.3 Third most chronically sensitive genus: Daphnia (cladoceran)

Logeshwaran et al. (2021) conducted a static-renewal unmeasured PFOA (95% purity, purchased from Sigma-Aldrich Australia) chronic toxicity test with the cladoceran, *Daphnia carinata*. Authors stated the chronic test protocol followed OECD guidelines (2012). Authors tested a negative control and five PFOA concentrations (i.e., 0.001, 0.01, 0.1, 1.0 and 10 mg/L PFOA). Each test treatment was replicated 10 times with one daphnid (six to12 hours old) per treatment. At test termination (21 days) test endpoints included survival, days to first brood, average offspring in each brood and total live offspring. No mortality occurred in the controls or lowest test concentration. Of the three endpoints measured, average offspring in each brood and total live offspring were the more sensitive endpoints with 21-day NOEC and LOEC values of 0.01 and 0.1 mg/L PFOA, respectively. The EPA was unable to calculate statistically robust EC_{10} estimates from C-R models for these endpoints, largely because of the 10X dilution series across five orders of magnitude. The LOECs for these endpoints were not selected as the chronic value because the LOECs produced a 29.23% reduction in the average number of offspring per brood relative to controls and a 39.89% reduction in the total living offspring relative to controls. Therefore, the MATC (i.e., 0.03162 mg/L) was selected as the quantitatively acceptable chronic

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value from this test. The MATC value of 0.03162 mg/L was the only acceptable chronic value for *Daphnia carinata,* and it served directly as the *Daphnia carinata* SMCV.

Centre International de Toxicologie (2003) and **Colombo et al. (2008)** conducted a 21-day renewal measured chronic test on PFOA with the daphnid, *Daphnia magna*. Authors stated that the toxicity test conducted followed OECD test guideline 211. Average number of live young was the most sensitive endpoint reported by Colombo et al. (2008), with a NOEC of 20 mg/L. The author-reported NOEC for the average number of live young was 20 mg/L, the LOEC was 44.2 mg/L and the MATC was 29.73 mg/L. The EPA performed C-R analysis for each reported endpoint. The most sensitive endpoint with an acceptable C-R curve was the average number of live young per starting adult, with an EPA-calculated EC_{10} of 20.26 mg/L PFOA and was acceptable for quantitative use.

Ji et al. (2008) conducted a chronic life-cycle test on the effects of PFOA with *Daphnia magna*. Authors stated that the *D. magna* test followed OECD 211 (1998). The most sensitive endpoint for *D. magna* reported in the publication was days to first brood with a 21-day NOEC of 6.25 mg/L (LOEC = 12.5 mg/L; MATC = 8.839 mg/L); however, number of young per starting female (an endpoint not reported in the publication, which only assessed number of young per surviving female) was calculated by the EPA and considered to be a more sensitive endpoint with an EPA-calculated EC_{10} of 7.853 mg/L. Therefore, the EPA-calculated EC_{10} of 7.853 mg/L PFOA for *D. magna* (number of young per starting female) was considered quantitatively acceptable.

Li (2010) conducted an unmeasured chronic life cycle 21-day test on the effects of PFOA on *Daphnia magna*. Authors stated the test followed OECD 211 (1998). The *D. magna* 21-day NOEC (reproduction as number of young per female, broods per female, and mean brood size)

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was 10 mg/L (LOEC = 32 mg/L; calculated MATC = 17.89 mg/L). The EPA performed C-R analysis for each reported endpoint. The EPA also revaluated all endpoints that were based on number of surviving females to be based on the number of starting females. This recalculation was done with the intent to account for starting females that were unable to contribute to the population as reproduction/female due to mortality. The most sensitive endpoint with an acceptable C-R curve was the number of young per starting female with an EPA-calculated EC_{10} of 12.89 mg/L PFOA and was acceptable for quantitative use.

Yang et al. (2014) evaluated the chronic 21-day renewal, measured test of PFOA with *Daphnia magna*, following ASTM E729 (1993). The author-reported *D. magna* 21-day EC_{10} for reproduction (total number of spawning) was 7.02 mg/L. The EPA performed C-R analysis for each reported endpoint. Both chronic survival and reproduction endpoints resulted in acceptable C-R curves. The EPA-calculated EC_{10} for reproduction as total number of spawning events was 6.922 mg/L, similar to the EC_{10} reported by the authors (i.e., 7.02 mg/L). Chronic survival was more sensitive than reproduction, with an EPA-calculated EC_{10} of 5.458 mg/L PFOA. Therefore, the survival based EC_{10} calculated by the EPA (i.e., 5.458 mg/L) was acceptable for quantitative use.

Lu et al. (2016) evaluated the chronic toxicity of PFOA (CAS# 335-67-1, 98% purity, purchased from Tokyo Chemical Industry Co., Ltd., Tokyo, Japan) on *Daphnia magna* immobilization, growth and reproduction in a 21-day semi-static test with unmeasured treatment solutions. Authors stated the test protocol followed OECD Test Method 211. Neonates (<24 h old) were exposed to PFOA in one of six PFOA treatments (i.e., 0 [control] 0.032, 0.16, 0.8, 4 and 20 mg/L), with 20 replicates for each treatment. The 21-day growth and reproductive NOEC and LOEC values were 0.032 and 0.16 mg/L PFOA, respectively. The EPA was unable to fit a

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C-R model with significant parameters to the chronic data associated with reproduction from this test. The EPA-calculated EC_{10} values for mean intrinsic rate of increase (r; population-level endpoint that accounts for births and deaths over time) and growth (as length) were 0.0173 mg/L and 0.0124 mg/L, respectively. Both EC_{10} values were nearly two times lower than the NOEC for both endpoints (i.e., 0.032 mg/L) and four times lower than the LOEC values (i.e., 0.16 mg/L) for both endpoints, where a 15.2% reduction in intrinsic rate of natural increase ® and an 11.9% reduction in length were observed. As a result, the MATC of 0.0716 mg/L for growth and reproduction was selected as the most appropriate chronic value for quantitative use to in deriving the chronic water column-based criterion.

Yang et al. (2019) evaluated the chronic effects of PFOA (CAS# 335-67-1, purchased from Sigma-Aldrich in St. Louis, MO) on *Daphnia magna* via a 21-day unmeasured, static-renewal test that assessed reproductive effects. The protocol for testing followed OECD Guideline 211. Authors tested a negative control and four PFOA treatment concentrations (6.708, 10.10, 15.11, and 22.61 mg/L), with each treatment replicated 10 times and each replicate containing one neonate (12–24 hours old) in a 100 mL glass beaker. The reproductive NOEC and LOEC values were 6.708 and 10.10 mg/L PFOA, respectively. The EPA performed C-R analysis for the test. The EPA-calculated EC_{10} based on mean offspring at 21-days as a proportion of the control response was 8.084 mg/L and was used quantitatively to derive the chronic water column criterion.

The chronic values from Centre International de Toxicologie/Colombo et al. (2003/2008; EC_{10} = 20.26 mg/L; endpoint = average number of live young), Ji et al. (2008; EC_{10} = 7.853 mg/L; endpoint = number of live young per starting female), Li (2010; EC_{10} =12.89 mg/L; endpoint = number of young per starting female), Yang et al. (2014; EC_{10} = 5.458 mg/L;

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endpoint = survival), Lu et al. (2016; MATC = 0.0716 mg/L; endpoint = length and rate of natural increase), and Yang et al. (2019; EC_{10} = 8.084 mg/L; endpoint = mean offspring as a proportion of control response) were taken together as a geometric mean to serve as the *Daphnia magna* SMCV (i.e., 4.317 mg/L).

The *D. carinata* SMCV (i.e., 0.03162 mg/L) and the *D. magna* SMCV (i.e., 4.317 mg/L) were used to calculate the *Daphnia* GMCV of 0.3695 mg/L. Exclusion of the *D. carinata* SMCV under the basis of it being an overly sensitive outlier (relative to *D. magna* and the overall quantitatively acceptable chronic data) would have resulted in the *Daphnia* GMCV being potentially underprotective. Conversely, excluding the *D. magna* SMCV under the basis of being a tolerant outlier (relative to *D. carinata*) would result in the *Daphnia* GMCV being highly influenced by a single test/species with a relatively sensitive chronic value. The *D. carinata* chronic value was also an MATC, calculated as the geometric mean of the NOEC (0.01 mg/L) and LOEC (0.1 mg/L) from a 10X dilution series, meaning the MATC was influenced by a relatively low NOEC and broadly spaced dosing. However, the corresponding LOEC (i.e., 0.1 mg/L) remains relatively sensitive and produced effects of 29.23% to 39.89%, depending on the specific offspring-based endpoint. Using both the *D. magna* and *D. carinata* SMAVs resulted in a *Daphnia* GMCV (0.3695 mg/L) that was among the four most sensitive genera and in the general range of the data overall.

3.1.1.3.4 Fourth most chronically sensitive genus: Brachionus (rotifer)

Zhang et al. (2013a) conducted a chronic life-cycle renewal test of PFOA (CAS # 335-67-1, 96% purity) with *Brachionus calyciflorus*. The test consisted of a negative control and four PFOA concentrations (0.25, 0.5, 1.0, 2.0 mg/L PFOA). For each treatment level, fifteen amictic rotifers were placed individually into culture plate wells containing two mL of test solution that was renewed daily. Numbers of eggs produced and starting rotifer lifetimes were recorded for

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every individual, and the test was conducted until every starting rotifer from every treatment level died, which occurred around 200 hours after test initiation. Data from this test were used to construct survivorship and fertility tables using conventional life-history techniques, which were used to calculate net reproductive rate, generation time, and intrinsic rate of natural increase. The EPA calculated EC_{10} values from C-R data reported in the publication, and the most sensitive endpoint with an acceptable C-R curve was the intrinsic rate of natural increase, with an EC_{10} of 0.5015 mg/L PFOA.

The intrinsic rate of natural increase (d^{-1}) is a population-level endpoint that accounts for births and deaths over time. In Zhang et al. (2013a), the intrinsic rate of natural increase was calculated as the natural log of the lifetime net reproductive rate for all individuals within a population (defined here as a PFOA treatment level) divided by the average generation time of those individuals.

The EC_{10} calculated for the intrinsic rate of natural increase was similar to the EC_{10} value for average net reproductive rate (0.514 mg/L). Zhang et al. (2013a) also reported significant reductions in egg size, with an EPA-calculated EC_{10} = 0.193 mg/L. However, this endpoint displayed a relatively poor concentration response relationship and may not be relevant for assessing population level effects. For these reasons, it was not selected as the primary effect concentration from this study. Zhang et al. (2013a) also reported effects to average juvenile period, which was a relatively tolerant endpoint. Juvenile period decreased with increasing exposure concentration, with the average juvenile period being about 16% faster than the control responses in the highest treatment concentration (2.0 mg/L). Effects to chronic apical endpoints in this publication and Zhang et al. (2014b) generally appear as a threshold effect from 0.25 mg/L to 1.0 mg/L, providing further support for selection of the EC_{10} value (i.e., 0.5015 mg/L)

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based on rate of natural increase as the primary chronic value for quantitative use from Zhang et al. (2013a).

In addition to the life cycle exposure, Zhang et al. (2013a) also conducted a second multi-generational 28-day study to measure effects of PFOA on growth patterns, population density, and population dynamics. The 28-day test consisted of a negative control and two PFOA concentrations (0.25, and 2.0 mg/L PFOA). Population densities were lower than controls at both PFOA treatment levels; however, because this study was limited to two treatment levels, it was considered to be of secondary importance compared to the life-cycle test.

Zhang et al. (2014b) describes the results of three experiments involving *Brachionus calyciflorus* exposures to PFOA (CAS # 335-67-1, 96% purity). The effects of PFOA concentration on mictic ratios of *B. calyciflorus* was examined by placing individual neonates in culture plate wells with two mL of medium containing of two PFOA concentrations (0.25 mg/L and 2.0 mg/L) plus a control. Each treatment level, as well as the control, was replicated three times. All eggs produced by these exposed individuals were individually incubated in culture wells with one mL control medium. The mature F_1 offspring were subsequently identified as producing mictic or amictic eggs, and these data were used to calculate mictic ratios. The proportions of mictic eggs increased with increasing PFOA concentration (0.56 – control, 0.72 – 0.25 mg/L, 0.75 – 2.0 mg/L), and the results were statistically significant ($p<0.05$). In contrast, mictic ratios were not affected by PFOA concentrations in Zhang et al. (2013a). Because of the inconsistent result in the mictic ratio endpoint between Zhang et al. (2013a) and Zhang et al. (2014b), it was not selected as the representative endpoint from either publication.

The effects of PFOA concentration on resting egg production of *B. Calyciflorus* was examined by exposing rotifers to one of five PFOA concentrations (plus control) in the dark for

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six days. Resting eggs were collected on the sixth day and then hatched in control medium 30 days later. Resting egg production decreased with increasing PFOA concentration. The EPA-calculated EC_{10} calculated from C-R data reported in Figure 1 of Zhang et al. (2014b) was 0.076 mg/L. Because there was only one replicate (as implied by lack of error bars in Figure 1 of the publication, no clear description of replicates in the methods section, and no author-reported statistical analysis of this endpoint), resting egg production from this study was not considered quantitatively acceptable but was retained for qualitative use. In a second resting egg exposure study, resting eggs were produced under control conditions, then allowed to hatch while exposed to one of five PFOA concentrations plus a control. In this study, the effects of PFOA exposure on resting egg hatching rate were not statistically significant.

Finally, the effects of PFOA concentration on *B. calyciflorus* population growth was examined during a four-day study in which 10 neonates were placed into chambers with 10 mL of medium containing one of eight PFOA concentrations, plus a control. Each treatment level, as well as the control, was replicated at least six times. After four days, the total numbers of rotifers in each chamber were counted, and these data were used to calculate the intrinsic rate of natural increase (d^{-1}), the most sensitive acceptable endpoint from this study, with an EPA-calculated EC_{10} of 1.166 mg/L. Beyond Zhang et al. (2013a) and Zhang et al. (2014b), no other quantitatively acceptable chronic tests were available for *Brachionus calyciflorus*. The EPA-calculated EC_{10} values from Zhang et al. (2013a) (i.e., 0.5015 mg/L; endpoint = rate of natural increase) and Zhang et al. (2014b) (i.e., 1.166 mg/L; endpoint = rate of natural increase) were taken together as a geometric mean to serve as the *Brachionus calyciflorus* SMCV (i.e., 0.7647 mg/L). No other quantitatively acceptable chronic toxicity data were available for other members

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of the genus *Brachionus* and the *Brachionus calyciflorus* SMCV (i.e., 0.7647 mg/L) served directly as the *Brachionus* GMCV.

Table 3-7. Ranked Freshwater Genus Mean Chronic Values.

Rank[a]	GMCV[b] (mg/L PFOA)	MDR Group[c]	Genus	Species	SMCV[b] (mg/L PFOA)
1	0.147	E	*Hyalella*	Amphipod, *Hyalella azteca*	0.147
2	0.288	C	*Lithobates*	American bullfrog, *Lithobates catesbeiana*	0.288
3	0.3695	D	*Daphnia*	Cladoceran, *Daphnia carinata*	0.03162
				Cladoceran, *Daphnia magna*	4.317
4	0.7647	G	*Brachionus*	Rotifer, *Brachionus calyciflorus*	0.7647
5	2.194	D	*Moina*	Cladoceran, *Moina macrocopa*	2.194
6	>3.085	H	*Neocloeon*	Mayfly, *Neocloeon triangulifer*	>3.085
7	9.487	C	*Oryzias*	Medaka, *Oryzias latipes*	9.487
8	23.56	D	*Ceriodaphnia*	Cladoceran, *Ceriodaphnia dubia*	23.56
9	>30	B	*Gobiocypris*	Rare minnow, *Gobiocypris rarus*	>30
10	>40	A	*Oncorhynchus*	Rainbow trout, *Oncorhynchus mykiss*	>40
11	>76	B	*Pimephales*	Fathead minnow, *Pimephales promelas*	>76
12	88.32	F	*Chironomus*	Midge, *Chironomus dilutus*	88.32

a Ranked from the most sensitive to the most resistant based on Genus Mean Chronic Value.
b From Appendix C: Acceptable Freshwater Chronic PFOA Toxicity Studies.
c MDR Groups identified in Footnote C of Table 3-3.

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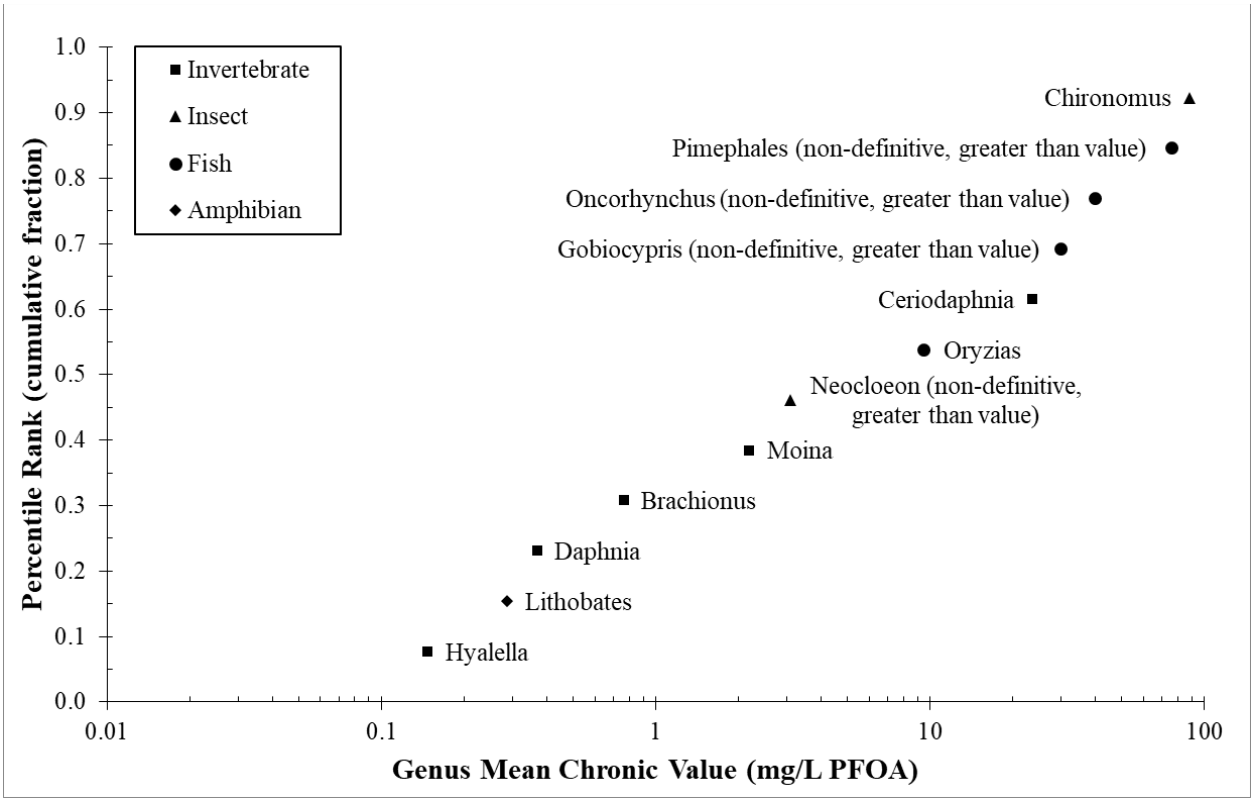


Figure 3-3. Freshwater Genus Mean Chronic Values for PFOA.

3.1.1.4 Summary of Chronic PFOA Toxicity Studies Used to Derive the Estuarine/Marine Aquatic Life Criterion

Quantitatively-acceptable empirical data for chronic PFOA toxicity were available for two estuarine/marine species, fulfilling two of the eight MDRs (Table 3-8).

3.1.1.4.1 Most chronically sensitive estuarine/marine species: Oryzias (fish)

Oh et al. (2013) evaluated the chronic toxicity of PFOA on the Japanese medaka, *Oryzias latipes*, in a 30-day static exposure. Prior to test initiation, the fish were acclimated to a seawater environment. Fish were exposed for 30 days to one PFOA concentration (1.0 mg/L), a 0.22 µm filtered seawater control, and a DMSO carrier solvent control. The 30-day condition factor NOEC of 1.0 mg/L PFOA was selected as the primary endpoint from this study. The methods section of Oh. et al. (2013) also stated, "In our preliminary study, fish mortality was altered 30 days after perfluorinated compound exposure, suggesting that repeated exposure to

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PFCs for 30 days at 1 µg/mL [1 mg/L] causes adverse effect on *O. latipes*." The statement about mortality-based effects in their preliminary test is in direct conflict with the condition-based results from the primary test that was the focus of the publication. Few details are provided about the preliminary test. Results of the final test (i.e., condition factor NOEC of 1.0 mg/L reported in Table 1 of Oh et al. 2013) were retained as quantitatively acceptable because they provide chronic estuarine/marine data that were otherwise limited.

3.1.1.4.2 Second most chronically sensitive estuarine/marine species: Paracentrotus (sea urchin)

Savoca et al. (2022) tested chronic toxicity of perfluorooctanoic acid (PFOA, >98% purity) to sea urchins (*Paracentrotus lividus*) in a 28-day measured, static experiment. Four sea urchins were placed into one of nine aquariums containing 15 L of seawater at nominal concentrations (0 [control], 10, and 100 mg/L), with three replicates per concentration treatment. The average recovery of PFOA was stable and close to nominal across all treatments throughout the experiment, and PFOA in control water was less than 10 ng/L. Coelomic fluid was sampled from all individuals weekly to measure PFOA uptake. During the exposure period, sea urchins at the highest test concentration showed sublethal signs of toxicity, including reduced spine mobility, spine loss, and reduced ability to remain anchored to the bottom of the test vessels. Mortality was only observed at the highest test concentration. Adult mortality, adult PFOA accumulation in coelomic fluid, percentage of normal and abnormal embryos, and gene expression in embryos were measured. The NOEC and LOEC for adult mortality were 10 mg/L and 100 mg/L, respectively, and the MATC of 31.62 mg/L was determined to be acceptable for quantitative use.

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Table 3-8. Ranked Estuarine/Marine Genus Mean Chronic Values.

Rank[a]	GMCV[b] (mg/L PFOA)	MDR Group[c]	Genus	Species	SMCV[b] (mg/L PFOA)
1	>10	A	*Oryzias*	Japanese medaka, *Oryzias latipes*	>10
2	31.62	E	*Paracentrotus*	Purple sea urchin, *Paracentrotus lividus*	31.62

a Ranked from the most sensitive to the most resistant based on Genus Mean Chronic Value.
b From Appendix D: Acceptable Estuarine/Marine Chronic PFOA Toxicity Studies.
c MDR Groups identified in Footnote C of Table 3-3.

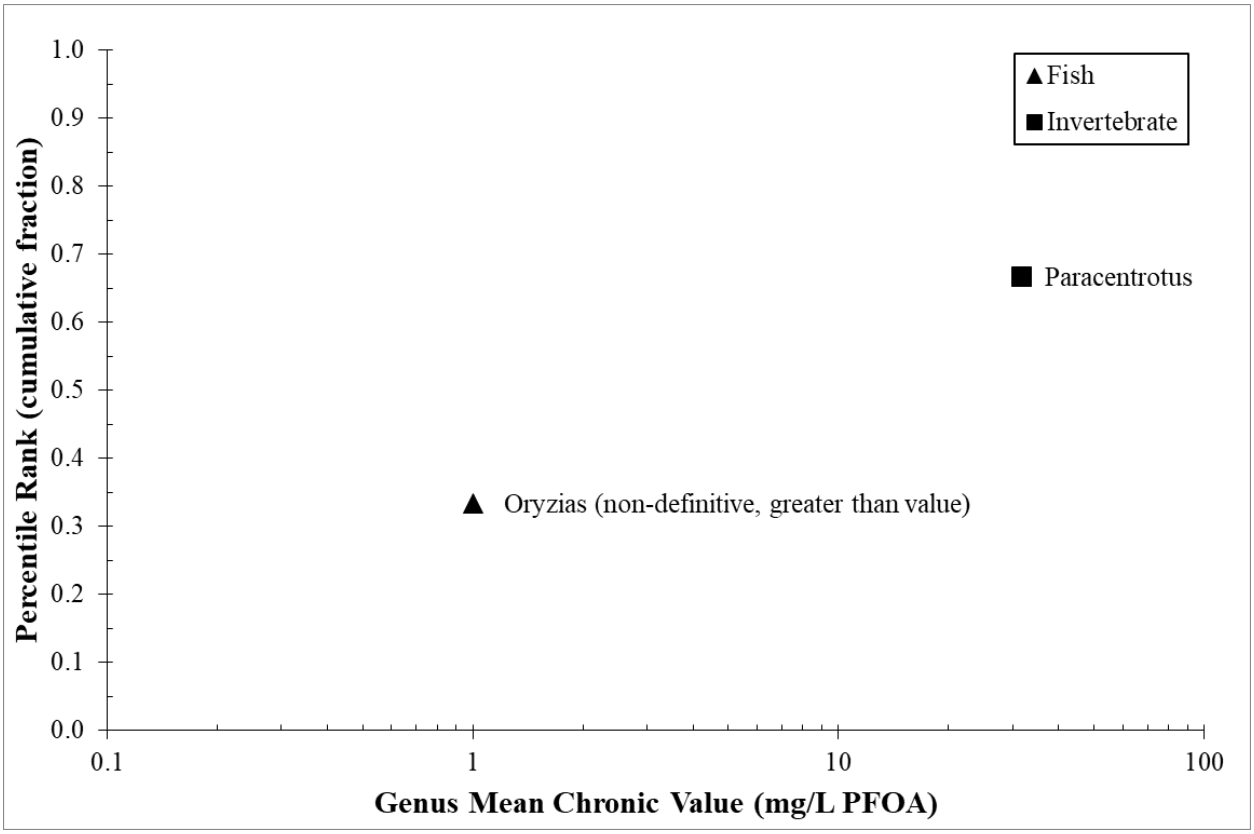


Figure 3-4. Estuarine/Marine Genus Mean Chronic Values for PFOA.

3.2 Derivation of the PFOA Aquatic Life Criteria

3.2.1 Derivation of Water Column-based Criteria

3.2.1.1 Derivation of Acute Water Criterion for Freshwater

The acute data set for PFOA contains 19 genera representing all eight taxonomic MDR groups. GMAVs for the four most sensitive genera were within a factor of 16.1 of each other.

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The freshwater Final Acute Value (FAV) (i.e., the 5th percentile of the genus sensitivity distribution, intended to address 95 percent of the genera) for PFOA is 6.237 mg/L, calculated using the procedures described in the 1985 Guidelines (Table 3-9). The FAV is lower than all the GMAVs for the tested species. The FAV was then divided by two to obtain a concentration yielding a minimal effect acute criterion value. Based on the above, the FAV/2, which is the freshwater acute criterion water column magnitude (criterion maximum concentration, CMC), is 3.1 mg/L PFOA (rounded to two significant figures) and is expected to be protective of 95% of freshwater genera exposed to PFOA under short-term conditions of one-hour of duration, if the one-hour average magnitude is not exceeded more than once in three years (Figure 3-5).

Table 3-9. Freshwater Final Acute Value and Criterion Maximum Concentration.

Calculated Freshwater FAV based on 4 lowest values: Total Number of GMAVs in Data Set = 19						
Rank	**Genus**	**GMAV (mg/L)**	**ln(GMAV)**	**ln(GMAV)^2**	**P=R/(N+1)**	**sqrt(P)**
1	*Moina*	8.885	2.18	4.77	0.050	0.224
2	*Neocloeon*	13.05	2.57	6.60	0.100	0.316
3	*Chydorus*	93.17	4.53	20.56	0.150	0.387
4	*Daphnia*	142.8	4.96	24.61	0.200	0.447
		Σ (Sum):	**14.25**	**56.54**	**0.50**	**1.37**

S^2 =	208.28	S = slope
L =	-1.396	L = X-axis intercept
A =	1.831	A = lnFAV
FAV =	6.237	P = cumulative probability
CMC =	**3.1 mg/L PFOA** (rounded to two significant figures)	

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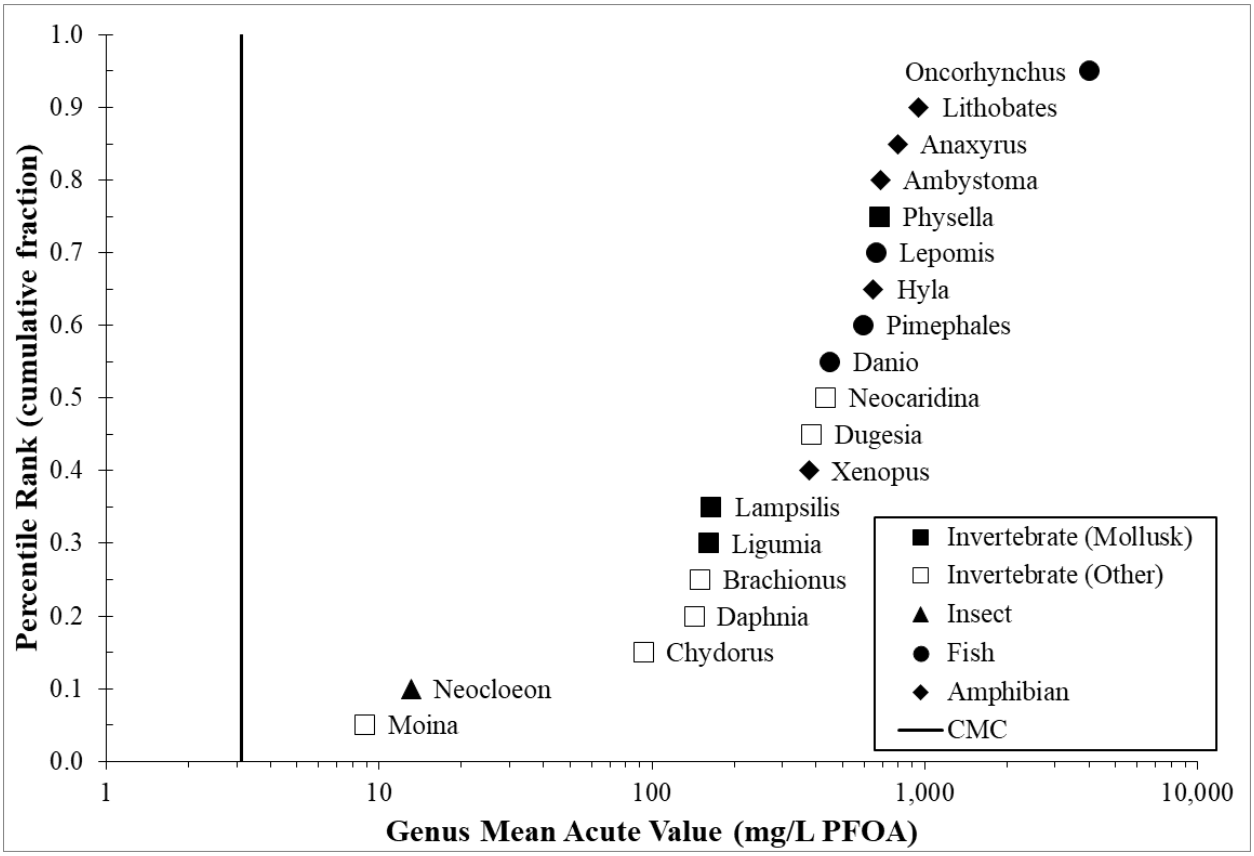


Figure 3-5. Ranked Freshwater Acute PFOA GMAVs and CMC.

3.2.1.2 Derivation of Acute Water Criterion for Estuarine/Marine Water

The 1985 Guidelines state that data from a minimum of eight families are needed to calculate an estuarine/marine FAV. Insufficient data exist to fulfill all eight of the taxonomic MDR groups. Notably, no acceptable test data on fish species were available. Since data were available for only three families, an estuarine/marine FAV could not be derived, and consequently, the EPA cannot derive an estuarine/marine acute criterion. The EPA has, however, developed an estuarine/marine acute benchmark value using available empirical data and the EPA/ORD's web-ICE tool to estimate missing data. The acute estuarine/marine benchmark is provided in Appendix L.

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3.2.1.3 Derivation of Chronic Water Criterion for Freshwater

The freshwater Final Chronic Value (FCV) (i.e., the 5th percentile of the genus sensitivity distribution, intended to address 95 percent of the genera) for PFOA is 0.1041 mg/L, calculated using the procedures described in the 1985 Guidelines (Table 3-10). The freshwater chronic criterion water column magnitude (CCC) is the FCV rounded to two significant figures, or 0.10 mg/L PFOA, and is expected to be protective of 95% of freshwater genera potentially exposed to PFOA if the four-day average magnitude is not exceeded more than once in three years.

Table 3-10. Freshwater Final Chronic Value and Criterion Continuous Concentration.

Calculated Freshwater FCV based on 4 lowest values: Total Number of GMCVs in Data Set = 12						
Rank	**Genus**	**GMCV (mg/L)**	**ln(GMCV)**	**ln(GMCV)^2**	**P=R/(N+1)**	**sqrt(P)**
1	*Hyalella*	0.147	-1.917	3.676	0.077	0.277
2	*Lithobates*	0.288	-1.245	1.550	0.154	0.392
3	*Daphnia*	0.3695	-0.996	0.991	0.231	0.480
4	*Brachionus*	0.7647	-0.268	0.072	0.308	0.555
		Σ (Sum):	**-4.43**	**6.29**	**0.77**	**1.70**

S^2 =	32.54	S = slope
L =	-3.538	L = X-axis intercept
A =	-2.262	A = lnFCV
FCV =	0.1041	P = cumulative probability
CCC =	**0.10 mg/L PFOA** (rounded to two significant figures)	

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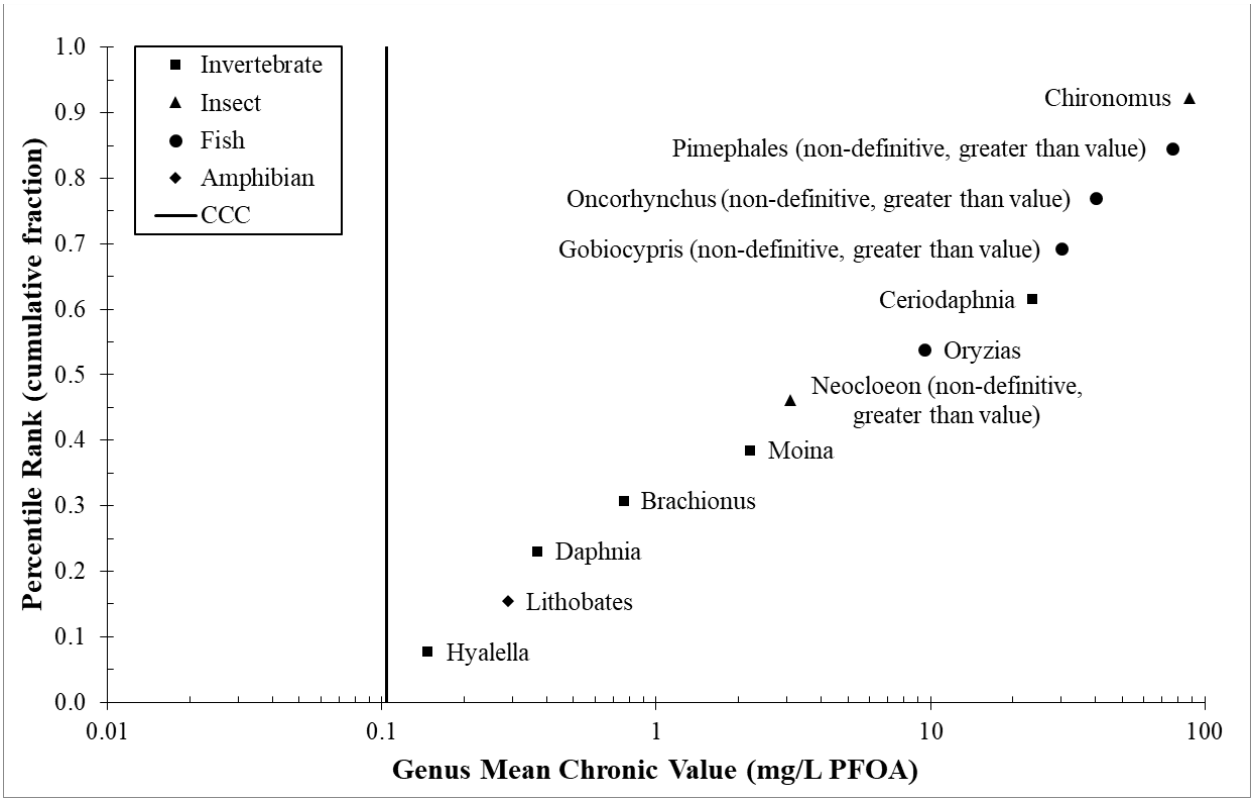


Figure 3-6. Freshwater Quantitative GMCVs and CCC.

3.2.1.4 Deriving A Protective Duration Component of the Water Column-Based Chronic Criterion

The EPA 1985 Guidelines set the standard chronic duration at four days for two primary reasons. The 1985 Guidelines state, "*An averaging period of four days seems appropriate for use with the CCC for two reasons. First, it is substantially shorter than the 20 to 30 days that is obviously unacceptable. Second, for some species it appears that the results of chronic tests are due to the existence of a sensitive life stage at some time during the test.*"

Among tests with chronically sensitive genera, Bartlett et al. (2021) measured effects of PFOA on *H. azteca* (the most chronically sensitive GMCV) survival at 7, 14, 21, 28, 35, and 42 days and concluded, "Toxicity increased approximately two-fold over the duration of exposure, with LC_{50}s of 110 mg/L after seven days and 51 mg/L after 42 days." Based on Table S6 of Bartlett et al. (2021), LC_{50} values decreased from seven to 21-days and remained generally stable from 28 to 42 days, suggesting the chronic PFOA LC_{50} value became time-independent between 21 and 28 days. Although *H. azteca* survival was tolerant at seven days, clear time-dependent toxicity may not occur for more sensitive endpoints such as reproduction.

Bartlett et al. (2021) determined effects to reproduction to be more sensitive than long-term survival, but only measured effects to reproduction after 42 days of exposure, which is substantially longer than the four-day chronic duration. Bartlett et al. (2021) noted, effects to amphipod reproduction are typically the result of effects to growth under the premise, "larger amphipods have a greater reproductive output" and "reduced growth delays sexual maturity." However, results observed in Bartlett et al. (2021), suggested "the effects on reproduction may also have occurred independently of growth." Therefore, the reproductive-specific effects observed by Bartlett et al. (2021) may not have been caused by the long-term effects of reduced growth but were possibly the result of a sexually-developing and uniquely-sensitive life stage

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that existed during a relatively brief duration within the longer 42-day test. Such instances are among the two primary reasons why the 1985 Guidelines prescribed the standard four-day chronic duration.

PFOA effects observed for other chronically sensitive and short-lived species further suggests a four-day chronic duration was appropriate. For example, the SMCV for *Brachionus calyciflorus* and the *Brachionus* GMCV (fourth most sensitive genus) are both the geometric mean of a full life-cycle test (i.e., up to 200 hours) test by Zhang et al. (2013a) and a four-day test by Zhang et al. (2014b). Chronic values for both studies correspond to the effect on population intrinsic growth rate. The full life-cycle test lasted up to 200 hours and yielded an EPA-calculated EC_{10} of 0.5015 mg/L. The four-day test yielded an EPA-calculated EC_{10} of 1.166 mg/L, suggesting chronic PFOA effects to short-lived species may occur after four days and increase with exposure duration.

Similarly, the SMCV for *Moina macrocopa* and the *Moina* GMCV (fifth most sensitive genus) are based on a seven-day life-cycle test by Ji et al. (2008), which also suggested reproductive effects (endpoint of number of young per starting female) occur in as little as seven days.

Overall, no chronic PFOA toxicity tests systematically evaluated time-to-effect, reported effect data at time intervals at a high enough resolution to model the speed of toxic action, assessed time variable PFOA exposures, or assessed the potential for latent toxicity. However, chronic tests, including life cycle tests with relatively short-lived species suggest chronic effects may occur at durations shorter than those of standard toxicity tests (e.g., 28 days) and a chronic four-day duration component of the water column criterion was considered protective for these species/genera. Therefore, the EPA has set the duration component of the PFOA chronic water

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column criterion at four days to reflect the chronic criterion duration recommended in the 1985 Guidelines. This four-day duration component of the chronic water column criterion is also consistent with U.S. EPA (1991), which considered the default four-day chronic averaging period as "the shortest duration in which chronic effects are sometimes observed for certain species and toxicants," and concludes that four-day averaging "should be fully protective even for the fastest acting toxicants."

3.2.1.5 Derivation of Chronic Water Criterion for Estuarine/Marine Water

The 1985 Guidelines recommend that data from a minimum of eight families are needed to calculate an estuarine/marine FCV or sufficient data to transform an estuarine/marine FAV to a CCC through the use of an ACR. Insufficient data exist to fulfill all eight of the taxonomic MDR groups. There are only two quantitatively acceptable GMCVs for estuarine/marine genera and no estuarine/marine ACRs. Consequently, the EPA could not derive an estuarine/marine chronic criterion (see Appendix L for derivation of acute estuarine/marine benchmarks).

3.2.2 Derivation of Tissue-Based Criteria

Chronic PFOA toxicity data with measured tissue concentrations were limited. There were no aquatic life tissue-based toxicity studies considered acceptable for quantitative use. Therefore, there were not sufficient data to derive chronic tissue criteria using a sensitivity distribution approach. Instead, the water column chronic criterion was transformed into corresponding tissue-based criteria through a BAF approach, as outlined in Section 2.11.3. The chronic PFOA tissue-based criteria were derived by translating the chronic freshwater column criterion (i.e., 0.10 mg/L; see equation *1* in Section 3.2.1.3) into corresponding tissue-based criteria. The resulting tissue criterion corresponded to the tissue type from the 20th percentile BAF used in the equation (see Section 2.11.3). The 20th centile BAF was used to derive tissue-

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based criteria as a relatively conservative BAF estimate in order to protect species across taxa and across water bodies with variable bioaccumulation conditions. That is, use of the 20th centile BAF protects species and conditions where the bioaccumulation of PFOA and resultant tissue-based exposures is relatively low as well as those conditions with the bioaccumulation potential of PFOA is relatively high.

3.2.2.1 PFOA Bioaccumulation Factors (BAFs)

Section 2.11.3.1 above summarizes the literature search, calculation, and evaluation of the PFOA BAFs for aquatic life. These BAFs were compiled by and can be found in Burkhard (2021). BAFs used in the derivation of the PFOA tissue-based criteria consisted of two or more water and organism samples each and were collected within one year and 2 km distance of one another. In order to derive more protective tissue criteria across and within water bodies, the distributions of BAFs used to derive tissue criteria were based on the lowest species-level BAF reported at a site. When more than one BAF was available for the same species within the same waterbody, the species-level BAF was calculated as the geometric mean of all BAFs for that species at that site. Summary statistics for the PFOA BAFs used in derivation of the tissue-based criteria are presented in Table 3-11 and individual BAFs are provided in Appendix O.

Table 3-11. Summary Statistics for PFOA BAFs in Invertebrate Tissues and Various Fish Tissues[1].

Category	n	Geometric Mean BAF (L/kg-wet weight)	Median BAF (L/kg-wet weight)	20th Centile BAF (L/kg-wet weight)	Minimum (L/kg-wet weight)	Maximum (L/kg-wet weight)
Invertebrates	21	105.3	84.8	11.76	0.985	9,680
Fish Muscle	17	7.152	7.94	1.331	0.292	656
Fish Whole Body	25	198.6	219	64.93	1	16,273

[1] Based on the lowest species-level BAF measured at a site (i.e., when two or more BAFs were available for the same species at the same site, the species-level geometric mean BAF was calculated, and the lowest species-level BAF was used to represent that site).

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3.2.2.2 Deriving Tissue-Based Criteria from the Chronic Water Column Criterion

Invertebrate whole-body, fish whole-body, and fish muscle tissue criteria were derived separately by multiplying the freshwater chronic water column criterion by the respective 20th centile of the distribution of BAFs described in Section 3.2.2.1, using Equation *1* from Section 2.11.3. The use of a 20th centile BAF results in more protective tissue criteria than those derived from a BAF based on a central tendency measure (e.g., geometric mean or median), which would only be protective on average or approximately 50% of the time.

The invertebrate whole-body tissue chronic criterion was calculated by multiplying the 20th centile BAF of 11.76 L/kg wet weight and the PFOA freshwater chronic water criterion of 0.10 mg/L, which resulted in a chronic invertebrate whole-body tissue criterion of 1.18 mg/kg wet weight. The fish muscle tissue chronic criterion was calculated by multiplying the 20th centile BAF of 1.331 L/kg wet weight and the PFOA freshwater chronic water criterion of 0.10 mg/L, which resulted in a chronic fish muscle-based chronic criterion of 0.133 mg/kg wet weight. The fish whole-body tissue chronic criterion was calculated by multiplying the 20th centile BAF of 64.93 L/kg wet weight and the PFOA freshwater chronic water criterion of 0.10 mg/L, which resulted in a chronic fish whole-body tissue criterion of 6.49 mg/kg wet weight. The chronic tissue-based criteria are expected to be protective of 95% of freshwater genera potentially exposed to PFOA under long-term exposures if the tissue-based criteria magnitudes are not exceeded.

The EPA acknowledges that there is uncertainty in deriving protective tissue criteria magnitudes by transforming the chronic water column criterion (which was based on tests that only added PFOA to the water column) into tissue concentrations through field-measured bioaccumulation data of paired water and tissue concentrations in waterbodies. Nevertheless, the

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chronic water column criterion is based on chronic toxicity tests that fed test organisms. In these tests, PFOA can directly affect species based on direct water column exposure and/or sorb to added food that is consumed by test organisms before eliciting chronic effects from dietary exposure. Therefore, the chronic water column criterion magnitude accounts for water column-based and, to a possible lesser extent, dietary-based effects, while the field-based BAFs account for water column-based and dietary-based PFOA exposure in tissues.

The tissue criteria will provide information to states, Tribes, and stakeholders on potential effects to aquatic organisms based on aquatic tissue monitoring data. No available quantitatively acceptable data on the effects of dietary exposures to aquatic species were available, thus the EPA elected to develop protective values for aquatic organism tissues based on the observed relationship between water column concentrations and tissue concentrations and observed PFOA toxicity in chronic tests where PFOA was only added directly to the water column.

3.2.2.3 Deriving Protective Duration and Exceedance Frequencies for the Tissue-based Chronic Criteria

3.2.2.3.1 Duration: Chronic Tissue-Based Criteria

PFOA concentrations in tissues are generally expected to change only gradually over time in response to environmental fluctuations. The chronic tissue-based criteria averaging periods, or duration components, were therefore specified as instantaneous, because tissue data provide point, or instantaneous, measurements that reflect integrative accumulation of PFOA over time and space in population(s) at a given site.

3.2.2.3.2 Frequency: Chronic Tissue-Based Criteria

The PFOA tissue-based criteria frequencies are set as “not to be exceeded” to ensure protection of aquatic life populations. This frequency accounts for the many variables influencing ecological recovery and the uncertainty in PFAS-specific ecological recovery time due to the lack of case studies on recovery rates following elevated PFOA concentrations in

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aquatic biota. Ecological recovery times following chemical disturbances are context-dependent, being largely dependent on: (1) biological variables such as the presence of nearby source populations or generational time of taxa affected, (2) physical variables such as lentic and lotic habitat considerations where recovery rates in lentic systems may be slower than lotic systems where the pollutant may be quickly flushed downstream, and (3) chemical variables such as the persistence of a chemical and potential for residual effects.

PFOA-specific case studies are unavailable to directly inform rates of ecological recovery following elevated concentrations in fish and aquatic invertebrates. Metals and other chemical pollutants may be retained in the sediment and biota, where they can result in residual effects over time that further delay recovery. Few studies are available concerning PFOA elimination or depuration half-life in aquatic animals, however the data that exist indicate a short half-life. For example, the elimination half-life for PFOA in adult rainbow trout exposed to PFOS for 28 days via the diet followed by 28 days depuration was estimated to be seven days in muscle tissue (Falk et al. 2015), while the terminal half-life in rainbow trout receiving a one-time intra-arterial injection of PFOA was 12.6 days (Consoer et al. 2014). Additionally, the depuration half-life in northern leopard frog tadpoles via 40-day aqueous exposure to 0.10 mg/L PFOA was estimated to be only 2.6 days (Hoover et al. 2017). It's unclear whether PFOA half-life in aquatic organism tissues is the mechanistic result of rapid depuration via gills or an artifact of these measurements that are taken during relatively short testing times (e.g., 28 days) where a steady state condition between PFOA and water and tissues has not occurred. Long-term uptake and subsequent excretion rates of PFOA have been extensively studied in humans relative to aquatic life. For example, Li et al. (2017) reported a median PFOA half-life of 2.7 years in human serum

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following exposure to PFOA in drinking water, which authors stated was in the range of previously published estimates.

Due to chemical retention in both the environment and tissues, ecosystems impacted by discharges of bioaccumulative pollutants (such as selenium) recover from chemical disturbances at relatively slow rates. For example, Lemly (1997) concluded that although water quality in Belews Lake, North Carolina, (a freshwater reservoir) had recovered significantly in the decade since selenium discharges were halted in 1985, the threat to fish had not been eliminated. The effects of selenium that led to severe reproductive failure and deformities in fish, were still measurable (as fish deformities) in 1992 (seven years later) and in 1996 (ten years later). Lemly (1997, pg. 280) estimated based on these data that "*the timeframe necessary for complete recovery from selenium contamination from freshwater reservoirs can be on the order of decades.*"

Beyond bioaccumulation, chemical-specific considerations such as degradation vs. persistence may also provide a mechanism influencing ecological recovery rates. The persistence of PFOA has been attributed to the strong C-F bond, with no known biodegradation or abiotic degradation processes for PFOA (see Section 2.3). Similarly, metals do not degrade and may persist in aquatic systems following elevated discharge. The persistence of metals may explain why metals had the second longest median recovery time of any disturbance described in a systematic review of aquatic ecosystem recovery (Gergs et al. 2016). Gergs et al. (2016) showed recovery times following metal disturbances ranged from roughly six months to eight years (median recovery time = one year; 75^{th} centile ~ three years; n = 20). Unlike metals, however, PFOA is not naturally-occurring and aquatic organisms possess no evolved detoxification mechanisms to aid in recovery at the individual level. Furthermore, the degradation of other

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PFAS into PFOA may represent a continued source of PFOA in aquatic systems that further delays recovery.

The persistence and bioaccumulative/human-made nature of PFOA in aquatic systems, in combination with the documented recovery times of pollutants with similar chemical attributes (Lemly 1997; Gergs et al. 2016; Mebane 2022), suggests aquatic systems may recover from PFOA tissue criteria exceedances on the order of five to 10 years. However, recovery times could be longer if the source of PFOA and other PFAS that degrade into PFOA is not removed. There is a large amount of uncertainty in specifying a time interval associated with ecological recovery from PFOA tissue criteria exceedances given the lack of PFOA-specific examples of ecological recovery and the many situational-specific factors influencing recovery (Mebane et al. 2020). For example, the lack of PFOA degradation in the environment, and the fact that other PFAS in the environment can degrade into PFOA could act as ongoing PFOA sources that further delay recovery. Given these uncertainties, the PFOA tissue-based criteria frequencies are set as "not to be exceeded" to ensure protection of aquatic life populations. Moreover, if tissue-based criteria were exceeded, then PFOA has likely built up through the food web and PFOA source reservoirs are likely to exist, representing a broad level of PFOA contamination throughout the aquatic ecosystem.

The "not to exceed" frequency components of the tissue-based criteria do not suggest aquatic ecosystems could never recover from PFOA tissue-based criteria exceedance, under the right conditions. For example, ecological recovery from such an exceedance could begin once PFOA sources are decreased or eliminated, PFOA source reservoirs existing within the ecosystem (including other PFAS that degrade into PFOA), became permanently isolated from possible uptake by the ecosystem (e.g., long-term burial with no benthic disturbances), and

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unaffected organisms were able to repopulate the system through immigration and/or reproductive events producing generations that are no longer exposed to PFOA.

Evaluation of PFOA concentrations in tissues would likely include evaluating the central tendency of tissue concentrations of samples for a given species, collected at a specific site and time. Considering a measure of central tendency to assess tissue-based exposures in the field relative to the criteria is appropriate because the criteria are intended to protect aquatic life populations.

3.3 Summary of Freshwater PFOA Aquatic Life Criteria and the Acute Estuarine/Marine Benchmark

This Aquatic Life Ambient Water Quality Criteria for PFOA document includes water column based acute and chronic criteria and tissue-based criteria for fresh waters. Acute and chronic water column criteria magnitudes for estuarine/marine waters could not be derived at this time due to data limitations; however, an acute estuarine/marine benchmark is provided for states/authorized tribal consideration (see Appendix L). The freshwater acute water column-based criterion magnitude is 3.1 mg/L, and the chronic water column-based chronic criterion magnitude is 0.10 mg/L. The fish whole-body tissue criterion magnitude is 6.49 mg/kg wet weight, the fish muscle tissue criterion magnitude is 0.133 mg/kg wet weight and the invertebrate whole-body tissue criterion magnitude is 1.18 mg/kg wet weight (Table 3-12). The assessment of the available data for fish, invertebrates, amphibians, and plants indicates these criteria will protect the freshwater aquatic community.

The freshwater chronic water column criterion is more strongly supported than the chronic tissue-based criteria because the water column-based chronic criterion was derived directly from the results of empirical toxicity tests. The chronic tissue-based criteria are relatively less certain because they were derived by transforming the chronic water column

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criterion into tissue concentrations through BAFs, with any uncertainty and variability in the underlying BAFs then propagating into the resultant tissue-based criteria magnitudes.

Table 3-12. Recommended Perfluorooctanoic acid (PFOA) Ambient Water Quality Criteria for the Protection of Aquatic Life in Freshwater.

Type/Media	Acute Water Column (CMC)[1,4]	Chronic Water Column (CCC)[1,5]	Invertebrate Whole-Body[1,2]	Fish Whole-Body[1,2]	Fish Muscle[1,2]
Magnitude	3.1 mg/L	0.10 mg/L	1.18 mg/kg ww	6.49 mg/kg ww	0.133 mg/kg ww
Duration	One-hour average	Four-day average	Instantaneous[3]		
Frequency	Not to be exceeded more than once in three years on average	Not to be exceeded more than once in three years on average	Not to be exceeded[6]		

[1] All five of these water column and tissue criteria are intended to be independently applicable and no one criterion takes primacy. All of the above recommended criteria (acute and chronic water column and tissue criteria) are intended to be protective of aquatic life. These criteria are applicable throughout the year.
[2] Tissue criteria derived from the chronic water column concentration (CCC) with the use of bioaccumulation factors and are expressed as wet weight (ww) concentrations.
[3] Tissue data provide instantaneous point measurements that reflect integrative accumulation of PFOA over time and space in aquatic life population(s) at a given site.
[4] Criterion Maximum Concentration; applicable throughout the water column.
[5] Criterion Continuous Concentration; applicable throughout the water column.
[6] PFOA chronic freshwater tissue-based criteria should not be exceeded, based on measured tissue concentrations representing the central tendency of samples collected at a given site and time.

This Aquatic Life Ambient Water Quality Criteria and Acute Saltwater Benchmark for PFOA document includes a water column based acute benchmark for estuarine/marine waters. The derivation of this benchmark is described in detail in Appendix L. The saltwater acute benchmark 7.0 mg/L (magnitude component), expressed as a one-hour average (duration component), that is not to be exceeded more than once in three years on average (Table 3-13).

Aquatic life benchmarks, developed under 304(a)(2) of the CWA, are informational values that the EPA generates when there are limited high quality toxicity data available and data gaps exist for several aquatic organism families. The EPA develops aquatic life benchmarks to provide information that states and Tribes may consider in their water quality protection programs. In developing aquatic life benchmarks, data gaps may be filled using new approach

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methods (NAMs), such as computer-based toxicity estimation tools (e.g., the EPA's Web-ICE) or other new approach methods intended to reduce reliance on additional animal testing (https://www.epa.gov/chemical-research/epa-new-approach-methods-work-plan-reducing-use-vertebrate-animals-chemical), including the use of read-across estimates based on other chemicals with similar structures. The EPA's aquatic life benchmark values are not regulatory, nor do they automatically become part of a state's water quality standards.

Table 3-13. Acute Perfluorooctanoic Acid (PFOA) Benchmark for the Protection of Aquatic Life in Estuarine/Marine Waters.

Type/Media	Acute Water Column Benchmark
Magnitude	7.0 mg/L
Duration	One hour average
Frequency	Not to be exceeded more than once in three years on average

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4 EFFECTS CHARACTERIZATION FOR AQUATIC LIFE

This section describes supporting information for the derivation of these PFOA aquatic life criteria. Specifically, this chapter: (1) assesses the influence of including non-North American resident species in criteria derivation (Section 4.1), (2) considers relatively sensitive toxicity data from qualitatively acceptable studies that were used as supporting information (Section 4.2), (3) describes the available PFOA ACRs (Section 4.3), (4) compares the tissue-based criteria magnitudes to the empirical tissue-based effect concentrations available (Section 4.4), (5) evaluates aquatic plant tolerance to PFOA exposures (Section 4.5), and (6) evaluates the tolerance of threatened and endangered species to PFOA exposures (Section 4.6).

4.1 Influence of Using Non-North American Resident Species on PFOA Criteria

The EPA conducted an additional analysis of the water column-based criteria by limiting the toxicity datasets to organisms that are residents to the conterminous United States that have established populations to evaluate the influence of including non-North American resident species in criteria derivation.

4.1.1 Freshwater Acute Water Criterion with Resident Organisms

Three species, the green neon shrimp (*Neocaridina denticulata*), the cladoceran (*Daphnia carinata*) and the planarian (*Dugesia japonica*), are not resident or reproducing in the conterminous United States, while it remains uncertain if there are established resident zebrafish (*Danio rerio*) populations in the conterminous United States (U.S. FWS 2018). Nevertheless, zebrafish are common ecotoxicity test organisms that serve as taxonomic surrogates for untested fish species and are also considered in effects assessments conducted under the Toxic Substances Control Act (TSCA) and the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Removal of the green neon shrimp, *Daphnia carinata*, and *Dugesia japonica*, while retaining

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zebrafish truncated the freshwater acute dataset to 24 species representing 17 genera (Table 4-1). The freshwater acute dataset truncated to North American resident species only was missing one MDR group (a benthic crustacean). The *Daphnia carinata* SMAV was the third most sensitive; however, its removal along with the removal of the other non-North American resident species had limited impact on the exploratory FAV and subsequent acute water column concentration (Table 4-2). The acute water column concentration based on North American resident species only, including zebrafish, was 2.6 mg/L PFOA, which was slightly lower than the chronic criteria CMC (CMC of 3.1 mg/L) based on both North American and non-North American species. Had zebrafish also been removed from the exploratory FAV and acute water column concentration based on North American resident species only, the four most sensitive genera would have remained the same, but the number of genera in the dataset would have decreased by one, which causes the resulting exploratory FAV (i.e., 4.793 mg/L) and acute water column concentration (i.e., 2.4 mg/L) to decrease slightly. The exploratory FAV and CMC based on North American resident species only with zebrafish excluded were both similar to the FAV and CMC described in Section 3.2.1.1.

Table 4-1. Ranked Freshwater Genus Mean Acute Values with North American Resident Organisms.

Rank[a]	GMAV (mg/L PFOA)	MDR Group[c]	Genus	Species	SMAV[b] (mg/L PFOA)
1	8.885	D	*Moina*	Cladoceran, *Moina macrocopa*	166.3
				Cladoceran, *Moina micrura*	0.4747
2	13.05	F	*Neocloeon*	Mayfly, *Neocloeon triangulifer*	13.05
3	93.17	D	*Chydorus*	Cladoceran, *Chydorus sphaericus*	93.17
4	150.0	H	*Brachionus*	Rotifer, *Brachionus calyciflorus*	150.0

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Rank[a]	GMAV (mg/L PFOA)	MDR Group[c]	Genus	Species	SMAV[b] (mg/L PFOA)
5	161.0	G	*Ligumia*	Black sandshell, *Ligumia recta*	161.0
6	164.4	G	*Lampsilis*	Fatmucket, *Lampsilis siliquoidea*	164.4
7	208.7	D	*Daphnia*	Cladoceran, *Daphnia magna*	213.9
				Cladoceran, *Daphnia pulicaria*	203.7
8	377.0	C	*Xenopus*	Frog, *Xenopus sp.*	377.0
9	450.4	B	*Danio*	Zebrafish, *Danio rerio*	450.4
10	593.6	B	*Pimephales*	Fathead minnow, *Pimephales promelas*	593.6
11	646.2	C	*Hyla*	Gray treefrog, *Hyla versicolor*	646.2
12	664.0	B	*Lepomis*	Bluegill, *Lepomis macrochirus*	664.0
13	681.1	G	*Physella*	Bladder snail, *Physella acuta*	681.1
14	689.4	C	*Ambystoma*	Jefferson salamander, *Ambystoma jeffersonianum*	1,070
				Small-mouthed salamander, *Ambystoma texanum*	407.3
				Eastern tiger salamander, *Ambystoma tigrinum*	752.0
15	793.9	C	*Anaxyrus*	American toad, *Anaxyrus americanus*	793.9
16	951.5	C	*Lithobates*	American bullfrog, *Lithobates catesbeiana*	1,020
				Green frog, *Lithobates clamitans*	1,070
				Northern leopard frog, *Lithobates pipiens*	751.7
				Wood frog, *Lithobates sylvatica*	999
17	4,001	A	*Oncorhynchus*	Rainbow trout, *Oncorhynchus mykiss*	4,001

a Ranked from the most sensitive to the most tolerant based on Genus Mean Acute Value.
b From Appendix A: Acceptable Freshwater Acute PFOA Toxicity Studies.
c MDR Groups identified in Footnote C of Table 3-3.

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Table 4-2. Freshwater Exploratory Final Acute Value and Acute Water Column Concentration with North American Resident Organisms (zebrafish included).

Calculated Freshwater FAV based on 4 lowest values: Total Number of GMAVs in Data Set = 17						
Rank	**Genus**	**GMAV (mg/L)**	**ln(GMAV)**	**ln(GMAV)^2**	**P=R/(N+1)**	**sqrt(P)**
1	*Moina*	8.885	2.18	4.77	0.059	0.243
2	*Neocloeon*	13.05	2.57	6.60	0.118	0.343
3	*Chydorus*	93.17	4.53	20.56	0.176	0.420
4	*Brachionus*	150.0	5.01	25.11	0.235	0.485
		Σ (Sum):	**14.30**	**57.04**	**0.59**	**1.49**

S^2 =	181.32	S = slope
L =	-1.444	L = X-axis intercept
A =	1.567	A = lnFAV
FAV =	4.793	P = cumulative probability
CMC =	**2.4 mg/L PFOA** (rounded to two significant figures)	

4.1.2 Freshwater Chronic Water Criterion with North American Resident Organisms

Three species, the cladoceran (*Daphnia carinata*), the rare minnow (*Gobiocypris rarus*) and the medaka (*Oryzias latipes*), are not resident or reproducing in the conterminous United States. Removal of these species truncated the freshwater chronic dataset to ten species representing ten genera (Table 4-3). The freshwater chronic dataset truncated to North American resident species fulfilled all MDR groups. Calculating the FCV based on the chronic GSD comprised of North American resident species only resulted in an exploratory FCV of 0.05857 mg/L and a chronic water column criterion of 0.059 mg/L (rounded to two significant figures; Table 4-4). The exploratory chronic water column concentration CCC (0.059 mg/L PFOA) based on North American species only was about half of the CCC based on North American and non-North American species (0.10 mg/L PFOA) and is lower than all of the quantitatively-acceptable GMCVs (Table 3-7). The reduction in the exploratory FCV based on North American resident species only was primarily an artifact of the FCV calculation procedure rather than inclusion of more sensitive toxicity data. That is, the reduced "*n*" used in the exploratory criterion calculation

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and the increase in the *Daphnid* GMCV (which was the result of excluding *D. carinata* SMCV), increased the slope of the GSD which decreased the extrapolated FCV. The EPA retained the chronic water column criterion which includes North American and non-North American species, with a magnitude of 0.10 mg/L, to ensure the fullest, high-quality dataset available is used to represent the thousands of untested aquatic taxa present in U.S. ecosystems when deriving the chronic criterion for PFOA.

Table 4-3. Ranked Freshwater Genus Mean Chronic Values with Resident Organisms.

Rank[a]	GMCV[b] (mg/L PFOA)	MDR Group[c,d]	Genus	Species	SMCV[b] (mg/L PFOA)
1	0.147	E	*Hyalella*	Amphipod, *Hyalella azteca*	0.147
2	0.288	C	*Lithobates*	American bullfrog, *Lithobates catesbeiana*	0.288
3	0.7647	G	*Brachionus*	Rotifer, *Brachionus calyciflorus*	0.7647
4	2.194	D	*Moina*	Cladoceran, *Moina macrocopa*	2.194
5	>3.085	H	*Neocloeon*	Mayfly, *Neocloeon triangulifer*	>3.085
6	4.317	D	*Daphnia*	Cladoceran, *Daphnia magna*	4.317
7	23.56	D	*Ceriodaphnia*	Cladoceran, *Ceriodaphnia dubia*	23.56
8	>40	A	*Oncorhynchus*	Rainbow trout, *Oncorhynchus mykiss*	>40
9	>76	B	*Pimephales*	Fathead minnow, *Pimephales promelas*	>76
10	88.32	F	*Chironomus*	Midge, *Chironomus dilutus*	88.32

a Ranked from the most sensitive to the most resistant based on Genus Mean Chronic Value.
b From Appendix C: Acceptable Freshwater Chronic PFOA Toxicity Studies.
c MDR Groups identified in Footnote C of Table 3-3.

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Table 4-4. Freshwater Exploratory Final Chronic Value and Chronic Water Column Concentration with North American Resident Organisms.

Calculated Freshwater FCV based on 4 lowest values: Total Number of GMCVs in Data Set = 10						
Rank	**Genus**	**GMCV (mg/L)**	**ln(GMCV)**	**ln(GMCV)^2**	**P=R/(N+1)**	**sqrt(P)**
1	*Hyalella*	0.147	-1.917	3.676	0.091	0.302
2	*Lithobates*	0.288	-1.245	1.550	0.182	0.426
3	*Brachionus*	0.7647	-0.268	0.072	0.273	0.522
4	*Moina*	2.194	0.786	0.617	0.364	0.603
		Σ (Sum):	**-2.64**	**5.91**	**0.91**	**1.85**

S^2 =	82.45	S = slope
L =	-4.868	L = X-axis intercept
A =	-2.838	A = lnFCV
FCV =	0.05857	P = cumulative probability
CCC =	**0.059 mg/L PFOA** (rounded to two significant figures)	

4.2 Consideration of Relatively Sensitive Qualitatively Acceptable Water Column-Based Toxicity Data

A multitude of studies were identified as not meeting the EPA's data quality guidelines for inclusion in the criteria derivation; however, these studies were used qualitatively as supporting information to the PFOA criteria derived to protect aquatic life and provide additional evidence of the observed toxicity and effects of PFOA, including the relative sensitivities. Most of these studies produced relatively tolerant effect concentrations relative to the criteria and are listed in Appendix G. The key studies used qualitatively in the derivation of the PFOA criteria were identified as being from either relatively sensitive genera or relatively sensitive tests and are described below. That is, qualitatively acceptable data for tests with species among the four most sensitive genera that were used to derive the criteria magnitudes are discussed. Qualitatively acceptable tests with relevant exposure durations and apical effects that also observed effect concentrations less than or similar to (e.g., factor of two) the corresponding criteria magnitude are discussed. Qualitatively acceptable studies described below were separated by acute (Section 4.2.1) and chronic (Section 4.2.2) data and only included those

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studies that reported apical endpoints. The toxicity values summarized as part of this Effects Characterization were not used in any quantitative analyses or in the numerical derivation of the PFOA aquatic life criteria.

4.2.1 Consideration of Qualitatively Acceptable Acute Data

4.2.1.1 Qualitatively Acceptable Acute Data for Species Among the Four Most Sensitive Genera Used to Derive the Acute Water Column Criterion

4.2.1.1.1 Most acutely sensitive genus, Moina

There were no qualitatively acceptable acute tests for species within the genus, *Moina*.

4.2.1.1.2 Second most acutely sensitive genus, Neocloeon

There were no qualitatively acceptable acute tests for species within the genus, *Neocloeon*.

4.2.1.1.3 Third most acutely sensitive genus, Chydorus

There were no qualitatively acceptable acute tests for species within the genus, *Chydorus*.

4.2.1.1.4 Fourth most acutely sensitive genus, Daphnia

3M Co. (2000a) exposed *D. magna* to PFOA (CAS # 335-67-1) in a 48-hour static, unmeasured acute toxicity test that followed USEPA-TSCA Guideline 797.1300. The toxicant was part of the 3M production lot number 269 and was characterized as mixture of PFOA (96.5-100% of the compound) and C_6, C_7 and C_9 perfluoro homologue compounds (0-3.5% of the compound). The 48-hour reported EC_{50}, based on death/immobility, was 360 mg/L PFOA. This test was not acceptable for quantitative use because of possible mixture effects from other perfluoro homologue compounds in the test substance, the amount of isopropanol and missing exposure details, but was retained for qualitative use.

3M Co. (2000a) summarized four 48-hour static, unmeasured APFO (CAS # 3825-26-1) acute toxicity tests with the cladoceran, *Daphnia magna* and APFO. The toxicant was part of the 3M production lot number 37 and was characterized as a mixture of APFO (96.5-100% of the compound) and C_6, C_7 and C_9 perfluoro analogue compounds (0-3.5% of the compound). The

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48-hour EC_{50} determined from tests conducted in May 1982, based on death/immobility, was >1,000 mg/L APFO, while the EC_{50} for a subsequent test in June 1982 was reported to be 126 mg/L APFO. Possible mixture effects of other perfluoro analogue compounds, and the authors indication that the tests may have included food, did not make these tests acceptable for quantitative use and they were retained for qualitative use.

3M Co. (2000a) summarized a 48-hour static, unmeasured acute toxicity test with the cladoceran, *Daphnia magna* and APFO (CAS # 3825-26-1). The toxicant was part of the 3M production lot number 390 and was characterized as a mixture of APFO (78-93% of the compound) and C_5, C_6 and C_7 perfluoro analogue compounds (7-22% of the compound). The author-reported 48-hour EC_{50}, based on mortality, was 221 mg/L APFO. The possible mixture effects of APFO with other perfluoro analogue compounds in the test material and possible low (<80%) test substance purity did not make this test acceptable for quantitative use. This test was retained for qualitative use only.

3M Co. (2000a) summarized a 48-hour static, unmeasured acute toxicity test with the cladoceran, *Daphnia magna* and APFO (CAS # 3825-26-1). The acute test followed USEPA-TSCA Guideline 797.1300 protocol. The toxicant was part of the 3M production lot number HOGE 205 and was not sufficiently characterized but was considered a mixture of APFO (30% of the compound) and water (80% of the compound). The author-reported 48-hour EC_{50}, based on mortality, was 1,200 mg/L test substance. The authors reported that the test substance was considered a mixture of APFO (with unreported purity) and other impurities, so the EC_{50} does not accurately reflect the toxicity of APFO and therefore the value was not acceptable for quantitative use but was retained for qualitative use.

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3M Co. (2000a) summarized a 48-hour static, unmeasured acute toxicity test with the cladoceran, *Daphnia magna* and APFO (CAS # 3825-26-1). The acute test followed test guidance from OECD 202. The toxicant was part of the 3M production lot number 2327 and was characterized as a mixture of APFO (<45% of the compound), water (50% of the compound), inert perfluorinated compound (<3% of test substance), and C_5 and C_7 perfluoro analogue compounds (1-2% of the compound). The author-reported 48-hour EC_{50}, based on death/immobility, was 584 mg/L test substance. Because of the possible mixture effects of the inert perfluorinated compounds, other perfluoro analogue compounds and unreported test substance purity, the test was not acceptable for quantitative use but was retained for qualitative use.

3M Co. (2000a) summarized a 21-day static-renewal, unmeasured chronic toxicity test with the cladoceran, *Daphnia magna,* and APFO (CAS # 3825-26-1) and also briefly described a corresponding acute test with a reported 48-hour EC_{50} of 266 mg/L APFO. Very few details were provided about the acute test methodology. The test compound was assumed to be that of the chronic test, where the toxicant was part of the 3M production lot number 37 and was characterized as a mixture of APFO (96.5-100% of the compound) and C_6, C_7 and C_9 perfluoro analogue compounds (0-3.5% of the compound). The 48-hour EC_{50} from this test was not used quantitatively because of missing study details and the possible presence of additional PFAS, but the study was retained for qualitative use.

Overall, these *D. magna* acute effect concentrations were all greater than the FAV (i.e., 6.237 mg/L) and the acute criterion magnitude (i.e., 3.1 mg/L). These additional data suggest the *Daphnia* GMAV (i.e., 142.8 mg/L) used to derive the acute criterion was sufficiently protective.

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4.2.1.2 Consideration of Relatively Sensitive Freshwater Tests based on Qualitatively Acceptable Data

This section focuses on qualitatively acceptable tests that were most relevant to informing the appropriateness of the acute freshwater criterion. Specifically, those tests used to qualitatively inform the acute freshwater criterion magnitude were identified as most relevant if they met all parameters listed below:

1. reported effect concentrations that were less than or similar to (e.g., factor of two) the acute criterion magnitude;
2. evaluated an animal species;
3. conducted the test for a relevant acute exposure duration (e.g., ~48 hours to ~96 hours);
4. evaluated apical effects (i.e., acute mortality/inhibition), and;
5. not already discussed in the previous section (i.e., not a species discussed among the four most sensitive genera).

The toxicity values summarized below were not used quantitatively to derive the acute PFOA criterion. Results of each individual study (as well as the rationale why a study was not quantitatively acceptable) were considered relative to the acute criterion magnitude to ensure the acute PFOA criterion was not underprotective and to provide additional supporting evidence of the potential toxicity of PFOA to aquatic organisms.

4.2.1.2.1 Genus: Danio (zebrafish)

Truong et al. (2014) evaluated the sub-chronic effects of 1,060 compounds (U.S. EPA ToxCast phase 1 and 2) on zebrafish, *Danio rerio*, through the use of high-throughput characterization of multidimensional *in vivo* effects. The effects of APFO and PFOA on mortality, growth, behavior, morphology, histology and physiology were observed until 120 hours post fertilization (hpf) (114-hour exposure duration) with the water quality conditions not reported. The most sensitive endpoint was mortality with a reported LOEC of 0.02759 mg/L APFO. There were no effects of PFOA on mortality for zebrafish embryos with a reported NOEC of 26.50 mg/L PFOA. This test was not used quantitatively and retained for qualitative

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use only because the exposure durations were too long for an acute test and too short for a chronic test.

Han et al. (2021) evaluated the bioconcentration factors and phenotypic toxicities of 74 PFAS in zebrafish after five days of exposure. Toxicity tests followed OECD test guidance with minor modifications. Embryos (64-cell stage) were exposed to one measured PFAS concentration or DMSO solvent controls with solutions renewed daily. At test termination no mortality effects were observed at 3.94 µM PFOA (1.631 mg/L) and 3.67 µM APFO (1.582 mg/L). This test was not used quantitatively and retained for qualitative use only because the exposure durations were too long for an acute test and too short for a chronic test with no effects observed.

Rericha et al. (2021) conducted a 114-hour static unmeasured PFOA toxicity test with the zebrafish, *Danio rerio.* The authors reported a 114-hour mortality NOEC of 0.60 µM, or 0.2484 mg/L PFOA, based on a molecular weight of 414.07 g/mol. This test was not acceptable for quantitative use as the exposure duration was too long to be an acute test and too short to be a chronic test. Additionally, the authors only tested one exposure concentration that produced a relatively low NOEC. Although relatively low, the NOEC of 0.2484 mg/L does not suggest *D. rerio* early life stages are sensitive to sub-chronic PFOA exposures.

Haimbaugh et al. (2022) evaluated the acute toxic effects of low-level (≤700 ng/L) PFOA on zebrafish from zero to five days post fertilization. Unmeasured test concentrations (7, 70, or 700 ng/L PFOA) were renewed daily. At test termination, the highest test concentration (700 ng/L or 0.0007 mg/L) had no effects on mortality or abnormal development. This test was not used quantitatively and retained for qualitative use only because the exposure durations were too long for an acute test and too short for a chronic test with no effects observed.

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Yu et al. (2022) evaluated the sub-chronic effects of PFOA on embryonic *Danio rerio*. Exposure to PFOA concentrations up to 0.100 mg/L had no effect on growth/length, mortality/hatch, or survival of larvae. The 70-hour growth, mortality, and hatch NOECs of 0.100 mg/L PFOA were not acceptable for quantitative use because of the short exposure duration, especially in the context of other available tests for this species that were of a sufficient exposure duration. Yu et al. (2022) also reported that heartbeat (at 48 hpf) and locomotor behavior (at 120 hpf) were significantly decreased by PFOA at 0.025 mg/L; however, these effects did not translate to effects on growth, mortality, or hatch at nominal test concentrations that were four times greater.

Liu et al. (2023b) evaluated the acute effects of PFOA on zebrafish embryos (5 hpf) exposed to one of five test concentrations (1, 2, 5, 10, and 20 mg/L). Test concentrations were renewed daily and test concentrations were measured with hatching rate, mortality and deformity recorded at test termination (96 hpf). The author reported that the 91-hour LC_{50} was approximately 2 mg/L PFOA. This test was not acceptable for quantitative use because the exposure duration was not a 96-hour exposure duration and other quantitatively acceptable data suggests the relatively-sensitive LC_{50} reported here (~2 mg/L) is an outlier, with the *Danio* SMAV being 450.4 mg/L.

Wang et al. (2023) evaluated the acute effects of PFOA on zebrafish embryos (2 hpf) exposed to 5 or 500 µg/L up to 120 hours post fertilization. Test concentrations were renewed daily and PFOA concentrations were measured using high-performance liquid chromatography-tandem mass spectrometry. At 96 hpf, there were no effects observed on mortality or abnormal development at 491.5 µg/L (0.4915 mg/L PFOA). Since this exposure was shorter than the

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recommended 96 hour exposure (only 94 hours) and no effects were observed, the test was only used qualitatively.

Quantitatively acceptable acute tests used to calculate the SMAV (Ye et al. 2007; Hagenaars et al. 2011; Zhao et al. 2016; Godfrey et al. 2017a; Stengel et al. 2017, 2018) suggested *D. rerio* is relatively tolerant to acute PFOA exposures with a *D. rerio* SMAV of 450.4 mg/L. Another quantitatively acceptable acute test with the zebrafish was conducted by Corrales et al. (2017). However, the LC_{50} value from this test was excluded from the SMAV calculation because a comparative assessment between this LC_{50} value and the other seven quantitatively-acceptable values available indicated the LC_{50} was an outlier, about 5 times lower than the other lowest LC_{50} value. It is expected that *D. rerio* will be tolerant to acute PFOA exposures.

4.2.2 Consideration of Qualitatively Acceptable Chronic Data

4.2.2.1 Qualitatively Acceptable Chronic Data for Species Among the Four Most Sensitive Genera Used to Derive the Chronic Water Column Criterion

4.2.2.1.1 Most chronically sensitive genus, Hyalella

Kadlec et al. (2024) tested the sub-chronic toxicity of PFOA (96-99% purity) to *Hyalella azteca* for seven days in a measured, static-renewal experiment. Testing protocols followed ASTM methodologies (ASTM 2002) with a shortened exposure period. The test was conducted with a 0.5x dilution series of measured PFOA concentrations, with four replicates of each concentration, and ~10 organisms per replicate (note: some replicates were overstocked and included 11 test organisms). Mean test concentrations were 0.53 (control), 5.3, 11, 21, 41 and 83 mg/L. Amphipods were placed in 100 mL glass beakers with two holes (covered by stainless-steel mesh) on opposite sides and filed with 60 mL of test solution. Beakers also included 2.5 mL of silica sand substrate to fully cover the bottoms of each chamber and each test chamber was renewed daily. Little to no mortality was observed in any treatment with survival ranging from

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98-100% at test termination. The author reported EC_{20} for biomass was 5.0 mg/L. The EPA did not recalculate an EC_{10} from this study since the exposure duration was too short for a chronic exposure. However, this value is much larger than the 42-day exposure (Bartlett et al. 2021) with an EPA-calculated EC_{10}, based on reproduction, of 0.147 mg/L PFOA.

4.2.2.1.2 Second most chronically sensitive genus, Lithobates

Hoover et al. (2017) tested PFOA (96% purity) toxicity on the northern leopard frog, *Lithobates pipiens* (formerly, *Rana pipiens*) in a chronic renewal toxicity test using measured PFOA treatment concentrations. The 40-day NOEC was ≥1.0 mg/L PFOA based on Gosner stage reached at test termination and snout-vent length. The test used water renewals rather than the required flow-through design for chronic ALC development; however, leopard frogs commonly do not tolerate flow-through test systems and the use of renewal system was appropriate for this study organism. Also, PFOA was detected in the control organisms at concentrations three orders of magnitude lower than any PFOA treatment groups, indicating the trace contamination in controls may not be considered a significant issue. The 40-day NOEC of ≥1.0 mg/L was classified as acceptable for quantitative use based on meeting data quality objectives; however, it was not used to derive the chronic criterion because the study showed no adverse effects at the highest treatment concentrations (i.e., 1.0 mg/L). Because the highest treatment group that showed no effects was a relatively low treatment concentration, including this NOEC value in the criterion calculation would have resulted in the criterion magnitude being influenced by the relatively low-test concentration selected by study investigators (that did not produce an adverse response), rather than a concentration-response relationship. Therefore, this test was not used quantitatively and was considered qualitatively acceptable for use in criterion derivation.

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Flynn et al. (2021) evaluated the chronic effects of PFOA (CAS # 335-67-1, ≥96% purity, purchased from Sigma-Aldrich) on northern leopard frogs, *Lithobates pipiens* (formerly *Rana pipiens*), via a 30-day sediment-spiked, static outdoor mesocosm study. At test termination (30 days) there was no effect on survival or growth (snout-vent length and weight). The 30-day NOEC, based on survival and growth, was 0.066 mg/L. However, on test-day five and at test termination all frogs in the spiked sediment mesocosm were less developed, based on Gosner stage, than the control mesocosms. The study was not acceptable for quantitative use because the test design was an outdoor spiked sediment mesocosm exposure with algal and zooplankton communities present and because of the relatively low NOEC value that did not quantitatively inform criteria derivation based on an exposure-response effect.

Flynn et al. (2022) evaluated the chronic effects of PFOA on the northern leopard frog [*Lithobates* (formerly *Rana*) *pipiens*] during a 30-day measured renewal exposure. Animals were monitored daily for mortality and abnormalities and sampled to quantify snout–vent length (SVL), body mass, and developmental stage. The SVL and body mass were used to calculate the scaled mass index (SMI). The NOEC for SVL was >1.376 mg/L and not used quantitatively because of a lack of a clear dose-response relationship and high variability in organismal responses despite a 10X dilution series. The NOEC and LOEC for growth (as mass) were 0.1251 and 1.376 mg/L resulting in a MATC of 0.4149 mg/L, which was also not used quantitatively for the same reasons. The effects of PFOA on SMI and Gosner stage were also not quantitatively acceptable because, while the highest test concentration was over 100X greater than the lowest, the response in the highest test concentration did not differ from control responses. Results of this test were retained for qualitative use.

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Overall, these three studies showed minimal effects to the northern leopard frog at the concentrations tested, while the indoor laboratory test by Flynn et al. (2019; used to derive the *Lithobates catesbeiana* SMCV) showed a ~7% reduction in SVL after 72-day exposures at 0.288 mg/L. Although Hoover et al. (2017) reported a NOEC of 1.0 mg/L, the tests only consisted of a 40-day exposure, which may not have been long enough to elicit the chronic effects to SVL observed by Flynn et al. (2019) after 72 days. For example, Flynn et al. (2019) reported effects of PFOS on *Lithobates catesbeiana* tadpole mass after 21, 42, 56, 63, 70, and 72 days, with PFOS dose-dependent effects only becoming apparent at 56 days. Results of Flynn et al. (2021) could not meaningfully inform the appropriateness of the chronic criterion or the *Lithobates catesbeiana* SMCV (0.288 mg/L) because Flynn et al. (2021) did not observe effects of PFOA on *Lithobates pipiens*, with a relatively low NOEC of 0.066 mg/L. Similarly, results of Flynn et al. (2022) did not suggest the *Lithobates* GMAV value was underprotective, as Flynn et al. (2022) did not observe obvious PFOA effects with increasing exposure concentrations.

4.2.2.1.3 Third most chronically sensitive genus, Daphnia

3M Co. (2000a) summarized a 21-day static-renewal, unmeasured chronic toxicity test with the cladoceran, *Daphnia magna*, and APFO (CAS # 3825-26-1). The toxicant was part of the 3M production lot number 37 and was characterized as a mixture of APFO (96.5-100% of the compound) and C_6, C_7 and C_9 perfluoro analogue compounds (0-3.5% of the compound). The test followed U.S. EPA (1982) and OECD (1997) test protocols. The 21-day NOEC and LOEC, based on reproduction and survival were 22 and 36 mg/L APFO, respectively with a corresponding MATC of 28.14 mg/L. This test was acceptable for qualitative use only because of the possible mixture effects of other perfluoro analogue compounds and missing exposure details but does not suggest *D. magna* will be chronically sensitive relative to the chronic freshwater criterion.

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Seyoum et al. (2020) evaluated the chronic effects of PFOA (CAS# 335-67-1, >99%, purchased from Sigma) on *Daphnia magna* neonates via a 21-day unmeasured, static-renewal study. The study authors did not report following any specific protocol. The 21-day reproductive (fecundity) LOEC of 0.4141 mg/L PFOA was reported by the study authors, where a ~38.25% reduction in mean number of daphnids relative to the control was observed. The EPA was unable to fit a model with significant parameters to the reproduction-based concentration-response data due to a lack of clear concentration-dependent effects beyond the LOEC. The reproduction-based LOEC (i.e., 0.4141 mg/L) was selected as the chronic value from this test; however, it was not considered acceptable for quantitative use because chronic responses in this test did not display concentration-dependent effects beyond the LOEC despite a 25X increase in treatment concentrations. Moreover, additional EC_{10} values from other, quantitatively acceptable tests, were available to inform the chronic sensitivity of *Daphnia magna* in criteria derivation.

4.2.2.1.4 Fourth most chronically sensitive genus, Brachionus

The qualitatively acceptable chronic value for *Brachionus* from **Zhang et al. (2014b)** was discussed in greater detail in Section 3.1.1.3.4. Briefly, Zhang et al. (2014b) conducted a full life-cycle test using renewal conditions for approximately four days on the rotifer, *Brachionus calyciflorus*. Zhang et al. (2014b) reported several endpoints, including intrinsic rate of natural increase, which was selected as the primary endpoint for criterion derivation. Zhang et al. (2014b) also observed effects to resting egg production. Resting egg production is an ecologically important endpoint for this species because it represents the final result of sexual reproduction. NOEC and LOEC values were not reported for resting egg production, but 0.25 mg/L PFOA produced more than a 50% reduction in resting egg production. Based on the authors description of results in the text, it was assumed the *B. calyciflorus* four-day NOEC for resting egg production was 0.125 mg/L and the LOEC was 0.25 mg/L and the calculated MATC

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was 0.1768 mg/L, suggesting resting egg production may be a relatively sensitive endpoint. Because there was only one replicate (as implied by lack of error bars in Figure 1 of the publication, no clear description of replicates in the methods section, and no author-reported statistical analysis of this endpoint), resting egg production from this study was not considered quantitatively acceptable and was instead considered in a qualitative manner. Overall, effects to chronic apical endpoints for this genus, reported in this publication and Zhang et al. (2013a), generally appear as a threshold effect from 0.25 mg/L to 1.0 mg/L, providing support for the endpoint and effect level selected for quantitative use in criterion derivation (i.e., intrinsic rate of natural increase), and further suggests the chronic criterion magnitude is adequately protective of the genus, *Brachionus*.

4.2.2.2 Consideration of Relatively Sensitive Freshwater Tests based on Qualitatively Acceptable Data

This section focuses on qualitatively acceptable chronic tests that were most relevant to informing the appropriateness of the chronic freshwater criterion. Specifically, those tests used to qualitatively inform the chronic freshwater criterion magnitude were identified as most relevant if they met all parameters listed below:

1. reported effect concentrations that were less than or similar to (e.g., factor of two) the chronic freshwater criterion magnitude;
2. evaluated an animal species;
3. conducted the test for a non-acute exposure duration (e.g., greater than seven days);
4. evaluated apical effects (i.e., long-term survival, growth, and/or reproduction), and;
5. not already discussed in the previous section (i.e., not a species discussed among the four most sensitive genera).

The toxicity values summarized below were not used quantitatively to derive the chronic PFOA freshwater criterion. Results of each individual study (as well as the rationale why a study was not quantitatively acceptable) were considered relative to the chronic criterion magnitude to

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ensure the chronic PFOA criterion was not underprotective and to provide additional supporting evidence of the potential toxicity of PFOA to aquatic organisms.

4.2.2.2.1 Genus: Chironomus (midge)

Stefani et al. (2014) conducted a chronic (10 generation) test of PFOA with a midge, *Chironomus riparius*. The 10 generations (each approximately 20 to 28 days) were tested under static conditions. The NOEC for the study, based on effect on emergence, reproduction or sex ratio at the only concentration tested, was 0.0089 mg/L PFOA. **Marziali et al. (2019)** provides further analysis of the same chronic test conducted by Stefani et al. (2014; reported in Table G.1) by reporting measurements of alterative endpoints/responses. The LOEC based on developmental time, adult weight was 0.0098 mg/L (time-weighted average; NOEC <0.0098 mg/L). While Stefani et al. (2014) reported no effects across the chronic test, Marziali et al. (2019) reported effects to select generations. Overall, however, effects were sporadic with reductions in growth observed in several generations. There were no effects on "survival, development, or reproduction" and Marziali et al. (2019) concluded "no effects at population level (population growth rate) were proved, thus a toxicity risk in real ecosystems at the tested concentrations seems unlikely." The results from these studies were deemed not acceptable for quantitative use because of limited test concentrations assessed, and uncertainty pertaining to sediment characteristics, as well as poor control survival in four of the 10 generations.

Zhai et al. (2016) exposed *Chironomus plumosus* larvae to PFOA (perfluorooctanoic acid, obtained from Acros Organics, Morris Plains, NJ, 96% purity) spiked in sediment for 10.3 days. The sediment was collected from the upstream region of the Yongding River in Beijing, China. Sediments were physically mixed with a steel blender at 60 rpm for 24 hours in the darkness at room temperature. Then, 1 mL of PFOA methanol solution (20 mg/L) was added to obtain a concentration of 100 ng/g PFOA, and the sample was thoroughly mixed in a fume hood.

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When the methanol had evaporated, 300 mL of distilled water was added to each beaker. Finally, the beakers were sealed, kept in the darkness at 25℃, and aged for 60 days before test initiation. The midge larvae used in this study were collected from the uncontaminated upstream area of the Yangliuqing River in the outer suburbs of Tianjin, China. Male larvae in the third or fourth instars of similar size were chosen and placed in pure water to purify their guts for more than 48 hours in the laboratory. There were 20 larvae in each 500 mL beaker containing sediment and 300 mL of solution and three replicates per concentration (9.8 ng PFOA/g sediment) and control (pure water). The static measured exposure lasted 10 days without food supply and involved a 16:8 hour (light:dark) photoperiod at 25 ± 1℃. At the end of the experiment, the surviving larvae were counted. The 10-day mortality NOEC was 9.8 ng/g, the only concentration tested. The test was not acceptable for quantitative use because: (1) exposures were spiked sediments rather than water only, (2) test duration (~10 days) was sub-chronic, too long for an acute test and too short for a chronic test, and (3) no effects were observed at the highest concentration tested which produced a relatively low "> NOEC" value that did not provide information on the sensitivity of this species to PFOA at concentrations consistent with criteria magnitudes. Results of this test were retained for qualitative use.

Quantitatively acceptable midge data (McCarthy et al. 2021) were available to derive the chronic PFOA freshwater criterion and these chronic data further suggest *Chironomus* is relatively tolerant to chronic PFOA exposures.

4.2.2.2.2 Genus: Salmo (Atlantic salmon)

Spachmo and Arukwe (2012) exposed Atlantic salmon (*Salmo salar*) to PFOA (95% purity) in a 52-day flow-through test with unmeasured treatment concentrations. The 52-day growth NOEC and LOEC were 0.10 and >0.10 mg/L PFOA, respectively. These data were acceptable for quantitative use based on meeting data quality objectives; however, were not used

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in deriving the chronic criterion because the study only included one treatment group that showed no adverse effects. Because the one treatment group that showed no effects was a relatively low treatment concentration, including this NOEC value in the criterion calculation would have resulted in the criterion magnitude being strongly influenced by the low test concentration selected by study investigators (that did not produce an adverse response), rather than a concentration-response relationship.

Arukwe et al. (2013) exposed Atlantic salmon (*Salmo salar*) embryos to PFOA at 100 µg/L for 49 days. This test was not used quantitatively because of the lack of effects in the one treatment group tested. The 49-day growth-based NOEC of 0.1 mg/L PFOS was selected as the most sensitive and relevant endpoint. However, given there was only one treatment group and that the test concentration was a relatively low concentration (at 0.1 mg/L) compared to the other PFOA data, resulting in a > low value, this test was not informative enough for quantitative use in the derivation of the PFOA aquatic life criteria. Results of this test were retained for qualitative consideration.

4.2.2.2.3 Genus: Cyprinus (carp)

Petre et al. (2023) evaluated the bioconcentration and biotransformation of PFOA in common carp (*Cyprinus carpio*) through a 14-week exposure and 3-week depuration period. Carp (30-40 g) were exposed to one of two PFOA treatments (10 and 100 µg/L) in a static renewal measured experiment with solutions renewed every 48 hours. After 14 weeks, the fish were visually analyzed, measured, and weighed. No mortalities or visible physiological were observed in any treatment. Therefore, the 14-week NOEC, based on mortality, weight and length, was >92.1 µg/L (>0.0921 mg/L). The test not acceptable for quantitative use because the chronic value was a "greater than" NOEC which would have influenced the criterion magnitude despite no effects observed at the chronic value.

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4.2.2.2.4 Genus: Danio (zebrafish)

Jantzen et al. (2017a) evaluated the effects of PFOA on the morphometric, behavioral and gene expression in *D. rerio* exposed via five-day static unmeasured exposures. Zebrafish embryos were exposed at 3-hpf to PFOA for 120 hours in what is equivalent to a rapid early-life stage test. The observation period in clean water was extended beyond the exposure time points from 120 hpf to 14 days post fertilization (dpf) to assess possible latent effects. The five-day (plus nine days for observation) chronic value for growth-based endpoints, including body length, was an MATC of 0.6325 mg/L (NOEC = 0.2 mg/L; LOEC = 2.0 mg/L), but the MATC for swimming activity, a non-apical endpoint, was reported as 0.06325 mg/L (NOEC = 0.02 mg/L; LOEC = 0.2 mg/L). The reported chronic values based on growth and swimming activity were not considered quantitatively acceptable because of the relatively brief chronic (i.e., 5-day) exposure duration compared to other acceptable acute exposures that indicated *D. rerio* was tolerant to brief (i.e., 96-hours) PFOA exposures.

4.2.2.2.5 Genus: Oryzias (medaka)

Ji et al. (2008) evaluated the chronic toxicity of PFOA (CAS # 335-67-1, purity not provided) to the Japanese medaka, *Oryzias latipes*, via renewal unmeasured exposures. For the F0 fish exposure study, breeding medaka pairs were exposed to PFOA for 14 days. Eggs were counted every day, and the eggs spawned on the seventh day were saved for the F1 generation exposure study. For the F1 fish exposure study, fertilized eggs collected from F0 fish were exposed until all living embryos had hatched. Newly hatched larvae were then randomly transferred to 100 mL beakers and observed daily for swim-up success and survival for an additional two weeks. Larvae were fed *Artemia nauplii ad libitum* twice daily. After 14 days, replicates from each treatment group were transferred to beakers without PFOA for observation through 100 days post hatch. The F0 (parental generation) adult survival, condition factor and

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adult male and female GSI and HSI 14-day LOECs were all >10 mg/L PFOA. For the F1 (progeny generation), the LOEC for larval survival was 0.1 mg/L, while the corresponding NOEC was considered <0.1 because effects were observed in the lowest concentration tested. This test was not used quantitatively because uncertainties associated with the responses across the range of concentrations tested. In many instances, the authors did not report increasing chronic effects with increasing concentrations that differed by an order of magnitude. Additionally, endpoints associated with longer term effects to juveniles were also rejected because of pseudoreplication resulting from a lack of replicates in the hatching stage. Since this test is a static-renewal unmeasured test, the EPA chose to rely exclusively on the test by Lee et al. (2017) to derive the SMCV for this species since Lee et al. (2017) was a flow-through measured test with fewer concerns pertaining to test design (i.e., no pseudoreplication) and results (lack of increasing effects despite a 10-fold increase in exposure concentrations).

4.3 Acute to Chronic Ratios

When sufficient empirical data are not available, the 1985 Guidelines allow the use of a Final Acute-to-Chronic Ratio (FACR) to convert the FAV to a FCV as an alternative approach to derive the chronic criterion (U.S.EPA 1985). An ACR approach was not used for the derivation of the chronic freshwater PFOA criterion, which was derived from empirical chronic data with all of the eight MDRs met. For illustrative purposes only, 11 individual ACRs for five invertebrate species, and one amphibian could be calculated from the quantitatively acceptable acute and chronic toxicity data (Appendix A and Appendix C). Appendix I includes the ACRs for freshwater aquatic species with quantitatively acceptable acute values for which comparable quantitatively acceptable chronic values were reported from the same study or same investigator and laboratory combination. For each species where more than a single ACR was calculated,

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Species Mean Acute-Chronic Ratios (SMACRs) were also calculated as the geometric mean value of individual ACRs. In the case of a single ACR within a species, that ACR was the SMACR.

Individual ACRs ranged from <4.229 to 3,493 across all species and SMACRs ranged from <4.299 to 3,493. Except for *D. magna*, all SMACRs consisted of a single ACR. *Lithobates catesbeiana* had the largest ACR (i.e., 3,493). The denominator of the *L. catesbeiana* ACR was a LOEC where authors reported a significant effect to snout vent length (SVL) despite a reduction of only ~7% relative to control responses (Flynn et al. 2019). The ~7% decrease to SVL observed at the LOEC was a relatively mild effect level compared to the denominator (i.e., chronic value) of most other PFOA ACRs, with chronic effect levels typically being EC_{10} values or MATCs that had corresponding LOECs that produced a >10% effect. Consequently, the relatively mild effect to SVL observed by Flynn et al. (2019) may have contributed to an artificially high ACR relative to the other PFOA ACRs available.

Daphnia carinata had the second highest ACR (2,113) and the denominator was based on a MATC, with the corresponding NOEC and LOEC (which reduced reproduction by ~40%) that differed by a factor of 10 (Logeshwaren et al. 2021). The 10X difference between the *D. carinata* NOEC and LOEC published by Logeshwaran et al. (2021) likely contributed to an artificially low MATC that, in turn, produced an artificially high ACR.

The mayfly, *Neocloeon triangulifer*, had the lowest non-definitive ACR (<4.229). The 96-hour LC_{50} of 13.05 mg/L was divided by the highest chronic test concentration from Soucek et al. (2023) that did not result in any adverse survival, weight or emergence effects at test termination (i.e., NOEC > 3.085 mg/L). The relatively high acute sensitivity of this species produced a low ACR compared to other test organisms.

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Four out of the five *D. magna* ACRs ranged from 14.50 to 69.08, with the remaining ACR from Lu et al. (2016) being 1,602. The *D. magna* ACR from Lu et al. (2016) was removed from the SMACR calculation because it was an order of magnitude greater than other ACRs for the species. Overall, the range of SMACRs was greater than a factor of 100 and there was not an apparent relationship between SMACRs and SMAVs. The 1985 Guidelines do not provide for calculation of a FACR under these circumstances.

4.4 Tissue-based Toxicity Studies Compared to the Chronic Tissue-based Criteria

Tissue-based PFOA toxicity data were reported for four species (three fish and one frog species) across five publications, all of which were classified as qualitatively acceptable. Feng et al. (2015) conducted a 96-hour study with juvenile goldfish (*Carassius auratus*) and observed no effects of PFOA on mortality or antioxidant enzyme activity in the highest aqueous PFOA treatment concentration (4.931 mg/L, measured), which corresponded to liver, gill, and muscle PFOA concentrations of 17.11, 35.13, and 6.07 mg/kg dry weight, respectively.

Giari et al. (2016) measured PFOA in several tissues of two-year-old common carp (*Cyprinus carpio*) exposed to nominal PFOA water concentrations of 0.0002 mg/L and 2 mg/L, plus a control, for 56 days. Corresponding tissue PFOA average concentrations in blood, liver, and muscle in fish from the 2 mg/L treatment after 56 days were 0.0649, 0.0281, and 0.0075 mg/kg wet weight, respectively. No effects of mortality, condition factor, hepatic somatic index (HSI) or gonadal somatic index (GSI) were observed. Manera et al. (2017) performed a separate study that replicated the study design of Giari et al. (2016), in which two-year-old common carp (*Cyprinus carpio*) were exposed to nominal PFOA water concentrations of 0.0002 mg/L and 2 mg/L, plus a control, for 56 days. PFOA was measured in liver, and average concentrations in fish exposed to 2 mg/L for 56 days was 0.0284 mg/kg wet weight, similar to Giari et al. (2016).

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PFOA in the livers of fish exposed to 0.0002 mg/L and the control were below detection (<0.0002 mg/kg ww). No apical endpoints were reported; however, evidence of degenerative liver morphology in PFOA exposed fish was observed.

Hagenaars et al. (2013) exposed adult zebrafish (*D. rerio*) to aqueous PFOA for 28 days. Several reproductive and biochemical endpoints were measured. Whole-body PFOA concentrations in the highest concentration (1 mg/L PFOA, nominal) after 28 days averaged 0.550 mg/kg wet weight in males and 0.301 mg/kg wet weight in females. No statistically significant differences were observed in reproductive endpoints (total egg production, fertilized egg production, and hatching rate) for any treatment levels compared to controls. Statistically significant effects were observed among non-apical endpoints. Decreased whole body glycogen content was lower in male and female fish across all exposure treatments, and liver mitochondrial electron transport activity was lower in males exposed to the highest PFOA concentration. Differences in several liver proteins of PFOA exposed males and females were also observed.

Hoover et al. (2017) exposed juvenile (Gosner stage 26) northern leopard frogs (*Lithobates pipiens*, formerly, *Rana pipiens*) to three PFOA concentrations (0.011, 0.109, and 1.11 mg/L PFOA, respectively) for 40 days. Survival, growth (snout-vent length), and developmental time were measured. Whole body PFOA concentrations in frogs exposed to the highest aqueous treatment level averaged 3.61 mg/kg dry weight after 40 days. Tadpole moisture content was not reported. In order to convert the reported dry weight concentrations to wet weight concentrations, so that they would be more directly comparable to the whole-body fish tissue criterion, a whole-body moisture content of 72.1% was applied, calculated as the average for all fish collected as part of the USGS National Contaminant Biomonitoring Program (NCBP

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Fish Database). The resulting whole-body concentration at the highest treatment level after 40 days was 1.01 mg/kg wet weight. No effects of PFOA on mortality, growth, or development time were reported.

Tissue PFOA concentrations reported in all but one of the qualitative studies were lower than the chronic freshwater tissue-based criteria (i.e., invertebrate whole-body criterion = 1.18 mg/kg ww; fish whole-body criterion = 6.49 mg/kg ww; fish muscle criterion = 0.133 mg/kg ww). The exception was reported by Feng et al. (2015), where the 96-hour muscle-based NOEC (i.e., 6.07 mg/kg dw) was greater than the muscle tissue criterion magnitude of 0.133 mg/kg. However, the liver- and muscle-based NOECs reported by Feng et al. (2015) were from an acute duration (96-hour exposure), whereas the tissue-based values were derived to protect species from longer-term chronic exposures, where effects to sensitive species at concentrations lower than the whole body-based NOEC reported by Feng et al. (2015) may occur. In addition, the tissue concentrations were reported by Feng et al. (2015) as dry weight, as tissue specific percent moisture contents were not available. Had the values in Feng et al. (2015) been expressed as wet weight, the magnitude of the differences would have been smaller.

Although all other tissue-based concentrations were lower than the corresponding tissue-based criteria, no statistically significant effects of apical endpoints were observed in any of these studies. Results of these studies do not provide any evidence that the aquatic community will experience unacceptable chronic effects at tissue-based criteria magnitudes.

4.5 Effects on Aquatic Plants

Available data for aquatic plants and algae were reviewed to determine if aquatic plants were likely to be adversely affected by PFOA and if they were likely to be more sensitive to PFOA than aquatic animals (see Section 4 and Appendix E: Acceptable Freshwater Plant PFOA

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Toxicity Studies). Toxicity values for freshwater plants reported in Appendix E were all greater than the chronic freshwater criterion (i.e., 0.10 mg/L PFOA). The lowest effect concentrations reported were all NOECs for the green alga (*Chlorella pyrenoidosa*). All of these were relatively low NOEC values, which do not provide meaningful information about the sensitivity of this alga relative to the chronic water column criterion. However, a definitive EC_{50} for the same species of 190.99 mg/L (Xu et al. 2013) suggests the PFOA criteria magnitudes are protective of *C. pyrenoidosa*. Excluding the relatively low NOECs, effect concentrations for freshwater plants and algae ranged from 5 to 745.7 mg/L relative to animal chronic values of 0.03162 to 88.32 mg/L (Appendix C). Therefore, it was not necessary to develop a criterion based on the toxicity of PFOA to aquatic plants and the PFOA freshwater criteria are expected to be protective of freshwater plants.

4.6 Protection of Threatened and Endangered Species

The PFOA acute and chronic datasets include some data representing species that are listed as threatened or endangered by the U.S. Fish and Wildlife Service and/or National Oceanic and Atmospheric Administration (NOAA) Fisheries. Summaries are provided here describing the available PFOA toxicity data for listed species indicating that the PFOA criteria are protective of these listed species, based on available scientific data.

4.6.1 Quantitatively Acceptable Acute Toxicity Data for Listed Species

Quantitatively acceptable acute toxicity test data evaluating the effects of PFOA on threatened and endangered freshwater species were available for rainbow trout (*Oncorhynchus mykiss*) with a SMAV of 4,001 mg/L PFOA (DuPont Haskill Laboratory 2000). The rainbow trout SMAV is more than 1,290 times greater than the recommended acute criterion (CMC) of 3.1 mg/L, indicating the acute criterion is protective of rainbow trout and expected to be

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protective of other listed salmonid species. There were no acceptable acute toxicity data for endangered or threatened estuarine/marine aquatic species.

4.6.2 Quantitatively Acceptable Chronic Toxicity Data for Listed Species

Quantitatively acceptable chronic toxicity test data evaluating the effects of PFOA on threatened and endangered freshwater species were available for rainbow trout (*Oncorhynchus mykiss*) with a SMCV of >40 mg/L PFOA (Centre International de Toxicologie 2004; Colombo et al. 2008). The rainbow trout SMCV is 400 times greater than the recommended chronic criterion (CCC) of 0.10 mg/L, indicating the chronic criteria are protective of rainbow trout and other listed salmonid species. There are no acceptable chronic toxicity data for endangered or threatened estuarine/marine aquatic species.

4.6.3 Qualitatively Acceptable Toxicity Data for Listed Species

Focusing on qualitatively acceptable tests with apical endpoints and water column exposures, there available data for the listed Atlantic salmon (*Salmo salar*). Spachmo and Arukwe (2012) and Arukwe et al. (2013) observed no adverse effects for growth at the highest treatment concentration (0.1 mg/L PFOA) following 49-day and 53-day exposures, respectively. For both exposures, the qualitatively-acceptable NOECs were greater than the recommended acute criterion (CCC) of 0.10 mg/L, which further indicates that the chronic criteria are protective of listed salmonid species. There were no qualitative acute or chronic toxicity data for endangered or threatened estuarine/marine aquatic species.

4.7 Summary of the PFOA Aquatic Life Criteria and the Supporting Information

The PFOA aquatic life criteria were developed to protect aquatic life against adverse effects, such as mortality, altered growth, and reproductive impairments associated with acute and chronic exposure to PFOA. This Aquatic Life Ambient Water Quality Criteria for

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Perfluorooctanoic acid (PFOA) document includes water column based acute and chronic criteria and tissue-based criteria for fresh waters. Acute and chronic water column criteria magnitudes for estuarine/marine waters could not be derived at this time due to data limitations; however acute estuarine/marine benchmarks are provided in Appendix L. The freshwater acute water column-based criterion magnitude is 3.1 mg/L, and the chronic water column-based chronic criterion magnitude is 0.10 mg/L. The fish whole-body tissue criterion magnitude is 6.49 mg/kg wet weight, the fish muscle tissue criterion magnitude is 0.133 mg/kg wet weight and the invertebrate whole-body tissue criterion magnitude is 1.18 mg/kg wet weight (Table 3-12). Although empirical PFOA toxicity data for estuarine/marine species were not available to fulfill the eight MDRs directly, the EPA included an acute aquatic life benchmark for estuarine/marine environments in Appendix L, using available estuarine/marine species toxicity data and a NAM application of ORD's peer-reviewed webICE tool. The estuarine/marine acute water column-based benchmark magnitude is 7.0 mg/L; this value provides information on a concentration that should be protective of aquatic estuarine/marine life from acute PFOA exposures. As noted earlier, the benchmark value has greater uncertainty than the freshwater PFOA criteria, due to the paucity of empirical data of PFOA effects on estuarine/marine organisms.

The EPA evaluated the influence of including non-North American resident species on the acute and chronic criteria magnitudes and concluded their inclusion did not substantiality affect the criteria magnitudes. These PFOA aquatic life criteria are expected to be protective of aquatic life, such as fish and aquatic invertebrates, on a national basis.

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Appendix A Acceptable Freshwater Acute PFOA Toxicity Studies

A.1 Summary Table of Acceptable Quantitative Freshwater Acute PFOA Toxicity Studies

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Author Reported Effect Conc. (mg/L)	EPA Calculated Effect Conc. (mg/L)	Final Effect Conc. (mg/L)[e]	Species Mean Acute Value (mg/L)	Reference
Planaria (0.9 cm), *Dugesia japonica*	S, U	96 hours	PFOA >98%	-	25	LC_{50}	458	-	**458**	-	Li 2008
Planaria (0.9 cm), *Dugesia japonica*	S, U	96 hours	PFOA >98%	-	25	LC_{50}	337[h]	321.8	**321.8**	-	Li 2009
Planaria (0.9 cm), *Dugesia japonica*	S, U	96 hours	PFOA >98%	-	25	LC_{50}	337[h]	383.0	**383.0**	383.6	Li 2009
Fatmucket (glochidia, <24 hours), *Lampsilis siliquoidea*	S, M	24 hours	PFOA 96%	8.46	20	EC_{50} (viability)	164.4	-	**164.4**	-	Hazelton et al. 2012, Hazelton 2013
Fatmucket (juvenile, 4-6 weeks), *Lampsilis siliquoidea*	R, M	96 hours	PFOA 96%	8.46	20	LC50	>500	-	>500[f]	164.4	Hazelton et al. 2012, Hazelton 2013
Black sandshell (glochidia, <24 hours), *Ligumia recta*	S, M	24 hours	PFOA 96%	8.46	20	EC_{50} (viability)	161.0	-	**161.0**	-	Hazelton et al. 2012, Hazelton 2013
Black sandshell (juvenile, 4-6 weeks), *Ligumia recta*	R, M	96 hours	PFOA 96%	8.46	20	LC_{50}	>500	-	>500[f]	161.0	Hazelton et al. 2012, Hazelton 2013
Pewter Physa (mixed age), *Physella acuta* (formerly, *Physa acuta*)	S, U	96 hours	PFOA >98%	-	25	LC_{50}	672[h]	762.0	**762.0**	-	Li 2009
Pewter Physa (mixed age), *Physella acuta*	S, U	96 hours	PFOA >98%	-	25	LC_{50}	672[h]	659.9	**659.9**	-	Li 2009
Pewter Physa (mixed age), *Physella acuta*	S, U	96 hours	PFOA >98%	-	25	LC_{50}	672[h]	628.3	**628.3**	681.1	Li 2009
Rotifer (<2-hour old neonates), *Brachionus calyciflorus*	S, U[b]	24 hours	PFOA 96%	-	20	LC_{50}	150.0	-	**150.0**	150.0	Zhang et al. 2013a
Cladoceran (<24 hours), *Chydorus sphaericus*	S, U	48 hours	PFOA Unreported	-	20	EC_{50} (death/immobility)	91.10[c]	93.17[c]	**93.17[c]**	93.17	Le and Peijnenburg 2013

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Author Reported Effect Conc. (mg/L)	EPA Calculated Effect Conc. (mg/L)	Final Effect Conc. (mg/L)[e]	Species Mean Acute Value (mg/L)	Reference
Cladoceran (6-12 hours), *Daphnia carinata*	S, U	48 hours	PFOA 95%	-	21	EC_{50} (death/immobility)	78.2	66.80	**66.80**	66.80	Logeshwaran et al. 2021
Cladoceran (<24 hours), *Daphnia magna*	S, U	48 hours	PFOA ≥97%	-	21	EC_{50} (immobility)	223.6	-	**223.6**	-	Boudreau 2002
Cladoceran (STRAUS-clone 5; 6-24 hours), *Daphnia magna*	S, U	48 hours	APFO 99.7%	-	18-22	EC_{50}	480[d]	-	**480[d]**	-	Colombo et al. 2008
Cladoceran (<24 hours), *Daphnia magna*	S, U	48 hours	PFOA Unreported	-	21	EC_{50} (immobility)	476.52	542.5	**542.5**	-	Ji et al. 2008
Cladoceran (<24 hours), *Daphnia magna*	S, U	48 hours	PFOA >98%	7.82-7.91	25	LC_{50}	181[h]	220.8	**220.8**	-	Li 2009
Cladoceran (<24 hours), *Daphnia magna*	S, U	48 hours	PFOA >98%	7.82-7.91	25	LC_{50}	181[h]	157.9	**157.9**	-	Li 2009
Cladoceran (<24 hours), *Daphnia magna*	S, U	48 hours	PFOA >98%	7.82-7.91	25	LC_{50}	181[h]	207.3	**207.3**	-	Li 2009
Cladoceran (<24 hours), *Daphnia magna*	S, M	48 hours	PFOA 96%	-	20	EC_{50} (death/immobility)	211.6[c]	216.1[c]	**216.1[c]**	-	Ding et al. 2012a
Cladoceran (<24 hours), *Daphnia magna*	S, M	48 hours	PFOA 99%	7	22	LC_{50}	201.85	222.0	**222.0**	-	Yang et al. 2014
Cladoceran (<24 hours), *Daphnia magna*	S, M	48 hours	PFOA >96%	7.0-7.82	20	EC_{50} (immobility)	239	215.6	**215.6**	-	Barmentlo et al. 2015
Cladoceran (<24 hours), *Daphnia magna*	S, U	48 hours	PFOA 98%	-	20	EC50 (death/immobility)	110.7	114.6	**114.6**	-	Lu et al. 2016
Cladoceran (12-24 hours), *Daphnia magna*	S, U	48 hours	PFOA Unreported	6-8.5	20	LC_{50}	120.9[c]	117.2[c]	**117.2[c]**	-	Yang et al. 2019
Cladoceran (<24 hours), *Daphnia magna*	S, U	48 hours	APFO ≥98%	-	20	EC_{50} (death/immobility)	156.9	-	**156.9**	213.9	Chen et al. 2022
Cladoceran (<24 hours), *Daphnia pulicaria*	S, U	48 hours	PFOA ≥97%	-	21	EC_{50} (immobility)	203.7	-	**203.7**	203.7	Boudreau 2002
Cladoceran (<24 hours), *Moina macrocopa*	S, U	48 hours	PFOA Unreported	-	25	EC_{50} (immobility)	199.51	166.3	**166.3**	166.3	Ji et al. 2008
Cladoceran (<48 hours), *Moina micrura*	S, U	48 hours	PFOA ≥98%	-	27	LC_{50}	0.4747	-	**0.4747**	0.4747	Razak et al. 2023

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Author Reported Effect Conc. (mg/L)	EPA Calculated Effect Conc. (mg/L)	Final Effect Conc. (mg/L)[e]	Species Mean Acute Value (mg/L)	Reference
Green neon shrimp, *Neocaridina denticulata*	S, U	96 hours	PFOA >98%	-	25	LC_{50}	454[h]	499.7	**499.7**	-	Li 2009
Green neon shrimp, *Neocaridina denticulata*	S, U	96 hours	PFOA >98%	-	25	LC_{50}	454[h]	428.1	**428.1**	-	Li 2009
Green neon shrimp, *Neocaridina denticulata*	S, U	96 hours	PFOA >98%	-	25	LC_{50}	454[h]	375.5	**375.5**	431.5	Li 2009
Mayfly (<24 hr larva), *Neocloeon triangulifer*	S, M	96 hours	PFOA 95%	-	23	LC_{50}	13.45	13.05	**13.05**	13.05	Soucek et al. 2023
Rainbow trout (2.8 cm, 0.21 g), *Oncorhynchus mykiss*	S, M	96 hours	APFO 99.4%	7.1-7.2	11.8	LC_{50}	4,001	-	**4,001**	4,001	DuPont Haskell Laboratory 2000
Zebrafish (embryo), *Danio rerio*	R, U	96 hours	PFOA Unreported	7-8.5	26	LC_{50}	499	-	**499**	-	Ye et al. 2007
Zebrafish (embryo), *Danio rerio*	S, U	96 hours	PFOA ≥97%	7.2-7.5	26	LC_{50}	>500	-	**>500**	-	Hagenaars et al. 2011
Zebrafish (3 mo), *Danio rerio*	S, M	96 hours	PFOA 98%	-	23	LC_{50}	118.82	122.5	**122.5**	-	Zhao et al. 2016
Zebrafish (embryo), *Danio rerio*	S, U	96 hours	PFOA Unreported	7.5	26-28	LC_{50}	24.6	22.77	22.77[g]	-	Corrales et al. 2017
Zebrafish (embryo, 4 hpf), *Danio rerio*	R, U	96 hours	PFOA Unreported	7-7.5	28	LC_{50}	473[h]	548.00	**548.0**	-	Godfrey et al. 2017a
Zebrafish (embryo, 4 hpf), *Danio rerio*	R, U	96 hours	PFOA Unreported	7-7.5	28	LC_{50}	473[h]	508.5	**508.5**	-	Godfrey et al. 2017a
Zebrafish (embryo, 4 hpf), *Danio rerio*	R, U	96 hours	PFOA Unreported	7-7.5	28	LC_{50}	473[h]	547.0	**547.0**	-	Godfrey et al. 2017a
Zebrafish (embryo), *Danio rerio*	R, U	96 hours	PFOA Unreported	-	26	LC_{50}	759	806.6	**806.6**	450.4	Stengel et al. 2017, 2018
Fathead minnow, *Pimephales promelas*	S, U	96 hours	PFOA 95-98%	7.5-7.7	19-20	LC_{50}	843	852.7	**852.7**	-	3M Co. 2000a
Fathead minnow (larva), *Pimephales promelas*	S, U	96 hours	PFOA Unreported	7.5	25	LC_{50}	413.2	-	**413.2**	593.6	Corrales et al. 2017
Bluegill (2.1 cm, 0.228 g), *Lepomis macrochirus*	S, U	96 hours	APFO 99%	6.9-7.4	21.4–22.1	LC_{50}	634	664.0	**664.0**	664.0	DuPont Haskell Laboratory 2000

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Author Reported Effect Conc. (mg/L)	EPA Calculated Effect Conc. (mg/L)	Final Effect Conc. (mg/L)[e]	Species Mean Acute Value (mg/L)	Reference
American toad (larva, Gosner stage 26), *Anaxyrus americanus*	S, U	96 hours	PFOA Unreported	-	21	LC_{50}	711[h]	781.4	**781.4**	-	Tornabene et al. 2021
American toad (larva, Gosner stage 41), *Anaxyrus americanus*	S, U	96 hours	PFOA Unreported	-	21	LC_{50}	711[h]	806.6	**806.6**	793.9	Tornabene et al. 2021
Gray treefrog (larva, Gosner stage 26), *Hyla versicolor*	S, U	96 hours	PFOA Unreported	-	21	LC_{50}	557	646.2	**646.2**	646.2	Tornabene et al. 2021
American bullfrog (tadpole, Gosner stage 25), *Lithobates catesbeiana* (formerly, *Rana catesbeiana*)	S, U	96 hours	PFOA Unreported	-	21	LC_{50}	1,004	1,006	**1,006**	-	Flynn et al. 2019
American bullfrog (larva, Gosner stage 26), *Lithobates catesbeiana*	S, U	96 hours	PFOA Unreported	-	21	LC_{50}	1,060	1,035	**1,035**	1,020	Tornabene et al. 2021
Green frog (larva, Gosner stage 26), *Lithobates clamitans* (formerly, *Rana clamitans*)	S, U	96 hours	PFOA Unreported	-	21	LC_{50}	1,070	-	**1,070**	1,070	Tornabene et al. 2021
Northern leopard frog (larva, Gosner stage 26), *Lithobates pipiens* (formerly, *Rana pipiens*)	S, U	96 hours	PFOA Unreported	-	21	LC_{50}	752	751.7	**751.7**	751.7	Tornabene et al. 2021
Wood frog (larva, Gosner stage 26), *Lithobates sylvatica* (formerly, *Rana sylvatica*)	S, U	96 hours	PFOA Unreported	-	21	LC_{50}	999	-	**999**	999	Tornabene et al. 2021
Frog (embryo stage 8.5), *Xenopus sp.*	R, U	96 hours	PFOA Unreported	-	23	LC_{50}	377[c]	-	**377[c]**	377	Kim et al. 2013

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Author Reported Effect Conc. (mg/L)	EPA Calculated Effect Conc. (mg/L)	Final Effect Conc. (mg/L)[e]	Species Mean Acute Value (mg/L)	Reference
Jefferson salamander (larva, Harrison stage 40), *Ambystoma jeffersonianum*	S, U	96 hours	PFOA Unreported	-	21	LC_{50}	1,070	-	**1,070**	1,070	Tornabene et al. 2021
Small-mouthed salamander (larva, Harrison stage 40), *Ambystoma texanum*	S, U	96 hours	PFOA Unreported	-	21	LC_{50}	474	407.3	**407.3**	-	Tornabene et al. 2021
Small-mouthed salamander (larva, Harrison stage 45), *Ambystoma texanum*	S, U	96 hours	PFOA Unreported	-	21	LC_{50}	1,000	-	1,000[f]	407.3	Tornabene et al. 2021
Eastern tiger salamander (larva, Harrison stage 40), *Ambystoma tigrinum*	S, U	96 hours	PFOA Unreported	-	21	LC_{50}	752	-	**752**	752	Tornabene et al. 2021

a S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

b Chemical concentrations made in a side-test representative of exposure and verified stability of concentrations of PFOA in the range of concentrations tested under similar conditions. Daily renewal of test solutions.

c Reported in moles converted to milligram based on a molecular weight of 414.07 mg/mmol.

d Concentration of APFO in publication indirectly determined through quantification of the anion (PFO-).

e Values in bold used in the SMAV calculation.

f Only the most sensitive life-stage used in the SMAV calculation.

g Value is considered an outlier and not used in SMAV calculation.

h Author pooled test of life stages.

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A.2 Detailed PFOA Acute Toxicity Study Summaries and Corresponding Concentration-Response Curves (when calculated)

The purpose of this section is to present detailed study summaries for tests that were considered quantitatively acceptable for criterion derivation, with summaries grouped and ordered by genus sensitivity. C-R models developed by the EPA that were used to determine acute toxicity values used for criterion derivation are also presented. C-R models included here with study summaries were those for the four most sensitive genera. In many cases, authors did not report concentration-response data in the publication/supplemental materials and/or did not provide concentration-response data upon request by the EPA. In such cases, the EPA did not independently calculate toxicity values and the author-reported effect concentrations were used to derive the criterion.

A.2.1 Most acutely sensitive genus – *Moina*

Ji et al. (2008) performed a 48-hour static, unmeasured acute test of PFOA (CAS # 335-67-1, purity unreported; obtained from Sigma Aldrich, St. Louis, MO) with *Moina macrocopa*. Authors stated the test followed U.S. EPA/600/4-90/027F (2002). *M. macrocopa* used for testing were obtained from brood stock cultured at the Environmental Toxicology Laboratory at Seoul National University, Korea. Test organisms were less than 24-hours old at test initiation. Dilution water was moderately hard reconstituted water (total hardness typically 80-100 mg/L as $CaCO_3$). Experiments were conducted in glass jars of unspecified size and fill volume. Photoperiod was assumed as 16-hour:8-hour, light:dark, the same conditions as the daphnid cultures. Preparation of test solutions was not described. The test involved four replicates of five daphnids each in five unmeasured test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 62.5, 125, 250, 500 and 1,000 mg/L. Test temperature was maintained at 25 ± 1°C. Authors noted water quality parameters (pH, temperature, conductivity, and dissolved oxygen)

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were measured 48-hours after exposure, but the information was not reported. Survival of daphnids in the negative control was not reported, although EPA/600/4-90/027F requires at least 90% survival for test acceptability. The author-reported 48-hour EC_{50} for the study was 199.51 mg/L (95% C.I. = 163.9 – 245.1). The EPA performed C-R analysis for the test. The EPA-calculated EC_{50} was 166.3 mg/L PFOA (95% C.I. = 138.6 – 194.1 mg/L) and was acceptable for quantitative use.

Razak et al. (2023) tested the acute toxicity of perfluorooctanoic acid (PFOA) to *Moina micrura* in a 48 hour static measured experiment. In addition to acute toxicity, the effects of PFOA on heart rate, heart size, and individual size were also examined. PFOA (≥98% purity) analytical standards were purchased from Dr. Ehrenstorfer GmbH (Augsburg, Germany), and PFOA and solvents for making test solutions were purchased from Fisher Scientific (New Jersey, USA). Organisms were obtained from the Aquatic Animal Health and Therapeutics Laboratory (Aquahealth) at the Institute of Bioscience, Universiti Putra Malaysia. Culturing procedures followed International Organisation for Standardization (ISO) procedure 6341:2012. Cultures were kept under a 12:12 light:dark cycle at 27±1°C. Culture water was renewed every two weeks, and culture organisms were fed green algae (*Chlorella vulgaris*) three times weekly. Both culture and test water was filtered (0.2 µm) surface lake water. A stock solution of 100 mg/L PFOA with filtered surface lake water was made just before testing began. Testing methods followed OECD 202 (OECD 2004) with nominal testing concentrations of 10, 25, 50, 75, 100, 250, 500, 750, 1,000, 2,500, 5,000, 7,500, and 10,000 µg/L, plus a control, with four replicates per treatment. Measured concentrations were not reported, but the authors noted they were 94.3±6.1% of nominal on average. Each replicate consisted of 10 neonates (<48 hours old) in 50 mL of solution in a 100 mL beaker, and organisms were not fed during the study. Nonparametric

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Kruskal-Wallace tests followed by post-hoc tests were used to calculate significant ($P<0.05$) differences between controls and treatment concentrations for all endpoints. The lethal effect concentrations (LC_{10}, LC_{50}, LC_{75}, LC_{90}) were calculated using Probit analysis, and the 48-hour LC_{50} value of 474.7 µg/L, or 0.4747 mg/L was determined to be acceptable for quantitative use. C-R data could not be obtained for this test (beyond the visual presentation in the Razak et al. (2023), so the EPA was unable to perform independent C-R analysis.

A.2.2 Second most acutely sensitive genus – *Neocloeon*

Soucek et al. (2023) exposed the parthenogenetic mayfly, *Neocloeon triangulifer*, to PFOA (CAS # 335-67-1, 95% purity) in a 96-hour acute toxicity test. The test was performed under static, non-renewal conditions beginning with <24-hour old larvae. Exposures consisted of five mayfly nymphs per 30 mL polypropylene cup filled with 20 mL test solution. The control and each of six PFOA test concentrations were replicated five times for a total of 25 test organisms per treatment. Nominal test concentrations were 0.0 (control), 1.25, 2.5, 5.0, 10, and 20 mg/L PFOA. Mean measured PFOA concentrations (EPA Analytical Method 1633; LC-MC/MS) were 0.0003 (control), 1.765, 3.896, 8.137, 13.39 and 30.40 mg/L PFOA, respectively. Mayflies were exposed at 23 ± 1°C under a 16:8-hour light:dark cycle and fed live diatom biofilm scraping beginning on day 0. Feeding only occurred on day 0, and the authors indicated that test organisms required food to survive the entire 96-hour exposure, with previous studies demonstrating greater than 80% mortality at 48 hours with no food (Soucek and Dickinson 2015). Percent survival in the control treatment after 96 hours was 100%. A steep concentration-response relationship between percent survival and increasing PFOA test concentration was observed. Survival decreased from 100% at 8.137 mg/L PFOA to 38.5% at 13.39 mg/L, and to 0% at 30.40 mg/L. The EPA-calculated acute LC_{50} (i.e., 13.045 mg/L) was similar to the author-

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reported LC_{50} of 13.451 mg/L. The EPA-calculated LC_{50} value (i.e., 13.045 mg/L) was acceptable for quantitative use in deriving the acute freshwater PFOA criterion.

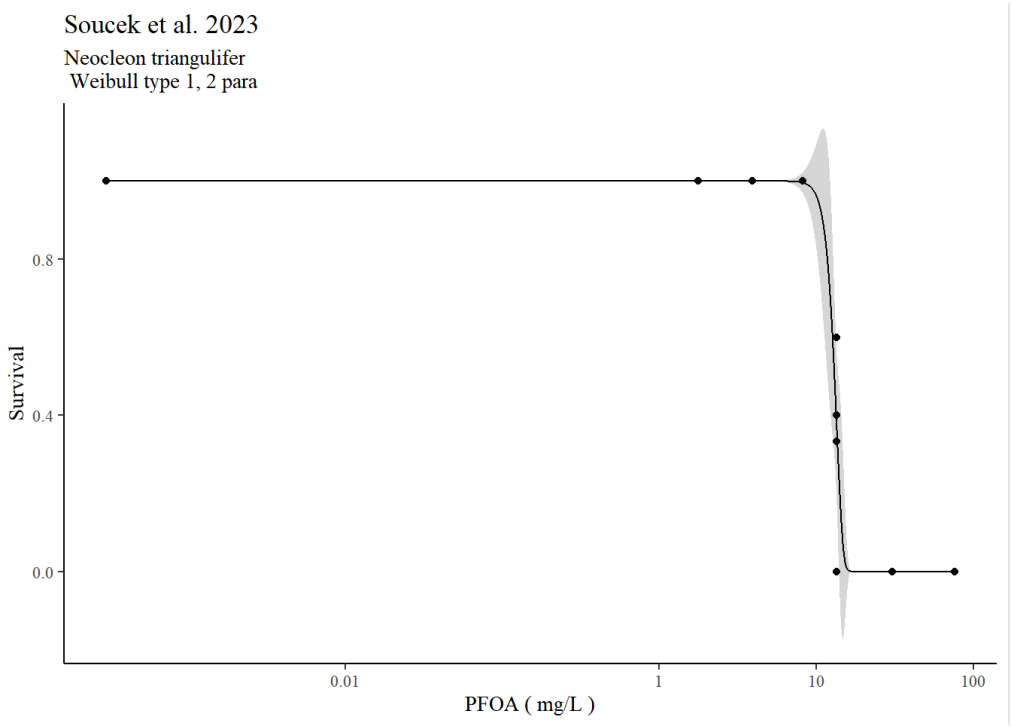
Recent research has led to the development of successful culturing methods for mayflies that are used in laboratory-based toxicity studies (Soucek and Dickinson 2015; Soucek et al. 2023). These resulting toxicity studies have shown that mayflies (including *Neocloeon triangulifer*) are commonly among the most sensitive taxa to different chemical exposures, including PFOA, PFOS, major geochemical ions, pesticides, and heavy metals (Johnson et al. 2015; Kim et al. 2012; Raby et al. 2018; Soucek and Dickinson 2015; Soucek et al. 2020; Soucek et al. 2023; Wesner et al. 2014). The high sensitivity of mayflies to contaminant exposures has also been observed In mesocosm-based experiments (Mebane et al. 2020) and field-based surveys (U.S. EPA 2011). Many of these laboratory-based toxicity tests used mayflies capable of adapting to laboratory settings. It is hypothesized that mayfly species unable to survive in laboratory settings may also be more sensitive to contaminant exposures than the relatively hardy mayfly species (e.g., *N. triangulifer*) commonly used for toxicity testing.

Publication: Soucek et al. (2023)
Species: Mayfly (*Neocloeon triangulifer*)
Genus: *Neocloeon*
EPA-Calculated LC_{50}: 13.045 mg/L (95% C.I. = 12.46 – 13.63 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	10.8557	6.1850	1.7552	0.0792
e	13.4934	0.3271	41.248	$<2.0e^{-16}$

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Concentration-Response Model Fit:



A.2.3 Third most acutely sensitive genus – *Chydorus*

Le and Peijnenburg (2013) performed a 48-hour static unmeasured test on PFOA (unreported purity) with the cladoceran, *Chydorus sphaericus*. Authors stated the test followed the protocol of the "Chydotox toxicity test" developed by the National Institute for Public Health and the Environment, The Netherlands. In-house cultures of neonates (<24 hours) were exposed to 250 ML of test solutions in 2 ML vials of unreported material. Each vial contained five neonates and each test concentration was replicated four times. No solvent was used in the test solutions with 18-20 test concentrations. *C. sphaericus* was cultured at 20 ± 1°C and a cycle of 16-hour:8-hour light:dark without the addition of food. At test termination vials were shaken slightly and the mobility of the neonates was determined. The author-reported 48-hour EC_{50} was 0.22 MM PFOA (91.10 mg/L). The EPA performed concentration-response (C-R) analysis for

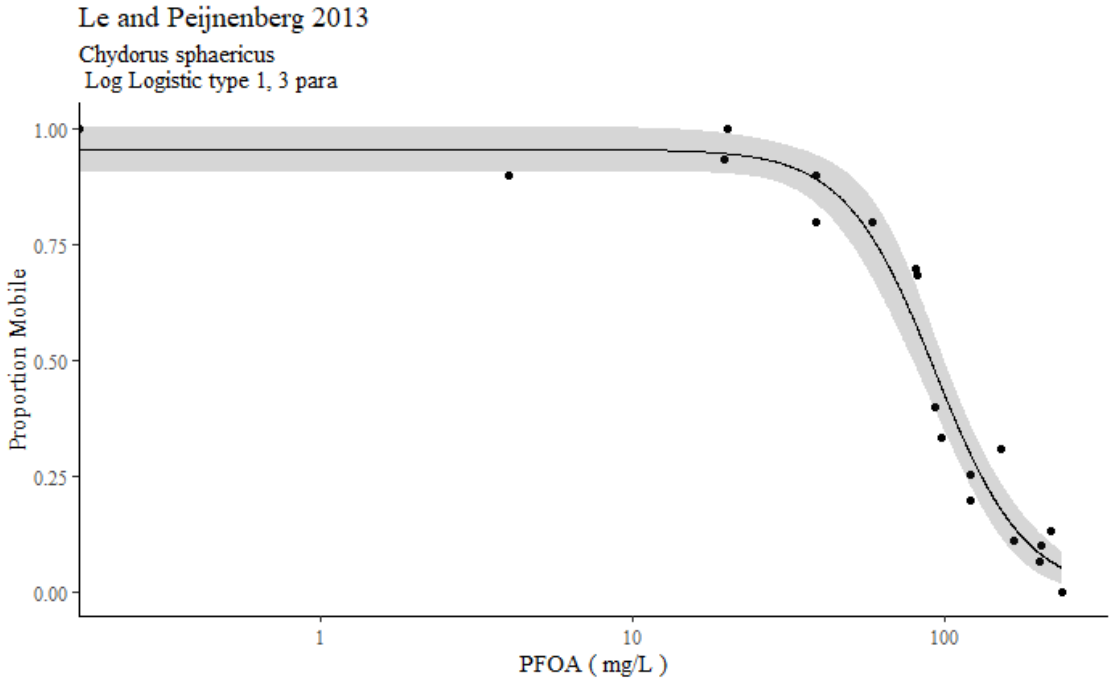
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the test and calculated a LC_{50} of 93.17 mg/L PFOA (95% C.I. = 82.52 – 103.8 mg/L) that was acceptable for quantitative use.

Publication: Le and Peijnenburg (2013)
Species: Cladoceran (*Chydorus sphaericus*)
Genus: *Chydorus*
EPA-Calculated LC_{50}: 93.17 mg/L (95% C.I. = 82.52 – 103.8 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	3.007	0.4165	7.2181	$5.27e^{-13}$
d	0.9560	0.0248	38.5566	$<2.2e^{-16}$
e	5.9057	5.9057	15.7767	$<2.2e^{-16}$

Concentration-Response Model Fit:



A.2.4 Fourth most acutely sensitive genus – *Daphnia*

Logeshwaran et al. (2021) conducted acute and chronic toxicity tests with the cladoceran, *Daphnia carinata*, and PFOA (95% purity, purchased from Sigma-Aldrich Australia). In-house cultures of daphnids were maintained in 2 L glass bottles with 30% natural spring water in deionized water, 21°C and a 16-hour:8-hour light:dark photoperiod. The acute test protocol followed OECD guidelines (2000) with slight modifications. A PFOA stock

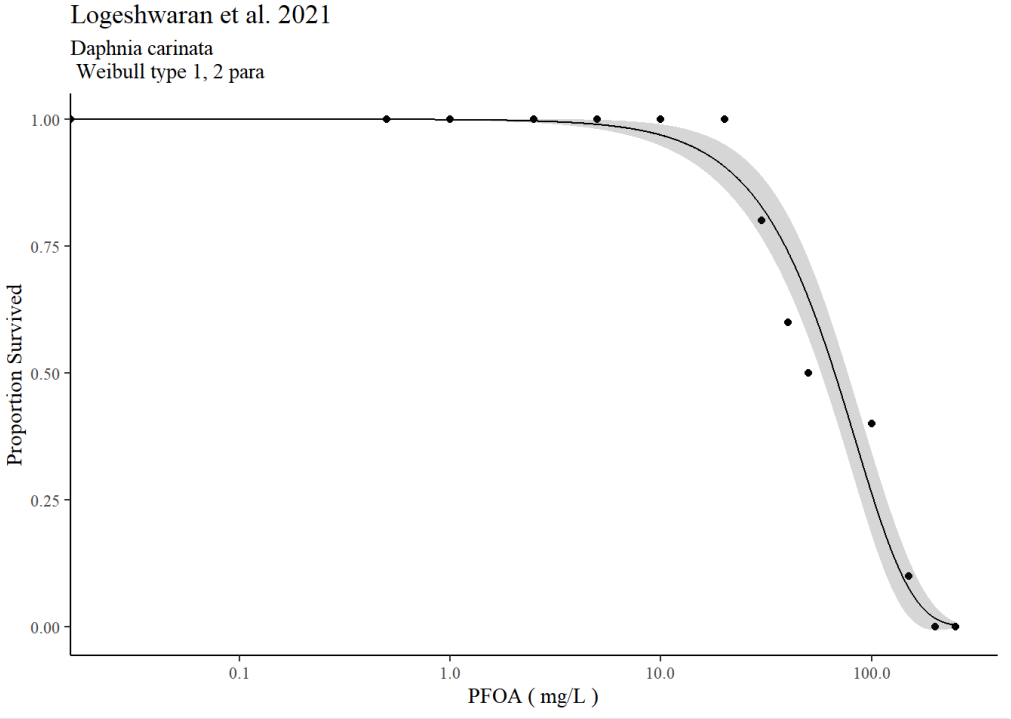
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solution (100 mg/L) was prepared in deionized water. Cladoceran culture medium was used to prepare the PFOA stock and test solutions. Ten daphnids (six to 12 hours old) were transferred to polypropylene containers containing one of 14 nominal test concentrations (0, 0.5, 1, 2.5, 5, 10, 20, 30, 40, 50, 100, 150, 200 and 250 mg/L PFOA). Each test treatment was replicated three times and held under the same conditions as culturing. At test termination (48 hours) immobility was determined after 15 seconds of gentle stirring. No mortality occurred in the controls. The author-reported 48-hour EC_{50} was 78.2 mg/L PFOA. The EPA-calculated 48-hour EC_{50} value was 66.80 mg/L (95% C.I. = 57.10 – 76.50 mg/L), which was acceptable for quantitative use.

Publication: Logeshwaran et al. (2021)
Species: Cladoceran (*Daphnia carinata*)
Genus: *Daphnia*
EPA-Calculated LC_{50}: 66.80 mg/L (95% C.I. = 57.10 – 76.50 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	1.6249	0.1565	10.3860	$<2.2e^{-16}$
e	83.6974	5.9263	14.1230	$<2.2e^{-16}$

Concentration-Response Model Fit:



Boudreau (2002) performed a 48-hour static unmeasured test on PFOA (CAS # 335-67-1, ≥97% purity) with *Daphnia magna* and *Daphnia pulicaria* as part of a Master's thesis at the University of Guelph, Ontario, Canada. The results were subsequently published in the open literature (Boudreau et al. 2003). Authors stated the test followed ASTM E729-96 (1999). Daphnids used for testing were less than 24-hours old at test initiation. *D. magna* were obtained from a brood stock (Dm99-23) at ESG International (Guelph, ON, Canada). *D. pulicaria* were acquired from a brood stock maintained in the Department of Zoology at the University of Guelph. Dilution water was clean well water obtained from ESG International. Total hardness was softened by addition of distilled deionized water to achieve a range of 200-225 mg/L of $CaCO_3$. Photoperiod was 16-hours of illumination under cool-white, fluorescent light between 380 and 480 lux. Laboratory-grade distilled water was used for all solutions with maximum concentrations derived from stock solutions no greater than 450 mg/L. Test vessels consisted of 225 mL polypropylene disposable containers containing 150 mL of test solution. All toxicity testing involved three to four replicates of 10 daphnids each in five unmeasured test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 26.3, 52.6, 105, 210 and 420 mg/L. Experiments were conducted in environmental chambers at a test temperature of 21 ± 1°C. Authors note that temperature and pH were measured at the beginning and end of the study, but this information is not reported. Mortality of daphnids in the negative control was also not reported, although ASTM E729-96 requires at least 90% survival for test acceptability. The 48-hour *D. magna* EC_{50} reported in the publication was 223.6 mg/L. The 48-hour *D. pulicaria* EC_{50} reported in the publication was 203.7 mg/L.

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Publication: Boudreau (2002)
Species: Cladoceran (*Daphnia pulicaria*)
Genus: *Daphnia*
EPA-Calculated LC_{50}: Not calculable, concentration-response data not available
Concentration-Response Model Fit: Not Applicable

Publication: Boudreau (2002)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated LC_{50}: Not calculable, concentration-response data not available
Concentration-Response Model Fit: Not Applicable

Colombo et al. (2008) conducted a 48-hour static unmeasured acute test on ammonium perfluorooctanoate (APFO, CAS # 3825-26-1, 99.7% purity) with the daphnid, *Daphnia magna*. The authors stated that the toxicity test was conducted following OECD test guideline 202 (1992). Neonates, six to 24-hours old, were acclimated to test conditions for six-hours before test initiation with test solutions made in reconstituted M4 media. There were four replicates for each test treatment containing five animals each. Exposure vessel material and size were not reported. Based on loading, exposure vessels contained at least 100 mL test solution. Nominal test concentrations were used based on the known stability of the test substance in water. The nominal test concentrations included control, 100, 178, 316, 562 and 1,000 mg/L. Dissolved oxygen was >60% saturation and temperature were maintained between 18-22°C. Illumination involved 16-hours of light with an unreported intensity. No mortality was observed in the controls. C-R data were available for this acute test; however, the EPA was unable to fit a model with significant parameters and relied on the 48-hour EC_{50} reported in the study of 480 mg/L, which was acceptable for quantitative use. The authors note the contribution of ammonia from APFO exposure indicates that un-ionized ammonia could be a potential contributor to the observed acute toxicity of APFO. The EPA believes ammonia does not contribute substantively to the acute toxicity to *D. magna* in this test based on the following rationale. U.S. EPA (2013)

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derived a SMAV of 157.7 mg N/L at pH=7 and temperature of 20°C for *D. magna*. Using the EPA equations, this translates to approximately 30.36 mg N/L at the authors' assumed acute test pH=8.1 (from their Table 7) and their midrange test temperature of 20°C, which in turn translates to an un-ionized ammonia concentration of approximately 1.76 mg un-ionized ammonia/L at this pH and temperature. The authors' Table 7 lists the un-ionized ammonia concentration at their APFO EC_{50} as 0.73 mg un-ionized ammonia/L, which is 2.4-fold lower than the EPA's SMAV for D. *magna* re-expressed as an un-ionized ammonia concentration for the test condition. Therefore, it is unlikely that ammonia contributes substantively to the acute toxicity of APFO to *D. magna* in this test, and therefore, the 48-hour EC_{50} is used in the calculation of the SMAV for this species.

Publication: Colombo et al. (2008)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated LC_{50}: Not calculable, unable to fit a model with significant parameters
Concentration-Response Model Fit: Not Applicable

Ji et al. (2008) also performed a 48-hour static, unmeasured acute test of PFOA (CAS # 335-67-1, purity unreported; obtained from Sigma Aldrich, St. Louis, MO) with *D. magna*. Authors stated that the test followed U.S. EPA/600/4-90/027F (2002). *D. magna* used for testing were obtained from brood stock cultured at the Environmental Toxicology Laboratory at Seoul National University, Korea. Test organisms were less than 24-hours old at test initiation. Dilution water was moderately hard reconstituted water (total hardness typically 80-100 mg/L as $CaCO_3$). Experiments were conducted in glass jars of unspecified size and fill volume. Photoperiod was assumed as 16-hour:8-hour, light:dark, the same conditions as the daphnid cultures. Preparation of test solutions was not described. The test involved four replicates of five daphnids each in five unmeasured test concentrations plus a negative control. Nominal concentrations were 0 (negative

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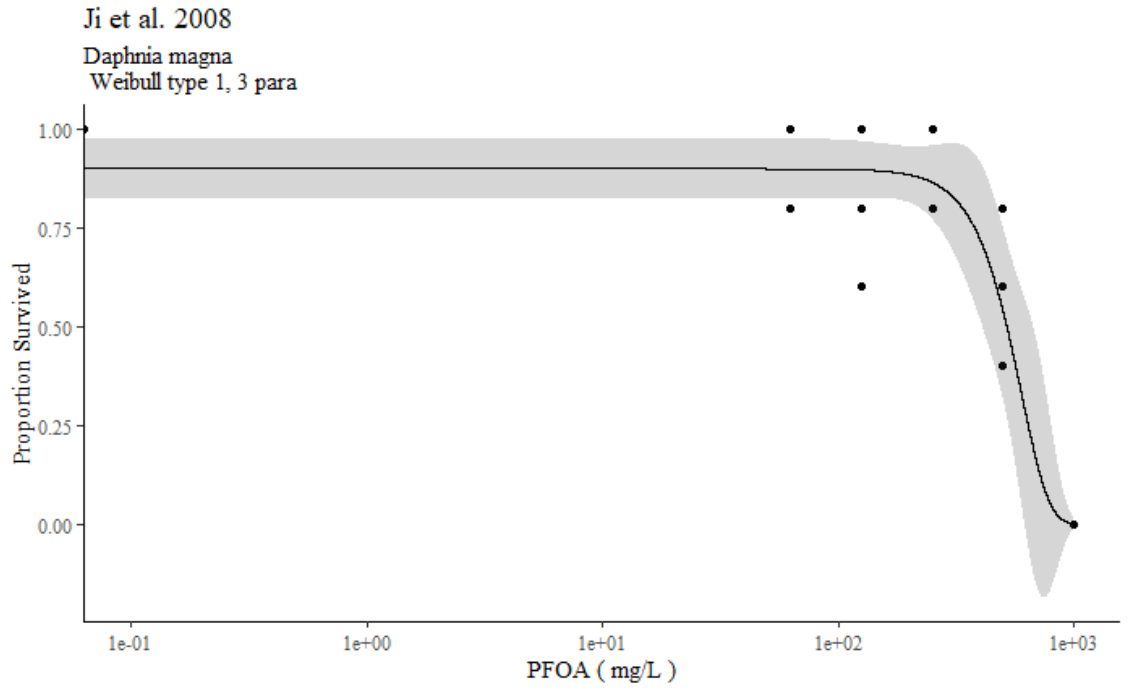
control), 62.5, 125, 250, 500 and 1,000 mg/L. Test temperature was maintained at 21 ± 1°C. The authors noted that water quality parameters (Ph, temperature, conductivity, and dissolved oxygen) were measured 48-hours after exposure, but the information was not reported. Mortality of daphnids in the negative control was not reported, although EPA/600/4-90/027F requires at least 90% survival for test acceptability. The author-reported 48-hour EC_{50} for the study was 476.52 mg/L (95% C.I. = 375.3 – 577.7 mg/L). The EPA performed C-R analysis for the test. The EPA-calculated EC_{50} was 542.5 mg/L PFOA (95% C.I. = 461.1 – 623.8 mg/L), which was acceptable for quantitative use.

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Publication: Ji et al. (2008)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated LC_{50}: 542.5 mg/L (95% C.I. = 461.1 – 623.8 mg/L),
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	3.7248	1.8230	2.0432	0.0410
d	0.8985	0.0393	22.8879	$< 2.0\ e^{-16}$
e	598.5588	66.9972	8.9341	$< 2.0\ e^{-16}$

Concentration-Response Model Fit:



Li (2009) conducted a 48-hour static unmeasured acute test on PFOA (ammonium salt, >98% purity) with *Daphnia magna*. The authors stated that the test followed OECD 202 (1984) with slight modifications. *D. magna* used for the test were less than 24-hours old at test initiation. Dilution water was dechlorinated tap water. The photoperiod consisted of 12-hours of illumination at an unreported light intensity. A primary stock solution was prepared in dilution water and did not exceed 400 mg/L. Exposure vessels were polypropylene of unreported dimensions and 50 Ml fill volume. The test employed five replicates of six daphnids each in five

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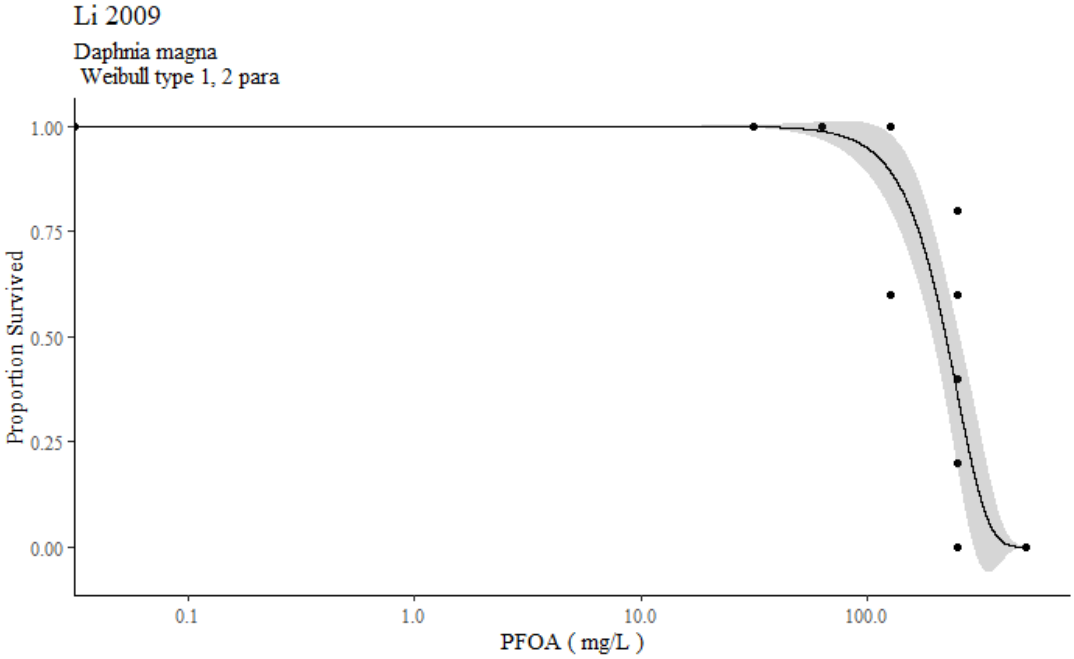
test concentrations plus a negative control. Based on water solubility of test chemicals and preliminary toxicity results, nominal test concentrations were in the range of 31-250 mg/L for PFOA. The test was conducted in a temperature incubator at 25 ± 2°C. Water quality parameters including water Ph, conductivity, and dissolved oxygen were measured at the beginning and at the end of each test. Initial values of Ph were 7.82 ± 0.12 and 7.91 ± 0.03 after 48-hours. At the start of the bioassays, dissolved oxygen and specific conductivity were 67.7 ± 6.8% saturation and 101.8 ± 6.8 µS/cm, respectively. After the 48-hour testing period, dissolved oxygen and specific conductivity were 55.6 ± 1.26% saturation (implying 4.56 mg/L) and 109.1 ± 3.5 µS/cm, respectively. None of the control animals became immobile at the end of the test. The author-reported 48-hour EC_{50} for the study was 181 mg/L (95% C.I.: 166-198 mg/L) which was averaged across three tests. The EPA performed C-R analysis for each individual test. All three tests had acceptable curves with the EPA-calculated EC_{50} values of 220.8 mg/L (95% C.I. = 191.8 – 250.0 mg/L), 157.9 mg/L (95% C.I. = 135.9 – 180.0 mg/L), and 207.3 mg/L (95% C.I. = 176.1 – 238.5 mg/L), which were acceptable for quantitative use.

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Publication: Li (2009)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated LC_{50}: 220.8 mg/L (95% C.I. = 191.8 – 250.0 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	3.2035	0.6834	4.6875	$2.766\ e^{-6}$
e	247.6075	17.6535	14.0260	$< 2.2\ e^{-16}$

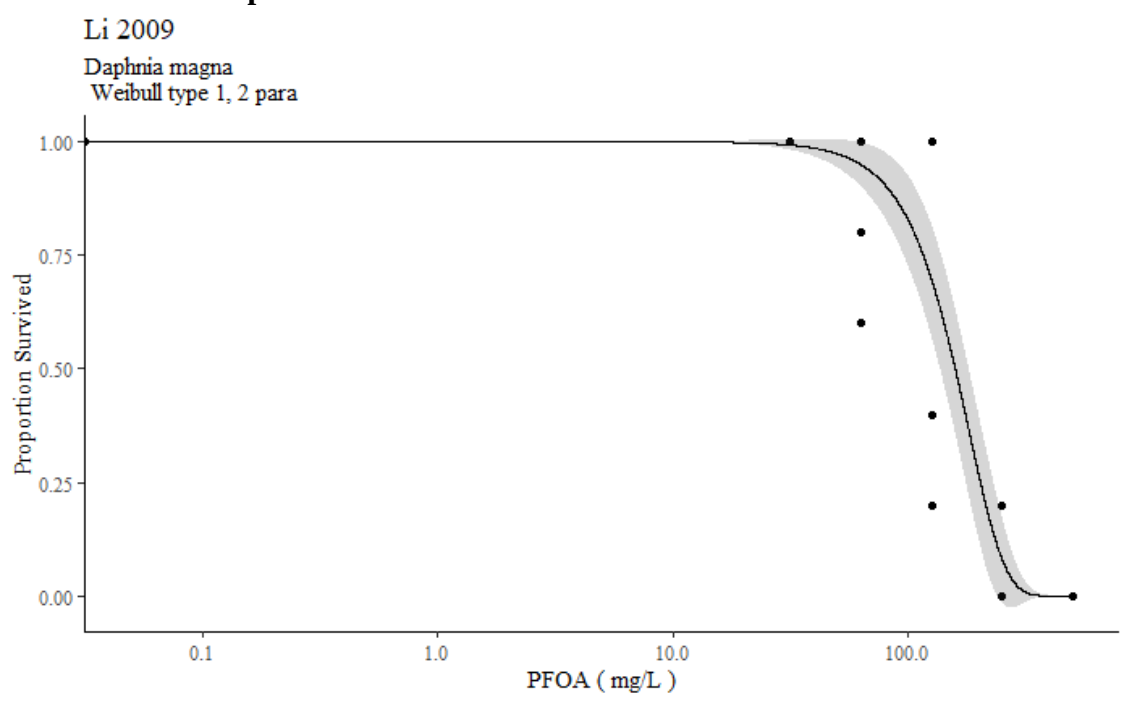
Concentration-Response Model Fit:



Publication: Li (2009)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated LC_{50}: 157.9 mg/L (95% C.I. = 135.9 – 180.0 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	2.8137	0.4368	6.4423	$1.177\ e^{-10}$
e	179.9061	12.3471	14.5707	$< 2.2\ e^{-16}$

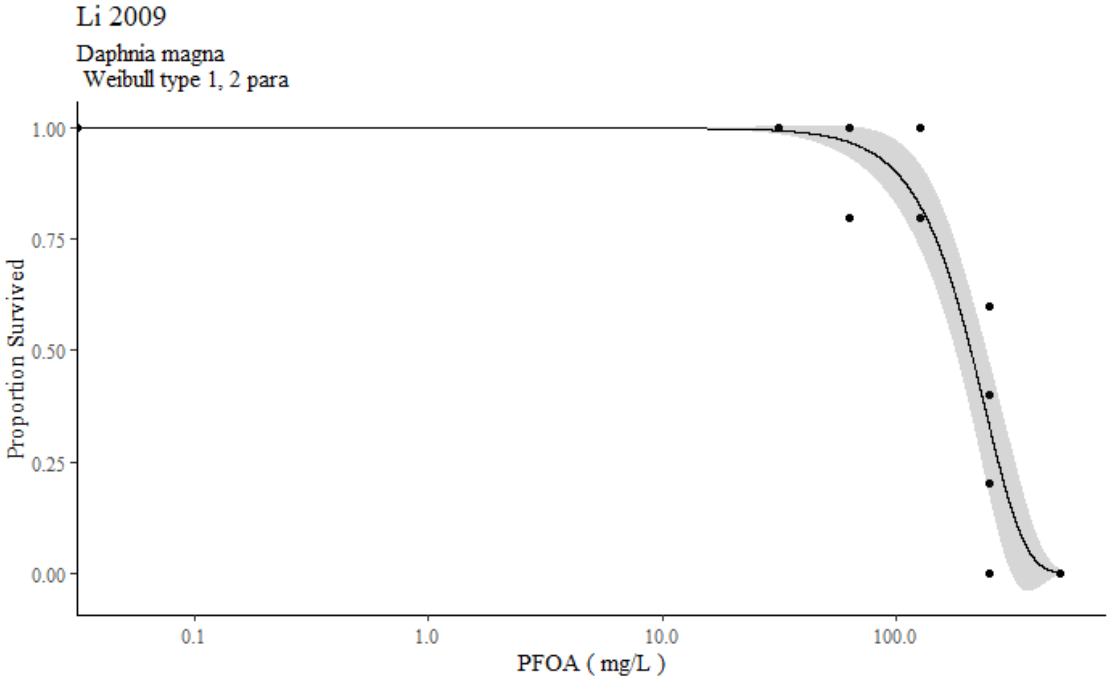
Concentration-Response Model Fit:



Publication: Li (2009)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated LC_{50}: 207.3 mg/L (95% C.I. = 176.1 – 238.5 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	2.5732	0.4477	5.7479	$9.036\ e^{-9}$
e	239.0336	19.0886	12.5223	$< 2.2\ e^{-16}$

Concentration-Response Model Fit:



Yang et al. (2014) conducted a 48-hour measured acute test of PFOA (CAS # 335-67-1, 99% purity) with *Daphnia magna*, following ASTM E729 (1993). Although the authors termed the test conditions "static", they also mentioned PFOA measurements before and after renewal; based on this distinction the test was assumed to be renewed at least once. Daphnids used for the test were donated by the Chinese Research Academy of Environmental Sciences. The daphnids were less than 24-hours old at test initiation. Dilution water was dechlorinated tap water (pH, 7.0 ± 0.5; dissolved oxygen, 7.0 ± 0.5 mg/L; total organic carbon, 0.02 mg/L; and total hardness, 190.0 ± 0.1 mg/L as $CaCO_3$). The photoperiod consisted of 12-hours of illumination at an

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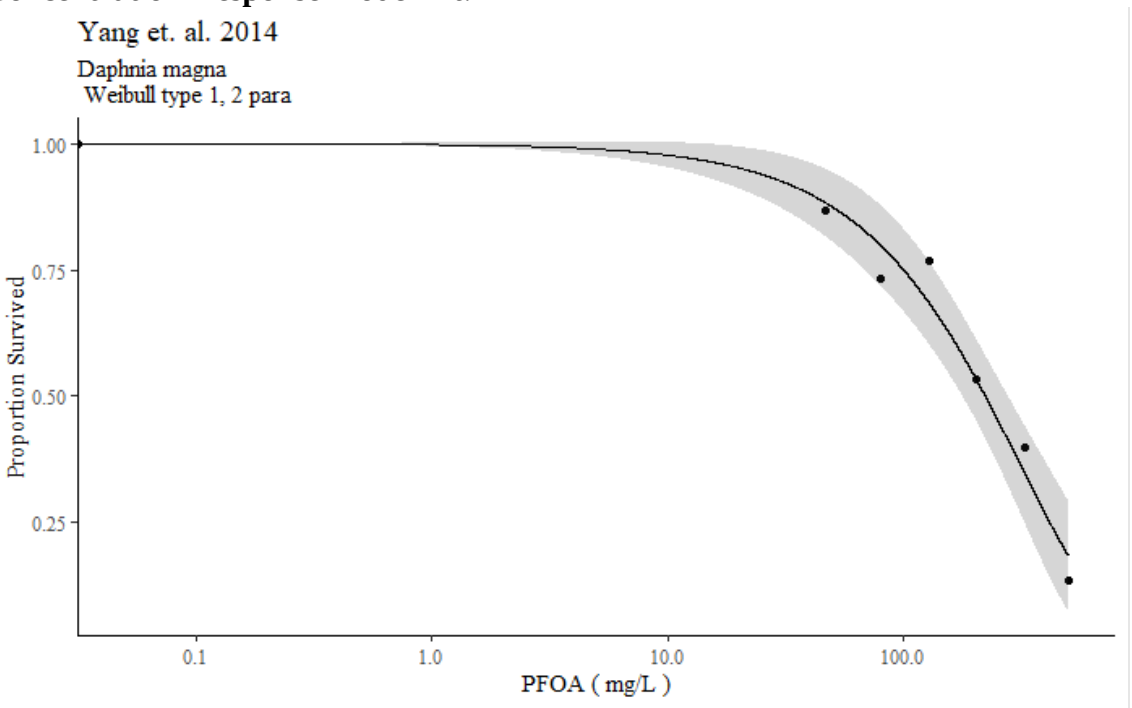
unreported intensity. A primary stock solution was prepared by dissolving PFOA in deionized water and solvent, DMSO, and proportionally diluted with dilution water to prepare the test concentrations. Exposure vessels were 200 mL beakers of unreported material type containing 100 mL of test solution. The test employed three replicates of 10 daphnids each in six test concentrations (measured in low and high treatments only) plus a negative and solvent control. Nominal concentrations were 0 (negative and solvent controls), 50, 80, 128, 204.8, 327.68 and 524.29 mg/L. The authors provided mean measured concentrations before and after renewal: 49.62 and 43.93 mg/L (lowest concentration) and 526.9 and 476.41 mg/L (highest concentration). Analyses of test solutions were performed using HPLC/MS and negative electrospray ionization. The concentration of PFOA was calculated from standard curves (linear in the concentration range of 1-800 ng/mL), and the average extraction efficiency was in the range of 70-83%. The concentrations and chromatographic peak areas exhibited a significant positive correlation ($r = 0.9987$, $p < 0.01$), and the water sample-spiked recovery was 99%. The temperature, D.O., and pH were reported as having been measured every day during the acute test, but results were not reported. Negative control and solvent control mortality were 0% each. The author-reported 48-hour LC_{50} for the study was 201.85 mg/L (95% C.I. = 134.7 - 302.5 mg/L). The EPA performed C-R analysis for the test and had an acceptable curve with an EPA-calculated LC_{50} of 222.0 mg/L PFOA (95% C.I. = 190.5 – 253.5 mg/L). The acute value was acceptable for quantitative use.

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Publication: Yang et al. (2014)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated LC_{50}: 222.0 mg/L (95% C.I. = 190.5 – 253.5 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	1.1031	0.1773	6.2226	$4.89\ e^{-10}$
e	309.4319	36.3820	8.5051	$< 2.2\ e^{-16}$

Concentration-Response Model Fit:



Barmentlo et al. (2015) performed a 48-hour static, measured acute test of PFOA (CAS # 335-67-1, >96%) with *Daphnia magna*. The authors stated the test followed OECD 202 (2004) guidelines for testing. *D. magna* used for testing were obtained from Grontmij, Amsterdam, and cultured in M4 media according to OECD 211 (2012). Test organisms were less than 24-hours old at test initiation. Dilution water was ISO medium. Experiments were conducted in 50 Ml polypropylene tubes with 20 Ml of test solution. The photoperiod consisted of 16-hours of illumination at an unreported intensity. PFOA stock was made with demineralized water. The test involved four to six replicates of five daphnids each in five test concentrations plus a

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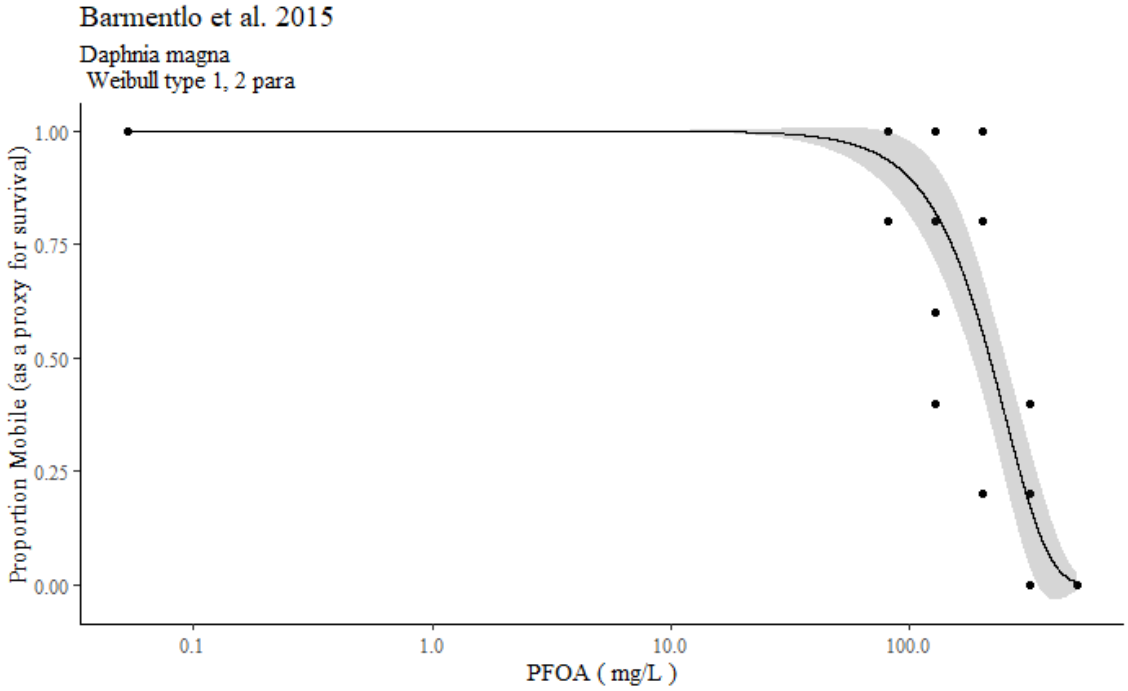
negative control. Nominal concentrations were not provided, but PFOA was measured in the control, lowest and highest test concentrations. Based on these measurements, the authors interpolated all test concentrations, 0.053 (negative control), 81, 128, 202, 318 and 503 mg/L. Test temperature was maintained at 20 ± 1°C, Ph ranged from 7.00-7.82, and D.O. ranged from 8.54-9.42 mg/L. Mortality of daphnids in the negative control was not reported. The author-reported 48-hour EC_{50} for the study was 239 mg/L (95% C.I.: 190 – 287 mg/L). The EPA performed C-R analysis for the test and had an acceptable curve with an EPA-calculated EC_{50} of 215.6 mg/L PFOA (95% C.I. = 181.7 – 249.5 mg/L). The acute value was acceptable for quantitative use.

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Publication: Barmentlo et al. (2015)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated LC_{50}: 215.6 mg/L PFOA (95% C.I. = 181.7 – 249.5 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	2.3893	0.4288	5.5728	$2.507\ e^{-8}$
e	251.3332	19.6475	12.7921	$< 2.2\ e^{-16}$

Concentration-Response Model Fit:



Ding et al. (2012a) conducted a 48-hour static, partially measured acute test on PFOA (CAS # 335-67-1; 96% purity from Sigma Aldrich) with *D. magna*. The test was performed following OECD test guideline 202 (2004) with slight modifications. *D. magna* used for testing were purchased from local suppliers and cultured for two months prior to use. Test organisms were less than 24-hours old at test initiation. Dilution water was M4 solution prepared following the OECD test guideline. The photoperiod consisted of a 16 hour:8-hour light:dark cycle at an unreported light intensity. A primary stock solution was prepared in dilution (reconstituted M4)

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water. Exposure vessels were 50 Ml polypropylene disposable tubes containing 20 Ml of test solution. The test involved four replicates of five daphnids each in six test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 0.35, 0.4, 0.45, 0.5, 0.55 and 0.6 Mm PFOA, or 0, 144.9, 165.6, 186.3, 207.0, 227.7 and 248.4 mg/L, respectively, after conversion by multiplying the Mm concentration by a molecular weight of 414.07 g/mol for PFOA. The subsequent concentrations are reported in the converted units of mg/L. Concentrations of PFOA were confirmed in the highest and lowest concentrations, though only nominal concentrations were reported. It was stated that the verified concentration was "well in line with nominal concentrations". Test temperature was maintained at 20 ± 1°C. Observations were made at 24-hours and 48-hours after test initiation. EC_{50} values were reported for both observational time periods. The 48-hour EC_{50} was reported as 211.6 mg/L with the 95% confidence levels of 184.7 - 255.5 mg/L and a NOEC of 207.0 mg/L. The EPA performed C-R analysis for the test. The EPA-calculated EC_{50} was 216.1 mg/L PFOA (95% C.I. = 206.1 – 225.9 mg/L) for *D. magna*, which was acceptable for quantitative use.

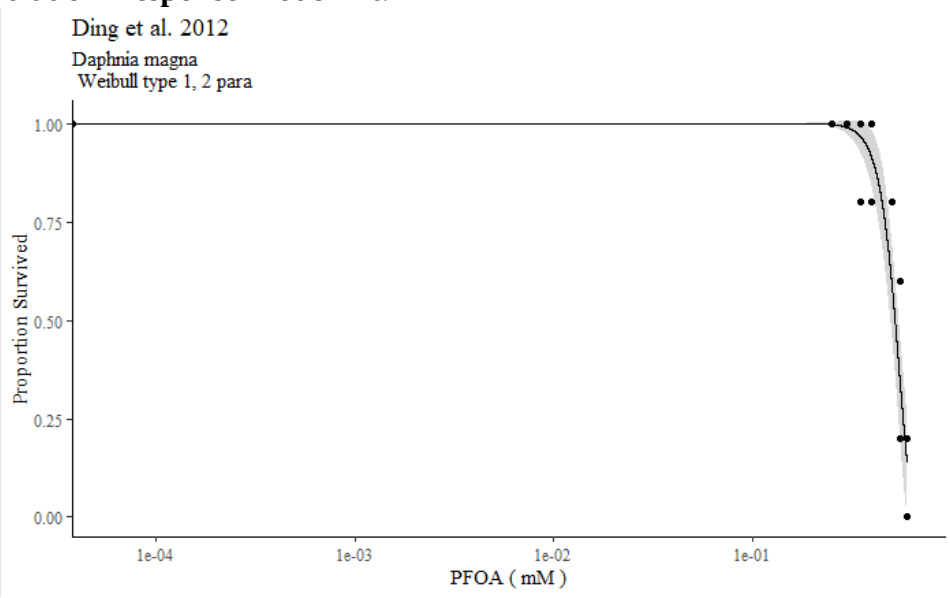
(It should be noted that these authors also conducted and reported on a similar acute toxicity test with *Chydorus sphaericus.* However, this test was not used qualitatively or quantitatively because personal correspondence with the authors indicated high control mortality. Raw data provided by the authors did not clearly show 24- and 48-hour EC_{50} data reported in the publication. Data provided by the authors contained many PFOA C-R datasets for *C. sphaericus*. Of these, the C-R dataset with nominal concentrations and 24- and 48-hour EC_{50} values that best matched those in the publication indicated high mortality in control responses. Therefore, the results of this test were not included in the PFOA aquatic life criteria document.)

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Publication: Ding et al. (2012a)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated LC_{50}: 216.1 mg/L PFOA (95% C.I. = 206.1 – 225.9 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	7.5008	1.3478	5.5650	$2.621\ e^{-8}$
e	0.5478	0.0128	42.6800	$< 2.2\ e^{-16}$

Concentration-Response Model Fit:



Lu et al. (2016) evaluated the acute toxicity of PFOA (CAS# 335-67-1, 98% purity, purchased from Tokyo Chemical Industry Co., Ltd., Tokyo, Japan) on *Daphnia magna* immobilization. Reconstituted daphnia culture media was used for both culturing and test solution preparation as described in OECD Test Guideline 202. *D. magna* cultures (originally obtained from the Chinese Center for Disease Control and Prevention (Beijing, China) were fed with the green algae *Scenedesmus obliquus* daily, maintained at 20°C and a light/dark photoperiod of 16-hour/8-hour and the medium renewed three times weekly. The 48-hour static unmeasured acute test was conducted via a modified OECD standard test procedure 202, whereby five concentration treatments (3, 10, 30, 100 and 300 mg/L) plus a blank control were

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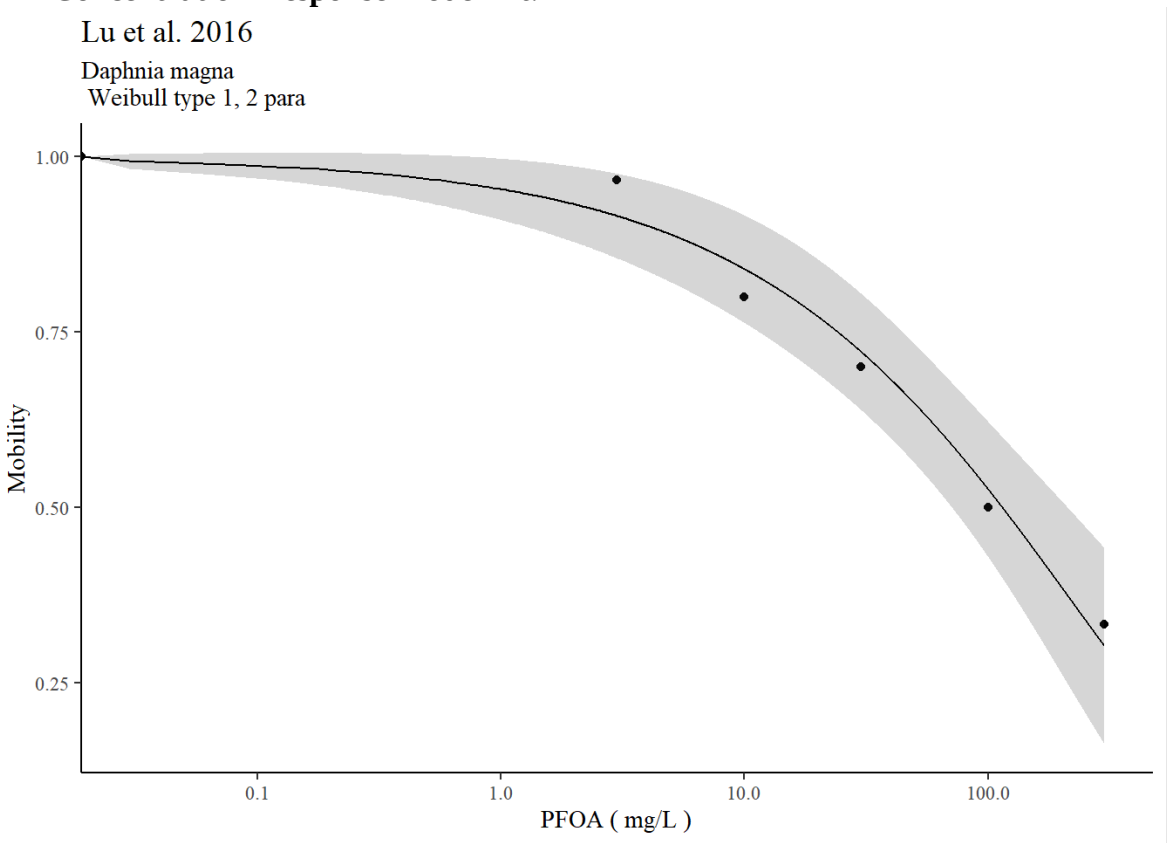
employed. Ten neonates (<24-hours old) from a designated brood were placed in a 100 Ml glass beaker containing 45 Ml test solution for each test concentration and control. Test daphnids were not fed during the testing period and each treatment was replicated three times. The status of immobilization and mortality was checked at 48 hours (daphnids unable to swim within 15 seconds after gentle agitation of the test container are considered to be immobile and those animals whose heartbeats have stopped are considered dead). The authors reported immobility/ survival to be a more sensitive endpoint than survival alone. The author-reported 48-hour EC_{50} for immobility/survival was 110.7 mg/L and the EPA-calculated 48-hour EC_{50} was 114.595 mg/L (95% C.I. = 93.71 – 135.5 mg/L).

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Publication: Lu et al. (2016)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated LC_{50}: 114.595 mg/L (95% C.I. = 93.71 – 135.5 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	0.5649	0.1050	5.3783	$7.517\ e^{-8}$
e	219.2463	68.2427	3.2127	0.0013

Concentration-Response Model Fit:



Yang et al. (2019) evaluated the acute effects of PFOA (CAS# 335-67-1, purchased from Sigma-Aldrich in St. Louis, MO) on *Daphnia magna* via a 48-hour unmeasured static exposure. *D. magna* cultures were originally obtained from the Institute of Hydrobiology of Chinese Academy of Science in Wuhan, China. Organisms were cultured in Daphnia Culture Medium according to the parameters specified in OECD Guideline 202. Protocol for all testing followed OECD Guideline 202. Cladocerans were cultured in artificial freshwater maintained at 20 ± 1°C

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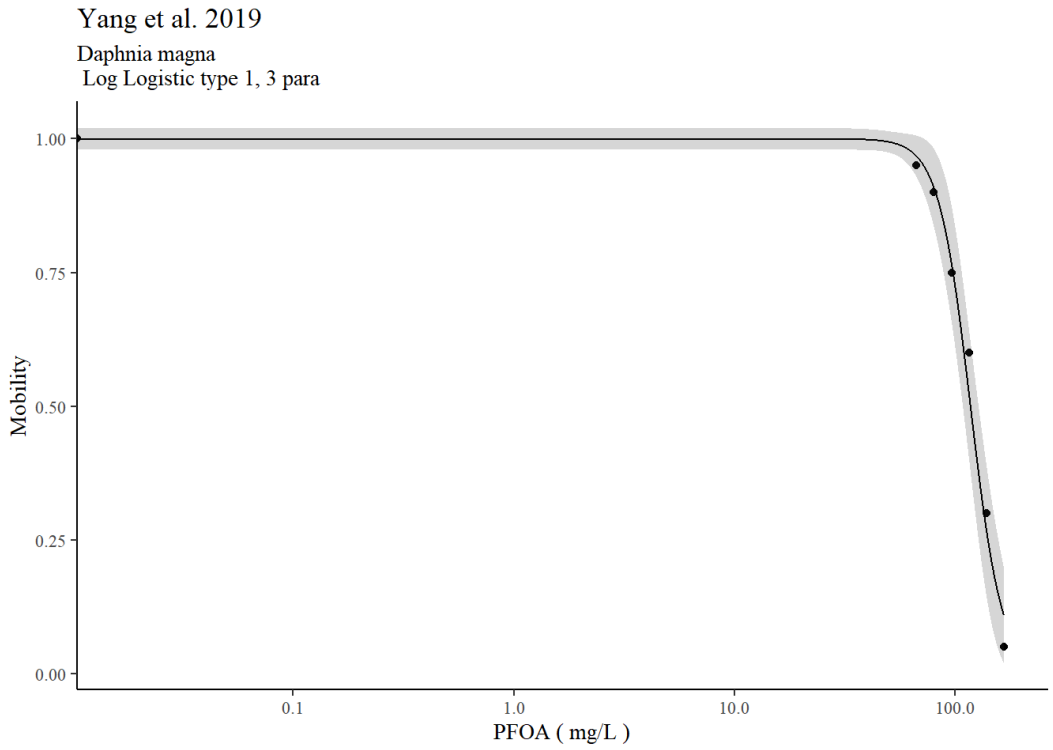
under a 16-hour:8-hour light:dark photoperiod and a light intensity of 1,000-1,500 lux at the surface of the water. Cultures were fed *Scenedesmus obliquus* daily and the water was changed twice weekly. Reported water quality parameters include total hardness of 140-250 mg/L as $CaCO_3$ and Ph of 6-8.5. Acute test concentrations included 0 (control), 0.000161, 0.000193, 0.000232, 0.000278, 0.000334 and 0.000401 mol/L (or 0 (control), 66.67, 79.92, 96.06, 115.1, 138.3 and 166.0 mg/L, respectively, given the molecular weight of the form of PFOA used in the study, CAS # 335-67-1, of 414.07 g/mol). Five neonates (12-24 hours old) were placed randomly in 100 Ml glass beakers filled with 60 Ml test solution, with four replicates per concentration. Organisms were observed for mortality at 48 hours, and the authors reported a LC_{50} of 0.000292 mol/L, or 120.9 mg/L PFOA. The EPA-calculated 48-hour LC_{50} was 117.192 mg/L (95% C.I. = 112.2 – 122.2 mg/L).

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Publication: Yang et al. (2019)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated LC_{50}: 117.192 mg/L (95% C.I. = 112.2 – 122.2 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	6.0229	1.0808	5.5724	$2.512\ e^{-8}$
d	0.9998	0.0103	96.6600	$< 2.2\ e^{-16}$
e	117.1921	4.8691	24.0685	$< 2.2\ e^{-16}$

Concentration-Response Model Fit:



Chen et al. (2022) tested the acute toxicity of ammonium perfluorooctanoic acid (APFO) to *Daphnia magna* in a 48-hour unmeasured, static experiment. In addition, the authors tested the acute effects of pristine and aged polystyrene particles, and the combined effects of these microplastics and AFPO, but only the results of the AFPO exposure are summarized here. AFPO (≥98% purity) was purchased from Shanghai Aladdin Biochemical Technology Co., Ltd., China. Organisms were purchased from Everbright Algae Species Co., China. They were housed in

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culture medium described in method OECD 202 (OECD 2004) at 20±1°C under a 12:12 light:dark cycle at 2000±200 lux. Culture medium was renewed twice a week, and organisms were fed green algae daily. The acute APFO exposure generally followed test method OECD 202 (OECD 2004). Stock solution of 50 g/L APFO was prepared by mixing the chemical with ultrapure laboratory water. For each replicate, 10 neonates were exposed to 50 Ml of test solutions with nominal concentrations of 0, 10, 50, 100, 200, and 500 mg/L APFO, made by diluting the stock solution with culture medium. There were three replicates per treatment, and test vessels were housed on a bath oscillator rotating at 150 rpm. Test organisms were not fed during the experiment. A reference toxicity test was performed with K_2CrO_7. Control mortality was less than 10% in the AFPO and reference toxicity tests. The LC_{50} and EC_{50} values were calculated using a logistic model in GraphPad Prism, version 9.2.0, and the 48-hour EC_{50} for immobility was 156.9 mg/L, which was determined to be acceptable for quantitative use.

A.2.5 Fifth most acutely sensitive genus – *Brachionus*

Zhang et al. (2013a) performed a 24-hour static test of PFOA (CAS # 335-67-1, 96% purity) with *Brachionus calyciflorus*. Organisms were neonates less than two-hours old at test initiation. All animals were parthenogenetically-produced offspring of one individual from a single resting egg collected from a natural lake in Houhai Park (Beijing, China). The rotifers were cultured in an artificial inorganic medium at 20°C (16-hour:8-hour, light:dark; 3,000 lux) for more than six months before toxicity testing to acclimate to the experimental conditions. All toxicity tests were carried out in the same medium and under the same conditions as during culture (i.e., Ph, temperature, illumination). Solvent-free stock solutions of PFOA (1,000 mg/L) were prepared by dissolving the solid in deionized water via sonication. After mixing, the primary stock was proportionally diluted with dilution water to prepare the test concentrations. Exposures were in 15 Ml, six-well cell culture plates (assumed plastic) each containing at total of

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10 Ml of test solution. The test employed seven measured test concentrations plus a negative control. Each treatment consisted of one replicate plate of 10 rotifers each in individual cells and repeated six times. Nominal concentrations were 0 (negative control), 60, 80, 100, 120, 140, 160, and 180 mg/L. PFOA concentrations were not measured in the rotifer exposures, but rather, in a side experiment using HPLC/MS. The side experiment showed that the concentration of PFOA measured every eight-hours over a 24-hour period in rotifer medium with green algae incurs minimal change in the concentration range from 0.25 to 2.0 mg/L. The acute test was conducted without green algae added to the exposure medium. Although this rotifer species has a short life span, a 24-hour unfed test is not expected to cause starvation and 0% mortality was observed at test termination in the negative control. The study reported 24-hour LC_{50} was 150.0 mg/L. The acute value was acceptable for quantitative use.

Publication: Zhang et al. (2013a)
Species: Rotifer (*Brachionus calyciflorus*)
Genus: *Brachionus*
EPA-Calculated LC_{50}: Not calculable, concentration-response data not available
Concentration-Response Model Fit: Not Applicable

A.2.6 Sixth and seventh most acutely sensitive genera – *Ligumia* and *Lampsilis* (mussels)

Hazelton (2013) and Hazelton et al. (2012) evaluated the acute effects of PFOA (96% purity) on two freshwater mussels: *Lampsilis siliquoidea* and *Ligumia recta*. Acute toxicity was observed under static conditions over a 24-hour period (<24-hour old glochidia) or renewal conditions over a 96-hour period (four to six-week-old juveniles). The authors stated that the tests followed ASTM E2455-06 (2006). Dilution water was hard reconstituted water. Photoperiod and light intensity were not reported. No details were provided regarding primary stock solution and test solution preparation. Experiments were conducted in 3.8 L glass jars of unspecified fill volume. The test employed three replicates of 150 glochidia or seven juvenile mussels each in six measured test concentrations plus a negative control (10 juveniles for the

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control treatment). Nominal concentrations were 0 (negative control), 0.005, 0.05, 0.5, 5, 50 and 500 mg/L, while corresponding mean measured concentrations were less than the limit of quantification (LOQ, specifics not provided), 0.0051, 0.0484, 0.490, 4.8, 51 and 476 mg/L PFOA, respectively. Analyses of test solutions were performed at the U.S. EPA National Exposure Research Laboratory in Research Triangle Park, NC using HPLC/MS. Measured test concentrations of PFOA were within 10% of target in water from acute tests. Recovery of PFOA standards ranged from 91.2-108%. For all acute tests, alkalinity ranged from 97 to 110 mg/L as $CaCO_3$ with a mean of 104.4 mg/L; total hardness ranged from 132 to 162 mg/L as $CaCO_3$ with a mean of 149.6 mg/L; conductivity ranged from 514 to 643 µS/cm with a mean of 556.5 µS/cm; Ph ranged from 8.05 to 8.56 with a mean of 8.46; and dissolved oxygen ranged from 8.16 to 9.46 mg/L with a mean of 8.62 mg/L (n = 12 for alkalinity and total hardness, n = 55 for all other parameters). Exposures were conducted at 20°C. Mortality of mussels in the negative control was <10% in all exposures. The 24-hour EC_{50} reported for glochidia of *L. siliquoidea* was 164.4 mg/L (95% C.I.: 116.0 – 232.8 mg/L) and for *L. recta*, 161.0 mg/L (95% C.I.: 135.0 – 192.7 mg/L). The 96-hour LC_{50} values for the juvenile *L. siliquoidea* and *L. recta* were greater than the highest test concentration (500 mg/L). The study reported 24-hour EC_{50}s for *L. siliquoidea* and for *L. recta* represent acute values acceptable for quantitative use for the two mussel species. The juvenile life stage is less sensitive, such that its LC_{50}s were not used quantitatively in SMAVs.

A.2.7 Eighth most acutely sensitive genus – *Xenopus*

Kim et al. (2013) conducted a 96-hour renewal unmeasured assay with perfluorooctanoic acid (PFOA) using the frog embryo teratogenesis assay – *Xenopus* (FETAX). PFOA stock solutions were prepared by dissolving PFOA in dimethyl sulfoxide (DMSO), and then diluting in FETAX medium for exposure solutions (DMSO did not exceed 0.15%). Adult *Xenopus* were purchased from Nasco (Fort Atkinson, WI) and housed in clear plastic aquariums with

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dechlorinated tap water at 18 ± 2°C with a 12-hour light cycle and fed three times a week. Ovulation was induced by injecting 1,000 IU of human chorionic gonadotropin just under the skin of a female in the evening. The next day, females laid eggs in 60 mm plastic dishes. The eggs were immediately fertilized in 0.1X modified Barth solution (MBS) (*Xenopus* testes were obtained from sacrificed males). Following successful fertilization, the jelly coat was removed by swirling the embryos in a 2% L-cysteine solution. The embryos were then transferred to 1X MBS containing 3% Ficoll 400. Unfertilized eggs and dead embryos were removed and maintained at 22 ± 0.5°C. Finely cleaved embryos in the blastula stage (stage 8.5) were selected, with 20-25 embryos used per concentration (nominal concentrations of 100, 500, 750, 1000 and 1,250 µM PFOA, or 41.4, 207.0, 310.6, 414.1 and 517.6 mg/L PFOA, respectively). DMSO alone (0.1%) and FETAX medium alone were used as controls. Embryos were incubated at 23°C until the end of the assay. The media were changed every day, and dead embryos were removed. At the end of the experiments, embryo mortality was recorded and surviving embryos were fixed in 4% formaldehyde to check for malformation. Head-tail lengths and malformations were analyzed to measure growth inhibition. The authors reported a 96-hour LC_{50} of 377 mg/L PFOA and the value was acceptable for quantitative use.

A.2.8 Ninth most acutely sensitive genus – *Dugesia*

Li (2008) conducted a 96-hour static, unmeasured acute toxicity test on PFOA (CAS # 3825-26-1, >98% purity) with the planarian, *Dugesia japonica* (a non-North American species). The test organisms were originally collected from Nan-shi stream located in Wu-lai, Taipei County, Taiwan in 2004 and maintained in the laboratory in dechlorinated tap water. The planarians had a body length of 0.9 ± 0.1 cm at test initiation. The dilution water was dechlorinated tap water and a primary stock solution of PFOA was prepared in the same dilution water. The photoperiod consisted of 12-hours of illumination at an unreported intensity.

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Exposure vessels were polypropylene beakers of unreported dimensions with a 50 Ml fill volume. The test employed five replicates of five planarians each in at least five test concentrations plus a negative control. Nominal test concentrations were in the range of 100-750 mg/L PFOA. The test temperature was maintained at 25 ± 1°C. No other water quality parameters were reported for test solutions. Survival of negative control animals was not reported. The study reported a 96-hour LC_{50} was 458 mg/L (95% C.I. = 427 – 491 mg/L). The acute value was acceptable for quantitative use.

Li (2009) conducted a second 96-hour static, unmeasured acute test of PFOA (ammonium salt, >98% purity) with *Dugesia japonica.* Again, the tested individuals were originally collected from Nan-shi stream located in Wu-lai, Taipei County, Taiwan in 2004 and maintained in the laboratory in dechlorinated tap water. The planarians had a body length of 0.9 ± 0.1 cm at test initiation. The dilution water was dechlorinated tap water and a primary stock solution of PFOA was prepared in the same dilution water. The photoperiod consisted of 12-hours of illumination at an unreported intensity. Exposure vessels were made of polyethylene with unreported dimensions and 50 Ml fill volume. The test employed three replicates of 10 planarians each in at least five test concentrations plus a negative control. The test was repeated three times with different test concentrations. Nominal test concentrations were in the range of 150-750 mg/L PFOA. The test temperature was maintained at 25 ± 2°C. Water quality parameters including Ph, conductivity, and D.O. were reported as having been measured at the beginning and end of each test, but the information was not provided. Organisms were not fed, and no mortality was observed in the control groups in any of the three tests. The author-reported 96-hour LC_{50} was 337 mg/L (95% C.I. = 318-357 mg/L) which was averaged across the three tests. The EPA performed C-R analysis for each individual test. Two of the tests had acceptable

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curves with the EPA-calculated LC_{50} values of 321.8 mg/L PFOA (95% C.I. = 290.6 – 353.1 mg/L) and 383.0 mg/L PFOA (95% C.I. = 347.8 – 418.2 mg/L) which were acceptable for quantitative use. The third curve had a poor concentration response and the LC_{50} (427.7 mg/L; 95% C.I. = 251.4 – 604.1 mg/L) was, therefore, not used quantitatively but considered for qualitative use only.

A.2.9 Tenth most acutely sensitive genus – *Neocaridina*

Li (2009) conducted a 96-hour acute test on PFOA (ammonium salt, >98% purity) with the freshwater shrimp species, *Neocaridina denticulata* (a non-North American species). Test conditions were static (no solution renewal), and test concentrations were unmeasured. Test organisms were obtained from an unspecified local supplier and acclimated in the laboratory for at least seven days prior to the experiments. *N. denticulata* of unspecified age were used at test initiation and were reported to be 1.3 ± 0.2 cm long. Dilution water was dechlorinated tap water. The photoperiod consisted of 12-hours of illumination at an unreported light intensity. A primary stock solution was prepared in dilution water. Exposure vessels were polypropylene beakers of unreported dimensions and 1 L fill volume. The test employed five replicates of six organisms each in at least five test concentrations plus a negative control. Each treatment was tested three different times. Nominal test concentrations were in the range of 50-1,000 mg/L PFOA. The test temperature was maintained at 25 ± 2°C. Water quality parameters including Ph, conductivity, and D.O. were reported as having been measured at the beginning and end of each test, but the information is not reported. Mortality of negative control animals was 10% for one treatment, but 0% in others. The author-reported 96-hour LC_{50} reported in the study was 454 mg/L (95% C.I.: 418-494 mg/L) which was averaged across three tests. The EPA performed C-R analysis for each individual test. All three tests had acceptable curves with the EPA-calculated LC_{50}s of 499.7

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mg/L (95% C.I. = 457.4 – 542.1 mg/L), 428.1 mg/L (95% C.I. = 396.3 – 459.9 mg/L), and 375.5 mg/L (95% C.I. = 296.5 – 454.4 mg/L), which were acceptable for quantitative use.

A.2.10 Eleventh most acutely sensitive genus – *Danio*

The acute effects of PFOA on the zebrafish, *Danio rerio*, have been reported by numerous researchers. **Ye et al. (2007)** evaluated the acute effects of perfluorooctanoic acid (PFOA, purity not reported) on *D. rerio* in a 96-hour static-renewal test with unmeasured treatment concentrations. The PFOA stock solution of 1,500 mg/L was maintained at a Ph of 8.2 with phosphate buffer and test substances were agitated in the reconstituted water by ultrasonification. The solutions were stored at 4 ± 1°C. No added solvents were used to formulate test concentrations from the stock solution. Test fish (AB strain) were obtained from the School of Life Sciences at Fandan University, Shanghai, China. Breeding fish (1.5 years old) were fed live brine shrimp twice daily and kept with a light:dark period of 14:10 in aquaria containing aerated natural water. The Ph ranged from 7 to 8.5 and water temperature was maintained at 26 ±1°C in test solutions. Embryos were obtained from spawning adults, usually five male and three female. For each toxicant concentration, 48 embryos were randomly distributed into each well of 24-well polystyrene multi-well plates, with four eggs per well. Each well was filled with 2.5 mL of test solution, which was totally renewed daily by transferring embryos in newly cleaned wells. Nominal exposure concentrations were 0 (control), 1.5, 45, 100, 400, 800 and 1,500 mg/L PFOA. The multi-well plates were kept at 26 ± 1°C, with a photoperiod of 16:8-hour light:dark. The observations of embryos were made at distinct stages, which represent important steps of zebrafish development. The author reported 96-hour LC_{50} was 499 mg/L PFOA. The EPA could not calculate an LC_{50} value because sufficient C-R data were not reported by Ye et al. (2007). The author-reported LC_{50} value (i.e., 499 mg/L) was acceptable for quantitative use in deriving the freshwater acute PFOA criterion.

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Hagenaars et al. (2011) exposed *D. rerio* embryos to PFOA (CAS #335-67-1, purity ≥97%) under static unmeasured conditions for 120 hours. The PFOA was dissolved in medium-hard reconstituted laboratory water, which was aerated and kept at 26°C until use (no solvent). Adult wildtype zebrafish (breeding stock) were obtained from a commercial supplier (Aqua hobby, Heist-op-den-berg, Belgium) and kept in aerated and biologically filtered medium-hard reconstituted freshwater. Four males and four females were used for egg production, with fertilized eggs collected in egg traps within 30 minutes of spawning. Eggs were transferred to the test solutions within 60 minutes after spawning. Eggs with anomalies or damaged membranes were discarded, and fertilized eggs were separated from the non-fertilized eggs using a stereomicroscope. Twenty normally shaped fertilized eggs per exposure concentration were divided over a 24-well plastic plate and each embryo was placed individually in 2 mL of the test solution. The remaining four wells were filled with clean water and used for the control eggs. Two replicate plates were used for each exposure concentration resulting in 40 embryos per exposure condition at the beginning of the experiment. The 24-well plates were covered with a self-adhesive foil, placed in an incubation chamber at 26 ± 0.3°C, Ph 7.2-7.5 and subjected to a 14-hour:10-hour, light:dark cycle. A test was considered valid if more than 90% of the controls successfully hatched and showed neither sublethal nor lethal effects. The authors reported a 96-hour LC_{50} of >500 mg/L PFOA and was classified as quantitative.

Zhao et al. (2016) performed a 96-hour static acute PFOA (98% purity; obtained from J&K Scientific) test on zebrafish, *D. rerio*. Authors stated that the test followed OECD Guideline 203. Zebrafish were obtained from Wuhan Institute of Hydrobiology at the Chinese Academy of Science. Test organisms were three months old and 2.5-3.0 cm in length at test initiation. The dilution water used for testing was not provided. Experiments were conducted in 5-liter glass fish

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tanks filled with three liters of solution. The photoperiod and preparation of test solutions was not described. The test involved 10 fish in five unmeasured test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 72.3, 86.8, 104.2, 125.0 and 150.0 mg/L. However, nominal concentrations of 50, 100, 200 mg/L PFOA were confirmed by HPLC in a side study without organisms. Measured concentrations in the side study were 80-120 percent of nominal. Test temperature was maintained at 23 ± 2°C, but other water quality parameters were not reported. There was no mortality in the negative control at the end of the exposure period. The author-reported 96-hour LC_{50} was 118.82 mg/L (95% C.I. = 107.46 – 134.33 mg/L). The EPA performed C-R analysis for the test and calculated an LC_{50} of 122.5 mg/L PFOA (95% C.I. = 119.1 – 125.8 mg/L), which was acceptable for quantitative use in deriving the acute PFOA freshwater criterion. *D. rerio* embryos (4 hours post-fertilization; hpf) were also subjected to PFOA by **Godfrey et al. (2017a)** in a 96-hour acute toxicity test using static renewal exposures that were not analytically confirmed. Stock solutions were prepared by dissolving PFOA in 1 L of reverse osmosis (RO) water containing 12.5 µL Replenish (Seachem Laboratories Inc.) and then adjusted to neutral Ph (7-7.5). Adult zebrafish, AB wild-type, were maintained at a water temperature of 28 ± 1°C and a photoperiod of 14-h L:10-h D. Fish were fed twice daily, *Artemia* nauplii in the morning and Tetramin in the afternoon, and genders were kept separate overnight at a ratio of 2 males:1 female. Randomly collected embryos (20 per concentration, gastrula stage, 4-hpf) were placed in plastic petri dishes containing 25 Ml of exposure solution for 96-hours at 28°C. Each test consisted of a minimum of two replicates per dose and test solutions were renewed daily (nominal exposure solutions ranged from 250-1,000 mg/L PFOA). The author-reported 96-hour LC_{50} was 473.0 mg/L PFOA which was averaged across four tests. The EPA performed C-R analysis for each individual test. Three tests had

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acceptable curves with the EPA-calculated LC_{50}s of 548.0 mg/L (95% C.I. = 530.6 – 565.5 mg/L), 508.5 mg/L (95% C.I. = 471.4 – 545.6 mg/L), and 547.0 mg/L (95% C.I. = 516.0 – 578.0 mg/L), which were acceptable for quantitative use. The fourth test had an unacceptable curve and therefore the EPA-calculated LC_{50} of 560.1 mg/L PFOA (95% C.I. = 556.4 – 563.8 mg/L) was not used.

Stengel et al. (2017, 2018) exposed *D. rerio* embryos to PFOA for 96-hours using renewal unmeasured procedures as specified in OECD (2013) guidelines. PFOA stock and exposure solutions were prepared in reconstituted laboratory water. All adult zebrafish used for breeding were wild-type descendants of the "Westaquarium" strain and obtained from the Aquatic Ecology and Toxicology breeding facilities at the University of Heidelberg. Details of zebrafish maintenance, egg production and embryo rearing are provided as described previously (Kimmel et al. 1995, 1988; Nagel 2002; Spence et al. 2006; Wixon 2000) and have been updated for the purpose of the zebrafish embryo toxicity test by Lammer et al. (2009). Embryos were exposed at the latest from 1 hpf in glass vessels, which had been preincubated (saturated) for at least 24 hours, to a series of nominal PFOA dilutions (0, 400, 512, 640, 800 and 1,000 mg/L). After verifying fertilization success, embryos were individually transferred to the wells of 24-well plates, which had been pre-incubated with 2 mL of the test solution per well for 24 hours prior to the test start and kept in an incubator at 26.0 ± 1.0°C under a 14-hour:10-hour light:dark regime. In order to prevent evaporation or cross-contamination between the wells, the plates were sealed with self-adhesive foil. Embryo tests were classified as valid if the mortality in the negative control was ≤10%, and if the positive control (3,4-dichloroaniline) showed mortalities between 20% and 80%. All fish embryo tests were run in three independent replicates. The author-reported 96-hour LC_{50} was 759 mg/L PFOA. The EPA performed C-R analysis for the

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test and had an acceptable curve with an EPA-calculated LC_{50} of 806.6 mg/L (95% C.I. = 773.6 – 839.6 mg/L) and was determined to be quantitatively acceptable for criterion derivation.

Corrales et al. (2017) exposed *D. rerio* embryos to PFOA for 96-hours employing static unmeasured procedures (U.S. EPA 2002, OECD 2013). Tropical 5D wild type adult zebrafish were kept at a density of less than four fish per liter in a z-mod recirculating system with water (Ph 7.0, 260 ppm Instant Ocean) maintained at 26-28°C and a 16-hour:8-hour light/dark cycle. Zebrafish were fed twice daily with brine shrimp (*Artemia sp*. Nauplii) and once per day with TetraMin Tropical Flakes. Sexually mature fish were bred to produce embryos for toxicity studies. Glass beakers were used as experimental units; 15 zebrafish embryos in 100 Ml beakers containing 30 ml test solution. Before the start of each experiment, all solutions were titrated to Ph 7.5 following standard methods. General water chemistry measures (e.g., alkalinity, total hardness, dissolved oxygen, and temperature) were also routinely monitored (assume same culture and test physico-chemical test conditions). The author-reported 96-hour LC_{50} was 24.6 mg/L PFOA. The EPA-calculated LC_{50} was 22.77 mg/L PFOA (95% C.I. = 13.30 – 32.20 mg/L), which was acceptable for quantitative use. This LC_{50} value, however, was excluded from derivation of the acute criterion because a comparative assessment between this LC_{50} value and the other seven quantitatively-acceptable zebrafish LC_{50} values available (Ye et al. 2007; Zhao et al. 2016; Godfrey et al. 2017a; Hagenaars et al. 2011; Stengel et al. 2017, 2018), indicated that the LC_{50} reported by Corrales et al. (2017) was an outlier, falling out more than five times lower than the next lowest *D. rerio* LC_{50} value (Zhao et al. 2016) and nearly 20 times lower than the final *D. rerio* SMAV.

A.2.11 Twelfth most acutely sensitive genus – *Pimephales*

The **3M Company (2000a)** conducted a 96-hour static, unmeasured acute toxicity test with the fathead minnow, *Pimephales promelas*, and PFOA (CAS # 335-67-1). The toxicant was

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part of the 3M production and was characterized as a mixture of PFOA (95-98% of the compound) and perfluorochemical inert compounds (1-5% of the compound). No specific test protocol was identified. A stock of PFOA was made by dissolving the test substance with NaOH and diluting the stock with carbon-filtered well water to make five test concentrations (690, 750, 810, 870 and 930 mg/L) plus a control (well water only). Exposures were conducted in glass beakers with 5 L of test solution and five fish per beaker (0.5 g/L fish loading). There were two replicates for each treatment. Test conditions throughout the experiment varied little (D.O.: 6.1-7.7 mg/L; Ph: 7.5-7.7; 19-20℃). No mortality occurred in the control and PFOA treatments ≤750 mg/L. The author-reported 96-hour LC_{50} was 843 mg/L. The EPA performed C-R analysis for the test. The EPA-calculated LC_{50} was 852.7 mg/L PFOA (95% C.I. = 834.4 – 870.9 mg/L), which was acceptable for quantitative use and was used for criterion derivation.

Corrales et al. (2017) also evaluated the acute toxicity of PFOA to the fathead minnow (*Pimephales promelas*). Embryos were exposed to PFOA for 96-hours employing static unmeasured procedures (U.S. EPA 2002, OECD 2013). Fish were housed in a flow-through system supplied with aged, dechlorinated tap water at a constant temperature of 25 ±1°C under a 16-hour:8-hour light/dark photoperiod. They were fed twice daily with brine shrimp (*Artemia sp*. Nauplii) and TetraMin Tropical Flakes. Individuals were aged to at least 120 days before breeding at which time they were placed in tanks in a 1:4-5 male to female ratio. Embryos were collected, and within 24 hours post hatched larvae were used for toxicity studies. Glass beakers were used as experimental units; 10 fathead minnow larvae were placed in each 500 Ml beaker containing 200 ml test solution. Before the start of each experiment, all solutions were titrated to Ph 7.5 following standard methods. General water chemistry measures (e.g., alkalinity, total hardness, dissolved oxygen, and temperature) were also routinely monitored (assume same

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culture and test physico-chemical test conditions). The reported 96-hour LC_{50} was 413.2 mg/L PFOA and was determined to be quantitatively acceptable for criterion derivation.

A.2.12 Thirteenth most acutely sensitive genus – *Hyla*

Tornabene et al. (2021) conducted an acute PFOA (purchased from Sigma Aldrich, Catalog # 171468-25G; purity not provided) toxicity test with the gray treefrog, *Hyla versicolor*. The acute test followed standard 96-hour acute toxicity test guidance (U.S. EPA 2002; ASTM 2017). Frog egg masses were collected from the field in the wetlands of Indiana near the campus of Purdue University. Collected egg masses were raised outdoors in 200 L polyethylene tanks filled with well water. Experiments began when frogs reached Gosner stage 26, defined as when larvae are free swimming and feeding. Before test initiation larvae were acclimated to test conditions (21℃ and 12-hour:12-hour light:dark photoperiod) for 24 hours. A stock solution of PFOA (2,000 mg/L) was made in UV-filtered well water and diluted with well water to reach test concentrations (ranged from 0-2,000 mg/L PFOA). Test concentrations were not measured in test solutions based on previous research that demonstrated limited degradation under similar conditions. Larva were transferred individually to 250 Ml plastic cups with 200 Ml of test solution and were not fed during the exposure period. There were nine to 10 replicates for each treatment and no mortality occurred in the controls. The author reported 96-hour LC_{50} was 557 mg/L and the EPA-calculated 96-hour LC_{50} values was 646.2 mg/L (95% C.I. = 588.0 – 704.4 mg/L), which was acceptable for quantitative use. Note, the authors also reported a qualitatively acceptable test for the same species (Gosner stage 40) that is described in Table G.1.

A.2.13 Fourteenth most acutely sensitive genus – *Lepomis*

The **DuPont Haskell Laboratory (2000)** evaluated the acute toxicity of ammonium perfluorooctanoate (APFO, 99% purity) to the bluegill sunfish, *Lepomis macrochirus*. The static unmeasured GLP study exposed 2.1 cm fish for 96 hours (dilution water not identified). Fish

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used in this study were not fed approximately 24-hours prior to and during the test. Bluegill sunfish were assigned to the test chambers using random numbers. Nominal APFO concentrations were 262, 328, 410, 512, 640, 800 and 1,000 mg/L. Glass aquaria (20L) containing 10 L of test solution were employed. Positions of test chambers in the water bath used to maintain constant temperature were assigned using random numbers. Ten fish were added to each replicate using random numbers (2 replicates per concentration; total 20 fish per concentration). A photoperiod of 16 hours light (312-344 lux) versus eight hours darkness was employed with 25 minutes of transitional light (<2.15 lux) preceding and following the 16-hour light interval. Observations for mortality and behavioral effects were made daily. All chemical and physical parameters were within expected ranges. Total alkalinity and EDTA total hardness of the dilution water control were 79 mg/L $CaCO_3$ and 76 mg/L $CaCO_3$, respectively. During the test, dissolved oxygen concentrations ranged from 6.7-8.5 mg/L, Ph ranged from 6.9-7.4, and temperature ranged from 21.4-22.1°C. No fish died in the controls. The authors reported a 96-hour LC_{50} of 634 mg/L APFO. The EPA performed C-R analysis for the test and had an acceptable curve with an EPA-calculated LC_{50} of 664.0 mg/L (95% C.I. = 631.4 – 696.7 mg/L), which was determined to be quantitatively acceptable for criterion derivation.

A.2.14 Fifteenth most acutely sensitive genus – *Physella*

Li (2009) conducted a 96-hour static unmeasured acute test on PFOA (ammonium salt, >98% purity) with the snail species, *Physella acuta* (Note: formerly called *Physa acuta*). The test organisms were collected from a ditch located in Shilin of Taipei City in June 2005. Snails were fed with lettuce and half of the culture medium was changed with dechlorinated water every two weeks, implying a holding time of greater than two weeks. Snails of mixed ages (shell length 0.6 ± 0.2 cm) were used at test initiation. The dilution water was dechlorinated tap water, and a primary stock solution of PFOA was prepared in the same dilution water. The photoperiod

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consisted of 12-hours of illumination at an unreported intensity. Exposure vessels were made of polyethylene with unreported dimensions and 1 L fill volume. The test employed five replicates of six snails each in at least five test concentrations plus a negative control. Nominal test concentrations were in the range of 100-1,000 mg/L PFOA. The test temperature was maintained at 25 ± 2°C. Water quality parameters including pH, conductivity, and D.O. were reported as having been measured at the beginning and end of each test, but the information is not reported. Organisms were not fed, and no animals died in the control groups. The author-reported 96-hour LC_{50} was 672 mg/L (95% C.I.: 635-711 mg/L) which was averaged across three tests. The EPA performed C-R analysis for each individual test. All three tests had acceptable curves with the EPA-calculated LC_{50}s of 762.0 mg/L (95% C.I. = 706.1 – 817.9 mg/L), 659.9 mg/L (95% C.I. = 607.9 – 711.8 mg/L), and 628.3 mg/L (95% C.I. = 582.9 – 673.7 mg/L), which were acceptable for quantitative use.

A.2.15 Sixteenth most acutely sensitive genus – *Ambystoma*

Tornabene et al. (2021) conducted acute toxicity tests with three species of salamanders in the genus *Ambystoma* and PFOA (purchased from Sigma Aldrich, Catalog # 171468-25G; purity not provided). Acute tests followed standard 96-hour acute toxicity test guidance (U.S. EPA 2002; ASTM 2017). The three test species (Jefferson salamander, *Ambystoma jeffersonianum*; small-mouthed salamander, *A. texanum*; eastern tiger salamander, *A. tigrinum*) were collected from the field in the wetlands of Indiana near the campus of Purdue University. Collected egg masses were raised outdoors in 200 L polyethylene tanks filled with well water. Experiments began when salamanders reached Harrison stage 40, defined as when larvae are free swimming and feeding. Before test initiation larvae were acclimated to test conditions (21°C and 12-hour:12-hour light:dark photoperiod) for 24 hours. An additional acute test with Harrison stage 45 small-mouthed salamanders was run to determine if toxicity varied between life stages.

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A stock solution of PFOA (2,000 mg/L) was made in UV-filtered well water and diluted with well water to reach test concentrations (ranged from 0-2,000 mg/L PFOA). Test concentrations were not measured in test solutions based on previous research that demonstrated limited degradation under similar conditions. Larva were transferred individually to 250 Ml plastic cups with 200 Ml of test solution and were not fed during the exposure period. The number of replicates varied by species, life stage and treatment; five replicates per treatment for Jefferson salamander and Harrison stage 45 small-mouthed salamander, five to seven replicates per treatment for Harrison stage 40 small-mouthed salamander, and 20 replicates in the control and 10 replicates in each treatment for eastern tiger salamander. Only one salamander larva died in the controls across all tests (eastern tiger salamander test). acute values from the four tests include:

- **Jefferson salamander**: The author-reported 96-hour LC_{50} was 1,070 mg/L. The EPA was unable to fit a C-R model with significant parameters and relied on the author reported value as quantitatively acceptable.
- **Harrison stage 40 small-mouthed salamander**: The author-reported 96-hour LC_{50} was 474 mg/L. The EPA-calculated LC_{50} was 407.3 mg/L (95% C.I. = 303.7 – 0.510.9 mg/L), which was acceptable for quantitative use.
- **Harrison stage 45 small-mouthed salamander**: The author-reported 96-hour LC_{50} was 1,000 mg/L. The EPA was unable to fit a C-R model with significant parameters and relied on the author-reported value as quantitatively acceptable; however, the LC_{50} from this test was more than two times greater than the Harrison stage 40 small-mouthed salamander indicating the Harrison stage 45 was a relatively tolerant life stage. As a result, the LC_{50} from this test was not used in the SMAV calculation for *A. texanum*.
- **Eastern tiger salamander**: The author-reported 96-hour LC_{50} was 752 mg/L. Concentration-response data from this test lacked partial effects and the EPA was

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unable to fit a C-R model with significant parameters and relied on the author reported value as quantitatively acceptable.

A.2.16 Seventeenth most acutely sensitive genus – *Anaxyrus*

Tornabene et al. (2021) conducted acute PFOA (purchased from Sigma Aldrich, Catalog # 171468-25G; purity not provided) toxicity tests with the American toad, *Anaxyrus americanus*. The acute tests followed standard 96-hour acute toxicity test guidance (U.S. EPA 2002; ASTM 2017). The toad egg masses were collected from the field in the wetlands of Indiana near the campus of Purdue University. Collected egg masses were raised outdoors in 200 L polyethylene tanks filled with well water. Experiments began when frogs reached Gosner stage 26, defined as when larvae are free swimming and feeding. An additional acute test with Gosner stage 41 was conducted to determine if toxicity varied between life stages. Before test initiation larvae were acclimated to test conditions (21℃ and 12-hour:12-hour light:dark photoperiod) for 24 hours. A stock solution of PFOA (2,000 mg/L) was made in UV-filtered well water and diluted with well water to reach test concentrations (ranged from 0-2,000 mg/L PFOA). Test concentrations were not measured in test solutions based on previous research that demonstrated limited degradation under similar conditions. Larva were transferred individually to 250 Ml plastic cups with 200 Ml of test solution and were not fed during the exposure period. The number of replicates varied by treatment for both tests; 10 replicates for each treatment except the 1,750 mg/L PFOA exposure which had nine replicates. No mortality occurred in any of the control groups. The authors did not find a significant difference between the life stages of the American toad, so results of the two tests were pooled to determine the 96-hour author-reported LC_{50} of 711 mg/L. The EPA-calculated 96-hour LC_{50} value was 781.4 mg/L (95% C.I. = 748.3 – 814.4 mg/L) for the Gosner stage 26 test and was 806.6 (95% C.I. = 760.6 – 852.6 mg/L) mg/L for the Gosner stage 41 test, both of which were quantitatively acceptable for use.

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A.2.17 Eighteenth most acutely sensitive genus – *Lithobates*

Flynn et al. (2019) evaluated the acute effects of PFOA (CAS# 335-67-1, purchased from Sigma-Aldrich) on the American bullfrog (*Lithobates catesbeiana*, formerly, *Rana catesbeiana*) during a 96-hour static unmeasured study. Testing followed Purdue University's Institutional Animal Care and Use Committee Guidelines Protocol #16010013551. American bullfrog eggs were taken from a permanent pond in the Martell Forest outside of West Lafayette, Indiana. The eggs from a single egg mass were acclimated in 100 L outdoor tanks filled with 70 L of aged well water and covered with a 70% shade cloth. Once hatched, tadpoles were fed rabbit chow and TetraMin *ad libitum* and were acclimated to laboratory conditions for 24 hours before testing (21ºC and a 12-hour:12-hour light:dark photoperiod). A 2,000 mg/L PFOA stock solution was prepared with reverse osmosis water to produce 12 nominal test concentrations of PFOA [0 (control), 10, 100, 250, 500, 750, 1,000, 1,250, 1,500, 1,750, 2,000 and 2,500 mg/L]. Each test treatment contained 10 replicates with one Gosner Stage 25 tadpole in each 250 Ml plastic tub. Mortality was monitored twice daily. The author reported a 96-hour LC_{50} value of 1,004 mg/L PFOA. The EPA performed C-R analysis for the test and the EPA-calculated 96-hour LC_{50} was 1,006 mg/L (95% C.I. = 992.8 – 1,018 mg/L).

Tornabene et al. (2021) conducted acute PFOA (purchased from Sigma Aldrich, Catalog # 171468-25G; purity not provided) toxicity tests with four species of frogs in the genus *Lithobates* (formerly, *Rana*). Acute tests followed standard 96-hour guidance (U.S. EPA 2002; ASTM 2017). The four test species (American bullfrog, *Lithobates catesbeiana*; green frog, *L. clamitans*; northern leopard frog, *L. pipiens*; wood frog, *L. sylvatica*) were collected from a field in the wetlands of Indiana near the campus of Purdue University. Collected egg masses were raised outdoors in 200 L polyethylene tanks filled with well water. Experiments began when frogs reached Gosner stage 26, defined as when larvae are free swimming and feeding. Before

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test initiation larvae were acclimated to test conditions (21℃ and 12-hour:12-hour light:dark photoperiod) for 24 hours. A stock solution of PFOA (2,000 mg/L) was made in UV-filtered well water and diluted with well water to reach test concentrations (ranged from 0-2,000 mg/L PFOA). Test concentrations were not measured in test solutions based on previous research that demonstrated limited degradation under similar conditions. Larva were transferred individually to 250 mL plastic cups with 200 mL of test solution and were not fed during the exposure period. The number of replicates varied by species and treatment; 30 replicates in the control and five to 20 replicates in each treatment for American bullfrog, 10 replicates for each treatment for green frog, northern leopard frog and wood frog. No mortality occurred in any of the control groups. Acute values from the four tests include:

- **American bullfrog**: The author-reported 96-hour LC_{50} was 1,060 mg/L. The EPA-calculated LC_{50} was 1,035 mg/L (95% C.I. = 1,020 – 1,049 mg/L), which was acceptable for quantitative use.
- **Green frog**: The author-reported 96-hour LC_{50} was 1,070 mg/L. The EPA was unable to fit a C-R model with significant parameters and relied on the author reported value as quantitatively acceptable.
- **Northern leopard frog**: The author-reported 96-hour LC_{50} was 752 mg/L. The EPA-calculated LC_{50} was 751.7 mg/L (95% C.I. = 713.0 – 790.5 mg/L), which was acceptable for quantitative use.
- **Wood frog**: The author-reported 96-hour LC_{50} was 999 mg/L. The EPA was unable to fit a C-R model with significant parameters and relied on the author reported value as quantitatively acceptable.

A.2.18 Nineteenth most acutely sensitive genus – *Oncorhynchus*

The acute effects of ammonium perfluorooctanoate (APFO, 99.4% purity) to *Oncorhynchus mykiss* were investigated by researchers at the **DuPont Haskell Laboratory (2000)**. The static measured GLP study exposed 2.8 cm fish for 96-hours (dilution water not

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identified). Rainbow trout used in this study were not fed approximately 29-hours prior to and during the test. Rainbow trout were assigned to the test chambers using random numbers. The addition of fish to the test solutions was initiated approximately 41 minutes after test solution mixing was completed. Mean measured concentrations of ammonium perfluorooctanoate were 554, 1,090, 2,280, 4,560 and 9,360 for the 625, 1,250, 2,500, 5,000 and 10,000 mg/L nominal dose levels, respectively (measured directly by high performance liquid chromatography/tandem mass spectrometry). Control solutions showed no detectable concentrations of ammonium perfluorooctanoate. All test substance solutions were clear and colorless with no insoluble test substance present during the test. Test chambers were stainless steel aquaria that held approximately 9 L of test solution. Two replicate test chambers were used per test concentration with 10 fish in each chamber (total of 20 fish per concentration). Each chamber was covered with a glass plate to prevent fish from escaping. Mortality and behavioral observations were made at test start, every 24-hours thereafter, and at test end. All chemical and physical parameters for the definitive test were within expected ranges. Total alkalinity and EDTA total hardness of the dilution water control were 49 mg/L $CaCO_3$ and 122 mg/L $CaCO_3$, respectively. During the test, dissolved oxygen concentrations ranged from 7.5-11.2 mg/L, pH ranged from 7.1-7.2, and mean temperature was 11.8°C (range 11.6-12.1°C). A photoperiod of 16 hours light (approximately 199-450 lux) and eight hours darkness was employed, which included 30 minutes of transitional light (11-157 lux) preceding and following the 16-hour light interval. The authors reported a 96-hour LC_{50} of 4,001 mg/L APFO and no mortality or sublethal effects were observed at concentrations ≤2,500 mg/L APFO. Unlike Colombo et al. (2008), DuPont Haskell Laboratory (2000) did not observe any ammonia toxicity resulting from the APFO test salt, perhaps a result of the relatively lower pH and temperature used by DuPont Haskell Laboratory

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(2000), which decreased the proportion of un-ionized ammonia. Results of this study were considered quantitatively acceptable for use in criterion derivation.

Appendix B Acceptable Estuarine/Marine Acute PFOA Toxicity Studies

B.1 Summary Table of Acceptable Quantitative Estuarine/Marine Acute PFOA Toxicity Studies

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Salinity (ppt)	Effect	Author Reported Effect Conc. (mg/L)	EPA Calculated Effect Conc. (mg/L)	Final Effect Conc. (mg/L)[e]	Species Mean Acute Value (mg/L)	Reference
Purple sea urchin (embryo), *Strongylocentrotus purpuratus*	S, M	96 hours	PFOA 95%	-	15	30	EC50 (normal development)	19	20.63	**20.63**	20.63	Hayman et al. 2021
Mediterranean mussel (larva), *Mytilus galloprovincialis*	S, U	48 hours	PFOA Unreported	7.9-8.1	16	36	EC50 (malformation)	>1	-	>1[c]	-	Fabbri et al. 2014
Mediterranean mussel (embryo), *Mytilus galloprovincialis*	S, M	48 hours	PFOA 95%	-	15	30	EC50 (normal and surviving)	9.98	17.58	**17.58**	17.58	Hayman et al. 2021
Mysid (3-days old), *Americamysis bahia*	S, M	96 hours	PFOA 95%	-	20	30	LC_{50}	24	-	**24**	24	Hayman et al. 2021
Mysid (neonate, <24 hours), *Siriella armata*	S, U	96 hours	PFOA 96%	-	20	-	LC_{50}	15.5	-	**15.5**	15.5	Mhadhbi et al. 2012

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

[b] Values in bold used in the SMAV calculation

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B.2 Detailed Study Summaries of Acute Saltwater PFOA Toxicity Studies Considered for Use in Saltwater Criterion Derivation

The purpose of this section is to present detailed study summaries for acute estuarine/marine tests that were considered quantitatively acceptable for criterion derivation, with summaries grouped and ordered by genus sensitivity. Unlike Appendix A.2 and Appendix C.2, the EPA-calculated C-R models were not presented below for the four most sensitive estuarine/marine genera because an estuarine/marine criterion was not developed exclusively based on these empirical data. Rather, an estuarine/marine benchmark was derived using a NAM, which is further described in Appendix L.

B.2.1 Most acutely sensitive estuarine/marine genera – *Siriella* (mysid)

Mhadhbi et al. (2012) performed a 96-hour static, unmeasured acute test with PFOA (96% purity) on the mysid, *Siriella armata*. A stock solution of PFOA was made either with filtered sea water from the Ria of Vigo (Iberian Peninsula) for low exposure concentrations, or with DMSO for high PFOA concentrations (a final maximum DMSO concentration of 0.01% (v/v) in the test medium). However, the authors do not indicate what is considered a high-test concentration, so it is unclear which test concentrations actually used DMSO as a solvent. If DMSO was used, a solvent control was also included. Mysids were exposed to one of ten nominal PFOA treatments (0.1, 0.5, 1, 2, 5, 10, 20, 30, 40 and 80 mg/L). Mysids were also collected from the same source as the dilution water and quarantined before use in 100 L plastic tanks with circulating sand-filtered seawater. The adult stock was fed daily and maintained at laboratory conditions (17-18°C, salinity between 34.4-35.9 ppt, and oxygen 6 mg/L). Twenty neonates (<24-hours old) were used per each treatment. To prevent cannibalism, a single individual was added to each glass vial with 2-4 Ml of test solution. Vials were incubated at 20°C with a 16-hour light period. Neonates were fed 10-15 *Artemia salina* nauplii daily and

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mortality was recorded after 96 hours. The 96-hour LC_{50} reported in the study was 15.5 mg/L PFOA and was acceptable for quantitative use.

B.2.2 Second most acutely sensitive estuarine/marine genus – *Mytilus* (mussel)

The acute toxicity of perfluorooctanoic acid (PFOA, purity not provided) on the Mediterranean mussel, *Mytilus galloprovincialis,* which occurs in California and other parts of the Pacific Northwest (Green 2014), was evaluated by **Fabbri et al. (2014)**. Sexually mature mussels were purchased from an aquaculture farm in the Ligurian Sea (La Spezia, Italy) and held for two days for gamete collection. Gametes were held in artificial sea water (ASW) made of analytical grade salts and at a constant temperature of 16 ± 1°C. It is assumed that the gametes were held at the same environmental conditions as the adults, so test salinity was assumed to be 36 ppt with a Ph of 7.9-8.1. Embryos were transferred to 96-well microplates with a minimum of 40 embryos/well. Each treatment had six replicates. Embryos were incubated with a 16-hour:8-hour light:dark photoperiod and exposed to one of six nominal PFOA concentrations (0.00001, 0.0001, 0.001, 0.01, 0.1 and 1 mg/L) or controls. The PFOA stock was made with ethanol, and ASW control samples run in parallel. This included ethanol at the maximal final concentration of 0.01%. Each experiment was repeated four times. At test termination (48 hours), the endpoint was the percentage of normal D-larvae in each well, including malformed larvae and pre-D stages. The acceptability of test results was based on controls for a percentage of normal D-shell stage larvae of >75% (ASTM 2004). Authors noted that controls had ≥80% normal D-larvae across all tests. PFOA was only measured once in one treatment which was similar to the nominal concentration, 0.000081 mg/L versus the nominal concentration of 0.0001 mg/L. PFOA was below the limit of detection in the control ASW (0.04 ng/L). The percentage of normal D-larva decreased with increasing test concentrations. The NOEC and LOEC reported for the study were 0.00001 and 0.0001 mg/L, respectively. However, the test concentrations failed to elicit

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50% malformations in the highest test concentration, and an EC_{50} was not determined. Therefore, the EC_{50} for the study was greater than the highest test concentration (1 mg/L). The 48-hour EC_{50} based on malformation of >1 mg/L was acceptable for quantitative use.

Hayman et al. (2021) report the results of a 48-hour static, measured test on the effects of PFOA (CAS # 335-67-1, 95% purity, purchased from Sigma-Aldrich, St. Louis, MO) on the Mediterranean mussel, *Mytilus galloprovincialis*. The authors note that the tests followed U.S. EPA (1995b) and ASTM (2004) protocols. Mussels were collected in the field (Sand Diego Bay, CA) and conditioned in a flow-through system at 15℃. Mussels were induced to spawn by heat-shock and approximately 250 embryos (2-cell stage) were added to 20 Ml borosilicate glass scintillation vials with 10 Ml of test solution. There were five replicates per test concentration. Test conditions were 30 ppt, 15℃ and a 16-hour:8-hour light:dark photoperiod. Six test solutions were made in 0.45 µm filtered seawater (North San Diego Bay, CA) with PFOA dissolved in methanol. The highest concentration of methanol was 0.02% (v/v). Measured test concentrations ranged from 1.5-52 mg/L. Controls were made in the same seawater and the acute test also included a solvent control. At test termination (48 hours), larvae were enumerated for total number of larvae that were alive at the end of the test (normally or abnormally developed) as well as number of normally-developed (in the prodissoconch "D-shaped" stage) larvae. There were no significant differences between solvent control and filtered seawater, suggesting no adverse effects of methanol. The author reported 48-hour EC_{50}, based on normal survival larvae, was 9.98 mg/L PFOA. The EPA-calculated 48-hour EC_{50} value was 17.58 mg/L (95% C.I. = 13.73 – 21.43 mg/L), which was acceptable for quantitative use.

B.2.3 Third most acutely sensitive estuarine/marine genus – *Strongylocentrotus* (sea urchin)

Hayman et al. (2021) report the results of a 96-hour static, measured test on the effects of PFOA (CAS # 335-67-1, 95% purity, purchased from Sigma-Aldrich, St. Louis, MO) on the

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purple sea urchin, *Strongylocentrotus purpuratus*. The authors noted that tests followed U.S. EPA (1995b) and ASTM (2004) protocols. Sea urchins were collected in the field (Sand Diego Bay, CA) and conditioned in a flow-through system at 15°C. They were induced to spawn by KCl injection and approximately 250 embryos (2-cell stage) were added to 20 Ml borosilicate glass scintillation vials with 10 Ml of test solution. There were five replicates per test concentration. Test conditions were 30 ppt, 15°C and a 16-hour:8-hour light:dark photoperiod. Six test solutions were made in 0.45 µm filtered seawater (North San Diego Bay, CA) with PFOA dissolved in methanol. The highest concentration of methanol was 0.02% (v/v). Measured test concentrations ranged from 1.5-52 mg/L. Controls were made in the same seawater and the acute test also included a solvent control. At test termination (96 hours), the first 100 larvae were enumerated and observed for normal development (four-arm pluteus stage). There were no significant differences between solvent control and filtered seawater, suggesting no adverse effects of methanol. The author reported 96-hour EC_{50}, based on normal development, was 19 mg/L PFOA. The EPA-calculated 96-hour EC_{50} value was 20.63 mg/L (95% C.I. = 19.74 – 21.52 mg/L), which was acceptable for quantitative use.

B.2.4 Fourth most acutely sensitive estuarine/marine genus – *Americamysis* (mysid)

Hayman et al. (2021) conducted a 96-hour static, measured test to assess effects of PFOA (CAS # 335-67-1, 95% purity, purchased from Sigma-Aldrich, St. Louis, MO) on the mysid, *Americamysis bahia*. The authors noted that tests followed U.S. EPA (2002) protocols. Mysids were purchased from a commercial supplier (Aquatic Research Organisms, Hampton, NH) and acclimated to test conditions (30 ppt, 20°C and a 16-hour:8-hour light:dark photoperiod). Six test solutions were made in 0.45 µm filtered seawater (North San Diego Bay, CA) with PFOA dissolved in methanol. The highest concentration of methanol was 0.02% (v/v). Measured test concentrations ranged from 1.1-29 mg/L. The highest test concentration (61.7

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mg/L) was reported as nominal only because the sample was mistakenly not sent to the lab for verification. Controls were made in the same seawater and the acute test also included a solvent control. Five mysids (three-days old) were added to 120 Ml polypropylene cups and 100 Ml of test solution with six replicates per treatment. Living mysids were counted and dead organisms were removed daily. There were no significant differences between solvent control and filtered seawater, suggesting no adverse effects of methanol. No organisms were found dead in the controls at test termination. The EPA was unable to fit a concentration-response model with significant parameters and relied on the author-reported 96-hour LC_{50} of 24 mg/L PFOA as the quantitatively acceptable acute value.

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Appendix C Acceptable Freshwater Chronic PFOA Toxicity Studies

C.1 Summary Table of Acceptable Quantitative Freshwater Chronic PFOA Toxicity Studies

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Chronic Value Endpoint	Author Reported Chronic Value (mg/L)	EPA Calculated Chronic Value (mg/L)	Final Chronic Value (mg/L)[c]	Species Mean Chronic Value (mg/L)	Reference
Rotifer (<2-hours old neonates), *Brachionus calyciflorus*	R, U[b]	Up to 200 hours	PFOA 96%	-	20	EC_{10} (intrinsic rate of natural increase)	0.3536	0.5015	**0.5015**	-	Zhang et al. 2013a
Rotifer (<2-hours old neonates), *Brachionus calyciflorus*	R, U[b]	4 days	PFOA 96%	-	20	EC_{10} (intrinsic rate of natural increase)	2.828	1.166	**1.166**	0.7647	Zhang et al. 2014b
Cladoceran (<8 hours), *Ceriodaphnia dubia*	R, M	7 days	PFOA 99.5%	7.72 (7.6-7.78)	24.7 (24.0-25.2)	EC_{10} (neonates/female)	26.2	20.42	**20.42**	-	Kadlec et al. 2024
Cladoceran (<8 hours), *Ceriodaphnia dubia*	R, M	7 days	PFOA 99.5%	7.58 (7.47-7.67)	24.5 (24.0-25.2)	EC_{10} (neonates/female)	25.1	21.69	**21.69**	-	Kadlec et al. 2024
Cladoceran (<8 hours), *Ceriodaphnia dubia*	R, M	7 days	PFOA 99.5%	7.64 (7.59-7.69)	24.9 (23.9-25.8)	EC_{10} (neonates/female)	33.8	29.54	**29.54**	23.56	Kadlec et al. 2024
Cladoceran (6-12 hours old), *Daphnia carinata*	R, U	21 days	PFOA 95%	-	21	MATC (average # of offspring per brood and total # of living offspring)	0.03162	-	**0.03162**	0.03162	Logeshwaran et al. 2021
Cladoceran (STRAUS-clone 5; 6-24 hours old), *Daphnia magna*	R, M	21 days	APFO 99.7%	7.56-8.26	18-22	EC_{10} (average # offspring per starting adult)	29.73	20.26	**20.26**[d]	-	Centre International de Toxicologie 2003; Colombo et al. 2008
Cladoceran, *Daphnia magna*	R, U	21 days	PFOA Unreported	-	21	EC_{10} (# young/starting female)	17.68	7.853	**7.853**	-	Ji et al. 2008
Cladoceran (<24 hours old), *Daphnia magna*	R, U	21 days	APFO >98%	-	20	EC_{10} (# young/starting female)	17.89	12.89	**12.89**	-	Li 2010
Cladoceran (<24 hours old), *Daphnia magna*	R, M	21 days	PFOA 99%	7	22	EC_{10} (survival)	7.02[g]	5.458	**5.458**	-	Yang et al. 2014
Cladoceran (<24 hours old), *Daphnia magna*	S, U	21 days	PFOA 98%	-	20	MATC (growth and reproduction)	0.07155	-	**0.07155**	-	Lu et al. 2016

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Chronic Value Endpoint	Author Reported Chronic Value (mg/L)	EPA Calculated Chronic Value (mg/L)	Final Chronic Value (mg/L)[c]	Species Mean Chronic Value (mg/L)	Reference
Cladoceran (12-24 hours old), *Daphnia magna*	R, U	21 days	PFOA Unreported	6-8.5	20	EC_{10} (# of offspring)	8.231[f]	8.084[f]	**8.084[f]**	4.317	Yang et al. 2019
Cladoceran (<24 hours old), *Moina macrocopa*	R, U	7 days	PFOA Unreported	-	25	EC_{10} (# young/starting female)	4.419	2.194	**2.194**	2.194	Ji et al. 2008
Amphipod (2-9 days old), *Hyalella azteca*	R, M	42 days	PFOA 96%	8.1	25	EC_{10} (# of juveniles/female)	0.0265	0.147	**0.147**	0.147	Bartlett et al. 2021
Midge (2-day old larvae), *Chironomus dilutus*	R, M	19 days	PFOA 97%	6.8-8.7	20.0-24.0	EC_{10} (survival)	89.8	88.32	**88.32**	88.32	McCarthy et al. 2021
Mayfly (<24 hr larva), *Neocloeon triangulifer*	R, M	23 days	PFOA 95%	-	23	NOEC (survival, weight, emergence)	>3.085	-	**>3.085**	>3.085	Soucek et al. 2023
Rainbow trout (embryo-larval-juvenile), *Oncorhynchus mykiss*	F, M	85 days (ELS)	APFO 99.7%	6.0-8.5	11.1-14.4	LOEC (growth and mortality)	>40	-	**>40[d]**	>40	Centre International de Toxicologie 2004; Colombo et al. 2008
Rare minnow (adult), *Gobiocypris rarus*	F, U	28 days	PFOA 98%	-	25	LOEC (survival)	>30	-	**>30**	>30	Wei et al. 2007
Fathead minnow (<18 hpf), *Pimephales promelas*	R, M	21 days	PFOA 96%	7.4-7.8	25	LOEC (mortality and growth)	>76	-	**>76**	>76	Bartlett et al. 2021
Medaka (adult-F0, embryo-F1, F2), *Oryzias latipes*	F, M	259 days[e]	PFOA Unreported	7.5	25	MATC (F2: sac-fry survival; F0, F1, F2: fecundity)	9.487	-	**9.487**	9.487	Lee et al. 2017
American bullfrog (tadpole, Gosner stage 25), *Lithobates catesbeiana* (formerly, *Rana catesbeiana*)	R, U	72 days	PFOA Unreported	-	21	LOEC (snout vent length)	0.288	-	**0.288**	0.288	Flynn et al. 2019

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

[b] Chemical concentrations made in a side-test representative of exposure and verified stability of concentrations of PFOA in the range of concentrations tested under similar conditions. Daily renewal of test solutions.

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[c] Values in bold used in SMCV calculation.
[d] Concentration of APFO in publication indirectly determined through quantification of the anion (PFO-).
[e] Total exposure period across F0, F1, and F2 generations.
[f] Reported in moles, converted to grams based on a molecular weight of 414.07 g/mol.
[g] Value represents an EC_{10} based on reproduction.

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C.2 Detailed PFOA Chronic Toxicity Study Summaries and Corresponding Concentration-Response Curves (when calculated)

The purpose of this section is to present detailed study summaries for tests that were considered quantitatively acceptable for criteria derivation, with summaries grouped and ordered by genus sensitivity. C-R models developed by the EPA that were used to determine chronic toxicity values used for criterion derivation are also presented. C-R models included here with study summaries were those for the four most sensitive genera. In many cases, authors did not report concentration-response data in the publication/supplemental materials and/or did not provide concentration-response data upon request by the EPA. In such cases, the EPA did not independently calculate toxicity values and the author-reported effect concentrations were used to derive the criterion.

C.2.1 Most chronically sensitive genus – *Hyalella*

Bartlett et al. (2021) evaluated the chronic effects of PFOA (CAS# 335-67-1, 96% purity, solubility in water at 20,000 mg/L, purchased from Sigma-Aldrich) on *Hyalella azteca* via a 42-day static-renewal, measured study. Methods for this study were adapted from Borgmann et al. (2007), and organisms were two to nine days old at the test initiation. Experiments were conducted in standard artificial media with water quality characteristics of 52 to 60 mg/L alkalinity as $CaCO_3$, average specific conductivity of 0.41 Ms/cm, dissolved oxygen of 5.2 to 8.8 mg/L, total hardness of 120 to 140 mg/L $CaCO_3$, average Ph of 8.1 and average temperature of 25ºC. A 100 mg/L stock solution was prepared to yield measured test concentrations of 0 (control), 0.84, 3.3, 8.9, 29 and 97 mg/L PFOA. Two separate tests were performed with five replicates per concentration and 20 amphipods per replicate in 2-L HDPE containers filled with 1 L of testing solution, 2.5 mg of ground TetraMin and one piece of 5x5 cm cotton gauze. Test organisms were fed 2.5 mg TetraMin three times a week during weeks one

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and two, 5 mg TetraMin three times a week during weeks three and four, and 5 mg TetraMin five times a week during weeks five and six. At test termination (day 42), adults were sexed and weighed, as well as their young counted. The 42-day author-reported LC_{10} value for survival was 23.2 mg/L PFOA. The author-reported EC_{10} values for growth and reproduction were 0.160 mg/L and 0.0265 mg/L, respectively. The EPA only performed C-R analysis for the growth and reproduction-based endpoints for this test, given the apparent tolerance of the survival-based endpoint. The EPA calculated EC_{10} values for the 42-day growth endpoint (i.e., control normalized wet weight/amphipod) and the 42-day reproduction endpoint (i.e., number of juveniles per female). The 42-day growth-based EC_{10} of 0.488 mg/L (95% C.I. = 0.319 – 0.657 mg/L) was not selected as the primary endpoint from this test because it was more tolerant than the reproduction-based EC_{10} of 0.147 mg/L (95% C.I. = 0.147 – 0.147 mg/L). The EPA-calculated EC_{10} was 0.147 mg/L with a corresponding EC_{50} of 0.911 mg/L. While the EC_{10} was relatively uncertain due to a lack of partial effects around the 10% effect level, the EC_{50} estimate remained relatively certain given the 47% effect observed in the lowest treatment concentration. EC_{50} to EC_{10} ratios from all quantitatively acceptable chronic concentration-response curves with similar species (i.e., small members of the subphylum Crustacea) and endpoints (i.e., offspring/female) were evaluated to understand the variability in the EC_{50}:EC_{10} ratios and provide further context to the reasonableness of the *H. azteca* EC_{10} estimate. Overall, three quantitatively acceptable chronic concentration-response curves with similar species/endpoints were available. See Table C-1 below for a description of the individual C-R curves and resultant EC_{50}:EC_{10} ratios from each C-R curve.

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Table C-1. EC_{50} to EC_{10} ratios from all quantitatively acceptable chronic concentration-response curves with species similar to *H. azteca* (i.e., small members of the subphylum Crustacea) and with endpoints that were based on reproduction per female.

Citation	Species	Endpoint	EPA-Calculated EC_{50} (mg/L)	EPA-Calculated EC_{10} (mg/L)	EC_{50}:EC_{10} Ratio
Ji et al. 2008	*Daphnia magna*	(# young/starting female)	61.67	7.853	7.853
Li 2008	*Daphnia magna*	(# young/starting female)	40.75	12.89	3.161
Ji et al. 2008	*Moina macrocopa*	(# young/starting female)	12.77	2.194	5.819

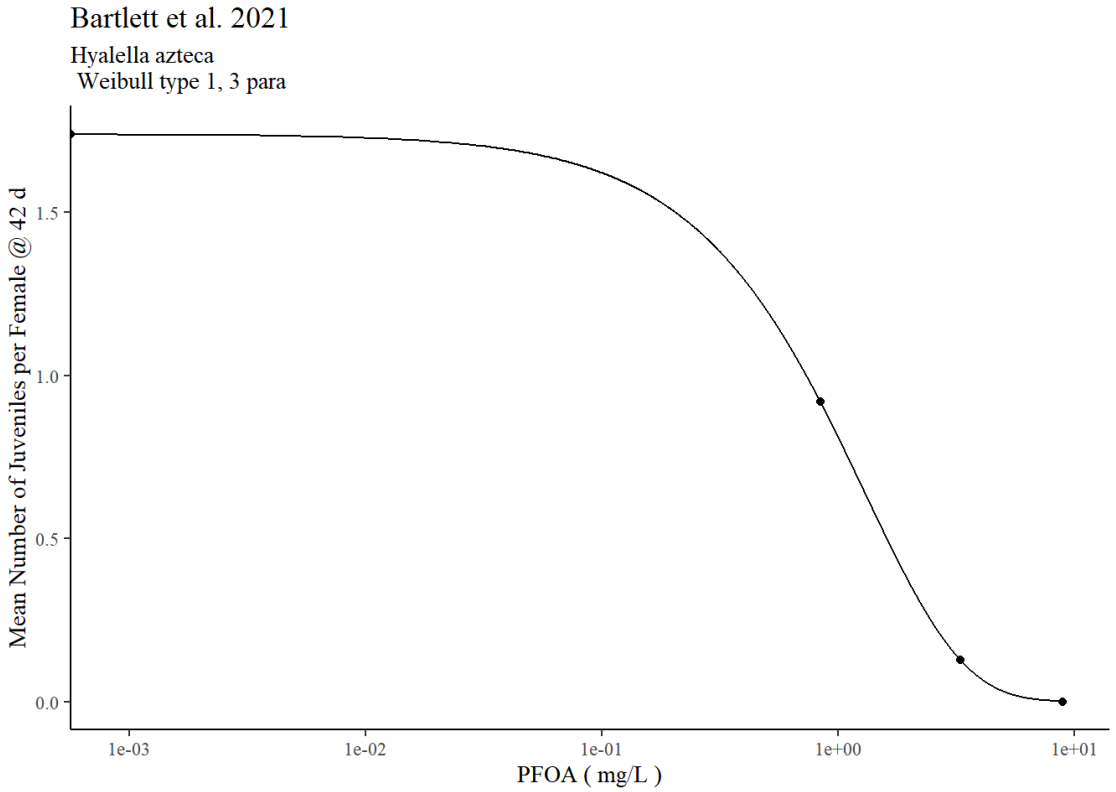
EC_{50}:EC_{10} ratios from the three tests with similar species/endpoints ranged from 3.161 to 7.852 with a geometric mean ration of 5.247. Dividing the *H. azteca* reproduction-based EC_{50} (i.e., 0.911 mg/L) by the geometric mean EC_{50}:EC_{10} ratio (i.e., 5.247) produced an estimated *H. azteca* EC_{10} of 0.174 mg/L, which was similar to EC_{10} value calculated directly from the *H. azteca* C-R curve (i.e., 0.147 mg/L). The EC_{10} value calculated directly from the *H. azteca* C-R dataset was, therefore, hypothesized to provide a robust estimate of a 10% reproductive-based effect concentration despite the lack of partial low-level effects observed along the C-R curve. The 42-day average number of young per female EC_{10} value of 0.147 mg/L (95% C.I. = 0.147 – 0.147 mg/L) calculated from C-R data reported by Bartlett et al. 2021 was retained for quantitative use.

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Publication: Bartlett et al. (2021)
Species: *Hyalella azteca*
Genus: *Hyalella*
EPA-Calculated EC_{10}: 0.147 mg/L (95% C.I. = 0.147 – 0.147 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	1.0325	2.1536 e^{-6}	479432	1.328 e^{-6}
d	1.7400	1.3029 e^{-7}	1335511	4.767 e^{-7}
e	1.2996	2.5393 e^{-6}	511775	1.244 e^{-6}

Concentration-Response Model Fit:



C.2.2 Second most chronically sensitive genus – *Lithobates*

Flynn et al. (2019) evaluated the chronic effects of PFOA (CAS# 335-67-1, purchased from Sigma-Aldrich) on the American bullfrog (*Lithobates catesbeiana*, formerly, *Rana catesbeiana*) during a 72-day static-renewal unmeasured exposure. Testing followed Purdue University's Institutional Animal Care and Use Committee Guidelines Protocol #16010013551. American bullfrog eggs were taken from a permanent pond in the Martell Forest outside of West

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Lafayette, Indiana. The eggs from a single egg mass were acclimated in 100 L outdoor tanks filled with 70 L of aged well water and covered with a 70% shade cloth. Once hatched, tadpoles were fed rabbit chow and TetraMin *ad libitum* and were acclimated to laboratory conditions for 24 hours before testing (21ºC and a 12-hour:12-hour light:dark photoperiod). A 2,000 mg/L PFOA stock solution was prepared with RO water to produce three concentrations for the chronic test (0, 0.144 and 0.288 mg/L). Each chronic test treatment contained 10 tadpoles (Gosner stage 25), replicated four times, in 15-L plastic tubs filled with 10 L of aged UV-irradiated, filtered well water. Complete water changes were performed every three to four days, at which time chemical treatments were reapplied. Each experimental unit was fed daily at a constant rate (10% per capita) based on tadpole wet biomass in the control treatment to assure that food was not limiting. On day 72 of the experiment, all tadpoles were euthanized, measured (snout vent length and mass) and staged. The most sensitive chronic endpoint was growth (snout-vent length), with a 72-day NOEC and LOEC of 0.144 mg/L and 0.288 mg/L, respectively. The EPA could not independently calculate an EC_{10} value because there were minimal effects observed across the limited number of treatment concentrations tested. Consequently, the EPA used the LOEC of 0.288 mg/L as the chronic value from this chronic test. The LOEC was used preferentially to the MATC from this test because a ~7% reduction in snout-vent length relative to control responses was observed at the LOEC (i.e., 0.288 mg/L).

Publication: Flynn et al. (2019)
Species: American bullfrog (*Lithobates catesbeiana*)
Genus: *Lithobates*
EPA-Calculated EC_{10}: Not calculable, unable to fit a model with significant parameters
Concentration-Response Model Fit: Not Applicable

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C.2.3 Third most chronically sensitive genus – *Daphnia*

Logeshwaran et al. (2021) conducted a PFOA (95% purity, purchased from Sigma-Aldrich Australia) chronic toxicity test with the cladoceran, *Daphnia carinata*. In-house cultures of daphnids were maintained in 2 L glass bottles with 30% natural spring water in deionized water, 21℃ and a 16-hour:8-hour light:dark photoperiod. The chronic test protocol followed OECD guidelines (2012). A PFOA stock solution (100 mg/L) was prepared in deionized water. Cladoceran culture medium was used to prepare the PFOA stock and test solutions. One daphnid (6-12 hours old) was transferred to each 100 Ml polypropylene container containing 50 Ml of the nominal test solution (0, 0.001, 0.01, 0.1, 1.0 and 10 mg/L PFOA). Each test treatment was replicated 10 times with test solutions renewed and daphnids fed daily. At test termination (21 days) test endpoints included survival, days to first brood, average offspring in each brood and total live offspring. No mortality occurred in the controls or lowest test concentration. Of the three endpoints measured, average offspring in each brood and total live offspring were the more sensitive endpoints with 21-day NOEC and LOEC values of 0.01 and 0.1 mg/L PFOA, respectively. The EPA was unable to calculate statistically robust EC_{10} estimates from C-R models for these endpoints, largely because of the 10X dilution series across five orders of magnitude. The LOECs for these endpoints were not selected as the chronic value because the LOECs produced a 29.23% reduction in the average number of offspring per brood relative to controls and a 39.89% reduction in the total living offspring relative to controls. Therefore, the MATC (i.e., 0.03162 mg/L) was selected as the quantitatively acceptable chronic value form this test.

Publication: Logeshwaran et al. (2021)
Species: Cladoceran (*Daphnia carinata*)
Genus: *Daphnia*
EPA-Calculated EC_{10}: Not used, unable to fit a statistically robust model
Concentration-Response Model Fit: Not Applicable

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Ji et al. (2008) conducted a chronic life-cycle test on the effects of PFOA (CAS # 335-67-1, purity was not reported; obtained from Sigma Aldrich, St. Louis, MO, USA) with *Daphnia magna*. The test was done under renewal conditions over a 21-day period and test solutions were not analytically confirmed. Authors stated that the *D. magna* test followed OECD 211 (1998). *D. magna* used for testing were obtained from brood stock cultured at the Environmental Toxicology Laboratory at Seoul National University, Korea. Test organisms were less than 24-hours old at test initiation. Dilution water was moderately hard reconstituted water (total hardness typically 80-100 mg/L as $CaCO_3$). Experiments were conducted in glass jars of unspecified size and fill volume. Photoperiod was assumed to be 16-hours of illumination, the same conditions as the daphnid cultures used as the source of the experimental organisms. Preparation of test solutions was not described. The test involved 10 replicates of one daphnid each in five nominal test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 3.125, 6.25, 12.5, 25 and 50 mg/L and test solutions were renewed three times per week. Test temperature was 21 ± 1°C for the *D. magna* test. Authors note that the water quality parameters (pH, temperature, conductivity, and dissolved oxygen) were measured after changing the medium, but the information is not reported. Survival of daphnids in the negative control was 100%. The most sensitive endpoint for *D. magna* reported in the publication was days to first brood with a 21-day NOEC of 6.25 mg/L (LOEC = 12.5 mg/L; MATC = 8.839 mg/L); however, number of young per starting female (an endpoint not reported in the publication, which only assessed number of young per surviving female) was calculated by the EPA and considered to be a more sensitive endpoint with an EPA-calculated EC_{10} of 7.853 mg/L

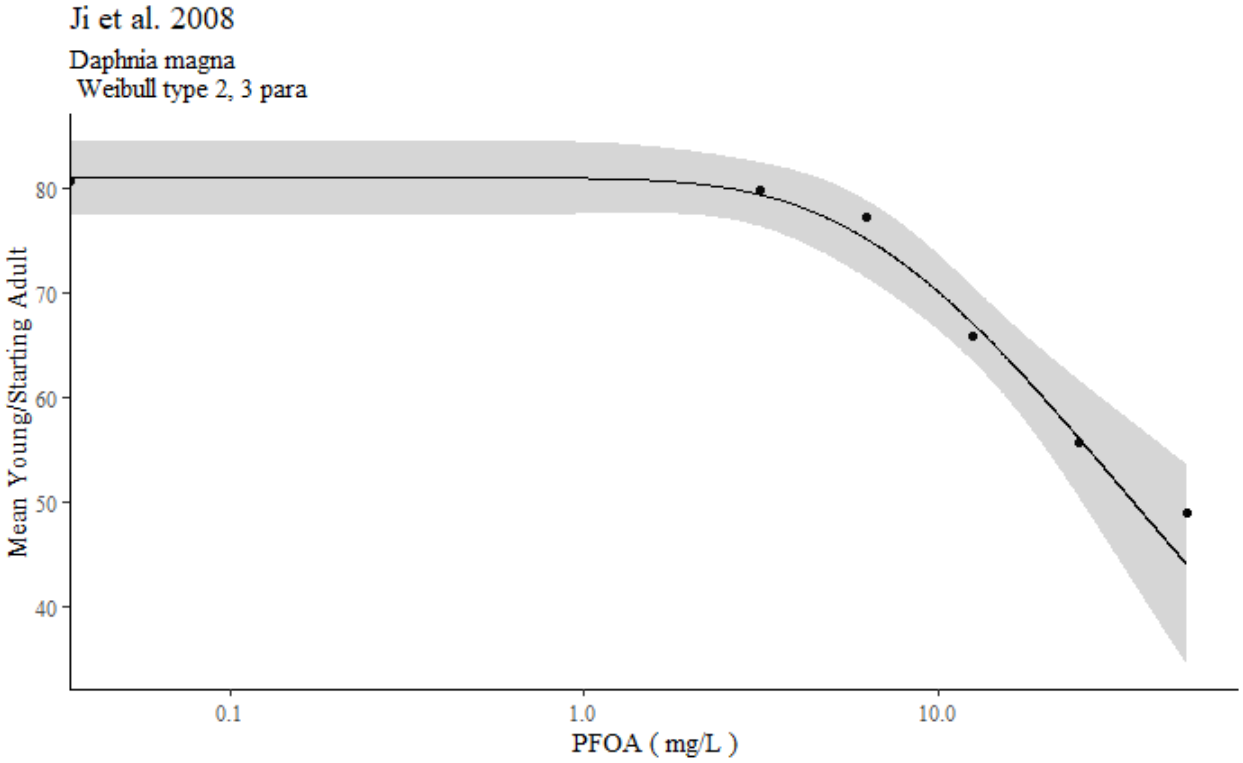
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(95% C.I. = 4.253 – 11.45 mg/L). Therefore, the EPA-calculated EC_{10} of 7.853 mg/L PFOA for D. *magna* (number of young per starting female) was considered quantitatively acceptable.

Publication: Ji et al. (2008)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated EC_{10}: 7.853 mg/L (95% C.I. = 4.253 – 11.45 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	-0.4609	0.0633	-7.2762	0.0054
d	83.0500	3.3807	24.5662	0.0001
e	37.5761	6.5642	5.7244	0.0106

Concentration-Response Model Fit:



Li (2010) conducted an unmeasured chronic life cycle 21-day test on the effects of PFOA (ammonium salt, >98% purity) on *Daphnia magna*. The authors stated that the test followed OECD 211 (1998). *D. magna* used for the test were maintained in the laboratory for more than one year and were less than 24-hours old at test initiation. Dilution water was distilled water with

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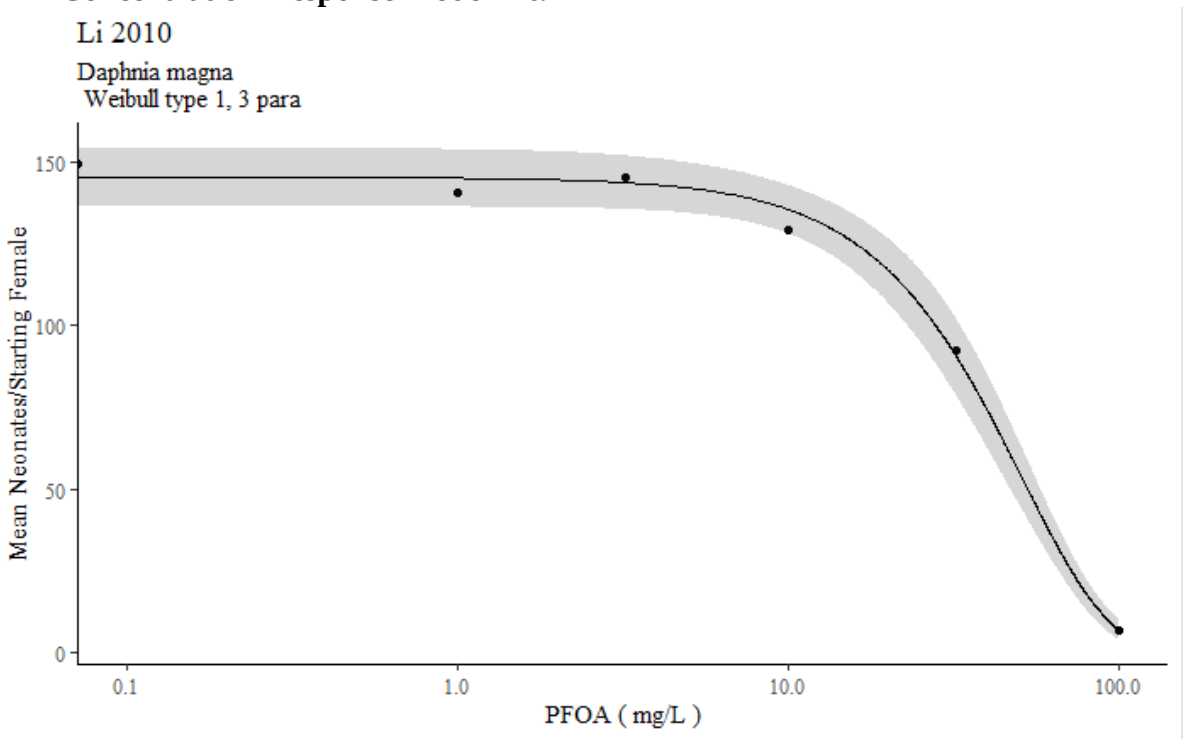
ASTM medium salts added (0.12 g/L $CaSO_4.2H_2O$, 0.12 g/L $MgSO_4$, 0.192 g/L $NaHCO_3$, and 0.008 g/L KCl). The calculated total hardness was 169 mg/L as $CaCO_3$. The photoperiod had 16-hours of illumination with an unreported light intensity. A primary stock solution (1,000 mg/L) was prepared in ASTM medium. Exposure vessels were 50 Ml polypropylene culture tubes with 50 Ml fill volume. The test involved 10 replicates of one daphnid each in five nominal test concentrations plus a negative control and each test was repeated three times. Nominal concentrations were 0 (negative control), 1, 3.2, 10, 32 and 100 mg/L. Test temperature was maintained at 20 ± 1°C. Water quality parameters measured in test solutions were not reported. Survival of daphnids in the negative control was 96.7% across all three tests. The *D. magna* 21-day NOEC (reproduction as number of young per female, broods per female, and mean brood size) was 10 mg/L (LOEC = 32 mg/L; calculated MATC = 17.89 mg/L). The EPA performed C-R analysis for each reported endpoint. The EPA also revaluated all endpoints that were based on number of surviving females to be based on the number of starting females. This recalculation was done with the intent to account for starting females that were unable to contribute to the population as reproduction/female due to mortality. The most sensitive endpoint with an acceptable C-R curve was the number of young per starting female with an EPA-calculated EC_{10} of 12.89 mg/L PFOA (95% C.I. = 8.292 – 17.49 mg/L) and was acceptable for quantitative use.

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Publication: Li (2010)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated EC_{10}: 12.89 mg/L (95% C.I. = 8.292 – 17.49 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	1.2765	0.2577	4.9540	0.0158
d	145.8089	3.0147	48.3655	$1.946\ e^{-5}$
e	57.4122	8.7260	6.5795	0.0071

Concentration-Response Model Fit:



Yang et al. (2014) evaluated the chronic 21-day renewal, measured test of PFOA (CAS # 335-67-1, 99% purity) with *Daphnia magna*, following ASTM E729 (1993). Daphnids used for the test were donated by the Chinese Research Academy of Environmental Sciences. The daphnids were less than 24-hours old at test initiation. Dilution water was dechlorinated tap water (Ph, 7.0 ± 0.5; dissolved oxygen, 7.0 ± 0.5 mg/L; total organic carbon, 0.02 mg/L; and total hardness, 190.0 ± 0.1 mg/L as $CaCO_3$). The photoperiod consisted of 12-hours of illumination at an unreported intensity. A primary stock solution was prepared by dissolving

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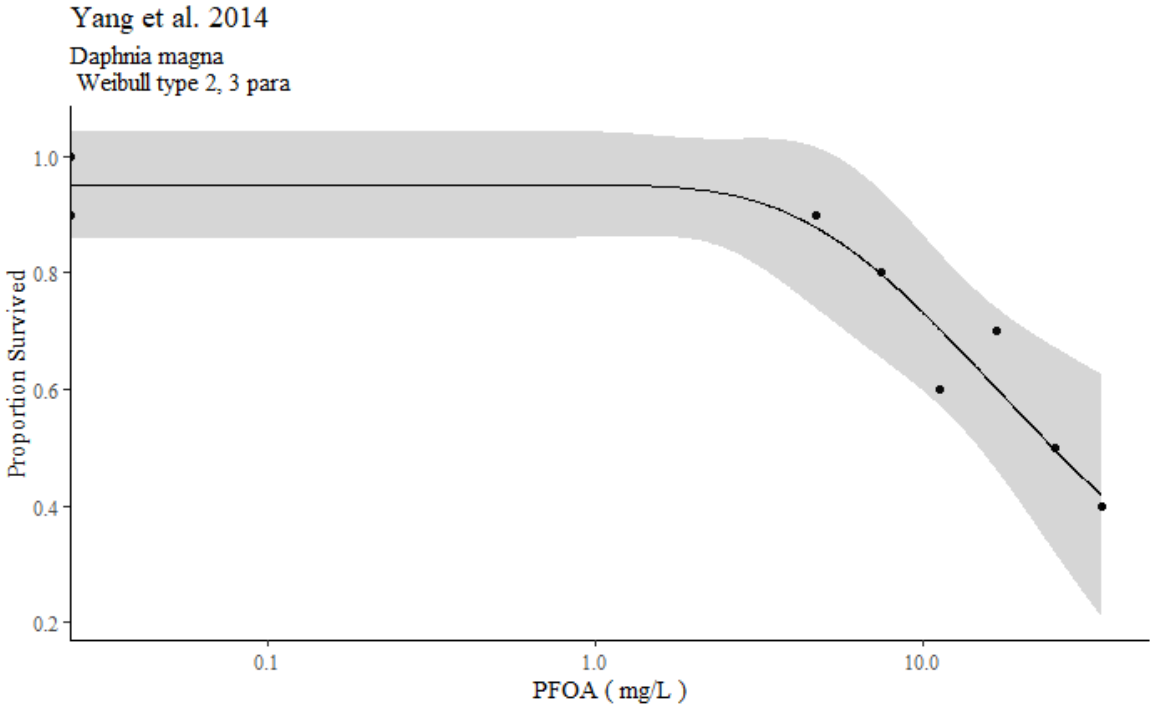
PFOA in deionized water and DMSO solvent, and proportionally diluted with dilution water to prepare the test concentrations. Exposure vessels were 200 Ml beakers of unreported material type containing 100 Ml of test solution. The test employed ten replicates of one daphnid each in six test concentrations plus a negative and solvent control. Nominal concentrations were 0 (negative and solvent controls), 5, 7.5, 11.25, 16.88, 25.31 and 37.97 mg/L and were renewed at 48-hour intervals. Test concentrations were measured in low and high treatments only. The authors provided mean measured concentrations before and after renewal: 4.96 and 4.49 mg/L (lowest concentration) and 37.66 and 32.88 mg/L (highest concentration). Analyses of test solutions were performed using HPLC/MS and negative electrospray ionization. The concentration of PFOA was calculated from standard curves (linear in the concentration range of 1-800 ng/Ml), and the average extraction efficiency was in the range of 70-83%. The concentrations and chromatographic peak areas exhibited a significant positive correlation ($r = 0.9987$, $p < 0.01$), and the water sample-spiked recovery was 99%. The temperature, DO, and Ph were reported as having been measured every day during the test, but results are not provided. Negative control and solvent control survival were 90% and 100%, respectively. The author-reported *D. magna* 21-day EC_{10} for reproduction (total number of spawning) was 7.02 mg/L. The EPA performed C-R analysis for each reported endpoint. Both chronic survival and reproduction endpoints resulted in acceptable C-R curves. The EPA-calculated EC_{10} for reproduction as total number of spawning events was 6.922 mg/L (95% C.I. = 4.865 – 8.979 mg/L), similar to the EC_{10} reported by the authors (i.e., 7.02 mg/L). Chronic survival was more sensitive than reproduction, with an EPA-calculated EC_{10} of 5.458 mg/L PFOA (95% C.I. = 3.172 – 7.743 mg/L). Therefore, the survival based EC_{10} calculated by the EPA (i.e., 5.458 mg/L) was acceptable for quantitative use.

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Publication: Yang et al. (2014)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated EC_{10}: 5.458 mg/L (95% C.I. = 3.172 – 7.743 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	1.2765	0.2577	4.9540	0.0158
d	145.8089	3.0147	48.3655	$1.946\ e^{-5}$
0.0158	57.4122	8.7260	6.5795	0.0071

Concentration-Response Model Fit:



Centre International de Toxicologie (2003) and **Colombo et al. (2008)** conducted a 21-day renewal measured chronic test on ammonium perfluorooctanoate (APFO CAS # 3825-26-1, 99.7% purity) with the daphnid, *Daphnia magna*. The authors stated that the toxicity test was conducted followed OECD test guideline 211. There were 10 replicates for each test treatment containing one neonate, six to 24-hours old, each. Exposure vessel material and size were not reported but filled with 50 Ml of test solution. Stock solutions of APFO were prepared by dissolving the test substance directly in M4 media. The stock was diluted with M4 media to

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make the nominal test concentrations: control, 6.25, 12.5, 25, 50 and 100 mg/L. Test solutions were analyzed by ion chromatography with electrochemical detection. Measured concentrations were <LOQ, 4.31, 9.16, 20, 44.2 and 88.6 mg/L. Dissolved oxygen was >60% saturation and temperature were maintained between 18-22°C. Illumination included 16-hours of light with an unreported intensity. Test solutions were typically renewed every three days and daphnids were fed daily. Control survival met the minimum survival guidance (80%). Average number of live young was the most sensitive endpoint reported by Colombo et al. (2008), with a NOEC of 20 mg/L. Based on the author-reported EC_{50} for the average number of live young, the LOEC was 44.2 mg/L and the MATC was 29.73 mg/L. The EPA performed C-R analysis for each reported endpoint. The most sensitive endpoint with an acceptable C-R curve was the average number of live young, with an EPA-calculated EC_{10} of 20.26 mg/L PFOA (95% C.I. = -75.48 – 116.0 mg/L), which was acceptable for quantitative use. Although the *D. magna* C-R curve from Colombo et al. (2008) displayed relatively wide 95% confidence bands, the C-R curve was retained for use because the EC_{10} is just beyond the NOEC, where effects quickly increase from 0% to nearly 100%. Although there is a lack of partial effects, there appears to be a threshold effect that occurs above the NOEC. Note, Colombo et al. (2008) reported treatment-mean C-R data for the number of offspring per starting adult. In contrast, Centre International de Toxicologie (2004) reported replicate-level C-R data for number of offspring per surviving adult (producing an EPA-calculated EC_{10} of 21.25 mg/L; Model = Weibull Type 1, 3 parameters). Basing the number of offspring on starting adult (as reported by Colombo et al. [2008]) rather than per surviving adult (as reported by Centre International de Toxicologie [2003]), produces a more sensitive endpoint that accounts for those parents that could not contribute to the overall offspring count as a result of their own mortality. Because Colombo et al. 2008 and Centre

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International de Toxicologie (2003) both reported only treatment-mean C-R survivorship data, the number of offspring per starting adult was based on treatment mean data rather than replicate-level data.

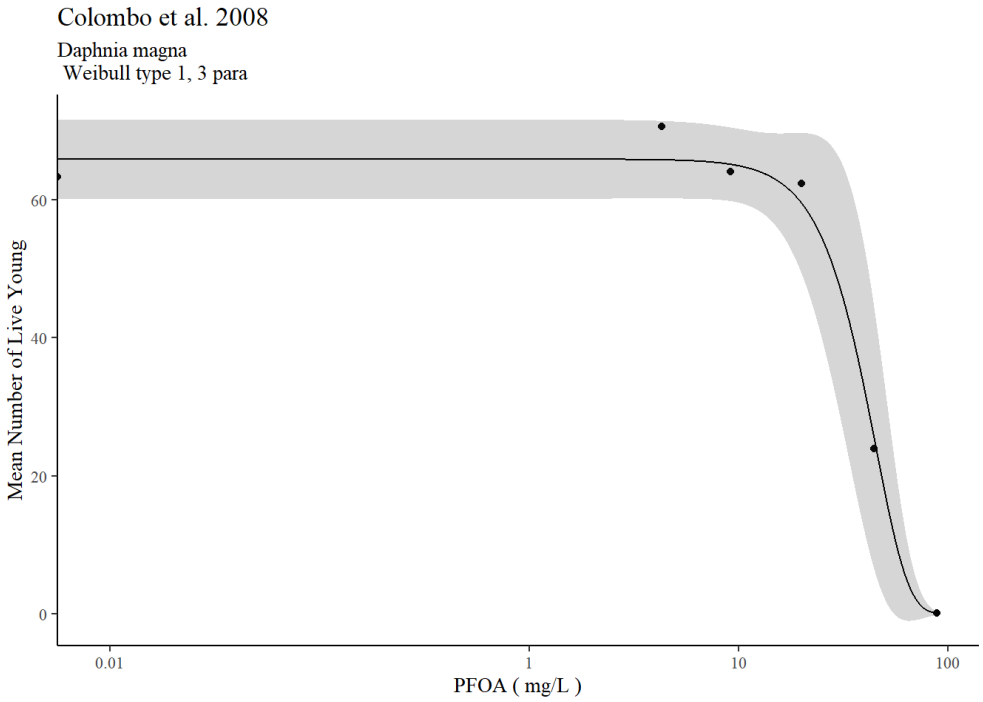
The authors note that the contribution of ammonia from APFO exposure in this test indicates that un-ionized ammonia could be a potential contributor to the observed chronic toxicity of APFO. The EPA believes ammonia does not contribute substantively to the chronic toxicity to *D. magna* in this test based on the following rationale. US EPA (2013) derived a GMCV of 41.46 mg N/L at pH=7 and temperature of 20°C for *D. magna*. Using the EPA equations, this translates to 12.6 mg N/L at the authors' assumed acute test pH=8.2 (from their Table 7) and the midrange reported test temperature (20°C). This in turn translates to an un-ionized ammonia concentration of approximately 0.91 mg un-ionized ammonia/L at this pH and temperature. Table 7 of Colombo et al. (2008) lists un-ionized ammonia concentration at the APFO 21-day reproductive NOEC as 0.048 mg un-ionized ammonia/L, which is almost twenty times lower than the EPA's SMAV for D. *magna* re-expressed as an un-ionized ammonia concentration for the test condition. Therefore, it is highly unlikely that ammonia contributed to the chronic toxicity of APFO to *D. Magna* in this test, and therefore, the EPA-calculated EC_{10} of 20.26 mg/L APFO is used in the calculation of the GMCV for this species.

Publication: Colombo et al. (2008)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated EC_{10}: 20.26 mg/L (95% C.I. = -75.48 – 116.0 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	2.79764	0.39868	7.0172	0.005944
d	65.85398	1.79847	36.6167	$4.48\ e^{-5}$
e	45.28323	4.01408	11.2811	0.001494

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Concentration-Response Model Fit:



Lu et al. (2016) evaluated the chronic toxicity of PFOA (CAS# 335-67-1, 98% purity, purchased from Tokyo Chemical Industry Co., Ltd., Tokyo, Japan) on *Daphnia magna* immobilization, growth and reproduction. Reconstituted daphnia culture media was used for both culturing and test solution preparation as described in OECD Test Guideline 202. *D. magna* cultures (originally obtained from the Chinese Center for Disease Control and Prevention (Beijing, China) were fed with the green algae *Scenedesmus obliquus* daily, maintained at 20°C and a light/dark photoperiod of 16-hours/8-hours and the medium renewed three times weekly. The 21-day chronic test endpoints were assessed by a semi-static unmeasured test according to OECD Test Method 211. Neonates (<24-hours old) were exposed to six concentrations of PFOA [0 (control), 0.032, 0.16, 0.8, 4 and 20 mg/L] maintained at 20 ± 1°C. One test organism was exposed in a 100 mL glass beaker filled with 45 mL of test solution, and there were 20 replicates for each exposure concentration. The daphnids were fed 1×10^6 cells of *Scenedesmus obliquus* per animal per day, and the test solution was renewed every other day. Survival, growth and

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reproduction (fecundity) was determined during the 21-day exposure. The 21-day growth and reproductive NOEC and LOEC were 0.032 and 0.16 mg/L PFOA, respectively. The EPA was unable to fit a C-R model with significant parameters to the chronic data associated with reproduction from this test. The EPA-calculated EC_{10} values for mean intrinsic rate of increase ® and growth (as length) were 0.0173 mg/L (95% C.I. = 0.0170 – 0.0177 mg/L) and 0.0124 mg/L (95% C.I. = 0.0048 – 0.0200 mg/L), respectively. Both EC_{10} values were nearly two times lower than the NOEC of 0.032 mg/L and four times lower than the LOEC value (i.e., 0.16 mg/L) where only 15.2% and 11.9% reductions in intrinsic rate of natural increase (r) and length were observed, respectively. As a result, the MATC of 0.07155 mg/L for growth and reproduction was selected as the most appropriate chronic value for quantitative use to in deriving the chronic water column-based criterion.

Publication: Lu et al. (2016)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated EC_{10}: Not used, unable to fit a statistically robust model
Concentration-Response Model Fit: Not Applicable

Yang et al. (2019) evaluated the chronic effects of PFOA (CAS# 335-67-1, purchased from Sigma-Aldrich in St. Louis, MO) on *Daphnia magna* via a 21-day unmeasured, static-renewal test that assessed reproductive effects. *D. magna* cultures were originally obtained from the Institute of Hydrobiology of Chinese Academy of Science in Wuhan, China. Organisms were cultured in Daphnia Culture Medium according to the parameters specified in OECD Guideline 202. Protocol for all testing followed OECD Guideline 211. Cladocerans were cultured in artificial freshwater maintained at 20 ± 1°C under a 16-hour:8-hour light:dark photoperiod and a light intensity of 1,000-1,500 lux at the surface of the water. Cultures were fed *Scenedesmus obliquus* daily and the water was changed twice weekly. Reported water quality parameters

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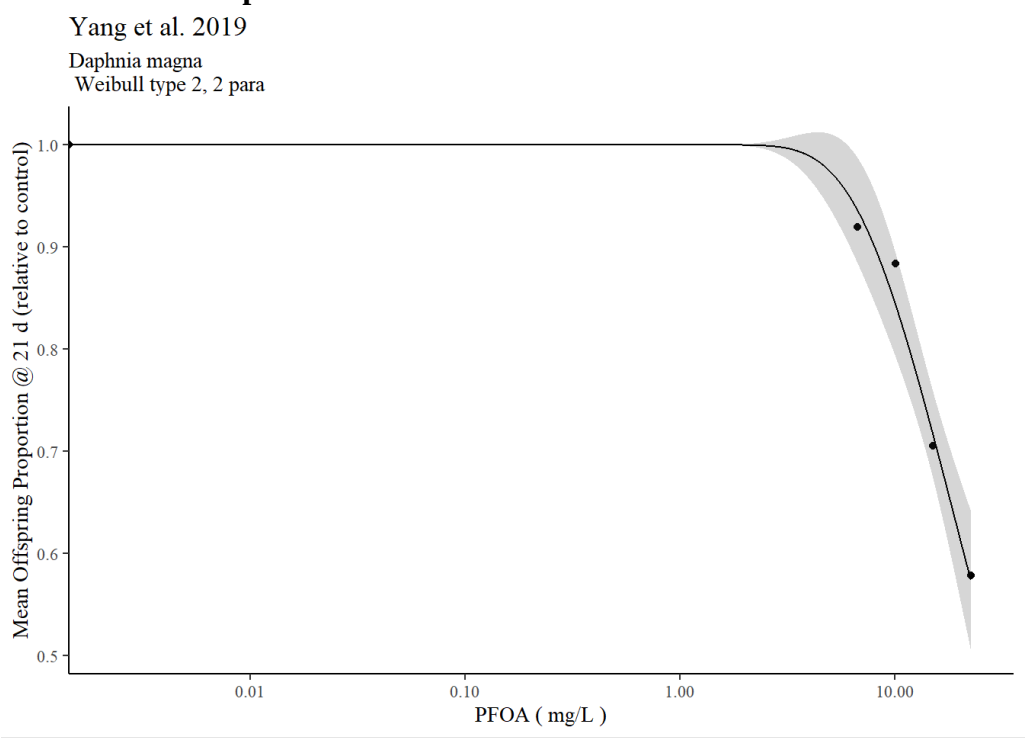
include total hardness of 140-250 mg/L as $CaCO_3$ and pH of 6-8.5. The 21-day chronic study had nominal concentrations of 0 (control), 0.0000162, 0.0000244, 0.0000365 and 0.0000546 mol/L (or 0 (control), 6.708, 10.10, 15.11 and 22.61 mg/L, respectively, given the molecular weight of the form of PFOA used in the study, CAS # 335-67-1, of 414.07 g/mol). One neonate (12–24 hours old) was placed in A 100 mL glass beaker, replicated 10 times, and each container filled wiTH 80 mL of test solution maintained at 20 ± 1ºC and a 16-hour:8-hour light:dark photoperiod with a light intensity of 1,000-1,500 lux. *D. magna* were fed *S. obliquus* and test solutions were renewed every 72 hours. Test organisms were counted daily, with any young removed. The reproductive NOEC and LOEC were 0.0000162 and 0.0000244 mol/L, or 6.708 and 10.10 mg/L PFOA, respectively. The EPA performed C-R analysis for the test. The EPA-calculated EC_{10} based on mean offspring at 21-days as a proportion of the control response was 8.084 mg/L (95% C.I. = 7.830 – 8.334 mg/L) and was used quantitatively to derive the chronic water column criterion.

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Publication: Yang et al. (2019)
Species: Cladoceran (*Daphnia magna*)
Genus: *Daphnia*
EPA-Calculated EC_{10}: 8.084 mg/L (95% C.I. = 7.830 – 8.334 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	-0.9632	0.1065	-9.0420	0.0029
e	19.2161	0.9269	20.7320	0.0002

Concentration-Response Model Fit:



C.2.4 Fourth most chronically sensitive genus – *Brachionus*

Zhang et al. (2013a) conducted a chronic life-cycle renewal test of PFOA (CAS # 335-67-1, 96% purity) with *Brachionus calyciflorus*. The test duration was up to 200-hours in a full-life cycle test (primary emphasis), and 28 days in a population growth test (secondary emphasis: only two concentrations plus a control). Test organisms were less than two-hours old at test initiation. All animals were parthenogenetically-produced offspring of one individual from a single resting egg collected from a natural lake in Houhai Park (Beijing, China). The rotifers

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were cultured in an artificial inorganic medium at 20°C (16-hours:8-hours, light:dark; 3,000 lux) for more than six months before toxicity testing to acclimate to the experimental conditions. Culture medium was an artificial inorganic medium and all toxicity tests were carried out in the same culture medium and under the same conditions as during culture (i.e., pH, temperature, illumination). Solvent-free stock solutions of PFOA (1,000 mg/L) were prepared by dissolving the solid in deionized water via sonication. After mixing, the primary stock was proportionally diluted with dilution water to prepare the test concentrations. Exposures were carried out in 24-well cell culture plates (assumed plastic) containing 2 mL of test solution per cell. The test employed four measured test concentrations plus a negative control. Each treatment consisted of one replicate plate of 15 rotifers, with one rotifer per cell. Treatments were repeated six times. Nominal concentrations were 0 (negative control), 0.25, 0.5, 1.0 and 2.0 mg/L. PFOA concentrations were not measured in the rotifer exposures, but rather, in a side experiment using HPLC/MS. The side experiment showed that the concentration of PFOA measured every 8 hours over a 24-hour period in rotifer medium with green algae incurs minimal change in the concentration range from 0.25 to 2.0 mg/L. One hundred percent survival was observed at 24 hours in the negative control in the corresponding acute test, but survival information is not provided for the life-cycle test. Zhang et al. (2013a) demonstrated rotifer body size and mictic ratio after 28-days were relatively tolerant endpoints with reported NOECs of ≥ 1.0 mg/L and 2.0 mg/L, respectively. The EPA performed C-R analysis for the remaining reported endpoints from C-R data reported in the publication. The most sensitive endpoint with an acceptable C-R curve was the intrinsic rate of natural increase with an EPA-calculated EC_{10} of 0.5015 mg/L PFOA (95% C.I. = 0.1458 – 0.8572 mg/L), which was acceptable for quantitative use. The intrinsic rate of natural increase (d^{-1}) is a population level endpoint that accounts for births and deaths over

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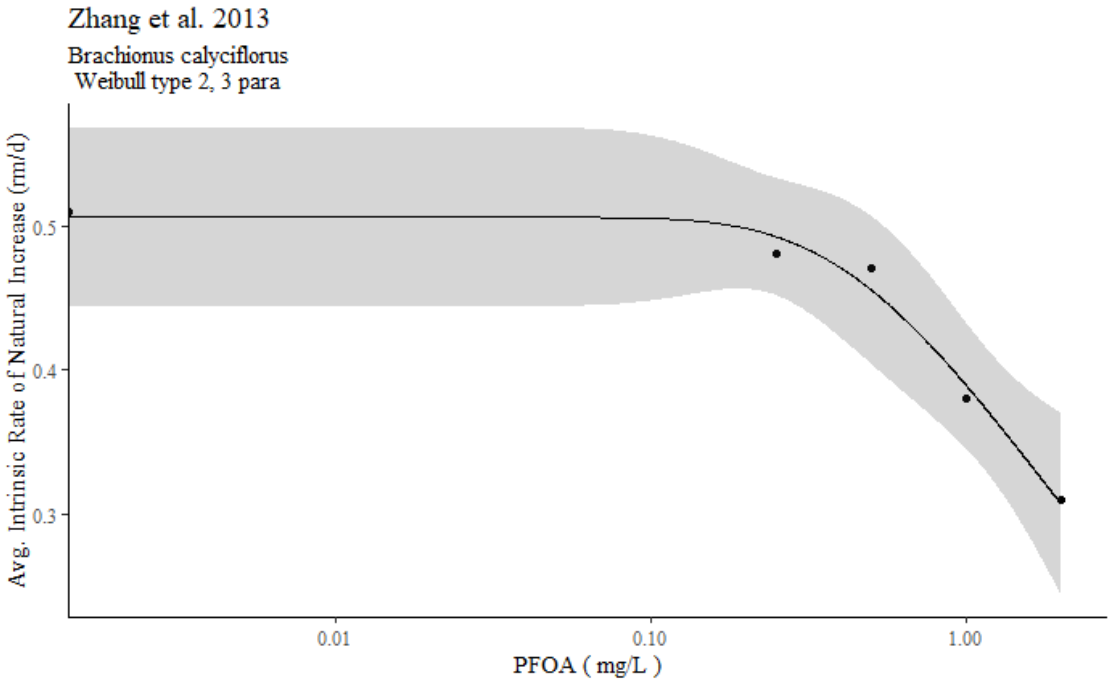
time. In this study, the intrinsic rate of natural increase was defined as the natural log of the lifetime net reproductive rate for all individuals within a population (defined here as a PFOA treatment level) divided by the average generation time of those individuals. The effect associated with intrinsic rate of natural increase is similar to other chronic apical effects reported by Zhang et al. (2013a). For example, Zhang et al. (2013a) also reported net reproductive rate and juvenile period which produced an EPA-calculated EC_{10} value of 0.514 mg/L (95% C.I. = 0.1958 – 0.8329 mg/L). Zhang et al. (2013a) also reported effects to average juvenile period, which was a relatively tolerant endpoint. Juvenile period decreased with increasing exposure concentration, with the average juvenile period being about 16% faster than the control responses in the highest treatment concentration (2.0 mg/L; the EPA was unable to fit a statistically-robust C-R model for this endpoint). Zhang et al. (2013a) reported significant reductions in egg size with an EPA-calculated EC_{10} = 0.193 (95% C.I. = -0.1606 – 0.5466 mg/L); however, this endpoint displayed a relatively poor concentration response relationship and may not be relevant for assessing population level effects and was, therefore, not selected as the primary effect concentration from this test. Effects to chronic apical endpoints in this publication and Zhang et al. (2014b) generally appear as a threshold effect from 0.25 mg/L to 1.0 mg/L, providing further support for the endpoint and effect level selected for quantitative use from Zhang et al. (2013a).

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Publication: Zhang et al. (2013a)
Species: Rotifer (*Brachionus calyciflorus*)
Genus: *Brachionus*
EPA-Calculated EC_{10}: 0.5015 mg/L (95% C.I. = 0.1458 – 0.8572 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	-0.6515	0.1231	-5.2930	0.0339
d	0.5058	0.0144	35.0478	0.0008
e	1.8042	0.2240	8.0546	0.0151

Concentration-Response Model Fit:



Zhang et al. (2014b) reports the results of a similar chronic life-cycle test of PFOA (CAS # 335-67-1, 96% purity) with *Brachionus calyciflorus*. The full life-cycle test used renewal conditions for approximately four days. *B. calyciflorus* used for the test were less than two-hours old at test initiation. All animals were parthenogenetically-produced offspring of one individual from a single resting egg collected from a natural lake in Houhai Park (Beijing, China). The rotifers were cultured in an artificial inorganic medium at 20°C (16-hours:8-hours, light:dark; 3000 lux) for more than six months before toxicity testing to acclimate to the experimental

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conditions. Culture medium was an artificial inorganic medium and all toxicity tests were carried out in the same culture medium and under the same conditions as during culture (i.e., Ph, temperature, illumination). Solvent-free stock solutions of PFOA (1,000 mg/L) were prepared by dissolving the solid in deionized water via sonication. After mixing, the primary stock was proportionally diluted with dilution water to prepare the test concentrations. Exposure vessels and size were not reported for the four-day reproductive assay but were likely 6-well cell culture plates (assumed plastic) each containing at total of 10 Ml of test solution. The test employed eight test concentrations plus a negative control. Each treatment consisted of six replicates of 10 rotifers each in individual cells. The numbers of living rotifers were counted after four days for each treatment level. Nominal concentrations were 0 (negative control), 0.125, 0.25, 0.50, 1.0, 2.0, 4.0, 8.0 and 16.0 mg/L. PFOA concentrations were not measured in the rotifer exposures, but rather in a side experiment using HPLC/MS. The side experiment showed that the concentration of PFOA measured every eight-hours over a 24-hour period in rotifer medium with green algae incurs minimal change in the concentration, ranging from 0.25 to 2.0 mg/L. Negative control survival was not provided for the life-cycle test.

Resting egg production is an ecologically important endpoint for this species because it represents the final result of sexual reproduction. Based on authors description of results in the text, “PFOA exposure significantly reduced resting egg production of *B. calyciflorus* females during the three-day period.” NOEC and LOEC values were not reported, but 0.25 mg/L PFOA produced more than a 50% reduction in resting egg production. Therefore, it is assumed The *B. calyciflorus* four-day NOEC for resting egg production was 0.125 mg/L and the LOEC was 0.25 mg/L, with a calculated MATC is 0.1768 mg/L. Concentration response data from Figure 1 of

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Zhang et al. (2014b) were estimated (WebPlotDigitizer[1]) and used to derive an EPA-calculated EC_{10} of 0.076 mg/L (95% C.I. = 0.054 – 0.098 mg/L), further suggesting resting egg production may be a relatively sensitive endpoint. Because there was only one replicate (as implied by lack of error bars in Figure 1 of the publication, no clear description of replicates in the methods section, and no author-reported statistical analysis of this endpoint), resting egg production from this study was not considered quantitatively acceptable but was retained for qualitative use. Beyond resting egg production, PFOA did not clearly affect hatching rate of resting eggs when exposed to PFOA during the formation or hatching period, enhanced hatching rate relative to controls in most treatments (nominal test concentration range = 0 – 2.0 mg/L; see figures 3 and 4 of Zhang et al. 2014b) and displayed no clear concentration-response relationship, suggesting rotifer hatching rate was a relatively tolerant endpoint from this publication. In contrast to Zhang et al. (2013a), which observed no effect of PFOA on mictic ratio after 28 days at a nominal concentration as high as 2.0 mg/L PFOA, Zhang et al. (2014b) stated PFOA significantly increased the F1 mictic ratio from 0.56 in the control treatment to 0.75 and 0.72 in nominal PFOA test concentrations of 0.25 mg/L and 2.0 mg/L, respectively. Given conflicting results of PFOA on rotifer mictic ratio, it was not selected as the primary endpoint from Zhang et al. (2014b). The most sensitive quantitatively acceptable endpoint was the intrinsic rate of natural increase. The intrinsic rate of natural increase (d^{-1}) is a population level endpoint that accounts for births and deaths over time. In this study, the intrinsic rate of natural increase was defined as the natural log of the net increase in the number of rotifers (surviving parents and offspring) for each PFOA treatment level over a four-day exposure period. This endpoint was conceptually

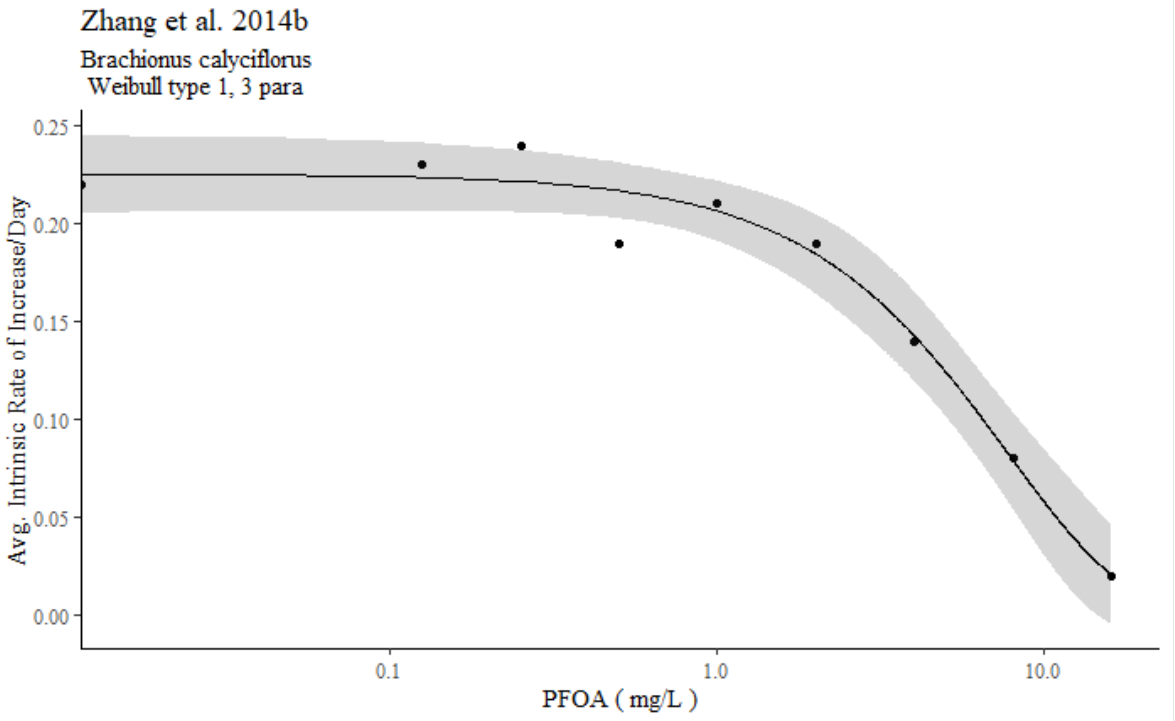
[1] WebPlotDigitizer is an online application used to convert values shown in figures to numerical values. This application was used to obtain numerical concentration-response data when they were only reported in figures. The application is free and available online (WebPlotDigitizer - Extract data from plots, images, and maps (automeris.io)).

equivalent to the intrinsic rate of natural increase endpoint calculated by Zhang et al. (2013a) but was a simplification of the calculations performed in Zhang et al. (2013b), in that it only applied to the four-day observational period, whereas the intrinsic rate of natural increase calculated in Zhang et al. (2013a) represented the full lifetimes of all individuals within each population (i.e., exposure concentration). The EPA-calculated EC_{10} for this endpoint was 1.166 mg/L (95% C.I. = 0.7720 – 1.559 mg/L).

Publication: Zhang et al. (2014b)
Species: Rotifer (*Brachionus calyciflorus*)
Genus: *Brachionus*
EPA-Calculated EC_{10}: 1.166 mg/L (95% C.I. = 0.7720 – 1.559 mg/L)
Concentration-Response Model Estimates:

Parameter	Estimate	Std. Error	t-stat	p-value
b	1.1913	0.2118	5.6236	0.0014
d	0.2253	0.0081	27.9366	$1.392\ e^{-7}$
e	7.7080	0.8191	9.4102	$8.183\ e^{-5}$

Concentration-Response Model Fit:



C.2.5 Fifth most chronically sensitive genus – *Moina*

Ji et al. (2008) conducted a chronic life-cycle test on the effects of PFOA (CAS # 335-67-1, purity unreported; obtained from Sigma Aldrich, St. Louis, MO, USA) with *Moina macrocopa*. Tests were done under renewal conditions over a seven-day period and test solutions were not analytically confirmed. Authors stated that the *M. macrocopa* test followed a protocol developed and reported by S.R. Oh (2007) (Master's thesis, Seoul National University, Seoul, Korea), which is similar to OECD 211 (1998), but with slight modification (i.e., shorter test duration, exposure temperature and different feeding regime: 100 µL yeast:cerophyll:Tetramin mixture and 200 µL algae suspension per day). *M. macrocopa* used for testing were obtained from brood stock cultured at the Environmental Toxicology Laboratory at Seoul National University, Korea. Test organisms were less than 24 hours old at test initiation. Dilution water was moderately hard reconstituted water (total hardness typically 80-100 mg/L as $CaCO_3$). Experiments were conducted in glass jars of unspecified size and fill volume. Photoperiod for the test was not reported but was assumed to be 16-hours of illumination, the same conditions as the daphnid cultures reported in this same publication. Preparation of test solutions was not described. The test involved ten replicates of one individual each in five nominal test concentrations plus a negative control. Nominal concentrations were 0 (negative control), 3.125, 6.25, 12.5, 25 and 50 mg/L and test solutions were renewed three times per week. Test temperature was 25 ± 1°C for *M. macrocopa*. Authors note that the water quality parameters (Ph, temperature, conductivity, and dissolved oxygen) were measured after changing the medium, but the information was not reported. Survival of daphnids in the negative control was 100%. The *M. macrocopa* seven-day NOEC (reproduction: number of young per adult) was 3.125 mg/L, the LOEC was 6.25 mg/L and the MATC is 4.419 mg/L. The EPA performed C-R analysis for this study. The most sensitive endpoint with an acceptable C-R curve was the number of young per

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starting female. The EPA-calculated EC_{10} was 2.194 mg/L PFOA (95% C.I. = -0.7120 – 5.010 mg/L) for *M. macrocopa*. The lowest treatment concentration produced a greater than a 10% effect which forced the EC_{10} calculation to extrapolate beyond the lowest treatment concentration (i.e., not the control, but the nominal treatment of 3.25 mg/L). However, the resultant EC_{10} value (i.e., 2.194 mg/L) was considered acceptable for quantitative use because it was largely in agreement with the 14.3% effect observed at the test concentration of 3.125 mg/L.

C.2.6 Sixth most chronically sensitive genus – *Neocloeon*

Soucek et al. (2023) conducted a chronic life-cycle test to determine the effects of PFOA (CAS # 335-67-1, 95% purity) on the parthenogenetic mayfly, *Neocloeon triangulifer*. The test was performed under renewal conditions over 28 days beginning with <24-hour old nymphs. Single mayfly exposures were static without renewal for the first four days due to the small size of starting organisms and renewed three times per week thereafter by transferring organisms to new exposure chambers. From day 0 to 14, mayflies were exposed in 30 Ml polypropylene cups with 20 Ml exposure water. Organisms were transferred after 14 days into 250 Ml glass beakers with 100 or 150 Ml of test water (or control) and to 300 Ml tall form beakers for emergence. At test initiation, there were 16 replicates per test concentration and control. Nominal test concentrations were 0.0 (control), 0.047, 0.094, 0.375, 0.750, 1.500 and 3.000 mg/L PFOA. Mean measured PFOA concentrations (EPA Analytical Method 1633; LC-MC/MS) were 0.000176 (control), 0.043, 0.078, 0.419, 0.672, 1.739 and 3.085 mg/L PFOA, respectively. Mayflies were exposed at 23 ± 1°C under a 16:8-hour light:dark cycle and fed 0.2 Ml diatom slurry plus small scraping on test days 0 and 4 followed by live diatom biofilm scraping after day 4 on solution renewal days. Percent survival in the control after 14 days was 94%. Percent survival of mayflies after 14 days in the remaining seven test concentrations ranged from 75 to 100%. On test day 14, replicates one through eight were destructively sampled to evaluate 14-

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day weight. Replicates 9-18 were maintained under test conditions until test day 23. No clear effects of PFOA on 14-day weight or survival were observed in any of the treatments. Similarly, after 28-days of exposure, no clear effects of PFOA were observed on survival to pre-emergent nymph (PEN) stage, survival to emergence, number of days to emergence, imago live weight, or survival to subimago. The relatively high >NOEC (i.e., >3.085 mg/L) suggests *N. triangulifer* is relatively tolerant to chronic PFOA exposures and does not occur among the four most sensitive genera. The >NOEC (i.e., >3.085 mg/L) was acceptable for quantitative use in deriving the chronic freshwater PFOA criterion.

C.2.7 Seventh most chronically sensitive genus – *Oryzias*

Lee et al. (2017) conducted a multiple generation exposure to determine the effects of PFOA (CAS # 335-67-1, purity was not reported) on the reproductive toxicity and metabolic disturbances to *Oryzias latipes*. Fish were originally received from the Department of Risk Assessment of the National Institute of Environmental Research (NIER; South Korea) and maintained according to the following conditions: dissolved oxygen 7-8 mg/L, Ph 7.5 ± 0.2, water temperature 25 ± 1°C, 16-hour light, 8-hour dark photoperiod and total hardness 55-57 mg/L (as $CaCO_3$). *O. latipes* were fed *Artemia salina* once daily, based on the OECD test guideline 240 feeding schedule. Adults (about 13 weeks old, when genders could be visually differentiated) through the F2 generation were exposed to three nominal concentrations of PFOA (0.3, 3 and 30 mg/L PFOA) for a total exposure period of 259 days. At test initiation, four pairs of both genders were introduced into the test chambers (8 L glass tank) of a flow-through exposure system. PFOA solutions were replenished five times daily to keep the same water quality as fish maintaining condition. PFOA exposure continued for three weeks, during which eggs produced by mating of F0 fish were removed from test chamber and counted daily for fecundity. During test week four, (spawning period), the F1 generation eggs (n = 192) were

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obtained per concentration. Right after the spawning period was finished, F0 fish were used to evaluate metabolism disturbance. The F1 eggs were pooled and redistributed into an incubation chamber containing PFOA solution. After the hatching was completed, the test organisms were returned into test chambers and raised under flow-through PFOA exposure conditions until they reached adult stage (at about 13 weeks old), during which sac-fry survival rate, hatching rate, and abnormality of F1 were analyzed. When F1 fish reached the adult stage, sex ratio of total F1 fish was determined and 32 individuals of F1 fish were used to analyze gonadosomatic (GSI), hepatosomatic (HSI), condition factor (K), VTG expression, and histological alterations. In addition, other F1 fish (32 male and female fish) were used for obtaining the F2 generation eggs same as the F0 generation. The exposure conditions to F2 fish were carried out in the same manner as F1 fish. Consequently, F0 fish were exposed to PFOA for four weeks and F1 and F2 fish were exposed to PFOA across all life cycle stages without exposure pause. The exposure regime was applied equally in all test groups. The 259-day MATC of 9.487 mg/L PFOA was reported for F2 sac-fry survival and fecundity for the F0, F1 and F2 generations and represented the most sensitive endpoints from the study. Reproductive responses reported by Lee et al. (2017) appear to be control normalized; however, use of control normalized data in this study does not alter conclusions from hypothesis-based testing (i.e., use of a NOEC, LOEC, or MATC). Beyond F2 survival (which had control mortality), the EPA attempted C-R analysis for all endpoints reported by Lee et al. (2017). Given the large dilution factor between PFOA treatments, C-R models could either not be fit, or when models could be fit, they performed poorly on statistical metrics and were not used. Therefore, the 259-day MATC of 9.487 mg/L PFOA was considered to be quantitatively acceptable for criterion derivation. The large dilution

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factor from this test does not support concentration response modeling, consequently EPA relied on an MATC (i.e., 9.487 mg/L) as the chronic effect level from this test.

C.2.8 Eighth most chronically sensitive genus – *Ceriodaphnia*

Kadlec et al. (2024) tested the chronic toxicity of pefluorooctanoic acid (PFOA) to *Ceriodaphnia dubia* for seven days in three measured, renewal experiments. Similar chronic tests were also performed with *Chironomus dilutus* and *Hyallela azteca*, but this summary is limited to the results of the *C. dubia* tests. Test chemicals were obtained from Sigma, Alfa Aesar, Synquest, and Toronto Research Chemical (purity 96-99%). Test organisms were obtained from in-house cultures maintained following ASTM and EPA protocols. Test water was UV-treated and sand-filtered Lake Superior water supplemented with Na_2SO_4, NaCl, KCl, $CaCl_2$ x $2H_2O$, and $MgCl_2$ x $6H_2O$. Testing protocols followed species-specific ASTM methodologies (ASTM 2002). Three separate tests were conducted, each with a 0.5x dilution series of measured PFOA concentrations, with ten replicates of each concentration, and one organism per replicate. Test 1 mean concentrations were 0.019 (control), 0.19, 0.31, 0.62, 1.3, 2.7, 5.5, 11, 22, 44 and 91 mg/L. Test 2 mean concentrations were 0.67 (control), 6.7, 14, 28, 55, and 109 mg/L. Test 3 mean concentrations were 0.35 (control), 3.5, 6.8, 14, 30 and 57 mg/L. *C. dubia* neonates (<8-hour) were placed in one ounce polystyrene cups filled with 15 mL of test solution. Dissolved oxygen and pH were measured twice in each exposure per treatment and twice in the stock solutions. Test chambers were placed in a water bath to maintain a steady temperature under a 16:8 light:dark cycle. Study authors reported average water quality measurements of 24.7°C, 8.6 mg/L DO, 7.8 pH, 52 mg/L as $CaCO_3$ hardness, 41 mg/L as $CaCO_3$ alkalinity, and 145 µmhos/cm conductivity. Testing solutions were renewed daily, and organisms were fed daily with 100 µg/L YCT and algae. Control survival was 96.8% with a mean reproduction of 26.8 offspring per surviving female. EC_{20}s and EC_{50}s for survival and young per surviving female were calculated

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following methods described in Mount et al. (2016), using custom software written with Intel Visual Fortran Compiler Xe (Intel Corporation) and Winteracter 13.0 (Interactive Software Services). The author reported EC_{20}s for young per surviving female for tests 1, 2, and 3 were 26.2, 25.1, and 33.8 mg/L, respectively. Concentration-response data were reported for these tests, allowing the EPA to independently model concentration-response curves using the dose-response curve package in R. The EPA-calculated EC_{10} values for tests 1, 2, and 3 were 20.42, 21.69, and 29.54 mg/L, respectively, which were determined to be acceptable for quantitative use.

C.2.9 Ninth most chronically sensitive genus – *Gobiocypris*

The chronic toxicity of PFOA (98% purity) on the rare minnow (*Gobiocypris rarus*; not North American resident species) was investigated by **Wei et al. (2007)** using flow-through unmeasured exposure conditions. Two hundred and forty mature male and female rare minnows (about nine months old, 1.4 ± 0.4 g, 47.7 ± 3.6 mm) were obtained from a laboratory hatchery and randomly assigned to eight 20 L glass tanks (30 individuals per tank). Fish were supplied with dechlorinated tap water under continuous flow-through conditions at 25 ± 2°C and a photoperiod of 16-hours:8-hours light:dark. During the 28-day exposure period, fish were fed a commercial granular food (Tetra) at a daily rate of 0.1% body weight. Waste and uneaten food were removed daily. After a one-week acclimation period, 30 randomly selected male and 30 female rare minnows (gender determined by observing the shape of the abdomen and the distance between the abdomen fin and the stern fin) were assigned to one of the four nominal PFOA exposures (0, 3, 10 or 30 mg/L PFOA). Each treatment was performed in duplicate tanks. The flow rate of the test solution was 8 L/hour, and actual PFOA concentrations in the tanks were not verified by chemical analysis. During the exposure period, there were separate inputs for water and PFOA and the mixer helped mix PFOA and water before flowing into the tanks.

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The concentration of mixed solution flowing out from the mixer were kept at 3, 10 or 30 mg/L PFOA by adjusting the input flow rate of concentrated PFOA and water, respectively. After 14-day and 28-day exposure periods, fish were anesthetized on ice, and liver samples were taken and immediately frozen in liquid nitrogen and stored at -80°C until analyzed. No mortality was observed in any treatments. The 28-day LOEC (survival) was >30 mg/L PFOA and was acceptable for use as a high-unbounded value from a high-quality study which provides relevant sensitivity information for this fish species.

C.2.10 Tenth most chronically sensitive genus - *Oncorhynchus*

Centre International de Toxicologie (2004) and **Colombo et al. (2008)** evaluated the chronic effects of ammonium perfluorooctanoate (APFO, CAS #3825-26-1, 99.7% purity) to embryos of the rainbow trout, *Oncorhynchus mykiss*. Stock solutions of APFO were prepared by dissolving the test substance directly in the test media or dilution water and then diluting the stock solution to provide a geometric series of test concentrations (nominal concentrations of 3.13, 6.25, 12.5, 25 and 50 mg/L APFO). The early-life-stage (ELS) test was performed under flow-through conditions and in compliance with OECD test guideline 210. Unfertilized trout eggs and sperm were received from a commercial supplier and the eggs were fertilized in the laboratory. One hundred and eighty newly fertilized eggs were randomly selected and allocated, 60 eggs per replicate, to the three replicate test vessels for each control and test concentration. Authors stated that the number of surviving fish was reduced randomly to 30 per replicate just after the end of the hatching period (day 26) in the control. The number of surviving fish was again reduced randomly to 15 per replicate when swim-up and feeding began on day 50. Actively feeding juveniles were fed trout chow two to four times per day, corresponding to approximately 4% of their body weight per day, from day 50 to the end of the 85-day test. Test solutions were continuously renewed during the study by pumping the stock solutions into

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flowing dilution water with a peristaltic pump system at a replacement rate of 5.76 times the test vessel volume per day. Dilution water pH was 6.0-8.5, total hardness was 150 mg/L as $CaCO_3$, and water temperature was kept between 11.1 and 12.5°C for embryos and between 11.6 and 14.4°C for larvae and juvenile fish. The dissolved oxygen concentration was greater than 60% air saturation, the light/dark cycle was maintained at constant darkness until seven days after hatching, then 16 hours light and eight hours dark through test end. Observations were made daily as follows: eggs-marked loss of translucency and change in coloration, white opaque appearance; embryos-absence of body movement or heartbeat; larvae and juvenile fish-immobility, absence of respiratory movement or heartbeat, white opaque coloration of the central nervous system, lack of reaction to mechanical stimulus, and abnormalities. The reported 85-day growth and mortality NOEC was 40 mg/L PFO^-; however, the authors' note that the contribution of ammonia from APFO exposure indicates that un-ionized ammonia could be a potential contributor to the observed toxicity of APFO. Although the authors cite U.S. EPA (1999) for un-ionized ammonia toxicity values, that document (and the subsequent U.S. EPA [2013] criteria document) expressed toxicity in terms of a relationship between total ammonia nitrogen and pH and temperature. For rainbow trout, U.S. EPA (1999) declined to specify a chronic value, due to inconsistencies between tests. However, U.S. EPA (2013) set the rainbow trout chronic value at 6.66 mg TAN/L (Total Ammonia Nitrogen/L) at pH = 7. Using the normalization equations in U.S. EPA (2013), the rainbow trout chronic value translated to 3.60 mg N/L at the authors' assumed chronic test pH of 7.8 (see table 7 of Colombo et al. [2008]), which in turn translated to a rainbow trout chronic value as un-ionized ammonia of 0.064 mg un-ionized ammonia/L at pH 7.8 and a reported test of temperature (13°C). Table 7 of Colombo et al. (2008) listed the un-ionized ammonia concentration at their APFO NOEC as 0.013 mg un-ionized ammonia/L, which

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is 4.9-fold lower than the EPA's chronic value for rainbow trout re-expressed as an un-ionized ammonia concentration for the test condition. Therefore, the EPA does not believe ammonia was a confounding factor in this test and the study was determined to be quantitatively acceptable for criterion derivation.

C.2.11 Eleventh most chronically sensitive genus – *Pimephales*

Bartlett et al. (2021) also evaluated the chronic effects of PFOA (CAS# 335-67-1, 96% purity, solubility in water at 20,000 mg/L, purchased from Sigma-Aldrich) on fathead minnows (*Pimephales promelas*) via a 21-day early-life stage static-renewal, measured study. The authors followed OECD Test Guideline 210, except that the test ended at 16 days post-hatch (dph) compared to 28 dph for the standard OECD test. Test water (i.e., stock solutions, exposure solutions and controls) was charcoal-filtered UV-sterilized Burlington City water from Lake Ontario (total hardness 120–130 mg/L, alkalinity 89–93 mg/L, Ph 7.4–7.8), and was maintained in a header tank prior to use in testing. Fathead minnow eggs (<18-hour post fertilization) were purchased from Aquatox Labs (Guelph, ON) and exposed to nine nominal PFOA concentrations: 0.01, 0.032, 0.1, 0.32, 1, 3.2, 10, 32 and 100 mg/L. The tests were divided into low concentration (0.01-10 mg/L) and high concentration (32-100 mg/L) tests, with five days in the egg stage and 16 days in the larval fish stage. Tests were initiated with eggs from five to ten egg batches (from different fathead minnow breeding groups) to maximize genetic diversity and variability. There were 20 eggs per beaker, with eight replicates of controls and four replicates of each PFOA concentration in each of the two tests. Embryos and larvae were held in glass, Nitex mesh bottomed (mesh size 500 µm) egg cups within 800-Ml HDPE beakers filled to 700 Ml with test solution. Beakers containing fathead minnow eggs/larvae were aerated, loosely covered, and held in a 25°C incubator with a photoperiod of 16 hours light and 8 hours dark. Larvae were fed 10 µL/fish (0–9 dph) and 20 µL/fish (9–16 dph) of newly hatched brine shrimp slurry per day. The

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first feeding (half of the daily aliquot) was two hours prior to the daily solution changeover (to remove excess food and waste), and the second feeding (the other half of the daily aliquot) was after solution changeover, so that food was available at all times during the tests. Endpoints evaluated were survival to hatch, time to hatch, hatching success, deformities at hatch, uninflated swim bladder, survival from the egg until nine and 16 dph, and weight, length, tail length, and condition factor of larvae at nine and 16 dph. The reported 21-day NOEC for mortality, weight, length, and condition factor was 76 mg/L PFOA. The EPA could not independently calculate an EC_{10} value because no effects were observed across the range of concentrations tests. Because the NOEC of 76 mg/L was a relatively tolerant NOEC value it was considered quantitatively acceptable for criteria derivation.

C.2.12 Twelfth most chronically sensitive genus - *Chironomus*

McCarthy et al. (2021) conducted a 19-day "abbreviated full life cycle" PFOA (97% purity, purchased from Sigma-Aldrich) toxicity test on the midge, *Chironomus dilutus*. The PFOA stock solution was dissolved in reconstituted moderately hard water without the use of a solvent and stored in polyethylene at room temperature until use. Authors reported that they followed standard protocols (ASTM 2005; U.S. EPA 2000) with slight modifications. Exposure vessels for both experiments were 1 L high-density polyethylene beakers containing natural field-collected sediment with 60 mL of sediment and 105 mL of test solution. PFOA test solutions were added via pipette to the beakers with the tip just above the sediment substrate. Nominal test concentrations were 0, 26, 87, 149, 210 and 272 mg/L PFOA, respectively. Test concentrations were based on the results of a 10-day range finding test conducted by McCarthy et al. (2021). Egg cases were obtained from Aquatic Biosystems or USGS Columbia Environmental Research Center and held as free-swimming hatched embryos (<24 hour after hatch) before testing. Each beaker held 12 organisms with five replicates per exposure treatment.

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Solutions were renewed every 48 hours. PFOA treatment concentrations were measured on days 10, 15 and 20 in the 20-day exposure. Mean measured PFOA concentrations in the 20-day exposure were 0 (control), 19.9, 59.4, 145, 172 and 227 mg/L PFOA. Percent survival in the control treatment was 82%. The most sensitive endpoint was survival with an author reported 19-day EC_{10} of 89.8 mg/L PFOA. The EPA-calculated survival-based EC_{10} was 88.32 mg/L (95% C.I. = 15.40 – 161.3 mg/L), which was acceptable for quantitative use.

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Appendix D Acceptable Estuarine/Marine Chronic PFOA Toxicity Studies

D.1 Summary Table of Acceptable Quantitative Estuarine/Marine Chronic PFOA Toxicity Studies

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Salinity (ppt)	Chronic Value Endpoint	Author Reported Chronic Value (mg/L)	EPA Calculated Chronic Value (mg/L)	Final Chronic Value (mg/L)[b]	Species Mean Chronic Value (mg/L)	Reference
Purple sea urchin (adult), *Paracentrotus lividus*	S, M	28 days	PFOA >98%	-	17.00	35	MATC (survival)	31.62	-	**31.62**	31.62	Savoca et al. 2022
Japanese medaka, *Oryzias latipes*	S, U	30 days	Perfluoro-octanoate 96%	7.72	24.82	34.52	NOEC (growth - condition factor)	1.0	-	**>1.0**	>1.0	Oh et al. 2013

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

[b] Values in bold used in the SMCV calculation

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D.2 Detailed Study Summaries of Chronic Saltwater PFOA Toxicity Studies Considered for Use in Saltwater Criterion Derivation

The purpose of this section is to present detailed study summaries for chronic estuarine/marine tests that were considered quantitatively acceptable for criterion derivation, with summaries grouped and ordered by genus sensitivity. Unlike Appendix A.2 and Appendix C.2, the EPA-calculated C-R models were not presented below for the four most sensitive estuarine/marine genera because a chronic estuarine/marine criterion or benchmark was not developed.

D.2.1 Most chronically sensitive estuarine/marine genera – *Oryzias*

Oh et al. (2013) evaluated the chronic toxicity of PFOA on the Japanese medaka, *Oryzias latipes,* in a 30-day static exposure. PFOA (96% pure, CAS No. 335-67-1) was dissolved in filtered seawater with a minimal concentration (<0.001%) of DMSO used as a vehicle to prevent cellular damage to the fish. Only nominal concentrations were used throughout the study. Prior to test initiation, the fish were acclimated to a seawater environment. The fish were maintained at 25°C under a constant photoperiod of 16:8 hour (light:dark) and water quality was monitored by measuring the pH, dissolved oxygen, and temperature. Fish from the 3rd generation of *O. latipes* (n = 7/group) that had acclimated to seawater for over one month were used in the exposure experiments. Fish were exposed for 30 days to one PFOA concentration (1.0 mg/L), a 0.22 µm filtered seawater control, and a DMSO carrier solvent control. Test conditions were maintained at an average temperature of 24.82°C, pH of 7.72, dissolved oxygen of 6.04 mg/L, and salinity of 34.52 practical salinity units, with fish fed daily. The 30-day condition factor NOEC of 1.0 mg/L PFOA was selected as the primary endpoint from this study. In the methods section, Oh et al. (2013) also stated, "In our preliminary study, fish mortality was altered 30 days after perfluorinated compound exposure, suggesting that repeated exposure to PFCs for 30 days

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at 1 µg/mL [1 mg/L] causes adverse effect on *O. latipes*." The statement about mortality-based effects in their preliminary test is in direct conflict with the condition factor-based results from the primary test described in the publication. Few details are provided about the preliminary test. Results of the final test (i.e., condition factor NOEC of 1.0 mg/L; reported in Table 1 of Oh et al. 2013) were retained as quantitatively acceptable because they provide chronic estuarine/marine data that were otherwise limited.

D.2.2 Second most chronically sensitive estuarine/marine genera – *Paracentrotus*

Savoca et al. (2022) tested chronic toxicity of perfluorooctanoic acid (PFOA) to sea urchins (*Paracentrotus lividus*) in a 28-day measured, static experiment. Analytical grade PFOA (>98% purity) was obtained from Sigma-Aldrich. Thirty-six adult sea urchins were collected off the coast near Capo Zafferano, Italy, a site where little to no PFOA exposure was expected, and were acclimated in the laboratory for eight days in 200 L of filtered (30 µm) seawater. Four sea urchins were placed into one of nine aquariums containing 15 L of seawater at nominal concentrations (0 (control), 10, and 100 mg/L), with three replicates per concentration treatment. Organisms were kept at 17±1°C with a 35±1% salinity under a 12:12 light:dark cycle. To avoid PFOA uptake, organisms were not fed during the experiment and tanks did not have filtration. Instead, continuous aeration was employed, and PFOA in test water was monitored weekly in each tank. The average recovery of PFOA was stable and close to nominal across all treatments throughout the experiment, and PFOA in control water was less than 10 ng/L. Coelomic fluid was sampled from all individuals weekly to measure PFOA uptake. During the exposure period, sea urchins at the highest test concentration showed sublethal signs of toxicity, including reduced spine mobility, spine loss, and reduced ability to remain anchored to the bottom of the test vessels. Mortality was only observed at the highest test concentration. After the exposure, or in the case of urchins exposed to the highest PFOA concentrations, after the onset of adverse

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effects, egg samples were dissected from the gonads of each organism, fertilized, and held at 18±1°C for 48 hours. Adult mortality, adult PFOA accumulation in coelomic fluid, percentage of normal and abnormal embryos, and gene expression in embryos were measured. Adverse effects of PFOA were observed for all endpoints. ANOVA or Kruskal-Wallis tests were used to assess significant differences in PFOA treatments compared to controls. The NOEC and LOEC for adult mortality were 10 mg/L and 100 mg/L, respectively, and the MATC of 31.62 mg/L was determined to be acceptable for quantitative use.

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Appendix E Acceptable Freshwater Plant PFOA Toxicity Studies

E.1 Summary Table of Acceptable Quantitative Freshwater Plant PFOA Toxicity Studies

Species	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Reported Effect Concentration (mg/L)	Reference
Cyanobacteria, *Microcystis aeruginosa*	S, U	12 days	PFOA ≥95%	-	25	MATC (population abundance – cell density)	15.81	Hu et al. 2023
Green alga, *Chlamydomonas reinhardtii*	S, U	96 hours	PFOA >96%	6.8	25	EC_{50} (growth)	51.9	Hu et al. 2014
Green alga, *Chlamydomonas reinhardtii*	S, U	8 days	PFOA >96%	6.8	25	MATC (cell number)	28.28	Hu et al. 2014
Green alga, *Chlamydomonas sorokiniana*	S, U	96 hours	PFOA ≥96%	7.1	25	EC_{50} (population abundance inhibition rate)	140.59	Zhao et al. 2023
Green alga (7.0×10^5 cells/mL), *Chlorella pyrenoidosa*	S, M	96 hours	PFOA >98%	-	25	EC_{50} (growth)	190.99	Xu et al. 2013
Green alga, *Chlorella pyrenoidosa*	S, M	10 days	PFOA >98%	7.1	23	NOEC (biomass)	0.73	Hu et al. 2020
Green alga, *Chlorella pyrenoidosa*	S, M	10 days	PFOA >98%	7.1	23	NOEC (biomass)	0.95	Hu et al. 2020
Green alga, *Chlorella pyrenoidosa*	S, M	10 days	PFOA >98%	7.1	23	NOEC (biomass)	0.95	Hu et al. 2020
Green alga, *Chlorella pyrenoidosa*	S, M	10 days	PFOA >98%	7.1	23	NOEC (biomass)	0.86	Hu et al. 2020
Green alga, *Chlorella pyrenoidosa*	S, M	10 days	PFOA >98%	7.1	23	NOEC (biomass)	0.84	Hu et al. 2020
Green alga, *Chlorella pyrenoidosa*	S, M	10 days	PFOA >98%	7.1	23	NOEC (biomass)	0.97	Hu et al. 2020
Green alga, *Chlorella pyrenoidosa*	S, M	10 days	PFOA >98%	7.1	23	NOEC (biomass)	0.94	Hu et al. 2020
Green alga, *Chlorella pyrenoidosa*	S, M	10 days	PFOA >98%	7.1	23	NOEC (biomass)	0.95	Hu et al. 2020
Green alga, *Chlorella pyrenoidosa*	S, M	10 days	PFOA >98%	7.1	23	NOEC (biomass)	0.83	Hu et al. 2020
Green alga (9×10^5 cells/mL), *Chlorella pyrenoidosa*	S, U	96 hours	PFOA ≥95%	-	25	NOEC (growth)	0.1	Li et al. 2021b

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Species	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Reported Effect Concentration (mg/L)	Reference
Green alga (1.5 x 10^4 cells/mL), *Chlorella vulgaris*	S, U	96 hours	PFOA 95%	-	23	IC_{50} (cell density)	115.5	Boudreau 2002
Green alga, *Raphidocelis subcapitata* (formerly, *Pseudokirchneriella subcapitata* and *Selenastrum capricornutum*)	S, U	14 days	APFO 96.5-100%	-	23	EC_{10} (cell count)	5	3M Co. 2000a; Elnabarawy 1981
Green alga (1.5 x 10^4 cells/mL), *Raphidocelis subcapitata*	S, U	96 hours	PFOA 95%	-	23	IC_{50} (cell density)	123.4	Boudreau 2002
Green alga (log phase growth), *Raphidocelis subcapitata*	S, M	96 hours	APFO 99.7%	-	21-25	MATC (biomass and growth rate)	16.07	Colombo et al. 2008
Green alga (7.0 x 10^5 cells/mL), *Raphidocelis subcapitata*	S, M	96 hours	PFOA >98%	-	25	EC_{50} (growth)	207.46	Xu et al. 2013
Green alga, *Scenedesmus obliquus*	S, U	96 hours	PFOA >96%	6.8	25	EC_{50} (growth)	44.0	Hu et al. 2014
Green alga, *Scenedesmus obliquus*	S, U	8 days	PFOA >96%	6.8	25	NOEC (cell number)	40	Hu et al. 2014
Green alga, *Scenedesmus quadricauda*	S, M	96 hours	PFOA 99%	7	22	EC_{50} (growth inhibition rate)	269.63	Yang et al. 2014
Duckweed, *Lemna minor*	S, M	96 hours	PFOA ≥97.6%	6.5	25	NOEC (population growth rate)	9.478	Wu et al. 2023
Water milfoil (4 cm apical shoots), *Myriophyllum sibiricum*	S, M	14 days	PFOA Unreported	8.3–8.7	17.8-22.0	EC_{10} (dry weight)	8.7	Hanson et al. 2005
Water milfoil (4 cm apical shoots), *Myriophyllum sibiricum*	S, M	21 days	PFOA Unreported	8.3–8.7	17.8-22.0	EC_{10} (dry weight)	7.9	Hanson et al. 2005
Water milfoil (4 cm apical shoots), *Myriophyllum sibiricum*	S, M	35 days	PFOA Unreported	8.3–8.7	17.8-22.0	EC_{10} (wet weight)	21.6	Hanson et al. 2005
Water milfoil (4 cm apical shoots), *Myriophyllum spicatum*	S, M	14 days	PFOA Unreported	8.3–8.7	17.8-22.0	EC_{10} (dry weight)	18.1	Hanson et al. 2005
Water milfoil (4 cm apical shoots), *Myriophyllum spicatum*	S, M	21 days	PFOA Unreported	8.3–8.7	17.8-22.0	EC_{10} (plant length)	5.7	Hanson et al. 2005
Water milfoil (4 cm apical shoots), *Myriophyllum spicatum*	S, M	35 days	PFOA Unreported	8.3–8.7	17.8-22.0	EC_{10} (dry weight)	19.7	Hanson et al. 2005

Species	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Reported Effect Concentration (mg/L)	Reference
Lettuce (seed), *Lactuca sativa*	S, U	5 days	PFOA 96%	-	-	EC50 (root elongation)	745.7[b]	Ding et al. 2012b

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, NR=not reported

[b] Reported in moles converted to milligram based on a molecular weight of 414.07 mg/mmol.

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E.2 Summary of Quantitatively Acceptable Plant PFOA Toxicity Studies

E.2.1 Cyanobacteria, *Microcystis aeruginosa*

Hu et al. (2023) tested perfluorooctanoic acid (PFOA) on *Microcystis aeruginosa* for 12 days in a static, unmeasured experiment. PFOA (≥95% purity) was purchased from Sigma-Aldrich Corp. (St. Louis, MO, USA). Test organisms were obtained from the Freshwater Algae Culture Collection at the Institute of Hydrobiology in Wuhan, China, and were cultured in BG-11 medium within Erlenmeyer flasks at 25°C and 30µmol $m^{-2}s^{-1}$ photosynthetic photon flux density. *M. aeruginosa* in the exponential growth phase were added to 250 mL Erlenmeyer flasks containing 100 mL of test solution at a density of approximately $1.45x10^6$ cells/mL. The experimental design consisted of nominal concentrations of 0 (control), 1, 10, 25, and 50 mg/L PFOA, diluted from a PFOA stock solution of 1,000 mg/L prepared in BG-11 medium. All concentrations were repeated in triplicate, and each Erlenmeyer flask was manually shaken twice daily during the 12-day experiment. One mL of algal-test chemical solution was sampled from each flask daily to measure cell density. Chlorophyll *a*, photosynthesis, respiration, cellular ROS production, growth inhibition, enzyme activity, emission spectra, carbohydrate content, and total RNA were also measured. Statistical differences between treatments and controls were assessed using ANOVA and Dunnett's tests ($P<0.05$). Algal cells began showing signs of growth inhibition after two days of exposure, and decreased cell density in the highest PFOA concentration after four days. Starting on day five, cell density was significantly lower than controls in the 25 and 50 mg/L treatments. The 12-day NOEC and LOEC for cell density were 10 and 25 mg/L, and the MATC of 15.81 was determined to be acceptable for quantitative use.

E.2.2 Green alga, *Chlamydomonas reinhardtii*

Hu et al. (2014) evaluated the growth inhibition of PFOA (>96% purity) with *Chlamydomonas reinhardtii* in 96-hour and eight-day static exposures. Authors stated that the

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tests followed OECD test guidance 201 (OECD 2006). *Chlamydomonas reinhardtii* were supplied by UTEX Culture Collection of Algae, University of Texas at Austin. Dilution medium was described as modified high-salt media at a pH of 6.8. Algae in exponential growth phase were exposed to nominal concentrations of 0 (negative control), 1, 3.16, 10, 31.6, 100, 316 and 1,000 mg/L in the 96-hour exposure, and 0, 5, 10, 20 and 40 mg/L in the eight-day exposure. Experiments were initiated by inoculating equal cell numbers of $1x10^4$ cells/mL in the 96-hour exposure and $5x10^6$ cells/mL in the eight-day exposure into 250 mL flasks containing a total volume of 100 mL of algal cell suspension per flask. There were five replicates per treatment in the 96-hour exposure and three replicates in the eight-day exposure. Algae were incubated at 25°C under cool-white fluorescence lights at 85-90 µmol photons/[m^2 x s] irradiance with a 16-hour:8-hour light:dark cycle. The 96-hour growth EC_{50} (inhibition based on optical density) was 51.9 mg/L. The 8-day MATC based on cell number was 28.28 mg/L (NOEC and LOEC are 20 and 40 mg/L, respectively). The plant values from the study were acceptable for quantitative use.

E.2.3 Green alga, *Chlamydomonas sorokiniana*

Zhao et al. (2023) tested perfluorooctanoic acid (PFOA) on *Chlorella sorokiniana* for 96 hours in a 96-hour, static, unmeasured experiment. The study also investigated the effects of polystyrene microplastics on *C. sorokiniana,* both independently and in combination with PFOA, but only the independent effects of PFOA are summarized here. PFOA (≥96% purity) was purchased from Aladdin (Shanghai, China). Algae were purchased from the Freshwater Algae Culture Collection at the Institute of Hydrobiology in Wuhan, China. Before the experiment, the algae were cultured in BG-11 media in an illumination incubator at 25±1°C on a 12:12 hour light-dark cycle at a light intensity of 2,000±50 lux. Algal cultures were shaken three times daily. *C. sorokiniana* in the exponential growth phase were added to test vessels containing test solution at a density of approximately $1.0x10^6$ cells/mL. The experimental design consisted of

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nominal concentrations of 0 (control), 0.05, 0.5, and 5.0 mg/L PFOA, diluted from a PFOA stock solution of 500 mg/L prepared in BG-11 medium, with three replicates per treatment. Cell density and chlorophyll *a* were measured every 24 hours, and population growth inhibition rate was calculated after 96 hours. Several additional endpoints related to morphology and oxidative stress were also measured after 96 hours. Statistically significant ($p<0.05$) differences between treatment were assessed using ANOVA and least significant different tests. The EC_{50} for population growth inhibition rate was calculated using SPSS 19 software. The 96-hour EC_{50} value of 140.59 mg/L for population growth inhibition rate was determined to be acceptable for quantitative use.

E.2.4 Green alga, *Chlorella pyrenoidosa*

Xu et al. (2013) performed a 96-hour static, measured algal growth inhibition test on PFOA (>98% purity) with *Chlorella pyrenoidosa*. Algae were obtained from the Aquatic Organism Research Institute of the Chinese Academy of Science and precultured for three generations prior to initiating the test. Dilution medium consisted of number one culture medium supplemented with aquatic number four nutrient solution (Zhou and Zhang 1989). Algae in logarithmic growth phase (7.0×10^5 cells/mL) were inoculated in medium containing PFOA at 0 (negative control), 30, 60, 90, 120, 150, 180, 240, 300 and 360 mg/L. Tests were conducted in 100 mL conical flasks with 50 mL of solution with each concentration replicated three times. Exposure concentrations were verified via UHPLC-MS/MS using the Agilent 1290 Infinity UHPLC system interfaced with an Agilent 646-0 Triple Quadrupole mass. Algae were exposed under a 12-hour:12-hour light:dark cycle at 3,000-4,000 lux and 25°C. Chlorophyll concentration and permeability of cell membranes was determined after 96-hours of exposure. The reported 96-hour growth EC_{50} (inhibition based on optical density) was 190.99 mg/L and was considered to be acceptable for quantitative use.

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Hu et al. (2020) also evaluated the toxic effects of PFOA (>98% purity) on the green alga, *Chlorella pyrenoidosa,* in both nutrient rich and nutrient limited media. PFOA was dissolved in deionized water to make stock solutions. Green algae were purchased from the Chinese Academy of Sciences and cultivated in sterile blue-green medium (BG11) with a 14-hour photoperiod and pH of 7.1, at 23 ± 1°C. Algae in the cultures were in the logarithmic growth phase before they were used for testing. Nominal PFOA test concentrations in standard growth media (BG11) were 0.05, 0.2, 0.5 and 1.0 mg/L. In the eight nutrient-limited, -enriched, or -starved tests only one PFOA test concentration (1.0 mg/L) was examined. All experiments included controls, lasted for 10 days and were replicated three times. The initial cell density for each treatment was 1.0 x 10^6 cells/mL and followed OECD test guidelines (OECD 2011). PFOA was measured in all test treatments at test termination. After exposure day 10, cell density, dry biomass, chlorophyll content, malondialdehyde content, catalase/peroxidase activities, and cell membrane property of algae were measured. In all tests there was no effect on plant biomass compared to the controls at the highest or only test concentration. The 10-day biomass NOECs for the study were 0.73, 0.95, 0.95, 0.86, 0.84, 0.97, 0.94, 0.95 and 0.83 mg/L PFOA for the BG11 media, N,P-limited, N-limited, P-limited, N,P-enriched, N,P-starved, N-starved, P-starved and N,P-enriched tests, respectively. All these NOECs were considered acceptable for quantitative use. Although these NOEC values are relatively low compared to the other plants and animals tested, they represent NOEC values and, therefore, do not suggest effects are expected to occur at these relatively low concentrations.

Li et al. (2021b) conducted a 12-day static, unmeasured toxicity test with PFOA (≥95% purity, purchased from Sigma-Aldrich) on the green alga, *Chlorella pyrenoidosa*. The FACHB-9 strain of the green alga was purchased from the Institute of Hydrobiology, Chinese Academy of

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Sciences. The alga was cultured in BG-11 medium at 25℃ under a 12-hour:12-hour light:dark photoperiod (2,000 lux) and shaken manually every 12 hours. Two PFOA solutions (0.100 and 100 µg/L) were prepared in sterile water and control solutions were sterile water only. Test solutions were added to flasks containing an initial density of 9 x 10^5 cells/mL growing in BG-11 medium, with three flasks for each treatment. The variation in algal density was observed every day over the 12-day exposure period and chlorophyll pigment content and photosynthetic activity was observed on days 3, 6, 9 and 12. During the first half of the test there was no significant difference in growth of PFOA treatments and the control. On day 12, the growth was reduced by 6.76 and 14.4% relative to the control, in the 0.1 and 100 µg/L PFOA treatments, respectively. Later time points (i.e., > 4 – 12 days of exposure) were not used quantitatively use because the exposure duration was too long (U.S. EPA 2012). The four-day cell density-based endpoint with a NOEC of 0.1 mg/L was acceptable for quantitative use.

E.2.5 Green alga, *Chlorella vulgaris*

Boudreau (2002) performed a 96-hour static algal growth inhibition test on PFOA (acid form, CAS # 335-67-1, 95% purity) with *Chlorella vulgaris* as part of a Master's thesis at the University of Guelph, Ontario, Canada. The author stated that the algal growth inhibition tests followed protocols found in ASTM E 1218-97a (ASTM 1999) and Geis et al. (2000). *Chlorella vulgaris* (UTCC 266 strain) used for testing were obtained as slants from the University of Toronto Culture Collection (UTCC; Toronto, Canada). Stock concentrations were prepared in laboratory-grade distilled water with a maximum concentration that did not exceed the critical micelle concentration for PFOA of 450 mg/L. Dilution medium was Bristol's algal growing media. Toxicity testing consisted of a range-finder test and at least two definitive tests. Nominal test concentrations were 0 (negative control), 6.7, 12.5, 25, 50, 100, 200 and 400 mg/L. Tests were conducted in 60 x 15 mm polyethylene disposable Petri dishes containing 20 mL of test

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solution. Each Petri dish was inoculated with 1.5 x 10^4 cells/mL at initiation and replicated four times per test concentration. Tests were continuously illuminated with cool-white, fluorescent light between 3,800 and 4,200 lux and incubated at 23 ± 1°C. Replicate Petri dishes were manually shaken twice a day during testing. Toxicity test endpoints included cell density and chlorophyll-*a* content. The reported IC_{10}, IC_{25} and IC_{50} based on growth inhibition (measured as either chlorophyll-*a* or cell density) were 0.014 M (95% Confidence Interval, C.I.: 0.013-0.016), 0.034 M (95% C.I.: 0.032-0.040) and 0.279 M (95% C.I.: 0.249-0.320). Note that the Icx's for PFOA were reported in molar (M) units, but the EPA judged the units were misreported and were actually millimolar (mM) units. This judgement was based on the reported test concentrations in Table 3.1 of the publication and the reported effect concentrations (ICx) would not fall within this range unless the values were in mM units. Accordingly, the Icx reported as mM were converted to mg/L by multiplying the mM concentration by a molecular weight of 414.07 g/mol for PFOA. The calculated 96-hour IC_{10}, IC_{25} and IC_{50} expressed as mg/L from the study were 5.797, 14.07 and 115.5, respectively and acceptable for quantitative use.

E.2.6 Green alga, *Raphidocelis subcapitata*
(formerly known as *Selenastrum capricornutum* and *Pseudokirchneriella subcapitata*)

Elnabarawy (1981) and **3M Company (2000a)** provide the results of four separate toxicity tests completed with the green alga, *Raphidocelis subcapitata* (formerly *Selenastrum capricornutum*), and APFO (CAS # 3825-26-1). The toxicant was part of the 3M production lot number 37 and was characterized as a mixture of APFO (96.5-100% of the compound) and C_6, C_7 and C_9 perfluoro analogue compounds (0-3.5% of the compound). The toxicity tests followed a protocol modified from U.S. EPA-600/9-78-018 (1978) and ASTM-E-35.23 (1981). There were four separate exposure regimes: 1) a four-day exposure + 10-day recovery period, 2) a seven-day exposure + seven-day recovery period, 3) a 10-day exposure + four-day recovery

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period, and 4) a 14-day continuous exposure. Only the results of the continuous exposure are presented here due to the confusion if reported effect concentrations are reported before or after the recovery period. A bacteria-free culture of the alga was obtained from the USEPA (Corvallis, OR) and stored in the dark until testing. Seven-day old stock cultures with an initial density of 1 x 10^4 cells/mL were placed in 250 mL flasks with 50 mL of test solution. There were three replicates for each of the six nominal test concentrations (100, 180, 320, 560, 1000 and 1800 mg/L) and control. Nutrient medium was used as the dilution media for all test treatments and were not renewed during the exposure. Algae were grown at 23°C and continuously shaken at 100 rpm. The author-reported EC_{10}, based on cell counts, was 5 mg/L for the 14-day exposure and is acceptable for quantitative use.

Boudreau (2002) also performed a 96-hour static algal growth inhibition test on PFOA (acid form, CAS # 335-67-1, 95% purity) with *Raphidocelis subcapitata* as part of the Master's thesis at the University of Guelph, Ontario, Canada. The author stated that the algal growth inhibition test with *R. subcapitata* similarly followed protocols found in ASTM E 1218-97a (ASTM 1999) and Geis et al. (2000). *R. subcapitata* (UTCC 37 strain) used for testing were obtained as slants from the University of Toronto Culture Collection (UTCC; Toronto, Canada). Stock concentrations were prepared in laboratory-grade distilled water with a maximum concentration that did not exceed the critical micelle concentration for PFOA of 450 mg/L. Dilution medium was Bristol's algal growing media. Toxicity testing consisted of a range-finder test and at least two definitive tests. Nominal test concentrations were 0 (negative control), 6.7, 12.5, 25, 50, 100, 200 and 400 mg/L. Tests were conducted in 60 x 15 mm polyethylene disposable Petri dishes with 20 mL of test solution. Each Petri dish was inoculated with 1.5 x 10^4 cells/mL at initiation and replicated four times per test concentration. Tests were continuously

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illuminated with cool-white, fluorescent light between 3,800 and 4,200 lux and incubated at 23 ±1°C. Replicate Petri dishes were manually shaken twice a day during testing. Toxicity test endpoints included cell density and chlorophyll-*a* content. The reported IC_{10}, IC_{25} and IC_{50} based on growth inhibition (measured as either chlorophyll-*a* or cell density) were 0.130 M (95% C.I.: 0.020-0.162), 0.197 M (95% C.I.: 0.166-0.231) and 0.298 M (95% C.I.: 0.274-0.317). As noted above, although the Icx for PFOA were reported in molar (M) units in the thesis, the EPA judged the units were misreported and were actually millimolar (mM). This judgement was based on the reported test concentrations in Table 3.1 of the publication and the reported effect concentrations (ICx) would not fall within this range unless the values were in mM units. Accordingly, the Icx reported as mM were converted to mg/L by multiplying the mM concentration by a molecular weight of 414.07 g/mol. The calculated 96-hour IC_{10}, IC_{25} and IC_{50} expressed as mg/L from the study were 53.83, 81.57 and 123.4, respectively and acceptable for quantitative use.

More recently, **Xu et al. (2013)** conducted a 96-hour static, measured algal growth inhibition test on PFOA (acid form, >98% purity) with *Raphidocelis subcapitata*. Algae were obtained from the Aquatic Organism Research Institute of the Chinese Academy of Science and precultured for three generations prior to initiating the test. Dilution medium consisted of number one culture medium supplemented with aquatic number four nutrient solution (Zhou and Zhang 1989). Algae in logarithmic growth phase (7.0×10^5 cells/mL) were inoculated in medium containing nominal concentrations of PFOA at 0 (negative control), 30, 60, 90, 120, 150, 180, 240, 300 and 360 mg/L. Tests were conducted in 100 mL conical flasks with 50 mL of solution. Each test concentration and the control were replicated three times. Exposure concentrations were verified via UHPLC-MS/MS using the Agilent 1290 Infinity UHPLC system interfaced with an Agilent 646-0 Triple Quadrupole mass. Algae were exposed under a 12-hour:12-hour

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light:dark cycle at 3,000-4,000 lux and 25°C. Chlorophyll concentration and permeability of cell membranes was determined after 96 hours of exposure. The reported 96-hour growth EC_{50} (inhibition based on optical density) was 207.46 mg/L and was considered to be acceptable for quantitative use.

Colombo et al. (2008) evaluated growth inhibition with *Raphidocelis subcapitata* on ammonium perfluorooctanoate (APFO, the ammonium salt of PFOA, CAS # 3825-26-1, 99.7% purity). Authors stated that the 96-hour algal growth inhibition test followed OECD test guidance 201 and European Commission directive 92/69/EEC. The source of *R. subcapitata* used for testing was not reported, but presumably from an in-house culture as the medium reported to be used for both culturing and testing was reconstituted water recommended via the French algae test guideline (AFNOR T 90-304). The media differs slightly from the OECD recommended media with regard to concentrations of P, N, and chelators. Stock solutions of APFO were prepared by dissolving the test substance directly in the test media and diluting to provide a geometric series of test concentrations. A range-finding and two definitive tests were conducted. Definitive tests included six negative control replicates and three replicates at each PFOA concentration. Tests were initiated via inoculation with 1×10^4 cells/mL from an algal culture in log phase growth and carried out under continuous illumination with approximately 2,000 lux and at 21-25°C. Test solutions were agitated to keep algae in suspension during the 96-hour exposure and growth was determined at 24-hour intervals by counting an aliquot of test solution from each replicate test chamber. Test concentrations measured in the second definitive algal test and were 0 (negative control), 5.76, 11.37, 22.70, 46.33, 95.87, 180.67 and 369.67 mg/L. APFO was determined as PFOA from a calibration curve of peak area against APFO concentrations in standard solutions. The limit of quantification (LOQ) of the analytical method was 1 mg/L.

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Linearity was checked with a resulting coefficient of determination for the calibration curve of greater than 0.999 in the range of 1-100 mg/L. Accuracy and precision were demonstrated by analyzing six solutions containing nominal concentrations of 2.03 and 50.7 mg/L APFO in Milli-Q water. The mean measured concentrations were 2.02 and 53.7 mg/L, respectively, with calculated precision of 6% and 2% and accuracy of 99% and 106%, respectively. The reported 96-hour NOEC, based on biomass and growth rate, was 11.37 mg/L. The reported 96-hour LOEC was 22.70 mg/L. The calculated MATC was 16.07 mg/L and was considered to be acceptable for quantitative use.

E.2.7 Green alga, *Scenedesmus obliquus*

Hu et al. (2014) evaluated algal growth inhibition of PFOA (>96% purity) with *Scenedesmus obliquus* in both a 96-hour and eight-day static unmeasured exposures. Authors stated that the tests followed OECD test guidance 201 (OECD 2006). *S. obliquus* were supplied by UTEX Culture Collection of Algae, University of Texas at Austin. Dilution medium was HB-4 media adjusted to a pH of 6.8. Algae in exponential growth phase were exposed to nominal concentrations of 0 (negative control), 1, 3.16, 10, 31.6, 100, 316 and 1,000 mg/L in the 96-hour exposure, and 0, 5, 10, 20 and 40 mg/L in the eight-day exposure. Experiments were initiated by inoculating equal cell numbers of 5×10^3 cells/mL in the 96-hour exposure and 5×10^6 cells/mL in the eight-day exposure into 250 mL flasks containing a total volume of 100 mL of algal cell suspension per flask. There were five replicates per treatment in the 96-hour exposure and three replicates in the eight-day exposure. Algae were incubated at 25°C under cool-white fluorescence lights at 85-90 µmol photons/[m^2 x s] irradiance with a 16-hour:8-hour light:dark cycle. The 96-hour growth EC_{50} (inhibition based on optical density) was 44.0 mg/L. The eight-day NOEC based on cell number was 40 mg/L (the highest test concentration). The plant values from the study were acceptable for quantitative use.

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E.2.8 Green alga, *Scenedesmus quadricauda*

Yang et al. (2014) conducted a 96-hour renewal, measured test on the growth effects of PFOA (acid form, CAS #335-67-1, 99% purity) with the green alga, *Scenedesmus quadricauda*. Algae were obtained from in-house cultures originally supplied by the Chinese Research Academy of Environmental Sciences. The algae used for testing were inoculated at a cell density equal to 2.0×10^4 cells/mL in 50 mL beakers. PFOA was dissolved in deionized water and DMSO (amount not provided) and then diluted with M4 medium. Algae in logarithmic growth phase were exposed to 0 (solvent control), 80.00, 128.00, 204.80, 327.68, 524.29 and 838.86 mg/L. Each treatment was replicated three times. Measured concentrations ranged from 75.68 mg/L (before renewal) to 78.8 mg/L (after renewal) in the lowest treatment, and from 764.13 (before renewal) to 831.45 mg/L (after renewal) in the highest treatment. The experiments were conducted at 22 ± 2°C with a 12-hour:12-hour light:dark cycle. The initial pH of the test solution was 7.0 ± 0.5, total hardness was 190 ± 0.1 mg/L as $CaCO_3$, and total organic carbon was 0.02 mg/L. Algae concentrations in the beakers were measured daily with a microscope. The 96-hour growth inhibition EC_{50} was reported as 269.63 mg/L and was acceptable for quantitative use.

E.2.9 Duckweed, *Lemna minor*

Wu et al. (2023) tested perfluorooctanoic acid (PFOA) on duckweed, *Lemna minor*, for 96 hours in a static, measured experiment. PFOA (≥97.6% purity) was obtained from Dr. Ehrenstorfer GmbH (Augsburg, Germany). DMSO solvent (≥ 99.9% purity) was obtained from Merck (Germany). Duckweed was obtained from in house cultures that had been grown in a modified Swedish Standards Institute (SIS) medium. Duckweed cultures were housed in 150 mm petri dishes with 100 mL SIS medium that was changed every two weeks. SIS medium pH was adjusted to 6.5 by using NaOH or HCl. Plants were cultured at 25±1°C and 60% humidity under a 12:12 light dark cycle at 2,000 lux. Duckweed was precultured for 1 week in clean SIS media

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for seven days prior to testing. Duckweed experiments were conducted in 6-well poly-propylene plates to avoid PFOA sorption to container walls. Each replicate well contained 10 mL of test material and two colonies approximately the same size of a 3-frond *L. minor*. Nominal test concentrations were 0 (control), 0.001, 0.1, and 10 mg/L PFOA. All test chambers included DMSO solvent, and each treatment had three duplicates. PFOA concentrations measured on day 0 were 0.93±0.04, 97.2±0.89, and 9,478±4.74 µg/L. PFOA in solvent controls were not reported for day 0 but was below detection levels when measured after 96 hours. The number of fronds in each treatment well were counted after 48 and 96 hours. In addition, Fourier-transform infrared spectroscopy (FTIR) was performed on a subset of fronds from each treatment at the end of the 96-hour exposure to examine responses to PFOA at the biochemical level. Statistically significant ($p<0.05$) differences between treatment groups were assessed with one-way ANOVA followed by Dunnett's tests using SPSS Statistics 26. No statistically significant differences in frond number were observed. However, FTIR analysis revealed structural and functional alterations in response to PFOA at the biochemical level. The reported NOEC of 9.478 mg/L for population growth rate was determined to be acceptable for quantitative use.

E.2.10 Watermilfoil, *Myriophyllum sp.*

Hanson et al. (2005) conducted a 35-day microcosm study on PFOA (sodium salt donated by 3M Co., purity not provided) with the submerged watermilfoils, *Myriophyllum spicatum* and *M. sibiricum*. The study was conducted in 12,000 L outdoor microcosms at the University of Guelph Microcosm Facility located in Ontario, Canada using in-house cultures of *Myriophyllum* spp. Each microcosm was below ground and was flush with the surface. Plastic trays filled with sediment (1:1:1 mixture of sand, loam and organic matter, mostly manure) were placed in the bottom of each microcosm. The total carbon content of the sediment was 16.3%. Ten apical shoots, 4 cm in length, from in-house cultures using the same sediment were

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transferred to each microcosm, with three separate microcosms used for each treatment (nominal concentrations 0, 0.3, 10, 30 and 100 mg/L). Endpoints of toxicity that were monitored on days 14, 21 and 35 of the study included growth in plant length, root number, root length, longest root, node number, wet mass, dry mass and chlorophyll-*a* and -*b* content. PFOA treatments were dissolved in the same water (well water) used to supply the microcosms. Results showed that measured concentrations remained similar to nominal concentrations throughout the entire exposure period and did not change appreciably over the course of the study. The time-weighted average measured concentrations were 0 (negative control), 0.27, 0.65, 23.9 and 74.1 mg/L. Water quality over the length of the 35-day microcosm experiment was: dissolved oxygen: 7.3-8.5 mg/L; temperature: 17.8-22.0°C; pH: 8.3-8.7; total hardness: 217.5 mg/L as $CaCO_3$. The light:dark cycle was outdoor ambient cycles beginning June 13, 2000 (Guelph, Ontario). The watermilfoil species were equally sensitive to PFOA. The 35-day EC_{10} (based on weight) was 21.6 mg/L for *M. sibiricum* and 19.7 mg/L for *M. spicatum*. The plant values were acceptable for quantitative use.

E.2.11 Lettuce, *Lactuca sativa*

Ding et al. (2012b) conducted a microcosm study where water lettuce, *Lactuca sativa,* was exposed to PFOA (CAS# 335-67-1, 96% purity) for 5 days. Authors stated the test protocols followed U.S. EPA (1996). Test vessels were plastic and test solutions were static and unmeasured. The test employed six exposure concentrations and a negative control, with each treatment being replicated three times. Petri dishes containing lettuce seeds were placed in a plant test chamber with a constant room temperature of 18°C ±2°C and a photoperiod or 16-hours light and 8-hours dark. After 5 days, the number of germinated seeds was counted, and the length of the roots was measured with a ruler to the closest millimeter. The author reported EC_{50}

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(endpoint = root elongation) was 1.801 mM, which was converted to 745.7 mg/L and was retained for quantitative use.

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Appendix F Acceptable Estuarine/Marine Plant PFOA Toxicity Studies

Species	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Salinity (ppt)	Effect	Reported Effect Concentration (mg/L)	Reference
Green alga, *Chlorella sp.*	S, U	96 hours	PFOA >98%	-	23	30[b]	EC_{50} (population abundance)	127.35	Mao et al. 2023

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, NR=not reported

[b] Salinity of Erdschreiber's medium

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F.1 Summary of Quantitatively Acceptable Plant PFOA Toxicity Studies

F.1.1 Green alga, *Chlorella sp.*

Mao et al. (2023) tested perfluorooctanoic acid (PFOA) on an estuarine/marine *Chlorella sp.* For seven days in a static, unmeasured experiment. PFOA (>98% purity) was obtained from Tokyo Chemical Industry Co. Ltd. Algae were obtained from the Freshwater Algae Culture Collection at the Institute of Hydrobiology in Wuhan, China. Algae were obtained from the Algae Culture Collection at the Institute of Hydrobiology in Wuhan, China. Algae were cultured in Erdschreiber medium within a conical flask inside an illumination incubator at 23±1°C under a 12:12 light:dark cycle at 5,000 lux. Algae were shaken three times per day to prevent sticking to the sides of the flask, and inoculated once every two weeks to maintain optimal growth. *Chlorella sp.* In the exponential growth phase were added to test vessels containing test solution at a density of approximately $5.0x10^4$ cells/mL. The experimental design consisted of nominal concentrations of 0 (control), 5, 10, 20, 40, 80, 160, and 320 mg/L PFOA. Testing protocols followed OECD guidelines, and all experiments were performed in triplicate. Statistical analysis included one-way ANOVA, using SPSS version 26 software. Algal cell density and size were measured daily, and algal growth inhibition was calculated using the equation provided in the OECD guidelines. Chlorophyll *a*, maximum quantal yield, cell membrane integrity, esterase activity relative to control, relative electron transfer rate, and reactive oxygen species were reported after 1, 3, 5, and 7 days, respectively. Algae exhibited maximum growth at 20 mg/L, but growth significantly declined at 80 mg/L and higher concentrations. Increasing PFOA concentrations also inhibited chlorophyll *a*, and increased oxidative stress. The 96-hour EC_{50} for algal growth inhibition was 127.35 mg/L, and was determined to be acceptable for quantitative use.

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Appendix G Other Freshwater PFOA Toxicity Studies

G.1 Summary Table of Qualitative Freshwater PFOA Toxicity Studies

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Cyanobacteria, *Anabaena sp.*	S, M	24 hours	PFOA 96%	-	-	EC_{50} (bioluminescence inhibition)	-	19.81	Duration too short for a plant test, missing some exposure details, non-apical endpoint	Rodea-Palomares et al. 2012
Cyanobacteria, *Anabaena sp.*	S, U	24 hours	PFOA 96%	7.8	28	EC_{50} (bioluminescence inhibition)	-	78.88	Duration too short for a plant test, missing some exposure details, non-apical endpoint	Rodea-Palomares et al. 2015
Blue green alga, *Synechocystis sp.*	S, M	4 days	PFOA 96%	7.5	30	NOEC (population abundance)	1->1	1	Duration, focus of study was PFOA removal	Marchetto et al. 2021
Blue green alga, *Synechocystis sp.*	F, M	12-15 days	PFOA 96%	7.5	30	NOEC (biomass)	1->1	1	Duration, focus of study was PFOA removal	Marchetto et al. 2021
Green alga, *Raphidocelis subcapitata* (formerly, *Selenastrum capricornutum*)	S, U	96 hours	PFOA 96.5-100%	2.3-10.3	-	EC_{50} (cell density and growth rate)	-	90	Possible mixture effects of other perfluoro homologue compounds and the amount of isopropanol, wide pH range	3M Company 2000a
Green alga, *Raphidocelis subcapitata*	S, U	96 hours (+ 10-day recovery period)	APFO 96.5-100%	-	23	EC_{10} (cell count)	-	5.3	Unclear if chronic value determined before or after recovery period	3M Company 2000a/Elnabarawy 1981
Green alga, *Raphidocelis subcapitata*	S, U	7 days (+ 7-day recovery period)	APFO 96.5-100%	-	23	EC_{10} (cell count)	-	3.3	Unclear if chronic value determined before or after recovery period	3M Company 2000a/Elnabarawy 1981
Green alga, *Raphidocelis subcapitata*	S, U	10 days (+ 4-day recovery period)	APFO 96.5-100%	-	23	EC_{10} (cell count)	-	2.9	Unclear if chronic value determined before or after recovery period.	3M Company 2000a/ Elnabarawy 1981

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Green alga, *Raphidocelis subcapitata*	S, U	96 hours	APFO Unknown	-	-	EC_{50} (cell count)	-	1,980	Test substance was not characterized but considered a mixture of APFO and other PFAS impurities; test substance purity unknown and not used quantitatively because other tests from 3M Company (2000a) indicated test purity as low as 78%. 3M Company 2000a also indicated other tests with green alga lacked information on test substance purity.	3M Company. 2000a
Green alga, *Raphidocelis subcapitata*	S, M	72 hours	PFOA 96%	-	21-24	EC_{50} (growth)	-	96.2	Duration too short for a plant test, missing some exposure details	Rosal et al. 2010
Green alga, *Raphidocelis subcapitata*	S, U	4.5 hours	PFOA 96%	-	-	EC_{50} (photosynthetic efficiency)	-	748.2[c]	Duration too short for a plant test, missing some exposure details, non-apical endpoint	Ding et al. 2012b
Green alga (10^4 cells/mL), *Scenedesmus obliquus*	S, U	72 hours	PFOA Unreported	7.5	22	NOEC (growth rate)	-	828.1[c]	Duration too short for a plant test	Liu et al. 2008a
Duckweed, *Lemna gibba*	S, U	7 days	PFOA 95%	-	-	IC_{50} (wet weight)	-	79.92	Culture water not characterized, missing some exposure details	Boudreau 2002
Protozoa, *Tetrahymena pyriformis*	S, U	2 hours	PFOA Unreported	7.2	25	EC50 (population abundance)	-	713.9[c]	Single cell organism	Lim 2022

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Protozoa, *Tetrahymena pyriformis*	S, U	96 hours	PFOA Unreported	7.2	25	EC50 (population abundance)	-	65.1	Single cell organism	Lim 2022
Tubificid worm (0.03 g, 0.8 cm), *Limnodrilus hoffmeisteri*	S, M	96 hours	PFOA 99%	7	22	LC_{50}	-	568.20	Atypical source of organisms	Yang et al. 2014
Planaria (0.9 cm), *Dugesia japonica*	S, U	96 hours	PFOA >98%	-	25	LC_{50}	-	427.7	Poor concentration-response curve	Li 2009
Planaria (10-12 mm), *Dugesia japonica*	R, U	96 hours	PFOA 96%	-	20	LC_{50}	-	39.35	Atypical source of the test organisms	Yuan et al. 2015
Planarian, *Dugesia japonica*	R, U	10 days	PFOA 96%	-	20	LOEC (decrease mRNA expression levels of neural genes DjFoxD, DjotxA and DjotxB)	<0.5-0.5	0.5	Duration too long for an acute test and too short for a chronic test, non-apical endpoint	Yuan et al. 2016b
Planarian, *Dugesia japonica*	S, U	10 days	PFOA 96%	-	20	LOEC (elevated lipid peroxidation; increased mRNA expression levels of HSP 40 and HSP 70)	<0.5-0.5	0.5	Duration too long for an acute test and too short for a chronic test, non-apical endpoint	Yuan et al. 2017
Planarian, *Dugesia japonica*	R, U	10 days	PFOA Unreported	-	25	LOEC (growth, behavioral, genetic and biochemistry changes)	-	15	Duration, effects no longer seen after 8-day recovery period	Zhang et al. 2020
Planarian, *Dugesia japonica*	R, U	10 days	PFOA Unreported	-	-	LOEC (genetic and biochemistry changes)	-	15	Duration too long for an acute test and too short for an acute test, atypical endpoints	Zhang et al. 2022
Chinese pond mussel (1 year), *Sinanodonta woodiana* (formerly, *Anodonta woodiana*)	S, U	48 hours	PFOA Unreported	7.0	24	LC_{50}	-	192.08	Missing some exposure details, duration	Xia et al. 2018

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Snail (adult, 1 yr), *Sinotaia aeruginosa* (formerly, *Bellamya aeruginosa*)	Sediment	21 days	PFOA >96%	7.98-8.02	24	LOEC (biochemistry and enzyme changes)	-	0.00276 – 0.00286	Sediment exposure, missing exposure details	Xiang et al. 2021
Mud snail (4.0 g, 2.0 cm) *Cipangopaludina cathayensis*	S, M	96 hours	PFOA 99%	7	22	LC_{50}	-	740.07	Atypical source of organisms	Yang et al. 2014
Rotifer (<2-hour old neonates), *Brachionus calyciflorus*	R, U[d]	4 days	PFOA 96%	-	20	EC_{10} (resting egg production)	0.125 – 0.25	0.1768 (EPA-Calculated EC_{10}: 0.07758)	Only one replicate	Zhang et al. 2014b
Cladoceran, *Daphnia magna*	S, U	48 hours	PFOA 96.5-100%	7.5-8.4	19.4-20.2	EC_{50} (death/immobility)	-	360	Possible mixture effects of other perfluoro homologue compounds and the amount of isopropanol; missing exposure details	3M Company 2000a
Cladoceran, *Daphnia magna*	S, U	48 hours	APFO 96.5-100%	-	-	EC_{50} (death/immobility)	-	>1,000	Possible mixture effects of other perfluoro analogue compounds; <50% effect in highest test concentration; Authors indicate test may have included food	3M Company 2000a
Cladoceran, *Daphnia magna*	S, U	48 hours	APFO 96.5-100%	-	-	EC_{50} (death/immobility)	-	126	Possible mixture effects of other perfluoro analogue compounds; authors indicate test may have included food	3M Company 2000a

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Cladoceran (<24 hours old), *Daphnia magna*	S, U	48 hours	APFO 78-93%	8.0-8.1	21	EC_{50} (death/immobility)	-	221	Possible mixture effects of other perfluoro analogue compounds; low test substance purity (i.e., 78%).	3M Company 2000a
Cladoceran (<24 hours old), *Daphnia magna*	S, U	48 hours	APFO Unreported	8.1-8.3	20.3-20.8	LC_{50}	-	1,200	Test substance is considered a mixture of APFO and other impurities; test substance purity unknown and not used quantitatively because other tests from 3M Company (2000a) indicated test purity as low as 78%.	3M Company 2000a
Cladoceran (<24 hours old), *Daphnia magna*	S, U	48 hours	APFO Unreported	8.1-8.4	19.5-20.1	EC_{50} (death/immobility)	-	584	Possible mixture effects of the inert perfluorinated compounds and other perfluoro analogue compounds; test substance purity unknown and not used quantitatively because other tests from 3M Company (2000a) indicated test purity as low as 78%.	3M Company 2000a
Cladoceran, *Daphnia magna*	R, U	48 hours	APFO 96.5-100%	-	-	EC_{50} (death/immobility)	-	266	Missing test details	3M Company 2000a
Cladoceran, *Daphnia magna*	R, U	21 days	APFO 96.5-100%	-	-	MATC (survival and reproduction)	22-36	28.14	Missing test details	3M Company 2000a

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Cladoceran (<24 hours old), *Daphnia magna*	R, U	21 days	PFOA >99%	7.5	23	LOEC (fecundity)	<0.4141-0.4141	0.4141[c]	Chronic responses in this test did not display concentration-dependent effects beyond the LOEC despite a 25X increase in treatment concentrations	Seyoum et al. 2020
Cladoceran (adult, ~14 days), *Daphnia magna*	S, M	48 hours	APFO 98%	-	21	MATC (arginine, lysine, uridine G-6mountG-6ation)	27.88-46.33	35.94	Non-apical endpoint	Labine et al. 2022
Amphipod (7 days), *Hyalella azteca*	R, M	7 days	PFOA 99.5%	7.31 (6.85-7.76)	22.6 (21.9-23.2)	EC_{20} (growth – biomass)	-	5.0	Duration too short for a chronic exposure	Kadlec et al. 2024
Oriental river prawn (0.30 g, 4.0 cm), *Macrobrachium nipponense*	S, M	96 hours	PFOA 99%	7	22	LC_{50}	-	366.66	Atypical source of organisms	Yang et al. 2014
Midge (larva, 10 days old), *Chironomus dilutus*	R, U	10 days	PFOA >97%	-	23	NOEC (survival and growth)	-	100	Lack of effects in all concentrations tested; Range-finding experiment only with few details reported in the publication; Primary focus of the publication was on PFOS	MacDonald et al. 2004
Midge (larva, 10 days old), *Chironomus dilutus*	S, M	10 days	PFOA 97%	-	-	MATC (mortality)	26-272	84.10	Range-finding experiment only; results of the definitive 19-day test by McCarthy et al. 2021 were used preferentially over this test.	McCarthy et al. 2021
Midge (Instar, 3 days), *Chironomus dilutus*	R, M	7 days	PFOA 99.5%	6.96 (6.77-7.19)	22.7 (22.2-23.0)	EC_{20} (growth – biomass)	-	70.6	Duration too short for a chronic exposure	Kadlec et al. 2024

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Midge (Instar, 3 days), *Chironomus dilutus*	R, M	7 days	PFOA 99.5%	6.96 (6.86-7.11)	23.3 (23.0-23.8)	EC_{20} (growth – biomass)	-	94.0	Duration too short for a chronic exposure	Kadlec et al. 2024
Midge (Instar, 3 days), *Chironomus dilutus*	R, M	7 days	PFOA 99.5%	7.39 (7.26-7.60)	22.9 (20.3-24.0)	EC_{20} (growth – biomass)	-	94.2	Duration too short for a chronic exposure	Kadlec et al. 2024
Midge (multi-generational), *Chironomus riparius*	S, M	~20-38 days / generation	PFOA Pure (unspecified)	7.8-8.2	20	NOEC (emergence, reproduction, sex ratio)	-	0.0089	Only one exposure concentration, static chronic exposure	Stefani et al. 2014
Midge (multi-generational), *Chironomus riparius*	S, M	~20-38 days / generation	PFOA Pure (unspecified)	7.8-8.2	20	NOEC (increased mutation rate)	-	0.0089	Only one exposure concentration, static chronic exposure	Stefani et al. 2014
Midge (larva, 1st instar), *Chironomus riparius*	S, M	~1 year[b]	PFOA Unreported	7.5-8.2	20.1	LOEC (F10 developmental time, adult weight, exuvia length)	<0.0098-0.0098	0.0098	Only one exposure concentration, static chronic exposure, low control survival in 4 of the 10 generations	Marziali et al. 2019
Midge (0.05 g, 1.2 cm), *Chironomus plumosus*	S, M	96 hours	PFOA 99%	7	22	LC_{50}	-	402.24	Atypical source of organisms	Yang et al. 2014
Midge (larva, 3rd-4th instar), *Chironomus plumosus*	S, M	10.33 days	PFOA 96%	-	25	NOEC (mortality)	-	9.8 ng/g (sediment)	10-day subchronic sediment exposure and no effects at the highest concentration tested resulting in a relatively low greater than value that does not inform species sensitivity	Zhai et al. 2016
Rainbow trout (juvenile, 40-50 mm), *Oncorhynchus mykiss*	S, U	96 hours	APFO 99.7%	6.0-8.5	13-17	LC_{50}	-	707[e]	High ammonia concentration in treatment solutions	Colombo et al. 2008

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Rainbow trout (fry), *Oncorhynchus mykiss*	Diet, U	70 days	PFOA Unreported	-	14	MATC (liver somatic index)	200-1,800 (mg/kg)	600 (mg/kg diet)	Non-apical endpoint	Tilton et al. 2008
Rainbow trout (fry), *Oncorhynchus mykiss*	Diet, U	6 months	PFOA Unreported	-	14	MATC (palmitoyl CoA β-oxidation – liver enzyme)	200-1,800 (mg/kg)	600 (mg/kg diet)	Non-apical endpoint	Tilton et al. 2008
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Diet, U	15 days	PFOA Unreported	-	12	MATC (increase plasma vitellogenin)	5-50 (mg/kg)	15.81 (mg/kg diet)	Test design and lack of exposure details	Benninghoff et al. 2011
Rainbow trout (fry, 10-15 weeks old), *Oncorhynchus mykiss*	Diet, U	6 months	PFOA Unreported	-	12	LOEC (increase tumor multiplicity and size)	<2,000-2,000	2,000 (mg/kg diet)	Test design and lack of exposure details	Benninghoff et al. 2012
Rainbow trout (oocyte, ova), *Oncorhynchus mykiss*	S, M	3 hours	PFOA >97%	-	6	NOEC (accumulation residue)	-	10.58	Duration too short for an acute test	Raine et al. 2021
Rainbow trout (oocyte, ova), *Oncorhynchus mykiss*	S, M	3 hours	PFOA >97%	8.5	6	NOEC (accumulation residue)	-	10.11	Duration too short for an acute test	Raine et al. 2021
Rainbow trout (juvenile, 7 months), *Oncorhynchus mykiss*	R, M	10 days	PFOA Unreported	-	12	LOEC (7-Benzyloxy-4-trifluoromethylcoumarin O-debenzylase levels)	-	0.0005	Test was too long for an acute exposure and too short for a chronic exposure; non-apical endpoint	Solan et al. 2022
Atlantic salmon (embryo-larval), *Salmo salar*	F, U	52 days	PFOA 95%	-	5-7	NOEC-LOEC (growth – weight and length)	0.1->0.1	>0.1	No effects at the highest concentration tested resulting in a relatively low greater than value that does not inform species sensitivity	Spachmo and Arukwe 2012
Atlantic salmon (embryo), *Salmo salar*	R, U	49 days	Perfluoro-n-octanoic acid Unreported	-	5-7	NOEC (growth – weight and length)	0.1->0.1	>0.1	Lack of treatment concentrations and lack of effects observed at a relatively low NOEC	Arukwe et al. 2013

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Goldfish (6.0 g, 7.0 cm), *Carassius auratus*	S, M	96 hours	PFOA 99%	7	22	LC_{50}	-	606.61	Atypical source of organisms	Yang et al. 2014
Goldfish (juvenile, 27.85 g), *Carassius auratus*	S, M	96 hours	PFOA >98%	7.25	23	Antioxidant enzyme activity	-	>4.931[c]	Only two exposure concentrations, non-apical endpoint	Feng et al. 2015
Goldfish (juvenile, 12 months), *Carassius auratus*	F, M	7 days	PFOA >96%	9	-	LC_{50}	-	>471.5	Test was too long for an acute exposure and too short for a chronic exposure	Dong et al. 2023
Goldfish (juvenile, 12 months), *Carassius auratus*	F, M	7 days	PFOA >96%	9	-	LC_{50}	-	>456.3	Test was too long for an acute exposure and too short for a chronic exposure	Dong et al. 2023
Goldfish (juvenile, 12 months), *Carassius auratus*	F, M	7 days	PFOA >96%	9	-	LC_{50}	-	>411.7	Test was too long for an acute exposure and too short for a chronic exposure	Dong et al. 2023
Goldfish (juvenile, 12 months), *Carassius auratus*	F, M	7 days	PFOA >96%	9	-	LC_{50}	-	>433.2	Test was too long for an acute exposure and too short for a chronic exposure	Dong et al. 2023
Goldfish (juvenile, 12 months), *Carassius auratus*	F, M	7 days	PFOA >96%	9	-	LC_{50}	-	>451.1	Test was too long for an acute exposure and too short for a chronic exposure	Dong et al. 2023
Goldfish (juvenile, 12 months), *Carassius auratus*	F, M	7 days	PFOA >96%	9	-	LC_{50}	-	>440.1	Test was too long for an acute exposure and too short for a chronic exposure	Dong et al. 2023
Common carp (juvenile, ~12 cm, ~20 g), *Cyprinus carpio*	F, M	96 hours	PFOA 99.8%	6.9	23	LOEC (vitellogenin (VTG) activity)	-	6.582	Broad range of test treatments, non-apical endpoint	Kim et al. 2010

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Common carp (adult – 2 years old), *Cyprinus carpio*	F, U (tissue)	56 days	PFOA 96%	6.7-8.0	10-15	LOEC (PCNA-positive hepatocyte abundance)	0.0002-2	2	Poor test design, only two exposure concentrations, non-apical endpoint	Giari et al. 2016
Common carp (adult – 2 years old), *Cyprinus carpio*	F, U (tissue)	56 days	PFOA 96%	6.7-8.0	10-15	LOEC (liver biomarkers)	0.0002-2	2	Only two exposure concentrations, non-apical endpoint	Manera et al. 2017
Common carp (adult – 2 years), *Cyprinus carpio*	F, U	56 days	PFOA Unreported	6.7-8.0	10-15	LOEC (number of rodlet cells)	-	0.0002	Non-apical endpoint	Manera et al. 2022b
Common carp (adult – 2 years), *Cyprinus carpio*	F, U	56 days	PFOA Unreported	-	-	LOEC (histological effects)	-	0.0002	Non-apical endpoint	Manera et al. 2022a
Common carp, *Cyprinus carpio*	R, M	14 weeks	PFOA Unreported	7.71	21.8	NOEC (mortality, length and weight)	-	>0.0921	Greater than low value	Petre et al. 2023
Zebrafish (embryo), *Danio rerio*	R, U	96 hours	APFO 98%	-	26	LC_{50}	-	386.3[c]	Inability to verify LC50	Ding et al. 2012c, 2013
Zebrafish (embryo), *Danio rerio*	S, U	72 hours	PFOA 95%	8.3	28.5	LC_{50}	-	262	Duration too short for acute test	Zheng et al. 2012
Zebrafish (embryo), *Danio rerio*	S, U	96 hours	PFOA 95%	8.3	28.5	EC_{50} (malformation)	-	198	Non-apical endpoint	Zheng et al. 2012
Zebrafish (embryo, 4 hpf), *Danio rerio*	R, U	120 hours	PFOA Unreported	-	28	NOEC-LOEC (increase relative mRNA expression of hhex and pax 8)	0.1-0.2	-	Duration too short for a chronic test and too long for an acute test, non-apical endpoint, only three exposure concentrations	Du et al. 2013
Zebrafish (adult), *Danio rerio*	R, U (tissue)	28 days	PFOA 96 %	-	26	NOEC (reproduction: fecundity, fertility and hatching)	1->1	1	Not a true ELS test	Hagenaars et al. 2013
Zebrafish (adult), *Danio rerio*	R, U (tissue)	28 days	PFOA 96 %	-	26	LOEC (alterations of gene transcripts)	<0.1-0.1	0.1	Not a true ELS test, non-apical endpoint	Hagenaars et al. 2013

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Zebrafish (embryo, 4 cell stage), *Danio rerio*	S, U	Fertilization to 144 hours post-fertilization (6 days)	PFOA Unreported	7.2-7.6	26	EC_{50} (lethal and sublethal endpoint)	-	350	Static chronic exposure	Ulhaq et al. 2013
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hours	APFO Unreported	-	-	LOEC (mortality)	<0.02759-0.02759	0.02759[c]	Duration too long for acute test	Truong et al. 2014
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hours	PFOA Unreported	-	-	NOEC (mortality)	26.50->26.50	26.50[c]	Duration too long for acute test	Truong et al. 2014
Zebrafish (adult), *Danio rerio*	R, U	21 days	PFOA 96 %	-	27	MATC (decrease in inflammatory cytokines (IL-1ß and IL-21) in spleen)	0.05-0.1	0.0707	Duration too short for a chronic test, non-apical endpoint	Zhang et al. 2014a
Zebrafish (embryo, 2 days pf), *Danio rerio*	S, U	72 hours	PFOA 96%	-	28.5	LC_{50}	-	157.3[c]	Duration too short for an acute test	Kalasekar et al. 2015
Zebrafish (embryo), *Danio rerio*	S, U	72 hours	PFOA Unreported	-	26	NOEC (embryo toxicity)	-	132.5[c]	Only one exposure concentration and duration too short for an acute test	Bouwmeester et al. 2016
Zebrafish (gastrula stage, 4.5 hpf), *Danio rerio*	R, U	Embryo development to 28 days post-hatch	PFOA Unreported	-	28	LOEC (swim bladder development)	-	4.7	Unconventional test design, diet and water concentrations were not measured	Godfrey et al. 2017b
Zebrafish (3 hpf), *Danio rerio*	S, U	5-day + 9-day observation	PFOA Unreported	7.2-7.7	26-28	MATC (growth – total body length, interocular distance, yolk sac area)	0.2-2	0.6325	Duration too long for an acute test,	Jantzen et al. 2017a
Zebrafish (3 hpf), *Danio rerio*	S, U	5-day + 9-day observation	PFOA Unreported	7.2-7.7	26-28	MATC (swimming activity – distance traveled)	0.02-0.2	0.06325	Duration too long for an acute test, non-apical endpoint	Jantzen et al. 2017a
Zebrafish (embryo, 72 hpf), *Danio rerio*	S, M	48 hours	PFOA Unreported	-	27	LC_{50}	-	>500	Duration too short for an acute test	Rainieri et al. 2017
Zebrafish (embryo, ≤2 hpf), *Danio rerio*	S, U	96 hours	PFOA 96%	-	28	LC_{50}	-	<50	Results only reported graphically, control mortality not reported	Weiss-Errico et al. 2017

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Zebrafish (embryo, 3 hpf), *Danio rerio*	S, U	117 hours + 9 days observation	PFOA Unreported	7.2-7.7	27	MATC (morphology)	0.008281-0.08281	0.02619	Duration too long for an acute test	Annunziato 2018
Zebrafish (embryo, 6 hpf), *Danio rerio*	R, M	7 days	PFOA 95%	7.8	25	LOEC (aromatase, CYP19A1 mRNA, estrogen receptor alpha mRNA, 17-beta estradiol, androgen binding protein)	<0.4969-0.4969	0.4969[c]	Duration too long for an acute test and too short for a chronic test, non-apical endpoint	Chen et al. 2018
Zebrafish (embryo), *Danio rerio*	S, U	168 hours	PFOA Unreported	-	-	LC_{50}	-	362.5	Duration too long for an acute test	Stinckens et al. 2018
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hours	PFOA Unreported	-	-	Benchmark Dose at 10% extra effect (abnormal development)	-	27.75[c]	Duration too long for an acute test and too short for a chronic test, non-apical endpoint	Thomas et al. 2019
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	18 hours	APFO Unreported	-	-	Benchmark Dose at 10% extra effect (immobility)	-	27.59[c]	Duration too long for an acute test, non-apical endpoint	Thomas et al. 2019
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hours	APFO Unreported	-	-	Benchmark Dose at 10% extra effect (mortality)	-	24.50[c]	Duration too long for an acute test and too short for a chronic test, non-apical endpoint	Thomas et al. 2019
Zebrafish (embryo, 2 hpf), *Danio rerio*	R, M	118 hours	PFOA >96%	-	28	EC_{50}	-	210.8[c]	Duration too long for an acute test, no true replication	Vogs et al. 2019
Zebrafish (embryo, 2 hpf), *Danio rerio*	R, M	118 hours	PFOA >96%	-	28	EC_{20} (deformities)	-	147.2[c]	Duration too long for an acute test, no true replication	Vogs et al. 2019
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	66 hours	PFOA 96%	-	28	NOEC (survival and development)	20.70->20.70	20.70[c]	Duration too short for an acute test, only one exposure concentration	Dasgupta et al. 2020
Zebrafish (embryo, 3 dpf), *Danio rerio*	S, U	24 hours	PFOA Unknown	-	28	LC_{50}	-	96.06[c]	Duration too short for an acute test, missing exposure details	Gebreab et al. 2020

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Zebrafish (embryo, 3 dpf), *Danio rerio*	S, U	7 days	PFOA Unknown	-	28	LC_{50}	-	>41.41 to <82.81[c]	Duration too long for an acute test and too short for a chronic test, missing exposure details	Gebreab et al. 2020
Zebrafish (embryo, 4-64 stage), *Danio rerio*	S, M	144 hours	PFOA ≥98%	7.2-7.6	26	NOEC (survival and development)	61->61	61	Duration too long for an acute test and too short for a chronic test	Menger et al. 2020
Zebrafish (embryo, 1 hpf), *Danio rerio*	S, U	48 hours	PFOA Unreported	-	28	LC_{50}	-	300	Duration too short for an acute test	Pecquet et al. 2020
Zebrafish (embryo, 1 hpf), *Danio rerio*	S, M	24 hours	PFOA Unreported	-	28	LOEC (increase neutrophil migration)	<0.685-0.685	0.685	Duration too short for an acute test, atypical endpoint	Pecquet et al. 2020
Zebrafish (embryo, 5-6 hpf), *Danio rerio*	R, U	90-91 hours	PFOA >99%	-	28	LC_{50}	-	57.6	Duration too short for an acute test	Wasel et al. 2020
Zebrafish (embryo, 5-6 hpf), *Danio rerio*	R, U	90-91 hours	PFOA >99%	7	28	LC_{50}	-	487.4	Duration too short for an acute test	Wasel et al. 2020
Zebrafish (embryo), *Danio rerio*	R, M	5 days	APFO >95%	-	25	NOEC (mortality)	-	>1.582[c]	Duration too long for an acute test and too short for a chronic test	Han et al. 2021
Zebrafish (embryo), *Danio rerio*	R, M	5 days	PFOA >95%	-	25	NOEC (mortality)	-	>1.631[c]	Duration too long for an acute test and too short for a chronic test	Han et al. 2021
Zebrafish (embryo, 4 hpf), *Danio rerio*	R, U	5 days	PFOA 96%	7.6-7.8	25.3-25.7	NOEC (abnormal development, growth and survival)	30->30	30	Duration too long for an acute test and too short for a chronic test	Kim et al. 2021
Zebrafish (embryo, 6-8 hpf), *Danio rerio*	S, U	112-114 hours	PFOA >98%	-	28	NOEC (mortality)	-	0.2484[c]	Duration too long for an acute test and too short for a chronic test	Rericha et al. 2021
Zebrafish (embryo, 6-8 hpf), *Danio rerio*	S, U	112-114 hours	PFOA >98%	-	28	MATC (combined effects)	2.538-6.451[c]	4.047[c]	Duration too long for an acute test and too short for a chronic test	Rericha et al. 2021

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Zebrafish (embryo, 2 hpf), *Danio rerio*	R, M	166 hours	PFOA Unreported	-	28.5	LOEC (behavior, gene expression)	<0.00882-0.00882	0.00882	Duration too long for an acute test and too short for a chronic test, non-apical endpoints	Yu et al. 2021
Zebrafish, *Danio rerio*	R, U	21 days	PFOA Unreported	-	-	LOEC (mRNA gene expression in kidneys)	0.05-0.1	0.1	Non-apical endpoint	Zhang et al. 2021
Zebrafish (adult, 4-5 months old), *Danio rerio*	R, U	7-day exposure + 1 day of observation	PFOA Unreported	7.2	27	NOEC (immobility)	1.0->1.0	1.0	Duration too short for a chronic exposure, atypical endpoint	Adedara et al. 2022
Zebrafish (embryo, <4 hpf), *Danio rerio*	R, U	5 days	PFOA 95%	-	27	NOEC (mortality, development)	-	>0.0007	Duration too long for an acute test and too short for a chronic test	Haimbaugh et al. 2022
Zebrafish (embryo, <4 hpf), *Danio rerio*	R, U	5 days + 4-6 week observation	PFOA 95%	-	27	NOEC (reproduction, growth)	-	>0.0007	Duration too long for an acute test and too short for a chronic test	Haimbaugh et al. 2022
Zebrafish (embryo, 3 hpf), *Danio rerio*	S, U	117 hours	PFOA Unreported	7.2	28	LC_{50}	-	>20.70[c]	Duration too long for an acute test and too short for a chronic test	Lindqvist and Wincent 2022
Zebrafish (embryo, 5 hpf), *Danio rerio*	S, U	19 hr	PFOA Unreported	7.5	28	LC_{50}	-	33.89[c]	Duration too short	Satbhai et al. 2022
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	PFOA Unreported	-	28	NOEC (mortality, development and morphology)	-	>41.41[c]	Duration too long for an acute test and too short for a chronic test	Truong et al. 2022
Zebrafish (embryo, 6 hpf), *Danio rerio*	S, U	114 hr	APFOA Unreported	-	28	NOEC (mortality, development and morphology)	-	>43.11[c]	Duration too long for an acute test and too short for a chronic test	Truong et al. 2022
Zebrafish (embryo 2 hpf), *Danio rerio*	S, M	70 hours	PFOA Unreported	7.2-7.4	-	NOEC (growth-length, mortality, and hatch)	0.1->0.1	0.1	Duration too short for an acute test	Yu et al. 2022
Zebrafish (embryo, 6 hpf), *Danio rerio*	R, U	90 hours	PFOA Unreported	-	28	NOEC (development and growth)	-	>33.13[c]	Duration too short	Phelps et al. 2023
Zebrafish (larva, 72 hpf), *Danio rerio*	R, U	72 hours	PFOA >98%	-	28.5	LC_{50}	-	132.9[c]	Duration too short	Sun et al. 2023a

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Zebrafish (larva, 72 hpf), *Danio rerio*	R, U	72 hours	PFOA >98%	-	28.5	LOEC (growth – length)	-	41.41[c]	Duration too short	Sun et al. 2023a
Zebrafish (embryo, <4 hpf), *Danio rerio*	R, M	116 hours	PFOA Unreported	-	-	LOEC (immunological responses)	0.0001	0.0001	Duration too long for an acute test and too short for a chronic test, atypical endpoint	Tang et al. 2023
Zebrafish (embryo, 2 hpf), *Danio rerio*	R, M	94 hours	PFOA >96%	-	27	NOEC (mortality and development)	-	0.4915	Duration too short	Wang et al. 2023
Zebrafish (embryo, 1 hpf), *Danio rerio*	S, U	119 hours	PFOA 95%	7.2	28	LC_{50}	-	561.01	Duration too long for an acute test and too short for a chronic test	Wasel et al. 2022
Zebrafish (embryo, 5 hpf), *Danio rerio*	R, U	122 hours	PFOA Unreported	6.8-7.0	28	LC_{50}	-	>41.41[c]	Duration too long for an acute test and too short for a chronic test	Hawkey et al. 2023
Zebrafish (embryo, 5 hpf), *Danio rerio*	R, M	91 hours	PFOA 96%	7.0-8.0	28.5	LC_{50}	-	~2	Duration too short for an acute test	Liu et al. 2023b
Zebrafish (2 months), *Danio rerio*	R, U	14 days	APFOA Unreported	7	28	LOEC (biochemical and enzymatic effects)	-	0.03	Non-apical endpoint, duration too long for an acute test and too short for a chronic test	Liu et al. 2023a
Rare minnow (male, 9 months old, 1.4 g, 47.7 cm), *Gobiocypris rarus*	F, U	28 days	PFOA 98%	-	25	MATC (increase relative mRNA expression of AhR in gills)	3.0-10	5.477	Non-apical endpoint	Liu et al. 2008b
Rare minnow (female, 9 months old, 1.4 g, 47.7 cm), *Gobiocypris rarus*	F, U	28 days	PFOA 98%	-	25	MATC (decrease relative mRNA expression of CYP1a and increase relative mRNA expression of PXR in gills)	10.0-30	17.32	Non-apical endpoint	Liu et al. 2008b
Rare minnow (adult, 9 months old), *Gobiocypris rarus*	F, U	28 days	PFOA 98%	-	25	LOEC (polymerase chain reaction (PCR) alterations of genes in liver)	<3-3	3	Non-apical endpoint	Wei et al. 2008b

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Rare minnow (adult, 9 months old), *Gobiocypris rarus*	F, U	28 days	PFOA 98%	-	-	MATC (change in m-RNA M-H-FABP)	3.0-10	5.477	Non-apical endpoint	Wei et al. 2008a
Rare minnow (adult, 9 months old), *Gobiocypris rarus*	F, U	28 days	PFOA 98%	-	-	LOEC (protein spots identified by MALDl-TOF/TOF)	<3-3	3	Non-apical endpoint	Wei et al. 2008a
Rare minnow (9 months old female, 1.4 g, 47.7 mm), *Gobiocypris rarus*	F, U	28 days	PFOA 98%	-	25	MATC (increase relative mRNA expression of PPARγ in gills)	3.0-10	5.477	Non-apical endpoint	Liu et al. 2009
Rare minnow (9 months old male, 1.4 g, 47.7 mm), *Gobiocypris rarus*	F, U	28 days	PFOA 98%	-	25	MATC (increase relative mRNA expression of PPARγ and PPARα in gills and CYP4T11 in liver)	10.0-30	17.32	Non-apical endpoint	Liu et al. 2009
Rare minnow (9 months old male, 1.3 g), *Gobiocypris rarus*	F, U	14 days	PFOA 98%	-	25	LOEC (apolipoprotein gene expression)	-	3	Duration too short for a chronic test, non-apical endpoint	Fang et al. 2010
Fathead minnow (juvenile), *Pimephales promelas*	S, U	96 hours	APFO Unknown	7.2-7.9	21.8-22.5	LC_{50}	-	2,470	Test substance was not characterized but considered a mixture of APFO and other PFAS impurities; test substance purity unknown and not used quantitatively because other tests from 3M Company (2000a) indicated test purity as low as 78%.	3M Company 2000a
Fathead minnow, *Pimephales promelas*	S, U	96 hours	PFOA 96.5-100%	-	-	LC_{50}	-	440	Lack of exposure details, possible mixture effects of other perfluoro homologue compounds; only one replicate;	3M Company 2000a

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Fathead minnow, *Pimephales promelas*	S, U	96 hours	PFOA 96.5-100%	-	-	LC_{50}	-	140	Possible mixture effects of other perfluoro homologue compounds and the amount of isopropanol, low initial pH (3.0-4.3) in highest test concentration	3M Company 2000a
Fathead minnow, *Pimephales promelas*	S, U	96 hours	APFO 96.5-100%	-	-	LC_{50}	-	70	Highest test concentration produced 20% effect, LC_{50} based on extrapolation	3M Company 2000a
Fathead minnow, *Pimephales promelas*	S, U	96 hours	APFO 96.5-100%	7.9-8.0	19	LC_{50}	-	776	Lack of replication	3M Company 2000a/Elnabarawy 1980
Fathead minnow, *Pimephales promelas*	S, U	96 hours	APFO 96.5-100%	7.9-8.0	19	LC_{50}	-	754	Lack of replication	3M Company 2000a/Elnabarawy 1980
Fathead minnow, *Pimephales promelas*	S, U	96 hours	APFO 78-93%	7.7-8.0	20	LC_{50}	-	301	Possible mixture effects of other perfluoro analogue compounds; low test substance purity	3M Company 2000a
Fathead minnow (juvenile), *Pimephales promelas*	S, U	96 hours	APFO Unreported	7.4-8.4	21-22	LC_{50}	-	>1,000	Highest treatment did not produce >50% effect; test substance purity unknown and not used quantitatively because other tests from 3M Company (2000a) indicated test purity as low as 78%.	3M Company 2000a
Fathead minnow (embryo, 48 hpf), *Pimephales promelas*	F, U	30 days post hatch	APFO 96.5-100%	7.0-7.3	25	NOEC (hatch, survival and growth)	100->100	100	Lack of replication for early life stage test	3M Company 2000a

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Fathead minnow (64 days old), *Pimephales promelas*	S, M	13 days	APFO 96.5-100%	-	-	BCF	-	1.8 (L/Kg)	Steady state not documented, static uptake study; exposure duration is too short for a chronic test	3M Company 2000a
Fathead minnow (adult, 6-8 months), *Pimephales promelas*	F, M	96 hours	PFOA >95%	8.2	25	LC_{50}	-	>16.62	LC50 not reported, inferred, other definitive data available for the species	Villeneuve et al. 2023
Fathead minnow (adults), *Pimephales promelas*	S, M	39 days	PFOA 19.4%[f]	8.5	10.6-26.6	LOEC (mean total egg production)	74.1->74.1	>74.1	Atypical exposure, started with adults, not a true ELS test	Oakes et al. 2004
Topmouth gudgeon (4.0 g, 4.0 cm), *Pseudorasbora parva*	S, M	96 hours	PFOA 99%	7	22	LC_{50}	-	365.02	Atypical source of test organisms	Yang et al. 2014
Topmouth gudgeon (4.0 g, 4.0 cm), *Pseudorasbora parva*	R, M	30 days	PFOA 99%	7	22	EC_{10} (survival)	-	11.78	Not a true ELS test (started with older life stage), atypical source of organisms	Yang et al. 2014
Nile tilapia, *Oreochromis niloticus*	Dietary	6 days	PFOA Unreported	-	22	MATC (survival and growth)	1.0-5.0 (mg/g)	2.236 (mg/g)	Duration too short for a chronic test, dietary exposure, water concentration not reported	Han et al. 2011
Bluegill, *Lepomis macrochirus*	S, U	96 hours	APFO 96.5-100%	7.8-8.0	18-19	LC_{50}	-	569	Only one replicate per treatment	3M Co. 2000a
Mosquitofish, *Gambusia affinis*	S, U	96 hours	PFOA >98%	7.2	25	LOEC (genetics: AKT serine/threonine kinase 3 mRNA)	-	0.50	Non-apical endpoint	Liu et al. 2022

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Murray River rainbowfish (male, adult, 1 year old), *Melanotaenia fluviatilis*	R, M	14 days	PFOA ≥96%	7.1-7.4	23	NOEC (growth and mortality)	9.0->9.0	9.0	Duration too long for acute test and too short for a chronic test, not NA species	Miranda et al. 2020
Medaka (<6 hpf), *Oryzias latipes*	R, U	Embryo development to 48 hours post-hatch	PFOA Unreported	-	25	LOEC (swim bladder development)	-	4.7	Only one exposure concentration	Godfrey 2017
Medaka (adult, male), *Oryzias latipes*	R, U	14 days	PFOA Unreported	-	25	NOEC (adult survival, GSI%, HSI%, K%)	10->10	10	Duration too long for acute test and too short for a chronic test	Ji et al. 2008
Medaka (adult, female), *Oryzias latipes*	R, U	14 days	PFOA Unreported	-	25	NOEC (adult survival, GSI%, HSI%, K%)	10->10	10	Duration too long for acute test and too short for a chronic test	Ji et al. 2008
Medaka (F1 generation, <12 hours old, embryo), *Oryzias latipes*	R, U	7-14 days (assumed)	PFOA Unreported	-	25	NOEC (% hatchability)	10->10	10	Duration too long for acute test and too short for a chronic test	Ji et al. 2008
Medaka (F1 generation, <12 hours old, embryo), *Oryzias latipes*	R, U	7-14 days (assumed)	PFOA Unreported	-	25	MATC (time to hatch)	1.0-10	3.162	Duration too long for acute test and too short for a chronic test	Ji et al. 2008
Medaka (F1 generation, <12 hours old, embryo), *Oryzias latipes*	R, U	28 days post-hatch (assumed)	PFOA Unreported	-	25	NOEC (swim up success)	10->10	10	Pseudoreplication that occurred at hatching stage	Ji et al. 2008
Medaka (F1 generation, <12 hours old, embryo), *Oryzias latipes*	R, U	100 days post-hatch	PFOA Unreported	-	25	NOEC (growth – length and weight)	10->10	10	Pseudoreplication that occurred at hatching stage	Ji et al. 2008
Medaka (F1 generation, <12 hours old, embryo), *Oryzias latipes*	R, U	100 days post-hatch	PFOA Unreported	-	25	NOEC (male/female GSI% and HSI%)	0.1->0.1	0.1	Pseudoreplication that occurred at hatching stage	Ji et al. 2008

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Medaka (F1 generation, <12 hours old, embryo), *Oryzias latipes*	R, U	28 days post-hatch	PFOA Unreported	-	25	LOEC (larval survival)	<0.1-0.1	0.1	Pseudoreplication that occurred at hatching stage	Ji et al. 2008
Medaka, *Oryzias latipes*	S, U	96 hours	PFOA Unreported	7.0-7.5	25	NOEC (mortality)	-	473	Missing exposure details, only one exposure concentration	Godfrey et al. 2019
Medaka (embryo, <6 hpf), *Oryzias latipes*	R, U	10 days	PFOA Unreported	7.0-7.5	25	NOEC (growth)	-	4.7	Duration too short for a chronic test, only one exposure concentration	Godfrey et al. 2019
Medaka (adult, 16 weeks old, 0.38 g), *Oryzias latipes*	R, U	21 days	PFOA 96%	-	25	LOEC (fecundity)	<10-10	10	Only one exposure concentration, tolerant LOEC value	Kang et al. 2019
Medaka (embryo), *Oryzias latipes*	S, U	3 dph	PFOA >98.0%	7.3	27	LOEC (genetic and hormonal changes)	-	25	Non-apical endpoint	Myosho et al. 2022
Medaka (fry), *Oryzias latipes*	S, U	3 dph	PFOA >98.0%	7.3	27	NOEC (genetic changes)	-	2.5	Non-apical endpoint	Myosho et al. 2022
Northern leopard frog (larva, Gosner 26), *Lithobates pipiens* (formerly, *Rana pipiens*)	R, M	40 days	PFOA 96%	-	20	NOEC (snout-vent length and Gosner stage at 40 d)	1->1	1	No effects at the highest concentration tested resulting in a relatively low greater than value that does not inform species sensitivity	Hoover et al. 2017
Northern leopard frog (larva, Gosner 25), *Lithobates pipiens*	S, M	30 days	PFOA ≥96%	7.8	26.2	NOEC (survival and growth)	0.066->0.066	0.066	Mesocosm exposure	Flynn et al. 2021
Northern leopard frog (larva, Gosner stage 25), *Lithobates pipiens*	R, M	30 days	PFOA ≥96%	-	20	MATC (growth – weight)	0.1251-1.376	0.4149	Highly variable dose-response	Flynn et al. 2022

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Black-spotted pond frog (adult), *Pelophylax nigromaculatus* (formerly, *Rana nigromaculatus*)	S, U	21 days	PFOA >98%	-	-	LOEC (gene expression)	-	0.01	Non-apical endpoint	Lin et al. 2022a
Black-spotted pond frog, *Pelophylax nigromaculatus*	R, U	21 days	PFOA >98%	6.5	20	LOEC (cholesterol and triglyceride levels)	-	0.0025	Non-apical endpoint	Lin et al. 2022b
Black-spotted pond frog (adult), *Pelophylax nigromaculatus*	S, U	21 days	PFOA >98%	6.5	20	LOEC (reduced glutathione)	-	0.91	Non-apical endpoint	Lin et al. 2022c
Black-spotted pond frog, *Pelophylax nigromaculatus*	S, U	21 days	PFOA >98%	6.5	20	MATC (biochemical, genetic and immunological effects)	0.00111-0.01094	0.003485	Non-apical endpoint	Liu et al. 2023c
Gray treefrog (larva, Gosner 40), *Hyla versicolor*	S, U	96 hours	PFOA Unreported	-	21	LC_{50}	-	191	Poor control survival, low number of individuals per treatment.	Tornabene et al. 2021
Tiger salamander (larva, Harrison stage 46), *Ambystoma tigrinum*	R, M	30 days	PFOA ≥96%	-	20	NOEC (snout-vent length, weight, and mortality)	0.8677->0.8667	0.8677	Highly variable dose-response	Flynn et al. 2022
American toad (larva, Gosner stage 25), *Anaxyrus americanus*	R, M	26-45 days	PFOA ≥96%	-	20	MATC (days to metamorphosis)	0.09403-0.8728	0.2865	Highly variable dose-response	Flynn et al. 2022
American toad (larva, Gosner stage 25), *Anaxyrus americanus*	R, M	26-45 days	PFOA ≥96%	-	20	NOEC (growth, mortality)	0.8728->0.8728	0.8728	Highly variable dose-response	Flynn et al. 2022
Asiatic toad (tadpole, 1.8 cm, 0.048 g), *Bufo gargarizans*	R, M	96 hours	PFOA 99%	7	22	LC_{50}	-	114.74	Atypical source of organisms	Yang et al. 2014

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Asiatic toad (tadpole, 1.8 cm, 0.048 g), *Bufo gargarizans*	R, M	30 days	PFOA 99%	7	22	EC_{10} (survival)	-	5.89	Not a true ELS test, atypical source of organisms	Yang et al. 2014

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

[b] C1 year corresponds to the total duration of the 10-generations study. Most generations did not show statistically significant effects.

[c] Reported in moles converted to milligram based on a molecular weight of 414.07 g/mol PFOA or 431.1 g/mol APFO.

[d] Chemical concentrations made in a side-test representative of exposure and verified stability of concentrations of PFOA in the range of concentrations tested under similar conditions. Daily renewal of test solutions.

[e] Concentration of APFO determined as the anion (PFO-).

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Appendix H Other Estuarine/Marine PFOA Toxicity Studies

H.1 Summary Table of Qualitative Estuarine/Marine PFOA Toxicity Studies

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Salinity (ppt)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Bacterium, *Vibrio fischeri*	S, M	15 minutes	PFOA 96%	-	18	-	EC_{50} (bioluminescence inhibition)	-	524	Duration too short for a plant test, missing some exposure details, non-apical endpoint	Rosal et al. 2010
Cyanobacterium, *Anabaena sp.*	S, M	24 hours	PFOA 96%	-	28	-	EC_{50} (bioluminescence inhibition)	-	72.3	Duration too short for a plant test, missing some exposure details, non-apical endpoint	Rosal et al. 2010
Cyanobacterium, *Geitlerinema amphibium*	S, U	72 hours	PFOA Unreported	7.6-7.8	20	8	EC_{50} (growth)	-	248.4[b]	Duration too short for a plant test, missing some exposure details	Latala et al. 2009
Dinoflagellate, *Pyrocystis lunula*	S, M	24 hours	PFOA 95%	-	19	-	EC50 (bioluminescence inhibition)	-	18	Duration too short for a plant test, atypical endpoint	Hayman et al. 2021
Golden brown alga, *Isochrysis galbana*	S, U	72 hours	PFOA 96%	-	20	-	EC_{50} (growth inhibition)	-	163.6	Duration too short for a plant test, missing some exposure details	Mhadhbi et al. 2012
Green alga, *Chlorella vulgaris*	S, U	72 hours	PFOA Unreported	7.6-7.8	20	8	EC_{50} (growth)	-	977.2[b]	Duration too short for a plant test, missing some exposure details	Latala et al. 2009
Diatom, *Skeletonema marinoi*	S, U	72 hours	PFOA Unreported	7.6-7.8	20	8	EC_{50} (growth)	-	368.5[b]	Duration too short for a plant test, missing some exposure details	Latala et al. 2009
Purple sea urchin (fertilized eggs), *Paracentrotus lividus*	S, U	48 hours	PFOA 96%	-	20	-	EC_{50} (growth inhibition)	-	110.0	Duration too short for an acute test	Mhadhbi et al. 2012
Blue mussel, *Mytilus edulis*	R, U	21 days	PFOA Unreported	-	16-19	-	LOEC (catalase activity)	<0.2-0.2	0.2	Atypical endpoint	Li et al. 2021a

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Salinity (ppt)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Mediterranean mussel (adult), *Mytilus galloprovincialis*	R, U	16 days	PFOA ≥98%	7.98	15.2	37.9	NOEC (biochemistry, enzymatic changes)	0.100->0.100	0.100	Duration too short for a chronic exposure, non-apical endpoints	Geng et al. 2021
Green mussel (60-65 mm), *Perna viridis*	R, M	7 days	PFOA 96%	-	25	25	MATC (relative condition factor)	0.0114-0.099	0.03359	Exposure duration too short for chronic test and too long for acute test, non-apical endpoint	Liu et al. 2013; 2014c
Green mussel (adult), *Perna viridis*	R, M	7 days + 7 days observation	PFOA 96%	-	25	30	EC_{50} (integrative genotoxicity)	0.093-0.950	0.5940	Exposure duration too short for chronic test and too long for acute test, non-apical endpoint	Liu et al. 2014a
Green mussel (adult), *Perna viridis*	R, M	7 days	PFOA 96%	-	25	25	MATC (CAT and SOD activity)	0.099-1.12	0.3330	Exposure duration too short for chronic test and too long for acute test, non-apical endpoint	Liu et al. 2014b
Green mussel, *Perna viridis*	R, M	7 days + 7 days observation	PFOA 96%	8	25	30	MATC (hemocyte cell viability)	0.0114-0.099	0.03359	Exposure duration too short for chronic test and too long for acute test, non-apical endpoint	Liu and Gin 2018
Manila clam (3.64 cm), *Ruditapes philippinarum*	R, M	21 days	PFOA Unreported	-	12	35	NOEC (mortality)	0.00093->0.00093	0.00093	Only one exposure concentration, apical endpoints are not the focus of study	Bernardini et al. 2021
Manila clam, *Ruditapes philippinarum*	R, M	21 days	APFO >98%	-	12	35	NOEC (biochemistry, cell diameter, cell volume, hematocyte count)	0.00093->0.00093	0.00093	Only one exposure concentration, non-apical endpoints	Fabrello et al. 2021
Dolphinfish (embryo, <8 hr post spawn), *Coryphaena hippurus*	S, M	48 hours	PFOA 96%	-	27	-	LC_{50}	-	4	Duration too short for an acute test, high control mortality	Gebreab et al. 2022
Japanese medaka (adult), *Oryzias latipes*	R, U	7 days	PFOA ammonium salt 98%	-	25	-	NOEC (survival, condition factor)	100->100	100	Exposure duration too short for chronic test and too long for acute test	Yang 2010

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Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Salinity (ppt)	Effect	Chronic Limits (NOEC-LOEC) (mg/L)	Reported Effect Conc. (mg/L)	Deficiencies	Reference
Dusky rockcod (adult), *Trematomus newnesi*	S, U	10 days	PFOA Unreported	-	-1	-	LOEC (gene expression)	-	1.5	Duration too long for an acute test and too short for a chronic test, atypical endpoint	Pacchini et al. 2023
Marbled flounder (adult), *Pseudopleuronectes yokohamae*	R, M	14 days	PFOA Unreported	-	15	37	LOEC (vitellogenin levels)	<0.197-0.197	0.197	Atypical duration, non-apical endpoint	Li et al. 2018b
Turbot (embryo), *Scophthalmus maximus* (formerly, *Psetta maxima*)	R, U	6 days	PFOA 96%	-	18	-	LC_{50}	-	11.9	Exposure duration too short for chronic test and too long for acute test	Mhadhbi et al. 2012

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

[b] Reported in moles converted to milligram based on a molecular weight of 414.07 mg/mmol.

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Appendix I Acute-to-Chronic Ratios

I.1 Acute-to-Chronic Ratios from Quantitatively Acceptable Tests.

Species	Chemical / Purity	Acute Test Duration	Chronic Test Duration	Acute Effect	Chronic Effect	Acute Effect Conc. (mg/L)	Chronic Effect Conc. (mg/L)	ACR	SMACR	Reference
Rotifer, *Brachionus calyciflorus*	PFOA 96%	24 hours	Up to 200 hours	LC_{50}	EC_{10} (intrinsic rate of natural increase)	150	0.5015	299.1	299.1	Zhang et al. 2013a
Water flea, *Daphnia carinata*	PFOA 95%	48 hours	21 days	EC_{50}	MATC (# of average number of offspring per brood and total # of living offspring)	66.8	0.03162	2,113	2,113	Logeshwaran et al. 2021
Cladoceran, *Daphnia magna*	APFO 99.7%	48 hours	21 days	EC_{50}	EC_{10} (average # of live young)	480	20.26	23.69	-	Colombo et al. 2008
Cladoceran, *Daphnia magna*	PFOA Unreported	48 hours	21 days	EC_{50} (immobility)	EC_{10} (# young/starting female)	542.5	7.853	69.08	-	Ji et al. 2008
Cladoceran, *Daphnia magna*	PFOA >98%	48 hours	21 days	LC_{50}	EC_{10} (# young/starting female)	193.3[a]	12.89	15.00	-	Li 2009, 2010
Cladoceran, *Daphnia magna*	PFOA 99%	48 hours	21 days	LC_{50}	EC_{10} (survival)	222.0	5.458	40.67	-	Yang et al. 2014
Cladoceran, *Daphnia magna*	PFOA 98%	48 hours	21 days	EC_{50}	MATC (growth and reproduction)	114.6	0.07155	1,602[b]	-	Lu et al. 2016
Cladoceran, *Daphnia magna*	PFOA Unreported	48 hours	21 days	LC_{50}	EC_{10} (# of offspring)	117.2	8.084	14.50	27.05	Yang et al. 2019

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Species	Chemical / Purity	Acute Test Duration	Chronic Test Duration	Acute Effect	Chronic Effect	Acute Effect Conc. (mg/L)	Chronic Effect Conc. (mg/L)	ACR	SMACR	Reference
Cladoceran, *Moina macrocopa*	PFOA Unreported	48 hours	7 days	EC_{50} (immobility)	EC_{10} (mean young/adult)	166.3	2.194	75.80	75.80	Ji et al. 2008
Mayfly, *Neocloeon triangulifer*	PFOA 95%	96 hours	23 days	LC_{50}	NOEC (survival, weight, emergence)	13.05	>3.085	<4.229	<4.229	Soucek et al. 2023
American bullfrog, *Lithobates catesbeiana*	PFOA Unreported	96 hours	72 days	LC_{50}	LOEC (snout vent length)	1,006	0.288	3,493	3,493	Flynn et al. 2019

a Geometric mean of three LC50 values.

b Value not used in the SMACR calculation, because the value is an order of magnitude greater than other ACRs for the species.

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Appendix J Unused PFOA Toxicity Studies

J.1 Summary of Unused PFOA Toxicity Studies

Author	Citation	Reason Unused
Arukwe, A. and A.S. Mortensen	2011. Lipid peroxidation and oxidative stress responses of salmon fed a diet containing perfluorooctane sulfonic- or perfluorooctane carboxylic acids. Comp. Biochem. Physiol. Part C 154: 288-295.	Force-fed (oral gavage); only one exposure concentration
Consoer, D.M.	2017. A mechanistic investigation of perfluoroalkyl acid kinetics in rainbow trout (*Oncorhynchus mykiss*). A dissertation submitted to the faculty of the University of Minnesota.	Injected toxicant; only one exposure concentration
Consoer, D.M., A.D. Hoffman, P.N. Fitzsimmons, P.A. Kosian and J.W. Nichols	2014. Toxicokinetics of perfluorooctanoate (PFOA) in rainbow trout (*Oncorhynchus mykiss*). Aquat. Toxicol. 156: 65-73.	All fish were surgically altered (dorsal aortic cannula, plus a urinary catheter); no controls; non-apical endpoints only
Cui, Y., W. Liu, W. Xie, W. Yu, C. Wang and H. Chen	2015. Investigation of the effects of perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) on apoptosis and cell cycle in a zebrafish (*Danio rerio*) liver cell line. Int. J. Environ. Res. Public Health 12(12): 15673-15682.	Excised cells (liver cell line)
De Silva, A.O., P.J. Tseng and S.A. Mabury	2009. Toxicokinetics of perfluorocarboxylate isomers in rainbow trout. Environ. Toxicol. Chem. 28(2): 330-337.	Study involved a mixture of ECF PFOA, linear PFNA, and isopropyl PFNA added to diet
Dragojevic, J., P. Maric, J. Loncar, M. Popovic, I. Mihaljevic, and T. Smital	2020. Environmental Contaminants Modulate Transport Activity of Zebrafish Organic Anion Transporters Oat1 and Oat3. Comp. Biochem. Physiol. C Toxicol. Pharmacol.231:8 p.	The test duration was extremely brief (~10 mins), the exposure was in vitro, and no apical effects were evaluated.
Elnabarawy, M.T.	1980. Aquatic Toxicity Testing: FC-143 (Lot-37) L.R. 5626 S. Report No. 037; OPPT Administrative Record AR226-0504:3780-3786.	Results reported in another publication
Fernández-Sanjuan, M., M. Faria, S. Lacorte and C. Barata	2013. Bioaccumulation and effects of perfluorinated compounds (PFCs) in zebra mussels (*Dreissena polymorpha*). Environ. Sci. Pollut. Res. 20:2661–2669.	Mixture
Garoche, C., A. Boulahtouf, M. Grimaldi, B. Chiavarina, L. Toporova, M.J. Den Broeder, J. Legler, W. Bourguet and P. Ba.	2021. Interspecies differences in activation of peroxisome proliferator-activated receptor gamma by pharmaceutical and environmental chemicals. Environ. Sci. Technol. 55(24): 16489-16501.	In vitro
Gonzalez-Naranjo, V. and K. Boltes	2014. Toxicity of ibuprofen and perfluorooctanoic acid for risk assessment of mixtures in aquatic and terrestrial environments. Int. J. Environ. Sci. Technol. 11: 1743-1750.	Severe lack of exposure details (cannot judge against data quality objectives)
Gorrochategui, E., S. Lacorte, R. Tucker and F.L. Martin	2016. Perfluoroalkylated substance effects in *Xenopus laevis* A6 kidney epithelial cells determined by ATR-FTIR spectroscopy and chemometric analysis. Chem. Res. Toxicol. 29: 924-932.	The tests were performed on cell cultures obtained from an outside source; whole organisms were not investigated
Holth, T.F., M. Yazdani, A. Lenderink and K. Hyllan	2012. Effects of fluoranthene and perfluorooctanoic acid (PFOA) on immune functions in Atlantic cod (*Gadus morhua*). Abstracts Comp. Biochem. Physiol. Part A. 163: S39-S42.	Abstract only; cannot judge against data quality objectives

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Author	Citation	Reason Unused
Hoover, G.M.	2018. Effects of Per/Polyfluoroalkyl Substance Exposure on Larval Amphibians. Ph.D.Thesis, Purdue University, West Lafayette, IN	Test is unused because the source material is a PhD Thesis and has not undergone peer review. Only peer-reviewed data are considered in deriving aquatic life criteria
Hoover, G., S. Kar, S. Guffey, J. Leszczynski, and M.S. Sepulveda	2019. In Vitro and In Silico Modeling of Perfluoroalkyl Substances Mixture Toxicity in an Amphibian Fibroblast Cell Line. Chemosphere233:25-33.	In vitro exposure
Jantzen, C.E., K.M. Annunziato and K.R. Cooper	2016. Behavioral, morphometric, and gene expression effects in adult zebrafish (*Danio rerio*) embryonically exposed to PFOA, PFOS, and PFNA. Aquatic Toxicology. 180:123–130.	Single concentration test where exposure to PFOA was of an acute (117-hours) duration but endpoints were measured at 6 months of age
Jantzen, C.E., F. Toor, K.M. Annunziato and K.R. Cooper	2017b. Effects of chronic perfluorooctanoic acid (PFOA) at low concentration on morphometrics, gene expression, and fecundity in zebrafish (*Danio rerio*). Reproduct. Toxicol. 69: 34-42.	Unable to determine dietary exposure concentration
Khan, E.A., X. Zhang, E.M. Hanna, F. Yadetie, I. Jonassen, A. Goksoyr and A. Arukwe	2021. Application of Quantitative Transcriptomics in Evaluating the Ex Vivo Effects of Per- and Polyfluoroalkyl Substances on Atlantic Cod (*Gadus morhua*) Ovarian Physiology. Sci. Total Environ.755(1): 11 pp.	In vitro exposure
Lee, W. and Y. Kagami	2010. Effects of perfluorooctanoic acid and perfluorooctane sulfonate on gene expression profiles in medaka (*Oryzias latipes*). Abstracts. Toxicol. Letters 196S: S37-S351.	Abstract only, cannot judge against data quality objectives
Li, M.H.	2011. Changes of cholinesterase and carboxylesterase activities in male guppies, *Poecilia reticulata*, after exposure to ammonium perfluorooctanoate, but not to perfluorooctane sulfonate. Fresenius Environ. Bull. 20(8a): 2065-2070.	Each treatment group for PFOA was run two times at separate times (not simultaneously) and the sample size for each treatment group was unclear.
Liang, X. and J. Zha	2016. Toxicogenomic applications of Chinese rare minnow (*Gobiocypris rarus*) in aquatic toxicology. Comp. Biochem. Physiol. Part D 19: 174-180.	Review paper
Liu, C., Y. Du and B. Zhou	2007a. Evaluation of estrogenic activities and mechanism of action of perfluorinated chemicals determined by vitellogenin induction in primary cultured tilapia hepatocytes. Aquat. Toxicol. 85: 267-277.	In vitro, cultured hepatocytes
Liu, C., K. Yu, X. Shi, J. Wang, P.K.S. Lam, R.S.S. Wu and B. Zhou	2007b. Induction of oxidative stress and apoptosis by PFOS and PFOA in primary cultured hepatocytes of freshwater tilapia (*Oreochromis niloticus*). Aquat. Toxicol. 82: 135-143.	In vitro, cultured hepatocytes
Mahapatra, C.T., N.P. Damayanti, S.C. Guffey, J.S. Serafin, J. Irudayaraj and M.S. Sepúlveda	2017. Comparative in vitro toxicity assessment of perfluorinated carboxylic acids. J. Appl. Toxicol. 37: 699-708.	In vitro exposure, zebrafish liver cell cultures
Martin, J.W., S.A. Mabury, K.R. Solomon and D.C.G. Muir	2003a. Bioconcentration and tissue distribution of perfluorinated acids in rainbow trout (*Oncorhynchus mykiss*). Environ. Toxicol. Chem. 22: 196-204.	Bioaccumulation (steady state not documented); only 12 days
Martin, J.W., S.A. Mabury, K.R. Solomon and D.C.G. Muir	2013. Progress toward understanding the bioaccumulation of perfluorinated alkyl acids. Environ. Toxicol. Chem. 32(11): 2421-2423	Review paper
Mortensen, A.S., R.J. Letcher, M.V. Cangialosi, S. Chu and A. Arukwe	2011. Tissue bioaccumulation patterns, xenobiotic biotransformation and steroid hormone levels in Atlantic salmon (*Salmo salar*) fed a diet containing perfluoroactane sulfonic or perfluorooctane carboxylic acids. Chemosphere. 83: 1035-1044.	One dietary dosage level provided over a 6-day period; not intended as a toxicity test

Author	Citation	Reason Unused
Otero-Sabio, C., M. Giacomello, C. Centelleghe, F. Caicci, M. Bonato, A. Venerando, J.M. Graic, S. Mazzariol, L. Finos	2022. Cell Cycle Alterations Due to Perfluoroalkyl Substances PFOS, PFOA, PFBS, PFBA and the New PFAS C6O4 on Bottlenose Dolphin (Tursiops truncatus) Skin Cell. Ecotoxicol. Environ. Saf.244:10 p.	In vitro
Padilla, S., D. Corum, B. Padros, D.L. Hunter, A. Beam, K.A. Houck, N. Sipes, N. Kleinstreuer, T. Knudsen, D.J. Nix and D.M. Reif	2012. Zebrafish developmental screening of the ToxCastTM Phase I chemical library. Reprod. Toxicol. 33: 174-187.	Severe lack of exposure details, only one exposure concentration
Popovic, M, R. Zaja, K. Fent and T. Smital	2014. Interaction of environmental contaminants with zebrafish organic anion transporting polypeptide, Oatp1d1 (Slco1d1). Toxicol. Appl. Pharmacol. 280(1): 149-158.	Excised cells
Prosser, R.S., K. Mahon, P.K. Sibley, D. Poirier and T. Watson-Leung	2016. Bioaccumulation of perfluorinated carboxylates and sulfonates and polychlorinated biphenyls in laboratory-cultured *Hexagenia spp*., *Lumbriculus variegatus* and *Pimephales promelas* from field-collected sediments. Sci. Total Environ. 543: 715-726.	Mixture (filed collected sediment, contained PFAS mixtures and PCBs)
Rotondo, J.C, L. Giari, C. Guerranti, M. Tognon, G. Castaldelli, E.A. Fano and F. Martini	2018. Environmental doses of perfluorooctanoic acid change the expression of genes in target tissues of common carp. Environ. Toxicol. Chem. 37(3): 942-948.	Two exposure concentrations 10,000-fold apart; atypical endpoint
Sanderson, H., T.M. Boudreau, S.A. Mabury and K.R. Solomon	2003. Impact of perfluorooctanoic acid on the structure of the zooplankton community in indoor microcosms. Aquat. Toxicol. 62: 227-234.	Poor experimental design/performance
Stevenson, C.N., L.A. MacManus-Spencer, T. Luckenbach, R.G. Luthy and D. Epel	2006. New perspectives on pefluorochemical ecotoxicology: inhibition and induction of an efflux transporter in marine mussel, *Mytilus californianus*. Environ. Sci. Technol. 40: 5580-5585.	Excised cells (gills)
Sun, X., Y. Xie, X. Zhang, J. Song, and Y. Wu	2023b. Estimation of Per- and Polyfluorinated Alkyl Substance Induction Equivalency Factors for Humpback Dolphins by Transactivation Potencies of Peroxisome Proliferator-Activated Receptors. Environ. Sci. Technol.57(9): 3713-3721.	In vitro; mammalian study
Tang, J., X. Jia, N. Gao, Y. Wu, Z. Liu, X. Lu, Q. Du, J. He, N. Li, B. Chen, J. Jiang, W. Liu, Y. Ding, W. Zhu and H. Zhang	2018. Role of the Nrf2-ARE pathway in perfluorooctanoic acid (PFOA)-induced hepatotoxicity in *Rana nigromaculata*. Environ. Pollut. 238: 1035-1043.	No apical endpoints were measured; control survival was not reported; test duration of 14 days relatively short for a chronic amphibian study; not NA species
Thienpont, B., A. Tingaud-Sequeira, E. Prats, C. Barata, P.J. Babin and D. Raldua	2011. Zebrafish eleutheroembryos provide a suitable vertebrate model for screening chemicals that impair thyroid hormone synthesis. Environ. Sci. Technol. 45(17): 7525-7532.	Only one exposure concentration; no apical endpoints
Ulhaq, M., S. Orn, G. Carlsson, J. Tallkvist and L. Norrgren	2012. Perfluorooctanoic acid toxicity in zebrafish (*Danio rerio*). Abstracts. Toxicol. Letters 211S: S43-S216.	Abstract only, cannot judge against data quality objectives
Williams, T.D., A. Diab, F. Ortega, V.S. Sabine, R.E. Godfrey, F. Falciani, J.K. Chipman and S.G. George	2008. Transcriptomic Responses of European Flounder (*Platichthys flesus*) to Model Toxicants. Aquat. Toxicol. 90(2): 83-91.	Injected toxicant; only one exposure concentration
Xia, X., X. Chen, X. Zhao, H. Chen and M. Shen	2012. Effects of carbon nanotubes, chars, and ash on bioaccumulation of perfluorochemicals by *Chironomus plumosus* larvae in sediment. Environ. Sci. Technol. 46: 12467-12475.	PFCs mixed in sediment

Author	Citation	Reason Unused
Xia, X., A.H. Rabearisoa, X. Jiang and Z. Dai	2013. Bioaccumulation of perfluoroalkyl substances by *Daphnia magna* in water with different types and concentrations of protein. Environ. Sci. Technol. 47: 10955-10963.	Bioaccumulation (steady state not documented); unmeasured test; only 3 days
Xia, X., Z. Dai, A.H. Rabearisoa, P. Zhao and X. Jiang	2015a. Comparing humic substance and protein compound effects on the bioaccumulation of perfluoroalkyl substances by *Daphnia magna* in water. Chemosphere. 119: 978-986.	Bioaccumulation (steady state not documented); unmeasured test; only 3 days
Xia, X., A.H. Rabaerisoa, Z. Dai, X. Jiang, P. Zhao and H. Wang	2015b. Inhibition effect of Na+ and Ca2+ on the bioaccumulation of perfluoroalkyl substances by *Daphnia magna* in the presence of protein. Environ. Toxicol. Chem. 34(2): 429-436.	Bioaccumulation (steady state not documented); unmeasured test; only 3 days
Yang, Z., L. Fu, M. Cao, F. Li, J. Li, Z. Chen, A. Guo, H. Zhong, W. Li, Y. Liang, and Q. Luo.	2023. PFAS-Induced Lipidomic Dysregulations and Their Associations with Developmental Toxicity in Zebrafish Embryos. Sci. Total Environ.861:9 p.	Injected toxicant
Yuan, Z. J. Zhang, C. Tu, Z. Wang and W. Xin	2016a. The protective effect of blueberry anthocyanins against perfluorooctanoic acid-induced disturbance in planarian (*Dugesia japonica*). Ecotoxicol. Environ. Saf. 127: 170-174.	Only one exposure concentration; not NA species; non-apical endpoints; static, unmeasured chronic exposure
Zhang, J., B. Wang, B. Zhao, Y. Li, X. Zhao and Z. Yuan	2019a. Blueberry anthocyanin alleviates perfluorooctanoic acid-induced toxicity in planarian (*Dugesia japonica*) by regulating oxidative stress biomarkers, ATP contents, DNA methylation and mRNA expression. Environ. Pollut. 245: 957-964.	Only one exposure concentration; not NA species; non-apical endpoints
Zhang, H., J. He, N. Li, N. Gao, Q. Du, B. Chen, F. Chen, X. Shan, Y. Ding, W. Zhu, Y. Wu, J. Tang and X. Jia	2019b. Lipid accumulation responses in the liver of *Rana nigromaculata* induced by perflurooctanoic acid (PFOA). Ecotoxicol. Environ. Saf. 167: 29-35.	No apical endpoints were measured; control survival was not reported; test duration of 14 days relatively short for a chronic amphibian study; not NA species

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Appendix K EPA Methodology for Fitting Concentration-Response Data and Calculating Effect Concentrations

Toxicity values, including LC_{50} and EC_{10} values, were independently calculated from the data presented in the toxicity studies meeting the inclusion criteria described above (see Section 2.10.3.3) and when adequate concentrations-response data were published in the study or could be obtained from authors. When concentration-response data were not presented in toxicity studies, concentration-response data were requested from study authors to independently calculate toxicity values. In cases where study authors did not respond to the EPA's request for data or were unable to locate concentration-response data, the toxicity values were not independently calculated by the EPA, and the reported toxicity values were retained for criteria deviation. The EPA also retained author-reported effect concentrations when data availability did not support effect concentration calculation by the EPA. This retention was done to be consistent with use of author-reported toxicity values in previous criteria documents and retain informative toxicity values (that would have otherwise not been used only on the basis of lacking the underlying C-R data). Where concentration-response data were available, they were analyzed using the statistical software program R (version 3.6.2) and the associated dose-response curve (drc) package.

In some cases, the author-reported toxicity values were different than the corresponding effect concentrations calculated by the EPA. Overall, the magnitude of such discrepancies was limited and largely occurred for several potential reasons such as: (1) instances where authors were presumed to calculate effect concentrations using replicate level data, but the EPA only had access to treatment mean data; (2) the model selected to fit a particular set of C-R data, and; (3) the software used to fit a model to C-R data and calculate an effect concentration.

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K.1 Fitting Concentration Response Data in R

Concentration-response data were obtained from quantitatively-acceptable toxicity studies when reported data were available. In many scenarios, toxicity studies report treatment-level mean concentrations and mean organismal responses; however, individual-replicate data may also be reported. When fitting C-R curves, replicate-level data were preferred over treatment-level data, if both types of data were available. Within R, the drc package can fit a variety of mathematical models to each set of C-R data.

K.1.1 Fitting Acute Mortality Data

K.1.1.1 Dichotomous Data

Dichotomous data are binary in nature (e.g., live/dead or 0/1) and are typical of survival experiments. They are usually represented as a proportion survived.

K.1.2 Fitting Chronic Growth, Reproduction, and Survival Data

K.1.2.1 Continuous Data

Continuous data take on any value along the real number line (e.g., biomass).

K.1.2.2 Count Data

Count data take on only integer values (e.g., number of eggs hatched).

K.1.2.3 Dichotomous Data

Dichotomous data are binary in nature (e.g., live/dead or 0/1) and are typical of survival experiments. They are usually represented as a proportion survived.

K.2 Determining Most Robust Model Fit for Each C-R curve

The R drc package was used to fit a variety of models to each individual C-R dataset. A single model was then selected from these candidate models to serve as the representative C-R model. The selected model represented the most statistically-robust model available. To

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determine the most-statistically-robust model for a C-R dataset, all individual model fits were assessed on a suite of statistical metrics.

K.2.1 Selecting Candidate Models

Initially, models were ranked according to the Akaike information criteria (AIC). The AIC provides a measure of the amount of information lost for a given model by balancing goodness of fit with model parsimony. The models with the lowest AIC, relative to other models based on the same data, tend to be optimal. In some instances, however, the model with the lowest AIC possessed a questionable characteristic that suggested said model was not the most appropriate. Rather than selecting a model based solely on the lowest AIC, the initial ranking step was only used to identify a subset of candidate models that were more closely examined before selecting a model fit for each C-R dataset.

K.2.2 Assessment of Candidate Models to Determine the Most Appropriate Model

Candidate models (i.e., models with low AIC scores relative to other models produced for a particular C-R dataset) were further evaluated based on additional statistical metrics to determine a single, statistically robust curve for each quantitatively-acceptable toxicity test. These additional statistical metrics were evaluated relative to the other candidate curve fits produced for each C-R dataset. Of these statistical metrics, residual standard errors, confidence intervals relative to effects concentration estimates, and confidence bands carried the most weight in determining the most appropriate model to be representative of an individual C-R dataset. These additional statistical metrics included:

K.2.2.1 Comparison of residual standard errors

As with AIC, smaller values were desirable. Residual standard errors were judged relative to other models.

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K.2.2.2 Width of confidence intervals for EC estimates

Confidence intervals were assessed on standard error relative to estimate and confirming that the intervals were non-negative. Judged in absolute and relative to other models.

K.2.2.3 Width of confidence bands around the fitted model

A general visual inspection of the confidence bands for the fitted model. Wide bands in the area of interest were undesirable. Judged in absolute and relative to other models.

K.2.2.4 P-values of parameters estimates and goodness of fit tests

Hypothesis tests of parameter values to determine whether an estimate is significantly different from zero. Goodness of fit tests were used to judge the overall performance of the model fit. Typically, the level of significance was set at 0.05. There may have been occasional instances where the 0.05 criterion may not be met, but there was little recourse for choosing another model. Judged in absolute terms.

K.2.2.5 Residual plots

Residuals were examined for homoscedasticity and biasedness. Judged in absolute and relative to other models.

K.2.2.6 Overly influential observations

Observations were judged based on Cook's distance and leverage. When an observation was deemed overly influential, it was not reasonable to refit the model and exclude any overly influential observations given the limited data available with typical C-R curves. Judged in absolute terms.

K.3 Determining Curve Acceptability for use in Criteria Derivation

The final curve fits selected for each of the quantitatively-acceptable toxicity tests were further evaluated and classified to determine whether the curves were: 1) quantitatively-

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acceptable for use, 2) qualitatively acceptable for use, or 3) unacceptable. To determine curve acceptability for use in deriving an effect concentration, each individual curve was considered based on the statistical metrics described above and assessed visually to compare how the calculated effect concentration aligned with the underlying raw C-R data. Instead of evaluating curves fits relative to other curve fits for the same data (as was previously described to select the most-robust curve for each test), curve fit metrics were used to assign each curve a score:

- **Quantitatively Acceptable Model**. Model performed well on most/all statistical metrics and resultant effect concentrations were typically used in a quantitative manner.
- **Qualitatively Acceptable Model**. Model generally performed well on statistical metrics; however, the model presented some characteristic(s) that called estimates into question. Such models were considered with caution. These problems may have consisted of any number of issues such as a parameter with a high p-value, poor goodness of fit p-value, wide confidence bands for fit or estimate interval, or residuals that indicate model assumptions are not met. Broadly, effect concentrations from models that were deemed qualitatively acceptable were not used numerically in criteria derivation if quantitatively acceptable models for different endpoints or tests from the same publication were available. If quantitatively acceptable models for different endpoints or tests from the same publication were not available, effect concentrations from the qualitatively acceptable model were used numerically in criteria derivation on a case-by-case basis.
- **Unacceptable Model**. Model poorly fit the data. These models were not used for criteria derivation.

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No single statistical metric can determine a given model's validity or appropriateness. Metrics should be considered as a whole. As such, there is a slightly subjective component to these evaluations. That said, this assessment methodology was developed to aid in evaluating models as to their quantitative or qualitative attributes in a transparent and relatively repeatable manner.

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Appendix L Derivation of Acute Protective PFOA Benchmarks for Estuarine/Marine Waters through a New Approach Method (NAM)

L.1 Background

The 1985 *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (U.S. EPA 1985) recommend that data for a minimum of eight families be available to fulfill taxonomic minimum data requirements (MDRs) to calculate criteria values, including to calculate estuarine/marine aquatic life criteria. Acute estuarine/marine test data are currently available for only three families, a mysid (*Siriella* and *Americamysis*), a sea urchin (*Strongylocentrotus*), and a mussel (*Mytilus*), addressing only three of the eight MDRs; thus, the EPA was not able to derive an acute estuarine/marine criterion element for PFOA based on the 1985 Guidelines MDR specifications (Section 2.10.1). However, the EPA was able to develop an acute PFOA protective benchmark using a New Approach Methods (NAMs) process, via the application of Interspecies Correlation Estimation (ICE) models (Raimondo et al. 2010). Although not a criterion based on 1985 Guidelines specifications, because of gaps in available data for several of the taxonomic MDRs listed in the 1985 Guidelines for the derivation of aquatic life criteria, this benchmark represents an aquatic life value derived to be protective of aquatic communities. The ICE model predictions supplement the available test dataset to help fill missing MDRs and allow the derivation of acute an estuarine/marine benchmark for aquatic life using procedures consistent with those in the 1985 Guidelines. This is important as it provides an approach by which values that are protective of aquatic life communities can be developed, even when MDRs are not fulfilled by direct PFOA test data. This approach is consistent with both the 1985 Guidelines "good science" clause, the EPA's interest in providing useful information to states and Tribes regarding protective values

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for aquatic life, and the EPA's intention to reduce the use of animal testing via application of NAMs (https://www.epa.gov/chemical-research/epa-new-approach-methods-work-plan-reducing-use-animals-chemical-testing).

L.1.1 Introduction to Web-ICE

ICE models, developed by the EPA's Office of Research and Development, are log-linear regressions of the acute toxicity (EC_{50}/LC_{50}) of two species across a range of chemicals, thus representing the relationship of inherent sensitivity between those species (Raimondo et al. 2010). Each model is derived from an extensive, standardized database of acute toxicity values by pairing each species with every other species for which acceptable toxicity data are available. Once developed, ICE models can be used predict the sensitivity of an untested taxon (predicted taxa are represented by the y-axis) from the known, measured sensitivity of a surrogate species (represented by the x-axis; Figure L-1).

ICE models have been developed for a broad range of different chemicals (e.g., metals and other inorganics, pesticides, solvents, and reactive chemicals) and across a wide range of toxicity values. There are approximately 3,400 significant ICE models for aquatic animal and plant species in the most recent version of web-ICE (v3.3, https://www3.epa.gov/webice/, last updated June 2016; Raimondo et al. 2015).

Models were validated using leave-one-out cross validation, which formed the basis for the analyses of uncertainty and prediction robustness. For this process, each datapoint within the model (representing the relative sensitivity of two species for a particular chemical) is systematically removed, one at a time. The model is then redeveloped with the remaining data (following each removal) and the removed value of the surrogate species is entered into the model. The estimated value for the predicted species is then compared to the measured value for that species (Raimondo et al 2010; Willming et al. 2016).

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ICE models have high prediction accuracy when values are derived from models with robust parameters (e.g., mean square error, R^2), that fall within a defined range of acceptability, and with close prediction confidence intervals that facilitate evaluating the fit of the underlying data (Brill et al. 2016; Raimondo et al. 2010; Willming et al. 2016). Results of these analyses provide the basis of the user guidance for selecting ICE predicted toxicity with high confidence (Box 1).

ICE models have undergone extensive peer review and their use has been supported for multiple applications, including direct toxicity estimation for endangered species (NRC 2013; Willming et al. 2016) and development of Species Sensitivity Distributions (SSDs) (Awkerman et al. 2014; Bejarano et al. 2017; Dyer et al. 2006, 2008; Raimondo et al. 2010, 2020). The application of ICE-predicted values to develop protective aquatic life values by multiple independent, international groups confirms that values developed from ICE-generated SSDs provides a level of protection that is consistent with using measured laboratory data (Dyer et al. 2008; Feng et al. 2013; Fojut et al. 2012a, 2012b; Palumbo et al. 2012; Wu et al. 2015, 2016; Wang et al. 2020; Zhang et al. 2017). A recent external review of ICE models additionally supports their use in regulatory applications based on the reliability of underlying data, model transparency, statistical robustness, predictive reliability, proof of principle, applicability to probabilistic approaches, and reproducibility of model accuracy by numerous independent research teams (Bejarano and Wheeler 2020).

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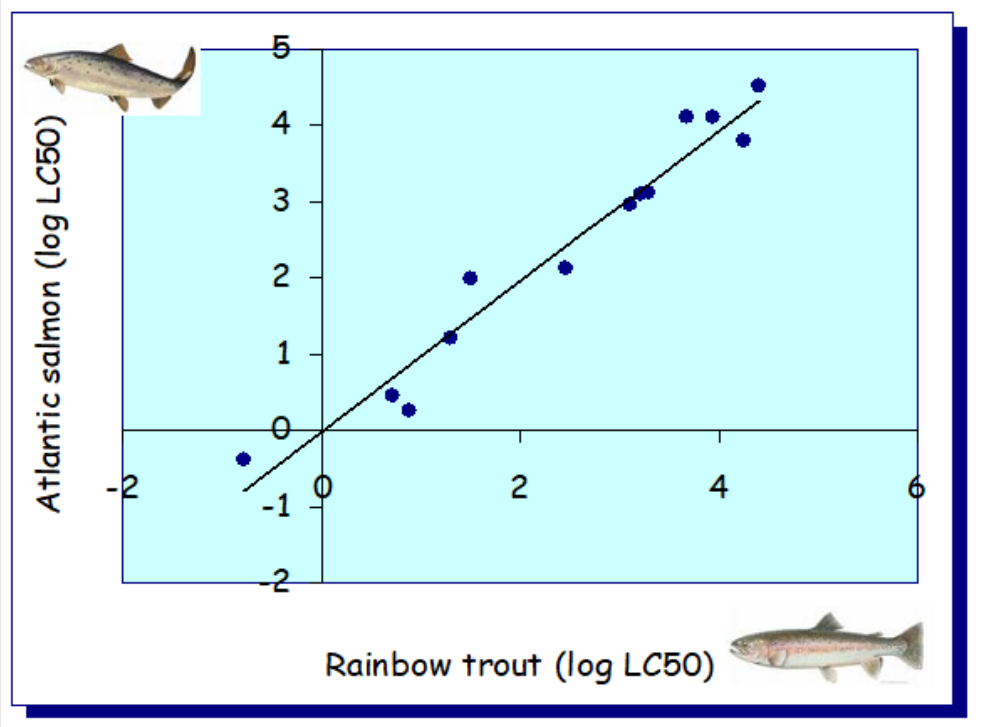


Figure L-1. Example ICE Model for Rainbow Trout (surrogate) and Atlantic Salmon (predicted).
Each model datapoint is a common chemical that was tested in both species to develop a log-linear regression.

Box 1. ICE Model User Guidance Recommended for Listed Species (Willming et al. 2016):

- Close taxonomic distance (within class)
- Low Mean Squared Error (<~ 0.95)
- High R^2 (>~ 0.6)
- High slope (>~ 0.6)
- Prediction confidence intervals should be used to evaluate the prediction using professional judgement for the application (Raimondo et al. 2024).
- For models between vertebrates and invertebrates, using those with lower MSE or MOA-specific models (not available for PFAS) has been recommended for listed species predictions (Willming et al. 2016).

L.1.2 Application of Web-ICE with PFOA

As previously discussed, ICE models have been developed using a diversity of compounds (e.g., metals and other inorganics, pesticides, solvents, and reactive chemicals)

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across a wide range of toxicity values; however, PFAS are not included in Web-ICE v3.3 due to the lack of available toxicity data at that time. PFAS acute values (typically reported as mg/L) can be greater than those used to develop an ICE model (ICE database toxicity range $1E^{-4}$ to $1E^{8}$ µg/L) such that the input PFAS value of the surrogate would be outside the model domain. In these cases, a user can either enter the value as µg/L and allow the model to extrapolate beyond its range or enter the toxicity as a "scaled" value (i.e., estimate the value as mg/L). The principal assumptions of ICE models are: 1) they represent the relationship of inherent sensitivity between two species, which is conserved across chemicals, mechanisms of action, and ranges of toxicity and; 2) the nature of a contaminant that was tested on the surrogate reflects the nature of the contaminant in the predicted species (e.g., effect concentration [EC_{50}] or lethal concentration [LC_{50}]), percentage of active ingredient, technical grade (Raimondo et al. 2010). While neither of these assumptions are violated by either extrapolating beyond the range of the model or using scaled toxicity data, the uncertainty of using ICE models in either manner had not been thoroughly evaluated. Additionally, since PFAS were not included in the database used to develop Web-ICE v3.3, the validation of ICE models to accurately and specifically predict to these compounds has not been previously explored. We address both these topics in the sections below.

L.2 Prediction Accuracy of Web-ICE for Scaled Toxicity and Values Beyond the Model Domain

The accuracy of using scaled toxicity data as input into ICE models was evaluated using an analysis with the existing ICE models and is described in detail in Raimondo et al. (2024). Briefly, ICE models containing a minimum of 10 datapoints and spanning at least five orders of magnitude were separated into two subsets: 1) a lower subset that contained all paired chemical data corresponding to values below the 75^{th} percentile of surrogate species values and; 2) an

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upper subset containing paired chemical data above the 75th percentile of surrogate values. The lower subset was used to develop "truncated" ICE models. The surrogate species values in the upper subset were converted to mg/L and entered into the truncated ICE models. The predicted mg/L value was compared to the respective value of the measured predicted species. Prediction accuracy was determined as the fold difference (maximum of the predicted/measured and measured/predicted) between the predicted and the measured value, consistent with previously published evaluations of ICE models (Raimondo et al. 2010; Willming et al. 2016). Accuracy of using scaled toxicity as input into ICE models was compared to overall ICE prediction accuracy as previously reported and prediction accuracy of the respective upper subset data points that were entered into the models as µg/L (i.e., values beyond the model domain). A total of 3,104 datapoints from 398 models were evaluated. A match-paired comparison showed that the average fold differences of toxicity values predicted using scaled toxicity was not significantly different than the respective average fold differences of all cross-validated data points reported in Willming et al. (2016) (Wilcoxon paired rank sum test, V = 42741, p-value 0.11). Additionally, Raimondo et al. (2010) and Willming et al (2016) showed a consistent and reproducible relationship between the taxonomic distance of the predicted and surrogate species, which was also reproduced using scaled values; the percentage of datapoints predicted using scaled toxicity was within five-fold of the measured value for over 94% of all validated datapoints for species pairs within the same order, with a reduction in accuracy coinciding with decreasing taxonomic relatedness (Raimondo et al. 2024). Comparison of scaled values with those predicted from µg/L values beyond the model domain showed that predicted values varied by a factor of 10 for models with slopes ranging from 0.66 – 1.33. Toxicity values predicted from models with slopes within this range had a median fold difference of 2.4 using mg/L values and 2.8 using µg/L

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values (Wilcoxon paired rank sum test, V = 1334749, p-value 0.77). These results and a detailed review of ICE model assumptions are provided in Raimondo et al. (2024)[2].

L.3 Direct Comparison of Web-ICE and Measured Toxicity Values

Since limited PFOA toxicity test data are available for estuarine/marine species, the ability of ICE models to predict PFOA toxicity was evaluated using direct comparisons of freshwater species sensitivity as reported in the criteria document and predicted by Web-ICE. In this comparison, the measured SMAVs for PFOA reported in Appendix A.1 and Appendix B.1 were used as values for surrogate species to predict to all possible species that also had a measured PFOA SMAV reported. The available SMAVs for PFOA that could be used as ICE surrogate values, along with the number of ICE models corresponding to each surrogate, are shown in Table L-1.

[2] Use of scaled toxicity values and the use of surrogate toxicity values beyond the bounds of the ICE model that are input as µg/L are two approaches that both make extrapolations beyond the bounds of the underlying data. Actual predictions resulting from the two approaches from the same ICE model begin to deviate from one another the further the slope of the ICE model deviates from 1.0 (which is a primary reason why scaled toxicity data were only employed on ICE models with slopes ranging from 0.66 – 1.33). Overall, use of the scaled approach compared to direct extrapolation results a negligible change in the final estuarine/marine benchmark, primarily because the four most sensitive estuarine/marine GMAVs were based on direct toxicity test results, and secondarily, because only a subset of ICE models required use of scaled toxicity data to account for predicting beyond the bounds of the underlying ICE model. For example, the final acute PFOA estuarine/marine benchmark was 7.0 mg/L (see section L.5). Had the values in Table L-4 been predicted using unscaled data that were input as µg/L only (and the model slope requirement of 0.66 -1.33 been retained), the final acute estuarine/marine benchmark would remain unchanged at 7.0 mg/L. Had the values in Table L-4 been predicted using unscaled data input as µg/L only (and the model slope requirement of 0.66 -1.33 was removed), the final acute estuarine/marine benchmark would increase slightly to 7.5 mg/L. While both approaches contain uncertainty, use of the scaled approach resulted in a more protective acute PFOA estuarine/marine benchmark (i.e., CMC = 7.0 mg/L) than an exploratory benchmark that used acute toxicity data estimated through direct extrapolation, with the model slope requirement of 0.66 -1.33 removed (i.e., exploratory CMC = 7.5 mg/L).

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Table L-1. Surrogate Species Measured Values for PFOA and Corresponding Number of ICE Models for Each Surrogate.

For example, there are 53 species for which *Daphnia magna* can predict toxicity.

Broad Taxon	Species		PFOA SMAV (mg/L)	Number of ICE Models
	Common Name	Scientific		
Amphibian	Bullfrog	*Lithobates catesbeiana* [a]	1,020	9
Amphibian	Clawed frog	*Xenopus sp.* [b]	377	2
Crustacean	Mysid	*Americamysis bahia*	24	28
Crustacean	Water flea	*Daphnia magna*	220[c]	53
Fish	Zebrafish	*Danio rerio*	450.4	2 (juvenile models) 6 (embryo models)
Fish	Bluegill	*Lepomis macrochirus*	664	68
Fish	Rainbow trout	*Oncorhynchus mykiss*	4,001	77
Fish	Fathead minnow	*Pimephales promelas*	593.6	74
Mollusc	Fatmucket	*Lampsilis siliquoidea*	164.4	29
Mollusc	Black sandshell	*Ligumia recta*	161	1

[a] *Lithobates catesbeianus* was used in Web-ICE

[b] *Xenopus laevis* was used in Web-ICE

[c] *D.magna* species mean acute value used in Appendix L is 220.0 mg/L, which differs slightly from the *D. magna* species mean acute value reported in Appendix A.1 (i.e., 213.9 mg/L). This discrepancy was the result of including late-breaking data ahead for the release of the 2024 Final PFOA Aquatic Life Criteria document. The discrepancy in the *D. magna* SMAV used here vs. Appendix A.1 has no influence on the 2024 PFOA acute estuarine/marine benchmark (7.0 mg/L) because the four most sensitive genera used to derive the PFOA acute estuarine/marine are based entirely on empirical, laboratory-based toxicity data.

Table L-2 shows direct comparisons for PFOA measured and ICE-predicted values. The regressions for these comparisons are provided in Section L.6. Comparisons are limited by the number of measured toxicity values and models available. To be included in this comparison, a measured value was needed for both species in an ICE model pair. For direct comparison of predicted and measured PFOA values, the measured SMAV of the surrogate species is entered into a model for which the measured SMAV for the intended predicted species is also known. The PFOA toxicity predicted to this model is then compared to the measured SMAV for the predicted species listed in Appendix A.1, Appendix B.1 and Table L-1. This allows both species of an ICE model to serve as either the predicted or surrogate species. The exception to this was in cases involving zebrafish embryos, as web-ICE v3.3 only included models for which zebrafish embryos were used as surrogates. Accuracy of ICE predictions are presented as the "fold-

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difference" between the measured and the predicted species, such that fold difference is the maximum of the ratio of the predicted LC_{50}/measured LC_{50} or measured LC_{50}/predicted LC_{50}. Analyses of ICE prediction accuracy have shown that ICE models over- and under-estimate toxicity values randomly, i.e., there is no systematic bias associated with the models (Table L-2, Raimondo et al. 2010; Raimondo et al. 2024). For accuracy assessments, the fold difference provides a simplified metric to easily see how close predictions are to measured values at a glance. A five-fold difference has been demonstrated to be the average interlaboratory variability of acute aquatic toxicity tests and represents a conservative amount of variance under standardized test conditions for a given life stage (Fairbrother 2008; Raimondo et al. 2010). This inter-test variation can increase significantly where experimental variables differ between tests; however, all ICE models are based on standardized life stages to minimize extraneous variability (Raimondo et al. 2010).

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Table L-2. Comparison of ICE-predicted and measured values of PFOA for species using both scaled values (entered as mg/L) and values potentially beyond the model domain (entered as µg/L).

Measured SMAVs are for the predicted species as listed in Appendix A.1, Appendix B.1 and Table L-1. Footnotes indicate where predictions or models do not meet one or more of the user guidance criteria. Footnotes also indicate any differences between species mean acute values here that differ from species mean acute values reported in Appendix A.1.

		Toxicity Values Potentially Beyond Model Domain				Scaled Toxicity Values			
Predicted Species	**Surrogate Species**	**Measured SMAV (µg/L)**	**Web-ICE Predicted (µg/L)**	**Confidence Interval (µg/L)**	**Fold Difference**	**Measured SMAV (mg/L)**	**Web-ICE Predicted (mg/L)**	**Confidence Interval (mg/L)**	**Fold Difference**
Bullfrog (*Lithobates catesbeianus*)	Bluegill (*Lepomis macrochirus*)	1020000	351962.71	47028.33 – 2634108.91	2.9[ab]	1020	1085.27	358.55 – 3284.91	1.06
	Daphnid (*Daphnia magna*)		250407.71	42580.36 – 1472604.12	4.07		265.51	41.71 – 1689.91	3.84
	Fathead minnow (*Pimephales promelas*)		530164.94	178236.61 – 1576976.01	1.92		841.35	368.83 – 1919.18	1.21
	Rainbow trout (*Oncorhynchus mykiss*)		3874927.81	1530344.80 – 9811557.16	3.8		8676.1	4670.29 – 16117.78	8.51
African clawed frog (*Xenopus laevis*)	Fathead minnow (*Pimephales promelas*)	377000	317645.95	5245.20 – 19236405.56	1.19[ab]	377	854.79	96.46 – 7574.84	2.27[a]
Mysid (*Americamysis bahia*)	Bluegill (*Lepomis macrochirus*)	24000	101324.58	39595.31 – 259290.08	4.22[b]	24	88.82	61.09 – 129.12	3.7
	Daphnid (*Daphnia magna*)		30882.91	15730.51 – 60630.86	1.29		95.62	67.73 – 134.98	3.98
	Fathead minnow (*Pimephales promelas*)		25492.89	4248.75 – 152959.48	1.06[c]		34.09	14.21 – 81.79	1.42[c]
	Rainbow trout (*Oncorhynchus mykiss*)		381425.97	119491.45 – 1217541.25	15.89[bc]		655.82	412.11 – 1043.64	27.33[c]
Daphnid[e] (*Daphnia magna*)[e]	Bluegill (*Lepomis macrochirus*)	220000[e]	159433.9	88808.47 – 286224.59	1.38[c]	220[e]	256.05	191.88 – 341.67	1.16[c]
	Bullfrog (*Lithobates catesbeianus*)		482481.09	76477.24 – 3043886.00	2.19		1174.46	256.08 – 5386.36	5.34
	Fathead minnow (*Pimephales promelas*)		94631.7	46980.95 – 190612.55	2.32[c]		183.63	115.53 – 291.86	1.2[c]
	Fatmucket (*Lampsilis siliquoidea*)		331623.04	78520.34 – 1400577.72	1.51		111	31.65 – 389.26	1.98
	Mysid (*Americamysis bahia*)		22344.14	12674.03 – 39392.40	9.85		78.04	54.00 – 112.78	2.82
	Rainbow trout (*Oncorhynchus mykiss*)		516125.21	246588.64 – 1080281.84	2.35[c]		1642.27	1213.56 – 2222.43	7.46[c]
	Zebrafish embryo (*Danio rerio*)		87831.04	13398.62 – 575752.58	2.5[c]		55.49	7.49 – 410.87	3.96[ac]
Bluegill (*Lepomis macrochirus*)	Bullfrog (*Lithobates catesbeianus*)	664000	1501135.53	114395.51 – 19698393.38	2.26[ab]	664	601.13	166.16 – 2174.76	1.1
	Daphnid (*Daphnia magna*)		81671.31	52906.69 – 126074.85	8.13		801.26	627.74 – 1022.74	1.21
	Fathead minnow (*Pimephales promelas*)		218193.44	111739.02 – 426067.60	3.04		357.51	244.06 – 523.68	1.86
	Fatmucket (*Lampsilis siliquoidea*)		408413.42	32355.12 – 5155335.38	1.63[ac]		295.92	21.91 – 3996.50	2.24[ac]

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Predicted Species	Surrogate Species	Toxicity Values Potentially Beyond Model Domain				Scaled Toxicity Values			
		Measured SMAV (µg/L)	Web-ICE Predicted (µg/L)	Confidence Interval (µg/L)	Fold Difference	Measured SMAV (mg/L)	Web-ICE Predicted (mg/L)	Confidence Interval (mg/L)	Fold Difference
	Mysid (*Americamysis bahia*)		23663.56	13808.02 – 40553.53	28.06		266.08	195.07 – 362.94	2.5[d]
	Rainbow trout (*Oncorhynchus mykiss*)		3129709.92	2269044.40 – 4316832.32	4.71		4818.01	4250.43 – 5461.39	7.26
	Zebrafish embryo (*Danio rerio*)		271173.18	34573.71 – 2126901.59	2.45[a]		214.38	35.96 – 1278.11	3.1
Rainbow trout (*Oncorhynchus mykiss*)	Bluegill (*Lepomis macrochirus*)	4001000	353682.57	274243.78 – 456131.98	11.31	4,001	524.72	466.57 – 590.13	7.63
	Bullfrog (*Lithobates catesbeianus*)		781571.06	313951.07 – 1945695.88	5.12		376.93	177.31 – 801.30	10.61
	Daphnid (*Daphnia magna*)		56931.33	35836.37 – 90443.76	70.28[c]		630.92	485.50 – 819.91	6.34[cd]
	Fathead minnow (*Pimephales promelas*)		206200.6	127654.61 – 333075.99	19.4		255.44	192.66 – 338.66	15.66
	Fatmucket (*Lampsilis siliquoidea*)		736514.01	14043.59 – 38626348.23	5.43[abc]		201.6	39.91 – 1018.32	19.85[c]
	Mysid (*Americamysis bahia*)		17330.67	9740.08 – 30836.72	230.86		192.8	137.35 – 270.65	20.75[d]
	Zebrafish embryo (*Danio rerio*)		309598.05	62068.02 – 1544288.83	12.92		91.52	30.44 – 275.13	43.72
Fathead minnow (*Pimephales promelas*)	African clawed frog (*Xenopus laevis*)	593600	524824.76	4876.97 – 56477848.18	1.13[ab]	593.6	257.81	16.14 – 4116.88	2.3[a]
	Bluegill (*Lepomis macrochirus*)		387148.61	201381.26 – 744279.98	1.53		1427.45	1024.71 – 1988.48	2.4
	Bullfrog (*Lithobates catesbeianus*)		1012520.93	299871.50 – 3418793.08	1.71		758.77	320.24 – 1797.81	1.28
	Daphnid (*Daphnia magna*)		111877.81	66019.39 – 189590.43	5.31[c]		1709.52	1209.11 – 2417.01	2.88[cd]
	Fatmucket (*Lampsilis siliquoidea*)		675590	54952.40 – 8305767.53	1.14[ac]		3450.51	576.51 – 20651.62	5.81[c]
	Mysid (*Americamysis bahia*)		34114.93	11148.28 – 104395.31	17.4[c]		635.95	321.17 – 1259.27	1.07[cd]
	Rainbow trout (*Oncorhynchus mykiss*)		3296419.88	1797095.10 – 6046638.29	5.55		8360.63	6502.51 – 10749.71	14.08
	Zebrafish embryo (*Danio rerio*)		400424.37	203694.32 – 787158.28	1.48		724.18	302.07 – 1736.11	1.22
Fatmucket (*Lampsilis siliquoidea*)	Black sandshell (*Ligumia recta*)	164400	153582.08	28669.47 – 822737.61	1.07	164.4	109.67	9.40 – 1278.86	1.5[a]
	Bluegill (*Lepomis macrochirus*)		97837.12	12334.24 – 776059.00	1.68[ac]		733.53	111.00 – 4847.23	4.46[c]
	Daphnid (*Daphnia magna*)		69944.45	23967.21 – 204121.63	2.35		406.14	160.97 – 1024.70	2.47
	Fathead minnow (*Pimephales promelas*)		23355.28	2752.96 – 198138.64	7.04[ac]		104.49	11.80 – 925.23	1.57[ac]

Predicted Species	Surrogate Species	Toxicity Values Potentially Beyond Model Domain				Scaled Toxicity Values			
		Measured SMAV (µg/L)	Web-ICE Predicted (µg/L)	Confidence Interval (µg/L)	Fold Difference	Measured SMAV (mg/L)	Web-ICE Predicted (mg/L)	Confidence Interval (mg/L)	Fold Difference
	Rainbow trout (*Oncorhynchus mykiss*)		41091.9	3178.59 – 531223.75	4[abc]		1143.35	381.34 – 3428.01	6.95[cd]
Black sandshell (*Ligumia recta*)	Fatmucket (*Lampsilis siliquoidea*)	161000	171536.98	34311.02 – 857594.23	1.07	161	237.72	25.46 – 2219.07	1.48[a]

[a] Confidence interval >1.5 order magnitude.

[b] Input data outside model range.

[c] Guidance for model mean square error, R^2, and/or slope not met.

[d] Does not meet slope criteria for using scaled toxicity (0.66-1.33).

[e] *D.magna* species mean acute value used in Appendix L is 220.0 mg/L, which differs slightly from the *D. magna* species mean acute value reported in Appendix A.1 (i.e., 213.9 mg/L). This discrepancy was the result of including late-breaking data ahead for the release of the 2024 Final PFOA Aquatic Life Criteria document. The discrepancy in the *D. magna* SMAV used here vs. Appendix A.1 has no influence on the 2024 PFOA acute estuarine/marine benchmark (7.0 mg/L) because the four most sensitive genera used to derive the PFOA acute estuarine/marine are based entirely on empirical, laboratory-based toxicity data.

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These comparisons are consistent with web-ICE user guidance, previously published reports on ICE model accuracy (Raimondo et al. 2010; Willming et al. 2016), and the above described uncertainty analysis of using scaled toxicity as model input. ICE models predict with acceptable accuracy for PFOA when invertebrates were used to predict to invertebrate species and vertebrates were used to predict to vertebrate species in these comparisons. Models validated across a wide range of species, chemicals, and toxicity values show an acceptable level of prediction accuracy (>90% values predicted within five-fold of measured value) when adhering to the model guidance listed in Box 1 (Raimondo et al. 2010; Willming et al. 2016). The results summarized in Sections L.1 and L.2 demonstrate that the relationship of inherent sensitivity is preserved across taxa, chemicals, and range of toxicity values when using robust ICE models. While the current analysis uses freshwater species to predict to estuarine/marine species, previous model validation and uncertainty analyses did not indicate the habitat of the species to be an influential source of ICE model uncertainty (Raimondo et al. 2010; Willming et al. 2016).

L.4 Prediction of Estuarine/Marine Species Sensitivity to PFOA

A value of PFOA sensitivity was predicted with web-ICE v3.3 for all possible species using all available surrogate species (Table L-1). Predicted values were obtained by entering all available surrogate species into the web-ICE SSD generator, which predicts to all possible species from all available surrogates simultaneously and exports results into an excel spreadsheet. Web-ICE results were generated using both mg/L and µg/L values to evaluate the full set of possible predictions using both units of measure against the model domain, confidence intervals, and model parameters. First, all available models were evaluated based on the parameter (MSE, R^2, slope) guidance in Box 1, which are the same for an ICE species pair regardless of input value (Table L-3). Models that did not meet the parameter criteria in Box 1

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were rejected in this first pass. In the next step, values that were predicted using µg/L were evaluated against the model domain and selected for the next tier of evaluation when the surrogate value was within the range of data used to develop the model. If the surrogate value reported as µg/L was beyond the model domain, the mg/L value was evaluated if it was within the model domain and if the model slope was between 0.66-1.33 (Raimondo et al. 2024). Cases in which both units were outside the model domain were not included quantitatively, but the value with the narrowest confidence intervals was included for qualitative considerations. Values (using either µg/L or mg/L input value) were excluded quantitatively from the SMAVs but retained for qualitative consideration if an evaluation of confidence intervals, model parameters, and the model domain indicated the relationship between surrogate and predicted species was not informed by robust underlying data. At this stage, specific predictions should be based on holistic evaluation of all available information provided by the model, confidence interval, and data used to develop the model. Decisions to exclude a prediction from the SMAV are clarified in footnotes. Because the sensitivity of a single species can be predicted by multiple surrogates, we calculated the SMAV where multiple robust models were available for a predicted species. Each predicted species was then assigned to the appropriate saltwater MDRs as defined in the 1985 Guidelines:

a) Family in the phylum Chordata
b) Family in the phylum Chordata
c) Either the Mysidae or Penaeidae family
d) Family in a phylum other than Arthropoda or Chordata
e) Family in a phylum other than Chordata
f) Family in a phylum other than Chordata
g) Family in a phylum other than Chordata
h) Any other family

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The acute sensitivity of estuarine/marine species to PFOA is presented in Table L-4. A total of 48 models representing 21 estuarine/marine species were available in Web-ICE to predict the toxicity of PFOA to saltwater species (Table L-4). Of these, 14 models were initially rejected based on model parameters not meeting the guidance in Box 1, reducing the number of predicted species to 19 represented by 34 models. Further evaluation of ICE predictions resulted in 13 SMAVs representing crustaceans, molluscs, and fish and demonstrated the potential to meet the saltwater MDRs. The range of sensitivity for the predicted taxa is consistent with the range of sensitivity of freshwater species for this compound.

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Table L-3. All ICE Models Available in Web-ICE v3.3 for Saltwater Predicted Species Based on Surrogates with Measured PFOA.

Model parameters are used to evaluate prediction robustness. Cross-validation success is the percentage of all model data that were predicted within 5-fold of the measured value through leave-one-out cross-validation (Willming et al. 2016). Taxonomic distance describes the relationship between surrogate and predicted species (e.g., 1 = shared genus, 2 = shared family, 3 = shared order, 4 = shared class, 5 = shared phylum, 6 = shared kingdom).

Predicted Species	Surrogate Species	Slope	Intercept	Degrees of Freedom (N-2)	R^2	p-value	Mean Square Error (MSE)	Surrogate Model Minimum Value (µg/L)	Surrogate Model Maximum Value (µg/L)	Cross-validation Success (%)	Taxonomic Distance	Use in Criteria
Acartia tonsa	*Daphnia magna*	0.59	1.31	2	0.91	0.0443	0.17	2.24	38514.7	50	5	Rejected
Allorchestes compressa	*Daphnia magna*	0.83	1.59	3	0.8	0.039	0.12	5	184.54	100	5	Accepted qualitatively
Allorchestes compressa	*Pimephales promelas*	0.84	0.15	3	0.96	0.0028	0.02	163.05	26895.72	100	6	Accepted
Americamysis bahia	*Daphnia magna*	0.83	0.02	160	0.68	0	0.93	0.07	840000	64	5	Accepted
Americamysis bahia	*Lepomis macrochirus*	1.01	-0.92	138	0.66	0	0.95	0.13	290000	59	6	Accepted
Americamysis bahia	*Oncorhynchus mykiss*	0.92	-0.5	150	0.6	0	1.08	0.06	1100000	57	6	Rejected
Americamysis bahia	*Pimephales promelas*	0.95	-1.12	46	0.55	0	1.75	2.27	70200000	35	6	Rejected
Chelon labrosus	*Lampsilis siliquoidea*	1.27	1.5	1	0.99	0.0403	0	19.01	281	na	6	Accepted
Chelon macrolepis	*Pimephales promelas*	1.51	-1.04	2	0.97	0.0114	0.05	26	2533.38	100	4	Accepted qualitatively
Crassostrea virginica	*Americamysis bahia*	0.44	1.76	114	0.34	0	0.88	0.003	117648.2	55	6	Rejected
Crassostrea virginica	*Daphnia magna*	0.44	1.54	116	0.28	0	1.08	0.08	137171.43	58	6	Rejected
Crassostrea virginica	*Lampsilis siliquoidea*	0.82	-0.28	3	0.95	0.0041	0.06	30	22000	100	4	Accepted
Crassostrea virginica	*Lepomis macrochirus*	0.66	0.71	112	0.51	0	0.64	0.36	290000	69	6	Rejected
Crassostrea virginica	*Oncorhynchus mykiss*	0.59	0.97	120	0.5	0	0.68	0.02	570000	68	6	Rejected
Crassostrea virginica	*Pimephales promelas*	0.75	0.44	24	0.61	0	0.68	1.24	206300.75	69	6	Accepted
Cyprinodon bovinus	*Lepomis macrochirus*	0.66	0.7	1	0.99	0.0326	0	7.43	7326.2	na	4	Accepted
Cyprinodon bovinus	*Oncorhynchus mykiss*	0.72	0.8	2	0.91	0.0427	0.08	4.93	1637.92	100	4	Accepted qualitatively
Cyprinodon bovinus	*Pimephales promelas*	0.67	0.65	2	0.99	0.0043	0	10.49	7847.42	100	4	Accepted
Cyprinodon variegatus	*Americamysis bahia*	0.57	1.88	88	0.56	0	0.67	0.0025	182000	64	6	Rejected
Cyprinodon variegatus	*Daphnia magna*	0.53	1.79	84	0.49	0	0.72	0.08	304000	64	6	Rejected
Cyprinodon variegatus	*Lampsilis siliquoidea*	0.72	0.76	1	0.99	0.0392	0	30	22000	na	6	Accepted
Cyprinodon variegatus	*Lepomis macrochirus*	0.74	0.87	82	0.65	0	0.47	0.77	157000	82	4	Accepted
Cyprinodon variegatus	*Oncorhynchus mykiss*	0.75	0.9	87	0.65	0	0.56	0.82	12700000	75	4	Accepted
Cyprinodon variegatus	*Pimephales promelas*	0.69	0.98	24	0.74	0	0.43	2.27	16500000	77	4	Accepted
Farfantepenaeus duorarum	*Americamysis bahia*	1.03	0.06	6	0.81	0.0022	0.55	0.01	720	50	4	Accepted
Farfantepenaeus duorarum	*Daphnia magna*	1.08	0.14	16	0.76	0	1.32	0.04	65686.02	44	5	Rejected
Farfantepenaeus duorarum	*Lepomis macrochirus*	1.16	-1.21	15	0.67	0	1.88	2.32	130000	35	6	Rejected

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Predicted Species	Surrogate Species	Slope	Intercept	Degrees of Freedom (N-2)	R^2	p-value	Mean Square Error (MSE)	Surrogate Model Minimum Value (µg/L)	Surrogate Model Maximum Value (µg/L)	Cross-validation Success (%)	Taxonomic Distance	Use in Criteria
Farfantepenaeus duorarum	*Oncorhynchus mykiss*	1.2	-1.36	15	0.72	0	1.54	0.57	221000	47	6	Rejected
Fenneropenaeus merguiensis	*Daphnia magna*	0.82	1.43	4	0.66	0.0473	0.4	5	1251.41	67	5	Accepted
Gasterosteus aculeatus	*Lepomis macrochirus*	1.15	0	3	0.95	0.0039	0.09	0.36	340	80	4	Accepted qualitatively
Gasterosteus aculeatus	*Oncorhynchus mykiss*	1.05	0.29	4	0.9	0.0038	0.18	0.61	890	83	4	Accepted qualitatively
Hydroides elegans	*Daphnia magna*	0.49	1.59	2	0.96	0.0182	0.01	5	1251.41	100	6	Rejected
Hydroides elegans	*Oncorhynchus mykiss*	0.2	2.3	1	0.99	0.0179	0	1.84	13390.93	na	6	Rejected
Lagodon rhomboides	*Lepomis macrochirus*	1.61	-2.02	1	0.99	0.0301	0	110	760	na	3	Accepted qualitatively
Litopenaeus stylirostris	*Americamysis bahia*	1.04	0.01	5	0.6	0.0401	0.29	0.58	24.09	57	4	Accepted qualitatively
Menidia beryllina	*Lepomis macrochirus*	0.79	0.9	5	0.89	0.0012	0.19	12.3	93800	86	4	Accepted
Menidia menidia	*Lepomis macrochirus*	1.05	-0.35	4	0.96	0.0005	0.14	2.85	97000	83	4	Accepted
Menidia menidia	*Oncorhynchus mykiss*	1.28	-1.4	3	0.94	0.005	0.23	11.24	91000	60	4	Accepted
Menidia peninsulae	*Americamysis bahia*	0.63	0.91	3	0.88	0.0162	0.32	0.01	1160	80	6	Accepted qualitatively
Menidia peninsulae	*Lepomis macrochirus*	0.9	-0.1	3	0.97	0.0012	0.06	0.77	2480	100	4	Accepted
Menidia peninsulae	*Oncorhynchus mykiss*	1.01	-0.36	2	0.91	0.0421	0.35	0.82	1600	50	4	Accepted qualitatively
Metamysidopsis insularis	*Daphnia magna*	0.86	0.93	3	0.94	0.0057	0.18	6.97	317472.74	80	5	Accepted
Metamysidopsis insularis	*Lampsilis siliquoidea*	1.03	0.62	2	0.99	0.0027	0.02	19.01	87705.88	75	6	Accepted
Mugil cephalus	*Lepomis macrochirus*	1.06	-0.15	3	0.92	0.0093	0.09	0.77	118.76	100	4	Accepted qualitatively
Mugil cephalus	*Oncorhynchus mykiss*	1.44	-0.37	3	0.89	0.0144	0.12	0.82	29.18	100	4	Accepted qualitatively
Tigriopus japonicus	*Lepomis macrochirus*	0.6	1.73	3	0.92	0.0095	0.1	1.2	11202.42	80	6	Accepted qualitatively
Tigriopus japonicus	*Pimephales promelas*	0.81	1.12	5	0.76	0.0103	0.11	195.14	27000	86	6	Accepted
Tisbe battagliai	*Daphnia magna*	0.86	1.25	2	0.94	0.0289	0.08	0.61	184.54	100	5	Accepted qualitatively

NA = Not Available

Table L-4. ICE-estimated Species Sensitivity to PFOA.

Values in bold and underlined are used for SMAV.

Common Name	Predicted Species	Surrogate Species	Input Unit	Estimated Toxicity (mg/L)	95% Confidence Intervals (mg/L)	SMAV
Calanoid copepod	*Acartia tonsa*	*Daphnia magna*	µg/L	30.97[abc]	(0.84 – 1138.99)	NA
Amphipod	*Allorchestes compressa*	*Daphnia magna*	mg/L	3608.27[b]	(604.53 – 21536.48)	306.14
		Pimephales promelas	mg/L	**<u>306.14</u>**	(167.3 – 560.19)	
Mysid	*Americamysis bahia*	*Daphnia magna*	µg/L	**<u>30.88</u>**	(15.73 – 60.63)	52.37
		Lepomis macrochirus	mg/L	**<u>88.82</u>**	(61.09 – 129.12)	
		Oncorhynchus mykiss	µg/L	381.43[bc]	(119.49 – 1217.54)	
		Pimephales promelas	µg/L	25.49[c]	(4.25 – 152.96)	
Thicklip mullet	*Chelon labrosus*	*Lampsilis siliquoidea*	mg/L	**<u>21448.8</u>**	(5726.99 – 80330.23)	21448.8
Bigscale mullet	*Chelon macrolepis*	*Pimephales promelas*	mg/L	1475.56[d]	(400.78 – 5432.58)	NA
Eastern oyster	*Crassostrea virginica*	*Americamysis bahia*	µg/L	5.08[c]	(2.55 – 10.1)	111.23
		Daphnia magna	µg/L	8.16[bc]	(3.27 – 20.37)	
		Lampsilis siliquoidea	mg/L	**<u>34.96</u>**	(13.16 – 92.9)	
		Lepomis macrochirus	µg/L	37.78[bc]	(15.7 – 90.87)	
		Oncorhynchus mykiss	µg/L	86.67[bc]	(31.82 – 236.06)	
		Pimephales promelas	mg/L	**<u>353.9</u>**	(161.95 – 773.33)	
Leon springs pupfish	*Cyprinodon bovinus*	*Lepomis macrochirus*	mg/L	**<u>385.84</u>**	(100.03 – 1488.19)	363.56
		Oncorhynchus mykiss	mg/L	2637.1[ab]	(135.14 – 51456.4)	
		Pimephales promelas	mg/L	**<u>342.56</u>**	(204.07 – 575.01)	
Sheepshead minnow	*Cyprinodon variegatus*	*Americamysis bahia*	µg/L	24.42[c]	(12.11 – 49.24)	377.3
		Daphnia magna	µg/L	43.97[c]	(18.29 – 105.67)	
		Lampsilis siliquoidea	mg/L	**<u>236.12</u>**	(42.61 – 1308.27)	
		Lepomis macrochirus	mg/L	**<u>975.2</u>**	(695.11 – 1368.14)	
		Oncorhynchus mykiss	µg/L	**<u>834.95</u>**	(288.9 – 2413.1)	
		Pimephales promelas	µg/L	**<u>105.41</u>**	(29.42 – 377.63)	
Pink shrimp	*Farfantepenaeus duorarum*	*Americamysis bahia*	mg/L	**<u>31.16</u>**	(5.31 – 182.77)	31.16
		Daphnia magna	µg/L	825.2[abc]	(47.76 – 14258.5)	
		Lepomis macrochirus	µg/L	350.34[abc]	(11.8 – 10398.14)	
		Oncorhynchus mykiss	µg/L	4187.17[abc]	(97.76 – 179343.3)	
Banana prawn	*Fenneropenaeus merguiensis*	*Daphnia magna*	mg/L	**<u>2395.84</u>**	(373.14 – 15382.93)	2395.84
Threespine stickleback	*Gasterosteus aculeatus*	*Lepomis macrochirus*	mg/L	1867.23[ab]	(239.79 – 14539.92)	NA
		Oncorhynchus mykiss	mg/L	12299.55[ab]	(605.28 – 249929.11)	

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Common Name	Predicted Species	Surrogate Species	Input Unit	Estimated Toxicity (mg/L)	95% Confidence Intervals (mg/L)	SMAV
Polychaete	*Hydroides elegans*	*Daphnia magna*	µg/L	17.26[abc]	(1.79 – 166.56)	NA
		Oncorhynchus mykiss	µg/L	4.67[bc]	(2.22 – 9.84)	
Pinfish	*Lagodon rhomboides*	*Lepomis macrochirus*	mg/L	342.29[d]	(121.48 – 964.44)	NA
Blue shrimp	*Litopenaeus stylirostris*	*Americamysis bahia*	mg/L	28.4[a]	(3.76 – 214.22)	NA
Inland silverside	*Menidia beryllina*	*Lepomis macrochirus*	mg/L	**1373.42**	(509.99 – 3698.68)	1373.42
Atlantic silverside	*Menidia menidia*	*Lepomis macrochirus*	mg/L	**419.03**	(151.91 – 1155.88)	859.43
		Oncorhynchus mykiss	mg/L	**1762.7**	(281.3 – 11045.23)	
Tidewater silverside	*Menidia peninsulae*	*Americamysis bahia*	mg/L	61.53[ad]	(8.51 – 444.5)	279.81
		Lepomis macrochirus	mg/L	**279.81**	(97.91 – 799.61)	
		Oncorhynchus mykiss	mg/L	1974.29[ab]	(15.61 – 249609.1)	
Mysid	*Metamysidopsis insularis*	*Daphnia magna*	mg/L	**894.87**	(209.96 – 3814.04)	853.17
		Lampsilis siliquoidea	mg/L	**813.42**	(361.18 – 1831.9)	
Striped mullet	*Mugil cephalus*	*Lepomis macrochirus*	mg/L	730.34[ab]	(36.69 – 14537.49)	NA
		Oncorhynchus mykiss	mg/L	65159.7[abd]	(132.99 – 31925133.65)	
Harpacticoid copepod	*Tigriopus japonicus*	*Lepomis macrochirus*	mg/L	2812.24[d]	(976.85 – 8096.09)	2432.2
		Pimephales promelas	mg/L	**2432.2**	(825.63 – 7164.93)	
Harpacticoid copepod	*Tisbe battagliai*	*Daphnia magna*	mg/L	1923.22[ab]	(204.62 – 18075.62)	NA

NA = Not Available

[a] Both confidence intervals >1.5 order magnitude

[b] Input data outside model range

[c] Guidance for model mean square error, R^2, and/or slope not met

[d] Does not meet slope criteria for using scaled toxicity (0.66-1.33)

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L.5 Derivation of Acute Water Benchmark for Estuarine/Marine Water

The Web-ICE predicted acute data set for PFOA contains 10 genera representing the eight MDR groups that would be necessary for developing an estuarine/marine criterion. However, the EPA supplemented this dataset with acceptable quantitative study data (discussed in Section 3.1.1.2). In scenarios where both empirical LC_{50} values and estimated LC_{50} values were available for the same species, only the empirical data were used to derive the species mean acute value. The ranked GMAVs for these combined data along with the MDR met by each GMAV is summarized in Table L-5. From this dataset, an acute benchmark was calculated using procedures consistent with the 1985 Guidelines and with those used for the derivation of freshwater criterion values for PFOA. GMAVs for the four most sensitive genera were within a factor of 1.5 of each other (Table L-5). The estuarine/marine FAV (the 5^{th} percentile of the genus sensitivity distribution) for PFOA is 14.07 mg/L (Table L-6). The FAV was lower than all of the GMAVs for both the tested species and for values derived using Web-ICE. The FAV is then divided by two to obtain a concentration yielding a minimal effects acute effect value. Based on the above, the FAV/2, which is the estuarine/marine acute water column benchmark magnitude, is 7.0 mg/L PFOA (rounded to two significant figures) and is expected to be protective of 95% of saltwater genera potentially exposed to PFOA under short-term conditions of one-hour of duration, if the one-hour average magnitude is not exceeded more than once in three years (Figure L-2).

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Table L-5. Ranked Estuarine/Marine Genus Mean Acute Values.

Values in bold are derived from empirical PFOA toxicity tests with the species.

MDR Group[1]	Common Name	Species	SMAV (mg/L)	GMAV (mg/L)	Rank	Percentile
C	**Mysid**	***Siriella armata***	**15.5**	**15.5**	1	0.07
D	**Mediterranean mussel**	***Mytilus galloprovincialis***	**17.6**	**17.6**	2	0.14
F	**Purple sea urchin**	***Strongylocentrotus purpuratus***	**20.63**	**20.63**	3	0.21
C	**Mysid**	***Americamysis bahia***	**24**	**24**	4	0.29
F	Pink shrimp	*Farfantepenaeus duorarum*	31.16	31.16	5	0.36
D	Eastern oyster	*Crassostrea virginica*	111.2	111.2	6	0.43
E	Amphipod	*Allorchestes compressa*	306.1	306.1	7	0.50
A	Leon springs pupfish	*Cyprinodon bovinus*	363.6	370.4	8	0.57
	Sheepshead minnow	*Cyprinodon variegatus*	377.3			
B	Inland silverside	*Menidia beryllina*	1,373	691.2	9	0.64
	Atlantic silverside	*Menidia menidia*	859.4			
	Tidewater silverside	*Menidia peninsulae*	279.8			
C	Mysid	*Metamysidopsis insularis*	853.2	853.2	10	0.71
G	Harpacticoid copepod	*Tigriopus japonicus*	2,432	2,432	11	0.79
F	Banana prawn	*Fenneropenaeus merguiensis*	2,396	2,396	12	0.86
H	Thicklip mullet	*Chelon labrosus*	21,449	21,449	13	0.93

1: Estuarine/Marine MDR Groups

a) Family in the phylum Chordata
b) Family in the phylum Chordata
c) Either the Mysidae or Penaeidae family
d) Family in a phylum other than Arthropoda or Chordata
e) Family in a phylum other than Chordata
f) Family in a phylum other than Chordata
g) Family in a phylum other than Chordata
h) Any other family

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Table L-6. Estuarine/Marine Final Acute Value and Protective Aquatic Acute Benchmark. Bold values represent genera for which empirical toxicity data were available.

Calculated Estuarine/Marine FAV based on 4 lowest values; n=13						
Rank	**Genus**	**GMAV (mg/L)**	**ln(GMAV)**	**ln(GMAV)^2**	**P=R/(N+1)**	**sqrt(P)**
1	*Siriella*	15.5	2.74	7.51	0.071	0.267
2	*Mytilus*	17.6	2.87	8.22	0.143	0.378
3	*Strongylocentrotus*	20.63	3.03	9.16	0.214	0.463
4	*Americamysis*	24	3.18	10.10	0.286	0.535
		Σ (Sum):	**11.81**	**35.00**	**0.71**	**1.64**

S^2 =	2.73	S = slope
L =	2.275	L = X-axis intercept
A =	2.644	A = lnFAV
FAV =	14.07	P = cumulative probability
PVAL=	**7.0 mg/L PFOA** (rounded to two significant figures)	

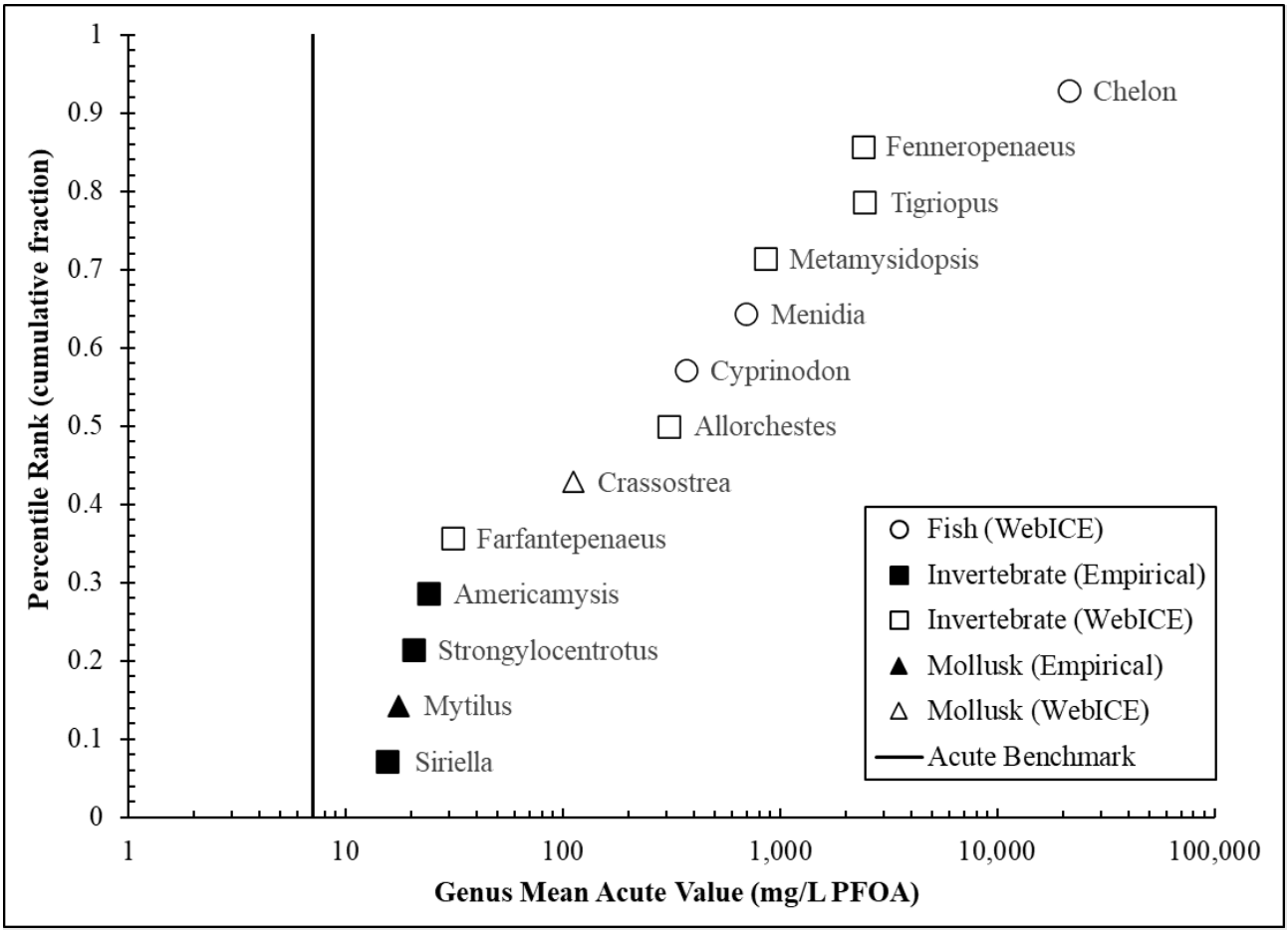


Figure L-2. Ranked Estuarine/Marine Acute PFOA GMAVs Used for the Aquatic Life Acute Benchmark Calculation.

L.5.1 Estuarine Marine/Benchmark Uncertainty

The epistemic uncertainty of individual ICE estimates used for SMAV calculation was quantified through the calculation of corresponding 95% confidence intervals for each ICE estimate. Of the individual models and resultant ICE-estimated LC_{50} values from the available and quantitatively acceptable models (see bolded and underlined values in Table L-4; n =21), the range of individual 95% CIs (i.e., 95% CI range = upper 95% CI – lower 95% CI) as a percent of the corresponding LC_{50} estimate (i.e., = [95% CI range/LC50 estimate]*100) ranged from 69.01% to 626.49%. The ICE model with the lowest 95% CI range relative to the LC_{50} estimate (i.e., 69.01%) employed *Lepomis macrochirus* as the predictor species and *Cyprinodon variegatus* as the predicted species. The ICE model with the largest 95% CI range relative to the LC_{50} estimate (i.e., 626.49%) employed *Daphnia magna* as the predictor species and *Fenneropenaeus merguiensis* as the predicted species. Nineteen of the 21 ICE-predicted values in Table L-4 that were used for SMAV calculation had 95% CI ranges that were greater than the corresponding LC_{50} estimate (i.e., 95% CI range was >100% of the LC_{50} estimate). The relatively wide ranging 95% CIs demonstrate the underlying uncertainty in the PFOA estuarine/marine benchmark.

Four of the 13 GMAVs used to derive the acute PFOA estuarine/marine benchmark were based on empirical toxicity tests. The four GMAVs based on empirical data were also the four most sensitive GMAVs in the GSD (Figure L-2), meaning final estuarine/benchmark magnitude was primarily based on relatively certain empirical toxicity tests and the inherent uncertainty in the ICE models had little influence on the final acute estuarine/marine benchmark magnitude.

The estuarine/marine benchmark appears adequately protective based on the available high quality empirical data (Appendix B.1). The acute PFOA estuarine/marine benchmark (i.e., 7.0) is more than two times lower than the lowest GMAV (i.e., 15.5 mg/L), which was based on

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empirical data for *Siriella*. The EPA further evaluated the appropriateness of the estuarine/marine benchmark by comparing it to empirical, but qualitatively acceptable, data for estuarine/marine species. The EPA specifically focused on qualitatively-acceptable estuarine/marine tests reported in Table H.1 that (1) tested an animal species, (2) exposed test organisms to PFOA for a duration that was reasonably similar to standard acute exposures (e.g., 48 hours to seven days), (3) reported acute apical effects, and (4) reported effect concentrations that were lower than the acute estuarine/marine benchmark final acute value (i.e., 14 mg/L). The EPA identified three individual tests in Table H.1 as meeting the previous criteria:

1. Liu et al. (2013, 2014c) evaluated the chronic effects of PFOA (96% purity, purchased from Sigma-Aldrich) on green mussels, *Perna viridis*, via a seven-day measured, static-renewal study. A NOEC of 0.0114 mg/L and a LOEC of 0.099 mg/L was determined for a decrease in the relative condition factor (RCF). The study was acceptable for qualitative use only because of the atypical test duration, which is too long for an acute test and too short for a chronic test. Additionally, the PFOA test displayed a questionable concentration-response patten where there was no difference between the RCF at the LOEC (i.e., 0.099 mg/L) and the highest test concentration, which contained a PFOA concentration that was more than 10X greater (i.e., 1.120 mg/L). The large magnitude between these two concentrations in combination with the lack of effects to the RCF observed between the LOEC and the highest treatment concentration suggests a true concentration-response relationship was not observed for PFOA in this test.
2. Bernardini et al. (2021) reported the results of a 21-day chronic study with the Manila clam, *Ruditapes philippinarum*. Subsamples of clams (n=20) were also

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collected on test day seven. No significant effects of mortality were observed in the single treatment group throughout the exposure, including at test day seven. The seven-day NOEC, based on mortality, was 0.00093 mg/L PFOA. Although the seven-day NOEC is less than the acute estuarine/marine benchmark, the authors did not report any significant effects to mortality and this study was not useful in understanding the relative protectiveness of the acute PFOA estuarine/marine benchmark.

3. Mhadhbi et al. (2012) conducted a six-day acute test on the turbot, *Scophthalmus maximus* (a non-North American species). Endpoints included dead embryos, malformation, hatch success at 48-hours and larvae survival (missing heartbeat and a non-detached tail) at six days. The reported six-day LC_{50} of 11.9 mg/L PFOA was not used quantitatively because the test duration was longer than the standard 96 hour acute exposure. Nevertheless, this six-day test suggests early life stages of *S. maximus* may be sensitive to acute PFOA exposures. The EPA concluded the acute PFOA estuarine/marine benchmark to be protective on the six-day LC_{50} reported by Mhadhbi et al. (2012) because (1) it was reasonably similar to the most sensitive GMAV used to derive the acute estuarine/marine benchmark (i.e., *Siriella* GMAV = 15.5 mg/L) and (2) the 96-hour LC_{50} that corresponds to the six-day LC_{50} reported by Mhadhbi et al. (2012) was hypothesized to be greater than or equal to the six-day LC_{50} under the premise that acute effect concentrations typically decrease with exposure time (until an incipient lethal concentration is reached).

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4. Gebreab et al. (2022) exposed the marine mahi-mahi fish, *Coryphaena hippurus* to PFOA in a 48-hour static acute test with measured PFOA treatments. Authors stated that the test followed a new embryotoxicity assay for mahi mahi that was adapted from assays previously developed and validated for zebrafish embryotoxicity (Berry et al. 2007; Gebreab et al. 2020; Weiss-Errico et al. 2017). The author-reported 48-hour LC_{50} (i.e., 4 mg/L; 95% C.I. = 2-6 mg/L) was less than the acute estuarine/marine FAV of 14 mg/L. Results of this test were not used quantitatively primarily because there was 20-30% mortality in the negative control at the end of the exposure period. The high control mortality suggests the exposed organisms were stressed in the laboratory setting, which compounded any effects of PFOA and likely produced an artificially low LC_{50} value. Therefore, this qualitatively acceptable test did not provide sufficient evidence to conclude the estuarine/marine benchmark was underprotective of *C. hippurus*.

Overall, results of quantitatively- and qualitatively- acceptable empirical toxicity studies with estuarine/marine organisms do not provide any evidence that the aquatic estuarine/marine community will experience unacceptable chronic effects at the acute estuarine/marine PFOA benchmark.

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L.6 ICE Regressions Supporting the Acute Estuarine/Marine Benchmark

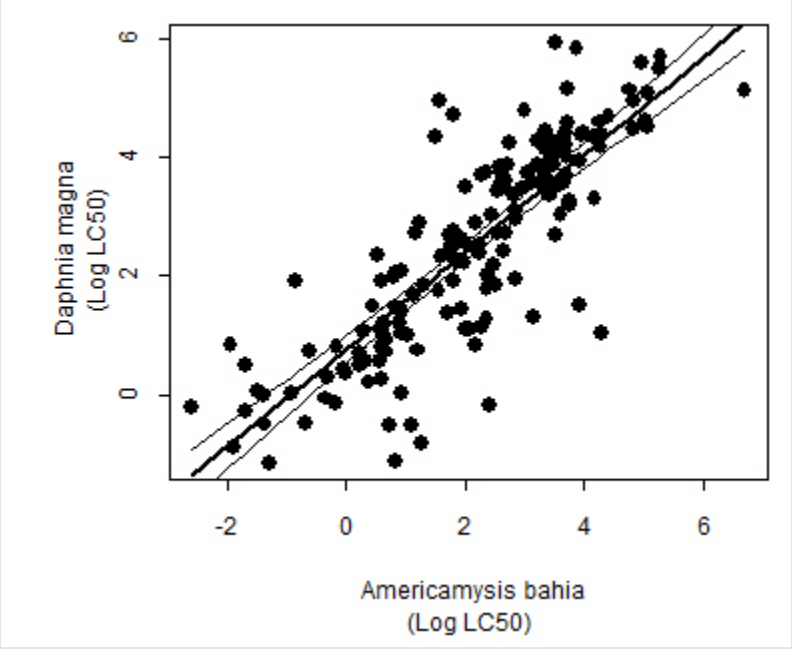


Figure L-3. *Americamysis bahia* (X-axis) and *Daphnia magna* (Y-axis) regression model used for ICE predicted values.

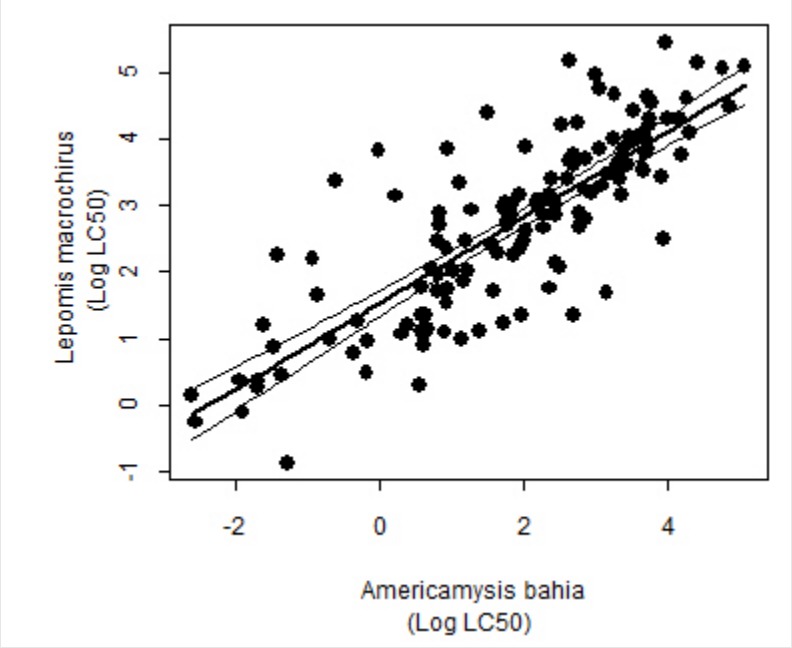


Figure L-4. *Americamysis bahia* (X-axis) and *Lepomis macrochirus* (Y-axis) regression model used for ICE predicted values.

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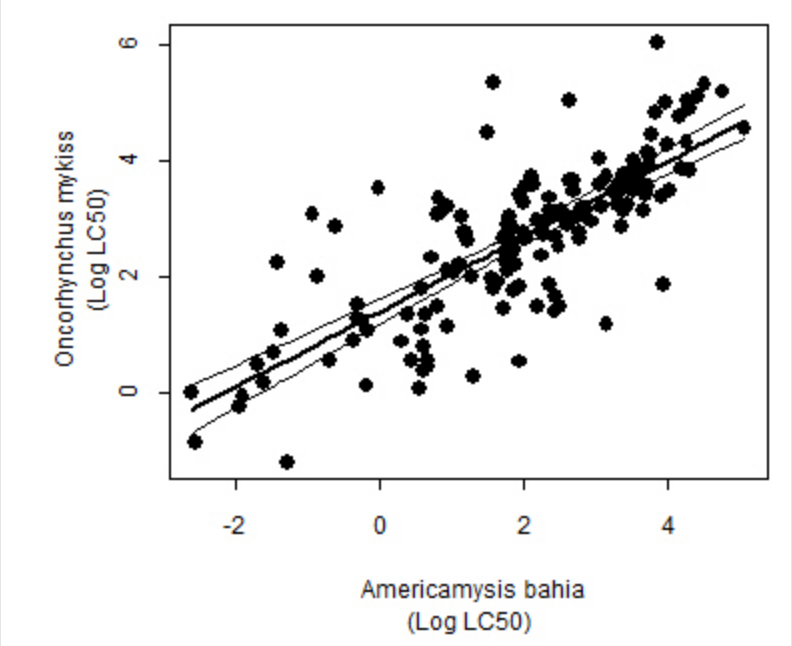


Figure L-5. *Americamysis bahia* (X-axis) and *Oncorhynchus mykiss* (Y-axis) regression model used for ICE predicted values.

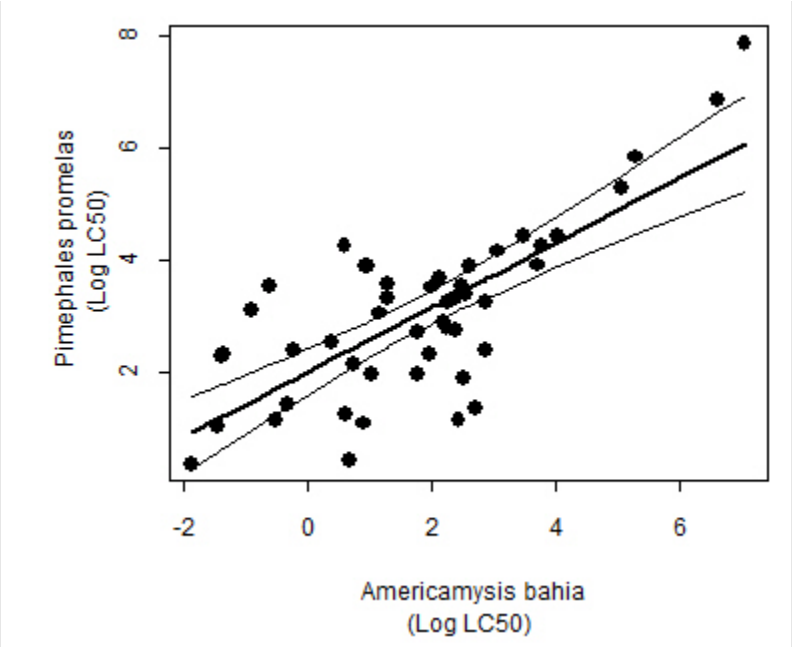


Figure L-6. *Americamysis bahia* (X-axis) and *Pimephales promelas* (Y-axis) regression model used for ICE predicted values.

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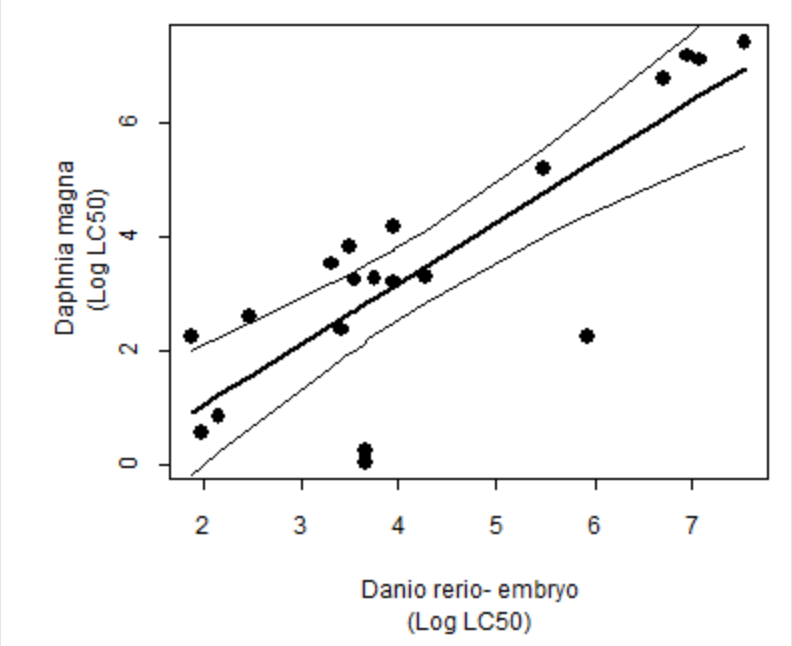


Figure L-7. *Danio rerio* – embryo (X-axis) and *Daphnia magna* (Y-axis) regression model used for ICE predicted values.

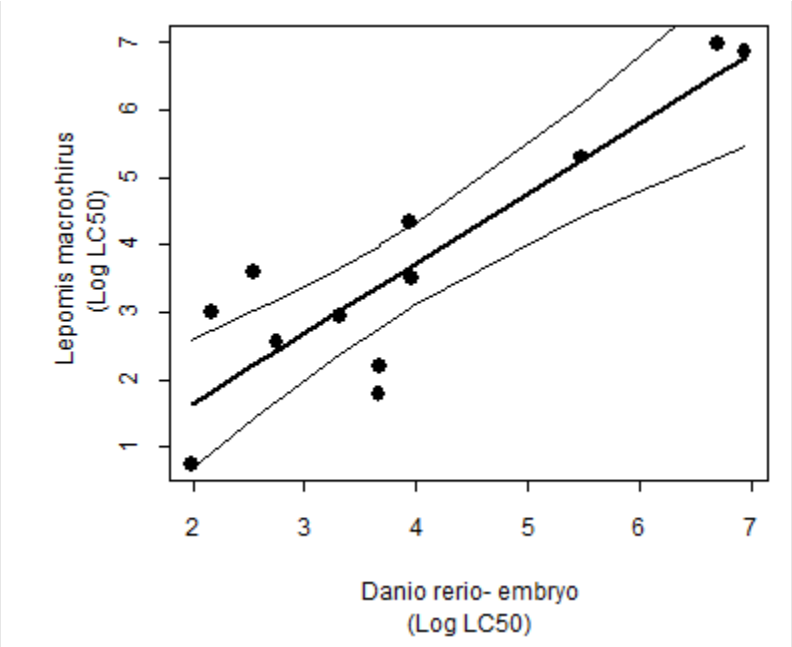


Figure L-8. *Danio rerio* – embryo (X-axis) and *Lepomis macrochirus* (Y-axis) regression model used for ICE predicted values.

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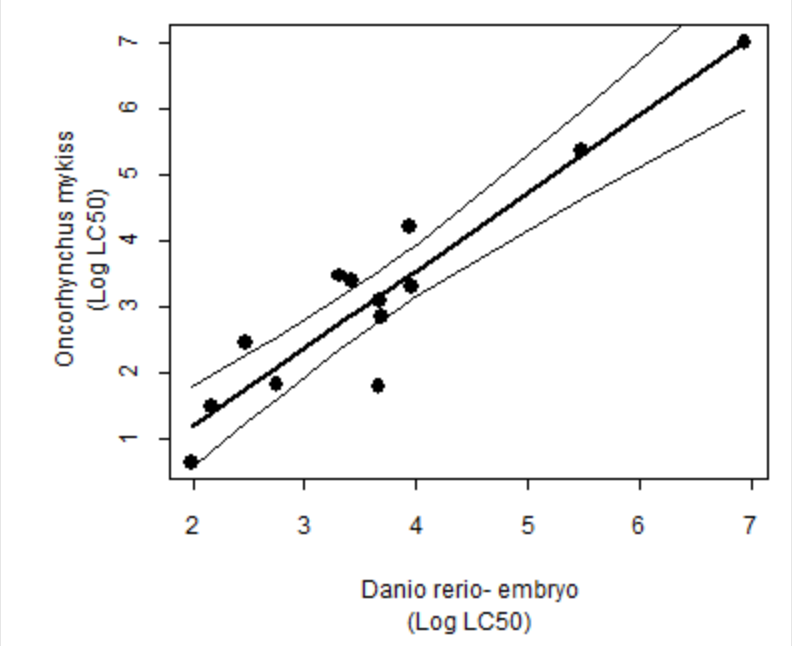


Figure L-9. *Danio rerio* – embryo (X-axis) and *Oncorhynchus mykiss* (Y-axis) regression model used for ICE predicted values.

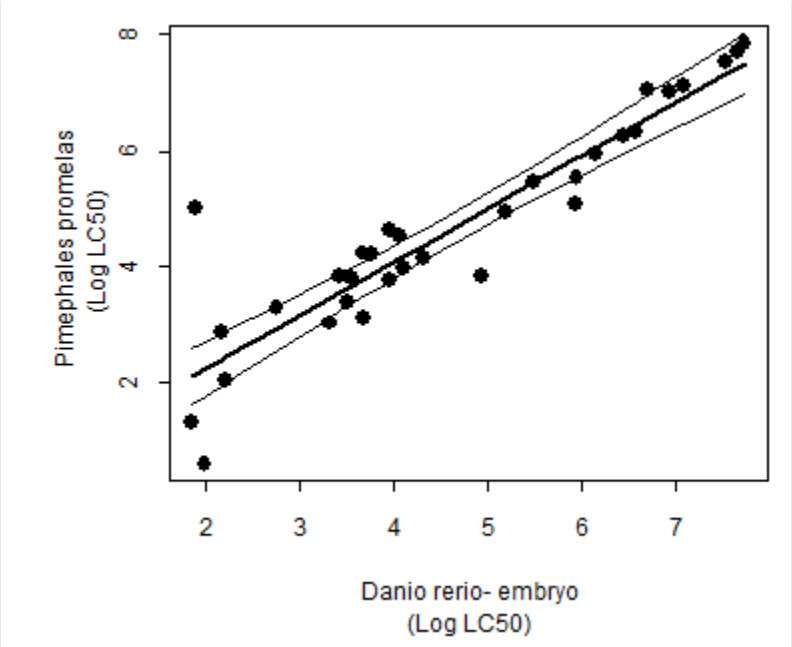


Figure L-10. *Danio rerio* – embryo (X-axis) and *Pimephales promelas* (Y-axis) regression model used for ICE predicted values.

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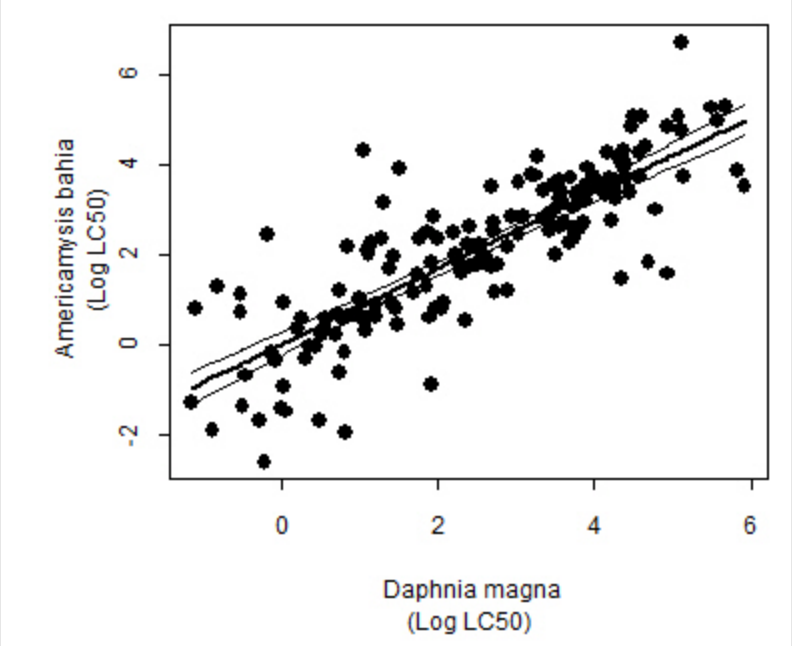


Figure L-11. *Daphnia magna* embryo (X-axis) and *Americamysis bahia* (Y-axis) regression model used for ICE predicted values.

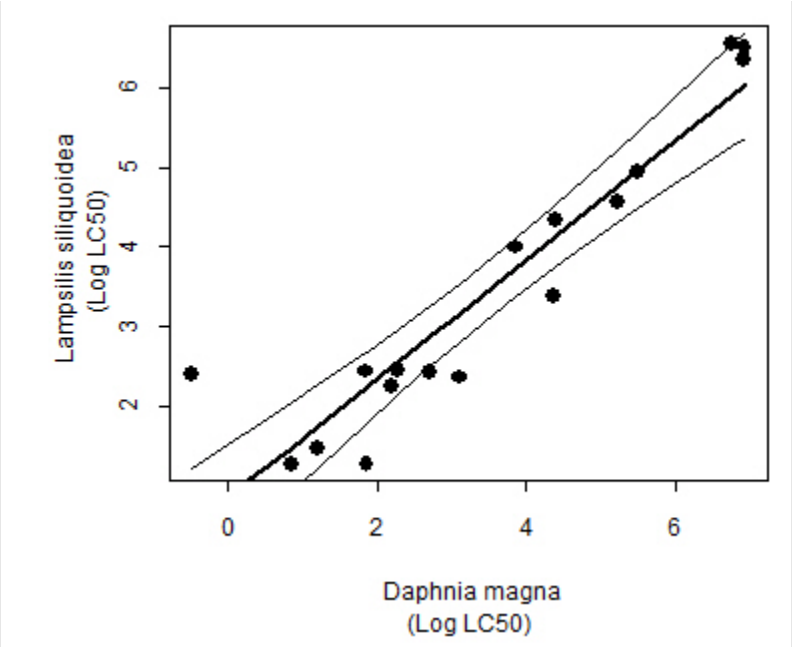


Figure L-12. *Daphnia magna* (X-axis) and *Lampsilis siliquoidea* (Y-axis) regression model used for ICE predicted values.

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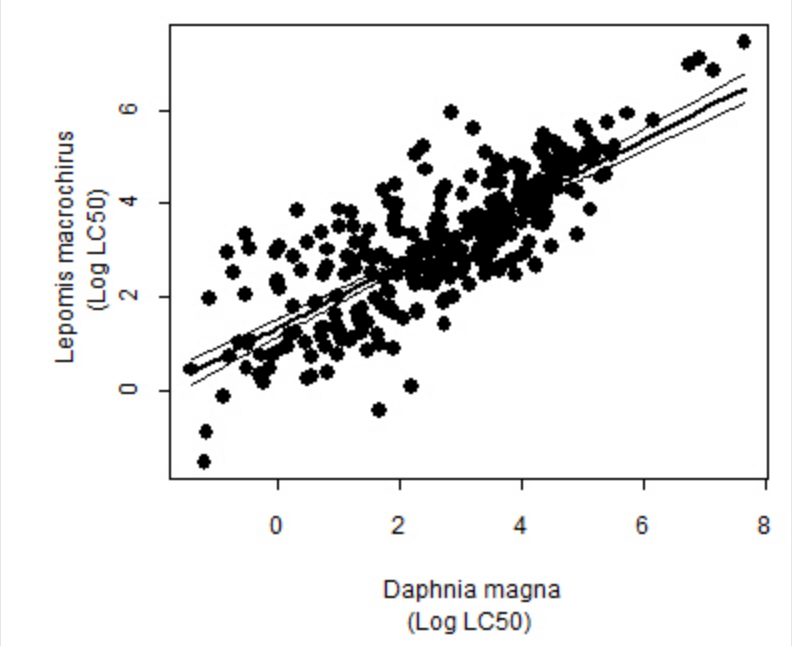


Figure L-13. *Daphnia magna* (X-axis) and *Lepomis macrochirus* (Y-axis) regression model used for ICE predicted values.

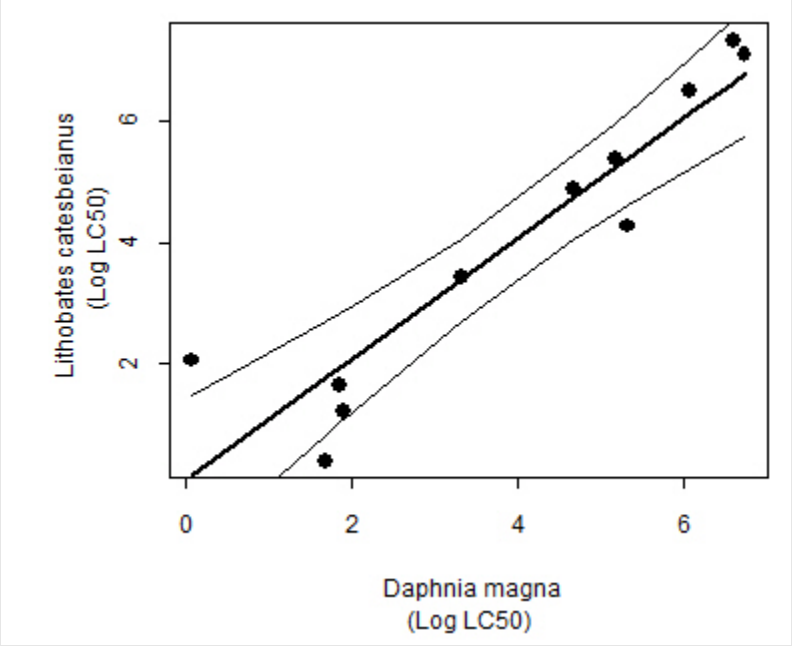


Figure L-14. *Daphnia magna* (X-axis) and *Lithobates catesbeianus* (Y-axis) regression model used for ICE predicted values.

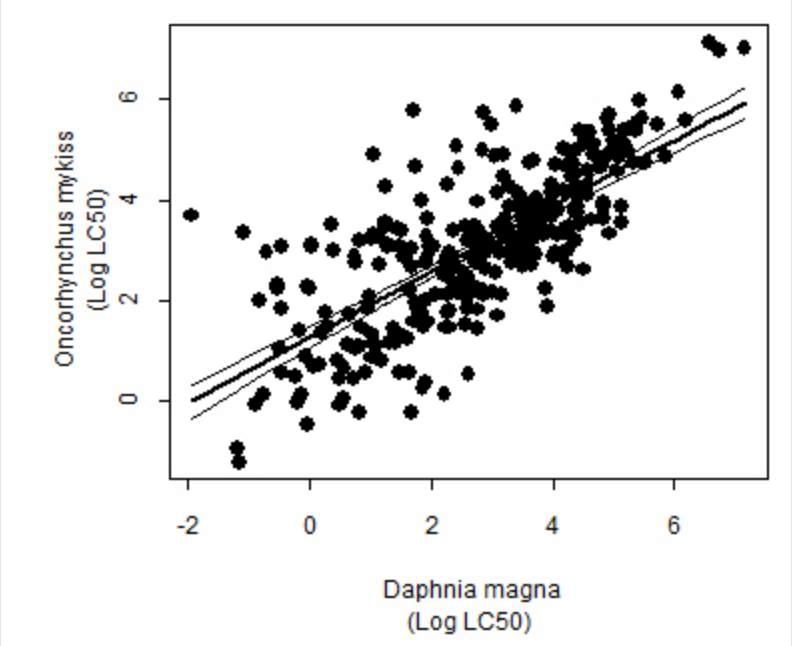


Figure L-15. *Daphnia magna* (X-axis) and *Oncorhynchus mykiss* (Y-axis) regression model used for ICE predicted values.

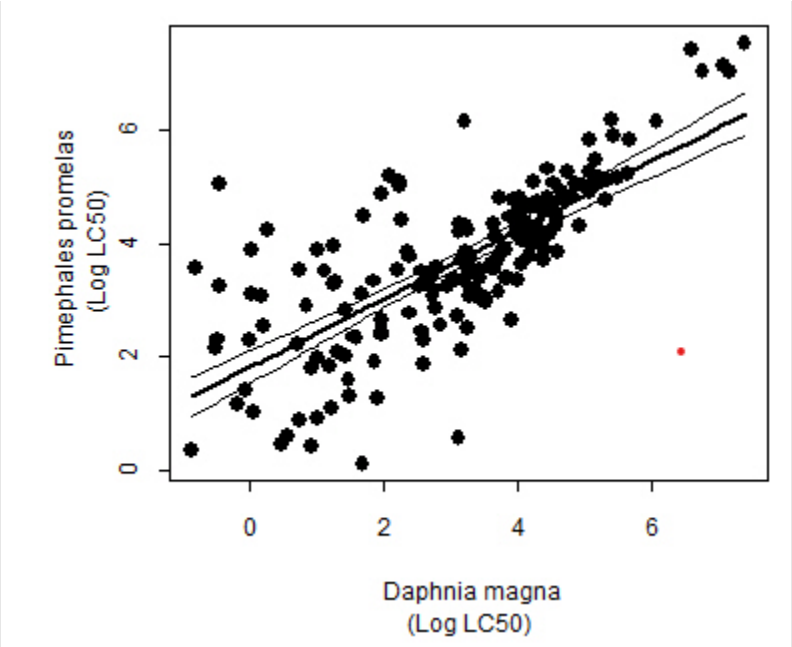


Figure L-16. *Daphnia magna* embryo (X-axis) and *Pimephales promelas* (Y-axis) regression model used for ICE predicted values.

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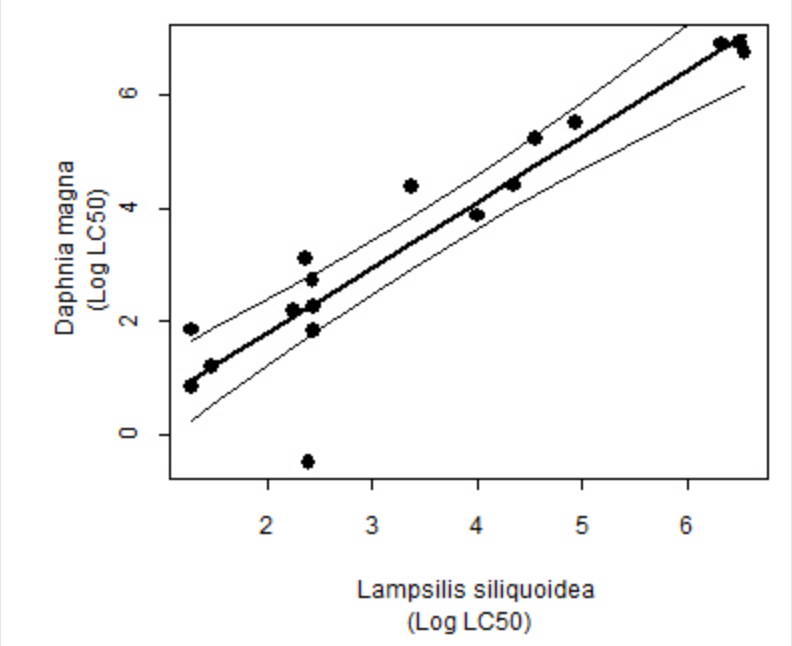


Figure L-17. *Lampsilis siliquoidea* (X-axis) and *Daphnia magna* (Y-axis) regression model used for ICE predicted values.

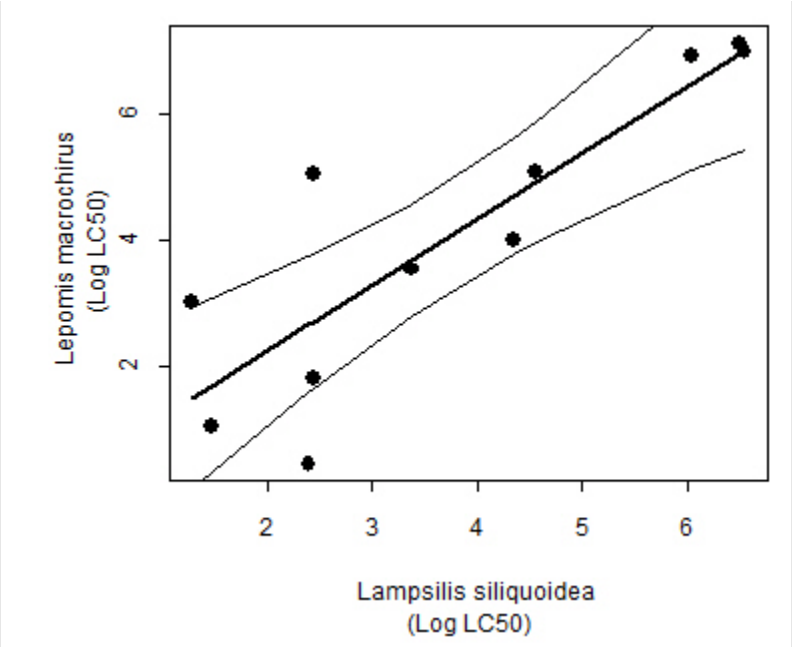


Figure L-18. *Lampsilis siliquoidea* (X-axis) and *Lepomis macrochirus* (Y-axis) regression model used for ICE predicted values.

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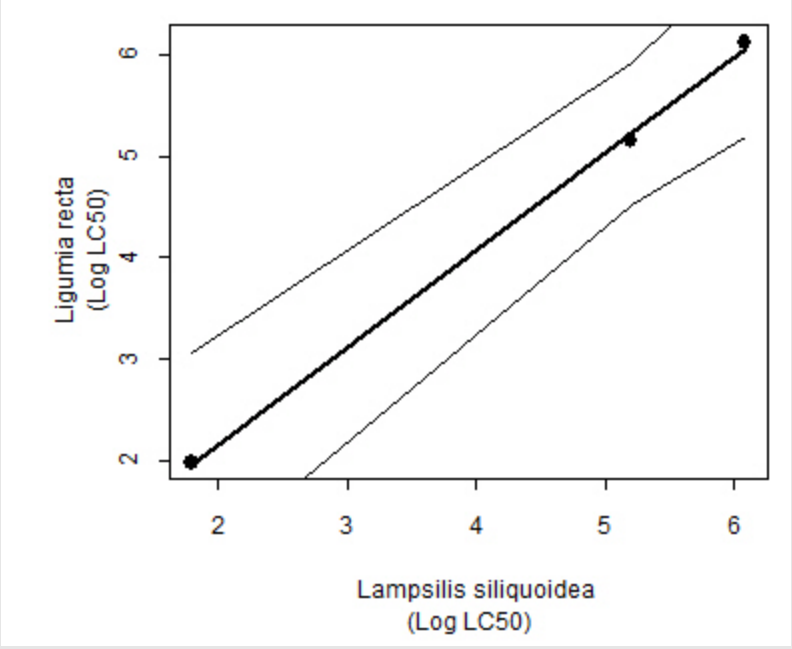


Figure L-19. *Lampsilis siliquoidea* (X-axis) and *Ligumia recta* (Y-axis) regression model used for ICE predicted values.

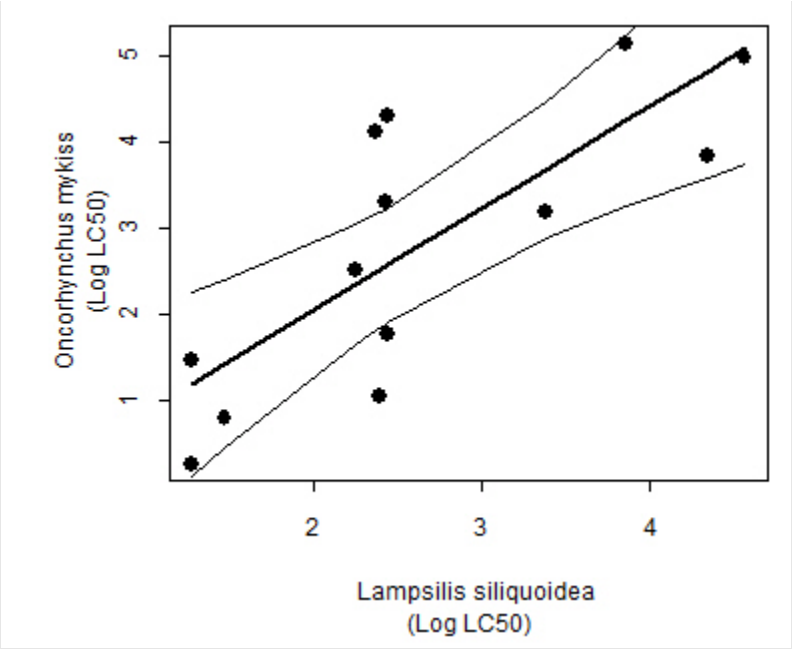


Figure L-20. *Lampsilis siliquoidea* (X-axis) and *Oncorhynchus mykiss* (Y-axis) regression model used for ICE predicted values.

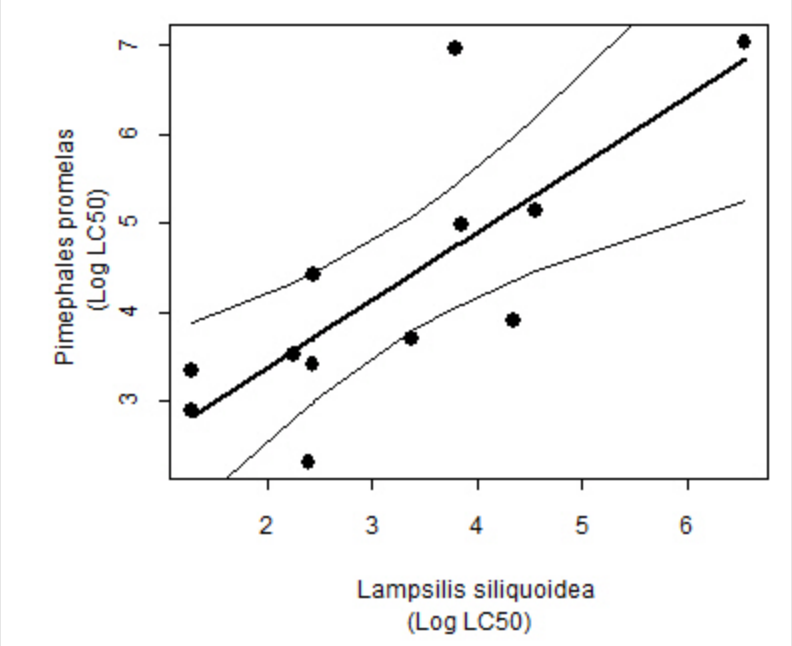


Figure L-21. *Lampsilis siliquoidea* (X-axis) and *Pimephales promelas* (Y-axis) regression model used for ICE predicted values.

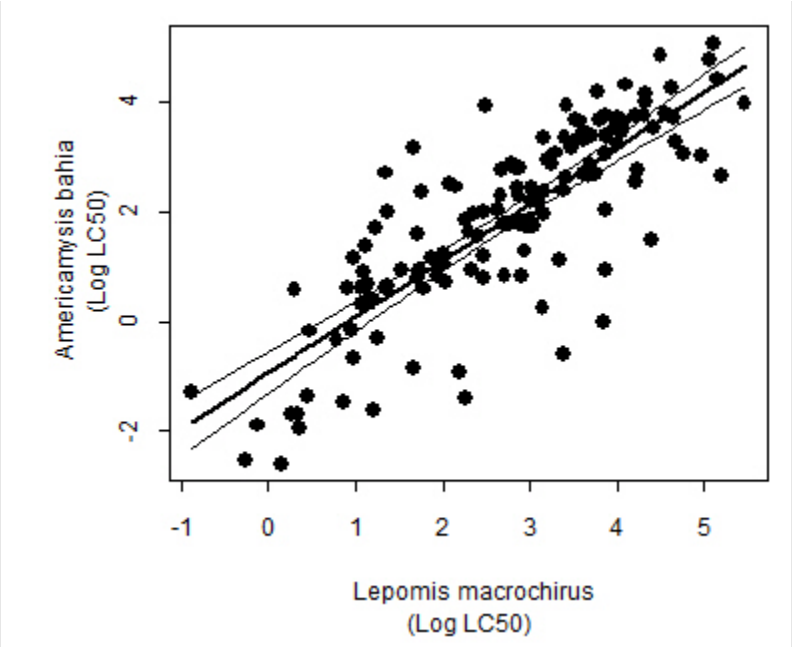


Figure L-22. *Lepomis macrochirus* (X-axis) and *Americamysis bahia* (Y-axis) regression model used for ICE predicted values.

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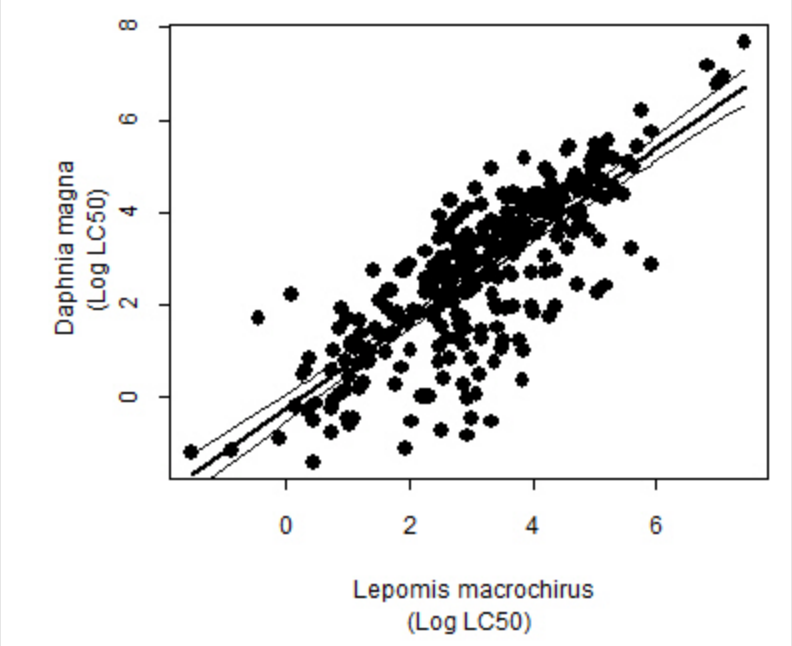


Figure L-23. *Lepomis macrochirus* (X-axis) and *Daphnia magna* (Y-axis) regression model used for ICE predicted values.

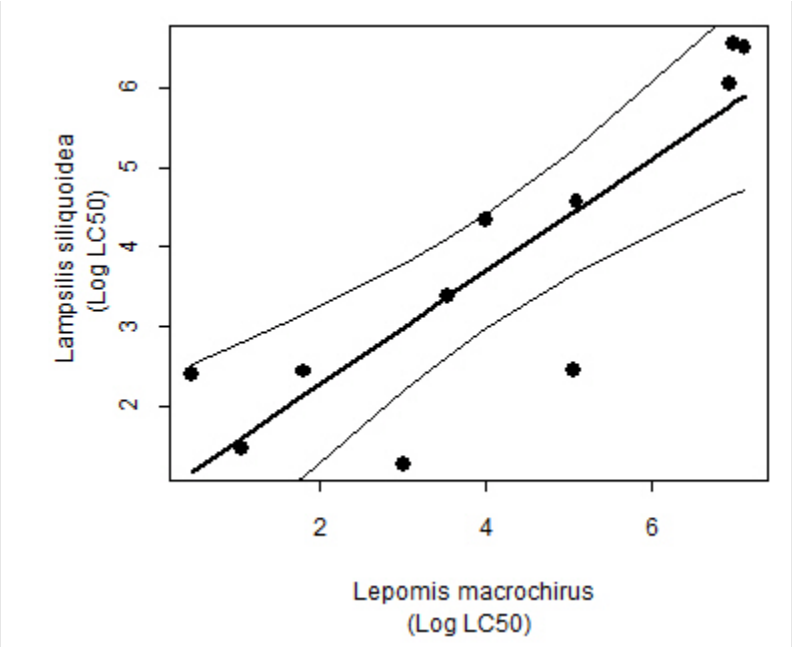


Figure L-24. *Lepomis macrochirus* (X-axis) and *Lampsilis siliquoidea* (Y-axis) regression model used for ICE predicted values.

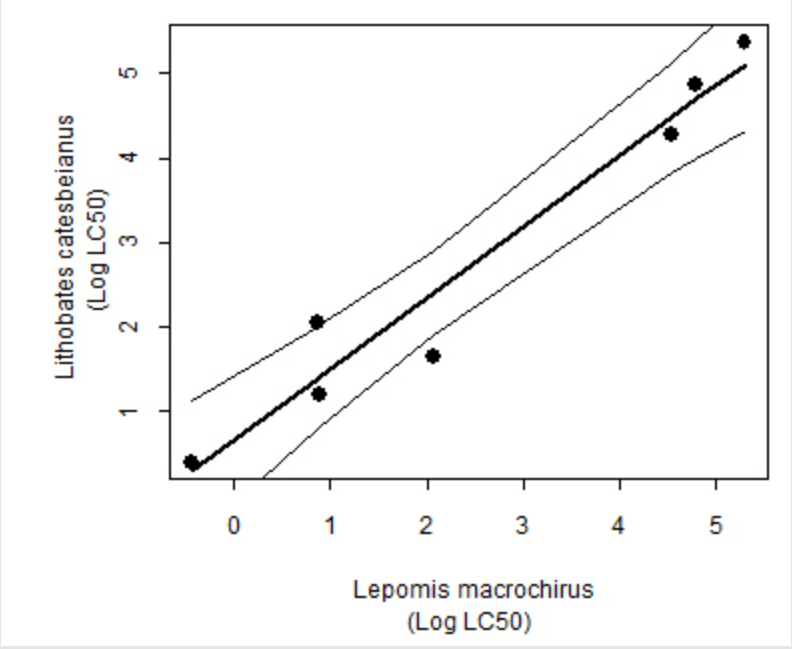


Figure L-25. *Lepomis macrochirus* (X-axis) and *Lithobates catesbeianus* (Y-axis) regression model used for ICE predicted values.

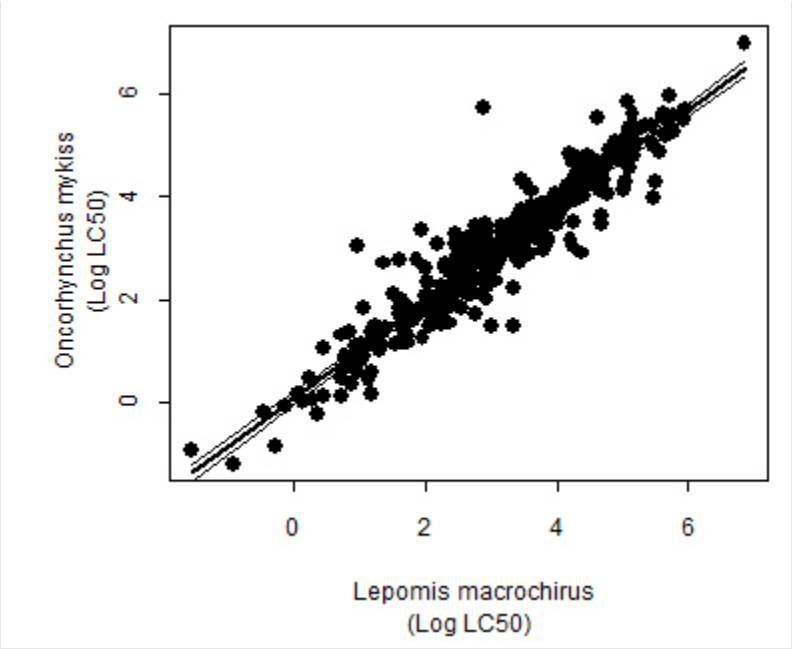


Figure L-26. *Lepomis macrochirus* (X-axis) and *Oncorhynchus mykiss* (Y-axis) regression model used for ICE predicted values.

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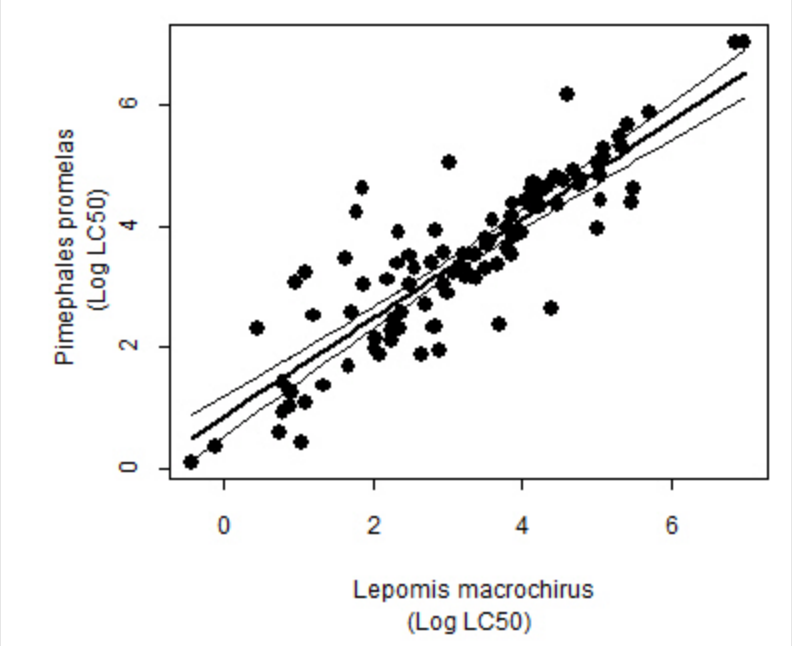


Figure L-27. *Lepomis macrochirus* embryo (X-axis) and *Pimephales promelas* (Y-axis) regression model used for ICE predicted values.

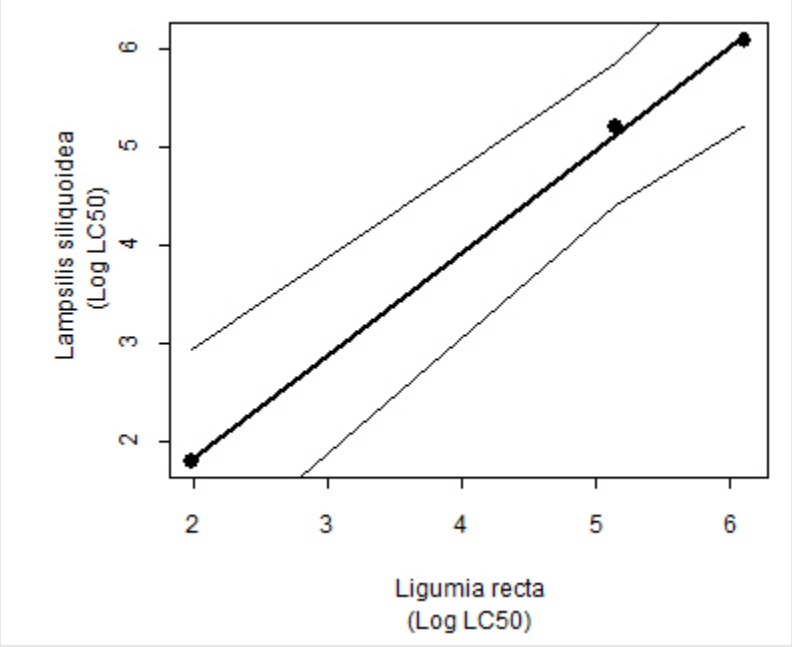


Figure L-28. *Ligumia recta* (X-axis) and *Lampsilis siliquoidea* (Y-axis) regression model used for ICE predicted values.

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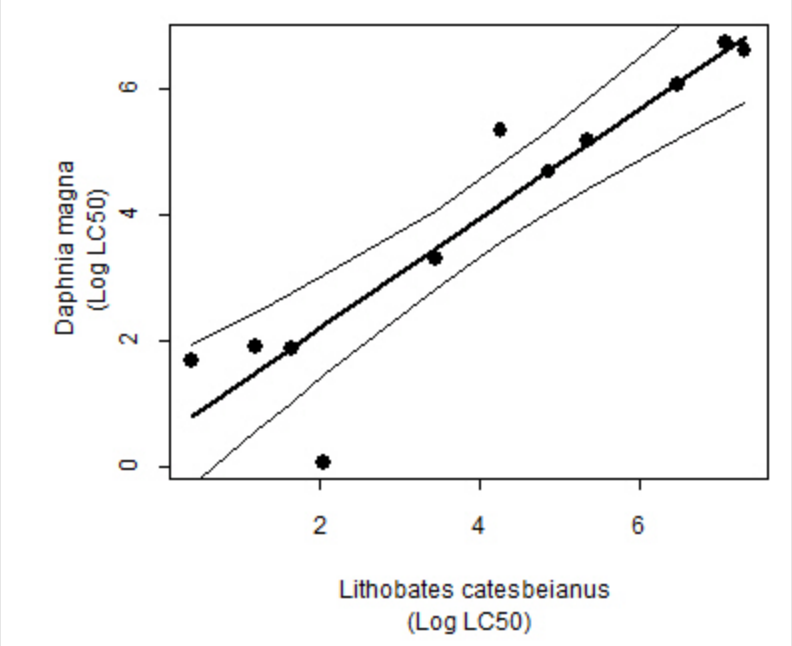


Figure L-29. *Lithobates catesbeianus* (X-axis) and *Daphnia magna* (Y-axis) regression model used for ICE predicted values.

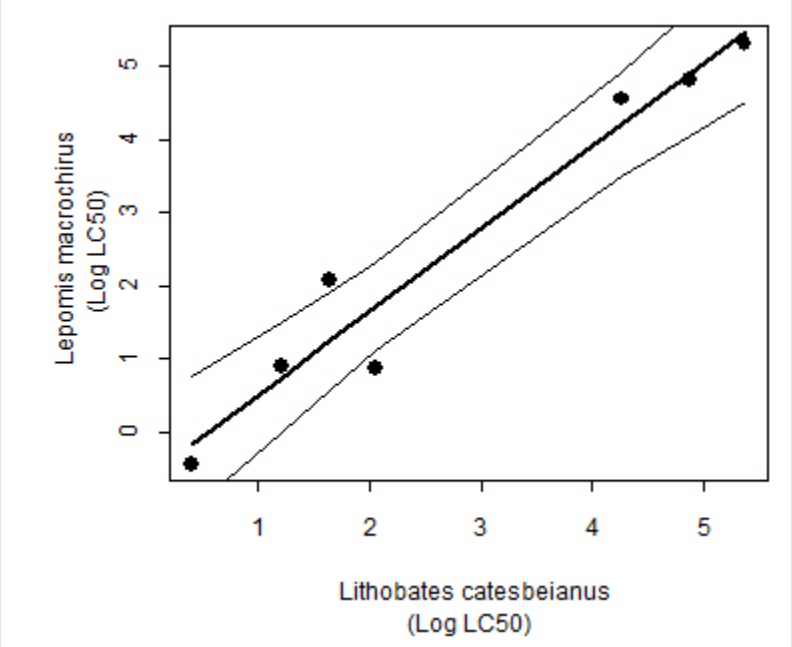


Figure L-30. *Lithobates catesbeianus* (X-axis) and *Lepomis macrochirus* (Y-axis) regression model used for ICE predicted values.

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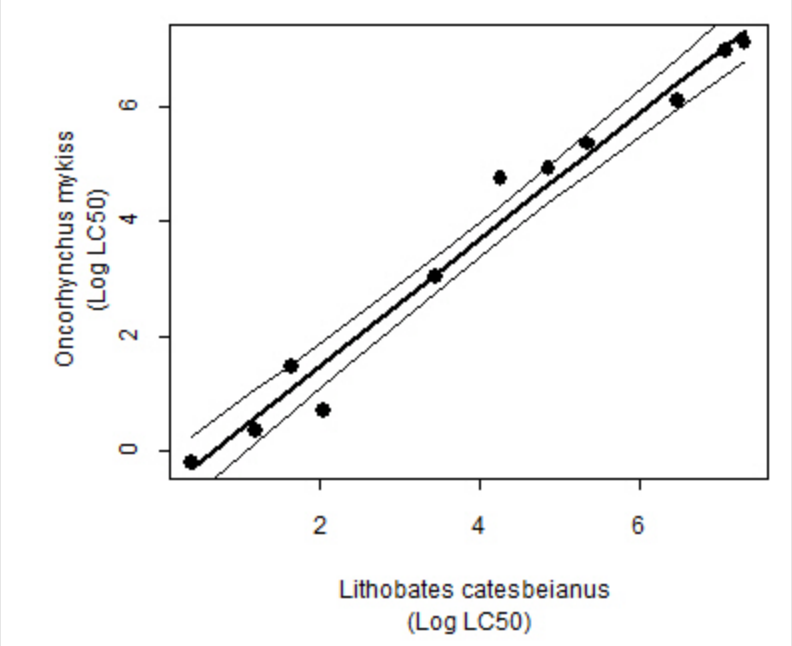


Figure L-31. *Lithobates catesbeianus* (X-axis) and *Oncorhynchus mykiss* (Y-axis) regression model used for ICE predicted values.

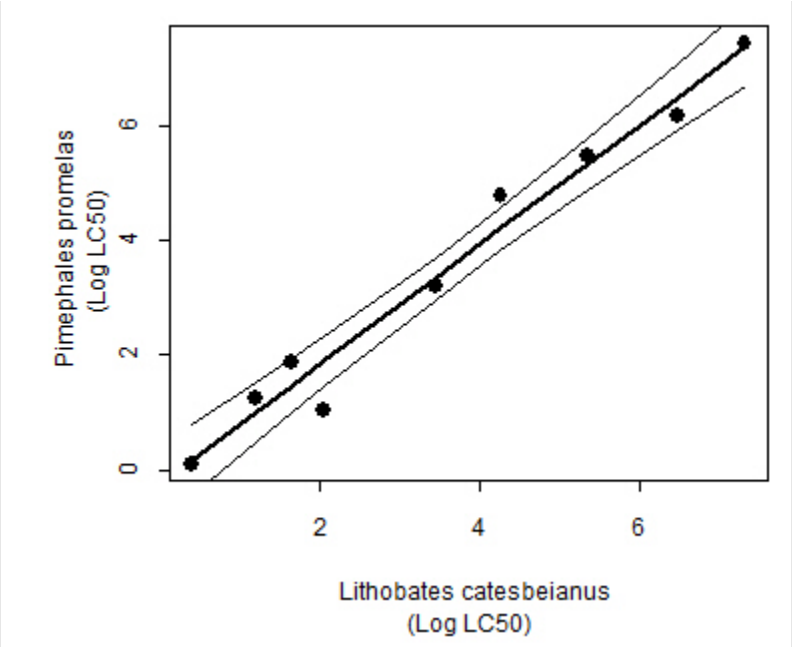


Figure L-32. *Lithobates catesbeianus* (X-axis) and *Pimephales promelas* (Y-axis) regression model used for ICE predicted values.

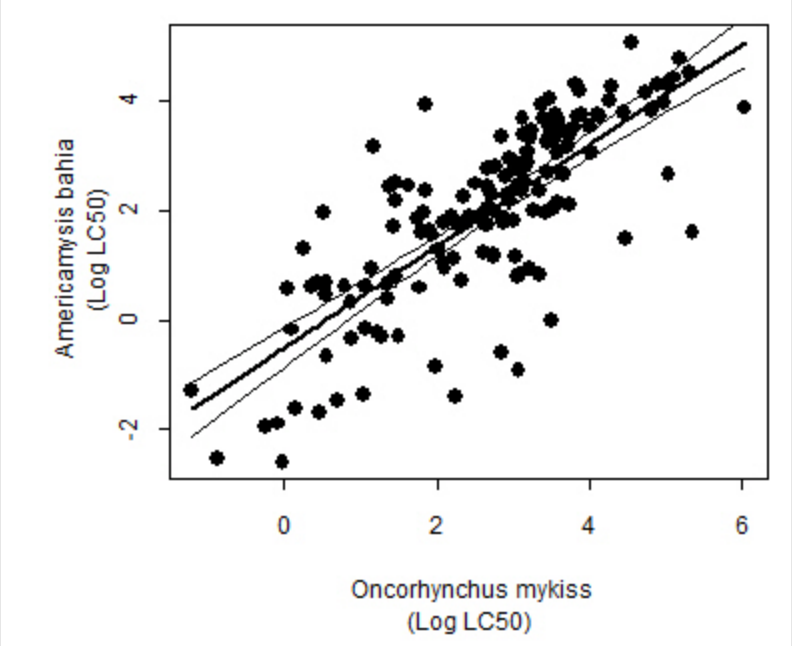


Figure L-33. *Oncorhynchus mykiss* (X-axis) and *Americamysis bahia* (Y-axis) regression model used for ICE predicted values.

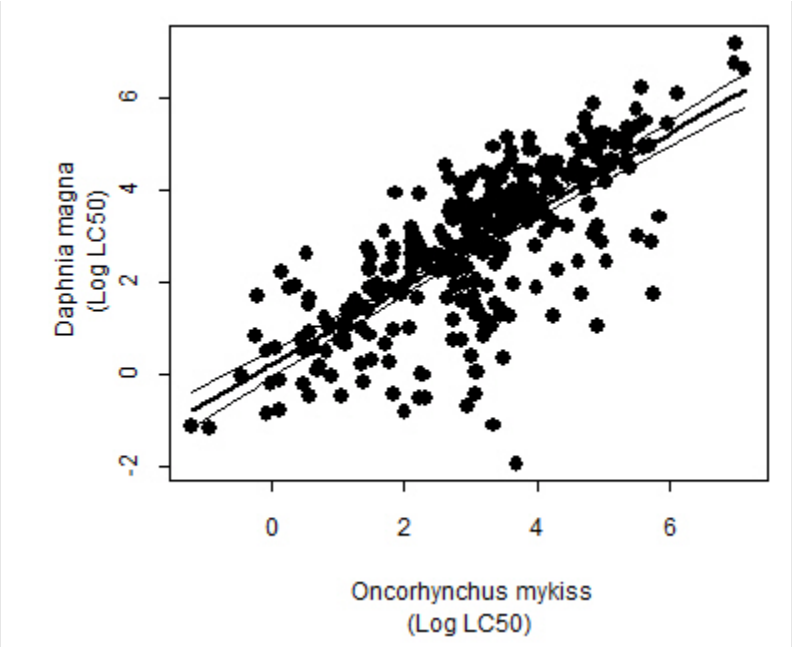


Figure L-34. *Oncorhynchus mykiss* (X-axis) and *Daphnia magna* (Y-axis) regression model used for ICE predicted values.

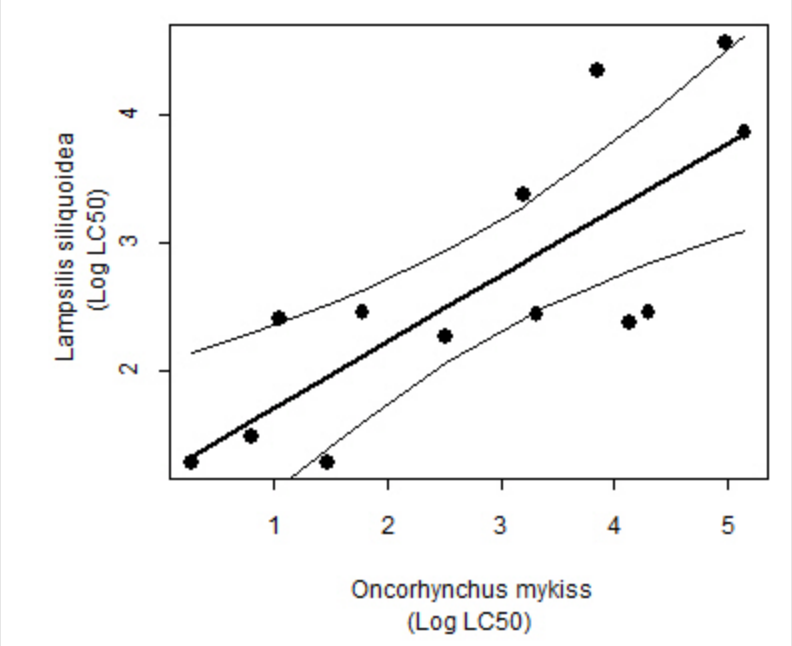


Figure L-35. *Oncorhynchus mykiss* (X-axis) and *Lampsilis siliquoidea* (Y-axis) regression model used for ICE predicted values.

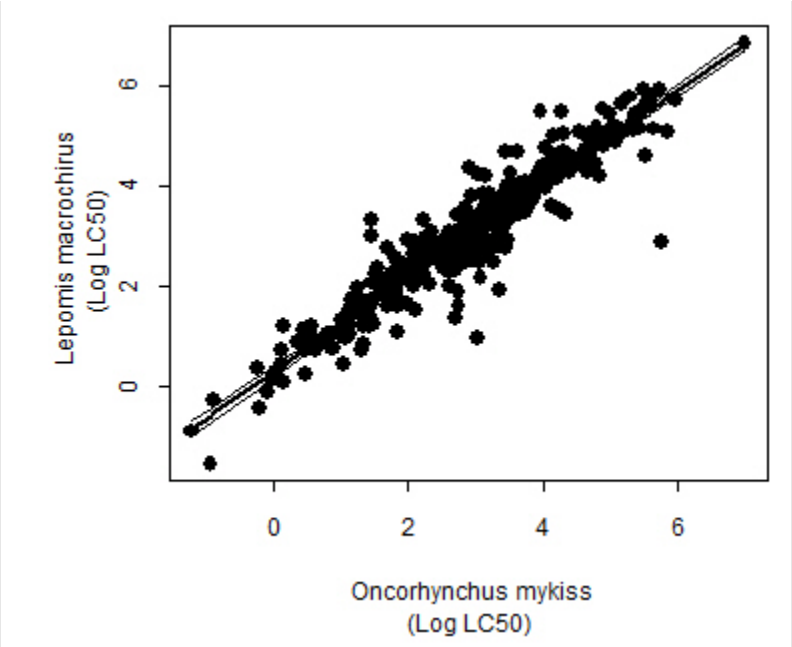


Figure L-36. *Oncorhynchus mykiss* (X-axis) and *Lepomis macrochirus* (Y-axis) regression model used for ICE predicted values.

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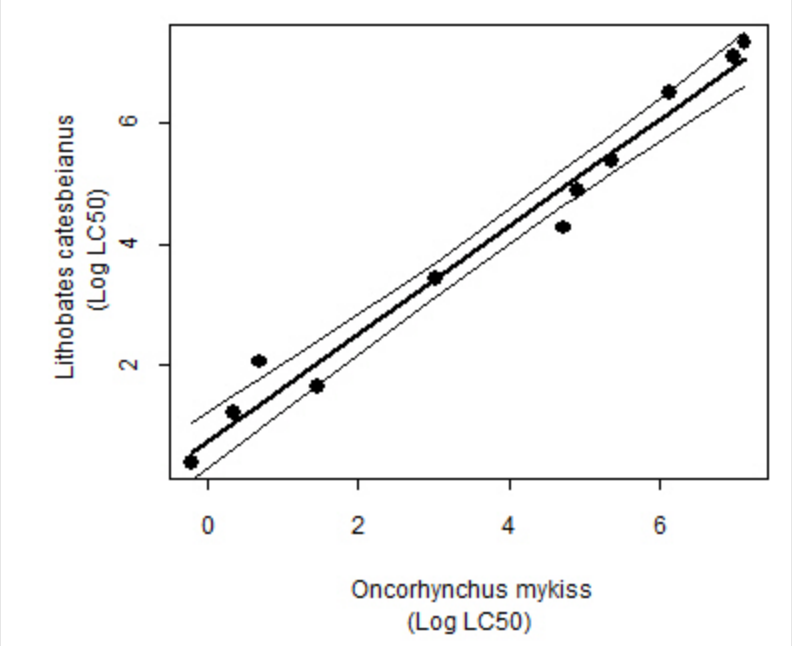


Figure L-37. *Oncorhynchus mykiss* (X-axis) and *Lithobates catesbeianus* (Y-axis) regression model used for ICE predicted values.

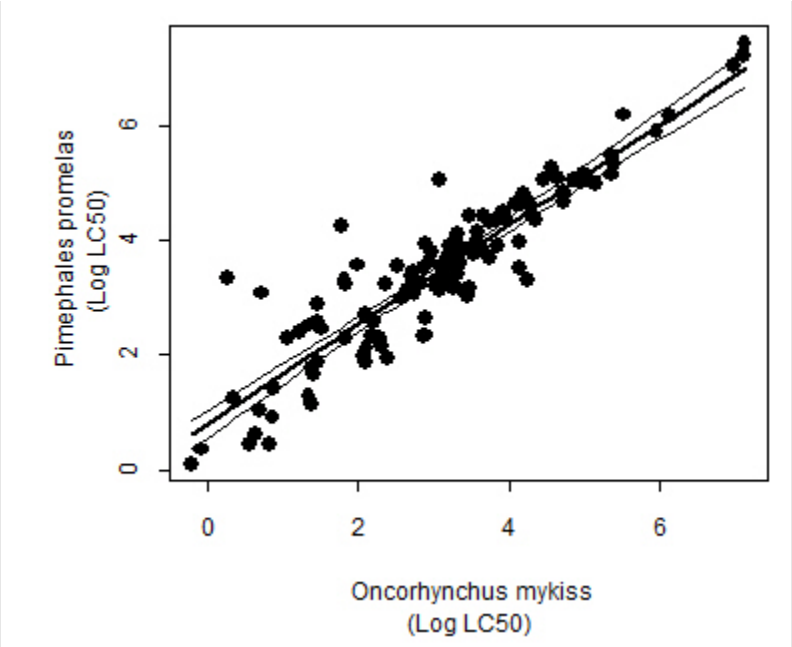


Figure L-38. *Oncorhynchus mykiss* (X-axis) and *Pimephales promelas* (Y-axis) regression model used for ICE predicted values.

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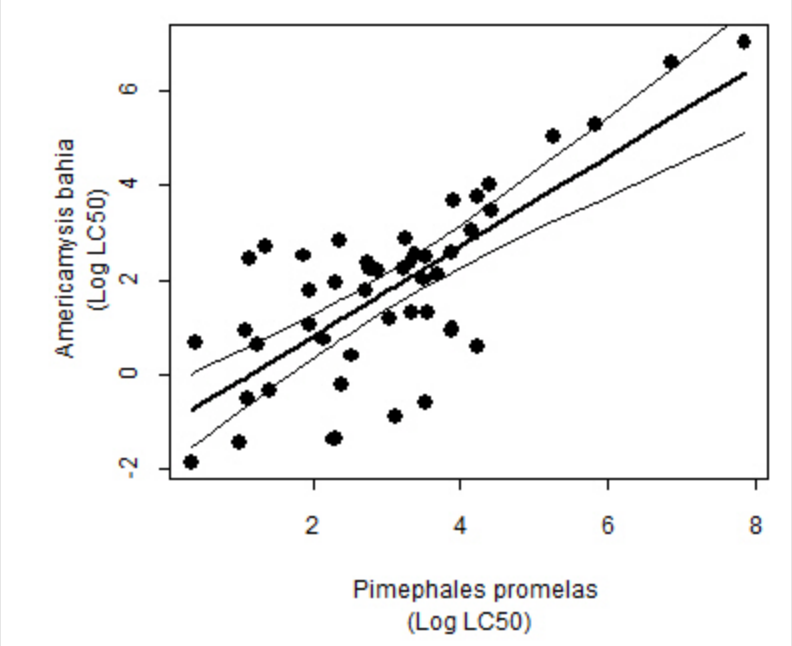


Figure L-39. *Pimephales promelas* (X-axis) and *Americamysis bahia* (Y-axis) regression model used for ICE predicted values.

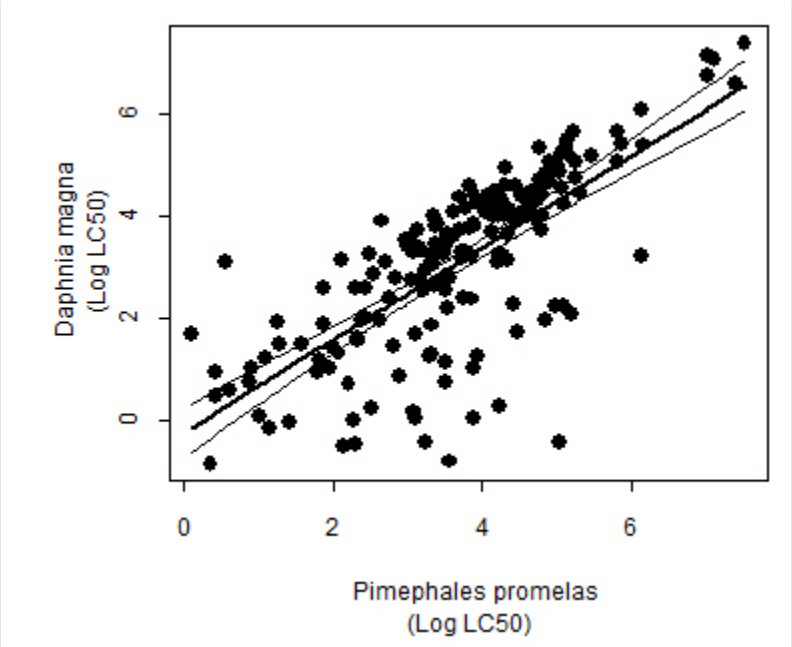


Figure L-40. *Pimephales promelas* (X-axis) and *Daphnia magna* (Y-axis) regression model used for ICE predicted values.

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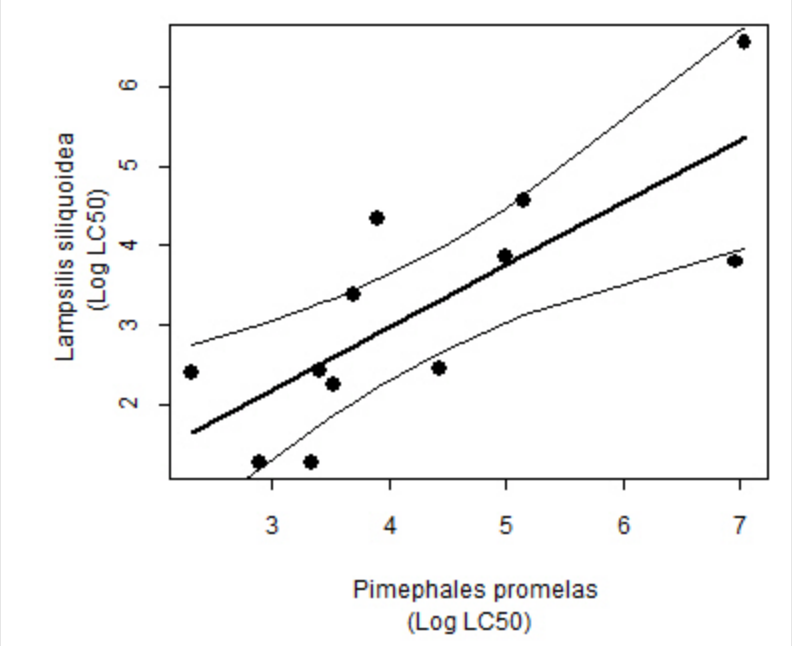


Figure L-41. *Pimephales promelas* (X-axis) and *Lampsilis siliquoidea* (Y-axis) regression model used for ICE predicted values.

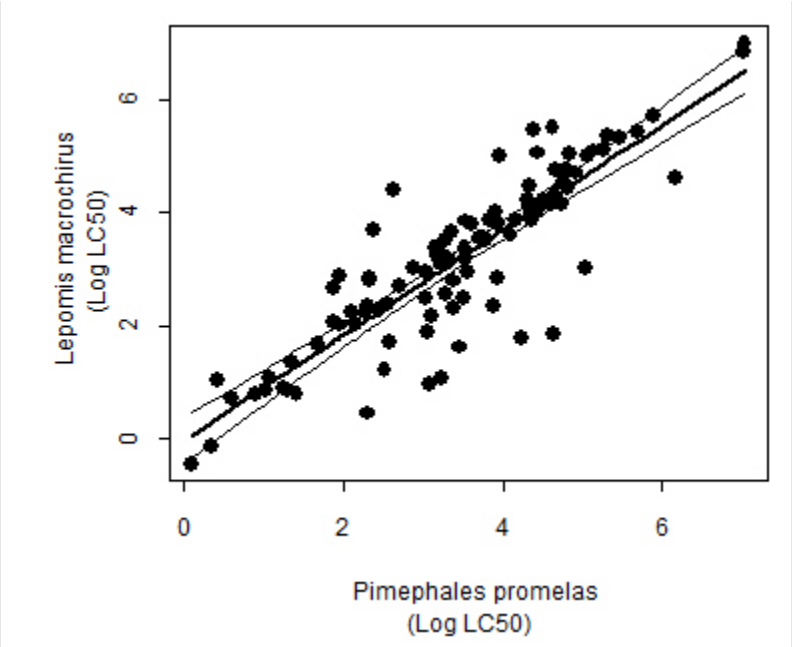


Figure L-42. *Pimephales promelas* (X-axis) and *Lepomis macrochirus* (Y-axis) regression model used for ICE predicted values.

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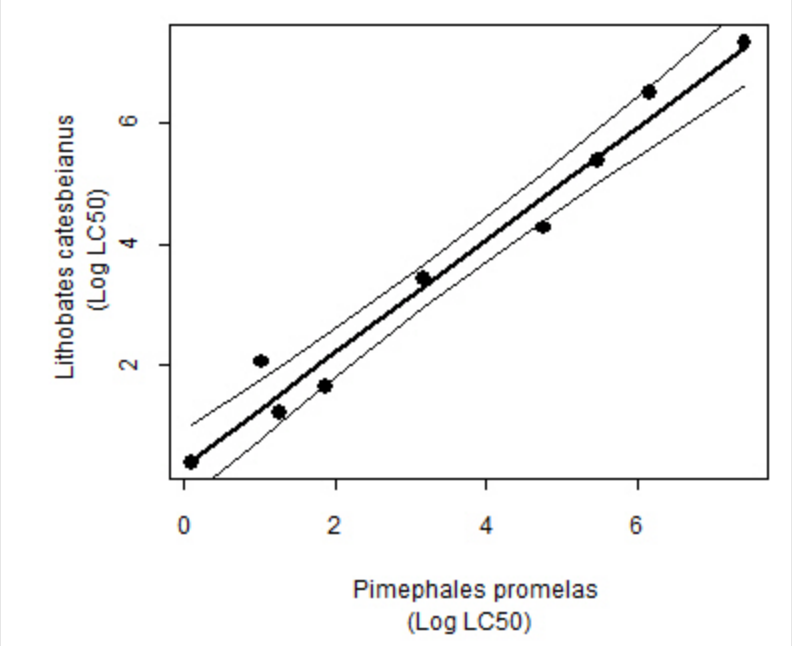


Figure L-43. *Pimephales promelas* (X-axis) and *Lithobates catesbeianus* (Y-axis) regression model used for ICE predicted values.

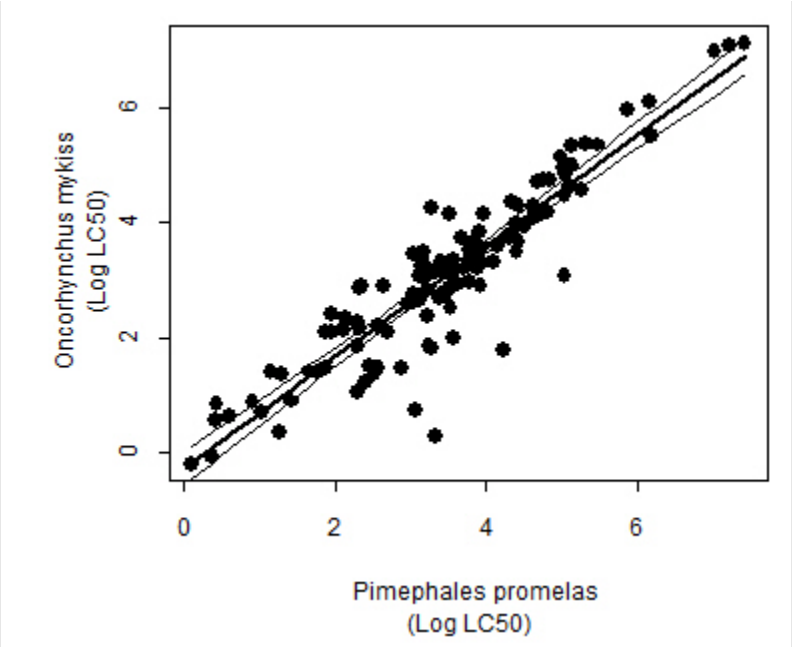


Figure L-44. *Pimephales promelas* (X-axis) and *Oncorhynchus mykiss* (Y-axis) regression model used for ICE predicted values.

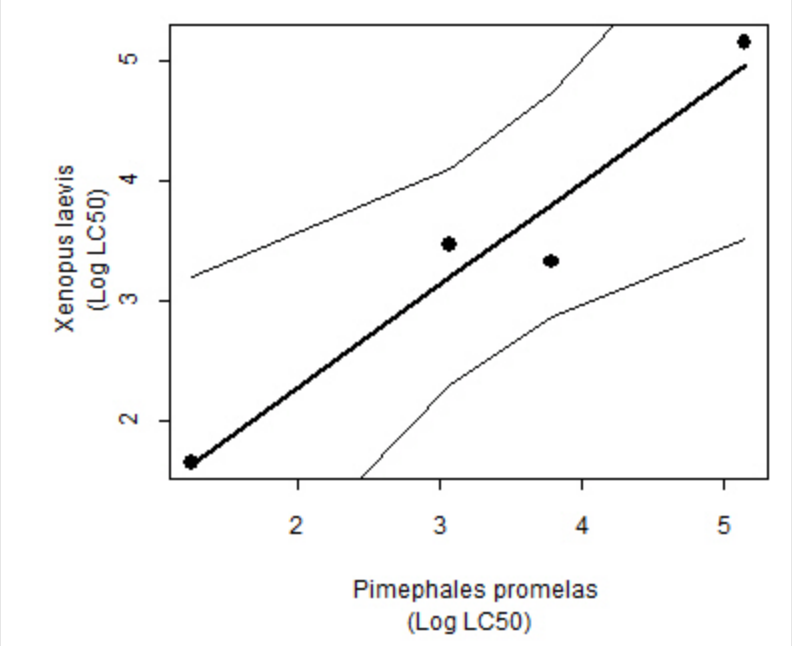


Figure L-45. *Pimephales promelas* (X-axis) and *Xenopus laevis* (Y-axis) regression model used for ICE predicted values.

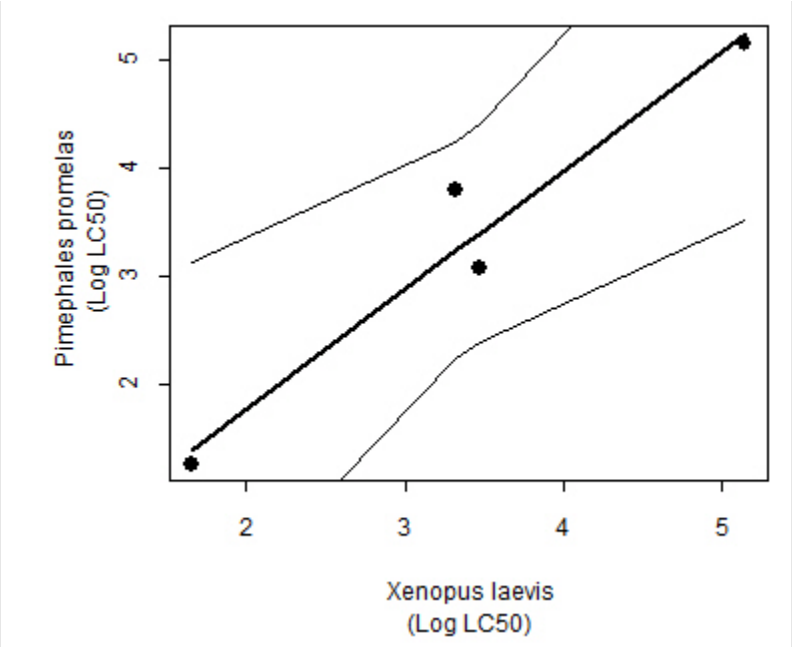


Figure L-46. *Xenopus laevis* (X-axis) and *Pimephales promelas* (Y-axis) regression model used for ICE predicted values.

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Appendix M Occurrence of PFOA in Abiotic Media

M.1 PFOA Occurrence in Surface Waters

Table M-1. Measured Perfluorooctanoic acid (PFOA) Concentrations in Surface Waters Across the United States.

State	Waterbody[1]	Arithmetic Mean PFOA Concentration (ng/L)	Median PFOA Concentration (ng/L)	Range of PFOA Concentrations (ng/L)	Reference
Lake Erie		18.33	15	13-27	Sinclair and Kannan 2006
		35.75	33.5	30-46	Boulanger et al. 2004
		5.460	5.852	3.367-7.16	De Silva et al. 2011
		1.9	1.9	1.6-2.2	Furdui et al. 2008
Lake Huron		3.222	3.475	0.656-4.72	De Silva et al. 2011
		0.592	0.433	0.1-1.1	Furdui et al. 2008
Lake Michigan		1.840	1.840	0.28-3.4	Simcik and Dorweiler 2005
		4.100	3.788	3.579-5.243	De Silva et al. 2011
Lake Ontario		not provided	21	18-34	Sinclair and Kannan 2006
		44.75	48.5	27-55	Boulanger et al. 2004
		4.465	4.150	3.226-6.710	De Silva et al. 2011
		3.773	2.900	1.8-6.7	Furdui et al. 2008
Lake Superior		0.255	0.236	0.095 – 0.395	De Silva et al. 2011
		0.233	0.3	0.1 – 0.3	Furdui et al. 2008
		0.246	0.124	0.074 – 0.996	Scott et al. 2010
Alabama	Waterbody in Decatur	7.5<x<25	7.5<x<25	<7.5 – (7.5<x<25)	3M Company 2001
	Pond in Decatur	60	60	60	
	Waterbody in Mobile	55.5	57.0	26.5-83	3M Company 2001
	Pond in Mobile	21.63	21.63	21.63	
	Tennessee River (upstream of Baker's Creek)	<25	<25	<25	Hansen et al. 2002
	Tennessee River (downstream of Baker's Creek)	335.2	355.0	<25-598	
California	Upper Silver Creek	not provided	not provided	10-36	Plumlee et al. 2008
	Coyote Creek	not provided	not provided	<4-13	
Colorado	Animas River	<0.76	<0.76	<0.76	Colorado Department of Public Health and the Environment 2020
	Arkansas River	1.58	0.69	0.36-3.90	
	Arvada Blunn Reservoir	0.80	0.80	0.80	
	Barker Reservoir	<0.78	<0.78	<0.78	
	Bessemer Ditch	2.60	2.60	2.60	

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State	Waterbody[1]	Arithmetic Mean PFOA Concentration (ng/L)	Median PFOA Concentration (ng/L)	Range of PFOA Concentrations (ng/L)	Reference
	Big Thompson River	2.90	2.90	2.90	
	Blue River	1.40	1.40	1.40	
	Boulder Feeder Canal	<0.71	<0.71	<0.71	
	Boyd Lake	1.50	1.50	1.50	
	Cache la Poudre River	6.68	6.68	<0.72-13.0	
	Clear Creek	3.05	3.05	3.00-3.10	
	Colorado River	0.77	0.93	<0.77-1.00	
	Coon Creek	<0.76	<0.76	<0.76	
	Eagle River	1.40	1.40	1.40	
	East Plum Creek	<0.67	<0.67	<0.67	
	Erie Lake	0.81	0.81	0.81	
	Fairmount Reservoir	<0.81	<0.81	<0.81	
	Fountain Creek	11.3	13.0	4.30-15.0	
	Fraser River	1.10	1.10	1.10	
	Gore Creek	2.00	2.00	2.00	
	Gunnison River	<0.78	<0.78	<0.78	
	Horsetooth Reservoir	<0.71	<0.71	<0.71	
	Jackson Creek	<0.70	<0.70	<0.70	
	Jerry Creek	<0.77	<0.77	<0.76-<0.78	
	Kannah Creek Flowline	<0.78	<0.78	<0.78	
	Lakewood Reservoir	<0.71	<0.71	<0.71	
	Little Fountain Creek	<0.73	<0.73	<0.73	
	Maple Grove Reservoir	8.50	8.50	8.50	
	Marstron Reservoir	<0.75	<0.75	<0.75	
	McBroom Ditch	3.10	3.10	3.10	
	Mclellen Reservoir	2.20	2.20	2.20	
	Mesa Creek	<0.77	<0.77	<0.77	
	Michigan River	<0.72	<0.72	<0.72	
	Molina Power Plant Tail	<0.78	<0.78	<0.78	
	North Fork Gunnison River	<0.75	<0.75	<0.75	
	Purdy Mesa Flowline	<0.77	<0.77	<0.77	
	Purgatoire River	<0.73	<0.73	<0.73	
	Ralston Reservoir	<0.72	<0.72	<0.72	
	Rio Grande	<0.75	<0.75	<0.75	
	Roaring Fork River	0.88	0.88	0.88	
	San Juan River	<0.69	<0.69	<0.69	

State	Waterbody[1]	Arithmetic Mean PFOA Concentration (ng/L)	Median PFOA Concentration (ng/L)	Range of PFOA Concentrations (ng/L)	Reference
	Sand Creek	14.25	14.25	5.50-23.0	
	Severy Creek	<0.74	<0.74	<0.74	
	Somerville Flowline	<0.75	<0.75	<0.75	
	South Boulder Creek	0.74	0.74	0.74	
	South Platte River	9.68	11.0	4.60-14.0	
	St. Vrain River	5.40	5.40	5.40	
	Strontia Springs	<0.80	<0.80	<0.80	
	Taylor River	<0.70	<0.70	<0.70	
	Uncompahgre River (delta)	0.73	0.73	0.73	
	Welton Reservoir	1.20	1.20	1.20	
	White River	<0.73	<0.73	<0.73	
	Yampa River	<0.74	<0.74	<0.74	
DE, NJ, PA	Delaware River	5.95	5.24	2.12-14.9	Pan et al. 2018
Florida	Waterbody in Pensacola	<7.5	<7.5	<7.5	3M Company 2001
	Pond in Pensacola	<7.5	<7.5	<7.5	
	Waterbody in Port St. Lucie	7.5<x<25	7.5<x<25	7.5<x<25	
	Small pond in Port St. Lucie	422.8	422.8	97-748.5	
	Sarasota Bay	3.6	not provided	not provided	Houde et al. 2006b
Georgia	Waterbody in Columbus	22.92	26.00	<25-26.5	3M Company 2001
	Pond in Columbus	<7.5	<7.5	<7.5	
	Conasauga River	478.9	366.5	32.4-1,150	Konwick et al. 2008
	Altamana River	3.067	3.1	3-3.1	
	Streams and ponds in Dalton	171.7	169.5	51.80-296.0	
	Oostanaula River	115.7	113	100-134	Laiser et al. 2011
	Coosa River	104	104	104	
Louisiana	Waterbodies (locations of concern) near Barksdale A.F.B.	62.67	30.00	<10-370	Cochran 2015
	Reference waterbodies near Barksdale A.F.B.	<10	<10	<10	
Michigan	Raisin River	14.7	14.7	14.7	Kannan et al. 2005
	St Clair River	4.467	4.4	4-5	
	Siskiwit Lake	0.576	0.576	0.558-0.594	Scott et al. 2010
Minnesota	Upper Mississippi River	119.4	2.80	<2-3,600	Newsted et al. 2017; Oliaei et al. 2013
	Lake of the Isles	0.46	0.46	0.46	

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State	Waterbody[1]	Arithmetic Mean PFOA Concentration (ng/L)	Median PFOA Concentration (ng/L)	Range of PFOA Concentrations (ng/L)	Reference
	Lake Calhoun	19.44	19.44	19.44	Simcik and Dorweiler 2005
	Lake Harriet	3.38	3.38	3.38	
	Minnesota River	1.2	1.2	1.2	
	Lake Tettegouche	0.47	0.47	0.47	
	Lake Nipisiquit	0.14	0.14	0.14	
	Lake Loiten	0.7	0.7	0.7	
	Little Trout Lake	0.31	0.31	0.31	
New Jersey	Echo Lake Reservoir	4.9	4.9	4.9	NJ DEP 2019
	Passaic River	13.55	13.55	13-14.1	
	Raritan River	8.7	8.7	8.7	
	Metedeconk River	31.1	31.1	28.3-33.9	
	Pine Lake	13.6	13.6	13.6	
	Horicon Lake	1.9	1.9	1.9	
	Little Pine Lake	25.9	25.9	25.9	
	Mirror Lake	13.2	13.2	13.2	
	Woodbury Creek	7.2	7.2	7.2	
	Fenwick Creek	10.5	10.5	10.5	
	Cohansey River	4.6	4.6	4.3-4.9	
	Harbortown Road	3.738	3.738	3.738	Zhang et al. 2016
	Passaic River	18.65	13.24	0.871-47.25	
New Mexico	Alamogordo Domestic Water System	<1	<1	<1	New Mexico Environment Department 2020, 2021
	Animas River	<0.97	<0.95	<0.89-<1.1	
	Canadian River	<0.935	<0.935	<0.89-<1.1	
	Cloud Country Estates WUA	<0.93	<0.93	<0.93	
	Gila River	<0.93	<0.93	<0.93	
	Holloman AFB Golf Course Pond 1	97	97	97	
	Holloman AFB Golf Course Pond 2	117	117	117	
	Holloman AFB Lagoon G	2,450	2,450	2,450	
	Holloman AFB Outfall	74.6	74.6	74.6	
	Holloman AFB Sewage Lagoon	941	941	941	
	Karr Canyon Estates	<0.93	<0.93	<0.93	
	La Luz MDWCA	<1.3	<1.3	<1.3	
	Lake Holloman	1,297	1,300	990-1,600	

State	Waterbody[1]	Arithmetic Mean PFOA Concentration (ng/L)	Median PFOA Concentration (ng/L)	Range of PFOA Concentrations (ng/L)	Reference
	Mountain Orchard MDWCA	<0.89	<0.89	<0.89	
	Pecos River	0.628	<0.96	<0.94-0.936	
	Rio Chama	<0.98	<0.98	<0.96-<1.0	
	Rio Grande	0.791	0.474	<0.86-1.95	
	Rio Puerco	<1.3	<1.3	<1.3	
	San Juan River	<1.06	<0.96	<0.89-<1.9	
	Tularosa Water System	<0.89	<0.89	<0.89	
New York	Washington Park Lake	10.1	10.4	4.83-15.8	Kim and Kannan 2007
	Rensselaer Lake	6.79	7.2	3.27-10.6	
	Iroquois Lake	7.365	not provided	not provided	
	Unnamed lake 1 outside Albany, NY	2.246	not provided	not provided	
	Unnamed lake 2 outside Albany, NY	4.341	not provided	not provided	
	Niagara River	19.67	19	18-22	Sinclair and Kannan 2006
	Finger Lakes	not provided	14	11-20	
	Lake Onondaga	50.67	49.00	39-64	
	Lake Oneida	19	19	19	
	Erie Canal	38.0	30.0	25-59	
	Hudson River	not provided	35	22-173	
	Lake Champlain	not provided	24	10-46	
	Lower NY Harbor	2.02	2.02	2.02	Zhang et al. 2016
	Staten Island	4.049	4.049	4.049	
	Hudson River	7.333	7.333	2.805-11.86	
North Carolina	Cape Fear River	43.4	12.6	<0.2-287	Nakayama et al. 2007
Rhode Island	Narragansett Bay	1.2	1.2	1.2	Benskin et al. 2012
	Allen Cove Inflow	3.784	3.784	3.784	Zhang et al. 2016
	Bristol Harbor	1.168	1.170	1.014-1.320	
	Brook at Mill Cove	36.81	36.81	36.81	
	Buckeye Brook	8.455	8.455	8.455	
	Chickasheen Brook	1.006	1.006	1.006	
	EG Town Dock	1.972	1.972	1.972	
	Fall River	0.64	0.64	0.64	
	Green Falls River	0.6470	0.6470	0.5860-0.7080	
	Hunt River	6.978	6.978	6.978	
	Mill Brook	9.237	9.237	9.237	
	Narrow River	0.9850	0.8985	0.6630-1.480	
	Pawcatuck River	16.98	16.98	14.99-18.97	

State	Waterbody[1]	Arithmetic Mean PFOA Concentration (ng/L)	Median PFOA Concentration (ng/L)	Range of PFOA Concentrations (ng/L)	Reference
	Pawtuxet River	7.546	7.546	7.546	
	Queens River	0.898	0.898	0.898	
	Sand Hill Brook	6.905	6.905	6.905	
	Secret Lake – Oak Hill Brook	0.849	0.849	0.849	
	Slack's Tributary	2.363	2.363	2.363	
	South Ferry Road Pier	0.267	0.267	0.267	
	Southern Creek	10.08	10.08	10.08	
	Woonasquatucket River	7.034	7.034	5.236-8.832	
South Carolina	Charleston Harbor	9.5	not provided	not provided	Houde et al. 2006b
Tennessee	Waterbody near Cleveland	7.5<x<25	7.5<x<25	7.5<x<25	3M Company 2001
	Conasauga River	<0.007[1]	<0.007[1]	<0.007[1]	Laiser et al. 2011
Texas	Rio Grande	3.4	4.3	1.2-4.7	NM Environment Department 2020, 2021
Washington	Puget Sound	2.297	1.680	0.160-8.220	Dinglasan-Panlilio et al. 2014
	Clayoquot Sound	1.180	1.010	0.600-1.770	
	Barkley Sound	1.4	1.4	1.4	
Multiple States (10 Air Force Bases across the continental U.S.)	Surface waters impacted by aqueous film forming foam use	not provided	382	210,000 (maximum)	Anderson et al. 2016

[1] Reported as ng/g by study authors.

M.1.1 PFOA Occurrence and Concentrations in the Great Lakes Region

The Great Lakes are among the most widely studied waterbodies in the U.S. for PFOA occurrence; however, data remain relatively limited in this system. Comparisons across the Great Lakes system indicate PFOA concentrations are higher in Lakes Erie and Ontario than in Lakes Huron, Michigan, and Superior (Figure M-1). For example, mean PFOA concentrations in Lake Erie and Lake Ontario from several studies ranged from 1.9 to 35.75 ng/L and 3.7 to 44.7 ng/L, respectively (Boulanger et al. 2004; Furdui et al. 2008), while the range of reported mean PFOA concentrations in Lake Superior, Lake Huron, and Lake Michigan were comparatively lower. The mean PFOA concentration range was 1.8 to 4.1 ng/L in Lake Michigan and 0.59 to 3.2 ng/L

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in Lake Huron (Furdui et al. 2008; De Silva et al. 2011; Simcik et al. 2005). The most western and upstream lake within the great lakes system, Lake Superior, consistently had lower PFOA concentrations than the other Great Lakes, with mean concentrations reported in the literature ranging from 0.23 to 0.25 ng/L (Furdui et al. 2008; Scott et al. 2010; De Silva et al. 2011).

The higher PFOA concentrations in Lakes Erie and Ontario are likely due to higher levels of urbanization around these lakes (Boulanger et al. 2004; Remucal 2019). A mass balance constructed for Lake Ontario by Boulanger et al. (2005) indicated that surface water and wastewater effluent are the major sources of PFOA to the lake. In contrast, inputs from Canadian tributaries and atmospheric deposition of PFAS were the major contributing sources of PFOA to Lake Superior. Inputs from Canadian tributaries and atmospheric deposition were estimated to contribute 59% and 35% of PFOA inputs into Lake Superior, respectively (Scott et al. 2010).

Within the Great Lakes, Remucal (2019) noted there were limited PFOA data to evaluate temporal trends in surface waters. If the dataset was limited to Lake Ontario, which is one of the most well-studied waterbodies for PFOA occurrence in the U.S. (with data from 2002 to 2010) there appears to be a mild decrease in PFOA concentrations over time. This decrease was likely due to the reduction in PFOA manufacturing; however, the downward PFOA trend in Lake Ontario was statistically insignificant, with authors noting additional data over longer time scales were needed to fully inform conclusions (reviewed in Remucal 2019).

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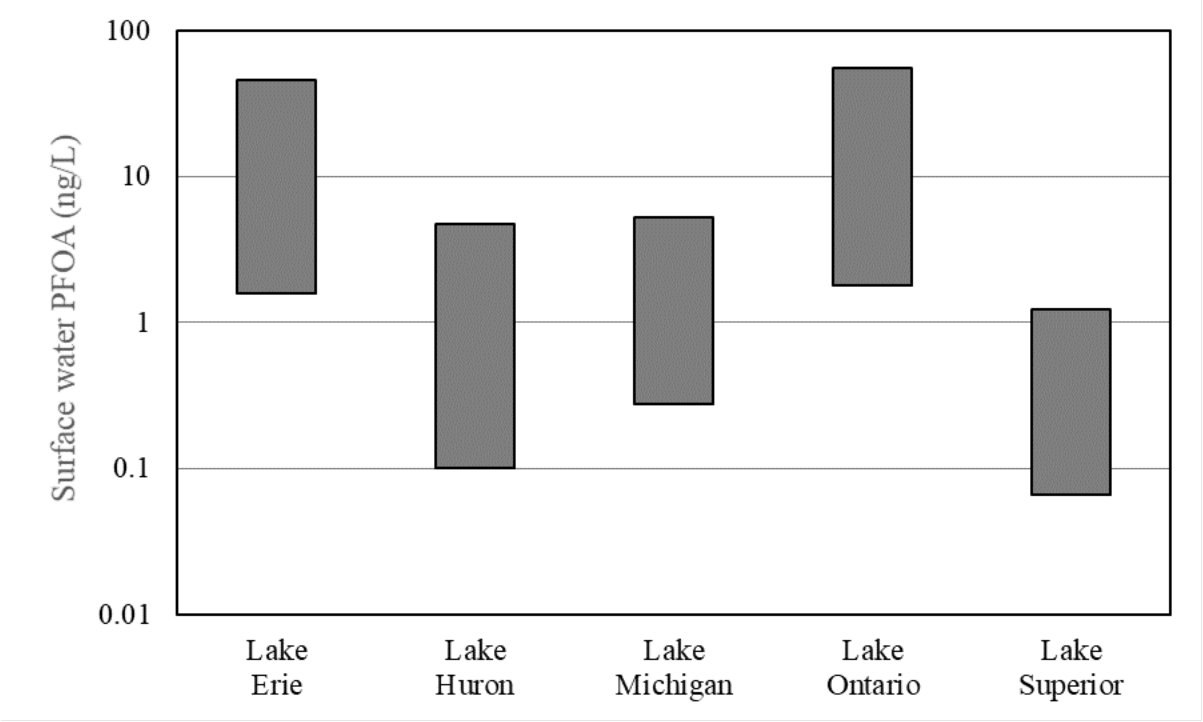


Figure M-1. Distribution of the minimum and maximum concentrations (ng/L) of Perfluorooctanoic acid (PFOA) measured in surface water samples collected from the Great Lakes as reported in the publicly available literature.
This distribution is arranged alphabetically by waterbody.

M.1.2 PFOA Occurrence and Concentrations in the Midwestern U.S.

Similar PFOA concentrations are reported in the publicly available literature for waterbodies in urban areas across the Midwest and northeastern U.S. along with lower PFOA concentrations associated with remote areas in the same states (Newsted et al. 2017; NJ DEP 2019; Simcik and Dorweiler 2005; Sinclair et al. 2006). In Minnesota, Simcik and Dorweiler (2005) observed PFOA concentrations ranging between 0.46 and 19 ng/L in urban areas near Minneapolis and concentrations ranging between 0.14 to 0.7 ng/L in remote areas in northern Minnesota.

M.1.3 PFOA Occurrence and Concentrations in the Northeastern U.S.

In New York, Sinclair et al. (2006) quantified (limit of quantification = 2 ng/L) PFOA in all waters sampled across the state. Unlike PFOS, PFOA was detected at relatively elevated

concentrations across all sites with comparatively little variability (median PFOA concentrations across nine sites ranged from 14 to 49 ng/L) (Sinclair et al. 2006). Additionally, the New Jersey Department of Environmental Protection (NJ DEP) measured PFOA in surface water samples collected from 14 different sites across the state. PFOA concentrations ranged from 1.9 ng/L to a high of 33.9 ng/L, which was quantified in the Metedeconk River downstream of a wastewater treatment plant. NJ DEP (2019) also indicated the Metedeconk River is impacted by PFOA-contaminated groundwater originating from an industrial source. Zhang et al. (2016) reported the surface water median PFOA concentration was 4.05 ng/L (n = 9; Zhang et al. 2016) in 2014 in the New York City Metropolitan area, including sites in New Jersey.

M.1.4 PFOA Occurrence and Concentrations in the Southeastern U.S.

Measured PFOA concentrations in surface waters among southeastern states of the U.S. are highly variable with some of the highest observed concentrations occurring in specific waterbodies near areas with PFOA manufacturing. In 2001 the 3M Company conducted a multi-city study measuring PFOA concentrations across waterbodies with known manufacturing and/or industrial uses of PFOA. In the 3M Company's 2001 report, PFOA concentrations from sites with known PFOA manufacturing uses were compared to PFOA concentrations in waterbodies with no known sources of any PFAS (3M Company 2001). In this comparison study, cities with PFOA manufacturing uses included Mobile and Decatur, Alabama, Columbus, Georgia, and Pensacola, Florida. Measured PFOA concentrations in surface waters, including lentic systems, ranged from not detected (with a detection limit of 7.5 ng/L stated in the report; 3M Company 2001) to 83 ng/L in the cities with known PFOA use in manufacturing processes. These PFOA concentrations were compared to those measured in control cities with no known PFOA applications in manufacturing. These control cities were Cleveland, Tennessee and Port St. Lucie, Florida. PFOA concentrations ranged from not detected to not quantified (limit of

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quantification = 25 ng/L; 3M Company 2001) in flowing surface waters. PFOA concentrations, however, ranged from 97 ng/L to 748.5 ng/L in lentic systems (i.e., ponds, lakes, and reservoirs; 3M Company 2001) in St. Lucie, Florida. Lentic water samples were not collected at the other city described as a "control," Cleveland, Tennessee. At the time of the report from the 3M Company, the source of PFOA in lentic waters near Port St. Lucie, Florida was unknown; however, the report noted the presence of visible litter, a greenish film on the water, and contributions from a culvert creating a grayish plume as it entered the waterbody (3M Company 2001). Aside from the samples collected in Port St. Lucie, Florida, this report demonstrated that measured PFOA concentrations in surface waters tend to be higher in areas with PFOA manufacturing and/or industrial use (3M Company 2001).

In separate studies, PFOS and PFOA concentrations were measured in surface waters by Hansen et al. (2002) near Decatur, Alabama and Konwick et al. (2008) in Georgia. Hansen et al. (2002) studied a stretch of the Tennessee river near Decatur, Alabama and Konwick et al. (2008) focused on the Conasauga River in Georgia as areas with known PFOA exposure and use. Hansen et al. (2002) reported discharge from a fluorochemical manufacturing facility entered the Tennessee River towards the middle of the sampling area of the study, allowing for a comparison of PFOA concentrations in relation to the fluorochemical manufacturing facility. In contrast, Konwick et al. (2008) compared the PFOA concentrations measured in the Conasauga River with those from reference sites (i.e., not impacted) along the Altamaha River. In both studies, mean PFOA concentrations were higher in the study areas near manufacturing sources of organic fluorochemicals. Specifically, Hansen et al. (2002) did not detect PFOA above the limit of quantification (i.e., 25 ng/L) upstream of the fluorochemical manufacturing facility. Downstream of the facility, PFOA concentrations ranged from below the limit of quantification at two sites

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immediately downstream of the facility to 598 ng/L with a mean concentration of 335.2 ng/L. Similarly, Konwick et al. (2008) observed higher measured PFOA concentrations in the Conasauga River, which ranged from 32.4 to 1,150 ng/L, compared to those in the Altamaha River, ranging between 3.0 and 3.1 ng/L. Consistent with the report from the 3M Company summarized above, the effluent from manufacturing facilities were determined to be the source of increased PFOA concentrations in both the Tennessee and Conasauga rivers (Hansen et al. 2002; Konwick et al. 2008). PFOA concentrations in contaminated areas of the Conasauga River and Altamaha River were relatively consistent with those measured in Alabama and Georgia (3M Company 2001).

Similarly, Nakayama et al. (2007) and Cochran (2015) measured PFAS, including PFOA, in the Cape Fear Drainage Basin in North Carolina and waterbodies on Barksdale Air Force Base in Bossier City, Louisiana; respectively. PFOA and PFOS were found to be the dominant PFAS detected in both studies. Nakayama et al. (2007) reported PFOA exceeded the level of quantification (i.e., 1 ng/L) in 82.3% of samples. PFOA concentrations in the Cape Fear Drainage Basin ranged between < 1 (the lower limit of quantification) and 287 ng/L with a mean concentration of 43.4 ng/L. Cochran (2015) detected PFOA in 64% of all water samples collected with an average concentration of 62.67 ng/L. As in other studies summarized above, lower PFAS concentrations were found in the smallest upland tributaries and highest in the middle reaches of the Cape Fear River. WWTP effluents were identified as the source of PFAS in the study area (Nakayama et al. 2007).

M.1.5 PFOA Occurrence and Concentrations in the Western U.S.

PFOA concentrations in urbanized areas of western U.S. states were consistent with concentrations measured in northeastern states (Sinclair et al. 2006; Zhang et al. 2016) but remained lower than contaminated areas of southeastern states (3M Company 2001). Plumlee et

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al. (2008) measured PFOA in surface water samples collected from Coyote Creek and a tributary of Upper Silver Creek in San Jose, California. PFOA concentrations in Coyote Creek ranged from below the detection limit (4 ng/L) to 13 ng/L and from 10 ng/L to 36 ng/L in Upper Silver Creek. Plumlee et al. (2008) postulated a combination of atmospheric deposition of volatile precursors and surface runoff are likely sources of PFOA to both Coyote and Upper Silver Creeks.

Dinglasan-Panlilio et al. (2014) measured PFOA concentrations along the Puget Sound in Washington, as well as Clayoquot and Barkley Sounds in British Columbia, Canada. Broadly, sampling locations spanned these inland marine systems and included freshwaters and estuarine/marine waters. Overall, PFOA was detected at all sampling locations (PFOA concentration range = 0.16 ng/L – 8.2 ng/L), but concentrations were lower than those observed from sites with known manufacturing and/or industrial PFOA uses. These concentrations were consistent with those reported in the publicly available literature for remote areas, such as the northern Great Lakes and rural Minnesota (Simcik and Dorweiler 2005). Dinglasan-Panlilio et al. (2014) speculate these specific regional sources as well as atmospheric deposition are likely contributors of PFOA to these remote areas (Dinglasan-Panlilio et al. 2014).

M.1.6 Summary of PFOA Occurrence and Concentrations across the U.S.

Despite the wide use and persistence of PFOA in aquatic ecosystems, current information on the environmental distribution of PFOA in surface waters across the U.S. remains limited. Present data are largely focused from freshwater systems collected along the east coast, southeast, and upper Midwest, focusing primarily on study areas with known manufacturing or industrial uses of PFAS. Current data indicate that PFOA concentrations measured in U.S. surface waters vary widely across five orders of magnitude (Figure M-2). Additional data,

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particularly in saltwater systems, are needed to better understand PFOA occurrence in aquatic ecosystems.

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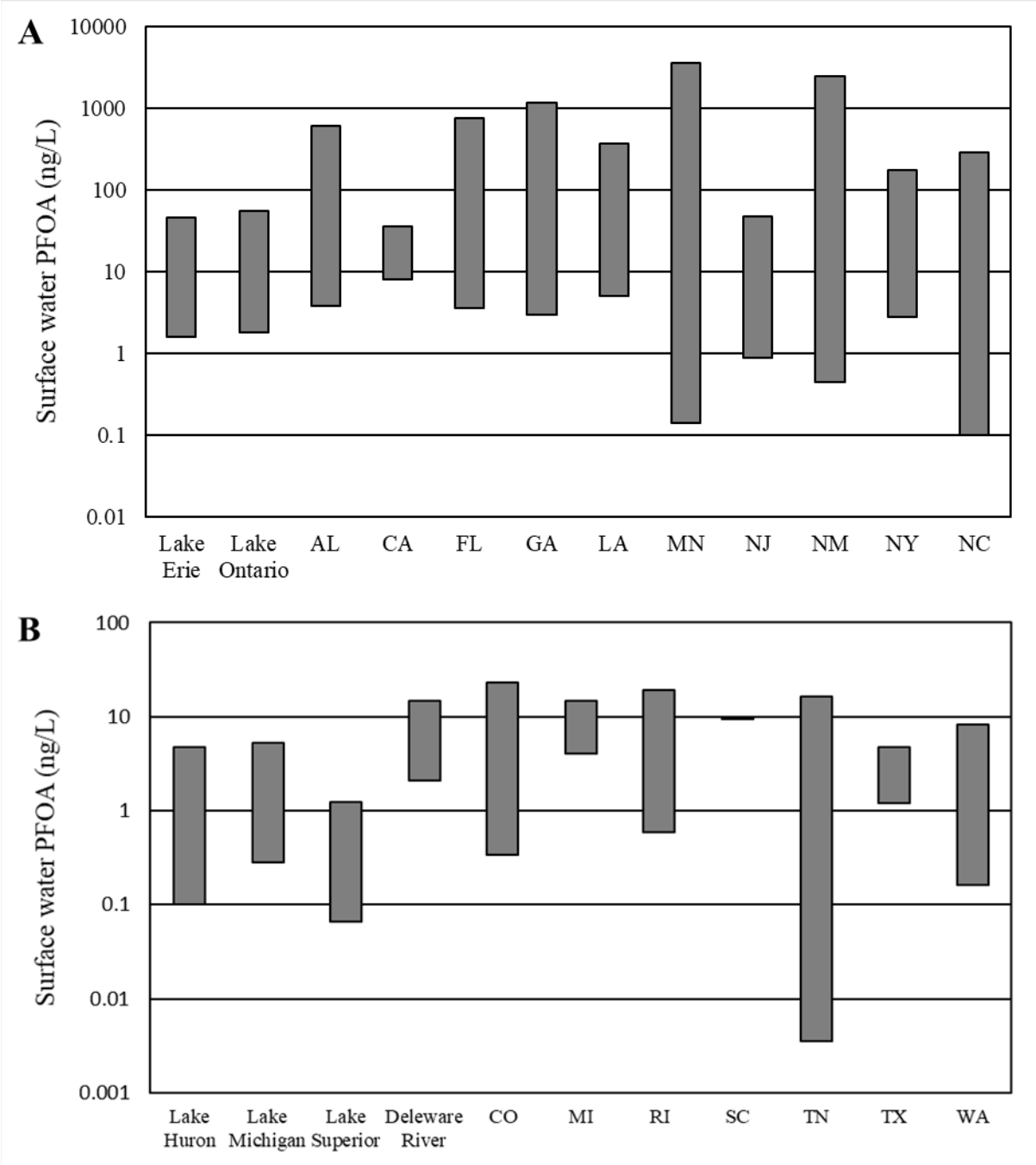


Figure M-2. Comparison of relatively high (A; greater than 30 ng/L) and low (B; less than 30 ng/L) maximum Perfluorooctanoic acid (PFOA) concentrations (ng/L) measured in surface water samples collected across the United States (U.S.) as reported in the publicly available literature.

M.1.7 Comparison to Global Occurrence of PFOA in Surface Waters

Similar to PFAS occurrence in surface waters in the U.S., generally PFOS and PFOA were the dominant PFAS detected in surface waters around the world (Ahrens 2011). On a global scale, concentrations of PFOA measured in surface waters generally range between pg/L and ng/L with some concentrations in the µg/L range. PFOA concentrations measured in the U.S. appear to be similar to those detected in studies with sampling sites in other countries. Global surface water PFOA concentrations reported in the public literature range between not detected and 11,300 ng/L near a PFAS spill site (as summarized below), and Zareitalabad et al. (2013) reported a median PFOA concentration in surface water of 24 ng/L across Canada, Europe, and Asia.

In Canada elevated concentrations of PFOA in surface waters were generally distributed among urbanized areas, suggesting that urban and industrial areas with high population densities contributed to the elevated concentrations of PFOA in surface waters (Gewurtz et al. 2013; Scott et al. 2009). In a systematic, cross-Canada study of PFAS in surface waters, Scott et al. (2009) observed that PFOS and PFOA were the predominant PFAS detected and that generally PFOS concentrations were higher overall, ranging between < 0.02 and 34.6 ng/L, than PFOA concentrations, which ranged between 0.044 and 9.9 ng/L. From the systems sampled in Canada, Scott et al. (2009) indicated that PFOA concentrations measured in Canadian surface waters were lower than those measured in the U.S., Europe, and Asia. However, elevated PFOA concentrations were observed in Etobicoke Creek, a tributary to Lake Ontario, after an accidental spill of a fire-retardant foam containing perfluorinated surfactants at L.B. Pearson International Airport in Toronto, Ontario in June 2000. The measured concentrations of PFOA ranged between not quantified (with a quantification limit of 9 ng/L) to 11,300 ng/L (Moody et al. 2002).

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PFOA concentrations measured in surface waters across Europe are similar to those observed in the U.S. Specifically, in a European Union (EU)-wide study of polar organic persistent pollutants, Loos et al. (2009) detected PFOA in 97% of samples with a median concentration of 3 ng/L in surface waters sampled across a wide range of sampling sites (including contaminated and pristine rivers and streams of various sizes). However, relatively high PFOA concentrations of nearly 200 ng/L were detected in the Po River, Italy. Mean PFOA concentrations observed by Pan et al. (2018) were similar to those reported in Loos et al. (2009) and across the U.S. with mean surface water concentrations from waterbodies across western Europe, specifically the Thames River, Mälaren Lake, and Rhine River, ranging between 2.31 ng/L to 8.51 ng/L, with a maximum concentration of 11.7 ng/L detected in the Thames River. Kwadijk et al. (2010) detected PFOA in all surface water samples collected from 20 locations across the Netherlands, with concentrations ranging from 6.5 to 43 ng/L. Huset et al. (2008) measured similar PFOA concentrations in three rivers in the Glatt Valley Watershed, Switzerland, and reported averages from three rivers ranging from 7.0 to 7.6 ng/L. Like in the U.S. and Canada, elevated concentrations of PFOA in surface waters across Europe are higher in urbanized areas and sources have been attributed to waste water treatment plant effluent, AFFF spills, and fluorochemical manufacturing facilities (Ahrens 2011; Huset et al. 2008; Kwadijk et al. 2010; Loos et al. 2007 and 2009).

PFOA concentrations observed in surface waters across eastern Asia were broadly similar to the U.S., Canada, and Europe. In Japan, Saito et al. (2003) observed PFOA concentrations ranging between 0.1 and 456 ng/L in surface waters samples collected from various locations. Similarly, Nguyen et al. (2011) reported PFOA concentrations ranging between 5 and 31 ng/L collected from an urbanized section of the Marina catchment in Singapore. Pan et al. (2018)

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reported PFOA concentrations from 112 samples across eastern Asia ranging from 0.15 ng/L to 52.8 ng/L. These 112 samples were collected from eight different water bodies, including; the Yangtze River (median PFOA = 12.2 ng/L; n = 35), Yellow River (median PFOA = 2.45 ng/L; n = 15), Pearl River (median PFOA = 1.82 ng/L; n = 13), Liao River (median PFOA = 9.39 ng/L; n = 6), Huai River, (median PFOA = 6.01 ng/L; n = 9), Han River (median PFOA = 3.69 ng/L; n = 6), Chao Lake (median PFOA = 8.17 ng/L; n = 13) and Tai Lake (median = 17.95 ng/L; n = 15).

Overall, these studies show the widespread distribution and variability of PFOA concentration in surface waters around the world and that surrounding land use and urbanization with high population densities have a large influence on the overall occurrence of PFOA in surface waters (Ahrens 2011; Gewurtz et al. 2013; Loos et al. 2007; Loos et al. 2009; Scott et al. 2009).

M.2 PFOA Occurrence and Detection in Aquatic Sediments

Although aquatic sediments are not anticipated to be a major PFOA sink (Ahrens 2011; Ahrens et al. 2009), PFOA has been detected in aquatic sediments in relatively remote regions. For example, maximum PFOA concentrations of 1.7 µg/kg dry weight (dw) were detected in lake sediments in the Canadian Artic (Butt et al. 2010). Typically, in the U.S., soil and sediment measurements of PFOA near contaminated sites and manufacturing plants occur in the µg/kg dry weight range. For example, PFOA ranged from below the limit of detection (0.017 µg/kg) to 700 µg/kg in sediments near a fluorochemical manufacturer in West Virginia (Lau et al. 2007).

Across ten U.S. Air Force bases where there is a known historic use of AFFF, Anderson et al. (2016) measured sediment (0-1 foot below top of the sediment) samples between March-September of 2014 at the ten locations with PFOA concentrations detected in 67% of samples.

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The median concentration of PFOA across all sites was 2.45 µg/kg, with a maximum concentration of 950 µg/kg (Anderson et al. 2016). Lasier et al. (2011) measured PFOA in sediment from the Coosa River, Georgia watershed, upstream and downstream of a land-application site of municipal/industrial wastewater, at concentrations ranging from 0.06-1.97 µg/kg dry weight. Values reported in various locations across San Francisco Bay ranged from below detection to 0.292 µg/kg dry weight (San Francisco Bay RWQCB 2020, Sedlak et al. 2017). Internationally, values ranged from below detection in areas with relatively low population density to µg/kg wet weight in areas of higher human population density, including <LOQ, Gufunes Bay, Iceland (Butt et al. 2010); <LOQ, Faroe Islands (Butt et al. 2010); 0.96 µg/kg wet weight, Tidal Flats of Ariake Sea, Japan (Nakata et al. 2006); 0.29-0.36 µg/kg dry weight, Tokyo Bay, Japan (Ahrens et al. 2010) and <0.05-0.2 µg/kg wet weight, Toronto, Ontario (Vedagiri et al. 2018).

M.3 PFOA Occurrence and Detection in Groundwater

Similar to surface water, PFOS and PFOA are the dominant PFAS detected in groundwater. Subsurface soil samples in Minnesota indicated PFOA concentrations increase with depth, suggesting the migration of PFOA from the surface, through soils, and into groundwaters (Xiao et al. 2015). Generally, PFOA concentrations tend to range in the ng/L range, with some elevated occurrences in µg/L (Ahrens 2011; Xiao 2017). Previous detections of PFOA in groundwater have been associated with the use of AFFF and fire-training locations (Ahrens 2011; Xiao 2017). For example, a maximum PFOA concentration of 105 µg/L was quantified in Michigan groundwater near a site formerly used for military fire-training operations that had been decommissioned for nearly five years prior to sampling (Moody et al. 2003). Similarly, the Minnesota Pollution Control Agency (MPCA) detected PFOA concentrations as

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high as ~ 23 µg/L in ground water near a PFAS disposal site, with concentrations decreasing to < 0.1 µg/L 1.4 km from the PFAS disposal site (Xaio et al. 2015). Despite not having been an active-fire training area, PFOA was still present on various U.S. Air Force Installations where there is a known history of use of AFFF to extinguish hydrocarbon-based fires. Anderson et al. (2016) measured groundwater samples between March and September of 2014 at the ten locations with PFOA concentrations detected in 90% of samples. The median concentration of PFOA across all sites was 0.41 µg/L, with a maximum concentration of 250 µg/L (Anderson et al. 2016). These concentrations are consistent with groundwater samples from Holloman Air Force Base in New Mexico measured in 2017 with PFOA groundwater concentrations in evaporation ponds and fire training areas ranging from 0.746 -254 µg/L (NMED 2021).

PFOA was detected in groundwater samples across Minnesota in 2006/2007, approximately five years after the 3M Corporation phased out PFOS production in Minnesota in 2002 (MPCA 2008). Analyses of samples collected from vulnerable, shallow aquifers in both urban and agricultural areas across Minnesota, with a variety of potential contamination sources (i.e., industrial and municipal stormwater, pesticides, land application of contaminated biosolids and atmospheric deposition), indicated that perfluorinated chemicals were present in concentrations of potential concern in areas beyond the disposal sites and aquifers associated with them (MPCA 2008). Groundwater samples ranged from <0.001 to 0.0324 µg/L with a reporting limit of 0.025 µg/L.

M.4 PFOA Occurrence and Detection in Air and Rain

Air concentrations of PFOA in the atmosphere is widely distributed globally. In an urban area in Albany, NY perfluorinated acids were measured in air samples in both the gas and particulate phase in May and July 2006 (Kim and Kannan 2007). PFOA in the gas phase had a

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mean concentration of 3.16 pg/m^3 (range: 1.89-6.53) and in the particulate phase had a mean concentration of 2.03 pg/m^3 (range: 0.76-4.19) (Kim and Kannan 2007). Kim and Kanaan (2007) also reported mean PFOA concentrations of 2.53 ng/L and 4.89 ng/L in rain and snow, respectively. In an urban area in Minneapolis, MN, PFOA was measured in both the particulate and gas phase. PFOA in the particulate phase ranged from 1.6-5.1 pg/m^3 and from 1.7-16.1 pg/m^3 in the gas phase across the five samples (MPCA 2008). The mean concentration value reported from a location in Resolute Bay, Nunavut, Canada was 1.4 pg/m^3 (Stock et al. 2007). These concentrations are greater than PFOA concentrations measured in the particle phase of air samples measured in Zeppelinstasjonen, Svalbard (Butt et al. 2010). PFOA was measured in September and December of 2006 and August and December of 2007, with mean concentrations of 0.44 pg/m^3 (Norwegian Institute for Air Research, 2007a,b).

M.5 PFOA Occurrence and Detection in Ice

Very little information is provided about PFOA concentrations in ice. The PFOA concentration from a Russian Arctic ice core sampled in 2007 was 131 pg/L (Saez et al. 2008; Martin et al. 2010). During the spring of 2005 and 2006 surface snow was collected and the following values were reported for the Canadian Arctic and Greenland, respectively: 13.1-53.7 pg/L and 50.9-520 pg/L (Young et al. 2007).

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Appendix N Translation of The Chronic Water Column Criterion into Other Fish Tissue Types

The PFOA freshwater aquatic life criteria (summarized in Section 3.3) includes chronic tissue criteria for fish whole body, fish muscle, and invertebrate whole-body tissues. Additional values for fish liver, fish blood, and fish reproductive tissues were also calculated by transforming the freshwater chronic water column criterion (i.e., 0.10 mg/L) into representative tissue concentrations using tissue-specific bioaccumulation factors (BAFs). Fish liver, fish blood, and fish reproductive BAFs were identified following the same approaches used to identify fish wholebody, mush muscle, and inverterbrate whole body BAFs, which are described in detial in section 2.11.3.1. Briefly, BAFs were determined from field measurements and calculated using the equation:

$$BAF = \frac{C_{biota}}{C_{water}} \qquad \text{(}\textit{Equation N-1}\text{)}$$

Where:

C_{biota} *= PFOA concentration in organismal tissue(s)*
C_{water} *= PFOA concentration in water where the organism was collected*

To identify the representative BAFs, a literature search for reporting on PFOA bioaccumulation was implemented by developing a series of chemical-based search terms to identify studies that were reviewed for reported BAFs and/or reported concentrations in which BAFs could be calculated for both freshwater and estuarine/marine species. BAFs from both freshwater and estuarine/marine species were considered because; (1) inclusion of estuarine/marine BAFs expanded the relatively limited PFOA BAF dataset and (2) Burkhard (2021) did not specifically observe notable differences in PFAS BAFs between freshwater and estuarine/marine systems, instead stating additional research is needed to formulate conclusions.

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Sources with relevant BAF information were further screened to determine if the reported BAF information from each source was of low, medium, or high quality. Only BAFs of high and medium quality were used to derive the tissue-specific BAFs and corresponding tissue-based values described below.

BAFs based on reproductive tissues identified by Burkhard (2021) were further screened to ensure only BAFs based on adult females were considered, because female reproductive tissues are most relevant to potential maternal transfer to offspring. This subset of reproductive-based BAFs and corresponding species and sampling locations are described in Table N-1.

Table N-1. Characteristics of adult fish sampled for the calculation of PFOA reproductive tissue BAFs.

All sampled fish were adults, and all reproductive tissues identified as gonad. Weights, lengths, and BAFs are averages.

Author	Species	Collection Date	n	Sex	Age (yr.)	Weight (g-ww)	Length (cm)	BAF (L/kg)
Ahrens et al. 2015	European perch (*Perca fluviatilis*)	10/12/2012	3	F	7-9	N.R.	N.R.	3.1
Shi et al. 2015, 2018	Crucian carp (*Carassius carassius*)	July 2014	30	24 F 6 M	N.R.	79.4 (F) 60.5 (M)	15.0 (F) 13.7 (M)	6.59
Shi et al. 2015, 2018	Crucian carp (*Carassius carassius*)	July 2014	13	9 F 4 M	N.R.	352.3 (F) 320.7 (M)	24.6 (F) 24.8 (M)	4.64
Wang et al. 2016	Crucian carp (*Carassius carassius*)	April 2014	8	N.R.	N.R.	(16.8-65.1)[1]	(10.0-14.7)[1]	85.4

N.R. = Not Reported

[1] Range.

Additional details on BAF compilation and ranking can be found in Section 2.11.3.1 and Burkhard (2021). The distributions of fish liver, fish blood, and fish reproductive BAFs identified in the literature used to calculate tissue-specific BAFs were determined in the same manner as invertebrate, fish muscle, and fish whole body BAFs (Section 3.2.2). Briefly, distributions of BAFs used to derive additional tissue values were based on the lowest species-level BAF reported within a waterbody. When more than one BAF was available for the same

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species at the same site, the species-level BAF was calculated as the geometric mean of all BAFs for that species at that site. Summary statistics for the PFOA BAFs used in the derivation of the additional tissue-based values are presented below (Table N-2) and individual BAFs are provided in Appendix O.

Table N-2. Summary Statistics for PFOA Freshwater BAFs in Additional Fish Tissues[1].

Category	n	Geometric Mean BAF (L/kg-wet weight)	Median BAF (L/kg-wet weight)	20th Centile BAF (L/kg-wet weight)	Minimum (L/kg-wet weight)	Maximum (L/kg-wet weight)
Liver	13	15.59	10	2.349	0.732	1,109
Blood	5	80.71	34.1	14.90	14	636
Reproductive Tissue	4	9.488	5.62	3.1	3.1	85.41

[1] Based on the lowest species-level BAF measured at a site (i.e., when two or more BAFs were available for the same species at the same site, the species-level geometric mean BAF was calculated, and the lowest species-level BAF was used).

Equation N-2 was used to transform the chronic freshwater column criterion (see Section 3.2.1.3) into tissue values using the 20th centile BAFs from the distributions of BAFs described above and summarized in Table N-2:

$$Tissue\ Value = Chronic\ Water\ Column\ Criterion\ \times 20th\ Centile\ BAF \qquad (Equation\ N\text{-}2)$$

The resulting tissue values that correspond to the 20th centile tissue-specific BAFs used in Equation N-2 are reported in Table N-3. The values reported in Table N-3 represent tissue-based concentrations that offer a level of protection that is equal to the magnitude components of the chronic water column criterion as well as the fish whole body, fish muscle, and invertebrate whole body tissue-based criteria; however, the tissue-based values reported in Table N-3 are only presented for comparative purposes and are not recommended criteria.

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Table N-3. PFOA Concentrations for Additional Fish Tissue Values.[1, 2]

Category	PFOA Concentration (mg/kg ww)
Liver	0.2349
Blood	1.490
Reproductive Tissue	0.3100

[1] These PFOA concentrations are provided as supplemental information and are not recommended criteria.
[2] Tissue concentrations are expressed as wet weight (ww) concentrations.

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Appendix O Bioaccumulation Factors (BAFs) Used to Calculate PFOA Tissue Values

O.1 Summary Table of PFOA BAFs used to calculate tissue criteria and supplemental fish tissue values

Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
goldfish	*Carassius auratus*	Blood	611.0	**611.0**	high	17 sites in six major rivers, Korea	Lam et al. 2014
mandarin	*Siniperca scherzeri*	Blood	739.0	739.0	high	17 sites in six major rivers, Korea	Lam et al. 2014
Crucian carp	*Carassius carassius*	Blood	635.6	**635.6**	high	Beijing Airport, China	Wang et al. 2016
European perch	*Perca fluviatilis*	Blood	14.00	**14.00**	medium	Lake Halmsjön, near Stockholm, Sweden	Ahrens et al. 2015
Cruician carp	*Carassius carassius*	Blood	18.50	**18.50**	high	Tangxun Lake	Shi et al. 2018
Cruician carp	*Carassius carassius*	Blood	34.06	**34.06**	high	Xiaoqing River, China	Shi et al. 2018
common carp	*Cyprinus carpio*	Blood	85.11	85.11	high	Xiaoqing River, China	Pan et al. 2017
Crucian carp	*Carassius carassius*	Gonad	85.41	**85.41**	high	Beijing Airport, China	Wang et al. 2016
European perch	*Perca fluviatilis*	Gonad	3.100	**3.100**	medium	Lake Halmsjön, near Stockholm, Sweden	Ahrens et al. 2015
Cruician carp	*Carassius carassius*	Gonad	4.641	**4.641**	high	Tangxun Lake	Shi et al. 2018
Cruician carp	*Carassius carassius*	Gonad	6.594	**6.594**	high	Xiaoqing River	Shi et al. 2018
common carp	*Carassius auratus*	Liver	134.0	**134.0**	high	17 sites in six major rivers, Korea	Lam et al. 2014
mandarin	*Siniperca scherzeri*	Liver	601.0	601.0	high	17 sites in six major rivers, Korea	Lam et al. 2014
Mozambique tilapia	*Oreochromis mossambicus*	Liver	7.017	7.017	medium	Matikulu at N2 Bridge	Fauconier et al. 2020
Cape stumpnose	*Rhabdosargus holubi*	Liver	2.714	**2.714**	medium	Matikulu at N2 Bridge	Fauconier et al. 2020
Crucian carp	*Carassius carassius*	Liver	1109	**1109**	high	Beijing Airport, China	Wang et al. 2016
tilapia	tilapia	Liver	67.00	**58.02**	medium	Key River, Taiwan	Lin et al. 2014
tilapia	tilapia	Liver	53.00		medium	Key River, Taiwan	Lin et al. 2014
tilapia	tilapia	Liver	55.00		medium	Key River, Taiwan	Lin et al. 2014
European perch	*Perca fluviatilis*	Liver	7.100	**7.100**	medium	Lake Halmsjön, near Stockholm, Sweden	Ahrens et al. 2015
European chub	*Leuciscus cephalus*	Liver	10.00	**10.00**	high	Orge River, near Paris, France	Labadie and Chevreuil 2011
goldfish	*Carassius auratus*	Liver	1000	1000	high	Pearl River Delta, China	Pan et al. 2014

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Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
Mud carp	*Cirrhinus molitorella*	Liver	7943	7943	medium	Pearl River Delta, China	Pan et al. 2014
Leather catfish	*Clarias fuscus*	Liver	158.5	**158.5**	high	Pearl River Delta, China	Pan et al. 2014
grass carp	*Ctenopharyngodon idellus*	Liver	3981	3981	high	Pearl River Delta, China	Pan et al. 2014
Common carp	*Cyprinus carpio*	Liver	2512	2512	high	Pearl River Delta, China	Pan et al. 2014
Chub	*Hypophthalmichthys molitrix*	Liver	398.1	398.1	high	Pearl River Delta, China	Pan et al. 2014
Snakehead	*Ophicephalus argus*	Liver	199.5	199.5	high	Pearl River Delta, China	Pan et al. 2014
Bream	*Parabramis pekinensis*	Liver	794.3	794.3	high	Pearl River Delta, China	Pan et al. 2014
Tilapia	*Tilapia aurea*	Liver	199.5	199.5	high	Pearl River Delta, China	Pan et al. 2014
Silver perch	*Bidyanus bidyanus*	Liver	14.00	**14.00**	high	Shoalhaven region, Australia	Terechovs et al. 2019
common shiner	*Notropis cornutus*	Liver	24.55	**24.55**	high	Spring/Etobicoke Creek, Toronto, Canada	Awad et al. 2011
Cruician carp	*Carassius carassius*	Liver	6.316	**6.316**	high	Tangxun Lake	Shi et al. 2018
Mozambique tilapia	*Oreochromis mossambicus*	Liver	0.7315	**0.7315**	medium	Mvoti at Gledhow	Fauconier et al. 2020
Mozambique tilapia	*Oreochromis mossambicus*	Liver	0.8882	**0.8882**	medium	Mvoti Estuary Mouth	Fauconier et al. 2020
Cruician carp	*Carassius carassius*	Liver	8.654	**8.654**	high	Xiaoqing River, China	Shi et al. 2018
common carp	*Cyprinus carpio*	Liver	17.38	17.38	high	Xiaoqing River, China	Pan et al. 2017
Slender glassy	*Ambassis natalensis*	Muscle	1.809	**1.809**	medium	Matikulu, Estuary Mouth	Fauconier et al. 2020
Mozambique tilapia	*Oreochromis mossambicus*	Muscle	1.434	1.434	medium	Matikulu, N2 Bridge	Fauconier et al. 2020
Cape stumpnose	*Rhabdosargus holubi*	Muscle	1.163	**1.163**	medium	Matikulu, N2 Bridge	Fauconier et al. 2020
Crucian carp	*Carassius cuvieri*	Muscle	1.442	**1.442**	high	Asan Lake, South Korea	Lee et al. 2020
Common seabass	*Dicentrarchus labrax*	Muscle	98.89	98.89	high	Gironde estuary, SW France	Munoz et al. 2017
Spotted seabass	*Dicentrarchus punctatus*	Muscle	190.6	190.6	high	Gironde estuary, SW France	Munoz et al. 2017
Anchovy	*Engraulis encrasicolus*	Muscle	85.00	**85.00**	high	Gironde estuary, SW France	Munoz et al. 2017
tilapia	tilapia	Muscle	51.00	**47.94**	medium	Key River, Taiwan	Lin et al. 2014
tilapia	tilapia	Muscle	45.00		medium	Key River, Taiwan	Lin et al. 2014
tilapia	tilapia	Muscle	48.00		medium	Key River, Taiwan	Lin et al. 2014

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Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
European perch	*Perca fluviatilis*	Muscle	37.00	**37.00**	high	Lake Halmsjön, near Stockholm, Sweden	Ahrens et al. 2015
Brown Bullhead	*Ameiurus nebulosus*	Muscle	10.00	10.00	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. 2016
Common Carp	*Cyprinus carpio*	Muscle	12.59	12.59	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. 2016
Northern Pike	*Esox lucius*	Muscle	7.943	**7.943**[c]	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. 2016
Channel Catfish	*Ictalurus punctatus*	Muscle	10.00	10.00	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. 2016
Pumpkinseed	*Lepomis gibbosus*	Muscle	10.00	10.00	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. 2016
Smallmouth Bass	*Micropterus dolomieu*	Muscle	7.943	**7.943**[c]	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. 2016
Largemouth Bass	*Micropterus salmoides*	Muscle	7.943	**7.943**[c]	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. 2016
Yellow Perch	*Perca flavescens*	Muscle	7.943	**7.943**[c]	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. 2016
White Crappie	*Pomoxis annularis*	Muscle	12.59	12.59	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. 2016
Black Crappie	*Pomoxis nigromaculatus*	Muscle	25.12	25.12	medium	Lake Niapenco, Ontario, Canada.	Bhavsar et al. 2016
Adult char	*Salvelinus alpinus*	Muscle	5.882	**5.882**	high	Meretta Lake, Canadian High Arctic	Lescord et al. 2015
eel	*Anguilla anguilla*	Muscle	13.18	**13.18**	high	Netherlands	Kwadijk et al. 2010
Adult char	*Salvelinus alpinus*	Muscle	37.23	**37.23**	high	Resolute Lake, Canadian High Arctic	Lescord et al. 2015
goby	*Gobio gobio*	Muscle	655.6	**655.6**	medium	Roter Main, Upper Franconia, Germany	Becker et al. 2010
Silver perch	*Bidyanus bidyanus*	Muscle	9.000	**9.000**	high	Shoalhaven region, Australia	Terechovs et al. 2019
crucian	*Carassius cuvieri*	Muscle	97.24	97.24	high	Taihu Lake, China	Fang et al. 2014
Lake Saury	*Coilia mystus*	Muscle	313.0	313.0	high	Taihu Lake, China	Fang et al. 2014

Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
gobies	*Ctenogobius giurinus*	Muscle	45.28	45.28	high	Taihu Lake, China	Fang et al. 2014
Mongolian culter	*Culter mongolicus*	Muscle	178.7	178.7	high	Taihu Lake, China	Fang et al. 2014
common carp	*Cyprinus carpio*	Muscle	213.0	213.0	high	Taihu Lake, China	Fang et al. 2014
minnow	*Hemiculter leucisculus*	Muscle	135.0	135.0	high	Taihu Lake, China	Fang et al. 2014
silver carp	*Hypophthalmichthys molitrix*	Muscle	14.21	**14.21**	high	Taihu Lake, China	Fang et al. 2014
mudfish	*Misgurnus anguillicaudatus*	Muscle	196.1	196.1	high	Taihu Lake, China	Fang et al. 2014
white bait	*Reganisalanx brachyrostralis*	Muscle	175.6	175.6	high	Taihu Lake, China	Fang et al. 2014
Chinese bitterling	*Rhodeus sinensis Gunther*	Muscle	105.5	105.5	high	Taihu Lake, China	Fang et al. 2014
Cruician carp	*Carassius carassius*	Muscle	1.557	**1.557**	high	Tangxun Lake	Shi et al. 2018
Mozambique tilapia	*Oreochromis mossambicus*	Muscle	0.2918	**0.2918**	medium	Mvoti, Estuary Mouth	Fauconier et al. 2020
Mozambique tilapia	*Oreochromis mossambicus*	Muscle	0.3798	**0.3798**	medium	Mvoti, Gledhow	Fauconier et al. 2020
Cruician carp	*Carassius carassius*	Muscle	2.207	**2.207**	high	Xiaoqing River, China	Shi et al. 2018
common carp	*Cyprinus carpio*	Muscle	2.884	2.884	high	Xiaoqing River, China	Pan et al. 2017
Juvenile char	*Salvelinus alpinus*	WB	434.8	**434.8**	high	9-Mile Lake, Canadian High Arctic	Lescord et al. 2015
grass goby	*Zosterisessor ophiocephalus*	WB	133.4	**133.4**	medium	AC Site, Orbetell lagoon, Italy	Renzi et al. 2013
Common carp	*Cyprinus carpio*	WB	182.0	**182.0**	high	Baiyangdian Lake, China	Zhou et al. 2012
herring	*Clupea harengus membras*	WB	218.8	**218.8**	medium	Baltic Sea	Gebbink et al. 2016
spat	*Sprattus sprattus*	WB	331.1	331.1	medium	Baltic Sea	Gebbink et al. 2016
Grass carp	*Ctenopharyngodon idellus*	WB	8160	**8160**	medium	Bantou Reservoir, Xiamen Sea, China	Dai and Zeng 2019
Crucian carp	*Carassius carassius*	WB	641.9	**641.9**	high	Beijing Airport, China	Wang et al. 2016
grass goby	*Zosterisessor ophiocephalus*	WB	132.7	**132.7**	medium	FC Site, Orbetell lagoon, Italy	Renzi et al. 2013
Spotted seabass	*Dicentrarchus punctatus*	WB	343.0	**343.0**	high	Gironde estuary, SW France	Munoz et al. 2017

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Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
Chameleon goby	*Tridentiger trigonocephalus*	WB	16273	**16273**	medium	Gulf Park, Xiamen Sea, China	Dai and Zeng 2019
Chinese icefish	*Neosalanx tangkahkeii taihuensis*	WB	61.90	**61.90**	medium	Lake Chaohu, China	Pan et al. 2019
lake trout	*Salvelinus namaycush*	WB	31.00	**156.9**	high	Lake Erie	De Silva et al. 2011
Lake Trout	*Salvelinus namaycush*	WB	794.3		medium	Lake Erie	Furdui et al. 2007
walleye	*Sander vitreus*	WB	266.0	266.0	high	Lake Erie	De Silva et al. 2011
European perch	*Perca fluviatilis*	WB	1.000	**1.000**	medium	Lake Halmsjön, near Stockholm, Sweden	Ahrens et al. 2015
Lake Trout	*Salvelinus namaycush*	WB	3981	**3981**	medium	Lake Huron	Furdui et al. 2007
Lake Trout	*Salvelinus namaycush*	WB	2512	**2512**	medium	Lake Michigan	Furdui et al. 2007
lake trout	*Salvelinus namaycush*	WB	402.0	**400.0**	high	Lake Ontario	De Silva et al. 2011
Lake Trout	*Salvelinus namaycush*	WB	398.1		medium	Lake Ontario	Furdui et al. 2007
lake trout	*Salvelinus namaycush*	WB	55.00	**331.3**	high	Lake Superior	De Silva et al. 2011
Lake Trout	*Salvelinus namaycush*	WB	1995		medium	Lake Superior	Furdui et al. 2007
Juvenile char	*Salvelinus alpinus*	WB	77.06	**77.06**	high	Meretta Lake, Canadian High Arctic	Lescord et al. 2015
grass goby	*Zosterisessor ophiocephalus*	WB	97.07	**97.07**	medium	NC Site, Orbetell lagoon, Italy	Renzi et al. 2013
Yellowfin goby	*Acanthogobius flavimanus*	WB	2441	2441	medium	Omuta River mouth and estuary, Japan	Kobayashi et al 2018
Sea Bass	*Lateolabrax*	WB	294.1	**294.1**	medium	Omuta River mouth and estuary, Japan	Kobayashi et al 2018
Grey mullet	*Mugil cephalus*	WB	382.4	382.4	medium	Omuta River mouth and estuary, Japan	Kobayashi et al 2018
Juvenile char	*Salvelinus alpinus*	WB	5387	**5387**	high	Resolute Lake, Canadian High Arctic	Lescord et al. 2015
medaka	*Oryzias latipes*	WB	330.0	**330.0**	high	Seven locations across Japan	Iwabuchi et al. 2015

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Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
common shiner	*Notropis cornutus*	WB	7.586	**7.586**	high	Spring/Etobicoke Creek, Toronto, Canada	Awad et al. 2011
Cruician carp	*Carassius carassius*	WB	2.775	**2.775**	high	Tangxun Lake	Shi et al. 2018
Bleak	*Alburnus alburnus*	WB	199.5	199.5	medium	Xerta, Ebro Delta, Spain	Pignotti et al. 2017
Common carp	*Cyprinus carpio*	WB	158.5	158.5	medium	Xerta, Ebro Delta, Spain	Pignotti et al. 2017
Mullet	*Liza sp.*	WB	100.0	100.0	medium	Xerta, Ebro Delta, Spain	Pignotti et al. 2017
Roach	*Rutilus rutilus*	WB	125.9	125.9	medium	Xerta, Ebro Delta, Spain	Pignotti et al. 2017
Rudd	*Scardinius erythrophtalmus*	WB	79.43	**79.43**	medium	Xerta, Ebro Delta, Spain	Pignotti et al. 2017
European catfish	*Silurus glanis*	WB	125.9	125.9	medium	Xerta, Ebro Delta, Spain	Pignotti et al. 2017
Ebro chub	*Squalius laietanus*	WB	100.0	100.0	medium	Xerta, Ebro Delta, Spain	Pignotti et al. 2017
Cruician carp	*Carassius carassius*	WB	3.713	**3.713**	high	Xiaoqing River, China	Shi et al. 2018
Snail	Gastropoda	Invert	10.58	**10.58**	medium	Matikulu, N2 Bridge	Fauconier et al. 2020
zooplankton	zooplankton	Invert	199.5	**199.5**	medium	Baltic Sea	Gebbink et al. 2016
Ghost Crab	*Ocypode stimpsoni*	Invert	7440	**7440**	medium	Fenglin, Xiamen Sea, China	Dai and Zheng 2019
Copepods	Copepoda	Invert	358.0	29.92	medium	Gironde estuary, SW France	Munoz et al. 2017
Copepods	Copepoda	Invert	2.500		high	Gironde estuary, SW France	Munoz et al. 2019
Brown shrimp	*Crangon crangon*	Invert	458.0	33.94	medium	Gironde estuary, SW France	Munoz et al. 2017
brown shrimp	*Crangon crangon*	Invert	2.500		high	Gironde estuary, SW France	Munoz et al. 2019
Oyster	*Crassostrea gigas*	Invert	20.00	20.00	high	Gironde estuary, SW France	Munoz et al. 2017
Gammarids	Gammarus	Invert	1250	1250	medium	Gironde estuary, SW France	Munoz et al. 2017
Mysids	Mysidacea	Invert	108.0	**16.43**	medium	Gironde estuary, SW France	Munoz et al. 2017
mysids	Mysidacea	Invert	2.500		high	Gironde estuary, SW France	Munoz et al. 2019
White shrimp	*Palaemon longirostris*	Invert	377.0	29.45	medium	Gironde estuary, SW France	Munoz et al. 2017

Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
white shrimp	*Palaemon longirostris*	Invert	2.300		high	Gironde estuary, SW France	Munoz et al. 2019
Pacific Oyster	*Crassostrea gigas*	Invert	9680	**9680**	medium	Gulf Park, Xiamen Sea, China	Dai and Zheng 2019
snails	*Bithynia tentaculata*	Invert	47.01	47.01	high	Hogsmill, Chertsey Bourne, Blackwater Rivers	Wilkinson et al. 2018
amphipod	*Gammarus pulex*	Invert	11.16	**11.16**	high	Hogsmill, Chertsey Bourne, Blackwater Rivers	Wilkinson et al. 2018
Orange-striped hermit crab	*Clibanarius infraspinatus*	Invert	6263	**6263**	medium	Jimei Bridge, Xiamen Sea, China	Dai and Zheng 2019
Pacific Oyster	*Crassostrea gigas*	Invert	6410	6410	medium	Jimei Bridge, Xiamen Sea, China	Dai and Zheng 2019
Ghost Crab	*Ocypode stimpsoni*	Invert	6490	6490	medium	Jimei Bridge, Xiamen Sea, China	Dai and Zheng 2019
worms	Sabellidae	Invert	44.21	44.21	medium	Mai Po Marshes, Hong Kong	Loi et al. 2011
zooplankton	zooplankton	Invert	11.70	**11.70**	medium	Mai Po Marshes, Hong Kong	Loi et al. 2011
Snail	*Cerithidea rhizophorarum*	Invert	267.6	**267.6**	medium	Omuta River mouth and estuary, Japan	Kobayashi et al 2018
crab	*Carcinus aestuarii*	Invert	105.6	105.6	medium	Orbetell lagoon, AC Site, Italy	Renzi et al. 2013
bivalve	*Mytilus galloprovincialis*	Invert	128.3	128.3	medium	Orbetell lagoon, AC Site, Italy	Renzi et al. 2013
prawn	*Palaemon serratus*	Invert	113.8	113.8	medium	Orbetell lagoon, AC Site, Italy	Renzi et al. 2013
bivalve	*Ruditapes decussatus*	Invert	84.78	**84.78**	medium	Orbetell lagoon, AC Site, Italy	Renzi et al. 2013
crab	*Carcinus aestuarii*	Invert	47.34	47.34	medium	Orbetell lagoon, FC Site, Italy	Renzi et al. 2013
bivalve	*Mytilus galloprovincialis*	Invert	241.8	241.8	medium	Orbetell lagoon, FC Site, Italy	Renzi et al. 2013
prawn	*Palaemon serratus*	Invert	52.81	52.81	medium	Orbetell lagoon, FC Site, Italy	Renzi et al. 2013
bivalve	*Ruditapes decussatus*	Invert	38.56	**38.56**	medium	Orbetell lagoon, FC Site, Italy	Renzi et al. 2013
crab	*Carcinus aestuarii*	Invert	234.2	234.2	medium	Orbetell lagoon, LC Site, Italy	Renzi et al. 2013
prawn	*Palaemon serratus*	Invert	205.6	205.6	medium	Orbetell lagoon, LC Site, Italy	Renzi et al. 2013
bivalve	*Ruditapes decussatus*	Invert	139.8	**139.8**	medium	Orbetell lagoon, LC Site, Italy	Renzi et al. 2013
bivalve	*Ruditapes decussatus*	Invert	102.0	**102.0**	medium	Orbetell lagoon, M Site, Italy	Renzi et al. 2013
crab	*Carcinus aestuarii*	Invert	57.55	**57.55**	medium	Orbetell lagoon, NC Site, Italy	Renzi et al. 2013
bivalve	*Mytilus galloprovincialis*	Invert	327.9	327.9	medium	Orbetell lagoon, NC Site, Italy	Renzi et al. 2013
prawn	*Palaemon serratus*	Invert	65.62	65.62	medium	Orbetell lagoon, NC Site, Italy	Renzi et al. 2013
bivalve	*Ruditapes decussatus*	Invert	62.24	62.24	medium	Orbetell lagoon, NC Site, Italy	Renzi et al. 2013
crab	*Carcinus aestuarii*	Invert	210.2	210.2	medium	Orbetell lagoon, PC Site, Italy	Renzi et al. 2013

Common Name	Scientific Name	Tissue[a]	BAF (L/kg-ww)	Site Species BAF (L/kg-ww)[b]	Ranking	Location	Reference
bivalve	*Mytilus galloprovincialis*	Invert	11.86	**11.86**	medium	Orbetell lagoon, PC Site, Italy	Renzi et al. 2013
prawn	*Palaemon serratus*	Invert	186.4	186.4	medium	Orbetell lagoon, PC Site, Italy	Renzi et al. 2013
bivalve	*Ruditapes decussatus*	Invert	216.4	216.4	medium	Orbetell lagoon, PC Site, Italy	Renzi et al. 2013
waterlouse, water boatmen, amphipods, roundworm	Isopoda, Hemiptera, amphipoda, nematoda	Invert	171.0	**171.0**	medium	Site A Stockholm Arlanda Airport	Koch et al. 2019
Mayflies, Caddisflies, Dragonflies, Water boatmen, Waterlouse, Fresh water amphipods	Ephemeroptera, Trichoptera, Odonata, Hemiptera, Isopoda, Amphipoda	Invert	50.00	**50.00**	medium	Site K the Kvarntorp area	Koch et al. 2019
Fresh water amphipods	Amphipoda	Invert	520.0	**520.0**	medium	Site R Ronneby Airport	Koch et al. 2019
pearl mussel	Unionidae	Invert	47.64	47.64	high	Taihu Lake, China	Fang et al. 2014
freshwater mussel	Unionidae	Invert	15.04	**15.04**	high	Taihu Lake, China	Fang et al. 2014
zooplankton	zooplankton	Invert	55.91	55.91	high	Taihu Lake, China	Fang et al. 2014
zooplankton	zooplankton	Invert	87.10	87.10	high	Taihu Lake, China	Xu et al. 2014
Shrimp	Caridea	Invert	0.9847	**0.9847**	medium	uMvoti, Gledhow	Fauconier et al. 2020
Snail	Gastropoda	Invert	3.840	3.840	medium	uMvoti, Gledhow	Fauconier et al. 2020
amphipod	Gammarus, Hyalella	Invert	2591	**2591**	high	Welland River, Hamilton, Ontario, Canada	De Solla et al. 2012

a – WB (Fish whole body); Invert (Invertebrate whole body)
b – Lowest species level BAF (highlighted in bold) at each site represents the site-level BAF
c – One site level BAF represented by four species tied for lowest species level BAF

O.2 Summary of PFOA BAFs used to calculate tissue criteria and supplemental fish tissue values

Field measured BAFs used to calculate fish and invertebrate PFOA tissue criteria (fish muscle, fish whole body, invertebrate whole body) and supplemental fish tissue values (blood, reproductive tissue, liver) are shown in Appendix O.1. Summary statistics for the BAFs from this table used to derive tissue criteria and additional tissue values (i.e., lowest species-level BAF from each site) are reported in Table 3-11 and Table N-2, respectively. Rankings for individual BAFs were determined by Burkhard (2021), who devised a ranking system based on five characteristics: 1) number of water samples; 2) number of tissue samples; 3) spatial coordination of water and tissue samples; 4) temporal coordination of water and tissue samples; and 5) general experimental design. For the first four characteristics, a score of one to three was assigned, based on number of samples or how closely the water and tissue measurements were paired. For the experimental design characteristic, a default value of zero was assigned; unless the measured tissues were composites of mixed species, in which case it was assigned a three (Burkhard 2021). These sub-scores were then summed and assigned a rank based on the final score. Studies with high quality rankings had scores of four or five, studies with medium quality rankings had scores of five or six, and studies with low quality rankings had scores of seven or higher (Burkhard 2021). Parameters for the scores assigned to the five characteristics are listed in Table 2-2, and additional details can be found in Burkhard (2021). Only BAFs from studies with high or medium quality rankings were included for the final BAF geometric mean calculations used to derive tissue criteria (Table 3-12) and supplemental tissue values (Table N-3).

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O.3 PFOA BAFs References

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Appendix P Example Data Evaluation Records (DERs)

Background: This set of published literature was identified using the ECOTOXicology database (ECOTOX; https://cfpub.epa.gov/ecotox/) as meeting data quality standards. ECOTOX is a source of high-quality toxicity data for aquatic life, terrestrial plants, and wildlife. The database was created and is maintained by the EPA, Office of Research and Development, Center for Computational Toxicology and Exposure. The ECOTOX search generally begins with a comprehensive chemical-specific literature search of the open literature conducted according to ECOTOX Standard Operating Procedures (SOPs). The search terms are often comprised of chemical terms, synonyms, degradates and verified Chemical Abstracts Service (CAS) numbers. After developing the literature search strategy, ECOTOX curators conduct a series of searches, identify potentially applicable studies based on title and abstract, acquire potentially applicable studies, and then apply the applicability criteria for inclusion in ECOTOX. Applicability criteria for inclusion into ECOTOX generally include:

1. The toxic effects are related to single chemical exposure (unless the study is being considered as part of a mixture effects assessment);
2. There is a biological effect on live, whole organisms or *in vitro* preparation including gene chips or omics data on adverse outcome pathways potentially of interest;
3. Chemical test concentrations are reported;
4. There is an explicit duration of exposure;
5. Toxicology information that is relevant to OW is reported for the chemical of concern;
6. The paper is published in the English language;
7. The paper is available as a full article (not an abstract);
8. The paper is publicly available;
9. The paper is the primary source of the data;
10. A calculated endpoint is reported or can be calculated using reported or available information;
11. Treatment(s) are compared to an acceptable control;
12. The location of the study (*e.g.*, laboratory vs. field) is reported; and
13. The tested species is reported (with recognized nomenclature).

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Following inclusion in the ECOTOX database, toxicity studies are subsequently evaluated by the Office of Water. All studies were evaluated for data quality generally as described by U.S. EPA (1985) in the 1985 Guidelines and in the EPA's Office of Chemical Safety and Pollution Prevention (OCSPP)'s Ecological Effects Test Guidelines (U.S. EPA 2016b), and EPA OW's internal data quality SOP, which is consistent with OCSPP's data quality review approach (U.S. EPA 2018). These toxicity data were further screened to ensure that the observed effects could be primarily attributed to PFOA exposure. Office of Water completed a DER for each species by chemical combination from the PFOA studies identified by ECOTOX. Example DERs are presented here to convey the meticulous level of evaluation, review, and documentation each PFOA study identified by ECOTOX was subject to. Appendix P.1 shows an example fish DER and Appendix P.2 shows an example aquatic invertebrate DER.

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P.1 Example Fish DER

Part A: Overview

I. Test Information

Chemical name:

CAS name: CAS Number:
Purity: Storage conditions:
Solubility in Water (units):

____ **Controlled Experiment** (*manipulated*) ____ **Field Study/Observation** (*not manipulated*) (*Place X by One*)

Primary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)

Secondary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)
(*At least one reviewer should be from EPA for sensitive taxa*)

Citation: *Indicate: author(s), year, study title, journal, volume, and pages*.
(e.g., Slonim, A.R. 1973. Acute toxicity of beryllium sulfate to the common guppy. J. Wat. Pollut. Contr. Fed. 45(10): 2110-2122)

Companion Papers: *Identify any companion papers associated with this paper using the citation format above.*

-

Were other DERs completed for Companion Papers? ____ **Yes** ____ **No** (*If yes, list file names of DERs below*)

Study Classification for Aquatic Life Criteria Development: *Place X by One Based on Highest Use*

_____ Acceptable for Quantitative Use
_____ Acceptable for Qualitative Use
_____ Not Acceptable for Use/Unused

General Notes: *Provide any necessary details regarding the study's use classification for all pertinent endpoints, including non-apical endpoints within the study (e.g., note all study classifications for each endpoint if the use varies)*

Major Deficiencies (note any stated exclusions): *Check all that apply. Checking any of these items make the study "**Not Acceptable for Use**"*

_____ Mixture (for controlled experiments only)
_____ No Controls (for controlled experiments only)
_____ Excessive Control Mortality (> 10% for acute and > 20% for chronic)
_____ Dilution water not adequately characterized
_____ Bioaccumulation: steady state not reached
_____ Dermal or Injection Exposure Pathway
_____ Review paper or previously published without modification
_____ Other: *(if any, list here*)

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POTENTIAL CHEMICAL MIXTURES: *Describe any potential chemicals mixtures as characterized by study authors (including any confirmation of chemical mixtures).*

DESCRIPTION OF DILUTION WATER: *Describe concerns with characterization of and/or major deficiencies with dilution water.*

General Notes:

Minor Deficiencies: *List and describe any minor deficiencies or other concerns with test. These items may make the study "**Acceptable for Qualitative Use**"* **(exceptions may apply as noted)**

***For Field Studies/Observations**: A field study/observation may be considered "**Acceptable for Quantitative Use**" if it consisted of a range of exposure concentrations and the observed effects are justifiably contributed to a single chemical exposure*

_____ Mixture (observed effects not justifiably contributed to single chemical exposure)
_____ Uncharacterized Reference Sites/Conditions

POTENTIAL CHEMICAL MIXTURES PRESENT AT SITE: *Describe any potential chemicals mixtures present at the site as characterized by study authors (including any confirmation of chemicals present at study site).*

EXPOSURE VARIABILITY ACROSS STUDY SITE(S): *Describe any exposure variability across study site(s) as characterized by study authors (i.e., description of study design with reference and contaminated sites).*

General Notes:

Reviewer's Comments: *Provide additional comments that do not appear under other sections of the DER.*

ABSTRACT: *Copy and paste abstract from publication.*

SUMMARY*: Fill out and modify as needed.*

Acute:

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Hardness (mg/L as $CaCO_3$) or Salinity (ppt)	DOC (mg/L)	Effect	Reported Effect Concentration (mg/L)	Verified Effect Concentration (mg/L)	Classification
											Quantitative / Qualitative / Unused

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

Chronic:

Species (lifestage)	Method[a]	Test Duration	Chemical / Purity	pH	Temp. (°C)	Hardness (mg/L as $CaCO_3$) or Salinity (ppt)	DOC (mg/L)	Chronic Limits	Reported Chronic Value (mg/L or µg/g)	Verified Chronic Value (mg/L or µg/g)	Chronic Value Endpoint	Classification
												Quantitative / Qualitative / Unused

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

II. Results *Provide results as reported in the publication (including supplemental materials). Include screen shots of tables and/or figures reporting results from the article following tabulated data table in each associated results section for all studies. Complete tabulated data tables for all studies for studies marked "**Acceptable for Quantitative Use"** and **"Acceptable for Qualitative Use**".*

Water Quality Parameters: *If only general summary data of water quality parameters is provided by study authors (i.e., no specific details of water quality parameters on a treatment level is provided), summarize any information regarding water quality parameters under General Notes below and indicate data not provided in* Table A.II.1.

General Notes: *For aquatic life criteria development, measured water quality parameters in the treatments nearest the toxicity test endpoint(s), e.g., LC_{50}, EC_{20}, etc., are most relevant.*

-

Table A.II.1. Measured Water Quality Parameters in Test Solutions.

Dissolved oxygen, temperature, pH and [other parameters (hardness, salinity, DOC)] in test solutions during the *[X]*-day exposure of *[test organism]* to *[concentration of treatment(s)]* of *[test substance]* under *[static renewal/flow-through]* conditions.

Parameter	Treatment	Mean	Range
Dissolved Oxygen (% saturation or mg/L)	*[1]*		
	[2]		
	j		
	j		
Temperature (°C)	*[1]*		
	[2]		
	j		
	j		
pH	*[1]*		
	[2]		
	j		
	j		
Other (e.g., hardness, salinity, DOC)	*[1]*		
	[2]		
	j		
	j		

Chemical Concentrations: *Summarize the concentration verification data from test solutions/media. Expand table to include measured concentration data for each media type (i.e., water, diet, muscle, liver, blood, etc.).*

General Notes: *Provide any necessary detail regarding the measured concentrations, including any identified cause for substantial differences between nominal and measured concentrations, if samples were collected on separate days (and if so provide details), and any potential cross contamination.*

Table A.II.2. Measured (and Nominal) Chemical Concentrations in Test Solutions/Media.

[Analytical Method] verification of test and control concentrations during an [X]-day exposure of [test organism] to [test substance] under [static renewal/flow-through] conditions.

Treatment	Nominal Concentration (units)	[Mean] Measured Concentration (units)	Number of Samples	Non-Detect[a]	Number of Samples Below Non-Detect	[Standard Deviation or Standard Error]	Range
Control							
[1]							
[2]							
[3]							
[4]							
[5]							
[6]							
j							

[a]Non-Detect: 0 = measured and detected; 1= measured and not detected; if not measured or reported enter as such

Mortality: *Briefly summarize mortality results (if any).*

General Notes: *Comment on concentrations response relationship and slope of response if provided. Compare mortality in treatments with control group and/or the reference chemical.*

Table A.II.3. Mean Percent [Mortality or Survival].

Mean percent mortality [or number of immobilized, survival] of [test organism] exposed to [test substance] for [test duration] under [static/renewal/flow-through] conditions.

Treatment	[Mean % Mortality]	[Standard Deviation or Standard Error]
Control		
[1]		
[2]		
[3]		
[4]		
[5]		
[6]		
[LCx]		
NOEC		
LOEC		

[a] Use superscript to identify the values reported to be significantly different from control.

Growth: *Briefly summarize growth results (if any).*

General Notes: *Comment on concentrations response relationship and slope of response if provided. Compare growth endpoints in treatments with control group and/or the reference chemical.*

Table A.II.4. Mean [Growth].

Mean growth [length and/or weight] of [test organism] exposed to [test substance] for [test duration] under [static/renewal/flow-through] conditions.

Treatment	Mean Growth [Length/Weight] (units)	[Standard Deviation or Standard Error]	Mean Percent Change in [Length/ Biomass]	[Standard Deviation or Standard Error]
Control				
[1]				
[2]				
[3]				
[4]				
[5]				
[6]				
j				
[ECx]				
NOEC				
LOEC				

[a] Use superscript to identify the values reported to be significantly different from control.

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Reproductive: *Briefly summarize reproduction endpoint results (if any). For multi-generational studies, copy and paste* Table A.II.5 *below for each generation with reproductive effects data.*

General Notes: *Comment on concentrations response relationship and slope of response if provided. Compare reproductive endpoints in treatments with control group and/or the reference chemical.*

Table A.II.5. Mean [Reproductive] Effect.

Mean [reproductive] effects for [generation] of [test organism] exposed to [test substance] for [test duration] under [static/renewal/flow-through] conditions.

Treatment (units)	[Mean Number of Spawns]	[Standard Deviation or Standard Error]	[Mean Number of Eggs]	[Standard Deviation or Standard Error]	[Mean Percent Hatch]	[Standard Deviation or Standard Error]	[Mean Hatch Percent Survival Post]	[Standard Deviation or Standard Error]
Control								
[1]								
[2]								
[3]								
[4]								
[5]								
[6]								
j								
[ECx]								
NOEC								
LOEC								

[a] Use superscript to identify the values reported to be significantly different from control.

Sublethal Toxicity Endpoints: *Include other sublethal effect(s), including behavioral abnormalities or other signs of toxicity, if any. Copy* Table A.II.6 *as needed to provide details for each sublethal effect observed.*

General Notes: *Briefly summarize observed sublethal effects otherwise not captured in the results table(s) below.*

Table A.II.6. Mean [Sublethal] Effect.

*Mean [*Sublethal effect, *(e.g., behavioral abnormalities, etc.)]* in *[test organism]* during [test duration (*acute/chronic*)] exposure to *[test substance]* under *[static/renewal/flow-through]* conditions.

Treatment	[Mean Sublethal Response] (units)	[Standard Deviation or Standard Error]
Control		
[1]		
[2]		
[3]		
[4]		
[5]		
[6]		
j		
[ECx]		
NOEC		
LOEC		

[a] Use superscript to identify the values reported to be significantly different from control

Reported Statistics: *Copy and paste statistical section from publication*

Part B: Detailed Review

I. Materials and Methods

Protocol/Guidance Followed: *Indicate if provided by authors.*

Deviations from Protocol: *If authors report any deviations from the protocol noted above indicate here.*

Study Design and Methods: *Copy and paste methods section from publication.*

TEST ORGANISM: *Provide information under Details and any relevant or related information or clarifications in Remarks.*

Parameter	Details	Remarks
Species:	Common Name: Scientific Name:	North American species? ____ Surrogate for North American Taxon? ____ *(Place X if applicable)*

Strain/Source:
• Wild caught from unpolluted areas [1]
  o Quarantine for at least 14 days or until they are disease free, before acclimation [1]
• Must originate from same source and population [1]
• Should not be used:
  o If appeared stressed, such as discoloration or unusual behavior [1]
  o If more than 5% die during the 48 hours before test initiation [1]
  o If they were used in previous test treatments or controls [2]
• No treatments of diseases may be administered:
  o Within 16 hour of field collection [1]
  o Within 10 days or testing or during testing [1]		

Age at Study Initiation:
Acute:
• Juvenile stages preferred [1]
Chronic:
• Life-cycle test:
  o Embryos or newly hatched young < 48 hours old [2]
• Partial life-cycle test:
  o Immature juveniles at least 2 months prior to active gonad development [2]
• Early life-stage test:
  o Shortly after fertilization [2]		

Was body weight or length recorded at test initiation?	____ Yes ____ No	
Was body weight or length recorded at regular intervals?	____ Yes ____ No *If yes, describe regular intervals:*	

STUDY PARAMETERS: *Provide information under Details and any relevant information of deficiencies in Remarks. Complete for both Controlled Experiments and Field Studies/Observations.*

	Parameter	Details	Remarks
For Both Controlled Experiments and Field Observations	**Number of Replicates per Treatment Group:** • At least 2 replicates/treatment recommended for acute tests [1] • At least 2 replicates/treatment recommended for chronic tests [3]	Control(s): Treatment(s):	
	Number of Organisms per Replicate/ Treatment Group: • At least 10 organisms/treatment recommended [3] • At least 7 organisms/treatment acceptable [4]	Control(s): Treatment(s):	
	Exposure Pathway: *(i.e., water, sediment, gavage, or diet).* *Note: all other pathways (e.g., dermal, single dose via gavage, and injection) are unacceptable.*		
	Exposure Duration: **Acute** • Should be 96 hours [2] **Chronic** • Life-cycle tests: o Ensure that all life stages and life processes are exposed [2] o Begin with embryos (or newly hatched young), continue through maturation and reproduction, and should end not less than 24 days (90 days for salmonids) after the hatching of the next generation [2] • Partial life-cycle tests: o Allowed with species that require >1 year to reach sexual maturity, so that all major life stages can be exposed to the test material in <15 months [2] o Begin with immature juveniles at least 2 months prior to active gonad development, continue through maturation and reproduction, and end not less than 24 days (90 days for salmonids) after the hatching of the next generation [2] • Early life-cycle tests: o 28 to 32 day (60 day post hatch for salmonids) exposures from shortly after fertilization through embryonic, larval, and early juvenile development [2]	____ Acute ____ Partial Life Cycle ____ Early Life Stage ____ Full Life Cycle ____ Other *(please remark):*	
	Test Concentrations (remember units): *Recommended test concentrations include at least three concentrations other than the control; four or more will provide a better statistical analysis* [3]	Nominal: Measured: Media measured in:	
	Observation Intervals: • Should be an appropriate number of observations over the study to ensure water quality is being properly maintained [4]		

CONTROLLED EXPERIMENT STUDY PARAMETERS: *Provide information under Details and any relevant information of deficiencies in Remarks. Complete for Controlled Experiments only.*

For Controlled Experiments Only

Parameter	Details	Remarks
Acclimation/Holding: • Should be placed in a tank along with the water in which they were transported o Water should be changed gradually to 100% dilution water (usually 2 or more days) [1] o For wild-caught animals, test water temperature should be within 5°C of collection water temperature [1] o Temperature change rate should not exceed 3°C within 72 hours [1] • To avoid unnecessary stress and promote good health: o Organisms should not be crowded [1] o Water temperature variation should be limited [1] o Dissolved oxygen: ▪ Maintain between 60 – 100% saturation [1] ▪ Continuous gentle aeration if needed [1] o Unionized ammonia concentration in holding and acclimation waters should be < 35 µg/L [1]	Duration: Feeding: Water type: Temperature (°C): Dissolved Oxygen (mg/L): Health (*any mortality observed?*):	*Identify number of individuals excluded from testing and/or analysis (if any):*
Acclimation followed published guidance? *Describe, if any*	____ Yes ____ No *If yes, indicate which guidance:*	
Test Vessel: • Test chambers should be loosely covered [1] • Test chamber material: o Should minimize sorption of test chemical from water [1] o Should not contain substances that can be leached or dissolved in solution and are free of substances that could react with exposure chemical [1] o Glass, No. 316 stainless steel, nylon screen and perfluorocarbon (e.g. Teflon) are acceptable [1] o Rubber, copper, brass, galvanized metal, epoxy glues, lead and flexible tubing should not come into contact with test solution, dil. Water, or stock [1] • Size/volume should maintain acceptable biomass loading rates (see Biomass Loading Rate below) [1]	Material: Size: Fill Volume:	*Briefly describe the test vessel:*
Test Solution Delivery System/Method: • Flow-through preferred for some highly volatile, hydrolysable or degradable materials [2] o Concentrations should be measured often enough using acceptable analytical methods [2] • Chronic exposures: o Flow-through, measured tests required [2]	Test Concentrations Measured ____ Yes ____ No Test Solution Delivery System: ____ Static ____ Renewal *Indicate Interval:* ____ Flow-through *Indicate Type of Diluter:*	
Source of Dilution Water: • Freshwater hardness range should be < 5 mg/L or < 10% of the average (whichever is greater) [1] • Saltwater salinity range should be < 2 g/kg or < 20% of the average (whichever is greater) [1] • Dilution water must be characterized (natural surface water, well water, etc.) [3] o Distilled/deionized water without the addition of appropriate salts should not be used [2] • Dilution water in which total organic carbon or particulate matter >5 mg/L should not be used [2] o Unless data show that organic carbon or particulate matter do not affect toxicity [2]		
Dilution Series (*e.g., 0.5x, 0.6x, etc.*):		

	Parameter	Details	Remarks
For Controlled Experiments Only	**Dilution Water Parameters:** *Measured at the beginning of the experiment or averaged over the duration of the experiment (details of water quality parameters measured in test solutions should be included under the results section)*	Dissolved Oxygen (mg/L): pH: Temperature (°C): Hardness (mg/L as $CaCO_3$): Salinity (ppt): Total Organic Carbon (mg/L): Dissolved Organic Carbon (mg/L):	
	Aeration: • Acceptable to maintain dissolved oxygen at 60 – 100% saturation at all times [1] • Avoid aeration when testing highly oxidizable, reducible and volatile materials [1] • Turbulence should be minimized to prevent stress on test organisms and/or re-suspend fecal matter [1] • Aeration should be the same in all test chambers at all times [1]	____ Yes ____ No	
	Describe Preparation of Test Concentrations (e.g., water exposure, diet):		
	Test Chemical Solubility in Water: *List units and conditions (e.g., 0.01% at 20ºC)*		
	Were concentrations in water or diet verified by chemical analysis? *Measured test concentrations should be reported in* Table A.II.2 *above.*	__Yes __No *Indicate media:*	
	Were test concentrations verified by chemical analysis in tissue? *Measured test concentrations can be verified in test organism tissue (e.g., blood, liver, muscle) alone if a dose-response relationship is observed.* *Measured test concentrations should be reported in* Table A.II.2 *above.*	__Yes __No *Indicate tissue type:*	*If test concentrations were verified in test organism tissue, was a dose-response relationship observed?*
	Were stability and homogeneity of test material in water/diet determined?	__Yes __No	
	Was test material regurgitated/avoided?	__Yes __No	
	Solvent/Vehicle Type (Water or Dietary): • When used, a carrier solvent should be kept to a minimum concentration [1] • Should not affect either survival or growth of test organisms [1] • Should be reagent grade or better [1] • Should not exceed 0.5 ml/L (static) or 0.1 ml/L (flow through) unless it was shown that higher concentrations do not affect toxicity [3]		
	Negative Control:	____ Yes ____ No	
	Reference Toxicant Testing:	____ Yes ____ No	*If Yes, identify substance:*
	Other Control: *If any (e.g. solvent control)*		

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	Biomass Loading Rate: • Loading should be limited so as not to affect test results. Loading will vary depending on temperature, type of test (static vs. flow-through), species, food/feeding regime, chamber size, test solution volume, etc. [1] • This maximum number would have to be determined for the species, test duration, temperature, flow rate, test solution volume, chamber size, food, feeding regime, etc. • Loading should be sufficiently low to ensure: o Dissolved oxygen is at least 60% of saturation (40% for warm-water species) [1,5] o Unionized ammonia does not exceed 35 µg/L [1] o Uptake by test organisms does not lower test material concentration by > 20% [1] o Growth of organisms is not reduced by crowding • Generally, at the end of the test, the loading (grams of organisms; wet weight; blotted dry) in each test chamber should not exceed the following: o Static tests: > 0.8 g/L (lower temperatures); > 0.5 g/L (higher temperatures) [1] o Flow through tests: > 1 g/L/day or > 10 g/L at any time (lower temperatures); > 0.5 g/L/day or > 5 g/L at any time (higher temperatures) [1] • Lower temperatures are defined as the lower of 17˚C or the optimal test temperature for that species [1]		

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	Parameter	Details	Remarks

For Controlled Experiments Only	**Feeding:**
	• Unacceptable for acute tests [2]
	  o Exceptions:
	  ▪ Data indicate that the food did not affect the toxicity of the test material [2]
	  ▪ Test organisms will be severely stressed if they are unfed for 96 hours [2]
	  ▪ Test material is very soluble and does not sorb or complex readily (e.g., ammonia) [2]
		____ Yes ____ No	

	Lighting:
	• Depends on the type of test (acute or chronic) and endpoint (e.g., reproduction) of interest.
	  o Embryos should be incubated under dim incandescent lighting (≤ 20 fc) or total darkness during early life-stage toxicity testing
	  o Embryos must not be subjected to prolonged exposure to direct sunlight, fluorescent lighting, or high intensity incandescent lighting
	• Generally, ambient laboratory levels (50-100 fc) or natural lighting should be acceptable, as well as a diurnal cycle consisting of 50% daylight or other natural seasonal diurnal cycle.
	• Artificial light cycles should have a 15 – 30-minute transition period to avoid stress due to rapid increases in light intensity [1]		

Study Design/Methods Classification: *(Place X by One Based on Overall Study Design/Methods Classification)*
Provide details of Major or Minor Deficiencies/Concerns with Study Design in Associated Sections of Part A: Overview
This classification should be taken into consideration for the overall study classification for aquatic life criteria development in Part A.

_____ Study Design Acceptable for Quantitative Use
_____ Study Design Acceptable for Qualitative Use
_____ Study Design Not Acceptable for Use

Additional Notes: *Provide additional considerations for the classification of study use based on the study design.*

OBSERVATIONS: *Provide information under Details and any relevant information in Remarks. This information should be consistent with the Results Section in Part A.*

Parameter	Details	Remarks

Parameters measured including sublethal effects/toxicity symptoms:
Common Apical Parameters Include:
Acute
• EC_{50} based on percentage of organisms exhibiting loss of equilibrium plus the percentage of organisms immobilized plus percentage of organisms killed [2]
  ○ If not available, the 96-hr LC_{50} should be used [2]
Chronic
• Life-cycle/Partial Life-cycle test:
  ○ Survival and growth of adults and young, maturation of males and females, eggs spawned per female, embryo viability (salmonids only), and hatchability [2]
• Early life-cycle test:
  ○ Survival and growth [2]
	List parameters:	

Was control survival acceptable? **Acute** • > 90% control survival at test termination [2] **Chronic** • > 80% control survival at test termination [2]	____ Yes ____ No Control survival (%):	
Were individuals excluded from the analysis?	____ Yes ____ No *If yes, describe justification provided:*	
Was water quality in test chambers acceptable? • If appropriate, describe any water quality issues (e.g., dissolved oxygen level below 60% of saturation)	____ Yes ____ No	
Availability of concentration-response data: • Were treatment level concentration-response data included in study publication (can be from tables, graphs, or supplemental materials)? *Specify endpoints in remarks* • Were replicate level concentration-response data included in study publication (can be from tables, graphs, or supplemental materials)? *specify endpoints in remarks* • If treatment and/or replicate level concentration-response data were included, how was data presented? *(check all that apply)* • Were concentration-response data estimated from graphs study publication or supplemental materials? • Should additional concentration-response data be requested from study authors? *If concentration-response data are available, complete **Verification of Statistical Results (Part C)** for sensitive species.*	____ Yes ____ No ____ Yes ____ No ____ Tables ____ Graphs ____ Supplemental Files ____ Yes ____ No *If yes, indicate software used:* ____ Yes ____ No Requested by: Request date: Date additional data received:	

Part C: Statistical Verification of Results

I. Statistical Verification Information: *Report the statistical methods (e.g., EPA TRAP, BMDS, R, other) used to verify the reported study or test results for the five (5) most sensitive genera and sensitive apical endpoints (including for tests where such estimates were not provided). If values for the LC_{50}, LT_{50} and NOEC are greater than the highest test concentration, use the ">" symbol.*

Primary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)

Secondary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)
(*At least one reviewer should be from EPA for sensitive taxa*)

Endpoint(s) Verified:

Additional Calculated Endpoint(s):

Statistical Method (e.g., TRAP, BMDS, R, other):

II. Toxicity Values: *Include confidence intervals if applicable*

NOEC:
LOEC:
MATC:

EC_5:
EC_{10}:
EC_{20}:
EC_{50} or LC_{50}

Dose-Response Curve Classification: *(Place X by One)*
This classification should be taken into consideration for the overall study classification for aquatic life criteria development in Part A

_____ Dose-Response Curve Acceptable for Quantitative Use
_____ Dose-Response Curve Acceptable for Qualitative Use
_____ Dose-Response Curve Not Acceptable for Use

Summary of Statistical Verification: *Provide summary of methods used in statistical verification.*

Additional Notes:

Attachments:

1. *Provide attachments to ensure all data used in Part C are captured, whether from study results reported in the publication and/or from additional data requested from study authors*
    - *Data from study results of the publication should be reported in Results section of Part A*
    - *Additional data provided upon request from study authors should be reported in Table C.II.1 below and original correspondence with study authors should be included as attachments*
2. *Model assessment output (including all model figures, tables, and fit metrics)*
3. *Statistical code used for curve fitting*

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III. Attachments: *Include all attachments listed above after the table below.*

Additional Data Used in Response-Curve: *Provide all data used to fit dose-response curve not captured in Results section of DER above in Part A. Add rows as needed. First row in italicized text is an example.*

Table C.II.1 Additional Data Used in Dose-Response Curve.

Curve ID	Species	Endpoint	Treatment	Replicate	[Standard Deviation or Standard Error]	# of Survivors	N[a]	k[a]	n[a]	Response	Response Unit	Conc	Conc units
Alchronic1	*Ceriodaphnia dubia*	*# of young/female*	*0*	*6*			*10*	*10*	*1*	*18*	*count*	*0.03*	*mg/L*

[a] N = number of individuals per treatment; k = number of replicates per treatment level; n = number of individuals per replicate

Part D: References to Test Guidance

1. ASTM Standard E 739, 1980. 2002. Standard guide for conducting acute toxicity tests on test materials with fishes, macroinvertebrates, and amphibians. ASTM International, West Conshohocken, PA.
2. Stephan, C.E., D.I. Mount, D.J. Hansen, J.H. Gentile, G.A. Chapman and W.A. Brungs. 1985. Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and their Uses. PB85-227049. National Technical Information Service, Springfield, VA.
3. Stephan, C.E. 1995. Review of results of toxicity tests with aquatic organisms. Draft. U.S. EPA, MED. Duluth, MN. 13 pp.
4. OECD 203. 1992. Test No. 203: Fish, Acute Toxicity Test. OECD Guidelines for the Testing of Chemicals, Section 2, OECD Publishing, Paris, https://doi.org/10.1787/9789264069961-en.
5. American Public Health Association (APHA). 2012. Standard methods for the examination of water and wastewater. Part 8000 - Toxicity. APHA. Washington, DC.

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P.2 Example Aquatic Invertebrate DER

Part A: Overview

I. Test Information

Chemical name:

CAS name: CAS Number:
Purity: Storage conditions:
Solubility in Water (units):

____ **Controlled Experiment** (*manipulated*) ____ **Field Study/Observation** (*not manipulated*) (*Place X by One*)

Primary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)

Secondary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)
(*At least one reviewer should be from EPA for sensitive taxa*)

Citation: *Indicate: author(s), year, study title, journal, volume, and pages.*
(e.g., Keller, A.E and S.G. Zam. 1991. The acute toxicity of selected metals to the freshwater mussel, *Anodonta imbecilis*. Environ. Toxicol. Chem. 10(4): 539-546.)

Companion Papers: *Identify any companion papers associated with this paper using the citation format above.*

Were other DERs completed for Companion Papers? ____ **Yes** ____ **No** (*If yes, list file names of DERs below*)

Study Classification for Aquatic Life Criteria Development:

_____ Acceptable for Quantitative Use
_____ Acceptable for Qualitative Use
_____ Not Acceptable for Use/Unused

General Notes: *Provide any necessary details regarding the study's use classification for all pertinent endpoints, including non-apical endpoints within the study (e.g., note all study classifications for each endpoint if the use varies)*

Major Deficiencies (note any stated exclusions): *Check all that apply. Checking any of these items make the study "**Not Acceptable for Use**"*

_____ Mixture (for controlled experiments only)
_____ No Controls (for controlled experiments only)
_____ Excessive Control Mortality (> 10% for acute and > 20% for chronic)
_____ Dilution water not adequately characterized
_____ Bioaccumulation: steady state not reached
_____ Dermal or Injection Exposure Pathway
_____ Review paper or previously published without modification
_____ Other: *(if any, list here)*

POTENTIAL CHEMICAL MIXTURES: *Describe any potential chemicals mixtures as characterized by study authors (including any confirmation of chemical mixtures).*

DESCRIPTION OF DILUTION WATER: *Describe concerns with characterization of and/or major deficiencies with dilution water.*

General Notes:

Minor Deficiencies: *List and describe any minor deficiencies or other concerns with test. These items may make the study "**Acceptable for Qualitative Use**"* **(exceptions may apply as noted)**

***For Field Studies/Observations**: A field study/observation may be considered "**Acceptable for Quantitative Use**" if it consisted of a range of exposure concentrations and the observed effects are justifiably contributed to a single chemical exposure*

_____ Mixture (observed effects not justifiably contributed to single chemical exposure)
_____ Uncharacterized Reference Sites/Conditions

POTENTIAL CHEMICAL MIXTURES PRESENT AT SITE: *Describe any potential chemicals mixtures present at the site as characterized by study authors (including any confirmation of chemicals present at study site).*

EXPOSURE VARIABILITY ACROSS STUDY SITE(S): *Describe any exposure variability across study site(s) as characterized by study authors (i.e., description of study design with reference and contaminated sites).*

General Notes:

Reviewer's Comments: *Provide additional comments that do not appear under other sections of the template*.

ABSTRACT: *Copy and paste abstract from publication.*

SUMMARY*: Fill out and modify as needed.*

Acute:

Species (lifestage)	Method[a]	Test duration	Chemical / Purity	pH	Temp. (°C)	Hardness (mg/L as $CaCO_3$) or Salinity (ppt)	DOC (mg/L)	Effect	Reported Effect Concentration (mg/L)	Verified Effect Concentration (mg/L)	Classification
											Quantitative / Qualitative / Unused

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

Chronic:

Species (lifestage)	Method[a]	Test duration	Chemical / Purity	pH	Temp. (°C)	Hardness (mg/L as $CaCO_3$) or Salinity (ppt)	DOC (mg/L)	Chronic Limits	Reported Chronic Value (mg/L or µg/g)	Verified Chronic Value (mg/L or µg/g)	Chronic Value Endpoint	Classification
												Quantitative / Qualitative / Unused

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured, T=total, D=dissolved, Diet=dietary, MT=maternal transfer

II. Results *Provide results as reported in the publication (including supplemental materials). Include screen shots of tables and/or figures reporting results from the article following tabulated data table in each associated results section for all studies. Complete tabulated data tables for all studies for studies marked "**Acceptable for Quantitative Use**" and "**Acceptable for Qualitative Use**".*

Water Quality Parameters: *If only general summary data of water quality parameters is provided by study authors (i.e., no specific details of water quality parameters on a treatment level is provided), summarize any information regarding water quality parameters under General Notes below and include data not provided in* Table A.II.1.

General Notes: *For aquatic life criteria development, measured water quality parameters in the treatments nearest the toxicity test endpoint(s), e.g., LC_{50}, EC_{20}, etc., are most relevant.*

Table A.II.1. Measured Water Quality Parameters in Test Solutions.

Dissolved oxygen, temperature, pH and [other parameters (hardness, salinity, DOC)] in test solutions during the *[X]*-day exposure of *[test organism]* to *[concentration of treatment(s)]* of *[test substance]* under *[static renewal/flow-through]* conditions.

Parameter	Treatment	Mean	Range
Dissolved oxygen (% saturation or mg/L)	*[1]*		
	[2]		
	j		
	j		
Temperature (°C)	*[1]*		
	[2]		
	j		
	j		
pH	*[1]*		
	[2]		
	j		
	j		
Other (e.g., hardness, salinity, DOC)	*[1]*		
	[2]		
	j		
	j		

Chemical Concentrations: *Summarize the concentration verification data from test solutions/media. Expand table to include each measured concentration data for each media type (i.e., muscle, liver, blood, etc.).*

General Notes: *Provide any necessary detail regarding the measured concentrations, including any identified cause for substantial differences between nominal and measured concentrations, if samples were collected on separate days (and if so provide details), and any potential cross contamination.*

Table A.II.2. Measured (and Nominal) Chemical Concentrations in Test Solutions/Media.

[Analytical Method] verification of test and control concentrations during an [X]-day exposure of [test organism] to [test substance] under [static renewal/flow-through] conditions.

Treatment	Nominal Concentration (units)	[Mean] Measured Concentration (units)	Number of Samples	Non-Detect[a]	Number of Samples Below Non-Detect	[Standard Deviation or Standard Error]	Range
Control							
[1]							
[2]							
[3]							
[4]							
[5]							
[6]							
j							

[a]Non-Detect: 0 = measured and detected; 1=measured and not detected; if not measured or reported enter as such

Mortality: *Briefly summarize mortality results (if any).*

General Notes: *Comment on concentrations response relations and slope of response if provided. Compare mortality with control treatment and/or the reference chemical.*

Table A.II.3. Mean Percent [Mortality or Survival].

Mean percent mortality [or number of immobilized] or survival of [test organism] exposed to [test substance] for [test duration] under [static/renewal/flow-through] conditions.

Treatment	[Mean % Mortality]	[Standard Deviation or Standard Error]
Control		
[1]		
[2]		
[3]		
[4]		
[5]		
[6]		
[LC_x]		
NOEC		
LOEC		

[a] Use superscript to identify the values reported to be significantly different from control.

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Growth: *Briefly summarize growth results (if any).*

General Notes: *Comment on concentrations response relations and slope of response if provided. Compare growth endpoints with control treatment and/or the reference chemical.*

Table A.II.4. Mean [Growth].

Mean growth [length and/or weight] of [test organism] exposed to [test substance] for [test duration] under [static/renewal/flow-through] conditions.

Treatment	Mean Growth [Length/Weight] (units)	[Standard Deviation or Standard Error]	Mean Percent Change in [Length/ Biomass]	[Standard Deviation or Standard Error]
Control				
[1]				
[2]				
[3]				
[4]				
[5]				
[6]				
j				
[EC_x]				
NOEC				
LOEC				

[a] Use superscript to identify the values reported to be significantly different from control.

Reproductive: *Briefly summarize reproduction endpoint results (if any). For multi-generational studies, copy and paste* Table A.II.5 *below for each generation with reproductive effects data.*

General Notes: *Comment on concentrations response relations and slope of response if provided. Compare reproduction endpoints with control treatment and/or the reference chemical.*

Table A.II.5. Mean [Reproductive] Effect.

Mean [reproductive] effects for [generation] of [test organism] exposed to [test substance] for [test duration] under [static/renewal/flow-through] conditions.

Treatment (units)	[Mean Number of Spawns]	[Standard Deviation or Standard Error]	[Mean Number of Eggs]	[Standard Deviation or Standard Error]	[Mean Number of Offspring]	[Standard Deviation or Standard Error]
Control						
[1]						
[2]						
[3]						
[4]						
[5]						
[6]						
j						
[ECx]						
NOEC						
LOEC						

[a] Use superscript to identify the values reported to be significantly different from control.

Sublethal Toxicity Endpoints: *Include other sublethal effect(s), including behavioral abnormalities or other signs of toxicity, if any. Copy Table A.II.6 as needed to provide details for each sublethal effect observed.*

General Notes: *Briefly summarize observed sublethal effects otherwise not captured in the results table(s) below.*

Table A.II.6. Mean [Sublethal] Effect.

*Mean [*Sublethal effect, *(e.g., behavioral abnormalities, etc.)]* in *[test organism]* during [test duration (*acute/chronic*)] exposure to *[test substance]* under *[static/renewal/flow-through]* conditions.

Treatment	[Mean Sublethal Response] (units)	[Standard Deviation or Standard Error]
Control		
[1]		
[2]		
[3]		
[4]		
[5]		
[6]		
j		
[ECx]		
NOEC		
LOEC		

[a] Use superscript to identify the values reported to be significantly different from control

Reported Statistics: *Copy and paste statistical section from publication.*

Part B: Detailed Review

I. Materials and Methods

PROTOCOL/GUIDANCE FOLLOWED: *Indicate if provided by authors.*

DEVIATIONS FROM PROTOCOL: *If authors report any deviations from the protocol noted above indicate here.*

Study Design and Methods: *Copy and paste methods section from publication.*

TEST ORGANISM: *Provide information under Details and any relevant or related information or clarifications in Remarks.*

Parameter	Details	Remarks
Species:	Common Name: Scientific Name:	North American species? ____ Surrogate for North American Taxon? ____ *(Place X if applicable)*

Strain/Source:
• Wild caught from unpolluted areas [1]
  o Quarantine for at least 7 days or until they are disease free, before acclimation [1]
• Must originate from same source and population [1]
• Should not be used:
  o If appeared stressed, such as discoloration or unusual behavior [1]
  o If more than 5% die during the 48 hours before test initiation [1]
  o If they were used in previous test treatments or controls [2]
• No treatments of diseases may be administered:
  o Within 16 hours of field collection [1]
  o Within 10 days of testing or during testing [1]		

Age at Study Initiation:
Acute:
• Larval stages preferred [1]
• Mayflies and Stoneflies
  o Early instar [1]
• Daphnids/cladocerans:
  o < 24-hr old [1]
• Midges:
  o 2nd or 3rd instar larva [1]
• *Hyalella azteca* (chronic exposure)
  o Generally, 7 - 8 days old [3]
• Freshwater mussels (chronic exposure)
  o Generally, 2 month old juveniles [4]
• Mysids (chronic exposure)
  o < 24-hr old [1]		

Was body weight or length recorded at test initiation and/or at regular intervals?	____ Yes ____ No	
Was body weight or length recorded at regular intervals?	____ Yes ____ No *If yes, describe regular intervals:*	

STUDY PARAMETERS: *Provide information under Details and any relevant information of deficiencies in Remarks. Complete for both Controlled Experiments and Field Studies/Observations.*

For Both Controlled Experiments and Field Observations

Parameter	Details	Remarks
Number of Replicates per Treatment Group: • At least 2 replicates/treatment recommended for acute tests [1] • At least 2 replicates/treatment recommended for chronic tests [5]	Control(s):	
	Treatment(s):	
Number of Organisms per Replicate/ Treatment Group: • At least 10 organisms/treatment recommended.	Control(s):	
	Treatment(s):	
Exposure Pathway: *(i.e., water, sediment, or diet). Note: all other pathways (e.g., dermal, injection) are unacceptable.*		
Exposure Duration: **Acute** • Cladocerans and midges should be 48 hours [2] o Longer durations acceptable if test species not fed and had acceptable controls [2] • Freshwater mussel glochidia should be a maximum of 24 hours [4] o Shorter durations (6, 12, 18 hours) acceptable so long as 90% survival of control animals achieved (see below) [4] • Embryo/larva (bivalve mollusks, sea urchins, lobsters, crabs, shrimp and abalones) should be 96 hours, but at least 48 hours [2] • Other invertebrate species should be 96 hours **Chronic** • Daphnids/cladocerans should be 21 days (3-brood test) [2] o Exception 7 days acceptable for *Ceriodaphnia dubia* [2] • Freshwater juvenile mussels should be at least 28 days [4] • *Hyalella azteca* should be at least 42 days o Beginning with 7 - 8 day old animals [3] • Mysids should continue until 7 days past the median time of first brood release in the controls [4]	____ Acute ____ Chronic ____ Other *(please remark):*	
Test Concentrations (remember units): *Recommended test concentrations include at least three concentrations other than the control; four or more will provide a better statistical analysis.*	Nominal:	
	Measured:	
	Media measured in:	
Observation Intervals: • Should be an appropriate number of observations over the study to ensure water quality is being properly maintained [1]		

CONTROLLED EXPERIMENT STUDY PARAMETERS: *Provide information under Details and any relevant information of deficiencies in Remarks. Complete for Controlled Experiments only.*

For Controlled Experiments Only

Parameter	Details	Remarks
Acclimation/Holding: • Should be placed in a tank along with the water in which they were transported [1] o Water should be changed gradually to 100% dilution water (usually 2 or more days) [1] o For wild-caught animals, test water temperature should be within 5°C of collection water temperature [1] o Temperature change rate should not exceed 3°C within 72 hours [1] • To avoid unnecessary stress and promote good health: o Organisms should not be crowded [1] o Water temperature variation should be limited o Dissolved oxygen: ▪ Maintain between 60 - 100% saturation [1] ▪ Continuous gentle aeration if needed [1] o Unionized ammonia concentration in holding and acclimation waters should be < 35 µg/L [1]	Duration: Feeding: Water: Temperature (°C): Dissolved Oxygen (mg/L): Health (*any mortality observed?*):	*Identify number of individuals excluded from testing and/or analysis (if any):*
Acclimation followed published guidance? *Describe, if any*	____ Yes ____ No *If yes, indicate which guidance:*	
Test Vessel: • Test chambers should be loosely covered [1] • Test chamber material: o Should minimize sorption of test chemical from water [1] o Should not contain substances that can be leached or dissolved in solution and free of substances that could react with exposure chemical [1] o Glass, No. 316 stainless steel, nylon screen and perfluorocarbon (e.g. Teflon) are acceptable [1] o Rubber, copper, brass, galvanized metal, epoxy glues, lead and flexible tubing should not come into contact with test solution, dilution water or stock [1] • Size/volume should maintain acceptable biomass loading rates (see below) [1] • Substrate: o Required for some species (e.g., *Hyalella azteca*) [3] o Common types: stainless steel screen, nylon screen, quartz sand, cotton gauze and maple leaves [3] o More inert substances preferred over plant material, since plants may break down during testing and promote bacterial growth [3] o Consideration should be given between substrate and toxicant [3] ▪ Hydrophobic organic compounds in particular can bind strongly to Nitex® screen, reducing exposure concentrations, especially for studies using static or intermittent renewal exposure methods [3]	Material: Size: Fill Volume: Substrate Used *(if applicable)*:	*Briefly describe the test vessel here*

	Parameter	Details	Remarks

For Controlled Experiments Only	**Test Solution Delivery System/Method:**
	• Flow-through preferred for some highly volatile, hydrolyzable or degradable materials [2]
	  o Concentrations should be measured often enough using acceptable analytical methods [2]
	• Chronic exposures:
	  o Flow-through, measured tests required [2]
	  o Exception: renewal is acceptable for daphnids [2]
		Test Concentrations Measured
		____ Yes ____ No
		
		Test Solution Delivery System:
		____ Static
		____ Renewal
		Indicate Interval:
		
		____ Flow-through
		Indicate Type of Diluter:	

	Source of Dilution Water:
	• Freshwater hardness range should be < 5 mg/L or < 10% of the average (whichever is greater) [1]
	• Saltwater salinity range should be < 2 g/kg or < 20% of the average (whichever is greater) [1]
	• Dilution water must be characterized (natural surface water, well water, etc.) [2]
	  o Distilled/deionized water without the addition of appropriate salts should not be used [2]
	• Dilution water in which total organic carbon or particulate matter exceed 5 mg/L should not be used
	  o Unless data show that organic carbon or particulate matter do not affect toxicity [2]
	• Dilution water for tests with *Hyalella azteca*
	  o Reconstituted waters should have at least 0.02 mg bromide/L; natural ground or surface water presumed to have sufficient bromide [3]
	  o Recommended that control/dilution waters have chloride concentrations at or above 15 mg/L [3]		

	Dilution Series (*e.g., 0.5x, 0.6x, etc.*):		
	Dilution Water Parameters: *Measured at the beginning of the experiment or averaged over the duration of the experiment (details of water quality parameters measured in test solutions should be included under the results section)*	Dissolved Oxygen (mg/L): pH: Temperature (°C): Hardness (mg/L as $CaCO_3$): Salinity (ppt): Total Organic Carbon (mg/L): Dissolved Organic Carbon (mg/L):	
	Aeration: • Acceptable to maintain dissolved oxygen at 60 - 100% saturation at all times [1] • Avoid aeration when testing highly oxidizable, reducible and volatile materials • Turbulence should be minimized to prevent stress on test organisms and/or re-suspend fecal matter [1] • Aeration should be the same in all test chambers at all times [1]	____ Yes ____ No	
	Describe Preparation of Test Concentrations (e.g., water exposure, diet):		

	Parameter	Details	Remarks
For Controlled Experiments Only	**Test Chemical Solubility in Water:** • List units and conditions (e.g., 0.01% at 20ºC)		
	Were concentrations in water or diet verified by chemical analysis? *Measured test concentrations should be reported in* Table A.II.2 *above.*	____ Yes ____ No *Indicate media:*	
	Were test concentrations verified by chemical analysis in tissue? *Measured test concentrations can be verified in test organism tissue (e.g., blood, liver, muscle) alone if a dose-response relationship is observed.* *Measured test concentrations should be reported in* Table A.II.2 *above.*	____ Yes ____ No *Indicate tissue type:*	*If test concentrations were verified in test organism tissue, was a dose-response relationship observed?*
	Were stability and homogeneity of test material in water/diet determined?	____ Yes ____ No	
	Was test material regurgitated/avoided?	____ Yes ____ No	
	Solvent/Vehicle Type: • When used, a carrier solvent should be kept to a minimum concentration [1] • Should not affect either survival or growth of test organisms [1] • Should be reagent grade or better [1] • Should not exceed 0.5 ml/L (static), or 0.1 ml/L (flow through) unless it was shown that higher concentrations do not affect toxicity [5]		
	Negative Control:	____ Yes ____ No	
	Reference Toxicant Testing:	____ Yes ____ No *If yes, identify substance:*	
	Other Control: *If any (e.g. solvent control)*		
	Biomass Loading Rate: • Loading should be limited so as not to affect test results. Loading will vary depending on temperature, type of test (static vs. flow-through), species, food/feeding regime, chamber size, test solution volume, etc. [1] • This maximum number would have to be determined for the species, test duration, temperature, flow rate, test solution volume, chamber size, food, feeding regime, etc. • Loading should be sufficiently low to ensure: o Dissolved oxygen is at least 60% of saturation (40% for warm-water species) [1,6] o Unionized ammonia does not exceed 35 µg/L [1] o Uptake by test organisms does not lower test material concentration by > 20% [1] o Growth of organisms is not reduced by crowding • Generally, at the end of the test, the loading (grams of organisms; wet weight; blotted dry) in each test chamber should not exceed the following: o Static tests: > 0.8 g/L (lower temperatures); > 0.5 g/L (higher temperatures) [1] o Flow through tests: > 1 g/L/day or > 10 g/L at any time (lower temperatures); > 0.5 g/L/day or > 5 g/L at any time (higher temperatures) [1] o Lower temperatures are defined as the lower of 17˚C or the optimal test temperature for that species. [1]		

For Controlled Experiments Only	**Feeding:**
	• Unacceptable for acute tests [2]
	  o Exceptions:
	  ▪ Data indicate that the food did not affect the toxicity of the test material [2]
	  ▪ Test organisms will be severely stressed if they are unfed for 96 hours [2]
	  ▪ Test material is very soluble and does not sorb or complex readily (e.g., ammonia) [2]
		____ Yes ____ No	

	Lighting: • No specific requirements for lighting • Generally, ambient laboratory levels (50 - 100 fc) or natural lighting should be acceptable, as well as a diurnal cycle consisting of 50% daylight or other natural seasonal diurnal cycle • Artificial light cycles should have a 15 - 30 minute transition period to avoid stress due to rapid increases in light intensity [1] • Depends on the type of test (acute or chronic) and endpoint (e.g., reproduction) of interest.		

Study Design/Methods Classification: *(Place X by One Based on Overall Study Design/Methods Classification)*
Provide details of Major or Minor Deficiencies/Concerns with Study Design in Associated Sections of Part A: Overview
This classification should be taken into consideration for the overall study classification for aquatic life criteria development in Part A.

_____ Study Design Acceptable for Quantitative Use
_____ Study Design Acceptable for Qualitative Use
_____ Study Design Not Acceptable for Use

Additional Notes: *Provide additional considerations for the classification of study use based on the study design.*

OBSERVATIONS: *Provide information under Details and any relevant information in Remarks. This information should be consistent with the Results Section in Part A.*

Parameter	Details	Remarks

Parameters measured including sublethal effects/toxicity symptoms:
Common Apical Parameters Include:
Acute
• Daphnids/cladocerans:
  ○ EC_{50} based on percentage of organisms immobilized plus percentage of organisms killed [2]
• Embryo/larva (bivalve molluscs, sea urchins, lobsters, crabs, shrimp, and abalones):
  ○ EC_{50} based on the percentage of organisms with incompletely developed shells plus the percentage of organisms killed [2]
  ▪ If not available, the lower of the 96 hour EC_{50} based on the percentage of organisms with incompletely developed shells and the 96-hr LC_{50} should be used [2]
• Freshwater mussel (glochidia and juveniles):
  ○ Glochidia: EC_{50} based on 100 x number closed glochidia after adding NaCl solution - number closed glochidia before adding NaCl solution) / Total number open and closed glochidia after adding NaCl solution [4]
  ○ Juvenile: EC_{50} based on percentage exhibiting foot movement within a 5-min observation period [4]
• All other species and older life stages:
  ○ EC_{50} based on the percentage of organisms exhibiting loss of equilibrium plus the percentage of organisms immobilized plus the percentage of organisms killed [2]
  ▪ If not available, the 96 hour LC_{50} should be used [2]
Chronic
• Daphnid:
  ○ Survival and young per female [2]
• Mysids:
  ○ Survival, growth and young per female [2]
	List parameters:	

Was control survival acceptable?
Acute
• > 90% control survival at test termination [2]
  ○ Glochidia 90% after 24 hours, or, the next longest duration less than 24 hours that had at least 90% survival [4]
Chronic
• > 80% control survival at test termination [2]
  ○ 80% in 42 day test with *Hyalella azteca*, slightly lower in tests substantially longer than 42 days [3]
	_____ Yes _____ No
	Control survival (%):	

Parameter	Details	Remarks
Were individuals excluded from the analysis?	____ Yes ____ No *If yes, describe justification provided:*	
Was water quality in test chambers acceptable? • If appropriate, describe any water quality issues (e.g., dissolved oxygen level below 60% of saturation)	____ Yes ____ No	
Availability of concentration-response data: • Were treatment level concentration-response data included in study publication (can be from tables, graphs, or supplemental materials)? *specify endpoints in remarks* • Were replicate level concentration-response data included in study publication (can be from tables, graphs, or supplemental materials)? *specify endpoints in remarks* • • If treatment and/or replicate level concentration-response data were included, how was data presented? *(check all that apply)* • Were concentration-response data estimated from graphs study publication or supplemental materials? Should additional concentration-response data be requested from study authors? *If concentration-response data are available, complete **Verification of Statistical Results (Part C)** for sensitive species.*	____ Yes ____ No ____ Yes ____ No ____ Tables ____ Graphs ____ Supplemental Files ____ Yes ____ No *If yes, indicate software used:* ____ Yes ____ No Requested by: Request date: Date additional data received:	

Part C: Statistical Verification of Results

I. Statistical Verification Information: *Report the statistical methods (e.g., EPA TRAP, BMDS, R, other) used to verify the reported study or test results for the five (5) most sensitive genera and sensitive apical endpoints (including for tests where such estimates were not provided). If values for the LC_{50}, LT_{50} and NOEC are greater than the highest test concentration, use the ">" symbol.*

Primary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)

Secondary Reviewer: _____ **Date:** _____ ____ **EPA** ____ **Contractor** (*Place X by One*)
(*At least one reviewer should be from EPA for sensitive taxa*)

Endpoint(s) Verified:

Additional Calculated Endpoint(s):

Statistical Method (e.g., TRAP, BMDS, R, other):

II. Toxicity Values: *Include confidence intervals if applicable*

NOEC:
LOEC:
MATC:

EC_5:
EC_{10}:
EC_{20}:
EC_{50} or LC_{50}

Dose-Response Curve Classification: *(Place X by One)*
This classification should be taken into consideration for the overall study classification for aquatic life criteria development in Part A

_____ Dose-Response Curve Acceptable for Quantitative Use
_____ Dose-Response Curve Acceptable for Qualitative Use
_____ Dose-Response Curve Not Acceptable for Use

Summary of Statistical Verification: *Provide summary of methods used in statistical verification.*

Additional Notes:

-

Attachments:

1. *Provide attachments to ensure all data used in Part C is captured, whether from study results reported in the publication and/or from additional data requested from study authors*
    - *Data from study results of the publication should be reported in Results section of Part A*
    - *Additional data provided upon request from study authors should be reported in Table C.II.1 below and original correspondence with study authors should be included as attachments*
2. *Model assessment output (including all model figures, tables, and fit metrics)*
3. *Statistical code used for curve fitting*

III. Attachments: *Include all attachments listed above after the table below.*

Additional Data Used in Response-Curve: *Provide all data used to fit dose-response curve not captured in Results section of DER above in Part A, rows as needed. First row in italicized text is an example.*

Table C.II.1 Additional Data Used in Dose-Response Curve.

Curve ID	Species	Endpoint	Treatment	Replicate	[Standard Deviation or Standard Error]	# of Survivors	N[a]	k[a]	n[a]	Response	Response Unit	Conc	Conc units
Alchronic1	*Ceriodaphnia dubia*	*# of young/female*	*0*	*6*			*10*	*10*	*1*	*18*	*count*	*0.03*	*mg/L*

[a] N = number of individuals per treatment; k = number of replicates per treatment level; n = number of individuals per replicate

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Part D: References to Test Guidance

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January 2026

TECHNICAL AND REGULATORY GUIDANCE

Per-and Polyfluoroalkyl Substances (PFAS)



Prepared By
The Interstate Technology & Regulatory Council (ITRC)
PFAS Team

EXECUTIVE SUMMARY

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PFAS — Per- and Polyfluoroalkyl Substances

Technical and Regulatory Guidance

January 2026

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1 PFAS PRIORITY TOPICS

These topics were identified by both regulators and the scientific community as ones for which more information is needed. The Priority Topics are published as part of the ITRC PFAS Technical and Regulatory Guidance Document (PFAS-1) (https://pfas-1.itrcweb.org).

Section Number	Topic
1.1	**Priority Topics for History, Use, and Naming Conventions**
1.2	**Priority Topics for Firefighting Foams**
1.3	**Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization**
1.4	**Priority Topics for Human and Ecological Health Effects**
1.5	**Priority Topics for Sampling and Analysis**
1.6	**Priority Topics for Treatment Technologies**
1.7	**Priority Topics for Biosolids Land Application**
1.8	**Priority Topics for PFAS and Microplastics**

1.1 Priority Topics For History, Uses, and Naming Conventions

Section Number	Topic
1.1.1	**Semiconductor Industry Uses**
1.1.2	**Less-publicized PFAS Sources**
1.1.3	**Less-studied PFAS**

Information in these Priority Topics was prepared to supplement the information published in **Section 2**, which covers PFAS chemistry and naming conventions, history and use of PFAS, and sources of PFAS releases to the environment.

1.1.1 Semiconductor Industry Uses

This section provides more information on the uses of PFAS in the semiconductor industry and expands on the information presented in **Section 2.6.1.6**.

1.1.1.1 Background

Semiconductors, or chips, are small electronic devices used in a vast array of industries, including consumer electronics, manufacturing, medicine, commerce, military, artificial intelligence, and others. With the advent of artificial intelligence, data centers, and ever-expanding computational needs, chip manufacturing in the United States and around the world will continue to grow (SIA 2024). Many chip manufacturing processes rely on PFAS, some of which are proprietary, and other chemicals (for example, N-methylpyrrolidone, hydrochloric acid, and hydrofluoric acid) (NIST 2024), which may result in potential risks to workers and the environment. **Figure 2-20** provides an example conceptual site model for industrial sites and can be useful in the evaluation of semiconductor PFAS uses and releases.

1.1.1.2 PFAS Uses

Because of the unique properties of PFAS (see **Section 2**), many PFAS from multiple classes are used during semiconductor manufacturing. For example, fluoropolymers are used to filter out small particles from fluids during chip production and are an important component during the photolithography process. No known alternatives exist for many of the industry's uses of fluorocarbon-containing materials (SIA 2023, p. 3.), and once an alternative is invented, the process to qualify it for use is complex and may require many years to deploy for high-volume manufacturing (SIA 2023, p. 3.). Therefore, continued access to PFAS is currently a prerequisite for high-volume and advanced semiconductors. Given this, the focus on preventing exposures and the buildup of PFAS in the environment lies in materials management, particularly the management of wastes from semiconductor manufacturing, and perhaps even in the management of chips and semiconductor manufacturing equipment at the end of their service life.

When the bipartisan CHIPS and Science Act of 2022 was signed into law, it provided the Department of Commerce with $50 billion for a suite of programs to strengthen and revitalize the US position in semiconductor research, development, and manufacturing. The CHIPS Program Office's Final Programmatic Environmental Assessment contains tables describing the uses of PFAS in semiconductor manufacturing, Table C-4, (NIST 2024), and a list of chemicals used by the industry, Appendix D, (NIST 2024). The following subclasses, groups, or subgroups of PFAS were included on this list:

- fluorinated polymers, including polymeric perfluoropolyethers (PFPE), side-chain fluorinated polymers, and perfluoroalkoxy alkanes
- perfluoroalkane sulfonic acids (PFSAs) (for example, perfluorobutane sulfonic acid [PFBS], perfluorooctane sulfonic acid [PFOS])
- perfluoroalkane sulfonamides (FASAs) (for example, perfluorobutane sulfonamide [FBSA])
- perfluoroalkyl dicarboxylic acids (PFdiCAs) (for example, perfluorobutyl dicarboxylic acid [PFBdiCA])
- perfluoroalkane sulfonamido ethanols (FASEs) (for example, FBSE)
- perfluoroalkane sulfonamido acetic acids (FASAAs) (for example, perfluorobutane sulfonamido acetic acid [FBSAA])

More information about PFAS subclasses, groups, and subgroups is included in **Section 2.2.2** and **Figure 2-4**.

The industry phased out the use of legacy PFAS, such as PFOS and perfluorooctanoic acid (PFOA), years ago, replacing them typically with C4-short chain replacement compounds (see bulleted list above), including PFBS (SIA 2023). These shorter chain compounds are now found in the wastewater from semiconductor fabrication plants (Chen et al. 2024; Jacob, Barzen-Hanson, and Helbling 2021; Jacob and Helbling 2023). In addition, fluorinated gases (see **Section 1.1.3.4**) are used as a plasma etchant in semiconductor manufacturing.

1.1.1.3 Exposure Pathways

In general, potential PFAS release mechanisms and pathways at semiconductor facilities include wastewater and stormwater discharges; on- and off-site disposal of solid wastes; accidental releases; and stack and fugitive emissions. Refer to **Figure 2-20**. The conceptual site model presents exposure routes and receptors that may be associated with semiconductor facilities. Semiconductor manufacturing is typically completed in a closed loop, where clean-room facilities may limit worker

exposure. However, electronic waste recycling facilities may not provide such safeguards. Additional exposure pathways may include processing steps during materials recovery and scavenging during electronic waste recycling, including collection, processing, and disposal sites (Tansel 2022). Fluorinated gases (see **Section 1.1.3.4**) that are used in plasma etching processes are the largest source of greenhouse gas emissions from semiconductor production, and perfluorocarbons (PFCs) make up most of those releases (USEPA 2025).

Although often the focus is on industrial releases to wastewater treatment plants, the same chemicals could be released directly to land, surface water, groundwater, or air from leaks and spills. For example, GlobalFoundries' Essex Junction, Vermont, plant has a National Pollutant Discharge Elimination System (NPDES) permit to discharge directly into the Winooski River (Vermont DEC 2021). Although there are no regulations specific to discharges of PFAS from semiconductor wastewater, many states have regulations on industries or facilities with significant PFAS sources to perform and report discharge monitoring. Some of these states include Virginia, New Hampshire, and West Virginia. Missouri has a voluntary PFAS sampling program for facilities renewing existing wastewater or stormwater permits. Additional information is available in the **Regulatory Programs Table** and refer to the topic/focus area "Wastewater."

Many different types of solutions, rinses, inert equipment (such as molds and piping), and components are used in semiconductor manufacturing processes and have the potential to end up in waste streams. Studies have documented semiconductor waste streams containing PFAAs, including PFBS, perfluorohexane sulfonic acid (PFHxS), PFOS, perfluorohexanoic acid (PFHxA), PFOA, perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA), perfluoroundecanoic acid (PFUnA), and perfluorododecanoic acid (PFDoA) (see **Section 2.6.1.6**). A 2024 study identified effluent sample data from wastewater treatment plants associated with semiconductor facilities and identified perfluorobutane sulfonamido derivatives and ultra-short-chain PFAS (ultrashort PFAS) (see **Section 1.1.3.1**) as new trends associated with the semiconductor manufacturing industry (Chen et al. 2024). However, it should be noted that many of these newly identified PFAS are not included in typical commercial analytical laboratory PFAS methods; in addition, the toxicity or potential risk of these compounds is not known at this time.

Wastewater from processes that use wet chemical formulations (for example, chip production) containing PFAS may be discharged to the publicly owned treatment works (POTWs) without substantive PFAS removal, and generally, treatment works are not typically equipped to measure or remove PFAS from their effluent or biosolids. However, some companies are considering segregating, storing, and sending PFAS-containing process wastes off-site for treatment (NIST 2024; NIST 2024).

Fluorinated gases (see **Section 1.1.3.4**) that are used in plasma etching processes are the largest source of greenhouse gas emissions from semiconductor production, and PFCs make up most of those releases (USEPA 2025). Some of the more common PFCs used in the semiconductor industry include trifluoromethane (HFC-23), difluoromethane (HFC-32), tetrafluoromethane (PFC-14), hexafluoroethane (PFC-116), and octafluoropropane (PFC-218) (SIA 2023).

Semiconductor factories conduct wastewater pretreatment for other substances, such as acids, under wastewater discharge permits from POTWs. Pretreatment for PFAS at the end of a pipe, before the PFAS waste stream mixes with other wastes, could be an important component in addressing PFAS used in the production process.

1.1.2 Less-publicized PFAS Sources

As noted in **Section 2.5.2**, growing awareness of PFAS has led to both research and speculation about the use and occurrence of PFAS associated with an increasing number of products, and whether such occurrences may constitute a risk to human health and the environment. Although PFAS have been

previously identified in applications mentioned in **Section 2.5.1**, this section expands on the knowledge of the application and use of PFAS in these areas. In addition, some other potential less-publicized sources are discussed.

1.1.2.1 Hydraulic Fluids

Hydraulic fluid has many purposes, including transferring forces, lubricating surfaces, and acting as a sealant and coolant. PFAS are used in these applications primarily for their unique combination of properties that are beneficial in high performance and extreme condition environments. Two important criteria for hydraulic fluids are viscosity and additives that provide resistance to corrosion. Hydraulic fluids use PFAS for corrosion, chemical, temperature, and wear resistance for machines to operate smoothly.

The Organisation for Economic Co-operation and Development (OECD) (2025) report on PFAS in hydraulic oils and lubricants provided a comprehensive overview of the use of PFAS in hydraulic fluids and lubricants, emphasizing their technical functions and the challenges of substitution. Although comprehensive, the authors noted that the report is not exhaustive or definitive. For example, hydraulic oil and lubricant formulations are typically considered confidential business information, often limiting the available details, such as the percent of PFAS in each formulation (see the example safety data sheets below).

PFAS are "notable for their oil- and water-repellent characteristics and high thermal stability, have effectively reduced friction and wear in diverse mechanical systems" (Dias et al. 2024). Tribology is the study of friction which "most often involves the control and reduction of friction" (Watterson 2019). "A popular use of PFAS in tribological applications is the use of polytetrafluoroethylene (PTFE) in coatings and lubricants, renowned for its lubricity, resilience at high temperatures, and resistance to chemical attacks" (Dias et al. 2024) and referenced therein as Yeo et al. (2012), Dubey et al. (2015), and Zheng et al. (2023). In lubricants, PFAS are used in base oils (for example, PFPEs, polychlorotrifluoroethylenes [PCTFEs]), additives (for example, micropowder PTFE), and solvents, contributing to durability, reduced maintenance, and compatibility with various materials (OECD 2025). Table 2.1 in the OECD report summarizes the PFAS used in specific functions and in which applications this use may apply.

Glüge et al. (2020) further stated: "anionic PFAS (largely those with a sulfonic acid group) are used as additives in brake and hydraulic fluids due to their ability to alter the electrical potential of the metal surface and thus, protect the metal surface from corrosion through electrochemical oxidation."

Automotive Applications

In the automotive industry, PFAS-based lubricants are valued for their durability, low friction, and compatibility with diverse materials. They help reduce maintenance frequency and extend the lifespan of components such as gears and bearings. PFAS additives also support performance in high-temperature and high-load conditions (OECD 2025).

Zhu and Kannan (2020) stated that PFAS have been used as additives in automotive lubricant oils and hydraulic fluids, to reduce surface tension, and to prevent fires and evaporation. In the automotive sector, the use of PFAS has been noted in the development of some lubricants, engine oils, and hydraulic fluids (Wang et al. 2010; Rico et al. 2007). PFAS play a crucial role in supplying essential features such as anti-wear, anticorrosion, and antifoaming capabilities. The annual demand for vehicle lubricating oils in the United States is estimated at approximately 2.4 billion gallons (Research and Markets 2019).

Zhu and Kannan (2020) analyzed 18 lubricants purchased in the United States for PFAS; however, they noted that seven of the 18 lubricants were explicitly for use in aircraft applications. Several perfluoroalkyl carboxylic acids (PFCAs) and PFSAs were detected in the lubricants. They were analyzed before and after

oxidation using the total oxidizable precursor (TOP) assay. Following oxidation, lubricant extracts yielded total perfluoroalkyl acid (PFAA) concentrations up to two orders of magnitude higher than before oxidation, as high as 8,300 nanogram/gram (ng/g) mean. Long-chain PFCAs were the majority of PFAS detected prior to oxidation; however, variable and poor recoveries were noted for some of the volatile precursors during the TOP assay procedure.

Aviation Applications

PFAS additives have been used in aircraft hydraulic fluids due to their flame resistance, and erosion- and corrosion-inhibiting properties, which are essential for maintaining system integrity under extreme temperatures and pressures (OECD 2025). Applications in the aviation industry may include flight control systems and landing gear (OECD 2025). In broader aerospace applications, PFAS-containing hydraulic fluids maintain performance at a broader range of temperatures, where petroleum-based fluids may underperform at either temperature extreme (OECD 2025).

One PFAS cited in papers as being used in hydraulic fluids is perfluoroethylcyclohexane sulfonate (PFECHS) (MPART 2020) (see **Section 2.2.3.3**). Multiple reports have linked the use of PFECHS in aviation applications to environmental contamination. PFAS have been used in aircraft hydraulic fluids since the mid-1960s (De Silva et al. 2011; de Solla et al. 2012; MacInnis et al. 2017). For more information on PFECHS, see **Section 1.1.3.2**.

Examples of Corrosion-inhibitor Safety Data Sheets (SDS)

Corrosion inhibitors typically consist of fluorochemical surfactants which include PFAS. They may be used as additives to the acid media, or they may be applied as a thin, protective film on the metal prior to contact with the acid. Historical examples of fluorochemical surfactants used as corrosion inhibitors include FC-95, FC-98, FC-128, FC-134, and FX-161, FC-170, and FX-172 (3M Company 1963), and FC-5120 (3M Company 2012).

Safety Data Sheets reviewed (see call-out boxes) denote that the PFAS reported in fluorochemical surfactants used as corrosion inhibitors include salts of PFOS or PFECHS as more prevalent components, along with salts of other perfluoroalkyl sulfonates (for example, C4 through C7), including linear or cyclic isomers as minor components. More recently, PFBS-based surfactants are also reported, such as fluorosurfactant FC-5120 (3M Company 2012). Apart from salts of perfluoroalkylsulfonates, salts of perfluoroalkylcarboxylates appear to have also been used in some formulations of fluorochemical surfactants (see FC-118 example).

SDS for FC-118 FLUORAD Brand Fluorochemical surfactant

Issue Date: May 20, 1996

Source: **Specialty Chemicals Division, 3M Company**

The SDS includes the following ingredients:

- water (80%)
- ammonium perfluorooctanoate (18%–21%)
- ammonium perfluoroheptanoate (0.1%–1%)
- ammonium perfluorohexanoate (0–0.1%)
- ammonium perfluoropentanoate (0.1%–1%)

SDS for FC-135™ FLUORAD Brand Fluorochemical surfactant

Issue date: December 12, 2012

Source: **Environmental Health and Safety Services Department, 3M Canada Company**

The SDS includes the following ingredients:

- perfluoroalkylsulfonyl quaternary ammonium iodide (C8), which in water may produce PFOS (40%–44%)
- isopropyl alcohol (33%)
- fluoroalkyl quaternary ammonium iodides (C4, C5, C6, and C7) (0.1%–5%)
- methyl iodide (0.1%)

Cases for Continued Use

Despite the identification of several nonfluorinated chemical and technical alternatives, including

silicone oils, esters, graphite, molybdenum disulfide, and boron nitride, none fully replicate the multifunctional performance of PFAS. The OECD (2025) report highlighted that while alternatives may be viable for some uses, they often require reformulation, increased maintenance, or compromise on performance. Moreover, no commercially viable alternatives are known to currently exist for PFAS in aviation hydraulic fluids. The report concluded that substitution is technically and economically challenging, and that regulatory drivers, rather than market forces, are likely to be the primary catalyst for change. Table 2.2 of the OECD report (2025) provides a list of silicone-based alternatives and which PFAS they would be intended to replace.

In Canada and the United States, use of FC-98 is permitted in the aviation industry based on the lack of alternatives, its critical role in the safe performance of aircraft, and anticipated minimal environmental release (USEPA 2005).

In the USEPA Docket control number OPPTS-50639, the Boeing Company submitted comments to USEPA's PFAS proposed Significant New Use Rule, Supplemental Proposed Rule, published in the Federal Register on March 11, 2002 (67 Fed. Reg. 11014). Boeing mentioned the variety of commercial and military aircraft they manufacture and how many people they employ. They wrote in support of USEPA's proposal to exclude from the definition of significant new use, "1) the manufacture or import of certain PFAS chemicals for use as an anti-erosion additive (i.e., FC-95 and FC-98) in fire-resistant phosphate ester aviation hydraulic fluids; and 2) the use of these PFAS chemicals as intermediates to produce other chemicals used solely for the excluded aviation hydraulic uses."

In other sectors, the Association of Equipment Manufacturers (AEM) (**www.aem.org**) indicates PFAS are needed to meet objectives such as air quality, climate, safety, and sustainability and alternative power goals (AEM, 2024). The applications include such uses in seals, hoses, hydraulic systems, refrigerant, and alternative power technologies. Examples of machines and systems that use hydraulic power include excavators, cranes, forklifts, lifts, dozers, graders, loaders, shovels, trenchers, and concrete pumping systems, among others. Pinhole leaks, sudden drops in pressure, or contamination of the fluid can all cause serious safety issues for the operator or maintenance team (AEM 2024).

Additionally, the thinktank Industrial Resources Strategies issued a final report titled, "PFAS: Application, Technical Functions and Substitution Possibilities in the Industry" (Lang-Koetz, Hutschek, and Heil 2024), which examined suitable substitutes for various applications, including hydraulic fluids. To determine whether there are adequate substitutes that could replace PFAS, a specially developed artificial intelligence (AI) was used. Over 35,000 scientific documents were analyzed, and the AI-based system identified 420 materials and summarized them into 32 classes for five European companies. For the companies (which include an automobile company), the report claimed there were either none or only 2 to 3 identified materials that have the potential to replace PFAS in the future. "An adequate substitute that could be used immediately or in the near future was not found in any of the cases examined" (Lang-Koetz, Hutschek, and Heil 2024).

Canter (2024) provided information for companies involved in producing lubricants to minimize PFAS release and exposure. Canter (2024) recommended paying attention to the supply chain and establishing a system to determine the most likely source of PFAS. As well as a recommendation for a resource allocation plan, an assessment of all PFAS sources of contamination in water, fire suppression systems, and raw materials should be performed. Finally, Canter (2024) recommended that a lubricant manufacturer ask for a reformulated raw material without fluorine or find a supplier with a viable nonfluorine-containing alternative.

1.1.2.2 Pesticides

When identifying PFAS use in pesticides, it should be noted that organizations define PFAS differently. Refer to **Table 2-1** for more information on the various definitions of PFAS. Pesticides can contain

fluorinated compounds, but depending on what definition is used, they may or may not be identified as PFAS.

Two general categories of ingredients are used in pesticides: active and inert. Active ingredients are the primary elements that kill or suppress the targeted organisms, while the inert ingredients, including emulsifiers, fragrances, and dyes, are added to enhance the product and do not have to be disclosed (Donley et al. 2024). Donley et al. (2024) reported that several patents have identified fluorinated "inerts" as assisting with dispersal of spraying pesticides, preventing foaming, aiding in surfactancy, and penetrating organisms. Because the manufacturers of pesticides are not required to disclose when fluorinated substances are used as an inert ingredient, the full extent of PFAS in pesticides is uncertain.

Fluorination in pesticides can be used to modify chemical attributes such as stability and lipophilicity (Alexandrino et al. 2022). Active ingredients are often fluorinated in pesticides, with insecticides and acaricides (targeting ticks and mites) being highly fluorinated (Ogawa et al. 2020). Molecular stability can result from fluorination and can influence lipophilicity, allowing binding to target proteins (Alexandrino et al. 2022). The most common chemotype is a trifluoromethyl (CF3), followed by a monofluoromethyl group (CFH2) (Ogawa et al. 2020). Only a broad definition of PFAS would include these shorter chain chemicals under a PFAS classification. (Alexandrino et.al. 2022) discussed the increased use of fluorination in pesticides. It grew from 9% by the end of the twentieth century to over 50% between 2010 and 2020. Fluorinated pesticides made up nearly 70% of all new approved agrochemicals during the second half of 2010. Ogawa et al. (2020) said the difluoro[1]methyl group, CF2H, is emerging more rapidly than the CF3 group due to progress of synthetic methods.

Section 2.4.5 discusses the pesticide sulfluramid, which is manufactured in Brazil. The active ingredient in sulfluramid (a pesticide used for control of leaf-cutting ants) is n-ethyl perfluorooctane sulfonamide (EtFOSA), which is a direct precursor to PFOS. Although PFOS is listed under Annex B (restriction of use) in the UN Stockholm Convention on Persistent Organic Pollutants (POPs) (UNEP 2025), use of sulfluramid in insect bait has continued acceptable use in Argentina, Brazil, Costa Rica, and Vietnam from December 2020 onwards under the UN Stockholm Convention on POPs. Sulfluramid has prior registration for use in the United States in termite, ant, and roach bait stations (USEPA 2001). This may indicate prior potential for commercial and consumer use application both inside and outside of homes and buildings, as well as other locations.

A study in Denmark looked at worker exposure to PFAS-containing pesticides (including long-chain PFAS). This study, conducted between 1996 and 2001 on pregnant greenhouse workers, found elevated PFAS in their blood (Andersen et al. 2024), demonstrating higher exposure risk for this sector of people.

A study has identified PFAS as leaching from the coatings of pesticide containers (USEPA 2021). The practice of coating polyethylene plastic containers started as early as 1958 (Joffre 1957). Today this practice of coating agricultural containers continues (Rand and Mabury 2011). Often, molded plastic containers are treated under high temperature with fluorine gas (Kharitonov 2008). Recent activity includes:

- July 2024: EPA Grants Petition on 3 PFAS Found in Fluorinated Plastic Containers (USEPA 2024)
- October 2024: EPA Issued Test Order for PFAS Used in Manufacturing Under National Testing Strategy (USEPA 2024). This action orders Innovative Chemical Technologies, Chemours Company, Daikin America, Sumitomo Corporation of Americas, and DuPont to conduct and submit testing on 6:2 FTAc (6:2 fluorotelomer acrylate), which is used in manufacturing plastics, resins, textiles, apparel, leather, and other chemicals.

More work is needed to study fluorinated coated containers in the agricultural industry and containers used in other sectors to understand the impact on the environment and human health.

1.1.2.3 Other Less-publicized Sources

Table 1-1 provides less-publicized sources, in addition to those presented in Table 2-7 in **Section 2.5**.

Table 1-1. Additional examples of PFAS claims in other less-publicized sources.

Potential Use	Technical Basis	Documentation	Potential Conflicting Perceptions on Presence of PFAS and Significance of PFAS
Commercial Car Washes	Analysis of PFAS in car wash products and other consumer products.	Borg and Ivarsson (2017) Glüge et al. 2020	PFAS are used in some car wash products and may leach into wastewater. PFAS presence in such products can be significant, depending on their concentration and usage patterns.
Concrete Sealers	Review of different types of penetrating concrete sealers and their chemical composition.	Concrete Sealers USA (2016)	Concrete sealers may contain PFAS to enhance water resistance. The significance depends on the type of sealer and its PFAS content, which varies by manufacturer.
Toilet Paper	Analysis of PFAS presence in toilet paper and its contribution to wastewater.	Thompson et al. (2023)	Toilet paper can be a significant source of PFAS in wastewater. The level of PFAS varies, and its contribution to overall PFAS pollution depends on the volume of toilet paper used and its PFAS concentration.
Fracking Fluids	Media reports describe a review of publicly reported data (FracFocus database: **https://fracfocus.org/**) detailing the use of nonionic fluorosurfactants used in injection fluids for fracking of hydrocarbons. These reports indicate PFAS or PFAS precursors in thousands of wells across a handful of states. Colorado has banned the use of PFAS in fracking fluids as of January 1, 2024.	FracFocus (2025) Horwitt (2021) Friday (2022) Connor et al. (2021) Horwitt and Gottlieb (2023) Colorado General Assembly (2022) Murphy and Hewat (2008) Schramm (2000)	The use of PFAS in fracking fluids is likely; however, due to limited details in the database, the exact type of PFAS and extent of PFAS, or PFAS precursors used in current or historical specific fracking operations is unknown. PTFE (Teflon) is a potential concern with use in fracking operations.
Medical Devices	PFAS have widespread uses in medical devices and in vitro diagnostic reagents and instruments.[1] A consumer study[2] identified total organic fluorine content in 18 different soft contact lens products.	[1]PFAS Uses: Glüge et al. (2020) and Gaines (2022) [2]Contact Lenses Consumer Study: Segedie (2023) [3]Essential Uses, Patient Safety: Levy et al. (2023); Cousins et al. (2019); Spyrakis and Dragani (2023); Ozben et al. (2024); Rezvova et al. (2023) [4]Medical Testing and Safety: Henry et al. (2018); Maitz (2015); Ozben et al. (2024) [5]Polymer of Low Concern Analysis: Lohmann et al. (2020) [6]PFAS Serum Study: Kang et al. (2024)	Position papers[3] discuss the essential uses of some PFAS in medical devices (i.e., PTFE, polyvinylidene fluoride (PVDF) and volatile PFAS used as propellants in inhalers) and the impact that restrictions would have on patient safety. In a contact lens consumer study[2], organic fluorine levels ranged between 105 ppm to 20,700 ppm. Organic fluorine was detected in all 18 products; the study stated that the organic fluorine can be a marker for PFAS. Proponents[4] argue that PFAS—fluoropolymers in particular—are chemically and biologically inert and have a robust clinical history and testing of implanted medical devices supporting their safety in medical applications. However, others[5] point to new research in animals showing the potential for some fluoropolymers to be bioavailable. One US study[6] of young adults (aged 20—39 years) estimated a statistically significant increase in the body burden of PFAS in contact lens users as compared to non-contact lens users. No statistically significant difference in PFAS body

Potential Use	Technical Basis	Documentation	Potential Conflicting Perceptions on Presence of PFAS and Significance of PFAS
			burden was observed in a supplemental analysis of older adults aged 40–59 years. The study authors noted that not all potential confounders could be adjusted in the model and identified several limitations when interpreting the age-dependent observations.
Lithium-Ion Batteries	PFAS are widely reported components in lithium-ion batteries, including in the electrodes (cathode and anode), binder, electrolyte (main component and additives), and separator (porous membrane). The global clean energy sector may be an unrecognized and potentially growing source of international PFAS release into the environment, highlighting a need to evaluate clean energy impacts beyond just carbon dioxide emissions. A fire on Long Island at the largest utility-scale storage facility of lithium salt and battery cells burned on May 21, 2023. Elevated PFAS concentrations were detected in the extinguishing water concentrations. The concern over fluorinated compounds in lithium-ion batteries has led to research on fluorine-free batteries: Ma et al. (2024); Ma et al. 2024.	Vamosi (2023) Quant et al. (2023) Rensmo et al. (2023) Guelfo et al. (2024) Willstrand, Quant, and Hynynen (2025)	Savvidou et al. (2024) suggested PFAS-free alternatives are available in electrodes and electrolytes. PFAS-free lithium-ion batteries: Ma et al. (2024); Ma et al. 2024.
Dry Cleaners	PFAS may be used in dry-cleaning systems as replacements for tetrachloroethene-based systems. PFAS may also be in waste discharges from dry cleaners as a result of PFAS in the materials being laundered.	Gaines (2022) CA ARB (2006) FL DEP (2021)	Existing patents show the use of hydrofluoroethers with other PFAS as an alternative to tetrachloroethene or other solvents used in dry cleaning. Another patent mentions the use of carbon dioxide and a surfactant; fluoroalkyl substances are mentioned as a potential surfactant. The Zonyl series by DuPont is mentioned as a source of fluorinated compounds. California report discusses a replacement for tetrachloroethene called PureDry, which contains HFE-7200, FC-43, PF-5070, and PF-5060.
Explosives, Pyrotechnics, and Propellants	Published information on composition of explosives, propellants, and pyrotechnics is available.	Valluri, Schoenitz, and Dreizin (2019)	Although certain fluoropolymers are known to be components of some explosives, propellants, and pyrotechnics, data are not available on the fate and transport of fluoropolymers associated with these items. Research is underway to address data gaps.

1.1.3 Less-studied PFAS

Section 2 provides a summary of different PFAS classes, subclasses, and groups. This section expands on that discussion to provide information on some of the less-studied PFAS, including ultrashort PFAS, cyclic PFAS, volatile PFAS, and fluorinated gases.

1.1.3.1 Ultrashort PFAS

Ultra-short-chain PFAS (ultrashort PFAS) are generally described as having ≤3 carbons (Zheng, Eick, and Salamova 2023; Neuwald et al. 2022). Common examples of ultrashort PFAS include trifluoroacetic acid (TFA, C2), perfluoropropanoic acid (PFPrA, C3), perfluoropropanesulfonic acid (PFPrS, C3), and 1,1,1-trifluoro-N-[(trifluoromethyl)sulfonyl] methanesulfonamide (TFSI, C2) (**Table 1-2**). Some fluorinated gases may also be considered ultrashort PFAS (**Section 1.1.3.4**). Zhi et al. (2024) identified ultrashort PFAS found in environmental samples, including PFPrA, trifluoromethanesulfonic acid (TFMS, C1), perfluoroethane sulfonic acid (PFEtS, C2), and PFPrS. Ultrashort PFAS are known to be industrial chemicals used for a variety of direct applications or may be byproducts from the construction of complex chemicals. As examples, TFA and PFPrA are common reagents and catalysts used in laboratories (Zheng, Eick, and Salamova 2023), and TFSI is used in the production of lithium-ion batteries and as an additive to biodegradable natural rubber matrixes (Sowińska et al. 2021).

Existing studies have shown ultrashort PFAS tend to be as persistent as their longer chain homologues and are more mobile in the environment. In some cases, ultrashort PFAS may have higher acute ecological toxicity than short- and long-chain PFAS (Wang et al. 2014) and can be more difficult to remove from water (Ateia et al. 2019; Neuwald et al. 2022). Ultrashort PFAS are not typically included in studies focusing on capture and destruction of PFAS. Human health–related toxicological effects of ultrashort PFAS are discussed in **Section 1.4.4** on health effects of ultrashort PFAS.

Although TFA is a common example of a C2 ultrashort-chain PFAS, it is worth noting that under some existing definitions of PFAS, it would not be considered a PFAS (refer to **Section 2.2**). TFA has been found in the environment at concentrations orders of magnitude higher than other PFAS. TFA was found at higher occurrence in residential house dust and tap water in a study in Indiana (Zheng, Eick, and Salamova 2023). In Zhi et al. (2024), the authors noted the elevated TFA levels and that levels are increasing in the global environment. This paper also identified four additional ultrashort PFAS found in environmental samples, including PFPrA, TFMS, PFEtS, and PFPrS. In addition, large amounts of TFA are produced for use as an intermediate in chemical manufacturing and for other purposes (National Center for Biotechnology Information 2025, PubChem website).

Although TFA is extremely persistent, this ultrashort PFAS does not have well-established drinking water health advisories or regulatory limits (Arp et al. 2024). However, it should be noted that the Netherlands National Institute for Public Health and the Environment (RIVM) and the German Environment Agency (UBA) have developed drinking water guidelines for TFA of 2.2 ug/L (RIVM 2023) and 60 ug/L (UBA 2020), respectively.

Ultrashort PFAS are less studied than short- and long-chain PFAS and are often not included in analytical methods used for other PFAS because their highly polar characteristics make them difficult to analyze with current analytical methods (Björnsdotter et al. 2020; Liang, Steimling, and Chang 2023; Neuwald et al. 2022). Additional information about ultrashort PFAS analysis is found in **Section 1.5.3**. However, studies evaluating transformation of PFAA precursors suggest their contribution to human exposure to ultra-short-chain PFAS—specifically, polyfluoroalkyl carboxamides, polyfluorinated phosphate esters (PAP), FOSAs, FOSEs, FTOHs, and FTACs, among others (Zheng, Eick, and Salamova 2023).

TFA has been documented to form through the atmospheric degradation of several F-gases, including hydrofluorocarbons and hydrochlorofluorocarbons used in refrigerants (Jordan and Frank 1999; Liang,

Steimling, and Chang 2023). Similarly, ultrashort PFAS such as PFPrA and TFA can be produced through the breakdown of pharmaceuticals, pesticides, and polymers (Jordan and Frank 1999; Liang, Steimling, and Chang 2023). Ultrashort PFAS are also included in formulations of aqueous film-forming foam (AFFF) or are the result of the breakdown of other PFAS in AFFF. For example, PFPrA and TFA are breakdown products of perfluoro-2-methyl-3-pentanone (PFMP), which was marketed by 3M as a fire protection fluid replacement for chlorofluorocarbons and halons (Jackson et al. 2011), while other ultrashort PFAS (PFPrS and PFEtS) have been quantified in AFFF formulations manufactured between 1989 and 2001 (Barzen-Hanson and Field 2015). For additional examples and occurrences and health effects associated with ultrashort PFAS, see **Section 1.4.4**. In addition, see the updated **Table 4-1** for physical and chemical properties of some ultrashort PFAS.

Table 1-2 summarizes some ultrashort PFAS examples, with a notation of those covered in **Table 4-1** as well as those that can be currently analyzed by some environmental laboratories, see **Section 1.5.3** for more information about analysis of ultrashort PFAS. Note: The USEPA's CompTox Chemicals Dashboard (CompTox Chemicals Dashboard (epa.gov)) was used to standardize naming conventions and CAS numbers for ultrashort PFAS throughout the different sections of the Priority Topics documents.

Table 1-2. Ultrashort PFAS examples.

CAS No.	Chemical Name	Included in Table 4-1	Included on Current Commercial Lab Lists
381-73-7	Difluoroacetic acid (DFA)		
76-05-1	Trifluoroacetic acid (TFA)	X	X
422-64-0	Perfluoropropanoic acid (PFPrA)	X	X
421-85-2	Trifluoromethylsulfonamide		
78491-70-0	Perfluoroethanesulfonamide		
152894-03-6	Perfluoropropanesulfonamide		
423-41-6	Perfluoropropanesulfonic acid (PFPrS)	X	X
354-88-1	Perfluoroethanesulfonic acid (PFEtS)	X	X
1493-13-6	Trifluoromethanesulfonic acid (TFMS)	X	X
344324-36-3	Perfluoroethane-1-sulfinic acid		
359868-84-1	Perfluoropropane-1-sulfinic acid		
34642-42-7	Perfluoromethane-1-sulfinic acid		
674-13-5	Perfluoro-2-methoxyacetic acid (PFMOAA)	X	X
1036-91-3	Perfluoro-2-(trifluoromethoxy)ethanesulfonic acid		
374-09-4	Trifluoromethylphosphonic Acid		
103305-01-7	Pentafluoroethylphosphonic acid		
82113-65-3	1,1,1-trifluoro-N-[(trifluoromethyl)sulfonyl] methanesulfonamide (TFSI)	X	
90076-65-6	Lithium bis[(trifluoromethyl)sulfonyl]azanide (HQ-115)	X	X
34642-43-8	Perfluorobutane-1-sulfinic acid (PFBSi)		X
756-09-2	2,2,3,3-Tetrafluoropropanoic acid (2,2,3,3-TFPA)		X
359-49-9	2,3,3,3-Tetrafluoropropanoic acid (2,3,3,3-TFPA)		X

1.1.3.2 Cyclic PFAS

Cyclic PFAS include a carbon ring that may be partially or fully fluorinated or aromatic substances that have a fluorinated side chain. Although cyclic PFAS are not commonly tested for by USEPA standard test methods (for example, USEPA Method 1633A), some are included in ASTM methods such as D7979. Classification of these fluorinated compounds as PFAS is dependent on the definition of PFAS used. Examples of cyclic PFAS include:

- perfluorocycloalkyl sulfonates such as perfluoromethylcyclohexane sulfonate (PFMeCHS), perfluoropropylcyclopentanesulfonate (PFPCPeS), and perfluoroethylcyclohexane sulfonate (PFECHS)
- perfluorotoluene
- (perfluoropropyl)benzene
- fipronil

Certain cyclic structures can have much in common with noncyclic PFAS analogs and have been used in replacement chemistry. See **Section 2.2.3.3**.

Of the examples of cyclic PFAS, PFECHS is among those with the most available published peer-reviewed research. PFECHS is an 8-carbon cyclic PFAS that was produced by 3M and sold commercially as FC-98 as a corrosion inhibitor in some hydraulic fluid formulations (see **Section 1.1.2.1**) (de Silva et al. 2011). For example, PFECHS is considered an analog for PFOS and has been documented as a replacement compound for PFOS in some hydraulic fluids (O'Rourke et al. 2024). This is further supported by a multivariate statistical analysis demonstrating a positive correlation between PFECHS and PFOS (O'Rourke et al. 2024). In 2020, the Michigan PFAS Action Response Team (MPART), in conjunction with the Michigan Department of Health and Human Services, prepared a study noting occurrence of PFECHS in multiple media, including drinking water, surface water, sediment, marine organisms, and human blood (MPART 2020). Further, MPART noted the documented use of PFECHS and other perfluorocycloalkyl sulfonates in commercially available fluorochemical surfactants (MPART 2020). 3M phased out production of PFECHS and other perfluorooctyl-based compounds; however, it remains a permitted chemical in the United States and Canada due to "the lack of alternatives, its critical role in the safe performance of aircraft, and anticipated minimal environmental release" (de Silva et al. 2011).

SDS for FC-98 FLUORAD Brand Fluorochemical surfactant

Issue Date: September 10, 2002

The SDS includes the following ingredients:

- potassium perfluoroethyl cyclohexyl sulfonate (66%–70%)
- potassium perfluoromethyl cyclohexyl sulfonate (18%–22%)
- potassium perfluorodimethyl cyclohexyl sulfonate (9%–13%)
- potassium perfluorocyclohexyl sulfonate (1%–3%)
- residual organic fluorochemicals (not known)

Three studies cited by MPART (2020)—Wang et al. 2016, de Solla, De Silva, and Letcher (2012), and Letcher et al. (2015)—documented the greatest concentrations of PFECHS near airports. A review paper by Mahoney et al. (2022) discussed available information about PFECHS detection in environmental samples. PFECHS has been detected in surface water, herring gull eggs, and predator fish from the Great Lakes and other freshwater bodies (Mahoney et al. 2022; Muir et al. 2019; De Silva et al. 2011). Data reported by Szabo et al. (2022) indicate PFECHS in black swan serum and excrement and associated aquatic environmental media samples.

O'Rourke et al. (2024) noted that the similarity in persistence within living organisms to that of long-chain legacy PFAS may indicate that PFECHS and other replacement compounds such as F-53B are being used as substitutes for PFOS, suggesting comparable transportation pathways of environmental contamination in freshwater systems. Miaz et al. (2020) reported on analyses of serum samples from Swedish women collected from 1996 to 2017. Their study showed a declining trend in serum concentrations since 2000, with detectable concentrations of PFECHS of 0.06–0.28 ng/g. More research is needed to fully understand the toxicity and bioaccumulation properties of PFECHS.

PFECHS has biomagnification potential and is moderately bioaccumulative in the estuarine and marine food web (Wang et al. 2023). Although Mahoney et al. (2022) concluded PFECHS had a lower bioconcentration potential than PFOS in a trout cell assay, in 2023 Mahoney et al. (2023) found that PFECHS has potential to cause adverse effects at the cellular level in the marine system. Szabo et al. (2022) calculated a bioaccumulation factor for PFECHS of 593 L/kg versus the bioaccumulation factor for PFOS of 1,097 L/kg. In a study published by Wang et al. (2016), PFECHS and PFPCPeS were found to accumulate most significantly in the liver, kidney, blood, and bladder, with estimated average whole body bioaccumulation factors (log $BAF_{whole\text{-}body}$) of 2.7 and 1.9, respectively. Currently, PFECHS is thought to have a lower toxic potency than PFOS, but there is a need for additional research (Mahoney et al. 2023).

1.1.3.3 Volatile PFAS

Refer to the **PFAS-Vapor Intrusion Fact Sheet** for a discussion of the current state of the science for vapor-forming PFAS and their potential role in the vapor intrusion pathway. In addition, refer to **Section 4.2** for an introduction to the physical properties of volatile PFAS. USEPA vapor intrusion guidance (2015) considers a compound to be volatile if it has a vapor pressure greater than 1 millimeter of mercury (mm Hg) or a Henry's law coefficient greater than 10^{-5} atmosphere-meter cubed per mole (atm m^3 mol^{-1}). Numerous PFAS meet this volatility criteria, including both anionic and neutral PFAS (Abusallout et al. 2022; Schumacher et al. 2024).

As discussed in greater detail in **Section 4.2**, there are limited reliable data on the physical and chemical properties related to PFAS volatilization. For example, reported Henry's law coefficients can span multiple orders of magnitude for a single PFAS (see **Table 4-1**), making it difficult to know which values are most representative of the compound's behavior in the environment. Thus, it is not always clear whether certain compounds meet the USEPA volatility definition when the range of estimated or measured vapor pressures and/or Henry's law coefficients extends both below and above the thresholds. The PFAS listed in **Table 4-1** with sufficient vapor pressure and/or Henry's Law coefficient to be considered volatile are summarized in **Table 1-3**.

At this time, vapor-phase occurrence is mostly commonly associated with neutral PFAS, such as fluorotelomer alcohols (FTOHs), perfluorooctane sulfonamido ethanol (FOSE), perfluorooctane sulfonamide (PFOSA), and ultrashort-chain PFAS (considered to include 3 or fewer carbon atoms) (See **Section 1.1.3.1**). However, it should be noted that nonvolatile terminal PFAS, such as PFNA, PFOA, and perfluoroheptanoic acid (PFHpA), can also be formed from transformation of FTOHs, and PFOS can be released from transformation of FOSE. (See **Section 2.2.4** for more information about polyfluoroalkyl substances).

Some example uses of volatile PFAS include the following:

- fluorotelomer alcohols in paints (Cahuas et al. 2022).
- textile and leather production (MPCA 2023). FTOHs, N-EtFOSE, and MeFOSE are commonly used in textile manufacturing and in impregnation treatments for textiles and leather (MPCA 2023).
- medical industry as propellants in inhalers (Gaines 2022).

Table 1-3. PFAS listed in Table 4-1 with sufficient vapor pressure and/or Henry's law coefficient to be considered volatile.

PFAS	Sufficient Vapor Pressure per Table 4-1	Sufficient Henry's Law Coefficient per Table 4-1
Perfluorocarboxylic acids (PFCAs)		
Perfluorobutanoic acid (PFBA)	X	X
Perfluoropentanoic acid (PFPeA)	X	
Perfluoroalkane sulfonamides (FASAs)		
FBSA	X	
MeFOSA		X
EtFOSA		X
Perfluoroalkane sulfonamido ethanols (FASEs)		
N-methyl perfluorooctane sulfonamide ethanol (MeFOSE)		X
N-ethyl perfluorooctane sulfonamido ethanol (EtFOSE)		X
Fluorotelomer alcohols (FTOHs)		
4:2 FTOH	X	X
6:2 FTOH	X	X
8:2 FTOH	X	X
10:2 FTOH	X	X
Perfluoroalkyl ether carboxylic acids (PFECAs)		
Hexafluoropropylene oxide dimer acid (HFPO-DA)	X	X
PFMPA	X	
PFMBA	X	X

1.1.3.4 Fluorinated Gases

Fluorinated gases (F-gases) are humanmade, include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride, and other fluorinated compounds, and are used (both historically and currently) in a variety of industrial applications (**Table 1-4**). Under the very broad definition of PFAS recommended by the Organisation for Economic Co-operation and Development (OECD), fluorinated gases are considered PFAS (OECD 2021), fluorinated gases are considered PFAS. HFCs represent approximately 90% of all F-gases (European Commission n.d.). F-gases under the definition of PFAS typically contain between 1 and 7 carbons; some examples of F-gases are provided in **Table 1-4** (MPCA n.d.). The broad OECD PFAS definition encompasses many of the PFC and HFC gases used in semiconductor device manufacturing (see **Section 1.1.1**), as well as fluorinated heat transfer fluids (SIA 2023). As noted in **Section 1.1.3.1**, TFA has been documented to form through the atmospheric degradation of several F-gases, including hydrofluorocarbons and hydrochlorofluorocarbons used in refrigerants (Jordan and Frank 1999; Liang, Steimling, and Chang 2023).

Table 1-4. Examples of fluorinated gases.

F-Gas	CAS No.	Chemical Name	Use
HFC-23	75-46-7	Trifluoromethane	Refrigerant, fire extinguisher, semiconductor manufacturing
HFC-32	75-10-5	Difluoromethane	Refrigerant
HFC-41	593-53-3	Fluoromethane	
HFC-43-10mee	138495-42-8	Decafluoropentane	Cleaning solvent
HFC-125		Pentafluoroethane	Fire extinguisher
HFC-134	359-35-3	1,1,2,2-Tetrafluoroethane	
HFC-134a	811-97-2	1,1,1,2-Tetrafluoroethane	Refrigerant, fire extinguisher, foaming agent, medical propellants, aerosol propellants
HFC-143	430-66-0	1,1,2-Trifluoroethane	
HFC-143a	420-46-2	1,1,1-Trifluoroethane	Refrigerant
HFC-152	624-72-6	1,2-Difluoroethane	
HFC-152a	75-37-6	1,1-Difluoroethane	Refrigerant, foaming agent, aerosol propellant, temperature sensing agent
HFC-161	353-36-6	Fluoroethane	
HFC-227ea	431-89-0	Heptafluoropropane	Refrigerant, fire extinguisher, medical propellant
HFC-236cb	677-56-5	1,1,1,2,2,3-Hexafluoropropane	
HFC-236ea	431-63-0	1,1,1,2,3,3-Hexafluoropropane	
HFC-236fa	690-39-1	1,1,1,3,3,3-Hexafluoropropane	Refrigerant, fire extinguisher, foaming agent, medical propellant
HFC-245ca	679-86-7	1,1,2,2,3-Pentafluoroproane	Refrigerant
HFC-245fa	460-73-1	1,1,1,3,3-Pentafluoropropane	Refrigerant, foaming agent
HFC-365mfc	406-58-6	Pentafluorobutane	Refrigerant, foaming agent
PFC-14	75-73-0	Perfluoromethane; tetrafluoromethane	Plasma etchant, semiconductor manufacturing, refrigerant
PFC-116	76-16-4	Perfluoroethane; hexafluoroethane	Plasma etchant, semiconductor manufacturing
PFC-218	76-19-7	Perfluoropropane; octafluoropropane	Plasma etchant, semiconductor manufacturing, refrigerant, fire extinguisher
PFC-318	115-25-3	Perfluorocyclobutane; octafluorocyclobutane	Plasma etchant, cleaning agent, refrigerant, propellant in food industry
PFC-3-1-10	355-25-9	Perfluorobutane; decafluorobutane	Refrigerant, fire extinguisher
PFC-4-1-12	678-26-2	Perfluoropentane; dodecafluoropentane	Refrigerant, cleaning solvent
PFC-5-1-14	355-42-0	Perfluorohexane; tetradecane fluorohexane	Refrigerant, cleaning solvent, fire extinguisher
PFC-9-1-18	306-94-5	Perfluorodecalin	
c-C3F6	931-91-9	Perfluorocyclopropane	

Source: MPCA (n.d.) "Table of HFCs and PFCs and Pounds of Chemicals that Trigger Reporting Requirements."

F-gases are often used as replacements for ozone-depleting substances (such as halons), as these gases are not typically as harmful to the atmospheric ozone layer. However, F-gases are still highly regulated because they are strong greenhouses gases with a higher potential to contribute to global warming than carbon dioxide. Some of these regulations have banned F-gases such as HFC-23 due to their high potential to contribute to global warming (European Environment Agency 2025; EFCTC n.d.). F-gases are highly regulated by the US Clean Air Act, the Montreal Protocol for Greenhouse Gases, the Paris Agreement, and European Union air regulations. However, the World Meteorological Organization (UNEP 2018) estimates the global warming potential of some of these F-gases to be lower than carbon dioxide over a 100-year time horizon (it depends on the F-gas) and lists the ozone depletion potential of many F-gases to be 0. The atmospheric half-life of many of these compounds is on the order of days to years, depending on the chemical, via oxidation or photolysis in the atmosphere.

F-gases are used in many different products, equipment, and processes, such as refrigeration, air conditioning, heat pumps, insulation, fire protection, power lines, and aerosol propellants, as well as in industrial processes (European Commission n.d.; EFCTC n.d.). Electronics and aerospace industries use solvents containing F-gases to clean components (NetRegs n.d.). Several industries rely on F-gases for safe and reliable operations, including food storage, distribution to pharmaceutical production, and home heating and cooling. Benefits of F-gases include energy efficiency and less reliance on fossil fuels (Chemours n.d.).

Refer to EFCTC (n.d.) for additional information on the F-gases.

1.2 Priority Topics for Firefighting Foams

Section Number	Topic
1.2.1	**Firefighting Foam Inventory**
1.2.2	**Firefighting Foam Ecotoxicity**
1.2.3	**Transition Planning and Guidance**

Firefighting foam continues to be a driving concern as it relates to PFAS and potential impacts to the environment. Important considerations include management of the foam, mitigation once released, and elimination from use. These Priority Topics present updates to some of the information included in **Section 3**, including the existing Foam Inventory Table (**Table 3-1**), as well as recent updates on foam transition planning, guidance, and case studies, including updates to the existing Case Study Table (**Table 3-5**).

1.2.1 Firefighting Foam Inventory

ITRC continues to inventory both aqueous film-forming foam (AFFF) (foams with intentionally added PFAS) and fluorine-free foams (F3) to provide information regarding product name, manufacturer, and other relevant information. **Table 3-1** has been revised and now includes two tabs in the downloadable Table 3-1 Excel file. These include:

1. AFFF Inventory: A compilation of current and historical AFFFs from the DoD (Department of Defense) Qualified Product list (USDOD 2018), as well as state inventories.

2. F3 Inventory: A compilation of F3 foams from the Interstate Chemicals Clearinghouse (IC2) report titled “PFAS in Firefighting Foam” (IC2 2019) and GreenScreen for Safer Chemicals website (Clean Production Action 2024), as well as the DoD Military-Specification 32725 fluorine-free products (USDOD 2023).

1.2.2 Firefighting Foam Ecotoxicity

Recent tests reported in Fuller et al. (2024) on F3s show they are slightly more acutely toxic to aquatic organisms than AFFF, but their chronic toxicity is generally similar or less. The study analyzed the impact of six F3s on six aquatic species, finding that the acute toxicity of several of the F3s was greater than AFFFs with PFAS. Others had similar acute risks to AFFFs with PFAS. Chronic toxicity varied by species and formulation, with some F3s affecting growth and reproduction in specific species. In other testing, Hossain et al. (2024) conducted an acute avian study evaluating one short-chain PFAS-containing firefighting foam and six nonfluorinated firefighting foams. The results indicated that an analyzed F3 has less toxicity on chick growth than AFFF, but both the F3 and AFFF affected embryo development, leading to death of unhatched eggs. Work by Yeardley et al. (2024) compared the acute, chronic, and behavioral effects of two fluorine-free formulations with a PFAS-containing AFFF on two species of earthworms. The study indicated that F3s show varying acute toxicity to earthworms. Earthworms strongly avoided soils treated with F3 and AFFF; however, one F3 was much more acutely toxic than the compared AFFF. These three studies on ecological receptors and similar research provide essential data for selecting less environmentally toxic alternatives to AFFF. These findings, much like with AFFF, strongly suggest that thoughtful consideration should be taken with the selection of F3s and that best management practices (BMPs) continue to be used when handling, storing, applying, and remediating both AFFF and F3. See **Section 3.8.1** for more information about BMPs.

1.2.3 Transition Planning and Guidance

Section 3.11 includes information about firefighting foam system replacement. The following sections provide updates to the information about transition planning of foam systems from AFFF to F3 and available guidance.

1.2.3.1 State Activity

Several states are actively addressing AFFF, and specifically the transition of AFFF to F3. Many more states have initiated take-back programs or intend to initiate take-back programs. Some states have also developed or refreshed guidance to support foam transitions. According to Safer States (2025), at least seven states will consider policies to eliminate PFAS from firefighting foam, including phase-out, restrictions, or take-back programs. These include Connecticut, Maine, Montana, New Jersey, New York, Oregon, and Pennsylvania. A total of fifteen states has already adopted phaseouts of PFAS in firefighting foams.

State take-back program approaches have varied. According to the Environmental Council of States (ECOS 2025) compendium of States PFAS Action Report (April 2025), a total of nineteen states has completed take-back (or collection) programs. ECOS (2025) reported disposal of collected AFFF included hazardous waste landfills (10 states), incineration (three states), destruction technology using supercritical water oxidation (SCWO) (two states), and interim storage until a safe method is identified, or disposal method under development (three states). In addition, ECOS (2025) reported that states have collected over 1,672,500 pounds (which is approximately 167,250 gallons) of AFFF through take-back programs. Costs per gallon vary depending on what type of disposal/destruction method was chosen, as well as what other services may have been included (collection/storage, inventory activities, waste hauling, processing).

1.2.3.2 State Foam Transition Guidance

According to ECOS (2025), 32 states have already transitioned at least one fire department or airport from using AFFF to the use of F3, and 33 states have conducted outreach to fire departments, airports, and other users of AFFF ranging from surveying fire departments, coordinating with state fire marshals,

setting up informational web pages, developing fact sheets, and coordinating with their state Department of Transportation, among other efforts (ECOS 2025). States such as Washington and Minnesota have developed guidance to support foam transitions from AFFF to F3. A summary of each guidance document is below.

The Washington Department of Ecology's August 2024 interim guidance, "Best Management Practices for Deep Cleaning Fire Equipment Contaminated with PFAS-Containing Firefighting Foam in Washington State," outlines the following key practices (WA Dept. of Ecology 2024):

- **No PFAS cleaning standard** currently exists for firefighting equipment.
- **AFFF concentrate and rinsate** must be collected in labeled containers and **cannot** be disposed of in sanitary sewers, septic systems, storm drains, catch basins, or on the ground; disposal must go through a licensed hazardous waste hauler.
- **Foam replacement** should use only Green Screen-certified or DoD-specified F3 products.
- **Before replacement**, systems must be fully drained and dried; drained material should be stored in labeled containers.
- **Sampling of the new F3** at least 20 days after installation and keeping detailed cleaning and replacement records is recommended. PFAS is expected to be detected in the sample results, but it is not intentionally added, and should still be managed using BMPs.
- **Hot water rinsing (110°F–160°F)** of tanks and plumbing is recommended; use glycol-based detergents such as 20% butyl CARBITOL™, FluoroFighter™, or PerfluorAd®; circulate for at least 30 minutes.
- **A second rinse is recommended,** and an optional third rinse is suggested.
- **Sampling of rinsate** for halogenated organic compounds is recommended: if under 100 ppm, coordinate discharge with local publicly owned treatment works; if over 100 ppm, follow Washington State hazardous waste disposal rules.

The Minnesota Pollution Control Agency (MPCA) issued guidance in June 2023 and updated in December 2025 outlining the use and disposal of PFAS-containing firefighting foam (MPCA 2025). Key points include:

- **Phase-out deadlines**: Municipal and rural fire departments must stop using AFFF by the end of 2023; oil refineries have until the end of 2025 unless they have been explicitly granted a waiver to the end of 2027.
- **Airport requirements**: Airports and users at airports, except for fixed systems in hangars; must phase out PFAS-containing foam by the end of 2025 with fixed systems in airport hangars; by the end of 2027.
- **Usage and reporting**: All PFAS foam use or release must be reported within 24 hours and handled with full containment, collection, and disposal.
- **Disposal protocols**: Foam concentrate must be incinerated or solidified and landfilled as hazardous waste; runoff must be treated with granular activated carbon until PFAS levels meet Minnesota Department of Health guidance values and must be preapproved for sewer disposal.

- **F3 product standards**: Only Green Screen-certified or DoD-qualified F3 foams are permitted for replacement.

1.2.3.3 Federal Agency Guidance

Several federal agencies have published guidance pertaining to foam transitions. A summary of those follows:

DoD Guidance for Mobile Systems (March 2024) (USDOD 2024):

- **AFFF Phase-Out Deadline**: All land-based use of AFFF containing PFAS must stop by September 30, 2024.
- **Mobile System Requirements**: Mobile systems transitioning from AFFF must be fully drained, rinsed with water, and reconfigured for fluorine-free alternatives. Appropriate spill prevention and containment measures must be implemented.

DoD Guidance for Fixed Systems (July 2024) (USDOD 2024):

- **AFFF Phase-Out Deadline**: All land-based use of AFFF containing PFAS must cease by September 30, 2024.
- **Fixed System Transition**: Fixed systems must be drained, rinsed, and components drip-dried, with containment of foam and rinsate. Accidental releases must be reported if perfluorooctane sulfonic acid (PFOS) or perfluorooctanoic acid (PFOA) exceed 1 pound in a 24-hour period.
- **System Removal or Abandonment**: For abandoned or removed systems, a water rinse and drying process will be conducted before recycling or disposal.
- **Waste Disposal**: AFFF, rinsate, and impacted waste must be disposed of according to the Assistant Secretary of Defense (Energy, Installments, & Environment) ASD(EI&E) Interim Guidance on Destruction or Disposal of Materials Containing PFAS in the US (July 11, 2023)(USDOD 2023). Based on DoD analysis and consistent with USEPA guidance, four options are available including carbon reactivation, hazardous waste landfills, solid waste landfills, and hazardous waste incinerators. Hazardous waste storage may also be considered as well as underground injection control on a site-specific basis and existing or developing treatment or destruction technologies.

Federal Aviation Administration (FAA) Guidance:

- The FAA has published many documents to support airports with F3 transition planning and guidance. This includes an aircraft transition plan, four CertAlerts, and other materials. The FAA (2025) "Fluorine-Free Foam (F3) Transition for Aircraft Firefighting" website includes links for the documents:
    - **An FAA Aircraft Firefighting Foam Transition Plan (2023)** was published to support transition planning for FAA Part 139 airports. The plan was established in response to a December 2022 congressional directive for FAA to develop "a transition plan that would include all known legislative requirements, personnel training changes, and other operational aspects to be implemented for a certificate holder's transition to MILSPEC F3" (FAA 2023).
    - **Part 139 CertAlert 23-07** was published to describe availability of F3 on the Navy's Qualifed Products List (QPL)

- **Part 139 CertAlert 23-01** was published to describe new military specification for performance-based standards for F3s for aircraft fires.
- **Part 139 CertAlert 24-05** was published to describe rinsing procedures for cleaning out mobile systems transitioning from AFFF to F3.
- **Part 139 CertAlert24-11** was published to describe testing requirements and outputs after completion of F3 transitions.

Deadline Extension and Support:

- **Transition Deadline Extension**: The DoD has extended the AFFF transition deadline from September 30, 2024, to September 30, 2025, for both mobile and fixed systems due to the need for more time to replace AFFF with fluorine-free alternatives at 1,500 facilities and 6,000 mobile assets (USDOD 2024).
- **FAA Support for Airports**: The FAA is supporting airport transitions through the FAA Reauthorization Act of 2024 (FAA 2024), which includes funding and a PFAS replacement program for the switch to F3. As of September 2025, Congress had not appropriated funding for the PFAS replacement program. Section 767 of the act identifies the "PFAS-related resources for airports" (FAA 2024).

1.2.3.4 Other Guidance on Foam Transition

Other governments, as well as organizations representing foam users, have developed guidance on foam transition. Some additional representative guidance is presented below.

Queensland, Australia

The Queensland Department of Environment & Science released a 2021 policy for managing firefighting foam to minimize environmental harm, based on the precautionary principle. It outlines requirements for handling, transport, storage, use, release, treatment, and disposal of foam, emphasizing the need to assess environmental and health risks (Queensland Government 2021). Key points include:

- **Hazard assessment criteria**: All foams shall be evaluated for environmental persistence, bioaccumulation, toxicity (acute/chronic), mobility in soil and water, biodegradability, and biochemical oxygen demand.
- **Nonpersistent (fluorine-free) foams**: PFAS levels in systems shall be tested after 1 month of residence in existing system; limits are <10 mg/kg (combined specific PFAS compounds) and <6.4 mg/kg using total organic fluorine (TOF).
- **Management of fluorine-free foams**: Site managers shall take all reasonable and practical steps to contain, treat, or properly dispose of foam and runoff to avoid significant environmental harm.
- **Persistent foams (for example, AFFF)**: Concentrates must contain <10 mg/kg PFAS (specified compounds) and <50 mg/kg TOF. These foams must be fully contained on-site and disposed of as regulated waste.
- **Disposal planning**: A disposal plan shall be created within 3 months of the foam being removed from service or deemed surplus.

The Arctic Council

"The Arctic Council is the leading intergovernmental forum promoting cooperation, coordination and interaction among the Arctic States, Arctic Indigenous Peoples and other Arctic inhabitants on common Arctic issues, in particular on issues of sustainable development and environmental protection in the Arctic. It was formally established in 1996" (Arctic Council, 2025). In 2021, the Arctic Council initiated transition from AFFF to F3 foams (Arctic Council 2021), and a transition plan was finalized in August 2023 (Arctic Council 2023).

1.2.3.5 Transition from AFFF to F3 Case Studies

Case studies provide examples of AFFF transitions across industries and geographies globally. The case studies are intended to provide examples of the range of approaches to transition from AFFF to F3 and are not intended to be recommendations for specific approaches at other sites. **Table 3-5** includes the case studies collected to date.

Although there are commercial products available intended to clean residual PFAS from AFFF-impacted fire suppression systems, published literature evaluating the occurrence, duration, and concentrations of long-term PFAS rebound after the initial cleaning is lacking (Nguyen et al. 2025; Bonnet et al. 2025,; Vatankhah et al. 2025). PFAS rebound is when a PFAS-free foam is added to a system and PFAS remaining in the system infrastructure leaches back into the foam, making it a foam with PFAS in it. To date, no studies have published decontamination methods that fully remove residual PFAS from interior surfaces as indicated by PFAS rebound into replacement F3. Without aggressive surface agitation, postcleaning PFAS rebound is hard to avoid (Lang et al. 2022). To determine post-treatment efficiency of AFFF decontamination and before transitioning, swab samples are needed to assess PFAS remaining on surfaces (Bonnet et al. 2025).

More information pertaining to PFAS and AFFF can be found in **Section 3**.

1.3 Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization

Section Number	Topic
1.3.1	**Vadose Zone Characterization and Transport**
1.3.2	**Septic Systems**
1.3.3	**Perfluoroalkyl Acids Precursor Biotransformation**
1.3.4	**Groundwater Partitioning, Colloidal Transport, GW-SW Interactions**
1.3.5	**Understanding PFAS in Marine Environments**
1.3.6	**Effects of Suspended Sediment on Surface Water Sampling and Measurement of PFAS**
1.3.7	**Source ID, Differentiation, and Forensics**
1.3.8	**Site Characterization Tools and Techniques**

Information in these Priority Topics was prepared to supplement the information for Physical and Chemical Properties published in **Section 4**, Fate and Transport published in **Section 5**, Site Characterization published in **Section 10**, and Surface Water Quality in **Section 16**. Information about Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) projects for these topics can be found at **https://serdp-estcp.mil/**.

1.3.1 Vadose Zone Characterization and Transport

This section provides additional details on air-water partitioning behavior of PFAS and advances in vadose zone fate-and-transport modeling for PFAS. This content complements information in **Section 4**, **Section 5**, and **Section 10**. More specific references are provided for each subtopic.

1.3.1.1 Air-water Partitioning

Section 4.2.8, **Section 5.2.4.1**, and **Section 5.3.3** describe how competing hydrophobic and hydrophilic properties characteristic of surfactants, and specifically PFAS, result in complex transport dynamics. The presence of PFAS in porewater lowers interfacial tension and forms films at the air-water interface (AWI), with the hydrophobic carbon-fluorine tail oriented toward the air and the hydrophilic head group dissolved in water. AWI partitioning can retard PFAS migration and reduce leaching potential, with site-specific factors such as soil texture, salinity, and pH influencing the extent of retention. AWI can vary spatially in response to soil texture and heterogeneities, and temporally in response to saturation and recharge events. This behavior can significantly affect PFAS transport in the vadose zone (**Figure 1-1**).

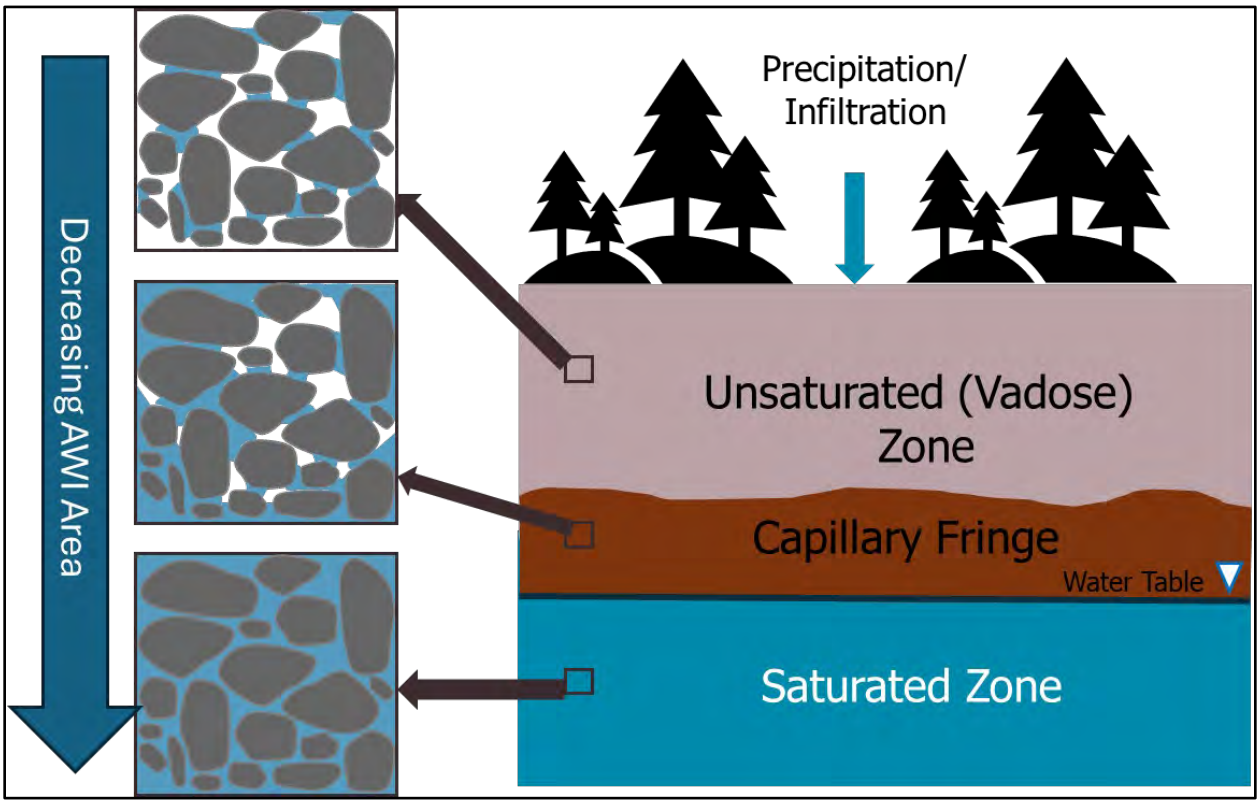


Figure 1-1. Partitioning and interfacial area. The degree of water saturation affects the amount of interfacial area in a nonlinear manner. Increased interfacial area increases retention. Factors that contribute to retention at the AWI include porewater ionic strength, PFAS concentration, and soil properties such as grain size, minerology, and moisture content, which affect the thickness of the capillary fringe.

Studies have shown that adsorption of PFAS such as perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) at the AWI can retard transport, contributing to around 50% of total retention under certain test conditions, depending on site-specific parameters (Brusseau 2018; Bigler et al. 2024). This adsorption to the AWI can be assumed to be instantaneous (Guo et al. 2022). This section primarily summarizes recent research on this rapidly evolving topic, emphasizing the need for continued

investigation and incorporation of AWI processes, in addition to vadose zone retention, into conceptual site models (CSMs) and, as the science advances, risk assessments.

Interrelated to vadose zone retention, AWI within the capillary fringe may also impact retention. Wallis et al. (2022) noted that prolonged periods of evapotranspiration exceeding rainfall result in periods of upward flux of PFAS mass, leading to evapoconcentration and associated persistence in the vadose zone. This process acts counter to downward flux to groundwater, as typically conceived. The capillary forces discussed above demonstrate the dynamic nature of the AWI and highlight factors to consider when evaluating PFAS retention in the vadose zone and capillary fringe.

The AWI area is influenced by both soil grain size and soil saturation. In particular, the AWI-saturation relationship is nonlinear, with high AWI at low saturation and zero AWI at full saturation (Guo, Zeng, and Brusseau 2020). For example, soils with higher percentages of silt and clay size particles typically support larger AWI areas than coarser grain soils for a given water saturation (Brusseau 2023). Brusseau noted that spatial variability in soil texture and soil moisture should be considered when evaluating AWI area. Similarly, temporal changes in soil saturation (from infiltration and drainage) also affect the AWI area and may be important to consider depending on the specific goals/objectives of the investigation. Specifically, Guo et al. (2022) showed that modeled long-term leaching of PFAS was adequately assessed assuming steady-state conditions. But modeling focused on short-term impacts of infiltration on AWI area and PFAS leaching should consider the dynamic nature of surfactant-induced flow, and rate-limited, nonlinear adsorption at solid-water and air-water interfaces. However, incorporating these factors comes with significant computational costs and the requirement for detailed input parameters. Last, it is noted that grain size also affects the extent of PFAS retention via conventional sorption methods, as discussed in **Section 5.2**.

Soil type (mineralogy, grain size, and surface area) and porewater ionic type and strength influence PFAS accumulation at the AWI. Coarser grain sizes having lower water content and more air-filled pore space can increase retention. The adsorption of PFAS at the AWI decreases with increasing concentration and increases with the number of perfluorinated carbons, indicating different retention behaviors for various PFAS (Silva, Martin, and McCray 2021). Additionally, Le et al. (2021) and Stults et al. (2023) both highlighted that increasing ionic strength significantly enhances PFAS accumulation and retention at the AWI. Le et al. (2021) demonstrated this effect through a mass-action model, showing orders-of-magnitude increases in adsorption with rising ionic strength. Stults et al. (2023) further emphasized the influence of ion type and concentration, refining predictive models by adding an empirical ionic strength correction factor accounting for these effects under environmentally relevant conditions. Both studies underscore the critical role of ionic strength in PFAS fate and transport. Note that tidally influenced sites could have significantly retarded PFAS transport due to a combination of higher ionic strengths in the vadose and saturated zones, as well as thickened capillary fringe. Understanding this retention behavior will support review of site-specific analytical results combined with soil profile data. Processes that contribute to retention of PFAS in the vadose zone are summarized in **Figure 1-2**. Refer to **Section 1.3.8.6**, and **Table 1-7** for sampling and analysis recommendations for grain size, soil classification, moisture content, and cation/anion exchange capacity that relate to vadose zone partitioning and leaching.

Research has shown significant variability in leaching behavior across different soils, emphasizing the need for site-specific assessment. Thompson et al. (2024) highlighted the benefits of site-specific leaching tests for PFAS risk assessment, demonstrating variability in leaching among five different soils compared to modeled data based on regulatory assumptions. Navarro et al. (2024) described how laboratory-scale leaching tests provide controlled insights into PFAS behavior but struggled to replicate in situ conditions, particularly for the AWI. Laboratory leaching methods, including synthetic precipitation leaching procedure (SPLP) tests, often rely on simplified, saturated conditions over extended periods. This can overestimate the leaching from soils collected from the water table interface, as fully saturated conditions do not reflect the reality of the vadose zone, where saturation is transient and varies in both

persistence and periodicity. Such methods overlook the important role of the AWI in PFAS accumulation and mobility, particularly for long-chain compounds. Ignoring adsorption to the AWI can result in soil screening levels that are significantly more stringent than otherwise (Brusseau and Guo 2023). As a result, standard tests may misrepresent leaching potential under field conditions. The observed variability in leaching behavior and the potential for laboratory studies to misrepresent leaching behavior together underscore the need for site-specific field validation approaches that account for climate, soil structure, wet-dry cycling, and variable saturation dynamics.

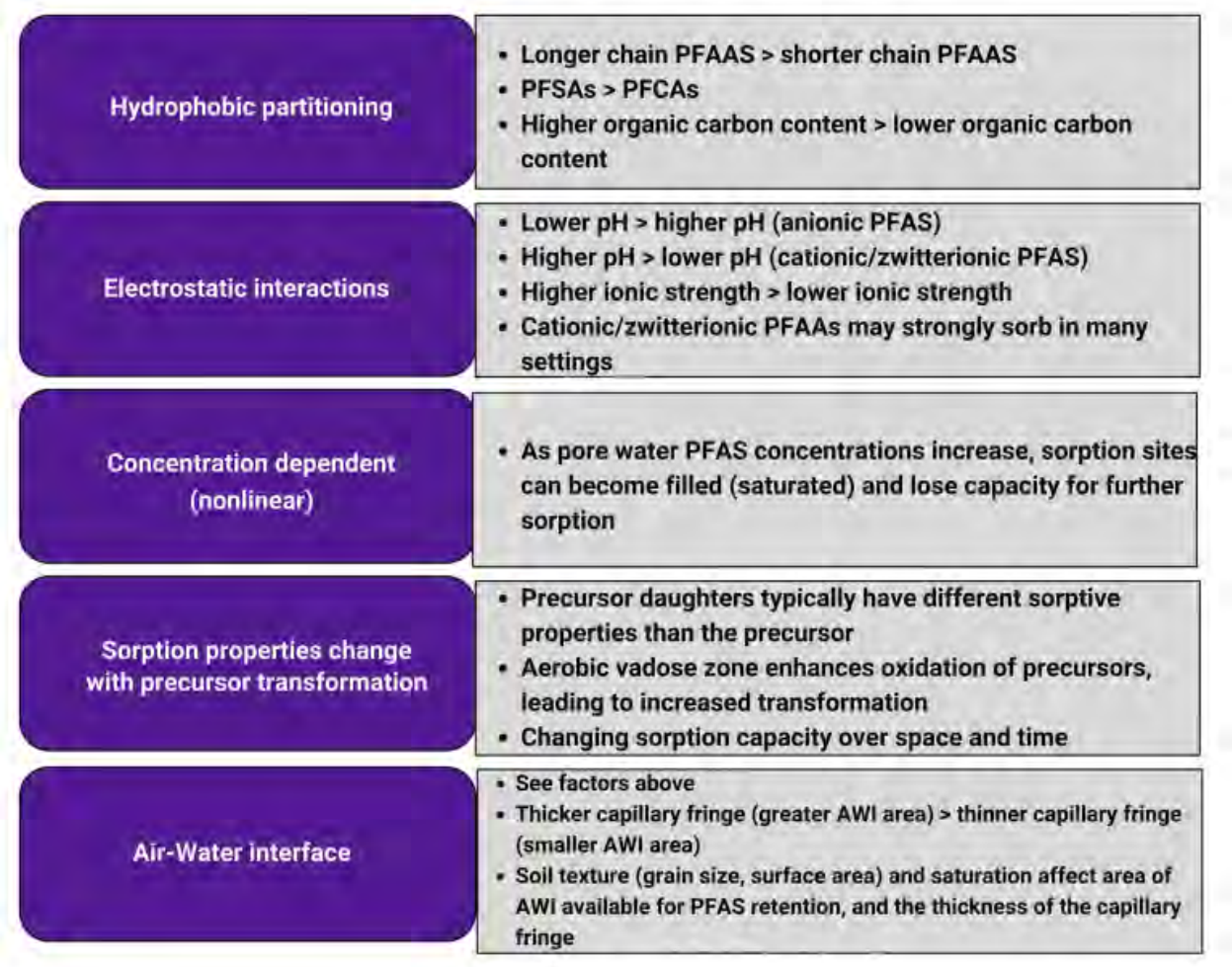


Figure 1-2. Factors influencing retention in the vadose zone.

Source: D. Drennan, BEM Systems. Used with permission.

Recent microscale modeling by Chen and Guo (2023) provided additional insight into PFAS transport through the vadose zone. Their work showed that although PFAS can move efficiently within individual pores, its movement slows down significantly in areas where water is held tightly between grains and connectivity is limited. These restricted zones can delay PFAS release and cause extended periods of low-level contamination after initial breakthrough. This research reinforces the importance of accounting for small-scale retention processes when predicting PFAS movement through unsaturated soils.

Arshadi et al. (2024) compared 1-D simulations of aqueous film-forming foam (AFFF) -associated PFAS transport in the vadose zone to field observations. The study indicated that a large portion of the mass of PFOA and PFOS exists at the solid phase and the AWI. This tends to limit transport in the vadose zone.

The rate of transport of PFAS in the aqueous phase is based on hydrogeologic properties, such as hydraulic conductivity and recharge rate. Their simulations also demonstrated the importance of considering the PFAS and other chemicals in the AFFF mixture because accumulation at interfaces is competitive and depends on the species present. Less surface–active PFAS (for example, shorter carbon chain length compounds such as perfluorohexane sulfonic acid (PFHxS), perfluorohexanoic acid (PFHxA), and perfluorobutane sulfonic acid (PFBS) (Guo, Saleem, and Brusseau 2023)) tend to have greater mobility when other chemicals are present.

Field studies also reveal gaps in our understanding of PFAS behavior at the AWI. Schaefer et al. (2024) used lysimeters to measure PFAS porewater concentrations at five AFFF-impacted sites, comparing field data with laboratory results from unsaturated soil cores and laboratory batch soil slurries. The study noted gaps in the scientific understanding of PFAS accumulation at the AWI. For instance, in the study PFAS accumulation at the AWI was orders of magnitude less than expected at two of the test sites. The research findings noted the potential importance of PFAS accumulation at the AWI in unsaturated soils and the impact of both soil texture and soil moisture content. The study also found that bench-scale testing of PFAS leaching and retention can be beneficial for understanding site-specific conditions but cautioned that improper accounting of AWI effects will result in misrepresentation of in situ leaching. The study noted significant concentrations of precursor compounds in 3 of 5 sites even after many years since original AFFF release. The authors stressed that sufficient understanding of precursor mass is essential for understanding long-term mass discharge and its role in the CSM. Last, the researchers noted that additional research is required to determine the extent to which their findings could be applied to more complex unsaturated zone conditions, such as dry and deep vadose zones with complex stratigraphy, and during extreme infiltration events. Disparities in field observations suggest a need to consider site-specific soil screening limits to account for wetting and drying cycles, soil texture, depth to water, and other parameters that may affect mass flux from the vadose zone. As such, vadose zone modeling techniques are being developed to define site-specific soil screening limits (Smith et al. 2024).

In a study of an AFFF-impacted site in a semi-arid region (27 cm average annual rainfall) where groundwater occurs at approximately 106 m below ground surface, researchers concluded that “99% of PFAS mass resided in the upper 3 m of the vadose zone” (Bigler et al. 2024). The researchers also noted that longer chain PFAS tended to remain within the uppermost (0–20 cm) portion of the vadose zone, while shorter chain PFAS accumulated at around approximately 1 m in depth, which is the top of a calcic horizon typically found in arid and semi-arid regions. PFAS of intermediate chain length were detected across the profile from surface to the calcic horizon (Bigler et al. 2024). It should also be noted that elevated PFAS concentrations (up to 40 ug/L) were observed along a 1- to 2-mile plume in deeper groundwater (water table at 100 m below land surface) in another portion of the site (USACE 2025), suggesting the importance of understanding subsurface heterogeneities that can affect PFAS in space and time.

1.3.1.2 Vadose Zone Modeling

Researchers from the University of Arizona have developed a comprehensive framework to model PFAS transport through the vadose zone (Brusseau and Guo 2023). Their research incorporated PFAS-specific retention mechanisms into the US Environmental Protection Agency’s (EPA’s) recommended process for determining migration to groundwater for soil screening levels (USEPA 1996); importantly, incorporation of these mechanisms can result in less stringent limits. Recently the Air Force Civil Engineer Center for Evaluation of Soil to Groundwater Leaching (AFCEC 2025) accepted this revised approach to developing the dilution attenuation factor. This does not necessarily imply regulatory acceptance, and practitioners should consult their specific regulators for guidance on how to determine a dilution attenuation factor and note that USEPA prefers multiple lines of evidence to support development of a site-specific dilution attenuation factor. The Smith, Brusseau, and Guo (2024) integrated modeling framework combines vadose-zone transport and groundwater dilution approaches, demonstrating that incorporating AWI

retention is essential to accurately characterize PFAS contamination risks, particularly for longer chain PFAS.

The role of the AWI in PFAS retention and leaching is important but complex. Zeng and Guo (2023) conducted systematic numerical simulations to test the hypothesis that subsurface heterogeneities, such as soil texture, accelerate the migration of PFAS in soils. Their evaluations predicted that longer chain PFAS would be strongly retained in shallow soils but could also migrate to deeper soils in response to subsurface heterogeneities, such that heterogeneity-generated preferential flow reduces the AWI area accessible to PFAS and may accelerate migration more for longer chain PFAS than for shorter chain PFAS. Overall, the study suggested that characterizing and representing soil heterogeneities is critical for determining the accessible AWI area and accurately quantifying PFAS migration. This finding aligns with Stults et al. (2024), who used laboratory column studies and the HYDRUS 1-D model to show that while equilibrium models could predict total mass leaching, they failed to accurately forecast effluent porewater concentrations. A novel two-site leaching model incorporating AWI partitioning and rate-limited desorption provided better predictions, particularly for long-chain PFAS such as PFOS and PFOA. The uncertainty in leaching rates is much higher for long-chain than short-chain PFAS. The short-chain PFAS exhibit less retention in the vadose zone and are more uniformly distributed with depth, in part because solid-phase adsorption and AWI retention are comparatively weak for short-chain PFAS. The differences in leaching between short- and long-chain PFAS imply that while short-chain PFAS mass discharge to groundwater will tend to occur relatively quickly, long-chain mass discharge to groundwater can persist for decades (Zeng, Brusseau, and Guo 2021).

Finally, Hort et al. (2024) examined PFOS retention above the water table in a marine setting using the MODFLOW-USG-Transport PFAS model, which includes AWI adsorption. Their findings indicated that recharge rates, recharge patterns, and sand grain size (fine versus coarse) significantly impact PFOS retention, with higher rates and more frequent recharge leading to less retention and coarse sands showing greater retention. The study explored inert gas sparging as a management strategy to concentrate PFOS in the vadose zone and simulated the effectiveness of retaining PFOS near the water table for extended periods. Additionally, the study results illustrated that long-term retention of PFOS in the vadose zone may be achieved by limiting or eliminating recharge via installation of an impermeable cap or cover. This suggests that effective management of soil to groundwater PFAS contamination can potentially be achieved by considering options that limit the downward flux to groundwater.

Recent advances in vadose zone modeling have improved our understanding of PFAS mobility, retention, and risk, particularly through the incorporation of AWI partitioning. Smith et al. (2024) developed an integrated vadose zone–groundwater framework that emphasized the importance of AWI retention, especially for long-chain PFAS. Subsequent modeling and laboratory studies (Zeng and Guo 2023; Stults et al. 2024) demonstrated how preferential flow, transient saturation, and nonequilibrium desorption contribute to the persistence of long-chain PFAS plumes, while short-chain PFAS concentrations tend to diminish more quickly. Hort et al. (2024) further highlighted the influence of recharge patterns and soil texture, with implications for both mass discharge and potential remedial strategies. Despite these advances, key uncertainties remain. Field-scale validation of AWI-inclusive models is limited, and model performance under transient conditions—especially wet–dry cycles and fluctuating recharge—remains poorly constrained (Stults et al. 2024; Zeng and Guo 2023). Site-specific factors such as climate variability, soil heterogeneity, and recharge dynamics are not yet fully integrated into most modeling efforts (Hort et al. 2024). Additionally, standard leaching tests such as SPLP may not reflect unsaturated conditions, potentially misrepresenting PFAS mobility (Stults et al. 2024). The interactive effects of PFAS mixtures and co-contaminants under dynamic flow conditions also require further investigation (Zeng, Brusseau, and Guo2021; Le et al. 2021). Additional information on co-contaminant effects on PFAS fate and transport may be found in **Section 1.3.4.1**.

1.3.2 Septic Systems

The following supplements **Section 2.6.4** (Wastewater Treatment and Wastewater Treatment Residuals and Biosolids), **Section 5.3** (Media-Specific Migration Processes), and **Section 10.3.2** (Nature of PFAS Sources) by further discussing the occurrence, fate and transport, and characterization of PFAS in groundwater at or near facilities with domestic septic systems (DSS) in proximity. In addition, a site characterization case study from the Raup et al. (2024) paper is presented in **Section 15.1.4**.

Several studies show that PFAS from DSS may be contributing to the contamination of private drinking water supply wells (Raup et al. 2024; Schaider et al. 2016; McMahon et al. 2022; Silver et al. 2023; Yang et al. 2017). Association with known septic contaminants is one line of evidence to determine if PFAS originate from a septic source (Raup et al. 2024; Silver et al. 2023). Common markers help determine whether a drinking water supply is contaminated by a septic system, including coliform and other bacteria. However, the minimum allowed distance between septic fields and downgradient private wells is designed specifically to prevent such bacteria from reaching neighboring water wells and is not designed to be protective of highly mobile PFAS that may be released from the septic system. Other chemical markers, such as caffeine, artificial sweeteners, or pharmaceuticals, are, like many PFAS, transported farther and at a faster rate than bacteria in groundwater and can be used in combination as first indicators of DSS influence on water sources (Raup et al. 2024, Silver et al. 2023).

Schaider et al. (2016) used sweeteners and pharmaceuticals and personal care products to establish a connection between DSS and PFAS contamination (**Figure 1-3**). Samples collected from five aquifer systems in the eastern United States in 2019 had a high co-occurrence of PFAS with VOCs and pharmaceutical chemicals, with higher pharmaceutical detections in an aquifer with a high abundance of septic systems relatively near water supply wells (McMahon et al. 2022). Silver et al. (2023) sampled 450 shallow wells from private residences throughout the state of Wisconsin and found that samples exceeding the EPA MCL for PFOA or PFOS tended to be associated with the presence of artificial sweeteners and pharmaceuticals, indicating a human waste source. Raup et al. (2024) sampled water supply wells near a superfund site in New York State and used the presence of septic tracers and multivariate statistics comparing PFAS composition to conclude that the probable source of PFAS to groundwater is the discharge of consumer products to septic systems.

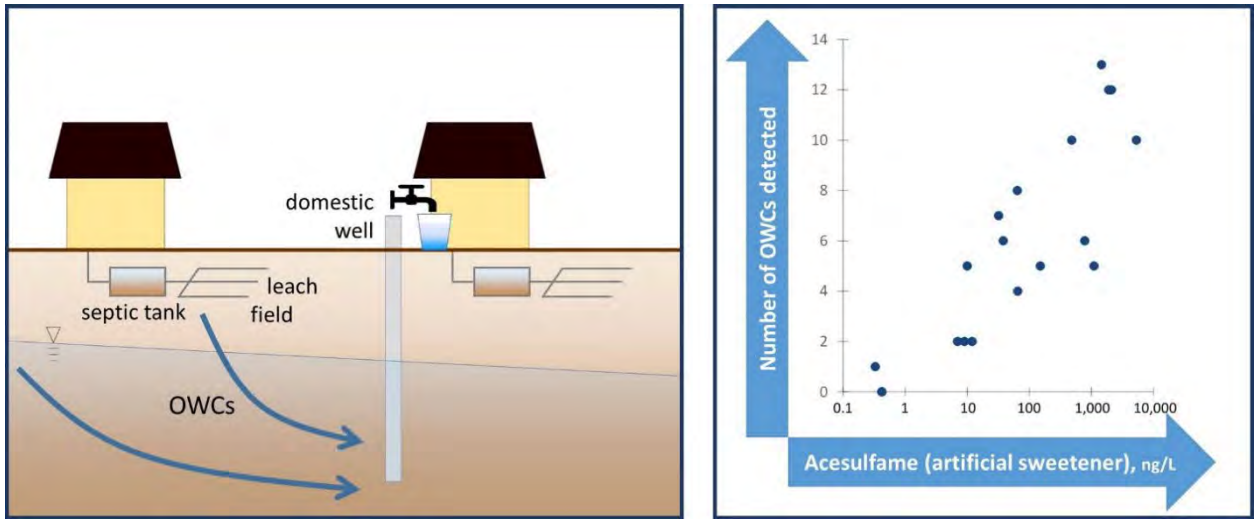


Figure 1-3. Conceptual model of drinking water contamination by neighboring organic wastewater compounds (OWCs) and use of sweetener as indicator of potential number of contaminants detected.

*Source: Schaider et al. 2016. Open Access, **https://creativecommons.org/licenses/by-nc-nd/4.0/**.*

Contamination of groundwater with PFAS from DSS is a challenge in site characterization projects given that the operation of domestic leach fields and the variety of consumer products that contain PFAS can lead to areas of diffuse contamination from wastewater sources. Examples of DSS can include leach fields and seepage pits, depending on local subsurface and environmental conditions. The presence of PFAS in consumer products, including cosmetics, cleaning products, cookware, carpets, upholstery, electronic products (Glüge et al. 2020), and certain foods (Hill et al. 2022; Lasters et al. 2022; Mikolajczyk et al. 2022; Ghisi et al. 2019; Lupton et al. 2014), can result in PFAS in household wastewater. Much like wastewater at public treatment plants, it should be expected for domestic wastewater to contain PFAS (MacMahon et al. 2022; Schaider et al. 2016).

It is important to emphasize that the existence of a significant statistical correlation between the levels of PFAS and markers such as sweeteners or pharmaceuticals and personal care products in private water supply wells does not eliminate the possibility that *other* sources of PFAS could also be contributing to the contamination. For example, Schaider et al. (2016) were not able to rule out potential influence from landfills in their conclusions. In fact, artificial sweeteners have been used to evaluate the impact of landfills on groundwater (Propp et al. 2022), and artificial sweeteners (Li et al. 2021) and pharmaceuticals (Kinney and Vanden Heuvel 2020) have been found in biosolids used on agricultural fields.

Other sources that could contribute to PFAS in groundwater or water supply wells have been documented. For example, Sivaram (2022) noted the presence of PFAS in commercially available garden soil mixes and composts, and at least one study documented downward migration of PFAS from compost (Saha et al. 2024), indicating that composts or other lawn and garden amendments have the potential to contribute PFAS to groundwater. PFAS contamination could also originate from a variety of diffuse sources such as wet precipitation (Pike et al. 2021) and dry deposition (Schroeder et al. 2021) that may infiltrate and percolate, transferring from the atmosphere into the vadose zone and groundwater (Guo, Zeng, and Brusseau. 2020). In addition, because the mix of consumer products used in a household or business can vary, the mixture of PFAS, or PFAS signature, should not be expected to be similar for all septic sources. Because of these potential complications and uncertainties, a multiple-lines-of-evidence approach should be used when investigating septic systems as potential PFAS sources.

1.3.3 Perfluoroalkyl Acids Precursor Biotransformation

This section presents information on precursor biotransformation to perfluoroalkyl acids (PFAAs). It builds upon **Section 5.4.2**, which introduced perfluoroalkyl acid (PFAA) precursors, and **Section 5.4.4.2** and **Section 5.4.4.3**, which discussed aerobic and anaerobic biological pathways, respectively. The introduction discusses why it is important to understand PFAA precursor biotransformation and provides background information on the process. This is followed by detailed information on the development of a precursor transformation database, and a short discussion on the application of PFAA precursor data.

1.3.3.1 Introduction

Some PFAS, commonly referred to as precursors, can undergo biotransformation processes, leading to the formation of degradation products and, ultimately, the terminal products of perfluoroalkyl acids (PFAAs). Understanding the transformation pathways and kinetics helps in predicting how PFAS mixtures change over time and how they travel and persist in different environmental media. This section describes PFAS biotransformation and the process of compilation of a database of precursor degradation rates. Please refer to **Section 2.2.2** for descriptions of PFAS nomenclature and PFAS groups and **Section 5.4** for discussion of transformation processes. Although **Table 4-1** is meant to be a compilation of biodegradation rates, not all studies described in **Table 4-1** have controls that definitively exclude the potential for *abiotic* transformation within the experiment. Additionally, not all studies had controls that excluded additional removal processes such as sorption.

Understanding the accumulation of PFAAs through biodegradation is important from a regulatory and risk assessment perspective. The mobility, toxicity, and bioaccumulation tendencies of terminal products appear to differ from the parent substances, and, as such, understanding the occurrence, diversity, and complexity of transformation pathways has become a priority in the assessment of PFAS risk. Consequently, documenting the current understanding of the number and types of transformation products, both terminal and intermediate, as well as the rates at which they are generated and transform, is an essential endeavor.

Additionally, the biological conversion of precursors can be impacted by remediation activities such as aeration in groundwater in the proximity of biosparging or air sparging wells (McGuire et al. 2014) or chemical oxidation (Houtz and Sedlak 2012). Understanding precursor transformations can also help in the assessment of appropriate remedial actions by enabling forecasts of transformation rates of various PFAS and enabling the quantification of "chemical retention" of PFAA precursors (future PFAAs) in a system alongside the geochemical retention of PFAAs through standard processes such as sorption or matrix diffusion (Newell et al. 2021). Collectively, the management of these retention processes is referred to as PFAS monitored retention (Adamson et al. 2025).

For further context, in most cases, cationic and zwitterionic PFAS tend to be retained in soil, whereas anionic PFAS exhibit greater mobility and are more likely to migrate into groundwater (see **Section 5**). Given that a significant proportion of zwitterionic and cationic PFAS are precursors—and considering that their retention in soil is not permanent—it is critically important to understand their transformation pathways and environmental fate. Further investigation into the fate and transport of zwitterionic and cationic PFAS is essential for assessing long-term contamination risks and developing effective remediation strategies (Tajdini et al. 2025)

Some studies of PFAS precursor biodegradation have focused specifically on PFAS present in AFFF. The study of PFAS transformation within AFFF sources has aided understanding of PFAS biodegradation pathways. Studies have shown that the pathways depend on the different source profiles produced by different AFFF production methods (for example, electrochemical fluorination [ECF] or fluorotelomerization, with precursors from these processes shown to degrade into perfluoroalkyl acids (PFAAs) as one of their terminal environmental products (Liu et al. 2021). To aid in general understanding of AFFF biodegradation pathways, some researchers have further classified precursors into primary and secondary ECF- or fluorotelomerization-based precursors. Primary precursors are those that were originally incorporated into AFFF formulations as intended PFAS components and are typically present at high concentrations. Secondary precursors, alternatively, are intermediate transformation products (excluding PFAAs) derived from primary precursors and are commonly detected in AFFF-impacted environments (Yan et al. 2024).

Awareness of complex PFAS precursor transformation pathways to intermediates and end products provides important context for understanding PFAS fate and transport. Development of reactive fate-and-transport models to predict the movement and behavior of PFAS in soil, water, air, and biota will require and benefit from enhanced understanding of biotransformation pathways and kinetics. By accounting for the diversity of transformation pathways and kinetic parameters, these models can provide more accurate assessments of PFAS behavior and environmental distribution.

1.3.3.2 Development of Precursor Transformation Database

The need for compilation of available precursor transformation kinetics was identified for practitioners to reference or use as guidance. A centralized table curated from peer-reviewed published literature was developed and presented as a tab named Biotransformation in **Table 4-1** to address this need.

Sources of data on transformation of PFAS in soil media were examined, giving priority to peer-reviewed scientific literature due to the vetted nature, traceability, and thus reliability of such data. All references

are included in the References tab of the table. While the data presented in **Table 4-1** are the current state of the science, the values are highly dependent on the experimental conditions. Study- or site-specific information extrapolated from **Table 4-1** to other situations may lead to erroneous assumptions of PFAS transformation rates and extent. Importantly, interested parties must be cautious about comparing half-lives or rate constants from different studies and using literature values from specific studies for other purposes. Additionally, some of the values are true biodegradation rates while others are based on source decay or release. For these reasons, the rate constants and related values presented in Table 4-1 should be considered estimates, since derivation of these parameters is sensitive to experimental conditions, substrates, and analytical error (since standards are not available for many precursors and daughter, intermediate, and downstream products).

Data Collection Method

Table 4-1 presents only papers in which a transformation rate or half-life was explicitly reported and thus does not represent the full extent of the published information on PFAS biotransformation. **Table 4-1** includes biotransformation pathways and kinetics for PFAS from a variety of sources, including AFFF. To access a detailed description of foam formulations and a compilation of PFAS frequently present in AFFF, please refer to **Section 3**. **Section 2.2.2**, and **Figure 2-5**, include information about the PFAS family and different groups and subgroups of PFAS.

The columns in **Table 4-1** include categories such as parent PFAS name, average atomic weight, primary daughter product(s), intermediate metabolites, downstream products (downstream metabolites, term defined and discussed below), the matrix in which the precursor transformation experiments or observations were completed, the period of observation (defined as assay length), geochemical condition under which the transformation rates were observed, the transformation kinetics information identifying if the values are half-lives or rate constants, and published literature references. Numerous studies in the scientific literature provide qualitative descriptions of transformation pathways and product accumulation; however, they were not included in this compilation because they do not explicitly report transformation rates or half-lives. Additionally, many studies present precursor transformation data—such as concentration versus time plots—without calculating or reporting a rate or half-life. These studies were also excluded from the database.

Perfluoroalkyl Acids Precursors in Table 4-1

The following 13 groups of PFAA precursors will be discussed for precursor transformation:

- fluorotelomer carboxylic acids (FTCAs)
- fluorotelomer sulfonic acids (FTSAs)
- perfluoroalkane sulfonamides (FASAs)
- perfluoroalkane sulfonamidoethanols (FASEs)
- perfluoroalkane sulfonamido acetic acids (FASAAs)
- fluorotelomer alcohols (FTOHs)
- polyfluoroalkyl phosphate esters (PAPs)
- polyfluoroalkyl amine oxides (PFNOs)
- perfluoroalkyl ether carboxylic acids (PFECAs)
- perfluoroalkyl ether sulfonic acids (PFESAs)
- other perfluoroalkyl compounds
- polyfluoroalkyl ether acids
- polymer mixtures

In addition to the above groups, there are some studies listed that report degradation of perfluoroalkyl acids, although most of these values are NDO (no degradation observed). The environmental matrix considered was primarily soil. However, if high-quality data were available in other media, including

activated sludge and sediment, they were also recorded. Experimental conditions included both aerobic and anaerobic systems, but most data were obtained under aerobic conditions.

Of the 13 different groups listed above, limited information was available for four groups, namely FASAs, FASAAs, FTOHs, and PAPs. Additional research is needed for precursor transformation rates.

Transformation Product Categories

The sequence or network of transformation products was split into different categories:

- intermediate products
- daughter products
- downstream products (downstream metabolites)
- terminal products

Intermediate products: Intermediate products were identified as detected compounds present in the transformation pathway between the parent and daughter product for which the reaction rate or half-life was reported. In cases where the intermediate product was reported, the authors determined the rate constant or half-life through the measured accumulation of the specified daughter product.

Daughter products: The daughter products were those determined to represent the reported rate constant or half-life at the authors' discretion. Many papers were not explicit and reported the reaction rates in relation to the removal of the parent compound but not in relation to the formation of a specific daughter compound. In these instances, the first measured compound identified in the transformation pathway resulting from the measured decrease in concentration of the parent/precursor compound was considered a daughter product. In some cases, the metabolic pathways were not singular and multiple daughter products were possible. In these instances, more than one daughter product was listed.

Downstream products: Downstream metabolites were any compounds detected as degradation products further along the reported pathway than the daughter product. Some papers reported molar yields or relative concentrations of multiple metabolites detected. This information was included in the table where available. PFAAs were the most frequent terminal products. However, given that many of the studies did not continue until complete transformation of the parent compounds, the publications identified partial degradation of compounds at different points along the transformation pathway. Relative concentrations of downstream metabolites documented a time-specific extent of transformation in the degradation pathway.

Terminal products: Terminal products are a subset of downstream metabolites after which there is most likely no further transformation. They are most often PFAAs. A few studies that investigated PFAAs as parent compounds and observed no further degradation have also been included in **Table 4-1**, providing additional support for the characterization of PFAAs as terminal transformation products.

Transformation Kinetics

Transformation kinetics data for the precursor/parent PFAS and transformation products such as reaction rate constants and half-life estimates were mined from sources whenever available. Liu and Liu (2016) found a negative correlation between the half-lives and corresponding molecular weights of 11 PFAS that undergo biotransformation in aerobic soils. This indicates that molecular weight may serve as a reliable indicator of the overall stability of low molecular weight PFAS that have shorter carbon-fluorine chains in aerobic environments. To provide a standardized frame of reference, whenever only either the rate constants or the half-life values were provided, the other value was calculated assuming the transformation reaction followed a first-order kinetics model. This occurred unless otherwise indicated in the study. Additionally, a few studies reported no observable degradation for certain PFAS; in these cases,

the kinetic data were recorded as no degradation observed (NDO). Importantly, reaction rates depend on factors such as temperature, pH, oxidation-reduction potential, moisture content, and similar parameters. Kinetic values should be considered site-specific and may vary over time. The reaction rates presented in **Table 4-1** are intended to provide a general understanding of which products are likely to prevail during transformations.

Transformation Conditions

Most reported transformations occur under aerobic conditions, which favor oxidizing reactions. Under anaerobic conditions, PFAAs are not always formed (**Section 5**). Experimental (or field) conditions such as temperature, pH, test duration, soil type, and test settings (for example, microcosm, culture) are recorded in **Table 4-1**. Transformation has been observed with multiple soils (except for some sulfonamide precursors), usually in presence of alternate organic substrates (for example, glycols in AFFF, acetate, glucose), suggesting some of the transformations may be catalyzed by microorganisms using these primary substrates via nonspecific oxygenases with cometabolic pathways for PFAS transformation (Yang et al. 2022; Olivares et al. 2022; Ruyle et al. 2023). Some studies have also reported the role of sulfur limitation in fluorotelomer transformation (Van Hamme et al. 2013).

1.3.3.3 Applications

The present envisioned uses for this type of PFAA precursor transformation data include:

- mapping of observed and traceable degradation pathways for contaminant forensics and fingerprinting
- introduction of reliable input variables for reactive transport models
- PFAS exposure assessments in which both PFAA precursors and PFAAs are present in the environment or within organisms for bioaccumulations models (Glaser et al. 2021)
- development of a baseline for prioritization of exposure and toxicity studies
- development of site-specific degradation rate estimations

As regulations continue to evolve to address PFAS impacts, including diverse transformation pathways in risk assessments is important to ensure regulatory compliance and design effective mitigation strategies. Understanding the full spectrum of PFAS transformation pathways helps regulators, remediation practitioners, and local infrastructure decision makers and operators to set appropriate guidelines and timeframes for PFAS management and remediation efforts. Accurately clarifying the diversity and complexity of PFAS transformation pathways in fate-and-transport modeling is essential for a comprehensive understanding of the environmental impact, human exposure risks, and regulatory implications associated with these persistent chemicals.

1.3.4 Groundwater Partitioning, Colloidal Transport, GW-SW Interactions

The following supplements **Section 5.2.5** and **Section 5.3.4** by further discussing the fate and transport of PFAS in groundwater and the effects of co-contaminants, colloidal transport, and groundwater-surface water interactions.

1.3.4.1 Co-contaminant Effects on Fate and Transport

In addition to the effects of aqueous chemistry and soil interactions, PFAS fate and transport may be affected by the presence of co-contaminants. **Section 5.2.5** provides a discussion of interactions

between PFAS and co-contaminants, including light nonaqueous phase liquid (LNAPL). Key interactions are as follows:

- LNAPL may contribute to PFAS retention via phase partitioning or interface accumulation; where only residual (immobile) LNAPL is present, LNAPL may contribute to a reduction in PFAS flux.
- PFAS accumulation at the LNAPL/water interface is likely to be less than accumulation at the AWI.
- LNAPL biodegradation can deplete oxygen, causing a local transition from aerobic to anaerobic conditions, which may affect the transformation of PFAS precursors.

Ongoing research continues to provide additional insights into PFAS interactions with co-contaminants. Multiple studies have evaluated relative effects of phase partitioning and interface partitioning in water-LNAPL systems, and many of these studies have involved calculation of partition coefficients for both processes. These studies have generally involved only a single co-contaminant (or a small number), whereas real-world scenarios involving multicomponent mixtures of PFAS and LNAPL (or other co-contaminants) are limited. In general, PFAS retention due to interface partitioning is reported to be greater than retention due to partitioning into bulk nonaqueous phase liquid (NAPL) phases. An overview of these studies is provided in the remainer of this section.

It should be noted that the authors of these studies use slightly different definitions for the terms and coefficients they present. Generally, three terms are commonly used: solid-phase partition (absorption) coefficient, K_d; NAPL-water partition (absorption) coefficient, K_n; and NAPL-water interface adsorption coefficient, K_{nw}. Interface adsorption may also be referred to as interfacial adsorption or accumulation. "Partition coefficient" may be used as a general partitioning term (K) or may be used to describe media-specific partitioning (for example, K_d). In some instances, the term "sorption coefficient" is used to describe absorption or adsorption if the precise nature of the partitioning is not determined.

Christie et al. (2023) explored the need to account for residual LNAPLs at AFFF-impacted sites as potential sources of PFAS contamination. Though interface accumulation was not studied, insights into AFFF formulations and occurrence in groundwater were provided. The research group evaluated PFAS in bulk LNAPL from groundwater monitoring wells at military AFFF sites, using targeted and non-targeted analytical methods for anionic and neutral PFAS (that is, fluorotelomer alcohols). PFAS were detected in most LNAPL samples, with most frequently detected compounds including PFOS (nondetect to 11,100 ng/L) and perfluoroalkyl sulfonamides, such as perfluorohexanoic acid (PFHxSA) (nondetect to 67,700 ng/L). Insights were provided into the source AFFF, with some samples showing signatures of various AFFF formulations (for example, ECF versus fluorotelomerization). The analysis evaluated bulk LNAPL and did not evaluate interface accumulation. The presence of residual LNAPLs at AFFF-impacted sites should be factored into the planning and execution of remediation strategies.

Fang et al. (2024) explored the partitioning of PFAS in LNAPL; they found that PFAS partitioning was significantly influenced by both the structure of PFAS and the characteristics of LNAPL, with LNAPL potentially serving as a transport reservoir. The team investigated the partitioning of six PFAS (PFBA, PFOA, PFBS, PFOS, 6:2 FTS, and 8:2 FTS) into a weathered, field-collected LNAPL. Individual partition coefficient (K, defined as ratio of LNAPL concentration to aqueous concentration) values were determined via batch experiments. The study showed that 1) K values increase with increasing perfluorocarbon chain length; 2) K values increase with greater C-F to C-H bond ratios; and 3) the structure of the head group did not strongly affect the K values. In all cases, a higher initial aqueous concentration of LNAPL resulted in a greater K value. The study demonstrated that batch experiments may be useful for determining LNAPL/aqueous partition coefficients for PFAS. Similar to Christie et al. (2023), this analysis evaluated bulk LNAPL and did not evaluate interface accumulation.

Ding et al. (2022) evaluated interaction between PFAS and chlorinated volatile organic compound dense nonaqueous phase liquid (DNAPL) associated with a fluoropolymer manufacturing facility. Chlorinated volatile organic compounds present at the site include dichloromethane, trichloromethane, 1,1,2-trichloroethane, carbon tetrachloride, trichloroethene, and tetrachloroethene (PCE). Seventeen target PFAS were analyzed, including select PFCAs, PFSAs, and precursors. Laboratory experiments and field samples were evaluated to calculate sorption coefficients (referred to by the authors as K_d). In field samples, elevated PFAS concentrations were detected in groundwater, with PFOA as high as 204 µg/L. Laboratory experiments showed that the presence of DNAPL caused the K_d values for nearly all PFAS to increase. The values increased with an increase in carbon chain length, with the K_d for PFOA increasing by a factor of nearly 4 in the deep aquifer (where DNAPL was inferred to be present). Similar to the studies discussed above, no investigation was made between absorption of PFAS into the bulk DNAPL versus adsorption of PFAS to the water-DNAPL interface.

Liu et al. (2024) evaluated the impact of heterogeneous LNAPL on PFAS transport via a laboratory study comprising two-dimensional (2-D) flow cells. Decane and PFOS were used as model NAPL and PFAS, respectively. Two flow regimes were created, one with NAPL in residual saturation and a second with NAPL in greater than residual (pool) saturation. An influent PFOS concentration of 30 mg/L was used to represent concentrations found in source zones. The method of temporal moments, a commonly used method for analyzing concentration breakthrough curves by comparing theoretical moments of concentration to breakthrough data (Pang et al. 2003), was used to calculate retardation factors, including the effects of solid-phase adsorption, NAPL-water interfacial adsorption, and absorption into bulk NAPL. The K_n value for PFOS in decane was measured at 0.02. The retardation factor in the NAPL residual saturation flow cell measured by moment analysis was 1.7, with solid-phase adsorption, NAPL-water interfacial adsorption, and NAPL absorption being 0.56, 0.43, and 0.1, respectively. The retardation factor in the NAPL pool flow cell measured by moment analysis was 1.4, which was attributed to minimal contribution to retardation by NAPL-water interfacial adsorption due to flow bypass. In 3-D numerical simulations, the retardation factors varied from 1.13 to 2.65, with higher values being associated with closer proximity to the NAPL source zone. Therefore, the spatial distribution of LNAPL likely influences PFAS mobility, retardation, and occurrence of potential preferential pathways for PFAS transport.

Van Glubt and Brusseau (2021) studied PFAS retention by NAPL partitioning and interface adsorption, as well as the effect of PFAS on NAPL mobilization and distribution. PFAS aqueous solutions contained PFOS, PFOA, or PFPeA (perfluoropentanoic acid), while decane and trichloroethene (TCE) were used as NAPLs. Batch and column experiments were used to determine partitioning of PFAS into the bulk NAPL phase and PFAS transport in the presence of residual NAPL. Batch solubilization experiments were conducted to investigate the effect of PFOS concentrations on the aqueous concentration of TCE. Column experiments were also used to determine whether PFAS could cause NAPL mobilization. Batch experiment-derived K_n values for PFOS were 0.11 in TCE and 0.022 in decane, while batch experiment-derived K_n values for PFOA were 0.19 in TCE and 0.065 in decane. For NAPL-water interfacial tension, the activity was observed to increase with carbon chain length. Other factors influencing K_n values include the protonation/deprotonation status of the PFAS, as described by the pK_a value. Overall, the K_n values for PFOS and PFOA are small compared to other NAPLs. Retardation factors for PFOS in columns with TCE NAPL ranged from 2.5 to 3.3, while for decane NAPL they ranged from 1.7 to 2.6. The retardation factor for PFOA in a column with TCE NAPL was 1.5. However, the contribution of partitioning to the bulk NAPL phase was minimal for all these experiments, ranging from 0.5% to 19% of total retention. The results of Van Glubt and Brusseau (2021) also suggest that PFAS typically only significantly affect NAPL solubilization and mobilization when present at high concentrations (hundreds of milligrams per liter) that are rarely observed at legacy AFFF source-zone sites but may apply to both recent AFFF releases and historical-release situations.

Kosteleros et al. (2021) performed laboratory studies looking at the effects of LNAPL (jet fuel) on AFFF mobility in the vadose zone. These studies were conducted on five AFFFs and one fluorine-free foam using phase behavior and column experiments. The latter were performed to mimic AFFF migrating

through the soil column and encountering LNAPL. The outcomes found that there was the formation of a microemulsion that had a higher viscosity than either the LNAPL or the AFFF and was immobile and stable in the laboratory for at least one year. The result also showed that the LNAPL was a sink for the surfactants/PFAS associated with AFFFs. No conclusions were generated concerning the long-term stability in the environment of the microemulsion, including binding the PFAS/LNAPL in place. Nor was there an evaluation of impact on the biodegradation rate of the LNAPL.

Liao et al. (2022) investigated the effect of residual NAPL on transport and retention of individual PFAS and PFAS mixtures. The six PFAS employed were PFBS, PFHxS, perfluoroheptanoic acid (PFHpA), PFOA, PFOS, and perfluorononanoic acid (PFNA). Tetrachloroethene (PCE) was chosen as the NAPL. Interfacial tension measurements were conducted with PCE NAPL and aqueous-phase PFAS, and batch reactor experiments were used to assess PFAS partitioning into PCE NAPL and adsorption on the solid phase. Column experiments were performed to investigate the impact of residual PCE NAPL on PFAS transport in a quartz sand, and a mathematical model was developed to account for PFAS accumulation at the NAPL-water interface and partitioning into the NAPL and solid phases. PFAS partitioning into PCE NAPL was linear. The PFOS NAPL-water coefficient K_{nw} was 0.098, while the PFNA NAPL-water coefficient K_{nw} was 0.048. The NAPL-water coefficient K_{nw} for PFOA, PFHpA, PFHxS, and PFBS in a mixture ranged from 0.028 to 0.034. There was a minimal effect on partitioning values due to the PFAS being in a mixture. The sand mixture was found to have a low adsorption capacity for PFAS in column experiments. Column experiments were then performed with a residual PCE saturation of 16%, using PFOS and PFNA. These experiments showed a delay in peak arrival times, with NAPL-water interfacial accumulation accounting for 83% and 88% of the retardation for PFOS and PFNA, respectively. In contrast, PFBS, PFHpA, PFHxS, and PFOA were only slightly delayed in their breakthrough, showing that they minimally accumulate at the NAPL-water interface. Also, the effect of PFAS on PCE solubility was minimal over a PFAS concentration range from 0.01 to 10 mg/L.

Costanza et al. (2020) focused on NAPL-water and air-water interfacial tension values for PFOA, PFOS, perfluorooctane sulfonamide (FOSA), and AFFF formulations at concentrations from 0.1 to 1,000 mg/L. NAPLs tested included jet fuel, PCE, and dodecane. Interfacial tensions were measured for both air-water and NAPL-water experiments. Of note are the calculations performed for the mass of PFOA, PFOS, and FOSA in the aqueous phase, adsorbed to soil, and at the air-water and dodecane-water interfaces for a sandy soil. These results showed that for concentrations below 1 mg/L, most of the mass of PFOA, PFOS, and FOSA is at the AWI, and little is at the dodecane-water interface with a dodecane saturation of 2%. This study highlighted the importance of PFAS accumulation at the AWI in assessing mass transport of PFAS in aqueous systems.

Brusseau (2018) proposed a comprehensive conceptual model for PFAS retention and transport in porous media systems. Literature was searched for physicochemical property data, including phase-distribution coefficients, for PFOA and PFOS, which were then used to calculate retardation factors. Each of the phase-distribution coefficients contributes to the combined retardation factor in a porous media system, including air-water partitioning, adsorption at the AWI, adsorption to the solid phase, NAPL-water partitioning, and adsorption at the NAPL-water interface. Assumptions in the conceptual model included the insignificance of gas phase transport relative to aqueous-phase transport (thereby making volatilization to the gas phase a retention process), and that NAPL is immobile and has a minimal impact on solid surfaces in terms of blocking solid phase adsorption. A sandy quartz vadose zone soil with moderately low organic content, a water saturation of 78%, a NAPL saturation of 2%, and an air saturation of 20% was assumed. PFOA, PFOS, and 8:2 fluorotelomer alcohol (a precursor to PFOA and other PFCAs such as PFNA and PFHpA) were included. Partition coefficients were gathered from the literature. Notably, reported K_{ow} values were used as a surrogate for K_{nw} partition coefficients. For PFOA and PFOS, the contribution of NAPL-water partitioning was small: for PFOA, the total retardation factor was 14.1, with NAPL-water partitioning contributing 16%; for PFOS, the total retardation factor was 47.9, with NAPL-water partitioning contributing 8.2%. For both PFAS, the dominant contributor to retardation was air-water interfacial adsorption. For FTOH, however, NAPL-water partitioning contributed 98% to the total

retardation factor of 9,906. This study (Brusseau 2018) did not involve any laboratory or field aspects. It is important to note that the K_{ow} values used as surrogates for K_{nw} values ranged from 83 (PFOA) to 282 (PFOS) to 380,189 (FTOH). It is important to better understand the K_{nw} for FTOH given its role as a PFOA precursor. Last, because the model developed by Brusseau (2018) was based on the available literature at the time, more recent literature should be used for the partition coefficients of the subject PFAS if the model is to be used. **Table 1-6** summarizes the partition coefficients in this section.

Please note Table 1-5 was removed from the document and webpage.

Table 1-6. Summarized PFAS: NAPL partition coefficients (based on references in this section).

PFAS	Weathered LNAPL	Decane	TCE	PCE
PFBA	0.02 to 0.22			
PFBS	0.06 to 0.33			0.0291
PFOA	7.485 to 9.034	0.02 0.065[1]	0.19[1]	0.0321
PFOS	11.65 to 38.8	0.022[1]	0.11[1]	0.098
6:2 FTS	1.11 to 1.52			
8:2 FTS	18.69 to 19.10			
PFNA				0.048 0.0402
PFHpA				0.0276
PFHxS				0.0340

[1] Batch NAPL-partitioning experiment values from Van Glubt and Brusseau (2021).

1.3.4.2 Colloidal Transport of PFAS in Groundwater

Colloid and colloid-facilitated solute transport have been investigated in the subsurface in recent years. Deb and Chakma (2023) "identified fundamental mechanisms of colloid mobilization and the principal mathematical relationship describing colloid transport including attachment-detachment, size exclusion, and air-water interfacial area." The paper also considered mobile colloid attachment at the AWI and the air-water-solid contact line present during infiltration and water table fluctuations.

Bierbaum et al. (2023) investigated the sorption processes that affect PFAS transport during leaching by creating a continuum model and a particle tracking model and comparing results to data from previously conducted column and lysimeter experiments. The authors proposed that colloid-facilitated transport in column and lysimeter experiments resulted in "premature leaching" of PFOA and PFOS. Sorption processes investigated included equilibrium and rate-limited sorption to soil and AWIs, and colloid-facilitated transport. The study highlighted that precursor transformation may be more relevant for long-term leaching of PFAS in the environment compared to rate-limited sorption, and that AWI sorption has the potential to be the dominant retention mechanism at PFAS-contaminated sites. The authors also noted that results of the model simulations suggest that "premature leaching" may be a result of colloid-facilitated transport, and that this mechanism appears to be more significant for PFOS than PFOA, likely due to the increased sorption affinity of PFOS compared to PFOA.

Borthakur et al. (2021) noted that flow interruptions from groundwater injection in clay-rich soil caused increased leaching of PFBA and PFOA associated with increased soil colloid concentrations. Concentrations of PFOA were higher than PFBA in effluent samples, indicating that colloid transport is more significant for long-chain PFAS due to their higher sorption affinity. This was corroborated in a

series of column studies by Das et al. (2024) to simulate managed aquifer recharge, which showed that a greater fraction of PFOS in the effluent was associated with particulates compared to PFBS, which was predominantly in the dissolved phase. The authors noted that colloids may play a higher role in PFAS transport in conditions that release colloids (Borthakur et al. (2021), which could include natural fluctuations in groundwater flow, extreme precipitation events, or soil disturbance.

Microplastics are often associated with PFAS and can be transported as colloids (see **Section 1.8.4**).

1.3.4.3 Groundwater–Surface Water Interactions

Understanding the fate and transport of solute contaminants at the groundwater-surface water interface is an important component of site characterization and CSMs (see **Section 16.7**). This interface (also known as the hyporheic zone) consists of saturated sediments comprising streambeds, stream banks, and floodplains that exist between surface water and underlying/laterally adjacent aquifer materials. **Section 5.3.4.1** discusses PFAS in the hyporheic zone in the context of how changing redox conditions can affect biodegradation. This section provides information for additional topics and references.

Bed sediments often have different physical and chemical characteristics relative to the aquifer itself. These characteristics include:

- reduced hydraulic conductivity associated with silt and clay (discretized as a zone of reduced "conductance" in groundwater flow models)
- increased organic carbon content
- changes in geochemical parameters (redox, solute concentrations)
- presence of biota
- brackish, saline, and tidally influenced conditions in coastal areas

As discussed in **Section 5.2.3**, sorption of PFAS can be influenced by a variety of factors, including grain size, organic carbon (OC), presence of co-contaminants, and carbon chain length of the PFAS molecule. In general, the characteristics of the hyporheic zone would tend to inhibit PFAS flux in groundwater by reducing seepage and enhancing sorption to OC.

In coastal areas, PFAS sorption to the aquifer or sediment matrix is enhanced by the ionic strength of brackish or saline water. Early in the progression of PFAS research, Chen et. al (2012) noted that sorption of PFOS to marine sediments was strong—approximately 10 times higher than that in fresh water. The sorption affinity was well correlated with the sediment OC content, confirming the significance of hydrophobic interactions. This phenomenon is more recently referred to as "PFAS salting out," defined by Hort et al. (2024); (see **Section 1.3.5.1** for more details on the salting-out effect), which becomes an increasingly dominant process as "PFAS in fresh groundwater mixes with saline groundwater near marine shorelines, resulting in increased sorption to aquifer solids" (Hort et al. 2024).

Studies that directly explore PFAS behavior at the groundwater–surface water boundary are sparse, with some authors calling for more research in this area (Divine et al. 2023). Tokranov et al. (2021) examined the impact of groundwater–surface water boundaries on PFAS transport and transformation in a flow-through lake, fed by contaminated groundwater, and its downgradient surface water–groundwater boundary. PFAA precursors made up 45% of the total PFAS concentration in the oxic lake, which was impacted by a fire training area and historical wastewater discharges. In shallow porewater downgradient from the lake, the proportion of PFAA precursors decreased by 85%; the decrease was attributed to enhanced precursor transformation at the boundary between surface water and groundwater. Tokranov et al. (2021) also explored the effect of seasonality on both sorption capacity and transformation rates in the hyporheic zone. The study noted increased PFAA concentrations in the hyporheic zone and in groundwater downgradient of the lake in winter months, showing an inverse correlation with temperature (increased PFAA with decreased temperature) and a strong inverse correlation with nitrate. Seasonal

changes could not be explained by precursor transformation or AWI sorption. The authors noted large temporal variations in field-derived K_d values and suggested that future work should investigate whether there are biological mechanisms driving sorption. Tokranov et al. (2021) conclude that biogeochemical conditions at the groundwater-surface water interface result in complex and competing transport and transformation processes.

Given the large number of variables affecting PFAS interactions in the hyporheic zone, practitioners may find it advantageous to collect site-specific data. In these instances, several tools exist to characterize site-specific partitioning of PFAS to the range of media and phases and to measure flux of PFAS between groundwater and surface water. These include drive-point piezometers, porewater samplers (USEPA 2023), seepage meters, tide charts, stilling wells (gauged or with pressure transducers), sediment cores, and biological tissue sampling.

PFAS passive samplers are also becoming available for deployment in sediments at the groundwater-surface water interface that allow for discrete, time-weighted sampling and the assessment of PFAS distribution and flux (Eldridge et al. 2025; Carter et al. 2025). See also the ITRC "Passive Sampling Technology Update" (ITRC 2024).

1.3.5 Understanding PFAS in Marine Environments

This section describes some of the key factors affecting the fate of PFAS in transport from fresh water to the marine environment, in ocean spray via aerosolization and in ocean foam, as well as the bioaccumulation of PFAS to marine life. This topic supplements **Section 16** and **Section 5.3.4**, which address PFAS in a freshwater environment.

1.3.5.1 Salting-Out Effect

An important factor influencing the behavior of PFAS at the freshwater/marine water interface is the salting-out effect. As discussed below, the solubility of PFAS decreases in the presence of elevated salinity in water (that is, high cation and anion concentrations), and PFAS has a higher tendency to sorb to solid-phase materials. This process has the potential to increase retention of PFAS in saline environments. This phenomenon was observed by Munoz et al. (2017) in a survey of PFAS in an estuary discharging to the Atlantic Ocean in France. These authors observed an increase in the affinity of PFAA compounds to particulate matter in the presence of increasing saltwater concentrations. Using field data, these authors derived sorption coefficients based on both particle concentration and salting-out effects for C7–C9 PFCAs and C6–C8 (branched and linear) perfluoroalkane sulfonic acid (PFSA).

Yin et al. (2022) conducted a series of PFAS sorption/desorption studies at different salinities using marine sediment collected from the South China Sea. The results showed that the sorption coefficient increased with increasing PFAS chain length and salinity, indicating that hydrophobic and electrostatic processes are involved. In a literature-based study of PFAS in groundwater plumes discharging to sandy beaches, Hort et al. (2024) used a multivariate regression model developed from data at three PFAS sites to estimate the increased sorption of PFOS with ionic strengths as follows:

- low ionic strength (< 10 ppt), estimated a 1- to 2.5-fold increase in PFOS sorption
- medium ionic strength (10 to 20 ppt), a 2- to 6.4-fold increase in PFOS sorption
- higher ionic strength (> 20 ppt), a 3.8-fold to 25-fold increase in PFOS sorption

In an earlier study, López-Fontan et al. (2005) demonstrated the gradual micellization (self-aggregation) of sodium perfluorooctanoate (SPFO) in water with increasing ionic strength. At low ionic strength (0.01 mol decimeter^{-3} [dm]$^{-3}$), pre-micelles of perfluorooctanoate ions are formed. At 0.02 mol dm^{-3}, sodium ions (Na^+) are captured and form micelles at a critical micelle concentration of 0.03 mol dm^{-3}. At the

critical micelle concentration, the micelles are significantly ionized. At around 0.06 mol dm^{-3}, the degree of ionization was lower, suggesting the micelles are more compact.

Other studies have found that the type of cation present in the saltwater environment can influence the salting-out effect. In a series of isotherm studies, Steffens et al. (2021) found that divalent cations such as Ca^{2+} and Mg^{2+} resulted in more surface aggregation (accumulation at the air-water interface, see **Section 4.2.8**) and bulk aggregation (formation of micelles see **Section 4.2.7**) of PFOS at lower ionic concentrations compared to monovalent cations such as Na^{+} and K^{+}. Similarly, column experiments by Li et al. (2021) showed that an increase in ionic strength led to greater retardation of PFOA in unsaturated columns, and that Ca^{2+} resulted in greater retardation than Na^{+}. Using a mass-action model to determine the impact of monovalent versus divalent salts on the air-water partitioning coefficients for PFOA, Le et al. (2022) also found that divalent cations had a much larger impact on increasing the air-water distribution coefficient of PFOA than monovalent cations. An earlier column study by Lyu and Brusseau (2020) noted that while PFOA retardation was affected by changes in ionic strength under unsaturated conditions, the impact was minimal under saturated conditions—emphasizing the importance of the AWI to adsorption and retardation.

Based on literature, Hort et al. (2024) identified conceptual mechanisms for the retention of PFAS in groundwater and saturated soils with high salinity: neutralizing surface charge; salting out process leading to: increased sorption to solids and increased AWI sorption; bridging by divalent cations, leading to increased sorption to solids; and, increased formation of micelles from increased cation concentrations.

Last, several studies have shown that the type of PFAS also influences the salting-out effect and the retention of PFAS. For example, Yin et al. (2022) showed that the sorption of PFCAs on marine sediments was lower than PFSAs with the same chain length, and PFOS showed much stronger sorption than 6:2 FTSA. As discussed by Steffens et al. (2021), although the PFAS C-F bond exhibits low polarizability (see **Table 4-2**), the functional head of individual PFAS (for example, carboxyl, sulfonate) governs the extent of polarizability (see **Section 2.2.3**). Others cited by Steffens et al. (2021) have shown a higher polarizability of PFOS than of PFOA, resulting in greater increases in K_d values for PFOS compared to PFOA in increasingly saline solutions.

In a series of column leaching studies using different soils contaminated with AFFF, Tsou et al. (2024) demonstrated that the type of PFAS has an influence on its fate in a saltwater environment. These authors found that PFOA moved through the columns faster than other PFAS analytes tested (PFOS and two precursors) at all water salinities tested. However, zwitterionic PFAS moved through the columns at different rates depending on the charge of the terminal group (and the soil type tested). Salt water accelerated the transport of a positive terminal group zwitterion, N-dimethyl ammonio propyl perfluorohexane sulfonamide (AmPr-FHxSA), but slowed down zwitterions with a terminal negative charge, such as, 6:2 fluorotelomer sulfonamido betaine (6:2 FTAB). These authors also reported that salt water increased the mobility of the branched AmPr-FHxSA.

1.3.5.2 Hydrodynamic Effects

Hydrodynamic effects such as tidal currents, wind action, and wave action can influence the amount of mixing of groundwater and salt water and , in turn, the occurrence and distribution of PFAS in the marine environment. An example of this is the salting out effect discussed in **Section 1.3.5.1** which is driven by fresh water-salt water gradients that are influenced by currents and wind and wave actions (Santos et al. 2012; Robinson et al. 2018). As noted by Hort et al. (2024), based on Robinson et al. 2007), the extent of mixing is influenced by the magnitude of the groundwater influx, the tidal range, coastal topography, and the aquifer's hydrogeology. Of these, the groundwater flux and tidal amplitude were found to have the greatest influence. The relative strengths of these two forces will determine the extent of the mixing within a shallow coastal aquifer and subsequent discharge into an estuarine/marine environment.

For an aquifer with a low groundwater flux relative to the tidal amplitude, the saline water will be able to circulate through the nearshore shallow aquifer to a much greater extent. Under these circumstances (and depending on the PFAS present), the salting-out effect could be an important attenuation mechanism for PFAS in nearshore aquifers and limit the discharge of PFAS to the ocean (Newell et al. 2021; 2022). In a modeling study of groundwater dynamics in a coastal aquifer, Li et al. (2022) demonstrated that the salting-out effect reduced the peak PFOS discharge rate and its dispersion in a discharged plume. In addition, these authors observed that PFOS became concentrated at the center of the upper saline plume where salinity concentrations were higher, forming a lobe-shaped plume. Furthermore, these authors observed that the salting-out effect for PFOS was more pronounced at greater tidal amplitudes, particularly at tidal amplitudes > 0.25 meters (no impacts observed at tidal amplitudes of < 0.25 meters or for small solid-water sorption coefficients of around 0.1 L/kg). Last, as noted by Hort et al. (2024), the sorption of PFAS to beach sediment means there is also the potential for the PFAS to be remobilized should salinity change, which could be an important factor to consider in beach/estuary environments. which could be an important factor to consider in beach/estuary environments.

Other factors such as the concentration of suspended particulates, sediment OC, and biogeochemical factors have been reported to influence the fate and transport of PFAS in the freshwater environment (see **Section 5.3.4**) and are likely to also play a role in the fate of PFAS in the marine environment.

1.3.5.3 Aerosolization and Ocean Foam

This section presents the causes of aerosolization and the formation of foam in oceanic environments, as well as how those two processes affect PFAS in the environment.

Aerosolization

Aerosolization is the process whereby air trapped below the water surface due to wave action scavenges particles such as salt and PFAS from the water and releases them to the atmosphere as bubbles burst. This was described in a study by McMurdo et al. (2008) regarding the aerosol enrichment of the anionic perfluorooctanoate (PFOA). In a series of laboratory studies, these authors demonstrated that wave-induced aerosols had significantly higher concentrations of PFOA than the source water body. In addition, these authors speculated that the PFOA on the droplet surface is protonated, which is the acid form of PFOA that is released to the atmosphere. In a 2021 paper regarding sampling of sea spray aerosol and PFAS in Norway, the authors stated that there are three main sources of PFAS to the atmosphere: "(1) direct emission from manufacturing sources such as fluoropolymer plants, (2) formation in the atmosphere via degradation from volatile precursors such as fluorotelomer alcohols (FTOHs), and (3) water-to-air transfer via sea spray aerosol (SSA) emission" (Sha et al. 2021). SSA emissions occur at the shoreline and away from shore following wave and wind action. The following focuses on this third source because of wave action at the shoreline and what it means for aerial transport of PFAS.

According to a study published by de Leeuw et al. (2011), SSA consists mainly of liquid droplets suspended in air that are generated at the surface of the sea. The radii of the droplets range from around 10 nanometers to at least several millimeters, but most are less than 1 micrometer (µm). The residence time of the SSA in the atmosphere ranges from seconds to minutes for the larger droplets (removal by gravitational force) to days for the smaller particles (removal primarily by rainfall). The longer the residence time, the greater the potential distance that SSA particles can travel. It is estimated that SSA particles that are 1 µm in size (at 80% humidity) can travel up to 1,000 kilometers (Radoman et al. 2022).

The formation of SSA is not complicated. As waves crash upon the ocean surface, air becomes entrained in water in a cloud of bubbles. These bubbles work their way upward to the surface and burst. When a bubble bursts, upward of 1,000 droplets are released into the atmosphere. The number and size of droplets released from each bubble depend primarily on the size of the bubble (**Figure 1-4**).

As air is entrained below the sea surface, surface-active substances such as PFAAs and decaying organic matter can be captured at the AWI of the bubbles. As the bubbles burst, the SSA released to the atmosphere will include the PFAS, along with organic matter, salt ions, and similar substances found in ocean water. Sha et al. (2021) used laboratory-derived enrichment factors, along with measured concentrations of PFOS and PFOA in seawater. They concluded that the fluxes of PFOS and PFOA to the atmosphere provided by SSA "were comparable with the other two sources of atmospheric PFAAs (that is, direct emission from manufacturing sources and degradation from volatile precursors), suggesting the potential of SSA as an important source of PFAAs to the atmosphere" (Sha et al. 2021).

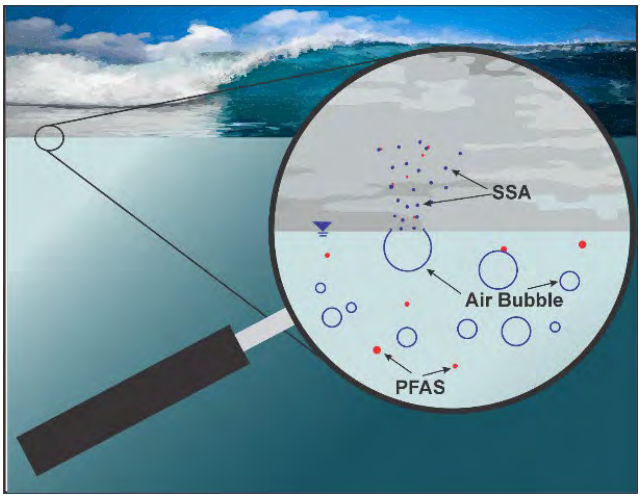


Figure 1-1. Illustration of air trapped below the water surface.

Source: A. MacDonald, used with permission.

Casas et al. (2020) sampled seawater, the surface microlayer (SML), and SSA simultaneously. Results were compared to determine SML and SSA enrichment factors. The calculated enrichment factors ranged from 1.2 to 5 for the SML and 522 to 4,690 for the SSA, the latter of which was estimated by normalizing atmospheric PFAS in SSA based on measurements of Na^{+} as a representation of the amount of seawater released during bubble bursting and wind driven SSA formation. Casas et al. (2020) concluded that "the amplification of concentrations in the SML is consistent with the surfactant properties of PFAS, while the large enrichment of PFAS in atmospheric SSA may be facilitated by the large surface area of SSA and the sorption of PFAS to aerosol organic matter." In addition, as discussed in **Section 1.3.5.1**, Steffens et al. (2021) found that the presence of seawater ions such as Ca^{+2} and Mg^{+2} enhanced the enrichment of some long-chain PFAS. Casas et al. (2020) noted that the implications of these findings include interactions with microorganisms inhabiting the surface layer as well as SSA playing a role in the global transport of PFAS.

Studies by McMurdo et al. (2008), Sha et al. (2021), and Casas et al. (2020) support the conclusion that aerosolization in seawater scavenges PFAS from oceanwater and releases it to the atmosphere, where it can potentially be transported long distances. Aerosolization can therefore be a cause of potential exposure, primarily via the inhalation route, from the shoreline to potentially considerable distances inland. The concentrations of PFAS found in the SSA depend on the concentration in the ocean during formation of the SSA. Outside of areas of PFAS sources, those concentrations can be relatively low but may still result in continuous loading of PFAS to inland soil, surface water, and groundwater.

Sha et al. (2021) and Casas et al. (2020) provide information about their sample collection procedures, which may be useful to practitioners interested in evaluating SSA. For details on sampling equipment and methods, please refer to the studies. Placement of the samplers depends on the goals of the evaluation. For example, if the study goal is to investigate concentrations in SSA in the breathing zone, then the intake for the sampler should be positioned to collect SSA from the approximate height of the breathing zone should be positioned to collect SSA from the approximate height of the breathing zone.

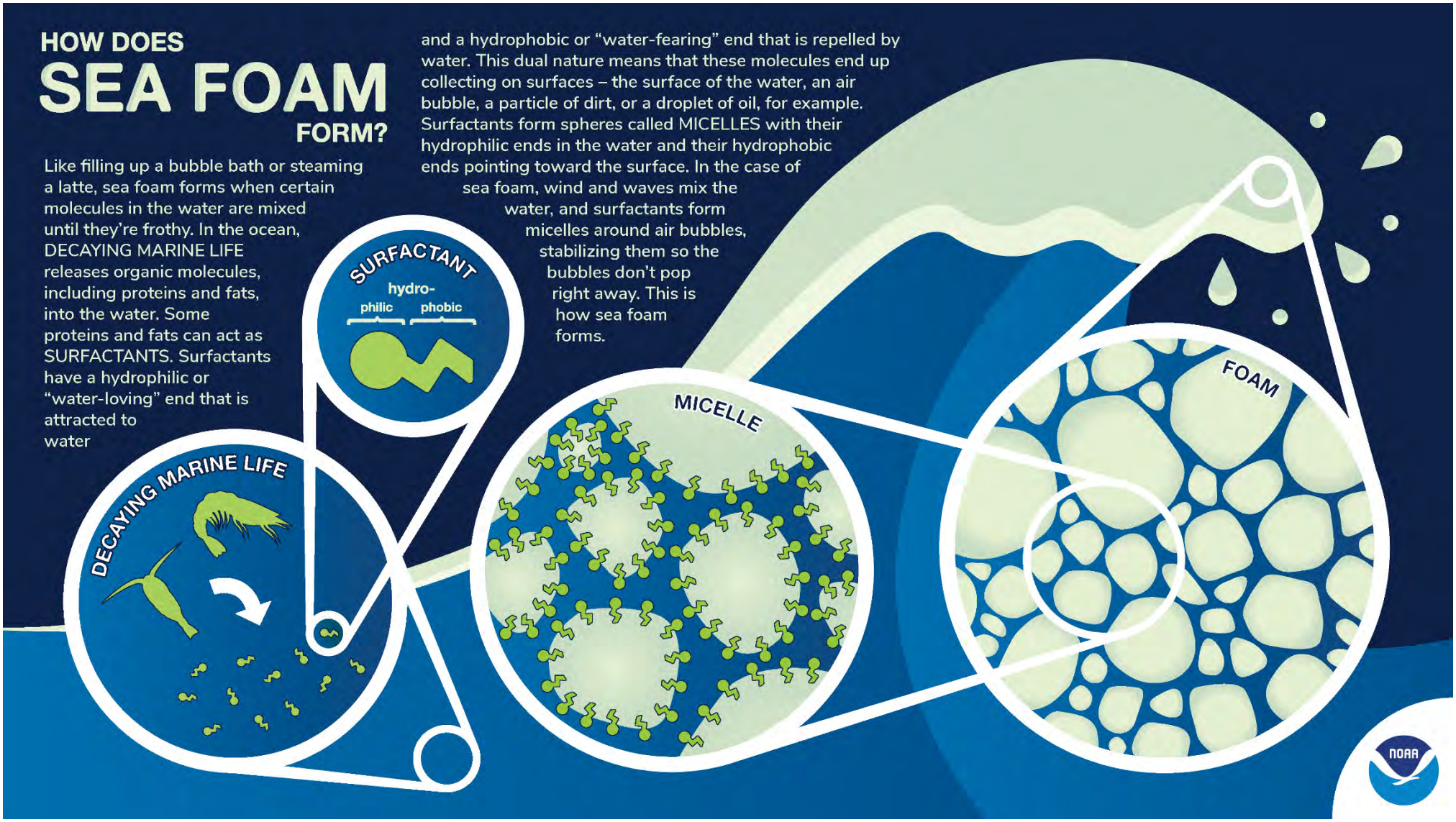


Figure 1-5. Formation of sea foam.

Source: NOAA (2024) Image credit: Kaleigh Ballantine/NOAA Office of Education.

Ocean Foam

The previous paragraphs provided information regarding aerosolization and the release of SSA into the atmosphere. Not all the bubbles created by wave action immediately burst and release SSA. Instead, foam can form from the grouping of bubbles. The National Oceanic and Atmospheric Administration (NOAA) provided the following figure (**Figure 1-5**) on how foam is formed in the ocean (NOAA 2024).

If there are sufficient concentrations of surfactants available, they will group together around nonpolar substances forming spheres called micelles. In the case of sea foam, the micelles form around air bubbles, stabilizing them and keeping them from bursting right away. The stabilized bubbles combine and form foam (NOAA 2024).

Although the primary source of surfactants in the ocean is the decay of dead algae and phytoplankton (particularly from "blooms"), PFAS are surfactants that can enhance foam formation, but are not required to be present. When the algae/phytoplankton die off-shore, they release large amounts of decaying matter, which can wash toward the shore, providing the surfactants necessary to form micelles. Foam forms as this organic matter is churned up by the surf and air is entrained below the ocean surface as in the first phase of aerosolization (NOAA 2024). This foam can be quite stable, in contrast to foam formed in nonsaline rivers, which generally exists for minutes to hours before collapsing back into the water column (see **Section 16.5**). The stability and nuisance factor of the ocean foam can be seen in this video: https://www.youtube.com/watch?v=rZM6SrFlxn0.

As with aerosolization, the entrained air bubbles scavenge PFAS, organic matter, and salts. During the collection of the stabilized bubbles and micelles, these scavenged materials are included in the formed ocean foam. The PFAS will be similarly enriched in the foam as it is in the SSA during aerosolization. This foam can remain near the shore, move onto the shore (as seen in the referenced video), or move out to sea. Over time, the foam will collapse, releasing SSA and some of the content of the bubbles back into the ocean water as the bubbles burst or fall apart.

Like aerosolization, ocean foam can transport enriched concentrations of PFAS beyond the source area (ocean water) and provide another route of exposure from contact with the foam or release from the foam as bubbles release SSA into the atmosphere.

1.3.5.4 Bioaccumulation of PFAS in Marine Biota

Although there are many studies on the bioaccumulation of PFAS in fresh water (see **Section 5.5**), there are fewer studies on the bioaccumulation of PFAS in marine waters. Some recent studies have reported the bioaccumulation of PFAS in apex predators such as sharks off the coast of the New York Bight, as far afield as the Bahamas (Lee et al. 2024), and in the northwest Atlantic Ocean (Marciano et al. 2024). As with freshwater studies, these show that longer chain PFAS (> C10) were frequently detected above reporting limits and concentrations were higher in blood plasma than in muscle collected from the same organism. With PFAS precursors detected in sharks from New York Bight but not the Bahamas, Lee et al. (2024) speculated that this reflected the greater diversity of PFAS sources in a highly populated region.

Khan et al. (2023) provided a comprehensive review of the scientific literature for PFAS bioaccumulation in marine organisms, looking at data for PFAS in wild marine organisms (invertebrates, fish, reptiles, birds, and mammals) from research over the past two decades. The authors also evaluated PFAS data for plankton, surface water, and sediment. Their review found patterns of PFAS accumulation consistent with those of freshwater studies, such as preferential accumulation of shorter chain PFCAs in plankton and longer chain PFCAs in invertebrates, fish, birds, and mammals, and generally higher body burdens of PFCAs and PFSAs in higher trophic-level organisms, with the overall highest levels found in marine mammals.

Burkhard (2021) conducted an evaluation of PFAS bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) reported in scientific literature. Although the data are fairly rich for carbonyl and sulfonyl PFAS, the data for phosphate, fluorotelomer, and ether classes are poor to nonexistent. As with other studies for PFAS, Burkhard (2021) found that PFAS concentrations were greatest in liver and lowest in muscle, with whole body concentrations in between. A comparison of freshwater to marine water BCFs and BAFs was limited by the lack of data for marine organisms.

In a later study, Burkhard and Votava (2023) assembled biota-sediment accumulation factors (BSAF) for PFAS in 17 different taxonomic classes, with one of the objectives being to find out whether there are differences between freshwater and brackish/marine species. These authors found that the highest BSAFs were for bony fish and annelid worms, whereas certain plants and bivalves had the lowest BSAFs. Although a larger dataset was available for BSAF (compared to BAFs), the results were variable, with few differences observed between freshwater and marine species. The authors highlighted the need for more paired sediment:biota data with which to derive BSAFs in the marine environment. SERDP is currently conducting research into the environmental factors that influence PFAS bioaccumulation in the marine food web, Project ER22-3359. More information can be found on the SERDP website **https://serdp-estcp.mil**.

Last, as discussed by Higgins et al. (2007), because PFAS have different affinities for organic carbon in sediment and tissue residues are controlled by active transport rather than lipid, the theory of equilibrium cannot be used to describe PFAS partitioning. Hence, where there are data available, it is recommended that PFAS BSAFs be expressed as kg-organic carbon/kg-ww rather than as kg-organic carbon/kg-lipid.

1.3.6 Effects of Suspended Sediment on Surface Water Sampling and Measurement of PFAS

This section provides information regarding the development of surface water sampling efforts for PFAS, including in water bodies with high suspended solids content. This information builds on various sections that should also be reviewed to properly use the information provided here:

- Surface Water Sampling and Analysis, **Section 16.4**
- Transfer of PFAS Between Groundwater, Surface Water, Pore Water and Sediment, **Section 5.3.4**
- Sampling and Analytical Methods, **Section 11.1**
- Surface Water Body Secondary Sources, **Section 10.3.1.2**

Several factors can affect the concentration of PFAS in surface water samples. This is due in large part to the fact that PFAS tend to sorb to suspended sediments. Concentrations of suspended sediments in surface water increase during stormwater runoff events due to higher sediment concentrations in runoff and mobilization of sediment from the river bottom due to increased flow velocity. As a result, the sample location, timing of collection, depth, sample type (for example, aqueous, bed sediment, and (or) suspended particulate matter), and sample analysis methods (dissolved, solid phase, or total) should be considered when designing a surface water sampling plan. Whether investigating impacts from an individual source area or impact(s) within a watershed, an investigator may need to sample during ambient (baseflow) *and* various storm conditions (before, during, or after peak flow) to properly understand the PFAS source(s), concentrations, mobility, and impact. **Section 5.3.4.2**, **Section 6.4**, **Section 11.1.7.3**, and **Section 11.2.1.2**, discuss the collection and analysis of stormwater runoff samples provides additional information not provided by sampling conducted during ambient conditions.

Because this section discusses considerations on the design of a sampling plan to measure PFAS in surface water, it is intended to augment other references that detail the collection of water quality data in general. For example, the US Geological Survey has produced a National Field Manual for the Collection of Water-Quality Data (USGS 2019). That reference, along with additional references found in **Section 1.3.6.1**, and **Section 16.4**, provide information and guidance to help in designing and conducting a

sampling and analysis plan for the collection of water quality samples from surface water, including some with PFAS-specific sampling techniques and some with an emphasis on stormwater.

1.3.6.1 Surface Water Sampling During/After Stormwater Runoff Events

Samples collected during ambient (baseflow) conditions reflect PFAS impacts from various non-stormwater-related discharges (groundwater discharging to a surface water body, wastewater, excess landscape irrigation, aerial or windblown deposition). However, various factors affect a surface water sample collected during rain events, making planning, collecting, and analyzing the results of the sampling more complex. For example, a dilution effect can occur if the waters that are flushed from upstream areas and subbasins during rainfall events contain lower PFAS concentrations compared to the areas of interest, thereby decreasing the measured PFAS concentrations downstream. Conversely, rainfall events can also *increase* PFAS and PFAS-sorbed particulates in surface water from PFAS source areas (such as biosolids application areas, AFFF sites, industrial areas) and the general urban environment. This occurs by mobilizing particles and bottom sediments on which PFAS are sorbed as well as solubilizing PFAS on surfaces (Borthakur, et al., 2021). Rainfall can also flush and deposit atmospheric PFAS on the ground, freeing it to be carried to storm drains and eventually surface water. Rainfall events can remove microplastics from the atmosphere and ground surfaces and deposit them into surface water where they act as suspended particulate matter (SPM) that provides additional surfaces for PFAS and other pollutant adsorption, see **Section 2.2.2** of the ITRC Microplastics (MP-1) Document (ITRC 2023). Thus, sampling only ambient conditions may not provide a complete understanding of PFAS impacts on surface water. Because rainfall often varies spatially and temporally (amount, intensity, and timing) across large watersheds, each storm may produce varying amounts of runoff from upstream subbasins, some of which may contain sources of PFAS and others not. The amount and source(s) of PFAS measured by the sample would depend in large part on storm dynamics in the watershed upstream of the sample location.

The degree of mixing within a stream may also influence how much of the dissolved and particulate-sorbed PFAS is measured at the sample location. That is, the PFAS may or may not be well mixed with depth or across the width of the stream, a condition that also holds for ambient flow conditions affected by wastewater and contaminated groundwater discharges (see **Section 1.3.6.3**).

In addition, stormwater events are associated with increased flow and turbulence in surface waters, along with additional mass of PFAS and other surfactant-type materials in the surface water. These conditions can lead to the formation of PFAS-containing foam. This foam removes a portion of PFAS from the water column, at least temporarily, and acts as a transport mechanism and new source of PFAS downstream or to another location when transported by wind away from the surface water. This complicates the assessment of PFAS in the water body. These concepts are discussed in more detail in **Section 16.5** and in **Section 1.3.5.3**.

To summarize, ambient (baseflow) sampling and stormflow sampling measure different aspects and components of PFAS in a watershed. Depending on the sampling objectives, any surface water sampling plan should consider whether to sample during ambient flow, during stormwater runoff conditions, or both, and should consider sample location, timing, depth, and type (aqueous, solid phase, or total).

1.3.6.2 PFAS Concentrations and Transport During Stormwater Runoff

Several studies, including those described in **Section 5.3.4.2**, have shown changes in surface water conditions during stormwater runoff events that influence dissolved and sorbed PFAS concentrations. Some of the results depend on site-specific conditions. The findings include the following:

- Short-chain PFAS (those with less than 7 carbon atoms) predominated in the aqueous-phase. Long-chain PFAS (those with 7 or more carbon atoms) predominated in the sorbed phase (Ahrens et al. 2010).
- During stormwater runoff events SPM contained significantly higher concentrations of PFAS than the sediments on the water body bed, showing that the increase was related to runoff from PFAS source areas more so than mobilization of sediment from the bed (Borthakur et al. 2021).
- SPM increased during stormwater runoff events (Borthakur, et al. 2021).
- SPM can be a sink, source, or transport vehicle of particle-bound substances such as PFAS, metals, and polychlorinated biphenyls (Gockener et al. 2022).
- Concentrations of PFAS on SPM originating from PFAS-impacted source areas can be much higher than found on SPM by equilibrium distribution (**Section 5.4.3.2**).
- Microplastics entering the water body increase during the stormwater runoff event and taper off as microplastics have been removed from paved and soil surfaces, as well as from the atmosphere (see ITRC 2023).
- "SPM-bound PFASs are positively correlated with transparent exopolymer particles (TEPs) content, providing evidence that TEPs may accumulate and concentrate more PFASs on the SPM" (Shiu et al. 2023).
- Surface waters where the predominant PFAS sources are from wastewater discharges and similar point sources tend to have highest PFAS concentrations during dry periods when stormwater runoff is low. Conversely, when the dominant PFAS sources are nonpoint sources (for example, biosolids application areas), the peak concentrations are during periods of stormwater runoff due to mobilization of PFAS from the source areas and conveyance to the surface water body by stormwater (Carneiro et al. 2025).

In addition to the studies above, SERDP-ESTCP has several projects to evaluate PFAS in stormwater, particularly at military facilities. These projects primarily look at treatment technologies for removing PFAS from stormwater runoff. More information can be found on their website **https://serdp-estcp.mil**.

1.3.6.3 Hypothetical Scenario to Illustrate Surface Water Sampling

The following discussion provides a hypothetical scenario to illustrate key considerations for sampling of surface water and is based on the information presented in the preceding sections. In addition, information is included for high-turbidity samples.

Figure 1-6 is a conceptualized representation of surface water conditions and PFAS distributions in surface water. The upper portion of **Figure 1-6** shows a cross-section in a water body during non-stormwater runoff events. PFAS are found throughout the water column with shorter chain PFAS more prevalent in the upper part of the water column and higher concentrations of longer chain PFAS sorbed to solids that are suspended in the water column and found in the river bottom sediments. River flows are not fluctuating significantly and PFAS molecules are in constant exchange, partitioning between the aqueous and solid states as mediated by the predominant sorption and desorption conditions. The riverbed is steadily being added to and moved slowly downstream.

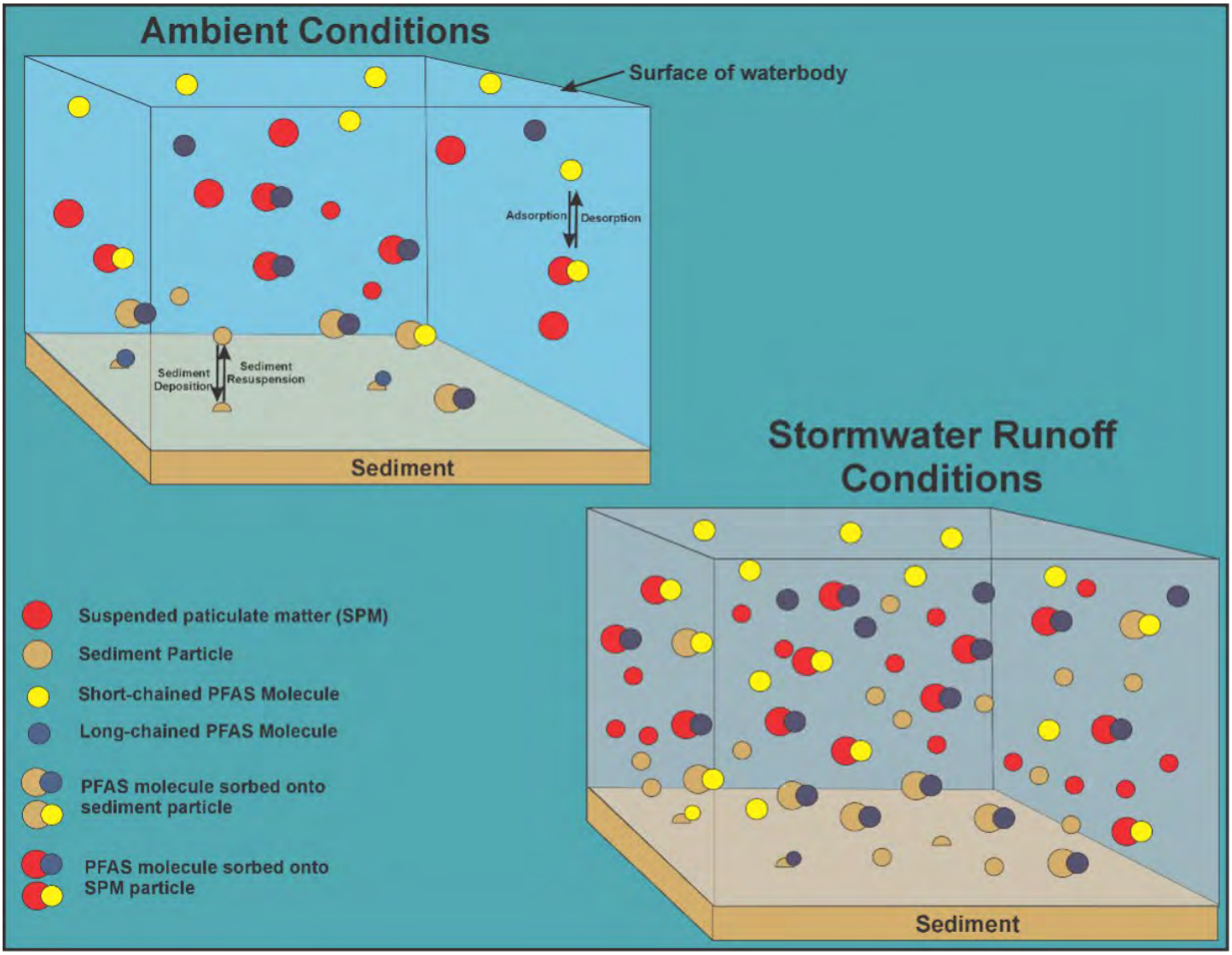


Figure 1-6. Water body conditions and conceptualized PFAS distributions.

Source: A. MacDonald, used with permission.

The bottom right portion of **Figure 1-6** shows the water column during a period of stormwater runoff. Total PFAS and SPM concentrations have increased. PFAS move between phases in response to differing mixtures and concentrations of PFAS, sorption to SPM and sediment, and concentration and makeup of SPM. Higher concentrations of SPM allow for additional sorption sites for PFAS and other pollutants. This sorption can potentially allow for increased PFAS transport downstream and deposit into the sediments of the riverbed. The system slowly reverts to ambient conditions as the storm subsides, and stormwater runoff ceases. Thus, depending on what questions are being addressed by collecting PFAS samples, the timing and location of sample collection must be carefully determined.

Factors Impacting When to Sample

PFAS concentrations and mass flux (concentration times the flow rate) in the aquatic system vary over time, during and following a storm. As discussed above, depending on the site and setting, storm flow that flushes otherwise PFAS-free subbasin(s) may dilute PFAS concentrations in downstream locations.

Often though, during a stormwater runoff event, PFAS will increase in the receiving water, and be expected to eventually diminish as runoff ebbs and first-flush effects have mobilized available PFAS, with lesser PFAS amounts available for flushing as the storm continues.

If the goal is to evaluate the PFAS impacts associated with runoff from a single facility, there are numerous stormwater sampling guides established under National Pollutant Discharge Elimination System (NPDES) permitting programs by states and the federal government. The guidance provided in those documents was not developed with PFAS in mind, but the guides are applicable to PFAS. As examples, Oregon, Washington, and California, as well as USEPA, have developed such guides (WA Dept. of Ecology 2015; CA Water Boards 2001; USEPA 2021). These guides provide information on selecting locations, storm events to be targeted, and timing to obtain samples during the first-flush of stormwater runoff.

Sample timing in a larger target area such as an entire watershed or urban area is more difficult to establish, as there may be several PFAS source areas at varying distances from the water body being evaluated. Peak runoff from these areas may arrive at different times depending on local rainfall intensity, slope, and land cover. Determining the appropriate timing of sample collection can be difficult, so high frequency sample collection, collection of time-weighted composite samples, or using integrated samplers may be preferred to single grab samples to reduce the potential of missing high or low concentrations (Beisner et al. 2024). Single grab samples can augment the data collected by these other compositing/integrating sample methods.

Factors Impacting Where to Sample

The choice of sample locations depends on the objectives of the sampling. Do the objectives include looking for peak concentrations, average concentrations at a point in time, average concentrations over an extended period of time, concentrations that may impact benthic organisms or organisms residing in the water column or both, impacts associated with a particular site, impacts associated with an entire watershed, a need to provide information for selection and monitoring of PFAS treatment/mitigation measures, or any combination of these and other potential objectives? The degree of mixing within a water body will also affect the selection of sample locations. Below is an ***example*** that highlights sample location considerations and the above components for consideration. It uses concepts, designs, and nonspecific results from a study conducted on surface water impacts as part of an NPDES permit. The example does not specifically represent the location and specifics of that project.

Example of Where to Sample

Figure 1-7 shows an urban area with two major rivers, one tributary to the other. The river coming from the right is the dominant of the two and has received discharges from a vast expanse of farmland upgradient of the urban area. The river coming in from the left originated in the mountains and has received drainage predominantly from the mountains and part of the surrounding urban area. A significant amount of rainfall has occurred providing sufficient runoff meeting the criteria for collection of samples for evaluating impacts from stormwater runoff. Note the darker color of the river receiving runoff from farmland compared to the river receiving only mountain and urban runoff. This indicates a greater turbidity (increased SPM) from the farmland river along with a greater potential for PFAS associated with biosolids application. There are no known significant industrial sources of PFAS in the surrounding urban area. he objective of a proposed study is to determine the impact on the dominant river from the urban area.

Where, and from what depth should the samples be collected?

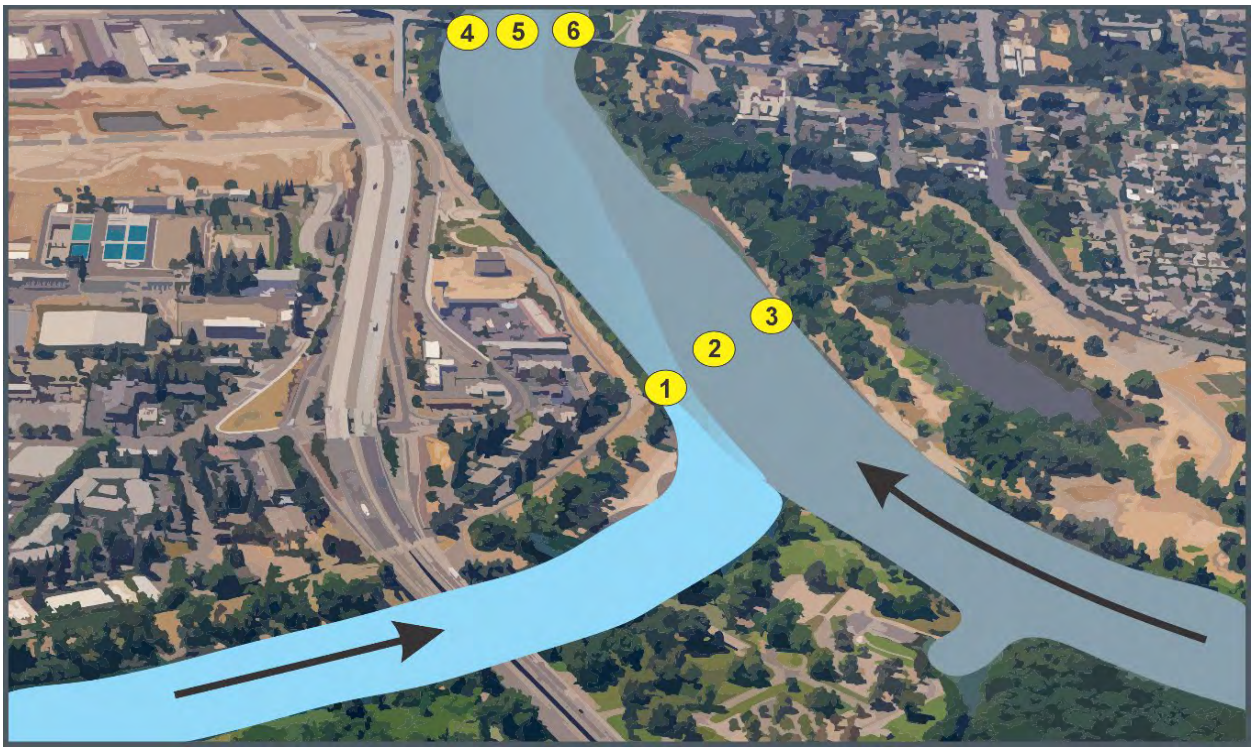


Figure 1-7. Example urban area with two major rivers.

Source: A. MacDonald, used with permission.

Discussion of sampling locations and depths

Because the goal is to determine impacts from the urban area, samples are needed just upstream of the first urban stormwater discharge points to the river to determine ambient concentrations. "Ambient" in this context means the river already impacted by the farmland, but not yet impacted by the study area. Those would be found upstream of points 1, 2, and 3, off the figure to the right. These samples would provide information for comparison to water quality standards and be used to determine the increase or decrease in PFAS concentration due to discharges from the urban area. Samples would also be needed at a downstream point in the river where there are no more urban stormwater runoff discharge points contributing to the river. This would be found some distance past the top of the figure. To determine which individual areas are contributing PFAS, point discharges of stormwater within the study area should be sampled. These sampling points would represent the discharge from the diffuse PFAS source areas in the watershed served by the discharge point.

If samples were to be collected at points labeled 1, 2, or 3 on the figure, the results could be misleading. Sampling at only location 1 would be representative mostly of the water entering from the river to the left. Sampling only location 2 would be representative of some sort of mixture of the two rivers. Sampling only location 3 would be representative only of the main river. The color of the receiving water provides a clue to the mixtures. One could sample all three locations and use the average of the three to represent the average concentrations across the cross-section of the river. However, this would likely not provide sufficient information for the study if there are additional urban inputs downstream. The same logic can be used for locations 4, 5, and 6. Ideally, the sampling is conducted even farther downstream, past all the urban discharge inputs and prior to other stormwater discharge inputs. If the downstream sample location occurs following a significant bend in the river that allows the river to mix across the entire cross-section, then representative samples can be gathered from several locations downstream of the bend. The concentrations could then be averaged if river velocity and depth of the river measurements are obtained at both the ambient and downstream locations. If that is not the case, then samples should be considered at several locations across the width of the river and at several depths at each location to account for some vertical stratification of SPM, resuspension of bed sediments, and potential reduced vertical mixing of urban runoff inputs.

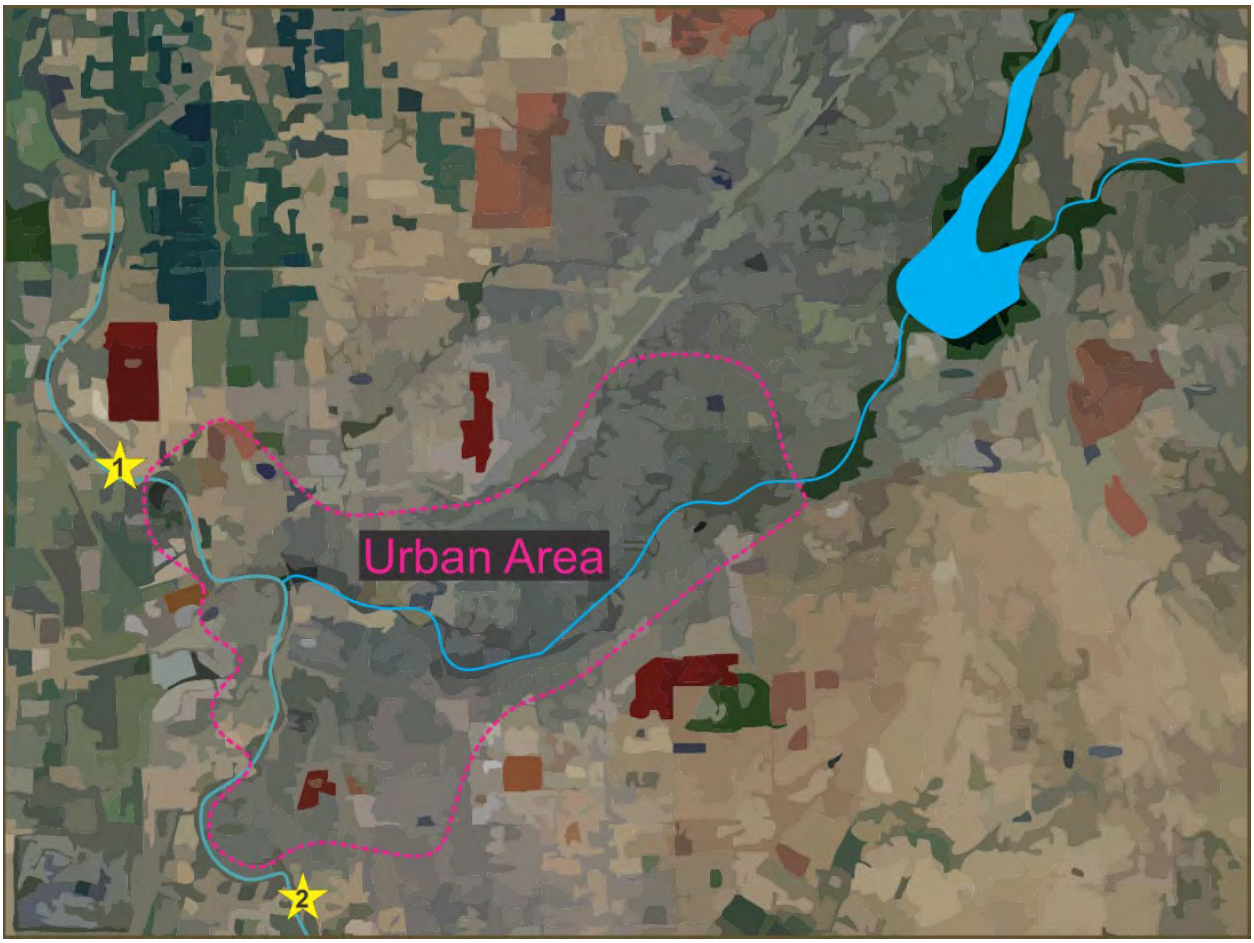


Figure 1-8. Example area with upstream and downstream locations identified.

Source: A. MacDonald, used with permission.

Figure 1-8 shows upstream sample location 1 and downstream location 2. Note location 2 is past the urban study area and downstream of a nearly 90-degree turn in the river, allowing for mixing across the river. Site-specific configuration of the river, and wastewater and stormwater discharge locations, will drive locations for sampling.

Because PFAS, if present, tends to be found throughout the water column, with a preference for some accumulation at the air-water interface (AWI), samples should be collected at several depths at a given location. The top sample would be at the AWI to include that accumulation site. The deepest sample would be near the river bottom to measure the higher turbidity that may be found there during higher river velocities mobilizing sediment. Additional samples between those two could be collected if needed, depending upon the depth of the receiving water and objectives of the sampling.

As mentioned above, there are many federal- and state-published guidelines on conducting sampling, including sampling to assess impacts of stormwater runoff. These should be consulted prior to developing a site-specific sampling and analysis plan.

Analytical Considerations with High Turbidity Samples

As described above, samples collected from stormwater and stormwater-impacted water bodies will have an increased solids content providing additional particles that can sorb PFAS and other pollutants. The analysis of high solids–containing samples (high turbidity samples) poses some additional complexity. This must be kept in mind and the objectives of the sampling must be discussed with the laboratory

analyzing the samples so the analysis can provide the information needed to address those objectives. **Section 11.2.1.2** includes information about preparing aqueous samples with particulates and suspended solids.

1.3.7 Source ID, Differentiation, and Forensics

This section supplements the material described in **Section 10.5** and highlights key forensic concepts tailored to PFAS site characterization. Environmental forensics is a multidisciplinary field that integrates chemistry, environmental science, historical research, and data analytics to identify contaminant sources. Although many techniques used for legacy contaminants (for example, polychlorinated biphenyls, polyaromatic hydrocarbons, and dioxins) are also applicable to PFAS (Plumb 2004; Johnson et al. 2015; Cejas and Barrick 2020; Bock et al. 2021), PFAS present distinct challenges that require tailored interpretation strategies (Dorrance, Kellogg, and Love 2017; Morrison 2000; Morrison and Murphy 2006; Mudge 2008; Murphy and Morrison 2015; Sullivan et al. 2001; Wang and Stout 2006).

1.3.7.1 Lines of evidence

Unlike many legacy contaminants, PFAS forensic evaluations must account for precursor transformation, differential partitioning, and complex transport behavior that can alter chemical fingerprints over time (see **Section 1.3.3**, **Section 1.3.4**, **Section 4**, and **Section 5**). These processes can mimic or obscure source contributions if not properly considered.

Despite these challenges, several lines of evidence can support reliable source identification, including:

- unique compound ratios and isomer distributions reflective of specific manufacturing processes
- indicator PFAS associated with particular industries or waste streams
- distinct spatial trends influenced by differential sorption and migration
- precursor transformation signatures detectable via advanced analyses
- use of non-targeted analysis and suspect screening techniques to expand the analytical window and reveal compound classes unique to specific sources

The accuracy of forensic interpretations depends on integrating analytical results with contextual data, including site history, use patterns, and fate-and-transport mechanisms. When interpreted holistically, forensic approaches can offer critical insights into source apportionment and plume evolution.

1.3.7.2 Historical Research

Several studies have shown that many sites are impacted by multiple PFAS sources (Anderson et al. 2016; Sun et al. 2016; Guelfo and Adamson 2018; Brusseau et al. 2020). This is particularly important in urban or industrialized areas. PFAS do not occur naturally but are found throughout the globe, including in remote areas (Herzke et al. 2023; Muir et al. 2019; Washington et al. 2019). Regional anthropogenic background levels reflecting nonpoint sources are present globally and can represent a significant fraction of the PFAS at a site. These ambient PFAS levels vary regionally and are often elevated in urban areas when compared to rural environments and remote locations (**Section 6**). In addition to identifying anthropogenic background, plausible PFAS-associated point sources in the vicinity of the investigation area should be identified and investigated.

Central to any source investigation is the evaluation of who or what may be wholly or partially responsible for site contamination based on when, how, and how much was contributed by each potentially responsible party (Sullivan et al. 2001). The answers to these questions almost always require an understanding of site history to develop information regarding:

- identification of possible local sources and site-specific anthropogenic background
- product usage history, accidental spills, or emergency response releases, environmental violations, waste handling, emission pathways and amounts
- plausible discharge pathways, such as aerial deposition, groundwater and surface water flow, soil disturbances and relocation

Numerous resources describe in more detail best practices for conducting historical research (Petrisor 2014; Sullivan et al. 2001; Murphy and Morrison 2015; Morrison 1999). The collected information should be interpreted in the context of the history of PFAS manufacture and use (**Section 2**). Note that historically, PFAS were often not included on material data sheets, therefore making it more challenging to determine whether historically used chemical formulations contain PFAS. As part of these investigations, surrogate non-PFAS markers of site wastes, discharge pathways, and transport pathways should be leveraged where appropriate.

1.3.7.3 Data Collection

Targeted sampling should follow historical research to test source hypotheses and characterize PFAS fingerprints (see **Section 10** for field investigation strategies). This section highlights how analytical method selection can support forensic differentiation (see **Section 11.2** for analytical methods for PFAS).

The diversity of PFAS formulations often necessitates looking beyond standard targeted methods. Although USEPA Method 1633A (2024) quantifies 40 PFAS, this may not fully capture site-specific profiles, especially when distinguishing between AFFF and non-AFFF sources.

To increase forensic resolution, high-resolution mass spectrometry techniques such as suspect screening and non-targeted analysis can detect a broader range of compounds and isomers, including precursors and source-specific chemistries (Glüge et al. 2020; Dasu et al. 2022). These approaches improve the statistical power and granularity of source attribution analyses (Strynar et al. 2023; Transport Research, Board NASEM 2023).

1.3.7.4 Preliminary Data Evaluation

Prior to applying advanced visualization techniques or multivariate data analytics methods, preliminary evaluation of the data quality is necessary. The integrity of forensic conclusions depends on understanding and addressing several common data issues:

- Censored values (below the detection limit): Nondetects should be reviewed in the context of detection and reporting limits, which may vary across samples or compounds. Decisions on data treatment (for example, substitution, statistical imputation) should align with data quality objectives (USEPA 2006; Helsel 2010).
- Approximate values (above but near the detection limit): Detected concentrations below the reporting limit may introduce uncertainty. Their influence on PFAS fingerprints should be evaluated, especially if they constitute a large portion of a profile.

- Extreme values (potential anomalies/outliers): Outliers may reflect analytical error or real, high-concentration releases. Graphical and statistical tools can help determine if such values distort the interpretation or reflect site-specific events (Helsel et al. 2020).

- Missing values (data gaps due to variable analytical methods): Variability in analytical methods over time (for example, USEPA Methods 537, 537.1, 1633A; see **Section 11.2.1** for more information about quantitative analytical techniques) can result in inconsistent compound lists. This may necessitate focusing multivariate analyses on a common subset of analyte, or the use of methods that accommodate missing data.

Early-stage data screening helps guide appropriate methods for fingerprinting, visualization, and multivariate evaluation. These steps support robust forensic interpretation by ensuring that statistical outputs reflect meaningful environmental trends rather than analytical artifacts.

1.3.7.5 Data Visualization

Typical site characterization visualization methods such as groundwater iso-concentration plume maps, hydrogeologic cross-sections or fence diagrams, and 3-D CSMs may be used to depict the horizontal and vertical extent of PFAS. Other visualization methods that depict the relative or absolute abundances of the various PFAS include:

- Bar charts: Side-by-side comparison of multiple PFAS (the bars), with bar height relating to relative or absolute abundance (**Figure 1-9**). Many constituents can be shown on a bar chart, with the overall pattern of the bars forming a sample's profile.

- Pie charts: Circular graphic (**Figure 1-10**) with compounds represented as adjacent quadrants and area proportional to relative abundance. Pie charts are readily displayed on maps.

- Radar plots: Circular graphic with concentrations displayed on individual axes, with increasing values away from the center (**Figure 1-11**). Unique fingerprints often form distinct shapes on a radar plot.

- Ternary plots: Triangular plots that depict the relative proportions of three PFAS in a mixture (**Figure 1-12**). These plots are commonly employed in soil science to differentiate soil types consisting of differing proportions of grain sizes, and in chemistry to differentiate chemical mixtures, among other applications.

- Scatter plots: Comparison of chemicals on rectangular (Cartesian) axes, to assess correlation, groups, or other trends.

- Family tree–style 3-D bar charts (Gamlin et al. 2024).

Bar, pie, and radar charts may be further enhanced by organizing PFAS by functional group, and sorting by physicochemical properties (chain length). Organizing the data in this way can assist with the interpretation of perfluoroalkyl carboxylic acid (PFCA) versus PFSA content and shed light on potential fate-and-transport signatures (that is, differential presence of shorter chain compounds). **Section 10.5.1.3** includes examples of visual representations of data. Additional figures are included here.

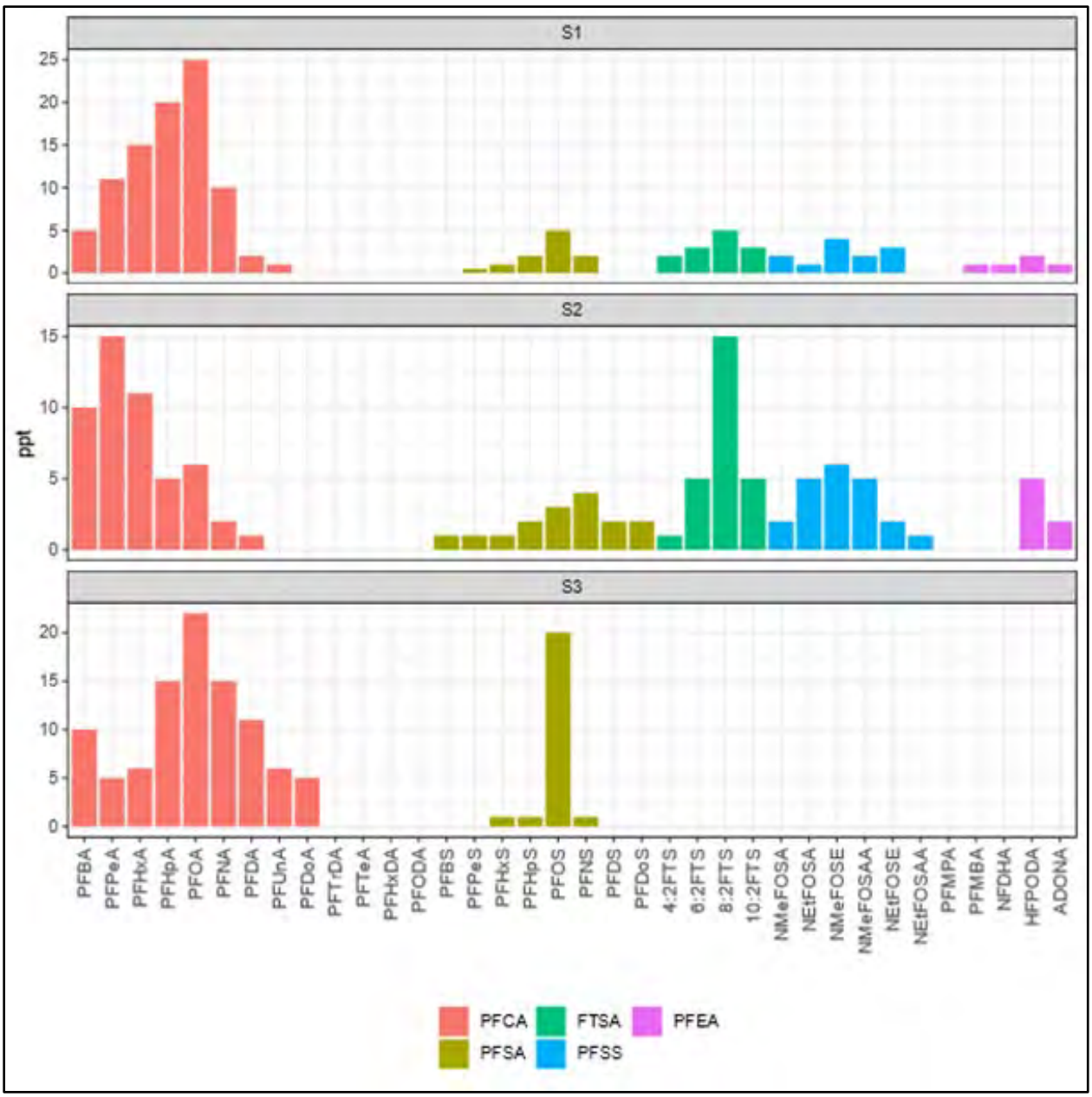


Figure 1-9. Comparison of PFAS signatures in samples S1, S2, and S3 using bar graphs. The concentration of each PFAS is shown on the y-axis, with the y-axis for each sample separately to maximize the plot area.

Source: Provided by Michael Bock, PhD. Used with permission.

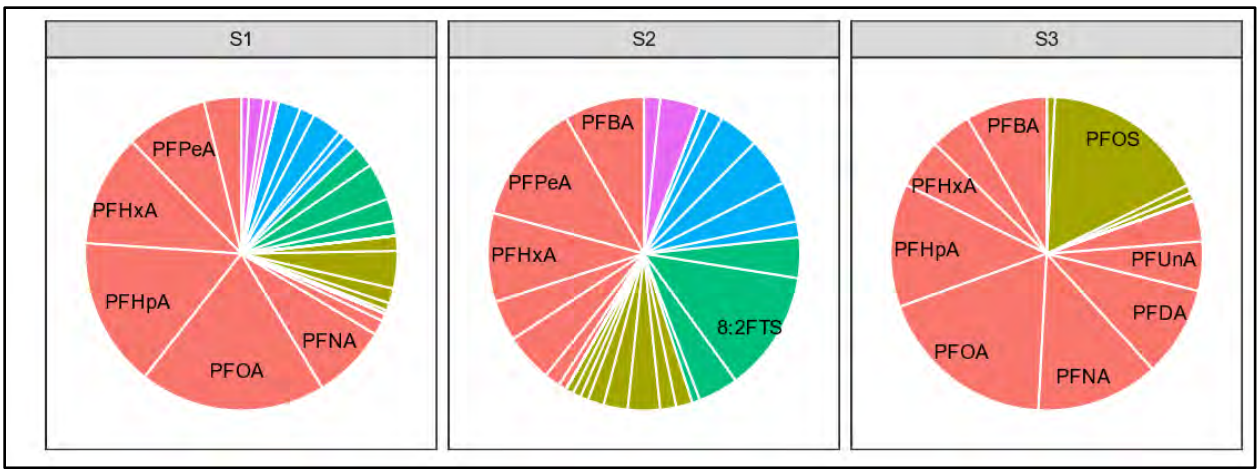


Figure 1-10. Comparison of PFAS signatures in samples S1, S2, and S3 using pie charts. The concentration of each PFAS has been divided by the sum of all measured PFAS to represent the relative abundance of PFAS in each sample.

Source: Provided by Michael Bock, PhD. Used with permission.

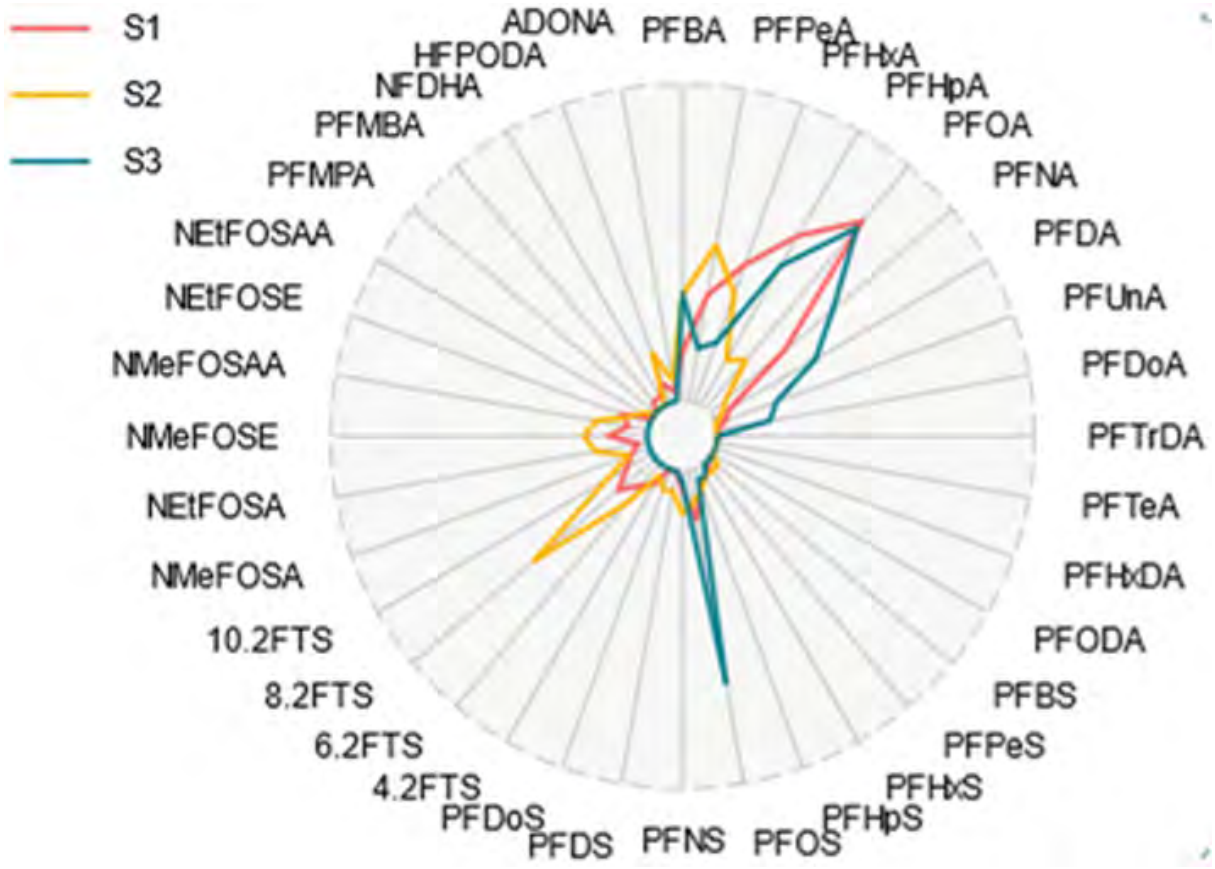


Figure 1-11. Comparison of PFAS signatures in samples S1, S2, and S3 using radar plots. The concentration of each PFAS has been divided by the sum of all measured PFAS to represent the relative abundance of PFAS in each sample.

Source: Provided by Michael Bock, PhD. Used with permission.

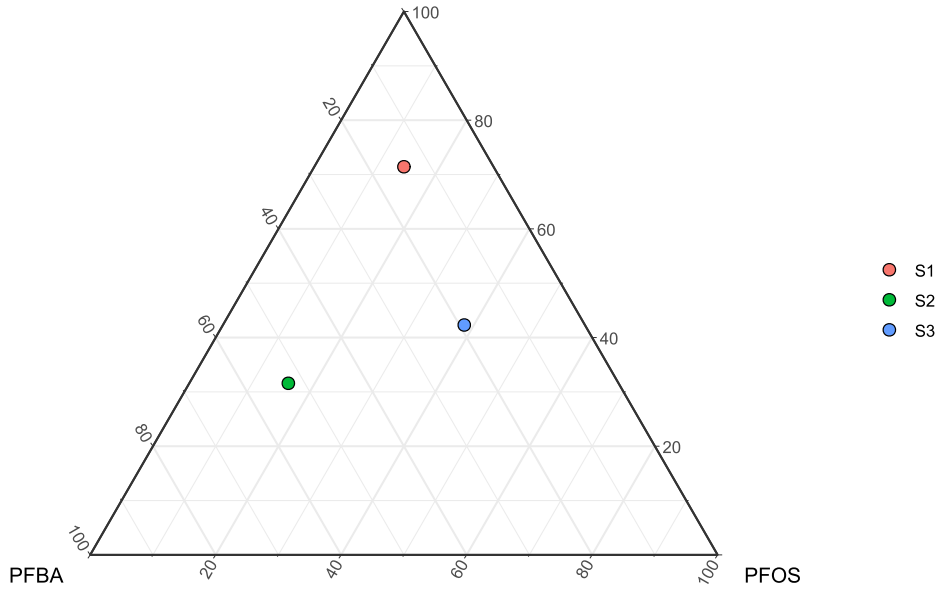


Figure 1-12. Comparison of PFAS signatures in samples S1, S2, and S3 using a ternary plot. The ratios of PFBA, PFOA, and PFOS in each sample are plotted.

Source: Provided by Michael Bock, PhD. Used with permission.

In some applications of PFAS forensics, it may be beneficial to show similarities or differences between samples using either the concentrations or relative abundances of one or more PFAS ratios. Double ratio plots (**Figure 1-13**) are a common tool in polycyclic aromatic hydrocarbon forensics (Sauer and Uhler 1994; Douglas et al. 1996; McCarthy et al. 2000), where ratios of one or more constituents are shown on the axes of a scatter plot. Double ratio plots greatly enhance the power to differentiate between samples and sources and have been applied to PFAS forensics.

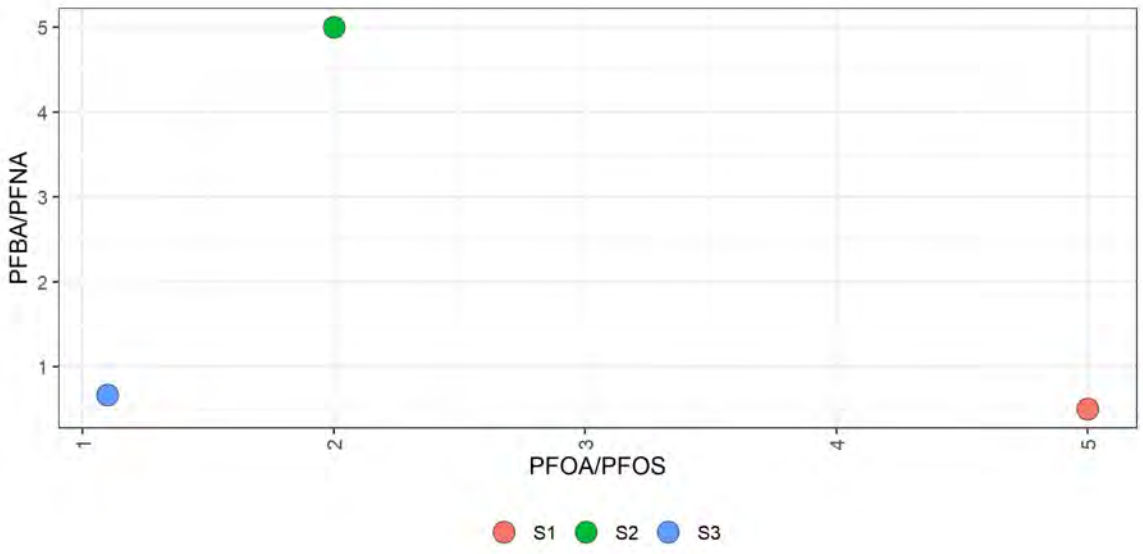


Figure 1-13. Comparison of PFAS signatures in samples S1, S2, and S3 using double ratio plots. The ratios of PFBA/PFNA and PFOA/PFOS in each sample are plotted.

Source: Provided by Michael Bock, PhD. Used with permission.

Raup et al. (2024) (see **Section 15.1.4**) used pie charts to depict fingerprint changes between surface water and overburden and bedrock groundwater, with potential contributions from septic systems. For this study, six PFAS were selected based on drinking water criteria, but a larger analyte list could potentially reveal more nuances in the chemical signatures. Tracers, such as artificial sweeteners and nitrogen species, were used alongside other lines of evidence (such as nearby wastewater treatment plant sample signatures) to support the notion of septic or other source contributions, or both. Ratios between PFAS concentrations and total PFAS clarified fingerprints within and between sampling areas, as well as potential source types. Low standard deviations calculated for many ratios indicated general geographic homogeneity of the signatures. Means and standard deviations served as statistical indicators for anomalous samples that could represent potential sources and further characterization targets. Additional case study examples are discussed in **Section 15.1**.

Gamlin et al. (2024) recently introduced a new method to visualize PFAS sample profiles (**Figure 1-14**). The method helps in identifying and interpreting patterns by organizing data by PFAS class, carbon number, and oxidation state. The concentrations or proportions are shown using 3-D bar plots. This framework can incorporate any analyte list, allowing it to evolve with advancements in analytical capabilities and scientific understanding. A 3-D modification of the Gamlin plot permits depiction of concentration levels as well.

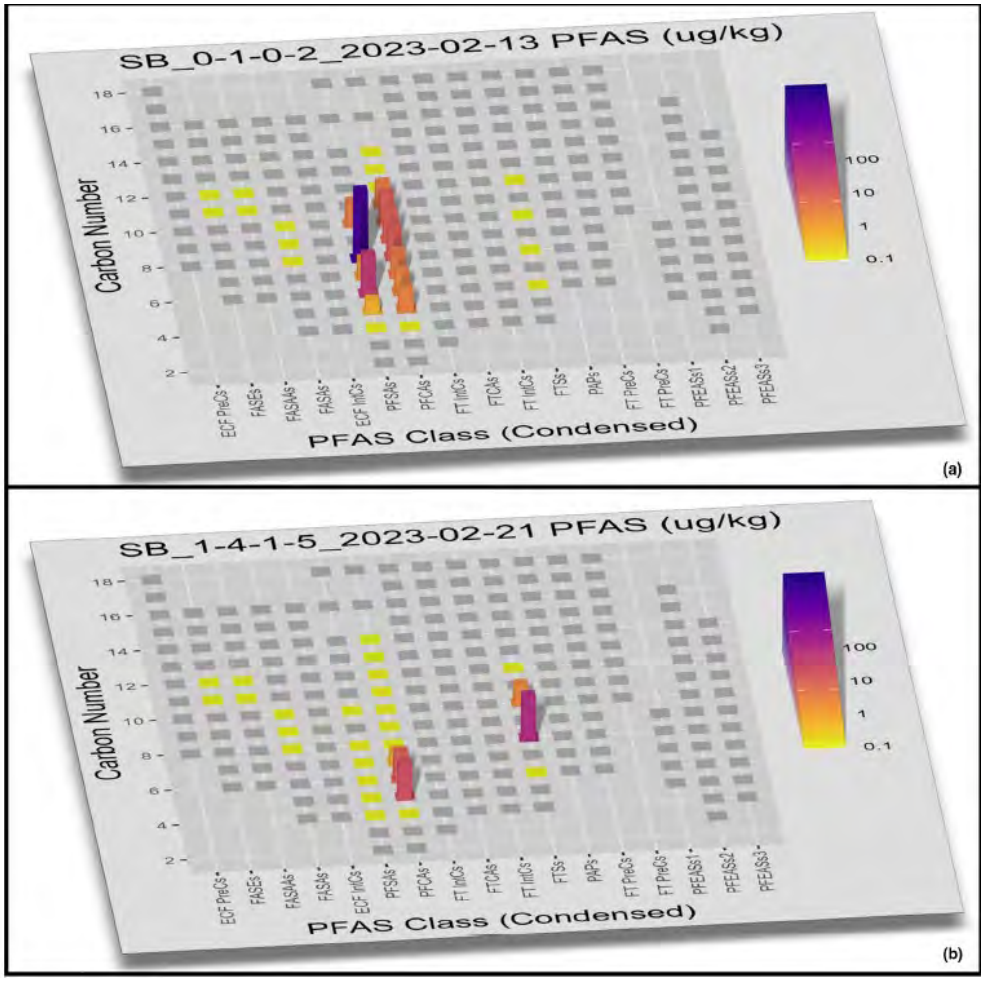


Figure 1-14. Comparison of PFAS signatures in two samples from Gamlin et al. (2024).

Source: Open Access. Gamlin et al. (2024). ***https://creativecommons.org/licenses/by/4.0/****.*

Most plots discussed here share a common disadvantage that only a few samples may be shown at a time, necessitating advanced (multivariate) methods that address the full chemical profile of many samples simultaneously.

1.3.7.6 Fingerprinting Calculations

Correlation coefficients and cosine-theta are two similarity indexes that are commonly used in a forensic evaluation to compare samples to each other and to sources (Davis 2002; Johnson et al. 2006). They have both been applied to PFAS forensics (Rose et al. 2024). These methods are adaptable to various PFAS sources and can be used to refine CSMs for better risk assessment and remediation. The correlation between two samples is calculated by ordering the PFAS in each sample before calculation. The resulting correlation coefficient provides an index of the similarity between these two samples. When calculated across many samples, the correlation matrix can be used to identify similarities. As with correlation metrics, cosine-theta provides a relative index of pattern or signature similarity of PFAS from samples, wells, or sources. It is also used to identify PFAS families in various cluster analysis approaches. No threshold value indicates a match (Johnson et al. 2006), but rather the determination of the strength of any match is based on the professional judgment of the statistician and the reader.

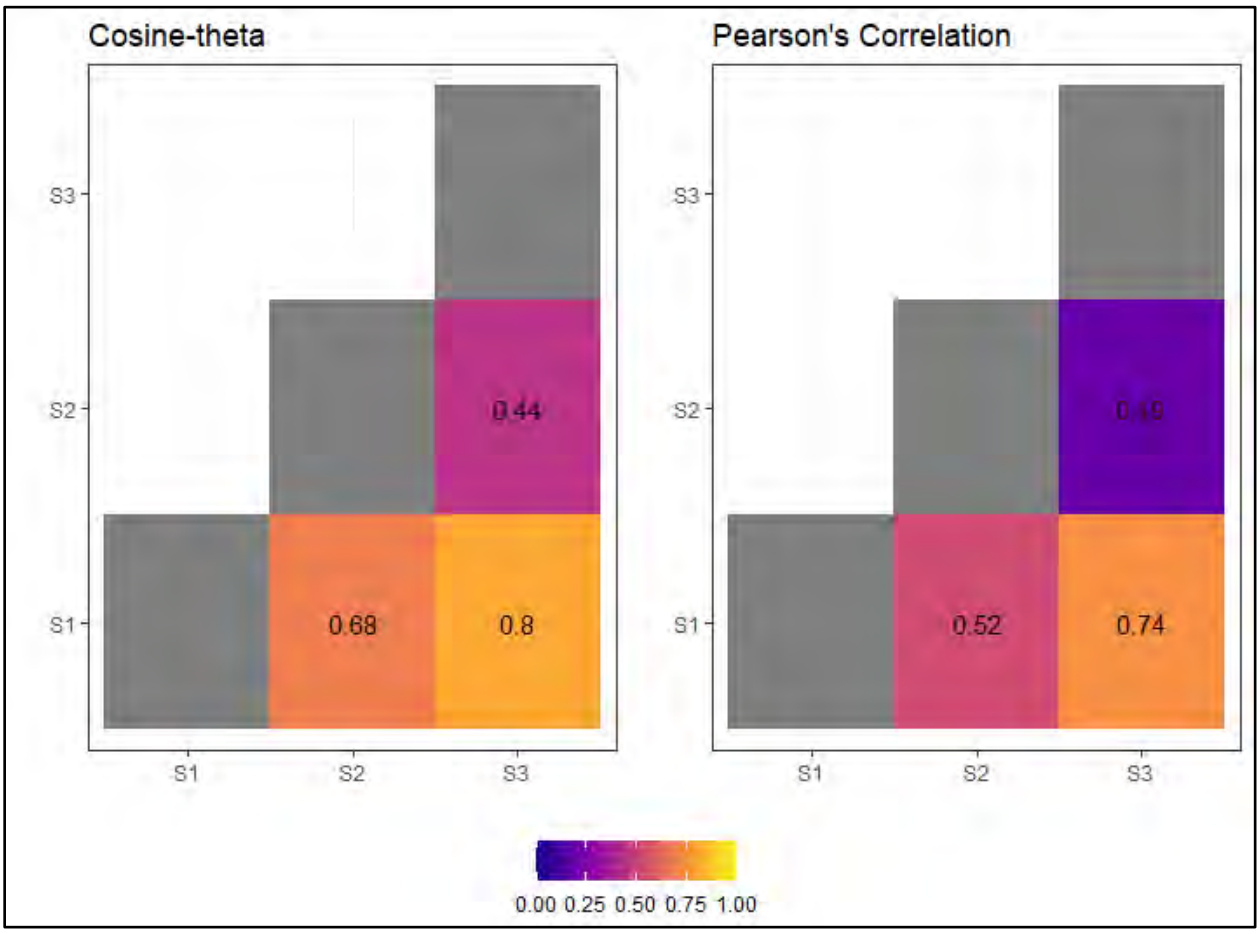


Figure 1-15. Comparison of PFAS profiles in three samples using cosine-theta and Pearson's correlation coefficients as a matrix. These are the same PFAS profiles depicted in Figures 1-9, 1-10, 1-11, 1-12 and 1-13.

Source: Provided by Michael Bock, PhD. Used with permission.

Figure 1-15 shows a Pearson's Correlation matrix and cosine-theta matrix for the sample profiles depicted in Figures 1-9 through 1-13. In the two matrix plots, higher values (illustrated with the color ramp from purple, low values, to yellow, high values) indicate a higher degree of similarity between the samples, with samples S1 and S3 being the most similar (lighter orange), S1 and S2 the next most similar (orange and pink), and S2 and S3 the least similar (darker pink and purple). The results demonstrate that these indexes provide a relative indication of similarity. It is up to the statistician to assess the importance of the specific values of these indexes. It is up to the statistician to assess the importance of the specific values of these indexes.

Correlation coefficients, such as Pearson, Spearman, or Kendall, can detect monotonic positive or negative relationships between columns of data, such as assessing the similarity of concentration trends between individual PFAS, between PFAS and other environmental chemicals (co-contaminants), or between PFAS and potential site-specific explanatory variables (distance to a source). For example, Pearson's correlation (r) compares observations, means, and standard deviations of two data columns, such that higher values near 1.0 indicate a strong, positive linear correlation, values near -1.0 indicate a strong, negative linear correlation, and values near 0.0 indicate no correlation (Helsel et al. 2020). Strong positive or negative correlations may indicate that spatially and temporally, individual PFAS align with specific spatial site features or other contaminants (or their absence). This type of assessment may be useful for assisting the interpretation of sources and subsurface processes.

Cosine-theta similarity is a traditional fingerprinting metric that geometrically represents the vector correlation between two data rows/samples (Nagai et al. 2019). The dot product produces a measure of alignment between chemical signatures, yielding a value of 1.0 for perfectly matching rows, and 0.0 for rows that do not match at all. This calculation is helpful for comparing a sample of unknown origin with a known or suspected chemistry source profile, to check for a positive match.

Together, these methods are adaptable to various PFAS sources and can be used to refine CSMs for better risk assessment and remediation. They support and are augmented by advanced analytics calculations that may more fully describe column-wise correlation (dimensionality reduction/regression) or row-wise similarity (clustering/classification).

1.3.7.7 PFAS Isomers

The PFAS analytical results described and visualized above combine the results for the various isomers into a single value (see **Section 11.3.5** and **Section 11.4.2** for more information about analyses of linear and branched isomers). As described in **Section 3.5**, PFAS such as PFOA can exist as a variety of isomers that have the same chemical formula, and the relative abundance of different isomers can be diagnostic of the original source. The ratio of branched to linear isomers is typically used to differentiate between PFAS produced using the electrochemical fluorination (ECF) process versus the telomerization process. For example, ammonium perfluorooctanoate (APFO)/PFOA was produced between 1947 and 2002 through ECF. Post-2002, virtually all PFOA was produced by telomerization. The ECF process would be expected to produce 70%–80% linear PFOA isomers and 20%–30% branched PFOA isomers while the telomerization process would produce 100% linear isomers (Buck et al. 2011). If investigators suspect multiple sources may be present in a PFAS plume, quantification of branched isomers may be an important line of evidence to show that an additional source exists or begin to identify its location. However, postrelease fate-and-transport processes may affect the distribution of the different isomers (see **Section 5**; Schulz, Silva, and Klaper 2020), potentially masking the isomeric composition of the original source material, so care must be taken when interpreting PFAS isomer data as a line of evidence in a forensic evaluation.

1.3.7.8 Data Gaps

Following the initial field investigation and data visualization, data gaps may become apparent that warrant additional sampling. For example, if sampled locations do not reflect known historical site processes or contaminant migration pathways, further sampling of source areas may be required. Inspection of concentration maps or time-series charts may also reveal potential but incomplete trends that would benefit from further characterization. Finally, additional quality assurance/quality control (QA/QC) samples may be needed to demonstrate exceptionally high or low levels of PFAS in a given area or vertical zone.

1.3.7.9 Advanced Data Analysis

At its core PFAS forensics is largely derived from, and benefits greatly from, the lessons that have been learned from the rich history of chemical forensic methods and applications. Multivariate methods have been applied to investigate sources of PFAS across the globe in a variety of matrixes, from serum in the Faroe Islands (Hu et al. 2018), to surface water in the United States (Zhang et al. 2016), and sediment in China (Pan et al. 2014). Multivariate methods are broadly categorized as self-training (unlabeled data) or predictive (labeled data). There is an acknowledgment in the forensics literature that many of these legacy methods generally fit under the umbrella of machine learning.

Self-training methods, which derive patterns without explicitly predefined labels, have been used for fingerprinting other chemical mixtures for decades. Recent years have seen an increased focus on predictive methods, where the data are linked to one or more columns of labels. Both approaches are described in more detail below in the Self-training Methods and Predictive methods sections.

Self-training Methods

Self-training methods are unique for forensics investigations, in that the algorithm is not provided a starting point with labels for the source profiles but rather uses the data itself to develop the model. PFAS signatures are inherently multivariate in that they comprise mixtures of multiple compounds. Often, site-specific chemistry data lack well-characterized source sampling records or clear, representative sampling locations for ambient levels. This makes it difficult to distinguish a range of different source profiles from each other or from fate-and-transport signatures, or to separate nonpoint ambient levels from nonpoint impacts. Certain algorithms, such as dimensionality reduction and clustering, are self-training in that they have been used to derive source (and other) signatures and latent (not explicitly measured) structure in the data.

Dimensionality Reduction

The objective of dimensionality reduction is to capture the essence of many data columns (that is, analytes) and express it with fewer columns (that is, relative source contributions). This operationally distills the data structure into a more focused format for an analyst to understand sources and their contributions. Dimensionality reduction can be performed in multiple ways, each with a different objective.

Principal Components Analysis

Principal components analysis (PCA) was first proposed by Karl Pearson in 1901 (Pearson 1901). It fits a series of orthogonal lines (the principal components) through a data cloud to preserve its variance. Often, PCA is performed using singular value decomposition (Joliffe and Cadima 2016), which resolves the data table into scores (representative of the data rows) and loadings (representative of the data columns). Visualized together on the same graphic, scores and loadings form a biplot, permitting the user to assess the relative effect of each analyte loading on each sample (score), as well as the overall configuration of

the data cloud (**Figure 1-16**). Figure 1-16, **Figure 1-17** and **Figure 1-18** use the same data. Fiedler et al. (2022) used PCA to identify correlations of three PFAS in multiple media and their trends in 266 samples from 26 developing countries, finding generally higher levels in biotic solid media from the Caribbean and Latin America. Li et al. (2022) likewise used PCA to differentiate trends in Florida surface water from four regional sampling locations, and in tap water from three regional locations. Antell et al. (2024) incorporated total oxidizable precursor (TOP) assay data into PCA to differentiate trends and patterns, separating multiple potential PFAS sources, including AFFF, wastewater treatment plants, and landfills. In each publication referenced above, biplots were used to draw visual conclusions regarding the separation or overlap of different groups, and assess trends in the data cloud pertaining to different PFAS chemicals, separating multiple potential PFAS sources, including AFFF, wastewater treatment plants, and landfills. In each publication referenced above, biplots were used to draw visual conclusions regarding the separation or overlap of different groups, and assess trends in the data cloud pertaining to different PFAS.

Sample	PFOS	PFOA	PFBA	PFBS	PFNA
1					
2					
3					
4					
5					
6					
7					
8					

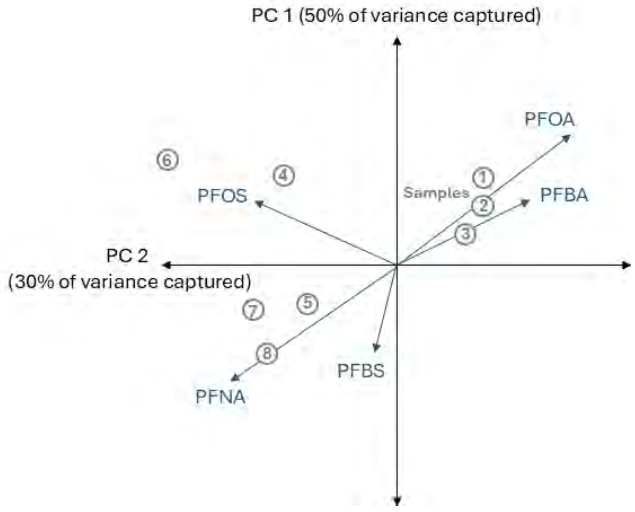


Figure 1-16. Example of a PCA biplot. Data columns (PFAS) are displayed as arrows and mathematically related to rows (samples) that are displayed as points. Sample position along the direction of an arrow indicates more of a specific compound, and proximity to other samples indicates chemical similarity.

Source: S. Sorsby, WSP. Used with permission.

Receptor Models

Similar to PCA, receptor models use a variety of similar methods collectively called factor analysis to likewise resolve a chemistry data table into scores and loadings. However, forensic use of factor analysis typically does not require the loadings to be mathematically orthogonal, and instead are permitted to align obliquely with unique signatures in the data (that is, potential sources or fate-and-transport patterns; (**Figure 1-17**). Depending on the method of preprocessing used, patterns derived by receptor models may approximate sourcelike compositions. As part of the receptor modeling process, the user must specify the number of unique signatures to derive, requiring site-specific knowledge to make a reasonable estimate. Capozzi et al. (2023) used positive matrix factorization to assess PFAS signatures related to a nearby landfill, and make inferences about precursor depletion in the subsurface. Wang et al. (2022) used a similar method—nonnegative matrix factorization—to identify groundwater PFAS signatures, including a signature dominated by short-chain compounds interpreted to represent the phaseout of legacy PFOS and PFOA. Rose et al. (2024) used polytopic vector analysis to assess the effects of variable seeding methods, sample size, and noise on factor analysis of synthetic PFAS datasets with literature-based source profiles, with better results for datasets of 25 or more samples and specific automated seeding methods.

Sample	PFOS	PFOA	PFBA	PFBS	PFNA
1					
2					
3					
4					
5					
6					
7					
8					

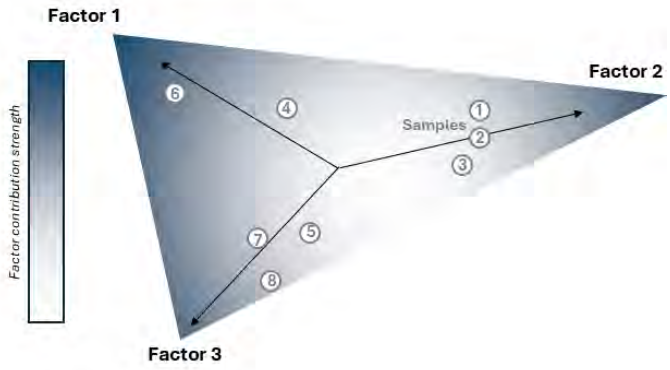


Figure 1-17. Conceptual schematic of a receptor model/factor analysis. Data columns are combined into primary chemical profiles and represented as directions in the data, pointing to corners of the data cloud (fingerprints). Sample (point) proximity to a corner is proportional to the strength of the corresponding signature.

Source: S. Sorsby, WSP. Used with permission.

Manifold Learning

A newer class of dimensionality reduction methods, known as manifold learning, has emerged. Uniform Manifold Approximation and Projection (UMAP) is an example of manifold learning whereby the chemical similarity of samples (that is, the manifold) considering all data columns is preserved in fewer columns. Unlike PCA and receptor models, manifold learning methods are nonlinear and can fit to curved regions of the data cloud. Antell et al. (2024) used UMAP to strengthen differentiation of source signatures using TOP assay data, including different AFFF formulations.

Dimensionality Reduction Method Selection

Several concepts should be kept in mind when selecting a dimensionality reduction method. Because PCA identifies orthogonal directions in the data, it is good at summarizing the data cloud in a way that is visualized in 2-D or 3-D with Cartesian coordinates (that is, standard scatter plot axes). However, the principal components themselves do not describe source signatures unless the sources themselves align with the axes. Receptor models resolve oblique angles in the data that may more accurately represent source signatures. However, additional lines of evidence are necessary to determine the number of factors to use. Nonlinear methods such as t-distributed stochastic neighbor embedding (t-SNE) and UMAP identify potentially nonlinear structure in the data and warp the manifold to fewer dimensions for easy visualization. The principal advantage of these methods over PCA is that all the variability is expressed in two axes of one plot while with PCA only a fraction is expressed. The disadvantage is that the reduced dimensions are still subject to complex sample relationships (that is, are modeled with network graphs), and groups and trends must be interpreted carefully by an experienced analyst. Most manifold learning methods do not capture the relationship between columns (analytes) and rows (samples).

Clustering

Unlike dimensionality reduction methods that identify numeric trends in the data, clustering methods identify categorical groups. Some methods, such as K-means, identify optimal partitions between

discrete bins of similar data points. Others, such as Gaussian mixture modeling (GMM), rely on underlying statistical properties to resolve potentially overlapping groups. As with receptor models, clustering methods require the user to estimate the number of signals present in the data. If the user-specified number of clusters is more than the actual data structure accommodates, contiguous samples may be artificially separated into different signatures. Inspection of resolved clusters is needed to verify the outputs of partitioning methods.

Partitioning Methods

Partitioning-based cluster methods are helpful for quickly identifying groups that are clearly separated, by relating sample chemistries into similar groups (**Figure 1-18**). Zeng et al. (2024) used K-means to derive clearly distinct signatures differentiating various industrial, agricultural, and domestic sources of PFAS to the Pearl River Basin. Zhang et al. (2016) used hierarchical clustering to identify major sources of PFAS contamination in diverse watersheds in the northeastern United States. PCA and hierarchical clustering identified three distinct groupings of PFAS, showing different mixtures of compounds at various sites. Clustering-derived signatures were interpreted to relate to contemporary point sources such as airports and textile mills, waste-sector sources, and metal-plating operations. Ogunbiyi et al. (2024) studied the distribution of PFAS in surface and bottom water from the inshore and offshore areas in the Biscayne Bay area (Miami, FL) using the K-means clustering algorithm.

Results included three distinct clusters, each interpreted to represent different sources or levels of PFAS contamination associated with industrial discharge, urban runoff, or atmospheric deposition/agricultural runoff. The geographical mapping of these clusters revealed that industrial discharge was more prevalent in areas close to manufacturing sites, while urban runoff was dominant in densely populated regions, key supporting lines in a forensic evaluation.

Sample	PFOS	PFOA	PFBA	PFBS	PFNA
1					
2					
3					
4					
5					
6					
7					
8					

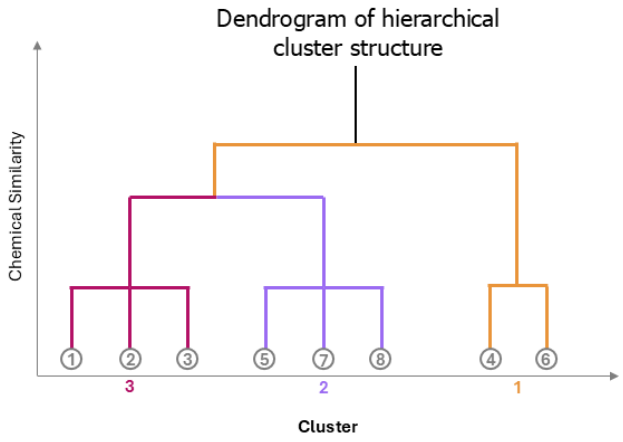


Figure 1-18. Conceptual schematic of hierarchical clustering analysis. Samples ("leaves") are terminal nodes in a treelike "dendrogram" that catalogs chemical similarity by joining them together with successive "branches," until all are related. "Cutting the tree" at a certain level returns cluster groupings at that level of similarity.

Source: S. Sorsby, WSP. Used with permission.

Probability-based Methods

Probabilistic clustering methods, such as GMM, fit potentially overlapping statistical distributions to the data to resolve groups. Due to the additional information provided by using prespecified statistical

distributions, goodness-of-fit metrics such as Bayesian information criterion may be computed to assist with the selection of the number of clusters. GMM was proposed for use in characterizing site-specific metals background levels in soil (USEPA 2019). Anderson and Modiri (2024) later used a large dataset comprising thousands of surface soil samples from Air Force bases, representing both anthropogenic background and AFFF-impacted soils. GMMs were applied to log-transformed PFOS concentrations to model the distribution of PFOS in these samples. Various methods were employed to handle nondetects (approximately 8% of the data). Multiple GMMs were fitted, each with different numbers of components to capture the distribution of PFOS concentrations. Goodness-of-fit measures, such as the Bayesian information criterion and Akaike information criterion, were used to evaluate the models. These diagnostics were interpreted to support the existence of two clusters, establishing a general ambient range of potential nonpoint-source levels for PFAS, and distinguishing them from AFFF-impacted soils.

Clustering Method Selection

Several considerations may assist users in the selection of a clustering method. Theoretical support for the presence of underlying distributions would promote the use of statistical model-based methods such as GMM. These methods are also amenable to resolving overlapping clusters. Partitioning-based methods may be useful in situations where clusters are more clearly resolved or do not adhere to a set of theoretical probability distributions, or both.

Predictive Methods

Some statistical models are called predictive, in that they mathematically link user-specified input variables to one or more categorical or continuous output variables. Unlike self-training methods discussed in the Self-training Methods section above, the user must specify the continuous target (in the case of regression) or a categorical target (in the case of classification). Due to the requirement of prespecified labels, careful problem framing is required. It is important to keep in mind that statistical models do not typically incorporate physical or chemical heuristics (as a fate-and-transport model would), and must be interpreted as a line of evidence alongside physical and chemical site conceptualizations.

Regression

Regression methods relate one or more input data columns (X) to one or more numeric output columns (Y). Due to the requirement of the output column(s) to be of numeric form, regression-based approaches to PFAS forensics in the literature have mostly focused on relating PFAS concentrations to other variables, to add contextual links for source identification and environmental occurrence. An approach of this nature is a more advanced form of correlation analysis, relating potentially many drivers, co-contaminants, or other explanatory features to one or more outputs (PFAS levels). As with a correlation analysis, regression may be helpful as one line of evidence to support the overall conclusions of forensic investigation but should be accompanied by other lines of evidence.

Linear regression is a long-standing example of this effort, where the relationship(s) between inputs and outputs are linked by slopes and an intercept. Hu et al. (2016) used multiple linear regression to relate a large dataset of US drinking water samples from the US EPA UCMR3 program to the abundance of source types (major industrial sites, military fire training sites, AFFF-certified airports, and wastewater treatment plants) in eight-digit hydrologic-unit code watersheds. The results indicate that the source sites in a given watershed correlated with higher PFAS concentrations of PFBS, PFHxS, PFHpA, PFOA, PFOS, and PFNA, potentially linking impacts to their corresponding source types and providing diagnostic indicators for sites within a given watershed.

Other regression models used in the environmental sciences include nonlinear tree-based models. Breitmeyer et al. (2023) correlated the sum of 33 target PFAS from 161 sampled streams to land-use features and potential sources via a conditional inference tree. They found that upstream urban

developments were a primary driver of general increases in PFAS concentrations, with proximal water-pollution control and electronic-manufacturing facilities as key potential sources to surface water. As with Hu et al. (2016), regression formed the basis for linking specific source types to PFAS impacts in a forensic context.

DeLuca et al. (2023) used a random forest regression model to leverage geographic and industrial variables to predict the spatial distribution of summed PFAS in fish tissue due to a variety of sources in the Columbia River Basin of Washington State. Like other regression-based studies, the inclusion of a variety of potential sources in the analysis permitted forensic insight. Important drivers of PFAS in fish potentially included proximity to fire training facilities, metal coating facilities, paint facilities, and airports. The authors noted that cement manufacturing and glass production facilities were also scored as potentially significant drivers of PFAS contributions to surface water, although they were among the least represented industries in the dataset and should be interpreted carefully. The use of a "PFAS prospecting" regression model to support forensic inferences could hence support the identification of local sources or ambient levels of PFAS to environmental media and reveal potential data gaps in a source location analysis (undersampled/understudied pathways).

Classification

Classification methods relate one or more input variables to a categorical output. In environmental forensics, source types are a popular categorical association made during identification and allocation. Due to the relatively straightforward problem framing of relating source type labels to chemistry data, classification methods are more prolific in PFAS forensics literature. Prediction of source type based on chemistry data is useful as a screening tool to assist with characterizing impacts of unknown origin. As with other methods presented in this document, it is important to apply methods on a site-specific basis, or otherwise bring site-specific insight into a more generally trained model.

Kibbey et al. (2021) focused on distinguishing between AFFF and non-AFFF sources to groundwater PFAS impacts, using 12 different classification methods. Of the 12 methods, random forest and neural network classifiers were found to exhibit the highest accuracy (96.1% and 95.5%, respectively). The authors noted that PFAS with higher frequency of detection were generally more predictive features in the classifiers.

Kibbey et al. (2024) explored multiclass classification of PFAS sources, including AFFF, wastewater treatment plants, and landfills. The authors employed a tiered framework to identify chemical profiles from a variety of sources, and to recognize novel samples that differed from any sources in the training dataset. Blind prediction of site samples indicated reasonable predictive capability of the model. This study raises the important question of novel samples, which are different from all previously trained data classes, which must be considered when building a classification model.

Joseph et al. (2023) employed a supervised machine learning approach using support vector machines to classify PFAS sources. Support vector machines are particularly adept at handling high-dimensional data, which is common in PFAS analysis due to the large number of compounds and potential sources. The researchers used a kernel function to transform the data into a higher-dimensional space, making it easier to find a hyperplane that separates the classes. The study successfully identified distinct PFAS profiles for AFFF-impacted groundwater and landfill leachate, demonstrating the potential of support vector machines in environmental forensics.

Antell et al. (2024) created a predictive classifier that uses TOP assay data to predict source types. Sources included were AFFF sites, wastewater treatment plants, and landfills. A custom nearest-neighbor search algorithm was used to associate samples with source types. Preprocessing the data via principal components analysis improved the resolution of the classifier, with 88%–99% accuracy of the sources.

Predictive Method Selection

The choice between regression or classification methods varies depending on the study objective. When a numeric value is desired, regression methods may be used. Classification methods are suited for separating samples into different, user-specified groups.

To select a regression-based method, there are several considerations. Target (dependent) variables must be screened for extreme values, as these points may exert higher leverage during the fitting process and focus on less-representative structure in the data. Data transformations, such as logarithms or square roots, may assist in reducing the influence of extreme values deemed representative of site data. The relationships should also be assessed for nonlinearity. In the event of a nonlinear dataset, inclusion of feature interactions may make linear regression flexible enough to adequately fit the target, but must be assessed by an experienced practitioner. Nonlinear regression algorithms, like decision trees, may capture nonlinear structure. Care must be taken to not "overfit" the data (memorize the inputs without abstracting well), which may be alleviated by ensemble-based nonlinear regressors (for example, random forest or xgboost).

Classification methods likewise require a consideration of linearity. For classes that are visually separable by a straight line on a scatter plot, linear methods such as logistic regression or linear discriminant analysis may suffice. Nonlinear decision boundaries between classes may require a more flexible model, such as k-nearest neighbors or a decision tree. As with regression methods, ensemble models such as random forest or xgboost may achieve a balance of accuracy and generalizability (avoids overfitting), with sufficient tuning by an experienced user.

1.3.7.10 Model Validation

An often-overlooked aspect of many of the multivariate methods and models applied to PFAS forensics is validation. As with any statistical model, validation of the model should not be overlooked. Johnson et al. (2015), Gauthier and Hawley (2007), Ginevan (2007), and Bock et al. (2021) provided useful examples of model validation methods and examples of their use. Basic model validation techniques and tools include:

- comparison of the modeled versus the original chemical profiles, often in the form of bar plots
- plot of observed versus modeled, including the 1:1 best fit line
- goodness-of-fit statistics such as cosine-theta, r^2, and mean squared error
- evaluation of the data for trends unrelated to the CSM, such as systematic differences between analytical laboratories, analytical methods, or samples collection methods
- rigorous evaluation of the CSM, hypotheses, and alternative hypotheses. For example, is a change in profiles attributable to:
  - different sources.
  - differential fate and transport.
  - precursor transformation.
- comparison to source libraries
- comparison to potential anthropogenic background levels and profiles

PFAS mixtures are frequently impacted by nonpoint sources. These nonpoint sources are often classified as anthropogenic background, regional nonpoint sources, or baseline (see **Section 10.2**). The influence of potential anthropogenic background can be an important component of the results of a forensics evaluation. A discussion of methods to characterize anthropogenic background is beyond the scope of this section, but understanding how they can influence a forensic evaluation and how they are considered in the CSM should be determined prior to beginning the investigation.

1.3.8 Site Characterization Tools and Techniques

This section supplements the information in **Section 10** on unique considerations for PFAS site characterization and provides practical guidance for conducting PFAS site characterization, including strategy, approach, tools, and techniques. Because of the unique properties and environmental behavior of PFAS, site characterization efforts at PFAS sites may require collecting different types of information compared to investigations for other types of contaminants. Some tools provide one line of evidence, while others may have the ability and data to support more than one. This approach to assembling the key elements of site characterization is supported by **Section 11**, which provides greater detail on sampling and analysis tools and techniques for specific data acquisition.

1.3.8.1 Investigation Approaches

Investigation approaches are typically based on project goals and site characteristics, including but not limited to site history, setting, watershed characteristics, number and types of sources, and potential receptors. Two approaches are discussed below: "outside in" and "inside out." While each approach is described separately for simplicity, a combined or hybrid approach might be appropriate, depending on the characteristics of the site, regulatory program requirements, and other factors.

Outside-In Approach

The outside-in approach is generally based on a receptor-protection concept, whereby the extent of PFAS migration is identified first along with affected receptors, if any, distal to on-site PFAS sources. This would involve prioritizing the sampling of potential receptors (for example, supply wells, surface water bodies) and downgradient monitoring locations before source identification and pathway characterization. The investigation would then proceed back toward the site of interest and to on-site source locations. Though appropriate for proactive receptor protection, this approach may be confounded by commingled PFAS from other sources, especially in industrialized areas and where such facilities share a common surface water body to which PFAS discharge. An outside-in approach may be the only option when a PFAS plume has been identified without knowledge of the source.

Inside-Out Approach

This approach applies to the characterization of discrete sources of PFAS interior to a site and the investigation of potential migration pathways from those sources to delineation, receptors, or boundary conditions. Where such delineation is feasible, it will provide higher confidence in understanding overall impacts and long-term fate and transport concerns.

The inside-out approach is incremental and sequential, as follows:

- identify potential on-site sources of PFAS based on site history and use
- conduct targeted soil and groundwater sampling to confirm presence of PFAS associated with the release or application locations
- conduct broader lateral and vertical soil and groundwater sampling for PFAS to determine nature and extent from the source
- sample groundwater and surface water migration pathways until delineation, boundary condition, or receptor is encountered
- focus management measures on the source-pathway-receptor connection

This approach allows the investigator to isolate and proactively address PFAS occurrence emanating from a specific source and along migration pathways.

1.3.8.2 Surface Water Receptors

In many jurisdictions, surface water criteria are close to analytical detection limits due to concerns about bioaccumulation of PFAS and emerging human health criteria (for example, reference doses [RfDs]) related to surface water uses (see **Section 16** and the Environmental Media Values Table). Surface water receptors may be a sink for PFAS released from multiple commercial or industrial sources. Consequently, careful consideration should be exercised before sampling a surface water receptor (for example, river, estuary, lake, ocean) for PFAS, including its sediment or sediment porewater. **Section 16.4.1** includes information about surface water sampling for PFAS. An extension of the inside-out characterization approach is to conduct mass flux and dilution analysis where diffuse discharge of PFAS from groundwater to surface water is suspected (ITRC 2010). This again allows the investigator to isolate and proactively address PFAS occurrence emanating from a specific source and along particular migration pathways that are not confounded with multiple other PFAS discharges to surface water. In other instances, the site setting and promulgated or pending surface water criteria may warrant surface water sampling.

Mathematically, contaminant mass flux is the product of the contaminant concentration in groundwater and the groundwater flux. Evaluating mass flux will help determine the mass of PFAS discharging from groundwater to surface water, and the associated impacts to surface water or sediment. **Figure 1-19** illustrates the mass flux evaluation concept, which requires one or more vertical planes of discrete monitoring points. This represents a depth-discrete groundwater sampling approach, which is consistent with Kornuc et al. (2022). See the ITRC "Use and Measurement of Mass Flux and Mass Discharge" Technology Overview for more details on mass flux analysis (ITRC 2010).

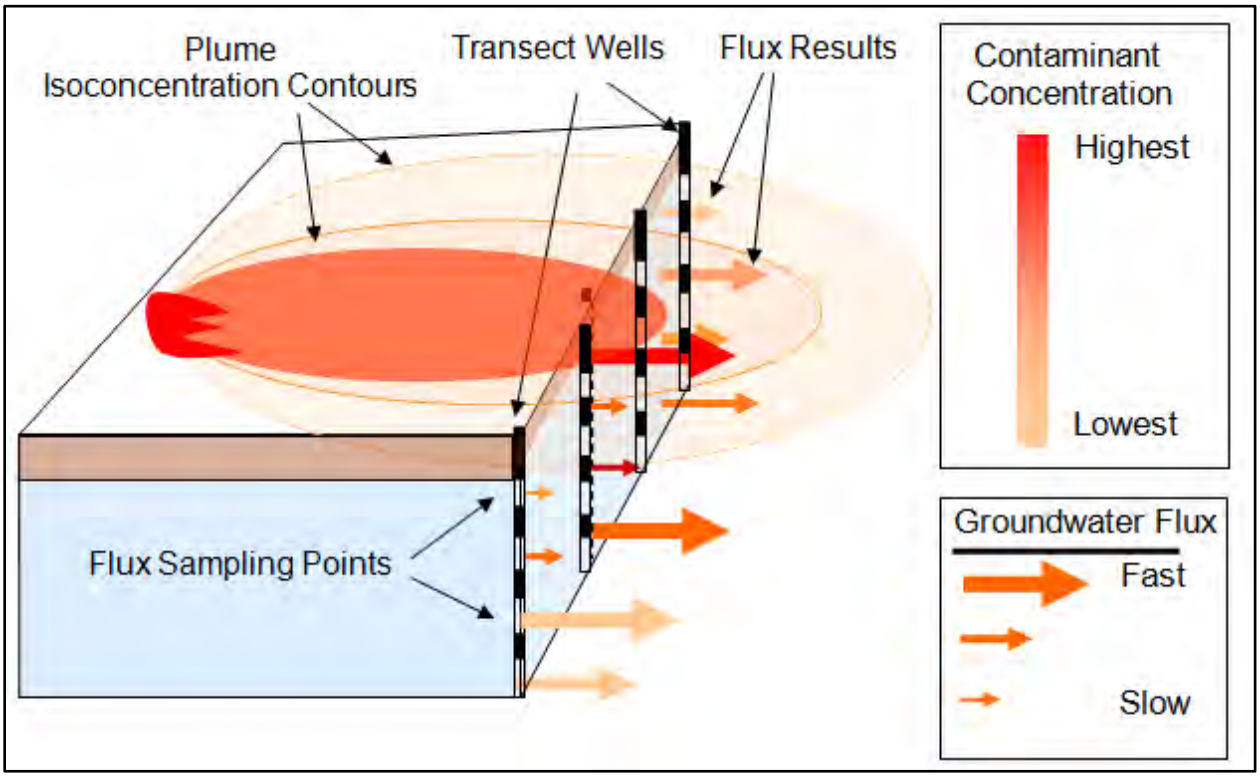


Figure 1-19. Measuring mass flux using wells along a transect. Results illustrate spatial variations in mass flux across a contaminant plume.

Source: (Graphic courtesy HydroGeoLogic Inc.) Figure 2-4. in ITRC Use and Measurement of Mass Flux and Mass Discharge (ITRC 2010).

1.3.8.3 Selection of Analytical Methods

There has been rapid development of a variety of methods for analyzing environmental media for PFAS and other fluorinated compounds. When selecting methods, their utility and limitations should be understood to avoid employing unnecessary methods or inaccurate interpretation of results. See **Section 11.2** for more information about analytical methods.

The following list provides suggestions and caveats for strategic use of these methods:

- Target analyses—Target analytical methods (for example, USEPA Method 1633A, USEPA 2024) are most commonly used and appropriate for PFAS site investigations. They use certified calibration standards to detect and quantify a list of specific PFAS in a variety of environmental media. Often, the full method analyte list is run, particularly for initial site investigation. Multiple analytes allow for: 1) forensic assessment, 2) determination of firefighting foam composition, 3) identification of precursors and associated transformation, 4) PFAS fractionation evaluation, and 5) accounting for type and mass of multiple PFAS affecting treatment and remediation. Reducing the reporting list may be warranted after collection of a robust data set and thorough investigation of potential PFAS sources.

- Non-targeted analyses — Combined with a suspect screening search, non-targeted analyses can identify the presence of a broad range of PFAS not typically reported with target analytical methods. Non-targeted analyses, such as quadrupole time-of-flight (qTOF), are useful for forensic purposes and to validate the detection of individual PFAS by target analyses but are not quantitative. Non-targeted analysis may also identify unexpected PFAS that may warrant additional inquiry or explanation. See **Section 11.4.3**.

- Total organic fluorine analyses—Analytical methods for the detection of total organic fluorine, such as adsorbable organic fluorine or extractable organic fluorine, have been in recent development. Results may include PFAS and non-PFAS and do not identify individual PFAS or other compounds. These methods typically have higher method detection limits than target analyses. Of these methods, USEPA Method 1621, Determination of Adsorbable Organic Fluorine in Aqueous Matrices by Combustion Ion Chromatography, is multilab-evaluated and accredited for compliance monitoring (USEPA 2024; see **Section 11.2.2.4)**. This type of analysis may be useful for applications such as treatment system design or performance monitoring by mass removal, where the system is affected by all organofluorine molecules. This type of analysis should not be used as a site investigation "dragnet" for the broad detection and identification of PFAS. Such an approach would result in nonspecific results that could be affected by non-PFAS or unregulated PFAS with no criteria for evaluation, potentially creating an unfounded inference that the site is adversely affected by regulated PFAS.

- TOP assay—This method has been in existence for several years and is generally well established. The method subjects a sample to aggressive oxidation conditions, which forcibly transforms precursor PFAS to fully fluorinated terminal PFAS. It is useful to evaluate the potential for precursor transformation in the environment or within certain treatment systems (for example, emerging destructive technologies such as supercritical water oxidation [SCWO]). It can also be used to normalize concentrations of samples in various stages of precursor degradation for forensic comparison. Ateia et al. (2023) provided additional insight for the applications and challenges of TOP assay. The oxidation step in TOP assay transforms precursor PFAS to terminal PFAAs, but the terminal products in this reaction are not necessarily the same as the ones that would be produced in nature. For example, TOP assay transforms PFSA precursors into PFCAs. Also, the strongly oxidizing conditions can result in chain-cutting reactions, such that the mixture of PFAA compounds produced may be smaller on average than would be found under normal environmental conditions. TOP assay results should not be construed to indicate that precursors

will necessarily degrade to terminal degradation products in the environment because TOP assay laboratory conditions do not represent field conditions (see **Section 11.2.2.2** for more information about the TOP assay).

1.3.8.4 Appropriate Application of Criteria

Regulatory criteria have been (and are being) developed for PFAS in a variety of environmental media with certain ecological and human exposure scenarios in multiple jurisdictions (see the **Environmental Media Values Table**). Sometimes these criteria are misapplied out of a sense of caution/conservatism, convenience, or due to misunderstanding of the CSM. Certain comparisons may be protective as a screening-level evaluation but may warrant additional site-specific assessment before they drive remedial action. Examples include comparing leachate concentrations to groundwater criteria or comparing groundwater results to surface water criteria. Investigation data should be collected in a manner that supports comparison to applicable regulatory criteria.

- ***Drinking water criteria are not necessarily applicable to groundwater concentrations.*** Drinking water criteria are commonly the basis for groundwater remediation standards. In some instances, groundwater may be nonpotable, restricted, or of insufficient yield. Turbid groundwater samples can reflect an elevated PFAS concentration in water that would not be consumed by humans due to the turbidity. Well development/rehabilitation and proper well construction should be implemented to reduce turbidity for groundwater samples that are more representative of potential drinking water. In some instances, groundwater criteria are based on various aquifer classifications or use scenarios. Criteria should be selected according to site conditions and setting. Exceeding a generic drinking water criterion may warrant further evaluation.

- ***Soil leachate sample results do not represent groundwater concentrations.*** PFAS in soil leachate samples (for example, synthetic precipitation leaching procedure [SPLP]) are measured under laboratory conditions and differ from field leachate concentrations (see **Section 1.3.8.6** for additional information about leaching). Leachate may undergo additional processes before encountering groundwater (for example, resorption as leachate migrates through the vadose zone, precursor transformation, and dilution in groundwater). Leachate sample results should be compared to leachate-specific regulatory criteria where these criteria exist. Otherwise, a site-specific evaluation relative to potential groundwater impacts may be warranted (see **Section 1.5.1**).

- ***Groundwater results do not represent surface water concentrations.*** Groundwater discharge to surface water often involves additional sorption to organic sediments, enhanced sequestration to sediments due to brackish or saline porewater, and dilution in the surface water body. If groundwater concentrations exceed surface water criteria, additional evaluation is warranted. Refer to **Section 1.3.4** on PFAS Groundwater-Surface Water Interactions and **Section 1.3.8.2** on Surface Water Receptors for a mass-flux approach to evaluate the potential impact to surface water.

- ***There are multiple factors for surface water criteria.*** Surface water criteria are commonly very stringent (close to analytical detection limits) due to the potential for bioaccumulation of PFAS to higher trophic levels, other ecological effects, and for protection as drinking water. Ecological criteria for surface water may be less stringent when they reflect the effect of PFAS on certain organisms without bioaccumulation. In some instances, there are surface water criteria for human recreation, based on dermal exposure and limited/incidental ingestion; these tend to be less stringent. Surface water criteria may also be differentiated based on fresh versus brackish versus seawater; these should not be used interchangeably. Emerging human health concerns, unrelated to drinking water, are also driving stringent criteria (for example, full-body-contact recreation sites, aquatic life harvesting, and subsistence fishing).

1.3.8.5 Repurposing and Refining the Conceptual Site Model

PFAS may occur at a site for which a CSM has already been developed for other contaminants. In this case, it can be efficient and cost-effective to use findings and elements from the existing CSM for purposes of the PFAS investigation. Such elements include hydrostratigraphic framework, groundwater flow direction, seepage velocity, aquifer structural/matrix properties, pathways, and receptors. In some instances, PFAS may interact with other known contaminants (for example, NAPL) that should be accounted for in the CSM. In most cases, the CSM will likely require additional PFAS-specific spatial, physical, and chemical information to be useful and reliable.

Characterization of PFAS vertically through the soil profile is an important aspect of the PFAS CSM, due to unique retention properties (for example, air-water interfacial sorption) and accumulation at discrete horizons (for example, clay– or organic carbon–enriched layers). Pre-existing, detailed soil characterization can be repurposed in the PFAS CSM or profiled in detail for the first time to support the PFAS CSM. Continuous and discrete vertical characterization of PFAS in the soil profile should be considered (at least at targeted locations) and can be augmented with potentially unconventional tools such as lysimeters to characterize PFAS concentration in porewater/retained at the AWI.

A strategic consideration for the PFAS CSM is the effect of the capillary fringe (tension-saturated zone above the water table and below the unsaturated zone). Fluctuations in the capillary fringe may mobilize PFAS (Das et al. 2024), especially where they are otherwise retained by air-water interfacial sorption. Porewater characterization (for example, sampled with lysimeters) of the capillary fringe is a means to quantify aqueous concentrations of PFAS in this zone of saturation above the water table, which could not otherwise be sampled via a monitoring well.

PFAS CSMs should also account for migration, attenuation, and transformational processes affecting PFAS: precursor degradation, sorption, dispersion, and matrix diffusion (Kornuc et al. 2022; Newell et al. 2021; Newell et al. 2021). Adamson et al. (2022) noted the marked concentration reduction of PFAS measured in groundwater along the migration pathway from the source areas, attributing this to nondestructive retardation/retention processes of hydrophobic, air-water interfacial sorption, and electrostatic partitioning. **Section 5** includes information about PFAS fate and transport process.

1.3.8.6 PFAS Characterization by Media and Pathway

This section describes the approach, tools, and techniques for sampling and investigation design. **Figure 1-20** presents a conceptual graphic for the characterization of PFAS, using an AFFF site as an example. Sites with other PFAS sources may require different conceptualization for investigation design.

Beyond sampling for PFAS specifically, several site-specific parameters related to soil and aquifer matrix properties and solutions chemistry affect the partitioning, mobility, and distribution of PFAS. These include soil type (mineralogy and grain size), pH, and organic matter/total organic carbon (TOC) (Hubert et al. 2023; Feng et al. 2024, Wanzek et al. 2023). Refer to **Section 5.2** for information about phase partitioning. For information about collecting samples for PFAS, refer to **Section 11.1**.

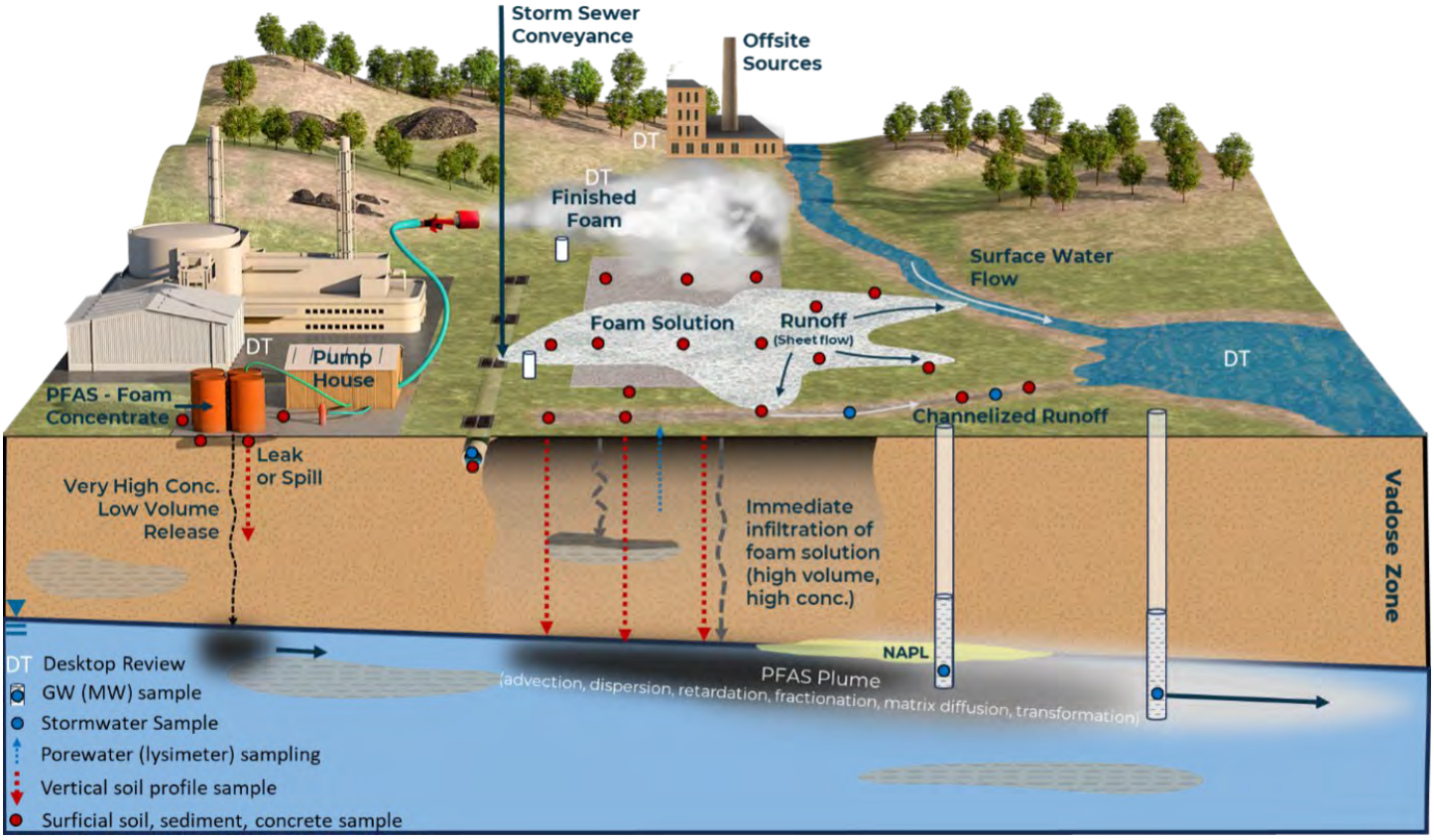


Figure 1-20. Illustrated PFAS characterization approach.

Source: J. Hale and J. West, Kleinfelder. Used with permission.

Soil

Many PFAS (for example, PFOS) are sorptive, recalcitrant, and nonvolatile. When released to the surface of soil, they may be retained for relatively long durations (depending on soil characteristics), preserving the pattern of the original surface release. High-density, shallow soil sampling of suspected source areas and drainage ways for PFAS analysis is often appropriate. This can be conducted by manual methods (for example, hand-auger, shovel, or trowel) or direct-push sampling apparatus. Designating a percentage of these samples (spatially distributed) for PFAS leachate analysis (for example, SPLP) will provide an indication of PFAS leaching potential. As noted above, laboratory leachate results are not a direct indicator of expected groundwater PFAS concentrations. Consider also sampling soil downwind (which may be hydraulically upgradient) where PFAS may have migrated by aerial dispersion and deposition or deposition by mist drift, as with firefighting foam.

Though retained in shallow soil, PFAS are commonly distributed vertically through the vadose zone, partitioning to organic carbon and charged mineral surfaces (**Figure 1-21**). PFAAs and other amphiphilic PFAS are also retained by air-water interfacial adsorption, which is unique to this class of contaminants (Brusseau et al. 2019; Brusseau and Van Glubt 2019). See **Section 1.3.1** for more information about vadose zone characterization and transport and **Section 1.5.1** for information about leaching methods. Retention by air-water interfacial sorption is transient and cyclic, as PFAS may be leached and mobilized to groundwater by infiltration and subsequently resorbed, as air and water phases return in the pore space. Inversely, PFAS may also be mobilized vertically upward in the soil profile because of evapotranspiration or fluctuation of the capillary fringe (Wallis et al. 2022). **Figure 1-21** illustrates a hypothetical **example** vertical PFAS concentration profile relative to soil type and TOC concentration. The

figure shows the discrete vertical distribution of PFAS both by concentration and proportion of individual PFAS and how they are affected by discrete soil characteristics.

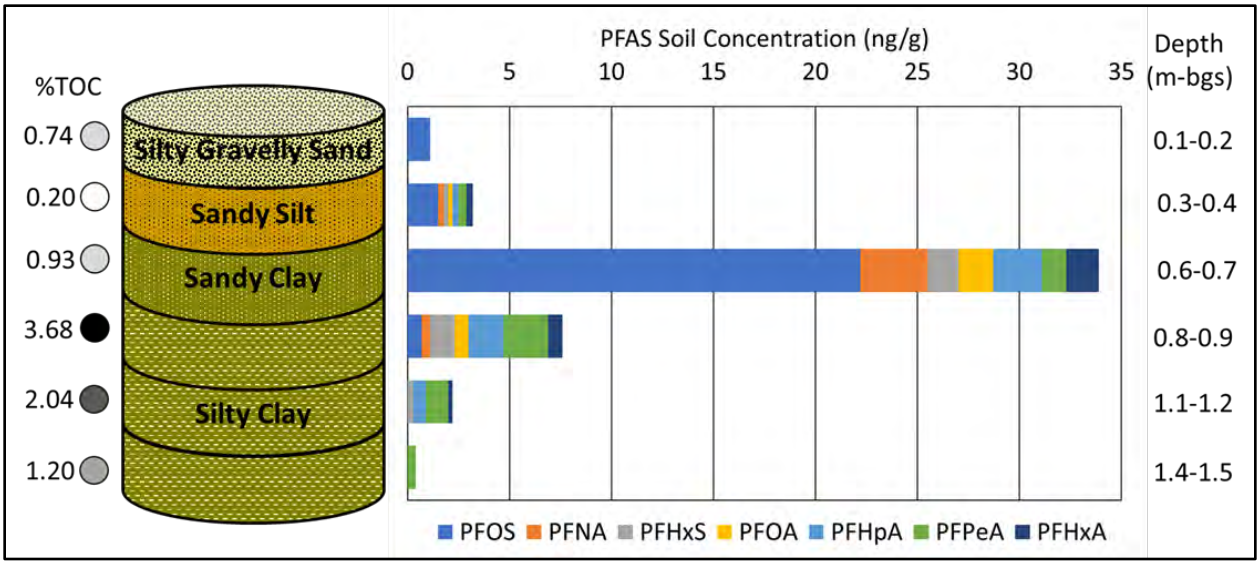


Figure 1-21. Hypothetical example of PFAS vadose zone distribution and matrix. Depth given in meters below ground surface (m-bgs).

Source: J. Hale, Kleinfelder. Used with permission.

Table 1-7 provides a summary of the types of soil characteristics that can be collected to produce a vertical profile of the vadose zone, including the purpose or utility and suggested sampling frequency for each category of soil characteristics. Campos-Pereira et al. (2023) described the effects of pH, surface charge, and soil properties on PFAS partitioning to solids in a variety of soils. A proportion of surface soil sample locations should be designated for vertical profiling, selected to provide spatial coverage, and biased toward areas of natural runoff. High-resolution and depth-discrete soil sampling is consistent with the approach taken by Kornuc et al. (2022).

Table 4-1 shows that laboratory and field studies have resulted in a wide range of sorption values (K_d or K_{oc}) for individual PFAS, indicating the degree of sorption or leaching for various PFAS species is highly dependent on the setting due to parameters noted above. Because of this variation, some regulatory agencies, including the USEPA, advise the derivation and use of site-specific sorption coefficients to inform potential risk of PFAS leaching to groundwater. Two common methods are discussed in USEPA (2025) and are summarized below. Navarro et al. (2024) provided a comprehensive summary of additional methods for evaluating PFAS leaching from soil and other solid materials.

SW-846 Test Method 1312: Synthetic Precipitation Leaching Procedure is a relatively common method for assessing PFAS leachability from soil (USEPA 1994). The procedure involves mixing an extraction fluid composed of reagent water adjusted to a pH of 4.2 or 5.0 (depending on the sample's geographical origin) with a mix of nitric and sulfuric acids and shaking the mixture for 18 hours with the intent to simulate natural leaching in the environment. The USEPA (2025) guidance described a modified SPLP procedure that is specific to PFAS. Modifications include differences in materials as well as a reduction of sample volume and the use of a methanol solution for total extraction in parallel with the standard extraction fluid.

Lysimeters can be used to extract and analyze porewater from the vadose zone and capillary fringe, where PFAS may be sequestered via air-water interfacial sorption. Lysimeters are purged by applying

vacuum to the system, which moves porewater through the apparatus into a secondary containment vessel. The sample volume from each purge event of the lysimeter may be less than the required volume for analysis. In this case, samples from multiple events may need to be composited or arrangements made with the laboratory to analyze a lesser sample volume. Ideally, samples will be acquired during discrete events that reflect the then-current porewater saturation and infiltration conditions. USEPA (2025) noted that while lysimeters have the advantage of measuring actual pore water conditions at a site, there are uncertainties regarding whether commonly used materials in lysimeters adsorb PFAS and the implementation and interpretation of results is complex compared to SPLP. Results of studies using lysimeters to derive site-specific values to protect groundwater should be interpreted with caution.

Table 1-7. Vertical soil profile sampling.

Testing/Analysis	Purpose	Sample Selection
Field Description		
Texture, Grain Size, Moisture	Understanding of soil type; cofactors in PFAS sorption & leachability	Continuous vertical description
Soil Mineralogy		
Color		
Organic Matter, Staining, NAPL		
PFAS		
Soil PFAS	PFAS distribution in soil profile	One sample per discrete interval (0.5 ft or 0.1 m)
SPLP PFAS	Leachability of PFAS and correlation to soil concentration	
Porewater PFAS	PFAS porewater concentrations and migration to groundwater potential	Collected via dedicated lysimeters over time to capture range of infiltration and soil moisture conditions
Geotechnical, General Chemistry, & Matrix Parameters		
Grain Size (sieve and hydrometer)	Understanding of soil type; cofactors in PFAS sorption & leachability	One sample per soil type per boring
Unified Soil Classification System (USCS) Soil Classification; Engineering		
Soil Mineralogy		
Soil pH		
Soil Salinity/Conductivity		
Anions (sulfate, fluoride, chloride)		One sample per soil type (minimum one sample from each material type comprising the soil; samples from multiple locations preferred)
Cations (Ca^{2+}, Mn^{2+}, Mg^{2+}, Fe^{3+})		
Cation/Anion Exchange Capacity		
Moisture Content		One sample per discrete interval (0.5 ft or 0.1 m)
Total Organic Carbon (TOC)		

Groundwater

Table 1-8. Aquifer matrix and groundwater chemistry sampling.

Testing/Analysis	Purpose	Sample Selection
Field Parameter Measurements		
pH	Lower pH (elevated hydrogen ion activity [H^+]) enhances anionic PFAS sorption (reduced aqueous concentration)	Measure with field meter at every monitoring well sampled
Salinity/Specific Conductivity	Positively correlated to PFAS sorption (reduced aqueous concentration)	
Oxidation-Reduction Potential (ORP)	Oxidizing conditions conducive to aerobic precursor transformation; reducing conditions limit aerobic transformation	
Turbidity	PFAS adhere to solid particles and colloids. Turbidity can affect and skew PFAS concentration results	
Aqueous Laboratory Analyses		
Calcium Ion (Ca^{2+}) Concentration	Positively correlated to PFAS sorption (reduced aqueous concentration)	Discretionary analysis for more robust characterization of sorption influences
Aquifer Matrix Parameters		
Grain Size (sieve and hydrometer)	Understanding of aquifer matrix and permeability	Laboratory analysis. Obtain from prior investigation or collect from saturated zone when installing monitoring wells for PFAS sampling (minimum one sample from each material type composing the aquifer matrix; samples from multiple locations preferred)
USCS Soil Classification; Engineering		
Total Organic Carbon (TOC)	Positively correlated to PFAS sorption (reduced aqueous concentration)	
Cation/Anion Exchange Capacity	Cofactors in PFAS sorption & leachability	
Bulk Density	Fate & transport retardation parameter	
Effective Porosity	Key parameter for seepage velocity of dissolved PFAS	Select samples of aquifer matrix (in saturated zone) acquired via borings or in conjunction with monitoring well installation
Aquifer Hydraulic Characteristics		
Hydraulic Conductivity	Key parameter for seepage velocity of dissolved PFAS	Slug testing of select monitoring wells or aquifer testing. Data may exist from prior site characterization

In some circumstances, existing monitoring wells are useful for initial groundwater characterization of PFAS. The following considerations should be evaluated when using an existing monitoring well network for initial PFAS investigation:

- location of monitoring wells relative to the suspected source and in the downgradient direction, informed by PFAS soil characterization results
- depth and screened interval of monitoring wells
- status of monitoring well construction, development, and rehabilitation
- potential for prior use of PFAS-containing materials in the construction of the monitoring wells
- presence of NAPL

Notably, turbidity in monitoring wells is problematic due to the sorptive nature of certain PFAS and the low detection/regulatory criteria (ng/L) for PFAS. Consequently, redevelopment of existing monitoring wells, and proper design (screen slot size and filter pack) and development (bidirectional surging, purging, and field parameter monitoring) of new monitoring wells, are important to reduce turbidity. The analytical laboratory should be consulted if the groundwater samples remain visually turbid.

In the absence of suitable existing monitoring wells, new monitoring wells should be installed based on knowledge of PFAS sources and groundwater flow directions, informed by the desktop review and surficial soil sampling. Monitoring wells should be constructed with and installed using PFAS-free equipment and materials. As an example, the US Navy conducted a study on coated bentonite pellets used in monitoring wells and found PFAS in the leachate from several different brands of pellets (Radford et al. 2023). Drill cuttings and purge water may have special handling and disposal requirements based on the potential presence of PFAS.

PFAS are soluble, so screen interval and placement should not be based on expectations of a "floating" or "sinking" separate phase, but rather potential for vertical hydraulic gradients. The occurrence of PFAS in groundwater will be determined during the initial phase of PFAS characterization sampling of groundwater monitoring wells. Similar to other solutes, PFAS in groundwater migrate by advection and dispersion and, depending on the specific PFAS, may be subject to varying degrees of retardation (though generally expected to be less than in the vadose zone). Investigators should obtain hydraulic conductivity from existing site characterization information or conduct aquifer testing (for example, slug or pumping tests) by conventional means for the calculation of seepage velocity, if needed. Aquifer matrix characteristics and aquifer chemistry influence the sorption of and potential precursor transformation of PFAS. Refer to **Table 1-8** for aquifer matrix and groundwater chemistry parameters for measurement and analysis.

Retention of PFAS in Concrete

PFAS are known to partition into and leach from concrete. Consequently, concrete surfaces (for example, fire training pads, storm sewers) represent sinks and sources of PFAS. PFAS in concrete can be characterized by coring, cutting into discrete disks, and laboratory analysis of PFAS and PFAS in leachate (for example, SPLP). Alternatively, PFAS-free water can be rinsed over or maintained in contact with concrete surfaces and subsequently analyzed for the accumulation of PFAS in the water. The phenomena of PFAS sorption and release from concrete, along with methods for analysis, are addressed by Thai et al. (2025, 2025). See **Section 1.5.6** for more information about concrete and asphalt sampling and analysis.

Surface Water Runoff and Storm Sewer Flow

Informed by the desktop analysis, investigators should sample soil and sediment from stormwater conveyances and accumulation features (swales, drainage channels, and stormwater sewer pipes) that may convey PFAS from the source or release locations.

Even after PFAS have partitioned into environmental media following release or application, conveyance by stormwater flow may occur. PFAS can be desorbed from soil, sediment, and concrete during transient precipitation events, or soil and sediment with sorbed PFAS may be mobilized by stormwater flow. Collect aqueous samples of stormwater runoff and storm sewer flow based on prior soil/sediment sampling and desktop review. It may be necessary to coordinate this sampling with forecasted precipitation or simulate the flow, as with concrete washing.

1.4 Priority Topics for Human and Ecological Health Effects

Section Number	Topic
1.4.1	**Potential Human Health Effects of PFAS Exposure Arising from AFFF in Drinking Water**
1.4.2	**Potential PFAS Exposures from Consumer Products**
1.4.3	**Dermal Uptake of PFAS in the Environment**
1.4.4	**Health Effects of Ultra-short-chain PFAS**
1.4.5	**New Information on Considerations for Addressing PFAS as a Class**
1.4.6	**Potential PFAS Exposures in Occupational Setting**
1.4.7	**Evaluating Risk to Livestock from PFAS Exposure**
1.4.8	**Reptiles Toxicity Data**

1.4.1 Potential Human Health Effects of PFAS Exposure Arising from AFFF in Drinking Water

Releases of AFFF (aqueous film-forming foam) to the environment have contaminated drinking water with PFAS worldwide, including in the United States and Scandinavia, with emerging threats to human health still being studied (Hu et al. 2016; Reinikainen et al. 2022; and additional references discussed in this section). Detailed information on AFFF is found in **Section 3**. Health effects studies of populations who ingest AFFF-contaminated drinking water are of interest because AFFF contains a mixture of PFAS, and these populations therefore typically receive higher exposures to multiple PFAS than the general population. The most extensive and complete investigations to date of the potential health effects of exposure to PFAS in AFFF-contaminated drinking water are from a population in Ronneby, Sweden. However, the design of the studies of the Ronneby population was ecologic (as opposed to, for example, cross-sectional or case control) in that PFAS exposure was based on groups categorized by timeframe for use of residential drinking water with high or low PFAS concentrations, not on individual serum levels of PFAS or other measures of individual exposure. The uncertainty associated with the results of this type of study may be addressed in the future as federal Agency for Toxic Substances and Disease Registry (ATSDR)-sponsored studies of the health effects based on individual serum PFAS levels in several US communities with AFFF-contaminated drinking water are published (ATSDR 2025; Pavuk et al. 2025). The potential human health effects of PFAS are discussed in detail in **Section 7.1** and **Section 17.2**.

In the municipality of Ronneby, Sweden, approximately one-third of the households received drinking water described by the investigators as being "highly contaminated" with PFAS arising from AFFF during the mid-1980s to 2013 (Xu et al. 2021). The highly contaminated water supply (one of two water supplies that served Ronneby) was closed shortly after PFAS detection in 2013. The AFFF originated at a nearby military base; however, there are no detailed records of the composition of the AFFF that was used (Xu et al. 2021). A 2013 analysis of perfluoroalkyl carboxylic acids (PFCAs) and perfluoroalkane sulfonic acids (PFSAs) in drinking water from the most contaminated water supply showed that the PFAS present at the highest concentration were perfluorooctane sulfonic acid (PFOS) (8,000 ng/L) and perfluorohexane sulfonic acid (PFHxS) (1,700 ng/L), followed by perfluorohexanoic acid (PFHxA) (320 ng/L), perfluorobutane sulfonic acid (PFBS) (130 ng/L) and perfluorooctanoic acid (PFOA) (100 ng/L), among other lesser occurring PFAS (Xu et al. 2021). Although the proportions of specific PFAS found in AFFF-contaminated water differed among locations, the PFAS reported in Ronneby are also frequently prominent in AFFF-contaminated water elsewhere, including in the United States (see **Section 3.1**, **Section 3.5.1**, and **Section 3.5.3**). Biomonitoring of ~3,300 Ronneby residents in 2014 revealed geometric mean serum levels of PFHxS, PFOS, and PFOA of 114, 135, and 6.8 ng/mL, respectively. These serum levels were approximately 135, 35, and 5 times higher, respectively, than PFAS levels in a reference

population in which concentrations of measured PFAS in drinking water were below detection limits (Xu et al. 2021).

Several studies have been reported from the population that lived in Ronneby at any time during the period of PFAS contamination (1985–2013). These studies examined associations between exposure to PFAS from the contaminated drinking water and health conditions, including cancer (Li et al. 2022); thyroid disease (Andersson et al. 2019); thyroid hormone levels (Li et al. 2021); birthweight (Engström et al. 2022); type 2 diabetes (Xu et al. 2023); breastfeeding (Nielsen et al. 2022); COVID (Nielsen and Joud 2021); inflammatory bowel disease (Xu et al. 2020); and bone fractures (Xu et al. 2023), and are further discussed below.

To characterize exposure, the study authors relied on residency records that linked individual residence addresses to drinking water delivered by the contaminated water supply and another nearby water supply that was minimally contaminated. Another unexposed municipality served as a reference population. Several categories were used by these authors (Li et al. 2020, 2022; Andersson et al. 2019; Li et al. 2021; Engström et al. 2022; Xu et al 2021; 2023; 2023; Hammarstrand et al. 2021; Nielsen et al. 2022; Nielsen and Joud 2021) to categorize PFAS exposure groups relevant for their analysis. Most authors categorized residents who had received the most highly contaminated water as “ever high,” while “never high” was defined as Ronneby residents supplied by the minimally contaminated water source (PFOS = 27 ng/L, all other measured PFAS individually <=10 ng/L) and who never received highly contaminated water during the entire study period of 1985–2013 (Li et al. 2020; Hammarstrand et al. 2021 ; Xu et al. 2021; Li et al. 2022; Xu et al. 2023; 2023). Additional exposure subcategories of “early high” (residential time: 1985–2004) and “late high” (residential time: 2005–2013 and may include 1985–2004) were used to evaluate the impact of the time period when residents had received highly contaminated water. Residents in the “late high” group had higher serum levels of PFOS (geometric mean: 239 ng/mL), PFHxS (geometric mean: 210 ng/mL), and PFOA (geometric mean: 13 ng/mL) when compared to the “early high” (geometric mean: PFOS: 48 ng/mL, PFHxS: 43 ng/mL, and PFOA 3.6 ng/mL) or the “never high” (geometric mean: PFOS: 40 ng/mL, PFHxS: 30 ng/mL, and PFOA 3.5 ng/mL) exposure groups. Geometric mean serum levels of the “never high” exposure group were similar to the “early high” exposure group (Li et al. 2022; Xu et al. 2023; 2023). The mean geometric serum associated with the “ever high” category was reported as PFOS: 199 ng/mL, PFHxS: 179 ng/mL, and PFOA: 11 ng/mL (Li et al. 2022).

Using these exposure groupings, Li et al. (2022) evaluated PFAS exposure and cancer in Ronneby residents across each exposure group and in comparison, to an external reference group consisting of residents from a neighboring municipality whose drinking water was not contaminated with PFAS during the exposure period. The overall risk of cancer was not elevated in the exposed populations, and there was no excess prostate or breast cancer risk. Statistically insignificant increases in hazard ratios (HRs) were observed for several cancers (such as kidney, bladder, brain, bone and cartilage, thyroid, and testicle) in the “ever high” group. The authors concluded that there was some evidence for an elevated risk of kidney cancer. This conclusion was based on an increased (non-statistically significant; HR: 1.27; 95% CI: 0.85, 1.91) standardized cancer incidence ratio for kidney cancer in the “ever high” versus “never high” groups, with a non-statistically significant increase in the HR of kidney cancer in the “late high” (HR: 1.85; 95%CI: 1.00, 3.40) versus “early high” (HR: 1.05; 95%CI: 0.64, 2.84) group.

Xu et al. (2023) used the same exposure categories to examine the risk of bone fractures and PFAS exposures in the Ronneby population. There were significantly increased HRs of major osteoporotic fractures (HR 1.11, 95% CI 1.03–1.19) and a non-statistically significant increase in hip fractures (HR: 1.12; 95% CI: 1.00–1.24) between the “ever high” and “never high” exposure groups. Significantly increased HRs for major osteoporotic fractures (HR 1.29, 95% CI 1.16–1.44) and for hip fractures (HR 1.22, 95% CI 1.01–1.47) were also documented in individuals in the “late high” group when compared to the “early high” group.

Andersson et al. (2019) found no increased risk of hyperthyroidism among those residents who received PFAS-contaminated drinking water; an increased risk in a surrogate measure of hypothyroidism was attributed to chance given that the response was not dose-related. Similarly, no consistent evidence was reported by Li et al. (2021) to link ingestion of PFAS-contaminated drinking water to alterations in the levels of hormones (free T3 and free T4 or thyroid-stimulating hormone) affecting thyroid function.

Hammarstrand et al. (2021) reported that exposure to higher levels of PFAS were associated with significantly higher HR for polycystic ovarian syndrome (HR: 2.18; CI: 1.43, 3.34) and non-statistically significant elevated HR for uterine leiomyoma (HR: 1.28; CI: 0.95, 1.74), but not for endometriosis in premenopausal women.

HRs for diagnosed inflammatory bowel disease (IBD), such as Crohn's disease, ulcerative colitis, and "other IBD," were not increased in "mid" (a group who received highly contaminated drinking water during 1995–2004) and "late" (2005–2013) period exposure groups, while individuals in the "early" period exposures (1985–1994) had increased HRs for Crohn's disease and nonspecified IBD (Xu et al. 2020). Xu et al. (2020) concluded that there was no consistent evidence for PFAS increasing the occurrence of IBD given that individuals exposed in the "late" period had higher PFAS serum levels than those from the "early" period and that IBD cases in the "early" and "late" exposure groups had 2.5 versus 4.8 years of early exposure prior to diagnosis, respectively. Thus, the higher HRs in the "early" period were not explained by either higher PFAS exposure or a longer exposure time.

Consistent with the studies included in the recent reviews by the European Food Safety Authority (EFSA) (2018) and others (see **Section 17.2.4**), Li et al. (2020) reported statistically significant increases in mean total cholesterol and low-density lipoprotein in the "total exposed" population (recently exposed + nonrecent/uncertain exposure). Li et al. (2020) also found positive associations between serum levels of PFOS, PFHxS, and PFOA and serum levels of total cholesterol, LDL, and high-density lipoprotein (HDL) in the "recently exposed" group (that is, those who were provided contaminated drinking water in 2005–2013).

Long-term exposure to PFAS in drinking water was also associated with increased risk for type 2 diabetes in the Ronneby population (Xu et al. 2023). Xu et al. (2023) found elevated HRs for type 2 diabetes in the "ever high" (HR: 1.18, CI: 1.03–1.35) exposure group, including the subgroups of "early high" (HR: 1.12, CI: 0.98–1.50) and "late high" (HR: 1.17, CI: 1.00–1.37) when compared to the "never high" exposure group after adjustments for age and sex. A higher HR was associated with younger age group (18–45 years old) when compared to the older age group (>45 yrs old), indicating the potential for early onset diabetes. This HR estimate was attenuated when the study sample was adjusted for educational level as a socioeconomic factor but still indicated the direction of association toward higher HRs (Xu et al. 2023).

Standardized incidence ratios (SIR) for occurrence of COVID-19 were significantly higher in both the overall Ronneby population (SIR: 1.19; 95% CI: 1.12, 1.27) and in the contaminated area (SIR: 1.16; 95% CI: 1.01, 1.30) (Nielsen and Joud 2021). The total Ronneby population has greater concentrations of PFAS in the serum than the general population, and this may reflect an association between COVID-19 and PFAS exposure, but this needs to be explored further. This study was based on aggregate data collected over the first year of the pandemic and thus, the individual data that would have been preferable to explore effect relationships at the lower exposure levels are lacking.

Pregnant women in the Ronneby municipality were recruited between 2015 and 2020 to study PFAS in serum, breast milk, and colostrum of mothers exposed to PFAS in drinking water (Blomberg et al. 2023; Blomberg et al. 2023). Seven PFAS—PFOS, PFOA, PFHxS, perfluorononane sulfonic acid (PFNA), perfluorodecanoic acid (PFDA), perfluoroundecanoic acid (PFUnDA), and PFHpS—were found in samples of serum, colostrum, and breast milk, with higher concentrations strongly correlating to highly exposed mothers. On average, PFHxS and PFOS were the largest contributors to total PFAS in colostrum and breast milk (Blomberg et al., 2023; Blomberg et al. 2023). PFAS concentration also varied over the course

of lactation, with PFOS increasing by 21% while PFOA and PFHxS decreased by 17% and 12%, respectively, from colostrum to mature breast milk (Blomberg et al. 2023). Over an 8-month lactation period, the general trend was a greater monthly decrease in PFOA concentrations, while PFHxS and PFOS exhibited small and nonsignificant decreases (Blomberg et al. 2023). The transfer efficiencies of PFAS from serum to colostrum and breast milk were similar across exposure groups (categorized by the PFHxS concentration) with greater transfer efficiencies for PFCAs (such as PFOA) than PFSAs (such as PFHxS and PFOS) (Blomberg et al. 2023). The higher transfer efficiency may contribute to the faster decline in PFOA observed over the course of lactation (Blomberg et al. 2023). The transplacental transfer efficiency reported in a similar study found that overall transfer efficiencies were higher for PFHxS, PFOA, and branched PFOS, and lowest for the n-PFOS isomer (Norèn et al. 2025). These studies have indicated that high exposure to PFAS leading to high maternal serum concentrations may result in higher absolute prenatal exposure (Norèn et al. 2025), as well as newborn exposure throughout the lactating period (Blomberg et al. 2023; Blomberg et al. 2023).

Additionally, Nielsen et al. (2022) studied breastfeeding initiation and duration in Ronneby mothers. A non-statistically significant increase in not initiating breastfeeding at birth (relative risk: 1.2; 95% CI: 0.9, 1.6) was observed in mothers who lived at an address served by the highly contaminated water supply for one year or longer. Regarding duration of breastfeeding, there was a statistically significant 1.6-fold increased risk (95% CI: 1.2, 2.1) of not breastfeeding at 6 months and a non-statistically significant 1.2-fold increased risk (95% CI: 0.9, 1.6) of not exclusively breastfeeding at 3 months in highly exposed (i.e., living at an address served by the highly contaminated water supply for one year or longer) mothers.

PFAS contamination was associated also with birth weight variations, which differed in direction in males versus females, in the Ronneby population. Engström et al. (2022) found statistically significant differences in birth weight for “high exposure” infants born after 2005 but not before. “High exposure” was defined as an infant whose mother was exposed to highly contaminated water for at least one year of the 5 years before the birth of the infant, whereas “low exposure” referred to infants whose mothers had lived in an area of Ronneby without highly contaminated drinking water. For male infants, these differences were exhibited as lower mean birthweights, whereas female infants had higher mean birthweights. These birthweight differences were approximately 50 g in both sexes, a change that the authors considered to be small and indicative of a “minor influence” on birth weight. The findings in this study add to the discussion in **Section 17.2.4**, where it was noted that long-chain PFAS, particularly PFOA and PFOS, were associated with changes in infant birthweight.

This review focused on the PFAS exposure from AFFF contamination in drinking water in the Ronneby population during the mid-1980s to 2013. These studies indicated high exposure to PFAS may be associated with an observed increased risk for several health outcomes, such as osteoporotic fractures, female reproductive diseases (polycystic ovarian syndrome and uterine leiomyoma), higher cholesterol levels, type 2 diabetes, and COVID-19 in the exposed Ronneby community. Prenatal exposure to PFAS was also of concern because high transplacental transfer efficiencies were demonstrated for several PFAS in pregnant women (Norén et a. 2025). Evidence was also presented for PFAS in the serum, colostrum, and breast milk of exposed mothers, indicating exposure to PFAS through breastfeeding (Blomberg et al. 2023; Blomberg et al. 2023). Furthermore, the presence of PFAS in mothers was associated with changes in breastfeeding patterns (Nielsen et al. 2022) and small variations in birthweight (Engström et al. 2022). However, these studies were not without limitations, as most of them were based on ecological study of exposure groups that were location- and time period–specific rather than on serum concentration or other more specific attributes of exposure (Nielsen and Jöud 2021; Hammarstrand et al. 2021; Nielsen et al. 2022; Xu et al. 2023; Xu et al. 2023). Most of the health effects data came from census and other health registers with limited individual information on relevant potential confounding variables (Hammarstrand et al. 2021; Li et al. 2020; Li et al. 2022; Nielsen et al. 2022; Xu et al. 2023; Xu et al., 2023). Nevertheless, similar associations were found in several epidemiological studies, as presented in **Section 17.2.4**, noting PFAS exposure, particularly to PFOA and PFOS and changes in serum cholesterol, birthweight, immunity, and carcinogenicity.

1.4.2 Potential PFAS Exposures from Consumer Products

Section 2.5 presents information about PFAS that may be found in products. In this section, potential direct exposures to PFAS from consumer products are discussed. Direct exposure refers to the human intake of PFAS that may occur during the intended use of a consumer product, such as dermal absorption from treated textiles, ingestion from food contact materials, or inhalation of volatilized substances, and excludes exposure due to environmental dispersion, legacy contamination, or degradation of PFAS-containing waste materials. This section summarizes information on major categories of consumer products that may contain PFAS and may contribute to human exposure, but this should not be viewed as a definitive and exhaustive review given the evolving understanding about the uses of PFAS in consumer products, the state of analytical methods (see **Section 1.5.4**), and regulatory definitions that may include or exclude certain PFAS from existing reporting requirements. The **Regulatory Programs Table** includes information about regulations related to the ban of PFAS in certain categories of consumer products.

Existing literature has sought to identify and categorize PFAS use across applications, including consumer products. One of the earliest comprehensive efforts was Glüge et al. (2020), who published an overview of PFAS uses in distinct product categories, including consumer and industrial applications using information from databases, patents, PFAS manufacturers, and primary literature. The overview further differentiated industrial categories (for example, building and construction materials) and other use categories, including certain consumer products (Glüge et al. 2020). More recent efforts have focused on similar categories of consumer products for comparing PFAS concentrations as reported by manufacturers or identified through independent analyses. Dewapriya et al. (2023) reviewed available data and publications for 1,040 consumer products from 15 countries to compare total PFAS concentrations that ranged from parts per thousand (ppt) to parts per million (ppm). Textile products (381 products) had the highest mean concentration of total PFAS (303 ppm), followed by household cleaning products such as fabric treatments and detergents (122 products) estimated to have a mean concentration of 208 ppm, and then lower mean concentrations in lubricants and oils (121 ppm across 5 products), building materials (79 ppm across 62 products), and cosmetics (58 ppm across 75 products) (Dewapriya et al. 2023). However, the maximum concentrations reported within each of these consumer product categories demonstrate significant variability of total PFAS concentrations that range by a factor of 2–10. As noted in the Dewapriya et al. (2023) review article, there are inherent uncertainties about the reported concentrations in various products due to a lack of standardized analytical methods, quality assurance/quality control (QA/QC) practices for different matrixes, and changes in target analytes. Such reviews highlight the likely occurrence of PFAS in consumer products with considerable variability in total concentrations and provide a framework of subcategories to further evaluate and prioritize for human exposure potential.

Outside of primary literature, the US Consumer Product Safety Commission (CPSC) commissioned a report to summarize available information on the potential for human exposures to PFAS in consumer products (RTI 2023), including releases to the environment from initial production to disposal. RTI (2023) reviewed 28,299 patents across consumer product categories including “childcare products; clothing, apparel, jewelry, and accessories; containers and packaging; electronics; food products; household products; infant formula; outdoor recreation, sports, and fitness.” The report identified PFAS based on available peer-reviewed literature, patent reporting, and multiple US Environmental Protection Agency (USEPA) databases, with limited examples of specific PFAS, but it is not an exhaustive listing of the amounts and types of each individual PFAS in consumer products. With respect to human exposure, the report concluded that several processes, including abrasion, transfer to indoor surfaces, transfer to skin, transfer to saliva, absorption into food, and the volatilization of PFAS in various consumer products, likely contribute to multiple exposure pathways (RTI 2023). However, quantifying the risk is complicated due to the diversity of products and limited quantitative information on these processes.

A significant challenge for characterizing the occurrence of PFAS in consumer products by the studies of Dewapriya et al. (2023) and RTI (2023) and other reports or studies has been the historical lack of PFAS

labeling requirements in products. There have generally been no labeling requirements specific to PFAS based on the intentional use of PFAS in final consumer products or for the unintentional addition of PFAS through manufacturing processes, or the presence of PFAS in ingredients or components in the final product. Although not specific to PFAS, other consumer product labeling requirements such as ecolabels (for example, Cradle to Cradle Certified, Green Seal, Declare 2.0) include certain definitions of PFAS or reporting requirements for very specific groups of consumer products (USEPA 2023; 2025). Much of the available primary literature on the presence of PFAS in products is the result of product-specific testing rather than broader sampling of products across larger categories of consumer products. **Section 8.2.3.1** and the **PFAS Regulatory Programs Summary** Excel File provide more specific information about state-level regulations that may require labeling for products containing PFAS; however, the adoption and implementation deadlines for these requirements are frequently changing and readers are advised to confirm current labeling requirements with state regulatory agencies.

The following sections provide summaries of available information on exposure to PFAS in subgroups of consumer products. These subcategories include the products and related products through common applications (for example, upholstery/carpets and carpet cleaning agents). Given the potential variety of consumer product categorization schemes, combined with the limited literature for each of these highly specified groupings, the following sections reflect groupings that are based on broader categories of related products or similar intended function of PFAS in consumer products. The groupings in the following sections also considered similarity of potential exposure pathways from products. The aforementioned reports (Dewapriya et al. 2023; RTI 2023) provide detailed information about specific consumer products. Other sections of this ITRC document provide more details about PFAS in product categories that apply to both personal consumer goods and commercial or industrial applications (**Sections 2.5** and **2.6.1**). This includes a summary in **Table 2-6**.

1.4.2.1 Textiles, Including Furniture, Furnishings, and Apparel

PFAS are applied to fabrics and textiles used in furniture, upholstery, carpets, and other products to impart water-, oil-, and stain-repellant properties. During production, treatment, use, or disposal of these materials, workers and consumers may potentially be exposed to PFAS (European Environment Agency 2024). Potential consumer exposure could occur through direct skin contact and absorption, hand-to-mouth transfer after handling these textiles, direct contact with the mouth (for example, mouthing behaviors of infants and small children) or the generation of dusts, volatiles, or other airborne forms of PFAS that might be inhaled.

Nationally, regulatory oversight of textiles and fabric products in apparel, furniture, carpeting, and similar materials generally falls to either the CPSC or Federal Trade Commission (RTI 2023). Regarding home application of fabric treatments, a case study found elevated levels of PFHxS in the blood of household members, when compared to contemporary community averages, that was traced to frequent application of stain-resistant carpet treatment and indoor upholstery (Beesoon et al. 2012). Beesoon et al. (2012) found PFHxS in dusts (2,780 ng/g) and sampled carpeting (2,880 ng/g) and inferred that these contributed to exposure via indirect ingestion or inhalation of dusts. Some recent studies also rely on estimates of exposure from survey data matched with serum PFAS concentrations (Zhu et al. 2021) or inferring carpet-related exposures from associated dusts (Wu et al. 2020). However, direct measurement of exposure from treated carpet and flooring is challenging due to varied behaviors that influence direct and indirect contact with these surfaces, their potential for absorption by compound, and PFAS exposure from other sources.

The historical phaseout of certain PFAS (for example, PFOS) as textile and fabric treatment is summarized in **Section 2.4**. Recent state-level bans on PFAS in textile products have set requirements for reporting and phasing out PFAS in certain textile products (see **PFAS Regulatory Programs Summary** for state-specific information). One example is California's Assembly Bill (AB) 1817 (CA Assembly 2022), which prohibits PFAS in textiles beginning January 1, 2025, with exemptions for outerwear for extreme

conditions that are not marketed to the public. New York's Senate Bill 56291A prohibits PFAS in apparel beginning January 1, 2025, although "professional uniforms" and "outerwear intended for extreme conditions" are excluded (NY DEC 2025). **Section 2.5.3** includes information about efforts to reduce or eliminate PFAS in products.

1.4.2.2 Children's Products

The CPSC defines children's products as consumer products designed for use by infants and children under 12 years old (CPSC 2025). Examples of such products include, but are not limited to, toys, bedding and mattresses, school uniforms, certain games, and crafts materials. Further guidance on the determinants of children's products is available (CPSC 2020). A major determinant of whether a product is a children's product is whether it is intended for use by or is marketed to children less than 12 years old (CPSC 2020; 2025), which is notably different from the USEPA's definition of children (conception to ≤21 years of age) used for typical human health risk assessments of environmental media (USEPA 2021). Beyond such regulatory definitions, similar terminology is used throughout the primary literature to characterize consumer products for children, as well as adolescents less than 18 years old, which creates challenges for aligning regulatory reporting requirements with primary literature studies.

Children's products have elevated concern for exposure due to the behaviors of infants and small children. Normal development behaviors such as teething or mouthing present an obvious exposure via the oral route, where toys, fabrics, food packaging, and crafting supplies, despite labeling, may end up in a child's mouth. Skin contact with clothing, bedding, and other items for children has been routinely identified as a concern with any chemical exposure due to the relatively thin skin of infants and children in comparison to adults. As with other consumer products, the primary challenges are identifying products that likely have PFAS present (labeling), quantifying the total amount of PFAS present in these items, and then accurately estimating potential for exposure (for example, transfer efficiency) in a variety of exposure scenarios.

An example of the analytical challenges is Rodgers et al. (2022), who tested for the presence of PFAS in children and adolescent products that were labeled as "green" or with other terms used for advertising safer product chemistry. This study used a combination of a total fluorine assay, targeted analysis of solvent extractions (11 analytes), and the total oxidizable precursor (TOP) assay (see **Section 11.2.2.2**) to evaluate for PFAS in 93 products. This included apparel (for example, clothing, face masks, and underwear), bedding (sheets, mattress protectors, and pillow protectors), and furnishings such as area rugs and upholstered chairs. They found that "green" labeling for children's products was not predictive of the presence/absence or concentration of total fluorine or specific PFAS in any tested materials, despite the presumption of green labeling being indicative that a children's product is PFAS-free (see **Section 2.5.3**). Rodgers et al. (2022) observed a correlation between total fluorine and the presence of several PFAS analytes, which is consistent with PFAS results reported in children's products from other studies (Liu et al. 2014; Lassen et al. 2015; Robel et al. 2017; Xia et al. 2022).

1.4.2.3 Cosmetics and Personal Care Products

Cosmetics and personal care products are consumer products regulated by the U.S. Food and Drug Administration (USFDA). Cosmetics are used internally or externally to alter any aspect of appearance (USFDA 2013). Personal care products do not possess a specific regulatory definition and are evaluated on a case-by-case basis as related to their usage and may include certain cosmetics, drugs, soaps, and devices. The report by RTI (2023) identified 15,409 patents for cosmetics and personal care products that potentially contain PFAS based on product information or functional characteristics.

PFAS may be intentionally added to cosmetics or personal care products to function as surfactants, emulsifiers, solvents, and conditioning and viscosity agents (Ragnarsdottir et al. 2022; Schultes et al. 2018; Whitehead et al. 2021; Namazkar et al. 2024). Additionally, some PFAS may be unintentionally

added to cosmetic or personal care products due to impurities in the raw materials or due to breakdown of unidentified precursor PFAS that are intentionally added (USFDA 2024), as well as their presence in the production of certain plastic containers (Whitehead and Peaslee 2023). As related to direct exposures, dermal contact is the primary route of concern given the intended application of cosmetic and personal care products, although incidental ingestion also requires consideration, depending on the article. **Section 1.4.3** provides a detailed discussion about the nuance of dermal absorption, factors that require consideration for exposure estimation and sources of uncertainty, especially as they pertain to differences in physicochemical characteristics of individual PFAS. Products that are designed to remain in the skin, form films or barriers, or otherwise produce prolonged contact (for example, lotions, creams, makeup) create exposure scenarios in which there is more time for potential absorption across the skin. Abraham and Monien (2022) highlighted the significance of dermal absorption with a study that monitored uptake of radiolabeled PFOA (110 µg) into a volunteer who applied the full dose via sunscreen application (30 g) across their entire body. Interpretation of the findings merit caution, as the study relied on only a single participant, but the worst-case scenario of PFOA bioavailability from the sunblock application was estimated to be approximately 1.6% using certain assumptions about toxicokinetics (for example, a volume of distribution of 0.17 L/kg). The contribution to the volunteer's background PFOA serum concentration was estimated to be nearly 9.4% (Abraham and Monien 2022). More recently, Chen et al. (2024) used simulated sunblock mixtures with in vitro and in vivo (mouse) models to estimate dermal uptake rates and other kinetic parameters for several PFSAs and PFCAs. That study is further described in **Section 1.4.3**. Keawmanee et al. (2024) provided an example of a quantitative approach to estimating PFAS exposure doses from cosmetic products and found relatively low risk based on their assumptions about the rates of product use and existing toxicity factors for select PFAS (PFOA, PFOS, PFBS). When considering other cosmetic or personal care products, a diversity of applications and products creates vastly different exposure scenarios for evaluating potential risks (for example, makeup versus dental floss), which is furthermore complicated by potential off-label applications by consumers.

PFAS have been detected using total organic fluorine (TOF) analysis and some targeted analyses in several cosmetic and personal care products, including anti-aging cream, eyeliner, antiperspirants, body creams and lotions, shampoo, soaps, sunscreens, and period products (tampons and menstrual pads) (Rodgers et al. 2022; Zhou et al. 2023). As with other media, discussed in **Section 11.2**, methods for these products may be challenged by the sample matrix and other chemicals present in these products.

The FDA acknowledges the presence of certain PFAS in cosmetics products (USFDA 2024). Based on past reporting requirements and the Organisation for Economic Co-operation and Development (OECD) definition of PFAS (OECD 2021), the FDA identified 35 specific PFAS likely used across 578 cosmetic products. The FDA is tentatively expected to release a risk assessment of PFAS in cosmetics in late 2025 that would provide more updated information specific to the United States (USFDA 2024). Internationally, a risk assessment of PFAS in cosmetic products conducted by the Danish Ministry of Environment and Food determined that the presence of various PFAS in a sample of 18 cosmetic products from the Danish market presents risks to consumers based on several exposure and toxicity assumptions used at that time (Ministry of Environment and Food of Denmark EPA 2018). Products included blemish balms, body lotions, color-correcting creams, concealer, cream/lotion, eyeliner, eye shadow, facial scrubs, foundation, hair spray, highlighter, and powder.

1.4.2.4 Food Packaging and Cookware

PFAS are used in food packaging, cookware, and other products that may result in contamination of food. This is a concern for human exposure to PFAS by ingestion of food or liquids containing PFAS. Food contact materials (FCMs) are materials that come in contact with food and beverages during storage, packaging, or consumption (USFDA 2025), and PFAS may be added to these FCMs to impart grease- and water-resistant functionality. Cookware, such as nonstick frying pans, have been identified as consumer products that may contain PFAS (Glüge et al. 2020). Last, PFAS may be used as a processing aid in food preparation equipment that has the potential to contaminate food. In all these cases, the migration of

PFAS from the product into food or beverages is the primary concern for direct exposure (Ramírez Carnero 2021; Begley et al. 2005; Choi et al. 2018; Curtzwiler et al. 2021). Populations with higher reliance on packaged foods, such as children, students, and individuals in institutional settings, may experience disproportionate dietary PFAS exposure due to higher consumption of processed foods and associated FCMs (Susmann et al. 2019; Susmann et al. 2023; Hampson et al. 2024; Hampson et al. 2025; Pacyga et al. 2025). Due to the varied migration rates of PFAS from food packaging into dietary items, consumer risk assessments are scarce, as there is inherently high uncertainty from the limited data on PFAS concentrations in these materials and variability in related food consumption patterns.

Several studies have examined the presence of PFAS in FCMs via TOF, extractable organic fluorine (EOF), and targeted analytical methods (for example, Vázquez Loureiro et al. 2024; Hu et al. 2025). Whitehead and Peaslee (2023) identified fluorinated plastic containers as a potential source of PFAS exposure because short-chain PFCA migrate into the food. **Section 11.2** includes references and explanations of existing methods that have been used for food packaging, including targeted analysis and particle-induced gamma-ray emission (PIGE).

Similar to other categories of consumer products, multiple state-level bans have been either proposed or passed that target PFAS in food packaging and cookware. Nationally, the USFDA (2025) announced the market phaseout and revocation of use for PFAS in grease-proofing of food packaging sold in the United States.

1.4.3 Dermal Uptake of PFAS in the Environment

Since dermal uptake of PFAS was initially addressed in **Section 17.2.3**, information on dermal uptake of PFAS has continued to evolve. There is now recognition of the fact that perfluoroalkyl acids (PFAAs) are largely ionized in aqueous solution at environmental pH (~pH 6–8) and that dermal uptake of these charged forms of PFAS is limited due to their ionic character (ATSDR 2024; USEPA 2025; Mellard, 2024; Franko et al. 2012). The dermal uptake of other PFAS from both aqueous and nonaqueous media remains largely uncharacterized. This section provides information on our current understanding of dermal uptake of PFAS in aqueous solutions and briefly describes the results of one study of dermal uptake of neutral PFAS from the gas phase (Kissel et al. 2023, 2023). There are currently no data on the extent of dermal uptake of PFAS from soil or dust; however, the USEPA Regional Screening Levels (RSLs) for PFCAs and PFSAs incorporate an assumption that 10% of these PFAS are dermally absorbed from soil (USEPA 2025). Note that two of the studies discussed in this section were previously mentioned in **Section 17.2.3** (Fasano et al. 2005; Franko et al. 2012) but are described in more detail here to provide a more complete picture of our current understanding of dermal uptake of PFAS.

How, and to what extent, dermal uptake of PFAAs or other PFAS occurs from cosmetics, sunscreen, or other consumer products is likely more variable than uptake from aqueous solutions and is also harder to predict given the complex mixtures that comprise many consumer products. Other than the studies of Abraham and Monien (2022) and Chen et al. (2024), who examined the dermal absorption of PFOA from sunscreen (see **Section 17.2.3** and **Section 1.4.2**), no publications have quantified the dermal uptake of PFAS from consumer products.

1.4.3.1 The Process of Dermal Absorption

Human skin consists of three different layers (epidermis, dermis, hypodermis), with the outer layer of the epidermis—the stratum corneum—providing an important barrier function (National Center for Biotechnology Information [NCBI], 2024). The main pathway for chemicals to move through the stratum corneum is by passive diffusion; chemicals can also cross human skin via sweat glands and hair follicles. For a chemical to be available for absorption through the skin and to become “bioaccessible,” it must be in solution (in sweat or sebum) and be in contact with the skin. Some or all of the bioaccessible chemical can then be absorbed and is potentially able to reach the systemic circulation (Ragnarsdottir et al. 2022).

Chemicals retained in the epidermis may or may not reach the circulatory system in that they may be removed by desquamation (the normal sloughing of dead epidermal cells) if they persist in human skin—without absorption—for extended periods (USEPA 2004).

A recent review by Yeh et al. (2024), as well as studies by Fasano et al. (2005); Franko et al. (2012), and Ragnarsdottir et al. (2024), have recognized several kinetic parameters used to characterize dermal absorption of PFAS:

- the fraction absorbed (expressed as a percentage of applied dose)
- steady-state flux J_{ss}, μg/cm^2-h—that is, the rate at which a chemical is absorbed through the skin once constant (steady state) absorption has been reached
- dermal permeability K_p, cm/h—that is, the rate at which a chemical is able to penetrate the stratum corneum

Two different types of experimental approach—finite and infinite dose protocols—are used in the assessment of dermal uptake (Yeh et al. 2024).

An "infinite dose" experimental protocol uses concentrations of a chemical selected to ensure a continuous excess of test compound in order to achieve maximal amounts of dermal absorption; depletion of the chemical does not occur (Frasch et al. 2014). Infinite dose protocols are considered appropriate to determine J_{ss} and K_p, as they can approximate steady-state conditions. Although an infinite dose testing protocol is consistent with OECD guidance (OECD 2004), it is not directly relevant to real-life conditions where much lower and noncontinuous doses are expected. Instead, "finite" dose protocols are used to mimic environmentally realistic exposure amounts, with limited amounts of chemical applied. Finite dose protocols are considered appropriate to determine the fraction of chemical that is dermally absorbed (Frasch et al. 2014).

Several studies have reported the fraction (percentage) of one or more PFAS that was absorbed following dermal exposure (Fasano et al. 2005—ammonium perfluorooctanoate in water; Franko et al. 2012—PFOA in acetone [primary experiment]; Ragnarsdottir et al. 2024—17 individual PFAAs and PFSAs in methanol; Espartero et al. 2025—mixture of 30 PFAS in methanol, and perfluorobutanoic acid (PFBA), perfluorobutane sulfonamide (FBSA), perfluoropentanoic acid (PFPeA), and perfluoropropanesulfonic acid (PFPrS) individually in water). However, the fraction of PFAS (or other chemical) that is absorbed depends on the applied dose (Kissel 2011), as well as on the vehicle. Because organic solvents such as acetone and methanol likely increase the dermal absorption of PFAS by potentially increasing solubility or enhancing both diffusion and uptake (Chiang et al. 2012; ATSDR 2024; Ragnarsdottir et al. 2024), the absorption estimates of Franko et al. (2012) and Ragnarsdottir et al. (2024) and the mixtures experiments of Espartero et al. (2025) likely reflect greater dermal absorption than would occur in experiments that used water as the vehicle. Buist et al. (2009) and Kissell (2011) have also pointed out that an inverse relationship may exist between dermal loading and fractional absorption. Because of the dependence of absorption on dose, the USEPA (2004) recommended that dermally absorbed dose calculations use K_p, the skin permeability coefficient (cm/h) (see discussion below).

1.4.3.2 Relative Permeability of Animal and Human Skin

Studies in animals have demonstrated that dermal absorption of PFAS does occur, as evidenced by rodent toxicity studies that have shown systemic adverse effects after dermal dosing (for example, Kennedy 1985; Shane et al. 2020; Weatherly et al., 2023; Weatherly et al. 2024). In a study designed to evaluate the photocarcinogenic potential of PFAS, Donslund et al. (2025) detected PFOA in the serum (57–160 ng/mL) and liver (90–2,614 ng/g) of hairless mice treated topically with 10 μg/g (that is, 10 mg/kg) three times over the course of a week following exposure to ultraviolet radiation. PFOA was

detected at substantially higher concentrations (40,059–316,309 ng/g) in the livers of hairless mice (not previously exposed to ultraviolet) measured 1, 4, or 24 hours after a single topical application of 10 mg/g PFOA. Rodent skin has been estimated to be several-fold to approximately 34 times more permeable than excised human skin (from surgeries or cadavers) (Fasano et al. 2005; Jung and Maibach 2015). These species-dependent differences in absorption mean that direct extrapolation from rodent dermal uptake data to humans will likely overestimate human dermal uptake.

Hall et al. (2023) showed that PFCAs were absorbed across freshly collected porcine skin in an in vitro flow-through model system at pH 7.3–7.5. Over the 8-hour exposure period, the relative rates of absorption were PFBA > PFHxA > PFOA for both artificial perspirant (that is, artificial sweat) and acetone vehicles. The PFOA K_p's measured (8.28×10^{-5} cm/h and 5.73×10^{-5} cm/h for artificial perspirant and acetone, respectively) were comparable to those measured by Franko et al. (2012) with human skin at pH 5.5. These results indicated that porcine skin may be more appropriate than rodent skin for assessing dermal uptake in humans (Franko et al. 2012).

Human skin equivalent models, which were used in a recent study of PFAA dermal uptake (Ragnarsdottir et al. 2024), may also be more permeable than intact human skin used by Franko et al. (2012), Fasano et al. (2005), and Espartero et al. (2025). These human skin equivalents consist of reconstructed human skin that is grown from keratinocyte stem cells. Although they reportedly possess many characteristics of intact human skin, the extent of the difference between dermal absorption of PFAS in human skin equivalents and intact human skin has not been characterized; thus, results should be interpreted or extrapolated with caution (see discussion of Ragnarsdottir et al. (2024) in **Section 1.4.3.5**).

1.4.3.3 Toxicokinetics of Dermal Exposure

Several recent publications have reported on the use of rodent models to evaluate the toxicokinetics of dermal uptake of PFAS. As discussed in **Section 1.4.3.2**, there are differences in the permeability of rodent and human skin that preclude direct extrapolation between species. Nonetheless, these rodent studies provide information regarding the potential for extended uptake due to the potential retention of PFAS in skin postexposure. For example, Chen et al. (2022) used rats to estimate the dermal penetration efficiency of 15 PFAS applied as a mixture to shaved skin in "low" and "high" exposure groups (1.25 µg/cm^2 and 6.25 µg/cm^2, respectively). Exposure was maintained for 6 hours by occluding the area of application then removing any residue. At 144 hours after the end of exposure, between 4.1% and 18.0% and 5.3% and 15.1% of the applied PFAS in the low and high groups, respectively, were absorbed, with peak concentrations of PFAS in plasma attained at 8–72 h. This indicates that concentrations of PFAS in the blood continued to increase following the end of exposure and that PFAS retained in one or more skin layers likely served as a reservoir for the continued movement of PFAS into the circulation.

To support development of a physiologically based pharmacokinetic (PBPK) model of PFAS uptake, Zhu et al. (2023) studied differences in the toxicokinetics of PFAS in mice administered a mixture of PFHxS, PFOS, and PFOA by oral, nasal instillation, or dermal exposure. For the dermal portion of this study, equal amounts of the three PFAS in an aqueous solution of 0.5% TWEEN (1 mg/kg of each PFAS [low dose] or 5 mg/kg of each PFAS [high dose]) were administered in a single 50 µL intradermal injection—a procedure that introduces the chemicals directly into the dermis, bypassing the epidermis. The results of this study were described in terms of whether the PBPK model provided reasonable estimates of observed PFAS uptake—raw data on uptake were not included. Despite this limitation, the results of Zhu et al. (2023) appear to indicate that the time to reach peak plasma concentrations was estimated to be much longer (34.1–83.0 h) after dermal exposure than after nasal instillation (0.960 h) or oral exposure (time not specified). The data of Zhu et al. (2023) also indicate that the exposure route affects the rate and extent of PFAS uptake in mice, with dermal exposure resulting in the lowest uptake and bioavailability of the three exposure routes considered.

Using mixtures of 13 different PFAAs, PFCAs (10, with carbon chain lengths of 4 to 12 and 14) and PFSAs (3, with carbon chain lengths of 4, 6, and 8), Chen et al. (2024) investigated the dermal absorption and accumulation of PFAS in mice following exposure to PFAS in laboratory-formulated sunscreens and commercial sunscreens. Although these exposures are not truly environmental in character, this study is included here as it provides some insight on the relative dermal uptake of PFCAs and PFSAs following an ex vivo 36-h exposure or a 30-day exposure period in whole animals. In the ex vivo exposures, there was significantly higher bioaccessibility of all of the PFAS in the control water-in-oil (W/O) than in the control oil-in-water (O/W) formulations (31.7%–54.2% and 15.2%–39.6%, respectively), potentially due to enhancement of partitioning into the lipid-rich stratum corneum by the oil dispersion system in the W/O sunscreen. For animals exposed to PFAS for 30 days, the absorption fraction of PFAS was similar between sunscreens and varied from 10.9% to 45%, depending on the PFAS (not on the formulation). In general, shorter chain PFAS were more highly absorbed than longer chain PFAS, and PFSAs were more highly absorbed than PFCAs with the same number of fluorinated carbons. The results of the ex vivo study were used to select the O/W and W/O formulations most favorable to dermal penetration of PFAS ("worst-case" formulations) for the subsequent in vivo study.

In the in vivo study, dermal penetration and absorption of the 13 PFAS were evaluated in male mice at time points up to 30 days using the laboratory formulations identified as "worst case" in the ex vivo study (O/W with high concentrations of chemical sunscreen, TiO2, and moisturizer, and W/O with high concentrations of chemical sunscreen and moisturizer) and two commercial sunscreens, one O/W and one W/O. After 30 days of exposure, the absorption fraction of the 13 PFAS ranged from 15.8% to 45.0% in the "worst case" O/W laboratory formulation, 14.9% to 29.4% in the commercial O/W sunscreen, 10.9% to 42.6% in the "worst case" W/O laboratory formulation, and 10.8% to 33.4% in the commercial W/O sunscreen. In contrast to the ex vivo results, the absorption fraction of short-chain PFAS in the laboratory-formulated sunscreens was 1.4%–8.6% higher in the W/O formulations, while long-chain PFAS were 0.8%–7.3% higher in the O/W group. These findings notwithstanding, in both the mice exposed to the "worst case" O/W and W/O laboratory formulations, short-chain PFAS were absorbed to a greater extent than long-chain PFAS (0.6–31% higher), and there was greater absorption of PFSAs than PFCAs with the same number of fluorinated carbons. PFAS levels in the dermis continued to increase throughout the 30-day exposure period, with the dermis identified as the likely main reservoir of PFAS in skin. This finding is consistent with Chen et al. (2022), who concluded that one or more layers of the skin may store PFAS after dermal exposure, with potential for its release over time into the bloodstream.

1.4.3.4 Effect of Ionization on Dermal Uptake

Franko et al. (2012) provided the clearest example of the effect of ionization on the dermal absorption of PFAAs from aqueous solution. Using PFOA and an in vitro protocol with human skin, they showed an approximately 1,000-fold difference between dermal uptake of the acidic (protonated) form and the ionized form of PFOA. In 24-h exposures to aqueous solutions of PFOA, experiments at pH 2.25, where PFOA would have existed as the protonated acid, the K_p was 5.5 x 10^{-2} cm/h. In solutions of aqueous buffer at pH 5.5, where PFOA would have existed as the anion, the K_p was 4.4 x 10^{-5} cm/h.

1.4.3.5 Estimates of K_p (cm/h)

The USEPA has recently identified or estimated certain chemical property parameters in support of calculating tap water Regional Screening Levels (RSLs) for select PFAS (USEPA 2025). RSLs are medium-specific and risk-based concentrations back-calculated from a target noncancer hazard quotient or a target cancer risk level, and they are intended to account for multiple routes of exposure specific to the medium. The tap water RSL includes exposure via the dermal pathway (for example, bathing). USEPA calculated K_p values for select PFAS using chemical-specific log octanol water partition coefficients (log Kow) and methodology presented in USEPA (2004) or USEPA (2017). K_p values are provided for a number of PFCAs and PFSAs and their salts, Gen X, and lithium bis [(trifluoromethyl)sulfonyl]azanide) (see **Table 1-9**). The USEPA (2025) also provided other parameters needed to estimate the dermally absorbed dose;

these include the lag time per dermal exposure event (t_{event}) and the time to reach steady state (t*). The tap water dermal parameters were used in combination with cancer slope factors (PFOA and salts) or noncancer reference doses (all other PFAS evaluated) to derive tap water dermal RSLs.

Table 1-9. K_p values for select PFAS (USEPA 2025).[1]

PFAS	K_p (cm/h)
Hexafluoropropylene oxide dimer acid (HFPO-DA—Gen X)	8.7 E-02
Lithium bis[(trifluoromethyl)sulfonyl]azanide	4.1 E-06
PFBS	1.9 E-05
PFBA	4.1 E-03
PFDA	6.0 E-01
PFDoDA	3.2 E+00
PFHxS	2.6 E-04
PFHxA	2.7 E-04
PFNA	2.0 E-04
PFODA	4.7 E+02
PFOS	4.7 E-07
PFOA	2.2 E-05
PFPrA	1.8 E-03
PFTetDA/PFTA	1.7 E+01
PFUDA	1.4 E+00

[1] All K_p values calculated by the USEPA (2025) were based on parameters in EPISuite (USEPA 2017) or on methods in "Risk Assessment Guidance for Superfund"(RAGs), Volume I, Human Health Evaluation Manual, Part E (USEPA 2004). Additional details of how the K_p values were derived are not provided in the RSL tables.

The ATSDR used their SHOWER model to estimate K_p values for 13 different PFAS (ATSDR 2024; Mellard 2024) (**Table 1-10**). For those PFAS evaluated by both the USEPA and the ATSDR, the majority of the USEPA's K_p values are greater than those of ATSDR, with some greater by 1 to 4 orders of magnitude. For PFOA, the K_p values are similar between the two agencies (2.2×10^{-5} and 8.74×10^{-5} cm/h, for the USEPA and ATSDR, respectively).

These PFOA K_p values are also similar to the experimentally determined PFOA (ionic form) K_p's of 5.8×10^{-5} and 4.4×10^{-5} cm/h determined by Franko et al. (2012). ATSDR's K_p values for PFAAs other than PFOA and for Gen X compounds are also generally similar in magnitude to the K_p determined experimentally by Franko et al. (2012) for ionized PFOA and indicate that dermal absorption of these PFAAs from aqueous solutions is not expected to be extensive given the low K_p values. Fasano et al. (2005) determined a K_p for PFOA of 9.5×10^{-7} cm/h. It is not clear why this K_p is lower than the results of Franko et al. (2012), as both were measured at similar pH.

The recently published experimental results of Ragnarsdottir et al. (2024) are not consistent with the experimental results of Fasano et al. (2005) or Franko et al. (2012), or the estimates of the USEPA (2025) or ATSDR (2024). For example, Ragnarsdottir et al. (2024) determined a PFOA K_p (cm/h) of 3.83×10^{-3}, which is approximately 100 times greater than these other sources. K_p values were also determined for seven other PFAAs; where K_p values were available for comparison, those determined by Ragnarsdottir et al. (2024) are also higher than those estimated by the USEPA or ATSDR. The reason(s) for the higher estimated dermal uptakes of Ragnarsdottir et al. (2024) is not known with certainty but may be attributable to the use of human skin equivalent as opposed to human skin; to the possibility that the

PFAAs were protonated (the pH was not reported), or to the use of methanol as a solvent for the PFAS. Although the effects of using methanol as a solvent are not known with certainty, it is possible that it solubilized skin lipids and allowed greater dermal penetration of PFAAs (Ragnarsdottir et al. 2024).

Table 1-10. PFAS K_p values determined by ATSDR for use in its SHOWER model v2.1(Mellard 2024).

Source: Table adapted from ATSDR Table 9. PFAS Parameter Values. Provided by D. Mellard, ATSDR.

PFAS	K_p (cm/h)	Source—See Notes
PFBA	2.95E-05	1
PFHxA	4.63E-05	1
PFHpA	6.23E-05	1
PFOA	8.74E-05	1
PFNA	1.26E-04	1
PFDA/PFDeA	1.73E-04	1
PFUA/PFUnA	2.41E-04	1
PFDoA	3.53E-04	1
PFBS/PFBuS	1.11E-04	2
PFHxS	1.11E-04	2
PFOS	1.11E-04	1
PFHxSA	NA	3
PFOSA	NA	3
MeFOSAA/Me-PFOSA-AcOH	NA	3
EtFOSAA/Et-PFOSA-AcOH	NA	3
HFPO-DA Ammonium Salt (GenX)	5.0E-05	4
HFPO-DA (GenX)	5.0E-05	5

[1] Theoretical K_p calculated using experimental log K_{ow} from Jing, Rodgers, and Amemiya (2009)
[2] Theoretical K_p for PFOS
[3] Compound does not have a K_p value in the SHOWER model v2.1
[4] Experimental K_p from RIVM (2016)
[5] Experimental K_p for HFPO-DA ammonium salt

1.4.3.6 Dermal Uptake of Neutral PFAS

As discussed, anionic PFAS molecules appear to have a low potential for dermal permeation. However, dermal uptake may be more extensive for neutral PFAS. Kissel et al. (2023, 2023) estimated the potential for dermal uptake of neutral PFAS based on partitioning from the gas phase to the skin. For 11 PFAS, this model-based exercise yielded dermal-to-inhalation ratios of sufficient magnitude to indicate that direct dermal absorption of neutral PFAS may contribute a greater proportion of exposure than for ionic PFAS. These PFAS include:

- N-Methylperfluorooctanesulfonamidoethanol (N-MeFOSE)
- N-Ethylperfluorohexanesulfonamidethanol (N-EtFOSE)
- N-Methylperfluorobutanesulfonamidoethanol (N-MeFBSE),
- N-Methylperfluorohexanesulfonamidoethanol (N-MeFHxSE)
- N-Ethylperfluorohexanesulfonamidoethanol (N-EtFHxSE)
- N-Ethylperfluorobutanesulfonamidoethanol (N-EtFBSE)
- PFAS with -diol and -amide functional groups

1.4.4 Health Effects of Ultra-short-chain PFAS

1.4.4.1 Introduction

Although definition(s) of ultra-short-chain (ultrashort) PFAS from government agencies or other authoritative organizations were not identified, ultrashort PFAS are generally considered to be PFAS with three or fewer carbon atoms (Ateia et al. 2019; CFPUA, undated; Neuwald et al. 2022; Liang, Steimling, and Chang 2023; Zheng et al. 2023). In general, shorter chain PFAS are equally persistent as their longer chain homologues, but they are more mobile in the environment and more difficult to remove from water (Ateia et al. 2019; Neuwald et al. 2022).

Examples of ultrashort PFAS include:

- perfluorocarboxylic acids (PFCAs): trifluoroacetic acid (TFA), and perfluoropropanoic acid (PFPrA), with two and three carbons, respectively
- perfluorosulfonic acids (PFSAs): trifluoromethanesulfonic acid (TFMS), perfluoroethane sulfonic acid (PFEtS), and perfluoropropane sulfonic acid (PFPrS), with one, two, and three carbons, respectively
- perfluoroether carboxylate: perfluoro-2-methoxyacetic acid (PFMOAA)
- 1,1,1-trifluoro-N-(trifluoromethyl)sulfonylmethanesulfonamide (TFSI) and its salt, lithium bis[(trifluoromethyl)sulfonyl]azanide (HQ-115), which have two carbons.

It should be noted that TFA is not considered to be a PFAS under some existing definitions of PFAS (for example, definitions that exclude compounds with only one fully fluorinated carbon) (see **Section 2.2**). For more examples and additional detail, see **Section 1.1.3.1**.

Of the ultrashort PFAS listed in **Table 1-2**, in **Section 1.1.3.1**, health effects information was identified for TFA (CASRN 76-05-1), PFPrA (CASRN 422-64-0), PFMOAA (CASRN 674-13-5), TFMS (CASRN 1493-13-6), and TFSI (CASRN 82113-65-3) and its lithium salt, HQ-115 (CASRN 90076-65-6), and this information is reviewed below. When information is available, a summary of the environmental occurrence of these PFAS is also provided; these occurrence summaries are not intended to be comprehensive.

Although ultrashort PFAS are highly persistent in the environment, as longer chain PFAS are, they are expected to be less bioaccumulative than longer chain PFAS, although this may not necessarily always be the case. Because the same dose of a less bioaccumulative PFAS results in a lower body burden (for example, blood serum level) than would a more bioaccumulative PFAS, doses that cause toxicity are expected to be higher for ultrashort PFAS than for longer chain PFAS, all other things being equal. Again, this cannot be assumed to be the case for all ultrashort PFAS. This is because the dose that causes toxicity depends on both a compound's toxicity when it is present at a certain concentration within the body, which may vary among PFAS independent of their chain length, and the concentration within the body after a certain external dose, which is expected to be lower for ultrashort PFAS than longer chain PFAS.

1.4.4.2 Trifluoroacetic Acid (TFA)

This section discusses relevant studies that were identified in the scientific literature or in publicly available secondary sources (for example, European Chemicals Agency (ECHA) and EFSA documents) as of October 2024. Information on the toxicokinetics and toxicity of TFA was reviewed by EFSA (2014), Umweltbundesamt (UBA) (2020), ECHA (2022), the National Institute for Public Health and the Environment in The Netherlands (RIVM) (2023), and Dekant and Dekant (2023). More recent ECHA documents (ECHA 2025; ECHA 2025) review additional biomonitoring, toxicokinetic, and toxicology studies that are not discussed below.

Occurrence

TFA has been detected in numerous environmental media, including surface water, groundwater, drinking water, wastewater, precipitation, the ocean, the atmosphere, sediments, vegetation, and aquatic biota, and concentrations in the environment appear to be increasing (reviewed by Garavagno et al. 2024; Arp et al. 2024; Albers and Sültenfuss 2024). In some studies, TFA was present in surface water or drinking water at higher concentrations than other PFAS. For example, in a study of Indiana residences, TFA was found in house dust in 84% of residences at ≥ 73 ng/g (median—220 ng/g; maximum—1,400 ng/g) and in tap water in 95% of residences at ≥ 27 ng/L (median—79 ng/L; maximum—210 ng/L) (Zheng et al. 2023). In this study, median TFA concentrations in drinking water were >1 to several orders of magnitude higher than any of the other ultra-short-, short-, and long-chain PFAS analyzed.

Biomonitoring

Kim et al. (2022) first reported detection of TFA in human urine samples. In a study of Indiana residents, TFA was found in the blood serum of 74% of the participants at ≥ 4.4 ng/L (median—6.0 ng/L; maximum—77 ng/mL) and in the urine of 31% of the participants at ≥ 3.5 ng/L (maximum—290 ng/mL) (Zheng et al. 2023). It was detected in the blood serum of 97% of subjects, at a median concentration of 8.46 ng/L, in a study of adults from a highly industrialized Chinese city (Duan et al. 2020).

Toxicokinetics

Information on the toxicokinetics of TFA is summarized in ECHA (2022). TFA is rapidly absorbed orally. It is also absorbed via inhalation, and it is predicted to be absorbed through the skin at noncorrosive/irritant concentrations based on its physical/chemical properties. It is not metabolized, and it is distributed throughout the body in the anionic form. Laboratory animal studies summarized by ECHA (2022) indicate that TFA crosses the placenta and is found in amniotic fluid. It is released into the small intestine in bile, after which it can be reabsorbed from the gastrointestinal tract and undergo enterohepatic circulation, and it is also excreted in urine. The half-life in rabbits after intravenous administration was 34.4 hours and was reduced to 15.6 hours when enterohepatic circulation was eliminated via a bile fistula (EFSA 2014).

Zheng et al. (2023) estimated the human half-life of TFA as 12 days based on urinary clearance determined from paired urine-serum measurements and the assumptions that urine is the only route of excretion and that the volume of distribution of TFA is the same as for PFBA. TFA is a metabolite of the anesthetic halothane, and the half-life of TFA in children after administration of halothane was estimated as 42 hours (approximately 2 days; Wark et al. 1990) from the change in daily urinary TFA excretion over time after halothane was administered. It is not known whether the difference in these two half-life estimates is age-related or due to differences in the way each half-life was determined.

Human Epidemiology Studies

No human epidemiology studies specific to TFA were identified by ECHA (2022) or in a PubMed literature review.

Laboratory Animal Toxicology Studies

The toxicological information for TFA and its salt, sodium trifluoroacetate, reviewed below, includes acute oral and inhalation studies in rats, a subchronic dietary (oral) study in rats, a subchronic inhalation study in rats and guinea pigs, a chronic (one year) drinking water study (oral) in rats, a one-generation dietary (oral) reproductive/developmental study in rats, oral (gavage) developmental toxicity studies in rats and rabbits, and several in vitro genotoxicity assays. Additional studies are reviewed in ECHA (2025a,b). No studies of the potential carcinogenic effects of TFA are available. TFA dissociates to its anionic form in

the body, and the salt form, sodium trifluoroacetate, was tested instead of TFA in some studies in order to avoid potential irritating/corrosive effects resulting from the very low pH of TFA.

Oral Toxicity

ECHA (2022) reported that the oral acute median lethal dose (LD_{50}) of TFA in rats is between 500 and 1,000 mg/kg and that acute effects of oral exposure included hemorrhage and necrosis of the mucous membranes of the stomach. In contrast, oral administration of a dose of 7,000 mg/kg of the neutralized acid (the salt form) did not cause mortality or tissue damage, indicating that the toxicity of the acid form results from its corrosive properties.

In a subchronic (90-day) rat study described by ECHA (2022), identified as Bayer CropScience (2007) in ECHA (2025), sodium trifluoroacetate was administered in the diet at 0, 160, 1,600 and 16,000 ppm (0, 8.4, 82.3, 876 mg/kg/day in males; 10.1, 103.3, 1,021 mg/kg/day in females). Absolute and relative liver weight were increased in both sexes at the mid- and high doses. Histopathological changes in the liver at the mid-dose, or high-dose group, or both groups, included hepatocellular hypertrophy and loss of periportal hepatocellular vacuolation in both sexes, and an increased incidence of hepatocellular necrotic foci in high-dose males. Other effects included decreased body weight at the highest dose in both sexes, hematologic changes (decreased hemoglobin, mean corpuscular volume, and hematocrit) in mid-dose or high-dose females, or both groups of females, increased serum levels of liver enzymes in mid- and high-dose males, and decreased serum levels of total bilirubin and glucose and increased urinary ketones in both sexes at the mid- and high doses. The low dose (160 ppm, corresponding to 8.4 mg/kg/day in males and 10.1 mg/kg/day in females) was identified as the no observed adverse effect level (NOAEL). Based on results of this study and other toxicological data, RIVM (2023) concluded that TFA is 2,000-fold less potent than PFOA in male rats in regard to increased relative liver weight after subchronic exposure.

UBA (2020) and RIVM (2023) provided information on a study, identified as WuXi AppTech (2019) in ECHA (2025), in which TFA was administered to rats in drinking water at concentrations of 0, 30, 120, and 600 ppm (corresponding to 0, 1.8, 7.6, and 37.8 mg/kg/day) for up to one year; the full study report does not appear to be available online. The histopathological changes in the liver (hepatocellular hypertrophy and necrotic foci) reported at doses of approximately 100 and 1,000 mg/kg/day in the 90-day dietary rat study described above were not observed at the lower doses (up to 37.8 mg/kg/day) administered in the one-year drinking water study. In the one-year study, serum alanine aminotransferase (ALT), an enzyme that is an indicator of liver damage, was not increased at an interim timepoint of 90 days of exposure to TFA, but it was significantly increased by severalfold after one year of exposure to drinking water containing 120 and 600 ppm (7.6 and 37.8 mg/kg/day), with a greater increase at 120 ppm than 600 ppm. ALT returned to control levels 6 weeks after the one-year exposure period ended, indicating that liver damage caused by TFA in this study may be reversible (UBA 2020). UBA (2020) also presented data from other shorter duration studies of TFA in drinking water in which ALT levels were elevated after exposure to concentrations greater than 600 ppm. UBA (2020) reported that Solvay Hannover, the sponsor of the one-year drinking water study, concluded that the NOAEL in this study was 600 ppm (corresponding to 37.8 mg/kg body weight in males), which was the highest dose in the study. However, UBA (2020) concluded that the NOAEL in this study was 30 ppm in drinking water, corresponding to 1.8 mg/kg/day, based on increased ALT at the higher doses.

ECHA (2022) reported on a one-generation reproductive/developmental study in rats, identified as Labcorp Laboratories (2021) in ECHA (2025), in which sodium trifluoroacetate was administered in the diet at concentrations of 0, 120, 600 or 3,000 ppm, corresponding to 0, 10, 50, and 250 mg/kg/day, for 10 weeks during premating (males and females), gestation, and lactation. Because food consumption is higher during lactation, dietary concentrations were decreased to 0, 60, 300 and 1,500 ppm in lactating females. These lower concentrations were also administered to offspring from weaning at postnatal day 21 until postnatal day 35, and offspring were then dosed with the original concentrations (0, 120, 600, and 3,000 ppm) until sacrifice at age 13 or 14 weeks.

In addition to reproductive and developmental parameters, systemic effects (for example, organ weights, histopathology, clinical chemistry, urinalysis) were evaluated in the parental (F0) and offspring (F1) generations, and several statistically significant effects, primarily at the higher dose levels, that are not directly related to reproduction or development, were reported in the F0, F1, or both F0 and F1 animals. Increased relative liver weight, an effect common to many PFAS (see **Section 17.2**), occurred at the two highest doses in both sexes of the parental (F0) and offspring (F1) generations but was not considered adverse because no histopathological changes in the liver were observed. Kidney weights were increased in both sexes in the parental generation, and plasma sodium and potassium levels were increased in males and females, respectively, in both the parental generation and the offspring. These renal effects were considered "non-adverse within the context of this [developmental] study," because there were no effects on kidney weight in the offspring, urinary parameters in the parental generation, or renal histopathological changes in either generation. Testes weight was decreased in male offspring, but changes in sperm parameters were not consistently observed. TFA also caused histopathological changes, described as minimal to slight, in the glandular stomachs of parental (F0) and offspring (F1) females, but the study authors did not consider these effects adverse because food consumption and body weight were unaffected. Clinical chemistry changes, primarily at the two higher doses, in one or both sexes in the F0 and F1 generations included decreased levels of glucose, free fatty acids, triglycerides, and bilirubin in the plasma. Hematologic changes, although not noted in the study summary, were reported in both the parental and offspring generations. Decreased levels of serum thyroxine (T4) occurred in both sexes in both the parental generation and offspring, but this change was not considered adverse because it was not associated with effects on reproductive and developmental parameters that depend on normal thyroid function.

The study authors stated that no adverse effects were observed on "general condition, body weight or food consumption, reproductive performance, fertility or offspring development/sexual maturation." It was concluded that the NOAEL for reproductive, developmental, and general systemic toxicity in this study was 3,000/1,500 ppm (dose decreased during lactation), corresponding to approximately 203–222 mg/kg/day, which was the highest dose used.

ECHA (2022) also reported on a developmental toxicology study, identified as Huntingdon Life Sciences (2010) in ECHA (2025), in which pregnant rats were dosed by oral gavage with 0, 37.5, 75, or 150 mg/kg/day on gestation days 6–19 and sacrificed on gestation day 20. Soft tissue abnormalities were evaluated in half of the fetuses, and skeletal abnormalities and ossification state were evaluated in the other half. There were no effects at any dose on maternal mortality, body weight/body weight gain, food consumption, reproductive parameters (pregnancy rate, number of aborted fetuses, pre- and postimplantation loss, number of resorptions, number of dead fetuses, pregnancy duration, number of live offspring, fetal weight, sex ratio, litter size or weight, weight of the placenta and uterus) or fetal abnormalities, variations, or ossification parameters. TFA caused increased maternal liver and kidney weight, but the study authors did not consider these effects adverse. The NOAEL was identified as 150 mg/kg/day, the highest dose used.

An additional rat study, Saillenfait et al. (1997), evaluated hepatic and renal effects of TFA in dams and offspring after maternal exposure to 75 or 150 mg/kg/day via oral gavage on gestation days 10–20. There were no effects on duration of gestation, litter size, or offspring survival to postnatal day 3. Maternal absolute and relative liver weights were increased at both doses at the end of gestation, while there were no effects on liver weight in the offspring at age 7 weeks. Serum levels of glutamate dehydrogenase (GDH) and aspartate aminotransferase (AST), enzymes indicative of liver damage, and urea were elevated at postnatal day 3, but not at postnatal days 12 or 49 (age 7 weeks). Kidney weight was not affected in dams or offspring, but urinary levels of beta-2-microglobulin, an indicator of damage to the renal tubules, were elevated in offspring at 150 mg/kg/day on postnatal day 3 and 75 mg/kg/day at age 7 weeks.

In addition to the rat studies discussed above, ECHA (2022) reported on a developmental toxicity study, identified as Covance Laboratories (2021) in ECHA (2025), in which pregnant rabbits were dosed by oral gavage with 0, 180, 375, or 750 mg/kg/day sodium trifluoroacetate from gestation days 6–28 and sacrificed on gestation day 29. Maternal effects included decreased body weight gain, adjusted for the weight of the gravid uterus, by 20, 48 and 56% compared to control at 180, 375, and 750 mg/kg/day, respectively; the decreases at the two higher doses were statistically significant. Food consumption was decreased until the middle of the study (gestation days 14, 15, or 16) and increased at the end of the study (gestation days 26–28) in the dosed groups. Hepatic effects (increased relative liver weight, hepatocellular hypertrophy, and bile duct hyperplasia/fibrosis) occurred in a dose-related manner in all treated groups.

Mean weights of the fetus and total litters were significantly reduced at 375 and 750 mg/kg/day in a dose-related manner. In contrast to the developmental studies in rats described above, there was an increased incidence of major abnormalities in the fetuses, predominantly in the eyes, including multiple folded retinas and absent aqueous/vitreous humor, at the two higher doses compared to both concurrent and historical controls. At the low dose, microphthalmia with multiple folded retinas and absent aqueous/vitreous humor occurred in one fetus. ECHA (2022) stated that although this occurrence was within the historical control range, "a relationship to treatment could not be completely ruled out." Based on these data, the NOAEL for maternal toxicity was identified as 180 mg/kg/day, and the NOAEL for developmental toxicity was identified as <180 mg/kg/day (that is, below the lowest dose tested), indicating that developmental toxicity occurs at doses below those that cause maternal toxicity.

Inhalation Toxicity

Studies of acute inhalation toxicity of TFA in rats are reviewed in ECHA (2022). In a preliminary study in which rats were exposed to TFA concentrations of 0, 30, or 300 mg/m^3 for 4 hours, indicators of inflammation (alkaline phosphatase levels and the number of neutrophils) were increased in bronchioalveolar lavage fluid at 300 mg/m^3, and males were more sensitive than females. In the main study, male rats were exposed to 0, 30, 100, and 300 mg/m^3 for 4 hours. The only effect observed was very slight focal degeneration of the epithelium of the dorsal part of the nasal septum, indicative of local irritation, in high-dose rats sacrificed one day after exposure ended. This effect did not occur in animals sacrificed 14 days after exposure ended, indicating that it was reversible. There were no effects on body weight, bronchioalveolar lavage parameters, or histopathology of other parts of the respiratory tract or other organs in the main study.

ECHA (2022) described a subchronic inhalation study in which rats and guinea pigs "were exposed to a mixture of vapors and aerosols" of TFA at concentrations "between 0.025 and 0.05 mg/L or 0.4 and 0.7 mg/L." The animals were exposed for 4 hours per day, 6 days per week for four (guinea pigs) or five (rats) months. ECHA (2022) stated that detailed information on the study design was not available, and that TFA caused severe respiratory and ocular irritation, effects in the liver and kidney, and decreased body weight; a NOAEL was not identified. While ECHA (2022) did not provide a citation for the study, it was later described and identified as Institute of Work Health and Safety of the USSR (1964) in ECHA (2025).

In Vitro Genotoxicity

In vitro genotoxicity assays of sodium trifluoroacetate were negative, and no in vivo genotoxicity data are available (ECHA 2022). Specifically, sodium trifluoroacetate was negative in the bacterial reverse mutation assay in five strains of *Salmonella typhimurium* both with and without metabolic activation; the chromosome aberration assay in human primary lymphocyte cultures; and the mammalian cell gene mutation assay in mouse lymphoma L5178Y cells.

1.4.4.3 Perfluoropropanoic Acid (PFPrA)

Occurrence

PFPrA has been detected in surface water and groundwater. For example, it was detected in surface and ground water used as drinking water sources in Germany (median—12.6 ng/L, maximum 180 ng/L; Neuwald et al. 2022), and is stated to have been found in surface and groundwater in the vicinity of manufacturing facilities by USEPA (2023). It has been reported in drinking water in several studies. For example, it was the most frequently detected PFAS among the 70 PFAS analyzed in a study by Pelch, McKnoght, and Reade (2023) of 44 tap water samples from locations known or suspected to be contaminated with PFAS in 16 U.S. states. In this study, PFPrA was detected at concentrations of 2.5–140 ng/L in 24 of the 30 samples in which any PFAS was detected (Pelch, McKnoght, and Reade (2023)). PFPrA was also found in house dust (median—26 ng/g; maximum—200 ng/g) and tap water (median—6.9 ng/L; maximum—19 ng/L) in Indiana residences (Zheng et al. 2023).

Biomonitoring

PFPrA has been detected in blood serum, urine, and semen in individuals from the general population. It was found in the blood serum (median—1.0 ng/mL; maximum—2.9 ng/mL) and urine (median—0.051 ng/mL, maximum—6.8 ng/mL) in a study of residents of Indiana (Zheng et al. 2023), as well as in blood serum in three studies of Chinese populations (median values: 0.48 ng/mL, Duan et al. 2020; 0.16 ng/mL, Li et al. 2017; 0.62 ng/mL, Song et al. 2018). Song et al. (2018) also detected it in semen (median value—0.95 ng/mL).

Toxicokinetics

The human half-life of PFPrA was estimated as 88 days, based on urinary clearance determined from paired urine-serum measurements. These estimates were based on the assumptions that urine is the only route of excretion and that the volume of distribution of PFPrA is the same as for PFBA (Zheng et al. 2023). No other toxicokinetic data were identified.

Human Epidemiology Studies

USEPA (2023) identified three studies (Duan et al., 2020; Song et al. 2018; Li et al. 2017) that examined associations of health effects with PFPrA blood concentrations in humans. Each of these was a cross-sectional study from the general population in China. As reviewed by USEPA (2023), these studies did not demonstrate statistically significant associations with the health endpoints evaluated (glycemic indicators, thyroid hormones, semen parameters) after adjustment for potential confounding factors and or had limitations in their design or reporting.

Laboratory Animal Toxicology Studies

USEPA (2023) summarized information on laboratory animal toxicology studies of PFPrA. USEPA (2023) discussed two oral studies of PFPrA in rats—a 14-day range-finding study and a 28-day study.

No acute, chronic, or reproductive/developmental studies by any exposure route or repeated dose inhalation studies were discussed by USEPA (2023) or identified in a PubMed literature search.

In the oral 14-day range-finding study, rats were dosed with 0, 50, 250, or 1,000 mg/kg-day PFPrA. USEPA (2023) stated that information provided about this study is limited (for example, no information on number and sex of the animals, methods of endpoint evaluation, or quantitative dose-response data). USEPA (2023) reported that effects included changes in hematologic parameters and organ weights in all dose groups. Clinical chemistry abnormalities and necropsy findings were in the mid- and high-dose

groups, and clinical signs of toxicity, changes in body weights, and histopathology were observed in the high-dose group.

In the 28-day study, male and female rats (6 per dose level per sex) were dosed by oral gavage with 0, 5, 20, 80, or 320 mg/kg-day PFPrA. The study included control and high-dose animals recovery groups that were sacrificed 14 days after dosing ended. Body weight and food intake were not affected by exposure to PFPrA. Like other PFAS (**Section 17.2**), PFPrA caused hepatic toxicity. Male rats were more sensitive to these effects than females. However, because no toxicokinetic data are available, it is unknown whether this sex difference is due to more rapid excretion in male rats than female rats such as occurs for several other perfluoroalkyl acids (**Section 17.2**). Absolute and relative liver weight were increased in a dose-related manner at 20, 80, and 320 mg/kg/day in males, with statistically significant increases in relative liver weight at the two highest doses; this effect persisted in high-dose animals throughout the recovery period. Smaller increases in relative liver weight that were not statistically significant occurred in females. Histopathological changes in the livers of males included a dose-related increase in the incidence of hepatocellular hypertrophy, as well as slight focal necrosis in 1 of 6 animals in each of the two highest dose groups (80 and 320 mg/kg/day). These effects were not observed in the high-dose group after the recovery period. Serum levels of alanine aminotransferase (ALT) and alkaline phosphatase (ALP), markers of liver damage, were increased in a dose-related manner in males, with statistically significant increases in the higher dose groups (80 ng/kg/day and 320 ng/kg/day). Other effects, some of which did not occur in a dose-related manner, included decreased total bilirubin in males at all doses and in females at the two highest doses, increased relative kidney weight in both sexes, and decreased total cholesterol in males.

Genotoxicity Studies

In vitro genotoxicity assays of PFPrA were negative, and no in vivo genotoxicity studies were reported (USEPA 2023). Specifically, PFPrA was negative for mutagenicity in the bacterial reverse mutation assay (Ames test) in four strains of *Salmonella typhimurium* and in *E. coli,* both with and without metabolic activation. It was also negative in the chromosomal aberration assay in Chinese hamster lung fibroblasts, both with and without metabolic activation.

1.4.4.4 Perfluoro-2-methoxyacetic Acid (PFMOAA)

Occurrence

PFMOAA has been detected at high concentrations (~10,000 ng/L) in the United States in finished drinking water whose source is a river impacted by discharge from an industrial facility (McCord et al. 2018) and in private wells near this industrial facility at up to >200 ng/L (Kotlarz et al. 2024). It has also been found in coastal waters and aquatic species downstream of a Chinese industrial source (Li et al. 2023).

Biomonitoring

In a study of individuals living near a Chinese fluorochemical plant, PFMOAA was detected in the blood serum of all 977 subjects with a median concentration of 12.9 ng/mL and a maximum concentration of 158.2 ng/mL (Yao et al. 2023). PFMOAA was also detected in the blood serum of all subjects in a study of 294 children, age 7–10, from Yiwu, China. The median concentration was 0.29 ng/mL and the range was 0.01–53.6 ng/mL (Xu et al. 2025),

PFMOAA was also detected in the breast milk in 95.5% of 1,099 women from locations throughout China at a median concentration of 3.4 ng/L and a maximum of 1,086 ng/L (Yao et al. 2023). PFMOAA was measured in cord blood and neonatal (first postnatal week) urine in a subset of 80 mother-child pairs in this study. It was detected in 98.8% of cord blood samples with a median of 122.5 ng/L (0.12 ng/mL) and

a maximum of 4,628 ng/L (4.6 ng/mL) and in 100% of neonatal urine samples with a median of 35.3 ng/L and a maximum of 2,784 ng/L.

Toxicokinetics

Yao et al. (2023) estimated the half-life of PFMOAA in infants to be 0.221 years (80.7 days) based on urinary clearance determined from the paired urine-cord blood measurements mentioned above. This half-life estimate assumed that urine is the only route of excretion and that the volume of distribution of PFMOAA in human infants is the same as for perfluoro(3,5,7-trioxaoctanoic) acid PFO3OA in mice, based on its structural similarity to PFMOAA.

In a developmental toxicity study in rats in which PFMOAA (10–450 mg/kg/day) was administered to dams from gestation day 8 to postnatal day 2, PFMOAA concentrations in serum and liver increased linearly with dose, with concentrations in serum approximately 3 times higher than in liver (Conley et al. 2024).

Human Epidemiology Studies

In a study of 977 individuals residing near a Chinese fluorochemical facility, all of whom had measurable concentrations of serum PFMOAA, serum PFMOAA was significantly associated with decreased serum glucose but not with other biochemical parameters, including serum lipids and liver enzymes (Yao et al. 2020).

In a study (Xu et al. 2025) of 294 Chinese children 7–10 years of age, all with measurable concentrations of serum PFMOAA, serum PFMOAA was significantly associated with serum levels of high-density lipoprotein but not with serum levels of other lipid parameters, including total cholesterol, triglycerides, low-density lipoprotein, and apolipoproteins A1 and B. In statistical analysis of the association of exposure to mixtures of serum PFAS and serum lipid parameters using Weighted Quantile Sum regression, PFMOAA had the most influence on serum levels of high-density lipoprotein of the 14 PFAS evaluated in the study (Xu et al. 2025).

Laboratory Animal Toxicology Studies

No acute, subchronic, or chronic oral or inhalation studies of PFMOAA in laboratory animals were identified.

Developmental effects of PFMOAA in rats were evaluated in a study in which dams were administered 0, 10, 30, 62.5, 125, or 450 mg/kg/day by oral gavage from gestational day 8 to postnatal day 2. Birth weight was decreased at doses $\geq$30 mg/kg/day (Conley et al. 2024). In pups sacrificed at birth, liver glycogen was depleted at all doses, hypoglycemia occurred at the two highest doses, and there were changes in expression of genes involved with fatty acid and glucose metabolism. On postnatal day 2, pup survival was decreased at the two highest doses. At this timepoint, effects observed at all doses in both dams and pups included increased liver weight, increased serum levels of the liver enzyme AST, and decreased levels of thyroid hormones. Additionally, serum cholesterol was markedly elevated in the pups.

The potential for PFMOAA (0, 0.00025, 0.025, and 2.5 mg/kg/day) to cause toxicity to the immune system was evaluated in a 30-day oral gavage study in male and female mice (Woodlief et al. 2021); these doses are much lower than those in the rat developmental toxicity study (Conley et al. 2024) discussed above. In this study, PFMOAA did not affect body weight; absolute liver, spleen, or thymus weight; thymus or splenic cellularity; subpopulations of thymus T cells or spleen cells; or hepatic activity of a marker for peroxisome proliferation. Relative liver weight was increased by 7% in high-dose females, but this change was not statistically significant.

PFMOAA, at concentrations up to 80 micromolar (approximately 16 mg/L) did not cause developmental toxicity or suppress the respiratory burst (a component of immune function in which neutrophils and macrophages rapidly produce reactive oxygen species) in larval zebrafish (Phelps et al. 2023).

Other Studies

PFMOAA, at concentrations up to 80 micromolar, did not suppress the respiratory burst in cultured human nHL-60 neutrophil-like cells (Phelps et al. 2023).

1.4.4.5 1,1,1-Trifluoro-N- (trifluoromethanesulfonyl)methanesulfonamide (TFSI) and Lithium bis[(trifluoromethyl)sulfonyl]azanide (HQ-115)

The information below comes from the USEPA (2023) Office of Research and Development (ORD) Human Health Toxicity Value for lithium bis[(trifluoromethyl)sulfonyl]azanide (HQ-115) and the ECHA (2020) Registration Dossier for Lithium bis(trifluoromethylsulfonyl)imide (90076-65-6) (Note: The latter is another synonym for HQ-115). Health effects information on HQ-115 (the lithium salt of TFSI) is also applicable to TFSI, since HQ-115 completely dissociates to TFSI in the human body (USEPA 2023).

Occurrence

USEPA (2023) stated that TFSI or HQ-115 has been detected in surface water and wastewater near manufacturing facilities.

Biomonitoring

No information on biomonitoring is reported in USEPA (2023) or ECHA (2020).

Toxicokinetics

No information on toxicokinetics (absorption, distribution, metabolism, excretion) is reported in USEPA (2023) or ECHA (2020).

Human Epidemiology Studies

No information on human epidemiology studies is reported in USEPA (2023) or ECHA (2020).

Laboratory Animal Toxicology Studies

No inhalation toxicology studies of TFSI or HQ-115 were identified. Dermal and oral toxicity studies are reviewed below.

Dermal Toxicity

In a study using male and female rabbits and doses of 200, 350, 500, or 2,000 mg/kg and an observation period of 2 weeks, the dermal LD_{50} of HQ-115 in rabbits was estimated as 371 mg/kg in males and 418 mg/kg in females, suggesting that dermal absorption occurred. In contrast, in a rat study using a dose of 2,000 mg/kg and an observation period of 2 weeks, the dermal LD_{50} of HQ-115 was estimated as >2,000 mg/kg (USEPA 2023; ECHA 2020).

Oral Toxicity

Three acute oral rat studies of HQ-115 are summarized in USEPA (2023). In a study using doses of 50, 500, or 5,000 mg/kg and an observation period of 2 weeks, the LD_{50} was estimated as 160 mg/kg in

males and 210 mg/kg in females. In a study of male and female rats using doses of 25 or 200 mg/kg HQ-115 and an observation period of 2 weeks, mortality occurred at 200 mg/kg and the oral LD_{50} was estimated at >200 mg/kg. In a third study of female rats using a dose of 200 mg/kg of HQ-115, the LD_{50} was estimated as >200 mg/kg (USEPA, 2023; ECHA 2020).

A 7-day oral gavage study of HQ-115 in male and female rats (Huntingdon Research Center, 1992; summarized by USEPA 2023) used doses of 0, 10, 20, 50, or 100 mg/kg/day. Rats dosed with 100 mg/kg/day were sacrificed after the second dose due to severe clinical signs of toxicity, including piloerection, hunched posture, abnormal gait, pallor in the extremities, tremors, lethargy, and loose feces. Less severe clinical signs were also reported at 50 mg/kg/day. Other reported effects included reduced food consumption in females at ≥ 50 and males at 100 mg/kg/day, reduced body weight gain in both sexes at 100 mg/kg/day, and increased absolute liver weight (14%–16% in males; 8%–19% in females) at ≥ 30 mg/kg/day.

Two studies in which HQ-115 was administered to male and female rats by oral gavage for 4 weeks (28 or 29 days) are discussed by USEPA (2023) and summarized below.

In a study conducted by Huntingdon Research Center (1993), male and female rats were dosed with 0, 1.67, 10, or 60 mg/kg/day HQ-115 by oral gavage for 28 days, and with additional control and high-dose (60 mg/kg/day) recovery groups maintained for 14 days after the dosing period ended. Reported effects included decreased body weight gain in females dosed with 60 mg/kg/day and clinical signs of toxicity at 10 and 60 mg/kg/day in both sexes. Increased relative liver weight and hepatocellular hypertrophy occurred in both sexes at the high dose (60 mg/kg/day), and the liver was enlarged in one high-dose male at the end of the recovery period. Hepatic extramedullary hematopoiesis, which may indicate hepatic toxicity, occurred at lower doses in both sexes and in high-dose females at the end of the recovery period. Serum alkaline phosphatase (ALP), stated by USEPA (2023) to be a marker of hepatobiliary damage, was significantly elevated at the high dose (60 mg/kg/day) in males and at all doses, although not significantly, in females. Additionally, a dose-dependent increase in the serum albumin/globulin ratio, which may result from liver or kidney toxicity, occurred at all doses in both sexes. Serum cholesterol was decreased at the highest dose in males and at all doses in females, and serum triglycerides were also decreased in high-dose males. Absolute or relative kidney weight, or both were increased at the high dose in both sexes; other effects related to renal function included increased blood urea nitrogen and increased urine volume in high-dose males and decreased urinary pH at mid- and high doses in both sexes. Several other effects in dosed groups, not detailed herein, were considered sporadic or of unclear biological significance (USEPA 2023).

In a study conducted by a chemical registrant and reported in ECHA (2020), male and female rats were dosed with 0, 15, 45, or 90 mg/kg/day HQ-115 by oral gavage for 29 days. The study included control and high-dose recovery groups maintained for 14 days after dosing ended. In this study, body weight gain was decreased in mid-dose males and females and high-dose males, while body weight gain and food consumption were increased in high-dose females. Clinical signs of toxicity were reported in both sexes at the mid- and high doses. Increased absolute and relative liver weight, as well as hepatocellular hypertrophy, occurred in mid- and high-dose males and high-dose females. Increased liver weight did not persist in the high-dose recovery groups, and hepatocellular hypertrophy data were not reported. In the high-dose groups, serum alanine aminotransferase, albumin, and albumin/globulin ratio were increased in both sexes, and alkaline phosphatase was increased in males. There was a dose-related decrease in serum cholesterol and triglycerides at all doses in both sexes. Other effects included increased white blood cells at the mid- and high doses and relatively small decreases in red blood cell parameters in both sexes at all doses, changes in the thyroid in high-dose females, and the presence of foamy alveolar macrophages at the high dose in both sexes (USEPA 2023).

Finally, ECHA (2020) described a one-generation rat reproduction/developmental toxicity study of HQ-115 conducted by a chemical registrant. Males were dosed with 0, 15, 30, or 60 mg/kg/day for 2 weeks prior

to mating and up to 2 weeks during mating; females were dosed at the same levels for 2 weeks prior to mating, during mating, and during and after gestation through lactational day 4. Mortality occurred in parental males and females at both 30 and 60 mg/kg/day, and no females in the high (60 mg/kg/day) dose survived until the end of the study. Body weight or body weight gain was decreased in parental males at some time points at 60 mg/kg/day and at 15 and 30 mg/kg/day during lactation in parental females. Clinical signs of toxicity occurred at 60 mg/kg/day in both sexes and in one male at 30 mg/kg/day. Reproductive effects were reported in females at doses at which systemic toxicity occurred, including a lower number of pregnancies at 30 and 60 mg/kg/day and increased postimplantation loss and, changes in indicators of estrus cyclicity at 60 mg/kg/day. Only a few females in the high-dose (60 mg/kg/day) group delivered. There was a dose-dependent increase in the percent of offspring that died by postnatal day 4 in all dose groups, with no pups in the 60 mg/kg/day group surviving. There were also dose-dependent decreases in offspring body weight/body weight gain on postnatal days 1 and 5 and increases in the number of litters with pups with no milk in the stomach in all dose groups.

In Vitro Genotoxicity Studies

Eight reports on genotoxicity studies of HQ-115 are reviewed in USEPA (2023). Four reports included results of mutagenicity assays in *Salmonella typhimurium* and *E. coli* with and without metabolic activation, all of which were negative. A mutagenicity study in mouse lymphoma L5178Y cells and two chromosomal aberration studies in human lymphocytes, with and without metabolic activation, were also negative. In a chromosomal aberration study in Chinese hamster lung fibroblasts, the proportion of cells with chromosome aberrations was increased both with and without metabolic activation, with the doses causing this effect varying with the time period of exposure. Additionally, in cells exposed for 48 hours (the longest exposure duration in the study) without metabolic activation, the proportion of polyploidy cells was increased at the highest concentration tested.

1.4.4.6 Trifluoromethanesulfonic Acid (TFMS)

Unless otherwise noted, the information below comes from ECHA (2021).

Occurrence

In aqueous samples from several European nations, TFMS was detected in urban effluent at approximately 10–100 ng/L, surface water at approximately 1 to > 1,000 ng/L, groundwater at approximately 1–100 ng/L, and drinking water at <1 to approximately 1,000 ng/L (Zahn et al. 2016).

Biomonitoring

No biomonitoring data for TFMS were identified.

Toxicokinetics

No studies of the toxicokinetics of TFMS were identified. Systemic toxicological effects (for example, in the liver, kidney, and spleen) after oral exposure to TFMS indicate that oral absorption occurs (ECHA 2021). Based on its perfluorinated chemical structure, it is not expected to be metabolized (ECHA 2021). ECHA 2021 also concludes that TFMS is expected to be excreted in the urine and that it has no bioaccumulation potential.

Human Epidemiology Studies

No epidemiology studies of TFMS were identified.

Laboratory Animal Toxicology Studies

Dermal and oral toxicity studies are reviewed below.

Dermal Toxicity

In an acute dermal toxicity study in rats, application of 50 mg/kg TFMS to shaved skin did not cause mortality, but 2,000 mg/kg caused severe local effects (for example, ulceration) necessitating humane sacrifice of the test animals. The dermal LD50 was not determined (ECHA 2021).

In a dermal irritation study, TFMS (0.5 ml undiluted compound) was applied to the shaved skin of a rabbit at three sites with exposure times of 3 minutes, 1 hour, or 4 hours, and skin irritation was assessed at time points up to 7 days after exposure ended. TFMS caused irritation (erythema and edema), and necrosis was present 7 days after exposure ended for all three exposure periods (ECHA 2021).

TFMS was negative for skin sensitization in a study performed in guinea pigs (ECHA 2021).

Oral Toxicity

As noted above, the information in this section comes from ECHA (2021), unless otherwise noted. The acute toxicity of TFMS was evaluated in male rats (10 per dose group) dosed with 0, 539, 700, 910, 1,183, 1,538, and 2,000 mg/kg via oral gavage and observed for 14 days; these doses were selected based on a preliminary study in which mortality occurred at 2,000 mg/kg but not at 500 mg/kg. There was no mortality at $\leq$ 910 mg/kg, and mortality occurred in 1/10, 6/10, and 7/10 animals at 1,183, 1,538, and 2,000 mg/kg, respectively. The LD_{50} was determined to be 1,605 mg/kg. Clinical signs such as decreased spontaneous movement and sedation were observed, with more effects at higher doses, and weight gain was decreased at $\geq$ 1,183 mg/kg. Gross and microscopic pathology examination revealed damage to the stomach and small intestine, as well as other organs, including liver, spleen, and thymus.

The repeated dose toxicity of TFMS was evaluated in male and female rats (6 per dose group) dosed via oral gavage with 0, 8, 40, 200, and 1,000 mg/kg/day for 28 days, and additional control (0 mg/kg/day) and high dose (1,000 mg/kg/day) were evaluated at the end of a 14-day recovery period. TFMS did not cause mortality or affect body weight or food consumption. TFMS at 1,000 mg/kg/day caused slight, non-statistically significant decreases in hematologic parameters related to red blood cells (decreased hemoglobin, hematocrit, mean corpuscular volume, and mean corpuscular hemoglobin) in males; only the decrease in mean corpuscular hemoglobin persisted through the recovery period. In females dosed with 1,000 mg/kg/day, platelet count was increased, and this effect did not persist through the recovery period. In females dosed with 1,000 mg/kg/day, serum levels of protein were reduced and urea nitrogen and creatinine were increased, and these changes did not persist through recovery. In males dosed with 200 mg/kg/day, serum cholinesterase was increased, and there were several clinical chemistry changes, including increased total cholesterol and triglycerides in the high-dose (1,000 mg/kg/day) group at the end of the recovery period. In females dosed with 1,000 mg/kg/day, urinary ketone bodies and glucose levels were increased, and these effects did not persist through recovery. No effects on organ weight were observed in males or females.

Effects in the forestomach (boundary ridge protrusion) and glandular stomach mucosa (reddening in males; roughening and blackening in females) were observed at necropsy at 1,000 mg/kg/day. Histopathological changes included squamous epithelium hyperplasia in the forestomach in males at 200 mg/kg/day and both sexes at 1,000 mg/kg/day. Reduction in glandular stomach parietal cells, surface epithelial cell hyperplasia, submucosal bleeding, and loss of villi in the duodenum were observed in both sexes at 1,000 mg/kg/day; and necrosis of the duodenal mucosa, renal tubular necrosis, and urinary casts were observed in females at 1,000 mg/kg/day. Some of these effects were observed in males dosed with 1,000 mg/kg/day at the end of the 14-day recovery period.

Reproductive and developmental effects of TFMS were evaluated in a study in which 0, 100, 300, or 1,000 mg/kg/day were administered via oral gavage to male and female rats (10 per sex per dose level) starting 2 weeks prior to mating and during the mating period, and, in females, throughout gestation until postnatal day 4. In parental males and females, there was no mortality, and body weight and food consumption were not affected. There were no effects on pairing, mating, or fertility, and effects on mean delivery date were not considered to be toxicologically significant. At sacrifice, no effects on reproductive organ weight or macroscopic or microscopic pathological changes of the reproductive organs were noted. Offspring were sacrificed on postnatal day 5. There were no effects on pup viability, no changes in body weight that were considered toxicologically significant, or and no effects on the percentage of males versus females at birth. Organ weight and gross and microscopic pathological changes were not evaluated in the offspring. ECHA (2021) concluded that the NOAELs for parental toxicity, parental reproductive performance, and toxicity to offspring were 1,000 mg/kg/day, the highest dose used in the study.

Zhou et al. (2020) evaluated effects on the liver and intestine in male mice dosed with 0, 0.001, 0.01, or 0.1 mg/kg/day TFMS via oral gavage for 12 weeks. This study used lower doses and a longer exposure duration than the studies reported in ECHA (2021). Body weight and liver:body weight ratios were not significantly affected by TFMS, while epididymal fat and the ratio of epididymal fat:body weight were decreased in a dose-related manner. Changes in levels of serum lipids and glucose occurred at one or more doses, but they did not exhibit a consistent dose-response relationship. Hepatic triglyceride levels were significantly reduced at all doses, while hepatic total cholesterol was not significantly changed at any dose. Histopathological examination revealed inflammatory cell infiltration in the liver at the two higher dose levels. Changes in intestinal microbiota were also observed in mice treated with TFMS.

In Vitro Genotoxicity Studies

In vitro genotoxicity studies of TFMS include two bacterial reverse mutation studies, a mammalian chromosome aberration study, and a mammalian cell gene mutation test (ECHA 2021).

TFMS was negative in bacterial reverse mutation assays, with and without metabolic activation. One study included four strains of *S. typhimurium* and one strain of *E. coli,* while another included two of the four *S. typhimurium* strains used in the first study.

TFMS was also negative in mammalian gene mutation assays using L5178Y mouse lymphoma cells, with and without metabolic activation, and in a mammalian chromosome aberration test using Chinese hamster lung fibroblasts, both with and without metabolic activation.

Based on results of these studies, ECHA (2021) concluded that TFMS is not genotoxic.

1.4.5 New Information on Considerations for Addressing PFAS as a Class

Considerations for regulation of PFAS as an entire class were previously reviewed in Section **7.1.7**. As reviewed in **Section 7.1.7**, toxicity has been evaluated for only a small number of the thousands of PFAS used commercially. Of those PFAS that have been studied (all of which are nonpolymeric PFAS), all were capable of causing adverse effects in animals and or humans (see **Section 7.1** and **Section 17.2**). Because substantial time and resources are required to characterize the chemical and physical properties and potential health effects of each individual chemical (for example, **NTP 2022**), the conclusion that it is not feasible and is not necessarily health-protective to follow the “chemical-by-chemical” regulatory paradigm for PFAS has gained increasing attention. For example, ECHA proposed to restrict all PFAS with a single regulation (**ECHA 2023**) based on concerns about their common property of persistence, since virtually all PFAS persist indefinitely or can transform to terminal PFAS that persist indefinitely. It is important to note the distinction between approaches for addressing the entire class of PFAS, which are

generally not based on risk assessment considerations, and approaches for human health risk assessment of PFAS mixtures (discussed in **Section 7.1.5** and **Section 17.2.7**), which require health effects information for each of the specific PFAS that are included in such an approach. Although efforts to address PFAS as a class do not assume that all PFAS are equally toxic and are generally not based on risk assessment considerations, the underlying rationale for addressing PFAS as a class is, as stated by Cousins et al. (2020), "The continuous release of persistent chemicals will lead to widespread, long-lasting, and increasing contamination, which will inevitably result in increasing probabilities of known and unknown adverse effects on human health and the environment."

Section 7.1.7 reviewed proposed strategies for grouping PFAS as of 2023. This section reviews more recent considerations related to addressing PFAS as a class, including examples of actions taken by regulatory agencies to address PFAS as a broad class and analytical techniques used to estimate total PFAS. As discussed below, such considerations are different for PFAS intentionally added to products than for PFAS present in environmental media (for example, drinking water). As discussed in **Section 2.2**, the suite of compounds defined as PFAS varies among authoritative organizations, notably differing as to whether compounds with one fully fluorinated carbon (for example, trifluoroacetic acid) are included.

Until recently, most actions to address PFAS as an entire class focused on products that contain PFAS rather than PFAS that are present in environmental media (for example, drinking water). Approaches that address PFAS as a class in products based on intentional use, including use in processing aids in manufacturing, are typically based on knowledge of the components used to make the products and do not require that the products be analyzed to determine whether any PFAS are present. In addition to the ECHA and California Department of Toxic Substances Control (DTSC) efforts to regulate PFAS as a class in certain consumer products (reviewed in **Section 7.1.7**), several state agencies, including Maine DEP (2025), Minnesota Pollution Control Agency (undated), and Washington state described by Smith et al. (2024), have enacted legislation to address PFAS as a class in products or certain categories of products. An additional example of a regulation that addresses PFAS as a class is the USEPA Toxic Substances Control Act (TSCA) rule scheduled to go into effect in 2026 (USEPA 2025). This rule requires that "any person that manufactures (including import) or has manufactured (including imported) PFAS [as defined by TSCA] or PFAS-containing articles in any year since January 1, 2011, to electronically report information regarding PFAS uses, production volumes, disposal, exposures, and hazards (USEPA 2024)."

Considerations for addressing PFAS as an entire class in drinking water or other environmental media differ from those for addressing PFAS that are intentionally present in products because the identities of all PFAS that are present are not known. Specifically, current targeted analytical techniques detect only a subset of the individual PFAS that may be present, and current methods that estimate the concentration of aggregate ("total") PFAS (reviewed below) may not be inclusive of all PFAS that may be present. Additionally, such methods may not be approved for regulatory use for the medium of concern. Additionally, because all PFAS that are present may not be effectively removed by the same treatment removal technologies (for example, granular activated carbon), multiple treatment removal approaches may be required to remove PFAS as a class from environmental media, such as drinking water or wastewater (see **Section 12**).

As reviewed below, several states have evaluated addressing PFAS as the entire class in environmental media, most commonly drinking water, or plan to do so. In response to a legislative requirement, the Vermont Agency for Natural Resources (VT ANR 2020) evaluated regulation of PFAS in drinking water as a class or subclass. VT ANR (2020) concluded that it was "technically infeasible" to establish a maximum contaminant level (MCL) for PFAS as a class because the necessary toxicological information and analytical methods were not available. They also concluded that a treatment technique–based standard was not appropriate.

The Hawaii Department of Health Interim PFAS Guidance (HI DOH 2024) and supporting files (HI DOH 2024), include a screening approach for estimation of the potential human health risk of total PFAS in soil

and water samples. This approach is based on assumed additive toxicity for mixtures of PFAS, specifically the sum of the hazard quotients for 1) PFAS included in target analysis for which toxicity factors are available; 2) PFAS precursors that are converted in the total oxidizable precursor (TOP) assay to terminal PFAS that are target analytes with available toxicity factors; and 3) additional PFAS whose concentration is estimated with a total organic fluorine (TOF) method. The toxicity of these additional unidentified PFAS, which is stated to be typically composed of ultrashort PFAS, is assumed to be the same as the ultrashort PFAS perfluoropropionic acid (PFPrA). HI DOH explained that this approach is intended for use as an initial screening tool to guide further evaluation.

California Assembly Bill 178 (CA Assembly 2022) included requirements to "develop standard operating procedures for and validate a broad-spectrum test for the class of PFAS" in drinking water and "develop a treatment-based regulation for the entire class of PFAS" in drinking water.

In response to these requirements, the CA Water Board conducted a method comparison study to determine the "most appropriate broad-spectrum analytical method for characterizing the occurrence of 'total PFAS' in drinking water" (CA Water Board 2024). The study tested samples from nine public water system wells and evaluated the recovery of several categories of PFAS over a wide concentration range in the analytical methods that were evaluated. Methods evaluated (reviewed below) included an adsorbable organic fluorine-combustion ion chromatography (AOF-CIC) method using an extraction procedure modeled after USEPA Method 1621; an extractable organic fluorine-combustion ion chromatography (EOF-CIC) method using an extraction procedure modeled after USEPA Method 533; and non-targeted and target analysis using several different sample preparation approaches.

AOF-CIC with Method 1621 extraction procedures was identified as the "the most appropriate and commercially available broad-spectrum analytical method available" (CA Water Board 2024). Compared to EOF-CIC with Method 533 extraction, it was concluded that the AOF-CIC method with Method 1621 extraction was superior in both capturing organic fluorine and minimizing interference from inorganic fluorine compounds. Results presented in CA Water Board (2024) appear to indicate that a considerable portion of organic fluorine captured by the AOF-CIC method was not captured by a targeted analytical method. Currently, a larger study of almost 4,000 public wells serving disadvantaged communities in rural and urban areas throughout California is ongoing and is expected to be completed in 2026. In this study, samples are being analyzed with both AOF-CIC (broad-spectrum PFAS) and ion chromatography-mass spectrometry-mass spectrometry (IC-MS/MS, for ultrashort PFAS, which are missed by AOF-CIC), and with the targeted USEPA Method 533 for comparison. About 700 of the 4,000 samples will also undergo "full non-target analysis" with the assistance of USEPA. Results of this study will inform California's regulatory process for a treatment-based approach for PFAS as a class (CA Water Board 2024).

The New Jersey legislature (2024) enacted S3176/A4760, a law that requires the New Jersey Department of Environmental Protection to conduct "an assessment of the feasibility of establishing an MCL or other standard for the entire class, or for certain subclasses or mixtures, of PFAS in drinking water, rather than for each individual substance."

The USEPA Drinking Water Contaminant Candidate List 5 (CCL5) (USEPA 2022) includes PFAS as a group. However, USEPA (2022) explained that listing PFAS as a group instead of as individual contaminants "does not necessarily mean that EPA will make subsequent regulatory decisions for the entire group." USEPA (2022) stated that the intent of listing PFAS as a group is to "limit duplication of … efforts, such as data gathering, analyses and evaluations" and that USEPA "will evaluate scientific data on the listed groups, subgroups, and individual contaminants included in the group to inform any regulatory determinations." USEPA (2024) requested public input on drinking water analytical methods for contaminants listed in CCL5, including PFAS as a group, and asked for "comments to support development and consideration of aggregate PFAS measurement."

USEPA (2025) and Idowu et al. (2025) reviewed methods that can be used to estimate total PFAS concentrations in environmental samples, and they are illustrated in **Figure 1-22**. Methods that measure organic fluorine include TOF, extractable organic fluorine (EOF), and adsorbable organic fluorine (AOF).

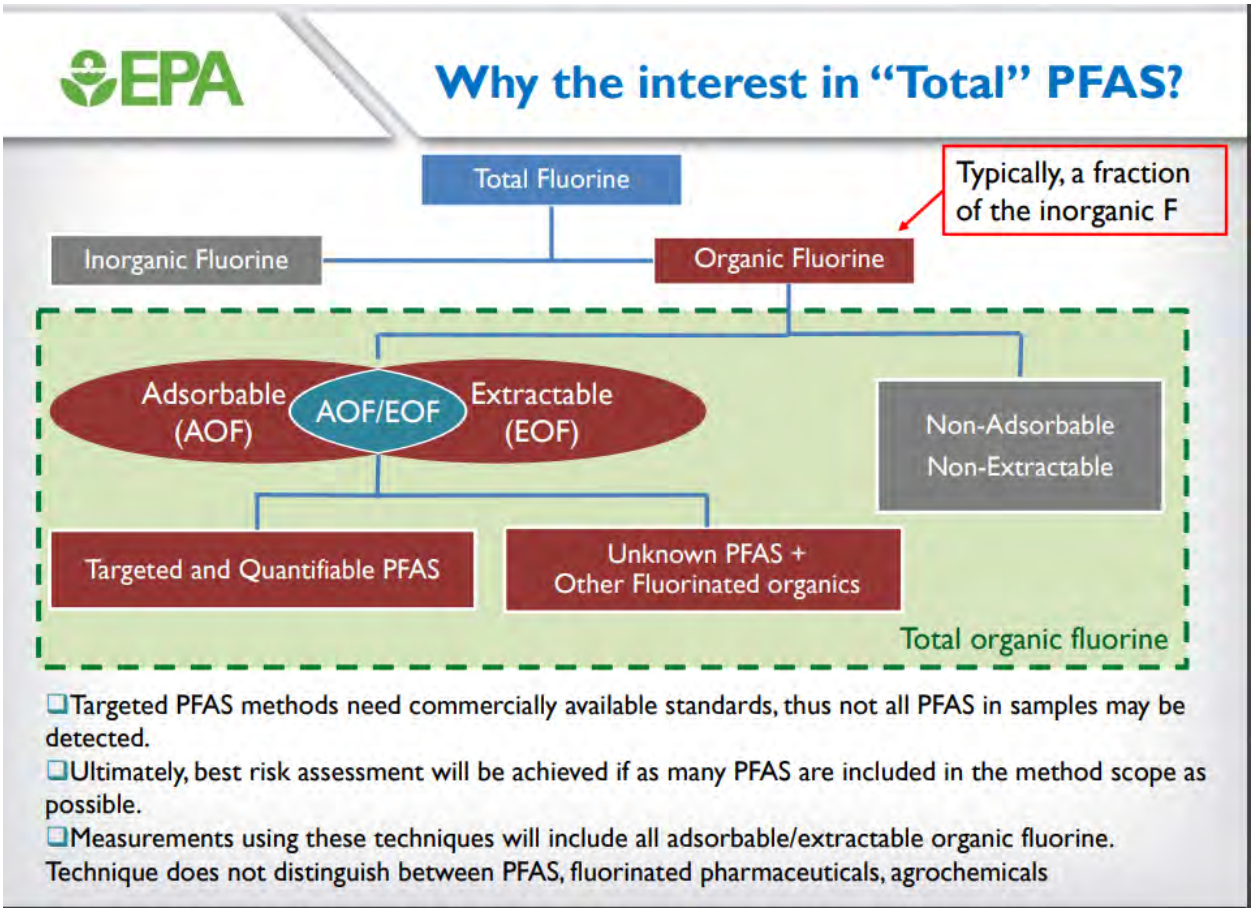


Figure 1-22. Why the interest in "Total" PFAS?

Source: Slide from Small Drinking Water Systems Webinar, PFAS Drinking Water Methods: Past, Present, and Future, USEPA (2023).

USEPA 2025 includes information about PFAS analytical techniques that can potentially be used for analyzing wastewater discharge samples for NPDES monitoring. The analytical techniques discussed include TOF, AOF, EOF, TOP Assay, PIGE, and ^{19}F-NMR. Each technique results in concentration measurements that may include PFAS, organofluorine compounds that are not PFAS, and inorganic fluorine. TOF, AOF, and EOF use CIC to completely decompose fluorinated organic compounds present in the sample, and the concentration of organic fluorine is estimated from concentration of inorganic fluoride produced during CIC. Inorganic fluoride present in the sample is also measured and must either be accounted for or removed from the sample. Available data indicate that targeted analytical methods may not account for a considerable portion of the organic fluorine present in drinking water. However, fluorinated organic compounds that are not PFAS (for example, some fluorinated pharmaceuticals and pesticides) contribute to the organic fluorine measured in drinking water with AOF and EOF (Spaan et al. 2023). Additionally, the adsorption or extraction steps in these methods may not capture all the organic fluorine that is present.

Factors affecting the differences in the results of the methods include the sample preparation steps and detection limits that can be achieved. Strengths and weaknesses of each technique and the expected

results are summarized in USEPA (2025). Additional information about TOP assay, USEPA Method 1621, including AOF and EOF, and PIGE are included in **Section 11.2.2**.

USEPA Method 1621 is detailed in (USEPA 2024). Additional information is given in USEPA (2024) about the use of Method 1621. The detection limit for Method 1621, is much higher than the detection limits for individual PFAS in USEPA Method 533 (USEPA 2019), Method 537.1 (USEPA 2020), and Method 1633A (USEPA 2024). Additional information about quantitative techniques is in **Section 11.2.1**. Ultrashort PFAS such as trifluoroacetic acid (TFA) and perfluoropropionic acid (PFPrA), which may contribute a considerable percentage of the total PFAS in a water sample, are not accurately measured by AOF (Neuwald et al. 2022).

USEPA 2024 is a federal register notice that includes information about a draft USEPA method EOF (extractable organic fluorine) for screening of drinking water samples.

These methods provide estimates of total PFAS concentration without identification of the specific PFAS present, see **Section 11.2.2** and **Section 1.5.4**. Therefore, the data obtained with these methods cannot be used in estimating the health risks of the PFAS mixture using the mixtures risk assessment approaches discussed in **Section 7.1.5** and **Section 17.2.7**.

Because specific treatment removal technologies remove different PFAS from environmental media (for example, drinking water) with higher or lower efficiencies, multiple technologies used sequentially would likely be necessary to effectively remove the entire class of PFAS from drinking water or wastewater (see **Section 12**). Additionally, a treatment-based standard for the entire class of PFAS would require the use of analytical methods that can determine whether all PFAS have been removed.

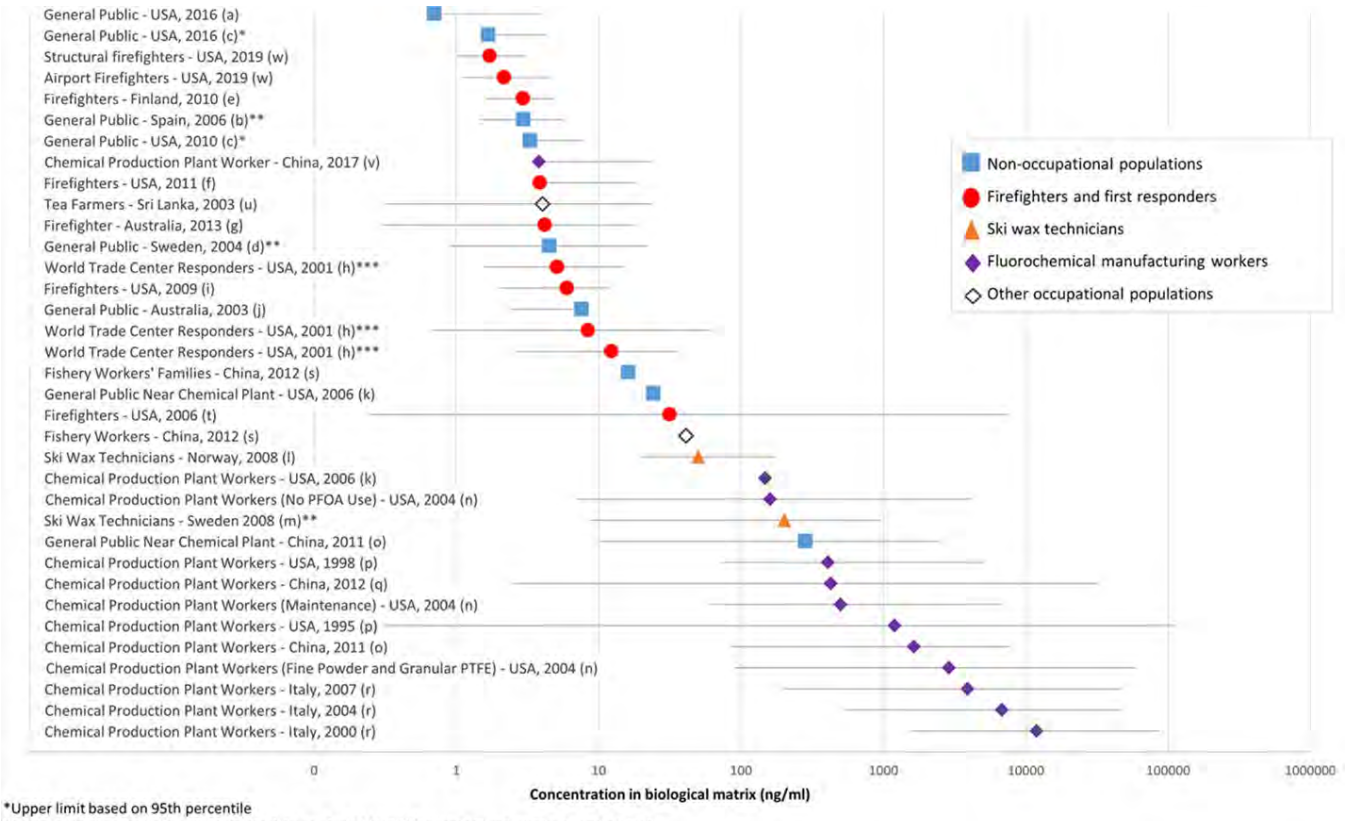
1.4.6 Potential PFAS Exposures in Occupational Settings

Section 2.3.1 indicates that workers in some occupations may be more highly exposed, and more at risk, than other populations. The text in this section provides more detailed information about specific occupations where workers may have elevated PFAS exposures based on the existing literature.

As indicated in **Section 2.1** and **Figure 2-2**, human exposure to PFAS may occur as a result of (1) direct interaction with PFAS in the workplace during manufacturing, (2) professional use of PFAS-containing materials, (3) use of or contact with commercial and consumer products containing PFAS, or (4) exposure to environmental media impacted by PFAS. Occupational exposures include both workplace exposure and professional use/application of PFAS-containing materials. This is an important category of exposure to discuss because there is the potential for much higher exposures than those in the general population. In addition, occupational exposures can be regulated by different laws and rules than environmental exposures, which may be incurred by the general population. The **Regulatory Programs Table** and **Section 2.5** include information about regulations related to the ban of PFAS in certain categories of consumer products.

Christensen and Calkins (2023) conducted an extensive literature search on PFAS exposure in occupational settings using four literature databases and searching for peer-reviewed articles published between 1980 and 2021. They found that most early research focused on fluorochemical workers, but additional workers in other occupations were studied after 2010. These additional occupations include firefighters and ski wax technicians, with fewer studies on other occupational settings including (but not limited to) textile mill workers, metal plating workers, clothing retail workers, office workers, fishermen, and barbers. It should be noted that PFAS exposures of fishermen/fishery workers were driven by consumption of fish from contaminated water bodies rather than by other exposure pathways and media. Therefore, worker exposure comparisons to fishermen/fishery workers were not included in the discussions in the following sections. Christensen and Calkins (2023) provided figures presenting a comparison of the levels of PFOA and PFOS in serum, plasma, or whole blood in workers of various

occupations based on results of their literature search, which are reproduced as **Figure 1-23** and **Figure 1-24**, respectively, here. Additional information for the studies included in the literature review is available in the Christensen and Calkins (2023) paper.



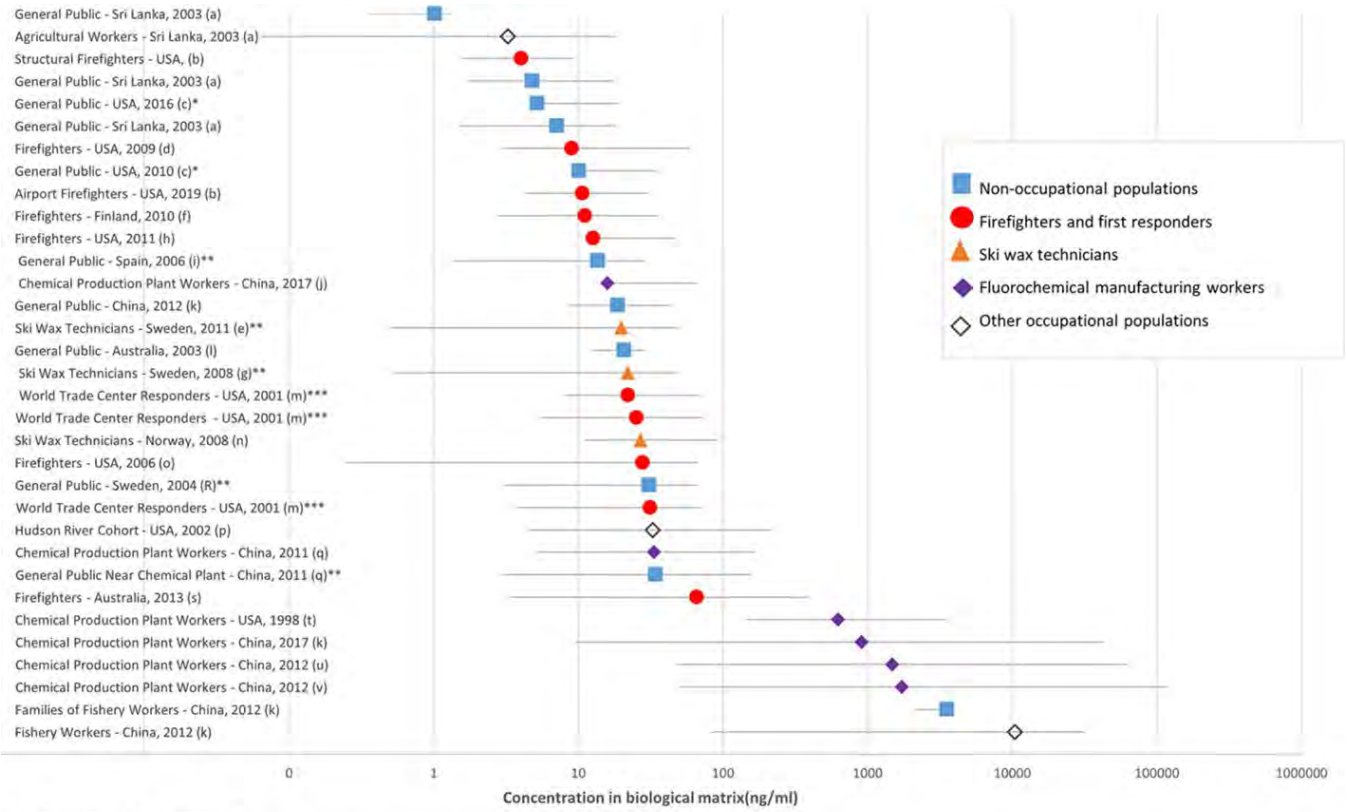
*Upper limit based on 95th percentile
**Whole blood sample. Serum concentration multipled by 1.8 for comparison to serum and plasma
***Plasma sample
(a) Kato et al., 2018[102]; (b) Ericson et al., 2007[103]; (c) CDC, 2019[17]; (d) Karrman et al., 2006b[105]; (e) Laitinen et al., 2014[79]; (f) Dobraca et al., 2015[72]; (g) Rotander et al., 2015[77]; (h) Tao et al., 2008[32]; (i) Shaw et al., 2013[71]; (j) Karrman et al., 2006a[104]; (k) Steenland et al., 2009[101]; (l) Freberg et al., 2010[44]; (m) Nilsson et al., 2010[81]; (n) Woskie et al., 2012[29]; (o) Wang et al., 2012[66]; (p) Olsen et al., 2007[63]; (q) Fu et al., 2016[27]; (r) Costa et al., 2009[62]; (s) Zhou et al., 2014[83]; (t) Jin et al., 2011[78]; (u) Guruge et al., 2005[31]; (v) Lu et al., 2019[68]; (w) Leary et al., 2019[70]

Figure 1-23. PFOA in serum, plasma, or whole blood by population, geographic region, and year of most recent sample collection.

Source: Christensen and Calkins (2023). U.S. Government work and not under copyright protection in the US. Author manuscript available from PubMed website, ***https://pubmed.ncbi.nlm.nih.gov/36977833/#full-view-affiliation-2****.*

This section discusses currently available information regarding potential occupational exposures to PFAS by workers in a few of these occupational settings. This section should not be viewed as a definitive and exhaustive discussion of all potential occupational exposures, given the ongoing studies in various occupational settings.

The Department of Defense developed an occupational medicine fact sheet that includes a brief discussion of the different exposure pathways for PFAS (USDOD 2024). These include occupational exposures through inhalation of aerosols and particulates containing PFAS. The fact sheet indicates that more research is needed to evaluate how inhalation exposures compare to other potential exposure routes. The Agency for Toxic Substances and Disease Registry does not consider skin absorption as a significant exposure route for PFAS (ATSDR 2021). A detailed discussion with additional information on dermal absorption of PFAS is provided in **Section 17.2.3** and in **Section 1.4.3**.



*Upper limit based on 95th percentile
**Whole blood sample. Serum concentration multipled by 1.8 for comparison to serum and plasma
***Plasma sample
(a) Guruge et al., 2005; (b) Leary et al., 2019; (c) CDC, 2019; (d) Shaw et al., 2013; (e) Nilsson et al., 2013; (f) Laitinen et al., 2014; (g) Nilsson et al., 2010; (h) Dobraca et al., 2015; (i) Ericson et al., 2007; (j) Lu et al., 2019 (k) Zhou et al., 2014; (l) Karrman et al., 2006a; (m) Tao et al., 2008; (n) Freberg et al., 2010; (o) Jin et al., 2011; (p) Tanner et al., 2018; (q) Wang et al., 2012; (r) Karrman et al., 2006b; (s) Rotander et al., 2015; (t) Olsen et al., 2007; (u) Gao et al. 2016; (v) Fu et al., 2016

Figure 1-24. PFOS in serum, plasma, or whole blood by population, geographic region, and year of most recent sample collection.

Source: Christensen and Calkins (2023). U.S. Government work and not under copyright protection in the US. Author manuscript available from PubMed website, ***https://pubmed.ncbi.nlm.nih.gov/36977833/#full-view-affiliation-2****.*

1.4.6.1 Fluorochemical Workers

Fluorochemical workers may be exposed to PFAS by touching surface dust and breathing in PFAS-contaminated air. Among fluorochemical workers, the extent of exposure is dependent on specific job tasks (for example, cell and chemical operator, waste operator, maintenance worker), with cell and chemical operators having the highest reported serum levels of PFOA, PFOS and PFHxS. Table 5-27 of ATSDR (2021) presents the range of concentrations of PFOA, PFOS, and PFHxS measured in the serum of fluorochemical workers at several facilities in the United States, Belgium, and Italy and indicates that the levels in workers were frequently 100 to 1,000 times higher than in the general population. PFOA mean concentrations in serum ranged from 262 to 19,700 ng/mL, PFOS mean concentrations in serum ranged from 403 to 2,440 ng/mL, and PFHxS mean concentrations in serum ranged from 170 to 290 ng/mL. Based on their literature review, Christensen and Calkins (2023) reported that fluorochemical workers had the highest blood concentrations of PFOA and PFOS compared to other workers in other occupations. Table 1a of Christensen and Calkins (2023) presented the median serum PFAS levels in fluorochemical workers and indicated PFOA median serum levels ranging from 11 to >10,000 ng/mL, PFOS median serum levels ranging from 11 to 10,000 ng/mL, and PFHxS median serum levels ranging from <1 to 1,000 ng/mL. Figures 3 and 4 of Christensen and Calkins (2023) (reproduced as **Figure 1-23** and **Figure 1-24**

here) provided a comparison of PFOA and PFOS levels in blood of workers by industry (and in the general population), indicating that fluorochemical workers had the highest PFOA and PFOS levels measured in blood.

1.4.6.2 Firefighters

Potential occupational exposures of firefighters to PFAS include inhalation of aerosolized aqueous film-forming foam (AFFF); skin contact with AFFF, contaminated fire equipment and personal protective equipment ("turnout gear"), and PFAS-contaminated dust; and inhalation of PFAS in smoke, air, and dust while firefighting and at fire stations (for example, Nilsson et al. 2022; Rosenfeld et al. 2023). Christensen and Calkins (2023) reported firefighter blood concentrations of PFOA and PFOS in comparison to the general population and other occupational workers. Table 1a of Christensen and Calkins (2023) presented the median serum PFAS levels in firefighters and indicated PFOA and PFOS median serum levels ranging from 1 to 100 ng/mL. Figures 3 and 4 of Christensen and Calkins (2023) (reproduced as **Figure 1-23** and **Figure 1-24** here) provided a comparison of PFOA and PFOS levels in blood by industry (and in the general population), indicating that both PFOA and PFOS levels in firefighters' blood were lower than those reported in fluorochemical workers, and PFOA levels in firefighters' blood were lower than those reported in ski wax technicians.

Nilsson et al. (2022) examined the serum concentrations of 40 different PFAS in 799 Australian firefighters. The results showed that the arithmetic mean serum concentrations of PFHxS, PFHpS, and PFOS in firefighters with historical exposure to AFFF were higher than the corresponding mean serum concentrations among the general Australian population of similar age (PFHxS: 14 versus 2.1 ng/mL; PFHpS: 1.7 vs. 0.24 ng/mL; PFOS: 27 versus 5.7 ng/mL). However, the mean PFOA levels in firefighters were similar to the general Australian population. Rosenfeld et al. (2023) reviewed 10 published studies and found that firefighters were reported to have elevated serum levels of various PFAS, including PFOA, PFOS, PFNA, PFHxS, PFHpS, PFDeA, PFDoA, PFDA, and PFUnDA. However, not all studies found elevated serum levels of PFAS; there were many instances among the studies reviewed in which the geometric mean serum levels for specific PFAS were not statistically significantly higher than control populations, and most studies analyzed only a few PFAS.

PFAS are used in firefighter turnout gear due to their water- and oil-repellent properties. Several studies (Peaslee et al. 2020; Maizel et al. 2023) have shown that the textiles used in turnout gear are a potential source of PFAS exposure to firefighters. Mazumder et al. (2023) provided a summary of the findings from available studies of the presence of PFAS in textiles used in various components (moisture barriers, outer shells, and thermal liners) of turnout gear. PFAS-treated textiles in turnout gear can degrade during washing and high temperature situations, resulting in release of volatile PFAS and fabric dust/lint, which may lead to exposure through inhalation, ingestion, or dermal contact.

Maizel et al. (2023) evaluated the presence of PFAS in the manufacturing of new firefighter turnout gear. PFAS were detected in all 20 textiles that were analyzed, with the number of detected PFAS ranging from 1 to 17 out of 53 PFAS analyzed. A higher number of PFAS detected and higher concentrations were found in textiles used for moisture barriers and outer shells. The total PFAS concentrations varied among textile types, with the largest differences observed among moisture barrier textiles, suggesting that the amount of PFAS depends on the specific textiles used in manufacturing the turnout gear. The highest concentrations detected were of three fluorotelomers: 2-(Perfluorohexyl)ethyl methacrylate(6:2 FTMAC), 6:2 fluorotelomer alcohol (FTOH), and 6:2 fluorotelomer sulfonic acid (FTS).

The Department of Defense (2024) developed an occupational medicine fact sheet that includes a brief discussion of the various PFAS exposure pathways for firefighters. These include exposures through contact with AFFF, turnout gear, and inhalation of aerosols and particulates containing PFAS. The fact sheet notes that dermal absorption of PFAS is not thought to be a significant exposure route (ATSDR

2021). A detailed discussion with additional information on dermal absorption of PFAS is provided in **Section 17.2.3** and in **Section 1.4.3**.

1.4.6.3 Professional Ski Waxers

Ski waxers apply glider waxes onto the bottom of skis and snowboards to enhance glide across the snow. The waxes are available in powder, solid block, or liquid form, and often contain PFAS. The powder and solid waxes are melted onto the ski by a heated iron, while the liquid waxes are dripped or sprayed onto the ski. In addition to applying glider waxes, ski waxers manually remove excess glide wax using plastic scrapers and rotating brushes (Freberg et al. 2013; Fang, Plassmann, and Cousins 2020). The waxing process can release PFAS into volatile, aerosol, or particulate fractions, which can be inhaled or settle in the vicinity of the worker (Nilsson et al. 2013; Freberg et al. 2010; 2013; 2014; Hämeri et al. 1996). Exacerbating the situation, ski waxers often work in poorly ventilated areas (Freberg et al. 2013; 2014; Hämeri et al. 1996).

Freberg et al. (2010) presented the results of PFAS analyses on 11 solid glide wax blocks and 11 glide wax powders from six different manufacturers. Twelve PFAS were detected in the samples, with higher maximum detected concentrations in glide wax powders than in solid blocks for all PFAS analyzed except perfluorotridecanoic acid (PFTrDA). The highest detected concentrations were of perfluorotetradecanoic acid (PFTeDA), followed by PFDoDA, PFOA, and PFHxA.

Christensen and Calkins (2023) reported ski wax technician blood concentrations of PFOA and PFOS in comparison to the general population and other occupational workers. Table 1a of Christensen and Calkins (2023) presented the median serum PFAS levels in ski wax technicians and indicated PFOA median serum levels ranging from 11 to 1,000 ng/mL and PFOS median serum levels ranging from 11 to 100 ng/mL. Figures 3 and 4 of Christensen and Calkins (2023) (reproduced as **Figure 1-23** and **Figure 1-24** here) provided a comparison of PFOA and PFOS levels in blood by industry (and in the general population), indicating that ski wax technicians had PFOA levels measured in blood that were lower than fluorochemical workers. Christensen and Calkins (2023) also found that ski wax technicians had PFOS levels measured in blood that were lower than fluorochemical workers and firefighters.

Paris-Davila et al. (2023) conducted a literature search for peer-reviewed articles published through December 2022 addressing occupational exposures to PFAS via inhalation. Results indicated that ski waxers were exposed to the highest total PFAS air concentrations compared to other reported occupations, including textile manufacturing, firefighting, and floor waxing. For ski waxing, the maximum reported total PFAS air concentration was 10 µg/m^3. For ski waxers, PFOA, PFHxA, PFDoDA, and PFDA were detected at a maximum concentration of 1 µg/m^3 (per PFAS) in personal sampling, a concentration approximately two to four orders of magnitude (depending on the specific PFAS) higher than those reported for other occupations. In ski waxing facilities, FTOH 8:2 air concentrations were reported as high as 1,000 µg/m^3, approximately two orders of magnitude higher than in other occupations. Freberg et al. (2010) measured 14 PFAS in the serum of professional ski waxers and observed that the highest median serum levels were for PFOA, followed by PFOS, PFNA, and PFDA.

Nilsson et al. (2013) also reported that blood levels of PFOA are elevated among professional ski waxers due to high PFAS concentrations in workplace air during ski waxing. Nilsson et al. (2013) reported that ski waxers are exposed to high levels of volatile FTOHs in air, with 8:2 FTOH detected in 100% of personal measurements (cartridge samples – samplers worn during work) and 6:2 FTOH and 10:2 FTOH detected in 96% of the personal measurements (n=84). The highest PFAS concentration in the personal measurements was 8:2 FTOH at 997 µg/m^3 (average = 113 µg/m^3), while the average 6:2 FTOH and 10:2 FTOH concentrations were 2.22 µg/m^3 and 0.32 µg/m^3, respectively. The average PFHxA, PFOA, PFTrDA, and PFTDA levels in personal measurements were 3.89 µg/m^3, 0.526 µg/m^3, 0.043 µg/m^3, and 1.27 µg/m^3, respectively. As indicated in Nilsson et al. (2010), FTOHs can be metabolized to PFCAs (for example, 8:2 FTOH metabolized to PFOA) in the body.

1.4.6.4 Textile Manufacturing Workers

Textile manufacturing facilities can be a source of PFAS exposures for workers where water-, oil-, or stain-resistant textiles are produced. Exposure pathways can include both dust ingestion and air inhalation.

PFAS are used in manufacturing some high-performance fabrics to protect against water, stain, and oil penetration. Heydebreck et al. (2016) evaluated the presence of PFAS in air, airborne particles, and settled dust in a textile manufacturing plant in China. The plant produces both heavyweight and lightweight garments such as uniforms, fashion clothes, sportswear, and outdoor clothes. Thirty-two PFAS were analyzed in the samples; 27 PFAS (12 neutral PFAS and 15 ionic PFAS) were detected in air samples, 27 PFAS (12 neutral PFAS and 15 ionic PFAS) were detected in airborne particle samples, and 16 PFAS were detected in settled dust samples. Worker exposures in the textile manufacturing plant via inhalation were estimated using PFAS concentrations detected in air, airborne particles, and dust samples. PFOA (ionic), PFDA (ionic), 8:2 FTOH (neutral), and 10:2 FTOH (neutral) were the dominant PFAS detected in air and airborne particle samples, while PFOA, PFDA, and PFNA (ionic) were the dominant PFAS detected in settled dust. Results indicated that inhalation exposures to neutral PFAS were three orders of magnitude higher than to ionic PFAS. Worker exposures (in China) to FTOH in air were estimated to be up to five orders of magnitude higher than background exposure of the general population in Western countries.

Results from Heydebreck et al. (2016) also indicated that estimated exposures to PFAS via dust ingestion were much lower than estimated exposures via air inhalation, with air inhalation exposures estimated to be orders of magnitude higher primarily due to inhalation of neutral PFAS.

Christensen and Calkins (2023) reported textile worker blood concentrations of PFOA, PFOS, and PFNA in comparison to other occupational workers. Table 1a of Christensen and Calkins (2023) presented the median serum PFAS levels in textile workers and indicated median serum levels ranging from 1 to 10 ng/mL for PFOA, PFOS, and PFNA. Table 1a of Christensen and Calkins (2023) also provided a comparison of PFOA, PFOS, and PFNA levels in blood by industry, indicating that textile workers had PFOA and PFOS levels measured in blood that were lower than fluorochemical workers, ski wax technicians, and firefighters, and PFNA levels measured in blood that were lower than ski wax technicians.

1.4.6.5 Summary

Most early research (1980–2010) on PFAS exposure in occupational settings focused on fluorochemical workers. After 2010, additional occupations were studied, but most were related to firefighters and ski wax technicians. However, some post-2010 studies evaluated occupational settings, including textile mill workers, metal plating workers, clothing retail workers, office workers, and barbers (Christensen and Calkins 2023).

There are inherent uncertainties in making direct comparisons between occupational settings and drawing conclusions about potential exposure. Some sources of uncertainty may include the specific PFAS analyzed (which vary between studies), the lack of standardized analytical methods, and differences in QA/QC practices incorporated into the study. The types of environmental matrixes sampled (for example, surfaces, dusts, particulate fraction in air, aerosol fraction in air, volatile fraction in air) also vary between studies. In addition, the location where air samples were collected (personal monitoring versus area monitoring) varies. Other factors that contribute to uncertainties in comparisons include the sampling time/duration, the number of samples collected (number of observations), and the time of sampling in relation to the time of exposure. A significant source of uncertainty is introduced when attempting to correlate environmental matrix data (for example, air data) to blood serum data and make comparisons between exposure levels.

1.4.7 Evaluating Risk to Livestock from PFAS Exposure

1.4.7.1 Introduction

The subject of PFAS contamination in agricultural settings has received considerable attention over the past decade; for example, USEPA recently released its draft document "Sewage Sludge Risk Assessment for Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonic Acid (PFOS)" (USEPA 2025). The US Department of Agriculture's Agricultural Research Service (USDA ARS) recently developed a research roadmap for PFAS in U.S. agriculture to address challenges and identify solutions for PFAS in the agricultural industry (USDA ARS 2024). AFFF releases, either directly or indirectly, have contaminated soil, groundwater, and surface water bodies, and atmospheric deposition from facility emissions can have long-range impacts to land and water across broad areas (see **Section 5** and **Section 6**). Biosolids have been used for decades as a low-cost fertilizer for adding nutrients and organic matter to farmland, including use on food crops, pasturage, forested land, and reclamation sites (Marchuk et al. 2023), often resulting in PFAS contamination of farmland. For this section the term "biosolids" will be used to refer to treated sewage sludge (see **Section 1.7**). The biosolids may be generated from residential sources or from utilities that receive a mixture of residential and commercial and industrial wastewater inputs (see **Section 1.7** for discussion of PFAS sources, migration pathways, and bioaccumulation for biosolids).

Certain PFAS have been shown to accumulate in pasturage and crops grown on contaminated farmland, resulting in accumulation of PFAS in livestock that graze or consume feedstock from that land. For example, biosolids from a wastewater treatment plant contaminated with PFOS had been historically applied to fields at a farm in Michigan, resulting in PFOS in beef samples taken from this farm at levels warranting a human consumption advisory (MI DHHS 2023). Similarly, the State of Maine discovered PFAS contamination in cows' milk at a small dairy farm that had its well water, soil, and hay contaminated with PFAS, with PFOS being the primary PFAS detected in all media. The Maine Department of Environmental Protection has been investigating PFAS in other farmlands in the state where sludge and septage have been applied and have detected PFAS in water, soil, hay, and milk (ME DEP 2023). In 2022, Maine banned the land application and distribution of sludge and sludge-derived compost without first testing and screening for PFAS, and later amended legislation to encompass a larger ban of wastewater biosolids for use as soil amendments or fertilizers (Maine Legislature 2022).

An abundance of information indicates that certain PFAS readily bioaccumulate in animals, with most data limited to PFAAs (for example, Houde et al. 2011; Giesy and Kannan 2001). Many studies have focused on understanding the direct effects of PFAAs on plants, laboratory animals, some aquatic organisms, and wildlife, as well as on evaluating potential health risks associated with PFAS exposure to humans through diet (see **Section 1.7.3**). Studies have shown that some PFAS accumulate in chickens, eggs, and other protein sources at levels that, in some instances, could potentially be significant with respect to human exposure and health risk (for example, Arcadis 2024; USEPA, 2025; also see **Section 9.1.2** and **Section 1.7**). To date, however, there has been little focus on the direct toxic effects of PFAS on livestock. Note that the term "livestock" is herein defined to include cattle, sheep, goats, and other ungulates, and, for convenience, poultry, rabbits, and other terrestrial animals typically farmed for human consumption.

This section presents an overview of the available scientific information on PFAS exposure and health effects in livestock. This topic discusses the exposure routes through which livestock may be exposed to PFAS in agricultural environments, summarizes available information on PFAS bioaccumulation in various livestock species, describes potential health effects to livestock associated with PFAS exposures, discusses methodologies of evaluating the risk of harm to livestock, and concludes with a discussion of data gaps and uncertainties associated with the current state of toxicology and risk characterization of these receptors.

1.4.7.2 Exposure Pathways

Relevant exposure pathways for livestock may include direct soil and water contamination from spills, atmospheric deposition, or land application of biosolids. PFAS may also be transported through the environment via runoff of PFAS in soils into nearby surface water bodies, leaching of PFAS into underlying groundwater (and subsequent migration in groundwater), generation of dust that can become airborne, and volatilization of certain volatile PFAS. PFAS can also accumulate in pasture vegetation and crops used for feedstock. See **Section 1.7** for more information and **Figure 1-28** for a conceptual site model of PFAS transport and migration pathways.

Based on these transport mechanisms, livestock could be exposed to PFAS through contact with contaminated soils, dust, surface water, or groundwater that is used for pasturing, grazing, and watering. Livestock may be exposed by consuming plants grown as forage and feedstock. Livestock exposure to PFAS is not only limited to exposures incurred on a farm. Off-farm sources, such as PFAS-contaminated commercial feed and bedding materials may also be important sources of PFAS exposure.

The primary exposure pathways for livestock to be exposed to PFAS include diet, drinking water ingestion, and incidental ingestion of soil. As discussed below, while absorption of PFAS through the skin and inhalation of PFAS (either through dust entrainment or volatilization) may also be viable pathways, it is expected that exposure via these routes is less significant than exposure via ingestion, based on currently available information. PFAS can also be transferred from mother to offspring during fetal development and nursing. These exposure pathways are discussed in more detail below, although the discussion does not include quantitative estimates of exposure, which can be found elsewhere in the scientific literature (for example, USEPA 2025). **Figure 1-25** illustrates the main exposure pathways for livestock, as discussed in the following sections.

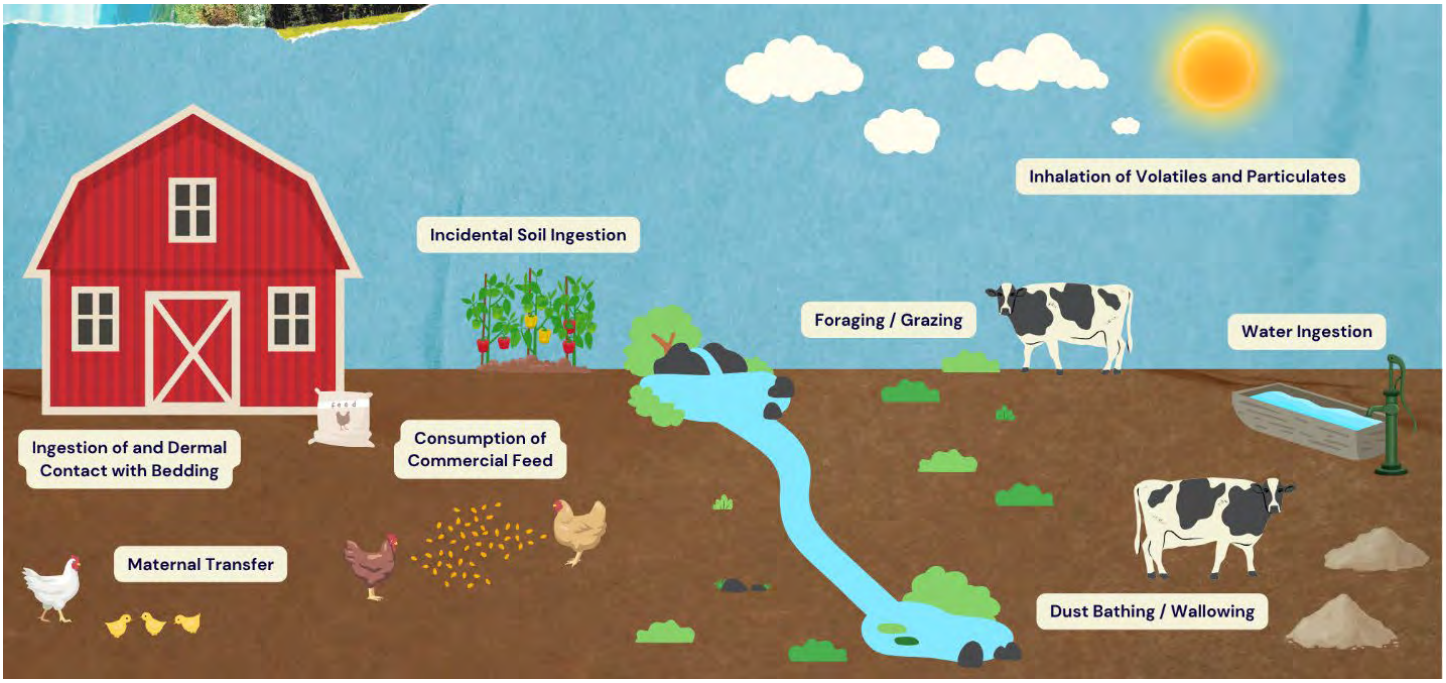


Figure 1-25. Conceptual site model for main exposure pathways for livestock.

1.4.7.2.1 Drinking Water Ingestion

All livestock consume water. Dairy cows can consume up to 50 gallons of water per day while lactating, and up to 80% of their daily water intake can come from their drinking water supplies, with the remainder

from moisture in food items (Becker 2024). Groundwater or surface water contaminated by PFAS sources can thus be a major source of PFAS exposure to livestock.

Drew, Hagen, and Champness (2021) described a case study where beef cattle and sheep were exposed to PFAS in stock water over several years. The stock water was obtained from an impoundment at a farm that had been contaminated from a nearby AFFF release and had PFOS initially detected at concentrations up to 6,690 nanograms per liter (ng/L). The study authors collected stock water, soil, and blood serum samples over multiple sampling rounds spanning several years. PFOS and other PFAS (primarily 6:2 FTS, PFHxA, PFPeA, PFHxS, perfluoroheptanoic acid (PFHpA), PFBS, and PFBA) were consistently detected in stock water samples. In soil, PFOS, PFHxS, PFNA, PFPeA, PFHxA, and PFHpA were detected at "very low" concentrations; the authors estimated PFAS intake (for cattle) from soil to represent only 1% of the calculated PFAS intake from water. No PFAS were detected in pasture grass samples. However, PFOS and PFHxS were detected in serum from both sheep and cattle; PFOS concentrations ranged up to 1,944 nanograms per milliliter (ng/mL) and 248 ng/mL for cattle and sheep, respectively, whereas PFHxS was detected at levels up to 840 ng/mL and 170 ng/mL, respectively. PFAS serum levels decreased concomitantly with decreases in stock water PFAS levels over time.

Wilson et al. (2021) conducted a study where laying hens were exposed to drinking water containing PFOS, PFOA, PFHxS, and PFHxA over a 61-day period, at concentrations up to 300,000 ng/L. PFOS and PFHxS were detected in eggs at the overall highest (and similar) concentrations, followed by PFOA and PFHxA. The study determined that >99.7% of total PFAS accumulated in the yolk relative to the albumen. Egg residues remained relatively stable for 20–30 days postexposure. The authors found a strong, positive linear correlation between PFOS, PFHxS, and PFOA levels in drinking water and eggs; this association was observed for PFHxA only at the highest administered dose. From this study, the authors calculated average half-lives of 3.5 days, 7 days, and 5.4 days for PFOS, PFHxS, and PFOA in eggs, respectively, and 2 days for PFHxA (only at the highest administered dose).

1.4.7.2.2 Food Ingestion

Livestock may ingest PFAS through grazing on pasture or through silage and other feedstock. The uptake of PFAS into plants has been well documented (for example, Adu, Ma, and Sharma 2023; Wang et al. 2020) (see **Section 1.7**, **Section 5.6** and **Section 6.5.1**). Hay, silage, and other feed crops grown on contaminated agricultural land can accumulate PFAS, potentially resulting in exposure for livestock that rely on those food items.

Omnivorous free-range poultry such as chickens and turkeys may also ingest PFAS by consuming insects, worms, and other small animals upon which they prey, where those prey items accumulate PFAS from their environment. PFAS (primarily PFOS followed by PFOA) levels in eggs from free-range chickens in a Dutch study were attributed to PFAS in earthworms, even though PFAS soil concentrations were relatively low and did not correlate with the concentrations found in chicken eggs; PFOS and other long-chain PFAS were present in soil at concentrations considered representative of background levels (Arcadis 2024).

Animal byproduct feeds (for example, animal fats, fish oils, fish meal, hydrolyzed proteins, collagens, milk, eggs) may also be a PFAS source because long-chain PFAS have been found to bioconcentrate in animal products and particularly in those that are fish-based. For example, Choi et al. (2023) detected PFAS in multiple types of animal feed used for laboratory animals, finding that plant-based feeds contained mainly short-chain PFCAs and feeds that contained animal ingredients (such as insects, fish, and shrimp) contained longer chain PFSAs, with total PFAS levels as high as 215.6 micrograms per kilogram (µg/kg) (dry weight). Fishmeal is often fed to swine, poultry, cattle, and sheep for its high protein content, and this product could be an important source of PFAS to livestock's diet even in uncontaminated settings. In a study by Granby et al. (2024), nine PFAAs were detected in eggs from organic farms in Denmark (primarily PFOS), whereas eggs from larger commercial farms had either low or no PFAS detected. The

elevated PFAS concentrations in the organic eggs were believed to be related to the fishmeal used in feedstock. PFAS levels in eggs decreased following elimination of fishmeal from the diet.

1.4.7.2.3 Soil Ingestion

Soil ingestion by livestock can constitute a considerable part of the livestock diet (Fries, Marrow, and Snow 1982; Healy, 1968; Beyer et al. 1994). Soil may be ingested either indirectly via foraging/grazing or preening, or intentionally via geophagy for minerals, and chickens and other poultry may ingest soil by obtaining grit to aid digestion. However, few experimental data are available to accurately quantify livestock soil ingestion rates, which are also dependent on the density of livestock and the amount of bare soil within a foraging area. For example, pastured dairy cows may consume soil at an average of 4%–8% of total dry matter (that is, food and soil) intake, although intake can vary considerably depending on plant availability and growing season, with soil representing up to 14% of the dry matter intake in seasons with poor plant growth; and similar soil ingestion patterns exist for beef cattle and sheep (Fries, Marrow, and Snow 1982; Healy 1968). Beyer et al. (1994) estimated that soil composed approximately 9% of a wild turkey's diet, and similar amounts may occur for free-range domestic turkeys. Jurjanz et al. (2015) found that the soil percentage in the diet of free-range hens (allowed to forage but also provided with chicken feed) was approximately 4% or less of total dry matter, and the percentage varied with the age of the chicken and whether the yard was tree- or grass-covered. For free-range poultry that have regular access to soil in which they can scratch, forage, and bathe, soil intake may be a significant source of environmental contaminants. As discussed earlier, earthworms may contain contaminated soil and accumulate PFAS. Additionally, livestock may consume plants may have soil deposited on leaves and stems.

1.4.7.2.4 Dermal Contact

Dermal exposure is typically considered a less-significant exposure pathway for wildlife relative to soil and food/water ingestion (for example, Sample and Suter, 1994). However, many livestock species frequently engage in dust bathing and wallowing behaviors, suggesting that PFAS in soil or water could be deposited on the skin and then potentially absorbed. Additionally, animal bedding generated from recycled paper, wood materials, and crop byproducts could potentially contain PFAS. Fernandes et al. (2023) detected PFAS in various bedding materials, with median total PFAS (sum of PFOS, PFOA, PFNA, and PFHxS) concentrations ranging from 6 µg/kg wet weight (ww) in unused wood shavings (control material) to 16 µg/kg ww in bedding made with dried paper sludge. The authors also found that these four PFAS accumulated in muscle, skin, and liver, as well as eggs from hens raised on bedding material that contained PFAS. Livestock, particularly poultry, may also inadvertently ingest bedding material and inhale dust while foraging.

Dermal absorption studies in laboratory rodents have shown that some PFAS can be absorbed through the skin, particularly for personal care products (see **Section 1.4.3** and **Section 17.2.3**). However, livestock studies on the absorption of PFAS through the skin because of contact with soil or water are not yet available.

1.4.7.2.5 Inhalation

PFAS can be transported through the air in volatile form or entrained on soil or dust particles and subsequently inhaled by livestock. Poultry can generate a substantial amount of dust through litter, feces, dander, and feathers while foraging and preening. As with the dermal route, little information is available for livestock on inhalation exposure of PFAS. Conceptually, livestock at farms located closer to industrial emissions may have higher exposure potential via inhalation of aerosols and particulates, whereas livestock kept largely indoors (without the benefit of outdoor dilution) may potentially have higher exposure potential to dust inhalation from soil and bedding material. However, the implications of this potential exposure pathway with regard to livestock health are currently unclear.

1.4.7.2.6 Maternal Transfer

Studies show that, in mammals, PFAS can cross the placenta and be transferred to the developing fetus (for example, Guruge et al. 2008; **Gronnestad et al. 2017**; **Houde et al. 2006**; see **Section 7.1.2**). PFAS also can be transferred in milk, which has been shown to be a major excretion route, as it is rich in proteins (Kowalcyzk et al., 2013; Milolajczyk et al. 2023). This transfer has been demonstrated by studies in Michigan, Maine, New Mexico, and other states showing detectable concentrations of PFAS in dairy products (in addition to meat and eggs) resulting from exposure to PFAS in biosolids/residuals on agricultural lands (ME DEP 2023). Thus, both fetal and nursing mammalian livestock can be exposed to PFAS via both transplacental and lactational transfer pathways up through weaning. Conversely, increased milk yield can result in overall decreased PFAS levels for the lactating animal (van Asselt et al. 2013). Also, hens may transfer PFAS to their eggs following a hen's exposure to PFAS-contaminated soil, food, or water (for example, Wilson et al. 2021).

1.4.7.3 Bioaccumulation in Livestock

Oral absorption has been studied for several PFAS, and it has been demonstrated that PFAS are readily absorbed through the gastrointestinal tract and that protein-rich tissues (for example, blood serum, liver, kidneys) are the primary PFAS accumulation sites (see **Section 17.2.3**). Although accumulation of PFAS can be highly variable depending on the organism, route of ingestion, and types and concentrations of PFAS to which the organism is exposed, *in general*, the long-chain PFAS (such as PFOS) tend to accumulate at a greater rate in animals relative to the short-chain PFAS (Houde et al. 2011). Functional group (for example, sulfonic vs. carboxylic acid) also appears to have a larger role in bioaccumulation potential relative to chain length, consistent with general findings from a wide range of tissue residue studies in wildlife (for example, Rupp et al. 2023; Draghi et al. 2024) and laboratory animals, as discussed in **Section 17.2.3**. Perfluoroalkyl sulfonic acids tend to accumulate at a higher rate relative to perfluoroalkyl carboxylic acids due to the higher binding capacity of sulfonates within the body (for example, Ng and Hungerbühler 2014).

With respect to livestock, much of the available information on PFAS accumulation is associated with food studies of animal products (milk and other dairy products, meat, eggs) intended for human consumption. Consequently, while there is ample information on PFAS residuals in various types of livestock tissues, there is not always corresponding information on the animal's exposure to PFAS prior to processing. Given their utility for both meat and dairy products, there are currently more studies on bioaccumulation of PFAS in cattle relative to other livestock (Death et al. 2021).

Animal product studies that focused on human health risks from food exposure also highlight bioaccumulation potential in livestock. Guruge et al. (2008) analyzed PFOS and other PFAS in blood and liver samples from a variety of farm animals across multiple farms and regions of Japan and found that PFOS was detected at the highest concentrations and frequency relative to other PFAS. In general, chicken had the highest blood serum PFOS concentrations, followed in decreasing order by cattle, goat, horse, and pig. Liver PFOS concentrations were again highest in chicken, followed by pigs and cattle. However, no information on PFAS levels in farm soil, water, or fodder was provided in this study. Death et al. (2021) provided a review of bioaccumulation studies (both dosed and ambient studies) in cattle, sheep, poultry, and pigs (as well as wild game species). Collectively, the authors indicated similarities in PFAS tissue distribution among the different animals. PFOS was typically the most prevalent of the PFAS, and concentrations were generally highest in blood, liver, and kidney relative to muscle. Notable differences in PFAS concentrations were also observed among species, dose, and sex.

The disposition of PFAS in livestock mirrors the findings from studies of laboratory animals (see **Section 17.2.3**). For example, Kowalczyk et al. (2012) found that urinary excretion was the primary PFOA clearance route for dairy sheep exposed via corn silage with PFOA over a 21-day period, accounting for 51%–55% of clearance compared to 1%–2% for feces and less than 1% for milk. This same study found

that PFOA levels in plasma, liver, kidney, and muscle tissue were reduced to nondetectable levels after a PFAA-free feeding period of 21 days. The excretion of PFOS was less clear; the authors estimated that approximately 5% and 2% of PFOS was excreted in feces and milk, respectively. This study did not report PFOS concentrations in urine.

Numata et al. (2014) found that of the PFAS they studied (seven PFCAs and five PFSAs), most accumulated in the blood plasma (up to 51%) and the muscle and fat tissues, collectively (up to 49%), with relatively low accumulation observed in the liver (<7%) and kidney (<2%). The exception to these general findings was PFOS, which preferentially accumulated in liver (35%) relative to other tissues. The authors also indicated that in pigs, PFAAs had a higher affinity for plasma (relative to other tissues) than that observed for sheep and cattle.

Studies also demonstrate interspecies variability. In a study by Numata et al. (2014), PFAAs (mainly PFOS, PFHxS, and PFBS) were found to have longer elimination half-life in pigs than has been observed in other types of livestock. For example, PFOS had a serum half-life of 634 days in pigs versus 74 days in cattle (Drew, Hagen, and Champness 2021).

1.4.7.4 Toxicology

Toxicological effects data for PFAS remain under development, and data suitable for determining risk to livestock are lacking for the majority of individual PFAS and receptor groups. Overall, there are relatively few toxicity studies specifically on livestock species. Toxicological data from avian and mammalian studies that potentially may be applied to livestock are available only for a few relatively well-understood PFAS (for example, PFOS and PFOA). The following sections summarize toxicity data for birds and mammals that are representative of typical livestock species. A more comprehensive discussion of PFAS effects data is presented in **Section 7.2** and in review documents such as Ankley et al. (2021) and Johnson et al. (2021).

Birds

PFAS uptake and effects have been studied in various avian species, and these results may potentially be applied to evaluating risk in poultry based on the relevance of the toxicological endpoints (survival, growth, reproduction). See **Section 7.2.3.3** for a discussion of wild bird studies. However, many of these studies were egg injection studies, with fewer studies conducted on dietary intake, which is a more relevant route of exposure for livestock. Overall, toxicity studies in birds have demonstrated effects on developing bird embryos and hatchlings, endocrine pathways and neurodevelopment, with adult mortality typically occurring only at the highest dose levels (see **Section 7.2.3.3**).

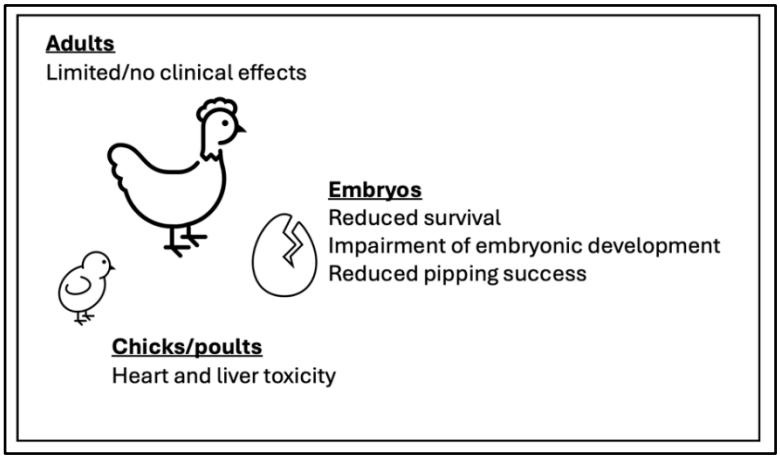


Figure 1-2. PFAS Effects noted in poultry studies.

Egg injection and embryonic studies on domestic chickens show that certain PFAS at high doses may result in effects on chick pipping success, embryo development and chick behavior, on the liver and heart, and on the endocrine system, especially thyroid hormone–responsive genes (**Figure 1-26**).

For example, Cassone et al. (2012) conducted an egg injection study of PFHxS and PFHxA in chicken embryos and demonstrated that PFHxS exposure resulted in a reduction in pipping success and embryonic development. The study also found that PFHxS exposure caused upregulation of hepatic and neuronal mRNA expression of thyroid hormone–responsive genes, and a reduction of free T4 concentrations in plasma. These effects were not observed in PFHxA-exposed eggs. Vongphachan et al. (2011) conducted an in vitro study on domestic chickens and herring gulls, and found that several PFAS (PFHxA, PFHpA, and PFNA) altered changes in mRNA expression of thyroid hormone–responsive genes, noting that PFAS with fewer than eight carbons (PFBS, PFHxA, PFHxS, and PFHpA) altered mRNA expression to the greatest extent compared to longer chain PFAS. Pinkas et al. (2010) found that in ovo exposure to PFOA and PFOS was associated with reduced survival and hatching, and elicited behavioral changes (reduced imprinting ability) in chicks after hatching. Ni et al. (2023) reported that in ovo exposure to PFOA resulted in cardiotoxicity and hepatotoxicity in hatchlings, and that cardiotoxicity persisted for several months following exposure.

Limited studies exist related to toxicological effects from dietary exposure of PFAS on domestic poultry (for example, chickens, turkeys), and those studies suggest limited or even no clinical significance of PFAS exposure via ingestion on posthatch birds. The Wilson et al. (2021) study described in **Section 1.7.3** (in which adult laying hens were administered PFAS in drinking water) noted no negative health outcomes (hen weight, egg production, or other observable adverse effects) at any of the administered PFAS doses. Yeung et al. (2009) exposed 1-day-old male chicks to PFOA by oral gavage at doses up to 1.0 mg/kg body weight with no dose-dependent statistically significant differences in body/organ weights. Yoo et al. (2009) similarly did not observe clinical effects (body weight, growth rate, histological changes, blood biochemistry) other than a reduction in cholesterol and phospholipids associated with PFOS in male leghorn chickens exposed to PFOS and PFOA via subcutaneous implants for 4 weeks.

Mammals

Although there are a growing number of studies on bioaccumulation of PFAS in ungulate livestock (for example, horses, cattle, pigs, sheep; see **Section 1.4.3**), of the few toxicological studies identified for this group of animals, most were biomarker studies, and none reported clinical effects. Death et al. (2021) described several short-term studies in cattle, sheep, and pigs. However, these studies did not evaluate direct adverse effects of PFAS exposure to livestock. Numata et al. (2014) conducted a study on a mixture of PFAAs in feed into edible tissues of 24 fattening pigs. The study focused on bioaccumulation and elimination, and although the study did not directly evaluate adverse effects on the pigs, the authors assessed the general health of the test subjects and did not report any observed adverse effects. Watanabe et al. (2010) investigated effects of PFAS and other contaminants in wild pigs. Although positive correlations were observed between other pollutants (PCBs, pesticides) and various blood, hepatic, and immunological endpoints, the investigators did not find any significant correlation between PFAS concentrations and these effects. Several in vitro studies on swine ovaries evaluated reproductive effects of PFOA or PFOS, showing inhibition of granulosa cell proliferation and steroidogenesis (Basini et al. 2023; Chaparro-Ortega et al. 2018). Rock et al. (2023) found significant associations between the levels of multiple PFAS in horse serum and biomarkers of liver and kidney function.

As mentioned, most laboratory toxicity studies for PFAS have been conducted in rodents. General effects from exposure to PFAS in laboratory animal studies have included reduced body weight gain, liver damage, developmental effects, immunotoxicity, and mortality (see **Section 7.1**). Although these studies have demonstrated the acute and chronic toxicological effects of PFAS in mammals (see **Section 7.1**), their utility in evaluating risks to mammalian livestock is unknown, given ungulates' differences in size, dietary requirements, uptake and elimination kinetics, gestational period length, and unique digestive system.

1.4.7.5 Risk Characterization

Although little work has been done on PFAS risk assessment of livestock, work has been conducted to evaluate effects from other types of contaminants. For example, Stickney et al. (2001) and API (2004) derived health-based concentrations of petroleum compounds in cattle's drinking water. The methods used to calculate health-based concentrations were similar to methods described by USEPA (1997) in the "Ecological Risk Assessment Guidance for Superfund" for evaluating risks to wildlife and included derivation of toxicological benchmarks and estimation of daily dose of chemicals from drinking water ingestion and soil ingestion.

The basic hazard quotient (HQ) equation is:

HQ=Exposure Dose/Toxicity Reference Value

Where the HQ is unitless, the exposure dose is in milligrams of constituent per kilogram body weight per day (mg/kg-d) and the toxicity reference value (TRV) is in units of mg/kg-d (USEPA, 1993).

The exposure dose represents the cumulative intake of a contaminant through multiple exposure pathways. For livestock, this equation might be represented as follows:

Exposure dose = Food intake + Water intake + Soil intake

The ecological risk assessment approach for wildlife (see **Section 9.2**) includes a standard hazard quotient (HQ), which can also be used to assess the risk from PFAS intake for various livestock species (see sidebar.) The USEPA (1993) Wildlife Exposure Factors Handbook provides equations to model intake of contaminants in wildlife (see sidebar). These same equations may be applied to livestock when used in conjunction with receptor-specific life history and physiological attributes such as grazing area, dietary composition, food and water ingestion rates, and body weights. The USEPA exposure model is based heavily on dietary concentrations, which for livestock could include measured PFAS concentrations in livestock food items or be based on bioaccumulation or transfer factors (for example, soil to forage plant; see **Section 1.7**). Transfer factors representing the ratio of the concentration of PFAS in livestock to the concentration of PFAS in abiotic media (for example, bioconcentration factors/bioaccumulation factors/soil-plant-livestock transfer factors) can be used to estimate animal-specific tissue concentrations. For example, Drew, Hagen, and Champness (2021) derived transfer factors from water to cattle serum, and Wilson et al. (2021) developed transfer factors from water to hens.

The modeled intake dose is compared to a toxicity reference value (TRV) to calculate an HQ. HQs equal to or greater than 1 may suggest a potential health risk to the livestock. Similar to the methodology used by USEPA (2005) in developing Ecological Soil Screening Levels, TRVs for evaluating risks to livestock could be developed based on the existing body of avian and mammalian toxicity data described previously, with the caveat that livestock-specific toxicological studies on PFAS are not available for most species. Adjustment factors (such as body scaling or use of uncertainty factors) could potentially be required. Dennis et al. (2021), Newsted et al. (2005), and others have already developed avian TRVs for use in risk assessment. Others have derived PFAS risk-based screening levels for avian and mammalian wildlife species (Divine et al. 2020; Grippo et al. 2024). To date, few studies (Newsted et al. 2005; Dennis et al. 2021) have developed tissue-based (versus dose-based) TRVs that could be compared with estimated or measured livestock tissue concentrations.

1.4.7.6 Uncertainties and Data Gaps

Many of the uncertainties related to characterization of risk to livestock from PFAS exposure are the same as those identified for human health and ecological risk (see **Section 7** and **Section 9**). These uncertainties center around the general lack of information on the numerous PFAS to which livestock may be exposed (and the mixtures of these PFAS), and variability among species in both PFAS accumulation and sensitivity. Existing livestock bioaccumulation studies have focused on a relatively limited number of PFAS analytes, whereas thousands of individual PFAS exist and most of these have not been routinely or ever analyzed in the environment.

In terms of dietary intake, uptake of PFAS in plants depends on several factors (type of plant, type of PFAS, soil characteristics). Likewise, uptake into animals can vary considerably depending on the species, age, sex, gestation/lactation status, feed supply, and other behavioral and physiological factors. The contribution of both direct and indirect PFAS exposure pathways can also vary according to environmental contamination and feed and bedding sources, as discussed previously. Another key uncertainty in the exposure assessment is the proportion of livestock diet that consists of grazed/foraged dietary items versus supplemental commercial feed and drinking water. For example, even if site-specific risk assessments incorporate measured concentrations of diet, feed, and water, the relative intake rates of each are expected to vary substantially, depending on livestock management practices.

Existing studies indicate that toxic effects to livestock from PFAS exposures have generally not been observed unless exposure occurs at levels higher than those generally expected from land application of biosolids (Death et al. 2021) or resulting from background sources such as precipitation. However, there is a paucity of toxicological studies focused on livestock species. Most studies have centered on poultry, and even within those studies, many focused on in ovo exposures. It is unclear how the results from egg or subcutaneous injection studies relate to real-life exposures from feed and the environment.

Some livestock species are also entirely unrepresented in the existing literature. For example, camels are replacing cattle in areas subject to extended drought in areas such as Kenya (Hochet-Bodin 2024), but there is no PFAS information on uptake or toxicity of PFAS in camelids.

Given these uncertainties, although there are standard risk assessment tools available to use for evaluating livestock risk, it is unclear if the risk to livestock from PFAS contamination in the agricultural setting can be meaningfully quantified at this time (Sharp et al. 2021). Studies show that livestock exposures to PFAS are routinely occurring, and additional toxicological studies specific to livestock species are needed to fill in data gaps and provide a more accurate representation of health risk to these species. Various agencies are recognizing the need to address these data gaps; for example, the University of Maine recently expanded their partnership with the USDA ARS to explore the effects of PFAS on US agriculture (**USDA** 2024).

1.4.8 Reptiles Toxicity Data

Section 7.2 includes information about available toxicity information for invertebrates, vertebrates, and mammals. **Section 7.2.3.2** includes information primarily for amphibians, and as noted, previously no studies for reptiles were found in the literature. This section provides a brief review of the currently available research for reptiles.

Although PFAS exhibit high environmental persistence and growing ecological concern, relatively few toxicological studies have been conducted on reptiles exposed to PFAS, and toxicity to reptiles remains a significant data gap for ecological risk assessment. The following is a summary of currently available toxicological data for reptiles, noting that additional data regarding bioaccumulation of PFAS and effects on non-apical endpoints (for example, metabolic responses) are also available, but not covered herein.

Bangma et al. (2019) conducted a study in diamondback terrapins (*Malaclemys terrapin*). A total of 75 terrapin plasma samples were collected from five creeks in Charleston County, South Carolina, and investigated for 15 legacy PFAS. Three PFAS (PFOS, PFNA, and PFHxS) were observed to have negative correlations between plasma and body mass (Bangma et al. 2019).

Furst et al. (2019) presented results from a pseudo-gavage study of PFOS and PFHxS exposure on the brown anole (*Anolis sagrei*). The study indicated that 90-day PFOS exposure to adult males at doses up to 1.35 mg/kg/day (the highest exposure level) elicited no strong effects on either body or organ mass, although significant effects on growth of young lizards after 35 days was observed at a dose rate of 2 mg

PFOS/kg/day. Exposure to PFHxS for 63 days was not found to have a significant effect on body or organ size of either males or females, but did result in decreased egg viability in females.

Salice et al. (2025) conducted two studies on brown anole to develop toxicity testing protocols for the species and to generate toxicity data to support ecological risk assessment. During the two studies, subadult males and then mature males were dosed with PFOS via pseudo-gavage with maximum doses in the range of 2 mg/kg/day. Subadults were exposed for 35 days and adult males were exposed for 90 days. Although no significant mortality was observed, PFOS significantly reduced subadult male size and growth rate at a dose rate of 2.98 mg/kg/day, with a corresponding no-effect level of 0.20 mg/kg/day. There were no significant effects on size metrics of mature male anoles from the 90-day study, although several metrics showed dose-dependent decreases (Salice et al. 2025).

Zhang et al. (2020) conducted a study on Mongolia racerunner lizards (*Eremia argus*). Organisms were exposed to PFOA in soil at 0.05 mg/kg, 0.5 mg/kg, and 5 mg/kg for 60 days, and were evaluated for various physiological and biological effects. By day 60, a significant reduction in growth was observed in males at all three test levels, and in percent survival in the highest test level; these reductions were not observed, however, in females (Zhang et al. 2020). Australia and New Zealand used the Zhang et al. (2020) study as the basis for deriving their interim Ecological Guideline Value for PFOA in soil of 0.005 mg/kg for reptiles (HEPA 2025).

Lettoof et al. (2023) conducted a study on wild-caught tiger snakes (*Notechis scutatus occidentalis*) in which liver tissues were analyzed for 28 PFAS. The investigators found that a higher liver concentration of PFAS (largely consisting of PFOS) was associated with a lower body condition, although noted that results could have been explained in part by other contaminants such as metals. The study also found that PFAS exposure resulted in the significant enrichment of 11 different groups of metabolites, suggesting perturbation of metabolic pathways. The authors postulated that the observed lower body condition may be a result of PFAS-induced perturbation of energy production pathways (Lettoof et al. 2023).

1.5 Priority Topics for Sampling and Analysis

Section Number	Topic
1.5.1	**Leaching Methods**
1.5.2	**Fish Sampling and Laboratory Homogenization**
1.5.3	**Ultrashort-chain PFAS Analysis**
1.5.4	**Consumer Product Testing**
1.5.5	**ISM for PFAS Sampling**
1.5.6	**Concrete and Asphalt Sampling and Analysis**
1.5.7	**Field Screening Tools**

Information in these Priority Topics was prepared to supplement the information published in **Section 11** and the **PFAS Analytical Methods** Excel file. Information about Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) projects for Sampling and Analysis can be found at **https://serdp-estcp.mil/**.

1.5.1 Leaching Methods

Approaches, methods, and tools available to evaluate PFAS leachability were previously discussed in **Section 10.4.1**. Information presented here provides an update on the current state of methods and studies since the last update of the Guidance Document in 2023.

The US Environmental Protection Agency (USEPA) has published two hazardous waste methods (SW-846) relating to leaching. One, SW-846 Method 1311 (USEPA 1992), the Toxicity Characteristic Leaching Procedure (TCLP), simulates landfill leachate conditions to evaluate the mobility of organic and inorganic analytes present in liquid, solid, and multiphase wastes. The other, SW-846 Method 1312 (USEPA 1994), the Synthetic Precipitation Leaching Procedure (SPLP), simulates weathering in situ by acid rain to model the leaching of organic and inorganic analytes present in liquids, solids, and multiphase wastes under normal weather conditions.

In addition to these two methods, the Leaching Environmental Assessment Framework (LEAF) is the result of long-standing collaboration between experts and scientists in association with the Vanderbilt University School of Engineering, the Energy Centre of the Netherlands, Arcadis-US Inc., and the USEPA Offices of Research and Development and Solid Waste and Emergency Response. In 2011, USEPA released a report providing detailed background information for the LEAF Methods (USEPA 2011). The LEAF documentation provides for standardizations of multiple leach testing methods and pairs premade laboratory data collection templates with both laboratory data management and data analysis tools.

LEAF testing is currently represented by four defined methods:

- Method 1313—Liquid-Solid Partitioning as a Function of Extract pH Using a Parallel Batch Extraction Procedure (USEPA 2017)
- Method 1314—Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio for Constituents in Solid Materials Using an Up-Flow Percolation Column Procedure (USEPA 2017)
- Method 1315—Mass Transfer Rates of Constituents in Monolithic or Compacted Granular Materials Using a Semi-Dynamic Tank Leaching Procedure (USEPA 2017)
- Method 1316—Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio Using a Parallel Batch Extraction Procedure (USEPA 2017)

These four leaching test procedures follow a tiered approach presented by Kosson et al. (2002) (Vanderbilt University 2025) and can provide insights into the rate and extent of leaching processes through evaluation of pH, liquid-to-solid ratio, and leaching time representing the tested conditions.

Use of such innovative testing, data management, modeling, and presentation tools is of immense benefit to environmental practitioners related to data evaluation and sharing and reflects the increasing availability of powerful data processing technologies.

The framework is supported by the following downloadable tools (Vanderbilt University 2025)

- Preliminary versions of USEPA leaching test methods
- Data templates for collecting, archiving, and uploading laboratory leaching test data
- Latest “for distribution” version of LeachXS Lite
- Various publications (or links to sources) that support and demonstrate LEAF for several materials

The downloads are free but require application submission to obtain a free user license. The USEPA has developed a LEAF How-To Guide and currently maintains a website regarding LEAF Methods and Guidance (USEPA 2019). The relevant LEAF supporting downloads are only available through Vanderbilt University. These links are provided above.

Both the LEAF methods and guidance and the two SW-846 methods have not, however, been validated specifically for use in evaluating per- and polyfluoroalkyl substances (PFAS) mobility (Strock 2024). SERDP has funded one project (ER23-3761) focused on the optimization of LEAF for the evaluation of PFAS mobility. Vanderbilt University and the USEPA are evaluating these optimized protocols through a multilaboratory validation study. Release of these optimized protocols is pending the outcome of this validation effort. Release of these optimized protocols is pending the outcome of this validation effort.

Outside of the US, entities have published their own leaching procedures. For example, Australia published the Australian Standard Leaching Procedures tests, AS4439.2:2019: *Wastes, sediments, and contaminated soils. Part 2: Preparation of leachates—Zero headspace procedure* and AS4439.3:2019: *Wastes, sediments, and contaminated soils, Part 3: Preparation of leachates—Bottle leaching procedure*. However, these tests have also not been optimized for the evaluation of PFAS leachability. See Appendix H of HEPA (Heads of EPA Australia and New Zealand) (2025) for more information. Kleja et al. (2025) evaluated the ISO leaching tests and Kalbe, Pieochotta, and Bandow (2024) evaluated European leaching tests for use on soils containing PFAS.

New Jersey Department of Environmental Protection (NJDEP) has a developed guidance and a spreadsheet calculator for site-specific soil-to-groundwater screening levels and soil-water partition coefficients (Kd) for specific PFAS using Synthetic Precipitation Leaching Procedure (SPLP) results. Within the "Soil and Soil Leachate Migration to Ground Water Exposure Pathway Calculator," SPLP analytical results are adjusted to field conditions through NJDEP's calculator and are intended to be compared to existing soil leachate remediation standards (NJDEP 2025).

A number of publications have evaluated the application of existing leaching methods to PFAS (for example, Navarro et al. 2024; Kalbe et al. 2024; Rayner et al. 2022), all of which support the conclusion that optimization for the evaluation of PFAS is needed. Others evaluated PFAS leaching in situ using high-resolution characterization techniques (for example, Bigler et al. 2024). PFAS sorption and desorption processes with a focus on understanding leaching is another active research area. For example, Bierbaum et al. (2023) examined rate-limited leaching in column and lysimeter experiments, the relevance of sorption to the air-water interface, and colloid-facilitated transport. USEPA (2025) provides information about using SPLP with modifications for PFAS.

1.5.2 Fish Sampling and Laboratory Homogenization

The goal of this section is to summarize current knowledge on fish sample collection and preparation. The sample collection discussion presents information about containers, shipping, and general best practices, as available in the literature. Seasonal variability is discussed. Avoiding cross contamination with processing steps such as homogenization is discussed, including parameters to be considered (for example, whole body fish, fillets, skin on/skin off). Sampling procedures for fish are discussed in **Section 11.1.7.11**. Information presented here provides an update on the current state of methods and studies since the last update of the Guidance Document in 2023.

1.5.2.1 Sampling Design Considerations

Multiple studies in the literature have measured PFAS in fish, but few standardized approaches inform field collection and laboratory preparation of fish. Most recently, USEPA released Method 1633A, a standardized method including general guidance for sample collection, preparation, and analysis of 40 PFAS in biological tissues (USEPA 2024). FDA C-010.03 provides laboratory preparation and analysis guidance for 30 analytes in food matrixes, including fish and shellfish, with validation in salmon and clams (USFDA 2024). USDA CLG-PFAS 2.04 provides laboratory preparation and analysis of 16 PFAS in catfish muscle, as well as some mammalian and poultry tissues (USDA 2023) .

Beyond USEPA Method 1633A, more detailed protocols for fish sampling activities remain limited. However, some existing guidance designed for other contaminants may provide general guidance for fish sampling efforts for PFAS (USEPA2000). Additionally, general techniques and best practices that delineate sampling in other matrixes may be applicable to fish and other biota. For example, field and laboratory activities should avoid PFAS-containing equipment and supplies to minimize the risk of cross-contamination, as recommended for collection of water, sediment, and other ecological matrixes (MI DEQ 2019; USEPA 2024).

PFAS levels in fish vary based on organism phenology or seasonal environmental fluctuations impacting ambient PFAS levels (Petali et al. 2024; Taylor 2019). For example, fish have been demonstrated to transfer PFAS to their eggs depurate PFAS during egg-laying (Conard et al. 2022). Seasonal migration, dietary changes, or behavioral changes can also impact organismal interactions with the environment and resulting PFAS accumulation (Petali et al. 2024). Seasonal hydrodynamics may cause changes to ambient PFAS levels in water and may impact observed body burdens in resident fish, though some data suggest migratory patterns may primarily drive PFAS body burdens as compared to ambient water levels (Pignotti et al. 2017; Tokranov et al. 2021; Taylor 2020). Stocked fish may rapidly accumulate PFAS in situ depending on ambient water concentrations, therefore stocking date should be considered if sampling stocked fish (Danielson 2023). Additionally, operational and safety constraints may limit site accessibility to certain seasons or periods. The timing of collection activities should consider relevant seasonality or periodicity impacting target species; those studies seeking interannual comparisons should collect fish within a similar time frame each year.

Varied diet, habitat, and migratory choices result in inherent variability in PFAS concentrations found in fish, with implications for sample size goals (Petali et al. 2024). Guidance offered by a state fish collection standard operating procedure suggests at least ten fish should be collected, including both sexes (MI DEQ 2019). A modeling effort examining the impact of sample size on derived mean and median concentrations suggested collection of at least 20 individuals per location, with a suggested sample size of 30–50 individuals, to derive robust concentration medians for use in human health risk assessment (Taylor 2019). In practice, budget constraints and laboratory bandwidth are also key factors dictating sample size.

The size of fish included in PFAS sampling may vary, as the relationship between fish length and PFAS body burden is unclear. This uncertainty has notable implications for study design. Some studies suggest PFAS levels correlate to animal size—for example, mass or length—while others find no such relationship or nuanced size–PFAS relationships in different species or habitats (Taylor 2019; Hedgespeth et al. 2023; Fair et al. 2019). In practice, a range of fish lengths may be sampled to achieve population summary data, while only fish of a specific size class, as an indicator of age class, may be targeted for derivation of more accurate bioaccumulation or biomagnification characteristics.

Given the unique factors influencing PFAS body burdens in fish, a work plan delineating study design, field sampling plans, and associated quality assurance measures should be constructed prior to initiating field efforts, specifically considering how sampling elements facilitate PFAS study goals. For example, if spatial comparison is an objective, wide-ranging, common species that occur across the region of interest should be targeted. If human health risk assessment is a project goal, fish species and sizes typically consumed by anglers should be sampled. If ecological risk assessment is the primary goal, fish species and sizes regularly consumed by birds, mammals, or other focal predatory species should be collected.

1.5.2.2 Sampling, Equipment, and Supplies

Multiple mechanisms exist to collect fish, including seine trawls, electrofishing, rod and line, or fish traps; shellfish may be collected by hand or bottom trawl. Each approach is inherently opportunistic, as sampling efforts are constrained to those individuals randomly inhabiting a given location and capable of

interacting with the collection gear. No data exist documenting the impact of collection mechanism on PFAS body burdens in fish, though some guidance suggests the risk of contamination during collection is minimal given the presence of PFAS within internal tissue reservoirs and the order of magnitude difference of biota concentrations (typically ppb) compared to water (typically ppt).

Sample container material recommendations depend on the size and number of fish or shellfish to be collected. USEPA Method 1633A recommends wrapping collected fish in aluminum foil or storing in polyethylene tubing, whereas MI DEQ (2019) guidance suggests rinsing fish with ambient water before storing individually in polyethylene bags. Literature studies used polyethylene bags, high-density polyethylene (HDPE) or polypropylene vessels, or glass vessels to store fish samples (Blazer et al. 2024; Fair et al. 2019; Soudani et al. 2024). USEPA Method 1633A recommends storing collected fish or fish tissues at or below 6°C from the time of collection until receipt by the processing laboratory for a maximum of 24 hours. If a longer transport time is necessary, 1633A recommends freezing the sample upon collection before storage and shipment on dry ice or otherwise chilling to maintain sample temperature below 6°C.

Once received by the laboratory, USEPA Method 1633A recommends sample storage in a manner protected from light at or below -20°C until prepared for laboratory activities. USEPA Method 1633A also recommends that sample storage should be no more than 90 days from collection to sample extraction. Preliminary data from a 2023 USEPA retrospective study of archived tissues suggest fish fillet tissue samples may be frozen for up to 5 years without significant impacts on PFAS measurements, but further study may be required to validate holding times for specific species and tissue types to be used for regulatory purposes (McCarty et al. 2024).

1.5.2.3 Sample Dissection, Homogenization, and Lyophilization

Materials that directly contact fish tissue during dissection and sample processing should be PFAS-free. Recommended decontamination approaches include rinsing equipment and consumables with water and available/appropriate solvents prior to use and between samples (MI DEQ 2019; USEPA 2024). Existing guidance suggests general dissection procedures used to obtain tissue samples for other contaminant monitoring efforts may be used to obtain fish tissue samples for PFAS analysis, accounting for PFAS-specific contamination risk (MI DEQ 2019; NY DEC 2023; USEPA 2000). Fish plasma, muscle fillets with and without skin, muscle plugs, liver, and internal organs have been used for PFAS measurements in addition to whole fish carcass (whole body) samples (Nilsen et al. 2024; Blazer et al. 2024; Levanduski et al. 2024; Miranda et al. 2023). Although skin-off fillets have been found to contain lower PFAS concentrations compared to skin-on fillets, the decision to retain skin should consider routine consumption trends and prior sampling practices to ensure data comparability to any archived samples (Figueroa-Munoz et al. 2025). Muscle plugs have been used for PFAS analysis, though no published information currently compares concentrations derived via plugs to whole muscle samples, as has been demonstrated for heavy metals (Miranda et al. 2023; Stahl et al. 2021). Additionally, no published information documents the impacts of homogenization on subsequent PFAS measurement in tissue, though a limited comparative effort suggests variable homogenization efficiency between different tools (Shaw et al. 2024). Lyophilization may be used during tissue preparation to address variable water content in different tissue matrixes and increase extraction efficacy of organic solvents. Literature suggests partial loss of some volatile compounds during lyophilization of tissue with good retention of long-chain PFAAs (Balgooyen et al. 2025; Carrizo et al. 2023). USEPA Method 1633A does not include lyophilization, and multiple datasets have derived PFAS measurements directly from wet tissue (Blazer et al. 2024; USEPA 2022).

1.5.2.4 Analysis

Analytical strategies validated for analysis of fish tissue are detailed by recently published methods such as USEPA Method1633A (USEPA 2024), FDA C-010.03 (USFDA 2024), and USDA CLG-PFAS 2.04 (USDA

2023) , as well as a substantial body of peer-reviewed literature (Valsecchi et al. 2013; Nakayama et al. 2019). These methods provide separation and detection conditions for specific anionic analytes in fish tissue and other complex matrixes. Regardless of applied method, the complexity of endogenous chemicals (for example, lipids, fatty acids, and proteins) inherently present in fish tissues varies by species and life stage, which may present unique analytical challenges. Some endogenous chemicals may interfere with analytical measurements of PFAS conducted using tandem mass spectrometry platforms. Variable preparation strategies, separation techniques, or high-resolution mass spectrometry (HRMS) can be leveraged to confirm or refute potential interferences (Bangma et al. 2024;, MI EGLE 2024). Endogenous molecules may also impact ionization efficiency; some peer-reviewed studies include the use of matrix-matched curves to better account for matrix effects during analysis and quantification (Carrizo et al. 2023; Malinsky et al. 2011). Continued efforts seek to refine analytical strategies for fish tissues and other complex matrixes, leveraging techniques such as HRMS and non-targeted analysis, ion mobility, total oxidizable precursor (TOP) assay, and extractable organofluorine analysis to expand analytical coverage of PFAS in fish tissues (Boatman et al. 2024; Pickard et al. 2022; Pickard et al. 2024). These methods have not been validated or standardized across the range of fish species and tissue types; therefore, data derived using these methods should be used with caution.

1.5.3 Ultrashort-chain PFAS Analysis

This section provides information regarding the analysis of ultrashort-chain PFAS (ultrashort PFAS), including the feasibility and challenges of using existing PFAS analytical methods. This topic supplements **Section 11.2**, which addresses analytical methods and techniques. For additional information about ultrashort PFAS, see **Section 1.1.3.1**. For additional examples and occurrences and health effects associated with ultrashort PFAS, see **Section 1.4.4**. In addition, see the updated **Table 4-1** for physical and chemical properties of some ultrashort PFAS.

1.5.3.1 Overview

The measurement of ultrashort PFAS was not seen to be as important as the measurement of short-chain and long-chain PFAS in the early days of PFAS testing. However, the implementation of "replacement" PFAS, the higher concentrations of ultrashort PFAS in the environment, and the presence of ultrashort PFAS almost everywhere increased the importance of ultrashort PFAS measurement over time. Much of the development for the measurement of ultrashort PFAS has occurred in recent years as the need to evaluate them has increased (Ateia et al. 2019). USEPA added two ultrashort PFAS to the Regional Screening Levels table: perfluoropropanoic acid (PFPrA) and 1,1,1-trifluoro-N-[(trifluoromethyl)sulfonyl]methanesulfonamide (TFSi).

1.5.3.2 Ultrashort-chain PFAS

Table 1-11 lists ultrashort PFAS that currently have commercially available analytical reference materials. As of September 2025, no consensus methods have been published for this class of compounds. Most ultrashort PFAS analyses will not include all these compounds, but any of them may be expected to be reported from an ultrashort PFAS analysis. Note that the salt forms associated with these acids will have different CAS Registry numbers. See "Anions Versus Acids" in **Section 2.2.3.1** for an explanation.

Numerous methods have been developed and published for the analysis of ultrashort PFAS (for example, Wang et al.2024; Zou et al. 2024; Liang, Steimling, and Chang 2023; Jacob and Helbling 2022). A significant challenge in measuring ultrashort PFAS is their incompatibility with reversed-phase liquid chromatography, which is the preferred technique for analysis of PFAS having four or more carbon atoms.

This challenge is commonly overcome using a different stationary phase. Various choices are available, including hydrophobic-interaction liquid chromatography (HILIC), ion exchange chromatography, and

various hybrids of those reversed-phase, HILIC, and ion exchange stationary phases (Bjornsdotter et al. 2020). The ideal column, mobile phases, and gradient will depend on the ultrashort PFAS being analyzed.

Aside from issues with retention on the cartridge or column, another major challenge with measuring ultrashort PFAS is blank contamination, particularly from TFA. This can impact the interpretation and quantitation of analytical results. Prior work has shown that laboratory consumables, particularly those containing fluoropolymers, can leach ultrashort-chain PFAS such as TFA (Joudan et al. 2024).

Table 1-11. Commonly reported ultrashort-chain PFAS.

Analyte Name	Acronym	CAS Number
2,2,3,3-Tetrafluoropropanoic acid	2,2,3,3-TFPA	756-09-2
2,3,3,3-Tetrafluoropropanoic acid	2,3,3,3-TFPA	359-49-9
Perfluoropropanoic acid	PFPrA	422-64-0
1,1,1-Trifluoro-N-[(trifluoromethyl)sulfonyl]methanesulfonamide	TFSi	82213-65-3
Trifluoroacetic acid	TFA	76-05-1
Trifluoromethanesulfonic acid	TFMS	1493-13-6
Perfluoropropane-sulfonic acid	PFPrS	423-41-6
Perfluoroethanesulfonic acid	PFEtS	354-88-1
Difluoroacetic acid	DFA	381-73-7
Perfluoro-2-methoxyacetic acid	PFMOAA	674-13-5

1.5.3.3 Simultaneous Analysis of Ultrashort-chain and Other PFAS

For the most part, the use of these alternative liquid chromatography (LC) stationary phases prevents the inclusion of larger PFAS in the same analysis, although 4-, 5-, and even 6-carbon PFAS may be analyzed along with the ultrashort PFAS. Larger PFAS typically have less retention on these columns as the number of carbons increases, although exceptions may exist. More complicated chromatographic systems involving combinations of columns can be attempted to address this issue, but the desire to have a single analysis must be balanced against the increased complexity and vulnerability to problems that increase with such an approach.

Recently, LC stationary phases that mix either HILIC or ion exchange or both with reversed-phase LC stationary phases provide some hope that ultrashort PFAS may be analyzed in the same analysis as larger PFAS (Waters Corporation 2023; Restek Corporation 2024). This aspect of ultrashort PFAS analysis is very much in its early phase, and one can reasonably expect that things will change. Until new approaches to simultaneously analyze a wide range of PFAS with varying carbon chain lengths emerge, analysis of ultrashort PFAS will often be a separate analysis from the short- and long-chain PFAS.

1.5.3.4 Sample Preparation

Sample preparation before analysis is another area of active development. Water samples of various sorts are typically handled by weak-anion exchange (WAX)/reverse-phase hybrid SPE sorbents. Solid samples likewise follow other methods in that an initial extraction of the solid in basic methanol is followed by dilution in water and SPE in the same manner as water samples. The QuECHeRs (Quick, Easy, Cheap, Rugged, and Safe) method has been explored for food samples, but it is not clear whether stable-isotope-labeled extraction standard recoveries were comparable to those obtained with WAX SPE (Santa-Mayor et al. 2023).

Other options for sample preparation for the analysis of ultrashort PFAS include preparation for direct injection analysis and on-line SPE (Jacob and Helbling. 2022). Direct injection analysis is particularly appropriate for many ultrashort PFAS due to the near-ubiquitous presence of ultrashort PFAS in all parts of the environment and the relatively high concentrations in the environment of many of them. One study from the State of California Division of Drinking Water showed elevated detection limits when performing direct injection analysis compared to WAX SPE (CA Water Boards 2024).

On-line SPE combines the process of extraction and analysis of a sample into a single process by placing SPE columns in-line with the analytical LC column. This technique simplifies and reduces the cost of SPE when it works well, but the relatively small bed volume of SPE columns and reusable nature of them can lead to degradation in SPE performance, contamination, and building of back-pressure that can cause analysis to halt.

1.5.3.5 TOP Assay

Many implementations of the TOP assay have not included any measurement of ultrashort PFAS (Neuwald et al. 2022). Conversion of precursors containing four or more carbons to end products having three or fewer carbons is therefore not assessed. Likewise, conversion of molecules with two or three carbons is not assessed when ultrashort PFAS are not measured.

TOP assay typically produces a higher concentration of perfluorocarboxylic acids (PFCAs) with decreasing chain length thereof. Thus, in a typical measurement of PFCAs having between 4 and 14 carbons, perfluorobutanoic acid (PFBA) is the most increased in abundance, followed by perfluoropentanoic acid (PFPeA), then perfluorohexanoic acid (PFHxA). That pattern suggests that one should reasonably expect that PFPrA would be more abundant than PFBA, and TFA more abundant than PFPrA. Although the precise proportion of conversion products is not known, it is a reasonable assumption that a significant proportion of conversion products is not captured when ultrashort PFAS are not measured. Note that other possible distributions of products could occur, depending on the precursors present. More information about TOP assay is included in **Section 11.2.2.2**.

One example of a study in which ultrashort PFAS were analyzed after oxidation can be found in Tsou et al. (2023). This study showed, as expected, that both PFPrA and TFA were found in samples that had been oxidized. The relative proportions of the ultrashort PFAS to one another and short- and long-chain PFAS varies from sample to sample, but the ultrashort PFAS content is, as one would anticipate, significant relative to the other PFAS. Another example can be found in Janda et al. (2019), which provides information on an improved protocol for the TOP assay when targeting 2- to 14-carbon chains.

1.5.3.6 High-Resolution Mass Spectrometry of Ultrashort-chain PFAS

Studies of ultrashort PFAS using HRMS for non-targeted analysis (NTA) are relatively few, but ultrashort PFAS should be detectable in NTA, provided they are high enough in concentration to be detected. Those ultrashort PFAS with reference standards can be unambiguously identified. Other compounds may be more difficult to identify.

As with any HRMS NTA, the precise concentration of a compound cannot be known without a quantitative standard. Both ionization and fragmentation can be (and usually are) affected by changes in molecular composition or structure. Therefore, one cannot determine a detection limit without a quantitative standard. These factors result in some uncertainty in the ability to detect compounds in an NTA.

As with targeted analysis, high polarity of ultrashort PFAS introduces another difficulty in that a column other than the usual reversed-phase column must be used to separate the ultrashort PFAS from other components to avoid distortion of the mass spectrum from interfering compounds.

1.5.4 Consumer Product Testing

This section describes the current testing methods, types of analyses, data uses, and regulations related to the testing of PFAS in consumer products such as textiles, food packaging, cosmetics, nonstick cookware, and juvenile products. This topic supplements **Section 11.1.7**, which discusses PFAS sampling in various media but does not discuss consumer products.

1.5.4.1 Current Testing Methods

A variety of analytical methods is available for PFAS testing; however, only a few of them have been validated for consumer products and other chemical products with complicated matrixes. Testing of PFAS in consumer products can be addressed through multiple analyses and may use a workflow combining fluorine content analysis, target analysis, and non-targeted or suspect screening analysis methods. See ASTM F3700-25 Standard Guide for Selecting and Applying Analytical Methods to Evaluate PFAS in Consumer and Related Products (ASTM 2025).

Consumer products testing presents unique challenges due to the sample matrix, differentiating them from environmental media testing. The sample matrix for products is typically a complex composition from diverse materials (paper, fabric, natural materials, plastics). PFAS could be included in consumer products at percent levels to provide a certain function or could be residues or impurities from the manufacturing process. Other chemicals in the matrix can interfere with PFAS analytical processes from sample preparation to instrument analysis. Extra techniques are required to reduce matrix effects but issues such as co-elution in chromatography, ion suppression in mass spectrometry, or signal masking, may still be present. Sample preparation can be difficult for consumer products made with polymeric PFAS.

1.5.4.2 Targeted Analysis

In targeted analysis, testing methods generally involve LC or gas chromatography (GC), and mass spectrometry (MS). LC/MS is capable of monitoring short-chain PFAS and ionic PFAS, while GC/MS will measure the more neutral and volatile PFAS (TemaNord 2024). In commercial labs, LC/MS is more available for PFAS analyses.

Validated methods for PFAS testing in consumer products are very limited. USEPA has a single laboratory validated method from 2024 for testing 31 PFAS in plastic container walls such as HDPE by LC/MS/MS, and it may be used with modifications for solid samples such as fabric or packaging paper (USEPA, 2024). ISO published an LC/MS/MS method to determine extractable nonvolatile PFAS in leather and coated leather (ISO 23702-1:2023 | IULTCS/IUC 39-1) (ISO 2023). This method is specifically designed for long-chain PFAS (C7-C14). Europe combined LC and GC in method EN 17681-1:2025 (European Committee for Standardization (CEN) 2025) and EN 17681-2: 2022 (European Committee for Standardization (CEN) 2022) to test textiles and textile products for selected extractable PFAS (PFOA, PFOS).

In instances when a validated method does not exist for a specific consumer product, methods validated for soil, sludge, and solids, such as USEPA Method 1633A (USEPA 2024), DIN 38414-14 (DIN 2014), ASTM D7979 (ASTM 2020), and ISO 25101(ISO 2009), are often modified or used as the basis for testing. All targeted methods have a list of predefined PFAS. A primary limitation of these methods comes from the availability of analytical reference standards for individual PFAS.

Other targeted analytical techniques are still in the research phase and lack established or standard methods. For example, pyrolysis-gas chromatography-mass spectrometry (pyr/GC/MS) can be used for the bulk characterization of fluorinated polymers (polymeric PFAS) in consumer products. Pyr/GC/MS methods involve pyrolyzing a sample directly (without extraction) at temperatures between 250°C and

1,000°C, followed by online analysis of the degradation products. Skedung et al. (2024) used a pyrolysis method, applying a maximum pyrolysis temperature of 700°C to 45 consumer products and identified polytetrafluoroethylene (PTFE, most used fluorinated polymer) in cookware, dental products, and electronics at concentrations as low as 0.1–0.2 wt%. It was also possible to use pyr/GC/MS to distinguish between three different side-chain fluorinated polymers in textiles (Skedung et al. 2024). Recent work has established solid-phase microextraction protocols for both aqueous- and gas-phase PFAS analysis (Martínez-Pérez-Cejuela et al. 2025). Such work may allow for outgassing or emissions testing of consumer products; ASTM (2025) acknowledges the application of "off-gassing techniques to determine the potential release of PFAS from products over the product life cycle" (F3700-25, 1.4). Earlier emissions work employed thermal desorption focusing on fluorotelomer alcohols (FTOHs) (Robbins et al. 2023).

In addition to these targeted methods, some laboratories have applied TOP assay to measure PFAAs derived from precursors that undergo oxidation by hydroxyl radicals. To measure precursor concentrations, the most common target PFAS are measured before and after the oxidation using conventional targeted PFAS analysis such as LC/MS (Ateia et al. 2023). However, some PFAS precursors may not be extracted, and incomplete oxidation can occur (for example, PFAS with ether functional groups that are resistant to oxidation), or oxidation products could be missed (for example, ultrashort PFAS) in traditional target analysis. The limitation of TOP assay on ultrashort PFAS is not limited to consumer product testing and is also discussed in **Section 1.5.3.5**.

Targeted analysis is the most sensitive and confirmative method to measure PFAS in consumer products. But major challenges still exist, including the lack of standard methods, the limited number of individual PFAS that can be measured, and the need for optimalization of extraction procedures (TemaNord 2022).

1.5.4.3 Fluorine Screening

Although they are not yet validated, this section discusses several useful methods for detecting fluorine instead of individual PFAS. For fluorine screening, it is important to note that while all PFAS contain fluorine, not all fluorine-containing compounds are considered PFAS. NTAs discussed in this section include methods that look for totals, such as extractable organic fluorine or total fluorine, and do not reference the NTA looking at suspect screening or unknown targets present in a sample.

Polymeric vs. Nonpolymeric PFAS

Many state-level legislative actions for consumer product bans use total organic fluorine (TOF) as the determining factor for presence or absence of PFAS. If a legislative action does not specifically exclude polymeric PFAS in the TOF content, then it should be assumed that polymeric PFAS is included as part of the TOF. For example, New Mexico's legislation on PFAS (HB 212), signed on April 8, 2025, specifically excludes fluoropolymers from the legislative action. Inclusion or exclusion of polymeric PFAS is an important factor in determining which analytical tests are the best fit for determining organic fluorine content. For more information about analytical tests for determining organic fluorine, see **Section 1.4.5**.

Types of Analysis

TOF refers to *all* organic fluorine present in a given sample. Although there is currently no test to directly measure TOF, there are methods to approximate a TOF concentration. The current conventional tests for fluorine include:

- Total fluorine (TF), which includes all fluorine present in a sample, inorganic and organic, including polymeric and nonpolymeric forms if present. This can be used for both aqueous and solid samples.

- Inorganic fluoride (IF), which includes soluble inorganic fluoride. This can be used for both aqueous and solid samples.

- Extractable organic fluorine (EOF), which includes organofluorine compounds, encompassing both PFAS and non-PFAS. This can be used for aqueous and solid samples.

- Adsorbable organic fluorine (AOF), which includes organofluorine compounds that will adsorb to carbon, encompassing both PFAS and non-PFAS. This applies only to aqueous samples.

Each of these have some limitations. Where TF includes all fluorine present in a sample, this could overestimate the concentration of organofluorine compounds in the sample. EOF will include only the organofluorine compounds amenable to the extraction process. For example, aqueous samples will depend on the type of solid-phase extraction (SPE) cartridge used. Weak-anion exchange (WAX) cartridges will target anionic PFAS and mostly exclude cationic and zwitterionic PFAS. A hydrophilic-lipophilic balance cartridge may include a larger range of PFAS (Idowu et al. 2025). For solid samples, EOF efficiency will be based on the extraction solvent used and the affinity for each class of PFAS to that extraction solvent (example methodology can be found in Spaan et al. 2020; Spaan et al. 2021). EOF may contain some polymeric PFAS but will not include all polymeric PFAS present in a sample. AOF is limited to aqueous samples. The affinity for shorter chain PFAS (< C4 chain length) to carbon may present a negative bias for shorter chain PFAS. AOF may include some but will not include all polymeric PFAS if present.

To put this in perspective, the potential concentrations for each group would be TF > TOF > EOF > AOF (Ateia et al. 2023). As there is currently no method to directly measure TOF, it is typically reported mathematically by subtracting the IF concentration from the TF concentration, but this method has limitations. These limitations include differences in reporting limits, with limits for inorganic fluoride in the mg/kg (ppm) range and limits for TF and EOF in the ng/g (ppb) range. Use of this calculation may also be confounded by insoluble inorganic fluoride, including naturally occurring minerals such as fluorite, also known as fluorspar (CaF_2). There are currently no published methods for the quantification of insoluble inorganic fluoride. Both EOF and AOF may be reported as TOF, however, the limitations discussed above should be considered when using this convention. It is important to consider the type of consumer product being tested and the potential types of IF, as well as polymeric PFAS, that could be present in a sample. For example, testing TF may be sufficient for determining presence or absence of PFAS in a sample when IF is not present. Conversely, a consumer product high in insoluble inorganic fluoride may need a different approach. It is equally important to consider the end use of the data because TOF may detect organofluorine chemicals that are not PFAS.

These analyses are not specific to consumer product testing but are very relevant tools when TOF or TF are part of a regulation for PFAS in consumer products.

Combustion Ion Chromatography

Combustion ion chromatography (CIC) is used to measure TF, IF, AOF, and EOF, see **Section 11.2.2.4**. If a sample is combusted by CIC prior to adsorption or extraction, then the resulting fluoride concentration corresponds to TF, which refers to both the organically and inorganically bound fluoride present in the sample. TF may not be as reliable of a proxy for PFAS if, for example, fluorine-containing minerals or IF are present at high concentrations in the sample.. USEPA Method 1621 quantifies the concentration of AOF in aqueous samples by adsorbing the organofluorine compounds to a granular activated carbon cartridge that then is combusted (USEPA 2024). EOF can measure organic fluorine in both aqueous and solid samples by extracting the organofluorine compounds from the sample prior to combustion. The methods used for EOF extraction are similar to those used for targeted PFAS extraction with the addition of a step that removes the inorganic fluorine from the sample (Ruyle et al. 2023). There is no standardized EOF method, but it has been validated through interlaboratory comparisons (Kärrman et al.

2021). Ruyle et al. (2023) provides a table of recommended best practices for EOF analysis that can be referenced because there is no standardized method yet.

Other Total Fluorine and Organofluorine Methods

- Particle-induced gamma-ray emission (PIGE), see **Section 11.2.2.3**. This is a nondestructive rapid screening tool that measures TF. Like TF above, PIGE does not distinguish between types of fluorine and would include inorganic fluorine, polymeric PFAS, nonpolymeric PFAS, and other organic fluorine.

- X-ray photoelectron spectroscopy (XPS). This analytical technique is used to measure fluorine on the surface of a product, looking at the top few nanometers of a sample (Tokranov et al., 2018). This process is highly sensitive to fluorine. XPS can distinguish between different types of chemical bonds, differentiating classes of PFAS (but not identifying individual compounds). There are sample preparation challenges, because XPS requires samples to be analyzed under high vacuum, which can cause issues for certain matrixes.

- Soluble inorganic fluoride in consumer products can be measured by extracting with water or weak acid followed by analysis by a published method. Methods that include soluble inorganic fluoride include USEPA Method 300.1 (USEPA 1997); ASTM D1179 (ASTM 2021); and ASTM D4327 (ASTM 2025).

- TOP assay, see **Section 11.2.2.2**. The TOP assay is a proxy method to determine additional PFAS present in a sample that cannot be measured by current targeted methods. This method uses the current targeted analytical methods, with a pre- and post-oxidation sample analysis. The difference in PFCAs between these two samples is attributed to the conversion of oxidizable precursors to PFCAs.

Fluorine Screening Methods

There are currently no validated methods that are specific to TOF in consumer products. In European standards, there is no method specified for the determination of organic fluorine in consumer products, only a reference to EN 14582:2016 Characterization of Waste (European Committee for Standardization 2016), which specifies a combustion method for the determination of halogen and sulfur contents. Oxygen combustion in closed systems and determination methods is frequently referenced for consumer product testing. A few research papers compared the target analysis with TF or TOF analysis and revealed the huge discrepancy between fluorine and speciated PFAS. It was consistently found in consumer product testing that the total amount of fluorine cannot be correlated with the sum of speciated PFAS. For example, Rodgers et al. (2002) tested 54 samples with total fluorine over 10 ppm for 36 targeted PFAS via a methanol extraction followed by LC/MS/MS and found that the total amount of fluorine attributable to methanol-extractable target PFAS analytes and to PFAAs generated from oxidizable precursors in samples never exceeded 0.1% of the total F measured in these products.

1.5.4.4 Non-targeted Analysis

Suspect screening and NTA are designed to detect and identify a wide array of known and unknown PFAS without prior knowledge of the chemicals' exact structures or identities, see **Section 11.4**. Though NTA, such as HRMS, has been successfully applied to a wider range of PFAS in contaminated matrixes, these analytical approaches are not yet common in consumer product analysis (Bugsel, Zweigle, and Zwiener 2023). Most method developments are in the research phase.

A notable study by Stroski et al. (2024) developed NTA workflows to investigate unknown PFAS in various food packaging materials, including paper-based and foil wrappers. The research identified both legacy

and emerging PFAS, such as 6:2 fluorotelomer phosphate diester (6:2 diPAP) and its transformation product 2H-perfluoro-2-octenoic acid, also known as 6:2 fluorotelomer unsaturated carboxylic acid (6:2 FTUCA), in these materials. Beyond food packaging, NTA has revealed the presence of PFAS in several other consumer products, including textiles, cosmetics, and household items. A recent study by the National Institute of Standards and Technology (NIST) employed liquid chromatography-HRMS combined with suspect screening to analyze over 4,000 PFAS in firefighter turnout gear textiles (NIST 2025). One major challenge of using HRMS for PFAS detection in consumer products is the lack of analytical standards and reference spectra for the thousands of known and emerging PFAS. In addition, complex product matrixes (for example, cosmetics, textiles) can interfere with PFAS signal detection and introduce false positives or reduce confidence in compound annotations (Bugsel, Zweigle, and Zwiener 2023). Recent work has applied machine learning and two-dimensional GC analysis for consumer product emissions testing, which may establish a new workflow for PFAS emissions testing (Watson et al. 2025).

1.5.4.5 Regulations

The **Regulatory Programs Table** includes information about regulations related to the ban of PFAS in certain categories of consumer products.

Manufacturers can use PFAS testing data to show compliance with regulations, ensure consumer safety, maintain brand reputation, or identify potential contamination sources and take appropriate measures to ensure the integrity of their products. On the other hand, regulatory agencies use PFAS testing data to bring the regulated industries into compliance, guide remediation or prevention efforts, and inform rule-making decisions.

Compliance and enforcement usually require testing to follow strict quality assurance/quality control (QA/QC) procedures, use accredited laboratories, and use standardized analytical methods that are rigorously validated for various PFAS and matrixes.

1.5.5 ISM for PFAS Sampling

Incremental sampling methodology (ISM) is a method for collecting and compositing soil samples to achieve a result that is more representative of a given decision unit. Practitioners have found that the sampling density afforded by collecting many increments, together with the disciplined processing and subsampling of the combined increments, in most cases yields more consistent and reproducible results than those obtained by discrete sampling approaches (ITRC 2020). Given the unique properties and potentially low action levels associated with PFAS, there is substantial interest in determining whether ISM is an effective approach for these compounds and whether there are concerns or limitations to its use. This topic supplements **Section 11.1**, which discusses sampling equipment and procedures for PFAS in soil but does not address ISM. **Section 1.7.2.4** discusses the application of ISM-type sampling for biosolids land application sites.

Although peer-reviewed research on ISM for PFAS sampling is, to date, very limited, the Department of Defense (DoD) Environmental Data Quality Workgroup (EDQW) has evaluated the use of ISM for PFAS and identified several factors to consider that were enumerated in a white paper released on 31 January 2025 (DOD EDQW 2025). In short, the current DoD position is that ISM sampling and analysis protocols should not be adopted for PFAS without first performing a validation study of the protocol to determine and remedy sources of positive and negative bias inputs followed by publication of the validated method by the USEPA. The issues identified by the EDQW include some field sampling but are mainly laboratory processes.

Following is a general outline of the concerns highlighted in the DoD report (DOD EDQW, 2025): The grinding step cannot be performed on the ISM soils due to the decontamination procedure that would be required after each sample would cause increased surface rusting of the equipment. Another potential

concern related to grinding is the level of volatilization of the more volatile PFAS chemicals that may result from the heat generated during the grinding process. The drying and grinding steps could also potentially promote volatilization and loss of the ultrashort- and short-chain PFAS analytes. Extracted internal standard (EIS), ongoing precision and recovery (OPR), and low-level ongoing precision and recovery (LLOPR) spikes require reference materials that are not commercially available, and even if they were, would likely be cost-prohibitive and taxing on manufacturers of such standards. Finally, when collecting soil samples in the field, typical ISM sampling is performed within the top 18 inches of the soil surface. However, the report cited concerns that PFAS would likely be deeper in the soil column.

Although DoD has published their reservations with several aspects of ISM, at least three states (Hawai'i, Maine, and Michigan) are actively using modified versions of ISM for investigations involving PFAS impacts (HI DOH 2025; ME DEP 2023; ME DEP 2023; MI EGLE 2024). Specific Maine Department of Environmental Protection (DEP) methods are not outlined in reports but are referred to in their published homeowner guidance and legislative report. Hawai'i employs the Decision Unit and Multi Increment methodologies, which are similar to the ISM-type investigation methods (HI DOH, 2025). Michigan has used the full ISM to investigate areas that land-applied biosolids (MI EGLE 2024). Generally, states seem to use the planning and data quality objectives from ISM and find them applicable to sampling for PFAS in some scenarios, but there are still some debates on the 8330b laboratory processing methods. For example, Maine DEP has used a modified ISM procedure that excludes drying and sieving in the laboratory as an effort to alleviate the issues outlined by the DoD (see **Section 1.7.2.4**).

1.5.6 Concrete and Asphalt Sampling and Analysis

Frequent, historical use of aqueous film-forming foam (AFFF) at various firefighting training grounds (for example, military bases, airports, and oil refineries) has led to significant contamination of PFAS in many industrial areas to the infrastructure materials present. Two such materials of concern are the contamination present in concrete and asphalt, which are common matrixes at industrial sites. There are currently no standardized methods for sampling and analysis of PFAS in these matrixes, although many principles applied to sampling and analysis of other solid matrixes may apply.

For the purpose of this section, concrete matrixes are inorganic matrixes formed from aggregate, sand, and a complex cement (for example, Portland cement), which can vary significantly regarding ratios and input materials. Other materials, such as reinforcing steel bars and plastic fibers, have also commonly been used to enhance the engineered functions. Concrete properties can vary over time as minerals age and fracture, with rehealing also possible. Douglas et al. (2023) reviewed literature on PFAS in concrete and asphalt and found relatively little information available at present, though information on the distribution and leaching of PFAS is emerging. Although essentially a monolithic material, porosity is important for concrete sorption properties, including anticipated transport, ingress, and egress of water and PFAS (Douglas et al. 2023). Asphalt is a mixture dominated by aggregate in an organic bitumen matrix. Partitioning of PFAS in asphalt may therefore be more influenced by hydrophobic interactions than electrostatic interactions that may play a more prominent role for concrete (Douglas et al. 2023). Asphalt may also change significantly in properties over time as lower molecular weight organic solvents are lost to volatilization and other components are subject to oxidative change. Douglas et al. (2023) also concluded that use and contamination with other products, such as hydraulic fluids, oils, and degreasing solvents, can also change PFAS interactions with both concrete and asphalt.

PFAS sampling in concrete and asphalt is an important tool in managing these materials post-PFAS contamination (for example, reuse, remediate, or dispose), understanding if the contaminated matrix could pose as a secondary source of PFAS runoff during precipitation events, and determining the fate and transport of PFAS through the matrix. To date, most studies have focused on concrete with regards to understanding PFAS impacts. Best practices regarding sample collection, extraction, and analysis of concrete matrixes are discussed in the following sections. Additionally, the fate and transport of PFAS

within the matrix is also discussed to highlight considerations when trying to collect a representative sample.

Although there is currently no federal or state guidance available, the purpose of this section is to promote consistency of approaches for sampling and analysis of concrete and asphalt until more formal guidance is available. This topic supplements **Section 11.1.7**, which discusses PFAS sampling procedures for various media but does not cover concrete or asphalt.

1.5.6.1 Sample Collection and Extraction

Due to the complexities of concrete and asphalt matrixes, and the potential for changes over time, sampling is not straightforward. Work at a concrete firefighting training pad from Baduel et al. (2015) showed that PFAS concentrated in the top few centimeters, with penetration to depth largely correlating with chain length or molecular weight. In contrast, Williams et al. (2023) showed that for a different firefighting training pad, there was considerably more variability in concentrations and relationships between different PFAS with depth, with chain length a poor predictor of penetration distance. These differences could be due to the chemistry of the AFFF released, environmental conditions (for example, precipitation), or the exact composition of the concrete, as this is not uniform. Any sampling plan for PFAS analysis in these matrixes must consider potential for spatial heterogeneity and site-specific conditions.

Asphalt and concrete samples are collected as cores for transport to the laboratory. Standard coring techniques can be used. Air- and water-cooled corers are available. If water-cooled corers are used, the water used for lubrication/cooling should be verified as PFAS-free to an appropriate limit of reporting prior to use. Cores can be subsampled by dry cutting with a diamond saw into segments for monolith leach testing and for subsampling monoliths (Vo et al. 2023; Williams et al. 2023; Srivastava et al. 2024). Potential for PFAS transformation due to heat when cutting or coring does not appear to have been studied.

Cores can be collected using drilling or coring techniques that use PFAS-compatible materials (for example, stainless steel). Reused parts contacting the core should be decontaminated between each core collected. Once cores have been collected, they should be transported to the laboratory in a PFAS-compatible container (for example, an HDPE bag) at 4°C.

Although cores are valuable, obtaining sufficient cores to understand horizontal spatial variability will rarely be practical. Researchers to date have reported collecting surface samples by creating dust with a handheld electric drill (Williams et al. 2023; Vo et al. 2023; Thai et al. 2025; Thai et al. 2025). This method has also been used for sample preparation for laboratory analysis (see **Section 1.5.6.2**).

Shipping, storage, and holding times should follow guidance for other solid matrixes, for example, USEPA Method 1633A, in the absence of guidance specific to concrete and asphalt.

Samples need to undergo a methanol solvent extraction for analysis, which requires the asphalt/concrete to be finely ground to ensure sufficient extraction from the solid phase. Methods such as drilling or crushing can be used to create asphalt/concrete powder that is then subjected to the methanol extraction process. To date there has not been a standardization on the drilling/crushing of asphalt/concrete. Variables such as particle size, drill hole depth, drill bit diameter, and drill speed could alter concentrations of PFAS that are obtained in the dust sample. Though no standardized method has been developed for sample collection, any drill bit or saw blade, for example, used to process the sample for extraction should be cleaned with methanol prior to sample collection.

Methanol extraction can be enhanced by the addition of an acid or base to improve extraction efficiencies of charged PFAS. Enhanced methanol extraction in addition to sequential extraction could benefit the analysis of more complex matrixes, such as asphalt.

Information about SERDP and ESTCP projects designed to establish standardized methods for sampling asphalt and concrete contaminated with PFAS can be found on their website (**https://serdp-estcp.mil**).

1.5.6.2 Sample Analysis

LC/MS/MS is the most common analytical technique used for the measurement of PFAS in environmental samples. Paired with solid-phase extraction (to remove matrix bias and improve detection limits) or centrifugation, this method has been used for analyzing PFAS in both asphalt and concrete samples (Baduel et al. 2015; Li et al. 2024; Liu et al. 2024; Srivastava et al. 2022). There are no specific instrumental analytical considerations for concrete and asphalt extracts, but proper sample preparation is crucial to obtain more accurate results.

1.5.6.3 Fate and Transport of PFAS in Concrete

The fate and transport of PFAS within concrete is important in understanding the extent of contamination that occurs within the matrix. Horizontal transport of PFAS from a source typically behaves similarly to the natural flow path of the concrete pad. Williams et al. (2023) studied a concrete pad from a fire training area where AFFF has been used. They found that concentrations of PFAS varied considerably within relatively short distances. Understanding the contaminant flow path may help in collecting spatially representative samples. Additionally, Williams et al. (2023) identified that PFAS was found to migrate within the vertical length of the core. Depth of PFAS impacts varied depending on the concrete material (which may affect diffusion/back diffusion), age of the material, bulk flow over the material (for example, stormwater), and the material's adsorption/desorption capacity. Additionally, transport of PFAS tended to be species dependent, for both horizontal and vertical movement (Williams et al. 2023).

The transport of PFAS from a concrete slab during precipitation events can indicate whether the matrixes serve as a secondary source of contamination. Thai et al. (2022) conducted a study of concrete from a fire training area where AFFF has been used to understand the effect of rainfall to release PFAS from the concrete. During successive rainfall simulations the similar concentrations of PFAS in the simulated runoff suggested the water evaporation between simulations may generate a potential wicking effect in the concrete bringing PFAS back to the surface (Thai et al. 2022). The PFAS can be released with the next stormwater runoff event, supporting the theory that concrete could serve as a secondary source of PFAS contamination. Ponding was another scenario that Thai et al. (2022) investigated, with regards to surface water impacts from PFAS-impacted concrete. Results indicated that an initial rapid release of PFAS concentrations occurred, while subsequent ponding events noted decreased concentrations (though similar concentrations between subsequent events). This would also support the potential for concrete to serve as a secondary source of contamination (Thai et al. 2022).

1.5.6.4 Leaching Testing of Concrete

To date, information regarding leachability of PFAS from concrete is limited, one study (Srivastava et al. 2024) is discussed below, and further research is required to develop and validate leaching tests under field conditions to fully assess leaching behavior in concrete. However, it is a topic of interest because understanding leaching behavior can determine disposal needs, potential remediation methods, and reuse options.

Based on a 2024 study (Srivastava et al. 2024) some leaching characteristics and considerations were preliminarily determined. Using a modified LEAF 1315 method (USEPA 2017), three long-chain (PFOS, PFOA, and PFHxS) and one short-chain (PFHxA) compound were analyzed for their leaching behaviors.

The study determined that, of the four constituents, PFOA was retained in the concrete, with relatively low leachability, while PFHxS readily leached out of the material. This highlights the variability in behavior based on species present.

Unlike samples analyzed in a powder form, leaching tests in this study (Srivastava et al. 2024) were conducted with quartered pucks extracted from a core collected in the field, resulting in a more complex surface (rather than a homogenized mixture). As such, leaching behavior was assumed to be driven by characteristics of the concrete being tested. For example, the age of the concrete was an important factor. As concrete ages, it experiences a net loss of alkalinity and cations via surface wicking (rainfall or other fluid distribution over the surface). This can influence adsorption and desorption within concrete pores. Development of secondary minerals over time may also decrease accessibility to pore space and adsorption/desorption potential of PFAS.

Similarly, van der Waals interactions may influence sorption/desorption of charged species to the surface of the concrete. Hydrophobic properties can also develop within the matrix and influence the ability for PFAS to bind to the matrix (Srivastava et al. 2024). The formation of micelles (colloidal particles with a hydrophobic core and a hydrophilic exterior), which has previously been observed in sediment matrixes, may also be a factor in leaching behavior for concrete given its porous nature (Srivastava et al. 2024). Further research is needed to fully understand and define these interactions, and resulting concentrations of PFAS in leachate produced from concrete. Better understanding of matrix interactions and characteristics that affect observed PFAS concentrations can help determine best practices for representative sample collection for this analysis method in the future.

1.5.7 Field Screening Tools

The goal of this section is to briefly summarize the development and availability of options for field screening for PFAS. Field screening tools are of interest because of the potential for portability (on-site use), ease of use, rapid results, and cost-effectiveness, all of which can improve the effectiveness and efficiency of PFAS analysis, and, ultimately, site characterization and remediation. However, there are currently no validated analytical methods that apply to field screening tools. This topic supplements **Section 11.2**, which addresses laboratory analytical methods/techniques.

Although not yet widely accepted by regulators, several PFAS screening approaches and tools are in various stages of development and validation (Erickson 2023; Menger et al. 2021), and some have recently been commercialized. SERDP released a Statement of Need in November 2024 titled *Real-Time Sensors for Detection and Quantitation of PFAS in Soil and Groundwater at AFFF-Impacted Sites* (SERDP 2024). More information about SERDP projects can be found on their website (**https://serdp-estcp.mil**).

Sensing technologies that have been evaluated in academic laboratories include those based on electrochemistry, optics, and nonconventional approaches, such as hydrogel swelling and thermal detection (Thompson, et al. 2024). Nanoparticle-based sensors, which may be made of metal-based nanoparticles, quantum dots, or carbon dots, can measure PFAS by detecting the optical or electrochemical changes that occur because of interaction with PFAS (Sendão et al. 2023). Different technology approaches provide different results, with some tools yielding total PFAS or TOF results and others reporting individual compounds, such as PFOS or PFOA, down to single-digit nanogram per liter levels for comparison to drinking water standards. As an alternative approach, fixed commercial laboratories are offering modified HPLC-MS/MS analyses, generally based upon ASTM D8241-25 (ASTM 2025), USEPA Method 537 (USEPA 2020), or USEPA Method 8327 (USEPA 2021), but perhaps omitting some sample preparation or quality assurance/quality control steps to achieve faster turnaround times, on the order of 1–10 days. Additionally, these streamlined analyses can be performed for a lower cost, as much as 50% reduced from full, National Environmental Laboratory Accreditation Program (NELAP)-certified analyses. It should be noted that screening tools, even when fully developed, properly validated, and commercialized, may not be approved by regulatory agencies for decision-making regarding site

risks, comparison to standards, or assessment of remedial actions. It is likely that results will have to be confirmed with an accredited laboratory using a validated and published analytical method.

1.6 Priority Topics for Treatment Technologies

Section Number	Topic
1.6.1	**Thermal Treatment Update**
1.6.2	**Supercritical Water Oxidation**
1.6.3	**Investigation-derived Waste**
1.6.4	**Treatment of Sediment**
1.6.5	**Treatment of Biosolids**
1.6.6	**Updated and Recent and Relevant Technology Review Papers**

Information in these Priority Topics was prepared to supplement the information published in **Section 12** and **Table 12-1 Treatment Methods Table** Excel file. The new Sorption-based Treatment Technologies Guidance is included in **Section 18**. ECOS (2025) compiled information from state environmental agencies about their policies and actions to address PFAS, including topics around remediation, destruction, and disposal. Information about Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) projects for Treatment Technologies can be found at **https://serdp-estcp.mil/**.

1.6.1 Thermal Treatment Update

Thermal methods have been used to treat a variety of contaminants in both solids and liquids for decades. The impacts of thermal methods on many hazardous compounds are well known, particularly when executed within hazardous incinerators, which have been regulated since the 1970s. The ability of individual methods to destroy or recover PFAS specifically is less well documented, though efforts to do so have increased in the last several years.

1.6.1.1 Thermal Methods

Three thermal technologies are considered and discussed below for PFAS treatment: incineration, pyrolysis/gasification, and thermal desorption. The general operating conditions and equipment for each thermal technology are also described below. The conditions under which each technology is applicable are discussed. Incineration, pyrolysis/gasification, and thermal desorption generally rely on thermal energy to drive their respective treatment mechanisms; however, there are some key differences. Incineration relies on combustion processes in the presence of excess oxygen; pyrolysis and gasification are thermal processes that operate in the absence of oxygen or at levels below what is required for complete combustion (sub-stoichiometric). Thermal desorption uses heat to volatilize PFAS from impacted media followed by subsequent gas phase destruction.

Other thermal technologies, such as supercritical water oxidation (SCWO) (see **Section 12.6.3.12** and **Section 1.6.2**), hydrothermal alkaline treatment, carbon reactivation (see **Section 12.6.5**), and smoldering technology (see **Section 12.7.2**), are not included in this section. Incineration and pyrolysis/gasification may be applied to solids or liquids containing PFAS with mechanisms of PFAS desorption and destruction, whereas thermal desorption is applicable for the treatment of PFAS-impacted solids (case studies limited to soils). The destruction of PFAS through pyrolysis may also occur during thermal desorption, though the PFAS affected and their permanence will be less inclusive and complete.

Incineration

Information on incineration is included in **Section 12.4**. In the United States, hazardous waste incinerators (HWIs) are regulated primarily by the Resource Conservation and Recovery Act (1976) and the Clean Air Act of 1963 and its subsequent amendments (1977, 1979, and 1990). HWIs destroy contaminants in the presence of oxygen at temperatures ranging from 1,600°F to 2,500°F (870°C–1,370°C) (Winchell et al. 2024; USEPA 2025). Gases produced during the process are treated further in an afterburner heated to high temperatures prior to atmospheric discharge (Weitz et al. 2024). Solids are retained as ash and recovered as particles in several stages of air treatment equipment. These include virtually all solid capture methods available, including centrifugal and wet and dry methods, due to the importance of achieving success. Solid treatment residuals (ash) are characterized and disposed at a hazardous waste landfill, with or without solidification, as allowed in the facilities permits.

Pyrolysis and Gasification

Pyrolysis and gasification are similar processes to convert or destroy organic matter. They differ by the temperature of the process and the amount of oxygen present. Pyrolysis produces biochar and hydrocarbon gases in the absence of oxygen. Gasification produces chemical feedstocks for industry and either liquid or gaseous fuel by further refining the biochar in the presence of oxygen, air, or steam (Winchell et al. 2023). The fuel, or synthetic fuel (synfuel), is often used to power electrical generation plants. Pyrolysis and gasification are discussed individually below.

Pyrolysis—Organic waste is heated to 570°F–1,650°F (300°C –900°C) in the absence of oxygen. Organic materials are converted to smaller organic molecules in the form of solids, liquids, and gases. This process is primarily used to produce biofuels and char/biochar and has been evaluated for the treatment of PFAS-impacted materials as discussed further in **Section 1.6.1.2**. Due to the strong carbon-fluorine bonds in PFAS molecules, high temperatures are required for complete decomposition. These elevated temperatures may not be achievable through pyrolysis alone.

Gasification—This process is conducted at temperatures from 1,470°F to 2,190°F (800°C–1,200°C). Organic material is heated in an atmosphere with a specific oxygen concentration. The most common product is synthetic gas (syngas), which can be burned to produce heat or electricity. Syngas can be used to produce synfuels. Gasification for PFAS destruction is an area of active research (Kumar et al. 2023; Abu-Orf 2025; USEPA 2021).

Thermal Desorption

Thermal desorption is a low-temperature physical separation process in which heat is applied to waste material (for example, soil, sediment, sludge) for the purpose of volatilizing water and organic contaminants. As relevant for PFAS, thermal desorption has been demonstrated for ex situ application as discussed in **Section 12.7.2**. Ex situ soil treatment through thermal desorption can be considered using various technologies such as thermal conductive heating technology. Thermal desorption generally entails a temperature range from 350°C to 400°C (662°F to 752°F) (Crownover et al. 2019; Stallings et al. 2023; NAVFAC 2024).

1.6.1.2 Performance

The performance of thermal technologies with respect to PFAS and PFAS-impacted materials is not well documented in peer-reviewed literature. Incineration is a PFAS destruction technology included in the US Environmental Protection Agency (USEPA) interim guidance and 2024 updated interim guidance on the destruction and disposal of PFAS and materials containing PFAS (USEPA 2020 and 2024).

For the non-incineration technologies, most thermal treatment data are collected from pilot and small-scale projects conducted without clear guidance on performance criteria (such as generation of products of incomplete combustion or destruction [PICs/PIDs]). This challenge has been slowly addressed as more providers increase their testing and inform or involve regulators and as analytical and testing methods become available through research, testing, and technology demonstrations.

The crux of the comparison challenge is the PFAS concentration in the tested material. If the concentrations of one or more PFAS are not sufficiently high in the original material and the treated material concentrations are not sufficiently low, calculation of destruction and removal efficiency (DRE) of PFAS of at least six orders of magnitude (99.9999%; historic performance required for hazardous incinerators for chemicals such as dioxin, polychlorinated biphenyls) is not mathematically achievable due to the available detection limits. This situation can be addressed by adding a larger mass of one or more PFAS to the original material (spiking) to raise PFAS concentrations in both the raw and treated material above nondetection levels and enable calculation of DRE values.

Before selecting a non-incineration thermal treatment technology, it is important to know if the technology can meet a DRE of 99.9999% preferably, or if it can achieve ~100% PFAS reduction regardless of feedstock concentrations. In cases where PFAS concentration in the original material is too low to support calculation of a DRE of 99.9999, some providers of thermal destruction or separation technologies present nondetection treated sample analytical results as proof of performance equal to hazardous incinerators that can prove 99.9999 DRE. Note that uncertainties are associated with this approach. Nondetection results arise from the capabilities and limitations of the analytical method and equipment. A DRE of 99.9999 means 999,999 of 1,000,000 PFAS molecules have been destroyed. Detection or nondetection at 1 microgram per gram requires a starting PFAS concentration of 1,000,000 micrograms per gram to demonstrate comparable control. These concentrations are rarely present in waste materials treated via incineration except for some PFAS-containing water or soil or in concentrated volumes of unused liquids—for example, aqueous film-forming foam (AFFF). Therefore, generally it is impossible for any thermal destruction technology to demonstrate a 99.9999 DRE without using spiked materials.

Incineration

The performance of incineration in the destruction of PFAS wastes, PFAS-based materials, such as firefighting foams, and waste containing PFAS, such as textiles, is the subject of continued uncertainty and research. Uncertainties exist around the degree to which PFAS mineralization occurs (breaking of all C-F bonds in a PFAS molecule and conversion to CO_2 and water). Additional uncertainties exist regarding the concentration and composition of PICs. Further uncertainties of the incineration process include factors such as, but not limited to, temperature and residence time. Research to resolve these uncertainties includes the development of emission sampling methods to detect and capture PFAS and analyze their thermal decomposition byproducts (Meegoda et al. 2022; USEPA 2020; Ryan and Gullett 2020).

Most HWIs operate from 980°C to 1200°C. The thermal destruction of most organics in the waste, including PFAS, will be achieved at HWIs, whose operating temperature range is roughly twice as high as the temperature required for thermal destruction of most organic compounds (Meegoda et al. 2022). Notably, in one full-scale study by Solo-Gabriele et al. (2020), increasing incinerator temperatures decreased total treated PFAS concentrations. Importantly, not all PFAS species decreased with increasing temperature. Shields et al. (2023) found that for a legacy AFFF (containing primarily PFOS and PFHxS) combusted at temperatures above 1090°C, destruction efficiencies were greater than 99.99% for ten PFAS, with relatively few volatile PFAS PIDs observed. However, while temperatures below 1000°C often resulted in destruction efficiencies greater than 99.99%, at these lower temperatures there were higher concentrations of volatile PFAS PIDs. **Section 3.1** includes information about AFFF formulations.

USEPA (2024) noted that some uncertainties remain about the effectiveness of hazardous waste incinerators but also concluded that research suggests that the use of higher temperatures, well mixed combustion environments, and longer residence times may be more conducive to destroying PFAS and controlling related products of incomplete combustion.

As part of permit compliance, permitted HWIs are required to document strict adherence to discharge limitations. A study at the Aragonite facility in Utah on stack samples was done in conjunction with the DoD using USEPA OTM-45, OTM-50, and 0010 (which will become OTM-55) methods (USEPA 2025). The results showed the following:

- DRE values for all spiked PFAS, except hexafluoropropylene oxide dimer acid (HFPO-DA), were 99.999% to greater than 99.9999%. DRE values for HFPO-DA were 99.95% to 99.998%.
- OTM-45: 69% of stack gas emission results were nondetects.
- OTM-50: In USEPA's analyses, six potential PIDs in the stack gas were identified above the method detection limit, but below the reporting limit; two compounds were detected in the blanks.
- 0010: No fluorinated compounds were identified.
- DRE values for hexafluoroethane (C_2F_6) were greater than 99.99% to greater than 99.9999%.
- Air emission modeling results were 2–8 orders of magnitude lower than identified regulatory standards or guidelines from five state regulatory agencies (Michigan, Minnesota, New Jersey, New York, and Texas), see Appendix M, Table M-1 in USEPA (2025).

USEPA (2025) presented information about the evaluation of the HWI stack emissions.

Pyrolysis/Gasification

One difference between pyrolysis and gasification is that gasification produces synthetic fuel. One potential concern with synthetic fuel is that it will be distributed to multiple outlets, industrial and residential, where it may be combusted at temperatures below those adequate to destroy PFAS in their very short residence in the combustion chamber then released to the atmosphere through a stack without an afterburner or emissions controls.

Facilities using pyrolysis or gasification are regulated under the Clean Air Act and must meet strict emissions monitoring and reporting requirements, as do HWIs. As for the performance of these processes for the destruction of PFAS-impacted material, the high temperatures and residence times coupled with thermal oxidation could potentially destroy PFAS by breaking carbon-fluorine bonds; however, generation of PIDs is also possible (USEPA 2021).

PFAS desorption and destruction mechanisms and completeness through pyrolysis/gasification have not been well studied (Wallace et al. 2023). In one study, pyrolysis bench testing was performed on PFAS-impacted biosolids (Williams et al. 2021). In this study biosolids were treated in the absence of oxygen at temperatures of 500°C and 700°C. Pyrolysis resulted in the formation of biochar, bio-oil, and pyrogas. The feedstock for testing included 500 grams of 95% dry biosolids in which 20.09 µg of total PFAS were identified with perfluorooctane sulfonic acid (PFOS) and N-ethyl perfluorooctane sulfonamido acetic acid (EtFOSAA) as the dominant PFAS. After pyrolysis at 500°C, PFAS were still detected in the biochar and pyrogas. PFHxS, perfluorooctanoic acid (PFOA), PFHxA, and perfluoropentanoic acid (PFPeA) were found to dominate. However, after pyrolysis at 700°C, PFAS was detected only in the pyrogas, with PFNA, PFHxA, PFPeA, and PFOA predominating the weight percentage. Results from this bench test (Williams et

al. 2021) highlighted the potential for PFAS to concentrate or biotransform into the pyrogas after pyrolysis. Further, these results suggest that to achieve complete destruction of PFAS through pyrolysis, a temperature exceeding 700°C would be required. Additional factors such as residence time and the presence of catalyst, which could help lower the required temperature for PFAS destruction, can be additional factors in the performance of this technology. Additional testing is needed to evaluate the potential for short-chain PFAS byproducts in the resulting pyrogas.

Another project, conducted as a pilot study, by Thoma et al. (2022), used a commercial pyrolysis system to process biosolids to investigate the reduction of PFAS concentrations in the biochar that was produced. Samples from the biosolids were analyzed for 41 PFAS, resulting in 21 being detected (reported range of approximately 2 µg/kg–85 µg/kg). The samples from the biochar were below the detection limits. Air emissions were analyzed for some PFAS. Additional research is needed to understand the PICs and potential concentrations of PFAS that were not in the 41 analyzed.

In contrast to pyrolysis, gasification uses higher temperatures as discussed in **Section 1.6.1.1** and requires that some oxygen be present, though less as compared with incineration. Given the inherent higher temperatures, gasification is a promising technology for treating PFAS-contaminated material (for example, biosolids, wastewater sludge). Potentially, gasification could break down PFAS in waste but publications are extremely limited. Similar to pyrolysis, byproducts (for example, biochar and syngas) would need to be evaluated for PFAS composition as compared with the original material. Gases could require further treatment in a thermal oxidizer potentially outfitted with a scrubber to address potential hydrofluoric acid (HF) production. A benefit of gasification is the reduction of overall waste volume as the waste is converted to gas, leaving smaller volume residuals that could require landfill disposal. More research is needed to fully understand the potential PIDs with gasification.

Thermal Desorption

Thermal desorption is the removal of compounds from solids via the addition of heat followed by treatment of the gases and vapors and the reuse of the resulting solid material for construction and other purposes. This can be done in two modes, either at a permanent facility or more recently, via mobile equipment to treat impacted soil on site, either in situ or ex situ. Both have been effective for removal of many common contaminants, with a history of documented success treating petroleum hydrocarbons and chlorinated solvents. SERDP and ESTCP are funding a number of thermal desorption projects (for example, ER20-5198, ER20-5250, ER23-8369, and ER23-8378).

Thermal desorption has been demonstrated to address excavated PFAS-impacted soils. Results from a laboratory treatability study show that at temperatures of 350°C and 400°C, PFAS soil concentrations were reduced by 99.91% and 99.998%, respectively (Crownover et al. 2019; Heron et al 2021; Stallings et al. 2023). In situ application is also possible. A study from Beale Air Force Base, California, focused on an in situ thermal desorption approach for removing PFAS from vadose zone soil (NAVFAC 2024). Impacted soils with high PFAS concentrations and located in remote areas distant from fixed facilities for incineration or landfills would make this treatment approach attractive. This technology will require PFAS off-gas management. It can be combined with a scrubber to transfer the desorbed PFAS in vapors to the liquid condensate, which is a concentrated, low-volume solution. GAC can also be used as an off-gas management technique. Desorption providers continue to improve their designs and equipment to improve performance and control costs. See also **Section 12.7.2**.

1.6.1.3 Applicability

Based on thermal technologies described above, three areas are considered critical when evaluating thermal technologies for PFAS treatment. Considerations of these areas during treatment system design would reduce risks and result in the preferred outcome.

- Critical temperature—Individual PFAS are stable until exposed to a critical temperature unique to each. Above that temperature the effects are unique to each compound or group of compounds. Effects include PFAS desorption into vapors, pyrolysis/gasification (incomplete combustion to one or more fragments of the original compound), and complete destruction of all carbon-fluorine bonds.

- Treatment duration—While temperature is the primary treatment metric the duration of suitable and maintained temperatures determines how long the PFAS-containing materials are exposed to the temperature. The duration is critical to the completeness of destruction. Incomplete destruction can form unwanted PFAS intermediates or byproducts (PIDs).

- Confirmation of the treatment process—Elevated temperatures have differing effects on PFAS-impacted solids and liquids. Such effects can include, but are not limited to, evaporation of water, combustion of organic matter in solids, desorption of PFAS, transformation and incomplete destruction of PFAS, and possibly complete destruction of all individual PFAS. All solid, liquid, and gas residuals and emissions must be carefully monitored, contained, destroyed, and managed to eliminate impacts to the environment.

1.6.2 Supercritical Water Oxidation

This section focuses on supercritical water oxidation, including a description of the process, state of development, effectiveness, and sustainability considerations. Information in this section was prepared to supplement the information published in **Section 12** and **Table 12-1 Treatment Methods Table**.

1.6.2.1 Treatment Description

Supercritical water oxidation (SCWO) is a technology designed to destroy organic contaminants, including PFAS. SCWO operates above water's critical point (374°C, 22.1 MPa). SCWO systems typically function at 400°C—650°C and 22–28 MPa, achieving high destruction efficiencies for organic compounds. SCWO operates by using the unique properties of water at conditions above water's critical point, where phase boundaries are absent—neither fully liquid nor gas. This state exhibits enhanced solubility for organic compounds and oxygen, promoting rapid oxidation reactions and thus enhancing mass transfer. Water itself actively participates in hydrolysis reactions, further facilitating contaminant breakdown.

SCWO allows for the destruction of hazardous organic materials, including PFAS in both liquid and solid waste streams. SCWO is suitable for treating solids that can be effectively slurried or suspended in an aqueous solution. Solids such as soils, sediments, or other materials that are challenging to slurry or maintain in suspension are generally not appropriate feedstocks for SCWO systems. Oxygen, air, or hydrogen peroxide is introduced as the oxidizing agent, breaking down the carbon-fluorine bonds found in PFAS. SCWO enables the mineralization of PFAS into end products such as water, carbon dioxide, and salts. SCWO is not a new technology and has been evaluated and applied to various organic compounds in liquid streams for decades (Tester et al. 1993). With the appropriate reaction temperatures, pressures, and residence times, almost any organic pollutant can be destroyed by SCWO. More recently, with a focus on PFAS, bench- and pilot-scale systems have been evaluated (Jama et al. 2020; Hori et al. 2008; USEPA 2021; McDonough et al. 2022; Krause et al. 2022; Li et al. 2023).

When the supercritical point is reached, the rapid reaction time (2–10 seconds) allows for continuous processing and scalability while minimizing equipment footprint requirements (Krause et al. 2022). Typical residence times in SCWO reactors depend on reactor design, feed characteristics, and target contaminants. Monitoring of PFAS and non-PFAS parameters for reaction byproducts (for example, incompletely oxidized contaminants, HF, greenhouse gas or unreacted harmful oxidants) may be detected depending on the SCWO feedstock and operation processes.

1.6.2.2 Treatment Mechanism

Treatment of PFAS by SCWO is a destructive process that leverages the supercritical phase of water achieved by increasing temperature and pressure of a solution to a minimum of 374°C and 22 MPa, respectively, as shown in the conceptual diagram in **Figure 1-27**. In this phase, oxygen is fully soluble, resulting in rapid and complete oxidation of organics, transforming the feedstock into carbon dioxide (CO_2), water, and inorganic salts (Krause et al. 2022). In terms of PFAS treatment, SCWO results in the mineralization of both long- and short-chain PFAS, producing CO_2, water, and HF. HF production is typically mitigated using a neutralization dosing agent such as sodium hydroxide (NaOH) at the system effluent or elsewhere in the treatment system. Because this is an oxidative process, an oxidant source must be present in sufficient quantity to account for the total organic carbon content of the waste being processed. Typical oxidant sources for SCWO applications include air, pure oxygen, or hydrogen peroxide (H_2O_2). An advantage to PFAS treatment by SCWO is that any organic co-contaminants will also be destroyed during waste processing. Another distinguishing feature of the supercritical phase is that salts precipitate out of solution. Depending on the treatment technology, waste streams with high salt content may pose an issue for treatment by SCWO and require a salt separation pretreatment step.

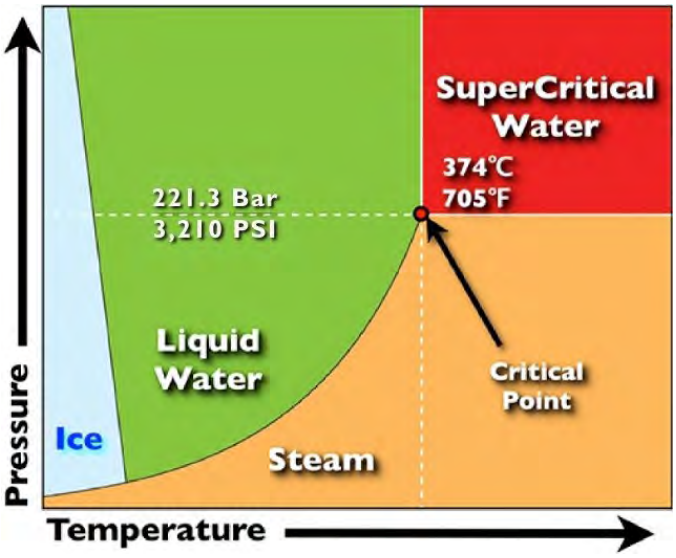


Figure 1-3. Conceptual water temperature-pressure phase diagram highlighting the supercritical region. Value for the pressure (in bar) was corrected to 221.3.

*Source: **Jonathan Kamler**, **Attribution-Share Alike 4.0 International**.*

1.6.2.3 State of Development

SCWO technology has been developed and commercialized since the 1990s and thus has not been considered a new technology. However, its application for PFAS destruction is considered more recent and has shown promising results. For example, Sahle-Demessie et al. (2022) tested SCWO through partnership agreement with technical providers to verify PFAS destruction within AFFF. The same study showed that in all USEPA-Office of Research and Development tests, PFAS and total organic carbon destruction efficiencies were greater than 99.99%. PFAS target compounds were not detected above the background level in the gas analyses.

McDonough et al. (2022) adopted OTM 45 for stack sampling in a field trial to destroy PFAS in diluted AFFF. The study suggests greater than 99.999% destruction and removal efficiency of 12 perfluoroalkyl acids (PFAAs) after two ~120-min continuous flow trials with overall defluorination of ~62.6%. Various

bench-scale SCWO studies for PFAS destruction in aqueous matrixes were also documented (Scheitlin et al. 2023) with 5-log (99.999%) reduction in concentrations.

Chiang et al. (2023) tested the PFAS destruction in one spent granular activated carbon (GAC) sample and two spent anion exchange resin (AER) samples. AERs are a specific type of resins used for ion exchange (IX). See **Section 12.2.1.1** for more information about GAC and **Section 12.2.1.2** for more information about IX. The study revealed effective PFAS destruction and the decomposition of GAC and AER in a field-scale SCWO treatment system, leaving no solid wastes requiring further management. This study suggests the potential of SCWO to treat solid wastes, although more studies on feedstock characterizations and PFAS mass balance are needed. The readiness of SCWO systems for full-scale PFAS destruction can vary by technology provider but are generally more mature for destruction of liquid concentrates, particularly diluted AFFF. The scale-up SCWO system has been chosen by state agencies as part of their AFFF take-back programs to destroy AFFF. Several states are actively addressing AFFF, and specifically the transition of AFFF to F3. Many more states have initiated take-back programs or intend to initiate take-back programs.

In 2023, ESTCP partnered with the Defense Innovation Unit to demonstrate SCWO technology, among other treatment methods, for destruction of PFAS in multiple media. Cost and performance results of these demonstrations are forthcoming (USDOD 2023). More information about analytical methods is included in **Section 11.2** and **Section 1.5**.

1.6.2.4 Effectiveness

The broad effectiveness of variations of SCWO to destroy various groups of PFAS is well established in the literature (Hori et al. 2008; Hori et al. 2012; Hori et al. 2015; Jama et al. 2020; Pinkard et al. 2021; USEPA 2021; Krause et al. 2022; Li et al. 2022; McDonough et al. 2022; Sahle-Demessie et al. 2022; Austin et al. 2023; Chiang et al. 2023; Li et al. 2023; Scheitlin et al., 2023). The completeness of this defluorination (mineralization) has been verified to the extent practicable using commercially available analytical and sampling tools. The liquid effluent from SCWO demonstration studies in the literature and industry consistently achieves decreases to near or below relevant detection limits for those PFAAs typically reported (Li et al. 2022; McDonough et al. 2022; Sahle-Demessie et al. 2022; Austin et al., 2023; Chiang et al. 2023; Li et al. 2023; Scheitlin et al. 2023). Numerous gaseous sampling and analytical technologies have been used to verify the completeness of PFAS mineralization using SCWO, with satisfactory results (Hori et al. 2008; Li et al. 2022; McDonough et al. 2022; Sahle-Demessie et al. 2022; Chiang et al. 2023; Li et al. 2023; Scheitlin et al. 2023), however PFAS analysis in air samples continues to evolve. More data would be needed to confirm no breakthrough of PFAS in the air effluent stream. Extremely low detections of PFAAs reported based on gaseous sampling techniques are likely related to ambient PFAS within cooling/neutralization water (McDonough et al. 2022; Sahle-Demessie et al. 2022) or associated with the sampling apparatus itself. Four to six orders of magnitude reduction in less than 30 seconds for liquid, gaseous, or both effluent streams is a consistent result when using SCWO to destroy PFAS (Krause et al. 2022; Li et al. 2022; McDonough et al. 2022; Sahle-Demessie et al. 2022; Austin et al. 2023; Li et al. 2023; Scheitlin et al. 2023).

Many effectiveness demonstrations of SCWO include most of the typical list of PFAAs (that is, C4 to C14 PFCAs and C4 to C10 PFSAs). The application of SCWO to mineralize trifluoroacetate (TFA) has also been recently observed (Li et al. 2023), suggesting that SCWO (when operated ~650°C) is likely applicable to ultrashort PFAS (<C4) as well. More studies investigating the fate of ultrashorts in gaseous and liquid effluents from SCWO reactors are needed. In keeping with various PFAS destruction technology verification studies, fluorine mass balances have been attempted with confirmed defluorination ratios of ~36% to 100% (Hori et al. 2008; Hori et al. 2012; Hori et al. 2015; Pinkard et al. 2021; Krause et al. 2022; Li et al. 2022; McDonough et al. 2022; Sahle-Demessie et al. 2022; Austin et al. 2023; Li et al. 2023; Scheitlin et al. 2023). The range of defluorination percentages versus consistent complete fluorine mass balances has been hypothesized to include partially defluorinated volatile

species (Hori et al. 2008; Austin et al. 2023; Li et al. 2023), variable operating conditions, and unquantified inorganic fluoride within the steam effluent (McDonough et al. 2022).

The complexity of a waste stream has less influence on the effectiveness of SCWO to destroy PFAS than some other PFAS-relevant destruction technologies. As SCWO has been historically validated for the destruction of organic constituents, optimized concentrations of organic constituents may enable autogenic operation where the influent organics can sustain the necessary reaction temperature. This can offset energy demands in achieving supercritical conditions (Tester et al. 1993; Hong and Spritzer 2002; Yesodharan 2002; General Atomics 2005; Marrone 2013; Adar et al. 2019; Wang et al. 2019; USEPA 2021; Wei et al. 2021; Krause et al. 2022). The presence of inorganic constituents in high concentrations may necessitate the management of precipitated solids, corrosion, and scaling, though innovations in the technology over time have found relevant management solutions (Tester et al. 1993; Kritzer and Dinjus 2001; Yesodharan 2002; Marrone et al. 2004; Marrone 2013; Adar et al. 2019). Because inorganic constituents are not applicable to SCWO and separate from the fluid prior to discharge, common deleterious air emissions (for example, nitrogen and sulfur oxides) are not concerns with SCWO (Tester et al. 1993; Pinkard et al. 2021).

Although the effectiveness of SCWO to achieve mineralization of a broad range of PFAS is established, its current applicability is best suited to smaller volumes of high PFAS concentrations. The comparatively rapid residence time for SCWO is attractive for a continuous flow application (Tester et al. 1993; Krause et al. 2022; Austin et al. 2023; Li et al. 2023); however, the capital cost and equipment footprint to construct SCWO reactors capable of achieving 10s of gallons per minute may be infeasible in many scenarios (Tester et al. 1993; Kritzer and Dinjus 2001; Marrone 2013; Adar et al. 2019). The SCWO technology is insensitive to the initial PFAS concentration; however, there is a considerable energy demand to initiate supercritical conditions and pretreatment strategies to concentrate PFAS will improve the energy per mass effectiveness (Jama et al. 2020; Li et al. 2022; McDonough et al. 2024). Importantly, pretreatment of a waste stream to increase the PFAS concentration factor will also concentrate inorganic constituents that may challenge the efficiency/effectiveness of SCWO and require corrosion and scaling management (Tester et al. 1993; Kritzer and Dinjus 2001; Marrone et al. 2004; Li et al. 2022; Chiang et al. 2023).

1.6.2.5 Design/Operating Considerations

SCWO presents a viable solution for treating many PFAS-contaminated waste streams. Operating above water's critical point (374°C, 22.1 MPa), SCWO systems typically function at 400°C–650°C and 22–28 MPa, achieving high destruction efficiencies for organic compounds. Prior to treatment, a comprehensive waste stream assessment is crucial. Key parameters to evaluate typically include PFAS concentration, total organic carbon, chemical oxygen demand, TOF, organohalide content, pH, conductivity, total dissolved and suspended solids, and metals. PFAS speciation may be useful for regulatory or reporting purposes but is not typically necessary for SCWO system operation. Operational considerations include feed and oxidant flow rates, reactor temperature, system pressure, residence time, and post-SCWO effluent stream management (air, condensate, effluent and mineral residuals). Safety assessments should address corrosivity, material compatibility, and potential for fouling or hazardous gas formation. SCWO facilities require significant electrical power, water supply, and oxidant sources (typically pure oxygen, air, or hydrogen peroxide). Ambient temperature should be noted as a key operating consideration for SCWO, as systems installed outdoors in cold climates may require supplemental heating to maintain operational stability (similar to other systems installed outdoors); additionally, SCWO relies on highly specialized equipment and skilled personnel, which can impact site readiness and deployment planning. Permitting for SCWO operations involves navigating complex environmental, local, state, and federal regulations, including specific PFAS-related requirements, safety protocols, and waste management standards. SCWO may be viewed favorably in the permitting process, as verified analytical results from both liquid and vapor effluent streams provide greater transparency to regulatory permitting

agencies. Early engagement with regulatory agencies is essential to ensure compliance with all applicable permits and operational guidelines.

1.6.2.6 Sustainability Considerations for Supercritical Water Oxidation

Considerations for SCWO technology sustainability metrics may be aligned with the fundamental principles of environmental, societal, and economic interrelated factors. As noted in **Section 12.9**, Sustainability of PFAS Treatment, best management practices for SCWO may incorporate life cycle analysis (LCA) for materials destruction. A key consideration is the need for a pre-SCWO volume reduction step, such as concentration (for example, foam fractionation, reverse osmosis, evaporation), because SCWO systems are best suited for treating lower volumes of high-concentration PFAS waste streams rather than large volumes of dilute PFAS waste. Few SCWO units are available on the commercial market at this time, and therefore, materials may need to be transported significant distances to be managed with SCWO.

Examples of SCWO LCA facets may include:

- whether SCWO is performed on-site or waste is transported off-site for treatment or concentration affects environmental impacts such as carbon and greenhouse gas emissions
- whether the number of required samples before, during, and after treatment, and carbon footprint for the sample analysis at a remote laboratory, affect environmental impacts such as carbon and greenhouse gas emissions
- whether the permitted SCWO facility is located in a disproportionately disadvantaged community and is treated as a societal impact
- whether the cost per unit volume in energy consumption, sample analysis, and the going market rates are project- and community-viable

SCWO unit permitting requirements may vary by state. Those located in states where complete or nearly complete destruction is required prior to any residuals disposal may be weighted preferentially over those SCWO units located in states with less rigorous permitting standards. This consideration may allow for greater confidence in ending the PFAS waste cycle.

Sustainability balancing factors may include how complete or full destruction is defined by the regulating authority for a given material type and composition. This may dictate the degree to which these sustainability factors, including environmental compliance with liquid and vapor effluent regulatory requirements, are valued and weighted by project stakeholders.

1.6.3 Investigation-derived Waste

This section describes some of the key factors affecting the management of PFAS-impacted investigation-derived waste (IDW), with an emphasis on portable and field-adaptable technologies suitable for handling heterogeneous waste streams generated during site investigations. It includes the current state of practice regarding this topic and recent research efforts. Information in this section was prepared to supplement the information published in **Section 12** and **Table 12-1 Treatment Methods Table**. This section focuses on field-relevant strategies, that are modular, portable, or scalable that address the logistic constraints and episodic nature of PFAS-impacted IDW. Given the accelerating pace of PFAS site investigations and the associated accumulation of IDW, the development of sustainable on-site PFAS management strategies has become a priority.

Prior to any remediation activities, to identify PFAS-impacted source zones and optimize management strategies, comprehensive site investigations need to be conducted. These investigations, however, have introduced a secondary challenge: the management of IDW (Yanagida et al. 2022).

The majority of IDW generated during well development, installation, and sampling at PFAS-impacted sites comprises purged groundwater, equipment decontamination residues, soil, drill cuttings, and debris from the removal of asphalt and concrete (Vatankhah et al. 2023). This generated waste frequently contains varying concentrations of PFAS alongside other co-occurring organic and inorganic contaminants. Current IDW management practices primarily involve transportation to waste landfills or incineration facilities. However, these methods are both costly and too limited to fully address the long-term environmental liabilities posed by PFAS-contaminated waste (Singh et al. 2019).

Additionally, at many large PFAS-impacted sites, ex situ remediation of impacted water matrixes, through sequestration techniques such as sorption-based processes and high-pressure membrane systems, often begins concurrently with ongoing site investigations (Murray et al. 2023). This introduces an additional challenge, as the accumulation of exhausted media and membrane reject streams exacerbate the existing difficulties associated with IDW generation.

With respect to remediation efforts, numerous advanced sequestration technologies have been implemented for capture and removal of PFAS from IDW streams and impacted soil. Although soil washing is common in large-scale remediation, it is generally not practical for IDW due to the limited and variable waste volumes. For solid IDW, thermal desorption using roll-off boxes or covered soil piles may offer a more feasible alternative (Lei et al. 2023). Some of the most established sequestration technologies include GAC (Murray et al. 2021; Appleman et al. 2014; Yu et al. 2009; Carter et al. 2010), IX (Franke et al. 2019; Franke et al. 2021; Boyer et al. 2021; Tajdini et al. 2023), high-pressure membranes (that is, nanofiltration), (NF), and reverse osmosis (RO)) (Liu and Sun 2021; Liu, Strathmann, and Bellona 2021). See **Section 12.2.2.1** for more information about NF and **Section 12.2.2.2** for more information about RO. Despite the effectiveness of these technologies for separation and removal of PFAS, they serve only as interim treatment actions involving physical mass transfer. For aqueous IDW, integration into existing on-site PFAS treatment systems such as modular GAC or IX units can provide an efficient management route. Alternatively, discharge to municipal facilities with PFAS treatment capabilities may be appropriate where allowed.

To effectively mitigate the long-term risk of recontamination from IDW, PFAS-laden sorbents, and membrane reject streams, it is imperative to evaluate both on-site and off-site end-of-life disposal technologies that achieve complete mineralization of PFAS. Depending on the quantity of the IDW, while on-site approaches reduce transportation and handling, off-site options may be more cost-effective depending on local infrastructure and waste volume. Eliminating the long-term risks associated with impacted IDW requires technologies that ensure complete defluorination, as degradation or partial defluorination may result in formation of more recalcitrant byproducts, also known as PIDs (for example, volatile PFAS, unsaturated PFAS, PFCAs, -F/+X-substituted PFAS) with elevated risks of bioaccumulation (Evich et al. 2022).

In recent years, a series of focused research efforts has been initiated and led by SERDP to develop and investigate a series of innovative end-of-life disposal technologies capable of complete mineralization of all PFAS in IDW (Vatankhah et al. 2023). SERDP and ESTCP projects for field-scale evaluations of PFAS-impacted IDW include ESTCP project ER19-1403, which examined UV/TiO_2-activated alkaline treatment for concentrated liquid residuals, and ER21-7591, which tested hydrothermal alkaline treatment (HALT) technology in a field deployment.

To better understand the end-of-life technologies during the management of IDW, it is important to assess PFAS destruction by evaluating the extent of PFAS degradation and defluorination as represented in Equations 1 and 2, where $[F^-]$ corresponds to fluoride ions, N_F is the quantity of fluorine atoms, $[PFAS]_0$

is the initial concentration of PFAS, and $[PFAS]_{degraded}$ is the concentration of degraded PFAS (Banayan Esfahani et al. 2022).

Defluorination efficiency (%) = $F^{-}/([PFAS]_0 \times N_F) \times 100$	(1)
Degradation efficiency (%) = $[PFAS]_{degraded}/[PFAS]_0 \times 100$	(2)

These metrics apply specifically to destructive technologies designed to achieve mineralization of PFAS in concentrated IDW streams. Although such calculations can be valuable for benchmarking performance, they are not applicable to nondestructive technologies such as GAC, IX, or membrane processes. In those cases, PFAS are removed by separation or sequestration, not destruction, and mass balance calculations may be misleading.

Additionally, attempts to evaluate fluorine mass balance in complex treatment systems must consider the transformation of precursors between treatment stages. For example, PFAS precursors may convert to terminal PFAS during biological or chemical processes that precede final treatment. If sampling is limited to inlet and outlet points, this transformation can lead to under- or overestimation of PFAS removal. Given these complexities, mass balance should not be viewed as a stand-alone indicator of technology performance. To avoid misinterpretation, technology decision makers are encouraged to consider guidance from the USEPA's PFAS Treatment Efficacy Framework (TEF) (USEPA 2024) and assess technology readiness using established technology readiness levels (TRL) criteria (USDOD 2025).

For performance evaluation, standardized parameters must be established for both sequestration (for example, membrane recovery rate, media usage rate, adsorption capacity at various breakthrough levels) and destructive technologies (for example, defluorination efficiency, fluorine mass balance to determine the extent of mineralization). Analytical and process-related interferences often pose challenges in establishing a reliable fluorine balance, particularly during early development stages. Nonetheless, achieving a conclusive fluorine balance is a key performance metric linked to a technology's commercial readiness (Leeson et al. 2021).

Critical factors in economic assessments include the type of PFAS-impacted matrix (for example, groundwater, surface water, soil) and matrix characteristics (for example, total organic carbon, total dissolved solids, total suspended solids), as well as PFAS influent and target effluent concentrations. Additionally, standardized performance data, such as cost per cubic meter of treated effluent at normalized concentrations, chemical usage rates, and pH levels, must be quantified to accurately estimate capital and operational expenditures.

Integrating nondestructive and destructive treatment technologies is emerging as a promising approach for managing PFAS-impacted IDW, offering potential improvements in energy efficiency and cost-effectiveness. A crucial factor in this integration is the compatibility of certain destructive technologies (for example, sonication, oxidation-reduction methods) with the initial PFAS concentrations. Employing nondestructive technologies, such as high-pressure membranes, to concentrate the feed can enhance the performance of subsequent destruction techniques. However, accurate assessments are necessary to determine the optimal feed concentration for these destructive technologies. This aspect will ultimately dictate the operating conditions of sequestration technologies (for example, membrane recovery and concentration factors), directly impacting energy and cost efficiency (Vatankhah et al. 2023).

1.6.4 Treatment of Sediment

This section focuses on the treatment of PFAS-contaminated sediment. Information in this section was prepared to supplement the information published in **Section 12.3** and **Section 12.7**.

Sediments are impacted by PFAS through both groundwater to surface water interaction (**Section 5.1.3**) and where impacted stormwater or surface water is in contact with sediments. PFAS impacts sediments through both hydrophobic partitioning to organic carbon and electrostatic interactions between charged surfaces. These processes can affect the transfer of PFAS between surface water and sediment. Varying degrees of retention on sediments can contribute to differential transport where certain PFAS (for example, short-chain, anionic) are more rapidly transported than others.

Little information is available regarding regulations or guidance for the treatment of PFAS in sediments, but it is known that PFAS in sediments can impact the benthic community and bioaccumulation can take place, thereby impacting uptake in higher trophic species such as fish (for example, Conder et al. 2008; Pulster et al. 2022).

Contamination in sediments can be addressed either in situ, meaning where they lay (without removal), or ex situ, which typically involves dredging or excavation of impacted sediments in some form. Typically, in situ methods are less invasive and have less impact on habitat or the benthic community. Ex situ methods are typically more expensive and remove the existing benthic community. Generally, contaminated sediment remediation is complex and requires unique permitting requirements, particularly if it is being carried out in navigational areas. With regard to in situ treatment technologies, existing sediment remediation techniques are available that have been demonstrated to successfully deliver adsorptive materials to the sediments (for example, powder-activated carbon). Many of these adsorptive materials are the same as those being applied for immobilization of PFAS in soil (see **Table 12-1 Treatment Methods Table** Excel File). Sediments can also be removed and treated ex situ using methods such as soil washing. Other conventional methods for ex situ management of contaminated sediment include transporting impacted sediment to a landfill. ITRC provides other guidance (ITRC 2014) on a range of methods for managing or remediating contaminated sediment.

1.6.5 Treatment of Biosolids

This section focuses on the treatment of PFAS-contaminated sewage sludge and biosolids. It includes incineration, landfill disposal, sorption and stabilization, pyrolysis/gasification, supercritical water oxidation, hydrothermal liquefaction, and biological treatment. Additional information about Biosolids is included in **Section 1.7**.

The terms “sewage sludge” and “biosolids” are often used interchangeably. However, the USEPA provides a technical distinction between the two. Typically, the USEPA uses the term “biosolids” to refer to sewage sludge that has undergone sufficient treatment (for example, pathogen and vector attraction reduction) to meet the requirements outlined in 40 CFR Part 503—Standards for the Use and Disposal of Sewage Sludge and is intended for land application as a soil conditioner or fertilizer. “Sewage sludge” is generally reserved for untreated municipal wastewater residual that has a high solids content and may have undergone dewatering to increase the relative solids content and reduce residual volume. In common conventional wastewater treatment, large objects and readily settleable solids (primarily inorganic) are removed during the initial screening and grit removal stages. The materials removed during screening and grit removal are typically managed separately and do not become part of the “sewage sludge” residual. In general, “sewage sludge” consists of solids removed during primary settling (primary sludge) and solids removed during biologically mediated treatment processes that may include higher proportions of cell mass (that is, secondary sludge). Sewage sludge that then undergoes treatment for land application, often with the intended beneficial use as a fertilizer, is referred to as “biosolids.”

Managing PFAS impacts to sewage sludge and biosolids is an active area of focus for state and federal regulatory agencies. Multiple states have proposed regulatory frameworks for managing the land application of biosolids, and on January 14, 2025, the USEPA released the Draft Sewage Sludge Risk Assessment for PFOA and PFOS (USEPA 2025). A more detailed discussion of the regulatory landscape and other factors related to PFAS-impacted biosolids is included in **Section 1.7**.

This section focuses on the treatment alternatives that may be considered to address PFAS impacts to sewage sludge, or biosolids, or both. Conventional sewage sludge or biosolids treatment methods are widely considered ineffective in removing PFAS (Rahman et al. 2025). Specifically, the treatment technologies presented below are considered in the context of the USEPA definition of "sewage sludge," specifying the treatment of domestic wastewater (which may include contributions from industrial sources) at publicly or privately owned treatment works. This section is not intended to address sludges derived from privately owned industrial wastewater treatment works; however, some of the treatment technologies may be applicable. An effort was made to limit the discussion of treatment technologies to those that are already widely applied for sewage sludge or biosolids management or those identified by the authors as showing promise for PFAS treatment effectiveness. The list of treatment alternatives included in this section is not comprehensive (see the **ITRC disclaimer**).

Depending on the nature of the domestic wastewater treatment facility, there may be numerous sources of PFAS (for example, residential, commercial, industrial, groundwater intrusion) that contribute to PFAS loading. PFAS entering the wastewater treatment facility may be associated with solid-phase components or aqueous-phase components (dissolved) of the raw wastewater. PFAS can accumulate in biosolids via settling processes or the phase partitions processes described in **Section 5.2**.

Initially, sewage sludge and biosolids collected as a wastewater treatment residual contain a high relative water content and are often dewatered prior to final disposition. Some of the sewage sludge and biosolids treatment alternatives described below require the biosolids to be flowable, therefore a higher water content may be favorable, while others benefit from lower water content. This section does not separately address the treatment of the liquid-phase residual associated with sewage sludge and biosolids dewatering. See **Section 12.2** and **Section 12.6** for discussion of liquid-phase treatment alternatives.

This section focuses on describing sewage sludge and biosolids treatment alternatives for PFAS, serving as an extension of **Section 12.1.4.3**, and has been prepared to provide a treatment-focused discussion to supplement **Section 1.7**. Biosolids and sewage sludge treatment alternatives described below are categorized as either field-implemented or limited application and developing technologies in accordance with the framework defined in **Section 12**.

1.6.5.1 Field-implemented Biosolids Treatment Technologies

Incineration

Sewage sludge or biosolids incineration can take multiple forms in the context of PFAS treatment. Broadly, there are two applications of incineration that may be relevant to sewage sludge or biosolids PFAS treatment. First is the application of permitted sewage sludge incinerators (SSIs) historically designed and operated to serve as a terminal disposal alternative for sewage sludge or biosolids, without consideration for PFAS. Second is the application of high-temperature incineration at a permitted Resource Conservation and Recovery Act Subtitle C hazardous waste combustor, designed and operated as a terminal disposal option for hazardous wastes. In general, the application of incineration processes has demonstrated some degree of success in PFAS destruction. However, the degree to which PFAS are completely mineralized is highly dependent on the specific application (Weitz et al. 2024). Both SSI and high-temperature incineration are discussed separately below.

For additional information and resources regarding incineration, see **Section 12.4** and **Section 1.6.1**.

Sewage Sludge Incinerators (SSIs)

Biosolids incineration via permitted SSIs is a common biosolids management approach. In 2023, USEPA estimated that approximately 14% of biosolids were disposed of through incineration (USEPA 2025)

Operation and associated air emissions of SSIs are regulated by Section 129 of the Clean Air Act, titled "Solid Waste Combustion;" however, current emissions standards do not consider PFAS (USEPA 2024). Additionally, SSI air emissions are regulated under 40 CFR Part 503 Standards for the Use or Disposal of Sewage Sludge, Subpart E—Incineration, but current emissions standards do not consider PFAS.

Two common types of SSIs include multiple hearth furnaces and fluidized bed furnaces, with typical operating temperatures of approximately 300°C–500°C and 700°C–800°C, respectively (USEPA 2003; Winchell et al. 2021). Recent studies have evaluated the fate and transport of PFAS in SSIs and concluded that typical SSI implementations have variable PFAS destruction efficiencies (Seay et al. 2023; Winchell et al. 2024). Researchers have determined that additional work is necessary to better understand how the optimization of SSI processes or the implementation of additional treatment(s) (for example, thermal oxidizer) could increase SSI PFAS treatment efficiency. Thermal oxidizers are common air pollution control devices that are routinely added to thermal treatment processes to treat a wide range of organic contaminants that may be present in process air emissions. Thermal oxidizers rely on high temperature combustion processes and residence time to mineralize organic contaminants present in gas phase emissions. Through integration of energy recovery, operation of thermal oxidizers has become increasingly efficient (95-99% efficiency). Thermal oxidizers with integrated energy recovery as often referred to as regenerative thermal oxidizers (USEPA 2003).

High-temperature Incineration

High-temperature incineration at a permitted Resource Conservation and Recovery Act Subtitle C hazardous waste combustor is an established disposal alternative for a variety of PFAS-impacted wastes, spanning a wide range of physical properties (for example, liquids and solids). In addition to several other operating factors, high-temperature incineration is characterized by operating temperatures greater than 1,000°C. However, uncertainty remains regarding the ultimate fate of PFAS during permitted hazardous waste combustor high-temperature incineration processes. See **Section 12.4** and **Section 1.6.1**.

Landfill Disposal

Landfills remain a common method for disposing of sewage sludge and biosolids. In 2023, approximately 24% of the biosolids generated by POTWs in the United States was disposed of in landfills (USEPA 2025). Tolaymat et al. (2023) estimated that landfilling of biosolids contributes approximately 850 kg of PFAS mass to municipal solid waste landfills annually, approximately 11% of the 7,480 kg of extractable PFAS mass estimated to have entered municipal solid waste landfills in 2018. Due to widespread concerns about PFAS levels in biosolids, some states have begun placing limitations or bans on the use of land application as a disposal option for biosolids. For example, the State of Maine banned land application of biosolids through a bill passed by the Maine legislature in 2022. This ban resulted in 90% of the biosolids generated in the state being received by a single landfill (Brown and Caldwell 2023). Other states, primarily through the regulatory rulemaking process, have developed thresholds for PFAS levels that may limit land application options and acknowledge that such thresholds may result in additional demand for landfill disposal of biosolids (MPCA 2025). If the use of landfills for biosolids disposal increases due to limitations on other disposal options, demand may outstrip capacity for biosolids disposal in landfills in many areas, thus increasing the need for other biosolids disposal or treatment options.

Sorption and Stabilization

Sorption and stabilization is a nondestructive PFAS immobilization approach that relies on the addition of amendments to reduce the mobility of PFAS and its ability to leach from the biosolids or biosolids-amended soil into other environmental compartments (for example, groundwater, surface water, biota). Sorption and stabilization may be applied in situ to address impacts associated with historical land application of PFAS-impacted biosolids. For additional information regarding sorption and stabilization applications for PFAS-impacted solids, see **Section 12.3.1**.

The ability of sorption and stabilization amendments to effectively immobilize PFAS and the resulting impact on agricultural productivity are active areas of research. Recent studies have focused on biochar as a promising carbon-based soil amendment at PFAS-impacted biosolids land application sites (Sanchez-Hernandez et al. 2024). Compared to activated carbon, the effects of biochar on agricultural soil conditions are relatively well studied. Studies have demonstrated the ability of biochar derived from various feedstocks to sorb PFAS; however, the impact of soil conditions and other environmental factors on sorption capacity and sorption longevity are a focus area for future research (Sanchez-Hernandez et al. 2024).

Holly et al. (2024) evaluated PFAS leaching from land-applied biosolids and the effects on leaching from amending biosolids with biochar. The soil samples were collected from various sites and included silt loam, silt clay loam, sandy loam, and sandy clay loam soil types. Column leaching tests were performed on soil only, soil that had received biosolids, and soils with biosolids and amended with biochar; columns were treated weekly with simulated precipitation over a six-month period. The authors found that leachate from all treatments contained measurable PFAS concentrations (23 of 28 analytes), and the PFAS replacements 6:2 FTS and HFPO-DA were found in leachate although not in initial/untreated samples of either soil or biosolids. The authors indicated that water-holding capacity and organic carbon content of soils influenced leaching potential, and that biochar amendments reduced leaching potential of PFAS; however, this impact was highest for long-chain PFAS, whereas it had only limited impact for the short-chain (<C7) PFAS, with exceptions including PFBS, PFHxA, and PFHxS.

1.6.5.2 Limited Application and Developing Biosolids Treatment Technologies

Pyrolysis/Gasification

Pyrolysis and gasification are thermal decomposition processes that are being evaluated for the ability to destroy PFAS in impacted sewage sludge and biosolids (Garg et al. 2023). Historically, pyrolysis and gasification have been applied on organic-rich waste products with the goal of resource recovery. In general, the pyrolysis and gasification processes running on biosolids feedstock can recover resources in the solid (for example, biochar), liquid (for example, bio-oil), and gas (for example, syngas) phases that may undergo additional refinement for beneficial use. The balance of the resource phases varies between the process and operating conditions. In general, pyrolysis tends to produce more abundant liquid- and solid-phase resources and gasification produces more abundant gas-phase resources (Thoma et al. 2022; Winchell et al. 2022). The fate and transport of PFAS under varying pyrolysis and gasification process operating conditions remain an active area of research (McNamara et al. 2023).

Pyrolysis and gasification units can operate under varying conditions—typically operating at temperature ranges between 300°C and 800°C and 800°C and 1,000°C, respectively (Winchell et al. 2022). Another key distinction between pyrolysis and gasification is the amount of oxygen introduced into the reaction chamber; pyrolysis occurs in the absence or near absence of oxygen, while gasification occurs with an oxygen content less than the stoichiometric minimum for complete combustion (Winchell et al. 2022). For additional information and resources regarding the treatment mechanisms and operation of pyrolysis and gasification systems, see **Section 12.7.2** and **Section 1.6.1**.

Commercial-scale pyrolysis treatment systems for PFAS-impacted sewage sludge or biosolids are not widely implemented in the United States. Winchell et al. (2022) identified one full-scale pyrolysis and one full-scale gasification unit operating in the United States on biosolid feedstock with several additional facilities in design or under construction. Several bench-scale and pilot-scale studies have shown promise that pyrolysis can be used to reduce PFAS concentrations in biosolids, while retaining land application benefits of the biosolids as a biochar product.

Bamdad et al. (2022) completed a bench-scale pyrolysis study that documented the fate of 29 target PFAS. They observed a reduction of quantifiable PFAS in the solid biochar product stream by 97–100

wt% at a processing temperature of 500°C, and by 99.6–100 wt% at a processing temperature of 700°C. Thoma et al. (2022) completed a pyrolysis pilot study of PFAS-impacted biosolids. See **Section 1.6.1.2** for more information.

Winchell et al. (2024) evaluated the fate of biosolids-bound PFAS through a bench-scale pyrolysis unit (operating temperature of 600°C) coupled with a thermal oxidizer (operating temperature of 1,000°C) for air emissions control. Winchell et al. (2024) documented between 91.5% and greater than 99.9% reduction of targeted PFAS through the coupled pyrolysis and thermal oxidizer bench-scale system. On a molar basis, the researchers calculated removal of 99.4% of the total quantified PFAS through the system. Additionally, the researchers sampled the thermal oxidizer exhaust gas and analyzed for targeted PFAS by USEPA OTM-45. Winchell et al. (2024) noted that short-chain PFAS predominated quantifiable PFAS in the thermal oxidizer exhaust gas, ranging between 54.4% and 79.5% of the PFAS moles measured in the exhaust gas. Winchell et al. (2024) identified the need for additional research regarding the fate of PFAS in thermal oxidizer systems.

Supercritical Water Oxidation

Supercritical water oxidation (SCWO) is a destructive technology that uses unique properties of water above its critical point at 374°C and 22 MPa and the addition of an oxidizing agent (for example, air, oxygen, hydrogen peroxide) to generate a highly reactive environment. Although the exact mechanisms of PFAS destruction under SCWO conditions are not well understood, well operated SCWO systems have exhibited high rates (greater than 99.9%) of PFAS mineralization across various PFAS-impacted media (Scheitlin et al. 2023; Chiang et al. 2023). For additional information and resources regarding the treatment mechanisms and operation of SCWO systems, see **Section 12.6.3.12** and **Section 1.6.3**.

In the context of sewage sludge or biosolids treatment, SCWO is being evaluated as a destructive technology. The availability of published literature is limited regarding the application of SCWO to effectively manage PFAS-impacted sewage sludge or biosolids. However, technology developers and municipal wastewater treatment facilities (for example, Orange County California; Orlando, Florida) are actively partnering to conduct pilot testing (Orange County Sanitation District 2022; USEPA 2024). Several studies suggest the viability of SCWO as a destructive technology for PFAS-impacted biosolids based on the documented success of SCWO in mineralizing PFAS and other refractory organic contaminants in a wide range of PFAS-impacted matrixes (Chiang et al. 2023; Berg et al. 2022; Garg et al. 2023).

Effective treatment of PFAS-impacted sewage sludge or biosolids via SCWO relies on the flowability of the material. Additionally, SCWO treatment of sewage sludge biosolids is subject to similar considerations pertaining to more mature applications of SCWO, including effective pretreatment to limit scaling in the reactor and management of reactor materials against the highly reactive SCWO environment. The ultimate fate of PFAS in SCWO reactors is an active area of study, with increased focus on gaseous-phase emissions from SCWO reactors. Furthermore, the scalability of SCWO applications for full-scale biosolids management is uncertain and is the focus of additional research.

Hydrothermal Alkaline Treatment

Hydrothermal alkaline treatment (HALT) is a hydrothermal process that relies on a high-temperature, high-pressure, and high-pH (alkaline) environment to promote PFAS destruction. Diverging from SCWO, the HALT approach occurs below the critical point of water, typically around 350°C and 16.5 MPa in alkali-amended solutions (e.g., 1–5 M sodium hydroxide) (Wu et al. 2019; Hao et al. 2021). HALT reactors have demonstrated the ability to destroy a wide range of PFAS, achieving greater than 99% destruction in a continuous flow system treating AFFF-impacted fire training pit water (Pinkard et al. 2023). For additional information and resources regarding the treatment mechanisms and operation of HALT systems, see **Section 12.6.5**.

The availability of published literature is limited regarding the application of HALT to destroy PFAS in biosolids. A Water Research Foundation project is evaluating HALT technology in the context of treating PFAS-impacted biosolids (Gao 2025). Effective treatment of PFAS-impacted biosolids via HALT relies on the flowability of the biosolids material. Additionally, the scalability of HALT applications for full-scale biosolids management and potential high chemical demands (for example, alkali) is uncertain and is the focus of ongoing research.

Hydrothermal Liquefaction

Hydrothermal liquefaction (HTL) is a high-temperature, high-pressure process for converting biomass into biofuel. HTL relies on the water content of the biomass to enter a subcritical or supercritical state, depending on the reactor conditions. Water under these conditions creates a highly reactive environment, able to depolymerize macromolecules present in the biomass and convert them to smaller, hydrocarbon-like compounds that can be further refined into liquid fuel products (Toor, Rosendahl, and Rudolf 2011). Based on the elevated water content of biosolids, HTL has garnered interest for its potential to create biofuels from biosolids.

Recently, researchers have started to focus on evaluating the HTL process for its ability to mineralize PFAS present in biosolids and other sources of biomass. Based on preliminary findings, HTL has demonstrated the ability to mineralize PFAS, including refractory PFAAs; however, the extent of PFAS mineralization varies between compounds (Yu et al. 2020; Zhang et al. 2020). In a bench-scale study, Yu et al. (2020) concluded that HTL was able to achieve degradation rates of PFCAs greater than 99%, while degradation rates of PFSAs were limited, falling to 67% for 8:2 FTS and 34% for PFOS. Other researchers have focused on evaluating catalytic amendments to the biosolids or biomass to promote PFAS mineralization, with mixed results (Zhang et al. 2020; Zhang and Liang 2022).

In general, HTL has demonstrated limited effectiveness in completely mineralizing the complex mixtures of PFAS typically present in biosolids. However, additional research is ongoing regarding alternatives to optimize the HTL process for more robust PFAS mineralization efficiency.

Biological Treatment

Biological treatment processes are commonly applied to reduce pathogens and stabilize biosolids for land application scenarios. The USEPA identifies aerobic digestion, anaerobic digestion, and composting as biologically mediated treatment processes for biosolids stabilization (USEPA 1993). Several studies have investigated the ability of common biologically mediated biosolids stabilization approaches to destroy PFAS and have generally concluded that these biological processes are ineffective at mineralizing recalcitrant PFAAs (Garg et al. 2023; Kim Lazcano et al. 2019; Li et al. 2022; Kumar et al. 2023). However, these studies have documented the transformation of polyfluorinated PFAA precursors present in the biosolids material during these biologically mediated stabilization processes, which is generally consistent with the findings of other biodegradation studies of PFAS discussed in **Section 12.6.4**.

Looking more broadly at biologically mediated treatment processes for PFAS-impacted biosolids, alternative approaches, such as phytoremediation, are being evaluated (Zhang and Liang 2022; Zhang, Tran, and Liang 2022; Wen et al. 2016). Additional research is needed to better understand the potential applicability of biologically mediated processes for biosolids treatment.

1.6.6 Updated and Recent and Relevant Technology Review Papers

This section provides information about updated and recent technology review papers focusing on PFAS treatment technologies and supplements the information published in **Section 12** and Table 12-1 Treatment Methods Table.

- Overview: Meegoda et al. 2022. A review of PFAS destruction technologies. International Journal of Environmental Research and Public Health 19.
- Liquids: DiGuiseppi et al. 2024. Available and emerging liquid treatment technologies for PFAS. Remediation 34(3).
- Thermal: Longendyke et al. 2022. PFAS fate and destruction mechanisms during thermal treatment: A comprehensive review. Environmental Science: Processes & Impacts 24, 196-208.
- Biosolids: Garg et al. 2023. Treatment technologies for removal of per- and polyfluoroalkyl substances (PFAS) in biosolids. Chemical Engineering Journal 453(2). Per- and polyfluoroalkyl substances thermal destruction at water resource recovery facilities: A state of the science review. Water Environment Federation, 93:826-843. https://doi.org/10.1002/wer.1483
- Soils: Mahinroosta and Senevirathana 2020. A review of the emerging treatment technologies for PFAS contaminated soils. Journal of Environmental Management, 255.
- Wastes: Berg et al. 2022. Developing innovative treatment technologies for PFAS-containing wastes. Journal of the Air & Waste Management Association, 72(6), 540-555.
- Wastewater treatment effluent: Ling et al. 2024. Is removal and destruction of perfluoroalkyl and polyfluoroalkyl substances from wastewater effluent affordable? Water Environment Research, 96(1).

1.7 Priority Topics for Biosolids Land Application

Section Number	Topic
1.7.1	**Introduction: Application of Biosolids to Lands Supporting Animals and Crops**
1.7.2	**Conceptual Site Model**
1.7.3	**Assessing Potential Risk from Agricultural Impacts**
1.7.4	**Plant Uptake**
1.7.5	**Uptake by Animals**
1.7.6	**Conclusion**

These Priority Topics are focused on per- and polyfluoroalkyl substances (PFAS) in biosolids applied to land as fertilizer and include discussion of the fate and transport, leaching, and plant and animal uptake of PFAS following biosolids application. Biosolids-related information is referenced in multiple sections of the PFAS-1 Guidance Document (https://pfas-1.itrcweb.org/) including wastewater treatment residuals as a source in **Section 2.6.4**. Fate and transport topics such as partitioning, leaching, and transformation are briefly discussed in **Section 5**. **Section 5.6** discusses uptake to plants across multiple site types. **Section 6.2.3** describes reported PFAS levels in land-applied soils, and biosolids. Related information is found in new Priority Topics in **Section 1.4** which includes human and ecological effects information and **Section 1.6.5** which discussed treatment of biosolids.

Publicly owned treatment works (POTWs) are present in communities around the world treating wastewater and generating biosolids on a continuous basis. Biosolids are produced from sewage sludge that is derived from domestic wastewater (which may include contributions from industrial sources) at POTWs or privately owned wastewater treatment plants. Biosolids do not typically include sludges derived from privately owned industrial wastewater treatment works, although those byproducts may also be licensed for land application. Land application has been a common practice since the 1970s in the United States (USEPA 1972). Although a large fraction of biosolids is land-applied, a relatively small fraction of US farmland is fertilized with biosolids (Beecher et al. 2022).

Biosolids and their connection to PFAS in soil, groundwater, crops, livestock, and other animals, and potential human health exposures, are a growing area of research, and public awareness has increased around this issue. For example, a review by Ehsan et al. (2024) highlighted biosolids as one of several significant sources of PFAS in soil and noted that accumulation in plants and uptake into ecological food chains are potential concerns and topics of ongoing research. In a study by Pepper et al. (2021), PFAS were detected in soils with historical biosolids applications, although concentrations were relatively low (up to 4.1 µg/kg for perfluorooctane sulfonic acid (PFOS)).

General media articles also reflect increased public awareness of PFAS in agricultural settings and food. For example, Kirchner (2024) reported on PFAS testing of "off the shelf" milk and discussed cases in Michigan and Maine where the source on farms was related to fields fertilized with biosolids. Regulatory programs have also acknowledged the potential impact of land application sites. The US Food and Drug Administration is evaluating PFAS in food supplies; biosolids are acknowledged as one of many pathways through which PFAS may be introduced to the food supply (USFDA 2025), along with environmental contamination (presence in water) or presence in cookware. Following the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) designation of widely used PFAS as hazardous substances, the US Environmental Protection Agency (USEPA 2024) recognized that land application of biosolids should be excluded along with several other categories from Superfund site consideration.

The terms "sewage sludge" and "biosolids" are often used interchangeably. However, the USEPA makes a technical distinction between the two. Typically, the USEPA uses the term "biosolids" to refer to sewage sludge that has undergone sufficient treatment (for example, pathogen and vector attraction reduction) to meet the requirements outlined in USEPA 40 CFR §§ 503 "Standards for the Use or Disposal of Sewage Sludge," and is intended for land application as a soil conditioner or fertilizer. "Sewage sludge" is generally reserved for untreated municipal wastewater residual that has a high solids content and may have undergone dewatering to increase the relative solids content and reduce residual volume. In conventional wastewater treatment, large objects and readily settleable solids (primarily inorganic) are removed during the initial screening and grit removal stages. The materials removed during screening and grit removal are typically managed separately and do not become part of the "sewage sludge" residual. In general, "sewage sludge" consists of solids removed during primary settling (primary sludge) and solids removed during biologically mediated treatment processes that may include higher proportions of cell mass (secondary sludge). "Sewage sludge" that then undergoes treatment for land application, often with the intended beneficial use as a fertilizer, is referred to as "biosolids." For clarity in this section the term "biosolids" will be used to refer to treated sewage sludge. the term "biosolids" will be used to refer to treated sewage sludge.

In the United States, biosolids can be divided into two primary classes based on pathogen density, as measured by the presence of indicator organisms (for example, Salmonella and fecal coliform). Class A biosolids have stricter guidelines for pathogen content, as these can be applied directly to fertilize food crops, to a lawn, or a home garden, or when biosolids are sold or given away in a bag or other container for application to the land. Class B biosolids can be used on agricultural land with specific crop and harvest restrictions. Class B biosolids are also spread on forested land, pastures for animals, and reclamation sites (Boczek et al. 2023; Beecher et al. 2022). Whereas Class A and B biosolids require

distributors to meet some permitting requirements, biosolids treated to meet all the requirements in USEPA 40 CFR §§ 503.10(e), (f), and (g) are defined as Class A EQ (exceptional quality). These are typically sold or given away in consumer quantities that are exempt from land application regulations. Typical approaches for treating sludge to meet biosolids criteria do not target PFAS.

Biosolids are briefly discussed in several sections—for example, **Section 2.6.4** and **Section 6.2**. These Priority Topics summarize the current understanding of the science of PFAS in biosolids focused on the land application end use for this material. Land application of biosolids represents a potential PFAS release mechanism to the environment, including through leaching and uptake. Up to 60% of biosolids in the United States may be going to beneficial reuse (USEPA 2025).

1.7.1 Introduction: Application of Biosolids to Lands Supporting Animals and Crops

Biosolids contain a high ratio of nutrients and organic carbon to volume, making them a desirable product for agricultural fertilizer. The application of biosolids on agricultural land as a low-cost fertilizer is a common practice. However, the presence of PFAS and other contaminants such as microplastics and pharmaceuticals and personal care products has increased the scrutiny of land application of biosolids (Xia et al. 2005; Jones-Lepp and Stevens 2007; Carsella et al. 2022; Marchuk et al. 2023). Spreading rates for agricultural sites in the United States are regulated by 40 CFR Parts 503.12, 503.13, and 503.14. These regulations outline annual pollutant (non-PFAS) loading rates that, in addition to agronomic requirements, dictate application rates. In 2012, it was reported that Western European countries land spread about 41% of biosolids produced (Kelessidis and Stasinakis, 2012). Land application rates increased through the 1980s prior to regulation (USEPA 2000). Data for 2022 indicate 56% of biosolids were land applied. In addition to land application, the United States incinerates 16% of biosolids, landfills 27%, and uses alternate methods of disposal for the remaining 1% (USEPA 2023).

Based on a survey of US states reported in April 2025 (ECOS 2025), with respect to state actions addressing PFAS in biosolids, Maine has banned land spreading of biosolids, Connecticut has banned use and sale of biosolids that contain PFAS, and several other states have or are planning to issue guidance or regulations. For example, New Hampshire requires biosolids to be sampled for PFAS before spreading with a goal of using the data to support reduction of PFAS concentrations in biosolids (ECOS 2023).

A recent survey of biosolids management globally (Saliu and Sauvé 2024) found that China produced nearly 8 million tons dry weight of biosolids annually, compared to 4.75 million tons in the United States in 2019. Other countries, including India, Japan, Vietnam, South Korea, and Germany, showed annual production of approximately 2 million tons dry weight in the survey (Saliu and Sauvé 2024). Most developed countries around the world report application of biosolids to agricultural land or composting as a primary outlet for managing organic waste. Europe overall is similar to the United States with a rate of about 50%. China land applied approximately 29%, Australia and New Zealand applied approximately 89% to lands, and some utilities in Colombia and Chile reported similar rates of 65% and 75%, respectively, for the years reported (Saliu and Sauvé 2024).

Several methods have been employed to apply biosolids on agricultural lands, reclamation sites, forested areas, and residential properties (including gardens). Low percent solid biosolids have 2%–6% dry weight and are sprayed onto the ground surface and tilled into the soil or injected into the shallow subsurface. Dewatering processes can reduce the water content to 75%–80%, creating a semisolid material that can be spread using conventional agricultural equipment (for example, manure spreaders). To reduce contact with the material, land application may be followed by mixing surface-applied biosolids into the shallow subsurface, a process known as incorporation (USEPA 2025).

1.7.2 Conceptual Site Model

The PFAS and biosolids conceptual site model (CSM) is a written and illustrative description of the potential release sites and pathways based on known environmental and site information and presents several unique aspects compared to typical CSMs. **Figure 1-28** presents a general CSM for biosolids at land application sites. For typical biosolids from POTWs, PFAS can be sourced from upstream PFAS-impacted industrial, commercial, and residential wastewaters. Some of the PFAS in the wastewater impacts the generated sludge and ultimately the biosolids. Biosolids application for beneficial use in agriculture is commonly regulated, managed, and permitted at the state level. PFAS-impacted biosolids resulting from PFAS discharge to a wastewater treatment plant (WWTP) may be applied at one or a few locations or at hundreds of farm fields such that distribution can be very widespread.

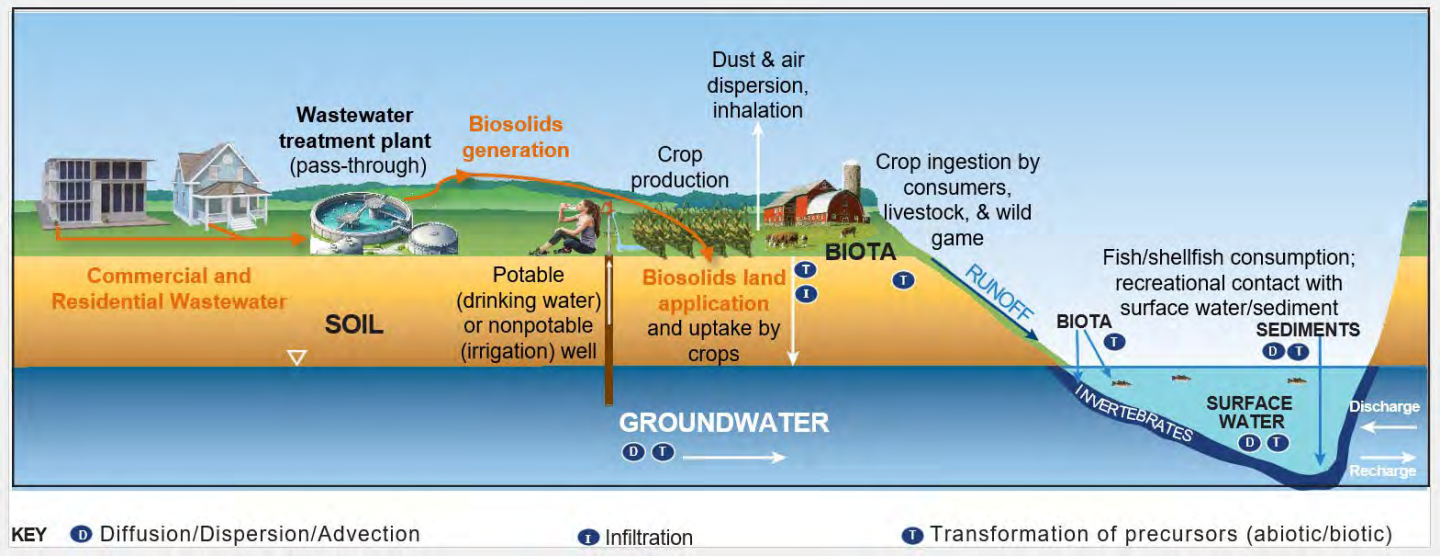


Figure 1-28. Conceptual site model at biosolids land application sites.

*Source: Figure created by L. Trozzolo, TRC, using Microsoft® Online 3D Models. "Bird's eye view of a wastewater treatment plant" image generated by Microsoft® 365 Copilot AI Chatbot, **https://copilot.cloud.microsoft/**, February 14, 2025. Used with permission.*

The application of biosolids containing PFAS on farm fields can impact several types of receptors via different exposure routes:

- Drinking water wells can be impacted from PFAS leached from biosolids and transferred through the vadose zone to groundwater.
- Agricultural crops can uptake PFAS from biosolids, as discussed in **Section 1.7.4**.
- Livestock and wild game can ingest PFAS from biosolids through several pathways, as discussed in **Section 1.7.5**, including consumption of contaminated well water; consumption of silage, grass, and hay from farm fields; or in the case of poultry, from consumption of insects and invertebrates living on or in soil contaminated by biosolids.
- Surface water and sediments can be impacted by runoff and erosion, where uptake to fish or other biota may occur.
- Soil with PFAS impacts from biosolids may be ingested and dust may be inhaled.

The fate of PFAS in biosolids includes diffusion, adsorption, dispersion, and advection during migration in soil, groundwater, surface water, and sediment. PFAS may also be dispersed in air—for example, by windblown particles. Through these pathways, PFAS precursors may transform to perfluoroalkyl acids

(PFAAs). Biosolids themselves are high in organic carbon and can retain PFAS, particularly longer chain PFAS and sulfonates, resulting in long, slow release and extending the natural migration and attenuation of PFAS. Biosolids application sites may also have some PFAS impacts not from biosolids, such as anthropogenic background from atmospheric deposition to soil.

1.7.2.1 Factors Influencing PFAS Mobility in Soils

PFAS mobilized from surface soil after biosolids application enter the unsaturated zone of soil above the groundwater in the vadose zone. Behavior of PFAS in the vadose zone is a major topic of interest because it has been shown that PFAS can be retained in this compartment for years to decades (Sharifan et al. 2021). This is important because retention in the vadose zone can translate to a long-term PFAS source to groundwater.

Climate/location and soil properties can influence PFAS transport in the vadose zone at biosolid application sites. Site-specific and climate-related factors, such as precipitation amount and frequency, depth to water, and infiltration rates, will affect the rate at which the system is flushed (Guo, Zeng, and Brusseau 2020; Brusseau 2020). Soil properties such as cation and anion exchange capacity, pH, carbon content, and soil texture will also affect contaminant transport through the vadose zone (Nguyen et al. 2020). See **Section 5.2** for additional details. Land-applied biosolids can influence these factors and affect PFAS transport. For example, microbial weathering processes can influence decomposition of the biosolids, in turn impacting partitioning of the PFAS and enhancing degradation of precursors (Lewis et al. 2023). Biosolids treatments prior to land application may also affect PFAS transport. Sludge stabilization has been found to decrease the sorption capacity for PFAS relative to secondary sludge and differences in partitioning behavior of PFAS have been observed depending on whether the sludge is aerobically or anaerobically digested (Ebrahimi et al. 2021).

PFAS interacts with climate and soil factors based on physical-chemical interactions on a microscale. Most research in this area is on PFAAs, which are recognized to be affected by hydrophobic effects, electrostatic interactions, and interfacial behaviors, such as sorption at air-water and NAPL-water interfaces. These are discussed in detail in **Section 5.2.4.1** and **Section 5.2.5** and summarized in the context of biosolids sites below.

PFAAs tend to associate with the organic carbon fraction of soil, with sorption to organic carbon generally increasing with an increase in perfluorinated carbon chain length, which is also associated with increased hydrophobicity (Higgins and Luthy 2006; Guelfo and Higgins 2013; Sepulvado et al. 2011; Campos Pereira et al. 2018). Given the relatively high organic carbon content in biosolids, organic carbon partitioning is likely an important factor for considering PFAS transport and fate at biosolids sites. One study (Evich et al. 2025, 2025) of two agricultural sites with a history of sludge application found that organic matter had a greater influence on mobility of long-chain versus short-chain PFAS. PFAS concentrations in agricultural soil are also found to be correlated with soil organic matter and pH (Oviedo-Vargas et al. 2025). Studies have shown that in the context of PFAS partitioning in biosolids, protein fractions and, to a lesser extent, lipid fractions, were also important solid-specific properties to consider (Ebrahimi et al. 2021).

Another factor with potential influence on PFAS behavior in land-applied soils is the presence of microplastics (MP) in biosolids (Siddiqui 2024). Evaluation of land application sites has correlated use of biosolids with increases in MP in soil (Crossman et al. 2020; Tran et al. 2023; Adhikari et al. 2024), and PFAS are known to be associated with MP through direct degradation of fluoropolymers and through sorption and desorption processes (Lohmann et al. 2020, Salawu et al. 2024). This linkage is a topic of ongoing research and could represent an additional factor affecting fate and transport in soil. More information on PFAS and MP is included in **Section 1.8**.

Solid-phase and solution chemistry plays a role in affinity of PFAAs for the solid phase. Changes in pH potentially impact electrostatic processes by altering surface charges, or possibly the ionic nature of the PFAS (Nguyen et al. 2020), and higher amounts of polyvalent cations, such as calcium, iron, and magnesium, can also affect electrostatic interactions and increase sorption of PFAAs (Higgins and Luthy, 2006 ; McKenzie et al., 2016). See **Section 5.2.3.2**. Data from Evich et al. (2025, 2025) showed that electrostatic interactions at mineral surfaces exerted greater influence on short-chain PFAS sorption than on longer chain PFAS sorption, which was driven by interaction with the air-water interface and organic carbon.

Because PFAAs are surfactants, they have been shown to reside in the bulk phase and to align themselves at the interfaces between phases, such as at the air-water interface and NAPL-water interface. Air-water interfacial sorption is likely a large contributor to vadose zone retention (Sepulvado et al. 2011; Ahrens and Bundshuh 2014; Sharifan et al. 2021). As discussed in **Section 4.2.7**, the surfactant properties of some PFAS may result in aggregation into micelles.

Transport of PFAS through the vadose zone after surface releases is an evolving topic, and there are still many uncertainties with PFAS vadose zone retention both generally and specifically for biosolids sites. For additional details on these processes, see **Section 5** and the latest vadose zone fate and transport research in **Section 1.3.1**.

1.7.2.2 Nature and Extent of PFAS at Land Application Sites

PFAS, including precursors, can enter the wastewater stream from numerous sources, including residential, commercial, and industrial wastewaters. **Section 6.2.3** discusses the reported concentrations of PFAS found in biosolids material across different time periods and from different sources or treatment plants. The concentration variability is directly related to the source inputs at each facility. The variable biosolid concentrations in combination with application rates, years of application, and other factors all contribute to different levels of impact observed at land application sites (USEPA 2025). Research is ongoing to evaluate PFAS impacts at land application sites and to assess the extent of impacts to soil and other media.

For example, Alvarez-Ruiz et al. (2024) reported on a study from a group of fields with a 38-year history of land application, in this case from a wastewater treatment plant that serves mainly domestic sources along with a hospital, dentist, and dry cleaner. Approximately 5,700 m^3 of 4%–5% solids biosolids were injected annually at the study site. The authors reported soil core concentrations across several orders of magnitude with total PFAS of 1,700 ng/g in the top 30 cm, decreasing to approximately 2 ng/g at 120 cm–150 cm. In a control field where no application occurred, the maximum total PFAS was approximately 1 ng/g. The authors discussed detections of several PFAS classes that may act as precursors, such as polyfluoroalkyl phosphoric acid diesters (diPAPs) and fluorotelomer carboxylic acids (FTCAs).

Maine Department of Environmental Protection (MEDEP) recently issued an updated summary report based on statewide sampling of private water supplies and soil at biosolids application sites, septage sites, and landfills (MEDEP 2025) and found that domestic water supplies exceeding the Maine Interim Drinking Water Standard of 20 ng/L for a sum of six PFAS were typically within 1,000 feet of those sites. The statewide study also showed that in Maine at land application sites where average total PFAS soil levels are 20 ng/g or less, the average detected total PFAS in private water supplies is below 50 ng/L, and across the state for all wells tested near land application sites, only 20% exceed the Maine Interim Standard. The data distribution for the 2,919 residential well samples collected statewide as of November 2024, in relation to all biosolids sites tested, is presented in **Figure 1-29**. based on concentrations in ng/L.

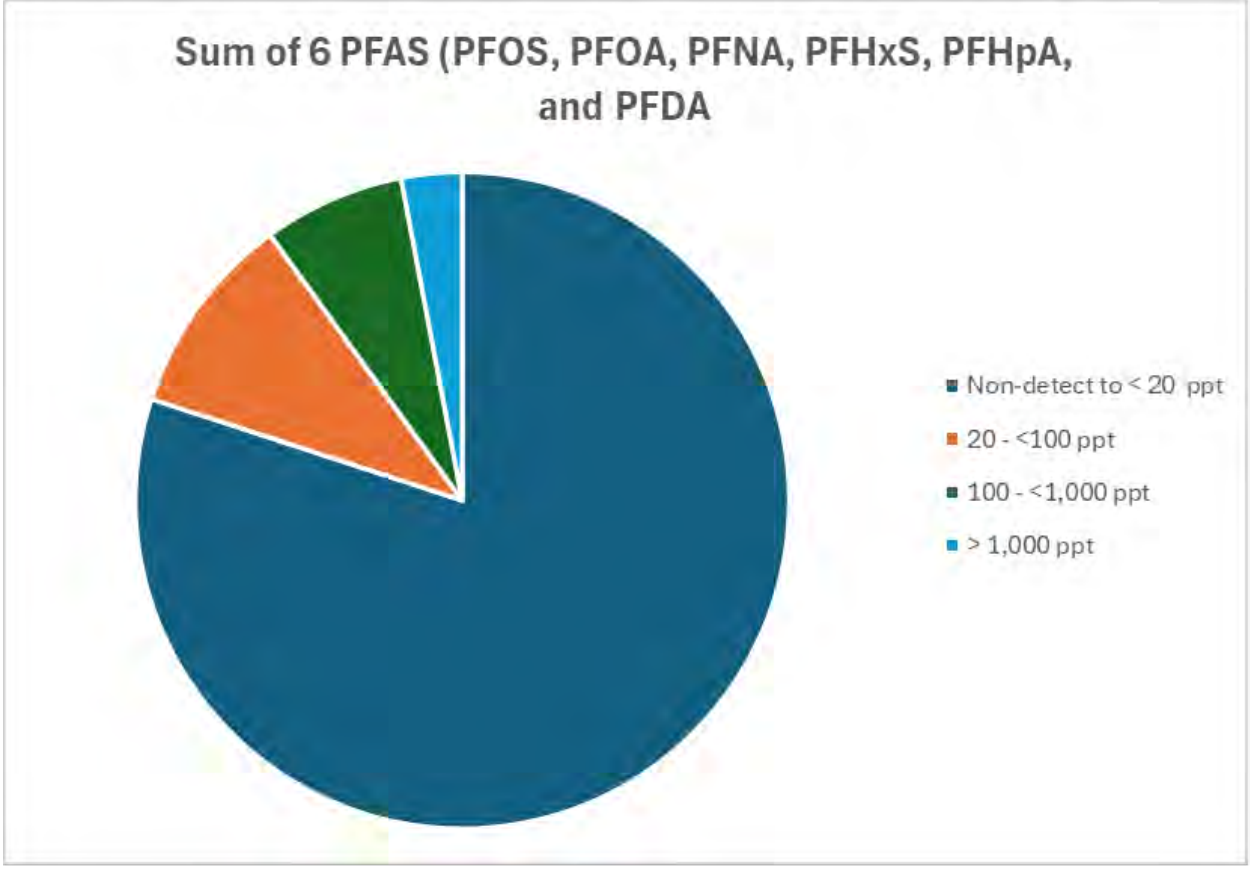


Figure 1-29. Data distribution for residential well samples near biosolids sites in Maine (concentrations in ng/L).

Source: Figure generated by Chris Evans, MEDEP, based on data from the Second Biennial Report (ME DEP 2025) , used with permission.

There are many sources of PFAS to agricultural fields, aside from biosolids, that may increase concentrations in soil and groundwater. These sources may include manure from contaminated farms, commercially available fertilizers and pesticides, contaminated irrigation well water, and rainwater deposition (see **Section 2.5** and **Section 2.6**). Other potential sources may be windblown dust from adjacent contaminated fields (Borthakur et al. 2022) or anthropogenic background atmospheric deposition to soil (see **Section 6.2.1**). The relative contribution of cumulative inputs to the total mass of PFAS present in any given field will be very site-specific and dependent on the history of the site and its location relative to other sources.

PFAS tend to remain in the soil as a long-term source to other environmental media. Soil cores collected from multiple study sites show vertical migration of PFOA to depths of up to 9 m with most of the PFAS mass remaining in the top 30 cm (Johnson 2022). Ratios of long- to short-chain perfluorinated compounds decrease with depth due to the retention of longer chains in surface soils (Washington et al. 2010; Sepulvado et al. 2011; Borthakur et al. 2021). Oviedo-Vargas et al. (2025) studied 10 farms with varied biosolids application and found concentrations decreased with depth and lower concentrations were correlated with increased chain length in the deeper 15 cm–30 cm interval. Polyfluorinated precursors (for example, N-methylperfluorooctane sulfonamidoacetic acid, N-MeFOSAA) have been found in surface soils at concentrations over 60 µg/kg but are detected at lower concentrations or not at all at greater depths due to their transformation into perfluorinated compounds and greater retention in surface soils due to their differences in physical-chemical properties (Sepulvado 2011). Pepper et al. (2021) also

found that PFAS concentrations declined with depth and that precursors such as N-MeFOSAA were detected in biosolids but not in soils following land application, suggesting that transformation occurred.

Extensive research has been conducted on the leaching of PFAS to groundwater (see **Section 5**). Although most early research focused on aqueous film-forming foam (AFFF) sites, there is increasing interest in biosolids and land application sites. Although some states have documented extensive impacts to groundwater near land application sites (ME DEP 2025), other studies have not found that leaching of PFAS to groundwater is significant (Peter and Lee 2025). Leaching of PFAS from soil will occur at higher rates in areas with shallow groundwater and high amounts of water percolating through the soil due either to precipitation or irrigation (Pepper, Kelley, and Brusseau 2023). Site-specific leaching rates can be estimated using laboratory tests (see **Section 1.5.1**), such as Leaching Environmental Assessment Framework (LEAF) or Synthetic Precipitation Leaching Procedure (SPLP), however, the accuracy of such test methods, which is complicated by biosolids physical and chemical properties, requires further research (Navarro et al. 2024).

Discharge to nearby surface water is also an important consideration. Peter and Lee (2025) identified PFAS in a stream hydrologically linked to a field receiving biosolids in a study in Indiana, with maximum perfluorooctanoic acid (PFOA) and PFOS concentrations of 10.8 and 3.7 ng/L, respectively. A recent study of 10 farms in Pennsylvania with 2 to 26 years of biosolids application (Oviedo-Vargas et al. 2025) found max concentrations of PFOA and PFOS in surface water of 250 ng/L and 110 ng/L, respectively. These are lower concentrations by 1–2 orders of magnitude than what has been reported where industrially impacted biosolids were used (Lindstrom et al. 2011) but highlight that leaching or runoff to surface water is an important factor for PFAS migration at these sites.

1.7.2.3 Potential New Classes of PFAS in Biosolids that May Require Non-targeted Analysis

Occurrence data for PFAS in biosolids, including PFAAs and select precursors, are provided in **Section 6.2.3**.

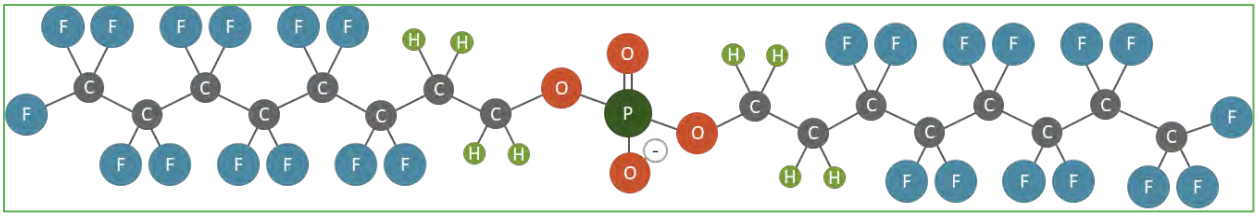


Figure 1-30. 6:2 polyfluoroalkyl phosphoric acid diester (6:2 diPAP).

Multiple studies have shown that standard PFAS target analyte lists are not reporting the full extent of PFAS present in wastewater or biosolids. Analytical techniques may include non-targeted analysis (NTA), which can be used to identify PFAS beyond those included in the conventional analyte list, and various "total PFAS" analytical methods (see **Section 11.2** and **Section 11.4.3** for additional information on NTA instrumentation and procedures). NTAs have identified primary classes of precursors that comprise significant fractions of PFAS in biosolids, including diPAPs, perfluorophosphonic acids (PFPAs), and various classes of cationic and zwitterionic precursors. Of these, 6:2 diPAP (**Figure 1-30**) has been the predominant PFAS detected in biosolids in multiple studies (Thompson et al. 2023; Schaefer et al. 2023; Lazcano et al. 2019), and diPAPs have been identified as potential perfluoroalkyl carboxylic acids (PFCA) precursors when applied under field conditions (Lämmer et al. 2022). Alternative non-targeted methods that have estimated total PFAS also suggest that unidentified precursors tend to account for much of the PFAS presence in biosolids. Associated studies are summarized below. Conventional sampling of biosolids or associated land-applied soils, for example, as conducted under regulatory requirements, would typically be limited to the analyte list included in USEPA Method 1633A (or similar methods) and

may not include these non-targeted analytes. See **Section 2.2** for more information about PFAS chemistry and **Section 11.2** for more information about analytical methods.

A 2023 study (Thompson et al. 2023) evaluated PFAS content at eight facilities in untreated sewage sludge samples and in biosolids after treatment for pathogen removal . Treatment methods included composting, anaerobic digestion, lime treatment, and heat treatment (90°C–120°C). The sum of PFAS concentrations ranged from 182 µg/kg to 1,650 µg/kg. Of detected PFAS, diPAPs were the predominant compounds, comprising an average of 54% ± 15% of total detected PFAS. PFAAs accounted for a relatively small fraction of the total PFAS detected; prior to treatment for pathogen removal, precursors comprised 82% ± 11% of total detected PFAS. Pathogen treatments had varying impact on the PFAS composition. Most treatments resulted in substantial increases in short-chain PFCAs while impacts of treatment on long-chain PFCAs and PFSAs were variable and were generally minor compared to variations in other compounds. Interestingly, concentrations of diPAPs increased following heat treatment. A primary source of diPAPs in wastewater, and associated biosolids, has been identified as toilet paper (Thompson et al. 2023).

Schaeffer et al. (2023) analyzed PFAS content in wastewater influent/effluent and biosolids at 38 treatment plants; targeted PFAS analysis was supplemented with the total oxidizable precursor (TOP) assay and NTA. TOP assay results indicated that unidentified precursors comprised 21%–88% of total fluorine. NTA identified several classes of precursors present in waste streams. Predominant among these precursors, PFPAs and diPAPs were detected in 100% and 92% of biosolids samples, respectively.

Multiple studies have evaluated fluorine nuclear magnetic resonance (^{19}F-NMR) as a useful tool for evaluating total PFAS (for example, Camdzic et al. (2023); Lewis et al. 2023; and Gauthier and Mabury 2023). Camdzic et al. (2023) evaluated ^{19}F-NMR as an alternative method for quantifying total PFAS in wastewater. In this study, ^{19}F-NMR was compared to TOP assay and liquid chromatography with high resolution mass spectrometry (LC-HRMS). ^{19}F-NMR detected 63% and 65% more PFAS than TOP assay and LC-HRMS, respectively, suggesting that TOP assay and LC-HRMS techniques may underreport total PFAS. Furthermore, ^{19}F-NMR was able to identify ultrashort-chain PFAS (ultrashort PFAS), such as trifluoroacetic acid (TFA), that might not be included in conventional target PFAS analytical methods. Limitations for ^{19}F-NMR include higher detection limits and difficulty in resolving complex PFAS mixtures. Lewis et al. 2023 used ^{19}F-NMR to screen sorbent materials for PFAS uptake. Gauthier and Mabury (2023) measured ^{19}F-NMR spectra for hundreds of PFAS and used the resulting data to evaluate the total PFAS presence in an environmental sample from a site impacted with AFFF and published the resulting ^{19}F-NMR spectra database for use in other projects.

Lazcano et al. (2019) used liquid chromatography–quadrupole time-of-flight (LC-QToF) to evaluate precursor content in biosolids after conventional treatment processes—including heating, composting, blending, and thermal hydrolysis—were applied to remove pathogens and select organic constituents. In this analysis, diPAPs were the most commonly detected precursors, detected in all samples. Fluorotelomer sulfonates and carboxylates (FTSAs and FTCAs, respectively) were also detected. Of the treatment methods evaluated for pathogen removal, heat treatment and composting had the greatest effect on transformation of precursors into PFAAs.

As an additional consideration, fluorinated pharmaceuticals are frequently present in wastewater streams and may complicate evaluation of total PFAS. In particular, extractable organic fluorine (EOF) data are often represented as “total PFAS” but may also include fluorinated pharmaceuticals. Ruyle et al. (2025) evaluated wastewater influent and effluent from eight US POTWs and found that PFAA and PFAA precursors estimated from the TOP assay accounted for only 24%–37% of EOF, whereas mono- and polyfluorinated pharmaceuticals made up 62%–75% of EOF. Polyfluorinated pharmaceuticals containing -CF3- or -CF2- moieties accounted for the majority of EOF (53%–58%). In terms of utility, the study suggested that EOF is useful as a screening tool for organofluorine presence, although total PFAS did not correlate well with EOF results. Spaan et al. (2023) found fluorinated pharmaceuticals to account for

approximately 22% of identified compounds in EOF, compared to approximately 5% for PFAA and PFAA precursors, in WWTP sludge from Sweden. Fluorinated pharmaceuticals may or may not be considered PFAS, depending on the definition used for PFAS. The definition distinction may have implications in terms of future considerations for regulating PFAS as a class, but PFAS measured using targeted analysis were present in all waste streams (Ruyle et al. 2025). At this time, data gaps associated with fluorinated pharmaceuticals include toxicology and ecotoxicology for the complex chemical mixtures, as well as their behavior in the environment once land-applied on farmland.

1.7.2.4 Assessment of PFAS at Land Application Sites

When assessing PFAS related to biosolids land application, it is critical to understand the history of the site, rates of application, area licensed, and inputs to wastewater treatment that may have changed over time, affecting both concentrations and types of PFAS. Gewurtz et al. (2024) evaluated the concentration trends and fate of 42 PFAS compounds throughout the treatment processes (influent, effluent, and biosolids) of multiple wastewater treatment plants in Canada. Results of this study indicated widespread presence of both short- and long-chain PFAS. Highest PFAS concentrations were generally detected in WWTPs receiving landfill leachate. Except for PFOS, concentrations of long-chain PFCAs decreased over approximately a decade in influent, effluent, and biosolids, coincident with the phaseout of certain PFAS in industrial production, whereas short-chain PFCA concentrations increased over time in influent and effluent (although not in biosolids, where they were infrequently detected), reflecting increased industrial use of replacement compounds. PFAS patterns in biosolids generally differed from the patterns observed in influent and effluent samples, which may be from enhanced sorption to solids in the sludge material. In biosolids samples, long-chain PFCAs, PFOS, long-chain precursors, and intermediate transformation products were detected the most frequently, in over 60% of samples, while PFOS, perfluorobutanoic acid (PFBA), and 5:3 FTCA (a short-chain precursor) were detected at the highest concentrations. Across WWTPs, higher PFAS concentrations were generally observed for facilities using anaerobic and aerobic sludge digestion; Gewurtz et al. (2024) postulated that this difference may be due to precursor transformation as well as a reduction of volatile solids in sludge, which further concentrates PFAS.

To assess whether PFAS in soil at a land application site is a potential risk to drinking water or farm operation, an accurate characterization of PFAS concentrations in soil is required. Heterogeneity is a significant concern when characterizing soils in an area of land application, particularly where there is a long history with multiple amendments or applications from different sources, or a variety of crops grown across the property. Heterogeneity of source material and site soil conditions contributes to field heterogeneity. Variable application rates based on the nutrient requirements of different crops are also a potential factor across different fields where the same fertilizer source is in use. For example, corn requires higher fertilizer inputs than pasture or other crops, such as wheat or oats (USDA 2023; Ketterings and Workman 2022), so those fields may have higher associated levels of PFAS based on the higher fertilizer application rates. Studies of nitrogen, potassium, and phosphorus distribution show that concentration variation within fields may be 4x to 10x despite an agricultural goal of uniform concentrations (Fu et al. 2013; Mancini et al. 2024). Fu et al. (2013) also discussed the influence of pastured animal behavior and field access points on land application of manures or fertilizers.

Research into nutrient variability conducted to improve optimization of fertilization needs also provides insight into potential underlying variability of PFAS related to land application. Marcaida et al. (2025) documented spatial variability of pH, phosphorus, and potassium in corn fields based on grid-based soil data. They found that grid cell density impacted interpreted spatial distribution of the parameters tested and subsequent fertilization recommendations. Virk et al. (2024) completed a similar study illustrating the influence of grid size selection of 1-, 2.5-, 5-, 7.5-, and 10-acre cells on evaluations of field variation of pH, phosphorus, and potassium. An earlier study (Cambardella and Karlen 1999) used grid-based sampling to assess variations in soil nutrient parameters, including pH and total organic carbon, in an “organic” field fertilized in part with biosolids and a field farmed with conventional practices. Cambardella and Karlen (1999) concluded that greater variability in the organic field suggested that a smaller grid cell

size was required to assess fertilization needs, and soil cores showed variation with depth from 0 to 30 cm at each grid cell. Data showed, for example, that organic carbon decreased from about 51 g/kg to 33 g/kg on average across the field. Based on the potential relationship of PFAS sorption to pH, organic carbon, and other soil parameters (as in **Section 1.7.2.1**), as well as potential variations related to heterogeneous distribution of biosolids when applied, the findings indicate that design of sample plans for PFAS in these settings should consider these factors.

Assessment of risk to groundwater or from uptake to crops or animals at land application sites is often based on a risk evaluation of a relatively large area with inherent variability as described above. Incremental sampling methodology (ISM) is one way to assess potential heterogeneity and limit its effects when collecting soil data from sites where the objective is to determine a representative value for that area or decision unit. These methods are detailed in multiple sources, including USEPA (2019), ITRC (2020), and Clausen, Georgian and Bednar (2013).

At least three states—Hawai'i, Maine, and Michigan—are currently implementing either full or partial ISM or ISM-like field management protocols for projects that involve evaluation of PFAS impacts to field areas. These states have either modified standard ISM or ISM-like sampling protocols to account for PFAS-specific heterogeneity concerns or are using ISM-based sampling protocols to obtain sampling results more representative of the populations than grab or simple composite sampling techniques.

Hawai'i's Hazard Evaluation and Emergency Response Office Technical Guidance Manual, which specifies the use of multi-increment sampling, has been updated to include PFAS as a Contaminant of Potential Concern (HI DOH 2024). The Technical Guidance Manual Table H-1 lists PFAS as an example of Highly Leachable, Non-Volatile Contaminants. The Technical Guidance Manual has added USEPA Region 4 Operating Procedure LSASDPROC-205-R4 "Field Equipment Cleaning and Decontamination," which includes a note stating, "Equipment utilized for PFAS sampling will not be cleaned in the field" (USEPA 2020; HI DOH 2024). Michigan's Department of Environment, Great Lakes, and Energy (EGLE) reports the routine use of multi-increment sampling for PFAS investigations, including those specifically for biosolids. Michigan EGLE has posted a number for field reports presenting the results of the ISM sampling (MI EGLE 2021). MI EGLE (2021) evaluated ISM and composite sampling as part of their site investigations. Their current ISM approach is summarized in MI EGLE (2024). As of September 2025, Maine had not published their methods or findings for public review.

USEPA has not formally released guidance for ISM and PFAS, and there are potential concerns related to laboratory processing of samples. The Department of Defense (DoD) recently released a white paper listing several concerns with application of ISM to PFAS sites in general, primarily focused on the sample preparation and handling at the laboratory (DoD EDQW 2025). Details related to specific concerns about using ISM, particularly if attempting to strictly follow USEPA Method 1633A for testing and USEPA Method 8330B for laboratory sample processing, are included in **Section 1.5.5**. Additional work is needed to validate this approach for PFAS and land application sites, and project teams need to carefully consider the site data quality objectives and goals of the work.

1.7.2.5 Treatment Options for PFAS in Biosolids

Research is ongoing to develop treatment options for biosolids prior to disposal or land application. Other studies are evaluating technologies to eliminate PFAS prior to biosolids production, via treatment of wastewater prior to generation of sewage sludge or industrial pretreatment prior to discharge to a WWTP. The Michigan EGLE Industrial Pretreatment Program PFAS Initiative reduced PFAS in treated wastewater discharge and biosolids by requiring certain POTWs to identify industrial sources that generated wastewater with PFAS concentrations exceeding screening criteria (11 or 12 ng/L for PFOS). For industrial sources required to mitigate PFAS, mitigation measured included application of pretreatment (typically using granular activated carbon [GAC]), PFAS-containing source removal, leak mitigation, or reducing the volume of landfill leachate accepted. Concentrations of PFOS were reduced in all nine plants

that required pretreatment, and reductions were greater than 90% in seven of nine treatment plants (MI EGLE 2020). Additional research is ongoing into remediation or treatment of agricultural soils impacted by PFAS from historic land application and associated leaching to groundwater and plant and animal uptake at those sites. See **Section 1.6.5** for information on these studies.

One side effect of some potential treatment options is that the nutrient value of the resulting material may no longer be desirable as fertilizer, which will affect distribution of treated biosolids or could affect continued agricultural or forestry use of treated land. For example, thermal or chemical treatments may negatively affect soil fertility in an agricultural site (Sanchez-Hernandez et al. 2024).

Studies have evaluated treatment options to reduce PFAS mobility or bioavailability in soils with land-applied biosolids. For example, Holly et al. (2024) conducted column studies evaluating PFAS leaching from land-applied biosolids and the effects on leaching from amending biosolids with biochar. Results indicated that leachate from all treatments contained measurable PFAS concentrations, and biochar amendments reduced leaching potential of PFAS, with greatest impact noted for long-chain PFAS. Additional details are provided in **Section 1.6.5**.

1.7.3 Assessing Potential Risk from Agricultural Impacts

Due to widespread use of PFAS in industrial manufacturing and consumer products and their ability to pass through conventional wastewater treatment processes and partition to the solid fraction, elevated concentrations of diverse PFAS have been widely identified in biosolids, generating concern for the environmental and human health risks associated with land application on agricultural fields and potential for uptake into plants and animal products consumed by humans (see the conceptual site model, **Figure 1-28**). In January 2025, USEPA released a draft risk assessment for PFOA and PFOS in biosolids (USEPA 2025). This document summarized a screening-level assessment and a refined risk assessment focused on people living on or close to land application or surface disposal sites, who almost exclusively consume food and animal products and drinking water from land where biosolids were applied. This draft risk assessment does not reflect risk for the public, which has diverse food sources, and does not consider cumulative exposure from multiple pathways or other sources.

The draft risk assessment quantitatively estimates potential human exposure and risk to PFOS and PFOA under four modeled scenarios: 1) farm scenario with pasture-raised livestock, 2) farm scenario growing fruits and vegetables, 3) land reclamation scenario for restoring grazed pastureland, and 4) surface disposal site scenario. A series of modeling approaches was conducted including farms with one application of biosolids at a rate of 10 dry metric tons per hectare over 40 consecutive years of application at this rate. Preliminary findings (USEPA 2025) of the refined model, which calculated risk under median or central tendency conditions, suggest there may be human health risks exceeding USEPA's acceptable thresholds for scenarios where land-applied biosolids contained 1 part per billion (ppb) of PFOA or PFOS, which is considered on the low end of measured U.S. biosolid concentrations, near current detection limits. This initial evaluation showed risk for all pathways assessed, including consumption of water, milk, crops, and meat products such as beef and chicken eggs. The draft risk calculations are not considered to be conservative estimates because they model only risks associated with biosolids containing 1 ppb of PFOA or PFOS, reflect median exposure conditions, do not include other exposure sources of PFOA or PFOS, and do not account for the combined risk of PFOA and PFOS together or exposures from PFOA and PFOS precursors. See the draft risk assessment document (USEPA 2025) for complete details on modeling approaches and risk calculations.

The document highlights the importance of site-specific factors such as hydrogeology, climate, agronomic practices, and human behavioral patterns and their impacts on potential risks. USEPA (2025) is planning the next National Sewage Sludge Survey to collect PFAS data from sewage sludge at 200–300 treatment plants nationwide, in conjunction with a POTW influent study to assess wastewater inputs. This information will help inform assessment of current biosolids inputs to the modeled scenarios

(USEPA 2025). The conceptual site model (**Figure 1-28**) illustrates the potential pathways of concern related to PFAS and biosolids when applied to the land. The following sections summarize in further detail the uptake of PFAS to plants and animals and the modeling that may help predict when there is a risk from that uptake.

1.7.4 Plant Uptake

The research on PFAS interactions with plants is extensive, exploring a range of topics including uptake from various types of soils and covering a variety of herbaceous plant species as well as trees. Some key issues of interest regarding plant uptake of PFAS include the need to understand whether the nature and magnitude of uptake from biosolids-amended soils is different from that of nonamended soils, and whether there is a difference in accumulation between crops that are grown in biosolids-amended soils for consumption by livestock (for example, silage, hay, forage) versus crops grown for human consumption (for example, fruits, produce). A key metric used to estimate uptake and accumulation by plants is the bioconcentration factor (BCF), sometimes referred to as the bioaccumulation factor (BAF) or transfer factor (TF), which is defined as the PFAS concentration in plant (mass/mass), in dry weight or wet weight, divided by the PFAS concentration in soil (mass/mass), in dry weight. It is important to be aware how these units are expressed for plants and soils when reporting and using uptake factors.

Uptake of PFAS from different types of soils into both agricultural and nonagricultural plants is summarized in **Section 5.6** and **Table 5-2**. It includes general studies on uptake from soils in PFAS-contaminated sites and greenhouse studies, as well as studies that are more focused on sewage-amended and biosolids-amended agricultural soils, the latter of which is relevant to this topic. The Draft Sewage Sludge Risk Assessment for PFOA and PFOS released by USEPA in January 2025 includes a review of available data on crops grown in biosolids-amended soils and observed differences in uptake factors reported in greenhouse studies versus field studies (USEPA 2025). The USEPA review and the ITRC summary (**Table 5-2**) note some important factors and apparent trends in BCFs to consider when evaluating plant uptake of PFAS from biosolids-amended soils and in agricultural settings. The bioconcentration of PFAS from biosolids-amended soils depends strongly on the physical-chemical properties and concentrations of PFAS, the soil properties, and species and physiology of the plants, as outlined below.

1.7.4.1 Reported BCFs for Plant Uptake

Most studies that report BCFs for plants focus on uptake of the terminal PFAA, which generally show increasing accumulation in plant tissues with a decrease in perfluorinated carbon chain length (see **Section 5.6.2**). Few studies have investigated uptake and biotransformation of precursor PFAS in plant tissues. It should be noted that interpretation of BCFs for PFAA may be influenced by the presence of diverse mixtures of precursor PFAS in biosolids-amended soils that can undergo degradation via microbial activity in the soil or within the plant-specific root exudates or other plant compartments (Wen et al. 2018; Wen et al. 2021; Bizkarguenaga et al. 2016).

PFAS uptake and accumulation is typically greater in the vegetative portions of plants (foliage, stems, roots), than in the reproductive parts (seeds, fruits). Plant uptake may also be impacted by aftermath growth with mixed evidence of potential high uptake of PFAS in subsequent cuttings of plants such as grass (Stahl et al. 2009). A study conducted by the state of Maine showed that cuttings of plants such as grass and hay had higher uptake of PFOS in the secondary cuttings compared to the initial growth season (Simones et al. 2024). The BCFs selected in the draft USEPA review (2025) for PFOS and PFOA (Table 13 in that document) fall within a range of 0.07–1.3 for selected crop types, classified as forage, fruit, root vegetables, silage, and aboveground vegetables. The majority of the BCF values for 14 different PFAS compounds, as compiled in the ITRC summary (**Table 5-2**), fall within a range of 0.1–10, and vary with chain length, species, and study methodology. USEPA also provides a modeling approach for estimating

crop concentrations of PFOS and PFOA in produce and feed, based on estimated soil concentration within the tilling depth, plant type-specific BCFs, and plant tissue-specific moisture adjustment factors.

1.7.4.2 Influence of PFAS Properties

PFAS with lower chain lengths and higher solubilities can enter the soil solution and tend to have greater uptake potential in plants. Short-chain compounds tend to accumulate at higher concentrations in leafy vegetables and fruits, whereas long-chain compounds tend to accumulate more in roots. Several studies have found that PFCAs accumulate at higher rates than PFSAs. Shilling Costello and Lee (2020) found that precursors and other emerging classes of PFAS may represent important long-term sources when retained in rhizomes or root zones. They summarized several studies where precursors were present in soil while intermediate and terminal degradation products were concentrated in shoots or roots. The authors also noted that potted plant and field studies often yield different BCFs in part based on factors related to air-water interface and degree of saturation in those settings. For more information about how PFAS properties influence their fate and transport, see **Section 5**.

1.7.4.3 Effects of Treatment Plant Processes on PFAS Uptake

Broadbent et al. (2023) evaluated potential use of drinking water treatment residuals (DWTRs) as biosolids amendments that could reduce the rate of PFAS uptake in plants (phytoavailability) grown on biosolids-amended soils. DWTRs are byproducts of drinking water treatment using coagulants that are typically rich in calcium (calcium hydroxides), iron (iron sulfates or chlorides), or aluminum (aluminum hydroxides); these substances are currently used to immobilize excess nutrients and other contaminants and have been found in other studies to sorb PFAS and reduce their mobility in the environment (for example, Hearon et al. 2022). Broadbent et al. (2023) conducted phytoavailability studies for an agricultural scenario (tomato plants grown on biosolids) and a mine reclamation scenario (ryegrass grown in soil amended with biosolids), using Class A biosolids containing a variety of PFAS and three different DWTRs. This study found that most of the PFAS detected in biosolids were not found in plant tissue; only three PFCAs (PFBA, perfluoropentanoic acid (PFPeA), and perfluorohexane sulfonic acid (PFHxA)) were detected in all plant samples, with PFBA found at the highest concentrations. Tomato plants also were found to contain PFOA in almost all samples and generally had PFAS concentrations approximately 2–4 times higher than those in ryegrass. The authors concluded that aluminum- and iron-based DWTRs did not significantly reduce overall PFAS uptake under either scenario (except for reduced PFBA uptake in ryegrass treated with iron-based DWTR), although these results may have been influenced by relatively high concentrations of aluminum and iron and low concentrations of organic matter in the biosolids used in their experiments. Calcium-based DWTRs, however, significantly reduced the accumulation of PFBA in ryegrass and PFHxA in tomatoes, although the authors postulated that this may have been a result of pH modification.

Biochar-based sorbents may also be effective at reducing availability of PFAS. Openiyi et al. (2024) applied aluminum chlorohydrate DWTR and biochar to biosolids-amended soil columns, finding that PFAS concentrations in soil leachate from both residuals-treated soils were substantially reduced compared to untreated soils. These findings suggested that sorbents may reduce PFAS mobility and thus bioavailability.

Research evaluating the links between the processes employed by POTWs to reduce pathogens and subsequent bioavailability of PFAS following land application of biosolids is ongoing and additional work is needed to fully assess this topic.

1.7.4.4 Influence of Soil Properties

Beyond the physical and chemical properties of PFAS, environmental factors such as soil properties also play a crucial role in the uptake process by plants (Shilling Costello and Lee 2020). Research has

highlighted the influence of soil organic carbon, pH, and cation types and concentrations on PFAS sorption (Mei et al. 2021; Li et al. 2018; Campos Pereira et al. 2018). Although organic carbon generally enhances the sorption of organic contaminants in soil, its effect on PFAS can vary depending on the soil type. Higher soil pH typically reduces PFAS sorption, thereby increasing their mobility and bioavailability, though the presence of cations can complicate this relationship. Inorganic anions such as phosphate may also reduce PFAS sorption by competing for binding sites in the soil.

Nitrogen-rich amendments also may alter PFAS bioaccumulation characteristics. Adu et al. (2025) showed that uptake of PFOA, hexafluoropropylene oxide dimer acid (HFPO-DA), and 6:2 chlorinated polyfluoroalkyl ether sulfonate (6:2 Cl-PFESA) in hydroponically grown lettuce was enhanced through addition of nitrogen fertilizers, including ammonium sulfate and potassium nitrate. Wu et al. (2023) demonstrated enhanced PFAS bioavailability through addition of ammonium ion to soil. This study also showed that nitrogen amendments in soils containing PFAS resulted in a decrease in the diversity and stability of soil microbial communities. Additional research is needed to further elucidate the effects of inorganic anionic and cationic constituents.

Unique mechanisms such as PFAS retention at the air-water interface in unsaturated soils further add complexity to their transport and bioavailability (Lyu et al. 2018; Brusseau et al. 2019). When PFAS have low sorption to soil, they remain more mobile in soil water. This increased mobility raises the PFAS concentration in the soil solution, making them more bioavailable and thus more accessible for uptake by plant roots. Conversely, strong sorption between soil particles and PFAS limits the amount of PFAS in the soil water, decreasing their bioavailability and subsequently reducing the amount that plants can take up. The abovementioned environmental conditions indirectly control the amount of PFAS that remains in the soil solution versus being bound to soil particles, shaping the extent to which PFAS can enter plant systems.

Greenhouse studies of potted plants with biosolids-amended soils have often reported higher BCFs than field studies (Blaine et al. 2013). Uptake of PFAS in produce plants was also greater when grown in fields that were situated near industrial sources (potentially due to air deposition or irrigation water) (Bao et al. 2020). In general, higher PFAS concentrations in soil are correlated with higher PFAS concentrations in plants; however, the increase in concentrations may not be directly proportional. Soil organic matter has been found to sequester PFAS and limit plant uptake in some studies reviewed. However, other studies note that in field studies at locations where biosolids had been applied, there does not appear to be a significant or consistent correlation between PFOA and PFOS uptake factors and soil concentration, pH, organic matter content, or cation exchange capacity (Simones et al. 2024). More detailed discussion of these findings and trends for PFOS and PFOA is presented in the USEPA draft risk assessment (USEPA 2025). The ITRC summary compilation and review (**Table 5-2**) presents information for multiple PFAS and include both edible and nonedible plant species.

1.7.4.5 Plant Response to PFAS Exposure

In general, plant uptake from soil includes both the process of initial uptake into the roots and subsequent translocation to and accumulation in varying portions of the plant. Unlike conventional neutral organic chemicals and ionic compounds, PFAS exhibit a greater range of anionic and both lipophilic and hydrophilic behaviors (Mei et al. 2021). Studies have indicated that the uptake of PFAS in plant tissues is influenced by the physicochemical properties of the PFAS, especially the carbon chain length and functional groups, while the accumulation may be influenced by plant morphological traits such as internal organization and functioning of the root and shoot systems (Lesmeister et al. 2021; Ghisi et al. 2019; Adu et al. 2023; Wang et al. 2020; Mei et al. 2021). For instance, PFAS with longer carbon chains tend to accumulate in the roots with limited movement to the upper parts of the plant, whereas those with shorter carbon chains are more likely to translocate and accumulate in the shoots. Additionally, plants generally take up more PFCAs compared to perfluorosulfonic acids (PFSAs), when the carbon chain length is the same (Ghisi et al. 2019). The water-soluble fraction of PFAS in soil is negatively

related to PFAS carbon chain length and log Kow values, while it positively correlates with PFAS levels in plant shoots and total plant biomass (Zhang et al. 2021).

When exposed to PFAS, plants undergo growth stress and exhibit a range of responses. At the cellular and metabolic level, research has shown that PFAS exposure can cause considerable impact, including structural changes in root cell organelles and disruptions to cell walls, especially with prolonged exposure (Li et al. 2020). This physiological impact weakens the plant's resilience to environmental stresses by hindering the production of new proteins. PFAS exposure has also been linked to changes in membrane permeability in plant cells, which can impair cellular function (Lin et al. 2020). Additionally, PFAS can affect photosynthetic pigments, with the effects differing among plant species (Lan et al. 2018; Li et al. 2020; Chen et al. 2020). PFAS exposure may also trigger the production of reactive oxygen species such as hydrogen peroxide and superoxide anions, resulting in oxidative stress (Lin et al. 2020; Yang et al. 2015; Li et al. 2021; Li et al. 2021) To mitigate this stress, plants upregulate enzymatic antioxidants, such as superoxide dismutase, catalase, and peroxidase. However, when PFAS concentrations are high, these defense mechanisms can be overwhelmed, leading to decreased antioxidant production and increased plant toxicity due to disrupted nutrient uptake (Qu et al. 2010; Fan et al. 2020; Li et al. 2020; Li et al. 2020).

On a molecular level, PFAS can influence the expression of genes associated with stress responses and metabolic pathways (Li et al. 2020; Fan et al. 2020). Additionally, PFAS exposure can cause imbalances in primary and secondary metabolites in plants (Li et al. 2020). These molecular changes highlight the substantial impact of PFAS on plant physiology and biochemistry, revealing a complex interaction between PFAS and plant health, with effects that vary across different plant species.

1.7.4.6 Mechanistic Studies of Plant Uptake of PFAS

The mechanistic study on PFAS uptake by plants conducted by Wen et al. (2013) identified that protein carriers in maize roots, likely involving aquaporins (protein-based water channels in root cells) and anion channels, play a role in the uptake process of PFOA and PFOS. Further research by the same authors explored the relationship between PFOA/PFOS accumulation and the protein and lipid content in the roots of seven plant species (Wen et al. 2016). Their findings indicated that root proteins facilitate while lipids inhibit the uptake of PFOA and PFOS.

Zhang et al. (2019) later discovered that the uptake of PFAAs with a carbon chain length between 2 and 8 in wheat is primarily an energy-dependent active process mediated by carrier proteins, including aquaporins and anion channels. However, at higher concentrations in hydroponic systems (3 mg/L), ultrashort PFCAs (such as trifluoroacetic acid (TFA) and perfluoropropionic acid (PFPrA)) were transported into wheat cells passively, without the involvement of carriers. They also suggested that competition for uptake might occur among PFAS compounds that share the same transport carriers. Once PFAAs enter the wheat xylem (vascular tissue), they are distributed throughout the plant via the transpiration stream.

A similar uptake mechanism was proposed by Wang et al. (2020) for the Asian water plantain (*Alisma orientale)*, where PFOA and PFOS are initially taken up by the root cell wall. A portion of these compounds can actively pass through the cell wall and plasmalemma, likely facilitated by aquaporins and anion channels. A variety of pathways in both living (symplastic) and nonliving (apoplastic) plant tissues contribute to PFAS translocation.

1.7.4.7 Modeling Plant Uptake of PFAS

Researchers are increasingly turning to machine learning (ML) tools to predict the uptake and accumulation of PFAS in plants (Adu et al. 2024; Xiang et al. 2023; Song et al. 2023; Bagheri et al. 2020). By leveraging data from previous studies on plant uptake, these efforts have shown that key uptake indices—such as root concentration factor, shoot concentration factor, BAF, and translocation factor—

can be accurately predicted. These predictions are based on a range of input variables, including plant species, plant root protein content), PFAS functional groups, PFAS molecular weight, pKa value of PFAS, log Kow of PFAS, PFAS exposure concentration, exposure duration, soil organic carbon content, pH, soil texture, and soil cation exchange capacity.

1.7.5 Uptake by Animals

There is an abundance of information indicating that certain PFAS (such as PFOS) bioaccumulate in fish, birds, and mammals (for example, Houde et al. 2011; Giesy and Kannan 2001; Guckert et al. 2023). The use of biosolids for land application has the potential to contaminate crops and cover crops with PFAS due to uptake into plants (Blaine et al. 2013; Blaine et al. 2014; Costello and Lee 2020; Felizeter et al. 2021; Knight et al. 2021; Yoo et al. 2011) (see **Section 1.7.4**), and leach from the land-applied soil into groundwater and surface waters (see Section **5.3.3**). This in turn can lead to uptake into terrestrial organisms, including livestock and game animals that graze on contaminated farmland and ingest contaminated plants grown as forage or feedstock or contaminated water that leaches from the soil (Brake et al. 2023; Death et al. 2021; Mikkonen et al. 2023; Simones et al. 2024; van Asselt et al. 2013). The primary exposure pathways through which livestock may be exposed to PFAS from biosolid sources include diet, drinking water ingestion, and incidental ingestion of soil (see **Section 1.4.7**). Aquatic organisms such as fish may also be exposed to this contamination source due to soil leaching, runoff, or erosion into nearby surface waters (see Section **5.5**).

Few studies have investigated uptake of PFAS into livestock and game animals exposed to biosolid-impacted farm fields (Death et al. 2021; Kowalczyk et al. 2012), with some studies showing that PFAS accumulates in chickens, eggs, and other protein sources at levels that could potentially be significant with respect to human exposure (Wilson et al. 2020; Lasters et al. 2022; Mikkonen et al. 2023; van Asselt et al. 2013) (see **Section 9.1.2**). The Maine Department of Environmental Protection (ME DEP) has been investigating PFAS in farmlands in the state where sludge and septage have been applied, finding PFAS in water, soil, hay, and milk (ME DEP 2023). Testing of deer and turkey meat from areas in Maine with fields that had PFAS-impacted biosolids applied resulted in “Do Not Eat” advisories for deer and wild turkey (ME DIFW 2023). In Michigan, PFOS-containing biosolids that were applied to fields at a cattle farm resulted in PFOS detected in beef samples at levels warranting a human consumption advisory (MI DHHS 2023). Other states are just beginning to investigate impacts on livestock from biosolid sources. For additional detail on the toxicological effects of PFAS on animals see **Section 1.4**.

1.7.5.1 Modeling PFAS Uptake to Livestock at Land Application Sites

Farms impacted by PFAS, whether through contamination in soil in fields used to grow crops for animal feed, in purchased feed, or drinking water, face the challenge of PFAS moving into the food products they produce (Death et al. 2021). Models that relate PFAS levels in soil, feed, or water to potential levels in a farm’s product, such as beef, pork, cow’s milk, or chicken eggs, are instrumental to risk assessors, farmers, and agencies assisting farms dealing with PFAS. Models that accurately estimate PFAS levels in livestock animal tissue following exposure and subsequent decline in PFAS levels if exposure ceases can provide useful information on when a product may have reduced PFAS levels, what fields or water sources a farm may want to avoid using, or can assist in cropping decisions to decrease PFAS levels in feed.

Several research groups have now developed such models to estimate PFAS levels in livestock. These models generally focus on PFOS, perfluorohexane sulfonic acid (PFHxS), and PFOA and are available for dairy cows, beef cattle, swine, and chicken eggs. Mikkonen et al. (2023) developed a dynamic exposure population toxicokinetic model for beef cattle focused on estimating PFOS and PFHxS in serum, liver, and muscle tissue. This dynamic model accounts for varying PFAS exposure levels from feed, water, and soil over the lifespan of a beef cow. Based on a one-compartment toxicokinetic model, daily PFAS intake from water, feed, and soil is translated into PFAS levels in serum, liver, and muscle. A benefit of this dynamic

modeling approach is the estimation of PFAS tissue levels resulting from varying PFAS exposure due to seasonal feeding patterns and changes in feed or water sources. Chou et al. (2023) developed a physiologically based pharmacokinetic (PBPK) model to estimate PFOS, PFHxS, and PFOA levels in beef cattle or milk from dairy cows. Given a soil or water PFAS concentration, the PBPK model estimates PFOS, PFHxS, and PFOA levels in liver, kidney, and muscle of exposed beef cattle and in dairy cows' liver, kidney, muscle, and milk. This model estimates the number of days required following exposure cessation (a withdrawal interval) for a PFAS tissue level to be below a prespecified level, such as an action level or maximum contaminant level. Chou et al. (2023) provided their model as a web-based tool (Lin 2023) for estimating this withdrawal interval for a given exposure in beef cattle or dairy cows.

The German Federal Institute for Risk Assessment also developed a web-based tool for estimating PFAS tissue levels from contaminated feed or water in beef cattle, dairy cows, pigs, and chicken eggs. This web-based Contaminant Transfer Predictor, or ConTrans tool, models PFOS and PFHxS levels in beef cattle blood, liver, and muscle, and for dairy cow's blood, liver, muscle, and milk. The modeling for beef cattle and dairy cows in the ConTrans tool is largely based on the dynamic model developed by Mikkonen et al. (2023). For swine the tool provides estimates for seven individual PFAS (PFBS, PFHxS, PFHpS, PFOS, PFHxA, PFHpA, and PFOA) in blood, fat, liver, kidney, and muscle tissue based on the swine exposure model developed by Numata et al. (2014) and Siemen et al. (2017). For chicken eggs, the tool provides estimated levels of PFBS, PFHxS, PFOS, PFHxA, PFOA, and perfluorononanoic (PFNA) in eggs with specified levels in feed. The chicken egg estimations are based on studies of PFAS exposure from contaminated feed (Kowalczyk et al. 2020) or drinking water (Wilson et al. 2021). Although these models in their development have used measured PFAS data in tissues, such as milk, beef, and serum, at impacted farms for validation and confirmation of their model estimates, application of the various models at farms with known PFAS exposures with comparisons to tissue biomonitoring data will be useful in assessing their accuracy and predictive power.

For more standard risk assessment practice in developing soil or water screening levels for livestock, exposure pathway equations from the USEPA Preliminary Remediation Goals for Radionuclides (PRGR) or Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities can be modified and implemented using PFAS-specific parameters (USEPA 2005; USEPA 2024). The general model with these equations is consistent daily exposure under assumed steady state conditions to relate PFAS levels in soil or water to levels in an animal tissue, such as beef muscle, cow's milk, or chicken eggs. For example, the Maine Center for Disease Control and Prevention (Maine CDC 2020) modified PRGR equations for soil screening levels for a soil-to-cow's-milk pathway to derive a soil screening level for PFOS (Maine CDC 2020). These types of models are useful for setting screening levels to determine whether more investigation at a farm may be warranted and when a farm product may need to be tested for PFAS.

1.7.6 Conclusion

As described in these Priority Topics and referenced sections in the PFAS-1 Document, biosolids represent an important potential PFAS source consideration due to the large volumes generated daily at wastewater treatment plants around the world. PFAS in biosolids present major challenges to municipalities that are generating biosolids but are passive receivers of upstream sources of PFAS. The widespread land application of biosolids as fertilizer may represent a risk from factors such as subsequent PFAS leaching to groundwater, uptake to crops used for food or animal feed, and resulting accumulation in terrestrial and aquatic organisms. The strong retention and slow leaching of PFAS in vadose zone soils means that historical sources from decades-old practices can impact human health and environment in the present day.

Many factors influence PFAS leaching, transport, and uptake, including site-specific geology and hydrogeology, PFAS concentrations, presence of precursors and non-targeted PFAS, and the frequency and rates of land application. Ongoing research into fate and transport of PFAS in agricultural settings,

rates of uptake into crops and both wild game and domestic animals consumed for food, and continuing efforts to reduce PFAS concentrations in the wastewater stream will be important considerations when evaluating whether biosolids warrant attention on a site-specific basis.

1.8 Priority Topics for PFAS and Microplastics

Section Number	Topic
1.8.1	**Composition and Definitions**
1.8.2	**Co-sources of PFAS and Microplastics**
1.8.3	**Sampling and Analysis**
1.8.4	**Fate and Transport**
1.8.5	**Risk Assessment**
1.8.6	**Treatment**
1.8.7	**Regulatory and Guidance Considerations**
1.8.8	**Changing Weather Patterns**

These Priority Topics discuss the available information about the interconnections between PFAS and microplastics (MP). The unique issues around MP and PFAS (for example, heterogeneity, persistence, and toxicity concerns at low levels) warrant additional study of the potential interaction of these two groups of contaminants when they occur in the same environmental matrix. Additionally, there are significant interaction issues noted in literature on fate, transport, and bioavailability (see **Section 1.8.4**).

This section focuses mainly on the interactions and co-occurrence of PFAS and MP. For the detailed discussions on PFAS and MP exclusively, refer to the PFAS Technical and Regulatory Guidance Document **(PFAS-1)** and the Microplastics Technical and Regulatory Guidance Document **(MP-1)**, respectively.

Information about Strategic Environmental Research and Development Program (SERDP) projects for PFAS and Microplastics can be found at **https://serdp-estcp.mil/**.

1.8.1 Composition and Definitions

ITRC has defined “microplastics” as particles that are greater than 1 nanometer (nm) and less than 5,000,000 nm (or 5 millimeters [mm]) in their longest dimension and consist of solid polymeric materials to which chemical additives or other substances may have been added. This definition includes microfibers (**Section 1** in MP-1). Polymers that are derived in nature (for example, cellulose, amber, proteins, wool, or silk) that have not been chemically modified, other than by hydrolysis, are excluded from this definition (MP-1). This definition is similar to that developed by the State of California (CA SWRCB 2020).

Plastic particles less than 1,000 nm in their longest dimension are also referred to as nanoplastics (NP). Although the definition of NP is still being debated, it is generally accepted in scientific literature that they are produced by the fragmentation of MP (or larger particles), measure between 1 nm and 1,000 nm in length, and demonstrate a colloidal behavior. MP can be classified as primary or secondary. Primary MP are small plastic particles manufactured for a particular use. Primary MP include microbeads for use in various applications, including laboratory testing and agriculture (Bangs 1996; Ugelstad et al. 1992; Langlet et al. 2024), as well as small plastic beads, or nurdles, for use in industrial processes (**Figure 1-31**). Secondary MP are small plastic fragments that are created by the breakdown, degradation, or weathering of larger plastics, such as water bottles and bags (Arthur, Baker, and Bamford (eds.) 2009).

This breakdown is from physical, chemical, or biological processes, or some combination of those processes.

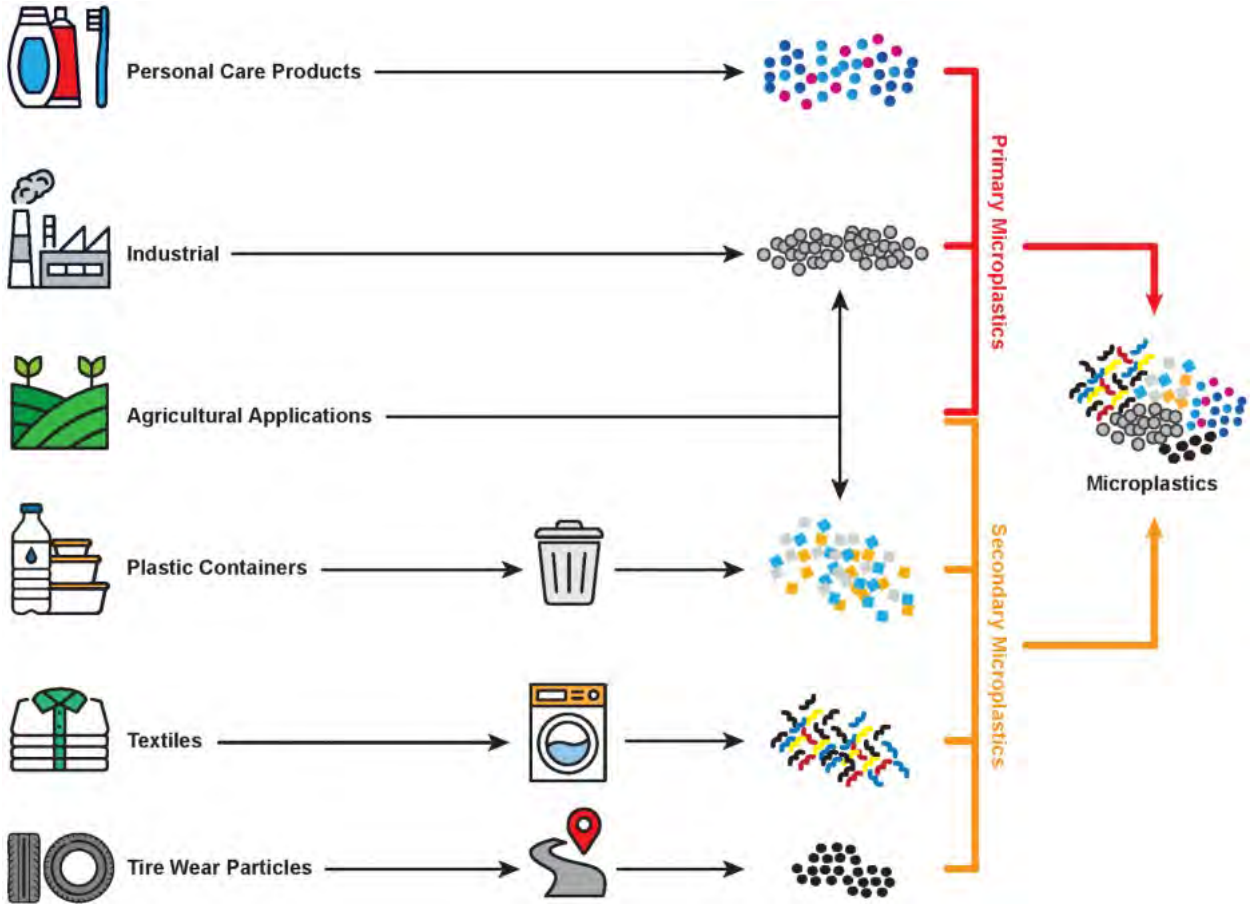


Figure 1-31. Primary and secondary microplastics.

*Source: Figure 2-2.**MP-1**, Jonathan MacDonald.*

PFAS include a wide variety of molecules with different physical and chemical properties and molecular weights with perfluoroalkyl moieties as common structural features. This variety of PFAS with diverse properties is organized in the form of a PFAS family tree (**Figure 2-4**) that includes two primary classes: polymers and nonpolymers. In plastic products, additives and processing agents are often added to enhance the properties of the plastics, while nonpolymer PFAS is one of the important processing aids. The nonpolymer PFAS processing aids may be found as impurities in some fluoropolymer products. More information is included in **Section 2.2.2.1** in PFAS-1. Nonpolymer PFAS are most commonly detected in the environment and typically referred to simply as PFAS. Polymeric PFAS such as, fluoropolymers, side-chain fluorinated polymers, and poly- or perfluoropolyethers (Lohmann et al. 2020) can break down into MP (Cook and Steinle-Darling 2021). Some plastics are polymer PFAS (for example, polytetrafluorethylene (PTFE)), or contain nonpolymer PFAS, or both. These polymer PFAS may be primary MP or may be present as secondary MP in the environment, or both (Bergmann et al. 2017; Ebnesajjad 2013; Cook and Steinle-Darling 2021). Both PFAS and MP are families of contaminants, with thousands of different species and additives, respectively, which result in a wide range of physical and chemical properties.

1.8.2 Co-sources of PFAS and Microplastics

Plastics and PFAS are often applied in the same products to improve their stability and durability, and these products release both contaminants into the environment through their manufacturing processes, uses, and disposal (Gaines 2022, Weis and Alava 2023). Polymeric PFAS materials used in commerce (for example, personal protective equipment, outdoor equipment) that are subject to weathering and physical stress have the potential to release PFAS-containing MP to the environment (Peaslee et al. 2020; Schellenberger et al. 2022). Some food packaging materials are coated with PFAS due to its functional properties to repel oil, grease, and water (Curtzwiler et al. 2021). These food contact materials could potentially release and transfer MP and PFAS into the food chain, profoundly impacting human health and the environment (Perkins 2021; Parashar, Mahanty, and Hait 2023; Koelmans et al. 2016). Alternatively, PFAS and MP can occur in separate upstream sources, which then result in PFAS sorbing to MP that could continue to flow together through environmental systems or trophic chains (**Section 2** in MP-1; **Section 5.1** in PFAS-1) (Parashar, Mahanty, and Hait 2023; Koelmans et al. 2016).

Despite the co-occurrence of PFAS and MP in various systems, predicting where these contaminants will primarily be concentrated is challenging. Because both PFAS and MP are heterogeneous classes of contaminants that possess a range of physical chemical properties, the fate of both depends heavily on both the properties of the MP and PFAS, as well as the environmental system in which they are found (see also **Section 1.8.4**). For example, effluent from wastewater treatment plants (WWTPs) is known to be a source of MP and PFAS to ecosystems (Liu et al. 2021; Nguyen et al. 2022). At the same time, PFAS and MP are found in the sludge or biosolids generated from WWTPs (Nguyen et al. 2022; Ziajahromi et al. 2021). The removed PFAS and MP in different treatment processes of WWTPs are transported to landfills (Nguyen et al. 2022). Landfills have been demonstrated to receive MP and PFAS from WWTPs, especially in the waste solids (Prada et al. 2024; Ma et al. 2025). However, the leachate coming from these landfills can also contain both PFAS and MP that are then sent back to WWTPs or released to the environment (Rahman, Sultan, and Alam 2023; Prada et al. 2024). Furthermore, numerous products and materials containing these contaminants are improperly discarded at the end of life, allowing the release of MP and PFAS into the environment (Coffin, Reeves, and Cassidy 2023; Lohman et al. 2020).

1.8.3 Sampling and Analysis

This sampling and analysis section focuses on issues relating to the co-occurrence/co-measurement of MP and PFAS. No standard methods exist for the measurement of PFAS sorbed on MP. For sampling and analysis guidance on MP and PFAS, including methods, issues, and uncertainties, consult **Section 3** in MP-1 and **Section 11** in PFAS-1. Understanding the interactions around adsorption and subsequent bioavailability of PFAS from microplastics needs further research. Several issues on co-occurrence have been identified in review literature (for example, Parashar, Mahanty, and Hait 2023). Sampling and analysis issues for PFAS and MP include:

- Does PFAS to sorb to microplastics and how does that influence sampling and analysis?
- Are microplastics a source of small molecule PFAS arising either from manufacturing residuals or from side-chain PFAS polymer degradation (Li et al. 2017)?
- Do MP behave the same as natural non-MP solids during sampling and analysis on the issues of PFAS partitioning and sampling representativeness?

Studies have indicated that MP can adsorb contaminants, such as PFAS, from the surrounding environment and act as carriers of these contaminants. This can alter the bioavailability and toxicity of these substances to human health and the environment. This interaction complicates efforts to assess the overall impact of these pollutants and underscores the need for comprehensive studies and sampling and analysis guidelines to address their combined effects. As discussed in **Section 1.8.2**, due to the

widely different physical and chemical properties of MP and PFAS, their co-occurrence measurement involves separate analyses for MP and PFAS, bringing in increased uncertainty.

One academic study by Scott et al. (2021) measured PFAS sorbed on MP; indicating the ability to successfully measure sorbed PFAS. Scott et al. (2021) also found that PFAS sorption on MP was significantly higher in the field than in laboratory studies. They wrote that this sorption was "greatly enhanced by the presence of inorganic and/or organic matter associated with these materials in the environment" (Scott et al. 2021).

In 2024, the US Environmental Protection Agency (USEPA) released a new methodology for detecting low levels of PFAS on high-density polyethylene (HDPE) plastic containers (USEPA 2024). This was developed by USEPA after learning of potential PFAS contamination for certain mosquitocide products and the fluorinated HDPE containers they were stored in (see **Table 2-7** in PFAS-1). The new method can identify 32 specific PFAS directly from the container walls. This allows industries, such as pesticide manufacturers, to test containers before use, ensuring that contamination is minimized (USEPA 2024; USEPA 2024). Although this method is validated for extraction of PFAS from a bulk plastic of one kind only, it is an example of an analytical method for measurement of certain PFAS from plastics.

Side-chain fluoropolymers (especially fluorotelomer-based) where the PFAS-containing moiety is attached to the polymer backbone, rather than being part of the backbone, are known as a significant source of fluorotelomer alcohols and perfluoroalkyl carboxylates in the environment (Li et al. 2017; Lohmann and Letcher 2023). As the plastics abrade in the environment into MP, the side-chain PFAS are subject to cleavage and reaction to form PFAS such as fluorotelomer alcohols (FTOHs), perfluoroalkyl carboxylic acids (PFCAs), and sulfonamides. In addition, previously uncharacterized PFAS have also been identified and measured as arising from other types of side-chain fluoropolymers (Chu and Letcher 2017). Many gaps still exist in the sampling and analyses of these types of MP-PFAS interactions, but they have been hypothesized as a significant source of PFAS (Li et al. 2017).

1.8.4 Fate and Transport

Information sources on the fate and transport of PFAS comingled with MP are still limited in the scientific literature. The fate and transport of PFAS has been well documented (see **Section 5** and **Section 1.3** in PFAS-1). This section focuses on the fate and transport of MP as it relates to the potential for PFAS transport. An understanding of role of MP in the overall fate and transport of PFAS is emerging. However, the detailed science is still being investigated, which would support quantitatively explaining the role of MP in fate and transport of PFAS. Significant research is still needed to understand these relationships.

The environmental fate and transport of PFAS is strongly influenced by their physical and chemical properties. Considering that PFAS represent thousands of chemicals and their transformation products, one would expect to observe a wide range of different fate and transport behavior, which adds complexity to characterizing and quantifying their environmental fate. Research based on the understanding of a select number of well-studied PFAS, however, enables an appreciation of various factors that are important when attempting to study their environmental fate and transport (see **Section 5** and **Section 1.3** in PFAS-1). Characteristics of MP that are important to understand include the size, shape, density (polymer composition), and surface functionality (see **Section 2** in MP-1). For example, relatively large MP (>1 mm), which have densities >1, will have higher deposition rates in both air and water as compared to 1 micron-size MP with densities around 1. Some caution is warranted, however, because these generalizations can be influenced by the environmental system properties into which MP are released. Thus, similar to PFAS, MP complexity results in significant challenges when assessing their fate and transport individually or when co-occurring with PFAS.

Until recently, the majority of MP studies focused on water column and soil environments using virgin plastic materials. By comparison, current research is focused on understanding the fate, transport, and

distribution of NP and MP within water, soil, sediment, and air matrixes, and introducing real-world confounding factors such as ultraviolet (UV) and physical weathering, biofilm formation, and natural organic matter sorption along the surface and pore regions of weathered plastics. It is due to these real-world factors that MP can have a potentially increased capacity as transport vectors for contaminants, such as PFAS and metals, and pathogenic microorganisms in the environment (Wang, Guo, and Xue 2021). The role and contribution of PFAS adsorption to MP as a transport vector is complex and currently not well understood compared to other factors influencing the fate and transport of PFAS.

Salawu, Olivares, and Adeleye (2024) reported long-chain PFAS, such as perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS), have been observed to be the "most abundant PFAS adsorbed to MP," referencing Cheng et al. (2021) and Navarathna et al. (2023). PFOS and PFOA, for instance, have also been observed to sorb to naturally occurring particulate and dissolved organic carbon, and in some instances electronic interactions between these chemicals and different soil minerals can be observed (see **Section 5** in PFAS-1). In general, the long-chain PFAS may increase the mobility of longer polymer MP, such as PTFE, in the subsurface (Zhao et al. 2025).

Atmospheric transport and deposition of PFAS and MP result in their accumulation in aquatic systems, which is the result of direct (wet/dry deposition) and indirect (surface runoff) deposition (Kurwadkar et al. 2022; Huang et al. 2021). Although most studies have concentrated on atmospheric deposition to water and soil, recent research has shown that MP, combined with emerging contaminants such as PFAS, can be re-released into the atmosphere from marine and soil environments due to strong winds or water turbulence (Borthakur et al. 2022; Allen et al. 2022). For example, there is clear evidence of MP being deposited from land to the ocean (Ryan et al. 2023; Amelia et al. 2021). However, some evidence implies MP re-emittance in onshore winds and sea spray mist, facilitating ocean-to-atmosphere transmission (Allen et al. 2022). A 2020 study, based on a short-term pilot project (on the French Atlantic coast), provided analytical results from air samples of MP in the marine boundary layer and indicated the potential for MP, enriched with other pollutants, to be released from the marine environment into the atmosphere (Allen et al. 2020). Given that various PFAS have been reported to adsorb onto MP in aquatic environments (Bere et al. 2023; Scott et al. 2021), MP can become enriched with PFAS and potentially be reintroduced into the atmosphere from water. Some of these atmospheric transmission processes are being studied.

Section 2 in MP-1 includes information about environmental distribution, fate, and transport of MP, including degradation of plastics once released to the environment. As noted, secondary MP are generated through chemical, physical, and biological degradation of larger plastic products in the environment. The plastic degradation processes are important in determining the fate and effects of MP in environmental media. Most plastics are subjected to abiotic (for example, mechanical, thermal, and photodegradation) and biotic degradation processes involving chemical, physical, and biological reactions. Zhang et al.(2021) is a review article that summarizes literature on the degradation processes of plastics and generation of MP in the environment.

Mechanical degradation (**Section 2.9.1** in MP-1) is the breakdown of plastics due to external forces. In the environment, external forces can come from the collision and abrasion of plastics with rocks and sands caused by wind and waves. Freezing and thawing of plastics in aquatic environments can also result in the mechanical degradation of polymers (Niaounakis 2015; Pal et al. 2018; Alimi et al. 2021; Acharjee et al. 2022). The wider literature suggests that the release of MP stems from thermal and mechanical degradation; as such, MP release is likely to be exacerbated if hard or sharp utensils are used with plastic and PTFE-coated cookware or these materials are heated to higher temperatures. Sobhani et al. (2020) found that MP can be generated from daily activities, such as cutting plastics using scissors or knives and tearing or twisting to open plastic containers, bags, tapes, and caps. Depending on the condition of the plastic materials' stiffness, thickness, density, and size, Sobhani et al. (2020) reported the generation of 0.46 to 250 MP/cm. Generation of MP depends on the composition of the original plastic,

its use, and where it is used. Plastic debris represents a complex issue, in that the degradation and weathering of plastic debris may represent an important source of secondary MP.

Thermal degradation (**Section 2.9.1**, in MP-1) refers to the breakdown of plastics due to energy input stemming from elevated temperature. Plastics can undergo thermo-oxidative reactions at high temperature. When sufficient heat is absorbed by the polymer to overcome the energy barrier, the long polymer chains can be broken, generating radicals (Pirsaheb, Hossini, and Makhdoumi 2020; Peterson and Hubbart 2021).

Photodegradation (**Section 2.1.2** in MP-1) in the natural environment as facilitated by UV irradiation is a known and important pathway for plastic weathering and fragmentation. Barthelemy et al. (2024) investigated UV irradiation in addition to mechanical stress, such as sediment abrasion and water motion, on plastic fragmentation in intermittent rivers and ephemeral streams. The team determined that plastic fragmentation increases with the duration and severity of drying episodes between rainstorms. Additionally, reservoirs with long hydraulic residence times, such as the Great Lakes (Fuschi et al. 2022), and thermal stratification (Zhang et al. 2023) could play a significant role in bioaccumulation and the persistence of NP and MP.

Biotic degradation (**Section 2.9.2** in MP-1) can occur in the environment through a variety of processes. Some organisms (for example, bacteria, mealworms) in soils can degrade specific polymers (Gu 2003; Yang et al. 2015). Other studies have reported physical breakdown of plastics by organisms through chewing or digestive fragmentation (Cadée 2002; Cau et al. 2020; Dawson et al. 2018; Jang et al. 2018; Mateos-Cárdenas et al. 2020; Porter, Smith, and Lewis 2019).

Fragmentation and weathering can increase the surface area, roughness, morphology, and functional groups available for sorption of chemicals to MP. Further, the formation of biofilms and adsorption of natural organic matter changes the surficial hydrophobicity of MP, potentially leading to changes in fate and transport behavior in the environment (Yu et al. 2024) and potentially leading MP to act as a sink for contaminants (Bhagwat et al. 2021). Scott et al. (2021) studied the interaction of MP and PFAS in natural lakes and in a controlled laboratory environment. The results indicated that the adsorption of PFAS by MP was increased (up to 259 times) by the presence of inorganic and organic matter from the lake water as compared to the laboratory environment. One study by Bhagwat et al. (2021) monitored the long-term aging of plastic in the marine environment. Over the course of 10 years, the team identified that mechanical and UV weathering coupled with biofouling of HDPE sleeves encasing wooden poles in an Australian oyster aquaculture farm exhibited higher concentrations of metaloids, polycyclic aromatic hydrocarbons (PAHs), and PFAS in the plastic-associated inorganic and organic matter. A second study by Bhagwat et al. (2021) determined that increased PFOS adsorption to aged microfibers (from polypropylene, polyethylene, nylon, and polyester ropes) in a marine environment was due to the higher surface area and the changed characteristics facilitated by biomass accumulation compared to the virgin samples. Shi et al. (2023) compared the adsorption for virgin and weathered MP in freshwater, using two long-chain and two short-chain PFAS and two common microcystins (a class of cyanotoxins). In contrast to the findings by Bhagwat et al. (2021) and Scott et al. (2021), Shi et al. (2023) found that “up to 50% adsorption of PFOS was observed for virgin PVC compared to 38% for weathered PVC.” Shi et al. (2023) concluded that “natural weathering of MP surfaces may decrease adsorption by introducing hydrophilic oxygen-containing functional groups, and adsorption is driven by specific polymer types and dominated by hydrophobic interactions.”

MP aging occurs in natural environments (Xiao et al. 2023), changing their physical and chemical properties through a range of processes, including mechanical degradation, photodegradation, chemical degradation, and freeze-thaw cycles, as mentioned above. Aged MP demonstrated increased capacity for heavy metal adsorption (Xie et al. 2025). Understanding the adsorption mechanisms of heavy metals onto aged MP is crucial for evaluating the interactions among MP, PFAS, and heavy metals (Xie et al. 2025).

As mentioned, MP can provide a unique substrate for microorganisms. Wang et al. (2021) studied MP that have biofilms on them and found that MP with biofilms sorb a larger concentration of organic pollutants compared to MP without biofilms. The MP that have biofilms can transport organic pollutants and attached microorganisms in the environment. MP are quickly and easily colonized by microorganisms and subsequently form biofilms that influence additional sorption by natural organic matter, metal ions, pollutants, and pathogenic bacteria. Additionally, MP facilitate bacterial antimicrobial resistance due to their higher propensity for facilitating biofilms (Gross et al. 2025). Biofilm cells attached to MP had elevated resistance to drugs, which can promote antibiotic-resistant bacteria and infections in the environment and healthcare settings (Gross et al. 2025).

Agricultural soils are a source of MP because of biosolids amendments (Yu et al. 2023). Yu et al. (2023) determined that polyester fibers affected soil physical properties differently compared to polypropylene granules because of their very different shapes. These differences may have an effect on soil physical properties at higher MP concentrations. A study by Borthakur et al. (2022) also looked at PFAS and MP in biosolids and indicated that aged MP could affect PFAS adsorption on MP.

To date, there is limited research on the distribution, fate, and transport of MP comingled with PFAS in the environment, although SERDP identified projects to investigate this topic; more information is on their website **https://serdp-estcp.mil/**. Similarly, little research has been done on the combination of atmospheric deposition of PFAS and MP in urban systems.

1.8.5 Risk Assessment

This section provides an overview of the available information relevant to risk assessment considerations for the co-exposure of PFAS and MP. As an overview of the knowledge related to the specific co-exposure and health effects of MP and PFAS, this section refers to detailed information for evaluating PFAS toxicity (**Section 7** in PFAS-1) and the application for risk assessments (**Section 9** in PFAS-1), as well as information on exposure and toxicity (**Section 4** in MP-1) and risk assessment (**Section 4.7** in MP-1) about MP without consideration of PFAS.

Robust information is currently lacking about the potential interactive effects of MP and PFAS on exposure and health effects for both wildlife and humans. Thus, the risk assessment science on PFAS-MP interaction is best characterized as uncertain due to the small number of available empirical studies on this topic. Although the potential for co-exposure to PFAS and MP in various media has been discussed in some recent review articles (Siddiqui 2024; Soltanighias et al. 2024; Dai et al. 2022), these articles focused on modeled or proposed interactions of these contaminant classes with limited quantitative information about co-occurring exposures to and combined toxicity from MP and PFAS. Similar to other contaminant mixtures, study design limitations for evaluating even a small number of possible mixture combinations are challenging when using historical or contemporary testing methods. This problem is compounded by the diversity of both the PFAS and MP families, and the potential varying blends of their constituents that may be occurring in different environments. As discussed in **Section 7.1.5** in PFAS-1, approaches for quantitative risk assessment of PFAS mixtures alone are still limited by insufficient data, but some approaches are being investigated within the primary literature (original research articles and review studies) or as risk management strategies by regulatory or public health agencies.

From an exposure standpoint, interactions between MP and PFAS can potentially influence fate and transport in the environment (see **Section 1.8.4**), indicating a need to investigate the subsequent impacts on relevant exposure pathways for risk assessment. The potential for PFAS and MP to co-occur and interact within exposure media has been poorly studied and documented, creating a level of uncertainty that may drastically increase the likelihood for either over- or underestimation of exposure. Although concerns about co-occurring exposures to PFAS and MP across various media and receptors (aquatic and terrestrial wildlife, as well as humans) have been expressed (Dai et al. 2022; Siddiqui 2024; Yu et al.

2024; Kang et al. 2024), they are difficult to quantify, in part, due to the widely varying physical and chemical properties of and diversity of constituents in both groups of contaminants.

Regarding human health risk assessment or mammalian model studies (rat or mouse studies) typically used to derive human health benchmarks, toxicity information for the combined exposure to PFAS and MP is almost entirely limited to in silico estimations or secondary literature (review articles). Compared to the literature available for PFAS and MP as separate classes of contaminants, not co-exposures, almost no primary literature for epidemiological, animal, in vitro, or in silico studies exists that may be used to adequately characterize biological responses to co-exposures of PFAS and MP. With respect to human epidemiology, there is a significant lack of studies evaluating the combined effects using exposed populations; however, some efforts have been made to postulate potential effects through computer modeling (Du et al. 2023; Enyoh et al. 2023) Given the diversity of both PFAS and MP, others have suggested that the interaction of PFAS with plastic additives may affect the toxicity of certain additives on female reproduction based on computational modeling approaches to toxicity assessment (Du et al. 2023). Limited studies are available for animal models that assess the effects of specific PFAS combined with typically laboratory-grade types of MP. For example, in a single mammalian study evaluating PFAS and polystyrene MP (10 µm) , altered bioaccumulation of perfluorobutane sulfonic acid (PFBS) was reported in the liver, and associated changes in molecular markers of liver function were observed (Jiang et al. 2025). Additional studies using animal or in vitro models exist, but the differences in specific PFAS, types of MP, exposure routes, and concentrations complicate evaluation of consistent effects across the limited literature at this time (for example, O'Connor et al. 2024; Lv et al. 2025; Zhang et al. 2025; Zhou et al. 2025; Zou et al. 2025). Currently, there are no quantitative human health risk assessment methodologies for evaluating combined exposure to PFAS and MP as mixtures. There are currently no human health–based toxicity factors (for example, reference doses (RfDs) or cancer slope factors (CSFs), see **Section 7** in PFAS-1) or adjustment factors for specifically evaluating co-exposures of PFAS and MP.

Similar to human health, there are no finalized toxicity factors for combined exposures to MP and PFAS of ecological receptors (aquatic and terrestrial receptors). As previously discussed, MP may pose risks due to their physical, chemical, morphological, and adsorbed contaminant properties and could influence PFAS-related exposure and subsequent risks. This creates a significant challenge for developing toxicity studies for evaluating ecological risks for a small combination of MP and PFAS, let alone the broader families for both contaminant classes that are reasonably expected to co-occur in the environment. The physically mediated adverse effects of MP are influenced primarily by their physical particle characteristics (such as particle size, shape) and behavior. Furthermore, the potential different responses (additive, antagonistic, or synergistic) to varying combinations of PFAS and MP constituents are of interest to toxicologists. For example, one combination exposure study on medaka (Japanese rice fish) embryos attributed embryotoxic effects to PFOS and not MP (polyethylene, 4–6 µm) or their interaction (Le Bihanic et al. 2020). Other studies using aquatic invertebrates *(Daphnia magna)* reported both additive and synergistic effects on fecundity following exposure to PFOS, PFOA, and combination with polyethylene terephthalate (38–50 µm) (Soltanighias et al. 2024). For a terrestrial receptor (earthworms), Sobhani et al. (2021) reported that polyvinyl chloride (PVC)-MP (<125 µm) enhanced the uptake, bioaccumulation, and reproductive toxicity of PFOS and PFOA. The limited number of studies across taxonomic groups and lack of studies for specific PFAS-MP mixtures all contribute to a high degree of uncertainty for characterizing or quantifying risks to ecological receptors. Currently, each class of contaminant has been evaluated separately for exposure of and risks to ecological receptors. Detailed information for these risk assessments is provided in **Section 4.6** in MP-1 and **Section 7.2** and **Section 16** in PFAS-1.

Additional research on PFAS-MP interaction and effects to human and ecological receptors from varying blends of constituents from these classes is needed for conducting robust data-driven risk assessments for human health and ecological receptors. The current challenges for producing high-quality data across

the diverse families of MP, PFAS, and their potential real-world mixtures have limited efforts to quantify both human health and ecological risk at this time.

1.8.6 Treatment

The widespread production and use of PFAS, as well as the many sources of PFAS release to the environment, have resulted in trace levels of PFAS in most environmental media worldwide. Although MP exist as particulate matter in aqueous streams at a wide range of particle sizes, PFAS are more often found in the dissolved phase. Although several technologies exist that can treat PFAS or MP in aqueous media, there is a challenge for a singular technology when the goal is to remove both sets of contaminants, which have different inherent properties. SERDP has identified projects to investigate treatment of PFAS and MP; more information is on their website **https://serdp-estcp.mil/**.

MP can present a favorable medium to complex with (adsorb) contaminants, including PFAS such as PFOS and FOSA, via electrostatic or hydrophobic interactions (Alimi et al. 2018; Salawu, Olivares and Adeleye 2024; O'Donovan et al. 2018). These potential interactions demonstrate the need for effective treatment solutions targeting both sets of contaminants.

The development of treatment technologies for these two groups of contaminants is rapidly evolving, but at different levels of maturity. Although treatment of PFAS has been studied more extensively (**Section 12** in PFAS-1), MP treatment technologies are still being developed (**Section 6.2** in MP-1). Effective treatment technologies targeting both contaminant groups have not been accomplished at full-scale, and the literature is limited on effective efforts completed at the pilot- and bench-scale. However, comprehensive literature reviews (Ali et al. 2023; Satyam and Patra 2024) regarding the challenges and remediation of MP from different media could be very useful. Considering the co-existence of MP and PFAS, co-removal advanced technologies in a treatment train approach are highly desirable to effectively remove both MP and PFAS from affected environmental matrixes. Conceptually, individual technologies exist in the developmental stage (laboratory-scale) targeting both contaminants and should be investigated further (Tang and Hadibarata 2021; Pico et al. 2022; Nasir et al. 2024).

1.8.6.1 Field-implemented Treatment Train Approaches for the Removal of Microplastics and PFAS

Water Matrixes

Conventional treatment of wastewater is relatively effective as a bulk removal mechanism for MP. Results vary depending upon the source water, size and type of MP encountered, and the methodology employed by investigators (for example, enumeration per unit volume versus mass per unit volume, size cutoff due to analytical detection methodology). Overall, conventional water treatment methods have shown favorable removal efficiencies for MP. Grit chambers, settling and clarifying mechanisms, coagulation and flocculation, dissolved air flotation, and sand or mixed media filtration have all demonstrated significant removal efficiencies (Talvite et al., 2017; Pivokonsky et al. 2018; Ali et al. 2021), although direct comparison of removal efficiencies between studies that have a different minimum size cutoff (for example, 1 µm vs 20 µm) is difficult. Currently, it is difficult to speculate on specific quantitative efficiencies and metrics, because further studies are needed. Although conventional wastewater treatment technologies are not designed for PFAS removal, if PFAS have complexed with MP, it is likely that both sets of contaminants would be removed, along with the PFAS removed by complexing with organic matter present in the wastewater. There is a significant research gap in these areas, and further conclusive studies are needed. Based on our understanding, full-scale studies demonstrating removal efficiencies for PFAS and MP have not been completed. 5). Additionally, consideration must be given to the final fate of the contaminants (see **Section 1.8.2** and **Section 1.8.4**). If retained in the residuals from wastewater treatment (sludge or biosolids), understanding the final disposition of the residuals is important if land application is planned, to avoid re-release of contaminants to the

environment. Finally, when considering the volumes of water in treatment processes and the MP remaining in treated effluent, wastewater remains a significant contributor of MP to the environment. Murphy et al. (2016) found that approximately 65 million MP particles are released post-treatment each day from a municipal wastewater treatment plant that processes approximately 7 million gallons per day. Dong et al. (2025) evaluated reported PFAS concentrations at WWTPs in California and found "more than 80% of WWTPs exhibit an increased sum of 39 PFAS [identified in the study] concentrations in the effluent, with over half of these facilities facing a significant risk of surpassing a 70 ng/L threshold for PFAS levels in wastewater."

Removal of PFAS from aqueous solutions has been demonstrated in many studies using separation and adsorbent technologies (See **Section 12** and **Section 18** in PFAS-1). Nanofiltration and reverse osmosis processes have been shown to be effective for membrane applications, while granular activated carbon and single-use and regenerable anion exchange resins are effective PFAS adsorbents as demonstrated in bench-, pilot-, and full-scale evaluations (Boo et al. 2018; Johnson et al. 2019; Kempisty, Xing, and Racz 2018; Liu and Sun 2021; Ross et al. 2018; Zhang, Zhang, and Liang 2019). Novel medias such as cyclodextrin and modified organoclays have also demonstrated the ability to remove PFAS from aqueous waste streams (Kempisty, Xing, and Racz 2018; Yan et al. 2020). Similarly, when operated efficiently, these technologies would conceptually remove both PFAS and MP, but it is unclear at this time whether they will be effective. Granular activated carbon, ion exchange media, novel adsorbents, and any filterable pretreatment media will act as a filter and remove MP in addition to dissolved PFAS. **Section 12.8** and **Figure 12-7** in PFAS-1 discuss integrated water treatment solutions and pre-treatment technologies for PFAS treatment trains. Similar to wastewater treatment technologies, residuals management associated with backwashing and spent media should be considered to avoid reintroduction of contaminants into the environment.

By combining these proven treatment techniques of separation and filtration of conventional wastewater treatment and PFAS removal technologies, a more comprehensive approach can be deployed. The treatment train would integrate wastewater treatment technologies for removal of MP potentially combined with PFAS while the PFAS adsorbent or separation technologies would synergistically remove MP via filtration mechanisms.

Additional technologies that could be combined to form an effective treatment train are discussed in **Table 6-3** in MP-1 and **Section 12** in PFAS-1.

Solid Matrixes

Treatment technologies for PFAS in solid matrixes have been studied and demonstrated at full-scale (**Section 12.3** in PFAS-1), whereas MP treatment technologies in solid matrixes has not been widely studied (**Section 6.2.2** in MP-1). Literature for evaluating the simultaneous removal of PFAS and MP in solid media, such as soil, sediments, and biosolids, was found to be limited during writing of this section. A recent study evaluated the treatment of PFAS, MP, and pharmaceuticals and personal care products (PPCPs) present in biosolids from municipal wastewater via pyrolysis conversion into biochar (Keller et al. 2024). The study employed pyrolysis at an existing operating facility to destroy these contaminants and produce biochar as a valuable byproduct. Contaminants removal was over 99.9% for PFAS and PPCPs, and between 91% and 97% for MP. The production of biochar, which revealed no PFAS detections and less than 1.4 particles of MP per gram of biochar (less than 250 µm particle size), could constitute an economic benefit from the process of treating biosolids. However, the net benefit of converting biosolids into biochar must be compared against the net benefit of using biosolids for land application. **Section 1.6.5** in PFAS-1 presents information about treatment of biosolids.

1.8.6.2 Developing Technologies for Effective Microplastic and PFAS Removal

Water Matrixes

Electrochemical Treatment

Electrochemical oxidation is a promising zero-sludge process that has been used to remove both PFAS and MP from water. The technology applies electrical potential across electrodes, creating two mechanisms for contaminant destruction. The first is the formation of hydroxyl radicals that nonselectively oxidize encountered organic species, to include PFAS and polymer bonds (Liang et al. 2022). The second mechanism involves direct oxidation of a contaminant at the anode surface. Pilot- and bench-scale efforts have demonstrated success with varying levels of effectiveness (Kiendrebeogo et al. 2021; Ning et al. 2023). Water quality characteristics such as conductivity need to be considered to understand and optimize treatment effectiveness. High conductivity may result in the formation of perchlorate, bromate, or other undesirable products, while low conductivity solutions may negatively affect kinetics and increase treatment time and costs (Radjenovic et al. 2020; Radjenovic et al. 2022).

In addition to electrochemical oxidation, other electrochemical approaches such as electrocoagulation are being explored; under this mechanism, cations produced by a metal electrode bind to the MP and coagulate them into larger particles (Ning et al. 2023). Nevertheless, full-scale application of electrochemical technologies continues to develop with no known full-scale treatment deployed specifically targeting both MP and PFAS.

Foam Fractionation

Foam fractionation systems have been designed and operated to remove PFAS from water streams (**Section 12.2.3** and **Section 18**, in PFAS-1) and total suspended solids from water streams (Pfeiffer, Baptiste, and Wills 2024). It follows that, at least conceptually, separation of MP from water using foam fractionation might be effective. However, this has not yet been demonstrated. Dissolved air flotation, which is a separation technology conceptually similar to foam fractionation, has been tested for removal of MP from water (De Somer et al. 2024; Saczek et al. 2024; Monira and Pramanik 2025; Wang et al. 2021; Pit et al. 2025).

Solid Matrixes

Information on developing technologies for the simultaneous treatment of PFAS and MP is not available at this time. PFAS treatment technologies, such as stabilization and soil washing, for solid matrixes are mature and available (**Section 12.3** in PFAS-1), whereas there are no fully demonstrated treatment technologies for MP in solid media (**Section 6.2.2** in MP-1).

1.8.7 Regulatory and Guidance Considerations

Several regulations at the state, federal, and international level govern MP. Similarly, there are current and developing regulations pertaining to PFAS across these geographies. For specific information pertaining to MP regulations, see **Section 5** in MP-1. For specific information about the regulatory landscape around PFAS, see **Section 8** in PFAS-1.

Several regulations mention both PFAS and MP together as emerging contaminants. Although they are mentioned together, they are not evaluated or considered as to relevance or impact related to co-existence in the environment. As an example, the Clean Water and Drinking Water State Revolving Fund Provisions of the Bipartisan Infrastructure Law (USEPA 2022) provide $5B to reduce exposures to PFAS and other emerging contaminants (such as MP) from public drinking water and wastewater systems. Several states, as a result, have included both PFAS and MP similarly in their State Chemicals of Concern

(CEC) programs. ITRC summarized State CEC Monitoring programs in the **CEC Monitoring Programs Fact Sheet**.

1.8.8 Changing Weather Patterns

There is limited information on changing weather patterns impacting environmental fate of PFAS and MP in the current literature. Changing weather patterns can impact transformation rates of PFAS and MP among the environmental media (Gander 2025; Hung et al. 2022). Transfer of PFAS from "air to surfaces, water to sediments, and ice to water [is] affected by changes in ambient temperatures … snow, rainfall, and the cryosphere" (Hung et al. 2022). Rising global temperatures influence the movement, concentration, and impact of pollutants such as PFAS and MP in water bodies and groundwater (Gander 2025). Increased temperatures remobilize persistent organic pollutants from melting sea ice into the Arctic Sea water and back to the atmosphere (Hung et al. 2022). MP and persistent organic pollutants in the melting Arctic Sea ice are released into the Arctic marine ecosystem and can potentially expose marine life and indigenous populations (Galgani, Hanke, and Maes 2015; Hung et al. 2022). The breakdown of MP into carbon dioxide (CO_2) and methane (CH_4) during degradation increases the release of greenhouse gases in the environment. It also disrupts the natural carbon and nitrogen cycles in the environment, leading to increased emissions of greenhouse gases (Gander 2025). In addition, MP absorb sunlight, which can contribute to the melting of snow and ice (Gander 2025). Ingestion of MP reduces phytoplankton growth and the ability of phytoplankton to absorb atmospheric carbon dioxide (Raju et al. 2021; Gander 2025).

Extreme rainfall events due to changing weather patterns increase leaching of pollutants to groundwater and surface waters and enhance deposition of pollutants in floodplains and low-lying urban areas (Gander 2025). Urban stormwater runoff can release significant amounts of MP to the receiving waters (Paterson, Miller, and Lin 2024). Monsoonal rains can increase leaching of MP from pesticides used in agricultural areas to aquifers (Gander 2025). Severe flooding can cause overflow of wastewater treatment plants and unplanned releases of contaminated water into the environment (Gander 2025). Additionally, changing weather patterns modify microbial communities and microbial degradation rates, which impact the degradation rates of persistent organic pollutants in the environment (Hung et al. 2022).

2 PFAS CHEMISTRY AND NAMING CONVENTIONS, HISTORY AND USE OF PFAS, AND SOURCES OF PFAS RELEASES TO THE ENVIRONMENT

This section provides a basis for the discussion of PFAS in the environment by presenting foundational information about its discovery, commercial use, health and environmental awareness, chemistry, and terminology.

Section Number	Topic
1.1	**Priority Topics for History, Use, and Naming Conventions (2025)**
2.1	**Environmental Significance**
2.2	**Chemistry, Terminology, and Acronyms**
2.3	**Emerging Health and Environmental Concerns**
2.4	**PFAS Reductions and Alternative PFAS Formulations**
2.5	**PFAS Uses and Products**
2.6	**PFAS Releases to the Environment**

In 1938, Roy J. Plunkett at the DuPont Company's Jackson Laboratory discovered polytetrafluoroethylene (PTFE) while conducting commercial experiments with chlorofluorocarbon refrigerants (**Science History Institute 2017**).

Since the 1950s, many products commonly used by consumers and industry have been manufactured with or from PFAS, as the unique physical and chemical properties of PFAS impart oil, water, stain, and soil repellency, chemical and thermal stability, and/or friction reduction to a range of products. These products have applications in many industries, including the aerospace, semiconductor, medical, automotive, construction, electronics, and aviation industries, as well as in consumer products (such as carpets, clothing, furniture, outdoor equipment, food packaging), and firefighting applications (**3M Company 1999**; **Buck et al. 2011**; **KEMI 2015**; **USEPA 2017**).

The number of PFAS and their uses have expanded over the years. It has been estimated that the PFAS family may include more than 12,000 chemical substances (**USEPA 2020**). A 2021 inventory of PFAS identified more than 4,700 PFAS with Chemical Abstracts Service (CAS) Registry Numbers that could have been, or may be, on the global market (**OECD 2021**), although the uses of each of these PFAS may not be known (**KEMI 2015**). Publicly available health and toxicity studies are limited to only a small fraction of PFAS, and modern commercially available analytical technologies typically identify and quantify only about 50–60 PFAS, but these lists are increasing. An industry survey, reported in Buck et al. (**2021**), noted that only 256 of the 4,700 PFAS with CAS Registry Numbers are commercially relevant, with others of lesser environmental significance but potentially still occurring in the environment. However, it should be noted that (1) the results of this survey reflect responses from only three major global producers of PFAS that use the fluorotelomerization manufacturing process, (2) the results of this survey do not include any producers that use the electrochemical fluorination manufacturing process; and (3) some of the information provided by the participating companies was flagged as confidential business information.

Scientific, regulatory, and public concerns have emerged about potential health and environmental impacts associated with chemical production, product manufacture and use, and disposal of PFAS-containing wastes. These concerns have led to efforts to reduce the use of or replace certain PFAS, such as certain long-chain perfluoroalkyl carboxylates, long-chain perfluoroalkane sulfonates and their

precursors, including two widely produced, commonly encountered, and most studied compounds: perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) (**USEPA 2016**; **WA DER 2017**). Refer to the Environmental Media Values Table Excel file, the Regulatory Programs Summary Table Excel file, and **Section 8** for updated regulatory actions, and **Section 13** for stakeholder perspectives.

PFAS have followed a similar pattern of emergence and awareness exhibited by many other anthropogenic environmental contaminants. **Figure 2-1** provides a general timeline of PFAS emergence and awareness that includes categories of 1) synthesis/development, 2) commercial production, 3) health concerns, 4) environmental detection, and 5) reduction/alternatives. There may be evidence of some activities occurring before or after dates provided in this timeline; the intent of the figure is to capture the years of significance for each category.

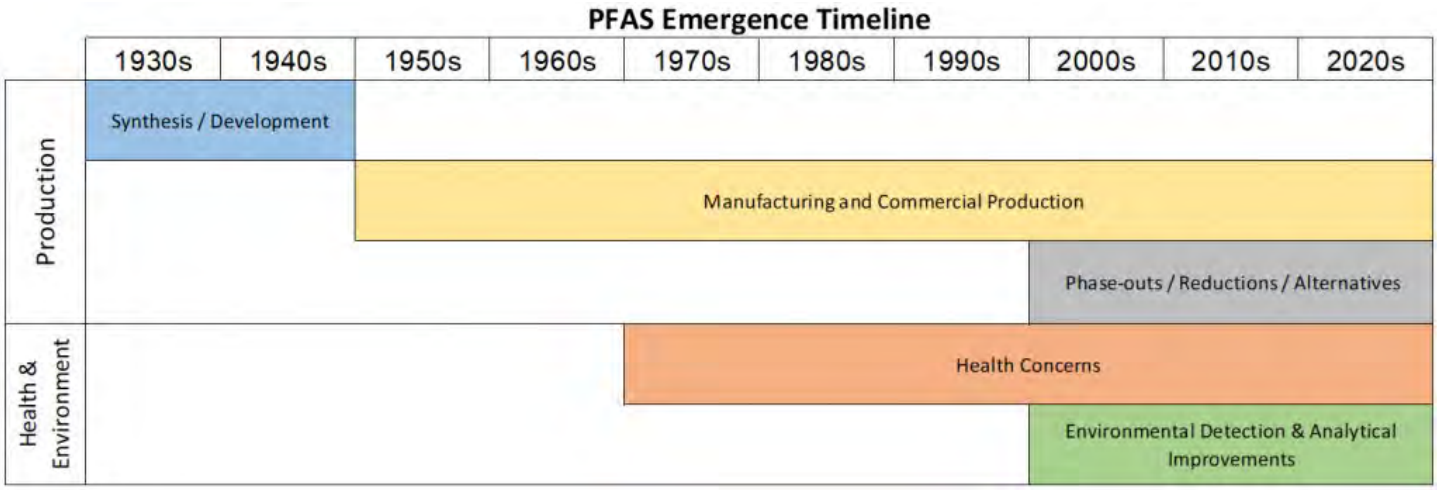


Figure 2-1. General timeline of PFAS emergence and awareness.

Graphic provides general indication of PFAS emergence and awareness by decade. Specific activities and events are described in more detail within this chapter. "Reductions/alternatives" refers to reduction in production/use and includes other PFAS that have replaced legacy chemistry.

Source: J. Hale, Kleinfelder. Used with permission.

The objective of this section is to lay a foundation for identifying potential PFAS sources in the environment.

2.1 Environmental Significance

PFAS have been and still are widely used, but not all types and uses of PFAS result in the same level of environmental impact and exposure. When considering potential environmental impacts from PFAS, it can be useful to be as specific as possible not only about the particular PFAS involved, but also where and how they are released to the environment. For example, a stable, insoluble fluoropolymer such as PTFE may pose little environmental/ecological or health risk once it is in a product. However, potentially significant environmental releases of other PFAS historically or currently used in the manufacturing process (for example, perfluoroalkyl acids [PFAAs], GenX, ADONA) have occurred. Such considerations may help to focus investigation resources on major sources. Addressing PFAS in a holistic manner is an emerging subject (**Cousins et al. 2019**) that may be helpful considering data are not available, for example, on the environmental fate and transport, environmental toxicity, or bioavailability, for all individual PFAS chemicals.

Figure 2-2 illustrates a conceptual PFAS lifecycle beginning at PFAS synthesis (raw materials). These raw materials are then used in a variety of manufacturing processes and industrial/commercial applications to create commercial and consumer products that contain or are treated with PFAS. Throughout this life cycle, variable types and amounts of PFAS may be released to the environment from manufacturing waste streams, fugitive emissions, spills, disposal of PFAS-containing or -treated materials, and general wear and tear of consumer products. Sometimes the intended use of the PFAS product (for example, firefighting foams) requires direct release to the environment. PFAS from a host of sources also may be conveyed through and aggregated in wastewater treatment plant effluent and sludges, creating sources of releases to the environment. The volume, concentration, and mixture of PFAS released to the environment varies based on the source (process, material, or product), release mechanism(s), and environmental controls employed throughout this life cycle. Exposure to PFAS may occur as (1) direct interaction with the manufacturing process, (2) professional or intensive use of PFAS-containing materials, (3) use of or contact with commercial and consumer products containing PFAS, or (4) exposure (human or ecological) to environmental media that have been impacted by PFAS. The relative significance of these exposures will also vary widely.

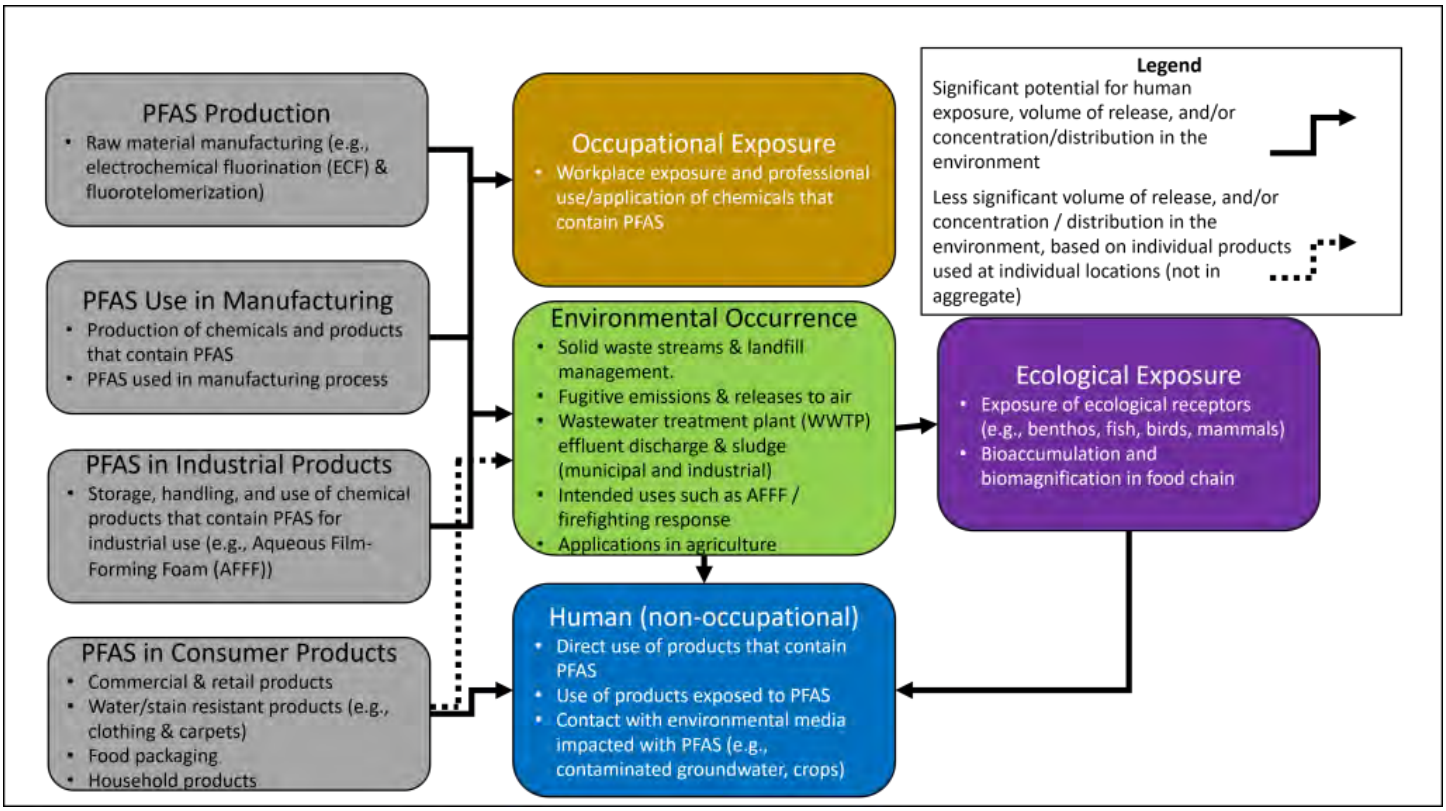


Figure 2-2. Generalized PFAS uses and relative exposure and environmental impact potential from PFAS life cycle.

This figure is not exhaustive with regard to all sources or release mechanisms from those sources. Multiple sources may exist at a site, and the relative potential of exposure and environmental impact may vary based on several considerations. Due to the widespread use of PFAS in commercial and consumer products, other minor point source or diffuse releases of PFAS to the environment may occur during use and disposal of some PFAS-containing products. Although these may result in locally significant environmental impacts, these releases typically affect smaller geographic areas and have lower total PFAS mass than major sources, such as PFAS chemical manufacturing, PFAS use in certain industries, and some applications of certain firefighting foams.

Different PFAS products and sources differ in their relative environmental significance, volumes released, distribution mechanisms, area affected, and relative concentration of impacted media. For instance, nonpolymer PFAS used in Class B firefighting foam may impact a moderate area near the source and may exhibit high concentrations in impacted media. In contrast, a similar volume of nonpolymer PFAS air emissions from a fluoropolymer manufacturing facility may be more widely dispersed and present at lower concentrations in impacted media.

The type of PFAS involved also determines the relative environmental significance. Nonpolymer PFAS (both per- and polyfluorinated) and some side-chain fluorinated polymer PFAS are likely to pose greater risks when released to the environment than certain fluoropolymer sources, such as the fluoropolymers PTFE, fluorinated ethylene-propylene (FEP), perfluoroalkoxy polymer (PFA), and ethylene tetrafluoroethylene (ETFE). These fluoropolymers are considered to be polymers of low concern (**Section 2.2.2.1**) because they are relatively stable, insoluble in the environment, and not bioavailable (**Henry et al. 2018**). However, environmental impact from the production or manufacturing uses of fluoropolymers can pose a significant risk if emissions are not properly controlled at the industrial site. Also, releases to the environment from the disposal of fluoropolymers cannot be ruled out, as nonpolymer PFAS (such as the PFAAs used as polymerization aids) may be found at trace levels as impurities and byproducts in some fluoropolymer products (**3M Company 1999**). Many fluoropolymers may be resistant to transformation. For example, in one study, PTFE did not significantly transform under certain incineration conditions (**Aleksandrov et al. 2019**). However, research suggests side-chain fluorinated polymers are likely to break down to nonpolymer PFAS over time (**Li et al. 2018**). For example, commercial fluorotelomer-based polymers (a kind of side-chain fluorinated polymer) have been documented to biotransform under environmental conditions (**Washington et al. 2015**) and to abiotically transform by hydrolysis under environmental and consumer-use conditions (**Washington and Jenkins 2015**). For additional information on transformation of polyfluorinated PFAS, see **Section 5.4**; transformation of PFAS polymers is discussed in **Section 5.4.5**.

Finally, another consideration regarding environmental impacts is the issue of anthropogenic (human-caused, not naturally occurring) ambient or anthropogenic “background” levels of PFAS. As discussed in **Section 6**, the long duration of PFAS use and their release from many types of sources may have resulted in low-level contamination of environmental media worldwide. Cousins et al. (**2022**) compares concentrations in environmental media to proposed guidelines from USEPA, Denmark, the Netherlands, and the European Union. The implications of ambient levels of PFAS should be considered in evaluating exposures and risk levels, establishing site action levels and cleanup goals, and identifying PFAS sources.

2.2 Chemistry, Terminology, and Acronyms

The Priority Topics for History, Use, and Naming Conventions include information about less-studied PFAS (see **Section 1.1.3**), ultrashort PFAS, cyclic PFAS, volatile PFAS, and fluorinated gases.

This section focuses on chemistry, terminology, names, and acronyms for those PFAS most commonly reported in the environment, identified in scientific literature, and those PFAS most commonly tested for by current analytical methods. Other important classes of PFAS are introduced. This section also introduces the chemical manufacturing processes that influence the types of PFAS that are found in the environment.

The definition of PFAS continues to evolve to reflect continued study of these compounds and takes different forms depending on the regulatory body, operational criteria used, and the intended scope and application of the included list of chemicals. There is no universally accepted definition of PFAS. However, in general, PFAS are compounds characterized as having carbon atoms linked to each other and bonded to fluorine atoms at most or all of the available carbon bonding sites.

Table 2-1 provides examples of several definitions of PFAS (**Hammel et al. 2022**) developed by several authoritative agencies and researchers. In addition, **Schymanski et al. (2023)** describes a user-friendly resource to explore >7 million PFAS and >21 million fluorinated compounds in the National Institutes of Health (NIH) PubChem database by establishing the "PFAS and Fluorinated Compounds in PubChem" Classification Browser (or "PubChem PFAS Tree").

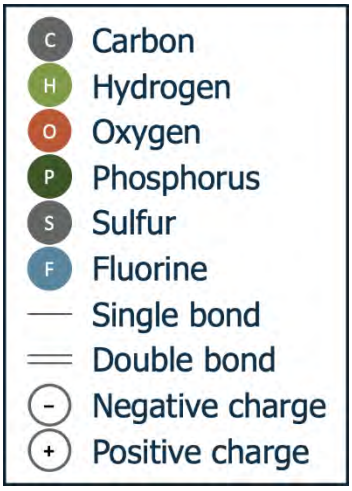
Table 2-1. Examples of PFAS definitions/Working Descriptions (Hammel et al. 2022, Table 2)(CC BY-NC-ND 4.0).

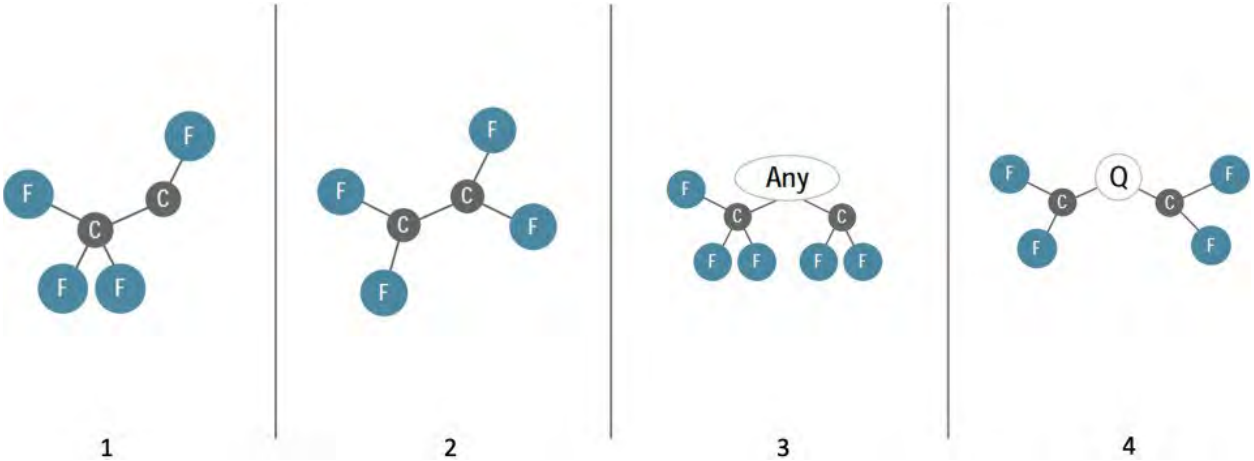
Source of Definition	Year Defined	Definition	Additional Comments
Buck et al.	2011	"highly fluorinated aliphatic substances that contain one or more carbon (C) atoms on which all the hydrogen (H) substituents (present in the nonfluorinated analogues from which they are notionally derived) have been replaced by fluorine (F) atoms, in such a manner that they contain the perfluoroalkyl moiety C_nF_{2n+1}–."	**Buck et al. (2011)** is an open-access paper that provides a detailed explanation of PFAS terminology, classification, and origins, and recommends specific and descriptive terminology, names, and acronyms for PFAS.
OECD	2021	"PFASs, including perfluorocarbons, that contain a perfluoroalkyl moiety with three or more carbons (i.e., $-C_nF_{2n}-$, n ≥ 3) or a perfluoroalkylether moiety with two or more carbons (i.e., $-C_nF_{2n}OC_mF_{2m}-$, n and m ≥ 1)."	Updated in 2021
OECD	2021	"fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e., with a few noted exceptions, any chemical with at least a perfluorinated methyl group ($-CF_3$) or a perfluorinated methylene group ($-CF_2-$) is a PFAS."	**OECD (2021)** expanded the **Buck et al.(2011)** definition to include chemicals that contain the $-C_nF_{2n}-$ moiety in addition to the $C_nF_{2n+1}-$ moiety, which encompasses chemicals with both ends of the carbon-fluorine chain connected to a hydrogen or a functional group, as well as cyclic analogs of linear PFAS.
Gluge et al.	2020	In addition to substances containing C_nF_{2n+1}, where n ≥ 1, it also "includes (i) substances where a perfluorocarbon chain is connected with functional groups on both ends, (ii) aromatic substances that have perfluoroalkyl moieties on the side chains, and (iii) fluorinated cycloaliphatic substances. Additionally, "polymeric PFAS with the $-CF_2-$ moiety and non-polymeric PFAS with the $-CF_2-CF_2-$ moiety [excluding] non-polymeric substances that only contain a $-CF_3$ or $-CF_2-$ moiety, with the exception of perfluoroalkylethers and per- and polyfluoroalkylether-based substances. For these two PFAS groups, substances with a $-CF_2OCF_2-$ or $-CF_2OCFHCF-$ moiety are also included."	**Glüge et al. (2020)** acknowledged the **Buck et al. (2011)** and **OECD (2018)** definitions while also considering the definition of PFAS to include: • substances in which a perfluorocarbon chain is connected with functional groups on both ends • aromatic substances that have perfluoroalkyl moieties on the side chains • fluorinated cycloaliphatic substances.

Source of Definition	Year Defined	Definition	Additional Comments
TURA Program, Massachusetts (**TURA 2023**)	2023	"Certain PFAS not otherwise listed includes those PFAS that contain a perfluoroalkyl moiety with three or more carbons (e.g., $-C_nF_{2n}-$, n ≥ 3; or $CF_3-C_nF_{2n}-$, n ≥ 2) or a perfluoroalkylether moiety with two or more carbons (e.g., $-C_nF_{2n}OC_mF_{2m}-$ or $-C_nF_{2n}OC_mF_{2m}-$, n and m ≥ 1), wherein for the example structures shown, the dash (–) is not a bond to a hydrogen and may represent a straight or branched structure, that are not otherwise listed."	
USEPA OPPT	2021	"a structure that contains the unit R-$CF_2-CF(R')(R")$, where R, R', and R" do not equal "H" and the carbon-carbon bond is saturated (note: branching, heteroatoms, and cyclic structures are included)."	Chemicals for review under TSCA to evaluate human health and environmental risks
NDAA, WA, CA, VT, ME	2019, 2020, 2021	Organic chemicals containing at least 1 fully fluorinated carbon atom	Authorities whose legislation defines PFAS as a class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom.
USEPA CCL5	2022	"For the purposes of CCL5, the structural definition of per- and polyfluoroalkyl substances (PFAS) includes chemicals that contain at least one of these three structures: (1) $R-(CF_2)-CF(R')R"$, where both the CF_2 and CF moieties are saturated carbons, and none of the R groups can be hydrogen; (2) $R-CF_2OCF_2-R'$, where both the CF_2 moieties are saturated carbons, and none of the R groups can be hydrogen; (3) $CF_3C(CF_3)RR'$, where all the carbons are saturated, and none of the R groups can be hydrogen."	The USEPA CCL5 definition is less inclusive than the OECD definition, but it is more inclusive than the USEPA TSCA definition.
MPART	2023	PFAS means per- and polyfluoroalkyl substances that contain the perfluoroalkyl moiety with two adjacent fully fluorinated carbons, $R-(CF_2)-C(F)(R')R$", or perfluoroalkyl ether moiety, $R-(CF_2)-O-(CF)(R')R$", where R, R', and R" represent any functional group or atom except hydrogen (H). This includes perfluoroalkyl substances with $R-CF_2-CF_2-R'$ and CF_3-CF_2-R units or perfluoroalkyl ether substances with $R-CF_2-O-CF_2-R'$, and CF_3-O-CF_2-R units.	MPART has not agreed to a PFAS definition, but has accepted this working description of PFAS, which is subject to change. This working description borrows from the OECD 2021 and the EPA TSCA definitions of PFAS. In 2024, the Subgroup is examining this working description closer and is considering physicochemical and toxicological properties.

Definitions of PFAS: **Buck et al. (2011)** definition: "highly fluorinated aliphatic substances that contain one or more carbon (C) atoms on which all the hydrogen (H) substituents (present in the nonfluorinated analogues from which they are notionally derived) have been replaced by fluorine (F) atoms, in such a manner that they contain the perfluoroalkyl moiety CnF2n+1 –."
OECD (2021) definition: "fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e., with a few noted exceptions, any chemical with at least a perfluorinated methyl group (–CF3) or a perfluorinated methylene group (–CF2–) is a PFAS."

The USEPA's CompTox Chemicals Dashboard (CompTox Chemicals Dashboard (epa.gov)) provides a large publicly available resource for PFAS structures and predicted properties (**Williams et al. 2017**; **Williams et al. 2022**). This effort has taken two approaches to defining PFAS. The first, denoted PFASMASTER (**USEPA 2020**), was based on a simple join, or combination, of publicly available lists of PFAS chemicals reported by other entities, such as the **OECD (2018)** report. The second approach applied a small set of structure filters to the entire EPA DSSTox database (currently exceeding 1,200,000 substances), resulting in a list containing more than 8,000 PFAS structures, denoted PFASSTRUCTV3 (**USEPA 2020**); the 2022 version is PFASSTRUCTV5 (**USEPA 2022**) containing more than 14,000 structures. Please check USEPA's CompTox Chemicals Dashboard for the most current version. The 2022 PFASMASTER file exceeds 12,000 substances and includes both PFAS structures (from PFASSTRUCV5) and structures and non-structurable chemicals (such as mixtures and polymers) from combining several public PFAS lists. Hence, the structure-based filters used in this effort expand the PFAS definition beyond the **Buck et al. (2011)** and **OECD (2021)** definitions and are designed to fully encompass publicly available PFAS lists, as well as to be inclusive of small, fluorinated chemicals of potential concern to USEPA. The 2022 PFASSTRUCTV5 uses a combination of four substructural filters (see **Figure 2-3**) and/or a threshold of 30% fluorine without hydrogen based on molecular formula count (not weight). The substructural filters (shown in **Figure 2-3**) are designed to be simple, reproducible and transparent, yet general enough to encompass the largest set of structures having sufficient levels of fluorination to potentially be considered PFAS. (**USEPA 2022**).





Note: Q can be any of the following atoms: B, O, N, P, S or Si.

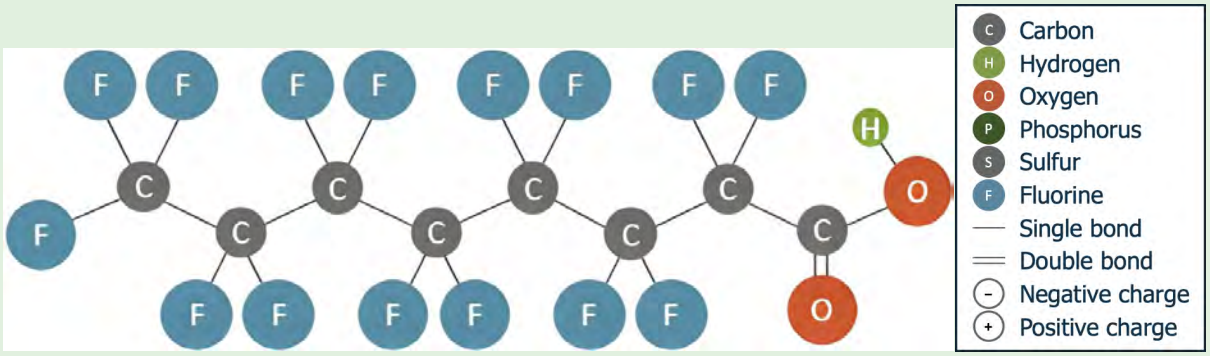
Figure 2-3. Four Substructural Filters of PFAS Used in Development of USEPA's CompTox Dashboard for PFAS (USEPA 2022) (see legend above figure).

Whereas some PFAS definitions such as provided by USEPA's CompTox Dashboard are designed to be broadly inclusive, definitions used in regulatory applications often must be more circumscribed and

precisely worded. Examples of definitions used in regulatory applications include those used by USEPA TSCA and the USEPA Drinking Water Contaminant Candidate List 5 (CCL5); see **Table 2.1**. Information about state regulatory programs for PFAS is included in the Regulatory Programs Summary Table. For example, the state of Maine defines PFAS as substances that include any member of the class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom (**Maine State Legislature 2021**).

General Concepts of Organofluorine Chemistry for PFAS

Organofluorine Chemistry: A branch of organic chemistry involving organic molecules with a carbon-fluorine bond. Organofluorine molecules have many commercial uses. They include PFAS, such as PFOA, shown below:



Example PFOA molecule, acid form (see legend right of figure).

Gray spheres represent carbon atoms linked together in a chain; there are eight of them, so "octane" is used in the name. Blue spheres represent fluorine atoms bonded to carbon atoms. Red spheres represent oxygen atoms. Green sphere represents a hydrogen atom that dissolves away in water, which makes this an acid. Fluorine atoms are attached to all possible bonding sites, making this perfluorinated. If some of the fluorine atoms were replaced by other atoms (such as oxygen or hydrogen), it would be polyfluorinated. Without the hydrogen, the "head end" takes on a negative charge and can bond to things through electrostatic attraction. The fluorine "tail end" is strong and stable, giving it lipid- and water-repelling properties, but also making it persistent in the environment.

Isomer: A molecule with the same molecular formula as another molecule, but with a different chemical structure. Isomers contain the same number of atoms of each element, but have different arrangements of their atoms. See **Figure 2-16** for an example; linear and branched PFOS contain the same number of carbon, fluorine, oxygen, and sulfur atoms, but these atoms are arranged differently depending on whether it is a linear or branched isomer of PFOS.

Homologue Groups and Homologous Series: A group of organic compounds, usually listed in order of increasing size, that has a similar structure (and therefore also similar properties) and whose structures differ only by the number of carbon atoms in the chain. For example, all of the linear and branched isomers of PFOS would be in the C8 homologue group, while all of the linear and branched isomers of perfluorohexane sulfonic acid (PFHxS) would be in the C6 homologue group. The C_4-C_{12} PFSAs are a homologous series of perfluoroalkane sulfonates.

Throughout Section 2, the **Buck et al. (2011)** definition has been used for simplicity of discussion in the depiction of naming conventions of PFAS.

2.2.1 Naming Convention Considerations

There is confusion among the environmental community and the public due to overgeneralization when describing PFAS and the lack of consistent naming of specific PFAS. The use of consistent naming conventions would reduce confusion and support clearer communication (**Buck et al. 2011**; **Wang et al. 2017**).

"PFAS," not "PFASs": The acronym "PFAS" stands for "per- and polyfluoroalkyl substances." No single chemical within the PFAS family can be both perfluorinated and polyfluorinated, so by definition "PFAS" is plural and a small "s" is not needed. Some authors elect to add a small "s" to this acronym (PFASs) to emphasize the fact that it is plural, but it is not needed. When referring to a single chemical within the PFAS family, it is more accurate to simply name that specific chemical.

Consistent naming also helps to distinguish PFAS from other organic compounds that contain fluorine. As defined in the literature, PFAS may include only one fluorinated aliphatic (carbon chain) substance. Alkyl/aliphatic groups are fully saturated carbon chains, which can be either cyclic, non-cyclic, branched or unbranched. Alkyl and aliphatic can be used interchangeably. Depending on the definition, PFAS may or may not include fluorinated compounds that contain aromatic (carbon ring) features in their structures (for example, active pharmaceutical ingredients, crop protection agents, or chlorofluorocarbons [refrigerants]) (**Gaines, Sinclair, and Williams 2023**; **Glüge et al. 2020**; **Hammel et al. 2022**). The inclusion of aromatic components in a chemical structure in the PFAS classification varies depending on what definition is applied. As **Gaines, Sinclair, and Williams 2023** describes, including aromatics in a PFAS definition confounds things as the "PFAS" acronym includes the word "alkyl" that does not include aromatics. The authors go on to say that the "A" in PFAS could also be used to mean both aliphatic and aromatic, but this could also cause confusion as PFAS have not been used widely with this interpretation.

The use of nonspecific acronyms, such as perfluorinated compound (PFC), has hampered clarity of investigative results. The acronym "PFC" is poorly defined in the scientific literature, but typically refers to "perfluorinated compounds." "PFC" is widely used in the climate community, referring to perfluorocarbons, which are a subset of PFAS. PFC does not include "polyfluorinated substances," which are increasingly recognized as important contaminants at many PFAS sites.

CAS numbers are another helpful tool for clearly identifying the chemical that is being referenced; however, care must be taken in selecting the correct CAS number to avoid confusion regarding the chemistry and behavior of the chemical being described. Some PFAS may exist in various ionic states, such as acids, anions (negatively charged), cations (positively charged), and zwitterions (both positively and negatively charged dipolar molecules), and each has its own CAS number (and some have no CAS number). The ionic state determines electrical charge and physical and chemical properties, which in turn control fate and transport in the environment (**Section 5**) and potential human health and ecological effects (**Section 7**). The ionic state of individual PFAS can result in significantly different physical and chemical properties (**Section 4**), such as solubility, volatility, and bioaccumulative potential.

International Union of Pure and Applied Chemistry (IUPAC) (https://iupac.org) nomenclature may also be used for identifying PFAS chemicals. The IUPAC nomenclature system is typically used in more formal literature such as patents. Examples of the IUPAC naming convention are provided below.

- PFOA: 2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-Pentadecafluorooctanoic acid
- PFOS: 1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluorooctane-1-sulfonic acid

Some chemicals in the PFAS family can exist in various ionic states (for example, acids, anions, cations), which have important implications for their chemical and physical properties. In most cases for PFAAs, this section uses the anionic form of a given PFAS name, as this is the state in which most PFAAs exist in the environment.

In the future, it may be necessary to expand the current naming conventions and acronym approaches to ensure that standardized naming is available for additional members of the PFAS family of compounds.

2.2.2 Introduction to the PFAS Family

PFAS are comprised of a wide variety of molecules with different physical and chemical properties and molecular weights with perfluoroalkyl moieties as common structural features, as noted by **Cousins et al. (2020)**, who identified specifically:

> *"…the PFAS class comprises distinct substances with very different structures and properties: high-molecular-weight polymers and high-molecular-weight non-polymers; neutral, anionic, cationic and zwitterionic substances; solids, liquids, and gases; highly reactive and non-reactive (inert) substances; soluble and insoluble substances; and volatile and involatile substances. In the environment, some PFAS are mobile and others immobile, and some bioaccumulate while others do not."*

This variety of PFAS with diverse properties is organized in the form of a PFAS family tree (**Figure 2-4**) that includes two primary classes: polymers and nonpolymers. Each class may contain many subclasses, groups, and subgroups, some of which are shown in the figure. This document focuses primarily on those nonpolymer PFAS most commonly detected in the environment and those PFAS that may be significant as "precursors" that can transform to more persistent forms.

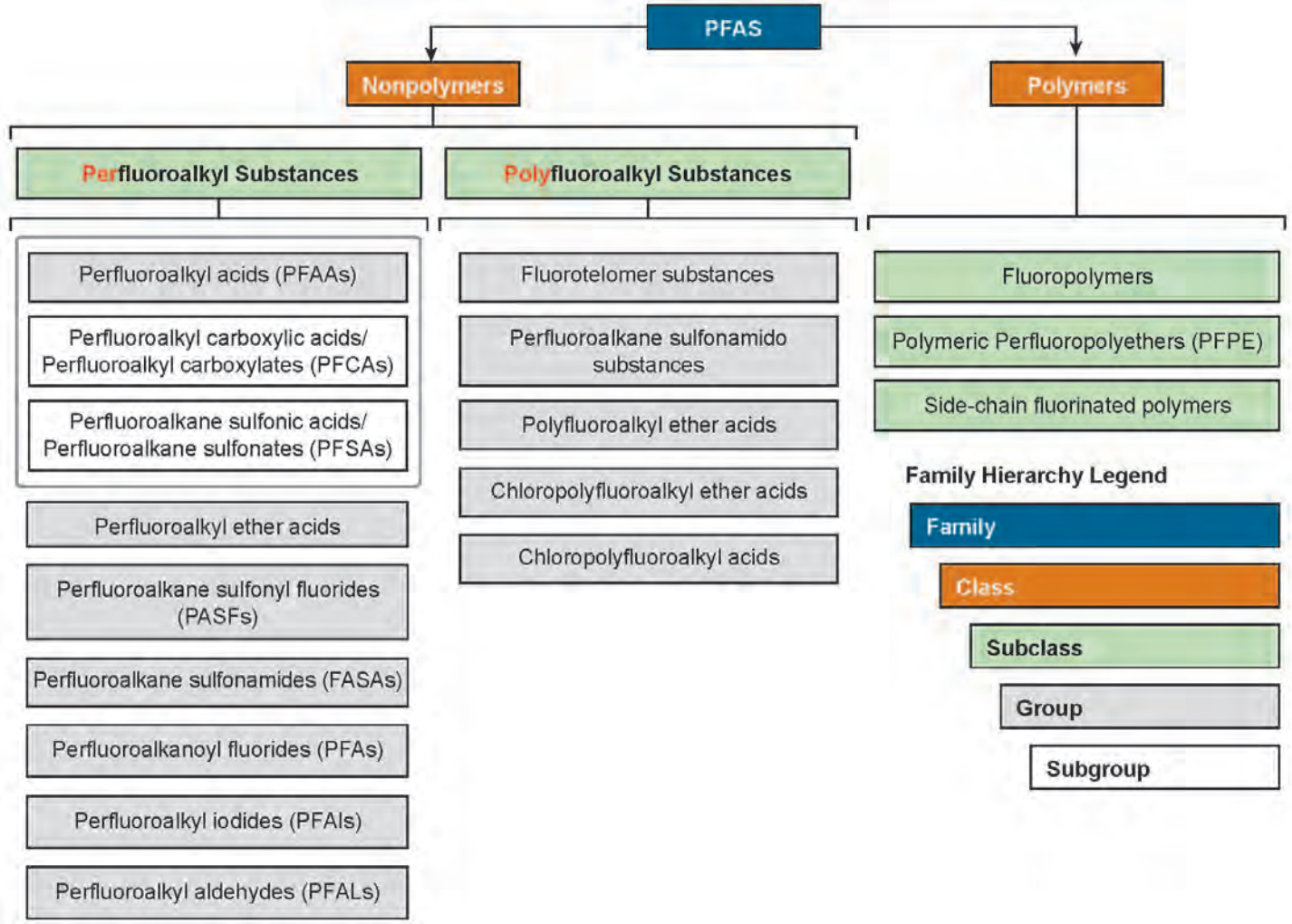


Figure 2-4. The PFAS family.

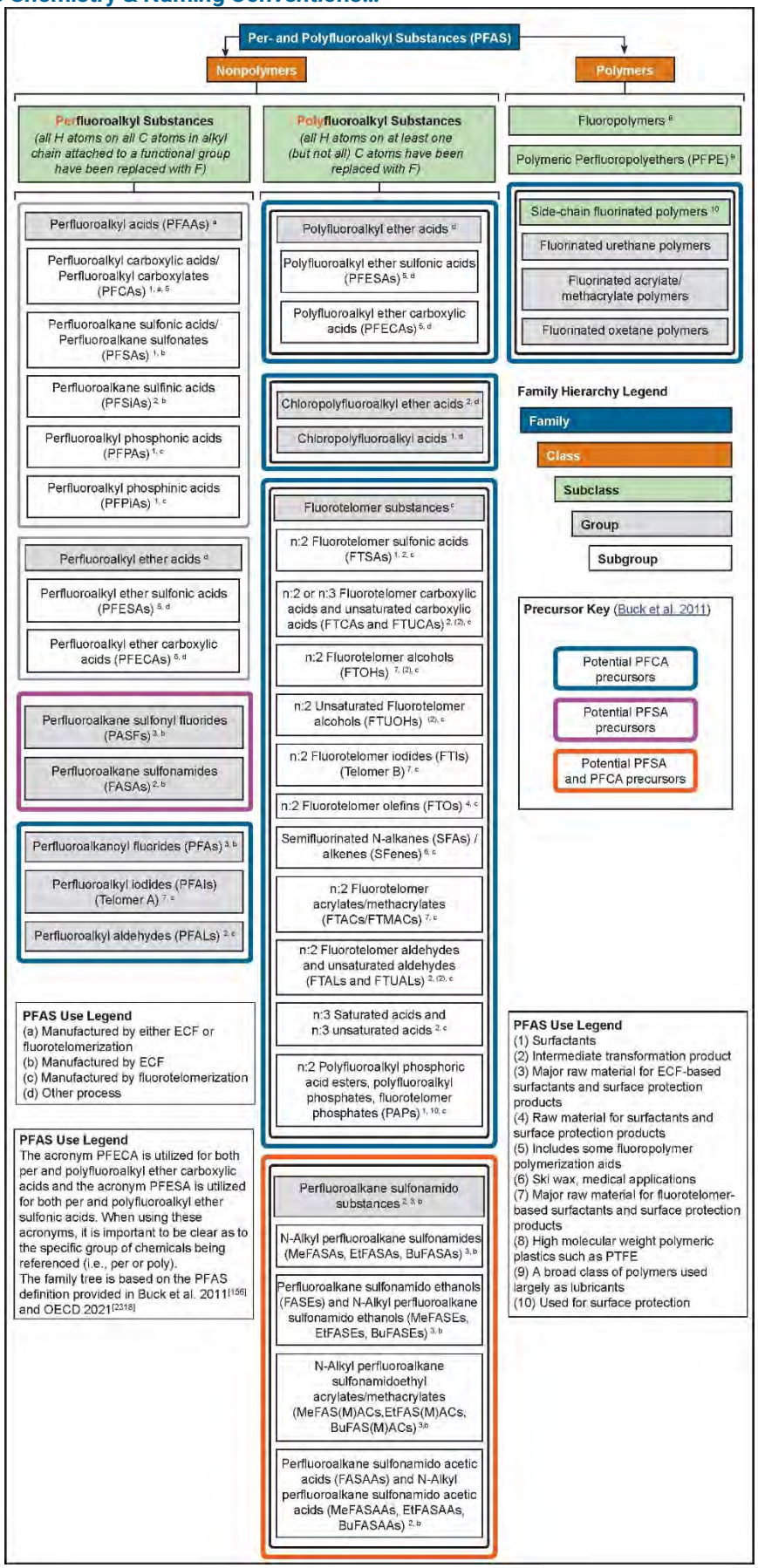


Figure 2-5. PFAS family tree. *Adapted from a graphic provided courtesy of Paul Caprio, EA Engineering.* A stand-alone **PDF version of Figure 2-5** is available.

The family tree is further expanded in **Figure 2-5**, based on nomenclature provided in **Buck et al. (2011)**, Organization for Economic Co-operation and Development **OECD (2015)**, and **Wang et al. (2017)**, with further introduction to some of these chemicals provided later in this section. Future updates to the family tree and nomenclature are expected to be necessary given the evolving public knowledge of these compounds. For example, other PFAS without analytical standards are being identified using nontarget analyses by research laboratories (**Section 11**). These PFAS do not necessarily have associated CAS numbers but are being identified by molecular structure. Naming conventions and categories of PFAS are developed as a means to communicate, manage, and address this class of many chemicals, which can include alternate naming conventions and a variety of rationales for assigning categories.

2.2.2.1 Polymer PFAS

Polymers are large molecules formed by combining many identical smaller molecules (or monomers, which are shorter chain molecules with no repeating units) in a repeating pattern.

The PFAS polymer class includes fluoropolymers, polymeric perfluoropolyethers, and side-chain fluorinated polymers (**Henry et al. 2018**; **Buck et al. 2011**; **Wang et al. 2013**):

- Fluoropolymers contain a carbon-only polymer backbone with fluorines directly attached to the carbon. Fluoropolymers include polymers like PTFE, ETFE, copolymer FEP, and PFA, which were historically made using processing aids ammonium perfluorooctanoate (APFO) or sodium perfluorooctanoate (NaPFO), which are salts of perfluorooctanoic acid (PFOA). Fluoropolymers also include polyvinylidene fluoride (PVDF), which was historically made using ammonium perfluorononanoate (APFN), the ammonium salt of perfluorononanoic acid (PFNA) (**OECD 2015**; **Buck et al. 2011**).

- The specific fluoropolymers PTFE, FEP, ETFE, and PFA have been referred to as "polymers of low concern" in two studies. **Henry et al. (2018)** notes that these specific fluoropolymers have high molecular weight and are extremely stable and PTFE has been demonstrated not to be bioavailable (**Henry et al. 2018**). Polymers of low concern are reported to pose little environmental or health risk once in a consumer product, and based on this, **Henry et al. (2018)** suggested that "polymers of low concern" should be considered separately from other PFAS when evaluating risk. An additional study (**Korzeniowski et al. 2023**) describes the composition, uses, performance properties and functionalities of 14 fluoropolymers, including fluoroplastics and fluoroelastomers, and presents data to show that they satisfy the widely accepted polymer hazard assessment criteria to be considered polymers of low concern (PLC). Further, the study results show that fluoropolymers are a distinct and different group of PFAS and should not be grouped with other PFAS for hazard assessment or regulatory purposes.

- However, during the manufacture of some fluoropolymers, nonpolymer PFAS are used as processing aids and may be found as impurities in some fluoropolymer products (**3M Company 1999**; **CalEPA 2018**; see **Section 5.4.5**). For this reason, in order to prevent potential releases of nonpolymer PFAS processing aids (see APFO and NaPFO discussion above) and short-chain polymeric byproducts/impurities, such as unreacted monomers, environmental controls are necessary during the manufacturing and further processing of fluoropolymers. However, it should be noted that another study (**Lohmann et al. 2020**) found that there was insufficient evidence to consider fluoropolymers as being of low concern for environmental and human health and that group of fluoropolymers should not be given a blanket exemption from regulatory review. According to **Lohmann et al. (2020)**, the assessment and management of fluoropolymer products should consider the complete life cycle, including associated emissions during production and disposal.

- Polymeric perfluoropolyethers (PFPE) contain a carbon and oxygen polymer backbone with fluorines directly attached to carbon. Relatively little is known about these chemicals in the environment.

- Side-chain fluorinated polymers contain a nonfluorinated polymer backbone, off of which fluorinated side chains branch. These PFAS include fluorinated urethane polymers, fluorinated acrylate/methacrylate polymers, and fluorinated oxetane polymers. A few side-chain fluorinated polymers can become precursors for PFAAs, (**Section 2.2.3.1**) by transformation, when the point of connection of a fluorinated side chain on a polymer is broken to release a PFAA, or by release of fluorinated monomer residuals, or both.

2.2.2.2 Nonpolymer PFAS

Nonpolymer PFAS encompass two major subclasses: perfluoroalkyl substances and polyfluoroalkyl substances, which include many groups and subgroups of chemicals. **Figure 2-6** provides general classification and chemical structures, examples of each group and/or subgroup, and examples of the primary uses of some of the nonpolymer PFAS highlighted in **Figure 2-4** and **Figure 2-5**.

Nonpolymer PFAS were selected as the focus of this document because:

- they are included in most laboratory PFAS analyte lists (**Section 11**)

- they are the PFAS most commonly detected (to date) in humans, biota, and other environmental media and appear to be relatively more abundant at PFAS investigation sites (**Section 6**)

- data may be available regarding potential human health and ecological effects from environmental exposure for some of these chemicals (**Section 7**)

- state or federal standards or guidance values may exist or be under development for some of these chemicals (**Section 8**).

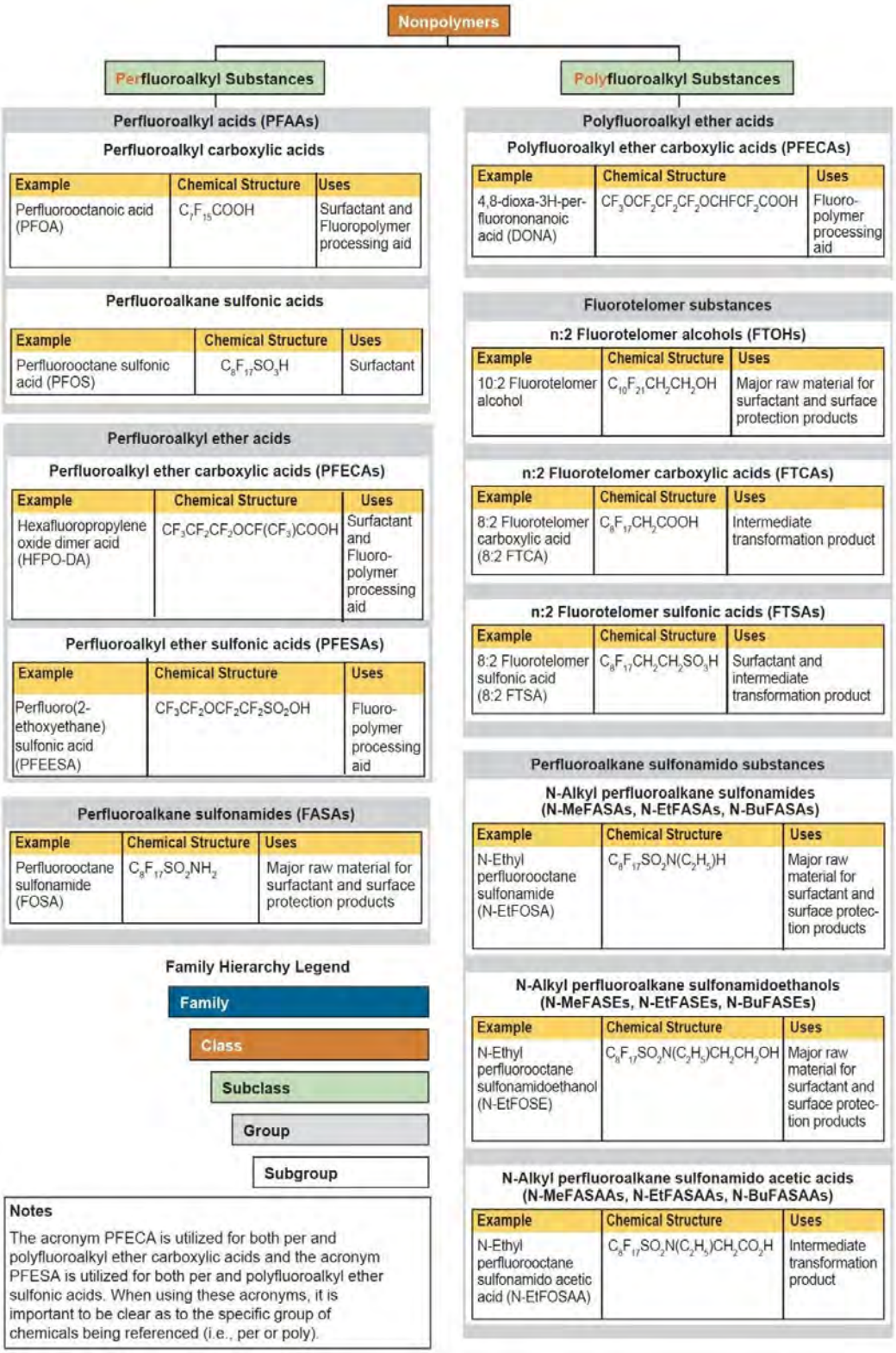


Figure 2-6. Examples of some nonpolymer PFAS subclasses discussed in this document.

*Source: Adapted with permission from Buck, R.C., J. Franklin, U. Berger, J. M. Conder, I. T. Cousins, P. de Voogt, A. A. Jensen, K. Kannan, S. A. Mabury, and S. P. van Leeuwenet. 2011. "Perfluoroalkyl and Polyfluoroalkyl Substances in the Environment: Terminology, Classification, and Origins." Integrated Environmental Assessment and Management, 7:513-541. Open access. Copyright 2011 SETAC. **http://dx.doi.org/10.1002/ieam.258**.*

2.2.3 Perfluoroalkyl Substances

Perfluoroalkyl substances are fully fluorinated alkane molecules that include (but are not limited to):

- perfluoroalkyl acids (PFAAs) and
- perfluoroalkane sulfonamides (FASAs).

The basic chemical structure is a chain (or *tail*) of two or more carbon atoms with a charged functional group (or *head*) attached at one end. The functional groups commonly are carboxylates or sulfonates, but other forms are also detected in the environment. Fluorine atoms are attached to all possible bonding sites along the carbon chain of the tail, except for one bonding site on the last carbon where the functional group head is attached. This structure, which is illustrated in **Figure 2-7** for PFOS and PFOA, can be written as:

$$C_nF_{2n+1}\text{-R}$$

where "C_nF_{2n+1}" defines the length of the perfluoroalkyl chain tail, "n" is >2, and "R" represents the attached functional group head. Note that the functional group may contain one or more carbon atoms, which are included in the total number of carbons when naming the compound.

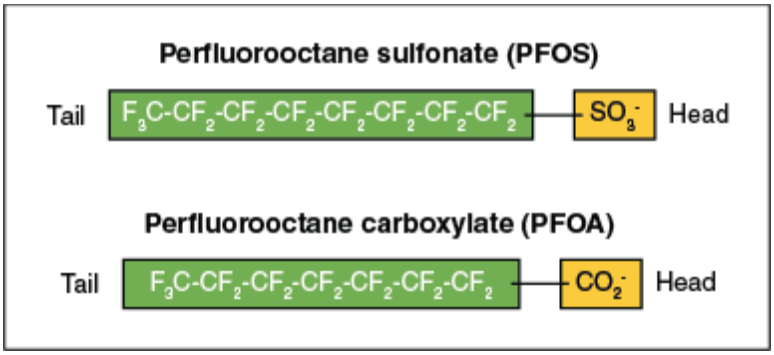


Figure 2-7. The tail and head structure of PFOS and PFOA molecules.

2.2.3.1 Perfluoroalkyl Acids (PFAAs)

PFAAs are some of the least complex PFAS molecules. They are essentially non-degradable under normal environmental conditions. Biotic and abiotic transformation of many polyfluoroalkyl substances may result in the formation of PFAAs. As a result, PFAAs are sometimes referred to as "terminal PFAS" or "terminal transformation products," meaning no further transformation products will form from them under environmental conditions. Polyfluoroalkyl substances that transform to create terminal PFAAs are referred to as "***precursors***." Longer chain PFAAs are not known to biotransform to shorter chain PFAAs.

The PFAA group is divided into two major subgroups (as shown in **Table 2-2** and **Figure 2-4**).

- ***Perfluoroalkyl carboxylic acids*** (PFCAs), or perfluoroalkyl carboxylates, are used commercially and can be formed as terminal transformation products of select precursor polyfluoroalkyl substances, such as fluorotelomer alcohols (FTOHs). An example PFCA is PFOA.
- ***Perfluoroalkane sulfonic acids*** (PFSAs), or perfluoroalkane sulfonates, also are used commercially and can be formed as terminal transformation products of select precursor polyfluoroalkyl substances, such as perfluoroalkane sulfonamido ethanols (FASEs). An example PFSA is PFOS.

Other subgroups of PFAAs are introduced below. Some of these are compounds that are receiving increasing attention, are being added to commercial laboratory target analyte lists, and are being detected in the environment. Other PFAAs include:

- perfluoroalkane sulfinic acids (PFSiAs), associated with the electrochemical fluorination (ECF) process and also occurring as intermediate environmental transformation products
- perfluoroalkyl phosphonic acids (PFPAs) and phosphinic acids (PFPiAs), associated with the fluorotelomerization process and used as surfactants

PFAAs are the group of PFAS that make up the majority of PFAS typically included in commercial laboratory target analyte lists and are the primary PFAS for which federal or state health-based guidance values have been established. As a result, PFAAs tend to drive site investigation and remediation decisions, so it is helpful to understand the naming conventions for this class. Many of the commonly detected PFAAs are denoted using the following structural shorthand acronym:

PFXY where:
PF = perfluoro
X = the carbon chain length (using the same naming conventions as hydrocarbons based on the number of carbons (for example, B for butane or 4 carbons, Pe for pentane or 5 carbons)
Y = the functional group (for example, A = carboxylate or carboxylic acid and S = sulfonate or sulfonic acid)

Table 2-2 illustrates how this naming structure works for the PFCAs and PFSAs, which collectively are referred to as PFAAs.

Table 2-2. Basic naming structure and shorthand for PFAAs.

X	Y	Acronym	Name	Formula	CAS No.[1]	DTXSID[2]
B = buta (4 carbon)	A = carboxylate or carboxylic acid	PFBA	Perfluorobutanoate[1]	$C_3F_7CO_2^-$	45048-62-2	80892480
			Perfluorobutanoic acid[1]	C_3F_7COOH	375-22-4	4059916
	S = Sulfonate or sulfonic acid	PFBS	Perfluorobutane sulfonate	$C_4F_9SO_3^-$	45187-15-3	60873015
			Perfluorobutane sulfonic acid	$C_4F_9SO_3H$	375-73-5	5030030
Pe = penta (5 carbon)	A = Carboxylate or carboxylic acid	PFPeA	Perfluoropentanoate	$C_4F_9CO_2^-$	45167-47-3	00892487
			Perfluoropentanoic acid	C_4F_9COOH	2706-90-3	6062599
	S = Sulfonate or sulfonic acid	PFPeS	Perfluoropentane sulfonate	$C_5F_{11}SO_3^-$	175905-36-9	70892479
			Perfluoropentane sulfonic acid	$C_5F_{11}SO_3H$	2706-91-4	8062600
Hx = hexa (6 carbon)	A = Carboxylate or carboxylic acid	PFHxA	Perfluorohexanoate	$C_5F_{11}CO_2^-$	92612-52-7	20892484
			Perfluorohexanoic acid	$C_5F_{11}COOH$	307-24-4	3031862
	S = Sulfonate or sulfonic acid	PFHxS	Perfluorohexane sulfonate	$C_6F_{13}SO_3^-$	108427-53-8	80873012
			Perfluorohexane sulfonic acid	$C_6F_{13}SO_3H$	355-46-4	7040150
Hp = hepta (7 carbon)	A = Carboxylate or carboxylic acid	PFHpA	Perfluoroheptanoate	$C_6F_{13}CO_2^-$	120885-29-2	60892483
			Perfluoroheptanoic acid	$C_6F_{13}COOH$	375-85-9	1037303
	S = Sulfonate or sulfonic acid	PFHpS	Perfluoroheptane sulfonate	$C_7F_{15}SO_3^-$	146689-46-5	8059920
			Perfluoroheptane sulfonic acid	$C_7F_{15}SO_3H$	375-92-8	20892505

X	Y	Acronym	Name	Formula	CAS No.[1]	DTXSID[2]
O = octa (8 carbon)	A = Carboxylate or carboxylic acid	PFOA	Perfluorooctanoate	$C_7F_{15}CO_2^-$	45285-51-6	40892486
			Perfluorooctanoic acid	$C_7F_{15}COOH$	335-67-1	8031865
	S = Sulfonate or sulfonic acid	PFOS	Perfluorooctane sulfonate	$C_8F_{17}SO_3^-$	45298-90-6	80108992
			Perfluorooctane sulfonic acid	$C_8F_{17}SO_3H$	1763-23-1	3031864
N = nona (9 carbon)	A = Carboxylate or carboxylic acid	PFNA	Perfluorononanoate	$C_8F_{17}CO_2^-$	72007-68-2	80892485
			Perfluorononanoic acid	$C_8F_{17}COOH$	375-95-1	8031863
	S = Sulfonate or sulfonic acid	PFNS	Perfluorononane sulfonate	$C_9F_{19}SO_3^-$	474511-07-4	60873010
			Perfluorononane sulfonic acid	$C_9F_{19}SO_3H$	68259-12-1	8071356
D = deca (10 carbon)	A = Carboxylate or carboxylic acid	PFDA	Perfluorodecanoate	$C_9F_{19}CO_2^-$	73829-36-4	40892481
			Perfluorodecanoic acid	$C_9F_{19}COOH$	335-76-2	3031860
	S = Sulfonate or sulfonic acid	PFDS	Perfluorodecane sulfonate	$C_{10}F_{21}SO_3^-$	126105-34-8	00873014
			Perfluorodecane sulfonic acid	$C_{10}F_{21}SO_3H$	335-77-3	3040148
Un = undeca (11 carbon)	A = Carboxylate or carboxylic acid	PFUnA or PFUnDA	Perfluoroundecanoate	$C_{10}F_{21}CO_2^-$	196859-54-8	30892475
			Perfluoroundecanoic acid	$C_{10}F_{21}COOH$	2058-94-8	8047553
	S = Sulfonate or sulfonic acid	PFUnS PFUnDS	Perfluoroundecane sulfonate	$C_{11}F_{23}SO_3^-$	441296-91-9	40904578
			Perfluoroundecane sulfonic acid	$C_{11}F_{23}SO_3H$	749786-16-1	40904573
DoD = dodeca (12 carbon)	A = Carboxylate or carboxylic acid	PFDoDA	Perfluorododecanoate	$C_{11}F_{23}CO_2^-$	171978-95-3	00892482
			Perfluorododecanoic acid	$C_{11}F_{23}COOH$	307-55-1	8031861
	S = Sulfonate or sulfonic acid	PFDoDS	Perfluorododecane sulfonate	$C_{12}F_{25}SO_3^-$	343629-43-6	00904574
			Perfluorododecane sulfonic acid	$C_{12}F_{25}SO_3H$	79780-39-5	20873011
TrD = trideca (13 carbon)	A = Carboxylate or carboxylic acid	PFTrDA	Perfluorotridecanoate	$C_{12}F_{25}CO_2^-$	862374-87-6	20892489
			Perfluorotridecanoic acid	$C_{12}F_{25}COOH$	72629-94-8	90868151
	S = Sulfonate or sulfonic acid	PFTrDS	Perfluorotridecane sulfonate	$C_{13}F_{27}SO_3^-$	NA	00904579
			Perfluorotridecane sulfonic acid	$C_{13}F_{27}SO_3H$	791563-89-8	20904576
TeD = tetradeca (14 carbon)	A = Carboxylate or carboxylic acid	PFTeDA	Perfluorotetradecanoate	$C_{13}F_{27}CO_2^-$	365971-87-5	60892488
			Perfluorotetradecanoic acid	$C_{13}F_{27}COOH$	376-06-7	3059921
	S = Sulfonate or sulfonic acid	PFTeDS	Perfluorotetradecane sulfonate	$C_{14}F_{29}SO_3^-$	343629-46-9	30904582
			Perfluorotetradecane sulfonic acid	$C_{14}F_{29}SO_3H$	1379460-39-5	80904577

NA = not available
[1]Older nomenclature may use butyrate or butyric acid.
[2] Link to DTXSID: **CompTox Chemicals Dashboard (epa.gov)** (helpful to use as a means of finding structural depictions and availability of other public data)

Note that for PFCAs, the total number of carbons used for naming the compound includes the carbon in the carboxylic acid functional group (COOH). For example, although PFOA has seven carbons in its

fluoroalkyl tail, all eight of the carbons in the molecule are used to name it, hence *perfluorooctanoate*. But in terms of chemical behavior, PFOA would be more analogous to seven-carbon perfluoroheptane sulfonate (PFHpS) than to eight-carbon perfluorooctane sulfonate (PFOS).

Table 2-2 shows the PFAA names and formulas in both the anionic (also referred to as "deprotonated" or negatively charged) and acid (also referred to as protonated or neutral) forms. The anionic form is the state in which PFAAs are found in the environment, except in very rare situations (for example, extremely low pH). The anionic and acid forms of PFAA names are often incorrectly used interchangeably (for example, perfluorooctane sulfonate and perfluorooctane sulfonic acid), and the same acronym (in this case, PFOS) applies to both forms. However, as discussed below and in **Section 4**, their physical and chemical properties are different, and it is important to know which form is being described.

Until recently, PFCAs and PFSAs have been the subgroups most commonly tested for in the environment; however, a wide range of PFAS with other functional groups exists for which the same "PFXY" shorthand shown above may or may not apply. For naming conventions for these compounds, please refer to **Buck et al. (2011)**.

Long-Chain Versus Short-Chain Distinction

PFAS, predominantly PFAAs, are sometimes described as *long-chain* and *short-chain* as a shorthand way to categorize PFCAs and PFSAs that may behave similarly in the environment; however, it is important not to generalize about PFAA behavior based only on chain length. As recent research suggests, other factors besides chain length may affect bioaccumulation potential of PFAS (**Ng and Hungerbühler 2014**).

According to the **OECD (2013)**:

- *Long-chain* refers to:
  - PFCAs with eight or more carbons (seven or more carbons are perfluorinated)
  - PFSAs with six or more carbons (six or more carbons are perfluorinated)
- *Short-chain* refers to:
  - PFCAs with seven or fewer carbons (six or fewer carbons are perfluorinated)
  - PFSAs with five or fewer carbons (five or fewer carbons are perfluorinated)

Table 2-3 illustrates the differences in the short-chain and long-chain PFCAs and PFSAs.

Table 2-3. Short-chain and long-chain PFCAs and PFSAs.

Number of Carbons	4	5	6	7	8	9	10	11	12
PFCAs	Short-chain PFCAs				Long-chain PFCAs				
	PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA
PFSAs	PFBS	PFPeS	PFHxS	PFHpS	PFOS	PFNS	PFDS	PFUnS	PFDoS
	Short-chain PFSAs		Long-chain PFSAs						

Anions Versus Acids

As noted above, the names for the anionic and acid forms of PFAAs are often used interchangeably, but it is critical to know which form is being discussed because of differences in their physical and chemical

properties and behavior in the environment (**Section 6**). Some important things to keep in mind regarding the anionic versus acid forms are:

- Most PFAAs are present in environmental and human matrices in their anionic form. For example, PFOS is present in the environment in the anionic form, perfluorooctane sulfonate.
- Although laboratories may be reporting PFOA or PFOS using the acid form of their name, they are actually measuring the anionic form (for example, perfluorooctanoate or perfluorooctane sulfonate), as this is the form that exists in the environment.
- The acid form and their associated cationic salts have CAS numbers, while the anionic forms may not (**Table 2-2**). For example, PFOS can exist as different salts (cationic), including sodium, lithium, potassium, or ammonium. Each of these salts will have a different CAS number:
    - PFOS, acid form CAS No.: 1763-23-1
    - PFOS, potassium salt CAS No.: 2795-39-3
    - PFOS, ammonium salt CAS No.: 29081-56-9
- When the salt or acid exists in water or other liquids, it will dissociate (lose its hydrogen or associated ion), and the salt or acid will break off and form the **anion** (for example, COO– or SO3–). **Figure 2-8** illustrates the dissociation of PFBA.

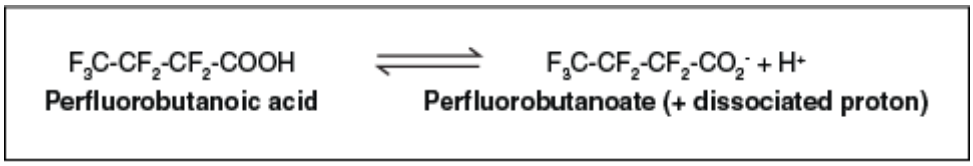


Figure 2-8. Dissociation of PFBA.

It is most important to distinguish between the acid form and anionic form when reporting the physical and chemical properties. The discussion of PFAS properties in this guidance document generally refers to the anionic form; it will be specifically called out if the acid form is being discussed.

A Note About PFAS Naming in Laboratory Reports (see Section 11)

*Even though PFAAs occur as anions in the environment, some laboratories report all of their results in the acidic form, while others may report PFCAs as acids (for example, **perfluorooctanoic acid**) and PFSAs as anions (for example, **perfluorooctane sulfonate**). Different naming conventions in laboratory reports have led to confusion regarding exactly which form of the PFAA the labs are measuring. Although the lab is measuring the concentration of PFAA anions present in the sample, where the results are reported as an acid, the lab has adjusted for the H+ cation (which has so little mass, this does not affect the resulting concentration). It should be noted that the standards used by laboratories to perform analyses may be prepared from PFAA salts, as is often the case for sulfonate standards. If so, the lab must adjust the reported concentration to account for the mass of the counterion (typically Na+ or K+). The calculation to do this is described in section 7.2.3 of EPA Method 537 (USEPA 2009) and section 15.2 of EPA Method 1622 (USEPA 2024).*

2.2.3.2 Perfluoroalkane Sulfonamides (FASAs)

FASAs, such as perfluorooctane sulfonamide (FOSA), are products and/or intermediates from the ECF process for surfactants and surface protection products. FASAs can transform to form PFAAs such as PFOS.

2.2.3.3 Other Perfluoroalkyl Substances

Other perfluoroalkyl substances shown on **Figure 2-4** and **Figure 2-5** include:

- perfluoroalkane sulfonyl fluorides [PASFs, such as perfluorooctane sulfonyl fluoride (POSF) and perfluorobutane sulfonyl fluoride (PBSF)], and perfluoroalkanoyl fluorides (PAFs), associated with the ECF process
- perfluoroalkyl iodides (PFAIs) and perfluoroalkyl aldehydes (PFALs), associated with the fluorotelomerization process
- perfluoroalkyl ether acids, including perfluoroalkyl ether carboxylic acids (PFECAs) and perfluoroalkyl ether sulfonic acids (PFESAs)

As discussed in **Section 2.4**, some PFECAs have been developed or used as replacements for other PFAS that are phased out of production and use. This includes GenX chemicals (see **text box**). Other emerging fluorinated replacement PFECAs more recently detected in the environment, such as perfluoro-2-methoxyacetic acid (PFMOAA), are described in **Sun et al. (2016)**.

GenX Chemicals

A PFECA, commonly referred to by the trade name "GenX," has been used by one manufacturer as a replacement for APFO (PFOA) as a surfactant and polymerization aid in the production of their PTFE product. GenX actually refers to the GenX processing aid technology, while the major chemicals used include:

- hexafluoropropylene oxide (HFPO) dimer acid (HFPO-DA, CAS No. 13252-13-6, also known as 2,3,3,3-tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)propanoic
- its ammonium salt (ammonium, 2,3,3,3- t [$CF_3CF_2CF_2OCF(CF_3)COO^-NH_4^+$, CAS No. 62037-80-3, als

(Wang et al. 2013; Buck 2015; USEPA 2018).

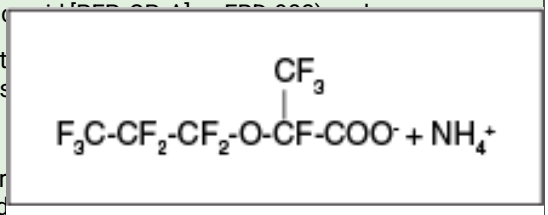


Figure 2-1. Example replacement chemistry structure for GenX Ammonium Salt.

Prior to their use in PTFE production, GenX chemicals were pr processes (NC DEQ 2018). From the GenX Toxicity Assessment d manufacture other HFPO-DA derivatives, fluoropolymers a agrochemical, semiconductor, and pharmaceutical applications. can be formed from reaction of HFPO-DA.

Further discussion of the GenX chemicals is provided in Section 2.4.6. The chemical structure of the ammonium salt is shown in Figure 2-9.

In addition to linear and branched structures, certain cyclic structures have much in common with the noncyclic PFAS and are consistent with the definitions/descriptions provided above. As an example, **Figure 2-10** illustrates the structure of perfluoro-4-ethylcyclohexanesulfonate, also perfluoro-p-ethylcyclohexylsulfonic acid (PFECHS), which some classify as a PFAS (**MPART 2020**). It is used in airplane hydraulic fluids and has been found both in the environment (**Kaboré et al. 2018**; **Howard and Muir 2010**; **De Silva et al. 2011**; **Lescord et al. 2015**; **Houde et al. 2016**) and in human blood (**Miaz et al. 2020**). The characteristics of PFECHS include:

- fully fluorinated six-carbon ring
- nonaromatic
- sulfonate active group
- perfluorinated two-carbon tail

PFECHS fits the **Buck et al. (2011)** description by having a fully fluorinated aliphatic tail of one or more carbon atoms attached to a charged functional group head. **Section 1.1.3.2** includes more information about cyclic PFAS.

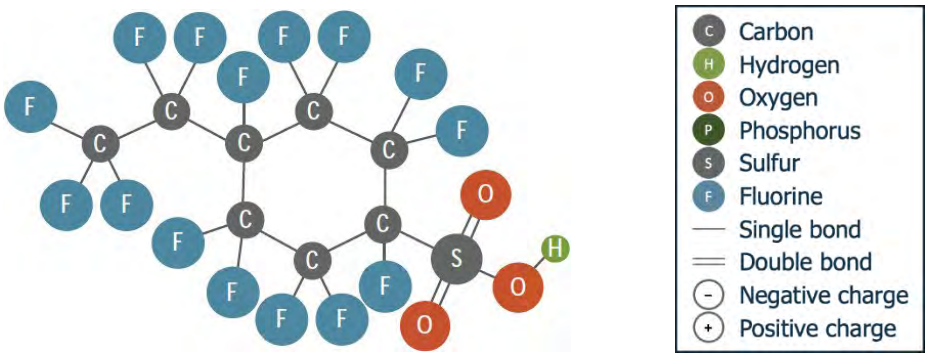
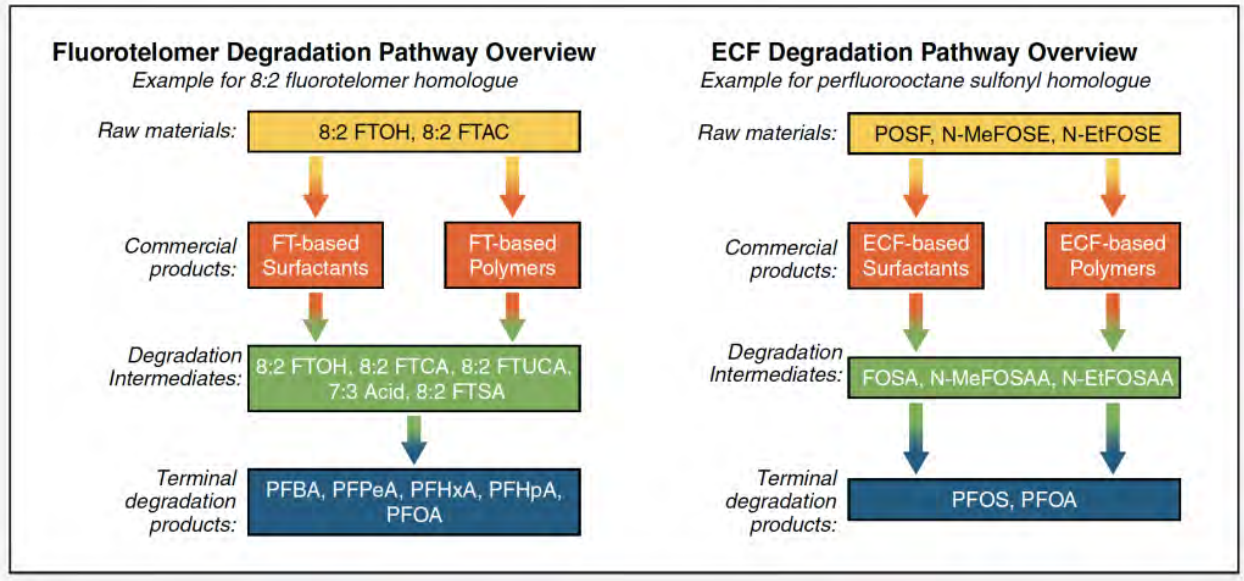


Figure 2-10. Illustration of perfluoro-p-ethylcyclohexyl sulfonic acid structure (see legend right of figure).

2.2.4 Polyfluoroalkyl Substances

Polyfluoroalkyl substances including some side-chain fluorinated polymers are increasingly being identified as important to understanding the occurrence, fate, and transport of PFAS at release sites and in the environment (**OECD 2013**; **Butt, Muir, and Mabury 2014**; **Liu and Mejia-Avendaño 2013**; **Wang et al. 2011**; **Mejia-Avendaño et al. 2020**). **Figure 2-4** and **Figure 2-5** highlight the groups of polyfluoroalkyl substances that, to date, have most commonly been detected at PFAS sites (see **Barzen-Hanson et al. 2017**; **OECD 2018**). Of the approximately 4,700 PFAS identified in the OECD (**2018**) study, about 90% were potential precursors to PFAAs.



(Note that transformation of POSF-based products is for the terrestrial environment, but transformation into lower homologues of PFCAs and PFSAs in the atmosphere is also possible, see references in the paragraph above.)

Figure 2-11. Example polyfluoroalkyl substance transformation pathways.

Polyfluoroalkyl substances are distinguished from perfluoroalkyl substances by not being fully fluorinated. Instead, they are aliphatic substances for which all hydrogen atoms attached to at least one (but not all) carbon atoms have been replaced by fluorine atoms, in such a manner that they contain the perfluoroalkyl moiety CnF2n+1 (**Buck et al. 2011**), see **Figure 2-6**.

The carbon-hydrogen (or other nonfluorinated) bond in polyfluoroalkyl molecules creates a "weak" point in the carbon chain that may be susceptible to biotic or abiotic transformation. As a result, many polyfluoroalkyl substances that contain a perfluoroalkyl CnF2n+1 moiety are potential precursor compounds that have the potential to be transformed into PFAAs.

Figure 2-11 provides examples of transformation pathways for environmentally relevant polyfluoroalkyl precursors derived from two PFAS production methods, fluorotelomerization and ECF, respectively (**Buck et al. 2011**; **Liu and Mejia-Avendaño 2013**; **Butt, Muir, and Mabury 2014**; **Martin et al. 2006**). Note that these figures include some PFAS not discussed in this guidance document, but described in **Buck et al. (2011)**. Refer to **Section 5.4** and **Section 1.3.3** for further information on transformation processes, noting that not all transformation products will be formed through every environmental transformation process.

2.2.4.1 Fluorotelomer Substances

Fluorotelomer substances are polyfluoroalkyl substances produced by the fluorotelomerization process. As shown in **Figure 2-11**, the transformation of fluorotelomer-based substances is a potential source of PFCAs in the environment, but not PFSAs (**Buck et al. 2011**).

Fluorotelomer-based polyfluoroalkyl substances are named using an "n:x" prefix where "n" indicates the number of fully fluorinated carbon atoms (n > 2) and "x" indicates the number of carbon atoms that are not fully fluorinated (x > 1). An example of a polyfluoroalkyl substance is shown in Figure 2-12, which also illustrates the "n:x" naming convention.

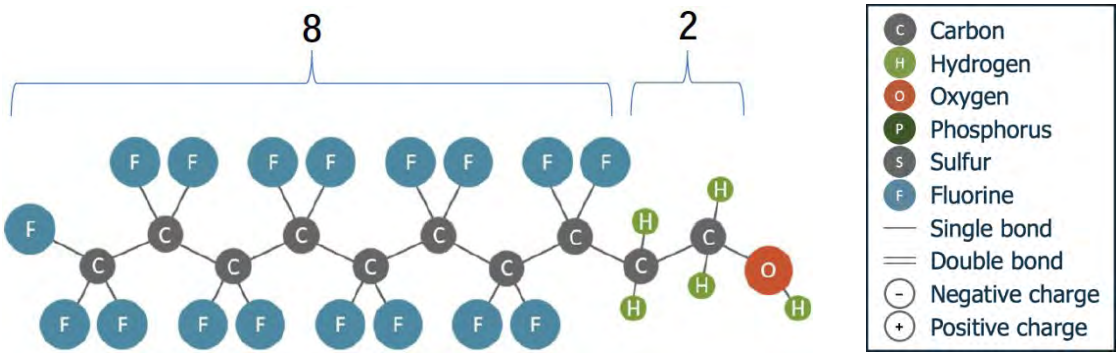


Figure 2-12. Example of a polyfluoroalkyl substance (see legend right of figure).

Some of the fluorotelomer substances most commonly detected in the environment to date are as follows (**Section 6**):

- *Fluorotelomer alcohols* (FTOH): The n:2 fluorotelomer alcohols (n:2 FTOHs) are key raw materials in the production of n:2 fluorotelomer acrylates and n:2 fluorotelomer methacrylates (**Buck et al. 2011**).

- *Fluorotelomer sulfonic acids* (FTS): The n:2 fluorotelomer sulfonic acids (n:2 FTSs) have been detected in environmental matrices at sites where aqueous film-forming foam (AFFF) has been used, and also in wastewater treatment plant effluents and landfill leachate. FTSs are precursor compounds and can undergo aerobic biotransformation to form PFCAs (**Buck et al. 2011**).

- *Fluorotelomer carboxylic acids* (FTCA): These compounds form through the biotransformation of FTOHs (**Figure 2-11**; (**Buck et al. 2011**; **Mejia-Avendaño et al. 2016**) and have been detected in landfill leachate. Note that the –COOH functional group on these fluorotelomer compounds

means they may have either an even or odd number of carbons, so they may have n:2 or n:3 prefixes.

Other fluorotelomer (FT) substances are shown in **Figure 2-5** and **Figure 2-6**.

2.2.4.2 Perfluoroalkane Sulfonamido Substances

The subgroups of perfluoroalkane sulfonamido substances shown in **Figure 2-5** and discussed below have been detected in the environment and humans (**Buck et al. 2011**). Perfluoroalkane refers to the fully fluorinated carbon chain tail, but these compounds also contain one or more CH2 groups in the head of the molecule attached to the sulfonamido spacer (**Figure 2-13**). They are either used as raw materials for surfactant and surface treatment products, or they are present as intermediate transformation products of these raw materials. As shown in the transformation pathways in **Figure 2-11**, some perfluoroalkane sulfonamido substances have been found to transform to PFOS (**Mejia-Avendaño and Liu 2015**). Environmentally relevant perfluoroalkane sulfonamido substances include:

- *N-Alkyl perfluoroalkane sulfonamides* (N-alkyl FASAs) are raw materials used for surfactant and surface treatment products that include N-methyl perfluorooctane sulfonamide (N-MeFOSA) and N-ethyl perfluorooctane sulfonamide (N-EtFOSA) (**Buck et al. 2011**)

- *Perfluoroalkane sulfonamido ethanols* (FASEs) and *N-alkyl perfluoroalkane sulfonamido ethanols* (N-MeFASEs, N-EtFASEs, N-BuFASEs) are raw materials for surfactant and surface treatment products (**Buck et al. 2011**). **Figure 2-13** illustrates the structure of N-EtFOSE

- *Perfluoroalkane sulfonamido acetic acids* (FASAAs) and *N-alkyl perfluoroalkane sulfonamido acetic acids* (N-MeFASAAs, N-EtFASAAs, N-BuFASAAs) are intermediate transformation products of FASEs, N-MeFASEs, N-EtFASEs, and N-BuFASEs (**Figure 2-11**) (**Buck et al. 2011**)

- *N-alkyl perfluoroalkane sulfonamidoethyl acrylates/methacrylates* (N-MeFAS(M)ACs, N-EtFAS(M)ACs, N-BuFAS(M)ACs)

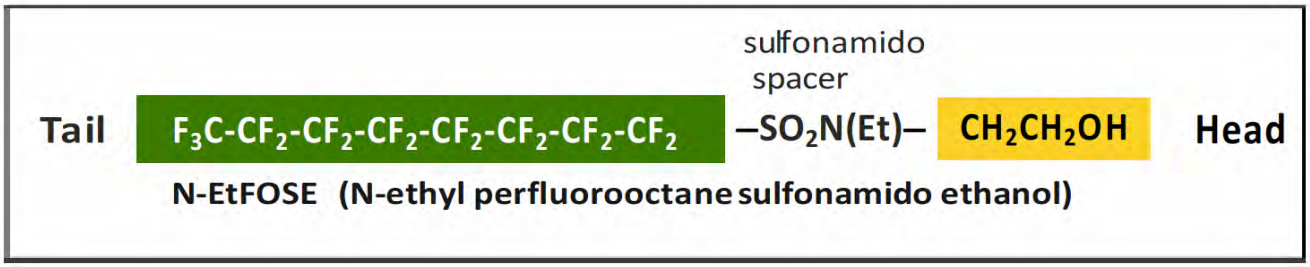


Figure 2-13. Example of a perfluoroalkane sulfonamido ethanol (FASE).

2.2.4.3 Other Polyfluoroalkyl Substances

Other polyfluoroalkyl substances shown in **Figure 2-5** include:

- polyfluoroalkyl ether acids, including polyfluoroalkyl ether sulfonic acids (PFESAs) and polyfluoroalkyl ether carboxylic acids (PFECAs)

- chloropolyfluoroalkyl ether acids
- chloropolyfluoroalkyl acids

As discussed in **Section 2.4.6**, some PFAS have been developed or used as replacements for other PFAS that are phased out of use and production.

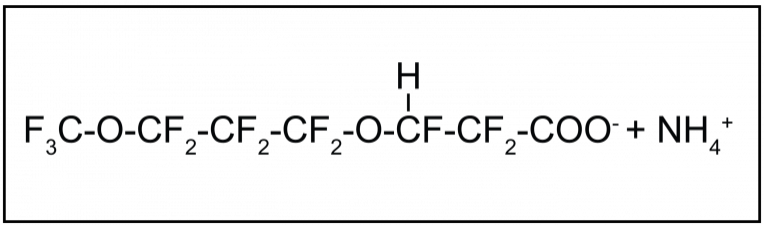


Figure 2-2. Chemical structure for ADONA ammonium salt.

One replacement compound for the use of PFOA as a polymerization aid in the production of PTFE is a polyfluoroalkyl ether carboxylic acid: ammonium 4,8-dioxa-3H-perfluorononanoate (CF3OCF2CF2CF2-OCHFCF2COO–NH4+ (CAS No. 958445-44-8), commonly referred to by the trade name ADONA (**Gordon 2011**). The chemical structure is shown in **Figure 2-14**.

Other replacement polymerization compounds for the manufacture of PTFE and polyvinylidene fluoride (PVDF) include polyfluoroalkyl ether acids, also referred to as cyclic or polymeric functionalized perfluoropolyethers (PFPEs) (**Wang et al. 2013**). A sample chemical structure of a chloropolyfluoroalkyl ether acid is shown in **Figure 2-15**.

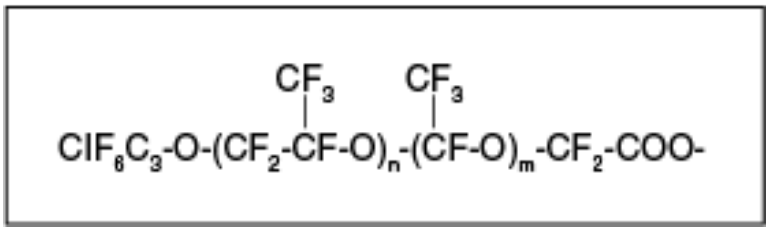


Figure 2-3. Sample chemical structure for a chloropolyfluoroalkyl ether acid.

2.2.5 Chemical Manufacturing

To differentiate among PFAS in understanding a conceptual site model for environmental risk assessment, it is important to know about the chemical manufacturing processes. The various manufacturing processes produce different types of PFAS, such as linear and branched isomers (as discussed in this section), which may affect the environmental fate, treatment, toxicology, and site forensics for these chemicals. The type of PFAS that might be formed by the transformation of precursor PFAS at or related to an environmental release site also may depend on the manufacturing process (refer to the family tree in **Figure 2-5**).

2.2.5.1 Processes

Two major processes, *electrochemical fluorination (ECF)* and *fluorotelomerization*, have been (and are) used to manufacture PFAS that contain perfluoroalkyl chains: side-chain fluorinated polymers, PFAAs and polyfluoroalkyl surfactants (**USEPA 2003**; **Benskin, DeSilva, and Martin 2010**; **KEMI 2015**; **OECD 2018**). The fluorotelomerization process may also be characterized as "oligomerization," as it involves, for example, using tetrafluoroethylene (TFE) monomer and adding one to nine TFE monomers to form a perfluoroalkyl chain (**Kissa 2001**; **Rao and Baker 1994**). ECF and fluorotelomerization can be used to create some of the same PFAS, as shown on **Figure 2-5**. PFSAs are produced only using the ECF process, whereas PFCAs can be produced by both ECF and fluorotelomerization (**USEPA 2003**; **CONCAWE 2016**).

More than 600 intermediate processes have been used to further produce certain PFAS and the associated final products. Further discussion of the intermediate processes may be found in the general scientific literature and numerous textbooks specifically written about fluorinated organics and fluoropolymers (**Banks, Smart, and Tatlow 1994**).

Electrochemical Fluorination (ECF)

The Simons ECF process was licensed by 3M in 1945; 3M subsequently built an ECF pilot in 1949 and started commercial production in 1951 (**3M Company 1999**) In the ECF process, an electric current is passed through a solution of an organic feedstock and liquid anhydrous hydrogen fluoride, which causes the hydrogen atoms to be replaced by fluorine atoms, thereby creating carbon-fluorine bonds (**3M Company 1999**; **USEPA 2003**; **Buck et al. 2011**). ECF is used to create perfluoroalkane sulfonyl fluorides (PASFs), which are the building blocks for other sulfonyl-based PFAS, as well as perfluoroalkyl carboxylate derivatives. These ECF-synthesized PFAS can contain a variable mixture of linear and branched perfluorinated isomers, as well as other homologues, byproducts, and impurities (**USEPA 2003**; **Buck et al. 2011**). The variable composition is caused by the process conditions, raw materials, and equipment used by the ECF process (**3M Company 1999**; **CONCAWE 2016**). Subsequent processes (for example, hydrolysis, base neutralization) are then used to refine the compounds (**USEPA 2003**).

Historically, the ECF process was primarily used to produce POSF which was then used to make PFOS-based materials. PFOS is often a terminal transformation product of POSF-based compounds. ECF was also used to produce perfluorooctane carbonyl fluoride which was then used to produce PFOA and other derivatives (for example, using perfluorooctane carbonyl fluoride to produce PFOA and its salts, such as APFO). As part of the phaseout of production of select long-chain PFAS in the United States, 3M has ceased using ECF to make certain long-chain PFAS, such as POSF-based compounds (PFOS and PFHxS) and PFOA (**Buck et al. 2011**; **Section 2.4.1**). 3M's phaseout did not include other, shorter chain PFAS-based products, such as those based on PBSF (**3M Company 2018**).

Fluorotelomerization

A typical fluorotelomerization process involves the reaction of perfluoroethyl iodide (PFEI, CF_3CF_2-I) with tetrafluoroethylene (TFE, CF_2=CF_2) to yield a mixture of even-numbered carbon linear perfluoroalkyl iodides (C_nF_{2n+1}-I, n= 4, 6, 8, 10, etc.), commonly known as "Telomer A." Telomer A is then reacted with ethylene to make "Telomer B" (fluorotelomer iodide, $C_nF_{2n+1}CH_2CH_2$-I, n= 4, 6, 8, 10, etc.). Telomer B is reacted to make fluorotelomer alcohols (FTOHs, $C_nF_{2n+1}CH_2CH_2$-OH, n= 4, 6, 8,10, etc.) Telomer A, Telomer B, and FTOHs are the basic raw materials used to manufacture fluorotelomer-based surfactant (nonpolymer) and polymer products (**Kissa 2001**; **Rao and Baker 1994**).

As part of the USEPA 2010/2015 Stewardship Program (**USEPA 2018**; **Section 2.4.3**), eight major global fluoropolymer and fluorotelomer manufacturers phased out production of long-chain fluorotelomer-based products that were potential precursors to PFOA and other long-chain perfluoroalkyl carboxylic acids (PFCAs). Today, the major global fluorotelomer manufacturers are reported to have refined their processes and predominantly manufacture short-chain (C6) fluorotelomer-based products (**American Chemistry Council 2021**). Some manufacturers outside of the United States (for example, China, India) have not phased out long-chain PFAS production (**Song et al. 2018**).

Fluorotelomerization has been primarily used to produce linear (straight-chain) PFAS isomers with an even number of carbon atoms (**Buck et al. 2011**), although some sources indicate that the process can also produce compounds with an odd number of carbons and branched chains (**Lindstrom, Strynar, and Libelo 2011**; **Danish EPA 2015**).

2.2.5.2 Linear and Branched Isomers of PFAS

Many PFAS may be present as mixtures of linear and branched isomers (**Figure 2-16**) depending on the manufacturing process that was used. These structural differences are important because they may

affect how the compounds behave in the environment and may provide an indicator of their source. Structural differences are described below:

- A *linear isomer* is composed of carbon atoms bonded to only one or two carbons, which form a straight carbon backbone. There can be only one linear isomer in a Cn homologue (compounds with the same number of carbons in their tail) series.

- In a *branched isomer*, at least one carbon atom is bonded to more than two carbon atoms, which forms a branching of the carbon backbone. There can be many isomers per Cn homologue series.

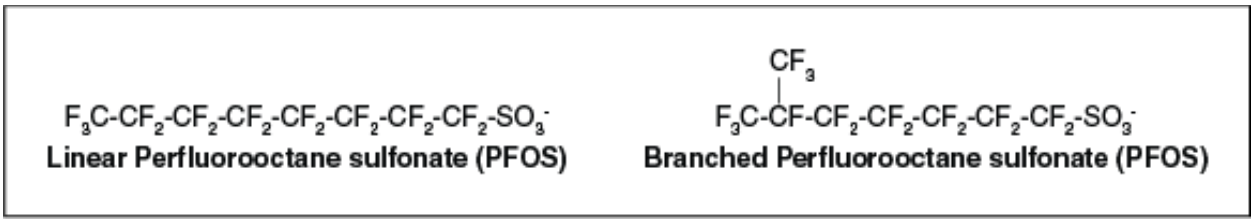


Figure 2-16. Linear and one branched isomer of PFOS.

For simplicity, both linear and branched isomers are abbreviated using the same acronym in this document. Note that other nomenclature conventions further identify PFAS by labeling linear isomers (for example, n-PFOS) and branched isomers based on the location of the branch in the carbon chain (for example, 5m-PFOS) (**Benskin, DeSilva, and Martin 2010**).

The formula "C_nF_{2n+1}-" (where n is greater than or equal to 3) includes linear and branched isomers. For example, PFOS and PFHxS are routinely present in environmental samples as a mixture of linear and branched isomers (**Beesoon et al. 2011**; **Beesoon et al. 2012**; **Benskin, DeSilva, and Martin 2010**).

Table 2-4. Manufacturing processes and potential PFAAs produced.

Manufacturing Process	Commonly Found Polyfluorinated Substance (Precursors)	Potential PFAAs Produced
Fluorotelomerization	FTS[1]	Linear PFCAs[3]
	FTCA[2]	Linear PFCAs[3]
	FTOH	Linear PFCAs[3]
Electrochemical fluorination	FASE	Branched and linear PFCAs Branched and linear PFSAs
	FASAA	Branched and linear PFCAs Branched and linear PFSAs

[1]Fluorotelomer sulfonic acid: for example, may be found at AFFF sites
[2]Fluorotelomer carboxylic acids: for example, 5:3 FTCA may be found in landfill leachate
[3]Under certain instances, can produce mixture of linear and branched PFCAs

Accurate quantification of PFAS that are mixtures of linear isomers and branched isomers in environmental matrices can be difficult (**Riddell et al. 2009**). However, the relative contributions of isomers may be useful in understanding sources of PFAS and the age of the source, because the production of isomers varies by manufacturing processes. For example, as discussed above, the fluorotelomerization process has been primarily used to produce mostly linear PFAAs, whereas the ECF process produces a mixture of linear and branched PFAA isomers (**Table 2-4**). Refer to **Section 10.5** for

more information on PFAS source identification. The presence of linear and branched isomers may also have implications for partitioning, transport, and bioaccumulation (**Section 10.5.1.1**).

2.3 Emerging Health and Environmental Concerns

Like other emerging contaminants, knowledge and concern about PFAS in the environment have evolved through a series of phases discussed in this section:

- discovery and/or synthesis of PFAS (**Section 2.2.5**), followed by growth in commercial production and use (**Section 2.5**)
- emerging health and environmental concerns, including:
  - awareness of potential health impacts (**Section 2.3.1**)
  - analytical developments (**Section 2.3.2**)
  - detection in the environment (**Section 2.3.3**)
  - growing awareness and concern (**Section 2.3.4**)
- subsequent efforts to reduce use of contaminants of concern and/or replace the contaminants of concern with alternate technologies and chemicals, accompanied by health and environmental questions about those chemicals (**Section 2.4**)

2.3.1 Awareness of Potential Health Impacts

Occupational studies in the 1970s found detections of some PFAS in the blood of exposed workers, and further studies in the 1990s reported detections in the blood of the general human population (**Buck et al. 2011**). In recent years, the presence of several long-chain PFAAs (PFOA, PFOS, PFNA, and PFHxS) have been measured in the low parts per billion (ppb, equivalent to nanograms per milliliter (ng/ml)) range in the blood serum of almost all residents of the United States and other industrialized nations (**Kato and Calafat 2015**; **CDC 2022**). These PFAS are present whether or not people were exposed in the workplace, likely due to the widespread use of PFAS in consumer products and industries (**Kannan et al. 2004**; **Kärrman et al. 2006**; **Olsen et al. 2003**). However, there have been decreasing concentrations of long-chain PFAAs in people's blood serum, likely due to the voluntary reductions in production, especially PFOA and PFOS; refer to the CDC data presented in **Figure 2-17**. Further information and discussion of studies and human health effects can be found in **Section 7.1**.

Unit	Mass per liter (L)	Mass per milliliter (mL)
1 part per million (ppm)	1 mg/L	1 µg/mL
1 part per billion (ppb)	1 µg/L	1 ng/mL
1 part per trillion (ppt)	1 ng/L	1 pg/mL

Notes: mg = milligrams, µg = micrograms, ng = nanograms, pg = picograms
1 ppm = 1,000 ppb = 1,000,000 ppt

These findings led to increased awareness of PFAAs in the environment, associated human exposure, and the potential for health effects. Occupational workers may be more highly exposed, and at risk, than other populations (**ATSDR 2018**). Laboratory studies using animals and epidemiological studies of human populations show that exposure to some PFAS may be associated with a wide range of adverse human health effects (**USEPA 2016**; **USEPA 2016**; **ASTDR 2021**). Toxicity studies have mostly focused on PFOS and PFOA, as well as some other long-chain PFAAs (**Section 7.1**). More recently, the toxicology of other PFAS, such as fluorotelomers and shorter chain PFAAs, as well as replacement PFAS chemicals (such as GenX chemicals, **Section 2.4.6**), have received increased attention (**CONCAWE 2016**; **USEPA 2016**; **USEPA 2021**).

ATSDR is undertaking a national, multi-site PFAS health study to evaluate the health impacts of PFAS in drinking water (**ATSDR 2020**). The study was authorized by the National Defense Authorization Acts of 2018 and 2019. According to ATSDR, "The information learned from the multi-site study will help all communities in the U.S. with PFAS exposures, including those that were not part of the study." The multi-site health study builds on the Pease Health Study at former Pease Air Force Base in Newington, NH, which effectively serves as a pilot program. The health study is intended to provide a better understanding of the cause and effect relationship between PFAS at various concentration and specific health outcomes based on adults and children. The study is expected to improve upon epidemiological studies with limited information about exposure factors.

In addition to the PFAS health study, ATSDR conducted PFAS Exposure Assessments at 10 locations in the United States. The 10 locations selected had PFOA and PFOS in the public drinking water that had previously exceeded the EPA 2016 health advisory level of 70 ng/L and/or other state guidelines. Through the Exposure Assessments, ATSDR was able to estimate exposures to PFAS in these communities and compare those exposure estimates to measured levels in blood collected from participants. Results of these Exposure Assessments are published in ATSDR's Final Report (**ATSDR 2022**).

The Centers for Disease Control (CDC) has been including biomonitoring for specific PFAS in blood serum in its National Health and Nutrition Examination Survey (NHANES) surveys of the U.S. general population since 1999-2000, and the latest NHANES PFAS data are from 2017-18 (**CDC 2022**). Blood serum levels of some PFAS in NHANES monitoring have decreased over time, as shown in **Figure 2-17**.

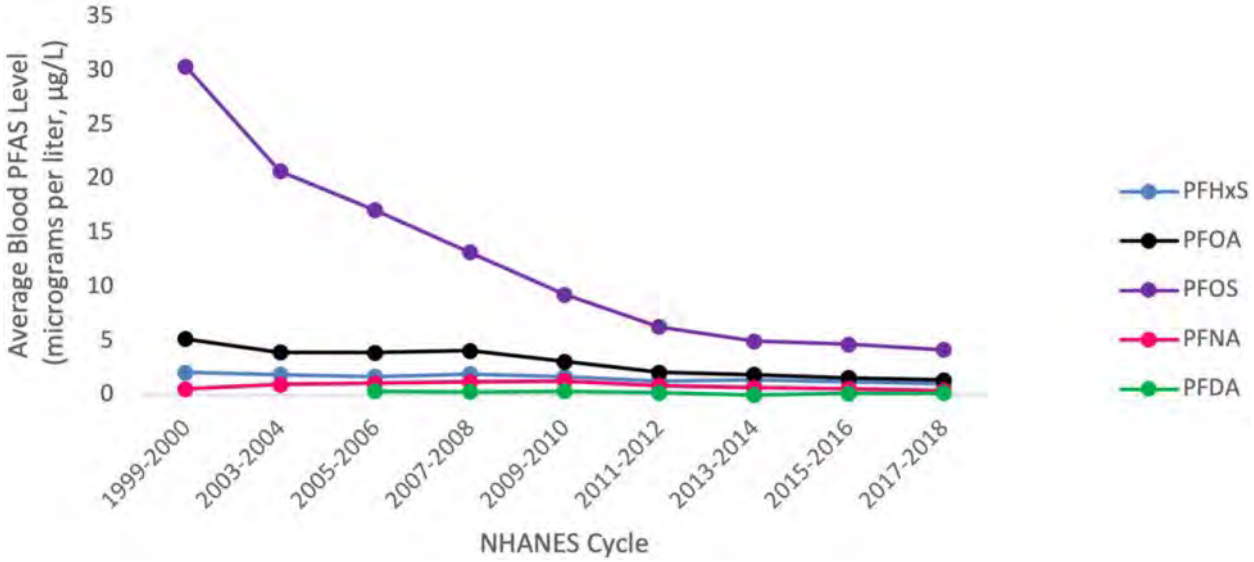


Figure 2-17. Blood Serum Levels of Specific PFAS Frequently Detected in the U.S. General Population (NHANES) Over Time (data from CDC 2022).

2.3.2 Analytical Developments

Early detection of PFAS in environmental media was hindered by the analytical capability challenges arising from the unique surface-active properties of PFAS (**Giesy and Kannan 2001**; **3M Company 2000**). Since the 2000s, methods have been, and continue to be, developed with lower detection limits (for example, parts per trillion [ppt]) in water, that are commensurate with levels of potential human health effects. The number of commercial laboratories that offer PFAS analysis is increasing. Analytical methods continue to be developed and improved to test a variety of media and additional PFAS; these continue to improve our knowledge of PFAS in the environment and potential human health effects.

Since the early 2000s, three analytical methods have been developed, validated, and published by USEPA for the analysis of PFAS in drinking water. These include Methods 537, 537.1, and 533 (**USEPA 2020**). These methods were developed for finished drinking water from groundwater and surface water sources. According to USEPA, these methods were developed for accuracy, precision, and robustness and have been through multi-lab validation and peer review (see **Section 11**). USEPA notes that Method 537 was used extensively during Unregulated Contaminant Monitoring Rule 3, described below. In December 2019, USEPA published Method 533: Determination of Per- and Polyfluoroalkyl Substances in Drinking Water by Isotope Dilution Anion Exchange Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (**USEPA 2019**). While each method includes analytes not included in the other, the analytes targeted by Method 533 include shorter-chain PFAS and fluorotelomers (see **Section 11.2.1.1**). Methods 537.1 and 533 have both been validated for the analysis of HFPO-DA (a component of the GenX processing aid technology). The PFAS analytes associated with Methods 537.1 and 533 are listed in Table 2-5 (**separate PDF**) and categorized according to the family tree hierarchy. The USEPA has also published USEPA Method 1633 that tests for up to 40 PFAS in eight environmental media (**USEPA 2024**). For further information on USEPA analytical methods, refer to **Section 11**.

The number of PFAS that can be identified and quantified by analysis has also evolved over time, with longer lists of compounds and changing commercial availability linked to evolving health and environmental concerns. Early focus was on PFOA and PFOS, but nationwide testing of drinking water supplies under the USEPA's Third Unregulated Contaminant Monitoring Rule (UCMR3) led to four additional PFAAs (PFHpA, PFNA, PFBS, PFHxS) gaining greater attention. More information about UCMR3 is provided in **Section 6.3**, and a summary of the occurrence data for the six PFAAs analyzed during UCMR3 is provided in **Section 8.2**. UCMR5 is occurring in 2023–2025 and includes 29 PFAS using USEPA Methods 533 and 537.1. UCMR5 includes all large systems serving over 10,000 people, all small systems serving 3,300 to 10,000 people, and 800 randomly selected small systems serving less than 3,300 people (**USEPA 2021**).

Many state regulatory agencies now request or require testing for an expanded list of long- and short-chain PFAAs, and some potential precursors to PFAAs, such as fluorotelomers. Other polyfluoroalkyl substances are also receiving increased attention, as illustrated in **Figure 2-18**. Many of these PFAS are also summarized in **Figure 2-6**.

Other analytical methods and approaches are available to detect and quantify PFAS not included in the standard methods mentioned above, including nontarget analysis, total organic fluorine, and total oxidizable precursor assay (see **Section 11**).

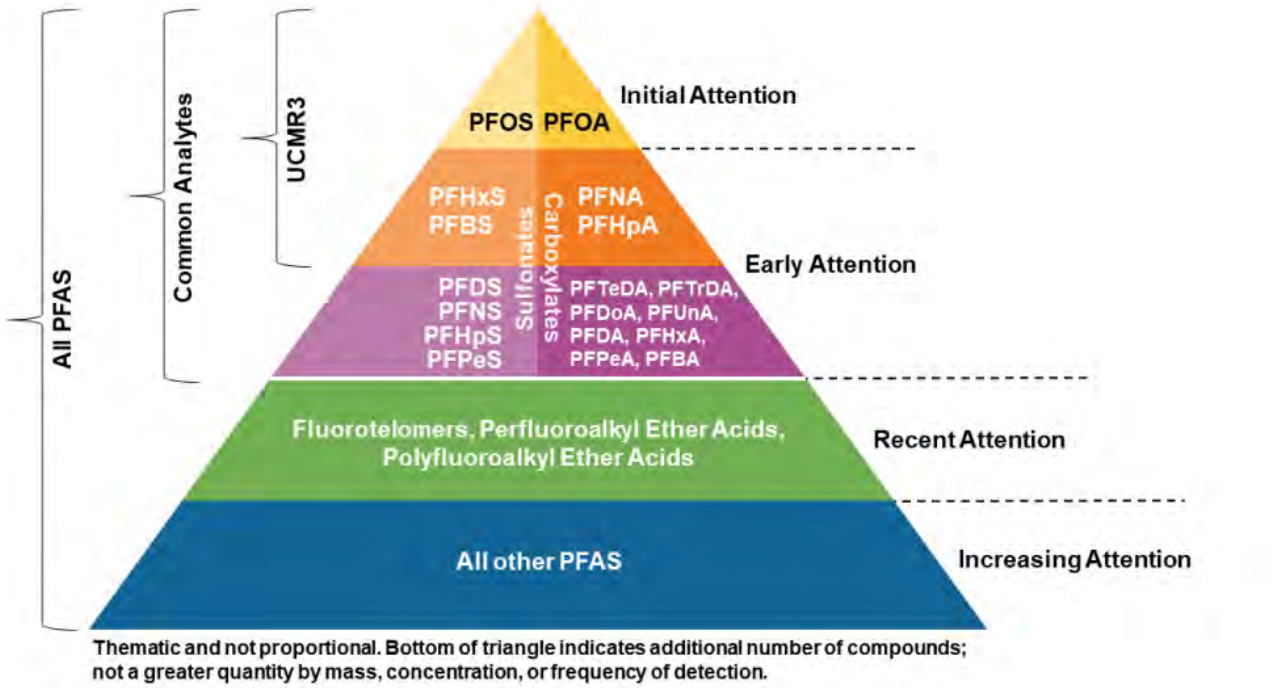


Figure 2-18. Emerging awareness and emphasis on PFAS occurrence in the environment.

Source: J. Hale, Kleinfelder. Used with permission.

2.3.3 Detection in the Environment

Although some PFAS have been manufactured since the 1950s, PFAS were not widely documented in environmental samples until the early 2000s, as PFAS testing was not widely available until that time. Since the early 2000s, however, the occurrence of PFAS in the environment has been a very active area of research. The occurrence of certain PFAS has been reported in a wide variety of matrices, including sediments, surface water and groundwater, and wildlife (**Kannan et al. 2004**; **Yamashita et al. 2005**; **Higgins et al. 2007**; **Rankin et al. 2016**). UCMR3 sampling detected PFAS in 4% of drinking water supplies across the country, including in 33 states, three territories, and one Native American community (**Hu et al. 2016**). However, the Hu et al. study used a non-final download of the UCMR3 dataset, so final statistics may be different. Initially, investigations focused mainly on major releases from manufacturing sources and significant PFAS uses such as firefighting foam application sites.

In recent years, with more sensitive analytical methods available, studies have detected PFAS (especially PFAAs) in locations throughout the globe, even in areas well beyond where they were initially used or manufactured (**Houde et al. 2011**). Detections of certain PFAS in the environment in various media are detailed in **Section 6**, and ecological effects are described in **Section 7.2**.

2.3.4 Growing Awareness and Concern

Societal awareness and concern about PFAS have increased since regulatory activity began in the early 2000s. Societal awareness and response are documented in the form of scientific progress and health advisories, regulatory actions, and legal actions. Major milestones for these activities within the United States are summarized in **Figure 2-19**. Other milestones, such as the growth of knowledge and investigation at major manufacturing and DOD sites in various U.S. states, are not discussed here.

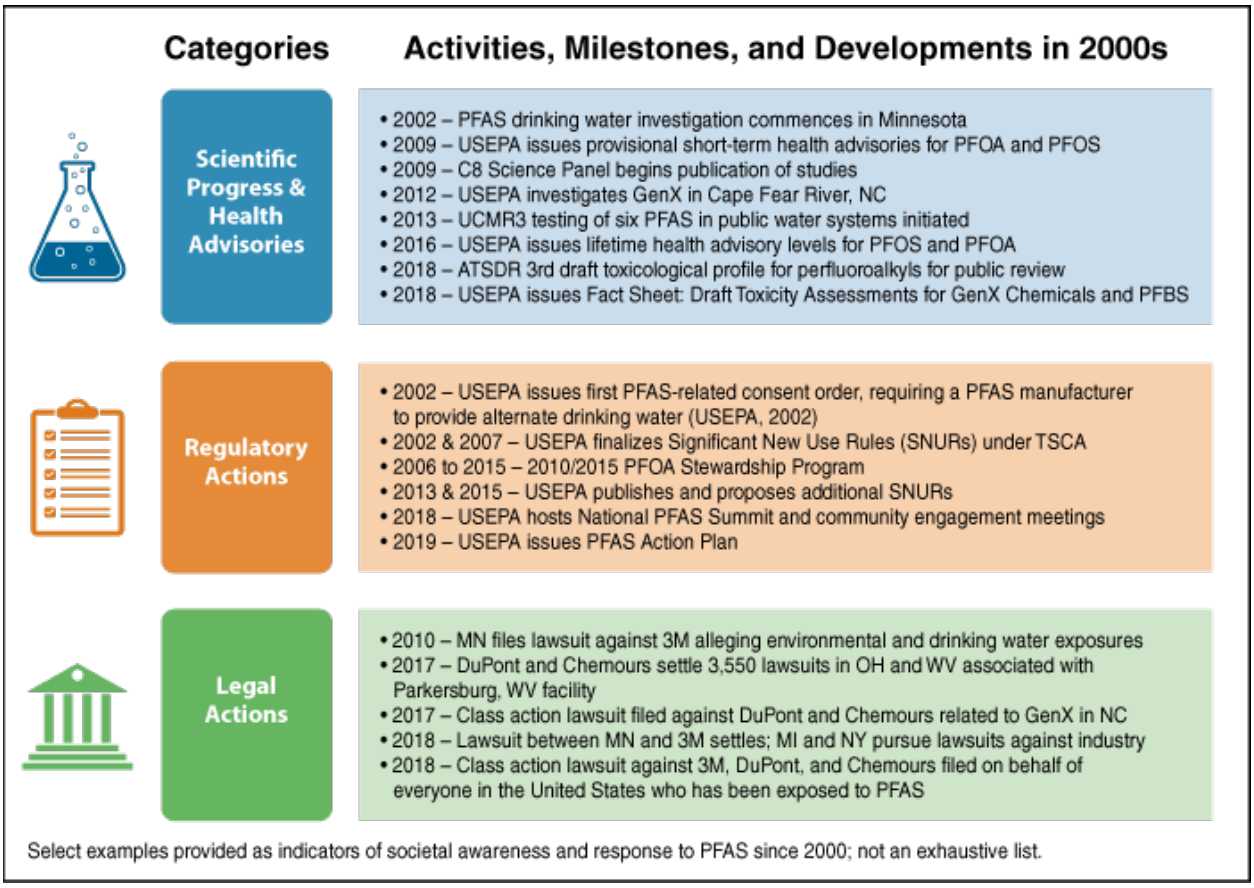


Figure 2-19. Growing awareness and concern 2000-2019.

2.4 PFAS Reductions and Alternative PFAS Formulations

Concern regarding the persistence, bioaccumulation, and possible ecological and human health effects of long-chain PFAAs has led manufacturers to use replacement PFAS chemistries, which include reformulating or substituting longer chain substances with generally shorter chain perfluoroalkyl or polyfluorinated substances that should not transform to long-chain PFAAs, or replacing manufacturing processes with nonfluorinated chemicals or alternate methods (**USEPA 2006**; **OECD 2017**). Manufacturing reductions and phaseouts are described in this section.

2.4.1 3M Voluntary Phaseout of Certain Long-Chain PFAS

In early 2000, 3M was the principal worldwide manufacturer of PFOA and POSF-derived PFAS (for example, PFOS) (**Buck et al. 2011**). This represented about 80–90% of global POSF-based production (**Prevedouros et al. 2006**), with 3M the sole U.S. manufacturer of PFOS (**USEPA 2003**). In 2000, 3M announced a voluntary, unilateral phaseout (this only applied to 3M) of POSF-derived PFAS, which at the time represented more than 95% of the company's perfluorooctanyl production (**3M Company 2000**). The 3M phaseout included the six-, eight-, and ten-carbon PFSAs (PFHxS, PFOS, and PFDS) and related precursors, as well as PFOA (**Buck et al., 2011**). 3M reportedly completed most of the phaseout by the end of 2002, with the remaining phaseout completed by 2008 (**USEPA 2017**; **3M Company 2017**).

At the time of the phaseout, 3M's POSF-derived PFAS were used in several applications:

- ~41% for paper and packaging protectors

- ~36% for textiles, leather, and carpet treatment and fabric protectors
- ~19% as industrial surfactants, additives, and coatings (including electroplating and etching surfactants, household additives, insecticides, and other applications)
- ~3% in firefighting foam (**3M Company 2000**).

The paper and packaging protectors included POSF-based side-chain fluorinated polymers and phosphate diesters (**Wang et al. 2013**).

PFOA produced by 3M was primarily used as a fluoropolymer processing aid, with only about 3% of PFOA production used for other applications: mostly in antistatic coatings in medical films, with limited quantities used for electronics applications (for example, to create a humidity barrier on printed circuit boards and to coat precision bearings with silicone oil) (**3M Company 2003**).

This phaseout applied only to 3M, and only to select PFAS. 3M subsequently used (and reportedly continues to use) ECF to produce PBSF-based PFAS (for example, the four carbon PFSA: PFBS) (**OECD 2013**; **Wang et al. 2015**). Any new manufacture and/or import of the PFAS phased out by 3M requires USEPA review based on the Significant New Use Rules (SNURs) described in **Section 2.4.2**. Based on the 2012 Chemical Data Reporting effort, no company reported manufacture or import of PFOS into the United States (reporting was required for quantities greater than 25,000 pounds) (**USEPA 2018**).

When 3M stopped producing PFOA in the early 2000s, it is reported that the manufacture of PFOA was continued by other domestic and international producers using fluorotelomerization (**USEPA 2003**; **Wang et al. 2014**). Domestic PFOA production was later phased out by the eight major domestic producers, as described in **Section 2.4.3**. Global production is summarized in **Section 2.4.4** and **Section 2.4.5**.

In December 2022, 3M issued a press release stating the company would discontinue the manufacturing of PFAS and the use of PFAS in its products by the end of 2025. This will include discontinuing the manufacturing of all fluoropolymers, fluorinated fluids, and PFAS-based additive products and the use of PFAS across their product portfolio.

2.4.2 USEPA Significant New Use Rules (SNURs)

In conjunction with these voluntary reductions and phase-outs, USEPA used its authority under the Toxic Substances Control Act (TSCA) to finalize SNURs between 2002 and 2020 to require notification to USEPA before any manufacture (including import) of select PFAS, which include, but are not limited to, some of the PFAS included in 3M's voluntary phaseout of PFOS and related chemicals (**Section 2.4.1**). The July 2020 SNUR restricts products containing certain PFAS that have been phased out from being imported into the United States (**USEPA 2021**). According to USEPA (**2021**), this SNUR levels the playing field for companies that had already voluntarily phased-out the use of long-chain PFAS under EPA's PFOA Stewardship Program. As of February 2023, 1,422 PFAS are on the TSCA Chemical Substance Inventory, a list of all existing chemical substances that are either currently or have historically been manufactured (including imported) or processed in the United States. Of these, 711 are considered "active" in commerce, meaning they were manufactured (including imported) or processed over the 10-year period ending June 21, 2016, or more recently. Updates to the TSCA inventory are published generally on a quarterly basis, including the number of chemicals on the "active" inventory (**USEPA 2023**). USEPA has reviewed more than 300 of the commercially active PFAS under the New Chemicals Program and regulated about 200 PFAS with consent orders and/or new chemical SNURs (**USEPA 2021**). A new proposed SNUR has been added regarding 300 PFAS that "have not been manufactured (including imported) or processed for many years and are consequently designated as inactive on the TSCA Chemical Substance Inventory" (**USEPA 2023**).

2.4.3 USEPA PFOA Stewardship Program

In January 2006, USEPA initiated the 2010/2015 PFOA Stewardship Program (**USEPA 2006**). Most PFOA produced in 2003 (around the time of the phaseout described in **Section 2.4.1**) was used as a processing aid in the manufacture of fluoropolymers, such as PTFE (**USEPA 2003**), and this was likely still the case at the time the stewardship program began.

The eight major manufacturing or processing companies that participated in the program are reportedly those that manufactured or processed the majority of these chemicals, including Arkema, Asahi, BASF Corporation (successor to Ciba), Clariant, Daikin, 3M/Dyneon, DuPont, and Solvay Solexis (**USEPA 2018**). There may be other manufacturing or processing companies that did not participate in the program (**USEPA 2015**). USEPA indicated that the eight participating companies successfully met the program goals, meeting a 95% reduction by 2010 in global facility emissions and product content, and eliminating production (100% reduction) of PFOA, certain longer chain PFCAs (higher homologues such as PFNA and PFDA), and related PFOA precursors (for example, 8:2 FTOH) by 2015 (**USEPA 2017**). Even though the program goals were met by the eight companies, the ongoing use of PFOA stock and imported materials has not been fully restricted (**USEPA 2018**). Products manufactured and imported prior to 2015, and materials with ongoing uses, may still contain these PFAS (**USEPA 2018**), and PFOA may be present as a trace contaminant in some other PFAS and fluoropolymer products (**3M Company 2003**). As discussed in **Section 2.4.5**, production is ongoing in other nations. Additional information on current US regulatory activities can be found in **Section 8.2**.

2.4.4 Stockholm Convention on Persistent Organic Pollutants

The Stockholm Convention on Persistent Organic Pollutants (POPs) is a United Nations treaty signed in 2001 aimed at reducing or eliminating the production, use, and release of key POPs. POPs are defined as synthetic, organic compounds that, to varying degrees, resist photolytic, biological, and chemical transformation (**KEMI 2004**, **2015**; **USEPA 2017**). Chemicals listed as POPs satisfy screening criteria for persistence, bioaccumulation, long-range environmental transport, and adverse effects (**Stockholm Convention 2001**). The Stockholm Convention targets PFAS in these ways:

- In 2009, *Annex B of the Stockholm Convention* (which restricts production and use) was amended to include PFOS (and its salts and POSF), because it is persistent in the environment and is not known to transform at any environmental condition. Currently, the United States has not ratified the amendment (**KEMI 2017**). Annex B is not an outright ban; it allows certain approved uses and exemptions of POPs. Prior to 2019, approved, ongoing uses for PFOS under Annex B included select applications in photoimaging, semiconductor coatings and etching agents, metal plating, insect baits, chemically driven oil production, aviation hydraulic fluids, some medical devices, and color printer electronic parts (**UNEP 2008**, **2009**).

- Additionally, the following amendments and recommendations have been made:

    - In May 2019, Annex B was amended to discontinue several of the previously allowed ongoing uses (**UNEP 2019**).

    - Annex A was amended in May 2019 to prohibit and/or eliminate the production and use of PFOA (its salts and PFOA-related compounds), with certain exemptions (**UNEP 2019**).

    - the POPs Review Committee recommended in October 2019 to list PFHxS (and its salts and related compounds) in Annex A without specific exemptions (**UNEP 2019**)

2.4.5 Global Manufacture and Use of PFAS

PFAS are still manufactured globally, despite some PFAS (most notably PFOA and PFOS) no longer being produced in the United States, Europe, and Japan; for further information, see OECD's Country Information page on the OECD Portal on Per and Poly Fluorinated Chemicals (**OECD 2017**), "Risk Reduction Approaches for PFASs" (**OECD 2015**), and "Toward a New Comprehensive Global Database of Per- and Polyfluoroalkyl Substances" (**OECD 2018**). In addition to the domestic reductions discussed in **Section 2.4.1** and **Section 2.4.3**, some of the phase-outs and restrictions are summarized below.

In 2017, the South Australia state government took initial steps to develop legislation banning environmentally harmful foams, such as Class B firefighting foams containing PFAS (**SA EPA 2017**).

Canada embarked on an Environmental Performance Agreement with four major manufacturers to phase out PFOA and related compounds from 2010 to 2015 (**CEPA 2006**). In 2008, Canada prohibited the use of most PFOS, with select exemptions such as use of existing stocks of PFOS-based firefighting foams, and then added PFOS to the Virtual Elimination List in 2009 and to the Prohibition of Certain Toxic Substances Regulations in 2016 (**CEPA 2018**). By 2016, Canada prohibited the import, manufacture, use and sale of PFOS, PFOA, and other long-chain PFCAs (and salts and precursors), with limited exemptions (**CEPA 2018**), and subsequently in 2018, Canada proposed further modification to those restrictions (**Government of Canada 2018**).

In 2009, the European Union (EU), through the European Chemicals Agency (ECHA), regulated PFOS as a POP, and use of PFOS is limited to certain restrictions (**Vierke et al. 2012**). In 2017, the EU banned the sale, use, and import of PFOA, its salts and PFOA-related substances through Annex XVII of the European Chemicals Regulation (REACH), with phase-outs occurring through 2032 and certain allowed uses. ECHA is currently considering restrictions for other long-chain PFCAs, their salts and precursors, as well as other compounds, such as PFHxA (**ECHA 2018**). On February 7, 2023, ECHA proposed restrictions on PFAS as a class; this proposal was prepared by Denmark, Germany, the Netherlands, Norway, and Sweden (**ECHA 2023**).

In Japan, there are restrictions on the manufacture, import, export, and use of PFOS and its salts (**OECD 2015**).

The global reduction anticipated with the U.S. phaseout of PFOA has potentially been offset by increased production of PFOA and related PFAS in China, India, and Russia (**OECD 2015**). PFAS manufacture began in China in the 1980s (**World Bank 2017**, **2017**), and PFOS production in China increased coincident with the long-chain PFAA phaseout in the United States (**CONCAWE 2016**; **OECD 2015**). In 2016, PFOS and its derivatives were still being produced in Germany, Italy, and China (**TTE 2016**), but by early 2017, China was the only known producer of PFOS. China has ratified the Stockholm Convention on POPs and was awarded a grant from the Global Environment Facility (GEF) in 2017 to support the reduction of PFOS in China (**World Bank 2017**). China has developed some guidance for restriction and limitations of some PFAS (**OECD 2015**). In Brazil, EtFOSA, which is a precursor to FOSA and PFOS and used in the pesticide sulfluramid, which is still being produced on an industrial scale, is allowed as an approved use by the Stockholm Convention (**Löfstedt Gilljam et al. 2016**). **Section 1.1.2.2** includes information about PFAS use in pesticides.

There does not appear to be a comprehensive reference publicly available to document the individual PFAS and the quantity of PFAS produced over the years. This is possibly because these data are proprietary or because quantities produced did not meet USEPA reporting requirements under TSCA, but could also be due to modifications to chemistries and products over the years (**Lindstrom, Strynar, and Libelo 2011**), complexity of the issue, and the general lack of publicly available data (**OECD 2018**). That said, some estimates of production and emissions of select PFAS have been made based on the limited available data.

Prevedouros et al. (2006) estimated global emission of PFCAs at about 3,500–8,000 tons between the 1950s and 2002, with approximately 80% of emissions related to fluoropolymer manufacture (and use), based on overall annual production estimates of:

- APFO (ammonium salt of PFOA)-about 335–525 tons per year between 1951 and 2002
- APFN (ammonium salt of PFNA)-about 60–225 tons per year between 1975 and 2004
- POSF (building block for PFOS)-about 9,550 tons per year from 1960 to 2002.

Other production and emissions estimates for PFCAs are available from **OECD (2015)** and **Wang et al. (2014)**, and for PFOS and PFOS precursors from **Armitage et al. (2009)** and **Paul, Jones, and Sweetman (2009)**. **OECD (2015)** called for a new, comprehensive survey to evaluate both historical and ongoing emissions.

2.4.6 PFAS-Based Replacement Chemistry

With the emerging awareness of potential health and environmental impacts of some PFAS and related limitations on production of some PFAS, such as the SNURs (**Section 2.4.2**) and 2010/2015 PFOA Stewardship Program (**Section 2.4.3**), manufacturers began efforts to replace the use of long-chain PFAS chemistries with nonfluorinated chemicals, alternate technologies, and/or other, shorter chain PFAS (**Wang et al. 2013**). For example, decorative chrome plating typically now uses less toxic chromium III instead of chromium VI so that PFAS are not needed (**Wang et al. 2013**).

Some of the replacement chemicals are said to achieve the same performance effectiveness of some of their predecessors. A carpet manufacturer has found that performance of fluorine-free alternatives is "equivalent or superior to the fluorinated treatments" pg. 66, (**CalEPA 2018**). Conversely, a 2015 study concluded that there are no nonfluorinated alternatives that provide equivalent technical performance in textiles (**Danish EPA 2015**). Refer to **Section 3** for a discussion of PFAS-free AFFF that meets U.S. Department of Defense performance specifications.

Several studies suggest some of the alternate PFAS chemistries may or may not be less hazardous than the long-chain predecessors, although publicly available information on most replacement chemicals is limited (**Wang et al. 2015 RIVM 2016**; **OECD 2015**). Documentation regarding the USEPA's review of hundreds of "shorter chain-length PFAS telomeric" substitutes is available under the TSCA New Chemicals Program (**OECD 2013**; **USEPA 2017**), and other documentation regarding replacement PFAS chemistries is available from the **Performance Fluoropolymer Partnership (2021)** and **American Chemistry Council (2021)**. Draft toxicological evaluations have been provided for public comment by the USEPA for GenX chemicals and PFBS (**USEPA 2018**, **2018**) with the PFBS Toxicity Assessment finalized in 2021 (**USEPA 2021**), and the GenX Toxicity Assessment finalized in 2021 as well (**USEPA 2021**) . For further discussion of toxicity documentation for select PFAAs and replacement chemistries, see **Section 7**.

Although a full discussion of such PFAS chemistries is not possible here, it is important to be aware of the trend toward shorter chain chemistries, as some of these PFAS increasingly may be detected in the environment. Some replacement PFAS have been detected in the environment and generated public concern and regulatory actions; however, information on significant environmental contamination by replacement PFAS is limited, and most are not detected by standard analytical methods (**Wang et al. 2013**). Some PFAS used as replacement chemicals, such as HFPO-DA and ADONA (used as replacements for APFO/PFOA in PTFE manufacture), and F-53B (11-Chloroeicosafluoro-3-1455 oxaundecane-1-sulfonic acid [11Cl-PF3OUdS or F-53B Minor], 9-Chlorohexadecafluoro-3-1456 oxanonane-1-sulfonic acid [9Cl-PF3ONS or F-53B Major]) (used as a replacement for PFOS in plating), have recently

been added to USEPA Method 537.1 (**USEPA 2018**). Certain treatment processes used to remove these chemicals from waste streams may not be as effective as with longer chain PFAS (**Sun et al. 2016**).

Alternate PFAS chemistries are being used to replace long-chain PFAAs that have been phased out of production and/or use. In many cases, although similar legacy PFAAs were manufactured and used by many companies, these same companies have transitioned to the use of many different types of other PFAS as alternative chemicals. Many of these replacement PFAS are structurally similar to their long-chain predecessors, and are typically also manufactured using electrochemical fluorination (ECF) or fluorotelomerization (**Wang et al. 2015**; **CONCAWE 2016**). Some of these fluorinated substitutes may transform to form short-chain PFAAs. Some short-chain PFAAs, PFECAs (both per and poly), and related chemicals were manufactured as early as the 1980s, or earlier (**Wang et al. 2015**). Some PFAS used to replace long-chain PFAS are presented below (**Hori et al. 2006**; **OECD 2007**; **Herzke, Olsson, and Posner 2012**; **Buck 2015**; **Wang et al. 2013**; **Wang et al. 2014**; **Wang et al. 2015**; **KEMI 2015**; **Sun et al. 2016**; **Holmquist et al. 2016**):

- short chain homologues of the long-chain PFAAs, including PBSF-based derivatives (for example, 4-carbon chain PFBS in lieu of POSF-based six-, eight-, and ten-carbon chain compounds) in many applications, including surface treatment
- perfluorohexane sulfonyl fluoride (PHxSF, which can transform to PFHxS and is considered to be phased out in the United States) as an alternative to PFOS, primarily in China
- fluorotelomer-based products such as FTOH, for example, those with a six-carbon perfluorohexyl chain, including 6:2 fluorotelomer-based compounds in AFFF formulations and other six-carbon fluorotelomer-based products, side-chain fluorinated polymers, and PFPE products for surface treatment of food contact materials
- per- and poly-fluoroalkyl ether acids used as polymerization aids in manufacture of fluoropolymers, such as GenX chemicals (perfluoroalkyl ether acids) and ADONA (polyfluoroalkyl ether acids) used as a replacement for APFO in the manufacture of PTFE, as well as other types of perfluoroalkyl ether acids, also referred to as cyclic or polymeric functionalized PFPEs as a replacement for APFN in the manufacture of polyvinylidene fluoride (PVDF)
- 6:2 fluorotelomer-based compounds, a PFBS-based compound, and PFAS known as F-53 and F-53B in lieu of PFOS in metal plating applications.

2.5 PFAS Uses and Products

This section provides information on PFAS uses (**Section 2.5.1**), potential PFAS use or occurrence in some specific products (**Section 2.5.2**), and PFAS certifications (**Section 2.5.3**). Each section includes a table summarizing available information. The tables are not exhaustive.

The Priority Topics for History, Use, and Naming Conventions include information about less-publicized PFAS Sources (see **Section 1.1.2**) including hydraulic fluids and pesticides. Other less-publicized sources are presented in **Table 1-1**, which supplements **Table 2-7**. The Priority Topics for Human and Ecological Health Effects include information about potential PFAS exposures from consumer products (see **Section 1.4.2**). The Priority Topics for Sampling and Analysis include information about testing consumer products for PFAS (see **Section 1.5.4**).

2.5.1 PFAS Uses

PFAS have been produced on a commercial scale since the 1950s, and production continues today. The unique physical and chemical properties of PFAS impart oil, water, stain, and soil repellency, chemical and temperature resistance, friction reduction, and surfactant properties to a wide range of products, some of which are considered essential to health, safety, or modern life (**Glüge et al. 2020**). **Glüge et al. (2020)** categorized PFAS by uses according to industry application and practical use and identified more than 200 uses for more than 1,400 individual PFAS.

Table 2-6 provides a general (not exhaustive) introduction to some of the uses of PFAS chemistries that are, or have been, marketed or used (**3M Company 1999**; **Poulsen et al. 2005**; **OECD 2006**; **Washington State Department of Ecology 2021**; **OECD 2011**; **OECD 2013**; **Fujii, Harada, and Koizumi 2013**; **OECD 2015**; **Performance Fluoropolymer Partnership 2021**; **Henry et al. 2018**). The specific applications for all PFAS are not well documented in the public realm. For example, of the 2,000 PFAS identified in a 2015 study, only about half had an associated listed use (**KEMI 2015**). Further discussion of select uses that may be associated with potentially significant environmental releases are provided in **Section 2.6**.

As discussed in **Section 2.2.2.1**, most polymer PFAS are considered to pose relatively less risk to human health and the environment than some nonpolymer PFAS. For this reason, **Table 2-6** distinguishes between these two major classes of PFAS and where they are used in various industries and products. **Glüge et al. (2020)** provided a detailed listing of PFAS by use category/subcategory, function, and properties; however, it is not organized according to polymer versus nonpolymer PFAS used in these instances.

The major industries and applications summarized in the table are described in more detail in **Section 2.6.1**.

Table 2-6. Sample historical and current uses of PFAS.

Industry / Application	PFAS Type	Documented Use and Examples of Some PFAS
Aviation and Aerospace	Polymer	Mechanical components made of fluoropolymers (such as PTFE and Perfluoroalkoxy tubing, piping, seals, gaskets, cables, and insulators)
	Nonpolymers	Hydraulic fluid additives made from PFSA salts (such as PFOS at about 0.1%) to prevent evaporation, fires, and corrosion
Automotive	Polymer	Mechanical components made of fluoropolymers, including wiring and cable, fuel delivery tubing, seals, bearings, gaskets and lubricants, and some polymer coatings on carpets
	Nonpolymers	Surface treatment for textiles, upholsteries, carpets, leather and exterior surfaces
Biocides (Herbicides and Pesticides)	Polymer	None reported
	Nonpolymers	Active ingredients such as short-chain sulfonamides in plant growth regulators and herbicides, and EtFOSA (sulfluramid) in ant and termite baits; inert enhancing ingredients in pesticides; PFPAs and PFPiAs as anti-foaming agents in solutions
Biotechnology	Polymer	Polymers used for reaction vessels, stirrers, and other components, filtration, and moisture barrier
	Nonpolymers	Cell cultivation by delivery of oxygen and other gases and ultrafiltration and microporous membranes to prevent bacterial growth.
Building and Construction	Polymer	Fluoropolymer membranes and coatings (such as PTFE, PVDF, and/or side-chain fluorinated polymers) in architectural materials (like fabrics, roofing membranes, metals, stone, tiles, concrete, radomes); adhesives, seals, caulks; additives in paints (for example, low- and no-VOC latex paints), varnishes, dyes, stains, sealants; surface treatment agent and laminates for conserving landmarks
	Nonpolymers	Additives in paints, coatings, and surface treatments (PASF- and fluorotelomer-based compounds, ammonium salt of PFHxA)

Industry / Application	PFAS Type	Documented Use and Examples of Some PFAS
Cable and Wiring	Polymer	Coatings and jacketings made of fluoropolymers (such as PTFE and PVDF) for weathering, flame, and soil resistance, with cables used in many applications, including communication facilities, antennae, and computer networks
	Nonpolymers	None reported
Chemical Industry	Polymer	Fluoropolymers used to coat chemical tanks and pipes to enhance corrosion and high temperature resistance, as sealing and gasket materials for chemical processing, and for filtration media used in chemical manufacturing processes and emissions controls
	Nonpolymers	Fluoropolymer processing aids, stabilization and binder for certain chemicals, elimination of imperfections, and provide inert reaction media
Cosmetics/Personal Care Products	Polymer	Dental floss, toothpaste, dental creams, tooth powders, throat lozenges, chewing gums, sunscreens, cosmetics, and micro powders used in creams and lotions.
	Nonpolymers	Cosmetics, shampoos, nail polish, eye makeup, denture cleaners, eye drops, contact lenses, and others
Electronics	Polymer	Fluoropolymers (such as PVDF and PTFE) used in insulators, solder sleeves, printed circuit boards, cell phones, computers, speakers, and transducers
	Nonpolymers	Flame retardants for polycarbonate resin (such as the potassium salt of PFBS)
Energy	Polymer	Fluoropolymer films (such as FEP, PVDF) to cover solar panel collectors, electrolyte fuel cells, PTFE expansion joint materials for power plants, filtration of fly ash from stack emissions
	Nonpolymers	Fuel cell and battery electrolyte (such as the lithium salt of PFAAs)
Explosives, Propellants, Guns, and Ammunition	Polymer	Fluoropolymers (PTFE) applied to guns for lubrication and antidegradation during long term storage, tungsten-iron-fluoropolymer shot alloys (replacement for lead in hunting waterfowl and coots), fluoropolymer use in visual flares, warheads, incendiaries, and others
	Nonpolymers	PFCAs used in energetics, infrared flares, ignitor pyrolant, coating of reactive metallic powders, combustion behavior modification and other processes
Firefighting/Safety	Polymer	Fluoropolymers used in firefighting equipment and protective clothing (such as those woven with PTFE). Other polymer coatings using side-chain fluorinated polymers
	Nonpolymers	Coatings and materials used as water repellents and some Class B foam (may contain PFCAs, PFSAs, and fluorotelomer-based derivatives), vapor suppression for flammable liquids (for example, gasoline storage)
Food Processing	Polymer	Fluoropolymer fabrication materials (such as PTFE) (liners for trays, ovens, grills)
	Nonpolymers	May be used as coatings on food packaging
Household and Cleaning Products	Polymer	Nonstick coatings (fluoropolymers such as PTFE); aftermarket treatment for textiles, upholsteries, carpets, and leather (such as Fluorotelomer-based side-chain fluorinated polymers); sewing machine presser feet; glass
	Nonpolymers	Aftermarket treatment for textiles, upholsteries, carpets, and leather (such as PASFs; floor polishes (such as the ammonium salt of PFDA), coatings, and floor finishes (PFPAs and PFPiAs) and cleaning agents and alkaline cleaners; automobile waxes; may include PFAAs, PASF- and fluorotelomer-based derivatives, anti-reflective coatings, dry cleaning agent (PureDry®) replacement for perchloroethylene
Medical Products	Polymer	Fluoropolymers (such as PTFE) used in surgical patches, cardiovascular grafts, raw materials for human body implants (such as catheters, stents, sutures, device surface coatings, needles, and other) given biocompatibility and extremely low coefficient of friction, dialysis membranes, anesthesia, machine components (o-rings, filters, tubing, and other)
	Nonpolymers	X-ray film, stain- and water-repellent protective medical fabrics (like surgical drapes and gowns) created from PASF- or fluorotelomer-based (meth)acrylate polymers and polyurethanes, burn wound care cleaning product, oxygen and oxygen carriers used to improve therapeutic outcomes
Metal Plating	Polymer	None reported
	Nonpolymers	Wetting agent, mist suppression for harmful vapors, and surfactants (may include potassium, lithium, diethanolamine and ammonium salts of PFOS or 6:2 FTS)
Oil Production	Polymer	Lining of gas pipes
	Nonpolymers	Marketed for and potential instances of use in oil well production
Mining	Polymer	None reported
	Nonpolymers	Instances of surfactants used in ore mining flotation and leaching, improve separation of materials, and concentration of ore by destruction of mineral structure

Industry / Application	PFAS Type	Documented Use and Examples of Some PFAS
Nuclear Industry	Polymer	Lubricants used for valves and centrifugal bearings in enrichment processes
	Nonpolymers	None reported
Oil and Gas Industry	Polymer	Lining of gas pipes and insulation of cable and wire during drilling, and membranes for filtration
	Nonpolymers	Marketed for and potential instances of use in oil well production to change the permeability of the target formation, reduce viscosity for transport, prevent evaporative loss during storage, tracers
Paper and Packaging	Polymer	Oil and grease and water repellent to paper, paperboard, molded pulp products (including food contact materials), and LDPE bags; examples include side-chain fluorinated polymers in which the PASF- or fluorotelomer-based alcohols or their acrylate or methacrylate esters are attached on side chains; PFPEs
	Nonpolymers	Phosphate ester salts (esterification of PASF or Fluorotelomer-based alcohols with phosphoric acid
Pharmaceutical Industry	Polymer	Polymers used for reaction vessels, stirrers, and other components, filtration, and moisture barrier
	Nonpolymers	Processing aids in the manufacture of microporous particles, additives and ingredients in certain types of medicine for drug delivery
Photographic Industry	Polymer	None reported
	Nonpolymers	Photographic processing aids to reduce air bubbles and prevent foaming, wetting agents, stabilizers, and antistatic agents, prevent spots, and create uniform edge in multilayer coatings, anti-reflective agents
PFAS Production	Polymer	None reported
	Nonpolymers	Emulsion polymerization processing aids for fluoropolymers (such as PTFE, FEP, PFA, PVDF), (co)monomer of side-chain fluorinated polymers; (co)monomer of fluoropolymers and to make fluoroelastomers; may use salts of long-chain PFCAs (such as PFOA and PFNA), salts of short-chain PFCAs (such as PFHxA), or PFECAs
Photolithography & Semiconductor	Polymer	Equipment raw materials (such as PFA) for molded wafer baskets to handle corrosive liquids and gases, use as fluids in mechanical vacuum pumps
	Nonpolymers	Photolithography (such as using PFOS) in manufacture of semiconductor chips
Plastics and Rubber	Polymer	Fluoropolymers (such as PTFE) are used as processing aids, as a raw material in plastics and rubber production, and as an intermediate material. Used in molded material production to enable easy release and reduce imperfections, polymer processing aids
	Nonpolymers	Surface tension reduction for foams, etching of plastic, and production of rubber
Recreational and Musical Equipment	Polymer	Fluoro waxes used to reduce wear and abrasion on: stringed sports equipment (for example, tennis racquets) and stringed instruments; fishing rods and reels; lubricants; piano keys; ski wax
	Nonpolymers	None reported
Recycling and Material Recovery	Polymer	None reported
	Nonpolymers	Fluorosurfactants are used to recover metals, including rare earth metals, and n-hexane from waste gases
Refrigerants	Polymer	None reported
	Nonpolymers	Perfluorocarbons (PFCs), a subset of PFAS, used in refrigerant fluid and compressor systems for both heat transfer and lubrication
Textiles (Upholstery, Carpets), Leather, and Apparel	Polymer	Fluoropolymers (such as PTFE) are used in the construction of outdoor gear, clothing, and housewares; side-chain fluorinated polymers (such as PASF- or fluorotelomer-based (meth)acrylate polymers and -polyurethanes) may be used in oil- and water-repellent and stain release finishing and treatment coatings
	Nonpolymers	PFOA-based chromium treatment for paper and leather. Nonpolymer coatings used to treat textiles to provide oil- and water- repellent and stain release finishes
Wood Industry	Polymer	Polymeric PFAS fabric used during bleaching process, clear coating of wood substrate
	Nonpolymers	Adhesive resin on wood particle board

Information presented in this table captures potential instances of use but is not intended to indicate universal use. In addition, the table is not exhaustive of PFAS use in various industries.

2.5.2 Potential PFAS Use or Occurrence

Growing awareness of PFAS has led to both research and speculation about the use and occurrence of PFAS associated with an increasing number of consumer and commercial products, and whether such occurrences may constitute a risk to human health and the environment. **Table 2-7** provides a high-level technical assessment of such recent claims, some of which have been popularized in the news media. **Section 1.1.2** includes information about less-publicized PFAS sources, such as hydraulic fluids and pesticides. Other less-publicized sources are presented in **Table 1-1**, which supplements **Table 2-7**.

Table 2-7. Summary of Claims of PFAS Use and Occurrence.

Potential Use or Occurrence	Technical Basis	Documentation	Conflicting Perceptions on Presence of PFAS and Significance of PFAS
Cosmetics and Personal Care Products	Higher dermal absorption of PFOA from sunscreen than was previously reported for dermal absorption of PFOA: 1.6% of the applied dose was absorbed over time in a human volunteer.	Journal Articles, **Abraham and Monien 2022**; **Whitehead et al. 2021**, **2021**	One study demonstrates significant uptake of a PFAA via transdermal absorption in humans may occur via PFOA mixed into sunscreen, indicating past occurrence of PFAS in some cosmetics may have contributed to this route of exposure. Other article discusses the use of PFAS in North American cosmetics to increase their durability and water resistance.
Face Masks	Chemical analysis of PFAS in face masks and calculations of leaching to landfill leachate.	Journal Article, **Muensterman et al. 2022**	Nine varieties of masks were tested. Homologous linear PFCAs and 6:2 FTOH indicated a fluorotelomer origin. Wearing masks treated with high levels of PFAS for extended periods can be a notable source of exposure with potential human health risk. Modeled annual disposal of ~29–91 billion masks assuming 100% leaching of individual PFAS into landfill leachate indicates mask disposal would contribute an additional 6% of annual PFAS mass loads and less than 11 kg of PFAS discharged to U.S. wastewater.
Fluorinated HDPE Containers	Testing of a limited number of fluorinated and non-fluorinated HDPE containers for presence of PFAS by EPA's Analytical Chemistry Laboratory at Fort Meade (initial and follow-up testing). Leaching of PFAS from container walls to liquid contents (methanol and water) was demonstrated for fluorinated containers. Degree of leaching relates to the brand of fluorinated containers and duration of liquid storage in container. Higher amounts of PFAS were detected in methanol solvent versus water.	USEPA Memos **USEPA 2021**; **USEPA 2022**	Through the fluorination process of HDPE containers, PFAS may be formed and then partly leach into the products inside the containers. These containers are believed to explain the occurrence of PFAS in mosquito control insecticide tested by an environmental group and published by news outlets.
Food Packaging	Consumer Reports (CR) tested total organic fluorine content in multiple samples collected from 118 paper food packaging products from 24 restaurants and grocery chains. A subset of 50 products was tested by a method only identified as being "regularly used by industry, regulators, and researchers."	Consumer Reports, **Loria 2022**	The organic fluorine levels were averaged for each product. Thirty-seven products had an average organic fluorine concentration above 20 ppm, and 22 products had an average above 100 ppm. PFBA was found at the highest concentrations in the subset of 50 products analyzed by an alternate method.
Pesticides	Fluorinated pesticides may meet certain definitions of PFAS and therefore would be considered PFAS-containing.	Scientific American, **Wilcox 2022**	Article notes at least three active pesticide ingredients currently allowed by the USEPA—broflanilide, pyrifluquinazon and noviflumuron—meet its definition for a PFAS.
Pesticides	A university laboratory tested pesticide products. PFAS were detected in some of the products.	**Lasee et al. 2022**; **USEPA 2023**	USEPA's Analytical Chemistry Branch repeated the analyses for PFAS and conducted additional analyses. In USEPA's results no PFAS were detected above the method detection limits.

Potential Use or Occurrence	Technical Basis	Documentation	Conflicting Perceptions on Presence of PFAS and Significance of PFAS
Synthetic Turf	Media reports describe testing by non-profit organizations that detected PFOS on backing of older discarded turf material and 4 PFAS (PFOS, PFOA, PFHxS and 6:2-FTS) in nearby wetland water, 6:2 FTS on backing of newer turf material, and fluorine in 8 samples of grass blades acquired directly from distributors.	Fact Sheet, **TURI 2020** CT DPH Review, **CT DPH 2022** Lab analyses of PFAS in turf and wetland waters, **Eurofins 2019** PEER Letter of Complaint to MassDEP, **PEER 2019** **Massey and Pollard 2023** City of Portsmouth, NH Evaluation of PFAS in Synthetic Turf, **City of Portsmouth 2022** Project report, **Tetra Tech 2021** Journal article, **Lauria et al. 2022**	Staff at Connecticut Department of Public Health (CT DPH) have retrieved and reviewed the original lab reports that were the basis of the media reports for PFAS detected in newer and older fields (and nearby wetland water) and determined that the available data do not provide scientific evidence that the detected PFAS originate from the artificial turf itself; their presence in turf may be attributable to other sources of PFAS, including sample contamination. The PFAS concentrations detected in turf and in nearby waterways are within the range of "background" levels of PFAS detected in soils in remote areas and in surface waters collected near urban areas. The Portsmouth, NH study evaluated analyses of synthetic turf samples utilizing standard PFAS analyses and TOP Assay; low-levels of select PFAS detected were determined to not represent a human health risk to users of the turf. Staff at CT DPH were unable to identify lab reports of the detection of fluorine in grass blades. Negligible PFAS leachate concentrations were also noted well below applicable criteria associated with synthetic turf at the Martha's Vineyard Regional High School Athletic Fields. A study of artificial turf in Sweden determined that PFAS were detected intermittently and at low concentrations in backing (<LOD–0.63 ng of F/g; 71% DF) and filling (<LOD–0.15 ng of F/g; 18% DF) and were completely absent in blades. Studies reviewed did not show risk but not all manufacturers and products evaluated thus far.

2.5.3 PFAS Certification and Acceptability of Products

Numerous labels and certifications related to reduction or elimination of PFAS in products exist in the marketplace but there is great variation in the terms used to indicate PFAS content in products. Commonly used PFAS-related terms for products include: PFAS-free, PFOS-free, PFOA-free and Fluorine-free. However, many certifications allow a minimum limit to be present. The USEPA Sustainable Marketplace website (**USEPA 2023**) provides a useful compilation of PFAS-specific product certifications that lists the basis of the required and optional criteria. Many of the certifying organizations offer labels and criteria that may cover a wide range of chemicals and other sustainability considerations. The user should check the primary certifying organization's documentation to verify their requirements for obtaining PFAS-specific certifications.

Table 2-8 provides examples of some of the most commonly-used product labels and certifications for intentionally-added PFAS. Several definitions exist for the term "intentionally added" in legislation and regulation. Examples of "intentionally added" definitions include:

- Maryland: H275/S273 "(C) Intentionally added means the act of deliberately using a chemical in the formation of a product where the chemicals continued presence is desired in the product to provide a specific characteristic."

- Colorado: H1345(12) (a) "Intentionally added PFAS chemicals" means PFAS chemicals that a manufacturer has intentionally added to a product and that have a functional or technical effect on the product. (b) "intentionally added PFAS chemicals" includes PFAS chemicals that are intentional breakdown products of an added chemical.

- Hawaii: HB1644/S3000 "Intentionally introduced" means deliberately utilizing PFAS in the formulation of a package or packaging component where the continued presence of the PFAS is

desired in the final package or packaging component to provide a specific characteristic, appearance, or quality."

- California: A2771 "(c) Intentionally added PFAS means either (1) PFAS chemicals that a manufacturer has intentionally added to a product and that have a functional or technical effect on the product; or (2) PFAS chemicals that are intentional breakdown products of an added chemical."

Many countries and states also have enacted individual bans for PFAS, or intentionally added PFAS, in products and some trade groups have developed product-specific certifications (for example, furniture, floor care products). Due to the dynamic and evolving nature of these labeling programs and requirements, users should consult the primary reference to get the most current information.

Certifications for unintentionally added PFAS have also been issued. The European Union's ECHA program requires that PFOA cannot exceed 25 ppb and PFOS cannot exceed 10 ppm as impurities (See Annex 1, Part A, **European Union 2019**).

Table 2-8. Examples of Certifications – Intentionally Added PFAS.

Institution	Products	Criteria	Reference
USEPA Sustainable Marketplace	Comprehensive web site of multiple product categories	Links to multiple Standards and Ecolabel	https://www.epa.gov/greenerproducts/how-epas-recommended-standards-and-ecolabels-address-and-polyfluoroalkyl-substances
USEPA – Safer Choice	Industrial and consumer products	PFAS not specifically prohibited but EPA has determined that PFAS no longer meet the Safer Choice standard; **Exceptions** allowed; will be specifically called out as not meeting the standard in March of 2023 **Other** labels also listed	https://www.epa.gov/greenerproducts/how-epas-recommended-standards-and-ecolabels-address-and-polyfluoroalkyl-substances
FDA	Food-contact equipment & packaging	Authorized **limited** PFAS use for certain categories of food contact products	https://www.fda.gov/food/chemical-contaminants-food/authorized-uses-pfas-food-contact-applications
Green Screen	PFAS-free AFFF, cleaners and degreasers, furniture and fabrics, food service ware, and textiles	Separate limits for intentionally added PFAS **(0-100 ppm)** versus contamination as Total Organic Fluorine **(1-100 ppm)**, which vary by product category.	https://www.greenscreenchemicals.org/resources/entry/pfas-free-preferred-products
Biodegradable Products Institute (BPI)	Compostable products and packaging	No intentionally added PFAS; Limit of **100 ppm** total fluorine; SDS review; BPI-approved lab testing	https://bpiworld.org/fluorinated-chemicals https://www.epa.gov/greenerproducts/how-epas-recommended-standards-and-ecolabels-address-and-polyfluoroalkyl-substances
EWG	EWG-Verified Program for consumer products	Products cannot contain the PFAS that are on "Unacceptable" list of ingredients; Right to perform **random testing**	https://www.ewg.org/ewgverified/get-the-mark.php https://www.ewg.org/ewgverified/standards-cleaning.php
PFAS-Central	Referrals to PFAS-free products	Based on declared **company policy**, no independent verification	https://pfascentral.org/perch/resources/products/pfas-free-products-list-eligibility-one-pager.pdf

2.6 PFAS Releases to the Environment

This section summarizes sources of PFAS releases to the environment that have the potential for significant environmental impact, based on the type and magnitude of the release, and the types and concentrations of PFAS associated with that release. These sources are sites where PFAS could be, or are known to have been, released to the environment, even if the site is not the location where the PFAS were generated or used. Refer to **Section 2.1** for a discussion of the relative significance of releases and source control, as not all of these facilities will have, or have been documented to have, PFAS releases, and not all releases are of the same magnitude. "In the absence of high-quality testing data, PFAS contamination could be presumed" (**Salvatore et al. 2022**) at major sources and certain facilities as mentioned below. In addition, USEPA has developed an online database called the PFAS Analytic Tools that provides access to different sources of information about potential PFAS sources, drinking water sampling data, occurrence in environmental media, among others (**USEPA 2023**).

These major sources are located both in the United States and abroad, and include:

- industrial facilities that produce PFAS or process PFAS, or facilities that use PFAS chemicals or products in manufacturing or other activities (**Section 2.6.1**)
- areas where fluorine-containing Class B firefighting foams are stored, used, or released (**Section 2.6.2**)
- waste management facilities, such as landfills (**Section 2.6.3**)
- wastewater treatment residuals and areas of biosolids production and application, with more significant impacts associated with industrial wastewater discharges (**Section 2.6.4**).
- commercial inputs like schools, hotels, and box stores that can discharge high concentrations, linked to commercial cleaning activities like floor treatments (**Section 2.6.1.7**)

The fate and transport processes and distribution of PFAS in the environment are discussed in **Section 5**. Media-specific occurrence data are discussed in **Section 6**. Information about risk assessment, and human and ecological receptors is included in **Section 9**. Discussion of conceptual site model (CSM) components for each of the PFAS release categories listed above are included in **Section 10.2**.

2.6.1 Major Manufacturing and Industry Sources

Industrial source sites include primary and secondary manufacturing facilities. Primary manufacturing facilities are those where PFAS-containing products are synthesized and made into products or chemical feedstocks, or where PFAS are used as processing aids in fluoropolymer production. PFAS processing aids are not intended to be in the final product, but may be present at trace quantities (**3M Company 2003**; **Buck et al. 2011**).

Secondary manufacturing facilities may use fluoropolymers and PFAS-based materials produced at primary manufacturing facilities as part of industrial processes, such as the application of coatings to finished products. In some industrial settings, PFAS have been used for worker safety purposes, such as using 6:2 FTS or PFOS-based materials to suppress harmful mists during electroplating activities (**Section 2.6.1.3**).

USEPA (2021) includes PFAS manufacturers and PFAS formulators in the organic chemicals, plastics, and synthetic fibers (OCPSF) point source category, which includes a broad range of sectors, raw materials, and unit operations that may manufacture or use PFAS. PFAS manufacturers are defined as

facilities that manufacture PFAS through electrochemical fluorination, fluorotelomerization, or other processes. PFAS formulators are defined as facilities that blend, convert, or integrate PFAS feedstocks with other materials to produce new commercial or intermediate products. **USEPA (2021)** identified six OCPSF PFAS manufacturing facilities and seven OCPSF PFAS formulators located in Illinois, Alabama, New Jersey, North Carolina, West Virginia, Minnesota, Pennsylvania, Ohio, Virginia, and Michigan.

PFAS composition and release mechanisms will vary for each facility. The composition of PFAS released from industrial facilities depends on the type of PFAS produced or used by the facility.

The general PFAS release mechanisms and pathways at industrial facilities are illustrated in CSM **Figure 2-20** and include wastewater and stormwater discharges; on- and off-site disposal of solid wastes; accidental releases such as leaks and spills; and stack and fugitive emissions. Stack emissions may result in aerial deposition of PFAS to soil and surface water (with subsequent leaching and infiltration to groundwater) related to the facility (**Davis et al. 2007**; **Shin et al. 2011**), as well as short- and long-range air transport of PFAS. Industrial facilities may also contain areas where fire training or fire response using AFFF has occurred, AFFF storage areas, and AFFF fire suppression systems inside buildings. Like many AFFF release sites, industrial sites may also have releases of co-contaminants (solvents, petroleum products, etc.) that could potentially influence fate and transport of PFAS.

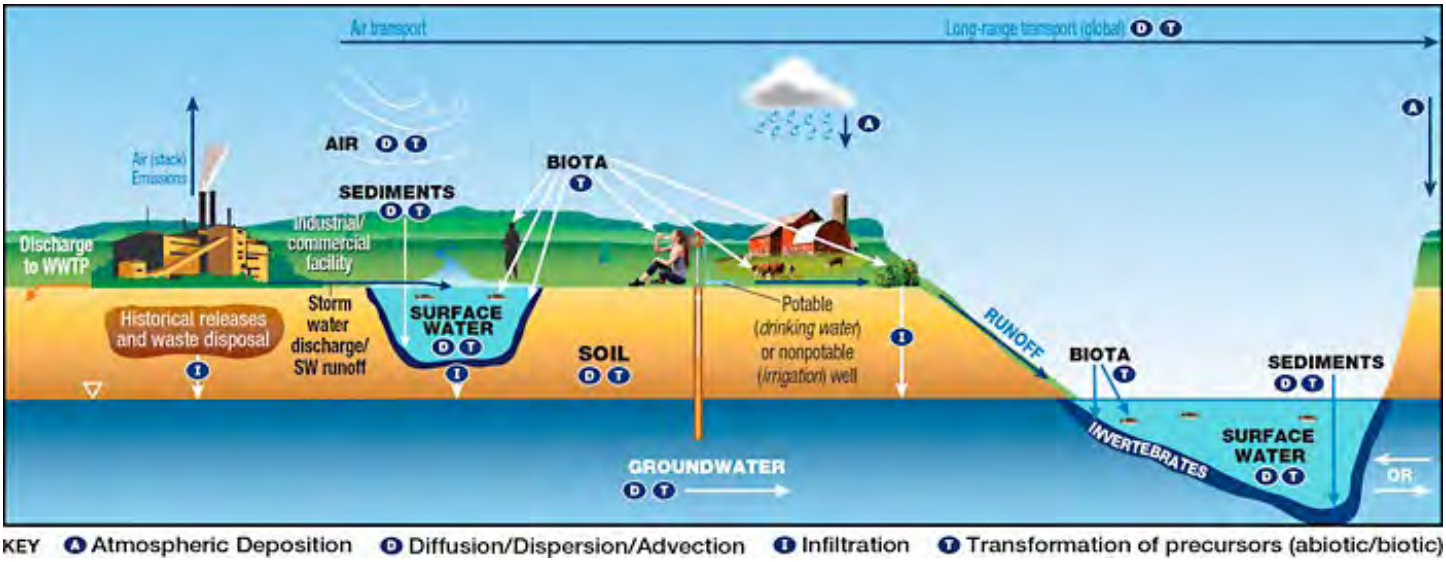


Figure 2-20. CSM for industrial sites.

Source: Adapted from figure by L. Trozzolo, TRC, used with permission.

The following subsections provide further details regarding potential sources of PFAS releases to the environment from PFAS use in manufacturing or industrial processes; these are not presented in order of the potential for significance of a release.

2.6.1.1 Building and Construction

Similar to other products, the chemical attributes of PFAS have led to advancements in building and construction materials. One particular application has been in composite wood and oriented strand board (OSB). Over the last 50 years, wood-based materials have used numerous additives for product strength and durability. A recent study performed on wood samples and OSB found primarily short-chain PFCAs and PFOA at concentrations ranging from 1.38 to 13.9 micrograms per kilogram (µg/kg) (**Bečanová et al. 2016**). Furthermore, wood fiber insulation has been shown to contain high amounts of PFHpA and other 5- to 8-carbon chain PFCAs (**Bečanová et al. 2016**). Many manufacturers use urea- or phenol-

formaldehyde due to their performance and low cost; however, the composition of the resins used by many manufacturers is proprietary.

Other materials, including certain types of building insulation (phenolic foam) have shown high amounts of PFOS. Additionally, PFAS (predominantly C8–C20 gamma-omega-perfluorotelomer thiols with acrylamide) have been used in the production of lightweight concrete, concrete sandwich panels, and lightweight concrete blocks (**Bečanová et al. 2016**; **Posner et al. 2013**). The prevalence of these building materials in the construction of fire training areas, AFFF storage facilities, and other areas potentially exposed to PFAS led to potential issues with demolition waste. The porous nature of these materials (for example, concrete, brick) could lead to PFAS adsorption/absorption, representing a potential source of PFAS when disposed in landfills or recycling facilities (**Australia Government DOD 2021**).

PFAS, including fluoropolymers such as PTFE, are used in the manufacture of architectural fabrics, such as those used in the construction of roof domes, including large stadiums and transportation facilities (**Performance Fluoropolymer Partnership 2021**; **Glüge et al. 2020**).

PFOS-related chemicals have several uses in paint and varnishes. They can be used as wetting, leveling, and dispersing agents, and have also been used to improve gloss and antistatic properties. Additionally, they can be used as additives in dyestuff and ink. Furthermore, they can be used as pigment grinding aids or as agents to combat pigment flotation problems (**KEMI 2004**; **RPA 2004**). Fluorosurfactants are commonly used in coatings application for substrate wetting, leveling, reduction of surface tension, oil repellency, and dirt pickup resistance (**Danish EPA 2015**; **Posner et al. 2013**).

Information received from different suppliers within the paint and varnish industry suggests that fluorinated surfactants in general are much more expensive alternatives compared to other surfactants. Therefore, fluorosurfactants are used only for special purposes in paint and varnishes, where it is necessary to gain such a low surface tension that no other (nonfluorinated) alternatives can achieve (**Danish EPA 2015**).

Studies pertaining to PFAS in building materials continue to be published. The Green Science Policy Institute recently published a report that summarizes currently available studies for the purposes of informing those in the building and construction industry of the presence of PFAS and eliminating unnecessary uses (**Fernandez, Kwiatkowski, and Bruton 2021**).

2.6.1.2 Cable and Wiring

In the 1950s the wire and cable industry began to use extruded grades of PTFE. This is a suspension polymerization process, which does not require surfactants, unlike dispersion polymerizations (for example, Teflon-coated pans). Melt extrusion is the process by which most fluoropolymers are applied to wires. For instance, FEP, PFA, and PVDF are heated to 260°C and then melt extruded over wire to continuous lengths. The equipment used for melt-processable fluoropolymers requires temperature sensitivity of 427°F. PTFE is processed via paste extrusion for coating PTFE over wires due to its high melting point (**ASTSWMO 2015**; **Kotthoff et al. 2015**; **Lau et al. 2007**; **Lindstrom, Strynar, and Libelo 2011**; **Oliaei et al. 2013**; **Renner 2001**; **Trudel et al. 2008**). For more information on the safe handling of fluoropolymer resins during processing, see the **Plastics Industry Association (2019)** guidance document.

2.6.1.3 Metal Finishing and Plating

Electroplating is a process that uses electric current to apply a metal coating to the surface of an object. Metallic ions in an acidic electrolyte solution are used in the electrochemical deposition of metal coatings to the surface of the cathode (**USEPA 1996**).

PFAS, particularly PFOS, have been used as mist suppressants that are added to metal plating and finishing baths to prevent air emissions of toxic metal fumes. **USEPA 2021** estimates that approximately half of the 1,339 chromium electroplating facilities in the United States still apply PFAS-based mist and fume suppressant. PFAS-containing chemicals may also be used in this industry as wetting agents, to reduce mechanical wear, and as surface coatings for reduced corrosion / enhanced appearance (**USEPA 2021**). **Glüge et al. (2020)** identified PFAS use in chrome, nickel, copper, tin, and zinc plating for lowering surface tension. In the United States, amendments to the National Emissions Standards for Hazardous Air Pollutants (NESHAP) under the Clean Air Act included a requirement to phase out the use of PFOS-based fume suppressants (a fume suppressant that contains 1% or greater PFOS by weight) in chromium electroplating by 2015 (**USEPA 2012**). Some countries (including the United States) have phased out the use of PFOS in some electroplating operations, adopting the use of other fluorotelomers (for example, 6:2 FTS) as a substitute in hard chrome plating operations (**Danish EPA 2015**; **KEMI 2015**) or changing decorative chrome plating operations to employ the less toxic trivalent chromium. PFAS known by the trade name F-53B have been used as metal plating mist suppressants in China (**USEPA 2021**; **Bao et al. 2019**). The toxicology of F-53B is reviewed in **Section 17.2.6.1** (note that toxicological research may use different nomenclature for F-53B, namely 6:2 chlorinated polyfluoroether sulfonate (6:2 ClPFESA) and 8:2 ClPFESA (**Munoz et al. 2019**). Non-fluorinated fume suppressants are also now available.

Many different types of electroplating solutions can be used in plating activities, including hard and decorative chrome plating; chromic acid anodizing; nickel, cadmium, or lead plating; metal plating on plastics; and alkaline zinc plating. Chrome electroplating is the most significant contributor as it relates to PFAS use. In this process, PFAS are used as surfactants to reduce the surface tension of the electrolyte solution. Historically, PFOS was commonly used at a concentration of 5–10% to limit the development of bubbles and the emission of hexavalent chromium aerosols to workplace air, thereby reducing the potential hazard to workers posed by hexavalent chromium (**USEPA 2009**) (**OSHA 2013**) (**Danish EPA 2015**).

Studies show use of PFAS in these settings can result in high concentration wastewater discharges (**USEPA 2009**) and air emissions. Once the electrolyte solution can no longer be used, it may be treated to remove chromium and other metals, but PFOS and other PFAS may be present in effluent and deposited in sewage sludge (**Danish EPA 2015**). Investigations in Minnesota traced PFOS releases from one chrome plating operation to a wastewater treatment plant (WWTP) where elevated levels of PFOS were detected in the biosolids, effluent water, and fish in the receiving surface water (**ATSDR 2008**). Air emissions from another Minnesota chrome plater were found to have accumulated on the roof of the facility and from there contaminated stormwater and snow melting from the roof, which in turn contaminated the groundwater, a nearby surface water system, and fish (**MPCA 2016**). In another study in Minnesota looking at PFAS air and deposition monitoring, elevated PFAS were found in the vicinity of a chromium plater (**MPCA 2022**).

According to a study in Michigan by the Michigan Department of Environment, Great Lakes, and Energy (EGLE), 320 metal finishers that had a history of using fume suppressants were found to have PFOS in wastewater effluent. The report noted that 15% of metal finishers were discharging to WWTPs at concentrations greater than screening criteria (12 ppt PFOS) and 5% were discharging greater than 1,000 ppt PFOS (**MI EGLE 2020**). Of the metal finishers discharging PFOS above screening criteria, 89% used hexavalent and/or trivalent chromium in their current or past processes. Chrome platers in Michigan were determined to be in compliance with the NESHAP and many replaced PFOS with a fume suppressant containing 6:2 FTS. Some chrome platers did not use PFOS-containing chemicals to control fumes and have not been found to be sources of PFOS to WWTPs. Nearly half of the chrome platers regulated under the NESHAP used mechanisms other than chemical fume suppression. It was concluded that current effluent containing PFOS from facilities that have complied with NESHAP originates from historical use of PFOS-containing fume suppressants.

2.6.1.4 Industrial Surfactants and Fluoropolymer Production

PFAS have been, and currently are, instrumental as surfactants in industrial and commercial production. In the recent past, some information pertaining to specific surfactant uses of PFAS has become publicly available, though much information still remains unavailable. Most well documented is the historical use of PFOA as a processing aid in the manufacturing of PTFE, where APFO is used to help mix together the chemicals needed to combine units of tetrafluoroethylene (TFE) to make PTFE. Similarly, APFN, the ammonium salt of perfluorononanoic acid (PFNA), has also been used in the production of PVDF. PVDF polymers that are produced with the aid of APFN are sold in solid phase, with notable residual APFN concentrations (100–200 ppm) (**Prevedouros et al. 2006**).

Since the voluntary phaseout of PFOA and related PFAS chemistries, replacement chemistries such as ADONA and the GenX process chemicals are now used in the production of fluoropolymers.

The PFAAs used as polymerization aids may occur as impurities/residuals in some fluoropolymer products, as discussed in detail in **Section 2.2.2.1**.

PFAS are also used in the manufacturing of plastics and fluoropolymers, rubber, and compression mold release coatings. These have applications in tubing, piping, drums, molds, and resins (**Poulsen et al. 2005**; **Prevedouros et al. 2006**).

2.6.1.5 Paper Products and Packaging

Since the 1960s, PFAS have been used as grease-proofing agents on food contact materials (FCM) to prevent oil, grease, and moisture from foods from leaking through the packaging. This includes coated paper and cardboard such as pizza boxes, microwavable popcorn bags, parchment paper, fast food wrappers, paper cups, pet food bags, and other items (**Rao and Baker 1994**; **Hekster, Laane, and De Voogt 2003**; **Poulsen et al. 2005; Trudel et al. 2008**; **Buck et al. 2011**).

The U.S. Food and Drug Administration (FDA) currently approves more than 90 unique monomer and polymer PFAS in FCMs (**USFDA 2016**). In January 2016, the FDA rescinded approval for three families of long-chain PFAS used in FCMs, but these had been voluntarily removed from the market in 2011. N-MeFOSE and N-EtFOSE were historically used to produce surface coatings for textiles and paper products (**Zaggia and Ameduri 2012**). PFAS currently used in FCM include polyfluorinated polyether-based polymers and shorter chain PFAAs (**Wang et al. 2015**; **Schaider et al. 2017**). See **Section 8.2** for additional information regarding a voluntary phaseout of 6:2 FTOH.

The most common PFAS detected in U.S. fast food wrappers include PFCAs (for example, PFOA and PFHxA), PFSAs (for example, PFBS), and fluorotelomer sulfonates (for example, 6:2 FTS) (**Schaider et al. 2017**). Six of 20 FCM tested were found to contain detectable levels of PFOA even though in 2011 U.S. manufacturers had voluntarily agreed to stop distributing FCM that were manufactured using PFOA via an FDA initiative. The methodology was not sensitive enough to detect if the PFAS were intentionally added to the packaging material or if they were attributed to unintentional background levels (**Schaider et al. 2017**). Refer also to **Section 2.4.3** on the USEPA 2010/2015 PFOA Stewardship Program, which discusses the phaseout of PFOA and potential sources of PFOA that may remain in commercial and consumer products.

2.6.1.6 Photolithography/Semiconductor Industry

The Priority Topics for History, Use, and Naming Conventions include information about semiconductor industry uses of PFAS (see **Section 1.1.1**).

The semiconductor industry historically has used PFOS for their surface-active properties in the fabrication of imaging devices such as digital cameras, cell phones, printers, and scanners (**Poulsen et al. 2005**). Studies have shown semiconductor waste streams containing the PFAAs PFBS, PFHxS, PFOS, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, and PFDoA (**Lin, Panchangam, and Lo 2009**). Similarly, in photolithography processes, PFOS has been used predominantly in applying top-layer antireflective coatings (TARCs), bottom antireflective coatings (BARCs), and etchants. Smaller quantities of PFOS and longer-chain PFAS have been used in wet etchants, film developers, cleaners, protective coatings, and color filters (**SIA 2008**), with ongoing uses permitted (**Section 2.4**).

2.6.1.7 Textiles, Leather, and Apparel (Including Carpet and Furniture)

Surface treatment of textiles, leather, carpet, and furniture upholstery with PFAS to make them stain, oil, and water repellent occurs both before (that is, at the factory) and after consumer acquisition for ongoing stain, oil, and water repellency (**Prevedouros et al. 2006**; **Ahrens 2011**; **Herzke, Olsson, and Posner 2012**). Aftermarket PFAS-containing stain-repellent products for carpets allow consumers to treat carpets and textiles at home (**Renner 2001**; **Hekster, Laane, and De Voogt 2003**). Losses to the environment can be related to dry cleaning and laundering activities (**Poulsen et al. 2005**; **3M Company 2000**).

Home textiles, including furniture and carpeting, as well as aftermarket PFAS surface treatment products, are also sources of long-chain perfluorinated chemical exposure (**Guo et al. 2009**). Textile coating operations may use water-emulsion or powdered feedstocks that contain greater proportions of PFCAs compared to PFSAs (**Lassen et al. 2015**; **Gremmel, Frömel, and Knepper 2016**). According to California EPA (CalEPA) **CalEPA 2018**, pg. 12, "The PFAS polymers used in carpets, rugs, and other textiles can contain various amounts of mobile residual raw materials, impurities, or transformation products, including PFAAs and other PFAA precursors such as fluorotelomer alcohols (FTOHs) and perfluoroalkyl sulfonamide alcohols." Releases to the environment could occur from disposal of carpet cleaning wastewater (**CalEPA 2018**). Physical degradation of some consumer products (such as PFAS-treated textiles and carpets, as well as paper) may be a source of PFAS in house dust (**Björklund, Thuresson, and de Wit 2009**). The weathering of certain textiles can also be the causes of potential releases of PFAS (**Schellenberger et al. 2022**; **van der Veen et al. 2020**).

It should be noted that many treated home textiles and carpets are now manufactured with alternatives to long-chain PFAS; however, these products can have a long useful life, making it possible that items previously treated with long-chain PFAS are still in use (**Brooke and Nwaogu 2004**). A 2009 study of over 100 consumer products conducted by the USEPA and Arcadis indicated that pretreated carpet, treated upholstery and textiles, as well as other floor treatments, are likely the largest source of PFAS receptor exposure in American homes (**Guo et al. 2009**).

Other studies have since shown nonpolymeric PFAS in leather samples and outdoor textiles to impart water, oil and stain resistance; applications include protective clothing, outerwear, footwear, umbrellas, tents, and sails (**OECD 2013**; **Walters and Santillo 2006**; **Kotthoff et al. 2015**). Durable water repellent (DWR) is a fabric surface finish that creates a protective barrier. It is typically added at the factory, but is also available to consumers for apparel maintenance (**Brooke and Nwaogu 2004**). The finishes/treatments are applied to materials in mills/tanneries and as aftermarket applications by professionals or do-it-yourself consumers as aqueous dispersions. In some aftermarket applications, they are applied as solutions in hydrocarbon-based or halogenated solvents (**OECD 2013**).

2.6.1.8 Other Potential Commercial or Domestic Sources of PFAS Releases to the Environment

There is the potential for everyday uses of PFAS to result in relatively smaller releases of PFAS to the environment. Of note, these may include, but are not limited to leaching from materials to media (for

example, well construction and plumbing materials), discharges to on-site wastewater disposal systems from use of household products and cosmetics, discharges from car washing and waxing, and use of ski waxes (professional ski wax technicians may have significant inhalation exposures to PFAS (**Nilsson et al. 2013**). Snowmelt and surface waters (**Kwok et al. 2013**), as well as snow, soil, and groundwater (**Carlson and Tupper 2020**), near ski areas may have measurable PFAS impacts.

2.6.2 Class B Fluorine-Containing Firefighting Foams

Some Class B firefighting foams designed for extinguishing flammable liquid hydrocarbon fires and vapor suppression may contain fluorine. These foams can be a major source of local PFAS release to the environment, with the CSM included in **Figure 2-21**.

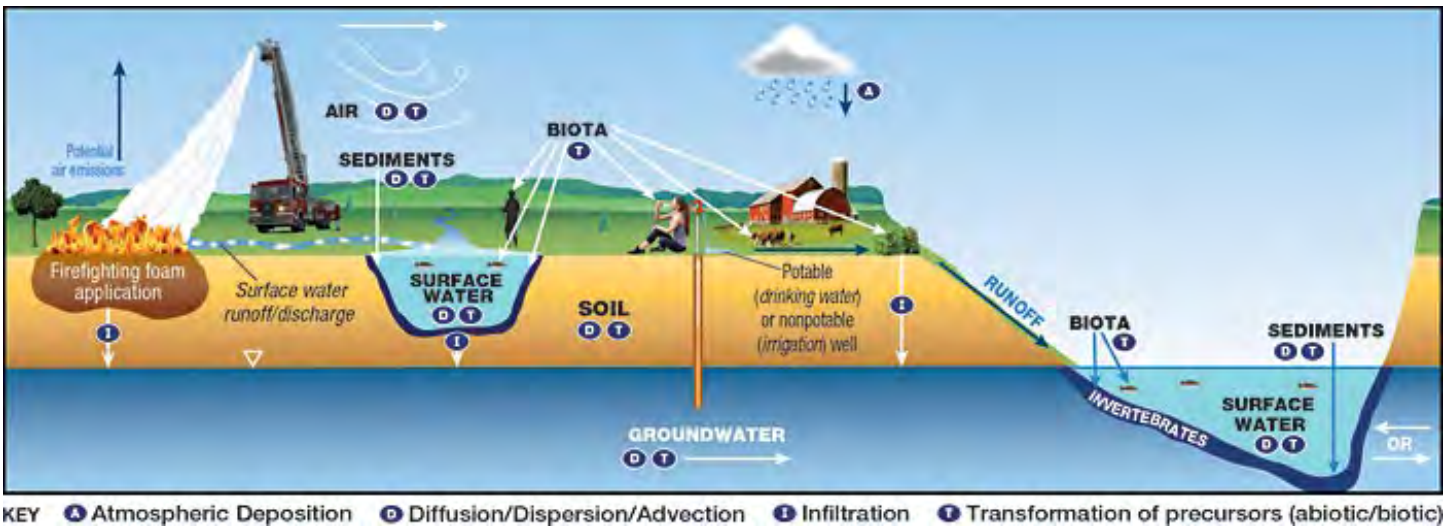


Figure 2-21. CSM for fire training areas.

Source: Adapted from figure by L. Trozzolo, TRC, used with permission.

Class B firefighting foams are commercial surfactant solutions that have been (and continue to be) stored and used for fire suppression, fire training, and flammable vapor suppression at military installations and civilian facilities and airports (**Hu et al. 2016**), as well as at petroleum refineries and bulk storage facilities, and chemical manufacturing plants and storage facilities (**CONCAWE 2016**). Additionally, local fire departments in communities have used and may maintain quantities of firefighting foam in their inventories for use in training and emergency response. Facilities that manufactured firefighting foams and landfills that received firefighting waste are also potential sources. Refer to **Section 3** and **Section 1.2** for more detailed information about firefighting foams.

2.6.3 Solid Waste Management Facilities

Environmental releases associated with the use of PFAS-containing products are primarily related to management of solid waste (for example, disposal of used items in a landfill or other legacy disposal areas). Other solid waste facilities, such as scrap yards and metal salvage facilities, might also be a potential source of release to the environment. Some PFAS are considered hazardous waste by some states (**Section 8**). Additional information pertaining to disposal of PFAS and PFAS-containing materials at MSW landfills can be found in the 2020 USEPA Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances (**USEPA 2020**).

Landfills can be sources of PFAS because they are the ultimate repositories for PFAS-contaminated industrial waste, sewage sludge from wastewater treatment facilities, and waste from site mitigation, as well as for PFAS-bearing consumer wastes, such as goods treated with hydrophobic, stain-resistant coatings (**Busch et al. 2010**; **Eggen, Moeder, and Arukwe 2010**). But the type and concentration of PFAS vary greatly among landfills, due to variations in the waste streams. Industrial waste can be a significant source of PFAS in landfills (as well as in wastewater and biosolids), particularly those that accept waste from facilities involved in the production or application of PFAS (**Oliaei et al. 2013**). Although MSW will contain PFAS due to its presence in so many consumer products, it generally is expected to have lower concentrations than landfills that accept industrial waste. Given the production timeline of PFAS, industrial, commercial, and consumer products and waste disposed since the 1950s are potential sources of PFAS release to the environment. As PFAS manufacturing processes change with time, the resulting type and composition of waste streams also change. PFAS production and use began several decades before the enactment of federal and state regulations governing waste disposal; as a consequence, environmental and drinking water impacts from disposal of legacy PFAS industrial and consumer waste have been documented (**Oliaei, Kriens, and Weber 2010**; **Shin et al. 2011**; **MPCA 2017**).

Figure 2-22 illustrates common elements of CSMs associated with the potential release scenarios at waste management facilities.

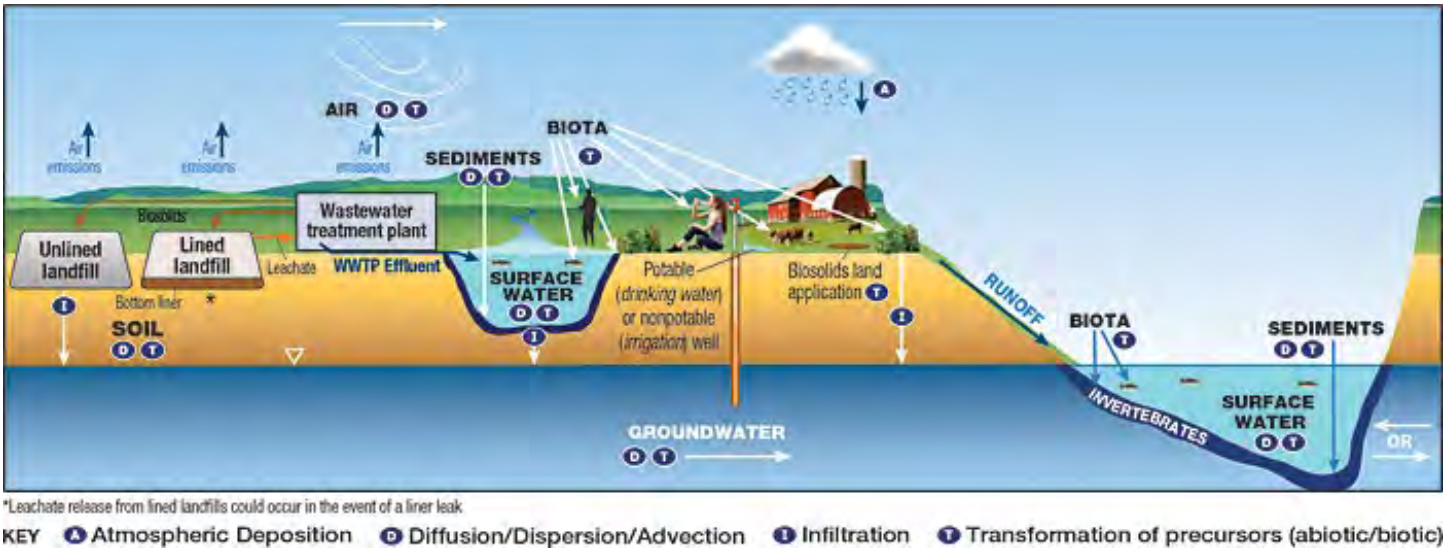


Figure 2-22. CSM for landfills and WWTPs.

Source: Adapted from figure by L. Trozzolo, TRC, used with permission.

2.6.3.1 Landfill Construction

Landfills are either lined or unlined (**Figure 2-22**). Municipal solid waste (MSW) landfills constructed since the 1990s are required by federal or state regulations to install a composite liner, a layer of compacted soil, and a leachate collection system (40 CFR 258.40). Although some states may have implemented construction standards at an earlier date, most landfills constructed before the 1990s were not required to have synthetic flexible membrane liners, compacted soil liners, or leachate collection systems, causing waste to be in direct contact with underlying soil or groundwater. Hazardous waste (Subtitle C) landfills have similar design requirements for the liner system, though an additional composite layer and leak detection layer are required (40 CFR 264.301). Construction and demolition (C&D) landfills or nonmunicipal solid waste landfills are subject to the requirements specified in 40 CFR 257 Part A (and if they intend to accept very small quantity generator waste, they are also subject to 40 CFR 257 Part B). Minimum design criteria for landfill liners are not specified in 40 CFR 257. Therefore, new C&D and

nonmunicipal solid waste landfills may be permitted and constructed (or new cells added to existing facilities) without synthetic liners. Some states may have more restrictive requirements. Therefore, unlined landfills (and legacy disposal areas not classified as landfills) have a higher potential of contributing PFAS to groundwater (**Oliaei et al. 2013**). Properly constructed and operated modern landfills provide one of the few available disposal/management options for PFAS-containing waste, including wastewater solids, remedial/treatment waste, and consumer products. The USEPA Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances provides further discussion about the use of landfills for management of PFAS-containing wastes, the potential for PFAS to be released to the environment from landfills, and the additional research and data that are needed to further assess the effectiveness of managing PFAS discharges and emissions from all landfills (**USEPA 2020**).

Landfills are currently required to use a daily cover or alternate daily cover. It is acceptable for alternative daily cover to include materials such as sludge, sludge-derived products, shredded automotive parts, spray-on foams, and other materials (**Pohland and Graven 1993**) that are possible sources of PFAS. Landfill caps reduce infiltration of water to waste and may reduce the overall mass of PFAS entering the environment from a landfill, but more research on their effectiveness is needed (**Hamid, Li, and Grace 2018**).

Leachate from some MSW landfills has been shown to be a source of PFAS release to the environment (**Busch et al. 2010**; **Eggen, Moeder, and Arukwe 2010**), although the fate and transport processes for PFAS through landfills into leachate are not well understood at this time. The processes for managing leachate have implications on the ultimate fate and transport of PFAS. If landfill liners or leachate collection systems fail, PFAS may directly enter the environment. Leachate collected from landfills is typically treated on site or transported to either a WWTP or evaporation ponds. Modern landfills with properly constructed and operated liner and leachate collection systems should generally protect the underlying groundwater from PFAS releases. Leachate treatment by WWTPs is common prior to discharge to surface water or distribution for agricultural or commercial use (**Lang 2016**). However, standard WWTP technologies are generally ineffective at reducing or eliminating PFAS (**Hamid and Li 2016**; **Ahrens et al. 2016**; **CRC CARE 2017**). As a result, the discharge of landfill leachate, even if treated at WWTPs, can be a significant source of release of some PFAS to the environment (**Ahrens et al. 2016**; **CRC Care 2017**). Although landfill leachate PFAS concentrations can be relatively high, landfill leachate discharged to WWTPs for treatment generally is considered a relatively minor source to the environment because the volume of leachate generated annually and sent to a WWTP for treatment is low compared to the flow volume in most WWTPs (**Busch et al. 2010**; **Masoner et al. 2020**; **MWRA 2019**). On a site-specific basis, the impact of leachate on combined wastewater influent PFAS mass loading can vary depending on the relative volumetric contribution of leachate to combined influent flows and the nature of the landfilled waste materials (**Masoner et al. 2020**). Furthermore, USEPA's Effluent Guidelines Program Plan, (**USEPA 2023**) states "EPA evaluated discharge data from over 200 landfills from across the country and found PFAS present in the leachate at over 95 percent of the landfills. PFAS detections included 63 different PFAS with average concentrations for an individual compound as high as 14,000 parts-per-trillion (ppt)." However, in a limited study of five wastewater treatment facilities in Florida, **Masoner et al. (2020)** did not identify differences in the effluent PFAS loading of wastewater treatment facilities that received landfill leachate relative to those that did not, suggesting the PFAS load present in wastewater treatment effluent is attributable to numerous sources. A similar finding was noted by **MWRA (2019)**, though only PFOA and PFOS were investigated.

As part of EPA's final Effluent Limitations Guidelines Plan 15, **USEPA (2023)** announced its plans to proceed with a rulemaking to address PFAS discharges from landfills; refer to **Section 16.6** for more information on this rulemaking.

2.6.3.2 Waste Age

Landfills containing sources of PFAS may continue to release PFAS to leachate at slow but relatively steady rates for decades following initial placement. In modeled anaerobic landfill reactors, most of the release is attributed to biological, not physical, mechanisms, indicating that the low solubility of the compounds is not solely responsible for slow release rates from landfills (**Allred et al. 2015**; **Lang et al. 2016**). Legacy industrial waste landfills may constitute a major source of PFAS release to the environment (**ATSDR 2008**, **2012**).

2.6.3.3 PFAS Composition

PFAS composition and concentration in leachates vary depending on waste age, climate, and waste composition (**Allred et al. 2015**; **Lang et al. 2017**). Relative concentrations of PFAS in leachate and groundwater from landfills are different from those at WWTPs and AFFF-contaminated sites. PFAS with fewer than eight carbons tend to dominate landfill leachate because they are less hydrophobic and therefore more likely to partition to the aqueous phase (**Huset et al. 2011**; **Higgins and Luthy 2007**). In particular, 5:3 fluorotelomer carboxylic acid (FTCA) is a common and often dominant constituent of PFAS found in landfills and is released from carpet in model anaerobic landfill reactors. This compound could prove to be an indicator of PFAS in the environment originating from landfills (**Lang et al. 2017**, **2016**).

PFAS may also be released to the air from landfills, predominantly as fluorotelomer alcohols (FTOHs) and perfluorobutanoate (PFBA). In one study, total PFAS concentrations were 5–30 times greater at landfills than at background reference sites (**Ahrens et al. 2011**). PFAS release rates vary with time for a given waste mass, with climate (for example, rainfall) as the apparent driving factor for the variations (**Lang et al. 2017**; **Benskin et al. 2012**). Gas collection systems commonly employed at modern landfills should reduce possible PFAS emissions to air.

2.6.4 Wastewater Treatment and Wastewater Treatment Residuals and Biosolids

The Priority Topics for Biosolids Land Application (see **Section 1.7**) include information that supplements the Biosolids information included here.

Consumer and industrial use of PFAS-containing materials, including disposal of landfill leachate and firefighting foam, may discharge PFAS-containing wastewater to municipal and industrial WWTPs (**Lin, Panchangam, and Lo 2009**; **Ahrens et al. 2009**) private septic systems (see **Section 1.3.2**), or other wastewater disposal systems.

2.6.4.1 Wastewater Treatment

WWTPs receive PFAS from a host of sources conveyed thru and aggregated in effluent and sludges, which can provide the following pathways for PFAS releases to the environment (**Figure 2-22**):

- point source discharges of effluent
- leakage or unintended releases from surface impoundments and structures
- air emissions
- management (for example, land application) and disposal (for example, landfilling, incineration) of biosolids (https://www.epa.gov/biosolids), wastewater solids and sludges, and other byproducts generated during the treatment process (**Section 2.6.4.2**). Refer to **Section 12** for more information on incineration.

The composition of PFAS in these media is a function of the different sources to the WWTP influent and the WWTP processes (**Chen, Lo, and Lee 2012**; **Oliaei, Kessler, and D. Kriens 2006**; **Frömel et al. 2016**; **Schultz et al. 2006**), including:

- type and concentration of PFAS received by the WWTP
- biological and chemical transformation of polyfluorinated substances (that is, precursor PFAS) to intermediate and terminal transformation products, such as PFAAs
- physical or chemical partitioning, or both.

In addition to PFAAs, fluorotelomer sulfonates, and sulfonamides, another family of PFAS precursor compounds, polyfluoroalkyl phosphate monoesters (PAPs) and polyfluoroalkyl phosphate diesters (diPAPs) (particularly 6:2 and 8:2 PAP; and 6:2 and 8:2 diPAP) have been documented in wastewater treatment plant (WWTP) samples and especially biosolids (**Eriksson, Haglund, and Karrman 2016**; **Fredriksson et al. 2022**; **Kim Lazcano et al. 2020**; **Lee et al. 2014**). This family of PFAS precursors plays an important role since they are typically found at much higher concentrations than commonly measured PFAS (**Aro et al. 2021**; **Fredriksson et al. 2022**; **Moodie et al. 2021**; **Schaefer et al. 2022**) and they have been shown to biotransform to PFAAs (**Eriksson, Haglund, and Karrman 2016**). **Fredriksson et al. (2022)** reported diPAPs accounting for 66% of the total concentrations of PFCAs precursors in sludge samples with the sum of diPAPs reaching up to 632 µg/kg, consistent with findings by **Schaefer et al. (2022)**. As a result of precursor biotransformation, the concentrations of PFAAs can increase from influent to effluent, while the concentrations of these PFAS precursors decrease (**Chen et al. 2018**; **Dauchy et al. 2017**; **Houtz, Wang, and Park 2018**).

PFAS occurrence is reported in small municipal wastewater treatment plants with only domestic sources (**Sinclair and Kannan 2006**). PFAS in non-industrial wastewater is attributed to environmental transformation of polyfluorinated microfibers that might be released by different sources, for example, water-resistant clothing during laundry (**Schellenberger et al. 2019**), food packaging (**Choi et al. 2019**; **Schaider et al. 2017**), human excretion after oral exposure (**Ma, Zhu, and Kannan 2020**; **Worley et al. 2017**), and tap water (**Andrews and Naidenko 2020**; **Filipovic and Berger 2015**).

Thompson et al. (2022) suggested that domestic wastewater accounts for most of the PFAS load in WWTPs while historically industrial discharges was believed to cause the majority of the PFAS releases from WWTPs.

Conventional sewage treatment methods used in WWTPs do not efficiently remove PFAAs (**Ahrens et al. 2011**; **Schultz et al. 2006**). Even WWTPs with advanced treatment technologies (such as granular activated carbon (GAC), powdered activated carbon (PAC), or reverse osmosis (RO)) may not fully remove all PFAS if these systems were not designed with the intent to remove PFAS in addition to other targeted contaminants. Some PFAAs are frequently detected in WWTP effluent (for example, PFOA and PFBS), with concentrations of some PFAS up to hundreds of ng/L (**Tavasoli et al. 2021**). **Ahrens et al. (2011)** and **Hamid and Li (2016)** suggested that WWTP effluent can be a major source of PFAAs to surface waters.

Evaluation of full-scale WWTPs has indicated that conventional primary (sedimentation and clarification) and secondary (aerobic biotransformation of organic matter) treatment processes can change PFAS concentrations and subgroups. For example, studies have shown increased concentrations of PFAAs in effluent, presumably from transformation of precursor PFAS (**Schultz et al. 2006**), and the possible creation of PFAAs from the oxidation of polyfluorinated precursors during the treatment process (**Oliaei, Kessler, and D. Kriens 2006**; **Frömel et al. 2016**; **Houtz, Wang, and Park 2018**).

PFAS may be concentrated in wastewater solids (for example, sewage sludge) generated throughout the wastewater treatment process (**Schultz et al. 2006**). PFAS may also be present in septage (solids removed from septic systems). Depending on waste management and disposal practices, land

application or landfill disposal of wastewater solids, biosolids, or septage could potentially contaminate the environment.

Hu et al. (2016) suggested that the presence of WWTPs in an area could be predictive of the presence of PFOS and PFOA in drinking water. PFOS and PFOA are two of the most frequently reported PFAS in wastewater (**Hamid and Li 2016**) in addition to other relevant PFAS such as diPAPs (**Schaefer et al. 2023** and **Thompson et al. 2023**); see **Section 6.2.3** for more information. Using WWTP effluent-impacted surface water as a source of drinking water can, in turn, recycle the PFAS back to the WWTP, recirculating PFAS in the water cycle (**Hamid and Li 2016**).

At some WWTPs, studies have shown concentrations of PFAS in ambient air at WWTPs to be 1.5–15 times greater than background reference sites (**Hamid and Li 2016**). **Hamid and Li (2016)** noted that these elevated air concentrations of total PFAS include polyfluoroalkyls and that this has important implications considering the potential for their long-range transport and subsequent transformation to recalcitrant PFAAs. PFAS distribution (primarily PFAAs and FTOH, with higher concentrations of FTOH) changes based on the specific PFAS sources in the effluent and the type of treatment methods employed at the WWTP.

Michigan EGLE has a program for evaluating PFAS in WWTP influent, effluent, and biosolids including conducting studies to better understand the fate and transport of PFAS from land application of biosolids (**MI EGLE 2021**). This included sampling of WWTP influent, effluent, and associated sludge or biosolids at 42 WWTPs and sampling of soils, groundwater, and surface waters at eight biosolids land application sites. The land application sites that received biosolids with "typical" levels of PFAS generally exhibited non-detectable to low concentrations of PFAS in soils and surface waters. The sites that received biosolids with higher PFAS levels that EGLE considered to be "industrially-impacted" showed higher concentrations of PFAS in the soils, surface water and groundwater with some results exceeding certain Michigan criteria. Results from the broad biosolids sampling were used to develop an Interim Biosolids Land Application PFAS Strategy (**MI EGLE 2024**), which in conjunction with the other State initiatives, allowed the majority of WWTPs to maintain the option to land apply biosolids while maintaining protectiveness. Restrictions were placed on land application of biosolids containing PFAS above certain criteria. Additional information about the MI EGLE biosolids programs are linked from their web site (**https://www.michigan.gov/egle/about/organization/Water-Resources/biosolids/pfas-related**).

Human exposure to PFAS can occur from wastewater through leaching into groundwater from biosolids land application or landfill operations, bioaccumulation into food or unplanned/planned potable reuse (**Ahrens et al. 2011**; **Glover, Quinones, and Dickenson 2018**; **Hu et al. 2016**; **Lindstrom et al. 2011**). More information about human exposures to PFAS is included in **Section 9.1.2**.

2.6.4.2 Biosolids Production and Application

Biosolids or "sewage sludge" are products of liquid separation from solids in wastewater treatment systems which undergo further physical chemical treatments to produce nutrient-rich products. Biosolids are residuals that have been treated thermally and/or chemically to meet state and federal standards to allow beneficial reuse. Biosolids are managed through beneficial reuse with land application (agriculture, turf grass, land reclamation) or composting (fertilizer) or disposed of by landfilling, incineration, or other form of surface disposal (**NACWA 2023**). Biosolids must meet state and federal requirements prior to land application in agricultural and reclamation sites. Land application of biosolids can offer economic and waste management benefits to municipalities and farmers (**Stulp 1995**). It should be noted that biosolids are not wastewater solids, industrial-derived sludges, or sludges that are the untreated solids/sludge removed during the process of treating wastewater.

PFAS presence in wastewater treatment residuals generated at municipal WWTPs is the result of widespread presence in engineered and natural systems, including numerous consumer products and certain industrial processes. The residuals can contain varying levels of PFAS commensurate with sewer shed characteristics, one of which is the type of and degree of influence that industrial dischargers have on municipal WWTPs. Several studies have reported results of testing of biosolids for PFAS (**MI EGLE 2022**). PFAS (measured as PFCAs and PFSAs) have been found in domestic sewage sludge (**Higgins et al. 2005**; **Yoo et al. 2009**), and PFAS occurrence in biosolids is reported to be prevalent and nationwide (**Venkatesan and Halsden 2013**).

PFAS are not known to be intentionally added to biosolids during processing or application since WWTPs are largely considered passive recipients of these chemicals.

There are a number of methods currently used to manage biosolids. According to **USEPA (2023)**, around 43% of biosolids are land applied (typically as agricultural fertilizer), 42% landfilled, 14% incinerated, and 1% are stored or deep-well injected in the United States. The National Biosolids Data Project (https://www.biosolidsdata.org/) similarly reports about half of the biosolids are land applied, 25% are disposed in landfills, and 15% managed through incineration. Given the significant proportion of biosolids land applied for agriculture, there is the potential for release of PFAS to the environment associated with biosolids production and application. A small number of states have placed restrictions on incineration of PFAS containing material until the efficiency of destruction is better understood through on-going studies. Landfilling biosolids may lead to increased PFAS in landfill leachate which must be managed or increase the potential for releases to groundwater or air. However, there may be a greater reliance on landfilling in some states as restrictions are made on other management options. Long term landfilling of biosolids would also stress existing landfill capacity. In addition, a small number of states have also restricted the land application of biosolids due to concerns related to PFAS.

Biosolids can be land applied in several ways, including subsurface injection of liquid biosolids, surface application of liquid biosolids, surface application of dewatered (semi-solid) biosolids, or application and incorporation of dewatered (semi-solid) biosolids. Once introduced to the environment through land application, PFAS may enter surface water through runoff or infiltrate to groundwater (**Lindstrom, Strynar, and Libelo 2011**). Biosolids are also dried/pelletized for direct use as a soil amendment/fertilizer and for use in fertilizer blends that are then marketed commercially. The potential effects on groundwater or surface water may depend on many factors including but not limited to the amount and composition of PFAS present in biosolids, soil properties, infiltration rate, land application practices, land use, precipitation, climate, and land slope. PFAS concentrations can be elevated in surface water and groundwater in the vicinity of agricultural fields that received PFAS-contaminated biosolids over an extended period of time (**Washington et al. 2010**). The Washington et al. study was completed in an area that received industrial wastewater discharges from several PFAS-related industrial dischargers. Other studies indicate that the potential PFAS releases from municipal biosolids (for example, those generated at WWTPs that do not receive significant inputs from industries linked to PFAS), may still impact water quality, but at an apparent lower relative impact than at the industrial-influenced biosolids application sites (**Gottschall et al. 2017**). **Pepper et al. (2021)** examined PFAS in soil in Arizona following long-term application of biosolids. The study concluded “long-term land application resulted in low incidence of soil PFAS” and “PFAS soil concentrations in irrigated agricultural plots with or without land application of biosolids were similar” (**Pepper et al. 2021**).

The most abundant PFAS found in biosolids (PFOS and PFOA) are the same as those found in WWTP effluent, although biosolids may also contain other long-chain PFAS (**Hamid and Li 2016**; **Washington et al. 2010**). Although multiple studies have reported statistically significant data showing transformation of polyfluorinated substances to PFAAs in land-applied biosolids (**Yoo et al. 2010**; **Sepulvado et al. 2011**; **Washington et al. 2010**), other evidence indicates that some polyfluorinated substances remain in biosolids-amended soils for many years to decades (**Yoo et al. 2010**; **Rich et al. 2015**; **Washington et al. 2018**).

Application of municipal or industrial biosolids as a soil amendment can result in a transfer of PFAS to soil (**Sepulvado et al. 2011**). These PFAS can then be available for uptake by some plants and soil organisms (**Yoo et al. 2011**). There are indications that PFAAs can enter the food chain through the use of biosolids-amended soil (**Lindstrom, Strynar, and Libelo 2011**; **Blaine et al. 2013**; **Blaine et al. 2014**; **Navarro et al. 2017**). It is noted, however, that PFAAs present at one municipal biosolids application site were not found in grain grown in the application plot (**Gottschall et al. 2017**). **Hamid and Li (2016)** suggested that short-chain (< C7) PFAAs in biosolids subsequently used in land applications can lead to contamination of food (**Section 5.6**). Significant data gaps exist regarding the fate and transport mechanisms associated with land application of PFAS impacted biosolids and the associated impacts to the food chain are an active area of study (see **Section 6.5**).

Refer to **Section 2.6.4.1** for information on Michigan EGLE's program for evaluating PFAS in WWTP influent, effluent, and biosolids including conducting studies to better understand the fate and transport of PFAS from land application of biosolids (**MI EGLE 2021** and **MI EGLE 2024** which includes links to field report addenda for individual application sites). The Environmental Council of the States (ECOS) collected information in November 2022 from state environmental agencies about management of biosolids and published a report of their findings (**ECOS 2023**).

3 FIREFIGHTING FOAMS

The purpose of this section is to assist aqueous film-forming foam (AFFF) users (first responders, regulators, environmental managers, and environmental professionals) who manage AFFF releases. The section includes information about the applications, environmental impacts, and regulations associated with firefighting foams.

Section Number	Topic
1.2	**Priority Topics for Firefighting Foams (2025)**
3.1	**Foam Formulations**
3.2	**AFFF Characteristics**
3.3	**Mechanisms for Release to the Environment**
3.4	**AFFF Fate and Transport**
3.5	**Forensic Analysis of AFFF**
3.6	**AFFF Procurement and Inventory**
3.7	**Foam Systems and Operations**
3.8	**Emergency Firefighting Operations**
3.9	**Immediate Investigative and Cleanup Actions**
3.10	**AFFF Disposal**
3.11	**Firefighting Foam System Replacement**
3.12	**Federal, State and International Regulations and Guidance**
3.13	**Foam Research and Development**

It should be noted that the priority of firefighters and first responders is to protect life and property. The information provided supports decision-making about firefighting using AFFF so that potential impacts to the environment can be minimized and mitigated once the fire emergency is ended, or at such time that sufficient resources are deployed to the scene to both handle the fire emergency and mitigate the environmental risks posed by AFFF use. Fluorine-free foam (F3) alternatives are also discussed; these foams are not "film-forming" and are mechanistically different than AFFF in how they work to extinguish a fire. **Figure 3-1** illustrates the life cycle considerations of AFFF. The considerations are discussed in subsequent sections.



Figure 3-1. Life cycle considerations for Class B Foams.

Source: S. Thomas, Battelle. Used with permission.

3.1 Foam Formulations

There are two major classes of firefighting foam, Class A and Class B foams. Class A foams are not considered in this document as

they are intended for use on Class A or wood fuel fires. They are made from hydrocarbon-based surfactants, do not contain intentionally added PFAS, and are appropriate to use for their intended purpose. They are covered under NFPA 1150 (Standard on Foam Chemicals for Fires in Class A Fuels) (**NFPA 2022**).

Class B firefighting foams are commercial surfactant solutions that are designed and used to combat Class B flammable fuel fires. PFAS (fluorinated surfactants) are the active ingredient in Class B fluorinated foams. When mixed with water and discharged, the fluorinated foam forms an aqueous film that quickly cuts off the oxygen to the fire, cools it, extinguishes the fire, and prevents the fire from relighting. Class B foams have been (and continue to be) stored and used for fire suppression, fire training, and flammable vapor suppression at military installations and civilian facilities and airports (**Hu et al. 2016**), as well as at petroleum refineries and bulk storage facilities and chemical manufacturing plants (**CONCAWE 2016**). Additionally, local community fire departments have used and may maintain quantities of firefighting foam in their inventories for use in training and emergency response. Facilities that manufactured fluorinated firefighting foams and landfills that received firefighting waste are also potential sources of PFAS in the environment.

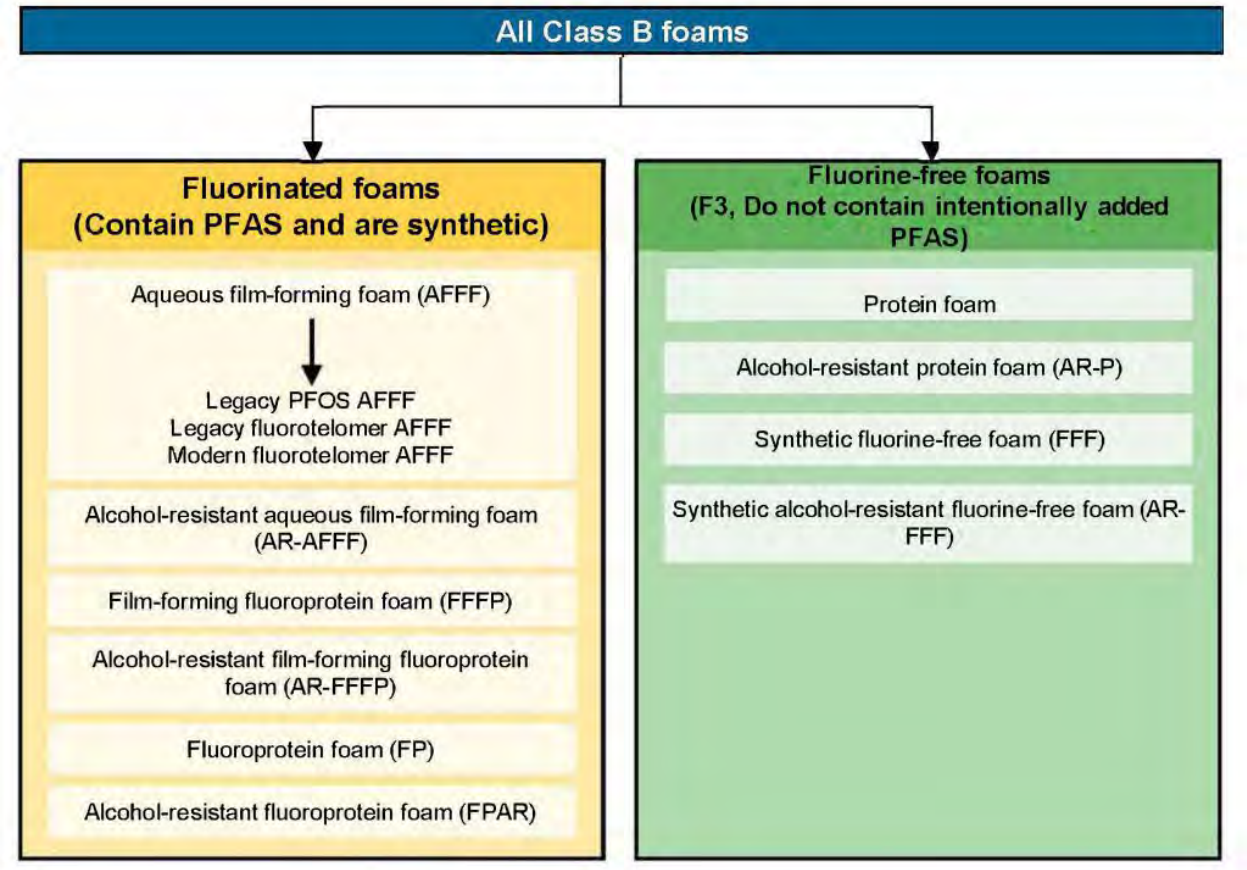


Figure 3-2. Types of Class B foams.

Source: S. Thomas, Battelle. Used with permission.

All Class B foams are not the same in composition and use different mechanisms to extinguish fires. Although not usually categorized this way from a fire protection viewpoint, they can be divided into two broad categories from a PFAS composition perspective: fluorinated foams that contain PFAS and F3 that do not contain intentionally added PFAS. **Figure 3-2** highlights the two broad categories of Class B foams and their general subcategories. Both fluorinated and fluorine-free foam examples are presented. As the

fluorine-free options continue to expand, the nomenclature and acronyms also expand. Synthetic fluorine-free foam may also be referred to as Fluorine-free foam (FFF), Synthetic Fluorine-free Foam (SFFF) or Non-fluorinated Foam (NFF). Similarly, synthetic alcohol-resistant fluorine-free foam may be referred to as Alcohol-resistant Fluorine-free foam (AR-FFF), (AR-SFFF, AF-NFF).

All Class B foams have the potential to create an adverse environmental impact if uncontrolled releases to the environment occur, particularly if the foam reaches drinking water sources, groundwater, surface water, or other natural waters. For all Class B foams, including F3, there is a potential for acute aquatic toxicity and excessive biological and chemical oxygen demand, as well as nutrient loading, depending on where the discharge occurs (see Section **3.11.1.3**). The Priority Topics for Firefighting Foams include information about recent studies of firefighting foam ecotoxicity (see **Section 1.2.2**).

This section is focused on AFFF because of its long-term and widespread use and associated impacts to human health and the environment. AFFF is of particular concern because it contains PFAS.

As discussed elsewhere in this document, many PFAS are highly persistent and mobile in the environment and are not removed by traditional drinking water treatment methods typically used by public water suppliers.

Other foams such as alcohol-resistant foams (AR-AFFF), film-forming fluoroprotein foams (FFFP), alcohol-resistant film-forming fluoroprotein foams (AR-FFFP), fluoroprotein foam (FP), and alcohol-resistant fluoroprotein foam (FPAR), as illustrated in **Figure 3-2**, also contain PFAS and similar precautions and considerations should be taken.

The fluorosurfactants in AFFF formulations can be produced either using the electrochemical fluorination (ECF) process or the fluorotelomerization (FT) process. Both ECF-derived and telomer-derived AFFF contain diverse mixtures of PFAS (**Barzen-Hanson et al. 2017**). The ECF process results in a PFAS mixture dominated by perfluoroalkyl acids (PFAAs)—both perfluoroalkane sulfonate (PFSA) and perfluoroalkyl carboxylate (PFCA) homologues, while the fluorotelomerization process exclusively produces AFFF formulations consisting of polyfluorinated compounds (**Houtz et al. 2013**). ECF-based AFFF formulations were voluntarily phased out of production in the United States in approximately 2002 (**Section 2.4.1**). Despite the phaseout, however, ongoing permitted use of legacy AFFF can still result in long-chain PFAA contamination. Several organizations (for example, U.S. Department of Defense) commenced systematic replacement of legacy PFOS AFFF with modern fluorotelomer AFFF as early as 2018, but some legacy AFFF remains in service or stockpiled at other facilities (**Section 3.11.1**).

Fluorotelomer foams have been in use since the 1970s and became the predominant foam after 2001, when the major manufacturer (3M) of long-chain ECF-based foams (legacy PFOS foam) discontinued production (**Leeson et al. 2021**). Fluorotelomerization-derived AFFF is still manufactured and used in the United States but has been reformulated with the goal to eliminate, long-chain PFAS; these foams are now referred to as modern fluorotelomer foams. Studies show ECF-based AFFF is a primary source of PFAS at AFFF-impacted sites, likely due to the longer period of ECF-based AFFF use and the relative coincidence of implementation of engineering controls for releases with increased use of fluorotelomer-based AFFF (**CONCAWE 2016**; **Anderson et al. 2016**).

To further classify AFFF products in terms of current usage and environmental considerations, they can be divided into three categories, including legacy PFOS AFFF, legacy fluorotelomer AFFF, and modern fluorotelomer AFFF (as shown in **Figure 3-2**).

- Legacy PFOS AFFFs were created in the 1960s by 3M and manufactured in the United States from the late 1960s until 2002 exclusively by 3M and sold under the brand name “Light Water” (**USDOD 2014**). 3M was the sole supplier from the mid-1960s until 1973. 3M did license some companies overseas to use their products and formulations. Legacy PFOS AFFFs contain PFOS and PFSAs such as perfluorohexane sulfonate (PFHxS) (**Backe, Day, and Field 2013**). Although

phased out of production in 2002, legacy PFOS AFFFs are the dominant source of PFAS at AFFF-impacted sites (**CONCAWE 2016**). Furthermore, because of its long shelf life, stock of legacy PFOS AFFF could exist at any given fire department today.

- Legacy fluorotelomer AFFF were manufactured and sold in the United States from the 1970s until 2016 and encompass all other brands of AFFF besides 3M Light Water or their licensed products (**Schultz et al. 2006**). Specifically from 1973 onward, several manufacturers created fluorotelomer-based AFFFs that met the Mil-Spec criteria. Although they are not made with PFOA, they contain polyfluorinated precursors (**Backe, Day, and Field 2013**; **Place and Field 2012**) that are known to transform to PFCAs, including PFOA (**Weiner et al. 2013**; **Harding-Marjanovic et al. 2015**).

Modern fluorotelomer AFFF became the predominant foam as users transitioned from legacy foams starting in 2006 through 2015 in response to the USEPA 2010/2015 voluntary PFOA Stewardship Program (**USEPA 2018**). By 2015, foam manufacturers transitioned to the production of only short-chain (C6) fluorotelomer-based fluorosurfactants. These modern fluorotelomer AFFFs, or "C6 foams," do not contain or break down in the environment to PFOS or PFOA and are currently considered to be less toxic and have reduced bioaccumulative potential compared to long-chain (C8) fluorosurfactants. But under particular environmental conditions, breakdown products of C6 foams can include PFHxA, PFPeA, and 5:3 FTCA (**Kempisty, Xing, and Racz 2018**). Modern fluorotelomer AFFF may contain smaller levels of PFOA as an unintended manufacturing impurity or byproduct.

Fluorotelomer foams, short-chain fluorotelomer foams, and C6 foams are analogous and will be referred to as "modern fluorotelomer foams." When discussing legacy PFOS or C8 foams, the term "legacy foams" will include both legacy PFOS AFFF and legacy fluorotelomer AFFF.

Legacy foams were first introduced by the naval firefighting services in 1964 (**Gipe and Peterson 1972**). The U.S. Naval Research Laboratory (NRL) began research on the development of firefighting foams in the 1960s. This led to advancements in fire suppression performance and increased firefighting safety (**US Naval Research Laboratory 2017**). In 1969, the U.S. Department of Defense (USDOD) issued military specification MIL-F-24385, which dictates the performance of all AFFF (with performance standards referred to as "Mil-Spec"). AFFFs shown to perform to MIL-F-24385 requirements are listed on the U.S. military's AFFF Qualified Product Listing (QPL). The first date AFFF was placed on this list was May 15, 1970 (MIL-F-24385 QPL/QPD History of Type 6 AFFF). DOD maintains the online qualified products database (QPD) that lists all AFFF agents that have been tested and qualified by the NRL to meet the Mil-Spec, currently referenced as MIL-PRF-24385, (**USDOD 2018**). On July 1, 2006, the Federal Aviation Administration (FAA) required that commercial airports certified under 14 CFR Part 139 purchase only AFFF that is Mil-Spec compliant (**FAA 2016**; 14 CFR 139.317). The FAA Reauthorization Act modified that requirement. In January 2023, the performance specification for F3 land-based, freshwater applications was released as MIL-PRF-32725. This latest specification requires manufacturers to certify that PFAS has not been intentionally added to the formulation and that the concentrate contains a maximum of 1 ppb of unintentionally-added PFAS (**USDOD 2023**). More information can be found in **Section 3.12.3**.

Different types of AFFF were produced to meet firefighting specifications, such as Mil-Spec, rather than formulated to contain a specified mixture of PFAS. AFFFs are a complex mixture of both known and unidentified PFAS. Multiple AFFF formulations have been produced over the years, and the exact composition of any given AFFF used or manufactured in any given year is variable (**Backe, Day, and Field 2013**). However, due to the production methods, any given AFFF formulation contains complex mixtures of PFAS, many of which can be identified only by nontargeted analytical methods (**Barzen-Hanson et al. 2017**) (see **Section 11** for information about analytical methods).

AFFF is typically formed by combining hydrocarbon surfactants, organic solvents, fluorosurfactants, polymers, and other additives (**Kempisty, Xing, and Racz 2018**). AFFF concentrates are commercially

available in 1%, 3%, and 6%. **Figure 3-3** illustrates the typical composition of a 3% AFFF concentrate; estimates are that water/diluent makes up more than 60% of the concentrate, up to 20% is solvents, and as much as 15-18% is surfactants, of which less than 2% is fluorosurfactants. When the concentrate is mixed with water, the resulting solution achieves the interfacial tension characteristics needed to produce an aqueous film that spreads across the surface of a hydrocarbon fuel to extinguish the flame or reduce the hydrocarbon vapors. This is a general estimate and composition can vary.



Figure 3-3. Typical composition of 3% AFFF concentrate.

Source: S. Thomas, Battelle. Adapted from Kempisty, Xing, and Racz 2018.

3.2 AFFF Characteristics

As sectors and industries continue to transition from fluorinated foams to F3s and investigation and remediation activities related to AFFF continue, an understanding of current and historical AFFF products is an invaluable asset to identify and delineate potential sources. This includes, where available:

- whether an AFFF product is/was considered a modern or legacy foam and if it is/was manufactured using fluorotelomerization or electrochemical fluorination
- when an AFFF product is/was approved for use and for what specific use/application and to what specific performance standard(s)
- any other pertinent and available information on the product (for example, compatibility, composition information, equipment requirements)

Table 3-1 provided as a separate Excel file, includes the above information for specific AFFF products. The Priority Topics for Firefighting Foams include information about recent studies of firefighting foam ecotoxicity (see **Section 1.2.2**).

Some research has been conducted to specifically characterize AFFF formulations in both legacy and modern foams. **Barzen-Hanson et al. (2017)** presented information about AFFF composition over time. **Field et al. (2017)** summarized information on the commercial formulations approved for use by the DOD in a document, "FAQs regarding PFAS associated with AFFF use at U.S. military sites." **Shojaei et al. (2022)** characterized PFAS composition in Buckeye Platinum Plus C6 3% MS-AFFF (i.e., Platinum Plus C6) using targeted analysis, total oxidizable precursor assay (TOP), suspect screening, and nontargeted analysis. Results show that the sum of PFAS identified during target analysis comprised only 0.2 percent of total PFAS. 6:2 FTS and PFHxA were the most abundant target PFAS among the 12 monitored target PFAS. Suspect screening identified seven PFAS in six classes, which were largely comprised of C6 FT-based precursors (>99%). The most prevalent class was n:2 FTSAPr-DiMeAn, which may be a byproduct of fluorotelomer betaine synthesis. Nontarget analysis identified ten PFAS within nine classes of n:2 fluorotelomer sulfonamides, with 6:2 FTSAPr-AmHOPrS (CASRN 76201-56-4) being the most prevalent PFAS. PFAS composition of Platinum Plus C6 is different from the older Premium 3MS reported by Han et al. (**2021**).

ECF-based AFFFs contained primarily C6–C8 perfluoroalkyl sulfonates, with some zwitterionic C4–C6 perfluoroalkyl sulfonamides (FASAs) containing carboxylic acid and tertiary amine functionalities. Fluorotelomer-based AFFF formulations normally contained fluorotelomer thioamidosulfonates (FtTAoS) (4:2, 6:2 and 8:2) with 6:2 FtTAoS as the dominant compound, and very low perfluoroalkyl sulfonates or carboxylates (**Backe, Day and Field 2013**).

Some legacy nonfluorinated foams, notably those that are protein-based, form thick, viscous foam blankets on liquid hydrocarbon fuel surfaces. These foams are typically referred to as mechanical foams. These foams extinguish fires using strong bubble structure to smother the fire as opposed to the film and bubble structure of AFFF. More recent F3s are similar to the legacy protein foams in that they rely solely on the foam blanket to contain the fuel vapors to extinguish the fire (F3s do not produce a surfactant film on the fuel surface like AFFF). As a result, air-aspirating discharge devices may be required to optimize the capabilities of these products (**NFPA Research Foundation 2022**).

Many of the commercially available F3s have been tested to, and or listed/approved to, the legacy foam test protocols. These protocols include but are not limited to Underwriters Laboratories (UL), Factory Mutual (FM), European Standards (abbreviated EN), and International Civil Aviation Organization (ICAO) standards (**NFPA Research Foundation 2022**).

3.3 Mechanisms for Release to the Environment

Firefighting foam is applied by mixing foam concentrate and water to make the firefighting foam solution, which typically contains less than a fraction of a percent of fluorinated surfactants once in mixture. When applied to a fire, the foam solution is aerated at the nozzle, yielding finished firefighting foam. Thousands of gallons of foam solution may be applied during a given event. **Figure 3-4** illustrates the use of firefighting foam, how it may be released to the environment, and potentially affected media. Once released to the environment, AFFF can contaminate soil, surface water, sediment, and groundwater. **Section 5** includes details and references for fate and transport of PFAS in the environment.

Firefighting foams are released into the environment through various practices and mechanisms (**Anderson et al. 2016**; **Hale 2016**; **Thalheimer et al. 2017**) such as:

- low-volume releases of foam concentrate during storage, transfer, or operational requirements that mandate periodic equipment calibration
- moderate-volume discharge of foam solution for apparatus testing and episodic discharge of AFFF-containing fire suppression systems within large aircraft hangars and buildings
- occasional, high-volume, broadcast discharge of foam solution for firefighting and fire suppression/prevention for emergency response
- periodic, high-volume, broadcast discharge for fire training
- accidental leaks from foam distribution piping between storage and pumping locations, and from storage tanks and railcars.

AFFF-impacted sites often are also contaminated with petroleum hydrocarbons from unburned fuel. PFAS and hydrocarbon plumes at these sites may follow the same flow paths, though the extent of contamination may be significantly different. These co-contaminants, particularly light nonaqueous phase liquids (LNAPLs), may affect the fate and transport of AFFF-derived PFAS (**Guelfo and Higgins 2013**; **Lipson, Raine, and Webb 2013**; **McKenzie et al. 2016**), see **Section 5.2.5**. Certain air-based or in situ oxidation remedial activities aimed at treating co-contaminants may affect PFAS composition, fate, and transport as well (**McKenzie et al. 2015**). Additionally, the altered soil and groundwater geochemistry and redox conditions may result in oxidation of some PFAS precursor compounds, degrading them to terminal PFAAs (**Harding-Marjanovic et al. 2016**; **McKenzie et al. 2016**; **McGuire et al. 2014**). For additional detail on transformations of precursors see **Section 5.4** and **Section 10.4.6**.

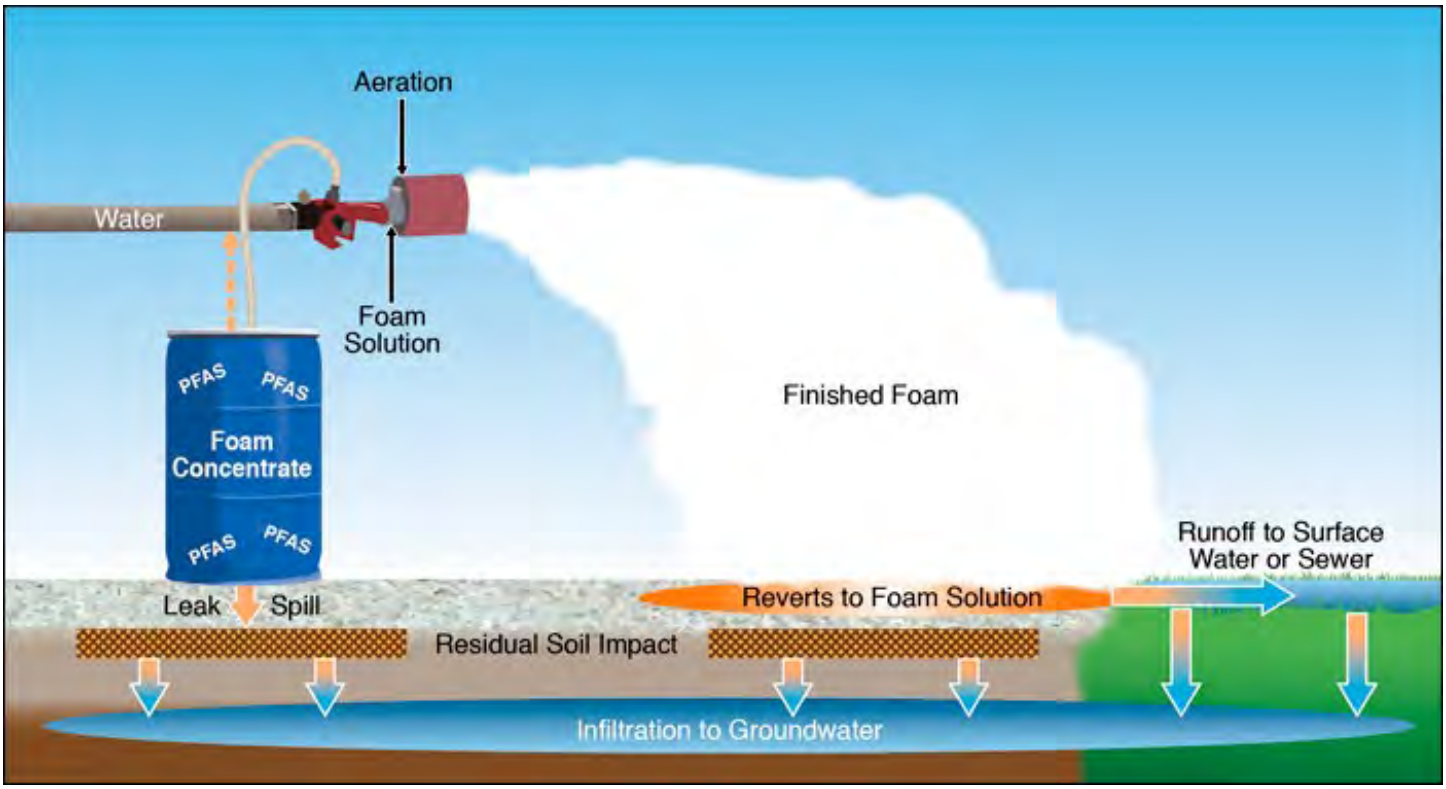


Figure 3-4. Release of firefighting foam.

Source: Adapted from figure by J. Hale, Kleinfelder. Used with permission.

The USDOD has undertaken an evaluation of potential firefighting foam contamination at its facilities nationwide (**Anderson et al. 2016**). Similar efforts have been undertaken by some states. For example, the Minnesota Pollution Control Agency (MPCA) conducted a statewide survey of firefighting foam use at training sites. Working with the State Fire Chiefs Association, the MPCA identified more than two dozen locations where Class B foams were likely used in firefighting training (**Antea Group 2011**).

Figure 2-21 illustrates common elements of CSMs associated with the potential AFFF release scenarios at fire training areas.

3.4 AFFF Fate and Transport

3.4.1 Physical and Chemical Characteristics

Factors that affect fate and transport of PFAS from AFFF releases, as concentrate or in mixture with water, include the chain lengths of the PFAS, their ionic states, the type of functional group(s), and the extent of fluorination. These factors strongly influence the extent of PFAS partitioning and transformation that occurs in the environment. The distribution and composition of legacy PFOS AFFF and legacy and modern fluorotelomer AFFF differ in the environment based on their different chemical constituents and physical and chemical properties (**MPART 2020**). It is important to consider any precursor PFAS that can transform to PFAAs over time and add to concentrations of known PFAAs in the environment, such as PFOS and PFOA. The relatively high solubilities of most PFAS in AFFF contribute to their migration rates in groundwater. Current published data and physical properties of PFAS differ and some chemical data are experimental, extrapolated, or modeled. **Section 4** summarizes some of the available physical and

chemical properties for PFAS. Tabulated values and references are included in Table 4-1 (provided as a separate Excel file).

3.4.2 Fate and Transport Processes

Fate and transport process information is used to address questions related to potential risk, conceptual site model (CSM), and treatment of PFAS. The mechanisms of partitioning, transport, and transformation of PFAS, which occur across different environmental media, are summarized in **Table 3-2** below. **Section 5** provides the detailed discussion and references.

Table 3-2. Fate and transport process considerations.

Fate and Transport Process	Description	Role in Transport
Partitioning Refer to **Section 5.2**	• Competition between hydrophobic and lipophobic C-F "tail" and nonfluorinated polar and hydrophilic head groups causes partitioning to interfaces such as: soil/water water/air water/NAPL co-contaminants	• Controls distribution in environment • Preference for air-water interface influences aerosol transport and deposition, and vadose zone transport (unsaturated conditions provide significant air water interfacial area)
Advection, Diffusion, Dispersion Refer to Sections **5.3**, **10.4**	• PFAS dispersion in groundwater is slow but greater in air and surface water • Atmospheric transport, e.g., from AFFF applications, results in deposition to soil/surface water/surfaces • PFAS are mobilized from soil to groundwater or to surface water through runoff and leaching	• Facilitate transport of PFAS in and across media • Increase contaminant distribution. Research on the potential impacts of diffusion on PFAS persistence in natural soils is ongoing. **Adamson et al. (2020)** conducted a study that estimated the relative distribution of different PFAS between high and low permeability soils at AFFF fire training area
Abiotic Transformation Refer to **Section 5.4.4.1**	• Abiotic processes that can transform precursors under ambient environmental conditions include hydrolysis, photolysis, and oxidation	• Results in chemicals with different physical and chemical properties • May alter risk • May affect treatment selection
Biotic Transformation Refer to Sections **5.4.4.2** and **5.4.4.3**	• PFOA, PFOS, and other PFAAs are resistant to microbial degradation • Biotransformation of various precursors has been reported	• Results in chemicals with different physical and chemical properties • May alter risk • May affect treatment selection

3.4.3 Fate and Transport Considerations for AFFF Remediation

Knowledge of the type of AFFF and the constituents released to the environment is critical for adequate site characterization and CSM development. Physical and chemical properties and environmental processes play key roles in identifying contaminant capture and collection methods and selection of treatment technologies. The effects of co-contaminants, such as petroleum hydrocarbons, on fate and transport of AFFF constituents is addressed in **Section 3.3** and partitioning into NAPL co-contaminants is addressed in **Section 5.2.5**. Many traditional technologies, such as air stripping and soil vacuum

extraction, which rely on volatilization, have been found to be ineffective for PFAS, which typically have low volatilities and are highly soluble. The stability and persistent nature of PFAS in the environment also make current bioremediation approaches ineffective.

Proven and developing treatment technologies for treatment of PFAS are presented in **Section 12**, which also includes details on the roles of physical and chemical characteristics and transport processes in technology selection. For example, water treatment technologies, such as GAC adsorption and ion exchange, have been proven to be effective because they rely on the hydrophobic and ionic properties of PFAS. Field-implemented technologies for soil include excavation and landfill disposal or mixing with sorbent for stabilization. The potential for leaching associated with disposal is reduced by stabilization. Many new technologies that rely on the unique properties of PFAS are under development.

3.5 Forensic Analysis of AFFF

Forensic analysis of AFFFs should be based on fingerprinting the composition of unknown samples and comparison with published fingerprints that are further discussed in this section. Many limitations must be considered in such investigations, including the changes in original manufactured product fingerprint due to precursor transformation through time, potential presence of impurities due to manufacturing processes and/or equipment used, and differences in original fingerprints for distinct manufactured batches. While there are tests that may be performed to help understand and overcome some of these limitations, every case should be based on site-specific data and historical information. For example, total oxidizable precursors (TOP) analysis may be performed to evaluate the changes in original AFFF fingerprints due to precursor transformations through time and the data should be interpreted within site-specific context considering potential deviations due to site-specific conditions. The fingerprint of AFFF products stored for long periods of time may have changed from the original PFAS fingerprint even if those products were not released and exposed to environmental conditions. Therefore, when trying to identify the type and original composition of AFFF products, multiple lines of evidence should be employed, including historical information, chemical fingerprinting via targeted PFAS analysis, TOP analysis, and total organic fluoride (TOF) content. Ultimately, nontargeted PFAS analysis may also be employed for in-depth evaluations and matching of foams with suspected sources. More information on these specific tests is provided in **Section 10.5** and **Section 11**.

Although many types of PFAS are identified in the AFFF formulations, due to the lack of analytical standards, quantitative information is not available for all identified individual PFAS, whereas qualitative detections and area counts are reported (**D'Agostino and Mabury 2014**; **Barzen-Hanson et al. 2017**; **D'Agostino and Mabury 2017**; **Ruyle et al. 2021**). There is quantitative information on the composition of a series of AFFF formulations manufactured in different years by several manufacturers, including 3M, ChemGuard, Ansul, Buckeye, and National Foam (**Annunziato et al. 2020**; **Houtz et al. 2013**; **Backe, Day, and Field 2013**; **Ruyle et al. 2021**; **Herzke, Posner, and Olsson 2009**; **KEMI, 2015**). The chemistry of AFFF is complex, consisting of anionic, cationic, zwitterionic, and neutral compounds; in addition, different formulations of AFFF from the same manufacturer may also vary in chemistries (**Backe, Day, and Field 2013**; **Houtz et al. 2013**; **Barzen-Hanson et al. 2017**). AFFF includes many fluorinated and nonfluorinated surfactants. Total surfactants are thought to range from approximately 15 to 18 percent. Some references cite about 5–10% (w/w) are nonfluorinated surfactants and 0.9–1.5% (w/w) are PFAS (**Backe, Day, and Field 2013**; **D'Agostino and Mabury 2014**). These nonfluorinated surfactants have also been detected in the AFFF-impacted groundwater (**García et al. 2019**). For forensic analysis, evaluating the source attribution of PFAS from AFFF used for emergency response or fire training operations and understanding the manufacturing history, timing of release, potential sources, degradation products, isomer profiles, and environmental partitioning of PFAS during transport are very important (**Dasu et al. 2022**; **Guelfo et al. 2021**; **Dorrance et al. 2017**).

3.5.1 Manufacturing and Chemistry

PFAS are commonly produced by two manufacturing processes: electrochemical fluorination (ECF) and fluorotelomerization. For example, legacy 3M AFFF brand name Light Water was manufactured by electrochemical fluorination, and the legacy longer chain and the new replacement shorter chain (C6) fluorotelomer-based AFFFs are manufactured by the fluorotelomerization process. More detailed information on these processes is presented in **Section 2.2.5**, and more detailed information on AFFF as it relates to these processes is presented in **Section 3.1**. Despite the recorded differences and complex composition of AFFF products, several general traits have been established in the literature based for each manufacturing processes and the final products and byproducts formed by using these two processes are different.

The ECF process results in a mixture of linear and branched fluorinated molecules of various carbon chain lengths, both even and odd carbon chains (**Buck et al. 2011**). The ratio of linear and branched isomers ranges from 70 to 80% linear and 20 to 30% branched isomers (**Kissa 2001**; **Buck et al. 2011**; **Benskin et al. 2007**). The ECF process produces varying amounts of C2–C10 PFAAs (**Backe, Day, and Field 2013**). Some of the ECF chemistries are based on perfluorooctane sulfonyl fluoride (POSF), a major raw material used to manufacture surfactants (such as perfluorooctane sulfonate (PFOS)), and other raw materials such as sulfonamides, sulfonamido alcohols, and related monomers (**Backe, Day, and Field 2013**; **D'Agostino and Mabury 2014**; **Buck et al. 2011**).

The other important manufacturing process of PFAS is the telomerization process, which mainly produces linear isomers with an even number of carbon chains as the major products, although some odd-numbered carbon chains have also been produced (**Kissa 2001**). The nomenclature of PFAS manufactured by the telomerization process includes n:2 fluorotelomers (see **Section 2.2.4.1**), where n represents the perfluorinated carbon chain length and 2 represents the nonfluorinated ethane attached to the functional group, such as alcohols, carboxylates, sulfonates, etc. (**Buck et al. 2011**). Fluorotelomers (FT) are predominantly produced in 4:2-, 6:2-, 8:2-, and 10:2-carbon chain lengths, although 12:2 has been seen in FT Mil-Spec AFFF (**Backe, Day, and Field 2013**). Fluorotelomer alcohols or iodides are commonly used as raw materials in the telomerization process to produce fluorotelomer sidechain polymers. At many of the AFFF-impacted sites, perfluorooctanoic acid (PFOA), PFOS, and perfluorohexane sulfonic acid (PFHxS) are the most prevalent PFAS detected. The phaseout of the longer chain PFAS by global manufacturers has resulted in quantifiable increase in shorter-chain concentrations and decreased concentrations of longer chains at some of the areas investigated (**Ruyle et al. 2021**).

3.5.1.1 Reported PFAS Profiles in AFFFs Manufactured Via ECF vs. Telomerization.

In spite of the recorded differences and complex composition of AFFFs, several main traits may be established among AFFFs manufactured by each mentioned process based on the literature-reported data (**Annunziato et al. 2020**; **Houtz et al. 2013**; **Backe, Day, and Field 2013**; **Ruyle et al. 2021**; **Herzke, Posner, and Olsson 2009**; **KEMI 2015**). These traits provide the basis for chemical fingerprinting of PFAS in AFFFs and environmental media.

AFFFs manufactured via ECF process (by 3M) are reported to contain both precursor PFAS (including: PFBSAm, PFPeS-Am, PFBS-AmA, PFPeS-AmA, and PFHxS-AmA) and PFSAs (which are typically predominant) and PFCAs. The AFFFs manufactured via fluorotelomerization process are reported to contain mostly precursor PFAS, with some PFCAs also being reported in some of these AFFFs (**Ruyle et al. 2021**). Upon oxidation (for example, transformation of precursor PFAS in time and due to exposure to environmental conditions), both main types of AFFFs generate PFCAs with distinct profiles described below.

- The profiles of PFCAs in ECF-manufactured AFFFs after oxidation are consistent among various manufactured batches and years and are different from the profiles reported before oxidation.

The oxidized ECF-manufactured AFFFs PFCA profiles should be more representative for environmental profiles of spilled AFFFs and have the following common traits: the predominance of PFHxA (61–75%), followed by PFBA (12–26%), and PFPeA (2–25%) (**Houtz et al. 2013**). Smaller amounts of PFOA and PFHpA are also reported in these oxidized foams.

- The profiles of PFCAs in AFFFs manufactured by telomerization generated after AFFF oxidation have several common traits among manufacturers (for example, Chemguard, Ansul, Buckeye, National Foam), which seem to be preserved along the years. These traits include the predominance of PFPeA (25–49%), followed by PFBA (19–28%), PFHxA (13–20%), and PFHpA (3–20%), and the presence of smaller amounts of PFOA (1–9%) and PFNA (1–4%) (**Houtz et al. 2013**).

- The profiles of PFSAs in manufactured (nonoxidized) AFFFs are preserved among ECF-manufactured AFFFs from different years (1988, 1989, 1992, 1993, 1998, 1999, 2001), including batches from the same years, as reported by **Houtz et al. (2013)**. The PFAS profiles of 3M-manufactured AFFFs are consistent in the strong predominance of PFOS (85–90%), followed by PFHxS (7–12%), with smaller amounts of PFHpS and PFBS also detected. Similar profiles are reported by **Backe, Day, and Field (2013)** and by **Ruyle et al. (2021)**, with the addition of PFPeS detected in small amounts.

- The profiles of PFCAs in manufactured AFFFs (non-oxidized) vary more among the reported manufactured batches and years than in the case of the PFAS profiles mentioned before. Despite these variations, several traits can be observed: In some of the analyzed AFFFs manufactured by ECF (**Houtz et al. 2013**), PFPeA predominates, followed by PFHxA and PFOA, while in ECF-manufactured AFFFs analyzed by other authors, these proportions change to some extent with the predominance of PFHxA and PFOA, and with smaller amounts of PFPeA, PFBA, and PFHpA also reported (for example, see data reported by **Backe, Day, and Field 2013**, **Annunziato et al. 2020**, and **Ruyle et al. 2021**).

In AFFFs manufactured by telomerization, only a few had PFCAs detected before oxidation and the profiles were quite variable, as reported by **Ruyle et al. (2021)**, with the predominance of PFHxA and PFBA in many analyzed foams, and the predominance of PFHpA, PFOA, and PFNA in few other foams. In several different analyzed foams, **Herzke, Posner, and Olsson 2009** reported the predominance of PFHxA and PFPeA, followed by PFOA and PFBA, with PFDcA (at comparable amounts with PFBA) reported in one foam, while smaller amounts of PFDoA were reported in another foam.

Benotti et al. (2020) reported PFAS profiles for several FT-manufactured modern AFFFs, consistent with those described here and reported by other authors mentioned before (for example, **Herzke, Posner, and Olsson 2009**), consisting predominantly of 6:2 FTS among detected precursor PFAS and PFHxA among detected PFCAs. Additionally, the **Benotti et al. (2020)** study pointed out the predominance of even-numbered PFCAs (PFBA, PFHxA) over their odd-numbered homologues in AFFFs manufactured via telomerization. Notably, this study also pointed out the presence of smaller amounts of long-chain PFCAs (including PFOA, PFDA, PFDoA) and PFSAs (PFHxS and PFOS) in the modern AFFFs that were analyzed. The authors attributed these findings to the manufacturing process from fractional distillation of feedstock or to cross-contamination during manufacturing and handling.

3.5.2 Factors Affecting the PFAS Fate and Fractionation

PFAS forensic analysis of environmental samples is often challenging as many of the PFAS-contaminated sites consist of comingled sources. Many of the AFFF-impacted sites often contain a mix of different formulations of AFFF, either from the same manufacturing source (ECF or telomer-based), or a mix of different sources. Many of the PFAS analytes exhibit a wide range of physical and chemical properties, and hence are transported from the source zones and redistributed downstream through

environmental fractionation (**Lindstrom et al. 2011**; **McGuire et al. 2014**). Higher water solubility and mobility of short-chain PFAS contribute to the relatively high concentrations of short-chain PFAAs in aqueous matrices downstream from the source areas. The isomer profiles present at the source of contamination will change and redistribute after a certain distance from the source (**Adamson et al. 2020**; **Nickerson et al. 2021**). Due to the high solid/water distribution coefficient (K_d), longer chain PFAS have a greater affinity than shorter chain PFAS to partition to sediments, sludge, and soils (**Higgins and Luthy 2006**; **Kwadijk, Korytár, and Koelmans 2010**; **Schulz, Silva, and Klaper 2020**). PFAS, due to their electrostatic nature, may also adsorb onto soils due to the soils' electrostatically charged surfaces (**Adamson et al. 2020**). Groundwater transport of PFAAs depends on the concentration, chain length, soil characteristics, partitioning behavior, and in situ precursor biotransformation followed by the redistribution of the transformation products (**Guelfo and Higgins 2013**; **McGuire et al. 2014**; **Anderson et al. 2016**). Additionally, the presence of co-contaminants and/or remediation products in the subsurface may also affect PFAS fate and transport (**Guelfo and Higgins 2013**; **McKenzie et al. 2015**; **Brusseau 2018**; **Hatton et al. 2018**) and should be considered in a forensic investigation.

All these factors indicate that the PFAS fingerprint at the source could be different compared to the downstream sample locations. Hence, forensic analysis of such complex AFFF-impacted comingled sources would require consideration of many factors and multiple lines of evidence to better understand the identification and delineation of sources. These include: (1) PFAS profiles, including PFCAs and PFSAs isomer profiles and chain-length ratios, which may differ from source, based on the environmental fractionation; (2) unique source-specific markers, which require a detailed understanding of known sources to identify a source related to a sample (**McGuire et al. 2014**; **KEMI 2015**; **Guelfo and Adamson 2018**); and (3) high-resolution mass spectrometry (HRMS) tools to help identify and characterize a broad suite of PFAS analytes to understand the source-specific markers (**D'Agostino and Mabury 2014**; **Barzen-Hanson et al. 2017**; **D'Agostino and Mabury 2017**; **Newton et al. 2017**; **Ruyle et al. 2021**). In addition to HRMS analysis, application of statistical analysis tools showed great promise in identifying sources of PFAS contamination (**Zhang et al. 2016**; **Kibbey, Jabrzemski, and O'Carroll 2020**; **Nason et al. 2021**). However, statistical analysis of any PFAS data sets should be done with caution, considering comparability between data sets in terms of sampling and analytical techniques used, as well as environmental transformations expected based on sample location and site-specific parameters. A forensic approach based on multiple independent lines of evidence increases certainty. Examples of lines of evidence that may be developed for PFAS forensic evaluation include chemical profiles of PFCAs and PFSAs, isomer profiles, signature PFAS (for example, via nontargeted analysis), historical document review, and fate and transport evaluation and modeling (see also Sections **4**, **5**, **10**, and **11**).

3.5.3 Summary of Forensic Analysis of AFFF

Employing a lines of evidence approach to identify what AFFF product or products have been used at a particular site is a useful first step during site assessment. The identification of products may help the practitioner to predict what PFAS compounds may be present, including likely precursors and degradation products. Understanding product use will improve site conceptual model development at the outset. Lines of evidence that may be used to identify AFFF products include interviews with site users, bills of lading or procurement records, and finally, analysis of environmental samples. Foam product groups (for example, legacy ECF-manufactured AFFFs, legacy fluorotelomer AFFFs, and modern AFFFs) differ in key ways as presented below.

The proprietary nature of source information, complex PFAS chemistry, and lack of analytical standards pose many challenges in understanding the source identification (see also **Section 10.5** and **Section 11.4**) and attribution at AFFF-impacted sites. Using only targeted PFAS analysis may be useful, since several common traits are evident in AFFFs and may help differentiate between AFFFs and other types of PFAS sources. However, differentiation between multiple AFFF sources may become more difficult based just on targeted analysis data (for example, PFCA and PFSA data), especially for comingled plumes away from the source area where environmental fractionation may play an important role. Nontargeted analysis

using HRMS helps in understanding the chemistry beyond the standard targeted analysis data and shows great promise in identifying and delineating PFAS contamination; however, HRMS is still a relatively new and developing tool and its results should be interpreted carefully in the context of the specific investigation. Considering multiple lines of evidence while conducting forensic investigations helps to identify PFAS source attribution and manage AFFF-impacted sites.

A series of recent publications provide data and information relevant to AFFF source evaluation, as synthesized below:

- AFFF fingerprints seem to be preserved in fish from polluted freshwater systems and were used to differentiate AFFF versus other PFAS sources in fish, namely the paper industry and long-range atmospheric transport (**Langberg et al. 2022**). Specifically, a total of 454 liver samples and 581 muscle samples from 11 fish species were investigated. The fish samples from AFFF-polluted sites had a predominance of PFOS, suggestive of legacy ECF-manufactured AFFFs. High percentages of PFOS were also observed in fish samples contaminated from the paper industry, but the PFCA profiles were distinct from those in fish contaminated by AFFFs. In fact, the profiles of PFCAs were distinct between AFFFs and the other PFAS sources (paper industry and long-range atmospheric transport). The PFCAs profiles in fish from waters contaminated from the paper industry and via long-range atmospheric transport had higher percentages of long-chain PFCAs, as compared with those from fish in waters contaminated by AFFFs. Additionally, PFUnDA/PFDA and PFTrDA/PFDoDA ratios were different between the two non-AFFF sources, being higher in the case of long-term atmospheric transport.

- **Dasu et al. (2022)** performed a comprehensive review of PFAS concentration profiles from both main direct (fluorochemical manufacturing plants, consumer products, metal-plating operations, AFFF use) and indirect sources (landfills and wastewater treatment plants). They found that both groundwater and soil at or near AFFF-contaminated sites had higher median PFOA and PFOS concentrations as compared to those from groundwater and soils near the other main studied sources. **Dasu et al. (2022)** pointed out the potential for environmental transformation of many unknown PFAS present in AFFF into persistent PFAS, acting as long-term PFAS sources. From a fingerprinting perspective, the study indicates that the commonly analyzed PFAS compounds are ubiquitously detected in environments contaminated by distinct main sources, pointing out the need for high-resolution tools such as nontargeted analysis and combined methods of total fluorine and/or extractable fluorine for better source attribution of PFAS. However, **Dasu et al. (2022)** did not include an analysis of the relative proportions of individual PFAS compounds in media contaminated by different sources, which could have forensic relevance.

- The high precision methods used by **Liu et al. (2022)** in analyzing PFAS-contaminated soil and groundwater at four Canadian airports, consisting of HRMS and an improved total oxidizable precursor (TOP) assay, may be of high utility in forensic applications. Based on these analytical techniques, 93 classes of PFAS could be investigated and characterized at these Canadian airports.

- A comprehensive study of PFAS in surface water near U.S. Air Force bases (**East, Anderson, and Salice 2021**) determined that, according to the legacy AFFF composition, a four-chemical mixture composed of PFOS, PFHxS, PFHxA, and PFOA generally accounted for >80% of the sum of all routinely reported PFAS in a sample. This observation is relevant in building AFFF-representative PFAS fingerprints.

- The predominance (90%) of 6:2 fluorotelomer sulfonate in modern AFFFs has been confirmed by **Ruyle et al. (2021)**, who developed and applied a “novel method (Bayesian inference) for reconstructing the fluorinated chain lengths, manufacturing origin, and concentrations of oxidizable precursors obtained from the total oxidizable precursor (TOP) assay” (**Ruyle et al.**

2021). These authors were able to identify 14 major fluorotelomer compounds present in modern AFFF "yielding a priority list that accounts for almost all detectable PFAS in contemporary AFFF." Testing for these fluorotelomers may help differentiate between AFFF and non-AFFF sources of PFAS.

- **Kibbey, Jabrzemski, and O'Carroll (2020)** "explored the use of supervised machine learning classifiers for allocating the source of PFAS contamination based on patterns identified in component concentrations." "The deep neural network and Extra Trees exhibited particularly high performance at classification of samples from a range of sources, [showing that] patterns exist in PFAS water sample data that can allow forensic source allocation." While these methods are complex and evolving, they show promise for PFAS allocation at complex sites.

- **Shojaei et al. (2022)** provided useful data on the chemical composition of AFFFs currently certified for use by the U.S. military. These authors used several distinct analysis techniques, including targeted analysis by HRMS, TOP, and nontargeted analysis. The study identified nine novel classes of PFAS comprising 10 individual compounds that made up ~90% of total PFAS measured in the tested foam. The combination of TOP with nontargeted analysis holds great potential for PFAS source identification.

3.6 AFFF Procurement and Inventory

This section discusses procurement and inventory of AFFF, including suggestions for storing inventory to minimize the potential for accidental releases.

3.6.1 Foam Selection and Requirements

Multiple manufacturers in the United States and abroad produce AFFF concentrate in 1%, 3%, or 6% concentrations. Most AFFF sold or in stock in the United States is either 1) listed by Underwriters Laboratory (UL) based on conformance with UL Standard 162, "Foam Equipment and Liquid Concentrates," or 2) tested by NRL and granted qualification by U.S. Naval Sea Systems Command in accordance with the Mil-Spec. Only AFFF meeting the Mil-Spec has been used in military applications and at FAA-regulated airports.

Military and FAA AFFF applications subject to Mil-Spec account for more than 75% of AFFF used in the United States (Airport Cooperative Research Program **ACRP (2017)**). Hence, the production of AFFFs has historically been driven by firefighting specifications, such as Mil-Spec, which requires a specific percentage concentration of PFAS. Current Mil-Spec AFFFs contain ≤ 1% (approx. 0.5–0.6%) fluorosurfactants after the concentrate is mixed with water to create the final foam solution used to extinguish or prevent high-hazard flammable liquid fires; however, the exact AFFF PFAS mixtures are highly variable. Non-Mil-Spec Class B foams can vary from fluorine-free to having concentrations of PFAS similar to Mil-Spec AFFF. Furthermore, where fire risk allows it, users who are not subject to Mil-Spec requirements are less likely to use foam formulations that contain PFAS given the environmental implications and increasing prevalence of F3. However, the knowledge of environmental implications of PFAS was historically lacking and is still not widely understood by first responders, and there are many historical examples of AFFF use by municipal fire departments during fire response activities.

3.6.2 AFFF Storage and Handling

AFFF concentrate is available from the manufacturers in containers ranging from 5-gallon buckets to 5,000-gallon tanker trucks. The most common method of shipping is in 5-gallon buckets, 55-gallon drums, or 265-gallon intermediate bulk containers. Shipping containers are typically not double walled but made of plastic, steel, or steel reinforced plastic tote construction to resist damage/puncture. Per National Fire

Protection Association (NFPA) 11, Section 4.3.2.3, bulk liquid storage tanks should be fabricated from or be lined with materials compatible with the concentrate, designed to minimize evaporation of foam concentrate, and stored within the listed temperature limitations (**NFPA 2016**).

In fire suppression systems, the AFFF concentrate is typically stored in either an atmospheric (nonpressurized) tank or a bladder tank (pressurized). Atmospheric tanks are single- or double- walled tanks and can supply proportioning foam concentrate pumps or venturi-based proportioners that feed the suppression system. Atmospheric tank piping arrangements may include recirculation from downstream of the pump back to the tank. The bladder tanks contain a bladder filled with foam concentrate that is squeezed by water between the shell of the tank and the bladder. As long as the bladder integrity is maintained, the foam concentrate does not mix with the shell water.

Safety data sheets are provided by all manufacturers for each specific type of AFFF. Labels on shipping containers conform to U.S. Department of Transportation (USDOT) standards. AFFF and AFFF-impacted materials (soils and absorption materials), including concentrate being disposed, rinsate, and foam supply system materials, are not currently considered to be hazardous materials under federal regulations. Some individual states have passed legislation to include PFOS, PFOA, and other PFAS on their hazardous substances list and otherwise restrict the sale and use of AFFF (for example, (**Washington Senate 2018**) (**New York State 2017**). USEPA published the designation of PFOA and PFOS as CERCLA Hazardous Substances in May 2024 (**USEPA 2024**). Regulations are discussed further in **Section 3.12**

As with any potentially hazardous substance, the best practice for storage and handling is to ensure containment until proper disposal. AFFF materials should be labeled to clearly indicate the contents of the container. It is important that all containers are kept clean so that any signs of leakage can be easily and quickly identified during container inspections, with the labeling pointed outward for easier reading.

3.7 Foam Systems and Operations

Class B firefighting foams are employed globally to fight flammable liquids fires where risk of damage to property or human life is high. These products are particularly prevalent in airport settings. This section describes common AFFF system operations, including system testing and training. Additionally, information is provided in **Section 3.11** for organizations that want to replace legacy PFOS AFFF systems with modern fluorotelomer AFFF or F3.

3.7.1 Fixed System Testing

Fixed fire suppression systems that utilize any of the foam types and application methods are permanent designs and should incorporate the containment, collection, and runoff components in the event of system discharge into the design. Examples include flammable liquid warehouse, waste treatment facility, and aircraft hangar fire suppression systems. New systems should be designed to include foam containment and collection mechanisms such that foam releases that occur during testing or activation are not released to the environment, or the AFFF can be captured for disposal. AFFF design standards require minimum durations for foam system discharge to meet the suppression/control requirements and in some cases require specific volumes of concentrates and foam solution to be contained in on-site storage tanks. Fixed AFFF proportioning systems that are connected to city water mains should be fitted with backflow preventers to protect the city water mains from potential AFFF contamination.

Codes, standards, and authorities having jurisdiction over fixed system testing, such as NFPA Standards 16 (**NFPA 2019**) and 25 (**NFPA 2017**), can require that the equipment produce a foam/foam solution that can be tested and compared to laboratory standards. System testing generates a small amount of foam that should be contained or controlled by the design to the best extent possible for proper disposal. Foam

can be wetted with fog nozzles/mist to knock down the foam and dilute it. Gentle squeegee and sweeping are required to keep the solution from aspirating during cleanup and dilution. Alternatives, such as testing with water (without foam) or testing with fluorine-free training foam or surrogate liquids having similar physical properties, may be considered to minimize disposal issues. Check applicable regulatory requirements for testing to determine frequency and type of testing required, as well as what is specifically mandated for foam type before any alternatives are considered to ensure compliance with appropriate laws.

3.7.2 Mobile Firefighting Equipment Testing

Firefighting equipment requires inspection, calibration, and testing to ensure reliability and performance to specifications. In accordance with fire protection standards (for example, NFPA Standard 412, (**NFPA 2020**) and manufacturer's recommendations, the testing of mobile firefighting equipment should be conducted routinely and documented.

Multiple pieces of equipment can be tested or inspected simultaneously. Mobile equipment, including but not limited to mobile foam extinguishers, firefighting vehicles, and marine craft, can be collected, tested, and cleaned and foam concentrate samples can be collected in a single location to minimize potential impacts. It is recommended that testing of mobile firefighting equipment is executed at purpose-built facilities specifically designed to capture and contain all generated foam and wastewater for treatment, reuse, or disposal.

Conditions during equipment testing should include secondary containment measures to ensure foam solutions can be captured and managed and environmental impact minimized. Alternatives to traditional testing methods may be considered, such as:

- using water or surrogate solutions for training
- testing equipment indoors
- spraying into drums or other containers
- testing within lined pits or spill containment equipment
- testing with closed-loop AFFF testing systems to minimize and eliminate discharge (**FAA 2023**).

Other controls include not testing during adverse weather conditions, not testing where the facility is not deemed fit for purpose, conducting a risk assessment of the activity, and minimizing foam wastewater volume generated whenever possible. As with fixed fire suppression systems, mobile equipment that complies with NFPA Standard 412 requires that the equipment produce a foam/foam solution that can be tested and compared to laboratory-analyzed solutions (**NFPA 2020**).

3.7.3 Training Exercises

Facilities should have specifically designed areas and structures to conduct training exercises involving flammable liquid fires and foam systems. The fire training areas (FTAs) should be arranged to contain/control the training site for the safety of the persons being trained. Control of training fires as well as applied foam and/or foam solutions is maintained by the facility design. The FTA should also be designed for collection/recovery of unburned fuels as well as the foam solution and fire water following the completion of training exercises. Conducting outside exercises during windy weather conditions should be avoided, as the foam solutions can be difficult to contain due to natural aspiration and windblown transport.

Past training exercises at airports and military installations employed large quantities of foam/foam solutions. To prevent further releases to groundwater, USDOD issued a policy in January 2016 requiring prevention of "uncontrolled land-based AFFF releases during maintenance, testing, and training activities.

Current USDOD policies prohibit using AFFF with PFOS for testing, maintenance, or training exercises with the exception of shipboard activities.

Consider minimizing the volume of foam used to the greatest extent possible. If permitted by the applicable regulatory requirements for training, consider entirely discontinuing the practice of using expired legacy AFFF and modern fluorotelomer AFFF as training foam. Whenever possible, seek fluorine-free alternatives for training events; consider training with water or training foam where practicable, not Class B foam, and certainly not with Class B foam containing PFAS. Any wastewater or foam generated from training activities should be kept to a minimum and foam spraying should be restricted to target areas only (not sprayed over wide areas). Preplanning responses that deploy AFFF can identify weaknesses in both AFFF use strategies and in fuel and fire water runoff and containment. This can also identify the need for calling mutual aid early to assist with containment tactics.

Training protocols with F3s must be established. While F3 foam does not contain PFAS, some F3 foams may contain other additives or chemicals that could be harmful to the environment or human health. As such, any training involving F3s should also consider the mitigation measures established for AFFF.

3.8 Emergency Firefighting Operations

Fire response planning in advance can identify various options for firefighting and contingency planning for fire wastewater capture. Where possible and as setup allows, consider containing and recovering AFFF used for emergencies for disposal. Use mutual aid resources to assist with containing the fuel and fire water runoff should your department not have the resources available to fight the fire emergency and contain the runoff (**Section 3.7**). Although federal law currently does not prohibit the use of existing stocks of legacy AFFF, any discharge of foam containing PFAS to public waters can be considered a release of a "pollutant or contaminant" under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), 42 U.S. Code § 9601, and therefore may be subject to remediation requirements.

Emergency scenarios vary case by case. Industrial plant fire brigades and responding emergency crews utilize portable foam generators or monitor nozzles to apply foam to pooled flammable liquids (potential fires) or existing fires. In cases where the fire involves a fixed system, it is critical that an arrangement for containment/control of runoff is included in the design. The following are examples of how preplanning can better inform the use and containment of AFFF at an industrial facility:

Consideration should be given to parts of facilities not protected by the fixed foam system that could be subject to AFFF application in the event of an emergency incident and opportunity for containment of foam.

- Industrial processes have many components, and only portions of the process are protected by the fixed foam systems. For example, a scrubber, or filter found within industrial smokestacks, may be part of the process that is not protected by the foam system and may be outside the discharge area where design considerations have been made for containment/control. Emergency response units may be required to apply foam/water to the location of the scrubber, outside the planning boundaries, in the event the fire that originated in the process was conveyed to the scrubber unit.

- At oil refineries, F3 may be used for small incidents and fluorinated foam reserved for the large tank fires. Fluorine-free and new generation C6 foams have been tested in large-scale tests (involving up to 40 m foam travel requirements) and could be considered suitable for application to fires involving some tank sizes and the associated dike area fires. But firefighting foam use is rapidly evolving, and as such, those responsible for tank application foam selection should refer to the latest test results from any recognized independent source (for example, LASTFIRE) to determine whether F3 could meet the performance requirements.

- On some remote industrial sites, where no immediate threat to life or property exists, and given the additional resources necessary to manage the wastewater produced, the best response may be to let the fire burn instead of applying AFFF.

3.8.1 Best Management Practices (BMPs)

BMPs are key to the use of AFFF in the most environmentally responsible manner with the goal of minimizing risk from their use. It is important to establish BMPs prior to use in an emergency so that BMP equipment, procedures, and training are already in place. Although firefighting personnel may be aware that the foams they are using contain chemicals, they may not be aware of the potential environmental effects of AFFF use. Training of firefighting personnel is important to ensure BMPs are discussed and employed consistently and effectively.

Example BMPs, adapted from the Fire Fighting Foam Coalition (**FFFC 2016**) are summarized in **Table 3-3**. Table 3-3 also includes some information from Angus Fire (**2017**). Users should follow BMPs to protect themselves, others, and the environment when using AFFF and other foams. Further BMP guidance can be found in other documents, such as the Best Practice Guidance developed by the Fire Fighting Foam Coalition (**FFFC 2016**), and the **US National Fire Protection Association's NFPA 11 NFPA (2016)**. Users at DOD facilities have other BMPs to follow. Other industry associations such as American Petroleum Institute (API) have also issued BMPs (**API 2020**).

Other foams such as alcohol-resistant foams (AR-AFFF), film-forming fluoroprotein foams (FFFP), alcohol-resistant film-forming fluoroprotein foams (AR-FFFP), fluoroprotein foam (FP), and alcohol-resistant fluoroprotein foam (FPAR), as illustrated in Figure 3-2, also contain PFAS and similar precautions and considerations should be taken.

Section 3 provides supporting information for the BMPs presented in **Table 3-3**, as follows:

- Foam selection and storage are discussed in **Section 3.6** (AFFF Procurement and Inventory).
- Use is detailed in **Section 3.7** (Foam Systems and Operations).
- Planning and mitigation are covered in Sections **3.8** (Emergency Firefighting Operations) and **3.9** (Immediate Investigative and Cleanup Actions).
- Disposal is addressed in **Section 3.10** (AFFF Disposal).

Table 3-3 addresses current operating procedures for selection, storage, use, planning and mitigation. For complete change-out and transition from AFFF to fluorine-free across an entire system, detailed consideration should be made regarding performance, compatibility, decontamination, treatment, and disposal.

Table 3-3. BMPs for AFFF (and Other Foams) Selection, Storage, Use, Planning and Mitigation, and Disposal (adapted from FFFC 2016).

Life Cycle	BMP
Foam Selection	1. Public safety first. Use AFFF and other fluorinated Class B foams only in the following situations: • Class B liquid fires and/or spills with significant risks to public safety or of property loss, where specific extinguishing rates and burnback times are necessary • Facilities where AFFF is required until F3 replacement that meets Mil-Spec has been approved
	2. Evaluate whether Class B foam is needed for a specific hazard, or if an alternative product, such as an F3 can provide the needed level of protection. The proper agent to use for your hazard "must be evaluated well in advance of an emergency situation" (**FFFC 2016**).

Life Cycle	BMP
Storage	1. Develop a foam inventory and stock tracking system documenting foam composition, date of purchase, lot number, brand, and manufacturer.
	2. "Obtain and follow manufacturers' recommendations for foam concentrate and equipment" (**FFFC 2016**). The amount of foam in the system should be at least enough for the group of hazards that simultaneously need to be protected against.
	3. Designate transfer areas and store Class B foam concentrate (all foam, not only AFFF) in a covered area with secondary containment.
	4. Design storage tanks to minimize evaporation of concentrate. Label containers clearly to identify the type of concentrate and its intended concentration in solution. Keep foam within the temperature limitations provided by the manufacturer.
	5. Properly maintain foam systems to prevent accidental discharges. Conduct regular inspections of tanks, storage containers, and any associated piping and machinery. Any leaks of foam concentrate should be addressed immediately to minimize environmental impacts. Maintain records of accidental releases, including date, volume, and foam type. Be cognizant of state and local reporting requirements for releases.
	6. Corrosion is reported by some to generally not be an issue with foam concentrates, but exceptions exist. Check safety data sheets to evaluate corrosivity of your product. Manufacturers recommend stainless steel, high-density polyethylene (HDPE), or polypropylene containers for AFFF storage. Avoid using aluminum, galvanized metal, and zinc in storage tanks, piping, and handling equipment for foam concentrates (**Angus Fire 2017**).
	7. Ensure compatibility of foams per manufacturer specifications before change-outs. Do not mix different types or brands of foam concentrates unless all the foams are compatible. As an example, all foams that meet Mil-Spec 24385 are considered compatible.
Use	1. Consider the firefighter and public safety first.
	2. Eliminate the use of AFFF and other fluorinated "Class B foams for training and testing of foam systems and equipment" whenever possible. Instead, use specially designed nonfluorinated, PFAS-free "training foams available from most foam manufacturers." (**FFFC 2016**).Be aware that such training foams result in longer extinguishments and less burnback protection.
	3. If the authority having jurisdiction requires testing of equipment or training of firefighters using AFFF, training foams that do not contain fluorinated compounds are preferred and, in many cases, required. All foams, regardless of type, should be captured during training and testing.
	4. Evaluate firefighting strategy to determine if Class B foam is needed or if a Class A foam or just water can succeed in fighting the fire.
	5. Provide containment, treatment, and proper disposal of foam solution. Avoid direct release to the environment to the greatest extent possible.
	6. Collect, treat, and properly dispose of runoff/wastewater from training events or live fire events to the greatest extent possible. Prevent discharge to storm drains and surface water to the greatest extent practicable.
	7. Use appropriate personal protective equipment (PPE) when handling and using AFFF and identify how to decontaminate and or dispose of PPE materials and gear that come into contact with foam.
	8. "Follow applicable industry standards for design, installation, maintenance, and testing of foam systems" (**FFFC 2016**).
	9. Keep records of when and where foam is used to respond to incidents, including foam type, manufacturer, brand, and amount used.
	10. Make note of any sensitive receptors (for example, streams, lakes, homes, wells) identified in the vicinity of foam use and report to environmental agencies as required.
Planning and Mitigation	1. Develop and communicate documented processes for a facility or installation with the stakeholders and regulatory agencies before a release occurs. Stakeholders may include local fire department, elected officials, landowners, interested parties, and local environmental groups.
	2. Prepare runoff collection plans, equipment, and training processes for all foam and those specific to fluorinated Class B foam use.
	3. Create mitigation plans for uncontrolled releases of foam concentrate or foam solution to minimize environmental impacts (**FFFC 2016**).
	4. Quickly and thoroughly clean up any contaminated environmental media after foam release following established mitigation plans.
	5. Design new firefighting systems to accommodate F3s. Consider their different properties, modes of action, and effectiveness.
	6. Prioritize education, training, and preplanning to ensure the safest and most efficient use of foam and equipment during an incident.
Disposal	1. Proper disposal of foam is imperative. See **Section 3.10**. When available, consider disposal of AFFF inventory to state collection and disposal programs. Refer to Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances – Version 2 (**USEPA 2024**).
	2. Terminate any donation programs for expired or unused AFFF concentrate (for example, donation to fire training school). Instead, as stated above, encourage collection/proper storage/disposal of expired or unused AFFF.
	3. Monitor developments in new treatment and disposal technologies.

3.8.2 Personal Protective Equipment

The use of personal protective equipment (PPE) is highly recommended when exposure to AFFF, as well as other firefighting foams, is anticipated. A critical aspect of PPE is ensuring the proper use of the equipment. The equipment should be used correctly, maintained, and decontaminated routinely (**Queensland Government 2021**).

During the application or immediate cleanup of AFFF foam, the use of a self-contained breathing apparatus or positive pressure–supplied air respirator is recommended to avoid respiratory exposure. Dermal exposure should also be avoided, as skin contact can result in irritation and dryness. When responding to fires, first responders should wear appropriate turnout gear, or proximity gear per their specific department requirements.

PPE cleanup after using AFFF (as well as other foams) is discussed in the next section.

3.8.2.1 Decontamination

Although PPE will prevent initial exposure to AFFF, contamination of the PPE itself can present health risks. Decontamination of the PPE and personal hygiene are crucial preventative measures in reducing or avoiding exposure to AFFF, as well as in avoiding cross-contamination. Since there is little PFAS-specific guidance on PPE decontamination, general PPE use and decontamination approaches should be used, as discussed below.

When handling AFFF concentrate or foam, it is imperative to avoid hand-to-mouth contact. After the use or cleanup of AFFF, responders should wash hands and use other decontamination procedures to remove any residual AFFF from the skin. Responders should remove contaminated clothing and launder before reuse.

PPE should be placed in a bag and container after exposure to AFFF as well as other foams. In 2014, NFPA released its latest edition of NFPA 1851: Selection, Care and Maintenance of Protective Ensembles for Structural Firefighting and Proximity Firefighting. This standard provides guidance for proper care of firefighting protective gear as well as health hazards associated with improper maintenance or contamination of protective equipment (**NFPA 2014**). The standard outlines different decontamination measures for turnout gear as well as proximity gear.

Turnout gear is the general PPE for firefighting. It should be machine washed in warm water in the normal cycle. Turnout gear should be spot treated with warm water, a soft brush, and mild detergent prior to being machine washed. When hand washing and spot treating PPE, wear protective gloves—either latex or PVC— to avoid skin contact with any residual AFFF. No fabric softener or bleach should be used. The turnout gear should never be washed in home washing machines, as this practice has the potential to contaminate personal clothing. Advanced cleaning is suggested at least on a yearly basis (**Avsec 2015**).

Although PPE decontamination prior to reuse is important, it is equally important to recognize when decontamination is not possible. In this case, the gear should be discarded in accordance with local, state, and federal regulations.

When decontaminating or laundering PPE, the disposition of the waste stream should be considered. The potential for environmental impacts due to laundering in washing machines is not well defined, but the potential does exist. Regulatory agencies should consider including decontamination procedures when working with firefighters, refinery safety personnel, and other potential first responders to develop BMPs.

3.8.3 Initial Mitigation Efforts for Firefighting Foam

Initial mitigation efforts following a release of firefighting foam include source control, containment tactics, and recovery tactics. Each is further described in this section.

Discharges of AFFF can occur during firefighting operations, system testing, equipment malfunctions, or incidental releases. In addition to foam, a large amount of water is often applied when attempting to suppress a fire. Due to the highly miscible nature of AFFF, the main objective of the initial mitigation efforts should be to reduce the footprint of contamination by limiting the spread of foam and fire water. This is often done through various containment and recovery tactics while making sure that the release has been abated and response personnel are safe.
Specific department or facility fire wastewater management considerations may be outlined in a fire response plan, which should include information such as resources available within the facility or department fire protection jurisdiction to contain and recover fire water, protect sensitive areas (for example, public and private water systems, storm drains, surface water, critical wildlife habitat), and address safety considerations when conducting water management tactics. By using the fire response plan, first responders familiar with the content can increase the potential for a successful response while reducing or eliminating any imminent or substantial threat to human health, safety, welfare, or the environment.

3.8.3.1 Source Control

In addition to AFFF application for emergency response, accidental discharge of AFFF can occur from faulty or malfunctioning equipment such as hard-lined fire suppression systems in aircraft hangars or equipment used to apply or contain foam (for example, fire engines or storage tanks). The first step in any response is to stop the accidental discharge or release at the source by disabling or shutting off the system, if possible, and then temporarily or permanently repairing the malfunctioning equipment. By controlling the source, the impact to the environment is minimized.

3.8.3.2 Containment Tactics

Due to AFFF's miscible nature, as well as the large amount of water often applied in combination with the foam, containment tactics that prevent or minimize surface water runoff are critical during and after emergency response activities. Proper containment tactics may also reduce the footprint of the affected area to make the containment and cleanup easier. Depending on resources available to response personnel and conditions of the release, tactics such as ditching, berming, diking, damming, and blocking storm drains, culverts, or other surface inlets can help to contain runoff. When using these tactics, it is important to ensure that any digging activity will not result in breaking through a confining layer that would allow contaminated water to move more quickly into the subsurface and specifically to groundwater. Several response organizations have tactics manuals available online for review, including the Spill Tactics for Alaska Responders (STAR) Manual (**AK DEC 2014**) and Alaska Clean Seas Tactics Manual (**Alaska Clean Seas 2017**). Most manuals are targeted at tactics proposed to be conducted after a release of oil or other petroleum products, but most of these tactics will also apply to AFFF releases. General guidance, similar to this section, on containment tactics to be conducted after a foam discharge has been provided by several other organizations, including the Firefighting Foam Coalition (**FFFC 2016**, **2018**) and the Queensland Department of Environment and Science (**Queensland Government 2021**).

As stated previously in this section, preplanning can greatly assist with prioritizing sensitive areas or locations that need protection during the mitigation or response effort after an AFFF discharge, as well as the resources necessary to succeed with this strategy. The containment tactics used and resources required will differ among sites. Preparedness can be increased by identifying potentially sensitive areas. Also, designing infrastructure such as aircraft hangars with foam-applying fire suppression systems so

that the discharged foam is automatically directed to storage tanks or containment structures can minimize the need for any cleanup. The DOD has provided guidance via Engineer Technical Letters (**USACE 2018**) that address containment/disposal system design for AFFF discharges from open systems (such as nozzle and deluge sprinkler systems) and closed systems (in which individual sprinkler heads are activated only by heat of a fire).

Because no single set of containment tactics is going to be applicable to all facilities or departments where a foam discharge occurs, it is important for each user to conduct preplanning to identify solutions that fit its facilities, objectives, and specific response scenarios.

3.8.3.3 Initial Recovery Tactics

Recovery tactics can differ depending on the amount of AFFF released, as well as whether the AFFF is discharged during firefighting operations or accidentally (for example, from malfunctioning equipment). Collection of large volumes of AFFF concentrate or the 1%, 3%, or 6% AFFF mixture combined with water could require the use of mechanical devices such as pumps or vacuum trucks, while absorbent material might suffice to clean up after a smaller release. The AFFF and water mixture has a low flammability and a high flash point, so there is no need to use intrinsically safe pumps or mechanical devices unless other, more flammable compounds are present in the fire water being recovered.

It may be beneficial to remove affected AFFF saturated materials such as soil and vegetation to reduce or eliminate surface or subsurface migration of potential contaminants. Removal of contaminated media may reduce or eliminate the need for additional investigation and cleanup in the future; however, focus during the initial mitigation effort should be on the more easily recoverable media such as affected waters or slurries. Initiating recovery tactics as soon as possible after a release of AFFF will greatly reduce the footprint of PFAS-contaminated materials and lower the cost of the total mitigation effort.

3.9 Immediate Investigative and Cleanup Actions

A series of immediate investigative actions can be taken after the use of AFFF at the site of a fire to determine the level, nature, and extent of the contamination. First responders should collect, to the best of their ability, information regarding the volume of AFFF discharged, its concentration, active ingredients, and discharge location information.

Information about actions to be taken after the immediate actions is included in **Section 10**, Site Characterization; **Section 11**, Sampling and Analysis; and **Section 12**, Treatment Technologies.

Traditional field-screening methods used for other types of contaminants (for example, PID field screening for petroleum) are not effective for PFAS due to their unique chemistry, generally low volatility, and lack of development of colorimetric or reactive chemistry technologies. Some efforts have been made to develop mobile analytical laboratories, which are covered in **Section 10.3.1.3** of this document.

3.9.1 Visual Site Delineation

Visual site delineation refers to outlining the affected area of contamination based on visual clues, such a visible foam and wet ground, as a guide. The extent of foam should be marked using survey tape, lathe, and pin flags placed to identify locations of AFFF contamination. This technique of determining the initial expanse of the contamination is simple to perform directly after a discharge and can be useful for reference in future testing on the site. In addition, photographs of the site taken during or immediately after the incident can be used to determine the extent of AFFF impacts.

3.9.2 The Shake Test

The shake test is an informal qualitative field-screening method that provides a visual analysis of the site contamination. The shake test can apply to both water and soil-water solutions. In the shake test, a small sample (10–25 mL) is collected on site by the field personnel and shaken. After it is shaken, if there is foaming in the sample, it should be noted and then submitted for analysis (**Transport Canada 2017**). Photographs of the samples may be helpful. If AFFF foam was used to fight the fire, then the presence of foam strongly suggests the sample may be contaminated with PFAS. This test is a good indicator for high concentration contamination. It may not be able to detect lower concentrations of contaminants, so lab testing may still be required. This may be true of soil and water samples taken around the foam application location where the shake test does not show foaming but the sample media may still have PFAS above background in it.

3.9.3 Initial Investigative Sampling

Investigative sampling is used to determine the nature and extent of contamination, including concentrations at and surrounding release areas. Initial investigative sampling can help to determine whether additional characterization is necessary, in addition to informing the need for and extent of interim or permanent remedial actions. Combining the information gained from investigative and confirmation sampling with information from a CSM will inform project managers as to whether further site characterization and remediation or mitigation efforts are needed. See **Section 5**, Environmental Fate and Transport Processes, **Section 10** and **Section 12** for additional information on the actions that may be needed following initial response.

3.9.4 Interim Removal

Following the information gathering described above, or possibly prior to initial investigative sampling, additional source control can be achieved through removal of soils that are expected to be highly contaminated. During an initial removal action intended to target PFAS hot spots, soil excavation can be guided by shake tests (**Section 3.9.2**). An interim removal is not necessarily designed or expected to remove all contamination but can help to reduce the migration of PFAS into other media, including groundwater and surface water. After this initial removal effort, it may be appropriate to hire an environmental professional to perform further mitigation efforts. To determine how to dispose of the soil, see **Section 12**.

3.9.5 Confirmation Samples

Once removal actions take place, confirmation samples are taken to confirm that an excavation or interim removal successfully removed the soil contamination that exceeds applicable regulatory or risk-based levels. If confirmation sampling determines that soil contamination still exists at levels of concern, additional removal actions or other types of remediation or mitigation may be required. The type, number, and distribution of confirmation samples is determined on a site-specific basis according to local regulatory guidance.If confirmation sampling is delayed due to weather events—for example, a rainfall event—the results from such sampling should be interpreted carefully.

3.10 AFFF Disposal

BMPs recommend that volumes of AFFF foam concentrate be carefully monitored and recorded at each storage location, from fire trucks to suppression systems to storage containers (see **Table 3-3**). Weights of other AFFF system components requiring disposal should be similarly observed. Disposal certificates for materials bound for removal should indicate volumes of AFFF concentrate or solution or weights of

system components or debris, as applicable. Total volumes or weights generated for disposal should match that indicated on disposal certificates.

Disposal of AFFF concentrate represents a significant challenge for any owner of firefighting foam concentrates. The disposal of AFFF concentrates through standard disposal options may carry risks. Practitioners should be aware of possible disposal options, best management practices, and disposal hierarchy, as explained by USEPA (**USEPA 2024**). Manufacturers' product literature and local regulatory agencies should be consulted for information regarding the specific foam concentrate to be disposed. Some disposal options that are currently available for AFFF concentrates and AFFF-impacted natural media are presented in USEPA's *Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances* (**USEPA 2020**). The discussion in Section 3.10 is based on the 2020 version of the USEPA guidance and the reader is encouraged to review the updated 2024 Version 2 guidance. Additional information can be found in **Stoiber, Evans, and Naidenko (2020)** and **Aleksandrov et al. (2019)**.

Currently available AFFF concentrate disposal options are briefly presented below and in **Table 3-4**. Table 3-4 also presents advantages and disadvantages associated with each disposal method and new disposal technologies that were under development when this table was prepared. The disposal options that are currently available for materials impacted with dilute AFFF wastes are presented in **Section 12**, and include stabilization and landfilling, incineration, and deep well injection.

As stated in the USEPA interim PFAS destruction and disposal guidance (**USEPA 2024**), one option for addressing disposal concerns related to environmental releases of foam, byproducts, or other possible releases is to store AFFF in warehouse storage to provide time for completion of studies for destruction, disposal, or stabilization of the AFFF. Stakeholder concerns regarding AFFF waste disposal practices are presented in **Section 13.1.11**.

Each of the currently available disposal options presented below and in **Table 3-4** has different advantages and disadvantages that the practitioner should consider when deciding how to dispose of AFFF concentrates, including availability, cost, effectiveness, and potential long-term risks associated with nondestructive disposal options.

3.10.1 Stabilization and Landfill Disposal

Waste stabilization and landfilling is a nondestructive disposal methodology wherein waste, including AFFF concentrates, are mixed with stabilizing materials (for example, Portland cement) and disposed at a landfill that is licensed to accept and manage these wastes. This disposal method is nondestructive in that the waste is not destroyed but immobilized and encapsulated to prevent exposure and reduce potential mobility. Ultimately the stabilized and landfilled AFFF concentrate is managed with other wastes disposed of at the same landfill through landfill best management practices (for example, liners, leachate collection, cap management, groundwater monitoring, etc.). Stabilization and landfill disposal is an accepted waste management strategy in some states, though the long-term stability of stabilized AFFF concentrate is not well understood.

Practitioners with AFFF concentrates requiring disposal should collaborate with their local or state agency waste management personnel, as applicable, to determine current availability and acceptability of stabilization and landfill disposal as a waste management practice. AFFF concentrate bound for disposal should be properly documented (for example, a proper manifest or bill of lading) as a best practice and in compliance with state and federal transportation regulations (as discussed in **Section 3.6.2**). After the concentrate product has been disposed of, a certificate of disposal may be generated by the disposal facility, transmitted to the product owner, and retained by the disposal facility. This certificate of disposal may be transmitted to the state regulatory agency for review and maintained on file by the product owner.

3.10.2 Incineration

Incineration is a destructive disposal technology wherein AFFF concentrate is destroyed, or mineralized, through the application of heat. Heat is applied to the AFFF concentrate at incineration facilities that have the capability to manage high temperatures and residence times required to destroy AFFF concentrate, as well as vaporized combustion products (flue gases) that are captured and/or further incinerated. Most AFFF concentrate has historically been disposed of using incineration in the United States (**FFFC 2016**). However, the effectiveness of incineration, and the temperature and time conditions required to achieve complete PFAS destruction, are not well understood (**USEPA 2020**). Legal, technical, and political challenges to incinerating AFFF exist based on gaps in research on the effectiveness of incineration (**Earthjustice 2020**). For example, the New York State DEC prepared a sampling report in 2021 near one incineration facility in response to concerns about emissions from the facility (**NY DEC 2021**). USEPA researchers are currently studying PFAS incineration, sampling and analytical methods development, and industrial field sampling. Thermal stability of PFAS, the ability to fully capture and identify PFAS and their thermal decomposition byproducts, and the efficacy of emission control technologies are areas of targeted research (**USEPA 2020**). The NDAA for fiscal year 2022 (**https://www.congress.gov/bill/117th-congress/senate-bill/1605**) established a temporary moratorium on incineration of AFFF generated by DOD. The temporary moratorium began no later than 120 days after enactment of the NDAA FY22 (4/26/2022). The DOD published a memo about the temporary prohibition on April 26, 2022 (**USDOD 2022**).The DOD published a memo with interim guidance about destruction or disposal of materials containing PFAS on July 11, 2023 (**USDOD 2023**). A follow-up statement was published on July 17, 2023 about additional planning and coordination that is needed before incineration is implemented (**USDOD 2023**). Additional information is included in the DOD Incineration Report to Congress (**USDOD 2024**).

This technology is currently the only known AFFF destruction technology in widespread use, though the efficacy of incineration as an effective disposal option for AFFF concentrate is an area undergoing further study (**USEPA 2024**). More information is also included in **Section 12.4**. At the time of publication there are a number of studies ongoing to evaluate destruction temperatures and treatment time required to achieve complete AFFF destruction, the potential to generate products of incomplete combustion, flue-gas analyses to assess mobilization of AFFF concentrates, and other risk factors. Owners of AFFF concentrates requiring disposal should consider contacting their local or state agency waste management personnel, as applicable, to determine current acceptability of incineration as a disposal practice prior to disposal.

3.10.3 Deep Well Injection

Another disposal approach, available in some states, is to dispose of AFFF concentrate through deep-well injection. In some cases, disposal via landfilling of a stabilized concentrate or deep well injection at a licensed hazardous waste management facility has been used. This disposal option eliminates discharges to surface water and shallow groundwater, similar to stabilization and landfilling, but does not destroy or degrade disposed wastes. Deep well injection is an available option that is being used given the currently limited number of disposal options for AFFF concentrate. Class I deep injection wells, as defined by USEPA, accept both hazardous and nonhazardous liquid wastes (**USEPA 2019**), including AFFF waste materials such as dilute AFFF (fire water) and AFFF concentrates. The USEPA has published guidance on the requirements for the use of deep injection wells, including siting, construction, operation, monitoring, testing, record keeping, reporting, and closure (**USEPA 2019**). The USEPA has also studied the risks associated with underground injection wells (**USEPA 2001**), and these risks are documented for consideration by generators prior to disposal of AFFF concentrates through deep-well injection.

3.10.4 Potential Future Disposal Technologies

The currently available disposal options for AFFF waste are limited and carry inherent unknowns in terms of long-term reliability. This is of particular importance when considering nondestructive disposal means such as stabilization and landfill disposal and deep well injection. These unknowns translate into short- and long-term risks for the practitioner. Additional disposal options may be available in some areas (for example, deep well injection) for AFFF concentrate wastes and AFFF-impacted materials. Alternate treatment and disposal technologies are presented in **Section 12**. New treatment and disposal technologies are an active area of research and development by a number of groups; some are presented in **Table 3-4**. All technologies will require extensive evaluation to ensure they are fit-for-purpose.

Table 3-4. PFAS Waste Materials Disposal Options.

Current as of October 2022.

Current Disposal Practice	Advantages	Disadvantages
Stabilization and Landfill Disposal (**Section 3.10.1**)	1. AFFF concentrate mass is encapsulated and immobilized in a stable form 2. Disposal is at a licensed landfill with monitoring programs and leachate collection systems designed to ensure disposed mass remains controlled 3. Long-term management of the disposed waste is part of the overall landfill management and monitoring program	1. Disposed AFFF concentrate mass remains in place with no known and documented destruction mechanisms 2. Risks associated with comingled waste disposed of at the waste management facility 3. Long-term testing of stabilized PFAS waste materials under landfill conditions is limited. Some studies are available (**CONCAWE 2016**; **Oliaei et al. 2013**; **Weber et al. 2011**) 4. PFAS mass from disposed wastes can form mobile leachates, which require long-term collection, management, and disposal (**Stoiber, Evans, and Naidenko 2020**) 5. Some PFAS may be emitted by the landfill gas collection and management system
Deep Well Injection (**USEPA, 2019**; **USEPA 2024**; **Marine 2020**) (**Section 3.10.3**)	1. AFFF concentrate mass is injected deep underground in previously defined tectonically stable strata 2. Waste is injected well below drinking water aquifers, reducing potential for future impacts to drinking water resources 3. Waste immobility and lack of potential for unacceptable migration must be documented prior to waste injection 4. Long-term management of the injected waste is the responsibility of the operator while the disposal facility is in operation	1. Disposed AFFF concentrate mass remains in place with no documented destruction mechanism known 2. Waste materials are injected with no modifications or additives to reduce migration potential or enhance degradation 3. Deep well injection facilities are generally operated with limited mandated monitoring to document lack of long-term waste migration 4. The long-term stability of injected wastes is undocumented
Incineration—General (**Section 3.10.2**)	1. Incineration (at properly licensed and operated disposal facilities) is the only disposal technology currently available that has the potential to result in the destruction of PFAS 2. PFAS destruction through incineration has been documented in laboratory studies (e.g., **Aleksandrov et al. 2019**; **Khan et al. 2020**) but known studies analyzed only for a subset of PFAS 3. PFAS destruction reduces/eliminates future risk 4. Some incineration facilities maintain successful track records of operating within permit requirements based on system performance monitoring data collection	1. The efficacy and operational requirements of incineration are currently under question and require additional study (**USEPA 2020**) 2. Existing laboratory experiments on the incineration of PFAS do not address the full spectrum of potential PFAS byproducts that could form during incineration (**Stoiber, Evans, and Naidenko 2020**; **USEPA 2024**) 3. Current regional and local moratoria exist in some locations against incinerating PFAS waste. Practitioners should confirm disposal vendor licensing and operational status prior to shipping AFFF concentrate for disposal

Current Disposal Practice	Advantages	Disadvantages
Incineration—Municipal	1. Municipal incinerators are readily available and offer a comparatively low-cost disposal option if operated at sufficient temperatures and residence times and if equipped with appropriate emissions controls	1. Municipal incinerators may not be permitted to accept AFFF concentrate for disposal 2. Temperatures, residence times and emissions controls may not be adequate to fully degrade PFAS 3. Potential for partial decomposition of PFAS to shorter carbon chain-length PFAS (**USEPA 2024**) 4. Existing laboratory experiments on the incineration of PFAS do not address the full spectrum of potential PFAS byproducts that could form during incineration (**Stoiber, Evans, and Naidenko 2020**; **USEPA 2024**)
Incineration—Hazardous Waste	1. Some specialized incinerators exceed minimum temperature required 2. Some are designed to handle flue gases and scrubber wastes 3. Generators may be able to obtain a disposal certification from the incineration facility	1. Temperatures, residence times, and emissions controls may not be adequate to fully degrade PFAS at some standard commercial facilities 2. Potential for partial decomposition of PFAS to shorter carbon chain-length PFAS (**USEPA 2024**) 3. Difficulty handling high-water content wastes
Incineration—Cement Kiln	1. Temperatures and residence times in excess of minimum required (1100°C and 2 seconds) 2. Effective permanent capture of fluorine 3. No extra energy required above normal kiln processing	1. Potential for partial decomposition of PFAS to shorter carbon chain-length PFAS (**USEPA 2024**)
Experimental Disposal Technologies (Section 3.10.4)		
Electrochemical Oxidation (**Le et al. 2019**; **Ensch et al. 2020**)	PFAS is degraded in a closed-cell reactor using metallic electrodes and electrical current. Several different types of electrodes (titanium oxide, boron-doped diamond, etc.) have degraded some PFAS to varying degrees of success and several studies were underway in 2020. In previous laboratory-scale studies, PFAS destruction was achieved, though at relatively low throughput rates. This disposal technology is applicable to liquid waste streams only.	
Enhanced Contact Plasma Reactor (**Singh et al. 2019**)	PFAS are degraded in a closed system using water, electricity, and argon gas to degrade PFAS through a series of sequential destruction steps. At laboratory scale the destruction of PFAS was observed within their ability to measure, limited by analytical method detection limits. Air Force Civil Engineering Center (AFCEC) and Clarkson University were field testing this technology at Wright-Patterson Air Force Base, Ohio in 2020.	
Alkaline Hydrothermal Treatment (HaLT) (**Wu et al. 2019**)	Perfluorooctane sulfonate (PFOS) and potentially other PFAS are degraded through the application of hydrothermal conditions (condensed water at high temperature [200–350 °C] and high pressure [2–16.5 MPa]) to solutions amended with NaOH. Initial studies document PFOS destruction within 90 minutes. Expanded laboratory studies continue to investigate efficacy over a broader range of PFAS compounds.	
Supercritical Water Oxidation (**SERDP-ESTCP 2020**)	Supercritical water oxidation at high temperature (greater than 373 °C) and high pressure (greater than 22 MPa) has been demonstrated to degrade PFAS. Battelle Memorial Institute has patented a process called PFAS Annihilator to apply this technology for the destruction of PFAS. In addition, an ESTCP-supported study at Duke University began in May 2020 to demonstrate the efficacy of this technology at higher throughput rates (approximately 907 kg of waste material per day).	

3.10.5 Fire Water and Flush Water Containing PFAS

Fire water produced during training or emergency response, as well as flush water produced during the rinsing of firefighting systems and equipment, may be managed and disposed of as a generated waste because these waters contain dilute concentrations of PFAS. Practitioners may consult with local regulatory agency personnel ideally prior to the generation of fire- and flush water so that there is a good understanding of local laws and regulations governing disposal. Standard practices for foam containment and cleanup should be developed prior to use such that response teams have the needed equipment and training before an event occurs; **Table 3-1** provides additional information for BMPs. Some fire water disposal options are focused on reducing the volume of wastewater through concentration and disposal of the generated concentrate via incineration, landfilling, stabilization, or other mechanisms. See **Section 3.10.1** for comments related to these disposal methods. Widely used treatment methods, as presented in **Section 12** are as follows:

- granular activated carbon treatment

- discharge to and treatment at a wastewater treatment plant
- pumping AFFF-impacted fire water into watertight, secure containment basins and allowing the water phase to evaporate, leaving behind a solid or semi-solid material containing the AFFF concentrate. The remaining material is then disposed of at a certified waste management facility (**USDOD 1997**). This method is an option only in some localities and where climatic conditions are favorable.

3.11 Firefighting Foam System Replacement

The Priority Topics for Firefighting Foams include updates to the information in this section (see **Section 1.2.3**). The updates include information about transition planning of foam systems from AFFF to F3 and a summary of available guidance. One case study was added to the **Case Study Table** (Table 3-5).

The AFFF application design is specific for each foam and use case and system design can vary significantly by location, manufacturer, foam product, and system objective. Changing between foam types or application objectives could require a complete system review and, potentially, redesign and modification of system components to meet the new objectives or material and performance requirements. When objectives or requirements are changed, each subject system should be evaluated and modified individually to ensure that operational objectives are met.

Procurement at U.S. airports is primarily driven by regulatory performance requirements, notably the DOD Mil-Spec, MIL-PRF-24385, as well as FAA requirements (**ACRP 2017**). DOD recommends complete replacement of the required AFFF concentrate supply and rinsing of the storage and discharge system prior to refilling with a different concentrate product (**USDOD 2017**). This not only prevents any unforeseen incompatibility issues, but also greatly reduces possible cross-contamination and the uncertainty of AFFF formulations (PFAS profile and content).

Applicable replacement products standards include NFPA Standards 11 (**NFPA 2016**) and 16 (**NFPA 2019**) for foam water sprinkler and foam water spray systems and NFPA Standards 1901 (**NFPA 2016**) and 412 (**NFPA 2020**) for equipment.

3.11.1 Replacement Products

Replacing foams and foam systems generally follows four steps:

1. Assess and understand the specific hazards and application objectives.
2. Ensure that foam product to be adopted is listed and approved for use on the specific assets that are being protected and the hazards that that are being mitigated.
3. Ensure that the foam product storage system and the foam/water application system meet product storage (for example, materials compatibility and storage temperature), proportioning, and application requirements.
4. Ensure that the selected foam product(s) meet applicable requirements (Requirements are based on where and how the foam is being used and rely on sector-specific standards such as Mil-Spec, Underwriters Laboratories (UL), or Factory Mutual compliance). These organizations audit manufacturers to ensure compliance with their standards.

Where two or more foam products meet applicable performance requirements, the foam with the best environmental performance may be considered for use. Alternatives currently available as replacement products for legacy AFFF include products discussed in the following sections.

3.11.1.1 Fluorine-Free Foams (F3)

Most foam manufacturers now produce Class B F3s. Performance of these foams should be evaluated carefully as future purchasing decisions are made. As of spring 2024, there are three military-specified F3s approved for use on Class B fires at federal- and FAA-regulated facilities that require Mil-Spec–compliant AFFF. For a list of the most recent military-specified foams, go to the Qualified Products Database hosted by the DoD at **https://qpldocs.dla.mil/**. For other F3s, the GreenScreen for Safer Chemicals website provides a list of PFAS-free firefighting foams that do not contain intentionally added PFAS. The website is **https://www.greenscreenchemicals.org/certified/fff-standard**.

3.11.1.2 Modern Fluorotelomer Foams

If it is determined that the performance of a fluorinated Class B foam is required for a specific hazard (for example, the federal regulation requiring AFFF use for military applications, at FAA-regulated airports, and/or other high hazard Class B fires and potential incidents), users should purchase modern fluorotelomer foams. Most foam manufacturers have transitioned to the production of only short-chain (C6) fluorosurfactants, so it is likely that any AFFF bought today meets that requirement. But foams made with only short-chain (C6) PFAS may still contain smaller quantities (parts per billion) of PFOA and PFOA precursors as byproducts of the manufacturing process. This should be confirmed with the supplier.

Although there are currently mandated specifications requiring the use of fluorinated foams at airports and military installations, users should be aware that some compounds in modern fluorotelomer foams are regulated by several states and are known to have probable effects on human health (**Section 7.1**). Use of these foams may be restricted to emergency situations only and not for use in firefighting training activities. Local and state regulations may require reporting of their release, including emergency use. **Section 3.12** discusses the current state of regulations on AFFF use.

3.11.1.3 Replacements, Certifications, and Alternatives Assessments

Several efforts are underway to evaluate F3 AFFF replacements for environmental and human health effects, as well as performance effectiveness. SERDP and ESTCP programs continue to "fund several research and development projects to evaluate performance, lifecycle impacts, and health and safety implications of commercially available, non-fluorinated alternatives." For example, **Jones et al. (2022)** examined the direct lethal effects of seven F3 and a PFAS-containing AFFF on 14 aquatic species using a series of lethal concentration (LC50) tests. Across all aquatic species tested, they discovered that exposure to at least one F3 was more or as toxic as exposure to the PFAS-containing AFFF. This illustrates that more research is needed to understand new F3 formulations to ensure they are not regrettable substitutions. Additional information regarding PFAS toxicity, data gaps, and research needs is presented in **Section 7.1**. The DOD SERDP program has invested heavily in these efforts; representative studies supporting these efforts are listed in **Section 3.13**.

In related efforts, some organizations have developed certification processes to help consumers understand which products are considered "PFAS-free" (see **Section 2.5.3**). For example, Clean Production Action developed the first-ever ecolabel for firefighting foam products via their GreenScreen certification process, which identifies products as eco-labeled but does not include a release of liability. They worked with a technical review team of scientists, firefighting foam researchers, and governments to ensure the PFAS-free standard is protective, achievable, and supports purchasers to choose foam products that are safer and better for the environment. Clean Production Action defines PFAS-free as zero PFAS intentionally added to the product and PFAS contamination in the product less than 0.0001

percent by weight of the product (1 part per million) total organic fluorine as measured by combustion ion chromatography. There are currently more than two dozen certified firefighting foam products available. Go to https://www.greenscreenchemicals.org/certified/fff-standard for more information.

Alternatives assessments have been another mechanism to further evaluate F3 alternatives in terms of regrettable substitution. The first-ever alternatives assessment for AFFF (**Wood Environment & Infrastructure, 2020**) was completed for the European Commission and European Chemicals Agency. This assessment included an evaluation of substances in formulation, a market analysis, emissions and hazards evaluation, remediation costs and technology, an analysis of alternatives and socioeconomic impacts, and regulatory management options. As a result, a Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) restriction proposal for AFFF was submitted in 2022. **Tickner (2022)**, funded by SERDP, completed an alternatives assessment for AFFF. The assessment focused on understanding alternatives assessments completed, supporting assessment and decisions about substitutes regarding "safer" and "sufficient performance," and supporting needs related to adoption. **Tickner (2022)** developed six guiding considerations, including:

1. "Determine the function of the chemical of concern for the specific application. Understand this function within the production chain.

2. Define the application-specific use scenario(s). Identify alternatives that are fit for that particular purpose.

3. Establish and/or use performance standards independent of the standards dependent on using chemicals/materials of concern. Adjust based on available alternatives or alternatives on the horizon.

4. Use a range of performance standard benchmarks, e.g., 'inadequate' to 'sufficient' to 'best in class.'

5. Consider technical performance separately from technical feasibility.

6. Consult stakeholders for determining acceptable tradeoffs between performance results and other elements such as environmental health and safety."

3.11.2 System Decontamination and Sampling During Foam Replacement

The replacement of Mil-Spec legacy foam with the modern foams requires review of system components, particularly the proportioning system, to ensure that appropriate system performance will be maintained. During foam replacement, a thorough clean-out of storage tanks and associated pipework is highly recommended prior to filling with replacement foam concentrate. There is potential for PFOS and PFOA contamination from legacy AFFF, as described in **Section 3.1**, and from PFOA and other PFAS from fluorotelomer foams. For nonmilitary applications, legacy AFFF and replacement modern foams may not be compatible. In these cases, the foam manufacturers should be consulted when a foam change is required and current best practices for foam replacement, system decontamination, and verification sampling should be considered. The degree of cleanliness required and the cost balance between cleaning and replacing system components should be considered during the planning phase of a foam concentrate change-out event.

Currently, there are no regulatory guidelines or requirements pertaining to the clean-out of AFFF firefighting systems when foam concentrates containing legacy foams are replaced with alternative foams; however, local and state governments and other organizations continue to develop policy and guidance on replacing foams. DOD (and other foam users) have performed triple water rinsing step after the legacy AFFF is removed (**USDOD 2018**). The rinse water is containerized and managed as a waste

material as presented in **Section 3.6.2**. Proprietary cleaning solutions and coagulants have also been used for AFFF clean-out (**CTDEEP 2022**). These methods have been compared to the triple water rinse. No single cleaning method has yet been proven to be 100% effective in eliminating residual PFAS concentrations (**CTDEEP 2022**). Use of proprietary methods is more costly than triple water rinse, but these methods are more effective at reducing PFAS concentrations (>99% compared to approximately 95% removal) (**CTDEEP 2022**). Organizations should check with local and state regulatory agencies regarding local policies and guidance for foam change-out and system clean-out requirements or recommendations. Sampling of rinsate to ensure that residual contamination has been removed may be considered before adding replacement foams, and sampling of replacement foams that have gone through the system may provide the best assurance that PFAS will not continue to be released when the systems are used.

3.11.3 AFFF Transition Planning

The Priority Topics for Firefighting Foams include updates to the information about transition planning of foam systems from AFFF to F3 (see **Section 1.2.3**). Protocols around transition planning and execution of foam change-out are becoming ever more important to understand. Several factors need to be carefully considered when F3 alternatives, including but not limited to:

- What will the foam be used for and max volume of fuel source handled?
    - Fuels fires and max volume (large atmospheric storage tanks or other)
    - Chemical fires and max volume (large atmospheric storage tanks or other)
    - Other
- What are the current performance specification requirements for the foam?
    - Mil-Spec
    - Other
- What application and application technique are anticipated?
    - Fire suppression system
    - Fire response vehicles
    - Industrial fire extinguisher
    - Other
- What water type is used for mixing?
    - Fresh water (compatible with most foam products)
    - Salt water (incompatible with some foam products)
- What other types of foam characteristics should be considered? (**NFPA 2020**)
    - Viscosity of the foam concentrate (Newtonian and thixotropic)
    - Suitability for use with existing proportioning hardware
    - Homogeneous mixing of concentrate with water
    - Compatibility with materials in the system (for example, plastic, rubber seals, metals)
    - Stability of foam concentrate or premix solution (separation, stratification, sedimentation)

- Suitability for use on the flammable liquids in question
- Suitability of application method (aspirated, non-aspirated, forceful, gentle)
- Extremes of ambient temperature that may be encountered in an incident
- Suitability of the expansion ratios produced by existing equipment for effective firefighting performance
- Suitability of the application rates produced by existing equipment for effective firefighting performance
- Suitability in specific climate (extreme ambient temperatures, both high and low)

Table 3-5 (provided as a separate Excel file) is presented to provide example case studies for transition planning and execution (see also **Section 1.2.3.5**). Case studies from the aviation industry and the oil and gas industry are provided. Case studies also vary by geography to illustrate potential variability by country. They are provided only as examples of how sites are implementing transition planning, but are not intended to represent guidance to be applied at other sites. The following items are included in the table:

- foam procurement, including selection criteria used to evaluate and select alternatives
- system decontamination and sampling, specifically how replacement versus clean-out was evaluated, how and whether sampling was conducted, and the definition of "clean"
- treatment and disposal, including type of cleaning reagent, waste streams generated, and how they were managed.

Because there are currently no federal or state standards on how much residual fluorine contamination in replacement foam is acceptable, each foam user is responsible for determining whether sampling and analysis of the replacement foam is necessary, and if sampled and analyzed, if the cross-contamination of replacement foam is considered acceptable for their use.

3.11.3.1 AFFF Replacement and System Clean-out

Both system replacement and system clean-out are options when transitioning to F3. There is currently no known standard practice for AFFF system clean-out procedure that is widely recommended by state or federal regulatory agencies. However, system clean-out using triple water rinse has been used by the U.S. Department of Defense, and hot water rinse (<100° F) is approved for use in some states (for example, Connecticut and New York) and is recommended in an article published by the International Fire Fighter website (**Preiss 2022**). U.S. vendors are developing clean-out methodologies that may be more effective than currently used methodologies—for example, rinsing with low- or high- temperature solvents or acids. Most methodologies are currently being performed as demonstration projects, are not widely used, and have not been proven on a wide scale as of the publication of this document.

When selecting a methodology for cleaning out a system, practitioners should aim to achieve the maximum level of clean-out to minimize potential for future PFAS release when the system is deployed, considering both objectives and costs. It's important to understand that more aggressive clean-out procedures will generally be more expensive and generate more waste that will require proper management and disposal. However, inadequate system clean-out may result in the presence of residual AFFF, which may contaminate new F3 with PFAS when the system is refilled.

For mobile systems, DOD recommends a single rinse using water (heated or unheated) that is employed after the old AFFF foam has been drained from the system and containerized (**USDOD 2024**). The State of Connecticut recommends a sitting time of 30 minutes with hot water or 1–2 hours with cold water for

municipal systems such as trailers and trucks (**State of Connecticut 2022**). Note that there are no established standard guidelines for cleaning procedures due to the immense variety of foam delivery systems for which the procedures can vary greatly even among the same manufacturer. All rinsing fluids and other waste generated during the system clean-out process should be containerized, labeled, and managed for proper future disposal. After the system has been cleaned out and rinse waters have been completely drained, new foam concentrate can be added. The practitioner should be aware that changing foam products may necessitate changes to system components, such as proportioners and discharge nozzles.

Foam change-out practitioners should also be aware of and take measures to mediate potential hydrogen sulfide generation in rinse waters that are improperly stored (**Sheinson and Williams 2007**). Hydrogen sulfide can be generated when foam contains sulfate (such as PFOS) or the water source itself contains sulfate. As a result, hydrogen sulfide may be in foam change-out rinse waters that are stored in sealed containers and that are allowed to transition into anoxic conditions. The hydrogen sulfide is generated through anaerobic microbial transformation of sulfate in the rinse water to sulfide followed by complexation of sulfide and hydrogen. Hydrogen sulfide generation can result in risk to site workers, particularly if starting sulfate concentrations in the rinse water are high. Regular inspection of stored rinse waters is necessary to detect any potential hydrogen sulfide generation, allowing for early implementation of mitigation steps.

3.12 Federal, State, and International Regulations and Guidance

The Priority Topics for Firefighting Foams include updates to the information in this section (see **Section 1.2.3**). The updates include information about state activities and guidance, federal agency guidance, and other guidance on foam transition.

3.12.1 Overview

This section summarizes representative information on the regulation of PFAS-containing firefighting foams (AFFF). Although federal law currently does not prohibit the use of existing stocks of legacy AFFF, any discharge of foam containing PFAS to public waters can be considered a release of a "pollutant or contaminant" under CERCLA, 42 U.S. Code § 9601, and therefore subject to remediation requirements. In February 2019, the USEPA announced in its PFAS Action Plan that the agency is beginning to evaluate designating PFOA and PFOS as "hazardous substances" through one of the available statutory mechanisms, including potentially CERCLA Section 102 (**USEPA 2019**). In October 2021, the EPA published the *PFAS Strategic Roadmap: EPA's Commitments to Action 2021-2024* (**USEPA 2021**). The USEPA's stated goals for addressing PFAS are focusing on research, restriction, and remediation. The strategic roadmap includes actions across the different divisions of USEPA. More information about USEPA's actions in 2021 to address PFAS are available on their website (**USEPA 2021**).

As of February 2021, 18 states have established restrictions on the use of AFFF, ranging from limitations on training, notification of PFAS content and/or release, storage, and firefighter personal protective equipment (PPE) (**Horst et al. 2021**). AFFF use is explicitly regulated by some states, such as the State of Washington and the State of New York (**Table 3-6**); however, other states regulate PFOA, PFOS or their salts, and other PFAS in AFFF as hazardous substances or hazardous waste. These regulations effectively limit the storage and/or environmental release of legacy AFFF (both legacy PFOS AFFF and legacy fluorotelomer AFFF), as well as potentially triggering cleanup actions. Similar bills, banning the use of AFFF for testing and training, have been passed in other states such as Arizona, Colorado, Georgia, Kentucky, and Minnesota.

Examples of hazardous substance and hazardous waste regulations, as well as other federal, state, and international guidance pertaining to AFFF, are presented below. For more information pertaining to the regulation of PFAS, see **Section 8**. This section addresses only regulations related to AFFF.

Table 3-6. Representative state AFFF regulatory and legislative activity.

State	Regulation or Bill	Initial Effective Date	What is Regulated?	Specific Requirement	Reference
New York	6NYCRR Part 597	March 2017	PFOS, PFOA, and Class B foams	PFOS and PFOA are hazardous substances. Storage and registration requirements for class B foams if those foams contain at least 1% by volume of PFOS and PFOA (acid and salt) and prohibit the release of 1 pound or more of each into the environment during use. If a release exceeds the 1-pound threshold, it is considered a hazardous waste spill and must be reported. Clean-up may be required under the state's superfund or brownfields program (NYDEC 2017). New York's Chemical and Bulk Storage regulations may also trigger further registration and storage requirements for foams that contain one of the four PFAS designated as hazardous substances (NY CRR Parts 596-599).	(**NY DEC 2017**)
Washington	WAC 296-24-33001	July 2020	Class B foams	Class B firefighting foams cannot be used or discharged for training purposes, and manufacturers of firefighting personal protective equipment must provide written notification to purchasers if the equipment contains PFAS. Beginning July 1, 2020, manufacturers of class B firefighting foams may no longer manufacture, sell, or distribute for sale PFAS-containing class B firefighting foams except for the following uses: applications where the use of a PFAS-containing firefighting foam is required by federal law, including but not limited to the requirements of 14 CFR 139.317 (such as military and FAA-certified airports). Other exceptions include: Petroleum Terminals (as defined in RCW 82.23A.010), Oil Refineries, Chemical Plants (WAC 296-24-33001)	(**Washington State Legislature 2018**)
Virginia	House Bill 2762ER	January 2020	PFAS-containing AFFF	Virginia Department of Fire Programs and the Virginia Fire Services Board begin assisting municipal fire departments to transition to F3, where possible. Effective the same date, the bill bans the discharge or use of PFAS-containing AFFF foams for testing or training unless the facility has implemented containment, treatment, and disposal measures to prevent release to the environment.	(**State of Virginia, 2019**)

3.12.2 Take-Back Programs

Several states have implemented “take-back” programs for AFFF. For example, in May 2018, the Massachusetts Department of Environmental Protection (MA DEP), in partnership with the Massachusetts Department of Fire Services, implemented a take-back program to assist fire departments in the proper disposal of legacy firefighting foams that could impact water resources (**MA DEP 2018**). MA DEP provided funding to assist local fire departments in identifying these foams in their stockpiles and for MA DEP to dispose of them. Any AFFF manufactured before 2003 is eligible under the take-back program. Vermont also announced a take-back program (**VT ANR 2022**). Users should contact their state regulatory agency for information on available take-back programs.

3.12.3 Federal Guidance

As of publication, F3s do not meet the performance requirements of the Mil-spec and therefore are not used at federal- and FAA-regulated facilities. A mandate within the FAA Reauthorization Act of 2018 (enacted October 5, 2018) directs the FAA to stop requiring the use of fluorinated foam no later than 3 years from the date of enactment (October 4, 2021), however, per Cert Alert 21-05, no fluorinated Mil-Spec existed as of that date. In January 2023, the FAA released a Cert Alert to all Title 14 CFR Part 139

Certificated Airport Operators and Aircraft Rescue and Firefighting Departments and Mutual Aid Providers (**FAA 2023**). The alert noted that FAA will accept the airport operator's use of the new F3 extinguishing agent at certificated Part 139 airports once the agent passes the military performance standards and qualification testing and is added to the Navy's Qualified Products' List/Qualified Products' Database. The alert further noted that currently, the FAA will not require certificated Part 139 airports to transition to the new F3, and airport operators are authorized to continue using AFFF, but should check with their state and local municipalities for any local requirements. The National Defense Authorization Act of fiscal Year 2020 (signed into law Dec 20, 2019) requires the DOD to phase out its use of AFFF at all military installations by Oct. 1, 2024, with limited exceptions, and immediately stop military training exercises with AFFF.

In January 2023, DOD released a new Mil-Spec (MIL-PRF-32725) to replace AFFF with F3s at military installations. The F3 Mil-Spec contains a product qualification step that requires a "non-detect" for PFAS as measured by Draft USEPA Method 1633, and also a specification limitation on PFAS content, prohibiting F3s from containing more than one part per billion PFAS (**USDOD 2023**).

3.12.4 International Guidance on AFFF

Internationally, there are many governmental agencies that have developed guidance or operational policy for AFFF. Some examples are briefly presented in **Table 3-7**. The international guidance and regulations are shaped by the unique regulatory structure and regional history of the areas in which they are implemented. As such, they may not necessarily provide informative insights to readers who are unfamiliar with those specific contexts.

Table 3-7. Representative international AFFF regulatory and guidance activity.

Country	Initial Effective Date	What is Regulated?	Specific Requirement	Reference
Canada	January 2018	PFOS, PFOA, long-chain PFCAs	Canada prohibits the manufacture, use, sale, or import of a number of PFAS-containing chemicals and products, such as AFFF, that have these chemicals. Canada allows certain exemptions, including the use of AFFF that contains residual levels of PFOS at a maximum concentration of 10 ppm; the use and import of AFFF contaminated with PFOS in military equipment returning from a foreign military operation; and the import, use, sale, and offer for sale of AFFF that contains PFOA and/or LC-PFCAs used in firefighting.	(**ECCC 2017**)
Canada	2022	PFOS, PFOA, long-chain PFCAs, polybrominated diphenyl ethers (PBDEs), and hexabromocyclododecane (HBCD)	The proposed prohibition would remove or provide time limits for exemptions for PFOS, its salts and precursors, PFOA, its salts and precursors, long chain PFCAs, PBDEs, and HBCD to further restrict the manufacture, use, sale, and import of these substances, and products that contain them. It would also prohibit the manufacture, import, use, sale, and offer for sale of Dechlorane Plus (DP) and decabromodiphenyl ethane (DBDPE), and products that contain them, with exemptions.	(**ECCC 2022**)
Germany	May 2013	AFFF	The German Federal Environment Agency released a Guide for the Environmentally Responsible Use of Fluorinated Fire-fighting Foams. The guidance discusses what AFFFs are, when it is necessary for use, why it endangers humans and the environment, and the consequences of use.	(**German Federal Environment Agency 2013**)
Australia	July 2016	Firefighting foam	The Queensland Department of Environment and Heritage Protection issued an Operational Policy on the Environmental Management of Firefighting Foam. The objective of the policy was to define the requirements and expectations for the handling, transport, storage, use, release, waste treatment, disposal, and environmental protection measures of AFFF.	(**Australia Government DOD 2007**)

Country	Initial Effective Date	What is Regulated?	Specific Requirement	Reference
Australia	July 2016	Firefighting foam	Australia's state of Queensland established restrictions on application and procurement of C8-AFFF (eight carbon-fluorine bonds or greater) and designated that C6-AFFF (six carbon-fluorine bonds or less) replacement foams contain less than 10 mg/kg PFOS and less than 50 mg/kg of PFOA, PFOA precursors, and their long-chain homologues.	**Queensland DES 2021** (replaced Queensland DES 2016)
Australia	January 2018	Firefighting foam	Australia's state of South Australia instituted a ban on fluorinated firefighting foams with a grace period of 2 years to complete foam transition.	**SA EPA May 2019**
European Union	July 2020	PFOA, its salts, and related substances	Prohibit the manufacture of PFOA and related substances on their own from 4 July 2020. Products manufactured after 4 July 2020 should not contain PFOA and its salts greater than 25 ppb or sum of PFOA-related substances (e.g., precursors) greater than 1,000 ppb.	**European Commission 2017**
European Union	December 2021	PFHxA, its salts, and related substances	Proposed a restriction on the manufacture of PFHxA and related substances on their own, as well as in products that contain concentrations equal to or above 25 ppb for the sum of PFHxA and its salts or 1,000 ppb for the sum of PFHxA-related substances.	**European Chemicals Agency (ECHA) 2021**
European Union	February 2023	C9–C14 PFCAs, their salts, and C9–C14 PFCA-related substances	Prohibit the manufacture of C9–C14 PFCAs and related substances on their own from 23 February 2023. Products manufactured after 25 February 2023 should contain less than 25 ppb for the sum of C9–C14 PFCAs and their salts or less than 260 ppb for the sum of C9–C14 PFCA-related substances.	**European Commission 2021**

3.13 Foam Research and Development

Current modern AFFF fluorosurfactant alternatives are largely short-chain C6 telomer-based fluorosurfactants. The fluorosurfactants do persist in the environment, and they have the potential to create breakdown products that are also persistent. Although numerous fluorine-free alternatives are already on the market, there is still a need to develop novel firefighting foams that provide the desired firefighting performance while not being harmful to human health and the environment. Research is currently being conducted to further evaluate modern fluorotelomer and fluorine-free alternatives. Research is discussed below.

3.13.1 Research on Current AFFF

Research is being conducted to provide a better understanding of AFFF in the environment and to develop novel technologies to clean up or remove AFFF at contaminated sites. Due to the ability of these legacy AFFF to spread quickly and prevent re-ignition of fuel fires, combined with the fact the USEPA did not require manufacturers to remove their long-chain inventory as part of the 2010/2015 PFOA Stewardship Program, some legacy stockpiles are still being used today (**Barclift 2013**).

Since 2017, the Strategic Environmental Research and Development Program (SERDP) has been funding research intended to identify and test F3s that meet the performance requirements defined in MIL-PRF-24385. New formulations must be compatible with existing AFFF and supporting equipment. Projects include evaluation of persistence and aquatic toxicity of the alternative materials and will provide human health and environmental impact assessments on the ingredients, formulations, and byproducts being studied. **Table 3-8** summarizes the current AFFF alternatives studies supported by SERDP-Environmental Security Technology Certification Program (ESTCP). The user is encouraged to view the results and full reports of these and future projects on the SERDP-ESTCP website (https://serdp-estcp.org/).

Table 3-8. Summary of the AFFF alternatives studies supported by SERDP-ESTCP.

Lead Investigator	Objectives	Expected Completion	Project Link
Dr. Joseph Tsang, Naval Air Warfare Center Weapons Division	Proof-of-concept for the development of the next generation of fluorine-free firefighting foam formulations as a replacement for existing aqueous film-forming foam (AFFF). The novel foam systems produced in this research are derived from polysaccharide copolymers and nanoparticles that are sustainable, nontoxic, and water-soluble (or water-dispersible), and will be applied using existing military firefighting equipment.	Aug-18	https://serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Waste-Reduction-and-Treatment-in-DoD-Operations/WP-2737/WP-2737
Dr. John Payne, National Foam	Improve understanding of the physical and chemical processes that underlie firefighting foams, and how the components of a foam formulation can deliver the properties required for good fire-extinguishing performance while minimizing environmental burdens. Statistical method will be employed to develop a fluorine-free surfactant formulation that meets the performance requirements defined in MIL-F-24385. A life cycle assessment will compare the environmental impact of each foam type and identify routes to improving environmental performance.	Sept-19	https://serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Waste-Reduction-and-Treatment-in-DoD-Operations/WP-2738/WP-2738
Dr. Ramagopal Ananth, U.S. Naval Research Laboratory	Develop a fluorine-free firefighting surfactant formulation that meets the performance requirements of MIL-F-24385F and is an environmentally friendly drop-in replacement for the current environmentally hazardous AFFF.	Dec-20	https://serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Waste-Reduction-and-Treatment-in-DoD-Operations/WP-2739/WP-2739
Prabhat Krishnaswamy Engineering Mechanics Corporation of Columbus (Emc2)	WP22-7521. This project's technical objective is to develop a novel approach for fighting gasoline pool fires based on fire-retardant additive releasing smart beads.	Initiated 2022	https://www.serdp-estcp.org/projects/details/352aa6f8-fae0-4cf6-8080-0fc319700142/wp22-7521-project-overview
Dr. Girish Srinivas, TDA Research, Inc.	WP22-7456. TDA Research, Inc.'s objective is to collect baseline data for the PFAS-free foam under MIL-PRF-24385F to inform what specifications could be adjusted to fully evaluate PFAS-free foams for fire suppression and environmental impact.	Initiated 2022	https://www.serdp-estcp.org/projects/details/baa72637-e3c8-40ee-a007-f295311c72ad/wp22-7456-project-overview
Dr. Tirumalai Sudarshan, Materials Modification Inc.	WP22-3456. This project's technical objective is to develop a novel approach for fighting gasoline pool fires based on fire-retardant additive releasing smart beads.	Initiated 2022	https://www.serdp-estcp.org/projects/details/b4cada93-5acf-47ff-ab68-c115a9c6c6ab/wp22-3436-project-overview
Eric Sievert, Naval Air Warfare Center Weapons Division	WP21-3461. During this follow-on effort, the capabilities of the top fluorine-free products will be assessed and validated against the test configurations used to assess the capabilities of AFFF 30–40 years ago.	2021	https://www.serdp-estcp.org/projects/details/1bed98f7-dbe6-4bdd-98d2-1f9cfeb5f3d9/wp21-3465-project-overview
Dr. Satya Chauhan, Battelle Memorial Institute	WP20-5335. The objective of this project is to provide comparative and unbiased demonstration and validation of mature Fluorine-Free Fire Suppression Alternatives (FF_FSA) against military specifications (MIL-SPEC), specifically MIL-PRF-24385F, as amended, to permit transition to field use as a firefighting agent.	2020	https://www.serdp-estcp.org/projects/details/164cac28-0322-4d7a-8980-80a1146b5afa/wp20-5335-project-overview
Kevin Roth, ADA Technologies, Inc.	WP20-5381 Testing of New Fluorine-Free Green Surfactants Mixture to Replace AFFF	4/20/2022 Project Brief	https://serdp-estcp-storage.s3.us-gov-west-1.amazonaws.com/s3fs-public/project_documents/WP20-5381%2BProject%2BOutbrief.pdf?VersionId=5e69zE0HUHJoVs.NrGmWPp1ZiZM1wWjH
Dr. Bridgett Ashley, Air Force Civil Engineer Center	WP 20-5381. The goal of a water mist system in an aircraft hangar is to suppress and mitigate fire events and prevent damage to aircraft surfaces that are directly above and/or adjacent to the fuel spill fire.		https://www.serdp-estcp.org/projects/details/cb97638e-8d4e-4892-adce-343575ca862c/wp21-5212-project-overview

Examples of other ongoing research includes:

- European Chemicals Agency, 2020. Assessment of Alternatives to PFAS-Containing Fire-Fighting Foams and the Socio-Economic Impacts of Substitution.
- European Commission, 2020. The Use of PFAS and Fluorine-Free Alternatives in Fire-Fighting Foams.
- The Fiscal Year 2020 National Defense Authorization Act (NDAA), passed in December 2019, included $49M in research funding for AFFF and F3 activities.
- The Fiscal Year 2022 National Defense Authorization Act (NDAA), passed in December 2021, included more than $500 million for PFAS provisions
- **NFPA Research Foundation (2022)**, Fire Fighting Foams: Fire Service Roadmap.

4 PHYSICAL AND CHEMICAL PROPERTIES

This section provides information about available physical and chemical properties of PFAS. Understanding of the physical and chemical properties of PFAS is important for the prediction of their fate and transport in the environment. The available information about physical and chemical properties varies between the different PFAS. Tabulated values are included in the Physical and Chemical Properties Table (Table 4-1) that is provided as a separate Excel file. The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include information about perfluoroalkyl acid (PFAA) precursor biotransformation (see **Section 1.3.3**). In addition, a new tab named Biotransformation was added to the Physical and Chemical Properties Table (Table 4-1). The biotransformation table includes a compilation of available precursor kinetics data (see **Section 1.3.3.2**).

Section Number	Topic
1.3	**Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization (2025)**
4.1	**Challenges and Limitations Related to PFAS Physical and Chemical Properties**
4.2	**Physical Properties**
4.3	**Chemical Properties**

4.1 Challenges and Limitations Related to PFAS Physical and Chemical Properties

Understanding the physical and chemical properties of PFAS is important for the prediction of their fate and transport in the environment. More specifically, reliable values are very important when attempting to explain the environmental behavior of PFAS through mathematical fate and transport modeling, where small variations in values can have large implications on predictions (see **Section 10.4** on data analysis and interpretation, which includes a discussion of fate and transport modeling). There is large variation in both the quantity and robustness of published data (a lot is known about some PFAS, but almost nothing about others) on chemical and physical properties of PFAS. Reliable physical and chemical properties of PFAS are scarce (for example, vapor pressure and Henry's Law constants), and some of the available values are estimated using predictive mathematical techniques, which predict properties of compounds from knowledge of their chemical structure. These are collectively referred to as quantitative structure-activity relationship (QSAR) models. Predicted, as opposed to directly measured, values are accompanied by additional uncertainty that may be significant in certain fate and transport modeling scenarios. In addition, many of the available properties are based on the acid form of the PFAAs, which is not present in the environment except at low pH. These uncertainties can result in wide ranges of reported values and thus limit confidence in the precision of current fate and transport models. The Physical and Chemical Properties Table (Table 4-1 provided as a separate Excel file) summarizes some of the physical and chemical properties that are available for PFAS. The object of this table is to serve as a starting point for the research and selection of relevant properties by the practitioner. Selection of appropriate physical and chemical parameters for a specific use is beyond the scope of this document.

4.2 Physical Properties

This section briefly describes some standard physical properties of PFAS. Additional references for more information are provided. In addition, the Physical and Chemical Properties Table (Table 4-1 provided as a separate Excel file) summarizes some of the physical and chemical properties that have been published for PFAS and are discussed in this section.

4.2.1 Physical State/Appearance

Most PFAS are solids, often crystalline or powdery in form, at room temperature; however, shorter chained compounds (the acid forms of PFCA and PFSA, FTS and FTOH with a 4- to 6-carbon tail) tend to take liquid form at room temperature (melting point is addressed in **Section 4.2.3**).

4.2.2 Density

Density (ρ) is the mass per unit volume of a substance. For an individual PFAS compound (or mixture of PFAS) that exists as a liquid at ambient temperatures, density can influence its behavior in the environment.

If the density of the liquid PFAS is greater than that of water, the liquid PFAS has the potential to migrate downward through the water column in groundwater or surface water as a dense nonaqueous phase liquid (DNAPL); see **ITRC (2003)** for discussion on density and solubility impacts on DNAPL behavior. For example, 4:2 FTOH, which is a liquid at 20ºC and has a density and aqueous solubility of 1.59 g/cm^3 and 974 mg/L (**Table 4-1**), respectively, would be predicted to behave similarly to carbon tetrachloride (with a density of 1.59 g/cm^3 and a solubility of 800 mg/L) if released into the environment as a pure product (also referred to as a neat liquid). However, if 4:2 FTOH dissolved in water, the change in density of the solution relative to water is unlikely to result in a separate layer. Floating separate-phase liquid layers have been observed on the surface of aqueous PFOA and PFOS solutions at high concentrations (**Costanza et al. 2019**). However, the formation of these layers appears to be driven by the tendency of PFAAs to accumulate and aggregate at air-water interfaces, and not by density. See Sections **4.2.8**, **5.2.2.2**, and **5.2.4.1** for additional information on the behavior of PFAS at air-water interfaces and in aqueous solutions.

4.2.3 Melting/Boiling Points

Melting and boiling point information refers to the temperature of phase transitions of pure compounds. These properties determine whether a specific pure PFAS compound will exist as a liquid, solid, or gas under typical environmental temperatures. These data can vary among references. Predicted melting and boiling point values are available for most PFAS, but empirically derived values are not available for many compounds. Predicted values are generally useful in understanding the various physical states of PFAS; however, the accuracy of these results is still unknown and warrants further investigation. Available data indicate that melting and boiling points of PFAS will tend to increase as the fluorinated chain increases in length. For example, the melting point of PFBA is -17.5°C while the melting point of perfluorotetradecanoic acid (PFTeDA) is 130–135°C. See **Table 4-1** for a list of melting and boiling points.

4.2.4 Solubility

Solubility (S) refers to the ability of a given substance, the solute, to dissolve in a solvent. It is measured in terms of the maximum amount of solute dissolved in a solvent at a specified temperature and pressure. Typical units are milligrams per liter (mg/L) or moles per liter (mol/L). Currently, experimentally measured data for the solubility of PFAS in water are available for many of the well-studied compounds, but values are still needed for less studied compounds. This limited availability of experimental data should be considered when relying on PFAS solubility data. Most cited values are based on predicted or modeled values and the input values to these calculations may themselves be estimates. Further, because some PFAS can form different types of supramolecular assemblies, as discussed in **Section 4.2.7**, the reported water solubilities may include microdispersions of micelles or hemi-micelles in addition to truly solubilized molecules.

Values of solubility for the acid forms of PFAAs and other PFAS are summarized in **Table 4-1**. Reported values for solubility of individual PFAS analytes may vary depending upon the method used to determine solubility, the form of the analyte (that is, acid or salt), pH, salinity, and whether the value is empirical or obtained through modeling. For example, laboratory studies of water solubilities for PFOS indicate that solubility decreases when the water salt content increases (**3M Company 2000**). Other factors may affect the reported value of solubility as well.

4.2.5 Vapor Pressures (V_p)

Vapor pressure is an indication of the tendency of a substance to partition into the gas phase. Vapor pressure is a measure of volatility in that the higher the vapor pressure of a compound, the more volatile it is. Compounds with higher vapor pressures, because they are in the gaseous phase or sorbed to aerosols in the atmosphere, have a higher potential for long-range transport. Compounds with lower vapor pressures, which are more likely to remain in solid or liquid form, are transported only via soil or surface/groundwater (**Barton, Botelho, and Kaiser 2008**), unless they are dissolved into airborne water droplets or sorbed on airborne particulates, as discussed in Sections **5.3.2** and **6.1**. **Section 1.1.3.3** includes information about volatile PFAS. See also the **PFAS and Vapor Intrusion Fact Sheet** developed in 2025.

Values for vapor pressure of PFAS are summarized in **Table 4-1**. Although there are multiple values for PFCAs, FASEs, and FTOHs, very little data exist for measured vapor pressure values for PFSAs, fluorotelomer acids, and perfluoroalkyl ether compounds, and much of the data are extrapolated or modeled. Caution must be taken when using the vapor pressures for PFAAs listed in **Table 4-1** with respect to the acid or **anion** form of the compound, which may have very different vapor pressures. Efforts were made to report the values for the acidic form in **Table 4-1**, but references are not always clear. These values also should not be used for their corresponding salt form for the same reason (for example, the vapor pressure of ammonium perfluorooctanoate has been measured experimentally to be three orders of magnitude lower than the vapor pressure of perfluorooctanoic acid at 25°C (**Barton, Botelho, and Kaiser 2009**)).

4.2.6 Henry's Law Constant (K_h)

The Henry's law constant (K_h), as well as the air-water partition coefficient (K_{aw}), indicate the relative concentrations of a compound between an aqueous solution and gas phase at equilibrium (air-water distribution ratio) and provide an indication of the propensity of a chemical to remain dissolved in water versus volatilizing into the gas phase. A chemical with lower solubility and higher volatility will have a higher Henry's law constant than a chemical with higher solubility and lower volatility. **Section 1.1.3.3** includes information about volatile PFAS. See also the **PFAS and Vapor Intrusion Fact Sheet** developed in 2025.

For most organic compounds of moderate to low solubility, K_h can be approximated by:

$$K_h = (V_p)(M)/S$$

where K_h is the Henry's law constant, V_p is vapor pressure, M is molecular weight, and S is solubility. This constant can be expressed in a variety of units or as the inverse (water-air distribution ratio); thus, the units of expression should always be confirmed prior to use of this constant. K_h also displays nonlinear temperature-dependence and is typically reported at 25°C, which is higher than most ambient environmental conditions.

Experimental and modeled Henry's law constants are available for many PFAS in several families, including FTOHs (for example, **Wu and Chang (2011)** and **Xie et al. (2013)**), PFSAs, PFCAs, FTCAs, FTSAs, FASEs, and FASAAs (for example, **Kwan (2001)** and **Zhang et al. (2010)**). For PFAS that can

dissociate into anions or cations, as discussed in **Section 4.3.2**, the Henry's law constant is pH-dependent and reported constants may not be applicable depending on the pH conditions within the solution (for example, **Rayne and Forest (2009)** and **Johansson et al. (2017)**). In a study of airborne PFOA release in industrial settings, monitoring above sumps found concentrations 40 times greater when the pH was 1.8 than at neutral pH, and PFOA release from aqueous solution was found to be several times greater at pH 4 than at pH 7 (**Kaiser et al. 2010**). Henry's law constant values, converted between a variety of units, are presented in **Table 4-1**. Corresponding K_{aw} values and, where available, the temperature and pH at which the value is relevant, are also presented.

4.2.7 Critical Micelle Concentration

Given the difference in behavior between the "head" and "tail," traditional surfactants (surfactants that contain a hydrocarbon chain), when in water, tend to aggregate into micelles (form a sphere with the hydrophobic portion of the molecules on the inside) when present above a certain concentration. Surfactants can also form other supramolecular assemblies, such as hemi-micelles or mixed micelles (micelles composed of a mixture of surfactant-type molecules), either independently in solution or at boundaries occurring between phases (**Krafft and Riess 2015**).

Early studies of PFAAs concluded that they behaved like traditional surfactants and aggregated in both micelles and mixed micelles (**Pedone et al. 1997**; **Downer et al. 1999**). The theoretical threshold concentrations for aggregation, generally referred to as critical micelle concentrations (CMCs), for PFAS are presented in **Table 4-1**. However, there remain some observed properties of PFAS that do not fit the traditional understanding of micelle formation. For example, it appears that some reported CMC concentrations are above the known corresponding solubilities of that compound. For example, **López-Fontán, Sarmiento, and Schulz (2005)** reported a PFOA CMC of more than 12,000 mg/L when the reported solubilities of PFOA are generally less than 10,000 mg/L (see **Table 4-1**). Several reported CMC concentrations for PFOS are also above the reported solubility values (**Yu et al. 2009**; **Sørli et al. 2020**; **Bhhatarai and Gramatica 2011**). In addition, **Costanza et al. (2019)** reported a separate-phase liquid at the surface of high-concentration solutions of PFOS and PFOA. These anomalous breaks with traditional micelle formation behavior have yet to be fully explained in the literature. Some researchers have also postulated that the nature of PFAA supramolecular aggregations is much more complicated in environmental settings than formation of micelles at concentrations exceeding the CMC value, which is derived from single compound systems. Some have hypothesized that PFAA supramolecular aggregations may occur at concentrations much lower than the CMC in groundwater, due to interactions with particles and/or co-contaminants, formation of hemi-micelles, or spatially variable concentrations within soil matrices (**Johnson et al. 2007**; **Yu et al. 2009**). Other researchers have been studying the variable nature of PFAS micelles in the presence of solvents (**Dong et al. 2021**). These hypothesized supramolecular aggregations, coupled with the interrelationship of adsorption to interfaces such as the air-water interface, present an extremely complex set of interactions that may be occurring in the environment. It is evident that there is much more research to be done on this topic, which can aid our understanding in what may be a key PFAA characteristic that influences fate and transport in the environment. This topic is further discussed in **Section 5.2**.

4.2.8 Partitioning to Fluid-Fluid Interfaces

The amphiphilic structure of PFAAs (hydrophobic tail with hydrophilic head) implies that they behave like traditional surfactants, accumulating to the fluid-fluid interfaces (for example, air-water or NAPL-water) by orienting themselves along the air-water boundary so that their hydrophobic tails are in the air while their hydrophilic head groups are in the water (**Krafft and Riess 2015**; **Figure 4-1**). Although there has been a good deal of research done that confirms surface aggregation, the actual structure of the molecular assemblies has not yet been elucidated. Work done by **Hasegawa et al. (2017)**, however, has provided some theories that the aggregational shape of PFAS may be more complex than that of

traditional surfactants and depend on the length of the fluorinated tail. See **Section 1.3.1.1** for information about air-water partitioning.

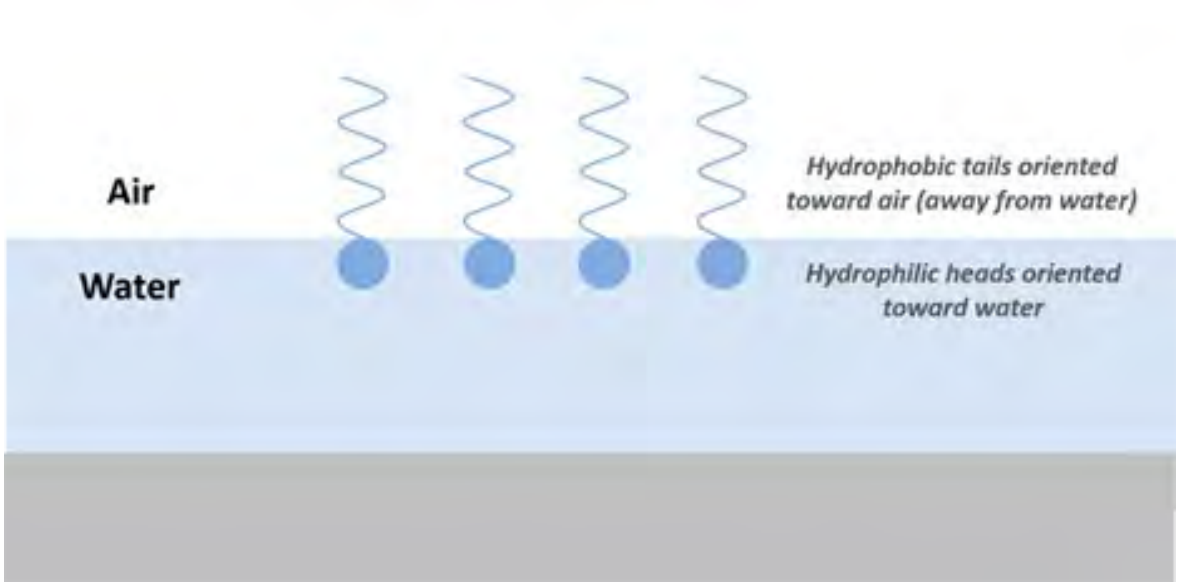


Figure 4-1. Example of expected orientation and accumulation of PFAS at air-water interface.

Source: D. Adamson, GSI. Used with permission.

Because of the low polarizability of the C-F bond relative to the C-H bond, PFAAs have a stronger affinity for interfaces than that of traditional hydrocarbon surfactants (**Brusseau 2018**). These strong surface-active properties and propensity toward self-assembly into films are what makes PFAAs extremely effective and widely used in a variety of applications such as water/grease repellent packaging and AFFF.

Studies have shown that PFAAs are enriched at the air-water interface up to eight times that of the bulk water concentration, with enrichment factors increasing with alkyl chain length (**Psillakis et al. 2009**; **Costanza et al. 2019**; **Silva et al. 2019**; **Schaefer et al. 2019**). A similar process is thought to occur for PFAAs at NAPL-water interfaces (**Brusseau 2018**; **Silva et al. 2019**; **Brusseau 2020**), however, the magnitude of accumulation at the NAPL-water interface appears to be far less than at the air-water interface at environmentally relevant concentrations. Recently, **Costanza, Abriola, and Pennell (2020)** reported that concentrations of PFOA, PFOS, and FOSA at the air-water interface were from 2 to 16 times greater than at the NAPL-water interface when the PFAS water concentrations were below 100 mg/L. This study also estimated that, in an unsaturated soil system with a dissolved water concentration below 1 mg/L, up to 87% of the PFOS mass accumulates at the air-water interface, while less than 4% of the mass occurs at the dodecane-water interface.

The degree of affinity that PFAAs exhibit for interfaces is related to the change in surface tension that occurs between the fluids when the compound is introduced to the system. Generally, the surface tension and affinity for the interface both go down as the amount of PFAA increases in the system, although the relationship is not linear. This means that the relationship is influenced by other factors that also effect the surface tension at interfaces (for example, the ionic strength and pH of the solution). For example, **Constanza et al. (2019)** found that the reduction in surface tension was more pronounced as the total dissolved solids increased (for TDS = 40, 400, and 1700 mg/L), which corresponded to greater accumulation of PFOA and PFOS at the air-water interface.

The adsorption coefficient for the fluid-fluid interfacial layer, termed the K_i (also called the K_{ai} or K_{ia} for the air-water interface or the K_{ni} for the air-NAPL interface) is one metric for the affinity of a compound for

fluid-fluid interfaces. However, calculation of the K_i is highly dependent on which assumed sorption model (Freundlich vs. Langmuir) is used, and values can vary by orders of magnitude at low concentrations (**Schaefer et al. 2019**). Because of this, it can be more useful to measure the affinity using the metric of surface excess (Γ, units of mg/m^2 or mol/m^2), which is the area-related concentration at the interface as compared to the bulk phase (**Costanza, Abriola, and Pennell 2020**). Because of the complicated nature of interfacial adsorption, adsorption coefficient values are not reported in **Table 4-1**.

4.2.9 Octanol/Water Partition Coefficient (K_{ow})

The K_{ow} is defined as "the ratio of a chemical's concentration in the octanol phase to its concentration in the aqueous phase of a two-phase system" (**USEPA 2015**). The Kow is a useful descriptor of the tendency of a compound to associate with hydrophobic or hydrophilic substances. Direct measurement of the K_{ow} of PFAAs has proven difficult because they tend to aggregate at the interface between octanol and water (**Kim et al. 2015**), although some researchers have employed nontraditional methods with some success (**Jing, Rodgers, and Amemiya 2009**). Alternatively, K_{ow} can be estimated using quantitative tools that predict physical and chemical properties. The K_{ow} values that are typically tabulated for the PFCAs and PFSAs are for the acid form and are therefore not directly relevant to the anionic forms of PFCAs and PFSAs that exist within the typical range of environmental pH, although the K_{ow} for the anionic form can potentially be estimated from the K_{ow} for the neutral species (**Escher et al. 2020**).

K_{ow} values are often used as surrogates for other properties, such as estimating K_{oc}, the soil organic carbon/water partition coefficient; bioaccumulation; uptake in biological systems; and ecotoxicity. However, in the case of PFAS, the use of their K_{ow} values as surrogates is generally not appropriate because PFAS do not behave like other well-researched nonionic polar chemicals. For example, the use of K_{ow} as a surrogate for bioconcentration assumes partitioning to lipids in fatty tissues, but ionic PFAS such as PFOA and PFOS generally bind to proteins. See **Section 5.5** for further discussion about PFAS uptake into aquatic organisms. For these reasons, K_{ow} values are not presented in **Table 4-1**.

4.2.10 Organic Carbon/Water Partition Coefficient (K_{oc})

K_{oc} is a metric commonly used to quantify the potential of a given dissolved compound to associate with, or sorb to, organic matter occurring in soil. Although short- and long-chain PFAAs both exhibit high potential mobility in water, long-chain PFAS are more likely to partition to sediment than short-chain PFAAs (**Dalahmeh et al. 2018**). Relative to commonly researched PFAS like PFOA and PFOS, studies have suggested K_{oc} can be appropriately defined as a distribution coefficient (K_d) normalized to organic carbon content, thus implying K_{oc} specifically represents the singular process of hydrophobic interaction (**Milinovic et al. 2015**). Broader reviews highlight the complexity and variability of processes that may contribute to the sorption of PFAS and significant differences between laboratory- and field-scale results (**Li, Oliver, and Kookana 2018**). These reviews, which cite the influence of pH, ionic composition, and other soil properties on sorption, suggest that simple hydrophobic interaction-based relationships may be unreliable for predicting partitioning for PFAS (see **Section 5.2** for more discussion on partitioning). As such, the current state-of-science supports K_{oc} being reported in relatively broad ranges on a compound-specific basis. The K_{oc} values included in **Table 4-1**, while not an exhaustive list, are an indicator of the number of values currently available for PFAS. Discussion of the use of K_{oc}, including site-specific K_{oc}, in the prediction of PFAS transport in remedial scenarios is included in **Section 10.4.2**.

4.2.11 Partitioning to Biota

The extent of accumulation of PFAAs in organisms is controlled by several mechanisms, including uptake from food and from water, depuration, growth dilution, and biotransformation. These processes are described in **Section 5**. Within organisms, PFAA accumulation differs among tissues, depending on transport factors (for example, the ability to cross the blood-brain barrier, as discussed in **Dassuncao et**

al. (2019) or active cellular transport (as discussed in **Section 17.2.3**) as well as partitioning. Partitioning is the subject of this section.

Similar to solids partitioning in the environment, the surfactant structure of PFAAs determines the types of interactions that occur within biota. Nonionic hydrophobic chemicals are known to partition into lipids within body compartments. PFAAs are amphiphilic, however, and thus are likely to interact with other organic molecules with both polar and nonpolar regions within living organisms. Many studies have found significantly different PFAA concentrations between body compartments, with the most accumulation occurring in the blood plasma, liver, and kidneys of many organisms (**Labadie and Chevreuil 2011**; **Goeritz et al. 2013**; **Murakami et al. 2011**). This marked difference in PFAA concentrations between bodily compartments has prompted some researchers to deem PFAAs "proteinophilic" to contrast with the description of other well-researched neutral hydrophobic environmental pollutants as "lipophilic" (**Kelly et al. 2009**; **Labadie and Chevreuil 2011**). Indeed, these differences in accumulation are likely, at least in part, due to interaction with/partitioning to proteins, which have binding pockets with varying charges that can interact with amphiphilic molecules like PFAAs. However, because the size, shape, and charge of binding pockets vary widely between proteins, there is an evident difference in PFAA binding between types of protein. Multiple studies have found strong interaction of PFAAs to serum albumin, fatty acid–binding proteins, and organic anion transporters (**Chen and Guo 2009**; **Zhang, Ren, and Guo 2013**). The magnitude of protein binding affinity differs with the type of PFAAs; **Zhang, Ren, and Guo (2013)** found that PFAA chain length and functional group determined the amount of binding affinity, but the relationship between binding and chain length was not linear. They also found that FTOHs (neutral charge molecules) did not bind to fatty acid–binding proteins, indicating that the charge of the functional group plays a large part in the protein interaction.

In addition to proteins, PFAAs likely interact with phospholipids (the basic building block of cell membranes). **Dassuncao et al. (2019)** found a positive correlation between PFAA and phospholipid content in several body compartments of pilot whales. It has been suggested that the interactions occur because of the amphiphilic nature of both phospholipids and PFAAs, which have the potential for binding at both their polar and nonpolar regions (**Armitage, Arnot, and Wania, 2012**). However, researchers have not found evidence that these interactions are the main determinant of tissue binding. **Dassuncao et al. (2019)** noted variability in the correlations between phospholipid content and tissue concentrations and concluded that the variability was likely due to the combined effect of protein and phospholipid partitioning.

For nonionic hydrophobic compounds, differences in lipid content can explain some of the variation in chemical concentration among organisms; under some conditions, individuals with higher lipid content have higher body burdens. In general, protein content differs to a much smaller extent among organisms than does lipid content, suggesting that differences in protein partitioning among individuals do not contribute strongly to differences in body burden among individuals. However, the sources of interindividual variation in PFAA body burdens is not well-understood and there is no current framework to incorporate our understanding of PFAS partitioning (for proteins and phospholipids, as well as lipids, which may still have a role) into reliable models for the prediction of bioaccumulation, biotransfer, or biomagnification.

4.3 Chemical Properties

This section briefly describes some standard chemical properties of PFAS. Additional references are provided for more information. In addition, the Physical and Chemical Properties Table (Table 4-1 provided as a separate Excel file) summarizes some of the physical and chemical properties that are available for PFAS.

4.3.1 Carbon-Fluorine (C-F) Bond Properties

The properties of PFAS are principally due to the unique properties of the carbon-fluorine bond. Some key chemical properties of this bond and the characteristics they impart to PFAS are provided in **Table 4-2**.

Table 4-2. Fluorine characteristics.

Fluorine Characteristic	Description	Effect	Resulting Property of PFAS
High electronegativity	Tendency to attract shared electrons in a bond	Strong C-F bond	Thermal stability
			Chemical stability (low reactivity)
		Polar bond with partial negative charge toward F	Strong acidity (low pKa)[1]
Low polarizability	Electron cloud density not easily impacted by the electric fields of other molecules	Weak intermolecular interactions	Hydrophobic and lipophobic surfactant properties[2]
		Low surface energy	
Small size[3]	Atomic radius of covalently bonded fluorine is 0.72 Å	Shields carbon	Chemical stability (low reactivity)

[1]When paired with an acid functional group such as a carboxylic or sulfonic acid
[2]When paired with a functional group that is hydrophilic (for example, a carboxylate)
[3]Smallest of the halogen atoms
Å = angstrom

Properties such as the high electronegativity and small size of fluorine lead to a strong C-F bond, the strongest covalent bond in organic chemistry (**Kissa 2001**). The low polarizability of fluorine further leads to weak intermolecular interactions, such as Van der Waals interactions and hydrogen bonding (**Kissa 2001**). These unique properties of fluorine give many PFAS their mutually hydro- and lipophobic (stain-resistant) and surfactant properties and make them thermally and chemically stable. But not all of these characteristics (for example, surface activity) are universal to all PFAS.

4.3.2 Functional Group Properties

PFAS functional groups include carboxylates, sulfonates, sulfates, phosphates, amines, and others, as introduced in **Section 2.2.2**. These functional groups, including dissociated and undissociated forms, govern many fate and transport properties of PFAS. The ionic state of a compound determines its electrical charge and its physical and chemical properties, which in turn control its fate and transport in the environment. For example, the state (anionic or undissociated acid) of a given PFAS may alter aspects such as volatility and bioaccumulative potential. As further described below, due to their low acid dissociation constants (K_a), PFAAs are found in the environment in the anionic (negatively charged) state, except in very rare situations (for example, pH <3).

Functional groups of some PFAS (ionic PFAS) can dissociate into anions or cations in aqueous solution under appropriate pH conditions. For example, as discussed in **Section 2.2.2**, PFOA dissociates into the perfluorooctanoate anion and the hydrogen ion when dissolved in water over a wide range of pH conditions. The ion associated with the fluoroalkyl portion of ionic PFAS can be a negatively charged anion, a positively charged cation, or a zwitterion. Therefore, PFAS can be divided into four classifications

based on functional groups (examples of the structures of many ionic PFAS can be found in **Barzen-Hanson et al. (2017)**:

- anionic–contains one or more acidic functional groups such as carboxylic acids, sulfonic acids, sulfates, and phosphates, and can release a hydrogen ion, thereby forming an anion (see **Figure 2-8** for PFBA dissociation)
- cationic–contains one or more basic functional groups such as amines, which can gain a hydrogen ion and form a cation, or have a permanent charge as in the case of a quaternary ammonium group
- zwitterionic–contains two or more functional groups, at least one of which can form an anion and one of which can form a cation
- nonionic–does not dissociate into ions; for example, alcohols.

Based on the behavior of other cationic and anionic surfactants, cationic PFAS are expected to have different environmental transport characteristics than anionic PFAS (**Place and Field 2012**). For example, sorption of organic anions such as PFAA anions is typically suppressed at higher pH due to electrostatic repulsion with the increasingly negative charge from deprotonated oxides and other functional groups present on the soil surface (**Lee and Mabury 2017**). Cations can be expected to sorb strongly to soils, which often possess a net negative charge over a range of environmentally relevant pHs. For example, cationic fluorotelomer-based PFAS in an AFFF product have been found to sorb strongly to soils and sediments (**Barzen-Hanson et al. 2017**). Zwitterionic PFAS can be expected to sorb to soils and sediment more strongly than anionic PFAS, but less strongly than cationic PFAS, owing to the mixed charges on the functional groups. The transport characteristics of specific PFAS are also highly dependent on matrix interactions, and detailed site-specific information is necessary to accurately predict PFAS transport (**Guelfo and Higgins 2013**). See **Section 5.2.3** for further discussion of partitioning onto solid matrices.

For acids such as PFAAs, the acid dissociation constant K_a is the equilibrium constant for the dissociation of the acid in aqueous solution into the anion and hydrogen ion, and at dilute to moderate concentrations, is defined by the equation:

$$K_a = [anion^-]*[H^+]/[acid]$$

where [acid] is the concentration of the undissociated acid form, $[anion^-]$ is the concentration of the anion, and $[H^+]$ is the concentration of the hydrogen ion at equilibrium.

The dissociation constant is also commonly expressed as its negative logarithm, pK_a, where:

$$pK_a = - \log_{10}(K_a)$$

Higher pKa values indicate that an acid will dissociate less in water at a given pH than will an acid with a lower pKa. When the pH of a solution equals the pKa for a particular constituent, then one half of the constituent molecules will exist as the undissociated acid and one half will exist as the dissociated anion. PFAS with pKa values of 4 or less will exist in aqueous solutions at neutral pH (7) almost entirely as the dissociated acid (see **Figure 4-2** for a representation of reported pKa values for PFOA in relation to environmental pHs). Because the undissociated acid and anionic forms of PFAAs may have very different physical and chemical properties, it is essential to distinguish between the undissociated acid form and the anionic form to select the appropriate physical and chemical parameters for fate and transport evaluations.

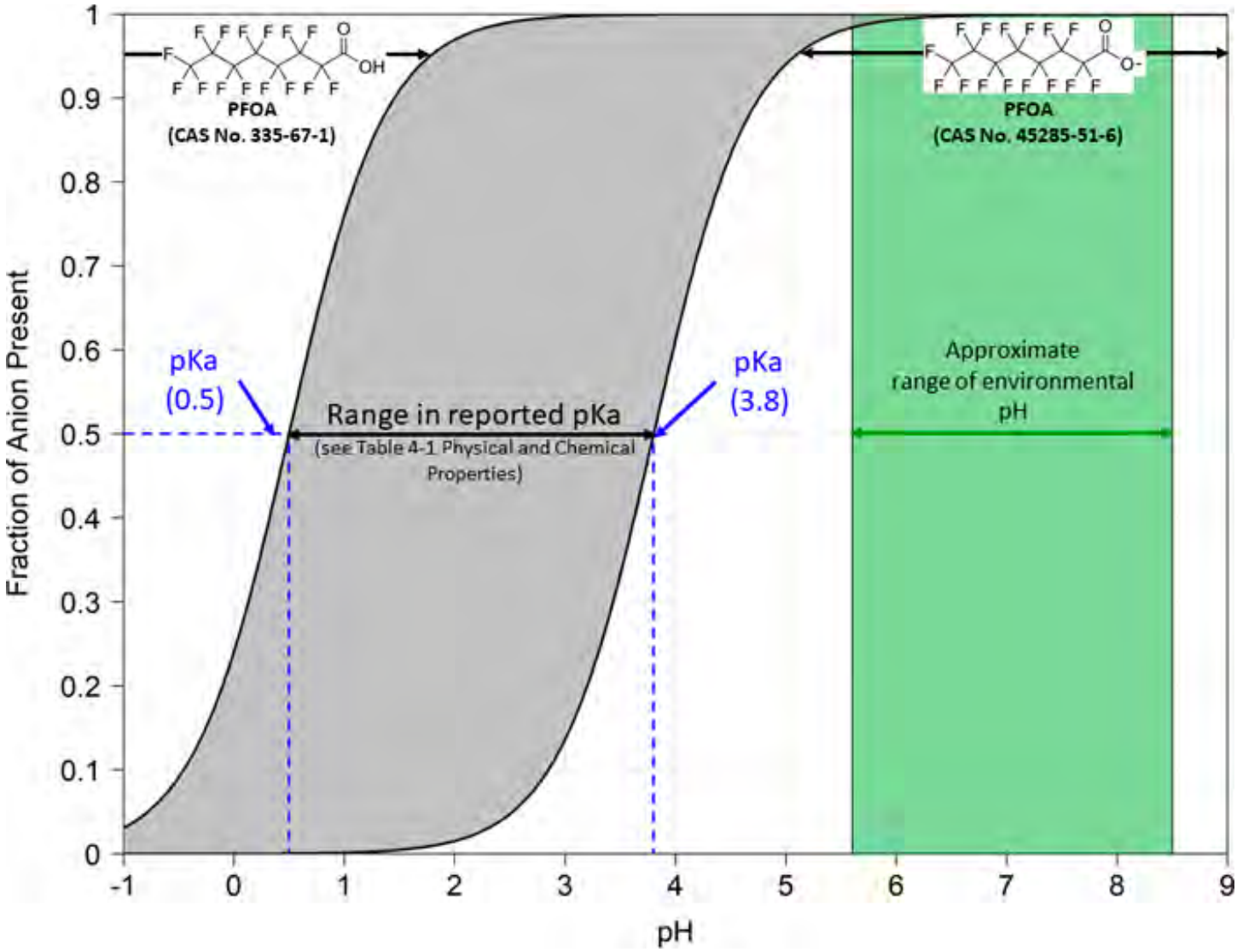


Figure 4-2. Titration curve for PFOA—relation of pKa to environmental pH.

Source: E. DiFilippo, S.S. Papadopulos & Associates, Inc. Used with permission.

Table 4-1 presents pK_a values for PFAS. Limited model-predicted and experimental values are available for most PFAAs.

4.3.3 Thermal Stability

Thermal stability, the degree to which a chemical remains intact under thermal stress, is an important property to predict how long a chemical will persist in the environment. PFAAs, such as PFOA and PFOS, are extremely stable, thermally and chemically, and resist degradation and oxidation. Thermal stability of PFAAs is primarily attributable to the strength of the C-F bond in the fluoroalkyl tail (**Kissa 2001**), but the relative stability is also determined by the specific functional group that is attached to the fluoroalkyl tail. PFCAs and PFSAs are the most thermally stable fluorinated surfactants. The temperatures at which PFAAs decompose and complete mineralization occurs is an area of active research (see **Section 12.4**). Reports on temperature needed to destroy PFAS vary, but it seems that to destroy PFAS in soil, temperatures upwards of 1,000°C may be required (**Colgan et al. 2018**; **Winchell et al. 2021**). It was

previously reported that limited PFOS, PFOA, and PFHxA mineralization (less than or equal to 72%) may occur at temperatures of 700ºC (**Watanabe et al. 2018**). In this same study, mineralization reportedly increased to 90% in the presence of granular activated carbon and sodium hydroxide. The thermal stability is lower for the salts of PFAA compounds and depends on which cation is the counterion. For example, the 20% decomposition temperature of sodium perfluorooctanoate is 298°C, but it is 341°C for lithium perfluorooctanoate (**Kissa 2001**). Additionally, salts of PFSAs are more thermally stable than the corresponding salts of PFCAs (**Kissa 2001**).

4.3.4 Chemical Stability

Like thermal stability, knowledge of the chemical stability of a molecule helps predict its persistence in the environment. PFCAs and PFSAs have been shown to be persistent in the environment. PFCAs are resistant to oxidation under environmental conditions; however, transformation has been demonstrated in the presence of oxidants under extreme pressure. In contrast, transformation of precursors can be associated with substantial changes in the physicochemical properties of those compounds (**CONCAWE 2016**). See **Section 1.3.3** for information about PFAA precursor biotransformation.

In the perfluorinated tail of the alkyl acids, the strength of the C-F bond, shielding of carbon by fluorine, and inductive effects (caused by fluorine electronegativity) also lead to chemical stability. For example, electron-rich chemical species called nucleophiles normally would be attracted to the partial positive charge of carbon. If these nucleophiles could get close enough to the carbon to bond, the subsequent reaction could replace a fluorine with the nucleophile and potentially make the molecule vulnerable to degradation. But the relatively large size of the fluorine atoms surrounding the carbon (when compared to hydrogen) prevents this from happening (**Schwarzenbach, Gschwend, and Imboden 2003**). This is why processes such as hydrolysis, which involve eliminating one or more fluorines, are ineffective at degrading the perfluorinated tails of PFAAs. Similarly, many PFAAs are resistant to degradation by oxidative processes that rely on a loss of electrons (**Kissa 2001**). PFAAs are also resistant to reductive processes, which involve gaining electrons. Despite having a high affinity for electrons, fluorine does not have vacant orbitals favorable for accepting additional electrons (**Park et al. 2009**). In contrast to the stability of perfluorinated tails, polar regions of PFAS (the functional groups), as well as polyfluorinated groups, can be vulnerable to a range of chemical transformations. See **Section 5.4** for further discussion of abiotic and biotic transformations.

5 ENVIRONMENTAL FATE AND TRANSPORT PROCESSES

This section provides current information about PFAS fate and transport in the environment. Understanding relevant fate and transport processes for PFAS is critical in evaluating the potential risk from a release, where to look for PFAS following a release, and what treatment alternatives may be effective. The available information about fate and transport processes varies between the different PFAS. PFAS fate and transport is a rapidly evolving field of science.

Section Number	Topic
1.3	**Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization (2025)**
1.8	**Priority Topics for PFAS and Microplastics (2025)**
5.1	**Fate and Transport Introduction**
5.2	**Phase Partitioning**
5.3	**Media-Specific Migration Processes**
5.4	**Transformations**
5.5	**PFAS Uptake into Aquatic Organisms**
5.6	**PFAS Uptake into Plants**

5.1 Fate and Transport Introduction

5.1.1 Overview of PFAS Fate and Transport

PFAS fate and transport describes the behavior of these compounds following their release to the environment. This includes the physical, chemical, and biological processes that influence distribution of PFAS in various media, as well as the extent of migration within and between media (for example, plume development, groundwater discharge to surface water). Given the wide variety of PFAS, it is not surprising that they collectively exhibit a wide range of different physical and chemical characteristics that can affect their behavior in the environment. This adds to the complexity of fate and transport assessments and highlights the risk in making broad assumptions based on the behavior of a few well-studied PFAS.

Understanding relevant fate and transport processes for PFAS is critical in answering several key questions:

- ***What are the transport mechanisms for PFAS in the environment?*** PFAS fate and transport characteristics can assist understanding of the mechanisms through which PFAS discharge and migration may occur (for example, atmospheric/vapor transport, surface water runoff, infiltration into the subsurface, vadose zone sorption/leaching, groundwater migration).

- ***What is the potential risk from a PFAS release?*** An understanding of fate and transport processes provides the basis for defensible predictions about occurrence, migration, persistence, and potential for exposure.

- ***Where do I need to look for PFAS following a release?*** Knowledge of PFAS fate and transport characteristics strongly informs site characterization by providing insight on where efforts should be focused and developing an appropriate conceptual site model (CSM).

- ***How can I treat PFAS?*** Establishing how these compounds behave in the environment is important in developing and/or selecting PFAS treatment strategies.

5.1.2 Factors Affecting PFAS Fate and Transport

Factors that influence PFAS fate and transport can be broadly divided into two categories:

- ***PFAS characteristics:*** Critical factors include the chain length, the ionic state of the compound (for example, the charge(s) carried by the molecule at a typical environmental pH), the type of functional group(s), and the extent of fluorination (for example, perfluorinated versus polyfluorinated compounds). These properties strongly influence the type and extent of PFAS partitioning and transformation that can be expected to occur. A description of these physical-chemical properties is provided in **Section 4**.

- ***Site characteristics:*** Site characteristics generally define the nature of the source but also have an effect on PFAS-media interactions. Potentially relevant characteristics include soil type (including properties such as permeability, surface charge, organic carbon content, exchange capacity, mineralogy, water content), depth to groundwater, aquifer characteristics (for example, geology, presence of confining layers), oxidation-reduction conditions, precipitation/infiltration rates, groundwater velocities/flow directions, groundwater/surface water interactions, surface water flow rates, prevailing atmospheric conditions, and the presence of co-contaminants.

The characteristics of sites with releases of PFAS often share many similarities with sites having releases of other contaminants, although there are some source scenarios that are relatively unique to PFAS (see **Section 2.6** for description of source scenarios). In addition, relevant transport pathways for PFAS can be similar to those for other contaminants. For example, transport of PFAS in groundwater as the result of advection is a potential concern at many sites where PFAS-containing products have been released. Although many PFAS share similar characteristics, such as resistance to transformation, those same PFAS may have widely varying physical-chemical properties, such as those associated with partitioning. As a result, PFAS fate and transport in the environment can be quite different from other contaminants. Therefore, this section focuses on mechanisms where PFAS behavior is different from other contaminants.

5.1.3 Section Organization

This section includes a detailed description of several processes that are particularly relevant for PFAS fate and transport and are illustrated in **Figure 5-1**.

- ***Partitioning:*** Both hydrophobic partitioning to organic carbon and electrostatic interactions between charged surfaces and PFAS are discussed, along with the tendency of PFAS to aggregate at air-water interfaces. These processes can affect migration in the environment by promoting retention within sediments and unsaturated soils, as well as retardation within groundwater. Varying degrees of retention on solids can contribute to differential transport where certain PFAS (for example, short-chain, anionic) are more rapidly transported than others.

- ***Media-specific processes:*** The potential impact of processes such as diffusion into low-permeability matrices, atmospheric transport, and leaching from soil to groundwater are described. Unlike the broader processes of partitioning and transformation, most of these processes are unique to specific media or a specific cross-media transport pathway.

- ***Transformation:*** Although a number of individual PFAS, such as perfluoroalkyl acids and perfluoroalkyl ether carboxylic acids, are highly persistent due to the strength of the C-F bond, a

number of polyfluorinated substances can be partially degraded via several different biological and abiotic mechanisms. Transformation of these precursors to PFAAs has been shown to occur in a variety of environmental media and can result in unexpected temporal and spatial trends in PFAS occurrence. The susceptibility of individual PFAS to transformation processes can also influence how each will bioconcentrate and bioaccumulate within various biotic species.

- ***Uptake into biota and plants:*** Once released into the environment, PFAS will migrate to both terrestrial and aquatic systems. Uptake into plants can occur within affected areas and may transfer PFAS to wildlife and humans that consume those plants. Some compounds have a propensity to bioaccumulate and then biomagnify up the food chain, with relatively low levels in invertebrates and fish and higher levels observed in animals at the top of the food chain (for example, seals, seabirds, polar bears).

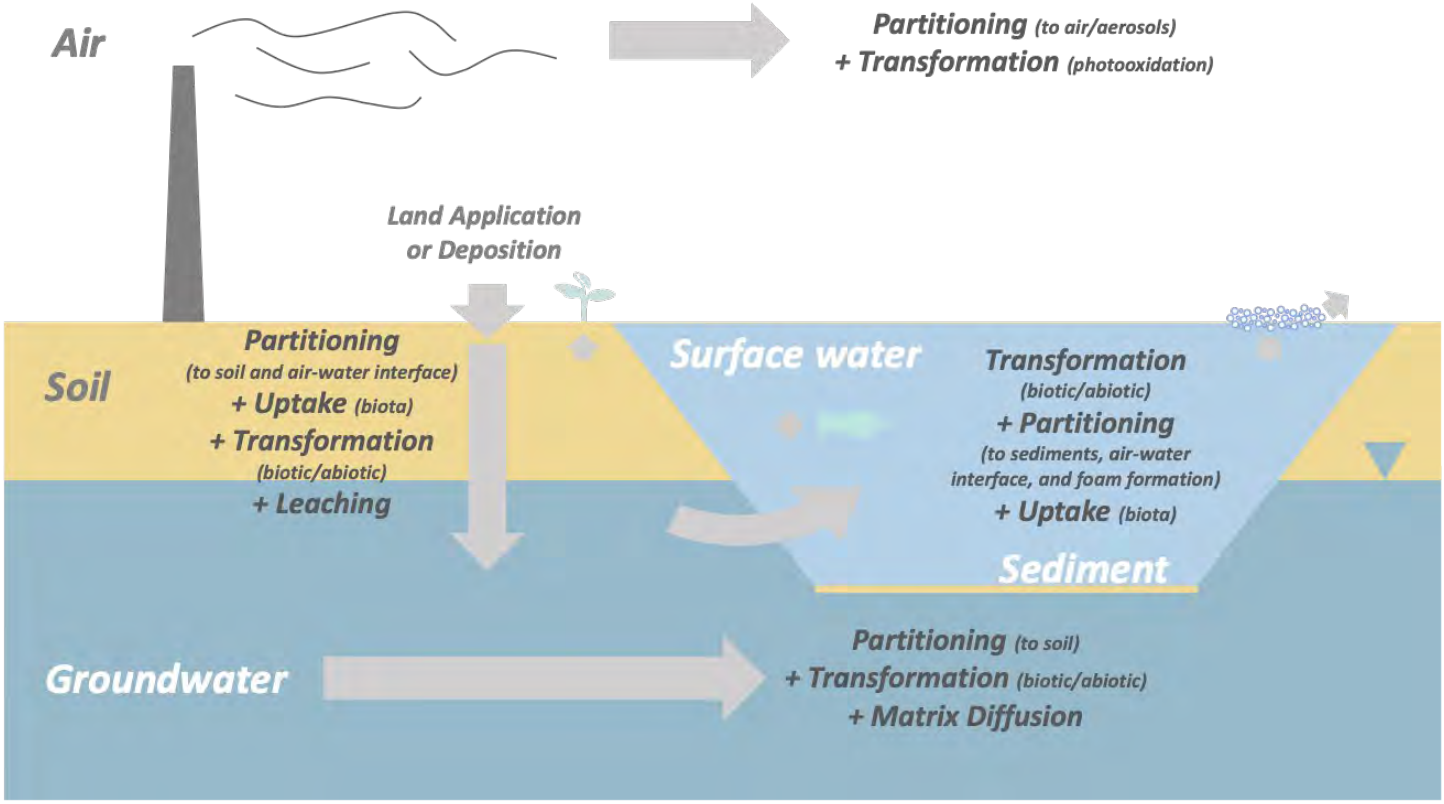


Figure 5-1. Fate and transport processes relevant for PFAS.

Source: D. Adamson, GSI. Used with permission.

As noted previously, the physical-chemical properties of PFAS, and the influence of these properties on PFAS fate and transport within environmental media, are critical in determining how these compounds behave after they are released. To date, our understanding of PFAS fate and transport has relied largely on assumptions based on these physical-chemical characteristics, even though the specific parameter values have proven challenging to estimate; however, there is an increasing amount of lab- and field-derived data that has improved the empirical basis for understanding PFAS fate and transport. This section focuses on findings from peer-reviewed studies that directly evaluated PFAS fate and transport and provided key insight on the processes described above. The material in this section is also intended to provide a technical basis for subsequent sections on site characterization (**Section 10**) and treatment of PFAS (**Section 12**).

5.2 Phase Partitioning

5.2.1 Introduction

PFAS most commonly detected in the environment typically have a carbon-fluorine tail and a nonfluorinated head consisting of a polar functional group (see **Section 2.2** for more information about naming conventions and terminology). The tail is hydrophobic and generally lipophobic (attracted neither to water nor to nonpolar organic matter), while the head groups can be polar and hydrophilic (attracted to water) (**Buck et al. 2011**). The competing tendencies of the head and the tail can lead to a widespread yet uneven distribution in the environment. Given the heterogeneity of subsurface environments, soils with different surface charges, organic carbon, interfaces between air and water, and interfaces with water and hydrocarbon co-contaminants, multiple partitioning mechanisms should be considered when characterizing PFAS fate and transport. PFAS may also exhibit different behavior depending on concentration, such as the tendency to form micelles at high concentrations (**Section 5.2.2.2**). Although the structure of PFAS makes them generally oil- and water-resistant in many products (for example, dry surface coatings), in the aqueous phase, PFAS may not exhibit lipophobic tendencies, as shown by the ability of a variety of PFAS to partition to phospholipid bilayers (bacterial membranes) (**Jing, Rodgers, and Amemiya 2009**; **Fitzgerald et al. 2018**).

Important PFAS partitioning mechanisms include hydrophobic effects, electrostatic interactions, and interfacial behaviors. Electrostatic effects are a function of the charge of the polar functional group at the head of the molecule and are one of the processes that generally drive the association with organic carbon in soils. For instance, natural soils and aquifer materials often have a net negative surface charge that can repel the negatively charged heads of PFAAs, which are usually present as anions in environmental media, while attracting cationic or zwitterionic PFAS. As is the case for all surfactants, the competing nature of the head and tail groups result in accumulation along interfaces of environmental media such as soil/water, water/air, and water/nonaqueous phase liquid (NAPL) co-contaminants (**Guelfo and Higgins 2013**; **McKenzie et al. 2016**; **Brusseau 2018**).

5.2.2 Considerations for PFAS Partitioning

5.2.2.1 Pure Phase PFAS

Due to high aqueous solubility, PFAS occurrence as a separate phase in the environment (for example, solid PFAS, LNAPL PFAS, or DNAPL PFAS) is uncommon. Although PFAS may exist as solid salts, typical product applications involve miscible solutions that are frequently mixtures of many different compounds. Several of these compounds exhibit relatively high solubility in water (the Physical and Chemical Properties Table, Table 4-1 provided as a separate Excel file), defined by **Ney (1995)** as exceeding 1,000 mg/L water. For example, PFOA has a reported solubility of 9,500 mg/L at 25°C (**USEPA 2017**). Note that PFAS interactions with NAPL co-contaminants within the subsurface have been reported and can impact migration in the subsurface (**Section 5.2.5**).

5.2.2.2 PFAS Micelles and Foam Formation

A surfactant is a substance that tends to lower the surface tension of a liquid into which it is dissolved. As discussed in **Section 4.2.7**, the surfactant properties of some PFAS may result in the assembly of PFAS molecules into supramolecular aggregations (micelles, mixed micelles, hemi-micelles, or bilayer structures; see **Figure 5-2**). The surfactant properties of PFAS are also what cause collection at interfaces like the air-water interface (see **Section 4.2.8** and **Figure 4-1**). The surfactant properties, along with heat resistance, have been exploited for applications such as AFFF, which forms a thin film of water over the fuel source.

With respect to supramolecular aggregations, there is experimental evidence that PFAS can act like ionic hydrocarbon surfactants and form micelles at a critical micelle concentration (CMC) (**Pedone et al. 1997**; **Downer et al. 1999**), and many have theorized that, also like ionic hydrocarbon surfactants, hemi-micelle formation may begin at concentrations as low as 0.001 times the CMC (**Johnson et al. 2007**, **Yu et al. 2009**). The majority of these data are focused on PFAAs, but GenX has also recently been shown to form micelles (**Kancharla et al. 2022**). CMCs for various PFAS are discussed in **Section 4.2.7**. More research is needed on the tendency for PFAS to form traditional micelles (oil-in-water emulsions), since there is some data that suggest PFAS supramolecular aggregation may not be directly analogous to ionic hydrocarbon surfactant behavior (**Costanza et al. 2019** and discussed in **Section 4.2.7**). Additionally, the interrelated functions of several environmental variables (presence of co-contaminants, ionic concentration, pH, etc.) present additional complexities that research has only begun to address.

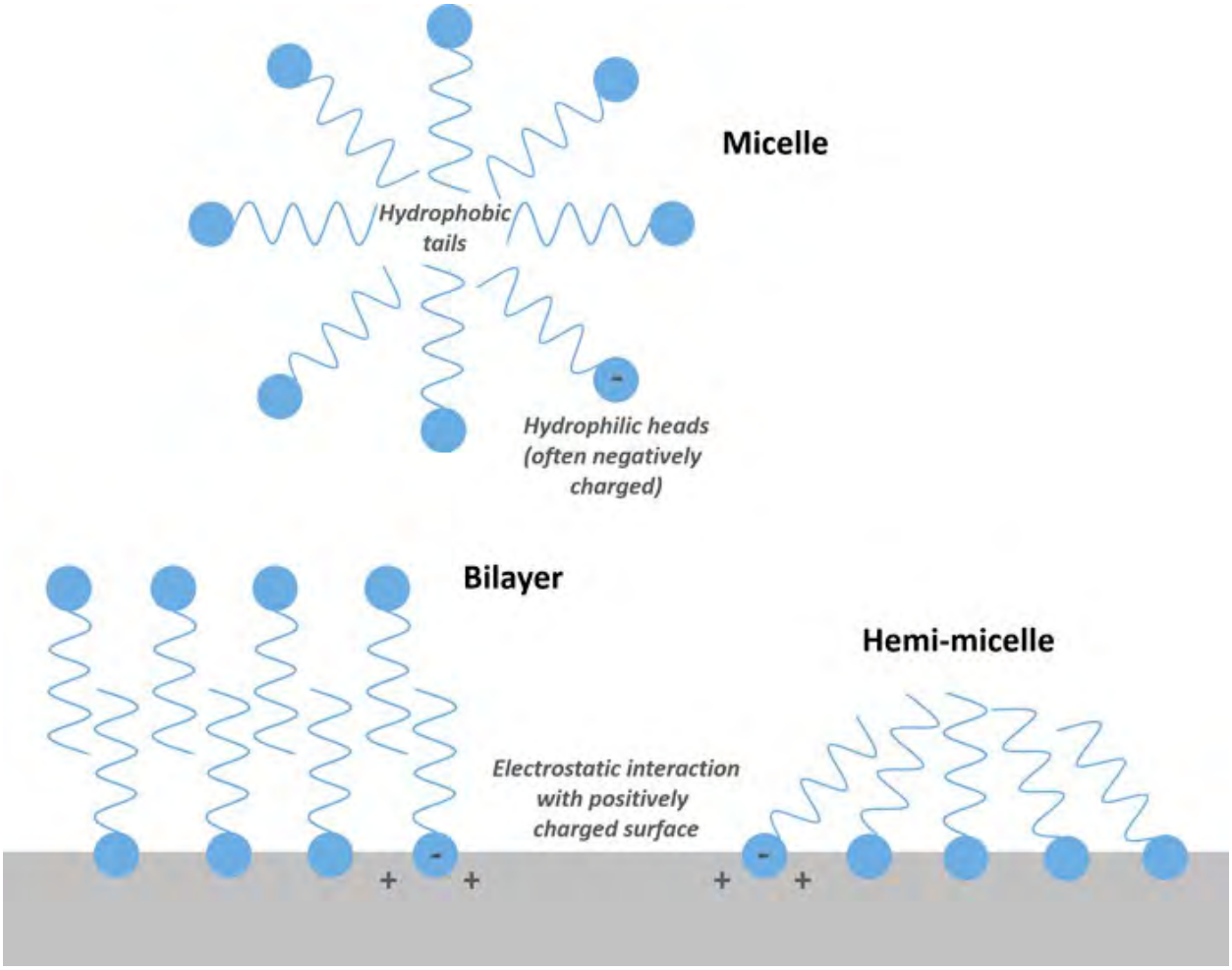


Figure 5-2. Illustration of the formation of PFAS micelles, hemi-micelles, and bilayers. Also shown is an example of aggregation at a positively charged surface. Note that the opposite effect (electrostatic repulsion of PFAS) can occur if the surface is negatively charged.

Source: D. Adamson, GSI. Used with permission.

Because the known CMCs of PFAAs are much greater than typical environmental concentrations (with the exception of possible AFFF source releases), some researchers have concluded that the behavior of PFAAs at the CMC likely has little practical relevance (**Horst et al. 2018**; **Brusseau et al. 2018**). However, like ionic hydrocarbon surfactants, hemi-micelle formation of PFAAs may begin at concentrations as low

as 0.001 times the CMC (**Johnson et al. 2007**; **Yu et al. 2009**), which is potentially relevant to the understanding of PFAA sorption for both the creation of potential treatment technologies and environmental fate and transport. The interaction of supramolecular aggregations of PFAAs with both charged and hydrophobic surfaces can affect the magnitude of sorption, but the extent and even the direction of influence is dependent on many factors (**Deng et al., 2012**; **Zhang, Zhang and Liang, 2019**; **Du et al. 2014**). For example, adsorption of the hydrophilic portions of PFAAs (that is, the "heads") onto positively charged absorbent surfaces can contribute to the formation and accumulation of hemi-micelles on surfaces. Simultaneously, it is possible that hemi-micelles and even micelles can block the intraparticle pores of porous surfaces, reducing the magnitude of sorption.

In surface water, PFAS may accumulate within the surface micro layer (SML) that is defined as the thin layer (50 µm) of water in contact with the ambient air (**Section 16.5.5**). This accumulation can also lead to foam formation above the surface water due to winds, waves, or other turbulent forces that introduce air into the water. In these cases, the presence of natural dissolved organic carbon within the water body can also enhance foam formation and contribute to enrichment of PFAS in these foams even at PFAS concentrations that are below reported CMCs (**Schwichtenberg et al. 2020**). This foam is different from AFFF because it is likely caused by the aggregation of dissolved-phase PFAS followed by agitation within a surface water body. As discussed in the Surface Water Foam Section (**Section 16.5**), the formation of this type of PFAS-containing foam above the surface of the water has been sampled and analyzed near or downgradient of areas where PFAS have been released (**MI EGLE 2021**).

5.2.3 Partitioning to Solid Phases

PFAS can partition to a number of different solid-phase materials, including soils and sediments (**Higgins and Luthy 2006**), biosolids (**Venkatesan and Halden 2013**), sewage solids (**Ebrahimi et al. 2021**), iron oxides in acidic environments (**Campos-Pereira et al. 2020**), and organic matter (**Fitzgerald et al. 2018**). Partitioning to solids results in retention of PFAS on the solids, thereby reducing or retarding leaching from vadose zone sources and retarding PFAS migration in the saturated zone. Conversely, PFAS may also partition to mobile colloids, resulting in facilitated transport rather than retardation (**Brusseau et al. 2019**), which may be particularly important in environments where colloidal transport is more likely to occur, such as sediment transport and deposition in moving water and environments undergoing wet-dry or freeze-thaw cycles (**Borthakur et al. 2021**). **Section 5.3.4.2** discusses surface water/sediment interactions.

In addition, published studies of migration of PFAS in bedrock aquifers are scarce, but many of the processes controlling sorption in soils will be limited in fractured crystalline bedrock aquifers, resulting in potential for migration of PFAS over longer distances once plumes migrate to the bedrock aquifer.

5.2.3.1 Partitioning Processes

As discussed in **Section 5.2.1**, partitioning of PFAS to solids and soils is widely studied and is thought to occur through two primary processes: 1) sorption through electrostatic interactions, and 2) sorption to organic matter via hydrophobic interactions (**Higgins and Luthy 2006**) (see **Sections 5.2.1** and **5.2.2** for a discussion of interfacial behavior, another subset of partitioning). The relative contribution of each process can vary depending on the PFAS, soil composition, surface chemistry, ion concentration, and other geochemical factors. Because the multitude of PFAS span a broad range of compositions and carbon chain lengths, PFAS partitioning to solids can be variable and uncertain, and dependent on site-specific factors.

5.2.3.2 Electrostatic Interactions

The contribution of electrostatic interactions to partitioning is highly dependent on soil type and soil chemistry (particularly pH and the presence of polyvalent cations). Most soils contain both fixed-charge

and variably charged surfaces, such that the net charge on the soil, as well as the charge of functional groups of individual PFAS, can be strongly influenced by pH. For example, the net negative charge on most clay minerals can result in electrostatic interactions with cationic functional groups that are present on some PFAS (**Barzen-Hanson et al. 2017**).

Changes in pH potentially impact these electrostatic processes by altering surface charges, or possibly the ionic nature of the PFAS (**Nguyen et al. 2020**). Lower pH values and higher calcium concentrations in soil solutions have been associated with increased sorption of anionic PFAS such as PFOS and other PFAAs (**Higgins and Luthy 2006**), although the buffering capacity of some soils (for example, carbonate minerals) may mitigate fluctuations in pH. Furthermore, increased concentrations of some polyvalent cations, such as Ca^{2+}, Mg^{2+} Fe^{2+}, which sorb strongly to permanent charge sites on clay minerals, can lead to increased partitioning to soil for some PFAS (**Higgins and Luthy 2006**; **McKenzie et al. 2015**), although the effect on cationic and zwitterionic PFAS can vary widely, which has been attributed to charge differences in the PFAS functional groups (**Mejia-Avendaño et al. 2020**). Although the literature has attributed anionic PFC sorption to iron-oxide materials, the dominant parameter influencing sorption in the **Higgins and Luthy (2006)** study was organic matter content.

5.2.3.3 Sorption to Organic Matter

In **Higgins and Luthy (2006)**, where organic carbon ranged from 0.56% to 9.66%, and other studies, organic carbon was found to be the dominant parameter driving the extent and kinetics of PFAS sorption (**Higgins and Luthy 2006**; **Li et al. 2018**; **Li et al. 2019**; **Sima and Jaffe 2021**; **Wei et al. 2017**). PFCAs and PFSAs tend to associate with the organic carbon fraction of soil or sediment (**Higgins and Luthy 2006**; **Guelfo and Higgins 2013**) in the saturated and unsaturated zones, although as anions at environmental pH values (see **Section 4.3.2**), they are relatively mobile in groundwater (**Xiao et al. 2015**).

Sorption to organic carbon generally increases with increasing perfluoroalkyl tail length, which is also associated with increased hydrophobicity (**Higgins and Luthy 2006**; **Guelfo and Higgins 2013**; **Sepulvado et al. 2011**; **Campos Pereira et al. 2018**; **Cai et al. 2022**), indicating that the short-chain PFSAs (for example, PFBS) and PFCAs (for example, PFBA) are less retarded than their long-chain counterparts (PFOS and PFOA, respectively). In addition, PFSAs tend to sorb more strongly than PFCAs of equal chain length (**Higgins and Luthy 2006**), and linear isomers are more sorptive than branched isomers (**Karrman et al. 2011**). Although simple correlations with organic carbon appear to be insufficient to predict PFAS partitioning coefficients, it is important to evaluate what PFAS are present and to quantify the fraction of organic carbon (f_{oc}) to model PFAS sorption as a potential predictive tool for estimating PFAS retention and retardation for certain PFAS.

5.2.3.4 Partitioning Coefficients

Table 4-1, provided as a separate Excel file, presents the range of available organic carbon partitioning coefficients (K_{oc}) for PFAS commonly observed in the environment. K_{oc} is a soil organic carbon-normalized adsorption coefficient and may serve as a useful parameter for evaluating potential retardation. However, this parameter does not directly capture any contributions from electrostatic interactions (**Higgins and Luthy 2006**), meaning that, depending on the PFAS being evaluated, estimating sorption by measuring the f_{oc} in soil in combination with a literature-derived K_{oc} value may underestimate (or in some cases, overestimate and the associated error could be significant) retardation. Additional site-specific information such as pH, presence of polyvalent cations, and electrostatic processes retardation coefficients, are mentioned in **Section 10.4.2**.

Li, Oliver, and Kookana (2018) compiled data from several literature studies and concluded that the bulk partitioning coefficients (Kd) estimated for various PFAS were best correlated with organic carbon content and pH. However, a study by **Barzen-Hanson et al. (2017)** showed a general lack of correlation between soil parameters (such as organic carbon) and partition coefficients derived for some PFAS, such

as anionic fluorotelomer sulfonates as well as several cationic and zwitterionic PFAS. **Anderson, Adamson, and Stroo (2019)** reviewed field data from a large number of AFFF release sites and deduced that organic carbon significantly influences PFAS soil-to-groundwater concentration ratios, and they used statistical modeling to derive apparent K_{oc} values for 18 different PFAS based on these data.

The use of partitioning coefficients to estimate sorption requires the assumption of steady state conditions, which rarely occur in natural systems. In idealized systems, PFAS sorption kinetics vary by functional group and carbon chain length, as well as soil composition, but equilibrium is generally achieved over several days to weeks (**Xiao et al. 2017**; **Schaefer et al 2021**). Lab-based and modeling studies have established that partitioning of PFAS cannot be easily modeled using equilibrium sorption parameters in some cases due to rate-limited sorption considerations (**Guelfo et al. 2020**;**Brusseau 2020**). Lab-based Kd values (derived using adsorption isotherms) could likely underestimate the impact of sorption during fate and transport modeling (for example, by underestimating the retardation factor or by overestimating the extent of desorption) (**Schaefer et al. 2021**). **Schaefer et al. (2021)** observed that the extent of desorption from soils exposed to PFAS decades ago generally was substantially less than predicted by published $K_{oc}f_{oc}$ relationships for the PFAS studied, suggesting that desorption from old PFAS releases may have a less pronounced impact on underlying groundwater, particularly for shorter chain PFAS. **Schaefer et al. (2022)** noted that much of the PFAS present in soils historically impacted with AFFF in their study was not readily leachable using the selected desorption procedure(s).

5.2.3.5 Nonlinear Sorption, Hysteresis, and Mass Transfer Limitations

Sorption processes of PFAS can be impacted by nonlinear sorption, hysteresis, and mass-transfer limitations. Nonlinear sorption typically implies that PFAS will sorb more strongly at low PFAS concentrations than high concentrations. Counter to typical nonlinear sorption tendencies, at least one field study observed greater sorption at higher concentrations (**Anderson et al. 2022**). There is also some evidence that desorption may occur more slowly than sorption for certain PFAS, which is hypothesized to be the result of entrapment and diffusion limitations (**Higgins and Luthy 2006**; **Chen et al. 2016**; **Zhi and Liu 2018**; **Xiao et al. 2019**). Several studies have observed that select PFAS can be subject to rate-limiting sorption (for example, diffusion limited), meaning that desorption of a portion of the sorbed PFAS will occur more slowly than other portions (**Xiao et al. 2019**; **Schaefer et al. 2021**). For example, **Brusseau et al. (2019)** showed that PFOS exhibited nonideal sorption/desorption behavior (tailing). Kinetic desorption modeling in the study indicated "that the rate of desorption was proportional to the PFAS aqueous diffusivity" (**Schaefer et al. 2021**), supporting the hypothesis that diffusion may also limit the rate of release from soil. Any portion of the released PFAS that is strongly retained within sediments or the soil matrix may be more persistent but likely less bioavailable and less subject to migration. This hysteresis effect on a portion of the sorbed PFAS in soils may also be a contributor to sorption included in the rationale for natural attenuation of some PFAS that was evaluated by **Newell et al. (2021)**.

PFAS partitioning due to electrostatic interactions has been shown to be nonlinear in some cases; **Xiao et al. (2019)** demonstrated that the variation in the coefficient of sorption for several zwitterionic PFAS to soils (for example, loams, clay loams) implies an increase in sorption as the PFAS concentrations decreased. The significant nonlinearity of zwitterionic PFAS observed by **Xiao et al. (2019)** also exhibited a high degree of hysteresis that was not related to soil organic matter or surface complexation and was postulated to be due to entrapment. For PFAS such as PFOA and PFOS that are anionic at environmentally relevant pH, measuring the anion exchange capacity in representative soils may serve as an indicator of the importance of electrostatic interactions with minerals. However, because soil pH can range considerably, pH can also serve as a useful measure of potential PFAS mobility. Measurements of **cation** concentrations or the ionic strength of an aqueous solution may also provide useful information on the potential contribution of electrostatic attraction to enhanced partitioning.

The findings discussed within this subsection are particularly relevant for strongly sorbing long chain PFAS such as PFOS (**Chen et al. 2016**) and sorbed PFAS that exhibit a high degree of hysteresis, such as

zwitterionic PFAS, and have important implications for PFAS fate and transport such as leaching from soil to groundwater (see **Section 5.3.3**), migration and retardation in the saturated zone, and whether sorption can function as a form of natural attenuation (**Newell et al. 2021**, **Newell et al. 2021**) (see **Sections 10.4.7** and **10.4.8**, **Table 10-1**, and **12.6.8** for further discussion). Additional research is needed to further evaluate if any of these bulk parameters can be used predictively for fate and transport studies (**Barzen-Hanson et al. 2017**) and to understand the parameters' role in irreversible sorption of PFAS that have been adsorbed for decades. Current research supports the conclusion that simple correlations of sorption with organic carbon or pH are insufficient to reliably predict PFAS partitioning coefficients for many PFAS. Thus, in the absence of a reliable model that predicts the role of different mechanisms on the extent of sorption (and hysteresis), site-specific data may be more appropriate for understanding PFAS transport (**Knight et al. 2019**; **Anderson et al. 2016**; **Li, Oliver, and Kookana 2018**) and considerations for pump-and-treat systems. Other considerations, such as air-water interface interactions, are discussed in **Section 5.2.4.1**.

5.2.4 Partitioning to Air

As discussed in greater detail in **Section 4.2**, reliable data on physical properties that relate to PFAS volatilization, such as vapor pressure and Henry's law constants (K_{aw}), are currently limited but the data set is growing. Additionally, volatilization from water to air of acidic PFAS, such as PFAAs, is affected by pH-dependent, aqueous phase dissociation from more-volatile acidic species to less-volatile anionic species (**Kaiser et al. 2010**). Measured vapor pressures are available for some select PFAAs, including the acidic forms of PFOA, perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA), perfluoroundecanoic acid (PFUnA), and perfluorododecanoic acid (PFDoDA) (**Barton, Botelho, and Kaiser 2008**; **Kaiser et al. 2005**), as well as FTOHs (**Krusic et al. 2005**). Henry's law constants (K_{aw}) for several PFAS are reported in **Section 4.2.6**. As noted by the values provided in **Table 4-1**, Kaw can vary over multiple orders of magnitude for a given PFAS; underlying causes for the large range in reported values are not clear, but may relate to variability in measurement conditions. For some PFAS that are acidic at environmentally relevant pH, such as PFOS and PFOA, the reported vapor pressures are low and reported water solubilities are high, limiting volatilization from water to air (**USEPA 2000**). Other PFAS, such as FTOHs, have specific functional groups that tend to impart greater volatility. In one study performed by **Roth et al. (2020)**, agitation of AFFF was demonstrated to release gas-phase PFAS, reportedly including PFOA. These experiments were performed in a controlled lab setting and resulted in detectable concentrations of five FTOHs and 10 PFCAs above background laboratory air concentrations. The potential for this type of partitioning to occur in field settings was not evaluated, and the veracity of the PFOA detections has been debated (**Titaley, De la Cruz, and Field 2020**; **Roth et al. 2020**). **Section 1.1.3.3** includes information about volatile PFAS. See also the **PFAS and Vapor Intrusion Fact Sheet** developed in 2025.

Under certain conditions, particularly within industrial stack emissions, or during fire suppression, incineration, or combustion, PFAS can be emitted and transported through the atmosphere. This can include volatiles like FTOHs that may be present in the gas phase (**Thackray, Selin, and Young 2020**) and anionic PFAS that may be sorbed to particulates (**Ahrens et al. 2012**). In the latter case, transport occurs through the association of anionic PFAS with airborne aerosols and other small particulates rather than direct partitioning to the gas phase. For example, PFOA and PFOS have been detected in airborne particulate matter in both urban and semirural areas, with PFOA dominant in the smaller, ultrafine particles and PFOS dominant in the larger, coarser fractions (**Dreyer et al. 2015**; **Ge et al. 2017**). These studies show that some PFAS can be adsorbed to particulates, likely reflecting the influence of local diffuse sources. As discussed in **Section 5.3**, removal of airborne PFAS can occur via wet and dry deposition processes that scavenge particle-bound PFAS or gaseous PFAS that has partitioned into water droplets (**Barton, Kaiser, and Russell 2007**; **Dreyer et al. 2010**). Wet deposition refers to the wash out of PFAS by rain droplets, where PFAS drops to the ground with no transfer of PFAS to the air (**Barton, Kaiser, and Russell 2007**). This has been shown to be a relevant mechanism for influencing airborne transport within a few kilometers downgradient of a major manufacturing source (**Barton, Kaiser, and Russell**

2007; **Davis et al. 2007**). Dry deposition is a naturally occurring process that depends on prevailing environmental conditions and particle characteristics. Since these deposition processes remove PFAS from the atmosphere, they can influence the location and magnitude of PFAS deposition to terrestrial and aquatic environments.

Kaiser et al. (2010) demonstrated the partitioning of PFOA to workplace air from water and dry surfaces. Partitioning to air from these substrates appears to depend on conditions within the substrate, with lower pH environments contributing more PFOA mass to air. The protonated acid form of PFOA has an elevated vapor pressure, which may explain these observations (**Kaiser et al. 2005**). Interestingly, these authors showed that more PFOA partitions from dry surfaces than from water and may contribute significantly to workplace exposures.

5.2.4.1 Partitioning to Air/Water Interfaces

As described above, PFAS often exhibit surfactant behavior because many display hydrophobic and hydrophilic properties. The impacts of these properties on transport are complex and are being actively investigated. By design, many PFAS will lower the interfacial tension and preferentially form films at the air-water interface (if present at elevated concentrations), with the hydrophobic carbon-fluorine (C-F) tail oriented toward the air and the hydrophilic head group dissolved in the water (**Krafft and Riess 2015**) (**Figure 4-1**). This behavior influences aerosol-based transport and deposition, and suggests that accumulation of PFAS at water surfaces will occur (**Prevedouros et al. 2006**).

This preference for the air-water interface has important implications for PFAS transport in the vadose zone, where unsaturated conditions provide significant air-water interfacial area (**Brusseau 2018**; **Brusseau et al. 2019**; **Brusseau and Guo 2022**). This includes the potential for enhanced retention in the vadose zone and the capillary fringe, which are the subject of significant ongoing research. For example, **Brusseau (2018)** showed that adsorption of PFOS and PFOA at the air-water interface can increase the retardation factor for aqueous-phase transport, accounting for approximately 50% of the total retention in a model system (well-sorted sand) with 20% air saturation. **Section 1.3.1** includes information about vadose zone characterization and transport, including air-water partitioning and vadose zone modeling.

As a result, air-water partitioning may contribute to retardation of PFAS in unsaturated soils. Using field data, **Anderson, Adamson, and Stroo (2019)** reported that soils with higher clay contents were associated with lower soil-to-water concentration ratios for multiple PFAS. The authors surmised that perhaps the more likely explanation was that the higher water content within these clay-rich zones (relative to other depth-discrete zones with more coarse-grained material) decreased the air/water interfacial area available for PFAS partitioning and thus decreased overall soil retention. This pattern is also consistent with the potential for negatively charged clay surfaces to reduce anionic PFAS adsorption through electrostatic repulsion. **Guo, Zeng, and Brusseau (2020)** highlighted the influence of soil type on air-water interfacial accumulation as a retention mechanism in a modeling study that demonstrated retardation factors for PFOS under their experimental conditions as between 233 and 1,355 in sands and 146 and 792 for finer-grained soils. This was attributed to weaker capillary forces in the sands that resulted in lower water contents and thus more air-filled pore space to promote PFAS partitioning. Note that the simulations performed by **Guo, Zeng, and Brusseau (2020)** examined only PFOS and did not use field-derived input parameters, so caution should be exercised when generalizing these results to the broader family of PFAS. In addition to the influence of soil type described above, ionic strength has been shown to affect air-water interfacial partitioning whereby PFAS retardation within unsaturated soils appears to be enhanced with increasing salinity (**Lyu and Brusseau 2020**; **Costanza, Abriola, and Pennell 2020**; **Le et al. 2021**).

The tendency for PFAS to accumulate at air-water interfaces has the potential to significantly influence mass retention and soil-to-groundwater leaching, as discussed further in **Section 5.3.3**.

This has stimulated interest in incorporating these processes into CSMs, as well as predictive fate and transport models. Estimates of the air-water interfacial area and the constituent-specific air-water adsorption coefficients, as well as direct measurements of mass discharge to groundwater, can help provide a quantitative basis for these types of models (**Brusseau 2019**; **Guo, Zeng, and Brusseau 2020**). In general, air-water adsorption coefficients for an individual PFAS decrease as the concentration increases, and the process appears to be nonlinear (for example, Freundlich-type partitioning) (**Schaefer et al. 2019**). Air-water adsorption coefficients also tend to increase as the number of perfluorinated carbons increases (**Brusseau 2019**; **Schaefer et al. 2019**) (see **Section 4.2**). This means that when PFAS are released as a multicomponent mixture, these processes will influence each compound to a different extent, with less retention of shorter chained PFAS (for example, PFBS, PFPeA) than longer chained PFAS (for example, PFOS, PFDA, PFNA) (**Silva, Martin, and McCray 2021**). **Silva, Martin, and McCray (2021)** also showed that preferential adsorption of the more surface-active PFAS within a mixed release is expected to reduce the adsorption of the other, less surface-active PFAS in the mixture. This type of competitive adsorption would influence the relative breakthrough times for different PFAS within a mixed release.

The potential retention of PFAS in the vadose zone due to adsorption at the air-water interface is an important component that should be addressed in the CSM, but the retention of PFAS is based on site-specific factors. At sites with shallow groundwater tables, or sites where the water content within the vadose zone soils is typically low, air-water interfacial partitioning may not be particularly relevant. As such, detailed site investigations are critical to understanding how these processes influence PFAS migration through the vadose zone of a specific site. For example, an extensive study of PFAS concentrations in soil at contaminated sites indicated significant retention of PFAS in the vadose zone over long periods of time, but vertical migration of PFAS to the water table was also evident, resulting in detectable PFAS in groundwater at a majority of the investigated sites (**Brusseau 2020**).

5.2.5 Partitioning into NAPL Co-Contaminants

PFAS and petroleum hydrocarbon fuels in the form of NAPLs may commingle at fire training areas, fire response sites, and other locations where fuels were used or disposed concurrently with PFAS-containing materials. In these settings, the released petroleum hydrocarbon fuel forms a NAPL into which the PFAS may partition and accumulate along the NAPL/water interface (**Brusseau 2018**). These processes may result in increased PFAS mass retained in NAPL source zones, increased PFAS sorption onto the NAPL/water interface and resulting retardation, and greater persistence of PFAS (**Guelfo and Higgins 2013**; **McKenzie et al. 2016**; **Brusseau 2018**). The contribution of this process relative to other PFAS partitioning mechanisms (for example, solid phase, air-water interface) will vary based on site-specific conditions. However, several studies have suggested that the PFAS mass accumulating at the NAPL-water interface is likely to be less than that at the air-water interface in systems where all these phases are present (**Brusseau 2019**; **Silva et al. 2019**; **Costanza, Abriola, and Pennell 2020**). The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include information about co-contaminant effects on PFAS fate and transport (see **Section 1.3.4.1**).

The presence of NAPL may have other effects on PFAS. The presence of biodegradable NAPL, such as petroleum light nonaqueous phase liquids (LNAPLs), may significantly alter the biogeochemistry and oxidation-reduction conditions in the subsurface. For example, subsurface petroleum LNAPLs remaining from a petroleum-based fire tend to locally deplete the concentration of oxygen and other electron acceptors and elevate the concentration of methane. The LNAPL creates a localized zone of anoxic reducing conditions where PFAS aerobic transformation processes are inhibited, and anaerobic transformation processes may occur. These transformation processes are discussed in more detail in **Section 5.4**.

5.3 Media-Specific Migration Processes

The potential impacts of processes such as diffusion into low-permeability matrices, atmospheric transport, and leaching from soil to groundwater are described. Unlike partitioning processes, which involve the exchange of chemicals between media, the following describes processes that occur within specific media that may be important considerations for PFAS migration.

5.3.1 Diffusion In and Out of Lower Permeability Materials

Diffusion is the movement of molecules in response to a concentration gradient. Diffusion in groundwater is often ignored because diffusion rates are slow relative to advection. In low permeability materials, migration of contaminants is mainly driven by molecular diffusion, and advective effects may be less dominant depending on the magnitude of hydraulic gradient. In the vicinity of groundwater pumping wells, analysis might need to be conducted by taking into account both the effects of molecular diffusion and advection simultaneously (**Al-Niami and Rushton 1977**). However, contaminant mass in groundwater can diffuse into the pore space of lower permeability soils or bedrock. Back-diffusion out of these low permeability materials may result in the long-term persistence of PFAS in groundwater even after source removal and remediation. Due to the lack of degradation of PFCAs and PFSAs, back-diffusion of these PFAS is also likely to be a more significant process than for conventional contaminants such as chlorinated solvents. **Adamson et al. (2020)** reported that approximately 82% of the total mass of PFAS measured at an AFFF site was found within soils that were classified as lower permeability. This included 91% of the polyfluorinated precursor mass, most of which was encountered in the vicinity of the presumed source area. The mass distribution at this site confirmed that diffusion into lower permeability soils had occurred and demonstrated that this process can contribute to long-term retention of PFAS. The relative impact of PFAS accumulation at the air-water interface was not fully investigated in this study, as the water table was very shallow, and the unsaturated/saturated transition zone was likely disturbed during excavation. PFAS may also diffuse into site materials such as concrete. For example, **Baduel, Paxman, and Mueller (2015)** reported that PFAS had penetrated 12 cm into a concrete pad at a fire training area, and diffusion was identified as a contributing process.

The potential impacts of diffusion on PFAS persistence in natural soils are a topic of ongoing research. Determining appropriate diffusion coefficients for the range of PFAS that may be present following a release is a key element in understanding how this process impacts PFAS persistence. **Schaefer et al. (2019)** reported experimentally derived diffusion coefficients for 9 different PFAAs and showed that aqueous diffusivity values decreased as the PFAS molar volume increased. However, this relationship was nonlinear due to the complex molecular interactions of fluorinated compounds, and the values showed reasonable agreement with some but not all comparable methods of deriving diffusion coefficients. In addition, the relative rates of diffusion of PFAS with differing charges (for example, anionic vs. zwitterionic/cationic) is a potential concern given that porous media particles may also be charged. In the study by **Adamson et al. (2020)** described above, 93% of the polyfluorinated mass that had diffused into the lower permeability zones was zwitterionic and/or cationic; a smaller percentage of the anionic polyfluorinated mass was found in these zones. Higher organic carbon and favorable electrostatic interactions likely contributed to further retention of PFAS. The results of this study suggest that matrix diffusion may enhance long-term retention and reduce PFAS mass discharge rates by transferring PFAS mass to less-transmissive zones.

5.3.2 PFAS Transport via Air

Many PFAS have been measured in air (**Section 6.1**) and are known to be released to air from a variety of sources (**Section 2.6**). Air serves as an important transport medium for PFAS, allowing PFAS to disperse in all wind directions, contributing to global dispersion, and leading to localized PFAS deposition to soils and surface water in the vicinity of emission sources (for example, (**Shin et al. 2012**)) which is of

potential concern to site investigations. **Section 1.1.3.3** includes information about volatile PFAS. See also the **PFAS and Vapor Intrusion Fact Sheet** developed in 2025.

The role of atmospheric transport depends on PFAS-specific properties such as vapor-particle partitioning, and mechanisms can be complex. Aerosols, representing a suspension of solid particles and liquid droplets in the air, provide a variety of environmental media and surfaces within or upon which a range of PFAS partitioning behavior can be observed. For example, **McMurdo et al. (2008)** described the release of concentrated PFAS aerosols from a water surface (where PFAS are often located). Airborne transport of PFAS is a potentially relevant migration pathway due to the common types of industrial release (for example, stack emissions). The specific means of PFAS releases from industrial sources have not been extensively studied, but could involve processes such as droplet mobilization from drying and agitation of liquid surfaces.

PFAS and other harmful air pollutants, including fluorinated products of incomplete combustion (PICs), can be released into the air from facilities that treat PFAS in air and solid media, such as incinerators, cement and lightweight aggregate kilns, sewage sludge incinerators, municipal waste combustors, soil desorbers, pyrolyzers, and spent carbon reactivation facilities (**Krug et al. 2022**; **Riedel et al. 2021**; **Stoiber, Evans and Naidenko 2020**). Few comprehensive waste characterization or full-scale demonstration studies have been conducted to document the performance of these treatment facilities in removing and destroying PFAS. In one recent study conducted under typical operations at a full-scale spent carbon reactivation facility, researchers reported full removal of PFAS compounds from the spent carbon and >99.99% destruction of PFAS compounds through the reactivation facility furnace and air pollution control systems (**DiStefano et al. 2022**). The importance of other sources, such as combustion emissions or windblown foam from fire training and fire response sites, may need to be assessed. **Section 12.4** includes additional information about incineration.

Once airborne, PFAS can occur in a gaseous state or be incorporated within particulate matter or other aerosols suspended within the air. The composition of the gas phase will be dependent on the industrial process(es) contributing to emissions. Neutral volatile precursor compounds, such as FTOHs, are often the dominant PFAS present in the gas phase (see **Section 17.1**) and can account for at least 80% of the total PFAS mass in ambient air in an urban area (**Ahrens et al. 2012**).

Over the open oceans and in remote regions, FTOHs also dominate neutral PFAS and almost all are present in the gas phase (**Bossi, Vorkamp, and Skov 2016**; **Lai et al. 2016**; **Wang et al. 2015**; **Dreyer et al. 2009**). In contrast, ionic PFAS, such as PFOA and PFOS, characterized by low vapor pressure and high water solubility, tend to be the dominant species found in airborne particulate matter. PFOA is associated with smaller, ultrafine particles, while PFOS is associated with larger, coarser fractions in both urban and semirural areas (**Ge et al. 2017**; **Dreyer et al. 2015**). Wet and dry deposition are the major mechanisms of removal of PFAS from the atmosphere and can occur from the scavenging of particle-bound PFAS or partitioning of gaseous PFAS to water droplets (**Dreyer et al. 2010**; **Barton, Kaiser, and Russell 2007**; **Hurley et al. 2004**). PFAS are commonly found in precipitation (rain and snow), with wet and dry deposition estimated to occur on a time scale of a few days (**Chen et al. 2016**; **Lin et al. 2014**; **Taniyasu et al. 2013**; **Zhao et al. 2013**; **Dreyer et al. 2010**; **Kwok et al. 2010**; **Liu et al. 2009**; **Barton, Kaiser, and Russell 2007**; **Kim and Kannan 2007**; **Hurley et al. 2004**). Certain PFAS, such as PFOS, have been found to persist in fine particulate matter (PM2.5) in the United States nearly 20 years after production was phased out, which confirms the presence of continuing sources (**Zhou et al. 2021**).

Atmospheric deposition can occur as dry or wet deposition, both of which are relevant for PFAS (**Barton, Kaiser, and Russell 2007**, **2010**; **Dreyer et al. 2010**; **Taniyasu et al. 2013**). During dry deposition, PFAS that are preferentially associated with liquid or particle phases in air (aerosols) can be naturally deposited onto surfaces via settling, diffusion, or other processes. When precipitation contributes to washout of these PFAS-containing aerosols, the process is known as wet deposition. Wet and dry deposition are the major mechanisms for removal of PFAS from the atmosphere and can occur from the scavenging of

particle-bound PFAS or partitioning of gaseous PFAS from water droplets (**Dreyer et al. 2010**; **Barton, Kaiser, and Russell 2007**; **Hurley et al. 2004**). Deposition is considered a sink term for the atmosphere because mass is removed and the potential for longer range atmospheric transport is reduced. However, this same process thus represents a potential source of PFAS to terrestrial and aquatic environments. Once settled, PFAS adsorbed onto soils or other surfaces (including indoor surfaces) can be resuspended when particulate matter is disturbed by wind or other physical means. See **Section 6.1** for further discussion of atmospheric deposition of PFAS.

Short-range atmospheric transport and deposition can result in PFAS contamination in terrestrial and aquatic systems near points of significant emissions, impacting soil, groundwater, and other media of concern (**Davis et al. 2007**). PFAS can migrate downward from surficial soils into the groundwater table via leaching processes described in **Section 5.3.3**. Evidence of releases has been observed in areas where hydrologic transport could not plausibly explain the presence of PFAS in groundwater, with the extent of contamination reaching several miles from sources and in distribution patterns independent of regional hydrology (**Frisbee et al. 2009**; **Post 2013**; **Post, Cohn, and Cooper 2012**; **NYS DOH 2016**; **NH DES 2017**; **VT DEC 2016**). Air emissions from industrial sources can cause contamination of drinking water sources and pose a potential increased risk to human health in communities over wide areas surrounding the emissions source (**Schroeder, Bond, and Foley 2021**). Releases of ionic PFAS from factories are likely tied to particulate matter (**Barton et al. 2006**), which settles to the ground in dry weather and is are also wet-scavenged by precipitation (**Slinn 1984**; **Sehmel 1984**). Key variables that should be used to predict impacts to groundwater wells include the rate of PFAS air emissions and distance from upwind sources, prevailing wind direction, soil characteristics, and well depth (**Roostaei et al. 2021**). In a study using a statewide data set to model PFAS in private wells (n~2300), researchers found that proximity to point sources, including plastics, rubber, and textile industries, was the most important predictor of impacts, with groundwater recharge, precipitation, soil sand and clay content, and hydraulic conductivity as secondary predictors (**Hu et al. 2021**).

Predictive models have been applied to estimate PFAS deposition (**D'Ambro et al. 2021**; **Shin et al. 2012**). The American Meteorological Society/USEPA regulatory model AERMOD system contains modules to estimate both wet and dry deposition of both aerosols and gases (**USEPA 2016**). The Community Multiscale Air Quality (CMAQ) model has also been applied to investigate the atmospheric fate and transport of PFAS emissions (including GenX) from a fluoropolymer manufacturing facility in North Carolina (**D'Ambro et al. 2021**). In this study, researchers predicted that 5% by mass of total emitted PFAS and 2.5% of total GenX are deposited within ~150 km of the source, with the majority of emissions being transported beyond 150 km (**D'Ambro et al. 2021**). Model validation is important and where uncertainty exists, model predictions should be interpreted with caution. Nevertheless, the model may be useful in understanding the pattern of PFAS found in soil and groundwater in the vicinity of PFAS emission sources (**Shin et al. 2012**). Key input parameters for emissions from a smokestack or vent include the height of the release point and adjacent structures, source emission rates and particle size distributions, stack effluent properties (temperature and volumetric flow rate), meteorological data, local topography, and land use characteristics. A number of states are actively engaged in the application and review of air models for evaluating the impact of PFAS emissions from industrial sources and can provide valuable information on their use and the interpretation of findings.

Long-range transport processes are responsible for the wide distribution of neutral and ionic PFAS across the earth as evidenced by their occurrence in biota, surface snow, ice cores, seawater, and other environmental media in remote regions as far as the Arctic and Antarctic (**Szabo et al. 2022**; **Langberg et al. 2022**; **Joerss et al. 2020**; **Yeung et al. 2017**; **Bossi, Vorkamp, and Skov 2016**; **Kirchgeorg et al. 2016**; **Rankin et al. 2016**; **Wang et al. 2015**; **Codling et al. 2014**; **Wang et al. 2014**; **Kirchgeorg et al. 2013**; **Kwok et al. 2013**; Benskin, **et al. 2012**; **Cai et al. 2012**, **2012**, **2012**; **Ahrens, Xie, and Ebinghaus 2010**; **Dreyer et al. 2009**; **Young et al. 2007**). Geochemical modeling of the contributions of atmospheric and oceanic inputs in the Arctic suggests that atmospheric inputs may account for as much as 34%–59% of measured PFOA concentrations in the polar mixed layer (PML) (**Yeung et al. 2017**). Declining trends in

the concentration of PFSAs in higher trophic arctic mammals has been largely attributed to reductions in long-range atmospheric transport as a result of industrial phaseout of certain PFAS (**Routti et al. 2017**). Distribution of PFAS to remote regions far removed from direct industrial input is believed to occur from both (1) long-range atmospheric transport and subsequent degradation of volatile precursors and (2) transport via ocean currents and release into the air as marine aerosols (sea spray) (**Lin et al. 2021**; **Casas et al. 2020**; **Joerss et al. 2020**; DeSilva, **Muir, and Mabury 2009**; **Armitage et al. 2009**; **Wania 2007**; **Ellis et al. 2004**).

5.3.3 Leaching

PFAS present in unsaturated soils are subject to downward leaching during precipitation, flooding, or irrigation events that promote dissolution and migration of contaminant mass (**Sepulvado et al. 2011; Ahrens and Bundshuh 2014**; **Sharifan et al. 2021**). This process can result in PFAS transport from surface soils to groundwater and surface water because PFAS releases often involve surface applications (for example, AFFF and biosolids) or atmospheric deposition (**Borthakur et al. 2022**; **Gellrich, Stahl, and Knepper 2012**; **Anderson, Adamson, and Stroo 2019**; **Galloway et al. 2020**). **Section 1.3.1** includes information about vadose zone characterization and transport, including air-water partitioning and vadose zone modeling. **Section 10.4.1** and **Section 1.5.1** include information about approaches, methods, and tools available to evaluate PFAS leachability.

PFAS migration from shallow soils to groundwater is influenced by several interacting processes, which may enhance or limit PFAS leaching rates. The leaching potential will be enhanced in areas with high water infiltration rates, which may include natural water sources such as precipitation or human-made sources such as irrigation. The thickness of the unsaturated zone (depth to water table) will also affect leaching potential. These factors are consistent with other (non-PFAS) contaminants in shallow soils. Conversely, several PFAS-specific processes, as described in **Section 5.2**, potentially limit the extent of PFAS leaching from shallow soil to groundwater. These include partitioning of PFAS to solid phases (for example, soil particles), adsorption at the air-water interface, and partitioning to NAPL. As a result, any soil properties that enhance the potential relevance of PFAS-sorptive processes may limit soil-to-groundwater leaching. This includes elevated levels of organic carbon, surface area and surface charge, increasing air content, and higher ionic strength within the vadose zone (**Guelfo and Higgins 2013**). The structural properties of the individual PFAS will also influence their transport, including the tendency for longer chain PFAAs to be less soluble and exhibit larger partitioning coefficients than shorter-chain PFAAs. In addition, several of these partitioning processes within the vadose zone have been shown to be nonlinear, which means that their relative contribution to leaching may change over time as concentrations change as a result of dilution and transformation (**Zeng and Guo 2021**). Finally, site conditions that influence the degree of flushing (for example, precipitation rates and depth to groundwater) should be considered when evaluating the potential for PFAS to leach from soil to groundwater.

While our understanding of these vadose zone processes continues to evolve, there are several possible implications that may be relevant for managing sites where PFAS have been released:

- These processes can affect the rate at which some PFAS migrate through the vadose zone to groundwater (breakthrough). As with hydrophobic partitioning, the relative importance of air-water interfacial partitioning is highly dependent on hydrogeologic and geochemical properties (for example, water content, salinity) of the formation (**Anderson, Adamson, and Stroo 2019**), as well as the air-water interfacial affinity of individual PFAS (**Brusseau 2019**). In general, air-water interfacial partitioning can contribute to the bulk soil retention of PFAS in a manner that is unique among organic contaminants. Time scales required for PFOS (and other PFAS that exhibit strong interfacial adsorption characteristics) to reach the underlying groundwater have been simulated to be from 1 or 2 years to several decades or longer. The extent of this retardation factor will likely vary due to climate conditions and PFOS concentrations (**Guo, Zeng, and Brusseau 2020**;

Brusseau 2020). This potential retardation could influence the selection and implementation of remedies, or even the duration of long-term management programs.

- Similar to the impact described above, retention within the vadose zone can occur because of the PFAS tendency to be associated with the air-filled pore space and (to a lesser extent) the solid phase, such that a limited portion of PFAS mass may be in the aqueous phase and subject to deeper infiltration (**Guo, Zeng, and Brusseau 2020**). Importantly, the interaction between solid phase sorption (hydrophobic partitioning and electrostatic interactions) and air-water interfacial partitioning could be important given that mass transfer limitations can create hysteretic desorption from soils with relatively high organic matter content (**Schaefer et al. 2021**).

Although some experimental and field-scale studies have reported PFAS transport by leaching (**Lindstrom et al. 2011**; **Filipovic et al. 2015**; **Hellsing et al. 2016**; **Bräunig et al. 2017**), others have observed long-term retention of longer chain PFAS on shallow soils after extended percolation (**Sepulvado et al. 2011**; **Stahl et al. 2013**; **Anderson et al. 2016**; **Anderson 2021**; **Anderson et al. 2022**). In a long-term lysimeter study using a silty soil with some clay and natural rainfall, PFOA and shorter chained PFCAs and PFSAs traveled more rapidly through the soil column than did PFOS (**Stahl et al. 2013**). However, even after 5 years, 96.88% and 99.98% of the mass of PFOA and PFOS, respectively, remained in the soil. This retention of PFOA and PFOS may increase the long-term persistence of the (soil-bound) source (**Baduel, Paxman, and Mueller 2015**). Due to the low (part per trillion) concentrations that are a concern in groundwater, slow leaching of PFAS from shallow soils may contribute to a persistent groundwater plume.

5.3.4 Transfer of PFAS between groundwater, surface water, porewater, and sediment

The interplay between PFAS and groundwater, porewater, surface water, and sediments is complex, and identifying the nature and implications of these interactions for PFAS fate and transport is very likely site-specific. The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include information about colloidal transport of PFAS in groundwater (see **Section 1.3.4.2**) and groundwater-surface water interactions (see **Section 1.3.4.3**).

For example, studies within the Little Neshaminy watershed in southeastern Pennsylvania indicate instances where PFAS-containing groundwater impacts surface water and other instances where surface water PFAS concentrations may be diluted by groundwater discharge (**Leidos 2019**; **Tetra Tech 2022**). Field investigations have also demonstrated the migration of PFAS from groundwater to surface water via infiltration of groundwater to stormwater utilities (**Leidos 2019**; **Wood 2020**). Other investigations have indicated transport of PFAS from groundwater to surface water features such as marshland (**Aerostar SES 2021**). Investigations involving larger tributaries also indicate that migration of PFAS from groundwater to surface water may be impacted by seasonal and local variations in stream flow that may affect groundwater flow direction and gradients (**Weston-ER Federal Services 2022**).

A complete understanding of fate and transport implications of transfer of PFAS between surface water and groundwater requires an understanding of the differing conditions between surface water, groundwater, and the hyporheic zone.

Development of surface water quality standards for PFAS is discussed in **Section 16**. Information about PFAS occurrence in surface water and groundwater is included in **Section 6.4** and **Section 6.3**, respectively and in **Section 17.1**. Additional case studies of PFAS transport between surface water and groundwater are discussed in **Section 15.5**.

5.3.4.1 Groundwater/Surface Water Interactions

Surface water and groundwater often have distinct chemistry or geochemistry, including differences in pH, ionic concentrations, dissolved oxygen, and sources and concentration of PFAS or other contaminants. Sediment porewater represents the boundary layer between groundwater and surface water where geochemical and redox transition zones may have significant fate implications for PFAS.

To date, there are very limited studies of PFAS at the surface water/groundwater boundary. One of the few published studies, **Tokranov et al. (2021)**, looked at the PFAS concentrations, dissolved oxygen, and nutrients in downwelling of lake surface water. They found that precursor concentrations decreased from surface water to groundwater across the porewater boundary and attributed this decrease to biotransformation and sorption.

Redox gradients at the sediment porewater zone are expected to impact the fate of PFAA precursors (for example, from anoxic groundwater flow into surface waters). Reaeration of anoxic groundwater during exfiltration to surface water will lead to shifts in microbial populations, which in turn may alter transformation of PFAA precursors. An analogous process occurred when increased PFAAs were detected after biosparging in the field (**McGuire et al. 2014**) and in column studies (**Nickerson et al. 2021**; also see **Section 5.4.4.2** and the case study in **Section 15.1.1**). This suggests groundwater/surface water redox transition zones have potential as hotspots for biotransformation. Additional abiotic transformations may also occur in anoxic groundwater to aerobic surface water boundaries.

There is limited information on how redox gradients impact PFAS sorption. However, aerobic transformation of PFAA precursors yields more mobile products (**Weber et al. 2017**), which in turn might be less likely to be adsorbed to solid phases. In addition to the impacts on precursor transformation, the perfluorocarbon chain length "head group, and a variety of environmental properties (for example, sediment organic carbon content, mineral and grain coating composition, pH, aqueous calcium and humic acid concentration) have all been shown to influence PFAS partitioning in laboratory experiments" (**Tokranov et al. 2021**). For example, **Steffens et al. (2021)** found that measured PFOS concentrations decreased significantly in ionic solutions due to an apparent "salting out" effect. The decrease in bulk solution PFOS concentrations with higher salinity was attributed to increased uptake of PFOS on the water-container interface, as well as increased aggregation at the air-water interface. The authors suggest that such an effect has implications on transport of PFAS in high-salinity environments or in areas where changes in salinity occur spatially or temporally, as increased salinity may lead to aggregation of PFAS on particulates, sediment, or other solids, as well as increased concentrations of PFAS in surface microlayers.

It is difficult to estimate the extent of PFAS introduction to surface waters from groundwater, especially when there are other surface point discharge sources, or transformation and sorption processes might significantly impact PFAS transport. However, **Pétré et al. (2021)** studied a site without direct outfalls of PFAS onto surface water and based on groundwater and surface water field measurements estimated up to 32 kg/yr for perfluoroether carboxylic acids (PFECAs) released from hyporheic exchange. Because of the high mobility and low retardation factor of PFECAs, the authors assumed low sorption and not enough time for transformation (days to months) assuming no transformation or sorption due to the low retardation factor of PFECAs. They indicated that adsorption would overestimate PFAS flux to surface water, and desorption would underestimate it.

5.3.4.2 Surface Water/Sediment Interactions

PFAS, particularly short chain PFAS, are mobile in the aquatic environment due to their high solubility in water (**Ahrens 2011**). This property further increases the difficulty of finding a correlation between concentrations in water, especially flowing water, and other media, such as sediments, fish, or invertebrates (**Campo et al. 2016**). A number of studies have sought to establish PFAS partitioning

between surface water and sediments in lakes or other stationary water bodies, such as wetlands and estuaries (**White et al. 2015**; **Mussabek et al. 2019**; **Bai and Son 2021**; **da Silva et al. 2022**).

Occurrence of PFAS in sediments can be the result of transfer (partitioning) from the surface water column or deposition of PFAS sorbed to suspended solids. The relative contribution of each process in PFAS transport to sediments remains unclear as partition coefficients measured in the field are consistently higher than those measured in the laboratory (**Zhang et al. 2015**; **Li, Oliver, and Kookana 2018**; **Rovero et al. 2021**). Suspended solids originating from erosion of PFAS-impacted soil may contain much higher levels of PFAS compared to suspended solids with PFAS due to equilibrium deposition (**Borthakur et al. 2021**; **Xiao et al. 2019**). These suspended solids, eroded from PFAS-impacted soils, may mix with particulates present in rivers and streams through turbulent mixing and may lead to higher PFAS concentrations in sediment when the suspended solids settle.

Dated sediment core analysis allows estimation of deposition rates and fluxes of PFAS to surface water bodies. Studies in the Great Lakes suggest it may be effective for long-chain PFAS that exhibit greater sorption to sediment, with concentration at a given depth interval representing deposition during that time period. Short-chain PFAAs showed less sorption and were apparently more mobile in the sediment column, and therefore were not effective indicators of PFAS deposition rates. The authors (**Codling et al. 2018**) also noted that as more short-chain PFAS are used as replacements for PFAS applications, sediment cores may have less utility for evaluating trends in deposition rates. Age-dated sediment cores in a Swedish study (**Mussabek et al. 2019**) allowed estimation of deposition rates and fluxes of PFAS to ponds impacted by AFFF releases. The study identified peak deposition rates occurring between 2003 and 2009, which correlated with reported activity near the water bodies. The study noted that interpretation of fluxes must consider seasonal variations in water chemistry, sedimentation, and partitioning (**Mussabek et al. 2019**). Heavy precipitation or storm events can also contribute to episodic or enhanced transport of sediment and resuspension or redistribution of contamination in some environmental settings. Resampling of marine sediment locations in Florida following the passage of a hurricane found sediment concentrations of total PFAS decreased 47% averaged across nine sites (**Ahmadireskety et al. 2021**). Sediments can also influence surface water concentrations. Tributary sediments with a mix of potential sources were shown to be potential secondary sources of PFAAs once those sediments were transported to a receiving water body (**Balgooyen and Remucal 2022**).

Because PFAS concentrations in sediment may be the result of average deposition conditions of discharges that may be episodic, passive porewater samplers may be useful to characterize the surface water concentrations and correlate them with the sediment PFAS concentrations. Passive sampling provides an accumulation of contaminants and so generates a time-weighted mean concentration instead of a snapshot of concentration at a discrete time point. However, careful consideration must be given to the type of sampler, as equilibrium devices may not be appropriate for episodic discharges and accumulation devices could potentially represent the average concentrations in sediments. See **Section 11.1.7** for more information about sampling environmental media.

In a recent study, PFBS, PFHxS, and PFOS in sediments collected from lake Sänksjön near Ronneby, Sweden, was found to be correlated to the sediment mineral content (Fe, Pb, Rb, and As) but not with the fraction of organic carbon (f_{oc}) based on principal component analysis (**Mussabek et al. 2020**). Other PFAS measured at the site (PFHxA, PFOA, and 6:2 FTS) had weaker associations with the mineral content. The sorption behavior of PFAS to sediments depends on both hydrophobicity and electrostatic interactions given the unique structure of PFAS with both polar and nonpolar moieties (**Ahmadireskety et al. 2021**; **Lampert 2018**). Sorption of PFAS to sediments is expected to be driven by similar variables as partitioning in soils. See **Section 5.3.2** for additional discussion of factors driving partitioning and sorption. In aquatic environments and the hyporheic zone, sorption and desorption are likely to have direct effects on the mechanisms of PFAS transport (for example, transport in dissolved phase, retention due to sorption, or particulate transport due to sorption).

5.4 Transformations

The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include information about perfluoroalkyl acid precursor biotransformation (see **Section 1.3.3**). In addition, a new tab named Biotransformation was added to the Physical and Chemical Properties Table (**Table 4-1**). The biotransformation table includes a compilation of available precursor kinetics data (see **Section 1.3.3.2**).

5.4.1 Introduction

Numerous studies have reported both biotic and abiotic transformations of some polyfluorinated PFAS. Polyfluorinated PFAS shown to transform are referred to as *precursors* and typically form PFAAs. However, PFAAs have not been shown to degrade or otherwise transform under ambient environmental conditions. The fundamental differences between polyfluorinated precursors and perfluorinated chemicals that affect transformation potential are the presence, location, and number of carbon-hydrogen (C-H) bonds and *potentially* carbon-oxygen (C-O) bonds throughout the alkyl carbon chain. Specifically, PFAS with C-H bonds are subject to a variety of biotic and abiotic reactions that ultimately result in the formation of shorter chain PFAAs. Although available studies on both biotic and abiotic transformation of polyfluorinated PFAS primarily consist of controlled laboratory experiments (discussed below), an increasing number of field studies have also been published that demonstrate the relevance of precursors at a variety of sites with different source scenarios (for example, **Weber et al. 2017**; **Dassuncao et al. 2017**).

5.4.2 PFAA Precursors

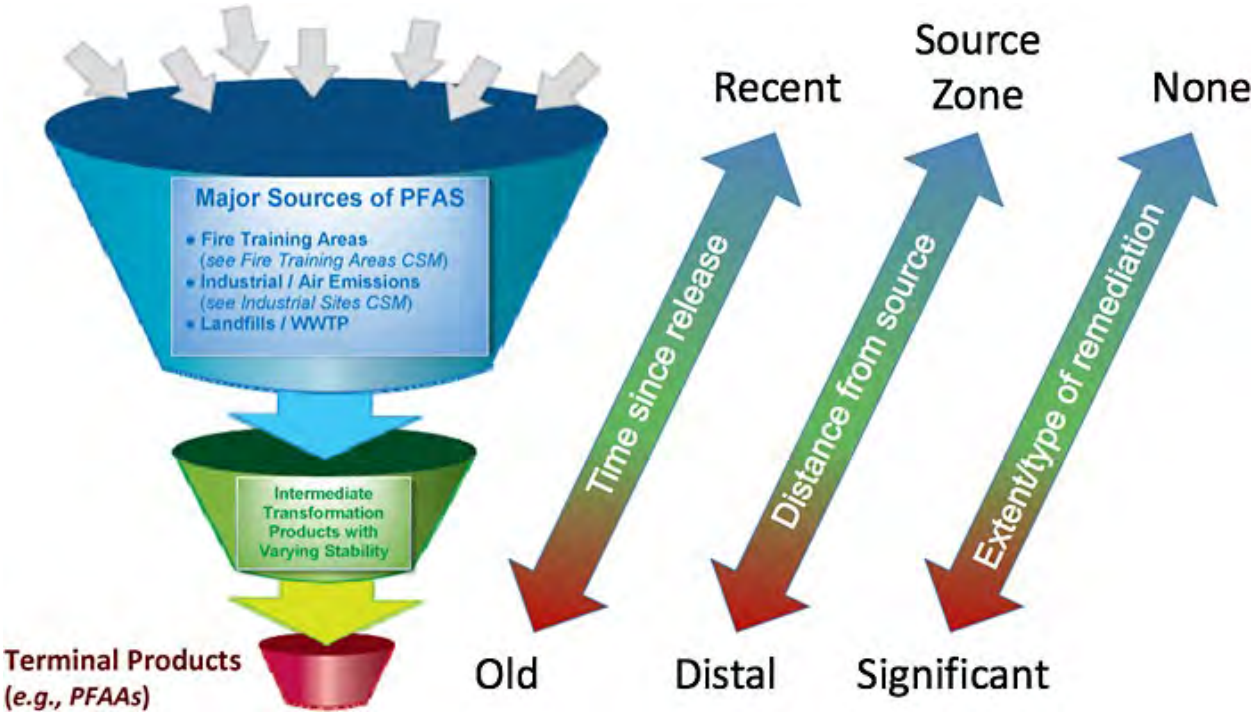


Figure 5-3. Illustration of precursor transformation resulting in the formation of PFAAs.

Source: L. Trozzolo, TRC, and C. Higgins, Colorado School of Mines. Used with permission and based on ***This Photo*** *by Unknown Author is licensed under* ***CC BY-SA****.*

Although PFAAs are limited to a fairly small number of homologous compounds that differ only with respect to carbon chain length and the terminal functional group, the number and diversity of polyfluorinated chemicals is vast. Thousands of PFAS are currently thought to exist (or have existed) on the global market, and the vast majority are polyfluorinated (**Wang et al. 2017**) (**Section 2**). However, transformation studies published to date are available for only of a small subsample of these PFAS, and therefore, much uncertainty exists regarding 1) the extent to which precursor transformation occurs on a global scale, 2) which environmental compartments represent the majority of transformation, 3) relevant environmental conditions that affect transformation processes, and 4) transformation rates and pathways. Nevertheless, the fraction of total PFAS that consists of PFAAs, both globally and (in particular) at contaminated sites, should be expected to increase due to transformation over time, over distance, and due to remediation, as depicted in **Figure 5-3**.

5.4.3 Atmospheric Transformations

Although direct emission of PFCAs has declined globally, atmospheric emission of PFCA precursors has been increasing (**Thackray and Selin 2017**; **Wang et al. 2014**). Similarly, emission rates for PFSA precursors are increasing globally (**Löfstedt Gilljam et al. 2016**). Atmospheric transport is an important distribution mechanism for PFAS on both regional and global scales, which has led to documented PFAS occurrence (including PFAAs and PFAA precursors) in remote locations, including arctic regions (**Young et al. 2007**). Ocean currents also transports PFAS to arctic regions, although the relative contribution of each mechanism is not well understood (**Yeung et al. 2017**). Regardless of the relative contributions of atmospheric and oceanic transport, atmospheric transport and subsequent transformation of precursors has been documented as an important source of PFAAs in the environment (**Young et al. 2007**).

Widely measured PFCA precursors in the atmosphere include primarily FTOHs (**Thackray and Selin 2017**; **Young and Mabury 2010**; **Martin et al. 2002**). **Wang et al. (2015)** collected marine atmospheric samples during an expedition research cruise that spanned the Southern Ocean, Atlantic Ocean, and Arctic Ocean; samples were analyzed for several precursors, including FTOHs, FTAs, FOSAs, and FOSEs. The researchers found that FTOHs were the predominant species.

Atmospheric transformation of precursors, including FTOHs, may be an important source of PFCAs in the environment, such as those identified in the Arctic (**Schenker et al. 2008**). Although direct photolysis of PFAS has not been observed, indirect photolysis of some precursors does occur in the atmosphere and can be a significant contributor to PFCA deposition (**Armitage, MacLeod, and Cousins 2009**; **Yarwood et al. 2007**). For example, hydroxyl and chlorine radicals degrade 8:2 FTOH to PFOA in the atmosphere through reactions with hydroxyl and chlorine radicals, with similar reactions for 6:2 and 4:2 FTOHs (**Ellis et al. 2004**) and perfluoroalkyl sulfonamides, which may degrade to PFCAs and PFSAs (atmosphere) (**Martin et al. 2006**) and PFSAs (terrestrial environment) (**Mejia Avendaño and Liu 2015**). In addition to FTOH, other semivolatile precursors may also undergo atmospheric transformation to PFCAs (**Young and Mabury 2010**).

Atmospheric transformation of precursors to PFCAs is a multistep process, and the PFCA product yield is a function of several factors, including ratio of nitrous oxides (NO_x) and peroxy radicals (RO_2) species. High NO_x levels result in lower long-chain PFCA yields, thus long-chain PFCA yields are typically higher in remote regions (**Young and Mabury 2010**). **Thackray and Selin (2017)** calculated theoretical maximum yields for formation of PFOA and PFNA from 8:2 FTOH that were highly variable, ranging from far less than 1% to 40% (PFOA) or 80% (PFNA), depending on local photochemical conditions.

5.4.4 In Situ Transformations

5.4.4.1 Abiotic Pathways

Abiotic processes shown to cause transformations of precursors in soil and water under ambient environmental conditions include hydrolysis, photolysis, and oxidation. Hydrolysis of some precursors, followed by subsequent biotransformation, can produce PFSAs. An important example is the production of PFOS from perfluorooctane sulfonyl fluoride (POSF) (**Martin et al. 2010**). Other hydrolysis reactions produce PFCAs. In particular, **Washington and Jenkins (2015)** showed that the hydrolysis of fluorotelomer-derived polymeric precursors forms monomeric precursors of PFOA and other PFCAs with half-lives of 50–90 years at neutral pH. Also, oxidation of precursors by hydroxyl radicals can occur in natural waters, with the fluorotelomer-derived precursors being oxidized more rapidly than electrochemical fluorination (ECF)-derived precursors (**Gauthier and Mabury 2005**; **Plumlee, McNeill, and Reinhard 2009**). Shorter chain PFCAs as well as PFSAs such as perfluorobutane sulfonate (PFBS) also can be produced by oxidation reactions between hydroxyl radicals and sulfonamido derivatives (**D'Eon et al. 2006**). Finally, in some cases, abiotic precursor transformations may not initially produce any PFAA (for example, the formation of various polyfluorinated sulfonamido intermediate compounds from ECF-derived precursors), though eventual formation of PFAAs may still be possible.

5.4.4.2 Aerobic Biological Pathways

Evidence of aerobic biotransformation is provided from studies of PFAS composition throughout the continuum of wastewater treatment (see **Arvaniti and Stasinakis (2015)** for a comprehensive review), field studies at AFFF-impacted sites (for example, **Houtz et al. 2013**; **McGuire et al. 2014; Anderson et al. 2016**; **Weber et al. 2017**), and most authoritatively from microcosm experiments.

The literature on aerobic biotransformation collectively demonstrates, or indirectly supports, conclusions such as the following:

- Numerous aerobic biotransformation pathways exist with relatively rapid kinetics.
- All polyfluorinated precursors studied to date have the potential to aerobically biotransform to PFAAs.
- Aerobic biotransformation of various fluorotelomer-derived precursors *exclusively* results in the formation of PFCAs, including PFOA.
- Aerobic biotransformation of various ECF-derived precursors *primarily* results in the formation of PFSAs, including PFOS.

In detail, most commonly studied in microcosm experiments have been the 6:2 and 8:2 FTOHs in soil, sludge, or aqueous matrices. Although observed degradation rates and intermediates are variable among these studies, ≤ C8 PFCAs have been consistently observed as terminal transformation products (**Dinglasan et al. 2004**; **Wang et al. 2005**, **2005**; **Liu et al. 2007**; **Saez, de Voogt, and Parsons 2008**; **Wang et al. 2009**). However, a pure culture experiment with *P. chrysosporium* (a white-rot fungus) reported much lower PFCA yields with alternate pathways (**Tseng et al. 2014**). Other telomer-derived polyfluorinated PFAS investigated include the 6:2 fluorotelomer mercapto alkylamido sulfonate (**Weiner et al. 2013**), the 6:2 fluorotelomer sulfonate (**Wang et al. 2011**), the 4:2, 6:2, and 8:2 fluorotelomer thioether amido sulfonates (**Harding-Marjanovic et al. 2015**), the perfluorooctane amido quaternary ammonium salt (**Mejia-Avendaño et al. 2016**), the 6:2 fluorotelomer sulfonamide alkylamine, and the 6:2 fluorotelomer sulfonamide alkylbetaine (**D'Agostino and Mabury 2017**). All demonstrate the formation of PFCAs with variable rates and inferred pathways. Aerobic biotransformation of various ECF-derived polyfluorinated PFAS has also been demonstrated in several studies. Studied PFSA precursors include N-

ethyl perfluorooctane sulfonamido ethanol (**Rhoads et al. 2008**; **Zhao et al. 2016**; **Zhang et al. 2017**), N-ethyl perfluorooctane sulfonamide (**Mejia Avendaño and Liu 2015**), and perfluorooctane sulfonamide quaternary ammonium salt (**Mejia-Avendaño et al. 2016**). All demonstrate formation of PFSAs with variable rates and inferred pathways.

5.4.4.3 Anaerobic Biological Pathways

Few studies have been published to date conclusively demonstrating biotransformation of per- and polyfluorinated PFAS under anaerobic conditions. Different end-products of PFAA precursors have been observed between aerobic and anaerobic conditions (**Choi et al. 2022**). Aerobic, and to some extent, denitrifying conditions lead to PFAAs (**Yi et al. 2022**), but more reducing anaerobic conditions, such as iron- and sulfate-reducing, lead to other transformation products (**Yi et al. 2018**; **Yan et al. 2022**). FTOHs were studied in two instances, demonstrating the production of stable polyfluorinated acids under methanogenic conditions with much slower kinetics relative to aerobic biotransformation (**Zhang et al. 2013**; **Allred et al. 2015**). In a recent study, PFOA and PFOS were demonstrated to be defluorinated by a specific microbial strain (*Acidimicrobium sp*. Strain A6) under conditions where ammonium is oxidized while iron is reduced, a condition known as Feammox (**Huang and Jaffé 2019**). The environmental significance of anaerobic biotransformations of polyfluorinated PFAS as sources of PFAAs is uncertain.

5.4.5 Polymer Transformation

Polymeric substances in the PFAS family include fluoropolymers, polymeric perfluoropolyethers, and side-chain fluorinated polymers (**Buck et al. 2011**). Detailed descriptions of these polymers appear in **Section 2.2.2.1**. Briefly,

- fluoropolymers are high–molecular weight solid plastics (> 100,000 Daltons, or Da according to **Henry et al. (2018)**) containing a carbon polymer backbone with fluorine directly attached to backbone carbon atoms.
- polymeric perfluoropolyethers contain an ether polymer backbone with F directly attached to carbon atoms. These polymeric PFAS are complex and mainly used as surfactants and surface protectants.
- side-chain fluorinated polymers contain a nonfluorinated polymeric backbone with fluorinated side chains; these are synthesized from telomer-derived precursors.

Polymer transformation research has indicated the following.

- Given the wide range of estimated half-lives, modeling assumptions for estimating the half-lives, different levels of residuals present in the polymer studied, highly variable molecular weights of the polymers studied with different surface area and size and with different extraction protocols, the polymer degradation studies are inconsistent.
- Other environmental conditions that need to be considered are redox, pH, temperature, percent moisture, and microbial activity in the soil microcosms for these long-term studies.
- Additional research is needed primarily on the biotransformation of side-chain fluorinated polymers, which are potential precursors to PFAAs.

Side-chain fluorinated polymers are widely used for many commercial and industrial applications as surfactant and surface-protecting products (**Buck et al. 2011**). Therefore, understanding the biotransformation potential of these polyfluorinated polymers is essential. However, few studies have reported on the potential biotransformation of side-chain polymers—for example, the fluorotelomer-based

urethane polymer (**Russell et al. 2010**). Given the complexity of side-chain fluorinated polymers, there are many discrepancies among these studies. Primarily, the inability to monitor polymer concentrations is problematic. Because analytical methods for direct quantitation of polymers are not available, all the studies except **Rankin et al. (2014)** monitored suspected FTOH degradation products rather than the disappearance of the polymer (**Wang et al. 2005**; **Liu et al. 2007**; **Wang et al. 2009**; **Dasu, Liu, and Lee 2012**; **Dasu and Lee 2016**). **Rankin et al. (2014)** qualitatively monitored the disappearance of the polymer using matrix-assisted laser desorption/ionization time-of-flight (MALDI-TOF) mass spectrometry, in addition to monitoring known degradation products. Also, the presence of impurities or nonpolymerized residuals (monomers, oligomers, PFCAs, FTOHs, etc.) complicates data interpretation and potentially confounds conclusions on polymer biodegradation. Finally, the time frame for the biodegradability studies (max = 2 years) is much shorter than the extrapolated half-lives (decades to thousands of years) of these side-chain fluorinated polymers. Hence, modeling assumptions are also critical sources of variability.

Russell et al. (2008); **Russell et al. (2010)** investigated the biodegradation potential of two types of side-chain fluoropolymers, fluorotelomer-based acrylate polymer and urethane polymer in soils for 2 years. Based on the experimental data for PFOA, the estimated half-life of acrylate polymer was 1,200–1,700 years and of urethane polymer was 28–241 years (geometric mean of 102 years). However, the polymer used in this study contained high residuals. Later, **Washington et al. (2009)** studied the biodegradation potential of fluorotelomer-based polyacrylate, which contained low residuals, and based on the experimental data for PFOA, the acrylate polymer half-life was estimated at 870–1,400 years. Further, based on the assumption that degradation is surface-mediated, the authors also modeled and estimated the half-life for finely grained polymers, which are typical of commercial products. They did this by normalizing to the estimated surface area of the polymer and derived a half-life of 10-17 years, which suggests fine-grained, side-chain fluoropolymer products may be a potentially significant source of PFCAs to the environment. **Washington et al. (2015)** studied the biodegradability of commercial acrylate polymer for 376 days in soils using exhaustive extractions (**Washington et al. 2014**) and estimated half-lives ranging from 33 to 112 years. In this study, it was also observed that the acrylate polymer can undergo OH-mediated hydrolysis in pH 10 water and it degrades 10-fold faster than in the neutral treatment. This is the only abiotic transformation of side-chain fluorinated polymer reported in the literature, so the mechanism of abiotic degradation needs further investigation. Another research group, **Rankin et al. (2014)** studied the biodegradation of laboratory-synthesized fluorotelomer-based acrylate polymer in soil, plant, and biosolids for 5.5 months. Degradation rates were faster in plants and biosolids than in soils. Even in this study, a broad range of estimated half-lives of 8–111 years was reported. The modeling assumptions used in different studies lead to variability in reported half-lives (**Russell et al. 2008**; **Russell et al. 2010**; **Washington et al. 2009**, **2010**, **2015**, **2018**).

5.4.6 Practical Implications

Precursor transformation can complicate CSMs (and risk assessments) and should be considered during comprehensive site investigations. For example, atmospheric emissions of volatile precursors can result in long-range transport where subsequent transformation and deposition can result in detectable levels of PFAAs in environmental media independent of obvious point sources (**Vedagiri et al. 2018**). Moreover, downgradient PFOA and PFOS groundwater concentrations, or downstream concentrations within treatment systems, can oftentimes be higher than near the source area/influent due to precursor transformation reactions such as oxidation. Also, PFOA and PFOS concentrations can exhibit an increasing trend over time as precursors transform with time and distance (**Figure 5-3**), which can influence the Remedial Investigation/Feasibility Study (RI/FS) scope and data evaluation.

With respect to site-related precursors, transformation of otherwise unmeasured PFAS into detectable PFAAs is obviously relevant to site investigations to the extent transformation occurs after initial site characterization efforts. Additionally, differential transport rates between precursor PFAS and the

corresponding terminal PFAA could also confound CSMs if transformation rates are slower than transport rates, as has been suggested (**Weber et al. 2017**).

To account for otherwise unmeasurable precursors, several surrogate analytical methods have been developed, including the total oxidizable precursor (TOP) assay (**Houtz and Sedlak 2012**), particle-induced gamma-ray emission spectroscopy (PIGE) (**Schaider et al. 2017**), and adsorbable organic fluorine (AOF) followed by combustion ion chromatography (**Wagner et al. 2013**). For more information on these surrogate analytical methods to measure precursor concentrations, see **Section 11.2**.

5.5 PFAS Uptake into Aquatic Organisms

Some PFAS have a propensity to bioaccumulate. That is, they are taken up and accumulate in organisms from environmental media. Moreover, some PFAS may biomagnify up the food chain; for these compounds, lower levels of PFAS are observed in tissue from organisms at the base of the food chain and in lower trophic-level invertebrates and fish and higher tissue PFAS levels are observed in predatory fish and in air-breathing animals at the top of the food chain (for example, seagulls, polar bears) (**Houde et al. 2011**; **Gobas, Kelly, and Kim 2020**; **Burkhard 2021**). Trophic transfer of PFAS and biomagnification appear to be higher in air-breathing organisms (aquatic-dependent birds and mammals) than in gill-breathing species (for example, higher trophic-level fish species), presumably because the respiratory elimination of PFAS via gills to water is much greater than elimination from lungs to air (**De Silva et al. 2021**). It should be noted that not all PFAS biomagnify, and for some (for example, PFOS), the evidence regarding biomagnification is mixed (**Franklin 2016**). **Section 1.3.5.4** includes information about bioaccumulation of PFAS in marine biota.

The major mechanisms controlling aquatic bioaccumulation of PFAS are uptake (from water and food), depuration (which includes elimination across the gill surface, urine, and in feces) (**Chen, Gong, and Kelly 2016**; **Zhong et al. 2019**), growth dilution, and biotransformation. Within organisms, the extent of accumulation differs among types of tissues (for example, whole body, muscles, liver).

An understanding of bioaccumulation in field populations rests on evaluation of the following factors, which are common to PFAS, as well as to other contaminants:

- Exposure concentrations (concentrations of PFAS in sediments and water)
- Exposure to precursors
- Trophic level (higher trophic levels often exhibit higher concentrations)
- Movement and migration patterns, which determine the extent of exposure to contaminated areas that lie within the home range of an organism
- Bioenergetics (respiration rate, growth rate)
- Toxicokinetics (gut uptake efficiency, gill transfer efficiency, fecal elimination, biotransformation rate, differential protein binding)

Unlike nonionic polar organic compounds, which accumulate in fatty tissues, the bioaccumulation of ionic PFAS in aquatic biota is generally characterized as associated with proteins. Several studies (**Jones et al. 2003**; **Han et al. 2003**) reported that PFOS and PFOA are generally bound to serum albumin, as well as proteins in the liver and kidney, and differences among tissues in type of protein explain much of the PFAS variation among tissues (**Ng and Hungerbuhler 2014**, **2015**). Binding to phospholipids is another mechanism for PFAS accumulation (**Dassuncao et al. 2019**). Thus, methods and models that characterize the bioaccumulation of nonionic polar compounds by assuming partitioning to lipids (using lipid normalization) are likely to be inappropriate for PFAS (see discussion of partitioning in **Section 4.2.10**).

Bioaccumulation of PFAS is generally characterized using three parameters:

- Bioconcentration factor (BCF)—the direct uptake of PFAS by an organism from the water column (for example, through the gills). This is measured in the laboratory. It is defined as the ratio of the concentration in an organism to that in the exposure water (typically in units of ng/kg wet weight / ng/L, or L/kg wet weight).

- Bioaccumulation factor (BAF)—the amount of PFAS taken up from water plus the contribution of PFAS in the diet of the organism. Both the organism and its diet are simultaneously exposed to the same exposure sources. This is generally measured in the field. The units are the same as for the BCF.

- Biomagnification factor (BMF)—the increase in tissue PFAS concentration moving up the food chain, based on a specific predator/prey relationship. The BMF is measured in the field and is typically reported in units of ng/kg wet weight in predator / ng/g wet weight in prey. The trophic magnification factor (TMF) similarly describes the increase in tissue PFAS concentration with trophic level, but it is estimated using data for multiple trophic levels. It is typically calculated as a regression of log(PFAS concentration) vs. trophic level, which is usually determined using the stable isotope 15N method (**Franklin 2016**).

BCFs, BAFs, and BMFs are used to understand the nature of bioaccumulation; for example, they are used in the European Union REACH designation of compounds as "bioaccumulative" in the Persistent, Bioaccumulative, and Toxic (PBT) and Very Persistent and Very Bioaccumulative (vPvB) assessments. They are also used to support risk assessments and in development of surface water quality criteria (see **Section 16**). Publications addressing PFAS BCFs, BAFs, BMFs/TMFs are too many and too broad to cover in this document. Several publications have reviewed PFAS bioaccumulation, including but not limited to **Burkhard (2021)**; **Houde et al. (2006)**; **Houde et al. (2011)**; **Martin et al. (2013)**; **Conder et al. (2020)**; **Gobas, Kelly, and Kim (2020)**; and **De Silva et al. (2021)**.

To support better understanding of PFAS bioaccumulation in aquatic species, available BCF and BAF data are provided in **Table 5-1** (as a separate Excel file). BCF and BAF values for both invertebrates and fish are included. PFOS is the compound for which BCFs and BAFs are most commonly reported. This is expected because it is generally the most abundant PFAS in the tissues of aquatic organisms. The **Table 5-1** Excel file consists of two sheets, the Database that reports values found in relevant literature and a Log sheet that lists each reference that was reviewed.

Table 5-1 includes BCF or BAF values reported in published studies that were compiled as of September 2021. All of the BCF studies were performed in the laboratory under controlled conditions, while the BAF studies were performed in the field. All studies were subject to quality review, which was performed in a qualitative manner. First, the table includes only BCF and BAF values that were reported in the publications. In some studies, PFAS concentrations were measured in water and biota, but BCF or BAF values were not reported. In such studies, BCF or BAF values may not have been reported due to several potential factors—for example, proper spatial and temporal matching of the data. In light of such uncertainties, BCF or BAF values were not calculated for the table. These studies are noted in the Log sheet, for the user's consideration.

In addition, a number of studies were reviewed but not included in the Database sheet for various reasons; these studies are also indicated in the Log sheet (column "BAFs or BCFs presented in **Table 5-1**?"), and notes on each study are provided in the column "Comment." A quantitative ranking was not conducted, along the lines of **Burkhard (2021)**, who developed a parallel and largely overlapping database of BAF values and classified each study into one of three data quality categories based on several factors (number of fish and water samples, temporal and spatial coordination between the water and fish sampling, and general experimental design). **Burkhard (2021)** concluded that "The distributions suggest

that there are not big differences across the three measurement quality rankings." This suggests that the lack of a quantitative quality review of each study in Table 5-1, along the lines provided by **Burkhard (2021)**, is not likely to be a significant limitation to the usefulness of the information. Additional information is provided in the README sheet of the Table 5-1 Excel file.

Information on best practices for conducting laboratory bioaccumulation tests is provided by **OECD (2012)**, **USEPA (2016)**, and **ASTM (2013)**. Information is also available concerning the design and interpretation of field and laboratory BAF studies (for example, **Burkhard 2003**; **Gobas et al. 2020**). These resources may be useful in guiding the interpretation of the studies included in the database.

The following sections provide overviews of the available PFAS bioaccumulation data.

5.5.1 Bioconcentration

Table 5-1 presents available BCFs for several PFAS. Variation in the reported values is observed in the BCFs and is related to the specific PFAS, exposed species, tissue type, and other factors.

Studies have indicated that chemical structure, particularly the length of perfluoroalkyl chain and the presence of functional groups (carboxylate vs. sulfonate), influence their bioaccumulation potential. **Martin et al. (2003)** exposed rainbow trout to individual PFAS for 12 days. The PFAS with shorter perfluoroalkyl carbon chain lengths (< 7 for carboxylates and < 6 for sulfonates) had negligible BCFs. At 8–12 carbon chain length, uptake of PFAS compounds was proportional to the carbon chain length and inversely proportional to the critical micelle concentration (CMC; the concentration at which one half of the molecules are associated as micelles). Others have also shown that shorter chain PFCAs and PFSAs (less than eight and six carbons, respectively) are not readily bioconcentrated or accumulated (**Conder et al. 2008**; **Martin et al. 2013**; **Houde et al. 2011**).

Martin et al. (2003) also showed that PFSAs had greater BCFs and half-lives than the corresponding PFCAs of equal chain length, indicating that hydrophobicity, as predicted by the CMC, is not the only determinant of PFAS bioaccumulation potential and that the functional group must be considered.

With respect to tissue types, **Martin et al. (2003)** showed that PFAS accumulated to the greatest extent in the blood, followed by the kidney, liver, and gall bladder. Lower levels accumulated in the gonads, followed by adipose tissue and muscle tissue. This tissue-dependent distribution has been shown in many other studies and is apparently due to PFAS having a high affinity for serum albumin and fatty acid–binding proteins (**Ng and Hungerbuhler 2014**, as well as to binding to phospholipids (**Dassuncao et al. 2019**).

5.5.2 Bioaccumulation

Table 5-1 presents available BAF data for several PFAS. As shown, BAFs may be reported using concentrations measured in whole bodies or specific tissues. BAFs reported for fish muscle or fillet are useful for human health risk assessments (for fish consumption) and for developing corresponding water quality criteria (see **Section 16**). Whole-body BAFs can be used in ecological risk assessments for higher trophic organisms (for example, predatory fish, piscivorous birds and mammals) and developing corresponding water quality criteria. However, **Conder et al. (2020)** proposed using lab-derived BCFs instead of field-based BAFs in ecological risk assessments, primarily because lab-based BCFs are less variable and generally more reliable than field-based BAFs. Furthermore, PFAS associated with freshly spiked laboratory media may be more bioavailable than in the field, potentially leading to conservative BCFs (higher than what would occur under field conditions). Field-based BAFs may be affected by the presence of precursors (**Langberg et al. 2020**), making risk assessments and water quality criteria based on these BAF estimates unreliable. However, site specificity of field-based BAFs may be important to

consider in specific situations, such as in the refinement of site-specific risk assessments and development of site-specific water quality criteria.

When comparing BAFs among organisms, or when developing statistical summaries of BAF values, differences among tissues in the extent of accumulation must be considered. The approach that is simplest, and which probably provides the most robust approach to comparisons of BAFs among organisms, is to report BAF values on a whole-body basis, since tissue-specific BAFs may vary among species due to differences in toxicokinetics. Such data may be collected using either whole-body samples or tissue-specific measurements that can be mathematically combined to yield equivalent whole-body concentrations. In aquatic organisms, PFAS concentrations in muscle are generally within a factor of two of whole-body concentrations (**Goeritz et al. 2013**; **Shi et al. 2015**).

Bioaccumulation of some PFAS has been observed in a variety of wildlife, generally fish-eating species, across the globe as demonstrated by the large number of studies reporting wildlife PFAS residues. Bioaccumulation data are now available for a wide range of environments, including water bodies directly adjacent to or downstream of manufacturers of PFAS, industries that use PFAS in manufacturing processes, firefighting, and wastewater treatment plants, as well as urban areas and areas distant from specific sources (**De Silva et al. 2021**). The majority of sampling has been conducted to support risk assessments and fish consumption advisories, as well as hypotheses concerning long-range fate and transport, temporal trends, and the identification of sources. Most of the work has been performed in the Northern Hemisphere, and some authors have found that levels are lower in the Southern Hemisphere (**Armitage et al. 2009**; **Ahrens et al. 2009**; **Ahrens 2011**; **Benskin et al. 2012**). One study in Australia, however, found among the highest PFOS concentrations reported worldwide in the livers of dolphins in heavily industrialized regions of South Australia (**Gaylard 2017**).

Some insights regarding PFAS bioaccumulation of PFCAs, PFSAs, and precursors are as follows:

- Similar to bioconcentration, bioaccumulation of PFAAs depends on carbon chain length (**Brendel et al. 2018**]). **USEPA (2017)** considers PFCAs with less than seven perfluorinated carbons (PFCAs shorter than PFOA) and PFSAs with less than six (such as PFBS) to less bioaccumulative. PFSAs are more bioaccumulative than PFCAs of the same carbon chain length.

- Bioaccumulation and biomagnification factors measured in the field vary widely (**Franklin 2016**; **Gobas, Kelly, and Kim 2020**; **Burkhard 2021**). Some PFAAs exhibit BAFs that overlap the range often used as criteria for bioaccumulation, for example by USEPA, Canada, and the European Union (1,000–5,000 L/kg).

Available BAFs in **Table 5-1** validate some of the above insights. For example, in comparing BAFs for PFOA with PFOS across all species, it is clear that the BAFs for PFOA are much lower than PFOS. Moreover, comprehensive reviews (**Ahrens and Bundshuh 2014**; **Houde et al. 2008**) indicate that PFOS (8-carbon chain PFSA) is typically the most common PFAS observed in fish, as well as air-breathing animals, although in invertebrates, PFOA and PFOS can exhibit similar concentrations (~1–10 ug/kg). **Ahrens and Bundshuh (2014)** attributed the lower bioaccumulation of PFOA than PFOS to shorter chain (7 perfluorinated carbons in PFOA vs. 8 perfluorinated carbons in PFOS). Overall, the data in **Table 5-1** indicate that for perfluorocarboxylates, BAFs increase until 11 or 12 perfluorinated carbons and decline for larger compounds.

Finally, it is important to note that PFAS precursors may contribute to the PFAS body burden. **Asher et al. (2012)** and **Langberg et al. (2020)** provided field data indicating an important contribution from precursors to PFOS concentrations in organisms via internal transformation. In addition, atmospheric measurements have shown the widespread occurrence of PFAS precursors like FTOHs and perfluorinated sulfonamide alcohols. Once absorbed by an organism, the precursor(s) may be metabolized to PFOA (for example, from 8:2 fluorotelomer alcohol) or to PFOS (for example, from N-ethyl

perfluorooctane sulfonamidoethanol) (**Gebbink, Berger, and Cousins 2015**; **Galatius et al. 2013**). Additional research on how PFAS precursors may contribute their bioaccumulation in fish and wildlife is needed.

5.5.3 Biomagnification

Biomagnification factors may be used in the regulatory determination of whether contaminants biomagnify up the food chain and in food web modeling in risk assessments. Key conclusions from published literature are summarized in this section.

Studies of PFAS in the Great Lakes and marine/arctic ecosystems have generally shown that there can be trophic-level biomagnification within a food web, particularly for PFOS and some long-chain PFCAs (**Martin et al. 2004**; **Houde et al. 2006**; **Houde et al. 2011**; **Butt et al. 2010**; **Tomy et al. 2004**, **2009**).

Martin et al. (2010) estimated BMFs for a pelagic food web in Lake Ontario, with the lake trout as the top predator. They were able to show, after adjusting for benthic versus pelagic organisms, that some PFAS compounds biomagnify, with TMFs ranging from 0.51 for FOSA to 5.88 for PFOS.

A study by **Houde et al. (2006)** looked at PFOS and C8–C14 perfluorinated carboxylates in the bottlenose dolphin at two marine sites (Sarasota Bay, FL, and Charleston, SC). Based on estimated TMFs, those authors concluded that PFOS and C8–C11 PFCAs biomagnified in this marine food web (**Table 5-1**, also cited by (**Franklin 2016**)). Interestingly, for PFCAs, PFOA had the highest TMF, with values progressively decreasing as chain length increased. **Conder et al. (2008)** reported similar results for perfluorinated acids, with BMF values ranging from 0.1 to 20 (geometric mean of 2). They concluded and **Lescord et al. (2015)** affirmed that PFCAs with less than seven carbons, and PFSAs with less than six carbons, do not biomagnify and that the bioaccumulation of PFCAs can be directly related to fluorinated carbon chain length (just as the bioaccumulation of persistent lipophilic compounds can be related to hydrophobicity). **Conder et al. (2008)** also noted that the biomagnification of PFCAs in aquatic food webs is lower than that of most persistent lipophilic compounds, with PFOS being the only perfluorinated acid consistently exhibiting the potential for biomagnification. Finally, **Butt et al. (2008)** observed biomagnification factors for PFAS in "ringed seal–polar bear" food webs of the Canadian Arctic. Biomagnification factors were greater than one for C8–C14 PFCAs, as well as for PFOS and PFOSA. Like **Houde et al. (2006)**, they observed a decrease in BMF as the carbon chain number increased.

Contrary to other freshwater studies, **Lescord et al. (2015)** did not find evidence for biomagnification in total PFAS, total PFCA, total PFSA, and PFOS. These authors observed negative relationships between trophic level, as measured using stable nitrogen isotope ratios (δ15N), and concentrations of the studied PFAS compounds (PFOS, total PFCA, total PFSA, and total PFAS) in several of the six lakes, suggesting no biomagnification in these freshwater arctic food webs. Overall, their results suggested that a taxon's horizontal but not vertical position in the food web affects its PFAS concentrations.

Because the BMF or TMF is the concentration in a predator divided by the concentration in its prey, calculated BMFs can be highly variable depending on what types of tissues were analyzed and what assumptions the researcher made in defining biomagnification relative to the animals' prey diet (often determined through analysis of stomach contents). **Franklin (2016**) analyzed the results of 24 peer-reviewed studies reporting field-derived BMFs or TMFs for 14 PFAS. BMF values ranged over several orders of magnitude, from 0.01 to 373 (including only nonzero values). TMFs varied from 0.1 to 20 (including only nonzero values). **Franklin (2016)** attributed this variability to several factors, including differing ways in which the metrics are expressed (for example, individual tissue analyses versus whole body), nonachievement of the assumed steady-state conditions, uncertainties in feeding ecology, and the metabolism of precursor compounds.

5.5.4 Characterization of Bioaccumulation in Criteria Development and Risk Assessments

In regulatory contexts, BMFs may be used to determine whether or not contaminants are considered bioaccumulative: a BMF greater than 1 indicates that a contaminant is bioaccumulative. The relationship between the BAF and BCF also provides relevant evidence.

Because consensus has not been reached regarding the extent of bioaccumulation and/or biomagnification of some PFAS, most importantly PFOS, the best approach to determining bioaccumulative status of PFAS and to conducting risk assessments is an active subject of discussion (**Franklin 2016**; **Conder et al. 2020**). **Franklin (2016)** made the case that "in practice, the study-to-study (and even within-study) variability of the results is so great that [field-measured BMFs and TMFs] are of very restricted usefulness for assessing bioaccumulation potential status." **Franklin (2016)** proposed basing the bioaccumulative status of a compound only on laboratory BCFs and on measurements of BMFs conducted under strictly monitored conditions, rather than relying on field-measured BMFs or TMFs. For fish, studies can make use of the OECD 305 protocol (**OECD 2012**). For terrestrial and avian species, dietary BMF determinations can be performed using laboratory rodents or cows or pigs fed with naturally contaminated feed, as well as avian species.

Similarly, **Conder et al. (2020)** proposed using laboratory-derived BCFs instead of field-based BAFs in ecological risk assessments, because lab-based BCFs may be less variable and generally more reliable than field-based BAFs. Moreover, lab-based BCFs are expected to provide conservative estimates of bioaccumulation, as PFAS may be more available in freshly spiked environmental media compared to aged PFAS in field samples. Furthermore, **Conder et al. (2020)** argued that laboratory BCFs avoid complications with the presence of PFAS precursors, which may transform into stable PFAS in field samples.

However, laboratory BCFs (studies in which organisms are exposed to contaminant in the water only) are subject to methodological limitations—for example, for substances that are highly sorptive. Furthermore, laboratory BCFs do not account for biomagnification, and for this reason will tend to provide low estimates of true BAFs. An approach similar to that proposed by **Franklin (2016)**, namely, combining laboratory-measured BCFs with BMFs measured under controlled conditions, may be reasonable.

Furthermore, while avoiding the complications of precursors, laboratory BCFs also do not account for the contributions of precursors to tissue concentrations of PFOS. PFOS BAFs measured by **Langberg et al. (2020)** were the highest in **Table 5-1**, ranging up to about 250,000 L/kg wet weight muscle for PFOS in yellow perch. This value far exceeds values that have been measured in other sites, generally in the range of 1,000–10,000 (**Table 5-1**). This high value was attributed to the primary role of precursors in determining organisms' tissue concentrations of PFOS at this site. In an ecological risk assessment for such a site, a tissue concentration determined using measured water column PFOS concentrations and a laboratory-derived BCF (on average, on the order of approximately 1,000 L/kg wet weight whole body for PFOS) would significantly underestimate the true tissue concentration. Thus, if tissue concentrations are primarily determined by precursor levels in the system, then measurement of the substance in water is not appropriate in the first place. Rather, the organism exposure to the precursor(s) itself needs to be measured.

Gobas, Kelly, and Kim (2020) proposed that the bioaccumulative nature of compounds can best be evaluated by focusing on the BMF as measured using dietary-based OECD 305 studies (**OECD 2012**) , interpreted using a two-compartment bioaccumulation model to estimate the BCF and the BAF. The domain of applicability of the model developed by **Gobas, Kelly, and Kim (2020)** was limited to nonionic organic chemicals, and so would have to be modified for application to PFAS.

Bioaccumulation rates may differ between linear and branched isomers of PFAS (**Conder et al. 2020**), and it is hypothesized that linear PFAS are more bioaccumulative than branched PFAS (**Houde et al. 2008**, **2011**). The use of more bioaccumulative isomers in laboratory BCF studies would result in a conservative, but potentially unrealistic, risk assessment for a field population exposed to a mixture of isomers. A full evaluation of the impact of isomer composition will require evaluation of the extent to which differences in bioaccumulation are significant, as well as the relative abundances of isomers in the environment.

Thus, in determining bioaccumulative status and in conducting risk assessments, the variability of field-measured BAFs and BMFs must be balanced against the biases and limitations associated with laboratory BCFs and BMFs. Such evaluations must be performed on a compound-specific basis, taking into account the confounding role of precursors. It is likely that a weight of evidence approach will be called for, given the uncertainties associated with PFAS bioaccumulation.

5.6 PFAS Uptake into Plants

Because PFAS contain a hydrophilic functional group, plants can be expected to take some of these compounds up through their root systems, after which they would be translocated to stems, shoots, leaves, and fruiting bodies. Plants growing closer to contaminated sources or irrigated with PFAS-containing water would be expected to accumulate higher concentrations of PFAS compared to plants more distant from the PFAS source (**Gobelius, Lewis, and Ahrens 2017**), subject to site-specific conditions such as soil properties. It has already been documented that the land application of biosolids may contaminate soil with PFAS and that animals fed silage from land-applied fields can have elevated concentrations of PFAS in their tissues (**Lindstrom et al. 2011**; **Skutlarek, Exner, and Farber 2006**). The Priority Topics for Biosolids Land Application include information about plant uptake (see **Section 1.7.4**) and uptake by animals (see **Section 1.7.5**).

This also raises concerns about contamination of wildlife consuming plants from agricultural areas. Airborne PFAS emissions from industrial sites in China were found to impact the concentration of PFAS in bark and tree leaves, with the theory that bioconcentration in the latter may occur through the stomata (**Shan et al. 2014**).

Understanding uptake of PFAS into plants is critical in evaluating the fate of PFAS among various environmental compartments, particularly along the food chains with implications for human and ecological exposures to PFAS. Human exposure may occur via consumption of PFAS-impacted produce and dairy and meat products from animals fed with PFAS-impacted plant-based feed. Potential wildlife exposure to PFAS may occur via PFAS taken up in plants at impacted sites and releases.

The following sections provide an overview of PFAS uptake pathways and mechanisms in plants and bioconcentration/bioaccumulation.

5.6.1 Uptake Pathways

Wang et al. (2020) provides an extensive review of uptake and accumulation of PFAS in plants. That study forms the basis of the overview provided in this section. As described in **Wang et al. (2020)**, uptake of PFAS has been well documented in different native and planted species to varying degrees. The majority of these studies have focused on PFOA and/or PFOS uptake by agricultural crops, although there are many other PFAS that have been shown to be subject to plant uptake. **Wang et al. (2020)** also reported that while most published studies were conducted under controlled lab conditions, at least 16 field studies were identified. These field studies typically have focused on point sources of PFAS, including manufacturing sites, fire training areas, wastewater treatment plants, or landfills.

PFAS may be introduced to plants from soil, water, or air by:

- irrigation with impacted water
- land application of biosolids
- leachates from landfills
- impacts or releases at PFAS sites
- emissions and atmospheric deposition

Plant uptake is both PFAS- and soil-specific. PFAS with higher aqueous solubilities/diffusivities with less soil/air-water interface (AWI) retention affinity are often observed with greater uptake potential (bioavailability). For example, **Wang et al. (2020)** compiled bioconcentration factors (BCFs) for different PFAS that had been reported in literature studies; the bioconcentration factor is the ratio of the PFAS concentration in the plant tissue to the concentration in the soil. This compilation showed the median BCF values for PFBA and other short-chain PFAS were generally more than an order of magnitude greater than the values for long-chain PFAS like PFOA and PFOS. These patterns confirm that the physical-chemical properties of PFAS influence the extent of plant uptake. Likewise, physical-chemical soil properties (for example, organic matter content and composition, pH, salinity, temperature) affect plant uptake of PFAS, although this has not been comprehensively studied. Also, plant species and physiology (for example, transpiration rate and protein content) are important factors as discussed below.

PFAS accumulation in plants occurs primarily via root uptake from soil and water (**Stahl et al. 2009**; **Lee et al. 2014**; **Wen et al. 2013**; **Zhang et al. 2019**). Aerial uptake of PFAS from the ambient environment (vapor-phase and particle-bound) have also been reported, such as into leaves and bark (**Stahl et al. 2014**; **Jin et al. 2018**; **Tian et al. 2018**; **Liu et al. 2019**). However, aerial uptake contributes minimally to overall PFAS accumulation in plants (**Wang et al. 2020**).

As noted above, availability of PFAS in soil porewater for root uptake is largely dependent on the aqueous solubility of specific PFAS (see **Section 4**) and controlled by interactions with the soil phases and the AWI (see **Section 5.2.3**). PFAS in soil porewater migrates toward plant roots by transpiration and diffusion resulting from a local concentration gradient (**Lechner and Knapp 2011**). Recent studies by **Zhang et al. (2019)** and **Wen et al. (2013)** indicate a concentration-dependent process in root uptake that is mediated by transport proteins in cell membranes such as aquaporins and anion channels. PFAS enter the vascular tissue after passing through the root epidermis, cortex, and endodermis via apoplastic and symplastic pathways (**Blaine et al. 2013**).

Once in the root xylem, PFAS are translocated to different parts of a plant, such as stem, shoots, leaves, fruits, and grains. The degree of PFAS translocation in these tissues appears to depend on the transpiration stream, with more PFAS accumulation occurring in parts with greater capacity for sorption or incorporation and receiving greater amounts of water (**Krippner et al. 2015**; **Lechner and Knapp 2011**; **Gobelius, Lewis, and Ahrens 2017**; **Stahl et al. 2009**). For example, in carrots, cucumbers, and potatoes grown in soil mixed with PFAS-contaminated sewage sludge, **Lechner and Knapp (2011)** found less PFOA and PFOS accumulation in peeled edible parts than in foliage, leaves and stalks., **Stahl et al. (2009)** found much higher PFOA and PFOS in grains than in straw of spring wheat, oat, and maize. In trees, **Gobelius, Lewis, and Ahrens (2017)** evaluated the distribution of PFAS at an AFFF release site and reported that total PFAS accumulation followed leaves > twigs > trunk/core or roots in birch and spruce.

5.6.2 Bioconcentration/Bioaccumulation

Table 5-2 (provided as a separate Excel file) contains BCF and BAF values for 14 different PFAS for a variety of plant species. In the cited plant uptake studies, BCF and BAF are defined as PFAS concentration in plant (mass/mass) divided by PFAS concentration in soil (mass/mass) and are used interchangeably. This differs from the definition of BCF and BAF for animals in **Section 5.5**. A number of BAF values were obtained from studies in which PFAS was introduced to crops through irrigation water or

biosolids-amended soils (**Blaine et al. 2013**, **2014**, **2014**). The materials harvested for analysis included both inedible (for example, plant leaves) and edible portions of crops (fruit, lettuce leaves, and roots). Other BCFs and BAFs were obtained from investigations of plants exposed to PFAS from soil, groundwater, surface water, or air in close proximity to PFAS release sites (**Mudumbi et al. 2014**; **Zhang et al. 2015**; **Gobelius, Lewis, and Ahrens 2017**). In general, it can be observed that 1) the shorter chain (more water soluble) PFAS are taken up more readily than the longer chain homologues, and 2) the majority of the plant BCFs and BAFs fall between a range of 0.1 and 10. A BCF or BAF of 1.0 indicates no net accumulation of PFAS from soil to plant. Such a BCF or BAF indicates that the soils and the plant of interest have the same concentration of PFAS per unit weight. This, however, does not indicate that an equilibrium condition exists between soils and plants. Some plants, like lettuce, contain a large percentage of water, which may help to explain the relatively high BAF of 56.8 observed by **Blaine et al. (2013)**. In the controlled studies of edible crops, short-chain PFCAs and PFSAs exhibited greater BAFs compared to long-chain compounds.

Blaine et al. (2013) studied the uptake of PFAAs by greenhouse lettuce and tomato grown in soils prepared to mimic an industrially impacted biosolids-amended soil, a municipal biosolids-amended soil, and a control soil (but incorporated contaminated biosolids equivalent to 10 times higher than the agronomic rates allowed for Class B biosolids), a municipal biosolids-amended soil, and a control soil. BCFs for many PFAAs were well above unity, with PFBA having the highest BCF in lettuce (56.8) and PFPeA the highest in tomato (17.1) in the industrially impacted biosolids-amended soil. BAFs for PFCAs and PFSAs were, in general, slightly higher in the industrially impacted soil than in the municipal soil (~0.3–0.8 log units). The BCFs for PFAAs in greenhouse lettuce decreased approximately 0.3 log units per -CF_2 group (one carbon, two fluorine groups in a molecule). They also conducted a limited field study, in which they measured PFAA levels in lettuce and tomato grown in field soil amended with only a single application of biosolids (at the agronomic rate for nitrogen). The PFAA levels were predominantly below the limit of quantitation (LOQ). In addition, corn stover, corn grains, and soil were collected from several full-scale biosolids-amended farm fields. At these fields, all PFAAs were below the LOQ in the corn grains and only trace amounts of PFBA and PFPeA were detected in the corn stover. The **Blaine et al. (2013)** study confirms that the bioconcentration of PFAAs from biosolids-amended soils depends strongly on PFAA concentrations, soil properties, type of crop, and analyte. BCFs developed in **Blaine et al. (2013)** can be seen in **Table 5-2**.

Ghisi, Vamerali, and Manzetti (2019) provided a review of PFAS uptake in agricultural plants, including the potential for uptake from groundwater, soil, and air. Factors contributing to plant uptake include PFAS chain length, functional group, plant species, growth media, soil organic matter, and other soil properties. In general, higher PFAS concentrations in soil are correlated with higher PFAS concentrations in plants; however, the increase in concentrations may not be directly proportional. Short-chain compounds tend to accumulate at higher concentrations in leafy vegetables and fruits, whereas long-chain compounds tend to accumulate more in roots. Several studies have found that PFCAs accumulate at higher rates than PFSAs. Soil organic matter has been found to sequester PFAS and limit plant uptake in some studies reviewed. Another review of bioaccumulation factors for agricultural plants is **Lesmeister et al. (2021)**.

Gobelius, Lewis, and Ahrens (2017) studied the uptake of 26 PFAS in plants (trees) at an AFFF (fire training) site with contaminated soil and groundwater. Samples from groundwater and different plant species (birch, spruce, cherry, ash, elder, beechfern, and wild strawberry) and tissues (that is, roots, trunk/cores, twigs, leaves/needles) were collected. Foliage had the highest BCFs of all tissues, ranging from 0 to 14,000 and accumulated the highest number ofPFAS (8 out of 26), with birch sap showing BCF values up to 41 for 6:2 FTSA. The highest mean BCFs were found for 6:2 FTSA (472; n = 52), PFOS (28; n = 36), PFHxS (10; n = 42), and PFOA (5; n = 24), which might correspond to the AFFF composition used at the site. For PFOA, the mean BCFs (±s.d.) were 18 ± 15 for spruce, followed by birch (1.2 ± 1.5) and cherry (0.25 ± 0.043). The authors concluded that PFAS were detected in all plant species, and the distribution followed the order of "shoots to roots"—that is, leaves > twigs/stems > trunk > roots. They cited other

authors who have shown that “this order has proven applicable to all samples and species.” Hence, PFAS tend to accumulate in the vegetative portions rather than in the plant storage tissues.

6 MEDIA-SPECIFIC OCCURRENCE

The long period of time during which PFAS have been produced and the many sources of PFAS release to the environment have resulted in low-level contamination of most environmental media worldwide. The concentrations of these human-caused ambient or "anthropogenic background" concentrations may vary widely, based on proximity to industrial areas, patterns of air and water dispersion, and many other factors. As a result, any claims regarding "universal" values for anthropogenic background levels of PFAS should be viewed skeptically.

This section provides a relative understanding of PFAS concentrations in various environmental media but does not represent an exhaustive literature review. These figures and summaries are intended to provide context to the reader and a starting point for further study. Media-specific occurrences of PFAS are constantly being added in the literature and on state, federal, and other countries' PFAS websites. USEPA has developed an online database called the PFAS Analytic Tools that provides access to different sources of information about potential PFAS sources, drinking water sampling data, occurrence in environmental media, and other types of information (**USEPA 2023**).

Section Number	Topic
1.4.4	**Health Effects of Ultra-short-chain PFAS (2025)**
1.7	**Priority Topics for Biosolids Land Application (2025)**
6.1	**Air**
6.2	**Soil, Sediment, and Biosolids**
6.3	**Groundwater**
6.4	**Surface Water**
6.5	**Biota**

The following sections include figures summarizing the observed concentrations of PFAS that have been reported in the recent literature (approximately 2017–2022) and new information to date on the occurrence of PFAS in media that were not included in the previous version of this guidance document for outdoor air, indoor air, precipitation, dust, soil, sediment and biosolids. The figures for ground water and surface water were updated with the new format, but the data are from the previous summary. The previous version of this section (June 2022) is archived as a PDF under **Archived External Tables and Sections** on the home page of this site. **Figure 6-5**, Observed PFAS concentrations in fish, has not been updated.

Tables (linked as PDFs) that include important details concerning the studies used in developing the figures below and interactive versions of the figures (linked as a web page) are in **Section 17.1**. The figures were developed using **R software** and the static figures were developed using ggplot2 (**Wickham 2016**). Media-specific occurrence information that was included in the previous version of this guidance document (June 2022) is archived as a Section 17.1 PDF, found under **Archived External Tables and Sections** on the home page of this site.

As discussed in **Section 2.6**, the presence of some PFAS in environmental media and ecological receptors has been traced to the migration of PFAS in air emissions and through the direct discharges to soil, groundwater, and surface water. Sections on Phase Partitioning (**Section 5.2**) and Media-Specific Migration Processes (**Section 5.3**) illustrate that PFAS occurrence in the air, aqueous, and solid phases is highly interrelated. Sections on Human Health Effects (**Section 7.1**) and Ecological Toxicology (**Section 7.2**) suggest that PFAS risks to human health may result from exposure via drinking water, groundwater, soils, food, and other media types. Further, ecological impacts are widely observed. This suggests that a complete assessment of PFAS sources and exposure risks, including fate and transport processes that

may drive future exposure concerns, requires understanding of PFAS occurrence across multiple phases. The processes that influence media-specific PFAS concentrations are illustrated in CSMs shown in **Figure 2-20**, **Figure 2-21**, and **Figure 2-22**. This section focuses on occurrence in air; soil, sediment, and biosolids; groundwater; surface water; and biota. **Section 1.4.4** focuses on available information for health effects of ultra-short-chain (ultrashort) PFAS. Summaries of available environmental occurrence data for ultrashort PFAS are included with the health effects information, but the summaries are not intended to be comprehensive.

Environmental PFAS occurrence is an area of active research. As discussed in **Section 11**, sampling and analytical methods are still being optimized and standardized, and vary between studies. Data-reporting formats also vary, often including the observed minimum, maximum, or percentiles to represent the range, and arithmetic mean, geometric mean, or median values to represent central tendency. In some cases, only the average or maximum values are reported. Studies also vary in terms of research objectives and site characteristics, focusing on relatively pristine (for example, rural) or impacted (for example, industrial) sites. Some studies focus on certain PFAS, Finally, variable method detection limits between studies introduces the potential for non-detect data to impose artificial patterns. Due to these data limitations, the ranges and averages of detected PFAS concentrations presented in the following figures should be considered as a general frame of reference, rather than precise, dispositive thresholds.

6.1 Air

Certain PFAS are found in ambient air, with elevated concentrations observed or expected in urban areas nearest to major emission sources described in **Section 2.6**. These include industrial facilities that produce PFAS or use PFAS chemicals or products in manufacturing; areas where Class B firefighting foams containing fluorine are used or released; waste management facilities, including landfills and wastewater treatment plants; and areas of biosolids production and application (**Borthakur et al. 2022**; **Barton et al. 2006**; **Ahrens et al. 2011**; **Liu et al. 2015**).

As discussed in **Section 5.3.2**, short-range atmospheric transport and deposition may result in PFAS contamination in terrestrial and aquatic systems near points of significant emissions, contaminating soil, groundwater, and other media of concern (**Davis et al. 2007**), as well as several miles from industrial emission sources (**Shin et al. 2011**; **Post, Cohn, and Cooper 2012**) (**NYS DOH 2016**; **NH DES 2017**; **VT DEC 2016**). Releases of ionic PFAS from factories are likely tied to particulate matter (Barton et al. 2006[241]), which settle to the ground in dry weather and are also wet-scavenged by precipitation as discussed in **Section 5.3.2**. Models indicate that deposition depends on amount of PFAS emissions, local topography, particle size, weather patterns, and release characteristics such as smokestack height, effluent flow rate, and effluent temperature. In addition to short-range transport and deposition, long-range transport processes are responsible for a wide distribution of PFAS across the earth, as evidenced by their occurrence in biota and environmental media in remote regions as far as the Arctic and Antarctic. Long-range transport processes and effects are similar to atmospheric transport of other recalcitrant contaminants.

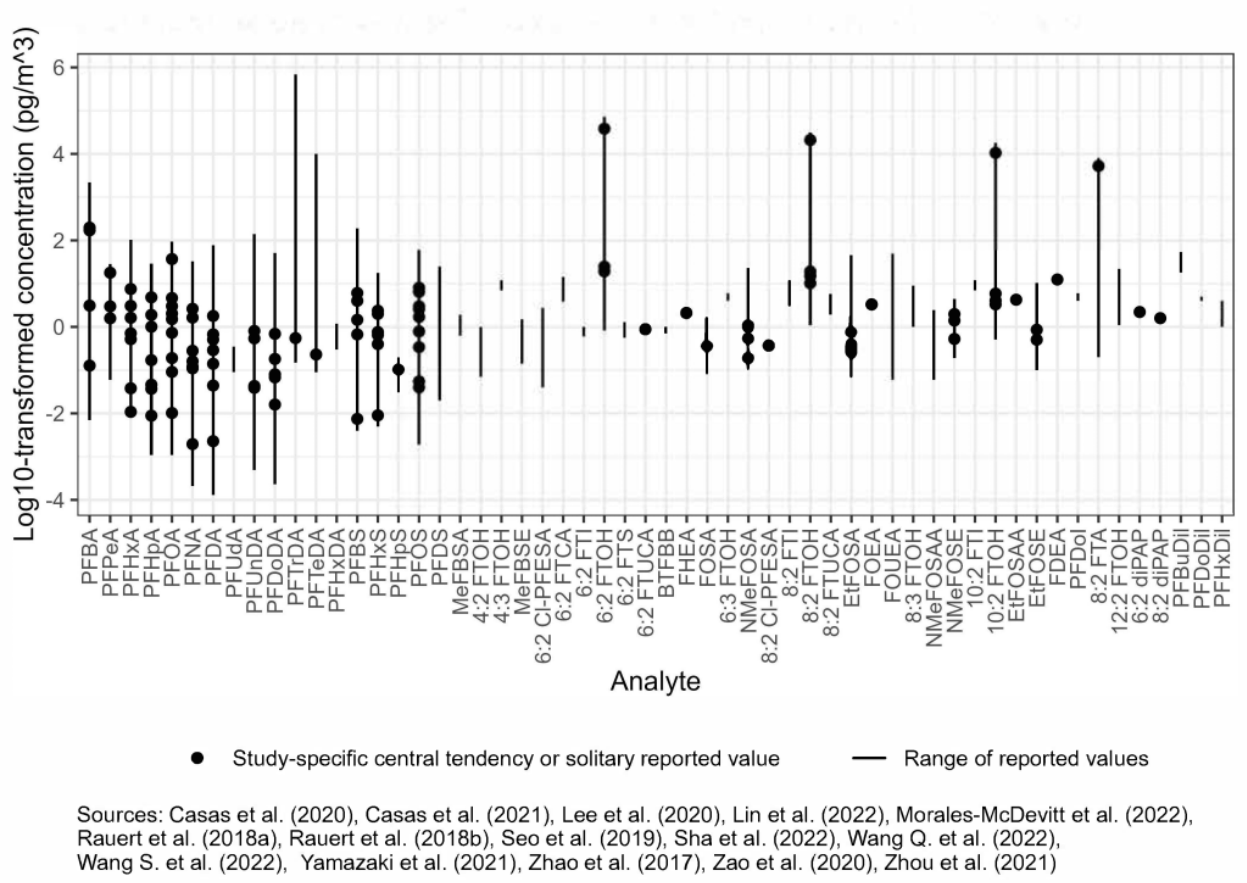
The **PFAS and Vapor Intrusion Fact Sheet** developed in 2025 includes information about PFAS in Soil Vapor, Indoor Air, and Outdoor Air. The Priority Topics for History, Use, and Naming Conventions include information about less-studied PFAS (see **Section 1.1.3**), including ultrashort PFAS, volatile PFAS, and fluorinated gases.

6.1.1 Outdoor Air

Concentrations of perfluoroalkyl acids such as PFOA and PFOS reported in outdoor air in the recent scientific literature (2017–2022) typically fall within a range of about 1–30 pg/m^3 (picograms/cubic meter) (**Figure 6-1A**). However, near major industrial sources, including fluorochemical manufacturing

complexes in China (**Zhao et al. 2020**) and South Korea (**Lee et al. 2020**; **Lin et al. 2020**; **Seo et al. 2019**), maximum PFOA concentrations in the range of about 50–200 pg/m^3 have been reported. In the United States, concentrations of PFOA as high as 900,000 pg/m^3 have been observed near a large manufacturing facility in Parkersburg, West Virginia (**Barton et al. 2006**). PFOS concentrations greater than 2,000 pg/m^3 have also been observed in outdoor air near major fluorochemical manufacturing complexes in South Korea (**Seo et al. 2019**). Concentrations of PFBA have been observed in the hundreds of pg/m^3 at a number of global monitoring sites and at concentrations greater than 1,000–2,000 pg/m^3 at sites in Canada (**Rauert et al. 2018**).

The literature range of concentrations of volatile PFAS such as FTOHs is in the hundreds of pg/m^3 in outdoor air (**Figure 6-1A**). Atmospheric transport and deposition of PFAS occur on regional and global scales, suggesting that low-level concentrations detected in soil or other media are not necessarily indicative of a local source (**Section 5.3.2**). More information is included in **Section 17-1**, Media-Specific Occurrence Tables.



Sources: Casas et al. (2020), Casas et al. (2021), Lee et al. (2020), Lin et al. (2022), Morales-McDevitt et al. (2022), Rauert et al. (2018a), Rauert et al. (2018b), Seo et al. (2019), Sha et al. (2022), Wang Q. et al. (2022), Wang S. et al. (2022), Yamazaki et al. (2021), Zhao et al. (2017), Zao et al. (2020), Zhou et al. (2021)

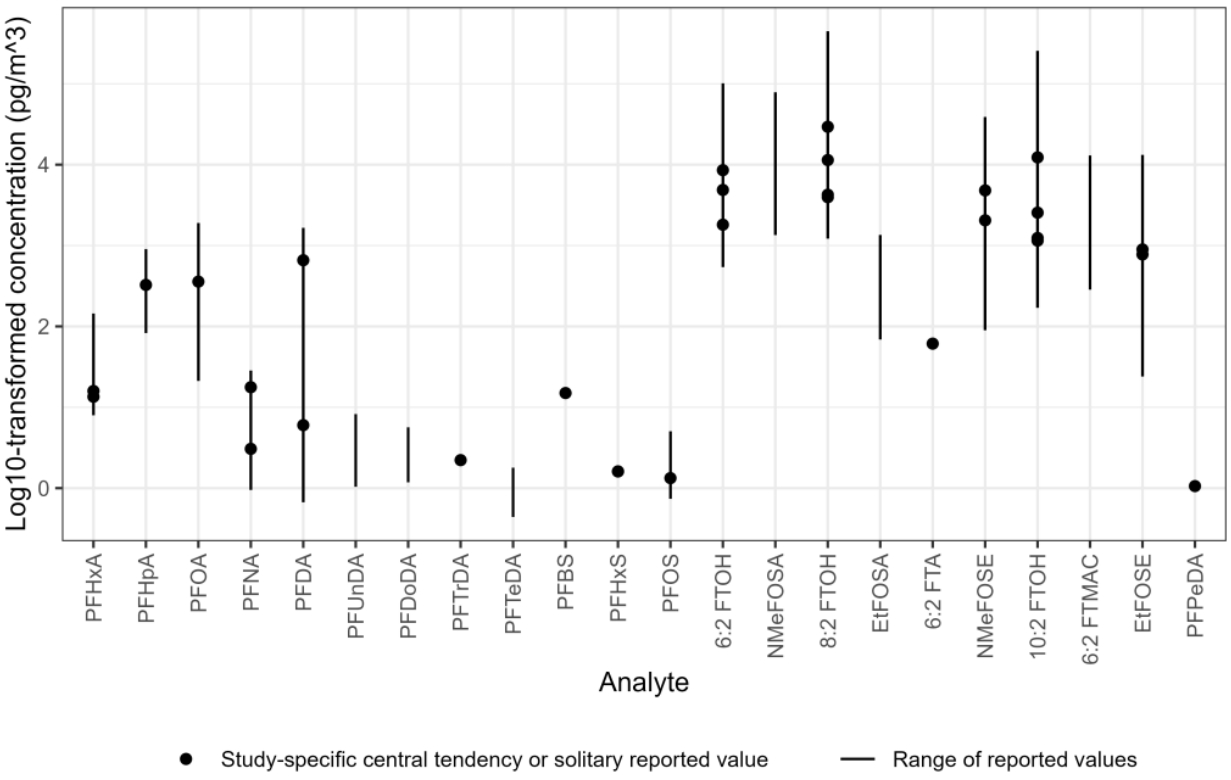
Figure 6-1A. Observed PFAS concentrations in outdoor air.

*Source: Figure developed using ggplot2 (**Wickham 2016**).*

6.1.2 Indoor Air

PFAS have also been observed in indoor air and dust in homes, offices, and other indoor environments (**Figure 6-1B**). Indoor air concentrations of certain PFAS can be higher than outdoor air concentrations due to the presence of indoor sources (**Fromme et al. 2015**; **Fraser et al. 2012**; **Goosey and Harrad 2012**; **Shoeib et al. 2011**; **Kaiser et al. 2010**; **Langer, Dreyer, and Ebinghaus 2010**; **Strynar and Lindstrom 2008**; **Shoeib et al. 2004**). Examples of indoor sources of potential PFAS exposure include stain- and water-

resistant coatings used on a number of consumer products, such as carpets, upholstery, clothing, grease-resistant paper, food packaging, and nonstick cookware and ingredients in cleaning products, personal care products, cosmetics, paints, varnishes, and sealants (**ATSDR 2019**; **Liu et al. 2015**; **Liu et al. 2014**) (**Gewurtz et al. 2009**; **Guo et al. 2009**). In the recent literature (2017–2022), PFOA concentrations in PM2.5 collected from indoor air across 17 kindergartens in Hong Kong ranged from about 200–1,900 pg/m^3 (**Li et al. 2021**). In a study of 57 households in eastern Finland, concentrations of PFOA and PFOS ranged from nondetect to about 100 pg/m^3 and 7 pg/m^3, respectively (**Winkens et al. 2017**).



Sources: Beesoon et al. (2012), Li et al. (2021), Padilla-Sanchez et al. (2017), Wilkens et al. (2017)

Figure 6-1B. Observed PFAS concentrations in indoor air.

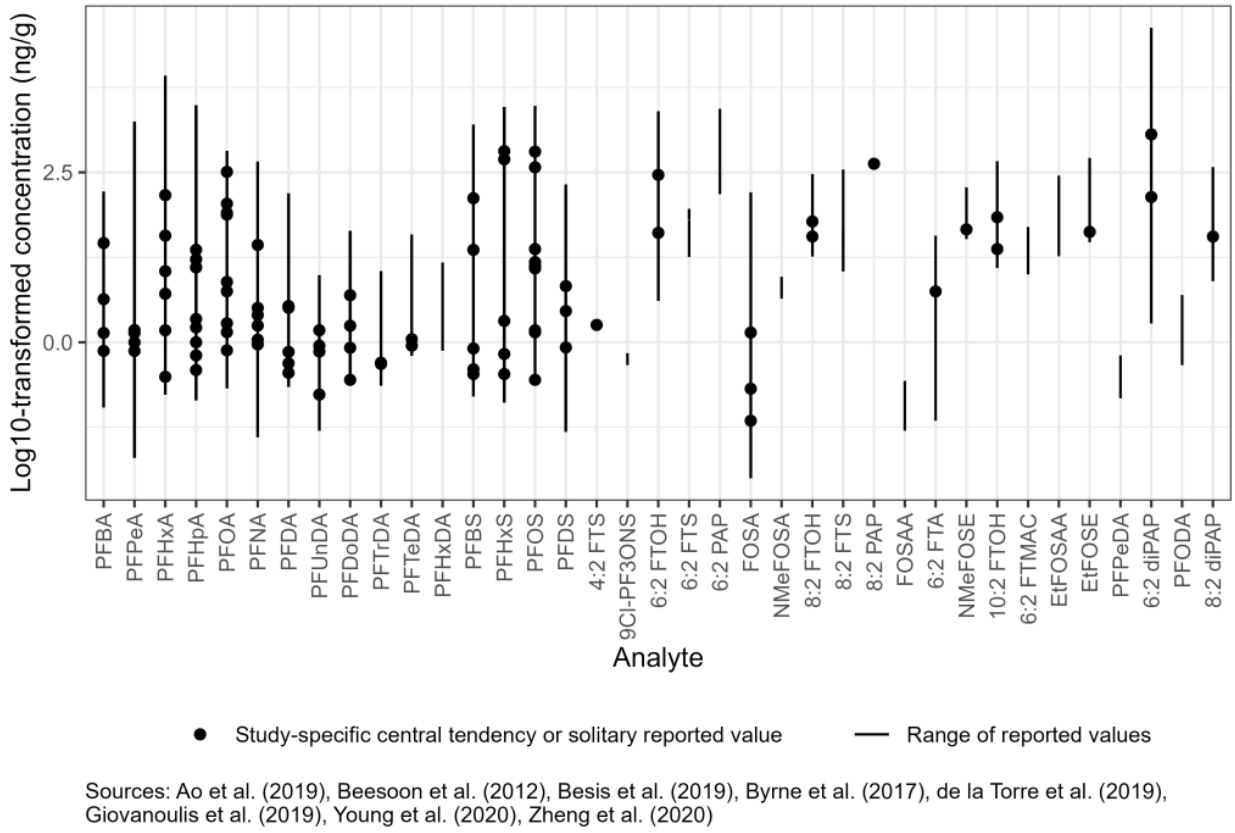
*Source: Figure developed using ggplot2 (**Wickham 2016**).*

Concentrations of volatile PFAS such as FTOHs have been reported on the order of 10,000–50,000 pg/m^3 in schools, homes, and offices. Concentrations of FTOHs have been observed in excess of 300,000 pg/m^3 inside commercial buildings (**Fromme et al. 2010**) and as high as 255,000 pg/m^3 in residences in the area of Oslo, Norway (**Padilla-Sanchez et al. 2017**). More information is included in **Section 17-1**, Media-Specific Occurrence Tables.

6.1.3 Settled Dust

PFAS have been measured in settled dust from floors and other surfaces and from samples collected from air conditioner filters, vacuum cleaner bags, and carpets from a variety of indoor environments, including schools and universities, preschools and childcare facilities, homes, and workplaces (**Young et al. 2020**; **Zheng et al. 2019**; **Ao et al. 2019**; **Besis et al. 2019**; **de la Torre et al. 2019**; **Giovanoulis et al. 2019**; **Byrne et al. 2017**; **Beesoon et al. 2012**). The literature range of concentrations of PFAS in dust in indoor environments vary over many orders of magnitude (**Figure 6-1C**). Concentrations of PFOA and PFOS range from nondetect to about 650 ng/g and 3,000 ng/g, respectively. Fluorotelomers have also

been observed in indoor dust, ranging from nondetect to about 2,500 ng/g for FTOHs. Fluorotelomer phosphate diesters (diPAPs) were reported in a study of preschools in the area of Stockholm, Sweden, and ranged from nondetect to greater than 42,000 ng/g (**Giovanoulis et al. 2019**). More information is included in **Section 17-1**, Media-Specific Occurrence Tables.



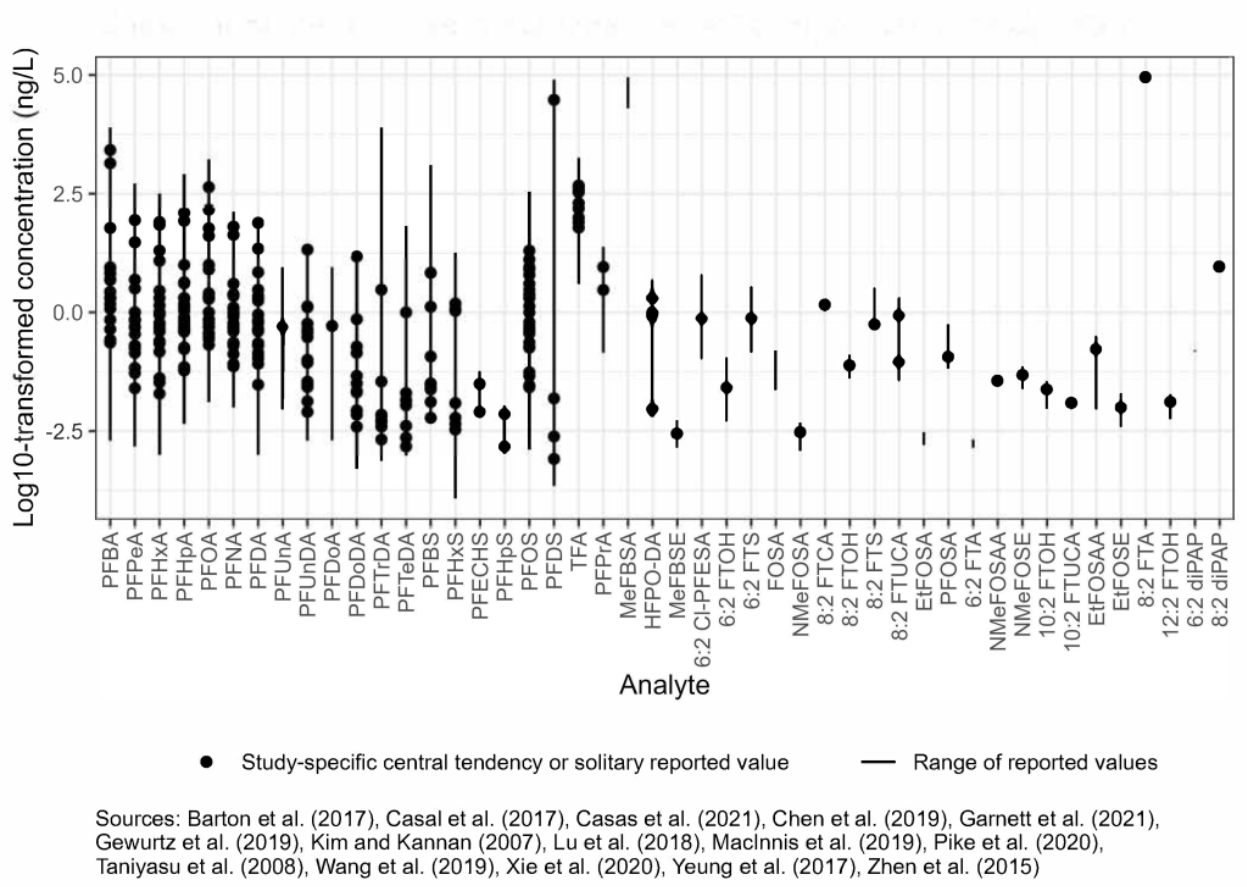
Sources: Ao et al. (2019), Beesoon et al. (2012), Besis et al. (2019), Byrne et al. (2017), de la Torre et al. (2019), Giovanoulis et al. (2019), Young et al. (2020), Zheng et al. (2020)

Figure 6-1C. Observed PFAS concentrations in settled dust.

*Source: Figure developed using ggplot2 (**Wickham 2016**).*

6.1.4 Precipitation

PFAS have also been observed in precipitation and other samples impacted by precipitation, including rainwater, surface and subsurface snow, sea ice, and meltwater. The literature range of concentrations of PFAS in precipitation vary over many orders of magnitude (**Figure 6-1D**) (**Casas et al. 2021**; **Pike et al. 2020**; **Xie et al. 2020**; **Chen et al. 2019**; **MacInnis et al. 2019**; **Wang et al. 2019**; **Lu et al. 2018**; **Casal et al. 2017**; **Yeung et al. 2017**; **Zhen et al. 2015**; **Taniyasu et al. 2008**; **Barton, Kaiser, and Russell 2007**; **Kim and Kannan 2007**). Lower levels of PFAS have been observed in precipitation from remote locations such as the Arctic and Antarctic as compared to more populated and urbanized, continental regions. Concentrations of perfluoroalkyl acids in precipitation, such as PFOA and PFOS, were typically <1 ng/L in remote regions, while concentrations greater than 1,600 ng/L and 50 ng/L were observed, respectively, in continental regions. Fluorotelomers, including FTOHs, fluorotelomer sulfonic acid (FTSA), and fluorotelomer unsaturated carboxylic acids (FTUCAs), have been observed in precipitation with concentrations of FTOHs and FTSA exceeding 100 ng/L (**Chen et al. 2019**; **Zhen et al. 2015**) and FTUCAs ranging from nondetect to about 2 ng/L (**Chen et al. 2019**; **Taniyasu et al. 2008**). Heptafluoropropoxy propanoic acid (HFPO-DA), or GenX, has also been found in precipitation as high as 5 ng/L (**Pike et al. 2020**). More information is included in **Section 17-1**, Media-Specific Occurrence Tables.



Sources: Barton et al. (2017), Casal et al. (2017), Casas et al. (2021), Chen et al. (2019), Garnett et al. (2021), Gewurtz et al. (2019), Kim and Kannan (2007), Lu et al. (2018), MacInnis et al. (2019), Pike et al. (2020), Taniyasu et al. (2008), Wang et al. (2019), Xie et al. (2020), Yeung et al. (2017), Zhen et al. (2015)

Figure 6-1D. Observed PFAS concentrations in precipitation.

*Source: Figure developed using ggplot2 (**Wickham 2016**).*

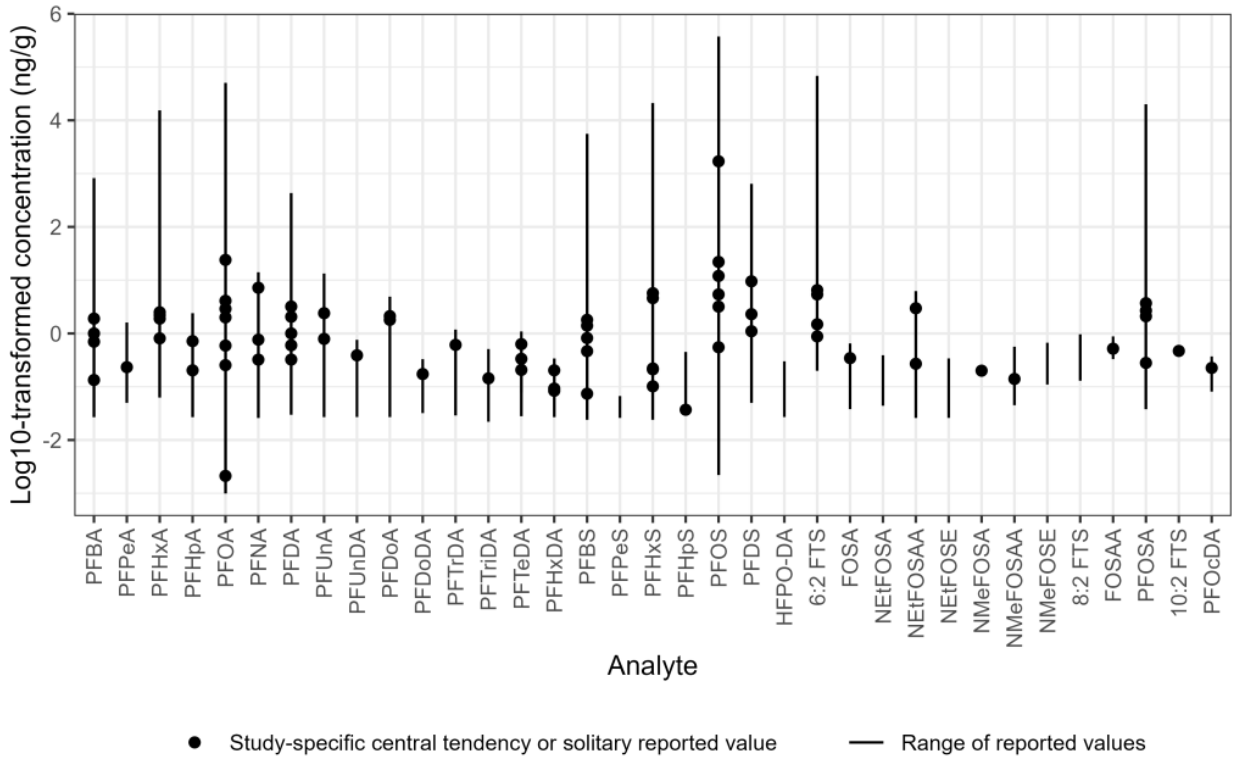
6.2 Soil, Sediment, and Biosolids

PFAS occurrence in soil and sediment can result from direct inputs (for example, AFFF releases or industrial discharge) or indirectly through exposure to impacted media (for example, atmospheric deposition, landfill leachate, or wastewater effluent). Another focus of current research is agricultural application of biosolids, compost, or pesticides, all of which are potential PFAS sources (**Table 2-6**). As a result of these inputs, soil and sediment may act as secondary sources of PFAS via leaching to groundwater and runoff to surface water through leaching and percolation processes, respectively. The concentration and distribution of PFAS observed in soils, sediments, and biosolids is complex and can be a function of source (direct versus indirect), site-specific considerations (for example, TOC, particle surface charges, and phase interfaces, see **Section 5.2.3**) and PFAS-specific chemistry (for example, alkyl chain length and ionic functional group). PFOS, PFOA, and other long-chain PFAAs are typically the predominant PFAS reported in surface soils and sediments (**Cai et al. 2022**; **Rankin et al. 2016**; **Strynar et al. 2012**; **Zhu et al. 2019**). Based on the increasing interest in biosolids, data related to that topic have been compiled separately from other sources.

6.2.1 Soil

Surface and subsurface soil are a significant reservoir for PFAS released to the environment. Numerous studies show individual PFAS concentrations in soil vary across multiple orders of magnitude, found at

low concentrations (<1 ug/kg) globally even in remote areas, and at concentrations exceeding 1,000 µg/kg at industrial and AFFF release sites (**Rankin et al. 2016**; **Brusseau et al. 2020**) (**Figure 6-2A**).



Sources: Brusseau et al. (2020), Groffen et al. (2019), Sanborn Head & Associates (2022), Sorengard et al. (2022), USGS (2022), Wang et al. (2018)

Figure 6-2A. Observed PFAS concentrations in site and anthropogenic background soil.

*Source: Figure developed using ggplot2 (**Wickham 2016**).*

Improving the understanding of anthropogenic background PFAS concentrations for comparison to site data has been a focus of recent work. A survey of anthropogenic background concentrations of PFAS in soil found PFOS ranging from 0.003 to 162 ug/kg and PFOA from 0.01 to 124 ug/kg (**Brusseau et al. 2020**). Although not focused on contaminated sites, many of the surveys were in or near populated regions and included agricultural fields. Recent studies in Maine and New Hampshire also focused on anthropogenic background soil levels without identified sources and in those studies PFOS ranged from nondetect to 5.4 and PFOA from nondetect to 5.3 ug/kg for the combined data. Median data for detected PFOS were 0.37 and 0.94 ug/kg, and for PFOA, 0.17 and 0.76 ug/kg for Maine and New Hampshire, respectively (**MEDEP 2022**; **Santangelo et al. 2022**). In contrast, data at known PFAS release sites such as fire training areas and biosolids application sites showed maximum concentrations of PFAS that may exceed anthropogenic background by several order of magnitude. PFOS and PFOA in fire training areas and other source zones may be as high as 373,000 and 50,000 ug/kg respectively, though the median values for AFFF source zones were much lower—18 and 1.4 ug/kg for PFOS and PFOA (**Brusseau et al. 2020**).

Published data on soil PFAS concentrations in industrial settings are limited, and can be highly variable, depending on the nature of PFAS release and proximity to the source. More information is included in **Section 17-1**, Media-Specific Occurrence Tables. Additional detail on AFFF is found in **Section 3**.

6.2.2 Sediment

Direct discharge of AFFF, leachate, wastewater effluent, and runoff to surface waters and subsurface discharge of contaminated groundwater to surface water has resulted in PFAS impacts to freshwater and marine sediments. Detected concentrations for surface sediments in lakes and rivers reported in the literature generally range from below detection limit to approximately 100 µg/kg, and concentrations and relative distributions of PFAS are variable depending upon types of sources and distance from point sources (**Figure 6-2B**).

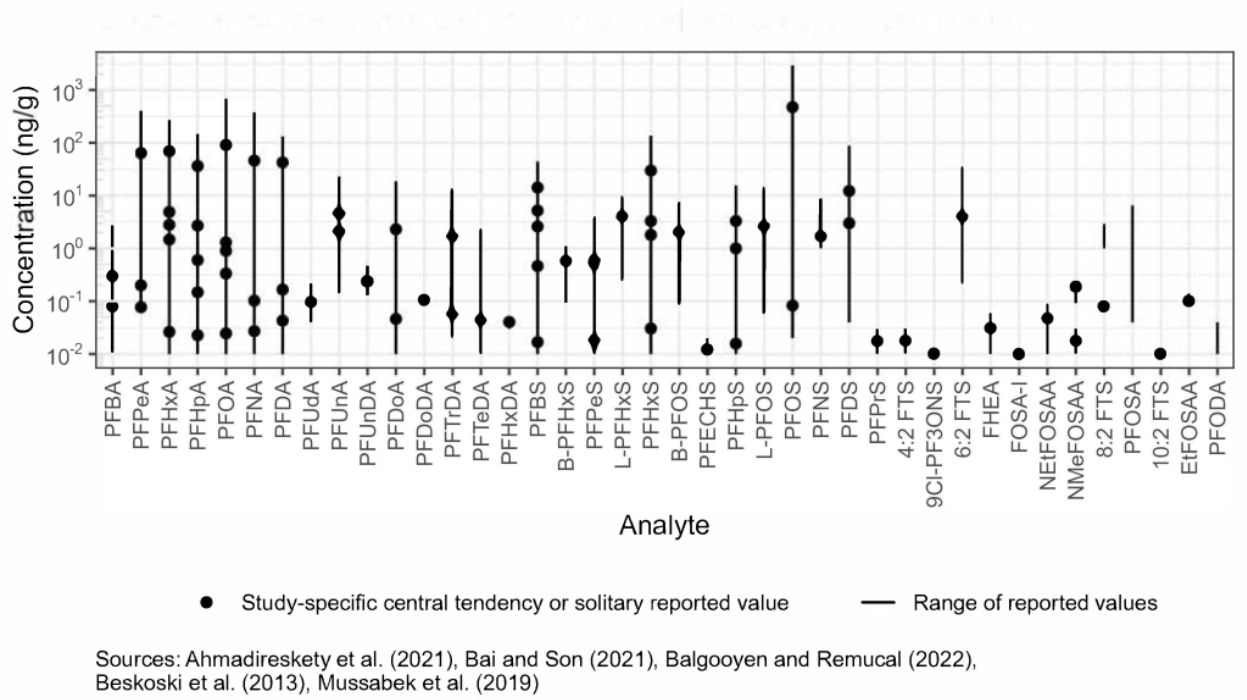


Figure 6-2B. Observed PFAS concentrations in sediment.

*Source: Figure developed using ggplot2 (**Wickham 2016**).*

A study of 48 lakes and two reservoirs with different limnological and geographic settings across China found surface sediment concentrations for a sum of detected PFCAs + PFOS ranged from 0.086 to 5.79 ng/g with a detection frequency of 100%. These samples collected in 2010–2013 showed that PFAS concentrations correlate to parameters such as TOC, nitrogen, and phosphorus in sediment (**Qi et al. 2016**).

A study from the Great Lakes (**Codling et al. 2018**) evaluated the use of dated sediment cores to assess PFAS deposition trends and analyzed for 22 PFAS. Reported values for the sum of PFAS in cores ranged from nondetect to 68.3 ug/kg dry weight, with the max value attributed to a detection of PFHpA of 46.6 µg/kg at that location. Concentrations typically increased with time in the cores. Grab samples were also collected, and PFOS ranged from 0.1 to 2.5 ug/kg, PFOA from nondetect to 3.0 ug/kg, and PFHpA from nondetect to 8.5 ug/kg. Concentrations in grab samples for the sum of PFAS ranged from nondetect to 26.0 ug/kg. Sediment core analysis may be effective for estimating deposition rates and fluxes for a subset of PFAS that exhibit strong sorption to sediment, with concentration at a given depth interval representing deposition during that time period (**Codling et al. 2018**).

A Swedish study of sediment cores in a lake and pond impacted by AFFF showed that PFOS and PFHxS were the dominant PFAS in sediment. Concentrations of PFOS and PFHxS ranged as high as 64 and 13

ng/g, respectively, and the study identified peak deposition rates occurring between 2003 and 2009, which correlated with reported activity near the water bodies (**Mussabek et al. 2019**).

Large precipitation or storm events can also contribute to episodic or enhanced transport of sediment and resuspension or redistribution of contamination in some environmental settings. Resampling of marine sediment locations in Florida following the passage of a hurricane found sediment concentrations of total PFAS decreased 47% averaged across nine sites. Highest concentrations of PFAS were spatially correlated to potential sources such as military installations and manufacturing facilities, and across all locations short-chain PFCAs dominated the total PFAS at 68% of locations, while long-chain PFAAs dominated the other 32% of sites (**Ahmadireskety et al. 2021**). Sediment in two urban watersheds showed concentrations of individual PFSAs as high as 88 ng/g, and found seasonal variability in sediment concentrations, potentially related to higher/lower water flows, or variation in organic matter and uptake during algal blooms (**Bai and Son 2021**). Once deposited, sediments can directly impact biota and can influence surface water concentrations. Tributary sediments with a mix of potential sources were shown to be potential secondary sources of PFAAs once those sediments were transported to a receiving water body (**Balgooyen and Remucal 2022**). **Figure 6-2B** illustrates the concentration distribution in sediment across multiple environmental settings from these recent studies. More information is included in **Section 17-1**, Media-Specific Occurrence Tables.

6.2.3 Biosolids

PFAS occurrence in biosolids is reported to be prevalent across the United States at a wide range of concentrations, and may be from municipal, residential, or industrial sources, or a combination of any of those sources. Biosolid designations may include “land applied,” Class A, Class B, Class C, unclassified, and mixed land-applied organic waste products. New information about PFAS occurrence at land application sites has been compiled in the Priority Topics for Biosolids Land Application, see **Section 1.7.2.2** and **Section 1.7.2.3**.

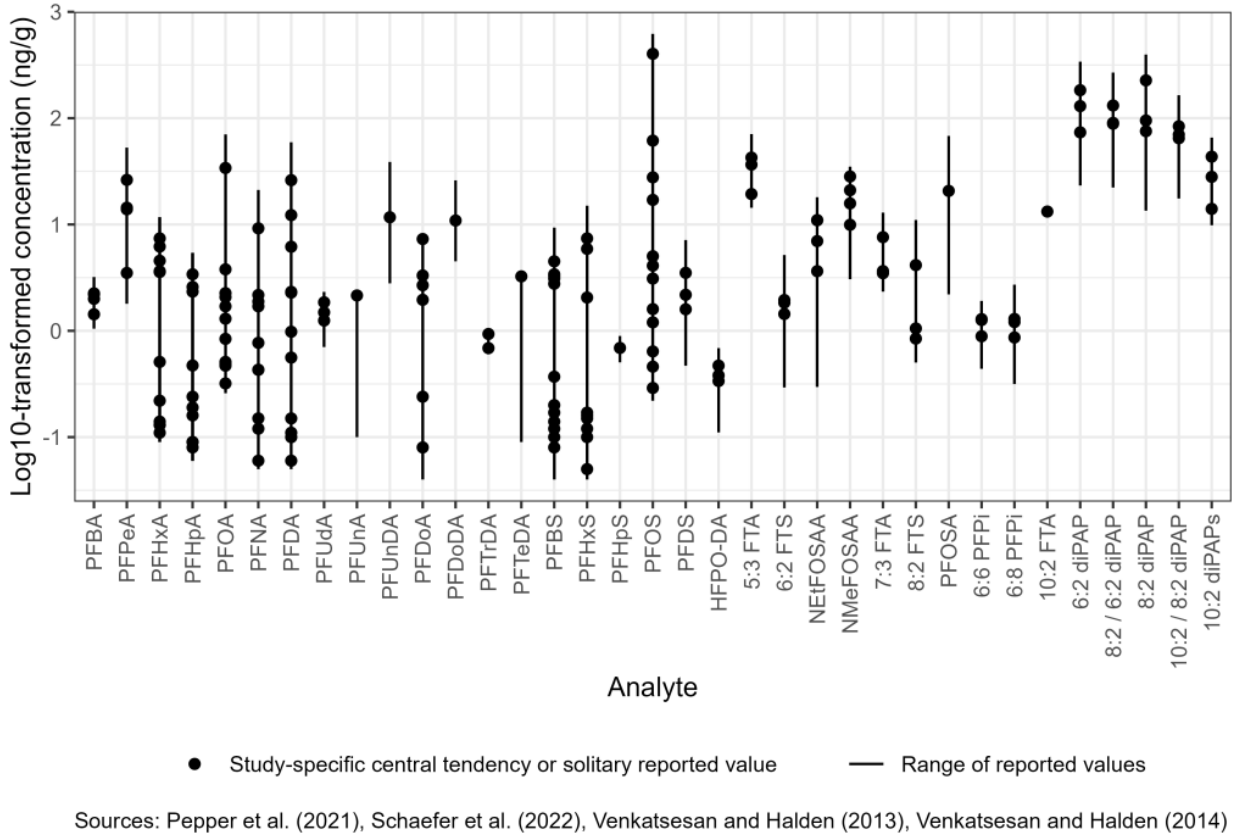
A 2013 study of archived samples of biosolids from 2001 in the United States, which targeted 12 PFAAs and PFOSA, reported mean concentrations of PFOS (403 ng/g) and PFOA (34 ng/g) with the mean values of other PFAAs ranging from 2 to 21 ng/g. With the exception of PFBA, PFBS, and PFHpA, the target PFAAs and PFOSA were detected in all samples (**Venkatesan and Halden 2013**). A 2021 review of reported values for biosolids, compost, and related biowastes highlighted the wide concentration range of reported PFAS (primarily PFAAs) and the relationship of biowaste source to resulting concentrations (**Bolan et al. 2021**). **Figure 6-2C** illustrates concentration ranges in biosolids for a selection of PFAS from a subset of recent data. Early studies reported that the most abundant PFAAs (see **Section 2.2.3.1**) found in biosolids (PFOS and PFOA) are similar to those found in wastewater effluent, although biosolids may also contain other PFAS, including long-chain PFAS (**Hamid and Li 2016**; **Washington et al. 2010**). Although multiple studies have reported data showing transformation of polyfluorinated substances to PFAAs in land-applied biosolids (**Yoo et al. 2010**; **Sepulvado et al. 2011**; **Washington et al. 2010**), other evidence indicates that some polyfluorinated substances remain in biosolids-amended soils for many years to decades (**Yoo et al. 2010**; **Rich et al. 2015**; **Washington et al. 2018**).

PFOS is the most frequently reported PFAS and typically at the highest concentration of the PFAAs most frequently reported (**Clarke and Smith 2011**; **Gallen et al. 2018**; **Moodie et al. 2021**; **Munoz et al. 2021**; **Pepper et al. 2021**). Target and nontarget precursor compounds are also commonly detected in biosolids, including 6:2 diPAP and 6:2 FTS (**Kim Lazcano et al. 2020**; **Schaefer et al. 2022**; **Moodie et al. 2021**), EtFOSAA, and cationic and zwitterionic electrochemical fluorination precursors to PFOS (**Munoz et al. 2021**). Biosolids tend to be enriched in long-chain PFAAs containing more than six carbon atoms (**Kim Lazcano et al. 2019**).

Repeated application of biosolids to agricultural soil can result in PFAS accumulation in shallow soil depths, and eventual leaching to groundwater, as well as uptake by agriculturally sourced products (**Ghisi**

et al. 2019). "Shallow soil" in this context will be variable depending on the crop or farm practices. For example, Maine considers 0–2 feet to be the "plow layer" (**ME DEP 2023**), whereas USEPA refers to shallow soil "extending to site-specific depths that can be sampled easily by manual methods," generally 0–12 inches (**USEPA 2023**). Based on the biosolid application rates in the United States and the mean total PFAS concentrations observed for archived biosolids from 2001, it is estimated that 1,375–2,070 kg of PFAS may have been added to agricultural land annually across the United States during that time (**Venkatesan and Halden 2013**). Data for more recent testing of biosolids and compost typically show lower concentrations of PFAAs and lower annual application rates (**Bolan et al. 2021**).

PFAS concentrations in soils at sites with applied biosolids or sludge will vary depending upon application rates, frequency, duration, geochemical and hydrogeologic factors, and concentration of PFAS in the applied material. Perfluorocarboxylic acids (PFCAs) and perfluoroalkylsulfonic acids (PFSAs) have been observed in surface soils treated with biosolids at 1 and 2 orders of magnitude higher than global anthropogenic background soils, respectively (**Johnson 2022**). In contrast, another study observed that even after decades of land application, the concentration and accumulation of PFAS in soils where biosolids were applied was comparatively low. In addition, the study observed that there was ~73% attenuation of measured PFAS from the shallow soil sample at 30.5 cm to the deepest interval of 183 cm (**Pepper et al. 2021**). This variability of reported data illustrates the importance of site-specific history and conditions to resulting concentrations in soil at land application sites.



Sources: Pepper et al. (2021), Schaefer et al. (2022), Venkatsesan and Halden (2013), Venkatsesan and Halden (2014)

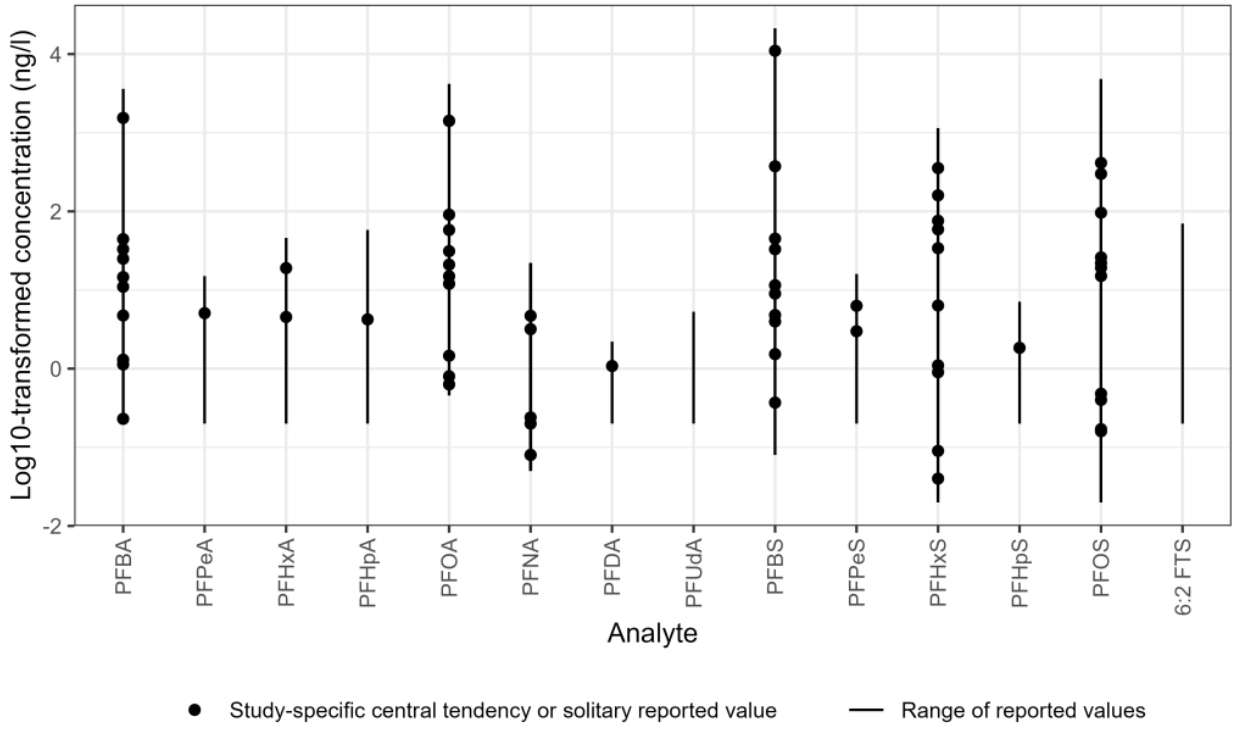
Figure 6-2C. Observed PFAS concentrations in biosolids and land-applied soil.

*Source: Figure developed using ggplot2 (**Wickham 2016**).*

Ultra-short-chain PFAS, certain precursors to PFAS, and new generation PFAS potentially account for a significant fraction of the total fluorine present in biosolids, but are largely unquantifiable by current standard methods (**Kim Lazcano et al. 2020**; **Munoz et al. 2021**; **Schaefer et al. 2022**). The highest

average minimum and maximum concentrations observed in recent publications were n:2 polyfluoroalkyl phosphoric acid esters, polyfluoroalkyl phosphates, and fluorotelomer phosphates (diPAPs). In addition to diPAPs, perfluoroalkane sulfonamido acetic acids (FASAAs), perfluorooctane sulfonamides, and fluorotelomer sulfonic acids (FTS) were abundant (**Munoz et al. 2021**; **Schaefer et al. 2022**). This suggests that limiting PFAS analysis of biosolids to the standard suite of analytes may not account for a substantial fraction of the overall fluorine mass (**Schaefer et al. 2023**; **Thompson et al. 2023**). Of the perfluoroalkyl acids (PFAAs), long-chain perfluoroalkyl sulfonic acids (PFSAs) were present at the highest concentrations, likely due to their hydrophobicity and greater tendency to remain sorbed to soils within the vadose zone (**Figure 6-2C**). More information is included in **Section 17-1**, Media-Specific Occurrence Tables.

6.3 Groundwater



Sources: Cao et al. (2019), Chen et al. (2016), Hepbern et al. (2019), Bao et al. (2019a), Liu et al. (2019), McMahon et al. (2022), MDE (2021), Sammut et al. (2019), Schaefer et al. (2018), Sharma et al. (2016), Wang et al. (2016a)

Figure 6-3. Observed PFAS concentrations in groundwater.

*Source: Figure developed using ggplot2 (**Wickham 2016**).*

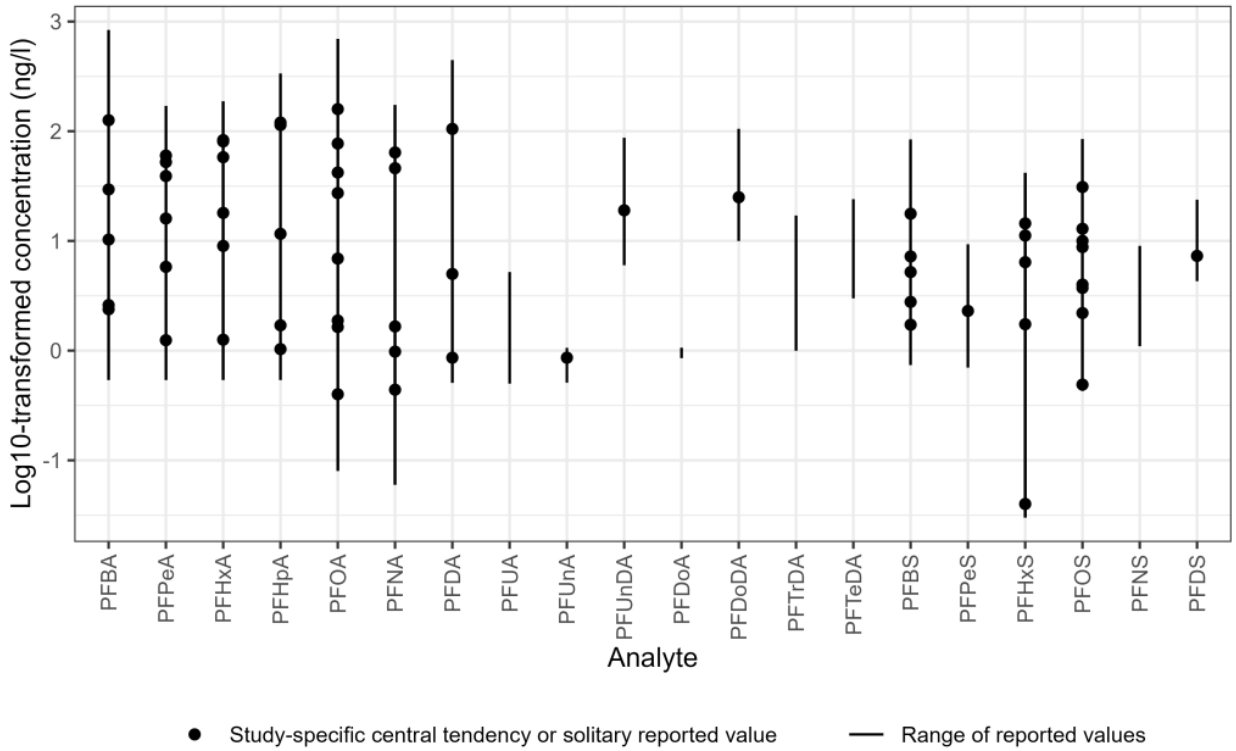
USEPA has assembled an extensive data set of the occurrence of six PFAAs in public drinking water. This data set is the result of required monitoring of approximately 4,900 public water systems (all large systems serving more than 10,000 people, plus a subset of smaller systems) for six PFAAs in finished drinking water at points of entry to the drinking water distribution system. The study was conducted between 2013 and 2015 under the third Unregulated Contaminant Monitoring Rule (UCMR3) and included the results from treated water that originated from groundwater wells (n = 22,494), groundwater under the direct influence of surface water (n = 436), surface water sources (n = 13,228), and mixed sources (n = 814) (**USEPA 2017**). A summary of the UCMR3 occurrence data, including analytical reports, is included in **Section 8.2.2.4**. An analysis conducted on the nonfinalized UCMR3 data set found that one or more

PFAAs were detected in 4% of the reporting public water systems (**USEPA 2017**); however, groundwater sources had approximately double the detection rate of surface water sources (**Hu et al. 2016**).

As of June 2022, USEPA issued interim health advisories for PFOA and PFOS in drinking water (**USEPA 2022**). These replace the former values USEPA issued in 2016 of 70 ng/L (**USEPA 2016**, **2016**). The interim values of 0.004 ng/L for PFOA and 0.02 ng/L for PFOS are lower than the minimum detection limit of 0.52 ng/L for drinking water methods (ITRC Table 11-3, PFAS Analytical Methods Excel file). Therefore, all detected concentrations would be above the interim health advisories. Detections were geographically widespread but showed quantifiable associations with suspected sources, including industrial sites, military fire training areas, AFFF-certified airports, and wastewater treatment facilities (**Hu et al. 2016**). Individual states are collecting information on PFAS occurrence in smaller public water supplies such as schools and mobile home parks that do not meet the threshold to comply with the Unregulated Contaminant Monitoring Rule, so were not sampled during UCMR3, and for which data are often publicly available, for example, in New Hampshire at **NH DES (2020)**. UCMR5 will include a larger list of PFAS analytes, public water systems (PWSs) serving 3,300 or more persons, and up to 800 smaller PWSs (**USEPA 2021**).

Groundwater occurrence data collected as part of domestic and international studies have also characterized the range of PFAS concentrations associated with AFFF release sites, industrial facilities, and landfills; examples of these study results are provided in **Figure 6-3**. More information is archived as a Section 17.1 PDF, found under **Archived External Tables and Sections** on the home page of this site.

6.4 Surface Water



Sources: Bai et al. (2020), Cao et al. (2019), Chen et al. (2016), Garnett et al. (2021), Gewurtz et al. (2019), Sharma et al. (2016)

Figure 6-4. Observed PFAS concentrations in surface water.

*Source: Figure developed using ggplot2 (**Wickham 2016**).*

Freshwater, marine water, and stormwater PFAS concentrations usually depend on proximity to the point of release and source concentrations. In addition to releases associated with identified sources, stormwater runoff from nonpoint sources may contribute significant loads of PFAS to surface water (**Wilkinson et al. 2017**; **Zushi and Masunaga 2009**). The sorption of PFAS to suspended solids may affect surface water PFAS concentrations. Suspended microplastics may also influence PFAS in surface water (**Llorca et al. 2018**). **Figure 6-4** presents examples of observed PFOS and PFOA surface water concentrations, organized by source type. In addition to PFOS and PFOA, many other PFAS have been observed in surface waters, including compounds other than PFAAs. For example, a recent study found perfluoro-2-propoxypropanoic acid (PFPrOPrA also known as the GenX chemical HFPO-DA) in untreated water drawn from the Cape Fear River in North Carolina at concentrations up to 560 ng/L, and GenX was just one of many non-alkyl acid PFAS identified (**Sun et al. 2016**). Surface water occurrence is also an important source of drinking water supply impacts (**USEPA 2018**; **Post et al. 2013**). More information is archived as a Section 17.1 PDF, found under **Archived External Tables and Sections** on the home page of this site.

6.5 Biota

Because PFAS are distributed globally and have a propensity to bioconcentrate, they have been found in fish, wildlife, and humans. PFAAs, particularly PFOS, are typically the dominant PFAS detected in biota (**Houde et al. 2011**). PFAA concentrations in biota are influenced by uptake and elimination of both PFAAs and their precursors, as well as biotransformation rates of PFAA precursors (**Asher et al. 2012**; **Gebbink, Bignert, and Berger 2016**). Therefore, concentrations of PFAAs observed in biota at one location may not reflect concentrations in other environmental media.

6.5.1 Plants

Studies show evidence of uptake and accumulation of PFAAs by plants in several settings and applications, including both controlled experiments and field investigations. Concerns about introducing PFAAs into livestock or crops have led to investigations of uptake and accumulation in plants (**Section 5.6**). Uptake mechanisms and the extent to which native plant species remove and accumulate PFAS have not been as well studied.PFAS may be introduced to plants from soil, water, or air by:

- irrigation water
- the application of biosolids or sludge-amended soils
- the application of pesticides
- soil and groundwater at PFAS sites or near releases of PFAS
- exposure through contact with rainwater and atmospheric deposition

Studies demonstrating plant uptake of PFAAs have focused on irrigated crops (**Stahl et al. 2009**; **Scher et al. 2018**; **Bolan et al. 2021**), crops in biosolids-amended soil (**Yoo et al. 2011**; **Blaine et al. 2013**; **Blaine et al. 2014**; **Felizeter et al. 2021**; **Costello and Lee 2020**; **Knight et al. 2021**), and aquatic plants in constructed wetlands (**Chen, Lo, and Lee 2012**). PFAS have also been found in pesticides (**Zabaleta et al. 2018**; **Lasee et al. 2022**). USEPA's Analytical Chemistry Branch repeated the analyses conducted by **Lasee et al. (2022)** for PFAS and conducted additional analyses. In USEPA's results no PFAS were detected above the method detection limits (**USEPA 2023**).Other investigations have focused on flora exposed to PFAAs in the natural environment (**Zhang et al. 2015**) or near known PFAS sources (**Shan et al. 2014**). Based on bioconcentration factors discussed in **Section 5.6**, concentrations in plants will generally reflect the same concentrations in soil and, for trees with deep roots, groundwater (**Gobelius, Lewis, and Ahrens 2017**).

6.5.2 Invertebrates

Invertebrates act as the main component of the food web base and play a key role in the dynamics of biomagnification. Aquatic invertebrates can reside in the water column, as well as on (or in) the sediment substrate. In higher trophic level organisms, PFOS has been documented as the dominant PFAS, with concentrations increasing up the food chain, while PFOA has a lower bioaccumulation potential with similar concentrations among species of different trophic level animals (**Houde et al. 2011**; **Conder et al. 2008**). In invertebrates, both PFOS and PFOA have maximum values within similar ranges (**Ahrens and Bundshuh 2014**). A recent review of PFAS occurrence in marine and estuary invertebrates (i.e., mollusks and crustaceans) found that patterns of PFAS bioaccumulation can vary slightly between these taxa, but historical differences in sampling and analytical methods complicate comparisons to more recent investigations (**Giffard et al. 2022**). Studies present a PFAS range of approximately 0.1–10 mg/kg in invertebrate tissue, although their sources predominantly address marine organisms (**Houde et al. 2011**). Similar levels of PFOS have been found in freshwater invertebrates (< 2–4.3 mg/kg) with a BCF (biota/water) estimated at 1,000 L/kg (**Kannan et al. 2005**). Concentrations of PFOS, PFCAs, and heptadecafluorooctane sulfonamide (PFOSA) have been observed in Lake Ontario invertebrates, ranging from < 0.5 to 280 mg/kg (**Martin et al. 2004**). The PFAS concentrations in invertebrates were greater than in fish from this lake.

In soil invertebrates, current research indicates that bioaccumulation potential of PFOS is low, as is biomagnification (increasing concentrations in predators over their prey) from lower to higher trophic level organisms (**CEPA 2017**). In biosolids-amended soils, the mean PFAS BAFs in earthworms have been found to range from 2.2 (PFOA) to 198 (PFDoA) g dry weight (dw) soil/g dw worm (**Navarro et al. 2016**). Maximum BAFs in earthworms for all PFAS types have been observed at <45 g dw soil/g dw worm for biosolids-amended soils and <140 g dw soil/g dw worm for soils contaminated with AFFF (**Rich et al. 2015**).

6.5.3 Fish

Accumulation of PFAS in fish is well documented, particularly for PFOS, longer chained PFCAs (with eight or more carbons), and perfluorodecane sulfonate (PFDS) (**Houde et al. 2011**; **Martin et al. 2013**; **Conder et al. 2008**). PFOS generally has the highest concentrations in fish due to the historically high use of this chemical and its bioaccumulation potential (**Houde et al. 2011**). PFDS, long-chain PFCAs, and other PFAS have also been measured in fish (**Houde et al. 2011**; **Fakouri Baygi et al. 2016**).

In fish, PFOS tends to partition to tissues of high protein density, including the liver, blood serum, and kidney (**Falk et al. 2015**; **Ng and Hungerbühler 2013**). This distribution pattern is contrary to other persistent chemicals, which tend to partition to adipose tissue. Concentrations of PFOS and other PFAAs tend to be higher in whole fish samples compared with fillets given that a major fraction of PFAAs is found in the carcasses of fish rather than fillets (**Fliedner et al. 2018**). PFAA concentrations sometimes increase with fish size; however, the relationship with fish size is not consistent as observed for other contaminants such as mercury (**Babut et al. 2017**; **Gewurtz et al. 2014**).

Fish data for PFOS collected near known sources (for example, AFFF sites) from some key studies are summarized in **Figure 6-5**. More information is archived as a Section 17.1 PDF, found under **Archived External Tables and Sections** on the home page of this site.

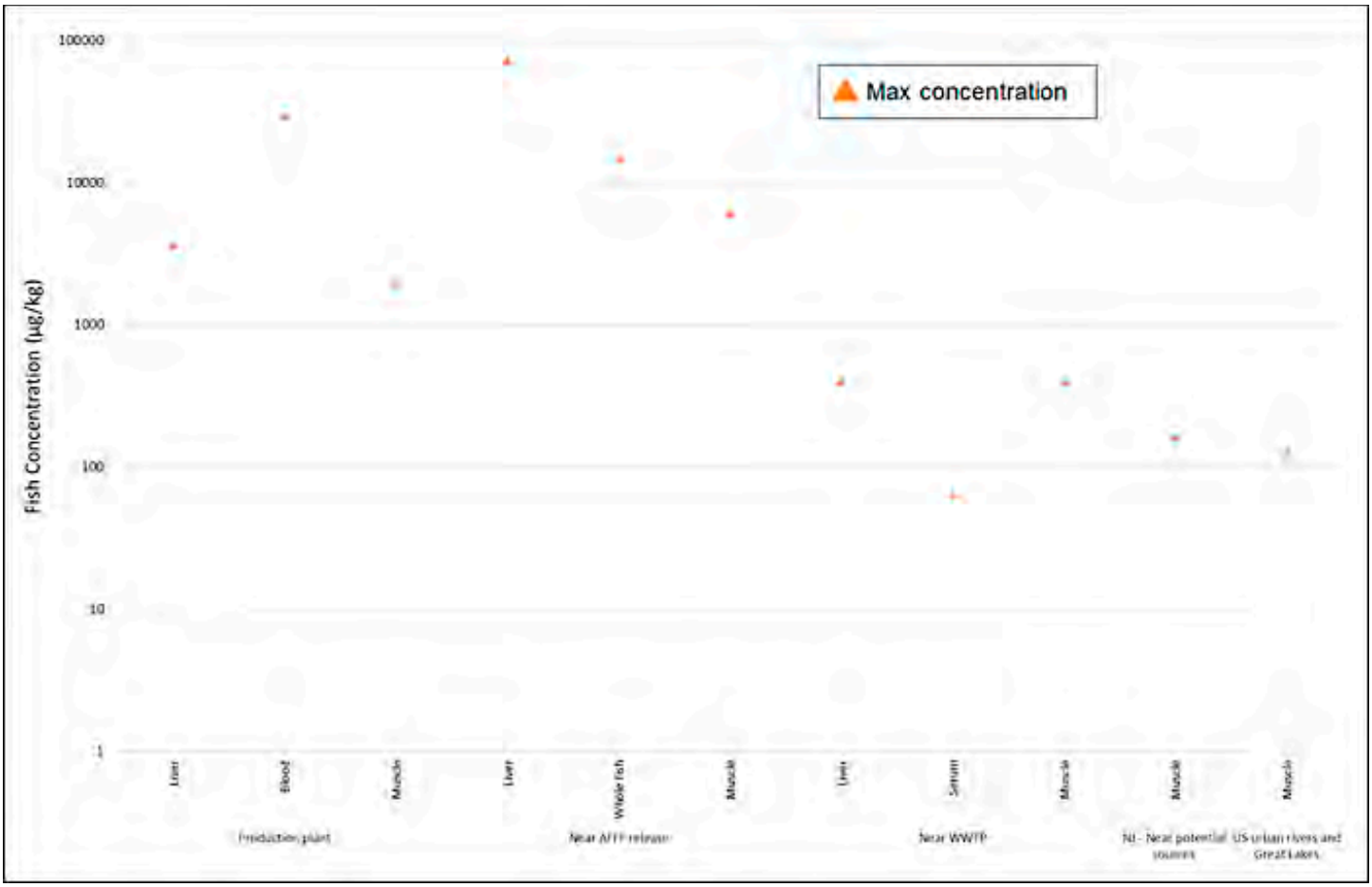


Figure 6-5. Observed PFAS concentrations in fish.

6.5.4 Vertebrates

Most research addressing PFAS concentrations in vertebrates focuses on temporal trends in animals at the top of the food chain, such as piscivorous birds (for example, osprey) and mammals (for example, dolphins, seals). The concentrations are often reported in protein-rich organs known to concentrate PFAS. For example, to evaluate temporal trends between 2002 and 2014, levels of PFAS were measured in liver samples of Indo-Pacific humpback dolphins and finless porpoises (136–15,300 and 30.5–2,720 ng/g dw, respectively) (**Gui et al. 2019**). Livers of Beluga whales in the Artic were the only organ sampled to better understand the relative bioaccumulation of persistent organic compounds (**Reiner et al. 2011**). These data using top marine predators as "sentinels" of PFAS are important in terms of assessing whether concentration trends are increasing or decreasing in the global environment.

PFAS bioaccumulation in terrestrial human food sources (livestock, livestock products, and game) is a critical area of occurrence discussions, and few research or review articles currently exist. Animals raised for food and wildlife species may come into contact with PFAS through contaminated air, water, soil, substrate, or feed. However, the extent to which these exposures contribute to PFAS concentrations in food products is not extensively researched (**Death et al. 2021**). A study focused on livestock drinking water and grazing found that sites with mean livestock drinking water concentrations as low as 0.003 µg PFOS/L may exceed action levels or advisory levels for PFOS in cattle meat (**Mikkonen et al. 2023**). Current understanding is that most PFAS accumulates in muscle tissue and milk (**Brake et al. 2023**). Some state agencies are conducting sampling surveys of game animals and issuing "Do Not Eat" advisories (**ME DIFW 2023**; **MPART 2023**).

7 HUMAN AND ECOLOGICAL HEALTH EFFECTS OF SELECT PFAS

This section discusses both the information related to assessing health effects of PFAS in humans (**Section 7.1**) and the adverse effects on ecological (nonhuman) species (**Section 7.2**). This is an active area of scientific research. **Section 7.1** provides information on human biomonitoring and exposure, toxicokinetics, toxicology in mammalian species, and human epidemiology for long-chain and short-chain PFAAs and the per- and polyfluorinated ether carboxylates (PFECAs) commonly known as the GenX chemicals and ADONA. The section is supplemented by additional material on each of these topics, which is included as **Section 17.2**. **Section 7.2** is organized to include ecological toxicology information on invertebrates (aquatic, benthic, terrestrial), vertebrates (fish, birds, reptiles, amphibians, mammals), and plants.

In December 2023, **ITRC (2023)** published their Contaminants of Emerging Concern (CEC) framework document that includes a discussion of sources of key variables to consider when evaluating human health risk and ecological risks. Links and references in the framework may be useful for understanding PFAS.

For further information on the scientific names and carbon chain length of PFAAs addressed in these sections, see **Section 2.2** of this document. Use of the human health effects information in guidance values is discussed in **Section 8.3** and in site risk assessment in **Section 9.1**.

Section Number	Topic
1.4	**Priority Topics for Human and Ecological Health Effects (2025)**
7.1	**Human Health Effects**
7.2	**Ecological Toxicology**
17.2	**Additional Information for Human Health Effects**

7.1 Human Health Effects

The PFAS discussed in this section and in **Section 17.2** include perfluorocarboxylic acids (PFCAs) with 4–14 carbons and perfluorosulfonic acids (PFSAs) with four or more carbons. Also covered are several PFECAs that are used as replacements for PFOA as processing aids in production of certain fluoropolymers, including the GenX chemicals, hexafluoropropylene oxide dimer acid (HFPO-DA) and its ammonium salt, (also known as perfluoro-2-propoxypropanoic acid [PFPrOPrA] and ammonium 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoate, respectively) and 4,8-dioxa-3H-perfluorononanoate, commonly known as ADONA. In addition, **Section 17.2.6** reviews other ether and polyether PFAS, fluorotelomer alcohols, and fluorotelomer sulfonic acids. They are included because they are of current interest and health effects data are available. There is little or no publicly available health effects information for most of the many other PFAS used in commerce (**Section 2.5**), including precursors that may be converted to PFAAs in the environment and in the human body. Several groups have developed systematic evidence maps that seek to collate available human and animal data for certain PFAS chemicals including a group of 29 PFAS (PFAS-Tox Database) (**Pelch et al. 2019**, **Pelch et al. 2022**) and the US EPA's Office of Research and Development Systematic evidence maps for several hundred PFAS chemicals (**Carlson et al. 2022**, **Radke et al. 2022**, **Carlson et al. 2024**, **Shirke et al. 2023**). These evidence maps are large data repositories, with interactive visualizations and downloadable datasets that are a resource for PFAS researchers to compare what data are available for different PFAS across this diverse chemical class.

The best studied PFAAs are PFOS and PFOA, although considerable information is available for some other PFAS, including PFNA, PFHxS, PFBA, PFBS, and the GenX chemical HFPO-DA. Laboratory animal toxicology studies and human epidemiological studies suggest health effects that may occur as a result of long-term exposure to PFOA and PFOS at environmentally relevant levels. **Figure 7-1** summarizes current health effects information, the references for which are discussed in this section. The other PFAS mentioned above cause generally similar effects in animal studies, with toxicity generally occurring at higher doses for the short-chain PFAAs than for long-chain PFAAs. These health effects, discussed in more detail in Sections **7.1.3**, and **7.1.4** are the basis for current guidance values and regulations for PFOA, PFOS, and several other PFAS. These are available in the **Environmental Media Values Table** Excel file.

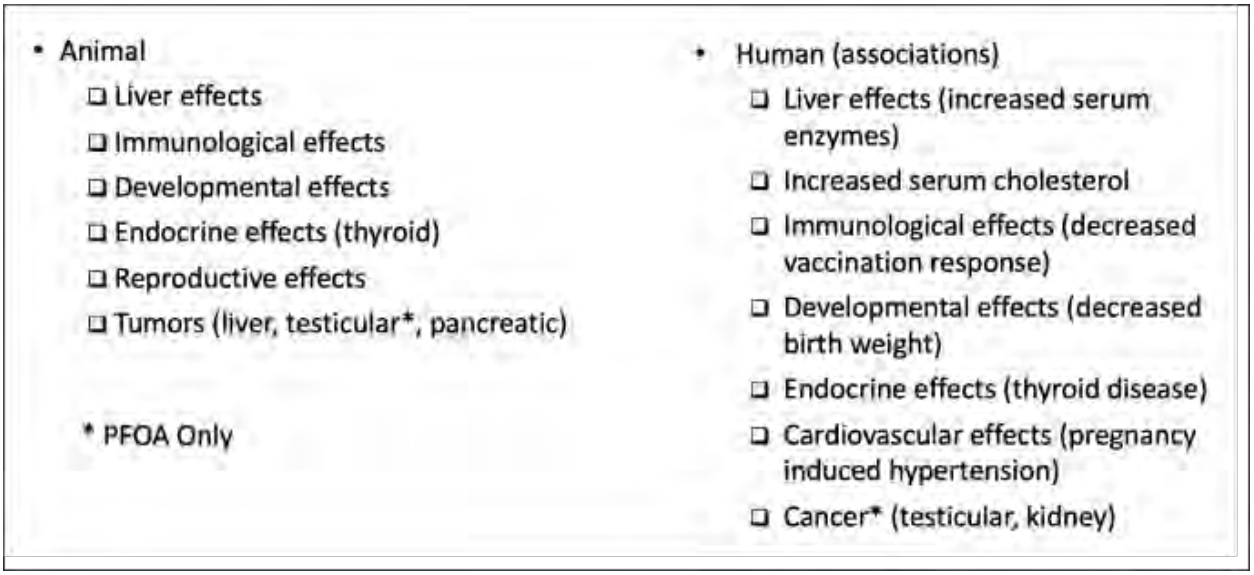


Figure 7-1. Some health effects of PFOA and/or PFOS identified from published studies (not exhaustive).

USEPA has finalized its toxicity assessments for the following PFAS:

- the GenX chemicals (**USEPA 2021**)
- PFBS (**USEPA 2021**)
- PFBA (**USEPA 2022**)
- Perfluoropropanoic acid (PFPrA)(**USEPA 2023**)
- Lithium bis[(trifluoromethyl)sulfonyl]azanide (HQ-115)(**USEPA 2023**)
- PFHxA (**USEPA 2023**)
- PFDA (**USEPA 2024**)
- 6:2 Fluorotelomer Sulfonic Acid (**USEPA 2024**)
- PFHxS (**USEPA 2025**)

As of April 2025, a draft IRIS assessment was available for PFNA (**USEPA 2024**).

USEPA (**USEPA 2021**; **2021**) developed draft updated toxicity assessment for PFOA and PFOS which were used as the basis for the updated PFOA and PFOS interim drinking water Health Advisories (**USEPA 2022**; **2022**). The **USEPA (2021)** also made a final regulatory determination to establish drinking water standards (maximum contaminant levels, MCLs) for PFOA and PFOS, proposed these standards in 2023 (**USEPA 2023**), and finalized them in 2024 (**USEPA 2024**). After consideration of public comments on the proposed **USEPA (2023)** MCLs, the USEPA finalized MCLs for PFOA and PFOS at 4.0 ng/L in 2024 (**USEPA 2024**). The USEPA toxicity evaluations of PFOA (**USEPA 2024**) and PFOS (**USEPA 2024**) that

support these MCLs reflect input from the USEPA Science Advisory Board (SAB) (**USEPA Science Advisory Board 2022**) and from public comments on the basis of the proposed MCLs. In the same National Primary Drinking Water Regulation, the USEPA finalized MCLs for three additional PFAS; PFNA, PFHxS, and GenX Chemicals (10 ng/L each) and an MCL of a Hazard Index of 1 for mixtures of any two or more of the following four PFAS: PFNA, PFHxS, PFBS, and GenX Chemicals (**USEPA 2024**).

Much of the information presented here is recent, and new studies continue to become available. Additionally, it should be noted that it was not possible to include all relevant citations, particularly for those compounds with large health effects data sets. Further information on the topics in this section can be found in databases such as the National Library of Medicine's PubMed (a database containing citations to relevant peer-reviewed publications), and in reviews such as **Kirk et al. (2018)** and **Lau (2012)**, and in several chapters of the Agency for Toxic Substances and Disease Registry (ATSDR) toxicological profile (**ATDSR 2021**); **DeWitt (2015)**, and **NICNAS (2018)** for PFAS in general. Some references for specific PFAS are included in this list:

- PFOA: **Australia Government DOH (2018)**; **USEPA (2016)**; **USEPA (2016)**; **NJDWQI (2017) NJDWQI (2017)**; **USEPA (2023)**
- PFOS: **USEPA (2016)**; **USEPA (2016)**; **MDH (2019)**; **NJDWQI (2018)**; **USEPA (2023)**
- PFNA: **NJDWQI (2015)**
- PFBS: **MDH (2022)**; **USEPA (2021)**
- PFBA: **USEPA (2021)**; **MDH (2018)**
- PFHxS: **MDH (2020)**
- PFHxA: **MDH(2021)** and **USEPA (2022)**
- GenX chemicals: **RIVM (2016)**, Chemours (posted online by **NC DEQ (2018)**); and **USEPA (2021)**
- Short-chain PFAAs: **Buck (2015)** and **Danish EPA (2015)**
- PFECAs: **Buck (2015)**; **NJDEP (2021)**

Human biomonitoring and sources of exposure are addressed in **Section 7.1.1**. Information on serum levels of long-chain PFAAs from communities with contaminated drinking water is presented in **Table 17-6**. The unique toxicokinetic properties of PFAS are discussed in **Section 7.1.2**. Table 17-7 summarizes available data on PFAS elimination half-lives in humans and experimental animals. The numerous reviews of potential epidemiological associations of health endpoints with PFAAs are discussed in **Section 7.1.3**. Toxicology studies in mammalian species are summarized in **Section 7.1.4**, and more detailed toxicology information is presented in **Section 17.2.5** and Table 17-8 Toxicological Effects Excel file (last updated November 2021). **Section 7.1.5** discusses PFAS mixtures. **Section 7.1.6** includes information about using new approach methodologies for evaluating PFAS. **Section 7.1.7** provides information about regulating PFAS as a class. **Section 7.1.8** includes information about PFAS inhalation toxicity, and **Section 7.1.9** includes data gaps and research needs. **Section 1.4.4** includes information about health effects of ultra-short-chain (ultrashort) PFAS.

7.1.1 Human Biomonitoring and Sources of Exposure

Numerous human biomonitoring studies (**CDC 2022**; **Olsen et al. 2017**) have demonstrated that certain PFAS, particularly long-chain PFAAs, are present in the blood serum of most U.S. residents. Long-chain PFAAs, with half-lives of one to several years, are slowly excreted in humans. Therefore, serum levels are indicators of long-term exposure to long-chain PFAAs and do not fluctuate greatly with short-term variations in exposure. Serum PFAA concentrations originate from direct exposure to the compounds and from metabolism of precursor compounds to PFAAs within the body (reviewed in **Kudo (2015)**). The largest U.S. general population biomonitoring studies are from the National Health and Nutrition Examination Survey (NHANES), a nationally representative survey conducted by the Centers for Disease Control and Prevention (CDC), which began monitoring for PFAS in 1999–2000 (**Figure 7-2**). As can be seen in **Figure 7-2**, serum PFAS levels in the general population have declined over time, most notably for PFOS. The most recent NHANES monitoring data (2017–2018) includes eight PFAAs (PFOA, PFOS, PFNA,

PFHxS, PFHxA, PFDA, PFUnDA, PFHpS) and four other PFAS (GenX, ADONA, 9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid, MeFOSAA); five additional PFAS (PFBS, PFHpA, PFDoDA, PFOSA, EtFOSAA) that were infrequently detected in earlier rounds of NHANES were not monitored in 2017–2018 (**CDC 2022**). Other adult U.S. general population biomonitoring data come from four studies of blood donors in 2000–2015 (**Olsen et al. 2017**) and the California Environmental Contaminant Biomonitoring Program (**CA OEHHA 2011**).

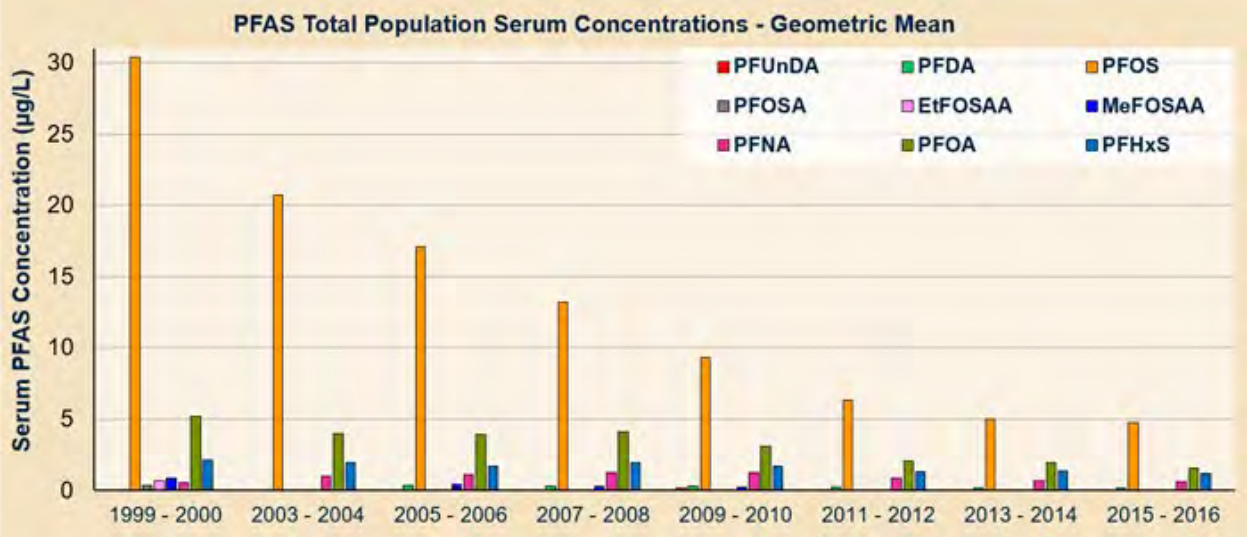


Figure 7-2. Geometric mean serum concentrations (ng/ml) of selected PFAAs (NHANES, 1999-2016).

In the general population, where this is no specific source of PFAS contamination and PFAA concentrations in drinking water and serum are in the typical "background" range, the primary sources of exposure to PFAAs and their precursors appear to be food and food packaging, and consumer products (particularly nonpolymer aftermarket treatments and coatings; **Section 2.5**), and house dust formed from such consumer products (**Trudel et al. 2008**; **Fromme et al. 2009**; **Vestergren and Cousins 2009**; **Beesoon et al. 2012**; **Gebbink, Berger, and Cousins 2015**). The Priority Topics for Human and Ecological Health Effects include information about potential PFAS exposures from consumer products (see **Section 1.4.2**).

PFAS have been detected in air (**ATSDR 2021**), and inhalation is therefore an additional potential exposure pathway. Serum levels of PFOS and PFOA documented by NHANES data appear to indicate that the phaseout of production and use of these chemicals in most products has resulted in decreased PFOS and PFOA exposures for the general population from these sources. As this occurs, the relative contribution from drinking water to these PFAAs will increase (where they are present in the drinking water).

In communities near sources of PFAS contamination, exposures that are higher than those in the general population can result from ingestion of contaminated drinking water or consumption of fish from contaminated waters. **Section 1.4.1** includes information about potential human health effects from PFAS exposure arising from AFFF in drinking water. As PFAS concentrations in drinking water increase, the contribution of drinking water to the total body burden increases and typically dominates an individual's exposure. Information on serum levels of long-chain PFAAs from communities with contaminated drinking water in several U.S. states and other nations is found in **Table 17-6**. Finally, occupational exposures to workers (for example, in fluoropolymer manufacturing facilities) can be higher than exposures from environmental media. **Section 1.4.6** includes information about potential PFAS exposures in occupational settings.

Specific considerations and exposure routes relevant to PFAS exposures in the fetus, breast-fed and formula-fed infants, and young children are discussed in **Section 17.2**. Also see **Section 17.2.2** for additional discussion of human biomonitoring and sources of human exposure.

7.1.2 Toxicokinetics

Toxicokinetics refers to the absorption, distribution, metabolism, and excretion of toxic substances. PFAAs and some other types of PFAS discussed herein have unique toxicokinetic properties as compared to other types of persistent organic pollutants (POPs). Unlike most other bioaccumulative organic compounds (for example, dioxins, PCBs), PFAAs do not have a high affinity for adipose tissue (fat). In contrast, PFAAs are water soluble, have an affinity for proteins, and generally distribute primarily to the liver and blood serum (**Bischel et al. 2011**; **Lau 2012**, **2015**; **Kato, Ye, and Calafat 2015**). Some PFAAs have also been found in kidney, bone, lung, brain, and other organs in laboratory animals and/or limited human studies (**Bogdanska et al. 2011**; **Perez et al. 2013**; **reviewed in USEPA 2023**). PFAAs, GenX chemicals, and ADONA are not metabolized (meaning they do not break down to other PFAS). However, some PFAS that are PFAA precursors (for example, fluorotelomer alcohols, **Section 17.2.5.2**) can be metabolized to PFAAs within the body.

Table 17-7 summarizes available data on PFAS elimination half-lives (the half-life is the length of time it takes for half of the chemical to be eliminated from the body) in humans and experimental animals. In general, short-chain PFAS are excreted more rapidly than longer chain PFAS in humans and other mammalian species. As discussed in more detail in **Section 17.2.3**, the excretion rates (for example, elimination half-lives) for specific PFAS can vary substantially between species, and in some cases between males and females of the same species. Half-lives in laboratory animals (rodents and nonhuman primates) generally range from hours to several months for long-chain PFAS, and hours to several days for short-chain PFAS. Human half-lives for PFAS are longer than in other mammalian species, with estimates of several years for long-chain PFAAs and several days to one month for shorter chain PFAAs such as PFBA, PFHxA, and PFBS. Because of the much longer human half-lives, animal-to-human comparisons must account for the much higher internal dose (for example, blood serum level) in humans than in animals from the same administered dose.

Toxicokinetics relevant to developmental exposures to PFAAs are important because developmental effects are considered to be sensitive endpoints for toxicity of long-chain PFAAs, and some human studies have found associations of long-chain PFAAs with decreased fetal growth. PFAAs cross the placenta (reviewed in **Lau (2012)** and **Kudo (2015)**) and are present in breast milk (**Luebker et al. 2005**; **White et al. 2009**; **Kato, Ye, and Calafat 2015**), and long-chain PFAAs have been found in cord blood, for example, (**Wang et al. 2019**), and amniotic fluid (**Stein et al. 2012**; **Zhang et al. 2013**). In human infants, exposures from breast milk result in substantial increases in long-chain PFAA serum levels during the first months after birth (**Fromme et al. 2010**; **Mogensen et al. 2015**). Due to the higher rate of fluid consumption by infants versus older individuals (**USEPA 2019**), exposures to infants from formula prepared with PFAS-contaminated water are also higher.

Toxicokinetic factors called clearance factors represent the volume of blood from which a substance is removed per unit time (L/kg/day). Clearance factors have been used to relate external doses (ng/kg/day) of PFOA and PFOS to steady-state serum levels (ng/L). When combined with average water ingestion rates (**USEPA 2023**), these clearance factors have been used to predict that the expected average increases in the levels of PFAS in blood serum from long-term drinking water exposure are at least 100-fold higher than the concentration in the drinking water (**Bartell 2017**; **NJDWQI 2017**; **Post, Gleason, and Cooper 2017**). See **Section 17.2.3.2** for more detail. Bartell (**2017**), **Lu and Bartell (2020)**, and **ATSDR (2022)** have developed online calculators that provide estimates of an individual's serum concentrations of PFOA, PFOS, PFNA, and PFHxS from the information that is entered, including drinking water levels of these PFAS and other relevant factors. It should be noted that these estimates are based on long-term exposure to a constant drinking water concentration and that serum PFAS concentrations are impacted

by interindividual variability in both toxicokinetic factors (for example, PFAS half-lives) and the daily drinking water ingestion rate.

Finally, toxicokinetics in rodents (**Loveless et al. 2006**; **De Silva et al. 2009**) and humans (**Zhang et al. 2013**; **Gao et al. 2015**; **Beesoon et al. 2011**) may differ among isomers of the same PFAA.

See **Section 17.2.3** for additional discussion of PFAS excretion and excretion rates, toxicokinetics relative to developmental exposure, the relationship of human exposure to serum levels, and isomer-specific toxicokinetics.

7.1.3 Human Epidemiology Studies

The epidemiological database for long-chain PFAAs, particularly PFOA and PFOS, is more extensive than for many other environmental contaminants. Many of the studies are recent, and the number of available studies is continually increasing. **USEPA (2023)** identified over 400 human epidemiology studies of PFOA and/or PFOS from searches of the following databases through February, 2022: Pub Med (National Library of Medicine); Web of Science (Thomson Reuters); ToxLine (incorporated into PubMed post 2019); and TSCATS (Toxic Substances Control Act Test Submissions). Many of these studies also evaluated other long-chain PFAAs and/or other PFAS. Some effects, such as changes in serum lipids, liver biomarkers, uric acid levels, thyroid endpoints, vaccine response, and fetal growth, have been evaluated in multiple studies and populations, while only one or a few studies were located for some other effects

These studies can be categorized based on the type of population evaluated: general population, communities with contaminated drinking water, or occupationally exposed workers. Almost all of these studies were published after 2009, with the exception of a small number of occupational studies from a few years prior to that time.

Although discussion of individual epidemiological studies is beyond the scope of this section and the corresponding appendix section, evidence for associations and/or causality for some PFAAs and certain health effects (for example, increased cholesterol, increased liver enzymes, decreased vaccine response, thyroid disease, and for PFOA, some types of cancer) has been evaluated by various academic researchers and government agencies. USEPA (**2023**; **2023**) has concluded that the noncancer human health effects with the strongest evidence for association with PFOA and PFOS are increased serum cholesterol, increased serum alanine aminotransferase (ALT; a marker of liver damage), decreased vaccine response, and decreased birth weight. **USEPA (2023)** has also concluded that PFOA is linked to testicular and kidney cancer in humans. The conclusions of some of these evaluations are discussed briefly below, with additional detail provided in **Section 17.2.4**.

For some health endpoints, including increased serum cholesterol, there is general consensus for consistent evidence for association with one or more long-chain PFAAs. Conclusions differ among evaluations by different groups of scientists for other endpoints, noting that the earlier evaluations considered fewer studies than the more recent evaluations. For additional endpoints, data are too limited to make a conclusion, results are inconsistent, or there is no evidence for an association. The general reviews cited in **Section 17.2.4** include detailed discussions of epidemiological data for PFOA, PFOS, and PFNA.

As shown in **Figure 7-1**, associations in human epidemiological studies of PFAAs (primarily PFOA and PFOS) for some endpoints (for example, increased liver enzymes, decreased fetal growth, decreased vaccine response) are consistent with animal toxicology studies (**Section 7.1.4**). For serum lipids (for example, cholesterol), observations of decreased cholesterol in rodents in some studies, while cholesterol is increased in humans, may result from the higher fat content in the diets of humans as compared to the diet used in most laboratory animal studies and/or large differences in the exposure

levels in human versus animal studies (**Tan et al. 2013**; **Rebholz et al. 2016** ; **NJDWQI 2017**; **USEPA 2023**).

Associations of some health endpoints with certain PFAAs are generally, although not totally, consistent, and some evaluations have concluded that the data for certain effects support multiple criteria for causality. Historically, risk-based toxicity factors (reference doses for noncancer effects and slope factors for cancer risk) developed by most government agencies are based on dose-response relationships from animal data, with the human data used to support the hazard identification component of toxicity factor development. One factor that has precluded the use of human data in the dose-response component of toxicity factor development is the concurrent exposure to multiple PFAAs in most or all study populations. Because serum levels of co-occurring PFAAs tend to correlate with each other, special modeling approaches must be used to determine the dose-response relationship for individual PFAAs, and the use of these approaches is currently increasing. That fact notwithstanding, **Hölzer, Lilienthal, and Schümann (2021)** and **Schümann, Lilienthal, and Hölzer (2021)** developed Human Biomonitoring Values (serum levels below which adverse effects are not expected) and the European Food Safety Authority (**EFSA 2020**) developed a Tolerable Weekly Intakes (TWI) of 4.4 ng/kg body weight for the sum of four PFAS (PFOA, PFOS, PFNA, and PFHxS) in food based on human data for decreased vaccine response from the general population. These values are lower than many of the values that are based on toxicity data from animals. More recently, California EPA and USEPA have developed reference doses for PFOA and PFOS (**CA OEHHA 2024**; **USEPA 2024; 2024**); cancer slope factors for PFOA (**USEPA 2024**; **CA OEHAA 2024**); and reference doses for PFHxS (**USEPA 2025**), PFDA (**USEPA 2024**), and draft reference doses for PFNA (**USEPA 2024)** based on human general population data that are far below current values for long-chain PFAS based on animal data.

The National Academies of Science, Engineering, and Medicine (**NASEM 2022**), at the request of ATSDR and the National Institute of Environmental Health Sciences (NIEHS), developed recommendations for testing for PFAS exposure and clinical monitoring for exposed individuals. ATSDR will consider these recommendations in updating its guidance to clinicians regarding PFAS. As part of its work, **NASEM (2022)** developed "strength of evidence" determinations based on human data for a variety of health effects that are collectively applicable to the total serum concentration of the seven PFAS (PFOA, PFOS, PFHxS, PFNA, PFDA, PFUnDA, and methyl-perfluorooctane sulfonamide [MeFOSA]) currently included in the CDC's National Report on Human Exposure to Environmental Chemicals (**CDC 2022**). The NASEM relied on risk-based assessments conducted by **EFSA (2020)** and the German Human Biomonitoring Commission (**2016**), (**2018**) to identify PFAS levels in serum or plasma to inform clinical care. The NASEM determined that: (1) adverse health effects related to PFAS exposure are not expected at PFAS serum levels less than 2 ng/mL; (2) there is a potential for adverse effects, especially in sensitive populations, for PFAS serum levels between 2 and 20 ng/mL; and (3) there is an increased risk of adverse effects for PFAS serum levels above 20 ng/ml. The NASEM recommended PFAS exposure reduction—if a source has been identified—for the two highest categories of PFAS serum concentrations. **NASEM (2022)** further recommended that clinicians should "offer PFAS [blood] testing to patients likely to have a history of elevated exposure," including those with potential occupational exposure and those who have lived in communities with known or potential PFAS contamination. The NASEM also recommended that clinicians conduct health screening for several health conditions when the sum of the seven PFAS in serum exceeds the recommended benchmarks. Also see the discussion of the NASEM document in **Section 7.1.8**, Regulation of PFAS as a Class.

See **Section 17.2.4** for additional discussion of epidemiologic studies that have been conducted on PFAS.

7.1.4 Animal Toxicology Studies

This section focuses on the most notable toxicological effects in mammalian studies of certain PFCAs, PFSAs, and PFECAs. All PFAS covered in this section for which data are available cause increased liver

weight; additional effects common to some of these PFAS include immune system, hematological (blood cell), and developmental toxicity, as well as more severe types of liver toxicity. Of the four PFAS that have been tested for carcinogenicity in rodents, PFOA, PFOS, and the GenX chemical HFPO-DA caused tumors while PFHxA did not.

In general, toxicity is dependent on both intrinsic potency of the compound (**Gomis et al. 2018**) and its toxicokinetics. Longer chain PFAAs are generally toxic at lower administered doses than shorter chain compounds because their slower excretion results in a higher internal dose from the same administered dose. Similarly, for those PFAS that are excreted much more rapidly in female rats than in males (**Section 7.1.2** and **Table 17-7**), higher doses in females than in males are needed to achieve the same internal dose.

Toxicological data from animal studies are used as the basis for many human health toxicity factors (for example, reference doses, cancer slope factors) for PFAS. However, as noted above, both California and the USEPA have based recent draft reference doses and/or cancer slope factors for on human data. Certain European toxicity factors are also based on human data (**Section 7.1.3**) (also see **Sections 8.3** and **9.1**). Unlike most other environmental contaminants, PFAS have been associated with health effects in humans at much lower exposure levels than the doses used in animal toxicology studies.

Table 17-8 Toxicological Effects Excel file provides information on toxicological effects in mammalian species (hazard identification information) for the following PFAS:

- PFCAs including PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, and PFDoA
- PFSAs including PFBS, PFPeS, PFHxS, PFHpS, and PFOS
- PFECAs including ADONA and the GenX chemical HFPO-DA.

Section 17.2.5.1 also summarizes information on systemic effects; reproductive and developmental effects, and chronic toxicity and tumorigenicity of these PFAS.

- Largest publicly available toxicological data sets for: PFOA and PFOS
- Considerable data for: PFBA, PFHxA, PFNA, PFDA, PFBS, and the GenX chemicals HFPO-DA and its ammonium salt
- One or a few studies for: PFHpA, PFUnA, PFDoA, PFHxS, and ADONA
- No toxicological data were located for PFPeA, PFTrDA, PFTeDA, PFPeS, PFHpS, PFNS, or PFDS.

Most toxicological studies of PFAS have been conducted in rats and mice, with a few studies in nonhuman primates (monkeys) and other species such as rabbits.

The National Toxicology Program (**NTP 2019**; **NTP 2019**) has conducted 28-day studies of seven PFAS (PFHxA, PFOA, PFNA, PFDA, PFBS, PFHxS, PFOS) in male and female rats that evaluated numerous toxicological endpoints and provided serum PFAA data for each dosed group; results of these studies are included in **Table 17-8 Toxicological Effects** Excel file. Although the doses at which effects occurred are not provided in this section or in the supporting appendix material, it is emphasized that No Observed Adverse Effect Level (NOAELs) and Lowest Observed Adverse Effect Level (LOAELs) vary widely between compounds for a given endpoint, between different endpoints for the same compound, and between species (and sexes in some cases) for the same compound and endpoint. Furthermore, the effects noted may not have been observed in all studies in which they were evaluated.

NTP (2020) has also conducted a chronic carcinogenicity study of PFOA administered in feed to rats that assessed the contribution of combined gestational and lactational (perinatal) exposure as compared to exposure beginning after weaning. It was concluded that there was clear evidence of carcinogenic activity in male rats based on the increased incidence of liver tumors and pancreatic acinar cell tumors, and some evidence of carcinogenic activity in female rats based on increased incidence of pancreatic acinar cell tumors. Non-neoplastic lesions were increased in the liver and pancreas in males and in the liver, kidney, forestomach and thyroid in females. There were very few significant differences in effects when exposure began in the perinatal period compared to when it began after weaning.

See **Section 17.2.5.1** for additional discussion of studies in animals that have evaluated the effects of these PFAS on noncancer and cancer endpoints.

There is increasing awareness and interest in potential human exposure to PFAS other than the PFAAs and the PFECAs, GenX and ADONA, that are discussed in **Section 17.2.5.1**. These include ether and polyether PFAS, dicarboxylic acid polyether PFAS, fluorotelomer alcohols, and fluorotelomer sulfonic acids. Information relevant to health effects of these additional PFAS is discussed in **Section 17.2.6.1**.

7.1.5 PFAS Mixtures

This section provides a summary of current toxicity-based approaches for addressing mixtures of PFAS and currently available information on toxicity of PFAS mixtures. This is an active area of research. Additional information is presented in **Section 17.2**.

Although humans are generally exposed to mixtures of PFAS, relatively few studies of the toxicity of PFAS mixtures, including defined mixtures (i.e., mixtures for which the identities and concentrations of the components are known) or complex mixtures (i.e., mixtures for which the identities and concentrations of the components are not fully characterized) such as AFFF, were located; they are summarized in **Section 17.2.7.2**. These include in vitro studies of nuclear receptor activation in cultured cells transfected with the receptor of interest, and toxicity in cultured cells; in vivo studies in zebrafish (a model species for human toxicity) and mammalian species; and epidemiologic studies of a population exposed to AFFF in drinking water.

7.1.5.1 Approaches for Assessing Toxicity of PFAS Mixtures

Multiple PFAS are present in the blood serum of almost all U.S. residents (**Section 7.1.1**), and PFAS often occur as mixtures of individual chemicals in the environment (for example, drinking water, fish, soil, and air). Therefore, approaches to assess the toxicity of PFAS mixtures are needed. Development of approaches for consideration of the health effects of mixtures of PFAS is a priority for USEPA, ATSDR, and other U.S. federal agencies, as discussed at a recent National Academy of Sciences (NAS) workshop on federal research on human health effects of PFAS (**NAS 2021**), and **USEPA (2023)** developed a draft framework for evaluation of non-cancer risk of PFAS mixtures that was reviewed by the **USEPA Science Advisory Board (2022)**. Approaches to assessing the toxicity of PFAS mixtures have also been the subject of several peer-reviewed publications (discussed below), including **Peters and Gonzalez (2011)**, **Bil et al. (2021)**, **Cousins et al. (2020)**, and **Goodrum et al. (2021)**. However, as discussed at the NAS workshop, relevant data on several aspects of this topic are limited. For example, there is a lack of information on in vivo and in vitro toxicity of PFAS mixtures, as well as on health effects in human populations when exposure to multiple PFAS has occurred (**NAS 2021**).

As is the case for mixtures of environmental contaminants in general, the toxicity of PFAS mixtures can be evaluated through studies of defined or undefined mixtures (mixtures of known concentrations of individual PFAS or complex mixtures that may include both known and unidentified PFAS, respectively). The small database of currently available toxicity studies of PFAS mixtures is summarized in **Section 17.2**. These include a few studies of the undefined PFAS mixtures found in AFFF and a limited number of

studies of defined PFAS mixtures, including in vitro studies of nuclear receptor activation in transfected cultured cells, and toxicity studies in cultured cells and zebrafish. Notably, no rodent or primate studies of defined mixtures of PFAS were located. When evaluating exposure and health effects for PFAS mixtures in drinking water or other media, it must be emphasized that identification of the PFAS that are present is dependent both on the composition of the mixture and the suite of PFAS detected by the analytical method that was used (**McDonough et al. 2019**). Methods currently used for routine analysis are described in **Section 11.2**. Additional analytical methods (for example, nontarget analysis) that are primarily used in research studies can identify numerous additional PFAS not currently included in standard methods.

As discussed in USEPA and ATSDR guidance for risk assessment of mixtures (**USEPA 1986**; **USEPA 2000**; **ATSDR 2018**), toxicological interactions among components of a mixture may include dose additivity, response additivity, synergism, and antagonism. Dose additivity is based on the assumption that the chemicals in the mixture have the same mode of action (MOA) and cause the same effects, and differ only in potency. The components are assumed to have similarly shaped dose-response curves, and the effect caused by the mixture is assumed to be the sum of the effects caused by each of the individual chemicals present. Because MOA information for PFAS is incomplete, the final **USEPA (2024)** framework for evaluation of risks of PFAS mixtures assumes dose additivity based on similarity of toxicological endpoint/health effects without requiring a common MOA. Response additivity is based on the assumption that the toxic effect of a mixture can be predicted by summing the doses of each chemical in the mixture (relative to each chemical's critical effect dose) such that the contribution from each chemical to the overall effect of the mixture is not influenced by the other chemicals. For example, when assuming additivity, the sum of the incremental cancer risks of multiple individual co-occurring carcinogens can be used to estimate the total cancer risk of the mixture. Toxicological interactions of components of mixtures may also be synergistic (greater than additive) or antagonistic (less than additive), resulting in larger or smaller effects than would occur with dose additivity or response additivity.

As discussed in this section, currently available toxicological information for PFAS does not clearly support a specific approach for conducting risk assessments of PFAS mixtures. While the toxicological effects of many PFAS are generally similar, the most sensitive toxicological endpoints may vary among PFAS. Additionally, multiple MOAs for PFAS toxicity are likely; these MOAs appear to be complex, and currently are not well understood. Furthermore, the MOA for a specific PFAS may not be the same for all effects (for example, hepatic toxicity, developmental toxicity), and a specific effect may not occur through the same MOA for all PFAS (for example, different MOAs for liver toxicity of PFOA and PFOS; **Peters and Gonzalez 2011**; **NAS 2021**). In the limited number of studies of PFAS mixtures, additive, synergistic, and antagonistic interactions among PFAS have been observed. As noted by **Wolf et al. (2014)**, toxicological interactions of PFAS are dependent on the identities and concentrations of the PFAS in the mixture, the biological model, and the endpoint being evaluated (see **Section 17.2**).

Some regulatory agencies consider the cumulative toxicity of PFAS that co-occur in environmental media, while other agencies consider PFAS individually as required by their regulatory process and/or the scientific uncertainty as to whether co-occurring PFAS are sufficiently similar to consider them as a group. Several approaches that have been proposed to address the toxicity of PFAS mixtures are discussed in **Section 17.2.7.1**. The goal of these approaches is to facilitate the risk assessment of PFAS mixtures detected at contaminated sites and to develop health-protective guidelines that potentially account for the combined effects of multiple PFAS. Some general approaches for assessing the cumulative effects of exposure to PFAS, as related to site risk assessment, are discussed in **Section 9.1.3.1**. Examples of the application of such approaches to PFAS are reviewed by **Cousins et al. (2020)**, who also provided a "summary of existing or proposed grouping approaches based on the sum of various PFAS in drinking water." Most of the approaches that have been proposed assume dose additivity, although scientific uncertainties are associated with this assumption, as discussed above and in **Section 17.2.7.1**.

7.1.5.2 Toxicology Studies of PFAS Mixtures

The relatively few studies of the toxicity of defined mixtures of PFAS that were located are summarized in **Section 17.2.7.2**. These include in vitro studies of nuclear receptor activation in cultured cells transfected with the receptor of interest, toxicity in cultured cells and zebrafish (a model species for human toxicity), and a few mammalian studies.

7.1.6 Evaluating PFAS using New Approach Methodologies

Traditional toxicity testing methods using in vivo mammalian models are time-, cost-, and labor-intensive. As noted in **Section 17.2.8**, including **Table 17-8 Toxicological Effects** Excel file, mammalian (most commonly rodent) toxicity information is available for only a relatively small group of PFAS, including a number of long- and short-chain PFCAs and PFSAs, certain fluorotelomer alcohols and fluorotelomer sulfonates, and several of the per- and polyfluoroether replacements, with PFOS and PFOA having the most extensive data sets. Under current USEPA risk assessment guidelines used by most states, in vivo mammalian laboratory animal or human data are required for development of chemical-specific toxicity factors (for example, reference doses) used as the basis for standards and guidance values for PFAS in drinking water and other environmental media. It is therefore important that in vivo mammalian data continue to be made available for those PFAS with a high level of public health concern, such as those detected at elevated concentrations in drinking water. However, in vivo mammalian studies are not feasible for all of the individual PFAS, of which there are thousands (**USEPA 2020**). Additionally, USEPA aims to refine and reduce the use of mammalian species in toxicology testing and to use non-animal testing methods when appropriate. With the goal of rapidly generating toxicity, MOA, toxicokinetic, and exposure information on PFAS and reducing the use of mammalian species in testing, the USEPA is collaborating with the National Toxicology Program (NTP) of the National Institutes of Environmental Health Sciences through the REACT (Responsive Evaluation and Assessment of Chemical Toxicity) Program. New Approach Methodologies, such as rapid toxicity assays in cultured cells and zebrafish, in silico (computational) approaches, and high throughput exposure modeling are being developed and used with the goal of generating data that will inform toxicology and risk assessment of PFAS (**Patlewicz et al. 2019**; **USEPA 2019**, **2019**). More information on this effort is provided in **Section 17.2.8**.

7.1.7 Regulation of PFAS as a Class

Recent estimates could have the total number of individual PFAS at more than 12,000 (see **Section 2** and **USEPA 2020**). Although not all of these PFAS are commercially important, more than 3,000 individual PFAS have been found in European commerce (**OECD 2018**), and approximately 4,700 PFAS are in the current global marketplace (**Cousins et al. 2020**). Of these, **Buck et al. (2021)** reported that 256 PFAS are commercially relevant on a global basis. Fewer than 20 PFAS are well-studied toxicologically (all of which are nonpolymer PFAS), and all of those that have been studied have been found to be capable of causing adverse effects in animals and/or humans (Sections **7.1**, **7.2**, and **17.2**). The Priority Topics for Human and Ecological Health Effects include additional considerations for addressing PFAS as a class (see **Section 1.4.5**).

Because substantial time and resources are required to adequately characterize the chemical and physical properties and potential adverse effects of an individual chemical (for example, **NTP, 2022**), the conclusion that it is neither feasible nor health-protective to follow the “chemical-by-chemical” regulatory paradigm for PFAS has gained increasing acceptance. Beginning with the Helsingør Statement (**Scheringer et al. 2014**) and continuing with the Madrid Statement (**Blum et al. 2015**) and Zurich Statement (**Ritscher et al. 2018**), groups of scientists and others have called for the coordinated regulation of all PFAS, citing their persistence, widespread use, and frequent lack of toxicity data, among other concerns. The FluoroCouncil (**Bowman 2015**) took issue with the Madrid Statement (**Blum et al. 2015**) for failing to acknowledge the fact that “fluorotechnology is essential technology,” and for ignoring

scientific information that indicates differences in persistence and toxicity between long- and short-chain PFAAs and the efforts of industry to limit environmental impacts of PFAS.

One of the various regulatory strategies proposed by **Blum et al. (2015)**, **Ritscher et al. (2018)**, and subsequently by **Cousins et al. (2019)**, is to limit ongoing uses of PFAS to those PFAS deemed to be "essential." **Cousins et al. (2019)** proposed that essential uses of PFAS are those "uses considered essential because they are necessary for health and safety or other highly important purposes and for which alternatives have not been established." Examples of essential uses are certain medical devices and occupational protective clothing (**Cousins et al. 2019**). **The European Commission (2020)** developed a strategy to phase out the use of PFAS in the European Union "unless it is proven essential for society." Similarly, while noting that "a ban on all PFAS as a group is neither practical, necessary, nor achievable," the **Royal Society of Chemistry (2021)** supported the concept of essential use for those PFAS defined as "vital or highly desirable by wider society." Other publications have also supported the concept of "essential use" as a regulatory strategy for PFAS (**Kwiatkowski et al. 2020**; **Dean et al. 2020**), with **Gluge et al. (2022)** describing the information requirements and analyses necessary to regulate PFAS under the concept of essential use.

Kwiatkowski et al. (2020) also emphasized the importance of eliminating nonessential uses of PFAS as an example of a class-based approach to PFAS regulation. Other class-based regulatory strategies cited by **Kwiatkowski et al. (2020)** include banning PFAS in certain product categories; prioritizing research and development funding for treatment and disposal/destruction methods that are targeted to (and effective for) PFAS as a class; and development of class-based cleanup standards so that all PFAS—not just a few—are remediated.

7.1.7.1 Grouping Strategies

The Zurich Statement (**Ritscher et al. 2018**) and others (**Cousins et al. 2020**; **Anderson et al. 2022**) have considered the utility of and strategies for grouping PFAS for more effective regulation, as distinct from treating all PFAS as a single class. **Cousins et al. (2020)** offered a number of potential bases for grouping PFAS, with the selected method depending on whether the intended action is to regulate based on intrinsic properties or to inform risk assessment. Each of the proposed grouping methods has different data requirements, advantages, and disadvantages (see **Cousins et al. 2020**). Examples of the grouping methods proposed by **Cousins et al. (2020)** are summarized in **Table 7-1**.

As described in its National PFAS Testing Strategy, the **USEPA (2021)** is working to understand the impacts of different categories of PFAS, in part to identify which PFAS will require testing under the Toxic Substances Control Act authority. The PFAS categorization will also support the prioritization of individual PFAS or "classes" of PFAS for additional research on human exposure or toxicity. The USEPA's categorization of PFAS is based on similarities in structure, physical-chemical properties, and toxicological properties. The USEPA plans to use these categories for hazard assessment and to support risk-based decision making and will also develop categories of PFAS based on removal technologies. The USEPA will draw on information from both of these approaches to prioritize research.

Anderson et al. (2022) considered several options for grouping of PFAS for the purpose of protecting human health from drinking water exposure and assessing risks of PFAS mixtures. No single grouping strategy was identified that was "sufficient" for all regulatory or public health risk assessment purposes. However, the study authors generally supported the conclusions that: "Not all PFAS should be grouped together, persistence alone is not sufficient for the purposes of assessing health risk, and that the nature and definition of the subgroups can only be defined on a situation-dependent and case-by-case manner" (**Anderson et al. 2022**).

A recent review of the properties of fluoroplastics and fluoroelastomer—two types of fluoropolymer—concluded that based on their high molecular weight, lack of biological availability, and other physical and

chemical properties, these PFAS are a distinct group of PFAS that "should not be grouped with other PFAS for hazard assessment or regulatory purposes" (**Korzeniowski et al. 2022**).

Table 7-1. Grouping approaches for PFAS (excerpted and adapted from Cousins et al. 2020, CC BY-NC 3.0).

	Individual approaches	PFAS grouped	Data requirements
Approaches based on intrinsic properties	P-sufficient approach[1]	All PFAS	None
	According to PBT/vPvB[2]	PFAS that are bioaccumulative	Bioaccumulation potential
	According to PMT/vPvM[2]	PFAS that are mobile in water	Water solubility
	Polymers of low concern (PLC)	Some fluoropolymers	Polymer composition, molecular weight, other properties
Approaches that inform risk assessment	Arrowhead[3]	Specific PFAAs and precursors	Degradation schemes
	Total organofluorine	Extractable or adsorbable PFAS	None
	Simple additive toxicity	2-20 PFAS, currently primarily PFAAs	Toxicity
	Relative potency factor	Multiple PFAAs	Toxicity, potency, toxicokinetics
	Grouping PFAS with similar adverse effects, mode of action, toxicokinetic	Limited PFAAs	Toxicity, mode of action, toxicokinetics

[1] P-sufficient = grouping based on the persistence of perfluoroalkyls and on the formation of perfluoroalkyls as stable end products of precursor polyfluoroalkyls.
[2] PBT = persistent, bioaccumulative, toxic; vPvB = very persistent and very bioaccumulative; PMT = persistent, mobile, and toxic; vPvM = very persistent and very mobile.
[3] Arrowhead = "when a representative PFAS, usually a PFAA, is managed together with its salts and precursors."

California's Department of Toxic Substances (DTSC) regulates PFAS as a class by prohibiting the sale of select consumer products if the product contains any PFAS and an Alternatives Analysis has determined that there are viable replacements. Supported by specific California laws that define environmental persistence and toxicity as hazard traits warranting regulation, the DTSC considers that (1) all PFAS or their degradation, reaction, or metabolic products are environmentally persistent, and (2) "nearly all" PFAS exhibit other hazard traits as defined by California law, including toxicity (**Balan et al. 2021**). PFAS-containing product categories that DTSC has identified for regulation include (1) carpets and rugs with perfluoroalkyl or polyfluoroalkyl substances, (2) treatments containing perfluoroalkyl or polyfluoroalkyl substances for use on converted textiles or leathers, such as carpets, upholstery, clothing, and shoes, and (3) plant fiber–based food packaging containing perfluoroalkyl or polyfluoroalkyl substances (**https://dtsc.ca.gov/scp/**). In August 2022, California's legislature banned the use of any PFAS "intentionally added" to a cosmetic product manufactured, sold, or delivered into the state of California. The text of the legislation cites the "highly toxic" and "highly persistent" "class of chemicals known as PFAS" (**California Assembly 2022**).

The National Academies of Science, Engineering, and Medicine (**NASEM 2022**) developed "strength of evidence" determinations collectively applicable to the seven PFAS currently included in the CDC's National Report on Human Exposure to Environmental Chemicals (**CDC 2022**) for each health effect that they considered, while recognizing that differences exist among these PFAS. Specifically, the **NASEM (2022)** stated: "Most people are exposed to mixtures of PFAS such that specific effects are difficult to disentangle. Considering these issues, and recognizing that some PFAS are infrequently measured, the committee provided one strength-of-evidence determination for all PFAS for each health effect, recognizing that providing one conclusion across PFAS may not account for the distinct physical, chemical, and toxicological properties of each type of PFAS."

The European Chemicals Agency (ECHA) proposed to restrict all per- and polyfluoroalkyl substances with a single regulation (**ECHA 2023**). The proposed regulation cites concerns that "all PFAS" are "very

persistent" in the environment and may adversely affect the health of humans and the environment. **ECHA (2023)** observed that if the proposal is put into effect, it would prevent the release of around 4.4 million tons of PFAS over a 30-year period.

In February 2023, Health Canada proposed to regulate all PFAS in drinking water that can be quantified with U.S. EPA Method 533, Method 537.1, or both. The sum of total detectable PFAS will be required to be no more than 30 ng/L, based on potential health effects from exposure to this group of PFAS in drinking water (**Health Canada 2023**).

7.1.8 PFAS Inhalation Toxicity

This section provides an overview of available information on inhalation exposure and toxicity of PFAS. While exposure to PFAS via inhalation can potentially occur both outdoors and indoors, most of the exposure studies that were identified focused on residential and nonresidential indoor environments. A review by **Savvaides et al. (2021)** reported that, in the available studies, the profile of PFAS detected in indoor air varied in different indoor environments and in different seasons of the year in the same location. The Priority Topics for History, Use, and Naming Conventions include information about less-studied PFAS (see **Section 1.1.3**) including ultrashort PFAS, volatile PFAS, and fluorinated gases. **Section 1.4.4** includes information about health effects of ultrashort PFAS. See also the **PFAS and Vapor Intrusion Fact Sheet** developed in 2025.

In general, inhalation exposure considerations differ for ionized (negatively charged) PFAS [(for example, PFAAs such as PFOA and PFOS, and perfluoroether carboxylates such as HPFO-DA, which have low volatility and occur primarily in indoor (for example, house) dust], as compared to neutral PFAS [(for example, FTOHs, FOSAs, and FOSEs), which are much more volatile and tend to occur in the vapor phase] (**Table 4-1**; **De Silva et al. 2021**). For this reason, the negatively charged and neutral PFAS are discussed in separate sections below. For example, **Shoeib et al. (2011)** and **Ericson Jogsten et al. (2012)** reported that PFAAs and neutral PFAS were both found in residential environments. However, the concentration of neutral PFAS was higher than PFAAs in residential indoor air while the concentration of PFAAs in house dust was higher than neutral PFAS. Furthermore, **Gustafsson et al. (2022)** reported that the total concentration of PFAS and the distribution of specific PFAS varied in different size fractions of house dust. The highest total PFAS concentration was found in the smallest particles, which represent the respirable fraction, while PFCAs were highest in the largest and smallest particles, with lower concentrations in the intermediate-size particles. Information about media-specific occurrence studies is included in **Section 6**.

Some neutral PFAS are "precursors" (i.e., PFAS that can be metabolized or otherwise degraded to form terminally stable PFAAs), so that inhalation exposure to PFAAs may occur both through "direct" and "indirect" pathways. For example, **Gomis et al. (2016)** characterized the contribution of "direct" exposure to PFOA and "indirect" exposure to 8:2 FTOH to the total serum PFOA concentrations in ski waxers exposed to PFAS via inhalation, and **Chang et al. (2017)** reported the metabolism of EtFOSE to PFOS in rats exposed via inhalation.

Although this section does not focus on development of reference concentrations and unit risk factors for inhalation exposure, it is noted that **ECOS (2024)** provides information on inhalation toxicity factors for PFAS that have been developed by some states. In general, inhalation toxicity studies that can be used to develop toxicity factors are not available for PFAS, and these inhalation toxicity factors are based on oral toxicity data and route-to-route (oral-to-inhalation) extrapolation; a recent publication (**Monnot et al. 2022**) supports this approach.

7.1.8.1 Negatively Charged PFAS

As mentioned above, negatively charged PFAS such as PFAAs and perfluoroether carboxylates (for example, HPFO-DA) are not highly volatile. The primary route of occupational exposure to PFAAs is "likely [to be] inhalation of aerosols complexed with airborne dusts," and elevated serum PFAA levels in occupationally exposed individuals indicates that absorption occurs via inhalation (**ATSDR 2021**). A major contributor to inhalation exposure to negatively charged PFAS in the general population is indoor dust containing PFAS that originates from consumer products (for example, treated carpets and furniture) and other potential sources; such dust can also contain neutral PFAS (**Savvaides et al. 2021**). Although exposure to dust can occur through direct ingestion, dust can also be inhaled and then swallowed after being trapped in mucous in the respiratory tract (**USEPA 2017**). Floor-stripping and waxing were also reported as sources of PFAAs in airborne particulate matter ($PM_{2.0}$; **Zhou et al. 2022**).

Depending on the individual chemical, there are limited or no laboratory animal data on the inhalation toxicity of negatively charged PFAS, including those with a large number of oral toxicology studies in laboratory animals. For example, ATSDR and/or USEPA toxicity evaluations cite two acute, one short-term, and one developmental rat inhalation study of PFOA (**ATSDR 2021**; **USEPA, 2016**), and a single acute rat inhalation study for each of three additional PFAS: PFNA **(ATSDR 2021**); PFOS (**USEPA 2016**); and GenX (**USEPA 2021**). In these inhalation studies, exposure was via aerosols or dust. No additional inhalation studies for PFOA or PFOS were identified in more recent draft USEPA evaluations (**USEPA 2023; 2023**), and no inhalation toxicity studies were identified by **ATSDR (2021)** for PFBA, PFHxA, PFHpA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, or PFOS, or by USEPA for PFBS (**USEPA 2021**), PFBA (**USEPA 2022**), or PFHxA (**USEPA 2023**).

In toxicokinetic studies, PFOA was detected in the blood serum of rats after inhalation exposure via aerosols (**Hinderliter 2003**; **Hinderliter, DeLorme, and Kennedy 2006**). However, little data are available on extent of absorption for inhalation vs. oral exposure, and an analysis by the Michigan Department of Environmental Quality (**MI DEQ 2018**) of PFOA data from Hinderliter, DeLorme, and Kennedy (**2006**) demonstrated that the relative extent of absorption from inhalation versus oral exposure was not constant over the concentration range in the study. Inhalation exposure to PFOA, PFOS, and PFNA caused systemic effects similar to oral exposure, including hepatic toxicity (**PFOA–Kennedy et al. 1986**; **Staples et al. 1984**; **PFNA–Kinney, Chromey, and Kennedy 1989**; **PFOS–Rusch, Rinehart, and Bozak 1979**) and decreased neonatal body weight after gestational exposure (**Staples et al. 1984**). Nasal and/or eye irritation, and/or respiratory effects, were also reported from acute exposure to relatively high concentrations of PFOA (**Rusch 1979**; **Griffith and Long 1980**; **Kennedy et al. 1986**), PFNA (**Kinney, Chromey, and Kennedy 1989**), PFOS (**Rusch, Rinehart, and Bozak 1979**), and GenX (**DuPont 2009**).

7.1.8.2 Neutral PFAS

Neutral PFAS such as FTOHs, FOSA, and FOSE are more volatile than negatively charged PFAS. They have been found in the vapor phase in indoor environments, including residences, classrooms and offices, outdoor gear/apparel and carpet stores, and ski waxing facilities (**Shoeib et al. 2011**; **Morales-McDevitt 2021**; **Gomis et al. 2016**), and inhalation can be a primary human exposure route (**De Silva et al. 2021**). Furthermore, **Titaley et al. (2022)** reported high concentrations of neutral PFAS in AFFF and predicted that vapor intrusion of these PFAS will occur from AFFF-contaminated groundwater.

The toxicokinetics of 6:2 FTOH and 8:2 FTOH in rats were reported to be similar after inhalation and oral exposure, including systemic absorption and the profile of metabolites formed (**Himmelstein et al. 2012**). As discussed in **Section 17.2.6.2**, metabolites of FTOHs include terminal PFCAs (for example, formation of PFHpA, PFOA, and PFNA from 8:2 FTOH), as well as persistent toxic metabolites in some cases (for example, 5:3 FTA from 6:2 FTOH) (**Kabadi et al. 2020**). Although no inhalation toxicology studies of FTOHs in laboratory animals were identified, the similarity in inhalation and oral toxicokinetics, including metabolite profiles, suggests that systemic toxicity is likely similar from both exposure routes. Similarly,

although no inhalation toxicity studies of FOSA or EtFOSE were identified, FOSA was reported to be metabolized to PFOS in humans believed to be exposed through inhalation (**Olsen et al. 2005**) and EtFOSE was metabolized to PFOS in rats (**Chang et al. 2017**).

7.1.9 Data Gaps and Research Needs

Although many studies relevant to health effects of PFAAs have become available in the last few years, important data gaps remain for most of the PFAAs and PFECAs discussed here and in **Section 17.2**, as well as for many additional PFAS used in commerce or found in AFFF. The data gaps (discussed in more detail in **Section 17.2.9**) include:

- Human half-lives and other toxicokinetic data are not available for some PFAS found in drinking water and other environmental media.
- Currently available data indicate that reactive intermediates may form in the body from the metabolism of PFAA precursors to PFAAs. More studies are needed to understand the toxicologic significance of these intermediates.
- Data on absorption and toxicity of PFAS via dermal contact and inhalation are very limited, and more studies to characterize these exposure routes are needed.
- There are relatively few epidemiological studies of communities exposed to AFFF, PFOS, and/or other PFAS in drinking water. Although a number of studies of associations of PFAS with a variety of health effects have recently been reported for populations exposed to AFFF-contaminated drinking water in Sweden (**Section 17.2.4**), more such studies from other locations are needed.
- Additional toxicology data are needed for some PFAAs found in environmental media, including drinking water. In particular, very little toxicologic data are available for PFHpA, and no information was located for PFPeA.
- There is also a need for additional toxicological studies on the effects of PFAS mixtures in that although humans are exposed to multiple PFAS, information on toxicological interactions of PFAS is limited.
- Multigenerational studies of the reproductive and developmental effects of additional PFAS are needed.
- Chronic toxicity and carcinogenicity studies are currently available for only four PFAS (PFHxA, PFOA, PFOS, GenX), and are needed for PFHxS, PFNA, ADONA, and other PFAS to which humans may be exposed.
- The majority of the many thousands of PFAS, including those in commercial use, have very limited or no toxicity data. This is a critical data gap in health effects information for PFAS.
- Similarly, current NHANES biomonitoring in blood serum includes only 11 PFAS, primarily PFAAs, and breast milk biomonitoring data for these PFAS are limited. There is limited or no biomonitoring data in blood serum or breast milk for many other PFAS produced or used in the United States, some of which are known to be bioaccumulative in humans.
- Information on PFAS in powdered and prepared infant formula are extremely limited. Monitoring data for formula are needed to understand this potentially important source of exposure to infants.

- Little is known about how racial or socioeconomic differences may affect susceptibility to the adverse effects of PFAS exposure. Studies are needed to address this.

7.2 Ecological Toxicology

This section is organized around currently available toxicity information for invertebrates (aquatic/benthic/terrestrial), vertebrates (fish, birds, reptiles/amphibians, mammals), and plants. Toxicological data can be obtained from a general literature review as well as by querying of the USEPA Ecotox Database (**USEPA 2023**). As discussed below, this is an active area of research, and interested readers are encouraged to query the literature for updated research and reviews, such as the Environmental Toxicology and Chemistry Special Issue on Understanding Environmental Risk from Exposure to Per- and Polyfluoroalkyl Substances (PFAS; Vol 40, Issue 3, March 2021 https://setac.onlinelibrary.wiley.com/toc/15528618/2021/40/3); **Argonne 2021**; **Zodrow et al. 2021**; and **Divine et al. 2020**. There are also much data available for PFOS and PFOA toxicity that were used to derive the USEPA's draft Aquatic Life Ambient Water Quality Criteria (**US EPA 2022**).

It is important to note that this section is not intended to represent an exhaustive review of PFAS ecological toxicology (referred to herein as "ecotoxicity") studies. Ecotoxicity of PFAS is an area of active research, with new information emerging regularly. Toxicological effects of apical endpoints presented and discussed herein are generally those considered most relevant to ecological communities—mainly survival, growth, and reproduction. Both acute and chronic exposure studies are discussed in this section. Although data have been generated for other toxicological endpoints, these studies are not the focus of this section, but may occasionally be referenced. Application of these data in ecological risk assessment is discussed in **Section 9.2**. The Priority Topics for Human and Ecological Health Effects include information for evaluating risk to livestock from PFAS exposure (see **Section 1.4.7**). The Priority Topics for Firefighting Foams include information about fluorine-free firefighting foam ecotoxicity (see **Section 1.2.2**).

7.2.1 Introduction

Biomonitoring studies across a variety of organisms, habitats, and geographies show that certain PFAS can accumulate in wildlife and that exposures are occurring on a global scale (**Reiner and Place 2015**; **Giesy and Kannan 2001**[]). Therefore, it is important to understand how PFAS exposure and bioaccumulation may manifest in adverse effects, particularly as these effects relate to ecological communities. Information on bioaccumulation of PFAS is addressed in **Section 6.5**. This section provides an overview of resources available and some published toxicological data relating exposure of PFAS to toxic effects on aquatic, benthic, and terrestrial organisms, with the goal of broadening the reader's understanding of known or potential effects in ecological systems, as well as highlighting areas where more data are needed. This information can also be applied for use in ecological risk assessments (ERAs), particularly because the ecological risk of PFAS is currently neither well understood nor uniformly assessed or regulated. However, the reader is encouraged to review the primary source literature from which cited ecotoxicity values have been derived to confirm and understand the basis and assumptions of the cited literature before using information obtained from this section in an ERA.

This review shows that ecotoxicity data are available for certain PFAS, particularly for PFOA and PFOS, with most studies focused to date on aquatic invertebrates. Although there are numerous studies on PFAS exposure in terrestrial vertebrates (for example, mammals, reptiles, birds), and ample toxicological studies in laboratory animals, there is, overall, relatively little to no ecologically relevant toxicity data for terrestrial vertebrates in the wild (though this is currently being investigated for avian receptors; see SERDP ER22-3202, https://serdp-estcp.org). Although some mechanistic studies have been conducted with aquatic organisms, little has been done with other organisms and even less has been done with different classes of PFAS in aquatic and terrestrial wildlife. However, see research funded under SERDP's

Statement of Need (SON): Improved Understanding of the Ecotoxicity of Mixtures of Per- and Polyfluoroalkyl Substances (ERSON-22-C1) for projects investigating mechanisms of PFAS toxicity and accumulation in aquatic and terrestrial receptors.

The focus of most ecotoxicity studies to date has been primarily on PFOS and PFOA. Therefore, most of the data discussed and summarized in this section are for those two compounds. However, data for other PFAS, including short-chain PFAS and precursors (**Section 2.2**), are also presented where available. Given the historical differences among older analytical methods and more recent advances in analyzing PFAS, the focus of the ecotoxicity studies covered in this review is generally on those published from approximately the year 2000 and later.

In general, single-chemical PFAS exposure studies indicate that the sensitivity of invertebrates to PFAS exposure can be chemical-specific and vary by organism and environmental factors (for example, see **Lewis et al. 2022**). Published studies of the toxicity of PFAS mixtures are available (**Section 17.2.7.2**), but the understanding of PFAS mixtures toxicity remains uncertain at this time. Risk assessment implications of exposure to mixtures are discussed further in **Section 9.2.1.3**. There is a paucity of field studies for avian and mammalian wildlife species, and confounding factors such as the co-occurrence of other stressors (other pollutants, physical stressors, etc.) makes it difficult to definitively associate PFAS exposure with adverse outcomes (**Custer 2021**). There are a handful of avian studies on multiple species that investigate egg hatching outcomes and potential correlations to PFAS exposures (**Custer et al. 2014**; **Groffen et al. 2019**; **Tartu et al. 2014**), and field-based effects studies on mammals are difficult to find (**ECCC 2018**). However, laboratory animal studies (see **Section 7.1**) suggest potential relationships between PFAS tissue concentrations and immunological, hematological, liver, kidney, and reproductive effects (**DeWitt 2015**; **ECCC 2018**).

Data from biomonitoring studies (see **Section 5.5**) indicate that PFAS exposure is occurring in wildlife; however, the lack of toxicity data for this group of organisms represents a significant data gap. This highlights the need for additional study of this class of compounds in general, as well as the need for expansion of toxicity studies to a larger group of PFAS and to a greater variety of taxa, and for field studies that may assess population-level effects.

Relative aquatic toxicity for PFAS is discussed in the following sections using descriptive criteria developed by the USEPA within their Design for the Environment Program for the Alternatives Assessments and the Safer Choice Program (**USEPA 2011**; **USEPA 2015**). These criteria are expressed as relative toxicity based on effects concentrations ranging from less than 0.1 mg/L (very high toxicity) to greater than 100 mg/L (low toxicity); criteria are provided in **Table 7-2**.

Table 7-2. Aquatic toxicity classification criteria (USEPA 2011) (in mg constituent/L water).

Toxicity	Very High	High	Moderate	Low	Very Low
USEPA: Aquatic Toxicity (Acute, LC_{50})	<1.0	1–10	>10–100	>100	NA
USEPA: Aquatic Toxicity (Chronic, LOEC)	<0.1	0.1–1	>1–10	>10	NA

7.2.2 Invertebrates

7.2.2.1 Aquatic

Aquatic invertebrates may be exposed to PFAS by direct contact with PFAS in the water column, as well as via the diet, including trophic transfer and particle ingestion. There are more toxicity data available for PFOS than for other PFAS. PFAS have a very wide range of toxicities to aquatic organisms under acute exposure scenarios following the USEPA Hazard Criteria (**Table 7-2**), but overall, they would be classified as having moderate to low toxicity to invertebrates. One exception with this generalization is that of

mussel exposures to PFOS and PFOA in the marine environment, where no effect was seen at 0.00001 mg/L but a LOEC was reported at 0.0001 mg/L (**Fabbri et al. 2014**); this would result in classification as a very high hazard using the USEPA Hazard Criteria. With the current body of literature, the sensitivity of marine invertebrates to PFOS and PFOA appears equivocal.

Given that PFAS are persistent pollutants, chronic exposure scenarios are most relevant for aquatic receptors. Importantly, compared to acute studies, there are relatively few chronic studies in aquatic invertebrates. Most chronic effects data are for PFOS and PFOA. Life cycle tests with multiple taxa have been conducted to evaluate the chronic toxicity of PFOS to freshwater aquatic invertebrates. The chironomid (*Chironomus tentans*) is currently reported as having the greatest sensitivity to chronic exposure, with reduced total emergence reported at 0.0023 mg PFOS/L (**MacDonald et al. 2004**). More recent studies, including **McCarthy et al. (2021)**, show impairment on survival in the chironomid (*C. dilutus*) at even lower concentrations, with EC10 and EC20 values in 20-day tests for PFOS at 1.4 and 1.7 ug/L, respectively. Studies by **Bots et al. (2010)** and **Van Gossum et al. (2009)** indicated that damselflies (*Enallagma cyathigerum*) may also be similarly sensitive to PFOS, with NOEC and LOEC values of 0.01 and 0.1 mg/L, respectively. In the marine environment, a life cycle toxicity test with the saltwater mysid (Mysidopsis bahia) yielded a NOEC of 0.24 mg PFOS/L based on growth and number of young produced (**Drottar and Krueger 2000**).

Some PFAS may potentially cause adverse effects in aquatic invertebrates that span across multiple generations. **Marziali et al. (2019)** evaluated generational effects in chironomids (*C. riparius*); each generation was exposed to a nominal concentration of 0.01 mg/L of PFOA, PFOS, and PFBS; all treatments showed reduced growth in at least several generations, with no observed induced tolerance to the studied PFAS. However, potential effects at the population level were not demonstrated in this study based on similar population growth rates between treatments and controls, suggesting that toxicity risk to an ecosystem is unlikely (**Marziali et al. 2019**).

Benthic Organisms and Sediment Toxicity

Toxicity to benthic (sediment-dwelling) organisms is generally the result of exposure to the chemical in overlying water, sediment, and porewater, including trophic transfer and sediment particle ingestion (**Zareitalabad et al. 2013**). There are relatively few published sediment toxicity studies on PFAS exposure to benthic invertebrates compared to those for aquatic invertebrates. The **UK Environment Agency (2004)** provided a freshwater sediment screening value of 0.0067 mg/kg (wet weight), based upon a predicted no-effect concentration (PNEC) of 2.5 µg/L and a river sediment K_d of 8.7 L/kg. Note, however, that sediment screening values based on K_d may not be applicable across all sites. **Section 9.2** (Ecological Risk Assessment) discusses application of K_d in deriving sediment screening values.

Additionally, **Bakke et al. (2010)** provided PFOS concentration ranges for marine sediment quality classified as background, good, moderate, bad, and very bad. The PFOS threshold for “good” sediment, for which no toxic effects are expected, was reported as 0.22 mg/kg. This value, however, is based on an aquatic PNEC of 72 µg/L derived from a limited data set and an unspecified Kd value, and thus is not a reliable concentration with which to predict toxic effects. More recently, **Simpson et al. (2021)** conducted a multimedia acute and chronic study on a variety of marine/estuarine invertebrates (including an amphipod, a copepod, a crab, and two species of bivalve) that included PFOS-spiked sediment toxicity tests. **Simpson et al. (2021)** found that PFOS significantly decreased survival and/or reproduction for the amphipod (Melita plumulosa) at sediment concentrations of 29 mg/kg or greater. Although they did not identify a relationship between toxicity and PFOS concentrations in sediment, they observed a strong relationship among toxicity, organic carbon content of sediments, and dissolved PFOS concentrations in the overlying water of the test vessel. These results suggested that the dissolved fraction of PFOS in water is likely a key contributor to sediment toxicity. Based on sediment concentrations normalized to 1% organic carbon (1%OC), the authors derived an LC10 of 132 mg/kg (1%OC) and LC50 of 150 mg/kg (1%OC) for PFOS, and EC10, EC20, and EC50 of 21, 35, and 89 mg/kg (1%OC), respectively, for

reproductive effects (**Simpson et al. 2021**). The focus of **Simpson et al. (2021)** was on the amphipod, but this publication also provided data for additional marine species. The authors also developed sediment thresholds using Kd and species sensitivity distributions from water exposures.

Laboratory-controlled freshwater and marine sediment toxicity tests for PFAS are sparse. With so few studies available and with variability in test organisms and testing methods, it is difficult to define PFAS toxicity thresholds for benthic organisms or to determine if benthic organisms are similarly sensitive to PFAS compared to other aquatic invertebrates. However, benthic organism toxicity thresholds do not need to be limited to just invertebrates, as shown by **Simpson et al. (2021)**, who developed PFOS thresholds from a species sensitivity distribution (SSD) generated from published data on other types of species using a K_d approach.

7.2.2.2 Terrestrial Invertebrates

Compared to aquatic invertebrates, there are fewer studies on the effects of PFAS on terrestrial invertebrates (i.e., invertebrates living in terrestrial habitats). **Brignole et al. (2003)**, whose study was summarized in **Beach et al. (2006)**, summarized results of acute oral and dermal studies of PFOS conducted on the honeybee (*Apis melifera*), although the dose was reported in terms of mass of PFOS per bee, which may not be relevant for evaluating ecological risks. However, these studies, when converted to a dose per kilogram of food (2 mg PFOS per kg sugar solution), suggested that PFOS was "highly toxic" to honeybees, as defined by the International Commission for Bee Botany. **Mommaerts et al. (2011)** identified in a chronic oral dosing study on the bumblebee (*Bombus terrestris*) an LC50 of 1.01 mg PFOS/L sugar water and noted that PFOS exposure caused detrimental reproductive effects (decreased ovarian size).

Effects on fecundity from exposure to various PFAS have been shown to carry down through multiple generations in the roundworm (*Caenorhabditis elegans)*. **Tominaga et al. (2004)** conducted a multigenerational study in *C. elegans* exposed to PFOA, PFOS, and PFNA, finding that concentrations orders of magnitude lower than those causing lethality decreased worm abundance, and that effects were observed even in the fourth generation. Other studies have evaluated the mechanisms of PFAS toxicity. **Xu et al. (2013)** indicated that exposure to PFOS induced oxidative stress and DNA damage in the earthworm, *Eisenia fetida*. **Stylianou et al. (2019)** evaluated food chain transfer of PFOS-treated *Escherichia coli* to *C. elegans* and noted distinct gene expression profiles associated with development, innate immunity, and stress response.

With regard to soil invertebrate toxicity testing, studies (while few in number) suggest a low to moderate toxicity of PFOS and PFOA, with toxicity generally occurring on a parts per million scale. These studies have mainly focused on the earthworm *Eisenia fetida*. **Sindermann et al. (2002)** conducted a 14-day chronic soil study on *E. fetida* with PFOS and identified a NOEC of 77 mg PFOS/kg soil, a LOEC of 141 mg/kg, and an LD50 of 373 mg/kg. Other chronic earthworm studies indicated toxic concentrations of a similar magnitude, with LC50s ranging from 84 mg/kg–447 mg/kg (**Mayilswami et al. 2014**; **Zareitalabad et al. 2013**). The Norwegian Pollution Control Authority **NPCA (2006)**, as reported in **Danish Ministry of the Environment (2015)**, conducted acute soil toxicity tests in *E. fetida*, looking at reproductive endpoints for PFOA, PFOS, and the short-chain 6:2 fluorotelomer sulfonate (6:2 FTS). Results of this study indicated that, overall, the evaluated PFAS exhibited a moderate-high toxicity. Reproductive effects (decreased number of cocoons, decreased hatchability, and decreased number and weight of juveniles) for PFOS and PFOA were noted. 6:2 FTS toxicity was found to be less than that for either PFOS or PFOA in the same study. **Karnjanapiboonwong et al. (2018)** conducted a 21-day soil study with *E. fetida* on bioaccumulation, mortality, and weight loss with PFBS, PFHxS, PFNA, and PFHpA and generally observed no effects at soil concentrations below 100 mg/kg in comparison with the controls. Importantly, the authors report tissue concentrations following exposures to PFBS, PFHxS, PFNA and PFHpA thus indicating potential for trophic transfer from soil to higher level organisms (**Karnjanapiboonwong et al. 2018**).

The limited amount of terrestrial invertebrate data presents a data gap; additional toxicity studies are needed to better characterize ecotoxicological effects in this group of organisms. Additionally, it will be important to understand how field/soil conditions (for example, organic carbon content, pH, etc.) may influence toxicity. For example, **Princz et al. (2018)** found that PFOS toxicity for two different species of soil invertebrates was approximately two to four times greater when organisms were tested on sandy loam versus clay loam soils.

7.2.3 Vertebrates

The following sections describe available toxicity data for vertebrate species, including fish, amphibians/reptiles, birds, and mammalian wildlife.

7.2.3.1 Fish

Acute freshwater LC50 values based on survival for PFOS range from 7.8 to 22 mg/L for Rainbow trout (*Oncorhynchus mykiss*), to 9.1 mg/L for fathead minnow (*Pimephales promelas*) (**Robertson 1986**; **Palmer, Van Hoven and Krueger 2002**).

There are relatively few chronic PFOS studies in fish, but (**Drottar and Krueger (2000)**) calculated a chronic NOAEL based on early life stage mortality in Pimephales promelas to be 0.29 mg/L. **Palmer, Van Hoven and Krueger (2002)** also calculated an acute NOAEL of 6.3 mg/L for *Oncorhynchus mykiss*. Saltwater acute values based on survival for *Oncorhynchus mykiss* were calculated to be 13.7 mg/L.

Other than PFOS, there are limited aquatic ecotoxicity data for other PFAS. Within the summary data presented here, acute exposure durations were for 6 days. One study was noted that investigated the chronic toxicity of PFNA following a 180-day exposure; the LOEC ranged from 0.01-1 mg/L depending on the endpoint (**Zheng et al. 2011**).

7.2.3.2 Amphibians/Reptiles

There are relatively limited toxicity data available for PFAS effects on amphibians, including several studies on various species of frogs; no studies on reptiles were found in the literature search. The data available for PFOS and PFOA show a wide range of effects-based concentrations. The Priority Topics for Human and Ecological Health Effects include information about reptiles toxicity data (see **Section 1.4.8**).

More amphibian data are available for PFOS in comparison to other PFAS, and indicate mortality generally tends to occur at levels of 10 mg/L or higher, whereas nonlethal effects (for example, growth; EC10) may occur at approximately 1–2 mg/L (that is, moderate to high toxicity) or lower (**Ankley et al. 2004**; **Yang et al. 2014**; **Fort et al. 2019**). However, more recent studies suggest chronic toxicity may occur at levels lower than 1 mg/L. Flynn et al. (**2019**), for example, found a 72-day LOEC in the American bullfrog (*Lithobates catesbeiana*) of 0.29 mg/L based on developmental effects (reduction in snout vent length).

Ankley et al. (2004) conducted a 5-week study on PFOS toxicity in the northern leopard frog (*Rana pipiens*) and observed that LC50s decreased with increasing test duration time; LC50s ranged from 12.5 mg/L at 1 week to 6.2 mg/L at 5 weeks. This study also anecdotally noted the presence of kinked tails, as well as a delayed time to initial metamorphosis and differences in limb bud and foot paddle emergence in the 1, 3, and 10 mg/L groups. A PFOS study, based on a 3M study reported in **OECD (2002)** on another frog species, African clawed frog (*Xenopus laevis*), suggested toxicity at concentrations of similar magnitude to those observed in the Ankley study, and identified inhibition of growth and malformation during development.

PFAS exposure has also been shown to affect the thyroid, and hence development, in amphibians (for example, **Cheng et al. 2011**; **Flynn et al. 2022**). A study by **Cheng et al. (2011)** that exposed African clawed frog (*X. laevis*) tadpoles to PFOS at concentrations ranging from 0.1 to 100 ug/L in water found up-regulation of several thyroid hormone–regulated genes, suggesting possible thyroid disruption. **Flynn et al. (2022)** conducted a chronic study that evaluated sublethal developmental effects on *R. pipiens*, the American toad (*Anaxyrus americanus*), and the eastern tiger salamander (*Ambystoma tigrinum*), following exposure up to 30 days to 10, 100, and 1,000 ug/L of PFOS, PFOA, PFHxS, and 6:2 FTS). They found a LOEC of 10 ug/L based on reduced body mass for all four PFAS in anurans, and PFOA, PFHxS, and 6:2 FTS in the salamander.

Amphibian studies suggest that PFOS may be less toxic than certain other PFAS (**Yang et al. 2014** and **Abercrombie et al. 2021**) **Brown, Flynn, and Hoverman (2021)** found increased trematode infection in the northern leopard frog resulting from exposure to 0.01 mg/L PFHxS, whereas no effect was observed for PFOS (however, no such effect was noted in the higher PFHxS treatment dose of 0.1 mg/L; the authors postulated that this could potentially be due to adverse effects of PFHxS to the trematode itself). **Pandelides et al. (2023)** recommended a chronic NOEC and LOEC for PFOA of 0.1 mg/L and 1.4 mg/L, respectively based on growth (body mass) for the northern leopard frog, and a chronic NOEC and LOEC for PFOS of 0.6 mg/L and 1.1 mg/L, respectively, based on the median time to complete metamorphosis in the western clawed frog.

Many of the older amphibian studies focused on early life aquatic exposures. More recent studies suggest that amphibians may be even more sensitive to PFAS if one looks at later life stages; nonlethal effects other than survival; growth and reproduction; terrestrial exposure routes; or multiple exposure media. **Abercrombie et al. (2021)** indicated LOECs ranging from 0.05-0.12 mg/L for a toad, frog, and salamander exposed to PFOS, PFOA, or PFHxS in a soil substrate. **Flynn et al. (2021)** found enhanced PFOS and PFOA toxicity in a spiked sediment outdoor mesocosm study, suggesting that evaluating only aquatic exposures may underestimate toxicity from exposure to PFAS in multiple media, which is more representative of actual field conditions.

7.2.3.3 Birds

There are currently a limited number of published laboratory studies available that address PFAS toxicity in avian wildlife species (**Newsted et al. 2006**; **Newsted et al. 2005**; **Newsted et al. 2007**; **Newsted et al. 2008**; **Dennis et al. 2020**; **Bursian et al. 2021**). The northern bobwhite quail (*Colinus virginianus*) and the mallard duck (*Anas platyrhynchos*) were exposed to PFOS (**Newsted et al. 2005**; **Newsted et al. 2006**; **Newsted et al. 2007**) or PFBS (**Newsted et al. 2008**) via the diet. The LD50s reported following acute exposure to PFOS are 61 mg/kg-bw/d and 150 mg/kg-bw/d for the northern bobwhite quail and the mallard, respectively (**Newsted et al. 2006**). In a separate chronic dietary study, **Newsted et al. (2007)** found that a feed concentration of 10 mg PFOS/kg resulted in an average daily intake (ADI) LOAEL of 0.77 mg/kg-bw/d based on increased liver weight in female quail. A feed concentration rate of 50 mg/kg resulted in an ADI LOAEL of 6.4 mg/kg-bw/d based on lethality in mallards (**Newsted et al. 2007**).

More recent avian studies on the northern bobwhite (**Dennis et al. 2020**) and Japanese quail (*Coturnix japonica*) (**Bursian et al. 2021**) evaluated dietary effects of PFOS, PFOA, PFHxS, and the AFFF formulations from 3M and Ansul. **Bursian et al. (2021)** estimated average daily doses causing 50% mortality (ADD50) at 5 days' exposure ranging from 38 mg/kg-d for PFOS (≥98% chemical grade) to 130 mg/kg-d for PFOS in feed spiked with 3M AFFF, which is a product formulation that is a mixture of fluorinated and other compounds (LC50 of 351–467 mg/kg of feed, respectively). More information about AFFF is included in **Section 3**. This subacute study also evaluated effects resulting from a mixture of PFOS and PFOA; the authors suggested that these results showed potential additive effects, and a relative potency of PFOA approximately half that of PFOS (**Bursian et al. 2021**). **Dennis et al. (2020)** evaluated chronic toxicity associated with PFOS and a mixture of PFOS and PFHxS in drinking water on the northern bobwhite quail. Reduced body weight in females and impaired hatching success were

observed at doses lower than those used in the Newsted study (**Newsted et al. 2007**), deriving a chronic toxic dose of 0.0031 mg PFOS+ PFHxS/kg-bw/d and 0.00245 mg PFOS/kg-bw/d, respective to the previously mentioned endpoints.

Some egg injection studies suggest exposure to PFOS may adversely affect chick development during incubation. For example, **Molina et al. (2006)** found that eggs injected with varying doses of PFOS had a lower rate of hatching success and had noted pathological changes in the liver in the leghorn chicken. However, there is some concern regarding the use of these data in risk assessments due to issues related to the method of exposure and other methodological issues that can influence the outcomes of the studies. Although these studies are useful for evaluating mechanisms and creating structure-activity relationships, they may not be appropriate for direct application in risk assessments.

Quail and mallard appear less sensitive to PFBS relative to PFOS. Acute dietary exposure to PFBS resulted in NOAELs of 3,160 and 5,620 mg PFBS/kg-feed for the northern bobwhite quail and mallard, respectively, for the lethal endpoint; these feed concentrations are equivalent to an ADI of 774 mg/kg-bw/d in quail and 2,190 mg/kg-bw/d in mallards (**Newsted et al. 2008**). A NOAEC for northern bobwhite quail reproduction following chronic dietary exposure to PFBS was reported at 900 mg/kg-feed, equivalent to an ADI of 87.8 mg/kg-bw/d (**Newsted et al. 2008**).

Although there are few PFAS laboratory toxicity studies for birds, there are even fewer effect-based field studies. **Custer et al. (2012)** and **Custer et al. (2014)** evaluated PFOS exposure in tree swallows (*Tachycineta bicolor*), identifying a negative association between PFOS concentration in eggs (~150 ng/g-ww) and hatching success. One issue with the findings as suggested by the authors is that the greatest observed effects on hatching were typically found in areas that likely have co-contamination issues (PCBs, PAHs, mercury); however, the influence of these other contaminants is still not clear. This issue of effects from co-contaminants came to light when **Custer et al. (2019)** conducted a field study evaluating the effects of PFAS on tree swallows in a more isolated area with known PFAS impacts (Clark's Marsh near the former Wurtsmith Air Force Base, MI); other potential contaminants were at or below regional anthropogenic background levels. This study resulted in mean PFOS egg concentrations of 662 ng/g-ww, and overall hatching success was not impacted. **Groffen et al. (2019)** conducted a field study in great tits (*Parus major*) near a former fluorochemical plant. They reported median egg concentrations of 48,056 ng/g-ww for PFOS, 18 ng/g-ww for PFOA, and 315 ng/g-ww for PFDS. The authors concluded that reduced hatching success in the birds was associated with a mixture of PFAS (PFOS, PFDS, PFDoDA, PFTrDA, and PFTeDA) (**Groffen et al. 2019**). Taken together, a linear relationship between PFAS exposure and potential effects in avian species remains uncertain; this highlights the importance of considering co-exposure of common environmental contaminants and PFAS mixtures when reviewing field studies.

Lastly, indirect effects, such as reduction in a local food source resulting from a PFAS release, may potentially affect bird populations. **de Vries et al. (2017)**, for example, found a decline in abundance of flamingos following a release of fire-fighting foams containing PFOS and other PFAS to a salt lake; the authors postulated that this decline was potentially related to a reduction in prey item abundance due to PFOS toxicity.

7.2.3.4 Mammalian Wildlife

PFAS exposure to wildlife is occurring on a global scale and across a variety of habitats (**Reiner and Place 2015**; **Giesy and Kannan, 2001**). Wildlife may accumulate PFAS from direct exposure to air, dust, water, soil, and sediments, as well as through diet. Maternal transfer of PFAS is also a relevant exposure route, as these compounds have been shown to cross the placenta (**Gronnestad et al. 2017**; **Houde et al. 2006**). PFAS have also been shown to biomagnify, so higher trophic level predators have higher PFAS levels in tissues compared with prey items (**Reiner and Place 2015**). Of the PFAS analyzed in wildlife exposure studies, PFOS is the one most frequently detected, and at the highest concentrations, in tissue

samples (**Reiner and Place 2015**). Concentrations in tissue have also been observed to vary with age, sex, and species (**DeSilva et al. 2021**).

Given the widespread occurrence of PFAS in wildlife, it is important to understand if such exposure manifests in adverse effects and ultimately how exposure may impact wildlife populations. Laboratory animal models show that, in general, PFAS are readily absorbed and distributed among protein-rich tissues (liver, serum, kidney) in mammals, and that certain PFAS (particularly long-chain compounds) have a relatively long half-life in the body. Toxicity tests on laboratory mammals (mice, etc.) have shown that exposure to PFAS may result in adverse effects on the hepatic, endocrine, and immune systems; development; and certain types of cancers, as discussed in **Section 7.1.4**.

Based on the findings from mammalian toxicity studies in laboratory animals, one might expect to find similar effects in mammalian wildlife (at similar exposure levels). Laboratory studies focusing on growth, reproduction, and survival effects on laboratory mammals provide data to support the development of toxicity reference values for use in ERA of wildlife species. NOAELs and LOAELs can be derived from these studies for use in ERA (as further discussed in **Section 9.2**, Ecological Risk Assessment), but these values should be used with caution and understanding of their associated uncertainty. Many of these studies may have also included other endpoints, such as systemic or metabolic endpoints, that are not typically used for ERA and may demonstrate effects at lower doses than the growth, reproduction, and survival effects.

Although there are numerous studies evaluating toxicity of PFAS in laboratory animals (as discussed in **Section 7.1.4**), and there are numerous exposure studies in mammalian wildlife, very few studies have evaluated PFAS toxicity with respect to wildlife exposures. The studies that have been conducted typically evaluated relationships between the concentrations of a small number of PFAS in various protein-rich biological media (for example, blood serum, liver) and expression of select biomarkers. One study on sea otters related concentrations of PFOA and PFOS in liver tissue to health condition and possible immune effects (**Kannan, Perotta and Thomas 2006**). **Table 7-3** summarizes these studies.

Table 7-3. Summary of PFAS toxicity studies in mammalian wildlife.

Species	Summary of Findings	Reference
Sea otter *Enhydra lutris*	Higher PFOS/PFOA concentrations in liver samples found in diseased otters versus nondiseased group	**Kannan, Perrotta and Thomas 2006**
Bottlenose dolphin *Tursiops truncatus*	Significant positive associations between serum total PFAS concentrations and multiple immunological, hematopoietic, renal, and hepatic function endpoints	**Fair et al. 2013**
Wood mouse *Apodemus sylvaticus*	Significant positive relationship between liver PFOS concentration and hepatic endpoints (relative liver weight, microsomal lipid peroxidation level); significant negative association with serum alanine aminotransferase (ALT) activity	**Hoff et al. 2004**
Wild pig *Sus scrofa*	No significant correlation between PFAS liver concentrations and multiple blood, hepatic, and immunological endpoints, whereas significant correlations were observed for other pollutants (for example, dioxin-like compounds, PCBs, organohaline pesticides)	**Watanabe et al. 2010**

It is important to note that while certain associations have been observed between PFAS concentrations and various immunological, hematopoietic, renal, and hepatic function biomarkers, these associations are not necessarily indicative of actual impairment to an individual organism or within a larger population.

Perhaps one of the biggest challenges with wildlife toxicity studies is that wildlife are exposed to multiple chemical, biological, and physical stressors, making it difficult to determine whether noted effects are directly related to PFAS, to other stressors, or to a combination of stressors. The accumulation of other types of POPs, such as PCBs, dioxins, and pesticides, and metals such as mercury, in wildlife has been well established and, in some studies, correlated body burden to adverse effects. Arctic mammal studies have reported relationships between organohalogen exposure and endocrine disruption, reduced immune function, and adverse effects on the liver and other organs (**Letcher et al. 2010**). Numerous nonchemical environmental factors such as climate change, habitat loss, and seasonal availability of food may also confound toxicity studies, making it difficult for field studies to discriminate those effects related solely to PFAS. As an example, **Watanabe et al. (2010)** found no association between PFAS levels and a variety of biomarkers in wild pigs, whereas the study found significant positive associations between these parameters and other types of contaminants (for example, PCBs) that were also detected in liver tissue samples.

Currently, there are few data points available for mammalian wildlife, and the current literature focuses on bioaccumulation and specific endpoints that may not be ecologically relevant, as discussed above. Additionally, bioaccumulation studies have traditionally focused on protein-rich tissues such as liver or blood serum because PFAS preferentially bind to proteins; because PFAS could also be present in other tissues, focus on only a subset of tissues can potentially underestimate the total body burden of PFAS. Thus, exposure cannot be fully characterized from these studies, and pinpointing correlations between target organ or whole-body effects and PFAS exposure is not possible at this point in time. A better understanding of mammalian exposures to the broad spectrum of PFAS, precursor compounds, and mixtures of PFAS, as well as other environmental contaminants, is critical in advancing this field of study. Given the challenges with conducting field studies, this information could be obtained in part through more robust dosing studies in mammals that are representative of various wildlife taxa, and on toxicological endpoints that are directly relevant to population-based effects; however, more field studies are also needed to confirm laboratory models. Groups such as the U.S. Department of Defense's Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP) have recently identified such critical data needs (**SERDP-ESTCP 2017**).

7.2.4 Plants

The following sections describe available toxicity data for aquatic and terrestrial plants.

7.2.4.1 Aquatic Plants

Data on the toxic effects of PFAS on aquatic plants are limited, with available studies focusing on PFOS included in USEPA Ecotox Database (**USEPA 2023**). The acute toxicity (EC50s) of PFOS to aquatic plants (such as *Selanastrum* and *Lemna* species) generally ranges from roughly 31 to 108 parts per million (mg/L), with NOEC values from the same studies being approximately 7–30 mg/L; (**Boudreau et al. 2003**; **Sutherland and Krueger 2001**; **Drottar and Krueger 2000**). Chronic effects (EC50s) were found to be similar to acute values, but varied over a wide range, depending on species and endpoint (2–305 mg/L), with NOECs from the same studies ranging from 0.3 to 11.4 mg/L (**Hanson et al. 2005**; **Boudreau et al. 2003**; **Desjardins et al. 2001**, **Desjardins et al. 2001**; **Desjardins et al. 2001**).

7.2.4.2 Terrestrial Plants

There are limited PFAS toxicity data for terrestrial plants; a review of the literature yielded only a few soil phytotoxicity studies. **Brignole et al. (2003)** evaluated PFOS exposure (21 days) on a variety of crop plants (alfalfa, onion, ryegrass, soybean, tomato, flax, and lettuce) using emergence, survival, and shoot height and weight as endpoints, and demonstrated effects occurring at concentrations ranging from 57 mg/kg to over 1,000 mg/kg. Other studies (**Li 2009**; **Zhao et al. (2011)**) conducted on both PFOS and

PFOA on multiple crop plants found a wide range of toxicity among species and also observed a range of toxicity within species (specifically, *Brassica rapa chinensis*). The most sensitive species may be *Triticum aestivum* where the 30-day NOEC reported was 1 mg/kg (**Zhao et al. 2014**). Toxicity may also be moderated by soil characteristics; for example, **Zhao et al. (2011)** showed that the amount of organic matter in soil significantly influenced toxicity, where higher organic carbon content decreased both accumulation of PFOA and PFOS and phytotoxicity. Additionally, PFAS chain length may affect uptake of PFAS into plant tissue; see **Section 5.6** for further discussion.

7.2.5 Uncertainties and Conclusions

This section presented ecotoxicological information with the intent of providing the reader with an overview of the types of organisms and ecotoxicity studies available for PFAS in the current literature (as of 2023). This section also presented available information about the ranges of concentrations of PFAS (notably, PFOS) in soil, sediment, and water that have been associated with adverse effects. In summary, ecotoxicity studies demonstrate a wide range of effects concentrations across the various terrestrial and aquatic biota. In general, aquatic invertebrates appear to be more sensitive to PFOS and other PFAS than their terrestrial counterparts. Differences in species sensitivities, analytical methods, environmental substrate, test conditions, and reproducibility of results make it difficult to generalize overall effects, and some species may be more or less sensitive than others.

Although there are numerous studies on the toxicity of select PFAS to aquatic invertebrates, these studies are generally limited to a very small number of PFAS (typically PFOS, and to a lesser extent, PFOA). Because PFAS represent a broad spectrum of compounds, it is important to expand ecotoxicity studies to evaluate additional PFAS, including short-chain and precursor compounds, as well as "next generation" replacement compounds. Recently, **Jones et al. (2022)** published a compilation of acute aquatic toxicity following exposures to "next-generation" foams and one reference foam (short-chain PFAS AFFF). Of the 14 species tested, the short-chain PFAS AFFF was least toxic in comparison to the next-generation foams in 11 taxa following acute exposure. In cross-species comparison for the short-chain PFAS AFFF lethality data, the mud snail (*T. obsoleta*) and the freshwater amphipod (*H. azteca*) were the most sensitive, and a variety of amphibian species were the least sensitive (**Jones et al. 2022**). More data are anticipated from these authors on chronic exposures to a subset of these species with projects funded under the SERDP Statement of Need ERSON-20-A1, which is aimed at quantifying the potential ecotoxicity of fluorine-free surfactant foam formulations (www.serdp-estcp.org). Other studies show that some of the short-chain replacements, such as GenX, are more toxic than PFOS-based foam formulations (**Conley et al. 2022**).

Importantly, the available studies on foam formulations and individual PFAS exposures indicate a wide range of effects levels for PFAS in aquatic invertebrates, suggesting a level of complexity that has not yet been adequately assessed.

Significantly fewer toxicity studies are available for other groups of aquatic or benthic organisms, and few to no studies are available for avian or mammalian wildlife or plants, presenting a significant gap in our understanding of how the widespread presence of PFAS in the environment may be affecting ecological communities. Additional (or any) data on toxicological endpoints most relevant to community-level effects, such as survival, growth, and reproduction, will be extremely beneficial in understanding potential ecological impacts.

8 BASIS OF REGULATIONS

This section describes various federal and state regulatory programs that apply to PFAS. Because state regulations for PFAS in environmental media are changing rapidly, only a few state regulations are summarized in this section, as examples. A **PFAS Regulatory Programs Summary** Excel file has been developed and is available as an Excel file. ITRC also maintains updated the PFAS **Environmental Media Values Table** Excel file that includes information on state, federal, and some international countries. This section includes a brief explanation of examples of various health effects and how they are used in the development of regulations and advisories.

Section Number	Topic
8.1	**Introduction**
8.2	**Regulatory Programs**
8.3	**Differences in the Available Regulations, Advisories, and Guidance**

8.1 Introduction

PFAS became contaminants of emerging concern in the early 2000s. In recent years federal, state, and international authorities have established a number of health-based regulatory values and evaluation criteria. As with the case for most emerging contaminants, the regulatory process dealing with PFAS is in various stages of development, and the values and criteria being established vary between individual states, the U.S. government, and international agencies. This section describes examples of various federal and state regulatory programs and includes links to tables that provide established PFAS health-based criteria.

The terms “regulatory” or “regulation” are used in this document to refer to requirements that have gone through a formal process to be promulgated and legally enforceable as identified under local, state, federal, or international programs. The terms “guidance” and “advisory” apply to all other policies and numerical values.

8.2 Regulatory Programs

8.2.1 Background to Regulation of PFAS

The scientific community is rapidly recognizing and evolving its understanding of PFAS in the environment, causing an increased pace of development of guidance values and regulations. the PFAS **Environmental Media Values Table** Excel file has been developed and is available as an Excel file. Human health protection is the primary focus of the PFAS regulations, guidance, and advisories developed to date. Regulations and guidance have focused on the PFAAs, precursor compounds, and FECAs. Like many other emerging contaminants, the regulatory and guidance values for PFAS can vary across programs, with differences due to the selection and interpretation of different key toxicity studies, choice of uncertainty factors, and approaches used for animal-to-human extrapolation. The choice of exposure assumptions, including the life stage and the percentage of exposure assumed to come from non-drinking water sources, may also differ. Thus, both differences in scientific conclusions and public health policy choices affect the myriad of regulatory and guidance initiatives for PFAS. More information is included in **Section 8.3**.

In addition to values that specify health-based concentration limits, agencies have used various strategies to limit the use and release of PFAS. For example, the USEPA worked with the eight primary U.S. PFAS manufacturers and processors to eliminate PFOA and many PFOA precursors and higher

homologues by 2015 (**USEPA 2017**). Additionally, the Organisation for Economic Co-operation and Development **OECD (2015)** has described various international policies, voluntary initiatives, biomonitoring, and environmental monitoring programs to control PFAS. More information regarding the history of these developments is in **Section 2.4**.

Authority for regulating PFAS in the United States is derived from a number of federal and state statutes, regulations, and policy initiatives. This section provides a brief overview of the major federal statutes and regulatory programs that govern PFAS.

8.2.2 Federal PFAS Regulations

Within the United States, currently both the USEPA and the FDA have regulatory or guidance initiatives for PFAS. The USEPA has the authority to regulate PFAS under several different statutes as outlined below. To date, USEPA has not yet finalized listing PFAS as hazardous wastes or substances under its available statutory authorities, including the Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), Emergency Planning and Community Right-to-Know Act, or the Clean Air Act. USEPA has also not yet finalized regulations for any PFAS under the Safe Drinking Water Act. However, USEPA has now proposed listing PFOS and PFOA as CERCLA hazardous substances (**Section 8.2.2.6**) and has proposed draft primary drinking water regulations for a number of PFAS (**Section 8.2.2.4**). The Key Actions to Address PFAS website includes more detailed information about the actions of some of these programs (**USEPA 2023**). Key Actions to Address PFAS website includes more detailed information about the actions of some of these programs.

Through the Office of Regulatory Affairs, the Office of Management and Budget maintains a list of regulatory actions which have been initiated by the USEPA and certain other federal agencies. That list is updated periodically to give the status of the regulations and is available at **https://www.reginfo.gov/public/Forward?SearchTarget=RegReview&textfield=PFAS**.

8.2.2.1 National Defense Authorization Act (NDAA)

Through the NDAA, which is enacted early each year, Congress mandates many actions that the Department of Defense (DOD) must comply with, some of them concerning PFAS. At times, separate PFAS-related requirements for the USEPA or other federal entities are also made. Although these activities are not regulatory or guidance in nature, they are important in advancing human health exposure studies of PFAS, remediation of PFAS-contaminated water, development of new technologies to reduce PFAS exposure, interagency collaboration on PFAS, and other PFAS-related actions at the federal level.

The **Regulatory Programs Summary** Excel file lists by responsible agency the PFAS actions enacted through each NDAA. The NDAA for 2018 was the first one to have a PFAS requirement mandating the Centers for Disease Control and Prevention (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR) to study PFAS exposure and health implications in communities near current or former military bases and known to have had PFAS in their drinking water, groundwater, or other sources of water. Subsequent NDAAs have had increasing numbers of PFAS-related requirements, as listed on the **PFAS Regulatory Programs Summary** Excel file.

8.2.2.2 USEPA PFAS Action Plan

USEPA issued a PFAS Action Plan (**USEPA 2019**) in February 2019 and an update a year later (**USEPA 2020**). The plan included a discussion about the process for moving forward to establish PFOA and PFOS MCLs for drinking water, and it included a number of main actions that encompassed more than just safe drinking water issues. More information about USEPA's previous actions to address PFAS is available on their website (**USEPA 2021**). The USEPA (2021) document was superseded by the strategic roadmap described below.

8.2.2.3 USEPA Strategic Roadmap

In October 2021, the USEPA published the *PFAS Strategic Roadmap: EPA's Commitments to Action 2021–2024* (**USEPA 2021**). The USEPA's stated goals for addressing PFAS are focusing on research, restriction, and remediation. The strategic roadmap includes actions across the different divisions of USEPA. More information about USEPA's actions to address PFAS under this roadmap is available on their website (**https://www.epa.gov/pfas**), and in a November 2022 progress report (**USEPA 2022**).

8.2.2.4 Safe Drinking Water Act (SDWA)

The SDWA is the federal law that protects public drinking water supplies throughout the nation (**USEPA 1974**). Under the SDWA, the USEPA has authority to set enforceable National Primary Drinking Water Regulations, such as MCLs, for specific chemicals and to require testing of public water supplies. The SDWA applies to all public water systems (PWSs) in the United States but does not apply to private domestic drinking water wells or to water not being used for drinking.

Much of the current occurrence data available regarding PFAS in public drinking water was generated by USEPA under the SDWA Unregulated Contaminant Monitoring Rule (UCMR) program (**USEPA 2017**). USEPA uses the UCMR to collect data for chemicals that are suspected to be present in drinking water but that do not have standards set under the SDWA. The third round of this monitoring effort, or UCMR3, included six PFAAs:

- perfluorooctanesulfonic acid (PFOS)
- perfluorooctanoic acid (PFOA)
- perfluorononanoic acid (PFNA)
- perfluorohexanesulfonic acid (PFHxS)
- perfluoroheptanoic acid (PFHpA)
- perfluorobutanesulfonic acid (PFBS).

Samples were collected during a consecutive 12-month monitoring period between 2013 and 2015 from large PWSs serving more than 10,000 people, and a limited number of smaller systems determined by USEPA to be nationally representative. Based on USEPA's UCMR3 reported limits of between 10 and 90 ng/L, depending on the specific PFAAs, at least one of the six PFAAs listed above was detected in 194 out of 4,920 PWSs tested (~4%), which serve about 16.5 million people in 36 states and territories (**Hu et al. 2016**).

Table 8-1. UCMR3 occurrence data for PFOA and PFOS.

Chemical	Analytical reporting limit (ppt)	Number of PWSs[1]	PWS (%)[1]
PFOS	40	46	0.9
PFOA	20	13	0.3
∑ PFOA + PFOS		63	1.3
[1] Number and percent of public water systems (PWS) that exceeded the 2016 health advisory by chemical.			

The USEPA and some states use occurrence data produced by the UCMR program, not only for PFOA and PFOS, but also for other PFAS as well (**Table 8-1** and **Table 17-3**), to help determine which substances to

consider for future regulatory action. All of the data from the UCMR program are published in the National Contaminant Occurrence Database (NCOD) and available for download from USEPA's website (**USEPA 2017**).

The Fifth Unregulated Contaminant Monitoring Rule (UCMR 5) was published in December 2021. UCMR5 requires sample collection for 30 chemical contaminants between 2023 and 2025. This includes a list of 29 PFAS with minimum reporting limits ranging from 2 to 20 ppt (**USEPA 2021**). Individual PWS data has been reported online (**USEPA 2024**). UCMR5 will include all US public water systems serving 3,300 or more people, which is a change from previous UCMRs that included systems serving 10,000 or more people.

The USEPA has established final regulations for PFAS under the SDWA. USEPA published a rule on April 26, 2024 that includes National Primary Drinking Water Regulations (NPDWRs) for six PFAS (**USEPA 2024**). In May 2025, the USEPA published a news release indicating their intention to review the current regulation (**https://www.epa.gov/newsreleases/epa-announces-it-will-keep-maximum-contaminant-levels-pfoa-pfos**). This includes the extension of the compliance deadlines for PFOA and PFOS, and the reconsideration of the regulatory determinations for PFHxS, PFNA, HFPO-DA (GenX), and the Hazard Index mixture of these three plus PFBS. USEPA plans to issue a proposed rule in the fall of 2025 and finalize this rule in the Spring of 2026. In the current rulemaking, USEPA has classified PFOA and PFOS as likely human carcinogens and proposes health-based MCLGs for PFOA and PFOS of zero, consistent with USEPA's approach for likely human carcinogens in general. The individual MCLs for PFOA and PFOS are at 4 ng/L, which is the analytical reporting level and practical quantitation level. This rulemaking includes MCLGs and MCLs for PFNA, PFHxS, and GenX individually at 10 ng/L provided they are not in a mixture as well as mixtures of PFHxS, Gen-X, PFNA, and PFBS at a total hazard index of 1 (unitless). All six of these PFAS are included in the UCMR5 analyte list.

For PFAS and other unregulated drinking water contaminants with limited occurrence data, the USEPA begins the process of making regulatory decisions under the SDWA by evaluating the nationwide extent of drinking water contamination and potential health effects that may result from exposure to contaminants via drinking water. This evaluation begins with considering contaminants for inclusion on the Contaminant Candidate List (CCL), which is a list of contaminants that are currently not subject to any proposed or promulgated national primary drinking water regulations but are known or anticipated to occur in public water systems. USEPA uses the CCL to identify priority contaminants for regulatory decision-making and information collection, including occurrence data collection under UCMR. On November 14, 2022, USEPA published the final CCL5, which includes PFAS as a chemical class (**USEPA 2022**).

In addition, when the USEPA determines there may be an "imminent and substantial endangerment" from a contaminant that is present in or likely to enter a PWS, under Section 1431 of the SDWA, it may issue emergency administrative orders (EAOs) to take any action necessary to protect human health if state and local authorities have not acted (42 U.S.C. §300i). USEPA has issued several such EAOs to protect public and private water supply wells contaminated with PFOA or PFOS (**USEPA 2009**, **2014**, **2015**, **2022**).

8.2.2.5 Toxic Substances Control Act (TSCA)

TSCA authorizes the USEPA to require reporting, record keeping, testing, and restrictions of chemicals and chemical mixtures that may pose a risk to human health or the environment. Section 5 of TSCA authorizes the USEPA to issue Significant New Use Rules (SNURs) to limit the use of a chemical when it is newly identified, or when a significant new use of an existing chemical is identified, before it is allowed into the marketplace (**USEPA 2017**). From 2002 to 2013, USEPA issued four final SNURs covering 271 PFAS, including PFOS and PFOA. The first three SNURs covered PFAS included in the 3M Corporation's voluntary phaseout of PFOS. The 2013 SNUR required notification to USEPA prior to manufacture or import of seven PFAS that had been reviewed by USEPA under the TSCA New Chemicals Program but

had yet to be commercially manufactured or imported into the United States. This SNUR also included long-chain perfluoroalkyl carboxylic acids (PFCAs) and their salts and precursors that were used in carpets or to treat carpets (**USEPA 2015**). Collectively, these SNURs placed notification requirements on the manufacture (including import) of specific PFAS for new use. The SNURs allowed for continued, low-volume use of some PFAS in photographic/imaging, semiconductor, etching, metal plating, and aviation industries (**USEPA 2017**). In January 2015, USEPA proposed another SNUR to require notification to USEPA before any future manufacture (including import) of PFOA and PFOA-related chemicals, including as part of articles, and processing of these chemicals. As a result of changes made to section 5(a) of TSCA when TSCA was amended in June 2016, USEPA undertook developing a supplemental SNUR for the import of certain long-chain PFCA and PFSAs as part of categories of certain articles (**USEPA 2018**).

As required by the NDAA, the USEPA finalized the supplemental SNUR in June 2020 and published the final notice in the Federal Register in July 2020 (**https://www.govinfo.gov/content/pkg/FR-2020-07-27/pdf/2020-13738.pdf**). The 2020 SNUR designates as a significant new use the manufacture, import, or processing of a specific subset of long-chain perfluoroalkyl carboxylate (LCPFAC) substances for any use that was not ongoing as of December 15, 2015, and for all other LCPFAC chemical substances for which there were no ongoing uses as of January 21, 2015. The SNUR also prohibits the import of certain LCPFAC as part of a surface coating on articles, and the import of carpet containing perfluoroalkyl sulfonate chemical substances, without USEPA review.

Finally, USEPA recently proposed a new SNUR for those PFAS that have not been manufactured (including imported) or processed for many years and are consequently designated as inactive on the TSCA Chemical Substance Inventory (**USEPA 2023**). Persons or companies subject to the SNUR would be required to notify USEPA at least 90 days before commencing any manufacture (including import) or processing of the chemical substance for a significant new use.

The USEPA continues to review new PFAS through USEPA's New Chemicals Program before approving commercialization. In October 2021, USEPA published the National PFAS Testing Strategy to "help EPA identify and select PFAS for which the Agency will require testing using TSCA authorities" (**USEPA 2021**). In 2023, USEPA released a new framework for addressing new PFAS and new uses of PFAS which is intended to require more extensive toxicity and fate data for PFAS with potential exposures or releases (**USEPA 2023**).

8.2.2.6 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)—"Superfund"

PFAS, other than PFOA and PFOS, are not currently listed as CERCLA hazardous substances but may be addressed as CERCLA pollutants or contaminants as defined by section 101 (33) of CERCLA (40 CFR 300.5). USEPA finalized a rule in April 2024 to designate PFOA and PFOS as hazardous substances (**USEPA 2024**). This rulemaking requires entities to immediately report releases of PFOA and PFOS that meet or exceed the reportable quantity to the National Response Center, state or Tribal emergency response commission, and the local or Tribal emergency planning committee (local emergency responders). Entities would not be required to report past releases of PFOA or PFOS as they were not yet listed as hazardous substances. In addition to the final rule, EPA is issuing a separate **CERCLA enforcement discretion policy** (**USEPA 2024**) that makes clear that EPA will focus enforcement on parties who significantly contributed to the release of PFAS chemicals into the environment, including parties that have manufactured PFAS or used PFAS in the manufacturing process, federal facilities, and other industrial parties.

CERCLA Protection of Human Health. CERCLA requires, among other things, that Superfund response actions ensure protectiveness of human health and the environment, and compliance with laws and regulations that constitute "applicable or relevant and appropriate requirements" (ARARs); the statute also provides possible ARAR waivers in limited circumstances. The lead agency (as defined in 40 CFR

300.5) identifies potential ARARs and to-be-considered values (TBCs), based in part on the timely identification of potential ARARs by states. Risk-based cleanup goals may be calculated and used to determine cleanup levels when chemical-specific ARARs are not available or are determined not to be sufficiently protective (**USEPA 1997**). The ARAR process can be complex and can result in impacts on scope, budget, and public acceptance components of a project (**USEPA 2019**).

The **Environmental Media Values Table** Excel file includes information from state, federal, and some international agencies. These values are not necessarily automatically recognized as ARARs and must be evaluated by the lead agency to determine their ARAR status. In the Superfund program, USEPA regions evaluate potential ARARs, including state standards, on a site-specific basis to determine whether a specific standard or requirement is an ARAR for response decision and implementation purposes. Determining if a state requirement is promulgated, substantive, and enforceable are some of the factors in evaluating whether a specific standard may constitute an ARAR or TBC (**40 CFR 300.5 2001**; **40 CFR 300.400 2019, (g)**; **USEPA 1988**, **1991**).

As mentioned above, risk-based cleanup goals may be calculated when chemical-specific ARARs are not available or are determined not to be protective (**USEPA 1997**). The USEPA's Regional Screening Levels (RSLs) Generic Tables (**USEPA 2023**) and the RSL online calculator (**USEPA 2017**) are used by risk assessors to identify screening levels and preliminary remedial goals for contaminants of potential concern at a site. These goals are typically based on toxicity values that have been selected in accordance with the USEPA's published hierarchy (**USEPA 2003**). In May 2022, USEPA added five PFAS (PFOA, PFOS, PFNA, PFHxS, and GenX) to the RSL table (**USEPA 2023**). PFBS had previously been listed in the RSL generic tables. For these six PFAS, the generic tables provide noncancer reference doses (RfDs), screening levels for soil and tap water, and soil screening levels for the protection of groundwater. USEPA issued a final toxicity value for PFBS in April 2021 (**USEPA 2021**). In October 2021, USEPA issued a final toxicity assessment for GenX chemicals (**USEPA 2021**). The online RSL calculator currently supports site-specific calculations for the same six PFAS. The USEPA also provides tables and a calculator for removal management levels (RMLs). In general, RMLs are not final cleanup levels, but can provide a reference when considering the need for a removal action (for example, drinking water treatment or replacement) (**USEPA 2016**).

Because RSLs and RMLs are periodically updated, they should be reviewed for revisions and additions before using them. RSLs and RMLs are not ARARs, but they may be evaluated as TBCs. The USEPA has emphasized that RSLs and RMLs are not cleanup standards (**USEPA 2023**) and suggests that final remedial goals be informed by a baseline risk assessment so that site-specific information can be incorporated. **Section 9** provides more information on site-specific risk assessment for PFAS.

CERCLA Protection of the Environment. CERCLA requires that remedies also be protective of the environment. Risk-based cleanup goals that are protective of the environment are site-specific and depend in part on the identification of the ecological receptors to be protected. Another example of a risk-based cleanup goal is a cleanup standard for a chemical in soil that is protective of groundwater quality and is developed on a site-specific basis. Given the challenge associated with deriving accurate physical and chemical properties for PFAS (Sections **4.1**and **5.1**), site-specific values will need to be derived.

8.2.2.7 Resource Conservation and Recovery Act (RCRA)

RCRA provides USEPA with the authority to regulate hazardous waste management, nonhazardous solid waste facilities and practices, and underground storage tanks holding petroleum or certain hazardous substances. No PFAS have been formally listed as RCRA hazardous waste for regulation under this program. However, there are at least a couple of examples where action on PFAS was taken under the auspices of RCRA. For example, in 2004 USEPA pursued violations of RCRA and TSCA at an E.I. DuPont de Nemours and Company (DuPont) facility in West Virginia due to environmental release of the hazardous constituent PFOA (**USEPA 2015**). In the case of DuPont, the facility already had a RCRA permit

for hazardous waste disposal and was under a Corrective Action Permit. Some states, Texas, for example, are regulating certain PFAS under their RCRA permits and requiring investigation and cleanup.

In February 2017, a U.S. District Court denied motions to dismiss RCRA "imminent and substantial endangerment" claims relating to PFAS (*Tennessee Riverkeeper, Inc. v. 3M Co.*, No. 5:16-cv-01029-AKK, 2017 WL 784991 (N.D. Ala. Feb. 10, 2017)). This case involved the alleged continuing contamination of the Tennessee River and associated public drinking water supplies with PFAS that the plaintiff claims originated from a local manufacturing facility and two local landfills. There were several arguments that the claims should be dismissed. One argument by the landfill owners was that the claims were an attack on existing, valid permits that included a solid waste permit authorizing disposal in the landfill of PFAS-bearing materials. The court denied the motion to dismiss, stating that the permits only authorize disposal of nonhazardous waste, and there is a dispute over whether the PFAS-containing material is a hazardous waste. Additionally, there are a continually growing number of citizen lawsuits filed under RCRA in state courts throughout the United States. Thus, the applicability of RCRA regulations and statutes to PFAS does not appear to be settled and can be complicated.

On June 23, 2021, New Mexico Governor Michelle Lujan Grisham petitioned USEPA Administrator Michael Regan to designate PFAS as "hazardous waste" under the Resource Conservation and Recovery Act, citing imminent and substantial endangerment. On October 26, 2021, EPA administrator Regan responded to the governor's petition (**USEPA 2021**). In February of 2024 USEPA proposed to add nine PFAS (PFOA, PFOS, PFBS, GenX, PFNA, PFHxS, PFDA, PFHxA, and PFBA) as RCRA Hazardous Constituents in Title 40 of the Code of Federal Regulations Part 261 Appendix VIII (**USEPA 2024**). In addition, USEPA has proposed a rulemaking to clarify that RCRA has the authority to require the cleanup of solid wastes that meet the statutory definition of hazardous waste. This will mean that "emerging contaminants such as PFAS can be cleaned up through the RCRA corrective action process." (**USEPA 2024**).

8.2.2.8 Clean Air Act (CAA)

Under the CAA, USEPA is required to regulate emissions of hazardous air pollutants from industrial facilities. USEPA may develop standards for controlling certain hazardous air emissions from sources in a specific industry group. Within 8 years of establishing emission standards, USEPA must determine whether the standards are sufficiently protective of human health and protect against adverse environmental effects. This determination also considers improvements in air pollution controls and evaluates effective and feasible alternatives. There are no air emission standards for PFAS at this time. There is no indication how far along USEPA is in this process for regulating PFAS under the CAA.

8.2.2.9 Clean Water Act (CWA)

Since 1972, the CWA has given the USEPA authority to control water pollution by regulating discharges into the nation's surface water by setting wastewater standards for industry. There are no nationally recommended water quality criteria for any PFAS at this time. However, USEPA published draft aquatic life criteria for PFOA and PFOS in summer 2022 (**USEPA 2022**, **2022**). USEPA released the Final 2016 Effluent Guidelines Program Plan in May 2018, which listed PFAS as a topic for future investigation (**USEPA 2018**). More recently, USEPA finalized Effluent Guidelines Plan 15 in January 2023 (**USEPA 2023**) (see **Section 16.6**).

In December 2022, USEPA released a memorandum relating to NPDES permitting for PFAS discharges which supersedes the April 2022 USEPA memo (**USEPA 2022**, **2022**). More information about these USEPA documents can be found in **Section 16.1**. The regulation of PFAS in discharge effluents by states is discussed below in **Section 8.2.3**, and in **Section 16.6**.

8.2.2.10 Toxics Release Inventory (TRI) Program

The Toxics Release Inventory (TRI) program requires the annual reporting of environmental releases of approximately 800 chemicals which the USEPA has concluded cause:

- Cancer or other chronic human health effects
- Significant adverse acute human health effects
- Significant adverse environmental effects

For chemicals regulated under the TRI, facilities that manufacture, process or use these chemicals in amounts above established levels must submit annual reporting forms for each chemical.

As stipulated by the NDAA, the USEPA finalized a rule requiring 180 PFAS be added to the list of chemicals that must be reported under the TRI program for Reporting Year 2022 (**USEPA 2023**). An additional nine PFAS were added to the list for Reporting Year 2023 (**USEPA 2023**) and an additional seven PFAS were added for Reporting Year 2024 (**USEPA 2024**). The PFAS subject to TRI reporting requirements under the original NDAA included all PFAS listed as an active chemical substances under TSCA's Section 8(b)(1) inventory. Each of these PFAS will have a 100-pound reporting threshold. In the 2022 changes to reporting requirements (**USEPA 2022**), these PFAS were added to the List of Lower Thresholds for Chemicals of Special Concern (chemicals of special concern), which eliminates the use of the *de minimis* exemption, which is expected to increase the reporting of PFAS found in mixtures or products in low concentrations (**USEPA 2023**). Reporting for each calendar year is due in July of the following calendar year; these data–as with all TRI data–will be publicly-available approximately 1 year after they were reported (**USEPA 2020**).

8.2.2.11 U.S. Food and Drug Administration (FDA)

One of the responsibilities of the FDA is regulation of "food contact substances" (FCSs), chemicals added to or components of "food contact materials" (FCMs), such as food wrappers and packaging. The FDA currently regulates certain PFAS used as grease-proofing agents for food packaging via a Food Contact Notification Program within the Center for Food Safety and Applied Nutrition's Office of Food Additive Safety. The PFAS used in FCMs and their known degradants and impurities have all undergone review for human health and environmental safety concerns through the food contact notification process and food additive petition process, which requires submission of chemical, toxicological, and environmental information on the FCS itself and on any potential impurities. Perfluorinated ion exchange membranes are also regulated under these processes.

In 2016 the FDA banned three perfluoroalkyl ethyl compounds from use in food packaging material (81 FRN 5, Jan. 4, 2016, Indirect Food Additives: Paper and Paperboard Components): diethanolamine salts of mono- and bis (1 H, 1H, 2H, 2H perfluoroalkyl) phosphates with even-numbered alkyl groups in the range of C8–C18; pentanoic acid, 4,4-bis [(*gamma*–*omega*-perfluoro-C8-20-alkyl)thio]; and perfluoroalkyl substituted phosphate ester acids, ammonium salts formed by the reaction of 2,2-bis[([gamma],[omega]-perfluoro C4–C20 alkylthio) methyl]-1,3-propanediol, polyphosphoric acid, and ammonium hydroxide.

In July 2020, the FDA announced that three manufacturers had agreed to a voluntary phase out of FCS that contain 6:2 fluorotelomer alcohol (6:2 FTOH). A fourth manufacturer had previously stopped sales of 6:2-FTOH-containing products in the US. The phase-out began in January 2021; the FDA predicted that it may take up to 18 months after that time to exhaust existing supplies of food contact papers that contain 6:2 FTOH (**USFDA 2020**).

As of February 2022, there were some FCS with PFAS listed on FDA's inventory of effective FCS notifications. The FDA (**2023**) inventory of FCS notifications is an online database. PFAS that are authorized for use in contact with food generally fall into four application categories:

- Nonstick cookware: PFAS may be used as a coating to make cookware non-stick.
- Gaskets, O-rings, and other parts used in food-processing equipment: PFAS may be used as a resin in forming certain parts used in food-processing equipment that require chemical and physical durability.
- Processing aids: PFAS may be used as processing aids for manufacturing other food contact polymers to reduce build-up on manufacturing equipment.
- Paper/paperboard food packaging: PFAS may be used as grease-proofing agents in fast-food wrappers, microwave popcorn bags, take-out paperboard containers, and pet food bags to prevent oil and grease from foods from leaking through the packaging (**FDA 2019**). However, the side-chain PFAS polymers used in grease-proofing are the subject of a voluntary phaseout agreement.

8.2.2.12 Other Federal Agency Actions

Other U.S. federal agencies and programs are actively involved in PFAS-related matters; however, their work largely focuses on data generation and analysis to help inform regulations/restrictions/regulatory action. These federal programs often provide valuable information, guidance, and resources for state regulatory and public health agencies. For example, the U.S. Centers for Disease Control and Prevention (CDC) National Health and Nutrition Examination Survey (NHANES) program provides valuable information about human exposure to chemicals (**CDC 2023**). Since 1999, the NHANES program has been providing an assessment of the exposure of the U.S. population to a small subgroup of PFAS. This information (PFAS concentrations in blood, serum, urine samples) is useful to scientists and regulatory agencies to understand "background" (that is, likely nonsite-related) human exposure levels and trends over time. In 2013-2014 CDC expanded their NHANES analysis to include evaluation of PFAS in serum and urine (**Kato et al. 2018**).

Under the Superfund Amendments and Reauthorization Act of 1986 (SARA) [42 U.S.C. 9601 *et seq.*] amendment to CERCLA (or Superfund) [42 U.S.C. 9601 *et seq.*], the U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry (ATSDR) was established to assess the potential public health risk from exposure to hazardous substances commonly found at National Priorities List facilities. CERCLA provides ATSDR with the authority to develop toxicological profiles that describe the health effects of these hazardous substances and to support site-specific response actions with health consultations and/or exposure investigations. A description of ATSDR's actions regarding PFAS is on their web page (**ATSDR 2018**). In May 2021, ATSDR released a final *Toxicological Profile for Perfluoroalkyls* (**ATSDR 2021**). In this revision, the agency discussed potential human health risks related to 14 specific PFAS and derived "provisional intermediate Minimal Risk Levels" (MRLs) for PFOA, PFNA, PFOS, and PFHxS.

ATSDR (2023) has posted an online calculator that the general public can use to estimate the increase in their blood serum levels from exposure to PFOA, PFOS, PFNA, or PFHxS in drinking water.

The U.S. Geological Survey (USGS) has had an emerging contaminants program for over a decade within which they measure emerging contaminants, including PFAAs, in various environmental media and ecological receptors. The objective of their work is to characterize environmental occurrence, sources, and source pathways that may contribute to environmental exposure. This has been a useful source of

information for scientists and regulatory agencies on occurrence, fate, and transport of PFAS. Information on the USGS program can be found on their web page (**USGS 2017**).

The U.S. Department of Defense SERDP and ESTCP are jointly managed with USEPA and the U.S. Department of Energy to develop the latest science and technology to improve DOD's environmental footprint and mission capabilities. Beginning in fiscal year 2011, SERDP and ESTCP have funded a significant number of projects related to developing a better understanding of PFAS occurrence, fate and transport, ecotoxicity, and remediation treatments, as well as investigating the next generation of fluorine-free firefighting foams. More information on SERDP and ESTCP funding projects and statements of need can be found on their website (**SERDP-ESTCP 2019**).

8.2.3 State PFAS Regulations and Guidance

State regulatory agencies often have the delegated authority to regulate and enforce environmental and public health requirements, although the states and US territories have different priorities, resources, and processes. Many states have been actively involved with addressing PFAS contamination across multiple regulatory programs. Examples of key state programs for water, soil, remediation, hazardous substances, and consumer products are described below, and information about regulatory, advisory, and guidance values is discussed in **Section 8.3**. The information below is meant to provide examples only; the **Environmental Media Values Table** Excel file should be consulted for more current and detailed information.

The Association of State and Territorial Solid Waste Management Officials (ASTSWMO) has a PFAS resources website that includes links to PFAS information for states and territories (**https://pfas.astswmo.org**). The Environmental Council of the States (ECOS) published their updated white paper, Processes and Considerations for Setting State PFAS Standards, in April 2024 (**ECOS 2024**).

ITRC has developed the **PFAS Regulatory Programs Summary** Excel file that summarizes the regulations and programs in each state that target PFAS. The focus of the table is on PFAS regulations that have been enacted by any of the states or territories of the United States. The table also includes state programs that may not be mandated by a specific regulation, but which state agencies are pursuing on a discretionary basis. This table does not include any numeric criteria, but instead includes a description of the type of regulation or program, and a link to the applicable website. For specific regulatory values, the **Environmental Media Values Table** Excel file should be consulted.

The following subsections describe several different categories of state-adopted laws and regulations along with a brief explanation of each; please refer to the **PFAS Regulatory Programs Summary** Excel file for the most up-to-date information. Note that due to the state legislative review and finalization process, only bills that have been finalized into law are included in the **PFAS Regulatory Programs Summary** Excel file.

8.2.3.1 Product Labeling and Consumer Protection Laws

Several states have programs regulating PFAS in consumer products, including product labeling. Some of these regulations include PFAS in food packaging, children's products, firefighting gear, and other products. More specific information is available in the **PFAS Regulatory Programs Summary** Excel file with details available at the links provided.

8.2.3.2 Designation of Hazardous Waste or Hazardous Substance

Regulations that target select PFAS as hazardous wastes or hazardous substances have not been promulgated in most states. Formal PFAS regulations as hazardous substances have been promulgated

in a number of states, and are under development in several other states. Please refer to the PFAS Regulatory Programs Summary Excel file for detailed information.

8.2.3.3 Drinking Water, Groundwater, Soil, and Remediation Programs

Several states have developed standards and guidance values for PFAS in drinking water, groundwater, and soil (see the Environmental Media Values Table Excel file). Some states adopted (by default) the USEPA LHAs published in either 2016 or 2022, while others adopted values developed via a risk assessment process, regulatory process, or legislative action. Some others use the LHA concentrations as advisory, nonregulated levels to guide the interpretation of PFAS detections. The May 2022 RSL table lists screening values for soil and tap water for six PFAS. Section 9 provides more information on site-specific risk assessment for PFAS.

In addition to the process using the USEPA RSL table mentioned above, some states have developed screening levels for various PFAS in soils assuming direct contact and/or ingestion.
See the Environmental Media Values Table Excel file and **USEPA (2021)** Certain states have also developed values for the protection of groundwater (see the Environmental Media Values Table Excel file).

Some states have "antidegradation" policies aimed at protecting the quality of groundwater and high quality (or Tier 2) surface waters. Those polices can be used in decisions on cleanup and discharge under permits. Please see the PFAS Regulatory Programs Summary Excel file as well as the Environmental Media Values Table Excel file for more information.

8.2.3.4 Surface Water Discharge and Permitting

National Pollutant Discharge Elimination System (NPDES) permits use a standard process for developing effluent limits for pollutants. Effluent and receiving water limitations for PFAS would be established in the same manner as other pollutants. A number of states have established surface water quality standards for PFAS. More information on surface water effects can be found in **Section 16**.

8.2.3.5 Other State Regulations or Programs

Another concern for PFAS is in the application of biosolids from municipal wastewater treatment plants to land for disposal or reuse. A number of states are currently in the process of considering and/or developing such regulations (**ECOS 2023**). An example of this type of regulation may include a law to prohibit the land application of sludge as well as the sale and distribution of products containing sludge and septage. Other potential regulations may focus on reducing PFAS inputs into wastewater treatment plants while further assessing the impacts associated with land application of biosolids containing PFAS. See Section 3 for a more detailed discussion of PFAS in biosolids.

Some states have developed an ambient air limit for PFAS. See the **PFAS** Environmental Media Values Table and the PFAS Regulatory Programs Summary Excel file for more information.

Finally, some states have issued state regulations or programs related to AFFF. For example, some states have established AFFF take-back programs to reduce the potential discharge of PFAS associated with AFFF into the environment. Other states are in the process of developing an AFFF take-back program. See **Section 3** for a more detailed discussion on AFFF and related regulations and guidance. A number of states have banned the manufacture, sale, and use of PFAS-containing AFFF in most applications (see PFAS Regulatory Programs Summary Excel file).

8.3 Differences in the Available Regulations, Advisories, and Guidance

Human health protection is the primary focus of the PFAS regulations, guidance, and advisories developed to date. Internationally, including in the United States, the nonpolymer PFAS have been the regulatory focus. Several toxicity evaluations are available for certain PFAS. This is an area of active research and regulatory activity. Additional information is presented in Sections **7.1** and **17.2**.

Table 8-2. Definition of terms associated with drinking water and/or groundwater standards or guidance.

Term	Acronym	Agency	Definition	Link
Minimum Risk Level	MRL	CDC ATSDR	An MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure. MRLs are intended to serve as screening levels to identify contaminants and potential health effects that may be of concern. MRLs are not intended to define cleanup or action levels for ATSDR or other agencies (**ATSDR 2018**). Importantly, the MRL is a daily dose, applicable for any oral exposure; it is not a threshold concentration in water or other environmental media.	https://www.atsdr.cdc.gov/mrls/index.asp
Regional Screening Level	RSL	USEPA Regions	Default screening level tables including chemical-specific concentrations for individual contaminants in air, drinking water, and soil that may warrant further investigation or site cleanup. Generic screening levels (SLs) are based on default exposure parameters and factors that represent reasonable maximum exposure conditions for long-term/chronic exposures and are based on the methods outlined in EPA's Risk Assessment Guidance for Superfund, Part B Manual (1991) and Soil Screening Guidance documents (1996 and 2002). It should be emphasized that SLs are not cleanup standards. (**USEPA 2019**)	https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide#intro
Health Advisory	HA	USEPA Office of Water	Health advisories provide information on contaminants that can cause human health effects and are known or anticipated to occur in drinking water. EPA's HAs are nonenforceable and provide technical guidance to state agencies and other public health officials on health effects, analytical methodologies, and treatment technologies associated with drinking water contamination. (**USEPA 2019**)	https://www.epa.gov/dwstandardsregulations/drinking-water-contaminant-human-health-effects-information
Maximum Contaminant Level Goa	MCLG	USEPA Office of Water	The MCLG is the maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of persons would occur, allowing an adequate margin of safety. MCLGs are nonenforceable public health goals. MCLGs consider only public health and not the limits of detection and treatment technology effectiveness. (**USEPA 2018**).For contaminants classified as known or likely human carcinogens, it is USEPA policy to set the MCLG at zero (0). (**USEPA 2023**)	https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations
Maximum Contaminant Level	MCL	USEPA Office of Water	The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCL goals as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards. (**USEPA 2018**)	https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations

Human health–based guidance values and/or regulatory standards have thus far been derived for a number of PFAS, including PFAAs, polyfluoroalkyl precursors, and fluorinated ether carboxylates (FECA) by state and/or federal agencies in the United States. The health-based values for these nonpolymeric PFAS vary across programs, with differences due to the selection and interpretation of different key toxicity studies, use of human or animal data as the basis, use of a noncancer reference dose or a cancer slope factor, choice of uncertainty factors when a reference dose is used, and approaches used for animal-to-human extrapolation. The choice of exposure assumptions, including the life stage and the percentage of the reference dose assumed to come from non-drinking water sources, also differs. Most available guidance values and/or regulatory standards are for PFOA and PFOS, and the key differences in

regulatory and guidance decisions within the United States for those chemicals can be seen in the ECOS white paper (**ECOS 2024**).

Table 8-2 provides the underlying definition and context for the various federal regulations, standards, and guidance values that may apply to PFAS in the United States.

8.3.1 Toxicity Values

As stated above, available PFAS regulations, guidance, and advisories are generally based on human health protection. However, the available values that are deemed protective of human health vary across international and U.S. jurisdictions. In general, there are similarities and differences in the understood toxicological effects, potencies, and modes of action for various PFAS, and there are differences in the interpretation of relevant toxicological data for individual PFAS.

Toxicological data from both animal and human epidemiology studies are used as the basis for U.S. state and federal PFAS human health toxicity factors and related standards or guidance. The European Food Safety Authority's tolerable weekly intake for the total of PFOA, PFOS, PFNA, and PFHxS is based on human data (**EFSA 2020**). More recently, California EPA and USEPA have developed draft reference doses for PFOA and PFOS (**CA OEHHA 2023**; **USEPA 2023**), as well as for PFHxS (**USEPA 2023**) and PFDA (**USEPA 2023**), and a draft cancer slope factor for PFOA (**USEPA 2023**; **CA OEHHA 2023**) based on human general population data that are far below current values based on animal data. See **Section 7** for a review of the toxicology data for PFAS. Many scientific considerations and decision points are involved in developing human health toxicity factors (RfDs and cancer slope factors) from animal toxicology data or human epidemiology data. For PFOA and PFOS, different scientific and regulatory policy conclusions have been made for nearly every decision point by different agencies. Some of the key topics that account for toxicity value differences are discussed below. More specific information on these differences can be found in the **Environmental Media Values Table** Excel file; as well as the **PFAS Regulatory Programs Summary** Excel file and the ECOS white paper (**ECOS 2024**).

Although previous PFAS regulations, standards, and guidance have largely been based on potential noncancer effects, several recent draft or proposed values are based on cancer risk. RfDs have been used by most U.S. states to describe the estimate of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime (**USEPA 2019**).

The New Jersey Drinking Water Quality Institute (NJDWQI) and California Office of Environmental Health Hazard Assessment (OEHHA) also considered potential cancer endpoints for PFOA and PFOS. In its recent proposed PFAS MCL rule, **USEPA (2023)** classified both PFOA and PFOS as likely human carcinogens and developed cancer slope factors for both. **NJDWQI (2023)** concurred with **USEPA (2023)** that PFOA is a likely human carcinogen. However, at the time of New Jersey's recent analysis, the **NJDWQI (2023)** was unaware of the information identified by **USEPA (2023)** that is the basis for its conclusion that PFOS is also a likely human carcinogen. The methodology for deriving chemical-specific toxicity values is generally applicable to both cancer and noncancer endpoints where dose-response relationships and weight-of-evidence analyses of available data sets are evaluated, and is described in detail.

The first step in deriving a human health-based toxicity value (RfD or CSF) is the review of applicable data to identify potential human health hazards (toxicity endpoints) based on sensitive effects that are consistently seen across several studies, are deemed related to an adverse health outcome or its known precursor, and are relevant to humans based on mode of action considerations. Not all agencies have utilized the same candidate studies and health endpoints for PFOA and PFOS due to differences in selection criteria and differences in opinion on the relevancy to human health and on adversity of effects seen in recent studies.

The estimation of an RfD includes two additional components: the selection of the dose-response method and uncertainty factors. For dose-response evaluation, either the benchmark dose or the study NOAEL or LOAEL is utilized as the point of departure. Uncertainty factors used include the standard risk assessment extrapolations, and the choice of uncertainty factors also varies by agency.

8.3.2 Exposure Assumptions

General exposure factors that are used in derivation of PFAS regulations and guidance values are discussed below.

8.3.2.1 Body Weights, Drinking Water Ingestion, and Exposure Durations

Once a human health toxicity value is derived in units of ug/kg-day (or ng/kg-day or mg/kg-day), the toxicity value is combined with exposure parameters to result in the ultimate threshold concentration in drinking water (guidance or standard). The choice of exposure parameters used can be a flexible science- and/or policy-based decision based on default assumptions or chemical-specific data, or may be set based on regulatory framework. The exposure parameters used under the U.S. CERCLA program (for example, USEPA regional screening levels) include default exposure parameters and factors that represent conditions for long-term/chronic exposures, including an exposure frequency of 350 days per year, exposure duration of 6 years for a 15-kg child who drinks 0.78 L water per day, or 26 years for an 80-kg adult who drinks 2.5 L of water a day. In contrast to CERCLA, drinking water guidance values and standards (MCLs and MCLGs) developed by USEPA or states are generally based on lifetime exposure using default adult parameters, and they do not usually include a duration of exposure parameter. For PFOA and PFOS, USEPA and state agencies have not always relied upon these default exposure parameters. Some have decided to utilize exposure parameters that are specific for more sensitive subpopulations (infants, children, or lactating/pregnant women) and/or a toxicokinetic model that considers exposures to the developing fetus and the higher exposures to the breast-fed infant. For example, MDH developed a toxicokinetic model to estimate the total exposure to breast-fed and formula-fed infants (**Goeden, Greene, and Jacobus 2019**), and this model was used to derive standards in Minnesota, New Hampshire, and Michigan.

8.3.2.2 Relative Source Contribution

Humans can be exposed to nonpolymeric PFAS, including precursor chemicals, via multiple sources, including air, food, and consumer and industrial products. The relative source contribution (RSC) term is used in health-based guidance and standards developed by the USEPA under the federal SDWA and related state programs to account for potential non-drinking water exposures to chemicals. In general, the concept ensures that when a criterion based on an RfD for noncancer effects is established for a single exposure pathway, such as drinking water, potential exposures that occur from other pathways are accounted for so that total exposure does not exceed the RfD (**USEPA 2000**). The default RSC of 20% means that the drinking water pathway is assumed to contribute only 20% of the RfD, and all other exposure pathways contribute the remaining 80%. In practice, therefore, the drinking water concentration based on RfD and drinking water consumption assumptions is multiplied by the RSC (for example, 20%) to account for exposure via the other pathways.

The RSC term generally does not exist in CERCLA/RCRA-based remediation programs because baseline risk assessments specifically investigate and quantify risks associated with all potential site-specific exposure routes (not just drinking water), and then consider a receptor's cumulative risk. Therefore, there is no downward adjustment to a residential groundwater (termed "tap water" by USEPA) drinking water screening level, for example, to account for potential other exposures—all site-specific exposures are quantified. See Section 9 for more information on site-specific risk assessments for PFAS.

9 SITE RISK ASSESSMENT

This section discusses the specific challenges associated with assessing and characterizing potential risks to human and ecological receptors exposed to PFAS in the environment. This includes challenges associated with quantifying the degree of exposure, assessing the hazard associated with PFAS, quantifying the dose-response relationship, and characterizing risks to support effective risk management decision-making. Generally, the challenges associated with performing a site risk assessment where the release of PFAS to the environment is suspected are not necessarily unique. Like any other chemical for which there is limited information, knowledge, or other technical complexity, working through the steps necessary to complete a risk assessment would be similar.

Section 17.3 provides additional information related to PFAS risk assessment, including (1) exposure pathways relevant for different exposure media, (2) considerations when calculating exposure point concentrations, and (3) selecting bioconcentration/bioaccumulation factors.

Section Number	Topic
1.4	**Priority Topics for Human and Ecological Health (2025)**
1.7	**Priority Topics for Biosolids Land Application (2025)**
9.1	**Human Health Risk Assessment**
9.2	**Ecological Risk Assessment**
9.3	**Uncertainty**
15.3	**Risk Assessment Case Study**
17.3	**Additional Information for Risk Assessment**

9.1 Human Health Risk Assessment

9.1.1 Toxicity Assessment

The toxicity assessment of a site risk assessment involves (1) hazard identification and (2) dose-response assessment. Hazard identification involves determining whether exposures to a chemical can cause an increased risk of an adverse human health effect; dose-response assessment involves quantifying the relationship between the degree of exposure to the chemical and the incidence or severity of the potential adverse effects. More background on each of these steps is detailed in other guidance (**USEPA 1989**; **ITRC 2015**) and is not repeated here.

This section discusses specific complications that may be encountered in completing the toxicity assessment for a site risk assessment involving PFAS.

The Priority Topics for Human and Ecological Health Effects include information about health effects of ultra-short-chain (ultrashort) PFAS (see **Section 1.4.4**).

9.1.1.1 Availability of Toxicity Values from a Variety of Sources

A toxicity value (for example, oral cancer slope factor (CSF), or reference dose (RfD)) is a numerical expression of the dose-response relationship for a given substance. It is used in combination with estimates of chemical exposure to calculate quantitative estimates of cancer risk or noncancer hazard (**USEPA 1989**). Several state, national, and international regulatory and advisory agencies have developed human toxicity values for various PFAS that could be potentially used in conducting risk assessments or

in support of establishing policies for PFAS risk management. Given this variety of sources, specific complications can be encountered in determining which toxicity values to use in conducting a risk assessment:

- Selection of toxicity values for PFAS is dependent on which PFAS are present at a given site. PFAS identification and quantification may vary based on analytical method.
- Differences among toxicity values for PFAS could arise because agencies may rely on different toxicity value derivation methods; select critical studies by different criteria, including animal or human data; use different uncertainty factors; and prioritize individual PFAS differently for toxicity value derivation. **Table 9-1** provides an example for PFOA and PFOS, showing that USEPA used human data while ATSDR used animal data.
- Available toxicity values may change over time as the results of new studies become available. Newer toxicity values derived by regulatory agencies may be based on more recent and/or different information, methods, and studies than older values, as well as differences in scientific professional judgment and/or different statutory policy requirements. These differences are described in more detail in **Section 8.3**.
- States may choose to derive their own toxicity values rather than use those developed by the USEPA, and values developed by other countries may differ from USEPA's.
- Some states may perform route-to-route extrapolation (from oral toxicity values to inhalation toxicity values) for evaluation of the inhalation pathway. However, uncertainties should be noted if using route-to-route extrapolation.

Table 9-1. Example of variability in noncancer toxicity factors for PFOA and PFOS—USEPA (2024), 2024 RfDs and ATSDR (2021) MRLs.

Noncancer Toxicity Values for Human Health Risk Assessment (ng/kg body weight*day)				
Source	***PFOA***	***Basis***	***PFOS***	***Basis***
USEPA Office of Water (2024) USEPA (**2024**) USEPA (**2024**) Reference Doses (RfDs)	0.03	Decreased antibody response to tetanus and diphtheria vaccinations in children, low birth weight, and increased total cholesterol	0.1	Low birth weight and increased total cholesterol in humans
ATSDR (**2021**) Minimal Risk Levels (MRLs)	3	Behavioral and skeletal effects in mice (following developmental exposure)	2	Delayed eye opening and decreased pup weight in rats

The most recent RfDs available should be used when preparing a human health risk assessment.

There are several options and procedures for selection of toxicity values, as has been described in ITRC guidance (**ITRC 2015**). For site risk assessments performed in the United States, USEPA, DOD, and other agencies have recommended a tiered hierarchy (Tier 1–Tier 3) of toxicity value sources to guide selection and use (**USEPA 2003**, **2013**); (**ECOS-DOD 2007**). This recommendation has since been implemented in numerous USEPA OSWER (Currently known as Office of Land and Emergency Management) directives

(**USEPA 1993**, **2003**, **2023**) that further establish a hierarchy and process for selecting toxicity criteria. For PFAS chemicals as of April 2024:

- Tier 1 values are peer-reviewed toxicity values published on the USEPA's Integrated Risk Information System (IRIS).
    - IRIS values are available for PFBA (**USEPA 2022**), PFHxA (**USEPA 2023**), PFDA (**USEPA 2024**), and PFHxS (**USEPA 2025**)
    - A draft IRIS assessment and toxicity values are available for PFNA (**USEPA 2024**). The status of the PFAS IRIS assessments can be found in the latest IRIS Program Outlook, available at **https://www.epa.gov/iris/iris-program-outlook**.
- Tier 2 toxicity values include Provisional Peer-Reviewed Toxicity Values (PPRTV).
    - PPRTV values are available for PFBS (**USEPA 2021**)
- Tier 3 toxicity values include those from additional USEPA and non-USEPA sources. They can include values that may or may not have been peer reviewed. As recommended by **USEPA (2003)**, in using values from Tier 3 sources, it may be appropriate to prioritize those that are the *most current*, have a *transparent* basis, are *publicly available*, have been *peer reviewed*, and are acceptable to local jurisdictions. USEPA (**2023**) prioritized available Tier 3 sources of toxicity values in its regional screening level (RSL) guidance, with the current relevant sources for PFAS identified as:
    - ATSDR minimal risk levels (MRLs) (for example, the oral MRLs for PFOA and PFOS (**ATSDR 2021**))
    - USEPA Office of Research and Development (for example, the oral toxicity value for PFPrA (**USEPA 2023**)
    - USEPA Office of Water health advisories or human health toxicity assessments (for example, the oral toxicity value presented in the drinking water health advisory for GenX [**USEPA 2021**; **USEPA 2022**])
    - Wisconsin Department of Health Services (for example, the oral toxicity value for PFDoDA) (**WDHS 2020**)
- Additional definitions and discussion of PFAS toxicity values that are available for use are provided in **Section 7** and **Section 17.2**.

The USEPA will continue to develop toxicity values for PFAS. In addition, USEPA may continue reviewing available Tier 3 toxicity values and recommending values in RSL table updates. Individual risk assessors can also select Tier 3 values as appropriate (when no Tier 1 or 2 values are available).

9.1.1.2 Characterizing Cancer Risk for Exposure to PFAS

The USEPA documents that provide the toxicological basis for the proposed USEPA maximum contaminant level goals (MCLGs) for PFOA and PFOS conclude that both PFOA and PFOS are likely to be carcinogenic to humans (**USEPA 2024**, **2024**). The USEPA MCLGs for PFOA and PFOS are zero, consistent with USEPA's general approach for MCLGs for known or likely human carcinogens. The International Agency for Research on Cancer (**IARC 2016**) classified PFOA as possibly carcinogenic to humans (Class 2B). IARC is currently re-evaluating the carcinogenic potential of PFOA and is evaluating the carcinogenic potential of PFOS (**IARC 2023**). A recent review by **NJDWQI (2023)** concurred with USEPA that PFOA is a likely human carcinogen; this review also concluded that PFOS has suggestive evidence but was not aware of some animal tumor data relevant to this evaluation that was considered by **USEPA (2024)** (see **Section 17.2.5.3**).

For GenX, USEPA concluded that there is suggestive evidence of carcinogenic potential in humans based upon liver, pancreatic, and testicular tumors observed in chronic rat studies, but also concluded that these data lacked a dose-response relationship and therefore did not support development of a CSF (**USEPA 2022**).

Although most risk-based values and screening levels developed by states have been primarily based on noncancer effects, USEPA and some select states (for example, **New Jersey—NJDWQI 2017**, **2018**; **California—OEHHA 2023**) have derived oral CSFs for PFOA and PFOS. **NJDWQI (2017)** developed identical drinking water concentrations for PFOA using the RfD for noncancer effects and the CSF and the 1 in 1 million cancer risk level. For PFOS, **NJDWQI (2018)** concluded that, although the CSF was too uncertain for use as the quantitative basis to develop a drinking water level, the level based on noncancer effects did not pose an unacceptably high cancer risk. CalEPA's **CA OEHHA (2019)**, however, issued notification levels for drinking water exposure, and developed draft public health goals (PHGs) for PFOA and PFOS that are driven by carcinogenicity (**CA OEHHA 2023**). The draft PHG for PFOA is based on kidney cancer in humans; the PHG for PFOS is based on liver and pancreatic tumors in rats (**CA OEHHA 2023**). As part of the basis for the USEPA MCLs for PFOA and PFOS, USEPA (**2024**; **2024**) developed a CSF for PFOA of 0.0293 $(ng/kg/day)^{-1}$ (i.e., 29,300 $[mg/kg/day]^{-1}$) based on kidney cancer in the human general population and a CSF for PFOS of 39.5 $(mg/kg/day)^{-1}$ based on liver tumors in rats. For site risk assessments, the derived CSFs developed by these agencies could be used.

Further discussion of the carcinogenicity of PFAS is presented in **Section 17.2.4.2** (Carcinogenicity), **Section 17.2.5.3** (Chronic Toxicity and Tumorigenicity), and **Section 8.2.2.6** (CERCLA).

9.1.1.3 Lack of Toxicological Values for Many PFAS

There are several thousand PFAS that could have been, or may be, on the global market (**OECD 2018**), although the uses of all of these PFAS may not be known (**KEMI 2015**). More information about PFAS in use is included in **Section 2**. In general, PFAS are considered to be bioavailable (i.e., following exposure, they are absorbed and enter the systemic circulation). However, toxicity values have been developed for only a few PFAS for which sufficient information is available. Because of the lack of hazard and dose-response information for other PFAS and the extensive level of effort needed to develop toxicity values, there are no readily available toxicity values for the majority of PFAS.

This lack of information precludes the establishment of compound-specific risk-based concentrations that can be helpful for a variety of applications, including data screening (used to help guide site investigation) and site-cleanup decision-making. In the absence of toxicity values, regulatory agencies and the regulated community are left with uncertainty regarding the potential risks associated with human exposure to impacted environmental media at sites, difficulties with creation of technically defensible risk management programs, and inability of the regulated community to be responsive to concerns about environmental risk.

An approach often used in HHRA in the absence of compound-specific toxicity values is to use toxicity values developed for structurally or chemically similar surrogate compounds with similar biological activity. In the case of PFAS, this would be for PFAS from the same structural subgroup (for example, long-chain perfluorocarboxylic acids). The use of surrogates, however, introduces uncertainty, because surrogates may produce adverse health effects by mechanisms different from the compound of concern, the dose-response curve for a surrogate may be different, and the target organ or toxicity endpoint may be different from the compound of concern. In the absence of chemical-specific toxicity values, preparation of health risk assessments may be limited to qualitative methods and have a higher level of uncertainty in the human health risk assessment as a result.

Further information and guidance are needed to identify appropriate surrogates for PFAS that do not currently have available toxicity values. USEPA's PFAS Action Plan (**USEPA 2019**) noted that USEPA would be working on developing an approach to PFAS toxicity testing that could lead to a methodology for inferring the toxicology of a given PFAS based on the toxicology of a PFAS subset whose toxicology is known. This involves "applying computational and high throughput toxicology tools for PFAS toxicity testing on a larger scale to enable faster understanding of potential toxicity for the universe of thousands of PFAS, most of which have little or no published toxicity data" (**USEPA 2022**). A discussion of new approach methodologies (NAMs) can be found in **Section 7.1.6** and **17.2.8**.

The USEPA has developed its National PFAS Testing Strategy in which PFAS manufacturers will be issued orders under Toxic Substances Control Act (TSCA) authorities to perform toxicity testing on compounds representative of certain PFAS classes (**USEPA 2021**). These classes are organized by similarities in structure, physical-chemical properties, and existing test data on compound toxicity. Thus, there is a plan to obtain toxicity information for each class via a representative compound that will potentially serve as a surrogate for the other compounds in the class.

9.1.2 Exposure Assessment

The exposure assessment of a site risk assessment involves characterizing the exposure setting, identifying relevant exposure pathways and scenarios, and quantifying the magnitude, frequency, and duration of potential human exposure to chemicals in environmental media. More background on the performance of exposure assessments is detailed in other guidance (**USEPA 1989**; **ITRC 2015**) and is not repeated here.

This section discusses specific complications that may be encountered in completing the exposure assessment for a site risk assessment involving PFAS. It should be recognized that the exposure assessment does not generally account for the presence of all PFAS at a site due to limitations in analytical methods. Therefore, there are uncertainties in the characterization of exposures (and associated risks) at PFAS sites that should be acknowledged in the uncertainty analysis section of the risk assessment.

PFAS may be present in biosolids at levels of potential concern. If biosolids contain PFAS and are applied to agricultural fields, the PFAS may contaminate crops and livestock. The Priority Topics for Biosolids Land Application provides updated information about biosolids (see **Section 1.7**).

Blaine et al. (2013) evaluated the uptake of PFAAs contained in industrially impacted biosolids-amended soil and municipal biosolids-amended soil by various crops and confirmed “that the bioaccumulation of PFAAs from biosolids-amended soils depends strongly on PFAA concentrations, soil properties, the type of crop, and analyte.” In addition, **Lindstrom et al. (2011)** evaluated the impacts of PFAS-contaminated biosolids from a local municipal wastewater treatment facility (that historically received waste from fluorochemical facilities) used as a soil amendment in local agricultural fields. Results showed relatively high transport from soils to surface water and groundwater in the vicinity of the agricultural fields. Based on these studies, two potential exposure pathways to PFAS in biosolids are drinking water ingestion and food ingestion. A discussion of the leaching potential from soil to groundwater for biosolids is provided in **Section 6.2.3**. As indicated in **Section 6.2**, a 2021 review of reported values for biosolids, compost, and related biowastes highlights the wide concentration range of reported PFAS (primarily PFAAs) and the relationship of biowaste source to resulting concentrations (**Bolan et al. 2021**).

Biosolids as a potential source of PFAS are mentioned in **USEPA’s (2021)** PFAS Strategic Roadmap. USEPA has developed a draft risk assessment for PFOA and PFOS in biosolids (**USEPA 2025**).

9.1.2.1 Determining Scenarios for Potential Human Exposure

A site-specific conceptual exposure model should be developed during the planning stage of the HHRA, confirmed by stakeholders, and updated as additional information and data are obtained, (see **Section 3** of the RISK-3 guidance (**ITRC 2015**)). The specific exposure scenarios that are applicable to an HHRA for PFAS include those that could occur in media at the release area (the site) and in media at distant locations (with the extent depending on PFAS properties and the site setting). In general, an HHRA for PFAS may be complex in comparison to HHRAs for other types of chemicals due to the persistence of PFAS, the complexities associated with PFAS toxicity, and complexities associated with estimating future concentrations or modeling their fate and transport, and the need to include more media than is typical. Figures **9-1**, **9-2** and **9-3** are provided below to illustrate conceptual site models (CSMs) for four sources (two sources are illustrated in **Figure 9-3**) of PFAS. **Section 2.6** discusses potential environmental releases of PFAS. A detailed discussion of fate and transport processes for PFAS and environmental media that may be affected is presented in **Section 5**.

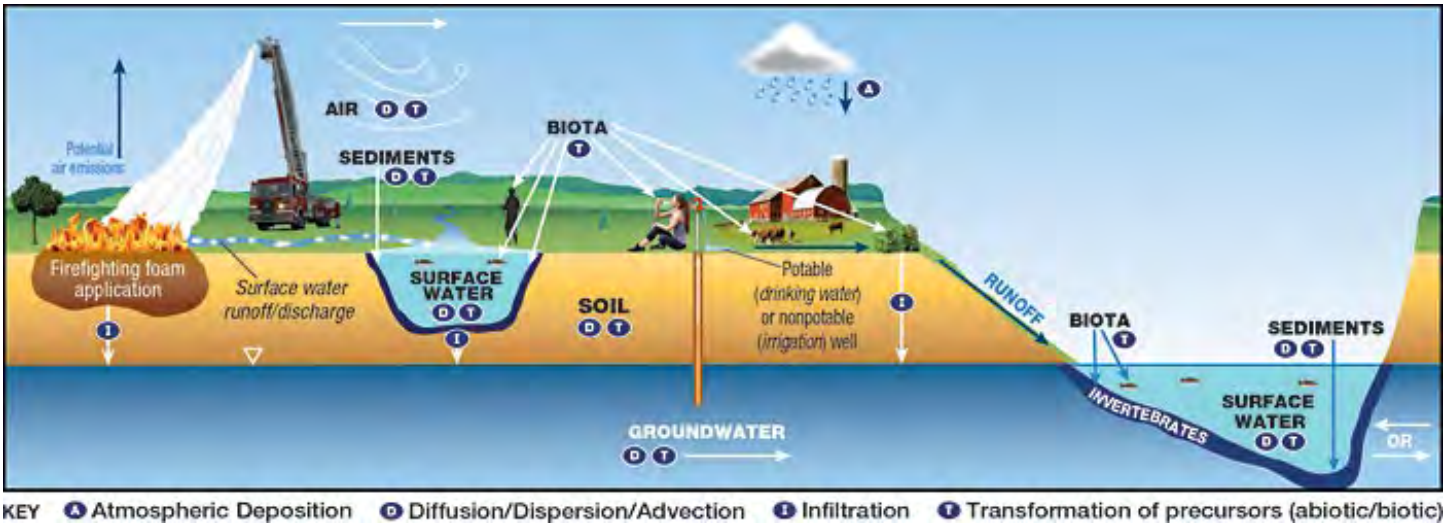


Figure 9-1. CSM for fire training area.

Source: Adapted from figure by L. Trozzolo, TRC. Used with permission.

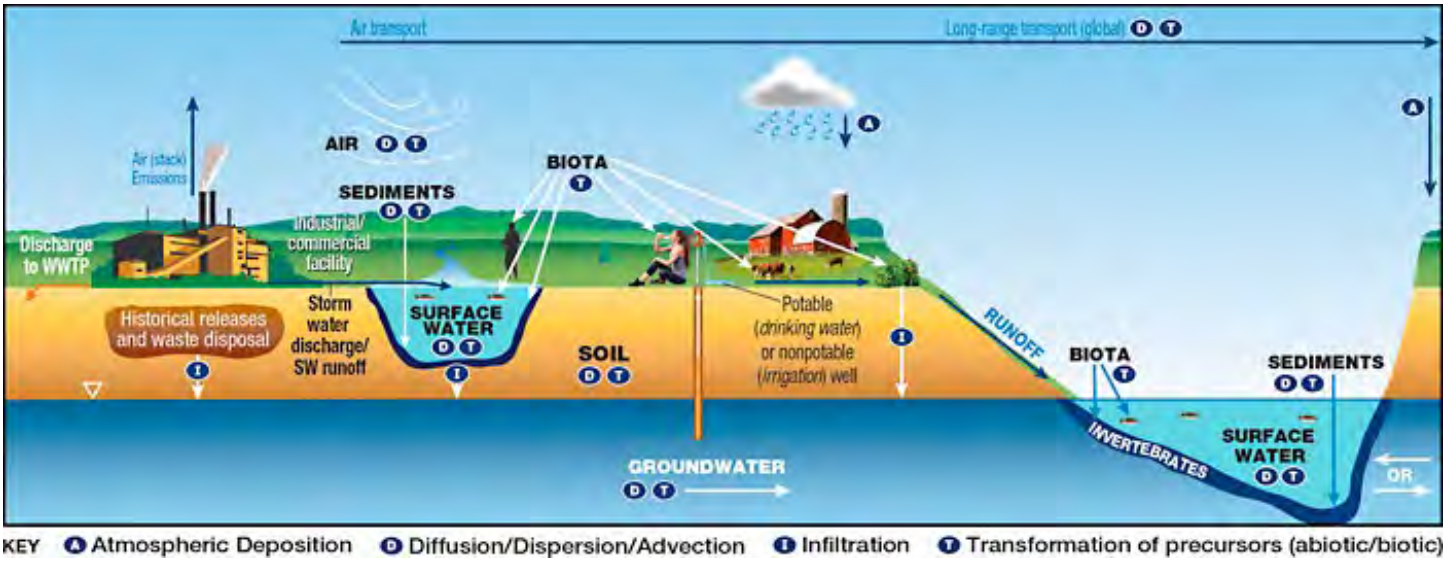


Figure 9-2. CSM for industrial sites.

Source: Adapted from figure by L. Trozzolo, TRC. Used with permission.

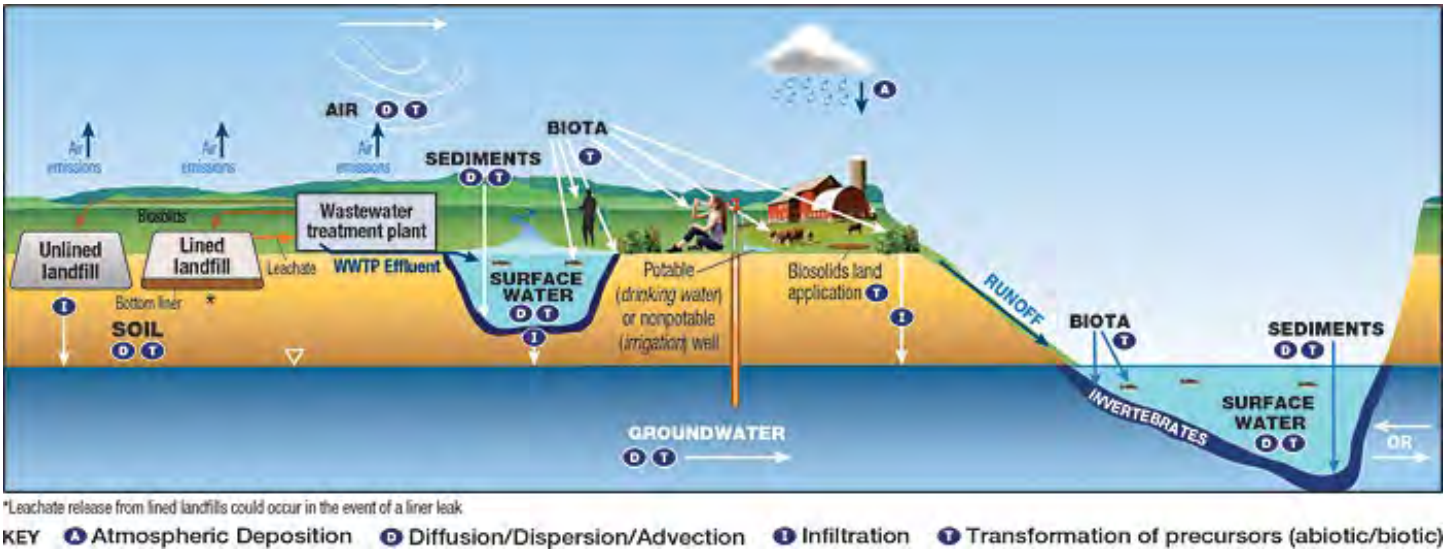


Figure 9-3. CSM for landfills and WWTPs.

Source: Adapted from figure by L. Trozzolo, TRC. Used with permission.

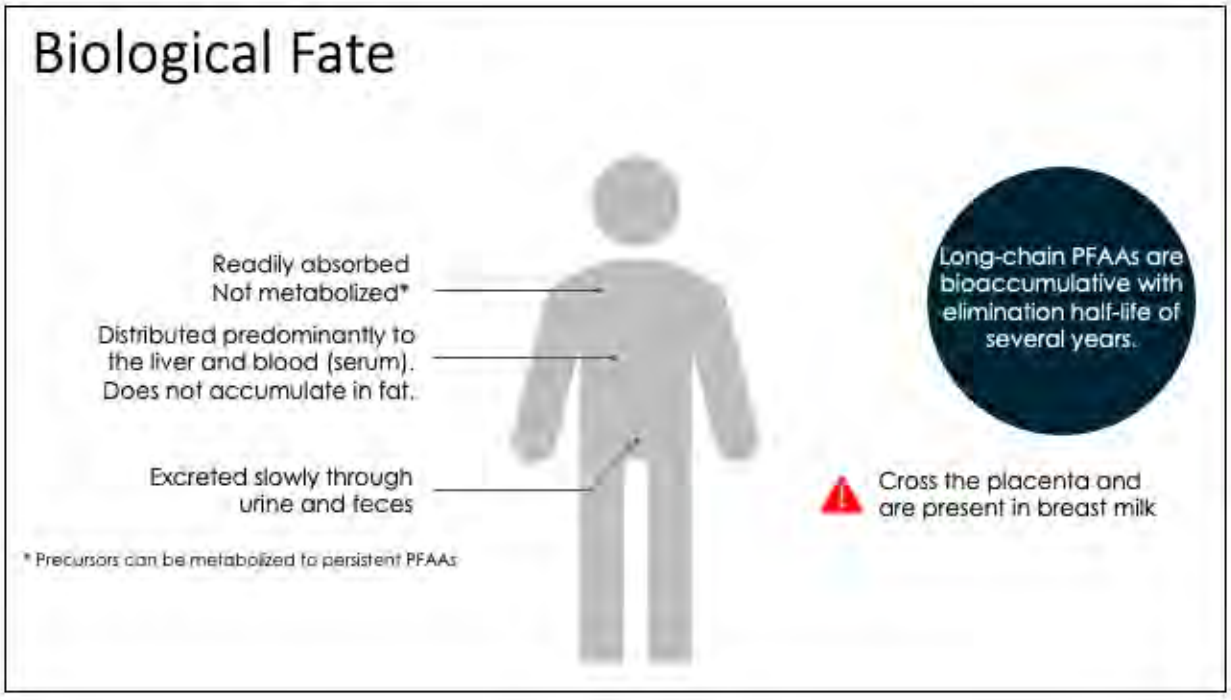


Figure 9-4. Biological fate of long-chain PFAAs.

Various exposure scenarios may be possible for a given site. Specific exposure scenarios that could be included in an HHRA are a site-specific decision.

The highest exposures to PFAS can occur during early life stages (**Goeden, Greene, and Jacobus 2019**). Exposures to infants from breast milk of exposed mothers (**Figure 9-4**) or formula prepared with contaminated water are higher (on a body weight basis) than in older age groups (**Fromme et al. 2009**; **Mogensen et al. 2015**; **Verner et al. 2016**, **Verner et al. 2016**; **Post, Cohn, and Cooper 2012**; **Goeden, Greene, and Jacobus 2019**). The higher exposures during pregnancy and to infants are of concern because fetuses and infants are potentially sensitive subpopulations for developmental effects of some

PFAS, including PFOA and PFOS (**USEPA 2024**, **USEPA 2024**), as discussed in **Section 7.1**. Therefore, exposure scenarios that include fetuses, infants, children, adolescents, and women of childbearing years should be considered in HHRAs.

Figure 9-5 illustrates the predominant exposure pathways. More detailed information about these exposure pathways, as well as other environmental medium-specific issues affecting potential human exposure scenarios, are provided in **Section 17.3.1**.

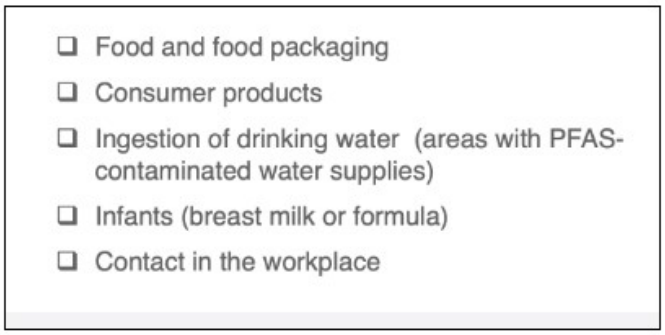


Figure 9-1. Predominant human exposure pathways.

9.1.2.2 Calculating Exposure Concentrations for PFAS via Fate and Transport Models

When using fate and transport models to calculate exposure point concentrations (EPCs) for PFAS, it is important to note that individual PFAS have different chemical properties that affect their fate in the environment (**Section 5**). Some PFAS are mobile, persistent, and bioaccumulative (in wildlife and humans), and others are not. Perfluoroalkyl acids (PFAAs) are persistent, and long-chain PFAAs bioaccumulate in humans (**USEPA 2003**; **ATSDR 2020**; **NTP 2016**; **CONCAWE 2016**). USEPA has compiled an online resource for PFAS information that includes guidance on environmental behavior and site characterization (**USEPA 2017**). The National Groundwater Association (NGWA) has also published a resource on PFAS that includes information about fate and transport (**NGWA 2017**). **Section 5.2.3** provides a discussion of fate and transport modeling for PFAS, including numerous citations. Additional information is included in **Section 17.3.2**.

When using environmental fate and transport models for estimating EPCs in biota, modeling should be focused on the part of the organism that may be consumed either by humans or by ecological receptors, recognizing that patterns of consumption may be influenced by a number of socioeconomic and cultural factors. PFAS generally bind to proteins and accumulate in protein-rich tissues, including the blood, liver, and kidneys (**ATSDR 2020**). Plant uptake and bioaccumulation and partitioning within the plant appear to depend on PFAS chemical structure and the plant species (see Section **5.6**). **Section 17.3.3** includes information about selecting bioaccumulation and bioconcentration factor values.

Measured concentrations at exposure points may differ from modeled EPCs. This may be due to other sources of PFAS (for example, a nearby site that had a PFAS release to the ground and that subsequently leached to groundwater) also contributing to concentrations at the exposure point and the limitations of the models currently available.

In surface water bodies, PFAS concentrations in foam formed at the air-water interface from wind or wave action may be much higher than PFAS concentrations present in the water column (see **Section 16.5**). Therefore, in surface water bodies where foam is present, the need to evaluate exposures to foam should be considered when planning an HHRA. At sites where foam exposures are evaluated in the HHRA, EPCs should be established separately for foam and surface water so that potential risks to foam are not underestimated.

9.1.3 Risk Characterization

The risk characterization of a site risk assessment combines the results of the exposure assessment and the toxicity assessment to provide a quantitative estimate of risk (**ITRC 2015**). It also may include a qualitative narrative designed to provide decision makers with information regarding key assumptions, uncertainties, or other issues that would be important to understand when making risk management

decisions. More background on the performance of risk characterizations is detailed in other guidance (**USEPA 1989**; **ITRC 2015**) and is not repeated here.

Because risk characterization involves combining the toxicity assessment and exposure assessment, the complexities discussed in **Sections 9.1.1** and **9.1.2** manifest themselves in the risk characterization. There are, however, additional specific complications that may be encountered in completing the risk characterization for a site risk assessment involving PFAS. This section discusses those specific complexities.

9.1.3.1 Assessing the Cumulative Effects of Exposure to PFAS

The overall potential for noncancer effects due to human exposure to more than one chemical is estimated using the hazard index (HI), which is computed as the sum of calculated chemical-specific hazard quotients (HQ). As explained by **USEPA (1989)**, "This approach assumes that simultaneous subthreshold exposures to several chemicals could result in an adverse effect. It also assumes that the magnitude of the adverse effect will be proportional to the sum of the ratios of subthreshold exposures to acceptable exposures." Risk characterizations commonly produce initial estimates of HI by calculating the sum of all HQs. When the HI is estimated to be greater than 1, there may be potential concern for adverse health effects. However, when this initially estimated HI is greater than 1, refinement of the HI estimate by segregating HIs by effect and mechanism of action may be appropriate to support a risk management decision.

Table 9-2. Summary of potential noncancer health effects of various PFAS.

Compound	# of Carbons	Liver	Develop-mental	Repro-ductive	Immune	Hema-tologic	Thyroid	Neuro-behavioral	Tumors
Perfluoroalkyl Carboxylates									
PFBA	4	■	■	■	□	■	■	□	□
PFPeA	5	□	□	□	□	□	□	□	□
PFHxA	6	■	■	■	□	■	■	□	□ (Negative)
PFHpA	7	■	□	□	□	□	□	□	□
PFOA	8	■	■	■	■	■	■	■	■
PFNA	9	■	■	■	■	■	■	□	□
PFDA	10	■	■	■	■	■	■	■	□
PFUnA	11	■	■	□	■	□	□	□	□
PFDoA	12	■	■	■	■	■	□	■	□
Perfluoroalkyl Sulfonates									
PFBS	4	■	■	■	■	■	■	□	□
PFHxS	6	■	■	□	□	■	■	■	□
PFOS	8	■	■	■	■	■	■	■	■
Per- & Polyfluoroalkyl Ether/Polyether Carboxylates; Fluorotelomer Alcohols (Examples)									
ADONA	6	■	■	□	□	■	□	□	□
GenX (HPFO-DA)	6	■	■	■	■	■	■	□	■
ClPFPECAs	8-14	■	□	□	■	■	■	■	□
6:2 FTOH	8 (6 fluorinated)	■	■	■	■	□	□	□	□

Notes: The colors used for the PFAS names distinguish between short-chain PFAS (green) and long-chain PFAS (blue). A filled-in (black) box indicates that the effect was reported in one or more laboratory animal studies. An empty box indicates that the effect was evaluated but not found, or effect has not been evaluated.

*Source: Adapted from (**ATSDR 2022**).*

USEPA has developed a Framework for Estimating Noncancer Health Risks Associated with Mixtures of Per- and Polyfluoroalkyl Substances (PFAS) (**USEPA 2024**). This document recommends assessment of noncancer health risks of PFAS mixtures based on dose additivity (for example, a hazard index [HI]

approach). **USEPA (2024)** is the basis for a MCLG and MCL of an HI of 1 for mixtures of four PFAS (PFBS, PFHxS, PFNA, GenX) (**USEPA 2024**). The draft MCLG and MCL use the "general" HI approach in which the HI considers toxicity values based on differing toxicological endpoints for the components of the mixture. More information on risk assessment of PFAS mixtures is found in **Section 7.1.5**.

As discussed in **Section 7.1**, several possible adverse health effects are associated with exposure to PFAS (**Table 9-2**). The type of information shown in this table can be used to segregate HIs by potential adverse effect in the risk characterization (i.e., the "Target Organ-Specific Hazard Index") when risks associated with exposure to specific PFAS are being evaluated and target organ-specific toxicity factors are available.

9.2 Ecological Risk Assessment

This section summarizes information that is currently available to conduct ecological risk assessment (ERA) of PFAS. The information presented is based on a review of current regulatory guidelines from within the United States and other jurisdictions, peer-reviewed publications, and other sources as noted. Sufficient information needed for performing ERAs exists only for some PFAS. When possible, discussions in this section indicate to which PFAS the discussions apply. Three recent publications funded by the US DOD, **Conder et al. (2020)**, **Divine et al. (2020)**, and **Argonne (2021)** discuss PFAS ERA in detail and provide a summary of much of the available data needed for conducting PFAS ERA within the U.S. These are the most comprehensive reports to date for completing PFAS ERAs within the U.S. The European Union (EU) also has a substantial amount of data available within their Environmental Quality Standards (EQS) for performing PFAS ERA, but the EQS use different guidelines and approaches than those in the U.S. Use of these data will likely result in conflicting values and differing conclusions on data usability and adequacy for performing an ERA. The Priority Topics for Human and Ecological Health Effects include information for evaluating risk to livestock from PFAS exposure (see **Section 1.4.7**).

This section discusses challenges within three key components of ERA: ecological effects assessment, exposure assessment, and risk characterization. **Conder et al. (2020)** and **Divine et al. (2020)** are referenced throughout those discussions as applicable. In addition, a workshop sponsored by the Society of Environmental Toxicology and Chemistry (SETAC) was held in August 2019 and focused on the state-of-the-science supporting risk assessment of PFAS. A breakout group within that workshop focused specifically on ecotoxicology and ecological risks of PFAS. The expert panel in that breakout group produced a detailed manuscript describing the currently available information, data gaps, and uncertainties, and approaches to address these needs (**Ankley et al. 2020**). Like the **Conder et al. (2020)** and **Divine et al. (2020)** reports, the recommendations of **Ankley et al. (2020)** are also directly related to conducting PFAS ERAs and are mentioned here to provide readers an understanding of subjects that are relevant but that still have uncertainty so they can assess the importance of those subjects for their specific needs. **Ankley et al. (2020)** is referenced throughout this section as applicable. Additional recommendations from **Ankley et al. (2020)** not included later in this section are listed below:

- a need for prioritizing which PFAS to study and evaluate relative to ecological risk and toxicity
- environmental monitoring beyond PFOS and PFOA
- advancing the understanding of PFAS uptake, elimination, and bioaccumulation
- broader understanding of toxicity across taxa
- the use of new approach methods (often referred to as NAMs) and
- studying and assessing PFAS as mixtures.

The remaining text for this section is organized into three main components of ERA: ecological effects assessment, exposure assessment, and risk characterization.

9.2.1 Ecological Effects Assessment

Identification of ecological risk-based toxicity thresholds is a challenge for many PFAS. Toxicity data are available as discussed in **Section 7.2**. Some of these data have been used to establish thresholds as discussed below. Some major considerations for ecological effects assessment are identifying ecological screening thresholds, understanding ecological receptor variability, and evaluating ecological toxicity of mixtures. These are discussed in the following sections.

9.2.1.1 Ecological Screening Thresholds

The recently published manuscript by **Ankley et al. (2020)** includes a discussion of media-specific ecological screening thresholds that are available for certain PFAS around the world: PFOS, PFOA, PFBA, PFPeA, PFHxA, PFBS, and PFHxS. **Ankley et al. (2020)** did not claim the list of thresholds to be comprehensive of all ecological thresholds for PFAS around the world. The discussion here in this section presents thresholds that are included within that document with discussion relevant to ITRC's intended audience. **Ankley et al. (2020)** can be referenced for a more detailed discussion and complete table of available thresholds from around the world.

U.S.—Federal Thresholds

USEPA has published draft national recommended aquatic life criteria for PFOA and PFOS in freshwater for public comment (**USEPA 2022**, **2022**) and a fact sheet for the criteria (**USEPA 2022**). In addition, USEPA had published their responses to external peer reviews of the draft criteria (**USEPA 2022**, **2022**). The draft criteria include acute and chronic water column values for freshwater environments and acute criteria for estuarine/marine environments. Tissue criteria are also proposed for whole body fish and benthic invertebrates and for fish muscle. These criteria are aimed at protection of aquatic life but are not protective of consumption by aquatic dependent wildlife (for example, birds and mammals foraging in aquatic environments). Currently, there are no ecological risk-based PFAS guidelines or media screening thresholds that are recommended by the USEPA for other PFAS.

In support of the Air Force Civil Engineer Center, Argonne National Laboratory developed ecological screening thresholds for surface water and soil (**Argonne 2021**). Values were developed for 4-, 6-, 8-, 9-, and 10-carbon linear PFCAs and the 4-, 6-, and 8-carbon linear PFSAs (see **Section 2** for detailed naming conventions). The soil screening values are protective of terrestrial plants, invertebrates, and mammalian and avian wildlife. The surface water values are protective of aquatic life and aquatic dependent wildlife. Work was completed in consultation with Tri-Services Environmental Risk Assessment Working Group, and USEPA's Ecological Risk Assessment Forum (**Ankley et al. 2020**).

There have also been a number of published studies and reports that follow U.S. federal guidelines (**USEPA 1995**) for developing aquatic life criteria. **Giesy et al. (2010)**, **Salice et al. (2018)**; **Conder et al. (2020)**, and **Divine et al. (2020)** all calculated thresholds protective of aquatic organisms exposed to PFOS in freshwater environments, though these were published before USEPA released their draft criteria. **Giesy et al. (2010)** also reported a Tier II freshwater value for PFBS, while **Conder et al. (2020)** derived Tier I values for PFOS in both freshwater and marine environments and for PFOA for freshwater. **Divine et al. (2020)** developed Tier I freshwater values for PFOS and PFOA and Tier II values for 23 other PFAS. Tier I values meet the data required described in **USEPA (1995)** guidelines while Tier II values are developed with methods that incorporate uncertainty factors when the availability of required data is insufficient. Section 16.3 provides greater detailed discussion on the methods for developing thresholds protective of aquatic life.

U.S.—Thresholds for Specific States

Several states have established some criteria that are intended to protect aquatic organisms in their respective surface waters. The text below is not intended to be exhaustive and summarizes only some of the values that were available at the time this text was developed (Spring 2021).

In Michigan, AWQC have been established for PFOS and PFOA based on Rule 57 17 (**MI EGLE 2019**). This rule is based on the USEPA Great Lakes Initiative (**USEPA 1995**), which provides procedures and methodologies to derive numerical criteria that are protective of aquatic ecosystems. Rule 57 presents a two-tiered methodology in which Tier I procedures are essentially the same as the methods used to derive federal national water quality criteria (NWQC) (**USEPA 1985**) and Tier II procedures can be used to derive values where the full extent of the toxicity data requirements of NWQC are not fulfilled. Rule 57 presents procedures to develop three categories of numeric criteria—final chronic values (FCVs), aquatic maximum values (AMVs), and final acute values (FAVs)—which can be developed under either Tier I or Tier II. Due to the greater uncertainties associated with Tier II values, and given their lesser data requirements, these values tend to be more conservative than those derived with Tier I methodologies. The PFOA and PFOS numeric criteria for Michigan are all Tier II values due to the limited amount of peer-reviewed aquatic toxicity data. The final chronic values for the protection of aquatic life (flora and fauna) for PFOA and PFOS were 880 and 140 µg/L, respectively, while aquatic maximum values were 7,700 and 780 µg/L, respectively. In addition, the Michigan Department of Community Health (**MDCH 2015**) derived provisional PFOS surface water values for mammalian and avian wildlife based on Rule 57 guidance. The surface water avian wildlife value, based on eagles, kingfishers, and herring gull characteristics, was 0.035 µg PFOS/L. The mammalian wildlife value, based on otter and mink characteristics, was 0.084 µg PFOS/L.

The State of Minnesota has also derived several surface water criteria for the protection of aquatic biota. These values are based on guidelines in Minnesota Rules chapter 7050 (MR7050). Continuous chronic criteria for the protection of aquatic biota in surface water are available for PFOA (1,700 µg/L) and PFOS (19 µg/L) (**Stevens and Coryell 2007**; **Stevens and Coryell 2007**). Florida has established Provisional Surface Water Screening Levels that are in the same range as those for Minnesota: 1,300 µg/L PFOA in freshwater, 37 µg/L PFOS in freshwater, and 13 µg/L PFOS in salt water (**FL DEP 2020**).

Table 9-3. SFB RWQCB groundwater ESLs: Aquatic habitat ecotoxicity levels for PFOS and PFOA (SFB RWQCB 2020).

Protected Organisms	PFOS (µg/L)	PFOA (µg/L)
Direct exposure ecotoxicity: Freshwater	0.56	540
Direct exposure ecotoxicity: Saltwater	2.6	540
Secondary poisoning ecotoxicity: Freshwater and saltwater	0.075	4.4

Table 9-4. Soil ESLs: Terrestrial habitat levels (SFB RWQCB 2020).

Protected Organisms	PFOS (mg/kg)	PFOA (mg/kg)
Significantly vegetated areas		
Plants and invertebrates	7.7	0.084
Mammals and birds (NOAEL-based)	0.013	0.57
Minimally vegetated areas		
Plants and invertebrates	33	0.84
Mammals and birds (LOAEL-based)	0.05	1.1

In California, the San Francisco Bay Regional Water Quality Control Board (SFB RWQCB) has released Interim Final Environmental Screening Levels (ESLs) for PFOS and PFOA (**SFB RWQCB 2020**). These values were specifically developed for use within the jurisdiction of the specific water board, not the state of California, not the California Department of Toxic Substances Control, and not the entirety of the United States. Other jurisdictions may use these values, as is often the case with many published thresholds. However, with the number of different water boards in California, it is important to understand the applicability of these ESLs. These values include groundwater protection levels that are protective for direct exposure to freshwater and marine organisms, including rare, threatened, and endangered species. The values are based on a 99% protection level (lower 1st percentile of a species sensitivity distribution [SSD]) compared to a 95% protection level (lower 5th percentile of an SSD) used for a typical AWQC. There are also groundwater ESLs that are protective of adverse effects to birds and mammals from the consumption of aquatic prey (**Table 9-3**). These wildlife protection values (listed by the SFB RWQCB and in **Table 9-3** as secondary poisoning ecotoxicity) are based on values published in **Divine et al. (2020)**. Separate soil ESLs are included in the SFB RWQCB document that are protective of (1) plants and invertebrates or (2) birds and mammals. There are two soil ESLs for each chemical for both significantly vegetated and minimally vegetated areas for a total of four distinct values each for PFOS and PFOA as shown in **Table 9-4**.

International Thresholds

Environment and Climate Change Canada (ECCC, previously known as Environment Canada) has proposed ecological Federal Environmental Quality Guidelines (FEQGs) for PFOS in surface waters, fish tissue, wildlife dietary values, and bird eggs (**ECCC 2018**). The PFOS threshold for surface waters was derived from a SSD based on long-term toxicity data that included data for amphibians, fish, invertebrates, phytoplankton, and macrophytes. The guideline to protect all aquatic life forms for indefinite exposure periods to PFOS in surface waters is 6.8 µg/L, and a whole-body fish tissue guideline value of 9.4 mg/kg wet weight (ww) was based on these fish data and bioaccumulation factors for bluegill from **Drottar, Van Hoven, and Kruger (2002)**. The tissue threshold is intended for both freshwater and marine environments. It was not calculated with both food and water (direct media) BAFs, and thus it could be underprotective. However, **Giesy et al. (2010)** did use **Drottar, Van Hoven, and Kruger (2002)** data to calculate an acute no-effect threshold of 87 mg/kg ww whole-body fish. To protect mammalian and avian consumers of aquatic biota, ECCC derived wildlife dietary toxicity reference values (TRVs) using mammalian studies and avian chronic toxicity data. For mammals, the dietary value for PFOS was 4.6 µg/kg ww food while the avian dietary value was 8.2 µg/kg ww food. Based on the avian reproduction studies that were the basis for the dietary values, a guideline of 1.9 µg/g ww whole egg was also derived for PFOS.

Screening level assessment values have also been derived for PFOA (**Environment Canada 2012**). Environment Canada derived several predicted no-effect concentrations (PNECs) for PFOA for ecological species. PNECs are intentionally conservative concentrations of chemicals designed to represent a concentration at which no adverse effects are likely. These PNECs for PFOA were based on LOAEL values from a limited set of single organism toxicity studies adjusted with uncertainty factors. FEQG values are developed from a distribution of acute and chronic studies conducted on groups of organisms with an intent to be protective of a set percentage of organisms in that category (for example, a 95% protection threshold). Thus, these PFOA PNECs are not equivalent to FEQGs, though they still provide utility for screening level ERA. The PNEC for aquatic organisms, based on a study with the freshwater alga *Pseudokirchneriella subcapitata*, was 20 µg/L; a mammalian wildlife study based on cynomolgus monkey *(Macaca fascicularis)* derived a liver-based PFOA PNEC of 158 µg/kg ww. However, given the uncertainties associated with these values, care should be taken in their application to ERA. FEQGs for PFOA are currently under development by ECCC (**ECCC 2018**).

The Australian and the New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ) have established

draft protective concentrations for freshwater organisms exposed to PFOS and PFOA. The values, as shown in **Table 9-5**, were developed by the Cooperative Research Centre for Contamination Assessment and Remediation of the Environment **(CRC CARE) (2018)**. Only the freshwater values have been adopted in the PFAS National Environmental Management Plan for Australia and New Zealand (**HEPA 2020**). The protocol for developing guideline values in Australia (**Warne et al. 2018**) includes some specifications for full lifecycle and multigenerational testing that were not sufficiently represented in the limited available marine studies. Instead, the freshwater values have been identified as interim thresholds for marine waters. The values from CRC CARE incorporated multiple studies and were based on SSD for each compound. The 90 and 95% protective thresholds for PFOS are 2.0 and 0.13 µg/L, respectively. These values are within the range of other published values (**Giesy et al. 2010**; **Qi et al. 2011**). A 99% protection value for PFOS was also proposed as 0.00023 µg/L, though this may be below ambient concentrations. It should be noted that the freshwater SSD and subsequent protection values are influenced by a multigenerational study (**Keiter et al. 2012**) with zebra fish (*Danio rerio)* that produced data that are noticeably lower than other data. Efforts to validate the data by repeating the study and its methods are ongoing at the US Army Corps of Engineers Environmental Research and Development Center (**Gust et al. 2021**). The ongoing work includes an expanded and more carefully determined dosing range, greatly increased replication base on statistical power analysis, expanded analytical chemistry with external validation, and an expanded suite of endpoints to improve overall toxicological context (**Gust et al. 2021**). All three of the PFOS protection values are taken from an SSD that includes studies on the low end that are well below the majority of other data points. Further, as indicated in table B3 of **CRC CARE (2018)**, data used in the SSD include a mix of effect levels (EC10) and no-effect levels (NOECs). Thus, decisions based on these values should be made with careful consideration.

For PFOA, the 90 and 95% protective thresholds were 632 and 220 µg/L, respectively; these are similar to those derived in Minnesota and Michigan. Marine threshold values for PFOS were 32 and 7.8 µg/L for the 90 and 95% protective levels. For PFOA, the 90 and 95% protective thresholds for marine water were 14,000 and 8,500 µg/L, respectively. It is of note that the threshold values for marine species were at least 1–2 orders of magnitude greater than those from freshwater. Thus, one should take care in using freshwater toxicity data or threshold values when evaluating marine and brackish systems, given the apparent differences in species sensitivity between these two environments. Likewise, caution should be used if employing marine values to evaluate other PFAS for which there are no freshwater threshold values.

Table 9-1. Aquatic thresholds developed by CRC CARE (CRC CARE 2018).

Species Protection (%)	PFOS (µg/L)	PFOA (µg/L)
Freshwater		
80	31	1,824
90	2	632
95	0.13	220
99	0.00023	19
Marine		
80	130	22
90	32	14
95	7.8	8.5
99	0.29	3

A number of thresholds for PFOS are also available from the European Union (EU) as described in the Environmental Quality Standards Dossier (EQS) for PFOS (**European Union 2011**, **2013**). These include maximum acceptable quality standards (MAC-EQS) for freshwater and marine ecosystems, and annual average quality standards (AA-EQS) for the same ecosystems. Standards are also available for secondary poisoning (that is, consideration of biomagnification through the consumption of contaminated prey). These values are shown in **Table 9-6**.

Table 9-6. Environmental quality standards (EQS) for PFOS (European Union 2011, 2013).

Category/Description	Units	Value
MAC-EQS (freshwater) (European Commission 2011, 2013)	µg/L	36
MAC-EQS (marine) (European Commission 2011, 2013)	µg/L	7.2
Pelagic Community EQS (freshwater) (European Commission 2011)	µg/L	0.23
Pelagic Community EQS (marine) (European Commission 2011)	µg/L	0.023
$QS_{biota,\ sec\ pois}$ (European Commission 2011)	mg/kg (ww)	0.033
$QS_{biota,\ sec\ pois}$ (freshwater) (European Commission 2011)	µg/L	0.002
$QS_{biota,\ sec\ pois}$ (marine) (European Commission 2011)	µg/L	0.00047
EQS (biota) (European Commission 2011, 2013)	µg/L	9.1
AA-EQS (freshwater) (European Commission 2011, 2013)	µg/L	0.00065
AA-EQS (marine) (European Commission 2011, 2013)	µg/L	0.00013

Notes: MAC-EQS = maximum acceptable environmental quality standard
AA-EQS = annual average environmental quality standard
QS biota, sec pois = secondary poison standard for concentration in fish tissue
QS = quality standard
EQS (biota) – environmental quality standard

Other Considerations for Thresholds

A survey of reports from various regulatory agencies demonstrates that although ecotoxicity data are available for various PFAS, including PFBA, PFBS, and fluorotelomers (including 8:2 FTCA, 8:2 FTUCA, and several FTOHs), to date these typically consider only a few aquatic species that include *D. magna*, a green alga, and perhaps a fish species. Some regulatory programs (for example, **USEPA 1985**; **Warne et al. 2018**) require a robust data set covering several classes of organisms, and due to limitations in the number of classes of organisms represented in the published peer reviewed data, it is difficult to derive ambient surface water quality criteria for other PFAS (beyond PFOS and PFOA). Limited relevant toxicity data is a greater issue for terrestrial wildlife given that the only chronic, reproductive studies with two PFAS (PFOS and PFOA) that have been conducted to date are in two species, the bobwhite quail (*Colinus virginianus*) and mallard duck (*Anas platyrhynchos*). However, more data are becoming available for other PFAS (for example PFHxS and PFHxA) in avian laboratory models (**Dennis et al. 2021**). Importantly, no ecologically relevant studies have been conducted with mink or an adequate surrogate. As a result, the development of benchmark or threshold concentrations for wildlife and aquatic organisms has been slow but information is beginning to emerge.

Research on observed effects in benthic invertebrates and other benthic aquatic life with direct exposure to sediments contaminated with PFAS is limited. However, more recent literature is becoming available for sediment exposures (**Marziali et al. 2019**), there are no published benchmarks and publications are few. Research has focused more on aqueous exposure pathways. Observational data and monitoring have been used in some cases to develop an understanding of what exposure may be associated with effects. The Norwegian Pollution Control Agency (NPCA) established a sediment no-effect threshold of 220 µg/kg, a chronic toxicity range of 220–630 µg/kg, and an acute short-term effects range of 630–3,100 µg/kg (**NPCA 2008**; **Bakke et al. 2010**) for benthic invertebrates. The technical basis for the NPCA values relied on the principles of equilibrium partitioning (EqP) between sediment and surface water using a partitioning coefficient (Kd). **Argonne (2021)** also outlines this approach for determining site-specific sediment thresholds. The NPCA no-effect sediment value is based on a PNEC of 72 µg/L from a limited data set and an unspecified Kd. A sediment screening value of 6.7 µg/kg (wet weight) from the United Kingdom's **UK Environment Agency (2004)** was also developed using EqP with a PNEC of 2.5 µg/L and a river sediment Kd of 8.7 L/kg. **Simpson et al. (2021)** have estimated sediment thresholds of 60

µg/kg PFOS and 250 µg/kg PFOS (both normalized to 1% organic carbon) protective of 99% and 95% of species, respectively, based on EqP using a Kd of 10 L/kg with an HC1 of 6 µg/L and HC5 of 25 µg/L. HC5 and HC1 are commonly established for contaminants from SSDs developed for the contaminant. These HCx (for example a HC5) represent the concentration above which the lower x proportion of species in the distribution may see adverse effects.

All of these sediment thresholds were reported for PFOS concentrations in marine sediments, though they provide some basis for screening level risk decisions for both marine and freshwater. Caution should be observed in using these values because associated effects, if any, are unclear, and the original work is not readily available. Caution should also be used in applying these NPCA sediment values from marine waters to freshwater because the freshwater organisms could be more exposed (as explained in **Section 9.1.2**) and either more or less sensitive than marine organisms. In its EQSD for PFOS, the **European Union (2011)** took the position that there is insufficient data available to confirm the need for a sediment quality standard and insufficient data to derive a threshold, thus electing not to develop a value. Similarly, a workgroup in northern Italy concluded that there was no need for a sediment environmental quality standard (EQS) for PFOA, PFBS, PFBA, and PFPeA and that data for a sediment EQS for PFHxA were insufficient (**Valsecchi et al. 2017**).

For soil, CRC CARE developed soil screening thresholds from SSDs for both PFOS and PFOA. The Canadian Council of Ministers of Environment (**CCME 2018**) has also developed several draft thresholds for PFOS in soil. A value protective of direct toxicity was developed from an SSD of plant and invertebrate IC25 values (the concentration at which a 25% reduction in a non-lethal biological measurement, such as growth or reproduction, occurs). Food chain models were used to develop values protective of soil and food ingestion by wildlife. **CCME (2018)** also developed a soil screening value protective of aquatic life for use at sites where off-site migration to nearby surface water bodies may be a concern. These values from CCME were issued draft for public comment, and final FEQGs have not yet been established. Soil threshold values for other PFAS, however, are limited.

9.2.1.2 Ecological Receptor Variability

Another major challenge with toxicity assessment for ERA is accounting for the large number of receptor types and the associated unknown variable sensitivity to PFAS. Although it is commonly understood that sensitivity to contaminants can vary widely across kingdoms or across classes of animals, the challenge for PFAS may be greater due to the lack of knowledge about this family of compounds. Studies have documented the presence of PFAS in various aquatic species since the 1950s (**Danish EPA 2015**; **Giesy and Kannan 2001**, **2002**), such as bottle-nosed dolphins (**Houde et al. 2006**), seals (**Butt et al. 2008**), squid (**Yang et al. 2012**), alligators (**Bangma et al. 2017**), and polar bears (**Smithwick et al. 2005**; **Smithwick et al. 2005**; **Greaves and Letcher 2013**). The detection of PFAS within organisms is clear evidence of exposure. Unlike many other commonly detected contaminants, however, the availability of toxicological data for PFAS is limited relative to the broad range of organisms within which PFAS have been detected.

Standard ERA practice includes developing TRVs that consider measures of exposure and effects that could adversely impact populations of wildlife (for example, chronic studies on reproduction, growth, and survival). Mammalian studies on numerous sublethal endpoints (for example, systemic, immunological, developmental, respiratory, cardiovascular, gastrointestinal, ocular, hepatic) have been conducted for PFOS, PFOA, and other PFAS and are well described in the *Toxicological Profile for Perfluoroalkyls* (**ATSDR 2021**), but these are less commonly used for TRV development for ERAs. These sublethal, mostly systemic or organ function-based TRVs are really only used for ERAs in the absence of reproduction, survival, or growth data. Mammalian TRVs for the purposes of ERA can be developed for the majority of the Third Unregulated Contaminant Monitoring Rule (UCMR3) PFAS compounds listed in **Section 8.2.2.2**. Recommendations for selecting TRVs from available data for conducting ERAs are included in **Divine et al. (2020)**, **Conder et al. (2020)**, and **Johnson et al. (2021)**. Avian oral dosing studies useful for ERA are

less available. The dietary acute and chronic studies by **Newsted et al. (2005)**; **Newsted et al. (2007)** examining PFOS exposure in mallard and bobwhite quail were the first published work relevant to ERA. **Divine et al. (2020)** and **Conder et al. (2020)** presented the data from their studies as well as data from other studies and for other PFAS that can be used for selecting avian TRVs. More recent publications relevant to ERA include that of **Bursian et al. (2021)**, who looked at oral exposure of Japanese quail (*Cortunix japonica*) to PFOS, PFOA, and AFFF (both 3M and Ansul products), and (**Dennis et al. 2020**, **2021**, **2021**) who looked at northern bobwhite quail exposed to PFOS, PFHxS, and PFHxA. **Newsted et al. (2005)** and **Molina et al. (2006)** have also reported the results of bird egg injection studies using PFOS, while **Cassone et al. (2012)** and **Norden, Berger, and Engwall (2016)** have published in ovo studies with other PFAS. A caution with interpreting these egg studies is the uncertainty as to whether naturally accumulated concentrations have the same adverse effect as concentrations administered via injection in ovo. There also can be differences when measuring whole egg, yolk, or albumin (**Custer, Gray, and Custer 2010**). Finally, there is currently not enough data for modeling egg tissue concentration for these chemicals.

Reptiles are among the least studied vertebrate taxa in ecotoxicology (**Hopkins 2000**; **Weir, Suski, and Salice 2010**) despite contamination threatening reptile populations worldwide (**Gibbons et al. 2000**). A recent study (**Furst, Weible, and Salice 2019**) exposing brown anoles (*Anolis sagrei*) to PFOS and PFHxS provides data relevant to ERA. Measures of apical endpoints included decreased growth of juveniles exposed to PFOS, while exposure to PFHxS resulted in decreased egg viability in female anoles. There are two more recent reptile studies on lizards (**Zhang et al. 2020**) and snakes (**Lettoof et al. 2023**), both of which suggest that PFAS exposure may result in decreased growth and/or body condition in reptiles. See **Section 7.2.3.2** for more information.

Amphibian toxicity data are also limited, though more are available than are reptile data. **Pandelides et al. (2023)** provides a comprehensive, critical review of recent amphibian ecotoxicity studies and the USEPA ECOTOX Database includes PFAS toxicity studies on toads, frogs and salamanders (**USEPA 2024**). See **Section 7.2.3.2** for more information.

For lower trophic-level organisms such as plants and invertebrates, toxicological data are typically generated through studies with direct exposure to spiked media. Studies are available to develop thresholds for use in ERAs, as has been done by **ECCC (2018)**, **CRC CARE (2017)**, **Conder et al. (2020)**, and **Divine et al. (2020)**. SSDs produced by **CRC CARE (2017)** showed lettuce to be more sensitive to PFOS than earthworms, but found the opposite occurred for PFOA. **Divine et al. (2020)** calculated Tier I water quality values for PFOS and PFOA, Tier II water quality values for another 21 PFAS, and soil screening values for plants and soil invertebrates for 6 PFAS each. **Giesy et al. (2010)** and **ECCC (2018)** generated PFOS SSDs for freshwater aquatic organisms, from which thresholds were derived. CRC CARE presented SSDs for PFOS and PFOA for marine waters and for soil to establish their thresholds. **Giesy et al. (2010)** noted that some guidelines for developing criteria from SSDs rely heavily on the four lowest effect concentrations; thus, results can be skewed if one genus or species is significantly more sensitive than others. In the freshwater SSD for PFOS generated by **Giesy et al. (2010)**, *Chironamous tentans* (a species of midge) were 40 times more sensitive than the next most sensitive species, the fathead minnow (*Pimephales promelas*). However, the **ECCC (2018)** SSD does not show the same difference in sensitivity with a reported 14-day growth LOEC for Japanese rice fish (*Oryzias latipes*) below the *C. tentans* 10-day NOEC. For marine waters, fish are among the most sensitive organisms for both PFOS and PFOA as shown in SSDs (**CRC CARE 2017**), but they are more sensitive by just an order of magnitude or less. Additional studies by **Simpson et al. (2021)** and **Hayman et al. (2021)** have expanded the understanding of potential toxic effects in aquatic organisms in marine waters but an SSD that includes data from both of these studies has not been published.

SSDs have not been published for avian, mammalian, reptilian, or amphibian species. Although SSDs could possibly be generated for laboratory mammalian species exposed to some PFAS, data are insufficient to generate robust SSDs that are applicable to wildlife species. Mammalian SSDs would

include mostly rat and mouse studies with a few monkey and rabbit studies. Extrapolation to other orders would be required. Existing data would be more conducive to an effects distribution because the number of species within the class of organisms would be so limited. A limited amount of published data is available for avian, reptilian, or amphibian animals, but these data are insufficient to determine a robust SSD or even an effects distribution.

Available toxicological data clearly do not adequately cover the range of organisms that are exposed to PFAS or within which PFAS have been detected, nor do the data have much breadth for chemicals beyond PFOS and PFOA. Sensitivity variation for aquatic organisms is evident from the SSDs, and likely sensitivity ranges for untested wildlife leave a clear knowledge gap for some or even most ERAs. However, this problem is not unique to PFAS. As with many other bioaccumulative and biomagnifying compounds, this knowledge gap can be addressed by using available data from surrogate organisms (for example, the closest taxonomic laboratory test species) and making some assumptions. The uncertainty in the potential difference in sensitivity needs to be acknowledged and discussed within ERAs. However, pending the outcome of quantitative analysis, risk conclusions and even risk management decisions are possible on a site-specific basis. Although extrapolations with surrogates is a common practice in ERA, caution should be used and decisions should be made in concurrence with regulatory agencies or other applicable stakeholders.

9.2.1.3 Ecological Toxicity of Mixtures

An additional major challenge in effects assessment for PFAS is considering the toxicity of mixtures. PFAS nearly always occur as complex mixtures in natural environments with multiple PFAS present at concentrations that vary by site and source of PFAS. At this time there are only limited data available to understand the toxicity of more than just a few chemicals based on single chemical exposure experiments such as direct toxicity to lower trophic level organisms or dietary exposures to upper trophic level wildlife. Thus, the ability to understand the toxicity of mixtures is limited by the scarcity of available toxicity data. However, in the absence of such data, several strategies using structural and physical properties and toxicity information from PFAS with available data may be helpful to infer potential mixtures effects, including mixtures with PFAS of unknown toxicity. These strategies include the use of in silico predictive techniques (for example, quantitative structure-activity relationships (QSARs)), using read-across from data-rich PFAS to inform data-poor PFAS, and estimating potential mixture risk using dose-addition risk assessment methods (for example, hazard index or relative potency factor approaches). Examples of published studies using QSAR for estimating PFAS toxicity include **Hoover et al. (2019)**, **Kovarich et al. (2012)**, and **Cheng and Ng (2019)** and additional citations within each of those publications. These studies typically evaluate an in vitro endpoint (such as cell death (**Hoover et al. 2019**)) or in silico measurements (such as the binding ability of known PFAS to specific cellular proteins (**Cheng and Ng 2019**; **Kovarich et al. 2012**) and then use QSAR to estimate how other PFAS would respond to that same endpoint or target. Similarly, **Droge (2019)** derived phospholipid membrane–water partition coefficients (K_{MW}) that were used within a model to predict induction of narcosis ($LC_{50,narc}$) and which could be used in the future with K_{MW}-QSARs.

Most of these studies aim to fill data gaps for individual PFAS. Since it is not yet clear how PFAS may cause toxicity to various ecological receptors, the applicability of these data to ecological risk assessment of mixtures is unknown. However, with additional chemical-specific data, methods for estimated combined toxicity, such as hazard index or relative potency factors, could then be applied. Caution should be used when applying any of these approaches; some of these methods are novel and others may be well established but are predicated on specific data-supported assumptions that have not been universally accepted. Standardized toxicity tests, such as those performed with terrestrial and aquatic invertebrates and plants, are available for performing controlled dosing experiments and for exposure tests with field samples containing natural mixtures. Laboratory dosing experiments with whole mixtures, mixtures of prioritized PFAS, or with specific formulations, and with exposure concentrations that bracket environmental relevance, are all needed to inform ecological toxicity of mixtures.

There are a number of ongoing research projects investigating simultaneous exposure of ecological receptors to multiple PFAS (primarily the UCMR3 chemicals) and their precursors, with these studies mostly using binary mixtures (**Lee et al. 2017**; **Flynn et al. 2019**; **Bursian et al. 2021**; **Dennis et al. 2020**; **McCarthy et al. 2021**). However, the relative toxicity, additivity, or synergistic effects of PFAS remain incompletely understood and still uncertain. **McCarthy, Roark, and Middleton (2021)** discussed some of the challenges with designing, conducting, and interpreting toxicity tests with mixtures of PFAS. The understanding of PFAS mixtures is still developing and there is little consensus in the scientific community regarding how to assess the potential adverse impacts of PFAS mixtures. Complicating a limited understanding of PFAS mixture toxicity is that both absolute and relative concentrations of PFAS mixtures will vary across sites and across time. Reliance on empirical data such as site-specific toxicity sampling or community structure studies ultimately may be needed to fully understand the potential impacts of mixtures.

9.2.2 Ecological Exposure Assessment

Detections of PFAS in tissues of top predators within both aquatic and terrestrial ecosystems (**Section 6.5**) points to ongoing exposure from bioaccumulative and possibly biomagnifying PFAS (**Section 5.5.3**). Thus, accuracy and realism within exposure and risk estimates for PFAS are important to making informed risk management decisions. With the challenges of accounting for multiple exposure pathways, building strong food web and ecological exposure pathway models is an important foundation of PFAS ERAs. Once completed, these models can be used to identify the key receptors and measures of exposure to complete the assessments.

For aquatic ecosystems, published data from laboratory studies and specific field sites are available that include both BCFs, BAFs, and biota-sediment accumulation factors (BSAFs). These values, some of which are discussed and presented in **Section 5** and Table 5-1 (provided as a separate Excel file), can be used to model the measures of exposure for aquatic ecosystems. (**Larson, Conder, and Arblaster 2018**) used such data to conduct food chain modeling in four different avian receptors. Published values for fish are common; however, to date these values are not standardized in how they are reported (for example, wet versus dry weight; organic carbon or lipid normalization). Most importantly, these data are highly variant (**Table 5-1**); **Environment Canada (2006)** reported that field BAFs for PFOS in Canadian biota range from 6,300 to 125,000. **Burkhard et al. (2012)** reported that within published data sources (**Giesy et al. 2010**; **Houde et al. 2006**), laboratory and field bioaccumulation metrics usually do not agree. According to **Burkhard et al. (2012)**, field-generated BAFs (wet weight tissue to field water plus some ingestion) for PFOS exceed BCFs (wet weight tissue to lab water) predicted in the laboratory. This is undoubtedly due to the inability or inaccuracy of laboratory models to account for both direct and food ingestion exposure pathways. **LaRoe et al. (2017)** pointed out that laboratory values include only accumulation across the gill membrane. Thus, ERAs are challenged with attempting to address both pathways. **Larson, Conder, and Arblaster (2018)** demonstrated that using environmentally relevant sediment concentrations with standard food chain models with both BSAFs and BAFs suggested sediment pathways may be underrepresented and studied. Although the combination of direct and ingestion pathways is primarily a challenge for aquatic systems, assessing risk to wildlife exposed to multiple media (for example, amphibians, semiaquatic wildlife) is also problematic. As noted by **Divine et al. (2020)**, there are differences between the numeric value of BSAFs developed from field data versus laboratory methods, and also between values from laboratory studies using the same methods.

In addition to fish, accumulation values for benthic organisms (California black worm, *Lumbriculus variegatus*, Higgins (**Higgins et al. 2007**) and (**Lasier et al. 2011**); oysters, *Ostrea edulis*, (**Thompson et al. 2011**) and pelagic invertebrates (*D. magna)*, (**Dai et al. 2013**)) have also been reported. Example BSAF values from **Lasier et al. (2011)** for PFOS, PFOA, PFNA, PFBS, and PFHpA range from 7 to 49 kg sediment/kg tissue wet weight (as reported by authors). **Divine et al. (2020)** and **Conder et al. (2020)** summarized BSAFs for aquatic invertebrates and bivalves and for aquatic crustaceans for 15 PFAS. Both reports also discussed a variety of PFAS BAFs for amphibians, aquatic plants, benthic invertebrates,

crustaceans, and fish. There is overlap, as well as difference, in the studies discussed and presented by **Conder et al. (2020)** and **Divine et al. (2020)**. Much of this data is also described in **Section 5.5**. The **Conder et al. (2020)** report leans toward describing available data while the **Divine et al. (2020)** report goes a step further and attempts to apply the data to develop screening values from wildlife food web models, similar to the secondary poisoning values available in the EU (**Table 9-6**).

Data for terrestrial systems are limited to primarily plants (agricultural crops) and earthworms, with little available for vertebrate prey tissue. One exception is **Müller et al. (2011)**, which published data for a soil-to-caribou-to-wolf BAF used by **ECCC (2018)** in establishing a soil threshold protective of terrestrial carnivores at 2.6 mg PFOS/kg soil. In nearly all cases, these BAFs and BSAFs are available only for PFOS, though the **Lasier et al. (2011)** study can be used to identify BSAFs for five of the six UCMR3 PFAS.

Caution should be used in applying any of the published bioaccumulation or biomagnification data for desktop exposure estimates that are in turn used to justify remedial action. Several factors and uncertainties are associated with performing desktop food chain modeling with the limited amount of published data. Some of these considerations include the following:

- differences in diets of receptors at investigation sites versus that of studies documented in the published literature: differences in the proportions of prey items; differences in the uptake and elimination rates of PFAS or overall bioaccumulation of PFAS by the prey

- differences in physiology between the site receptors and those in published literature: capacity and magnitude of transformation; metabolism and uptake and elimination rates of PFAS; the amount/composition of protein-containing tissues to which PFAS bind; species home range and migration

- differences in physiochemical properties of the abiotic media containing PFAS between investigation sites and published study sites: bioavailability and uptake of PFAS; environmental processes (photolysis, hydrolysis, microbial aerobic and anaerobic metabolism); the presence of precursors. There is not a sufficient set of bioaccumulation data to date to account for these variations. Such studies were part of the 2019 Statements of Need for **Strategic Environmental Research and Development Program**(SERDP) grant projects.

These uncertainties are not completely unique to PFAS, as there are many other contaminants for which risk assessments are performed. Though there is some uncertainty with desktop food chain models for PFAS based on abiotic media, quantitative modeling does not need to be avoided. Two conclusions should be reached through food chain modeling with abiotic media and literature based BAFs/BSAFs/BCFs: either concentrations at the site are sufficiently low such that it can be concluded that risk to the environment is negligible and acceptable or concentrations suggest further evaluation by either refined baseline problem formulation or a baseline ecological risk assessment (BERA). Conducting BERAs for sites with PFAS should not be substantially different from BERAs for sites with other chemicals. Either in situ or ex situ direct toxicity tests with representative organisms can and should be performed when exceeding the limited ecological risk thresholds that are available. Likewise, measured concentrations of PFAS in prey should be obtained if desktop food chain modeled exposure exceeds TRVs. But the biggest challenges for measuring PFAS in biota have to do with the unique analytical chemistry method issues (**Section 11**). Challenges such as selecting the correct biota to sample, matching the prey items to the diets of upper trophic level biota, or obtaining sufficient tissue volume for chemical analysis may exist, but these issues are not unique to PFAS investigations.

9.2.3 Risk Characterization

Some aquatic toxicity data are available for environmental risk assessment for a few PFAS, but wildlife data are still incomplete. Adequate, though not abundant, data are available for completing wildlife risk

assessment, primarily for PFOS. The ability to complete risk assessments for other PFAS regularly analyzed and detected in environmental investigations (**Section 6**) is limited. However, with the exposure data discussed in **Section 5.5** and **Section 6.5**, and methods discussed in **Section 9.2.2**, the foundations of a quantitative risk characterization can be completed for PFOS and to an extent, PFOA. Risk assessment for other PFAS can be made with some conservative assumptions and use of PFOS data as a surrogate. The ability to combine effects thresholds (**Section 7.2**) and exposures to characterize risk to environmental receptors is outlined in a few publicly available sources. **McCarthy, Kappleman, and DiGuiseppi (2017)**, **Conder et al. (2020)**, and **Divine et al. (2020)** have identified exposure factors and effects thresholds that can be used for completing quantitative ERA within current regulatory frameworks.

The risk characterization of any chemical has uncertainty associated with it, and ecological effects characterization for PFAS is no exception. However, at this time based on the data presented in this section, meaningful PFAS risk management decisions can be supported in some situations using the current state of ecological risk assessment science. Broad risk management decisions regarding the ecological risk of PFAS should not be made for most risk assessments. In some cases, with consideration of the knowledge gaps and uncertainties for the site-specific scenarios being evaluated, stakeholders can work together to reach defendable scientific management decisions. Such risk characterizations using non-site-specific abiotic media, surrogate information, and tools can form the basis of screening level assessments. These screening assessments can be used to make more informed decisions regarding the need for site-specific assessments, including the collection of site-specific tissue data. However, within these screening assessments, discussion of the uncertainties and data gaps and assumptions made should be included to inform the risk management decisions.

9.3 Uncertainty

In performing a site risk assessment, including information and a discussion regarding key factors of uncertainty in the risk characterization can be important. As noted by **USEPA (1989)**, the source and degree of uncertainty associated with the risk characterization is needed to help decision makers (for example, risk managers, stakeholders), with sufficient level of detail to allow them to make informed risk management decisions (**National Research Council 2009**).

As noted throughout this guidance, while the science of characterizing and evaluating potential risks associated with PFAS exposure continues to develop, there are still uncertainties that arise in conducting site-specific risk assessments for sites with PFAS impacts. This section lists potentially critical uncertainties that, depending on the methodologies and assumptions used in a particular site-specific risk assessment, may warrant a discussion to help decision makers and stakeholders interpret and appropriately use the results of a risk assessment.

9.3.1 Fate and Transport

Site-specific risk assessments typically characterize risks associated with potential contaminant exposure that could occur currently or in the future. To characterize potential future exposures, conservative models are often used as tools to predict the fate and transport of chemicals in the environment. With regard to PFAS fate and transport, uncertainties can be introduced as follows:

- Estimating future environmental concentrations due to airborne wet and dry deposition (**Section 5.3.2**)
- Estimating the transformation of PFAA precursors to PFAA daughter end products (**Section 5.4.2**, **Section 10.4.4**) in the environment

- Modeling groundwater transport considering such factors as chemical-specific retardation (**Section 10.4.1**) and back-diffusion (**Section 10.4.3.3**)

- Estimating the bioaccumulation/bioconcentration of PFAS (**Section 5.5.2**, **Section 9.2.1**, **Section 9.2.2**) in a particular animal/plant or via food chain modeling

9.3.2 Human Toxicity

Human health risk assessments typically involve the use of toxicity values that are derived in a manner that is intended to represent a "reasonable conservative estimate" (**USEPA 2012**) of the dose-response in humans. Most of the toxicity values that have been derived by agencies for PFAS for use in site risk assessments are based upon animal studies, with human data used to support the hazard identification component of the risk assessment. However, it is noted that USEPA (**2023**, **2023**, **2023**), as well as **CA OEHHA (2023)** recently used human epidemiological data as the basis for draft noncancer toxicity factors (RfDs) for PFOA and PFOS and CSF for PFOA (**Section 7.1.4**). Additionally, there is a lack of toxicity values for many PFAS, which with their absence could result in an underestimation of the risks associated with PFAS exposure.

Overall, with regard to PFAS human toxicity, uncertainties in conducting a risk assessment can be introduced as follows:

- Missing dose-response information for site-related PFAS to which receptors could be exposed (**Section 7.1**, **Section 9.1.1.2**)

- Using toxicity values for a particular PFAS as a surrogate for another (**Section 9.1.1.2**)

9.3.3 Ecological Toxicity

As with human health risk assessments, ERAs often use TRVs that are generic and not site-specific. These generic TRVs are conservative by design because they are used for screening purposes (**USEPA 2004**). Likewise, there is a degree of conservatism incorporated into the derivation of generic criteria (for example, ambient water criteria) to account for uncertainty (**Section 9.2.1**).

Overall, with regard to PFAS ecological toxicity, uncertainties in conducting a risk assessment stem from using toxicological information from surrogate organism(s) to evaluate potential risks for organisms for which toxicity studies do not exist (**Section 9.2.1**)

9.3.4 Accounting for Nonsite-Related PFAS

Site-specific risk assessments rely on site characterization information (and as needed, modeling) to help estimate the amount of exposure receptors could be subject to currently or in the future. Given the widespread presence of PFAS in the environment (**Section 6**), including the potential of upgradient off-site PFAS impacts to migrate onto subject properties (**Section 10.5**), discerning "background" anthropogenic or off-site PFAS impacts at a site from site-related impacts can be challenging. To streamline risk assessments, it may be conservatively assumed initially that concentrations of PFAS are entirely site-related. Doing so, however, may overestimate the risks associated with site-related releases.

10 SITE CHARACTERIZATION

The intent of this section is not to present general site characterization principles, but to highlight unique considerations or examples for this family of emerging contaminants. It is assumed that site characterization will follow all applicable state and federal (for example, CERCLA or RCRA) guidelines. The general principles of site characterization are similar for PFAS as for any contaminant, in that the physical setting, release specifics, proximity to receptors, and fate and transport characteristics will determine the sampling locations and requirements. Because of the toxicity, persistence, mobility, ubiquity, the large number of compounds in this family of chemicals, the variability and uncertainty of specific compounds and their criteria being regulated, and the emerging nature of PFAS, it is necessary to consider specific concerns in PFAS site characterization efforts.

Section Number	Topic
1.1	**Priority Topics for History, Use, and Naming Conventions (2025)**
1.3	**Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization (2025)**
1.5	**Priority Topics for Sampling and Analysis (2025)**
1.8	**Priority Topics for PFAS and Microplastics (2025)**
10.1	**Site Characterization Issues Relevant to PFAS**
10.2	**Initial Steps**
10.3	**Site Investigation**
10.4	**Data Analysis and Interpretation**
10.5	**Source Identification**
15.1	**Site Characterization Case Studies**

Exposure to PFAS can occur through a variety of transport pathways involving all environmental media, as is described in **Section 5**. Because ingestion of water is deemed a major route of exposure in humans, and the emerging nature of PFAS as contaminants of concern, regulatory interest has in the past several years been centered on this pathway. In turn, this focus has led to an increased emphasis on investigation of the connection between drinking water sources and groundwater, including direct use of groundwater as drinking water and connections between surface water and groundwater. Because of this regulatory and investigatory focus, this section places more emphasis on characterization of groundwater plumes than characterization of other media. Although groundwater may have in the past been more commonly the initial regulatory and investigatory focus, regulatory focus is broadening to other media such as surface water and biota and as a site-specific characterization process advances data are generally required from one or more other media including soil, sediment, surface water, stormwater, air, biota, or other media depending upon the nature, duration, and time of the release. **Section 2.2** includes detailed information about the wide range of PFAS chemistry. **Section 4** includes information about physical and chemical properties.

The guidelines below include general considerations for the most common types of PFAS sites. Many of the papers referenced in this section are products of studies sponsored by SERDP/ESTCP. A list of SERDP/ESTCP research projects related to PFAS and AFFF can be found at **https://www.serdp-estcp.org**.

10.1 Site Characterization Issues Relevant to PFAS

The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include information about site characterization tools and techniques (see **Section 1.3.8**).

Historical investigations may have missed the potential for PFAS contamination at a site because, until recently, these chemicals were not regulated, were not considered a health or environmental concern, or PFAS sampling and analytical procedures may not have been available. As a result, PFAS plumes had years to develop and migrate without detection or characterization. Reviewing available site information such as a timeline for processes, layout, chemical use, release history, and fire training and/or firefighting events when AFFF was used in comparison with the time period of PFAS use can be helpful in evaluating the types and potential occurrences of PFAS releases. Once the potential for a PFAS release(s) is reasonably established, initial sampling could be completed to verify whether PFAS is present. If PFAS is determined to be present at levels warranting further assessment, a site investigation would be completed to characterize the nature and extent of the release and subsequent PFAS distribution. However, a PFAS site may be one of the many without an identified source (**ATSDR 2021**).

The following are some important considerations specific to PFAS sites.

10.1.1 Evolving Science and Regulations

State of the science: Understanding of many aspects of PFAS, such as toxicology and behavior in the environment, is changing rapidly. This may require reevaluation of earlier assumptions and conclusions throughout the site characterization process.

Analytical methodologies: Analytical methodologies continue to be developed and improved. Specific attention must be paid to a wide variety of factors, such as analytical methods, detection/reporting limits, and parameter lists that are continuing to expand (see **Section 11.2**).

Sampling methodologies: Cross-contamination potential may exist due to the presence of PFAS in consumer products; many regulatory agencies require a precautionary approach to sampling prohibiting the use of materials that may be treated with PFAS. See **Section 11.1**, Sampling, for more details.

Regulatory environment: The regulatory environment remains in flux, with changing regulatory limits, sampling procedures, and compounds of interest. Investigators should review current regulatory requirements to identify impacts to the site characterization (see **Section 8**, and the **Regulatory Programs Summary Excel file**).

10.1.2 Source, Fate, and Transport Properties

Sources: PFAS sources are discussed in **Section 2.6**. AFFF releases are discussed in more detail in **Section 3.3**. In addition, **Salvatore et al. (2022)** proposed that PFAS releases to the environment could have occurred at AFFF discharge sites, industrial facilities included in 38 specific North American Industry Classification System (NAICS) codes, and PFAS-containing waste sites. There are also "secondary sources," such as PFAS concentrating into one portion of a plume (for example, groundwater into surface water) that then acts as a source to further groundwater contamination.

Further, because of the large number and varying chemical and physical properties of PFAS, and widespread use of PFAS-containing products, there may be multiple locations that act as a source of PFAS at a site. In addition, PFAS are often detected at low levels in samples from locations without any apparent or nearby sources. In those instances, there may be a need to evaluate the site-specific

anthropogenic ambient background concentrations and determine their contribution to PFAS concentrations in environmental media at a site. See, for example, **Strynar et al. (2012)**.

The Priority Topics for History, Use, and Naming Conventions include information about semiconductor industry uses of PFAS (see **Section 1.1.1**), less-publicized PFAS Sources (see **Section 1.1.2**), and less-studied PFAS (see **Section 1.1.3**), including ultrashort PFAS, cyclic PFAS, volatile PFAS, and fluorinated gases. The Priority Topics for Biosolids Land Application (See **Section 1.7**) include information that supplements the biosolids information in **Section 2.6.4**. See also the **PFAS and Vapor Intrusion Fact Sheet** developed in 2025. The Priority Topics for PFAS and Microplastics provide information about the interconnections between PFAS and Microplastics (see **Section 1.8**).

Pathways: PFAS may be present or migrate via pathways that are not typically observed with other compounds. For example, PFAS may be present in groundwater at a site via air deposition and no direct on-site release.

Complex transitions between media: The behavior of PFAS in the environment may deviate greatly from typical contaminants. Transitions between media may be complex because of specific characteristics of these compounds. For example, PFAS may disperse more upon reaching the water table than is typical for most other compounds, or a groundwater plume discharging into a surface water body may infiltrate into groundwater elsewhere, with contamination in the surface water acting as a secondary source. See Sections **5** and **6** for additional detail.

Partitioning: Because of their physical and chemical properties and the variability of those properties, certain PFAS may partition from water through different mechanisms (including hydrophobic effects, electrostatic interactions, and interfacial behaviors) to other media or forms, including air, micelles, foam, solids, NAPL, and interfaces between these phases. Physical and chemical properties are discussed in more detail in **Section 4** and phase partitioning is discussed in more detail in **Section 5.2** and as appropriate in several subsections in this section.

Secondary Sources

Sources created through movement of contaminated media into an area that was previously uncontaminated (for example, contaminated water from irrigation wells or reuse and application of biosolids, or atmospheric deposition) or an area where physical or chemical processes have concentrated PFAS, resulting in an additional source (for example, multi-media interfaces; see Sections **5** and **6**).

10.2 Initial Steps

A comprehensive initial assessment commonly starts with developing an understanding of potential PFAS uses in the area; history of the site operations that potentially used PFAS-containing materials; areas where fluorine-containing Class B firefighting foams were stored, used, or released; on-site or off-site air deposition patterns where PFAS may have been produced or processed (for example, manufacturer and/or industrial facilities that produce PFAS or use materials containing PFAS and are likely to have airborne emissions), and the regional geologic and hydrologic framework as it relates to contaminant transport to surface waters or drinking water wells. Following the initial assessment, several phases of site investigations may be required at a sufficient resolution to capture the effects of the heterogeneities that direct contaminant distribution, fate and transport, and remediation effectiveness. However, there may be a need to prioritize the evaluation of certain exposure pathways (for example, drinking water wells) during the beginning investigations to quickly assess potential human exposures and because of constraints on resources and schedule.

When historical PFAS releases have occurred upgradient of drinking water sources, drinking water sampling may be the first indication that there is a

Site-Specific Anthropogenic Ambient Background

Concentrations of PFAS present in environmental media at the site that are not the result of or influenced by site activities or releases.

problem. In areas where there is a concern that a PFAS source may be present, identification and sampling nearby drinking water sources (for example, groundwater and surface water) have in certain circumstances preceded typical site investigation work and can be considered in future situations to determine if PFAS are present in potable water sources and evaluate the potential exposure to human receptors. In cases where sources are not well defined, reconnaissance sampling may be useful to inform the development of the conceptual site model (CSM) and site investigation. Prior to further site characterization, proper notification to consumers and evaluating options to reduce or eliminate PFAS exposures, including alternative drinking water sources, may be required. In cases where sources are not well defined, reconnaissance sampling may be useful to inform the development of the CSM and site investigation plan.

CSMs are useful tools for the presentation and evaluation of site characteristics, releases, contaminant fate and transport, and exposure pathways, and it may be appropriate to develop an initial CSM prior to or as a part of preparing a site investigation plan. Generalized CSMs are presented in Figures **9-1**, **9-2**, and **9-3**. The referenced CSMs present most known and potential PFAS source areas, transport mechanisms, and pathways on a simplified physical setting. The CSMs also illustrate exposure routes and receptors.

CSM development is an iterative process over the project life cycle with information obtained during site investigation, remedy design, remedy implementation and optimization, and post-remedy monitoring (if applicable). Similar to the USEPA's data quality objectives (DQOs), it relies on a systematic objectives-based site characterization process (**ITRC 2015**). The CSM for a PFAS site is developed with information on potential ecological and human receptors, and PFAS sources and releases (whether occurring on site or off site from groundwater, surface water, sediment, or air), and should be updated as new information becomes available through site characterization, evaluation of all pathways, and potential receptors. Because many PFAS sites have had releases of other contaminants and subsequent follow-up site investigations, it is possible that a CSM may exist for the site that could serve as the basis for modifications to address PFAS.

10.3 Site Investigation

This section highlights some important considerations for site investigation that are relevant for PFAS. The general principles of site investigation are similar for PFAS as for any chemicals. In 2024, USGS published a guidance that reviews a broad range of considerations for site investigation and sampling in the context of Natural Resource Damage Assessment and Restoration (**Pulster et al. 2024**).

10.3.1 Development of Site Investigation Work Plan

PFAS investigation work plans should take into consideration the information provided in this guidance document (for example, Sections **2**, **4**, **5**, **6**, **9**, and **11**), including items such as sampling procedures and equipment to prevent cross-contamination, analytical methods, compounds to be reported, quality assurance/quality control, geographically variable and changing regulatory requirements and criteria, site-specific environmental setting, human health and/or ecological risk assessment, and potential treatment technologies and remedial approaches (see **Section 12**). From a general perspective the work plan will depend on the type of PFAS source and subsequent transport via various media, both of which should be discussed in the CSM section of the work plan. Investigative approaches should consider potential nearby sources and secondary sources, such as irrigation, sludge, or biosolids applications; atmospheric deposition; landfill leachate; and wastewater treatment plant discharge. As noted below, it is critical for the investigation to generate data that directly support subsequent risk assessments, feasibility studies, EE/CAs, and/or other evaluations of potential remedial alternatives. For PFAS, this may require a relatively high data collection effort, given typical release scenarios (for example, as a mixture of different PFAS) and low criteria values, and require more than one phase of investigation.

10.3.1.1 Geologic and Hydrogeologic Investigation

Evaluation of the geologic and hydrogeologic framework associated with the site is critical, and sometimes that framework may need to be addressed on a regional basis, as the PFAS impacts may extend significant distances from the site.

The amount of information to be collected to complete an adequate assessment is a site-specific determination based on many factors, such as complexity of stratigraphic and lithologic variability, project objectives, and available budget. In development of a work plan, consideration should be given to understanding the geologic history and geomorphology of the site and to evaluating how the subsurface materials and geometry control the fate and transport of contaminants. High-resolution site characterization (HRSC) techniques are normally appropriate to obtain adequate subsurface information (for example, grain size, lithological interfaces, and high transmissivity zones) to complete stratigraphic assessments (**USEPA 2016**). ITRC has guidance on implementing advanced site characterization tools (**ITRC 2019**).

Environmental sequence stratigraphy (ESS) is also an approach that may be applicable depending on site-specific circumstances. ESS is a method for understanding the geologic framework and related subsurface contaminant transport pathways, both regionally and underlying a site. The ESS approach is presented in USEPA Groundwater Issue Paper "Best Practices for Environmental Site Management: A Practical Guide for Applying Environmental Sequence Stratigraphy to Improve Conceptual Site Models" (**USEPA 2017**). A case study describing the use of ESS for PFAS investigations is described in **Section 15.1.3**.

The geologic and hydrogeologic investigation should define the hydrogeologic and geochemical parameters that are pertinent to PFAS migration and applicable to subsequent remedial actions. A thorough understanding of site soil types (for example, f_{oc}, bulk density, surface charge, anion and cation exchange capacity, grain size, minerology, and water content) and geochemistry (for example, ionic concentrations, ionic strength, dissolved oxygen, oxidation-reduction conditions, and pH) is needed to assess PFAS transformation, partitioning (including desorption), and migration in groundwater or soil. Hydrogeologic parameters such as groundwater recharge, hydraulic gradient, infiltration rate, permeability, hydraulic conductivity, and seepage velocity are vital components of the site investigation and help define the potential migration rate of PFAS. A thorough evaluation of the site hydrogeology will aid in evaluating and designing remedial alternatives. For example, the site geochemistry, including cations, anions, total dissolved solids, and fouling parameters (for example, iron, manganese, hardness, biochemical oxygen demand (BOD)), as well as other organic compounds in groundwater, may have a significant impact on the selection, design, and implementation of potential groundwater remedies.

Similarly, understanding the range of concentrations of PFAS in varying soil types and PFAS distribution in the vadose zone compared to the saturated zone is an important objective of site characterization. At sites with soils of varying permeabilities, the PFAS distribution within these different soil types should be established to better understand the feasibility of various remedial options, such as those that involve amendment distribution within the subsurface. This type of information is also beneficial for documenting natural processes that may be contributing to retention of PFAS within source areas and influencing downgradient transport.

10.3.1.2 Surface Water Body Secondary Sources

Because certain PFAS are mobile and resistant to breakdown in the environment, there have been cases of surface water creating very large dilute groundwater plumes through recharge (**ATSDR 2008**). Infiltration of PFAS along the course of surface water systems, including tidal zones, may result in widespread secondary sources to groundwater, further enlarging the contamination area (**Ju et al. 2008**).

A study assessing PFAS concentrations in river and groundwater from several locations found that concentrations and trends in groundwater were generally similar to those observed in surface water, suggesting the aquifer was contaminated with the same source as the surface water (**Sharma et al. 2016**). Areas with high hydraulic conductivity allow for the rapid spreading of PFAS over large areas. However, even in lower permeability geologic deposits, PFAS contamination is a problem because the combination of long groundwater residence times and persistence of most PFAS results in a long-time presence of these compounds in water resources (**Banzhaf et al. 2017**). In situations where PFAS-contaminated surface water is recharging groundwater, investigation of the potentially impacted groundwater should be conducted to fully characterize site-related contamination (**Divine et al. 2023**). Complicating surface water being a secondary source is that PFAS have been shown to concentrate at the surface water-air interface (**Ju et al. 2008**). PFAS contamination may also concentrate in naturally occurring surface water foam (due to an affinity to organic material in the foam and the higher PFAS concentrations at the surface water-air interface where the foam is formed). Therefore, site characterization must consider whether or not surface water bodies are the most downgradient extent of contamination. **Section 5.3.4** includes information on transfer of PFAS between surface water, sediment, and groundwater, including how changing conditions in the hyporheic zone are likely to affect PFAS transformation and partitioning. A brief discussion of surface water–groundwater interactions extending the areal impact of PFAS contamination is discussed in a case study in **Section 15.5**, and surface water quality is discussed in **Section 16**.

When evidence suggests that PFAS contamination is being transported between surface water and groundwater, it may be important to identify site-specific conditions of the hyporheic zone and to quantify PFAS concentrations in sediments or porewater, mass flux between groundwater and surface water, and factors such as redox conditions, salinity, and composition of sediment or suspended particulates (organic and mineral content) that may affect PFAS sorption and transformation (see Sections **5.2.3** and **5.3.4**).

PFAS levels in sediments can be an expression of the average deposition conditions of discharges that are episodic. Sampling of sediments on a dry-weight basis provides information on PFAS sorbed to sediments, but may underestimate or miss PFAS in mobile porewater, which makes passive porewater samplers practical tools to characterize the concentration and mass flux of PFAS in or across the hyporheic zone and correlate it with the sediment PFAS content. Some types of passive samplers allow accumulation of contaminants over time, thus generating a time-weighted mean concentration rather than a snapshot of concentration at a discrete time point as given by discrete porewater sampling. Therefore, depending on study objectives, passive sampling may provide data that are more representative of PFAS mass flux between surface water and groundwater as compared to sediment sampling or discrete porewater sampling. However, careful consideration of study objectives must be given when selecting the type of passive sampler, as equilibrium devices may not be appropriate for measuring episodic discharges. See Sections **11.1.7.4** and **11.1.7.7** for more information on porewater and sediment sampling for PFAS, respectively.

10.3.1.3 PFAS-Specific Tools for Site Screening or Characterization

Investigative techniques to characterize source soils and determine the three-dimensional extent of soil and groundwater contamination should be considered. HRSC technologies, while providing near real time subsurface lithological and hydrologic information, can be used to efficiently obtain discrete groundwater samples in the intervals of interest, such as the high transmissivity zones and lithological interfaces. Analytical procedures that can be used in a mobile laboratory and achieve ng/L detection limits are becoming more available and can be used on site in conjunction with discrete HRSC sampling techniques (**Quinnan et al. 2021**). Use of a mobile laboratory can be expensive and is cost-effective only in specific situations when a sufficient number of samples can be collected in a short time period to keep the mobile laboratory at or near its capacity. Use of a mobile laboratory and the quick turnaround of results they provide allow for adaptive selection of additional sampling locations for delineation or other

objectives. One of the main drawbacks associated with current field-screening methods is the inconsistency of results associated with measurement sensitivity to site-specific factors, including varying soil types and compositions. Furthermore, field screening methods should not be anticipated to replace fixed-laboratory analysis in terms of satisfying regulatory requirements.

Other field-screening methodologies have either been tried or are in the research and development phase, including ion selective electrodes to quantify PFOS and a mobile field-screening unit for PFOS and PFOA, both of which are attempting quantification to ng/L levels (**Deeb 2016**). Another method in the development stage is "a synergistic approach for the targeted affinity-based capture of PFOS using a porous sorbent probe" (**Cheng et al. 2020**) that may be able to obtain a detection limit for PFOS in water at about 0.5 ng/L. **Rodriguez et al. (2020)** provided a review of PFAS-detecting sensors and expected future direction for sensors. Multiple technologies for PFAS site investigation including passive and no-purge samplers, passive flux meters, mobile labs, real-time sensors, and novel techniques for reliable detection in complex matrices have been recently reviewed (**Horst et al. 2022**).

10.3.2 Nature of PFAS Sources

The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include information about characterizing PFAS in groundwater at or near facilities with septic systems (see **Section 1.3.2**).

The nature of primary and secondary PFAS sources at a site will largely determine the extent of PFAS contamination at the site. Multiple factors may contribute to the nature of PFAS sources at a site. Key factors to consider in development of a work plan include:

- Leaching from the vadose zone to the saturated zone: PFAS present in unsaturated soils due to retention mechanisms (for example, partitioning at the air/water interface and sorption to organic matter) are subject to downward leaching during precipitation or irrigation events (**Section 5.2**).
- Matrix diffusion: PFAS dissolved in groundwater that diffuses from higher permeability zones and accumulates in lower permeability silt/clay layers below the water table and may diffuse back into the higher permeability zones due to changing relative concentrations (**Section 5.3.1**).
- Desorption: PFAS resulting from desorption from solids in the vadose or saturated zones and resolubilizing in porewater or groundwater could occur when **adsorption** (that is, partitioning) is reversible (**Milinovic et al. 2015**); such desorption would have the effect of sustaining PFAS concentrations in porewater or groundwater.
- Nonaqueous phase liquids (NAPL) dissolution: PFAS entrained in NAPL in the subsurface may be associated with releases of chlorinated solvents and/or petroleum hydrocarbons.
- Other sources: Given the widespread use of some PFAS, additional sources upgradient or within a plume may be contributing to PFAS concentrations at a site. Collecting samples to allow for evaluation of anthropogenic ambient background and/or commingling of plumes may be necessary if it is suspected that other sources are a contributing factor.
- Atmospheric deposition: PFAS are sometimes associated with stack or other air-emission sources and may contribute to regional PFAS concentrations.
- Overland runoff: Runoff and stormwater conveyance systems can impact surface water locations downstream of the actual source or groundwater along the course of the conveyance system.

- Groundwater discharge to surface water or surface water recharge of groundwater: Gaining or losing surface water body (for example, rivers, streams, lakes, ponds, impoundments, and wetlands) conditions may influence the extent of a plume. Discharge or recharge (seepage) rates and directions may change seasonally, with extreme weather events, or during periods of drought or precipitation.

- Subsurface features, including utility lines: Preferential pathways may result from subsurface features. For example, flow may seep into or out of nonwatertight sewer lines based upon groundwater elevations relative to the utility. The bedding material of a subsurface line may also convey groundwater.

- Multicomponent mixtures: At some sites, numerous PFAS may be present in one or more source zones. Mixtures may be present for several reasons, including, but not limited to, the following: multiple sources, varying time frames, and a mixture of compounds introduced during production (Sections **5** and **10.5**).

- Precursors: Delineating, as practicable, the extent of precursors that may degrade to PFSAs and PFCAs will help the investigator understand sources and potential long-term concentrations.

10.3.3 Extent of PFAS

As with other chemicals, a site investigation for PFAS relies upon understanding the nature of sources as well as the lateral and vertical extents. A PFAS release can be localized or highly extensive, both horizontally and vertically. The extent is a function of many factors, such as site conditions, the nature of the PFAS source, transformation of precursors, and the relevant migration pathways. For example, some PFAS may be highly mobile in groundwater and some PFAS plumes may have had many years to develop and could consist of many compounds that are not expected to degrade, as discussed above. Therefore, PFAS plumes could be larger or deeper than expected, although there are currently limited quantitative data on PFAS plume lengths or depths in groundwater as compared to other contaminants. Sufficient delineation of PFAS extent in groundwater requires a monitoring well network with wells located throughout the plume (for example, source area, midplume, distal end, side-gradient, and clean sentry wells to define the plume boundaries). Such a well network will provide data to evaluate dissolved phase migration, potential precursor transformation trends, and/or plume stability.

Detailed vertical delineation as a component of HRSC should consider soil sampling at predetermined depths and distinct lithologic units within the vadose zone, the zone of water table fluctuation, and beneath the water table to a depth necessary to determine the vertical extent of impacts. In addition, consideration should be given to groundwater sampling of all saturated units to an appropriate depth. Collection of these data may necessarily be an iterative process requiring more than one phase of investigation to determine the vertical extent of PFAS impacts. This information is beneficial for evaluating potential accumulation points, matrix diffusion potential, varying groundwater conditions, and risk assessment, and to support remedial alternative evaluation.

At sites where PFAS has been released to the subsurface and reached groundwater, the velocity of groundwater movement (advection) is a key consideration for understanding plume migration potential, as well as those processes that act on PFAS during advective transport (for example, sorption, diffusion). At some sites, more mobile shorter chain PFAS have been observed to extend relatively farther in groundwater than longer chain PFAS due to less retardation in groundwater. The partitioning behavior of PFAS is discussed in **Section 5.2**.

Another factor in the extent of PFAS at mature sites is prior remediation intended to address other contaminants. For example, groundwater pump and treat systems designed and operating to address other contaminants may have partially captured PFAS or their discharge may have spread PFAS. Other

remediation methods such as oxidation may result in a change in the relative concentrations of individual PFAS (for example, oxidation of precursors).

Depending upon site-specific conditions, several pathways need to be considered to assess potential upgradient sources. PFAS migration in air from industrial or commercial sources can influence soil or groundwater a great distance from larger sources (**Section 6.1**), for example, see **Barton (2010)** and **Shin et al. (2011)**. Data from urban soils and groundwater indicate that for sites near metropolitan areas, there may be measurable contributions of PFAS from other sources, unrelated to site-specific sources, see the site-specific anthropogenic background text box in **Section 10.1.3** and **Xiao et al. (2015)**.

Commingling of contaminants has a potential to impact PFAS extent (note that PFAS commingling with other contaminants could also affect several other facets of a site characterization and/or risk assessment). For example, for PFAS sites associated with industry, fire training, or emergency response that have a chlorinated solvent or other NAPL source, investigators need to consider potential effects on PFAS in the subsurface and related data collection requirements. Laboratory studies have demonstrated that sorption or partitioning of PFAAs may increase in the presence of trichloroethene DNAPL in bench-scale tests (**McKenzie et al. 2016**). Conceptual modeling of published PFAS data suggests that NAPL-water partitioning and NAPL-water interface interactions may significantly increase retardation of some PFAS in source zones (**Brusseau 2018**; **Brusseau 2019**; **Brusseau et al. 2019**, **2019**; **Costanza, Abriola, and Pennell 2020**; **Lyu and Brusseau 2020**; **Schaeffer et al. 2019**; **Silva, Šimůnek, and McCray 2020**; **Sima and Jaffe 2021**). These enhanced attenuation processes are discussed in **Section 5.2.4.1** (partitioning adsorption to air/water interfaces) and **Section 5.2.5** (NAPL-water interface). This research suggests that if PFAS and NAPL are present in media that make effective source treatment unlikely—for example, in low-permeability soils or fractured rock—that fraction will represent a long-term contributor to groundwater plume persistence. At older sites where in situ (for example, oxidation) or pump and treat methods have been employed to reduce NAPL source areas prior to awareness of PFAS, those remedies may complicate characterization and distribution of PFAS. Depending upon the method employed, mobilization of some PFAS may have changed following treatment, and remedial actions may affect distribution and relative concentrations of individual PFAS (**McKenzie et al. 2016**; **McGuire et al. 2014**).

At most sites where PFAS is present in groundwater, the extent of PFAS contamination is likely to be a key objective for site characterization and used for identifying appropriate remedial options (if warranted). Estimating the plume advancement rate may provide beneficial information for the remedial decision process. For example, a plume that is advancing relatively slowly and without nearby receptors may be more amenable to different remedial approaches, such as in situ sorption or barrier-based approaches (see **Section 12.2.4**) or other less aggressive techniques (**Newell et al. 2022**), than plumes that are advancing rapidly towards nearby receptors. Determining plume stability (**Section 10.4.8**) and/or conducting contaminant transport modeling (**Section 10.4.9**) provide valuable data for assessing risk and evaluating remedial alternatives.

10.3.4 Investigation-Derived Waste (IDW)

The Priority Topics for Treatment Technologies include considerations for management of PFAS-impacted investigation-derived waste (see **Section 1.6.3**).

How to handle IDW that contains PFAS is currently a complicated topic, with differing laws and guidance in different states that affect on-site management, storage, labeling, and off-site transportation requirements (**ASTM 2024**). Investigators must remain vigilant to identify current state and local requirements for IDW generated during site characterization efforts. Site-specific waste handling and disposal plans should be provided in the site's Health and Safety Plan (HASP), Quality Assurance Project Plan (QAPP), or Sampling and Analysis Plan (SAP) prior to waste generation. During a typical site characterization effort, IDW generated consists of purge water, decontamination water, soil, sediments,

solids such as concrete and asphalt, single-use field equipment (for example, bailers, tubing), and personal protective equipment (PPE).

In general, industry has been using two methods to dispose of PFAS-containing solids IDW off-site: landfill disposal and thermal treatment. For liquid wastes containing PFAS, sorption treatment, thermal treatment, or underground injection has been used. On-site treatment of water IDW using existing aboveground treatment systems or temporary mobile units is another option. Treatment conducted on-site can minimize the volume of liquids requiring off-site disposal and may allow treated liquids to be discharged to a publicly owned treatment works or handled off-site as nonhazardous waste. As of March 2023, no PFAS meet the federal definition of a hazardous waste; therefore, most PFAS-impacted IDW is being disposed of as nonhazardous waste.

In 2020, the USEPA published a guidance document, Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances, Version 2 was published in 2024 (**USEPA 2020**, **USEPA 2024**). This interim guidance document outlined IDW that contains PFAS, destruction and disposal technologies currently available and in use, considerations for vulnerable populations that live near these destruction and disposal sites, and current research on this topic. Its focus is on providing options that have the potential to destroy the C-F bonds (thermal treatment) or that control migration of PFAS (with landfilling or underground injection).

Several guidance documents exist for managing PFAS-impacted IDW at U.S. Department of Defense (DOD) installations, including U.S. Army, U.S. Navy, and U.S. Air Force sites. Therefore, any PFAS-impacted IDW generated from a DOD installation should follow the associated required procedures (**USDOD 2018**; **USDOD 2020**; **USDOD 2020**). State or local requirements may be more restrictive than the DOD guidance.

10.3.4.1 IDW Options

Thermal Treatment

Thermal treatment is a broad category that includes several heating technologies: hazardous waste combustors, nonhazardous waste combustors, carbon reactivation units, and thermal oxidizers. Incineration specifically has come under scrutiny recently for its potential to affect communities adjacent to and downwind of incineration facilities through stack emissions if the PFAS are not broken down completely and data gaps associated with the control of products of incomplete combustion (**Schroeder et al. 2021**; **Stoiber, Evans, and Naidenko 2020**; **USEPA 2024**; **Galloway et al. 2020**; **Vollet Martin et al. 2022**). Please note—the definition of "incineration" varies based on different state or federal regulations or guidance.

On April 26, 2022, the DOD issued a memorandum to temporarily prohibit the incineration of DOD PFAS materials, until DOD issues guidance on implementing the USEPA guidance on the destruction and disposal of PFAS. The DOD published a memo with interim guidance about destruction or disposal of materials containing PFAS on July 11, 2023 (**USDOD 2023**). A follow-up statement was published on July 17, 2023 about additional planning and coordination that is needed before incineration is implemented (**USDOD 2023**).

On June 8, 2022, Illinois passed a law that bans the disposal by incineration of any PFAS, including, but not limited to, AFFF. Incineration was defined as any burning, combustion, pyrolysis, gasification, or use of an acid recovery furnace or oxidizer, ore roaster, cement kiln, lightweight aggregate kiln, industrial furnace, boiler, or process heater.

Landfill

The practice of disposing of PFAS via landfill works to control contaminants of concern through containment. For PFAS and PFAS-containing materials, hazardous waste landfills or lined municipal solid waste landfills could be viable disposal options if the landfills are willing to accept PFAS IDW. Current landfills can serve as long-term containment sites for PFAS, but they are not explicitly designed to control and hold PFAS and PFAS-containing materials. The ability for landfills to safely contain PFAS and PFAS-containing materials is an active area of research by the USEPA and state regulatory agencies.

Subtitle C (hazardous waste) landfills have a bottom liner and leachate collection system, and have been used to contain PFAS IDW. The utilization of Subtitle D (nonhazardous, municipal waste) landfills to contain PFAS IDW is state-dependent due to the potential for leaching into the subsurface. However, there remain concerns with Subtitle C landfills regarding how to handle the collected leachate. Typically, landfill leachate is disposed and treated off-site at municipal wastewater treatment plants, where the leachate is mixed with wastewater and then treated. However, a landfill that contains elevated PFAS in the leachate presents a difficulty for treatment. In addition, research has found that soluble PFAS with high vapor pressures can be emitted into the atmosphere via the gas generated at landfills (**Ahrens et al. 2011**; **Hamid et al. 2018**; **Wang et al. 2020**; **Weinberg, Dreyer, and Ebinghaus 2011**). This is an active area of research. Due to these concerns, not all Subtitle C landfills will accept PFAS wastes.

Deep Well Injection

Underground injection could be an option for liquid PFAS IDW. Disposal using this technology occurs under USEPA's underground injection control (UIC) regulations.

The UIC regulations give the USEPA the authority to permit the disposal of PFAS and PFAS-containing liquid IDW in Class I underground injection wells. Class I wells in either the nonhazardous or the hazardous waste categories are designed to dispose of and isolate liquid PFAS and PFAS-containing IDW. Class I underground injection wells are deep injection wells that inject the liquid of concern into a stable geologic formation below the lowermost underground sources of drinking water (USDW).

Underground injection to Class I nonhazardous and hazardous waste wells reduces the risks associated with surface-based disposal methods by avoiding a potential discharge of liquid IDW to surface and shallow groundwater and generating little to no air emissions of PFAS. Class I wells must be sited in areas that are geologically stable without the presence of natural fractures and faults that could allow the injected material to migrate into USDWs (**DeSilva 2019**; **Marine 2020**; **McCurdy 2011**; **USEPA 2001**; **USEPA 2015**).

Other/Developing Technologies

Additional methods, and methods in development for disposing of PFAS and PFAS-containing materials, are discussed in Section 12, including in situ and ex situ disposal methodologies for both soil and liquid PFAS and PFAS-containing IDW.

10.3.4.2 Other Considerations

PFAS IDW may also contain other commingled nonhazardous or hazardous substances. This will impact the options available for handling and disposal and should be considered during the project planning process. Of particular concern are wastes from sites where incineration of PFAS is not permitted that have co-contaminants usually disposed of through incineration (such as Toxic Substances Control Act wastes). In these cases, site managers may need to weigh the site characterization needs against the IDW disposal requirements and avoid generation of co-contaminated wastes.

10.4 Data Analysis and Interpretation

There are a number of approaches, methods, and tools available for analyzing and interpreting site characterization data from a wide range of contaminated sites. Examples of approaches, methods, and tools that may be relevant to PFAS sites are described below, but site-specific objectives and characterizations should be considered when determining an appropriate approach.

10.4.1 Vadose Zone Leaching

The Priority Topics for Sampling and Analysis include updated information about leaching methods (see **Section 1.5.1**). The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include information about vadose zone characterization and transport (see **Section 1.3.1**).

Recent research has illuminated the complexities of PFAS fate and transport in the vadose zone. The majority of this work has focused on lab-based or modeling studies, with an effort to understand how PFAS **surfactant** properties can enhance or reduce PFAS sorption, in particular at high concentrations such as those encountered at release locations (Sections **5.2.2.2**, **5.2.3**, and **5.2.4.1**). As indicated in Section 5, soil chemistry plays a major role in PFAS fate and transport.

For example, **Guo, Zeng, and Brusseau (2020)** conducted a sophisticated modeling study indicating that PFOS in the vadose zone at a hypothetical fire training site is primarily sorbed at the air-water interface and only 1–2% of PFOS is in the aqueous phase under the modeled conditions (see **Section 5.2.4**). This indicates that strong PFOS attenuation may occur in the vadose zone over time, although **Guo, Zeng, and Brusseau (2020)** showed that eventually there still may be discharge of PFOS to the underlying water table under their modeled conditions. This is consistent with high concentrations of PFOS observed at some fire training sites. **Rovero et al. (2021)** reviewed literature-reported sorption coefficients (Kd) of eight anionic short (C4)- to long- (C10) chain PFAS, including PFOA and PFOS. Given the broad range in Kd values from 3 to 5 log units, no single value seemed appropriate for estimating PFAS leaching using existing soil-water partition equations. Regression analysis was used to determine if any of the fifteen experimental parameters identified in the literature might be used to predict Kd values. The authors found that none of the values could individually explain variability in reported Kd values, but significant associations existed between Kd and soil calcium and sodium content, suggesting that soil cation content may be critical to PFAS sorption. Organic carbon was found to only be significant at elevated levels (>5%).

Zeng and Guo (2021) developed a three-dimensional model to evaluate the effects of surfactant-induced flow and heterogeneity on PFAS leaching in the vadose zone. Based on simulations using this model, they found that: 1) surfactant-induced flow had little impact on long-term PFAS leaching; 2) subsurface heterogeneity led to preferential flow that results in early arrival and accelerated leaching of PFAS; and 3) acceleration of PFAS leaching in high water-content preferential pathways or perched water above capillary barriers was more prominent than for conventional contaminants due to destruction of air-water interfaces (reduction of air-water interfacial area (A_{aw})). The authors of this study also recommended that multidimensional models be used to predict PFAS leaching in heterogeneous soils. Note that these conclusions were based on modeling results, and validation of the results using field data was beyond the scope of the study.

Modeling can be used to try to simulate PFAS transport in the vadose zone; however, it should be performed with careful selection of input values and should note appropriate caveats (see **Section 10.4.9**). For example, parameters that are important to understanding PFAS leaching processes, such as the air-water interfacial area (A_{aw}), may be challenging to estimate and/or not adequately captured using current models.

Analytical leaching methods such as the Synthetic Precipitation Leaching Procedure (SPLP) [SW-846 Method 1312 (**USEPA 2021**)] and the Toxicity Characteristic Leaching Procedure (TCLP) [SW-846 Method 1311 (**USEPA 2021**)] may be able to provide site-specific insight into the leachability of PFAS from vadose zone materials. The TCLP "is designed to determine the mobility of both organic and inorganic analytes present in liquid, solid, and multiphasic wastes" for waste characterization purposes (**USEPA 2021**). The SPLP is designed to determine the mobility of both organic and inorganic analytes present in liquids, soils, and waste to evaluate the potential of contaminants to leach into groundwater (**USEPA 2021**). Therefore, the SPLP is typically used for soils in site characterization contaminant leaching studies and allows for less acidic extraction fluids (simulating exposure to acid rain) than the TCLP test (simulating exposure in a landfill) so it can better represent environmental conditions expected to be encountered at a site. Currently some state agencies include the SPLP test as part of their PFAS assessment guidance, so state-specific guidance or requirements should be verified.

USEPA has also developed a Leaching Environmental Assessment Framework (LEAF). LEAF is a leaching evaluation framework consisting of four leaching tests (SW-846 Methods 1313, 1314, 1315, and 1316), a data management tool, and approaches for estimating constituent releases from solid materials (**USEPA 2019**). The four leaching tests discussed have been validated for inorganic constituents, but the methods and/or framework may be helpful when evaluating leaching of PFAS in the environment.

Optimizing LEAF leaching tests for use with PFAS is one component of an in-progress SERDP-ESTCP sponsored study: Development and Validation of Novel Techniques to Assess Leaching and Mobility of Per- and Polyfluoroalkyl Substances (PFAS) in Impacted Media, ER20-1126 (**SERDP-ESTCP 2021**). The project overview states that the study has the overarching goal of developing a framework for evaluation and prediction of the release of PFAS from AFFF-impacted media. Identified specific objectives include: 1) development of a standard leaching assessment methodology for AFFF-impacted media; 2) utilization of approaches including high-resolution mass spectrometry (HRMS), mid-infrared spectroscopy (MIR), and chemometrics to evaluate and develop a predictive model of PFAS sorption and desorption to AFFF-impacted media; and 3) comparison of results of laboratory testing to leaching and mobility under field-relevant conditions to develop an approach for translation of bench-scale test results to site-scale implications. Other SERDP-ESTCP sponsored studies include ER20-5088, which is evaluating how PFAS leaching is influenced by factors such as the soil to groundwater ratio (PFAS Leaching at AFFF-Impacted Sites: Insight into Soil-to-Groundwater Ratios), and ER18-1389: Baseline Data Acquisition and Numerical Modeling to Evaluate the Fate and Transport of PFAS within the Vadose Zone.

Many studies describe the complexity of soil retention mechanisms for an increasing number of nonpolymeric PFAS. This complexity is due to multiphase retention mechanisms that can include air-water interfacial sorption mechanisms as well as both hydrophobic and electrostatic interactions with the surface chemistry of soil particles (**Sima and Jaffe 2021**; **Sharifan et al. 2021**; **Guelfo et al. 2021**). In addition, studies have demonstrated rate-limiting solid-phase sorption kinetics (**Brusseau et al. 2019**), nonlinear sorption to both solids and air-water interfaces (**Schaefer et al. 2019**; **Li et al. 2019**), and desorption hysteresis (**Zhao et al. 2014**; **Ololade 2014**; **Schaefer et al. 2021**). Solution chemistry effects have also been shown to affect retention processes (**Cai et al. 2022**). All together, these multiphase retention mechanisms may complicate efforts to accurately predict long-term leaching potential from legacy source zones.

Stahl et al. (2013) completed a study evaluating the behavior of PFOA and PFOS in soil and the carryover from soil to plants. Plant samples and percolated water collected by a lysimeter were analyzed for PFOA and PFOS throughout a period of 5 years. PFOA was found to pass through the soil much more quickly than PFOS, and of the original mass applied, 96.88% of the PFOA and 99.98% of the PFOS was still present in the soil after a period of 5 years. Plants were found to have accumulated 0.001% of the PFOA and 0.004% of the PFOS. Loss through the soil leachate was reported to be 3.12% for PFOA and 0.013% for PFOS.

Given the complexity of estimating the mass discharge of PFAS from vadose soils to groundwater, care should be taken when selecting an approach(es) to estimate PFAS leachability to ensure it is appropriate for the site's physical environmental setting, and consideration should be given to developing multiple lines of evidence. Further, because of the limitations and uncertainties of the available estimation tools, care should be taken when evaluating and interpreting results. Currently available tools to consider include leaching methods (for example, SPLP or LEAF) as discussed above, modeling as discussed in **Section 10.4.9.1**, and soil lysimeters discussed below and in **Section 11.1.7.5**. Applicable regulatory guidance and requirements should also be considered.

Like grab samples, lysimeter samples represent a single-time result, which makes the representativeness of lysimeter results suspect when evaluating impacts to groundwater over a season or from year to year. Suction lysimeter samples are good for qualitative comparisons, but they cannot be used for quantitative analysis unless the variabilities of parameters involved are established (**ASTM International 2018**).

Collection of porewater data via lysimeters may provide pertinent empirical data for one line of evidence for qualitatively evaluating site-specific leaching of PFAS from the vadose zone to the groundwater. **Anderson (2021)** completed systematic measurements of porewater PFAS concentrations using lysimeters installed within relevant portions of a site. Mass discharge was estimated by multiplying observed lysimeter porewater concentrations by estimated vadose zone infiltration rates to determine the mass of PFAS leaching from the vadose zone to groundwater. However, lysimeter data may be biased by factors such as preferential flow, and samples may not be representative in dry or wet conditions. **Isch et al. (2019)** completed a study of water and bromide in bare soil using lysimeters compared to field plots and found that the transport of water and bromide in bare soil observed in lysimeters could not be directly compared to their transport observed in field plots. **Radolinski et al. (2022)** completed a study using lysimeters of how preferential flow alters solute mobility in soils and found that there was "evidence that (1) bypassing water flow can select for compounds that are more easily released from the soil matrix, and (2) this phenomenon becomes more evident as the magnitude of preferential flow increases."

Lysimeters have been suggested as a tool that can be used to measure the mobile mass fraction of PFAS concentrations in soil porewater (**Anderson 2021**). Lysimeters have been used by researchers investigating transport of AFFF at impacted field sites to benchmark the accuracy of laboratory batch extraction methods (**Schaefer et al. 2022**; **Quinnan et al. 2021**) and to understand temporal trends in PFAS concentrations in porewater (**Anderson et al. 2022**).

Fate and transport processes can have differential impacts on the individual components of chemical mixtures such as PFAS (see for example, **Bock et al. 2022**). Differences in the fate and transport process affecting chemical mixtures can result in changes in the relative abundance of these components. For example, more easily transported PFAS in a mixture could be preferentially leached in the source area and enriched downgradient. These processes should be considered when evaluating fate and transport, as well as when conducting a forensics evaluation of PFAS. It should be noted that chemical transformations, such as the conversion of PFAS precursors, will also result in changes in the relative abundance of PFAS in a mixture. These processes emphasize the importance of developing accurate estimates to predict the behavior of PFAS, including PFAS behavior in the vadose zone.

10.4.2 Retardation Coefficients and Travel Time in Groundwater

The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include updated information about groundwater partitioning, colloidal transport, and groundwater-surface water interactions (see **Section 1.3.4**).

The time that it takes for a contaminant in groundwater to travel to a particular downgradient location is highly influenced by the groundwater velocity, and the plume extent is further influenced by processes that may act on the contaminant during transport, as well as by physical chemical properties of the

contaminant itself (for example, solubility). As an initial step for evaluating PFAS transport, it may be helpful to estimate retardation coefficients for PFAS to evaluate contaminant-specific velocity and travel time in groundwater, particularly for longer PFAS plumes. As discussed in **Section 5.2.3**, a linear sorption isotherm is typically assumed for PFAS sorption to organic matter in soil, and sorption coefficients. The Physical and Chemical Properties Table (**Table 4-1**) provided as a separate Excel file presents a range of available organic carbon partitioning coefficients for environmentally relevant PFAS. Hydrophobic, electrostatic, air-water sorption in the vadose zone, and hydrophobic and electrostatic sorption in the saturated zone also play a role in transport mechanisms (**Newell et al. 2021**).

However, as noted in **Section 5.2.3**, it is important to evaluate the PFAS present and quantify the fraction of organic carbon for estimating K_{oc}. The current state-of-science supports K_{oc} being reported in relatively broad ranges on a compound-specific basis. **Section 4.2.9** presents a discussion of potential limitations in using K_{oc} values as a predictor of sorption and PFAS mobility. It is also important to note that other geochemical factors (for example, pH, presence of polyvalent cations, and electrostatic processes), possible hysteresis, and nonlinear sorption behavior might influence transport across different PFAS concentration ranges, and isomeric differences may impact PFAS sorption to solid phases (**Section 5.2.3**). Due to the variability of K_{oc} estimates, it may be appropriate to evaluate transport of an individual PFAS using a range of partitioning coefficients. In addition, empirical estimation of site-specific K_{oc} values in different areas of a site (for example, source zone versus downgradient plume) may be necessary if quantification of the retardation coefficient is important to its characterization.

For example, **McGuire et al. (2014)** described the calculation of site-specific K_{oc} values for various PFCAs and PFSAs at an AFFF-impacted site. These site-specific Koc values were calculated based on seven pairs of co-located groundwater and soil samples, and fraction of organic carbon (f_{oc}) measurements at each sampling location. The soil samples were collected near or at the water table, which was about 4.6–6.1 m below ground surface. **McGuire et al. (2014)** found that there was a range of between one and three orders of magnitude in site-specific K_{oc} values for the PFAAs analyzed. This may reflect the enhanced sorption of PFAS that occurs at the NAPL-water or air-water interface (**Brusseau 2018**). There may be smaller ranges in K_{oc} values for PFAAs at greater depths below the water table and downgradient of a source zone (where NAPL is not present). When using this type of site-specific K_{oc} analysis method, it is also important that the groundwater samples be representative of conditions where the point soil samples are collected.

As another alternative to the use of K_{oc} values and the assumption of a linear sorption isotherm, in situ or ex situ studies may be used to develop parameters for simulation of PFAS transport. Such studies could allow development of pseudo-constants to use in model simulations. In groundwater, a bulk retardation factor can be estimated by comparing the observed length of a PFAS plume to the distance that groundwater would be expected to travel during the time since the PFAS release occurred. This method provides an estimation and assumes that the release date is known, but it accounts for the multiple processes influencing PFAS migration in groundwater (as opposed to just hydrophobic partitioning to soil organic carbon).

Desorption of PFAS from solids below the water table could occur when partitioning is reversible; such desorption would have the effect of maintaining PFAS concentrations in groundwater. There is uncertainty regarding the extent to which sorption is irreversible and rate-limited versus an equilibrium process (**Section 5.2.3**). It may be important to characterize the extent and kinetics of desorption that may occur as a result of remedial activities at the site. Assuming equilibrium desorption may result in overestimation of PFAS removal during remediation activities (**Sima and Jaffe 2021**).

Because retardation coefficients, travel time, and many other fate and transport processes are based on the physicochemical properties of the individual PFAS, these processes may not affect all PFAS in a mixture equally. As predicted for PCBs in **Johnson and Bock (2014)**, in which aggressive physical weathering was simulated, differential fate and transport trends affecting the components of a chemical

mixture can manifest as changes in the chemical profile. For PFAS, more easily transported PFAS in a mixture could be depleted in the source area and enriched at the plume front. A simple model demonstrating the effect for PFAS mixtures based on Koc and foc using the RemChlor-MD model (**Farhat et al. 2018**) from **Bock et al. (2022)** predicts that these processes can have important ramifications for PFAS forensics.

10.4.3 Matrix-Diffusion

When evaluating fate and transport of PFAS in a groundwater plume, including time frame for remediation of PFAS, matrix diffusion may be an important process to consider (**Section 5.3.1**). As such, understanding the potential impacts of diffusion on PFAS persistence in natural soils is a topic of ongoing research.

During the characterization of PFAS plumes, it may be beneficial to collect PFAS soil samples from the transmissive zone directly above a silt/clay layer, and at different depths into the silt/clay layer, to evaluate the potential for back-diffusion to be occurring presently or in the future if there is a decline in PFAS concentrations in the transmissive zone (see **Parker, Cherry, and Chapman (2004)** and **Chapman and Parker (2005)** for an example of this sampling approach). Using this approach, **Adamson et al. (2020)** reported that the majority of the PFAS mass at an AFFF release site was associated with lower permeability soils, highlighting the importance of matrix diffusion on PFAS retention.

Diffusion coefficients for PFAS are generally uncertain but are in development using measurements and models (**Pereira et al. 2014**). **Schaefer et al. (2019)** calculated aqueous diffusivity values for nine PFAAs; however, prediction of the influence that diffusion from lower permeability material to a flow zone (i.e., back-diffusion) will have on PFAS remediation time frame remains uncertain because the back-diffusion of PFAS from low-permeability materials involves desorption. As discussed above, PFAS desorption may be a rate-limited process, and these rates have a high degree of uncertainty (**Sima and Jaffe 2021**). In addition, the irreversible fraction of PFAS in low permeability materials is uncertain at this time. Therefore, the uncertainty associated with modeling remediation time frames of PFAS back-diffusion should be noted. Further discussion of matrix diffusion modeling is included in **Section 10.4.9**.

10.4.4 Mass Flux/Mass Discharge

The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include information about using mass flux analysis for understanding PFAS migration in groundwater and potential discharge to surface water (see **Section 1.3.8.2**).

Mass flux and mass discharge can be valuable metrics for CSMs and understanding PFAS transport and supporting remedy selection. **ITRC (2010)** presented a variety of methods available for estimating mass flux and mass discharge, including the use of multiple transects of temporary or permanent monitoring wells across the width of a plume. Even simple methods such as chemical isoconcentration maps are suitable for developing an initial order of magnitude estimate for mass discharge. Calibration of solute transport models is another method that may be used to estimate the mass discharge of PFAS from a source zone, at a point in a plume, or to a surface water body. In addition, mass discharge estimates may be useful for understanding PFAS exchange between groundwater and surface water (**Divine et al. 2023**), and PFAS retention at the air-water interface could be an important fate and transport process (see **Section 5.3.2**) and may be considered when estimating the mass discharge from the vadose zone soils to groundwater. See **Section 10.4.1** for additional discussion of leaching that should be considered when estimating mass discharge from the vadose zone to groundwater.

Changes in mass discharge over time, as well as changes in mass discharge with distance from a source, can be used to assess attenuation/retention (see **Section 10.4.5**; **Newell et al. 2021**). At sites where multiple sources are present, it could also be used to identify the relative contribution of different sources

for prioritization purposes (see **Section 10.4.5**). Note that it may be challenging to estimate the relative mass flux contribution of different sources where low PFAS concentrations are present in porewater and groundwater. In addition, it is important to consider the potential for increases in dissolved mass flux of some PFAS due to biotransformation reactions, desorption between transects, and/or spatially varied infiltration.

10.4.5 Contributions from Different Sources

The potential impact to a site from multiple sources, particularly in proximity to urban or developed locations, needs to be accounted for when assessing site data or identifying data gaps. Each source then needs to be assessed in terms of its specific contributions, and their relative importance or magnitude. Although there are no naturally occurring background levels of PFAS, it may be important to gain an understanding of the Site-specific anthropogenic background (see the text box in **Section 10.1.2**) concentrations that may be present at a site, as these can have significant implications for site characterization, assessing exposures, evaluating ecological and human health risks, and establishing site action and cleanup levels. Most states have guidance on how to establish site-specific background concentrations for their regulated contaminants.

Tools available to quantify relevant contributions from different types of sources are discussed below.

10.4.5.1 Atmospheric Deposition

Certain PFAS may be present in ambient air and may be elevated near sources such as landfills, WWTPs, fire training facilities, and manufacturing plants (**Section 2.6**). Many PFAS exhibit relatively low volatility; however, airborne transport of some PFAS can be a relevant migration pathway for some industrial releases. Sections **5.3.2** and **6.1** provide an overview of transport of aerosols and particulates via air. To assess relative contributions from atmospheric sources, air sampling for PFAS can be conducted. Additionally, air dispersion models, such as AERMOD or Industrial Source Complex (ISC3) Model, can be employed to estimate airborne PFAS concentrations and total wet and dry deposition rates at designated receptor locations. Examples where AERMOD could be beneficial during site characterization activities include sites with no obvious source area and sites in industrial areas with multiple potential sources of airborne PFAS. See **Section 2.6** for additional details on the most typical PFAS source scenarios.

10.4.5.2 Upgradient Site Contributions

> ***Alternate Sources***
>
> Sources that may exist within, upgradient of, or near a site under investigation, that are distinct from the PFAS source being investigated.

PFAS persistence in the environment and their use in a multitude of industrial processes and commercial products result in potential for nonsite-related inputs, similar to other mobile contaminants (Figures **9-1**, **9-2** and **9-3**). Assessment of potential upgradient site inputs is recommended. The very low health advisory criteria for groundwater only increase the potential importance of identifying what might otherwise be considered “minor” upgradient sources and may result in alternate source identification (Sections **10.3.2** and **10.5**). As part of site investigation of an air deposition release, soil data can be statistically compared to background samples, evaluated for vertical stratification, and assessed for spatial distribution relative to the potential source. Groundwater data from the site may be compared to data from other locations using cluster analysis (i.e., a data analysis technique that explores the naturally occurring groups within a data set, which are known as clusters) to assess whether there was evidence of other source terms, or if the site in question appeared to be the sole source.

10.4.6 Transformation Pathways and Rates

The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include information about PFAA precursor biotransformation (see **Section 1.3.3**).

As discussed in **Section 5.4**, the transformation of precursors may result in increasing concentrations of PFAAs such as PFOS and PFOA along the flow path of a dissolved plume. Transformation reactions may occur due to aerobic biological or chemical oxidation. For example, **McGuire et al. (2014)** concluded that infusion of dissolved oxygen to bioremediate hydrocarbons downgradient of a former burn pit also likely caused the transformation of precursor compounds to PFAAs such as PFHxS. Some methods that may be used to assess the degree to which transformation is affecting PFAS plume extent and stability include:

- plotting concentration isopleths for precursors and various PFAAs, for example, **McGuire et al. (2014)**
- use of the total oxidizable precursor (TOP) assay to identify whether precursors are present that may be available for transformation to PFAAs at a point in the plume (**Section 11.2.2**)
- assessment of ratios of precursor and daughter product species at monitoring wells situated along the centerline of a plume, or the ratio of various PFAAs in various portions of a plume. For example, **McGuire et al. (2014)** plotted an isopleth map for the ratio of PFHxS to PFOS to show that in areas where dissolved oxygen was injected this ratio was as high as 50, and in other areas where bioremediation was not conducted this ratio was less than 1.
- use of concentration trends along a plume centerline and quantitative methods described in **USEPA (1998)** to estimate precursor transformation rates
- use of concentration trends along a plume centerline for precursors identified using high-resolution analytical techniques (see Section 11.2.2.5) to evaluate if transformation to presumptive intermediates and end products is occurring during plume transport (**Nickerson et al. 2020**)
- calculating the site-wide mass of precursors remaining vs. mass of PFAA end products (PFAAs) to estimate the time-averaged transformation rate since the time of release
- groundwater modeling to demonstrate that the relative plume lengths of different PFAAs with different retardation coefficients can be explained only through the transformation of precursors, for example, **McGuire et al. (2014)**.
- a literature review to identify potential precursor transformation mechanisms and evaluate whether site geochemistry and redox conditions are favorable for the occurrence of these mechanisms.

Another method that may be used to illustrate the occurrence of these transformations is radial diagrams. See the case study in **Section 15.1.1**.

Figure 10-1 shows three radial diagrams based on data from an AFFF release site (**McGuire et al. 2014**). Each radial diagram compares groundwater concentrations at a monitoring well within the oxygen infusion zone to concentrations at a well approximately 76 m upgradient. The radial diagram shown at the left of Figure 10-1 compares concentrations for five PFCAs between these two wells; the middle diagram shows concentrations from the TOP assay conducted using samples from each well; and the radial diagram on the right compares concentrations for four PFSAs.

These radial diagrams illustrate that oxygen infusion into groundwater likely stimulated the production of mainly PFHxA, PFPeA, PFHxS, and PFBS. The middle radial diagram shows that the difference in TOP assay results between the upgradient well and the well in the oxygen infusion zone does not explain the large PFAAs concentration increases that were observed at the well in the oxygen infusion zone. The TOP assay results were low at both wells throughout the area. This suggests that desorption and subsequent transformation of precursors were occurring within the oxygen infusion zone. These radial diagrams are also useful for evaluating relative concentrations of various PFAAs at each monitoring well. The use of radial diagrams for additional types of trend analysis is discussed further in **Section 10.4.9.4**.

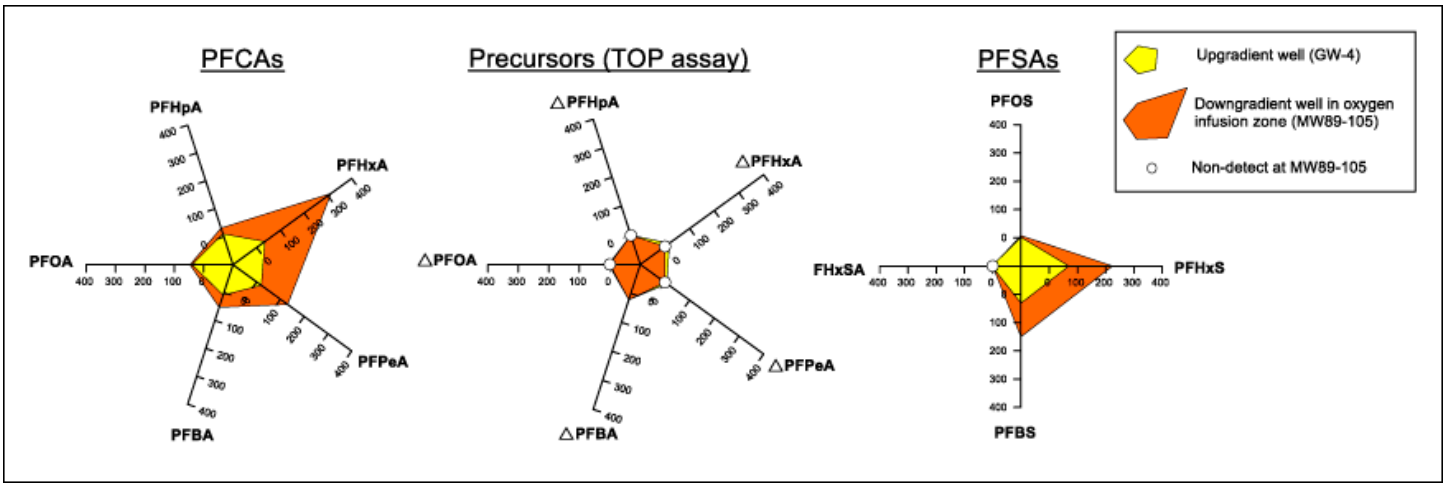


Figure 10-1. Radial diagrams showing the production of various PFAAs in the vicinity of an oxygen infusion zone at an AFFF release site remediated for hydrocarbons in groundwater.

Source: G. Carey, Porewater Solutions. Used with permission.

10.4.7 Assessing Retention, Migration, and Attenuation Processes

The degree to which PFAS are retained, migrate, and/or attenuate in site media has significant implications for site remediation and management. Migration of PFAS in groundwater is a primary concern at most sites, and the migration rates are influenced by the physical-chemical properties of individual PFAS, as well as different processes that act on PFAS during transport. Depending on site-specific conditions, several nondestructive processes can contribute to decreasing PFAS concentrations with respect to distance from the source area(s) or in the source area itself over time. Understanding these processes is critical for confirming that sufficient data have been collected to identify the relevant site-specific processes, establish migration rates, assess plume stability (see **Section 10.4.8**), model fate and transport (see **Section 10.4.9**), and ultimately inform further remedial decision-making (see **Section 12**). **Table 10-1** summarizes the types of data that could be collected and analyzed to evaluate and quantify PFAS retention, migration, and attenuation processes at a site. This table summarizes information in previous subsections and is structured similarly to the methodology included in **Newell et al. (2021)** as the basis for evaluating natural attenuation as part of a site remediation and management strategy. However, it should be recognized that this process is also applicable to any setting where the information would improve the CSM and remedy evaluation process for PFAS. Lastly, it is essential to understand that individual PFAS have unique properties that affect their retention and attenuation. Therefore, an evaluation of site-specific retention and attenuation processes should consider variations between individual PFAS. For example, it may be possible that PFOS may be significantly retained at a site whereas PFNA may experience less retention and/or attenuation.

Table 10-1. Methods to Assess PFAS Retention, Migration, and Attenuation (adapted from Newell et al. (2021)).

Topic	Investigative Method	Supporting Investigative Method
Evaluating whether sorption to solid-phase and/or air-water interface and matrix diffusion contribute to retention of PFAS	• Detailed sampling of soil and groundwater to establish distribution of PFAS mass between vadose zone vs. saturated zone, low permeability vs. high permeability soil zones, and sorbed vs. aqueous phase • Calculating the ratio of PFAS mass to PFAS mass discharge (high ratio implies higher retention) • Calculating the ratio of saturated zone PFAS mass to PFAS mass discharge (high ratio implies higher retention/attenuation)	• High-resolution stratigraphic data to facilitate estimation of matrix diffusion (for example, high percentage of low-permeability soils in groundwater-bearing unit is consistent with matrix diffusion effects • Collection of hydrogeologic and geochemical data such as organic carbon, anion and/or cation exchange capacity, salinity, moisture content, porosity, bulk density, and mineral content to evaluate their relationships with PFAS concentrations • Measurement and comparison of relative plume lengths for individual PFAS, PFAS subgroups, and/or PFAS chains
Evaluating transformation of precursor compounds and impact on migration	• Detailed sampling of soil and groundwater to establish distribution of PFAS between precursor forms vs. PFAAs throughout site • Evaluation of PFAA concentration and/or PFAAs as percent of total PFAS	• Estimation of bulk precursor attenuation rates using field data • Estimation of precursor attenuation rates using fate and transport modeling • Geochemical data showing where conditions are more supportive of degradation (aerobic) vs. less supportive of degradation, as well as influences of these conditions on observed trends (for example, where is majority of precursor mass: anaerobic or aerobic zones)
Quantifying influence of processes on PFAS migration/persistence	• Evaluation of concentration trends with distance along plume centerline • Evaluation of mass discharge with distance along plume centerline • Evaluation of mass discharge from vadose zone to groundwater over time • Evaluation of source area concentration(s) over time • Evaluation of whether the plume footprint is stable or shrinking over time • Evaluation of the advancement rate of the plume footprint and whether downgradient zones have sufficient assimilative capacity zones	• Comparison of expected PFAS plume length in the absence of retention/attenuation (i.e., length if plume was advancing at the groundwater seepage velocity) to the observed PFAS plume length • Predictions of plume behavior over time using screening-level fate and transport models that include multiple PFAS retention processes • Predictions of plume behavior over time using more detailed 3-D contaminant transport models that incorporate additional flow data and other site-specific parameters

10.4.8 Assessing Plume Stability

At sites where PFAS has been detected in groundwater, it may be necessary to evaluate PFAS plume stability—whether the plume is stable, receding, or expanding. Plume stability and plume advancement rates are an important consideration for remedy selection. Many PFAS plumes are expected to be long-lived and possibly expanding due to the presumed lack of transformation of PFAAs and the mobility characteristics of many PFAS (especially those with shorter carbon chain lengths and anionic functional groups). Methods for evaluating plume stability include qualitative evaluations of temporal plume trends or statistical evaluations such as Mann-Kendall (**ITRC 2013**; **ITRC 2016**; **AFCEC 2012**; **USEPA 2009**).

Data uncertainties may have a greater than usual impact on plume stability evaluations for PFAS sites because of the low concentrations assessed. Monitoring records may be relatively limited, both in terms of the number of locations and the number of events that are available to evaluate. Biotransformation of precursors may also have an impact on plume stability evaluations. As such, more frequent or longer duration monitoring may be required to confirm trends or plume stability. A fate and transport model may also help provide predictions of plume behavior over time, and may be adjusted as additional site-specific data become available to aid calibration.

10.4.9 Modeling PFAS Fate and Transport

Some modeling of PFAS fate and transport has been conducted for vadose zone, groundwater, and atmospheric dispersion (**McGuire et al. 2014**; **Barr 2017**; **Carey et al. 2019**; **Guo, Zeng, and Brusseau 2020**; **Persson and Andersson 2016**; **Gassmann, Weidemann, and Stahl 2021**). **Sima and Jaffe (2021)** provided a critical review of applicable transport processes, modeling approaches, and potential limitations and uncertainty associated with modeling PFAS transport using existing approaches. Modeling the fate and transport of PFAS may have significant uncertainty contributed by precursor concentrations, transformation pathways and rates, and other factors. Because several of the key PFAS have not been shown to degrade naturally in the subsurface, other processes such as sorption, diffusion, and dispersion may be more important for understanding PFAS behavior upon release. However, many of these processes, such as desorption, are not well understood for PFAS (**Sima and Jaffe 2021**), and the accurate measurement or estimation of input parameters can be difficult. Although modeling of PFAS transport may be desirable and appropriate under certain conditions, the uncertainty of PFAS transport simulations requires that the results be qualified. Site-specific data are important for evaluating some potential model input parameters such as K_{oc}, which can exhibit significant spatial variation. This is particularly true in source zones, vadose zones, and at or near the water table. There are situations where modeling of PFAS transport may not be appropriate due to a lack of site-specific input parameters or reliable physical chemical properties for a particular PFAS.

10.4.9.1 Vadose Zone Modeling of PFAS Fate and Transport

There may be cases where an investigator wants to conduct a general screening-level evaluation of PFAS transport in the vadose zone under different scenarios. In such cases, the use of an existing vadose zone model may provide some benefit, but only if there is a thorough understanding of the inherent limitations of the model and if the uncertainty in the results is properly communicated.

Vadose zone models such as USEPA's VLEACH (information and model available at https://www.epa.gov/water-research/vadose-zone-leaching-vleach), and Seview's Seasonal Soil (SESOIL) compartment model (information and model available at http://www.seview.com/aboutsesoil.htm) can simulate one-dimensional vertical transport in the vadose zone via diffusion, adsorption, volatilization, biodegradation, cation exchange, and/or hydrolysis. Most PFAS are resistant to biotic or abiotic degradation, and in general PFAS are far less volatile than many other contaminants. With the exception of the few volatile PFAS such as the FTOHs (**Section 4.2.5** and

Table 4-1), the most important vadose zone processes to model are the physical transport processes. However, these models do not include air-water interfacial processes that appear to be important for vadose zone migration of PFAS. Other limiting factors for these models include that they simulate flow in only one dimension (vertical), and they may not adequately capture complex nonlinear or rate-limited sorption processes for PFAS. It is also important to note that these existing models have not been validated for use with PFAS. For these reasons, these models may not be appropriate for use with PFAS at this time.

The Michigan Department of Environment, Great Lakes, and Energy (EGLE) completed a review in 2020 that evaluated several vadose zone models (**MI EGLE 2020**) to simulate transport of PFOA and PFOS from municipal biosolid-amended soil through the unsaturated zone to the saturated zone. Models were initially screened and nine models were selected for critical review. From the nine models reviewed, HYDRUS, an unsaturated flow and transport model (information and model available at **https://www.pc-progress.com/en/Default.aspx?hydrus**), was recommended as the most suitable model for vadose zone modeling of PFOA and PFOS at the time of the EGLE review. (**MI EGLE 2020**).

Several research groups are attempting to develop models for PFAS transport in the vadose zone that more accurately represent some or all of the relevant processes. In some cases, these efforts involve modifying HYDRUS to incorporate these processes, while other groups are developing their own vadose zone models to do the same. Several studies discussing vadose zone modeling are presented below with a simplified, possibly more efficient model discussed in **Guo et al. 2022**.

Guo, Zeng, and Brusseau (**2020**) (referenced in **Section 10.4.1** above) developed what they believed to be "the first mathematical model that accounts for surfactant-induced flow and solid-phase and air-water interfacial adsorption." They applied the model to simulate PFOS transport in the vadose zone at a model fire-training area site impacted by AFFF. The simulations were useful in developing general concepts of PFAS retention as described in **Section 10.4.1**. In addition, and more generally, the mathematical model provides a quantitative framework that can be extended to examine the complex interactions between dynamic flow and adsorption processes at field sites (**Guo, Zeng, and Brusseau (2020)**).

Zeng and Guo (2021) went on to develop a three-dimensional model for PFAS leaching in the vadose zone that allows for quantification of impacts from subsurface heterogeneities, which the authors concluded to be among the primary sources of uncertainty for predicting PFAS leaching and retention in the vadose zone.

"Due to significant computational cost and the requirement for detailed input parameters for the models," developed by **Guo, Zeng, and Brusseau (2020)** and **Zeng and Guo (2021)**, **Guo et al. (2022)** developed a simplified model better suited for a screening tool to quantify vadose zone PFAS leaching. The derived analytical solutions incorporate multiple transport processes (with simplifying assumptions such as linear sorption) and allow for varied initial conditions. The solutions were "then validated by application to miscible-displacement experiments under a wide range of conditions and by comparisons to a state-of-the-art comprehensive model under both experimental and field conditions applicable to PFAS-contamination sites" (**Guo et al. 2022**). Based on these results, the authors concluded that "the simplified analytical model provides an efficient and accurate screening-type tool for quantifying long-term PFAS leaching in the vadose zone" (**Guo et al. 2022**).

Silva, Simunek, and McCray (2020) modified the one-dimensional and two-dimensional versions of HYDRUS "to simulate the effects of non-linear air-water interface (AWI) adsorption, solution surface tension-induced flow, and variable solution viscosity on the unsaturated transport of PFAS in the vadose zone." Available literature-derived unsaturated transport data for PFOA and PFOS were used to validate the revised models and provide example simulations. The study simulations showed that while AWI adsorption of PFAS can be a significant source of retention within the vadose zone, it is not always the dominant source of retention (**Silva, Simunek, and McCray (2020)**. The contribution of solid-phase

sorption can be considerable in many PFAS-contaminated vadose zones (S**ilva, Simunek, and McCray 2020**). Further, the effects of soil textural heterogeneities on PFAS unsaturated transport are demonstrated in the example results.

A follow-up to a leaching study performed by **Stahl et al. (2013)** (referenced in **Section 10.4.1**) was completed by **Gassmann, Weidemann, and Stahl (2021)**. The study used 8 years of data from a lysimeter and MACRO—a one-dimensional, process-oriented, dual-permeability model for water flow and reactive solute transport in soil (information and model available at https://www.slu.se/en/Collaborative-Centres-and-Projects/SLU-centre-for-pesticides-in-the-environment/models/macro-52/). The study evaluated the ability of MACRO to simulate leaching and plant uptake of PFOA and PFOS using two adsorption concepts: a kinetic two-side sorption concept usually applied for pesticide leaching (scenario I) and the formation of what **Gassmann, Weidemann, and Stahl (2021)** called non-extractable residues (NER) (scenario II). NER are adsorbed PFAS that either do not leach or leach very slowly from soil. Leaching of PFOA and PFOS could be adequately simulated for scenario II, but scenario I was not able to reproduce sampled leaching concentrations (**Gassmann, Weidemann, and Stahl 2021**). Plant uptake was simulated well in the first year after contamination but was not simulated well in the following years (**Gassmann, Weidemann, and Stahl 2021**). The model results suggest that more than 90% of the original mass of PFOA and PFOS is present as NER after 8 years, which the team concluded was a larger percentage of the mass compared with other studies (**Gassmann, Weidemann and Stahl 2021**). The authors also concluded that even though there are open questions that necessitate additional research, "the study showed that it is possible to use an existing leaching model for the long-term simulation of PFOA and PFOS leaching in unsaturated soils and the short-term simulation of plant uptake." Furthermore, they concluded that even though not all environmental processes are yet understood, this model may already provide valuable information for groundwater protection and crop safety.

10.4.9.2 Groundwater Modeling of PFAS Fate and Transport

The development and application of modeling approaches for PFAS in groundwater is relatively limited to date, likely reflecting the complexity of PFAS fate and transport processes, the range of chemical properties, and the uncertainty regarding appropriate parameter values to use in existing models. Several processes that are expected to influence PFAS fate and transport (see **Section 5**) pose challenges for modeling PFAS in groundwater, including:

- Nonlinear sorption. Linear sorption implies that the distribution of a compound between its dissolved phase and any solid phases that are present (for example, soil particles) is independent of the concentration of the compound itself. PFAS sorption has been shown to be concentration-dependent, such that models that account for this behavior are better suited for applications with wide concentration ranges. However, this adds complexity because it relies on an understanding of the appropriate PFAS sorption isotherm(s) and associated parameters for the site-specific application.

- Rate-limited sorption. Solute transport models typically rely on an initial assumption of equilibrium partitioning between dissolved and sorbed phases on a compound. However, several studies have demonstrated that PFAS sorption-desorption is a rate-limited process. This requires a more detailed approach in which both the dissolved and sorbed phases are modeled to incorporate mass transfer between the phases.

- Precursor transformation. PFAS are typically released as mixtures of different compounds, a portion of which may not be identifiable using current analytical approaches. Solute transport models that rely on simplified assumptions (for example, first-order kinetics, stepwise reaction pathways) may not be able to accurately capture in situ transformation patterns. Even for PFAS transformation pathways that have been identified as potentially relevant using lab or field data, there is little understanding of in situ rates to use for modeling purposes.

Despite the challenges groundwater modeling is being attempted for some situations. Some groundwater modeling studies from the literature are discussed.

Pietrzak (2021) completed a review of available software for modeling organic pollutants in groundwater. One example, simulated transport using MODFLOW/MT3DMS (**Shin et al. 2011**), which summarized simulation of PFOA transport in several media, including groundwater, from a manufacturing source and linking the models. **Shin et al. (2011)** concluded that their models may be useful for estimating past and future concentration of PFOA in water wells in the study area. However, the effort did not include all processes that are now recognized as relevant for PFAS fate and transport.

Groundwater modeling studies published to date have focused on the impacts of specific processes and/or remediation on PFAS plume development. For example, **Gefell et al. (2022)** modeled hypothetical PFOA groundwater plumes using MODFLOW and MT3D based on purely hypothetical remediation and data. The study evaluated the differences between a plume resulting from a PFOA-only source compared to a source with precursors located in the overlying vadose zone. Because the plumes from both scenarios exhibited relatively similar concentrations and lengths in the absence of remediation, the authors concluded that source zone characterization is particularly important when predicting long-term plume behavior and that it may be appropriate to calibrate a model to both a terminal PFAA-only source plume and one from a precursor source. After remediation of the source and an extended postremediation flushing period, the scenario with a precursor-based source resulted in a longer plume with higher concentrations. The results for this scenario were sensitive to the precursor degradation rate, and the authors used literature values in their simulations that were derived from a combination of lab-based and field-based data.

As another consideration to improve modeling transport of PFAS in groundwater, the REMChlor-MD model (**Farhat et al. 2018**) has been proposed for evaluating the possible effects of matrix diffusion processes on PFAS distribution (**Newell et al. 2021**). This includes a study by **Kulkarni et al. (2022)** in which this screening-level model was used to estimate the impact of matrix diffusion on the PFOS plume extent using field data from a well-characterized AFFF site where significant PFAS mass was known to be present in lower permeability soils. The model predictions suggested that matrix diffusion contributed to a PFOS plume length at this site that was approximately 40% of the length that would have been observed in the absence of matrix diffusion. The study predicted that matrix diffusion was reducing the plume advancement rate, and that source remediation would have limited impact on the rate of future plume advancement. Another study used REMChlor-MD modeling to examine the types of sites where matrix diffusion processes would be most relevant, and the authors concluded that aquifers with embedded lower permeability layers and lenses exhibited shorter PFOS plumes than aquifers with underlying and/or overlying aquitards (**Farhat et al. 2022**). Long time frames were needed for plume stabilization, but these predictions were highly sensitive to dispersion parameter values since PFOS was assumed to not degrade over time. These results emphasize the site-specific nature of various PFAS fate and transport processes and highlight the importance of site-specific assessments.

In addition, selecting a representative source term for modeling may be difficult due to a lack of available data and/or limitations in the model for handling potentially complex source behavior. Ideally, groundwater transport models for PFAS should incorporate data from vadose zone models and air deposition models to provide a more holistic representation of the source term. As mentioned above, this linked approach was used in a 2011 study that examined regional transport of PFOA from a manufacturing source (**Shin et al. 2011**), but the model did not include all processes that are now recognized as relevant for PFAS fate and transport. In other cases, groundwater transport modeling with discharge to surface water was used to evaluate PFAS distribution within watersheds or regional scales (**Raschke et al. 2022**), though the level of complexity of such integrated modeling approaches may be high and could introduce additional uncertainty, particularly if the data available to calibrate the models are limited.

Another use of groundwater modeling is to evaluate groundwater surface interactions. **Divine et al. 2023** provided a brief discussion of the current state of modeling PFAS and concluded that current models lack do not include complexities such as mass transfer rate limitations and precursor transformation. Additional model development and verification is needed.

10.4.9.3 Air Modeling of PFAS Fate and Transport

Modeling PFAS transport in air is receiving more attention, and USEPA has recently developed an air quality model named the Community Multiscale Air Quality model (CMAQ) for these purposes (**USEPA 2022**). From a personal communication with James A. Thurman, Ph.D., USEPA/OAQPS/AQAD, Air Quality Modeling Group, CMAQ can handle any kind of atmospheric reactions PFAS would undergo during transport and would also include long-range transport, more than 50 km from the source of PFAS. As more information is learned about PFAS, CMAQ can be updated to include the atmospheric reactions for PFAS. See **D'Ambro (2021)** for an example of the use of CMAQ to evaluate a mixture of PFAS from a fluoropolymer manufacturing facility.

Another example of atmospheric modeling of PFAS was performed by **Moreno (2019)**. **Moreno (2019)** modeled transport of PFOA and HFPO-DA from two manufacturing facilities using CALPUFF, a non-steady state, long-range transport model. In addition, air quality models such as AERMOD or IISC3 Model are identified in **Section 10.4.5.1**. An example use of AERMOD can be found in **Barr 2017**. AERMOD was used to simulate the emission of PFOA from stacks at former manufacturing facilities in Bennington, Vermont, and the resulting air dispersion and deposition. The facilities applied PTFE to some fiberglass fabrics.

AERMOD is applicable in the near field, less than 50 km from the source of PFAS for qualitative assessment of local deposition from a source of PFAS when atmospheric reactions are not necessarily important (From a personal communication with James A. Thurman, Ph.D., USEPA/OAQPS/AQAD, Air Quality Modeling Group). AERMOD deposition fields could be used to analyze the spatial distribution of deposition near the source and identify areas of interest to consider for further study. More information for AERMOD can be found in **USEPA (1995)**; **Wesley, Doskey, and Shannon (2002)**; and **USEPA (2003)**.

USEPA provides a Support Center for Regulatory Atmospheric Modeling (SCRAM) website at https://www.epa.gov/scram (accessed August 10, 2023) that includes links to air quality models and tools.

10.4.9.4 Visualization Methods

One of the challenges associated with characterization of PFAS sites is the analysis of trends for a number of PFAS constituents that may be sampled in soil and groundwater, and then the communication of the results of these analyses to a less technical audience. Typical site characterization visualization methods such as plume maps, cross-sections, fence diagrams, 3D models may be used to depict the horizontal and vertical extent of PFAS plumes. Several other visualization methods may be helpful when analyzing PFAS data, including:

- bar charts that show the relative concentrations of individual PFAS constituents at each location to help evaluate PFAS composition trends in soil and groundwater (for example, figures 6 and 7 of 7 **Field (2017)**, **Figure 15-1**)
- radial diagrams to illustrate:
    - transformations of precursors to PFCAs and/or PFSAs along a flow path (for example, see **Section 15.1.1**)

- relative concentrations of constituents at each sample location to assist with source fingerprinting and to identify potential risk drivers in different parts of a plume
- locations of potential hot spots
- general extent of a PFAS plume.

Case study examples of these different methods are discussed in **Section 15.1**.

10.5 Forensics and Source Identification

The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include information source identification, differentiation, and forensics (see **Section 1.3.7**).

The field of environmental forensics is a formal technical discipline that spans chemistry, environmental science, and engineering (for example, **Morrison 2000**; **Morrison and Murphy 2006**; **Mudge 2008**; Murphy and Morrison 2015; **Sullivan et al. 2001**; **Wang and Stout 2007**). Environmental forensics is used to address problems such as source identification, timing of releases, and contaminant fate and transport. As compared to legacy contaminants such as PAHs and PCBs, the application of forensics to PFAS forensics is in its nascent stages. Researchers are still conducting studies to more fully understand the fate and transport of PFAS in the environment, and they continue to evaluate tools to investigate changes in PFAS composition for the purposes of source attribution. Multivariate methods have been applied to investigate sources of PFAS, including human exposure in the Faroe Islands (**Hu et al. 2018**), contributions to surface water in the northeast United States (**Zhang et al. 2016**), and contributions to surface water and sediment in South China (**Pan et al. 2014**). **Benotti et al. (2020)** and **Charbonnet et al. (2021)** both advocated the use of a variety of tools that are applied in a tiered approach for characterizing the PFAS signatures associated with source materials and environmental contamination. It has been observed that the PFAS sources profiles associated with different PFAS uses are frequently highly variable. Until a more complete understanding of the chemical composition of source materials is available, and until researchers understand the full scope of forensic information that may help elucidate sources, source libraries associated with different usage profiles are incomplete at best. Given these uncertainties, the best approach for associating or dissociating environmental contamination from one or more sources is to compare PFAS information in environmental samples to similar information from site-specific source areas. An overview of PFAS source identification analyses can be found in **Dorrance, Kellogg, and Love (2017)**.

To that end, any site-specific investigation begins with a careful review of available records. In a best-case scenario, such records may directly link a source to environmental contamination without significant contribution from any other potential sources. More often than not, source attribution of PFAS contamination is more complicated. Groundwater plumes of PFAS contamination can be heterogeneous due to weathering and differential rates of subsurface transport between PFAS. Care must be taken not to attribute changes associated with fate and transport to different sources. Recent experience shows that multiple groundwater plumes with a similar or disparate profiles are commonly observed to intersect and commingle. If there are two or more likely sources contributing to mixed contaminant plumes, defining the footprint associated with these different sources can be challenging. In addition, atmospheric transport and deposition of PFAS can be important and result in PFAS sources with regional impacts (**Ahrens et al. 2016**; **Davis et al. 2007**; **Galloway et al. 2020**).

When identifying PFAS sources, some important factors to consider include:

- *data quality*, where care must be taken to ensure that analytical results from different time periods, different methods, or different labs are comparable, as older data sets may provide incomplete information when compared to more recent data

- *target PFAS list*, where a reduced compound list may prevent full differentiation between sources. Linear versus branched (isomer) distinction may also be important in differentiating sources
- *matrix effects*, care must be taken to account for differences in PFAS profiles associated with different matrices. For example, soil PFAS profiles can be significantly altered during leaching to groundwater
- *temporal effect*, where an understanding of historical production, use, and release of PFAS becomes important, as is an understanding of differences between samples due to weathering processes that may be interpreted as different sources
- *spatial effect* of long-distance air deposition and regional sources versus local sources
- *sample collection procedures* to ensure there is no cross-contamination from other sources during sampling
- *rigorous exploration of potential sources* to ensure that all sources of potential interest have been identified and considered
- *weight of evidence* based on multiple lines of inquiry

The following sections describe some of the source identification tools that may be used or considered for use in identifying sources of PFAS.

10.5.1 Source Identification Tools

Chemical fingerprinting often involves the evaluation of the relative proportions of different substances in a mixture to link contaminants in the environment to one or more known or suspected sources (see the text box in **Section 10.4.5.2**). The data from available analytical methods can be evaluated using various graphical, statistical, and geospatial techniques. These methods have been commonly used for legacy contaminants such as petroleum and chlorinated compound source identification and can potentially be applied to PFAS mixtures. The following sections describe some of the forensic information that may be useful to evaluate sources, as well as some tools for comparing samples within a data set.

10.5.1.1 Manufacturing Signatures

PFAAs (PFCAs and PFSAs) can be produced as a mixture of homologues of different chain lengths depending on the various manufacturing process(es) used (**Section 2.2**). PFAAs produced by electrochemical fluorination (ECF) can include both even and odd chain-length homologues. PFAAs produced by fluorotelomerization contain mostly even chain-length homologues. However, transformation of some of the fluorotelomer precursors results in the formation of odd chain length PFCAs (**Prevedouros et al. 2006**; **Dasu, Liu, and Lee 2012**; **Liu and Mejia Avendano 2013**). Most commercial laboratories can report PFCA homologues ranging from C4 to C14 and select PFSA homologues between C4 and C12. **USEPA (2009)** published PFCA profiles in various commercial products that showed different patterns of PFCA chain lengths. So, while chemical fingerprinting for source identification may be useful for PFAS sites, changes in raw materials and processes over time, as well as environmental fractionation, must be taken into account.
Laboratories generally report the concentration of a given PFAA as the total of the branched and linear forms; however, the concentration of the linear form and an estimated concentration for the branched form can often be reported independently. The concentration of branched forms typically must be estimated because standards do not yet exist for most branched-chain PFAA (**Section 11.2.1**). **Benskin (2011)** used the absence of branched PFCA isomers in dated sediment cores of two lakes to support the conclusion that oxidation of FTOH was the major atmospheric source of PFCAs in the lakes and not

direct transport of PFOA. **Fredriksson (2016)** used isomer profiles along with homologue patterns to assess the sources of PFAS in avian eggs. However, the potential for environmental fractionation must be taken into account when evaluating isomer profiles because linear and branched-chain isomers have different physical and biological properties, adsorption, and bioaccumulation (**Fredriksson 2016**; **Miralles-Marco and Harrad 2015**). Other examples of isomer analysis for PFAS source identification include **Shi et al. (2015)**, **Benskin, DeSilva, and Martin (2010)**, and **Karrman et al. (2011)**.

Chiral fingerprinting through enantiospecific isomer differentiation is a potential method for source identification, although its use is still under development. **Asher et al. (2012)** applied this method to identify PFAS sources to an aquatic foodweb. However, they noted several limitations and assumptions when using this method for PFAS source identification.

10.5.1.2 High-Resolution Mass Spectrometry (HRMS)

High-resolution mass spectroscopic methods using quadrupole time-of-flight mass spectrometry (qTOF/MS) can be used to determine both the chemical formula and structure of unknown PFAS in source materials (see **Section 11.2.2.5** for further information on qTOF/MS) (**Newton et al. 2017**; **Moschet et al. 2017**; **Barzen-Hanson et al. 2017**; **Battelle 2020**; **Washington et al. 2020**; **Getzinger, Higgins, and Ferguson 2021**; **Guelfo et al. 2021**). PFAS suspect screening libraries have been developed to include broader lists of PFAS analytes found across many different PFAS sources (**Newton et al. 2017**; **Moschet et al. 2017**; **Barzen-Hanson et al. 2017**; **Getzinger, Higgins, and Ferguson 2021**). Because analytical standards are not available for most PFAS included under this extended list of analytes, often these analytical tools are used for qualitative/semiqualitative analysis. These methods have the potential to greatly increase the number of identified PFAS, including precursors and the transformation products, and hence provide more accurate source identification (**Washington et al. 2020**, Getzinger, Higgins, and **Ferguson et al. 2021**; **Guelfo et al. 2021**). The addition of a broader list of analytes increases the power to resolve differences in PFAS profiles and therefore characterize sources and source footprints.

10.5.1.3 Visual Representations of Data

It is common to show representations of measured PFAS in figures or graphs to give the reader a visual sense for relative abundance. Two common graphs for representing PFAS data are bar graphs and radar plots. If one is considering the role of concentration, then it may be helpful to plot PFAS concentrations on the axes. However, if one is considering the patterns of data, then it is helpful to plot relative abundance, or the concentration of each PFAS divided by the sum of all measured PFAS, on the axes. It is also suggested to group subclasses of PFAS together and order them by perfluorinated alkyl chain length. For example, PFCAs ordered from the shortest to longest perfluorinated alkyl chain length, followed by PFSAs ordered from the shortest to longest perfluorinated alkyl chain length, followed by fluorotelomer sulfonates ordered from the shortest to longest perfluorinated alkyl chain length allows the viewer to compare changes in compositional patterns both within and between different subclasses of PFAS to assess changes that may occur due to environmental fate and transport. When showing data in this fashion, it is common to report estimated concentrations or J-flagged values and use the value of zero (0) for nondetects. However, other methods for assessing nondetects could be considered (**Johnson et al. 2015**). A comparison of PFAS signatures between two samples (Sample A and Sample B) using either bar graphs (**Figure 10-2**) or radar plots (**Figure 10-3**) is shown below.

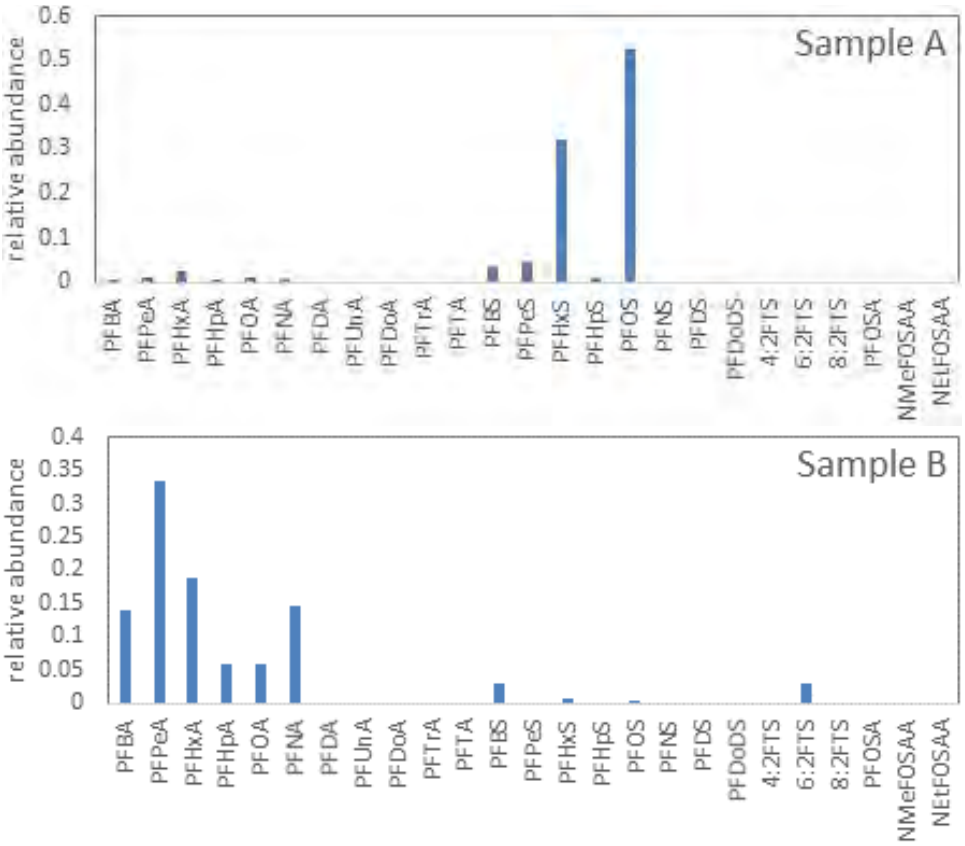


Figure 10-2. Comparison of PFAS signatures in Sample A and B using bar graphs. The concentration of each PFAS has been divided by the sum of all measured PFAS to represent the relative abundance of PFAS in each sample.

Source: M. Benotti, NewFields. Used with permission.

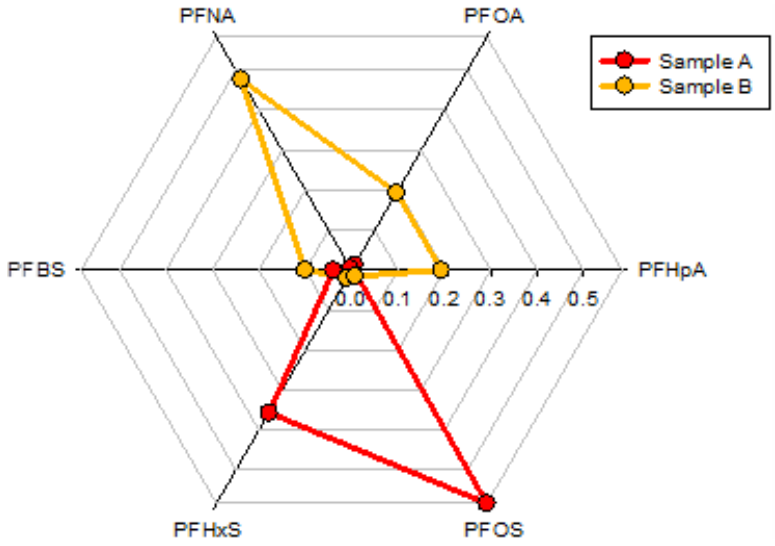


Figure 10-3. Comparison of PFAS signatures in Sample A and B using radar plots. The concentration of each PFAS has been divided by the sum of all measured PFAS to represent the relative abundance of PFAS in each sample.

Source: M. Benotti, NewFields. Used with permission.

10.5.1.4 Diagnostic Ratios

In some applications of PFAS forensics, it may be beneficial to show similarities or differences between sample signatures using relative abundances of one or more PFAS or diagnostic ratios, or double ratio plots. Without a comprehensive library of PFAS source materials, such ratios should be site-specific, and should be selected to query the data for a site-specific question and to show similarity or differences between contamination throughout the site and those in known or purported source area/s. Examples of factors that may help identify suitable diagnostic ratios include the relative abundance of PFCAs, PFSAs, or FTSs, the ratio of PFCAs to PFSAs (or more specifically the ratio of PFOA to PFOS), the ratio of even-numbered to odd-numbered PFCAs, the relative abundance of linear to branched isomers of selected PFAS, and others. **Table 10-2** shows some example diagnostic ratios for PFAS in Sample A and Sample B above.

Table 10-1. Example diagnostic ratios to compare PFAS signatures of Sample A and Sample B.

	Sample A	Sample B
relative abundance of PFCAs	0.062	0.93
relative abundance of PFSAs	0.94	0.041
relative abundance of FTSs	0	0.029
PFCAs/PFSAs	0.066	22
PFOA/PFOS	0.0217	13

10.5.1.5 Multivariate Statistical Tools

The statistical methods used in fingerprinting chemical mixtures range from simple visual comparisons of the relative chemical composition in environmental samples to more sophisticated multivariate statistical analyses of large environmental data sets (**Bock et al. 2021**; **Cejas and Barrick 2021**; **Wenning and Erickson 1994**; **Johnson et al. 2006**; **Otto 2016**; **Brereton 2009**). Multivariate statistical tools are ideally suited to the analysis of chemical mixtures. These tools have been applied to chemical mixtures such as PCBs, hydrocarbons, and dioxins for many decades. PFAS data sets, including TOP assay data, are similarly amenable to a variety of multivariate numerical data analysis techniques that provide a means to categorize PFAS compositional data. The advantages of multivariate numerical methods are that they provide a convenient means to analyze large data sets and reduce the output into relatively straightforward graphical output that describes the most important factors affecting chemical variability throughout the data set. Principal component analysis (PCA) is a multivariate statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. In other words, it identifies and graphically shows the most important features of data that describe similarities and differences between sample chemistries within a data set. The investigator can use this tool to identify samples that have similar or different PFAS signatures and what changes are driving those differences. Changes in PFAS patterns may be attributable to changes associated with fate and transport, or there may be changes that can be explained only by additional sources. **Figure 10-4** presents an example PCA scores plot, which demonstrates the similarity or dissimilarly of PFAS signatures between all samples in a data set. PCA is most effective when supplemented with other lines of evidence such as cluster analysis, ratios, and geospatial methods.

Examples of chemical fingerprinting for PFAS source identification can be found for wastewater treatment plants (**Clara et al. 2008**), differentiating AFFF sources (**KEMI 2015**; **Hatton, Holton, and DiGuiseppi 2018**; see also **Section 3.5**), landfills (**Lang et al. 2017**; **Xiao et al. 2012**), surface water (**Xie et al. 2013**), sediment (**Qi et al. 2016**), and groundwater (**Yao et al. 2014**). Multivariate statistical analyses (that is, PCA, cluster analysis, and unmixing models) and geospatial analysis have been used extensively to distinguish PFAS sources. **Guelfo (2017)** emphasized the importance of geospatial distribution of PFAS for source identification. **Qi et al. (2016)** used PCA–multiple linear regression, positive matrix factorization, and unmix models to identify four PFAS sources (textile treatment, fluoropolymer processing aid/fluororesin coating, textile treatment/metal plating, and precious metals). **Zhang et al. (2016)** used PCA, hierarchical clustering, and geospatial analysis to determine sources in the northeast

United States, and Lu et al. (2017)[652] used factor analysis to classify three categories of PFAS in impacted groundwater. **Pan et al. (2014)** used PCA in water and sediment samples to distinguish between rural/agricultural and urban/industrial sources.

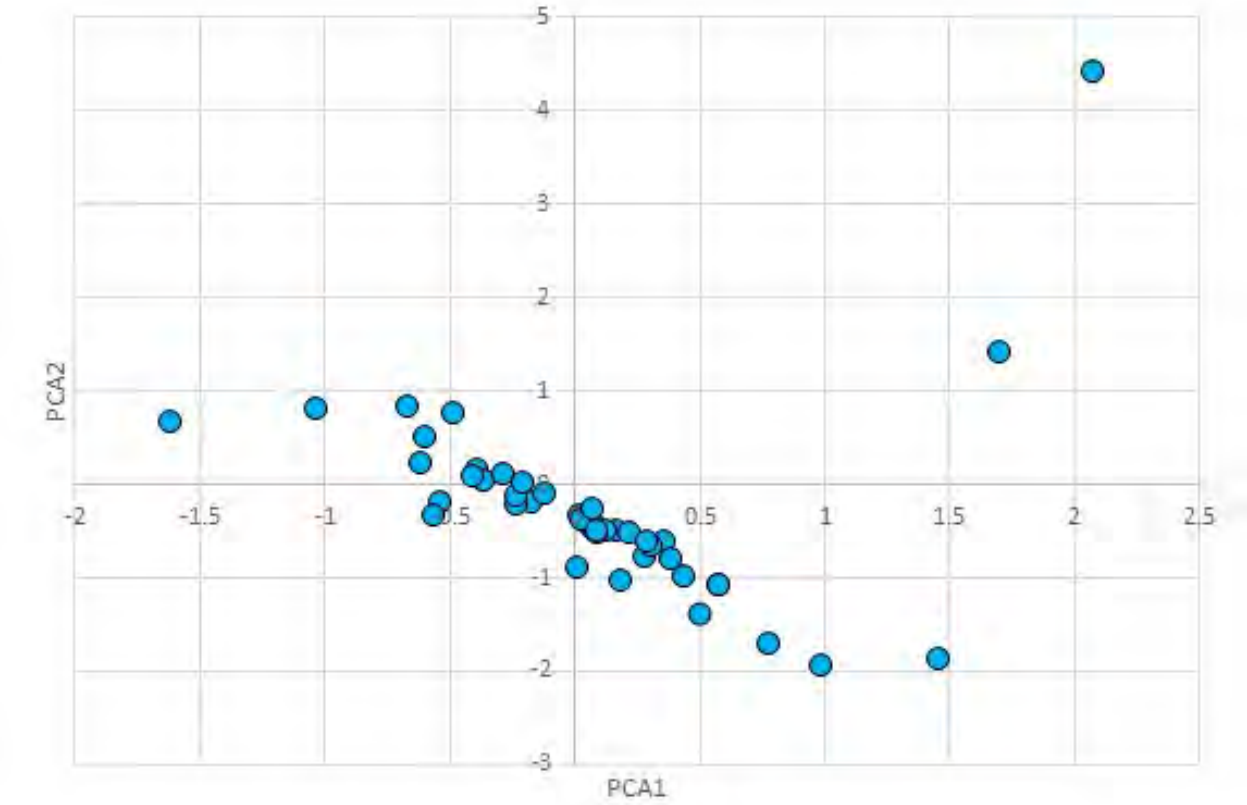


Figure 10-4. PCA scores plot of the analysis of a PFAS data set. Each circle represents the pattern of PFAS contamination of an individual sample. Samples that plot close together have similar PFAS signatures. Samples that plot apart have dissimilar PFAS signatures.

Source: M. Benotti, NewFields. Used with permission.

Other methods that have been applied to other chemical mixtures, such as statistical unmixing and big data/machine learning methods, also hold promise for the analysis of PFAS mixtures. As with any complex data analysis method, these methods have strengths and weaknesses that must be understood by the user. Thus, PFAS forensics practitioners must keep current on new developments in chemical forensics and statistical analysis. Given differences in the environmental fate and transport of different types of chemical mixtures and the complex behavior of PFAS, the forensics scientist must carefully evaluate any data analysis method to ensure it is being applied and interpreted appropriately. Because of the many complexities associated with PFAS production, historical usage, and fate and transport processes, the risk of incorrect conclusions can be especially high. We advocate for a weight of evidence approach based on (1) historical information regarding usage and other information, (2) a detailed consideration of transport pathways such as air emissions, spills, and wastewater discharge, (3) an analysis of transport processes such as local groundwater transport, the presence of groundwater divides and other barriers, and air speed and direction, (4) concentration gradients, (5) the analysis of diagnostic ratios, (6) multivariate statistical methods, (7) a consideration of branched versus linear isomers, and (8) other information that can be used to understand sources, discharges, and fate and transport.

SERDP PFAS Novel Methods for PFAS Source Tracking and Allocations

ER20–1375 Comprehensive Forensic Approach for Source Allocation of Poly- and Perfluoroalkyl Substances – Chris Higgins, Colorado School of Mines

ER20–1121 Establishing an Approach to PFAS Forensics and a PFAS Source Materials Forensic Library – Mark Benotti, NewFields Government Services

ER20–1205 Machine Learning Pattern Recognition for Forensic Analysis of Detected Per- and Polyfluoroalkyl Substances in Environmental Samples – Tohren Kibbey, University of Oklahoma

ER20–1265 Ultrahigh-Resolution Fourier-Transform Ion Cyclotron Resonance Mass Spectrometry for Fingerprinting, Source Tracking, and Allocation of Per- and Polyfluoroalkyl Substances (PFAS) – Jens Blotevogel, Colorado State University

ER20–1056 Improving Access and Utility of Analytical Data for the Confident Discovery, Identification, and Source-Attribution of PFAS in Environmental Matrices – Benjamin Place, NIST, Department of Commerce

11 SAMPLING AND ANALYSIS

Due to the extensive use of a wide array of PFAS resulting in trace levels of PFAS in most environmental media across the globe and the low parts-per-trillion screening and action levels, all aspects of a sampling and analysis protocol require a heightened level of rigor to avoid cross-contamination and achieve the level of accuracy and precision required to support defensible project decisions. This section focuses on providing the user with the appropriate tools and information to develop a site-specific sampling and analysis program to satisfy the project data quality objectives (DQOs). Accurate and representative data support the development of a defensible conceptual site model (CSM), and ultimately the final remedy.

Section Number	Topic
1.5	**Priority Topics for Sampling and Analysis (2025)**
11.1	**Sampling**
11.2	**Analytical Methods and Techniques**
11.3	**Data Evaluation**
11.4	**Source Identification**

Information on sample collection for PFAS is sparse, with only a handful of guidance documents available for a practitioner to reference. However, there are two peer-reviewed studies (**Denly et al. 2019**; **Rodowa et al. 2020**) on the potential for cross-contamination from commonly used sampling materials. These studies indicate that the potential for cross-contamination from the equipment used or possession of items that could potentially contain PFAS (for example, bug spray, food wrappers, and sunscreen) is extremely low and difficult to document. As of the date of this publication, most guidance documents default to a conservative approach due to a lack of information at the time of publication. Although the actual methods of sample collection are similar to those used for other chemicals, there are several considerations for the practitioner when establishing a sampling program for PFAS. These include selection of proper personal protective equipment (PPE), documentation of protocols for sample handling and decontamination procedures, use of nonbiasing material (for example, tubing, sample bottles, pumps) that will or could reasonably come into contact with the sample media, and implementation of quality control (QC) protocols to meet project DQOs, among other considerations. This section will give practitioners the tools needed to prepare a sampling program that adequately addresses project-specific DQOs and limits, to the extent practicable, potential cross-contamination and sources of potential bias.

Analytical methods are still evolving for PFAS analysis, with several in development (**USEPA 2024**). Although some methods have been published (**PFAS Analytical Methods** provided as an Excel spreadsheet), not all are discussed in this document because details included in these methods are subject to change prior to the methods being finalized.

The USEPA Office of Water has validated and published sample preparation procedures and analysis procedures applicable to groundwater, surface water, wastewater, landfill leachate, soil, sediment, biosolids, and tissue in EPA Method 1633A (**USEPA 2024**).

The USEPA Office of Land and Emergency Management has validated and published sample preparation procedure and analysis procedures applicable to groundwater, surface water, and wastewater. USEPA SW-846 Method 3512 is a sample preparation method, and USEPA SW-846 Method 8327 is the associated analytical method.

Three USEPA methods are validated and published for the analysis of PFAS in drinking water: USEPA Method 537 (**USEPA 2009**), USEPA Method 537.1, Version 2.0 (**USEPA 2020**), and USEPA Method 533 (**USEPA 2019**). For simplicity in the text, subsequent references to USEPA Method 537.1 assume the most current version. These methods are required for PFAS analyses of drinking water and include performance data for drinking water from surface water and groundwater sources. These methods are prescriptive in that changes to preservation (including sample collection, in the case of USEPA Method 537.1), sample extraction steps, and quality control requirements are prohibited by the methods.

The DOD has also validated and published a method (DOD AFFF01) for the determination of PFOA and PFOS in AFFF concentrates for demonstration of compliance to MIL-PRF-24385 (**Willey 2021**).

This section will be updated as new information on sampling considerations and analytical methods/procedures becomes available.

11.1 Sampling

11.1.1 General

Sampling conducted to determine PFAS concentrations in drinking water, other aqueous media, soil, sediment, air, biota, and other media is similar to that for other chemical compounds, but with several additional specific considerations and protocols. Typical guidance and procedures, such as ASTM International D 4823-95 and D 4448-01, USEPA compendium EPA 540/P-87/001a, OSWER 9355.0-14, USEPA SESDPROC-513-R2, and USEPA SESDPROC-305-R3, remain the basis for a PFAS sampling protocol. Because of the need for very low laboratory quantitation limits and the widespread use of PFAS in common materials, field and equipment blanks are needed in greater amount and frequency than in other analyses. In addition, special consideration may be needed to address the potential for background sources of PFAS in the environment, sample cleanup criteria, and the potential need for modified decontamination measures.

Examples of USEPA region-specific or program-specific PFAS sampling protocols include:

- **USEPA (2019)** Region 4, Laboratory Services and Applied Science Division, Athens, GA, *Field Equipment Cleaning and Decontamination at the FEC*, ASBPROC-206-R4, 2019

- DOD AFFF01 *Determination of Perfluorooctanoic acid and Perfluorooctanesulfonic acid in Aqueous Film Forming Foam (AFFF) for Demonstration of Compliance to MIL-PRF-24385* (**Willey 2021**)

- State guidance:
    - **MA DEP (2023)** Massachusetts Department of Environmental Protection, *Sampling and Analysis for PFAS at Disposal Sites Regulated under the Massachusetts Contingency Plan*.
    - **Washington Department of Ecology (2017)** *Quality Assurance Project Plan; Statewide Survey of Per- and Poly-fluoroalkyl Substances in Washington State Rivers and Lakes.*
    - **NH DES (2022)** New Hampshire Department of Environmental Services, *Laboratory Testing Guidelines for Per- and Polyfluoroalkyl Substances (PFAS) at Waste Sites,*
    - **MPCA 2022** Minnesota Pollution Control Agency, *Guidance for Per- and Polyfluoroalkyl Substances (PFAS): Sampling*
    - Michigan Department of Environment, Great Lakes, and Energy (EGLE) PFAS Sampling Guidance Documents including:
        - **MI EGLE (2024)** PFAS Sampling Guidance

- **MI EGLE (2019)** Surface Water Foam PFAS Sampling Guidance
- **MI DEQ (2018)** Wastewater PFAS Sampling Guidance
- **MI DEQ (2018)** Surface Water PFAS Sampling Guidance
- **MI DEQ (2019)** Fish Tissue Sampling Guidance

The list provided above is not comprehensive; project teams should consider state-specific and USEPA guidance as available.

A work plan (that is, a quality assurance project plan (QAPP)) should be implemented to address PFAS-specific considerations. If a work plan is not created for a project, the sampling and quality control (QC) elements outlined in **Section 11.1.6** should be implemented. If regulatory procedures, methods, or guidelines are inconsistent with the needs of a PFAS sampling program, such as requiring the use of fluoropolymer tubing, the governing agency should be contacted directly to determine if an exception can be made or an alternate approach is needed. A CSM (if available, see **Section 10.2**) should be evaluated to support development of the project-specific DQOs as part of the work plan. The review should include information on previous site uses, PFAS use/manufacturing/handling practices, other possible contaminants and their uses, and/or related remediation activities and historical PFAS data, to determine all possible source areas of PFAS. Previous or ongoing remediation of other contaminants of concern can add a layer of complexity to a site's geochemistry and the fate and transport of PFAS.

Although some sampling elements (for example, sample bottle, preservation, and holding times) are defined by analytical methods, these methods do not provide all the information that is needed to conduct a sampling event for PFAS. However, DOD AFFF01 contains the information needed to conduct sampling of AFFF concentrates. Tables 11-2 and 11-5 are included in the **PFAS Analytical Methods** Excel File, and cover the sample container types, sample size, number of containers required, and holding time and preservation requirements for each of these published PFAS analytical methods, respectively.

Communication with the laboratory before, during, and after sampling is conducted is critical in ensuring that project needs are met. If a sample is from an area known or suspected to be highly contaminated with PFAS, it is important that this is communicated to the laboratory. The chain-of-custody form should indicate samples that potentially contain a high concentration of PFAS. As stated in USEPA Method 1633A (**USEPA 2024**), laboratories should prescreen all samples to select the necessary sample preparation procedures and to avoid contamination of their laboratory equipment and contamination of other field samples.

Any water used for field QC blanks (for example, field and decontamination blanks) should be supplied by the laboratory performing the analysis. The laboratory should provide documentation verifying that the supplied water is PFAS-free. "PFAS-free" is the project-defined concentration that associated blank concentrations must be below (examples: less than the detection limit; less than half the limit of quantitation (LOQ)) to ensure an unacceptable bias is not introduced into the sampling and analysis processes and project data quality objectives can be met. The work plan should clearly state the project's definition of "PFAS-free." Review of the laboratory's standard definition of "PFAS-free" upfront is necessary to ensure that it meets project needs and is a critical step in laboratory selection for a project. Laboratories verify the PFAS content of each batch of supplied water through analysis. Documentation of this verification should be maintained for data validation purposes and should be reviewed by the project team to ensure that the project's definition of "PFAS-free" is met. If the water was not supplied by the laboratory, a sample of the water used in the field should be sent to the laboratory for testing.

11.1.2 Equipment and Supplies

Many materials used in environmental sampling can potentially contain PFAS. There is published research or guidance on how certain materials used by field staff or in sampling equipment affect sample results (see **Denly et al. 2019**; **Field et al. 2021**, Assessing the Potential for Bias in PFAS Concentrations during Groundwater and Surface Water Sampling, SERDP Project ER19-1205; **Rodowa et al. 2020**). However, a conservative approach is recommended to exclude materials known to contain the PFAS that are the target of the analysis from a sampling regimen, and such an approach should be documented accordingly in the work plan. Obtain and review all Safety Data Sheets (SDSs) before considering materials for use during PFAS sampling, as product manufacturing formulations can change over time. If PFAS or the terms "fluoro" or "halo" are listed on the SDS, it is recommended that piece of equipment/supply not be used. Exclusion from the SDS does not necessarily mean the equipment/supply is not contaminated with PFAS. PFAS may not have been used as a component of the equipment/supply, but as a material used in the manufacturing process itself (for example, mist suppressant or mold coating), which can result in the manufactured equipment/supply containing PFAS. If necessary, materials in question can be sampled and analyzed for PFAS, or thorough decontamination and collection of equipment blanks can provide sufficient quality assurances. Ultimately, a sampling program should produce defensible data, and the best way to protect the integrity of samples is to ensure they are not compromised by contaminants originating from sampling equipment or otherwise.

Due to the extensive use of a wide array of PFAS, sampling crews should review all materials and sampling protocols to avoid contamination and possible sorption issues. Examples of materials that, if used and contacted, could potentially introduce bias to samples include, but are not limited to:

- polytetrafluoroethylene (PTFE)
- waterproof coatings containing PFAS
- fluorinated ethylene-propylene (FEP)
- ethylene tetrafluoroethylene (ETFE)
- low-density polyethylene (LDPE)
- polyvinylidene fluoride (PVDF)
- pipe thread compounds and tape.

A tiered approach should be implemented for materials restrictions, where the first tier would include restrictions on the sampling materials that will come in direct contact with the sample media, and the second tier would include restrictions on what materials are allowed on sampling personnel or within the staging area. The focus on restrictions within the second tier should consider how reasonable the potential for contact with the sample media is when good sampling practices are employed, the practicality of the restriction (for example, does it compromise employee safety or increase an exposure risk), and the documentability of the requirement (can the restriction or measure be properly documented). Program-specific sampling protocols such as those previously listed in this section often identify materials and equipment that can be used in PFAS-focused investigations, as well as materials that should be avoided because they are known or suspected to be potential sources of PFAS. However, as noted in peer-reviewed studies (**Denly et al. 2019; Rodowa et al. 2020**), the potential for cross-contamination from sampling materials that are not likely to contact the sample media or incidental contact (for example, rain splatter off a treated raincoat) is minimal, therefore, the focus should be on material in direct contact with the sample media and with a reasonable potential for contact. It is also recognized that a PFAS-free alternative may not be readily available or confirmable. In such instances a robust quality assurance (QA) program consisting of appropriate equipment blanks can be implemented to address this.

There may be instances when it is not possible to eliminate sampling materials that may affect sample results. For example, problematic materials may be needed at sites where co-contaminant or facility hazards warrant the use of PPE such as Tyvek suits or flame-retardant coveralls for worker safety.

Additionally, this could be an issue in emergency response scenarios if a sampler needs to collect a sample before a proper program is established or before proper sampling materials can be obtained.

11.1.3 Bottle Selection

Sample container material recommendations are dependent on the analytical method. Containers should be supplied by the laboratory and laboratory-verified to be PFAS-free, as defined by the work plan. USEPA SW-846 Method 8327 was validated using polypropylene containers for groundwater, surface water, and wastewater sampling. However, USEPA SW-846 Method 8327 states that other types of containers such as high-density polyethylene (HDPE) may be used if the needs of the project can be met with their use. USEPA Method 533 and USEPA Method 537.1 require the use of polypropylene or other plastic containers, such as polyethylene, that meet the QC requirements (**Section 11.1.7.1**). USEPA Method 1633A requires the use of HDPE containers for wastewater, groundwater, surface water, landfill leachate, biosolids, soil, sediment, and tissue sampling.

The volume of aqueous sample that is required for analysis varies from method to method and the mass of solid material required for analysis is dependent on the matrix of the sample.

Non-potable water samples do not require a chemical preservative, unless otherwise required by the cited analytical method(s). Clean laboratory-provided HDPE or polypropylene bottles are recommended; typically, 125-mL to 1-L bottles may be used, but the sample volume may depend on the analytical method used.

In USEPA Method 1633A, samples are prescreened to determine if they contain high concentrations of PFAS analytes or other potential interferences (for example, landfill leachates) that would prohibit the whole aqueous sample from being prepared. For prescreening analysis, the method requires collection of an additional, smaller aliquot of wastewater, groundwater, or surface water. This second aliquot allows the laboratory to prescreen the sample without affecting the integrity of the sample collected for analysis. Coordinating with the laboratory is crucial to ensure an adequate number of each type of required sample container is provided for the field activity.

Best practices in sample preparation should be used when selecting the size, volume, and representativeness of samples. To minimize effects from analyte sorption on sample containers, USEPA Methods 537.1 and 533, and USEPA Method 1633A all require the laboratory to prepare the entire aqueous sample collected, including sample container rinsate(s). DOD AFFF01 requires the container holding the diluted AFFF concentrate be prepared in its entirety, including a rinse of the container.

11.1.4 Sample Preservation, Shipping, Storage, and Holding Times

Sample preservation, shipping, storage, and holding time requirements are dependent on the method used. Drinking water methods (USEPA Method 537.1 and 533) are the only USEPA methods requiring the addition of a chemical preservative at sample collection. USEPA Method 537.1 requires the addition of Trizma®, while USEPA Method 533 requires the addition of ammonium acetate, as detailed in section 8 of each of the methods. According to both methods, samples must be chilled during shipment and not exceed 10°C during the first 48 hours after collection. When they are received by the laboratory, samples must be at or below 10°C and stored in the laboratory at or below 6°C until extraction. These two methods differ in their required holding times, as USEPA Method 537.1 requires samples to be extracted within 14 days of collection, while USEPA Method 533 requires samples to be extracted within 28 days of collection.

The shipping, storage, and holding time requirements for wastewater, groundwater, and surface water samples stated in USEPA SW-846 Method 8327 differ than those provided by USEPA Method 1633A. USEPA SW-846 Method 8327 requires all samples and sample extracts to be chilled from the time of

sample collection to analysis and not exceed 6°C. Since a holding time study was not performed in conjunction with the validation of USEPA SW-846 Method 8327, the method offers a holding time of 14 days from sample collection to sample extraction and a 30-day holding time from sample extraction to sample analysis as a guideline.

The shipping, storage, and holding time requirements contained in USEPA Method 1633A are based on a published holding time study for PFAS by **Woudneh et al.2019**, as well as the holding time studies conducted in conjunction with the single- and multi-laboratory validation studies for USEPA Method 1633 (**Willey et al 2021**, **2023**, **2023**, **2023**, **2023**). While the statistically determined holding time requirements are similar for each matrix, they are not identical (see Table 11-5, included in the **PFAS Analytical Methods Excel File**). Observed losses and/or gains in the concentration of some PFAS, most likely caused by transformation of precursors, resulted in shorter holding times for samples and extracts. As stated in Method 1633A (**USEPA 2024**) for aqueous samples, "conversion of certain perfluorooctane sulfonamide ethanols and perfluorooctane sulfonamidoacetic acids have been observed after 7 days. Specifically, NMeFOSE and NEtFOSE may undergo transformation to NMeFOSAA and NEtFOSAA respectively when stored at 0 - 6 ºC, but not when stored at or below -20 ºC. Therefore, if NMeFOSE, NEtFOSE, NMeFOSAA and/or NEtFOSAA are analytes of concern for a given permit or project, either store the samples at or below -20 ºC, or extract the samples within 7 days of collection." Also, due to the observed extreme loss of NFDHA, an additional caveat in the method recommends samples be extracted and analyzed for solids and tissues as soon as possible if NFDHA is an important analyte for the project (**USEPA 2024**). This issue was addressed by the DOD Environmental Data Quality Workgroup in a March 2025 memo when using 1633A for PFAS investigations (**USDOD 2025**).

11.1.5 Decontamination Procedures

Sampling equipment should be thoroughly decontaminated before mobilization to each investigation area and between sample locations at each investigation area or as required in the site-specific work plan. Field sampling equipment, including oil/water interface meters, water level indicators, nondisposable bailers, and other nondedicated equipment used at each sample location requires cleaning between uses. The SDSs of detergents or soaps used in decontamination procedures should be reviewed to ensure fluorosurfactants are not listed as ingredients. Use laboratory-verified PFAS-free water for the final rinse during decontamination of sampling equipment. Decontaminate larger equipment (for example, drill rigs and large downhole drilling and sampling equipment) with potable water using a high-pressure washer or steam. To the extent practical, rinse parts of equipment coming in direct contact with samples with PFAS-free water. Heavy equipment is best cleaned within a decontamination facility or other means of containment (for example, a bermed, lined pad and sump, or a portable, self-contained decontamination booth). Potable water sources should be sampled in advance and analyzed for PFAS, as well as during the sampling event to verify the water remained PFAS-free. If the potable water source does not meet the project-defined criteria for PFAS-free water, an alternate water supply should be considered. Wherever possible, rinse equipment with laboratory-verified PFAS-free water immediately before use.

An example of decontamination procedures as published in the Minnesota Pollution Control Agency "Guidance for Per- and Polyfluoroalkyl Substances (PFAS): Sampling" (**MPCA 2022**) is as follows:

- Equipment caked with drill cuttings, soil, or other material will initially be scraped or brushed. The scrapings will be collected, containerized, and disposed in accordance with government regulations.
- Equipment will then be sprayed with potable water using a high-pressure washer.
- Washed equipment will then be rinsed with laboratory-verified PFAS-free water.

- Decontaminated downhole equipment (for example, drill pipe, drive casing, bits, tools, bailers, etc.) will be placed on clean plastic sheeting (PFAS-free) to prevent contact with contaminated soil and allowed to air dry. If equipment is not used immediately, it will be covered or wrapped in plastic sheeting to minimize airborne contamination.

- Field sampling equipment and other downhole equipment used multiple times at each sample location will require cleaning between uses utilizing a four-stage decontamination process. The equipment will first be rinsed in a bucket containing a mixture of potable water and PFAS-free soap. The equipment will then be rinsed in each of two buckets of potable water. Water used for the final rinse during decontamination of sampling equipment will be laboratory-verified PFAS-free water.

Decontamination solutions should be replenished between sampling locations as needed. Spent decontamination fluids should be containerized, properly labeled, and appropriately disposed of as investigation-derived waste (IDW), based on plans included in the site-specific QAPP or work plan.

11.1.6 Field QC Samples

Field QC samples are a means of assessing quality beginning at the point of collection. Such field QC samples typically include field reagent blanks, source water blanks, equipment rinse blanks, and field duplicates. Collection and analysis of field QC samples are important for PFAS investigations because of very low detection limits and regulatory criteria (parts per trillion (ppt)), to ensure accuracy and representativeness of the results for the sampled media, and to assess potential cross-contamination due to the extensive use of PFAS. A sampling program should be designed to prevent cross-contamination and anthropogenic influence. However, the widespread commercial use (historical and current) of PFAS-containing products, and especially their prevalence in commonly used sampling materials and PPE, should inform the sampling program. PFAS sites may also have a wide range of concentrations with varying families of PFAS, as well as co-contaminants. Furthermore, PFAS sites have the potential to be high profile in nature. Therefore, a comprehensive site-specific QAPP or work plan addressing DQOs and field QC samples, including frequency, criteria, and procedures, is vital to a PFAS sampling program (see also **Section 11.3**, Data Evaluation).

Table 11-1. Typical field QC samples.

QC Sample	Description	Minimum Suggested Frequency
Field reagent blank (FRB)	Laboratory-provided PFAS-free reagent water that, in the field, is poured into an empty sample bottle or a sample bottle containing only preservative (if required)	One per day per matrix per sample set
Source water blank	Water collected from potable water source that is used during the sampling processes (such as decontamination and drilling processes)	One per site, preferably prior to sampling event (if possible) and at least once during sampling event
Equipment rinse blank (ERB)	Final rinse sampling equipment with laboratory-verified PFAS-free water (decontamination blank); prior to the sampling event	One prior to the start of a sampling event per piece of sampling equipment following an initial decontamination One per day per piece of sampling equipment used for each matrix sampled (during or at the end of the day) following decontamination
Field duplicate	Two samples collected at the same time and location under identical circumstances	One per day per matrix, or one per 20 samples per matrix, whichever is greater

When planning QC sample frequency, the risk of cross-contamination should be considered. Cross-contamination can occur from several sources, including field conditions, ineffective decontamination, incidental contact with PFAS-containing materials, and sampling equipment and materials that were manufactured alongside PFAS-containing equipment.

Of all the USEPA PFAS methods, only USEPA Methods 537, 537.1 and 533 contain specific requirements for the field QC samples that must be collected and accompany samples to be analyzed for PFAS. These include field duplicates, matrix spikes and duplicates, and a minimum of one field reagent blank for each set of samples per sampling site. USEPA Methods 537, 537.1 and 533 specify the frequency of the field duplicate or matrix spikes in terms of extraction batch (one per extraction batch, not to exceed 20 field samples), not collection frequency. Although the other USEPA PFAS methods do not contain any field QC sample requirements, **Table 11-1** provides a list of field QC samples typical for the collection of these matrix types and their typical minimum frequency. Once field QC sample data are obtained, they should be evaluated against the field samples by a person knowledgeable on the DQOs set forth in the site-specific QAPP or work plan. For laboratory QC considerations, see **Section 11.2**, Analytical Methods/Techniques.

11.1.6.1 Field Reagent Blank

A field reagent blank (FRB), as described in USEPA Methods 537, 537.1 and 533 for collection of drinking water samples, consists of a sample bottle filled with PFAS-free reagent water prepared in the laboratory, sealed, and shipped to the sampling site along with the sample bottles. An empty sample bottle containing only preservatives (same as those used for the samples) is shipped along with each FRB into which the sampler pours the unpreserved PFAS-free reagent water contained in another bottle that was sent to the field and seals and labels the bottle for shipment along with the samples back to the laboratory for analysis. FRBs help to determine if PFAS were introduced into the samples during sample collection/handling and help to account for additional factors, such as introduction of contaminated airborne particles. A laboratory reagent blank is also analyzed in a laboratory setting to ensure that background contamination is not being introduced in the laboratory from reagents or water supplies.

FRBs may also be warranted during collection of sampling media other than finished drinking water. In lieu of using a prepared quantity of laboratory reagent water/preservative solution as for drinking water FRB, a field blank can be prepared in the field using laboratory-verified PFAS-free water (may be equivalent to the laboratory reagent water) and filling an empty sample container in the field, which is then sealed and labeled as a field blank. This sample will be analyzed in the same manner as the normal samples and can indicate whether or not PFAS were introduced during sample collection/handling, and help to account for additional factors, such as introduction of airborne particulates.

As discussed above, the frequency of FRB samples for finished drinking water sampling is one FRB for every sample set at each site. A sample set is described in USEPA Methods 537.1 and 533 as “samples collected from the same sample site and at the same time” (**USEPA 2020**; **USEPA 2019**).

11.1.6.2 Source Water Blank

Large quantities of water may be necessary to carry out a field sampling program for various reasons, including decontamination and certain drilling techniques (**Section 11.1.5**, Decontamination Procedures). Site groundwater or surface water should not be used as source water at sites that are under investigation for PFAS, as they have potential to contain PFAS. PFAS test results of publicly supplied water at a site should be evaluated when considering it for use as source water. Regardless, it is imperative that any water used as source water be sampled and analyzed. For equipment that may come into contact with samples of any media type, a multistep process is common to adequately prevent cross-contamination. Quantities of laboratory-verified PFAS-free water are generally limited and can be costly. Therefore, potable water sources are typically used in initial decontamination steps. It is

imperative that these water sources be sampled and analyzed in the same manner as normal samples, prior to and even during a PFAS sampling program, to ensure that source water is not contributing to PFAS detections in normal samples. Further, many laboratories do not provide a verification of the laboratory-supplied DI water being PFAS-free unless specifically requested. Submission of a laboratory deionized water blank could be required based on DQOs of the specific project.

Collect a sample from the source the same way it is collected for use (for example, if the source water is collected through a hose, collect the source water blank from that same hose). If there are unnecessary fittings or hoses attached for collection of the source water, consider removing them for the duration of the sampling program to avoid contamination from PFAS that may be present in these materials.

Frequency of collection of such source water blanks is up to the professional judgment of the project manager, site owner, and other stakeholders and is detailed in the project-specific work plan. The source water should be sampled at least once prior to starting the field sampling program and once during the sampling event in case the analysis reveals that a different water source should be found. A more conservative sampling program may include provisions for additional periodic sampling in cases where the conditions of the source water may change.

11.1.6.3 Equipment Rinse Blank

Equipment Rinse Blanks (ERB) should be collected from nondedicated equipment/supplies at the start of the sampling event prior to sample collection to verify that nondedicated equipment/supplies are PFAS-free (**Section 11.1.2**). Thereafter, ERBs should be collected from nondedicated sampling equipment at a minimum rate of once per day (either during or at the end of each day) following decontamination and prior to its next use for the duration of the sampling event.

ERBs are those collected by rinsing a piece of field sampling equipment/supplies with laboratory-verified PFAS-free water and collecting the rinse water in a sample container for PFAS analysis. ERB collection is not required by USEPA Methods 537.1 or 533 because drinking water compliance samples are generally collected from the source without the use of other equipment. ERB collection for other programs is dependent on the sampling media and methods that are employed at a site. Generally, any equipment that is reused throughout the sampling program, or is nondedicated, and must be decontaminated, should have an ERB collected from it. That is, if a piece of equipment is decontaminated, an ERB should be collected from it after decontamination and prior to its next use. The frequency of collection of ERBs can be reduced by using all dedicated or disposable equipment where possible. However, many of these options are limited due to the extensive use of PFAS in many of these equipment materials. ERBs should also be considered for dedicated equipment prior to and during a sampling event if the PFAS contribution from equipment is unknown or suspected.

Field ERB collection frequency is largely up to the professional judgment of the project manager or other stakeholders and is dependent on the sampling media and methods and project-specific DQOs. For instance, collection of ERBs prior to initiating an event may be appropriate if rental equipment or subcontractor material that could have been used on another site is being used. The project team may also consider collecting an ERB from each piece of equipment used by the sampling team (ERB per sample setup) when multiple sampling setups are being implemented. Collection of an ERB from decontaminated soil sampling trowels may only warrant a frequency of once per day, whereas groundwater pumps may warrant an ERB prior to the pump being deployed down each well, due to their more rigorous decontamination procedure and higher contact time with the groundwater being sampled.

11.1.6.4 Field Duplicate

Field duplicate (FD) samples are two samples collected at the same time and location under identical circumstances and treated exactly the same throughout field and laboratory procedures. The analytical

results from these identical samples are used to evaluate the precision of sample collection, preservation, storage, and laboratory methods.

USEPA Methods 537.1 and 533 do not specify the frequency of FD collection for finished drinking water samples; however, they do specify the frequency of preparation (once per extraction batch, not to exceed 20 field samples). A more conservative sampling program may indicate a frequency of one FD per 10 field samples per matrix. FD collection frequency should be discussed with stakeholders, as necessary, and be evaluated as part of the comprehensive site-specific QAPP or work plan.

11.1.6.5 Additional QC Samples

In addition to the field quality control samples described above, replicate volume or mass may be collected for split samples and/or matrix spikes to provide project managers additional quality assurance regarding identification of PFAS target analytes and precision and bias in measured sample concentrations. Split samples are defined here as co-located quality control samples, taken at the same time and each sent to a different laboratory. These types of samples do not apply to routine compliance monitoring situations and may not be required in all sampling events. Aqueous QC samples should not be split into two samples from the original container. Analysis of these QC samples provides a measure of interlaboratory variability.

A performance evaluation (PE) sample, which contains project analytes with known concentrations of PFAS, may be submitted to the laboratory as a blind sample. Analysis from this sample provides a positive control from a second source.

11.1.7 Sampling Procedures

The Priority Topics for Sampling and Analysis include information about leaching methods (see **Section 1.5.1**), fish sampling and laboratory homogenization (see **Section 1.5.2**), consumer product testing (see **Section 1.5.4**), ISM for PFAS sampling (see **Section 1.5.5**), and concrete and asphalt sampling and analysis (see **Section 1.5.6**).

Standard sampling procedures and practices can be used at most PFAS sites and only require extra care and attention paid to the types of materials used. However, there may be some exceptions and additional considerations related to PFAS behavior and issues associated with potential use of PFAS-containing or PFAS-adsorbing sampling equipment and supplies, as previously discussed. A site-specific QAPP or work plan must contain the standard operating procedures incorporating these considerations and regulatory agency or client requirements. Refer to **Section 11.1.2** for materials to avoid during sampling and drilling. Consult the supplier to determine if PFAS-free options are available.

Pretesting any equipment or supplies to be used is ideal, although it is recognized that this is not typically feasible. As such, ERBs are recommended to ensure the decontamination of supplies (for example, bailers, pumps, beakers, and dippers) is effective.

In addition, the sampling team must document any observations during the sampling event that could be a source of bias (for example, the presence of PTFE tape on a faucet).

11.1.7.1 Drinking Water

Sampling a “potable water source,” as defined by the USEPA SDWA (Section 1401(4), August 1998), is conducted according to protocols established in USEPA Methods 537.1 and 533. These protocols define sample bottle preparation, sample collection, field reagent blanks, sample shipment and storage, and sample and extraction holding times. The drinking water source is further defined here as a public drinking water supply, as opposed to a private drinking water supply, as it applies to USEPA Methods

537.1 and 533. USEPA Methods 537.1 and 533 may also apply in instances when the water quality of the private drinking water supply source is similar to finished drinking water (for example, has low level of total organic content). The following summarizes the sampling considerations described in these protocols:

- For Methods 537 and 537.1: Sample bottle is a laboratory-provided 250-mL polypropylene bottle fitted with a polypropylene screw cap. For finished (treated) drinking water sampling only, a preservation agent is provided inside each bottle prior to sample collection. This agent acts as a buffer (Trizma®, pH 7, 5 g/L) and removes free chlorine from chlorine-treated drinking water supplies.

- For Method 533: Sample bottle is a laboratory-provided 100–250-mL polypropylene, or other plastic that meets method QC requirements, bottle fitted with a polypropylene screw cap. For finished (treated) drinking water sampling only, a preservation agent is provided inside each bottle prior to sample collection. This agent (ammonium acetate, 1 g/L) sequesters free chlorine to form chloramine in chlorine-treated drinking water samples. The sample handler must avoid PFAS contamination during sampling by thoroughly washing their hands and wearing nitrile gloves.

- Open the tap and flush the water (approximately 3–5 minutes) to obtain a "fresh" sample. Collect the sample while water is flowing, taking care not to flush out preservative. Samples do not need to be headspace-free. Cap the bottle and, if applicable, agitate to completely dissolve preservative.

- Keep sample sealed and place sample on ice for shipment.

- Samples must be chilled during shipment and must not exceed 10°C during shipment.

- Laboratory extraction of the sample must take place within 14 days of collection (USEPA Method 537.1) or within 28 days of collection (USEPA Method 533).

Based on a review of industry experience and guidance, additional considerations for collecting drinking water samples for PFAS analysis are as follows:

- The sample should ideally be cold water collected from a tap or spigot located at or near the wellhead or pump house and before the water supply is introduced into any storage tanks or treatment units. If the sample must be collected at a point in the water line beyond a tank, a sufficient volume of water should be purged to provide a complete exchange of fresh water into the tank at the tap or spigot. If the sample is collected from a tap or spigot located just before a storage tank, spigots located downstream of the tank should be turned on to prevent any backflow from the tank to the tap or spigot. Several spigots may be opened to provide for a rapid exchange of water. If collecting a sample to characterize human or other exposure, the sample should be collected from the tap or spigot at the point of use.

- When sampling from a drinking water well that is not in regular use, purge water until water quality parameters (that is, pH, specific conductance, dissolved oxygen, oxidation-reduction potential, turbidity, and temperature) have stabilized according to project-specific requirements, to ensure formation water (as opposed to stagnant well column water) will be sampled. An adequate purge is achieved when the pH and specific conductance of the potable water have stabilized (for example, within 10% across three consecutive measurements) and the turbidity has either stabilized or is below 10 nephelometric turbidity units. Note: According to **USEPA (2013)**, pg. 21 *"[a] well with an intermittently run pump should, in all respects, be treated like a well without a pump. In these cases, [water quality] parameters are measured and the well is sampled*

from the pump discharge after parameter conditions have been met. Generally, under these conditions, 15 to 30 minutes will be adequate."

- When sampling from a tap, the tap must be protected from exterior contamination associated with being too close to a sink bottom or to the ground. Contaminated water or soil from the faucet exterior may enter the bottle during the collection procedure because it is difficult to place a bottle under a low tap without grazing the neck interior against the outside faucet surface. If the tap is obstructed in such a way that prevents direct collection into the appropriate sample container, it is acceptable to use a smaller container to transfer sample to a larger container. The smaller container should be made of HDPE or polypropylene and should be either new or decontaminated as specified in **Section 11.1.5**. Evaluation of the transfer container is recommended to ensure that it does not introduce a bias.

- When filling any sample container, care should be taken that splashing drops of water from the ground or sink do not touch either the interior of the bottle or cap.

- Leaking taps that allow water to discharge from around the valve stem handle and down the outside of the faucet, or taps in which water tends to run up on the outside of the lip, are to be avoided as sampling locations.

- Disconnect any hoses, filters, or aerators attached to the tap before sampling.

Taps where the water flow is not constant should be avoided because temporary fluctuation in line pressure may cause clumps of microbial growth that are lodged in a pipe section or faucet connection to break loose. A smooth flowing water stream at moderate pressure without splashing should be used. The sample should be collected without changing the water flow.

11.1.7.2 Groundwater

Groundwater is typically sampled from a well, and therefore specialized equipment is required. When constructing monitoring wells prior to groundwater sampling, care should be taken to ensure well-construction materials are free of PFAS. **Radford et al. (2023)** detected PFAS in coated and uncoated bentonite formulations with more individual PFAS present at higher concentrations in coated formulations. PFAS have also been added to various concrete formulations (**Kissa, 1994**). Drilling greases, grout, and all well construction materials should be confirmed to be PFAS-free prior to use. Additionally, water added to the formation for drilling purposes (mud mixtures, managing running sands, etc.) may need to be tested for PFAS prior to use and should be thoroughly developed out of the completed well prior to sampling. Some of the various types of purging and sampling equipment available for groundwater sampling are described in ASTM International Standard Guide for Sampling Ground-Water Monitoring Wells, D 4448-01 (**ASTM 2007**) or Compendium of Superfund Field Operations Methods (**USEPA 1987**).

Within the context of sample collection objectives outlined in a site-specific work plan, the sample depth selection should consider the potential stratification of PFAS within the aquifer, the potential for phase partitioning, and the tendency for PFAS to accumulate at the air/water interface. In addition to depth location within the water column, consideration should be given to the well construction, screened interval, and site geology to ensure that the well is representative of site conditions and all relevant chemicals of concern (COCs). For more information on phase partitioning, see **Section 5.2**.

The most inert material (for example, stainless steel, silicone, polypropylene, and HDPE), with respect to known or anticipated contaminants in the well(s), should be used whenever possible. Purging and sampling equipment could be manufactured from components that might include PFAS. For example, pump components, such as O-rings, gaskets, bladders, stopcocks, and wiring insulation, may contain

PFAS. Contact between the groundwater, the sample, and PFAS-containing equipment provides opportunities for the sample to become contaminated and should be avoided when possible. In some cases, components that contain PFAS can be switched out for HDPE or polyethylene. Consult with the equipment vendor to determine if they have PFAS-free alternatives. In addition to equipment, ensure that field supplies that may contact the sample, such as tubing or bailer twine, are PFAS-free and will meet the DQOs. Dedicated sampling equipment installed in existing wells prior to PFAS investigations may contain components that are not PFAS-free, and the equipment's chemical properties may be challenging to verify. It is best practice not to collect samples using dedicated equipment that may include PFAS-containing components. If samples are collected with dedicated equipment with some unknown components, PFAS detections should be evaluated in an uncertainty analysis.

Where sampling for co-contaminants requires use of PFAS-containing materials, sampling events should be separated to avoid contamination from these materials. The PFAS sampling event would be completed first, followed by the sampling event for the co-contaminants. In some cases, it may be acceptable to use the same equipment at a concurrent sampling event. For circumstances that warrant, such as very deep wells or sites with co-contaminants, samples may be collected in duplicate with and without existing dedicated equipment. If PFAS analyses show that the equipment does not impact results, the equipment may be kept and used long term. However, this determination is dependent upon project-specific requirements and should be allowed by a project manager only with full disclosure to all stakeholders. It may also be acceptable to simply collect an ERB after fully decontaminating equipment containing PFAS components to confirm it does not contribute to groundwater sample concentrations. A site-specific procedure should be outlined in the QAPP or work plan.

The practitioner should determine that the sampling method is compatible with the site DQOs, including whether the method:

- collects site-specific analytes of interest
- is effective at the expected concentrations
- provides sample volume that meets the lab method requirements
- minimizes turbidity
- minimizes purge water
- is likely to include equipment with PFAS-containing components that contact the sample

Low-flow or passive sampling techniques are preferred for collection of groundwater samples for PFAS to keep the turbidity of samples and purge-water volume to a minimum. PFAS are mobile in groundwater and have relevant transport pathways, including advection and diffusion, that are similar to those for other contaminants (**Section 5.1.2**) and conducive to passive sampling (**Section 11.1.7.6**) in groundwater. See **Section 11.2.1.2** for issues associated with elevated levels of suspended solids in aqueous samples.

Bailers should be used with caution due to the potential for PFAS to accumulate at the air/water interface, because they may increase turbidity, and because of the potentially large volume of purge water produced. If bailers are used, it is important to make sure that at least three well volumes are purged to remove static surface conditions and potentially stagnant or aerated water. Volume-purge pump sampling for PFAS is discouraged because of the large amounts of purge water generated and the tendency to increase turbidity.

For background guidance on the use of passive sampling, consult the ITRC's technical guidance document (**ITRC 2024**) which provides guidance on passive sampling technologies in aqueous environments (see also **Section 11.1.7.6**).

Samples should not be filtered, because filters may be either a source for contamination (**Ahrens et al. 2009**; **Arp and Goss 2009**) or PFAS may be adsorbed to the filter. If filtration is absolutely necessary, it

should be performed in the laboratory, using a validated procedure that includes steps to eliminate the bias that can occur due to sorption issues. As an alternative, laboratory-validated procedures may include centrifuging the sample due to potential filter sorption or contamination issues. See Preparation of Aqueous Samples with Particulates/Suspended Solids in **Section 11.2.1.2** for more details. In addition, USEPA Method 1633A strongly discourages composite sampling for Clean Water Act compliance monitoring, stating that samples from sources that flow freely are to be collected as grab samples.

11.1.7.3 Surface Water

Surface water PFAS sampling should be conducted in accordance with traditional methods such as those described in USEPA's Compendium of Superfund Field Operations Methods (**USEPA 1987**) with consideration for guidance developed specifically for PFAS by Michigan EGLE (**MI EGLE 2024**) and New York Department of Environmental Conservation (**NY DEC 2023**). Depending on the study objectives, sample collection should consider the potential stratification of PFAS in the water body and the tendency for PFAS to accumulate at the air/water interface due to partitioning, which will be of particular concern if foam is observed on the surface (see **Section 16.5** on PFAS-containing foam). Transfer containers such as beakers or dippers, which may be attached to extension rods, should be used. For additional information on surface water sampling, see **Section 16.4**.

- Within the context of sample collection objectives outlined in a site-specific QAPP or work plan, the sample location in the water column should consider the potential stratification of PFAS in solution and their tendency to accumulate at the air/water interface (see **Sections 5.2.2.2** and **5.2.4.1**). If possible, the sample container or transfer container will be lowered sufficiently below the water surface but above the bottom sediments.

- Transfer containers, such as beakers or dippers, which may be attached to extension rods, should be used only if sample containers have preservatives. Sampling by direct sample container immersion is not recommended in this case.

- Consider using a grab-sampler that seals the sample inside the device at the sample interval and isolates the sample from contact with water above the sample collection interval as the sampler is being removed.

11.1.7.4 Sediment Porewater

Similar in many ways to sampling techniques and equipment used in groundwater sampling for PFAS, porewater purging and sampling involves a variety of materials. The various types of purging and sampling equipment available for porewater sampling are described in *Pore Water Sampling Operating Procedure* (**USEPA 2013**). For PFAS sampling, peristaltic pumps with silicon and HDPE tubing are typically used for porewater sample collection, along with push-point samplers, porewater observation devices (PODs), or drive-point piezometers. Push-point samplers and drive-point piezometers are made of stainless steel, while PODs consist of slotted PVC pipe and silicon tubing. PODs and drive-point piezometers are permanent, or dedicated, sampling points typically installed and used for multiple sampling events, whereas push-point samplers are used as a temporary sampling location. Otherwise, the standard procedure for porewater purging and sampling using a peristaltic pump, as described in the *Compendium of Superfund Field Operations Methods* (**USEPA 1987**), can be followed. There is information on the development and commercialization of various diffusion-based passive samplers that may be an option to sample porewater within sediment (see **Section 11.1.7.6**). Installing samplers at interfaces between coarse and fine materials can capture perched porewater (**ASTM 2018**, section 7.5.2.8). This is consistent with the modeling work by **Zeng and Guo (2021)** described in **Section 10.4.1** in which PFAS was predicted to be found in perched water above capillary barriers.

11.1.7.5 Soil Porewater and Potential Lysimeter Use

The accurate characterization of PFAS in soil porewater within the vadose zone could provide valuable data for understanding the soil-water distribution of PFAS and its impact on groundwater concentration (see **Section 10.4.1**). One method that has been discussed is the use of lysimeters.

Lysimeters are devices installed within unsaturated soils that sample porewater either actively under positive and/or negative pressure (suction lysimeters) or passively during periods of excess drainage (drainage lysimeters). Lysimeters are widely available commercially and have been used as part of environmental investigations for decades (**Singh et al. 2018**). Early guidance documents on lysimeter sampling include **USEPA (1986)** and **ASTM (2018)**.

Sampling of suction lysimeters should occur immediately after infiltration events such as rainstorms, spring melts, or irrigations to capture higher porewater and contaminant flow rates (**USEPA 1986**, section 4.8.1; **ASTM 2018**, section 7.5.2.8). Pan lysimeters, or nonsuction porewater sample collection devices, may be more suitable at sites where macropore flow is expected (**USEPA 1986**, section 4.8.2; and **ASTM 2018**, section 7.6.1.6).

Prior to installation, lysimeters should be cleaned per the vendor's standard operating procedure, preassembled, and tested for air leaks. Typically, PVC pipe (equivalent to the depths of the borings) is attached to protect the sample tubes. If potential contaminant interactions with lysimeters is a concern, a laboratory study may be performed before installing at a site (**USEPA 1986**, section 4.8.3.2).

Like grab samples, lysimeter samples represent a single-time result and should be qualified as such when evaluating impacts to groundwater over a season or from year to year. Although suction lysimeter samples are good for qualitative comparisons, they cannot be used for quantitative PFAS investigation unless the variabilities of parameters involved are established (**ASTM 2018**, section 7.6.2.1). These parameters may include measured concentrations of PFAS in soil and porewater, as well as pH, permeability, total organic carbon (TOC), and anion and cation exchange capacity (AEC and CEC, respectively) in vadose zone soil; seasonal changes; weather; precipitation; depth; and soil type(s). Also consider measured PFAS concentrations in nearby groundwater wells.

There are limitations to the application of lysimeters, including on sites with:

- shallow groundwater at depths of around 5 feet or less from the surface (consult the manufacturer)
- bedrock that outcrops to the surface
- too little precipitation to result in sufficient soil moisture at depth
- insufficient co-located soil sample data including, but not limited to, TOC, pH, particle size, moisture content, CEC, and AEC

11.1.7.6 Passive Samplers in Aqueous Environments

Each aqueous medium (groundwater, surface water, or wastewater) has specific conditions that affect the transport of PFAS. These conditions will affect decisions regarding the use of passive samplers and the specific device deployed in the field. The following are advantages for the use of passive sampling devices for PFAS in groundwater:

- The elimination or reduction of purge water disposal and other wastes.
- May reduce or eliminate turbidity as compared to pumped samples.
- May reduce both the short-term and long-term costs of sample acquisition.
- Can be used to collect a representative sample in low-yielding wells.

Hydrogeologic conditions required for passive sampling in groundwater (**Imbrigiotta and Harte 2020** include:

- Adequate water in the saturated screen interval or the targeted open borehole interval so that the sampling interval is submerged at all times.
- Saturated screens that are not chemically degraded or clogged.
- Adequate residence time for equilibration of hydraulic (well flow), chemical (contaminant concentration), and field physiochemical characteristics (for example, pH, dissolved oxygen).

In most cases with saturated screens/open boreholes 10 feet in length or greater, passive samplers are positioned at the depth of highest mass flux of the constituent of interest. When the interval of highest mass flux is not known, a one-time profiling event can be performed in representative wells using multiple passive samplers deployed at two or more intervals in the saturated screen. When considering transitioning from pumping to passive sampling in wells that have saturated screens 10 feet in length or greater, a favorable comparison of side-by-side results in representative wells suggests that water is being sampled from the same source location by both methods. When the results do not favorably compare, profiling for the interval of highest mass flux is appropriate.

A publication on the use of dual membrane passive diffusion bag (DMPDB) samplers™ for PFAS (**Varhol and Varhol 2022**) provides results from bench and field tests that show a positive correlation with lab controls and with field samples taken by pumping methods.

Passive sampling methods can be selected to provide time-weighted average (TWA), time-integrated average, or instantaneous temporal data, as well as spatial contamination trends. Passive sampling devices (PSDs) are relatively low cost, simple to use, and do not generate IDW. Some passive samplers can also provide a means of correlating an organismal exposure with a biological effect to determine the biological importance of chemicals sampled by the device (**Alvarez et al. 2021**; **Burki et al. 2006**; **Vermeirssen, Suter, and Burkhardt-Holm 2006**).

There are several different approaches to passive sampling, most of which can broadly be categorized into three types: accumulation, equilibrium, and grab-samplers.

- Accumulation (integrative) devices concentrate the target chemical on a selective collecting medium such as an adsorbent or absorbent solid, a solvent, or a chemical reagent. Target molecules continue to accumulate on the collecting medium during the exposure period and do not come to concentration equilibration with the surrounding medium. The resulting sample mass, or flux, is used to calculate a TWA concentration of target compounds over the exposure period (**Huckins, Petty, and Booji 2006**; **Taylor et al. 2021**).

- Equilibrium devices use a semipermeable membrane to contain a collecting medium, which is usually a solvent such as deionized water or uses a performance reference compound (PRC) to calculate a fraction of equilibrium. Target molecules diffuse through the selective membrane and move from higher concentration to lower concentration, in and out of the sampler to maintain a dynamic equilibrium with the surrounding medium. After meeting a minimum residence time, in accordance with the device's specifications and the DQO's of the project, the device can be retrieved. Certain samplers can also be left in place at one event and recovered at another. The resulting aqueous sample represents the TWA concentration of target contaminants of the last few days prior to sampler retrieval.

- Grab samplers are devices that acquire a whole media sample in surface water or groundwater, at a specific interval. Once the sample is acquired, the sampler closes to isolate the sample from the surrounding fluids during retrieval. The resulting sample is an aqueous concentration representing the point in time when the sample was collected.

Practitioners have evaluated and used a variety of methods and devices for sampling PFAS in aquatic environments (**Taylor et al. 2021**; **Imbrigiotta and Harte 2020**; **Alvarez 2010**; **Gong et al. 2018**). A number of PSDs are currently in use and others are being investigated for monitoring PFAS in aquatic environments (**Becanova et al. 2021**; **McDermett et al. 2022**; **Godlewska, Stepnowski, and Paszkiewicz 2020**; **Fauvelle et al. 2017**; **Kaserzon et al. 2012**; **Wang et al. 2021**; **Yang et al. 2022**; **Divine 2020**; **Varhol and Varhol 2022**). Before using any passive sampling device, practitioners should ensure use of the proposed sampler has been validated with respect to the evaluation of the site-specific analytes of interest and is acceptable by the applicable regulatory agency. Refer to ITRC's Passive Sampling Document for more information on specific devices (**ITRC 2024**).

11.1.7.7 Sediment

Most core and grab sampling devices are constructed of stainless steel. Some core samplers include an HDPE sleeve inserted in the core barrel to retain the sample. Ensure that materials that contact the media to be sampled do not have water-resistant coatings that contain PFAS. Additional PPE may be required for sampling personnel, such as waders and personal flotation devices. Ensure materials that will potentially contact sampling media do not consist of water-resistant coatings or other PFAS-containing materials or substances. Ensure efficient and consistent homogenization procedures are followed in the field. Refer to **Section 11.1.2** for typical materials used during sampling and drilling.

11.1.7.8 Surface Soil

For surface soil sampling, refer to **Section 11.1.2** for equipment and supplies, and **Section 11.1.5** for decontamination procedures. Ensure efficient and consistent homogenization procedures are followed in the field. No additional considerations are recommended for PFAS sampling of surface soil.

11.1.7.9 Subsurface Soil

Ensure efficient and consistent homogenization procedures are followed in the field. No additional considerations are recommended for PFAS sampling of subsurface soil.

11.1.7.10 Biosolids

Biosolids sampling methods will vary based upon the state and homogeneity of the materials to be collected. Additionally, as the materials are often gathered and stored over days to weeks, varying PFAS concentrations in feedstock can cause varying concentrations within the biosolids matrix unless sufficient mixing is performed.

If high liquid content materials are stored for several hours or days, solids will settle from suspension. Mixing of the storage vessel prior to sampling is essential to ensure collection of representative materials. Dipper, bailer, or pump methods can be used to collect the samples from the midpoint of the storage vessel. If mixing cannot be performed, collection of multiple, stratified, liquid samples followed by compositing may be appropriate.

High solids content materials can often be sampled using traditional compositing techniques. Once again, the accumulation of biosolids over extended periods of time with varying feedstock characteristics can result in potential nonhomogeneous distribution of PFAS within the matrix being sampled. Nonhomogeneity can be reduced through thorough materials mixing and/or use of a high number of grab samples to form a composite for analyses.

For additional information regarding biosolid sampling plans, refer to the NEIWPCC Guide to Biosolids Sampling (**NEIWPCC 2006**) and the NEBRA PFAS Sampling (**NEBRA 2020**) guidances.

11.1.7.11 Fish

The Priority Topics for Sampling and Analysis include information about fish sampling and laboratory homogenization (see **Section 1.5.2**).

The species of fish collected, as well as the portion of fish sampled (whole versus fillet), depends on the project goals (for example, ecological risk or human health). Studies have shown that the majority of the PFAS in fish are stored in the organs, not the flesh (**Martin et al. 2004**) (**Yamada et al. 2014**). Communicating project objectives to the laboratory is important prior to fieldwork to determine the necessary quantity and quality of tissue, fish handling requirements, laboratory sample preparation (including single fish or composite fish samples, and whole or fillet preparation), and packing and shipping requirements. According to USEPA Method 1633A, whole fish or other biota samples should be wrapped in aluminum foil or food-grade polyethylene wrap and homogenized tissue samples should be placed in HDPE containers.

11.1.7.12 Air Emissions to Air and Ambient Air

There is an increasing need for the measurement of PFAS in emissions from stationary sources (for example, chemical manufacturing, industrial use, combustion and thermal treatment and other treatment systems not originally designed to treat PFAS from exhaust), as well as in ambient air. Due to the diverse nature of PFAS, multiple measurement approaches are needed to measure polar and nonpolar, volatile, semivolatile, and nonvolatile (particulate-bound) PFAS.

Emissions to Air

As of the date of this publication, there are no multilaboratory-validated sampling methods for PFAS in air emissions (for example, from thermal treatment in manufacturing plants or incinerators). In their absence, emissions measurements have been performed using modifications to USEPA SW846 Method 0010 (Modified EPA Method 5 Sampling Train) (**USEPA 1986**), a method designed for measurement of semivolatile organic compounds. Other methods have been adapted to capture specific individual compounds of interest.

USEPA and European groups (Verein Deutscher Ingenieure [VDI], an association of German engineers) are evaluating and investigating which sampling and analytical methods might be, in principle, the most suitable to capture PFAS and resulting byproducts in all fractions of the emissions (particles, moisture, gas phase).

PFAS can be partitioned in stack emissions into several different fractions due to the physical properties of these species. At the elevated temperatures typically encountered in stack emissions the vapor pressure can be sufficiently high that some PFAS are present in the gas phase. The lower molecular weight fluorotelomer alcohols (FTOHs) have lower boiling points and so may primarily be present as vapors. PFAS can adsorb to particulate matter, are highly water soluble, and can dissolve in water droplets if present in the stack. To measure these partitioned fractions, the stack effluent is sampled isokinetically (that is, the air enters the probe at the same velocity as it is moving in the stack, to accurately sample particles and droplets) and captured on a heated filter, an XAD-2 (polymer of styrene divinyl benzene) sorbent resin tube, and in water impingers. In some test programs a second XAD-2 sorbent cartridge is included in the sample train to determine if breakthrough has occurred. The filter, sorbent cartridge, and water impingers are recovered separately, and the sample train components are rinsed with a methanol/ammonium hydroxide solution.

In 2021, USEPA released Other Test Method (OTM) 45 *Measurement of Selected Per- and Polyfluorinated Alkyl Substances from Stationary Sources* (**USEPA 2021**). In July 2024, USEPA released Revision 1 to OTM-45 (**USEPA 2024**). This performance-based method was made available by USEPA as a

recommended method that can be used to measure 50 specific semivolatile and nonvolatile polar PFAS from a variety of stationary sources. USEPA OTM-45 is largely based on the USEPA SW-846 Method 0010 (Modified EPA Method 5 Sampling Train) with several modifications. PFAS are collected in four sample fractions: 1) filter; 2) primary XAD-2; 3) impingers (containing water); 4) secondary XAD-2 (for breakthrough determination). Each fraction, with its associated rinses, is extracted and analyzed separately. Analyses are performed by isotope dilution LC/MS/MS. The analytical approach is based largely on EPA Method 533 and includes many of the same analytical qualification criteria, with the additional requirement of monitoring confirmatory secondary transition ions, similar to USEPA Method 1633A. USEPA OTM-45 was released as an "Other Test Method (OTM)" by USEPA's Emission Measurements Center to promote consistency and is considered by USEPA to represent the current best practices to sample and analyze PFAS from stationary sources. This method is under evaluation and will be updated as more data from stakeholders become available. Field sampling programs must include collection of field blanks as a means of assessing PFAS artifacts present in sampling media and potentially introduced during sample handling in the field. Other QC measures that should be considered include the use of isotopically labeled PFAS field spikes, which are useful for quantifying losses associated with field collection techniques. For a PFAS field spike, isotopically labeled spike compounds are typically applied/spiked by the laboratory into the XAD-2 sorbent media prior to field deployment. These compounds serve to assess analyte ("native PFAS in air") collection efficiency, breakthrough, and the accuracy of the combined sample collection and analysis method on a sample-specific basis.

In 2024, USEPA released OTM 50 *Sampling and Analysis of Volatile Fluorinated Compounds from Stationary Sources* Using Passivated Stainless-Steel Canisters (**USEPA 2024**). This performance-based method was made available by USEPA as a recommended method that can be used to measure a list of 30 specific volatile fluorinated compounds (VFCs) indicative of incomplete decomposition of some PFAS from a variety of stationary thermal treatment sources. This method also allows for the detection of additional VFCs and non-fluorinated volatile compounds via non-targeted analysis. Samples are collected using a 6-liter passivated silicon ceramic lined stainless-steel canister or equivalent. Samples containing low moisture (<3% volume/volume) or acid content can be sampled directly into the canister; otherwise, a moisture and acid management system comprised of a filter and impingers system similar to that which is included in OTM-45 is utilized. Like OTM-45, this method is under evaluation and will be updated as more data from stakeholders become available.

USEPA ORD is researching and evaluating multiple PFAS measurement approaches for polar and nonpolar, volatile, semivolatile and nonvolatile PFAS, including further development of USEPA OTM-45 for nonpolar PFAS. The development of an additional method, OTM-55, is currently underway by USEPA to measure nonpolar semivolatile and volatile PFAS, including fluorotelomer alcohols (FTOHs) and products of destruction (PIDs) using whole canister sampling and analysis. USEPA ORD is also evaluating the use of Fourier Transform Infrared (FTIR) spectroscopy to measure select volatile PFAS in real-time. Several of the PFAS capable of being measured are also being evaluated as potential indicators or surrogates of PFAS destruction performance.

Multiple PFAS emissions tests have been performed at a variety of sources for multiple purposes including source characterization, assessment of control technology performance, and evaluation of treatment technologies. Stationary source, or stack, emissions of PFAS have been measured in North Carolina (**NC DEQ 2019**) and New Hampshire (**NH DES 2019**) from industrial facilities that synthesized PFAS (Chemours, NC) or used PFAS in manufacturing processes (Saint Gobain Performance Plastics, NH) (**Beahm and Marts 2019**). These test programs confirmed that stack emissions from industrial facilities contribute to ground and surface water contamination (**NC DEQ 2019**). An additional study at Chemours, NC, reported on the commissioning of an installed thermal oxidizer control system (**Weston Solutions, Inc. 2020**).

Ambient Air

There are no USEPA Federal Reference Methods (FRM) or Toxic Organic Methods (TO series) available specifically for the measurement of PFAS in ambient air. In their absence, some sampling and analysis of ambient air have been performed using modified TO methods, such as TO-13A and TO-9 (**USEPA 2020**). Both methods use high-volume air samplers fitted with a particulate glass fiber filter/quartz fiber filter (GFF/QFF) and sorbent cartridge for the collection of particulate and gaseous phases, respectively. USEPA TO-13A specifies collection of air samples at a flow rate of approximately 225 liters/minute, resulting in an air volume greater than 300 m3. The solid sorbent used consists of a "sandwich" of polyurethane foam (PUF) and XAD-2.

PFAS in ambient air have been measured using both active (with actual flow) and passive (gas diffusion) sampling techniques. Most techniques have made use of solid sorbents such as PUF, XAD-2, and sorbent-impregnated PUF (SIP). (Finely ground XAD-4 resin is often the sorbent of choice for impregnating the PUF). Active samples also include a particulate filter (glass or quartz fiber) ahead of the sorbent module. To optimize detection limits, high-volume air samples have been used most often.

Detection limits of air and emissions methods can be greatly influenced by PFAS artifacts found in the neat filter, sorbent media, or components within the sampler itself. For example, use of Teflon gaskets in high-volume samplers is not recommended. Field sampling programs must include collection of field blanks as a means of assessing PFAS artifacts present in sampling media and potentially introduced during sample handling in the field. Other QC measures that should be considered include collection of field duplicate or co-located samples and the use of isotopically labeled PFAS field spikes. The latter compounds are typically applied/spiked by the laboratory into the sorbent media prior to field deployment. These compounds serve to assess analyte ("native PFAS in air") collection efficiency, breakthrough, and the accuracy of the combined sample collection and analysis method on a sample-specific basis.

Passive samplers should also make use of mass-labeled PFAS as a sample-specific quality control measure to account for native PFAS losses during each sampling event. Volatilization of labeled PFAS during the deployment period provides sampling rates on a site-specific basis and accounts for both temperature and wind influences.

USEPA and European groups (VDI) are evaluating and investigating which sampling methods might be, in principle, the most suitable to capture PFAS and resulting byproducts in all fractions of the emissions (particles, moisture, gas phase). An important consideration is that fluorinated polymers are used in common sampling equipment, which may cause contamination of the samples. For the purposes of PFAS determinations, this material must be replaced. In addition to concerns over using fluorinated polymers in sampling equipment being a source of contamination, there are also concerns about the potential for sorption of PFAS to fluorinated polymers, thereby effectively reducing the observed concentration, or affecting any attempt to quantify the phase distributions between condensed and non-condensed phases (for example. PM vs gaseous). This is related, in part, to the concerns about quantification of ambient air concentrations and distributions, as published by Johansson, Berger, and Cousins (**2017**), showing that the use of GFF (and chemically deactivated glass fiber filters) may irreversibly bind fluoro-carboxylates during collection of samples containing fluoro-acids, which can be in the gas phase depending on their vapor pressure and ambient temperature, and the corresponding carboxylates. This issue for ambient air appears to negatively impact the estimates of phase distributions and so far, may not have a technique that is applicable for quantitative recovery (no answer to this problem has yet been published). A related issue, though separate from the ambient sampling confounding issues, is that quantification of acids/carboxylates via LC/MS does not/cannot distinguish between these two oxidation states, which is important to the phase distribution in ambient air (and emissions to air). There are other techniques (GC/MS or Chemical Ionization Mass Spectrometry (CIMS)

(**Riedel et al. 2019**) that may help address these LC/MS deficiencies, particularly with regard to air measurements.

11.1.7.13 Human Blood, Serum, Tissue

There are no official or standardized methods for testing human blood, serum, or tissue. Laboratories and the Centers for Disease Control and Prevention (CDC) are in the process of developing best methods. A procedure developed by the CDC's National Center for Environmental Health has been published (**CDC 2016**). There are also several laboratories advertising this capability; however, the analytical methods and modifications from validated environmental laboratory protocols may not be consistent among these vendors. Human testing is outside the scope of this document; however reference points that could be used for comparison of whole blood or serum results to geometric mean serum levels generated from the U.S. population are included in the ATSDR ToxGuide for Perfluoroalkyls (**ATSDR 2020**).

11.1.7.14 Potential High Concentration Samples

The CSM or historical data may indicate areas of high concentrations of PFAS for which single-use, disposable equipment is recommended. If single-use is not possible, take additional precautions such as implementing a greater frequency of ERBs and not reusing equipment to sample potentially low PFAS concentration samples. High concentration samples may require smaller sample volumes to be collected for analysis. High concentration samples should be segregated during shipping to the laboratory, and clearly identified on the sample chain-of-custody form.

Some projects may require the analysis of AFFF product that has been used at the site. All AFFF product samples must be considered high concentration samples. The method DOD AFFF01 contains steps to prepare AFFF concentrate samples. This method requires that a dilution of a subsample of the AFFF concentrate be prepared for extraction. A critical step in this procedure is the amount of time that must elapse, a minimum of 3 hours (**Willey 2021**) from the time PFAS-free reagent water is added to the aliquot of AFFF concentrate to create the dilution to the time when extracted internal standard can be added to the diluted sample. It was determined during method development and validation that some AFFF concentrates can take up to 3 hours to fully dissolve in the reagent water. In addition, this method requires each AFFF concentrate sample to be prepared and analyzed in duplicate, using another aliquot of the collected sample. It is recommended that these samples be segregated from other samples during sampling and shipping to avoid cross-contamination and clearly identified on the sample chain-of-custody form.

11.2 Analytical Methods/Techniques

11.2.1 Quantitative Techniques

11.2.1.1 General

Analytical methods are still evolving for PFAS analysis. Several methods are multi-laboratory validated and published. Three multilaboratory-validated methods, USEPA Methods 537, Version 1.1 (herein referred to as USEPA 537), 537.1, and 533 have been published for analysis of drinking water samples (**USEPA 2009**; **USEPA 2020**; **USEPA 2019**) and two methods for non-drinking water matrices have been published. USEPA Method 1633A (**USEPA 2024**) has been published for analysis of groundwater, surface water, waste water, soil, sediment, biosolids, tissue, and landfill leachate. USEPA SW-846 Method 8327, has been published for analysis of groundwater, surface water, and wastewater samples. The DOD has published a multilaboratory validated method, DOD AFFF01 (**Willey 2021**), for the analysis of AFFF concentrates to demonstrate compliance to the military specification for AFFF (MIL-PRF-24385). The USEPA released OTM 45 (**USEPA 2021**) and OTM 50 (**USEPA 2024**) for measurement of PFAS in

emissions to air from stationary sources. Also in January 2024, USEPA released draft OTM 50 for measurement of fluorinated compounds in emissions to air from stationary sources by GC-MS.

- USEPA Method 537, Version 1.1 tests for 14 PFAS analytes
- USEPA Method 537.1 tests for 18 PFAS analytes (including 4 PFAS not included in USEPA Method 533)
- USEPA Method 533 tests for 25 PFAS analytes (including 11 not included in USEPA Method 537.1)
- USEPA SW-846 Method 8327 tests for 24 PFAS analytes (does not include all PFAS included in USEPA Method 537.1 or 533)
- USEPA Method 1633A tests 40 PFAS analytes (includes all PFAS included in USEPA Method 537.1, 533, and 8327 and 11 additional PFAS analytes)
- DOD AFFF01 tests for PFOA and PFOS
- USEPA Other Test Method (OTM) 45 tests for 50 specific semivolatile and nonvolatile polar PFAS
- ASTM D8421-22 Standard Method for Determination of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous Matrices by Co-solvation followed by Liquid Chromatography Tandem Mass Spectrometry (LC/MS/MS)
- Draft USEPA OTM 50 tests for 30 specific volatile nonpolar fluorinated compounds

Other methods have been published by other organizations. Lists of these methods, by various categories, are provided in the **PFAS Analytical Methods** Excel File in the **separate tabs**:

- External **Table 11-2**–Published Method Basics. Provides information on basic principles of each method (media type, validation status, method type, sample container requirements, holding time, preservation requirements, and analytical instrument.
- External **Table 11-3**–Published Methods Specifics. Provides more details of the methods such as sample preparation requirements, quantitation scheme, confirmation ion requirements, quantitation limits, and isomer profile.
- External **Table 11-4**–Provides summaries of the analyte lists for each of the methods. The method analyte list for each of these methods varies.
- External **Table 11-5**–Draft Published PFAS-Related Analytical Methods Basics. Provides information on basic principles of each method (media type, validation status, method type, sample container requirements, holding time, preservation requirements, and analytical instrument).

11.2.1.2 Sample Preparation

USEPA Methods 537, 537.1, 533, and 1633A, and DOD AFFF01 all require aqueous samples to be prepared using the solid-phase extraction (SPE) technique, but may use different solid-phase selectivities. USEPA Method 1633A and DOD AFFF01 both require cleanup procedures be used on extracts and all associated batch QC samples to help eliminate matrix interferences (for example, bile salts, gasoline range organics) that could be present. USEPA Methods 537.1 and 533, USEPA Method 1633A, and DOD AFFF01 all require extraction of the entire sample collected (in the case of DOD AFFF01, the entire prepared dilution), including a rinse of the sample container (in the case of DOD AFFF01, the dilution container).

USEPA SW-846 Method 3512 is for the preparation of groundwater, surface water, and wastewater samples by diluting the sample collected with an equal volume of methanol and does not require a rinse of the sample container to be included unless the sample had to be transferred to a larger container in order to allow for the addition of the appropriate volume of methanol. USEPA SW-846 Method 3512 does not use SPE or carbon clean-up steps, which is another significant difference from the other USEPA published methods. USEPA SW-846 Method 8327 states that during method development, some PFAS analytes showed a potential for loss during sample preparation or standard preparation using USEPA SW-

846 Method 3512. This method states that a minimum organic cosolvent content must be maintained in standards and samples, and it cautions against aqueous subsampling prior to adding sufficient organic solvent.

USEPA Method 1633A prepares groundwater, wastewater, surface water, and landfill leachates using solid phase extraction (SPE) followed by carbon clean-up steps to eliminate matrix interferences. USEPA Method 1633A uses solvent extraction for soil, sediment, biosolids, and tissue preparation, followed by use of SPE cartridges and carbon clean-up steps to eliminate matrix interferences. Regardless of the method used, care must be taken to prevent sample contamination during preparation and extraction because the limits of quantitation and detection are 1,000 times below (ppt) those for more routine analyses such as volatiles or semivolatile analysis (ppb). It is recommended that all supplies be checked and confirmed as PFAS-free prior to sample preparation. Intermittent contamination can occur due to vendor or manufacturing changes.

Some PFAS analytical methods, such as USEPA Method 533 and USEPA Method 1633A, use isotope dilution and extracted internal standard quantification schemes to calculate sample concentrations. Isotope dilution analysis (IDA) quantitation requires the use of extracted internal standards (EIS) that are the isotopically labeled analogs of the method analytes. Method analytes for which corresponding isotopically labeled analogs are not commercially available are quantitated using the isotopically labeled analogs of a method analyte of similar chemical properties. Since isotopically labeled analogs of PFOA and PFOS are commercially available, DOD AFFF01 uses isotope dilution quantitation. USEPA SW-846 Method 8327 uses an external quantitation scheme to calculate the percent recovery of isotopically labeled analogs that are added to the sample prior to dilution with methanol. This method does not use isotopically labeled analog recoveries to account for sample preparation and matrix interference biases in the sample result. All of the methods discussed above require these isotopically labeled standards be added to the sample at a designated point in sample preparation, depending on the sample matrix:

- aqueous samples–added to field samples while in the original container prior to extraction/dilution
- AFFF concentrates or high concentration aqueous samples – added to dilution of sample prior to extraction
- solid samples and biota–added after homogenization and subsampling, prior to addition of water or extraction solvent

Ensuring a representative sample/subsample for analysis is critical. For aqueous samples, the entire sample and rinsate of the sample container received by the laboratory must be extracted by SPE to recover any PFAS that adhere to the sample container. Filtration is not recommended for samples with high particulate content because retention of PFAS onto filters has been noted. Centrifugation is often used to reduce or separate out sample particulates. See Preparation of Aqueous Samples with Particulates/Suspended Solids below for more details.

USEPA Method 1633A requires the screening of all aqueous samples using a separate sample container from the one which will be used for sample preparation, absent project-specific requirements. Due to limitations in SPE cartridge capacity and potential contamination of sample preparation and/or analytical equipment, the method requires samples containing high concentrations of PFAS (for example, AFFF concentrates) to be diluted prior to SPE and sample clean-up. In these cases, sorption onto the original sample container is not an issue, depending on the identified project-specific DQOs, because the amount of PFAS adsorbed onto the container walls may be negligible compared to the amount of PFAS in the sample.

USEPA Method 1633A requires the entire soil, sediment, and biosolid sample that is collected be homogenized in the laboratory prior to subsampling. Tissue samples are to be prepared according to project requirements (for example whole fish versus fillet) and homogenized prior to subsampling.

Cleanup procedures can be used on extracts and all associated batch QC samples (for example, method blank and laboratory control samples) when matrix interferences (for example, bile salts, gasoline range organics) could be present. USEPA Method 1633A and DOD AFFF01 require carbon cleanup techniques to be used for all sample matrices. USEPA Method 1633A and DOD AFFF01 require samples to be slowly concentrated to remove methanol from the extract to avoid loss of neutral and other highly volatile method analytes. In addition, USEPA Method 1633A states that if methanol is not sufficiently removed, its presence during SPE can result in poor recovery of long-chain carboxylic acids and sulfonates. Care must be taken to avoid these outcomes.

The preparation batch QC samples that are required by these PFAS methods vary. Common laboratory QC sample nomenclature and typical use frequencies are as follows:

- Method blank – (one per preparation batch of 20 or fewer field samples) PFAS are ubiquitous and found in many analytical instrument systems, reagents, containers, and common laboratory environments. The method blank is a similar matrix as associated field samples and undergoes the same sample preparation procedure as the associated field samples. It is a vital indicator of the absence of PFAS contamination in laboratory equipment, supplies, and reagents. Note that method blank is also referred to as Laboratory Reagent Blank in EPA drinking water methods.

- Sample (or laboratory) duplicate – (minimum of one per preparation batch of 20 or fewer field samples) A sample that is prepared and analyzed in duplicate in a single laboratory to ensure the laboratory's subsampling procedures are capable of achieving a known level of precision as defined in the QAPP or work plan.

- Laboratory control sample (LCS), ongoing precision and recovery (OPR), or laboratory fortified blank (LFB) – (typically one per preparation batch of 20 field samples) Must contain all project-specific PFAS in similar media as the associated field samples and is used to evaluate bias associated with sample preparation as well as analytical processes.

- Low-level laboratory control sample (LLLCS) or low-level ongoing precision and recovery (LLOPR) – (one per preparation batch of 20 field samples) Must contain all project-specific PFAS at a specified concentration (for example, 0.5–2 times the LOQ for USEPA SW-846 Method 8327 or 2 times the LOQ for USEPA Method 1633A) in similar media as the associated field samples and is used to evaluate bias associated with sample preparation as well as analytical processes.

- Certified reference material (CRM) – (if available, one per preparation batch of 20 or fewer field samples) Unlike LCSs, which contain no matrix interferences, CRMs can be of significant value when dealing with complex matrices such as soil, sediment, and tissue.

- Matrix spike (MS) and MS duplicate (MSD) – (one pair per prep batch of 20 or fewer field samples) An MS/MSD is not needed if IDA can be used for all PFAS of interest because the EIS recoveries account for the influence of matrix interferences in each sample. If EIS standards are not available for a PFAS of interest, an MS/MSD may be warranted to assess the effects of matrix interference on that specific PFAS.

For samples with high concentrations of PFAS, it is recommended that an LCS duplicate and a sample duplicate are prepared in lieu of an MS and MSD. DOD AFFF01 requires the sample duplicate to be prepared using a different aliquot from the same sample bottle to create the sample duplicate.

Preparation of Aqueous Samples with Particulates/Suspended Solids

USEPA Method 1633A contains a procedure for determining the solids content of aqueous samples. This determination is to be performed using the second, smaller container that is required for each sample, not the sample container used to prepare the sample for the PFAS analysis. The sample preparation procedures for PFAS analysis in USEPA Method 1633A are applicable to aqueous samples containing less than 50 mg of solids. The method provides additional steps to take if particulates clog the SPE cartridge during extraction, including the use of additional SPE cartridges. Solids accumulate high concentrations of PFAS and specifically some of the longer-chain PFAS. Care should be taken to resuspend any solids and to rinse bottles so that measured concentrations reflect the entire sample.

When aqueous samples contain greater than or equal to 50 mg of solids, depending on the laboratory procedure, if the contaminant mass in the solids is not determined, the reported PFAS (fingerprint) could be inaccurate for effective comparison. Ultimately, the data user needs to work with the laboratory to determine the appropriate procedure to be performed, depending on the end use of the data (for example, remedial action, human health or ecological risk assessment, permit compliance, etc.). The project objectives may specify quantification of the total aqueous sample, water plus solids, or may only include evaluation of the aqueous fraction for end use as drinking water, where the solids will not be consumed.

A survey conducted in 2020 by ITRC received responses from 16 laboratories. These responses demonstrated that the laboratory community is *not* consistently preparing aqueous samples in the presence of suspended solids.

- Several laboratories centrifuge the samples and decant off the water portion for subsequent extraction.
- Some laboratories may also extract the remaining particulates and combine the extract with the aqueous extract. However, only one of the surveyed laboratories does this routinely; the others do this only if requested by the client.
- Routine laboratory procedures are not dependent upon whether the matrix is groundwater, surface water, or wastewater.
- Several laboratories filter the samples, if requested by the client. This may result in sorption of PFAS from the samples and potential cross-contamination, and should be implemented with care.
- After decanting, some laboratories rinse the remaining particulates in the bottle with solvent for the SPE.
- Not all laboratories disclose when samples require special preparation (decanting, centrifuging, or filtering) due to the presence of particulates. Therefore, this would not always be known to the data user.
- Laboratories have different procedures for when particulates clog the SPE cartridge; some labs may re-extract at a dilution, while others may start a new cartridge and attempt to continue with the extraction of the remaining sample.

Laboratories should clearly state whether reported concentrations are dissolved (water only) or “total” PFAS measurements (including sample particulates). The project team will determine whether dissolved or “total” PFAS measurements are appropriate to meet project objectives and confirm with laboratories that correct procedures are in place. Sampling procedures should be designed to gather representative

samples to meet project objectives. Some issues to consider in the determination of the need for a total or dissolved PFAS measurement are discussed in this section.

Groundwater

- If minimizing presence of particulates is within the project objectives, use of low-flow groundwater sampling or no-purge samplers should be considered.
- If turbidity is >10 NTU, consider a "total" measurement if sampling groundwater for compliance, delineation, remedial design, or risk assessment. "Total" can be defined as centrifuge, decant, and extract both phases, to report the dissolved concentration and the suspended/solid concentrations either individually or summed in the report.
- Collect samples for TSS analysis to assist in the evaluation of sample data. In lieu of TSS, turbidity measurements can also be helpful in the evaluation.

Drinking Water

- Particulates are not addressed in the drinking water methods.

Surface Water and Wastewater

- Use a "total" measurement if sampling surface water or wastewater for compliance, permitting, remedial design, or risk assessment.
- A "total" measurement may not be required if sampling for a line of evidence in a source area, rather than for a regulation.
- Collect samples for TSS analysis to assist in the evaluation of sample data. In lieu of TSS, turbidity measurements can also be helpful in the evaluation.

For laboratories performing centrifugation and subsequent decanting, it should be noted that it is important that the extracted internal standards are spiked into the aqueous samples prior to centrifugation. It is important to communicate with your laboratory prior to the collection of samples on the approach that will be used.

Biosolids

Biosolids sample preparation methods can vary based on laboratory-specific protocols, the moisture content of the sample, and/or client or regulatory requirements. Because of the variability in sample preparation methods for this matrix, communication with the laboratory prior to submitting samples is essential to understand the laboratory's options for sample handling and to ensure that the laboratory will meet the project objectives and/or regulatory requirements.

The following preparation methods are possible for biosolids and may be dependent on the laboratory's standard operating procedures.

- Typical solid sample extraction procedures (e.g., homogenization and solvent extraction) may be used regardless of the moisture content if there are visible or settleable solids. Because regulatory criteria for biosolids are typically established on a mass/unit mass basis (e.g., µg/kg), this may be an approach needed to satisfy regulatory requirements.

- If there are no visible or settleable solids, the laboratory may treat the biosolids sample as an aqueous sample (e.g., passing the sample through a solid phase extraction [SPE] cartridge).
    - When aqueous samples are treated as dissolved PFAS samples, laboratories may centrifuge the samples to separate out any solids or particulates. The aqueous phase would then be decanted and prepared using SPE.
    - Some laboratories may also extract the remaining solid/particulate phase after decanting using a solvent and then use the eluate of this solid sample to elute the PFAS off the SPE cartridge used to extract the aqueous phase, thus combining the aqueous and solid phases into one extract.
    - If samples are not centrifuged, solid particles may become entrained on the SPE cartridge and PFAS from these solid particles may be extracted during the methanol rinse. However, there is also a chance that the solid particles could cause clogging of the SPE cartridge, which would not allow for a complete extraction.

Laboratories may also be able to perform biphasic extraction and report results separately for the aqueous and solid phases.

11.2.1.3 Sample Analysis

Instrument Type–LC/MS/MS

All methods published by the USEPA and DOD for targeted PFAS analysis use liquid chromatography-mass spectrometry-mass spectrometry (LC/MS/MS), which is especially suited for analysis of ionic compounds, such as the PFSAs and PFCAs. Gas chromatography-mass spectrometry (GC/MS) can also be used for PFAS analysis, specifically the neutral and nonionic analytes, such as the fluorotelomer alcohols (FTOHs), perfluoroalkane sulfonamides, and perfluoroalkane sulfonamido ethanols. GC/MS may be appropriate for (ambient) atmospheric samples. PFAS are either directly detected using large-volume injection (**Scott et al. 2006**) or detected as a derivatized compound that is GC/MS amenable (**Langlois et al. 2007**). At this time, OTM 50 is the only published GC/MS method and there is very limited commercial availability for this technique for PFAS analysis.

In contrast, LC/MS/MS analysis of PFAS is widely available. LC/MS/MS is typically operated in multiple reaction monitoring (MRM) mode, which allows for selective monitoring of both the precursor and (potentially) unique daughter ions that are produced upon fragmentation in the mass spectrometer; this allows for specific and selective monitoring for compounds of interest. MRM is performed by specifying the mass-to-charge ratio of the compound of interest for fragmentation within the MS/MS. The precursor mass of the compound of interest undergoes MS/MS fragmentation, followed by monitoring for product ions. Ions arising from that fragmentation are monitored for by the MS/MS, which yields improved specificity and sensitivity.

Standards Preparation and Storage

Certified analytical standards are available from several manufacturers. Products may have variable purity and isomer profiles, which may compromise the accuracy, precision, and reproducibility of data. Certified standards of the highest purity available are standards that can be used for accurate quantitation. Standards manufacturers should provide a certificate of analysis (COA) with each standard, which provides the analyte concentrations and the purity information. Regarding expiration dates, laboratories should have their own policy in place for expiration date determination.

Quantitative standards containing linear and branched isomers are not commercially available for all applicable analytes. As of the date of this publication, quantitative standards are available for PFOA, PFOS, perfluorononanoic acid (PFNA), perfluorohexane sulfonic acid (PFHxS), perfluorooctane

sulfonamide (PFOSA), N-methyl perfluorooctane sulfonamide (NMeFOSA), N-ethyl perfluorooctane sulfonamide (NEtFOSA), 2-(N-methylperfluorooctanesulfonamido) acetic acid (NMeFOSAA), 2-(N-ethylperfluorooctanesulfonamido) acetic acid (NEtFOSAA), methyl perfluorooctane sulfonamido ethanol (NMeFOSE), and N-ethyl perfluorooctane sulfonamido ethanol (NEtFOSE).

Technical grade standards, or qualitative standards, that contain branched and linear isomers are available for other PFAS, but these standards do not have the accuracy needed for quantitation purposes. USEPA Method 1633A and DOD AFFF01 both require the analysis of technical grade standards to verify which peaks represent the branched isomers for method analytes when these standards are available.

Stock standards of PFAS analytes, internal standards, and surrogate standards supplied in glass ampoules by the manufacturer are acceptable. Manufacturers of the certified analytical standards often provide laboratories storage and shelf-life guidance for stock and working standards. USEPA Methods 533, 537.1, 8327, Method 1633A, OTM-45, and DOD AFFF01 contain storage requirements for both reagents and/or standards.

Steps to Help Eliminate Laboratory/Instrument Contamination (Verification of Supplies, Instrument Blanks, Isolator/Delay Columns)

Laboratory and instrument contamination is of particular concern for PFAS, given that the limits of detection are in the ppt range. Additionally, nonpolymer PFAS may be found at trace levels as impurities in some polymer products (**3M 1999**). PFAS are found in commonly used laboratory items such as PTFE products, solvent lines, and methanol, which could lead to method interferences and elevated baselines in chromatograms if not checked. The evaluation criteria for equipment and standards that is applicable depends on the analytical method used. For instance, USEPA Methods 537.1 and 533 recommend that all of the above items must be "less than 1/3 the MRL (minimum reporting limit) for each method analyte under the conditions of analysis by analyzing laboratory reagent blanks." (**USEPA 2020**, pg. 7). USEPA Method 533 further specifies that the isotopically labeled analogs of method analytes and isotope performance standards meet this same requirement (**USEPA 2019**, pg. 7).

Most vendors have a PFAS kit available that replaces as many PFAS-containing components as possible. In addition, the liquid chromatograph can be fitted with an isolator or delay column to separate contamination arising from the solvent delivery systems. This can reduce the contribution of PFAS from the pump apparatus to the analysis and reduce detection limits. Guard columns should be used to protect analytical columns.

Ion Transition Selection (Recommended Transitions for Primary and Confirmation Ions, Including Ratio Criteria)

Quantification by LC/MS/MS may be accomplished using a variety of techniques. For relatively simple matrices such as drinking water, USEPA Method 537.1 quantifies analytes by comparing the product ion of one precursor ion and retention time in samples to calibration standards. For more complex matrices, additional product ions and their ion ratios can be used to distinguish analytes from matrix interference. In an MS/MS system, most analytes can be fractured into more than one ion. By monitoring the area of each ion and comparing the ratio of those area counts, a more definitive identification can be made. This identification allows the analyst to distinguish true target analytes from false positives. This more detailed quantification is not required for drinking water matrices, but it is useful for more complex matrices. USEPA SW-846 Method 8327, USEPA Method 1633A, and DOD AFFF01 all require two ion transitions from precursor to characteristic product ions be monitored and documented for each analyte, with the exception of those analytes without a suitable secondary transition (for example, species with nondetectable or low signal secondary transitions, such as PFBA, PFPeA, PFMPA, and PFMBA). These methods determine ion transition ratio criteria by comparison with the analysis of analytical standards and use these ratios to evaluate potential bias in sample results.

Mass Calibration, Calibration Criteria, and Calibration Verification

All LC/MS/MS instruments require mass calibration prior to initial calibration. Mass calibration and mass calibration verification should be performed at setup, after performing maintenance that is required to maintain instrument sensitivity and stability performance, and as needed based on QC indicators, such as calibration verifications, as required by USEPA Method 1633A. Mass calibration should be performed according to the manufacturer's instructions. In addition to the manufacturer-specified mass calibration verification, the method also requires the accuracy of the ion masses monitored by the method be verified.

Following mass calibration and mass calibration verification, an initial calibration should be performed and verified. All of the published USEPA methods and the DOD method contain requirements for instrument calibration and calibration verification specific to the PFAS concentrations expected in the media for which the method is applicable. USEPA Method 537.1 uses internal standard quantitation, while USEPA Method 533 and USEPA Method 1633A use isotope dilution and extracted internal standard quantitation. USEPA SW-846 Method 8327 uses external calibration quantitation. Isotope dilution quantitation is recommended for complex matrices. The instrument is required to be calibrated at setup and as needed following QC failures, such as initial calibration verification (ICV) or continuing calibration verification (CCV) failure. The lowest calibration point should be a concentration at or below the Minimum Reporting Limit (MRL), Minimum Level (ML), or Limit of Quantitation (LOQ), depending on the method. Most methods require the analysis of a standard at the MRL, ML, or LOQ concentration at least daily to document the instrument's ability to accurately quantitate down to that concentration. In addition, some methods also require a reporting limit check QC sample (for example, LLLCS or LLOQ verification sample) to be included with each sample preparation batch to demonstrate adequate quantitation at the lowest concentration is achievable using the sample preparation techniques required by the method.

Some methods, such as USEPA SW-846 Method 8327, require analysis of an ICV, which is a calibration verification standard prepared from a source separate from the calibration standards and analyzed after each initial calibration and before sample analyses are performed.. CCVs or CVs should be analyzed at the frequency specified in the analytical method. Most USEPA methods require at a minimum a CCV/CV to be analyzed prior to sample analysis on days an ICV is not analyzed, after every 10 field samples, and at the end of the analytical sequence. Some methods rotate the concentration of CCVs/CVs to cover the entire calibrated range of the instrument and vary the acceptance criteria depending on the concentration. For example, in USEPA Method 537.1, the calibration acceptance criteria for each analyte at the lowest calibration point must be within 50–150% of its true value while the other calibration points must be within 70–130% of the true values.

Isotope dilution and extracted internal standard quantitation can correct bias resulting from loss during sample preparation, such as in USEPA Methods 533 and 1633A. In the case of USEPA SW-846 Method 8327, isotopically labeled analogs are used as surrogates to monitor for loss without being used for recovery-correction of target analyte concentrations. Isotope dilution is a quantitation technique that considers sample matrix effects on each individual PFAS quantitation in the most accurate and precise manner possible. This technique quantifies an analyte of interest against the isotopically labeled analog of that analyte, which is added to the sample prior to the onset of sample preparation. EIS quantitation is the comparable technique used when an isotopically labeled analog of an analyte is not commercially available. Addition of EIS prior to sample preparation helps account for loss of analyte during the preparation process and for bias associated with the instrumentation. Calibration criteria for methods using isotope dilution and EIS quantification schemes can be found in USEPA Methods 533 and 1633A. Methods using isotope dilution should include isotopically labeled analog recovery for each sample and analyte in data reports. Isotopically labeled analog recoveries should be reported, and minimum/maximum isotopically labeled analog recoveries may be required by specific analytical procedures. For instance, USEPA Method 1633A determines the recovery of these analogs through comparison to the response of analogs typically called non-extracted internal standards (NIS) added to

the sample after extraction and prior to analysis. Depending on project DQOs, low isotope recovery may indicate that quantitation was inadequate; the data are then reported as estimated values or not at all.

Instrument Blanks: When Are They Needed, Criteria, and Corrective Actions to Take

Due to the extensive use of PFAS, instrument blanks are critical in determining if the instrument is potentially affecting PFAS concentrations in samples. Some methods, such as USEPA Method 1633A, require instrument blanks to be analyzed following the highest calibration standard analyzed, daily prior to sample analysis, after each CCV/CV, and following samples that exceed the calibration range to ensure carryover does not occur. The acceptance criteria for instrument blanks are dependent on the method. For example, USEPA SW-846 Method 8327 requires the concentration of each analyte to be ≤ ½ the LLOQ or < 10% of the sample concentration. USEPA Method 1633A is the only method which states that if instrument blanks indicate contamination following the highest calibration standard, corrective action, such as calibrating with a lower concentration for the highest standard, must be taken and successful analysis of an instrument blank following the highest standard analyzed determines the highest concentration for which carryover does not occur.

Matrix Interferences

Aqueous

Interferences related to the matrix can be caused by the co-extraction of contaminants from the sample. These matrix interferences can have considerable variation from sample to sample. For example, there are problems associated with high total organics content (TOC) in water, which can cause matrix suppression of target analytes and lead to poor recoveries.

Tissue

Interferences related to the matrix can be caused by the co-extraction of bile salts (for example, taurodeoxycholic acid, taurochenodeoxycholic acid, and tauroursodeoxycholic acid) with PFOS from the tissue sample. These bile salts can vary considerably from sample to sample and by species. The use of carbon clean-up steps, such as those required by USEPA Method 1633A, helps eliminate these interferences in most extracts; however, when excessive amounts are present in the extract, these steps may only reduce the amount of these bile salts. To address the potential interference, USEPA Method 1633A requires that the chromatographic conditions are adjusted such that these bile salts elute at a retention time beyond 1 minute from the retention time window of PFOS. Since bile salts can be associated with other matrix types (for example surface waters and wastewaters), the method requires this chromatographic separation to be demonstrated with each analytical sequence, regardless of the matrix type of the sample.

11.2.2 Qualitative Techniques

The Priority Topics for Sampling and Analysis include information about ultrashort-chain PFAS analysis (see **Section 1.5.3**), consumer product testing (see **Section 1.5.4**), and field screening tools (see **Section 1.5.7**).

Several techniques employing indirect measurement have been developed that can more comprehensively assess sites for a wider range of PFAS contaminants than in the typical LC/MS/MS or GC-MS/MS methods. These qualitative techniques are not yet standardized through a published USEPA method and range in commercial availability. To date, these techniques have not undergone multilaboratory validation and tend to be inherently nonquantitative; accordingly, data from these methods may supplement, but not replace, the results of quantitative methods.

11.2.2.1 Overview of Qualitative Techniques

Because of the large number of PFAS and their varied structural characteristics, a single targeted method on either LC/MS/MS or GC-MS/MS may be unable to quantify all PFAS that may be present in a sample. When the release source is well understood and the types of PFAS present are both known and amenable to regular PFAS analysis methods (for example, LC/MS/MS of ionic PFAS or GC-MS/MS analysis of neutral PFAS), a targeted analytical approach may be sufficient to adequately characterize a release. For releases that are not well understood or consist of multiple sources, alternative ways of measuring PFAS in a more comprehensive but less targeted fashion may be desirable. Additionally, PFAS that are in polymeric form, such as those used in coatings for paper and textiles, are not amenable to LC- and GC-based separation techniques; they may also not be effectively extracted, even with rigorous methods.

Five primary techniques have been developed to characterize unknown PFAS in a sample. Only USEPA Method 1621 has been multilaboratory validated but none have been promulgated by USEPA. They are described in more detail in the sections below.

- The total oxidizable precursor (TOP) assay measures PFAA precursors.
- Particle-induced gamma-ray emission (PIGE) spectroscopy measures elemental fluorine isolated on a thin surface.
- USEPA Method 1621, Determination of Adsorbable Organic Fluorine (AOF) in Aqueous Matrices by Combustion Ion Chromatography (CIC) and extractable organic fluorine (EOF), also paired with CIC, measure the organofluorine content of a sample as fluoride on an ion chromatograph.
- High-resolution mass spectrometry techniques, such as quadrupole time-of-flight (qTOF) MS/MS, can tentatively identify PFAS structures through library matching or in-depth data analysis.
- Chemical Ionization Mass Spectrometry (CIMS) technique detects gas-phase PFAS, particularly fluorotelomer alcohols (FTOHs) and other oxygenated PFAS.

11.2.2.2 TOP Assay

Technique Description

The TOP assay converts PFAA precursor compounds to PFAAs through an oxidative digestion. The increase in PFAAs measured after the TOP assay, relative to before, is an estimate of the total concentration of PFAA precursors present in a sample, because not all PFAS present will be subject to quantitation or oxidation, and some will remain as undetected PFAS. The PFAAs generated have perfluoroalkyl chain lengths equal to, or shorter than, the perfluoroalkyl chain lengths present in the precursors (**Houtz et al. 2013**; **Houtz and Sedlak 2012**; **Weber et al. 2017**; **Dauchy et al. 2017**).

The TOP assay is a technique developed to estimate oxidizable precursors that can transform to PFAA end products that are included in the target analyte list (**Houtz et al. 2013**; **Houtz and Sedlak 2012**). A sample is analyzed using conventional LC/MS/MS to determine the baseline levels of PFAAs present in the sample. A separate aliquot of the sample is then exposed to a highly basic persulfate solution and then placed in a sealed container at an elevated temperature (for example, 85°C, in a water bath or other heating device) to thermolyze persulfate into a sulfate radical. At elevated pH, the sulfate radical is scavenged by hydroxide and forms a hydroxyl radical, which then converts the free PFAA precursor compounds to PFAAs. The predominant products (for example, > 95% in control experiments) of the precursors are the perfluoroalkyl carboxylates, whether or not the precursors contain sulfonamido or telomer functionalities. After sufficient time has elapsed to convert all the persulfate, the samples are removed from the heated environment (for example, a water bath), cooled to room temperature, and

neutralized prior to LC/MS/MS analysis. The increased concentrations of PFAAs generated after the oxidation step provide an estimate of the concentration of oxidizable PFAA precursors.

The technique can be applied to aqueous (**Houtz et al. 2013**; **Houtz and Sedlak 2012**; **Houtz et al. 2016**; **Weber et al. 2017**; **Dauchy et al. 2017**) and solid samples (**Houtz et al. 2013**). In most cases, samples need to be pretreated prior to oxidation to remove competitive organic compounds. For aqueous samples, dilution may be sufficient, although extraction techniques may be used to further remove matrix effects. Soil samples are extracted prior to persulfate treatment, and the extracts are cleaned with ENVI-Carb prior to treating the evaporated extract. The specific extraction procedure used may affect which PFAA precursors are retained for oxidation. For example, acidic extraction procedures may be required to remove cationic precursor compounds from soils (**Barzen-Hanson 2017**; **Mejia-Avendaño et al. 2017**).

Possible Technique Uses

The TOP assay may be used to estimate a total concentration of free PFAA precursors in a sample. In some cases, oxidation can be incomplete (**Ventia 2019**). The total PFAA precursor or total PFAS concentration is considered conservative for the reasons explained below in Technique Limitations. Because the method depends on a compound containing a perfluoroalkyl group, it is highly specific to PFAS. The chain lengths of the PFAAs generated after oxidation provide an indication of whether the precursors are predominantly short- or long-chained, although the production of a particular Cn (where "n" signifies the number of carbons in the alkyl chain) PFAA is not equivalent to the concentration of PFAA precursors containing the same chain length. However, if significant amounts of PFOA are generated after oxidation, that is an indication that the sample contains a comparable concentration of C8 or longer PFAA precursor compounds.

The TOP assay is the most widely commercially available of the qualitative techniques and is typically accepted as a means of determining PFAS load on remediation media to estimate the replacement cycle, but not for site characterization.

Technique Limitations

As mentioned above, the TOP assay does not differentiate between precursors that contain telomer or sulfonamide functionalities, because all these precursors are chemically oxidized primarily to perfluoroalkyl carboxylates. This is significant because a precursor that would likely form PFOS in the presence of a mixed consortium of aerobic bacteria will convert to PFOA under the conditions of TOP assay. The production of branched perfluoroalkyl carboxylates could be attributed to precursors derived from an ECF-based manufacturing process, but environmental samples may not contain the same distribution of branched and linear isomers as was originally generated from the ECF manufacturing process.

The TOP assay results in a mixture of PFCA products from the conversion of fluorotelomer-based compounds (**Houtz and Sedlak 2012**). For example, 8:2 FTS was converted to 3% PFNA, 21% PFOA, 27% PFHpA, 19% PFHxA, 12% PFPeA, and 11% PFBA in control experiments. Two limitations of the technique arise because of this effect. First, the production of PFOA, for example, is not equivalent to the C8 precursor concentration, because PFOA can be generated from longer-chain telomer compounds and is only a partial product of C8 telomer products. Second, some shorter-chain PFCA products of telomer compounds are not captured, depending upon the analytical methods used for measurement. For example, only 73% of 6:2 FTS was recovered, from a mass balance standpoint, as PFCA products PFBA and longer in control experiments (**Houtz and Sedlak 2012**). As a result, the TOP assay may under-quantify short-chain PFAA precursors, including those that are telomer-based. Sulfonamido compounds in control experiments did not exhibit a distribution of products; the Cn precursor forms the Cn PFCA in a 1:1 molar ratio.

Some studies have been published on the effectiveness of the oxidative process of the TOP assay on large molecular weight polymer compounds or newer ether-linked PFAS such as ADONA (**Zhang et al. 2019**). Because PFAS polymers have shown limited ability to biodegrade (**Russell et al. 2008**; **Russell et al. 2010**; **Washington et al. 2009**) relative to low molecular weight free PFAA precursor compounds (**Wang et al. 2005**; **Lee, D'eon, and Mabury 2010**; **Wang et al. 2011**; **Harding-Marjanovic et al. 2015**), the TOP assay may be similarly ineffective at converting PFAS polymers to free PFAAs. The TOP assay cannot be used to measure large molecular weight polymeric PFAS unless they are proven to break down in the assay.

For many samples, the TOP assay requires adjustments in dilution, sample preparation, or reagent dosing to achieve complete conversion of PFAA precursors. Standardized quality guidelines are needed to ensure that TOP assay data reflect full conversion of PFAA precursors.

11.2.2.3 PIGE

PIGE is a nondestructive analytical technique that takes advantage of the unique gamma-ray wavelength emission of fluorine when impacted with a proton ion beam. The technique is not compound-specific, but is able to assess total fluorine content of a variety of materials isolated on a thin surface (0.22 mm) (**Ritter et al. 2017**). The sample is secured in the instrument and bombarded ex vacuo under a 3.4 MeV beam with an intensity of 10 nA for approximately 180 seconds. Two gamma rays characteristic of the decay of the 19F nucleus (110 keV and 197 keV) are measured and the responses integrated. Quantification is achieved with comparison to fluorine-based calibration standards.

In the published literature, PIGE has been used to demonstrate total organofluorine concentrations in papers and textiles (**Ritter et al. 2017**; **Robel et al. 2017**) and in food packaging (**Schaider et al. 2017**). It has also been used on an experimental basis to evaluate organofluorine concentrations in extracted water and soils, but those results are not yet available in the peer-reviewed literature.

Possible Technique Uses

PIGE is a rapid screening technique to measure fluorine on surfaces. If a sample does not contain significant amounts of fluoride or can be prepared to remove inorganic fluoride, PIGE can become a technique specific for organofluorine; however, it is not specific for PFAS. It is a proven way to measure total fluorine in matrices containing high concentration of fluorinated polymeric material, which is a limitation of both the TOP assay and AOF. It also requires relatively minimal sample preparation to analyze fluorine content in commercial products. Sample preparation of environmental samples for PIGE analysis is likely to require a similar level of sample preparation, along with the limitations of extraction techniques, as the TOP assay or AOF.

Technique Limitations

PIGE is not specific to PFAS and, depending on the preparation, it is also not specific to organofluorine. The polymeric compounds that PIGE has been used to detect in consumer products may not contain perfluoroalkyl groups or may not be capable of breaking down to free PFAS. In addition, PIGE cannot distinguish between organic and inorganic fluorine; therefore, the presence of inorganic fluorine can cause results to be biased high.

PIGE also does not provide any differentiation on PFAS perfluoroalkyl chain length present in a sample. Depending on how the sample is prepared prior to the instrumental analysis, samples may be biased toward measurement of long-chain PFAS, as with the TOP assay and AOF.

Extraction methods for PFAS in environmental samples have not yet been demonstrated for this technique. When using SPE to extract environmental aqueous samples prior to PIGE analysis, cartridges

that are suitable to hydrophobic and anionic PFAS may not retain positively charged PFAS of interest. For soil samples, the extraction method also determines the PFAS likely retained. However, by using targeted extraction techniques for PFAS in environmental samples, the method becomes much more specific for PFAS.

The range of operating conditions for PIGE has not been standardized and so far, the technique has been demonstrated with only one academic laboratory.

11.2.2.4 Adsorbable Organic Fluorine with Combustion Ion Chromatography

USEPA Method 1621, Determination of Adsorbable Organic Fluorine (AOF) in Aqueous Matrices by Combustion Ion Chromatography (CIC) measures the fluorine content of environmental samples (**USEPA 2024**). An aqueous sample is passed through a carbon-based sorbent on which the fluorine-containing organics adhere. A nitrate wash of the sorbent is used to eliminate inorganic fluorine. The carbon sorbent is then combusted at high temperatures and the gaseous stream is passed through deionized water, which is then analyzed for fluorine content (as fluoride) by ion chromatography.

The AOF/CIC and EOF/CIC techniques have also been demonstrated on human blood samples (**Miyake et al. 2007**; **Yeung et al. 2008**) and various environmental aqueous samples (**Miyake et al. 2007**; **Wagner et al. 2013**; **Dauchy et al. 2017**; **Willach, Brauch, and Lange 2016**). Presumably, the method could be adapted to other types of matrices to measure organofluorine in soils or biota. The matrices could be extracted for PFAS, the extract resuspended into an aqueous solution that could adhere to the activated carbon, and then analyzed with CIC. As with the TOP assay, the specific extraction procedures would influence whether some or all PFAS are retained and ultimately measured as combusted fluoride product. Alternatively, it is possible that the technique could be used without extraction to directly combust organofluorine-containing products.

Possible Technique Uses

AOF can be used to measure PFAS or other fluorine-containing compounds as an aggregate organofluorine concentration. It can be a screening tool to determine if a significant concentration of fluorine-containing compounds is present in an aqueous sample or other sample from which the organofluorine content can be extracted. A pooled MDL of 1.5 µg f^-/L is listed in EPA Method 1621 as achievable by a well-prepared laboratory (**USEPA 2024**).

Technique Limitations

Like PIGE, AOF is not specific to PFAS. If a sample contains relatively high concentrations of chemical compounds that are not targets of the investigation (for example, fluorine-containing pharmaceuticals), then the organofluorine may be falsely attributed to PFAS content and bias “total PFAS” measurements high.

AOF does not provide any differentiation on PFAS perfluoroalkyl chain length present in a sample. Some short-chain PFAS may be unable to sorb to the activated carbon material that is combusted, but this will depend significantly on laboratory-specific procedures.

Extraction methods for PFAS in commercial products and solid samples, coupled with this technique, have not yet been demonstrated. A high concentration of inorganic fluoride concentrations may be challenging to remove from some matrices and would result in samples biased high for total organofluorine that was actually attributable to fluoride.

Like PIGE, the range of operating conditions for AOF-CIC has not been standardized. In addition to the limitations mentioned above, some matrices may contain sufficient competitive organics or other materials that coat the activated carbon to prevent complete retention of organofluorine compounds.

11.2.2.5 High-Resolution Mass Spectrometry

Technique Description

Quadrupole time-of-flight mass spectrometry (qTOF/MS) can be used to determine both the chemical formula and structure of unknown PFAS in a sample however, analytical standards are required for unequivocal structural identification. More information is available in **Section 11.4.3**.

High-resolution mass spectrometry has been used to tentatively identify the molecular formulas and structures of unknown PFAS (**Newton et al. 2017**; **Moschet et al. 2017**; **Barzen-Hanson et al. 2017**). Similar to targeted PFAS analysis, techniques such as LC or GC are used to separate compounds in a sample so that individual PFAS can be resolved. The mass is measured using a time-of-flight or other high-resolution detector, and the molecular formula is proposed. If an MS-MS technique is used, the fragments of the precursor compound can be used to piece together the structural arrangement of the compound. To identify compounds that are specifically PFAS, versus other organics present in the sample, compounds with negative mass defects (that is, the accurate mass is slightly less than the nominal mass) can be selected. Fluorine is one of the few elements that has a negative mass defect, and the inclusion of multiple fluorines in a PFAS molecule means that net mass defect of the molecule will likely be negative. Compounds that are either 50 or 100 mass units apart also identify homologous series of PFAS separated by one or two CF2 groups. MS libraries of previously identified PFAS exist for targeted matching, although they will not definitively identify an unknown compound.

Possible Technique Uses

Such high-resolution mass spectrometry analyses of PFAS can tentatively identify the structures of unknown PFAS and can also be used, in comparison with analytical standards of known compounds, to semi-quantitatively estimate their concentrations. Accurate identification of compounds using high-resolution MS is a time-intensive and expensive process. Therefore, a high motivation for knowing the exact PFAS structure, for instance in differentiating forensically between two different sources, may be the biggest driver of its use for PFAS analysis. High-resolution MS is best suited for media in which unknown PFAS are likely to be present in significant concentrations. When many other non-PFAS are present in the sample, the MS signal of competing compounds will likely obscure the signal of PFAS. Sample preparation steps can inadvertently or intentionally select for certain types of PFAS. As user skill and data interpretation time increase, accurate identification of PFAS is likely to improve.

Technique Limitations

High-resolution mass spectrometry cannot definitively identify the exact structure or formulas of PFAS without comparison to reference materials or analytical standards.

Not all PFAS, even if present in a prepared sample, can or will ionize under the conditions to which the instrument is tuned. A skilled instrument operator may be able to adjust the instrument conditions to match the types of compounds expected.

False positives are much more likely to result using high-resolution MS than with the TOP assay, AOF, or PIGE. Compounds may be mistakenly identified as PFAS, and even when correctly identified, their concentrations may be greatly over- or underestimated when other compounds are used for comparative quantitative purposes.

11.2.2.6 Chemical Ionization Mass Spectrometry

Chemical ionization mass spectrometry (CIMS) can be used to detect gas-phase PFAS, particularly fluorotelomer alcohols (FTOHs), and other oxygenated PFAS.

Although GC/MS has only been applied to PFAS analysis in stack emissions with the release of OTM-50, it is also particularly applicable to (ambient) atmospheric samples. Other than OTM-50, there are no published methods for using GC/MS for PFAS analysis, despite the distinct advantages for certain compound classes (for example, fluoro-telomer alcohols) of using GC/MS directly or after derivatization (chemical reaction to convert analyte of interest to a GC/MS-amenable "derivatized compound") (**Langlois et al. 2007**), or using large-volume injection (**Scott et al. 2006**).

11.3 Data Evaluation

Evaluation of data involves looking at all the factors that indicate whether the data are:

- precise (agreement between results that are supposed to be similar)
- accurate (how close they are to the true concentrations)
- representative (results characterize the site properly)
- comparable (data compare well to other data)
- complete (all the samples and compounds requested were reported, especially for critical samples that represent a point of exposure, such as drinking water)
- sensitive (nondetect data reported with concentrations below required regulatory or risk-based level)

These factors are illustrated in **Figure 11-1**, and guide users through the process of looking at their data (field collection and laboratory information) with a critical eye.

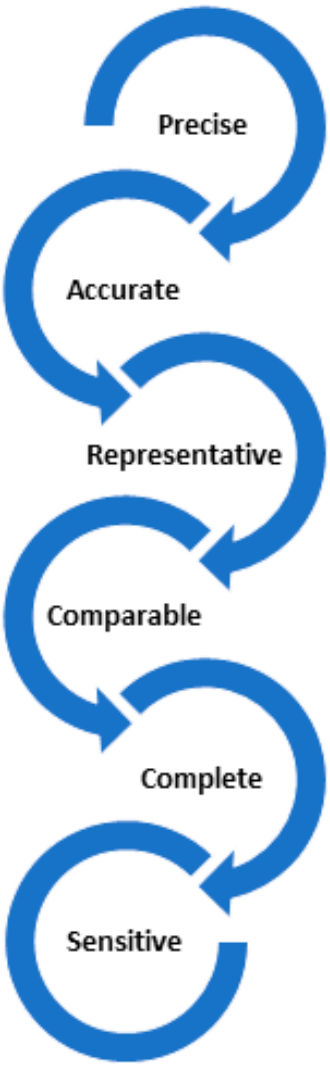


Figure 11-1. Data evaluation factors.

Source: H. Albertus-Benham, Wood Environment & Infrastructure, used with permission.

The USEPA has guidance to aid in evaluating PFAS drinking water data generated in accordance with USEPA 537 as well as a technical bulletin to aid in the review of PFAS data generated for all other media (**USEPA 2018**, **2019**). The USDOD EDQW has published PFAS Data Validation Guidelines, for evaluation of PFAS data generated in accordance with the *DOD/DOE Quality System Manual (QSM) Table B-24* (**USDOD 2022**). ASTM has published a Standard Guide for PFAS Data Evaluation (**ASTM 2025**).

11.3.1 Pre-sampling Planning

To ensure the usability of the data, communication with the laboratory that is performing the analysis is important. It is incumbent on the data user to collect information about the methodology to be employed by the laboratory. **Figure 11-2** contains laboratory considerations related to data usability in order to plan a sampling program.

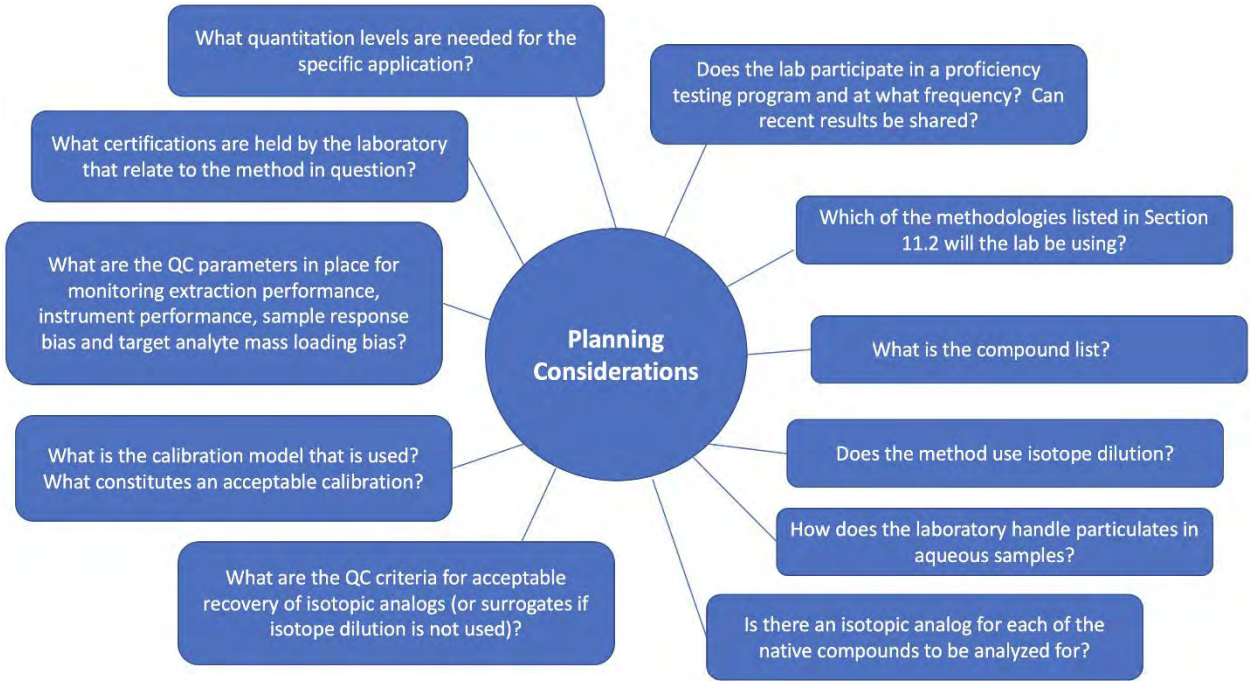


Figure 11-2. Laboratory planning considerations for data usability.

Source: Modified from figure by H. Albertus-Benham, Wood Environment & Infrastructure. Used with permission.

Throughout the rest of Section 11.3, pre-sampling planning will be indicated by these yellow call-outs.

The most important goal of data usability is to ensure that the PFAS data generated are usable to meet the stated data needs and that the user understands any limitations in the use of the data due to potential uncertainty or bias. Overall usability of data is judged by evaluating the quality of the results compared to the data quality objectives (DQO) of the project. Therefore, establishing these project DQOs and communicating them to the field sampling team and the laboratory prior to sample collection and sample analysis is vital to ensuring that the correct methods, correct compounds, and adequate sensitivity are reported for your samples.

11.3.2 Overall Usability of the Data

Three questions are most important in evaluating data: (1) Have the results exceeded a level of concern?, (2) Do these results make sense?, and (3) Are data of acceptable quality? To judge whether results have exceeded a level of concern, the potential bias or uncertainty in the data should be evaluated along with the sensitivity of the results. At a minimum, it is recommended that a report from the laboratory contains a cover letter (or narrative) explaining sample receipt, analytical methods, and any QC deviations plus data sheets for field samples and QC samples (method blanks, laboratory control samples, sample duplicates, matrix spikes), which should also contain results for sample-specific QC (such as internal standard recoveries). Often the most critical data for a project are the non-detects to prove the absence of compounds of concern at specific concentration levels (quantitation limits). Therefore, before evaluating QC associated with your samples, the data should be evaluated to ensure that all compounds required are reported with quantitation limits at or below the project's required sensitivity objective. If this sensitivity is not acceptable, then the data may be of very limited use.

If the reported compound list and quantitation limits are acceptable, then the associated QC results (for example, EIS recoveries, results of blanks, laboratory control sample recoveries, etc.) can be compared to

project DQOs to evaluate potential uncertainty in the data. The formal systematic process of this QC evaluation is called data review or validation. The approach to data validation is well documented; for example, see the USEPA National Functional Guidelines (**USEPA 2020**, **USEPA 2020**), and beyond the scope of this document; however, evaluation of all of the QC associated with the sampling and analysis of a set of samples will lead to an understanding of the uncertainty in the data.

Some critical QC issues might result in unusable data or concern for project actions. For example, if the data are considered biased low based on low QC results and the sample concentrations are at or near the level of concern or an action level, it may be that the true sample concentration exceeded the action level. Conversely, if the sample data are considered biased high based on high QC results and the sample concentrations are near but below the levels of concern or action level, then there is added certainty that the data do not exceed the action levels.

Once the data have been adequately reviewed for accuracy to determine if there are limitations to their use or uncertainties to be considered during use, the results should be evaluated by answering the following questions:

- Do field duplicates, if performed, indicate acceptable precision for the sampling and analysis?
- Do the data from the current sampling event compare well with historical data?
- Do the data make sense from a spatial and temporal point of view?
- Do the data make sense from a spatial point of view from one sampling point to the next across the project area?

Evaluating results may lead to overall project changes such as a need to increase sampling density to improve data representativeness, correction of procedures for collecting samples to minimize contamination, changes in methods of analysis to achieve project sensitivity requirements, etc.

This type of review can point out data trends or areas of concern (for example, interferences with project analytes) that could not be elucidated by looking at a single data point and may lead to overall project changes, such as a need to increase sampling density to improve data representativeness, correction of procedures for collecting samples to minimize contamination, changes in methods of analysis to achieve project sensitivity requirements, etc. Following this review, the data user can determine whether the data set is complete and sufficient for project decisions and data uses or whether additional samples need to be collected and analyzed.

11.3.3 Sensitivity

A quantitation limit (QL), or Limit of Quantitation (LOQ) is the limit of accurate quantitation for a specific analyte in a specific sample after any adjustments have been made for sample amount, dilutions, or percent moisture. Typically, the QL or LOQ concentration is selected as the lowest nonzero standard in the calibration curve for each analyte. It considers the sample size, matrix effects, and any dilutions made during the analysis of that particular sample. Because of varying properties between samples, the QL can vary from sample to sample and analyte to analyte. The QL should represent the level at which reliable qualitative and quantitative information is routinely reported (Table 11-3, included in the **PFAS Analytical Methods** Excel File). When project-specified decision levels or action levels are near the QL, at least one QL check is recommended in all sample batches to demonstrate adequate quantitation at the lowest concentration.

Sensitivity is related to the QL in that sensitivity refers to the capability of a method or instrument to identify a given analyte at a given concentration and reliably quantitate the analyte at that concentration. If a specified analyte is not reported by a laboratory to be in a specified sample, it does not necessarily

mean that the chemical is not present; it is an indication that the concentration of the analyte may be below the method sensitivity.

Detected PFAS results between the method detection limit (MDL) and QL (that is, "J" values) can generally be reported if all qualitative identification criteria are achieved. Typical QLs for PFAS are as follows:

- common PFAS analytes in aqueous matrices: 1–16 ng/L (ppt)
- common PFAS analytes in solid matrices: 0.16–1.6 ng/g (ppb)

It is imperative that the QLs (and not the MDLs) for each method are evaluated versus the project screening criteria prior to submitting samples to the laboratory. The QLs should be below the project screening criteria to ensure achievement of project objectives.

Sometimes even though lower QLs were planned for, the laboratory may have to perform dilutions, which causes the QLs to be elevated. Ensure that the dilution performed by the laboratory was reasonable. If there are elevated concentrations of specific target analytes or interferences, then the dilution is likely justified and the presence of elevated QLs may not be an issue if these other target analytes are present at very high levels.

If a dilution was performed and it is not obvious why (for example, low concentrations or nondetect results for target analytes), then inquire with the laboratory why the dilution was performed. This could happen due to elevated concentrations of non-target compounds but should be documented.

The QLs can also be affected by the sample preparation parameters, the mass of solid sample or volume of aqueous sample used in the extraction, or the final volume of the extracts. If a complex matrix is encountered, the sample sizes may be reduced and/or the extract volumes may be increased, causing the QL to be elevated accordingly.

11.3.4 Target Analyte Lists

The data user should work with the laboratory to ensure that the correct list is being reported, as dictated by the project objectives and regulatory compliance.

Target analyte lists for PFAS will vary by laboratory and regulatory program. The data user should work with the laboratory to ensure that the correct list is being reported, as dictated by the project objectives. In general, Table 11-4 (included in the **PFAS Analytical Methods** Excel File) includes the common PFAS reported by existing laboratories. The selected list may be dependent upon project objectives, regulatory requirements, as well as the potential source of PFAS contamination (for example, AFFF, landfill, chromium electroplating). Note that a published method may not include analytes important to characterization of a particular matrix, for example, diPAPs for biosolids characterization (**Dickman and Aga 2022**).

11.3.5 Linear and Branched Isomers

It is also important to note that PFOS and PFOA (and other PFAS as well) contain a mixture of linear and branched isomers, which can be significant when the laboratory is quantifying these chemicals. Very few standards are available for branched isomers; some standards are for qualitative evaluation and some are quantitative. If branched isomers are not included in the sample quantitation by the lab, the resulting concentrations will be underestimated.

In general, all laboratories should be reporting the sum of the linear and branched isomers for PFHxS, PFOS, PFOA, PFNA, PFOSA, NMeFOSE, NEtFOSE, NMeFOSA, NEtFOSA, NMeFOSAA, and NEtFOSAA because these are the PFAS for which both linear and branched analytical standards are available as of this publication. In the absence of a standard that includes branched isomers, only the peak associated with the linear isomer is integrated. As more analytical standards become available, more PFAS should be reported as linear and branched in the future.

Figure 11-3 shows an example of the integration performed correctly and incorrectly. It is the responsibility of the data user to ensure that the laboratory is performing the integration of the target PFAS to include both linear and branched isomers. This requires upfront communication with the laboratory and a possible independent review of the laboratory raw data by a qualified chemist/data user to verify the integrations were properly performed.

Ensure that the contracted laboratory is performing the integration of the target PFAS to include both linear and branched isomers.

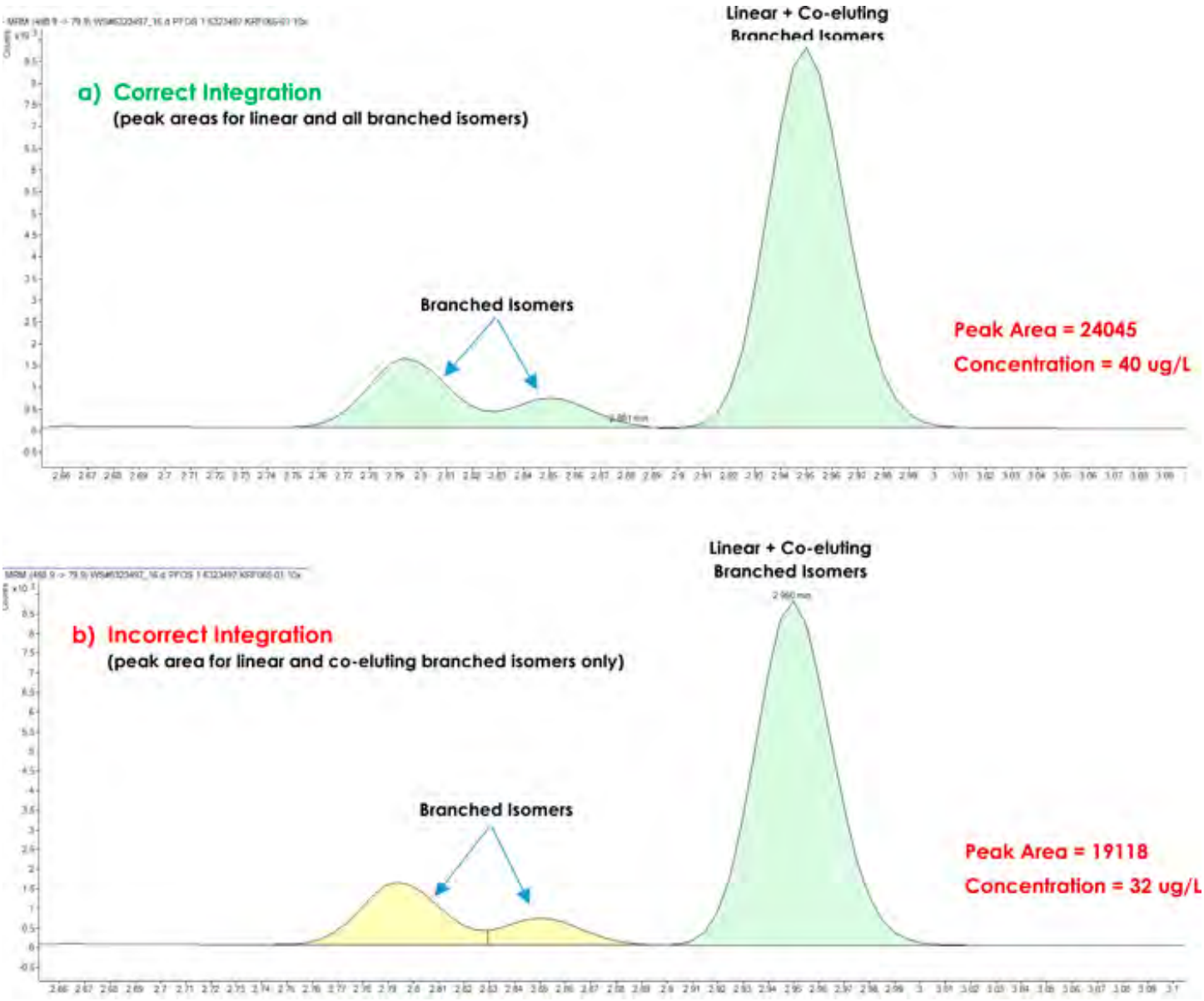


Figure 11-3. LC/MS/MS data illustrating a) complete integration of linear and branched PFOS, and b) partial integration of PFOS. Discrepancies in concentration will depend on the fraction of branched versus linear PFAS present, but in the current example PFOS concentrations in b) were 20% lower than in a).

Source: Bureau Veritas Laboratories, Mississauga, Ontario, Canada. Used with permission.

11.3.6 Isotope Dilution Standard Results and Surrogates

Isotope Dilution Standards

The isotope dilution technique involves quantitation of a compound of interest using a labeled isotope of that very compound. A variety of isotopically labeled analogs (for example, carbon-13 analogs of the compounds of interest) are added to a sample prior to extraction or prior to analysis when extraction is not required. These isotopically labeled analogs are sometimes referred to as extracted internal standards, as defined in USEPA Method 1633A, or isotope dilution analogues, as defined in USEPA Method 533, and function from a data usability standpoint as both an internal standard (used in the calculation of the target compounds) and as a surrogate standard (calculation of the recovery of the standard). Ideally, the number of isotopically labeled analogs used in the isotope dilution technique matches the number of target compounds. Non-extracted internal standards, as defined by USEPA Method 1633A, or isotope performance standards, as defined by USEPA Method 533, are also added to the sample or extract immediately preceding analysis and are used to calculate recovery of the extracted internal standards.

For the isotope dilution methods, quantitation of the target compounds is performed relative to the response of the isotopically labeled analog, which should recover in a manner similar to how the nonlabeled compounds recover. Effectively, the sample data are recovery-corrected for losses that might have occurred during sample processing. The isotope dilution recovery correction procedure greatly improves the accuracy of the analysis and is an improvement over other techniques for the analysis of complex samples for analytes requiring high sensitivity. Chemical standards manufacturers are working to make a wider variety of labeled isotope compounds available to further improve accuracy of the methods for all compounds under investigation (for example, fluorotelomers, precursors, various isomers of carboxylates and sulfonates).

Acceptance criteria or control limits for isotopically labeled analog recoveries are either developed by the laboratory or dictated by the requirements of the project (for example, work plan or QAPP-specified criteria, regulatory criteria, or method criteria). Poor recovery of EIS in complex matrices is common; however, if a project requires ongoing analysis of a problematic matrix, the laboratory should perform method development to improve recovery, if possible (for example, change in cleanup procedures, change in the transition ions monitored, etc.). If EIS recovery is very low (for example, < 10% recovery), nondetections associated with the EIS may be false negatives and may not be useable for project objectives. If EIS recovery is low but ≥10%, there may be an indeterminate bias for the affected PFAS. If EIS recovery is high, there will be no effect on non-detects, but positive results for PFAS may have an indeterminate bias.

In the case where an isotope dilution extract is analyzed and requires re-analysis at a high dilution, the sample extract may need to be refortified with labeled isotope compounds or, if possible, a smaller aliquot of sample may need to be extracted to obtain adequate responses of EISs. In reporting the final data, the isotope recovery results from the initial analysis should not be used to adjust the data from the secondary dilution analysis because these recoveries may be affected by ion suppression or ion enhancement due to the elevated concentrations of target PFAS and therefore may not be reflective of the extraction efficiency or other matrix interferences. The result from this scenario is no longer quantitated from an isotope dilution but is calculated from an internal standard calculation and should be noted as such in the case narrative.

Surrogates in Non-Isotope Dilution Procedures

Method 537.1 uses four surrogates for 18 target compounds, while EPA Method 8327 uses 19 surrogates for 24 target compounds. Injection internal standards are also added to the sample extract immediately preceding analysis. Quantitation of the target compounds and surrogates is performed relative to these

injection internal standards. The results from the non-isotope dilution technique report concentrations of the target compounds and recovery results for surrogates, and it is up to the data user to determine the impact (that is, bias) of the extraction and analysis on the sample results because results are not recovery-corrected.

Acceptance criteria or control limits for surrogate recoveries are either developed by the laboratory or dictated by the requirements of the project (for example, work plan or QAPP-specified criteria, regulatory criteria, or method criteria). Poor recovery of surrogates in complex matrices is common; however, if a project requires ongoing analysis of a problematic matrix, the laboratory should perform method development to improve recovery, if possible (for example, change in cleanup procedures, change in the transition ions monitored, etc.). If the recovery for a surrogate is below criteria, compounds associated with this surrogate may be biased low. If surrogate recovery is very low (for example, < 10% recovery), nondetections associated with the surrogate may be false negatives and may not be useable for project objectives. If surrogate recovery is high, there will be no effect on non-detects but positive results for PFAS may be biased high.

11.3.7 Blank Contamination

As a consequence of the extensive use of PFAS, samples that may not contain PFAS can become contaminated if they come into contact with samples or materials containing PFAS. The types of blanks commonly used to evaluate contamination are field-based blanks and lab-based blanks. Field-based blanks include field reagent blank (field blank), source water blank, and equipment rinse blank. Laboratory-based blanks include method blank, lab reagent blank, and instrument blank. Reagent, source, field, and method blanks are prepared and analyzed using the same procedures as for the field samples. Instrument blanks are analyzed periodically to verify the instrument is clean for analysis of subsequent samples.

The possible sources of contamination that may occur during field collection activities and sample preparation and analysis and the recommended procedures to minimize contamination have been previously addressed in Section 11.1.

The lab reagent blank is used to evaluate the potential PFAS contamination from the reagent water source used to generate the field-based and laboratory-based blanks. A systematic review of all of the blank results compared to the associated field sample results (the group of samples associated with the field-based and lab-based blanks, or the analytical batch of samples associated with a specific method blank) must be made to determine whether the field sample results are accurate. For example, if the reagent water source used in the field is nondetect for PFAS, but contamination is found in any of the other field-based blanks, this indicates potential contamination of the associated field samples from the sample bottle itself and/or during collection, handling, or transport to the laboratory. However, if a laboratory-based blank is also contaminated, the contamination observed in the field-based blanks may have been due to sample handling at the laboratory.

If the conclusion of this systematic blank data review is that an associated sample result may have been contaminated, then the sample result is considered to be biased high or may be a false positive, depending on the magnitude of the blank contamination compared to the field sample result. A general rule of thumb is that if a sample contains a contaminant within 5x–10x the concentration in the associated blank, the results may be biased high or result in a false positive in the sample (**USDOD 2019**).

11.3.8 Duplicate Results

Laboratory replicates are two separate aliquots of the same sample prepared at the laboratory and put through the entire sample preparation and analytical procedures. Field duplicates are two separate samples collected at the same location at the same date and time that are prepared and analyzed in the same manner. Laboratory replicates may be performed in lieu of an LCS duplicate or MSD. It should be noted that sometimes laboratories report the results of laboratory replicates performed on samples that

are from a different project (that is, batch QC); if the laboratory replicates reported are not from a sample at the site of interest, then these results should not be used in the evaluation of sample data.

During data evaluation, the relative percent difference of each detected analyte versus the acceptance limits should be reviewed. The acceptance limits should be provided within the laboratory report and are either regulatory- or method-specific. When both results are < 2x the QL, the potential uncertainty increases, and therefore, the acceptance criteria may need to be adjusted.

Review regulatory or method-specific acceptance limits with the laboratory, whether from a QAPP or laboratory-generated.

- If both results are < 2x the QL, relative percent difference criteria can be doubled.
- If one result is detected and one result is not detected, then the evaluation will depend on whether the detected result is > 2x the QL or not. If one result is > 2x the QL and the other result is nondetect, then the variability is considered unacceptable and there may be potential uncertainty in the results for this sample.

Variability in laboratory replicate and field duplicate analyses could be from the sampling process, such as inefficient homogenization procedure in the field. It could also be from the laboratory aliquoting process, or it could be due to heterogeneity in the sample matrix. The effect on project objectives will depend on the screening criteria and how far above or below these criteria the results are. If the results are close to the criteria with significant variability, this may require collection of more samples to better represent the location. If results are significantly above or below the screening criteria with high variability, it may not adversely affect the ultimate decision-making process.

11.3.9 Acid Versus Anion Form of PFAAs

The data user should be aware of the form of PFAS the laboratory is reporting when comparing to project screening criteria. PFAS are typically formulated as acids, but they are present in the environment and in humans in the anionic form. The differences in names used are the result of the different names for the acid form and the **anion** form of the chemical (see also **Section 2.2.3.1**). For example, when perfluorobutanoic acid (PFBA) disassociates and loses its hydrogen in water, it becomes the anionic form (perfluorobutanoate). This becomes more important when looking at physical and chemical properties of these chemicals, because whether they exist as an acid, an anion, or a salt will affect how they behave in the environment. Typically, laboratories are reporting the acid form of the perfluorocarboxylic acids and perfluorosulfonic acids.

Some target PFAS, such as PFHxS and PFOS, are not available as acids, but rather as their corresponding salts (for example, K^+, Na^+, and Li^+). These salts are acceptable starting materials for the stock standards, provided the measured mass is corrected for the salt content according to the equation below. Note that this correction will result in a minimal change to the mass of the acid but still should be performed for consistency and comparability with other results to ensure the data user that the correct form of PFAS is represented in the final concentration.

$$mass_{acid} = \text{measured } mass_{salt} * (MW_{acid}/MW_{salt})$$

MW_{acid} = molecular weight of PFAA

MW_{salt} = molecular weight of purchased salt

CAS numbers will change depending on if the acid, anion, or salt form of the PFAS is reported (**Table 11-7**).

Table 11-2. Example of CAS number differences between acid and anion.

Chemical	CAS number
PFOA: Perfluorooctanoate (anion)	45285-51-6
PFOA: Perfluorooctanoic acid (acid)	335-67-1

11.4 Source Identification

As discussed in **Section 10.5** and **Section 1.3.7**, one area of focus for PFAS investigations has been environmental forensics, specifically source identification. With so many industrial processes and transport pathways from which PFAS contamination can originate, attributing the occurrence of one or more PFAS to a particular source is of growing interest.

Source identification relies on the compilation of multiple lines of evidence from analytical data and site information, and the use of uni- and multivariate statistical analyses. Analytical lines of evidence include:

- Extended Target Lists
- Linear/Branched Speciation
- Non-Targeted Analysis (NTA)

These methods are briefly described in this section.

11.4.1 Extended Target Lists

Many commercial laboratories now analyze for more than 40 individual PFAS and some of these compounds may be indicative of a particular product or industrial process. Analyzing samples taken from or near these possible sources and comparing the profiles of those results to the area of concern, also known as chemical fingerprinting, may provide a demonstration of comparability.

11.4.2 Linear/Branched Speciation

The separate reporting of branched and linear PFAS can provide some indication of the process used to synthesize the PFAS detected. Electrochemical fluorination (ECF) produces a larger number of branched isomers than fluorotelomerization, which may be useful in differentiating sources (**Benskin, DeSilva, and Martin 2010**). Separate reporting of branched and linear PFAS is not typically the default laboratory reporting and should be requested in advance. However, due to isomer-specific differences in instrument response, and fate, transport and organism uptake/depuration, the use of speciated data for any inference more than presence/absence of a manufacturing source type is challenging.

11.4.3 Non Targeted Analysis (NTA)

The ability to identify compounds not targeted for measurement by existing methods is an important need. NTAs are critical to being able to identify these compounds. With NTAs, chromatography (liquid and gas) is combined with high resolution mass spectrometry and multiple ionization techniques to determine atomic molecular weight and associated fragments. These results can be compared to databases for tentative identification (**Liu et al. 2019**). Further spectral interpretation may result in structural identification. This is particularly useful where no chemical standards exist.

NTA includes high-resolution mass spectrometry and suspect screening and is discussed in more detail below.

11.4.3.1 High-Resolution Mass Spectrometry for Nontargeted Analysis

Although not widely commercially available, recent source research has focused on the use of high-resolution mass spectrometry (HRMS) for more comprehensive qualitative determination and fingerprinting for source attribution. See additional information in **Section 11.2.2.5**.

Many PFAS exist with no certified reference standard to make an initial calibration plot. As such, non-targeted PFAS may be present in samples that will not be identified or reported on a standard target analyte list, unless requested. HRMS is emerging as a means for discovery and reporting of non-targeted PFAS where each unknown peak may be tentatively identified and quantified at estimated concentrations. Non-targeted analytes can be reported by the identification of fragmented organic molecular ions (m/z) that are matched to an analytical reference library. The reporting includes detection of homologous series with or without the presence of nonfluorinated functional groups that create mass defects. Mass defect is the difference between the nominal and exact mass of an atom, which allows prediction of molecular formulas and is the key advantage to using HRMS for NTA. **Liu et al. (2019)** categorized PFAS into the main classes of:

- Per/polyfluoroalkyl carboxylic acids
- Per/polyfluoroalkyl sulfonic acids
- Fluorotelomers and per/polyfluoroalkyl sulfonamides
- Per/polyfluoroalkyl phosphates
- Per/polyfluoroalkyl alcohols
- Per/poly-fluoroalkylamides
- Per/polyfluoroalkyl sulfates
- N-per/polyfluoroalkyls

Tables are available on the NORMAN Suspect List Exchange (**https://www.norman-network.com/?q=node/236**). **Charbonnet et al. (2022)** defined the basic homologue series by CnF2n+1, where n > 2 with isomeric PFAS of the same chemical formula differentiated as structural isomers that may be linear, branched in the perfluoroalkyl tail or the head group, or have varying functional groups that could create mass defect.

As evidenced by SERDP-ESTCP funded projects listed below, the development of mass spectral libraries to match non-targeted analytes to source profiles is part of ongoing research. NTA uses HRMS such as time-of-flight (TOF), ion-trap, or Fourier transform ion cyclotron resonance (FT-ICR) to generate high resolution accurate mass data. As extensive data sets are generated using HRMS, informed data filtering approaches are used to filter the data specific to PFAS related analytes. The data are first screened against previously generated suspect screening libraries that contain chromatographic/spectrometric information for PFAS characteristic to sources such as AFFF formulation, industrial process, and/or manufactured products. Then, mass spectrometry-specific data analyses, such as Kendrick mass defect plots, and general uni- and multivariate statistical analyses, are used to attempt source identification based on the presence/relative abundance of PFAS identified against the suspect screening libraries and other information (**Benotti et al. 2020**; **Charbonnet et al. 2021**).

The Interstate Technology and Regulatory Council (ITRC) Contaminants of Emerging Concern (CEC) Team fact sheet on Adoption of Analytical Methods for Identifying CEC provides additional details on non-targeted analyses, including mass spectral libraries used and determining the confidence in compound identifications (**ITRC 2023**).

Secondary Sources

SERDP PFAS Novel Methods for PFAS Source Tracking and Allocations

https://www.serdp-estcp.org/News-and-Events/Blog/Novel-Methods-for-PFAS-Source-Tracking-and-Allocations

ER20–1375 Comprehensive Forensic Approach for Source Allocation of Poly- and Perfluoroalkyl Substances – Chris Higgins, Colorado School of Mines

ER20–1121 Establishing an Approach to PFAS Forensics and a PFAS Source Materials Forensic Library – Mark Benotti, NewFields Government Services

ER20–1205 Machine Learning Pattern Recognition for Forensic Analysis of Detected Per- and Polyfluoroalkyl Substances in Environmental Samples – Tohren Kibbey, University of Oklahoma

ER20–1265 Ultrahigh-Resolution Fourier-Transform Ion Cyclotron Resonance Mass Spectrometry for Fingerprinting, Source Tracking, and Allocation of Per- and Polyfluoroalkyl Substances (PFAS) – Jens Blotevogel, Colorado State University

ER20–1056 Improving Access and Utility of Analytical Data for the Confident Discovery, Identification, and Source-Attribution of PFAS in Environmental Matrices – Benjamin Place, NIST, Department of Commerce

12 TREATMENT TECHNOLOGIES

Treatment technologies for PFAS in environmental media are still evolving and it is prudent to use caution in implementing long-term remedies. Selection of remedial actions should prioritize protection of drinking water sources and human health, with consideration of other objectives (such as reducing risk to ecological receptors and environmental resources, liability, source area mass, mass flux, generation of PFAAs from precursors). At some sites, it might be reasonable to take short-term site actions that address impacted or threatened receptors with the intent of applying more robust and cost-effective technologies as these are developed.

Section Number	Topic
1.6	**Priority Topics for Treatment Technologies (2025)**
18	**Sorption-Based Technologies for Separation and Concentration of PFAS from Water (2025)**
12.1	**Overview**
12.2	**Field-Implemented Liquids Treatment Technologies**
12.3	**Field-Implemented Solids Treatment Technologies**
12.4	**Incineration**
12.5	**Air Treatment Technologies**
12.6	**Limited Application and Developing Liquids Treatment Technologies**
12.7	**Limited Application and Developing Solids Treatment Technologies**
12.8	**Integrated Remedial Solutions**
12.9	**Sustainability of PFAS Treatment**
12.10	**Improving Evaluation of PFAS Treatment Technologies**
15.2	**Treatment Case Studies**

The treatment technologies described in this section are organized into three categories by degree of development and implementation: field-implemented technologies, limited application technologies, and developing technologies. The criteria for each category are further described below.

In the sections below there are boxes with lists of SERDP, ESTCP, and/or Water Research Foundation (WRF), projects for PFAS Treatment Technologies. Due to the volume of information, these boxes are no longer being updated. Current links and information about SERDP/ESTCP projects for PFAS Treatment Technologies can be found at **https://serdp-estcp.mil/** and Water Research Foundation projects at **https://www.waterrf.org/**.

12.1 Overview

Treatment technologies exploit a contaminant's chemical and physical properties to immobilize, separate and concentrate, or destroy the contaminant. The physical and chemical properties of PFAS make many treatment technologies ineffective, including those that rely on contaminant volatilization (for example, air stripping, soil vapor extraction) or bioremediation (for example, biosparging, biostimulation, bioaugmentation). Even technologies such as thermal treatment and chemical oxidation may not be completely effective at treating PFAS, and multiple treatment technologies may be needed for each treatment scenario to address the mixture of different PFAS that may be present.

Treatment technologies can be employed either ex situ or in situ. For example, when groundwater is extracted via pumping from wells and treated, this would be considered an ex situ approach. In contrast, when treatment materials are injected into the subsurface to separate, destroy, or immobilize contaminants in groundwater under the surface, this would be considered an in situ approach. Many existing treatment technologies have generally been shown to be inadequate; therefore, the unique chemical properties of PFAS often require new technologies or innovative combinations of existing technologies.

A range of technologies exists for treatment of either liquids or solids that may be performed either in situ or ex situ. However, field-implemented technologies for treating PFAS in liquids are mostly limited to ex situ technologies.

Field-implemented full-scale treatment of PFAS-impacted liquids or solids is limited to sequestration technologies that remove or bind PFAS but do not destroy them. Sorption using granular activated carbon (GAC) and ion exchange (IX) media has been proven effective at full scale (see **Table 12-1 Treatment Methods Table** Excel File). Destruction and mineralization technologies, including bioremediation, chemical oxidation, chemical reduction, and thermal technologies, are being tested. This section discusses treatment technologies for liquids (waters, leachates, or other liquid wastes) and solids (soil, sediment, or other solid wastes).

The treatment technologies described in this section are organized by the degree of development and implementation documented in practice or in peer-reviewed literature, regulatory acceptance, and a consensus process. A consensus for the ranking of each technology is determined by the best professional judgment of members of the ITRC PFAS team after evaluating the current information and considering input from other external parties during regular reviews of the document. The three levels used in this discussion are field-implemented technologies, limited application technologies, and developing technologies.

Although categorized in this way for this document, the state of development and application of treatment technologies is a continuum that is ever-changing and evolving quickly. Technologies may progress through these categories between revisions of this guidance document. Most important is that by categorizing, ITRC neither endorses nor repudiates any technology or its proponents regardless of its state of development. Each technology should be evaluated independently to determine the applicability of the technology for the site conditions and desired treatment objectives. The three categories are:

1) **Field-implemented technologies** –Technologies that have been demonstrated at multiple sites, under diverse conditions, by multiple practitioners, are commercially available, and are well documented in practice or peer-reviewed literature. Field-implemented technologies have been demonstrated to meet site-specific PFAS treatment objectives, at the intended final application scale, and are widely accepted in the regulatory and scientific community.

2) **Limited-application technologies** –Technologies that have been implemented on a limited number of sites, by a limited number of practitioners, either at full-scale or field pilot-scale. For this document, full-scale is defined as operation of a fully capable system, intended to entirely address the appropriate aspects of the remedial action objectives (RAOs) for the treated media, and which is not intended to be expanded or supplemented in the future to achieve those final project goals. Field pilot-scale refers to a demonstration project intended to prove the effectiveness of the treatment technology in the field, under site conditions. While these projects may not address the RAOs explicitly or completely, these demonstration projects typically involve continuous operation over months of activity, with robust analytical monitoring, and published results in the peer-reviewed literature. Limited application technologies are supported by a growing body of evidence that they are effective at treating PFAS, but differ from full-scale implemented solutions in that there may not yet be a large body of evidence or broad consensus in the scientific community, including peer-reviewed literature, that the technology meets the

criteria for a field-implemented technology. Limited-application technologies for liquids and solids are contained in the Table 12-1 Treatment Methods Table Excel File and discussed in Sections **12.6** and **12.7**.

3) **Developing technologies** –Technologies that have been researched at the laboratory or bench scale. Often, the results from developing technologies are reported by only one group (for example, one university, practitioner, or vendor) or lack detailed independent verification of the treatment effectiveness or mechanisms. Among a wide array of experimental technologies under development, only developing technologies that show promise and have some level of publicly available documentation demonstrating effectiveness are included in this guidance document.

The technology evaluations presented herein provide information on the effectiveness of each treatment technology. This information varies widely among technologies and the data provided are based on the reported test conditions and results. Ultimately, the feasibility of a technology to meet applicable regulatory guidance values and standards often depends on site-specific conditions.

As detailed in **Section 8.2.2.4**, in the United States, the regulatory standards for PFAS treatment are primarily driven by drinking water mitigation and focused on a small subset of PFAS. PFOS, PFOA, PFBS, and HFPO-DA are the only compounds with federal health advisories (**USEPA 2022**), and most regulatory discharge criteria for PFAS focus on these compounds. USEPA published a final rule in April 2024 that includes National Primary Drinking Water Regulations (NPDWRs) for six PFAS containing MCL and MCLG values (**USEPA 2024**). Some states have guidelines, and several have regulatory criteria for additional PFAS not contemplated in USEPA's April 2024 final rule. The technology evaluation information presented here provides data about PFAS tested for a given technology. This information varies widely among technologies. Additional information on regulations is provided in **Section 8** and the PFAS Regulatory Programs Summary Excel File.

12.1.1 Factors Affecting Technology Selection

Selection of a remedy, with confidence that treatment targets can be achieved, depends on several key factors, including the ability to reliably define the nature and extent of contamination, the availability of proven treatment technologies, and the capacity and tools to measure progress and compliance with desired regulatory criteria. A well-prepared conceptual site model (CSM) requires adequate information and is also fundamental to understanding and presenting the rationale and justification for the selected remedy. Additional information on CSMs is provided in **Section 2.6**, **Section 9**, and **Section 10**.

Moreover, proven treatment technologies are limited in capacity and demonstrated ability to meet chosen treatment targets. The comprehensive discussions contained herein reveal many questions and uncertainties that must be addressed.

As an example, factors affecting PFAS remedy selection can include:

- **characteristics of PFAS.** The wide-ranging chemical and physical characteristics of PFAS affect the treatment effectiveness. Key factors include recalcitrance with respect to common technologies due to the strength of the carbon-fluorine bond, ionic state (anionic, cationic, and zwitterionic), types of ionic groups (sulfonate or carboxylate), lipo- and hydrophobicity, chain length and branching, partitioning coefficients, phase behavior, volatility, solubility, acidity, total PFAS mass, and total concentration.

- **changes in PFAS properties**. Naturally occurring processes or remedial actions for other (commingled) contaminants, such as chlorinated solvents and petroleum hydrocarbons, can affect PFAS distribution and mobility in groundwater (**McGuire et al. 2014**). Example changes include:

  - The alkyl functional group of some PFAA precursors may be more readily subject to chemical or biological transformation than the fully fluorinated aliphatic chain (PFAAs).
  - Partial degradation of the carbon-carbon bonds in the aliphatic chain reported for some chemical remedies generates short-chain PFAS, which may be more mobile (**Guelfo and Higgins 2013**).
  - Modifications in aquifer properties (for example, redox or pH) during remediation of commingled contaminants results in a conversion of some precursors to the more stable and mobile PFCAs (**McKenzie et al. 2015**; **McKenzie et al. 2016**).

- **co-contaminants, organic matter, and geochemistry.** The presence of co-contaminants, total organic carbon, natural organic matter, minerals, and anions can significantly affect remediation. Some technologies that are designed and implemented to treat PFAS co-contaminants may transform perfluoroalkyl acid (PFAA) precursors into more stable perfluorocarboxylic acids (PFCAs) (**McKenzie et al. 2015**).

- **community acceptance.** Stakeholders, including community members, are often faced with trade-offs in terms of cost, level of cleanup, and residual contamination as part of remediation efforts.

An additional element of technology selection relates to the optimal conditions under which a specific technology should be considered, as documented in the literature. Not all technologies have been demonstrated as suitable or effective under multiple treatment circumstances. For example, although sorption technologies, such as granular activated carbon or ion exchange media, have been documented in the literature as being both technically effective and generally cost-effective in treating high volume, low concentration liquids, such as drinking water, they are less well suited for low volume, high concentration liquids such as thermal system condensate, ion exchange regeneration fluids, fractionated (for example, reconstituted) foam, or landfill leachate. Conversely, several destructive technologies, such as electrochemical oxidation, nonthermal plasma, hydrothermal alkaline treatment, and supercritical water oxidation, have been shown to be effective for treatment of high concentration, low volume liquids, but may be less suitable for high volume, low concentration liquids. See **Section 12.1.4** for considerations for specific environmental media.

For those directly engaged in assessing the suitability of PFAS treatment technologies, a structured process for systematic evaluation is currently under development via a Strategic Environmental Research and Development (SERDP)-funded project (ER18-1633). The project focuses on five lines of evidence to evaluate technology performance and will provide resources to identify relevant information and data gaps and address key questions necessary for that assessment. Additional information is provided in **Section 12.9**.

12.1.2 Tiered Remedial Approach

Along with the factors affecting technology selection (**Section 12.1.1**), practitioners should also consider the use of a tiered remedial approach to mitigate the risks posed by PFAS. This may include prioritizing protection of known human receptors from exposure to drinking water contaminated by PFAS by using point of entry (POE) or point of use (POU) treatment systems or connecting residents to public water supplies. Reducing the potential risk to human and/or ecological receptors may require upgrades to wastewater treatment plants; however, large-scale retrofits of wastewater treatment plants for PFAS have not been widely enacted at this time. Once these actions are taken to control risk and exposure, the source(s) of the PFAS contamination can be addressed using the appropriate remedial technology. Cutting off sources and controlling ongoing contaminant flux will influence whether PFAS plumes becoming stable or shrink. Once sources and pathways to receptors are controlled, addressing the pathways of contaminant migration (for example, groundwater plumes, stormwater drainage networks,

surface water) becomes the final aspect of the tiered approach. A similar approach for site characterization is described in **Section 10.2**.

12.1.3 Section Organization

The information presented in the following sections reflects the availability of performance results published, presented, or otherwise publicly available. **Section 1.6.6** includes updated technology review papers.

Those technologies that have been implemented in the field at multiple sites, by multiple parties, and have peer-reviewed or practical documentation of performance are discussed in **Section 12.2** and **Section 12.3**. Projects funded by SERDP and the Water Research Foundation (WRF) are also highlighted. This section discusses the following key elements for each of these field-implemented technologies:

- *treatment description*–background and development of technology
- *treatment mechanism*–separation, sorption, or destruction
- *state of development*–applications and degree of commercial availability
- *effectiveness*–documented treatment effectiveness on PFAS and common co-contaminants along with water quality considerations and pretreatment need and options
- *design/operating considerations* –critical or unique operational or design needs
- *sustainability*–footprint, community enhancement, and cost.

Treatment case studies are presented in **Section 15.2**.

12.1.4 Considerations for Specific Environmental Media

The Priority Topics for Treatment Technologies include considerations for management of PFAS-impacted investigation-derived waste (see **Section 1.6.3**). **Section 1.6.6** includes updated technology review papers.

12.1.4.1 Drinking Water

Public-serving system components are often required to be certified through NSF 61 (**https://www.nsf.org**), which certifies that they are acceptable for potable water use. Treatment for PFAS in these systems typically uses adsorbents such as GAC (**Section 12.2.1.1**), IX (**Section 12.2.1.2**), or RO (**Section 12.2.2**). **Section 18** provides guidance for sorption-based technologies for separation and concentration of PFAS from water.

Remedial actions for PFAS-impacted drinking water from private wells and other nondistributed sources can include providing alternative drinking water supplies, such as bottled water, new nonimpacted source wells or surface water, point of entry (POE) treatment (also referred to as POET), and point of use (POU) treatment. POE treats water as it enters a home or building (for example, immediately after a pressure tank for a private well system) and POU treats water at one or more specific locations (for example, at a kitchen faucet where water is typically directly ingested or used for cooking). POE systems provide "whole supply" treatment while POU provides selected usage point treatment.

NSF International has incorporated PFOA and PFOS into two standards – NSF/ANSI 53 for adsorption systems and NSF/ANSI 58 for reverse osmosis systems – to verify the ability of a water treatment device to reduce PFOA and PFOS to achieve the USEPA health advisory levels of 70 ng/L (**NSF 2021**; **NSF 2019**). This method does not evaluate the removal of other PFAS that also may adversely impact water supplies. Systems with this certification are mainly small-scale POU systems such as sink faucet filters, refrigerator water filters, and pour-through filters. It should be recognized that although this certification exists, it is not required. This means that other POU systems as well as POE systems (larger wellhead or large public-serving systems) may not be certified under NSF/ANSI 53 or NSF/ANSI 58 but may be acceptable treatment of PFOA and PFOS.

12.1.4.2 Landfill Leachate

Currently, a majority of landfill leachate is treated for conventional constituents by directly discharging or hauling the leachate to publicly owned treatment works (POTWs). POTWs have been designed to remove these conventional constituents (for example, organics and nutrients), but these treatment systems are not effective at removing PFAS. A relatively small percentage of landfills perform pretreatment to address conventional parameters (for example, BOD, COD, TSS, ammonia-N) prior to discharging to POTWs or perform leachate treatment on-site and discharge the treated effluent under National Pollutant Discharge Elimination System (NPDES) permits. There are currently very few landfills that treat or pretreat leachate specifically to remove PFAS, but this may change as national and state surface water and/or pretreatment regulations are developed.

Wei, Xu, and Zhao (2019) presented a comprehensive review of the state of the science on PFAS treatment technologies for landfill leachate. They noted that various technologies have been widely tested for treating PFAS in drinking water or groundwater, but knowledge is limited on the treatability of PFAS in landfill leachate and the effects of the complex leachate matrix. Leachate contains many competing organic and inorganic constituents, and this complex matrix creates significant challenges when choosing a treatment technology for PFAS removal. Oftentimes, pretreatment of the leachate may be required before applying common PFAS sorption technologies such as GAC or ion exchange resins. If pretreatment is not performed to remove these competing compounds, the sorptive treatment media will foul quickly, which may result in operationally complex and/or expensive systems to treat landfill leachate for PFAS using these traditional technologies. Additional information on integrated remedial solutions is presented in **Section 12.8**.

Destructive technologies such as plasma, advanced oxidation, reduction, photochemical processes, and sonolysis are largely unproven at present on landfill leachate, and their effectiveness is expected to be reduced when used for treating leachate due to the severe water matrix effect **(Wei, Xu, and Zhao 2019**). In addition, these technologies have typically not been as effective when scaled up from laboratory studies to the field. Supercritical water oxidation (SCWO) destruction of landfill leachate containing PFAS has been demonstrated but is not well documented in peer-reviewed literature. More information about SCWO is included in **Section 12.6.3.12**.

Filtration systems such as RO have been proven effective as a separation technology for leachate for a wide range of constituents, including PFAS, but can generate a significant fraction of concentrated residuals that requires management by other disposal/treatment technologies. Foam fractionation shows promise in recent studies for selectively separating large percentages of PFAS from leachate (particularly the longer chain PFAS) while generating manageable fractions of high concentration residuals at a much smaller volume relative to RO reject (**Burns et al. 2022**; **McCleaf, Kjellren, and Ahrens 2021**; **Robey et al. 2020**; **Smith et al. 2022**).

Overall, further research is needed to develop and demonstrate cost-effective treatments for landfill leachate PFAS removal that are effective at field scale.

12.1.4.3 Biosolids

The Priority Topics for Treatment Technologies include information on treatment of PFAS-contaminated sewage sludge and biosolids (see **Section 1.6.5**). The Priority Topics for Biosolids Land Application include information about PFAS in biosolids (see **Section 1.7**).

Biosolids generated by wastewater treatment plants have been historically managed through land application, use or disposal at landfills, or incineration. The regulatory landscape for management of biosolids is evolving, and some states have started to require testing, prohibit land application if concentrations of certain PFAS are greater than specific levels, or have implemented bans on land application. Current regulations and guidance are discussed in **Section 8** and in the **PFAS Regulatory Programs Summary** Excel File.

The fate of PFAS in various thermal treatment processes (for example, incineration, pyrolysis) is an active area of research to better understand the potential formation of byproducts or products of incomplete combustion (**USEPA 2024**) and is covered in more detail in **Section 12.4**.

Additional information on biosolids is presented in the ITRC factsheet for Biosolids and Per- and Polyfluoroalkyl Substances (PFAS) (**/fact-sheets/**) and **Section 2.6.4**.

12.2 Field-Implemented Liquids Treatment Technologies

These technologies have been implemented in the field by multiple parties at multiple sites and the results have been well-documented in practice or peer-reviewed literature. The liquid treatment technologies in this section may be applied to a variety of PFAS-impacted media, including drinking water (regardless of source), surface water, groundwater, wastewater, stormwater, or landfill leachate. Not all technologies would be appropriate for all applications. Site-specific evaluation is necessary to identify the best technology alternative for a given liquid, system size, treatment goal, and residual media management scenario.

12.2.1 Sorption Technologies

Section 18 provides guidance for sorption-based technologies for separation and concentration of PFAS from water.

Sorption technologies have been used for both ex situ and in situ water treatment applications. Multiple sorption media types may be used in series for ex situ applications to optimize overall concentration reduction and removal capacity. Adsorption and ion exchange (IX) are two “sorption” mechanisms by which PFAS can be removed from water. Adsorption is a physical mass transfer process that uses Van der Waals and/or other weak ionic forces to bind the entire PFAS molecule to the surface areas of the adsorptive media. Ion exchange is the exchange of ions of the same charge. Ion exchange targets and binds to the hydrophilic ionized or functional end of the molecule (for example, the sulfonate in PFOS) while releasing an equivalent amount of an innocuous ion (for example, chloride) into the treated water. This technology is generally considered more applicable to high volume, low concentration liquids than low volume, high concentration liquids.

Several influent water parameters can therefore be expected to impact the sorption efficiency for a specific PFAS. These include pH, ionic strength, the nature and concentrations of organic co-contaminants present (including naturally occurring organic matter [NOM]), competing inorganic ions normally present (for example, sulfate, nitrate, bicarbonate, and chloride), and any suspended solids, potentially precipitating impurities (for example, iron, manganese, calcium carbonate), or biological growth that can foul and degrade the performance of the media. Pretreatment steps may be necessary to

optimize the performance of such media, including coagulation, precipitation, filtration, pH adjustment, or oxidant removal. Ion exchange media used for PFAS removal from water use both the adsorption and ion exchange mechanisms. The use of two or more different media in series can be considered if the expected increase in overall removal efficiency can be used to justify the increased equipment cost.

Life cycle cost assessments can be used to compare the long-term cost-performance benefits of various sorption media types. Spent media management can be an important consideration when selecting a treatment technology. Common options for spent media management are off-site disposal by thermal destruction (via commercial incineration or cement kilns), reactivation/regeneration for reuse (which may require management of additional waste streams), and landfilling. Information on specific management considerations for spent media are discussed in the respective sections below.

Related Past, Ongoing, and Recent Research Funded by SERDP (ER) and Water Research Foundation (WRF)

- ER18-1395 Electrically Assisted Sorption and Desorption of PFASs
- ER18-1417 Molecular Design of Effective and Versatile Adsorbents for Ex Situ Treatment of AFFF-Impacted Groundwater
- ER18-1052 Remediation of PFAS Contaminated Groundwater Using Cationic Hydrophobic Polymers as Ultra-High Affinity Sorbents
- ER18-1306 Combined In Situ/Ex Situ Treatment Train for Remediation of Per- and Polyfluoroalkyl Substance (PFAS) Contaminated Groundwater
- ER18-5015 Removal and Destruction of PFAS and Co-contaminants from Groundwater via Groundwater Extraction and Treatment with Ion-Exchange Media, and On-Site Regeneration, Distillation, and Plasma Destruction
- ER18-B3-5053 Evaluation and Life Cycle Comparison of Ex-Situ Treatment Technologies for Poly- and Perfluoroalkyl Substances in Groundwater
- WRF 4913 Investigation of Treatment Alternatives for Short-Chain PFAS
- ER21-1191 Determination of Thermal Degradation Products and Residuals of Per- and Polyfluoroalkyl Substances-Laden Sorbent Materials in Gas and Condensed Phases
- ER21-1238 Sustainable PFAS Treatment Using Layered Double Hydroxide (LDH) Sorbents
- ER20-5182 Validation of Colloidal Activated Carbon for Preventing the Migration of PFAS in Groundwater
- ER18-1026 Rational Design and Implementation of Novel Polymer Adsorbents for Selective Uptake of Per- and Polyfluoroalkyl Substances from Groundwater
- ER20-5252 Anion Exchange Permeable Adsorptive Barriers (PABs) for In Situ PFAS Immobilization and Removal
- ER20-5100 In Situ PFAS Sequestration in AFFF-Impacted Groundwater
- ER21-1185 Thermal Decomposition of PFAS on GAC: Kinetics, Mass Balance, and Reuse of Reactivated Carbon
- ER21-1256 Develop Synergetic Novel Macrocycle-based Sorbents with Thermal Destruction for Enhanced PFAS Removal in Groundwater and Drinking Water Treatment
- ER21-1124 Assessment of Long-Term Effectiveness of Particular Amendments for In Situ Remediation of PFAS in Mixed Plumes
- ER22-3150 Engineering an “All-In-One” Biochar-Surfactant System for Enhanced PFAS Sorption and Reductive Degradation Using a Coupled Ultraviolet and Ultrasonication Approach
- ER22-3155 In Situ Sequestration of PFAS from Impacted Groundwater using Injectable High Affinity Cationic Hydrophobic Polymers
- ER22-3415 Novel Swellable Ionomers for Enhanced PFAS Sorption and Destruction
- ER22-7363 Rapid and Inexpensive Delivery of Particulate Carbon for In Situ PFAS Treatment in Groundwater
- ER22-3119 High-Capacity Sustainable Sorbents for Treatment of PFAS
- ER22-3194 Green Remediation of PFAS in Soil and Water

Incineration and thermal reactivation/regeneration offer the possibility of destruction of PFAS waste streams, though incineration has received recent attention due to possible incomplete combustion and by-product generation and is the topic of current study to better understand the fate of PFAS. Incineration is discussed in **Section 12.4**.

12.2.1.1 Granular Activated Carbon (GAC)

Treatment Description: GAC is an effective sorbent media for organics that has historically been used to reduce contaminants in a variety of environmental media. The information contained in this section describes ex situ GAC treatment in which water is extracted and transferred from the source of contamination and directed through the treatment system.

Treatment Mechanism: Removal of PFAS by GAC is a physical mass transfer process (refer to **Section 12.2.1**) from the aqueous phase onto solid media that does not involve or trigger any form of chemical degradation or transformation.

State of Development: The application of GAC as a treatment technology for PFAS removal has been practiced for over 15 years at more than 45 military installations, as well as several industrial sites and publicly owned treatment works (**Forrester 2018**) involving private and municipal drinking water supplies.

Effectiveness: The following references were used to support the treatability effectiveness discussion presented below for PFAS by GAC: **Appleman et al. (2013)**; **Burdick et al. (2016)**; **Cummings (2015)**; **Dickenson (2016)**; **Ochoa-Herrera and Sierra-Alvarez (2008)**; **Szabo (2017)**; **Woodard, Berry, and Newman (2017)**; **Zeng et al. (2020)**. These references also include more comprehensive bibliographies if further details are needed on specific topics or studies. Literature and supporting column studies have shown that newly placed GAC can reduce effluent concentrations for PFAS listed in USEPA Method 537.1 (**Shoemaker and Tettenhorst 2018**) to below analytical detection limits until initial breakthrough begins to occur. Because GAC is generally used to treat many common groundwater contaminants, it is capable of also treating most organic co-contaminants that may be present, with the primary impact being increased GAC consumption due to greater loading per unit of time, which may require more frequent change-outs. Individual PFAS have different GAC loading capacities and corresponding breakthrough times (often defined as the number of bed volumes treated prior to detection in the effluent) (**Eschauzier et al. 2012**; **Zeng et al. 2020**). GAC removal capacity for PFOS is greater than PFOA, but both can be effectively removed (**McCleaf et al. 2017**). In general, shorter chain PFAS have lower GAC loading capacities and faster breakthrough times, but could be effectively treated if change-out frequency is increased. **Figure 12-1** provides an example of removal curves and breakthrough information for several PFAS performed at a specific influent concentration based on vendor-supplied column studies.

More studies are needed to confirm GAC treatment effectiveness for shorter chain PFAS or to identify complementary technologies/materials to supplement GAC removal capability. This may include studying the influence on sorption site competition from PFAS precursors that are often not quantified during the GAC system design. Recent accelerated column tests by vendors have shown the successful removal of a variety of PFAS, including the butyl (C4), pentyl (C5), and hexyl (C6) compounds (**Appleman et al. 2013**; **Dickenson 2016**; **Brewer 2017**; **Zeng et al. 2020**). Functional groups also impact the ability of GAC to adsorb PFAS. Compounds with sulfonate and sulfonamide groups are more readily adsorbed than those with carboxylates of the same chain length (**Appleman et al. 2013**; **Dickenson 2016**; **Zeng et al. 2020**). Studies in the developmental stage involve the use of other materials that can modify GAC surfaces to improve removal capabilities. Mixtures of powdered activated carbon, kaolinite, and amorphous hydroxide have been tested at the bench- and pilot-scale and have shown high removal rates for shorter chain PFAS in raw AFFF-impacted groundwater (**Chiang 2017**; **Kempisty, Xing, and Racz 2018**).

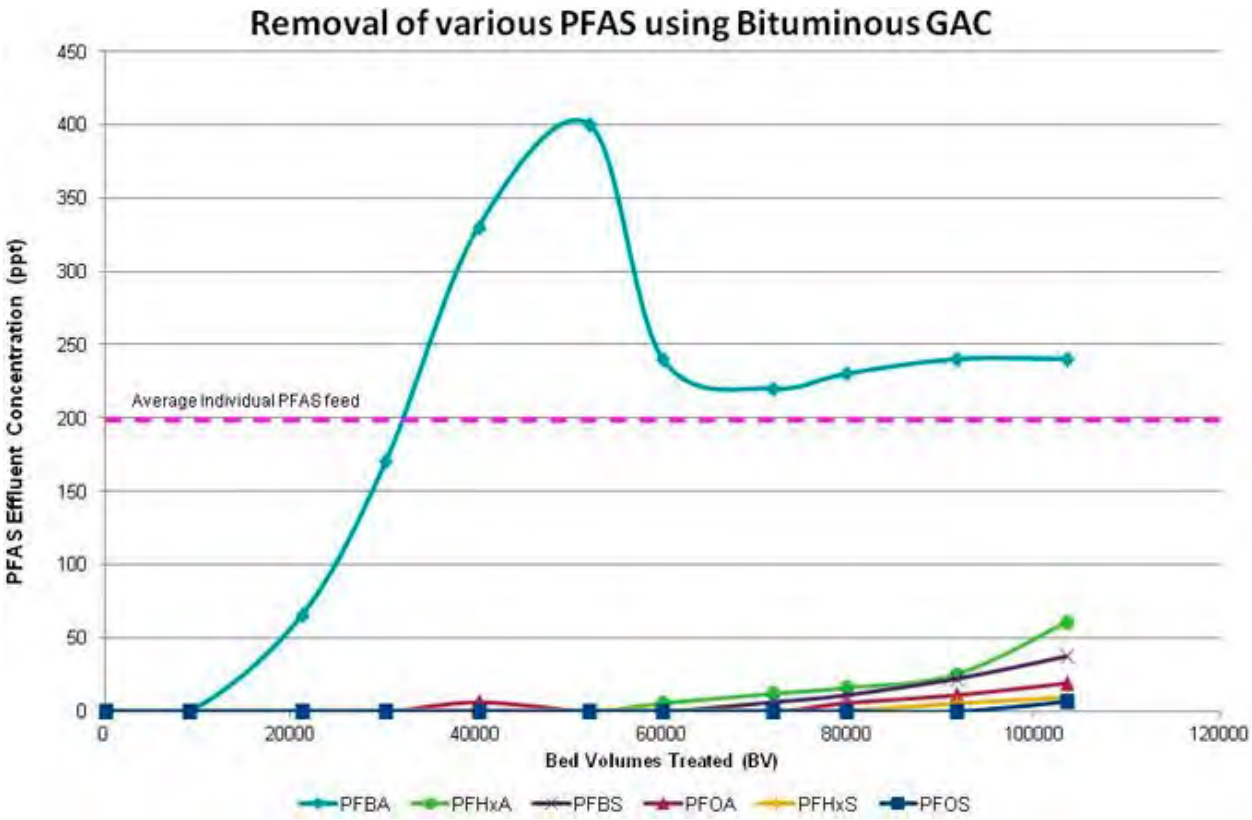


Figure 12-1. Example GAC removal curves at specific influent concentration (15-minute empty bed contact time).

Source: Used with permission from Calgon Carbon Corporation.

Most of the case studies on full-scale GAC-based systems used to treat PFAS in the literature are based on treatment of PFOA and PFOS in impacted drinking water sources. As such, limited information is available regarding the treatment of other PFAS, or PFAS in other source waters. The full-scale drinking water systems demonstrate that PFOA and PFOS can be removed to below analytical detection limits. More information is contained in the Table 12-1 Treatment Methods Table Excel File. Treatment of groundwater impacted with PFAS from an AFFF release area contaminated with PFAS such as fire training areas (FTAs) may require complex pretreatment and more frequent change-outs (higher influent concentrations compared to influent for drinking water treatment systems) and higher operation and maintenance (O&M) costs.

Design/Operating Considerations: Laboratory treatability tests (for example, rapid small-scale column testing (RSSCT) and accelerated column test (ACT)) are useful for evaluating treatability and determining initial design parameters. Larger scale pilot demonstrations are recommended to establish site-specific design parameters such as adsorption bed depth; GAC consumption rate to meet a given treatment objective; empty bed contact times (EBCTs); projections of breakthrough (based on bed volumes treated); and corresponding change-out frequency/costs. Column studies can also be used to compare loading capacity/breakthrough performance for different types of GAC (for example, different materials, preparation methods, and pore size distributions) offered by various vendors. These studies should always use site water to ensure that the effects of site-specific geochemical characteristics are assessed. Alternative analytical screening methods, for example, total oxidizable precursor (TOP) assay (**Section 11.2.2.2**), adsorbable organic fluorine (**Section 11.2.2.4**), and particle-induced gamma ray emission (PIGE) (**Section 11.2.2.3**), can be used to better estimate potential total mass load during the GAC remedial design phase. Field performance of GAC systems often varies significantly from that

predicted in the RSSCT and other bench tests. Proper monitoring is critical to demonstrate that the desired performance is being achieved, especially at system start-up and following media change-out events.

Temporary and permanent GAC systems can be rapidly deployed and require minimal operator attention, if intensive pretreatment is not needed. The GAC media are placed in packed-bed flow-through vessels generally operated in series (lead-lag configuration). EBCTs of 10–20 minutes per vessel are typical (**AWWA 2019**). PFAS breakthrough is monitored by testing the water, at a minimum, between the lead and lag vessels. Additional sampling ports can be added (for example, at 25%, 50%, and 75% of the depth of the media). When breakthrough exceeds identified change-out criteria, the lead bed is taken offline and the spent GAC is removed and replaced with either new or reactivated GAC. The spent media are disposed off site by thermal destruction or can be thermally reactivated for reuse. Treatment can be continuous if the lag bed is used as the lead bed while the media in the latter are changed out. **Figure 12-2** depicts a simple process flow diagram for a GAC treatment system.

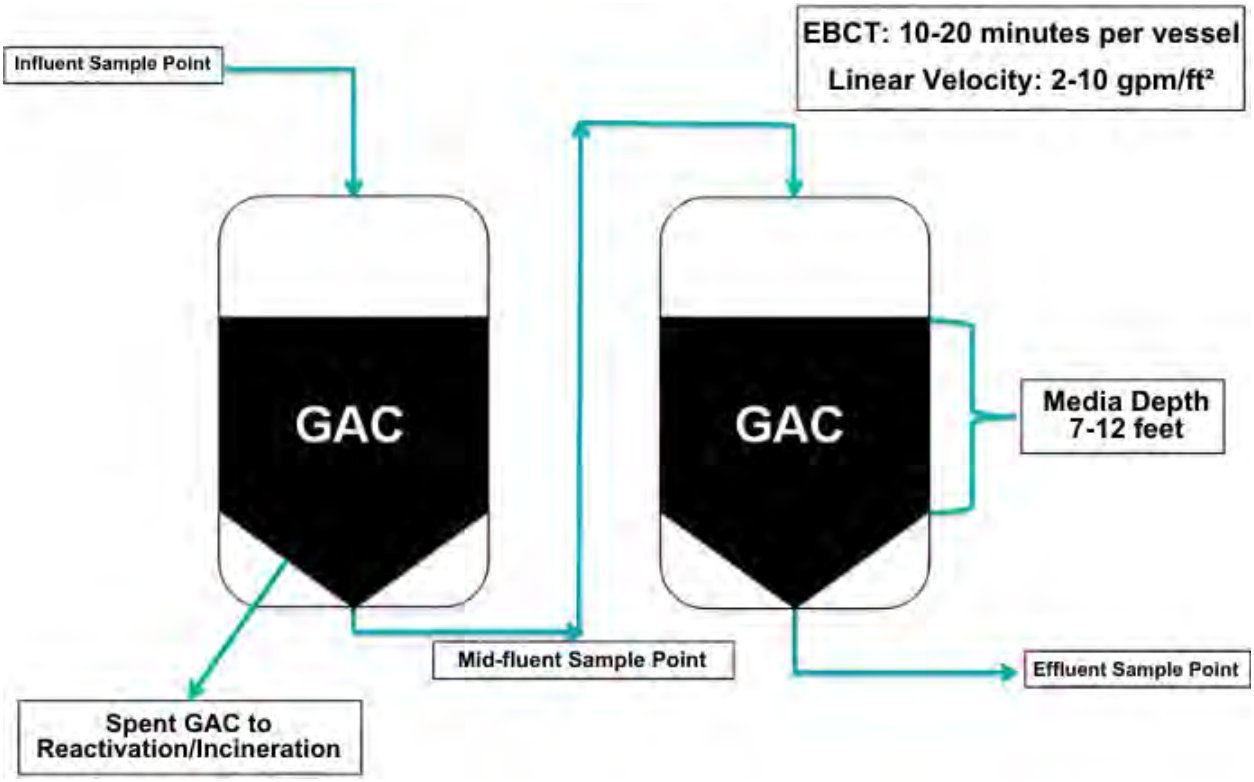


Figure 12-2. Typical GAC treatment system process flow diagram.

Source: Used with permission from Calgon Carbon Corporation.

Various GAC base materials (for example, bituminous coal, lignite coal, coconut shells) can be used for adsorption, though bituminous coal-based GAC has been used for the majority of existing sorption treatment systems for PFAS and current data show that bituminous-based products are more effective for PFAS removal (**McNamara et al. 2018**; **Westreich et al. 2018)**. Specialized GAC formulations and coconut-based GAC can also be effective. Media selection and life cycle cost will depend upon a number of factors, including PFAS and co-contaminant concentrations, media availability, and pricing.

GAC treatment applications will evolve as analytical methods improve and regulatory concerns encompass an increasing number of PFAS. Shorter chain PFAS exhibit faster breakthrough times (**Appleman et al. 2013**), so particular attention needs to be given to these compounds if their removal is

required. Alternative design optimization approaches or use of other technologies in combination with GAC (for example, ion exchange (IX) resins discussed in **Section 12.2.1.2**) can address high O&M costs that can be incurred for GAC treatment involving high influent PFAS concentrations, especially if shorter chain PFAS must be removed. As discussed in **Section 12.2.1.2**, specialty single-use and regenerable IX resins have been developed that have higher loading capacities for shorter chain PFAS. GAC and IX can also be used in series to optimize removal capacity and minimize O&M costs, generally with GAC ahead of IX to remove non-PFAS organics and longer carbon chain PFAS, followed by IX to remove the shorter carbon chain PFAS. This approach has been implemented in the field and is presented in a case study in **Section 15.2.2.1**.

Spent GAC that contains PFAS can be thermally reactivated and reused, which may result in a lower cost media replacement option versus new GAC. However, some regulatory agencies may not allow the use of reactivated GAC for drinking water systems. NSF/ANSI standards require that the use of reactivated GAC for drinking water systems involve only media generated by the treatment system owner/operator and cannot include a mixture of GAC that originated from other sources. The management of spent media should be planned during the life cycle assessment phase and be documented as the treatment system is executed. Commercial facilities are available for thermal reactivation of spent GAC, which currently are not available for other sorption media and can offer a potential life cycle cost benefit for spent media disposal. Based on vendor feedback (**Mimna 2017**), commercial thermal GAC reactivation is performed at higher operating temperatures than steam or nitrogen regeneration systems, and may be capable of complete desorption and destruction of PFAS from spent GAC (**Watanabe et al. 2016**; **Yamada et al. 2005**). However, similar to incineration, additional studies are needed to investigate the fate of PFAS in the GAC reactivation process.

Sustainability: GAC ex situ PFAS water treatment systems have unique sustainability considerations as well as considerations in common with other ex situ PFAS sorption media water treatment systems (treatment complex construction, utilities, water collection and pumping, and discharge infrastructure). Major sustainability considerations unique to GAC systems are associated with:

- raw material collection and transportation
- GAC manufacturing and transportation
- larger media vessels relative to IX due to longer EBCTs
- larger treatment complex size due to larger vessels
- spent media transportation followed by reactivation, destruction, or disposal.

Multiple resources are available for performing sustainability assessments for sorption remedial designs (**Amini et al. 2015**; **Choe et al. 2013**; **Choe et al. 2015**; **Dominguez-Ramos et al. 2014**; **Favara et al. 2016**; **Maul et al. 2014**; **Rahman et al. 2014**; **Ras and von Blottnitz 2012**). Additional information is included in **Section 12.9**.

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER21-1185 Thermal Decomposition of Per- and Polyfluoroalkyl Substances on Granular Activated Carbon: Kinetics, Mass Balance, and Reuse of Reactivated Carbon
- ER21-1111 An Investigation of Factors Affecting In Situ PFAS Immobilization by Activated Carbon
- ER20-3034 Thermal Reactivation of Spent GAC from PFAS Remediation Sites
- ER19-5181 Improved Longevity and Selectivity of PFAS Groundwater Treatment Using Sub-Micron Powdered Activated Carbon and Ceramic Membrane Filter System
- ER22-7363 Rapid and Inexpensive Delivery of Particulate Carbon for In Situ PFAS Treatment in Groundwater

12.2.1.2 Ion Exchange Resin

Treatment Description: Ion exchange (IX) resin is an effective sorbent for other contaminants and has historically been used for a variety of water treatment applications (for example, nitrate, perchlorate, arsenic). To date, IX for PFAS removal from water is limited to ex situ applications.
IX resin options for removal of PFAS include single-use and regenerable resins. Single-use anion exchange resins are used until breakthrough occurs at a pre-established threshold and are then removed from the vessel and currently disposed of by high temperature incineration or by landfilling, where permitted. Regenerable resins are used until breakthrough but are then regenerated on site using a regenerant solution capable of returning a reduced capacity to the resin. Temporary and permanent IX systems can be rapidly deployed.

Treatment Mechanism: Removal of PFAS by IX is a physical mass transfer process from the aqueous phase onto solid media that does not involve any form of chemical degradation or transformation. IX resins with positively charged functional groups remove negatively charged PFAS from water by forming ionic bonds (the sulfonic and carboxylic acid heads of PFOS and PFOA are negatively charged at the typical range of pH values found in natural water). Simultaneously, the hydrophobic end of the PFAS structures can adsorb onto the hydrophobic surfaces of the IX resins, leading to increased ion exchange affinity on resins with hydrophobic backbones. Some PFAS at high liquid-phase concentrations (for example, 1 g/L) have been shown to also exhibit nonexchange sorption onto IX resins (**Zaggia et al. 2016**). However, the specific conditions and underlying mechanisms leading to this nonexchange sorption are not yet fully understood.

State of Development: Ion exchange technology has been used since the late 1930 for common water treatment processes like softening, demineralization, and selective contaminant removal. The development and use of selective resins for PFAS removal is relatively new but already well established. Single-use resins are now widely used for PFAS removal from water due to their simplicity of use and effectiveness in reducing regulated PFAS to nondetect (ND) levels. As of 2019, a limited number of regenerable IX systems have been installed in full-scale applications after successful pilot testing. Collection of data on longer term treatment and on-site regeneration of the IX resin is ongoing at a case study site (**Section 15.2.2.2**). In general, the removal capacity of the single-use resin is higher than that of regenerable resin, and single-use resin can be more fully exhausted in a lead-lag vessel configuration than regenerable resin. The relative removal efficiency of regenerable and single-use resins depends upon PFAS and co-contaminant influent concentrations and treatment goals.

Effectiveness: Selective IX has been demonstrated to reduce concentrations for a broad suite of PFAS at the bench and field scale for influent concentrations as high as 100s of parts per billion (ppb) total PFAS to below analytical detection limits in effluent (**Kothawala et al. 2017**; **McCleaf et al. 2017**; **Woodard, Berry, and Newman 2017**; **Zeng et al. 2020**). The affinity of such resin for common subgroups of PFAS generally follows the order PFSA > PFCA. Within each subgroup, affinity increases with increasing carbon chain length, and are not necessarily sequential (that is, longer chain PFCA may be adsorbed better than shorter chain PFSA).

In general, IX resin systems being used for PFAS removal are not installed with the intention of removing co-contaminants. Co-contaminants (including organic and inorganic compounds) may significantly reduce the removal capacity of IX for PFAS, although this depends on the selectivity of the IX resin. Because of the variability in resin behavior, as well as site-specific chemistry and co-contaminants, influent characterization is needed to assess potential pretreatment options to remove co-contaminants. Pretreatment is necessary to prevent fouling (for instance, by iron or manganese) and preserve resin capacity for PFAS removal, particularly in the context of remediation where complex co-contaminant chemistry is expected. Pretreatment needs for drinking water applications may be simpler or not required. Another consideration for drinking water utilities is that, depending on the type of IX resin used, a freshly installed IX column may cause short-term disruptions in pH or corrosivity of effluent water,

which may necessitate mitigation strategies such as effluent blending or diverting initial effluent to waste (**Smith et al. 2023**).

Single-use PFAS-selective IX resins are well-suited to treat low-concentration PFAS such as is typically encountered in potable water treatment systems, where media change-out would be infrequent. **Figure 12-3** provides an example of removal curves and breakthrough information for a number of PFAS at the specified influent concentrations (in the legend) based on vendor-supplied data for a full-scale single-use system. Breakthrough is calculated as the ratio of the effluent concentration to the influent concentration (C/C_0). It is not uncommon to observe fluctuations in the breakthrough curve in some field pilot studies due to varied influent concentrations over time. For example, after a resin unit is in equilibrium with one PFAS at an initially higher influent concentration, a lower concentration influent can desorb PFAS from the resin, resulting in breakthrough higher than 100%. The typical breakthrough order observed in **Figure 12-3** is expected to be similar for various anion exchange resins, as relative ionic bond strengths and carbon chain lengths result in shorter chain PFCAs to longer chain PFCAs desorbing first, followed by shorter chain PFSAs to longer chain PFSAs. Similar responses also apply to GAC.

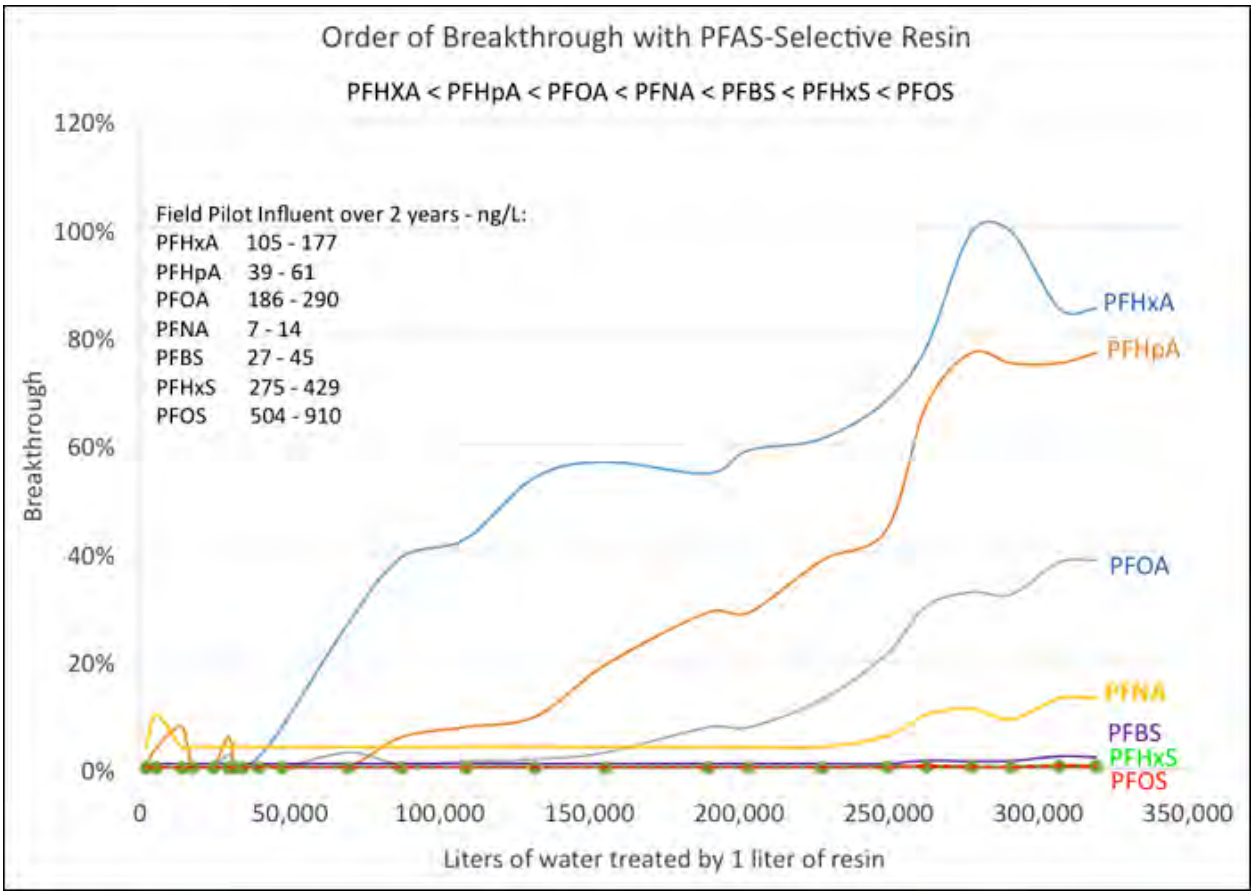


Figure 12-3. Example of IX removal curves from a field pilot study at specific influent concentrations (2.5-minute EBCT). (Note: Initial concentrations in ng/L or ppt.)

Source: Used with permission from Purolite Corporation.

Regenerable IX is not yet approved per NSF 61 for potable water treatment. Regenerable resins are better suited for removal of higher concentration PFAS where the savings realized from reusing the treatment media outweighs the cost of frequent replacement of nonregenerable media. Regenerable IX becomes more efficient than single-pass media when flow rate and concentration increase and RAOs go down,

because these factors increase the frequency and volume of media change-outs for single-pass media. These factors also increase the regeneration demand; however, regeneration frequency can be extended by using larger vessels. Cost efficiency and viability of regenerable IX relative to single-use IX and GAC media are evaluated in ESTCP ER18-5015.

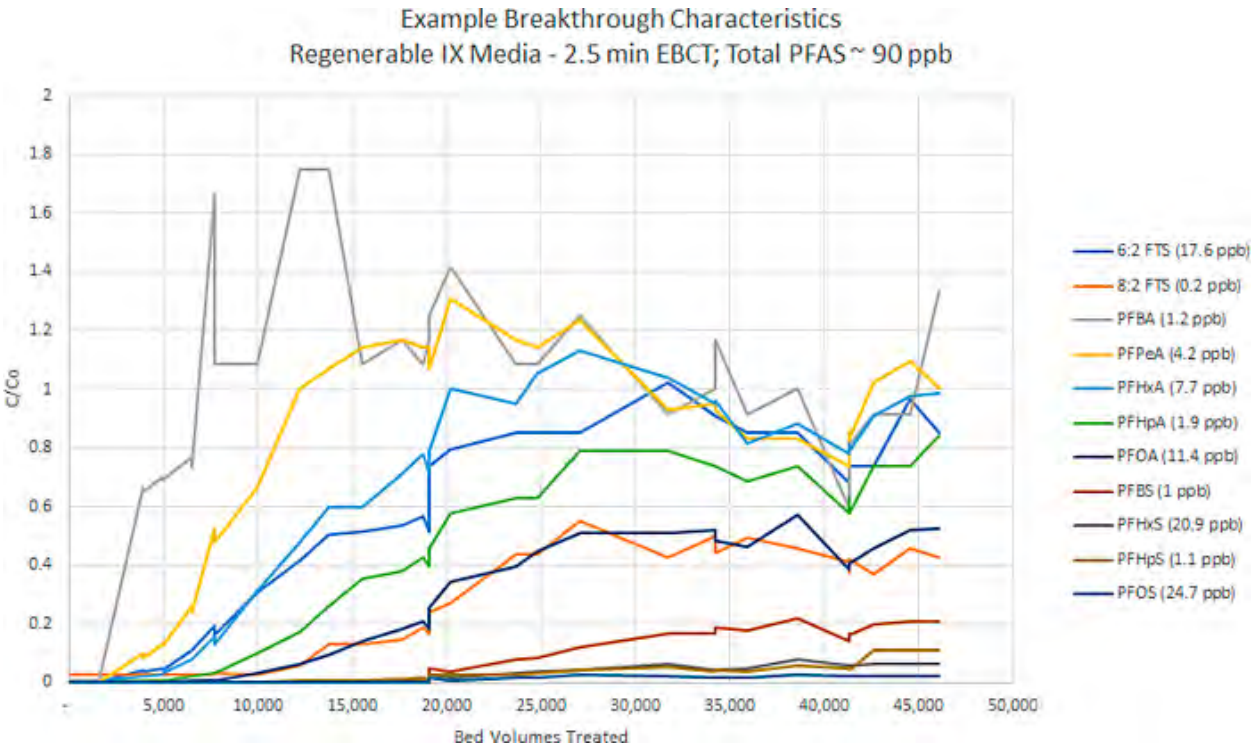


Figure 12-4. Example of regenerable IX removal curves from a field pilot study at specific influent concentrations (2.5-minute EBCT). (Note: Initial concentrations in µg/L or ppb.)

Source: Used with permission from ECT2.

An example of typical breakthrough curves for regenerable resin system is shown in **Figure 12-4**. On the graph the y-axis is sample concentration/original concentration (C/C_o), also note the influent PFAS concentrations (in the legend) in **Figure 12-4** are higher (reported in ppb) than presented in **Figure 12-3** (reported in ppt). Additional details on a regenerable resin system are provided in a case study in **Section 15.2.2.2**. The cost effectiveness for regenerable resin systems could increase significantly (and thus impact the system's practical implementability) when a central regeneration facility can be shared amongst multiple PFAS removal systems. The application of single-use versus regenerable resins must be evaluated on a site-specific basis.

Design/Operating Considerations: IX treatment systems are configured similarly to GAC systems. Refer to **Section 12.2.1** for a description of GAC systems that also applies to IX systems, and Section **12.2.1.2** for fouling considerations. **Figure 12-5** depicts a simple process flow diagram for a single-use IX treatment system.

Selective IX requires a relatively short EBCT of 1.5–3 minutes per vessel of resin (**AWWA 2025**), hence smaller resin volumes and smaller, less costly treatment vessels versus GAC, which requires EBCTs of about 10–20 minutes per vessel (**AWWA 2019**; **Brewer 2017**) and correspondingly larger volumes of media. Selective IX resins have shown high operating capacities when removing trace levels of PFAS (for example, 100,000–400,000 bed volumes; refer to **Figure 12-5**), resulting in fewer change-outs of spent IX

resin and reduced O&M costs. Capacity depends on the concentrations of competing anions, such as sulfate and nitrate, and on the specific PFAS breakpoint chosen for resin change-out. While lead-lag vessel design is standard, if space allows, it is possible to use a lead-lag-polisher design with three resin vessels in series. The addition of a polisher vessel provides a factor of safety for increasing the loading to the lead vessel, thereby reducing change-out frequency and cost. A lead-lag-polisher design will usually result in reduced operating expenses (OPEX) but higher capital expenses (CAPEX). Therefore, the decision to use it must be done on a case-by-case basis. Pretreatment may mitigate fouling and improve performance.

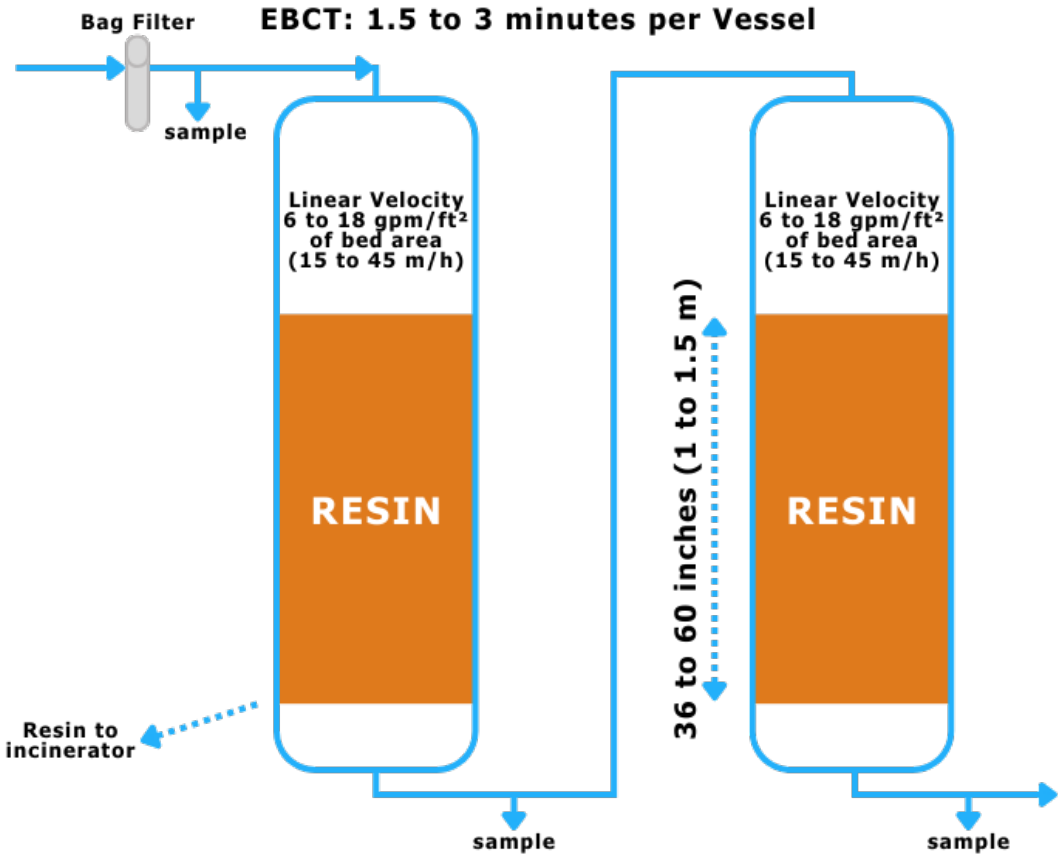


Figure 12-5. Single-use IX process flow diagram.

Source: Used with permission from Purolite Corporation.

For drinking water supplies with relatively clean water, the industry is rapidly moving to rely more and more on vendor-provided modeling for common PFAS with such modeling including predicted breakthrough curves and resin capacities for specific PFAS breakpoints. Modeling can evaluate a variety of "what-if" scenarios, such as changing water chemistries and assessing the economics of operating to nondetectable levels or stricter regulatory limits for selected PFAS.

Pretreatment for several influent water parameters has been recommended (**Section 12.2.1**). Natural organic matter (NOM) is of particular importance because it occurs at concentrations that are three orders of magnitude higher than PFAS. Therefore, NOM can compete for the same ion exchange sites on the resin and can also blanket the surface of the resin beads, thereby blocking access for PFAS to the internal sites on the beads. The negative impact of NOM in groundwater on resin capacity can usually be factored in at the design stage if appropriate data and models are available, because NOM is usually present at less than 2 mg/L. However, when treating surface water with NOM concentrations that can

seasonally rise to 5–10 mg/L (and even higher), it is particularly important to consider negative impact on resin capacity. **Dixit et al. (2020)** evaluated the impact of various dosages of Suwanee River NOM on resin capacity for PFAS and showed decreases of 22%, 50%, and 68% in resin capacity when adding dosages of 5, 10, and 20 mg/L NOM and using an organic scavenger acrylic resin in isotherm test solutions.

Despite the growing adoption of modeling, pilot testing is still recommended when evaluating breakthroughs for multiple PFAS or when the impact of TOC or other contaminants such as iron and manganese must be known to determine pretreatment requirements. In such cases, a technique referred to as accelerated piloting may be used, in which monitoring ports in the pilot column are set at 25%, 50%, and 100% of the resin height. This allows results to be obtained more quickly, but it is with the understanding that the breakthrough profile for each of the ports will be somewhat different. There is also growing interest in using the rapid small-scale column testing (RSSCT) technique for resins. Originally developed for use with GAC, the RSSCT technique uses crushed GAC and shorter EBCTs to quickly predict operating capacity. At this time, it is too early to know if this technique will reliably work for spherical resin beads when crushed.

Selective IX resins show much higher selectivity for PFAS than for common anions in water such as sulfate (SO_4^{2-}), nitrate (NO_3^-), chloride (Cl^-), and bicarbonate (HCO_3^-). However, these common anions are generally present in water at about three orders of magnitude higher than PFAS and will be the main competitors for the ion exchange sites on the resin. As such, they will largely determine the operating capacity of such resins. The choice between single-use and regenerable resins will in part be determined by the expected service period before the resin must be either replaced (single-use) or total regeneration costs (including capital and transportation costs). As PFAS concentration increases or as effluent criteria decreases, the frequency of regeneration or media change-out increases. As regeneration or media change-out increases, regenerable IX becomes more long-term cost-effective, if indeed the cost of regeneration is less than the cost of media replacement.

Regenerable IX resin can be reused long term if protected from contact with strong oxidizing agents, foulants, and chemical/mechanical stresses. In recent years, both pilot-scale and full-scale regenerable IX systems have demonstrated long-term durability of the media. One study, ESTCP ER18-5015, demonstrated greater than 95% removal capacity for regenerated media as compared to new media over six loading and regeneration cycles. IX regeneration is a chemical process. Field-demonstrated regeneration uses a solvent-brine solution in which the brine dislodges the ionic head of the PFAS molecule and the solvent desorbs the fluorinated carbon chain (or "tail") from the IX resin (**Woodard, Berry, and Newman 2017**; **Amec Foster Wheeler 2017**). For a regenerable IX system, it is possible to concentrate the regenerant solution and reuse it by distillation (**Nickelsen and Woodard 2017**). The distillate residue then contains a concentrated PFAS waste that can be super-loaded onto specialized resin to create a small volume of solid waste that can be managed by off-site disposal or potentially through on-site destruction using other technologies currently under development and discussed in **Table 12-1 Treatment Methods Table** Excel File (for example, plasma or electrochemical destruction).

By combining various technologies in a treatment train approach, it may be possible to achieve better overall treatment at lower cost (**Section 12.8**).

Sustainability: Ex situ ion exchange water treatment systems have unique sustainability considerations in addition to those shared with other ex situ sorption media water treatment systems. Major sustainability considerations for ion exchange systems are associated with:

- raw materials, which are generally synthetic, petroleum derivatives
- resin manufacturing and transportation, including from overseas
- regeneration materials, energy, and labor for regenerable IX media
- disposal or destruction of regeneration residuals

- long-distance transportation of spent media to limited available disposal outlets
- energy-intensive destruction methods for spent media

Related Past, Ongoing, and Recent Research Funded by SERDP (ER) and Water Research Foundation (WRF)

- ER18-1027 Ex Situ Treatment of PFAS-Contaminated Groundwater Using Ion Exchange with Regeneration
- ER18-1063 Regenerable Resin Sorbent Technologies with Regenerant Solution Recycling for Sustainable Treatment of PFASs
- ER18-5015 Removal and Destruction of PFAS and Co-Contaminants from Groundwater via Groundwater Extraction and Treatment with Ion-Exchange Media, and On-site Regeneration, Distillation, and Plasma Destruction
- ER 18-1306 Combined In Situ/Ex Situ Treatment Train for Remediation of Per- and Polyfluoroalkyl Substance (PFAS)-Contaminated Groundwater
- ER18-5053 Evaluation and Life Cycle Comparison of Ex Situ Treatment Technologies for Poly- and Perfluoroalkyl Substances in Groundwater
- WRF 4913 Investigation of Treatment Alternatives for Short-Chain PFAS
- ER20-5252 Anion Exchange Permeable Adsorptive Barriers (PABs) for In Situ PFAS Immobilization and Removal
- ER18-1320 Electrochemical Oxidation of Perfluoroalkyl Acids in Still Bottoms from Regeneration of Ion Exchange Resins

12.2.2 High-Pressure Membranes

In the context of this document, high-pressure membranes are defined as those meeting the characteristic separation performance of nanofiltration (NF) and reverse osmosis (RO) membranes. Both the NF and RO membrane categories span a range of selectivity (for example, loose NF to tight RO) and may rely on different rejection mechanisms to support the separation of PFAS from impacted water. However, under the correct application, both technologies have been proven to effectively remove PFAS from a variety of feed water sources. This technology is generally considered more applicable to high volume, low concentration liquids than low volume, high concentration liquids.

12.2.2.1 Nanofiltration (NF)

NF is a form of membrane technology that is pressure-driven and shown to be effective in the removal of PFAS (**Tang et al. 2007**). This method of filtration provides high water flux at low operating pressure (**Izadpanah and Javidnia 2012**). Typically, NF membranes exhibit high rejection of polyvalent ions and other molecules of sufficient size, but are susceptible to permeation by monovalent ions (for example, sodium, chloride) and smaller molecules. The most common membrane module configurations are spiral-wound (consisting of flat sheet membrane material wrapped around a central collection tube); however, hollow fiber NF modules may also be available for applications with higher fouling potential.

Available data on the removal of PFAS via NF consist of laboratory-scale tests performed on flat sheet membrane coupons (laboratory-scale sections of the membranes to be tested) and one full-scale drinking water treatment plant using an NF treatment train. Therefore, variations in performance due to fouling, flux, and concentration distributions in standard spiral-wound membrane configurations have not been characterized (**Boo et al. 2018**).

NF membranes tested include the DuPont (formerly Dow FilmTec) membranes NF-270, NF-200, and NF-90, and the SUEZ (formerly GE Water & Process Technologies) DK membrane. Reported rejections were generally > 95% for PFAS with molecular weights ranging from 214 grams per mole (g/mol) to 713 g/mol, though some compounds had lower rejections (PFPeA at 70% and perfluorooctane sulfonamide at 90%) (**Steinle-Darling and Reinhard 2008**; **Appleman et al. 2013**). Effective full-scale removal of PFAS by NF

membranes was confirmed based on nondetectable PFAS concentrations (<4 ng/L) in NF permeate (**Boiteux 2017**). Salt passage for PFOS was reported to range from < 1% for the tighter NF-90 membrane to about 6% for the looser NF-270 and DK membranes (**Tang et al. 2007**). New research has focused on functionalizing membrane surfaces to improve PFAS selectivity (for example, **Johnson et al. 2019**). An appropriate disposal or treatment of the membrane concentrate stream needs to be considered, especially the application of high-pressure membranes for inland communities. Fluoropolymers may be used to manufacture membranes, which brings into consideration the need for PFAS-bearing reagents to manufacture the membranes, disposal of manufacturing byproducts, and disposal of spent filters.

12.2.2.2 Reverse Osmosis (RO)

RO is a technology used to remove a large majority of contaminants (including PFAS) from water by forcing water, under pressure, across a semipermeable membrane as described below. A typical RO system consists of three streams: the untreated water (feed), the treated water (permeate), and the residual reject water (concentrate). The most common membrane module configuration is spiral-wound, which consists of flat sheet membrane material wrapped around a central permeate collection tube. Like most treatment technologies, RO is seldom used alone, but rather as part of a treatment train. Most efficient RO performance may require pretreatment. RO-treated effluent (that is, permeate) may require supplemental management to mitigate the corrosivity of demineralized water.

Treatment Description: RO membranes are effective in removing most organic and inorganic compounds from water solutions. In recent years, new polymer chemistry and manufacturing processes have improved efficiency, lowering operating pressures and reducing operating costs (**Lau et al. 2012**). As a result, RO membranes are increasingly used by industry to concentrate or remove chemicals. RO is commonly used around the world in household drinking water purification systems, the production of bottled mineral water, self-contained water purification units (for example, for branches of the U.S. military), and industrial applications (for example, water supply to cooling towers, boilers, and deionized water). The largest application of RO is in desalination. In comparison, high-pressure membrane applications typically have higher capital and operating costs relative to GAC or IX systems designed for PFAS removal.

Treatment Mechanism: RO removes compounds from water solutions by forcing pressurized water across a semipermeable membrane. The driving pressure required in RO systems is a function of multiple factors, including the osmotic pressure of the feed water, the membrane type, and the system configuration. Typically, size exclusion is the prevailing mechanism for contaminant removal in RO membrane systems. The physical barrier (that is, semipermeable membrane) underlying the size exclusion removal mechanism provides additional assurance regarding the treatment of PFAS spanning a wide range of physical and chemical properties. Treated water (permeate) passes through the membrane and the rejected water (concentrate) is collected for disposal or discharge, depending on the nature of the compounds present.

State of Development: RO has been studied in bench-scale studies and pilot plants for wastewater and drinking water applications, offering the opportunity to compare both treatments operating simultaneously (**Tang et al. 2006**; **Tang et al. 2007**; **Flores 2013**; **Glover, Quiñones, and Dickenson 2018**; **Dickenson 2016**; **Merino et al. 2016**; **Appleman 2014**; **Snyder 2007**). This allows for an understanding of the effectiveness of traditional drinking and wastewater treatment methods alongside PFAS-specific technologies.

Effectiveness: Pretreatment is important when working with RO membranes. Membranes can be susceptible to fouling (loss of production capacity) because some accumulated material cannot be removed from the membrane surface during routine cleaning and maintenance procedures. Therefore, effective pretreatment to mitigate the formation of organic or inorganic foulants is a necessity for many RO systems. Pretreatment technologies would be specific to the RO feedwater quality.

RO removal of PFAS from various waters (for example, semiconductor wastewater, drinking water, surface water, and reclaimed water) has been studied and several studies have combined RO with nanofiltration (NF). PFOS removal > 99% was achieved using four different types of membranes over a wide range of feed concentrations (0.5–1,500 ppm [mg/L]) (**Tang et al. 2006**). Another study by **Tang et al. (2007)** tested five RO and three NF membranes at feed concentrations of 10 ppm PFOS over 4 days. The PFOS rejection and permeate flux performances were > 99% for RO and 90–99% for NF. The use of RO and NF as advanced drinking water treatments is still limited, but both technologies have been shown to be successful for the removal of longer chain (> C5) PFAAs (**Baudequin et al. 2011**; **Loi-Brügger et al. 2008**; **Tang et al. 2006**).

Thompson et al. (2011) studied the fate of perfluorinated sulfonic acids (PFSAs) and carboxylic acids (PFCAs) in two water reclamation plants that further treat water from wastewater treatment plants (WWTPs) in Australia. One plant (Plant A) used adsorption and filtration methods alongside ozonation; the other (Plant B) used membrane processes and an advanced oxidation process to produce purified recycled water. At both facilities, PFOS, perfluorohexane sulfonate (PFHxS), perfluorohexanoate (PFHxA), and PFOA were the most frequently detected PFAS. Comparing the two reclamation facilities, Plant A showed some removal during the adsorption/filtration stages. Overall, however, Plant A failed to completely remove PFOS and the PFCAs shorter than PFNA in chain length. All PFAS present were removed by RO at Plant B from the finished water to concentrations below detection and reporting limits (0.4–1.5 ng/L).

Design/Operating Considerations: This section refers to design and operating considerations for both RO and NF systems. Typical high-pressure membrane systems can achieve recoveries between 70% and 85%, with some high recovery applications able to achieve >95% recovery (**Bond and Veerapaneni 2008**; **Safulko et al. 2023**; **Stover 2013**). Recovery is defined as the ratio of treated effluent (permeate) to feed water. The feed water not accounted for in the permeate is the reject or concentrate. In conventional systems, the concentrate fraction may represent 15%–30% of the feed flow or <5% of the feed flow for high recovery applications. In conventional or high recovery high-pressure membrane systems, recovery is typically limited by the feed water quality.

In the process of planning and implementing a high-pressure membrane filtration system, there are several important issues that affect system design and operation and could impact system performance and thus PFAS removal. These issues include membrane flux, water quality, and temperature.

- **Membrane Flux:** One of the major challenges in the application of membrane technology is fouling (significant flux loss due to continuous accumulation of colloidal and organic matter, precipitation of inorganic salts, and/or microbial growth). There are several ways to mitigate fouling: (1) changing operating conditions, (2) modifying the membrane, and (3) modifying the feed by adding antifoulants prior to filtration system (pretreatment) (**Roux et al. 2005**). Adequate pretreatment and appropriate membrane selection can slow the fouling rate, but routine membrane cleaning is an essential step in maintaining the performance of the membrane process. Membrane replacement is a necessary part of plant operation to maintain the quality of the produced water (**Abdul-Kareem Al-Sofi 2001**). Although there are a number of cleaning techniques, such as physical or chemical or a combination of both, chemical cleaning methods are more widely used by NF and RO industries for membrane cleaning and regeneration. Spent cleaning solution may contain PFAS and would need to be managed properly.

- **Water Quality:** Because water quality can have a significant impact on membrane flux, feedwater quality is also a primary design consideration for membrane filtration systems. Poorer water quality (high suspended and dissolved solids, co-contaminants) will reduce flux, which in turn increase the necessary membrane area and required number of membrane modules, adding to both the cost and the size of the system. However, pretreatment can often improve feedwater quality at a lower cost than additional membrane area. Because RO is a relatively expensive

technology, efforts to improve water quality with pretreatment processes ahead of the RO membranes (filtration, precipitation; see **Section 12.7**) will result in reduced capital and operating costs.

- **Temperature:** Like other water quality parameters such as turbidity and total dissolved solids (TDS) (for NF/RO systems), the temperature of the feedwater also affects the flux of a membrane filtration system. Water becomes increasingly viscous at lower temperatures; thus, lower temperatures reduce the flux across the membrane at constant transmembrane pressure or alternatively require an increase in pressure to maintain constant flux. Because rejection decreases as membrane pores expand at higher temperatures, more permeation of PFAS across the membrane could occur at higher operating temperatures.

Sustainability: The environmental footprint for this technology includes energy source and consumption during treatment system operation, as well as manufacturing/disposal of pretreatment/treatment media (examples may include solids from upstream precipitation/coagulation or microfiltration, used cartridge filters, and worn RO membrane modules) and cleaning solutions to maintain the membrane. RO requires power for high-pressure pumps and the management of concentrate, which can be energy intensive.

An issue inherent to contaminant removal by membrane processes is the disposal of the PFAS-enriched concentrate, which must be carefully considered. Development of effective treatment methods for the concentrate entails evaluating significant parameters, such as volume generated, concentration, characteristics of the feedwater, and operational conditions, and using well-verified analytical methods to detect trace amounts of contaminants. Concentrate treatment and management alternatives remain an active area of research (**Joo and Tansel 2015**). **Tow et al. (2021)** documented treatment and management alternatives specifically focused on PFAS-impacted concentrates. **Tow et al. (2021)** reviewed 22 different PFAS-impacted concentrate treatment or management alternatives that included application of additional separation technologies (for example, adsorbents, foam fractionation), destructive technologies, and disposal/sequestration options. There are numerous options to consider for PFAS-impacted concentrate treatment and/or management, and identifying the best alternative will be a function of site-specific factors including location, volume of concentrate, PFAS concentrations, and presence of co-contaminants.

12.2.3 Foam Fractionation

Treatment Description: In the PFAS water treatment space, the term foam fractionation is used to encompass a larger set of adsorptive bubble separation technologies including foam, bubble, and aerosol fractionation. Foam fractionation is a physical separation process that traditionally uses air or other gases to generate bubbles rising through a water column to strip amphiphilic substances such as PFAS from the bulk liquid (**Lemlich and Lavi 1961**; **Lemlich 1972**). Foam fractionation technology has been used for decades in the commercial-scale aquarium business to clean water by separating and removing proteinaceous waste and has been advanced to multistage configurations for PFAS separation and concentration. Amphiphilic PFAS adsorb to the surface of the bubbles as they rise upwards. PFAS that accumulate at the top of the column as a concentrated foamate are then removed for further treatment or disposal. This process has been implemented for ex situ water treatment, and in situ, down-hole foam fractionation approaches have also been tested but are in less developed stages.

Treatment Mechanism: Air or other gaseous bubbles are introduced into a PFAS-containing liquid, which causes amphiphilic PFAS and other amphiphilic organic compounds to adsorb to the bubble surface, separating them from the bulk water. As the bubbles migrate upwards, PFAS are removed from the bulk liquid. The top foamate layer is concentrated in PFAS and can be removed passively via overflow or actively via vacuum suction for further treatment. The extent to and rate at which PFAS are removed depends on individual PFAS physical chemical properties, background water quality properties, and operational considerations discussed in the subsequent sections. **Buckley et al. (2021)** presented a

detailed review, including description of key separation mechanisms, of foam fractionation for water treatment. **Stevenson and Li (2014)** produced a monograph on the theory and practical implementation of foam fractionation.

State of Development: Foam fractionation has been studied at the bench scale and implemented at the pilot- and full-scale level to remove PFAS in groundwater (**Burns et al. 2021**) leachate (**Burns et al. 2022**; **Newman 2022**; **Smith et al. 2022**; **McCleaf et al. 2021**; **Robey et al. 2020**), and industrial water (**Smith et al. 2023**). The first application of foam fractionation for PFAS treatment was developed and built in Australia and is currently operating at full-scale in Queensland, Australia and at other sites around the world (see the case study in **Section 15.2.4.1** and **Burns et al. (2021)**. Foam fractionation systems have successfully removed PFOS and PFOA to low level parts per trillion levels (**Burns et al. 2021**; **Burns et al. 2022**; **Newman 2022**; **Smith et al. 2022**; **Smith et al. 2023**). Additional research is underway to promote removal of short-chain PFAS such as PFBA and PFBS in foam fractionation, which to date have not been effectively removed across all waters tested. Short-chain carboxylates have proven especially difficult to remove. Foam fractionation is provided by multiple commercial vendors in the United States, Europe, Canada, and Australia. Maximum flow rates implemented in the field are on the order of 50–150 gallons per minute in single fractionators. Scale up to larger foam fractionators is theoretically feasible, and multiple fractionators in parallel have been deployed to treat higher flow rates.

Effectiveness: Foam fractionation is highly effective at removing PFOS and PFOA and longer chain PFAS (**Burns et al. 2021**; **Newman 2022**; **Burns et al. 2022**; **Smith et al. 2022**) to single-digit parts per trillion levels, but its performance at removing PFAS with fewer than six perfluorinated carbons remains mixed. Removal of PFAS during foam fractionation is dependent upon individual PFAS adsorption coefficients (**Burns et al. 2022**), which are derived from the adsorption isotherm under specific conditions for each compound for uptake onto a gas/liquid interface. As with adsorptive media, perfluoroalkyl sulfonates of an equivalent perfluoroalkyl chain length are removed more effectively than perfluoroalkyl carboxylates (for example, PFHxS is removed more effectively than PFHpA). Researchers and practitioners have identified that chemical additions, often in the form of cationic surfactants, can improve the removal of PFBS, PFHxA, PFPeA, and PFBA (**Newman 2022**; **Buckley et al. 2023**; **Vo et al. 2023**). A cationic surfactant that successfully removed PFBA in a deionized solution of sodium chloride was unable to remove PFBA from landfill leachate under similar operating conditions (**Buckley et al. 2023**; **Vo et al. 2023**). Foam fractionation is also effective at removing a wide range of PFAS concentrations (for example, nanograms per liter to milligrams per liter); however, greater orders of magnitude removal require longer hydraulic retention times and/or additional stages of treatment.

Foam fractionation can also be effective for PFAS removal on a wide range of water quality types without the need for additional pretreatment. The complexity of the leachate matrix is likely one reason why foam fractionation has been trialed so extensively on leachate (**Burns et al. 2022**; **Newman 2022**; **Smith et al. 2022**; **McCleaf et al. 2021**; **Robey et al. 2020**). Compared to PFAS treatment with GAC, anion exchange resin, and reverse osmosis, foam fractionation performance is impacted in a much more limited way by background analytes such as TOC, dissolved metals, and hardness that foul adsorptive media and membranes. The primary constituents that concentrate into the foamate through a foam fractionation process are suspended solids, PFAS, and other surfactants, including any used to enhance the foaming process, while other water quality characteristics such as dissolved anions and cations remain similar in concentration to the source water. See the case study in **Section 15.2.4.2**.

Site-specific water chemistry does impact foam fractionation performance, so laboratory testing is recommended to optimize pilot design. Some researchers have reported a higher degree of removal during foam fractionation as TDS increases in the source water (**Buckley et al. 2023**).

Design/Operating Considerations: Design parameters that can affect the performance of ex situ foam fractionators include the following:

- The non-PFAS characteristics of the water, including constituents that can increase or diminish the natural foaming potential of the water
- The hydraulic retention time of the fractionator; hydraulic retention times reported in the literature for stripping fractionators have typically fallen within the range of 10–60 minutes (**Smith et al. 2022**; **Buckley et al. 2023**; **Newman 2022**)
- Countercurrent or co-current flow of gas and water
- The amount, speed, and bubble size of gas introduced per volume of water in the fractionator. The bubble size is partially related to the type of gas introduced, with ozone bubbles typically introduced with a smaller size than air.
- The amount of turbulence introduced along with the gas. More turbulence tends to increase foam generation and has an overall beneficial impact on PFAS removal
- The height of the water column relative to the foam collection point (that is, a weir or overflow)
- The mechanism of foamate removal, which can include traditional spillover or application of a vacuum process
- The number of treatment units operated in series
- Batch, semicontinuous batch, or continuous flow operation, which is discussed in more detail below
- The introduction of chemical agents to increase foaming or removal of particular PFAS

In ex situ foam fractionation processes, foam fractionation can be operated in either "stripping-wet" or "enriching-dry" modes (**Smith et al. 2023**). In stripping-wet mode, the top of the water column is located very close to the weir or overflow so that foamate may readily exit the fractionator. This mode of operation does not allow for significant foam drainage of interstitial liquid prior to foamate exiting the fractionator, so a relatively wet foam is generated. Under the enriching-dry mode, the fractionator fill volume is set at a larger distance from the weir or overflow to allow for a greater degree of drainage of excess interstitial liquid from the foamate. The enriching-dry mode produces a low volume of foamate, but typically results in target PFAS remaining in the treated water exceeding low-level PFAS treatment criteria, so the underflow or raffinate will require further treatment. Setting the fill volume too low in relation to the weir can result in poor treatment due to ineffective collection of foamate.

Practitioners may elect to adopt either a single-batch, multistage semicontinuous batch, or continuous flow-through design depending upon PFAS target treatment criteria, required throughput, and desire to further reduce the foamate volume prior to proceeding to additional treatment. Foam fractionation setup as a batch process typically configures the stripping-wet stage first, followed by one or multiple enriching-dry stages. Foam setup as a continuous flow-through process can configure the first stage to operate in either stripping-wet or enriching-dry mode, followed by one or more additional stages to be able to reach the treatment goals by the final stage, where water height in each successive stage will require careful management. Each of the configurations has relative benefits and drawbacks. For example, batch typically has lower flow-through capacity compared to flow-through designs, but has faster stripping times per fractionation column.

The stripping of PFAS from bulk phase liquid into a gaseous phase raises relevant concerns about worker exposure to PFAS and other compounds that may be stripped out of the aqueous phase via the operation of these systems. In the **Smith et al. (2023)** study, PFAS were measured in aerosols and air around a foam fractionator; the mean measured sum of PFAS was twenty-seven times higher than the concentration measured at a reference site, with the highest concentration measured closest to the outlet of the fractionator. The composition of PFAS measured was also similar to that measured in the foamate. Emissions control devices and enclosure of all foam fractionator components may be needed to mitigate gaseous PFAS releases from the foam fractionation process.

The ultimate disposition of the resulting PFAS-enriched foamate varies. Options include concentrating the foamate onto an adsorptive media or delivering it to an aqueous destruction process. The concentrated nature of PFAS in foamate makes it a good candidate for pairing with various PFAS destruction technologies, and it also promotes increased loading onto media. Electrochemical oxidation of foamate has been reported in the peer-reviewed literature with only partial ability to break down target PFAS (**Smith et al. 2023**). The TDS concentration in the final waste foamate created by foam fractionation is appreciably lower than that of residual waste material from the regenerable ion exchange resin treatment process, and may therefore have an advantage when paired with certain PFAS destruction processes.

Sustainability: The environmental footprint for this technology includes energy source and consumption during treatment system operation. One provider has reported a system energy consumption of 0.8 kWh/m3 in a semibatch system with a 250 m3 throughput that performs secondary and tertiary foam refractionation (**Burns et al. 2021**). As longer hydraulic retention times and more stages of refractionation/enrichment of foamate are introduced, energy consumption per volume of water treated increases. The PFAS-enriched foamate requires disposal, often via loading onto an adsorptive media. Destruction of PFAS in foamate is also under consideration, and research activities supporting PFAS destruction in foamate are identified in the ongoing research funded by SERDP/ESTCP. Unlike RO, the concentrate generated by foam fractionation offers an appreciable reduction in volume and is thus better suited for a low throughput, high energy consumption PFAS destruction technology.

Related Past, Ongoing, and Recent Research Funded by SERDP or ESTCP

- ER19-5075 In Situ Treatment of PFAS Using D-FAS Technology
- ER22-3298 Utilizing PFAS Aggregation at the Gas-Water Interface for Energy-Efficient PFAS Destruction
- ER21-5124 Low-Cost, Passive In Situ Treatment of PFAS-Impacted Groundwater Using Foam Fractionation In an Air Sparge Trench
- ER22-3438 Extraction and Removal of PFAS from Impacted Water and Soil using Air Bubbles
- ER22-3352 Cost-Effective Treatment of PFAS in Landfill Leachate Using Foam Fractionation
- ER22-3221 Gas Sparging Directly in Aquifers to Remove or Sequester PFAS
- ER23-7939 Sustainable On-Site Removal and Destruction of PFAS Using Surface Active Foam Fractionation and Supercritical Water Oxidation

12.2.4 In Situ Remediation with Colloidal Activated Carbon

Treatment Description: The primary function of injectable colloidal activated carbon (CAC) is to immobilize contaminants and prevent their further horizontal and vertical migration in groundwater. By flowing CAC into the flux zones of an aquifer, dissolved contaminants migrating in groundwater, as well as those contaminants back-diffusing from lower permeability zones, are captured and taken out of solution, thereby lowering the risk to downgradient receptors (for example, drinking water wells, surface water bodies). Long-term performance is subject to various parameters, such as contaminant flux and media saturation, similar to GAC.

CAC may be injected in situ using a grid pattern in source zones to immobilize contaminants, or it may be injected in a transect pattern perpendicular to the width of a plume to mitigate contaminant flux. Direct push or vertical wells can be used to inject CAC into the subsurface (**McGregor 2020**).

Treatment Mechanism: CAC consists of colloidal-sized particles of activated carbon (2 microns diameter on average) in aqueous suspension (the consistency of black-colored water), which can flow into aquifer flux zones upon gravity-feed or low-pressure injection. After injection, CAC particles will attach strongly to the aquifer matrix, where they can act as passive sorbents for organic contaminants, including PFAS. This sorption mechanism is detailed in **Section 12.2.1**. Due to the small size of the particles, the kinetics of

PFAS sorption on colloidal carbon are much faster than can be achieved with GAC, resulting in higher removal efficiencies (**Xiao et al. 2017**).

Unlike larger powdered activated carbon (PAC) particles (50+ micron diameter), CAC particles are small enough to move through most aquifer material pore throats under low pressure, allowing for relatively even distribution within aquifer materials. **McGregor (2020)** demonstrated that trying to inject PAC was not as successful as injecting CAC because higher injection pressures were required, resulting in preferential PAC distribution in more permeable lenses of sand. **McGregor (2020)** also observed preferential accumulation of PAC within the sand packs of monitoring wells that were present at the time of injection at four sites, which would lead to false positive treatment results. CAC accumulation was not observed in the sand packs of the monitoring wells.

State of Development: Over the past decade, in situ CAC treatment technology has been well established with project sites contaminated with hydrocarbon and chlorinated solvent contaminants. The application of the technology to treat PFAS contamination in groundwater has been successfully employed on >25 project sites in North America, Europe, the Middle East, and Asia (for example, **McGregor 2020**; **Carey et al. 2022**). A case study is included in **Section 15.2.3**, which details a full-scale CAC project site to predict the theoretical longevity and performance of the CAC to treat PFAS in groundwater in the presence of hydrocarbons. Results indicated an anticipated longevity of successful PFAS treatment on the order of decades. The study noted that longevity of performance could be extended by increasing the CAC dose, by increasing the thickness of the treatment zone perpendicular to flow, or by additional injection upon any future PFAS breakthrough.

Effectiveness: **McGregor (2018)** discussed the in situ injection of CAC at a site in central Canada to mitigate mass flux of PFOS and PFOA from a fire training area source zone. Prior to CAC injection, PFOS and PFOA were measured in groundwater monitoring wells at concentrations up to 1,450 ng/L and 3,260 ng/L, respectively. Monitoring wells at the site were screened in a shallow, thin silty sand overburden unit at depths of approximately 5–10 feet below ground surface. CAC was injected into the source zone at low pressure through temporary wells installed using direct push technology. Postinjection core sampling indicated that CAC was measured at distances of up to approximately 15–20 feet from the injection wells. **Carey et al. (2022)** discussed the performance of this project site where no detections of PFAS in the CAC adsorption zone were detected over the first 5 years (10 sampling events) except for a single well where low detection of PFOS and PFUnA at 533 days was seen (but not reproduced). The first five monitoring events included analysis for only PFOS and PFOA. The last six monitoring events included analysis for a full suite of PFAAs. At event 11 (the 6-year point), the detection limits were lowered to 1 ng/L and several PFAS were observed slightly above the new detection limits.

Carey et al. (2022) presented performance data on 16 field-scale projects employing CAC to treat PFAS in groundwater. On nine of the sites PFAS have been reduced to concentrations at or below detection levels, including five projects that analyzed for both short- and long-chain PFAS. Another five project sites showed >90% reduction in PFAS constituents, while one site showed >80% reduction. On a site where treatment of PFAS in groundwater was attempted near a landfill, initial results indicated >91% reduction but were not sustained, presumably due to the high dissolved organic load (>20 mg/L) associated with commingled landfill leachate.

Design Considerations: The focus of a CAC treatment is to target the actual vertical zone in the subsurface carrying the PFAS contamination rather than simply treating a broad vertical section of aquifer, as is often the case with pumping systems. This targeting of the vertical PFAS flux zone allows for a more accurate interception of the PFAS mass requiring treatment and usually results in a much lower cost of treatment. The use of direct-push injection or dedicated injection wells targeting these flux zones allows for accurate application of the CAC suspension.

The longevity of any CAC treatment performance will be dependent upon PFAS composition, rates of PFAS mass discharge, presence of co-contaminants, CAC dosing, and CAC application design. **Carey et al. (2019)** performed modeling with respect to an actual full-scale CAC project site to predict the theoretical longevity and performance of the CAC to treat PFAS in groundwater in the presence of hydrocarbons. Results indicated an anticipated longevity of successful PFAS treatment on the order of decades. The study noted that longevity of performance could be extended by increasing the CAC dose, by increasing the thickness of the treatment zone perpendicular to flow, or by additional injection upon any future PFAS breakthrough.

Sustainability: The environmental footprint of in situ CAC treatment is relatively small when compared to treatment technologies requiring pumping of groundwater and aboveground separation of contaminants, hauling of waste, and then destruction of collected waste. CAC operates passively. Use of CAC avoids on-going energy requirements and greenhouse gas associated with operation and maintenance of pump and treat systems.

The **Danish EPA (2022)** performed a sustainable remediation methodology assessment (**ISO 2017**) generating a comparative full life cycle analysis (LCA) on the use of a commercially available CAC product, and pump and treat technology for treating groundwater contaminants. Results showed that over a 30-year operating period, the CAC treatment generated less than 5% of the greenhouse gases generated using the pump and treat approach. Although the actual site chosen for comparison in the study was treating trichloroethylene contamination, the comparative LCA results may provide information about the sustainability of the CAC treatment approach relative to pump and treat approaches for carbon-sorptive dissolved organic contaminants.

Related Past, Ongoing, and Recent Research Funded by SERDP (ER)

- ER20-5100 In Situ PFAS Sequestration in AFFF-Impacted Groundwater
- ER20-5182 Validation of Colloidal Activated Carbon for Preventing the Migration of PFAS in Groundwater
- ER21-1070 Hydraulic, Chemical, and Microbiological Effects on the Performance of In-Situ Activated Cardon Sorptive Barrier for PFAS Remediation in Coastal Sites

12.2.5 Supercritical Water Oxidation

The Priority Topics for Treatment Technologies include updated information for supercritical water oxidation (see **Section 1.6.2**).

12.3 Field-Implemented Solids Treatment Technologies

Field-implemented technologies are those that have been implemented in the field by multiple parties at multiple sites and have widespread regulatory approval, and the results have been documented well in the peer-reviewed literature. The technologies in this section may be applied to a variety of PFAS-impacted solid media, including soil, sediments, or sludge. The Priority Topics for Treatment Technologies include updated information about treatment of PFAS-contaminated sediment (see **Section 1.6.4**).

One unique class of solid waste that may require treatment is biosolids generated by wastewater treatment plants, which have been historically managed through land application, use or disposal at landfills, or incineration. These technology options have not been fully evaluated to determine their effectiveness for PFAS in field-implemented examples. The regulatory landscape for management of biosolids is evolving, and some states have started to require testing. A few prohibit land application if concentrations of certain PFAS are greater than specific levels. (see **Section 12.1.4.3**)

Site-specific evaluation is always needed to identify the best technology for a given treatment scenario. As with water treatment, solids treatment can be performed ex situ (for example, excavation or dredging) or in situ (for example, injection or reactive capping). At present, field-implemented solids treatment has been performed almost entirely ex situ. There are currently three known field-implemented technologies for treating soil contaminated with PFAS: sorption/stabilization, excavation/disposal, and soil washing.

12.3.1 Sorption and Stabilization

Treatment Description: Amendments are added to the soil and sediment to reduce the potential for PFAS to mobilize from soil and sediment to groundwater and surface water. For sorption purposes, PFAS-adsorbing materials (for example, activated carbon) can be applied through in situ soil mixing or ex situ stabilization (for example, pug mill mixing) to reduce the leachability of PFAS from contaminated soil/sediment through physical and/or chemical bonding.
Sorption and stabilization (considered "immobilization" or "chemical fixation" technologies) is a relatively quick, simple, and low-cost (relative to off-site disposal) way to reduce ongoing PFAS contamination transport to waterways and groundwater from source zones. The main disadvantage is that these technologies do not destroy the contaminants, but rather bind or immobilize them. For some amendments, established test methods have shown the binding to be stable over the long-term (see below).

Stabilizing PFAS in situ may reduce the effectiveness of future in situ soil treatments and thus limit future remediation to excavation and disposal to landfill or in situ remediation employing strong chemicals and/or high energy inputs to overcome stabilization bonds. Long-term project objectives should be carefully evaluated before implementing any technology that could limit future options. Additionally, in flood-prone areas, immobilized/stabilized soils with PFAS could be eroded and transported off site.

Treatment Mechanism: Amendments adsorb or stabilize PFAS to reduce their release from soil. This occurs primarily through electrostatic interactions between charges on the PFAS functional group and charges on the sorbent, as well as hydrophobic interactions between the amendment and the carbon-fluorine chain on the PFAS. "Principal component analysis" has shown "that electrostatic sorption dominates for shorter chained PFAS and that hydrophobic sorption dominates for longer chained PFAS" (**Sörengård et al. 2020**). Typical amendments that have been demonstrated in the field include activated carbon and activated carbon-composite materials, such as activated carbon blended with aluminum hydroxide, kaolin, and carbon. Some of these blends are said to be specifically designed to treat anionic, cationic, and zwitterionic long- and short-chain PFAS (**Kempisty, Xing, and Racz 2018**).

State of Development: Sorption and stabilization techniques using carbon-based amendments are considered field-implemented technologies. Various amendments have been applied to soil/sediment both in situ and ex situ. Different delivery methods for amendments, such as injection or in situ mixing, may provide different results depending on geology and objectives. Proprietary formulations of activated carbon with inorganic amendments have been developed with the intent of increasing their sorption of PFAS. One such product was used on a large-scale project involving the ex situ treatment of 900 tons of PFAS-impacted soil from an airport site in Australia (**Stewart 2017**). However, controlled third-party laboratory studies (**Sörengård et al. 2020**) and field tests (**USEPA 2017**) have shown little advantage to these formulations when compared to powdered activated carbon alone. Additional studies have been performed looking at biochar (**Zhang and Liang 2022**) and fly ash (**Sörengård et al. 2022**), with mixed results.

Effectiveness: Sorption and stabilization techniques vary in their effectiveness according to site conditions, PFAS types, mixing approaches, and amendments chosen.

The effectiveness of 44 different sorption amendments to treat a wide range of PFAS was studied and summarized in a detailed and controlled series of experiments (**Sörengård et al. 2020**). The study

included three forms of powdered activated carbon, a commercial proprietary blend of carbon and minerals, granular activated carbon, biochars, and a number of other sorbents. Results showed the powdered activated carbon amendments outperformed all other amendments in sorbing PFAS in all PFAS groups measured (short-chain C3–C7 PFCAs, long-chain C8–C17 PFCAs, and PFSAs, FTSAs, and FOSA).

A study conducted with an activated carbon-based blend amended with inorganic minerals showed that at average addition rates of around 2.5–5% (wt/wt), PFOS and PFOA in soil leachates were reduced by 95% to >99% following a 48-hour treatment process (**Stewart and MacFarland 2017**).

The charge on the PFAS affects sorption (for example, cations sorb more readily than zwitterions and anions). Aquifer and soil chemistry also affect the sorptive ability of PFAS onto the amendments. High organic content in soil can reduce effectiveness (**NGWA 2017**). Low pH, the presence of polyvalent cations in the soil, or treatment amendment also increases sorption, retardation, and metals precipitation. An independent study at the University of Adelaide, Australia, showed that environmental ranges of pH and ionic strength did not adversely affect the binding of a specialized amendment to PFOA (**Lath et al. 2018**). Co-contaminants also play a role in the effectiveness of PFAS sorption. A recent review article (**Li, Oliver, and Kookana 2018**) showed that the organic carbon component of natural soils and sediments plays less of a role in PFAS sorption than once thought; the mineral component of the soil/sediment and the pH conditions play a more important role in PFAS adsorption.

In independent studies, the Multiple Extraction Procedure (MEP; USEPA Method 1320; **USEPA 1986**) has been used to successfully demonstrate the simulated long-term stability of immobilized PFAS in amended soils (**Stewart and MacFarland 2017**). The MEP is designed to simulate 1,000 years of acid rain conditions in an improperly designed sanitary landfill. In another independent study, the accumulation of PFAS in earthworms and plants was reduced by >90% in soil treated by carbon-based immobilization compared to untreated soils (**Bräunig 2016**; **Kempisty, Xing, and Racz 2018**). The amended soil can be mixed with concrete and other stabilizers to improve performance; however, the concrete increases pH and may influence binder performance (**Ross et al. 2018**).

Design/Operating Considerations: To establish design and application parameters for implementation of sorption and stabilization technology in soils, it is necessary to perform site-specific laboratory and/or pilot treatability tests. Information and quantity of amendment material required (dose rates) for materials can be determined with either simple beaker or jar-type lab treatability tests. These studies are most applicable if site soils and water are used to ensure that the effects of site-specific geochemical characteristics are assessed. Once the dose of amendment material is determined, field pilot studies are often conducted to validate lab data and design for full-scale implementation.

For in situ soil mixing, the amendments are added to soils at the design dose or application rate under controlled conditions with specific types of equipment designed to perform mixing. In situ soil mixing can be performed on soils in place with a wide range of standard construction equipment, including excavators, large diameter augers, and in situ blenders. In addition to in situ soil mixing, soils can be removed and mixed in equipment such as a pug mill or other similar mixing systems. As for other contaminants that have been stabilized in projects executed over the past 30 years, the thoroughness of the mixing can impact performance of PFAS-specific stabilizing agents.

After implementation of in situ soil mixing, it is important to perform postconstruction quality assurance and quality control to verify design endpoints. This may include leachability (Toxicity Characteristic Leaching Procedure (TCLP), USEPA Method 1311(**USEPA 2021**); Synthetic Precipitation Leaching Procedure (SPLP), USEPA Method 1312(**USEPA 2021**); or Multiple Extraction Procedure (MEP), USEPA Method 1320(**USEPA 2021**)), hydraulic conductivity (ASTM D5084, **ASTM 2016**), and strength tests (various). ITRC has prepared a technical and regulatory guidance document on the development of

performance specifications for solidification/stabilization (**ITRC 2011**) that may prove useful in planning a PFAS soil stabilization/solidification project.

Sustainability: The environmental footprint for sorption and stabilization includes emissions from earthwork equipment, manufacturing, and transporting amendment material. This footprint can be smaller than excavation if the treated soil is reused on site. Community impacts include hindrance of redevelopment due to land use restrictions. However, if the land use is not expected to change, such as on active government-owned aviation or military sites, stabilization with amendments and reuse of the soil may be a viable and cost-effective approach. If PFAS regulations change in the future, which is likely, reusing the PFAS-impacted soil could expose a facility owner to future liability.

Resources are available for performing a sustainability assessment for sorption and stabilization remedial design, relating to other contaminants (**Goldenberg and Reddy 2014**; **Hou et al. 2016**; **Kuykendall and McMullan 2014**).

Related Past, Ongoing, and Recent Research Funded by SERDP or ESTCP

- ER22-3124 A New Concept of "Release-Capture-Destruction" to Enable Remediation of PFAS in Source Zone Soils
- ER22-3194 Green Remediation of PFAS in Soil and Water
- ER22-7313 Management and Mitigation of PFAS Leaching from Concrete

12.3.2 Excavation and Disposal

Treatment Description: This approach involves removing contaminated soil/sediment for off-site disposal. The contaminated material is disposed of at a permitted landfill, then the excavated area is filled with clean backfill. Treatment with stabilizing agents can reduce PFAS leachability from excavated soils and should be considered prior to landfilling. Sometimes, excavated soil/sediment can be treated on site using the sorption and stability approach or thermal treatment (as discussed in the Sections **12.4** and **12.7.2**) followed by soil reuse or off-site disposal.

Treatment Mechanism: This method is intended to remove PFAS from the source location. Transportation and disposal in a lined landfill is an option for excavated soil; however, leachate management should be a consideration at these facilities (see **Section 12.1.4.2**).

State of Development: Soil excavation and disposal is a well-demonstrated, proven technology. However, PFAS have been reported in landfill leachate (**Lang et al. 2017**), although the source for PFAS in leachate may be consumer product waste containing fluorochemicals. In some states, the leachate is not analyzed or regulated for PFAS. Disposal of PFAS waste to landfills potentially adds to the PFAS contaminant load in the landfill leachate. Some nonhazardous waste landfills do not accept PFAS waste.

Effectiveness: Excavation and disposal of PFAS-contaminated soil effectively removes a source area that may otherwise serve as a continuing source of groundwater contamination but does not result in destruction of the PFAS. Disposal of PFAS-impacted soils or wastes into unlined landfills should be avoided as unlined or improperly lined landfills can be sources of PFAS to the environment.

***Design/Operating Considerations*:** Difficulties in finding landfills willing to accept the waste, coupled with rapidly changing regulations regarding whether PFAS are hazardous or not, make this option less straightforward than one would expect. Case-by-case inquiries to landfill facility owners is likely the best course of action. Overall, issues related to disposal of PFAS in landfills are similar to issues commonly encountered with other contaminants. See **Section 2.6.3**, Solid Waste Management, for additional discussion on this topic.

Sustainability: The environmental footprint for excavation and disposal includes earth-moving equipment emissions, transporting contaminated soil and backfill, and resource extraction (such as borrow area fill material) of backfill material.

Truck hauling traffic affects the local community by creating additional traffic congestion, noise, and particulate matter emissions. The cost for this approach is high, but the solution is generally permanent and for smaller treatment volumes may be cost-competitive. Guidance is available for performing a sustainability assessment for an excavation and disposal remedial design (**Cappuyns and Kessen 2013**; **Goldenberg and Reddy 2014**; **Söderqvist et al. 2015**; **Song et al. 2018**).

12.3.3 Soil Washing

Treatment Description: Soil washing is generally considered a media transfer technology. It is an on-site, ex situ treatment process that uses physical separation and chemical desorption/extraction techniques to remove adsorbed PFAS mass from soil. Fundamentally, the application of soil washing systems relies on the principle that most environmental contaminants, with the propensity to interact with soil, will preferentially bind to the finer soil fraction (for example, clays and silts) versus the coarser grained soil fraction (for example, sands and gravels) (**USEPA 1996**). Soil washing systems use a wash solution usually consisting of water, but surfactant and/or an extraction solvent can also be used to dissolve and concentrate PFAS (**ESTCP 2022**). Physical size separation techniques are used to separate the finer grained from the coarser grained soil particles, thereby concentrating and reducing the PFAS-impacted soil volume that must be further treated or disposed. Refer to **Figure 12-6** for a typical soil washing process schematic.

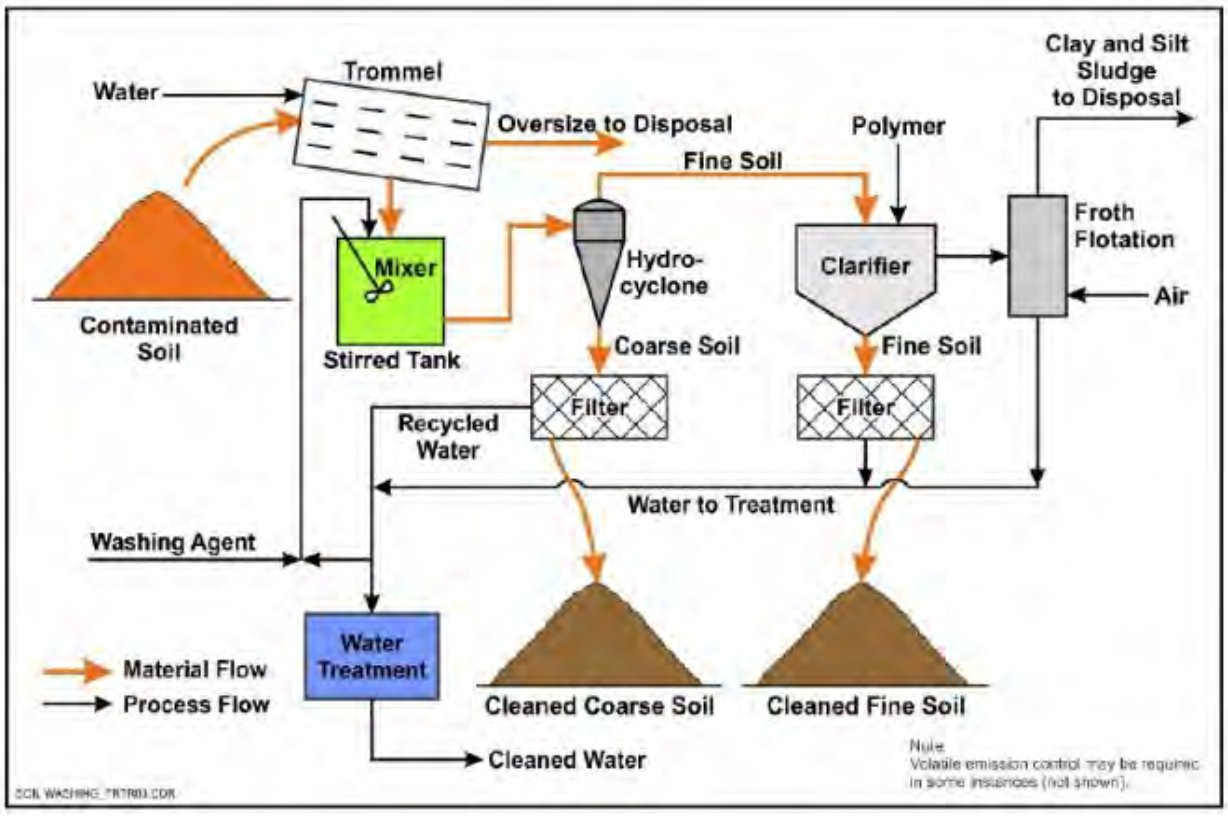


Figure 12-6. Soil washing process schematic.

*Source: Federal Remediation Technologies Roundtable (**https://www.frtr.gov/matrix/Soil-Washing/**).*

Treatment Mechanism: The concept of reducing PFAS soil contamination via particle size separation is underpinned by the preference of PFAS to sorb to soil fractions with high organic carbon content, promoting stronger hydrophobic interactions. Typically, finer soil fractions (for example, clays and silts) are enriched in organic carbon relative to coarser grained soil fractions (for example, sands and gravels). Therefore, using a fluid, such as water, to promote particle size separation can effectively segregate the soil fraction containing the highest PFAS impact. The PFAS impacted fine grained soil fraction can be further processed to minimize volume and managed separately for treatment or disposal from the coarser grained soil fraction. Several mechanical approaches can be implemented to facilitate the particle size separation process, including vibratory screens, trommels, hydrocylcones, and spiral classifiers (**USEPA 1999**).

During the soil washing process, the sorbed PFAS mass may transfer from the solid phase to the liquid phase through diffusion processes. Additionally, PFAS mass removal from impacted soil may be enhanced by promoting both desorption and dissolution into the liquid phase by flushing with water or an extraction solvent. PFAS extracted into the aqueous phase is then treated by other technologies (for example, GAC and/or IX) or staged for off-site disposal (**ESTCP 2022**). Leveraging desorption for PFAS mass reduction in impacted soil during the soil washing process is most effective for PFAS with lower distribution coefficients (i.e., less preference for the solid phase) and higher solubility in the wash solution.

State of Development: Soil washing is considered a field-implemented technology based on its history with other contaminants and has been evaluated for PFAS treatment efficacy in multiple field tests. The technology grew out of mining industry operations and was modified for environmental applications during the 1990s. It has historically been applied to soils contaminated with metals, semivolatile organics, and PCBs/pesticides (**USEPA 1999**; **USEPA 1993**). The same soil particle size separation and dissolution wash processes employed for these historical contaminants have been transitioned for application to PFAS-impacted soils based on similar physical and mass transfer properties. The transference of these separation and removal processes has been verified for PFAS-impacted soils by field demonstration projects performed to date. PFAS soil washing pilot/field demonstration projects have been performed at multiple Australian and U.S. sites (**Quinnan et al. 2022**; **ESTCP 2022**; **Becker 2022**). There are currently only a small number of vendors offering ex situ soil washing for full-scale applications. Further research and field studies are still required for alternative surfactants/extraction solutions that can be employed to remove PFAS more effectively from the finer grained soil fraction.

Effectiveness: A general guideline for contaminant reductions by soil washing is 90%–95% for the coarser grained soil fraction, assuming particle size separation of the coarser grained soils and mass transfer to the liquid phase for follow-up treatment/removal.

Results from an ESTCP pilot test confirmed that coarser grained sand and gravel fractions met performance goals, while the finer grained fraction was segregated for later treatment or disposal. The grain size composition was approximately 30% gravel, 40% sands, and 30% fines. Approximately 180 tons of PFAS-impacted soil was treated. Baseline PFOS concentrations detected in composite samples representing combined particle sizes ranged between 3.9 and 740 µg/kg, while detected baseline total PFAS concentrations ranged between 5.38 and 874 µg/kg. PFOS removal efficiencies were generally highest in the gravel fraction (94.6%–98.1%), followed by the sand fraction (88.6%–96.1%), and the finer grained fraction (-7.7%–61.8%, where variability in the PFAS concentrations in the finer grained fraction is thought to have caused the negative removal efficiency). The removal efficiencies for total PFAS for the coarser grained fraction were generally higher than PFOS for each stockpile, indicating that the soil washing process was effective at removing other PFAS (**Quinnan et al. 2022**; **ESTCP 2022**).

Another field-scale soil washing demonstration investigated the treatment of approximately 573 cubic yards of PFAS-impacted loamy sandy soil and sediments. Baseline stockpile characterization for PFOS concentrations ranged between approximately 3,000 µg/kg and 12,000 µg/kg for the coarser and finer

soil fractions, respectively. Following two rounds of soil washing treatment, the coarser grained soil fraction showed a PFOS reduction of 99% while the finer grain soils PFOS reduction was 89%. Because of the particle size separation, the total soil volume requiring off-site disposal was reduced by more than 90% (**Becker 2022**; **ESTCP 2022**).

Design/Operating Considerations: Determining the soil grain size distribution, as well as PFAS concentrations within the various grain size types, are the key design/operating considerations. Since soil particle size separation represents the primary PFAS removal/soil volume reduction mechanisms, soil washing is less cost-effective as the percentage of finer grained soils increases. A particle size distribution of 0.25–2 millimeters is considered optimal for soil washing, while <0.063 millimeters may not be viable, which correlates to <25% silts and clays considered optimal and >50% may not be viable (**USEPA 1990**; **1997**). High clay content with corresponding high moisture levels poses a material handling and feed challenge. Heterogeneity and inconsistent feed conditions can also impact PFAS removal efficiency, which can require preprocessing for homogenization. Soils may need to be segregated by order of magnitude concentrations and treated using different process conditions to optimize treatment throughput and minimize treatment costs. Other key process parameters include soil throughput, retention time, contaminant solubility, wash solution to soil ratios, soil cation exchange capacity, and design parameters associated with the wash solution treatment and soil dewatering processes.

Sustainability: Intensive energy usage is required for the various material handling, separation, and liquids treatment operations. The generated wash solution requires treatment but can be recycled for continuous reuse. Treated soils can potentially be redeposited on site if applicable regulatory criteria are met, which avoids off-site disposal. Separated finer grained soils that do not meet regulatory criteria require off-site disposal.

Related Ongoing Research Funded by SERDP

- ER20-5258 Ex Situ Soil Washing to Remove PFAS Adsorbed to Soils from Source Zones

12.4 Incineration

Because of the increasing interest in incineration from the public, press, and regulatory community, and the potential application of incineration to liquids or solids, the following information is being provided as a separate section. The Priority Topics for Treatment Technologies include updated information for incineration, pyrolysis/gasification, and thermal desorption (see **Section 1.6.1**).

Treatment Description: Incineration is defined as "burning hazardous materials at temperatures high enough to destroy the contaminants" (**USEPA 2012**). Incineration is destruction (mineralization) using combustion, which requires heat and oxygen. Heat is applied directly to the PFAS-contaminated solids (soil/sediment/spent adsorbents/waste) or liquids (AFFF/water/wastewater/leachate/chemicals). Vaporized combustion products can be captured (precipitation, wet scrubbing) and/or further oxidized at elevated temperature. Pyrolysis and gasification are related thermal treatment technologies. Some additional information about pyrolysis and gasification is discussed in **Section 12.5**, thermal treatment for air sources and in **12.7.2** thermal treatment for solids.

State of Development: Incineration is a mature technology that has been used for various solid and liquid wastes, but its ability to remove PFAS from waste streams is a topic of study. The USEPA has compiled a PFAS Thermal Treatment Database (**USEPA 2022**) to help synthesize the current body of research.

Effectiveness: Incineration is one of only a few technologies that can potentially destroy PFAS, though the conditions required to destroy PFAS are not well understood (**USEPA 2024**). In December 2020,

USEPA released a draft interim guidance on destruction and disposal of PFAS (**USEPA 2020**) and Version 2 was released in April 2024 (**USEPA 2024**). Recent testing and reporting of PFAS destruction by incineration has documented destruction efficiencies of greater than 99 percent for some PFAS (**Barr Engineering 2022**; **Chemours 2023**; **EA Engineering 2021**).

There are multiple areas of active research to evaluate the effectiveness of incineration which initially focused on destruction temperatures and treatment times. Ongoing research is also assessing the potential of incineration to generate byproducts of incomplete combustion, to analyze stack gas, to understand deposition onto land, and to manage incinerator wastes, along with other potential risk factors.

In April 2022, in response to a congressional requirement in the National Defense Authorization Act (NDAA), the Department of Defense (DOD) placed a temporary ban on incineration of PFAS-containing materials generated by the DOD up until such time as a PFAS disposal policy was developed consistent with **USEPA (2020)** and Section 343 of the 2022 NDAA. The DOD published a memo with interim guidance about destruction or disposal of materials containing PFAS, including AFFF that has been taken out of service, on July 11, 2023 (**USDOD 2023**). The DOD interim PFAS disposal guidance supersedes the previous temporary moratorium and is expected to be updated annually. **USDOD (2023)** identifies the following PFAS disposal options in order of prioritization: 1) Spent GAC reactivation at a RCRA permitted facility; 2) landfilling at a permitted RCRA Subtitle C hazardous waste facility; 3) landfilling at a permitted RCRA Subtitle D non-hazardous solid waste facility with an appropriate leachate and gas collection and management system; and 4) incineration at a permitted RCRA Subtitle C hazardous waste facility. Publicly available air testing results for PFAS incineration destruction efficiency and byproducts of incomplete combustion were considered in the development of the DOD interim PFAS disposal guidance, while ongoing PFAS incineration research and updates to **USEPA (2020)** will be incorporated into the future annual updates. A follow-up statement was published on July 17, 2023 about additional planning and coordination that is needed before incineration is implemented (**USDOD 2023**).

Design/Operating Considerations: Waste incinerators are fixed facilities. Federal and state permits dictate the materials processed, core incinerator operations (for example, temperature and time, turbulence), and control of process air, liquid, and solid wastes. Permit and design/construction similarities reduce the operational and performance differences between individual incinerators.

When considering waste disposal options, transportation costs, energy costs, regulatory approvals, and final disposition of process waste residues should be evaluated, as these differ among incineration facilities.

Sustainability: The environmental footprint for incineration includes transportation and supplemental fuel for the incineration process. Incineration of contaminated soil, liquid wastes, and IDW is energy-intensive and PFAS emissions, including potential PFAS combustion byproducts, from incinerators are currently not well understood (**USEPA 2020**). Truck hauling traffic affects the local community by creating additional traffic congestion, noise, and particulate matter emissions. The cost for this approach is high, but the solution may be cost-competitive for smaller treatment volumes.

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER19-1408 Analysis of Fate of PFAS during Incineration
- ER22-7470 Development and Application of Injectable Fuels/Adjuncts for In Situ Treatment of PFAS and Co-Occurring Chemicals in Source Areas by Smoldering Combustion

12.5 Air Treatment Technologies

PFAS vapors or particles can be generated during any activity that involves PFAS or materials containing PFAS. The multitude of sources for PFAS-containing vapors and particles, some of which are unique due to their specific function (for example, industrial or commercial processes), is complicated by a lack of basic understanding of the chemical and physical properties for PFAS that are not used as widely. Additionally, air emissions should be considered as part of any PFAS-related activity, regardless of whether it is the primary media being treated. For example, during landfill leachate treatment, air emissions could be generated, requiring treatment.

PFAS vapors or particulates may be captured by conventional air pollution control (APC) equipment that has been historically developed to control vapors, particles, and fine dusts emitted from permanent industrial sources or temporary environmental or construction sites. Though the effectiveness of conventional APC technologies in removing PFAS from air streams is not well understood, current practice is to apply these methods and practices of vapor and dust control that are presently used or required for similar equipment and processes. The performance of these technologies should continue to be researched and documented with a focus on those PFAS that can be reliably quantified. Specific research needs for the emissions from thermal treatment technologies, including those related to APC equipment, are discussed in USEPA (**2024**, section 3.a).

A standardized method for stack testing for PFAS emissions has only recently been developed (see **Section 11.1.7.12**), and stack testing to date has primarily focused on the overall removal efficiency for the destruction technology being evaluated (for example, see **Barr 2022**). Sampling stack emissions and performing adequate analysis is an active area of research and will need to be a part of assessing adequate treatment of any stack emissions thought to contain PFAS. Additional information on the effectiveness of thermal treatment technologies is included in **Section 12.7.2**.

12.5.1 Conventional Air Pollution Control (APC) Technologies

PFAS vapors may be captured by conventional APC equipment. However, this does not mean that older methods do not need to be tested to document their performance, nor does it mean the older methods should not be modified or entirely redesigned to account for PFAS. Rather, it means that conventional APC technologies that can treat vapors and particles containing PFAS may have some level of removal efficiency and should be evaluated to ensure appropriate capture or destruction is taking place.

Thermal treatment technologies for PFAS contained in emissions are an area of focus in the research community. A limited number of these technologies have been implemented and are currently being evaluated for their efficiency.

Technologies and equipment for control of potential emissions can be placed in four groups: 1) those that capture PFAS-containing particles; 2) those that capture PFAS-containing vapors, 3) those that capture PFAS in both vapors or particles, and 4) those that destroy PFAS in the air stream being emitted from the process. Destruction of PFAS through thermal oxidation and incineration is briefly covered here and is also covered in **Section 12.4**. Particle capture and vapor capture are further described below. More information about specific air pollution control technologies is available from **USEPA (2022)**, which is a web site with links to individual technology fact sheets.

12.5.1.1 Particle Capture

PFAS that are fully partitioned to particulate matter in the air stream could be removed by particle capture mechanisms:

- Bag houses and similar units rely on filter media whose pore openings are smaller than the smallest targeted particle or particulate. The nature of the targeted material is less important than its overall size and smallest dimension. The filter material may be configured as a bag or a sheet. Either may be flat or pleated to increase its surface area within a specific area perpendicular to the air flow.

- Cyclones accelerate the speed of a particle as it travels a circular path that continually decreases in diameter. As the same amount of air is forced through a smaller cross section, its velocity increases. The weight of a particle or particulate becomes the force that pushes it to the outer diameter of the spiral. A collection point in the design diverts the slice of total air flow containing all particles traveling along the outer wall to a collection vessel. This method generally works best when the air is relatively dry so that the solids do not adhere to the walls of the cyclone.

- Wet scrubbers add a liquid (typically water) to the air stream being treated. They are used to control airborne vapor and particles. There are two main reasons for the addition of water:
    - Water adsorbs to the particle to increase its weight and accelerate its settling under the force of gravity. The air flow is often horizontal to the unit, and the cross-section of the wet scrubber increases greatly (at least an order of magnitude) immediately after the point where the liquid is introduced.
    - Water in the liquid droplets, mist, or fine spray provides enormous area through which water-soluble or miscible vapors may dissolve. The rapidity of this transformation is important because the time the air stream is exposed to water droplets or vapors are in contact with the air stream is typically very limited.
        - Wet-scrubber air often flows horizontally to allow more volume or area for the particles to fall or settle.
        - Wet scrubbers (or scrubber towers) through which air travels vertically and is discharged at the top often employs a greater mass or volume of water to a given mass of particles or vapors than a horizontal configuration. This provides more water particle surface area and higher humidity, which improves capture of vapors and/or particles.

- Electrostatic precipitators (ESPs) contain one or more grids of fine wires perpendicular to the air flow. Electrical current applied to the grids creates a small, opposite charge on particles in the air or changes the charge on individual particles. These charges are intended to enhance the capture of particles on the charged grids and potentially other surfaces of the unit. Low humidity in the air to be treated is desirable.

12.5.1.2 Vapor Capture

APC technologies that specifically target vapors are few, though the use of various media allows capture of specific contaminants or mixtures of contaminants better than on one medium. The most common vapor treatment technique is adsorption of vapors, which may contain PFAS, from the treated airstream onto media. Media may include granular activated carbon, raw or coated clays, or synthetic resin. Some media may capture numerous PFAS while others perform better for groups (for example, short- or long-chain compounds or those with specific subgroups). The evaluation of the efficiency of these technologies depends on important operating conditions such as the empty-bed contact time (EBCT),

which can vary for each media type. Typical vapor control EBCTs range from seconds to a minute. Very fine (powdered) dry media can be injected into the air stream in special cases. However, the practice is unusual in environmental remediation and creates an additional waste stream (that is, the powdered media) that must be managed. These technologies will require continued evaluation and ongoing research to ensure that the objectives for PFAS removal in the air stream are adequate.

12.5.1.3 Thermal Treatment

The use of thermal treatment for PFAS destruction in stack emissions is a topic of current research and is dependent on having reliable methods for sample collection and analysis of PFAS contained in those emissions. Pyrolysis, gasification (see **Section 12.7.2**), and thermal oxidation are being investigated for their use and efficiency on PFAS-laden air streams. Some investigations have shown significant levels of PFAS removal using these methods (**Winchell 2022**; **Chemours 2020**; **Barr 2022**). Continued data collection on the efficiency of these systems will guide this important management option to control PFAS in stack emissions in the future. The Priority Topics for Treatment Technologies include updated information for incineration, pyrolysis/gasification, and thermal desorption (see **Section 1.6.1**).

12.6 Limited Application and Developing Liquids Treatment Technologies

The treatment technologies presented in this document are provided in a hierarchy defined in **Section 12.1**, which is based on level of implementation and confidence derived from widespread, well documented examples. The three development levels are: field-implemented technologies, limited application technologies, and developing technologies. Both in situ and ex situ technologies are included in this section. It is not always clear if a limited application or developing technology may be effective in situ, ex situ, or both; therefore, further distinction is not made in this section.
The field-implemented technologies described in the preceding sections have been applied at multiple sites and are well documented in the available literature. In addition to these well-demonstrated technologies, many technology approaches have been tested in academic and other research laboratories at the bench scale or have progressed as far as field pilot tests or limited field applications. These limited application technologies are briefly summarized in the **Table 12-1 Treatment Methods Table** Excel File. Additional information is provided in the following sections.

Not all of these limited or developing technologies have been demonstrated as suitable or effective under multiple treatment scenarios. For instance, destructive technologies, such as electrochemical oxidation, nonthermal plasma, hydrothermal alkaline treatment, and supercritical water oxidation, have been shown to be effective for treatment of high concentration, low volume liquids but may be less suitable for high volume, low concentration liquids.

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER18-1026 Rational Design and Implementation of Novel Polymer Adsorbents for Selective Uptake of Per- and Polyfluoroalkyl Substances from Groundwater
- ER18-1515 Cost-Effective Destruction of Per- and Polyfluoroalkyl Substances from DoD Subsurface Investigation-Derived Wastes using a New Class of Adsorptive Photocatalysts
- ER18-1417 Molecular Design of Effective and Versatile Adsorbents for Ex Situ Treatment of AFFF-Impacted Groundwater
- ER18-1395 Electrically Assisted Sorption and Desorption of Per- and Polyfluoroalkyl Substances
- ER18-1052 Remediation of Per- and Polyfluoroalkyl Impacted Groundwater Using Cationic Hydrophobic Polymers as Ultra-High Affinity Sorbents
- ER21-1018 Destruction of PFAS by Hydrodynamic Cavitation

12.6.1 Sorption Technologies

12.6.1.1 Coated Sand

Polymer-coated sand is an adsorbent material that has high affinity for organic contaminants. Cyclodextrin molecules are polymerized by a cross-linking agent and form inclusion complexes with many organics. The adsorbent material has two components: (a) polymer coat (active component that removes the contaminants) and (b) support base (inactive component); the combination of both provides an adsorbent with high selectivity and mechanical stability.

The adsorbent showed similar performance in removing PFOA and PFOS as GAC, but one of the key features of this technology is the high regenerability of the adsorbent (filter) for reuse (**Bhattarai, Manickavachagam, and Suri 2014**). Another important feature of the technology is that it can remove other organic pollutants such as chlorinated solvents (for example, trichloroethene (TCE), perchloroethylene (PCE), hexavalent chromium, and others (**Badruddoza, Bhattarai, and Suri 2017**). Surface modification has been shown to improve the adsorption of PFOS (**Zhou, Pan, and Zhang 2013**) by using organic polymeric surfactants.

Related Ongoing Research Funded by SERDP

- ER20-5100 In Situ PFAS Sequestration in AFFF-Impacted Groundwater
- ER20-5182 Validation of Colloidal Activated Carbon for Preventing the Migration of PFAS in Groundwater

12.6.1.2 Zeolites/Clay Minerals (Natural or Surface-Modified)

Zeolites are naturally occurring aluminosilicate compounds that are widely used in chemical separation and purification due to their high surface area and small uniform pore size among other properties (**Tao et al. 2006**). Zeolites are also being increasingly considered as a medium for the sorption of various pollutants, including cationic heavy metals, ammonium, and some volatile organic compounds, due to the aforementioned properties, as well as their high ion exchange capacity and low cost (**Delkash, Ebrazi Bakhshayesh, and Kazemian 2015**). Clay minerals, including natural and surface-modified (see below), are also used as adsorbents and are similar to zeolites in composition but have different crystalline or chemical structure. Surface-modified clays have been reported to have enhanced adsorption performance for a variety of organic and inorganic constituents (**Han et al. 2019**), as well as for PFAS (**Zhou et al. 2010**, **2013**).

Both zeolites and clay minerals can be used ex situ (that is, pump and treat) by being placed in packed-bed flow-through vessels or in situ via injection into aquifers. In situ applications of these materials are lacking in study or field application. Most available literature is limited to academic laboratory experiments (**Ochoa-Herrera and Sierra-Alvarez 2008**; **Punyapalakul et al. 2013**; **Zhou, Pan, and Zhang 2013**; **Zhou et al. 2010**). **Du et al. (2014)** and **Arias Espana, Mallavarapu, and Naidu (2015)** provided comprehensive literature reviews. Zeolite and clay minerals use both ion exchange and adsorption mechanisms to remove PFAS from water. These materials exhibit widely varying PFOS and PFOA adsorption capacities (**Du et al. 2014**), so PFAS adsorption performance should be assessed for each specific zeolite or clay-based media. However, synthetic processing of zeolite can create highly siliceous material (**Baerlocher 2007**) or can incorporate cationic surfactants into the surface structure (aka surface-modified zeolites–SMZ) (**Jiménez-Castañeda and Medina 2017**). One study indicated that engineered zeolites with a high Si/Al ratio were effective at adsorption of PFOS, presumably due to hydrophobic interactions rather than ion exchange (**Ochoa-Herrera and Sierra-Alvarez 2008**).

Surface-modified clays are made by intercalating a modification agent into the clay that has a high affinity for specific classes of contaminants. For PFAS adsorption, the modification agent is attached to

the clay via cation exchange sites and includes electrostatic and hydrophobic moieties that are highly specific for PFAS. Mechanistically, PFAS molecules diffuse into the interlayer space of the surface-modified clay and then are bound through ionic and van der Waals forces with the fixed modification agent (**Yan et al. 2021**).

Two modified clay-based adsorbent products are identified as being used in field pilots or small-scale field trial applications (**Arias et al. 2013**; **Arias Espana, Mallavarapu, and Naidu 2015**) to treat PFOA and/or PFOS.

A commercially available surface-modified clay was successful at adsorbing a variety of PFAS from AFFF-impacted groundwater. The media was resistant to fouling by groundwater constituents, such as natural organic matter, and common co-contaminants (diesel, TCE, and 1,4-dioxane) (**Yan et al. 2020**). Laboratory and pilot-scale column testing of surface-modified clay for PFAS removal from contaminated groundwater that is to be used for drinking water showed PFOS and PFOA removal to the treatment target (2 ng/L). This media demonstrated a shorter empty bed contact time (EBCT) and longer media bed life than 13 other adsorbents (**Pannu and Plumlee 2021**; **Hwang and Grieco 2021**). PFAS adsorption (short- and long-chain) by using surface-modified clay with a variety of water types was examined in **Grieco et al. (2021)** and **Najm et al. (2021)**.

High silica materials, such as H-form synthetic mordenite (HSM) and Y-form sodium zeolite (NA-Y80), and hydrotalcite clay provided adsorption capacities that were equivalent or exceeded powdered activated carbon (PAC). Surfactant-modified clays also performed as well as or better than PAC. It should be noted that none of these studies were conducted in flow-through column experiments, so applicability to ex situ treatment systems cannot be assessed. **Arias Espana, Mallavarapu, and Naidu (2015)** stated that organoclays, clay minerals, and highly siliceous materials have fast kinetics (0.4–3 hr to reach equilibrium), making them suitable for remediation applications.

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER18-1526 Complete Reductive Defluorination of Poly- and Perfluoroalkyl Substances (PFASs) by Hydrated Electrons Generated from 3-Indole-acetic-acid in Chitosan-modified Montmorillonite
- ER21-1238 Sustainable PFAS Treatment Using Layered Double Hydroxide (LDH) Sorbents
- ER22-7482 Demonstration-scale Evaluation of a Novel Surface-modified Clay Adsorbent: Comparison of Fluoro-Sorb, GAC, and IX Resin for the Removal of PFAS and Co-Contaminants in Groundwater

12.6.1.3 Biochar

Biochar is a hybrid word rooted in the words “biomass” and “charcoal.” Biochar is a carbon-rich porous solid that is synthesized by heating biomass, such as wood or manure, in a low oxygen environment (**Ahmad et al. 2014**). Biochar may be produced by pyrolysis of PFAS-impacted media (**Thoma et al. 2021**). This material has primary applications for carbon sequestration, improvement of soil fertility, and most recently as an adsorbent for pollutant removal. Biochar is characterized to have high affinity for organic contaminants, which is dependent on both the pore structure and the surface functional groups of the biochar material (**Guo et al. 2017**).Some of the key factors controlling the properties of biochar (for example, pore size composition and hydrophobicity) include the temperature of pyrolysis and biomass feedstock, among others. In many respects, the properties of biochar are similar to but generally lower than those of GAC for sorptive purposes.The variability of biochar with regard to performance parameters and quality control makes it challenging to implement on a large scale, and procuring large volumes of consistent materials and meeting design specifications can be challenging at large scales.

The available literature is limited to academic laboratory batch experiments on the bench-scale (**Chen et al. 2011**; **Inyang and Dickenson 2017**; **Kupryianchyk et al. 2016**; **Rahman et al. 2014**; **Xiao, Ulrich, et al. 2017**), with one published study reporting pilot-scale column operation (**Inyang and Dickenson 2017**).

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER22-3150 Engineering an "All-in-One" Biochar-Surfactant System for Enhanced PFAS Sorption and Reductive Degradation Using a Coupled Ultraviolet and Ultrasonication Approach
- ER22-3157 Hydrothermal Destruction of Per- and Polyfluoroalkyl Substances during Designer Biochar Reactivation
- ER23-3593 Tailored Carbonaceous Materials as Biofilter Amendments for PFAS Removal in Stormwater Runoff

12.6.1.4 Hydrogels and Fluorogels

Efficient removal of short-chain PFAS from water can be achieved using hydrogels and fluorogels because of their high selectivity and affinity for these compounds (**Ateia et al. 2019**; **Kumarasamy et al. 2020**). For example, **Ateia et al. (2019)** demonstrated selective, rapid removal of 16 PFAS using cationic polymer (hydrogel) poly (N-[3-(dimethylamino)propyl] acrylamide, methyl chloride quaternary (DMAPPAA-Q). While adsorption was not reversed in a standard environmental matrix, regeneration was possible using a simple solvent/salt matrix. Performance was maintained in six consecutive sorption/regeneration cycles.

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER22-3415 Novel Swellable Ionomers for Enhanced PFAS Sorption and Destruction
- ER22-3155 In situ Sequestration of PFAS from Impacted Groundwater Using Injectable High Affinity Cationic Hydrophonic Polymers

12.6.2 Precipitation/Coagulation/Flocculation

Precipitation/coagulation/flocculation is a common pretreatment approach used in wastewater treatment plants for removing various particles and dissolved constituents. Coagulants, either commodity or proprietary chemicals, can be added to water (conventional technology) or generated by anode-cathode reactions of metal plates inserted into the water (electrocoagulation). Common examples include:

- inorganic cationic coagulants (for example, alum, iron-based)
- commodity (for example, polyDADMAC) and specialty (for example, Perfluorad) polymers
- electrochemical precipitation

Coagulants assist in the formation of solids. Flocculation is typically conducted by adding a soluble polymer and slowly mixing to allow the particles to agglomerate and grow. Upon solid formation, constituents such as PFAS can be physically incorporated into, or sorbed onto, the flocculated particulate (which is known as co-precipitation). The precipitated solids are then separated from the water by sedimentation and/or filtration processes. The solid material containing the PFAS requires disposal, see the **Table 12-1 Treatment Methods Table** Excel File and **Section 12.3.2**.

Literature documents only bench-scale study results on treating PFAS via precipitation, flocculation, or coagulation; therefore, this is considered a partially developed technology. Evaluations have focused on conventional commodity chemical coagulation (for example, aluminum or ferric salts) and nonconventional coagulation (for example, proprietary chemical coagulants or electrocoagulation). Pilot- and full-scale applications have not been documented in the United States (**Birk 2017**), and specialty materials for PFAS applications will require strict quality control to ensure that performance characteristics are consistent.

Nonconventional precipitation (for example, electrocoagulation or advanced chemical precipitants) has shown more potential for direct PFAS treatment, but has very limited data. High-affinity cyclodextrin polymer has been tested in bench-scale reactors and was found to have superior removal capacity to GAC (**Xiao, Ling, et al. 2017**).

Electrocoagulation reactors, which range from basic to very sophisticated designs, have been reported to be highly efficient, compact, relatively low cost, and completely automatable (**Baudequin et al. 2011**; **Lin et al. 2015**). Recent studies have found that PFAAs, such as PFOA and PFOS, can be quickly sorbed on the surface of zinc hydroxide particulates generated by electrocoagulation (**Lin et al. 2015**).

Related Past, Ongoing, and Recent Research Funded by SERDP or ESTCP

- ER-2425 Development of a Novel Approach for In Situ Remediation of PFC-Contaminated Groundwater Systems
- ER18-1026 Rational Design and Implementation of Novel Polymer Adsorbents for Selective Uptake of PFASs from Groundwater
- ER20-5370 Sustainable Firefighting System Cleanout and Rinsate Treatment Using PerfluorAd®
- ER22-3194 Green Remediation of PFAS in Soil and Water

12.6.3 Redox Manipulation

Redox manipulation includes chemical oxidation and reduction technologies. These have been summarized in more detail in **Nzeribe et al. (2019)**. Chemical oxidation for PFAS is a technology approach that is achieved via the delivery of liquid, slurry, or gaseous oxidants to transfer electrons from a reactive oxidant species to a target (PFAS) and affect the cleavage of atoms in the PFAS molecular structure. Carboxylic or sulfonic group "heads" (functional groups) of PFAS are commonly more susceptible to redox transformation than the fluorinated carbon chain "tails." There is a lack of robust evidence of defluorination via chemical oxidation processes. The mechanisms involving multiple species of free radicals that trigger PFAS oxidation are not well understood. PFAA precursors are also known to be oxidized to form persistent and terminal PFAAs without further oxidation (**Houtz and Sedlak 2012**; **Anumol et al. 2016**). Consequently, care should be taken to monitor site and plume conditions and understand potential formation and transport of transformation products.

Additional mechanistic studies are needed to develop chemical oxidation as a feasible PFAS remediation approach and to further assess factors that may promote or limit this technology. Common oxidants that have been documented to treat PFAS and other organic contaminants (for example, chlorinated solvents) include ozone, catalyzed hydrogen peroxide, and persulfate, as discussed further below. The impacts of co-contaminants, quenching reactions, and metals mobilization are also considerations for redox-based remedies (for example, **ITRC 2005**, **2011**).

12.6.3.1 Ozone-Based Systems

Ozone can be coupled with other oxidants such as hydrogen peroxide and persulfate to promote the generation of a suite of aggressive free radicals capable of degrading PFAS. An ozone-based system was implemented for the treatment of PFAS in a single field-scale test by **Eberle, Ball, and Boving (2017)** using combined ozone and activated persulfate.

The main pathway and mechanism behind the ozone-based system tested by **Eberle, Ball, and Boving (2017)** is unknown, as detailed mechanistic studies have not been performed. However, they suggested that PFAS reduction in groundwater after treatment was not limited to partial degradation, but it is possible that sorption also had a role to play in the declining aqueous PFAS concentration. They

postulated that activated persulfate could lead to a decline in pH, thereby increasing sorption of PFAS to soil due to increased protonation.

This approach has been partially demonstrated in one field-scale setting, and results are encouraging for application using ex situ or in situ approaches. However, because there is an absence of supporting mechanistic data, it is likely that other factors could come into play that may promote or limit this technology.

The application of the ozone-based system for the treatment of PFAS has also been evaluated in bench studies (**Lin et al. 2012**; **Kerfoot 2014**; **Huang et al. 2016**; **Eberle, Ball, and Boving 2017**; **Thomas et al. 2020**). **Lin et al. (2012)** and **Thomas et al. (2020)** tested ozone systems without and inclusive of hydrogen peroxide addition in alkaline environments, and **Kerfoot (2014)** used hydrogen peroxide and ozone bubbles for a bench-scale test of groundwater from a monitoring well foam firefighting site in Canada. **Huang et al. (2016)** combined ozone with photolysis to produce hydroxyl radicals and photogenerated electrons. **Dai et al. (2019)** tested combinations of ultraviolet light, ozone, and air fractionation, and reported that ozonated air fractionation provided more than 95% reduction in PFAS concentrations.

In the field demonstration, PFAS concentrations in groundwater were reduced by 21–79% after treatment. Also, an initial pilot test at a fire training area using ozone and peroxide has shown removal of 98.5% and 92.3% for PFOS and PFOA, respectively, in groundwater and over 80% for PFOS on saturated soil with proportional release of fluoride (**Kerfoot 2016**).

In bench-scale studies, **Eberle, Ball, and Boving (2017)** decreased PFAS by 99.9% using PFAS-contaminated site groundwater and spiked deionized water. **Eberle, Ball, and Boving (2017)** also reported that the system was not sensitive to other groundwater organics. **Kerfoot (2014)** reported 89.8% removal of PFOS and > 80% for other PFAS (PFPeA 89.8%, PFHxA 86.2%n and PFHxS 98.1%). These studies, however, do not confirm destruction through mass balance and analysis of byproducts.

Each of these approaches and test conditions used different water matrices and starting concentrations. It is difficult to state whether published regulatory levels can be achieved in practice with these technologies, but in general they appear to be effective as a polishing technology to achieve low part-per-trillion treatment requirements.

Related Ongoing Research Funded by SERDP

- ER18-1545 Enhanced Oxidative Destruction of PFAS in Investigation-Derived Waste Soil and Water

12.6.3.2 Catalyzed Hydrogen Peroxide (CHP)–Based Systems

CHP is one of the strongest oxidant systems used in environmental remediation. It involves reaction of hydrogen peroxide with a catalyst to predominantly generate hydroxyl radicals. Some CHP systems produce nucleophiles and reductants, including superoxide and hydroperoxide (**Mitchell et al. 2014**). Common catalysts include transition metals such as iron (Fenton and Fenton-like reaction) or manganese, chelated metals, and naturally occurring minerals, for example, **Watts et al. (2005)** and **Teel et al. (2007)**.

Hydroxyl radicals attack the alkyl groups of both PFCAs and PFSAs, but do not attack the perfluoroalkyl chain. As a result, PFCA and PFSA precursors are transformed to PFCAs of related perfluorinated chain length (**Bruton and Sedlak 2017**). **Mitchell et al. (2014)** demonstrated that superoxide and hydroperoxide (which are nucleophiles and reductants generated as a reaction in CHP but are not chemical oxidants) generated in alkaline pH CHP systems mineralize PFOA but did not elucidate a mechanism.

Bench-scale testing has been successfully demonstrated. Field deployment of hydroxyl radical-based CHP systems may be limited due to decomposition of PFAS precursors to PFOA and other PFCAs as unreactive transformation products (**Bruton and Sedlak 2017**).

CHP systems that predominantly generate hydroxyl radicals partially transform PFAAs to their PFCAs of related perfluorinated chain length, which are not further transformed (**Houtz and Sedlak 2012**; **Bruton and Sedlak 2017**). Systems that generate superoxide and hydroperoxide have been demonstrated at the bench test level to mineralize PFOA (**Mitchell et al. 2014**), but effectiveness with other PFAS is unknown.

12.6.3.3 Activated Persulfate

Persulfate anion ($S_2O_8^{2-}$) is activated to generate reactive radical species, primarily sulfate radicals (2.6 volts, or V) and hydroxyl radicals (2.7 V). Methods to activate persulfate include transition metals, high pH, and heat activation (**Siegrist, Crimi, and Simpkin 2011**). Hydroxyl radicals are the predominant radicals formed at high pH conditions (**Furman et al. 2011**), while at acidic pH there is greater yield of sulfate radicals (**Siegrist, Crimi, and Simpkin 2011**).

PFCAs are attacked by sulfate radicals under acidic conditions, initiating a decarboxylation reaction, where cleavage of the carbon-to-carbon (C-C) bonds occurs between PFCAs and the carboxyl group (-COOH), forming unstable perfluoroalkyl radicals (C_nF_{2n+1}) (**Hori et al. 2010**; **Lee et al. 2012**; **Yin et al. 2016**). A stepwise series of decarboxylation and hydrogen fluoride (HF) elimination reactions continues to form shorter chain PFCAs until all PFCAs are mineralized to fluoride and carbon dioxide. PFSAs such as PFOS are unreactive with sulfate radicals (**Park et al. 2016**; **Bruton and Sedlak 2017**). Hydroxyl radicals attack the alkyl groups of both PFCAs and PFSAs, but do not attack the perfluoroalkyl chain. As a result, PFCA and PFSA precursors are transformed to PFCAs of related perfluorinated chain length (**Bruton and Sedlak 2017**). Under alkaline pH conditions the sulfate and hydroxyl radicals are reactive with the alkyl groups but similarly unreactive with the perfluoroalkyl chain, which is the basis of the TOP method (**Houtz and Sedlak 2012**).

Activated persulfate under acidic conditions has proven effective for PFOA (PFCAs) with nominal 100% degradation, but PFOS is not transformed. Sulfate radicals and hydroxyl radicals generated by alkaline persulfate activation transform PFCA and PFSA precursors to PFCAs of related perfluorinated chain length (**Bruton and Sedlak 2017**).

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER-2423 In Situ Treatment Train for Remediation of Perfluoroalkyl Contaminated Groundwater: In Situ Chemical Oxidation of Sorbed Contaminants (ISCO-SC)
- ER201729 Field Demonstration to Enhance PFAS Degradation and Mass Removal Using Thermally Enhanced Persulfate Oxidation Followed by Pump-and-Treat
- ER18-1545 Innovative Treatment of Investigation-Derived Waste Polluted with Per- and Polyfluoroalkyl Substance Contaminants and Other Co-Contaminants.

12.6.3.4 Sonochemical Oxidation/Ultrasound

The sonochemical process relies on the propagation of acoustic waves in liquids at frequencies ranging between 20 kHz and 1,000 kHz (**Furuta et al. 2004**), which results in cavitation. Operating parameters such as frequency (**Campbell and Hoffmann 2015**), power density (**Hao et al. 2014**), solution temperature, sparge gas, and initial concentration of PFAS (**Rodriguez-Freire et al. 2015**) play a significant role in the sonochemical degradation and defluorination rate of PFAS (**Cao et al. 2020**).

Sonochemical degradation occurs via two mechanisms: localized thermal treatment and free radical destruction (**Rayaroth, Aravind, and Aravindakumar 2016**). During cavitation, cyclic formation, growth,

and collapse of micro/nano bubbles result in an intense increase in temperature and pressure (5000 Kelvin (K) and 2000 atmosphere (atm)), along with the generation of free radicals (**Furuta et al. 2004**; **Chowdhury and Viraraghavan 2009**).

Sonochemical oxidation has been successfully applied for rapid degradation of PFAS to fluoride (F^-), sulfate (SO_4^{2-}) and carbon dioxide (CO_2). **Vecitis et al. (2008)** reported a complete recovery of SO_4^{2-} and >90% defluorination of PFOA and PFOS with initial concentrations of 0.24 µM and 0.20 µM, respectively, for a field-scale application to treat groundwater from below a landfill. At bench scale, sonolysis has been reported in the literature as one of the most effective treatment processes for PFAS-contaminated water, because they almost immediately mineralize to SO_4^{2-}, CO_2, carbon monoxide (CO), and F^- after cleavage of their C-C/C-S bond. Studies have reported >90 percent degradation and defluorination for PFOA and PFOS (**Moriwaki et al. 2005**; **Vecitis et al. 2008**; **Cheng et al. 2008**, **2010**). **Gole et al. (2018)** demonstrated removal and defluorination of AFFF in a 91-L sonolytic reactor. **Lei et al. (2020)** showed a synergistic treatment effect of a combined persulfate/ultrasound approach.

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER21-5045 Sonolysis-based In Situ PFAS Treatment within an HRX Well
- ER21-1018 Thermal Destruction of PFAS by Hydrodynamic Cavitation
- ER22-3394 Pulsed Electrosorptive Cavitation: A Cohesive Approach for Complete Mineralization of PFAS in Aqueous Systems
- ER22-3150 Engineering an "All-In-One" Biochar-Surfactant System for Enhanced PFAS Sorption and Reductive Degradation Using a Coupled Ultraviolet and Ultrasonication Approach

12.6.3.5 Photolysis/Photochemical Oxidation

A thorough review of photolysis/photochemical oxidation technology for PFAS decomposition is reported in **Wang et al. (2017)**. **Chen, Zhang, and Liu (2007)** and **Giri et al. (2011)** reported removal of PFAS by direct photolysis at 185 nm. **Hori et al. (2004)** and **Chen, Zhang, and Liu (2007)** reported that direct photolysis at 254 nm alone is not very effective because PFAS do not absorb light at wavelengths >220 nm due to their chemical structure. Chemical reagents/catalysts such as Fe^{3+}, $S_2O_8^{2-}$, TiO_2, heteropolyacid photocatalyst ($H_3PW_{12}O_{40}$), CO_3^{2-}, and IO_4^- when combined with ultraviolet (UV) (>220 nm) light can effectively decompose PFAS (**Hori et al. 2005**; **Chen and Zhang 2006**; **Zhang, Pan, and Zhou 2016**; **Hori et al. 2007**; **Wang et al. 2008**; **Cao et al. 2010**; **Gomez-Ruiz et al. 2018**; **Xu et al. 2020**). This is due to generation of strong and reactive oxidative species such as $OH^•$, $H^•$, $CO_3^{•-}$ and PFAS-Fe complexes. Photochemical oxidation of PFAS is said to be dependent on the light source (UV or vacuum ultraviolet), initial concentration of PFAS, environmental matrix, temperature, pH, and type of reagent used (**Lin et al. 2012**; **Giri et al. 2012**; **Lyu et al. 2015**, **2015**; **Xu et al. 2017**). Use of non-traditional photocatalytic methods such as fixating a photocatalyst within a porous media (**McIntyre et al. 2023**; **McIntyre et al. 2022**; **McIntyre et al. 2021**; **McIntyre and Hart 2021**) or the use of boron nitride may enhance destructive performance (**Qanbarzade et al. 2023**).

The major degradation pathways involved in the photochemical oxidation of PFAS are direct photolysis and free radical reactions. The C-C bond between PFAS is cleaved with the COOH group to form perfluoroalkyl radicals (**Hori et al. 2003**; **Hori et al. 2008**), which then react with water and undergoes hydrogen fluoride elimination to form shorter chain compounds (**Liu et al. 2017**). These then undergo hydrolysis to form subsequent shorter PFAS (losing CF2 units). During direct photolysis, the C-C and C-S bonds of PFAS are broken by photoelectrons to generate perfluoroalkyl radicals and carbon dioxide (**Wang et al. 2017**).

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER18-1595 A Combined Photo/Electrochemical Reductive Pathway towards Enhanced PFAS Degradation
- ER18-1513 Effective Destruction of Per- and Polyfluoroalkyl Substances in Water by Modified SiC-based Photocatalysts
- ER18-1515 A Cost-Effective Technology for Destruction of Per- and Polyfluoroalkyl Substances from DOD Subsurface Investigation-Derived Wastes
- ER18-1599 Pilot-scale Assessment of a Deployable Photocatalytic Treatment System Modified with BiPO4 Catalyst Particles for PFAS Destruction in Investigation-Derived Wastewater
- ER19-1403 Validation of UV/TiO2 Activated Alkaline Media (CFM) for Destruction of PFAS in Concentrated Liquid Waste Streams
- ER22-3258 Chemical-free Light-driven Destruction of Per- and Polyfluoroalkyl Substances Using Non-toxic Boron Nitride (BN)
- ER22-3187 Destruction of PFAS using Plasmonic Photocatalysts

12.6.3.6 Electrochemical Treatment

Electrochemical treatment occurs via anodic oxidation; a variety of materials have been used as anodes. The treatment effectiveness of PFOS and PFOA using different anodes can vary significantly. Most research on PFAS, particularly PFOS and PFOA removal, has been conducted using a boron-doped diamond (BDD) electrode due to its mechanical, chemical, and thermal stability (**Trautmann et al. 2015**; **Schaefer et al. 2017**; **Schaefer et al. 2019**; **Wang et al. 2019**; **Smith et al. 2023**). Some other electrodes, such as lead dioxide (PbO_2), titanium oxide (TiO_2), titanium suboxide ($Ti4O_7$), and tin oxide (SnO_2), also have the ability to treat PFAS-contaminated water (**Ochiai et al. 2011**; **Zhou et al. 2012**; **Zhao, Gao, et al. 2013**; **Liang 2017**; **Liang et al. 2018**). Operating conditions and parameters such as pH (**Lin et al. 2012**; **Zhou et al. 2012**), current density, electrolyte type (**Song et al. 2010**; **Zhuo et al. 2012**), electrode distance (**Lin et al. 2012**), initial PFAS concentration, and temperature are important factors that influence electrochemical oxidation of PFAS (**Niu et al. 2016**).

Electrochemical treatment proceeds via direct and indirect anodic oxidation (**Radjenovic and Sedlak 2015**; **Niu et al. 2016**; **Schaefer et al. 2018**). In direct electrolysis, contaminants are adsorbed onto and degraded directly at the electrode, while in indirect electrolysis, contaminants are degraded in the bulk liquid in reactions with oxidizing agents (that is, hydroxyl radicals) formed at the electrode (**Radjenovic and Sedlak 2015**).

Bench-scale studies have shown success in the degradation and defluorination of PFAS, including short-chain, long-chain PFAAs as well as PFAA precursors (**Chiang 2018**). Electrochemical oxidation of precursors may lead to the transient generation of perfluorinated carboxylates (**Schaefer et al. 2018**). Ultimately, fluoride is released, with typical recoveries ranging from 60 to 80%; the fate of the remaining fluoride is unknown, but studies have suggested that losses due to volatile perfluorinated alkanes may occur.

Electrochemical treatment has been tested as a stand-alone technology for PFAS concentrations at ppb levels and as a destruction technology to destroy concentrated PFAS waste streams generated from other treatment technologies such as ion exchange and foam fractionation (**Liang et al. 2018**; **Chiang 2018**). It has been partially demonstrated as an ex situ treatment of PFAS. But in situ application is also being considered and funded in the SERDP program. The issue of perchlorate formation as a byproduct during electrochemical oxidation of PFAS has been addressed by **Schaefer et al. (2017)** using a biological treatment polishing step. The issue can also be minimized by not using sodium chloride as the electrolyte (**Chiang 2018**).

The technology has been demonstrated via bench studies and pilot-scale reactor to be very effective for treatment of short-chain, long-chain PFAAs, as well as most commonly detected PFAA precursors in spike water systems and several remediation-derived waste streams laden with high PFAS concentrations.

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER-2424 Investigating Electrocatalytic and Catalytic Approaches for In Situ Treatment of Perfluoroalkyl Contaminants in Groundwater
- ER-2718 Synergistic Treatment of Mixed 1,4-Dioxane and PFAS Contamination by Combining Electrolytic Degradation and Electrobiostimulation
- ER18-1320 Electrochemical Oxidation of Perfluoroalkyl Acids in Still Bottoms from Regeneration of Ion Exchange Resins
- ER-2717 A Novel Reactive Electrochemical Membrane System for Treatment of Mixed Contaminants
- ER18-1491 Reactive Electrochemical Membrane (REM) Reactors for the Oxidation of Perfluoroalkyl Compound Contaminated Water
- ER22-3184 Deep Destruction of PFAS in Complicated Water Matrices by Integrated Electrochemical Oxidation and UV-Sulfite Reduction
- ER22-3394 Pulsed Electrosorptive Cavitation: A Cohesive Approach for Complete Mineralization of PFAS in Aqueous Systems

12.6.3.7 Solvated Electrons (Advanced Reduction Processes)

Advanced reduction processes (ARP) has been investigated for the reductive degradation of groundwater contaminants. ARP involves the combination of activation methods such as ultrasound, ultraviolet, microwaves, catalysis, and electron beam with reducing agents (reductants) such as ferrous iron, sulfide, sulfite, iodide, titanium (III) citrate and dithionite to generate very reactive reducing radicals and the hydrated electrons (e–aq) that mineralize contaminants to less toxic products (**Vellanki, Batchelor, and Abdel-Wahab 2013**; **Ochoa-Herrera et al. 2008**). The reducing hydrogen radical ($H^{\bullet}$) and the hydrated electron are strong reductants that react easily with halogenated organic compounds (**Buxton et al. 1988**). ARP-induced degradation rates depend on initial solution pH and reductant concentration (**Vellanki, Batchelor, and Abdel-Wahab 2013**). **Bentel et al. (2019)** described insights gained from a structure-activity relationship analysis of the mechanisms involved in the reaction of solvated electrons with PFAS. **Cui et al. (2020)** offered a detailed critical review focused on mechanisms of reductive PFAS destruction by solvated electrons.

The degradation pathway of PFAS using ARP differs from that of oxidizing agents in that the hydrated electron (**Song et al. 2013**) cleaves the C-F bond adjacent to the functional group of the PFAS rather than the C-C or C-S bond. **Qu et al. (2014)** proposed that hydrated electrons lead to the reductive cleavage of the C-F bonds, resulting in fluorine elimination from PFOA. Furthermore, they proposed that under UV irradiation, cleavage of the C-C bond between the COOH group and the perfluoroalkyl group occurred as shorter chain intermediates were detected in solution. **Qu et al. (2014)** therefore concluded that two reactions are responsible for the reductive defluorination of PFOA: (1) direct photolysis by UV irradiation, and (2) photoreduction by hydrated electrons. **Tenorio et al. (2020)** showed that PFAS treatment by solvated electrons varies widely among compounds.

Reductive processes have proven feasible for degradation of most PFAS, especially PFOS. It should be recognized that electrons will be scavenged by oxygen, nitrate, and chlorides, and this should be considered for treatment application. Recent research using UV-activated sulfite demonstrated effective generation of hydrated (aka solvated) electrons. Laboratory tests showed >50% defluorination of both PFOS and PFOA within 24 hours (**Strathmann 2018**).

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER-2426 Quantification of In Situ Chemical Reductive Defluorination (ISCRD) of Perfluoroalkyl Acids in Ground Water Impacted by AFFFs
- ER21-5152 Demonstration of Cost-effective and Sustainable Destruction of PFAS in Concentrated Waste Streams (Hydrated Electrons)
- ER22-3286 Treatment of PFAS-impacted Matrices by Dissolving Metal Reduction with Mechanochemical Mixing
- ER22-3298 Utilizing PFAS Aggregation at the Gas-Water Interface for Energy-Efficient PFAS Destruction
- ER22-3158 Electrocatalytic Reduction of PFAS in Groundwater and Aqueous Concentrates
- ER22-3345 A Novel Redox Material (FeSO3) for Efficient and Rapid Treatment of Concentrated PFAS Matrices
- ER21-7569 Photoactivated Reductive Defluorination PFAS Destruction

12.6.3.8 Plasma Technology

Plasma technology is a promising destructive PFAS treatment technology. Plasma is formed as a result of an electrical discharge from the addition of sufficient energy to gas (**Jiang et al. 2014**) and is classified into two major groups based on temperature and electronic density: thermal plasma (local thermal equilibrium) and nonthermal plasma (nonequilibrium plasma) (**Bogaerts 2002**). Due to lower energy requirements and selectivity, nonthermal plasma is most often used in water treatment processes (**Jiang et al. 2014**). In water treatment plasma applications, electrical discharges can be discharged above the liquid surface, directly to the liquid, or in the form of bubbles in liquids (**Locke, Lukes, and Brisset 2012**) (**Stratton et al. 2017**). These electrical discharges diffuse in liquids to initiate various chemical and physical effects, including high electric fields, intense UV radiation, shock waves, and formation of strong oxidative and reductive reactive species ($H^{\bullet}$, $O^{\bullet}$, $OH^{\bullet}$, H_2O_2 aqueous electrons, H_2, O_2, O_3), which are effective for the treatment and removal of contaminants (**Lukes, Appleton, and Locke 2004**; **Lukes et al. 2005**; **Stratton et al. 2017**; **Singh et al. 2019**).

Related Past, Ongoing, and Recent Research Funded by SERDP or ESTCP

- ER18-1306 Combined In Situ/Ex Situ Treatment Train for Remediation of Per- and Polyfluoroalkyl Substance (PFAS) Contaminated Groundwater
- ER18-1624 Plasma Based Treatment Processes for PFAS Investigation-Derived Waste
- ER18-1570 Application of Non-Thermal Plasma Technology for the Removal of Poly- and Perfluorinated Substances from Investigation-Derived Wastes
- ER18-5015 Removal and Destruction of PFAS and Co-contaminants from Groundwater
- ER18-1624 Plasma Based Treatment Processes for PFAS Investigation Derived Waste
- ER22-3316 Complete Destruction of Undiluted AFFF by a Plasma Spinning Disc Reactor
- ER22-3187 Destruction of PFAS Using Plasmonic Photocatalysts
- ER20-5355 An Innovative Plasma Technology for Treatment of AFFF Rinsate from Firefighting Delivery Systems
- ER21-3564 Non-thermal Treatment of Unused AFFF Concentrate by Liquid-phase Plasma Discharge Process

Determination of plasma treatment mechanisms and degradation pathways for PFAS is a research focus, and several mechanisms and pathways have been proposed. **Takeuchi et al. (2013)** proposed that the main reaction pathway for PFOA by plasma treatment is by thermal cleavage of the C-C bonds resulting in direct decomposition to gaseous products without formation of shorter chain PFCAs. Others have proposed that PFAS decomposition is due to conversion to unstable radicals during interaction of PFAS with the most energized ions in the plasma (**Hayashi et al. 2015**; **Obo, Takeuchi, and Yasuoka 2015**), or with positive ion(s) generated by the plasma (**Yasuoka, Sasaki, and Hayashi 2011**) at the bubble gas-

liquid interface. The unstable radicals produced during PFAS decomposition can result in a sequential loss of one carbon within the chain.

Plasma effectively degrades PFAS in a relatively short period of time (30-minute treatment) in both synthetic water and groundwater. It has been reported that plasma treatment provided 90% degradation of PFOA and PFOS, with only about 10% of the destroyed PFOA and PFOS being converted to shorter chain PFAAs (**Stratton et al. 2017**). The degradation rate is not affected by the presence of co-contaminants. This is an environment-friendly technology, because there is no demand on pressure or temperature and it does not require significant input of chemicals. Plasma also generates a broad range of reactive species.

12.6.3.9 Zero-Valent Iron (ZVI)/Doped-ZVI

ZVI is an inexpensive groundwater remediation technology. It is the most commonly used reductant for in situ groundwater remediation. It is a strong reducing agent capable of successfully reducing major groundwater contaminants such as chlorinated solvents. Recently nanoscale zero-valent iron (nZVI) has had increased attention due to its higher reactivity, surface area, and potential in situ injectability compared to the micro-sized ZVI.

In general, the removal of PFAS by ZVI in reductive processes involves the mass transfer of contaminants to the ZVI surface, and their adsorption and reaction (transformation of contaminants into less toxic/nontoxic species) on the ZVI surface, followed by the desorption and mass transfer of byproducts into solution (**Arvaniti et al. 2015**). Because the reduction of contaminants by ZVI is a surface-mediated electron transfer process, the surface properties of ZVI influence contaminant reactivity. (**Arvaniti et al. 2015)** found that PFOS removal using Mg-aminoclay-coated nZVI occurred via adsorption of PFOS to the ZVI surface followed by reduction. A similar decomposition mechanism for PFOS using ZVI in subcritical water was reported by **Hori et al. (2006)**, who suggested that adsorption of PFOS onto ZVI played a major role in PFOS decomposition, as fluoride was detected in the treatment solution after treatment.

This technology is highly effective for the removal of PFOS, reacts relatively quickly, and has proven feasible for degradation of most PFAS.

Related Past, Ongoing, and Recent Research Funded by SERDP or Air Force AFWERX

- ER-2426 Quantification of In Situ Chemical Reductive Defluorination (ISCRD) of Perfluoroalkyl Acids in Groundwater Impacted by AFFFs
- Contract Number FA864921P0368: Reactive Bimetallic-Carbon Media for Destruction of PFAS-Containing Aqueous Fire Fighting Foam Stockpile
- ER22-3286 Treatment of PFAS-impacted Matrices by Dissolving Metal Reduction with Mechanochemical Mixing
- ER22-3345 A Novel Redox Material (FeSO3) for Efficient and Rapid Treatment of Concentrated PFAS Matrices

12.6.3.10 Alkaline Metal Reduction

Alkaline metal reduction involves the use of alkali metals (that is, the reductant) to reduce organic compounds to their anion radical. Reductive degradation of branched PFOS has been reported with vitamin B_{12} as a catalyst and Ti(III)-citrate or nanosized zero-valent zinc as a bulk reductant (**Ochoa-Herrera et al. 2008**; **Park, de Perre, and Lee 2017**) where degradation rates increase with increasing solution pH, bulk reductant dose, and temperature.

The degradation pathway of PFAS by alkali metal reduction as postulated by **Ochoa-Herrera et al. (2008)** suggests that destruction of branched PFOS isomers occurs via chemical reductive dehalogenation. **Park, de Perre, and Lee (2017)** suggested that the ability of vitamin B_{12} to reduce branched PFOS isomer

and not linear is because the branched PFOS isomers possess greater electron density differences that are absent in linear PFOS isomers. Bench-scale studies have shown success for branched PFOS isomers and have proven to be efficient (greater than 70% removal; see **Ochoa-Herrera et al. (2008)**). In situ applications have not been tested. Removal and defluorination are lower for PFHxS relative to PFOS. Polyfluorinated sulfonate intermediates (C_5-C_8) are the final products (**Park, de Perre, and Lee 2017**).

Bimetallic $nNiFe_0$ particles supported on activated carbon have demonstrated transformation of both linear- and branched-PFOS isomers, achieving 94% PFOS transformation at 50°C (**Zenobio et al. 2020**). Transformation byproducts detected in the particle extracts indicate defluorination and desulfonation pathways.

12.6.3.11 High-Energy Electron Beam (eBeam)

High-energy electron beam (eBeam) is a high efficiency, flow-through, nonthermal, chemical-free technology that utilizes electron accelerators to generate large numbers of highly energetic electrons from electricity (**Cleland 2011**; **Pillai and Shayanfar 2016**). The technology has been commercialized globally for pasteurizing foods, sterilizing medical devices, cross-linking polymers, and eliminating insects and pests from fresh produce (**Cleland 2011**; **Pillai 2016**; **Pillai and Shayanfar 2016**; **Zembouai et al. 2016**). It provides a form of ionizing irradiation that does not involve the use of radioactive isotopes. The amount of energy from eBeam that is absorbed by an irradiated material per unit mass is called dose. The absorbed dose during eBeam treatment depends on the type and thickness of the material, the beam power, and the length of time the material is exposed to the electron beam (**Waite 1998**).

eBeam is applicable for use on soil and liquid matrices for many purposes: disinfection of sewage sludge (**Praveen et al. 2013**; **Waite 1998**); remediation of heavy hydrocarbon-contaminated soils (**Briggs 2015**); and remediation of volatile organic compounds (VOCs) and semivolatile organic compounds in liquid wastes such as groundwater, wastewater, and landfill leachate (**USEPA 1997**). During irradiation of water, three primary reactive species are formed: solvated electrons and hydrogen radicals, which are strong reducing species, and hydroxyl radicals, which are strong oxidizing species. This creates both advanced reduction and oxidation processes without the addition of any chemicals. The absolute concentration of radicals formed during irradiation is dose- and water quality-dependent, but it has been measured at greater than millimolar (mM) levels in potable, raw, and secondary wastewater effluent (**Waite 1998**).

Researchers at Texas A&M University recently demonstrated defluorination of PFOA in aqueous samples by eBeam technology (**Wang et al. 2016**). The study measured defluorination efficiency as a function of molar concentration of free fluoride ions and initial molar concentration of PFOA to be treated. Final defluorination efficiencies ranged from 34.6 to 95% under various increasing concentrations of nitrate, alkalinity, and fluvic acid. The defluorination is possibly due to the formation of aqueous electrons and the formation of secondary radicals (**Wang et al. 2016**). **Kim et al. (2019)** demonstrated eBeam defluorination of PFOS when used in combination with chemical oxidants.

An additional study further demonstrated eBeam-mediated defluorination of PFOS and PFOA with decomposition efficiencies of 95.7% for PFOA and 85.9% for PFOS in an anoxic alkaline solution (pH = 13). Radical scavenging experiments indicated that the aqueous electron and hydrogen radical were important in the eBeam degradation of PFOA and PFOS (**Ma et al. 2017**). Further evaluation of this technology for treating other PFAS (polyfluorinated precursors and other long- and short-chain PFAAs) in soil and water, as well as testing over a range of concentrations, will be necessary to further understand treatment performance potential and to identify any deleterious byproducts.

Related Ongoing Research Sponsored by SERDP

- ER18-1620 Ex Situ Remediation of Investigation-Derived Wastes containing PFAS by Electron Beam Technology

12.6.3.12 Supercritical Water Oxidation

The content in this section has been replaced with the Priority Topic for Supercritical Water Oxidation (see **Section 1.6.2**).

12.6.4 Biodegradation

A limited number of studies have tested microbial degradation of PFAS and many conflicting reports exist, all suggesting that more work needs to be performed to fully understand the biotic transformations of these compounds.

Microbial degradation of PFAS has been observed to occur with polyfluoroalkyl substances (**Butt, Muir, and Mabury 2014**), which contain some carbon-hydrogen bonds instead of C-F bonds (**Buck et al. 2011**). Recent research documented the aerobic biotransformation of fluorotelomer thioether amido sulfonate (FtTAoS) over a 40-day period to produce 4:2, 6:2, and 8:2 fluorotelomer sulfonate (FTS), 6:2 fluorotelomer unsaturated carboxylic acid (FTUCA), 5:3 fluorotelomer carboxylic acid (FTCA), and C4 to C8 perfluorinated carboxylic acids (**Harding-Marjanovic et al. 2015**). An unintended consequence of biologically mediated transformations is the conversion of precursors (polyfluorinated) to perfluorinated compounds.

PFOA and PFOS have been shown to be resistant to microbial biotransformation under a variety of growth conditions (**Liu and Mejia Avendaño 2013**). However, other PFAS, including chemicals in AFFF with nonfluorinated alkyl groups (polyfluorinated substances), are likely amenable to biotransformation. Most recently, defluorination of PFOA and PFOS were observed using an ammonium oxidizing autotroph (**Huang and Jaffé 2019**). Upon addition of PFOA or PFOS (0.1 mg/L and 100 mg/L, respectively) to the A6 culture, shorter chain perfluorinated products and acetate were observed. Incubations with hydrogen as a sole electron donor also resulted in the defluorination of up to 60% of PFOA and PFOS during 100-day incubations, while total fluorine (organic plus fluoride) remained constant. Reductive defluorination of perfluoroalkyl substances may be possible, as observed when using vitamin B12 and Ti(III)-citrate (**Ochoa-Herrera et al. 2008**).

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER-2422 Bioaugmentation with Vaults: Novel In Situ Remediation Strategy for Transformation of Perfluoroalkyl Compounds
- ER-2127 Remediation of Perfluoroalkyl Contaminated Aquifers using an In Situ Two-Layer Barrier: Laboratory Batch and Column Study
- ER20-1023 Microbially-Mediated Defluorination of High-Priority Per- and Polyfluoroalkyl Substances: Microorganisms, Genetics, and Biochemistry
- ER20-1219 Biotransformation and Potential Mineralization of PFOS, PFHxS, and PFOA by Acidimicrobiaceae sp. A6 under Iron Reducing Conditions
- ER20-1430 Biodegradation of Per- and Polyfluoroalkyl Substances (PFASs) via Superoxide-Hyper-Producing Bacteria
- ER20-1541 Identification, Characterization, and Application of Reductive Defluorinating Microorganisms
- ER22-3312 Cometabolic Transformation and Treatment of PFAS Precursors in PFAS-Impacted Soils and Aquifer Sediments

Research on the fungal degradation of PFAS has been ongoing due to the wide spectrum of substrate reduction catalyzed by extracellular ligninolytic enzymes. Experiments with white-rot fungus showed limited degradation of PFOA in microcosm studies under certain conditions (**Tseng 2012**). The innovative delivery of fungal enzymes for PFAS treatment requires further research.

The biodegradation of PFAS has been reported in a few studies as described above and in the following: 8:2 FTOH (**Wang et al. 2009**), 6:2 FTOH (**Liu et al. 2010**), 6:2 FTS (**Wang et al. 2011**), and N-ethyl perfluorooctane sulfonamidoethanol (**Rhoads et al. 2008**; **Rhoads et al. 2013**). Recently the PFOA-degrading strain YAB1 was isolated from soil that had been impacted by perfluorinated compounds through acclimation and enrichment culture, where perfluorooctanoic acid (PFOA) was amended as the sole carbon source (**Yi et al. 2016**). "This strain was preliminarily identified as Pseudomonas parafulva based on colony morphology, physiological and biochemical features, and 16S rRNA gene sequencing. Using shaking flask fermentation, the maximum tolerable concentration of YAB1 on PFOA was found to be 1,000 mg/L" (**Yi et al. 2016**), and the optimal PFOA concentration for the growth of YAB1 was 500 mg/L. After 96 hours of culture, the PFOA degradation rate was "32.4%. When 1 g/L glucose was added to the inorganic salt culture medium, the degradation rate increased to 48.1%. Glucose was the best exogenous carbon source for the degradation of PFOA" (**Yi et al. 2016**).

12.6.5 Alkaline Hydrothermal Reaction

Alkaline hydrothermal treatment involves degradation of PFAS under high pressure, high temperature, and high pH conditions. **Wu et al. (2019)** demonstrate rapid destruction of particularly recalcitrant PFOS during hydrothermal treatment of a solution amended with NaOH. They propose an initial cleavage of the functional group catalyzed by OH-, followed by sequential chain-shortening and decarboxylation to produce carbonate and fluoride salts. Other researchers (**Li et al. 2022**; **Hao et al. 2021**, **2022**) have demonstrated PFAS degradation in a variety of matrices, but generally long residence times (> 30 minutes) have been required for high degrees of PFAS degradation (for example, > 90%). **Pinkard et al. (2023)** demonstrated greater than 99% degradation in a continuous flow system.

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER18-1501 Hydrothermal Technologies for On-Site Destruction of Site Investigation Wastes Impacted by Per- and Polyfluoroalkyl Substances (PFAS)
- ER22-3157 Hydrothermal Destruction of Per- and Polyfluoroalkyl Substances during Designer Biochar Reactivation

12.6.6 Deep Well Injection

A potential alternative to treatment may be the use of on-site or off-site underground injection waste disposal wells for liquids containing PFAS. The **USEPA (2024)** considered deep well injection as one of three viable, commercially available disposal options. This approach eliminates discharges to surface water and groundwater, which could be a consideration given the present climate of varying discharge limitations for PFAS. However, deep well injection is not a destruction technology.

Class I wells, as defined by USEPA, are acceptable for both hazardous and nonhazardous liquid wastes (**USEPA 2019**). The USEPA has published guidance on the requirements for the use of injection wells, which include siting, construction, operation, monitoring, testing, record keeping, reporting, and closure (**USEPA 2019**). The USEPA has also studied the risks associated with underground injection wells (**USEPA 2001**), and these risks should be considered for the use of underground injection wells for PFAS-laden water. This option may be most attractive as a disposal option for high concentration liquids, such as RO reject water, anion exchange regeneration fluids, wastewater from manufacturing sites, and landfill leachate.

12.6.7 Monitored Natural Attenuation

Definition of MNA "The term "monitored natural attenuation," refers to the reliance on natural attenuation processes (within the context of a carefully controlled and monitored site cleanup approach) to achieve site-specific remediation objectives within a time frame that is reasonable compared to that offered by other more active methods" (**USEPA 1999**).

12.6.7.1 Introduction

Monitored natural attenuation (MNA) is fundamentally a risk management strategy. MNA is not a "presumptive" or "default" remedy—it represents a remedy component option that should be evaluated alongside other applicable remedy component options, including in combination with active treatment (for example, active treatment of "hot spots" and MNA for distal segments of a plume or as part of a treatment train). MNA is not considered a "no action" or "walk-away" approach but is rather considered "an alternative means of achieving remediation objectives that may be appropriate for specific, well-documented site circumstances where [the implementation of MNA] meets the applicable statutory and regulatory requirements" (**USEPA 1999**). In its guidance for the cleanup of contaminated soil and groundwater in the Superfund, RCRA Corrective Action, and Underground Storage Tank Programs, USEPA noted that "...there is often a variety of methods available for achieving remediation objectives at any given site, MNA may be evaluated and compared to other viable remediation methods (including innovative technologies) during the study phases" (**USEPA 1999**) informing remedy selection and periodically thereafter. A comprehensive long-term monitoring program is critical to any MNA remedy component to verify its continued viability. If plume migration trend data suggest a potential threat to receptors or lack of progress toward remediation objectives, additional contingency measures are likely to be to be required.

Attenuation Processes The "natural attenuation processes" include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These in situ processes include biodegradation; dispersion; dilution; sorption; volatilization; radioactive decay; and chemical or biological stabilization, transformation, or destruction of contaminants." (**USEPA 1999**).

MNA has been proposed as a strategic component to manage PFAS impacts at some sites (**Newell et al. 2021**, **2021**). MNA is an established management approach for a variety of contaminant classes that are subject to natural attenuation processes when released to the environment, including petroleum hydrocarbons and chlorinated solvents (**USEPA 1999**). In addition, MNA is an established management approach for certain metals and other inorganic constituents that do not degrade but are attenuated through various nondestructive processes (**ITRC 2010**; **USEPA 2015**), which can be considered analogous to PFAS. Although there are currently no recognized destructive attenuation mechanisms for PFAAs, numerous biotic and abiotic transformation pathways have been documented for several polyfluorinated PFAS (see **Section 5.4**). As research regarding natural attenuation mechanisms for PFAS continues, it is possible that additional biotic and abiotic attenuation pathways (including transformation, destruction, or mineralization) may be identified.

The predominant known processes for PFAS natural attenuation are those that contribute to plume stability resulting from natural retardation of PFAS transport and promote retention of PFAS mass in the subsurface away from potential receptors. These include solid phase partitioning (**Section 5.2.3**), partitioning at the air-water interface (**Section 5.2.4.1**), natural advection mechanisms, and matrix diffusion (**Section 5.3.1**).

In the subsurface, physical and geochemical processes can result in a stable plume by slowing PFAS migration through the unsaturated zone, reducing or preventing the mass discharge from the unsaturated zone to an underlying aquifer, and slowing the rate of PFAS migration within the saturated zone. The

preferential sorption characteristics of polyfluorinated compounds with cationic or zwitterionic head groups can also promote attenuation (refer to **Section 10.4.6**). This represents a form of "chemical retention" (**Newell et al. 2021**) because if naturally retained in the untransformed, cationic, or zwitterionic precursor state these compounds are anticipated to move more slowly than if they were transformed to more mobile anionic PFAAs.

12.6.7.2 Considerations for an MNA Remedy Component

MNA may be most applicable to PFAS sites with some combination of a stable plume, a long travel time to the nearest receptor, and low and/or decreasing mass discharge rates. A stable plume may be demonstrated if the attenuation rate offsets the migration rate (that is, steady state condition) (see **Section 10.4.7**). Practitioners may rely on multiple strategies, including concentration trend analysis, to demonstrate the degree to which PFAS plumes may be attenuating and/or stabilizing.

For documented stable plumes, and in the absence of immediate risk receptors or where exposures can be controlled, MNA may be considered as an effective management approach for the following scenarios: 1) as a final remedy component for plume segments where a comprehensive data set demonstrates natural attenuation trends that can achieve comparable reduction rates and time frames to attain the remediation objectives for PFAS groundwater concentrations versus active treatment technologies (for example, lower parts per trillion plumes or distal plume segments; scatter/random PFAS detections that do not represent a defined plume); or 2) as a final treatment train step to reach low parts per trillion cleanup levels once active treatment has reached a defined interim treatment objective or plateau condition/point of diminishing returns (assuming lines of evidence supporting MNA has been established).

Given the evolving state of understanding and associated uncertainties regarding the behavior of PFAS in the environment, development of reliable PFAS fate and transport models that are rigorous and include the derivation of site-specific parameters that govern PFAS fate and transport will be needed. High-resolution site characterization methods (including tracer studies) and fate and transport modeling may be beneficial in evaluating natural attenuation of PFAS. Consideration of MNA as a potential element of a remedial strategy may require implementation of source control measures (that is, hydraulic modifications, in situ injections, removals, etc.) and/or demonstration of stable conditions.

Comprehensive PFAS fate and transport modeling is further complicated by the uncertainties of precursor PFAS transformation in the environment. For more information regarding PFAS fate and transport modeling and assessing plume stability, see Assessing Plume Stability in **Section 10.4.8**.

Until a more thorough understanding of PFAS attenuation is developed, consideration of MNA should be evaluated cautiously, whether as the primary or complimentary technology at PFAS contaminated sites.

Related Past, Ongoing, and Recent Research Funded by ESTCP

- ER21-5198 Developing a Framework for Monitored Natural Attenuation at PFAS Sites

12.7 Limited Application and Developing Solids Treatment Technologies

The treatment technologies presented in this document are provided in a hierarchy defined in **Section 12.1**, based on level of implementation and level of confidence in the technology from peer-reviewed literature and extent of documented performance. The three development levels include field-implemented technologies, limited application technologies, and developing technologies. Where appropriate in the text both in situ and ex situ technologies are discussed. However, it is not always clear

if a limited application or developing technology may be effective in situ, ex situ, or both, thus further distinction between in situ and ex situ is not made in this section. Table 12-1 Treatment Methods Table Excel File presents limited application and developing technologies for solids, which may be applicable to soil, sediments, biosolids, or other solid media, including PFAS-laden materials (for example, GAC, resin, scrubbers, filters). Thermal treatment warrants further discussion as a limited application technology because it has been field-demonstrated at multiple sites by multiple practitioners but has not been well documented in peer-reviewed literature.

12.7.1 Sorption and Stabilization/Solidification

Limited application and developing materials being demonstrated or developed for sorption and stabilization include minerals (for example, organically modified clays) or stabilization agents (for example, Portland cement). Stabilization/solidification through mixing with cementitious materials (for example, Portland cement or other amendments) can be applied to encapsulate PFAS-impacted soil/sediment to restrict PFAS leaching or migration. In situ solidification is always performed with soils in place, and it is necessary to use specialized equipment and maintain careful control over the addition of amendments and water content. In batch experiments, a reduction of 95-99% of leachable anionic PFAS, including PFOS and PFOA, was achieved with amending contaminated soil with 0.5% to 5% by weight of a commercially-available surface-modified clay (**Wang et al. 2021**). Other laboratory (**Willett and Geary 2021**) and in situ field studies (**McDonough et al. 2021**) on soils mixed with up to 10% by weight of this surface-modified clay showed reduction in leaching of a number of PFAS. In situ solidification is intended to yield a high-compressive-strength monolith that has low permeability. A bench-scale study (**Sörengård, Kleja, and Ahrens 2019**) indicated that solidification using a binder (combination of Portland cement, fly ash, and ground granulated blast-furnace base slag) at a ratio of 9:1 reduced leaching for 13 out of 14 PFAS (except for PFBS). Introducing additional additives (for example, activated carbon, surface-modified clays) at a 2% concentration can further reduce leaching of PFAS in solidification-treated soil.

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER22-3124 A New Concept of "Release-Capture-Destruction" to Enable Remediation of PFAS in Source Zone Soils
- ER18-1652 Destruction of PFAS and Organic Co-Occurring Chemicals

12.7.2 Thermal Treatment

Thermal treatment is defined as mobilization or destruction, or both, of chemicals using heat. This can be accomplished by thermal desorption or thermal destruction. Heat is applied directly or indirectly to the PFAS-contaminated soil/sediment. The Priority Topics for Treatment Technologies include updated information for incineration, pyrolysis/gasification, and thermal desorption (see **Section 1.6.1**).

Ex situ thermal treatment has been demonstrated (450–954°C) at field pilot-scale studies by a few technology vendors and is considered a partially demonstrated technology (**Endpoint Consulting 2016**; **Enviropacific 2017**; **Colgan et al. 2018**; **Grieco and Edwards 2019**). The effectiveness depends upon the ability to deliver heat to achieve sufficient and evenly distributed temperature at field scale cost-effectively. The pilot studies conducted have reported >90% removal of PFAS from soil when high heat has been applied.

In addition, lower temperature thermal desorption has been demonstrated to be effective for PFAS at 350–400°C on the bench scale. During a recent proof of concept laboratory bench test, 99.99% removal of PFAS from soils was demonstrated while heating the target volume to 400°C (**Crownover et al. 2019**; **DiGuiseppi, Richter, and Riggle 2019**).

No documented examples of in situ thermal treatment for PFAS-impacted soil have been identified. However, the ex situ testing at 350–400°C suggests that these temperatures are sufficient for desorption of PFAS and therefore in situ treatment is potentially feasible for PFAS.

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER18-1501 Hydrothermal Technologies for On-Site Destruction of Site Investigation Wastes Contaminated with Per- and Polyfluoroalkyl Substances (PFASs)
- ER18-1556 Small-Scale Thermal Treatment of Investigation-Derived Wastes (IDW) Containing Per- and Polyfluoroalkyl Substances (PFAS)
- ER18-1572 Evaluation of Indirect Thermal Desorption Coupled with Thermal Oxidation (ITD/TO) Technology to Treat Solid PFAS-Impacted Investigation-Derived Waste (IDW)
- ER18-1593 Demonstration of Smoldering Combustion Treatment of PFAS-Impacted Investigation-Derived Waste
- ER18-1603 Field Demonstration of Infrared Thermal Treatment of PFAS-Contaminated Soils from Subsurface Investigations
- ER18-1672 Evaluation of Indirect Thermal Desorption Coupled with Thermal Oxidation (ITD/TO) Technology to Treat Solid PFAS-Impacted Investigation-derived Waste
- ER19-1408 Analysis of Fate of PFAS During Incineration
- ER20-5250 In Situ Thermal Treatment of PFAS in the Vadose Zone
- ER20-5198 Ex Situ Thermal Treatment of Perfluoroalkyl and Polyfluoroalkyl Substances
- ER20-5350 Supercritical Water Oxidation (SCWO) for Complete PFAS DestructionER21-1288 Multi-Scale Evaluation of PFAS Thermal Destruction Requirements
- ER21-1107 Improved Understanding of Thermal Destruction Technologies for Materials Laden with Per- and Polyfluoroalkyl Substances
- ER21-1019 A Quantum Chemical - Machine Learning Approach for the Prediction of Thermal PFAS Destruction
- ER21-1234 Experimental and Theoretical Validation of the Chemical Kinetics for the Thermal Destruction of Perfluoroalkyl Alkyl Substances
- ER21-1135 Improving Low Temperature Thermal Treatment of Per- and Polyfluoroalkyl Substances (PFAS) and Infrared (IR) Spectroscopy Methods to Monitor Treatment Efficacy
- ER20-5250 In Situ Thermal Treatment of PFAS in the Vadose Zone
- ER20-5198 Ex Situ Thermal Treatment of Perfluoroalkyl and Polyfluoroalkyl Substances
- ER21-1256 Develop Synergetic Novel Macrocycle-based Sorbents with Thermal Destruction for Enhanced PFAS Removal in Groundwater and Drinking Water Treatment
- ER21-1117 Thermal-Enhanced Photochemical and Alkaline Destruction of PFAS in Sorbent Regenerants and Membrane Concentrates
- ER22-3384 Bench-Scale Demonstration of Per-and Polyfluoroalkyl Substances (PFAS) (Destruction in Solids Using Supercritical Water Oxidation (SCWO)
- ER21-5119 On-Site Demonstration of Thermal Desorption Coupled with Thermal Oxidation Technology to Treat Solid PFAS-impacted Soil Investigation Derived Waste
- ER20-3044 Thermal Reactivation of Spent GAC from PFAS Remediation Sites
- ER22-4014 Thermal Treatment for Effective Per- and Polyfluoroalkyl Substances Decomposition in Solid Matrices and AFFF Concentrate

At bench, pilot, and field scales, limited data sets are available and data gaps still exist mainly regarding fate of volatilized PFAS and air emissions (**Lassen et al. 2013**; **USEPA 2020**; **Yamada et al. 2005**). Another concern is the volatilization of hydrogen fluoride, which could pose serious health and safety issues and could compromise equipment components. Hydrofluoric acid and other non-PFAS off-gas concerns can be managed through conventional off-gas treatment systems (scrubbers), as is further described in **Section 12.5** (Air Treatment). Although air emissions from the thermal treatment of PFAS have not been thoroughly studied at the field scale to date, some limited field-implemented air emission

studies from the thermal treatment of PFAS have been completed (**Barr Engineering 2022**; **Chemours 2023**). PFAS treatment via high temperature air incineration and subsequent acid-gas scrubbing is a common practice during carbon reactivation (**Mimna 2017**).

Pyrolysis and gasification are often described as heat-induced thermal decomposition processes, though these processes are not solely focused on treatment and are typically used to convert a waste product into a useful feedstock for another product, such as energy, fuels, and chemical commodities. These technologies have only recently been evaluated with respect to treating PFAS (**Winchell et al. 2022**; **Thoma et al. 2022**; **Bamdad et al. 2022**; **DiStefano et al. 2022**).

12.8 Integrated Water Treatment Solutions

This section provides guidance on the development and selection of treatment solutions for water containing PFAS in combination with other constituents. It is often necessary to combine treatment technologies into integrated solutions to achieve project objectives for co-contaminants. While PFAS can affect multiple media, the focus of this section is on treatment of water and the water treatment processes. The water matrix may contain constituents such as TOC, TSS, and TDS at levels that may require pretreatment because they could interfere with and reduce the effectiveness of the PFAS treatment technologies. Regulated organic and inorganic co-contaminants require treatment to meet their respective remedial objectives. An integrated solution can include a combination of treatment mechanisms (separation, sorption, and destruction) and development stages (for example, field-implemented, limited application, and developing). **Section 18** provides guidance for sorption-based technologies for separation and concentration of PFAS from water including considerations for pretreatment and co-occurring constituents.

12.8.1 Development of Alternative Water Treatment Trains

Many factors play into the development and selection of integrated treatment solutions and the considerations and examples provided here are intended to assist in the selection process. The remedial action or treatment objectives are key drivers in selecting treatment technologies and waste disposal methods. Liquid and solid waste stream generation is another critical factor in the selection process as waste may be subject to PFAS regulations. While the focus of this section is on water treatment, the treatment technologies applicable to solid wastes are discussed in **Sections 12.3**, **12.4**, and **12.6**. Factors affecting pre-treatment, primary treatment, and post-treatment selection are presented in **Section 12.1.1**. Selection of an integrated treatment solution may be an iterative process to select a primary treatment technology that best meets project objectives while minimizing the associated pre-treatment, post-treatment, and generated waste streams.

Figure 12-7 (provided as a separate PDF) shows a sample flow chart that includes a variety of options for integrated treatment solutions based on different water and process waste matrices. The water matrix column in the flow chart, which represents the composition of the water to be treated, includes examples of naturally occurring substances and inorganic and organic co-contaminants. The pre-treatment stage provides examples of technologies that can be used as standalone or in combination for treating different co-contaminants. The PFAS treatment system can also include multiple treatment technologies (treatment train) that each generate waste that must be subsequently treated or disposed of. The sample flow chart provides examples of wastes generated by different treatment technologies and corresponding potential disposition options. Factors in selecting PFAS treatment methods are presented in Sections **12.2**, **12.3**, **12.4**, **12.5**, **12.6** and **12.7**.

Related Ongoing Research Funded by SERDP

- ER18-1230 Development, Evaluation, and Technology Transfer of BMPs for Optimizing Removal of PAHs, PCBs, PFASs, and Metals from Stormwater at DoD Sites
- ER18-1278 An Electrocoagulation and Electrooxidation Treatment Train to Degrade Perfluoroalkyl Substances and Other Persistent Organic Contaminants in Groundwater
- ER-2714 Development of Coupled Physiochemical and Biological Systems for In Situ Remediation of Perfluorinated Chemical and Chlorinated Solvents Groundwater Plumes
- ER-2718 Synergistic Treatment of Mixed 1,4-Dioxane and Polyfluorinated Chemical Contaminations by Combining Electrolytic Degradation with Electrobiostimulation
- ER18-1652 Destruction of PFAS and Organic Co-Contaminants in Water and Soil Present in Investigation-Derived Waste at DoD Sites Using Novel Adsorbent and Ultrasound
- ER21-5136 Nanofiltration Followed by Electrical Discharge Plasma for Destruction of PFAS Co-occurring Chemicals in Groundwater: A Treatment Train Approach
- ER20-1286 A Synergistic Platform for Defluorination of Perfluoroalkyl Acids (PFAAs) through Catalytic Reduction Followed by Microbial Oxidation
- ER19-1410 Treatment Train for In Situ Mineralization of PFOS Using Heat-activated Persulfate Oxidation (HAPO)
- ER18-5015 Removal and Destruction of PFAS and Co-Occurring Chemicals from Groundwater via Extraction and Treatment with Ion Exchange Media, and On Site Regeneration, Distillation, and Plasma Destruction
- ER18-1482 Chemical Decomposition Combined with Physical Adsorption for the Treatment of Investigation-Derived Waste Containing PFASs
- ER18-1633 Lines of Evidence to Assess the Effectiveness of PFAS Remedial Technologies
- ER18-1306 Combined In Situ/Ex Situ Treatment Train for Remediation of PFAS-Impacted Groundwater
- ER18-1289 Treatment of Legacy and Emerging Fluoroalkyl Chemicals in Groundwater with Integrated Approaches: Rapid and Regenerable Adsorption and UV-Induced Defluorination
- ER18-1497 High-Performance Treatment of PFASs from Investigation-derived Waste: Integrating Advanced Oxidation-Reduction and Membrane Concentration
- ER-201729 Field Demonstration to Enhance PFAS Degradation and Mass Removal Using Thermally-Enhanced Persulfate Oxidation Followed by Pump-and-Treat
- ER22-3415 Novel Swellable Ionomers for Enhanced PFAS Sorption and Destruction
- ER22-3124 A New Concept of “Release-Capture-Destruction” to Enable Remediation of PFAS in Source Zone Soils
- ER22-3150 Engineering an “All-In-One” Biochar-Surfactant System for Enhanced PFAS Sorption and Reductive Degradation Using a Coupled Ultraviolet and Ultrasonication Approach

Every water source is different, so proper characterization is important for developing and selecting the proper integrated solution. The following questions may help guide the selection process:

1. What are the remedial action objectives and discharge criteria for all contaminants?
2. What information is available on geochemistry, natural organic matter, and potential inorganic constituents, and what are the remaining data needs for adequate characterization?
    a. What are the pre-treatment options for the identified matrix?
    b. What wastes are generated through pretreatment?
3. What other non-PFAS organic constituents (for example, volatile and semi-volatile organic co-contaminants) are present at levels that require treatment?
    a. What types of treatment technologies or combinations of technologies apply?

   b. What wastes are generated by application of each treatment technology?
   c. Can the co-contaminants be effectively treated by the same technology as PFAS, and, if so, could this adversely affect PFAS removal? Do the technologies compete with each other, and does this reduce effectiveness and efficiency of PFAS removal?

4. Are field-implemented treatment technologies available for the treatment or destruction of waste streams; if not, consider limited application and developing technologies and possibly pilot testing?

Lu et al. (2020) provided a critical review of PFAS treatment train approaches. Additional recent work is focusing on simultaneous coupling of technologies, where PFAS are sorbed onto reactive particles, which are then destroyed in the presence of catalyst (for example, **Zhang, Zhang, and Liang 2019**; **Xu et al. 2020**). **Pica et al. (2019)**; **Soriano, Gorri, and Urtiaga (2017)**; and **Soriano, Schaefer, and Urtiaga (2020)** described and evaluated combined filtration followed by electrochemical oxidation approaches.

12.9 Sustainability of PFAS Treatment

Federal and state environmental protection agencies have published myriad green remediation best management practice fact sheets and guidance documents covering a variety of remediation topics and emphasizing the minimization of environmental cleanup footprints (**USEPA 2012**, **2018**), including methods to quantify the environmental footprint (**USEPA 2019**). The best management practice fact sheets for excavation and surface restoration, implementing in situ thermal technologies, and (more generally) materials and waste management may offer supplemental sustainability information to that already included alongside the remediation technologies presented within this section (**USEPA 2008**, **2012**, **2013**).

Applying such a framework for PFAS cleanup projects, the environmental impact drivers for PFAS cleanup technologies that should be considered include the life cycle environmental footprint of all facets of the cleanup, including project site preparation; installation of the remedy; materials, equipment, and energy used to operate the remedy; waste materials generated by the cleanup technology; and demolition and deconstruction of the remedy. In alignment with greener cleanups, green and sustainable remediation recommends the "the site-specific employment of products, processes, technologies, and procedures that mitigate contaminant risk to receptors while making decisions that are cognizant of balancing community goals, economic impacts, and environmental effects" (**ITRC 2011, 2011, p. 3**). Economic and quality of life impacts to the community can be alleviated by early incorporation of green and sustainable remediation best management practices, including meaningful stakeholder engagement, creation of employment opportunities, and advancement of the local community's skill set to help manage treatment systems and public outreach (**USEPA 2012**). Lastly, climate change vulnerability and adaptation measures of remedial technologies should also be considered to ensure resiliency in the implemented remedial action (**USEPA 2013**, **2014**).

In alignment with sustainability principles, performance of early and meaningful risk communication can assist professionals in raising the community's awareness of environmental hazards, empowering community participation in risk reduction measures, and increasing the quality of life for the community impacted by contamination and related risk management activities (**USEPA 2007**). Several environmental and public health regulatory agencies have prepared information documents to assist professionals in performing effective risk communication for PFAS sites, for example, see **ATSDR (2018)**.

In addition, a communication plan can be developed to assist with information dissemination and stakeholder engagement (**Emmett et al. 2009**). **Section 14** provides further in-depth guidance on risk communication planning and performance. A risk communication toolbox is also being developed to help decision makers through the planning process and provide tools to assist with meeting performance

metrics at each planning step. Additional guidance on stakeholder concerns and engagement is provided within this document in **Section 13**.

12.10 Improving Evaluation of PFAS Treatment Technologies

Significant effort has been completed with respect to reviewing and compiling comparative information on PFAS treatment technologies. In a number of instances, proponents of innovative treatment technologies have claimed success in removing or destroying PFAS with limited confirmation of performance. For example, removal mechanisms may not have been proven, byproducts may not have been measured, and the effect of the technology in actual environmental matrices, at environmentally relevant concentrations, on PFAS mixtures, or with co-contaminants present may be unknown.

To guide future assessments and investments in developing PFAS treatment technologies, a SERDP project has prepared suggested lines of evidence, recommended metrics, and decision tools to assess the effectiveness of PFAS treatment technologies. These lines of evidence and decision-making tools can be used to identify priorities and next steps to advance a given technology, assess whether a technology is ready for field demonstration, and identify key areas of uncertainty regarding technology performance.

Further SERDP-funded work (ER18-5053) is focused on developing a comprehensive assessment framework for ex situ PFAS treatment technologies and generating data to compare established and emerging approaches on a life cycle assessment and costing basis.

Related Past, Ongoing, and Recent Research Funded by SERDP

- ER18-1633 Lines of Evidence to Assess the Effectiveness of PFAS Remedial Technologies
- ER18-5053 Evaluation and Life Cycle Comparison of Ex Situ Treatment Technologies for Per- and Polyfluoroalkyl Substances (PFASs) in Groundwater

13 STAKEHOLDER PERSPECTIVES

This section identifies the concerns of stakeholders who have been or may be affected by PFAS contamination. In this section, we summarize many of the concerns that have been expressed by local communities, tribes, and environmental groups. Evaluation of exposure levels and potential human health consequences are of paramount concern to stakeholders.

Section Number	Topic
13.1	**Stakeholder Concerns**
13.2	**Specific Tribal Stakeholder Concerns**
13.3	**Stakeholder Resources**

The term "stakeholder" is defined broadly by ITRC as members of environmental organizations, community advocacy groups, tribal entities or other citizens' groups that deal with environmental issues, or a concerned citizen who is not a member of any organization or group. Public stakeholders, such as advocacy groups, often speak for the communities that are affected by environmental issues. In this document, a differentiation is made between public stakeholders and interested parties (responsible parties, state regulators, and owners and operators of contaminated sites).

Stakeholders share greater ownership of outcomes when they have the opportunity to influence site characterization, remedy selection, and long-term site management. Because PFAS are so abundant in consumer products, stakeholders are also concerned with the production and eventual use of these products and are seeking safer alternatives and sometimes outright bans (see **Section 2.5** for information about PFAS Uses and information about certifications related to reduction or elimination of PFAS in products). Environmental regulators and responsible parties also benefit from informed, constructive stakeholder involvement because it can help them make better decisions, reduce the likelihood of costly, time-consuming repeated work, and allow those in affected communities to have a voice in governing the long-term use of land, water, and other resources. Often, stakeholders such as long-time residents have unique site knowledge as well as a major stake in the remedial outcome. In the case of PFAS, many national environmental organizations have made community outreach a major focus. Local grassroots organizations and one, the National PFAS Contamination Coalition (**https://pfasproject.net**), have led a major effort to inform the public and influence policy. In addition, ATDSR studies (for example, **ATSDR 2022**) and National Academy of Science (**NAS 2022**) studies have included community outreach efforts.

Developing site-specific characterization and remediation strategies for communities and tribal organizations can be challenging, because there are many misconceptions about PFAS. The lack of scientific knowledge about many of these PFAS further enhances the need to educate the public. Therefore, early and effective community engagement emphasizing timely access to test data, transparency, and responsiveness is imperative. Community engagement may be able to address many stakeholder concerns and help to communicate risks. The **ITRC Risk Communication Toolkit for Environmental Issues and Concerns** includes information about stakeholder engagement and is published as a separate document. **Section 14** addresses tools for PFAS-specific risk communication challenges, and provides some examples of PFAS risk communication issues.

This section identifies the concerns of stakeholders who have been or may be affected by PFAS contamination. Because PFAS are emerging contaminants and have been detected in ecological receptors (animals and plants, see sections **5.5** and **5.6**) and blood serum in many humans (**Section 7.1**), there are many individuals who are potentially affected worldwide.

In this section, we summarize many of the concerns that have been expressed by local communities, tribes, and environmental groups. Evaluation of exposure levels and potential human health consequences are of paramount concern to stakeholders. The list of concerns below is not all inclusive, as developments in science and identification of contaminants in the environment are likely to lead to additional concerns. This list was developed from general research on PFAS, direct communication and involvement with environmental and community groups, a consultant for one of the tribes, and extensive review of news reports. **This section is intended to highlight the concerns that have been expressed by various groups. It is not intended to be a definitive statement of the technical merits of those concerns.**

USEPA conducted five community engagement events and one event with tribal representatives during the summer of 2018. Meeting materials, information, and summaries of each event are provided on USEPA's website: **https://www.epa.gov/pfas/pfas-community-engagement**. Series-specific lists of concern and associated social factors identified from presentations by public and community stakeholders during the USEPA PFAS community meetings held in 2018 are provided in the **ITRC Risk Communication Toolkit for Environmental Issues and Concerns** which is published as a separate document, and are discussed in **Section 14.3.4.** See also **https://pfascommunityengagement.org** for information about EPA virtual listening sessions in Spring 2023.

The following concerns were identified during preparation of this document, with details of these concerns in the following sections.

• Lack of comprehensive regulatory standards or advisories for thousands of PFAS for the following (**13.1.1**): Drinking water (**13.1.1.1**) Environmental media other than drinking water (**13.1.1.2**) Human consumption of food (**13.1.1.3**) Ecological risk (**13.1.1.4**)	• Limited availability of information on the health effects of PFAS (**13.1.15**)
• Desire for one standard or screening level for PFAS (**13.1.2**)	• Responsibility for sampling and treatment on private property (**13.1.16**)
• Lack of Occupational standards (**13.1.3**)	• The potential for PFAS emissions from cleanup methods (**13.1.17**)
• Lack of comprehensive monitoring information (**13.1.4**)	• Lack of scientific evidence that current PFAS treatment and disposal methods and remedies are fully protective of human and ecological health and prevent toxic emissions (**13.1.18**)
• Need to apply a precautionary approach in decision making (**13.1.5**)	• Stormwater and PFAS manufacturing discharges that may contain PFAS (**13.1.19**)
• Safety of short-chain substitutes (**13.1.6**)	• Psychological effects (**13.1.20**)
• Contamination from AFFF release sites (**13.1.7**) and unused AFFF disposal (**13.1.8**)	• Economic consequences of local PFAS contamination (**13.1.21**)
• Duty to warn AFFF responders (**13.1.9**)	• Remediation of PFAS with other contaminants, especially chlorinated solvents (**13.1.22**)
• Limitations in sampling and analysis methods (**13.1.10**)	• Pesticides containing PFAS (**13.1.23**)
• Limited programs for health monitoring and blood testing (**13.1.11**)	• Artificial turf (**13.1.24**)
• PFAS in food packaging (**13.1.12**)	• Semiconductor manufacturing (**13.1.25**)
• Potential PFAS contamination in recycling, compost, and fertilizer (**13.1.13**)	• Remediation using monitored natural attenuation (MNA) (**13.1.26**)
• Lack of disclosure by product manufacturers (**13.1.14**)	

Stakeholders who use this document should consider that much of the information is very technical. Nevertheless, it aims to lay a framework by which to understand this set of compounds, the foundational nature of the science, and many of the uncertainties.

13.1 Stakeholder Concerns

13.1.1 Lack of Comprehensive Regulatory Standards or Advisories for Thousands of PFAS

This section discusses the lack of advisory standards or screening values for various environmental media and exposure pathways.

13.1.1.1 PFAS in Drinking Water

The USEPA published National Primary Drinking Water Regulations (NPDWR) for six PFAS (**USEPA 2024**).

Several states have regulatory values for some specific PFAS, but the majority of PFAS are not included in any of the states' regulations. Information about available current regulatory standards and guidance values for PFAS in drinking water are provided in **Section 8**, with a summary table linked on the **PFAS fact sheet page**.

Stakeholders are concerned because the health consequences of these other compounds remain uncertain. Firm conclusions relating individual PFAS to specific health outcomes remain elusive (**Guelfo et al. 2018**). Information about health impacts for other PFAS is provided in **Section 7.1**.

13.1.1.2 PFAS in Environmental Media Other than Drinking Water

With the exception of regional soil screening levels for a limited number of PFAS (**USEPA 2023**), there are no federal standards or screening levels for evaluating environmental media (air, soil, and surface water and groundwater not used for drinking) and limited federal requirements that compel such monitoring at the time of publication.

USEPA has developed interim recommendations for screening and remediation of groundwater for PFOS and PFOA at CERCLA and RCRA regulated sites (**USEPA 2019**). **Section 8** includes information about regulations, guidance, and advisories for PFAS. In addition, the **Environmental Media Values Table** Excel file is available.

There are few limits by the federal and most state governments on PFAS in biosolids being applied to land for food and/or nonfood crops. PFAS, such as PFOA and PFOS, have been detected in biosolids produced at wastewater treatment plants (WWTPs), and in soil, surface waters, and leachate from landfills. WWTP biosolids are commonly applied to land as a soil amendment, and can remobilize PFAS to other migration and exposure pathways. Stakeholders are concerned about uptake by crops eaten by humans and animals. **Section 2.6** introduces PFAS sources at landfills and WWTPs, and **Section 5.6** and **Section 6.5.1** discuss plant uptake of PFAS. USEPA will be performing a risk assessment of biosolids as part of the PFAS Strategic Roadmap (**USEPA 2021**).

There are few regulatory or guidance limits for PFAS in surface water that may affect fish and consumers of fish. In addition, PFAS in surface water also creates an exposure pathway that potentially affects ecological and human health. For more information on PFAS in surface water, see **Section 16**.

While recognizing that drinking water is the dominant exposure pathway, **Vestergren and Cousins (2009)** identified that PFAS impacts to other media need to be considered because "there is a clear need

of investigations of how to remediate the hotspot areas with focus on the unsaturated zone," because "PFAS that are pooled in the unsaturated zone will continue to infiltrate and spread from contaminated areas as long as the source is not removed, or infiltration of precipitation is inhibited."

13.1.1.3 Human Consumption of Food

Many stakeholders want clear advisories or standards on PFAS in food due to the occurrence of PFAS in a variety of food. In Europe important sources of human exposure to PFOA and PFOS have been found to include the consumption of fish, meat, and eggs (**EFSA 2018**). The US Food and Drug Administration (FDA) has published information on their PFAS studies on their website (**USFDA 2019[1768]**). Few screening levels or advisories have been posted; for example, Maine has developed screening levels for fish for PFBS, PFOS, and PFOA, and for milk and beef for PFOS (**ME DEP 2021**). Further information about development of standards for food consumption is found in **Section 8.2.2.11**. PFAS are found in a variety of foods, including homegrown produce and wildlife. Some areas of concern regarding foods include the following:

- PFAS have been found in food purchased at stores. Some occurrence information for foods collected as part of the FDA's Total Diet Study is published in **Genualdi et al. (2021)**.

- Some states have issued fish consumption advisories for specific lakes and rivers after tests confirmed the presence of PFAS in surface water. **Section 15.3** includes a case study example about a recently enacted fish consumption advisory by the New Jersey Department of Environmental Protection.

- In February 2018, the Environmental Protection Authority of Victoria, Australia, "assessed waterfowl from three wetlands to better understand the extent and distribution of PFAS contamination ahead of the duck hunting season. PFAS was detected in waterfowl from all three wetlands." As a result, health risk assessments were undertaken and human health advisories were issued (**Environmental Protection Authority Victoria 2019**), p.1).

- In Wisconsin, the Department of Natural Resources (DNR) recommended not consuming the liver of deer killed within a 5-mile radius of an industrial site where elevated levels of PFOS were found. "DNR And DHS Issue Do Not Eat Advisory for Deer Liver In Five-Mile Area Surrounding JCI/Tyco Site In Marinette", September 15, 2020, https://dnr.wisconsin.gov/newsroom/release/37921.

- Alaska Community Action on Toxics (ACAT) (**Byrne 2009**) reported that "A study by **Martin et al. (2004)** on the presence of PFOS in the livers of arctic animals revealed elevated PFOS levels in almost all species studied." Furthermore, it reported that "In a recent study (Ostertag et al. 2009[2119]) of foods consumed by a Canadian Inuit population, traditional foods were more widely contaminated and contained higher concentrations of PFCs [PFAS] than nontraditional foods. Caribou had the highest concentrations of perfluorinated compounds (PFCs), including PFOS." At the request of the Yupik people of St. Lawrence Island, the ACAT is conducting a study to determine the safety of the traditional foods they eat for subsistence (**Byrne 2009**).

13.1.1.4 Ecological Risk

There is wide stakeholder concern that ecological receptors have been or will be harmed by releases of PFAS to the environment (**Section 7.2**). Currently, there are no federal risk-based ecological guidelines or thresholds for environmental media. Ecotoxicity studies are generally limited to a relatively small number of PFAS (typically PFOA and PFOS). Stakeholders are asking for expanded studies in this field to evaluate additional PFAS, including short-chain precursor compounds as well as "next-generation" substitute

compounds. Several states have established some criteria that are intended to protect aquatic organisms in their respective surface waters (see **Section 16.3**).

13.1.2 Desire for One Standard or Screening Level for PFAS

Among stakeholders there is a difference of opinion regarding how standards for PFAS should be established. Many stakeholders believe that PFAS should be treated as a class of chemicals (**Kwiatkowski et al. 2020**), similar to how PCBs or dioxin are currently regulated. In 2021, Vermont concluded that further information is needed to evaluate the feasibility of regulating PFAS in drinking water as a class (**VT ANR 2021**,**2021**). **Section 7.1** includes information about approaches for assessing toxicity of PFAS mixtures.

Given the lack of toxicological information for the vast majority of PFAS, when even less is known about the potential additive and synergistic effects associated with PFAS mixtures (see **Section 7.1.5**), many stakeholders support evaluating the mass of total PFAS as a preferred screening method, rather than limited compound-specific testing using target analyte lists (**CSWAB 2018**). However, it is noted that given the lack of a method to test for total PFAS (see **Section 13.1.10**), screening might need to be completed using a method such as the TOP assay, total organic fluorine, or non-target analysis as descried in **Section 11**. For example, the Conservation Law Foundation in New England put forth a petition requesting that PFAS in drinking water be regulated as a group with a treatment technique drinking water standard. See https://www.nhpr.org/post/activists-ask-new-england-states-regulate-pfas-chemicals-class#stream/0 and https://www.mass.gov/lists/pfas-information-a-petition-for-rulemaking-to-establish-a-treatment-technique-drinking-water. However, some interested parties do not support treating PFAS as a class of chemicals, because some PFAS, such as certain fluoropolymers, like PTFE, might need less toxicological information because they are unable to enter cells, they are not mobile in the environment, they do not bioaccumulate, and they are therefore not available to cause adverse health effects (**Henry et al. 2018**), although this issue needs further study (**Lohmann et al. 2020[1821]**). See also **Section 2.2.2.1**.

13.1.3 Lack of Occupational Standards

There are few standards or guidance values for occupational exposure for PFAS. NIOSH identified occupations that might have a higher potential exposure to PFAS, and identified occupational exposure studies and other research (**NIOSH 2021**). Stakeholders are concerned that paper mills and wastewater treatment plants where PFAS have been documented in indoor air, and manufacturers and industrial users of PFAS, do not have specific occupational standards for all of the PFAS that the workers might be exposed to during workplace activities.

13.1.4 Lack of Comprehensive Monitoring Information

Many stakeholders are concerned that most individuals and communities do not have any testing for PFAS. Moreover, there is no comprehensive federal requirement for PFAS testing of all drinking water systems and private wells. Based on publicly available data, there is an estimate that up to 80 million people in the United States might have drinking water with PFOA and/or PFOS concentrations greater than 1 nanogram per liter (**Andrews and Naidenko 2020**).

Limited testing has occurred in some public water systems, and USEPA's Unregulated Contaminant Monitoring Rule (UCMR) and other regulatory programs have provided more (see **Section 8**). Some significant points regarding the status of a comprehensive monitoring effort follows:

- As described in **Section 8.2.2.4**, the third round of USEPA's required monitoring program (UCMR3), which occurred between 2013 and 2015, sampled for only six of

the thousands of PFAS. UCMR3 was limited to public water systems (PWS) serving more than 10,000 people and a nationally representative subset of smaller PWSs, but private wells and many smaller PWSs were not included. More information about the UCMR3 data is included in **Section 8.2.2.4**. From this data set, it was estimated that approximately 6 million residents of the United States have drinking water that exceeds the 2016 health advisory for PFOA or PFOS, or both (**APHA 2016**).

- Sampling for UCMR4 (**USEPA 2016**), which occurred between 2018 and 2020, did not include any PFAS in its analyte list (**USEPA 2020**). Many stakeholders are concerned that an opportunity to better understand the magnitude of PFAS contamination on PWSs was not taken.

- Summarizing information about the UCMR, **Siros (2018)** stated, "America's Water Infrastructure Act of 2018 … requires drinking water systems serving more than 3,300 people to test for unregulated contaminants pursuant to USEPA's [UCMR]. Prior to this new law, only drinking water systems that served more than 10,000 people were required to monitor for unregulated contaminants. …Th[e] new testing requirement, which goes into effect in 2021, is expected to add more than 5,000 drinking water systems to the list of systems that are required to test for these unregulated contaminants." UCMR5 testing, scheduled for 2023–2025, will analyze for 29 PFAS chemicals (for which there is a validated USEPA testing method) in systems serving more than 3,300 people using lower detection limits than previous UCMRs. UCMR5 will also include monitoring at a nationally representative subset of PWSs (approximately 800) serving fewer than 3,300 people, contingent on appropriations, (**USEPA 2023**). UCMR5 does not mandate sampling of private water wells (**USEPA 2023**).

- Some states (for example, New Hampshire, Massachusetts and Vermont) have initiated testing of private wells in certain locations where there is a high potential for PFAS contamination, and require testing of public water systems subject to maximum contaminant level (MCL) regulations. The Washington State Department of Health announced that it will be conducting additional testing for PFAS at several hundred untested water systems. The state of Michigan is also testing all public community water systems for PFAS (see https://www.michigan.gov/pfasresponse/drinking-water/statewide-survey). New Jersey requires that sellers of private homes must test the wells prior to the sale of a home, and requires that landlords test private wells every 5 years (https://dep.nj.gov/pfas/drinking-water/#is-testing-for-pfas-required-under-new-jerseys-pwta).

13.1.5 Need to Apply a Precautionary Approach in Decision Making

Given the lack of toxicological data for the great majority of PFAS and PFAS mixtures, many stakeholders want a precautionary approach to the use, treatment, and analysis of PFAS-containing chemicals. This precautionary approach presumes compounds of similar structure may be expected to have similar modes of action and pose a similar risk to human health and the environment, lacking evidence to the contrary. This is particularly true because there are many nonessential uses of PFAS in consumer products (see **Section 2.5**) that receive no regulatory scrutiny.

13.1.6 Safety of Short-chain Substitutes

Many stakeholders are concerned with the use of substitute short-chain PFAS. After concerns arose that PFOA and PFOS (both long-chain PFAS) have health risks at very low concentrations, industry began to substitute them with shorter chain PFAS (see **Section 2.4**). Although some short-chain PFAS appear to be less bioaccumulative, the publicly available data are limited. Some short-chain PFAS can be persistent, and tend to be more water–soluble and more mobile than long-chain PFAS. Because of their greater water solubility, studies indicate short-chain substitutes are more readily taken up by plants than longer chain PFAS, including food crops (**Higgins 2017**). In their Interim Chemical Action Plan for PFAS,

the **Washington State Department of Ecology and Washington State Department of Health (2019 p. 1)** states that short-chain PFAS are difficult to remove from water, noting further, "Without additional health and safety data, it is impossible for us to evaluate whether short-chain replacements are safe substitutes. If environmental exposures to short-chain PFAS are found to pose health risks to people or the environment, mitigation will be difficult and expensive." Precursor compounds for some short–chain PFAS are also of interest in future monitoring studies; for example, perfluoro-1-butane-sulfonamide (FBSA, a precursor to PFBS), has been documented with high detection frequency (32 out of 33 samples) in fish from North America (**Chu et al. 2016**; **Ericson, Jogsten, and Yeung 2017**). Finally, in the Helsingør Statement (**Scheringer et al. 2014**) and the Madrid Statement on Poly- and Perfluoroalkyl Substances (**Blum et al. 2015**), scientists and other professionals expressed concerns about the embrace of short-chain PFAS as preferable replacements for long-chain PFAS.

13.1.7 Contamination from AFFF Release Sites

Many stakeholders believe that all potential AFFF release sites should be investigated, and where necessary, potential exposure should be mitigated. Investigations to date have identified the use of AFFF as one of the main sources of PFAS releases to the environment, and AFFF releases have been responsible for PFAS contamination of multiple drinking water sources. Although AFFF foams typically contain less than 2% total PFAS, thousands of gallons of foam mixture may be applied during a given event, and the concentrations of concern for PFAS are very low (below 100 parts per trillion (ppt)). Typical locations where AFFF is stored and used include civilian airports, military bases, chemical plants, municipal fire departments, oil refineries, bulk fuel storage facilities and terminals, and crash sites. AFFF was used abundantly for training purposes at military bases with flight operations and at civilian airports. Additional information is presented in the ITRC **AFFF fact sheet** and in **Section 3**.

13.1.8 Contamination from Unused AFFF Disposal

Stakeholders are concerned that incineration of unused AFFF is not always specifically regulated with PFAS-specific emission conditions and limits, and that incineration may generate dangerous byproducts (see **Section 3.10** on AFFF Disposal; **USEPA 2020**; **Earthjustice 2020**). The U.S. military indicated plans to collect and destroy unused firefighting foam that contains PFOS and PFOA (**USDOD 2018**). In a 2017 request for AFFF disposal research project proposals (**U.S. Air Force 2017**), the Air Force acknowledged that the foam, which was designed to resist extremely high temperatures, is difficult to burn and that "the high-temperature chemistry of PFOS and PFOA has not been characterized, so there is no precedent to predict products of pyrolysis or combustion, temperatures at which these will occur, or the extent of destruction that will be realized." Stakeholders are concerned that there are no federally mandated protocols that require incineration to reach certain temperatures to specifically target PFAS. (See **https://theintercept.com/2019/01/27/toxic-firefighting-foam-pfas-pfoa/**)

The National PFAS Contamination Coalition (an assembly of stakeholder groups from across the U.S.) opposes incineration (and similar thermal treatment technologies) for disposal of PFAS-contaminated wastes and collected PFAS products because stakeholders are concerned that thermal treatment technologies may not be specifically permitted to treat PFAS, and that demonstration is needed that treatment will fully destroy PFAS, that is, reduce the molecules to carbon, fluoride salts, and/or other constituents (**National PFAS Contamination Coalition Statement on Incineration of PFAS – National PFAS Contamination Coalition (pfasproject.net)**). **See Section 13.1.18** below.

The USEPA's Interim Guidance, Version 2 (**USEPA 2024**) indicates that thermal treatment (which includes incineration) is commercially available and potentially has the capability to destroy PFAS or manage the migration of PFAS in PFAS-containing materials, but that further research activities are needed. Some facilities in the United States have been permitted by state regulatory agencies for the thermal treatment of PFAS.

The Foam Exposure Committee (FEC), a subgroup of the Fire Department Safety Officers Association (**FDSOA 2021**), whose objective is to reduce firefighter/first responder exposures to PFAS in firefighting foams, reports that the absence of federal and state regulations addressing disposal provides more opportunities for fire departments to expose their firefighters and contaminate their own communities with AFFF products. Current regulatory programs that address use and disposal of AFFF are provided in **Section 8.2**.

13.1.9 Duty to Warn AFFF First Responders

Aside from standard workplace safety requirements regarding hazardous materials right-to-know, stakeholders are concerned that there has been no legal duty to warn or to require notice of hazards to first responders who handle AFFF. Several studies have concluded that some PFAS were elevated in the blood of first responders.

- The New Hampshire Department of Health and Human Services PFC Blood Testing Program (**NH DHHS 2016**) results indicate the geometric mean levels of PFOS and PFHxS in the blood serum of firefighters were elevated versus the geometric mean levels of those who had not worked as firefighters. Numerous other studies indicated that blood serum levels were elevated in firefighters (**LeMasters et al. 2006**; **Jin et al. 2006**; **Dobraca et al. 2015**). It is difficult to tease out whether these higher levels are related to exposures to AFFF, PFAS in firefighter gear (clothing), consumption of water from PFAS-contaminated drinking-water wells in affected communities, especially those that may be located near training facilities that have used AFFF, or other sources.

- IPEN (International Pollutants Elimination Network) released a report that presents information from recent studies that firefighters using AFFF have elevated blood levels of both PFHxS and PFOS; see also **NIOSH (2021)** for links to additional research. Earlier IPEN reports describe fluorine-free firefighting foam alternatives that can replace uses of toxic fluorinated firefighting foams (**IPEN 2018**, **2019**). The FEC recommends replacing older stocks of AFFF with fluorine-free foam solutions (**FDSA 2021**).

13.1.10 Limitations in Sampling and Analysis Methods

Stakeholders are concerned that current PFAS site investigations may not adequately define the types and total mass of PFAS present, due to limitations in analytical methods (**see Section 11**) that are still evolving. Moreover, the PFAS family of compounds contains thousands of chemicals, but standard analytical methods can identify only a fraction of these chemicals.

A related concern is that the specification for shorter chain AFFF published by the Department of Defense (**USDOD 2018**; **NAVSEA 2017**) still allows concentrations of PFOA and PFOS up to 800 ppb in AFFF concentrate, because that is the lowest concentration of either PFOA or PFOS that can be measured in the concentrate with current analytical methods. This is because the overall high concentrations of the many chemicals in the AFFF concentrate "swamp" the lab instrument, interfering with its ability to detect any individual compound except when it is present at high concentrations. The DOD has recently published a draft analytical method, DOD AFFF01, to quantify PFOA and PFOS with a limit of quantitation of less than 25 ppb (**Willey 2021**). The modern short-chain AFFF formulations are fluorotelomer-based, so PFOS (and other PFSAs) should not be present and PFOA may be present only as contamination from the production process (as discussed in **Section 3.1**), but without analytical methods to prove this, users cannot know for certain if the new AFFF products are PFOS- and PFOA-free. The ITRC **AFFF fact sheet** and **Section 3** include more information about AFFF specifications.

13.1.11 Limited Programs for Health Monitoring and Blood Testing

Some PFAS (for example, PFOA, PFOS) bind to proteins in the blood, making blood testing a means of investigating human exposure to PFAS (see **Section 7**). Many communities where PFAS have been detected have asked that the government establish a program for blood serum testing and long-term health monitoring so that they can better understand any health risks associated with PFAS exposure. ATSDR established a multi-site study with seven partners across the country to better understand the connection between PFAS exposures and health effects (**ATSDR 2020**).

Some states have provided limited testing on people in high-impact areas. For example, New Hampshire provided blood serum testing for people who worked on, lived on, or attended childcare on an AFFF-impacted site and were exposed to contaminated drinking water (**NH DHHS 2016**). New Hampshire also performed blood tests in selected towns where people used private wells that tested above the 2016 health advisories for PFOA and PFOS. However, many state and local governments are wary of blood testing programs because there is no correlation between the PFAS level in blood serum and any definitive health effects. People who participate in such tests are usually informed of their results and provided context about how they compare with national and location-specific averages. Only limited long-term programs have been established to monitor the health outcomes of exposed populations (for example, C8 Science Panel (**C8 Science Panel 2020**). If there is no assistance from the government, many community members cannot afford to have their blood tested.

13.1.12 PFAS in Food Packaging

Many stakeholders are concerned that food packaging containing PFAS leaches into food. Food packaging, such as bowls, plates, clamshells, trays, and pizza boxes, often includes PFAS for anti-grease resistance, and PFAS is sometimes used in the molding process to manufacture paper plates and containers. A 2008 FDA study found that "fluorochemical paper additives do migrate to food during actual package use," and oil and grease "can significantly enhance migration of a fluorochemical from paper" (**Begley et al. 2008**).

There is only limited peer-reviewed information regarding PFAS transfer to food. One study documented that 6:2 FTOH moves from dishware or containers into food (**Yuan et al. 2016**). A Canadian analytical lab found that PFBA moves from cupcake liners into cupcakes (**CEH 2018**).

The FDA has approved 20 next-generation, short-chain PFAS for coating paper and paperboard used to serve food. The FDA Effective Food Contact Substance Notifications database is available online (**FDA 2018**). Concerns have been raised that these compounds have not been adequately tested for human impact. Because of trade secrecy laws with regard to patents, the government does not publicly disclose the identity of the specific chemicals in food packaging. However, according to The Intercept (**Lerner 2016**), in documents filed with the USEPA, under TSCA section 8(e) requirements, **DuPont (2010)** reported that substitute PFAS used to produce food contact paper could pose a "substantial risk of injury," including cancerous tumors in the pancreas and testicles, liver damage, kidney disease, and reproductive harm. For more information about FDA's PFAS activities and food contact materials (FCM) PFAS phaseouts, please see **Section 8.2**.

Although there are no enforceable PFAS limits in food or water at the federal level as presented above in **Section 13.1.1.3**, some states and cities are moving forward with bans. Several states, including Washington, Minnesota, Maine, New York, and Vermont, have enacted laws to ban PFAS use in some food packaging. See **Section 8.2** and the **Regulatory Programs Summary** Excel file for information about regulatory programs. Stakeholders are concerned because not only does PFAS in food packaging pose potential risks to consumers of the food, but the used packaging may end up in compost or landfills. Compost is eventually applied to soil and PFAS are potentially transferred to certain food

crops, and may leach to groundwater. If compost goes to a landfill, PFAS potentially ends up in the landfill's leachate.

13.1.13 Potential PFAS Contamination in Recycling, Compost, and Fertilizer

Carpeting, furniture, and numerous other items containing PFAS are often recycled. There is concern that the recycled materials are often used in products where the consumer has no way of knowing whether it is has PFAS contamination. Biosolids from wastewater treatment plants are used in some composts and fertilizers and PFAS sampling may not be part of the screening process for these products. However, this is changing; New Hampshire and Maine both require testing. Additionally, stakeholders are calling for more testing and regulation for land-applied or disposed paper mill waste due to potential PFAS impacts. Stakeholders are concerned that composting of paper mill waste to make fertilizer, which, for example, is still done in Michigan, should get more attention. It is difficult to know which mills make "waterproof" or food contact papers that contain PFAS.

13.1.14 Lack of Disclosure by Product Manufacturers

Some stakeholders are concerned that chemical and product manufacturers are not required to disclose when they sell, make, or use PFAS in their products because some formulations are proprietary and may not be listed on a Safety Data Sheet. For example, many sturdy, waterproof, and heat-resistant products containing PFAS are produced for the construction industry, including polished granite countertops. Additionally, there is lack of disclosure and transparency concerning the composition of AFFF, because AFFF suppliers claim that formulations are proprietary.

13.1.15 Limited Availability on Information on the Health Effects of PFAS

Some stakeholders are concerned that politics may delay or even prevent the full disclosure of PFAS toxicity information. For example, the 2018 release of ATSDR's Draft Toxicological Profile for PFAS was reportedly delayed because of concerns about the public response. This example, if replicated, may lead to distrust and reduce the efficacy of risk communication. Additionally, collected health data may not be clearly and fully shared or explained to stakeholders.

13.1.16 Responsibility for Sampling and Treatment on Private Property

When off-site contamination is suspected or discovered, stakeholders believe that the responsible parties should be accountable for establishing an entire program to deal with the problem. This includes sampling and analysis, disclosure of PFAS content, health monitoring, and if appropriate, remediation and mitigation. Upon detection of PFAS above state or USEPA limits, stakeholders maintain that responsible parties should be required to provide affected residents with alternative water supplies. Additionally, stakeholders believe that the cost of the program, including long-term treatment and monitoring, should be borne by responsible parties.

13.1.17 Potential PFAS Emissions from Cleanup Methods

Stakeholders believe that treatment systems (from large public water treatment systems to small private point-of-use systems) should be monitored for effectiveness, as the type and frequency of monitoring may vary for all systems. There is also concern that disposal or regeneration of GAC canisters, resins, and byproducts will add contaminant loads of PFAS to the air, land, and water. Stakeholders are concerned that companies that thermally treat spent carbon filters that contain PFAS do not

provide publicly accessible information that documents full destruction of all PFAS; some companies claim all PFAS are destroyed, yet the research appears to be focused on targeted PFAS (for example, PFOS and PFOA) destruction. More concerns about thermal treatment are discussed in **Section 13.1.8**, with further information provided in **Section 12.4**.

13.1.18 Lack of Scientific Evidence that Some PFAS Treatment and Disposal Methods and Remedies Are Fully Protective of Human and Ecological Health and Prevent Toxic Emissions

Historically, the three standard practices for PFAS waste management are landfilling, wastewater treatment, and incineration. Stakeholders' concerns with these disposal practices are highlighted in a study sponsored by the Environmental Working Group (EWG) (**https://www.ewg.org/news-insights/news-release/study-disposal-pfas-waste-increases-contamination**). One of the conclusions of that study is that all three methods have been found to not effectively contain or destroy PFAS. Tasha Stoiber, EWG senior scientist and primary author of the study, found that "The three common 'disposal' options for getting rid of PFAS do not eliminate these contaminants but rather end up just returning either the same chemicals or their byproducts back into the environment." Additionally, USEPA has confirmed that while "Thermal treatment technologies are common remediation approaches for contaminated media and waste, limited information exists on the efficacy, potential atmospheric emissions, operational conditions, costs, etc. for thermal treatment technologies specifically targeted for PFAS" (**Mills et al. 2020**).

Additionally, USEPA stated that "Research on thermal stability of PFAS compounds, the ability to fully capture and identify PFAS compounds and their thermal decomposition byproducts, and the efficacy of emission control technologies are areas of targeted research. These efforts, in cooperation with states and industries, [are] aimed at proper disposal of PFAS-laden wastes without media-to-media transfer or environmental release" (**USEPA 2019**). In USEPA's Interim Guidance, Version 2 (**USEPA 2024**), they identified areas for further study to assess the efficacy of destruction and disposal of PFAS-containing materials (that are not consumer products) to help protect public exposure to PFAS. Recent testing and reporting of PFAS destruction by incineration has been documented (see **Section 12.4**).

Additionally, it should be noted that other technologies besides the three methods can be used in remediation. These include ion exchange, granulated activated carbon (GAC), and reverse osmosis (see **Section 12**).

An example that demonstrates the stakeholders' concerns about adequate protection provided by disposal options is the Holston Army Ammunition Plant (Holston) in Tennessee. In a July 16, 2019, letter to USEPA Region 4 Administrator (**https://cswab.org/wp-content/uploads/2019/07/Holston-Citizen-Petition-Region-4-PFAS-July-2019.pdf**), several environmental groups stated that Holston will present a risk to human health and the environment by burning polymer-bonded explosives (PBXs) containing PFAS. The groups cited a recent decision by the neighboring State of Kentucky to prohibit the Blue Grass Army Depot from open-air burning or detonation (OB/OD) of "munitions wastes that are a potential source of Per- and polyfluoroalkyl substances (PFAS), including Teflon, Viton, and Viton-A. This includes both short and long chain PFAS." Both bases are located in USEPA Region 4. The groups stated: "Open air burning and detonation do not provide either sufficient or sustained temperatures times to achieve destruction. OB/OD activities at Holston are very likely resulting in the ongoing release and dispersion of PFAS to the environment, posing a potentially substantial health risk to workers and residents."

13.1.19 Stormwater and PFAS Manufacturing Discharges that May Contain PFAS

PFAS, including PFOA, have been detected at the storm drain outfalls at active facilities. Stakeholders are concerned that most NPDES effluent permits do not require PFAS sampling and the magnitude of PFAS concentrations in such discharges remains unknown. Older and inactive facilities' discharge areas, many of which have not been sampled for PFAS, may also act as long-term sources of stormwater and/or groundwater contamination due to residual PFAS in soil at stormwater discharge areas.

13.1.20 Psychological Effects

It was reported at one Superfund community (Tuscon AZ) that children in some communities are scared to drink water (**Strauss 2024**) where contaminated drinking water supplies have the effect of deterring children from drinking clean water. Additionally, blood level values have become an identity, and there are pictures of people holding up signs identifying their blood levels.

In addition, the Agency for Toxic Substances Disease Registry (ATSDR) has identified that studies "suggest that the experience of exposure to hazardous substances and the resulting psychosocial changes can result in adverse physical and psychological health effects" (**ATSDR 1995**).

13.1.21 Economic Consequences of Local PFAS Contamination

Individuals have voiced concerns about significant economic consequences on property values and businesses. See the USEPA community meetings information provided on USEPA's website: **https://www.epa.gov/pfas/pfas-community-engagement**. In one case in Massachusetts, the Board of Health added PFAS to the list of substances homeowners with private wells in certain areas of town must test for before selling their homes (**Town of Harvard, MA 2020**). In New Jersey, PFOA, PFOS, and PFNA were added to a list of chemicals that private well owners must test for prior to selling their homes under the NJ Private Well Testing Act. This also applies to landlords who rent homes with private wells (see **https://www.nj.gov/dep/rules/adoptions/adopt_20200601a.pdf**). In another instance, because PFAS was detected in water used by dairy cattle, the farmer had difficulty selling the milk products. Stakeholders are particularly concerned about facilities located in economically disadvantaged communities. These communities need the economic benefits of a facility but have few resources to demand enough testing of air emissions and of potential health impacts on the community.

13.1.22 Remediation of PFAS With Other Contaminants Especially Chlorinated Solvents

At many sites where PFAS has been found, especially military sites that are contaminated with AFFF, there is concern that past cleanup efforts have spread PFAS. Many military sites have been listed as Superfund sites because they are contaminated with chlorinated solvents (**https://www.epa.gov/fedfac**). The early remedy for removal of solvents from groundwater was pump and treat with air strippers. Since air stripping doesn't remove PFAS, groundwater contaminated with PFAS was, and in some cases continues to be, discharged into streams and rivers, through reinjection, discharge to wastewater treatment plants, or reuse such as irrigation or make-up water for recycling.

Even if remediation systems use GAC or other techniques to clean up chlorinated solvents (for example, PCE and TCE), these systems are not typically optimized for PFAS capture. If they are optimized for PFAS capture, it is unclear if they will be as effective for solvent capture. Additionally, it is not clear whether in the past PFAS was released during the regeneration process for solvent-laden GAC, thus spreading some

PFAS through air during the heating process. More information about treatment systems and co-contaminants is included in **Section 12.8**.

13.1.23 Pesticides containing PFAS

Some pesticides contain PFAS. PFAS have been used as an active and inert (or inactive) pesticide ingredient. PFAS can be used as herbicidal dispersants and wetting agents and to aid wetting and penetration in insecticides. A patent has been issued for insecticides and fungicides having branches composed of perfluoroalkyl chain molecules. Other pest control patents refer to compounds with some of the side chains composed of perfluoroalkyl (**Gaines 2022**). This creates a number of problems, including low levels residing in soil, uptake in food, and "masking" other sources of the PFAS in areas that have been historically sprayed with insecticides. Some pesticides have received new USEPA guidance, including https://www.epa.gov/pesticides/epa-stops-use-12-pfas-pesticide-products and https://www.epa.gov/pesticides/pfas-packaging. More information about PFAS uses is included in **Section 2.5**.

13.1.24 Artificial Turf

Many stakeholders are concerned that plastic grass blade and/or "rubber crumb" backing in artificial turf contains PFAS. Artificial grass blades are plastic and were found by one nonprofit organization to contain PFAS. This issue was investigated by the Connecticut Department of Energy & Environmental Protection (**CH DPH 2022**), which analyzed "grass" blades from a previous study and suggested that the PFAS had a different origin (see **Table 2-6**). While this may be true for the product analyzed, artificial turf in parks and schools is from many different manufacturers. Additionally, "[a]rtificial turf infill is often made from recycled tires, which may be another source of PFAS. Polymeric pellets manufactured specifically as infill are also available, and patents indicate that these materials may contain PFAS as well" (**Fernandez, Kwiatkowski, and Bruton 2021**). The City of Boston has recently banned all new artificial turf in city parks. (https://www.theguardian.com/environment/2022/sep/30/boston-bans-artificial-turf-toxic-forever-chemicals-pfas)

13.1.25 Semiconductor Manufacturing

There is concern that the semiconductor industry has long been a source of PFAS that has been overlooked. A recent survey of the technical literature by researchers from Cornell University "revealed that there are several specific examples of fluorocompounds that are currently in use by the semiconductor industry in the lithography process" (**Ober, Florian, and Deng 2022**). More information about PFAS use is available in reports from the Semiconductor Industry Association (**SIA 2023**; **SIA 2023**). As with the concern about remediation of PFAS with other contaminants, the manufacture of semiconductors has also seen releases of chlorinated solvents. In the remediation process, the industry used pump and treat with air stripping, which does not remove PFAS from contaminated water; thus, PFAS remained in the discharge waters. In one case (Moffett Field), the site was contaminated by a plume of chlorinated solvents that spread from a center for semiconductor development that is now commingled with the VOCs and other PFAS used at Moffett Field. Recently, NASA, which is the steward of the site, found PFAS from past use of AFFF and from the semiconductor industry adjacent to Moffett (**Tetra Tech 2022**).

13.1.26 Monitored Natural Attenuation (MNA) for PFAS

Although early in the research stages, using remediation techniques that employ MNA for PFAS presents a range of problems and concerns for community and tribal stakeholders. As this document points out in its discussion of these still unproven processes to remediate PFAS (see **Section 12.6.7**), there are no currently recognized destructive attenuation pathways for PFAAs (a class of PFAS) in natural settings.

Communities generally do not favor prolonged cleanup approaches with uncertain funding, with a commensurate degree of risk, and a shift of the burden for environmental cleanup to another generation. A related stakeholder concern is that the strictest cleanup standards be applied. Cleanup standards may differ from site to site based on risk assessments, site conditions, or state regulations Additionally, many community members perceive MNA as a "do-nothing" approach.

MNA for PFAS is similar to nondestructive retention processes for metals and radionuclides, thus leaving diluted PFAS in the environment (**ITRC 2010**, section 5 Stakeholder and Tribal Issues). This referenced document details major concerns that are specific to leaving contamination in place, including requirements for enhanced community participation; need for long-term monitoring and maintenance; future use considerations; and long-term health and safety, as well as many tribal concerns. The framework from ITRC (**2010**, section 5), is used here to address stakeholder perspectives and concerns about using MNA for PFAS.

- Enhanced Community Participation

Attenuation-based restoration projects require the community to coexist with some residual level of contamination for an extended period. Attenuation-based projects should always include communicating this temporal component. Prior to beginning attenuation projects, the public must be fully informed of planned activities and potential consequences. Afterwards, stakeholders must be informed about the progress in retaining chemicals "safely" in place and the risks of long-term environmental changes that may affect the retention capability of the subsurface, such as geochemical changes in the subsurface, earth movement, and a host of natural phenomena.

- Need for Long-Term Monitoring and Maintenance

Stakeholders may be concerned that attenuation-based restoration of PFAS will require extensive long-term monitoring and maintenance to ensure that public health and ecological parameters are met. Significant uncertainties in attenuation cleanup efficacy and timelines may conflict with stakeholder expectations. Consequently, stakeholders should receive additional communication of technical information, results of monitoring, and prognoses. Stakeholders will also be concerned about what will happen if attenuation does not proceed at the projected rate. Stakeholders may expect that target contamination levels be set for future dates and for reassessment of the cleanup strategy if monitoring shows that targets are not being met by natural attenuation. As an important precept, the responsible party must commit that the remedy will be revisited (for Superfund sites, this occurs every 5 years) and selection of attenuation will not hinder future investigations and consideration of other means to remove the contaminants.

- Future Use Considerations

Generally, the public favors site cleanup that leads to unrestricted use. If unrestricted use is not possible, the smallest area possible should be set aside, and institutional and engineering controls should be incorporated into the activity (see also **Section 14**). If the future use does lead to unrestricted use, a long-term stewardship program must be developed to ensure that the contaminants are reduced to acceptable levels or eliminated. While MNA may be less costly than other remediation techniques, the public generally is not concerned with simply reducing the overall restoration costs; they may be more concerned with removing the contamination quickly and gaining access to the land—or lifestyle—as before the contamination occurred. As such, the public should be full partners in future land-use decisions. If MNA is selected, the site should be visibly marked and documented for long-term identification.

13.2 Specific Tribal Stakeholder Concerns

Tribes share many concerns with other stakeholders; however, they differ from other stakeholders in several key aspects. The 573 federally recognized tribes are each culturally, governmentally, and socially unique. Some tribes view any level of contamination of their lands and natural and cultural resources as unacceptable. Many tribes have culturally significant or sacred areas, which may include springs, mountains, hunting areas, plant-gathering areas, or burial sites. When culturally significant or sacred areas are affected, traditional methodologies that nontribal environmental professionals rely on (such as the applicable exposure scenarios or factors for a risk assessment) may not be sufficient to portray the effect to a tribe. For example, some plants and animals can have tremendous cultural or religious importance to a tribe, including birds and feathers, game animals, and herbs. Many tribes sustain themselves through hunting, fishing, and gathering of foodstuffs. Additionally, many tribal cultural ceremonies include the use of water. Other areas of difference include diet (for example, some tribes consume more fish per capita) and growing crops or grazing animals on areas fertilized by biosolids from wastewater treatment facilities.

Tribes are sovereign entities that have established government-to-government relationships with federal, state, and local governments—relationships that must be recognized in the decision-making process. When a PFAS-contaminated site affects a tribe, the project timeline must include tribal approvals in addition to other typical agency approvals. Sampling, research, and services on tribal lands generally require institutional review board or tribal council approval. Each sovereign nation operates differently, ranging from tribes that have no research capacity to tribes that have a full review board with a formal application process. The initial steps in the approval process may include drafting a proposal, preparing a poster or podium presentation, and presenting to the tribal government.

Once tribal approval is granted and the project commences, the practitioner must obey tribal protocol with respect to cultural practices. The tribe may reserve the right to retain the findings in the case of exploratory research and restrict publication. Regulatory findings for water and soil concentration, level of treatment, and monitoring are first reported to the tribe's department of environmental quality or natural resources and then forwarded to state environmental organizations and USEPA.

A Tribal PFAS Working Group was formed in 2020 to "help address and reduce PFAS in Indian Country." The working group is comprised of members of the National Tribal Water Council, Tribal Science Council, National Tribal Toxics Council, Tribal Waste and Response Steering Committee, and Tribal Pesticide Program Council (**National Tribal Water Council 2023**).

Most of the concerns that tribes have are listed in **Section 13.1**. However, as mentioned above, there may be some distinctions that are important to tribes:

- PFAS in surface waters and lakes may have a higher level of concern when they are used for fishing, given that tribal members rely on these water bodies.
- Drinking water and irrigation water in the arid Southwest are limited, and there is heightened concern that tribes will be unduly impacted if drinking or irrigation water is contaminated. Stakeholders are concerned with lack of PFAS sampling of tribal PWSs. USEPA performed limited sampling of tribal PWS during the 2022–2023 timeframe with no PFAS results above the detection limit (**USEPA 2022**; **Mok et al. 2022**).
- Tribal lands are often close to installations that used AFFF (notably DOD) or other industrial sources of PFAS (manufacturers, leather tanneries).
- Tribal lands are often close to installations that used AFFF (notably DOD) or other industrial sources of PFAS (manufacturers, leather tanneries).

- Where biosolids have been applied to tribal farmlands or grazing lands, there is a need to sample these tribal lands for PFAS contamination. In some cases, cities may have paid tribal communities to spread biosolids from WWTPs that may have been unknowingly contaminated with PFAS.

- Activities on and near tribal lands may have involved use of PFAS-containing chemicals that could impact tribal members working in these facilities through inhalation and dermal exposure.

- Landfills on tribal lands that accepted outside waste need to be sampled for PFAS contamination, which may be in the landfill leachate. Companies that paid a fee to the tribes to use their land managed many of these landfills. Although most required sampling, often the sampling plans did not include sampling landfill leachate for PFAS.

- A big issue facing tribes is that tribal environmental offices and budgets are typically small, and they do not have the people or money to perform appropriate site investigations to determine if they have PFAS in their community.

13.3 Stakeholder Resources

Below are a number of resources for communities available at the time of publication. These resources are websites of major environmental organizations and projects that specifically deal with PFAS. These groups aim to help environmental and community groups to better understand the issues and science around PFAS. These websites have not been reviewed for accuracy or to determine if they are up to date.

https://cswab.org/pfas/about-the-pfas-campaign/ and https://cswab.org/wp-content/uploads/2010/09/List-of-military-fire-and-crash-training-sites-2014.pdf
https://pfasproject.com (A project of Northeastern University)
https://earthjustice.org/features/breaking-down-toxic-pfas
http://www.testingforpease.com
https://www.civilianexposure.org/the-military-covers-up-the-extent-of-pfas-contamination-across-the-country-while-it-continues-to-poison-hundreds-of-communities/
https://toxicfreefuture.org/science/chemicals-of-concern/pfas-nonstick-nightmare/
http://gatehousenews.com/unwellwater/
https://www.ewg.org
PFASCentral.org
https://greensciencepolicy.org/highly-fluorinated-chemicals/
https://www.sixclasses.org/videos/highly-fluorinated-chemicals
https://www.ucsusa.org/center-science-and-democracy/preserving-science-based-safeguards/toxic-threat-pfas-contamination-military-bases
https://www.nrdc.org/experts/anna-reade/epa-finds-replacements-toxic-teflon-chemicals-are-also
https://silentspring.org/research-area/about-highly-fluorinated-chemicals-pfass
https://clu-in.org/contaminantfocus/default.focus/sec/Per-_and_Polyfluoroalkyl_Substances_(PFASs)/cat/Policy_and_Guidance/
https://theintercept.com/2019/09/19/epa-new-pfas-chemicals/
https://stories.usatodaynetwork.com/unwellwater/foam-1995/
https://www.ewg.org/pfaschemicals/what-are-forever-chemicals.html
https://pfas-exchange.org
https://silentspring.org/project/women-firefighters-biomonitoring-collaborative
https://www.epa.gov/pfas/basic-information-pfas
https://health.ri.gov/water/about/pfas/
https://www.fdsoa.org/resourcepage (click on resources)
https://chemsec.org/app/uploads/2023/04/Check-your-Tech_230420.pdf

14 RISK COMMUNICATION

The ability to communicate potential risks to human health and the environment is a vital skill to facilitate community participation and decision-making. The process of informing people about potential hazards to their person, property, or community (**Hance, Chess, and Sandman 1991**; **USEPA 2022**) is called risk communication. Risk communication can be particularly challenging when dealing with science that is rapidly evolving, as in the case with PFAS. Communicators must grapple with competing interpretations of uncertain science and risk management strategies, while earning community trust and promoting meaningful engagement. This section addresses PFAS risk communication challenges and risk communication tools with PFAS-specific examples.

Section Number	Topic
14.1	**Role of Risk Perception**
14.2	**Risk Communication Challenges**
14.3	**Risk Communication Planning and Engagement Tools**
15.4	**Risk Communication Case Studies**

According to USEPA's Risk Communication in Action: The Risk Communication Workbook (**USEPA 2007, p.1**), the overall purpose of risk communication is *to assist affected communities [to]* ***understand*** *the processes of risk assessment and management, to* ***form*** *[scientifically valid]* ***perceptions*** *of the likely hazards, and to* ***participate*** *in making decisions about how risk should be managed*. Risk is the relationship between the probability of harm associated with an activity and vulnerability of exposed elements (**Slovic 1987**; **Slovic 2003**).

The **ITRC Risk Communication Toolkit for Environmental Issues and Concerns** is published as a separate document. In addition, guidance on general performance of risk communication for contaminated sites is provided in *Risk Communication in Action, the Risk Communication Handbook,* (**USEPA 2007**); *Decision Making at Contaminated Sites: Issues and Options in Human Health Risk Assessment,* (**ITRC 2015**); and *Improving Dialogue with Communities: A Risk Communication Manual for Government,* New Jersey Department of Environmental Protection, (**Hance 1991**).

The following subsections present risk communication challenges of PFAS and provide PFAS-specific risk communication information for components of risk communication planning.

14.1 Role of Risk Perception: Public Stakeholders and Decision Makers

It is essential for decision makers to understand stakeholders' risk perceptions of the hazard. Risk perception is the disposition that individuals or communities adopt toward hazards and is the product of their knowledge, beliefs, attitudes, judgments, and feelings, as well as wider cultural and social factors. Stakeholders include, but are not limited to, the community, public entities, potential responsible parties, regulatory agencies, and municipal and state officials. Risk perception for PFAS is challenging to address because the science is rapidly evolving, the exposure is perceived as involuntary, the risk mangagement strategies are a moving target, and health impacts are greatest for the most sensitive populations. The risk management strategies can be a moving target because of these challenges.

The environmental management community is acting largely based on growing evidence of health risks and general precaution as our understanding of PFAS exposure and associated risk is continuously redefined. In this context, risk amplification (heightened perception of risk) and attenuation (diminished perception of risk) can serve as guiding principles to better understand stakeholder context and site-

specific factors contributing to stakeholders' perceived risk to proposed risk management strategies. Risk amplification occurs when stakeholders perceive more risk from a hazard than the decision maker's perceived risk. Conversely, risk attenuation describes scenarios where decision makers perceive heightened risk from a hazard while stakeholders perceive less risk from the same hazard. For more information on factors that influence risk amplification and attenuation, see **section 2.8** of the Risk Communication Toolkit.

14.1.1 Role of Risk Perception and Public Stakeholders

In a scenario of risk amplification, stakeholders perceive their risk to a hazard as a major concern while experts assess the hazard as carrying a lesser degree of risk (for example, low or moderate) (**Kasperson and Kasperson 1996**). In the context of PFAS, risk perception is heightened by uncertainties and variability among policies and standards due to developing sampling methodologies and analytical procedures; new scientific information on health effects, risk assessment evaluations, and treatment technologies (**NGWA 2017**); and overall confidence/trust in the proponent or lead organization that is communicating risk. Additional human health and exposure factors that heighten risk perception for PFAS are summarized in **Section 14.2**. **Section 13** includes information about stakeholder perspectives on PFAS concerns.

This heightened sense of risk may result in opposition to proposed risk management strategies, such as source control (in which there is scientific uncertainty pertaining to the "safe" level of exposure, if any, without risk).

To address risk amplification challenges, it is important to build trust among the community by maintaining transparent communication of these uncertainties and variabilities early in the project life cycle (**USEPA 2005**, **2007**). New data findings and research on PFAS should be regularly shared with impacted stakeholders. Current knowledge, including uncertainties and information about variability of potential susceptibility to health effects in individuals with the same exposures, should be conveyed accurately in an understandable manner.

Uncertainties in individual causation and variability in regulatory guidance can cause the affected individuals to lack confidence in current scientific knowledge. Therefore, a risk communication project team should communicate these uncertainties to the affected individuals in collaboration with risk assessors, community involvement coordinators, and community members to develop site-specific messaging. It is important to understand that standards for the same chemical often differ depending on the entity setting them. This is not unexpected, because standard-setting guidance is not simply a mathematical formula. Risk assessment approaches used in standard-setting processes include best professional judgment in the selection of the factors involved. In addition, a collaborative effort can be made to develop performance metrics, supplemental to cleanup standards, that evaluate how the action will lead to measurable increased protection for public health and the environment, thus leading to the development of targets or objectives (**Hadley, Arulanantham, and Gandhi 2015**) that offer reductions in risk. These metrics are referred to as secondary risk management performance metrics and can be used to communicate and evaluate success of a proposed PFAS risk management strategy, as well as assist with alleviating stakeholder concerns associated with uncertainty. Examples of applicable secondary risk management performance metrics in the context of PFAS are reduction in contaminant bioavailability/loading, source control/removal, and mitigation of exposure pathways (**NGWA 2017**; **Harclerode et al. 2016**).

Furthermore, risk amplification can be heightened when a community perceives that they have limited control over risk. Explicit efforts to share control reduce outrage and risk amplification (**Sandman 2013**). Therefore, it is essential to create an atmosphere of collaboration. In situations where an open public forum is met by public outrage, it important to be compassionate and lend a listening ear. Acknowledgment and documentation of questions that cannot be answered communicates transparency

and can be a first step toward building trust. Effective participation is presented in the **ITRC Risk Communication Toolkit for Environmental Issues and Concerns**.

In contrast, in a risk attenuation scenario, experts judge hazards as relatively serious while stakeholders do not pay attention or pay comparatively little attention to that risk event (**Kasperson and Kasperson 1996**). This diminished sense of risk results in challenges in stakeholder participation in risk mitigation activities ("Why do we need to spend money/do testing, etc., for this?"). In the context of PFAS, risk mitigation and monitoring measures include participation in blood testing, installation of a water treatment system, and use of an alternate water source. To address risk attenuation challenges, site-specific risk perception factors related to inaction can be identified via stakeholder engagement and integrated into a communication plan (**NGWA 2017**; **Harclerode et al. 2015**; **Harclerode et al. 2016**).

14.1.2 Role of Risk Perception and Decision Makers

Due to the evolving science of PFAS, project managers, risk assessors, and risk communicators can also become caught in between those who amplify risk and those who deny risk. As noted, uncertainty in the toxicity and risk can lead to lack of consensus on how to evaluate risk and proposed risk management strategies. Due to risk amplification, there may be an elevated demand to take action to reduce potential risks beyond what is even technically and/or financially feasible. The underlying uncertainty feeding this risk amplification may also lead to opposition to proposed risk management strategies from some decision makers prior to establishment of the "right number" to dictate such action. When communicating with the public, it is essential to mitigate downplaying or embellishing risk due to lack of consensus on risk among decision makers.

Strategies should be implemented by the lead organization to navigate this rift to craft an approach and communicate a plan that is most likely to be reasonable and protective. One strategy is to incorporate the community's needs and values to place a greater weight on how risk management is considered. A second strategy is to develop secondary risk management objectives to help evaluate how interim and long-term action will lead to measurable increased protection for public health and the environment (**Hadley, Arulanantham, and Gandhi 2015**; **Harclerode et al. 2016**). These complexities highlight the importance of formulating a robust risk communication plan and team, including community and third-party involvement, as needed, as well as considering the dimension of perception as part of the risk communication process.

Case studies that showcase implementation of meaningful and effective community participation and inclusion of a third, neutral party to facilitate implementation of a successful risk communication strategy for PFAS-impacted communities are included in **Section 15.4**.

14.2 Risk Communication Challenges

There are many general challenges to risk communication about any environmental situation, including diversity of audience backgrounds, importance of establishing trust among the parties, and clearly communicating about the scientific and regulatory requirements. ITRC's Risk Communication Toolkit for Environmental Issues and Concerns includes a more detailed discussion of these challenges.

Emerging contaminants, and more specifically PFAS, pose unique challenges to achieving meaningful and effective risk communication. There is often divergent information available from different sources about the potential severity and uncertainty associated with exposure and adverse health impacts that may result from exposure, and the need for treatment or response actions. For example, people will do their own research, which may result in conflicting information. Communicators need to be prepared to explain the choices and decisions made regardless of the conflicting information. Some of the risk communication challenges for PFAS are discussed in the following sections.

14.2.1 Regulatory

There are regulatory challenges for emerging contaminants, see **Section 8**.

- PFAS are emerging contaminants, which means that they are the subject of intensive investigation, so new information, and thus our understanding of hazard, exposure, and risk, are emerging and evolving. This can challenge us to rethink determinations of protectiveness within very short time scales. More information is available from USEPA (**2023**, **2022**) about PFAS and emerging contaminants.

- Federal and state standards, guidance, and policies for PFAS are not uniform and are available for only a handful of compounds. This is also challenging given the recent expansion of additional PFAS analytes added to the USEPA Fifth Unregulated Contaminant Monitoring Rule (UCMR5) (**USEPA 2023**), the federal maximum contaminant levels (MCLs) (**USEPA 2024**), and the lack of consensus-based toxicity values for all PFAS analytes (see **Section 7.1** for information about human health effects).

- Regulatory standards and health advisories are in the parts per trillion range (or parts per quadrillion range), and it is difficult to explain to general audiences what these levels mean in terms of risk, how they were derived, or that, with current analytical methods, may not be detected.

- Most people have little to no understanding of risk assessment, risk management, and existing rules and legislation associated with chemical use and release. Risk communicators often need to provide this context before even discussing site or chemical specifics.

14.2.2 Fate and Transport

There are technical and scientific challenges and uncertainties around fate and transport of PFAS in the environment, see **Section 5**.

- There are many sources for PFAS and many of them have multiple release mechanisms, so simply explaining where the PFAS came from, including personal/lifestyle-based choices of individuals, and how PFAS got into the environment can be complicated.

- Most people have only a very basic understanding of (and lots of misconceptions about) chemistry, geology, environmental systems, and groundwater. Risk communicators often need to provide this context before even discussing site or chemical specifics.

- Fate and transport behaviors differ among individual PFAS (although broad generalizations may be appropriate based on chain length and functional groups).

- The environmental persistence, solubility, and mobility of PFAAs can result in:
    - very large impacted areas encompassing a wide range of environmental settings and potential transport pathways
    - complex transport pathways between interconnected environmental systems (groundwater-surface water; air-soil-groundwater; etc.).
    - bioaccumulation of PFAS into the food chain from impacted media, such as from contaminated sludges and/or biosolids.

- The multiplicity of sources and pathways (combined with the wide range of potential toxicity values discussed below) can create a sense that everything is equally contaminated and dangerous. Communicators need to help people understand the variability in the degree of contamination and relative risk related to each pathway.

- We are still identifying new PFAS sources (for example, PFAS from compost sites).

- Precursor transformation can affect how a PFAS site will evolve, but this is not well understood.

- Knowledge about uptake by plants and animals is increasing, but it is often difficult to answer questions about specific species.

14.2.3 Toxicological/Epidemiological Information and Risk Assessment

There are challenges and unknowns for toxicological and epidemiological information about PFAS, see Sections **7.1** and **17.2**.

- One of the greatest challenges to risk communicators is having to craft messaging in the face of often intense disagreements over the interpretation of available science and the magnitude of uncertainty; we are communicating health risks when the risks are not fully known or characterized.

- There is reliable toxicological information for only a small subset of PFAS.

- A select subset of PFAS has been studied in sufficient detail to support risk assessment and remedial decision-making.

- While human studies may conclude that there is evidence that elevated exposure to PFAS increases the risk of certain health effects, regulatory risk assessment focuses on populations. This means that it is not possible to relate a current health effect in a specific individual to PFAS exposure or to use risk assessment results to predict whether future health effects will occur on an individual basis.

- Although most people have some detectable level of PFAS in their blood serum from consumer products and diet (anthropogenic background), certain populations may have elevated exposure due to localized sources, such as aqueous firefighting foam (AFFF) and industrial discharge, which can contaminate environmental media, particularly drinking water, leading to increased blood serum PFAS to levels that may increase the risk to human health.

- Communities often learn that they have been unknowingly exposed to PFAS for up to several decades prior to the discovery of their presence.

- Community members may want to compare PFAS blood/serum concentrations to PFAS levels in drinking water or other environmental media. A limited number of public-facing tools are available for estimating blood/serum concentrations based on drinking water concentrations, including ATSDR's Estimator Tool (**ATSDR 2022**) and Silent Spring Institute's Digital Exposure Report-Back Interface (DERBI) (**Silent Spring Institute 2022**).

- Blood serum levels of certain PFAS can remain elevated for many years post-exposure, while levels of other PFAS decrease more rapidly, and currently there is no accepted method to hasten the reduction of PFAS blood levels.

- Individuals may be part of PFAS biomonitoring studies or can obtain their individual blood serum levels on their own. These individuals have access to information for comparison to regional and national reported levels, and thus may be more informed on their personal exposure than the medical practitioner.

- There is a need to provide understandable and informative public health advice to exposed individuals, including woman of childbearing age and pregnant woman who are making decisions about whether to nurse and/or use water known to be contaminated with PFAS to prepare formula (**Section 7.1**).

14.2.4 Technical

There are technical challenges in the areas of site characterization and treatment technologies, see Section **10** and **12**.

- There may be issues in the identification of responsible parties due to the difficulty in distinguishing between low levels of PFAS from use of consumer products (anthropogenic background) and PFAS contamination resulting from discrete sources, such as industrial uses.

- Although a subset of PFAS can be effectively removed by established treatment technologies, effective methods for the remaining compounds are in development.

14.2.5 Analytical Ability

There are technical challenges in laboratory analytical methods and field sampling, see **Section 11**.

- There are numerous PFAS in existence, yet not all can be measured. Sampling methodologies and analytical procedures to measure PFAS concentrations are still being developed and refined.

- Units used for reporting PFAS concentrations in environmental media and clinical tests are not uniform, and there are differences between blood and serum testing that are not standardized. For environmental professionals, converting and contextualizing these unit differences are routine practice for understanding risks. However, use of varying units may contribute to confusion for general audiences trying to compare and interpret testing results. There are difficulties in clearly and concisely communicating unknowns and limitations of analytical technologies related to the understanding of the extent of PFAS present in the environment, exposure pathways, and magnitude of the potential risk.

14.2.6 Challenges to Risk Communication around Health Risks

When performing risk communication, it is essential to acknowledge that individuals may receive their information from a variety of sources, which may provide conflicting or inconsistent messaging. As presented in **Section 7.1**, there is a growing body of research pertaining the adverse health impacts of PFAS in humans and laboratory animals. The discussion potential human health risks from PFAS exposure has been taken up in multiple venues, including peer-reviewed scientific studies, news media, and public comments on draft government documents and proposed regulations. The severity and uncertainty of adverse health impacts that may be associated with PFAS and the need for subsequent action has been communicated in an inconsistent manner. Because of the seriousness of potential health effects such as cancer, developmental delays and altered immune system response, as well as the persistence of PFAS in the human body, there is a case for prudence and precautionary mitigation practices to reduce exposures even in the absence of unequivocal human health consequences.

The risk communication challenge around health risks lends itself to a scenario in which stakeholders, including potential responsible parties and federal and state regulatory agencies, are not in consensus on the risk assessment and management strategy. Consistent messaging about uncertainties is essential for risk communication to be successful and to best help those in need. If stakeholders are in debate about the level of risk, then communicate by informing the public that all parties are striving to get the risk evaluation "right" but that there may be a delay in taking action. Communities that may be impacted may request an interim measure, such as an alternate water source, to alleviate concerns with potential exposure. Interim measures coupled with public outreach and community involvement can be a cost-effective risk management strategy in the short term. Public outreach should include measures being taken as well as associated milestones for future actions toward making a more informed risk management decision that utilizes limited resources efficiently, while integrating stakeholder values and community needs.

14.3 Risk Communication Planning and Engagement Tools

Prior to preparing risk communication materials and performing outreach, a project team should develop a risk communication plan to ensure there is a robust risk communication process in place from the outset. A risk communication plan is critical to guide decision makers to determine modes of information transfer as well as stakeholder engagement methods and tools that are appropriate and applicable for identified target stakeholders and site-specific characteristics. As stakeholder concerns and site characteristics are further defined, the communication team will need to continuously revisit the steps of communication planning. The **ERIS PFAS Risk Communications Hub** is a resource for risk communication information such as state FAQs, case studies and other resources.

In the case of PFAS, many national environmental organizations have made community outreach a major focus. Local grassroots organizations and one, the National PFAS Contamination Coalition (**https://pfasproject.net**), have led a major effort to inform the public and influence policy. In addition, ATSDR studies (for example, **ATSDR 2022**) as well as the National Academy of Science (**NAS 2022**) have included community outreach efforts.

14.3.1 Risk Communication Planning Model

The **ITRC Risk Communication Toolkit for Environmental Issues and Concerns** presents a risk communication planning model that has eight components, as shown in Figure 14-1. At the center of this model is a step to review and evaluate. This step indicates that communication planning with stakeholders is two-way, ongoing, and continuous, allowing for review of where you are in your outreach efforts and where you may need to go.

This planning model, adapted from the work of **NJDEP (2014)**, facilitates development of project-specific communication plans to be developed at each stakeholder engagement and/or outreach phase of a project. Of note, the NJDEP 2014 document relied on the work of Caron Chess, Billie Jo Hance, and Peter Sandman, Environmental Communication Research Program, Cook College, Rutgers University, as published by the New Jersey Department of Environmental Protection. The model is interactive, which allows for new information to be incorporated into the plan so that the outreach can be modified accordingly. This approach encourages establishing ongoing dialogue between the lead organization and all stakeholders so that the resulting outreach plan reflects the priorities and concerns from all parties. This will help you develop a robust risk communication plan. **Section 4** of the Risk Communication Toolkit provides detailed discussion of each of the communication planning model steps. The key aspects of the risk communication planning model are briefly summarized here.

- Issue identification helps you to clearly understand what the situation is in order to develop a responsive and effective risk communication plan.

- Goals are the big picture or ultimate impact that is desired for a project, issue or situation.
- Identification of communities with whom you need to establish a dialogue and those who wish to talk with your organization is important.
- Community assessment is needed to gain a deeper insight into stakeholder concerns and values that facilitate the development of a dialogue. **Section 13** addresses stakeholder perspectives for PFAS.
- Messages are the information you want/need to share with audiences about the issue or case, a question that you need them to answer, or both.
- A communication method is the means by which you communicate with your audiences.
- Once you have a clear goal, understand stakeholder concerns, know your message and have selected your method, it is time to lay out the strategy in order to implement the plan.
- Evaluation is the systematic collection of information about activities, characteristics, and outcomes of projects to make judgments about the project, improve effectiveness, or inform decisions about future programming. Many risk communication efforts require an ongoing presence or outreach to stakeholders. A debrief meeting is an opportunity for you to review the results of the evaluation and will identify what follow-up, if any is needed.

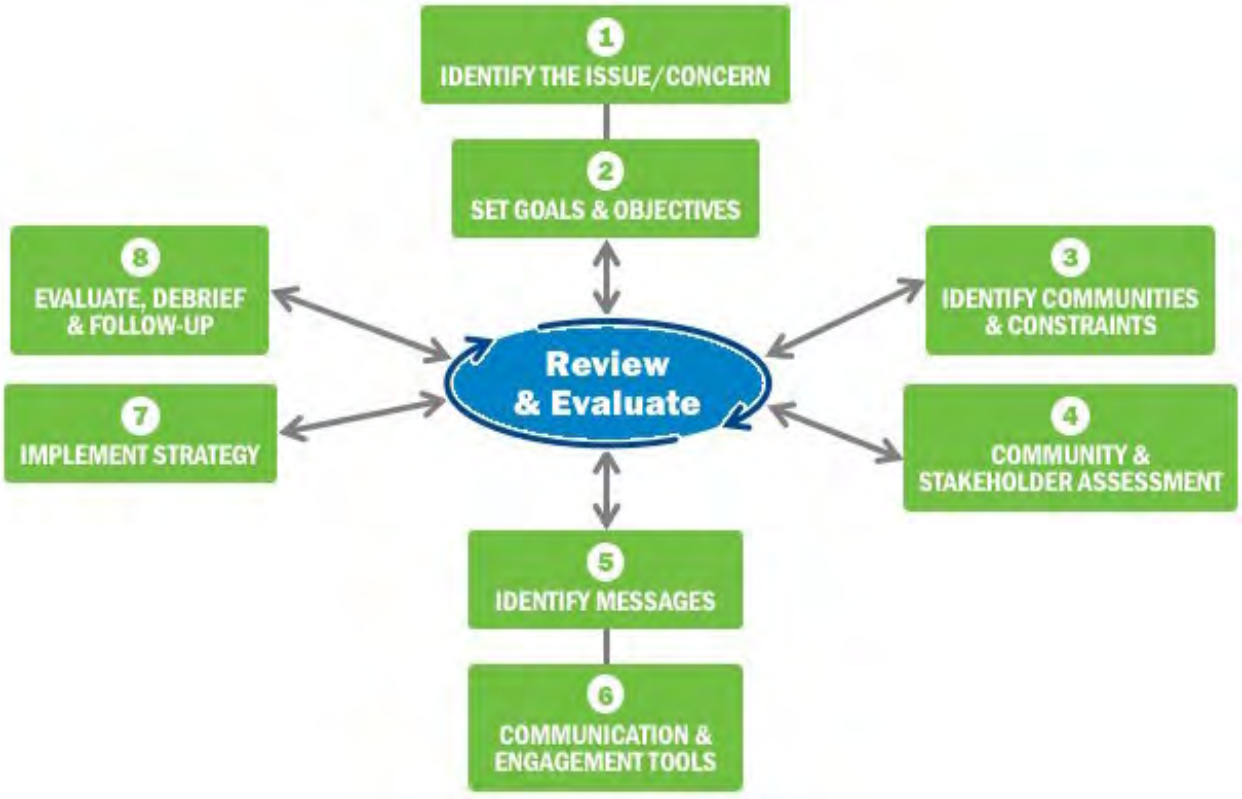


Figure 14-1. Communication plan process diagram.

Source: Modified from NJDEP 2014.

General information about risk communication planning is included in the **ITRC Risk Communication Toolkit for Environmental Issues and Concerns** document. This toolkit is a good resource for information about risk communication basics and tools. The toolkit can aid decision makers using this process and provide tools to assist with meeting performance metrics at each planning step. In addition, Minnesota Department of Health has developed the *Drinking Water Risk Communication Toolkit*, which can be accessed at **https://www.health.state.mn.us/communities/environment/water/toolkit/index.html**.

The following subsections are risk communication resources and tools with PFAS examples. The PFAS case studies in **Section 15.4** offer examples of community and stakeholder assessment strategies.

14.3.2 PFAS Risk Communication SMART Goals and Objectives

This section includes some examples of SMART (specific, measurable, attainable, relevant, and timely) goals for PFAS. In addition, example messages are included.

Example SMART Goals

Example of Communication of Goals

Issue: The governor established an independent PFAS science advisory panel of national experts to provide guidance to the state on protectiveness of criteria and develop science-based recommendations that will guide the administration and legislature on the best regulatory policy moving forward.

Goal: The PFAS Science Advisory Panel will complete a report within 6 months that will provide a general understanding of human health risks associated with PFAS in the environment. These science-based data will be used to develop a regulatory response that the administration and legislature will take and implement by (date).

Example of Assessing Stakeholder Concerns

Issue: Due to public health concerns, the state agency will conduct a statewide study of PFAS levels in X public water supplies at X schools that operate their own (private) wells by (date.)

Goal: By (date), the environmental agency will develop an inventory and location map of sites where PFAS has been used or disposed; prioritize sites for further investigation based upon the potential to impact drinking water supplies (based upon state groundwater maps, site history, and site ownership); incorporate data into a GIS-based data management system; and develop and implement a plan to sample private and or public water wells to assess potential impacts to drinking water supplies from prioritized sites.

For this example:

- specific: develop an inventory and location map
- measurable: testing
- attainable: implement a plan to sample private and public water supplies
- relevant: testing at prioritized sites will define impact
- timely: by X date

Example of a short-term SMART goal (from the Little Hocking Water Association case study, **Section 15.4.1**).

- By (date), the community is informed via the municipal website, flyers, and canvassing that bottled water is available as an alternate water source and utilized by 85% of the population.

- After (months), the extent of the impacted water supply is known via well testing and communicated to the community via a public meeting, municipal website, and newsletter.

Example of a long-term SMART goal (from the Little Hocking Water Association case study).

- By (date) and after (months), using a community-first strategy that includes the establishment of a community advisory committee and using multiple methods of communication—media, social media, internet, and meetings—determine whether the study area residents' blood PFOA levels are elevated and provide actions that 12,000 residents can take to produce a measurable reduction of PFOA blood levels.

14.3.3 Community Identification and Mapping Tools

Due to the persistent and recalcitrant nature of PFAS and its presence in the public drinking water supply, numerous and variant federal, state, private, and public stakeholders can be impacted. Actor mapping is a tool to help guide a communication team to lay out, track, and update stakeholder roles and relationships. During this exercise, practitioners learn who is the most affected by site information and decisions, as well as their level of interest and influence.

The outcome of the tool will assist in identification of unengaged/disinterested stakeholder populations, identify needs for relationship and/or capacity building, develop a site-specific communication team, and target outreach resources toward affected and unengaged/disinterested stakeholder populations. In the context of PFAS, this is of particular importance to identify and address affected groups who may not be participating in preventive and mitigation measures (such as an interim drinking water supply and a fishing ban) and/or at sites in which stakeholder groups are facing conflict resolution.

Simplified **examples** of an actor-linkage matrix and interest-influence matrix are presented, followed by resources to perform complex actor mapping, such as social network analysis. The examples provided are not representative of an existing project; stakeholder roles and relationships vary on a project-specific basis. Different types of mapping approaches can be used based on what visual communication method(s) work best for your organization and stakeholders. The examples provided here (actor-linkage matrix and interest influence matrix) are for demonstration purposes only and are not prescriptive.

Example Context: A PFAS site consisting of a groundwater plume that has impacted drinking water supply wells and has identified contaminants in the local fish population.

Example 1: Actor-Linkage Matrix: A tool that assist practitioners in describing relationships among stakeholders through codes (**Reed et al. 2009**) (**Figure 14-2**).

Example 1: Actor-Linkage Matrix Evaluation

- *Identify unengaged stakeholder populations*: potentially anglers and tourism business operators

- *Facilitate relationship/capacity building*: utilize the relationship between the responsible party and water purveyor to restore relationship between the responsible party and water users

- *Identify and develop the communication team*: team consists of a representative for the lead organization and for each regulatory agency, responsible party, water purveyor, and each low-power stakeholder group

- *Target communication strategy resources*: increase information transfer to unengaged stakeholder populations and rebuild intermittent and conflicted relationships with water users in alignment with risk communication strategy SMART goals

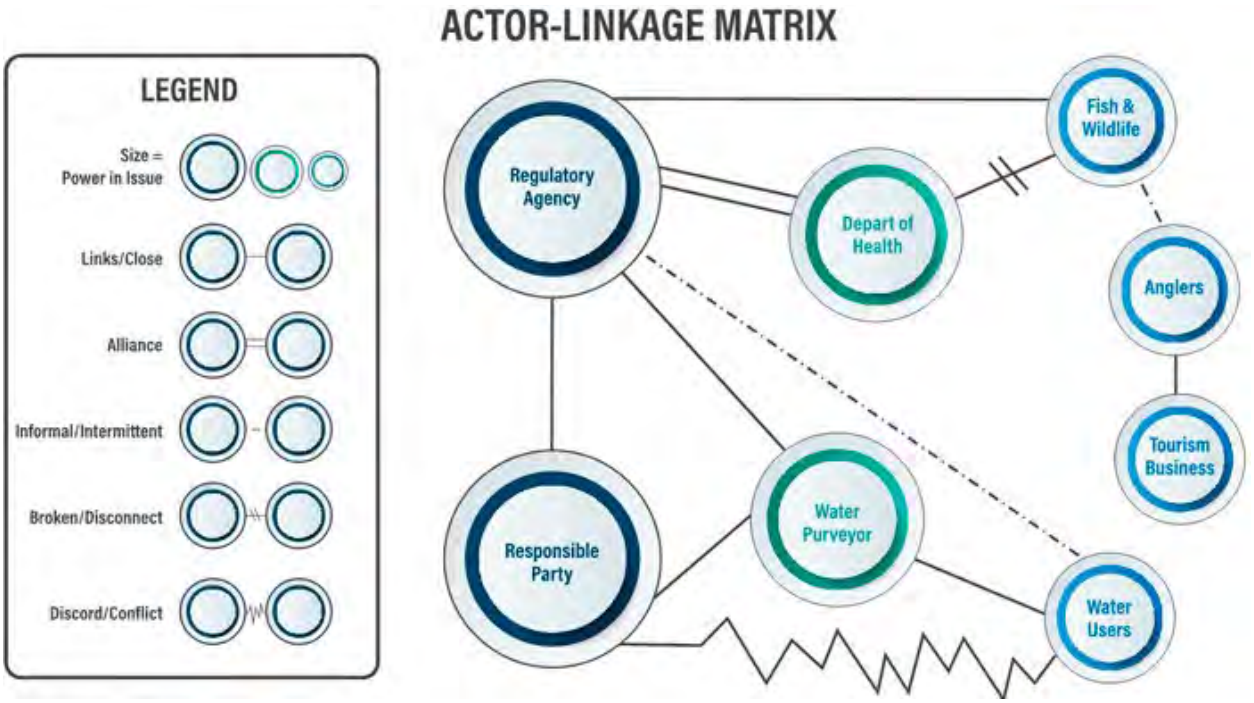


Figure 14-2. Example actor-linkage matrix.

The same example is used for the interest-influence matrix.

Example Context: A PFAS site consisting of a groundwater plume that has impacted drinking water supply wells and has identified contaminants in the local fish population.

Example 2: Interest-Influence Matrix: A tool that assist practitioners in identifying the stakes that social actors (stakeholders) have in a cleanup project. Identified stakeholders are placed in a matrix according to their relative interest and influence (**Reed et al. 2009**) (**Figure 14-3**).

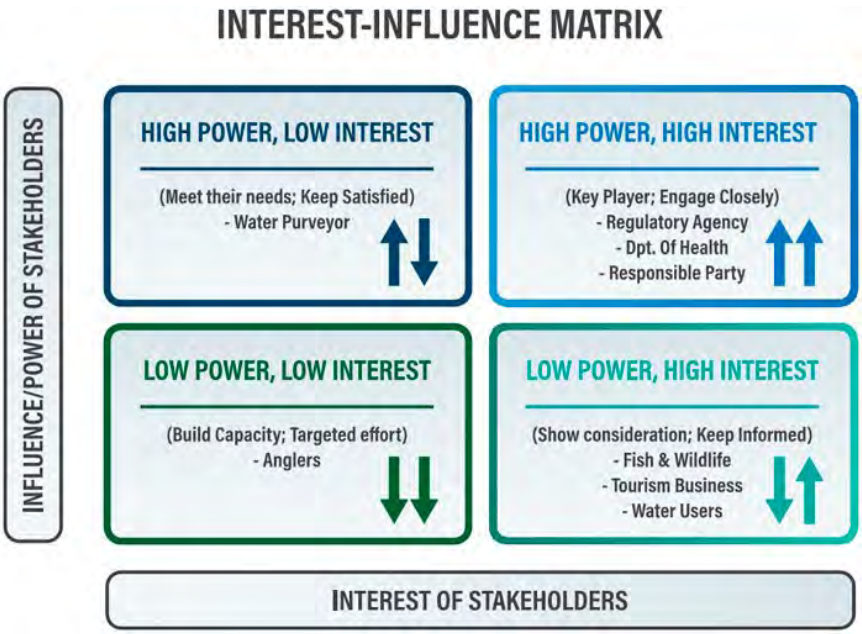


Figure 14-3. Example interest-influence matrix.

Example 2: Interest-Influence Matrix Evaluation

- *Identify unengaged stakeholder populations:* lead organization (for example, state agency or responsible party) (high-power) stakeholders have the role to engage lower power stakeholders who may not be currently engaged or are disengaged

- *Facilitate relationship/capacity building:* utilize high-interest stakeholders to build relationships with lower interest stakeholders, particularly ones with low power (such as the anglers)

- *Identify and develop the communication team:* team comprised of the lead organization and each regulatory agency, responsible party, water purveyor, and a representative of each low power stakeholder group

- *Target communication strategy resources:* increase information transfer to unengaged stakeholder populations and rebuild relationships with low-interest stakeholders in alignment with risk communication strategy SMART goals.

14.3.4 Social Factors Vision Board Tool

Stakeholder risk perception and associated social factors shape individuals' attitudes toward management of hazards that affect personal safety and public health, and play an important role in supporting legitimacy and compliance with policies and protection measures. Due to the evolving state of the science of PFAS, including appropriate risk management strategies and relevant public policy, the present public attitude toward legitimacy and acceptance of proposed policies and strategies is hindered.

The success of public outreach in terms of exerting a positive influence on community stakeholders and in preventing and mitigating their exposure to a risk is based on site-specific physical, psychological, sociological, and demographic characteristics or "social factors." Identification of these social factors among individual stakeholder groups can assist practitioners in refining engagement methods and outreach materials to maximize benefits to the community and meet specific needs of the targeted public sector.

A vision board can be used as a medium for stakeholders to rate their level of importance and/or interest on applicable social factors. Identified factors can then be used to further develop SMART goals and key messages, develop public outreach materials, and select engagement methods. The overall objective is to gain deeper insight into stakeholder concerns, values, and preferred communication method to facilitate a two-way street knowledge transfer and capacity building towards a successful risk management strategy. A social factors vision board tool can be used as starting materials for an engagement survey and interview. The target audience for this tool is an established community advisory group or a periodic outreach meeting, focus group, or decision maker stakeholders' group.

The vision boards (see **ITRC RC Social Factors Vision Board attachment**) developed for this toolkit are focused on a specific topic of concern and associated social factors identified from presentations by public and community stakeholders during the USEPA **PFAS community meetings** held in 2018.

Note that the vision boards for a specific project are living documents. The statements/questions and social factors should be updated to represent project-specific conditions and stakeholder concerns. Social factors presented on the toolkit vision boards are representative of affected communities' perceptions as opposed to expert opinion based on scientific studies. This toolkit was prepared as an example to provide a starting point for practitioners to understand the present needs and concerns of a PFAS-affected community. In addition, the rating system presented in each board is interchangeable to any social factor topic. More information on using the social vision board are provided in the **ITRC Risk Communication Toolkit for Environmental Issues and Concerns** document.

14.3.5 PFAS Key Messages

A message is information you want/need to share with communities about the issue or concern, a question that you need them to answer, or both. It is linked to the case specific goal and addresses key points about the issue that were learned through the community assessment. You start with the community and their concerns. Effective messages reflect what your target group needs are as well as what you need to communicate. In the case of emerging contaminants, elements of a message are likely to include: what is known and unknown about a contaminant, acknowledgement of uncertainty; commitment to share new information when it is learned; explanation of how decisions will be made with respect to protecting public health and remediating the problem, etc.

Message mapping is a process for developing your information so that it is concise and includes the information that is critical to convey. The objective is that the message is simple, yet comprehensive enough, and includes the most pertinent information relevant to your issue. A mapped message starts with a question, responds with three key ideas, is no more than twenty-seven words, and takes no longer than nine seconds to deliver. An example of key messages developed for a PFAS site is provided in **Table 14-1**. Additional resources on key messaging and mapping is provided in the **ITRC Risk Communication Toolkit for Environmental Issues and Concerns** document.

Table 14-1. Message Mapping Worksheet.

Stakeholder: Community member	**Question/Concern/Issue:** What are PFAS and why is the state concerned about them?	
Key Message/Fact 1: PFAS are a family of human-made chemicals in many products used by consumers and industry.	**Key Message/Fact 2:** PFAS are emerging contaminants of concern.	**Key Message/Fact 3:** Some PFAS may adversely impact human health.
Keywords: Supporting Facts 1.1 PFAS are a large group of thousands of manufactured compounds, produced and used for over 60 years. Some PFAS are still in use, some are not.	**Keywords:** Supporting Facts 2.1 PFAS are a contaminant of active scientific research. Scientific knowledge is changing rapidly.	**Keywords:** Supporting Facts 3.1 PFAS can build up in the body (bioaccumulate) and take a long time to leave the body.
Keywords: Supporting Facts 1.2 PFAS have been used in coatings for textiles, paper products, and cookware and to formulate some firefighting foams, and have a range of applications in the aerospace, photographic imaging, semiconductor, automotive, construction, electronics, and aviation industries.	**Keywords:** Supporting Facts 2.2 Laboratory methods may or may not exist to detect all the PFAS contaminants that we know about; methods are developing and evolving with the emerging science.	**Keywords:** Supporting Facts 3.2 Some PFAS, such as PFOA, have been found to impact fetal development and are passed to babies through nursing and bottles.
Keywords: Supporting Facts 1.3 PFAS are found throughout the environment, in people, and in animals and fish.	**Keywords:** Supporting Facts 2.3 Federal and state regulations are changing as the scientific knowledge evolves; this leads to guidance and recommendations that may vary across the country.	**Keywords:** Supporting Facts 3.3 Studies in exposed humans suggest that some PFAS may cause high cholesterol, higher liver enzymes in blood, decreased response to vaccines, decreased birth weight, and testicular and kidney cancer.

*Source: (**Covello, Minamyer, and Clayton 2007**).*

A template of the message mapping worksheet is included in **Covello, Minamyer and Clayton (2007)**.

14.3.6 Communication and Engagement Tools

14.3.6.1 Public Outreach

Public health and regulatory agencies have developed several public outreach materials to inform stakeholders about PFAS, from the compounds' origins and environmental distribution to exposure pathways, associated health effects, and management strategies. Outreach tools include community education classes to inform and support high school teachers, medical professionals, journalists, and municipal water managers. The following provides a summary of available resources for accessing and developing public education materials for PFAS-impacted communities. Although printed public education materials are effective at communicating information, techniques that include face-to-face communication, such as open house meetings, focus groups, and door-to-door canvassing, are often more effective at addressing fears and building trust. Additionally, face-to-face communication provides an opportunity for practitioners to learn from the public and other impacted stakeholders.

The **ITRC Risk Communication Toolkit for Environmental Issues and Concerns** document includes Guidance for Writing Analytical Results Letter, Guidance for Writing Press Releases.

14.3.6.2 Fact Sheets and Frequently Asked Questions (FAQs)

To achieve effective risk communication, it is essential for public education materials to be presented in a clear and simple manner that is understandable by nonscientists and speaks to a broad audience. Common rules of thumb include writing at a sixth-grade comprehension level, using simple terminology, and providing materials in multiple languages for nonnative speakers. Over the past few years, environmental and public health agencies, nonprofit advisory groups, trade associations, and regulatory agencies have prepared numerous fact sheets and FAQ documents on PFAS-related topics to inform stakeholders, including concerned residents, agricultural and recreational entities, water purveyors, end users, public health professionals, and others. These public education materials developed specifically for PFAS-impacted communities are typically available on the organization's website.

Fact sheets, FAQs, and other public outreach material should be distributed in multiple modes to maximize audience reach and increase opportunity for engagement. Recommended modes of distribution include mailings, websites, local municipal health departments, public health professional offices, public libraries, and information booths at community events.

The **ITRC Risk Communication Toolkit for Environmental Issues and Concerns** document includes additional information about FAQs.

- **Compilation of PFAS Fact Sheets, Frequently Asked Questions (FAQs)** and other resources developed by the Association of State and Territorial Health Officials (ASTHO) and the Environmental Council of the States (ECOS) are available:
    - https://www.astho.org/PFAS/
    - https://www.eristates.org/projects/pfas-risk-communications-hub/

14.3.6.3 Active Centralized Information Repository

Unlike a "passive" repository of site documentation at a central location, an "active" repository refers to a platform that remains up to date on site findings and enables two-way exchange of information among decision makers and the impacted community. A common platform for an active repository is a centralized website that contains a complete compilation of site documentation (among all agencies);

frequent updates on site activities, health information and regulatory policy; and a depiction of the CSM (such as a source-exposure pathway graphic and geologic maps). The website should also contain a platform to facilitate stakeholder involvement by providing an opportunity for them to ask questions, submit information, and join a listserv (an application that distributes messages to subscribers on an electronic mailing list).

Examples of centralized websites can be found at the following web links:

- Michigan Department of Environmental Quality, *Michigan PFAS Action Response Team (MPART):* **https://www.michigan.gov/pfasresponse/**

Michigan agencies representing health, environment, and other branches of state government have joined together to investigate sources and locations of PFAS contamination, to take action to protect people's drinking water, and to keep the public informed as we learn more about this emerging contaminant.

- New Hampshire Department of Environmental Services (NHDES), *NH PFAS Investigation*: **https://www4.des.state.nh.us/nh-pfas-investigation/**

NHDES maintains a website to update interested parties on NHDES's investigation into the presence of PFAS in New Hampshire. The website includes a map that shows PFOA and PFOS data from water samples collected around the state.

- Vermont Department of Environmental Conservation (VDEC), *Vermont PFOA Contamination Response*: **https://dec.vermont.gov/pfas/pfoa**

Numerous Vermont agencies, including VDEC, Department of Health (VDH), Emergency Management, Agency of Agriculture, and Agency of Education have joined together to investigate and address PFAS contamination in Vermont. VDEC and VDH have created and maintained web pages to push information out to the public as it becomes available to keep the public informed of the PFAS issue.

Not all stakeholders have access to the internet, and depending upon the seriousness of the site's situation, it may be appropriate to hold regular meetings and/or office hours to provide more than one mode for stakeholders to obtain information and engage with decision makers.

14.3.6.4 Community Education

Individual stakeholder groups and individuals themselves process information in a variety of modes and media. An effective risk communication strategy takes this factor into consideration and encompasses multiple forms of outreach. In addition to informative materials, such as fact sheets, stakeholder meetings and interactive sessions (such as poster presentations, question and answer sessions) can be held to involve individuals in the learning and understanding process. Prior to selection of a method, an audience assessment should be conducted to determine how a community communicates and to learn what tool is the most effective to use.

Community Education Example—Bennington College Community Education Strategy, Vermont

In 2016, PFAS were discovered in the public water system of Hoosick Falls, New York, and in hundreds of private residential wells in Petersburgh, NY, and North Bennington, Vermont. In response to this nearby problem, Bennington College asked how the scientific resources of a college or university might become a civic resource in times of environmental uncertainty. After some discussion about how to maintain the scientific and educational integrity of the college while also being a good neighbor to impacted communities, Bennington College decided to open the doors of its science classrooms to the problem of PFAS contamination. This was done primarily in two ways: (1) a new introductory class on PFOA was

offered to local communities free of charge, and (2) students in more advanced science classes in chemistry and geology worked to produce independent data on PFAS contamination in the region. More information about both of these strategies is below.

Many residents impacted by PFAS voiced a desire to learn about the science of the problem even as there was a recognition that much of that science was currently quite difficult for residents to grasp. Indeed, many of the risks and ramifications of PFAS contamination are currently published in daunting regulatory reports and peer-reviewed research articles (often behind paywalls). Addressing these concerns, Bennington College designed a new class to review the chemical properties, environmental pathways, and policy concerns of PFOA, entitled "Understanding PFOA." This class also taught residents how to collect water samples for PFAS analysis at a commercial lab and how to interpret laboratory results from PFAS analysis. Bennington College has offered this class every spring to local residents since 2016, free of charge. A number of local teachers, journalists, nurses, elected officials, parents, and students enrolled, and the class has become a vehicle for the community to get up to speed on the science of PFAS so they can engage the issue more productively.

Bennington College also put together faculty-led research teams to produce independent data on PFAS contamination in conversation with community questions. Bennington College realized that impacted communities often had interesting questions about PFAS that fell outside of the urgent protocols of state agencies, which rightfully focused on safeguarding public health. These community questions, however, provided useful pathways to educate residents about the problem and to encourage local participation in research into PFAS contamination. Working with residents of Hoosick Falls, Petersburgh, and North Bennington, the college helped investigate a number of community concerns, such as:

- "Is there any PFOA in my maple syrup?"
    - Bennington College tapped two maple trees in the spring and analyzed the sap, finding 8.8 parts per trillion (ppt) of PFOA in the sap of a maple tree about 1,000 feet from a plastics plant and 2.3 ppt of PFOA in the sap of a maple tree about a mile from the plant.
- "My well had high levels of PFOA but now I have a filtration system in my basement. If my well was contaminated for years, I wonder if there might be any residual PFOA in my water pipes. Could any built-up PFOA still be contaminating the water coming out of my kitchen faucet?"
    - Bennington College analyzed water from the kitchen faucet from three homes with high levels of PFOA in their well and a point of entry treatment filtration system (Hoosick Falls house, 2,100 ppt of PFOA in well; Petersburgh house, 1,800 ppt of PFOA in well; North Bennington house, 3,000 ppt of PFOA in well). In all three homes, PFAS were nondetectable in water from the kitchen sink.
- "When the state tested my well, they found PFOA levels just below the health guidance level and thus we did not get a filtration system. How stable are detected levels of PFOA in the groundwater?"
    - Bennington College reviewed data from over 200 residential wells that had been sampled and analyzed for PFOA at least twice in one year. They found an average variation of 24% in individual wells. PFOA levels increased in about half of the wells and decreased in about half the wells. This increase and decrease did not have an obvious spatial pattern (for example, a plume moving in one direction) but appeared to be fairly randomly scattered across the sampling area.

More information about Bennington College's ongoing engagement with PFAS can be found at **www.bennington.edu/pfoa**.

15 CASE STUDIES

The following case studies have been compiled from 2020 to 2025. Each case study has a date in the title indicating when it was added to this section. The case studies are provided for illustrative purposes and general reference. They demonstrate examples of methods and results from selected sites that may be applicable at other locations, depending on site specific conditions. The information is provided for general reference. Please see the ITRC disclaimer.

Section Number	Topic
15.1	**Site Characterization Case Studies**
15.2	**Treatment Case Studies**
15.3	**Risk Assessment Case Study**
15.4	**Risk Communication Case Studies**
15.5	**Surface Water Quality Case Studies**

The PFAS team has identified and included case studies supporting the following sections:

- **Section 10** Site Characterization
- **Section 12** Treatment Technologies
- **Section 9** Risk Assessment
- **Section 14** Risk Communication
- **Section 16** Surface Water Quality

15.1 Site Characterization Case Studies

15.1.1 Data Visualization at an AFFF Release Site (2020)

McGuire et al. (2014) and **McGuire (2013)** presented a detailed characterization of a subset of PFAS soil and groundwater concentrations, focused on PFAAs in the vicinity of a former unlined burn pit where fire training activities were conducted up to 1990. Data presented in **McGuire et al. (2014)** were used for this visualization example. For brevity, this example shows relative concentration trends between shallow and deep soil samples collected at six borings where total PFAA concentrations exceeded 5,000 ug/Kg in shallow soil. The inset map in the top left of **Figure 15-1** shows the former burn pit location, as well as the locations of these six borings (S-2, S-4, S-5, S-6, S-7, and S-10). Shallow soil samples were collected at a depth of approximately 2 ft below ground surface (ft bgs) (0.61 m), and the deep soil samples were collected at the water table, which is approximately 15–20 ft bgs (4.6–6.1 m) on average.

The bar chart in Figure 15-1a compares concentrations of shallow and deep soil concentrations for total PFAAs at these six boreholes and clearly demonstrates that shallow PFAA soil concentrations are much higher than deeper soil concentrations at the water table. This figure indicates that there is likely attenuation that limits vertical migration of PFAAs. **McGuire (2013)** attributed this to the high clay content of vadose zone soils, and high VOCs and TOC in this area, which may enhance retardation.

A different type of bar chart is shown in Figure 15-1b to illustrate the composition of the main PFAA constituents in shallow soil samples (PFHxS, PFOS, PFHxA, PFOA). Review of Figure 15-1b reveals the following trends:

- In three of the six boring locations, PFOS is greater than 95% of total PFAA concentrations in shallow soil.
- In the other three borings, PFOS is less than 50% of total PFAAs. These borings have higher relative concentrations of PFHxS, PFHxA, and PFOA.
- PFHxS, PFOS, PFHxA, and PFOA combined represent at least 80% of total PFAA concentrations in shallow soil.

The difference in PFOS composition shown in Figure 15-1b suggests that some borings were drilled in an area that was influenced by a mixture of different AFFF products, whereas other borings with a high proportion of PFOS may be influenced primarily by AFFF produced using electrochemical fluorination.

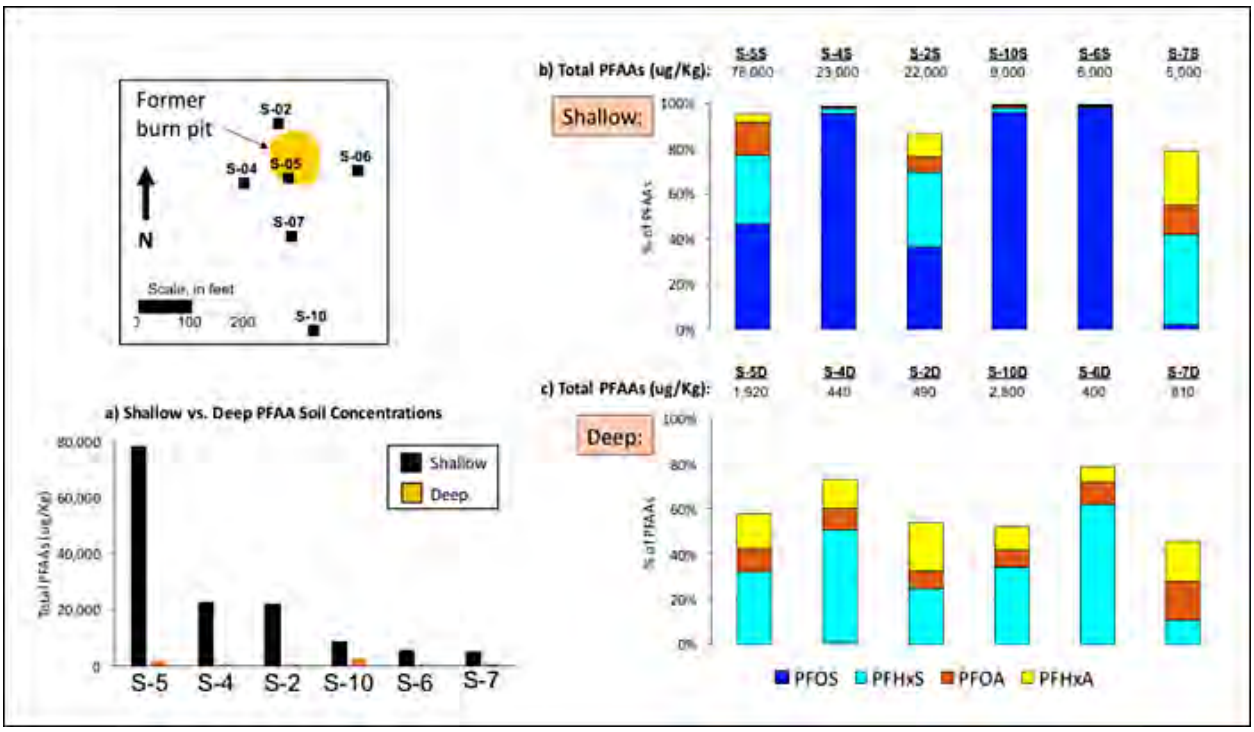


Figure 15-1. Comparison of shallow and deep soil samples at an AFFF release site.

Source: G. Carey, Porewater Solutions. Used with permission.

Figure 15-1c shows the same type of bar chart with relative percent of total PFAA concentrations for the deeper soil samples collected at the water table. Comparison of Figures 15-1b and 15-1c indicates that there is a clear difference in PFAA composition between the shallow and deep soil samples. PFOS is very low in terms of relative concentrations in deep soil samples, compared to the shallow soil samples where PFOS makes up a higher proportion of the total PFAA concentration. This may be due to enhanced retardation of PFOS in the vadose zone relative to the other compounds (PFHxS, PFHxA, and PFOA), which is consistent with the relative site-specific K_{oc} values determined by **McGuire et al. (2014)**. In addition, Figure 15-1c shows that these four compounds typically represent only around 50% of total

PFAA concentrations in the deep samples, which suggests that shorter chain compounds are more prevalent at the water table and in underlying groundwater, most likely due to precursor transformations.

Radial diagrams may also be used as visual aids to illustrate spatial and/or temporal trends for individual PFAS constituents or total concentrations for various PFAS groups. As an example, **Figure 15-2** presents a radial diagram map showing trends for various PFSAs (PFOS, PFHxS, PFBS) as well as perfluorohexane sulfonamide FHxSA, which is a precursor to PFHxS. The radial diagram legend in the top right portion of Figure 15-2 shows that the four axes are arranged in order of FHxSA, PFOS, PFHxS, and PFBS. There are two data series shown on the radial diagram legend: (1) the blue-filled data series, which represents PFAS constituent concentrations at monitoring well location; and (2) a darker blue outline that represents maximum source concentrations at well GW13, which is situated directly adjacent to the former burn pit area. This latter data series is a reference and is the same at all monitoring well radial diagrams. Including this reference data series makes it easier to visualize changes in concentrations throughout the plume. The radial diagram legend also shows how symbols may be plotted to represent where constituents were not detected in a groundwater sample. Another option for radial diagram symbols is to indicate where concentrations are above groundwater cleanup criteria at each well location (not shown). The compound axes are logarithmic in this example, to allow for visualization of order of magnitude concentrations between wells, or between compounds at any one well location.

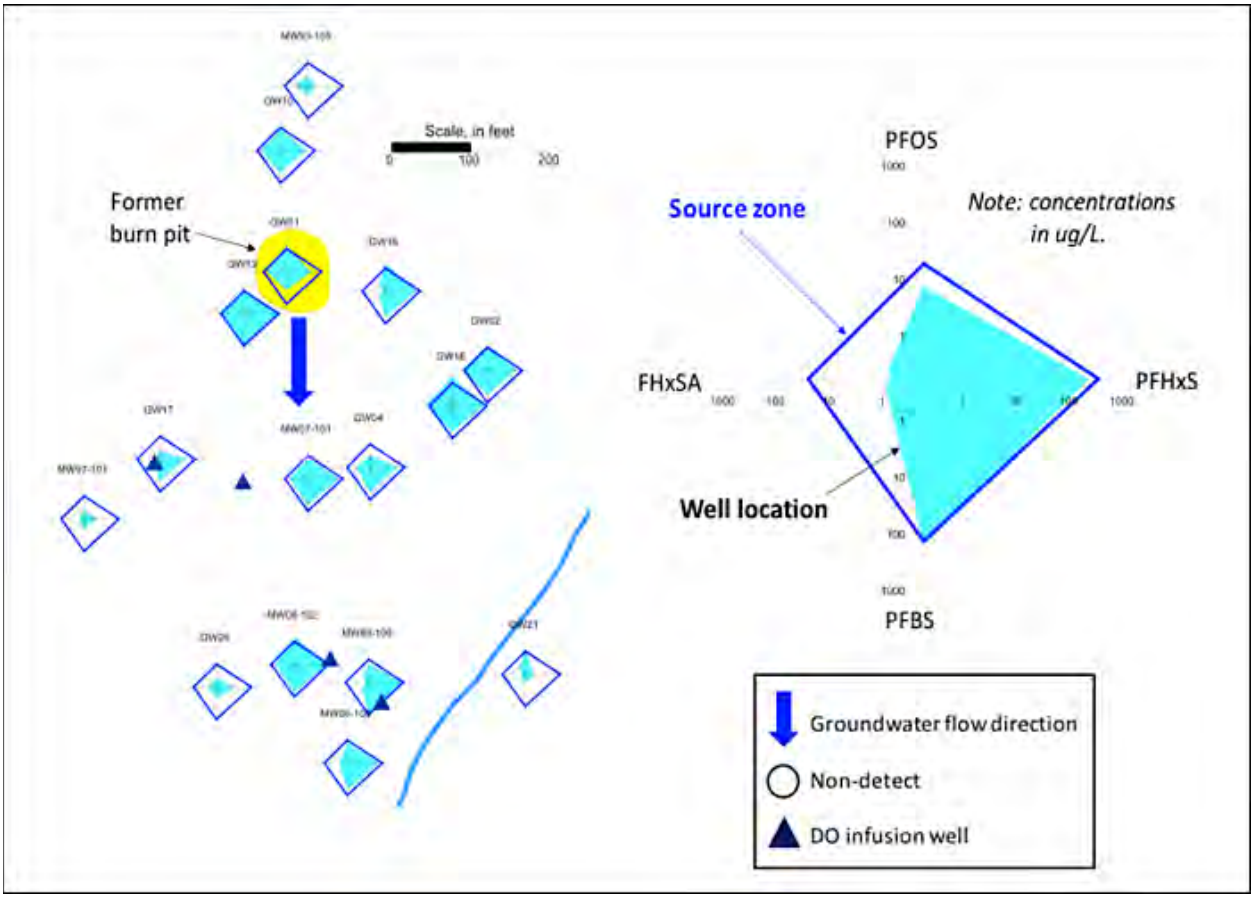


Figure 15-2. Radial diagrams illustrating PFSA trends at an AFFF release site.

Source: G. Carey, Porewater Solutions. Used with permission.

Groundwater flow in this area is generally to the south/southeast. The main radial diagram map shown in Figure 15-2 facilitates an analysis of how concentrations for these four constituents vary along the

groundwater flow path downgradient from the former burn pit area, and how concentrations vary across the width of the plume. For example, the radial diagram shown at GW01, which is located inside the footprint of the former burn pit, indicates that concentrations of the longer chain compounds (FHxSA and PFOS) are similar to those in the nearby well at GW13, whereas PFHxS and PFBS are about an order of magnitude lower at GW01 then GW13. The radial diagrams also clearly show that groundwater downgradient of the DO infusion wells (triangle symbols) has low to non-detect FHxSA, indicating that aerobic transformation of this precursor has occurred downgradient of these infusion wells (**Section 10.4.4**).

Although not shown with this case study, radial diagrams are also helpful for visualizing redox indicator trends, to confirm whether redox conditions are favorable for the transformation of precursors to PFAAs. Examples of a modified radial diagram method used for redox zone delineation are presented in **Carey et al. (1999)** and **Carey et al. (2003)**.

15.1.2 Application of Radial Diagrams (2020)

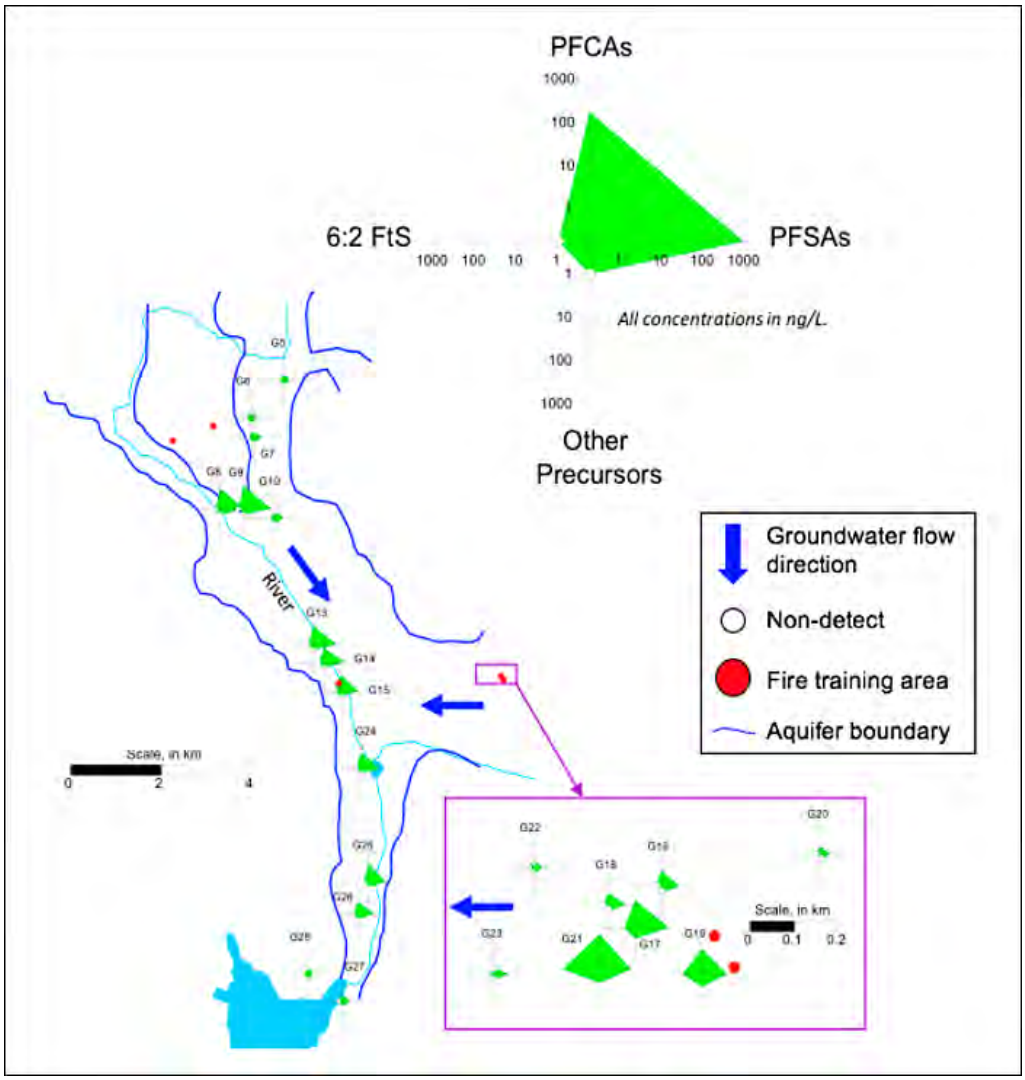


Figure 15-3. PFAS composition in groundwater.

Source: G. Carey, Porewater Solutions. Used with permission.

Figure 15-3 presents another type of application of radial diagrams for visualizing certain PFAS trends, in this case for an aquifer contaminated with PFAS from several fire training areas in the vicinity of Uppsala, Sweden. The blue outlines shown in Figure 15-3 represent the boundaries of eskers (deposits formed by streams flowing beneath a glacier), which essentially act to channel groundwater flow in the aquifer. The legend shown on Figure 15-3 indicates that the four axes of the radial diagram now represent concentrations of 6:2 FTS (which dominates the other FTSs), total PFCAs, total PFSAs, and total concentrations of other chemical-specific precursors. Symbols are shown to represent non-detects at each well location. Groundwater flow in the main aquifer channel is from northwest to southeast (parallel to the river channel) and is to the west in the inset box shown in the bottom center of **Figure 15-3**.

Examples of trends that are evident based on the radial diagram map (Figure 15-3) include:

- All chemical-specific precursors are nondetect in the main aquifer channel, indicating that precursors were effectively attenuated closer to the fire training areas.
- PFSA and PFCA concentrations appear to be declining along the main flow channel (for example, downgradient of G8 and G9.
- Concentrations of precursors in the vicinity of the fire training areas shown in the inset map are much higher than in the main groundwater flow channel. This indicates that precursors may be attenuating prior to reaching the main flow channel in this area, due to sorption, biotransformation, and/or possibly discharge to the nearby creek.
- The combination of elevated PFCAs and PFSAs, as well as high 6:2 FtS near at least two of the fire training areas, indicates that AFFFs produced using telomerization were used at one point at some of these fire training areas.

15.1.3 Application of Environmental Sequence Stratigraphy (ESS) (2023)

Due to the high mobility and persistence of PFAS, groundwater plumes may extend to greater distances than those observed for conventional contaminants such as hydrocarbons and chlorinated solvents. Consequently, PFAS plumes may be more susceptible to unusual groundwater plume flow patterns. For example, site geology may cause groundwater plumes to diverge from directions predicted based on evaluation of a groundwater potentiometric surface (hydraulic gradient). Furthermore, longer groundwater plumes experienced by PFAS may result in groundwater/surface-water interaction to a greater extent. The case study presents an example where environmental sequence stratigraphy (ESS) is used to update a conceptual site model (CSM) for a PFAS-impacted site.

ESS (**USEPA 2017**) is a data analysis technique designed to improve CSMs through enhanced understanding of interaction between site geology, groundwater flow patterns, and preferential contaminant transport pathways. ESS provides a framework for interpretation of data generated via high-resolution site characterization (HRSC), existing subsurface data, such as geologic boring logs, and (potentially) geophysical data. The data evaluation focuses on site depositional/erosion history to identify geologic sequences and patterns (geologic heterogeneity and anisotropy in hydraulic conductivity) that explain contaminant migration pathways. ESS is useful to identify patterns in sedimentary deposits (consolidated or unconsolidated) comprising clays, silts, sands, and gravels. ESS techniques are designed for sedimentary deposits and are not applicable to metamorphic/crystalline rock or glacial till; however, adjusted ESS techniques can also be applied to glacial outwash deposits, which have similar characteristics to nonglacial sedimentary deposits.

This case study describes a site where ESS predicted a groundwater plume that did not follow the direction expected via simple hydraulic gradient analysis.

15.1.3.1 Sequence Stratigraphy

Sequence stratigraphy involves the study of geologic heterogeneity in sedimentary deposits in the context of their depositional environments and is applicable to sites underlain by sedimentary aquifers (for example, intermixed gravels, sands, silts, and clays). Subtle geologic heterogeneities can have significant effects on groundwater and contaminant transport. The ESS framework is designed to evaluate and incorporate these heterogeneities into a CSM to improve understanding of contaminant fate and transport. ESS techniques involve three-dimensional evaluation of geologic data, with an experienced geologist looking for detailed patterns and trends in the depositional framework (for example, lateral and/or vertical continuity of geologic strata).

ESS implementation generally involves a three-step process. The first step involves review and understanding of the regional geology and depositional environment. The second step involves a detailed review of existing lithology data, to assess both vertical and horizontal grain-size sedimentary patterns. Additional information may also be incorporated at this step, such as geophysical data and/or manmade site features (for example, drainage pathways). The third step involves development of a CSM integrating the detailed geologic data collected during the preceding steps to develop a hydrostratigraphic understanding of what controls migration of groundwater and contaminants. During this third step, three-dimensional data-modeling tools may be used to interpret the lateral continuity of subsurface strata, identify trends and/or lithologic sequences, and integrate geology and geochemical data sets.

This method can identify preferential groundwater and contaminant flow pathways associated with the geology and hydrogeology that may not be apparent in conventional/engineering-focused investigations, and may not necessarily follow the general groundwater gradient. Furthermore, ESS techniques can be useful to map and predict contaminant mass transport, identify data gaps, and identify target locations for focused investigation and/or remediation.

15.1.3.2 Site Background

An updated CSM (**Trihydro 2019**) was prepared for Ellsworth Air Force Base, where previous training and incident response involving aqueous film-forming foam (AFFF) resulted in groundwater impacted by PFAS as documented in a PFAS site inspection report of aqueous film forming foam areas (**Aerostar 2019**). Historical site investigations were typically focused on specific operable units (OUs) in a piecemeal fashion. As a result, geologic and hydrogeologic connections between some OUs were not apparent. Furthermore, previous investigations focused on contaminants of concern such as trichloroethene (TCE).

A detailed evaluation of regional and site geology was conducted in accordance with the ESS framework and is summarized herein. Briefly, regional geology consists of confined and unconfined aquifers. The shallow, unconfined aquifer comprises unconsolidated sediments (terrace alluvium) overlying the Pierre Shale formation, which covers a large segment of the plains surrounding the Black Hills and is reported to be up to 860 feet thick at the site. The Pierre Shale is a low-permeability formation that functions as a barrier to vertical groundwater flow, and as a confining unit to deeper aquifers. Deeper, confined aquifers exist at depth beneath the Pierre Shale. The Pierre Shale is considered the bedrock surface at the site and is encountered between 0 and 40 feet below ground surface.

The CSM focused on the shallow aquifer, defined as a terrace alluvium, which includes a combination of paleochannel deposits, modern channel deposits, and undifferentiated sediments (see geologic cross-section shown in **Figure 15-4**). The undifferentiated sediments are poorly graded deposits associated with floodplains, wind, or other weathering, which are generally more fine-grained and lower permeability than the channel deposits. The paleochannel deposits consist of sand and gravel, deposited by ancient surface-water streams, with characteristics including high permeability and fining-upwards sequences. The paleochannel deposits underlying Ellsworth AFB provide preferred pathways for groundwater and

contaminants with unpredictable orientations that are not discernable from the direction of modern drainages.

For the updated CSM, the site depositional history was evaluated, along with historical geologic and hydrogeologic data sets. The project involved "synthesizing decades of lithology data, from over 1,100 boreholes [within a site area of approximately 4,800 acres] with varying geologic interpretation" (**Trihydro 2021**). Site depositional history was evaluated and lithology logs were compiled and integrated with manmade infrastructure features to map out fine-scale geologic features and identify trends and pathways that affect contaminant migration. The large number of existing boreholes provided a rich data set for ESS evaluation, and a multimonth effort was required to review the existing logs and convert the logs into digital format.

As part of the ESS evaluation, the project team "looked at fine scale stratigraphic patterns in the contaminant transport pathways to predict where additional remedial solutions should be located" (**Trihydro 2021**). One of the questions posed midproject was to figure out how the shallow groundwater, outside of the base boundary, had become impacted by PFOA/PFAS. The area was approximately 0.5 miles from any known release or storage area.

15.1.3.3 Results

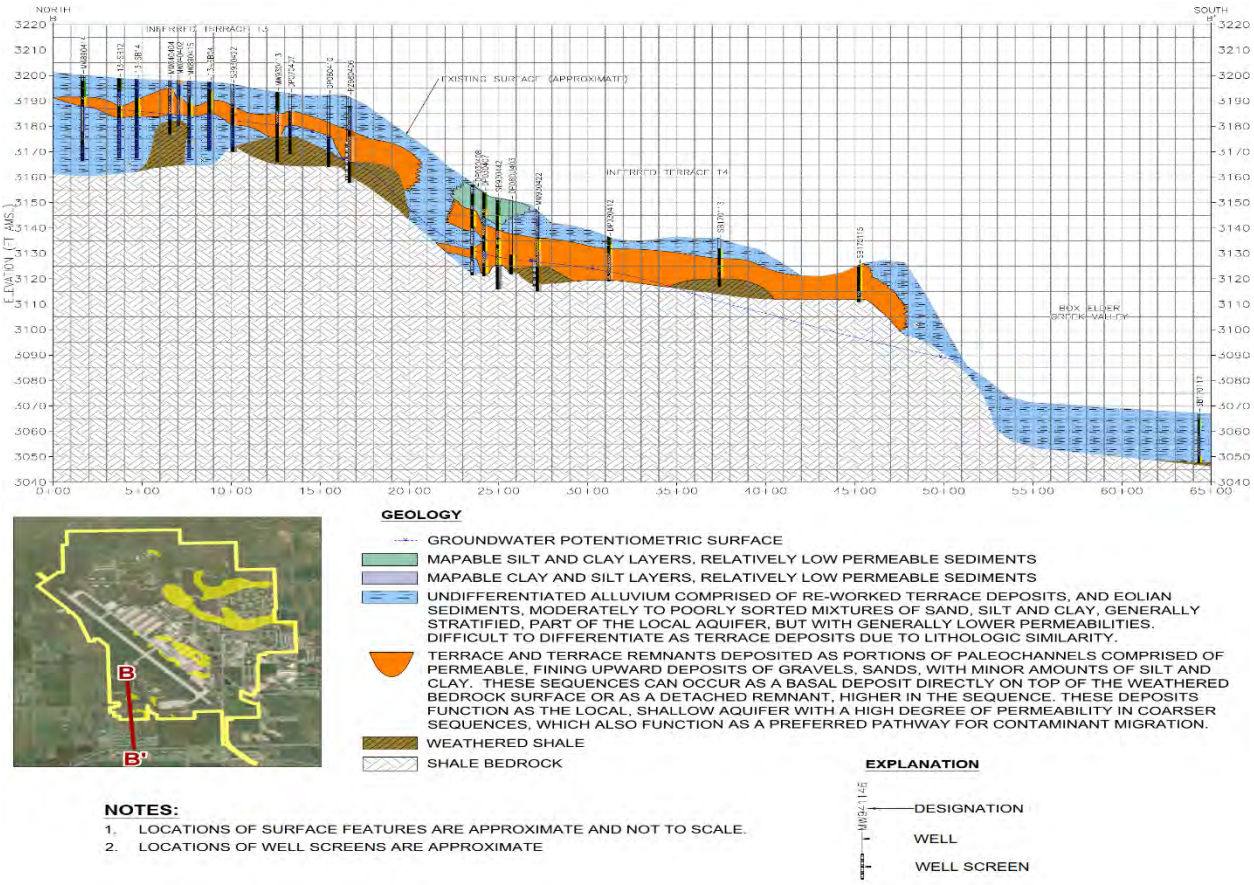


Figure 15-4. Geologic cross-section generated from ESS evaluation (Trihydro 2019).

Source: M. Olson, Trihydro. Used with permission.

The CSM developed for Ellsworth AFB used ESS techniques to show how geologic heterogeneity and anisotropy, resulting from site depositional history, caused multiple PFAS groundwater plumes to diverge from the direction predicted using simple potentiometric surface maps. The ESS evaluation identified several course-grained channel structures throughout the site. "More specifically, the CSM showed how buried paleochannel structures and a subtle weathered bedrock surface controlled contaminant migration pathways" (**Trihydro 2021**). In addition, subsurface stormwater structures were identified as high-permeability conduits, potentially providing secondary migration pathways for contaminants off site.

As illustrated in **Figure 15-5**, the groundwater plume (the TCE plume is shown in yellow) diverges from the prevailing groundwater flow direction (blue arrows) after encountering a course-grained paleochannel (shown in dark pink). The TCE plume is illustrated on **Figure 15-5** due to the extensive historical data set for TCE that is amenable to detailed plume mapping, better than would be the case for PFAS; the PFAS data set remains relatively limited (but growing) at the site. Detailed geologic cross-sections generated through the ESS evaluation (**Figure 15-4**) provide further insights into the structure of the paleochannels that influence the plume behavior. "Through ESS techniques, portions of previously unidentified plumes were found" (**Trihydro 2021**), and subsequent PFAS site characterization and/or remediation activities will rely on the new understanding moving forward to provide a more accurate remedial strategy.

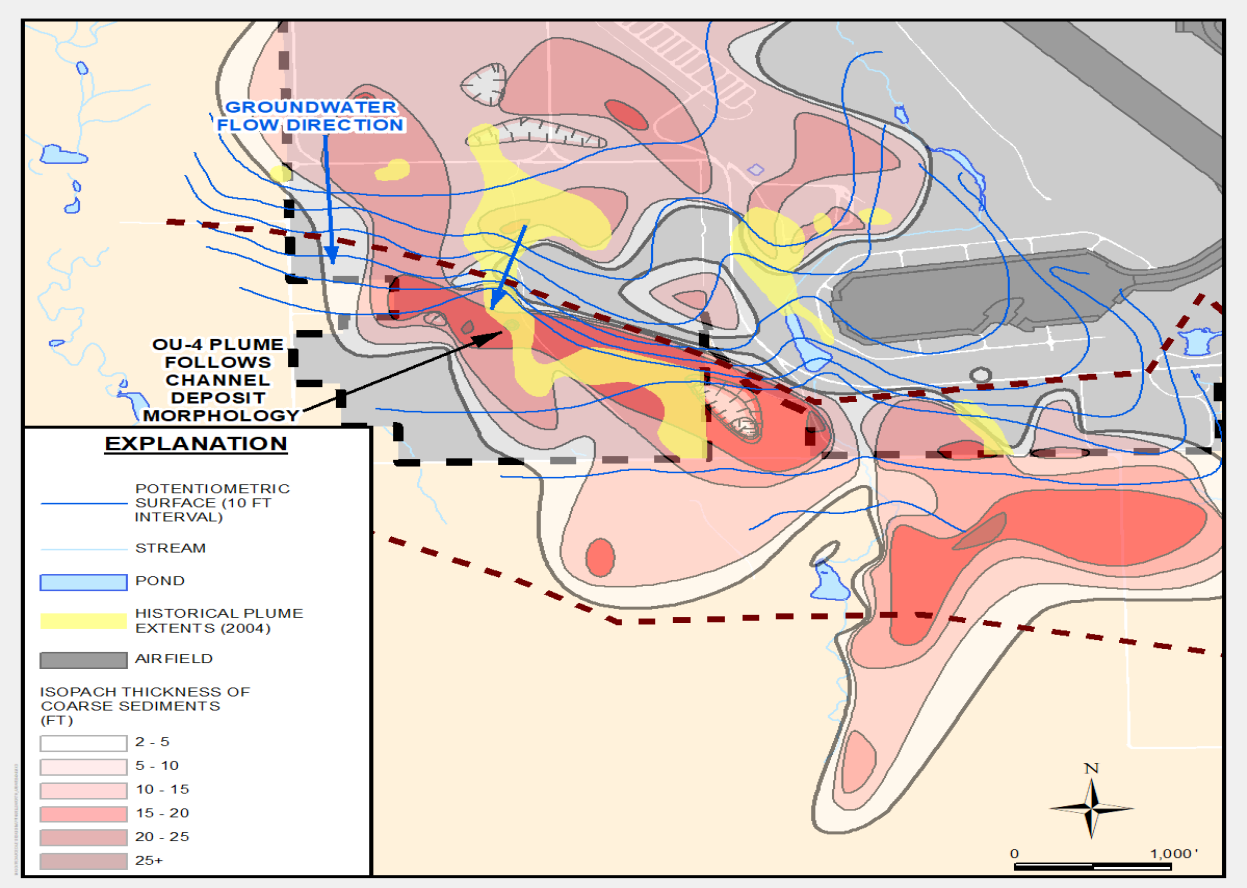


Figure 15-5. Excerpt from TCE plume map (Trihydro 2019).

Source: M. Olson, Trihydro. Used with permission.

15.1.4 Case Study: PFAS in Drinking Water Aquifer from Residential Septic Systems—A Conceptual Site Model (2025)

Contributed by Jenna Raup, TRC Engineers Inc., used with permission.

Multiple lines of evidence suggest that septic systems are contributing PFAS to overburden groundwater and fractured bedrock supply wells in a densely developed residential area lacking municipal water and sewer. As part of New York State's emerging contaminant sampling initiative, TRC Engineers Inc. (New York, NY), on behalf of the New York State Department of Environmental Conservation, sampled groundwater at a dry-cleaning State Superfund Site, and PFAS were detected above comparison criteria. The surrounding area was surveyed for sensitive receptors, and private water supply wells were tested to evaluate potential exposure. The presence of PFAS in groundwater at and near the State Superfund Site led to an investigation to determine the source(s) of PFAS in groundwater. A stepwise approach was implemented to identify potential sources via desktop review, followed by scoping and implementing targeted sampling at suspected source sites. Desktop sources reviewed included environmental reports, site and surrounding area history, environmental databases, historical documentation and maps, infrastructure construction records and maps, and numerous other publicly available records, including news reports and social media pages. Two hundred eighteen private water supply wells, which draw from the bedrock aquifer, are the domestic water source for approximately 50% of the properties within a ½-mile radius of the site (the Assessment Area). They are in locations that lack municipal water and sewer and were tested for PFAS. The results of the private well sampling were considered when searching for potential PFAS source sites.

Based on the desktop review and private water supply data, 12 potential PFAS source locations were identified for further investigation. These locations were associated with potential on-site use and release of PFAS-containing products, nearby private well sampling results indicative of a potential source, or geologic setting that represented a potential pathway to the bedrock water supply aquifer. The sampling program was designed to target potential release points, and minimize the number of samples collected. It was anticipated that concentrations of PFAS at a release point would suggest a potential source, and a subsequent remedial investigation may be warranted to define the nature and extent of the PFAS contamination. The targeted investigation program included soil or overburden groundwater sampling, or both, at each potential point source, access permitting, sediment and surface water sampling in the adjacent lake and at the discharge point of the publicly owned treatment works (POTW). In addition, the investigation program used the septic tracers, acesulfame potassium, sucralose, nitrate, and nitrite, in select bedrock water supply wells, and acesulfame potassium and sucralose in select overburden groundwater sampling locations. Though not used in this study, other common tracers such as surfactant metabolites, pharmaceuticals, antimicrobials, caffeine, boron, and others could have provided additional lines of evidence that the PFAS-rich groundwater did, in fact, co-occur with common wastewater (that is, septic) indicators. The lines of evidence presented below indicated that septic systems are the main source of PFAS in the Assessment Area bedrock water supply. Additional discussion of septic systems is included in **Section 1.3.2**.

- Other potential sources in the area were ruled out by the data. These included a firehouse that uses and stores aqueous film-forming foam; an oil recycling company which experienced a documented fire; a domestic septic pump out facility; boat detailing facilities; an apartment complex with on-site laundry and potential carpet cleaning; and potential sewer line inflow and exfiltration.

- PFAS concentrations in private wells were of similar order of magnitude throughout the Assessment Area. PFAS concentrations in overburden groundwater samples were of similar order of magnitude to PFAS concentrations in bedrock aquifer samples collected from private wells, and in many cases, were slightly higher.

- There is a connection between overburden and bedrock hydrogeologic units.
    - Prior studies identified a downward vertical groundwater gradient in the vicinity of the Superfund site.
    - Septic tracers were detected in overburden groundwater and private well–derived drinking water in every instance.

- The PFAS signatures of areawide wastewater and bedrock water supply closely match, with few exceptions.
    - Approximately 50% of the Assessment Area is served by municipal water and sanitary sewers. The effluent at the POTW that receives sanitary wastewater from approximately 50% of the Assessment Area was sampled, and the PFAS signature was used as a proxy for wastewater discharges in the area. There are clear similarities among the PFAS signatures of the POTW effluent, the bedrock water supply, and overburden groundwater (relative PFAS ratios included approximately 30%–40% perfluorooctanoic acid (PFOA) and 30%–40% perfluorooctane sulfonic acid (PFOS)), followed in lesser concentrations primarily by perfluorobutane sulfonate (PFBS) and perfluoroheptanoic acid (PFHpA). **Table 15-1-1** presents a statistical summary of PFAS analytical results for private wells in two discrete neighborhoods of the Assessment Area and for the POTW effluent.

- PFAS signatures in groundwater throughout the Assessment Area exhibited low variability (**Table 15-1-1**). In addition, in locations where both overburden groundwater and private water supply samples were analyzed, PFAS signatures matched (same predominant, secondary, tertiary PFAS).

Table 15-1-1. Statistical summary: PFAS analytical results.

	Composite Private Well Results for 91 Homes		Composite Private Well Results for 23 Homes		POTW Discharge Effluent
	Average	SDσ	Average	SDσ	Grab Sample Result
Total PFAS (ppt)	58.5	22.84	49.4	11.6	44.7
% PFOA	38.5	6.6	34.6	2.6	35.8
% PFOS	34.9	8.1	32.5	2.7	29.1
% PFBS	10.7	6.3	16.6	4.5	14.8
% PFHpA	10.1	2.7	9.7	1.1	9.4
% PFHxS	4.5	2.3	6.3	2.2	5.1
% PFNA	1.3	1.8	0.4	1.2	5.8

SD**σ**=standard deviation

Source: **Raup et al. 2024**, https://onlinelibrary.wiley.com/doi/10.1002/rem.70001. *Used with permission.*

The use of forensics and PFAS signature analysis was relatively limited due to the suite of PFAS reported for drinking water samples (6 PFAS) and the limited scope of environmental investigation (absence of upgradient, downgradient, and bedrock monitoring wells). However, based on multiple lines of evidence, the data did not substantiate the need for further investigation into any of the suspected sources. Taken together, the findings above support the following conceptual site model: consumer product use and discharge to domestic septic systems in a densely developed residential area have resulted in widespread presence of PFAS in shallow bedrock groundwater. **Figure 15-1-6** depicts this using pie charts to represent PFAS in domestic products, wastewater, and overburden and bedrock groundwater. More information about data visualization is included in **Section 1.3.7**. Downward vertical groundwater

gradients in the area and long-term supply well pumping have contributed to these impacts. It was concluded that the source of areawide PFAS impacts was unrelated to historic dry-cleaning operations at the site. A full case study is provided in **Raup, J., M. Eberle, E. Denly, D. Glass, S. Stefansky, J. Dyber, B. Scharf, S. Saucier. 2024. "A Conceptual Site Model for Per- and Polyfluoroalkyl Substances Water Supply Impacts in a Residential Community." Remediation Journal 35:e70001**.

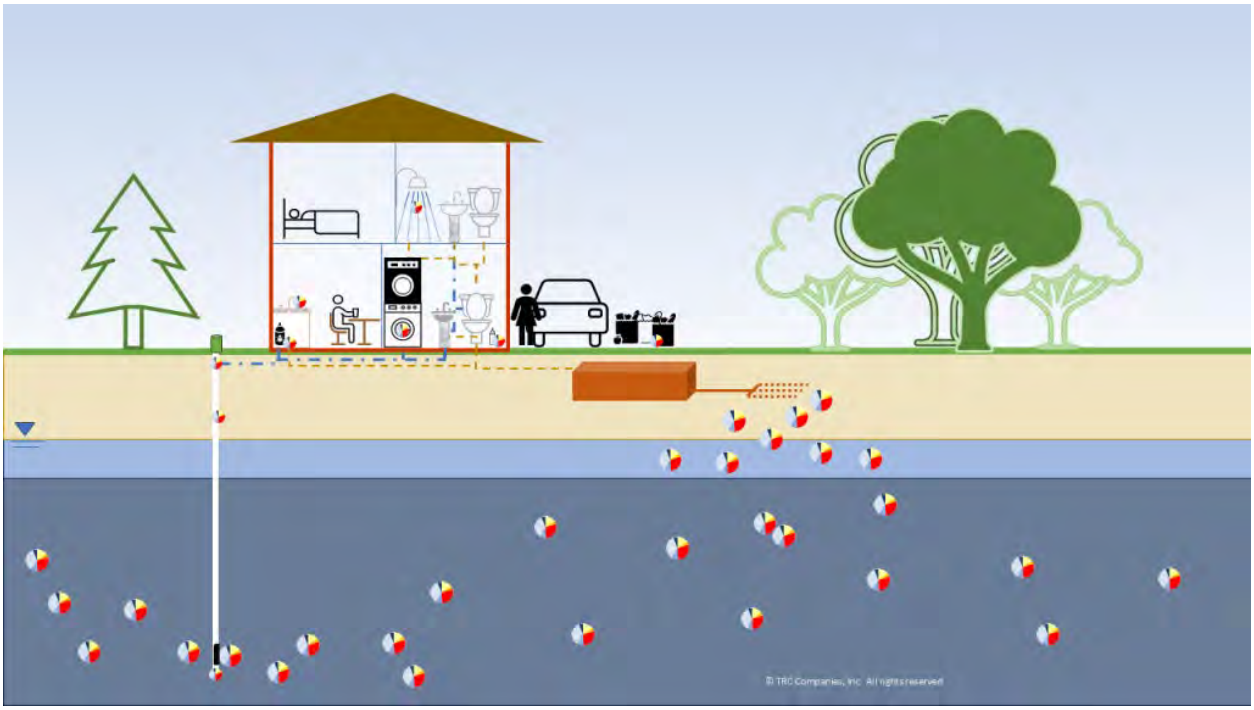


Figure 15-1-6. Conceptual site model.

Source: ***Raup et al 2024 https://onlinelibrary.wiley.com/doi/10.1002/rem.70001****. Used with permission.*

15.2 Treatment Case Studies

Several well-developed technology case studies are presented in the following sections. Additional information on other water treatment case studies is summarized in Table 15-1 provided as a separate Excel file.

15.2.1 Granular Activated Carbon (GAC) (2020)

Case Study: Granular Activated Carbon System—Oakdale, Minnesota (Contributed by Virginia Yingling, Minnesota Department of Health, used with permission)

Background

Oakdale is a suburban community located east of St. Paul, Minnesota, with a population of approximately 28,000. Prior to state or federal laws regulating such waste disposal, industrial wastes from a PFAS manufacturer were disposed of in a privately operated 55-acre unlined dumpsite (Oakdale Disposal Site, 1940–1960) and in the Washington County Landfill, a permitted 40-acre unlined municipal landfill in Lake Elmo, Minnesota (1969–1975). In 2005, PFAS were detected in six of the eight operating Oakdale city drinking water supply wells.

Eight PFAS have been detected in groundwater associated with these sites, with PFBA, PFHxS, PFOA, and PFOS being present at the highest concentrations. PFAS have also contaminated a stream that drains the wetlands that comprise part of the Oakdale Disposal Site and PFAS re-infiltration has contributed to groundwater contamination in areas not immediately downgradient of the waste disposal sites. Both sites underwent remedial activities in the 1980 to address industrial solvents and in 2009–2011 to address PFAS. These actions included soil and waste excavation with on- and off-site encapsulation, and groundwater pump and treat (GAC) for hydraulic containment.

The regional groundwater flow direction at both sites is to the south-southwest toward the Mississippi River, approximately 8 miles away. The primary source for PFAS impacts to groundwater appears to be the Oakdale Disposal Site, but the Washington County Landfill may have contributed to the contamination in the easternmost city wells.

Water Characteristics

The maximum concentrations detected to date in the city wells are shown in **Table 15-2** along with the relevant Minnesota health-based guidance values for PFAS in drinking water.

Table 15-2. Maximum concentrations of PFAS in drinking water from Oakdale city wells.

Chemical	Maximum Concentration Detected in Any Oakdale City Well (µg/L)	Minnesota Department of Health's Health-Based Guidance Value (µg/L)
PFBA	2.15	7
PFBS	0.136	3 (acute), 2 (chronic, subchronic)
PFPeA	0.176	None established
PFHxA	0.382	None established
PFHxS	0.142	0.047
PFOA	0.871	0.035
PFOS	1.38	0.015
NOTE: All concentrations reported as of August 2019 and guidance values reported are as of December 2019.		

The Minnesota Pollution Control Agency (MPCA), Minnesota Department of Health (MDH), City of Oakdale, and the chemical manufacturer agreed to address the situation by constructing a GAC treatment plant to treat the water from the two most highly contaminated wells. In addition, the city shut off one well and drilled a replacement well north of the contaminated area. Other wells with PFAS detections are used seasonally and to maintain pressure throughout the distribution system, but the pumping schedule is managed to ensure PFAS remain below MDH guidance values in the water delivered to the community. This includes meeting the MDH's Health Risk Index, which is a toxic equivalency quotient (TEQ)-like assessment of the additive toxicity of multiple PFAS.

Treatment Technology Design Details

The GAC treatment facility (**Figure 15-6**) began operations in October 2006. It consists of ten filter vessels (each containing 20,000 lbs. of GAC) set up in five parallel lead-lag pairs (shown below) housed in a 7,000 ft^2 facility. The system treats 2,500 gallons per minute with a minimum empty bed contact time (EBCT) of 10 minutes per vessel. The water is combined back into one stream, chlorinated and fluoridated to meet state and federal standards, and then piped to the distribution system.



Figure 15-6. GAC treatment system, Oakdale, MN.

Source: Courtesy of the Minnesota Department of Health.

System Performance

The city and MDH monitor the PFAS concentrations in the influent, lead vessel effluent (that is, between vessels), and post–treatment facility effluent (Figures **15-7** and **15-8**). Monitoring currently occurs quarterly for the first three quarters following GAC change-out and monthly in the final quarter prior to change-out.

The GAC is changed out approximately every 12 months to prevent breakthrough of any PFAS above MDH guidance values. GAC change-out may involve a complete replacement of all GAC or just the lead vessel GAC and change of flow to make the former lag vessel the new lead vessel. This will depend on the effluent concentrations at the time of change-out. Initial removal rates are 100% (below analytical limit of detection) for all seven PFAS analyzed (PFBA, PFPeA, PFHxA, PFOA, PFBS, PFHxS, PFOS).

Breakthrough order follows the expected sequence of shorter chain and PFCAs preceding longer chain and PFSAs. PFBA breakthrough of the full system typically occurs within 2 months after a complete GAC replacement, but because the influent PFBA does not exceed its health-based guidance value of 7 µg/L, this does not pose a health risk and does not trigger any response actions. Interestingly, PFBA effluent concentrations eventually exceed influent concentrations, presumably due to PFBA desorbing in the presence of more readily sorbed, longer chain PFAS. As shown in the graphs below, PFOS has broken through the full system only once (2012; max effluent concentration = 0.019 µg/L) and PFOA has broken through only four times (2010, 2012, 2015, 2018; max effluent concentration = 0.086 µg/L). At no time did any PFAS exceed the then-current health-based guidance values.

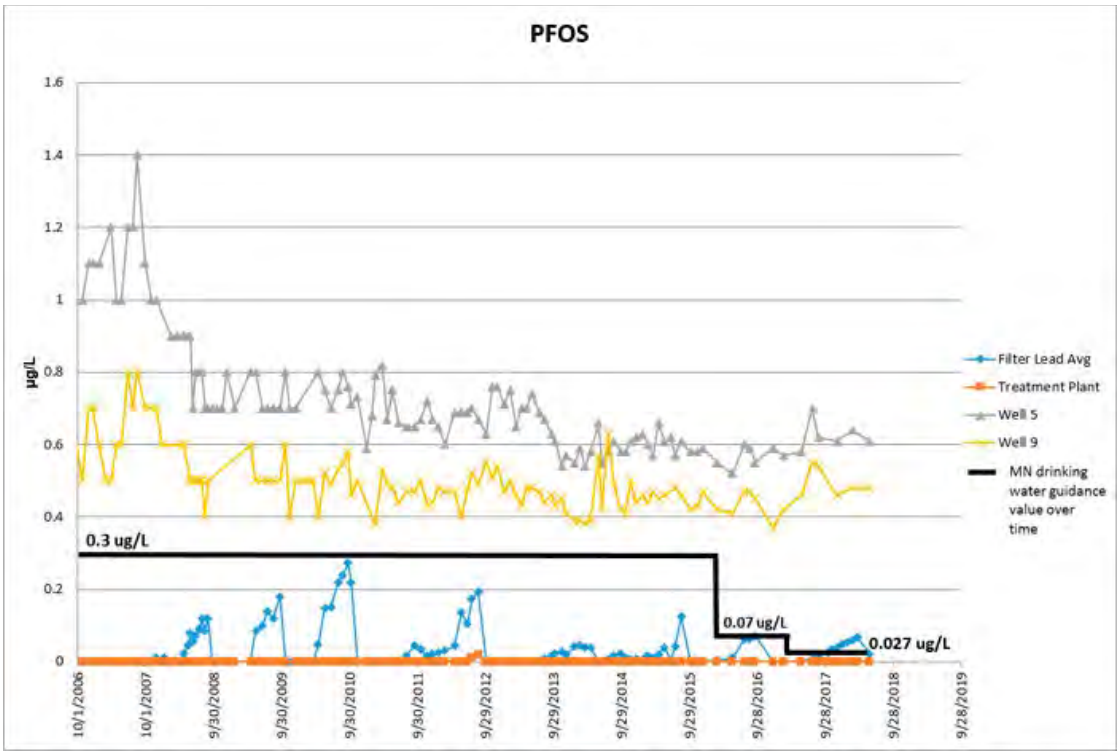


Figure 15-7. Influent and effluent concentrations for PFOS.

Source: Courtesy of the Minnesota Department of Health.

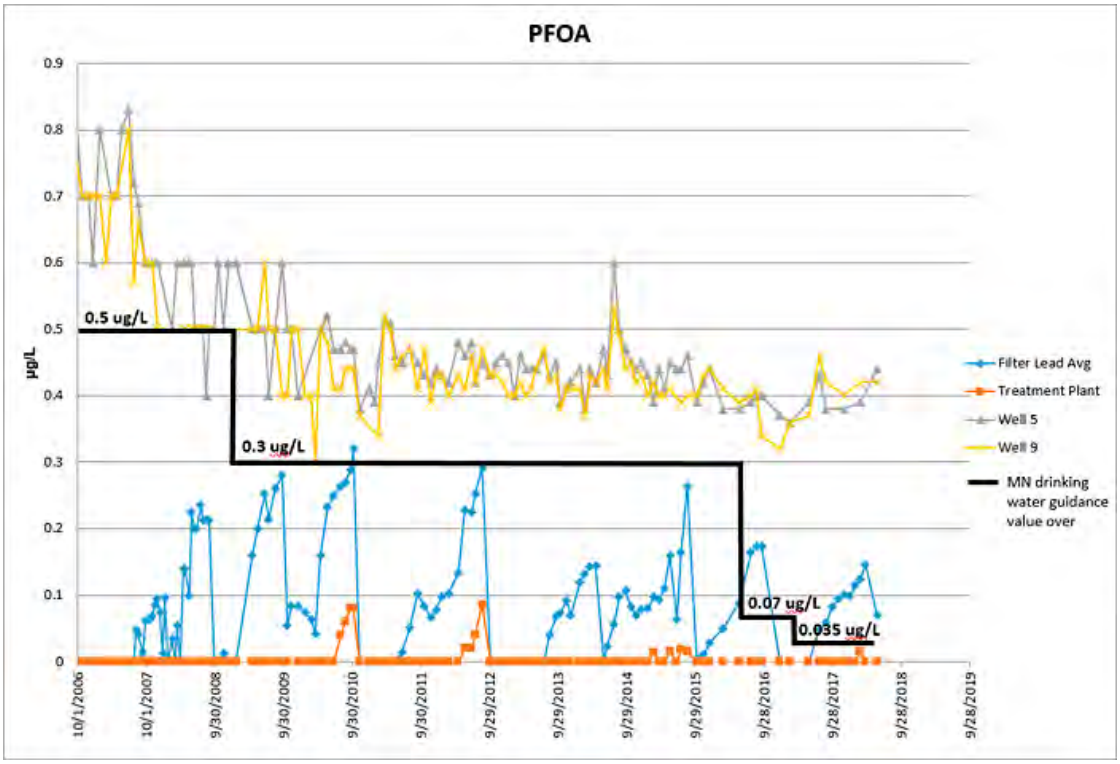


Figure 15-8. Influent and effluent concentrations for PFOS.

Source: Courtesy of the Minnesota Department of Health.

Costs

Capital costs for the GAC treatment facility were approximately $2.5 million. Annual operation and maintenance (O&M) costs, including sampling and GAC change-out, are approximately $250,000.

15.2.2 Ion Exchange (IX) Resins

Ion exchange resins can be utilized as single-use, where the media is disposed when it has reached the limit of its sorptive capacity, or regenerable, where the resin is regenerated and reused indefinitely (theoretically). The following two case studies outline field applications for these two related technologies.

15.2.2.1 Single-Use IX (2020)

Case Study: Horsham Township, Pennsylvania (Contributed by Francis Boodoo, Purolite Corporation, used with permission)

Background

The township of Horsham, Pennsylvania, located close to an AFFF release site, supplies drinking water to 7,800 residential, commercial, and industrial customers using 15 deep water wells. In 2014, five of the wells were confirmed to be impacted with PFAS. PFOS and PFOA were found in two wells at concentrations approaching the USEPA 2009 provisional health advisories (HAs) of 200 ppt and 400 ppt, respectively. These wells were immediately taken out of service. In June 2016, one month after EPA issued final HAs of 70 ppt for the combined concentrations of PFOS and PFOA, three more wells were removed from service due to elevated concentrations. The township began purchasing supplemental water from a nearby water supplier and began installing GAC filters to remediate and return the five impacted wells to service. Responding to consumer concerns, the township adopted an aggressive removal plan to reduce average PFOS/PFOA concentrations to less than 1 ppt (essentially to nondetect levels) in its entire water system by the end of 2016.

In addition to GAC filtration, the township started up a 50-gallon-per-minute selective ion exchange (IX) resin pilot in November 2016 on Well 10 to evaluate the performance of the resin in consistently reducing PFOS/PFOA to nondetect levels. A temporary 1-year permit was obtained from Pennsylvania Department of Environmental Protection (PA DEP) to install the resin pilot downstream of an existing GAC pilot that had been started up 20 days earlier. This was the first permit issued by the state of Pennsylvania for treating PFAS in drinking water using ion exchange resin.

Influent Water Characteristics

Influent concentration of a total of seven PFAS during the test period from November 2016 to August 2018 was an average of 103 ppt, a minimum of 78 ppt, and a maximum of 147 ppt. Individual PFAS concentrations are shown in **Table 15-3**. Average influent values for PFOS and PFOA were 34.1 and 20 ppt, respectively, somewhat lower than USEPA's 70 ppt combined 2016 HA. Other influent geochemical parameters included sulfate at 8–23 ppm, nitrate at 10–11 ppm, alkalinity at 148–232 ppm, chloride at 35–50 ppm, pH at approximately 7.5, TDS at 296–358 ppm, suspended solids at 0.5–0.6 ppm, TOC at 0.2 ppm, and one sample detection for 1,1-dichloroethane at 37 ppt.

Table 15-3. Influent PFAS Characteristics of Well 10*.

nanograms per liter (ng/L) (or parts per trillion (ppt))								
	PFBS	PFHpA	PFHxS	PFHxA	PFNA	PFOS	PFOA	Total PFAS
Lab Detection Level	1	1	2	1	2	2	1	
Minimum	6	4	17	6		27	13	78
Average	9	5	28	9		34	20	103
Maximum	14	8	41	13	2	48	40	147
* PFBS =perfluorobutanesulfonate; PFHpA = perfluoroheptanoate; PFHxA = perfluorohexanesulfonate; PFHxA = perfluorohexanoate; PFNA = perfluorononanoate, PFOS = perfluorooctanesulfonate, PFOA = perfluorooctanoate, PFAS = total poly- and perfluoroalkyl substances								

Treatment Technology Design Details: GAC and Ion Exchange System

Well 10, with a peak design flow rate of 100 gpm, was used for large-scale piloting at a reduced flow rate of 50 gpm under the terms of the permit from PA DEP. The water was first passed through a 20-micron suspended solids filter, then in series through two 2.5-ft diameter stainless steel vessels, each vessel containing 20 cubic feet of bituminous GAC. EBCT for each charge of GAC amounted to 2.8 minutes or a total of 5.6 minutes for the two GAC vessels; linear velocity was approximately 10 gpm/ft^2. The township recognized that EBCT was lower than the 10–20 minutes specified in the PA Public Water Supply design manual and that linear velocity, even though it complied with the PWS, was higher than the typical 4 gpm/ft^2 used for GAC; however, the township and PA DEP considered the design acceptable for the low levels of PFAS measured and for the temporary nature of the pilot. After initial treatment by the GAC pilot, the water was passed through a 2.5-ft diameter vessel containing 20 cubic feet of Purolite Purofine PFA694E selective resin. Bed depths for both the GAC and resin media were approximately 34 inches. Sampling points were installed on the outlet of each vessel. An extra sampling point was installed in the resin polishing vessel at two-thirds of the resin bed depth. This allowed monitoring corresponding to EBCT of 1.8 minutes at the two-thirds sampling point and 2.8 minutes EBCT for the entire resin bed. The two-thirds sampling point would provide advanced notice of PFAS breakthrough.

System Performance

The entire system became operational on November 29, 2016. PFOS and PFOA sampled at the two-thirds point of the resin bed remained consistently at nondetect levels until rising to 2.6 ppt on day 394 and 4 ppt on day 472 (see Figure 15-9). For reporting purposes, the township decided to use a minimum reporting level of 2.5 ppt for each of PFOS and PFOA; values below the minimum reporting level would be considered nondetect. Once the PFOA concentration reached 2.6 ppt at the two-thirds sampling point for the resin, the treated water was diverted to the local sanitary sewer in keeping with the PA DEP permit. PA DEP has since granted permission to bypass the GAC system to enable performance evaluation of just the resin.

On day 514, with permission from PA DEP, the two GAC vessels were taken out of service while the raw water was routed directly to the resin vessel, which continued to operate. In this way, the performance of the resin could be evaluated without pretreating with the GAC. The resin operated for 639 days before PFOA was detected at a concentration of 2 ng/L of PFOA in an effluent sample from the resin bed. At that point the concentrations of PFBS, PFHxS, and PFOS were still at nondetect levels. Operating capacity of the resin at that point was equivalent to treating 511,000 bed volumes (BVs) of water based on two-thirds of the resin volume, or 329,000 BV based on the entire volume of resin.

Following successful and consistent performance of the resin-only system, PA DEP has issued an operating permit for use of resin only in a pair of lead-lag ion exchange vessels. Similar permits have also been issued at neighboring townships.

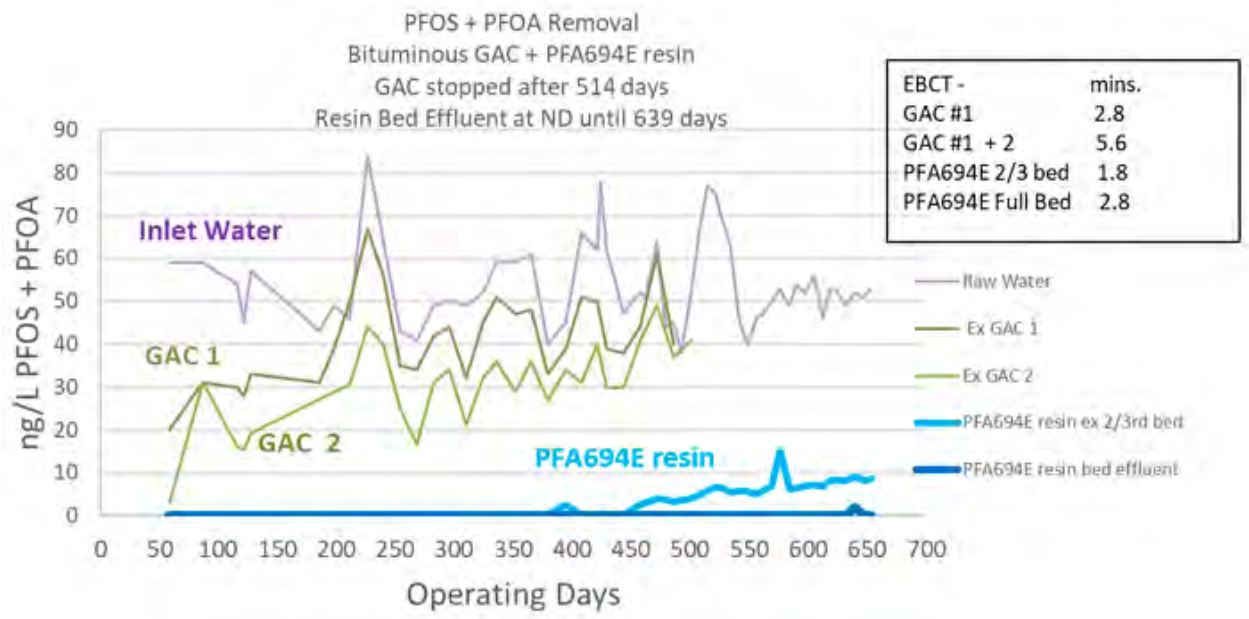


Figure 15-9. Combined PFOS/PFOA breakthrough.

Source: F. Boodoo, Purolite Corporation. Used with permission.

Even though PFOS and PFOA were the initial targets for reduction, consistent reduction of other short- and long-chain PFAS to nondetect levels was also achieved after passage through the resin. For conciseness, only total PFAS breakthrough graphs are shown in **Figure 15-10**, but the order of breakthrough observed was PFHxA < PFHpA < PFOA < PFNA < PFBS < PFHxS < PFOS.

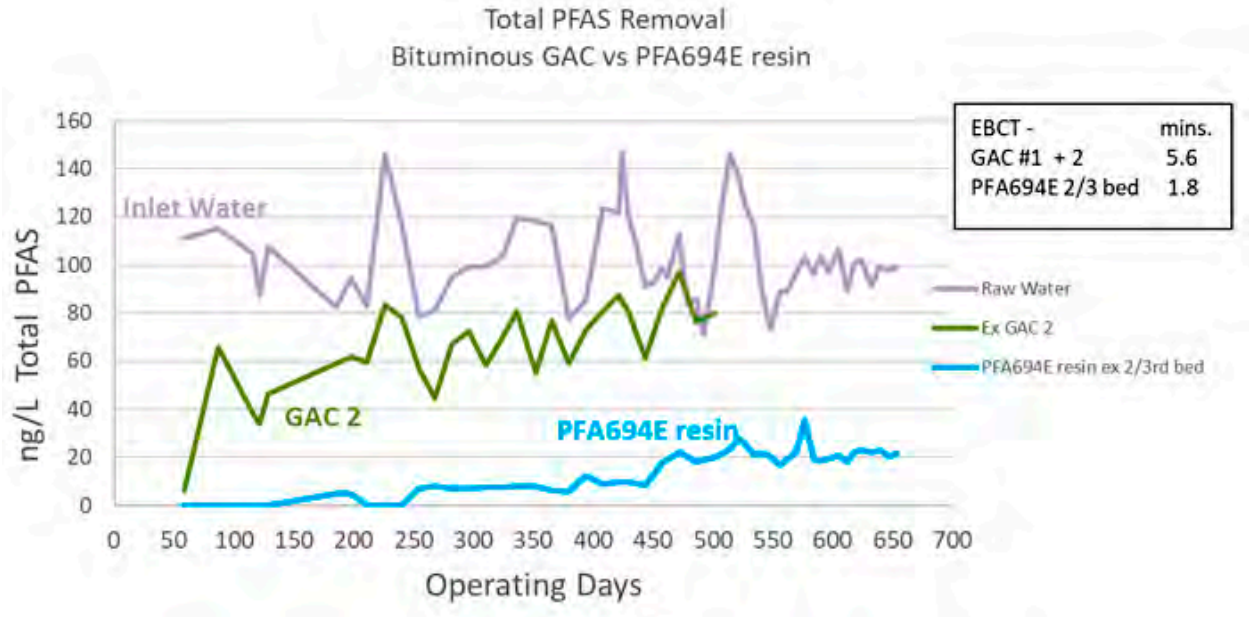


Figure 15-10. Combined breakthrough of total PFAS.

Source: F. Boodoo, Purolite Corporation. Used with permission.

Costs

The proposed permanent full-scale system is designed for a peak flow rate of 100 gpm with a pair of lead-lag vessels for the media. Design for ion exchange will include one 20-micron cartridge filter followed by two 4-ft diameter vessels with resin bed depth of 36 inches and EBCT of 2.8 minutes. Design for GAC will be one 20-micron cartridge filter followed by two 6-ft diameter vessels with GAC bed depth of 60 inches and EBCT of 10.6 minutes.

Annual operating cost, including replacement media, labor, trucking, spent media profiling, and incineration, is estimated at approximately $8,000 and $15,000, respectively, for ion exchange and GAC. These estimates are based on a very conservative operating capacity estimate of 350,000 BVs for a lead-lag pair of resin vessels; a generous capacity of 34,000 BVs is assumed for the GAC system. Operating costs are estimated at $0.16 and $0.29 per 1,000 gallons of water treated by the resin and GAC systems, respectively. Larger vessels needed for the GAC system will further add to the cost of using GAC versus the PFAS-selective resin.

15.2.2.2 Regenerable IX (2020)

Case Study: Regenerable Ion Exchange Resin Pilot Test and Full-Scale Application (Contributed by Steve Woodard, ECT2, and Nathan Hagelin, Wood Group, used with permission)

Background

The Air Force Civil Engineering Center (AFCEC) is conducting ongoing response activities to remove and remediate groundwater impacted by poly- and perfluoroalkyl substances (PFAS) at the former air force base in New Hampshire. The two primary PFAS found at the site are perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS), at combined concentrations (PFOA+PFOS) above the 2016 USEPA lifetime health advisory (LHA) of 0.07 micrograms per liter (µg/l). In 2015, the USEPA issued an administrative order to establish maximum hydraulic containment of PFAS compounds to reduce source zone mass and mitigate migration of PFAS compounds to off-site receptors.

AFCEC responded by contracting with Wood Group, PLC, to conduct a side-by-side pilot test in 2016, comparing the performance of Emerging Compound Treatment Technologies' (ECT2) regenerable ion exchange (IX) resin and bituminous GAC. The resin outperformed GAC and was selected for full-scale implementation, mainly on its life cycle cost advantages, as determined by the results of the pilot study.

To evaluate the resin's ability to be regenerated, regeneration trials were conducted throughout the pilot test using a proprietary regeneration procedure with a solution of organic solvent and brine. Overall, PFAS removal results for the regenerated resin were consistent with new resin, as shown in **Figure 15-11**. Extended follow-on pilot testing utilized multicycling to confirm the effectiveness of the regeneration procedure to restore the resin's

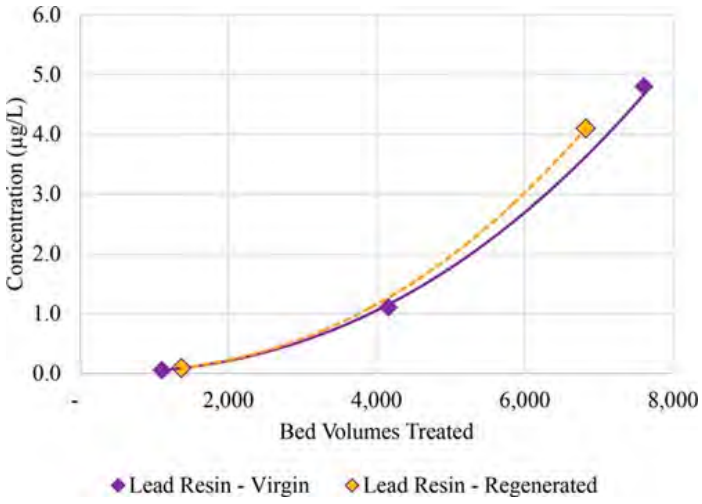


Figure 15-1. Postregeneration breakthrough curve (total PFAS).

Source: Steve Woodard, ECT2, and Nathan Hagelin, Wood Group, PLC. Used with permission.

PFAS removal capacity. The regenerable resin system was selected for full-scale application, based on system performance and a favorable life cycle cost comparison.

Influent Water Characteristics

Table 15-4 provides a summary of influent PFAS concentrations observed throughout the pilot test. Total PFAS concentrations ranged from 65 to 112 µg/l, with an average of 94 µg/l. Average influent concentrations for PFOS and PFOA were 26 and 12 µg/l, respectively. Influent general chemistry parameters included pH of 6.8, alkalinity of 115 milligrams per liter (mg/l), TDS of 230 mg/l, total suspended solids of less than 2 to 5.6 mg/l, sulfate of 17 mg/l, TOC of 4.5 mg/l, and chloride ranging from 30 to 250 mg/l.

Table 15-4. Influent PFAS Concentrations.

		Influent Concentration Observed During Pilot Test (µg/L)		
Analyte	**Analyte Acronym**	**Low**	**High**	**Average**
6:2 Fluorotelemer sulfonate	6:2 FTS	15	22	18
8:2 Fluorotelemer sulfonate	8:2 FTS	0.055	0.3	0.23
Perfluorobutane sulfonate	PFBS	0.81	1.3	1.1
Perfluorobutanoic acid	PFBA	0.89	2.1	1.3
Perfluoroheptane sulfonate	PFHpS	0.85	1.4	1.1
Perfluoroheptanoic acid	PFHpA	1.6	2.2	1.9
Perfluorohexane sulfonate	PFHxS	18	25	22
Perfluorohexanoic acid	PFHxA	5.9	8.9	7.7
Perfluorooctanoic acid	PFOA	9.1	13	12
Perfluorononanoic acid	PFNA	0.046	0.082	0.054
Perfluorooctane sulfonate	PFOS	4.2	32	26
Perfluoropentanoic acid	PFPeA	3.1	5.1	4.2
Sum of PFAS	-	65	112	94

Treatment Technology Design Details for Full-Scale System

The permanent full-scale resin system was designed for a maximum flow rate of 200 gpm (0.76 m^3/min), with influent total PFAS concentrations of approximately 90 µg/l. The primary project objective was to consistently produce treated water with combined PFOS plus PFOA concentrations below the 2016 USEPA lifetime health advisory (LHA) of 0.07 micrograms per liter (µg/l). The full-scale IX resin system was installed between fall 2017 and spring 2018, and the system officially commenced operation in April 2018.

Figure 15-12 shows a process flow diagram of the treatment system. The pretreatment portion includes bag filters to remove suspended solids and 6000-lb backwashable liquid GAC pretreatment filter to remove iron. The PFAS removal system consists of two parallel trains of lead-lag regenerable IX resin vessels, each 86" tall x 36" diameter, packed with 49 cubic feet of ECT's SORBIX A3F regenerable resin. These vessels are designed to operate up-flow during normal operation, and down-flow during regeneration. Two parallel, 86" tall x 36" diameter polish vessels are filled with IX resin for PFAS polishing, including short chains. The polish vessels operate in the down-flow mode and contain a blend of IX resins tailored to the general water chemistry and PFAS species and their relative concentrations.

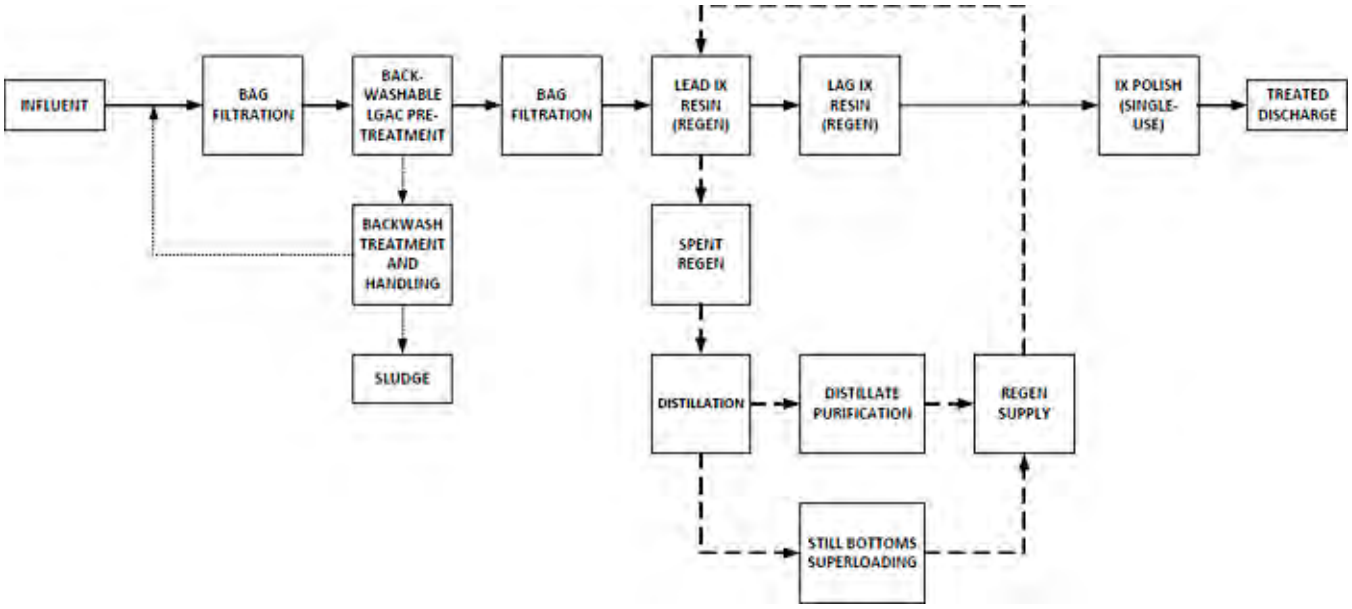


Figure 15-12. Block flow diagram of full-scale treatment system.

Source: Steve Woodard, ECT2, and Nathan Hagelin, Wood Group, PLC. Used with permission.

The in-vessel regeneration system (Figures **15-13** and **15-14**) consists of a regenerant solution holding tank and pump skid. The regenerant solution is a mixture of organic solvent and brine, which effectively strips PFAS from the IX resin and then flows into a spent regenerant holding tank. The spent regenerant is recycled for reuse in the next regeneration cycle by using a distillation and super-loading process. First, the spent regenerant is transferred to a solvent recovery unit. Solvent makes up the majority of the regenerant solution and is recovered through distillation, given its low boiling point relative to water, and transferred to the regenerant supply tank for reuse in the next regeneration cycle. The remaining distillate residue, known as the "still bottoms," is a low-volume, high PFAS concentration brine solution. The still bottoms are pumped through super-loader vessels that contain a proprietary resin blend, transferring the PFAS mass onto the super-loaded media. Super-loading is the process by which a relatively small volume of highly concentrated PFAS solution is passed very slowly through a small volume of media. The long EBCT approaches equilibrium (isotherm) conditions, thereby maximizing PFAS mass transfer onto the media and minimizing the amount of solid waste requiring disposal or incineration.



Figure 15-2. Regenerable and polish IX resin vessel skids.

Source: Steve Woodard, ECT2, and Nathan Hagelin, Wood Group, PLC. Used with permission.



Figure 15-14. Resin regeneration system.

Source: Steve Woodard, ECT2, and Nathan Hagelin, Wood Group, PLC. Used with permission.

System Performance

The PFAS remediation system has been successfully treating the groundwater since system start-up in April (**Figure 15-15**). Through December 2018, the effluent water quality from the IX resin system has been consistently nondetect for the monitored PFAS compounds, including the short-chain species, readily achieving compliance with the treatment objective of 0.70 µg/l LHA target for PFOS and PFOA. Although 6:2 FTS has not been detected in samples collected from the IX vessel effluent, it has been detected in the system effluent and is believed to be the result of transformation processes that are not yet understood.

The system has been operated in the 35- to 70-gpm range since start-up, somewhat less than the design flow rate. This has been done to accommodate higher than anticipated influent iron concentrations that have resulted in the requirement for frequent bag filter change-outs. The resulting extended EBCTs in both the backwashable GAC pretreatment vessel and the IX resin vessels have resulted in better than projected PFAS removals. Also, the resin regeneration schedule has been modified to accommodate the lower flow rate by removing one of the two parallel trains from service. This has allowed the resin vessels to be loaded closer to design values. Four resin regenerations have been performed successfully through December 2018; however, the IX media regenerated through December 2018 was not loaded to the full design capacity due to the reduced flow during early operation. Operational modifications have been made to address and correct minor challenges with the distillation system, and regenerant recovery and

super-loading processes have proven successful. The original super-loading media is still operational, having removed and concentrated greater than 99.99% of the recovered PFAS mass; therefore, no PFAS waste has needed to be hauled off site to date.

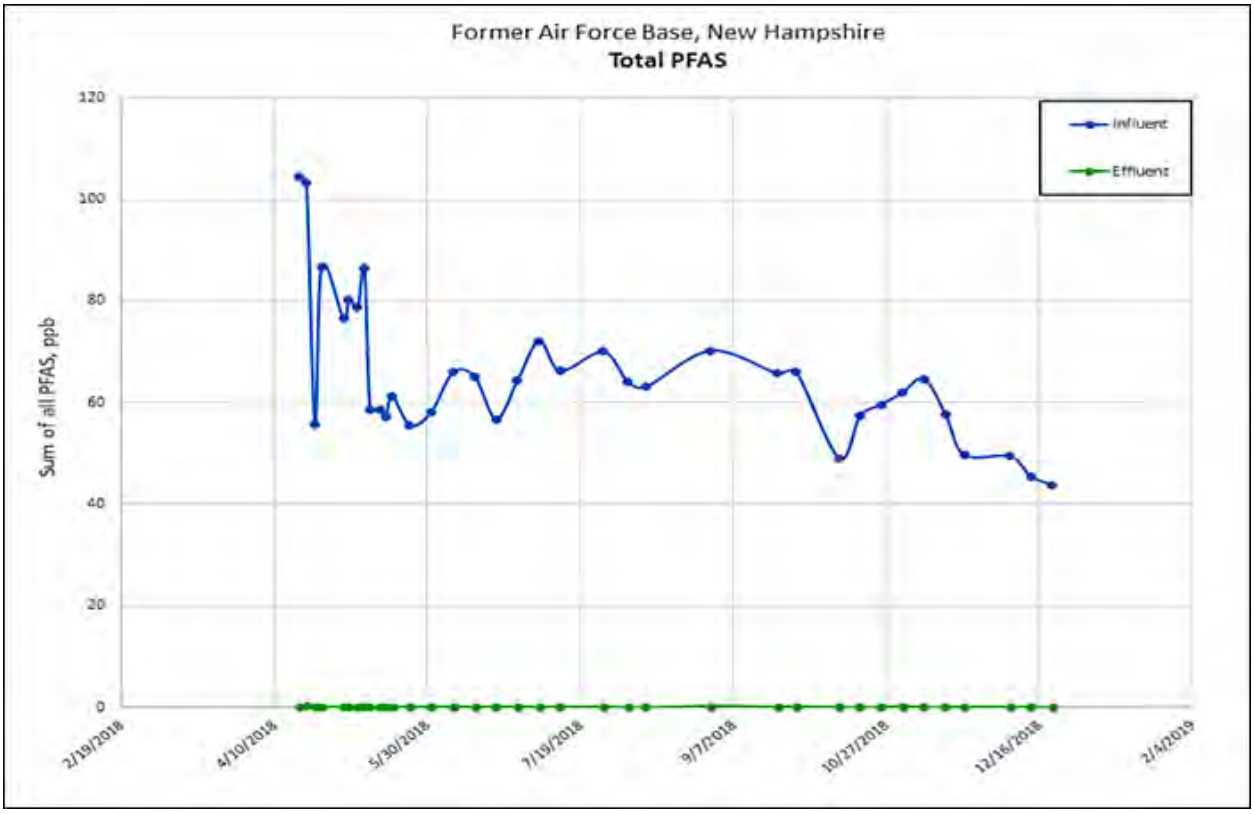


Figure 15-15. Influent and treated effluent total PFAS concentrations.

Source: Steve Woodard, ECT2, and Nathan Hagelin, Wood Group, used with permission

Costs

The capital cost for the regenerable IX was $2.9M for *all* treatment equipment, process piping, pumps, instrumentation, and system electrical. It does not include project management, construction management, the extraction network and field piping, or the building and building mechanical or electrical systems.

15.2.3 Colloidal Activated Carbon (2023)

Case Study: In Situ Colloidal Activated Carbon—PFAS in Groundwater in Crawford County, Michigan (Contributed by Scott Wilson, Regenesis, used with permission)

Background

Since the late 1980s, the Michigan Department of Military and Veterans Affairs (DMVA) has been implementing a range of technologies to remediate groundwater impacted by chlorinated solvents at Camp Grayling in Crawford County, Michigan, a year-round training center for the Michigan Army National Guard (MIARNG). In 2016, the DMVA became aware of the potential contamination of PFAS from past operations such as on-site firefighting training at Grayling Army Airfield (GAAF). Groundwater testing

revealed PFAS commingled with chlorinated solvents migrating toward the property boundary. The impacted groundwater was shallow at 15 feet below ground surface (bgs) and was shown to be moving at a velocity of about 250 ft/yr through a sandy gravel aquifer. Sensitive downgradient receptors included numerous residences and surface water bodies. See also Regenesis (**2020**) for more information.

Contaminant Characteristics

Target groundwater contaminants at the GAAF site included PFAS (PFOS and PFHxS) at a combined concentration of about 130 ng/L commingled with perchloroethylene (PCE), which was present at a concentration of about 10 ug/L. Data from dedicated passive flux samplers deployed at the project site indicated that groundwater contamination was primarily existing in a sandy contaminant flux zone located between 15 and 27 feet bgs.

Regulatory Involvement

The DMVA decided to perform a demonstration of in situ colloidal activated carbon (CAC) technology to treat the PFAS and PCE contamination at the GAAF site. This demonstration consisted of injecting CAC into a zone of the contaminated aquifer and actively monitoring groundwater moving through the treatment area. The primary reason DMVA chose this approach was its proven performance on other project sites where it rapidly removed PFAS from the dissolved phase and was expected to perform for decades with a single application. “Additionally, the project life-cycle cost was a consideration for the DMVA in their selection. The projected cost for installing” an in situ CAC treatment zone in the subsurface was significantly lower than installing and “operating a mechanical system over a similar timeframe” (**Regenesis 2020**).

Treatment Technology

CAC is composed of very fine particles of activated carbon (1–2 µm) suspended in water using organic polymer dispersion chemistry. When the CAC material is injected into the subsurface, the carbon particles bind to the aquifer matrix but do not obstruct pore throats. Groundwater flows through the treatment zone. Organic compounds such as PFAS sorb on to the carbon particles, removing them from groundwater.

To determine the amount of CAC required for the demonstration, a proprietary finite-difference model was used to determine dosing of carbon, expected contaminant retardation/competitive sorption, and expected performance longevity. The model accounts for site-specific factors such as hydrogeology and contaminant flux while considering competitive sorption and biodegradation (in the case of PCE) to determine the quantity of CAC required.

Ultimately “the application design consisted of a single row of nine direct push injection points positioned upgradient of a previously installed monitoring well, MW-29” (**Regenesis 2020**). The total amount of CAC injected was 2,400 lbs of a 4% (w/w) suspension and 2,400 lbs of a 20% (w/w) suspension. “The injection line was configured as an arc to account for temporal and spatial variability in the groundwater flow direction. Initially two downgradient well pairs (MW-29/29C and MW-29D/29E) were placed 6 feet and 16 feet downgradient of the barrier, respectively, to monitor the pilot test performance. Each well of a well pair was installed with a 5-feet screened section to monitor the upper and lower treatment interval sections” (**Regenesis 2020**). **Figure 15-16** shows the monitoring well layout.

“The vertical injection interval was specified from 15 to 27 feet below the ground surface (bgs) to match the PFAS flux zone and accommodate seasonal water table fluctuations. In the pilot test area, this PFAS flux zone predominantly comprised of sand and gravel overlying a clay layer” (**Regenesis 2020**).

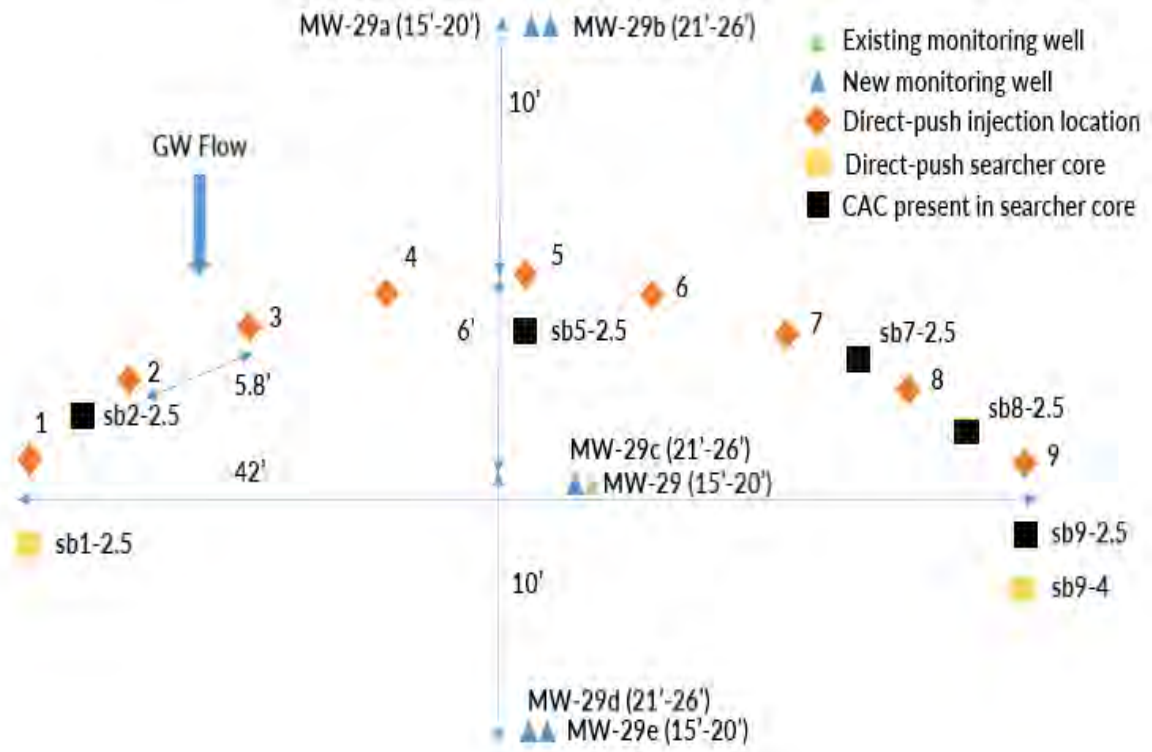


Figure 15-16. Wells used for the CAC demonstration project. Note that the values after the dash in the "sb" points are the distance from the injection point.

Source: Scott Wilson, Regenesis, used with permission.

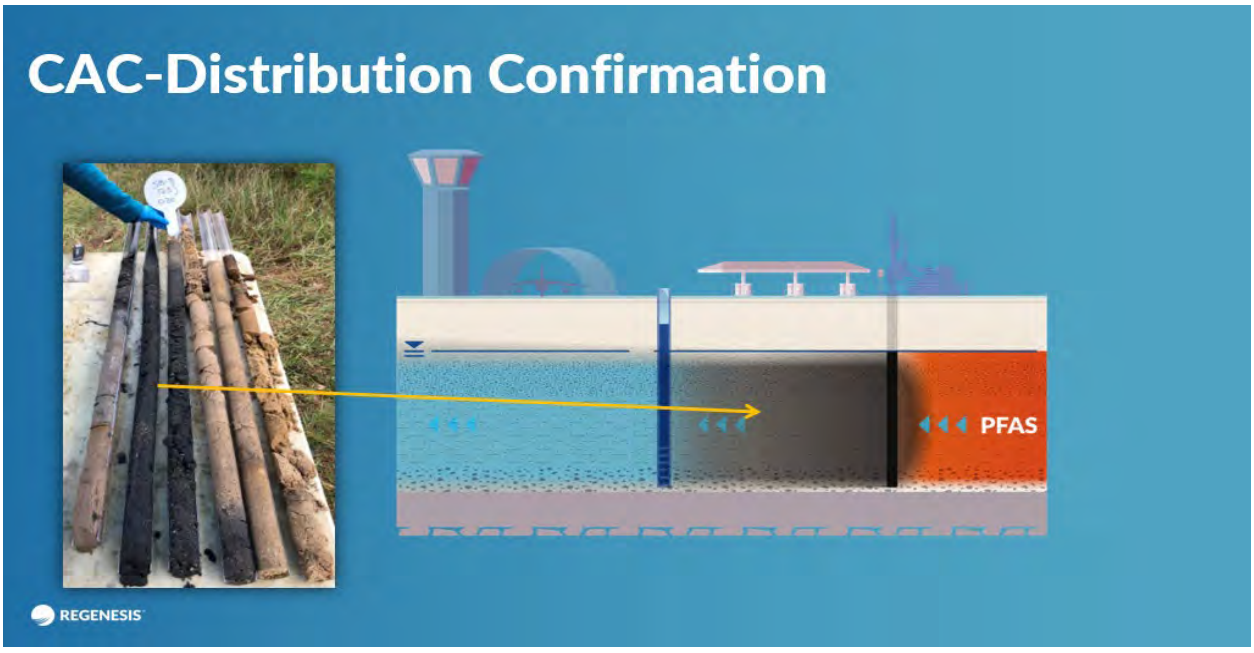


Figure 15-17. Vertical sections of a "searcher core" verifying the presence of CAC at the interval between 15 and 28 feet bgs.

Source: Scott Wilson, Regenesis, used with permission.

Injection of the CAC zone commenced in October 2018. Subsurface CAC distribution was optimized during injection by "adjusting injection variables including flow rate, screen size, injection volume, and injection point positioning" (**Regenesis 2020**). Verification of required CAC distribution was achieved "by collecting soil cores and groundwater samples from temporary piezometers placed between injection points. The soil cores revealed consistent CAC distribution over the target interval, while the groundwater samples collected from the piezometers indicated" (**Regenesis 2020**) required CAC presence in groundwater (**Figure 15-17**).

System Performance

By the first sampling event, approximately one month after injection, the CAC zone treatment had reduced PFAS "to concentrations below the standard method detection limit of 10 nanograms per liter (ng/L) in downgradient wells. Initial reductions were also observed in upgradient well-pair (MW-29A/B), indicating potential injection influence. However, by the second event, approximately two months after injection, concentrations in these upgradient wells had begun to rebound while the downgradient wells remained at non-detect" (**Regenesis 2020**). Since then, the CAC treatment has maintained PFAS concentrations below 10 ng/L in the downgradient wells for 3.5 years. **Figure 15-18** includes PFAS concentration data for upgradient and downgradient well pairs.

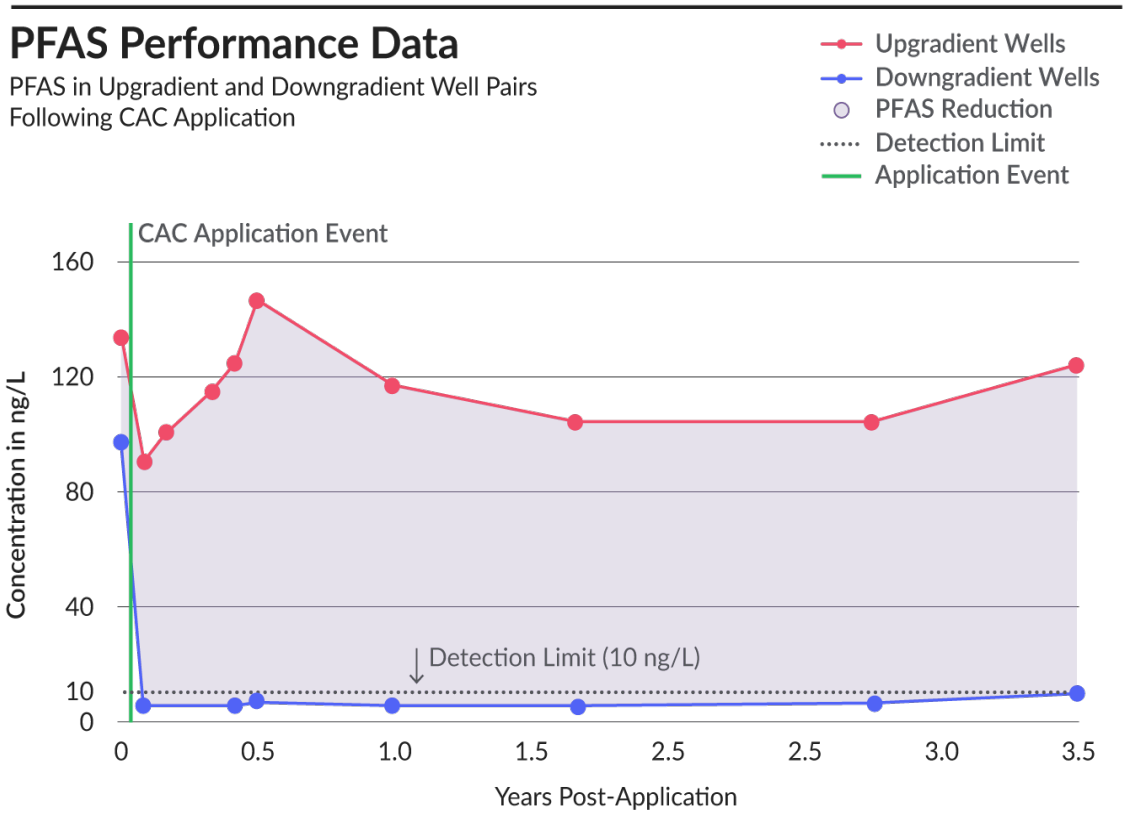


Figure 15-18. PFAS reductions as an average of monitoring well concentrations downgradient of CAC-treated zone.

Source: Scott Wilson, Regenesis, used with permission.

PCE concentrations followed a similar pattern as PFAS: reduction to nondetect (1 microgram per liter) by the first month, followed by sustained nondetect levels. **Figure 15-19** includes PCE concentration data for upgradient and downgradient well pairs.

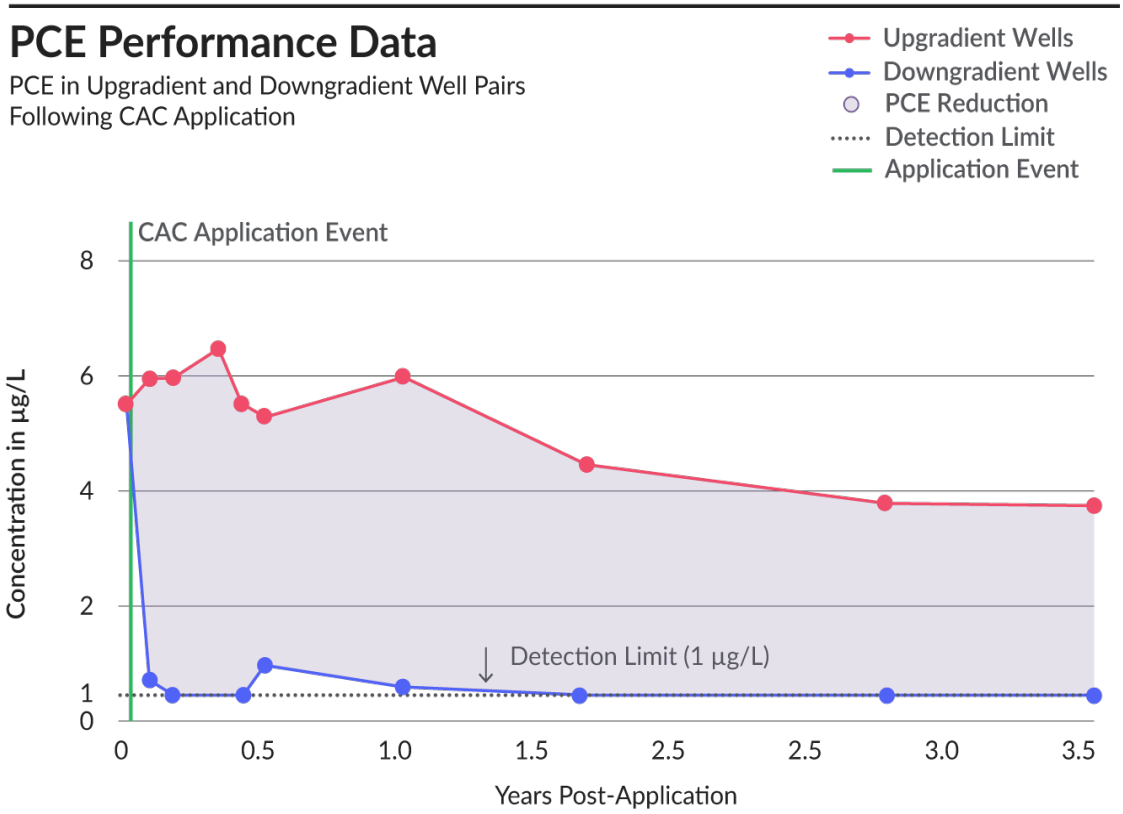


Figure 15-19. PCE reductions as an average of monitoring well concentrations downgradient of CAC-treated zone.

Source: Scott Wilson, Regenesis, used with permission.

The CAC demonstration has achieved all the remedial objectives to date (3.5 years) while modeling predictions suggest that the CAC installed will continue to remove PFAS and PCE for decades. Based on this demonstration project, the Michigan DMVA is considering expanded use of in situ CAC technology at other sites.

Cost

The total installation cost of the demonstration project was about $55,000, including the CAC material cost of $28,000 and field labor/subcontracting cost of about $27,000. There is no operation or maintenance cost. Sampling and analysis totals about $6,200 per year.

15.2.4 Foam Fractionation

15.2.4.1 Ex situ Groundwater Treatment (2023)

Case Study: Field Trial Conducted for the Australian Department of Defence (2019-2021) in Queensland, Australia (Contributed by David Burns, EPOC Systems)

EPOC Enviro LLC (USA), a subsidiary of OPEC Systems (Australia), was contracted by the Australian Department of Defence to provide a groundwater treatment field trial plant at the Army Aviation Centre

Oakey in Queensland, Australia. The field trial project was managed by WSP with project management and contract administration provided by GHD. The field trial plant required a design capacity to treat 250 m3/day (2.9l/sec or 46 gpm) to remove PFAS from groundwater, which included the primary treatment technology known as Surface-Active Foam Fractionation (SAFF®) and paired with an anion exchange (AIX) resin polishing treatment to ensure compliance with Australian and New Zealand Heads of EPAs (HEPA) drinking water guideline criteria prescribed by the PFAS National Environmental Management Plan (**NEMP, V2, Jan. 2020**). Groundwater had historically been contaminated by AFFF discharges from 1977 to 2005. Following the 3-year field trial, the Australian Department of Defence subsequently awarded a continuation of the groundwater treatment plant contract with increased treatment capacity of 345 m3/day (4.0l/sec or 63 gpm) and an expanded irrigation network.
A full case study is provided in the **Burns et al. (2021)** article, "PFAS Removal from Groundwaters using Surface-Active Foam Fractionation." https://onlinelibrary.wiley.com/doi/10.1002/rem.21694.

15.2.4.2 Ex situ Landfill Leachate Treatment (2023)

Case Study: Field Trial Conducted for Telge Återvinning AB, Sweden (2021–2022) (Contributed by David Burns, EPOC Systems)

EPOC Enviro LLC (USA), a subsidiary of OPEC Systems (Australia), was contracted by Telge Återvinning AB to provide a containerized treatment plant to treat leachate at the Telge Recycling Plant in Sweden. The initial field trial and project management were provided by EnvyTech Solutions AB. The treatment plant required a design capacity to treat 500 m3/day (5.8l/sec or 92gpm) to remove PFOS from landfill leachate water using Surface-Active Foam Fractionation (SAFF®) without any pretreatment or polishing treatments. The leachate, which exhibited a complex background chemistry including algal/zooplankton content, suspended solids, total organic carbon, and other organic and inorganic contaminants, was contained in a catchment pond with a volume of approximately 15,000 m3. A direct feed line drew water from the leachate pond to the SAFF® treatment plant using a submerged pump located approximately 1.5 m below the surface. The system achieved average treatment results for PFOS ≤2.34 ng/L, PFHxS ≤1.00 ng/L, and PFOA ≤1.28 ng/L, corresponding to removal percentages of ≥98.7%, ≥98.8%, & ≥99.7%, respectively. The mean concentration of PFOS was below 50 ng/L, which is defined by the voluntary Scandinavian REVAQ guideline.

A full case study is provided in the **Burns et al. (2022)** article, "Commercial-scale remediation of per- and polyfluoroalkyl substances from a landfill leachate catchment using Surface-Active Foam Fractionation (SAFF®): https://doi.org/10.1002/rem.21720.

15.2.4.3 PFAS Treatment Train Processing Using Surface-Active Foam Fractionation (SAFF®) and Eight Different PFAS Destruction Technologies—Lake Elmo, Minnesota (2025)

Contributed by Rebecca Higgins, AECOM, and Andri Dahlmeier, MPCA, used with permission.

The purpose of this case study is to present an example of a PFAS treatment train. While conditions at other locations will vary from the case study here, the results below are encouraging for application at other remediation sites. The full details of these results can be found in the final Project 1007 Feasibility Study report upon completion (**MPCA 2023**). Additional information about foam fractionation is included in **Section 12.2.3** of the Guidance Document. A surface water quality case study that describes PFAS-containing foam for Project 1007 is included in **Section 15.5.1**.

Background

The Project 1007 Corridor is in the Twin Cities East Metro Area of St. Paul, Minnesota, and is a large flood control project constructed by the Valley Branch Watershed District to mitigate flooding in the landlocked

subwatershed of the Tri-Lakes area. The conveyance system, consisting of open channels, pipes, dams, storm sewers, and existing surface water bodies, directs water from the Tri-Lakes area in Washington County to the St. Croix River. Within the drainage area of Project 1007, two PFAS source areas were identified as the former Oakdale Disposal Site and the closed Washington County Landfill. In addition to groundwater impacts resulting from two disposal areas, Project 1007 also facilitated a direct surface water to groundwater pathway along the corridor. This has resulted in widespread impacts extending approximately 120 square miles within six groundwater aquifers, including those used for drinking water in the Twin Cities East Metro. Impacts span multiple watersheds, groundwater divides, and drinking water supply aquifers. To read the full extent of investigation, including characterization and initial findings, please refer to the Source Assessment Progress Reports located on the Project 1007 website (**MPCA 2023**).

While the extent of the problem is still being defined, potential remedial options have been defined. Initial concepts of a remedial treatment train involved several steps. First, a concentration/separation step (for example, foam fractionation, reverse osmosis, filtration via granular activated carbon (GAC) or ion exchange resin (IX) for bulk PFAS removal from the source water. While these methods are typically effective at achieving applicable standards, it may be advantageous for the PFAS to be concentrated in an aqueous form. This may reduce operation and maintenance costs by reducing or eliminating the need for filtration media. This also allows for more options to destroy the PFAS removed from the bulk liquid.

This case study evaluated the treatment train of using foam fractionate to separate and concentrate PFAS prior to the testing of multiple PFAS destruction vendors.

SAFF® Process

SAFF® is a proprietary foam fractionation process that uses the foaming properties of PFAS to capture and concentrate PFAS in water. This technology takes advantage of the fact that PFAS are generally both hydrophobic and hydrophilic. The process effectively concentrates PFAS in foam at the water surface, which can be skimmed or vacuumed off the top. The SAFF® specifically uses a two-step process to remove and then concentrate the PFAS into a smaller volume for further processing or disposal. A third concentration step can also be used to additionally concentrate the PFAS to reduce costs associated with destruction. This was manually attempted as part of this pilot study. Additional information about foam fractionation can be found in **Section 12.2.3** and **Section 18.4**. More information about this pilot study can be found in the Project 1007 Feasibility Study (**MPCA 2023**).

Environmental Site Description and Results

The foam fractionation system was located in Tablyn Park (City of Lake Elmo) because of the ease of access to - impacted surface water (Raleigh Creek) and the two impacted aquifers (Shakopee and Jordan). These three water sources were treated separately by the foam fractionation system to better evaluate the treatment efficiency with different PFAS concentrations and water chemistries. A SAFF20 was deployed, which contains two primary fractionation vessels that remove PFAS from the bulk water, and a single secondary fractionation vessel which further concentrates the PFAS.

Treatment of water from Raleigh Creek showed a typical response in that foam readily formed during aeration, allowing PFAS to be removed from surface water. This foaming was a result of both PFAS and naturally occurring organic matter. With foam formation, PFOS and PFOA were readily removed from the bulk water treated at a treatment capacity of approximately 25,000–30,000 gallons per day (gpd) for the lowest effluent concentrations as shown in **Table 15-2-5**. Higher treatment capacities of up to 45,000 gpd could be achieved with PFOS and PFOA removal still above 95%. Other PFAS were also monitored. Longer chain PFAS, including perfluorohexanoic acid (PFHxS), were also removed; however, short-chain PFAS such as perfluorobutanoic acid (PFBA) had significantly limited removal efficiencies (less than 50%). Secondary fractionation treatment was tuned to limit the volume of water removed with the foam

to reduce the PFAS concentrate to a volume of less than 0.5 gpd with attempts to meter the concentrate at small volumes back into the secondary fractionation step. This mimics tertiary fractionation.

Table 15-2-5. Removal efficiencies for PFOS and PFOA in the Tablyn Park study.

	PFOS (ng/L)			PFOA (ng/L)		
Water Source	**Influent**	**Effluent**	**Concentrate^**	**Influent**	**Effluent**	**Concentrate^**
Raleigh Creek	2,940	2.9 (99.9)*	4,530,000	903	0.836 (99.9)*	1,780,000
Shakopee Aquifer	1,340	1.42 (99.9)*	19,100,000	392	3.57 (99.1)*	6,360,000
Jordan Aquifer	0.92	Below Detection	Not Available^	26.5	4.95 (81.3)*	Not Available^

Notes: All analytical results were completed by USEPA Method 1633.
^Concentrate was mixed with concentrate from other water samples in system holding tank.
*Percent removal

The system responded differently during the groundwater treatment from both aquifers due to a lack of organic matter which limited the foam formation. . To achieve higher removal efficiencies without the addition of a surfactant, the aeration amount was oscillated between high and low air injection to promote removal. These results indicate high PFOS and PFOA removal regardless of the surface water chemistry and PFAS concentrations of the influent water. The effluent was discharged under Minnesota Pollution Control Agency (MPCA)–approved discharge to nearby Raleigh Creek.

Higher concentrations were achieved in the concentrate from the Shakopee Aquifer because of recirculation of the collected concentrate back into secondary fractionation by manually metering in the concentrate. This is similar to what is done during tertiary fractionation. This was not achieved with concentrate formed during Raleigh Creek treatment because the higher organic matter resulted in too much foaming during manual metering. The resultant concentrate from the treatment of Raleigh Creek and the Shakopee Aquifer was used for the PFAS destruction testing.

Destruction Technologies Descriptions

The next phase of the treatment train was to evaluate currently identified destruction technologies for further PFAS treatment. For the purposes of this case study, destruction is defined as the process of transformation and reduction of targeted PFAS, focused on PFOA and PFOS. Total organofluorine, often measured as adsorbable organofluorine, was also used to measure reductions in total PFAS. The definition of destruction may differ among various technology vendors, and the reader is encouraged to specifically define destruction within pilot studies to establish a common reference and goal for varied technologies.

The MPCA posted a request for proposals for bench-scale testing of destruction technologies with the surface water foam fractionation concentrate. Responses were received for four categories of destructive technologies, some with multiple vendors that were considered for further testing. These included plasma, (1 vendor), UV-activated photoreduction (2 vendors), supercritical water oxidation (3 vendors), and electrochemical oxidation (1 vendor) (**Table 15-2-6**). See **Section 12.2** and **Section 12.6** for more information about water treatment technologies. A second electrochemical oxidation vendor was also tested in a pilot-scale demonstration with the concentrate from treatment of the Shakopee Aquifer. As bench-scale and pilot-scale results are difficult to compare, the pilot-scale results are not presented in this case study. A recent peer-reviewed publication includes detailed explanations of these processes (**Meegoda et al. 2022**).

The destruction technology evaluation project was large, and considered many variables, including PFAS using multiple analytical methods. For brevity, here we present abbreviated results for two of the most studied PFAS, PFOA and PFOS.

Destruction Testing Results

The PFAS concentrate from the foam fractionation system in Tablyn Park was sent to the vendors for processing through their PFAS destruction systems. Note that the initial PFAS values in **Table 15-2-6** and **Table 15-2-7** do not match those seen in **Table 15-2-5**, as some vendors performed dilutions to either increase the volume of waste for processing to accommodate the treatment capacity of their pilot unit (Vendor E) or to increase the transmittance (decrease natural organic matter concentration) of a sample (Vendor B). These variations in influent concentrations for Vendors B and E and the resulting final concentrations are shown in the tables below. While dilutions would not be required in the first instance in a field application, they would likely still be required in the second instance.

For the bench-scale results, the vendors targeted high destruction efficiencies. Multiple vendors noted that energy efficiencies may be achieved through reconcentration of the effluent from their systems. Instead of treating the concentrate to reach a discharge criteria, energy savings can be achieved by only treating waste with high PFAS concentrations. This may also reduce the number of systems required to treat the concentrate volume produced in a full-scale system.

Table 15-2-6. PFAS destruction technology results for Tablyn Park foam fractionation concentrate, PFOA*.

Technology	Vendor	Initial	Final
Plasma	Vendor A	1,700,000	290
Photochemical	Vendor B	338,100	20
	Vendor B	314,600	70
	Vendor C	1,500,000	86
Supercritical Water Oxidation	Vendor D	971,000	Not reported
	Vendor E	33,000	29
	Vendor E	34,000	12
	Vendor E	36,000	7.2
	Vendor E	132,146	7.3
	Vendor F	1,670,000	Not reported
Electrochemical Oxidation**	Vendor G	11,380,000	3.8

Notes: *Values in ng/L
**Pilot testing was also performed using another electrochemical oxidation method. These tests were performed using equipment in the field, and preliminary results have shown promise in significant PFOS and PFOA destruction. Additional studies are in progress.

Some vendors included other evidence of destruction. This is recommended in PFAS destruction testing. This included analysis of shorter chain PFAS, which results from sequential defluorination as is observed with photochemical reduction, electrochemical oxidation, and plasma. Increases in fluoride concentrations were also observed, but mass balances were not achieved. Some of the vendors also performed adsorbable organofluorine (AOF) and total oxidizable precursor (TOP) assay analysis, and this is recommended in the evaluation of destruction technologies. At this site, precursors are not found at high concentrations in the surface water and groundwater, so this was not of particular concern in the evaluation; however, elsewhere precursor analysis is important in understanding the destruction of all PFAS present. Additionally, AOF can provide insight into total PFAS destruction, including those compounds that are not included in USEPA Method 1633A. It should be noted that AOF does not capture ultra-short-chain PFAS (ultrashort PFAS). **See Section 11.2**, **Section 1.5.3**, and **Section 1.5.4** for more information about PFAS analysis.

Table 15-2-7. PFAS destruction technology results for Tablyn Park foam fractionation concentrate, PFOS*.

Technology	Vendor	Initial	Final
Plasma	Vendor A	3,200,000	2,100
Photochemical	Vendor B	930,700	230
	Vendor B	1,072,900	2,400
	Vendor C	2,400,000	220
Supercritical Water Oxidation	Vendor D	3,660,000	Not reported
	Vendor E	120,000	44
	Vendor E	130,000	7.4
	Vendor E	150,000	7.6
	Vendor E	341,070	4.9
	Vendor F	3,510,000	Not reported
Electrochemical Oxidation**	Vendor G	4,160,000	3.8

Notes: *Values in ng/L
**Pilot testing was also performed using another electrochemical oxidation method. These tests were performed using equipment in the field, and preliminary results have shown promise in significant PFOS and PFOA destruction. Additional studies are in progress.

In addition to the destruction capabilities, other factors should be considered when evaluating destruction technologies. These include potential byproducts, the destruction (or potential production) of short-chain and ultrashort PFAS, air emissions, energy consumption, operating conditions, and operation and maintenance needs. Electrochemical oxidation, photochemical reduction, and plasma are all known to sequentially defluorinate longer PFAS, resulting in increases in shorter chain PFAS. Issues with high detection limits in the starting concentrate limited the analysis of the production of these PFAS. These items were evaluated as part of the larger study but are not discussed here, because these items often require larger pilot studies to fully evaluate. Cost information was provided by some of the vendors, but those that included full-scale systems did caution that the costs were high-level estimates and that additional testing at the pilot scale would be required to better complete cost estimations. The treatment cost is also highly dependent on the treatment goals. Treatment for longer times or at higher energies can result in lower effluent concentrations, but this can also greatly increase energy demands and decrease treatment capacity, requiring larger systems to be installed.

Conclusions

Results suggest the four types of destruction technologies examined all provide a significant level of PFOA and PFOS reductions. Additionally, results indicate a treatment train approach using foam fractionation can be an effective method of decreasing the volume of PFAS-contaminated water that requires treatment, making PFAS destruction technologies more implementable and cost-effective. Many of the technologies also operate more efficiently at higher PFAS concentrations. Selection of a destructive technology depends on site-specific water chemistry, and multiple destruction technologies should be considered to evaluate potential interferences. For example, foam fractionation can concentrate natural organic matter, which decreases transmittance and decreases efficiency of one of the UV-activated photoreduction technologies. While some of the technologies had higher effluent concentrations, the effluent from destruction can be cycled back through the foam fractionation system to reconcentrate the remaining PFAS, further supporting a treatment train approach. Filtration with granular activated carbon or ion exchange could also be employed as a polishing step to further treat the effluent of the foam fractionation system if needed to meet the applicable regulatory criteria or site-specific goals.

For Project 1007, additional testing of the PFAS concentrate and subsequent destruction technologies may be conducted to determine the effectiveness with different PFAS mixtures and water chemistries. This will likely not occur until the location of the potential full-scale system is selected, as this may impact the PFAS mixture and concentration in the resulting PFAS concentrate treated by the destruction technologies. The results of this pilot study have been incorporated into a feasibility study to assess remedial options to reduce the migration of PFAS impacts within the East Metro.

15.2.5 Soil Washing

15.2.5.1 Full-scale Soil Washing of PFAS-contaminated Soil Stockpiles, Alaska (2025)

Case Study: Full-scale Soil Washing of PFAS-contaminated Soil Stockpiles, Alaska. Contributed by Toni Mehraban, Brice Engineering, LLC, Used with permission.

Background

During construction of new facilities and infrastructure at a military installation in Alaska, potentially PFAS-impacted soil was excavated during building foundations, site grading, and utility installation. To avoid construction delays, 145,793 cubic yards (cu yd) of soil was stockpiled on the installation. Through characterization in 2021, approximately 139,098 cu yds were determined to be impacted with PFAS and co-contaminants above Alaska Department of Environmental Conservation (AK DEC) cleanup levels (CULs). The installation disposed of 11,972 cu yds of PFAS-impacted soil off-site and in 2022 Brice Engineering, LLC (Brice) and their soil washing technology was selected to treat the remaining 127,126 cu yds in 42 stockpiles through a patented soil washing process with an objective to reduce levels below AK DEC CULs.

Treatment Technology Design

As described in **Section 12.3.3**, soil washing uses particle size separation of soil fractions through aggressive contact with wash water that encourages PFAS to desorb from the soil phase into the water phase where treatment is more readily available through a closed-loop water treatment system. Unlike many destructive soil treatment technologies that have high energy/electricity demands, soil washing is a very effective and efficient solution to bulk treatment, providing an opportunity for full-scale implementation at a high throughput to significantly reduce the volume requiring further treatment. Washed soils meeting the CULs can be beneficially reused on-site, while the reduced volume not meeting CULs after the first wash can be rewashed to meet CULs, disposed off-site, or treated through subsequent destructive treatment technologies. In the end, the vast reduction in PFAS-impacted soil quantities that remain after soil washing makes destructive soil treatment technologies that will eliminate off-site disposal more viable. For this case study, water from a nearby surface water body was used (with no amendments) as the wash fluid.

Soil Characteristics

In 2021, the stockpiled soils were characterized to determine in-place volume (bank cu yds), bulk density, gradation, total organic carbon (TOC), and bulk concentrations of PFAS and co-contaminants. The stockpiles processed via soil washing in 2023 and 2024 were labeled EIE365-1, EIE378-4, EIE405-1, EIE405-2, and EIE-405-3 and consisted primarily of silty sand with gravel or silty gravel with sand. Particle size distribution and TOC concentrations for the four stockpiles are presented in **Table 15-2-8** and initial bulk soil concentrations of PFAS and co-contaminants are presented in **Table 15-2-9** and **Table 15-2-10**, respectively (**USACE 2021**).

Table 15-2-8. Geotechnical and TOC characteristics[1].

Stockpile	% Gravel		% Sands			% Fines	Density (ton/cu yd)	TOC (mg/kg)
	Coarse	Fine	Coarse	Medium	Fine	Silt		
EIE365-1	17	31	7	7	26	12	-	9,950
EIE378-4	9	31	7	7	31	15	1.26	3,200
EIE405-1	11	29	15	15	20	10	1.28	6,400
EIE405-2	20	30	6	5	19	16	1.65	6,600
EIE405-3	27	28	6	5	18	16	1.79	2,600

Notes: [1]As reported in the Stockpile Characterization Report (**USACE 2021**)
"-"—not analyzed cu yd—cubic yard mg/kg—milligrams per kilogram TOC—total organic carbon

Table 15-2-9. Concentration of PFAS in preprocessed bulk soils[1].

Stockpile	PFOA (µg/kg)	PFOS (µg/kg)
AK DEC CUL[2]	1.7	3
EIE365-1	0.915	**7.88**
EIE378-4	0.71	**19.04**
EIE405-1	0.66	**29.26**
EIE405-2	**3.5**	**7.5**
EIE405-3	0.93	**31.50**

Notes: **RED**—concentration exceeds the AK DEC CUL
[1]The pretreatment bulk soil result is the highest 95% UCL among decision units (DUs) for each stockpile as reported in the Stockpile Characterization Report (**USACE 2021**)
[2]CULs are from 18 AAC 75.341, Table B1 Method Two—Soil Cleanup Levels (**AK DEC 2023**)
AK DEC—Alaska Department of Environmental Conservation CUL—cleanup level

Table 15-2-10. Concentration of co-contaminants in preprocessed bulk soils[1].

Stockpile Group	POL	Pesticides		PAHS		
	DRO	4,4'-DDD	beta-BHC	Naphthalene	Benzo(a)anthracene	Benzo(a)pyrene
AK DEC CUL[2]	250,000	98	10	38	700	1,500
EIE365-1	N/A	N/A	N/A	34.5	479.4	485.9
EIE378-4	N/A	N/A	N/A	**49.4**	**1,644**	**1,405**
EIE405-1	**45.92**	N/A	N/A	**140.5**	**2,057**	**1,614**
EIE405-2	**772,200**	29	N/A	31	306	290
EIE405-3	49.37	**180**	N/A	**40**	370	350

Notes: **RED**—concentration exceeds the AK DEC CUL
[1]The pretreatment bulk soil result is the highest 95% UCL among decision units (DUs) for each stockpile as reported in the Stockpile Characterization Report (**USACE 2021**)
[2]CULs are from 18 AAC 75.341, Table B1 Method Two—Soil Cleanup Levels (**AK DEC 2023**)
AK DEC—Alaska Department of Environmental Conservation BHC—hexachlorocyclohexane CUL—cleanup level
DRO—diesel range organics N/A—not applicable PAH—polycyclic aromatic hydrocarbon
POL—petroleum, oil, and lubricants

System Performance

During the 2023 and 2024 operational seasons (approximately 6 months of cumulative soil washing operations due to the winter conditions in Alaska) 32,431 loose cu yds of impacted soils (soils containing PFAS, diesel range organics ([DRO], polycyclic aromatic hydrocarbons [PAHs], and pesticides) were processed through the soil washing plant (**Table 15-2-11**). The effectiveness and quality of data for treatment were verified through 43 incremental sampling methodology soil samples (500 cu yd decision units [DUs], 30 soil increments per DU), 16 field triplicate incremental sampling methodology soil samples, 6 pretreatment discrete soil samples, 3 field duplicate pretreatment discrete soil samples, 71 field blank samples, 4 process water samples, and 1 processed water field duplicate sample. It should be noted that, based on contract payment schedule and equipment used, measurements of soil entering the soil washing plant were recorded in volume (loose cu yds via 2 cu yd industry standard excavator bucket loads) and measurements of processed soil exiting the soil washing plant were recorded in weight (tons via calibrated loader scale).

Table 15-2-11. Summary of preprocessed soil treated in 2023 and 2024.

TASK/F35 Project	EIE405			EIE365	EIE378
Associated Stockpile(s)	EIE405-3	EIE405-1	EIE405-2	EIE365-1	EIE378-4
Preprocessed Volumes (cu yd)	1,975	3,835	815	6,430	19,376
TOTAL PREPROCESSED VOLUME (cu yd)	**32,431**				

Notes: cu yd—cubic yard

Through soil washing, 30,768 tons of oversize and coarse-grained fractions were treated to below AK DEC CULs, of which 5,219 tons were also below May 2024 U.S. Environmental Protection Agency (USEPA) residential soil Regional Screening Levels (RSLs) used at the time and were reused by the installation for backfill and winter road maintenance (**Table 15-2-12**). Of the 6,398 tons of postprocessed fines not meeting the AK DEC CULs, 266 tons were rewashed at the end of the 2024 operational season to evaluate the effectiveness and efficiency of a second wash; these materials were successfully treated to below AK DEC CULs. Therefore, approximately 6,132 tons of postprocessed fines remain on-site for second wash, disposal, or possible future consideration of treatment with a destructive technology. As such, soil washing was able to reduce the volume of PFAS-impacted soils by 83%, representing a total of 31,034 tons of soils meeting AK DEC CULs out of 37,166 tons of postprocessed soils. **Table 15-2-13** and **Table 15-2-14** summarize the PFAS and co-contaminant concentrations for the postprocessed coarse and fines fraction from the first DU for each stockpile. It should be noted that the elevated concentration of postprocessed fines during processing of EIE405-1 and EIE365-1 soils is not indicative of PFAS concentrating on the fines fraction but an ineffective operating procedure that was corrected during treatment of EIE378-4.

Table 15-2-12. Summary of postprocessed soil treated in 2023 and 2024.

Stockpile(s)	Oversize (tons)	Coarse (tons)	fines (tons)	Total (tons)
EIE365-1	3,045	2,718	1,266	**7,029**
EIE378-4	8,383	10,965	3,090	**22,438**
EIE405-1	1,489	1,650	974	**4,113**
EIE405-2	365	381	295	**1,041**
EIE405-3	865	908	773	**2,546**
TOTAL POSTPROCESSED WEIGHT (tons)	**14,146**	**16,622**	**6,398**	**37,166**

Table 15-2-13. Treated sample results—PFAS.

PFAS Analyte	PFOS	PFOA	PFBA	PFBS	PFNA	PFHxA	PFHxS	HFPO-DA
AK DEC CUL[1]	3	1.7	NE	NE	NE	NE	NE	NE
USEPA RSL[2]	130	190	NE	1,900	190	3,200	1,300	230
Oversize Fraction								
405-2	0.14	0.006	ND [0.04] U	ND [0.08] U	0.003	ND [0.01] U	0.03	ND [0.02] U
378-4 Rewash	0.02	0.001 J+	ND [0.01] U	ND [0.002] U	ND [0.002] U	ND [0.002] U	0.002 J	ND [0.005] U
Coarse Fraction								
EIE365-1	1.07	0.106	ND [0.20] U	ND [0.04] U	0.02 J	0.04 J	0.32	ND [0.10] U
EIE378-4	0.54	0.027 J+	ND [0.20] U	ND [0.04] U	ND [0.05] U	0.04 J	0.06 J	ND [0.05] U
EIE405-1	0.49	0.013	ND [0.20] U	ND [0.04] U	ND [0.05] U	ND [0.05] U	0.04 J	ND [0.10] U
EIE405-2	0.42	0.04	ND [0.22] U	ND [0.05] U	0.03	ND [0.05] U	0.1	ND [(0.11] U
EIE405-3	1.33	0.020	ND [0.20] U	ND [0.05] U	0.02 [0.05] J	ND [0.05] U	0.08 J	ND [0.10] U
Fines Fraction								
EIE365-1	**8.73**	0.263	ND [0.21] U	0.03 J	0.09 J+	0.09 J	0.96	ND [0.11] U
EIE378-4	**9.87**	0.116 J	ND [0.23] U	ND [0.05] U	0.04 J	0.08 J	0.48	ND [0.12] U
EIE378-4 Rewash	2.77	0.042 J+	ND [0.21] U	ND [0.05] U	ND [0.05] U	0.03 J	0.19	ND [0.11] U
EIE405-1	**22.6**	0.108	ND [0.20] U	0.03 J	0.06 J	0.08 J	1.03	ND [0.10] U
EIE405-2	**5.19**	0.09	ND [0.22] U	ND [0.05] U	0.06	0.04	0.47	ND [(0.11] U
EIE405-3	**11.7**	0.067 J+	ND [0.20] U	ND [0.05] U	0.07 J	0.05 J	0.37	ND [0.10] U

Notes: All concentrations presented are in micrograms per kilogram (µg/kg)
RED—concentration exceeds the AK DEC CUL
[1] CULs are from 18 AAC 75.341, Table B1 Method Two—Soil Cleanup Levels (**AK DEC 2023**)
[2] USEPA RSL for residential soil with a hazard quotient of 1.0 and cancer risk of $1x10^{-6}$ (**USEPA 2023**)
Limit of detection shown in brackets [ ]
AAC—Alaska Administrative Code
AK DEC—Alaska Department of Environmental Conservation
DL—detection limit
USEPA—U.S. Environmental Protection Agency
HFPO-DA—hexafluoropropylene oxide dimer acid
J—the result is an estimated value greater than or equal to the DL and less than the LOQ
J+—the result is an estimated quantity, but the result may be biased high
LOQ—limit of quantitation
NE—not established
PFAS—per- and polyfluoroalkyl substances
PFOA—perfluorooctanoic acid
PFOS—perfluorooctanesulfonic acid
PFBA—perfluorobutanoic acid
PFBS—perfluorobutanesulfonic acid
PFNA—perfluorononanoic acid
PFHxA—perfluorohexanoic acid
PFHxS—perfluorohexanoic acid
RSL—Regional Screening Level
U—the analyte was not detected and was reported as less than the LOD

In addition to soil, 314 one-cu-yd sacks of vegetation were also generated as a result of soil washing operations and are being temporarily stockpiled on-site until waste characterization is complete, and disposition options are finalized.

The capacity of wash water in the soil washing plant is approximately 71,500 gallons, which is circulated in a closed loop through the soil washing plant for soil processing and treated through a water treatment plant consisting of two trains of pretreatment sand media, lead-lag granular activated carbon vessels, and lead-lag ion exchange resin vessels. During soil washing operations, this water capacity is circulated 20 times through the soil washing plant per day, resulting in the equivalent of approximately 1.4 million gallons of water per day processed through the water treatment system. Treatment system media is backwashed several times per day. Over the course of the operating season, a total of 86,000 gallons of process water was used (additional water was necessary above 71,500 gallons of the plant capacity due

to evaporation and accumulated water content in postprocessed materials). PFAS and co-contaminants of concern were treated to less than their respective AK DEC CULs and discharged on-site.

This project is ongoing with opportunities for process optimization to reduce the volume requiring rewash or disposal off-site, or both. Destructive technologies are also being considered for incorporation into the project, resulting in a complete treatment train that will provide a total on-site treatment and management solution.

Table 15-2-14. Treated sample results—co-contaminants.

Analyte Category	POL	Pesticides		PAHs		
Analyte	DRO	4,4′-DDD	beta-BHC	Naphthalene	Benzo(a)anthracene	Benzo(a)pyrene
AK DEC CUL[1]	250,000	98	10	38	700	1,500
Coarse Fraction						
EIE365-1	N/A	N/A	N/A	N/A	N/A	N/A
EIE378-4	N/A	N/A	N/A	ND [9.99] U	111	95.4
EIE405-1	N/A	N/A	N/A	ND [3.47] U	8.36	7.87 B
EIE405-2	16.40	0.015	ND [4.30] U	**ND [47.6] U**	0.06	0.10
EIE405-3	17,900	3.94	ND [1.33] U	ND [10.0] U	131	160
Fines Fraction						
EIE365-1	N/A	N/A	N/A	N/A	N/A	N/A
EIE378-4	N/A	N/A	N/A	ND [11.8] U	532	487
EIE405-1	N/A	N/A	N/A	ND [10.1] U	22.1	23.7
EIE405-2	ND [5,270] U	**152**	ND [4.22] U	**ND [50.6] U**	54.6	78.9
EIE405-3	64.5	10.2	ND [1.35] UJ	ND [20.2] U	81.0	102

Notes: All concentrations presented are in micrograms per kilogram (µg/kg)
RED—concentration exceeds the AK DEC CUL **Bold**—nondetect is reported at less than the DL, which is higher than the AK DEC CUL
[1] CULs are from 18 AAC 75.341, Table B1 Method Two—Soil Cleanup Levels (**AK DEC 2023**)
LOD shown in brackets [ ]
AAC—Alaska Administrative Code AK DEC—Alaska Department of Environmental Conservation
BHC—hexachlorocyclohexane DDD—dichlorodiphenyldichloroethane DL—detection limit
DRO—diesel range organics CUL—cleanup level EB—equipment blank
USEPA—U.S. Environmental Protection Agency
J—the result is an estimated value greater than or equal to the DL and less than the LOQ LOD—limit of detection
LOQ—limit of quantitation N/A—not applicable ND—not detected
PAH—polycyclic aromatic hydrocarbon POL—petroleum, oil, and lubricants
U—the analyte was not detected and was reported as less than the DL

Costs

The cost to implement soil washing is based on two main factors: 1) the total amount of soil to be processed and 2) the percentage of fines in the soil. The less soil to be treated and the higher the percentage of fines, the higher the unit cost. This is because mobilization/demobilization of labor and equipment does not vary substantially, as the same equipment and labor is needed regardless of the amount of soils to be treated on-site. Additionally, as the percentage of fines increases, treatment throughput decreases. Based on experience, the cost of soil washing can range between $350 and $650 per ton and is inclusive of management, planning/reporting, mobilization/demobilization, equipment, labor, laboratory analysis, power, and waste management (for example, disposal of postprocessed fines not meeting AK DEC CULs and spent water treatment media). These costs are competitive when compared to off-site disposal, especially in more remote project locations such as parts of Alaska.

For example, the cost of off-site disposal for this project was estimated to be almost $500 per ton just for labor and materials for loading, transportation, and disposal of PFAS-impacted soils via rail from the project location in Alaska to a Subtitle D landfill with leachate collection system in Oregon. This off-site disposal unit price does not include management, laboratory analysis and waste profiling, and reporting. Therefore, the cost per unit for soil washing provided above is very competitive. Additionally, soil washing minimizes generator risk by significantly reducing (in this case by 83%) the amount of PFAS-impacted soils requiring off-site transport and disposal to a long-term managed land application out of state. This risk is exacerbated by the ever-changing regulatory atmosphere surrounding PFAS, which is only expected to require more PFAS-impacted soils to be managed with disposal costs likely increasing over time.

15.3 Risk Assessment Case Study (2020)

The New Jersey Department of Environmental Protection (NJDEP) Division of Science, Research, and Environmental Health conducted an initial assessment of PFAS impacts at a select group of surface water bodies in New Jersey (**NJDEP 2018**) (**Figure 15-20**). The results of fish tissue sampling from each site were used in a risk assessment methodology to determine the need for fish consumption advisories for PFAS in each of those water bodies.

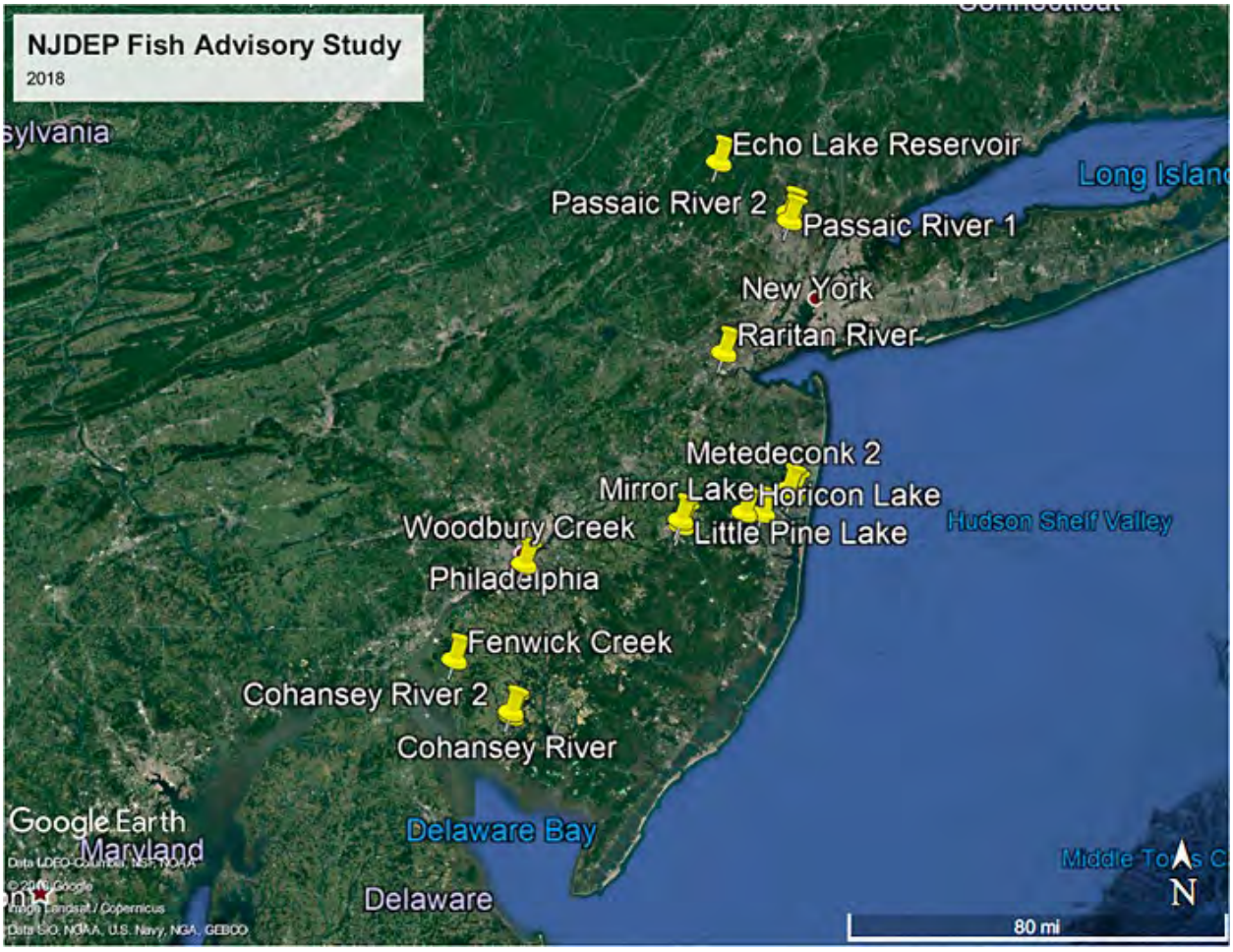
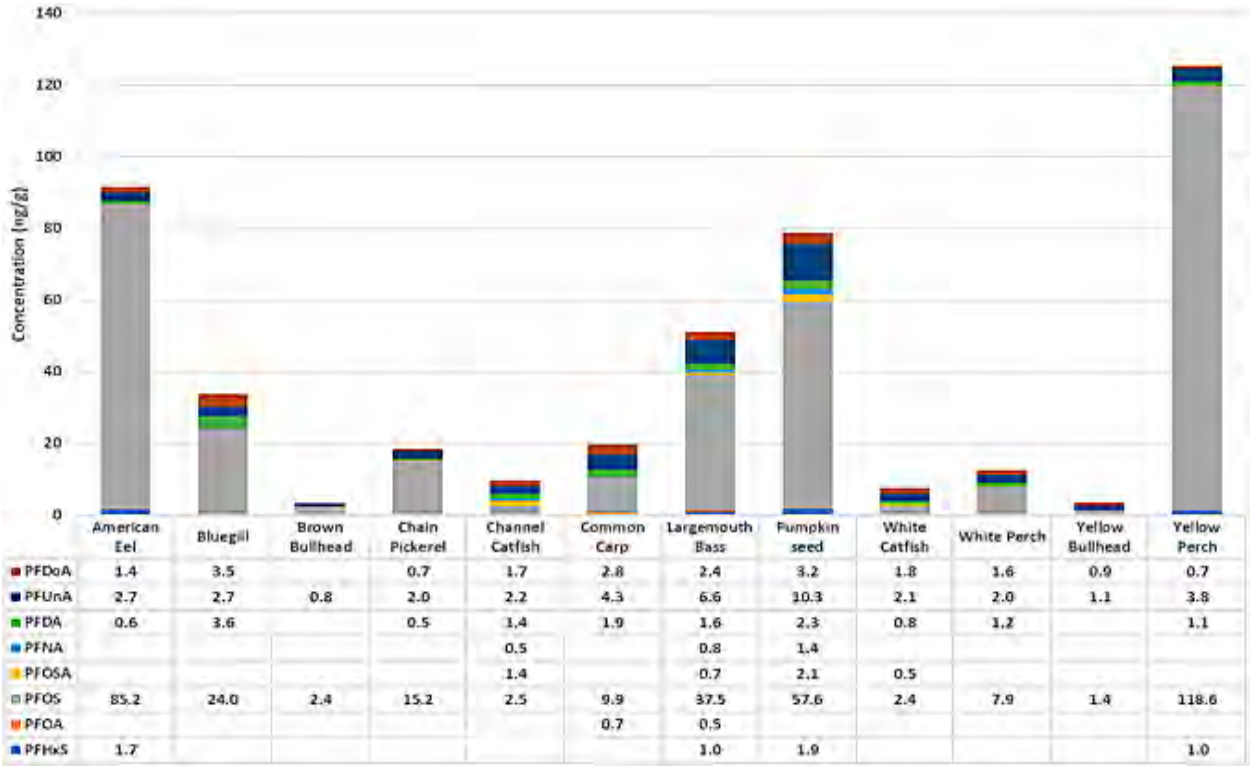


Figure 15-20. Map of water bodies included in NJDEP fish tissue study.

Overall, fish tissue samples from up to 12 different species were collected from 11 specific water bodies throughout the state. The water bodies were selected for sampling based upon their location relative to possible PFAS sources and the likelihood that they could be used for recreational fishing. Samples were analyzed for 13 PFAS (PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, PFDoA, PFBS, PFHxS, PFOS, and PFOSA), and as presented in **Figure 15-21**, the results indicated that the predominant PFAS detected in the fish tissues was PFOS.



	American Eel	Bluegill	Brown Bullhead	Chain Pickerel	Channel Catfish	Common Carp	Largemouth Bass	Pumpkin seed	White Catfish	White Perch	Yellow Bullhead	Yellow Perch
PFDoA	1.4	3.5		0.7	1.7	2.8	2.4	3.2	1.8	1.6	0.9	0.7
PFUnA	2.7	2.7	0.8	2.0	2.2	4.3	6.6	10.3	2.1	2.0	1.1	3.8
PFDA	0.6	3.6		0.5	1.4	1.9	1.6	2.3	0.8	1.2		1.1
PFNA					0.5		0.8	1.4				
PFOSA					1.4		0.7	2.1	0.5			
PFOS	85.2	24.0	2.4	15.2	2.5	9.9	37.5	57.6	2.4	7.9	1.4	118.6
PFOA						0.7	0.5					
PFHxS	1.7						1.0	1.9				1.0

Figure 15-21. Fish tissue sampling results. Average concentration detected per species.

*Data from **NJDEP (2018)**.*

Using the noncancer oral reference doses (RfDs) New Jersey Department of Environmental Protection derived for PFOA [2 ng/kg-day; (**NJDWQI 2017**)], PFOS [1.8 ng/kg-day; (**NJDWQI, 2018**)], and PFNA [0.74 ng/kg-day; (**NJDWQI 2015**)], and generic conservative assumptions regarding fish consumption exposure, NJDEP derived risk-based advisory triggers for each of these compounds based upon different fish consumption frequencies specifically, once/day, once/week, once/month, once/3 months, once/year.

The following equation was used to derive their risk-based triggers (which are presented in **Figure 15-22**):

$$C_{fish} = HQ \cdot RfD \left(\frac{BW \cdot AT_{nc}}{M \cdot CR} \right)$$

where

- C_{fish} is the risk-based fish concentration (ng/g)
- HQ is the target hazard quotient = 1 (unitless)
- M is the number of meals during the exposure period
- CR is the fish consumption rate (g/meal) = 8 oz/meal (227 gram/meal)
- BW is the body weight (kg) = 70 kg
- RfD is the chemical-specific oral reference dose (ng/kg-day)
- AT_{nc} is the noncancer averaging time (days)

	General Population			High Risk Population*		
	PFOA (ng/g; ppb)	PFNA (ng/g; ppb)	PFOS (ng/g; ppb)	PFOA (ng/g; ppb)	PFNA (ng/g; ppb)	PFOS (ng/g; ppb)
Unlimited	0.62	0.23	0.56	0.62	0.23	0.56
Once/Week	4.3	1.6	3.9	4.3	1.6	3.9
Once/Month	18.6	6.9	17	18.6	6.9	17
Once/3 months	57	21	51	N/A	N/A	N/A
Once/Year	226	84	204	N/A	N/A	N/A
Do Not Eat	>226	>84	>204	>18.6	>6.9	>17

**High risk individuals are considered to be at higher risk from contaminants in fish than members of the general public. This group includes infants, children, pregnant women, nursing mothers and women of childbearing age.*

Figure 15-22. Risk-based fish advisory triggers.

*Data from **NJDEP (2018)**.*

Because of concerns associated with the potential developmental health effects associated with these chemicals and given a lack of acute toxicity values for these compounds, NJDEP did not recommend advisory levels for the once/3 months and once/year exposure frequencies for high risj populations (young children, pregnant and lactating women, women of childbearing age), and the once/month value is the least frequent consumption category recommended for these high risk populations.

A comparison of the derived risk-based advisory levels with the measured concentrations in fish tissue samples from each of these waterways resulted in NJDEP recommending the following fish consumption advisories for the general population (**Figure 15-23**).

Site	Advisory (Driven By)
Echo Lake Reservoir	No more than once/month (PFOS, Largemouth Bass)
Passaic River 1&2	No more than once/3 months (PFOS, Largemouth Bass-Bluegill Sunfish)
Raritan River	No more than once/month (PFOS, Common Carp-White Perch)
Metedeconk 1&2	No more than once/3 months (PFOS, Largemouth Bass)
Pine Lake	No more than once/year (PFOS, American Eel-Largemouth Bass-Pumpkinseed Sunfish)
Horicon Lake	No more than once/month (PFOS, Chain Pickerel)
Little Pine Lake	No more than once/year (PFOS, Largemouth Bass-Yellow Perch)
Mirror Lake	No more than once/3 months (PFOS, American Eel-Bluegill Sunfish-Largemouth Bass)
Woodbury Creek	No more than once/3 months (PFOS, Largemouth Bass-Pumpkinseed Sunfish)
Fenwick Creek	No more than once/month (PFOS, Common Carp)
Cohansey River 1&2	No more than once/week (PFOS, White Perch)

Figure 15-23. NJDEP fish advisories for general population.

*Data from **NJDEP (2018)**.*

15.4 Risk Communication Case Studies

15.4.1 Little Hocking Water Association (LHWA), Ohio (2020)

The communication and community participation strategy used for residents served by the Little Hocking Water Association (LHWA) in southwest Ohio produced effective results in motivating actions by

individuals, government, and industry which led to a significant, measurable reduction in residents' blood PFOA levels.

A community-first strategy was implemented at the Little Hocking, Ohio, site to effectively communicate scientific results and findings in a manner that embodies the principles of community-based participatory research (CBPR). This type of strategy combines scientific methodology with community capacity-building strategies to address the disparities and power imbalances among stakeholder groups (business owners, residents, regulatory, and responsible party). If properly implemented, CBPR can result in trust rebuilding, management of environmental justice matters, empowerment to those affected by providing information for informed action, and improved research and data collection (**Viswanathan et al. 2004**; **Hartwig, Calleson, and Williams 2006**; **O'Fallon, Tyson, and Dearry 2000**; **Executive Order 12898 1994**). The following is a case study summary of the Little Hocking, Ohio, site (**Emmett et al. 2006**; **Emmett et al. 2009**; **Emmett and Desai 2010**).

15.4.1.1 Site Description

The LHWA is a rural water authority that serves several small communities with a total population of approximately 12,000 residents in 4,000 households. The reticulation system extends around 25 miles into Ohio from Little Hocking, a small rural community along the Ohio River in Washington County, Appalachian Ohio. Based on the 2010 U.S. Census, the total population of Little Hocking was 263, predominately Caucasian, majority between the ages of 18–64 years, and 21.5% of individuals live below the poverty level. The water intake wells for the LHWA are located directly across the Ohio River from a Teflon production plant that used ammonium perfluorooctanoate (APFO, the ammonium salt of PFOA). This plant was physically located in West Virginia; therefore, the enforcement and regulation of the plant and its emissions fell to the West Virginia agencies.

Since the 1950, the plant was known to historically release APFO into the air and water and to dispose of byproducts containing APFO in local landfills (**WV DEP 2002**). APFO readily converts to its anionic form, PFOA, in the environment. When tested in 2001 and 2002, the LHWA source wells had levels ranging from 0.855 ppb to 7.69 ppb. Community concerns were raised because PFOA detections in the water supply were considerably higher than any reported PWS in the United States at the time. Prior to the study summarized here, there was no information about the sources of PFOA that was being detected in human blood in widespread locations. In the absence of this information, the West Virginia Department of Environmental Protection convened the C-8 Assessment of Toxicity Team, and developed a health protective screening level for water at 150 ppb. In addition, an interim action level of 14 ppb was established by a USEPA Consent Order with the responsible party. In August 2002, groundwater borings advanced in the LHWA well field contained PFOA concentrations up to 78 ppb. A class action suit was initiated, and distrust increased among the affected community and both the government and responsible party.

To investigate community concerns about potential PFOA contamination of residents in the LHWA district, a partnership was formed between the University of Pennsylvania School of Medicine, a local health provider, and the Decatur Community Association, made up of residents living within the LHWA district. The partnership obtained an environmental justice research grant from the National Institute of Environmental Health Sciences. The research was designed to engage the affected community on all aspects of the study to determine (1) whether blood PFOA levels were elevated in the community, compared with Philadelphia residents and with published population values; (2) if blood PFOA levels were elevated, was the source air, water, or some other combination of exposures; and (3) if levels were elevated, were there changes in certain biomarkers of potential toxic effects.

A community advisory committee (CAC) was formed with local residents served by the water supply, local physicians, state and federal government representatives, a health researcher, and a school system representative. A community project coordinator was employed as a communication enabler. The CAC

met quarterly and all meetings were open to the public with the only participation restrictions being that the attorneys and plant representatives were not permitted to take part in the discussions. Community advice was particularly sought as to which scientific questions to address, development and wording of questionnaires, communications with residents, and citizen concerns. The CAC utilized newsletters to keep local residents and other stakeholders informed. These newsletters and CAC meeting minutes were posted on a CAC study website.

The study team collected blood serum PFOA, hematologic and biochemical biomarkers, a questionnaire to obtain information on demographic and occupational information, and health conditions from a stratified random sample of residents in the LHWA reticulation area. The median blood PFOA levels for residents were approximately 80 times those of the general population and similar to levels reported for production workers at the fluoropolymer facility. PFOA levels were higher in children and the elderly. Residents using LHWA water who worked in production areas of the plant had PFOA levels that reflected additive effects from both exposure pathways. Residents who primarily used well water for domestic purposes had PFOA levels that correlated with the PFOA concentration in well water. No impact was seen from living in areas with higher estimated air levels.

15.4.1.2 Community-First Communication Strategy

After data had been collected from participants, but before any results were available, the CAC discussed and developed a communication strategy. For this purpose, the CAC developed a set of general principles for communication and a list of priority targets representing the community's preferred order for communication of results:

LHWA Residents' General Principles for Communications, from **Emmett and Desai (2010)** and **Emmett et al. (2009)**.

- Results should be released promptly, but not before the investigators are comfortable in doing so.
- Individual participants should receive their results first to avoid participants first learning study results from the press, neighbors, or friends.
- The press should be informed in a manner that is both timely and allows the investigators to control the message as much as possible.
- The study must remain a credible source of information.
- Communications should maximize constructive responses to the findings.
- Communications should minimize pointless concern.
- Questions from individuals should be answered promptly.

LHWA District Residents' List of Priority Targets for Communication of Results, from **Emmett et al. (2009)**.

- study participants and community (residents of the water district)
- community advisory committee
- relevant authorities and representatives (county and state health departments, state Department of Environmental Protection, local water authorities, state and federal elected government representatives for the area, local townships, sheriffs' departments, USEPA)
- local medical providers
- local media
- national media, as necessary.

Once the general principles of engagement were established, the CAC developed a communication strategy and plan. The CAC determined that the strategy required multiple modes of engagement that enforced consistent simple messages and consideration of careful timing to mitigate development of inaccurate perception of risk and management strategies. The communication plan was a "living

document" to facilitate continued integration of stakeholder input, regulatory development, and scientific advancement. The sequence of communications commenced with mailings to participants at the end of July 2005 and culminated in a community meeting on August 15, 2005, where full results were presented.

15.4.1.3 Results and Use of Risk Communication Tools

1. *Notifications to Participants and Authorities*—Biomonitoring results were sent via next-day-delivery mailings to individual study participants. These results included the individual's blood PFOA and biomarker levels as well as comparative information on PFOA levels (including blood levels for national and site facility workers, general US population, and community neighborhoods) and a toll-free telephone number to contact a study physician with any questions. Letters containing aggregated, not individual, results were sent simultaneously to identified authorities and CAC members, to ensure that recipients would be able to respond appropriately to inquiries from the public.
    - *Lessons and Takeaways*: Calls often needed to be returned after business hours. Most concerns focused on higher levels in children and the elderly, and possible interactions of elevated PFOA levels and particular medical conditions.

2. *Initial Press Release and Briefing*—Key local and regional media were identified and informed of the communication plan around the date the participant letters were sent. An initial press release and briefing were made the second day after the results were mailed to ensure that participants did not first learn of the issue through the press, while still providing investigators an opportunity to be the primary source of information to the press. Identified media representatives and national news outlets were invited to the news briefing. The release simply identified that levels in LHWA residents were much higher than those in the general US population, and that water had been identified as the major source of exposure. Interested stakeholders were urged to attend a community meeting where comprehensive results would be released and discussed.
    - *Lessons and Takeaways:* The reporting by local and national media did not misconstrue information and local media participated as per the communication plan. The CAC perceived the media coverage as constructive. The community expressed great satisfaction that participants had received their results first.

3. *Closed Rehearsal of Community Presentation*—A full closed-door rehearsal presentation (summarized in the subsequent bullet) was presented by the study team to the CAC prior to the community meeting. The closed rehearsal ensured that the community meeting presentation was as inclusive and useful as possible.
    - *Lessons and Take-Away:* The CAC requested a presentation that was careful and simple to understand, incorporating a clear visual map so that residents could locate their residences with respect to the study results. During rehearsal, the CAC members provided feedback on the order of the agenda, comprehensibility of slides, choice of wordings to accord with terminology and usage in the area, structure of the presentation, and dealing with likely questions.

4. *Community Meeting*—The meeting commenced with "ground rules," such as lawyers were not to solicit clients and questions were to follow the presentation. It was also communicated that continual stakeholder feedback is a success factor of the communication plan. In addition, representatives from the facility were invited to attend but were not permitted to present. The 45-minute presentation given by the study team detailed partnership objectives and study methods, results, and recommendations. A two-hour question and answer period followed the presentation. A summary of the study, recommendations (including the use of bottled water), sources of information, and how to access a study physician were distributed to all attendees on

exit. The meeting summary and information on accessing free bottled water were mailed to households in the LHWA district and local authorities and representatives.

- *Lessons and Takeaways:* The meeting proceeded in a constructive manner as CAC community members had predicted and not in the angry manner outside public relations experts had predicted. Any anger was directed at the responsible party and not at the investigators.

5. *Publication of Results and Information*—Following the community meeting, a newsletter with test result summaries was issued. A website with meeting presentation slides, test results, and FAQs was also developed. A summary of results was sent to all LHWA district residents.
    - *Lessons and Takeaways:* The website received many hits. The study and recommendations did not prove controversial. The practitioners did not encounter antagonistic relationships between the different parties.

6. *Availability to Answer Questions*—Physicians from the study team made themselves available to the public to answer questions from individuals and also from treating health care professionals.
    - *Lessons and Takeaways*: This service was appreciated. Questions mostly focused on the impact on residents with particular conditions such as liver and kidney disease. The many uncertainties surrounding the risk to humans were openly acknowledged.

15.4.1.4 Effectiveness of Communications

On the day results were presented and approximately 2 weeks after the initial press release, the responsible party announced that it would make free bottled water available to LHWA district residents (3 liters per day per person). Seventy-eight percent of eligible households accepted the offer.

Sixteen months after dissemination of the study results, a follow-up study of participants was made, which included repeat blood PFOA levels and questions about any changes in water usage. Sixty-five percent of those in the initial study participated in the follow-up, of whom 95 percent had made some change in their residential water usage in a way that would be expected to reduce PFOA intake. Eighty-eight percent had followed study recommendations to switch to using bottled water. The group median blood PFOA had declined 26%, consistent with a large effect for a pollutant with a half-life of approximately 4 years in humans.

USEPA used the results to enter into a consent agreement with DuPont to provide bottled water for the other impacted communities near the plant with >0.5 ppb of PFOA in water, and the states of Minnesota and New Jersey set provisional standards for PFOA levels in drinking water.

Lessons and Takeaways: The results and communications strategy resulted in 95% of participants had made a change to their water source. This response greatly exceeds the usual level of response seen with public health interventions. All parties, individuals, corporations, and governments acted in a prudent way with the disseminated information. Not all residents reacted by adopting the specific recommendations from the study; the alternate actions some individuals took are consistent with the information being incorporated into individuals' own risk perceptions and with the development of a free market of solutions (individual decision making based on available information).

15.4.1.5 Case Study Summary

The Little Hocking Community-First Communication Strategy resulted in a great increase in alternate water source use by impacted community members and subsequently, a reduction in community PFOA

blood levels. The success of the communication plan at the Little Hocking site was underlain by the four dimensions of risk communication:

- **Understanding:** Investigators worked with the community through the CAC to establish the communities' preferences and priorities in the form of a communication strategy and plan to maintain simplified and consistent messaging among stakeholder groups and interested parties, such as the media.

- **Perception:** Risk perception factors were incorporated into the outreach strategy, including residents' knowledge of PFOA biomonitoring results and associated illnesses, ability to access a physician, presence of vulnerable subpopulations (higher PFOA levels in children and the elderly), proximity of individual residences to elevated concentrations within the study area (sense of a safe place), and possible interactions of elevated PFOA levels and particular medical conditions.

- **Participation:** The affected community actively participated in all components of the communications.

- **Evaluation:** Success and effectiveness of the communication process were assessed based on feedback from the CAC, surveys of residents, and review of newspaper articles and other media content. In addition, a follow-up study was performed that addressed the effectiveness in terms of lowered blood levels of PFOA and a questionnaire about whether and how community members had changed their drinking water source as a result of the risk communication strategy.

15.4.2 State-Led Community Involvement Case Studies (2020)

The Environmental Council of the States (ECOS), in collaboration with the USEPA Office of Research and Development and the Association of State and Territorial Health Professionals, has developed a series of case studies presenting how state regulatory agencies are performing risk communication to PFAS-impacted stakeholders: **https://www.ecos.org/documents/state-level-risk-communication-of-pfas-and-habs/**

15.4.3 Washington County, MN: A State's Approach to Risk Communication (2020)

Washington County is home to 3M's Cottage Grove manufacturing facility as well as several disposal facilities where PFAS had been routinely disposed. Beginning in 2002, the State of Minnesota pursued drinking water investigations at the 3M facility and later near 3M's waste disposal sites in Washington County. According to the 2010 US Census, the population of Washington County, Minnesota was about 238,136, with the majority being Caucasian and between the ages of 18 and 64. Over 1,800 private wells, four major aquifers, eight municipal water supply systems, and over 150 square miles of groundwater were affected by the contamination. This impacted the drinking water supply of over 140,000 residents. After they were determined as the responsible party, 3M remained involved in the remediation efforts and paid for the majority of sampling throughout the county in coordination with MPCA.

This case study is discussed in the context of the risk communication plan.

15.4.3.1 Identify the Issue

The most widespread PFAS compound found in the region is PFBA. Additional prominent compounds include PFOS, PFOA, PFHxS. PFPeA, PFHxA, and PFBS which were always present as a mixture. When investigations began in 2002, there were many challenges to determining the impact for people as the science was in the very beginning stages of development. Therefore, MDH developed health-based

guidance for PFOA and PFOS and the MDH lab developed the method to analyze water sample for PFOA and PFOS. As the science has progressed, MDH continues to update methods and health-based guidance.

Site communications are organized and performed in collaboration primarily between the Minnesota Department of Health and the Minnesota Pollution Control agencies. However, as with other PFAS sites, the site covers multiple local, county and state entities. Communications frequently entail only one or a few cities rather than the entire site. They may also need to be coordinated through all the cities and the county. This leads to multiple plans with multiple partners that are specific to an issue or communications plans developed for a specific project. The fundamental traits of successful risk communication over time and with all stakeholders for MDH include: empathy, care, competence, expertise, honesty, dedication, and commitment.

15.4.3.2 Set Goals

General communication goals and objectives for the site:

- Goal: Inform people about potential hazards to their person, property, or community and help them to make informed decisions about risks to their health.
    - Objective: Develop approved message blocks for PFAS topics and house in accessible format to encourage consistent information is used for all materials developed.
    - Objective: Provide regular updates about remediation activities at stakeholder group meetings including agency PFAS training meetings, county workgroup meetings, city council meetings and public meetings
    - Objective: Provide regular updates about health risks as scientific information changes/evolves at stakeholder group meetings including agency PFAS training meetings, county workgroup meetings, city council meetings and public meetings
- Goal: Encourage people to take precautions to reduce exposure to PFAS
    - Objective: Homes with contaminated drinking water are issued drinking water advisories and either connected to the city water or supplied with GAC filters that are maintained by the state.
    - Objective: Keep updated information about actions people can take to lower their exposure to PFAS on MDH website and MPCA website.
    - Objective: Mobilize stakeholder groups in the county or local communities to encourage people in their area to participate in remediation activities and processes offered by MPCA and contractors.
- Goal: Provide background information and present risks in an understandable way, using plain-language messaging.
    - Objective: Provide opportunities for people impacted by contamination to connect with appropriate staff to find information and to ask questions if concerned.
    - Objective: User test materials using MDH Plain Language Workgroup

- Goal: Bring new information as soon as available to build trust
    - Objective: Provide public meetings with open house sessions before and after a main presentation to bring new information to community
    - Objective: Provide availability sessions to encourage concerned people impacted by changes to learn more about their individual situations.

Project specific communications goals example:

Since 2002, there have been multiple changes in PFAS health based values provided by MDH, analytical advances which have impacted lab results, an investigation that looked at PFAS in garden produce and dust, multiple biomonitoring studies, fish monitoring and consumption guidance, drinking water and source water investigations, and a study to test point-of-use water treatment devices. All of these projects and scientific advances have resulted in specific communications to affected communities with goals and objectives tailored to the issue or project.

15.4.3.3 Identify Communities and Constraints

MDH catered their risk communication strategy to the following:

- Residents of affected communities
- Local governments: cities, townships, and their staff of varying sizes
- Washington County public health and environmental staff
- Legislators
- Other state agencies including MPCA

Constraints include the size of the area and the multiple local governments. The character of each township and city vary widely with different capacities to manage local information dissemination to affected residents. This requires communicators to develop relationships with each stakeholder group. The risks and impacts of PFAS contamination are managed differently for those on public water and private wells. Therefore, the correct information needs to be available in many different forms for different stakeholders.

15.4.3.4 Community and Stakeholder Assessment

Minnesota's risk communication strategy in response to the Washington County PFAS drinking water contamination has been centered around community engagement and forging strong relationships with community members. Building these relationships enabled them to build trust with the community and develop new communication channels.

The Minnesota Department of Health (MDH), in conjunction with the Minnesota Pollution Control Agency (MPCA), maintains a hands-on risk communication approach. Information about community needs for information is gathered through regular update meetings with stakeholder groups and local government leaders. Public meetings, availability sessions and face to face interactions with community members during remediation activities provides a base of information for the ongoing communication efforts. MDH also maintains a 24/7 email and phone line for people to access with concerns or for information about site activities.

Minnesota had been engaging directly with affected communities since 2002. Having had a long-standing relationship with affected communities, MDH has a history of responding to the specific needs of the affected communities and has tailored its messaging to their knowledge level. Although basic information about PFAS is always available, the general level of knowledge amongst key stakeholders is

high. For this reason and with these communities, MDH representatives lead with high-level information, as the attendees to the public meetings typically are interested in specific updates as opposed to rudimentary background information.

15.4.3.5 Identify Messages

MDH maintains a message block document with approved message blocks about a variety of topics for internal staff use. This document serves as the basis for specific information sheets developed for different stakeholder activities. It is also a resource to answer questions from concerned community members. Topics include health risk of PFAS, MDH guidance value information, current site activities, exposure information, fish consumption guidance, swimming, cumulative health risk, breastfeeding and health risks, PFAS and links to health problems, testing blood for PFAS, biomonitoring information, gardening and PFAS, and results of MN Cancer Surveillance System reports.

MDH notes the importance of discussing the scientific method with stakeholders to remain transparent about their course of action. They also share new knowledge as it becomes available and do not wait until they have a perfect message or until they know all of the facts to engage with the community. In an effort to uphold their principle of transparency, MDH acknowledges points of uncertainty and are clear about what they do not know when communicating with the public.

The messages are presented in different ways to different communities depending on the level of understanding that a community has about PFAS. For example, we had several meetings in 2018 for communities. One meeting was to a community which had not had PFAS contamination issues until 2018. The information for this community was presented in more of an elementary, broad overview style and level. Another presentation in the same month was to a neighboring community that had been involved with PFAS contamination since 2002. The presentation focused more on what the new information was rather than PFAS basics as the community had a more developed understanding of PFAS.

Examples of specific messages:

- Testing is available for households on private wells that would like their drinking water tested for PFAS. If test results show elevated levels, options are available from the MPCA for treating the water and reducing exposures.
- Currently, PFAS levels found in the drinking water supply in impacted communities have been within the margin of safety for the current drinking water guidance values, and outright negative health effects from these exposures are not expected with what is currently known about PFAS exposures and health effects.
- Affected water supplies are safe to use to water produce in home gardens.
- Biomonitoring Data Shows Interventions are working

Figure 15-24 includes biomonitoring data for three PFAS compounds over the time period from 2008 to 2012. This study shows that although we can't answer questions about health effects, we can demonstrate the work we are doing to reduce exposures has paid off.

- Because of the extreme persistence and mobility of these compounds, a PFAS megaplume developed which is much larger than early modeling predicted. One of the primary factors in this was the unanticipated transport of PFAS via surface water and then re-infiltration to groundwater far away from the source areas – a transport pathway not typically seen in persistent environmental contaminants, which tend to adsorb to organic carbon in soils and sediments.

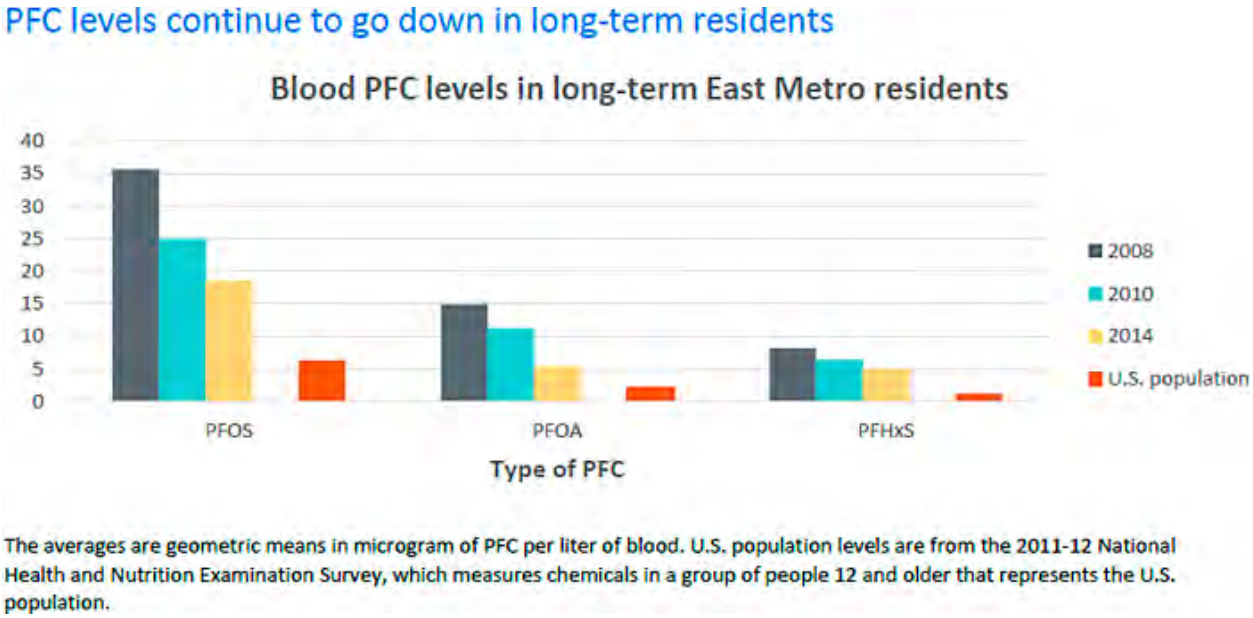


Figure 15-24. Biomonitoring Data.

Source: Courtesy of the Minnesota Department of Health.

15.4.3.6 Select Communication and Engagement Tools

MDH's risk communication strategy facilitates community engagement and open dialogue.

- Engaging with stakeholders and communities as soon as possible when there is any change in risk management of PFAS. Builds trust over time that MDH will be there to support and help communities.
- MDH sends the right people/experts/staff to deliver messages. Over time, staff have built relationships with stakeholders.
- When interacting with people impacted by the site, staff stays until all questions are answered – whether it is a phone call, a public meeting or availability session
- MDH has a service-oriented approach to community engagement. They recognize that educating the community members will carry a ripple effect. Attendees from the meetings who learn through the presentations and the open house format will then take the information and share it with other members of the community.

MDH used the following strategies to connect with and inform the affected communities:

- Hosting Public Meetings: Public meetings have been a significant part of community engagement in Washington County. MDH has held public meetings in an open house, presentation, and Q&A format. An open house is followed by a presentation given to the attendees, after which they provide a time for questions and answers, followed by additional open house time. Participants are able to ask questions about their particular situations in an open forum setting or in one-to-one conversations. For example, in Spring 2017, MDH in collaboration with MPCA held two presentations in different areas of Washington County. The city of Cottage Grove meeting attracted 130 people. In Lake Elmo, a region where the majority of residents have private wells, approximately 120 people attended the public meeting.

- Hosting Availability Sessions/Office Hours: MDH organized opportunities to provide people with time to interact with staff one on one and ask questions. Typically, MDH held these events after major sampling events happened or when new or updated information was released. MDH extended these opportunities upon request of the community. The events were widely used. In an event held in Fall 2017, the office hours held in Lake Elmo where the majority of residents have private wells attracted 45 people. With the affected area being so large, personal communication was helpful in establishing relationships with members of the community.

- Providing Online Resources: The MDH website outlined the history of PFAS in Minnesota as well as actions they have taken and health-based guidance information. An electronic online sampling request form was available on the MDH website. An electronic map on the website shows where MDH is sampling and community members could see and check their property's location in relation to the PFAS contaminated sites. MDH also had a widely used email address for residents to ask questions directly to the department. They could also subscribe to the government's delivery email list to get new information directly to their inbox.

- Communicating with Local Government: MDH prioritized communication with local government because it was a useful tool in keeping the communities informed. They visited city councils to provide updates on the PFAS investigations. They also provided technical support to local governments and their staff that were responsible for protecting public drinking water.

- Using the Media: MDH used press releases and interviews to disseminate information. Social media became a useful tool as well.

15.4.3.7 Implement Strategy

Strategies implemented included:

- Drinking Water Advisories: Over 2700 private wells have been sampled in the East Metro and over 1, 100 drinking water advisories have been issued. Homes that have been issued drinking water advisories are either connected to city water or provided bottled water and/or GAC filters maintained by the state. MDH and MPCA collaborated to communicate and coordinate action for this work.

- Public Water Systems: There are five community public water supplies in the East Metro that have individual wells above the MDH health-based guidance values. All of these cities put in place interim measures to manage their public water supply systems to provide drinking water at or below the MDH health-based guidance values. MDH collaborated with these communities to provide information to residents.

- Messages to Community: After developing health-based guidance values for PFAS compounds, MDH sought to explain to the community what these values mean and what concerns they address. They also explained the next steps in their action plan.

- Reiterating Commitment: MDH drives home the message that they are committed to bringing updated information to the communities to inform them of the status of their efforts. This assures the community that MDH is determined to support them and address their concerns.

- Collaboration with Other Stakeholders: MDH collaborated with MPCA on a response to the PFAS contamination. Any message that were released to the public by MDH was in conjunction with MPCA. ATSDR also developed a community engagement book which has guided MDH's risk communication strategy. Additionally, MDH worked closely with city administrators and community leaders to keep them informed prior to the public meetings.

- Concessions: When drinking water levels were found to be above guidance values in private wells, bottled water was provided by MPCA until a GAC system can be installed.

15.4.3.8 Evaluate, Debrief and Follow Up

Continuous improvement of risk communications and activities through evaluation and through providing feedback loops with stakeholders supports the ongoing implementation strategies described above. The sampling and remediation activities have been widely successful in part due to the community engagement and communications efforts that have built trust in the community for the state agencies.

Evaluation methods used to understand effectiveness of communications content and process include one on one surveys at events, hot washes with partner agencies after communications efforts, and feedback from community leaders at regular update meetings.

Continuously improving, refining, and developing materials to meet community concerns and needs that are identified by inquiries or contacts staff have with community members. Contacts are primarily through 24/7 email and phone line as well as in person while in the field or at public events.

Materials have been developed in many formats over the years and have changed due to capacity for communities to use various methods and MDH capacity to produce them – video, face to face meetings, print, social media in coordination with partners. Investigations and other information have also resulted from community concerns. These include Cancer Incidence Reports, home and garden study, site-specific meal advice for fish consumption, point-of-use filter testing, clinician information sheet, and an information sheet about testing blood for PFAS.

15.4.3.9 Successful Outcomes

The Minnesota Department of Health has been very successful in community engagement:

- They have earned the trust of the community, and residents are assured that MDH is working hard to solve the issue at hand. The number of people participating in sampling and remediation speaks to the efforts made to connect with affected people. Exit surveys from public events have shown that people feel staff are working hard and are good at the work they do.

- MDH also has invested their resources in research and has made strides in understanding the health impacts of the PFAS contamination their state is facing. Many of the investigations and projects were in response to concerns collected through contacts with community members and leaders. These include Cancer Incidence Reports, home and garden study, site specific meal advice for fish consumption, point-of-use filter testing, clinician information sheet, and an information sheet about testing blood for PFAS.

- They have used biomonitoring to demonstrate that their efforts have reduced the PFAS levels in people's bodies. This has provided the community with tangible evidence that the work they are doing is making a difference.

15.4.3.10 Lessons Learned

- It is vital to be on the ground and engage with the community face-to-face. This helps build trusting relationships with the community which has facilitated the remediation efforts and supported reducing exposures to PFAS for community members.

- The cross-agency effort to address the PFAS concerns in Minnesota is a challenge and takes effort to coordinate, but over time has been an effective strategy to address exposures to PFAS in a timely manner.

- Dealing with residential homes and homeowners can be complex. Because PFAS is a complex emerging contaminant for which research and information is constantly evolving, it can be a challenging to return to residents with new guidance values based on new health risks. The information has to fit for those who are familiar with PFAS and those who are new homeowners or residents in affected communities.

- It is important to learn what information residents are looking for and relay it in an articulate manner and in a way that is useful to them. Another concern Minnesota residents have had is a potential decline in property value, but this concern has faded with time.

- Additionally, it is important to be understanding and sympathetic toward the affected residents when they are upset. They are concerned for the well-being of their families.

15.4.3.11 Better Practices Moving Forward

Moving forward, MDH notes that sites across the state have similar circumstances and similar concerns. The lessons learned from sites they have already worked with have been beneficial in refining their approach with other affected communities and contaminants. They have had success with duplicating their strategies and methods at other sites. Although the general principles have been effective, every community is slightly different. MDH takes the time to understand the dynamics of each particular community and tailor their risk communication methods accordingly.

15.5 Surface Water Quality Case Studies

15.5.1 PFAS-Containing Foam (2023)

Case Study: Minnesota Project 1007 Feasibility Study (Contributed by Rebecca Higgins, MPCA)

15.5.1.1 Issue

The surfactant and micelle properties of per- and polyfluoroalkyl substances (PFAS) have proven to result in accumulation into foams on surface waters in many states. The observed foam has implications for exposure to people, aquatic life, wading and dabbling birds, and other wildlife. The concentrations of PFAS in these foams are documented to be thousands to millions of times higher than the concentrations in the water column.

15.5.1.2 Background

In May 2019, the Minnesota Department of Transportation (MNDOT) requested water sampling from the Minnesota Department of Health (MDH) within the area of a transit project in the East Metro of the Twin Cities Metropolitan Area (TCMA), potentially in an area of known PFAS contamination. In response, the MDH sampled surface water and foam above the surface water of Battle Creek located downstream from the area of interest for PFAS. At that time, analytical results indicated PFOS and PFOA impacts were present in the surface water at concentrations of 0.013 ppb and 0.017 ppb, respectively. Comparatively, PFOS and PFOA were present in the foam at 140,000 ppt and 11,000 ppt, respectively, indicating an enrichment compared to the paired surface water results.

In 2020, this occurrence of PFAS-containing foam led the Minnesota Pollution Control Agency (MPCA) to look for its presence as part of the Project 1007 Feasibility Study also in the East Metro under the 2018 3M settlement. Project 1007 conduit drains surface water across the northern portion of the east metropolitan area of the Twin Cities. Foam was noted on the surface of Raleigh Creek and in the corridor from the closed 3M Oakdale Disposal Site, and past the confluence of Raleigh Creek with the Project 1007 stormwater conduit (**Figure 15-25**). The foam was located on the flowing creek, stormwater ponds, and Lake Elmo. The foam was noted particularly after rain and wind events that occurred during the weeks of surface water and sediment sampling.

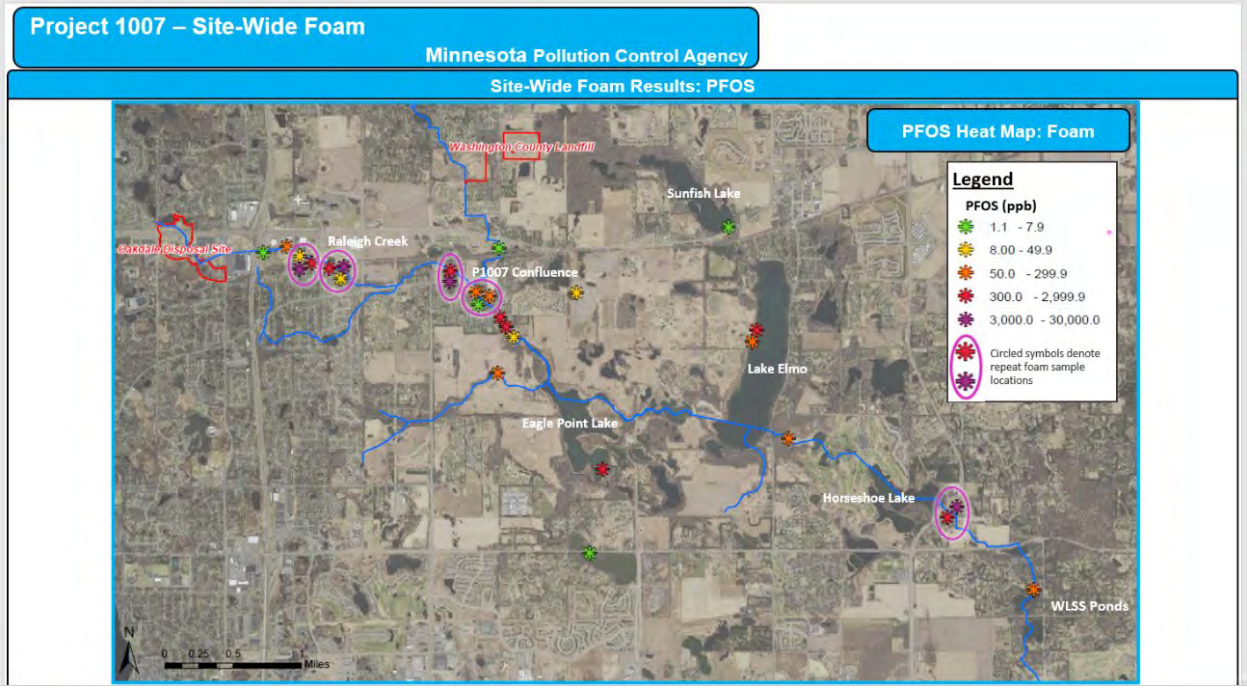


Figure 15-25. Heat map of PFAS-containing foam detections throughout Project 1007 study area.

*Source: Project 1007 Minnesota Pollution Control Agency (***MPCA 2023***).*

The foam has been collected throughout the feasibility study from surface water across the Project 1007 corridor in accordance with the Michigan PFAS Action Response Team (MPART) protocols (**MI EGLE 2019**). Following collection, the foam is allowed to condense in the PFAS-free baggie before being sent to AXYS SGS laboratory in Canada for analysis of up to 40 PFAS compounds. The foam samples are screened for potential high concentrations prior to analysis by AXYS SGS method MLA 110, which aids the laboratory in understanding the potential variation in foam concentrations prior to analysis.

15.5.1.3 PFAS-Containing Foam Varied Textures or Type

PFAS-containing foam can have several different appearances across the Project 1007 region. Specific types of foam were not tied to an exact location, precipitation events, or seasons apart from frozen foam. Examples of different foam types are shown in **Figure 15-26**.

At three locations in Project 1007 (RC5, RC7, and RC12) in 2020, foam was collected and analyzed for PFAS twice to assess potential variation in PFAS concentrations depending on foam type. At each location, a “fluffy” foam sample was collected for comparison against a “thin” foam. PFOS concentrations from the larger and fluffier piles of foam were between two and three orders of magnitude greater than

their thinner counterparts. The corresponding surface water samples had negligible variation in PFOS, suggesting that the PFAS enrichment in foam can be highly variable due to the environmental conditions.

Generic Foam Type	Description	Sampling Location Photo
Actively Generating and Reaccumulating	Foam is observed floating upstream of the accumulation point and continuing to actively accumulate at a location. Frequently source of generation is apparent, and foam will reaccumulate rapidly after sample collection. This foam can either accumulate in large quantities in singular locations or across a wide stretch of creek bank.	RC18A (5/5/20) 
Deflated (old)	Foam is typically thin, in smaller quantities, and discolored with organic matter present. Further, no foam is observed upstream or downstream of point of accumulation, and source of generation is not obvious. This foam is thought to be old because it has never been observed to be actively generating.	RC7 (8/12/2019) 
Frozen	Foam appears frozen, often has a different color and texture from surrounding snow and ice and is usually thin.	RC7A, 2/24/2020  EP19 2/25/20 

Figure 15-26. Examples of various PFAS-containing foam observations and characteristics.

*Source: Project 1007 Six-Month Investigation Progress Report, Minnesota Pollution Control Agency, October 13, 2020 (***MPCA 2020***).*

15.5.1.4 Formation and Accumulation

The requirements for PFAS-containing foam to form and accumulate are typically:

1. Turbulence—Air must be mixed into the water column for foam to form. This can be caused by water flowing over rocks, trees, or other debris in the stream. The water level greatly affects the locations of turbulence.

2. Solid substrate—After formation, the foam bubbles must have a solid substrate in relatively calmer water to accumulate along or against. Without accumulation, the foam bubbles will collapse back into the stream water column. Foam can be found to accumulate along the stream banks, debris, blocks of ice, and vegetation growing in the stream channel.

3. PFAS concentrations in surface water—Foam may naturally form regardless of the presence of PFAS. It is also not well understood how much PFAS will preferentially separate (enrich) into the foam relative to the PFAS in the corresponding surface water.

These and other factors affect the ability to predict occurrence and remediation of PFAS-containing foam. PFAS-containing foam has been encountered in surface water at the same order of magnitude (approximately 20 ppm) at a source area (Oakdale Disposal Site) and approximately 8 miles downgradient in the connected drainage system. Large masses of PFAS-containing foam have been visually noted to dissociate small portions of bubbles off from the larger mass, travelling downstream and potentially providing an additional PFAS source to the water bodies and/or sediments downstream. PFAS-containing foam has been observed to be intermittently present, as it may form and then dissolve back into the water column in a matter of minutes. This may impede response actions to removing the foam; reports of foam in known PFAS-impacted waters may not be present by the time a response action is attempted or it may form elsewhere in the surface water system.

15.5.1.5 PFAS-Containing Foam Enrichment Factors and Carbon Chain Length

An enrichment factor is the ratio of the PFAS concentration in the foam to that in the water (usually the top 6 inches of the water column). As shown in **Figure 15-27**, the enrichment factors for PFOS in the Project 1007 region varied by over an order of magnitude, supporting the environmental factors previously described as important to PFAS enrichment in foam in addition to PFOS concentrations in the corresponding surface water. The relative importance of environmental conditions that may influence PFAS enrichment are not well understood at this time.

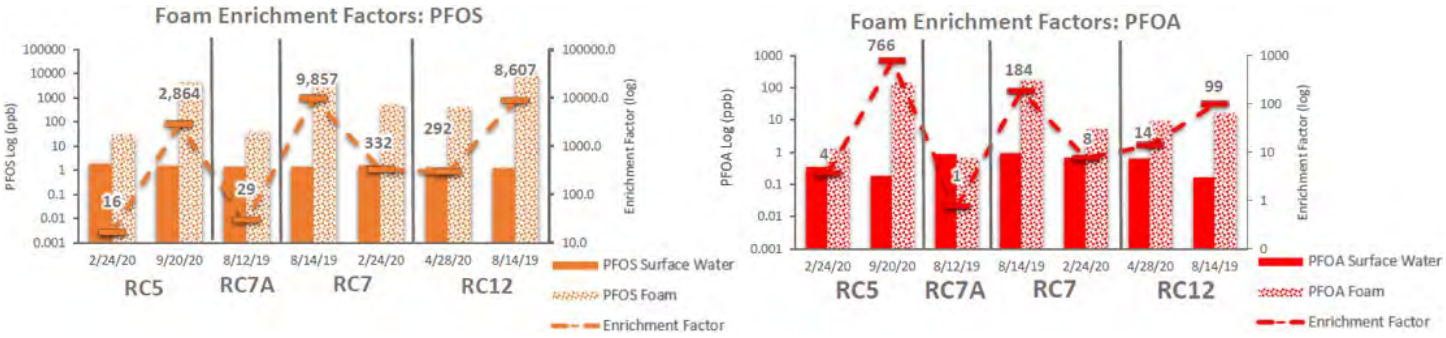


Figure 15-27. Foam enrichment factors for paired surface water and foam samples, showing PFOS and PFOA concentrations.

*Source: Project 1007 Minnesota Pollution Control Agency (***MPCA 2023***).*

Foam samples overwhelmingly consisted of long-chain PFSAs and PFCAs constituting up to 97% of the PFAS compounds in some samples (**Figure 15-28**). Longer chain PFAS like PFOA, PFOSA, PFOS, and N-EtFOSA tend to enrich or preferentially separate into the foam to a greater degree than shorter chain compounds like PFBA and PFBS because they are more hydrophobic.

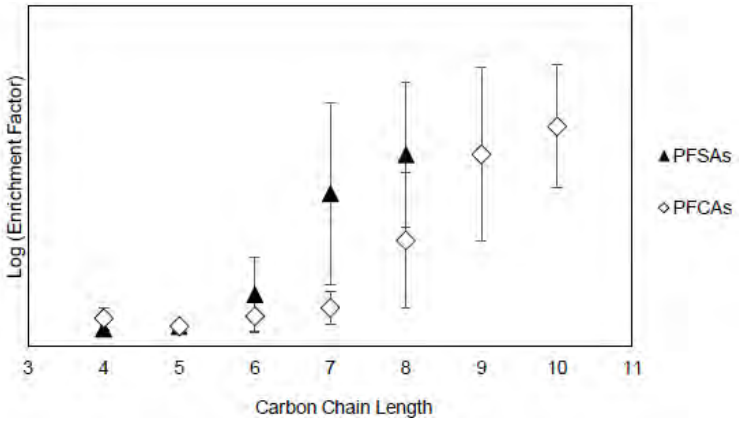


Figure 15-3. PFAS-containing foam enrichment factors and carbon chain length versus enrichment factors.

Source: Six-Month Investigation Progress Report (November 11, 2019—May 15, 2020) Project 1007 Minnesota Pollution Control Agency (MPCA 2020).

15.5.1.6 Risk Assessment

Risk assessments for PFAS are limited by lack of sufficient toxicological and exposure data for all but a few chemicals such as PFOS and PFOA. Therefore, to ensure protection to people and their pets who contact surface waters with PFAS-containing foams, the public needs to be broadly informed to avoid contact with any foam. Naturally occurring foams can also harbor bacteria and viruses. In areas with known PFAS contamination, targeted risk messages and outreach have also occurred.

According to the State of Michigan (**MI DHHS 2019**), incidental ingestion and extended, recurring, whole-body contact with PFAS-containing foam can result in a public health hazard for children and adults. Where PFAS-containing foam exists, the Michigan Department of Health and Human Services (MDHHS) recommends a health advisory to avoid the incidental ingestion of and whole-body contact with the foam as a precaution.

According to the Minnesota Department of Health (MDH), "PFAS-containing foam on surface water does not pose a risk to human health if skin contact with foam is minor and infrequent" **MPCA 2020**. MDH recommends informing people of observable foams in the PFAS-contaminated areas where concentrated PFAS could be encountered. Additionally, "MDH recommends:

- People and pets should avoid contact with foam on surface waters in this area.
- Wash skin that has come into contact with PFAS-containing foam with soap and water" **MPCA 2020**.

Other states, such as Wisconsin, provide a reporting system for suspected PFAS-containing foam across the state, and provide health advice to avoid the foam (**WI DNR 2022**).
More research is needed to determine how to estimate exposure to people, especially children; pets; aquatic organisms; water birds; and wildlife.

There are limitations on how to account for exposure estimates from foam concentrations, as well as the best way to sample for foam. Because the PFAS-containing foams form at the air-water interface, there are risks for higher exposure to swimmers, dabbling ducks, aquatic insects, etc., that are not accounted for with only collecting water column samples. Broad outreach to avoid any surface water foam is still not occurring.

In addition to outreach and messaging, using authorities from remediation or Clean Water Act regulations is critical for making progress on reducing the risks of PFAS to people and ecological species. Most

states and tribes have narrative standards in their water quality standards that prohibit nuisance conditions on surface waters. These could be applied to restrict sources causing PFAS-containing foams.

15.5.1.7 Take-Aways for PFAS-Containing Foam

Based on this case study, the following takeaways with respect to PFAS-containing foam are:

- Foam occurs on surface water bodies naturally but may contain PFAS compounds when located near a source of PFAS releases. The PFAS-containing foam may look like naturally occurring foam.
- The foam occurs more frequently during precipitation and wind events. The foam appears to be a concentrated form of PFAS compounds, at higher levels than PFAS occurring in the surface water below the foam.
- Based on data collected to date, the predominant forms of PFAS in the foam are the longer chain compounds such as PFOS, PFOA, PFOSA, and N-EtFOSA rather than the shorter chain compounds such as PFBA and PFBS.
- PFAS-containing foam has been found in multiple waters in the Twin Cities East Metro, including waters that border parks and residential areas such as Raleigh Creek and stormwater ponds in Oakdale (including Tablyn Park) and the city of Lake Elmo. PFAS-containing foam has also been found on Battle Creek in Battle Creek Regional Park in St. Paul. This has resulted in the need for institutional controls for new developments and specific outreach by letter to residents.
- The best risk assessment advice is to avoid any surface water foam, because even naturally occurring foam can carry microbial risk to people or pets contacting it.

What PFAS-Containing Foam Is Not

- Not all foam on surface water bodies contains PFAS.
- Where PFAS-impacted surface water exists, PFAS-containing foam may not always be present, as it occurs more frequently with precipitation and wind events.
- PFAS-containing foam may not be removable in all circumstances and may re-occur in locations where it has been previously removed.

More information on Project 1007 is located on the MPCA website (**MPCA 2023**).

15.5.2 Surface Water/Groundwater Interaction Case Study (2023)

As mentioned in Sections **16.4.5**, **5.3.4**, and **10.3.1.2**, surface water/groundwater interaction may play a role in a conceptual site model and locating places to sample. This case study provides three examples where this interaction can impact surface water quality.

15.5.2.1 North Carolina Example

The first example is found in the dialogue box in **Section 16.6.4.1** and looks at PFAS in groundwater impacting surface water. A surface water body in North Carolina was found to have unacceptable concentrations of PFAS. An adjacent industrial facility had caused the groundwater to be contaminated with the same PFAS. An investigation of the groundwater showed that it is discharging to the surface water and contributing approximately 60% of the PFAS load to the surface water. A portion of the remedy for the site included groundwater extraction, treatment, and discharge to reduce the mass flux of PFAS in groundwater to the receiving surface water (**NC DWR 2022**).

15.5.2.2 Minnesota Examples

The second example is from Minnesota and provides a case study of PFAS-contaminated groundwater impacting surface water and PFAS-contaminated surface water impacting groundwater. These processes have significantly contributed to a 150-square-mile PFAS plume in groundwater that has impacted eight municipal water systems and 2,700 individual private water supply wells in Washington County, east of St. Paul. Wastes containing high PFAS concentrations originating at a manufacturing facility were disposed in two off-site landfills and several burial pits at the industrial facility. PFAS contamination in groundwater was found downgradient from the two landfills. Additional locations of groundwater containing PFAS were found in areas that were not expected based on groundwater flow directions (westerly and southwesterly) at the landfills.

As it turns out, surface water emanating from wetlands around one landfill carried PFAS to the east where it infiltrated to groundwater 1 mile downstream. This groundwater resurfaced as surface water and flowed to the east in a system of creeks, ditches, and pipelines that entered several lakes and ponds. Stormwater runoff was conveyed by the same conveyance system providing additional transport of PFAS to the east. The surface water transport and the exfiltration from the conveyance features and lakes/ponds resulted in PFAS in groundwater along the surface water path and downgradient from the lakes. The PFAS contamination along this route was enhanced by the discharge of extracted groundwater containing PFAS and other pollutants adjacent the second landfill to the same stormwater conveyance system discussed above over a period of 7 years. This conveyance system terminates at the St. Croix River 6 miles downstream from the first landfill. Thus, at this site there is PFAS in groundwater, daylighting as a surface water and then re-entering groundwater as the water is transported downstream and temporarily resides in various lakes and pond. This results in exposure through use of the groundwater for municipal purposes and use of the surface waters for municipal purposes, fishing, recreation, and wildlife habitat. (**Regenesis 2019**).

The third example is from Minnesota and is a subset of the second example. In one location overlying the 150-square-mile groundwater PFAS plume is a site where several different mixtures of AFFF were used to put out a fire at a plastics manufacturer. The runoff from the fire suppression went down a ditch to a small surface water body. Migration of surface water to groundwater at that location resulted in contamination of groundwater by PFAS impacting several private water supply wells that were completed on the order of 250 feet in depth. Sampling showed that the less mobile, longer chained PFAS PFOS and PFHxS had the highest concentrations in the sediments along the ditch. The sediments at the surface water body still contained those two PFAS, but not at as high of a proportion relative to the more mobile, shorter chained PFAS PFOA and PFBA as found along the ditch. The water in the surface impoundment had substantially more PFOA and PFBA than PFOS and PFHxS. This shows not only the transport of PFAS in surface water to groundwater, but the changing composition of PFAS in the surface water due to varying portioning properties of PFAS.

15.5.2.3 Summary

These three examples demonstrate the need to assess the potential surface water/groundwater interactions when looking for sources of contamination, routes of exposure, and establishing a CSM. These examples show the potential for adverse impact, but do not provide an assessment of the potential change in PFAS constituents and concentrations that may occur during the movement of water from surface water to groundwater or groundwater to surface water. Those potential changes are associated with biotransformation that may occur due to water chemistry changes in the vicinity of the groundwater-surface water interface. A discussion of this issue is found in **Section 5.3.4.2**). An additional example of PFAS impacts from a groundwater/surface water interaction can be found in **Section 5.3.4**.

16 SURFACE WATER QUALITY

The purpose of this section is to support the PFAS Technical and Regulatory Guidance Document (PFAS Guidance Document) users (state and federal environmental staff, stakeholders, project managers, and decision makers) to gain a working knowledge of the current state of PFAS science and practice for surface water quality. The section does not include calculated criteria, rather it provides available information and references that can then be used to support development or review of criteria or guidance values to protect surface water quality.

Section Number	Topic
1.3	**Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization (2025)**
15.5	**Surface Water Quality Case Studies**
16.1	**Introduction**
16.2	**Protection of Human Health**
16.3	**Protection of Biota**
16.4	**Sampling and Analysis**
16.5	**Surface Water Foam**
16.6	**Effluent Limits for PFAS**
16.7	**Surface Water/Groundwater Interaction**

16.1 Introduction

This section provides information to help fill in the gaps related specifically to concerns with PFAS-impacted surface water and associated receptors. Several states have expressed a need for technical information to support the development of surface water quality criteria (WQC) or guidance values for uses other than drinking water, including but not limited to habitat for fish and other aquatic life. **USEPA (2020)** developed recommendations and provided derivation methods for surface water criteria "for determining when water has become unsafe for people and wildlife using the latest scientific knowledge." States and tribal governments may, and sometimes do, develop their own numerical criteria. To protect human health, the states and tribal governments may also establish water body–specific fish consumption advisories for certain aquatic species. These advisories are recommendations and not enforceable. This section provides technical information regarding PFAS in surface water that individual states and tribal governments can consider when developing criteria according to their own processes and policies. This information focuses on two main issues. First is the protection of human health from a variety of potential exposures to PFAS in surface water, such as drinking water, consumption of fish and other aquatic species, and from recreational activities. Second is the protection of biota, based on available ecotoxicity data, bioaccumulation and concentration factors, and aquatic-dependent wildlife considerations, among others.

USEPA has published draft national recommended aquatic life criteria for PFOA and PFOS in freshwater for public comment (**USEPA 2022**, **2022**) and a fact sheet for the criteria (**USEPA 2022**). In addition, USEPA had published their responses to external peer reviews of the draft criteria (**USEPA 2022**, **2022**). USEPA has also issued two memoranda for National Pollution Discharge Elimination System (NPDES) permits and PFAS. One addresses PFAS under USEPA-issued NPDES permits for wastewater and stormwater discharges (**USEPA 2022**) and the other discusses PFAS in state-issued NPDES permits and pretreatment programs (**USEPA 2022**). As of the writing of this document, there are few formally established surface water criteria for any PFAS that are protective of uses of surface water other than as

drinking water. Florida, Minnesota, and Michigan are examples of states that have aquatic life protection values (see the **Environmental Media Values Table** Excel file).

In addition to the well-established issues associated with PFAS in surface water, such as use of the surface water as a source of drinking water and accumulation of PFAS in biota, this section also includes a discussion of a relatively new issue related to surface water: PFAS-containing foam. Investigations in at least three states—Minnesota, Michigan, and Wisconsin—have found that concentrations of PFAS in surface water, or discharging to surface water, at sufficient levels can generate foam on surface water. That foam acts to remove PFAS from the water column, but also acts as a secondary source of PFAS as the foam leaves the surface water and is deposited in terrestrial or other aquatic locations.

16.1.1 Beneficial Uses

One of the first steps in developing the criteria is to determine the beneficial uses that are to be protected for the water body of concern. These have usually been developed by the state organization responsible for water quality and/or water resources for the state. That regulatory agency assesses potential beneficial uses and assigns appropriate designated uses for a water body. As examples, in Massachusetts this task is the responsibility of the Massachusetts Department of Environmental Protection, while in California it is under the purview of the nine Regional Water Quality Control Boards that establish potential beneficial and designated uses for the water bodies for each region. The process for establishing these beneficial uses in most instances follows protocol developed by **USEPA (2020)**.

With the potential adverse health effects associated with the ingestion of certain levels of various PFAS, negative impacts on beneficial uses of surface water may occur. Table 16.1 provides a fairly comprehensive list of potential beneficial uses for surface water. This table is a compendium taken from the *Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board, Central Valley Region, Fourth Edition, Sacramento and San Joaquin River Basins* (**RWQCB-CVR 2016**). Different jurisdictions use different lists of beneficial uses. The list in **Table 16-1** is used for illustration. For an evaluation of PFAS, the list may be substantially reduced in order to focus on those that are appropriate, as the presence of PFAS may not have an impact on a particular use (for example, navigation). In the table the list has been reduced by separating the beneficial uses that may be impacted by PFAS (light blue) and those that are not likely to be (light green). The list can be further reduced by combining several of the uses that evaluate similar issues, such as aquatic toxicity. As an example, the beneficial uses listed as WARM, COLD, EST, WILD, BIOL, and RARE (see **Table 16.1**) are each designed to protect aquatic species that have a range of attributes. The beneficial use for shellfish could be added to that grouping by expanding the evaluation under it to include benthic organisms and sediment quality.

Refining the list of beneficial uses reduces the number of evaluations to the following groupings:

1. Aquatic toxicity to both water column and benthic organisms. This beneficial use combines those listed as WARM, COLD, EST, WILD, BIOL, RARE, and SHELL in **Table 16-1**.
2. Protection of human health from ingestion of PFAS when surface water is used as drinking water. Listed as MUN in Table 16-1. The values for this are already covered in **Section 8** and in updated tables (the **Environmental Media Values Table** Excel file), and discussed further below.
3. Protection of human health from exposure to PFAS in the consumption of aquatic organisms, including benthic organisms. In Table 16-1 this encompasses the beneficial uses listed as COMM, AQUA, and SHELL.
4. Protection of human health from contact with and ingestion of PFAS in surface water during recreational activities such as swimming and fishing. This beneficial use is listed as REC-1 in Table 16-1.
5. Use of the surface water as an agricultural supply (AGR). Use of the surface water in this manner would allow for the uptake of PFAS into plants used for human and animal consumption, stock watering of animals used for human consumption and animal consumption, as well as recharge of excess water to groundwater or other surface water bodies (return water).

6. Groundwater recharge is also included, but the issues are the same as those for MUN, AGR, and IND as listed in Table 16-1.

Table 16-1. Beneficial Uses.

	Beneficial Use	Description	Does PFAS Have Impact on Use? Covered in this Section
1.	Municipal and Domestic Supply, Use as Drinking Water (MUN)	Uses of water for community, military, or individual water supply systems, including, but not limited to, drinking water supply.	Yes
2.	Agricultural Supply (AGR)	Uses of water for farming, horticulture, dairy operations, or ranching.	Yes
3.	Primary Water Contact Recreation (REC-1)	Uses of water for recreational activities involving body contact with water, where ingestion of water is reasonably possible.	Yes
4.	Groundwater Recharge (GWR)	Uses of water for natural or artificial recharge of groundwater.	Yes
5.	Commercial and Sport Fishing (COMM)	Uses of water for commercial or recreational collection of fish, shellfish, or other organisms.	Yes
6.	Aquaculture (AQUA)	Uses of water for aquaculture or mariculture operations.	Yes—not all components covered under other beneficial uses—harvesting of aquatic plants for human consumption
7.	Warm Freshwater Habitat (WARM)	Uses of water that support warm water ecosystems.	Yes—combine with COLD
8.	Cold Freshwater Habitat (COLD)	Uses of water that support cold water ecosystems.	Yes—combine with WARM
9.	Estuarine and Marine Habitats (EST)	Uses of water that support estuarine and marine ecosystems.	Yes—combine with WARM and COLD for ecotoxicity for all of the aquatic species
10.	Wildlife Habitat (WILD)	Uses of water that support terrestrial or wetland ecosystems.	Yes—food chain issues, in addition to WARM, COLD, and EST
11.	Spawning, Reproduction, and/or Early Development (SPWN)	Uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish.	Yes
12.	Shellfish Harvesting (SHELL)	Uses of water that support habitats suitable for the collection of filter-feeding shellfish.	Yes
13.	Hydropower Generation (POW)	Uses of water for hydropower generation.	No—PFAS not expected to impact POW
14.	Industrial Process Supply (PRO)	Uses of water for industrial activities that depend primarily on water quality.	No—as below for IND
15.	Freshwater Replenishment (FRSH)	Uses of water for natural or artificial maintenance of surface water quantity or quality.	No—issues covered under other beneficial uses
16.	Non-contact Water/Secondary Contact Water Recreation (REC-2)	Uses of water for recreational activities involving proximity to water, but where there is generally no body contact with water, nor any likelihood of ingestion of water.	No
17.	Preservation of Biological Habitats of Special Significance (BIOL)	Uses of water that support designated areas or habitats, such as established refuges, parks, sanctuaries, ecological reserves, or Areas of Special Biological Significance, where the preservation or enhancement of natural resources requires special protection.	Not covered individually—covered under WARM, COLD, EST, and WILD
18.	Rare, Threatened, or Endangered Species (RARE)	Uses of water that support aquatic habitats necessary, at least in part, for the survival and successful maintenance of plant or animal species established under state or federal law as rare, threatened, or endangered.	Not covered individually—covered under WARM, COLD, EST, and WILD
19.	Migration of Aquatic Organisms (MIGR)	Uses of water that support habitats necessary for migration or other temporary activities by aquatic organisms, such as anadromous fish.	No—issues already covered under other beneficial uses
20.	Industrial Service Supply (IND)	Uses of water for industrial activities that do not depend primarily on water quality, such as mining and cooling water.	No—concern is the discharge of the water to another location
21.	Navigation (NAV)	Uses of water for shipping, travel, or other transportation by private, military, or commercial vessels.	No—PFAS not expected to impact navigation

*Source: Adapted from **RWQCB-CVR (2016)**.*

These beneficial use groupings were used to identify the topics to be included in the remainder of this section.

16.1.2 Existing Methods of Protecting Surface Water for Beneficial Uses

This section provides information about the existing methods that regulatory agencies or organizations with jurisdiction use for protecting surface water bodies from discharges of various pollutants. This information provides context for what may be implemented to address potential sources of PFAS in surface water.

After establishing the beneficial uses for a given body of water (lake, stream, creek, estuary, ocean) the regulatory agency or organization implements processes designed to protect those beneficial uses. Typically, this begins with establishing water quality protectiveness standards/criteria or guidance values to protect those specific beneficial uses. As an example, to protect aquatic species, values are established for protection of the health of the fish to allow them to continue to exist in the environment and breed without curtailment. If the fish species is fished for human consumption, then values are also established to allow for fishing to occur without unacceptable effects on those consuming the fish. As values are established for each of the beneficial uses assigned for the water body, the most stringent of the values can be used as the value that is protective of all the designated beneficial uses. In that instance, that value would be used for comparison to other beneficial use values instead of individual values for drinking water and fish protection. For PFAS those values are just beginning to be established.

Once the protective value for the water body has been established, regulatory mechanisms exist to protect the water body to maintain or reduce the concentrations to below the protective values. Discharges to surface water are regulated by state- or federally issued permits. Effluent limits are established in those permits for constituents that could pose a threat to water quality. Establishing appropriate chemical-specific effluent limits protects beneficial uses. The effluent limitations are set so that the concentrations in the surface water body stay below the protective values. In addition to chemical-specific effluent limitations, the permits typically establish acceptable toxicity limitations that must be met in the total effluent. Both effluent and toxicity limitations can take into account mixing with the surface water body within a permitted mixing zone (dilution).

If a water body already has concentrations that are greater than the protective value, then the regulatory agency can establish total maximum daily loads (TMDLs). The TMDLs identify maximum mass discharges for the chemicals that exceed protective values and are used to identify mass loading limits on discharges in the watershed for that water body. Additionally, TMDLs have a component for evaluation of nonpoint sources of discharge within the watershed that include the chemical of concern. If needed, regulations of these nonpoint discharges could be adopted to also limit those discharges. Often, best management practices are established as the control mechanism for nonpoint discharges. If nonpoint discharges are the primary contributor of the pollutant, alternate approaches, such as watershed restoration plans, may be established in lieu of TMDLs. These plans can include best management practices and pollutant minimization components.

During times when a protective value is exceeded and before corrective measures are taken to bring concentrations down below those values, temporary use restrictions can be issued to protect users of the water body. Examples of such restrictions include banning recreation or issuing fish advisories that recommend restricting consumption of various fish species. If the water is being used as a source of drinking water, additional water treatment could be required.

Effluent limitations, TMDLs, watershed restoration plans, and use restrictions have been effective in protecting beneficial uses and reducing risk to receptors for numerous chemicals. It is likely that these measures will also be useful in addressing PFAS.

16.1.3 Status of State and Federal Surface Water Protection Efforts Regarding PFAS

At the time of publication, there were no national surface water values for PFAS in the U.S., and only a handful of states have addressed PFAS in surface water; see the **Environmental Media Values Table** for updates. Many of the challenges or obstacles to developing surface water criteria are the same as for groundwater, including the large number of individual PFAS, many of which lack toxicity and published physical and chemical properties data. In addition, surface water is used in a greater number of ways than groundwater, representing potential direct exposure routes through dermal contact and water ingestion, and indirect exposure through consumption of fish and shellfish. On October 18, 2021, the USEPA announced its PFAS Strategic Roadmap (**USEPA 2021**). The Roadmap includes actions that are planned to be undertaken by USEPA. Pursuant to the roadmap, USEPA published draft recommended ambient water quality criteria for the protection of aquatic life in June 2022 for PFOA and PFOS (**USEPA 2022**). USEPA also issued health advisories for PFOA and PFOS in June 2022 (**USEPA 2022**, **2022**) and surface water quality criteria for the protection of human health are expected fall 2024. In addition, USEPA is increasing the availability of data on PFAS in fish tissue that can be used to finalize the list of PFAS for establishing fish advisories.

Enforceable vs. Nonenforceable Federal and State Values

Standard – Promulgated values that are enforceable. Example: primary drinking water standard or maximum contaminant level

Criteria – Recommended nonenforceable values that can be used to establish a standard. Example: USEPA water quality criteria

Screening/Guidance Levels – Nonenforceable values that usually represent a de minimus risk and can be used to determine if further action may be necessary. Example: USEPA regional screening levels, action-levels.

At the state level, surface water criteria development has taken a range of approaches. Alaska has adopted health advisory levels for surface water used as drinking water. These levels are used as action levels and are not enforceable under the Clean Water Act. Michigan, Minnesota, and Florida developed their own statewide criteria based on water and fish consumption using state-specific inputs and addressed PFOA and PFOS. Other states are in the process of collecting data or evaluating what approach to take to develop their own criteria in the absence of federal guidelines. Wisconsin is collecting surface water and fish tissue data to support calculation of surface water values. New Hampshire and Vermont have released detailed reports outlining potential strategies and associated costs and timing for developing state criteria. The plan from Vermont describes how its Agency of Natural Resources has developed a framework to establish water quality standards and how it may apply to developing such standards for protection of human health and aquatic life from PFAS. The report concludes that technical challenges and the constraints of deriving water quality criteria (WQC) for PFAS are "logistically difficult, would take a long time, and be very expensive." It recommends developing fish consumption advisories, tracking USEPA development of aquatic biota criteria for PFAS, incorporating USEPA criteria when they are developed, and continued collaboration with New England states on developing plans for deriving water quality standards (**Vermont DEQ 2020**). The number of states that have established values for protection of aquatic life is small and includes Michigan and Florida, see the **Environmental Media Values Table** for updates to state values.

Surface water criteria are generally established by the states, either by adopting values recommended by USEPA per section 304(a) of the Clean Water Act, or by calculating state-specific criteria that must be approved by USEPA. States have specific responsibilities when setting surface water criteria and submitting that information to USEPA:

- Water bodies must have an appropriate designated use or uses.
- The WQC must support those uses.
- Antidegradation policies to protect high-value waters must be adopted.
- The status of waters must be monitored.

- The standards must be revisited on a regular basis and if a revision is required, the state must obtain USEPA approval.

Most states are still in the process of assessing the extent of PFAS in their surface waters, some only at specific potential source areas.

16.1.4 Survey of States

In the spring of 2020, the ITRC PFAS team sent a survey to the states to gather information on their efforts to address PFAS in surface water. The survey included questions on what media states are monitoring for PFAS, whether PFAS have been detected in surface water, if the states have fish consumption advisories in place for any PFAS, and if the states are contemplating developing surface water quality criteria or guidelines. Other questions addressed the availability of data and information on sampling methods, PFAS-containing foam, and whether states have restrictions to minimize the discharge of PFAS to surface water.

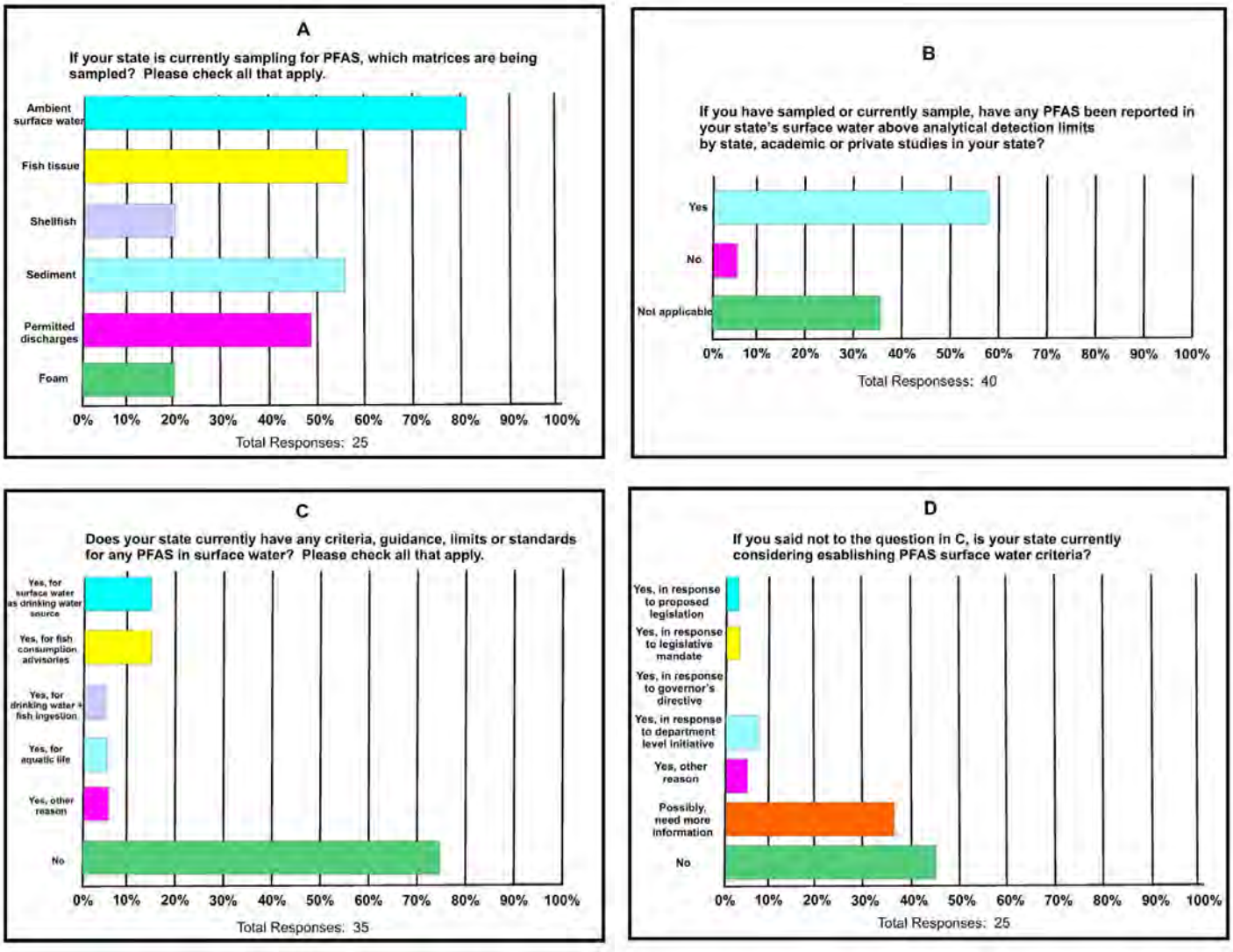


Figure 16-1A-D. Summary of Key Responses from the ITRC State Survey (2020).

A total of 42 states submitted responses. A summary of key responses is provided in Figures 16-1A-D. These show that of the different media being sampled, 80% of the states are sampling surface water (Figure 16-1A), and of those sampling for various PFAS in surface water, almost 60% detected one or more PFAS (Figure 16-1B). It was determined that 75% of states do not have any criteria, guidance, limits, or standards for PFAS in surface water (Figure 16-1C); however, it is noted that 16% do have some protective measure for surface water that is used as drinking water and 16% have guidance related to fish consumption advisories. Lastly, although 46% of the states were not considering development of criteria for PFAS in surface water, almost 40% felt they needed more information (Figure 16-1d); the remainder are currently developing criteria in response to proposed legislation, legislative mandates, or in response to department-level initiatives. For states that have developed surface water quality values, twice as many states reported using USEPA guidance for developing the values versus those using other procedures and methods.

Given the rapid pace in the state-of-the-science for PFAS and the desire for PFAS regulations in many states, it is likely there are updates since the time the survey was conducted. However, the PFAS team used the information from the survey to inform what areas to focus on in this surface water quality section and to document the fundamentals for states to consider when developing surface water quality protective values for PFAS. Where relevant, pertinent information from the survey is included in Sections 16.2–16.5.

For updates about states that have developed standards/guidance/limits, see the **Environmental Media Values Table** Excel File.

16.2 Protection of Human Health

This section discusses the human health aspects of PFAS in surface water. There are other sections in this document that discuss general human health–related PFAS issues in detail that supplement the information in this section. Those sections are **Section 7.1**, Human Health Effects and **Section 9.1**, Site Risk Assessment, Human Health.

Under the federal Clean Water Act, states must adopt water quality standards that consist of both designated uses and numerical and/or narrative criteria to protect these uses. As described in **Section 16.1**, a designated use (also called a "beneficial use" or "designated beneficial use") in some states is a use of surface waters that is considered desirable and should be protected. As noted in **Table 16-1**, surface waters have many different beneficial uses, some of which are relevant to human health and some that are not. Uses that are most relevant to human exposure and are considered for most chemicals include municipal and domestic supply (also referred to as drinking water use); agricultural supply (also commonly referred to as irrigation); primary contact recreation; secondary contact recreation/noncontact water recreation; commercial, subsistence, and sport (recreational) fishing (referred to in some states as fish ingestion); and aquaculture (also focused on fish ingestion).

In relation to beneficial uses, the exposure pathways for contaminants in surface water that most warrant consideration of human health for PFAS are included in **Table 16-2**.

Regulatory agencies use relevant and appropriate use-specific exposure factors combined with chemical-specific toxicity factors (reference doses; cancer slope factors) to develop ambient water quality criteria (AWQC) that are protective of human health for these uses and exposure pathways. The exposure pathways usually considered in development of AWQC are drinking water ingestion (for waters designated for drinking water use) and consumption of aquatic organisms.

At this time, exposure pathways involving ingestion are considered to be the most significant PFAS exposure sources. Recreational uses of surface waters for secondary contact activities, such as wading

and boating, which do not involve immersion but may result in dermal contact with water, are considered to be insignificant sources of PFAS exposures. See **Sections 17.2.2** and **17.2.3**.

Table 16-2. Exposure Pathways in Relation to Beneficial Uses.

Beneficial Use	Associated Human Exposure Pathway for PFAS
Municipal and domestic supply; use as drinking water	Drinking water ingestion and dermal contact during household use; secondary uses may include irrigation for home gardening and produce consumption
Commercial, subsistence, and sport (recreational) fishing	Consumption of aquatic organisms (fish and shellfish) that may bioaccumulate PFAS from surface water
Primary contact water recreation	Incidental ingestion and dermal contact with water and/or foam during immersion activities such as swimming, waterskiing
Non-contact/secondary contact water recreation	Dermal contact with water and/or foam during nonimmersion activities such as wading, boating, fishing; exposures considered to be insignificant for PFAS
Agricultural supply	Consumption of crops, dairy products, and meat that may bioaccumulate PFAS from irrigation water; some states may also consider direct contact with irrigation water
Aquaculture	Consumption of aquatic organisms (fish and shellfish) that may bioaccumulate PFAS from aquaculture water

Human health criteria for contaminant concentrations in surface water that are protective of fish consumption are also relevant to PFAS exposures. Additionally, some states have developed fish consumption advisories that recommend the frequency of consumption for recreationally caught fish based on levels of contaminants, including PFAS, measured in fish tissue from certain geographic regions or in specific water bodies (**Section 16.2.2.6**).

The salinity of the surface water body influences the beneficial uses considered and what type of criteria are appropriate (**USEPA 2002**, p.9). Freshwater criteria apply to waters with salinity less than one part per thousand. Saltwater criteria apply to waters with salinity greater than 10 parts per thousand. The more stringent of freshwater and saltwater criteria apply to waters with salinity between 1-10 parts per thousand. In general, saltwater criteria consider only the consumption of aquatic organisms (fish and shellfish), while freshwater criteria may consider exposure through consumption of aquatic organisms and/or drinking water. The designated uses for freshwater bodies may vary from state to state based on policy and/or actual uses as some water bodies may not support both potable use and aquatic biota consumption. Thus, criteria can be developed for the fish/shellfish consumption pathway alone or for the potable use and fish/shellfish consumption pathways combined. Surface water criteria are usually not developed for potable use alone and generally defer to guidelines such as maximum contaminant levels (MCLs) and maximum contaminant level goals (MCLGs) developed by USEPA and other agencies under drinking water programs. The combined use criterion will be more stringent than the criterion for consumption of organisms only for reasons detailed below.

16.2.1 Input Factors for Development of Surface Water Criteria and Fish Consumption Advisories

Section 16.2.2 includes information and an example equation used to develop human health criteria for relevant exposure pathways. **Section 16.2.2.6** provides information and an example equation used to develop fish consumption advisory triggers.

16.2.1.1 Toxicity Values

The development of toxicity values for PFAS is an evolving and dynamic field. Changes in methodology and values, as well as the number of PFAS with toxicity values, should be expected. As a result, the information in this document is current as of March 2023 and the reader is encouraged to consult the most current information at the time of use.

The toxicity values used for both human health criteria and fish consumption advisories are oral reference doses (RfD, ng/kg/day or mg/kg/day) for noncarcinogenic effects and oral cancer slope factors (mg/kg/day)-1 for carcinogenic effects. States may base their WQC and fish consumption advisories on toxicity values recommended by USEPA or toxicity values from sources other than USEPA or develop their own toxicity values (see **Section 8.3** for more detail). The toxicity values used for PFAS vary among agencies based on different choices of critical toxicological effect, uncertainty factors, exposure assumptions, and other considerations.

As of early 2023, the USEPA had either proposed or adopted toxicity factors for a limited number of PFAS but had not established surface water criteria for protection of human health. When information becomes available to develop surface water criteria for a PFAS, USEPA may follow a tiered process in selection of toxicity values, as it has done when developing criteria for other contaminants. When USEPA last updated its human health criteria (**USEPA 2015**), its primary source of updated toxicity values was the Integrated Risk Information System (IRIS), Other sources of toxicity values, for contaminants other than PFAS, reviewed by USEPA in its 2015 update of human health criteria include:

- USEPA Office of Pesticide Programs
- USEPA Office of Pollution Prevention and Toxics
- USEPA Office of Water
- USEPA Office of Land and Emergency Management (for example, Provisional Peer Reviewed Toxicity Values (PPRTVs))
- Agency for Toxic Substances and Disease Registry (ATSDR)
- Health Canada
- California EPA's Office of Environmental Health Hazard Assessment

The **USEPA (2015)** updates used a toxicity factor from one of the non-IRIS sources listed above if no IRIS toxicity factor was available, or if the toxicity factor from another source used a newer study or a more current risk assessment approach than IRIS.

USEPA toxicity factors for a limited number of PFAS are at different stages of development and adoption for use in human health risk assessment. The USEPA's PFAS Action Plan, which was first developed in 2019 and updated in 2020 (**USEPA 2020**), states that USEPA will evaluate several PFAS for development of toxicity values. Since then, USEPA has finalized toxicity assessments for a number of PFAS (See **Section 7.1**) which for some, serve as the basis of USEPA's final PFAS National Primary Drinking Water Regulation (**USEPA 2024**). Refer to **Section 7.1** for updates on PFAS toxicity assessments and information on PFAS health effects, and **Section 9.1** for information on the use of PFAS toxicity values in human health risk assessment.

16.2.1.2 Protected Populations and Target Risk Levels

The protected populations that are considered in the development of surface water criteria for human health typically include adults. In some cases, other populations, such as lactating women, women of childbearing age, children, and infants, may also be explicitly considered separately, depending on the nature of the chemical and the exposure route. As discussed in **Section 16.2**, the human health criteria most relevant to PFAS consider ingestion of aquatic organisms (fish and shellfish) and/or drinking water. In general, when calculating criteria for a surface water body that is used for both drinking water and fish

consumption purposes, exposure from ingestion of aquatic organisms will likely be greater than exposure from drinking water for PFAS such as PFOS that bioaccumulate in aquatic life when default ingestion rates and bioconcentration factors are assumed.

In the development of human health WQC based on standard exposure assumptions, the relative doses from fish consumption and drinking water are dependent on the bioconcentration factor (BCF) or bioaccumulation factor (BAF), the target population, and their assumed intake rates. The assumed daily dose from fish consumption (22 g/day) is greater than the assumed daily dose from drinking water ingestion (2.4 L/day) for bioaccumulative PFAS such as PFOS (see Sections **16.2.1.3** and **16.2.1.4**). However, exposures to bioaccumulative PFAS in drinking water are higher in infants, particularly in those that are breastfed, than in adults, and infants are considered to be a sensitive subpopulation for adverse effects of PFAS (**Goeden, Greene, and Jacobus 2019**). In contrast to human health criteria for surface water, drinking water guidelines for PFAS developed by USEPA (**USEPA 2016**, **USEPA 2016**) and some states are based on exposure assumptions or exposure modeling for sensitive life stages (for example, lactating women, infants (**Post 2021**)). Minnesota (**MPCA 2020**) has recently used modeling of early-life exposure in formula-fed and breastfed infants, as well as a higher fish consumption rate specific to women of childbearing age (**MPCA 2020**), to develop a human health surface water criterion for PFOS; they also developed a human health-based criterion for PFOS in fish tissue.

A target cancer risk level is used along with the cancer slope factor in calculation of criteria based on carcinogenic effects. The selection of the lifetime cancer risk level is a policy choice, not a scientific decision, and the target cancer risk level (for example, 1 in 100,000 or 10-5; 1 in 1,000,000 or 10-6) differs among states, which is one reason why criteria based on cancer risk can vary among different states. Criteria for noncarcinogenic effects are developed such that exposure to the contaminant will not exceed the RfD. When chemicals have the potential to exert both carcinogenic and noncarcinogenic effects (for example, PFOA), the final criterion may be based on the lower of the criteria based on cancer and noncancer effects.

16.2.1.3 Exposure Factors

The exposure factors typically considered in development of criteria for ingestion of drinking water and/or aquatic organisms include assumed body weight, drinking water and/or aquatic organism (fish/shellfish) consumption rates, and relative source contribution (RSC). These exposure factors and their use in developing criteria are described below.

As previously stated, the default adult body weight is usually used when developing human health criteria. USEPA currently recommends a default adult body weight of 80 kg for development of human health criteria (**USEPA 2015**). However, some states' criteria are based on the older recommended value of 70 kg. Alternative body weight assumptions for specific ages, sexes, or other subgroups can be found in the USEPA Exposure Factors Handbook (**USEPA 2011**), and certain states may use these values.

States typically use default ingestion rates recommended by the USEPA for the specified environmental media, for example, drinking water or fish tissue; however, some states use state-specific values, especially for fish ingestion. The adult drinking water consumption rate is usually used for human health criteria. In 2015, USEPA updated its recommended default adult drinking water consumption rate for human health criteria from 2 L/day to 2.4 L/day (**USEPA 2015**). It is noted that the relevant body weight-normalized exposure parameter (L/kg/day) is 0.03 L/kg/day with the updated body weight and ingestion volume, which represents a very small change from 0.029 L/kg/day based on the older values. Similarly, USEPA also updated the default rate of 22 g/day for fish consumption from the previous value of 17.5 g/day (**USEPA 2015**). Some states consider state- or region-specific rates that have been developed based on consumption data from their region, including higher consumption rates by tribes and/or for subsistence fishing in some cases (**USEPA 2014**).

Under current **USEPA (2000)** guidance, an RSC is used when a human health criterion is based on an RfD (noncancer effects), and USEPA used an RSC (**USEPA 2015**) in its updates of noncarcinogenic criteria. The RSC accounts for potential non-drinking water exposures to chemicals and is used in the development of health-based guidance and standards developed by the USEPA and related state programs. Conceptually, the RSC is the percent of total exposure assumed to come from exposure arising from surface water (ingestion of water and aquatic organisms, or ingestion of organisms only) at the criterion concentration (for example, an assumed RSC of 20% for a drinking water criterion means that the target population is assumed to be exposed to 80% of the RfD from non-drinking water sources). It is intended to ensure that total exposure from all sources (surface water and non-surface water–related) does not exceed the RfD. USEPA guidance specifies an RSC of 20–80 percent, with a default of 20 percent (the most stringent possible value) when data to derive a chemical-specific value are not available (**USEPA 2015**). Some states and USEPA use the 20 percent default value in their PFAS drinking water guidelines, while other states (for example, MN, NH, NY) use higher RSC values based on estimates of non-drinking water exposures from human biomonitoring data or in consideration of certain life stages.

16.2.1.4 Bioaccumulation, Bioconcentration, and Biomagnification Factors

Water to fish transfer factors are useful in the development of water quality criteria and to inform risk-based evaluations. Three types of factors can be used by risk assessors to relate environmental concentrations of a chemical (for example, in water, sediment, soil, or prey) to concentrations within certain organisms. These factors include bioaccumulation factors (BAF), bioconcentration factors (BCFs), biomagnification factors (BMFs) and associated trophic magnification factors, each of which are defined in the text box below, and detailed in **Section 5.5**. These factors are frequently used for risk assessment of biota such as fish and shellfish consumption by human fish consumers, as well as wildlife. The USEPA has outlined methods for developing BAFs, which are recommended for risk assessment of most chemicals, whereas BCFs and BMFs typically provide useful information about the fate, transport, and ecological risks of chemicals (**USEPA 2003**).

Certain PFAS are highly bioaccumulative in aquatic organisms such as fish, and this is especially true for long-chain PFAS such as PFOS. For the risk assessment of bioaccumulative and bioconcentrating chemicals such as PFAS, BAFs or BCFs should represent the tissues that are consumed by humans (for example, fillets or muscle tissue) and should also represent the trophic level of the fish species of interest (for example, secondary consumer or top-level predatory fish). Both BAFs and BCFs are specific to the chemical and organism in which it is detected. For BCFs, BAFs, or BMFs, larger values indicate greater accumulation in organisms, which in turn result in lower surface water criteria. At this time BCFs, BAFs, and BMFs for PFAS are primarily based on measured data. Examples of these values for PFAS in aquatic organisms are available in Table 5-1 (as a separate Excel file) and discussed in **Section 5.5**.

Transfer Factors

Bioconcentration factors (BCF, L/kg) represent the direct uptake of PFAS by an organism from the water column (through the gills) and are measured as the ratio of the concentration in an organism to the concentration in water. Typically derived from laboratory studies.

Bioaccumulation factors (BAF, L/kg) represent the amount of PFAS taken up from bioconcentration plus the contribution of PFAS in the diet of that organism. Typically estimated from field studies.

Biomagnification factors (BMF; typically unitless) describe the increase in tissue concentration as one moves up the food chain based on a predator/prey relationship (always measured in the field); often defined as the concentration of chemical in an organism divided by the concentration of chemical in its food.

Trophic magnification factors (TMF; typically unitless) express the change in contaminant level per trophic level, and therefore describe the biomagnification between different trophic levels of the food web.

When the standard USEPA equation shown in the text box in **Section 16.2.2** is used with standard exposure assumptions (drinking water ingestion – 2.4 L/day; fish consumption – 22 g/day) to develop human health criteria, the assumed contribution to total exposure from fish consumption is greater than

from drinking water when the BCF or BAF is >110. As the numerical value of the BCF or BAF increases, the proportion of assumed exposure from fish consumption continues to increase. Given the mathematical impact of BAFs, BCFs, and BMFs on resulting WQC, there are several considerations for data use and applicability. One example of these considerations is the applicability of values estimated from studies on nonnative species or from water bodies with different water chemistry from the sites intended for protection. The use of central tendency versus upper percentile values may result in less stringent criteria but may be less appropriate in cases where BAFs for a given compound vary by orders of magnitude. The USEPA encourages the use of site-specific modification to BAF, BCF, and BMF selection where such decisions are appropriate and scientifically defensible (**USEPA 2000**).

16.2.2 Human Health Criteria Development for Beneficial Uses of Surface Water

As shown below, USEPA's standard equation for development of surface water criteria incorporates terms related to receptor characteristics, exposure, and toxicity values, as described in earlier sections.

It is noted that the USEPA (**2015**) updated human health ambient water quality criteria describe a similar but more complex equation incorporating trophic level–specific fish consumption rates and BAFs (or BCFs) when available. However, this approach does not appear to be applicable to PFAS since current evidence indicates that BAFs for PFAS are not clearly associated with trophic level, and trophic level–specific BAFs have not been developed for PFAS.

Standard USEPA Equation for Combined Drinking Water + Fish/Shellfish Consumption

$$SWC = \frac{RfD \times BW \times RSC}{DI + ((BCF \text{ or } BAF) \times FIR)}$$

SWC = surface water criterion (mg/L)

RfD = reference dose (mg/kg/day)

BW = body weight (kg)

RSC = relative source contribution (unitless)

BCF = bioconcentration factor (L/kg)

BAF = bioaccumulation factor (L/kg)

FIR = fish ingestion rate (kg/day)

DI = drinking water ingestion rate (L/day)

USEPA (2000)

This section outlines issues that are relevant to development of surface water criteria for specific beneficial uses. These criteria are based on the protection of human health from exposure via intentional ingestion of contaminated media, including:

- drinking water use, **16.2.2.1**
- subsistence, commercial, and sport fishing, **16.2.2.2**
- drinking water combined with subsistence, commercial, and sport fishing, **16.2.2.3**
- contact recreation (incidental ingestion of and skin contact with surface water, sediment, and PFAS-containing foam), **16.2.2.4**
- use for agriculture, **16.2.2.5**
- fish consumption advisories, **16.2.2.6**.

Using USEPA methodology, the surface water criteria described in Sections **16.2.2.1**, **16.2.2.2**, and **16.2.2.3** can be derived using a variant of the equation in the text box to the right. As described in Sections **16.2.2.1** and **16.2.2.2**, terms accounting for exposure from drinking water or fish consumption can be removed as appropriate for the designated use of the water body.

The Environmental Council of the States (ECOS) published their updated white paper, Processes and Considerations for Setting State PFAS Standards in March 2023 (**ECOS 2023**).

16.2.2.1 Waters Designated for Domestic/Municipal Supply (Drinking Water Use)

As noted earlier, surface waters that are designated only for drinking water use may use drinking water guidelines already developed by USEPA or state agencies as WQC. Current state and federal drinking

water guidelines for PFAS are found in Environmental Media Values Table Excel File. How certain states apply this may depend on certain regulatory considerations and authorities (**ECOS 2023**). Some states derive this type of surface water criterion using the equation above but omit the denominator terms for bioaccumulation/bioconcentration factors and fish ingestion rates. This equation determines a drinking water value based on human health risk assessment but does not include consideration of analytical or treatment removal factors. Additional discussion of drinking water guidelines may be found in **Section 8.3**.

Numerically, surface water quality criteria for the protection of drinking water may be the same as or differ from drinking water standards such as MCLs, which apply to public water systems, or ambient groundwater quality standards. Drinking water standards such as MCLs are often higher than the strictly health-based goals derived by the previously described equation because they consider analytical and treatment limitations, which consider higher values. In contrast, surface water criteria do not consider these factors. However, almost all the current state and federal drinking water guidelines for PFAS are set at health-based goals because analytical and/or treatment removal considerations are not included as limiting factors in the development of the guidelines. Some states may have the authority to adopt existing drinking water values, such as MCLs, as surface water quality criteria for the protection of drinking water sources. This varies due to states' regulatory authorities and definitions of surface waters considered acceptable for potable use. Alternatively, some states may derive criteria that differ from drinking water guidelines due to consideration of drinking water use combined with other designated uses such fish/shellfish consumption.

16.2.2.2 Waters Designated for Subsistence, Commercial, and Sport (Recreational) Fishing (Consumption of Aquatic Organisms [Fish and Shellfish] Only)

Surface water criteria for fish and shellfish consumption rely on assumptions about consumption rates as well as the relationship between chemical concentrations in water and the resulting tissue concentrations in consumed aquatic organisms.

Default fish consumption rates recommended by USEPA and choices made by states to reflect regional consumption patterns were discussed in **Section 16.2.1.3**. The quantifiable relationship between chemical concentrations in water and the concentrations in tissue is represented by transfer factors such as BCFs, BAFs, or BMFs, which are defined in **Section 5.5** and included in the text box in **Section 16.2.1.4**.

The equation used to derive this type of criterion, using USEPA methods, would be the equation in the box above but omitting the drinking water ingestion rate. This equation relies on toxicity values (**Section 16.2.1.1**) and exposure factors (**Section 16.2.1.3**), as well as BAFs or BCFs for the specified chemical. More stringent toxicity values, higher exposure factors (for example, fish consumption rates), or larger BAFs or BCFs result in lower surface water criteria. For example, criteria based on the higher fish intake rates for subsistence fish consumers would be more stringent than criteria based on the average intake rates for U.S. consumers or sport fishers. Depending on state level or regional policies, such criteria may be developed separately for sport (recreational) and subsistence fishing practices. Aquaculture operations may be required to meet similar criteria for rearing, harvesting, or selling fish depending on the regulatory authority of certain states. This type of surface water criteria is typically developed in consideration of fish, especially predatory fish, as these are more commonly caught and consumed by the public than are shellfish. However, similar criteria can be developed for shellfish (for example, bivalves and crustaceans) using similar risk assessment methods.

16.2.2.3 Waters Designated for Combined Use as Drinking Water and for Subsistence, Commercial, and Sport (Recreational) Fishing

Freshwaters may support and/or be designated for both drinking water and fish consumption beneficial uses. This requires consideration of factors discussed in Sections **16.2.2.1** and **16.2.2.2**. The full

equation in the box above provides the USEPA method for deriving this type of criteria. Default input values would be similar to those listed for each use separately. Surface water criteria established for both drinking water and fish consumption will be more stringent than criteria for either use alone.

16.2.2.4 Waters Designated for Contact Recreation

WQC for recreational contact, such as swimming and wading, consider exposure primarily due to incidental ingestion and dermal contact with surface water, sediments, and potentially PFAS-containing foams. There is no standardized equation for development of criteria protective of exposure to recreational water, but certain equations in the USEPA's Risk Assessment Guidance for Superfund (RAGS) provide a framework for developing screening levels for recreational contact (**USEPA 2004**). Specifically, equations for estimating chemical intake by incidental ingestion of water and dermal absorption from water during swimming or wading are available in Chapter 3 of the RAGS Part E, Supplemental Guidance for Dermal Risk Assessment (**USEPA 2004**). There are several gaps in the current literature that limit the application of these equations, including scant information on skin permeability of several PFAS and how distribution in the water column influences dermal contact and potential for exposure to aerosols. Knowledge regarding volatilization and inhalation exposure is still evolving at this time.. Currently available information on partitioning of PFAS to air and the air/water interface is reviewed in Sections **5.2.4** and **5.2.4.1**.

Dissolved-Phase PFAS

At this time, primary or secondary contact recreation with surface water is not expected to be a significant pathway for human exposures to PFCAs and PFSAs (for example, PFOS) as compared to drinking water or to consumption of aquatic organisms. Current evidence suggests that PFAS are poorly absorbed through the skin (discussed in **Section 17.3.1.2**). Studies performed by some state agencies estimated the risks associated with observed PFAS concentrations in water via recreational exposures such as swimming, and concluded that the risks were low (**MDHHS 2019**, **MDH 2019**, **Vermont DEQ 2020**, **MPCA 2020**). Recreational screening levels are likely to be orders of magnitude higher than concentrations that are protective of consumption fish/shellfish, drinking water use, or some estimates of toxicity toward aquatic wildlife. However, there is uncertainty regarding dermal absorption capabilities (for example, skin permeability coefficients) of most PFAS, both short- and long-chain, that would have a significant impact on derived guidance values. One additional area of concern may come with inhalation in an environment where water-to-air transfer may occur from aerosol-borne PFAS in sea sprays or dam mist near known source areas (**Johansson et al. 2019**). Knowledge in these areas and knowledge regarding the volatilization and inhalation potential of PFAS is very preliminary, still evolving, and subject to change (see **Section 5.3**).

PFAS in Foams

In contrast to dissolved-phase PFAS, PFAS-containing foam may occur at and above the air-water interface on surface waters (see **Section 16.5** for details). However, as noted in Section 16.5, the presence of foam does not necessarily indicate the presence of PFAS. That said, observations concerning PFAS-containing foams present in surface waters have been reported in several states and present concerns for exposure from prolonged skin contact or incidental ingestion by small children. Unlike PFAS dissolved in water, foams may remain on the skin for a longer period, which may elicit public concerns. There are currently no WQC for the formation of foams, but some states may consider developing contact standards for exposure to foams. As noted above, a critical parameter in developing risk-based screening levels for recreational contact is the skin permeability coefficient, which is a measure of dermal absorption. There is currently high uncertainty and limited information available regarding skin permeability for PFAS (see **Section 17.3.1.2**), and this lack of data poses major challenges to risk assessment for human dermal contact with PFAS. It is anticipated that exposure to PFAS-containing foam on surface waters poses a significantly lower risk to human receptors than direct

ingestion from food and water, but if combined with drinking water or occupational exposure, could pose an added toxicological burden.

Using a similar approach to that described above, along with USEPA guidance (**USEPA 2000**, **2011**, **1989**), some states may decide to develop surface water criteria for PFAS-related foams. However, these surface water criteria would likely be far higher than any criteria needed to protect surface water for other uses by humans and wildlife and would be applicable to a limited number of sites. Some states, such as Minnesota, have published qualitative guidelines (**MPCA 2020**). In the future, some states may develop human health-based criteria for PFAS-containing foams in surface waters that would be protective of recreational exposures such as swimming and wading. It is also challenging to sample foam in surface waters, as described in **Section 16.5**.

16.2.2.5 Waters Designated for Agricultural Supply

One of the beneficial uses of fresh water is agricultural supply, for irrigation of crops for direct human consumption and silage for dairy or beef livestock that may ultimately lead to indirect human consumption (milk or beef ingestion). Since PFAS are known to bioaccumulate and have been detected in edible crops, produce, dairy, and meats (**Section 5.6**) (**ATSDR 2018**; **USFDA 2019**), there are potential concerns regarding acceptable levels of PFAS in surface water that will be protective of human health if used for irrigation of crops and silage.

The rapidly expanding literature about PFAS uptake into crops is useful in identifying a few general trends and is discussed in depth in Sections **5.2.3** and **5.6**. The potential for PFAS bioaccumulation in plants ranges from low (0.1) to approximately 10 times the soil concentration in many studies, although plants with high water content (for example, lettuce) could exhibit considerably higher bioaccumulation of certain PFAS (see **Table 5-2**, provided as a separate Excel file and discussed in **Section 5.6.2**). Chain length is a significant factor in availability for uptake into plants. While both longer chain and shorter chain PFCAs and PFSAs may be taken up by plant roots, there is generally greater translocation and distribution of shorter chain PFAS into the remainder of the plant, including the aboveground tissues (**Section 5.6.2**). In general, there is greater accumulation in vegetative tissues (for example, leaves and stems) than in storage tissues such as fruits and seeds (**Section 5.6.2**).

There is currently no USEPA guidance for development of surface water criteria for irrigation and livestock watering. However, approaches have been developed by some states, and other countries such as Canada (**ECCC 2017**), that consider human dermal and inhalation exposure to irrigation water and consumption of irrigated produce (for example, **University of Florida (2018)**). These references may be consulted for additional information on irrigation and livestock protection.

16.2.2.6 Fish Consumption Advisories Based on Consumption Frequency

Fish consumption advisories are health-protective recommendations developed by states for frequency of consumption of recreationally caught fish meals. These advisories may be applicable statewide, in certain regions of a state, or to specific water bodies or reaches/segments of water bodies. Fish consumption advisories are not surface water criteria and are not regulatory in nature. The advisories may be issued for the general public, and they may be more stringent for specific groups of people at higher risk, such as women of childbearing age, pregnant or nursing women, or children. At the time of publication of this document, several states (for example, AL, CT MI, MN, NJ, WI) have issued fish consumption advisories for PFAS, particularly PFOS.

Advisories are developed by comparing fish tissue concentrations in wet weight (“triggers”) that do not result in unacceptable risks for consumption of meals at different frequencies (for example, unlimited [daily]; once per week, once per month, once per year) with concentrations of the contaminant measured in fish tissue. The advisories may be species- and water body–specific, based on data for PFAS tissue

concentrations from the species in the water body, or they may apply regionally and/or to multiple species. Typically, limits are developed for muscle fillets of commonly caught and consumed fish, often accompanied by a recommendation to avoid consumption of skin, fat, and other nonmuscle parts of the fish. If there are populations whose consumption patterns exceed the assumptions of the advisory (for example, consumption of whole fish), there may be a potential for insufficient protection. Assumptions and parameters used in the calculation of fish tissue trigger levels include:

1. the reference dose for each PFAS
2. a consumer's body weight (BW)
3. the size of the fish meal

The generalized equation for development of fish tissue trigger concentrations based on noncancer effects used for fish consumption advisories are shown in the text box; a different equation (not shown) would be used for advisories based on cancer risk.

Standard USEPA Derivation of Fish/Shellfish Tissue Trigger Concentrations Used in Development of Consumption Advisories

$$DTC = \frac{RfD \times BW}{MS}$$

Where:

DTC = trigger concentration for daily consumption (µg/g)

BW = assumed human body weight (kg)

RfD = chronic oral reference dose (µg/kg/day)

MS = meal size (g/day)

Trigger concentrations for daily consumption are based on calculation of the concentration of a contaminant in fish tissue that results in exposure equal to the RfD from a fish meal. Trigger concentrations for less frequent meal consumption are calculated by multiplying trigger concentration for daily consumption by appropriate factor (for example, daily – 7; monthly – 30).

USEPA (2000)

16.3 Protection of Biota

16.3.1 Overview and Purpose

The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include information about recent studies of bioaccumulation of PFAS in marine biota (see **Section 1.3.5.4**).

This section presents the technical methods and information needed to develop or review surface water criteria for PFAS that would be protective of aquatic life and their uses. There are other sections in this document where general ecological issues associated with PFAS are discussed in detail, and that information supplements the information contained in this section. That additional information can be found in **Section 7.2**, Ecological Toxicology, and **Section 9.2**, Ecological Risk Assessment. **Section 16.3.2** provides information regarding ecotoxicological data for assessing water quality criteria for PFAS that were available during development of previous versions of this document and still provides a starting point for evaluation of available values. The section is not intended to present an exhaustive compilation of the currently available data as this is an active field of research in which new information is regularly provided. It is recommended that the reader search for updated ecotoxicological data prior to development of water quality criteria for the protection of wildlife.

The types of aquatic life to be protected are usually defined by the various beneficial uses related to surface water that are described in **Section 16.1.1**. USEPA guidance (**USEPA 1985**) for derivation of such criteria are primarily intended to protect all but the most sensitive aquatic organisms from exposure to chemicals in surface water or sediment porewater. Considerations also exist to derive criteria for protection of aquatic-dependent avian and mammalian wildlife via calculation of a "final residue value" that can factor into final selection of the chronic criterion (**USEPA 1985**), or a more explicit "wildlife criterion" using methods presented for the Great Lakes Initiative (GLI; (**USEPA 1995**)).

Aquatic life criteria share the levels of protection afforded by the Clean Water Act and USEPA guidelines (**USEPA 1985**) in that criteria are derived using toxicity tests with aquatic organisms in which survival, growth, and reproduction are measured. These data are compiled to derive criteria intended to protect against unacceptable adverse effects to most animal taxa in the aquatic community, which is most commonly calculated to represent protection of approximately the 95th percentile of tested aquatic genera. As a result, acute and chronic criteria concentrations are generally said to represent protection of all but 5% of the most sensitive aquatic species. Criteria can also be lowered to protect particularly important species such as recreationally or economically important species or listed threatened or endangered species.

The following sections summarize the general USEPA methods available for derivation of aquatic life criteria for PFAS, with a focus on how to select the most appropriate toxicity test endpoints related to USEPA guidance (**USEPA 1985**). Available ecotoxicity data are then summarized for all freshwater and marine aquatic species relevant for derivation of aquatic life criteria, including invertebrates, vertebrates, and algae/vascular plants. This section closes with a summary of information necessary to develop criteria to protect aquatic-dependent wildlife such as birds or mammals, including permissible tissue PFAS concentrations, bioaccumulation and bioconcentration factors, and other food chain effects.

16.3.1.1 Derivation of Aquatic Life Protection Criteria—Methods Summary

The general approach for derivation of aquatic life criteria, according to USEPA guidance (**USEPA 1985**), is briefly summarized below, along with the definition of key terms. The first step is to compile acute and chronic toxicity data that meet the **USEPA (1985)** guidelines for the relevance and reliability of each study. This evaluation for scientific relevance and reliability largely focuses on test duration, survival in the control treatment, and methods, with distinctions made between acute (short-term) or chronic (long-term) studies. For example, acute toxicity studies must have an exposure duration of 96 hours (although 48 hours is acceptable for more short-lived species, such as cladocerans and midges), organisms must not be fed during the study, and the endpoint must be mortality, immobilization, or a combination of the two. Chronic toxicity studies must be conducted using exposure durations that encompass the full life cycle or, for fish, early life stage and partial life cycle studies. The acceptable endpoints for chronic tests include survival, growth, and reproduction (see **Section 16.3.1.4**). The duration of chronic studies may be many days, weeks, or months.

Table 16-3. Minimum database requirements for derivation of aquatic life criteria (USEPA 1985).

Freshwater	Saltwater
A bony fish in the family Salmonidae	Two families in the phylum Chordata
A second family of bony fish (preferably a commercially or recreationally important warm water fish)	A family in a phylum other than Arthropoda or Chordata
A third family in the phylum Chordata	Either the Mysidae or Penaeidae family
A planktonic crustacean	Three other families not in the phylum Chordata (may include Mysidae or Penaeidae, whichever was not used above)
A benthic crustacean	Any other family
An insect	
A family in a phylum other than Arthropoda or Chordata	
A family in any order of insect or any phylum not already represented	

To develop criteria that are protective of the diverse array of aquatic biota, an extensive database representing multiple test species, genera, and taxa is required. A minimum database of acceptable studies representing at least eight specific taxonomic families of aquatic organisms is also required. This is done to ensure that criteria are derived based on data that represent the widest possible range of likely sensitivities encountered in the environment. These minimum database requirements differ for freshwater versus saltwater species as presented in **Table 16-3**.

For each species with acceptable acute toxicity data, the species mean acute value (SMAV) is calculated as the geometric mean of available 48- to 96-hr median lethal concentrations (LC50s) or median effect concentrations (EC50s) for each species. The genus mean acute value (GMAV) is then calculated as the geometric mean of available SMAVs for each genus. The lowest 5th percentile of the distribution of available GMAVs is identified as the final acute value (FAV), which is divided by two to determine the criterion maximum concentration, which is more commonly termed the "acute criterion." The criterion continuous concentration, or "chronic criterion" can either be calculated using the same 5th percentile calculation as the FAV if all eight minimum database requirements are met, or if they are not met by dividing the FAV by the ratio of acute to chronic effects, termed the acute to chronic ratio (ACR). The ACR is determined from those species with both acute and chronic data available usually as a geometric mean of the available species ACRs. ACR values are one of the factors used to derive chronic surface water criteria for chemicals (**USEPA 2008**). They may also be used in the development of aquatic life screening values when acute toxicity data may be available but not enough chronic toxicity data are available for a chemical. Generally accepted ACR values have not yet been developed for PFAS and would need to take into account the diversity of chemical structures and behavior of PFAS. See the discussion in **Section 16.3.2** regarding the availability of acute and chronic data for select PFAS.

16.3.1.2 Problem Formulation

Recently, USEPA has been developing ambient water quality criteria documents following an ecological risk assessment framework (**USEPA 1992**) to provide a logical approach to criteria derivation based on the chemical's characteristics, fate and transport, and mode of toxic action. This information for PFAS is summarized below to assist with the development of a conceptual model and identification of endpoints needed for states to derive aquatic life criteria.

16.3.1.3 Conceptual Model

A conceptual model consists of a written and/or graphical representation of the linkages between the exposure characteristics of the chemical and the ecological endpoints of relevance to criteria derivation. PFAS will be transported to surface waters from direct soil runoff, groundwater discharge, atmospheric deposition, or point source discharges (see **Figure 17-1**). Once transported into surface waters, PFAS exposures to aquatic organisms will occur via two main pathways: direct from water (bioconcentration) and via the organism's diet as well as water (bioaccumulation). These pathways are also described and quantified in **Section 5.5**.

Biomagnification is also an important factor for some PFAS (for example, those with carbon chain lengths of eight or more) (**Section 5.5**). **Section 16.3.3** describes procedures to evaluate uptake of PFAS in aquatic-dependent wildlife.

This simple conceptual model suggests that aquatic life criteria for PFAS will need to consist of two different kinds of toxicological information:

- Toxicity data generated from water-only exposures
- Toxicity data with effects measured on the basis of receptor tissue concentration and diet, from which bioaccumulation and bioconcentration factors are estimated to back-calculate to a protective PFAS concentration in water (see **Section 16.3.3.3**).

Toxicity data measured on the basis of receptor tissue concentration can also be used to derive purely tissue-based aquatic life protection criteria for PFAS. Tissue-based aquatic life criteria would be subject to less uncertainty because the effects levels directly relate toxic dose and exposure pathways, and because BAFs or BCFs would not be needed to back-calculate to a water concentration. This approach has recently been used for methylmercury (**USEPA 2010**) and selenium (**USEPA 2016**) in fish in which tissue-based criteria concentrations take precedence over water column-based concentrations.

16.3.1.4 Assessment Endpoints

Assessment endpoints represent the expression of environmental values to be protected by the management framework (**USEPA 1992**). In the case of ambient water quality criteria, the values to be protected are aquatic life and their uses. As discussed in Section 16.3.1, the levels and types of protection are those afforded by the Clean Water Act and USEPA guidelines (**USEPA 1985**). These guidelines specify protection of all but 5% of the most sensitive aquatic organisms with respect to survival, growth, and reproduction.

16.3.1.5 Measurement Endpoints

Measurement endpoints represent the direct empirical measurements of chemical exposure and biological effects that are used to ultimately represent the assessment endpoint (**USEPA 1992**). For PFAS, the relevant measurement endpoints are as follows:

- Measures of exposure: Given the conceptual model noted above, PFAS measurements would need to include both direct aqueous concentrations and aqueous concentrations estimated using appropriate bioaccumulation or bioconcentration factors (see **Section 16.3.3** and **Section 9.2.2**). Sufficient single chemical toxicity data for aquatic life criteria mainly exist for only PFOA and PFOS, although Tier II methods have been used by **Giesy et al. (2010)** for PFBS and by **Divine et al. (2020)** for acute and chronic values for 21 PFAS. Mixture studies for commonly detected PFAS are limited with no consensus on additivity, synergism, or antagonism. Thus, it is difficult to determine at this time whether measures of exposure could be considered additive for either PFOA + PFOS, or even for other PFAS.

- Measures of effect: According to USEPA guidance (**USEPA 1985**), measures of effect (either acute or chronic) are limited to those representing survival, growth, and reproduction. Therefore, only PFAS toxicity endpoints that either directly measure, or can directly represent, these endpoints should be used for derivation of aquatic life criteria. According to toxicity data summarized in Section 16.3.2 below (and in **Section 7.2**), available PFAS toxicity endpoints include several sublethal endpoints that could potentially be used to represent growth or reproduction. These include endpoints such as development, percent emergence, time to metamorphosis, and development of malformations. Therefore, states will need to determine whether or not these sublethal effects can be considered reliable quantitative measures of chronic effects of relevance to development of criteria. USEPA developed some logical considerations for this determination relative to endocrine-disrupting chemicals. These considerations may be applicable to PFAS (**USEPA 2008**).

16.3.2 Availability of Ecotoxicological Data

Toxicity data for establishing surface water quality criteria are available in peer-reviewed sources, mainly the primary literature. As noted in **Section 7.2**, most aquatic toxicity data are for PFOS, PFOA, and several other PFAS, including PFNA, PFBA, and PFBS. USEPA has curated peer-reviewed sources of ecotoxicity data for PFAS into the USEPA Ecotoxicology (ECOTOX) Knowledgebase (**USEPA 2024**). In addition, as stated in Section 16.1, USEPA has published draft national recommended aquatic life criteria for PFOA and PFOS in freshwater for public comment (**USEPA 2022**, **2022**) and a fact sheet for the criteria (**USEPA**

2022). Furthermore, USEPA has published their responses to external peer reviews of the draft criteria (**USEPA 2022**, **2022**).

This section provides a high-level overview of the available ecotoxicity data retrieved at the time and does not represent an exhaustive literature review for the classes of organisms specifically required for developing aquatic life surface water quality criteria. As noted in **Section 7.2**, the ecological toxicology of PFAS is an active area of research and users are encouraged to query the literature for updated values. Furthermore, states that undertake criteria development should review the studies discussed here and others that are subsequently published to determine if they meet regulatory requirements prior to using them for WQC development.

When developing surface water quality criteria protective of aquatic receptors, several criteria should be met when selecting appropriate studies, such as inclusion and adequate control animal responses and availability of details on experimental design. Test animals should be native and have reproducing wild populations. Also, note that many published endpoints are based on nominal rather than measured PFAS exposures; where measured concentrations are used, they can range from very low to very high percentages of the nominal values (<10–240%). Thus, it is recommended to use measured concentrations for establishing criteria.

The following sections highlight available data, or lack thereof, for the various taxonomic families required for WQC development (refer to **Table 16-3** and **Section 16.3.1.1**).

16.3.2.1 Bony Fish

Aquatic criteria development requires toxicity data for a salmonid species and one other species of bony fish. Fish toxicity studies are mainly focused on PFOS, for which data for multiple bony fish species (for example, rainbow trout (*Oncorhynchus mykiss*), sheepshead minnow (*Cyprinodon variegatus*), fathead minnow (*Pimephales promelas*), and zebrafish (*Danio rerio*) are available. As discussed in **Section 5.5**, PFOS preferentially accumulates in fish tissue relative to other PFAS. Overall, the data for other PFAS are generally limited to a single species or are lacking entirely (see **Section 7.2**).

16.3.2.2 Salmonids

Acute salmonid studies on the rainbow trout (*O. mykiss*) have been conducted under both fresh- and saltwater conditions for PFOS. EC50 range from 17 mg/L to 22 mg/L (**Robertson 1986**; **Palmer, Van Hoven, and Krueger 2002**); a no observed effect concentration (NOEC) was reported at 6 mg/L (**Palmer, Van Hoven, and Krueger 2002**). No chronic studies were identified for this or other salmonid species.

16.3.2.3 Other Fish Species

Several acute and chronic studies are available for non-salmonid species (see **Section 7.2**) and for PFAS other than PFOS. Data from these studies indicate acute toxicity of PFOS on the same order of magnitude as that observed for the rainbow trout, with some species perhaps even more sensitive; LC50s for zebrafish (*D. rerio*; a freshwater native to Asia) and fathead minnow (*P. promelas*, a freshwater native to North America) were approximately 10 mg/L, with EC50 and NOECs ranging between 1.5 and 3 mg/L (**Drottar and Krueger 2000**; **Ulhaq et al. 2013**). Data from an acute test on the North American saltwater species sheepshead minnow (*C. variegatus*) for PFOS suggest this species is less sensitive than its freshwater counterparts, with EC50 greater than 15 mg/L (**Palmer, Van Hoven, and Krueger 2002**).

Chronic studies of PFOS toxicity are more limited; only two studies of *P. promelas* were identified and indicated a NOEC of approximately 0.3 mg/L and EC50 of 7 mg/L (**Drottar and Krueger 2000**; **Oakes et al. 2005**) for early life stage development.

Acute and/or chronic zebrafish toxicity studies are also available for PFOA, PFBS, PFNA, PFBA, and PFDA. Acute toxicity is highly variable, but in general, these compounds appear to be less toxic than PFOS, with LC/EC50 reported up to 3,000 mg/L; the exception to this generality is PFDA, where an EC50 of 5 mg/L was reported (**Ulhaq et al. 2013**). Chronic toxicity data in this species for these compounds are more limited, but the few available studies suggest chronic toxicity may occur at substantially lower concentrations; for example, **Zhang et al. (2012)** reported a LOEC of 0.01 mg/L for growth/weight was for PFNA.

16.3.2.4 Other Aquatic Chordates—Amphibians

Amphibians represent an alternative class of aquatic/semi-aquatic chordates for which PFAS toxicity studies have been conducted. There are currently limited PFAS toxicity data available for amphibians, but this class of organisms is becoming more widely studied. Nearly all the available amphibian studies entail acute studies in aquatic life stages (with mortality as the endpoint) on PFOS exposures to several species, including the African clawed frog (*Xenopus laevis*), northern leopard frog (*Rana pipiens*), black spotted frog (*Rana nigromaculata*), spring creeper (*Pseudocris crucifer*), American bullfrog toad (*Lithobates catesbeianus*), and Asiatic toad (*Bufo gargarizans*). Of these, the northern leopard frog, spring creeper, and American bullfrog toad are native to North America. Amphibian data are discussed in **Section 7.2** for PFOS and PFOA. While mortality is observed in amphibians at water concentrations over 10 mg/L, recent studies such as those reported in **Pandelides et al. (2023)** indicate chronic toxicity occurs at lower levels (for example, a chronic LOEC for PFOA of 1.4 mg/L based on growth (body mass) for the northern leopard frog, and a chronic LOEC for PFOS based on the median time to complete metamorphosis in the western clawed frog of 1.1 mg/L).

16.3.2.5 Crustaceans

Freshwater

Acute

Acute toxicity data for freshwater crustaceans are focused on various daphnids (see **USEPA 2023**), with some data on freshwater shrimps such as the cherry shrimp (*Neocaridina denticulate*) (**Li 2009**). The largest number of publications are on the water flea, *Daphnia magna*, where 24–48-hour survival data are available for PFBA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, and PFOS. For most other freshwater species, acute toxicity data are limited to PFOA and PFOS.

Chronic

A smaller number of specific PFAS have been assessed for chronic toxicity in freshwater crustaceans. This includes PFOA, PFBS, PFOS, and GenX salt (ammonium 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)-propanoate) (**Drottar and Krueger 2001**). The 21-day survival and reproduction assay with daphnids is reported for both PFOS and PFOA **Section 7.2**). A series of studies evaluated bioavailability of certain PFAS with respect to exposure cofactors such as dissolved proteins, organic carbon composition, and other solutes (**Xia et al. 2015**; **Xia et al. 2015**; **Xia et al. 2013**). Although these studies do not estimate ECs or LCs for specified PFAS, they demonstrate that abiotic factors require consideration for exposure assessment and comparison across aquatic toxicity studies.

Saltwater

Acute

Two short-term studies (96 hours) provide some data on the acute toxicity of PFOS in marine crustaceans. The two tested species, both mysid shrimp, are *Siriella armata* and *Mysidopsis bahia,* for

which NOECs of 0.550—1.25 mg/L (**Drottar and Krueger 2000**; **Mhadhbi et al. 2012**) were derived; however, the values for *S. armata* were based on nominal concentrations (**Mhadhbi et al. 2012**). Additional studies are needed to evaluate other PFAS, as well as to discern differences in acute toxicity among benthic, epibenthic, and pelagic crustacean species.

Chronic

There are very few laboratory-based chronic toxicity studies available for marine crustaceans. One study was a 35-day growth, reproduction, and survival assay for PFOS using mysid shrimps (*Mysidopsis bahia*) (**Drottar and Krueger 2000**); (see **Section 7.2**). **Simpson et al. (2021)** more recently conducted a comprehensive study of PFOS sediment, overlying water, and/or porewater exposure to various benthic marine/estuarine species, reporting chronic effects data for an amphipod (*Melita plumulosa*), a copepod (*Nitocra spinipes*), and a crab (*Macrophthalamus* sp.).

While there are multiple studies regarding the occurrence of PFAS in wild-caught crustaceans, there is little information on biological effects. There is one recent report on wild-caught eastern school prawn (*Metapenaeus macleayi*) that found associations between metabolomic profiles and certain PFAS, but the exposure history for the animals was unknown (**Taylor et al. 2019**).

16.3.2.6 Mollusks

Freshwater

Acute

For freshwater mollusks, toxicity studies of PFOA and PFOS are limited to five species: bladder snail (*Physa acuta*), fatmucket clams (*Lampsilis siliquoidea*), black sandshell mussels (*Ligumia recta*), *Unio ravoisieri,* and zebra mussels (*Dreissena polymorpha*) (**Li 2009**; **Hazelton et al. 2012**; **Fernández-Sanjuan et al. 2013**; **Amraoui, Khalloufi, and Touaylia 2018**). The fatmucket and black sandshells are native to North America, whereas the remaining three are nonnative to the U.S. or are invasive species, as in the case of zebra mussels. Following 24- to 96-hour exposures, **Hazelton et al. (2012)** estimated lower EC50s for PFOS than for PFOA in both fatmucket clams and black sandshell mussels, where larvae were more sensitive than juveniles toward PFOS.

Chronic

Assessments of chronic effects in freshwater mollusks are limited to a single study with water concentrations that were much higher than those detected at most remediation sites. Following a 28-day exposure to PFOS, **Hazelton et al. (2012)** observed impaired growth effects in larval and juvenile fatmucket clams as determined by reductions in larval viability (LOEC of 0.0045 mg/L) and impaired metamorphosis (LOEC of 0.0695 mg/L), respectively. **Fernández-Sanjuan et al. (2013)** evaluated the physiological responses of nonnative and invasive zebra mussels toward a mixture of PFOA and PFOS (0.001—1 mg/L, 10 days), but did not report any mortality.

Saltwater

Acute

Acute toxicity studies for marine mollusks are currently limited to PFOA, PFNA, PFOS, and PFDA. A larger body of literature exists on occurrence and tissue concentrations in mussels and oysters, but almost none of these assessed whole or suborganism level effects. Two 96-hour acute toxicity tests reported NOECs for mortality in *Unio complamatus* (20 mg/L) and eastern oyster (*Crassostrea virginica*) (18 mg/L) (**Drottar and Krueger 2000**).

Chronic

Chronic studies for sublethal effects of PFAS on bivalve mollusks are limited to a few marine species, including green mussels (*Perna viridis*), Mediterranean mussels (*Mytilus galloprovincialis*) and California mussels (*Mytilus californianus*). In vitro and in vivo studies of California and Mediterranean mussels offer some information relative to effects on xenobiotic transport proteins and enzymatic activities, respectively (**Stevenson et al. 2006**; **Balbi et al. 2017**; **Gülsever and Parlak 2018**), but do not quantify ECs, NOECs, or LOECs for whole-organism exposures. A series of studies using green mussels reported on multiple endpoints following 7-day exposures to PFOS, PFOA, PFNA, and PFDA. These studies evaluated biochemical markers of altered xenobiotic metabolism (**Liu, Gin, and Chang 2014**), genotoxicity (**Liu et al. 2014**), oxidative stress (**Liu, Chang, and Gin 2014**), and immunotoxicity (**Liu and Gin 2018**) and reported NOECs ranging from 0.010-0.100 mg/L (PFOA and PFNA) down to 0.001-0.01 mg/L (PFOS and PFDA). **Simpson et al. (2021)** reported chronic no-effects levels for two species of bivalve mollusks (*Tellina deltoidalis* and *Soletellina alba*) of 0.22 mg/L and ≥ 0.85 mg/L, respectively.

16.3.2.7 Aquatic Insects

Freshwater

Toxicity data for aquatic insects (for example, midges, mayflies, dragonflies) are available in the literature, although they mainly stem from acute studies of PFOS, PFOA, and PFNA in the freshwater midge species *Chironomous riparius* and *C. tentans* (see **Section 7.2.2.1**). Of the aquatic invertebrate species, the chironomids are currently reported as having the highest sensitivity to PFOS (**MacDonald et al. 2004**). Acute effects are observed to generally occur at water concentrations of approximately 60 mg/L or greater, with chronic effects induced at concentrations less than 0.002 mg/L (see **Section 7.2.2.1**).

Toxicity data for other orders of aquatic insects are very limited, although some studies indicate that the odonates may also be highly sensitive to PFAS exposures. **Van Gossum et al. (2009)** found behavior changes following long-term (4-month) exposure of PFOS to damselflies (*Enallagma cyathigerum*) with NOECs reported from 0.010 mg/L to 0.100 mg/L. **Bots et al. (2010)** conducted a lifetime exposure study of PFOS on *E. cyathigerum*, finding adverse effects on egg development, larval hatching, development and survival, metamorphosis, and body mass, with NOECs ranging from less than 0.010 mg/L (for metamorphosis) to over 10 mg/L (for egg hatching success).

Saltwater

No toxicity information was found on marine insects.

16.3.2.8 Algae/Vascular Plant Data

Section 7.2.4.1 provides a summary of aquatic plant toxicity data. Data on the toxic effects of PFAS on aquatic plants are limited to studies that evaluated PFOS exposures on several algal/microalgal species, on duckweed (*Lemna gibba*), and on watermilfoil (*Myriophyllum spicatum)*. Acute toxicity of PFOS in freshwater aquatic plants has been found to range from approximately 30–100 mg/L, with chronic values generally about tenfold lower.

In a chronic study on a saltwater species of diatom (*Skeletonema costatum*) **Desjardins et al. (2001)** reported observed effects at approximately 3 mg/L. **Simpson et al. (2021)** reported a chronic NOEC of > 4.2 mg/L for growth rate as an endpoint.

16.3.3 Aquatic-Dependent Wildlife

This section considers aquatic-dependent wildlife (primarily birds and mammals) in developing surface water criteria for PFAS. It is important to note that the development of such criteria is still in its infancy because (i) there are few laboratory or field studies with data on the toxicity of PFAS to wildlife, (ii) data of sufficient/appropriate quality on the concentration of PFAS in the diet of aquatic-dependent wildlife are limited, and (iii) the unique properties of PFAS make the modeling of food chain uptake complicated. The following sections briefly discuss why aquatic-dependent wildlife should be considered and present methods that can be used to derive surface water quality criteria for their protection.

16.3.3.1 Why Consider Aquatic-Dependent Wildlife?

As described in **Section 16.3.1**, the focus for deriving surface water quality criteria is primarily on protecting aquatic life (for example, plankton, benthic invertebrates, fish, shellfish). However, it has long been recognized that wildlife species may be more sensitive than aquatic species toward certain contaminants as a result of dietary exposure, particularly if the contaminant is bioaccumulative (**USEPA 1985**, **1989**, **2005**).

Because some PFAS are known to be bioaccumulative (see **Section 5.5**), it cannot be assumed that surface water quality criteria derived for the protection of aquatic life will also be protective of aquatic-dependent wildlife. Protection of aquatic-dependent wildlife is of importance at contaminated sites, particularly for wildlife with smaller home ranges that coincide with the extent of PFAS impacts (**Conder et al. 2020**; **Divine et al. 2020**). In developing risk-based screening levels (RBSLs) for different classes of receptors, Divine and coworkers found that for some PFAS, RBSLs for aquatic-dependent wildlife are lower than RBSLs for aquatic life. Lastly, due to the long-range transport for some PFAS (see **Section 5.3**), there could be a need for surface water quality criteria protective of aquatic-dependent wildlife in remote areas where management actions to address human exposure may not address ecological exposures.

16.3.3.2 Surface Water Quality for the Protection of Wildlife

The principal approach to developing protective surface water quality for wildlife is to use standard desktop wildlife exposure models to solve for a media concentration that results in exposure being equal to a selected toxicity threshold. In modeling exposure, such an approach either uses measured contaminant concentrations in the tissue of the prey/forage or relies on BAFs (to estimate prey/forage tissue concentrations). The same toxicity threshold can be used in either case. Another approach is to determine a critical concentration in the tissue of a prey item that is protective of the wildlife receptor. The advantage of this "body burden" approach is that it avoids the uncertainties associated with relying on BAFs; however, it entails the collection of site-specific tissue data for implementation.

These two approaches are discussed in the following sections.

16.3.3.3 Calculation of a Protective Surface Water Quality Value for Aquatic-Dependent Wildlife

In 1995, USEPA published the Great Lakes Water Quality Initiative (GLI) Technical Support Document for Wildlife Criteria (**USEPA 1995**). The GLI Technical Support Document provided technical information on the derivation of surface water quality criteria to protect birds and mammalian wildlife. The method is similar to that used to derive noncancer human health criteria and relies on the use of BAFs in a food chain model to back-calculate a surface water value (**USEPA 2017**). USEPA has used this method for chemicals such as DDT, PCBs, 2,3,7,8-TCDD, and mercury, for which aquatic life-based criteria were modified to become more stringent in order to incorporate adverse effects to wildlife (**USEPA 1995**).

States and tribes bordering the Great Lakes, as well as other states, such as California, have since adopted this approach to derive aquatic-dependent wildlife surface water quality criteria.

The GLI Technical Support Document (**USEPA 1995**), Section III, provides the equations needed to calculate a protective surface water quality value for birds and mammals from exposure via food and water ingestion (see text box).

Standard Equation for Derivation of a Protective Surface Water Quality Value for Aquatic-Dependent Wildlife

$$\text{WV (mg/L)} = \frac{\text{TD(mg/kg bw/d)} * \left(1/(\text{UF}_\text{A} * \text{UF}_\text{S} * \text{UF}_\text{L})\right) * \text{BW(kg)}}{\text{W(L/d)} + \text{sum}\,[\text{FC}_\text{i}\text{(kg food/d)} * \text{BAF}_\text{i}\text{(L/kg)}]}$$

Where:

WV = wildlife value in milligrams of substance per liter (mg/L)

The bird WV is the geometric mean of the WVs calculated for the three birds and the mammalian WV is the geometric mean of the WVs calculated for the two mammalian wildlife species.

TD = test dose in milligrams of substance per kilogram per day (mg/kg-d) for the test species. This shall be either a NOAEL or a LOAEL (expressed either on a wet weight or dry weight basis for consistency with FC).

UF_A = uncertainty factor (UF) for extrapolating toxicity data across species (unitless). A species-specific UF shall be selected and applied to each representative species, consistent with the equation.

UF_S = UF for extrapolating from subchronic to chronic exposures (unitless)

UF_L = UF for LOAEL to NOAEL extrapolations (unitless)

BW = body weight in kilograms (kg) for the representative species

W = daily volume of water consumed in liters per day (L/d) by the representative species

FC_i = daily amount of food consumed from the i^{th} trophic level in kilograms per day (kg/d) by the representative species (expressed either on a wet weight or dry weight basis for consistency with TD)

BAF_i = bioaccumulation factor for the i^{th} trophic level in liters per kilogram (L/kg)c

By extension, this method can be used in the development of surface water values for PFAS. The GLI approach uses five representative species (bald eagle, herring gull, belted kingfisher, mink, and river otter), because these species are likely to be subjected to the highest exposure from bioaccumulative contaminants through the aquatic food web. However, depending on the conceptual model under evaluation, it might be more appropriate to select different representative species (for example, sandpiper species given their relatively high incidental ingestion of sediment). **Giesy et al. (2010)** provided good examples of using the GLI approach to calculate surface water criteria for trophic level IV predatory birds for two compounds, PFOS and PFBS.

The GLI Technical Support Document includes tables with values for the exposure parameters (body weight, water and food ingestion rates, as well as prey/forage trophic level). Other sources of receptor-specific exposure parameters can be found in USEPA's Wildlife Exposures Factor Handbook **USEPA (1993)**, **Conder et al. (2020)**, and **Divine et al. (2020)**. However, it is a best practice to select exposure parameters that are most representative of the populations living within the area to which the criteria will be applied. Climate, temperature, habitat, and many other factors specific to the region underlying the studies that are the basis of the exposure factors can vary significantly.

Key PFAS-specific components to this approach are the selection of, and sources for, BAFs to estimate prey or forage tissue concentrations, and the wildlife toxicity data for PFAS (no observed adverse effect levels [NOAELs] and lowest observed adverse effect levels [LOAELs]).

As noted in **Section 16.2.1.4**, given the influence of BAFs on calculation of a water quality value, their use and applicability need to be carefully considered. Information on a literature review and selection of BAFs is provided in Section 5, with a compilation of BAFs and their sources presented in Table 5-1 (see link in **Section 5.5**).

As noted, there are currently few PFAS toxicity data for wildlife in the scientific literature or standard toxicity databases. Furthermore, given the minimum toxicity database requirements for developing Tier I criteria (see **USEPA (1995)**), it is unlikely these requirements will be met for individual PFAS at the current time. Note that the GLI technical support document does provide guidance on developing Tier II wildlife values for contaminants with limited toxicity data (**USEPA 1995**). **Conder et al. (2020)** and **Divine et al. (2020)** are good sources of PFAS toxicity reference values (TRVs) for avian and mammalian wildlife that not only include tables of recommended values, but also provide guidance on reviewing toxicity studies reported in the literature and selecting the values.

16.3.3.4 Calculation of a Protective Prey/Forage Tissue-Based Value

USEPA published a science advisory board consultation document on tissue-based criteria for "bioaccumulative" chemicals as proposed revisions to aquatic life guidelines (**USEPA 2005**). The approach is based on the recognition that for bioaccumulative chemicals, there is a need to develop criteria that account for multiple routes of exposure such as the diet, sediment, and water.

The approach is similar to that for developing a water-based value in that it is based on a daily dietary dose of a chemical that is protective of most sensitive species and integrates it with exposure potential to estimate a chemical concentration in the dietary tissue of representative species, also referred to as a wildlife value (WV). The advantage of this approach over the water-based approach is that it eliminates the uncertainty associated with using BAFs but requires the sampling of appropriate prey biota for implementation.

The equation in the text box below used to develop a tissue-based WV is based on the GLI model for aquatic-dependent birds and mammals but expressed as the chemical concentration in the diet rather than in water (see **USEPA (2005)**, Section 4.4). As discussed above, sources of exposure information can be found in **USEPA (1993**, **1995)**, **Conder et al. (2020)**, and **Divine et al. (2020)**.

Note that if the target aquatic-dependent wildlife is exposed via several trophic levels, a WV will need to be calculated for each trophic level using BAFs, or if available, applicable BMFs for the targeted aquatic-dependent wildlife receptor (see **Section 5.6**). This will then guide which species of prey/forage to target when monitoring for compliance.

Standard Equation for Derivation of a Protective Prey Tissue Value for Aquatic-Dependent Wildlife

$$\text{WVww (mg/kg food)} = \frac{\text{TD(mg/kg bw/d)} * \left(1/(\text{UF}_\text{A} * \text{UF}_\text{S} * \text{UF}_\text{L})\right) * \text{BW(kg)}}{\text{sum } [\text{FC}_\text{i}\text{(kg food/d)}]}$$

Where:

WVww = wildlife value expressed as the chemical concentration in the diet of each representative species measured as wet weight

TD = test dose expressed as daily dietary dose (wet weight) from selected study, either a NOAEL or a LOAEL

UF = uncertainty factors for interspecies variation (UF_A), subchronic to chronic (UF_S), and LOAEL to NOAEL (UF_L)

BW = body weight of a representative species

FC_i = amount of daily food consumed for each species from the i^{th} trophic level

Because this approach was developed to address the bioaccumulation of lipophilic chemicals, it assumes the chemical contribution from water is negligible, which, as discussed in **Section 5.5.2**, may not be the case for some PFAS. Furthermore, it does not consider dietary intake via the incidental ingestion of sediment, which as noted above, can be included depending on the species of wildlife being evaluated. As indicated by **Larson, Conder, and Arblaster (2018)**, incidental sediment ingestion could be a significant contributor to exposure to aquatic-dependent wildlife.

16.4 Sampling and Analysis

The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include information about the effects of suspended sediment on surface water sampling and measurement of PFAS (see **Section 1.3.6**).

This section reviews the collection and analysis of surface water, biota, and surface sediment from aquatic systems. In most instances, the precautions taken to minimize biasing the concentrations of PFAS in the samples from sampling equipment and/or sampler protective clothing, among others, are the same as those described in **Section 11.1** when sampling groundwater, surface soils, or fish. There are some unique aspects about where to collect a surface water sample that are discussed in this section. For analysis, the methods used for PFAS in drinking water, soil samples, plant material, and groundwater described in **Section 11.2** are also used for surface water, biota, and surface sediment. Issues and recommendations unique to sampling PFAS-containing foam are covered in **Section 16.5**.

16.4.1 Surface Water Sampling

Surface water bodies include, but are not limited to, oceans, bays, estuaries, lakes, streams, ponds, creeks, springs, wetlands, reservoirs, and artificial impoundments. The sample collection for PFAS from a surface water body is essentially the same as for other chemicals or pollutants. Standard operating procedures for sampling equipment have the same limitations, such as PFAS-free samplers, that are used for collection of samples from potable water systems or groundwater monitoring wells. See **Section 11.1** for general sampling techniques and equipment requirements for PFAS sampling, including examples of PFAS-specific sampling protocols, and **Section 11.2** for analytical methods and techniques.

In addition to USEPA's Compendium of Superfund Field Operations Methods (**USEPA 1987**) for general guidance on sampling surface water, Michigan (**MI EGLE 2021**; **MI EGLE 2024**) and New York (**NY DEC 2023**) have recently developed guidance specifically for PFAS. Some examples of sampling consideration in a moving water body such as a creek include:

- sampling far enough downstream from the suspected source to allow for adequate mixing
- collecting samples from the upstream side of the sampler to minimize compromising the sample
- collecting the sample from mid-depth in the thalweg (that is, along the natural direction of water flow, below the air/surface water interface but above the surface water/surface sediment interface)
- depending on your sampling objectives, collecting samples from multiple depths to provide the necessary information. This is due to the potential for stratification of PFAS concentrations through the water column and the location of the receptors of concern (benthic organisms or fish).

Due to chemical properties of PFAS, concentrations in the surface water near the discharge location may be higher at or near the surface. Collecting samples only from the surface may inform you of the worst-case scenario but may not provide information on locations away from the discharge point, such as at a water intake for domestic and industrial use. The same concern applies to PFAS-containing foam. Including this foam in the sample will bias the PFAS concentration high due to the elevated concentrations in the foam (see **Section 16.5.5**).

Additional considerations for surface water sampling during site characterization are noted below in **Section 16.4.5**.

16.4.2 Biota Sampling

Because some PFAS are known to accumulate in aquatic biota and in some instances may drive the development of surface water quality criteria (see Sections **16.2.2.2** and **16.3.3**), sampling for biota may be an important component of a monitoring program or health assessment. The species of biota to collect and the tissue types to sample will depend on the study objectives. For example, a human health–based study should focus on collecting species within a size range targeted by recreational anglers or crabbers (**NJDEP 2018**), while an ecological-based study should focus on species representing different trophic levels, as well as benthic and pelagic habitats, and be of a size range targeted by piscivorous birds and mammals. In addition, because it has been shown that some PFAS bioaccumulate to a higher degree in the blood and liver compared to the flesh (see **Section 11.1.7.8**), collecting and analyzing different tissue types might be an important consideration in a study design.

General guidance on the use of different sampling techniques for fish and shellfish such as gill nets, seines, trawls, and electrofishing, can be found in **USEPA (2000)**, and many states have their own guidance, which should be considered. When sampling biota for PFAS analysis, the additional precautions described in **Section 11.1** should also be followed, and some states, such as Michigan, have developed their own PFAS-specific guidance (**MI DEQ 2019**). For example, collected biota should be wrapped in HDPE or polypropylene bags and/or aluminum foil, and stainless-steel tables, knives, and weighing scale hooks should be used for sample processing (in the field or in the lab), as well as untreated wooden cutting boards. Given that PFAS are widely present in the environment and human-made materials, it will be important to collect equipment blanks during sample collection and processing. Close coordination with the analytical laboratories will be needed to ensure similar PFAS-specific precautions are followed at all times (see **Section 11.2**).

Additional considerations include sampling surface water and surface sediment within the same area from which the biota are collected. While it is recognized that many aquatic biota are migratory or exhibit extended home ranges, this information will help support identification of PFAS sources as well as potentially the development of site-specific BCFs, BAFs, and biota-sediment concentration factors (BSAFs). BSAFs represent the amount of PFAS taken up by an organism from the sediment and are measured as the ratio of the concentration in an organism to the concentration in sediment. BSAFs are typically developed for those organisms in close contact with surface sediment, such as benthic and epibenthic invertebrates, as well as benthic fish (**Figure 17-1**).

16.4.3 Sediment Sampling

Because sediment can be a contaminant sink, a transport mechanism, and a source of contaminants to a surface water body and to benthic organisms, it may be necessary to sample sediment for PFAS to support an understanding of its contribution to the surface water quality and/or biota tissue concentrations. Conventional sediment sampling and coring techniques and protocols can generally be used to obtain samples for analysis of PFAS. **Section 11.1** describes sampling protocols for all types of samples, with additional detail for porewater in **Section 11.1.7.4** and sediment samples in **Section 11.1.7.7**

Examples of seven different sampling protocols typically used are detailed below:

- Where the sediment is accessible and can hold its form without collapsing, a corer or “Dormer Piston” sediment sampler could be used.
- When collecting samples from shore or wading, the sample should be collected from the upstream side of the sampler to minimize potentially compromising the sample from stirred-up sediment or from a waterproof coating on waders.
- Sediment core samples are collected directly from single-use liners and are not reused.

- There can be sites where the sediment is accessible but either the sediment is sloppy and would not hold its form, or there is a high density of tree roots or boulders and a corer or piston sampler would not be feasible. In these situations, a stainless-steel trowel could be used to collect surface sediment samples.
- For subtidal sediments, the depth below the sediment surface from which the sample is required determines what equipment is needed. For surface sediment samples, devices such as a modified van Veen grab, Ekman grab, or Ponar grab sampler can be used, while for deeper subsurface samples, devices such as a vibracorer should be used. This nondedicated equipment (equipment used for more than one water body or location) should be verified as PFAS free, and the sampling program should include collection of equipment blanks.
- For sampling subtidal sediments, the depth from which the sample is required dictates what specialized sampling equipment is needed.
- Samples should be collected in HDPE wide-mouth bottles provided by the laboratory, and fitted with an unlined (no Teflon) polypropylene screw cap. A minimum of 50 g of sample is needed. Field observations, including sediment type, texture, and color, should be recorded.

16.4.4 Analytical Methods

Analytical methods for the analysis of PFAS in a surface water share many of the same components as those used for PFAS in other non-drinking water media. A discussion of these analytical methods is found in **Section 11.2**. Most surface water samples for PFAS are analyzed by Modified USEPA 537.1 and use the DOD's Quality Systems Manual (QSM) for Environmental Laboratories, Version 5.3, Appendix B, table B-15 (**USDOD 2019**), providing the most current and comprehensive set of quality standards for PFAS analysis. In June 2019, USEPA validated USEPA SW-846 Method 8327 for the analysis of PFAS in surface water, groundwater, and wastewater (**USEPA 2021**). Method 8327 is available for use but has not yet been fully incorporated into SW-846. Method 8327 has not been widely used because it creates laboratory cleanup and accuracy issues and is not accepted by DOD.

16.4.5 Site Characterization

Conducting site characterization of PFAS at a site with a surface water body should begin with determining the beneficial uses as described in **Section 16.1.1**. Those beneficial uses should be used to select the types of samples to be collected. For example, if evaluating PFAS-containing foam, sample collection will be required near the surface; if evaluating potential impacts to benthic organisms, samples closer to the sediment/water interface should be collected, and if evaluating pelagic fish, it may be necessary to collect a surface water sample integrated throughout the water column. Point sources such as stormwater discharge pipes or a publicly owned treatment works (POTW)discharge should be located and potentially targeted for sampling to evaluate sources of PFAS to the water body. Establishing the locations of natural and human-made water inflow and outflow points to the water body will also help guide sample points and potential exposure sites. Groundwater/surface water interaction may also play a role in establishing the conceptual site model and locating places to sample. **Section 10** contains more specifics regarding site characterization and development of a conceptual site model.

16.5 Surface Water Foam

PFAS-containing foam (discussed in this section) is differentiated from AFFF (discussed in **Section 3**) in that it is the result of dissolved-phase PFAS in surface waters that have been agitated by wind or wave action and aggregated into a mass at or above the surface of the water, irrespective of the PFAS source type. As noted in **Section 16.2.2.4**, the presence of foam does not necessarily indicate the presence of PFAS. Foam can form naturally when the surface tension of water decreases and the concentration of

organic matter, such as dissolved organic carbon (DOC), increases and is mixed into the water. The decomposition of organic material into water, or a storm event mobilizing existing organic material, can lead to the natural formation of foam on surface water. For example, a study of PFAS and DOC in foam forming on a freshwater lake in Michigan showed that PFAS made up less than 0.1% of the DOC present in the foam samples, which indicated that DOC was the primary cause of the foam and not the presence of PFAS (**Schwichtenberg et al. 2020**).

This section discusses the formation of PFAS-containing foam, the characteristics of, and stratification within the foam, a brief discussion of analytical methods for foam, and the enrichment of PFAS concentrations in foam compared to the underlying water column. A case study on PFAS containing foam (the Minnesota Project 1007 Feasibility Study) is presented in **Section 15.5.1**.

16.5.1 Foam Above Water Interface

PFAS-containing foam may occur at and above the air-water interface on surface waters. In this context, surface water is subdivided and defined below. This subdivision describes vertically downward the air-water interface, surface micro layer (SML), neuston, and underlying water column. See **Figure 16-2**.

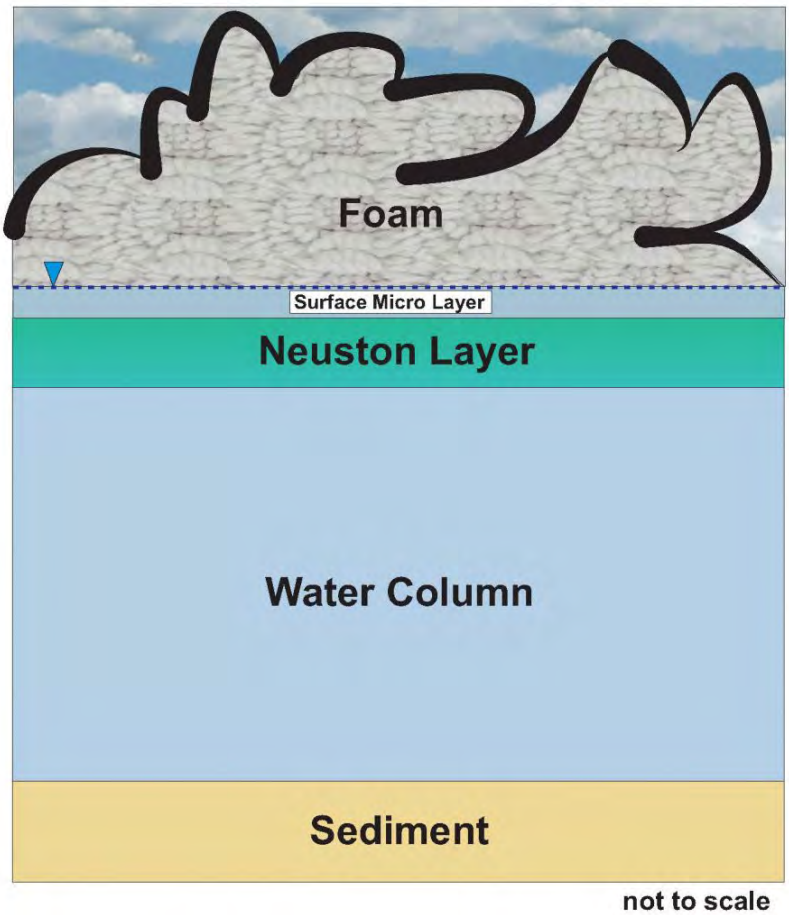


Figure 16-1. PFAS foam on surface water.

Although it is typical to find PFAS-containing foam near release source areas, it may also occur some distance away when surface water bodies are interconnected. Source proximity may impact the concentration of PFAS analytes in the foam column itself. However, concentrated PFAS-containing foam may occur on surface water bodies containing low to nondetect PFAS concentrations immediately below the foam itself some distance from the source areas (**MPCA 2020**; **Schwichtenberg et al. 2020**). Underlying partitioning considerations are discussed in **Section 5.2.2**, Considerations for PFAS Partitioning.

Variable surface water depth, flow conditions, and co-contaminant mixtures may affect the presence, aggregation, and physical movement of PFAS-containing foam in the SML and above the air-water interface. These factors may be considered when evaluating fate and transport of PFAS-containing foam, as it may partition back into solution in the water column as it moves with the flowing water. A foam column at and above the surface may be affected by physical forces, including precipitation, wind, and wave action, causing it to separate and travel as smaller foam source material “islands” or collapse and dissolve back into the water column as it travels with the wind and waves.

16.5.2 Foam Characteristics

PFAS-containing foam has wide-ranging visual and textural appearances. These characteristics range from deflated, dry, or aged in appearance, as small aggregations of bubbles accumulating into larger islands of billowed piles, frozen in standard bubble foam appearance or frozen in thin sheetlike membrane appearance, frozen on top of snow and ice, dark coloration due to detritus or organic content, and bright white, with an aerated shaving cream or whipped cream texture.

"High turbulence generated foam tends to be fluffy, actively regenerates, and does not appear to contain high levels of organic material; while older, deflated foam does not actively regenerate and appears to be rich in organic or non-organic particulates. Foam observed along creeks and streams tend to vary in appearance and can occur with any combination of the above-listed characteristics. Wind-generated foam has only been observed on lakes, has generally been white and fluffy, and has actively accumulated along a downwind shoreline. Both organic-rich foam and unfrozen foam with a wrinkled appearance have been observed to accumulate along ice dams or ice shelves" (**MPCA 2020**).

16.5.3 Stratification Within Foam

Surface water foam is known to be laden with bacteria, detritus, and other naturally occurring material. However, stratification of concentrations of PFAS within the foam column or pile may be due to a number of physical and chemical conditions. For example, co-contaminants may impact the degree of stratification in the surface water column and the foam itself. Additionally, the foam may be aged and in a dry condition toward the top of the foam column/pile, creating a concentration gradient toward the base of the column/pile.

Sampling should be conducted so as to maximize consistency and reproducibility during PFAS surface water sampling to understand PFAS stratification in the surface water column and the foam. The Michigan Department of Environment, Great Lakes, and Energy (EGLE) has published a surface water foam sampling guidance, a surface water foam study report, and has published other PFAS sampling guidance (**MI EGLE 2019**, **2024**, **2021**).

As of the date of this publication, the state of Minnesota is working with technical support from the USEPA Office of Research and Development to evaluate foam sampling techniques aimed at understanding the concentration variability within the foam, at the surface micro layer, and the underlying near-surface water column.

16.5.4 Frozen Foam

PFAS-containing foam has been confirmed in frozen form on surface water in Minnesota, Michigan, and Wisconsin (**MPCA 2019**). Appearance of the foam is difficult to distinguish from snow and ice along stream or lake embankments. PFAS-containing ice has been confirmed in Michigan and can visually take the form of thin film-type islands or within massive ice (**MPCA 2020**). The ice appears to stratify vertically in concentration where located in massive ice. Confirmation of the degree of stratification in massive ice is an on-going study at this time. Early results from Michigan indicate it appears to increase in concentration with elevation in the ice cores, indicating the ice/air interface may be where the highest concentrations exist, similar to the propensity for PFAS to travel at the air/water interface.

16.5.5 Surface Micro Layer

As previously discussed, PFAS in solution tends to accumulate at the air/water interface, also known as the surface water micro layer or SML. The SML in this context, is generally understood to mean the layer in contact with ambient air and is approximately 50µm thick (**MPCA 2020**). Variability in sample

collection techniques and the extent to which this interface is included or omitted in the collection of a bulk water sample may result in biased analytical results. This can further lead to incorrect conclusions about PFAS concentrations in surface waters at source areas and in the downgradient direction. Where the SML is not characterized and only the deeper water column is sampled, PFAS concentrations may be biased low . The SML may be the location of the highest PFAS concentration in the water column. Omitting collection of the SML could potentially lead to an inaccurate assessment of the risk to human and ecological receptors. Therefore, when preparing a sampling plan, it is important to consider the depth of the water column that is most relevant to the human and ecological receptors that may be exposed to PFAS; different receptors may require unique sampling strategies. At this time, methods to characterize PFAS concentrations and the nature of exposed biota in the SML are still under study (see SERDP project ER19-1205, **Field et al. 2021**).

Due to the physical and chemical properties of PFAAs, including their hydrophilic heads and hydrophobic tails, a given molecule may preferentially exist within the SML. **Section 4** includes information about PFAS physical and chemical properties. Sampling the SML in relative isolation from the neuston layer below it or the foam column above it may become an important factor in accurate representation of the concentrations emanating from the SML into foam above when physical agitation occurs. The Michigan EGLE guidance for sampling PFAS-containing foam provides a starting point to understanding the considerations of this sampling protocol in varied circumstances (**MI EGLE 2019**). Michigan EGLE has also published other PFAS sampling guidance that may be relevant for a project (**MI EGLE 2024**).

16.5.6 Neuston Layer

The neuston layer may be defined, for the purposes of studying PFAS-containing foam, as the zone directly underlying the SML that is typically enriched with biological life and aligns with the larger definition by **Wurl et al. (2017)**, which was related to strata thicknesses. **Wurl et al. (2017)** indicated:

> "The sea surface microlayer is the boundary interface between the atmosphere and ocean, covering about 70% of the Earth's surface. The SML has physicochemical and biological properties that are measurably distinct from underlying waters. Because of its unique position at the air-sea interface, the SML is central to a range of global biogeochemical and climate-related processes. Historically, the SML has been summarized as being a microhabitat comprised of several layers distinguished by their ecological, chemical and physical properties with an operational total thickness of between 1 and 1000 µm."
>
> "While this 1,000 µm SML definition is large enough to encompass the neuston, the refined definition of 50 µm thick SML provided above is considered the state-of-the practice for the purposes of understanding and evaluating PFAS-containing foam and layers of significance immediately underlying it. **Liss and Duce (1997)** clarify the neuston below the 50 µm SML as two distinct biological layers, "[The] neuston can be divided into epineuston and hyponeuston. The epineuston includes more than 40 species of water striders, *Halobates*, inhabiting the open ocean and coastal areas. The hyponeuston are organisms in the surface centilayer including hydrozoa, mollusks, copepods, isopods, decapod crustaceans, fishes, and the seaweed *Sargassum*."

Section 11.1.7.3 includes generalized surface water sampling guidance references. For PFAS-containing foam on surface water, it appears that the neuston layer is of particular importance in understanding dissolved-phase PFAS within the water column that may be available to the SML for aggregation and concentration into foam at the air-water interface. The neuston may also provide insight into the stratification of PFAS in the water column below the interface.

16.5.7 Analytical Methods

Analytical methods for the analysis of PFAS-containing foam are essentially the same as those used for PFAS in other non-drinking water media. A discussion of these analytical methods is found in **Section 11.2**. As with all non-drinking water samples, there is no USEPA-certified method for the analysis of PFAS at the time of this publication. Efforts are being undertaken to develop the various analytical methods for the various non-drinking water media. Since there may be very high levels of PFAS in PFAS-containing foam, the laboratory should be warned of this potential so that it can take the necessary precautions during analysis. In the Minnesota case study (**MPCA 2020**), a commercial laboratory analyzed PFAS-containing foams using their proprietary method of LC/MS/MS. These foam samples were collected following the Michigan foam sampling guidance noted above, with caution taken to prevent dilution of the sample by minimizing contact with the water during foam sample collection.

16.5.8 Enrichment Factors

Enrichment factors are defined for the context of this document as "the calculated fold increase (or decrease) of PFAS concentrations in foam compared to the co-located surface water sample. These values are unitless and are determined by dividing the foam concentration of a specific PFAS compound by the concentration of the same compound detected in the surface water sample. The foam enrichment factor for a given PFAS compound indicates whether that compound is preferentially concentrating into the foam from the bulk water column" (**MPCA 2020**).

As reported by **McMurdo et al. (2008)**, "**Kaiser et al. (2006)** observed that surface foam created by bubbling air through an aqueous solution was enriched in perfluorooctanoate PFO by up to 3.2 times." However, simple enrichment factors have been documented in PFAS analytical samples from sites in Minnesota with factors ranging up to >32,000 times (**MPCA 2020**).

Currently, the extent to which the presence of foam may deplete PFAS concentrations in surface water is unclear. Enrichment factors of short-chain versus long-chain PFAS differed in one Minnesota case study (**MPCA 2020**) where 33 PFAS analytes were provided. With few exceptions, "short chain PFAS did not tend to enrich into the foam. Often the four, five, and six-carbon length chains were not detected in the foam samples. If they were detected, their concentrations were lower compared to concentrations measured in the surface water sample. Long-chain PFAS were found to have relatively higher foam-to-water enrichment factors than short chain PFAS. In a majority of the samples, 2-(N-ethyl-perfluorooctane sulfonamide) acetic acid (ETFOSAA) and perfluorooctanesulfonamide (PFOSA) had the largest foam enrichment" (**MPCA 2020**).

The ability of surfactants to concentrate in surface water foam is well known, but may be particularly of interest near source areas due to the ability of PFOA to partition into air circumstantially. Both terminal PFOA and PFOS may become entrained in these foams at high concentration, posing particular risk to ecological receptors in the neuston, SML, and those species reliant on the biological life above and below these zones. In support of this notion, **Battelle (2018)** indicated, "Foams in the natural environment are metastable and generally dissipate within seconds to days. Compositionally, foams are very similar to the SML, they are formed from the air entrapment on SML and they destabilize back to form SML. Compared to bulk water, foams are significantly enriched in many dissolved and particulate components, including particulate and organic matter, clay minerals, lipids, hydrocarbons, proteins, bacteria, hydrophobic contaminants, and heavy metals. As such, foams can provide a mechanism for fast transport of the contaminants through aquatic systems and a potential exposure pathway for aquatic animals and humans." Due to concerns over potential adverse health effects from exposure to PFAS containing foam, the Michigan Department of Health and Human Services (MDHHS) recently issued a recommendation advising residents and visitors to avoid foam on Michigan waterbodies (**MPART 2023**).

16.6 Effluent Limits for PFAS

This section provides information about the current status of effluent limits for PFAS from discharges of wastewater to surface water. The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include information about PFAS in marine environments (see **Section 1.3.5**).

16.6.1 Introduction

The protection of surface water quality from the impacts of discharges from publicly owned treatment works (POTWs) and industrial wastewater treatment works is based on the establishment of effluent limits for pollutants in the discharges from those facilities. The effluent limits are enforced through National Pollution Discharge Elimination System (NPDES) permits. Those effluent limits are developed by establishing technology-based (TBELs) and water quality-based (WQBELs) effluent limits for a specific pollutant and using the most restrictive value of the two for the final effluent limit in the permit.

Effluent limits are also informed by effluent limit guidelines (ELGs) that are national wastewater discharge standards developed by USEPA on an industry-by-industry basis. These are technology-based regulations that are intended to represent the greatest pollution reductions that are economically achievable for an industry. The standards for direct dischargers are incorporated into NPDES permits issued by states and USEPA regional offices and permits or other control mechanisms for indirect dischargers (**https://www.epa.gov/eg/learn-about-effluent-guidelines**).

As of the date of this document, there are no USEPA-established ELGs for PFAS. USEPA outlined an approach for establishing ELGs for select PFAS in its PFAS Strategic Roadmap (**USEPA 2021**) and the agency released its Effluent Guidelines Program Plan 15 in 2023 (**USEPA 2023** (see **Section 16.6.5**). Currently, only North Carolina has an NPDES permit with TBELs for PFAS. These TBELs were established using Best Professional Judgment, (**USEPA 2010**), the process used when ELGs are not available. Minnesota has adopted an NPDES permit with WQBELs for PFOS (see **Section 16.6.4.1**).

16.6.2 ELG Development and Implementation

This section summarizes the state of practice for how technology-based ELGs are developed and used in the process for selecting NPDES permit effluent limits. This is followed by a discussion of the current state of knowledge regarding data collection and ELG development plans by USEPA for PFAS.

16.6.2.1 ELG Development

ELGs "represent the greatest pollutant reductions that are economically achievable for an industry" (USEPA 2021[2432]). ELGs for direct discharges to surface water are enforced through effluent limits established in NPDES permits issued by state and USEPA regional offices. For discharges to a POTW, the ELGs are enforced through a pretreatment program established by the POTW and enforced through its NPDES permit and the permits issued by the POTW for discharges into its collection system. For the process of using ELGs to develop TBELs for an NPDES permit, see section 5.2.1 of the Permit Writer's Manual developed by USEPA (**2010**).

ELGs are developed from empirical data that represent the performance of various technologies and best management practices available to any given industry type (See **Figure 16-3** for key steps in the process). For toxic and nonconventional pollutants such as PFAS, ELGs are developed based on Best Available Technology Economically Achievable (BAT) (**USEPA 2010**). The ELG based on BAT is established using the performance associated with the best control and treatment measures that facilities in an industrial category can achieve while also taking into consideration economic achievability as it relates to pollutant reduction benefits. Many other factors are also considered in establishing the ELG and not just for those

based on BAT. These factors can either be numeric or non-numeric/narrative limitations based on use of a specific best management practice (BMP). For more information, see section 5.2.1.1 of the Permit Writer's Manual (**USEPA 2010**).

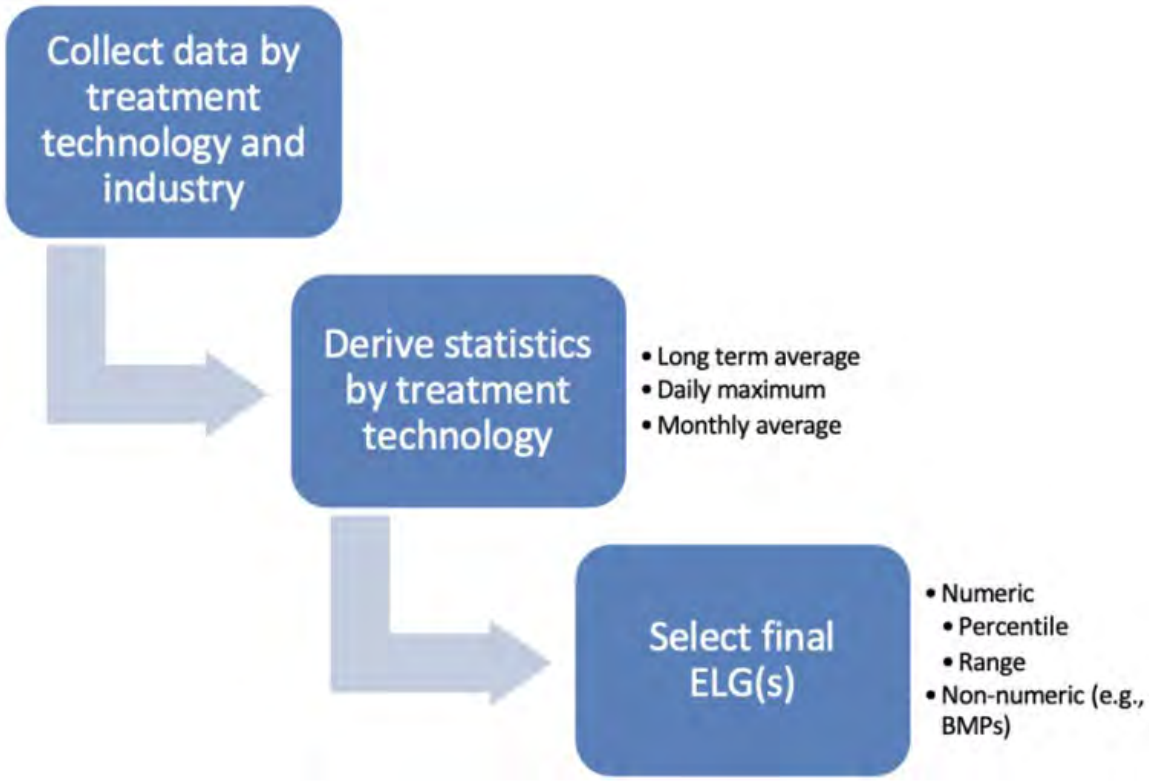


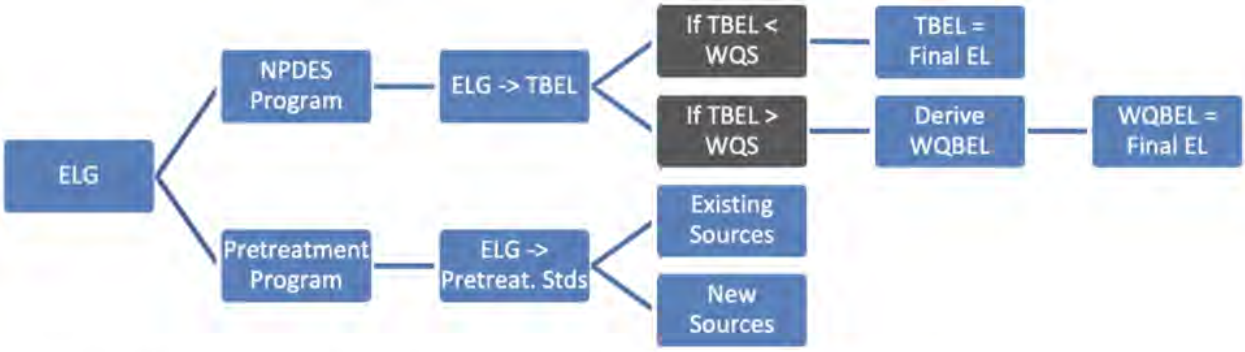
Figure 16-3. Key steps in the process of ELG development.

16.6.3 ELG Implementation

During the development of an NPDES permit, if it is found that the ELGs and/or state-established TBELs will not be sufficiently protective of water quality in the receiving water, then the CWA requires the development of WQBELs. WQBELs are developed so that the discharge authorized by the permit will not cause an exceedance of water quality standards that protect designated beneficial uses of the receiving water. See Section 16.1 for a discussion of beneficial uses for receiving waters. Some of the common beneficial uses include as drinking water, aquatic habitat, contact and non-contact recreation, and for commercial and sport fishing. Besides beneficial uses, the WQBELs take into account information about the receiving water that includes attributes such as ambient water quality, flow, dilution and additional discharges. For a comprehensive look at the WQBEL process, see Chapter 6 of the Permit Writer's Manual (**USEPA 2010**).

In summary, the implementation of ELGs depends on whether the permit is for "direct discharge" (a direct discharge from the facility to ambient surface water) or "indirect discharge" to a POTW and permitted via a pretreatment program (**Figure 16-4**). For direct discharges, the ELG is typically used to set the TBEL, which is then compared against the ambient water quality standard (WQS) to see if it can be achieved by the TBEL alone. If implementing a TBEL would not lead to an exceedance of the WQS, then the TBEL could be used to set the final effluent limitation, after consideration of site-specific factors. If the TBEL might lead to a WQS exceedance, then development of a WQBEL is typically required for setting the final effluent limitation. WQBELs must consider not only federal requirements but any state-specific requirements. Note that for PFAS, only a few states have WQS (see the Environmental Media Values

Table Excel File), so the availability of standards for use in setting WQBELs is as yet limited. As noted in **Section 16.1**, USEPA has published draft national recommended aquatic life criteria for PFOA and PFOS in freshwater (**USEPA 2022**; **USEPA 2022**). USEPA also plans to develop ambient water quality criteria for the protection of human health (based on drinking water and fish consumption) by Fall 2024. For more information on the potential risks to human health and ecological receptors from exposure to PFAS, see **Section 9.1** and **9.2**, respectively. For indirect discharges, pretreatment standards are selected from ELGs for existing sources, and for new sources.



- ELG = Effluent limit guideline (national technology-based discharge standards)
- TBEL = Technology-based effluent limit (minimum technologically achievable limit)
- WQBEL = Water quality–based effluent limit (limit needed to meet risk-based WQS instream)
- Final EL = Final effluent limit (allowable effluent discharge that meets WQS instream)
- WQS = Water quality standard (ambient, risk-based, for protection of aquatic life, human health, etc.)

Figure 16-4. Schematic for implementation of ELGs.

16.6.4 Status of ELGs and Effluent Limitations for PFAS

16.6.4.1 Existing ELGs and Effluent Limitations for PFAS

At the date of publication of this document, USEPA has not been established ELGs for PFAS. Therefore, while USEPA is in the process of developing ELGs and water quality criteria for PFAS, the agency released a memorandum in 2022 recommending that states develop permit-specific effluent limitations for PFAS based on TBELs (USEPA 2022). This was the approach taken by North Carolina in issuing an NPDES permit for the discharge of treated water from a groundwater remediation project (NC DWR 2022) (see text box below). The PFAS limits developed for this NPDES permit are considered TBELs, unique for this discharge, and should not be assumed protective for a different NPDES permit.

North Carolina NPDES Permit for a Groundwater Remediation Discharge

Problem: PFAS in groundwater discharging to river—60% of PFAS load to river.

Solution: Capture groundwater seeps to river and treat to remove PFAS.

Primary indicator PFAS – HFPO-DA (GenX); PFMOAA (perfluoro-2-methoxyacetic acid); PMPA (perfluoromethoxypropyl carboxylic acid). Sufficient reduction of these shown to be indicative of sufficient reduction of total PFAS in discharge.

Discharger provided evaluation showing that granular activated carbon (GAC) could remove the 68 PFAS listed in the permit by at least 99%. **Established as the TBEL**.

Effluent limitation set at 99% reduction on a monthly mass basis using the three indicator PFAS to show compliance. Based on current concentrations—the expected effluent would be less than 122 ng/L HFPO-DA, 643 ng/L PFMOAA, and 132 ng/L PMPA.

When USEPA adopts PFAS surface water quality criteria, a reasonable potential analysis will be conducted and the permit will be reopened to include new effluent limits based on water quality if they are more stringent than the TBEL.

Minnesota has issued an NPDES permit for a municipal wastewater treatment facility with effluent limitations for PFOS based on Minnesota's water quality standard for PFOS (**MPCA 2022**). The treatment facility discharges to a river. The effluent limitations for the permit, which are a daily maximum of 497 ng/L and a quarterly average of 287 ng/L, were developed based on a reasonable potential analysis. That analysis indicated a reasonable potential for exceedance of Minnesota's water quality standard of 12 ng/L PFOS for a river. As the facility is undergoing an expansion, the limits are enforceable upon completion and startup of the expansion, but no later than 6 months prior to permit expiration. The 2013 permit also contains a limit on the mass loading of PFOS in biosolids applied by land application of 0.384 lbs/acre. This limit is not found in subsequent permit updates in 2018 and 2022. These values were developed on a site-specific basis and are not necessarily protective for a different discharge.

16.6.4.2 USEPA PFAS Data Collection for ELG Development

USEPA's collection of data to support development of ELGs for PFAS has been primarily through its effluent guideline program plans (specifically Plans 14 and 15), a 2021 Advance Notice of Proposed Rulemaking (ANPRM), and a 2021 Multi-Industry PFAS Study. In addition, USEPA is collecting data from landfills to support possible development of PFAS effluent limits for landfill leachate, and from industrial discharges to POTWs for possible development of PFAS pre-treatment effluent limits. These activities are discussed below.

USEPA Effluent Guidelines Program Plan 14

In 2019, USEPA issued its Preliminary Effluent Guidelines Program Plan 14 (Preliminary Plan 14) (**USEPA 2019**) and a supporting report, The USEPA's Review of Per- and Polyfluoralkyl Substances (PFAS) in Industrial Wastewater Discharge (**USEPA 2019**). The preliminary plan and the report discussed an initial review of PFAS discharges to surface waters and POTWs and concluded that "…little is known about the identity, frequency, or amount of PFAS compounds discharged in industrial wastewater." The report recommended a follow-up study to collect data on PFAS manufacture, use, control, and discharge to surface water by industries USEPA determined to be likely dischargers of PFAS. These consisted of airports, organic chemical manufacturers, paper and paperboard manufacturers, and textile and carpet manufacturers. This became the Multi-Industry PFAS Study (see below). With publication of the final Plan 14 in 2021 (**USEPA 2021**), metal finishers were added to the Multi-Industry PFAS Study.

Advance Notice of Proposed Rulemaking

In March 2021, USEPA issued an Advance Notice of Proposed Rulemaking (ANPRM) titled "Clean Water Act Effluent Limitations Guidelines and Standards for the Organic Chemicals, Plastics and Synthetic Fibers Point Source Category" (**USEPA 2021**). The ANPRM noted that USEPA was "initiating further data collection and analysis to support potential future rulemaking under the CWA relating to ELGs, pretreatment standards, and new source performance standards applicable to the OCPSF point source category."

Multi-Industry PFAS Study

As an outcome of USEPA's effluent guideline program, The Multi-Industry PFAS Study (**USEPA 2021**) focused on collecting, compiling, and reviewing information and data on PFAS in discharges from industries in the following point source categories:

- Organic chemicals, plastics and synthetic fibers (OCPSF) manufacturers and formulators
- Metal finishing
- Pulp, paper, and paperboard manufacturers
- Textile mills
- Commercial airports (excludes USDOD facilities)

In addition, the study also attempted to acquire information on the types and concentrations of PFAS discharged in wastewater, as well as assess availability and feasibility of control practices and treatment technologies capable of reducing or eliminating PFAS in wastewater discharges. The information was collected through outreach to stakeholders, including company representatives and trade associations; state, regional, and local wastewater regulatory authorities; and treatment technology vendors. Data sources included 2019 and 2020 NPDES DMRs, USEPA's Industrial Wastewater Treatment Technology Database, USEPA's drinking water treatability database, and data made available through other federal agencies such as Department of Transportation, Federal Aviation Administration, Department of Health and Human Services, and Food and Drug Administration, and organizations such as the American Chemistry Council. The report includes detailed information on data sources, and whether any PFAS ELGs have been developed for industries within each of the point source categories.

USEPA Effluent Guidelines Program Plan 15

USEPA discussed its findings from the Multi-Industry PFAS Study and its plans to develop ELGs for PFAS in the 2021 Preliminary Effluent Guidelines Program Plan 15 (**USEPA 2021**) and the subsequent 2023 Effluent Guidelines Program Plan 15 (Plan 15) (**USEPA 2023**). A summary is provided below.

OCPSF Manufacturers and Formulators

In December 2021, USEPA used its authority under Section 308 of the CWA to collect data on characterization of wastewater generation, treatment, and discharge from PFAS manufacturing facilities. USEPA "verified that PFAS, including legacy long-chain PFAS and short-chain replacement PFAS, are present in wastewater discharges from OCPSF facilities" (**USEPA 2021**) to surface waters and POTWs. For both PFAS manufacturers and formulators, average concentrations of short-chain perfluoroalkyl carboxylic acids (PFCAs) and perfluoroalkane sulfonic acids (PFSAs) were generally higher relative to long-chain PFCAs and PFSAs. USEPA determined that the development of ELGs for PFAS manufacturers is warranted and plans to revise the existing OCPSF ELGs (40 CFR Part 414). As noted in Program Plan 15, depending on available resources, USEPA intends to publish a proposed rule in spring 2024. In addition, USEPA will continue to evaluate the need to develop regulations to address PFAS discharges from PFAS formulators/processors.

Metal Finishing

USEPA determined that PFAS have, and continue to be, used by metal finishing facilities in the United States. USEPA identified chromium electroplating facilities as the most significant source of PFAS due to their use of PFAS-based mist/fume suppressants to control toxic hexavalent chromium emissions. USEPA determined that the development of effluent guidelines and standards for chromium electroplating facilities is warranted and plans to revise the existing metal finishing ELGs (40 CFR Part 433). Depending on the availability of resources, USEPA intends to collect the data necessary to revise these ELGs, which will include conducting a survey of the industry and analysis of wastewater samples. According to the finalized Program Plan 15, USEPA intends to publish a proposed rule by the end of 2024.

Pulp, Paper, and Paperboard

While USEPA determined that PFAS have been and continue to be used by U.S. pulp, paper, and paperboard facilities, only a small subset of facilities are actively applying PFAS to paper products. The information collected by USEPA indicates that the industry phased out the use of PFOA and PFOS approximately a decade ago but continues to use FDA-approved short-chain PFAS in limited quantities for the manufacture of food contact packaging and specialty paper products. The industry is expected to transition to PFAS-free technologies and eliminate all application of PFAS in U.S. pulp and papermaking operations by 2024. This schedule coincides with an FDA agreement with chemical manufacturers to voluntarily phase out use of PFAS that contain or may degrade to 6:2 fluorotelomer alcohol (6:2 FTOH) in

food contact applications by 2024. As a result, a rulemaking on the pulp, paper, and paperboard category is not a priority for USEPA at this time. USEPA plans to continue to study this point-source category, paying particular attention to the potential for legacy discharges after the transition to PFAS-free additives.

Textile and Carpet Manufacturers

As reported in Preliminary Plan 15 (**USEPA 2023**), much of the information on textile and carpet manufacturers obtained was through a review of publicly available information and literature. Based on a small number of sample results, USEPA determined that PFAS, including legacy long-chain PFAS, are present in wastewater discharges from textile mills to POTWs and that most textile mills were not monitoring for PFAS. Subsequently in November 2021, USEPA used its authority under Section 308 of the CWA to require nine textile manufacturers to provide information on PFAS use and import, PFAS in industrial wastewater discharges, and treatment of PFAS-containing wastewater. Nineteen of 92 (21 percent) reported they used PFAS in 2020, and of those, 18 of the 19 (95 percent) indicated their intention to reduce or eliminate use of PFAS by the end of 2026 by using alternative surface treatment products or technologies. More than half of the textile mills that responded to the survey discharge their process water to a POTW. Two indicated they operate a wastewater treatment system that can effectively remove or eliminate PFAS in wastewater. USEPA plans to expand its study of this category through use of a mandatory, nationally representative questionnaire.

Commercial Airports

USEPA determined that commercial airports may generate PFAS-containing wastewater from live-fire firefighting training, emergency response activities, and accidental leaks from stockpiles of AFFF. However, one outcome of the Federal Aviation Administration (FAA) Reauthorization Act of 2018 was that the FAA has approved and encourages use of different types of AFFF testing equipment that do not require dispensing AFFF when airports conduct periodic equipment testing and training. As of March 2022, the FAA has approved and is funding the use of four different types of firefighting testing devices that do not dispense AFFF and more than half of certified airports have applied these procedures. In addition, as of June 2022, all firefighting foam formulations that meet current military specifications contain less than 800 ppb of PFOS or 800 ppb PFOA. Based on this information, USEPA is not prioritizing rulemaking for this category at this time. However, USEPA will continue to study commercial airport use of AFFF that contains PFAS and will continue to monitor the industry's transition to fluorine-free foam (see **Section 3.11** for more information).

Landfills

Based on public comments to Preliminary Plan 14, USEPA initiated a Landfill Leachate Detailed Study of wastewater discharges from landfills with a focus on PFAS discharges to surface waters and POTWs. Program Plan 15 notes that since September 2021, USEPA has collected data and information on the industry's facilities, discharge practices, and effectiveness of control practices/technologies to remove PFAS. Depending on available resources, USEPA intends to revise the existing Landfills Point Source Category ELG to address PFAS (schedule yet to be determined).

POTW Influent Study

As noted in Program Plan 15, USEPA intends to collaborate with wastewater treatment facilities to initiate a nationwide study on industrial discharges of PFAS to POTWs. This includes indirect discharges from industrial categories that have been reviewed, as well new categories for which there are very little PFAS data. The goal is to collect samples of PFAS from industrial sources upstream of POTWs (that is, before mixing and dilution from other waste streams). USEPA also intends to develop an Information Collection Request (ICR) and a sampling strategy providing more details about the POTW Influent PFAS Study.

16.7 Surface Water/Groundwater Interaction

The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include information about recent studies of PFAS at the groundwater-surface water interface (see **Section 1.3.4.3**) and conducting mass flux analysis to understand PFAS migration in groundwater and potential discharge to surface water (see **Section 1.3.8.2**).

As mentioned in **Section 16.4.5**, surface water/groundwater interaction may play a role in a conceptual site model and locating places to sample. It has been found that PFAS in groundwater that migrates to surface water can be a significant source of PFAS in the surface water, potentially impacting beneficial uses. The same can be said for PFAS in surface water migrating and impacting groundwater quality. These concepts are demonstrated by a case study presented in **Section 15.5.2** which describes two examples, one from North Carolina and one from Minnesota. Also see **Section 5.3.4.1** for information on the fate and transport of PFAS due to groundwater/surface water interactions and **Section 5.3.4.2** for information on surface water/sediment interactions.

17 ADDITIONAL INFORMATION

This section provides supplemental information for **Section 6** on media-specific occurrence, **Section 7.1** for human health effects, and for **Section 9** on site risk assessment.

Section Number	Topic
1.4	**Priority Topics for Human and Ecological Health Effects (2025)**
1.7	**Priority Topics for Biosolids Land Application (2025)**
17.1	**Additional Information for Media-Specific Occurrence**
17.2	**Additional Information for Human Health Effects**
17.3	**Additional Information for Risk Assessment**

17.1 Additional Information for Media-Specific Occurrence

This section includes links for the tables of media-specific occurrence information that are summarized in **Section 6** and included in the figures in that section.

- **Tables 17-1 A-C** – outdoor air, indoor air, settled dust, precipitation
- **Tables 17-2 A-C** – soil, sediment, and biosolids

The **Section 6 interactive plots webpage** provides additional information for the data included in the figures. The interactive figures were developed using **R software** and **plotly**.

The previous version of Section 6 (June 2022) is archived as a PDF under **Archived External Tables and Sections** on the home page of this site. The previous version of Section 17.1 (June 2022) is archived as a PDF under **Archived External Tables and Sections** on the home page of this site.

Table numbers 17-3, 17-4, and 17-5 are reserved for future updates in media-specific occurrence.

17.2 Additional Information for Human Health Effects

This section supplements information provided in **Section 7.1** on biomonitoring, exposure, toxicokinetic, toxicology, and epidemiology data for long-chain and short-chain PFAAs. The PFAS discussed in Sections 17.2.3 and 17.2.4 include perfluorocarboxylic acids (PFCAs) with four to fourteen carbons and perfluorosulfonic acids (PFSAs) with four or more carbons. Also covered are two per- or polyfluorinated ether carboxylates (FECAs)—ammonium 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoate (also known as perfluoro-2-propoxypropanoic acid (PFPrOPrA); hexafluoropropylene oxide [HFPO] dimer acid, commonly known as GenX) (**Section 2.2.3.5**); and 4,8-dioxa-3H-perfluorononanoate (commonly known as ADONA); and per- and polyfluoroether carboxylates (PFECAs); per- and polyfluoropolyether carboxylates (PFPECAs) including chlorinated PFPECAs (ClPFPECAs); per- and polyfluoroether sulfonates (PFESAs) including chlorinated PFESAs; per- and polyfluoropolyether sulfonates (PFPESAs), fluorotelomer alcohols, and fluorotelomer sulfonic acids. These PFAS that contain ether group(s) are replacements for PFOA, PFNA, and/or PFOS as processing aids in certain fluoropolymer production, and some are also formed as industrial byproducts. They are included because they are of current interest and health effects data are available. There is little or no publicly available health effects information for most of the many other PFAS used in commerce (**Section 2.5**), including precursors that can be converted to PFAAs in the environment and in the human body.

For further detail of scientific names and carbon chain length of PFAAs see **Section 2.2**.

17.2.1 Overview

Based on the number of studies located through searches of the National Library of Medicine's PubMed, a database containing relevant peer-reviewed publications, much of the information summarized here became available after 2005. Additional studies may be available, particularly for those compounds with large health effects data sets, and additional information on the topics in this section can be found in databases such as PubMed and references listed in **Section 7.1**.

The publicly available toxicological data set is currently largest for PFOA and PFOS, with considerable data also available for PFBA, PFBS, PFHxA, PFNA, PFDA, and GenX. Fewer studies are available for PFHxS, PFUnA, PFDoA, ADONA, and the other ether and polyether PFAS mentioned above, and little or no data for PFPeA, PFHpA, PFTrA, PFTA, PFPeS, PFHpS, PFNS, or PFDS. Most of the mammalian studies were conducted in rodents, with a few in nonhuman primates (monkeys). The most notable toxicological effects from the mammalian studies of these PFAS, with relevant citations, are discussed in **Section 17.2.5** and are summarized in **Table 17-8 Toxicological Effects** Excel file (last updated November 2021). However, due to the large size of the toxicological data set, it is beyond the scope of this section to identify no observed adverse effect levels (NOAELs) and lowest observed adverse effect levels (LOAELs) for these effects. The numerous reviews of potential epidemiological associations of health endpoints with PFAAs are discussed in Section 17.2.4. Many of the epidemiology studies evaluate associations of health endpoints with multiple PFAAs detected in the blood serum of the subjects. Epidemiologic data from the general population have been used to develop draft reference doses for PFOA and PFOS (**CA OEHHA 2023**; **USEPA 2023**), as well as for PFHxS and PFDA (**USEPA 2023**), and draft cancer slope factors for PFOA (**USEPA 2023**; **CA OEHHA 2023**) based on human data.

Finally, data gaps and research needs are discussed.

17.2.2 Human Biomonitoring and Sources of Exposure

Several long-chain PFAAs (from highest to lowest geometric mean [GM] serum levels, as follows: PFOS, PFOA, PFHxS, PFNA) are present in the low parts per billion (ng/ml) range in the blood serum of almost all adult residents of the United States, while other PFAS are detected in a smaller percentage of the population (**CDC 2022**; **Olsen et al. 2017**)). In contrast, short-chain PFAAs such as PFBS and PFHxA are more rapidly excreted and were infrequently detected in the blood serum of the U.S. general population (**CDC 2022**; **Olsen et al. 2017**). For example, PFBS was detected in less than 5% of serum samples in all National Health and Nutrition Examination Survey (NHANES) years except 2005–'06 (**CDC 2022**). Both NHANES and the blood donor studies show generally higher levels of long-chain PFAAs in males than females, with generally decreasing serum levels of long-chain PFAAs over time. NHANES 2013–'14 evaluated PFAS in children 3–11 years old (**CDC 2022**) and found serum levels of PFOS, PFOA, PFHxS, and PFNA generally similar to those in older adolescents and adults in the same time period. It was noted that most of the children studied were born after PFOS manufacturing was phased out in the United States in 2002 (**Ye et al. 2018**). Long-chain PFAA human serum levels in other industrialized countries are generally similar to the United States (**Kato 2015**) and may be lower in less developed nations (for example, Afghanistan) where they are less likely to be used industrially and consumer products containing them are less frequently used (**Hemat et al. 2010**). Testing in 2017 by the North Carolina Department of Health and Human Services (NC DHHS) did not detect HFPO-DA ("GenX") in the blood serum or urine of North Carolina residents with previous or current exposure from private wells, but did detect other PFAS (**NC DHHS 2018**). A North Carolina State University study of a public water system and its users included a larger list of PFAS analytes and, although no GenX was detected, they identified four newly identified PFAS in the drinking water and blood serum of most participants (**Hogue 2019**; **Hopkins et al. 2018**). A study of a potentially exposed population detected ADONA in only a few subjects (**Fromme et al. 2017**).

Human exposures can result from consumption of fish from waters contaminated with bioaccumulative PFAAs (for example, **MDCH 2014**). PFSAs with more than eight fluorinated carbons (that is, PFOS and longer chain for PFSAs; PFNA and longer chain for PFCAs) are substantially more bioaccumulative than shorter chain PFAAs, with PFSAs generally more bioaccumulative than PFCAs with the same number of fluorinated carbons (**Conder et al. 2008**; **Martin et al. 2003**). When drinking water is contaminated with even relatively low levels of long-chain PFAAs, exposure from drinking water may dominate contributions from exposure sources such as food and consumer products that are prevalent in the general population. For example, **USEPA (2011)** predicted that ongoing exposure to 20 ng/L PFOA in drinking water will increase serum PFOA levels more than two-fold from the U.S. median of 2 ng/L. Elevated serum levels of long-chain PFAAs have been observed in communities with contaminated drinking water in several U.S. states, including Ohio and West Virginia (**WV University 2008**; **Emmett et al. 2006**; **Steenland et al. 2009**) (**Hoffman et al. 2011**), New Hampshire (**NH DHHS 2015**), Alabama (**ATSDR 2013**), Minnesota (**MDH 2009**; **Landsteiner et al. 2014**), New York (**NYS DOH 2016**), and in other nations, including Germany (**Hölzer et al. 2008**) and Sweden (**Li et al. 2018**) (**Table 17-6**). **ATSDR (2022)** has conducted exposure assessments that included biomonitoring in eight U.S. locations impacted by PFAS in drinking water.

Understanding exposures to PFAS at different developmental phases (for example, fetus, infant) is important to ensure protection of the most sensitive subpopulations. Evidence for developmental effects from early life exposures to long-chain PFAAs in humans is discussed in **Section 17.2.4** and in animals in **Section 17.2.5**. PFAAs (primarily PFHpA and longer chain PFCAs; PFHxS and longer chain PFSAs) have been detected in human amniotic fluid (**Stein et al. 2012**; **Zhang et al. 2013**), umbilical cord blood (**Kato 2015**; **Kudo 2015**), and breast milk (**Liu et al. 2010**; **White et al. 2011**; **Post, Cohn, and Cooper 2012**; **Kato 2015**; **Kudo 2015**). Although the specific compounds analyzed for and/or detected vary among studies, other PFAAs that have been analyzed for in breast milk rarely exceeded the limit of quantitation (**Tao et al. 2008**; **Tao et al. 2008**). Serum levels of several long-chain PFAAs were higher in breast-fed infants than in their mothers and declined slowly following weaning (**Fromme et al. 2010**), and serum levels of infants who drank formula prepared with PFAS-contaminated water are predicted to be higher than in older individuals using the same water source (**Goeden, Greene, and Jacobus 2019**). Infants and toddlers may also receive higher exposures because of age-specific behaviors such as hand-to-mouth activity that results in greater ingestion of house dust, and more time spent on floors with treated carpets relative to older children or adults (**Trudel et al. 2008**; **Shoeib et al. 2011**).

Elevated serum levels of PFAAs, in some cases >100,000 ng/ml, have been found in industrially exposed workers (**Olsen 2015**). Serum concentrations of PFCAs (PFHpA and longer) were also increased in professional ski waxing technicians due to exposures to fluorinated ski waxes (**Freberg et al. 2010**; **Nilsson et al. 2010**). Higher serum levels of PFDA (**Dobraca et al. 2015**), PFOS, and PFHxS (**Rotander et al. 2015**) have been reported in firefighters relative to those in the general population.

17.2.3 Toxicokinetics

PFAAs for which data are available (PFOA, PFHpA, PFHxA, PFOS) were well absorbed orally (≥90%) in rodents (**Kudo 2015**). PFOA and PFNA were absorbed via inhalation as dusts or aerosols (**Kinney, Chromey, and Kennedy 1989**; **Hinderliter, DeLorme, and Kennedy 2006**). PFOA was absorbed to a limited extent from dermal exposure in studies of isolated human and rodent skin (**Fasano et al. 2005**; **Franko et al. 2012**). Several recent in vivo studies demonstrate dermal absorption in laboratory animals and humans. Chen et al. (**2022**) reported that the tested PFAS (PFCAs with 4 to 12 carbons; PFBS, PFHxS, PFOS; 6:2- and 8:2 diPAP) were absorbed after a single application to skin; the extent of dermal absorption varied with compound and dose. Weatherly et al. (**2023**) reported toxicity and gene expression changes in liver and skin, as well as detection in urine and serum, after daily application of PFPeA, PFHxA, and PFHpA to the skin of mice for 28 days. **Abraham and Monien (2022)** demonstrated dermal absorption of isotopically labelled PFOA mixed with sunscreen in a human volunteer. **Section 1.4.3** includes information about dermal uptake of PFAS in the environment. **Section 1.4.2.3** includes information about potential PFAS exposures from cosmetics and personal care products including sunscreen.

Table 17-6. Long-chain PFAA serum levels in populations exposed through drinking water (ng/ml = µg/L = ppb).

(Means, medians, and maximums available from the cited studies are shown. AM–arithmetic mean; GM–geometric mean; 95th–95th percentile; --- indicates that data are not available).

Location	Study Population	Attributed Source	Year	PFOA			PFOS			PFHxS		
				Mean	*Median*	*Max.*	*Mean*	*Median*	*Max.*	*Mean*	*Median*	*Max.*
C8 Study Population: WV/Ohio (**WV University 2008**) Includes occupationally exposed subject	n = ~69,000 <1 – >90 yrs. M-48%, F-52%	Industrial–PFOA	2005–06	83 (AM)	28	22,412	23 (AM)	20	759	---	---	---
Arnsberg, Germany (**Hölzer et al. 2008**)	n=90 Children 5–6 yrs.	Industrial waste applied to agricultural land–mainly PFOA	2006	25 (AM)	---	97	5 (AM)	---	21	1 (AM)	---	13
	n=164 Mothers 23–49 yrs.			27 (AM)	---	100	6 (AM)	---	17	1 (AM)	---	6
	n=101 Men 18–69 yrs.			29 (AM)	---	78	12 (AM)	---	36	3 (AM)	---	9
East Metro, MN (**MDH 2009**)	n = 196 20–86 yrs. M-45%, F-55%	Industrial–multiple PFAS	2008–09	23 (AM)	16	177	48 (AM)	41	448	15 (AM)	9	316
Decatur, AL (**ATSDR 2013**)	n=153 "child" – >60 yrs. M-41%, F-59%	Industrial–multiple PFAS	2010	16 (GM)	---	144	40 (GM)	---	472	6 (GM)	---	59
Ronneby, Sweden (**Li et al. 2018**)	n = 3418 4–83 yrs. M-47%, F-53%	AFFF	2014	14 (AM)	10	92	245 (AM)	176	1,870	228 (AM)	152	1790
Portsmouth, NH (**NH DHHS 2015**)	n = 108 < 12 yrs.	AFFF	2015	4 (GM)	5	12	9 (GM)	9	31	6 (GM)	7	26
	n= 363 >12 yrs.			3 (GM)	--	16	8 (GM)	---	75	8 (GM)	---	75
Hoosick Falls, NY (**NYS DOH 2016**)	n = 2,081 <17 – >60 yrs. M-45%, F-55%	Industrial–PFOA	Feb.–April 2016	24 (GM)	28	---	---	---	---	---	---	---
Merrimack, NH (**NH DHHS 2017**)	Public water system n = 217	Industrial–PFOA	2016	3.9 (AM)	---	10.1 (95th)	5.5 (AM)	---	15.2 (95th)	1.3 (AM)	---	3.2 (95th)
	Private wells N=219			4.4 (AM)	---	26.6 (95th)	5.4 (AM)	---	16.4 (95th)	1.3 (AM)	---	3.4 (95th)

Table 17-7. Half-lives of PFCAs, PFSAs, and perfluoroethers in rodents, nonhuman primates, and humans.

Notes: No information was located for PFPeA, PFDoA, PFTrDA, PFTeDA, PFPeS, PFNS, PFDS, ADONA; --- indicates that data are not available; h–hour, d–day, y–year.

	Mouse		Rat		Nonhuman primate		Human	
	Male	Female	Male	Female	Male	Female	Male	Female
PFCAs								
PFBA	13 h[a]	2.9 h[a]	9.2 h[a]	1.8 h[a]	40 h[a]	41 h[a]	72 h[a] (O; mean)	87 h[a] (O; mean)
PFHxA	~1 h[b]		~2 h[c]	~2 h[c]	5.3 h[c]	2.4 h[c]	32 d[e] (O; GM)	---
					14–47 h[d]			
PFHpA	----	----	2.4 h[f]	1.2 h[f]	----	----	---	<50 yrs. of age-1.2 y[g] (G-U)
							All M & F >50 yrs. of age-1.5 y[g] (G-U)	
PFOA	19 d[h]	17 d[h]	4–6 d[i]	2-4 h[i]	21 d[j]	30 d[j]	3.8 y (O; mean); 2.4 y (O; GM)[k] 2.3 y[z] (DW; median) 3.3 y[m] (DW; GM) 3.4 y[n] (DW; mean) 2.69 y[n] (DW; mean)	
							15–50 yrs. of age-4.6 y[n] (DW)	15–50 yrs. of age-3.1 y[n] (DW)
PFNA	34–68 d[o,p]	26–69 d[o,p]	30 d[o,p]	1–2 d[o,p]	----	----		<50 yrs. of age-2.5 y[g] (G-U)
							All M & F >50 yrs. of age-4.3 y[g] (G-U)	
PFDA	----	----	24 d[q]	29 d[q]	----	----		<50 yrs. of age-4.5 y[g] (G-U)
							All M & F >50 yrs. of age-12 y[g] (G-U)	
PFUnA	----	----	----	----	----	----		<50 yrs. of age-4.5 y[g] (G-U)
							All M & F >50 yrs. of age-12 y[g] (G-U)	
PFSAs								
PFBS	----	----	3.1–4.5 h[r,s]	2.4–4.0 h[r,s]	15–95 h[r,s]	8.1–83 h[r,s]	26 d (O; GM)[s]	
PFPeS	----	----	----	----	----	----	1.03 y[z](DW; median)	
PFHxS	29 d[t]	26 d[t]	29 d[t]	1.8 hd[t]	141 d[t]	87 d[t]	8.5 y (O; mean); 7.3 y (O, GM)[k] 5.3 y[n] (DW)	
							15–50 yrs. of age-7.4 y[n] (DW)	15–50 yrs. of age-4.7 y[n] (DW)
PFHpS	----	----	----	----	----	----	5.0 y[z](DW; median)	
PFOS	40 d[u]	34 d[u]	47–67 d[u,v]	40–48 d[u,v]	132 d[u]	110 d[u]	5.4 y (O; mean); 4.8 y (O; GM)[k] 3.4 y [n] (DW; mean) 2.89 y [n] (linear; DW; mean)	
							15–50 yrs. of age-4.6 y[n] (DW; mean)	15–50 yrs. of age-3.1 y[n] (DW; mean)

	Mouse		Rat		Nonhuman primate		Human	
	Male	Female	Male	Female	Male	Female	Male	Female
Perfluoroether (Replacement for PFOA in fluoropolymer manufacturing processes)								
GenX	21 h[w]	18 h[w]	3 h[x]	<3 h[x]	~2 h[y]	~2 h[y]	----	----
PFOS-branched isomers	----	----	----	----	----	----	2.87–5.57 y[z](DW, GM)	

DW–Based on decline in serum levels after exposure to contaminated drinking water ended.
GM–Geometric mean.
G-U–Mean value; based on urinary excretion in general population, with modeled menstrual excretion for F < 50 yrs. old. More uncertain than estimates based on decline in serum levels. (Not shown for PFAS with half-lives based on serum decline).
O–based on decline in serum levels in workers or retired workers after exposure ended.
[a] **Chang et al. (2008)**
[b] **Iwai (2011)**, reported in **Russell, Nilsson, and Buck (2013)**
[c] **Chengelis et al. (2009)**
[d] **Noker (2001)**, reported in **Russell, Nilsson, and Buck (2013)**
[e] **Russell, Nilsson, and Buck (2013)**
[f] **Ohmori et al. (2003)**
[g] **Zhang et al. (2013)**
[h] **Johnson and Ober (1979)**; **Kemper and Jepson (2003)**
[i] **Lau et al. (2006)**
[j] **Butenhoff et al. (2004)**
[k] **Olsen et al. (2007)**
[l] **Bartell et al. (2010)**
[m] **Brede et al. (2010)**
[n] **Li et al. (2018)**
[o] **Tatum-Gibbs et al. (2011)**
[p] **Ohmori et al. (2003)**
[q] **Gibbs et al. (2012)**
[r] **Chengelis et al. (2009)**
[s] **Olsen et al. (2009)**
[t] **Sundstrom et al. (2012)**
[u] **Chang et al. (2012)**
[v] **Butenhoff (2007)**
[w] **DuPont (2011)**
[x] **DuPont (2011)**
[y] **DuPont (2008)**

PFAAs, particularly long-chain PFCAs and PFSAs, have unique toxicokinetic properties as compared to other types of POPs. Unlike most other bioaccumulative organic compounds (for example, dioxins, PCBs), PFAAs do not have a high affinity for adipose tissue. In contrast, PFAAs are water soluble, have an affinity for proteins (which varies among compounds), and generally distribute primarily to the liver, blood serum (where they are bound to albumin and other proteins), and kidney (**Bischel et al. 2011**; **Lau 2012**, **2015**; **Kato 2015**).

PFAAs are highly resistant to chemical reactions. As such, they are not metabolized, and this is also true for HFPO-DA (**Gannon et al. 2016**) and ADONA (**Gordon 2011**). However, PFAA precursors can be metabolized to PFAAs within the body, and reactive intermediates may be formed in these metabolic pathways (**Rand and Mabury 2016**). Some examples are the metabolism of 6:2 fluorotelomer alcohol (6:2 FTOH) to PFBA, PFPeA, PFHxA, and PFHpA (**Buck 2015**); 8:2 FTOH to PFOA and PFNA (**Kudo 2015**; **Kabadi et al. 2018**); and perfluorooctane sulfonamidoethanols (FOSEs), perfluorooctane sulfonamides (FOSAs), and perfluorooctane sulfonamidoacetic acids (FOSAAs) to PFOS (**Gebbink, Berger, and Cousins 2015**). Additionally, larger PFAS molecules such as polyfluoroalkyl phosphoric acid diesters (diPAPs) have been found in human blood serum and can be metabolized to FTOHs, which are further metabolized to PFCAs (**D'Eon and Mabury 2011**; **Lee and Mabury 2011**).

Excretion of PFAAs and HFPO-DA is primarily through the urine, with a much smaller percentage, if any, eliminated in the feces. In women of childbearing age, excretion also occurs through menstruation and lactation (**Harada and Koizumi 2009**; **Thomsen et al. 2010**). Serum PFAS levels were lower in adult males undergoing venesection (ongoing blood withdrawal) for medical reasons (**Lorber et al. 2015**) and in firefighters who had donated blood, as compared to other firefighters (**Rotander et al. 2015**). The excretion rate for long-chain PFAAs varies substantially between animal species, and it is much slower in humans than in laboratory animals. Additionally, for some PFAS, including PFOA, PFNA, and others, the excretion rate is very different in males and females of the same rodent species, likely due to differences in the extent of secretion and reabsorption by organic anion transporter proteins (OATs) and possibly other transporter proteins in the kidney, reviewed in **Lau (2012)**; **Lau (2015)**; **Kudo (2015)**; and **USEPA (2023)**. Half-lives in rodents, nonhuman primates, and humans for the PFAS included in this section are shown in **Table 17-7**.

As shown in **Table 17-7**, excretion rates in mammalian species vary among PFAS for which half-life data are available, with short-chain PFAAs and GenX generally excreted more rapidly than longer chain PFAAs. Half-lives in rodents and nonhuman primates are generally in the range of several weeks to several months for long-chain PFAAs, and about 1 hour to several days for short-chain PFAAs and GenX. However, PFOA, PFNA, and PFHxS (reviewed in **Kudo 2015**) are excreted much more rapidly (hours to days) in female than male rats; this sex difference in rats also exists but is not as pronounced for PFBA, PFHxA, PFHpA, and PFBS (**Kudo 2015**). This difference in excretion rate is important in interpretation of rat toxicology studies of these compounds, particularly for developmental effects.

Human half-lives for PFAS are longer than in other mammalian species that have been studied, with estimates of several years for long-chain PFAAs (PFOA, PFNA, PFOS, PFHxS); 1 year for PFHpA, and several days to 1 month for shorter chain PFAAs (PFBA, PFHxA, PFBS; **Table 17-7**). The estimates of human half-life shown in **Table 17-7** are based on measured declines in serum PFAS levels in the same individuals over time after a source of elevated exposure, such as occupational exposure or ingestion of contaminated drinking water, ceases. Such estimates are less uncertain than population-based estimates from modeling of PFAS intake and biomonitoring data for serum PFAS levels from different sets of individuals from the general population at different time points. Half-life estimates based on urinary excretion are available for several PFAAs, including some with no serum-based half-life estimates ((**Zhang et al. 2013**) shown as G-U in **Table 17-7**); these urinary estimates are less certain because they include modeled estimates of menstrual excretion in women of childbearing age and do not consider fecal excretion or blood loss other than menstruation (for example, blood donation). It should be noted

that there are large inter-individual variations in human half-lives, which may arise from physiological factors (for example, differences in renal transport by OATs; **Yang, Glover, and Han 2010**).

Because of the large species and sex differences in excretion rates, the internal dose resulting from a given administered dose varies widely among species and, in some cases, males and females of the same species. Therefore, interspecies (for example, animal-to-human) comparisons must account for the large interspecies half-life differences with approaches such as use of internal dose (as indicated by serum level) as the dose metric, interspecies toxicokinetic extrapolation based on the ratio of half-lives in humans and animals, or use of physiologically based pharmacokinetic models.

17.2.3.1 Toxicokinetics Relevant to Developmental Exposures

Toxicokinetics relevant to developmental exposures to PFAAs are important because developmental effects are sensitive endpoints for toxicity of long-chain PFAAs in rodents, and prenatal exposure to some long-chain PFAA was associated with decreased fetal growth in some human epidemiology studies (see **Section 17.2.3.4**). Developmental exposures have been studied in rodents for several PFAAs, but not in nonhuman primates. PFAAs cross the placenta to reach the developing fetus in both humans and rodents (reviewed in **Lau 2012** and **Kudo 2015**), and are transferred to milk, resulting in exposure via lactation (**Luebker et al. 2005**; **White et al. 2009**; **Kato 2015**). In humans, long-chain PFAAs have been detected in cord blood (for example, **Wang et al. 2019**) and amniotic fluid (**Stein et al. 2012**; **Zhang et al. 2013**).

In humans, the greatest exposures to PFAAs in breast milk occur during the first few months of infancy because both PFAA concentrations in milk and the breast milk ingestion rate on a BW basis (ml/kg/day) are highest then; PFAA levels in milk may be lower in mothers who previously nursed other infants (**Tao et al. 2008**; **Haug et al. 2011**; **Thomsen et al. 2010**). Serum concentrations of long-chain PFAAs in breast-fed infants increase several-fold from the levels at birth during the first few months of life, followed by a decline in older infancy and early childhood (**Fromme et al. 2010**; **Mogensen et al. 2015**; **Verner et al. 2016**, **2016**; **MDH 2018**, **2019**; reviewed in **NJDWQI 2015**, **2017**, **2018**). Because of their higher rate of fluid consumption on a BW basis (**USEPA 2019**), exposures to infants who consume formula prepared with PFAS-contaminated water are also highest during the first few months of life. **Goeden, Greene, and Jacobus (2019)** presented a model that predicts transplacental transfer and exposure to breast-fed and formula-fed infants for long-chain PFAAs in drinking water.

17.2.3.2 Relationship of Human Exposures to Serum Levels

Clearance factors (CL) that describe the relationship between oral exposures or dose (ng/kg/day) and steady-state serum levels (ng/L) in humans have been developed for PFOA (**Lorber and Egeghy 2011**; **USEPA 2016**) and PFOS (**USEPA 2016**):

Dose [ng/kg/day] x CL [L/kg/day] = serum concentration [ng/L].

These clearance factors, which indicate bioaccumulative potential, are based on average values for human PFAS half-lives and volumes of distribution (Vd);

CL [L/kg/day] = Vd [L/kg Body Wt] x [Ln2/half-life in days].
Where Ln2 is the natural log of 2.

When combined with mean daily U.S. water ingestion rates (**USEPA 2011**), the CLs have been used to predict the expected average increase in serum levels (above the “baseline” serum level from non-drinking water sources) that results from ongoing exposure to a given drinking water concentration of PFOA or PFOS (**Bartell 2017**; **NJDWQI 2017**; **Post, Gleason, and Cooper 2017**). For PFOA, this average serum:drinking water ratio was predicted to be greater than 100:1 (**NJDWQI 2017**); this ratio is consistent with data from exposed populations and toxicokinetic modeling (**Emmett et al. 2006**; **Hoffman et al.**

2011; **Bartell 2017**). The CL for PFOS predicts an average serum:drinking water ratio of about 200:1 (**NJDWQI 2018**; **Post, Gleason, and Cooper 2017**; **Lu and Bartell 2020**), and available toxicokinetic data also support an estimated ratio of 200:1 for PFNA (**NJDWQI 2015**; **Lu and Bartell 2020**) and PFHxS (**Lu and Bartell 2020**). It should be noted that PFAA serum:drinking water ratios vary among individuals using the same source of contaminated drinking water, due to inter-individual differences in daily water consumption rates (L/kg/day) and/or physiological differences relevant to toxicokinetics.

Bartell (2017), **Lu and Bartell (2020)**, and **ATSDR (2022)** have developed online calculators that provide estimates of an individual's serum concentrations of PFOA, PFOS, PFNA, and PFHxS from the information that is entered, including drinking water levels of these PFAS and other relevant factors. These estimates are based on long-term exposure to a constant drinking water concentration and that serum PFAS concentrations are impacted by interindividual variability in both toxicokinetic factors (for example, PFAS half-lives) and daily drinking water ingestion rate.

17.2.3.3 Isomer-Specific Toxicokinetics

Some PFAAs exist as a mixture of linear and branched isomers; the isomer profile varies depending on the manufacturing process used (telomerization yields primarily linear PFAS; electrochemical fluorination yields a mixture of linear and branched PFAS; **Section 2.2.5.2**. Toxicokinetics may differ among isomers of the same PFAA in rodents (**Loveless et al. 2006**; **De Silva et al. 2009**) and humans (**Zhang et al. 2013**; **Gao et al. 2015**; **Beesoon et al. 2011**; **Xu et al. 2020**; **Li et al. 2022**).

17.2.4 Human Epidemiology Studies

As discussed in **Section 7.1.3**, the epidemiological database for long-chain PFAAs, particularly PFOA and PFOS, is more extensive than for many other environmental contaminants. Many of the studies are recent, and the number of available studies is constantly increasing. In contrast, there are few or no epidemiology studies for many other PFAS (**Carlson et al. 2022**; **Radke et al. 2022**).

Many U.S. general population studies are based on data from NHANES (**CDC 2022**), and other general population studies come from various worldwide locations. These include studies of specific subpopulations such as pregnant women, infants, children, or the elderly, as well as evaluations of associations of prenatal exposures with effects later in life. Data on communities exposed to PFOA through contaminated drinking water come primarily from the C8 Health Study evaluations of approximately 70,000 Ohio and West Virginia residents exposed in drinking water for at least 1 year at concentrations of 50 ng/L to >3,000 ng/L, including evaluations by the C8 Science Panel (**Frisbee et al. 2009**; **C8 Science Panel 2020**). This panel consisted of three prominent environmental epidemiologists charged with determining whether there are "probable links" (defined as "given the scientific evidence available, it is more likely than not that a connection exists between C8 exposure and a particular human disease among class members") between PFOA exposures in this study group and disease. Researchers who participated in the C8 Science Panel recently evaluated current epidemiologic evidence for PFOA and the diseases for which the C8 Science Panel had concluded in 2011–12 that there was a "probable link" with PFOA exposure (kidney and testicular cancer, high cholesterol, thyroid disease, pregnancy-induced hypertension, ulcerative colitis; C8 Science Panel Probable Link reports (**C8 Science Panel 2017**). They also reviewed evidence for associations of PFOA and additional health effects (**Steenland et al. 2020**). The conclusions of **Steenland et al. (2020)** for specific health effects are discussed below.

Until recently, health effects studies were not available from communities with drinking water contaminated with either the other PFAS discussed in this section or the complex mixtures of PFAS present in AFFF. Studies of associations of PFAS with a variety of health effects in a community exposed to AFFF-contaminated drinking water in Sweden have now been reported (**Andersson et al. 2019**; **Li et al. 2020**, **2021**, **2022**; **Xu et al. 2020**, **2022**; **Hammarstrand et al. 2021**; **Nielsen and Joud 2021**; **Engstrom et al. 2022**; **Nielsen et al. 2022**). Additional epidemiological studies of seven communities exposed to PFAS

found in AFFF or specific PFAS other than PFOA (for example, PFNA) are now being conducted through the ATSDR-funded multisite study (**ATSDR 2022**). **Section 1.4.1** includes information about potential human health effects from PFAS exposure arising from AFFF in drinking water.

Finally, health effects of several long-chain PFAAs, including PFOA, PFOS, and PFNA, have been studied in occupationally exposed workers (**Khalil 2015**). Because these workers were primarily male, relatively few women were included in these studies.

Exposure assessment in most but not all of the epidemiology studies of PFAS is based on blood serum levels of PFAS as an indicator of internal dose. The studies often evaluate associations between health endpoints and multiple PFAS detected in blood. Serum levels of long-chain PFAAs are indicators of long-term exposures (**Section 7.1.2**) that reflect individual differences in both exposure (for example, daily water consumption) and rate of excretion. Therefore, serum levels are less uncertain as indicators of exposure than external parameters such as drinking water concentration. In contrast to long-chain PFAS, there is little epidemiological information on short-chain PFAS because they are infrequently detected in blood serum due to their more rapid excretion. Exposure assessment in some of the C8 studies of communities with PFOA exposure from an industrial source is based on serum PFOA levels estimated from modeling of drinking water and air PFOA concentrations over time, rather than measured serum levels **Savitz et al. 2012**; **Winquist and Steenland 2014**, **2014**; **Dhingra et al. 2016**, **2016**; **Herrick et al. 2017**). Finally, exposure is based on job classification, rather than serum PFAA measurements in some occupational studies of PFOA (**Gilliland and Mandel 1993**; **Leonard 2003**; **Lundin et al. 2009**; **Raleigh et al. 2014**), PFNA (**Mundt et al. 2007**), and PFOS (**Alexander et al. 2003**; **Olsen et al. 2004**; **Alexander and Olsen 2007**; **Grice et al. 2007**).

As is the case for epidemiologic studies of environmental contaminants in general, the human studies of PFAAs are observational, in contrast to toxicology studies, which are experimental. Additionally, most epidemiology studies of PFAAs are cross-sectional, although some use other designs (prospective, retrospective, case-control). In cross-sectional studies, exposure and outcome are evaluated at the same point in time. Such cross-sectional studies cannot reveal whether increased exposure led to the health endpoint or vice versa, and reverse causality (for example, when a physiological change affects serum PFAS levels, rather than the serum PFAS levels causing the physiological change) has been hypothesized by some researchers as partially or totally explaining some of the associations in the epidemiological literature, including reduced birth weight and decreased kidney function (reviewed in **NJDWQI 2017**). In general, publications of epidemiology studies report results in terms of associations with the endpoints of interest based on statistical analysis. When there are multiple studies of associations of an environmental contaminant such as PFAA(s) with a health endpoint, results often differ among studies. The differing results can arise from difference in the study design (for example, sex, age, ethnicity of population studied; magnitude and/or duration of exposure; method for assessment of endpoint of interest), size of population studied (may be too small to detect statistically significant associations), method used for statistical analysis, consideration of potential confounding factors, or chance.

Therefore, conclusions about whether the overall body of evidence supports an association are based on scientific judgment and may differ among scientists who review the same body of data. Additionally, for PFAS, because many new epidemiology studies continually become available, more recent evaluations may include considerable data not available for earlier evaluations. Because observational studies are not designed to prove causality for health effects, conclusions about evidence for causality are based on criteria, such as the Hill criteria (**Lucas and McMichael 2005**) related to the overall body of relevant scientific information (for example, consistency, dose-response, biological plausibility, potential for reverse causality). For example, observations of associations with the same health endpoint in studies from multiple locations and in different types of populations (for example, general population, exposed communities, workers), as is the case for some effects associated with PFOA and PFOS (**Post, Cohn, and Cooper 2012**; **USEPA 2023; USEPA 2023**) strengthen the weight of evidence for that effect. Use of systematic review methods are increasingly used to evaluate the quality of epidemiological studies as

well as the potential confounders (for example, **USEPA 2023**). As is the case for associations, conclusions about causality may differ among scientists reviewing the same body of data.

17.2.4.1 Noncancer Health Endpoints

This section summarizes information for various categories of noncancer health endpoints: Changes in systemic markers, Fetal growth, Immune system effects, Thyroid effects, and Other effects.

Systemic Markers

For PFOA and PFOS (**Khalil 2015**; **USEPA 2023**, **2016**; **NJDWQI 2017**, **2018**; **ATSDR 2021**), PFNA (**NJDWQI 2015**; **ATSDR 2021**), and PFDeA (**ATSDR 2021**), the cited reviews concluded that associations are generally consistent for increases in total cholesterol and/or low-density lipoproteins. **Australia Government DOH (2018)** concluded, based on a review of key reports and published systematic reviews, that an association of both PFOA and PFOS with small changes in cholesterol is generally observed. Additionally, the C8 Science Panel concluded that there is a "probable link" between PFOA and clinically defined high cholesterol (**C8 Science Panel 2012**). **Rappazzo, Coffman, and Hines (2017)** concluded that the evidence for an association of prenatal or childhood exposure to PFAS with increased cholesterol is generally consistent; studies reviewed found associations with PFOA, PFOS, PFNA, and/or total PFAS. Regarding causality, **NJDWQI (2017)** concluded that the evidence supports multiple criteria for a causal relationship between increased serum cholesterol and PFOA, while **Australia Government DOH (2018)** concluded that it cannot be established whether PFOA or PFOS causes increased cholesterol based on currently available data. **NASEM (2022)** concluded that there is sufficient evidence for an association of PFAS with dyslipidemia in adults and children.

Steenland et al. (2020) noted continued consistent findings of an association between PFOA and high cholesterol. However, although high cholesterol is a risk factor for cardiovascular disease, the C8 Science Panel did not find a "probable link" for PFOA and heart disease, and subsequent studies have also not found an association. Relevant to this issue, **Steenland et al. (2020)** stated that this apparent inconsistency might be explained by associations of PFOA not only with increased cholesterol, but with increased high density lipoprotein (HDL) and decreased C-reactive protein, both of which decrease heart disease risk

Most reviews have concluded that PFOA (**Gleason et al. 2015**; **Khalil 2015**; **2023**; **NJDWQI**; **ATSDR 2021**) and PFNA (**NJDWQI 2015**) are generally associated with increases in certain liver enzymes, particularly alanine aminotransferase (ALT). **NJDWQI (2017)** concluded that there is some evidence to support a causal relationship between PFOA and ALT. In contrast, most earlier evaluations of PFOS have found weaker or no evidence for associations with increased liver enzymes (**Gleason et al. 2015**; **Khalil 2015**; **NJDWQI 2018**, **2018**. However, **ATSDR (2021)**, p. 26, concluded that "increases in serum enzymes and decreases in serum bilirubin, observed in studies of PFOA, PFOS, and PFHxS, are suggestive of liver alterations." **NASEM (2022)** concluded that there is limited or suggestive evidence for an association of PFAS with liver enzyme alterations in adults and children. For PFOA, **USEPA (2023)** concluded that there is consistent evidence of a positive association with ALT in adults, at median PFOA levels as low as 1.3 ng/mL. **USEPA (2023)**, p. 3-28 to 3-29, concluded that "there is generally consistent evidence of a positive association between exposure to PFOS and ALT. However, one source of uncertainty in epidemiology studies of PFAS is confounding across the PFAS, as individuals are exposed to a mixture of PFAS and it is difficult to disentangle the effects. This cannot be ruled out in this body of evidence given the attenuation of the association in **Lin et al. (2010)**, the only general population study that performed multi-pollutant modeling. ... Thus, while there is evidence of an association between PFOS and ALT, there is residual uncertainty. "**Australia Government DOH (2018)** concluded that an association of PFOA and PFOS with elevated levels of the liver enzyme ALT was observed in many studies. **Steenland et al. (2020)** also concluded that the limited currently available data do not support an association of PFOA and liver disease. However, **Steenland et al. (2020)** noted that the lack of human studies with sufficient power

to detect this effect, well established liver toxicity of PFOA in experimental animals, bioaccumulation of PFOA in human liver, and extensive evidence for associations with markers of liver damage indicate the need for additional research, particularly in regard to potential associations with nonalcoholic fatty liver disease.

Various reviews have concluded that there is some evidence or limited evidence for an association of increased serum uric acid and/or hyperuricemia with exposure to PFOA, PFOS, and/or PFNA (**Gleason et al. 2015**; **Khalil 2015**; **NJDWQI 2015**, **2017**, **2018**; **Australia Government DOH 2018**).

Fetal Growth

Exposure to PFOA and PFOS were associated with relatively small changes in measures of decreased fetal growth (for example, birth weight, [glossary_exclude]head [/glossary_exclude]circumference) in most studies, while some studies did not find such an association. A systematic review and meta-analysis by **Johnson et al. (2014)** found that there is "sufficient" human evidence that developmental exposure to PFOA reduces fetal growth in humans and provided a quantitative estimate of the decrease in birth weight per ng/ml serum PFOA. The main analysis included nine studies in which maternal or umbilical cord serum PFOA levels were measured in pregnant women. These studies met other inclusion criteria defined by the researchers; study subjects were from the general population in various locations. An additional analysis included a large study from the C8 Health Study population with exposure from contaminated drinking water in which maternal serum levels were retrospectively modeled. PFOA was associated with decreased birth weight in most of the studies from the general population but not in the study of the more highly exposed community. Inclusion of this study from the C8 Health Study population, in which serum PFOA levels during pregnancy were modeled from pre-pregnancy serum PFOA data and thus would not be impacted by potential changes in GFR, reduced the magnitude of decreased birth weight per ng/ml serum PFOA.

Several other reviews also evaluated the associations of PFOA and PFOS with decreased fetal growth. **Bach et al. (2015)** concluded that PFOA and PFOS are associated with decreased birth weight in most studies, but that associations in some studies were not statistically significant, and that the existing information is insufficient to determine whether or not there is an association. **Khalil (2015)** concluded that there is inconsistent evidence for association of decreased birth weight and PFAS. A later meta-analysis by **Negri et al. (2017)**, which included more recent studies not considered by **Johnson et al. (2014)**, also reported a quantitative relationship between decreased birth weight and serum PFOA and PFOS levels. A recent meta-analysis by **Steenland, Barry, and Savitz (2018)** considered additional studies not included in the two earlier meta-analyses, including the large studies from the C8 Health Study in which serum PFOA levels during pregnancy were modeled from pre-pregnancy serum PFOA data. Although **Johnson et al. (2014)** concluded that results from studies without measured serum data during pregnancy are too uncertain to include in a metanalysis, **Steenland, Barry, and Savitz (2018)** concluded that use of modeled or pre-pregnancy serum data may actually be preferable to serum levels measured during pregnancy because these exposure estimates would not be affected by potential reverse causality or confounding related to expansion of maternal plasma volume during pregnancy or renal glomerular filtration rate. Additionally, **Steenland, Barry, and Savitz (2018)** concluded that the decrease in birth weight in studies based on late pregnancy serum PFOA levels was larger than in those based on preconception or early pregnancy serum PFOA levels. They concluded that these findings are consistent with confounding or reverse causality as an explanation for the observed association of PFOA and decreased birth weight. A systematic review and modeling effort by **Verner et al. (2015)** found that PFOA is associated with decreased birth weight, and that a portion (less than half) of the reduction in birth weight results from confounding by associations of PFAS with decreases in both birth weight and maternal renal glomerular filtration rate (that is, reverse causality). USEPA (**2023**, **2023**) concluded that there is general consistency in associations of PFOA and PFOS with decreased fetal growth, including low birthweight/small for gestational age. However, they noted uncertainties about the potential bias due to impact of changes in maternal hemodynamics, which may impact both serum PFAS levels and fetal

growth, in the studies in which serum PFAS levels were evaluated later in pregnancy. The **USEPA (2023)** also concluded that PFDA is a likely developmental hazard based on evidence of decreased birth weight from studies of exposed humans where PFDA was measured during pregnancy.

ATSDR (2021), p.27, concluded that "evidence is suggestive of an association between serum PFOA and PFOS and small decreases in birth weight; the decrease in birth weight is <20 g (0.7 ounces) per 1 ng/mL increase in blood PFOA or PFOS level." **NASEM (2022)** concluded that there is sufficient evidence for an association of PFAS with decreased infant and fetal growth. Australia Government **DOH (2018)** concluded that PFAS exposure was often associated with generally small decreases in weight and length at birth in general population studies. **Steenland et al. (2020)** reviewed the factors considered in evaluation of epidemiologic studies of PFAS and birthweight that are discussed above and concluded that collectively, the studies of PFOA and birthweight that are currently available provide inconsistent results.

Immune System Effects

Of the several potential effects of PFAS on immune function, the discussion below focuses on associations with antibody response to vaccines, including in children, because this endpoint has been evaluated and reviewed most extensively. A systematic review by the National Toxicology Program (**NTP 2016**), p.1, concluded that PFOA and PFOS are "presumed to be an immune hazard to humans" based on a high level of evidence from animal studies and a moderate level of evidence from human studies for suppression of antibody response. **ATSDR (2021)**, p.27, concluded that "evidence is suggestive of an association between serum PFOA, PFOS, PFHxS, and PFDeA (meaning PFDA) levels and decreased antibody responses to vaccines." For PFOA, PFOS, PFHxS and PFDA, the **USEPA (2023)** identified decreased antibody response to vaccination in children as an effect of exposure to these PFAS. **Rappazzo, Coffman, and Hines (2017)** found that there is generally consistent evidence for association of PFAS with this effect in children. NJDWQI (**2017**, **2018**) concluded for PFOA that associations and decreased vaccine response are consistent among studies, and for PFOA, while decreased vaccine response was consistently observed, evidence is limited because most of the vaccine types were evaluated in only one or two studies. **Pachkowski, Post, and Stern (2019)** concluded that there is evidence that PFOS is associated with a decrease in some vaccine antibody responses following vaccination. **Chang et al. (2016)** concluded that a consistent association with vaccine response in general has not been demonstrated for PFOA and PFOS, and that some associations for specific vaccines are "striking in magnitude" but require replication in other studies. **Australia Government DOH (2018)**, p. 11, concluded, based on review of key reports and systematic reviews, that "the strongest evidence for a link between PFAS and clinically important immunological effects is for impaired vaccine response." They note both that the overall human evidence is weak, but that animal data suggests that "PFAS may alter immune function at concentrations found in humans with environmental and occupational exposures." **Khalil (2015)** stated that PFAS exposure has been associated with immunotoxicity, including decreased vaccine response, but that the data are inconsistent. **NASEM (2022)** concluded that there is sufficient evidence for an association of PFAS with decreased antibody response in adults and children. USEPA (**2023**, **2023**) concluded that PFOA and PFOS are associated with decreased antibody response to vaccines in children and concluded that the dose-response for each of these two PFAS can be modeled from the available human studies.

The C8 Science Panel concluded in 2012 that there was not a probable link between PFOA and common infections. **Steenland et al. (2020)** noted that there was insufficient evidence to infer such a probable link at that time, and that subsequent human and animal studies have evaluated the potential for PFOA to cause immunosuppression (for example, decreased vaccine response, increased infection) and hypersensitivity (for example, asthma, allergy). They reviewed the conclusions of several agencies (**NTP 2016**; **ATSDR 2018** draft; **EFSA 2018**) and other available reviews regarding the evidence for immune system effects of PFOA, as well as recent studies that are relevant to this topic. The overall conclusion made by **Steenland et al. (2020)** was that "a relatively large number of studies consistently report that

PFOA impairs immune function," but that "evidence that PFOA increases the risk of infectious disease or asthma is inconsistent."

Thyroid Effects

Evaluations of PFAAs and thyroid disease have reached varying conclusions. Although stating that the overall database was mixed, the C8 Science Panel determined a "probable link" for PFOA and thyroid disease (**C8 Science Panel 2012**). (**NJDWQI 2017**, **2018)** found limited evidence for association of PFOA and thyroid disease, while associations of PFOS with thyroid disease were not noted, and **Khalil (2015)** found that the data for PFAS in general are inconsistent. **Australia Government DOH (2018)** concluded that "there are no consistent associations between any particular PFAS and thyroid hormones," and that there is limited evidence of an association between PFOA and thyroid disease in women but not in men. **Rappazzo, Coffman, and Hines (2017)** stated that conclusions about PFAS and thyroid disease in children cannot be reached with certainty due to the small number of studies and variable results. **Coperchini et al. (2017)** found that hypothyroidism was the most consistent thyroid effect for PFOA, and for PFOS to a lesser extent, with women and children most susceptible. **Ballesteros et al. (2017)** stated that although there is a small number of studies with comparable data, there is some consistency in evidence for increased thyroid-stimulating hormone (TSH) with PFHxS and PFOS in pregnant women, and with PFNA TSH in teenage boys; associations with thyroid disease were not noted. More recently, a very large study (n = ~ 63,000) evaluated thyroid diseases in a Swedish community in which one-third of the population had previous residential exposure to very high levels of PFOS (8,000 ng/L) and PFHxS (17,000 ng/L) in drinking water. (**Andersson et al. 2019**). A consistent pattern of increased risk of hypothyroidism or hyperthyroidism was not found in men or women with residential exposure to the contaminated water. **Steenland et al. (2020)** concluded that there is less evidence for an association of PFOA and thyroid disease than when the "probable link" conclusion for this effect was made, and that studies of PFOA and thyroid hormone levels report inconsistent results. Similarly, **ATSDR (2021)**, p.264, concluded that associations between PFOA, PFOS, PFHxS, PFNA, PFDA, and PFUnA and thyroid-related hormones and thyroid disease are inconsistent across studies, with the majority of studies not finding associations, and that most of the small number of studies of PFDoDA and thyroid hormones did not find "consistent associations." **NASEM (2022)** concluded that there is limited or suggestive evidence for an association of PFAS with thyroid disease and dysfunction in adults and children. **USEPA (2023)** did not prioritize PFOA and thyroid disease as one of the key endpoints for evaluation of epidemiological associations. For PFOS, **USEPA (2023)** concluded that there is "slight evidence to suggest human endocrine toxicity, including associations between PFOS exposure and thyroid disease," and that this conclusion is based on only one study rated as being of high confidence.

Other Effects

The C8 Science Panel also found probable links for PFOA with ulcerative colitis (**C8 Science Panel 2012**) and pregnancy-induced hypertension [PIH] (**C8 Science Panel 2012**); PIH was also associated with PFOS in the same two studies that linked it with PFOA (**Stein, Savitz, and Dougan 2009**; **Darrow, Stein, and Steenland 2013**). **ATSDR (2021)**, p.26, concluded that "there is suggestive epidemiological evidence for an association between serum PFOA and PFOS and [PIH] and/or pre-eclampsia." In the opinion of **Steenland et al. (2020)**, current evidence continues to support a link of PFOA and ulcerative colitis, although more research is needed for a definitive conclusion, and NASEM (**2022**) concluded that there is limited or suggestive evidence for association of PFAS and this effect in adults. For pregnancy-induced hypertension, **Steenland et al. (2020)** reported mixed results; one recent study found an association with preeclampsia, a related effect, while another did not, and **NASEM (2022)** concluded that there is limited or suggestive evidence for association of PFAS and these effects.

For many other epidemiological endpoints that have been studied, generally consistent associations were not found and/or the available data are too limited to make firm conclusions.

It is notable that associations for several of the effects mentioned above (serum lipids, liver enzymes, vaccine response, birth weight) were observed even within the exposure range prevalent in the general population (without specific exposures from environmental sources), as well as at higher exposures. For several of these effects (for example, **cholesterol—Steenland et al. 2009**; **Frisbee et al. 2010**; **ALT—Gallo et al. 2012**), the dose-response curves (for example, serum lipids, liver enzymes) are steepest at very low exposures with a much flatter slope approaching a plateau at relatively low serum concentrations (for example, ~40 ng/L for PFOA and cholesterol).

17.2.4.2 Carcinogenicity

Several evaluations of the epidemiological evidence for carcinogenicity are available for PFOA and PFOS, while such evaluations have not been conducted for other PFAAs. The **C8 Science Panel (2012)** found a "probable link" of PFOA with testicular and kidney cancer based on an increased incidence of these cancers in the Ohio and West Virginia communities with drinking water exposure as well as data from other human and animal studies. Although some other occupational studies of PFOA, such as **Raleigh et al. (2014)**, did not find increased incidence of these tumors, increased kidney cancer was reported in workers exposed to PFOA in the West Virginia industrial facility (**Steenland and Woskie 2012**). In consideration of these findings, **IARC (2016)** classified PFOA as "possibly carcinogenic to humans" (Group 2B) based on limited evidence that PFOA causes testicular and renal cancer, and limited evidence in experimental animals. Based on reviews of key reports and systematic reviews, the **Australia Government DOH (2018)**, p.70, concluded that "the evidence on cancer risk is limited;" that it is possible that PFOA is associated with an increased risk of kidney and testicular cancer; and that the evidence does not support PFAS being a major contributor to cancer burden in workers or exposed community populations.

A recent study by the National Cancer Institute (**Shearer et al. 2021**) evaluated associations of serum concentrations of PFOA and other PFAS with renal cell cancer in a subset of participants in a much larger ongoing cancer screening trial. The analysis included 324 subjects diagnosed with renal cell cancer and 324 individually matched controls. PFAS were measured in blood samples taken prior to cancer diagnosis, and serum PFOA concentrations were within the range that was prevalent in the general population at the time of sample collection (1993–2001). Increased serum PFOA was associated with increased risk of renal cell cancer. This association remained even when subjects with decreased kidney function were excluded, and when only subjects with serum PFAS levels measured $\geq$ 8 years before cancer diagnosis were included. Associations of serum PFOS and PFHxS with increased renal cell cancer risk were not statistically significant after adjustment for the other PFAS, while the association of increased risk with PFOA remained after this adjustment. The authors concluded that these results "add substantially to the weight of evidence that PFOA is a renal carcinogen and may have important public health implications."

Steenland et al. (2020) concluded that the evidence for an association of PFOA and kidney and testicular cancer remains "supportive but not definitive." They stated that although the results of three newer studies (published since the C8 Panel's reports) are not consistent, the evidence for an association of PFOA with kidney cancer is strengthened by positive findings in the recent large case-control study in the general population (**Shearer et al 2021**).

NJDWQI (2017)–PFOA, **NJDWQI (2018)**–PFOS, concluded that PFOA and PFOS have suggestive evidence for human carcinogenicity, based primarily on animal data, while a more recent evaluation (**NJDWQI 2023**) concluded that current evidence for PFOA indicates that it is a likely human carcinogen. **USEPA (2023)** concluded that PFOA is a likely human carcinogen, citing recent animal (**NTP 2020**) and human (**Shearer et al. 2021**) studies that add support to earlier evidence of carcinogenicity. **USEPA (2023)** also concluded that PFOS is a likely human carcinogen, with a determination of a statistically significant trend for increased pancreatic acinar carcinomas in the chronic rat study (**Thomford 2002**; **Butenhoff et al. 2012**) adding support to earlier evidence. **USEPA (2018)** also concluded that GenX has

suggestive evidence for human carcinogenicity. **NASEM (2022)** concluded that there is sufficient evidence for an association of PFAS and kidney cancer in adults and that there is limited or suggestive evidence for PFAS and breast and testicular cancer in adults.

In contrast to PFOA, studies of cancer incidence in large populations with exposure to contaminated drinking water with elevated levels of only PFOS are not available although a recent study evaluated communities with exposure to drinking water contaminated with PFOA, PFOS, and PFHxS (present at the highest concentration) from AFFF (**Li et al. 2022**). **Arrieta-Cortes et al. (2017)** concluded that while associations with cancer were not observed in the available occupational and general population studies of PFOS, such associations cannot be ruled out because problems with the studies may have precluded detection of associations if they were present. They therefore concluded that there is "inadequate evidence of carcinogenicity" based on the human data. **Chang et al. (2014)** stated that "many positive associations with PFOA exposure were detected in community settings" but were not confirmed in studies of workers with much higher exposures, although increases in certain cancers in some occupational studies are noted within the paper. They concluded that a causal association between PFOA or PFOS and human cancer is not supported by the currently available epidemiological evidence.

17.2.5 Animal Toxicology Studies

Many scientific considerations and decision points are involved in developing human health toxicity factors from animal toxicology data. In the hazard identification component of the toxicity factor development, the toxicological endpoint selected as the basis for the reference dose should be determined to be well established (that is, supported by multiple studies), related to an adverse health outcome, and relevant to humans based on mode of action considerations.

Peroxisome proliferator-activated receptor-α (PPAR-α) is a nuclear receptor found in many human and animal tissues that is involved with numerous physiological processes (**Corton, Anderson, and Stauber 2000**; **Michalik et al. 2006**). The role of PPAR-α in the effects caused by PFAS and the human relevance of effects in rodents that are mediated by PPAR-α have been a focus of research on the mode of action for the toxicological effects of PFAAs (**Lau 2012**; **Post, Gleason, and Cooper 2017**). As reviewed by **Post, Gleason, and Cooper (2017)**, most PFAAs that have been evaluated for this effect can activate PPAR-α to some extent. Specific toxic effects of some PFAAs in rodent models occur wholly or partially via PPAR-α, while other effects are independent of PPAR-α. One important example is hepatic toxicity of PFAAs. For PFOS, hepatic effects are clearly primarily PPAR-α independent, while hepatic effects of PFOA and PFNA involve substantial contributions from both PPAR-α dependent and independent processes.

In the dose-response evaluation portion of toxicity factor development, the selected endpoint must provide the data needed to determine a point of departure (that is, benchmark dose [BMD], NOAEL, or LOAEL). To appropriately account for the large differences in PFAA half-lives among species, and among sexes of the same species in some cases, dose-response evaluation for long-chain PFAAs is most appropriately based on internal dose, as indicated by serum level, rather than external (administered) dose. Finally, in development of RfDs, uncertainty factors appropriate to the specific study and endpoint are selected and applied to the point of departure to account for factors such as sensitive human subpopulations, interspecies differences, shorter-than-chronic exposure duration, extrapolation from a NOAEL to a LOAEL, and potentially more sensitive toxicological effects (**Section 8.3**).

Toxicological effects that have been reported as statistically significant in mammalian laboratory animal studies for each PFAS, with relevant citations, are presented in the **Table 17-8 Toxicological Effects** Excel file. The sections following the table present general discussions of systemic, reproductive and developmental, and carcinogenic effects of these PFAS.

17.2.5.1 Systemic Effects

All of the PFAS included in the Table 17-8 Toxicological Effects Excel file for which data are available caused increased liver weight in the rodent and nonhuman primate species studied. For most of these PFAS, increased liver weight was accompanied by hepatocellular hypertrophy. Developmental (in utero or lactational) exposures to some PFAAs caused increased liver weight in rodent offspring. Many PFCAs, as well as PFOS and GenX, caused additional hepatic effects that are more severe in nature such as hepatocellular necrosis and/or vacuolation in rodents and nonhuman primates, or hepatic lipid accumulation in rodents. For PFOA (**Butenhoff et al. 2012**; **NJDWQI 2017**) and PFOS (**Butenhoff et al. 2012**; **NJDWQI 2018**), these hepatic effects increased in severity with longer duration of exposure and may represent a progression to neoplastic changes, including hepatic adenomas. Additional effects reported for some PFAS include bile duct toxicity in rodents and increased serum levels of liver enzymes in rodents and/or nonhuman primates.

Some PFAAs and PFECAs caused decreased serum cholesterol in rodents and/or nonhuman primates. The increased cholesterol in humans associated with much lower exposures to some PFAS may be attributable to interspecies differences, such as differences in activity of relevant receptors involved with cholesterol metabolism. However, these contrasting observations in rodents and humans may also arise from differences in the fat content of a typical low-fat laboratory diet and the higher fat diet in the humans who were studied (**Tan et al. 2013**; **Rebholz et al. 2016**), or to dose-related differences in this response, because the doses in the toxicology studies are much higher than human exposure levels.

Some long-chain PFAAs caused immune system toxicity in the (Table 17-8 Toxicological Effects Excel file. Decreased antibody response to antigens has been identified as a sensitive endpoint for PFOA and PFOS toxicity, and this endpoint in animal studies have been used as the basis for toxicity factors and health-based regulatory criteria developed by government agencies, including **MDH (2019)**; **ATSDR (2021)**; **NJDWQI (2018)**; **Pachkowski, Post, and Stern (2019)**.

The majority of PFAS covered herein have not been tested for neurobehavioral effects. Of those PFAAs that have been evaluated in rodents, exposure-related effects were not observed for PFBA and PFHxA, while exposure of adult rodents to PFOS and PFDA caused effects including changes in learning, memory, activity, and habituation or other effects indicative of cognitive defects (see studies cited in the Table 17-8 Toxicological Effects Excel file). Additionally, developmental exposures to PFOA, PFOS, and PFHxS caused persistent neurobehavioral effects in mice (**Johansson, Eriksson, and Viberg 2009**; **Onishchenko et al. 2011**; **Lee and Viberg 2013**).

17.2.5.2 Reproductive and Developmental

Reproductive effects in males and females and developmental effects of several PFAS have been evaluated in rodents (Table 17-8 Toxicological Effects Excel file), but these effects have not been studied in nonhuman primates. In addition to the considerations common to developmental toxicity studies in general, the much faster excretion of several PFAS in female rats than in males must be considered when interpreting results of the rat reproductive and developmental studies.

Dosing of pregnant females with PFAAs results in gestational exposure to the fetus and also to the offspring during lactation. Cross-fostering studies of PFOA (**White et al. 2009**) and PFOS (**Luebker et al. 2005**) in which dosed dams fostered pups from control dams and vice versa showed that effects such as delayed development can result from exposures during either gestation or lactation.

Although malformations have been reported in a few rodent studies of PFOA and PFOS, effects such as full litter resorptions, decreased litter or number of live pups at birth, decreased survival of neonates, and decreased fetal and neonatal weight have been more frequently and consistently found (**USEPA 2023**, **2023**). These developmental effects may result from toxicity to the placenta, as has been observed for

PFOA (**Suh et al. 2011**) and PFOS (**Lee et al. 2015**). With PFOS at relatively high doses, neonatal mice and rats appeared normal at birth but died within a few hours; the genesis of this phenomenon is not understood (multiple studies reviewed in **NJDWQI 2018**).

Decreased growth of offspring and/or delays in reaching developmental milestones was observed for several PFAS in rodent studies (Table 17-8 Toxicological Effects Excel file). For PFBS (**Feng et al. 2017**) and PFNA (**Das et al. 2015**), body weight decrements persisted until adulthood. PFOA caused delays in ossification of bones and eruption of teeth (**Lau et al. 2006**; **Yahia et al. 2010**). Developmental markers such as eye opening and/or reaching sexual maturity were also delayed by some PFAAs, while noting that sexual maturity was conversely accelerated in male mice by PFOA (**Lau et al. 2006**). Persistent neurobehavioral effects in mice resulted from developmental exposures to several long-chain PFAS (**Johansson, Eriksson, and Viberg 2009**; **Onishchenko et al. 2011**; **Lee and Viberg 2013**).

Certain developmental effects of some PFAAs persisted into adulthood. These include decreased size of uterus and ovaries, accompanied by decreased number of follicles and corpora lutea, and changes in reproductive and thyroid hormone levels in female mouse offspring exposed to PFBS (**Feng et al. 2017**). Developmental exposures of mice to PFOA caused persistent delays in mammary gland development (**White et al. 2009**) and persistent liver toxicity (**Quist et al. 2015**) at doses lower than those that caused other systemic and developmental effects; these endpoints have not been evaluated for other PFAS.

17.2.5.3 Chronic Toxicity and Tumorigenicity

PFAAs have generally not been found to be mutagenic or genotoxic (**Lau 2015**). Of the PFAS included in Table 17-8 Toxicological Effects Excel file, chronic studies that evaluated carcinogenicity and other effects of long-term exposure have been conducted in rats only for PFHxA, PFOA (three studies; one in males only), PFOS, and GenX. PFHxA did not increase the incidence of tumors in either sex of rats. PFOA increased the incidence of several types of tumors, including testicular Leydig cell adenomas in two of the three studies, and hepatic adenomas and/or carcinomas and pancreatic acinar cell adenomas and/or carcinomas in two of the three studies, and uterine adenocarcinomas in one of the three studies. In the chronic PFOS study, pancreatic acinar carcinomas and benign tumors in other organs were increased, including hepatic adenomas in females, and thyroid follicular cell adenomas in males only in the high dose "recovery group" (dosed for the first year only and evaluated at the end of the 2-year study). GenX increased the incidence of both hepatocellular adenomas and carcinomas in females, and the incidence of combined pancreatic acinar cell adenomas and carcinomas and testicular Leydig cell adenomas in males.

IARC (2016) classified PFOA as "possibly carcinogenic to humans" (Group 2B) based on limited evidence that PFOA causes testicular and renal cancer, and limited evidence in experimental animals. **IARC (2023)** is currently reevaluating the classification of PFOA and evaluating PFOS for the first time. Based on the **USEPA (2005)** Guidelines for Carcinogen Risk Assessment, **USEPA (2023**, **2023**, **2018**) described PFOA and PFOS as likely human carcinogens, and GenX as having suggestive evidence for human carcinogenicity. A recent review by **NJDWQI (2023)** concurred with **USEPA (2023)** that PFOA is a likely human carcinogen; this review also concluded that PFOS has suggestive evidence but did not consider the **USEPA (2023)** evaluation that found a statistically significant trend for pancreatic acinar tumors in the chronic rat study (see **Section 17.2.3.5**). For PFOA, **ATSDR (2018), draft** concluded that the hepatic tumors are unlikely to be relevant to humans. In contrast, **USEPA (2023)** concluded that, in the "absence of definitive information supporting a single, scientifically justified mode of action (MOA) and "evidence supporting the potential for multiple plausible MOAs, … USEPA takes the health-protective approach and concludes that the hepatic tumors observed [in two chronic rat studies]… can be relevant to human health." Human relevance was not discounted for the testicular and pancreatic tumors by either **ATSDR (2018)** or **USEPA (2023)**. For PFOS, **USEPA (2023)** and **NJDWQI (2018)** did not discount human relevance of the hepatic tumors. **NJDWQI (2017)** developed cancer slope (potency) factors for PFOA based on the incidence of testicular Leydig cell tumors in rats, while the California EPA (**CA OEHHA 2023**) and **USEPA**

(2023) slope factors are based on the incidence of kidney cancer in humans and are much more stringent than PFOA slope factors based on animal data. **NJDWQI (2018)** and **USEPA (2023)**) both developed cancer slope factors for PFOS based on the incidence of liver tumors in rats.

17.2.6 Health Effects Information for Some Additional PFAS of Current Interest

17.2.6.1 Information Relevant to Human Health Effects of Ether and Polyether PFAS

There is increasing awareness and interest in potential human exposure to PFAS other than PFAAs. These include ether and polyether PFAS and dicarboxylic acid polyether PFAS used as replacements for long-chain PFAAs. Additionally, ether and polyether PFAS and PFAS with other structures can be formed as unintentional byproducts of industrial processes (**Wang et al. 2019**). Health effects information for hexafluoropropylene oxide dimer acid (HFPO-DA, GenX), a 6-carbon perfluoroether, and ADONA, a 7-carbon polyfluoropolyether, which are both used as replacements for PFOA, is discussed in **Sections 7.1.4** and **17.2.5**. Information on the environmental occurrence, ecological effects, toxicology and toxicokinetics in laboratory animals, and bioaccumulation and potential health effects in humans is currently becoming available for additional non-PFAA PFAS at a rapid pace, particularly for additional ether and polyether PFAS (**Wang et al. 2019**). Collectively, this information indicates that the toxicological and bioaccumulative properties of some of these ether and polyether PFAS, particularly those with longer total chain lengths (carbons plus ether oxygens in the chain), are similar to those of the phased out long-chain PFAAs (for example, PFOA, PFOS, PFNA) (see **Figure 2-4**).

This section summarizes the currently available laboratory animal and human studies that are relevant to human health effects of some additional ether and polyether PFAS. This material expands the discussion of these groups of compounds beyond HFPO-DA (GenX) and ADONA that were discussed in **Section 17.2.5**. These additional ether and polyether PFAS include:

- per- and polyfluoroether carboxylates (PFECAs)
- per- and polyfluoropolyether carboxylates (PFPECAs)
- per- and polyfluoroether sulfonates (PFESAs)
- per- and polyfluoropolyether sulfonates (PFPESAs)

As discussed below, some of the most thoroughly studied PFESAs and PFPECAs have chlorine atoms on the terminal carbon (ClPFESAs and ClPFPECAs, respectively). Toxicity data for dicarboxylic acid PFPECAs are also discussed. Specifically, longer chain PFPECA analogues of GenX (HFPO-DA), including hexafluoropropylene oxide-trimer acid (HFPO-TA) and hexafluoropropylene oxide-tetramer acid (HFPO-TeA), and numerous other PFPECAs of various structures and chain lengths are of interest because they are used as replacements for phased-out long-chain PFAAs and/or formed as industrial byproducts. Many of these PFPECAs have been detected in the environment, including in drinking water in some cases (**Pan et al. 2019**; **Munoz et al. 2019**; **Wang et al. 2019**; **Kotlarz et al. 2020**). Industrial mixtures of ClPFPECAs of various chain lengths, as well as dicarboxylic acid polyether PFPECAs, are also of interest because they are used as alternatives for phased-out long-chain PFCAs, including PFNA (**NJDEP 2021**; **Wang et al. 2013**), and ClPFPECAs have been detected in environmental media near industrial sources (**McCord et al. 2020**; **Washington et al. 2020**; **Mazzoni et al. 2015**).

F53B is a PFOS alternative that consists primarily of 6:2 chlorinated polyfluoroether sulfonate (6:2 ClPFESA), with smaller proportions of 8:2- and longer chain ClPFESAs (**Munoz et al. 2019**; see also **Section 2.6.1.3**). These ClPFESAs are used primarily in China, and are of interest because they have been found in multiple environmental media and, as discussed below, in human biomonitoring studies. Nafion byproducts are PFPESAs formed as industrial byproducts in the production of Nafion, a sulfonated tetrafluoroethylene-based fluoropolymer-copolymer, and are of interest because they have been found in

drinking water impacted by industrial discharges (**Hopkins et al. 2018**). With some exceptions, the toxicity and bioaccumulative potential of PFAAs with similar structures (for example, PFCAs, PFSAs) generally increase with increasing carbon chain length (see **Section 7.1.4**). Similarly, currently available information on the ether and polyether PFAS with analogous structures (for example, HFPO-DA, -TA, -TeA; 6:2 and 8:2 ClPFESA) discussed in this section suggests that their toxicity and bioaccumulation also generally increase with increasing chain length (including both carbons and ether oxygens).

Human Biomonitoring and Health Effects Studies

PFECAs and PFPECAs

As discussed below, recent biomonitoring studies show that, as is the case for long-chain PFAAs, many ether and polyether PFAS are bioaccumulative in humans, although this may not be the case for some shorter chain members of this group such as GenX (HFPO-DA). Associations with changes in health-related endpoints (for example, clinical chemistry parameters) were also reported in some studies.

A biomonitoring study of Wilmington, NC, residents evaluated blood serum PFAS levels 5 months after cessation of exposure to drinking water from the Cape Fear River that was contaminated by multiple PFAS. Nafion byproduct 2 and two longer chain PFPECAs were detected in the blood serum of >85% of subjects; two other fluoroethers were less frequently detected. The shorter chain PFECA, GenX (HFPO-DA), which was also present in drinking water, and several other PFAS that were detected in the Cape Fear River, were not found in human serum (**Kotlarz et al. 2020**). This study did not evaluate potential associations of health effects and exposure to fluoroethers. **Yao et al. (2020)**, whose study population lived near a fluorochemical plant in China, also detected multiple PFECAs and PFPECAs, as well as sulfonate ether PFAS (discussed below), in blood serum. They reported associations between PFO5DoA, a long-chain PFPECA that has 7 carbons and 5 ether oxygens, and increased serum lipids, liver enzymes, and uric acid. Two other PFECAs (HFPO-TA, 9 carbons and 2 ether oxygens; PFO4DA, 6 carbons and 4 ether oxygens) were associated with increases in one or more serum lipid parameters, and PFO4DA was also associated with increased uric acid.

A summary of an unpublished biomonitoring study of workers with occupational exposure to industrial mixtures of ClPFPECA congeners of various chain lengths reported an estimated human half-life of 2.5–3 years. Associations with increased serum lipids, liver enzymes, triglycerides, albumin, albumin/globulin ratio, thyroid stimulating hormone (TSH), free thyroxine, and prostate-specific antigen (PSA), and decreases in estradiol and indicators of immune system function (alpha-2-globulins and immunoglobulins) were reported (**Solvay 2019**). It was noted that the changes in serum lipids and liver enzymes may have been confounded by exposure to PFOA, and that associations with increased TSH and PSA were less reliable because they were based on fewer data points (**Solvay 2019**).

PFESAs and PFPECAs

6:2 ClPFESA was consistently detected in human blood serum in several recent biomonitoring studies in China (**Jin et al. 2020**; **Liu et al. 2020**; **Pan et al. 2017**; **Yao et al. 2020**). The median and mean human half-life of 6:2 ClPFESA were estimated as 15.3 and 18.5 years, respectively, as compared to an estimated median and mean of 6.7 and 7.7 years, respectively, for PFOS in the same study (**Shi et al. 2016**). 6:2 ClPFPESA was included in the suite of PFAS measured in blood serum of U.S residents in NHANES for the first time in 2017–18 (**CDC 2022**). It was found at the detection limit (0.100 ng/ml) in the 95th percentile of the total population, and at the same or similar levels in most racial/ethnic groups as follows: Mexican Americans – not detected at 90th percentile, 0.100 at 95th percentile; non-Hispanic blacks - 0.100 ng/ml at 90th and 95th percentiles; non-Hispanic whites - not detected at 95th percentile; all Hispanics – not detected at 90th percentile, 0.100 at 95th percentile [values are geometric means]. The maximum level detected in any of these subgroups was 0.200 ng/ml. However, it was detected more frequently and at higher levels in Asians (0.200 ng/ml at 75th percentile; 1.00 ng/ml at 90th percentile;

2.30 ng/ml at 95th percentile; maximum – 10.9 ng/ml). It is not known whether the more frequent detections and higher serum levels in Asians results from their exposure while in Asia or from other sources such as consumption of foods contaminated with 6:2 ClPFESA that are imported from Asia.

As is the case for long-chain PFAAs, biomonitoring data demonstrate exposure to ClPFESAs in utero and through breast milk. Both 6:2 and 8:2 ClPFESA were found in matched maternal:umbilical cord blood samples, indicating fetal exposure, with 8:2 ClPFESA having a higher rate of transfer to cord blood (**Cai et al. 2020**; **Chen et al. 2017**; **Pan et al. 2017**; **Xu et al. 2019**). The only study that evaluated potential health outcomes associated with fetal exposure found no evidence of an association between ClPFPESAs exposure and birth outcomes (**Xu et al. 2019**). 6:2 and 8:2 PFESA were also found in human breast milk from several locations in China, but not from Sweden (**Awad et al. 2020**; **Jin et al. 2020**). Breast milk levels of these PFESAs were associated with decreased infant growth in one of these studies (**Jin et al. 2020**).

Rodent Toxicology Studies

PFECAs and PFPECAs

As discussed above, hepatotoxicity is an effect common to many PFAS. In mouse studies, HFPO-TeA, with 12 carbons and 3 ether oxygens, was more hepatotoxic than its shorter chain analogue HFPO-DA (GenX; **Wang et al. 2017**), and HFPO-TA, with 9 carbons and 2 ether oxygens, was more hepatotoxic than PFOA, which has an 8-carbon chain (**Sheng et al. 2018**). In mice, the bioaccumulation in blood serum and liver increased with chain length for a series of PFPECAs with two to four O-CF2 groups, and only the largest PFAS, with four such groups (PFO4DA), caused increased liver weight at the doses tested (**Guo et al. 2019**). A recent study (**Chen et al. 2021**) reported half-lives in male mice of 24 hours for PFO4DA and 43 days for its larger homologue, PFO5DoA after a single intravenous dose. In a 140-day study of male mice, both compounds accumulated in the liver and caused increases in body weight, relative liver weight, and serum glucose, triglycerides and free fatty acids, as well as biochemical changes in the liver consistent with reduced glycolysis (**Chen et al. 2021**).

As reviewed in **NJDEP 2021**, industrial products consisting of mixtures of ClPFPECA congeners of various chain lengths ranging from 8 carbons and 3 ether oxygens to 14 or 17 carbons and 5 ether oxygens caused toxicity to liver, lung, thymus, seminal vesicles, and thyroid in 4-week and/or 13-week rat studies, with some changes persisting after a several-week recovery period (**Research Toxicology Centre 2006**, **2016**). The doses at which hepatic effects occurred were similar to those reported for long chain PFCAs (for example, PFOA, PFNA; **NJDWQI 2015**, **2017**). The half-lives for five of the congeners (ranging from 8 carbons and 3 ether oxygens to 14 carbons and 5 ether oxygens) were reported as 8–29 days in male rats and 1.6–91 days in female rats. These half-lives are similar to those documented for PFOA (4-6 days) and PFNA (30 days) in male rats (**Table 17-7**).

Additionally, industrial products consisting of mixtures of another type of PFPECAs, dicarboxylic acid polyether carboxylates (chain lengths not specified), caused toxicity to the liver, lung, thymus, seminal vesicles, and kidneys, with hepatic effects at very low doses, in 4- and/or 13-week studies in rats. As for the ClPFPFECAs, some effects persisted after a several week recovery period. The estimated half-life in male rats after a single dose was 43 days, and the estimated half-lives after repeated dosing were approximately 8 days in males and 11 days in females (**Research Toxicology Centre, 2005**; **Research Toxicology Centre, 2006**). In contrast, PFOA and PFNA, with half-lives of 2-4 hours and 1-2 days, respectively, as well as some other PFAS, are much less persistent in female rats (**Section 17.2.3**; **Table 17-7**).

PFESAs and PFPESAs

6:2 ClPFESA, the primary component of F53B, and Nafion byproduct 2, also a PFPESA, caused liver toxicity in mice (**Zhang et al. 2018**; **Lang et al. 2020**). In a subchronic study of reproductive toxicity of 6:2 ClPFESA in male mice, relative weights of reproductive organs decreased at the highest dose tested. However, at the doses used in the study, there were no histopathological changes in these organs, and hormone levels, sperm counts, fertility, and expression of several testicular genes were not affected (**Zhou et al. 2018**). After subchronic exposure to mice, 6:2 ClPFESA accumulated in the small and large intestine, damaged the gut barrier, and caused inflammation of the colon (**Pan et al. 2019**).

Zebrafish Studies

Zebrafish are well accepted as an in vivo model system for human health effects. Zebrafish studies for the ether and polyether PFAS are relevant to evaluation of their potential human health effects and are discussed below.

PFECAs and PFPECAs

The hexafluoropropyl acids—HFPO-DA, HFPO-TA, and HFPO-TeA—caused estrogenic effects in zebrafish (**Xin et al. 2019**). A suite of PFPECAs of various chain lengths decreased thyroid hormone levels in developing zebrafish embryos, leading to thyroid hormone-dependent malformations of the swim bladder (**Wang et al. 2020**).

6:2 ClPFECA

A number of studies have reported toxic effects of 6:2 ClPFECA in zebrafish. These include: bioaccumulation in larvae and adults (**Wu et al. 2019**); hepatoxicity, in adults (**Shi et al. 2019**; **Wu et al. 2019**); reproductive toxicity in a two-generation study (**Shi et al. 2018**); disruption of cardiac development (**Shi et al. 2017**); and thyroid toxicity from developmental exposures to environmentally relevant concentrations (**Deng et al. 2018**) and in unexposed offspring after exposure of the parental generation (**Shi et al. 2019**). **Tu et al. (2019)** reported that 6:2 ClPFECA was more bioaccumulative and was a more potent disruptor of metabolism than PFOA in zebrafish.

17.2.6.2 Fluorotelomer Alcohols

Fluorotelomer alcohols (FTOHs) are polyfluoroalkyl substances synthesized as intermediates for the manufacture of various fluorosurfactants and fluoropolymers (**Dinglasan-Panlilio and Mabury 2006**; **ECHA 2012**). The telomer alcohols are named with the number of fully fluorinated carbon atoms first, followed by the number of partially fluorinated carbon atoms (for example, 8:2 FTOH, 6:2 FTOH). In the environment, FTOHs may degrade to PFCAs with 8:2 FTOH degradation capable of forming PFOA and PFNA (**Butt, Muir and Mabury 2014**). FTOHs are present in multiple consumer products, with 6:2 FTOH the primary FTOH manufactured for end use. Humans may be exposed by ingestion of FTOH-contaminated food or dust (**Yuan et al. 2016**). Some FTOHs are volatile, and human exposure may also occur via inhalation (**Huang et al. 2019**).

The following section summarizes currently available information on the toxicokinetics and adverse health effects of 6:2 and 8:2 fluorotelomer alcohol (6:2 and 8:2 FTOH, respectively) in experimental animals and humans. No peer-reviewed data were identified for other FTOHs.

Toxicokinetics

As polyfluoroalkyl substances, FTOHs are extensively metabolized in rodents and humans. Depending on the specific FTOH, the terminal metabolites include long- and/or short-chain PFCAs, unsaturated

fluorotelomer acids (FTUCAs), fluorotelomer acids (FTAs) and glutathione, sulfate, and glucuronide conjugates (**Kudo et al. 2005**; **Fasano et al. 2006**, **2009**; **Himmelstein et al. 2012**; **ECHA 2012**; **Nilsson et al. 2013**; **Kabadi et al. 2018**; **Huang et al. 2019**; **Rice et al. 2020**).

6:2 FTOH is rapidly absorbed following oral exposure, and undergoes metabolism in rats to form PFBA, PFPeA, PFHxA, PFHpA, certain FTAs, and glutathione, sulfate, and glucuronide conjugates (**Russell et al. 2015**; **Kabadi et al. 2018**). In vitro metabolic data from hepatocyte cultures indicate that 6:2 FTOH is likely metabolized similarly in rat, mice, and humans (reviewed in **Rice et al. 2020**). One of the non-PFCA metabolites, 5:3 FTA, is persistent, having an estimated half-life of ~100 days in male and female rats after repeated dosing (**Kabadi et al. 2020**). **Russell et al. (2015)** calculated an apparent geometric mean elimination half-life of 43 days for 5:3 FTA in humans based on occupational data of **Nilsson et al. (2010**, **2010**, **2013**). PFHxA and the other terminally stable short-chain PFCAs formed by the metabolism of 6:2 FTOH do not undergo further degradation and are eliminated rapidly in rodents (see **Table 17-7**). The metabolic pathways, rate determining steps, and elimination half-lives of the parent 6:2 FTOH and other metabolites have not been established.

8:2 FTOH administered orally or by inhalation is also rapidly absorbed and metabolized in rats and mice, with PFOA, 7:3 FTA, 8:2 FTA, PFNA, PFHxA, PFHpA, and glucuronide, glutathione, and other conjugates identified as metabolites (**Kudo et al. 2005**; **Fasano et al. 2006**, **2009**; **Himmelstein et al. 2012**; **ECHA 2012**). In vitro data from rat, mouse, and human hepatocytes indicate that 8:2 FTOH is metabolized to PFOA in rodents and humans, although rodent hepatocytes appear to transform greater amounts of 8:2 FTOH to PFOA than human hepatocytes. Other in vitro metabolites in rodent hepatocytes include 8:2 FTCA, 8:2 FTUCA, and PFNA (**ECHA 2012**).

Data from the NTP (**Huang et al. 2019**) confirmed that 8:2 FTOH is rapidly absorbed and distributed in male and female rats after a single oral or intravenous (IV) dose. The plasma elimination half-life of the parent compound was 1.1–1.7 hours, and the two primary metabolites were 7:3 FTA and PFOA. The half-life of 7:3 FTA was 2–3 days in both sexes of rats; PFOA's half-life was sex-dependent (approximately 8–15 days in males, and 4.5–6.9 h in females). **Nilsson et al. (2010**, **2010**) measured a mixture of 6:2, 8:2, and 10:2 FTOH and other PFAS in the workplace air of ski wax technicians and subsequently documented the presence of PFOA, PFNA, PFDA, PFDoA, PFTDA, 5:3 FTA, and 7:3 FTA in all samples of the technicians' blood (**Nilsson et al. 2013**). The metabolites, 8:2 FTUCA and 10:2 FTUCA, were also detected in blood samples from multiple technicians. Although concentrations of 8:2 FTOH were several-fold higher than other PFAS in workplace air, the relative importance of 8:2 FTOH and 10:2 FTOH to the metabolic formation of PFOA, PFNA, other long-chain PFCAs, or the FTAs cannot be determined from these data given that exposures were to multiple PFAS.

Toxicity

6:2 FTOH

Consistent with other data that have demonstrated a lack of genetic toxicity of PFAS (see **Section 17.2.5.3**), 6:2 FTOH was negative when tested in the Ames bacterial mutagenesis assay. It was not mutagenic in the mouse lymphoma assay and was not clastogenic in a chromosome aberration assay in human lymphocytes. It was found not to be a skin or eye irritant (**Serex et al. 2014**).

Given the metabolic transformation of 6:2 FTOH and 8:2 FTOH to several PFCAs, 5:3 FTA (6:2 FTOH metabolite), and multiple additional metabolites of unknown toxicity, it is unclear whether adverse effects associated with exposure of experimental animals to FTOHs (see following) are attributable to the parent FTOH, one or more metabolites, or to combined exposure to multiple compounds. With the exception of the persistent 5:3 FTA metabolite of 6:2 FTOH, for which limited data demonstrating toxicity are available (**Rice et al. 2020**), the relationship between the adverse effects of FTOHs and their metabolites has not been established.

Rice et al. (2020) synthesized toxicity data on 6:2 FTOH from a 28-day NTP study, a number of peer-reviewed publications (**Miyata et al. 2007**; **Kirkpatrick 2005**; **O'Connor et al. 2014**; **Serex et al. 2014**; **Mukerji et al. 2015**), and OECD-compliant studies submitted on behalf of FTOH manufacturers. These studies reported that 6:2 FTOH causes multiple effects in the liver (for example, increased serum liver enzymes, hepatocellular necrosis, and oval cell hyperplasia) and kidney (renal tubular necrosis, mineralization, and degeneration) in rats and mice, as well as decreased thymus weight in rats. Reproductive effects of 6:2 FTOH in rats were observed only when high maternal mortality occurred. In contrast, 6:2 FTOH caused decreased body weight gain during lactation, mammary gland lesions, decreased uterine and ovarian weights, and an increase in anestrus in mice. 6:2 FTOH elicited developmental effects in both rats and mice, including increased pup mortality, delayed skull ossification, decreased pup body weight gain in rats, and decreased pup survival during lactation in mice.

Rice et al. (2020) also summarized the results of a 2-week oral toxicity study of the persistent 6:2 FTOH metabolite 5:3 FTA as reported by the industrial manufacturer. Those data indicate that in rats, 5:3 FTA caused adverse effects on the liver (decrease in total cholesterol, hepatocyte necrosis); kidney (increase in creatinine and urine volume, decrease in total urine protein); thyroid (follicular cell hyperplasia); and thymus (decrease in thymus weight).

There are no publicly available chronic toxicity studies for 6:2 FTOH.

8:2 FTOH

8:2 FTOH was negative when tested in the Ames bacterial mutagenicity study (**NTP 2018**), and in micronucleus assays reported by the OECD (**ECHA 2012**).

The liver and kidney were the primary target organs in rats administered 8:2 FTOH orally over a 90-day period (**Ladics et al. 2008**). 8:2 FTOH caused hepatic necrosis in males, and induced kidney nephropathy in females. Urinary and/or plasma fluorine levels were elevated in animals from all dose groups, an effect attributed to metabolism of the parent compound and an associated increase in fluoride levels. **Wang et al. (2019)** also documented effects of 8:2 FTOH on the livers of mice, including cellular vacuolation and swelling; swelling of cell nuclei; and immune cell infiltration in animals exposed orally for 28 days. 8:2 FTOH significantly altered mRNA levels of inflammatory cytokines in the thymus and spleen, although it is unclear whether these changes would translate to biologically significant effects on the immune system, as there were no accompanying histological changes in these organs.

Mylchreest et al. (2005) assessed the developmental toxicity of 8:2 FTOH in rats, finding that increased skeletal malformations in pups (delayed pelvic bone ossification and wavy ribs) occurred only at a dose that also elicited maternal toxicity. **Mylchreest et al. (2005)** also evaluated the reproductive and developmental toxicity of a commercial mixture of FTOH in rats, and observed decreases in litter size, pup weights, and the number of live pups per litter on days 0 and 4 of lactation. Developmental effects were seen only at a dose that also caused maternal toxicity.

There are no publicly available chronic toxicity studies for 8:2 FTOH.

17.2.6.3 Fluorotelomer Sulfonic Acids

Fluorotelomer sulfonic acids (FTSAs) and their salts, the fluorotelomer sulfonates (FTS), are polyfluorinated chemicals that are formed both by direct manufacture and by the degradation of precursors found in certain AFFFs or other industrial products (see **Section 2.2.4.1**; **Field and Seow 2017**). Because FTSAs and FTSs exist in anionic form in the body, they are equivalent toxicologically, and the term FTSA is used here to refer to both forms of these chemicals.

4:2 FTSA, 6:2 FTSA, and 8:2 FTSA have been detected in human blood (**Lee and Mabury, 2011**; **Loi et al. 2013**; **Yeung and Mabry 2016**; **Eriksson et al. 2017**), and 6:2 FTSA and 8:2 FTSA can cross the human placenta (**Yang et al. 2016**). Humans may potentially be exposed to FTSAs through ingestion of contaminated drinking water or food, or by inhalation of dust (**Field and Seow 2017**). It is not known if the detection of FTSAs in human blood is due to direct exposure to the parent compounds or to indirect exposure to FTSA or precursors (**Field and Seow 2017**).

Toxicokinetics

Information on the toxicokinetics of FTSAs is limited. No studies have evaluated the absorption of FTS versus FTSA. Since FTS and FTSA exist in the same anionic form within the body, their toxicokinetics would not differ after absorption. **ECHA (2018)** provided summary information on a single rodent in vivo study that examined the disposition and metabolism of 6:2 FTSA (species and dose levels not given). Following a single oral dose of 6:2 FTSA, 65–68% of the parent compound was recovered in urine 4 days post-dosing, indicating that metabolism of the majority of the administered dose did not occur. However, because no data were provided on metabolite formation or elimination, many questions remain regarding the metabolism of 6:2 FTSA in animals. In vitro data from **ECHA (2018)** and **Hoke et al. (2015)** also suggested that 6:2 FTSA is not extensively metabolized in animals. When 6:2 FTSA was incubated with rat liver microsomal fractions for 2 hours (**ECHA 2018**) or with rainbow trout hepatocytes for 4 hours (**Hoke et al. 2015**), no metabolism was detected. FTSA may have the potential to bioaccumulate, in that substantial levels of FTSA were measured in the livers of mice administered FTSA for 28 days (**Sheng et al. 2017**). The potential of FTSA to bioaccumulate is supported by observations of **Yan et al. (2014)**, who found comparable levels of the bioaccumulative PFOA in the serum and livers of mice exposed under the same experimental conditions used for FTSA by **Sheng et al. (2017)**. In the few human biomonitoring studies that included 6:2 FTSA, it was detected infrequently. For example, the Biomonitoring California Asian/Pacific Islander Community Exposures Project reported no detections of 6:2 FTSA in 2016 (N=96) and FTSA was detected in only 3% of samples analyzed in 2017 (N=99) (LOD=0.05 ng/ml) (**CA OEHHA 2020**).

Toxicity

6:2 FTSA was not genotoxic in assays of bacterial mutagenesis, or in mammalian cell assays of DNA repair or damage, micronucleus formation, or chromosome aberrations (**ECHA 2018**).

ECHA (2018) reported the results of unpublished oral range-finding and reproductive toxicity studies in rats. The 14-day range-finding study identified a NOAEL of 10 mg/kg-d based on changes in body and kidney weights and clinical chemistry (creatinine and urea) in one or more dose and gender groups. In the 90-day reproductive toxicity study, 6:2 FTSA did not affect male or female fertility or reproductive performance, and there were no effects on the number of pups, or on pup survival, growth, or sex ratio. The NOAEL for reproductive effects was $\geq$ 45 mg/kg-d.

Adult male mice administered 6:2 FTSA at 5 mg/kg-d over 28 days exhibited increases in liver weight, hepatocellular hypertrophy, hepatocellular necrosis, and biochemical markers associated with liver inflammation. Serum levels of the liver enzyme AST, an indicator of liver damage, and albumin were also elevated, and histological evidence of liver necrosis was observed (**Sheng et al. 2017**).

Adult male and female mice administered were administered 6:2 FTS over 112 days. 6:2 FTS is the anionic form of 6:2 FTSA which dissociates into 6:2 FTS, as is described in **Section 2.2.3.1**. Male and female mice exhibited signs of immunotoxicity including decreased plaque-forming cells in the spleen in response to sheep red blood cells in males and females administered 5 and 25 mg/kg-d and increased spleen weight in males administered 5 mg/kg-d (**Bohannon et al. 2023**).

17.2.7 PFAS Mixtures

This section provides a brief overview of current toxicity-based approaches for addressing mixtures of PFAS and currently available information on toxicity of PFAS mixtures. This is an active area of research.

17.2.7.1 Proposed Approaches, for Addressing Toxicity of PFAS Mixtures

Total Concentration Approach (Called Simple Additive Approach by Cousins et al. 2020)

In this approach, a single guideline concentration is applied to the total concentration of a specified set of PFAS. This approach is based on the assumption that all of the included PFAS have the same toxic effects and MOA, are equally potent, and their combined toxicity is additive. In the absence of complete information on toxicity and MOA for all of the selected PFAS, this approach has been applied as a conservative public health-protective science-policy strategy.

Examples of this approach are the drinking water guidelines of 20 ng/L (Vermont) and 70 ng/L (Connecticut) for the total concentration of five long-chain PFAAs (PFOA, PFNA, PFHpA, PFOS, PFHxS) and 20 ng/L (Massachusetts) for the total concentration of six long-chain PFAAs (PFOA, PFNA, PFHpA, PFOS, PFHxS, PFDA) (**CT DPH 2016**; **Vermont DOH 2018**; **MA DEP 2019**), as well as in several other nations (**Cousins et al. 2020**).

MA DEP (2019) provided a detailed rationale for their approach based on the sum of the six long-chain PFAS. They concluded that this approach is supported by similarities in chemical structures, toxicity values developed by other agencies, toxicological responses, and long serum half-lives for these six PFAS. PFHxA was also considered but was not included, because it has a shorter half-life and causes toxicity at higher doses than the PFAS that were included.

MA DEP (2019) used results of Bayesian benchmark dose (BBMD) modeling of data for thyroid effects (free thyroxine; fT4) and increased liver weight for five of the six PFAS from NTP 28-day rat toxicology studies (**NTP 2019**). Using PFOA as an index compound with a BBMD of 1, relative BBMDs for fT4 for the other PFAS ranged from 0.5 to 3 on a serum-level basis and 0.8 to 4 on a human equivalent dose (HED) basis. For an increase in liver weight, relative BBMDs based on both serum PFAS levels or HEDs ranged from 0.2 to 2. **MA DEP (2019)** considered these BBMDs to be sufficiently similar to assume equivalence of the five PFAS.

As discussed by **MA DEP (2019)**, there is a lack of data on toxicological effects, potency, and half-life of PFHpA (the 7-carbon PFAA included in the Connecticut, Vermont, and Massachusetts approaches), and no toxicity values (for example, reference doses) have been developed. Although Massachusetts recognized that PFHpA's half-life is likely shorter than for PFOA, they concluded that there are no data to develop a compound-specific or relative toxicity value for PFHpA, or to conclude that it is toxicologically dissimilar to PFOA. Based on "read-across," (prediction of toxicity based on data from similar compounds) these states consider PFHpA to be equipotent to PFOA.

Hazard Index Approach

Human health risk assessment often uses a hazard index approach, first developed by **USEPA (1989)**, to evaluate the potential cumulative noncancer toxicity from co-exposure to multiple contaminants (**USEPA 1989**). As discussed in **Section 9.1.3.1**, calculation of a hazard index is based on the assumption of dose additivity, but it does not necessarily require that the MOA or toxicological endpoint is the same for all components of the mixture. As discussed in **USEPA (2023)**, the Hazard Index approach can be based on a "general" Hazard Index, in which noncancer toxicity factors for multiple contaminants are used regardless of whether they are based on effects in the same or different target organs, or a "target organ specific" Hazard Index in which noncancer toxicity factors are based on effects in the same target organ.

USEPA (2023) presented the basis for a proposed MCLG and MCL of a Hazard Index of 1 for mixtures of four PFAS (PFBS, PFHxS, PFNA, GenX). The draft MCLG and MCL use the "general" Hazard Index approach in which the Hazard Index considers toxicity values based on differing toxicological endpoints for evaluation of the toxicity of the mixture.

Health Canada (2018, 2018) has concluded that, although there are no in vivo studies of PFAS mixtures, the similarity in health effects of PFOA and PFOS support an assumption of dose additivity and thus support the use of a hazard index approach to address co-occurrence of PFOA and PFOS in drinking water. ATSDR has also applied the hazard index approach to evaluate potential risk from site-specific exposure to mixtures of several long-chain PFAAs, noting that their approach assumed dose additivity based on "toxicologic similarities" (**ATSDR 2020**).

Minnesota Department of Health (undated) uses a health risk index approach—similar to the target organ specific Hazard Index approach—to evaluate concurrent exposures to multiple chemicals in groundwater. It is based on grouping chemicals (including PFAS and others) that cause the same general type of adverse health effect (i.e., the same target organ—for example, thyroid, endocrine). In the Minnesota health risk index approach, multiple health endpoints may be considered for each individual contaminant.

Mumtaz et al. (2021) provided a "proof of concept" demonstration of the potential use of an ATSDR hazard index approach based on target organ toxicity doses (TTDs) for specific toxicological effects (endocrine, hepatic, reproductive, developmental, and/or immune) to assess the risks of PFOA, PFOS, tetrachlorodibenzo-p-dioxin (TCDD), and polybrominated diphenyl ethers (PBDEs). This approach is intended for use as a screening tool, with a hazard index of >1 for a specific effect indicating the need for further evaluation.

USEPA (2023) has recently proposed to regulate four PFAS (PFBS, PFHxS, PFNA, GenX) in drinking water based on the general Hazard Index approach.

Relative Potency Factor (RPF) Approach

In the RPF approach, each PFAS is assigned an RPF based on its potency compared to an index compound (for example, PFOA), which is assigned a potency factor of 1. The RPFs are applied to the concentration of each PFAS present in the mixture, and the toxicity of the total of the RPF-adjusted concentrations is assumed to be the same as the equivalent concentration of the index compound (for example, PFOA). See **USEPA 2023** for more information about the RPF approach.

The RPF approach is based on dose additivity of the compounds that are included (see discussion in Hazard Index section above). The RPF approach (also known as the toxicity equivalency factor approach) has been adopted for several groups of chemicals known to cause toxicity through a common and well-defined MOA, including cholinesterase-inhibiting pesticides (organophosphates) and dioxins (PCDDs) and dioxin-like compounds (furans [PCDFs]; PCBs) that cause toxicity through activation of the AhR receptor.

The application of the RPF approach for risk assessment of PFAS mixtures is associated with greater uncertainty than for the groups of compounds noted in the preceding paragraph. In contrast to the groups of compounds discussed above, the range of adverse effects of PFAS is not due to a single specific MOA, such as activation of a specific receptor. Furthermore, the MOA may not be the same for all toxicological effects (for example, hepatic toxicity; developmental toxicity) and may vary among PFAS (discussed in this Mixtures section above).

Bil et al. (2021) proposed RPFs for 22 PFAS, with PFOA as the index compound. This is an extension of an earlier proposal of RPFs for 18 PFAS developed by RIVM (Netherlands National Institute for Public Health and the Environment) scientists (**Zeilmaker et al. 2018**). The RPFs were based on hepatic effects of PFOA and 15 other PFAS in male rats from studies with durations of 40–98 days. Hepatic effects in

male rats were selected because these effects are common to many PFAS, and there is a large data set on these effects in male rats. Endpoints evaluated included relative liver weight (all 16 PFAS), absolute liver weight (15 PFAS), and hepatocellular hypertrophy (14 PFAS), and the final RPFs were based on relative liver weight because the data set was most complete. Relative liver weight data for all PFAS (based on external dose) were fit to parallel dose-response curves, which were determined to provide an acceptable fit to the data. BMDs for each PFAS for each effect were developed from the dose-response curves based on a 5% change in absolute or relative liver weight and a 10% change in the incidence of hepatocellular hypertrophy. RPFs were based on the ratio of the BMDs for each PFAS to the BMD for PFOA and ranged from 0.001 (PFBS) to 10 (PFNA). RPF ranges for seven additional PFAS for which no relevant data were available were estimated by read-across/interpolation.

In contrast, **Peters and Gonzalez (2011)** concluded that it is not appropriate to develop TEFs (similar to RPFs) for PFAS for reasons including differing modes of actions among PFAS. However, **Bil et al. (2021)** discussed that although the MOA for hepatic effects may differ among PFAS, the similarly shaped dose-response curves for these effects support the assumption of additivity and the application of RPFs for hepatic effects. They also note the need to determine whether the RPFs based on hepatic effects are applicable to other types of toxicity caused by PFAS, such as developmental and immune system effects—an analysis that has not yet been conducted. **Goodrum et al. (2021)** concluded that the shapes of the dose-response curves for hepatocellular hypertrophy for PFOS and PFHxS in male rats, based on administered dose, differ from the dose-response curves for this effect for other PFAAs. When based on internal dose (serum levels), the shape of the curve for PFHxS differed from the shape of the curves for the other long-chain PFAAs. These results suggest that PFHxS, and possibly PFOS, are not additive with other PFAAs for hepatocellular hypertrophy in male rats; curves for liver weight were not evaluated.

17.2.7.2 Toxicology Studies of Defined PFAS Mixtures

Only a few studies of the toxicity of mixtures of PFAS, including studies of defined mixtures (i.e., mixtures for which the identities and concentrations of the components are known) of PFAS and studies of complex mixtures (i.e., mixtures for which the identities and concentrations of the components are not fully characterized) of PFAS such as AFFF were located; these are summarized below. These include in vitro studies of nuclear receptor activation in cultured cells transfected with the receptor of interest, and toxicity in cultured cells, zebrafish (a model species for human toxicity), and rodents.

Mammalian Studies

Defined PFAS Mixtures

Several recent studies have evaluated effects of defined mixtures of PFAS in mammalian species. **Marques et al. (2021)** dosed pregnant mice fed either a standard lab diet or a high fat diet with 1 mg/kg/day PFOA, PFOS, or PFHxS, individually, or 1 mg/kg/day of all three PFAS, throughout gestation. The authors concluded that "the PFAS mixture had very distinct effects when compared to single compound treatment, suggesting cumulative properties of the mixture, particularly when evaluating PFAS transfer from dam to pup," and that "these results suggest that there are multiple pathways in which PFAS could add, synergize, or antagonize specific effects, and warrants further investigation of dose response data with model predictions of additivity." However, as noted by **USEPA (2023)**, "these studies did not include individual PFAS dose response data or conduct any mixture model-based analyses, so it is not possible to ascertain if the mixtures behaved in a dose additive or risk additive manner, or if interactions occurred."

Roth et al. (2021) evaluated the effects of exposure to a mixture of PFOA, PFOS, PFNA, PFHxS, and GenX (2 mg/L each) in drinking water in mice fed a high fat diet. This treatment increased serum cholesterol, sterol metabolites, and bile acids, and caused liver toxicity, with some differences between males and

females. However, the toxicological interactions among PFAS in this study cannot be determined because effects of individual PFAS were not evaluated.

Conley et al. (2022) evaluated the dose-response curves for range of effects in rat dams and their offspring from dosing with PFOA and PFOS alone and in combination during gestation and early lactation. Mixtures of PFOA and PFOS caused effects at lower doses compared to PFOA alone for endpoints including decreased offspring survival; maternal and offspring body weight; offspring serum T3 and glucose; and increased maternal kidney weight; maternal and offspring liver weight; and offspring bile acids, BUN, and bilirubin. Histopathological changes were observed in maternal liver and kidney and offspring liver after exposure to the mixture. The effect of co-exposure to PFOA and PFOS for effects in dams and offspring was consistent with dose additivity, with the exception of maternal body weight at term and gestational weight gain, which were less than additive. **USEPA (2023)** stated that "this work is ongoing with multiple KE analyses still to be conducted on samples collected during the studies. However, results thus far support the hypothesis of joint toxicity on shared endpoints from PFOA and PFOS co-exposure, and dose additivity as a reasonable assumption for predicting mixture effects of co-occurring PFAS."

Complex Mixtures—AFFF

McDonough et al. (2020) evaluated several endpoints in mice associated with exposures to a commercial AFFF formulation containing known concentrations of PFOS and PFOA. The results were compared to those from an unexposed control and another set exposed to a similar concentration of PFOA alone. The study identified elevated concentrations of several other perfluorosulfonic acids in the exposed mice compared to the controls, and statistically significant increases in liver mass. T-cell dependent antibody suppression in mice exposed to an AFFF dose, expressed as PFOS + PFOA, was comparable to that of an equivalent dose of PFOA alone, both of which were statistically significant in comparison to the control group. Blood serum analysis of the mice exposed to the AFFF showed that they had also been exposed to a range of perfluorosulfonic acids from PFPeS to PFDS, though PFHxs and PFOS were predominant.

Receptor Activation

As discussed in **Section 17.2.5**, an important MOA for many PFAS is activation of cellular receptors, including PPAR-α and others, that regulate expression of genes that control many biological pathways. **Wolf et al. (2014)** studied PPAR-α activation by PFOA, PFNA, PFHxA, PFOS, and PFHxS singly, and in binary mixtures of PFOA with each of the other four PFAAs using a cultured cell line transfected with the PPAR-α receptor. They concluded that there was additivity for PPAR-α activation in PFAS mixtures at concentrations up to 32 µM. An earlier study from the same research group used this test system with higher concentrations of PFAAs and found that PPAR-α activation in binary mixtures of PFOA, PFOS, PFNA, and PFHxS was antagonistic in the mixture of all four PFAS (**Carr et al. 2013**).

Activation of the estrogen and androgen receptors by PFOA, PFNA, PFDA, PFUnA, PFDoA, PFHxS, PFOS individually, and an equimolar mixture of all seven PFAAs, was evaluated in cultured cell lines transfected with these receptors (**Kjeldsen and Bonefeld-Jorgensen 2013**). The results of this study illustrated the complexity of interactions of mixtures of PFAS in regard to receptor activation. PFOA, PFOS, and PFHxS singly, as well as the mixture of the seven PFAAs, were weak agonists of the estrogen receptor and also enhanced activation by the endogenous estrogen, 17-beta estradiol. These three PFAS also inhibited activity of the androgen receptor, and the same three PFAS, as well as PFNA and PFDA, antagonized activation by the endogenous androgen, dihydrotestosterone. In contrast to some of the individual PFAAs, the PFAA mixture did not affect androgen receptor activity in the absence of dihydrotestosterone, but it did antagonize activation of the receptor by dihydrotestosterone. Comparison of the androgen receptor dose-response data for the inhibitory PFAAs and the mixture indicated a synergistic antagonistic effect (greater than additive inhibition) of the PFAAs in the mixture.

Nielsen et al. (2022) developed an in vitro system to predict the effects of defined PFAS mixtures on activation of human PPARα. They determined that PFCAs tended to act as full PPARα agonists and PFSAs tended to act as partial PPARα agonists, with individual PFAS differing in potency. **Nielsen et al. (2022)** also found that concentration additive approaches to predicting mixtures effects on PPARα may overpredict the effects of PFAS mixtures on PPARα activation.

Effects in Cultured Hepatocytes

Defined PFAS mixtures

The effects of PFHpA, PFOA, PFNA, PFDA, PFHxS, and PFOS individually, and in 11 binary and 4 ternary mixtures on cell viability of the human liver cell line, HepG2, were evaluated by **Ojo et al. (2020)**. The concentrations that were tested for each PFAS were based on dilutions of the concentration that caused 50% loss of cell viability. Effects of many binary and ternary combinations were synergistic, while other combinations were antagonistic at some concentrations. PFOS was synergistic with the other five PFAS at almost all concentrations, while interactions in mixtures that included PFOA were either synergistic or antagonistic, with synergism predominating at lower concentration levels. In another study of the same cell line, PFOA and PFOS induced and promoted apoptosis, and a mixture of both PFAS showed additivity for this effect (**Hu and Hu 2009**).

Effects on gene expression of six individual PFAS (PFOA, PFNA, PFDA, PFDoA, PFOS, 8:2 FTOH) and four mixtures (PFOA plus PFOS; three mixtures of all six PFAS in different proportions) were evaluated in primary cultures of hepatocytes from rare minnow (**Wei et al. 2009**). No clear patterns of response were observed, in those mixtures of PFAS affected the expression of some genes that were not affected by individual PFAS, and vice versa.

Complex Mixtures—AFFF

Ojo et al. (2022) evaluated the toxicity of 24-hour exposure to varying concentrations of two historically used AFFFs containing PFAS in the HepG2 human liver cell line. PFAS in one of the AFFFs were primarily long- and short-chain PFAAs, while PFAS in the second AFFF were at lower concentrations and was primarily 6:2 FTS. Both AFFFs caused concentration-dependent decreases in cell viability and increases in two biochemical markers of toxicity; the AFFF containing PFAAs was more potent for these effects. Cellular DNA damage was induced only at the highest concentration tested (0.038%) of the AFFF containing PFAAs.

Zebrafish Studies

Defined PFAS mixtures

Fey et al. (2022) evaluated the effects of varying concentrations of PFOS and 6:2 FTS singly and as a mixture on mortality, hatching, and developmental endpoints in zebrafish. The authors concluded that the relative potencies of PFOS and 6:2 FTS in this study were not constant and varied at different concentrations of the test substances, and, therefore, dose additivity could not be assumed.

The lethality of PFOA, PFOS, and a mixture of both chemicals was studied in zebrafish embryos (**Ding at al. 2013**). The interaction between PFOA and PFOS was concentration-dependent, with additive, synergistic, antagonistic, and then synergistic effects observed as the proportion of PFOS was increased.

Behavioral effects in zebrafish embryos were evaluated for PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFBS, PFHxS, PFOS, and 6:2 FTSA individually, and with mixtures of equal concentrations of all nine PFAS (**Menger et al. 2020**). PFHpA, PFOA, PFNA, PFHxS, PFOS, and 6:2 FTSA alone, as well as the mixture, caused behavioral effects in tests of locomotor activity, while PFBA, PFHxA, and PFBS did not. Specific

behavioral effects varied among individual PFAS. The mixture of PFAS was less potent than the individual PFAS present in the mixture, suggesting antagonistic interactions among the PFAS in the mixture.

17.2.7.3 Studies of Mixtures of PFAS and Contaminants Other than PFAS

Several additional studies evaluated toxicological interactions of individual PFAS with other environmental contaminants. In male mice, co-exposure to PFOS and PCB126 (a dioxin-like PCB) caused synergistic effects on hepatic expression of genes related to oxidative stress, inflammation, and atherogenesis; levels of a protein that is a biomarker for thrombosis and fibrosis (indicators of cardiovascular disease risk); and hepatic lipid levels. Co-exposure, but not the individual compounds, caused pathological changes indicative of liver injury.
The effects on gene expression in zebrafish embryos of PCB126 alone, PCB126 plus PFOS, PCB126 plus PFHxA, and PCB126 plus both PFOS and PFHxA were evaluated by **Blanc et al. (2017)**. The PFAS were not tested in the absence of PCB126. PCB126 with both PFOS and PFHxA had a greater effect on the expression of several genes than PCB126 alone or PCB126 with PFOS or PFHxA individually. The results suggest synergistic effects of PFOS and PFHxA on the effects of PCB126 in this test system.

17.2.8 Evaluating PFAS Using New Approach Methodologies

In one of its most resource-intensive efforts on PFAS to date, the USEPA developed a screening library containing PFAS. This USEPA-curated list spanned several public-interest lists of PFAS, including those from the USEPA, United States Food and Drug Administration (FDA), Department of Defense (DOD), Agency for Toxic Substances and Disease Registry (ATSDR), Consumer Product Safety Commission (CPSC), and state regulatory agencies. The screening library was developed to support the development of analytical methods, environmental monitoring, and toxicity testing. Further information on the initial list of 430 PFAS is available on USEPA's CompTox Chemicals Dashboard (**USEPA 2020**), which was developed by the USEPA's Chemical Safety for Sustainability Research Program (**USEPA 2020**). The purpose of the dashboard, along with related databases and web applications developed by the agency, is to support the USEPA's computational toxicology research efforts to develop new and innovative methods with the goal of incorporating advances in a wide variety of scientific disciplines (biology, biotechnology, chemistry, and computer science) to help identify important biological processes that may be disrupted by chemicals. Using computational toxicology research methods, it is hoped that thousands of chemicals can be rapidly evaluated for potential risk at small cost, and chemicals can be prioritized for further studies based on potential health risk information derived from this initial evaluation (**USEPA 2020**).

From the initial list of 430 PFAS (discussed above), a subset of 150 PFAS were chosen by USEPA with the overall goals of maximizing the ability to perform read-across (for example, predicting toxicity of a target PFAS compound by extrapolating such information from a PFAS compound that has been more extensively studied) and capturing structural diversity among PFAS. The USEPA also took into consideration likelihood of exposure or occurrence, and the availability of in vivo (mammalian) or in vitro (for example, cell culture) toxicity data for validation. Because compounds that exist as gases cannot be tested and some PFAS (for example, HFPO-DA [GenX]) rapidly degrade in dimethyl sulfoxide (DMSO), which is used as the vehicle in many of these assays (**Liberatore et al. 2020**), practical considerations such as the ability to procure in nongaseous form and to solubilize samples in the solvent DMSO without degradation were also considered (**Patlewicz et al. 2019**; **USEPA 2020**, **2020**).

This group of 150 PFAS is also currently being evaluated at Oregon State University, the University of Pittsburgh, East Carolina University, and other institutions in a USEPA-funded effort to use in vivo and in vitro methods to systematically study PFAS toxicity. The goal of this research is to support the prioritization of PFAS in risk assessment and risk management (**USEPA 2019**) by using a combination of in vivo toxicity screening assays and transcriptomics (evaluation of changes in RNA expression in specific tissues in response to biologic or environmental cues; these RNA molecules often code for

proteins) in the zebrafish model to characterize the toxicity and pharmacokinetics of a range of volatile and nonvolatile PFAS. The subset of 150 PFAS is also being evaluated in in vitro assays intended to be predictive of various endpoints such as hepatotoxicity, developmental toxicity, immunotoxicity, neurotoxicity, mitochondrial toxicity, developmental neurotoxicity, endocrine disruption, and general toxicity (**USEPA 2019**). Results of these studies will be used to group PFAS by structures and biological activity. As mentioned above, the intent is to capture the structural diversity across the spectrum of PFAS of interest to USEPA and to support determination of the feasibility of read-across within structure-based groupings, an approach in which information from PFAS with extensive in vivo toxicity data could be used to predict toxicity of other PFAS that lack such data.

It is hoped that the results of these high throughput assays will (a) inform PFAS hazard characterization, (b) provide toxicokinetic information that may help predict disposition and excretion of PFAS from the body, and (c) prioritize PFAS for risk assessment and further in vivo mammalian testing that is needed for risk assessment. A further goal of this program is to determine, based on data for PFAS that have been evaluated in both in vitro and mammalian in vivo systems, whether the read-across approach can be used to support in vitro to in vivo extrapolation for estimation of oral equivalent exposures for PFAS (**Fenton et al. 2020**).

17.2.9 Data Gaps and Research Needs

Although many studies relevant to health effects of PFAAs have become available in the last few years, important data gaps remain for most of the PFAAs and PFECAs discussed here, as well as for many additional PFAS used in commerce or found in AFFF.

Human half-lives and other toxicokinetic data are not available for some PFAS found in drinking water and other environmental media. This information is critical for adequately assessing the bioaccumulative potential and relevant routes of exposure (for example, placental and breast milk transfer), and for extrapolation of animal toxicity information to humans.

Available data suggest that reactive intermediates can form in the metabolic pathways that convert PFAA precursors to PFAAs within the body. Additional information on the formation and potential toxicity of these reactive intermediates is needed.

Additional toxicology data are needed for some PFAAs found in environmental media, including drinking water. For example, there are very limited toxicology data for PFHpA, and no information was located for PFPeA. Additionally, although humans are exposed to multiple PFAS, very little toxicological data are available for mixtures of PFAS. Multigeneration studies are important for assessment of reproductive and developmental effects, and they are available for only a few PFAS. PFHxS is a PFAA with a long human half-life that has been found in human serum and in drinking water impacted by both industrial discharges and AFFF. Although developmental effects of PFHxS are of concern, there are currently no multigenerational developmental studies for PFHxS. Available information from rodent studies suggests that developmental exposures to some long-chain PFAS (PFOA, PFOS, PFHxS) cause permanent neurobehavioral effects, but these data are limited. Additional studies are needed on neurobehavioral effects of PFAS, particularly from early life exposure.

Studies that provide data on chronic effects, including carcinogenicity, are available for only four PFAS (PFHxA, PFOA, PFOS, GenX), and such studies are needed for PFHxS, PFNA, ADONA, and other PFAS to which humans may be exposed. All of the chronic studies were conducted in rats, and chronic studies in a second species such as mice would provide valuable information, particularly for those PFAS that are rapidly excreted in female rats.

The mode(s) of action for the toxicological effects of PFAAs are not fully understood and continue to be the focus of ongoing research. Although not the focus of this section, data on bioavailability of PFAS

from environmental media other than drinking water (for example, soil) are limited, and such information can be useful in assessing exposures at contaminated sites.

Challenges related to the use of toxicity information from surrogates for PFAS for which no toxicity data are available are discussed in **Section 9.1.1.2**. There is a need to further develop and validate approaches for addressing groups and mixtures of PFAS, such as those described in **Section 17.2.7**.

Finally, **OECD (2018)** identified 4,730 PFAS-related CAS numbers, including compounds with many different structures, including some that have not been used commercially. The majority of these PFAS, including those in commercial use, have very limited or no toxicity data (**Wang et al. 2015**; **Wang et al. 2017**), indicating a critical data gap in health effects information for PFAS. The approaches currently under development at USEPA and the National Toxicology Program (NTP) that are discussed in **Section 17.2.8** may prove useful for screening of a large number of PFAS with rapid assays that evaluate parameters related to toxicokinetics and toxicity (**USEPA 2018**). Additional information is found on the USEPA CompTox website (**USEPA 2020**; **Williams et al. 2018**) and from the NTP Rapid Evaluation and Assessment of Chemical Toxicity (REACT) Program (**DeVito 2018**). If this effort is successful, the results could be used, along with data on human exposure, for prioritization of PFAS for more detailed toxicological studies (**USEPA 2018**).

17.3 Additional Information for Risk Assessment

17.3.1 Human Health Exposure Assessment

Figure 9-5 illustrates predominant exposure pathways. In the following sections, summary information is presented for exposures by environmental medium. Information about site risk assessment is in **Section 9**. Information about PFAS occurrence in environmental media is discussed in **Section 6**. Links are provided to other sections for more details on related topics.

17.3.1.1 Soil

Soil exposure scenarios are possible at a site. Many PFAS are mobile and persistent in soil. As indicated in **Section 5**, PFAS distribution in soils is complex, reflecting several site-specific factors and individual PFAS-specific factors.

Sorption and retardation generally increase with increasing perfluoroalkyl tail length, and functional groups contribute to the degree to which a PFAS has the affinity to leach from soil to groundwater. A detailed discussion of the fate of PFAS in soil is provided in **Section 5**. Receptors, such as humans, terrestrial animals, and plants, in contact with soil containing PFAS may be exposed to the compounds.

PFAS may be absorbed through the skin; some relevant studies are summarized in **Section 17.2.3**, **Section 1.4.3**, and by ATSDR (**2021**). Therefore, current evidence combined with existing toxicity factors suggest that dermal absorption from soils or associated groundwater is not expected to be an important exposure route for the general public compared to other exposure pathways, but may contribute to less significant exposures such as incidental ingestion of soils in combination with skin contact. Construction workers may contact PFAS in soils (if within the depth of construction activities).

17.3.1.2 Potable Water

Ingestion of PFAS-containing drinking water typically represents the dominant exposure pathway in comparison to ingestion of food or other exposure pathways especially when PFAS concentrations in drinking water reach a certain level (**Post, Gleason, and Cooper 2017**; **Bartell 2017**). **Section 1.4.1** includes information about potential human health effects from PFAS exposure arising from AFFF in

drinking water. However, the dominance of the drinking water pathway is relative and can be context specific as highly contaminated sources of food (e.g., fish or agricultural products) might result in significant exposure greater than that of water. As discussed and cited in **Section 7.1.2**, PFAS levels in young children (up to the age of 6) are often higher than in adolescents and adults consuming the same drinking water source (see also **Section 17.2**). This is most likely due to the relatively higher levels of water ingestion per unit of body mass at these ages. If bottled water is supplied for drinking water and food preparation purposes, potential exposures from potable water used for non-drinking water purposes (for example, showering, bathing, and hand-washing dishes) are expected to be minimal, with the possible exception of inhalation exposure to volatile PFAAs (see **Section 17.3.1.6**), which is not yet well characterized.

17.3.1.3 Groundwater

The same potential exposure pathways described above for potable water apply to groundwater when used as a potable source. As discussed for soils, construction workers may contact PFAS in shallow groundwater (if within the depth of construction activities), although dermal absorption potential from water is low. If PFAS-impacted groundwater is used as irrigation water for crops, homegrown produce, or animal watering, PFAS in groundwater may be transferred to biota (plants or animals), resulting in potential dietary exposures (see **Section 17.3.3**).

As indicated in **Section 5.3**, due to the mobility and persistence of PFAS in soil and groundwater, certain PFAS are expected to form larger plumes than certain less-soluble contaminants in the same hydrogeological setting. However, sorption and partitioning might restrict leaching rates from the vadose zone and reduce the advection-driven transport velocity of PFAS in groundwater, depending on specific properties of the PFAS. These processes might limit plume development and discharge to surface water and might provide time for transformation of PFAS precursors. Groundwater geochemistry can also affect the extent of biotic and abiotic transformation of PFAS precursors (**Liu and Mejia Avendaño 2013**).

17.3.1.4 Surface Water

Surface water impacted with PFAS by surface runoff or groundwater discharge also present possible exposures. Surface water exposures can occur through drinking water or by consuming aquatic biota from contaminated water bodies. Much of the PFAS reaching surface water tend to remain in solution, although there is likely to be partitioning to sediment and uptake to biota. Once in surface water, PFAS could contaminate groundwater through groundwater recharge (**Liu et al. 2016**; **ATSDR 2008**). See **Section 16.2** for human health aspects of PFAS in surface water. The Priority Topics for Fate and Transport, Surface Water, Source ID, and Site Characterization include information about PFAS in marine environments (see **Section 1.3.5**) and the effects of suspended sediment on surface water sampling and measurement of PFAS (see **Section 1.3.6**).

Biofilms on surface water are known to accumulate PFAS (**Munoz et al. 2018**), as do other organic-/protein-rich particles in aquatic systems (**Ahrens and Bundshuh 2014**). Therefore, surface water films that contain these matrices could be repositories (and potential sources of exposure), especially of long-chain PFAS. Similarly, PFAS-containing foams may form on certain surface waters and contribute to recreational exposures. PFAS-containing foam is discussed in **Section 16.5**.

17.3.1.5 Sediment

PFAS in surface runoff or groundwater discharge can partition to sediment and be taken up into biota. The exact processes that control affect sorption and bioavailability of PFAS in sediments are poorly understood and likely determined by several factors including the mixture of PFAS, salinity, and sediment composition (see **Sections 6.5** and **5.3.4.2**). Considerations for PFAS in sediments and the potential

implications for human health risk assessment (for example, bioaccumulation into fish and recreational contact) are detailed in **Sections 9.1** and **16.2**.

17.3.1.6 Air

PFAS inhalation exposure scenarios are possible. Examples include dusts containing PFAS may be generated from a site where PFAS are present in soil, as well as aerosols derived from surface waters (**Section 5.2.4**). In addition, some PFAS (for example, FTOHs and some perfluoroalkyl sulfonamides) have higher volatilities and can partition into air from other media (**Section 5.2.4**). Certain PFAS are found in ambient air with elevated concentrations observed or expected in urban areas near emission sources, such as manufacturing facilities, wastewater treatment plants, fire training facilities, and landfills (**Barton et al. 2006**; **Ahrens et al. 2011**; **Liu et al. 2015**). See **Section 6.1** for more information about PFAS occurrence in air. See also the **PFAS and Vapor Intrusion Fact Sheet** developed in 2025.

17.3.1.7 Diet

PFAS exposures may occur from food consumption, such as ingesting aquatic and terrestrial plants and animals that have taken up PFAS. Crops may be impacted by PFAS if irrigated with contaminated groundwater or surface water; if impacted by soil, runoff, or atmospheric deposition; or where biosolids have been applied to soil. In addition, because some PFAS biomagnify in food webs, ingestion of contaminated biota, especially fish and animals that eat fish, may be an important exposure route (**ATSDR 2020**; **ATSDR 2021**; **USEPA 2016**; **USEPA 2016**). Recreationally caught fish from areas with PFAS contamination may be a specific source of elevated exposures to PFAS that bioaccumulate in fish. PFAS exposures may also occur from food packaging materials containing PFAS (see **Section 17.3.1.8**, Consumer Products). The Priority Topics for Biosolids Land Application (see **Section 1.7**) include information about potential risks from agricultural impacts, plant uptake, and uptake by animals.

Breast Milk and Infant Formula

Consumption of breast milk and infant formula are potential exposure scenarios for infants. Breast milk may be impacted from a lactating mother's exposure to PFAS-contaminated media, and infants may ingest PFAS from formula prepared with PFAS-contaminated water (**Fromme et al. 2010**; **Mogensen et al. 2015**). Higher exposures to infants are of concern because infants are sensitive subpopulations for developmental effects of PFAS, as discussed in **Section 7.1** and **Section 17.2**. Infants may have a higher level of exposure to PFAS through breast milk or formula prepared with contaminated water than adults typically have through consuming contaminated water due to differences in the volume of water consumed relative to body weight. The USEPA Exposure Factors Handbook (**USEPA 2019**) provides detailed information on breast milk consumption rates and the higher water consumption rate of infants.

17.3.1.8 Consumer Products

Typically, exposure scenarios associated with consumer products are not included in human health risk assessments (HHRAs) for contaminated sites. However, the HHRA should acknowledge that analytical results for environmental media (including indoor air and dust) may reflect impacts from consumer products (for example, carpets and upholstered furnishings) containing PFAS that have degraded, released fibers, or volatilized (see **Section 2.5**). **Section 1.4.2** includes information about potential PFAS exposures from consumer products.

17.3.2 Other Considerations When Calculating Exposure Point Concentrations

Other contaminants present at the site can affect the movement of PFAS, which are not easily accounted for in fate and transport models. For example, petroleum hydrocarbon co-contaminants, particularly light nonaqueous phase liquids (LNAPLs), may affect the fate and transport of AFFF-derived PFAS (**Guelfo and Higgins 2013**; **Lipson, Raine, and Webb 2013**; **McKenzie et al. 2016**). As discussed in detail in **Section 5** and **Section 10.4**, PFAS movement in environmental media depends on both site-specific media properties and properties of the specific PFAS. Leaching potential is a function of both media properties (for example, pH, redox conditions) and PFAS structural properties (for example, chain length) (**Gellrich, Brunn, and Stahl 2013**; **Gellrich, Stahl, and Knepper 2012**).

It is critically important to collect site-specific soil partitioning and soil-to-groundwater pathway data for PFAS sites. Existing models and standard methods are not able to accurately predict or calculate soil-to-groundwater movement of PFAS given their hydrophobic and hydrophilic properties. Therefore, site-specific empirical data are necessary.

As discussed in detail in **Section 5.4**, the composition of PFAS can change in media. Studies have reported both biotic and abiotic transformations of some polyfluorinated substances (precursors), which may form PFAAs (**Buck et al. 2011**). Precursors that are ingested can be transformed in the body to PFAAs (**USEPA 2016**; **USEPA 2016**). However, PFAAs likely do not degrade or otherwise transform under ambient environmental conditions. PFAS composition may also change in surface water because of biotic and abiotic degradation of PFAA precursors. These complex transformations are not incorporated in current fate and transport models.

17.3.3 Information about Selecting Bioaccumulation and Bioconcentration Factors

Certain PFAS can bioaccumulate in the food web including aquatic organisms (see **Section 5.5** [PFAS Uptake into Aquatic Organisms] and **Section 6.5.3** [Fish]), terrestrial animals (for example, livestock and wild game), as well as plants. PFAAs, particularly PFOS, are typically the dominant PFAS detected in biota (**Houde et al. 2011**). **Section 5.5**, **5.6**, and **Section 16** provide detailed discussions of factors affecting the bioaccumulation potential of PFAS across a variety of organisms. The Priority Topics for Biosolids Land Application include information about plant uptake (see **Section 1.7.4**) and uptake by animals (see **Section 1.7.5**).

Figure 17-1 illustrates bioaccumulation pathways from sediment and surface water.

Section 6.5.3 (Fish) provides a detailed discussion of bioaccumulation of PFAS in fish. PFAS accumulation in fish has been documented, particularly for PFOS, longer chain PFCAs (with eight or more fluorinated carbons), and perfluorodecane sulfonate (PFDS) (**Houde et al. 2011**; **Martin et al. 2013**; **Conder et al. 2008**). In fish, PFOS tends to partition to the tissue of highest protein density, including the liver, blood serum, and kidney (**Falk et al. 2015**; **Ng and Hungerbühler 2013**). Available aquatic organism BCF and BAF data are presented in Table 5-1 (provided as a separate Excel file). Trophic level biomagnification in food webs (**Figure 17-1**) can occur for some PFAS (**Franklin 2016**; **Fang et al. 2014**) as discussed in further detail in **Section 5.5.3**.

Sections **5.6** and **6.5.1** discuss partitioning of PFAS to plants.

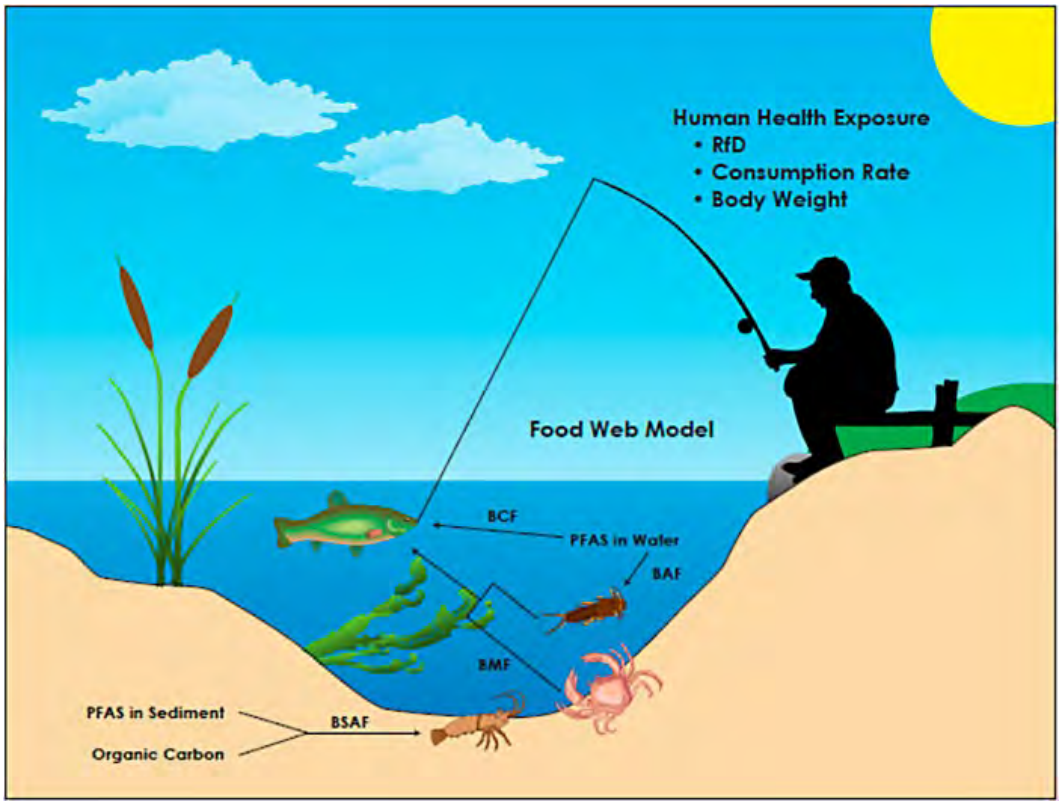


Figure 17-1. Bioaccumulation of PFAS from sediment and surface water. (BAF–bioaccumulation factor; BCF–bioconcentration factor; BSAF–biota-sediment accumulation factor; BMF–biomagnification factor; RfD–reference dose.

Source: J. Conder, Geosyntec. Used with permission.

Plant uptake, bioaccumulation, and partitioning within the plant appear to depend on PFAS chemical structure and the plant species. **Figure 17-2** illustrates bioaccumulation of PFAS in plants. Most studies report partitioning of PFAAs within plants, with longer chain PFAAs, especially PFSAs, partitioning to the roots and more soluble, shorter chain PFAAs, especially PFCAs, partitioning to other parts of the plant (**Lechner and Knapp 2011**; **Stahl et al. 2009**) Blaine (**Blaine et al. 2013**; **Blaine, Rich, Sedlacko, Hundal, et al. 2014**; **Yoo et al. 2011**; **Scher et al. 2018**; **Gobelius, Lewis, and Ahrens 2017**). Table 5-2 (provided as a separate Excel file) contains BCFs and BAFs for various PFAS in a variety of plant species. In general, most plant BCFs and BAFs fall between a range of 0.1 and 10.

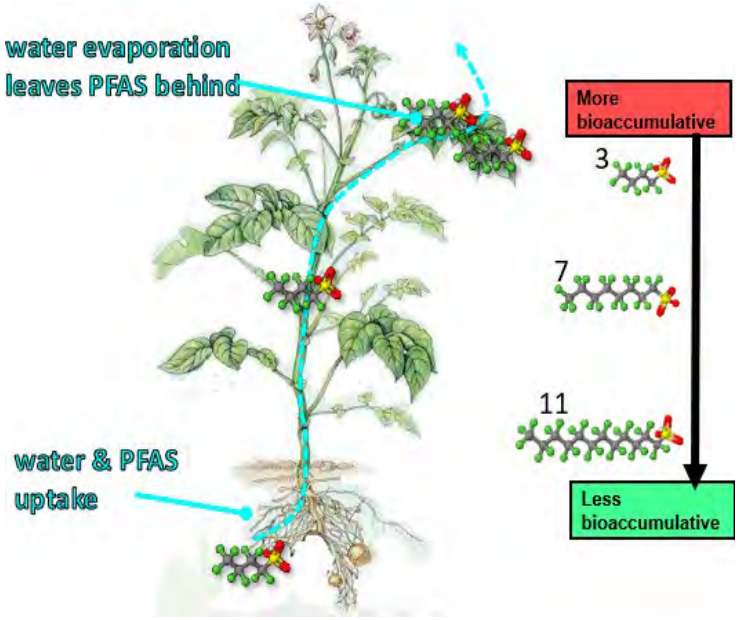


Figure 17-1. Bioaccumulation of PFAS in plants.

Source: J. Conder, Geosyntec. Used with permission.

As indicated in **Section 4.2.8** (Octanol/Water Partition Coefficient (K_{ow})) and **Section 5.5.2** (Bioaccumulation), it is difficult to measure K_{ow} for PFAS due to their complex chemistry, and because many PFAS have both hydrophilic and hydrophobic properties. Therefore, BAFs rely on calculations from empirical data instead of modeling (**Haukås et al. 2007**).

18 SORPTION-BASED TECHNOLOGIES FOR SEPARATION AND CONCENTRATION OF PFAS FROM WATER

The purpose of this section is to collate and summarize the current state of knowledge and practice for removal of PFAS from water by sorption-based technologies and provide a resource to assist regulators, consultants, and industry practitioners as they navigate the decision-making process. Topics addressed in this document include treatment objectives, characteristics of commonly treated waters, potential site-specific considerations, operation and testing of fixed-bed and fractionation-based treatment technologies, resources for decision-making, and outstanding challenges for treatment implementation.

ITRC already provides resources to help with issues related to treatment of PFAS in water in the PFAS-1 Guidance Document. **Section 12.2** includes a useful overview of the technologies discussed here (specifically, **Section 12.2.1** and **Section 12.2.3**), as well as several other effective PFAS treatment technologies that are not sorption-based, such as membrane processes. Readers are advised to familiarize themselves with the summaries and concepts in Section 12 to take maximum advantage of the information presented here. That said, exhaustive knowledge of the earlier text is not necessary for understanding this new Section 18, and relevant sections will be referenced or summarized as needed. Readers should note that **Section 12.2.1** is called "Sorption Technologies" and **Section 12.2.3** is titled "Foam Fractionation," but both fixed-bed adsorption by adsorbent media and adsorption to bubbles are considered "sorption-based" technologies in this Section. Readers specifically interested in point of use (POU) treatment or point of entry (POE) treatment (also referred to as POET) systems for treating drinking water, which are not specifically discussed in this new section, are advised to consult **Section 12.1.4.1**.

Section Number	Topic
18.1	**Introduction**
18.2	**Treatment Objectives and Considerations**
18.3	**Fixed-Bed Adsorbers**
18.4	**Foam Fractionation**
18.5	**Resources for Decision-Making**
18.6	**Barriers, Challenges, and Outlook**

18.1 Introduction

Removal of per- and polyfluoroalkyl substances (PFAS) from water has become an important concern for water utilities; landfill operators; industry professionals; and state, local, and tribal decision makers. One option for removal of PFAS from water is sorption-based technologies, which remove contaminants from the dissolved phase by adsorption to surfaces or absorption into bulk phases. Examples of sorption-based technologies include granular activated carbon (GAC), ion exchange (IX) resins, and foam fractionation. They have long-standing applications in water treatment and are recognized for their proven efficiency in removing PFAS. These technologies are frequently regarded as effective solutions due to their ability to target and remove a wide range of PFAS, especially longer chain PFAS (**Murray et al. 2023**; **Tajdini et al. 2025**), leveraging mechanisms that optimize contaminant capture and separation. Because of these characteristics, sorption-based technologies have planned or current deployment for PFAS treatment in more than half of US states (**ECOS 2025**). However, selecting the best treatment method or system configuration for removal of PFAS from water can be a daunting task, and PFAS-specific information on the topic is currently scattered across a variety of sources.

This section focuses on PFAS-specific concepts and practical considerations. It is not a nuts-and-bolts operational manual for water treatment systems, nor is it an exhaustive resource on the underlying

physical principles of adsorption and absorption. Readers interested in gaining deeper or broader knowledge than can be provided here are advised to consult general texts on IX resins (**Harland 1994**; **Helfferich 1995**; **Slater 2013**; **Zagorodni 2006**), GAC (**Worch 2012**), foam fractionation (**Lemlich 2012**; **Stevenson and Li 2014**), and water treatment (**Crittenden et al. 2012**; **Spellman 2008**) as appropriate.

Only adsorptive technologies considered "field-implemented" by the ITRC (defined in **Section 12.1**) as of September 2025 will be discussed in this document. Although novel media technology such as surface-modified clays, cyclodextrins, and many others may have demonstrated PFAS removal under pilot or bench-scale conditions, they have not yet (September 2025) demonstrated maturity in full-scale treatment systems. Accordingly, it is not possible to provide specialized information on testing and evaluation for these technologies in practice. However, the testing methodologies described in this document are still expected to provide a useful foundation for testing and evaluation of these novel sorbents as they become more technologically mature. Where applicable, some new or emerging technologies for regeneration of GAC and IX resins or destruction of treatment residuals are briefly discussed. Removal of PFAS from water in ex situ treatment systems by addition of powdered activated carbon (PAC) is not cost-effective except in some cases where modest PFAS removal (50% or less) is needed and a method for dealing with resulting sludge is available (**Ahrens et al. 2025**). Therefore, testing and evaluation of PAC are not examined here.

Ex situ treatment applications such as wastewater (industrial or municipal) treatment, treatment of extracted groundwater, and drinking water treatment, which are the focus of this document, have significant overlaps in site assessment, testing, and evaluation processes. In situ remediation methods, such as injection of colloidal activated carbon or other sorbents, differ significantly from ex situ methods in all these aspects and fall beyond the scope of this document.

18.1.1 Additional Resources

This section extends but is also distinct from content provided in the previously published PFAS-1 Document (**https://pfas-1.itrcweb.org**). Therefore, prior to continuing in this section, readers may find it useful to review and familiarize themselves with the following sections and external data tables:

- **Section 8: Basis of Regulations – PFAS – Per- and Polyfluoroalkyl Substances**
- **Section 8: PFAS Regulatory Programs Summary Excel File**
- **PFAS Environmental Media Values Table Excel File**
- **Section 10: Site Characterization**
- **Section 12.1.1: Factors Affecting Technology Selection**
- **Section 12.1.4: Considerations for Specific Environmental Media**

ITRC offers other resources covering in situ treatment technologies, including **Section 12.2.4** and **Section 15.2.3** and relevant slides in the **ITRC PFAS Beyond the Basics: PFAS Treatment Technologies Training**.

Some commonly asked questions about PFAS treatment methods are mapped to their respective sections in the section in **Figure 18-1**.

Information about Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) projects for sorption-based technologies can be found at **https://serdp-estcp.mil/**.

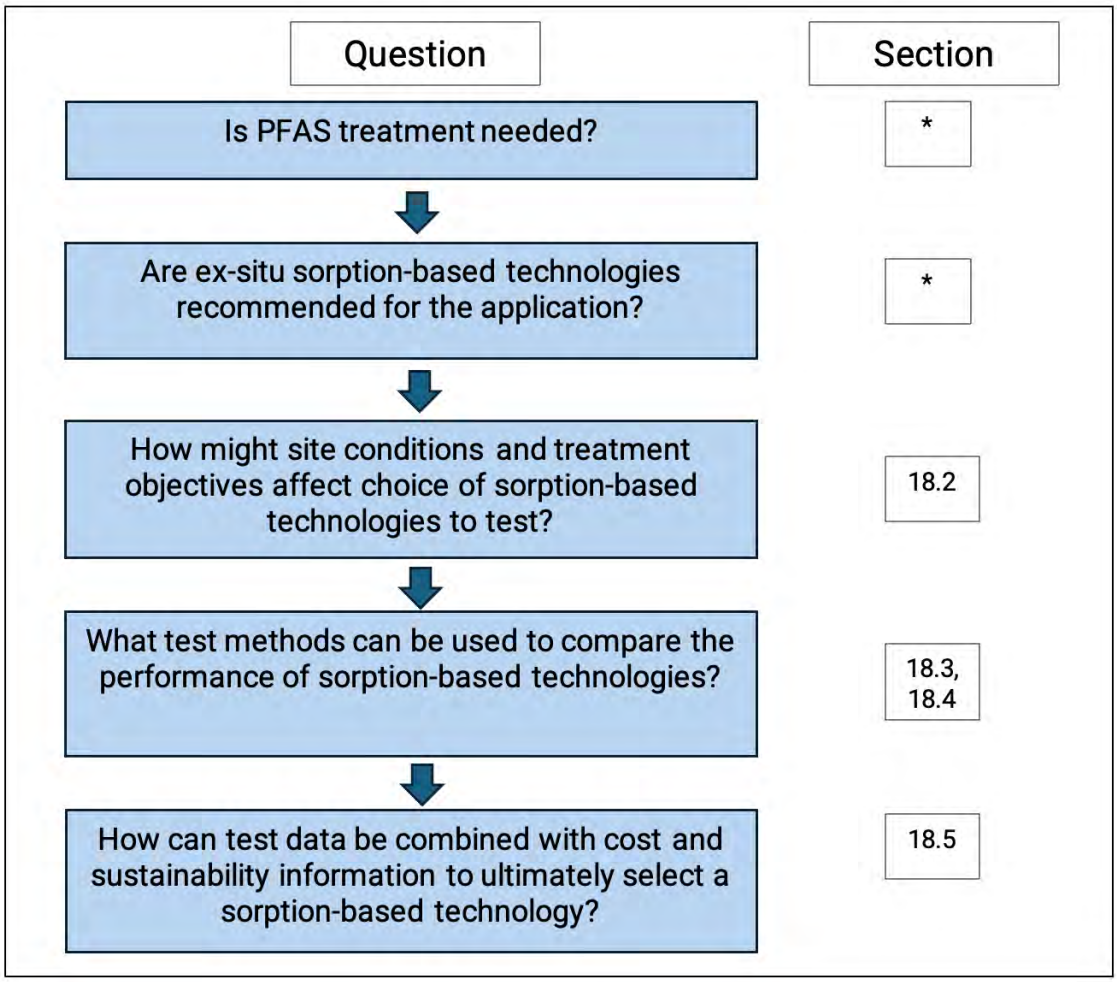


Figure 18-1. Diagram mapping document sections to pertinent questions for planning, testing, and evaluating sorption-based treatment options for PFAS in water. An (*) denotes questions answered before consulting this document using guidance from other resources, such as **Section 8** (Basis of Regulations) and **Section 12.1.1** (Factors Influencing Technology Selection).

18.2 Treatment Objectives and Considerations

18.2.1 Introduction

Location selection and sizing of sorption-based PFAS treatment facilities require a comprehensive evaluation of various factors, including PFAS treatment objectives, characterization of waters commonly treated and their influence in treatment process selection, and flow quantification. This section discusses these and other operational considerations. By thoroughly understanding these considerations, informed decisions can be made that balance efficiency, cost, and space constraints to develop an optimal PFAS treatment strategy.

18.2.2 Objectives

It is important to first recognize that the objective of sorption-based PFAS treatment is to remove PFAS from the water or liquid waste stream such that the treated water is made suitable for some consumptive

use or discharge. This is different from the objectives specific to remediation of a contamination site, but the use of such treatment may contribute to site remediation objectives. For the purposes of this guidance, all applications of treatment are ex situ. Treatment using GAC and IX resins achieves this objective by separating and concentrating PFAS onto the sorption media, while foam fractionation achieves this objective by separating and concentrating PFAS into a separate solution of reduced volume. Enhancing the concentration of separated PFAS allows it to be more efficiently and economically destroyed or properly disposed. Detailed discussion regarding the use of additional treatment for destruction of PFAS or technology for the containment/disposal of the separated PFAS is outside the scope of this guidance, but some factors regarding destruction and disposal are mentioned. Additional information on these destruction technologies is available in the following sections:

- **Section 12.4** Incineration
- **Section 12.6** Limited Application and Developing Liquids Treatment Technologies
    - **Section 12.6.3** Redox Manipulation
    - **Section 12.6.5** Alkaline Hydrothermal Reaction

The amount of removal needed will depend upon the concentration of PFAS in the source water or liquid waste stream and the intended end use or point of discharge and regulatory requirements. PFAS may be regulated individually, in combination with other PFAS or precursors, or both. Users can refer to the PFAS Environmental Media Values Table, and the Environmental Council of the States (ECOS) Compendium of State PFAS Actions, (**ECOS 2025**) for additional information regarding state- or country-specific regulatory information.

18.2.2.1 Consumptive Use Objectives

PFAS treatment of groundwaters or surface waters for consumption may include nonpotable uses but is more commonly associated with the production of drinking water. Treatment objectives to produce drinking water are related to public health, limiting the risk of potential health effects by limiting the concentrations of PFAS regulated in drinking water and thus limiting exposure to those contaminants. Concentrations may be established through primary standards, treatment techniques, goals, advisory levels, etc. There may be differences between concentrations associated with a regulatory goal and the minimum level of treatment established by a standard. These could be due to economic and technological limitations (for example, limits in the ability to practically quantitate the concentration of a particular PFAS). Despite such limitations, a drinking water supplier and its customers may establish treatment objectives that provide a level of service that goes beyond minimum regulatory requirements (for example, to produce water with no detectable levels of regulated PFAS, or to limit the concentration of certain unregulated PFAS). Achievement of PFAS treatment objectives for drinking water utilities is typically determined at the entry point into the distribution system, rather than at individual customer taps. Where PFAS treatment is provided for an individual household with a privately owned well, achievement of objectives may be determined either in the household after point of entry treatment for all uses, or at specific points of drinking water use.

18.2.2.2 Discharge Objectives

The objective of sorption-based PFAS treatment for the discharge of generated liquid waste streams is to reduce the concentration or mass loading, or both of regulated PFAS in the discharge to restore and maintain the chemical, physical, and biological integrity of the receiving water for the protection of public health, environmental, and designated uses. Wastewaters where sorption-based PFAS treatment may be used to meet discharge objectives may include but are not limited to municipal sewage, industrial process wastewaters, landfill leachates, contaminated groundwater, contaminated dewatering water, membrane reject concentrate, containment waters, and managed construction site water. Sorption-based

PFAS treatment may also be applied to industrial or municipal stormwater to achieve discharge objectives. Discharge objective criteria may be associated with:

- Regulated PFAS concentration or loading based on achieving certain water quality
- Regulated PFAS concentration or removal efficiency based on the treatment technology being applied
- Regulated PFAS concentration or loading established by a local publicly owned treatment works (POTW) based on contaminant loading to the POTW and ability to maintain its own discharge objectives
- Industry-specific guidelines
- Highest attainable conditions under standard variances or Pollutant Minimization Program goals where concentration reductions can occur over time with interim criteria
- Corporate or governmental environmental stewardship program goals

Objectives for discharges to groundwater may be associated with a specific use(s) of that groundwater for protection of human or ecological receptors, such as use as a source of drinking water by individual household private wells or public water utilities' wells. Discharge of some wastewaters to groundwater may be prohibited, depending on the nature of the liquid waste stream being generated, either categorically or in accordance with antidegradation requirements.

As listed above, discharges to a POTW may be subject to limitation of PFAS concentration and mass loading to the wastewater treatment plant to prevent pass-through of untreated PFAS and interference with the operation or performance of the treatment plant. This may include interference with the ability to land-apply biosolids or to provide other beneficial use. Because these limitations are established based on the needs of the individual wastewater treatment plant, they can vary widely, and individual POTWs should be consulted to verify requirements. Similarly, co-contaminants within the waste streams or additives used as part of the PFAS treatment process could also be subject to local limitation and could affect the efficiency of PFAS removal.

During the treatment method selection, the practitioner may evaluate more than one of the discharge options listed above where PFAS treatment objective criteria differ. Valuable insight on recommended practices for discharge of PFAS-contaminated treated water and liquid waste streams under the National Pollutant Discharge Elimination System (NPDES) program is provided in a December 5, 2022, US Environmental Protection Agency (USEPA) memorandum on "Addressing PFAS Discharges in NPDES Permits and Through the Pretreatment Program and Monitoring Programs" (**USEPA 2022**).

The USEPA has since published (draft as of December 2024) national recommended human health ambient water quality criteria for perfluorooctanoic acid (PFOA) (**USEPA 2024**), perfluorooctane sulfonate (PFOS) (**USEPA 2024**), and perfluorobutane sulfonate (PFBS) (**USEPA 2024**). The criteria provide recommendations as part of the development and adoption of water quality standards, but as stated in the associated USEPA Technical Fact Sheet, "National recommended human health ambient water quality criteria are not regulations, nor do they impose legally binding requirements." The USEPA has also published Final Recommended Aquatic Life Criteria and Benchmarks for Select PFAS (**USEPA 2024**; **USEPA 2024**; **USEPA 2024**).

In some circumstances where no existing regulations currently apply, but a reduction in PFAS is desired, PFAS treatment objectives may be determined by the responsible party.

18.2.2.3 Additional Objective Information

In addition to concentration, mass load, and removal efficiency components of PFAS treatment objectives are the components related to the location used to determine whether a PFAS treatment objective has been met, the treatment objective assessment frequency, and any calculation associated

with determining whether the PFAS treatment objective has been met. For PFAS treatment objectives associated with consumptive uses, such as drinking water, the location for determining whether a treatment objective has been met may be an entry point to where water is distributed, a specific point of entry, or a specific point or points of end use. Locations for determining whether PFAS treatment objectives associated with discharges have been met may include the point of effluent from the treatment system itself, the point of discharge (to a water body, a POTW, or groundwater), or monitoring wells. Reporting of monitoring at additional locations, such as influent or raw water, between stages of adsorptive media vessels or within media beds, may not be used to determine whether a PFAS objective has been met, but may inform the state of operational performance to help ensure a PFAS treatment objective will continue to be met. The assessment frequency for determining whether a PFAS treatment objective has been met may vary depending on the type of discharge or consumptive use or vary from location to location within the same treatment system. Assessment frequencies for PFAS treatment objectives can range from daily maxima to monthly averages to annual or running annual averages. Determinations may also be based on individual batch discharges. The PFAS treatment objective assessment frequency can factor in treatment design, redundancy, operation, and maintenance provisions.

It is also important to understand how qualified analytical results may be used in determining whether a PFAS treatment objective has been met. This includes the occurrence of estimated concentrations between method detection limits and a practical quantitation limit, or laboratory limit of quantitation, as well as when matrix interference causes the limit of quantitation to increase the concentration associated with reporting detections.

In some circumstances PFAS treatment objectives may be prescribed based on minimum operational conditions (**WI DNR 2022**). These may include minimum amounts of empty bed contact time (EBCT), maximum treated bed volumes between change-out of fixed-bed sorptive media, changing of lead/lag unit positions, or reporting of these tank rotation or media change-out conditions (**MI EGLE 2024**).

Although not directly tied to PFAS treatment objectives for consumption or discharge of waters, additional PFAS objectives may be associated with releases of air to the indoor environment or atmosphere that potentially contain PFAS associated with sorption-based PFAS treatment, or volatile co-contaminants. Pressure vessels used for fixed-bed adsorptive media include air vacuum/air release valves to allow for the flow of air in and out of the vessel. These air release valves are known to release small amounts of water as they close. Vapor-phase emissions from these vent valves in fixed-bed sorptive media vessels are assumed to be de minimis. Foam fractionation systems input air or gases into the treatment system that must also exit from the system. These releases of air or gas may include vapors or aerosols containing PFAS. There is ongoing research into the magnitude of these potential releases and several studies funded by the Environmental Security Technology Certification Program (ESTCP) are collecting samples to quantify PFAS in air emissions from foam fractionation (for example, **Sorenson 2023**; **Sorenson 2023**). The use of additional controls or air monitoring may be considered to meet objectives associated with these discharges of air.

It is important to determine PFAS treatment objectives at all levels of authority—federal, tribal, state/territory, and local—as one authority may have established objectives that are more restrictive than another. PFAS treatment objectives are expected to evolve as additional knowledge is accrued regarding the human health effects and toxicology associated with these contaminants, and as analytical method limits of quantitation are refined. By staying informed of proposed and future changes that could add or modify PFAS treatment objectives, the selected treatment can be evaluated in its ability to meet such

objectives or configured to allow for expanded PFAS treatment if needed in the future. These changes could include:

- Changes to regulated PFAS
- Changes to treatment objective concentrations or mass loading
- Changes to treatment removal efficiency objectives
- Changes to Pollutant Minimization Program goals or standard variance highest attainable condition target objectives

18.2.3 Characterization and Pretreatment Needs

The water to be treated must be adequately characterized to evaluate available treatment technologies. This includes characterizing the PFAS content of the water to be treated, the types of PFAS present and their respective concentrations, the concentration of co-occurring constituents, and other parameters. Both regulated and unregulated PFAS should be considered, including precursors. This information can be used to help understand competition for sorptive sites and to determine sorbent media loading capacity before saturation.

For industrial facilities, municipal wastewater treatment plants, and stormwater systems, making efforts to reduce or eliminate identified sources of PFAS to the extent practicable prior to determining the need for treatment can provide benefits such as reducing PFAS mass loading or the flow requiring treatment. These reductions can be achieved through industrial pretreatment programs, reducing or eliminating exposure to stormwater, industrial process and material changes, etc., and are normally more cost-effective in addressing PFAS than treatment of less concentrated and greater flow wastewaters and stormwaters at downstream points.

PFAS concentrations typically encountered in surface- and groundwaters across many different release sites, such as aqueous film-forming foam (AFFF) release sites, industrial facilities, and landfills, range from 0.1 to 10,000 parts per trillion (ppt) (**Section 6.3** and **Section 6.4**). PFAS concentrations in industrial wastewater discharges (**MI EGLE 2020**; **MI EGLE 2020**) and landfill leachates (**Sabba et al. 2025**), however, can be substantially higher—up to the low parts per million range. These potentially elevated concentrations can simply be due to the nature of the waste stream, such as in landfill leachate, or can be the result of a concentration step, such as reverse osmosis. Although all these sources have been treated with sorption-based technologies, highly concentrated sources require further evaluation of pretreatment needs, co-constituents, operation and maintenance (O&M) costs (for example, media change-out frequency).

Waters with highly complex background chemistry, such as landfill leachates, tend to have rapid PFAS breakthrough in sorptive media, as they often exhibit high total organic carbon (TOC, ~ 560 mg/L) and total dissolved solids (TDS) concentrations (~ 60,000 mg/L) (**Murray et al. 2023**; **Malovanyy et al. 2023**). These types of waters may be treated with minimal pretreatment with foam fractionation, depending on treatment objectives and type and concentration of co-constituents. Foam fractionation removal of PFAS is positively impacted by TDS, while TDS may deteriorate GAC and IX resin performance. Both GAC and IX resins may need pretreatment for organic carbon and metals removals while foam fractionation largely does not (**Buckley et al. 2022**).

For groundwaters and drinking waters with PFAS influent in the low-level ppt range, sorptive media are often the most cost-effective treatment option because the media will have a long lifetime, minimizing O&M. For media beds designed with typical EBCTs (see **Section 18.3.1.1** for IX and GAC), generally IX resins, including regenerable resins, provide a longer run time or total volume throughput to breakthrough for sulfonate PFAS compared to GAC (**Kassar and Boyer 2023**; **Liu et al. 2022**). More discussion about the relative efficacy of GAC and IX resins can be found in **Section 18.3.1.6**. The more frequently treatment media need to be replaced, the more economically favorable a reusable media or foam

fractionation approach may become (**Kempisty et al. 2024**). However, other factors, including removal efficiency, cost of maintenance and repair, and efficiency should be considered.

Solution characterization should also consider physical characteristics and the presence of co-contaminants—those that may interfere with treatment and those that are also regulated for simultaneous compliance considerations. Co-occurring organics, inorganics, and ions have all been demonstrated to affect PFAS treatment technologies and should be considered during the characterization of waters to be treated as different types of media might be needed (**Zeidabadi, Esfahani, and Mohseni 2023**). The presence of these water quality constituents may require pretreatment technologies to maintain effective PFAS treatment based on their concentration and the selected PFAS treatment method(s). Most adsorbents aside from gases are negatively impacted by organic compounds (for example, natural organic matter (NOM) in groundwater and surface water, as well as effluent organic matter in wastewater). Therefore, characterizing the organic matter by analyzing TOC or dissolved organic carbon (DOC) concentrations, or both is of critical importance. Total and dissolved fractions of iron and manganese should be analyzed due to their potential to foul media. Dissolved oxygen and oxidation/reduction potential also should be analyzed to determine natural or contaminant-induced redox conditions; microbial activity may impact treatment system fouling, especially for surface water and stormwater runoff treatment, and must be evaluated. The use of the Langelier Saturation Index (LSI) can be helpful in assessing the likelihood for calcium carbonate scale formation, which can also negatively impact adsorption media. Calculation of the LSI requires the following parameters: TDS concentration, pH, alkalinity, calcium concentration, and temperature. Depending on the source of the stream requiring treatment, characterization of volatile organic compounds (VOCs) and the oil and grease concentration may be important as well. Characterizing the nitrate, sulfate, and chloride concentrations is also important for applications using anion exchange IX resins.

Seasonal conditions can impact treatment. For example, nitrate from agricultural runoff and chloride salts from road de-icing can potentially interfere with the performance of IX resins treating ground or surface waters. Similarly, pH and organic matter, both of which can influence effectiveness of adsorption for several technologies, may also vary with seasonal conditions. Water sources impacted by industrial sources may experience high variability in PFAS concentrations, especially if operation of the industrial processes is seasonal or intermittent. Storm events and differences between dry weather and wet weather, including first-flush water quality conditions, should be evaluated to determine impacts to sorption-based treatment systems and pretreatment needs. This includes mobilized silt, sediment, turbid waters, and debris that can cause fouling.

Drinking water utilities may use multiple source waters of varying quantity and quality. If centralized

Table 18-1. Interference of water quality parameters with sorption-based PFAS treatments.

	GAC	IX Resins	Foam Fractionation
Suspended Solids	X	X	X
TOC	X	X	
Total Dissolved Solids (TDS)	X	X	
DOC	X	X	
Fe	X	X	X (if oxidized)
Mn	X	X	X (if oxidized)
VOC	X		X
Oils, Fats, Greases	X	X	X
Bacteria/Algae	X	X	
Disinfectants/Oxidants	X	X	
Nitrate		X	
Sulfate		X	
Chlorides		X	
Phosphate		X	
Alkalinity	X	X	
Hardness	X	X	X
pH	X	X	
Total and Dissolved Silica	X	X	X

treatment is being planned, all sources should be characterized to understand worst-case conditions and variation of co-contaminants.

Various water sources have differing water chemistries, which create differing alleviations or stressors on adsorption-based solutions. For example, landfill leachate and wastewater typically contain high TOC, which may take up sorption spaces on some technologies and affect downstream destruction. Similar membrane concentrates and IX regeneration brines may have high salinity, which may affect sorption as well as downstream destruction. **Table 18-1** includes examples of co-contaminants and other water quality parameters that may interfere with sorption-based treatment technologies based on information in **Section 18.3** and **Section 18.4**. Interference by co-contaminants depends on composition and concentration. For instance, presence of VOCs does not necessarily mean that PFAS removal by GAC will be heavily degraded (**Haupert et al. 2023**). Also, IX resins with different morphologies and chemistries have differing resistance to attack by oxidants, with macroporous resins being more rugged than gel-type resins. More details on interference by co-contaminants can be found in **Section 18.3** and **Section 18.4**.

The need for pretreatment prior to PFAS treatment can be substantially different from treatment of other contaminants. Pretreatment needs are directly related to the specific water or liquid waste stream and its geochemical properties. Assessing pretreatment needs and options is an important part of bench and pilot testing. Co-contaminants and other water constituents, such as total organic matter, solids, metals (for example, iron and manganese **Speth 2022**), and turbidity, can adversely affect the removal efficiency (decreased), operational life (decreased lifespan, increased media replacement frequency), and effort (for example, staffed operational hours, complexity and difficulty of maintenance tasks).

18.2.3.1 Types of Pretreatment

The type and extent of pretreatment can vary based on the PFAS treatment technology(ies) used. GAC, IX resins, and foam fractionation all generally require water and liquid waste stream co-contaminants to be removed and geochemical conditions improved to operate effectively. **Table 18-2** presents information about pretreatment methods summarized from information in **Section 18.3** and **Section 18.4** and cited literature therein. Operational and maintenance practices such as backwashing GAC may also be beneficial in managing adverse effects of water quality parameters on PFAS treatment.

Further, changes of organic matter characteristics (for example, aromaticity, molecular weight) through emerging pretreatment strategies such as ozonation (O_3) and biologically active filtration (BAF) have been shown to substantially improve PFAS removal in subsequent sorption-based treatment technologies (**Tajdini et al. 2023**). **Vatankhah et al. (2022)** demonstrated that low-dose ozonation transforms high molecular weight organic compounds into smaller, more bioavailable assimilable organic carbon, which reduces pore blockage and decreases site competition with PFAS molecules, ultimately improving PFAS removal during subsequent sorption. **Dai et al. (2019)** demonstrated a pilot-scale ozonated air fractionation and combined UV/ozone treatment for PFAS. BAF is another pretreatment strategy used for biodegradation or biotransformation of organic matter that ultimately leads to improved PFAS removal in the subsequent sorption step. Both ozonation and BAF, whether applied individually or in combination as pretreatment, enhance PFAS sorption in the subsequent treatment stage, with the combined configuration demonstrating the greatest improvement in performance (**Vatankhah et al., 2022**). However, it is also important to recognize that oxidation conditions can alter transformation product distribution and the range of intermediates and PFAS produced. Unintended generation of nontargeted intermediates or ultrashort-chain PFAS (ultrashort PFAS) may also occur during oxidation. For example, nontargeted products can occur during oxidation of PFAS with ether functional groups (**Ateia et al. 2023**). Our understanding of PFAS oxidation and biotransformation processes is limited and use of these pretreatment systems should be thoroughly evaluated.

Table 18-2. Pretreatment methods, water quality parameters pretreated.

Pretreatment	Suspended Solids Removal (for example, bag, cartridge, sand filters)	Iron and Manganese Removal (for example, greensand, aeration, oxidation)	Chemical Addition (anti-scaling agents, pH control, sodium bisulfite)	Ion Exchange (for example, water softening, demineralization, organic scavenger resins)	Membrane Processes (for example, nanofiltration)	Oil-Water Separation (for example, oil-water separators, organoclay)	Air Stripping	Settling / Clarification Tank (with or without coagulant or polymer addition)	GAC (sacrificial)	Disinfection (for example, UV, chlorine, ozone, biocides)
Water Quality Parameter Addressed by Pretreatment										
Suspended Solids	X	X			X	X				
TOC	X			X	X				X	
TDS		X		X	X	X				
DOC		X		X	X			X	X	X
Fe	X	X	X	X	X			X		X[1]
Mn	X	X	X	X	X			X		X[1]
VOC							X		X	X[1]
Oils, Greases, Fats						X				X[1]
Nitrate				X	X					
Sulfate				X	X					
Chloride				X		X				
Scaling (for example, carbonate, hardness)		X	X	X						
Phosphate			X	X	X			X	X	
Alkalinity			X	X	X					
pH			X							
Total and dissolved silica				X	X					
Bacteria/Algae					X					X
Disinfectants/Oxidants			X						X	

[1] Disinfection techniques using oxidants may also treat the indicated water quality parameters.

18.2.4 System Size

Estimates should be made regarding the rate of flow to be treated and the variability of that flow. Both present and future flow parameters should be considered over the expected design life of the treatment system. All of the sorption-based treatment systems presented in this guidance can be expanded with additional units to accommodate future flows using parallel treatment trains if needed, but this requires adequate planning. Examples of planning concepts to be considered are provided in this section.

Drinking water systems should be capable of meeting peak hour or instantaneous water demands. Existing or additional treated water storage volumes can be used to reduce the treatment flow capacity needed. The cost of additional treated water storage can be compared to the cost of treatment capacity. If treatment is centralized for multiple sources of water, flow rates and water quality associated with different source combinations should be considered when evaluating treatment capacity needs.

Municipal wastewater systems may need to consider diurnal flow conditions, the impact of inflow and infiltration, and combined sewer flow, along with flow and water quality from separately received materials, such as septage, hauled liquid wastes, and leachates, when evaluating treatment flow capacity needs. Industrial wastewater systems must consider what process flows will require treatment and how often those flows are generated. Landfills must consider the amount and quality of leachate generated from existing cells and the amount of leachate that will be generated from future cells. Landfills should also evaluate other flows for PFAS treatment, such as underdrain systems. Wastewater equalization storage capacity can be used to reduce the treatment flow capacity needed.

Scientists can measure dry weather flow conditions of stormwater systems and evaluate the volume of stormwater generated within PFAS-impacted catchment areas during various targeted storm events to select the desired treatment flow capacity and equalization storage capacity.

When treatment system effluents are beneficially reused (for example, on-site irrigation or dust control), the need for storage or alternative discharge/disposal methods can also affect system size needs. Such conditions can occur when on-site soils are saturated (for example, from storm events). The case study provided in **Section 15.2.4.1** provides an example of a foam fractionation treatment system with beneficial reuse of the treated water for on-site irrigation.

18.2.4.1 Footprint and Spacing Requirements

In addition to media selection, the size of PFAS treatment facilities is influenced by several factors, which determine the capacity and scalability of the treatment system. Before full-scale implementation, rapid small-scale column testing (RSSCT) and piloting are often important to validate the effectiveness of fixed-bed sorption media. The value of RSSCT and pilot testing depends on site-specific conditions such as PFAS type and concentration, the presence of adverse water quality parameters, treatment objectives, and permit requirements. For example, an RSSCT for a water stream with minimal potential fouling conditions and low PFAS concentrations may be of limited value compared to a water stream with significant potential fouling conditions, high PFAS concentrations, or both.

RSSCT involves using small-scale columns to simulate the performance of the treatment media under real-world conditions. This testing helps determine the optimal design parameters, such as appropriate contact time and the estimated number of bed volumes that can be treated before media replacement or regeneration is needed for each media being evaluated. Pilot studies involve deploying a smaller version of the treatment system to gather data on its performance, operational challenges, and efficiency. This step is crucial for refining the design and ensuring reliability before scaling up.

Residence time is the duration that a water or liquid waste stream must be processed within a treatment unit. For GAC, IX, and some pretreatment technologies (for example, sand filtration), this is commonly

referred to as empty bed contact time (EBCT). For foam fractionation and some pretreatment technologies (for example, solids coagulation, flocculation, and settling), this may be referred to as hydraulic residence time (HRT). PFAS residence times are generally highest in foam fractionation systems, followed by GAC, followed by regenerable IX resin, followed by single-use IX resin. Typical HRTs for foam fractionation range from 25 to 60 minutes (**We et al. 2024**). Typical ranges of EBCTs for GAC and IX are provided in **Section 18.3.1.1**. The specific residence time can vary between equipment design, media type, operating conditions, and the quality of the water or liquid waste stream treated. If there is limited space for PFAS treatment available, the sizing of equipment for any given flow rate and the corresponding treatment footprint is largely related to HRT or EBCT. Any required pretreatment or regeneration equipment would also add to the system footprint. The amount of fractional removal to meet PFAS treatment objectives may influence the treatment technology selection as well as the treatment system design. A system needing to achieve a 99.9% reduction in PFAS may need a more robust treatment design than one needing only a 50% reduction to meet the same concentration treatment objective. This could include more EBCT, longer batch times, or additional stages of treatment, or some combination of these.

As a hypothetical example, a containerized foam fractionation system may be able to treat 1,000 gallons of PFAS-contaminated groundwater over a 30-minute batch process in each of two primary fractionation tanks sized 6 feet in diameter with a water column 5 feet in height. Under this example, by alternating tank filling and processing, the system would be able to process 96,000 gallons operating 24 hours per day. However, if a municipal wastewater treatment plant that processes a higher flow of 1,000,000 gallons per day but with lower concentrations of PFAS needs a longer 60-minute batch processing time, the same containerized foam fractionation system would be able to treat only 48,000 gallons operating 24 hours per day, and 21 of these foam fractionation units would be needed to achieve a capacity of 1,000,000 gallons per day.

Under a hypothetical example for GAC, using 20 minutes of EBCT, two 8-foot diameter pressure vessels in a lead-lag configuration with a bed depth of 7 feet would be capable of treating a flow of 263 gallons per minute or 378,800 gallons per day under 24-hour operation. A municipal wastewater treatment plant needing to process 1,000,000 gallons per day would need to install at least three parallel treatment trains of these two-tank lead-lag systems. The pressure vessels alone would require approximately 400 square feet of spacing, along with more than 12 feet of ceiling height. This could be compared to a single-use IX system using 4 minutes of EBCT and two 3-foot-diameter pressure vessels in a lead-lag configuration with a bed depth of 5 feet, which would be capable of treating a flow of 132 gallons per minute or 190,250 gallons per day under 24-hour operation. The same municipal wastewater treatment plant needing to process 1,000, 000 gallons per day would need to install at least six parallel treatment trains of these two-tank lead-lag systems. However, the pressure vessel spacing requirements would be reduced to 108 square feet with a ceiling height of 10 feet.

18.2.5 Additional Site-Specific and Operational Considerations

Although PFAS treatment equipment and systems have many similarities to those used for treatment of other contaminants (for example, petroleum and chlorinated hydrocarbons, solids, and metals), there are operational considerations that are specific to or similar but significantly more critical to PFAS treatment for water and liquid waste streams.

18.2.5.1 Installation At Sites or Facilities with Existing Treatment

Treatment of existing water and liquid waste streams that were not previously treated for PFAS (for example, drinking water treatment plants, landfill leachates, industrial wastewater discharges, and contaminated groundwater treatment systems) is a growing need. Technologies used in existing treatment systems for conventional and other non-PFAS contaminants are typically unable or insufficient to effectively treat PFAS. For example, a treatment system for an industrial wastewater discharge may

include GAC, but the type of GAC and system design (for example, contact time, flow rate) currently in use are insufficient to remove the PFAS loading present. Some water and liquid waste streams may not have any treatment, such as some groundwater wells used to provide drinking water. These situations present challenges of incorporating PFAS treatment (and possibly pretreatment) within current space and utility constraints. Additionally, it may be necessary to implement immediate corrective actions while a longer term solution is developed.

Placement of sorption-based PFAS treatment for most existing municipal wastewater treatment plants and drinking water treatment plants will typically be as a tertiary process. For fixed-bed media systems, this reduces co-contaminant loading to the GAC or IX and helps limit the need for additional pretreatment. Foam fractionation systems may have more flexibility in their placement; however, placement as a tertiary process will limit the potential for generating odors. In municipal wastewater treatment plants, placement to treat a substream of plant flow, such as solids processing decant water recycle flow, may be considered depending on its PFAS load contribution. The placement of these sorption-based PFAS treatment systems in relation to disinfection processes must also be considered. The presence of chlorine or chloramines can cause degradation of anion resins. GAC will reduce or remove these disinfectants from the water. Similarly, the introduction of air or gases in foam fractionation can also reduce or remove disinfectant residuals. At the same time drinking water treatment plants and municipal wastewater treatment plants must maintain sufficient disinfectant contact time to meet their respective regulatory requirements. Non-PFAS co-contaminant simultaneous compliance treatment needs should also be evaluated. For example, because GAC can also be used to effectively reduce concentrations of disinfection byproducts, in a situation where the present value cost of a GAC system to address PFAS in drinking water is greater than other PFAS treatment technologies, the added benefit of disinfection byproduct removal may still make GAC treatment a preferable overall alternative.

Hydraulic evaluations should also be conducted at existing treatment systems to determine whether existing pumping equipment remains sufficient or requires modification, or if it should be used to meet the needs of the proposed PFAS treatment equipment to avoid the need for double pumping. GAC and IX media beds will create additional pressure head losses that must be overcome. The evaluation should consider the full range of pressure head loss increase over the fixed-bed media life cycle, including fouling potential. This type of planning may help avoid the need for premature media change-outs before full use of media sorption capacity can be achieved. The system must be able to maintain its rated treatment flow capacity.

18.2.5.2 Treatment Space Considerations

The following list of considerations should be evaluated when developing a treatment site layout:

- Sizes of treatment tanks, vessels, or containerized units
- Sizes of pretreatment equipment
- Space for pumps, piping, and other equipment
- Space for fixed-bed media storage, change-out, and delivery
- Space for chemical storage, feed systems, and delivery
- Space for control systems
- Sufficient space for operator access to repair and maintain equipment
- Equalization storage
- Treated water storage
- Backwash water storage
- Space for on-site monitoring and analytical equipment
- Space for mechanical, electrical, and plumbing equipment
- Space to allow for future treatment expansion or building addition
- Space for repair or replacement parts, particularly those with long lead times
- Heating and cooling needs, including freeze protection of exterior or unheated equipment

- Facilities for operator(s) (for example, restrooms, potable water, hot water)
- Space compliant with building, electrical, mechanical, and plumbing codes

18.2.5.3 Site Location Utilities

Selecting an optimal location for PFAS treatment facilities involves several logistic and regulatory factors. Adequate land availability is essential for the construction and operation of treatment facilities. Zoning regulations must be considered to ensure the site is suitable for industrial use and complies with local land-use policies. Locating the treatment facility close to the PFAS-contaminated water that will be treated minimizes the need for extensive piping and reduces potential to create or exacerbate contamination areas during water transportation. At the same time, the treatment system should be in an area that is easily accessible for maintenance, monitoring, and the delivery and removal of treatment materials.

Proximity to transportation infrastructure can help keep facility operations efficient. If access roads must be provided, ensure that they are sufficient for delivery vehicles with spacing provisions for delivery and pickup positions, and turnarounds. Determine whether seasonal weight restrictions on roads to and from the proposed treatment site may limit bulk delivery of consumables such as GAC, IX resin, or treatment chemicals to the site, or limit the off-site transport of spent media or foam concentrate for destruction or disposal.

Determine what source(s) of water are available at or near the proposed treatment site. The largest demands for water will generally be associated with any applicable fire protection needs, backwash operations for the specific media (**Section 18.3**), or safety equipment such as eyewashes or showers. If a source of backwash water is needed, it must be available at appropriate flow rates or stored in sufficient volumes for the duration of the backwash cycle. Consider whether the quality and quantity of treated effluent could be used for any of these water demands. Evaluate options for the disposal or treatment of backwash water. Although existing pretreatment processes such as coagulation/flocculation followed by clarification may be able to remove the solids loading from backwash recycled to the influent of the treatment system, some storage of the backwash may be necessary to limit the percentage of recycled backwash making up the influent flow to the treatment system. In some cases, it may be necessary to provide sufficient volumes of stored water on-site.

Determine the availability and capacity of electric and natural gas utilities and whether these resources are adequate to address the needs of the proposed treatment system. GAC and IX systems needs will depend largely on the total dynamic head loss that must be overcome by pumping systems. Head losses will depend on the media properties, vessel design (for example, media bed depth and underdrain design), EBCT requirements, and the number of stages used in the treatment process. Foam fractionation systems use several different pumping systems, including those used in the bubbling process, which make up a significant portion of the electrical capacity requirements. Pretreatment systems will also add to electrical demand considerations.

Any backup power requirements should be verified with the treatment system vendor(s) and any applicable regulatory authority. Some facilities are required to provide backup power for continuous operation. Some treatment equipment may need a limited supply of backup power to allow for a properly controlled shutdown of equipment, in accordance with the manufacturer/vendor requirements. If the facility has an existing source of backup power, it should be checked to determine whether it has enough remaining capacity to handle this additional load.

Security needs to prevent unauthorized access to treatment systems should be considered, including items such as fencing, video surveillance, intrusion alarms, and electronic fire walls. Higher security may be applied to certain areas of higher hazard. For example, some chemicals and equipment used in IX regeneration can be designated as hazardous classified locations where fire or explosion hazards exist.

Spill containment provisions should be determined along with the need for containment of stormwater in areas where potential exposures exist at the treatment site. Consider whether these containment waters can be processed by the proposed PFAS treatment system, or whether they must be transported off-site for disposal or destruction.

18.2.5.4 Separated PFAS Destruction and Disposal

System design should consider final fate of separated PFAS-laden wastes, which could include spent media, media regeneration residuals, or foamate. The project planner should consider whether PFAS destruction is a priority or whether sequestration in landfills or deep wells is acceptable. Detailed considerations for spent media and media regeneration residuals are presented in **Section 18.3.3**, and detailed considerations for PFAS-containing foams are presented in **Section 18.4.3**.

Thermal treatment, including hazardous waste incineration and GAC reactivation, are widely available, with about 22 hazardous waste combustors and 17 GAC reactivation facilities in the United States (**USEPA 2024**). Landfills and deep well injection are also currently available disposal methods but should be evaluated to consider acceptability of PFAS-containing wastes and tipping fees. Backup alternatives should also be determined in case the primary method of destruction or disposal becomes temporarily unavailable. Whichever option(s) are selected, dedicated space will be needed for these concentrate/media storage, media change-out, and treatment equipment operations. Thermal treatment, landfilling, and deep well injection are further described in **Section 10.3.4** and **Section 12** and as part of the Priority Topics for Treatment Technologies. The USEPA's Interim Guide for Destruction and Disposal Guidance for PFAS-Containing Wastes also provides context (**USEPA 2024**).

In addition to the commercially available PFAS disposal options listed above, emerging technologies are undergoing demonstration for PFAS destruction in multiple applications. One recent ESTCP project evaluated comparative performance and four liquid destruction technologies (hydrothermal alkaline treatment and multiple types of supercritical water oxidation) (see ESTCP projects ER23-8398, ER23-8435, ER23-8434, ER23-8400). Other developing technologies for disposal of liquid wastes include advanced reduction processes, nonthermal plasma, and electrochemical oxidation for PFAS destruction.

Some of these options are available for use on-site and should be compared with the long-term costs of available off-site options. In some areas destructive treatment systems may be set up as a regional hub, to serve multiple sites where spent media or PFAS liquid concentrates can be sent for processing. This may be a more economically viable destruction option if low volumes of materials are generated at the site.

The USEPA has also made changes to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), which designated PFOA and PFOS as hazardous substances and became effective on July 8, 2024 (**USEPA 2024**). These changes may affect transport and disposal of PFAS-containing wastes. The management of that concentrated waste or residual can be done on-site, or it can be managed by transporting it to a specialized location where the destruction is achieved or it is disposed in a safe manner. Determine if on-site versus off-site management of residuals is appropriate for an application as part of project planning. Understanding cost, sustainability, and risk implications of the residuals management is important to make informed project decisions.

Off-site residuals management includes management or disposal by commonly owned facilities, privately owned specialized facilities, or other instances where management is not integrated into the same system as the sorption or fractionation technology. Off-site residuals management is generally advantageous for sites that generate residuals infrequently or at lesser volumes. Other reasons to consider management of residuals off-site are when there is proximity to off-site facilities that can accept the residuals, lack of on-site expertise to manage residuals, unreasonable potential risks associated with on-site use of a destruction or disposal technology, or more complicated or costly regulatory

requirements associated with residuals management on-site. Off-site management may also reduce facility liability, depending on contracting conditions.

On-site residuals management and minimization of waste volume are important to reduce the potential liability associated with ultimate disposal. On-site residuals management may be necessary for remote sites due to the logistics and costs associated with off-site alternatives. There may be cost advantages for sites with large volumes or frequent generation of residuals. On-site management may present opportunities to use destruction technologies with limited unit capacities where smaller volumes of residuals are generated. In addition, management on-site can streamline residual management to the site of origination.

18.2.5.5 Community Concerns

Concerns of the community should be identified, considered, adequately addressed, and communicated back to members of the community. The ITRC **Risk Communication Toolkit** RCT-1 (**ITRC 2020**) includes mechanisms to provide effective communication with the community. Their concerns may include:

- transportation of spent media or foamate containing concentrated PFAS
- truck traffic to and from the site
- hours of operation and noise pollution
- release of PFAS into the air and potential deposition
- hazards from other treatment chemicals or additives
- spills or runoff from the treatment facility
- impacts to water and sewer user rates
- remaining PFAS in effluent or drinking water, or contaminated groundwater

These concerns may play a role in the types of treatment considered and selected.

18.2.5.6 Operations Oversight

Determine what level of operations oversight is necessary for the treatment technologies being evaluated, including any additional pretreatment. Determine the types and levels of operator certification required for these treatments. Consider how many on-site worker hours are expected, and what activities will need to be carried out. Determine whether this workload be taken on by existing operations staff or whether additional staff will be needed. If operations are contracted out, ensure the contractor has the technical expertise and experience for the proposed treatment. Consider whether the treatment system can be operated remotely and under what conditions, if any, remote operation is allowed. Consider what types of alarms and notifications will be provided and how they are communicated. Consider the compatibility of any existing supervisory control and data acquisition systems with the proposed treatment.

18.2.5.7 Sample Collection and Analytical Support

The locations and frequency of PFAS monitoring that will be required, and an understanding of under what conditions it may be reduced, should be reviewed as analytical costs associated with PFAS sampling can have a significant impact on annual operation costs.

Confirm the expected turnaround time from sample collection to receipt and reporting of analytical results to meet data quality objectives. If analytical results must be obtained and provided before discharge can occur, storage of treated water may be necessary with sizing to adequately accommodate this timing and any potential delays or inability for treated water to meet the treatment performance objectives.

Although PFAS treatment objectives may apply to only a limited number of PFAS, analysis and reporting of all PFAS analytes available within a specific method may be requested or required—for example, all 40 PFAS associated with USEPA Method 1633A (**USEPA 2024**). Monitoring of PFAS that do not have regulatory limits or treatment objectives, especially short-chain PFAS, can help act as a surrogate to monitor breakthrough and the need for media change-outs while maintaining treatment objectives, and not relying on estimated bed volumes treated.

Even though multiple PFAS may have a treatment objective, it may be only one PFAS that drives the design of the treatment system and in the case of fixed-bed media, the need for change-out of the media. This can help in the evaluation of each alternative and selection of treatment(s).

18.2.5.8 Sustainability

Understand the influence of the treatment technology on the environmental, social, and economic aspects of the project. **Section 12.9** identifies environmental impacts as a consideration in technology selection and provides references to guidance documents that can aide in an evaluation. Each location and application are unique, so overarching statements about sustainability by technology may be inaccurate. Often, preliminary understanding of proposed application to obtain equipment sizing, materials change-out frequencies, and performance monitoring frequency is needed to perform an evaluation, especially if seeking to perform a side-by-side comparison. One recent study compared life cycle energy use rates of different management options for spent adsorption media, including energy needs for virgin media production (**Ling et al. 2025**).

When evaluating the sustainability of a technology application, it is common that a preliminary accounting is conducted to understand based on the planned application what would create the largest impacts and how they match with the priorities for the site based on stakeholder engagement. Based on site prioritization and concerns, the team could decide to seek improvement of the planned application based on the priorities (for example, greenhouse gas, waste creation, energy use). Best management practices (BMPs) should be consulted and innovative approaches can be developed to reduce these areas. The USEPA maintains recommendations of BMPs available through CLU-IN (**CLU-IN n.d.**). The analysis can then be revised to incorporate the reductions gained by integrating the BMPs. The implementation and maintenance (as applicable) of the BMPs should be tracked as part of remedial construction and remedial operations reporting. Additional tools and resources for including sustainability in decision-making are discussed in **Section 18.5**.

18.2.5.9 Centralized vs. Distributed Treatment

Many public water supply systems consist of multiple sources of water that are geographically separated (for example, multiple well fields, surface water intakes, or combinations). Treatment at these systems may be provided at a centralized water treatment plant (centralized treatment), or at individual wells/well fields that connect directly to the water distribution system (distributed treatment). When evaluating whether to provide centralized or distributed PFAS treatment, the following differences may be considered.

Centralized treatment at a single location may allow for simplified operations oversight, monitoring, and reporting, while each distributed treatment system may have its own operations oversight, monitoring, and reporting requirements. However, distributed treatment systems can be tailored to the specific source water quality and flow, while centralized treatment must be capable of addressing variable source water quality depending on the mixture of source waters in use. The location of a centralized system can potentially be tailored to reduce fluctuations in source water quality to sustain optimal conditions for high-volume treatment. Centralized treatment may need to process greater flows of lower PFAS concentration water, which can reduce operational efficiency of the treatment and thus may increase overall treatment cost.

18.3 Fixed-bed Adsorbers

This section is an extension of **Section 12.2.1.1** and **Section 12.2.1.2**. It provides a technical overview of GAC and IX systems, including descriptions of the selected fixed-bed adsorptive media; techniques used to evaluate adsorptive media using bench, RSSCT, and pilot studies; and various aspects of system design and how they impact the ability of the system to effectively treat the contaminated water. Constraints and limitations of the technology, such as pretreatment needs, competitive effects of co-contaminants, and feasibility of treating short-chain PFAS and precursors, are discussed. This document is not intended to be a technical or design manual but does describe the basic concepts and considerations when testing and selecting fixed-bed adsorbers for PFAS removal.

18.3.1 Technical Overview

Fixed-bed adsorbers contain sorbent media such as GAC and IX resins that need to be replaced, reactivated, or regenerated once treatment performance no longer meets the desired water quality. Vessels containing the media are typically totally enclosed and constructed of metal or fiberglass to withstand the pressures required to overcome the range of total dynamic head loss across the bed and convey the treated water to the next treatment process, ultimate treated water storage location, or discharge point. Vessels sometimes contain freeboard to accommodate backwashing and swelling of IX resins. Filter basins using sorbent media that are open to the atmosphere are sometimes used at drinking water and wastewater treatment plants and primarily for activated carbon. Once target PFAS are measured at or near treatment goals in the treated water, the sorbent media must be exchanged or regenerated. Single-use media types are commonly removed from the vessel and replaced with fresh media. **Section 12** contains additional background information on mechanisms of PFAS removal for GAC and IX.

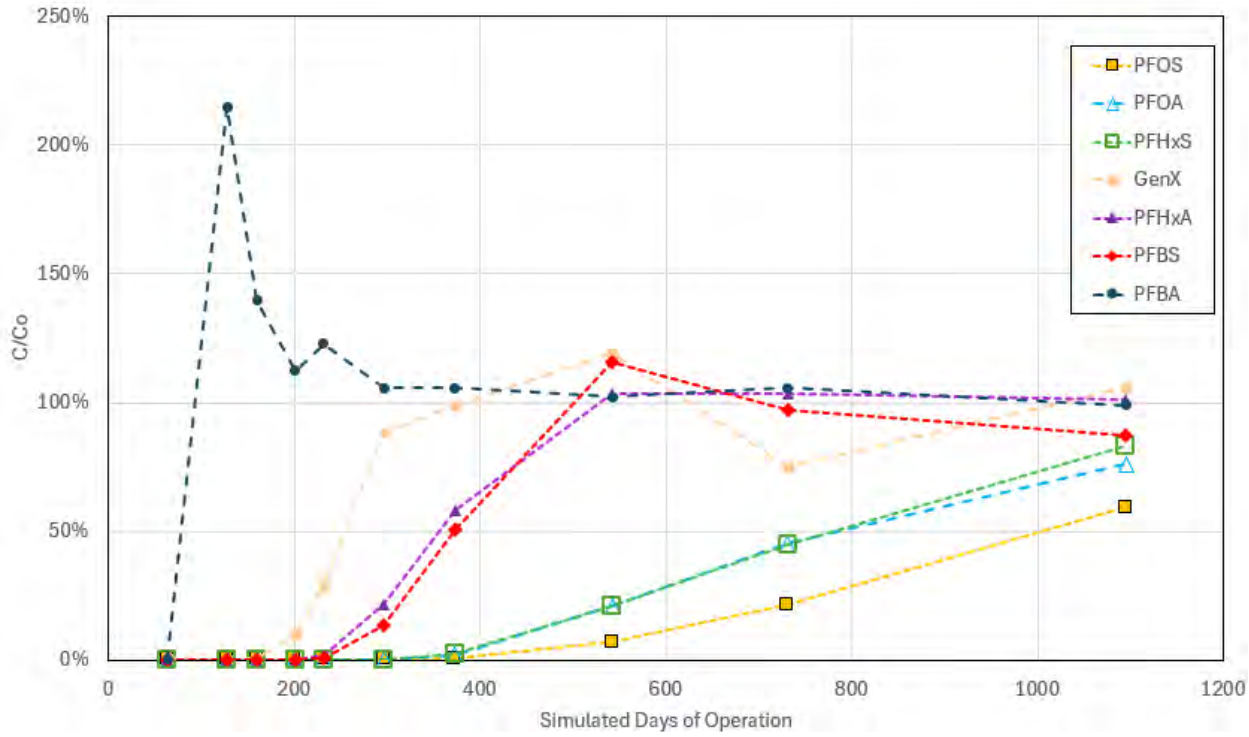


Figure 18-2. Example breakthrough curves for GAC (10-minute empty bed contact time).

Source: Used with permission from Calgon Carbon Corporation.

Fixed beds containing sorbent media differ from treatment processes such as reverse osmosis in that the contaminant molecules adhere to the sorbent surface until the sorbent's capacity is exceeded. This means that the effluent will contain essentially no measurable contaminant until the initial breakthrough occurs, at which point an increase in the concentration will take place until it reaches a concentration equal to the influent concentration. The variation of a fixed-bed effluent contaminant concentration with time or volume treated is commonly referred to as a breakthrough curve. Breakthrough is calculated as the ratio of the effluent concentration to the influent concentration (C/C0). Each contaminant compound will move through the sorbent media at a different rate and will thus have a unique breakthrough curve as shown in the example curves in **Figure 18-2**. If contaminants are desorbed from the sorbent media either because higher affinity contaminants displace them or because contaminant concentration was higher earlier in the bed's service run, it is possible for concentrations leaving the media bed to exceed concentration in the feed (**Figure 18-2**, first breakthrough (C/C0) curve, perfluorobutanoic acid (PFBA)).

18.3.1.1 Process Parameters

Two critical concepts for the effective removal of any specific compound using fixed-bed adsorbers are the media's equilibrium loading capacity and the kinetics of adsorption for the system. The equilibrium loading capacity is the mass of contaminant the media can hold for a given unit mass of media at the contaminant's influent concentration given a sufficiently long contact time. This is the media's inherent affinity for the compound of interest. The higher the affinity for a particular compound (equilibrium loading capacity), the slower that compound will work its way through the media, leading to a longer bed life. Regardless of a media's affinity for a particular compound, it takes some time for a given molecule of the compound once it enters the top of the media to find an adsorption or exchange site. Even for contaminants with an affinity for the sorption media, the sorption rate can be limited by mass- or phase-transfer processes. The evaluation of these rate-limited processes is referred to as kinetics.

If the kinetics of adsorption were instantaneous, then a band of media saturated with a given contaminant would simply move through the bed until it reached the effluent. In such a system, the effluent contaminant concentration would sharply transition from zero to the influent concentration at the point of breakthrough. But the kinetics of reals systems are not instantaneous, so there is always a thickness of media called the mass transfer zone (MTZ) on the leading edge of the saturated band as it moves through the bed. The MTZ is where the adsorption is occurring. The presence of an MTZ can be seen as the gradual, rather than instantaneous, increase in effluent concentration at the initial breakthrough point (**Figure 18-2**).

Thus, designers of fixed-bed adsorbers must allow for sufficient contact time to account for the kinetics of adsorption (the MTZ) and to provide a bed depth that provides a reasonably long bed life. The convention in the industry is to call this empty bed contact time (EBCT), and it is the media volume divided by the flow rate. EBCTs vary depending on the media used, contaminants present and their influent concentrations, desired effluent concentrations, and levels of co-contaminants (for example, natural organic matter (NOM)) present. Although typical EBCTs per GAC and single-use IX vessel range from 10 to 20 minutes and 1.5 to 3 minutes, respectively, for PFAS removal in drinking water and groundwater pump and treat applications (**AWWA 2019**; **AWWA 2025**), bench or pilot testing may validate EBCTs outside of these ranges for specific applications. GAC and IX adsorbers have been used to polish landfill leachate and industrial wastewater effluents. These applications can require significantly longer EBCTs than drinking water or groundwater treatment systems due to higher PFAS and co-contaminant concentrations. **Section 18.3.1.3** provides strategies to achieve longer EBCTs.

The velocity of the fluid through the sorption media must be fast enough to avoid maldistribution (or channeling) but not so high as to cause excessive pressure drop. This velocity, often referred to as the linear velocity, superficial velocity, or hydraulic loading rate (HLR), is simply the volumetric flow divided by the vessel cross-sectional area. Typical linear velocities range from 2 to 10 gallons per minute per square foot (gpm/ft^2) (5—25 m/h) for GAC and 6 to 18 gpm/ft^2 (15—45 m/h) for IX resin (**Section 12**), but

recommended HLRs may vary from this range depending on the application or specific media. The linear velocity dictates the vessel diameter or cross-sectional area, while the EBCT dictates the depth of the media bed.

18.3.1.2 Operational Considerations

When employing adsorbents such as GAC or IX resins, it is critical to exercise caution regarding the potential leaching of unintended toxic constituents, particularly during the initial operational phase. Newly installed media can release trace amounts of contaminants such as arsenic (**Gandy and Maas 2004**) due to impurities in the raw materials, or nitrosamines, from amine functional groups (**Flowers and Singer 2013**). These leachates can compromise treated water quality and pose regulatory compliance risks. Procedures for mitigating these issues are discussed in **Section 18.3.1.4**. Further, during the operation, backwashing of IX resins used for PFAS removal can disturb the established MTZ within the column, potentially redistributing PFAS-laden particles and altering the contaminant concentration profile along the bed depth (**Woodard, Nickelsen, and Sinnett 2018**). Such disruption may cause breakthrough challenges, complicating the interpretation of monitoring data and masking early signs of adsorbent exhaustion. Furthermore, disturbance of the MTZ can result in transient spikes of PFAS in the effluent, challenging the accuracy of performance assessments and compliance monitoring, particularly for trace-level regulatory limits. Backwashing of GAC can be conducted with minimal impact provided a backwash is conducted on a newly installed bed to stratify it.

18.3.1.3 Adsorber System Configurations

A lead/lag (vessels in series) configuration is often employed for fixed-bed vessels to provide a margin of safety for complying with effluent limitations and to lower the overall media consumption rate. The use of multiple vessels in series permits the lead vessel(s) to become more heavily loaded with contaminants prior to exchanging the media, thus driving the overall media usage rate down. Each time a lead vessel becomes spent, its media is replaced, reactivated, or regenerated, and the vessel's flow position is moved furthest downstream. While the lead vessel is temporarily offline, flow often continues through the lag vessel(s). The vessel that was formerly furthest downstream is then moved one vessel position upstream in the order of flow. In this mode of operation, the vessel with the cleanest media is always the last vessel in the order of water flow. Provided that the MTZ is small enough to fit within a single vessel, lead/lag operation potentially permits media to be changed out on near complete exhaustion, rather than initial breakthrough, leading to more efficient use of media.

In some instances, a lower cost sorptive media to remove co-contaminants can be used in front of higher cost media specific to PFAS removal. If the required flows exceed what can be treated by a single train of vessels in series, then additional trains can be introduced in parallel to increase total flow rates. Sufficient flow paths and valves must be present in interconnecting piping between multiple vessels in series when the intent is to hard pipe the vessels together and allow any of the vessels to be in the lead position. Strategies to increase the EBCT for a fixed flow rate include increasing vessel size or increasing the number of vessels in series or parallel. Or, for a given treatment system, the EBCT can be increased by decreasing the flow rate. In cases where a single vessel of media is used, sample taps located at 25%, 50%, and 75% of the bed depth, which are widely used in vessels in PFAS service, can be used to assess the extent of breakthrough before PFAS are detected in the vessel effluent. Sample taps can be useful in individual lead/lag vessels as well, enabling better prediction of breakthrough and evaluation of performance upsets.

18.3.1.4 Media Conditioning and System Startup

Fixed-bed sorption media require preparation prior to use, and while specific media manufacturer guidelines should be followed, this section will cover the general steps for both GAC and IX media.

With respect to GAC media, the startup process can be broken down into three distinct steps: the loading and wetting step, the backwashing step, and the conditioning step. The first step, loading and wetting, involves the transfer of the media from the delivery vehicle to the vessel and the soaking of the installed media in clean water. The goal of this step is to displace the entrapped air in the media's pore structure by soaking the media in water (usually overnight). Once the media is properly degassed, the second step can begin—the backwash step. The goal of the backwash step is to remove the media fines and to stratify the bed by size, with the smaller granules at the top and the larger granules at the bottom. By removing the fines and stratifying the bed, the hydraulics of the system are optimized and the clean-bed pressure drop minimized. In addition, the stratification of the bed by size minimizes the impact to the MTZ a subsequent operational backwash may have. The last step in the process is the conditioning step, which is a slow forward rinse-to-waste process. The goal of the conditioning step is to stabilize the media bed's effluent pH and remove soluble metals from the finished water stream. Reviewing the manufacturer's startup procedure is important to understand the volume of water required to commission a GAC system. Note that most media manufacturers also have options available to reduce the volume of water required if there are site constraints.

With respect to IX media, the startup process consists of two steps: the loading step and the conditioning step. Unlike GAC media, degassing IX media is usually not required since it is typically already wetted. Furthermore, there is usually no backwash step for IX media because the risk of media washout is high due to the relatively low specific gravity of the media. There is a conditioning step, which, like GAC, means a slow forward rinse-to-waste of the media. The goal of this conditioning step is to rinse off any manufacturing byproducts, such as nitrosamines, prior to commissioning the system. The conditioning step for IX media typically uses less water than the GAC conditioning step. Like GAC, IX media manufacturers have options available to reduce the volume of water required if there are site constraints. Freshly installed IX columns may cause short-term disruptions in pH or corrosivity of effluent water (see **Section 12.2.1.2**).

18.3.1.5 Water Quality Impacts and Pretreatment Needs

The matrix of co-contaminants, background NOM, and other water quality parameters often significantly impacts fixed-bed media consumption and performance for PFAS removal applications. Thus, pretreatment of the water is sometimes necessary to mitigate media fouling to extend bed life, and pilot testing is often recommended to accurately account for these impacts. Fixed beds in these applications are designed to sorb dissolved constituents, so prefiltration with 5-micron or 10-micron filters to remove suspended solids is commonly recommended to ensure the most cost-effective use of the media. Precipitation of iron and manganese particles can foul sorption media and can lead to biofouling from iron bacteria. This problem can be mitigated by treatment to reduce iron and manganese concentrations to below the secondary Maximum Contaminant Level (MCL) of 0.3 mg/L (or lower, depending on piloting data). Biocides or sodium hypochlorite are sometimes used to reduce naturally occurring microbial activity upstream of sorbent media that would otherwise result in biofouling. Disinfectant residuals, however, may damage some sorbent media, so consulting the media manufacturer is recommended. Hard water with a positive LSI can result in precipitation of calcium carbonate within the media, which blocks access to sorption sites. Targeting a neutral or slightly negative LSI can mitigate these concerns. Addition of anti-scaling agents such as phosphonates can reduce the risk of scale formation, but it is possible that these anti-scaling agents could compete with PFAS for exchange sites on IX resins (**Haupert et al. 2023**). In some instances, GAC may provide more flexibility than IX for sites with significant fouling risk due to suspended solids or precipitated metals (for example, iron or manganese) and without a means to pretreat the water because GAC can be backwashed with minimal impact to performance. It is easier to wash out the media and to disrupt the MTZ when backwashing IX resin.

TOC, including NOM, can interfere with the performance of both GAC and IX adsorption of PFAS. Advanced oxidation approaches such as ozonation (**Vatankhah et al. 2022**) can be used to transform and reduce TOC. However, ozonation and AOP can also increase concentrations of PFAS through precursor

transformation, potentially leading to a performance tradeoff for some water compositions. Pretreatment media such as GAC is also used to remove TOC prior to the PFAS treatment media. GAC that is used to remove TOC may have different characteristics (for example, different mesoporosity) than the GAC used to treat PFAS and may be designed for a different EBCT. In general, the impact of NOM on PFAS removal by IX depends on the characteristics of the resin and NOM. For example, removal of PFAS by polystyrene-based strong base IX resins is typically less affected by DOC than polyacrylic-based strong base IX resins that have a higher selectivity for DOC (**Hu et al. 2016**). The properties of the NOM are important as well: removal of PFAS decreases as the charge density, molecular weight, and aromatic carbon content (hydrophobicity) increase (**Boyer et al. 2021**).

Many PFAS exist in anionic (soluble) form in the ambient pH conditions commonly encountered in surface and groundwater. Physical adsorption onto GAC of some short-chain PFCAs that have pKas above 3 would be expected to improve as the pH drops and the ionic fraction decreases. PFSAs and long-chain PFCAs have pKas below 2 and are not likely to be impacted by pH (**Section 4.3.2**). **Boyer et al. (2021)** summarized the impacts of pH, background inorganic ions, and NOM on the removal of PFAS by IX resins in a comprehensive review. Strong base IX commonly used to treat PFAS are typically robust with respect to direct pH effects, with fixed groups being ionized over pH ranges of most applications. Weak base IX resins, whose charge is sensitive to pH, have generally exhibited a lower capacity for PFAS than their strong base analogs (**Liu and Sun 2021**; **Kassar and Boyer 2023**). As noted with GAC, only the charge composition of very short-chain PFCAs is likely to be strongly influenced by pH. Changes in pH also theoretically change the adsorption strength of some NOM fractions. Overall, the potential benefit to manipulating the pH has not been demonstrated to outweigh the added cost and complexity; therefore, GAC and strong base IX systems are commonly employed at ambient pH conditions.

IX resin (specifically anion exchange resin) is most sensitive to the presence of dissolved anionic species, such as nitrate, sulfate, and chloride, which will compete with PFAS for capacity on the IX media (**Wahman et al. 2023**). Waters with high salinity may be particularly challenging to treat with IX, and practitioners may consider testing other media in such situations. Pretreatment to remove major inorganic anions (for example, high-pressure membranes or demineralization by IX) is not commonly practiced and would be unlikely to make IX treatment more cost-effective overall. However, knowing the concentrations of major anions in the water to be treated is still valuable because that knowledge can be used in conjunction with modeling (**Section 18.3.2.1**) to aid in planning and design of pilot systems.

18.3.1.6 Media Description and Properties

IX Resins

Polymer-based IX resins used for PFAS treatment morphologies can be divided into two classes based on pore structure: gel-type and macroporous. The pores of gel-type resins are small enough (usually 1–2 nm) that they do not scatter light, giving these resins a translucent appearance. Macroporous resins, by contrast, usually have pore sizes larger than 20 nm, and are opaque. Gel-type resins usually contain more functional IX sites by volume than otherwise equivalent macroporous resins, which may lead to higher PFAS adsorption capacity for some applications. However, the pore and crosslinking structures in macroporous resins make them more rugged than gel-type resins and lead to faster exchange rates under some conditions. Accordingly, macroporous resins are often considered for applications involving regeneration or challenging water conditions. For example, in waters where biofouling potential is high, the ability to chlorine shock macroporous resin is key to avoiding costly media replacements. If the feed water contains a low level of chlorine residual (for example, 0.2–0.7 ppm, on average, from greensand filters continuously), using a macroporous resin can avoid the addition of a dechlorination step (such as sodium bisulfite addition). Macroporous resins are also expected to be more resistant to iron and manganese fouling than the gel-type resins, which may reduce the need for oxidant-based pretreatment in the first place.

IX resins of different polymer compositions (polystyrene and polyacrylic), pore structures (gel or macroporous), and functional groups (quaternary ammonium, tertiary amine, complex amino) have been used to remove PFAS. Most studies comparing IX resins have been done on PFOS (**Boyer et al. 2021**) and have found that polyacrylic/gel/weak base or polyacrylic/macroporous/strong base (type I quaternary ammonium functional group) resins have the highest capacity (**Chularueangaksorn et al. 2013**; **Deng et al. 2010**; **Schuricht et al. 2017**; **Schuricht et al. 2014**; **Zaggia et al. 2016**). When considering the removal of short- and long-chain PFCAs and PFSAs, **del Moral et al. (2020)** found that a polystyrene/macroporous/strong base IX resin (triethyl functional group) outperformed a polyacrylic/macroporous/strong base IX resin (triethyl functional group).

GAC Media Properties

The raw materials used to manufacture commercially available GAC primarily consist of bituminous and sub-bituminous coals, wood, and coconut shells. The adsorption pore structure and certain physical properties such as abrasion and inorganic mineral content of an activated carbon product are inherited from the raw material used to make it. For example, bituminous coal and coconut shells yield harder and denser activated carbon with more microporous structure compared to wood or sub-bituminous coal.

Every activated carbon product has a distribution of pore sizes, often categorized into micro (<2 nm), meso (2–50 nm), and macro (>50 nm) fractions. Although most of the adsorption occurs within the micro- and mesopores, macro porosity is important because it serves as a conduit to transport contaminants to the adsorption sites. **McNamara et al. (2018)** demonstrated that re-agglomerated, bituminous coal–based activated carbon outperformed coconut-based activated carbon for PFAS removal due to an enhanced transport pore network. During the manufacturing process, the raw materials used are crushed and processed and the GAC is screened to meet certain mesh size specifications. Common GAC mesh sizes employed in water treatment and their respective (US Mesh) size distributions are 12 x 40 (0.43–1.7 mm) and 8 x 30 (0.60–2.36 mm). Specifications for GAC products used in the drinking water industry are provided in AWWA B604 (**AWWA 2018**).

GAC/IX Comparisons

Many studies have been conducted comparing the PFAS removal performance of GAC and IX resin (**Liu et al. 2022**; **Zeng et al. 2020**; **Murray et al. 2021**; **Tajdini et al. 2025**). Although most studies have concluded that PFAS adsorption capacities and media lives for IX are greater than equivalently sized GAC beds, pilot-scale testing with site water as well as an evaluation of the total capital and operating cost on a net present value (NPV) of cost basis is recommended to select the most cost-effective remedy for an application. Numerous studies have confirmed two common trends in the removal of PFAS using sorbent media (**Zeng et al. 2020**). First, the longer chain PFAS within the same class adsorb better than the shorter chain PFAS. For example, in the class of perfluoroalkyl sulfonates, PFOS (C8) adsorbs more strongly than PFBS (C4), and in the class of perfluoroalkyl carboxylates, PFOA (C8) adsorbs more strongly than PFBA (C4). Second, the sulfonates adsorb better than their corresponding carboxylates of the same chain length. For example, PFOS adsorbs better than PFOA. This trend is especially pronounced in PFAS-selective IX resins, which often have even higher affinity for PFBS than for PFOA. Although IX resins, including regenerable IX resins, have higher capacity for short-chain sulfonate PFAS than GAC, they are considerably more expensive on a unit basis. It is also possible that the use of varying media in series can extend media lifetime by removing competing co-contaminants or water constituents such as organic matter. Due to the complexities of assessing relative performance and cost of GAC and IX systems, a site-specific economic evaluation of both types of media is recommended. Additional information about mixed media treatment systems can be found in **Section 18.3.2.3**.

18.3.1.7 Media Reactivation and Regeneration

Thermal GAC Reactivation

Although the terms "regeneration" and "reactivation" are sometimes used synonymously, there is a distinction. GAC reactivation is a thermal process that returns the GAC to a near virgin state. GAC reactivation is commercially available at large-scale, with about 17 facilities currently operating in the US (**USEPA 2024**). When spent GAC is returned to a reactivation facility, it enters a furnace where residual moisture is driven off and volatile contaminants are vaporized as the first step. Calcination and pyrolysis then occur, which char organics not previously volatilized. In the final step, steam gasification removes some of the carbon atoms within the biochar to return the activity level of the carbon to a near virgin state. The bulk of the adsorbed organic mass is thermally destroyed within the furnace, and emission abatement systems are used to capture and destroy remaining organics, acid gases, and particulate matter. The fate of adsorbed PFAS through a reactivation facility has been studied (see **Section 18.3.3**). GAC reactivation consumes between 15% and 30% of the media mass (**USEPA 2024**) and requires this amount of virgin media makeup for each reactivation cycle.

Reactivated GAC has demonstrated similar PFAS removal efficacy when returned to the original facility, but lower PFAS removal efficiency when using general-pool reactivated carbon from unknown origin (**McNamara 2018**). General-pool reactivated carbon should not be used for drinking water applications due to potential contamination from non-drinking-water sources. Sites considering GAC reactivation for PFAS treatment should contact reactivation facilities to see if they merit a site-specific reactivation contract (typically at least 80,000 pounds per change-out as of 2023 communications) (**Barr Engineering and Hazen and Sawyer 2023**). Consult activated carbon reactivation vendors to confirm minimum required quantities, as batch quantities less than 80,000 pounds may be possible.

GAC reactivation offers a similar service to high-temperature incineration, with about 17 facilities operating in the US and lower costs than high-temperature incineration (**USEPA 2024**). GAC reactivation can be used as a disposal method if facilities are replacing carbon with virgin carbon and reactivated carbon is returned to a general pool for resale. Alternately, facilities can accept reactivated carbon back for reuse. Using reactivated GAC offers a significant environmental benefit: a reduction in global warming potential of up to 80% compared to virgin carbon (**Vilen, Laurell, and Vahala 2022**). Destruction efficiencies of greater than 99.99% of targeted PFAS have been demonstrated through GAC reactivation (**DiStefano et. al 2022**), though full defluorination is difficult to demonstrate due to analytical limitations in closing the fluorine mass balance. Relative to high-temperature incineration with virgin media replacement, GAC reactivation and reuse is estimated to use less than half as much energy and incur less than half the operational expense (**Ling et al. 2025**).

GAC Regeneration

Regeneration refers to the process of partially restoring the capacity of a spent GAC, typically within the vessel, and uses either thermal (for example, steam) or chemical means to desorb contaminants in liquid-phase applications. Contaminants desorbed from the GAC must then be captured and destroyed or disposed by other means. Regeneration processes have been largely unable to completely restore the adsorption capacity of GAC and, therefore, experience decreasing efficiencies as the regeneration cycles proceed (**Vakili et al. 2024**). In-vessel GAC regeneration uses a basic solvent solution (**Siriwardena et al. 2021**). The spent regenerant solution is distilled and the resulting PFAS extract is proposed for destruction with supercritical water oxidation (SCWO) (**Scheitlin et al. 2023**), but could also be destroyed using other liquid destruction technologies, as further discussed in **Section 18.3.3**. The number of regeneration cycles a single vessel of these media can undergo may be limited, in part due to media degradation. However, application of in-place chemical regeneration of standard, bituminous GAC media has not yet been demonstrated widely on a commercial scale.

Several other technologies are being evaluated at lab-scale and pilot-scale for GAC regeneration, including hydrothermal alkaline treatment (HALT) regeneration (**Soker et al. 2023**), microwave regeneration (**Gagliano et al. 2021**), and plasma reactivation (**Bailey 2021**).

IX Regeneration

In some treatment systems, the adsorptive treatment media is regenerated within the vessel to replenish capacity. In situ regeneration of IX media for PFAS treatment for non-drinking-water applications is commercially available and has been used in cases of high PFAS influent concentrations or treatment of short-chain or ultrashort PFAS that would otherwise require very frequent media exchanges (**Woodard, Berry, and Newman 2017**; **Woodard, Nickelsen, and Sinnett 2019**, **Kempisty et al. 2024**). The book chapter by **Woodard, Nickelsen, and Sinnett (2019)** offers a comprehensive overview of regenerable IX resins for PFAS removal, including mechanisms of removal, importance of water quality analysis, key design parameters, loading and regeneration cycle data sets, and economic considerations. A case study demonstrating the use of regenerable IX resins, including a system diagram, is available in **Section 15.2.2.2**. Regenerable resins tend to be macroporous, rather than gel-type, because of the importance of ruggedness and fast kinetics during regeneration (**Liu and Sun 2021**). Some regenerable resins have lower capacities (**Ellis et al. 2022**) or require a longer EBCT to achieve similar capacity to single-use PFAS-selective resins, but this could be offset by O&M cost savings associated with on-site regeneration over off-site disposal (**Ling et al. 2025**).

Strong base IX regeneration involves the desorption of PFAS from the resin with a solvent brine solution that breaks both the hydrophobic and anionic interaction of the PFAS with the media. Multiple trials of regeneration using various combinations and concentrations of salts and solvents were conducted in (**Crimi et al. 2023**). These trials concluded high concentrations of alcohol solvents, for example, 75% by volume, and sodium chloride at 2% resulted in the most efficient and complete desorption of PFAS from the media. Research studies have also shown that even IX resins that are typically considered to be "single-use" resins can also be regenerated using 90% methanol brines (**Ellis et al. 2025**). After regeneration, the solvent is distilled for continued regeneration cycles and a PFAS concentrate known as a "still bottom" is the residual waste product of the process that can be further handled. Management of spent residuals is discussed further in **Section 18.3.3**.

Currently, no state agencies permit solvent regenerated IX (or GAC) systems for PFAS treatment of drinking water (**Ling et al. 2025**). Regenerable IX has been reused in full-scale PFAS remediation systems since 2018. Five years of performance data from a full-scale system demonstrated continuous use of IX resins without performance deterioration (**Kempisty et al. 2024**). Potential application scenarios for media regeneration include on-site regeneration and solvent recovery, on-site regeneration with off-site solvent recovery, and off-site regeneration of spent media vessels. Advantages of regenerable IX systems include reuse of the resin, reduced waste generation and associated liabilities, reduced size requirement of PFAS destruction technology, and lower operating costs, particularly when short-chain or ultrashort PFAS removals are required. An important consideration for life cycle cost is that high concentration solvents trigger the need for fire protection and intrinsically safe equipment. Moreover, the regeneration equipment itself represents important additional capital costs. The opportunity over time is cost savings associated with nonregenerable media replacement. Life cycle cost assessment (LCA) in **Hagelin et al. (2022)** suggested an expected return on those capital investments may occur during the time-horizon of a typical groundwater remediation system.

On-site or mobile regeneration of resin, typically using brines and/or solvents, provides the benefit of not having to physically remove and change out spent resin. Concentrated liquid produced during regeneration requires disposal. The primary waste product evolved from regenerable IX or GAC systems is the still bottom which contains high concentrations of PFAS and the regenerant salt. This material can be further concentrated with media in a process known as super-loading, which exposes the still bottoms to a mixed media bed with long contact times to achieve equilibrium isotherm conditions (case study

provided in **Section 15.2.2.2**; SERDP ER23-8391; **Haeglin et al. 2022**). Alternatively, the resulting still bottoms can be disposed of via traditional high-temperature incineration, SCWO, or an emerging destruction method such as HALT, plasma, or electrochemical treatment (**Singh et al. 2020**; **Maldonado et al. 2021**; **Liang et al. 2022**; **Pinkard et al. 2024**; **Higgins et al. 2025**), depending on the treatment equipment's ability to handle the still bottom salt content. Large-scale implementation could leverage a "hub-and-spoke" model with a regional regeneration and PFAS destruction facility servicing multiple facilities using IX resins, where vessels or media are sent to centralized facilities for regeneration and PFAS destruction (**Kempisty et al. 2024**). The additional capital costs associated with IX regeneration should be evaluated with an LCA; the payback period can be as little as 2 years or can be determined not to be feasible if the conditions do not provide an acceptable payback (for example, low flow rates, infrequent change-outs, or easily obtained treatment objectives). Similar approaches are being used for the regeneration of GAC and novel adsorbents (ESTCP Projects ER23-8379, ER23-8391), although the number of regeneration cycles these media can undergo may be limited. On-site or mobile electrochemical oxidation has also been used for the regeneration of GAC treating landfill leachate. As an example, one vendor uses an on-site solvent-based GAC regeneration process with a regional hub to process spent solvent for recovery reuse while separating desorbed PFAS for destruction at the hub using SCWO (**DiGuiseppi et al. 2024**). Hubs may be set up as centralized waste treatment facilities(**USEPA 2025**). Where regeneration solutions (additives) are used, the ability to demonstrate their removal from the media/vessel prior to reinstallation for treatment should be evaluated. Destruction of regeneration brines is further discussion in **Section 18.3.3**.

18.3.2 Performance Evaluation

18.3.2.1 Fixed-Bed Adsorption Models

The most accurate way to predict the breakthrough behavior of PFAS in fixed-bed adsorbers is to conduct bench- or pilot-scale column tests using water from a particular site. Conducting these tests, however, can be time-consuming and expensive. A faster, although often less accurate, method of assessing fixed-bed performance is to use modeling. A publicly available model from the USEPA's "Water Treatment Models" GitHub site (**USEPA 2021**) using the pore and surface diffusion model can incorporate the effects of fouling and predict performance of GAC. This model is based on the AdDesignS (Michigan Technological University, Houghton, MI) adsorption design software that was released into the public domain as part of the USEPA's Environmental Technologies Design Option Tool (ETDOT) (**USEPA 2023**). The challenge in using models such as this is that many of the model inputs parameters are not widely available and are quite difficult to determine (**Burkhardt et al. 2022**). Ideally, model inputs would include single solute Freundlich isotherm values of K and 1/n, external mass-transfer coefficients, internal diffusion coefficients, parameters for background NOM, and fouling factors for equilibrium capacity and kinetics (**Burkhardt et al. 2022**). PFAS isotherm parameters are sparse in the literature, however, some theoretical methods can estimate K and 1/n for PFAS with some success (**Burkhardt et al. 2023]**). **Burkhardt et al. (2022)** fit a pore and surface diffusion model to RSSCT breakthrough curves and then used the model to predict the impacts of changing fixed-bed parameters such as bed diameter, flow rate, and influent concentrations. Some activated carbon vendors have their own predictive models and databases. However, these vendor-specific tools are generally proprietary and not available to decision makers outside of consultation with vendors. The advent of machine learning methods has yielded novel approaches to estimating GAC performance in PFAS applications. For example, **Koyama et al. (2024)** compiled a data set of published PFAS breakthrough curves on GAC adsorbers and developed machine learning models using GAC characteristics, PFAS properties, and water quality parameters to predict throughput to 10% breakthrough (BV10). Although the machine learning model developed by Koyama et al. had mean errors of roughly 32% on BV10 and does not produce whole breakthrough curves, it is still a potentially useful tool for estimating the duration of GAC pilot studies.

Modeling tools for predicting the performance of IX resins for PFAS removal are few and far between—especially freely available or open-source models. As with GAC, various media vendors and consultants

have proprietary IX models for use internally, but these models are not typically published in peer-reviewed literature. It is accordingly difficult to comment on them because the underlying theory of their operation is unknown.

Use of empirical breakthrough curve models is common practice in literature and can be quite useful for interpolating data and comparing breakthrough curves among competing adsorbents. However, breakthrough curve models that neglect mass transport mechanisms or use purely empirical isotherms have difficulty correctly predicting the effects of changing system EBCT or variability in PFAS concentrations (**Haupert, et al. 2021**; **Haupert et al. 2023**), which are common concerns when interpreting pilot data and designing full-scale systems.

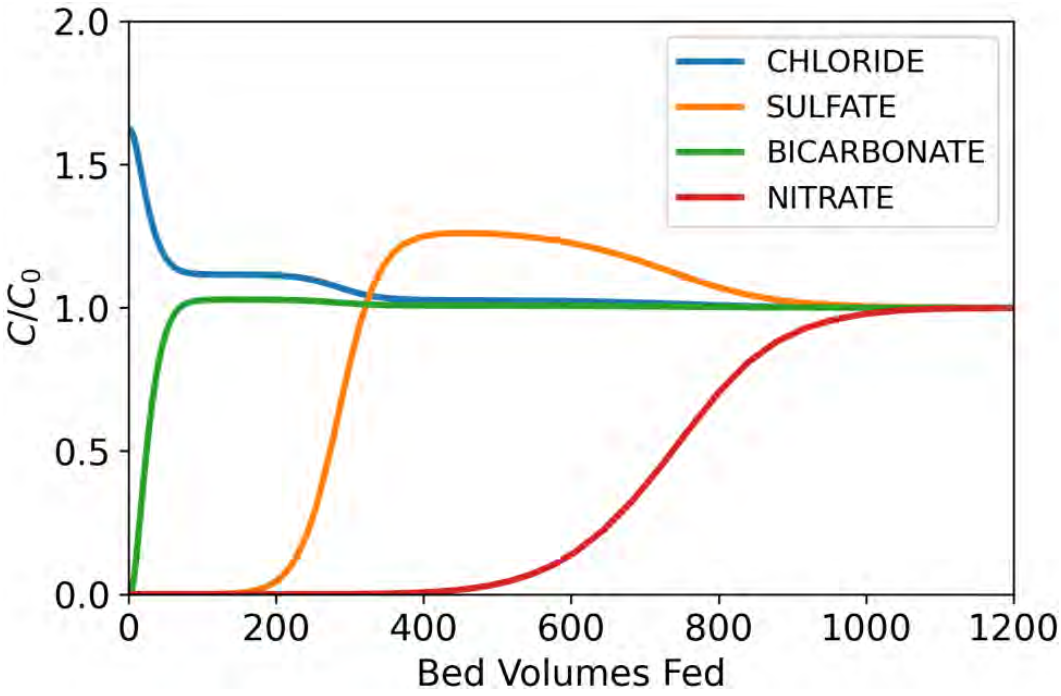


Figure 18-3. Example output of USEPA's IX model (USEPA 2021) showing influent-normalized effluent concentrations of commonly occurring anions in drinking water for an example system (Haupert et al. 2023). This output demonstrates the model's ability to predict chromatographic effects from displacement.

The USEPA has developed an IX performance model that closely follows the mechanistic conventions of the GAC model in AdDesignS, incorporating mass transfer resistances and combining them with multicomponent IX isotherms (**Smith et al. 2023**; **USEPA 2021**). This model explicitly includes competition effects from multiple ions in solution (**Figure 18-3**). Using IX isotherm parameters from the literature (**Fang et al. 2021**; **Wahman et al. 2023**), it is possible to make predictions about the impact of changes in commonly occurring anions (such as chloride, sulfate, and nitrate) on expected PFAS treatment performance. Unlike the GAC models, the IX models developed by USEPA do not currently have well developed methods for handling competition from NOM. Although the model can be used to estimate NOM impacts on performance in pilot data (**Haupert et al. 2023**), prediction is not yet rigorously possible. Some empirical, quantitative structure-property relationships (QSPRs) and pseudo-single solute models for estimating NOM effects on PFAS adsorption on IX systems have been developed for specific waters using AdDesignS (**Cheng et al. 2025**), but NOM is difficult to characterize and waters with similar TOC/DOC levels can have very different IX performance impacts (**Tajdini et al. 2023**). It is possible that additional research with carefully controlled water quality—for instance, with the use of lyophilized NOM in laboratory column studies (**Abulikemu et al. 2022**)—will shed light on the underlying mechanisms of

NOM interference on ion exchangers. Despite this limitation, it is still possible to use these models to make predictions about the effects of changing PFAS concentrations and changing operational parameters such as EBCT.

18.3.2.2 Summary of Testing Methods

As discussed in **Section 18.3.1**, general guidelines exist to help engineers design adsorption-based systems for PFAS removal. The media's performance and change-out frequency, however, cannot be generalized, as it is dependent on each site's water quality and proposed design. As a result, performance testing or evaluation of historical treatment data from analogous applications should be completed at each site to select the most cost-effective adsorptive media, including consideration of reactivation/regeneration, disposal, and/or replacement costs. Testing allows owners to make data-driven decisions regarding which technology is optimal for their scenario by looking at both performance and expected life cycle costs.

When it comes to adsorptive media, feed-water quality can have a significant impact on both operability and performance with respect to PFAS removal. For example, water sources with elevated levels of anions, such as sulfate and nitrate, tend to reduce media lifetime for IX resins. Similarly, water sources with elevated levels of TOC tend to be challenging for GAC media. Furthermore, sources with steady water quality (for example, groundwater) are usually well suited for lab tests. On the other hand, surface waters used for drinking water, which tend to see seasonal changes to their water quality, are not well suited for lab tests. These are some of the factors that need to be considered when evaluating different adsorptive media technologies and performance test options.

Table 18-3. Summary of performance test options for evaluating adsorption-based technologies.

Test Type	Relative Time to Completion	Relative Cost	Ability to Compare Media?	Predictability of Full-Scale Performance
Isotherm	Shortest	Least	Yes	Poor
Rapid Small-Scale Column Test	Moderate-low	Moderate-low	Yes[1]	Moderate[2]
Pilot	Moderate-high	Moderate-high	Yes	High[3]
Full-Scale Demonstration	Longest	Highest	No[4]	Best

[1] The RSSCT method has historically been used to compare the performance of GAC media. Although work is currently being done to modify the test for IX media, an industry consensus on the method has not been reached.
[2] GAC media RSSCTs for evaluating PFAS removal have been shown to either underpredict or overpredict the full-scale performance (**Cheng and Knappe 2024**; **Hopkins and Knappe 2024**; **Liu, Liu, and Sun 2024**). This issue is discussed in more detail in **Section 18.3.2.4**.
[3] The pilot study design plays a major role in the scalability of the results.
[4] Due to the scale of these tests, typically only one media is evaluated.

It is important to note that the term "feed water" does not necessarily mean the site's "raw water." PFAS treatment by fixed beds in wastewater and drinking water systems tends to be tertiary processes, within those systems, they are downstream of conventional treatment. Where the PFAS system is tied into the process can have a significant impact on the performance of the adsorptive media. For example, antiscalant from an upstream air stripper process may interfere with PFAS adsorption in downstream IX unit operations (**Haupert et al. 2023**). The same study found that low levels of VOCs in the feed water did not have a measurable impact on the performance of the GAC with respect to PFAS removal. Therefore, understanding the feed water quality to the future PFAS removal system can help owners select which adsorptive media to evaluate in their performance tests, and it is important to conduct testing on water that has already been subject to all intended pretreatment. More detail about applicable pretreatment strategies can be found in **Section 18.2.3**.

There are four main performance test options an owner can pursue when investigating different adsorptive media technologies for PFAS removal. The first two are lab-based tests—the isotherm test and the RSSCT. The other two are field-based tests—the pilot test and the full-scale demonstration test. As shown in **Table 18-3**, each option has advantages and disadvantages that will be discussed in more detail in the following subsections.

18.3.2.3 Isotherm Tests

One way to evaluate adsorbent media is via batch mode bench-scale experiment, whereby a known volume and concentration of PFAS-containing water is mixed for a set exposure time with a measured mass of adsorbent media to determine changes in the water's PFAS concentration. Typically, these batch tests are repeated with the same influent water (concentration and volume) but using varying doses of the adsorbent media. The data are then analyzed using an appropriate adsorption mathematical model (for example, Freundlich, Langmuir,) to develop an isotherm curve—a mathematical function relating the amount of PFAS adsorbed on the media to the remaining concentration of PFAS in the water at equilibrium.

In practice, it is common to use isotherm results as a means of identifying media that can remove the target contaminant for an application. Adsorbents showing the best performance can then be selected for further testing by RSSCTs or pilot tests. Batch isotherm tests using carefully controlled, synthetic waters have been used to obtain relative affinities for PFAS and common inorganic ions on some common IX resins (**Wahman et al. 2023**). These relative affinities can be used in conjunction with isotherm tests to make predictions about the effects changing concentrations of PFAS or common inorganic ions (for example, chloride, sulfate) have on IX performance. However, because NOM impacts on IX isotherms are still not well understood, the isotherm test is not able to rigorously predict PFAS breakthrough curves in practice. This limitation, along with the time, expense, and expertise needed to conduct such detailed batch experiments, means that these efforts are typically conducted by researchers rather than practitioners.

It is important to note that isotherm results provide an adsorbent media's capacity for PFAS at equilibrium. Notably the appropriate time to reach equilibrium in isotherm batch testing can vary with different media and different adsorbent doses (**Wahman et al. 2023**) and should be considered during experimental design. It is therefore important to confirm that bottle isotherm tests have reached equilibrium for proper interpretation of results. It is important to note that the kinetics of adsorption in bottle isotherm tests do not necessarily reflect the kinetics in column process. For this reason, isotherm results should not be used by themselves to extrapolate full-scale performance.

In situations where owners have time or budget constraints precluding further testing, isotherm results can be used with column performance models (for example, AdDesignS (**USEPA 2023**)) to obtain high level, estimated time to breakthrough for PFAS of interest. Although this approach is not the most accurate, it can provide a rough initial method of comparing adsorbent media performance to assist in planning. If the owners find themselves in this situation, they should keep three things in mind. First is to make sure they use their site's actual water, rather than synthetic water, for their testing to increase the representativeness of their results. If the site's water source is highly variable, the owner may want to run two isotherms (for example, winter and summer) to understand how the changes in water quality impact the adsorbent media's performance. Second, during the batch tests, any co-contaminants of interest also in the test water can be monitored. This allows owners to understand any potential added water quality benefits associated with adsorbent media. Last, water quality impacts (for example, fouling) and operational complexities (for example, backwash frequency) cannot be assessed in a batch test. Visiting a facility that already uses the adsorbent media(s) being evaluated can provide some operational knowledge to assist with this limitation of the isotherm test.

18.3.2.4 Rapid Small-scale Column Tests (RSSCTs)

A second lab-scale performance test available is the RSSCT. Originally developed around GAC media, the procedure for this test can be found in ASTM D6586-03, though it has not seen significant updates for PFAS applications (**ASTM 2021**). Due to the lack of industry consensus with respect to the IX RSSCT, some vendors and consultants recommend using the ASTM RSSCT method only with GAC media. With that said, it is imperative that practitioners understand that small errors in the test setup can lead to significant impacts on the results and conclusions of the test. To aid utilities in obtaining representative and accurate media performance relative comparison from RSSCT tests, here are some general guidelines to follow:

- The calculations in the ASTM D6586 RSSCT method should be followed.
- Ground media must be analyzed using sieve analysis (for example, alpine air jet sieve) to confirm size before testing; scaling should be recalculated based on results for each media.
- Full-scale mean particle diameter assumptions should be acquired from the media manufacturers.
- Small-scale column fill weight and volume should agree with the full-scale apparent density of the material tested.

Assumptions concerning the relationship between intraparticle diffusivity and carbon particle size can have a significant impact on the accuracy of RSSCTs to predict full-scale breakthrough (**Hopkins and Knappe 2024**). **Hopkins and Knappe (2024)** concluded that RSSCTs assuming constant diffusivity (CD) have shorter run times and are more accurate than proportional diffusivity (PD) at predicting the onset of PFAS breakthrough, but the shape of the breakthrough curve needs to be adjusted using the pore and surface diffusion model. An alternative presented by **Hopkins and Knappe (2024)** is to use a proportionality constant somewhere between CD and PD. In contrast to PD-RSSCTs, neither **Hopkins and Knappe's (2024)** method nor CD-RSSCTs need further adjustments to the breakthrough data need to be made to account for the effects of fouling.

RSSCTs provide a more accurate representation of adsorptive media performance, because they are operated under a scaled down HLR and EBCT, unlike the isotherm tests. As such, this is a great option for utilities that are evaluating multiple adsorbent media and want to select the best performing one(s) for further testing. Like the isotherm test, RSSCTs rely on a grab sample of water for completing the test. This means that results are tied to the water quality of that specific grab sample, which may or may not be representative of the water source as a whole or for every season. For this reason, the same grab water sample should be used as the feed water to each media RSSCT column being evaluated to minimize variables during the assessment. RSSCT run times and sample water volumes will vary depending on multiple factors, and typically range from 5 to 90 days and 25 to 55 gallons.

Results of the RSSCT can be applied directly to draw qualitative comparisons between media performance but should not be used in lieu of pilot testing for direct scale-up. RSSCTs capture performance on only a small sample of water from the affected site and may not be representative of long-term trends in water quality. RSSCT theory assumes similitude between the full-size and reduced-size adsorptive media to predict full-scale performance. From a morphological standpoint, this seems a reasonable assumption for GAC because both full-size and reduced-size GAC have been milled and have irregular particle shapes. However, **Abulikemu et al. (2023)** noted differences in specific surface area and surface oxygen content between GACs milled with different grinding methods. Differences in these properties were also observed in different size fractions even with a consistent milling method. Variability in PFAS adsorption in bottle isotherm tests has also been reported to depend on the size of milled GAC particles (**Abulikemu et al. 2025**). The effects of milling might be even more important for IX resins. Full-size IX resin beads are typically smooth, uniform spheres, but milling resin beads changes the morphology to irregular shapes. It is not yet clear how this change in morphology might affect

correspondence between RSSCTs results and pilot-scale IX behavior, though this is being actively studied in academia today.

Many studies have shown discrepancies between RSSCT predictions and pilot or full-scale performance, whereby sometimes they underpredict and sometimes overpredict performance (**Cheng and Knappe 2024**; **Hopkins and Knappe 2024**; **Liu, Liu, and Sun 2024**). This is especially true for IX RSSCTs. The current usefulness of this performance test for IX mostly lies in supporting media selection for pilot studies, rather than in substituting for them. This situation may change in the future as researchers and the water industry continue to research IX RSSCT methods and adsorption mathematical models.

GAC RSSCT test results can be used in tandem with column performance models (for example, AdDesignS) to obtain midrange full-scale bed life predictions for PFAS of interest. This option should be explored for utilities that lack the time or resources to pursue pilot testing. For sites with variable water quality, conducting two RSSCTs (for example, winter versus summer, or wet versus dry) is recommended to capture seasonal variations in testing. Although the accuracy of these RSSCT data–calibrated mathematical models is not as high as pilot testing, it can still provide good information for operations budgeting purposes.

18.3.2.5 Pilot Tests

Unlike the previous two performance tests discussed, pilot testing can provide both media performance comparisons and full-scale bed life predictions accurately for adsorption media. Although more time- and labor-intensive, pilot tests can capture water quality fluctuations, operational complexities such as fouling and backwash frequency, and PFAS removal performance simultaneously. It is important to note that the accuracy of the results will heavily depend on the pilot's design as compared to the proposed full-scale system.

The first step in the pilot testing process is to develop a robust test plan that considers the site's water quality, the media manufacturer's recommendations, and the pilot equipment's limitations. There are six main components to a good pilot test plan: feed-water considerations, media selection, column design, monitoring plan, project timeline, and data analysis. **Table 18-4** summarizes some of the common questions that should be addressed for each component.

As previously mentioned, the accuracy of the results of the pilot test depends heavily on the design of the pilot column, namely the selected HLR and EBCT. For GAC media, there are two main paths for sizing the column—targeting the full-scale HLR or targeting the full-scale EBCT. Both parameters are important in adsorption, with the MTZ length and shape being more strongly impacted by the selected HLR. Although the ideal pilot would match both full-scale parameters, this is usually not feasible in practice due to the larger sized pilot systems and resulting long testing durations required. Note that pilot-scale evaluations are typically scaled using the design or permitted flow for the facility rather than the average day flow.

When the pilot column is designed to mimic the full-scale EBCT, run time to breakthrough tends to be extended and the resulting HLR is usually significantly less than what the full-scale system would experience. This setup may lead to results that overpredict performance. Alternatively, when the pilot column is designed to mimic the full-scale HLR and the pilot column length is less than the full-scale bed depth, run time to breakthrough tends to be minimized and the resulting EBCT is usually a fraction of the full-scale system. Essentially, the media in the pilot column would be representative of a core sample taken from a fraction of the full-scale bed depth (for example, first 3 ft of media of a 12 ft bed depth). Under this scenario, the results may underpredict performance (more conservative) because the column essentially represents a cross-section of the full-scale bed. Although both options can provide good results, it is important to remember that the goal of a pilot test is to achieve contaminant breakthrough (at least 50%) in a reasonable amount of time. Thus, the recommended setup for pilot tests is to size the column matching the full-scale HLR.

Table 18-4. Components of a good pilot test plan[1].

Component	Topics/Questions
Feed Water	• What are the target contaminants for this site? • Are there co-contaminants to consider, and how do variations in type and concentration over time impact performance? • What are the treatment/effluent goals?
Media Selection	• Do you want to test multiple media? • Will different media be used for different contaminants? • Do you want to test multiple flow conditions?
Column Design	• What are the site's design and average flows? • What does the media manufacturer recommend for their media?
Monitoring Plan	• What discharge criteria need to be met, and what limitations apply under various conditional discharge scenarios (for example, irrigation, receiving water body, on-site dust suppression, sanitary sewer)? • What is the analytical budget? • What influent and effluent parameters will be monitored? • What operational parameters will be measured (for example, total flow, pressure drop)?
Project Timeline	• How long will the study last? • Do you need to test under multiple conditions (for example, seasons)?
Data Analysis	• Do you need specialized software to analyze the results? • Have you identified resources for troubleshooting?

[1] Note that this list is not exhaustive and is meant as a general guideline.

Equally important to the column design is selecting the locations and parameters to monitor during the pilot test. For GAC columns, it is recommended to monitor PFAS, as well any co-contaminants or water quality parameters of concern, such as TOC or VOCs. For IX columns, it is recommended to monitor PFAS alongside anions (for example, chloride, sulfate, nitrate) and metals (for example, iron, manganese). If the feed water contains an oxidant or turbidity, those can also be monitored through the study. Pilot-scale columns are typically anywhere between 2 and 6 inches in diameter, meaning the risk of channeling while sampling can be significant. To minimize risk of channeling, remember to collect samples using low flows through the bottom tap of a column. Ensuring that the column diameter is greater than eight times the average particle diameter of the media is also important for reducing channeling and wall effects (**Knappe et al. 1999**). If a pilot test consists of a single column, collecting samples from intermediate points along the column depth would be appropriate provided the column length is sufficiently long to contain the MTZ. Weekly PFAS sampling is recommended, alongside twice a week or weekly water quality monitoring samples. Samples should be collected from both the influent and effluent for proper analysis at the end of the study, and care should be taken to minimize sources of external contamination while collecting samples. Consider collecting samples in the opposite direction of flow for columns installed in series to avoid or minimize cross-contamination.

Once a robust test plan is developed, the next step is to procure the necessary equipment and media for the test. A few media manufacturers can provide piloting equipment, and most will provide their media for testing at little to no cost provided the results for their media are shared. The media manufacturer's recommended loading and startup procedures should be followed to minimize the risk of issues either with pilot operations or data analysis later. Once the system is online, it is important to track the column pressure or pressure drop, flow rate, and throughput daily. Additionally, the column is recommended to be operated to at least 50% breakthrough, because the shape of the breakthrough curve along with the operating parameters monitored daily are essential for determining media performance and scaling up the results.

At the end of the study, the PFAS and operations data should be compiled and used to create breakthrough curves (**Figure 18-2**). When comparing media performance across multiple types of media, it is recommended to modify the breakthrough curves prior to analysis. Instead of using operation time or bed volumes processed in the x-axis, use gallons treated or days in operation instead. The modified breakthrough curves can then be used to accurately compare the performance of tested media.

When the full-scale HLR is matched, this means that there is similitude between the number of bed volumes to initial and 50% breakthrough between the pilot column and the full-scale system. What changes is what one bed volume represents at each scale. For example, 1 bed volume in a 4-inch diameter pilot column with 3 ft of GAC media is approximately 2 gallons of water treated. In a 12 ft diameter, 40,000 lb vessel running at the same HLR, one bed volume is approximately 10,000 gallons of water treated. Therefore, if at the pilot-scale initial detection was at 30,000 bed volumes and 50% breakthrough at 45,000 bed volumes, then those same bed volume values are expected for the full-scale system. The change is that while the pilot treated only 60,000 gallons of water to initial detection (2 gal x 30,000 bed volumes), the full-scale system would instead treat 300 million gallons of water (10,000 gal x 30,000 bed volumes). Care should be taken when trying to compare performance between different sorption media with respect to the number of bed volumes treated before reaching an established breakthrough criterion. An example would be comparing IX and GAC, which typically have significantly different bed volumes. In this case, it is advisable to compare the performance based on a normalized measure such as pounds of media per million gallons treated.

For GAC media, the pilot test results can be combined with mathematical modeling software (for example, AdDesignS) to improve the accuracy of the pilot results and evaluate different flow conditions not investigated at the pilot scale. A few GAC media manufacturers offer this service if the pilot data are shared. Looking at AdDesignS as an example, the modeling software can be calibrated to the site's pilot results using a combination of influent data (which may be variable in time) and x and y points, where x is days in operation and y is percent breakthrough. Once the model is calibrated to the pilot results, it can then be used to simulate full-scale performance for a more accurate estimate to minimize the impact of the pilot design not matching both the HLR and EBCT at full-scale. Additionally, the model can also be used to predict performance at other flow conditions such as minimum day flow, average daily flow, and peak hourly flow. These additional simulations can provide important information regarding yearly carbon usage for a more well-rounded life cycle costs assessment. Note that the media manufacturers who supplied the media for pilot testing can provide budgetary price for media disposal, which should be considered during the LCA. Other items that should be considered when comparing pilot test results are operability (for example, frequency of backwashing), site requirements (for example, footprint), and complexity (for example, operator training), among others.

18.3.2.6 Multi-media Pilot Tests

New multi-media treatment processes are being considered now for PFAS applications. One such novel approach is GAC followed by IX resin. The idea behind this combination is for the GAC media to protect the downstream IX media (for example, oxidants, metals, organic compounds, biofouling), thus extending the life of the more expensive IX media with respect to PFAS. In these full-scale systems, the GAC media is exchanged at a predetermined breakthrough point, and the IX resin is kept as a polisher vessel rather than rotate vessel positions. The operation of these dual media systems is complex, because it requires more monitoring and more care when operating the system. Pilot testing these novel configurations can provide some insights into full-scale performance but typically cannot be properly scaled up. This is because the pilot test would require the GAC media column to be replaced at the predetermined breakthrough point each time it is reached to truly evaluate the bed life for the IX media. Because fresh GAC media is placed online at regular intervals, the timeline for these projects typically exceeds the available time a site has. So, while the pilot may not directly yield the expected bed life for the IX media within the project timeline, it can provide confirmation that the IX system works as intended along with a

conservative estimate of the minimum expected bed life. It can also provide information on how well the GAC protects the IX media, and how often the GAC media may need to be exchanged.

18.3.2.7 Full-Scale Demonstration Tests

Although rare, full-scale demonstration tests can be conducted to determine the effectiveness of an adsorptive media for PFAS removal. This style of testing is typically used after one adsorptive media has been selected and installed and is more commonly seen with GAC media. Remediation systems commonly go through an initial startup process to verify treatment system performance and to monitor the impact of geochemical parameters on the operation of the system. During this process, more thorough monitoring and testing is commonly conducted than during the long-term operational program. For example, sorption beds that have multiple sample taps along their depths can be sampled initially to gauge how quickly the bed is exhausting. After the media usage rate has been adequately characterized, the number of sample locations within a sorption bed and sampling frequency may be reduced.

The two most popular types of full-scale demonstration tests in drinking water treatment are gravity filters and potable reuse demonstration pilots. Usually located at drinking water treatment plants that use surface water sources, gravity filters remove turbidity through physical means and are usually filled with a mix of gravel, sand, and anthracite. Sites with taste and odor issues or elevated disinfection byproducts may have already made the transition to replacing the anthracite layer with a GAC layer. With the new PFAS MCLs and the fact that GAC can simultaneously remove multiple contaminants, these utilities are now evaluating the performance of their gravity filters for PFAS removal. If the plant has the redundancy to run without one filter, then a full-scale demonstration test can be conducted to determine the effectiveness of the GAC media for PFAS removal (**Prein & Newhof 2019**). The redundant filter can be retrofitted with GAC media and run in parallel with existing gravity filters (control) to compare performance and estimate bed life.

Gravity filter tests need to be designed with the understanding that there will be inherent limitations that will impact the variables able to be modified. One is the space available for the GAC media—the design must maintain enough freeboard between the top of the expanded bed (backwash) and the bottom of the trough. Another is any hydraulic constraints (for example, pressure drop, run time) for the system that may be impacted by a change in media type, media depth, or media mesh size. Although HLR tends to be low in gravity filter applications, the main limitation in these filters is the limited EBCT. Thus, gravity filter test plans should be reviewed and the media manufacturer consulted prior to determining the maximum bed depth and media type that can be used for the study.

Once the media type and bed depth are decided and the media is loaded and backwashed, the test can begin. Like with pilot testing, both sampling and operations data are key to a successful performance analysis in the end. Throughout the study, influent and effluent PFAS (and other constituents of concern) should be monitored frequently (for example, twice a week). Because one of the main goals of filtration in the drinking water treatment process is turbidity reduction, turbidity is another parameter that should be monitored throughout the test. The operating parameters to monitor are flow rate, throughput, and pressure drop. Alongside pressure drop, the frequency of backwashing or filter run time should also be noted and compared to the existing gravity filters.

Because the gravity filter is already full-scale size, the results of the test do not need to be scaled up. However, the data from the test can also be analyzed using AdDesignS to estimate the performance at other set points for the media tested. Note that while the modeling software can provide breakthrough estimates under different scenarios (for example, flows, bed depths), it cannot predict any operability impacts (for example, run time, turbidity). Thus, it is recommended that the design that is selected for the demonstration test be the one that may produce the greatest impact on the operability of the filter. That way, both impacts on operability and PFAS removal performance can be captured and any subsequent

modeling for PFAS will be for scenarios whose operability impacts are minimized. Note that when it comes to PFAS treatment, gravity filter retrofits may not be an economical solution for the site.

The other type of full-scale demonstration test to be discussed in this section is potable reuse pilots, which may use any of the discussed adsorptive media in the market. These pilots tend to use large-scale systems, and sometimes even involve entire setups or buildings where stakeholders can tour the facility and learn about the study. In these situations, large-scale sorptive media beds may be used as tertiary treatment processes that are in part targeting PFAS removal from wastewater effluent. The media manufacturer's guidelines for recommended HLR and EBCT should be followed when designing these demonstration pilots. Once in operation, the same parameters listed for gravity filter demonstrations should be monitored in these systems. The results may or may not need to be scaled up, depending on the size of the system selected for the test. Similarly to gravity filter tests, the results can be coupled with AdDesignS for further analysis.

In exceptional cases, it may be possible to use existing GAC adsorbers already in place for VOC removal to test PFAS removal efficacy at scale. However, this is usually not practical because of issues such as differences in needed EBCT and media change-out frequency.

It is important to note that full-scale systems, once online, should be routinely monitored not just for compliance, but to verify that the system is operating as designed. Changes in water demand that required higher flow rates through the filter or changing water quality (for example, PFAS species change, chemical spill, spikes in TOC) can impact the performance of the system. Therefore, keeping track of operations data (for example, flow rate, throughput, pressure drop) and influent and effluent sampling results is important. Media manufacturers should be able to provide guidance and troubleshooting help should the water quality or flow rate change, provided there is data available for them to review and analyze.

18.3.3 Fate of Spent Media and Treatment Residuals

The 2024 USEPA disposal and destruction guidance for PFAS-containing wastes lists landfilling and thermal treatment as established options for managing PFAS-laden waste streams (**USEPA 2024**). However, with an anticipated upcoming increase in GAC and IX resins use in municipal drinking water and industrial wastewater systems, additional disposal options may be warranted. Off-site GAC reactivation and on-site IX or GAC regeneration can reduce demand for virgin media, as well as operating costs and energy usage. Media reactivation and regeneration is addressed in more detail in **Section 18.3.1.7**.

Landfilling of PFAS-laden waste streams sequesters PFAS for a limited time, and landfills can serve as a short-term or medium-term source of PFAS to the environment through landfill gas and leachate (**Lin et al. 2024**). Costs vary depending on the type of landfill used. Municipal solid waste landfills have tipping fees of $40–$80 per ton (**USEPA 2024**). Costs for disposal in hazardous waste landfills is in the range of thousands of dollars per ton, similar to costs for hazardous waste incineration (**USEPA 2024**). For GAC containing PFAS, reactivation may be more economical depending on the distance between the source and the nearest GAC reactivation facility. The type of landfill used depends on regional requirements by landfill operators, with some municipal solid waste landfills choosing to not accept PFAS-laden spent media.

High-temperature incineration can be used to destroy PFAS-laden spent media, with about 20 facilities operating in the US. These facilities primarily operate as hazardous waste incinerators or cement kilns (**USEPA 2024**). A temperature of 1,100°C is typically considered high enough for PFAS mineralization, but lower temperatures may be sufficient under certain operational strategies and retention times (**Winchell et al. 2024**; **Wang et al. 2022**). PFAS destruction also depends on the contact time at these temperatures and the amount of turbulence within the incineration unit. Disposal fees for these facilities are typically in the range of $1,300–$1,900 per ton (**USEPA 2024**). Uncertainties remain regarding the final fate of all

PFAS given the lack of analytical capabilities to fully close the fluorine mass balance (**Wang et al. 2022**). In addition, some jurisdictions have limited incineration of PFAS-containing wastes (Illinois, New York, and the Department of Defense), leading to regulatory uncertainty around this disposal option.

Although SCWO is a field-implemented destruction technology, a new application for direct disposal of spent GAC and IX resin is being pilot tested. SCWO has the potential to be energy-neutral or energy-positive because of the high energy content in spent media. Lab tests to date have demonstrated over 99% removal efficiency of targeted PFAS (**Chiang et al. 2023**). Piezoelectric ball-milling has also been shown to destroy PFAS on spent IX resins (**Zhu et al. 2025**), but application of this technology is still in an early stage of development.

Spent regenerant from GAC and IX regeneration can undergo liquid treatment technologies to achieve PFAS destruction. The process concentration factors achieved by regeneration of IX resins depend upon treatment goals and matrix but can be as high as 30,000 (**Higgins et al. 2025**). Because of the high degree of concentration achieved via the adsorption and regeneration processes and the very high PFAS concentrations that result (mg/L range), still bottoms represent a low volume, high strength waste stream that can be treated via a PFAS destruction process. A high degree of PFAS destruction (>99%) has been demonstrated when applying PFAS destruction technologies, including electrochemical oxidation (**Liang et al. 2022**) and nonthermal plasma (**Singh et al. 2020**; **Higgins et al. 2025**), to the concentrated still bottoms matrix. High salt and organic matter content of the still bottom can limit the reaction kinetics of some destruction technologies, including plasma, electrochemical oxidation, and UV-based reduction systems (**Liang et al. 2022**). HALT treatment of PFAS in high ionic strength solutions similar to still bottoms has shown efficient and complete degradation of PFAS (**Pinkard et al. 2024**). There are ESTCP and Defense Innovation Unit Projects currently evaluating destruction of PFAS with HALT and SCWO in still bottoms (for example, ER23-8400, ER23-8434, ER23-8398, ER23-8435) with final reports expected in 2026. **Hagelin et al. (2022)** investigated distilling the alcohol from the spent regenerant with very little PFAS carryover. Other technologies being evaluated at lab-scale and pilot-scale for IX regeneration and PFAS destruction include using advanced reduction processes (**Cui and Deng 2023**). However, a study by **Liu et al. (2025)** applied advanced reduction processes to solutions containing highly PFAS-selective IX resins. They noted less effective PFAS destruction than was observed by **Cui and Deng (2023)**, suggesting that direct use of advanced reduction process on solutions containing PFAS-selective IX might be less efficient than using the advanced reduction process on regenerant solution.

18.4 Foam Fractionation

This section is an extension of **Section 12.2.3** and the case studies presented in **Section 15.2.4**. It is recommended that readers who are not familiar with foam fractionation familiarize themselves with that material before proceeding with the material presented in this section. Foam fractionation for the separation of PFAS can be applied either in situ or ex situ. However, as mentioned in **Section 18.1**, this guidance is focused on ex situ applications of sorption-based treatment. Although some of the material presented may also be applicable to in situ foam fractionation, this section is intended to cover only ex situ foam fractionation. Additional information on the progress to field-demonstrate and validate in situ foam fractionation is available under the ESTCP research project ER21-5124 and **Reynolds, Nelson, and Danko (2024)**.

In this document, foam fractionation means any adsorptive bubble separation technique in which amphiphilic substances (in this case PFAS) are adsorbed onto a gas-water interface that is then separated from the bulk liquid. Despite the name “foam fractionation,” this can be accomplished with and without the presence of a stable foam. There are several commercially available methods of foam fractionation using a variety of gases (for example, air, ozone) and flow-through configurations (for example, batch, countercurrent flow). This section is not intended to provide details of all foam fractionation configurations but to provide a general overview of factors to consider and tools to assess performance.

Foam fractionation may be used for a variety of liquid media. Below are some applicable/nonapplicable matrixes based on currently available systems. Advances in foam fractionation may enable treatment of nonapplicable matrixes in the future.

Applicable:

- Groundwater and surface water. When targeting these matrixes, water may not readily foam upon aeration, and additional foaming additives may be needed. Foam fractionation should be considered for waters, such as those impacted by AFFF, or water with substantial concentrations of organics or ions that may affect other sorptive technologies. Foam fractionation vendors may have typical PFAS concentration thresholds for cost-effectiveness in comparison with fixed-bed sorption media.

- Landfill leachate. Leachate typically foams readily due to other constituents and may be an ideal matrix for foam fractionation. It typically contains high concentrations of organics and salts that impede other separation technologies.

- Process water. There are various process waters from a variety of sources with disparate characteristics. Foam fractionation is well suited to process waters with high PFAS concentrations, those that foam readily, or those containing co-contaminants that affect other sorptive technologies.

- Soil wash water. Foam fractionation has been used to remove PFAS from soil wash water. Depending on the concentrations and the source of the wash water, foaming additives may be needed to enhance PFAS removal. After foam fractionation, wash water can be reused for subsequent washes or discharged.

- Reverse osmosis (RO) reject water. Foam fractionation is well suited to RO reject water, because it typically has higher PFAS and salt concentrations than the RO feed water, both of which can improve the efficiency of foam fractionation for PFAS removal. The preconcentration of salts can reduce the efficiency of other sorptive technologies but has been shown to assist in PFAS removal by foam fractionation.

- Drinking water. Although it may not be cost-effective for low PFAS influent streams, there are other considerations (such as media disposal and site access) that may make it suitable for some drinking water sources. These waters may not readily foam and additives may be needed. As with any drinking water system components and treatment chemical additives, foam fractionation system materials of construction and foaming additives should be selected carefully to ensure compliance with drinking water regulations such as National Sanitation Foundation (NSF)/American National Standards Institute (ANSI) standards certification requirements.

- Pretreatment to remove bulk PFAS. As discussed below, foam fractionation can be useful as a component of a treatment train to cost-effectively remove high concentrations of PFAS prior to a downstream polish using other sorptive media.

- Sewerage water. Due to the high concentrations of solids and organics, PFAS are difficult to remove from sewerage without significant pretreatment. Foam fractionation can remove PFAS from this matrix with minimal pretreatment, but high solids and biological loading may increase maintenance requirements.

- Oily waters (with pretreatment to remove oils).

Nonapplicable:

- High AFFF solution (>10 ppm PFAS). AFFF solutions with a high proportion of AFFF generate too much foam to effectively concentrate PFAS through foam fractionation. These waters are typically sufficiently enriched in PFAS for direct disposal or destruction without the need for concentration through foam fractionation.

- Liquids with densities greater than 1.15 (sludges with percent solids of 1% or greater). Dense liquids make it difficult to introduce air and generate sufficient foam to remove PFAS. Pretreatment would likely be required to remove solids prior to foam fractionation.

- Oily waters (without pretreatment to remove oils). The presence of nonaqueous phase liquid (NAPL) can impede PFAS removal by foam fractionation. NAPL creates a multiphase system with water and air that prevents PFAS from readily sorbing to the surface of air bubbles, limiting removal. Pretreatment to remove oils and grease (for example, an oil-water separator) is needed prior to foam fractionation.

There are several advantages and disadvantages to foam fractionation when compared to other sorptive technologies (for example, GAC and IX resin), and these should be considered when evaluating implementation of a sorptive-based remedy for PFAS treatment. In contrast to other sorptive technologies, foam fractionation does not require a solid adsorptive media; the PFAS sorb to rising air bubbles, which produces a PFAS-enriched liquid waste. This is a particular advantage for sites with limited capacity for managing large volumes of solids, or other logistic challenges. Because there is no physical sorptive media to be spent during PFAS removal, foam fractionation can be advantageous for aqueous matrixes with high PFAS concentrations that would rapidly break through other forms of sorptive media. This can provide cost savings even if GAC/IX resin are used downstream of foam fractionation. Foam fractionation is further advantaged over media systems for water sources with complex matrixes due to minimal pretreatment requirements for many co-constituents, potentially lowering cost and footprint required to address PFAS treatment needs. Foam fractionation systems can have a smaller footprint than comparable GAC or IX resin systems due to the lack of physical media. However, current commercial offerings tend to have limited throughput capacities and cannot be scaled as easily as media-based sorption technologies. Overall, foam fractionation is usually considered for sites with PFAS concentrations greater than 100 ng/L and flow rates less than 0.2 million gallons per day, or for waters with high co-contaminant loadings and projects where the logistics of handling spent physical media are of concern. Higher flow rates are currently achievable by installing multiple units in parallel. Advances in foam fractionation, including larger vessels, are expected to be available soon, enabling higher throughput systems.

18.4.1 Technical Overview

18.4.1.1 Bubble PFAS Adsorption

Foam fractionation and its derivative approaches (for example, bubble fractionation and aerosol fractionation) use the amphiphilic nature of PFAS typically comprising a hydrophilic functional head group and a hydrophobic tail group. The adsorption coefficient necessary for uptake onto a gas-liquid interface, such as a swarm of rising bubbles generated most economically from ambient air, is influenced by several factors.

Different PFAS are adsorbed by air bubbles at different rates and through different mechanisms (**We et al. 2024**). For example, long-chain PFAS are removed rapidly in the process of foam fractionation because of their greater adsorption coefficients. In contrast, short-chain PFAS are less readily removed due to their lower affinity and adsorption coefficient for gas/liquid interfaces, such as air-water surfaces provided by gas bubbles (**Burns, Stevenson, and Murphy 2021**; **Wang et al. 2023**; **Smith et al. 2022**; **Dai et**

al. 2019). See **Table 2-3** for the definition of long- and short-chain PFAS. Various gases can be used in foam fractionation. Air is typically used due to its low cost, but ozone and nitrogen have also been used as gas streams for foam fractionation (**Dai et al. 2019**; **Vo et al. 2024**; **Burghoff 2012**). The use of ozone may offer some benefits such as reductions in waste volumes, smaller bubble sizes, and the oxidation of precursor PFAS and/or organic co-contaminants. However, using ozone also has drawbacks, such as higher costs, production of byproducts (for example, bromate), lower total PFAS removal, and production of additional PFAS degradation products (for example, perfluorobutane sulfonamide [FBSA]) (**Vo et al. 2024**; **Dai et al. 2019**). There is limited information available on the use of nitrogen in foam fractionation for PFAS removal, but it has been used in other applications to prevent oxidation of metals or precursor PFAS (**Burghoff 2012**).

18.4.1.2 Bubble Separation

During foam fractionation, bubbles, along with adsorbed PFAS, rise to the surface of the bulk aerated water column and may be separated/concentrated in a single process step from the original contaminated water matrix with or without added co-surfactant to assist in removal of PFAS molecules with low adsorption coefficients (**Stevenson and Karakashev 2024**; **Lee and Venkatesan 2024**). Foam fractionation, contrary to its name, does not always require foam. In some cases, a stable foam is not produced but PFAS can still be accumulated and captured in an aqueous layer or as aerosols at the top of the column or vessel (**Nguyen et al. 2024**; **Stevenson and Karakashev 2024**).

While the column is being aerated to generate bubbles, the highly aerated liquid or foam concentrate is harvested from the foam fractionation vessel by a spillover weir, a real-time vacuum, displacement by clean water, or other means to collect the separated PFAS (**We et al. 2024**). The harvested foam containing concentrated PFAS is called foamate or concentrate. Once harvested, the foamate/concentrate can be collapsed into a liquid concentrate for enrichment, additional treatment, or disposal. Destructive treatment and disposal of foam concentrate is covered in **Section 18.4.3**.

18.4.1.3 Fractionation Enhancement

Additives, such as co-surfactants, can enhance the removal of PFAS during foam fractionation, with substantial improvement in the removal of short-chain PFAS (**Stevenson and Karakashev 2024**; **Lee and Venkatesan 2024**; **Buckley et al. 2023**). Because most regulated PFAS are anionic, cationic surfactants can associate with these PFAS to form complexes that are more readily removed. Surfactants can also help stabilize the foam layer to increase PFAS removal during foam harvesting and reduce the amount of water in the foamate. Nonionic and biologically derived surfactants have also been shown to improve PFAS removal and may be more biodegradable and have lower threshold ecological toxicity values (**Malovanyy, Forsén, and Lihammer et al. 2025**; **Ziaee, Ziaee, and Taseidifar 2021]**). Polymers, metals, and electrolytes have also been examined as potential foam fractionation additives (**Buckley et al. 2023**; **Buckley et al. 2022**; **Ziaee, Ziaee, and Taseidifar 2021**). Most foaming additives (for example, surfactants) are typically removed during the foam fractionation process and are concentrated in the foamate. However, residual co-surfactant additives may be present in the treated water and evaluated for acceptance with applicable limits. Low dosages (1 mg/L or less) of co-surfactants have been shown to enhance removal of four-carbon-chain-length PFAS, with removal rates greater than 98% for some waters (**Lee and Venkatesan 2024**; **Buckley et al. 2023**). Research (SERDP Project ER23-7892) is being conducted on the use of colloidal gas aphrons (microbubbles encapsulated by surfactant multilayers) to increase the surface area of supplied air-water interfaces, targeting both long- and short-chain PFAS. This method requires substantial amounts of co-surfactants to function effectively, and the process has challenges achieving trace-level removal criteria, which may be due to aphron bubble size (**Kulkarni et al. 2022**).

18.4.1.4 Operational Modes & Multistage Concentration

Some operational method variations among foam fractionation vendors are important to understand and consider, and all modes may not be applicable to every vendor. Foam fractionation has been implemented in batch, semibatch, and continuous configurations (**Figure 18-4**) (**Buckley et al. 2021**; **Burns, Stevenson, and Murphy 2021**; **Malovanyy, Forsén, and Lihammer 2025**). Continuous configuration may be either co-current or countercurrent (**Smith et al. 2022**; **McCleaf, Kjellgren, Ahrens 2021**). Under a continuous countercurrent configuration, a portion of the foam generated in a downstream column can be transferred into the upstream column to increase PFAS concentration, mass transport, and net PFAS removal efficiency. The last stage acts as a polishing step to achieve treated water concentration requirements. Foam fractionation may also be designed in single fractionation, twin fractionation, triple fractionation, or multifractionation stages in series, in parallel, and a variety of other configurations. Designs may include a primary stripping stage (does not require the formation of foam) to reduce PFAS to satisfy adopted criteria, followed by subsequent stages that enrich the primary fractionation waste stream to minimize waste destruction volumes. In other configurations, multiple enrichment stages are applied in series to gradually remove successive amounts of PFAS and enrich the waste volume. Additional stages of foam fractionation columns can be used to process the foamate and further concentrate PFAS to a desired level. Effluent water from secondary and tertiary stages can be recirculated back to prior stages for additional removal. For smaller volumes of water, it is also possible to operate a single column or vessel in a batch mode as either a primary or secondary stage.

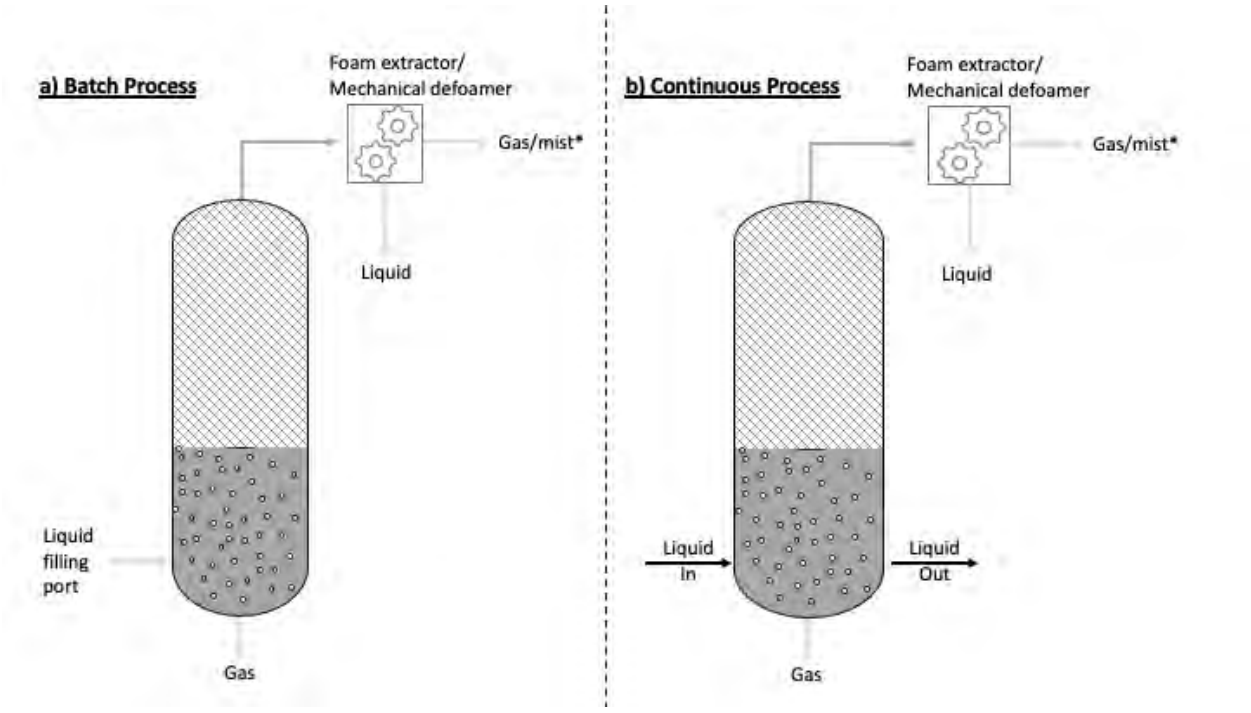


Figure 18-4. Diagram comparing batch (a) and continuous (b) foam fractionation processes. (*) Gas/mist may require monitoring or additional treatment for VOCs or PFAS.

Source: Drawing by Dr. Pradeep R Shukla, Aquarise Innovations.

Batch and semibatch foam fractionation takes place in a vessel that is filled with the water to be treated. Gas is introduced in the bottom for the duration of the treatment batch, and after the foamate is recovered, the treated water is discharged from the vessel (**Burns, Stevenson, and Murphy 2021**; **Malovanyy, Forsén, and Lihammer et al. 2025**). Continuous foam fractionation typically uses a vertical

column with water flowing countercurrent to the air stream. PFAS are removed by the bubbles into a foamate while the treated water is continually discharged (**Smith et al. 2022**; **McCleaf, Kjellgren, Ahrens 2021**). Management of foamate is presented in **Section 18.4.3**.

Most foam fractionation vendors operate traditional systems requiring the creation of a foam. When the feed-water chemistry lacks sufficient amphiphilic substances such as medium/high PFAS concentrations or other non-PFAS surfactants, the vendor's foam fractionation solutions typically add several foaming additives (for example, surfactants) to prevent depletion of amphiphilic substance during foam fractionation to maintain foam generation (**Buckley et al. 2022**; **Malovanyy, Forsén, and Lihammer et al. 2025**; **Klevan et al. 2025**). Alternatively, countercurrent operation can be used to increase foamability by transfer of foam generated in a downstream column into the upstream column, increasing the steady state concentration of surface-active species in the initial treatment stages (**McCleaf, Kjellgren, and Ahrens 2021**). Other commercialized foam fractionation systems have demonstrated effective removal of legacy PFAS without any froth/foam creation where the vendor system operates in either bubble fractionation mode or aerosol fractionation mode (**McCleaf, Kjellgren, and Ahrens 2021**; **Morrison et al. 2023**; **Nguyen et al. 2024**). Application of bubble separation techniques allows high levels of PFAS removal from nonfoaming waters.

For example, if the concentration of PFAS in the water to be treated is high and readily foams, then foam fractionation with normal aeration and vessel fill volumes is typically applied. If the subject water excessively foams, then reduced aeration or mixing various waste streams can be considered to bring the foaming range into the optimal operation range to remove the PFAS from treated water. Either way, the objective is to create a column of aerated water underneath a foaming phase on top. In bubble fractionation, the vessel fill volume is typically higher than with less foaming water. The nature of low-foaming waters prevents bubbly liquid from forming a froth/wet foam or dry foam via interstitial drainage, but higher vessel fill volumes (lower air/water ratios) result in very little frothing but removal of PFAS as bubbly liquid collected from the fractionation vessel (for example, by spilling over the primary fractionation weir). Bubble fractionation typically achieves lower treatment results compared to traditional foam fractionation because bubble fractionation does not provide an opportunity for froth to climb a froth/foam chimney (air gap) to drain interstitial liquid, which may carry residual PFAS, back into the aerated bulk subject water. Bubble fractionation also results in a wetter foamate, resulting in lower volumetric concentration factors. The lower volumetric concentration factor is not necessarily an indicator of PFAS removal but does increase the volume of foamate that needs to be treated or disposed of. The foamate volume generated is variable and depends on the foamability of the water being treated.

PFAS removal mechanisms during foam fractionation vary, and multiple mechanisms may contribute to PFAS removal depending on the water being treated and the specific foam fractionation equipment used. For example, some waters may exhibit significantly reduced bubble formation at the top of the aerated water column when treated in the usual manner. In such cases, aerosol fractionation may be the primary PFAS removal mechanism while bubble fractionation or foam formation may be less important. To enhance aerosol fractionation, vessel fill volume can be set low in a wide-body primary fractionator, reducing aeration and creating smaller bubbles that burst, forming aerosol fragments for condensing back into a liquid foamate. This method has been shown to remove long-chain PFAS if the fractionator can be operated to avoid creating a foam blanket that would capture aerosols before they can be condensed.

18.4.1.5 Pretreatment Considerations

For most waste streams, foam fractionation can be operated with little or no pretreatment and used as a stand-alone PFAS removal technology or incorporated into a treatment train (**Burns, Stevenson, and Murphy 2021**; **Sochacki, Michorczyk, and Vogt 2025**). Because there is little pretreatment required, a foam fractionation treatment process can be placed nearly anywhere in a treatment train. Ideally, foam fractionation placement prior to the generation of organic solids would be of great benefit as the

separation of PFAS during foam fractionation may limit the amount of PFAS that sorbs onto settleable solids. However, in some circumstances this may be problematic. For example, using foam fractionation to treat raw sanitary sewage may result in the generation of odors, and placement as a tertiary process after secondary treatment may be warranted. If odor is the only concern for the placement of the foam fractionation system, it can be mitigated by the design of off-gas recirculation or treatment as discussed below.

Most co-contaminants or impurities that affect solid phase sorption-based treatments (for example, metals, salts, and organic carbon) do not affect the efficiency of PFAS removal by foam fractionation, and in some cases, may enhance foaming and/or PFAS removal (**Buckley et al 2022,**; **Smith et al. 2023**; **Wang et al. 2023**). However, there are exceptions. The presence of suspended solids in the liquid sometime hinders complete PFAS removal. Suspended solids, especially carbonaceous materials, tend to adsorb PFAS to achieve an equilibrium between the PFAS concentration in the liquid and solid phase. These trapped PFAS are not removed during the foam partitioning and get carried over in the treated liquid (**We et al. 2025**). Operational strategies, including air injection rate modification and chemical addition, may be used to enhance the capture of suspended solids within the foamate to alleviate this concern. Another exception is measurable oil and grease or NAPL due to interactions between the air-water and NAPL-water interfaces (**Brusseau 2021**). Where oil and grease are present, an oil-water separator or other pretreatment is recommended prior to foam fractionation to bring the total oil and grease (TOG) concentration below 100 ppm. Dissolved air flotation may also be used for pretreatment to remove oils and grease (**Al-Shamrani, James, and Xiao 2002**).

Certain pollutants such as benzene, mercury, and other VOCs in the influent liquid will trigger the emissions impact assessment. The air or gases emitted from the treatment process could contain high levels of volatile pollutants due to the partitioning of these pollutants from the liquid phase to gas phase. Hence, a complete assessment of the influent liquid chemistry needs to be undertaken to ensure a proper design of the emissions management process. The foam fractionation process can also generate mist in the exhaust air, which can emit pollutants, including PFAS, into the atmosphere. Effective mist elimination, treatment, or recirculation systems should be evaluated and could include the use of demisting pads, a cyclonic demister system, and/or sorbent beds or canisters.

Although metals are unlikely to impact PFAS removal during foam fractionation, the aeration of water during treatment may affect redox-sensitive metals (for example, iron and manganese), which may precipitate as solids. The buildup of solids from precipitated metals, salts, and carbonates may increase the maintenance of foam fractionation equipment so the cost and benefits of additional pretreatment should be considered.

Foam fractionation aeration rates are not usually sufficient to replace other treatment (for example, air stripping) for the removal of volatile constituents from the aqueous stream, but the potential for these contaminants to be present in air emissions should be considered. Pretreatment or treatment of gaseous emissions can mitigate the release of volatiles.

18.4.1.6 Operational Considerations

During the design and operation of foam fractionation systems, there are numerous factors to consider that may affect PFAS removal and waste generation for a particular water stream. Some factors are applicable when selecting a particular piece of equipment while others can be adjusted during operations. When selecting equipment, there is a tradeoff between flexibility and capital cost that should be considered. Adjustable operating parameters may be proprietary, but they generally include:

- Batch vs. semicontinuous batch vs. continuous flow operation
- If batch or semicontinuous batch, the batch duration

- If continuous or semicontinuous, the flow direction (countercurrent or co-current), effluent location (for example, top, middle, or bottom), and overhead pressure
- Liquid level in the vessel
- Influent and effluent flow rate
- Type of gas used
- Volume of gas, velocity and turbulence of gas, size of the subsequent bubble once introduced to liquid
- Method of removing and handling PFAS concentrate within the system
- Number of active treatment stages in the multistage process with bypass feature
- Co-surfactant chemical feed dosage for enhanced PFAS removal, if used
- Additive chemical feed dosage to increase unit process flow, if used
- Off-gas treatment (if needed)

There is sometimes a tradeoff between concentration/enrichment factor and PFAS removal efficiency: Higher gas flow rates and additive dosing can increase PFAS recovery, but lower enrichment, leading to larger waste volumes (**Sochacki, Michorczyk, and Vogt 2025**; **Comfort et al. 2025**; **Klevan et al. 2025**; **Klevan et al. 2025**).

When selecting and optimizing a foam fractionation system, it is important to consider the feed water being supplied. If the feed water is seasonal or intermittent, batch or semibatch systems may provide flexibility if sufficient storage is available to equilibrate flow during high flow periods. Generally, these systems are not negatively impacted by downtime and can be restarted when feed water is available. As with any water treatment equipment, certain parts (for example, pumps, valves, and seals) should be regularly exercised or maintained during prolonged shutdowns.

When starting a foam fractionation system, there is typically a period of optimization during which there may be inconsistencies in treatment and, potentially, lower PFAS removal (**Burns, Stevenson, and Murphy 2021**; **Malovanyy, Forsén, and Lihammer et al. 2025**). Depending on the purpose of treatment and the requirements for discharge/use, it may be necessary to temporarily store treated water during optimization. This water can then be reprocessed after the system has been optimized and its capability to meet discharge requirements has been documented.

Like all water treatment equipment, foam fractionation systems require periodic cleaning and maintenance and may need to be fully drained for long-term storage or relocation. These activities may require storage and disposal of PFAS-impacted waters if there is not available alternative treatment on-site. If the shutdown is temporary, these waters may be stored and processed through foam fractionation when the system is restarted.

Seasonal variations in air and water temperatures are unlikely to affect foam fractionation performance. **We et al. (2024)** found no significant impact of temperature on long-chain PFAS removal, although there may be a slight improvement in short-chain PFAS removal at lower temperatures, but there have been limited studies on this subject.

18.4.1.7 Air Emissions

Releases of PFAS to the atmosphere from the foam fractionation process through volatilization or aerosolization are a concern but may be controlled. Volatile PFAS can be stripped from water and transferred to the vapor phase. Most PFAS of interest have low volatility, so minimal volatilization is expected. Vapor phase controls (for example, vapor-phase GAC) can be included to reduce emissions. Other volatiles (for example, VOCs) can also be stripped during foam fractionation and may require additional vapor phase controls. PFAS in air emissions can also be adsorbed to particulates or entrained in aerosols (**Smith et al. 2023**; **Lee and Venkatesan 2024**; **Nguyen et al. 2024**). These can be mitigated by the design of the system or additional controls such as filters, moisture traps, or knockout pots with

consideration for humid fractionation reactor conditions. Additional information regarding air treatment methods can be found in **Section 12.5** . Some systems have been configured so gases from fractionation vessels are reintroduced into the system. This could lead to the buildup of volatiles in the system if they are present in the water to be treated. The use of monitoring and controls to mitigate any associated risks may be needed. Some systems have been configured so gases from fractionation vessels are reintroduced into the system. This could lead to the buildup of volatiles in the system if they are present in the water to be treated. The use of monitoring and controls to mitigate any associated risks may be needed.

Long-chain PFAS (for example, PFOS, PFOA, PFHxS) can also be generated as aerosols, where small micro/nano bubbles (including macro bubbles) are allowed to burst at the top of the bulk aerated foam fractionation column in the absence of any froth/foam blanket or other mechanical/physical blanket, which would serve to entrap such aerosols (**Lee and Venkatesan 2024**; **Nguyen et al. 2024**).

Air toxics regulations and analytical methods should be evaluated and considered. The ITRC PFAS Air Criteria Table (**PFAS Environmental Media Values Table Excel File)** can be referred to for applicable standards and guidance values for PFAS in air.

In the United States in August 2024, New Jersey, New Mexico, and North Carolina petitioned the USEPA to designate PFOS, PFOA, PFNA, and HFPO-DA (GenX) as hazardous air pollutants, to be regulated under Section 112 of the Clean Air Act.

Section 11.1.7.12 provides sampling procedures for air emissions to air and ambient air, and **Section 11.2** provides additional information regarding USEPA Other Test Method 45 (OTM-45), *Measurement of Selected Per- and Polyfluorinated Alkyl Substances from Stationary Sources, Revision 1* (**USEPA 2024**), and Other Test Method 50 (OTM-50), *Sampling and Analysis of Volatile Fluorinated Compounds from Stationary Sources* (**USEPA 2024**). These could become a future cost driver or consideration as USEPA is increasing testing and developing new methods. For smaller emissions sources, such as the currently available foam fractionation systems, the sample collection protocols in OTM-45 may not be practical or cost-effective. Alternative, non-isokinetic sampling methods, such as those based on USEPA Method TO-13A (**USEPA 1999**), have been independently developed for some applications.

18.4.2 Performance Evaluation

Because PFAS adsorption mechanisms may vary for different water types and foam fractionation equipment, bench and pilot testing are recommended to assess potential performance and optimal operating parameters, which may include:

- The performance of different gas types (air, ozone, nitrogen)
- Bubble sizing
- Air flow rates
- Batch treatment times or hydraulic residence times
- The use and dosage of co-foaming additive(s)

Table 18-5 and subsequent sections describe some of the performance testing that can be completed to aid in the selection and design of foam fractionation systems. When evaluating foam fractionation, practitioners should consider these key questions and their purpose:

1. Is the liquid material to be treated listed as “applicable” or “non-applicable” in **Section 18.4**? This will help set the expectations for the potential to remove PFAS and determine treatment objectives; greater PFAS removal would be expected in applicable liquids.

2. Is there excessive foaming, insufficient foaming, or lack of bubble formation of site water upon conducting lab bench-scale feasibility testing? The foaming characteristics of the water will help determine the predominant PFAS removal mechanisms and corresponding foam fractionation equipment selection and operating settings. They can also determine the need for foam management/suppression systems or indicate the need for non-PFAS-containing foaming additives to enhance PFAS removal.

3. Is there a site history of anti-foaming agent usage (for example, to wastewater or leachate) or use of foam application to manage offensive odors (for example, landfill odor management)? This information will help clarify the expected quality and quantity of foam formed and the considerations in item 2 above (for example, anti-foaming agent presence in the liquid may hinder effective foaming rates, and conversely, the same may be true where foaming agents were used for odor or mist suppression.

4. How stable is the foam (for example, what is the foam collapse rate, such as millimeters of foam height drop over 2 minutes, measured during lab bench-scale feasibility testing, or the concentration of methylene blue–active substances in the liquid)? This can be used to determine whether the foam is stable or transient and can affect how foamate is managed after foam fractionation.

5. What is the optimal liquid height in the foam fractionation column? This will affect PFAS removal rates and overall system throughput.

6. What is the optimal aeration rate and pattern? The pattern of aeration and overall aeration rate can affect PFAS removal rates and the overall quantity of foamate generated. By tuning the system to optimal aeration rates and patterns, including pulsing or stepwise approaches, the PFAS removal rates may be optimized.

7. Should we use aerosol, bubble, or foam fractionation setup? The setup will affect the operating parameters (for example, fill height, aeration rate, foam collection method) that will yield the optimal PFAS removal rate.

8. Which foamate removal system should be applied (for example, weir or vacuum)? The foamate removal configuration can affect both PFAS removal rates and waste volume produced.

9. If short chains need removal, which foam booster of co-surfactant addition should be used, how much, and do these foam boosters transfer into foamate (waste) with PFAS or remain in treated water for recycling in a soil washing batch process? Foaming additives can add cost and complexity to systems and may have their own toxicity that should be considered and balanced against enhanced PFAS removal. Additional discharge permitting considerations should be weighed before deploying field-scale systems.

10. Is the addition of salt needed? High salt concentrations may improve foam fractionation performance, but the benefit must be considered against the additional cost, complexity, and maintenance.

11. What impact does altitude or environmental conditions, such as liquid temperatures, air temperatures, and humidity, have on stripping and enrichment performance? Although there is little evidence that these factors affect foam fractionation performance, difference between bench/pilot test conditions and field conditions should be considered when interpreting data.

12. If hard water is to be treated, how should it be managed (for example, pre-aeration plus filtration plus auto acid dosing to control pH post–foam fractionation at 6.8–7.6, anti-scaling chemical) to

prevent post-foam fractionation scaling and fouling polishing systems and/or aquifer reinjection? Scaling in water treatment equipment can increase maintenance costs and downtime. The potential for scale formation and solids precipitation should be considered and weighed against the cost of additional pretreatment.

13. If co-contaminants are present in the liquid, how might they affect system fouling or performance, either positively or negatively? Knowing the co-contaminant removal potential, such as organics that may increase cleaning frequency or volatile co-contaminants that may necessitate more frequent vapor treatment change-outs, may benefit the overall decision to deploy foam fractionation.

Additional site-specific considerations for foam fractionation include availability of suitable power, location of influent connections, location and type of discharge, location of safe temporary storage of concentrated PFAS waste, and the need for a level surface that can withstand the heavy loads of the treatment equipment (hardstand).

Table 18-5. Summary of performance test options for evaluating foam fractionation.

Test Type	Relative Time to Completion	Relative Cost	Ability to Assess PFAS Removal?	Predictability of Full-Scale Performance
Shake and Foamability Tests	Shortest	Least	No	Poor
Modeling	Short	Low	Maybe	Low[1]
Bench-scale Testing	Moderate-low	Moderate-low	Yes	Moderate[2]
Pilot	Moderate-high	Moderate-high	Yes	High[2]
Full-scale Demonstration	Longest	Highest	Yes	Best

[1] Current models are mostly empirical and are based on past performance. Limited data are available on comparisons among model, pilot, and full-scale foam fractionation systems.
[2] The size and scale of bench- and pilot-test equipment is typically smaller than the full-scale equipment and may provide only an approximation to full-scale operations. The nature and magnitude of uncertainties should be determined in conversations with vendors or consultants and included in interpretation of results.

18.4.2.1 Shake and Foamability Tests

Although not scientifically rigorous, simple shake tests may be used in screening tests to assess whether a specific water will generate foam without the addition of foaming agent (note: the presence/volume of foam created is not necessarily indicative of PFAS removal by foam fractionation). To obtain measurable results, a foamability test is recommended, in which a standard column 0.5 meter in height and 10 centimeters in diameter is used for generating foam in the liquid and the rates of foam formation and collapse are measured.

18.4.2.2 Bench-scale Testing

Bench-scale units can be used to treat a small volume of water using foam fractionation to assess potential PFAS removal rates, the quantity of foamate generated, and concentration factors. Bench-scale tests typically generate insufficient foamate volumes to test additional concentration or destruction steps, so field pilot testing is often used. Removal rates at bench scale may differ from those in full-scale optimized foam fractionation systems due to the limited volumes available for optimization. Aeration rates, fill volumes, treatment times, and surfactant addition (type, dose, rate) can all be tested during

bench or field pilot tests. Descriptions of bench-scale testing are provided in several published articles (**Buckley et al. 2023**; **Buckley et al. 2023**; **Buckley et al. 2022**).

18.4.2.3 Field Pilot Testing

Field pilot testing is the recommended way to assess the suitability of foam fractionation for a particular water (**Klevan et al. 2025**). A foam fractionation pilot test plan should include similar considerations to adsorptive media pilot test plans described in **Section 18.3.2.5**. Foam fractionation pilot tests can be completed using full-scale equipment or smaller equipment designed specifically for pilot testing (**Burns et al. 2022**; **Smith et al. 2022**). Although smaller equipment may decrease the costs of pilot testing, there may be some uncertainty in directly translating results to larger, scaled-up systems. One significant advantage of pilot testing is the ability to test multiple fractionation conditions over the course of the test, including different treatment times, fill volumes, aeration rates, and additive doses, without being limited by the volume of water available in a bench-scale test. The duration of the pilot test can be longer or shorter depending on the conditions to be tested, site-specific objectives, and variability of the source water. Influent and effluent samples are typically collected for each test condition to assess performance. In addition to analyzing samples for PFAS concentration, it may be useful to measure additional parameters such as metals (to assess changes due to oxidation), foaming additives (to measure removal), VOCs (to assess removal), and other parameters that may be useful for a particular application. Emissions control and testing may also be necessary to evaluate evolution of vapors (PFAS or other co-contaminants).

Pilot testing also provides an opportunity to evaluate integration of foam fractionation with existing infrastructure and as part of a treatment train and may be combined with testing additional PFAS removal technologies, such as downstream adsorptive media. Pilot tests should be performed with sufficient duration and treatment volumes to generate a representative volume of PFAS concentrate. Depending on the number of fractionation steps performed, a large volume of water may need to be treated to generate sufficient foamate for evaluation. The volume of final foamate generated can be compared with the volume of water treated to determine a concentration factor, which is useful for full-scale planning and estimating long-term operations and maintenance costs. Larger scale pilot testing can also be useful to generate sufficient foamate to test and evaluate destruction and disposal technologies.

18.4.2.4 Modeling

Laboratory, bench, and pilot testing are currently the best tools to predict performance. Pilot testing is typically the most accurate method for optimizing the design of a foam fractionation system, but has higher costs, especially when scaling up or evaluating multiple process parameters or system configurations. Ideally, process modeling could offer a cost-effective means to use testing data to optimize process parameters and down-select system configurations, reducing the need for extensive experimental trials. However, due to the complex and chaotic nature of the process, there are no known mechanistic models that can generally predict performance across fractionation applications. For instance, researchers have recently developed mechanistic models of varying complexity for protein enrichment applications (**Keshavarzi et al. 2022**; **Grassia 2023**), but so far, no similar model has been translated into a tool used by practitioners in the environmental remediation field. Several scientific publications have investigated the adsorption models and associated parameters for PFAS on bubbles and aerosols (**Buckley et al. 2023**; **Schaefer et al. 2019**; **Brusseau and Van Glubt 2019**; **Brusseau and Van Glubt 2021**; **Sha et al. 2021**; **Wang et al. 2023**), but to date, none of these efforts has been incorporated into publicly available process models for PFAS removal from water. Foam fractionation providers have developed empirical models that can be used to estimate removal of specific PFAS. The performance of these models has not been independently verified, but additional work is ongoing to gather performance data to improve predictive performance based on influent water chemistry. As foam fractionation evolves, further data are collected, and a greater understanding of water chemistry effects is obtained, algorithms may be improved, or empirical models developed.

18.4.3 Fate of PFAS-containing Foams

The objective of foam fractionation is to concentrate large volumes of water with dilute PFAS concentrations into small volumes with high PFAS concentration. Separated foam, bubbles, or aerosols from the initial fractionation stage can be processed through additional stages to provide further volume reduction and increasing PFAS concentration. Depending on the liquid matrix type (for example, groundwater, landfill leachate), volumetric concentration factors of 10 times to 1,000,000 times have been achieved, such that the processing of 1,000,000 gallons of influent results in the generation of 1 gallon of foam concentrate or foamate as the foam eventually condenses back to an aqueous solution (**Burns, Stevenson and Murphy 2021**; **Smith et al. 2022**; **Wang et al. 2023**). The volumetric concentration factor is unique for each water and foam fractionation process and cannot be easily predicted without bench and/or pilot testing. This foamate is then more economical and efficient for consideration to be processed by various field-implemented or emerging destructive treatment technologies or disposal methods, including, but not limited to, those listed below. When considering the economics of destruction and disposal, it is important to consider trade-offs between volumetric concentration, PFAS removal, and system throughput.

- Sorption and Stabilization/Solidification (**Section 12.7.1**)
- Supercritical Water Oxidation (SCWO) (**Section 12.6.3.12** and **Section 1.6.2**)
- Alkaline Hydrothermal Reaction (**Section 12.6.5**)
- Electrochemical Treatment (**Section 12.6.3.6**)
- Plasma Technology (**Section 12.6.3.8**)
- Photolysis/Photochemical Oxidation (**Section 12.6.3.5**)
- Incineration (**Section 12.4**)
- Deep Well Injection (**Section 12.6.6**)

18.5 Resources for Decision-Making

Many factors should be considered when identifying a PFAS solution, including the treatment objectives and site-specific factors discussed in **Section 18.2**. Competing cost drivers, environmental impacts, and life cycle sustainability considerations (**Section 12.9**) also factor into these decisions. Several resources are available to develop preliminary cost estimates.

USEPA has published example applications of their own cost models of PFAS treatment of drinking water for GAC, IX, and membrane systems (**USEPA 2023**). Although capital costs for adsorption-based technologies are somewhat transferable across applications, O&M costs will heavily depend on project specifics, including influent water quality, influent PFAS types and concentrations, and targeted effluent PFAS types and concentrations. Costs may also vary significantly based on the degree of pretreatment required prior to adsorptive treatment. A study commissioned by the Minnesota Pollution Control Agency (MPCA) provided cost curves for treating liquid waste streams using multiple adsorptive technology configurations, including GAC, IX, RO with GAC+IX treatment of concentrate, and foam fractionation (**Barr Engineering Co. & Hazen and Sawyer 2023**). In the MPCA study, pretreatment of wastewater effluent prior to adsorption accounted for one-third to one-half of 20-year costs, depending on facility size and characteristics. All costs presented included high-temperature incineration of treatment residuals. Cost curves included wastewater effluent for facilities treating between 0.1 million gallons per day (MGD) and

10 MGD and landfill leachate and compost contact water for facilities managing between 1 gpm and 100 gpm (**Barr Engineering Co. & Hazen and Sawyer 2023**). The costs developed for aqueous solutions were associated with individual treatment targets (objectives) to reduce concentrations to 5 ng/L each for PFOS, PFOA, PFHxA, PFBS, PFBA, and 6:2 FTS, with N-EtFOSAA included only for landfill leachate. Most notable were the targets of 5 ng/L associated with short-chain PFAS (PFBS and PFBA). For municipal wastewater treatment plant effluent, the cost study generally estimated 10,000 bed volumes treated before change-out using GAC, and 20,000 bed volumes using IX resins, with a 67% removal rate for each of PFBS and PFBA.

Consideration of social and environmental externalities may also drive decision-making for adsorption-based technology adoption. These can be positive externalities such as reduction in health impacts or improved community resources or negative externalities such as greenhouse gas emissions, ecotoxicity, or degradation of community resources. Social impacts may be difficult to quantify, but planners should engage with community stakeholders early in the project to align interests and communicate project goals. The **USEPA (2024)** has developed the Clean Water Act Financial Capability Assessment Guidance as a tool that can be used to consider economic impacts to a community and its capability to implement controls such as sorption-based PFAS treatment to meet PFAS treatment objectives. Environmental impacts can be evaluated using several different approaches. LCA tools have been used to compare environmental impacts of single-use media use versus IX regeneration and GAC reactivation (**Boyer et al. 2021**; **Ellis et al. 2023**). LCA considers ongoing use of chemicals, water, and energy across use, treatment, and residuals disposal and can be estimated using simple calculation-based models or more complex software such as OpenLCA or SimaPro. The USEPA provides a broader list of tools for environmental impact assessment applicable to remediation projects, many of which can be adapted to water treatment projects (**CLU-IN n.d.**). Additional sustainability evaluation resources are also available through USEPA (**USEPA 2025**).

An example decision matrix for assessment of GAC, IX resins (usually anion exchange resins), and foam fractionation can be found in **Table 18-6**. The example decision matrix compares three different adsorption treatments and provides an evaluation based on several decision-making criteria. For this example, all three treatments are assumed to be able to meet treatment goals. However, each treatment has different advantages and disadvantages depending on site-specific factors. General pros include (1) GAC generally has lower unit costs than IX resin, (2) IX may have a smaller footprint and higher mass loadings, and (3) foam fractionation has a high concentration factor and low pretreatment. This example table provides a comprehensive comparison of these three treatments based on various criteria to help in the decision-making process. Some states have also published decision-making tools for PFAS treatment selection. For instance, Arizona has published a set of decision trees to aid in selection between GAC, IX, and high-pressure membranes for PFAS treatment in drinking water (**AZ DEQ 2024**). This example matrix helps evaluate options and make informed choices by comparing them against specific criteria (effectiveness under varying conditions, capital and operational expenses, and other factors). Judgments in this table were derived from information presented in the PFAS-1 Document (**https://pfas-1.itrcweb.org**) and available literature (**Burns, Stevenson, and Murphy 2021**; **DiGuiseppi et al. 2024**; **Ellis et al. 2022**; **Grieco et al. 2021**; **Liu and Sun 2021**; **Murray et al. 2021**; **Murray et al. 2023**; **USEPA 2024**; **We et al. 2024**). This decision matrix table is provided as an example. Actual selection of technologies may vary depending on site-specific conditions.

When evaluating water containing PFAS to be treated, understanding the basic pros, cons, and limitations of available treatment technologies can assist decision-making. However, different states, counties, and industries are starting to create their own PFAS guidelines and, as a widespread emerging class of contaminants, PFAS and PFAS technologies are rapidly evolving. These challenges are discussed in greater detail in **Section 18.6**.

Table 18-6. Example decision matrix comparing foam fractionation, GAC, and IX resin.

Adsorption Treatment	Foam Fractionation[1] (FF)	Granular Activated Carbon (GAC)	IX Resin (IX)
Decision-Making Criteria			
Ability to Treat High Concentration (>1 ppm) PFAS Influent	Up to ~10 ppm limit, depends on mix of PFAS	Limited by size/cost	Limited by size/cost
Treatment of Short-Chains (<6C)	Low removal without foaming additives	Typically low efficiency but depends on specific PFAS and design EBCT	Moderate to slightly more efficient than GAC
End Waste Product Mass/Volume	Liquid PFAS waste 500–1,000,000x Volumetric concentration factor	ug/g to mg/g sorptive capacities possible, ~85% sorbent reuse with reactivation	ug/g to mg/g sorptive capacities possible; regeneration and reuse are possible but may not be economical
TOC, Ion, Metal Interference	Little to none	TOC competes for adsorption site and reduces PFAS adsorption capacity, increases of 0.1 to 1 mg/L can drop the bed volumes to breakthrough by an order of magnitude. Precipitation and clogging can increase backwashing frequency	Ions and organic acids can outcompete PFAS for exchange sites on the beads
Solids	Above 2% requires filtration	Suspended solids may clog access to surface area, requiring backwashing and potentially reduced adsorption capacity when fouled	Similar solids concern to GAC
Pretreatment Requirement	Oily water, very high solids	Oily water, solids, high TOC, high Fe/Mn	Oily water, solids, high TOC, salinity, and other anions
Capital Expenditure[2]	Medium	Low to medium, depends on pretreatment requirements	Low to medium, depends on pretreatment requirements
Operational Expenditure[2]	Low, generally less reoccurring costs than sorbents due to lack of media. Concentrate disposal is a consideration. Higher electric demand for low concentrations.	Medium, reoccurring cost of GAC and reactivation or disposal	Higher unit cost of sorbent than GAC
General Pros	High concentration factor/low pretreatment. Small liquid waste volumes. No sorptive media.	Reactivation possibility, generally stakeholder acceptable, generally lower unit cost than resin	May be a smaller footprint. Potentially for higher mass loadings and selectivity
General Cons	Most applicable to long chains/new developments still occurring. Limited throughput in current commercially available systems (<500 gpm). Not typically effective at low concentrations	Complex geochemistry interferes with PFAS removal. Perpetual change-outs and often more frequent than piloted change-outs	Higher unit cost of the sorbent, perpetual change-outs though frequency may be lower than with GAC

[1] Note that though this example decision matrix table evaluates technologies individually, foam fractionation can be combined with GAC/IX resin depending on site-specific concentrations and conditions.
[2] Capital and operational expenditures can vary depending on vendor-specific equipment.

18.6 Barriers, Challenges, and Outlook

Although adsorption-based technologies have proven successful at treating PFAS-impacted water in an array of applications and situations, and the state of knowledge and practice has matured significantly in recent years, practitioners and decision makers may still face challenges and barriers when selecting or implementing these technologies. Performance problems associated with poorly adsorbing PFAS or especially challenging matrixes have already been discussed in previous sections. Therefore, this section will instead focus on regulatory issues, knowledge gaps, and practical resource limitations.

The quickly evolving discovery and research regarding PFAS toxicology and impacts to human health and the environment, and the development and improvement of PFAS analytical techniques, will continue to drive regulatory changes that impact treatment objectives or the transport and disposal of treatment residuals. Although uncertainty exists, the potential for these changes should be considered in evaluating and selecting a PFAS treatment process because the expected lifespan of the treatment equipment may span multiple decades. Consider to what extent PFAS separation can be achieved by the proposed treatment. Consider whether treatment can be expanded in the future or whether other treatment(s) could be added to the treatment train expansion to meet future requirements. Consider the potential for other PFAS to become regulated or for existing PFAS regulatory standards to become more stringent. Depending on locality and application, practitioners and decision makers may encounter overlapping regulations, permitting requirements, and guidance. However, difficulties in this area will likely abate as rules and regulations are finalized and practitioners gain more familiarity with them as the number of full-scale treatment systems in operation increases.

Financial challenges, difficulty purchasing equipment, and lack of operator/maintenance availability can be particularly difficult for small drinking water systems or utilities in remote locations. The **USEPA (2024)** Small and Rural Systems Fact Sheet summarizes resources available for implementation, funding, and technical assistance to help utilities face these challenges.

Supply chain issues may lead to shortages of media and equipment due to dramatically increased demand. Also, capacity of related services such as analytical laboratory capacity for PFAS may be limiting. However, both issues are likely temporary and will lessen as manufacturers and labs expand operations to meet the increased demands. In addition to the laboratory capacity issues already noted, the lack of rapid, on-site quantitation techniques can present challenges for some applications. Also, quantification of PFAS in challenging matrices, such as waters containing high levels of non-target PFAS, can make quantitation of target PFAS challenging. Advances in techniques or technology may be needed to fully address these challenges.

Utilities, especially potable water utilities, may face challenges with communication issues regarding treatment decisions. For instance, customers may have questions about health risks or why only some PFAS are being treated. This challenge and some strategies for addressing it are discussed in more detail in **Section 14**. Furthermore, these issues are not necessarily unique to PFAS, and many utilities already confront similar issues for other water contaminants, such as disinfection byproducts. Utilities and remediation specialists are encouraged to work with state, tribal, and federal partners to develop communication plans to address these issues.

Performance modeling for adsorptive processes, which can be used to maximize utility of testing data and inform cost analysis, faces several challenges. Very few open-source, transparent models are available. USEPA has open-source tools for modeling GAC and IX columns, but parameters for only a few IX resins are published and the effects of background organic matter are difficult to model. A large contributor to these challenges has been the lack of useful laboratory and field data collected with modeling specifically in mind. It can be reasonably expected that additional laboratory studies and increasing availability of pilot data will enable further performance model development.

Along with performance modeling development, wider adoption of lab-scale test procedures such as RSSCTs could potentially increase productivity or reduce the cost of pilot testing and permitting. However, several knowledge gaps remain in this area, and protocols and practice are not yet standardized, especially for IX resins. There are still some basic questions about mechanisms of adsorption of PFAS on GAC and IX resins and the effects of grinding on IX resins that, if answered, would provide additional confidence in conclusions and predictions developed using RSSCTs and other lab-scale tests.

When designing and implementing treatment systems, practitioners often fall back on internal institutional knowledge or standards and design documents that were not designed for the challenges and unique behaviors of PFAS. As such, there is an important opportunity for development of consensus and industry standards of practice to reduce time and cost of designing, reviewing, and optimizing treatment systems.

Current foam fractionation methods can effectively remove long-chain PFAS, including most USEPA-regulated compounds, but struggle with shorter chain PFAS, including PFBS, which is also USEPA-regulated in drinking water. Cationic and non-ionic surfactants have shown promise in removing short-chain PFAS, including PFBS. However, the use of these additives faces challenges with approval and permitting due to knowledge gaps. For instance, analytical methods and detection limits for measuring additive discharge (especially if additives are proprietary) make studying them challenging. Additional research efforts, including toxicity and biodegradation studies, are likely needed before processes using these additives see wide adoption. Scale up of foam fractionation may also be a barrier for some applications. Current commercially available foam fractionation systems typically have flow rate limitations. Although they can be scaled by installing additional treatment units in parallel, this may reach a point of diminishing returns. Research and testing of larger scale foam fractionation systems, capable of treating millions of gallons per day, are ongoing but have not been demonstrated commercially.

Although many barriers and challenges have been discussed here, there is cause for optimism. In general, most of these challenges are expected to lessen as regulatory rules are finalized, regulators and practitioners reach consensus on best practices, and standards are established. Future advances in research and technology of novel sorbents, sorbent regeneration, and PFAS destruction technologies will bring more options for adsorbent and process selection and will potentially make adsorption-based technologies viable for a wider range of waters and site conditions.

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ACRONYMS

AACO	Army Aviation Centre Oakey
AA-QS	annual average quality standards
ADONA	trade name for 4,8-dioxa-3H-perfluorononanoate
AERMOD	American Meteorological Society/EPA Regulatory Model
AFCEC	Air Force Civil Engineering Center
AFFF	aqueous film-forming foam
ALT	alanine aminotransferase
AmPr-FHxSA	N-dimethyl ammonio propyl perfluorohexane sulfonamide
amu	atomic mass unit
ANSES	French National Agency for Food Safety, Environment and Labor
ANSI	American National Standards Institute
AOF	adsorbable organic fluorine
APC	air pollution control
APFN	ammonium perfluorononanoate
APFO	ammonium perfluorooctanoate
ARAR	applicable or relevant and appropriate requirement
AM	arithmetic mean
ANPRM	Advance Notice of Proposed Rulemaking
ARP	advanced reduction processes
ATSDR	Agency for Toxic Substances and Disease Registry
AWI	Air-water interface
AWQC	ambient water quality criteria

BAF	bioaccumulation factor
BARC	bottom antireflective coatings
BAT	best available technology economically achievable
BBMD	Bayesian benchmark dose
BCF	bioconcentration factor
BERA	baseline ecological risk assessment
bgs	below ground surface
BMD	benchmark dose
BMF	biomagnification factor
BMP	best management practices
BOHP	$Bi_3O(OH)(PO_4)_2$
BSAF	biota-sediment accumulation factor
BuFASA	*N*-butyl perfluoroalkane sulfonamide
BuFASE	*N*-butyl perfluoroalkane sulfonamido ethanols
BuFASAA	*N*-butyl perfluoroalkane sulfonamido acetic acid
BV	bed volume
BW	body weight
C	carbon
C8	historical name for PFOA
C&D	construction and demolition
CAA	Clean Air Act
CAC	colloidal activated carbon
CalEPA	California Environmental Protection Agency

CAP	chemical action plan, or corrective action plan
CAPEX	capital expenses
CAS	Chemical Abstracts Service
CBPR	community-based participatory research
CCL	Contaminant Candidate List
CCV	continuing calibration verification
CDC	U.S. Centers for Disease Control and Prevention
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CHP	catalyzed hydrogen peroxide
CIC	combustion ion chromatography
CIMS	chemical ionization mass spectrometry
CL	clearance factor
ClPFPECA	chloroperfluoropolyether carboxylate
CMC	critical micelle concentrations
CNT	carbon nanotube
COOH	carboxylic acid functional group
CSF	cancer slope factor
CSM	conceptual site model
CWA	Clean Water Act
Da	Dalton (unit of mass)
DDT	dichlorodiphenyltrichloroethane
DIN EN	Deutsches Institut für Normung, German Institute for Standardization, English

diPAPs	polyfluoroalkyl phosphoric acid diesters
DMSO	dimethyl sulfoxide
DNAPL	dense nonaqueous phase liquid
DOC	dissolved organic carbon
DQO	data quality objective
DRE	destruction and removal efficiency
DW	drinking water
DWR	durable water repellent
EAO	emergency administrative order
EBCT	empty bed contact time
ECCC	Environment and Climate Change Canada
ECF	electrochemical fluorination
ECHA	European Chemicals Agency
ECOS	Environmental Council of the States
ECT	Emerging Compound Treatment Technologies, Inc.
EE/CA	Engineering Evaluation/Cost Analysis
EIS	extraction internal standards
ELG	effluent limitation guidelines
EPC	exposure point concentration
ERA	ecological risk assessment
ERB	equipment rinse blank
ESS	Environmental Sequence Stratigraphy
ESTCP	Environmental Security Technology Certification Program

EtFASA	*N*-ethyl perfluoroalkane sulfonamide
EtFASE	*N*-ethyl perfluoroalkane sulfonamido ethanol (var: N-ethyl perfluoroalkane sulfonamide ethanol)
EtFASAA	*N*-ethyl perfluoroalkane sulfonamido acetic acid (var: *N*-ethyl perfluoroalkane sulfonamide acetic acid)
ETFE	ethylene tetrafluoroethylene
EtFOSA	*N*-ethyl perfluorooctane sulfonamide
EtFOSAA	2-(N-ethyl-perfluorooctane sulfonamide) acetic acid
EtFOSE	*N*-ethyl perfluorooctane sulfonamido ethanol (var: *N*-ethyl perfluorooctane sulfonamide ethanol)
EU	European Union
F	fluorine
F-53B	chlorinated polyfluorinated ether sulfonate (PFOS substitute for plating)
F3	fluorine-free foams
FAA	Federal Aviation Administration
FAQ	frequently asked questions
FASA	perfluoroalkane sulfonamide
FASE	perfluoroalkane sulfonamido ethanol (var: perfluoroalkane sulfonamide ethanol)
FASAA	perfluoroalkane sulfonamido acetic acid (var: perfluoroalkane sulfonamide acetic acid)
FBSA	perfluorobutane sulfonamide
FCM	food contact materials
FCS	food contact substances
FD	field duplicate
FDA	U.S. Food and Drug Administration

FEC	Foam Exposure Committee
FECA	fluorinated ether carboxylate
FEP	perfluorinated ethylene-propylene
FFFC	Fire Fighting Foam Coalition
FFFP	film-forming fluoroprotein foam
FhxSA	perfluorohexane sulfonamide
f_{oc}	fraction of organic carbon
FOSA, or PFOSA	perfluorooctane sulfonamide
FOSE	perfluorooctane sulfonamido ethanol (var: perfluorooctane sulfonamide ethanol)
FOSAA	perfluorooctane sulfonamido acetic acid (var: perfluorooctane sulfonamide acetic acid)
FP	fluoroprotein (used in the contex of firefighting foam formulations that contain a fluorinated surfactant)
FRB	field reagent blank
FRM	Federal Reference Method
FSANZ	Food Standards Australia and New Zealand
fT4	free thyroxine
FTA	fire training area
FTCA	fluorotelomer carboxylic acid
FT-ICR	Fourier transform ion cyclotron resonance
FTOH	fluorotelomer alcohol
FTSA or FTS	fluorotelomer sulfonate, fluorotelomer sulfonic acid
FtTAoS	fluorotelomer thioether amido sulfonate
FTUCA	fluorotelomer unsaturated carboxylic acid

FWQC	federal water quality goal
GAC	granular activated carbon
GC	gas chromatography
GC/MS	Gas chromatography/mass spectrometry
GEF	Global Environment Facility
GenX	trade name for a polymerization processing aid formulation that contains ammonium 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoate
GLI	Great Lakes Initiative
GM	geometric mean
GMAV	genus mean acute value
HA	health advisory
HALT	hydrothermal alkaline treatment
HASP	Health and Safety Plan
HDPE	high-density polyethylene
HFPO-DA	hexafluoropropylene oxide dimer acid
HHRA	human health risk assessment
HI	hazard index
HQ	hazard quotient
HRMS	high-resolution mass spectrometry
HRSC	High-resolution site characterization
IARC	International Agency for Research on Cancer
ICAO	International Civil Aviation Organization
ICV	initial calibration verification
IDA	isotope dilution analysis

IDW	investigation-derived waste
IPEN	International Pollutants Elimination Network
IRIS	Integrated Risk Information System
ITRC	Interstate Technology and Regulatory Council
IX	ion exchange
K_d	bulk partitioning coefficient
K_{oc}	organic carbon partitioning coefficent
K_{ow}	water/octanol coefficient
LC	liquid chromatography
LC/MS/MS	liquid chromatography/mass spectrometry/mass spectrometry
LCS	lab control sample
LCPFAC	long-chain perfluoroalkyl carboxylate
LDPE	low-density polyethylene
LEAF	Leaching Environmental Assessment Framework
LHA	lifetime health advisory
LHWA	Little Hocking Water Association
LNAPL	light nonaqueous phase liquid
LOAEL	lowest observed adverse effect level
LOEC	lowest observed effect concentration
LOQ	limit of quantitation
MA DEP	Massachusetts Department of Environmental Protection
MAC-QS	maximum acceptable quality standards
MALDI-TOF	matrix-assisted laser desorption/ionization time-of-flight

MCL	Maximum Contaminant Level
MDH	Minnesota Department of Health
MeFASA	*N*-methyl perfluoroalkane sulfonamide
MeFASE	*N*-methyl perfluoroalkane sulfonamido ethanol (var: *N*-methyl perfluoroalkane sulfonamide ethanol)
MeFASAA	*N*-methyl perfluoroalkane sulfonamido acetic acid (var: *N*-methyl perfluoroalkane sulfonamide acetic acid)
MeFOSA	*N*-methyl perfluorooctane sulfonamide
MeFOSAA	2-(N-methyl-perfluorooctane sulfonamide) acetic acid
MEP	Multiple Extraction Procedure
MGD	million gallons per day
ML	method limit
MNA	monitored natural attenuation
MOA	mode of action
MPCA	Minnesota Pollution Control Agency
MRL	minimal risk level, or minimum reporting limit (laboratory analytical)
MRM	multiple reaction monitoring
MS	mass spectrometry
MSD	matrix spike duplicate
MSW	municipal solid waste
MWCO	molecular weight cut-off
NAM	new assessment method
NaPFO	sodium perfluorooctanoate
NAPL	nonaqueous phase liquid
NCOD	National Contaminant Occurrence Database

NER	non-extractable residues
NESHAP	National Emissions Standards for Hazardous Air Pollutants
N-EtFBSE	N-Ethylperfluorobutanesulfonamidoethanol
N-EtFHxSE	N-Ethylperfluorohexanesulfonamidoethanol
N-EtFOSA	N-ethyl perfluorooctane sulfonamide
N-EtFOSE	N-Ethylperfluorohexanesulfonamidethanol
N-MeFBSE	N-Methylperfluorobutanesulfonamidoethanol
N-MeFHxSE	N-Methylperfluorohexanesulfonamidoethanol
N-MeFOSE	N-Methylperfluorooctanesulfonamidoethanol
NF	nanofiltration
NFPA	National Fire Protection Association
NGWA	National Groundwater Association
NHANES	National Health and Nutrition Examination Survey
NHDES	New Hampshire Department of Environmental Services
NJ DEP	New Jersey Department of Environmental Protection
NJDWQI	New Jersey Drinking Water Quality Institute
NMeFOSAA	N-Methylperfluorooctane sulfonamidoacetic acid
NOAEL	no observed adverse effect level
NOEC	no observed effect concentration
NOM	natural organic matter
NOx	nitrogen oxides
NPCA	Norwegian Pollution Control Agency
NPDES	National Pollutant Discharge Elimination System

NPDWRs	National Primary Drinking Water Regulations
NPL	National Priorities List
NSF	National Sanitation Foundation
NTP	National Toxicology Program
NWQC	national water quality criteria
NYDEC	New York State Department of Environmental Conservation
O&M	operation and maintenance
OAT	organic anion transporter protein
OC	organic carbon
OCPSF	organic chemicals, plastics and synthetic fibers
OECD	Organisation for Economic Co-operation and Development
OEHHA	Office of Environmental Health Hazard Assessment (California)
OH	hydroxide ion, or hydroxyl group (**Helmenstine 2018**)
OPEX	operating expenses
ORD	Office of Research and Development (USEPA)
OSB	oriented strand board
OU	operable unit
PAB	permeable absorptive barrier
PA DEP	Pennsylvania Department of Environmental Protection
PAC	powdered activated carbon
PAF	perfluoroalkanoyl fluorides
PAH	polycyclic aromatic hydrocarbon
PAPs	polyfluorinated phosphate esters

PASF	perfluoroalkane sulfonyl fluoride
PBSF	perfluorobutane sulfonyl fluoride
PBT	persistent, bioaccumulative, and toxic
PCA	principal components analysis
PCBs	polychlorinated biphenyls
PCE	perchloroethylene, tetrachloroethene
PE	performance evaluation
PFA	perfluoroalkoxy polymer
PFAA	perfluoroalkyl acid
PFAI	perfluoroalkyl iodides
PFAS	per- and polyfluoroalkyl substances
PFBA	perfluorobutanoate, perfluorobutanoic acid, perfluorobutyrate, perfluorobutyric acid
PFBE	perfluorobutyl ethylene
PFBS	perfluorobutane sulfonate, perfluorobutane sulfonic acid
PFC	perfluorocarbon (C_nF_{2n+1}, for example, perfluorooctane) *Do not use this acronym for any other description including perfluorinated compound or perfluorochemical.*
PFCA	perfluoroalkyl carboxylate, perfluoroalkyl carboxylic acid
PFDA	perfluorodecanoate, perfluorodecanoic acid
PFDoA, or PFDoDA	perfluorododecanoate, perfluorododecanoic acid
PFDoS, or PFDoDS	perfluorododecane sulfonate, perfluorododecane sulfonic acid
PFDS	perfluorodecane sulfonate, perfluorodecane sulfonic acid
PFECA	per- or polyfluoroalkyl ether carboxylic acid
PFEI	perfluoroethyl iodide (aka fluorotelomer iodide)

PFESA	per- or poly- fluoroalkyl ether sulfonic acid
PFEtA	perfluoroethanoate, perfluoroethanoic acid
PFEtS	perfluoroethane sulfonic acid
PFHpA	perfluoroheptanoate, perfluoroheptanoic acid
PFHpS	perfluoroheptane sulfonate, perfluoroheptane sulfonic acid
PFHxA	perfluorohexanoate, perfluorohexanoic acid
PFHxS	perfluorohexane sulfonate, perfluorohexane sulfonic acid
PFIB	perfluoroisobutylene
PFMOAA	perfluoro-2-methoxyacetic acid
PFNA	perfluorononanoate, perfluorononanoic acid
PFNS	perfluorononane sulfonate, perfluorononane sulfonic acid
PFO3OA	perfluoro(3,5,7-trioxaoctanoic) acid
PFOA	perfluorooctanoate, perfluorooctanoic acid, perfluorooctane carboxylate
PFOS	perfluorooctane sulfonate, perfluorooctane sulfonic acid
PFOSA, or FOSA	perfluorooctane sulfonamide
PFPA	perfluorophosphonic acid
PFPE	perfluoropolyether
PFPeA	perfluoropentanoate, perfluoropentanoic acid
PFPeS	perfluoropentane sulfonate, perfluoropentane sulfonic acid
PFPiA	perfluorophosphinic acid
PFPrA	perflurorpropanoate, perfluoropropanoic acid
PFPrS/strong>	perfluoropropane sulfonic acid
PFSA	perfluoroalkyl sulfonate, perfluoroalkane sulfonic acid

PFSiA	perfluoroalkyl sulfinic acid
PFTeDA, or PFTA, PFTDA	perfluorotetradecanoic acid
PFTeDS, or PFTS	perfluorotetradecane sulfonate, perfluorotetradecane sulfonic acid
PFTrDA, or PFTriA	perfluorotridecanoic acid
PFTrDS, or PFTriS	perfluorotridecane sulfonate, perfluorotridecane sulfonic acid
PFUnA, or PFUnDA	perfluoroundecanoate, perfluoroundecanoic acid
PFUnS, or PFUnDS	perfluoroundecane sulfonate, perfluoroundecane sulfonic acid
PVF	polyvinyl fluoride
pg/m^3	picogram per cubic meter
pH	negative log of hydrogen ion concentration (measure of acidity)
PHxSF	perfluorohexane sulfonyl fluoride
PICs	products of incomplete combustion
PIGE	partice-induced gamma-ray emission spectroscopy
PIH	pregnancy-induced hypertension
PILI	polymer with ionic liquid coated iron
PNEC	predicted no-effect concentration
POD	porewater observation device
POE	point of exposure
POET	point of entry treatment
polyDADMAC	Polydiallyldimethylammonium chloride
POP	persistent organic pollutant
POPRC-14	14th meeting of the POPs Review Committee
POSF	perfluorooctane sulfonyl fluoride

POU	point of use
PPAR-α	peroxisome proliferator-activated receptor-α
ppb	parts per billion
PPE	personal protective equipment
ppm	parts per million
ppt	parts per trillion
PPRTV	Provisional Peer-Reviewed Toxicity Values
PSA	prostate-specific antigen
PSD	passive sampling device
PTFE	polytetrafluoroethylene
PUF	polyurethane foam
PVDF	polyvinylidene fluoride
PWS	public water system
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
QL	quantitation limit
QPD	qualified products database
QPL	Qualified Product Listing
QSAR	quantitative structure-activity relationship
QSM	Quality Systems Manual
qTOF/MS	quadrupole time of flight-mass spectrometry
RAO	remedial action objective

RCRA	Resource Conservation and Recovery Act
REACH	European Chemicals Regulation
RfD	reference dose
RI/FS	Remedial Investigation/Feasibility Study
RIVM	Netherlands National Institue for Public Health and the Environment
RL	reporting limit
RML	removal management level
RO	reverse osmosis
RPD	relative percent difference
RPF	relative potency factor
RSC	relative source contribution
RSL	regional screening level (Note: In many commercial venues RSL means "restricted substances list.")
RSSCT	rapid small-scale column testing
SAP	Sampling and Analysis Plan
SCWO	supercritical water oxidation
s.d. or SD	standard deviation
SDS	Safety Data Sheet
SDWA	Safe Drinking Water Act
SERDP	Strategic Environmental Research and Development Program
SIP	sorbent-impregnated polyurethane foam
SL	screening level
SMART	specific, measurable, attainable, relevant, and timely (goal)
SMAV	species mean acute value

SML	surface micro layer
SMZ	surface-modified zeolites
SNUR	Significant New Use Rule
SPE	solid-phase extraction
SPFO	sodium perfluorooctanoate
SPLP	Synthetic Precipitation Leaching Procedure
SSD	species sensitivity distribution
STAR	Spill Tactics for Alaska Responders
TANA	Technical Assistance Needs Assessments
TARC	top-layer antireflective coatings
TBC	to-be-considered values
TBEL	technology-based effluent limits
TCE	trichloroethene
TCEQ	Texas Commission for Environmental Quality
TCLP	Toxicity Characteristic Leaching Procedure
TDS	total dissolved solids
TEQ	toxic equivalency quotient
TFA	trifluoroacetic acid
TFE	tetrafluoroethylene
TFMS	trifluoromethanesulfonic acid
TFSI	1,1,1-trifluoro-N-(trifluoromethyl)sulfonylmethanesulfonamide
TMDL	total maximum daily loads
TMF	trophic magnification factor

TO	Toxic Organic (method)
TOC	total organic carbon
TOF	time-of-flight
TOP	total oxidizable precursor
TRRP	Texas Risk Reduction Program
TRV	toxicity reference value
TSH	Thyroid-stimulating hormones
TSCA	Toxic Substances Control Act
TTDs	target organ toxicity doses
UCMR	Unregulated Contaminant Monitoring Rule
UF	ultrafiltration
mg/kg	micrograms per kilogram
UL	Underwriters Laboratories
U.S.C.	United States Code
USDOD	United States Department of Defense
USDW	Underground sources of drinking water
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VDEC	Vermont Department of Environmental Conservation
VDH	Vermont Department of Health
VOC	volatile organic compound
WQBEL	water quality-based effluent limits
WV	wildlife value

ww	wet weight
WWTP	wastewater treatment plant
ZVI	zero-valent iron

GLOSSARY

A

Adsorption
The mechanism whereby ions or compounds within a liquid or gas adhere to a solid surface upon contact. The term also refers to a method of treating wastes in which activated carbon is used to remove organic compounds from wastewater.

Anion
A negatively charged ion.

Arithmetic mean
The sum of a collection of numbers divided by the number of numbers in the collection, commonly referred to as the "average".

B

Biochar
A carbon-rich, porous solid synthesized by heating biomass, such as wood or manure, in a low-oxygen environment (pyrolysis).

Biomaterials
Materials derived from plants or animals created for use as sorption materials.

C

Cation
A positively charged ion.

Coagulation
The process of destabilizing a colloid or suspension that unbalances the forces that separate the particles, often by neutralizing the charges on the particles and allowing the particles to clump or settle.

E

Electro precipitation/electrocoagulation
The use of an electrical current to enhance the coagulation and precipitation of ionic compounds. The electrical current may attract the compounds to an anode or cathode, or create coagulating ions from a sacrificial anode, or both.

Empty Bed Contact Time (EBCT)
A measure of the time during which water to be treated is in contact with the treatment medium in a contact vessel, assuming that all liquid passes through the vessel at the same velocity. EBCT is equal to the volume of the empty bed divided by the flow rate (**Sacramento State University 2019**).

F

Flocculation
A process in which the suspended particles of a destabilized colloid or suspension form groups or

clumps (known as a “floc”). Coagulation and flocculation work together to separate solids and liquids containing colloids and suspensions.

Fluorotelomer substance
A polyfluoroalkyl substance produced by the telomerization process.

G

Geometric mean
The central tendency or typical value of a set of numbers, derived by multiplying the numbers in a set then finding the nth root of the product, where “n” is the number of values in the set.

H

Head
The part of a molecule that is a charged functional group attached at one end of the carbon chain tail.

I

Incineration
Thermal destruction process typically characterized by oxidation at temperatures in excess of 1,000°C.

Isomers
Chemicals with the same chemical formula, but different molecular structures.

M

Membrane fouling
Loss of production capacity of a membrane due to accumulation of compounds or biogrowth on the membrane.

Micelles
Particles in which long hydrocarbon tails, repelled by the water molecules and attracted to each other, make up the interior, whereas the negatively charged heads coat the surface and interact with the surrounding water molecules and positive ions (**Ege 1999**).

Mineralization/decomposition/destruction
The breakdown of a chemical compound into its constituent elements and carbon dioxide and water.

Moiety
A specific group of atoms within a molecule that is responsible for characteristic chemical reactions of that molecule (**Helmenstine 2019**).

O

Organoclays
A naturally occurring clay mineral that is organically modified to incorporate cations and enhance the sorption capability.

P

Perfluorinated chemical
Subset of PFAS. Have carbon chain atoms that are totally fluorinated. Examples are perfluorooctanoate (PFOA) and perfluorooctane sulfonate (PFOS) (Buck et al. 2011).

Perfluoroalkyl substance
Fully fluorinated alkane (carbon chain) molecule. They have a chain (tail) of two or more carbons atoms with a charged functional group (head) attached at one end.

Permeate
The water treated by a membrane filtration technology, which has passed through the membrane, and from which PFAS have been removed. The contaminants not passing the membrane accumulate in the filtrate, which also does not pass through the membrane.

Polyfluorinated chemical
Subset of PFAS. Have at least one carbon chain atom that is not totally fluorinated (Buck et al. 2011).

Polyfluoroalkyl substance
The molecule has a nonfluorine atom (typically hydrogen or oxygen) attached to at least one, but not all, carbon atoms, while at least two or more of the remaining carbon atoms in the carbon chain tail are fully fluorinated.

Polymer
Large molecules formed by combining many identical smaller molecules.

R

Reactivation
A specific, high-temperature process for restoring GAC's adsorptive capacity by thermal removal and oxidation of adsorbed matter.

Redox
Chemical reduction-oxidation processes and conditions that can result in the alteration of a chemical compound.

Regeneration
The act of restoring some or all of the sorption capacity of a sorptive media (such as activated carbon or ion exchange) by removing the adsorbed matter.

S

Sorption
Removal of a compound from solution by solid phase constituents. This term is often used when the mechanism of removal (adsorption, absorption, or precipitation) is unknown. (**Thompson and Goyne 2012**).

Stabilization
A process to reduce mobility of compounds in the environment through physical or chemical means.

Surfactant
A surface-active agent that lowers the surface tension of a liquid.

T

Tail
The part of a molecule that is a chain of two or more carbon atoms.

Thermal desorption
Thermal treatment process intended to remove the contaminants from a solid medium (such as soil, sediment, carbon) and drive them into the vapor phase.

Z

Zwitterion
An ionic compound containing both positively and negatively charged groups with a net charge of zero.

LINKS TO ONLINE RESOURCES

PFAS Data Tables

In many of the sections of the PFAS Guidance Document the team has developed tables that provide additional data and information to support the topics in the sections. These tables can be found in the link below, along with identity of the section with which the table is associated.

https://pfas-1.itrcweb.org/external-data-tables/

PFAS Fact Sheets

This online page includes links for the ITRC PFAS fact sheets, each last updated at various dates. The fact sheets are available as PDF files. The references and acronyms used in these Fact Sheets are maintained in the PFAS-1 Guidance Document.

https://pfas-1.itrcweb.org/fact-sheets/

PFAS Training Resources

Because the state of knowledge and regulatory approaches for PFAS continue to evolve rapidly, ITRC's goal is to periodically review and update the PFAS resources.

https://pfas-1.itrcweb.org/pfas-training/

Ecological Research on PFAS Contamination of Wildlife at Holloman Lake

Prepared for

New Mexico Environment Department
Santa Fe, New Mexico

Prepared by

DBS&A
a Geo-Logic Company

6020 Academy NE, Suite 100
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1. Introduction

Daniel B. Stephens & Associates, Inc. (DBS&A) has prepared this report for the New Mexico Environment Department (NMED) to present the results of ecological research on per- and polyfluoroalkyl substances (PFAS) contamination at Holloman Lake. To better understand the scope of potential and existing environmental contamination associated with PFAS around the state, NMED has worked with state and federal partners to conduct sampling for PFAS in sediment, surface water, and groundwater around the state. In 2021, with funding from NMED and in partnership with the University of New Mexico (UNM) Museum of Southwestern Biology (MSB), DBS&A began an ecological study on PFAS contamination at Holloman Lake, a wastewater lake located in a publicly accessible area of Holloman Air Force Base (AFB) in Otero County. Very high PFAS concentrations were documented in waterfowl tissue samples, prompting concern about duck hunting and human consumption of contaminated meat (Witt et al., 2024). Very high PFAS concentrations were also found in the tissues of small mammals both along the lake shoreline and in the uplands (Witt et al., 2024).

In early 2024, DBS&A and MSB proposed to expand the scope of the ecological study to conduct the following activities: (1) collect and analyze duck tissue samples from other New Mexico wetlands and, as needed, compare their PFAS contamination profiles with those from Holloman Lake, (2) analyze oryx (or gemsbok, *Oryx gazella*) tissue samples from White Sands Missile Range and other locations to investigate risks associated with hunting of large game species in the vicinity of Holloman Lake, (3) conduct post-mortem examinations of at least 10 euthanized animals from Holloman Lake with microscopic analysis of multiple organs including kidneys and liver, (4) analyze a small number of tissue samples obtained from carcasses of carnivores killed by vehicle traffic along U.S. Highway 70 (US 70) near Holloman Lake, and (5) document PFAS contamination levels at increasing distances from the shoreline, along transects extending in the direction of prevailing winds. The primary goals of the proposed research were to help determine risks to human communities outside of the immediate footprint of PFAS contamination at Holloman Lake and Holloman AFB, begin assessing ecological toxicity, and better understand what physical, chemical, biological, and historical factors contribute to some of the highest contamination levels in wildlife documented worldwide (Witt et al., 2024). The scope of this research does not include any assessment of the size, shape, and directionality of the PFAS groundwater plume, which remains to be investigated due to the continued lack of access for drilling exploratory wells (DBS&A, 2022).

2. Site Description

Established in 1942, Holloman AFB occupies approximately 50,763 acres of federally owned land in Otero County, New Mexico. It is located 6 miles southwest of the central business district of Alamogordo, southeast of and contiguous to the much larger (2.2 million-acre) White Sands Missile Range. US 70, which runs southwest-northeast across New Mexico, borders the south end of Holloman AFB (Figure 1).

Holloman Lake and so-called "Stinky" Playa immediately to the south are remnant alkali playa lakes that were modified in the 1960s through the construction of a non-engineered dam that now separates them (Photographs 1 and 2). The dam was intended to store domestic stormwater and effluent from a chain of wetlands and the Holloman AFB wastewater treatment plant (WWTP), all located upstream of Holloman Lake and forming a wastewater catchment system for the base. Around 2010, additional development at Holloman Lake involved opening the area to the public for camping, nature trails, and bird watching opportunities.



Photograph 1. View to the northwest from the dam at the southern end of Holloman Lake.



Photograph 2. View to the south from the dam at the southern end of Holloman Lake. The presence of water in "Stinky" Playa is indicative of seepage under the dam.

Today, Holloman Lake is an Audubon-designated Important Bird Area sustaining thousands of birds for at least part of the year. A total of 252 bird species have been recorded at Holloman Lake, 113 of which are aquatic species and 41 of which are game species that can be legally hunted (Witt et al., 2024). Through 2023, hunting was still permitted at Holloman Lake at designated times of the year. However, in light of mounting PFAS contamination evidence, Holloman AFB altered its stance on permissible recreational activities in 2024. It no longer authorizes hunting at the lake, though other public uses of the area, such as camping, continue. Cattle and oryx are also a common occurrence in the freshwater wetland at the northern end of the lake.

Holloman Lake currently receives a continuous flow of treated effluent at the north outfall (Figure 1). Before the current WWTP was built in 1996, wastewater was funneled through a series of storage/evaporation lagoons that discharged into the east outfall canal then into the lake. Today, the east outfall canal only carries stormwater; it is lined by vegetation dominated by the non-native, invasive saltcedar (*Tamarix* sp.). Salinity is high in Holloman Lake due to the abundance of calcium sulfate deposits in the area. At the north end of the lake, however, freshwater conditions prevail, sustaining the existence of a wetland with lush vegetation including southern cattail (*Typha domiguensis*), marsh fleabane (*Pluchea odorata*), saltcedar, and desert saltgrass (*Distichlis spicata*). A complete ecosystem exists at Holloman Lake and on the

surrounding uplands, from algae and diatoms to primary and secondary consumers to apex predators, including the peregrine falcon (*Falco peregrinus*), which preys on local waterfowl.

3. Background

PFAS are a large family (perhaps more than 8,000 [Buck et al., 2021]) of manmade organofluorine compounds that were developed in the early 1940s. Certain PFAS, such as perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS), are mobile, persistent, and bioaccumulative, and are not known to degrade in the environment. The chemical structure of PFAS gives them unique and valuable properties, including the ability to reduce friction and make products more resistant to soil, stain, grease, water, fire, and temperature. These chemical properties make them useful components in a wide array of industrial and commercial applications, such as textiles and leather products, metal plating, the photographic industry, photolithography, semiconductors, paper and packaging, non-stick cookware, food packaging, waterproof clothing, fabric stain protectors, lubricants, and pesticides. Some PFAS are also used as high-performance surfactants in products where an even flow is essential, such as paints, coatings, cleaning products, and fire-fighting foams, such as aqueous film-forming foam (AFFF), for use on liquid (hydrocarbon) fuel fires (U.S. EPA, 2009 and 2021).

PFAS are characterized by linear or branched carbon-fluorine chains connected to a functional group and can vary in length from 4 to 14 molecules. The number of carbon atoms, and therefore the length of the chain comprising a particular PFAS, affects its toxicity and persistence and behavior in humans, wildlife, and the environment. Perfluorosulfonic acids (PFSAs) with six or more carbons (e.g., PFOS) and perfluorinated carboxylic acids (PFCAs) with seven or more carbon atoms (e.g., PFOA) are considered long-chain substances (Buck et al., 2011; U.S. EPA, 2021; ATSDR, 2021). In general, as chain length increases, the bioaccumulation potential of PFAS appears to increase.

PFAS are extremely persistent in environmental mediums because the highly stable carbon-fluorine structure of PFAS can only be broken down at very high temperature. Larger PFAS compounds may transform in the environment to so-called "terminal" PFAS compounds, which are typically less than, or equal to, eight carbon-chain molecules such as PFOA and PFOS, and are resistant to environmental degradation processes such as biodegradation, atmospheric photo-oxidation, direct photolysis, and hydrolysis (ITRC, 2021). Dissipation is by advection, dispersion, and sorption to particulate matter. PFOS has low volatility in ionized form but can

adsorb under limited hydrogeochemical conditions to positively charged sediment particles and be deposited on the ground and into surface water bodies. Because of its persistence, it can be transported long distances in air or water (U.S. EPA, 2016).

Of particular concern at the Holloman site is the use of AFFF to extinguish fires involving highly flammable liquids. AFFF creates a vapor-sealing film on a hydrocarbon fuel surface, cooling the liquid fuel, depriving the fuel of oxygen, and providing protection against reignition by preventing evaporation (Leeson et al., 2021). In 1970, the U.S. Air Force (USAF) began purchasing and using PFAS-containing AFFF for extinguishing petroleum fires and during firefighting training activities (AFIMSC, 2017). By mid-2018, the USAF had transitioned to a new AFFF formula, Phos-Check 3 Percent, which is PFOS-free and contains only trace amounts of PFOA (AFCEC, 2018), although it is possible that stockpiles of old AFFF were used after that time. The USAF restricts use of AFFF to emergency responses and treats all releases as hazardous spills. AFFF contained in aircraft hangar fire protection systems was scheduled to be replaced by the end of 2018 (AFCEC, 2018).

The results of sampling for PFAS conducted by various parties in the Holloman-Alamogordo area indicate that releases of PFAS have occurred from several sources at Holloman AFB, including the AFFF source areas identified by the USAF, as well as Petroleum, Oils, and Lubricants (POL) site 2, and from as yet undetermined sources at the Alamogordo PFAS site in southwest Alamogordo. Additional investigations are required to determine the extent of PFAS contamination in both areas. In 2022, the NMED Ground Water Quality Bureau (GWQB) Superfund Oversight section was planning an additional investigation at the Alamogordo PFAS site, but the schedule for this work had not been determined (DBS&A, 2022).

PFAS concentrations documented at Holloman Lakes from 2021-2023 reached thousands and tens of thousands of nanograms per gram, wet weight (ng/g ww) in liver samples, or near world-records (Witt et al., 2024). The inclusion of historical specimens in the Witt et al. (2024) study showed that contamination of the local wildlife spanned a period of at least three decades. High contamination levels in waterfowl in particular raised concern about the possible ingestion of contaminated meat by local hunters, the apparent reason that Holloman AFB made the decision to no longer allow hunting at Holloman Lake in 2024. However, movement of waterfowl from Holloman Lake to other wetlands around the state still carries a risk for hunters elsewhere. A similar risk exists for large game hunters, as a herd of oryx was often observed at Holloman Lake (Witt et al., 2024). This species should be considered susceptible to PFAS ingestion in the vicinity of the lake.

Recent studies have reported ecological toxicity in Eurasian otters (*Lutra lutra*) (O'Rourke et al., 2024a), Macquarie River turtles (*Emydura macquarii macquarii)* (Beale et al., 2024), and tree swallows (*Tachycineta bicolor)* (Custer et al., 2012 and 2014) at lower or much lower concentrations than those observed at Holloman Lake. In tree swallows, for example, negative associations have been reported between hatching success and PFOS concentrations as low as 150 ng/g ww in eggs (Custer et al., 2012), with Custer et al. (2014) also finding a 20 percent decrease in hatching success at PFOS concentrations of 283 ng/g. In Australia, liver concentrations of PFSAs and PFCAs averaged 3.0 and 0.1 ng/g, respectively, in Macquarie River turtles (Beale et al., 2024). This level of contamination was high enough to produce significant metabolic disruptions in turtles, specifically related to amino acid and lipid metabolism, energy production, and oxidative stress responses. Although no gross or histopathological phenotypical abnormalities could be directly linked to PFAS exposure, proteomic analysis identified several biomarkers of early disease progression (Beale et al., 2024). Gravid females from contaminated sites also showed altered egg composition, particularly in magnesium to calcium ratios, while the biochemical profiles of egg albumin and yolk also exhibited significant differences in metabolites and lipids between contaminated and control sites, suggesting potential impacts on embryo development. Hatchling deformities (e.g., abnormal intergular scale shapes and marginal scale counts) were found to be more pronounced and occur at a higher incidence at the contaminated site. Of particular concern, a lack of juvenile recruitment into the breeding population was observed at the contaminated site, suggesting potential long-term population declines in Macquarie River turtles in Australia. In northern England, linear PFOS (L-PFOS) was detected at a median concentration of 1,740 ng/g ww in river otters (O'Rourke et al., 2024b), or a level of contamination approaching that typically observed at Holloman Lake (Witt et al., 2024). Laboratory studies have suggested associations between exposure to PFSAs and PFCAs and immunotoxicity in animals (Fenton et al., 2020), and in England and Wales, O'Rourke et al. (2024a) found enlarged adrenal glands and unilateral cryptorchidism (linked to environmental pollution) in four otters, three of which showed some of the highest PFOS contamination levels during the study.

4. Methodology

Research conducted in 2024 aimed at (1) studying the fate and transport of PFAS at Holloman Lake to better understand why the local wildlife is contaminated at such high levels, (2) documenting ecological toxicity using a combination of necropsies and reproductive

monitoring, and (3) assessing risks to hunters from the ingestion of contaminated waterfowl and/or oryx meat.

4.1 Ecosystem-Wide Contamination Profiles

4.1.1 Sampling

Collection efforts at Holloman Lake in 2024 resulted in obtaining or preparing 109 surface water, soil, and biological samples for PFAS screening. All collection occurred only in publicly accessible areas around the lake, primarily along the lake shoreline including the freshwater wetland to the north, and in the uplands to the east and northeast (Figure 1). Biological samples included muscle, liver, and bone tissue from birds, mammals, and reptiles, in addition to eggshells and plant, algae, invertebrate, and fish tissue. The shed skin of a western diamondback rattlesnake (*Crotalus atrox*) was also sampled for PFAS screening.

Four surface water samples were collected in the lake at the north and east outfalls and along the south and west shorelines. Soil samples were collected along the east shoreline and at 100-meter intervals along two 900-meter sampling transects extending to the northeast, in the direction of prevailing winds (Figure 1). Sampling of upland plants and invertebrates also occurred every 300 meters along the two transects. Soil, plant, invertebrate, fish, mammal, and/or bird samples were obtained both from the wetland and the main body of the lake, for a comparison of PFAS levels.

Birds were collected by licensed hunters using netting or shotguns with nontoxic shot, operating under federal and state scientific collecting permits and, for game species, in compliance with federal and state hunting regulations. Small mammals were trapped overnight using both live-capture Sherman traps and Museum Special (MS) snap and Victor rat traps, following standard protocols for museum collection and under state scientific collecting permits. Field research protocols were approved by the UNM Institutional Animal Care and Use Committee (Protocols 21-201225-MC and 19-200908-MC).

A coyote (*Canis latrans*) and a western coachwhip (*Masticophis flagellum*) killed by road traffic along US 70 near the turnoff to Holloman Lake were also collected and incorporated into the study.

4.1.2 PFAS Screening

All PFAS screening was conducted by Eurofins Environment Testing Northern California, LLC (Eurofins), where tissue extraction requires 1 gram (g) of homogenized material, weighed out to three significant figures. Tissues were spiked with isotopically labeled extracted internal standards (EISs), and then solvated with 0.4 percent potassium hydroxide (KOH) in methanol and sonicated for 1 hour. Samples were separated by centrifuge at 4,700 relative centrifugal force (RCF) followed by decanting the supernate to a new vessel prior to a second 0.4 percent KOH/methanol solvation. This solution was shaken briefly and sonicated and separated as above. Supernates were combined and the sample was diluted to 125 milliliters (mL) with deionized water and neutralized with glacial acetic acid to pH of 6 to 8. This extract was then passed over a conditioned WAX/graphite carbon black (GCB) solid phase extraction (SPE) (500 milligrams [mg], 50 mg, 6 mL). Cartridges were washed with small volumes of methanol in water prior to drying and then eluted with 0.3 percent ammonium hydroxide in methanol. Samples were not concentrated after SPE, but rather spiked with standards and brought to 10 mL of 80:20 methanol:water prior to analysis.

One method blank (MB) and two laboratory control sample (LCS)/LCS duplicate (LCS/LCSDs) containing 2 percent bovine serum albumin (BSA) for blood batches and 0.02 g corn oil for tissue batches were included with each field sample at a rate of 5 percent (1 MB, LCS/LCSD per 20 samples). The LCS/LCSDs were also spiked with known concentrations of native PFAS. These QC samples are standard practice among U.S. Environmental Protection Agency (EPA) methods and serve as both positive (LCS/LCSD) and negative (MB) controls, as they follow all field samples throughout extraction and analysis.

The analytical configuration consisted of an Exion LC system with two pumps and a SCIEX 5500 mass spectrometer for tissue analyses. Pump-A contained 20 millimole per liter (20mM) ammonium acetate and pump-B delivered 0.5 percent ammonium hydroxide (NH_4OH) in methanol. Pump-A was used to load 20 microliters (µL) of sample extract onto an analytical column (Gemini 3 um C18 50X2 mm) heated to 45°C, where compounds of interest were separated before introduction into the instrument source. The electrospray source was operated in negative polarity, and data were acquired in multiple reaction monitoring (MRM) mode with a minimum of 10 scans per peak. Prior to analysis, optimal voltages for both ionization and collision induced disassociation were determined by direct infusion. Analysis time for this process resulted in an approximate 9-minute cycle time.

4.2 Necropsies

A total of 24 animals (13 small mammals and 11 birds) (Table 1) were collected from Holloman Lake in 2024 and euthanized prior to undergoing necropsies and microscopic analyses of all their organs at the New Mexico Department of Agriculture Veterinary Diagnostic Services (VDS). PFAS screening of their livers and/or muscles was also conducted.

All gross necropsies and microscopic examinations of organ tissues were conducted by VDS pathologists Drs. John Ragsdale and Teresa Garcia. Necropsy reports included organ weights, together with findings of abnormalities listed by organ.

4.3 Bird Nest Monitoring

Nest searches were conducted weekly or biweekly from May through July 2024 along the accessible shoreline of Holloman Lake and in the uplands. Nests were geo-referenced and monitored to determine reproductive outcome to the extent possible.

4.4 Statewide Waterfowl Hunting Risk Assessment

A total of 47 avian tissue samples were sent to Eurofins for establishing a contamination profile specific to Holloman Lake and for PFAS pre-screening of waterfowl from wetlands around New Mexico. Of the 47 samples, 19 were from individual birds collected from 2021 to 2023 at Holloman Lake. The remaining 28 samples were from waterfowl collected at other wetlands around New Mexico. The majority of samples were pooled (or composite) samples that each consisted of several birds belonging to the same feeding guild (dabbling ducks, diving ducks, grazers) and, in most cases, from the same region of New Mexico, while also covering one of several time periods since the 1990s. The 47 samples were prepared from waterfowl livers, hearts, and muscles cryogenically preserved in liquid nitrogen and archived at the MSB. A limitation of the non-Holloman sample PFAS screening was that most of the waterfowl specimens archived at MSB are from northwestern New Mexico.

MSB also prepared and widely distributed a flyer to enlist the assistance of hunters from around New Mexico, asking for donations of (1) frozen carcasses that had been breasted out or (2) at least 4 grams of fresh-frozen liver and one frozen wing from each duck, in separate sealed bags, labeled with date and locality. Volunteer participants were asked to fill out an online form with their contact information for follow-up instructions on how to participate. This critical additional effort started just prior to the expiration of DBS&A's contract with NMED.

4.5 Oryx Hunting Risk Assessment

DBS&A and MSB could not enlist the participation of White Sands Missile Range for acquiring oryx samples from harvested animals. However, owners of the Walker Ranch (adjacent to Holloman Lake and home to a large oryx herd) were contacted, as were Major Wildlife Studios (a Las Cruces area taxidermist that processes many oryx monthly), and a Las Cruces meat processor that deals with hunter-collected oryx. These entities expressed early support for this project, and were projected to be the means of future sample collection.

5. Results and Discussion

5.1 PFAS Fate and Transport

Previous investigations of soil and groundwater indicate that the most significant PFAS source areas at Holloman AFB are the firefighting training area northeast of the main base and the evaporation pond used to test firefighting equipment in the West Area of the main base (DBS&A, 2022). PFAS released to soil at these locations (and potentially other source areas not yet investigated) likely migrated vertically through the vadose zone and impacted groundwater in the basin fill aquifer at and downgradient of the areas (DBS&A, 2022). The USAF investigation of the base-wide sewer system indicated that the sewer was probably leaking, and sampling confirmed that wastewater contained PFAS, making this another source of PFAS contamination in groundwater (DBS&A, 2022). Wastewater was also discharged directly to the now defunct unlined sewage lagoons and eventually to Lake Holloman before the WWTP was constructed in 1996 (DBS&A, 2022). After 1996, treated wastewater (containing PFAS) was discharged to Lagoon G, eventually reaching Lake Holloman (DBS&A, 2022). During a part of this time, treated effluent from the WWTP was used to water the Holloman AFB golf course (DBS&A, 2022). The initial assessment conducted by the USAF in 2017 identified impacts to soil, surface water, and groundwater. The USAF had not determined the extent of PFAS contamination at the base, but impacts reported at Lake Holloman likely extended off-site beyond the lake (DBS&A, 2022).

Ongoing analyses of data collected in 2024 show that surface water and soil contamination may reflect contamination by three (instead of just two) different generations of AFFFs. Sorption of PFAS from surface water to soils was primarily influenced by the length of the fluorinated chain, as expected based on published studies elsewhere (e.g., Fabregat-Palau et al., 2024). Due likely to a combination of factors (e.g., evaporation, a dilution effect from the input of less contaminated effluent at the north outfall), plants and animals collected in the wetland

appeared to be much less contaminated than biotas using the main body of the lake and its shoreline. Particularly low levels of PFAS contamination were detected in the western mosquitofish (*Gambusia affinis*) and the variegated meadowhawk (*Sympetrum corruptum*), both collected from the wetland. PFOS concentrations measured in two composite mosquitofish samples averaged 77 ng/g, while PFOS was detected in the meadowhawk, a dragonfly, at a concentration of only 1.1 ng/g.

PFAS concentrations in soil decreased rapidly to background levels at a distance of 200 meters from the shoreline along both transects but increased again at some of the most distant sampling locations. The rebound in PFAS concentrations was particularly notable at the end of the southern transect (NE4), 900 meters from the shoreline. At that sampling location, soils were found to have a PFOS concentration of 710 ng/g, greater than the concentration found at the edge of the lake along the same transect. Historical aerial and LANDSAT imagery revealed the explanation for this finding. The end of NE4 was shown to correspond to a ghost wetland, where dense vegetation (indicated by a normalized difference vegetation index [NDVI] value of 0.19) existed in 1996, but conditions have now reverted to desert uplands (Photograph 3).



Photograph 3. View to the east from the end of Transect NE-4, 900 meters northeast of the shoreline. A few iodine bushes and saltcedars are all that remain from a past contaminated wetland that has now almost completely reverted to desert vegetation.

Historical imagery further showed the past existence of an overflow spillway and ditch connecting the wastewater storage lagoons to the wetland. Further analysis of the transect

sampling data is forthcoming, but air transport of contaminated dust was ruled out as a mechanism responsible for the contamination of wildlife in the uplands. Instead, historical wastewater transport and possibly groundwater discharge may be more important. LANDSAT imagery of the study area with the ghost wetland is shown in Figure 2.

5.2 Contamination Profiles

Two degradation products of 6:2 FTS, the short carbon-chain perfluorocarboxylic acids PFHxA (six carbons) and PFPeA (five carbons), were the dominant PFAS in surface water in the lake. In contrast, PFOS was the main PFAS found in sediments along the shoreline. PFOS was the most abundant PFAS found in nearly all biological samples (except in some plants in the freshwater wetland and the uplands). Examples of contamination profiles are shown in Figures 3 through 8.

Among plants, there was a striking difference in the contamination profiles of saltcedar, fourwing saltbush (*Atriplex canescens*), and iodine bush (*Allenrolfea occidentalis*) along the main body of the lake (with PFOS dominant and overall PFAS concentrations much higher) versus southern cattail and fleabane in the wetland or saltbush in the uplands. A possible explanation is that saltcedar, saltbush, and iodine bush growing along the shore of the lake might reach the water table, whereas the other plants do not. As wetland plants, cattail and marsh fleabane in particular are both characterized by shallow, subsurface rhizomes as their root system (Chen et al., 2024; Nature Collective, 2025).

5.3 Bioaccumulation

High PFAS levels were detected in nearly all the biological samples from Holloman Lake analyzed in 2024, confirming contamination of the entire ecosystem from algae and terrestrial plants to macroinvertebrates, mammals, birds, and reptiles (Appendix A). PFOS was the most abundant PFAS congener in all animal tissue samples. The highest PFOS concentrations recorded to date are listed in Table 2.

PFAS contamination of wildlife was detected south and southeast of Holloman Lake. Two salvaged specimens found along US 70, a coyote and a western coachwhip—both killed by vehicle traffic—exhibited PFOS tissue concentrations of 640 ng/g ww (muscle) and 6,800 ng/g ww (liver), respectively.

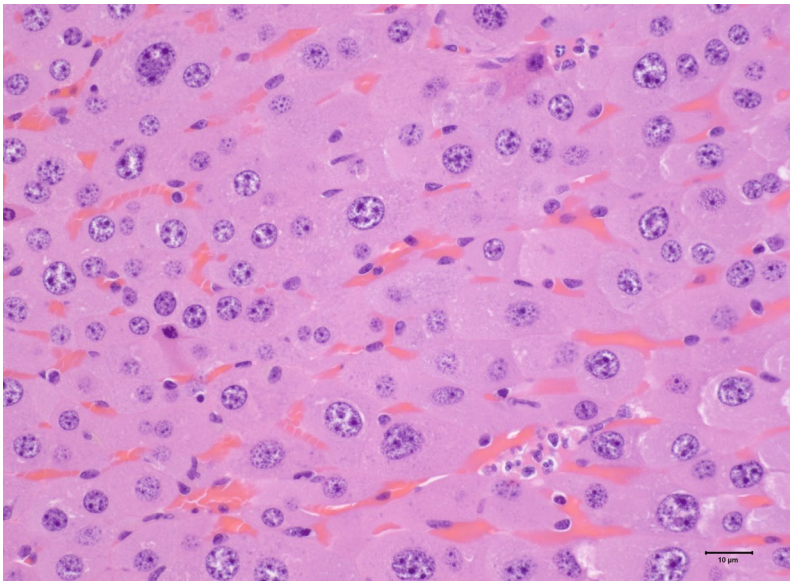
5.4 PFAS Ecological Toxicity

5.4.1 Necropsies

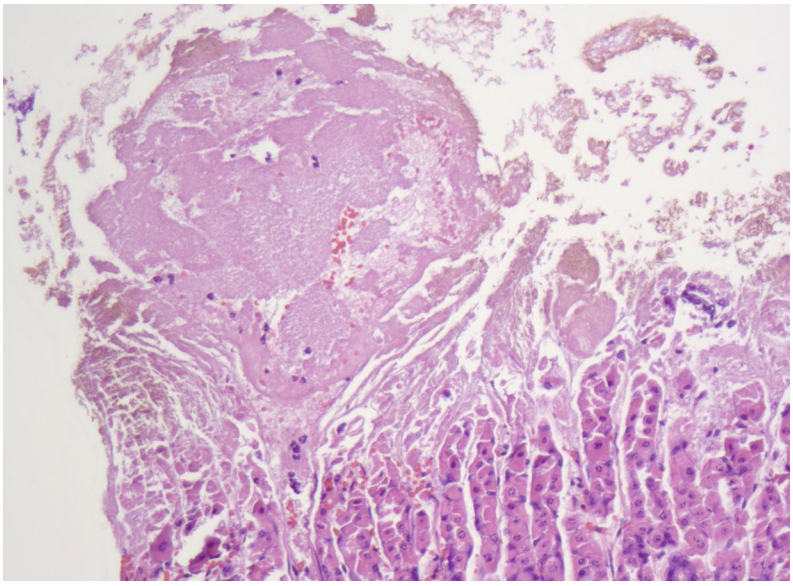
Results of the necropsies are summarized in Table 3. Complete results are provided in Appendix B.

All of the animals necropsied for this study were found to have PFOS concentrations greater than 1,000 ng/g in their livers or muscles. Normal tissues in several migratory birds present at Holloman Lake for only part of the year, two red-winged blackbirds (*Agelaius phoeniceus*) and two common yellowthroats (*Geothlypis trichas*), showed that acute, time-limited exposure does not necessarily lead to observable lesions at the organ or tissue level. The same was true with some of the rodents, all of which are year-round residents at Holloman Lake but also short-lived animals.

Possible abnormalities related to PFAS exposure included liver microgranulomas, spleen and adrenal hyperplasia, and gastric ulcers (Photographs 4 and 5), though these possible signs of toxicity can only be firmly established by also including a control group in future research activities. Possible diffuse cortical hypertrophy of the adrenal gland was discovered in particular in one deer mouse (*Peromyscus maniculatus*) with a PFOS concentration of 290 ng/g in its muscle tissues. Enlarged cells, the presence of anisocytosis (differing cell size), anisokaryosis (differing nuclear size), and multinucleated cells were most consistent with the diagnosis of diffuse cortical hypertrophy (Brändli-Baiocco et al., 2018). However, these same changes are not described in the context of cortical hypertrophy in guidelines from the International Harmonization of Nomenclature and Diagnostic Criteria for Lesions in Rats and Mice. Diffuse adrenocortical hypertrophy is typically caused by increased adrenocorticotropic hormone (ACTH) production—either due to stress or disease, or exogenously administered ACTH (Brändli-Baiocco et al., 2018). Although pollutants that inhibit steroid synthesis can cause cortical hypertrophy of the adrenal gland, they typically also cause increased vacuolation, not observed in the deer mouse that was necropsied.



Photograph 4. Possible diffuse adrenocortical hypertrophy in a deer mouse (*Peromyscus maniculatus*) from Holloman Lake. Anisocytosis, anisokaryosis, and multinucleation can all be observed in the adrenal cortex of this rodent.



Photograph 5. Multiple punctate gastric erosions/ulcers in a Merriam's kangaroo rat. The ulcers resulted in blood loss into the gastrointestinal tract. The underlying cause could not be determined, as there was no evidence of inflammation, infectious organisms, neoplasia, or parasites. Starvation and/or stress could not be ruled out.

A Merriam's kangaroo rat (*Dipodomys merriami*) with one of the highest PFOS concentrations recorded at Holloman Lake (94,000 ng/g ww in liver) showed a dry hypodermis during the postmortem gross examination. It appeared dehydrated, and the stomach, small intestine, and large intestine were filled with dark red to black digested blood. Histopathology showed multifocal necrosis of the glandular epithelium of the mucosa of the stomach that varied in thickness. The foci of necrosis were filled with necrotic debris, fibrin, hemorrhage, and hemoglobin-breakdown pigments. The submucosa associated with the mucosal epithelial necrosis was edematous. The adjacent gastric glandular epithelium was degenerate with hemorrhage in the associated lamina propria. No obvious underlying cause for the ulcers could be determined.

As indicated by O'Rourke et al. (2024a), it may be challenging to establish a definite link between PFAS exposure and disease in field studies due to many confounding variables with possible impacts on animal health and survival. An association between immune system health and environmentally relevant concentrations of PFCAs and PFSAs has been reported, with PFOA and PFOS concentrations significantly higher in sea otters (*Enhydra lutris*) that died of infectious disease compared to non-diseased animals (Kannan et al., 2006). Many of the animals necropsied had endoparasites, but so do wild rodents and birds in general (e.g., Mohammadi et al., 2022; Parsa et al. 2023).

5.4.2 Monitoring of Breeding Success

Since 2021, a total of 11 bird species have been documented breeding at Holloman Lake. These species consist of the Swainson's hawk (*Buteo swainsoni*), American avocet (*Recurvirostra americana*), black-necked stilt (*Himantopus mexicanus*), killdeer (*Charadrius vociferus*), snowy plover (*Charadrius nivosus*), white-winged dove (*Zenaida asiatica*), Say's phoebe (*Sayornis saya*), western kingbird (*Tyrannus verticalis*), northern mockingbird (*Mimus polyglottos*), red-winged blackbird, and common yellowthroat.

Nest searches were conducted from May through July 2024. A total of 10 shorebird nests were found and monitored for the rest of the breeding season. More nests likely occurred in shoreline areas with restricted access. All four of the monitored black-necked stilt nests failed, as did the two American avocet nests. A snowy plover nest succeeded, with three juveniles observed together with an adult. Two killdeer juveniles were observed at two different locations, though at least one of the monitored nests failed. At the other killdeer nest, two eggs never hatched, while another disappeared and a hatchling was found dead next to the nest, with

no evidence of predation (Photograph 6). In the uplands, a Swainson's hawk nest produced one fledgling from an observed brood of two nestlings.



Photograph 6. Killdeer hatchling found dead within 1 meter of its nest in June 2024.

The dead killdeer hatchling could not be necropsied, but one tissue sample was found to have a PFOS concentration of 48,000 ng/g, the highest PFAS concentration recorded in any bird during this study. The predicted no-effect concentration (PNEC) and toxicity reference value (TRV) derived by Newsted et al. (2005) for PFOS in egg yolk (based on acute and chronic laboratory exposure in northern bobwhite quail [*Colinus virginianus*] and mallard [*Anas platyrhynchos*]) are 1000 and 1700 ng/g, respectively.

A Say's phoebe (*Sayornis saya*) nest with two eggs was discovered on June 3, 2024 on a shelf in an abandoned shed at the northern end of Holloman Lake. As the eggs had not hatched more than two months later, they were collected on July 16, 2024 and one of them was analyzed for PFAS. PFOS eggshell concentration was found to be 1,500 ng/g, more than 5 times greater than the value associated with a 20 percent decrease in hatching success in a population of tree swallows in Minnesota and Wisconsin (Custer et al., 2014).

5.5 Statewide Waterfowl Hunting Risk Assessment

The 47 waterfowl tissue samples used for the preliminary statewide waterfowl hunting risk assessment are listed in Table 4, together with information on species and tissue type composition, collecting location, and PFOS concentration. Of the 47 samples, 19 represented single individual birds from Holloman Lake. These 19 birds exhibited a distinctive contamination profile based on the specific proportions of PFAS analytes detected in their tissues (Figure 9). As

with other wildlife from Holloman Lake, PFOS concentrations were highest by at least an order of magnitude, followed by PFHxS concentrations. PFOA concentrations typically averaged another order of magnitude lower than PFHxS concentrations, while PFHpS could also be abundant in tissue samples at more variable concentrations.

PFOS concentrations above 100 ng/g were found in 25 (89 percent) of the 28 non-Holloman samples (Table 4). In nearly half of the 28 samples, PFOS concentrations exceeded 500 ng/g—even reaching 1,000 ng/g in two instances—indicating high (or very high) contamination in at least some waterfowl that were represented in those samples (Table 4). None of the composite non-Holloman samples had PFOS concentrations below 100 ng/g. Results indicated waterfowl PFAS contamination in waterfowl in northwestern New Mexico and southeastern New Mexico in particular, though the contamination profiles appeared to differ from those found at Holloman Lake, with PFHxS concentrations low and long-chain PFCAs relatively more abundant (Figure 9). A red-breasted merganser (*Mergus serrator*) collected south of Rincon along the Rio Grande was also found to have a mean heart, liver, and muscle PFOS concentration of 750 ng/g, but PFHxS concentration was lower than perfluorodecanoic acid (PFDA) and PFOA concentrations.

PFAS screening of the 28 non-Holloman waterfowl samples should be viewed as an initial step to help guide a more robust, statewide waterfowl hunting risk assessment. More samples are being prepared to expand this effort.

5.6 Large Game Risk Assessment

To assess PFAS levels in mammalian game species potentially using Holloman Lake as a water/food resource, MSB has begun obtaining oryx samples for PFAS testing. Populations in and around the Holloman Lake area will be included, in addition to more distant populations from the Armendaris Ranch and Jornada Basin for an indication of background contamination levels. At the time of this report, MSB projected the collection and testing of approximately 30 to 50 oryx in 2025.

With assistance from individual licensed hunters, two oryx liver and muscle samples have already been tested from the following two animals:

- Specimen MSB:Mamm:341801: New Mexico, Otero County, Culp Canyon
- Specimen MSB:Mamm:348125: New Mexico, Otero County, White Sands Missile Range, Hunt Unit 19, Rhodes Canyon

Five more oryx specimens donated to MSB are available for PFAS testing:

- Specimen MSB:Mamm:196600: New Mexico
- Uncataloged specimen: New Mexico, Otero County, White Sands Missile Range, Hunt Unit 19, Rhodes Canyon
- Uncataloged specimen: Obtained from Major Wildlife Studio, Las Cruces, New Mexico
- Uncataloged specimen: New Mexico, Doña Ana County, San Andres Mountains
- Uncataloged specimen: New Mexico, Otero County. 23.5 km SE Orogrande

6. Conclusions and Recommendations

Extraordinary levels of PFAS contamination have been found in wildlife at Holloman Lake. Two Merriam's kangaroo rats collected in 2024 exhibited liver PFOS concentrations of 120,000 ng/g and 110,000 ng/g, respectively. Based on published studies, these concentrations are the highest reported in any wild animals to date, other than a wood mouse (*Apodemus sylvaticus*) liver sample near a fluorochemical plant in Belgium (Hoff et al., 2004). One saltcedar composite tissue sample from Holloman Lake was also found to have a PFOS concentration of 30,000 ng/g, an apparent world record for plants. Results from the ecological research conducted in 2024 are highly suggestive of ecological toxicity at Holloman Lake, while movements of waterfowl and large mammals indicate a likely risk associated with hunting and the consumption of contaminated game meat outside the immediate area around Holloman Lake. In the case of waterfowl, preliminary results of PFAS screening from other wetlands around New Mexico (but primarily in the northwestern part of the state) show surprisingly high contamination levels that should be further investigated. Some of the funding for this research was saved for testing of more samples with help from hunters recruited for this effort, particularly in areas of New Mexico poorly represented in the specimen collection at MSB.

High levels of contamination were found in bird eggs and in a hatchling found dead next to its nest. Because PFAS research on laboratory animals has shown impairment of both reproduction and development (Witt et al., 2024), the very high rate of nesting failure in shorebirds at Holloman Lake also needs to be investigated in relation to PFAS contamination levels, with monitoring of breeding success at Bitter Lake National Wildlife Refuge for a comparison. Necropsies of highly contaminated rodents from Holloman Lake revealed liver abnormalities such as aggregates of enlarged hepatocytes, in addition to spleen hyperplasia and gastric ulcers.

A definite link to PFAS exposure cannot be established without also including a control group from a nearby, non-contaminated site.

Specific recommendations include the following:

- Expand testing of waterfowl and oryx samples to better characterize the risk to hunters outside the immediate footprint of contamination at Holloman Lake/Holloman AFB.
- Conduct additional necropsies of rodents from Holloman Lake but also a nearby, uncontaminated site (control group) to statistically assess the significance of abnormalities detected during this study.
- Continue research on ecological toxicity at Holloman Lake and include the use of metabolic markers to identify early disease progression in short-lived species.
- Investigate the use of non-lethal tissue sampling methods to study and monitor wildlife at Holloman Lake.
- Monitor shorebird breeding success and implement a sampling protocol to determine hatching success in relation to egg PFAS concentrations, with monitoring of a control group of shorebirds at Bitter Lake National Wildlife Refuge.
- Investigate potential PFAS contamination of beef cattle raised in the Alamogordo and Holloman AFB area.
- Investigate bioaccumulation and community-wide transmission of PFAS using carnivores such as coyotes, badgers, and rattlesnakes
- Initiate a statewide monitoring program with surveys and PFAS monitoring for large game animals and other potential sentinel species.
- Continue to build partnerships with other organizations to expand monitoring and assess toxicity to wildlife and humans.

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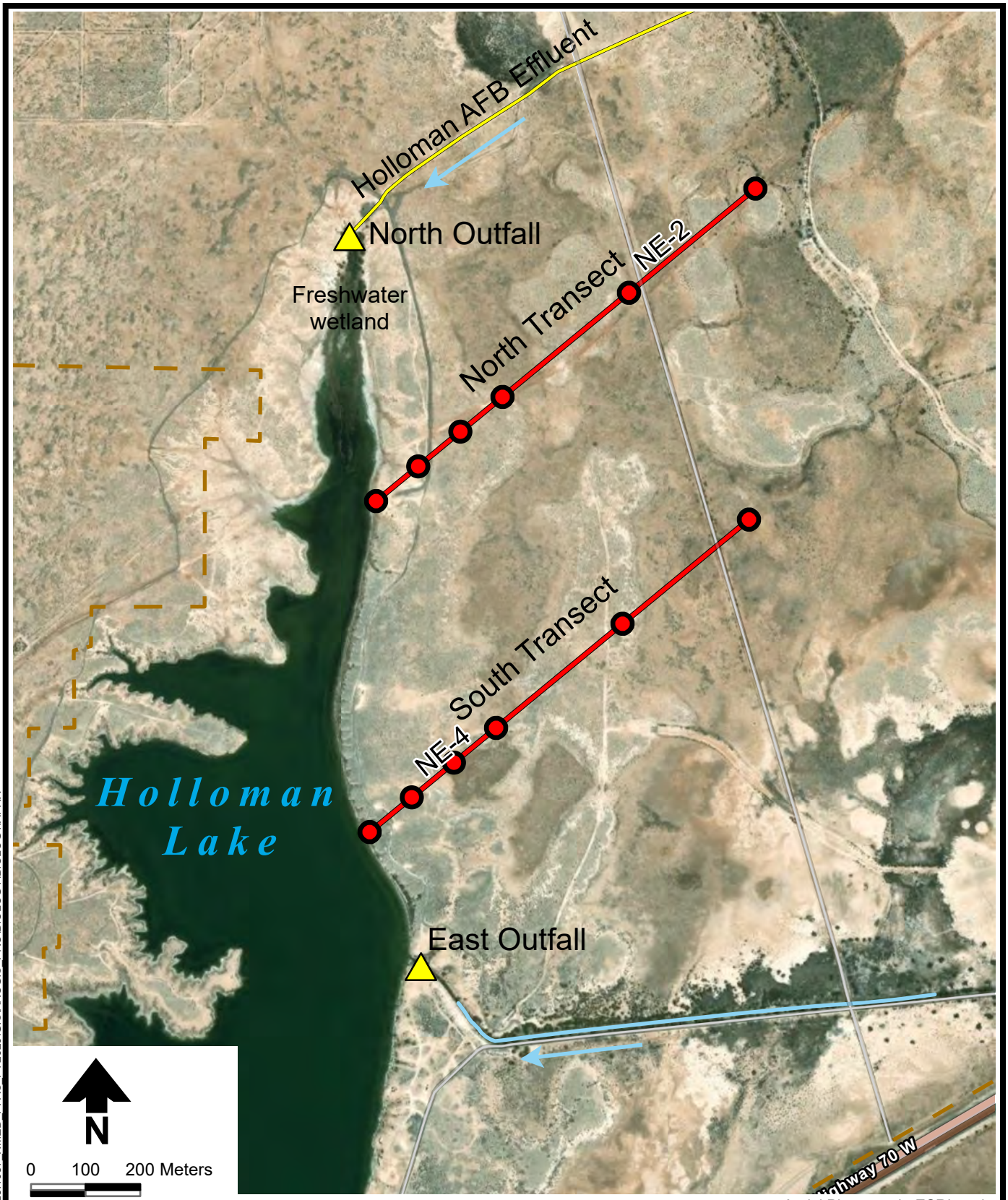
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Figures



Aerial Photograph: ESRI et al.

Explanation

- Transect sample location
- Holloman AFB boundary

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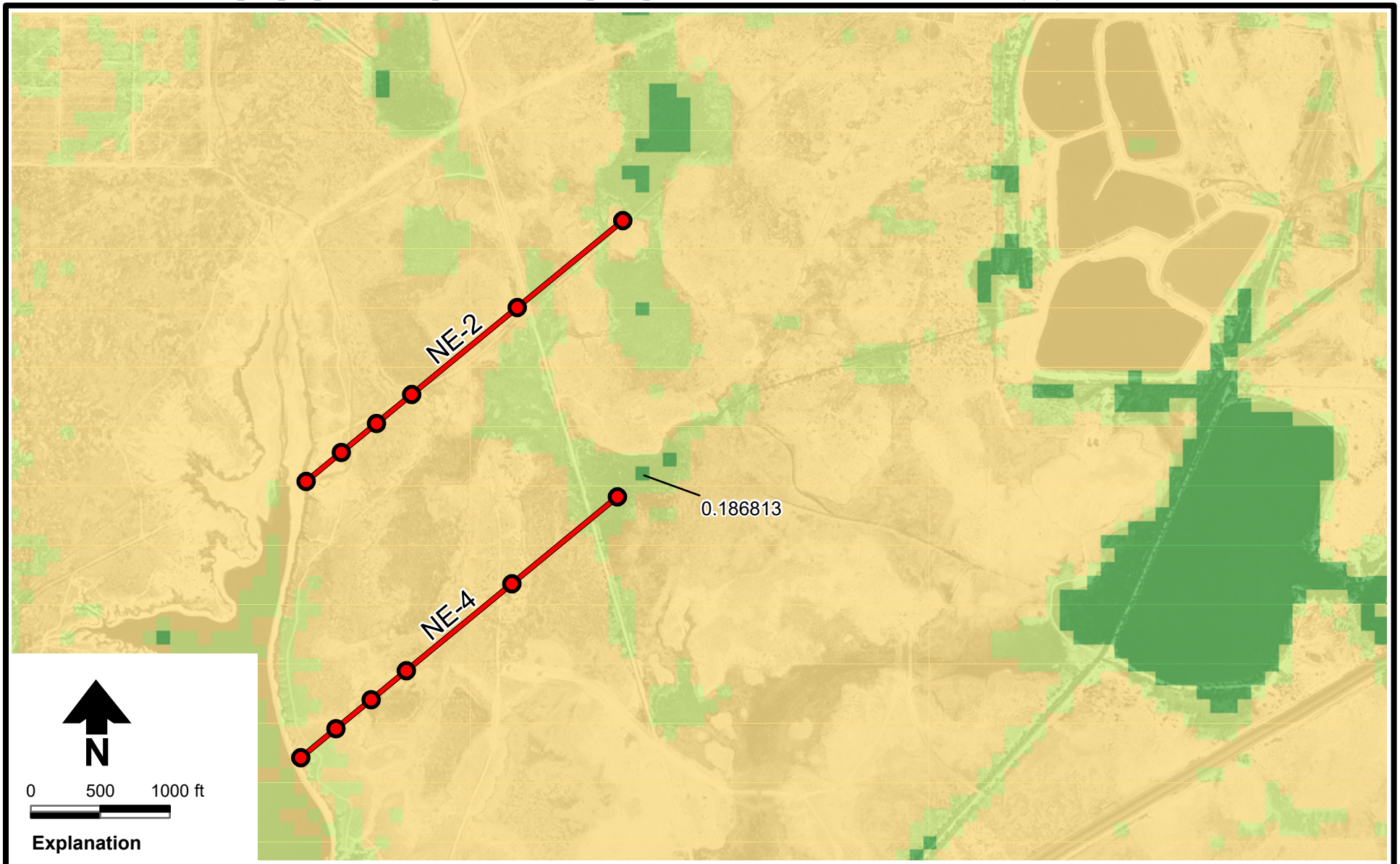
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NMED PFAS
Study Area

Figure 1
NMED Exhibits 65

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Landsat 5 T05_L1TP_033037_19960725_20200911_02_T1

NMED PFAS

Normalized Difference Vegetation Index (NDVI) July 25, 1996

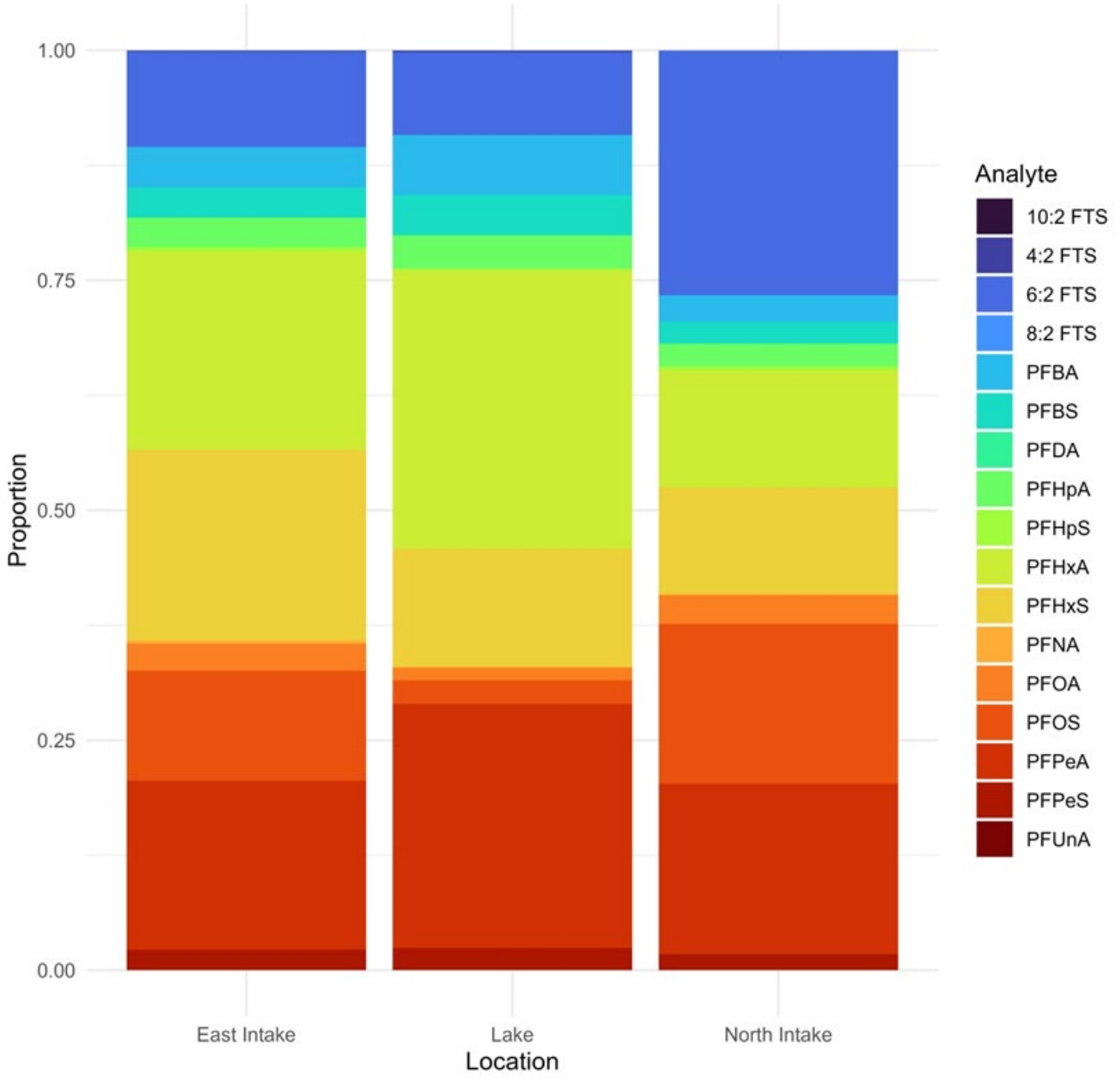
Figure 2

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NMED Exhibits 65



NMED PFAS

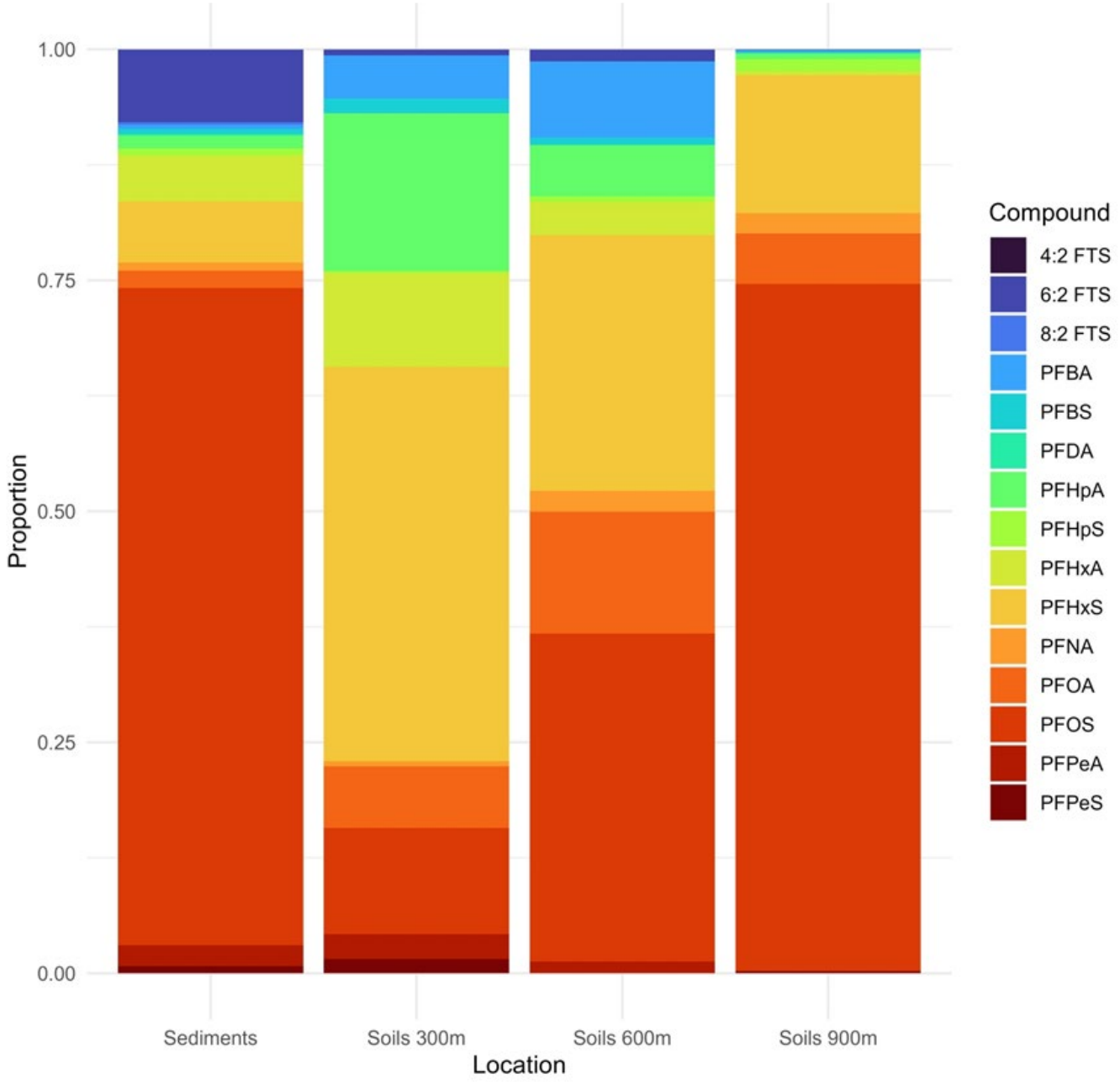
Proportions of PFAS Congeners Detected in Surface Water Samples

Figure 3

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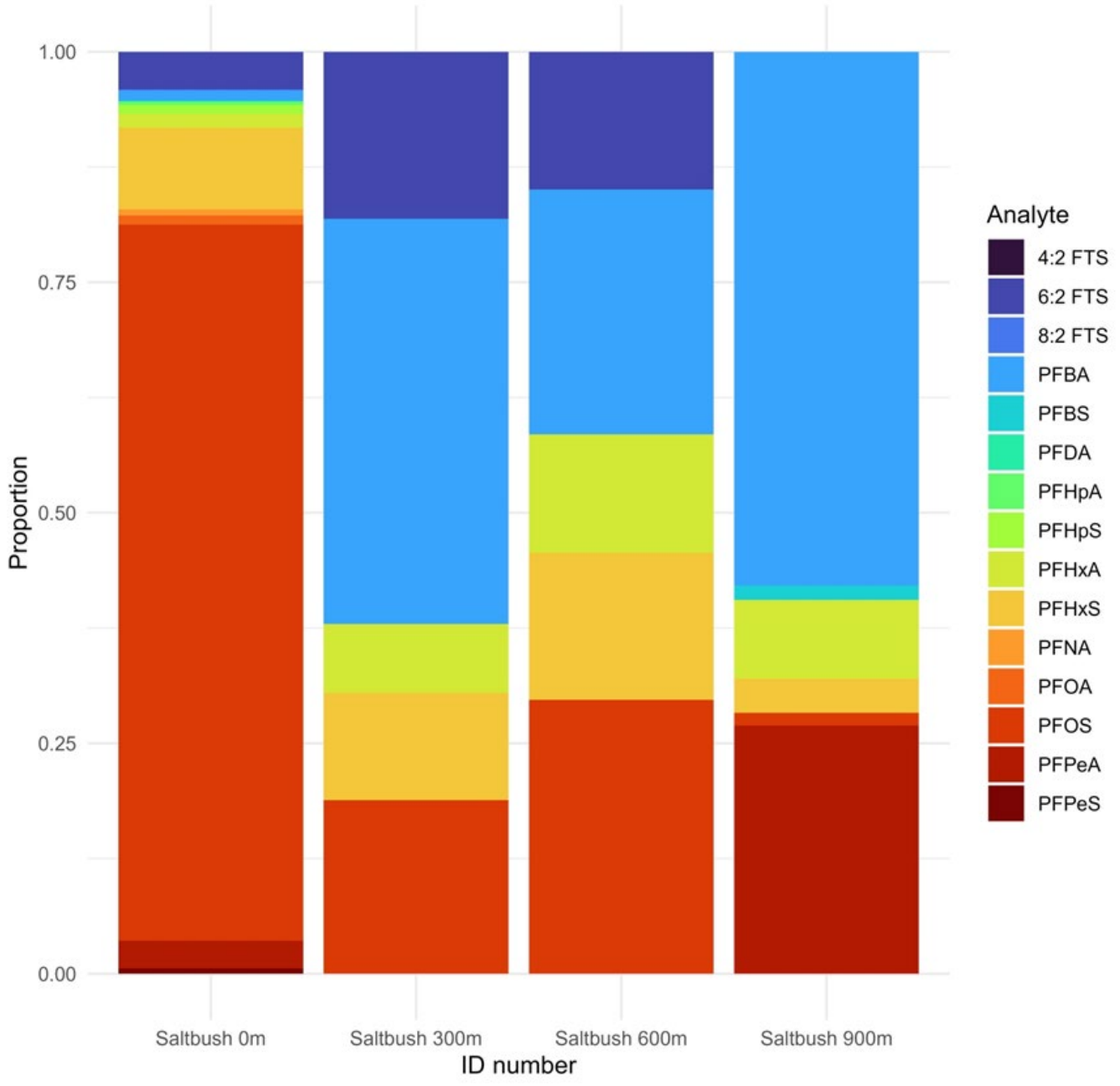
Proportions of PFAS Congeners Detected in Soil Samples as a Function of Distance from the Shoreline along the Two Transects

Figure 4

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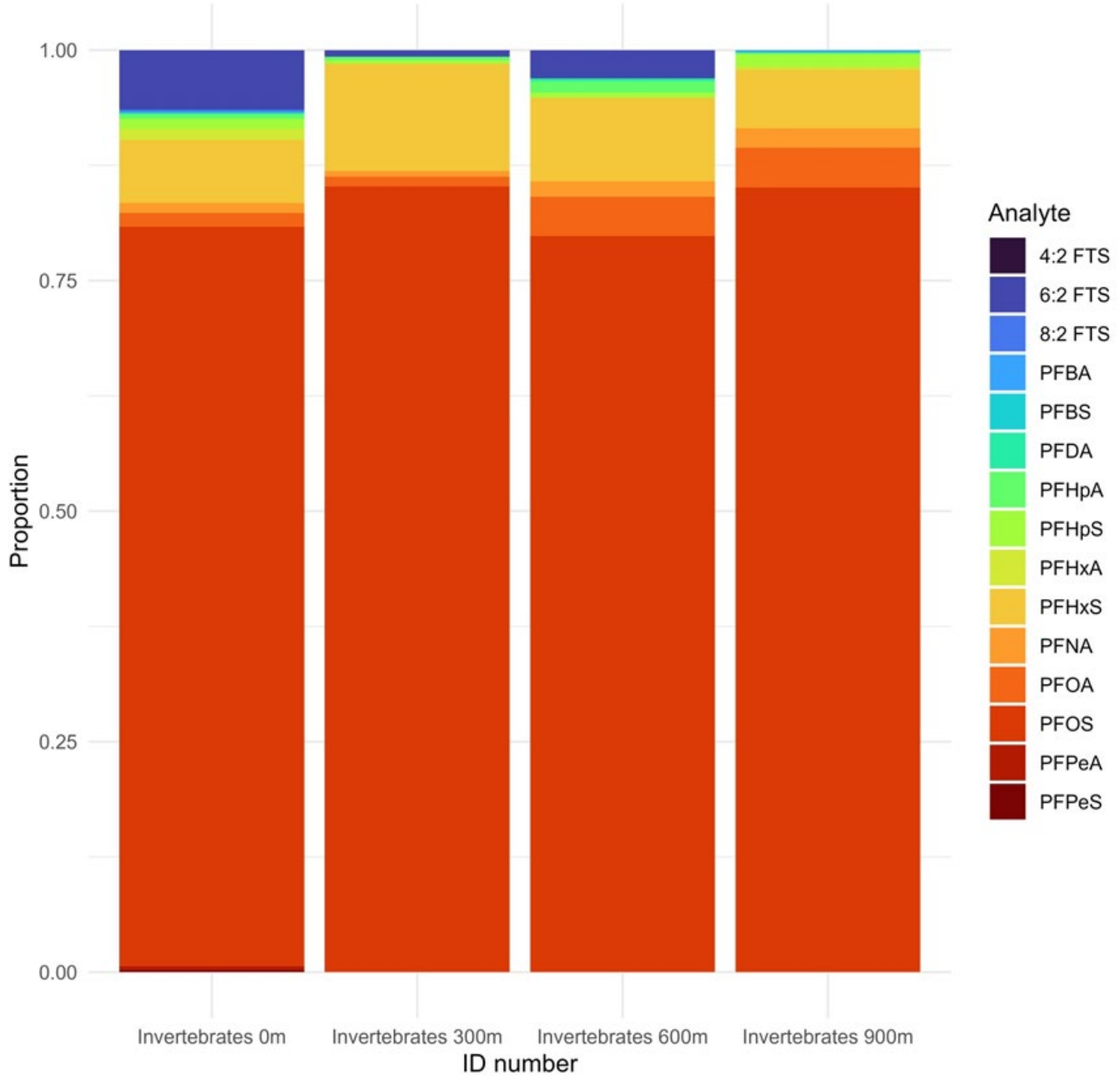
Proportions of PFAS Congeners Detected in Saltbush Samples as a Function of Distance from the Shoreline along the Two Transects

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Figure 5



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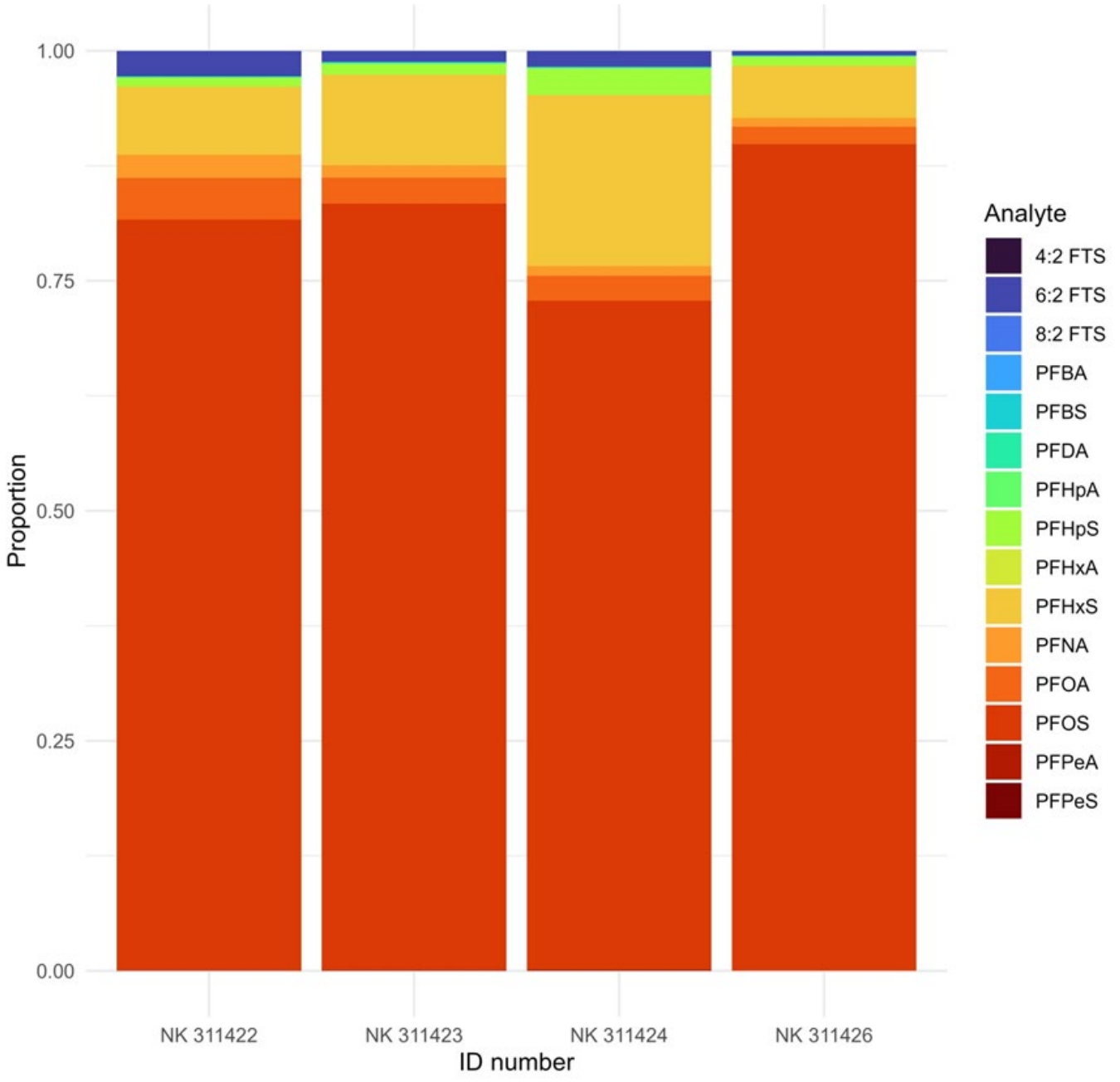
Proportions of PFAS Congeners Detected in Invertebrate Samples as a Function of Distance from the Shoreline along the Two Transects

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Figure 6



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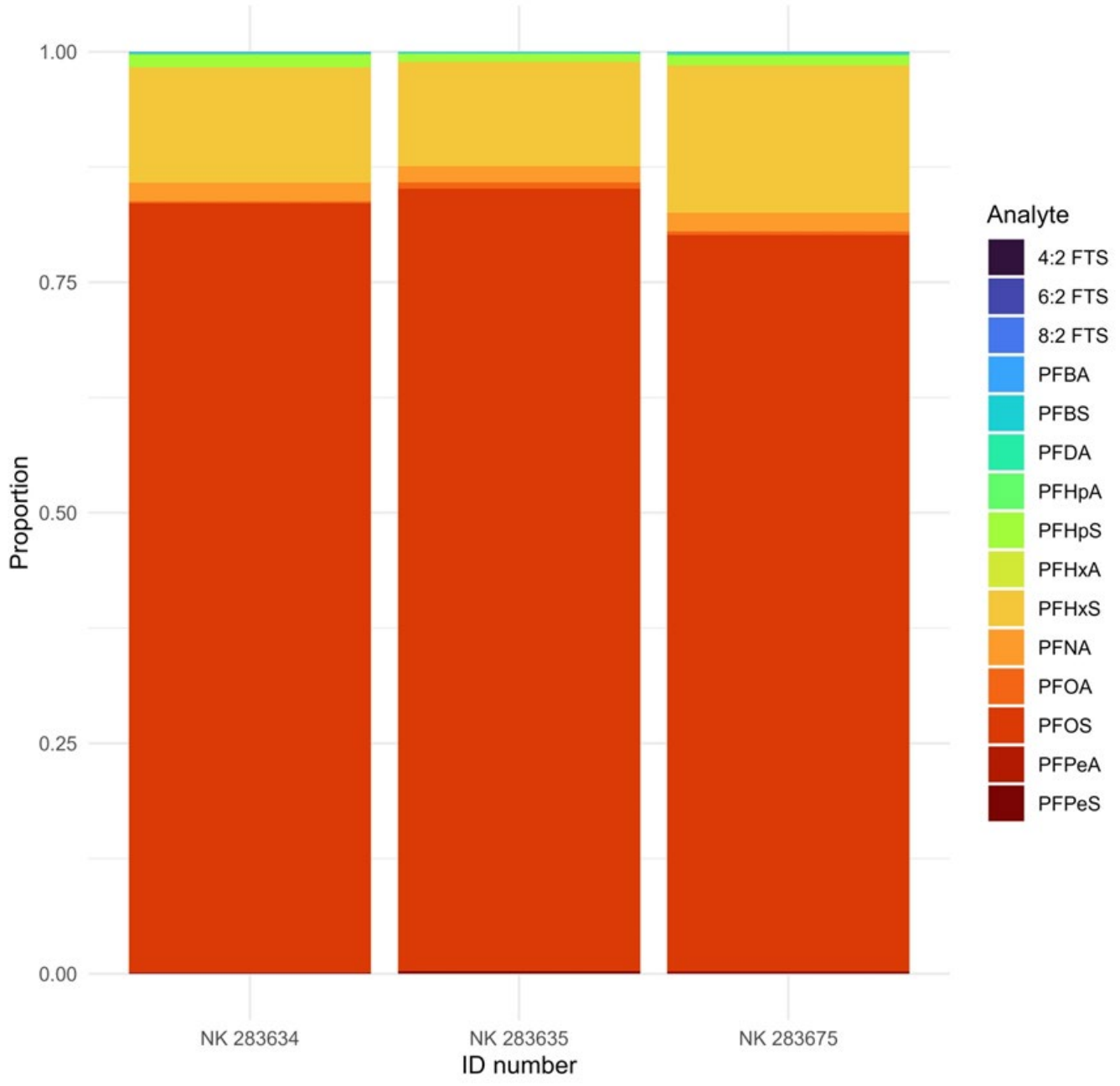
Proportions of PFAS Congeners Detected in Four Representative House Mouse (*Mus musculus*) Liver Samples

Figure 7

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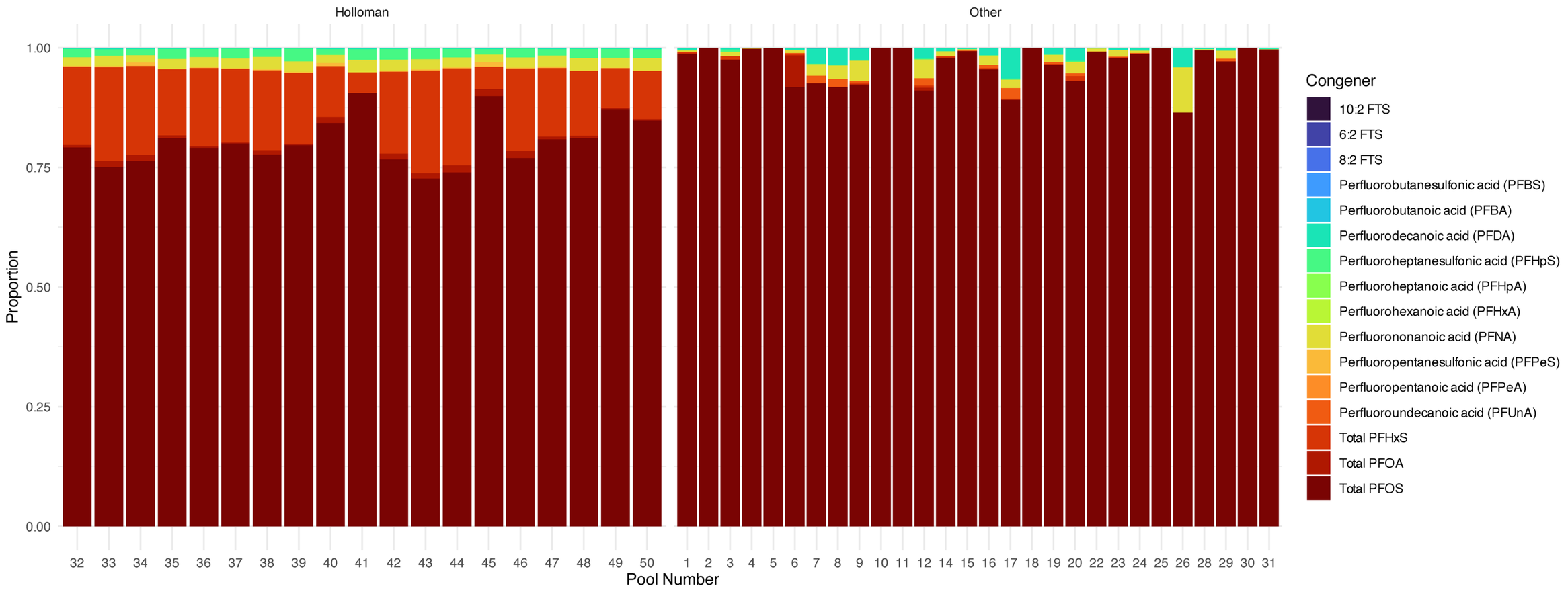
Proportions of PFAS Congeners Detected in Three Representative Green-Winged Teal (*Anas crecca*) Liver Samples

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Figure 8



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Comparison of PFAS Contamination Profiles between Waterfowl Tissue Samples from Holloman Lake and Other Wetlands around New Mexico

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Figure 9

Tables

Table 1. Animals Included in Necropsy Study

Common Name	Scientific Name	NK Number	Sex	Date	Method
Mammals					
Merriam's kangaroo rat	*Dipodomys merriami*	NK311130	M	5/16/2024	Sherman
House mouse	*Mus musculus*	NK 311135	M	5/16/2024	Sherman
White-footed mouse	*Peromyscys leucopus*	NK311134	M	5/16/2024	Sherman
White-footed mouse	*Peromyscus leucopus*	NK 311139	M	5/16/2024	Sherman
Deer mouse	*Peromyscus maniculatus*	NK 311138	F	5/16/2024	Sherman
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311147	F	11/13/2024	Sherman
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311148	M	11/13/2024	Sherman
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311149	M	11/13/2024	Sherman
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311150	M	11/13/2024	Sherman
Deer Mouse	*Peromyscus maniculatus*	NK 311151	M	11/13/2024	Snap trap
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311152	F	11/13/2024	Snap trap
Chihuahuan desert pocket mouse	*Chaetodipus eremicus*	NK 311153	F	11/13/2024	Sherman
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311154	M	11/13/2024	Snap trap
Birds					
Red-winged blackbird	*Agelaius phoeniceus*	NK 284441	F	7/11/2024	Netted
Killdeer	*Charadrius vociferus*	NK 284442	M	7/11/2024	Shot
American avocet	*Recurvirostra americana*	NK 284443	M	7/11/2024	Shot
Red-winged blackbird	*Agelaius phoeniceus*	NK 284444	F	7/11/2024	Netted
Red-winged blackbird	*Agelaius phoeniceus*	NK 284445	F	7/11/2024	Netted
Red-winged blackbird	*Agelaius phoeniceus*	NK 284446	F	7/11/2024	Netted
Western kingbird	*Tyrannus verticalis*	NK 284447	F	7/11/2024	Netted
Western kingbird	*Tyrannus verticalis*	NK 284448	M	7/11/2024	Netted
Common yellowthroat	*Geothlypis trichas*	NK 284449	M	7/11/2024	Netted
Common yellowthroat	*Geothlypis trichas*	NK 284450	F	7/11/2024	Netted
Common yellowthroat	*Geothlypis trichas*	NK 284451	M	7/11/2024	Netted

Table 2. Highest PFOS Tissue Concentrations Measured in Birds and Mammals from Holloman Lake and Upstream Wastewater Collection Ponds
Page 1 of 2

Common Name	Scientific Name	NK Identifier	PFOS Concentration (ng/g ww)	Substrate	Collection Site [a]	Collection Date
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311150	120,000	Liver	Holloman Lake	11/13/2024
		NK 311152	110,000	Liver	Holloman Lake	11/13/2024
White-footed mouse	*Peromyscus leucopus*	NK 31806	97,000	Liver	Lagoon G	8/16/1994
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311147	94,000	Liver	Holloman Lake	11/13/2024
		NK 311154	66,000	Liver	Holloman Lake	11/13/2024
House mouse	*Mus musculus*	NK 311422	65,000	Liver	Holloman Lake	10/30/2021
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311148	65,000	Liver	Holloman Lake	11/13/2024
House mouse	*Mus musculus*	NK 311426	57,000	Liver	Holloman Lake	10/30/2021
Killdeer [b,c]	*Charadrius vociferus*	NK 284439	48,000	Tissue	Holloman Lake	7/11/2024
Merriam's kangaroo rat	*Dipodomys merriami*	NK311145	47,000	Liver	Holloman Lake	7/3/2024
		NK 311149	46,000	Liver	Holloman Lake	11/13/2024
House mouse	*Mus musculus*	NK 311423	44,000	Liver	Holloman Lake	10/30/2021
		NK311424	43,000	Liver	Holloman Lake	10/30/2021
American wigeon	*Mareca americana*	NK 283623	38,000	Liver	Holloman Lake	1/15/2022
Spotted ground squirrel	*Xerospermophilus spilosoma*	NK 311146	24,000	Liver	Holloman Lake	7/3/2024
Killdeer	*Charadrius vociferus*	NK 283771	23,000	Liver	Holloman Lake	6/20/2022
Cactus mouse	*Peromyscus eremicus*	NK 311395	22,000	Liver	Holloman Lake	10/29/2021
Green-winged teal	*Anas crecca*	NK 283634	20,000	Liver	Holloman Lake	1/31/2022
Bufflehead	*Bucephala albeola*	NK 283693	20,000	Liver	Holloman Lake	1/30/2022
Northern shoveler	*Spatula clypeata*	NK 283666	17,000	Liver	Holloman Lake	1/8/2022
Chihuahuan pocket mouse [c]	*Chaetodipus eremicus*	NK311131	17,000	Liver	Holloman Lake	5/16/2024
Red-winged blackbird	*Agelaius phoeniceus*	NK284441	17,000	Liver	Holloman Lake	7/11/2024
House mouse	*Mus musculus*	NK 310921	16,000	Liver	Holloman Lake	5/5/2022
		NK 311887	15,000	Liver	Holloman Lake	5/5/2022
		NK 310884	14,000	Liver	Holloman Lake	3/4/2022

Notes are provided at the end of the table.

Table 2. Highest PFOS Tissue Concentrations Measured in Birds and Mammals from Holloman Lake and Upstream Wastewater Collection Ponds
Page 2 of 2

Common Name	Scientific Name	NK Identifier	PFOS Concentration (ng/g ww)	Substrate	Collection Site [a]	Collection Date
Redhead	*Aythya americana*	NK 283668	14,000	Liver	Holloman Lake	1/8/2022
House mouse	*Mus musculus*	NK 310959	13,000	Liver	Holloman Lake	5/6/2022
		NK 310922	13,000	Liver	Holloman Lake	5/5/2022
Green-winged teal	*Anas crecca*	NK 283635	12,000	Liver	Holloman Lake	1/30/2022
House mouse	*Mus musculus*	NK 310883	12,000	Liver	Holloman Lake	3/4/2022
Red-winged blackbird	*Agelaius phoeniceus*	NK284445	12,000	Liver	Holloman Lake	7/11/2024
House mouse	*Mus musculus*	NK 310882	11,000	Liver	Holloman Lake	3/4/2022
Green-winged teal	*Anas crecca*	NK 283675	11,000	Liver	Holloman Lake	1/8/2022
House mouse	*Mus musculus*	NK 311886	10,000	Liver	Holloman Lake	5/5/2022
Northern pintail	*Anas acuta*	NK 283604	10,000	Liver	Holloman Lake	12/10/2021
Red-winged blackbird	*Agelaius phoeniceus*	NK284446	10,000	Liver	Holloman Lake	7/11/2024

[a] Unless otherwise indicated, all specimens from Holloman Lake were collected at the lake surface, along the shoreline, or at the mouth of the east intake.

[b] Salvaged specimen (hatchling found dead near its nest).

[c] Collected in the uplands near the southern end of the lake.

ng/g ww = Nanograms per gram, wet weight

Table 3. Gross Necropsy and Histopathology Results
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Common Name	Scientific Name	NK Number	Findings
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311130	**Occasional, small aggregates of enlarged hepatocytes ("altered foci"), not unusual—at least in *Mus musculus*—and can increase with age and exposure to some carcinogens.**
House mouse	*Mus musculus*	NK 311135	No overt significant findings during gross necropsy and microscopic exam. In the small intestine, the lamina propria contains numerous lymphoid cells, but these are uniformly distributed; the number of lymphoid cells is judged to be within normal limits. The villus tips of the intestine are autolyzed, which makes interpretation difficult.
White-footed mouse	*Peromyscys leucopus*	NK311134	Mild, chronic, interstitial pneumonia. Mild to moderate, granulomatous hepatitis with intralesional trematodes (flatworms). **Lymphofollicular hyperplasia of the spleen, with the prominent germinal centers in the white pulp suggesting antigenic stimulation and marked erythropoiesis in the red pulp consistent with response to anemia**. Cestode within a lymph node adjacent to the pancreas. Occasional intracytoplasmic protozoal cysts (sarcocysts) in the tongue and in skeletal muscle surrounding bones.
White-footed mouse	*Peromyscus leucopus*	NK 311139	Extent and pattern of liver vacuolation within normal limits. Mild changes in the white and red pulp of the spleen likely within normal limits. Adrenal glands subjectively enlarged on gross necropsy but likely within normal limits and with no evidence of pathologic processes on microscopic exam (though anisocytosis, anisokaryosis, and multinucleated cells all noted).
Deer mouse	*Peromyscus maniculatus*	NK 311138	Frequent protozoal cysts (sarcocysts) within skeletal muscle fibers surrounding bones; occasional sarcocysts within the cytoplasm of skeletal muscle fibers in the wall of the esophagus and in the tongue. Liver vacuolation within normal limits for a post-prandial mouse; lymphoid cells surrounding a few bile ducts and a single small focus of necrosis in the liver considered incidental findings.

Notes are provided at the end of the table.

Table 3. Gross Necropsy and Histopathology Results
Page 2 of 3

Common Name	Scientific Name	NK Number	Findings
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311147	**Multiple punctate gastric erosions/ulcers**. The foci of necrosis are filled with necrotic debris, fibrin, hemorrhage, and hemoglobin-breakdown pigments. The submucosa associated with the mucosal epithelial necrosis is edematous. The adjacent gastric glandular epithelium is degenerate with hemorrhage in the associated lamina propria. No evidence of inflammation, infectious organisms, neoplasia, or parasites that could have caused the gastric ulcer. Rare microgranulomas in the liver (i.e., rare random and multifocal small infiltrates of small numbers of macrophages and lesser numbers of lymphocytes in the liver that are occasionally associated with apoptotic hepatocytes) considered incidental findings
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311148	Endoparasitism: Small numbers of adult cestodes (tapeworms) in the lumen of the small intestine. Rare microgranulomas in the liver are considered incidental findings.
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311149	**Gastric ulcer** with focally extensive necrosis of the lumenal aspect of the glandular epithelium of the mucosa of the stomach. The focus of necrosis is filled with necrotic debris, fibrin, hemorrhage, and hemoglobin-breakdown pigments. The submucosa associated with the mucosal epithelial necrosis is edematous. The adjacent gastric glandular epithelium is degenerate with hemorrhage in the associated lamina propria. No evidence of inflammation, infectious organisms, neoplasia, or stomach parasites that could have caused the gastric ulcer. Endoparasitism: The lumen of the small intestine contains small numbers of adult nematodes. Rare microgranulomas in the liver are considered an incidental finding.
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311150	No significant lesions. Rare microgranulomas in the liver are considered an incidental finding
Deer mouse	*Peromyscus maniculatus*	NK 311151	No significant lesions. Rare microgranulomas in the liver are considered an incidental finding.
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311152	Endoparasitism: Small numbers of sarcocysts in the skeletal muscle. Rare microgranulomas in the liver are considered an incidental finding.

Notes are provided at the end of the table.

Table 3. Gross Necropsy and Histopathology Results
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Common Name	Scientific Name	NK Number	Findings
Chihuahuan desert pocket mouse	*Chaetodipus eremicus*	NK 311153	No significant lesions.
Merriam's kangaroo rat	*Dipodomys merriami*	NK 311154	Endoparasitism: Small numbers of nematodes in the small intestine. Rare microgranulomas in the liver are considered an incidental finding.
Red-winged blackbird	*Agelaius phoeniceus**	NK 284441	Normal tissue.
Killdeer	*Charadrius vociferus*	NK 284442	Endoparasitism: Lumen of the proventriculus contains two small degenerate helminths.
American avocet	*Recurvirostra americana*	NK 284443	Endoparasitism in the small intestine and ventriculus. Inflammation in the mesentery, fat adjacent to the spleen, and liver likely in response to the endoparasitism; moderate to severe lymphocytic orchitis.
Red-winged blackbird	*Agelaius phoeniceus*	NK 284444	Normal tissue.
Red-winged blackbird	*Agelaius phoeniceus*	NK 284445	Normal tissue.
Red-winged blackbird	*Agelaius phoeniceus*	NK 284446	Very mild inflammation in the portal areas of the liver.
Western kingbird	*Tyrannus verticalis*	NK 284447	Airsac nematode, nematodes in the small intestine (endoparasitism), and flukes within the portal vein (avian schistosomiasis). **Mild lymphohistiocytic interstitial nephritis**, possibly the result of parasite migration through a kidney.
Western kingbird	*Tyrannus verticalis*	NK 284448	Endoparasitism (adult tapeworm in the small intestine); testicular atrophy possibly related to seasonal cycle of testicular activity/inactivity.
Common yellowthroat	*Geothlypis trichas*	NK 284449	Normal tissue.
Common yellowthroat	*Geothlypis trichas*	NK 284450	Normal tissue.
Common yellowthroat	*Geothlypis trichas*	NK 284451	*Sarcocystis* species protozoal cysts in the skeletal muscle (sarcocystosis, rice breast disease). Small focus of nonsuppurative encephalitis likely associated with prior trauma to the area.

Bold indicates the most notable findings.

Table 4. PFAS Screening of Composite and Individual Waterfowl Tissue Samples
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Sample No.	Species Name	Collection Locality	NK No.	Tissue Type	PFOS Concentration (ng/g)
1	Bufflehead (*Bucephala albeola*)	Fort Craig	5992	Liver	1,100
	Ring-necked duck (*Aythya collaris*)	San Marcial	5995	Liver	
	Ring-necked duck (*Aythya collaris*)	San Marcial	5998	Liver	
	Hooded merganser (*Lophodytes cucullatus*)	Watrous; 12 mi. W	14474	Liver	
	Common merganser (*Mergus merganser*)	Mescalero Lake	14866	Liver	
	Lesser scaup (*Aythya affinis*)	McAllister Lake	35807	Heart, liver	
	Common goldeneye (*Bucephala clangula*)	Los Ojos area along Rio Chama	35815	Heart, liver	
	Ruddy duck (*Oxyura jamaicensis*)	Kirtland Air Force Base	103113	Liver	
2	Snow goose (*Chen caerulescens*)	Bosque de Apache NWR	9098	Liver	67
3	Northern shoveler (*Spatula clypeata*)	Bosque del Apache NWR	2445	Liver	440
4	Redhead (*Aythya americana*)	San Marcial	2444	Liver	530
5	Redhead (*Aythya americana*)	Waterflow, San Juan County	35658	Liver	650
	Redhead (*Aythya americana*)	Waterflow, San Juan County	35659	Liver	
	Redhead (*Aythya americana*)	Waterflow, San Juan County	35660	Liver	
	Redhead (*Aythya americana*)	Waterflow, San Juan County	35799	Liver	
6	Wood duck (*Aix sponsa*)	Kirtland along San Juan River	35627	Heart, liver	1,000
	American wigeon (*Anas americana*)	Kirtland along San Juan River	35628	Heart, liver	
	Gadwall (*Mareca strepera*)	Kirtland, Schmitt marsh	35630	Heart, liver	
	American wigeon (*Anas americana*)	Kirtland along San Juan River	35632	Heart, liver	
	American wigeon (*Anas americana*)	Kirtland along San Juan River	35642	Heart, liver	
	Gadwall (*Mareca strepera*)	Kirtland, Schmitt marsh	35649	Heart, liver	
	Green-winged teal (*Anas crecca*)	North Shore Morgan Lake	35661	Heart, liver	
	Wood duck (*Aix sponsa*)	Kirtland, Schmitt property	35803	Heart, liver, muscle	
	Green-winged teal (*Anas crecca*)	N shore Morgan Lake	35805	Heart, liver, muscle	

Notes are provided at the end of the table.

Table 4. PFAS Screening of Composite and Individual Waterfowl Tissue Samples
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Sample No.	Species Name	Collection Locality	NK No.	Tissue Type	PFOS Concentration (ng/g)
6 (cont.)	Wood duck (*Aix sponsa*)	Kirtland, along San Juan River	35823	Heart, liver	1,000
	Gadwall (*Mareca strepera*)	San Juan River	35824	Heart, liver	
	Gadwall (*Mareca strepera*)	Kirtland, Schmitt marsh	35826	Heart, liver	
	Northern shoveler (*Spatula clypeata*)	Fruitland along San Juan River	35833	Heart, liver	
	Mallard (*Anas platyrhynchos*)	Kirtland, Schmitt marsh	35844	Heart, liver	
	Northern shoveler (*Spatula clypeata*)	Kirtland, Schmitt marsh	35845	Heart, liver	
	Northern shoveler (*Spatula clypeata*)	Kirtland, Schmitt marsh	35849	Heart, liver	
	Northern shoveler (*Spatula clypeata*)	Kirtland, Schmitt marsh	35852	Heart, liver	
	Northern shoveler (*Spatula clypeata*)	Kirtland, Schmitt marsh	35853	Heart, liver	
	Northern shoveler (*Spatula clypeata*)	Kirtland, Schmitt marsh	35854	Heart, liver	
	Northern shoveler (*Spatula clypeata*)	Kirtland, Schmitt marsh	35914	Heart, liver, muscle	
	Northern shoveler (*Spatula clypeata*)	Near Bloomfield on San Juan River	35915	Heart, liver, muscle	
	Mallard (*Anas platyrhynchos*)	Fruitland	35919	Heart, liver, muscle	
	Wood duck (*Aix sponsa*)	Kirtland along San Juan River	35931	Heart, liver, muscle	
	American green-winged teal (*Anas carolinensis*)	Kirtland, Schmitt marsh	35932	Heart, liver, muscle	
	Green-winged teal (*Anas crecca*)	Kirtland, Schmitt marsh	35936	Heart, liver, muscle	
	Mallard (*Anas platyrhynchos*)	Kirtland, Schmitt marsh	35937	Heart, liver	
	Northern pintail (*Anas acuta*)	Kirtland along San Juan River	177463	Heart, liver, muscle	
	Mallard (*Anas platyrhynchos*)	Kirtland along San Juan River	177464	Heart, liver, muscle	

Notes are provided at the end of the table.

Table 4. PFAS Screening of Composite and Individual Waterfowl Tissue Samples
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Sample No.	Species Name	Collection Locality	NK No.	Tissue Type	PFOS Concentration (ng/g)
7	Bufflehead (*Bucephala albeola*)	Kirtland along San Juan River	35626	Heart, liver	580
	Common merganser (*Mergus merganser*)	Kirtland along San Juan River	35639	Heart, liver	
	Common merganser (*Mergus merganser*)	Kirtland along San Juan River	35640	Heart, liver	
	Common goldeneye (*Bucephala clangula*)	Kirtland along San Juan River	35644	Heart, liver	
	Common goldeneye (*Bucephala clangula*)	Kirtland along San Juan River	35648	Heart, liver	
	Common merganser (*Mergus merganser*)	Kirtland along San Juan River	35652	Heart, liver	
	Common goldeneye (*Bucephala clangula*)	Kirtland along San Juan River	35653	Heart, liver	
	Common goldeneye (*Bucephala clangula*)	Kirtland along San Juan River	35654	Heart, liver	
	Common goldeneye (*Bucephala clangula*)	Kirtland along San Juan River	35655	Heart, liver	
	Common merganser (*Mergus merganser*)	Kirtland along San Juan River	35656	Heart, liver	
	Common goldeneye (*Bucephala clangula*)	Kirtland along San Juan River	35663	Heart, liver	
	Common goldeneye (*Bucephala clangula*)	Kirtland along San Juan River	35668	Heart, liver	
	Bufflehead (*Bucephala albeola*)	Kirtland along San Juan River	35798	Heart, liver, muscle	
8	Common merganser (*Mergus merganser*)	Pena Blanca along Rio Grande	35625	Heart, liver	250
	Common goldeneye (*Bucephala clangula*)	Kirtland along San Juan River	35646	Heart, liver	
	Common merganser (*Mergus merganser*)	Pena Blanca along Rio Grande	35811	Heart, liver, muscle	
	Ring-necked duck (*Aythya collaris*)	Pena Blanca along Rio Grande	35924	Heart, liver, muscle	
	Ruddy duck (*Oxyura jamaicensis*)	Bitter Lake NWR	142004	Heart, liver	
	Bufflehead (*Bucephala albeola*)	Bitter Lake NWR	142007	Heart, liver	
	Bufflehead (*Bucephala albeola*)	Bitter Lake NWR	142009	Heart, liver	
9	Northern pintail (*Anas acuta*)	Kirtland along San Juan River	35643	Heart, liver	350
	Mallard (*Anas platyrhynchos*)	Albuquerque	100368	Liver	
	Gadwall (*Mareca strepera*)	San Marcial	116458	Heart, liver	

Notes are provided at the end of the table.

Table 4. PFAS Screening of Composite and Individual Waterfowl Tissue Samples
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Sample No.	Species Name	Collection Locality	NK No.	Tissue Type	PFOS Concentration (ng/g)
10	Snow goose (*Chen caerulescens*) Snow goose (*Chen caerulescens*) Snow goose (*Chen caerulescens*)	Bitter Lake NWR Bitter Lake NWR Bitter Lake NWR	142478 142479 170946	Heart, liver, muscle Heart, liver, muscle Heart, liver, muscle	960
11	Redhead (*Aythya americana*)	Bitter Lake NWR	100328	Liver	2.6
12	Common merganser (*Mergus merganser*) Common scoter (*Melanitta nigra*) Surf scoter (*Melanitta perspicillata*)	Pena Blanca along Rio Grande Stubblefield Lake Just West of Mountainair	35665 165148 165232	Heart, liver Heart, liver Liver	280
13	Redhead (*Aythya americana*) Redhead (*Aythya americana*) Redhead (*Aythya americana*) Redhead (*Aythya americana*) Redhead (*Aythya americana*) Redhead (*Aythya americana*)	Waterflow Waterflow Waterflow Waterflow Waterflow along San Juan River Waterflow	35674 35676 35677 35679 35832 35925	Heart, liver Heart, liver Heart, liver Heart, liver Heart, liver, muscle Heart, liver, muscle	640
14	Mallard (*Anas platyrhynchos*) Wood duck (*Aix sponsa*) Wood duck (*Aix sponsa*) Wood duck (*Aix sponsa*) Wood duck (*Aix sponsa*) American wigeon (*Anas americana*) Wood duck (*Aix sponsa*) American green-winged teal (*Anas carolinensis*) Mallard (*Anas platyrhynchos*) Mallard (*Anas platyrhynchos*) Wood duck (*Aix sponsa*) American wigeon (*Anas americana*)	Kirtland along San Juan River Kirtland along San Juan River Kirtland along San Juan River Kirtland along San Juan River Kirtland along San Juan River Kirtland along San Juan River Kirtland along San Juan River Kirtland along San Juan River Kirtland along San Juan River Kirtland along San Juan River Kirtland along San Juan River Kirtland along San Juan River	35624 35672 35673 35678 35680 35890 35898 35903 35908 35909 35911 35913	Heart, liver, muscle Heart, liver Heart, liver Heart, liver Heart, liver Heart, liver, muscle Heart, liver, muscle Heart, liver, muscle Heart, liver Heart, liver Heart, liver, muscle Heart, liver, muscle	570

Notes are provided at the end of the table.

Table 4. PFAS Screening of Composite and Individual Waterfowl Tissue Samples
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Sample No.	Species Name	Collection Locality	NK No.	Tissue Type	PFOS Concentration (ng/g)
15	Common merganser (*Mergus merganser*)	Kirtland along San Juan River	35633	Heart, liver	340
	Common merganser (*Mergus merganser*)	Waterflow along San Juan River	35636	Heart, liver	
	Bufflehead (*Bucephala albeola*)	Kirtland	35647	Heart, liver	
	Ruddy duck (*Oxyura jamaicensis*)	Kirtland along San Juan River	35650	Heart, liver	
	Ruddy duck (*Oxyura jamaicensis*)	Kirtland	35651	Heart, liver	
	Common merganser (*Mergus merganser*)	Kirtland along San Juan River	35666	Heart, liver	
	Common merganser (*Mergus merganser*)	Waterflow along San Juan River	35667	Heart, liver	
	Common merganser (*Mergus merganser*)	Kirtland along San Juan River	35669	Heart, liver	
	Common merganser (*Mergus merganser*)	Kirtland along San Juan River	35670	Heart, liver	
	Common goldeneye (*Bucephala clangula*)	Kirtland along San Juan River	35671	Heart, liver	
	Hooded merganser (*Lophodytes cucullatus*)	Kirtland along San Juan River	35675	Heart, liver	
	Ring-necked duck (*Aythya collaris*)	Waterflow along San Juan River	35681	Heart, liver	
	Common merganser (*Mergus merganser*)	Kirtland along San Juan River	35828	Heart, liver	
	Common goldeneye (*Bucephala clangula*)	Kirtland along San Juan River	35856	Heart, liver	
	Ring-necked duck (*Aythya collaris*)	Waterflow	35891	Heart, liver, muscle	
	Hooded merganser (*Lophodytes cucullatus*)	Along San Juan River	35892	Heart, liver, muscle	
	Ring-necked duck (*Aythya collaris*)	Waterflow	35901	Heart, liver, muscle	
	Ring-necked duck (*Aythya collaris*)	Waterflow	35902	Heart, liver, muscle	
	Ring-necked duck (*Aythya collaris*)	Waterflow	35917	Heart, liver, muscle	
	Ring-necked duck (*Aythya collaris*)	Waterflow	35920	Heart, liver, muscle	
16	Red-breasted merganser (*Mergus serrator*)	S Rincon, along Rio Grande	35935	Heart, liver, muscle	750
17	Canada goose (*Branta canadensis*)	Fruitland, along San Juan River	35958	Heart, liver, muscle	260

Notes are provided at the end of the table.

Table 4. PFAS Screening of Composite and Individual Waterfowl Tissue Samples
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Sample No.	Species Name	Collection Locality	NK No.	Tissue Type	PFOS Concentration (ng/g)
18	Common goldeneye (*Bucephala clangula*)	Kirtland along San Juan River	35791	Heart, liver, muscle	330
	Common goldeneye (*Bucephala clangula*)	Waterflow along San Juan River	35792	Heart, liver, muscle	
	Common goldeneye (*Bucephala clangula*)	Kirtland along San Juan River	35793	Heart, liver	
	Ring-necked duck (*Aythya collaris*)	Waterflow along San Juan River	35800	Heart, liver	
	Ring-necked duck (*Aythya collaris*)	Kirtland, San Juan River	35801	Heart, liver, muscle	
	Ring-necked duck (*Aythya collaris*)	Waterflow along San Juan River	35802	Heart, liver	
	Canvasback (*Aythya valisineria*)	Waterflow along San Juan River	35806	Heart, liver, muscle	
	Common goldeneye (*Bucephala clangula*)	Kirtland along San Juan River	35816	Heart, liver	
	Canvasback (*Aythya valisineria*)	Waterflow along San Juan River	35818	Heart, liver, muscle	
	Bufflehead (*Bucephala albeola*)	Kirtland along San Juan River	35819	Heart, liver, muscle	
	Canvasback (*Aythya valisineria*)	Waterflow along San Juan River	35825	Heart, liver	
	Hooded merganser (*Lophodytes cucullatus*)	Flora Vista along Animas River	35827	Heart, liver	
	Ring-necked duck (*Aythya collaris*)	Kirtland along San Juan River	35897	Heart, liver, muscle	
	Ring-necked duck (*Aythya collaris*)	Kirtland along San Juan River	35906	Heart, liver, muscle	
	Hooded merganser (*Lophodytes cucullatus*)	Flora Vista along Animas River	35907	Heart, liver, muscle	
	Hooded merganser (*Lophodytes cucullatus*)	Kirtland	35927	Heart, liver, muscle	
	Canvasback (*Aythya valisineria*)	Waterflow	35929	Heart, liver, muscle	
	Hooded merganser (*Lophodytes cucullatus*)	Waterflow along San Juan River	35957	Heart, liver, muscle	
19	Northern pintail (*Anas acuta*)	Kirtland along San Juan River	35804	Heart, liver, muscle	510
	Northern pintail (*Anas acuta*)	Kirtland along San Juan River	35808	Heart, liver, muscle	
	Northern pintail (*Anas acuta*)	Kirtland along San Juan River	35814	Heart, liver, muscle	
20	Redhead (*Aythya americana*)	Waterflow	35876	Heart, liver, muscle	620
	Redhead (*Aythya americana*)	Waterflow	35878	Heart, liver, muscle	
	Redhead (*Aythya americana*)	Waterflow	35883	Heart, liver, muscle	
	Redhead (*Aythya americana*)	Kirtland along San Juan River	35916	Heart, liver	
	Redhead (*Aythya americana*)	Kirtland, along San Juan River	218166	Heart, liver, muscle	

Notes are provided at the end of the table.

Table 4. PFAS Screening of Composite and Individual Waterfowl Tissue Samples
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Sample No.	Species Name	Collection Locality	NK No.	Tissue Type	PFOS Concentration (ng/g)
21	Mallard (*Anas platyrhynchos*)	Kirtland	35875	Heart, liver, muscle	350
	Northern pintail (*Anas acuta*)	Kirtland	35884	Heart, liver, muscle	
	Northern pintail (*Anas acuta*)	Kirtland	35905	Heart, liver, muscle	
	Northern pintail (*Anas acuta*)	Kirtland	35910	Heart, liver, muscle	
	Northern pintail (*Anas acuta*)	Kirtland	35928	Heart, liver, muscle	
	American green-winged teal (*Anas carolinensis*)	Kirtland	35930	Heart, liver, muscle	
	Green-winged teal (*Anas crecca*)	Kirtland	218151	Heart, liver, muscle	
	Green-winged teal (*Anas crecca*)	Kirtland	218152	Heart, liver, muscle	
	Green-winged teal (*Anas crecca*)	Kirtland	218153	Heart, liver, muscle	
	Green-winged teal (*Anas crecca*)	Kirtland	218156	Heart, liver, muscle	
	Green-winged teal (*Anas crecca*)	Kirtland	218157	Heart, liver, muscle	
	Green-winged teal (*Anas crecca*)	Kirtland	218158	Heart, liver, muscle	
22	Canvasback (*Aythya valisineria*)	Waterflow along San Juan River	35817	Heart, liver, muscle	540
	Canvasback (*Aythya valisineria*)	Waterflow	35921	Heart, liver, muscle	
	Canvasback (*Aythya valisineria*)	Waterflow	35922	Heart, liver, muscle	
	Canvasback (*Aythya valisineria*)	Waterflow	35923	Heart, liver, muscle	
	Lesser scaup (*Aythya affinis*)	Kirtland along San Juan River	218164	Heart, liver, muscle	
23	Snow goose (*Chen caerulescens*)	Kirtland	35877	Heart, liver, muscle	590
	Canada goose (*Branta canadensis*)	Along San Juan River	218154	Heart, liver, muscle	
	Canada goose (*Branta canadensis*)	ca. 11.5 km S Farmington	218155	Heart, liver, muscle	
	Canada goose (*Branta canadensis*)	ca. 11.5 km S Farmington	218161	Heart, liver, muscle	
	Canada goose (*Branta canadensis*)	ca. 11.5 km S Farmington	218162	Heart, liver, muscle	
	Canada goose (*Branta canadensis*)	ca. 11.5 km S Farmington	218163	Heart, liver, muscle	
24	Redhead (*Aythya americana*)	Des Moines, Union Co.	282630	Heart, liver, muscle	6.2

Notes are provided at the end of the table.

Table 4. PFAS Screening of Composite and Individual Waterfowl Tissue Samples
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Sample No.	Species Name	Collection Locality	NK No.	Tissue Type	PFOS Concentration (ng/g)
25	American wigeon (*Anas americana*)	Bosque del Apache NWR	276722	Heart, liver, muscle	300
	Wood duck (*Aix sponsa*)	Albuquerque	276849	Heart, liver, muscle	
	Wood duck (*Aix sponsa*)	Corrales	276850	Heart, liver, muscle	
	Wood duck (*Aix sponsa*)	Albuquerque	276851	Heart, liver, muscle	
	Cinnamon teal (*Spatula cyanoptera*)	5.7 km SE Ojo Amarillo	278756	Heart, liver, muscle	
	Mallard (*Anas platyrhynchos*)	Red River	283740	Heart, liver, muscle	
26	Canvasback (*Aythya valisineria*)	Kirtland along the San Juan River	278744	Heart, liver, muscle	380
	Common merganser (*Mergus merganser*)	Chama	282546	Heart, liver, muscle	
	Common merganser (*Mergus merganser*)	Chama	282547	Heart, liver, muscle	
	Common merganser (*Mergus merganser*)	Chama	282564	Heart, liver, muscle	
	White-winged scoter (*Melanitta deglandi*)	Santa Fe	282565	Heart, liver, muscle	
	Common merganser (*Mergus merganser*)	Chama	282566	Heart, liver, muscle	
	Lesser scaup (*Aythya affinis*)	Carlsbad	282604	Heart, liver, muscle	
	Ruddy duck (*Oxyura jamaicensis*)	Albuquerque	282627	Heart, liver, muscle	
27	Canada goose (*Branta canadensis*)	Las Vegas	276660	Heart, liver, muscle	720
	Canada goose (*Branta canadensis*)	Albuquerque	282010	Heart, liver, muscle	
28	Blue-winged teal (*Spatula discors*)	Albuquerque	283698	Heart, liver, muscle	350
	Wood duck (*Aix sponsa*)	Corrales	282696	Heart, liver, muscle	
	Wood duck (*Aix sponsa*)	Corrales	203651	Heart, liver, muscle	
	Gadwall (*Mareca strepera*)	Albuquerque	283747	Heart, liver, muscle	
29	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283601	Liver	15,000
30	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283602	Liver	6,900
31	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283605	Liver	7,400
32	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283606	Liver	10,000

Notes are provided at the end of the table.

Table 4. PFAS Screening of Composite and Individual Waterfowl Tissue Samples
Page 9 of 9

Sample No.	Species Name	Collection Locality	NK No.	Tissue Type	PFOS Concentration (ng/g)
33	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283607	Liver	16,000
34	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283608	Liver	13,000
35	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283615	Liver	14,000
36	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283619	Liver	14,000
37	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283621	Liver	3,100
38	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283622	Liver	25,000
39	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283626	Liver	26,000
40	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283627	Liver	23,000
41	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283629	Liver	19,000
42	Redhead (*Aythya americana*)	Holloman Lake	283631	Liver	3,700
43	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283633	Liver	21,000
44	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283641	Liver	13,000
45	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283664	Liver	21,000
46	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283669	Liver	19,000
47	Northern shoveler (*Spatula clypeata*)	Holloman Lake	283674	Liver	22,000

ng/g = Nanograms per gram

Appendix A

Laboratory Reports

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ANALYTICAL REPORT

PREPARED FOR

Attn: Jean-Luc Cartron
University of New Mexico
Museum of Southwestern Biology
Division of Mammals
CERIA Bldg 83, Room 204
Albuquerque, New Mexico 87131

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JOB DESCRIPTION

Holloman Lake_Rodent tissue

JOB NUMBER

320-113143-1

Eurofins Sacramento
880 Riverside Parkway
West Sacramento CA 95605

See page two for job notes and contact information.

my EOL
NMED Exhibits 65

Job Notes

This report may not be reproduced except in full, and with written approval from the laboratory. The results relate only to the samples tested. For questions please contact the Project Manager at the e-mail address or telephone number listed on this page.

The test results in this report relate only to the samples as received by the laboratory and will meet all requirements of the methodology, with any exceptions noted. This report shall not be reproduced except in full, without the express written approval of the laboratory. All questions should be directed to the Eurofins Environment Testing Northern California, LLC Project Manager.

Authorization



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NMED Exhibit 65

Qualifiers

LCMS

Qualifier	Qualifier Description
*5+	Isotope dilution analyte is outside acceptance limits, high biased.
E	Result exceeded calibration range.
J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
¤	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CFU	Colony Forming Unit
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MCL	EPA recommended "Maximum Contaminant Level"
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
MPN	Most Probable Number
MQL	Method Quantitation Limit
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
NEG	Negative / Absent
POS	Positive / Present
PQL	Practical Quantitation Limit
PRES	Presumptive
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)
TNTC	Too Numerous To Count

NMED Exhibits 65

Job Narrative
320-113143-1

Receipt
The samples were received on 6/18/2024 9:20 AM. Unless otherwise noted below, the samples arrived in good condition, and where required, properly preserved and on ice. The temperature of the cooler at receipt was -33.8º C.

Receipt Exceptions
Samples were not received with a Chain-of-Custody Form, but the lab received a "Specimen Invoice" that does list the sample IDs under the Description section. The collection date and time were not listed. Client provide the collection date as May 16, 2024 in email received on June 18, 2024. The samples were logged in using a default time of 00:00.

LCMS
Method B/L/T PFAS: The concentration of one or more analytes associated with the following samples exceeded the instrument calibration range. These analytes have been qualified; however, the peak(s) did not saturate the instrument detector. Historical data indicate that for the isotope dilution method, dilution and re-analysis will not produce significantly different results from those reported above the calibration range. NK311130-Dipodomys merriami-muscle (320-113143-1), NK311134-Peromyscus leucopus-muscle (320-113143-2), NK311135-Mus musculus-muscle (320-113143-3), NK311138-Peromyscus maniculatus-muscle (320-113143-4) and NK311139-Peromyscus leucopus-muscle (320-113143-5)

Method B/L/T PFAS: Isotope Dilution Analyte (IDA) recovery is above the method recommended limit for the following samples. Quantitation by isotope dilution generally precludes any adverse effect on data quality due to elevated IDA recoveries. NK311130-Dipodomys merriami-muscle (320-113143-1), NK311134-Peromyscus leucopus-muscle (320-113143-2), NK311135-Mus musculus-muscle (320-113143-3), NK311138-Peromyscus maniculatus-muscle (320-113143-4), NK311139-Peromyscus leucopus-muscle (320-113143-5), (MB 320-773440/1-A), (LCS 320-773440/2-A) and (LCSD 320-773440/3-A)

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Organic Prep
Method SHAKE: A matrix spike/matrix spike duplicate (MS/MSD) was not performed with preparation batch 320-773440.

Method SHAKE: Elevated reporting limits (RL) are provided for the following samples due to limited mass available for extraction: NK311134-Peromyscus leucopus-muscle (320-113143-2), NK311135-Mus musculus-muscle (320-113143-3), NK311138-Peromyscus maniculatus-muscle (320-113143-4) and NK311139-Peromyscus leucopus-muscle (320-113143-5).

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Detection Summary

Client: University of New Mexico
Project/Site: Holloman Lake_Rodent tissue

Job ID: 320-113143-1

Client Sample ID: NK311130-Dipodomys merriami-muscle — Lab Sample ID: 320-113143-1

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	1.5		0.60	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.78		0.60	0.062	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	19		0.60	0.089	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	19		0.60	0.089	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	17		0.60	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	520	E	1.5	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	220	E	1.5	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	730		1.5	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.19	J	0.60	0.060	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK311134-Peromyscus leucopus-muscle — Lab Sample ID: 320-113143-2

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanoic acid (PFHpA)	1.4	J	1.6	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	3.7		1.6	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.56	J	1.6	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	4.3		1.6	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	2.8		1.6	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	2.3		1.6	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.91	J	1.6	0.44	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	1.5	J	1.6	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	85		1.6	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	83		1.6	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	3.2		1.6	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	420	E	4.0	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	110		4.0	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	540		4.0	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.90	J	1.6	0.68	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	2.9		1.6	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.17	J	1.6	0.16	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK311135-Mus musculus-muscle — Lab Sample ID: 320-113143-3

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.99	J	2.8	0.66	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	16		2.8	0.56	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	1.1	J	2.8	0.56	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	17		2.8	0.56	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	28		2.8	0.49	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.83	J	2.8	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	4.9		2.8	0.41	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	150		2.8	0.41	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	150		2.8	0.41	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	26		2.8	0.51	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	1700	E	6.9	0.56	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	680	E	6.9	0.56	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	2400		6.9	0.56	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	1.3	J	2.8	1.2	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.28	J	2.8	0.28	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Eurofins Sacramento

NMED Exhibits 65

Detection Summary

Client: University of New Mexico
Project/Site: Holloman Lake_Rodent tissue

Job ID: 320-113143-1

Client Sample ID: NK311138-Peromyscus maniculatus-muscle — Lab Sample ID: 320-113143-4

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	3.0		1.5	0.35	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	2.1		1.5	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	28		1.5	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	1.5		1.5	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	29		1.5	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	17		1.5	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	4.2		1.5	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.41	J	1.5	0.41	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.43	J	1.5	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	3.9		1.5	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	150		1.5	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	150	E	1.5	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	16		1.5	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	1400	E	3.7	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	410	E	3.7	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	1800		3.7	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	5.4		1.5	0.63	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	1.4	J	1.5	0.15	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK311139-Peromyscus leucopus-muscle — Lab Sample ID: 320-113143-5

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.49	J	1.1	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.45	J	1.1	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.23	J	1.1	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	2.0		1.1	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.34	J	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	4.4		1.1	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	4.4		1.1	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	1.8		1.1	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	250	E	2.7	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	42		2.7	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	290		2.7	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.77	J	1.1	0.47	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	2.0		1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.15	J	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Eurofins Sacramento

Client: University of New Mexico
Project/Site: Holloman Lake_Rodent tissue

Job ID: 320-113143-1

Client Sample ID: NK311130-Dipodomys merriami-muscle
Date Collected: 05/16/24 00:00
Date Received: 06/18/24 09:20

Lab Sample ID: 320-113143-1
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.60	0.14	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
Perfluoropentanoic acid (PFPeA)	ND		0.60	0.11	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
Perfluorohexanoic acid (PFHxA)	ND		0.60	0.16	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
Perfluoroheptanoic acid (PFHpA)	ND		0.60	0.070	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
L-Perfluorooctanoic acid	ND		0.60	0.12	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
Br-Perfluorooctanoic acid	ND		0.60	0.12	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
Total PFOA	ND		0.60	0.12	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
Perfluorononanoic acid (PFNA)	**1.5**		0.60	0.11	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
Perfluorodecanoic acid (PFDA)	**0.78**		0.60	0.062	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
Perfluoroundecanoic acid (PFUnA)	ND		0.60	0.16	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.60	0.10	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.60	0.11	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
Br-Perfluorohexanesulfonic acid	ND		0.60	0.089	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
Total PFHxS	**19**		0.60	0.089	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
L-Perfluorohexanesulfonic acid	**19**		0.60	0.089	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
Perfluoroheptanesulfonic acid (PFHpS)	**17**		0.60	0.11	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
L-Perfluorooctanesulfonic acid	**520**	**E**	1.5	0.12	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
Br-Perfluorooctanesulfonic acid	**220**	**E**	1.5	0.12	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
Total PFOS	**730**		1.5	0.12	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
4:2 FTS	ND		0.60	0.16	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
6:2 FTS	ND		0.60	0.26	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
8:2 FTS	**0.19**	**J**	0.60	0.060	ug/Kg		06/20/24 10:53	06/24/24 18:42	1
10:2 FTS	ND		0.60	0.061	ug/Kg		06/20/24 10:53	06/24/24 18:42	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*102*		*25 - 150*	*06/20/24 10:53*	*06/24/24 18:42*	*1*
13C5 PFPeA	*113*		*25 - 150*	*06/20/24 10:53*	*06/24/24 18:42*	*1*
13C2 PFHxA	*115*		*25 - 150*	*06/20/24 10:53*	*06/24/24 18:42*	*1*
13C4 PFHpA	*104*		*25 - 150*	*06/20/24 10:53*	*06/24/24 18:42*	*1*
13C4 PFOA	*92*		*25 - 150*	*06/20/24 10:53*	*06/24/24 18:42*	*1*
13C5 PFNA	*93*		*25 - 150*	*06/20/24 10:53*	*06/24/24 18:42*	*1*
13C2 PFDA	*108*		*25 - 150*	*06/20/24 10:53*	*06/24/24 18:42*	*1*
13C2 PFUnA	*116*		*25 - 150*	*06/20/24 10:53*	*06/24/24 18:42*	*1*
13C3 PFBS	*117*		*25 - 150*	*06/20/24 10:53*	*06/24/24 18:42*	*1*
18O2 PFHxS	*101*		*25 - 150*	*06/20/24 10:53*	*06/24/24 18:42*	*1*
13C4 PFOS	*96*		*25 - 150*	*06/20/24 10:53*	*06/24/24 18:42*	*1*
M2-4:2 FTS	*134*		*25 - 150*	*06/20/24 10:53*	*06/24/24 18:42*	*1*
M2-6:2 FTS	*112*		*25 - 150*	*06/20/24 10:53*	*06/24/24 18:42*	*1*
M2-8:2 FTS	*104*		*25 - 150*	*06/20/24 10:53*	*06/24/24 18:42*	*1*
13C2 10:2 FTS	*212*	**5+*	*25 - 150*	*06/20/24 10:53*	*06/24/24 18:42*	*1*

Client: University of New Mexico
Project/Site: Holloman Lake_Rodent tissue

Job ID: 320-113143-1

Client Sample ID: NK311134-Peromyscus leucopus-muscle
Date Collected: 05/16/24 00:00
Date Received: 06/18/24 09:20

Lab Sample ID: 320-113143-2
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.6	0.38	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
Perfluoropentanoic acid (PFPeA)	ND		1.6	0.28	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
Perfluorohexanoic acid (PFHxA)	ND		1.6	0.44	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
Perfluoroheptanoic acid (PFHpA)	**1.4**	**J**	1.6	0.19	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
L-Perfluorooctanoic acid	**3.7**		1.6	0.33	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
Br-Perfluorooctanoic acid	**0.56**	**J**	1.6	0.33	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
Total PFOA	**4.3**		1.6	0.33	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
Perfluorononanoic acid (PFNA)	**2.8**		1.6	0.28	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
Perfluorodecanoic acid (PFDA)	**2.3**		1.6	0.17	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
Perfluoroundecanoic acid (PFUnA)	**0.91**	**J**	1.6	0.44	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.6	0.27	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.6	0.29	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
Br-Perfluorohexanesulfonic acid	**1.5**	**J**	1.6	0.24	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
Total PFHxS	**85**		1.6	0.24	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
L-Perfluorohexanesulfonic acid	**83**		1.6	0.24	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
Perfluoroheptanesulfonic acid (PFHpS)	**3.2**		1.6	0.30	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
L-Perfluorooctanesulfonic acid	**420**	**E**	4.0	0.33	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
Br-Perfluorooctanesulfonic acid	**110**		4.0	0.33	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
Total PFOS	**540**		4.0	0.33	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
4:2 FTS	ND		1.6	0.43	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
6:2 FTS	**0.90**	**J**	1.6	0.68	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
8:2 FTS	**2.9**		1.6	0.16	ug/Kg		06/20/24 10:53	06/24/24 19:01	1
10:2 FTS	**0.17**	**J**	1.6	0.16	ug/Kg		06/20/24 10:53	06/24/24 19:01	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*116*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:01*	*1*
13C5 PFPeA	*114*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:01*	*1*
13C2 PFHxA	*121*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:01*	*1*
13C4 PFHpA	*107*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:01*	*1*
13C4 PFOA	*96*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:01*	*1*
13C5 PFNA	*100*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:01*	*1*
13C2 PFDA	*111*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:01*	*1*
13C2 PFUnA	*126*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:01*	*1*
13C3 PFBS	*127*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:01*	*1*
18O2 PFHxS	*106*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:01*	*1*
13C4 PFOS	*99*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:01*	*1*
M2-4:2 FTS	*124*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:01*	*1*
M2-6:2 FTS	*122*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:01*	*1*
M2-8:2 FTS	*111*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:01*	*1*
13C2 10:2 FTS	*251*	**5+*	*25 - 150*	*06/20/24 10:53*	*06/24/24 19:01*	*1*

Client: University of New Mexico
Project/Site: Holloman Lake_Rodent tissue

Job ID: 320-113143-1

Client Sample ID: NK311135-Mus musculus-muscle
Date Collected: 05/16/24 00:00
Date Received: 06/18/24 09:20

Lab Sample ID: 320-113143-3
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**0.99**	**J**	2.8	0.66	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
Perfluoropentanoic acid (PFPeA)	ND		2.8	0.49	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
Perfluorohexanoic acid (PFHxA)	ND		2.8	0.76	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
Perfluoroheptanoic acid (PFHpA)	ND		2.8	0.32	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
L-Perfluorooctanoic acid	**16**		2.8	0.56	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
Br-Perfluorooctanoic acid	**1.1**	**J**	2.8	0.56	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
Total PFOA	**17**		2.8	0.56	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
Perfluorononanoic acid (PFNA)	**28**		2.8	0.49	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
Perfluorodecanoic acid (PFDA)	**0.83**	**J**	2.8	0.29	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
Perfluoroundecanoic acid (PFUnA)	ND		2.8	0.76	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
Perfluorobutanesulfonic acid (PFBS)	ND		2.8	0.47	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
Perfluoropentanesulfonic acid (PFPeS)	ND		2.8	0.50	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
Br-Perfluorohexanesulfonic acid	**4.9**		2.8	0.41	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
Total PFHxS	**150**		2.8	0.41	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
L-Perfluorohexanesulfonic acid	**150**		2.8	0.41	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
Perfluoroheptanesulfonic acid (PFHpS)	**26**		2.8	0.51	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
L-Perfluorooctanesulfonic acid	**1700**	**E**	6.9	0.56	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
Br-Perfluorooctanesulfonic acid	**680**	**E**	6.9	0.56	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
Total PFOS	**2400**		6.9	0.56	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
4:2 FTS	ND		2.8	0.74	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
6:2 FTS	**1.3**	**J**	2.8	1.2	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
8:2 FTS	ND		2.8	0.28	ug/Kg		06/20/24 10:53	06/24/24 19:20	1
10:2 FTS	**0.28**	**J**	2.8	0.28	ug/Kg		06/20/24 10:53	06/24/24 19:20	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*120*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:20*	*1*
13C5 PFPeA	*128*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:20*	*1*
13C2 PFHxA	*131*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:20*	*1*
13C4 PFHpA	*115*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:20*	*1*
13C4 PFOA	*98*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:20*	*1*
13C5 PFNA	*106*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:20*	*1*
13C2 PFDA	*115*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:20*	*1*
13C2 PFUnA	*124*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:20*	*1*
13C3 PFBS	*140*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:20*	*1*
18O2 PFHxS	*115*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:20*	*1*
13C4 PFOS	*109*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:20*	*1*
M2-4:2 FTS	*149*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:20*	*1*
M2-6:2 FTS	*186*	**5+*	*25 - 150*	*06/20/24 10:53*	*06/24/24 19:20*	*1*
M2-8:2 FTS	*116*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:20*	*1*
13C2 10:2 FTS	*184*	**5+*	*25 - 150*	*06/20/24 10:53*	*06/24/24 19:20*	*1*

Client: University of New Mexico
Project/Site: Holloman Lake_Rodent tissue

Job ID: 320-113143-1

Client Sample ID: NK311138-Peromyscus maniculatus-muscle
Date Collected: 05/16/24 00:00
Date Received: 06/18/24 09:20

Lab Sample ID: 320-113143-4
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**3.0**		1.5	0.35	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
Perfluoropentanoic acid (PFPeA)	ND		1.5	0.26	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
Perfluorohexanoic acid (PFHxA)	ND		1.5	0.41	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
Perfluoroheptanoic acid (PFHpA)	**2.1**		1.5	0.17	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
L-Perfluorooctanoic acid	**28**		1.5	0.30	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
Br-Perfluorooctanoic acid	**1.5**		1.5	0.30	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
Total PFOA	**29**		1.5	0.30	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
Perfluorononanoic acid (PFNA)	**17**		1.5	0.26	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
Perfluorodecanoic acid (PFDA)	**4.2**		1.5	0.15	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
Perfluoroundecanoic acid (PFUnA)	**0.41**	**J**	1.5	0.41	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.5	0.25	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
Perfluoropentanesulfonic acid (PFPeS)	**0.43**	**J**	1.5	0.27	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
Br-Perfluorohexanesulfonic acid	**3.9**		1.5	0.22	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
Total PFHxS	**150**		1.5	0.22	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
L-Perfluorohexanesulfonic acid	**150**	**E**	1.5	0.22	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
Perfluoroheptanesulfonic acid (PFHpS)	**16**		1.5	0.28	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
L-Perfluorooctanesulfonic acid	**1400**	**E**	3.7	0.30	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
Br-Perfluorooctanesulfonic acid	**410**	**E**	3.7	0.30	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
Total PFOS	**1800**		3.7	0.30	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
4:2 FTS	ND		1.5	0.40	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
6:2 FTS	**5.4**		1.5	0.63	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
8:2 FTS	**1.4**	**J**	1.5	0.15	ug/Kg		06/20/24 10:53	06/24/24 19:40	1
10:2 FTS	ND		1.5	0.15	ug/Kg		06/20/24 10:53	06/24/24 19:40	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*108*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:40*	*1*
13C5 PFPeA	*118*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:40*	*1*
13C2 PFHxA	*113*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:40*	*1*
13C4 PFHpA	*108*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:40*	*1*
13C4 PFOA	*97*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:40*	*1*
13C5 PFNA	*103*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:40*	*1*
13C2 PFDA	*112*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:40*	*1*
13C2 PFUnA	*127*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:40*	*1*
13C3 PFBS	*129*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:40*	*1*
18O2 PFHxS	*110*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:40*	*1*
13C4 PFOS	*103*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:40*	*1*
M2-4:2 FTS	*137*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:40*	*1*
M2-6:2 FTS	*174*	**5+*	*25 - 150*	*06/20/24 10:53*	*06/24/24 19:40*	*1*
M2-8:2 FTS	*111*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:40*	*1*
13C2 10:2 FTS	*270*	**5+*	*25 - 150*	*06/20/24 10:53*	*06/24/24 19:40*	*1*

Client: University of New Mexico
Project/Site: Holloman Lake_Rodent tissue

Job ID: 320-113143-1

Client Sample ID: NK311139-Peromyscus leucopus-muscle
Date Collected: 05/16/24 00:00
Date Received: 06/18/24 09:20

Lab Sample ID: 320-113143-5
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.1	0.26	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
Perfluoropentanoic acid (PFPeA)	**0.49**	**J**	1.1	0.19	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
Perfluorohexanoic acid (PFHxA)	**0.45**	**J**	1.1	0.30	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
Perfluoroheptanoic acid (PFHpA)	**0.23**	**J**	1.1	0.13	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
L-Perfluorooctanoic acid	ND		1.1	0.22	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
Br-Perfluorooctanoic acid	ND		1.1	0.22	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
Total PFOA	ND		1.1	0.22	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
Perfluorononanoic acid (PFNA)	**2.0**		1.1	0.19	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
Perfluorodecanoic acid (PFDA)	**0.34**	**J**	1.1	0.11	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
Perfluoroundecanoic acid (PFUnA)	ND		1.1	0.30	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.1	0.19	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.1	0.20	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
Br-Perfluorohexanesulfonic acid	ND		1.1	0.16	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
Total PFHxS	**4.4**		1.1	0.16	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
L-Perfluorohexanesulfonic acid	**4.4**		1.1	0.16	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
Perfluoroheptanesulfonic acid (PFHpS)	**1.8**		1.1	0.20	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
L-Perfluorooctanesulfonic acid	**250**	**E**	2.7	0.22	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
Br-Perfluorooctanesulfonic acid	**42**		2.7	0.22	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
Total PFOS	**290**		2.7	0.22	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
4:2 FTS	ND		1.1	0.29	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
6:2 FTS	**0.77**	**J**	1.1	0.47	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
8:2 FTS	**2.0**		1.1	0.11	ug/Kg		06/20/24 10:53	06/24/24 19:59	1
10:2 FTS	**0.15**	**J**	1.1	0.11	ug/Kg		06/20/24 10:53	06/24/24 19:59	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*104*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:59*	*1*
13C5 PFPeA	*104*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:59*	*1*
13C2 PFHxA	*116*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:59*	*1*
13C4 PFHpA	*110*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:59*	*1*
13C4 PFOA	*91*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:59*	*1*
13C5 PFNA	*101*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:59*	*1*
13C2 PFDA	*108*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:59*	*1*
13C2 PFUnA	*116*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:59*	*1*
13C3 PFBS	*120*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:59*	*1*
18O2 PFHxS	*105*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:59*	*1*
13C4 PFOS	*98*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:59*	*1*
M2-4:2 FTS	*133*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:59*	*1*
M2-6:2 FTS	*119*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:59*	*1*
M2-8:2 FTS	*112*		*25 - 150*	*06/20/24 10:53*	*06/24/24 19:59*	*1*
13C2 10:2 FTS	*261*	**5+*	*25 - 150*	*06/20/24 10:53*	*06/24/24 19:59*	*1*

Isotope Dilution Summary

Client: University of New Mexico
Project/Site: Holloman Lake_Rodent tissue

Job ID: 320-113143-1

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Tissue

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-113143-1	NK311130-Dipodomys merriami-	102	113	115	104	92	93	108	116
320-113143-2	NK311134-Peromyscus leucopus-muscle	116	114	121	107	96	100	111	126
320-113143-3	NK311135-Mus musculus-muscle	120	128	131	115	98	106	115	124
320-113143-4	NK311138-Peromyscus maniculatus-muscle	108	118	113	108	97	103	112	127
320-113143-5	NK311139-Peromyscus leucopus-muscle	104	104	116	110	91	101	108	116
LCS 320-773440/2-A	Lab Control Sample	115	125	132	119	99	109	112	119
LCSD 320-773440/3-A	Lab Control Sample Dup	110	111	122	115	98	105	114	118
MB 320-773440/1-A	Method Blank	109	114	117	107	97	106	110	115

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
320-113143-1	NK311130-Dipodomys merriami-	117	101	96	134	112	104	212 *5+
320-113143-2	NK311134-Peromyscus leucopus-muscle	127	106	99	124	122	111	251 *5+
320-113143-3	NK311135-Mus musculus-muscle	140	115	109	149	186 *5+	116	184 *5+
320-113143-4	NK311138-Peromyscus maniculatus-muscle	129	110	103	137	174 *5+	111	270 *5+
320-113143-5	NK311139-Peromyscus leucopus-muscle	120	105	98	133	119	112	261 *5+
LCS 320-773440/2-A	Lab Control Sample	131	108	103	128	122	124	357 *5+
LCSD 320-773440/3-A	Lab Control Sample Dup	129	106	100	134	132	117	347 *5+
MB 320-773440/1-A	Method Blank	120	106	101	128	120	113	324 *5+

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
PFHxA = 13C2 PFHxA
C4PFHA = 13C4 PFHpA
PFOA = 13C4 PFOA
PFNA = 13C5 PFNA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS
PFHxS = 18O2 PFHxS
PFOS = 13C4 PFOS
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
M102FTS = 13C2 10:2 FTS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Lab Sample ID: MB 320-773440/1-A
Matrix: Tissue
Analysis Batch: 774184

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 773440

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.27	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
L-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
Total PFOA	ND		1.0	0.20	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.10	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.27	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
Total PFHxS	ND		1.0	0.15	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
L-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
Br-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
Total PFOS	ND		2.5	0.20	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
4:2 FTS	ND		1.0	0.27	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
6:2 FTS	ND		1.0	0.42	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
8:2 FTS	ND		1.0	0.10	ug/Kg		06/20/24 10:53	06/24/24 17:43	1
10:2 FTS	ND		1.0	0.10	ug/Kg		06/20/24 10:53	06/24/24 17:43	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*109*		*25 - 150*	*06/20/24 10:53*	*06/24/24 17:43*	*1*
13C5 PFPeA	*114*		*25 - 150*	*06/20/24 10:53*	*06/24/24 17:43*	*1*
13C2 PFHxA	*117*		*25 - 150*	*06/20/24 10:53*	*06/24/24 17:43*	*1*
13C4 PFHpA	*107*		*25 - 150*	*06/20/24 10:53*	*06/24/24 17:43*	*1*
13C4 PFOA	*97*		*25 - 150*	*06/20/24 10:53*	*06/24/24 17:43*	*1*
13C5 PFNA	*106*		*25 - 150*	*06/20/24 10:53*	*06/24/24 17:43*	*1*
13C2 PFDA	*110*		*25 - 150*	*06/20/24 10:53*	*06/24/24 17:43*	*1*
13C2 PFUnA	*115*		*25 - 150*	*06/20/24 10:53*	*06/24/24 17:43*	*1*
13C3 PFBS	*120*		*25 - 150*	*06/20/24 10:53*	*06/24/24 17:43*	*1*
18O2 PFHxS	*106*		*25 - 150*	*06/20/24 10:53*	*06/24/24 17:43*	*1*
13C4 PFOS	*101*		*25 - 150*	*06/20/24 10:53*	*06/24/24 17:43*	*1*
M2-4:2 FTS	*128*		*25 - 150*	*06/20/24 10:53*	*06/24/24 17:43*	*1*
M2-6:2 FTS	*120*		*25 - 150*	*06/20/24 10:53*	*06/24/24 17:43*	*1*
M2-8:2 FTS	*113*		*25 - 150*	*06/20/24 10:53*	*06/24/24 17:43*	*1*
13C2 10:2 FTS	*324*	**5+*	*25 - 150*	*06/20/24 10:53*	*06/24/24 17:43*	*1*

Lab Sample ID: LCS 320-773440/2-A
Matrix: Tissue
Analysis Batch: 774184

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 773440

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	10.0	10.4		ug/Kg		104	76 - 136

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Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-773440/2-A
Matrix: Tissue
Analysis Batch: 774184

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 773440

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits		
Perfluoropentanoic acid (PFPeA)			10.0	10.6		ug/Kg		106	69 - 129		
Perfluorohexanoic acid (PFHxA)			10.0	11.4		ug/Kg		114	71 - 131		
Perfluoroheptanoic acid (PFHpA)			10.0	10.4		ug/Kg		104	71 - 131		
L-Perfluorooctanoic acid			10.0	10.4		ug/Kg		104	72 - 132		
Total PFOA			10.0	10.4		ug/Kg		104			
Perfluorononanoic acid (PFNA)			10.0	9.53		ug/Kg		95	73 - 133		
Perfluorodecanoic acid (PFDA)			10.0	11.2		ug/Kg		112	72 - 132		
Perfluoroundecanoic acid (PFUnA)			10.0	11.5		ug/Kg		115	66 - 126		
Perfluorobutanesulfonic acid (PFBS)			8.88	10.1		ug/Kg		113	69 - 129		
Perfluoropentanesulfonic acid (PFPeS)			9.40	9.09		ug/Kg		97	66 - 126		
Total PFHxS			9.12	9.16		ug/Kg		100			
L-Perfluorohexanesulfonic acid			9.12	9.16		ug/Kg		100	62 - 122		
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.7		ug/Kg		112	76 - 136		
L-Perfluorooctanesulfonic acid			9.30	10.6		ug/Kg		114	68 - 141		
Total PFOS			9.30	10.6		ug/Kg		114			
4:2 FTS			9.38	11.5		ug/Kg		122	68 - 143		
6:2 FTS			9.52	9.69		ug/Kg		102	73 - 139		
8:2 FTS			9.60	10.6		ug/Kg		110	75 - 135		
10:2 FTS			9.66	9.78		ug/Kg		101	69 - 145		

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*115*		*25 - 150*
13C5 PFPeA	*125*		*25 - 150*
13C2 PFHxA	*132*		*25 - 150*
13C4 PFHpA	*119*		*25 - 150*
13C4 PFOA	*99*		*25 - 150*
13C5 PFNA	*109*		*25 - 150*
13C2 PFDA	*112*		*25 - 150*
13C2 PFUnA	*119*		*25 - 150*
13C3 PFBS	*131*		*25 - 150*
18O2 PFHxS	*108*		*25 - 150*
13C4 PFOS	*103*		*25 - 150*
M2-4:2 FTS	*128*		*25 - 150*
M2-6:2 FTS	*122*		*25 - 150*
M2-8:2 FTS	*124*		*25 - 150*
13C2 10:2 FTS	*357*	*5+	*25 - 150*

Lab Sample ID: LCSD 320-773440/3-A
Matrix: Tissue
Analysis Batch: 774184

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 773440

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)			10.0	10.9		ug/Kg		109	76 - 136	5	30
Perfluoropentanoic acid (PFPeA)			10.0	10.6		ug/Kg		106	69 - 129	0	30
Perfluorohexanoic acid (PFHxA)			10.0	11.4		ug/Kg		114	71 - 131	1	30
Perfluoroheptanoic acid (PFHpA)			10.0	10.2		ug/Kg		102	71 - 131	2	30

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCSD 320-773440/3-A
Matrix: Tissue
Analysis Batch: 774184

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 773440

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
L-Perfluorooctanoic acid			10.0	10.4		ug/Kg		104	72 - 132	0	30
Total PFOA			10.0	10.4		ug/Kg		104		0	
Perfluorononanoic acid (PFNA)			10.0	9.49		ug/Kg		95	73 - 133	0	30
Perfluorodecanoic acid (PFDA)			10.0	10.7		ug/Kg		107	72 - 132	5	30
Perfluoroundecanoic acid (PFUnA)			10.0	10.8		ug/Kg		108	66 - 126	7	30
Perfluorobutanesulfonic acid (PFBS)			8.88	9.74		ug/Kg		110	69 - 129	3	30
Perfluoropentanesulfonic acid (PFPeS)			9.40	8.80		ug/Kg		94	66 - 126	3	30
Total PFHxS			9.12	9.01		ug/Kg		99		2	
L-Perfluorohexanesulfonic acid			9.12	9.01		ug/Kg		99	62 - 122	2	30
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.2		ug/Kg		107	76 - 136	5	30
L-Perfluorooctanesulfonic acid			9.30	9.84		ug/Kg		106	68 - 141	7	30
Total PFOS			9.30	9.84		ug/Kg		106		7	
4:2 FTS			9.38	10.1		ug/Kg		108	68 - 143	12	30
6:2 FTS			9.52	9.34		ug/Kg		98	73 - 139	4	30
8:2 FTS			9.60	10.4		ug/Kg		108	75 - 135	2	30
10:2 FTS			9.66	9.27		ug/Kg		96	69 - 145	5	30

Isotope Dilution	*LCSD %Recovery*	*LCSD Qualifier*	*Limits*
13C4 PFBA	*110*		*25 - 150*
13C5 PFPeA	*111*		*25 - 150*
13C2 PFHxA	*122*		*25 - 150*
13C4 PFHpA	*115*		*25 - 150*
13C4 PFOA	*98*		*25 - 150*
13C5 PFNA	*105*		*25 - 150*
13C2 PFDA	*114*		*25 - 150*
13C2 PFUnA	*118*		*25 - 150*
13C3 PFBS	*129*		*25 - 150*
18O2 PFHxS	*106*		*25 - 150*
13C4 PFOS	*100*		*25 - 150*
M2-4:2 FTS	*134*		*25 - 150*
M2-6:2 FTS	*132*		*25 - 150*
M2-8:2 FTS	*117*		*25 - 150*
13C2 10:2 FTS	*347*	*5+	*25 - 150*

QC Association Summary

Client: University of New Mexico
Project/Site: Holloman Lake_Rodent tissue

Job ID: 320-113143-1

LCMS

Pre Prep Batch: 772949

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113143-1	NK311130-Dipodomys merriami-muscle	Total/NA	Tissue	In-House	
320-113143-2	NK311134-Peromyscus leucopus-muscle	Total/NA	Tissue	In-House	
320-113143-3	NK311135-Mus musculus-muscle	Total/NA	Tissue	In-House	
320-113143-4	NK311138-Peromyscus maniculatus-muscle	Total/NA	Tissue	In-House	
320-113143-5	NK311139-Peromyscus leucopus-muscle	Total/NA	Tissue	In-House	

Prep Batch: 773440

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113143-1	NK311130-Dipodomys merriami-muscle	Total/NA	Tissue	SHAKE	772949
320-113143-2	NK311134-Peromyscus leucopus-muscle	Total/NA	Tissue	SHAKE	772949
320-113143-3	NK311135-Mus musculus-muscle	Total/NA	Tissue	SHAKE	772949
320-113143-4	NK311138-Peromyscus maniculatus-muscle	Total/NA	Tissue	SHAKE	772949
320-113143-5	NK311139-Peromyscus leucopus-muscle	Total/NA	Tissue	SHAKE	772949
MB 320-773440/1-A	Method Blank	Total/NA	Tissue	SHAKE	
LCS 320-773440/2-A	Lab Control Sample	Total/NA	Tissue	SHAKE	
LCSD 320-773440/3-A	Lab Control Sample Dup	Total/NA	Tissue	SHAKE	

Analysis Batch: 774184

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113143-1	NK311130-Dipodomys merriami-muscle	Total/NA	Tissue	B/L/T PFAS	773440
320-113143-2	NK311134-Peromyscus leucopus-muscle	Total/NA	Tissue	B/L/T PFAS	773440
320-113143-3	NK311135-Mus musculus-muscle	Total/NA	Tissue	B/L/T PFAS	773440
320-113143-4	NK311138-Peromyscus maniculatus-muscle	Total/NA	Tissue	B/L/T PFAS	773440
320-113143-5	NK311139-Peromyscus leucopus-muscle	Total/NA	Tissue	B/L/T PFAS	773440
MB 320-773440/1-A	Method Blank	Total/NA	Tissue	B/L/T PFAS	773440
LCS 320-773440/2-A	Lab Control Sample	Total/NA	Tissue	B/L/T PFAS	773440
LCSD 320-773440/3-A	Lab Control Sample Dup	Total/NA	Tissue	B/L/T PFAS	773440

Lab Chronicle

Client: University of New Mexico
Job ID: 320-113143-1
Project/Site: Holloman Lake_Rodent tissue

Client Sample ID: NK311130-Dipodomys merriami-muscle
Lab Sample ID: 320-113143-1
Date Collected: 05/16/24 00:00
Matrix: Tissue
Date Received: 06/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	772949	06/18/24 12:51	RAC	EET SAC
Total/NA	Prep	SHAKE			1.66 g	10.0 mL	773440	06/20/24 10:53	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	774184	06/24/24 18:42	S1C	EET SAC

Client Sample ID: NK311134-Peromyscus leucopus-muscle
Lab Sample ID: 320-113143-2
Date Collected: 05/16/24 00:00
Matrix: Tissue
Date Received: 06/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	772949	06/18/24 12:51	RAC	EET SAC
Total/NA	Prep	SHAKE			0.62 g	10.0 mL	773440	06/20/24 10:53	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	774184	06/24/24 19:01	S1C	EET SAC

Client Sample ID: NK311135-Mus musculus-muscle
Lab Sample ID: 320-113143-3
Date Collected: 05/16/24 00:00
Matrix: Tissue
Date Received: 06/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	772949	06/18/24 12:51	RAC	EET SAC
Total/NA	Prep	SHAKE			0.36 g	10.0 mL	773440	06/20/24 10:53	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	774184	06/24/24 19:20	S1C	EET SAC

Client Sample ID: NK311138-Peromyscus maniculatus-muscle
Lab Sample ID: 320-113143-4
Date Collected: 05/16/24 00:00
Matrix: Tissue
Date Received: 06/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	772949	06/18/24 12:51	RAC	EET SAC
Total/NA	Prep	SHAKE			0.67 g	10.0 mL	773440	06/20/24 10:53	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	774184	06/24/24 19:40	S1C	EET SAC

Client Sample ID: NK311139-Peromyscus leucopus-muscle
Lab Sample ID: 320-113143-5
Date Collected: 05/16/24 00:00
Matrix: Tissue
Date Received: 06/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	772949	06/18/24 12:51	RAC	EET SAC
Total/NA	Prep	SHAKE			0.91 g	10.0 mL	773440	06/20/24 10:53	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	774184	06/24/24 19:59	S1C	EET SAC

Laboratory References:
EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

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Accreditation/Certification Summary

Client: University of New Mexico
Job ID: 320-113143-1
Project/Site: Holloman Lake_Rodent tissue

Laboratory: Eurofins Sacramento

All accreditations/certifications held by this laboratory are listed. Not all accreditations/certifications are applicable to this report.

Authority	Program	Identification Number	Expiration Date
Alaska (UST)	State	17-020	02-20-27
ANAB	Dept. of Defense ELAP	L2468	01-20-27
ANAB	Dept. of Energy	L2468.01	01-20-27
ANAB	ISO/IEC 17025	L2468	01-20-27
Arizona	State	AZ0708	08-11-24
Arkansas DEQ	State	88-0691	05-18-25
California	State	2897	01-31-26
Colorado	State	CA00044	08-31-24
Florida	NELAP	E87570	06-30-24
Georgia	State	4040	01-29-25
Hawaii	State	Eurofins Sacramento	01-29-25
Illinois	NELAP	200060	03-31-25
Kansas	NELAP	E-10375	10-31-25
Louisiana	NELAP	01944	06-30-24
Louisiana (All)	NELAP	01944	06-30-24
Maine	State	CA00004	04-14-26
Michigan	State	9947	01-29-25
Nevada	State	CA00044	07-31-25
New Hampshire	NELAP	2997	04-19-25
New Jersey	NELAP	CA005	07-02-24
New York	NELAP	11666	04-01-25
Ohio	State	41252	01-29-25
Oregon	NELAP	4040	01-29-25
Texas	NELAP	T104704399-23-17	05-31-25
US Fish & Wildlife	US Federal Programs	A22139	04-30-25
USDA	US Federal Programs	P330-18-00239	02-28-26
Utah	NELAP	CA000442023-16	02-28-25
Virginia	NELAP	460278	03-14-25
Washington	State	C581	05-05-25
West Virginia (DW)	State	9930C	01-31-25
Wisconsin	State	998204680	08-31-25
Wyoming	State Program	8TMS-L	01-28-19 *

* Accreditation/Certification renewal pending - accreditation/certification considered valid.

Method Summary

Client: University of New Mexico
Project/Site: Holloman Lake_Rodent tissue

Job ID: 320-113143-1

Method	Method Description	Protocol	Laboratory
B/L/T PFAS	Branched, Linear and Total PFAS	EPA	EET SAC
In-House	Tissue Preparation/Homgenization	NOAA	EET SAC
SHAKE	Shake Extraction with Ultrasonic Bath Extraction	SW846	EET SAC

Protocol References:

EPA = US Environmental Protection Agency

NOAA = National Marine Fisheries Service, National Oceanic And Atmospheric Administration, Seattle, WA, November 1988

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

NMED Exhibits 65

Sample Summary

Client: University of New Mexico
Project/Site: Holloman Lake_Rodent tissue

Job ID: 320-113143-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
320-113143-1	NK311130-Dipodomys merriami-muscle	Tissue	05/16/24 00:00	06/18/24 09:20
320-113143-2	NK311134-Peromyscus leucopus-muscle	Tissue	05/16/24 00:00	06/18/24 09:20
320-113143-3	NK311135-Mus musculus-muscle	Tissue	05/16/24 00:00	06/18/24 09:20
320-113143-4	NK311138-Peromyscus maniculatus-muscle	Tissue	05/16/24 00:00	06/18/24 09:20
320-113143-5	NK311139-Peromyscus leucopus-muscle	Tissue	05/16/24 00:00	06/18/24 09:20

LOAN 2024.069.Mamm

SPECIMEN INVOICE
Museum of Southwestern Biology
Division of Mammals
University of New Mexico
17 Jun 2024

320 113143 Chain of Custody

This loan document acknowledges the loan of specimens to:

Attn: Linda C. Laver
Eurofins Environment Testing Northern California
880 Riverside Parkway
West Sacramento, CA 95605

Approved by:

Joseph A. Cook

Loan Type: consumable

Nature of Material: Five muscle samples from Holloman air force base rodents for PFAS analysis.

Remarks:

Description: NK311130 - Dipodomys merriami-muscle; NK311134 - Peromyscus leucopus-muscle; NK311135 - Mus musculus-muscle; NK311138-Peromyscus maniculatus-muscle; NK311139-Peromyscus leucopus-muscle.

Instructions:

Upon receipt, sign and return one copy to:

Jonathan L. Dunnum, Senior Collection Manager
Division of Mammals
Museum of Southwestern Biology
CERIA, Rm #83
1 University of New Mexico
Albuquerque, NM 87131
MSC 03 2020 **Email:** jldunnum@unm.edu

Signature of recipient, date:

06/18/24
0920

Received By

-33.8°C

LOAN REQUIREMENTS: RECIPIENT ACKNOWLEDGES THE FOLLOWING TERMS:

Material loaned from the MSB should be properly acknowledged by MSB catalog number (MSB:Mamm.XXXX) in subsequent publications, reports, presentations, GenBank, IsoBank, MorphoSource or other data submissions - see Loan Instructions. PDFs of publications should be provided to the MSB. By signing this form, you agree to use these materials only for the study outlined in your original proposal. You must obtain written permission for any use outside of the scope of your original proposal. Transfer of MSB material to a third party is not allowed. Non-consumable specimens on loan should be returned to the MSB within 6 months using the same packing container and materials, shipping method, and insurance value unless other arrangements are made with the MSB Mammal Curator. Thank you for your cooperation.

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Sacramento Sample Receiving Notes (SSRN)

Tracking # 7769 0512 8500

Job: _____

(SO) PO / FO / SAT / 2-Day / Ground / UPS / CDO / Courier
GSL / OnTrac / Goldstreak / USPS / Other _____

Use this form to record Sample Custody Seal, Cooler Custody Seal, Temperature & corrected Temperature & other observations.
File in the job folder with the COC

Therm. ID L06 Corr. Factor (+ / -) NA °C

Ice _____ Wet _____ Gel _____ Other /

Cooler Custody Seal –

Cooler ID: –

Temp Observed: -33.8 °C Corrected: -33.8 °C

From Temp Blank ☐ Sample ☑

Opening/Processing The Shipment	Yes	No	NA
Cooler compromised/tampered with?	☐	☑	☐
Cooler Temperature is acceptable?	☑	☐	☐
Frozen samples show signs of thaw?	☐	☐	☑

Initials DM Date 06/18/24

Unpacking/Labeling The Samples	Yes	No	NA
Containers are not broken or leaking?	☑	☐	☐
Samples compromised/tampered with?	☐	☑	☐
COC is complete w/o discrepancies	☐	☑	☐
Sample custody seal?	☐	☐	☑
Sample containers have legible labels?	☑	☐	☐
Sample date/times are provided?	☐	☑	☐
Appropriate containers are used?	☑	☐	☐
Sample bottles are completely filled?	☑	☐	☐
Sample preservatives verified?	☐	☐	☑
Is the Field Sampler's name on COC?	☐	☑	☐
Samples w/o discrepancies?	☐	☑	☐
Zero headspace?*	☐	☐	☑
Alkalinity has no headspace?	☐	☐	☑
Perchlorate has headspace? (Methods 314, 331, 6850)	☐	☐	☑
Multiphasic samples are not present?	☑	☐	☐

**Containers requiring zero headspace have no headspace, or bubble < 6 mm (1/4")*

Initials SO Date 6/18/24

Notes: Dry Ice

1-S 10' NK HHHHHH

Trizma Lot #(s) _____

Ammonium Acetate Lot #(s) _____

Login Completion	Yes	No	NA
Receipt Temperature on COC?	☑	☐	☐
NCM Filed?	☑	☐	☐
Samples received within hold time?	☑	☐	☐
Log Release checked in TALS?	☑	☐	☐

Initials SO Date 6/18/24

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ANALYTICAL REPORT

PREPARED FOR

Attn: Jean-Luc Cartron
University of New Mexico
Museum of Southwestern Biology
Division of Mammals
CERIA Bldg 83, Room 204
Albuquerque, New Mexico 87131

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JOB DESCRIPTION

HollomanLake PFAS Research

JOB NUMBER

320-113430-1

Eurofins Sacramento
880 Riverside Parkway
West Sacramento CA 95605

See page two for job notes and contact information.

NMED Exhibits 65

my EOL

Job Notes

This report may not be reproduced except in full, and with written approval from the laboratory. The results relate only to the samples tested. For questions please contact the Project Manager at the e-mail address or telephone number listed on this page.

The test results in this report relate only to the samples as received by the laboratory and will meet all requirements of the methodology, with any exceptions noted. This report shall not be reproduced except in full, without the express written approval of the laboratory. All questions should be directed to the Eurofins Environment Testing Northern California, LLC Project Manager.

Authorization



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Authorized for release by
Linda C. Laver, Senior Project Manager
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(916)374-4362

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Definitions/Glossary

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Qualifiers

LCMS

Qualifier	Qualifier Description
*5+	Isotope dilution analyte is outside acceptance limits, high biased.
B	Compound was found in the blank and sample.
J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
¤	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CFU	Colony Forming Unit
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MCL	EPA recommended "Maximum Contaminant Level"
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
MPN	Most Probable Number
MQL	Method Quantitation Limit
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
NEG	Negative / Absent
POS	Positive / Present
PQL	Practical Quantitation Limit
PRES	Presumptive
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)
TNTC	Too Numerous To Count

Job ID: 320-113430-1 — Eurofins Sacramento

Job Narrative
320-113430-1

Comments
The following samples were canceled by the client on July 2, 2024 due to insufficient volume submitted for analysis: H2O West (320-113430-17), H2O -So (320-113430-18), H2O North Inlet (320-113430-19) and H2O East Inlet (320-113430-20).

The following samples were canceled by the client on July 10, 2024 due to limited sample mass submitted for analysis: Soil NE2-1 (320-113430-1), Soil NE2-2 (320-113430-2), Soil NE2-3 (320-113430-3), Soil NE2-4 (320-113430-4), Soil4-1 (320-113430-5), Soil4-2 (320-113430-6), Soil4-3 (320-113430-7) and Soil4-4 (320-113430-8).

Receipt
The samples were received on 6/27/2024 9:30 AM. Unless otherwise noted below, the samples arrived in good condition, and where required, properly preserved. The temperature of the cooler at receipt was 19.8º C.

Receipt Exceptions
Samples were received at the laboratory outside the required temperature criteria. Client was aware these were shipped without any cooling agent and approved the lab to perform the analyses.

The Chain-of-Custody (COC) was incomplete as received and does not list the requested analyses. Based on communications with the client, the samples were logged in for PFAS (17 Analyte List by 537 Mod).

LCMS
Method B/L/T PFAS: Isotope Dilution Analyte (IDA) recoveries are above the method recommended limit for the following samples. Quantitation by isotope dilution generally precludes any adverse effect on data quality due to elevated IDA recoveries. Saltbush 2-1 (320-113430-9), Saltbush 2-2 (320-113430-10), Saltbush 2-3 (320-113430-11), Saltbush 2-4 (320-113430-12), Saltbush 4-1 (320-113430-13), Saltbush 4-2 (320-113430-14), Saltbush 4-3 (320-113430-15), Saltbush 4-4 (320-113430-16), Algae So (320-113430-21), (MB 320-779766/1-A), (LCS 320-779766/2-A), (LCSD 320-779766/3-A)

Method B/L/T PFAS: Some results for the following sample were reported from the analysis of a diluted extract due to matrix interference and high concentration of target analyte(s) in the undiluted extract. The dilution factor was applied to the labeled internal standard area counts and these area counts were within acceptance limits. Saltbush 4-1 (320-113430-13)

Method B/L/T PFAS: Some results for the following sample were reported from the analysis of a diluted extract due to high concentration of target analyte(s) in the analysis of the undiluted extract. The dilution factor was applied to the labeled internal standard area counts and these area counts were outside acceptance limits. The internal standard is not used to quantitate target analyte concentrations; therefore, the data have been reported. Algae So (320-113430-21)

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Organic Prep
Method SHAKE: Insufficient sample was available to perform a matrix spike/matrix spike duplicate (MS/MSD) associated with preparation batch 320-779760 and 320-779766.

Method SHAKE: The following samples ranged in color from yellow to green after extraction. Saltbush 2-1 (320-113430-9), Saltbush 2-2 (320-113430-10), Saltbush 2-3 (320-113430-11), Saltbush 2-4 (320-113430-12), Saltbush 4-1 (320-113430-13), Saltbush 4-2 (320-113430-14), Saltbush 4-3 (320-113430-15), Saltbush 4-4 (320-113430-16) and Algae So (320-113430-21)

Method SHAKE: Elevated reporting limits are provided for the following samples due to insufficient sample (< 1 gram) provided for preparation. Saltbush 2-1 (320-113430-9), Saltbush 2-2 (320-113430-10), Saltbush 2-3 (320-113430-11), Saltbush 2-4 (320-113430-12), Saltbush 4-1 (320-113430-13), Saltbush 4-2 (320-113430-14), Saltbush 4-3 (320-113430-15) and Saltbush 4-4 (320-113430-16)

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Detection Summary

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Client Sample ID: Saltbush 2-1 — Lab Sample ID: 320-113430-9

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	22		1.7	0.39	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	17		1.7	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	5.2	B	1.7	0.46	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	1.9		1.7	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	1.7		1.7	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.7		1.7	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	2.9		1.7	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	2.4		1.7	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	2.3		1.7	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	15		1.7	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	13		1.7	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.31	J	1.7	0.31	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	5.7		4.2	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	4.9		4.2	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	11		4.2	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	9.2		1.7	0.71	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Saltbush 2-2 — Lab Sample ID: 320-113430-10

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	5.2		1.7	0.39	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.59	J B	1.7	0.46	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.68	J	1.7	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.68	J	1.7	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	0.78	J	4.2	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.52	J	4.2	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	1.3	J	4.2	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	1.1	J	1.7	0.71	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Saltbush 2-3 — Lab Sample ID: 320-113430-11

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	1.4		1.4	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.43	J B	1.4	0.38	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.40	J	1.4	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.40	J	1.4	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	0.48	J	3.5	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.31	J	3.5	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	0.79	J	3.5	0.29	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Saltbush 2-4 — Lab Sample ID: 320-113430-12

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	12		1.6	0.39	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	8.0		1.6	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	1.8	B	1.6	0.45	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.46	J	1.6	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	1.1	J	1.6	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	1.1	J	1.6	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	0.41	J	4.1	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	0.41	J	4.1	0.33	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Eurofins Sacramento

Detection Summary

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Client Sample ID: Saltbush 4-1 — Lab Sample ID: 320-113430-13

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	50		1.6	0.38	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	70	B	1.6	0.44	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	17		1.6	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	42		1.6	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	4.1		1.6	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	46		1.6	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	32		1.6	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.46	J	1.6	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	5.7		1.6	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	27		1.6	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	45		1.6	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	4.0		1.6	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA) - DL	140		81	14	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	50	J	81	12	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFHxS - DL	410		81	12	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	360		81	12	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	2100		200	16	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	1600		200	16	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS - DL	3600		200	16	ug/Kg	50		B/L/T PFAS	Total/NA
6:2 FTS - DL	190		81	34	ug/Kg	50		B/L/T PFAS	Total/NA

Client Sample ID: Saltbush 4-2 — Lab Sample ID: 320-113430-14

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.87	J	1.4	0.32	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.44	J B	1.4	0.37	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.93	J	1.4	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.86	J	1.4	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	0.76	J	3.4	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.54	J	3.4	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	1.3	J	3.4	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	1.4		1.4	0.57	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Saltbush 4-3 — Lab Sample ID: 320-113430-15

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.38	J	1.1	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.43	J B	1.1	0.31	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.67	J	1.1	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.64	J	1.1	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	0.67	J	2.9	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.48	J	2.9	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	1.2	J	2.9	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	1.0	J	1.1	0.49	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Saltbush 4-4 — Lab Sample ID: 320-113430-16

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	5.2		2.3	0.54	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.74	J B	2.3	0.62	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Eurofins Sacramento

NMED Exhibits 65

Detection Summary

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Client Sample ID: Algae So

Lab Sample ID: 320-113430-21

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	3.6		0.78	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	14		0.78	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	21	B	0.78	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	4.6		0.78	0.091	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	8.8		0.78	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.70	J	0.78	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	9.5		0.78	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	2.5		0.78	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.35	J	0.78	0.080	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	4.2		0.78	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	8.6		0.78	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	12		0.78	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	71		0.78	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	58		0.78	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	2.2		0.78	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	26		0.78	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.53	J	0.78	0.078	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.092	J	0.78	0.079	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	83		20	1.6	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	37		20	1.6	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	120		20	1.6	ug/Kg	10		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Client Sample ID: Saltbush 2-1
Date Collected: 06/25/24 08:00
Date Received: 06/27/24 09:30

Lab Sample ID: 320-113430-9
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**22**		1.7	0.39	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
Perfluoropentanoic acid (PFPeA)	**17**		1.7	0.29	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
Perfluorohexanoic acid (PFHxA)	**5.2**	**B**	1.7	0.46	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
Perfluoroheptanoic acid (PFHpA)	**1.9**		1.7	0.19	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
L-Perfluorooctanoic acid	**1.7**		1.7	0.34	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
Br-Perfluorooctanoic acid	ND		1.7	0.34	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
Total PFOA	**1.7**		1.7	0.34	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
Perfluorononanoic acid (PFNA)	ND		1.7	0.29	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
Perfluorodecanoic acid (PFDA)	ND		1.7	0.17	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
Perfluoroundecanoic acid (PFUnA)	ND		1.7	0.45	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
Perfluorobutanesulfonic acid (PFBS)	**2.9**		1.7	0.28	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
Perfluoropentanesulfonic acid (PFPeS)	**2.4**		1.7	0.30	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
Br-Perfluorohexanesulfonic acid	**2.3**		1.7	0.25	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
Total PFHxS	**15**		1.7	0.25	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
L-Perfluorohexanesulfonic acid	**13**		1.7	0.25	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.31**	**J**	1.7	0.31	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
L-Perfluorooctanesulfonic acid	**5.7**		4.2	0.34	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
Br-Perfluorooctanesulfonic acid	**4.9**		4.2	0.34	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
Total PFOS	**11**		4.2	0.34	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
4:2 FTS	ND		1.7	0.44	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
6:2 FTS	**9.2**		1.7	0.71	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
8:2 FTS	ND		1.7	0.17	ug/Kg		07/16/24 04:26	07/17/24 19:44	1
10:2 FTS	ND		1.7	0.17	ug/Kg		07/16/24 04:26	07/17/24 19:44	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*45*		*25 - 150*	*07/16/24 04:26*	*07/17/24 19:44*	*1*
13C5 PFPeA	*51*		*25 - 150*	*07/16/24 04:26*	*07/17/24 19:44*	*1*
13C2 PFHxA	*108*		*25 - 150*	*07/16/24 04:26*	*07/17/24 19:44*	*1*
13C4 PFHpA	*97*		*25 - 150*	*07/16/24 04:26*	*07/17/24 19:44*	*1*
13C4 PFOA	*91*		*25 - 150*	*07/16/24 04:26*	*07/17/24 19:44*	*1*
13C5 PFNA	*101*		*25 - 150*	*07/16/24 04:26*	*07/17/24 19:44*	*1*
13C2 PFDA	*124*		*25 - 150*	*07/16/24 04:26*	*07/17/24 19:44*	*1*
13C2 PFUnA	*108*		*25 - 150*	*07/16/24 04:26*	*07/17/24 19:44*	*1*
13C3 PFBS	*68*		*25 - 150*	*07/16/24 04:26*	*07/17/24 19:44*	*1*
18O2 PFHxS	*87*		*25 - 150*	*07/16/24 04:26*	*07/17/24 19:44*	*1*
13C4 PFOS	*107*		*25 - 150*	*07/16/24 04:26*	*07/17/24 19:44*	*1*
M2-4:2 FTS	*289*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 19:44*	*1*
M2-6:2 FTS	*170*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 19:44*	*1*
M2-8:2 FTS	*162*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 19:44*	*1*
13C2 10:2 FTS	*412*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 19:44*	*1*

NMED Exhibits 65

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Client Sample ID: Saltbush 2-2

Date Collected: 06/25/24 08:30
Date Received: 06/27/24 09:30

Lab Sample ID: 320-113430-10

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**5.2**		1.7	0.39	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
Perfluoropentanoic acid (PFPeA)	ND		1.7	0.29	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
Perfluorohexanoic acid (PFHxA)	**0.59**	**J B**	1.7	0.46	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
Perfluoroheptanoic acid (PFHpA)	ND		1.7	0.19	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
L-Perfluorooctanoic acid	ND		1.7	0.34	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
Br-Perfluorooctanoic acid	ND		1.7	0.34	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
Total PFOA	ND		1.7	0.34	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
Perfluorononanoic acid (PFNA)	ND		1.7	0.29	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
Perfluorodecanoic acid (PFDA)	ND		1.7	0.17	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
Perfluoroundecanoic acid (PFUnA)	ND		1.7	0.45	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.7	0.28	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.7	0.30	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
Br-Perfluorohexanesulfonic acid	ND		1.7	0.25	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
Total PFHxS	**0.68**	**J**	1.7	0.25	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
L-Perfluorohexanesulfonic acid	**0.68**	**J**	1.7	0.25	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.7	0.31	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
L-Perfluorooctanesulfonic acid	**0.78**	**J**	4.2	0.34	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
Br-Perfluorooctanesulfonic acid	**0.52**	**J**	4.2	0.34	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
Total PFOS	**1.3**	**J**	4.2	0.34	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
4:2 FTS	ND		1.7	0.44	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
6:2 FTS	**1.1**	**J**	1.7	0.71	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
8:2 FTS	ND		1.7	0.17	ug/Kg		07/16/24 04:26	07/17/24 20:04	1
10:2 FTS	ND		1.7	0.17	ug/Kg		07/16/24 04:26	07/17/24 20:04	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*42*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:04*	*1*
13C5 PFPeA	*53*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:04*	*1*
13C2 PFHxA	*101*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:04*	*1*
13C4 PFHpA	*87*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:04*	*1*
13C4 PFOA	*92*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:04*	*1*
13C5 PFNA	*106*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:04*	*1*
13C2 PFDA	*130*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:04*	*1*
13C2 PFUnA	*101*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:04*	*1*
13C3 PFBS	*65*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:04*	*1*
18O2 PFHxS	*84*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:04*	*1*
13C4 PFOS	*113*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:04*	*1*
M2-4:2 FTS	*242*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 20:04*	*1*
M2-6:2 FTS	*176*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 20:04*	*1*
M2-8:2 FTS	*162*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 20:04*	*1*
13C2 10:2 FTS	*577*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 20:04*	*1*

NMED Exhibits 65

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Client Sample ID: Saltbush 2-3
Date Collected: 06/25/24 09:00
Date Received: 06/27/24 09:30

Lab Sample ID: 320-113430-11
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**1.4**		1.4	0.33	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
Perfluoropentanoic acid (PFPeA)	ND		1.4	0.25	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
Perfluorohexanoic acid (PFHxA)	**0.43**	**J B**	1.4	0.38	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
Perfluoroheptanoic acid (PFHpA)	ND		1.4	0.16	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
L-Perfluorooctanoic acid	ND		1.4	0.28	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
Br-Perfluorooctanoic acid	ND		1.4	0.28	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
Total PFOA	ND		1.4	0.28	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
Perfluorononanoic acid (PFNA)	ND		1.4	0.25	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
Perfluorodecanoic acid (PFDA)	ND		1.4	0.15	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
Perfluoroundecanoic acid (PFUnA)	ND		1.4	0.38	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.4	0.24	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.4	0.25	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
Br-Perfluorohexanesulfonic acid	ND		1.4	0.21	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
Total PFHxS	**0.40**	**J**	1.4	0.21	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
L-Perfluorohexanesulfonic acid	**0.40**	**J**	1.4	0.21	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.4	0.26	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
L-Perfluorooctanesulfonic acid	**0.48**	**J**	3.5	0.29	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
Br-Perfluorooctanesulfonic acid	**0.31**	**J**	3.5	0.29	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
Total PFOS	**0.79**	**J**	3.5	0.29	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
4:2 FTS	ND		1.4	0.37	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
6:2 FTS	ND		1.4	0.60	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
8:2 FTS	ND		1.4	0.14	ug/Kg		07/16/24 04:26	07/17/24 20:23	1
10:2 FTS	ND		1.4	0.14	ug/Kg		07/16/24 04:26	07/17/24 20:23	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*31*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:23*	*1*
13C5 PFPeA	*50*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:23*	*1*
13C2 PFHxA	*109*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:23*	*1*
13C4 PFHpA	*91*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:23*	*1*
13C4 PFOA	*90*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:23*	*1*
13C5 PFNA	*107*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:23*	*1*
13C2 PFDA	*136*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:23*	*1*
13C2 PFUnA	*106*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:23*	*1*
13C3 PFBS	*69*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:23*	*1*
18O2 PFHxS	*83*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:23*	*1*
13C4 PFOS	*112*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:23*	*1*
M2-4:2 FTS	*215*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 20:23*	*1*
M2-6:2 FTS	*167*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 20:23*	*1*
M2-8:2 FTS	*196*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 20:23*	*1*
13C2 10:2 FTS	*376*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 20:23*	*1*

NMED Exhibits 65

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Client Sample ID: Saltbush 2-4

Date Collected: 06/25/24 10:00
Date Received: 06/27/24 09:30

Lab Sample ID: 320-113430-12

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**12**		1.6	0.39	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
Perfluoropentanoic acid (PFPeA)	**8.0**		1.6	0.29	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
Perfluorohexanoic acid (PFHxA)	**1.8**	**B**	1.6	0.45	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
Perfluoroheptanoic acid (PFHpA)	ND		1.6	0.19	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
L-Perfluorooctanoic acid	ND		1.6	0.33	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
Br-Perfluorooctanoic acid	ND		1.6	0.33	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
Total PFOA	ND		1.6	0.33	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
Perfluorononanoic acid (PFNA)	ND		1.6	0.29	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
Perfluorodecanoic acid (PFDA)	ND		1.6	0.17	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
Perfluoroundecanoic acid (PFUnA)	ND		1.6	0.45	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
Perfluorobutanesulfonic acid (PFBS)	**0.46**	**J**	1.6	0.28	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.6	0.30	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
Br-Perfluorohexanesulfonic acid	ND		1.6	0.24	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
Total PFHxS	**1.1**	**J**	1.6	0.24	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
L-Perfluorohexanesulfonic acid	**1.1**	**J**	1.6	0.24	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.6	0.30	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
L-Perfluorooctanesulfonic acid	**0.41**	**J**	4.1	0.33	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
Br-Perfluorooctanesulfonic acid	ND		4.1	0.33	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
Total PFOS	**0.41**	**J**	4.1	0.33	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
4:2 FTS	ND		1.6	0.44	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
6:2 FTS	ND		1.6	0.70	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
8:2 FTS	ND		1.6	0.16	ug/Kg		07/16/24 04:26	07/17/24 20:42	1
10:2 FTS	ND		1.6	0.17	ug/Kg		07/16/24 04:26	07/17/24 20:42	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*36*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:42*	*1*
13C5 PFPeA	*53*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:42*	*1*
13C2 PFHxA	*105*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:42*	*1*
13C4 PFHpA	*91*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:42*	*1*
13C4 PFOA	*89*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:42*	*1*
13C5 PFNA	*112*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:42*	*1*
13C2 PFDA	*146*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:42*	*1*
13C2 PFUnA	*129*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:42*	*1*
13C3 PFBS	*71*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:42*	*1*
18O2 PFHxS	*83*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:42*	*1*
13C4 PFOS	*114*		*25 - 150*	*07/16/24 04:26*	*07/17/24 20:42*	*1*
M2-4:2 FTS	*226*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 20:42*	*1*
M2-6:2 FTS	*162*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 20:42*	*1*
M2-8:2 FTS	*180*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 20:42*	*1*
13C2 10:2 FTS	*621*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 20:42*	*1*

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Client Sample ID: Saltbush 4-1

Date Collected: 06/24/24 15:00
Date Received: 06/27/24 09:30

Lab Sample ID: 320-113430-13

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	50		1.6	0.38	ug/Kg		07/16/24 04:26	07/17/24 21:02	1
Perfluorohexanoic acid (PFHxA)	70	B	1.6	0.44	ug/Kg		07/16/24 04:26	07/17/24 21:02	1
Perfluoroheptanoic acid (PFHpA)	17		1.6	0.19	ug/Kg		07/16/24 04:26	07/17/24 21:02	1
L-Perfluorooctanoic acid	42		1.6	0.33	ug/Kg		07/16/24 04:26	07/17/24 21:02	1
Br-Perfluorooctanoic acid	4.1		1.6	0.33	ug/Kg		07/16/24 04:26	07/17/24 21:02	1
Total PFOA	46		1.6	0.33	ug/Kg		07/16/24 04:26	07/17/24 21:02	1
Perfluorononanoic acid (PFNA)	32		1.6	0.28	ug/Kg		07/16/24 04:26	07/17/24 21:02	1
Perfluorodecanoic acid (PFDA)	0.46	J	1.6	0.17	ug/Kg		07/16/24 04:26	07/17/24 21:02	1
Perfluoroundecanoic acid (PFUnA)	ND		1.6	0.44	ug/Kg		07/16/24 04:26	07/17/24 21:02	1
Perfluorobutanesulfonic acid (PFBS)	5.7		1.6	0.27	ug/Kg		07/16/24 04:26	07/17/24 21:02	1
Perfluoropentanesulfonic acid (PFPeS)	27		1.6	0.29	ug/Kg		07/16/24 04:26	07/17/24 21:02	1
Perfluoroheptanesulfonic acid (PFHpS)	45		1.6	0.30	ug/Kg		07/16/24 04:26	07/17/24 21:02	1
4:2 FTS	ND		1.6	0.43	ug/Kg		07/16/24 04:26	07/17/24 21:02	1
8:2 FTS	4.0		1.6	0.16	ug/Kg		07/16/24 04:26	07/17/24 21:02	1
10:2 FTS	ND		1.6	0.16	ug/Kg		07/16/24 04:26	07/17/24 21:02	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*42*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:02*	*1*
13C2 PFHxA	*108*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:02*	*1*
13C4 PFHpA	*92*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:02*	*1*
13C4 PFOA	*88*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:02*	*1*
13C5 PFNA	*100*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:02*	*1*
13C2 PFDA	*135*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:02*	*1*
13C2 PFUnA	*127*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:02*	*1*
13C3 PFBS	*66*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:02*	*1*
13C4 PFOS	*88*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:02*	*1*
M2-4:2 FTS	*209*	*5+	*25 - 150*	*07/16/24 04:26*	*07/17/24 21:02*	*1*
M2-8:2 FTS	*168*	*5+	*25 - 150*	*07/16/24 04:26*	*07/17/24 21:02*	*1*
13C2 10:2 FTS	*553*	*5+	*25 - 150*	*07/16/24 04:26*	*07/17/24 21:02*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoropentanoic acid (PFPeA)	140		81	14	ug/Kg		07/16/24 04:26	07/19/24 18:00	50
Br-Perfluorohexanesulfonic acid	50	J	81	12	ug/Kg		07/16/24 04:26	07/19/24 18:00	50
Total PFHxS	410		81	12	ug/Kg		07/16/24 04:26	07/19/24 18:00	50
L-Perfluorohexanesulfonic acid	360		81	12	ug/Kg		07/16/24 04:26	07/19/24 18:00	50
L-Perfluorooctanesulfonic acid	2100		200	16	ug/Kg		07/16/24 04:26	07/19/24 18:00	50
Br-Perfluorooctanesulfonic acid	1600		200	16	ug/Kg		07/16/24 04:26	07/19/24 18:00	50
Total PFOS	3600		200	16	ug/Kg		07/16/24 04:26	07/19/24 18:00	50
6:2 FTS	190		81	34	ug/Kg		07/16/24 04:26	07/19/24 18:00	50

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFPeA	*78*		*25 - 150*	*07/16/24 04:26*	*07/19/24 18:00*	*50*
18O2 PFHxS	*72*		*25 - 150*	*07/16/24 04:26*	*07/19/24 18:00*	*50*
13C4 PFOS	*95*		*25 - 150*	*07/16/24 04:26*	*07/19/24 18:00*	*50*
M2-6:2 FTS	*94*		*25 - 150*	*07/16/24 04:26*	*07/19/24 18:00*	*50*

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Client Sample ID: Saltbush 4-2

Date Collected: 06/24/24 14:00
Date Received: 06/27/24 09:30

Lab Sample ID: 320-113430-14

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**0.87**	**J**	1.4	0.32	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
Perfluoropentanoic acid (PFPeA)	ND		1.4	0.24	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
Perfluorohexanoic acid (PFHxA)	**0.44**	**J B**	1.4	0.37	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
Perfluoroheptanoic acid (PFHpA)	ND		1.4	0.16	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
L-Perfluorooctanoic acid	ND		1.4	0.27	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
Br-Perfluorooctanoic acid	ND		1.4	0.27	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
Total PFOA	ND		1.4	0.27	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
Perfluorononanoic acid (PFNA)	ND		1.4	0.24	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
Perfluorodecanoic acid (PFDA)	ND		1.4	0.14	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
Perfluoroundecanoic acid (PFUnA)	ND		1.4	0.37	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.4	0.23	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.4	0.24	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
Br-Perfluorohexanesulfonic acid	ND		1.4	0.20	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
Total PFHxS	**0.93**	**J**	1.4	0.20	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
L-Perfluorohexanesulfonic acid	**0.86**	**J**	1.4	0.20	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.4	0.25	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
L-Perfluorooctanesulfonic acid	**0.76**	**J**	3.4	0.27	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
Br-Perfluorooctanesulfonic acid	**0.54**	**J**	3.4	0.27	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
Total PFOS	**1.3**	**J**	3.4	0.27	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
4:2 FTS	ND		1.4	0.36	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
6:2 FTS	**1.4**		1.4	0.57	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
8:2 FTS	ND		1.4	0.14	ug/Kg		07/16/24 04:26	07/17/24 21:21	1
10:2 FTS	ND		1.4	0.14	ug/Kg		07/16/24 04:26	07/17/24 21:21	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*39*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:21*	*1*
13C5 PFPeA	*49*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:21*	*1*
13C2 PFHxA	*96*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:21*	*1*
13C4 PFHpA	*92*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:21*	*1*
13C4 PFOA	*92*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:21*	*1*
13C5 PFNA	*111*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:21*	*1*
13C2 PFDA	*153*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 21:21*	*1*
13C2 PFUnA	*138*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:21*	*1*
13C3 PFBS	*64*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:21*	*1*
18O2 PFHxS	*85*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:21*	*1*
13C4 PFOS	*110*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:21*	*1*
M2-4:2 FTS	*238*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 21:21*	*1*
M2-6:2 FTS	*188*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 21:21*	*1*
M2-8:2 FTS	*201*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 21:21*	*1*
13C2 10:2 FTS	*576*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 21:21*	*1*

NMED Exhibits 65

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Client Sample ID: Saltbush 4-3
Date Collected: 06/24/24 13:30
Date Received: 06/27/24 09:30

Lab Sample ID: 320-113430-15
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**0.38**	**J**	1.1	0.27	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
Perfluoropentanoic acid (PFPeA)	ND		1.1	0.20	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
Perfluorohexanoic acid (PFHxA)	**0.43**	**J B**	1.1	0.31	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
Perfluoroheptanoic acid (PFHpA)	ND		1.1	0.13	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
L-Perfluorooctanoic acid	ND		1.1	0.23	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
Br-Perfluorooctanoic acid	ND		1.1	0.23	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
Total PFOA	ND		1.1	0.23	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
Perfluorononanoic acid (PFNA)	ND		1.1	0.20	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
Perfluorodecanoic acid (PFDA)	ND		1.1	0.12	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
Perfluoroundecanoic acid (PFUnA)	ND		1.1	0.31	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.1	0.20	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.1	0.21	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
Br-Perfluorohexanesulfonic acid	ND		1.1	0.17	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
Total PFHxS	**0.67**	**J**	1.1	0.17	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
L-Perfluorohexanesulfonic acid	**0.64**	**J**	1.1	0.17	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.1	0.21	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
L-Perfluorooctanesulfonic acid	**0.67**	**J**	2.9	0.23	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
Br-Perfluorooctanesulfonic acid	**0.48**	**J**	2.9	0.23	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
Total PFOS	**1.2**	**J**	2.9	0.23	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
4:2 FTS	ND		1.1	0.31	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
6:2 FTS	**1.0**	**J**	1.1	0.49	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
8:2 FTS	ND		1.1	0.11	ug/Kg		07/16/24 04:26	07/17/24 21:41	1
10:2 FTS	ND		1.1	0.12	ug/Kg		07/16/24 04:26	07/17/24 21:41	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*36*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:41*	*1*
13C5 PFPeA	*50*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:41*	*1*
13C2 PFHxA	*99*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:41*	*1*
13C4 PFHpA	*96*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:41*	*1*
13C4 PFOA	*91*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:41*	*1*
13C5 PFNA	*109*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:41*	*1*
13C2 PFDA	*150*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:41*	*1*
13C2 PFUnA	*143*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:41*	*1*
13C3 PFBS	*68*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:41*	*1*
18O2 PFHxS	*86*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:41*	*1*
13C4 PFOS	*117*		*25 - 150*	*07/16/24 04:26*	*07/17/24 21:41*	*1*
M2-4:2 FTS	*271*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 21:41*	*1*
M2-6:2 FTS	*200*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 21:41*	*1*
M2-8:2 FTS	*177*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 21:41*	*1*
13C2 10:2 FTS	*584*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 21:41*	*1*

NMED Exhibits 65

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Client Sample ID: Saltbush 4-4

Date Collected: 06/24/24 13:00
Date Received: 06/27/24 09:30

Lab Sample ID: 320-113430-16

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**5.2**		2.3	0.54	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
Perfluoropentanoic acid (PFPeA)	ND		2.3	0.40	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
Perfluorohexanoic acid (PFHxA)	**0.74**	**J B**	2.3	0.62	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
Perfluoroheptanoic acid (PFHpA)	ND		2.3	0.26	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
L-Perfluorooctanoic acid	ND		2.3	0.46	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
Br-Perfluorooctanoic acid	ND		2.3	0.46	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
Total PFOA	ND		2.3	0.46	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
Perfluorononanoic acid (PFNA)	ND		2.3	0.40	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
Perfluorodecanoic acid (PFDA)	ND		2.3	0.23	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
Perfluoroundecanoic acid (PFUnA)	ND		2.3	0.62	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
Perfluorobutanesulfonic acid (PFBS)	ND		2.3	0.39	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
Perfluoropentanesulfonic acid (PFPeS)	ND		2.3	0.41	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
Br-Perfluorohexanesulfonic acid	ND		2.3	0.34	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
Total PFHxS	ND		2.3	0.34	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
L-Perfluorohexanesulfonic acid	ND		2.3	0.34	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		2.3	0.42	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
L-Perfluorooctanesulfonic acid	ND		5.7	0.46	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
Br-Perfluorooctanesulfonic acid	ND		5.7	0.46	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
Total PFOS	ND		5.7	0.46	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
4:2 FTS	ND		2.3	0.60	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
6:2 FTS	ND		2.3	0.96	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
8:2 FTS	ND		2.3	0.23	ug/Kg		07/16/24 04:26	07/17/24 22:20	1
10:2 FTS	ND		2.3	0.23	ug/Kg		07/16/24 04:26	07/17/24 22:20	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*45*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:20*	*1*
13C5 PFPeA	*50*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:20*	*1*
13C2 PFHxA	*108*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:20*	*1*
13C4 PFHpA	*94*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:20*	*1*
13C4 PFOA	*96*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:20*	*1*
13C5 PFNA	*107*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:20*	*1*
13C2 PFDA	*133*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:20*	*1*
13C2 PFUnA	*122*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:20*	*1*
13C3 PFBS	*70*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:20*	*1*
18O2 PFHxS	*86*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:20*	*1*
13C4 PFOS	*113*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:20*	*1*
M2-4:2 FTS	*237*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 22:20*	*1*
M2-6:2 FTS	*162*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 22:20*	*1*
M2-8:2 FTS	*164*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 22:20*	*1*
13C2 10:2 FTS	*403*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 22:20*	*1*

NMED Exhibits 65

Client Sample ID: Algae So

Date Collected: 06/24/24 11:00
Date Received: 06/27/24 09:30

Lab Sample ID: 320-113430-21
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	3.6		0.78	0.18	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
Perfluoropentanoic acid (PFPeA)	14		0.78	0.14	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
Perfluorohexanoic acid (PFHxA)	21	B	0.78	0.21	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
Perfluoroheptanoic acid (PFHpA)	4.6		0.78	0.091	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
L-Perfluorooctanoic acid	8.8		0.78	0.16	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
Br-Perfluorooctanoic acid	0.70	J	0.78	0.16	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
Total PFOA	9.5		0.78	0.16	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
Perfluorononanoic acid (PFNA)	2.5		0.78	0.14	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
Perfluorodecanoic acid (PFDA)	0.35	J	0.78	0.080	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
Perfluoroundecanoic acid (PFUnA)	ND		0.78	0.21	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
Perfluorobutanesulfonic acid (PFBS)	4.2		0.78	0.13	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
Perfluoropentanesulfonic acid (PFPeS)	8.6		0.78	0.14	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
Br-Perfluorohexanesulfonic acid	12		0.78	0.12	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
Total PFHxS	71		0.78	0.12	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
L-Perfluorohexanesulfonic acid	58		0.78	0.12	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
Perfluoroheptanesulfonic acid (PFHpS)	2.2		0.78	0.14	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
4:2 FTS	ND		0.78	0.21	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
6:2 FTS	26		0.78	0.33	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
8:2 FTS	0.53	J	0.78	0.078	ug/Kg		07/16/24 04:26	07/17/24 22:39	1
10:2 FTS	0.092	J	0.78	0.079	ug/Kg		07/16/24 04:26	07/17/24 22:39	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*65*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:39*	*1*
13C5 PFPeA	*49*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:39*	*1*
13C2 PFHxA	*102*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:39*	*1*
13C4 PFHpA	*87*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:39*	*1*
13C4 PFOA	*87*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:39*	*1*
13C5 PFNA	*107*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:39*	*1*
13C2 PFDA	*144*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:39*	*1*
13C2 PFUnA	*146*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:39*	*1*
13C3 PFBS	*78*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:39*	*1*
18O2 PFHxS	*80*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:39*	*1*
13C4 PFOS	*98*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:39*	*1*
M2-4:2 FTS	*170*	*5+	*25 - 150*	*07/16/24 04:26*	*07/17/24 22:39*	*1*
M2-6:2 FTS	*118*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:39*	*1*
M2-8:2 FTS	*135*		*25 - 150*	*07/16/24 04:26*	*07/17/24 22:39*	*1*
13C2 10:2 FTS	*631*	*5+	*25 - 150*	*07/16/24 04:26*	*07/17/24 22:39*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	83		20	1.6	ug/Kg		07/16/24 04:26	07/20/24 15:32	10
Br-Perfluorooctanesulfonic acid	37		20	1.6	ug/Kg		07/16/24 04:26	07/20/24 15:32	10
Total PFOS	120		20	1.6	ug/Kg		07/16/24 04:26	07/20/24 15:32	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*97*		*25 - 150*	*07/16/24 04:26*	*07/20/24 15:32*	*10*

NMED Exhibits 65

Isotope Dilution Summary

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Tissue

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-113430-9	Saltbush 2-1	45	51	108	97	91	101	124	108
320-113430-10	Saltbush 2-2	42	53	101	87	92	106	130	101
320-113430-11	Saltbush 2-3	31	50	109	91	90	107	136	106
320-113430-12	Saltbush 2-4	36	53	105	91	89	112	146	129
320-113430-13	Saltbush 4-1	42		108	92	88	100	135	127
320-113430-13 - DL	Saltbush 4-1		78						
320-113430-14	Saltbush 4-2	39	49	96	92	92	111	153 *5+	138
320-113430-15	Saltbush 4-3	36	50	99	96	91	109	150	143
320-113430-16	Saltbush 4-4	45	50	108	94	96	107	133	122
320-113430-21	Algae So	65	49	102	87	87	107	144	146
320-113430-21 - DL	Algae So								
LCS 320-779766/2-A	Lab Control Sample	88	95	99	96	96	93	79	67
LCSD 320-779766/3-A	Lab Control Sample Dup	91	89	100	94	94	97	83	73
MB 320-779766/1-A	Method Blank	90	96	101	92	94	95	80	69

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
320-113430-9	Saltbush 2-1	68	87	107	289 *5+	170 *5+	162 *5+	412 *5+
320-113430-10	Saltbush 2-2	65	84	113	242 *5+	176 *5+	162 *5+	577 *5+
320-113430-11	Saltbush 2-3	69	83	112	215 *5+	167 *5+	196 *5+	376 *5+
320-113430-12	Saltbush 2-4	71	83	114	226 *5+	162 *5+	180 *5+	621 *5+
320-113430-13	Saltbush 4-1	66		88	209 *5+		168 *5+	553 *5+
320-113430-13 - DL	Saltbush 4-1		72	95		94		
320-113430-14	Saltbush 4-2	64	85	110	238 *5+	188 *5+	201 *5+	576 *5+
320-113430-15	Saltbush 4-3	68	86	117	271 *5+	200 *5+	177 *5+	584 *5+
320-113430-16	Saltbush 4-4	70	86	113	237 *5+	162 *5+	164 *5+	403 *5+
320-113430-21	Algae So	78	80	98	170 *5+	118	135	631 *5+
320-113430-21 - DL	Algae So			97				
LCS 320-779766/2-A	Lab Control Sample	92	92	94	108	111	84	167 *5+
LCSD 320-779766/3-A	Lab Control Sample Dup	89	90	94	99	111	85	193 *5+
MB 320-779766/1-A	Method Blank	88	95	94	107	107	84	197 *5+

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
PFHxA = 13C2 PFHxA
C4PFHA = 13C4 PFHpA
PFOA = 13C4 PFOA
PFNA = 13C5 PFNA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS
PFHxS = 18O2 PFHxS
PFOS = 13C4 PFOS
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
M102FTS = 13C2 10:2 FTS

NMED Exhibits 65

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Lab Sample ID: MB 320-779766/1-A
Matrix: Tissue
Analysis Batch: 781472

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 779766

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
Perfluorohexanoic acid (PFHxA)	0.401	J	1.0	0.27	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
L-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
Total PFOA	ND		1.0	0.20	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.10	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.27	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
Total PFHxS	ND		1.0	0.15	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
L-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
Br-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
Total PFOS	ND		2.5	0.20	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
4:2 FTS	ND		1.0	0.27	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
6:2 FTS	ND		1.0	0.42	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
8:2 FTS	ND		1.0	0.10	ug/Kg		07/16/24 04:26	07/17/24 18:46	1
10:2 FTS	ND		1.0	0.10	ug/Kg		07/16/24 04:26	07/17/24 18:46	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*90*		*25 - 150*	*07/16/24 04:26*	*07/17/24 18:46*	*1*
13C5 PFPeA	*96*		*25 - 150*	*07/16/24 04:26*	*07/17/24 18:46*	*1*
13C2 PFHxA	*101*		*25 - 150*	*07/16/24 04:26*	*07/17/24 18:46*	*1*
13C4 PFHpA	*92*		*25 - 150*	*07/16/24 04:26*	*07/17/24 18:46*	*1*
13C4 PFOA	*94*		*25 - 150*	*07/16/24 04:26*	*07/17/24 18:46*	*1*
13C5 PFNA	*95*		*25 - 150*	*07/16/24 04:26*	*07/17/24 18:46*	*1*
13C2 PFDA	*80*		*25 - 150*	*07/16/24 04:26*	*07/17/24 18:46*	*1*
13C2 PFUnA	*69*		*25 - 150*	*07/16/24 04:26*	*07/17/24 18:46*	*1*
13C3 PFBS	*88*		*25 - 150*	*07/16/24 04:26*	*07/17/24 18:46*	*1*
18O2 PFHxS	*95*		*25 - 150*	*07/16/24 04:26*	*07/17/24 18:46*	*1*
13C4 PFOS	*94*		*25 - 150*	*07/16/24 04:26*	*07/17/24 18:46*	*1*
M2-4:2 FTS	*107*		*25 - 150*	*07/16/24 04:26*	*07/17/24 18:46*	*1*
M2-6:2 FTS	*107*		*25 - 150*	*07/16/24 04:26*	*07/17/24 18:46*	*1*
M2-8:2 FTS	*84*		*25 - 150*	*07/16/24 04:26*	*07/17/24 18:46*	*1*
13C2 10:2 FTS	*197*	**5+*	*25 - 150*	*07/16/24 04:26*	*07/17/24 18:46*	*1*

Lab Sample ID: LCS 320-779766/2-A
Matrix: Tissue
Analysis Batch: 781472

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 779766

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	10.0	10.4		ug/Kg		104	76 - 136

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-779766/2-A
Matrix: Tissue
Analysis Batch: 781472

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 779766

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits		
Perfluoropentanoic acid (PFPeA)			10.0	9.15		ug/Kg		92	69 - 129		
Perfluorohexanoic acid (PFHxA)			10.0	10.7		ug/Kg		107	71 - 131		
Perfluoroheptanoic acid (PFHpA)			10.0	9.64		ug/Kg		96	71 - 131		
L-Perfluorooctanoic acid			10.0	10.5		ug/Kg		105	72 - 132		
Total PFOA			10.0	10.5		ug/Kg		105			
Perfluorononanoic acid (PFNA)			10.0	9.95		ug/Kg		99	73 - 133		
Perfluorodecanoic acid (PFDA)			10.0	10.4		ug/Kg		104	72 - 132		
Perfluoroundecanoic acid (PFUnA)			10.0	10.8		ug/Kg		108	66 - 126		
Perfluorobutanesulfonic acid (PFBS)			8.88	9.62		ug/Kg		108	69 - 129		
Perfluoropentanesulfonic acid (PFPeS)			9.40	9.51		ug/Kg		101	66 - 126		
Total PFHxS			9.12	9.19		ug/Kg		101			
L-Perfluorohexanesulfonic acid			9.12	9.19		ug/Kg		101	62 - 122		
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.6		ug/Kg		111	76 - 136		
L-Perfluorooctanesulfonic acid			9.30	9.11		ug/Kg		98	68 - 141		
Total PFOS			9.30	9.11		ug/Kg		98			
4:2 FTS			9.38	9.06		ug/Kg		97	68 - 143		
6:2 FTS			9.52	9.17		ug/Kg		96	73 - 139		
8:2 FTS			9.60	10.3		ug/Kg		107	75 - 135		
10:2 FTS			9.66	7.91		ug/Kg		82	69 - 145		

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*88*		*25 - 150*
13C5 PFPeA	*95*		*25 - 150*
13C2 PFHxA	*99*		*25 - 150*
13C4 PFHpA	*96*		*25 - 150*
13C4 PFOA	*96*		*25 - 150*
13C5 PFNA	*93*		*25 - 150*
13C2 PFDA	*79*		*25 - 150*
13C2 PFUnA	*67*		*25 - 150*
13C3 PFBS	*92*		*25 - 150*
18O2 PFHxS	*92*		*25 - 150*
13C4 PFOS	*94*		*25 - 150*
M2-4:2 FTS	*108*		*25 - 150*
M2-6:2 FTS	*111*		*25 - 150*
M2-8:2 FTS	*84*		*25 - 150*
13C2 10:2 FTS	*167*	**5+*	*25 - 150*

Lab Sample ID: LCSD 320-779766/3-A
Matrix: Tissue
Analysis Batch: 781472

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 779766

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)			10.0	10.2		ug/Kg		102	76 - 136	2	30
Perfluoropentanoic acid (PFPeA)			10.0	9.85		ug/Kg		99	69 - 129	7	30
Perfluorohexanoic acid (PFHxA)			10.0	9.61		ug/Kg		96	71 - 131	10	30
Perfluoroheptanoic acid (PFHpA)			10.0	10.5		ug/Kg		105	71 - 131	8	30

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCSD 320-779766/3-A
Matrix: Tissue
Analysis Batch: 781472

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 779766

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
L-Perfluorooctanoic acid			10.0	10.8		ug/Kg		108	72 - 132	3	30
Total PFOA			10.0	10.8		ug/Kg		108		3	
Perfluorononanoic acid (PFNA)			10.0	9.85		ug/Kg		99	73 - 133	1	30
Perfluorodecanoic acid (PFDA)			10.0	10.3		ug/Kg		103	72 - 132	2	30
Perfluoroundecanoic acid (PFUnA)			10.0	10.6		ug/Kg		106	66 - 126	2	30
Perfluorobutanesulfonic acid (PFBS)			8.88	9.76		ug/Kg		110	69 - 129	1	30
Perfluoropentanesulfonic acid (PFPeS)			9.40	10.4		ug/Kg		110	66 - 126	9	30
Total PFHxS			9.12	9.03		ug/Kg		99		2	
L-Perfluorohexanesulfonic acid			9.12	9.03		ug/Kg		99	62 - 122	2	30
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.2		ug/Kg		107	76 - 136	4	30
L-Perfluorooctanesulfonic acid			9.30	9.26		ug/Kg		100	68 - 141	2	30
Total PFOS			9.30	9.26		ug/Kg		100		2	
4:2 FTS			9.38	9.67		ug/Kg		103	68 - 143	6	30
6:2 FTS			9.52	9.78		ug/Kg		103	73 - 139	6	30
8:2 FTS			9.60	9.90		ug/Kg		103	75 - 135	4	30
10:2 FTS			9.66	8.09		ug/Kg		84	69 - 145	2	30

Isotope Dilution	*LCSD %Recovery*	*LCSD Qualifier*	*Limits*
13C4 PFBA	*91*		*25 - 150*
13C5 PFPeA	*89*		*25 - 150*
13C2 PFHxA	*100*		*25 - 150*
13C4 PFHpA	*94*		*25 - 150*
13C4 PFOA	*94*		*25 - 150*
13C5 PFNA	*97*		*25 - 150*
13C2 PFDA	*83*		*25 - 150*
13C2 PFUnA	*73*		*25 - 150*
13C3 PFBS	*89*		*25 - 150*
18O2 PFHxS	*90*		*25 - 150*
13C4 PFOS	*94*		*25 - 150*
M2-4:2 FTS	*99*		*25 - 150*
M2-6:2 FTS	*111*		*25 - 150*
M2-8:2 FTS	*85*		*25 - 150*
13C2 10:2 FTS	*193*	*5+	*25 - 150*

LCMS

Pre Prep Batch: 779760

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113430-9	Saltbush 2-1	Total/NA	Tissue	In-House	
320-113430-10	Saltbush 2-2	Total/NA	Tissue	In-House	
320-113430-11	Saltbush 2-3	Total/NA	Tissue	In-House	
320-113430-12	Saltbush 2-4	Total/NA	Tissue	In-House	
320-113430-13 - DL	Saltbush 4-1	Total/NA	Tissue	In-House	
320-113430-13	Saltbush 4-1	Total/NA	Tissue	In-House	
320-113430-14	Saltbush 4-2	Total/NA	Tissue	In-House	
320-113430-15	Saltbush 4-3	Total/NA	Tissue	In-House	
320-113430-16	Saltbush 4-4	Total/NA	Tissue	In-House	
320-113430-21 - DL	Algae So	Total/NA	Tissue	In-House	
320-113430-21	Algae So	Total/NA	Tissue	In-House	

Prep Batch: 779766

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113430-9	Saltbush 2-1	Total/NA	Tissue	SHAKE	779760
320-113430-10	Saltbush 2-2	Total/NA	Tissue	SHAKE	779760
320-113430-11	Saltbush 2-3	Total/NA	Tissue	SHAKE	779760
320-113430-12	Saltbush 2-4	Total/NA	Tissue	SHAKE	779760
320-113430-13	Saltbush 4-1	Total/NA	Tissue	SHAKE	779760
320-113430-13 - DL	Saltbush 4-1	Total/NA	Tissue	SHAKE	779760
320-113430-14	Saltbush 4-2	Total/NA	Tissue	SHAKE	779760
320-113430-15	Saltbush 4-3	Total/NA	Tissue	SHAKE	779760
320-113430-16	Saltbush 4-4	Total/NA	Tissue	SHAKE	779760
320-113430-21 - DL	Algae So	Total/NA	Tissue	SHAKE	779760
320-113430-21	Algae So	Total/NA	Tissue	SHAKE	779760
MB 320-779766/1-A	Method Blank	Total/NA	Tissue	SHAKE	
LCS 320-779766/2-A	Lab Control Sample	Total/NA	Tissue	SHAKE	
LCSD 320-779766/3-A	Lab Control Sample Dup	Total/NA	Tissue	SHAKE	

Analysis Batch: 781472

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113430-9	Saltbush 2-1	Total/NA	Tissue	B/L/T PFAS	779766
320-113430-10	Saltbush 2-2	Total/NA	Tissue	B/L/T PFAS	779766
320-113430-11	Saltbush 2-3	Total/NA	Tissue	B/L/T PFAS	779766
320-113430-12	Saltbush 2-4	Total/NA	Tissue	B/L/T PFAS	779766
320-113430-13	Saltbush 4-1	Total/NA	Tissue	B/L/T PFAS	779766
320-113430-14	Saltbush 4-2	Total/NA	Tissue	B/L/T PFAS	779766
320-113430-15	Saltbush 4-3	Total/NA	Tissue	B/L/T PFAS	779766
320-113430-16	Saltbush 4-4	Total/NA	Tissue	B/L/T PFAS	779766
320-113430-21	Algae So	Total/NA	Tissue	B/L/T PFAS	779766
MB 320-779766/1-A	Method Blank	Total/NA	Tissue	B/L/T PFAS	779766
LCS 320-779766/2-A	Lab Control Sample	Total/NA	Tissue	B/L/T PFAS	779766
LCSD 320-779766/3-A	Lab Control Sample Dup	Total/NA	Tissue	B/L/T PFAS	779766

Analysis Batch: 781907

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113430-13 - DL	Saltbush 4-1	Total/NA	Tissue	B/L/T PFAS	779766

Analysis Batch: 782156

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113430-21 - DL	Algae So	Total/NA	Tissue	B/L/T PFAS	779766

Lab Chronicle

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Client Sample ID: Saltbush 2-1

Lab Sample ID: 320-113430-9
Matrix: Tissue
Date Collected: 06/25/24 08:00
Date Received: 06/27/24 09:30

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	779760	07/15/24 17:19	JS	EET SAC
Total/NA	Prep	SHAKE			0.60 g	10.0 mL	779766	07/16/24 04:26	SJ	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	781472	07/17/24 19:44	C1P	EET SAC

Client Sample ID: Saltbush 2-2

Lab Sample ID: 320-113430-10
Matrix: Tissue
Date Collected: 06/25/24 08:30
Date Received: 06/27/24 09:30

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	779760	07/15/24 17:19	JS	EET SAC
Total/NA	Prep	SHAKE			0.60 g	10.0 mL	779766	07/16/24 04:26	SJ	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	781472	07/17/24 20:04	C1P	EET SAC

Client Sample ID: Saltbush 2-3

Lab Sample ID: 320-113430-11
Matrix: Tissue
Date Collected: 06/25/24 09:00
Date Received: 06/27/24 09:30

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	779760	07/15/24 17:19	JS	EET SAC
Total/NA	Prep	SHAKE			0.71 g	10.0 mL	779766	07/16/24 04:26	SJ	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	781472	07/17/24 20:23	C1P	EET SAC

Client Sample ID: Saltbush 2-4

Lab Sample ID: 320-113430-12
Matrix: Tissue
Date Collected: 06/25/24 10:00
Date Received: 06/27/24 09:30

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	779760	07/15/24 17:19	JS	EET SAC
Total/NA	Prep	SHAKE			0.61 g	10.0 mL	779766	07/16/24 04:26	SJ	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	781472	07/17/24 20:42	C1P	EET SAC

Client Sample ID: Saltbush 4-1

Lab Sample ID: 320-113430-13
Matrix: Tissue
Date Collected: 06/24/24 15:00
Date Received: 06/27/24 09:30

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	779760	07/15/24 17:19	JS	EET SAC
Total/NA	Prep	SHAKE			0.62 g	10.0 mL	779766	07/16/24 04:26	SJ	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	781472	07/17/24 21:02	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	779760	07/15/24 17:19	JS	EET SAC
Total/NA	Prep	SHAKE	DL		0.62 g	10.0 mL	779766	07/16/24 04:26	SJ	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	50	1 mL	1 mL	781907	07/19/24 18:00	S1C	EET SAC

Lab Chronicle

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Client Sample ID: Saltbush 4-2

Lab Sample ID: 320-113430-14

Date Collected: 06/24/24 14:00

Matrix: Tissue

Date Received: 06/27/24 09:30

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	779760	07/15/24 17:19	JS	EET SAC
Total/NA	Prep	SHAKE			0.74 g	10.0 mL	779766	07/16/24 04:26	SJ	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	781472	07/17/24 21:21	C1P	EET SAC

Client Sample ID: Saltbush 4-3

Lab Sample ID: 320-113430-15

Date Collected: 06/24/24 13:30

Matrix: Tissue

Date Received: 06/27/24 09:30

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	779760	07/15/24 17:19	JS	EET SAC
Total/NA	Prep	SHAKE			0.87 g	10.0 mL	779766	07/16/24 04:26	SJ	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	781472	07/17/24 21:41	C1P	EET SAC

Client Sample ID: Saltbush 4-4

Lab Sample ID: 320-113430-16

Date Collected: 06/24/24 13:00

Matrix: Tissue

Date Received: 06/27/24 09:30

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	779760	07/15/24 17:19	JS	EET SAC
Total/NA	Prep	SHAKE			0.44 g	10.0 mL	779766	07/16/24 04:26	SJ	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	781472	07/17/24 22:20	C1P	EET SAC

Client Sample ID: Algae So

Lab Sample ID: 320-113430-21

Date Collected: 06/24/24 11:00

Matrix: Tissue

Date Received: 06/27/24 09:30

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	779760	07/15/24 17:19	JS	EET SAC
Total/NA	Prep	SHAKE			1.28 g	10.0 mL	779766	07/16/24 04:26	SJ	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	781472	07/17/24 22:39	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	779760	07/15/24 17:19	JS	EET SAC
Total/NA	Prep	SHAKE	DL		1.28 g	10.0 mL	779766	07/16/24 04:26	SJ	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	782156	07/20/24 15:32	C1P	EET SAC

Laboratory References:

EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

NMED Exhibits 65

Accreditation/Certification Summary

Client: University of New Mexico
Job ID: 320-113430-1
Project/Site: HollomanLake PFAS Research

Laboratory: Eurofins Sacramento

All accreditations/certifications held by this laboratory are listed. Not all accreditations/certifications are applicable to this report.

Authority	Program	Identification Number	Expiration Date
Alaska (UST)	State	17-020	02-20-27
ANAB	Dept. of Defense ELAP	L2468	01-20-27
ANAB	Dept. of Energy	L2468.01	01-20-27
ANAB	ISO/IEC 17025	L2468	01-20-27
Arizona	State	AZ0708	08-11-24
Arkansas DEQ	State	88-0691	05-18-25
California	State	2897	01-31-26
Colorado	State	CA00044	08-31-24
Florida	NELAP	E87570	06-30-25
Georgia	State	4040	01-29-25
Hawaii	State	Eurofins Sacramento	01-29-25
Illinois	NELAP	200060	03-31-25
Kansas	NELAP	E-10375	10-31-25
Louisiana	NELAP	01944	06-30-25
Louisiana (All)	NELAP	01944	06-30-25
Maine	State	CA00004	04-14-26
Michigan	State	9947	01-29-25
Nevada	State	CA00044	07-31-25
New Hampshire	NELAP	2997	04-19-25
New Jersey	NELAP	CA005	06-30-25
New York	NELAP	11666	04-01-25
Ohio	State	41252	01-29-25
Oregon	NELAP	4040	01-29-25
Texas	NELAP	T104704399-23-17	05-31-25
US Fish & Wildlife	US Federal Programs	A22139	04-30-25
USDA	US Federal Programs	P330-18-00239	02-28-26
Utah	NELAP	CA000442023-16	02-28-25
Virginia	NELAP	460278	03-14-25
Washington	State	C581	05-05-25
West Virginia (DW)	State	9930C	01-31-25
Wisconsin	State	998204680	08-31-25
Wyoming	State Program	8TMS-L	01-28-19 *

* Accreditation/Certification renewal pending - accreditation/certification considered valid.

NMED Exhibits 65

Method Summary

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Method	Method Description	Protocol	Laboratory
B/L/T PFAS	Branched, Linear and Total PFAS	EPA	EET SAC
In-House	Tissue Preparation/Homgenization	NOAA	EET SAC
SHAKE	Shake Extraction with Ultrasonic Bath Extraction	SW846	EET SAC

Protocol References:

EPA = US Environmental Protection Agency

NOAA = National Marine Fisheries Service, National Oceanic And Atmospheric Administration, Seattle, WA, November 1988

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

NMED Exhibits 65

Sample Summary

Client: University of New Mexico
Project/Site: HollomanLake PFAS Research

Job ID: 320-113430-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
320-113430-9	Saltbush 2-1	Tissue	06/25/24 08:00	06/27/24 09:30
320-113430-10	Saltbush 2-2	Tissue	06/25/24 08:30	06/27/24 09:30
320-113430-11	Saltbush 2-3	Tissue	06/25/24 09:00	06/27/24 09:30
320-113430-12	Saltbush 2-4	Tissue	06/25/24 10:00	06/27/24 09:30
320-113430-13	Saltbush 4-1	Tissue	06/24/24 15:00	06/27/24 09:30
320-113430-14	Saltbush 4-2	Tissue	06/24/24 14:00	06/27/24 09:30
320-113430-15	Saltbush 4-3	Tissue	06/24/24 13:30	06/27/24 09:30
320-113430-16	Saltbush 4-4	Tissue	06/24/24 13:00	06/27/24 09:30
320-113430-21	Algae So	Tissue	06/24/24 11:00	06/27/24 09:30

Eurofins Sacramento
NMED Exhibit 63
7/23/2024

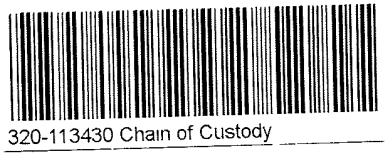
Eurofins Env. Testing Northern California
880 Riverside Parkway
West Sacramento, CA 95605
Phone: 916.373.5600

Chain of Custody Record

eurofins | Environment Testing America

Client Contact	Report To: Jean-Luc Cartron	Site Contact:	Date: 6/26/2024	COC No
Daniel B Stephens & Associates	email. jcartron@geo-logic.com, jlec@unm.edu	Lab Contact: Linda Laver	Carrier: FedEx	____ of ____ COCs
6020 Academy Road NE, Suite 100	Analysis Turnaround Time			Job No
Albuquerque/NM/87109-3315	Business Days (BD) ____			
Phone: 505-822-9400	TAT if different from Above ____			Field Sampler
Tel.	☐ 2 weeks			
Project Name. Holloman Lake PFAS Research	☐ 1 week			
Site: Holloman Lake Otero Co New Mexico	☐ 2 days			
P O #	☐ 1 day			

Sample Identification	Sample Date	Sample Time	Sample Type	Matrix	# of Cont.	Filtered Sample	Enter requested analyses in these fields	Sample Specific Notes:
Soil NE2-1	6/25/24	8:00am	Soil		1			
Soil NE2-2	6/25/24	8:30am	Soil		1			
Soil NE 2-3	6/25/24	9:00am	Soil		1			
Soil NE 2-4	6/25/24	10:00am	Soil		1			
Soil 4-1	6/24/24	3:00pm	Soil		1			
Soil 4-2	6/24/24	2.00pm	Soil		1			
Soil 4-3	6/24/24	1:30pm	Soil		1			
Soil 4-4	6/24/24	1:00pm	Soil		1			
Saltbush 2-1	6/25/24	8.00am	Plant tissue		1			
Saltbush 2-2	6/25/24	8:30am	Plant tissue		1			
Saltbush 2-3	6/25/24	9:00am	Plant tissue		1			
Saltbush 2-4	6/25/24	10:00am	Plant tissue		1			
Saltbush 4-1	6/24/24	3:00pm	Plant tissue		1			
Saltbush 4-2	6/24/24	2:00pm	Plant tissue		1			
Saltbush 4-3	6/24/24	1.30pm	Plant tissue		1			
Saltbush 4-4	6/24/24	1:00pm	Plant tissue		1			
H2O West	6/25/24	12:30pm	Water		1			
H2O -So	6/24/24	11:00am	Water		1			
H2O North Inlet	6/25/24	10:00am	Water		1			
H2O East Inlet	6/25/24	10 15am	Water		1			
Algae So	6/24/24	11:00am	Plant tissue		1			



Preservation Used. 1= Ice, 2= HCl, 3= H2SO4, 4=HNO3, 5=NaOH, 6= Other ____

Possible Hazard Identification
☒ *Non-Hazard* ☐ *Flammable* ☐ *Skin Irritant* *Poison B* *Unknown* ☐

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☐ *Return To Client* ☒ *Disposal By Lab* ☐ *Archive For* ____ *Months*

Special Instructions/QC Requirements & Comments:

Relinquished by: Jean-Luc Cartron	Company: DBS&A	Date/Time: 6/26/24	Received by: Driver	Company: Fed X	Date/Time: 4pm 6/26/24
Relinquished by:	Company:	Date/Time:	Received by:	Company: EETSac	Date/Time: 6/27/24 0930
Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:

eurofins | Environment Testing

Loc 320
113430

Sacramento Sample Receiving Notes (SSRN)

Tracking # 7770 8472 7112

Job _____

SO / PO / FO / SAT / 2-Day / Ground / UPS / CDO / Courier
GSL / OnTrac / Goldstreak / USPS / Other_____

Use this form to record Sample Custody Seal, Cooler Custody Seal, Temperature & corrected Temperature & other observations.
File in the job folder with the COC

Therm. ID: 107 Corr. Factor: (+ / -) N/A °C

Ice_____ Wet_____ Gel _____ Other None

Cooler Custody Seal: —

Cooler ID: _____

Temp Observed 19.8 °C Corrected: 19.8 °C
From Temp Blank ☐ Sample ☐

Opening/Processing The Shipment	Yes	No	NA
Cooler compromised/tampered with?	☐	☑	☐
Cooler Temperature is acceptable?	☐	☑	☐
Frozen samples show signs of thaw?	☐	☐	☑

Initials SO Date 6/27/24

Unpacking/Labeling The Samples	Yes	No	NA
Containers are not broken or leaking?	☑	☐	☐
Samples compromised/tampered with?	☐	☑	☐
COC is complete w/o discrepancies	☑	☐	☐
Sample custody seal?	☐	☐	☑
Sample containers have legible labels?	☑	☐	☐
Sample date/times are provided?	☑	☐	☐
Appropriate containers are used?	☑	☐	☐
Sample bottles are completely filled?	☑	☐	☐
Sample preservatives verified?	☐	☐	☑
Is the Field Sampler's name on COC?	☐	☐	☑
Samples w/o discrepancies?	☑	☐	☐
Zero headspace?*	☐	☐	☑
Alkalinity has no headspace?	☐	☐	☑
Perchlorate has headspace? (Methods 314, 331, 6850)	☐	☐	☑
Multiphasic samples are not present?	☑	☐	☐

Containers requiring zero headspace have no headspace, or bubble < 6 mm (1/4")

Initials DM Date 06/27/24

Notes: no cooling agent

Trizma Lot #(s). _____

Ammonium Acetate Lot #(s) _____

Login Completion	Yes	No	NA
Receipt Temperature on COC?	☑	☐	☐
NCM Filed?	☑	☐	☑ 06/27/24
Samples received within hold time?	☑	☐	☐
Log Release checked in TALS?	☑	☐	☐

Initials DM Date 06/27/24

eurofins | Environment Testing

ANALYTICAL REPORT

PREPARED FOR

Attn: Jean-Luc Cartron
University of New Mexico
Museum of Southwestern Biology
Division of Mammals
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Albuquerque, New Mexico 87131

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JOB DESCRIPTION

Holloman Lake_Waters & Soils

JOB NUMBER

320-113899-1

Eurofins Sacramento
880 Riverside Parkway
West Sacramento CA 95605

See page two for job notes and contact information.

NMED Exhibits 65
my EOL

Job Notes

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Authorization



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Qualifiers

LCMS

Qualifier	Qualifier Description
*5+	Isotope dilution analyte is outside acceptance limits, high biased.
F1	MS and/or MSD recovery exceeds control limits.
I	Value is EMPC (estimated maximum possible concentration).
J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
¤	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CFU	Colony Forming Unit
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MCL	EPA recommended "Maximum Contaminant Level"
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
MPN	Most Probable Number
MQL	Method Quantitation Limit
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
NEG	Negative / Absent
POS	Positive / Present
PQL	Practical Quantitation Limit
PRES	Presumptive
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)
TNTC	Too Numerous To Count

NMED Exhibits 65

Job ID: 320-113899-1 — Eurofins Sacramento

Job Narrative
320-113899-1

Receipt
The samples were received on 7/18/2024 9:20 AM. Unless otherwise noted below, the samples arrived in good condition, and where required, properly preserved and on ice. The temperature of the cooler at receipt was 2.3º C.

Receipt Exceptions
The Chain-of-Custody (COC) was incomplete as received and does not list the requested analyses. Based on communications with the client, the samples were logged in for PFAS (17 Analyte List by 537 Mod).

LCMS
Method B/L/T PFAS: Isotope Dilution Analyte (IDA) recovery is above the method recommended limit for the following sample. Quantitation by isotope dilution generally precludes any adverse effect on data quality due to elevated IDA recoveries. Hol-East H2O (320-113899-2)

Method B/L/T PFAS: Results for the following samples were reported from the analysis of a diluted extract due to matrix sample of the target analyte in the analysis of the undiluted extract. The dilution factor was applied to the labeled internal standard area counts and these area counts were within acceptance limits. Hol-East H2O (320-113899-2), Hol-South H2O (320-113899-3), Hol-West H2O (320-113899-4), Hol NE4-0=1 Soils (320-113899-5), Hol NE4-900=4 Soils (320-113899-8) and Hol NE2-0=1 Soils (320-113899-9)

Method B/L/T PFAS: The "I" qualifier means the transition mass ratio for the indicated analyte was outside the established ratio limits. The qualitative identification of the analyte has some degree of uncertainty. However, analyst judgment was used to positively identify the analyte. Hol-South H2O (320-113899-3). and Hol NE2-900=4 Soils (320-113899-12)

Method B/L/T PFAS: The matrix spike / matrix spike duplicate (MS/MSD) for preparation batch 320-785917 has recoveries outside control limits for some analytes. Sample matrix interference and/or non-homogeneity are suspected because the associated laboratory control sample (LCS) recovery is within acceptance limits.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Organic Prep
Method 3535: Insufficient sample volume was available to perform a matrix spike/matrix spike duplicate/sample duplicate (MS/MSD/DUP) associated with preparation batch 320-781606.

Method 3535: The following samples were yellow in color following extraction. Hol-East H2O (320-113899-2), Hol-South H2O (320-113899-3) and Hol-West H2O (320-113899-4)

Method 3535: Due to the matrix, the following samples were prepared at a reduced volume from the standard operating procedure. The reporting limits (RLs) have been adjusted proportionately [2X]. Hol-East H2O (320-113899-2), Hol-South H2O (320-113899-3) and Hol-West H2O (320-113899-4)

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Detection Summary

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Client Sample ID: Hol-North H2O — Lab Sample ID: 320-113899-1

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	25		4.2	2.0	ng/L	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	160		1.7	0.41	ng/L	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	110		1.7	0.49	ng/L	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	21		1.7	0.21	ng/L	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	23		1.7	0.72	ng/L	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	4.0		1.7	0.72	ng/L	1		B/L/T PFAS	Total/NA
Total PFOA	27		1.7	0.72	ng/L	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	1.3	J	1.7	0.23	ng/L	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.66	J	1.7	0.26	ng/L	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	20		1.7	0.17	ng/L	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	15		1.7	0.25	ng/L	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	18		1.7	0.48	ng/L	1		B/L/T PFAS	Total/NA
Total PFHxS	100		1.7	0.48	ng/L	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	82		1.7	0.48	ng/L	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	3.6		1.7	0.16	ng/L	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	87		1.7	0.45	ng/L	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	60		1.7	0.45	ng/L	1		B/L/T PFAS	Total/NA
Total PFOS	150		1.7	0.45	ng/L	1		B/L/T PFAS	Total/NA
6:2 FTS	230		4.2	2.1	ng/L	1		B/L/T PFAS	Total/NA

Client Sample ID: Hol-East H2O — Lab Sample ID: 320-113899-2

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	5500		200	96	ng/L	20		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	4000		80	10	ng/L	20		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	3200		80	34	ng/L	20		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	510		80	34	ng/L	20		B/L/T PFAS	Total/NA
Total PFOA	3700		80	34	ng/L	20		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	390		80	11	ng/L	20		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	13	J	80	12	ng/L	20		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	4100		80	8.0	ng/L	20		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	2800		80	12	ng/L	20		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	620		80	7.6	ng/L	20		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	6800		80	22	ng/L	20		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	8300		80	22	ng/L	20		B/L/T PFAS	Total/NA
Total PFOS	15000		80	22	ng/L	20		B/L/T PFAS	Total/NA
4:2 FTS	150		80	9.6	ng/L	20		B/L/T PFAS	Total/NA
6:2 FTS	13000		200	100	ng/L	20		B/L/T PFAS	Total/NA
8:2 FTS	45	J	80	18	ng/L	20		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA) - DL	23000		400	98	ng/L	100		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA) - DL	27000		400	120	ng/L	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	4900		400	110	ng/L	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	26000		400	110	ng/L	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	21000		400	110	ng/L	100		B/L/T PFAS	Total/NA

Client Sample ID: Hol-South H2O — Lab Sample ID: 320-113899-3

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	4200		200	96	ng/L	20		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

NMED Exhibits 65

Client Sample ID: Hol-South H2O (Continued)

Lab Sample ID: 320-113899-3

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanoic acid (PFHpA)	2400		80	10	ng/L	20		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	710		80	34	ng/L	20		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	110		80	34	ng/L	20		B/L/T PFAS	Total/NA
Total PFOA	830		80	34	ng/L	20		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	44	J I	80	11	ng/L	20		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	2800		80	8.0	ng/L	20		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	1500		80	12	ng/L	20		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	2000		80	23	ng/L	20		B/L/T PFAS	Total/NA
Total PFHxS	8400		80	23	ng/L	20		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	6400		80	23	ng/L	20		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	69	J	80	7.6	ng/L	20		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	620		80	22	ng/L	20		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	610		80	22	ng/L	20		B/L/T PFAS	Total/NA
Total PFOS	1200		80	22	ng/L	20		B/L/T PFAS	Total/NA
4:2 FTS	120		80	9.6	ng/L	20		B/L/T PFAS	Total/NA
6:2 FTS	5900		200	100	ng/L	20		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA) - DL	18000		400	98	ng/L	100		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA) - DL	19000		400	120	ng/L	100		B/L/T PFAS	Total/NA

Client Sample ID: Hol-West H2O

Lab Sample ID: 320-113899-4

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	4400		200	96	ng/L	20		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	2400		80	10	ng/L	20		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	850		80	34	ng/L	20		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	140		80	34	ng/L	20		B/L/T PFAS	Total/NA
Total PFOA	990		80	34	ng/L	20		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	57	J	80	11	ng/L	20		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	3000		80	8.0	ng/L	20		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	1700		80	12	ng/L	20		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	2100		80	23	ng/L	20		B/L/T PFAS	Total/NA
Total PFHxS	8600		80	23	ng/L	20		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	6600		80	23	ng/L	20		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	91		80	7.6	ng/L	20		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	1200		80	22	ng/L	20		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	1100		80	22	ng/L	20		B/L/T PFAS	Total/NA
Total PFOS	2200		80	22	ng/L	20		B/L/T PFAS	Total/NA
4:2 FTS	130		80	9.6	ng/L	20		B/L/T PFAS	Total/NA
6:2 FTS	6000		200	100	ng/L	20		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA) - DL	17000		400	98	ng/L	100		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA) - DL	21000		400	120	ng/L	100		B/L/T PFAS	Total/NA

Client Sample ID: Hol NE4-0=1 Soils

Lab Sample ID: 320-113899-5

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	2.3		0.20	0.046	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	8.8		0.20	0.041	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	14		0.20	0.031	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	3.0		0.20	0.038	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

NMED Exhibits 65

Client Sample ID: Hol NE4-0=1 Soils (Continued) — Lab Sample ID: 320-113899-5

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	7.0		0.20	0.053	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.63		0.20	0.053	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	7.6		0.20	0.053	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	4.8		0.20	0.022	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.1		0.20	0.048	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.086	J	0.20	0.042	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	1.7		0.20	0.038	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	2.0		0.20	0.037	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	5.0		0.20	0.049	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	2.1		0.20	0.035	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	3.8	J	10	1.5	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFHxS - DL	29		10	1.5	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	25		10	1.5	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	350		10	2.2	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	160		10	2.2	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS - DL	500		10	2.2	ug/Kg	50		B/L/T PFAS	Total/NA
6:2 FTS - DL	46		10	1.4	ug/Kg	50		B/L/T PFAS	Total/NA

Client Sample ID: Hol NE4-300=2 Soils — Lab Sample ID: 320-113899-6

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	1.1		0.19	0.044	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	0.84		0.19	0.039	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	2.6		0.19	0.030	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	3.4		0.19	0.037	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	1.0		0.19	0.051	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.18	J	0.19	0.051	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.2		0.19	0.051	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.14	J	0.19	0.021	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.38		0.19	0.037	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.36		0.19	0.036	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	2.1		0.19	0.028	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	8.0		0.19	0.028	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	5.9		0.19	0.028	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.086	J	0.19	0.047	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	1.7		0.19	0.041	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	1.2		0.19	0.041	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	2.9		0.19	0.041	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.17	J	0.19	0.026	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Hol NE4-600=3 Soils — Lab Sample ID: 320-113899-7

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	1.2		0.20	0.045	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	0.20		0.20	0.040	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.41		0.20	0.030	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.36		0.20	0.037	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	0.20		0.20	0.052	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.20		0.20	0.052	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: Hol NE4-600=3 Soils (Continued) — Lab Sample ID: 320-113899-7

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	0.058	J	0.20	0.022	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.079	J	0.20	0.037	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.16	J	0.20	0.028	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.90		0.20	0.028	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.74		0.20	0.028	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	0.44		0.20	0.042	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.30		0.20	0.042	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	0.74		0.20	0.042	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.14	J	0.20	0.027	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Hol NE4-900=4 Soils — Lab Sample ID: 320-113899-8

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	1.1		0.19	0.044	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	0.71		0.19	0.039	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	2.6		0.19	0.029	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	5.0		0.19	0.036	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.80		0.19	0.045	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.22		0.19	0.040	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	1.1		0.19	0.036	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	1.3		0.19	0.035	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.59		0.19	0.026	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.38		0.19	0.033	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	47		9.5	2.5	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid - DL	4.9	J	9.5	2.5	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOA - DL	52		9.5	2.5	ug/Kg	50		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	21		9.5	1.0	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	18		9.5	1.4	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFHxS - DL	140		9.5	1.4	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	120		9.5	1.4	ug/Kg	50		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	13		9.5	2.3	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	470		9.5	2.0	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	240		9.5	2.0	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS - DL	710		9.5	2.0	ug/Kg	50		B/L/T PFAS	Total/NA

Client Sample ID: Hol NE2-0=1 Soils — Lab Sample ID: 320-113899-9

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	8.0		0.19	0.044	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	14		0.19	0.021	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.8		0.19	0.046	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.19		0.19	0.040	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	9.7		0.19	0.036	ug/Kg	1		B/L/T PFAS	Total/NA
4:2 FTS	0.23		0.19	0.049	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	3.5		0.19	0.033	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.055	J	0.19	0.036	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA) - DL	39		19	3.9	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA) - DL	91		19	3.0	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA) - DL	27		19	3.6	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	27		19	5.1	ug/Kg	100		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: Hol NE2-0=1 Soils (Continued) — Lab Sample ID: 320-113899-9

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Br-Perfluorooctanoic acid - DL	5.1	J	19	5.1	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOA - DL	32		19	5.1	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS) - DL	14	J	19	3.5	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	23		19	2.8	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	110		19	2.8	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	90		19	2.8	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	11	J	19	4.7	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	670		19	4.1	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	350		19	4.1	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	1000		19	4.1	ug/Kg	100		B/L/T PFAS	Total/NA
6:2 FTS - DL	120		19	2.6	ug/Kg	100		B/L/T PFAS	Total/NA

Client Sample ID: Hol NE2-300=2 Soils — Lab Sample ID: 320-113899-10

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.66		0.20	0.045	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	0.18	J	0.20	0.040	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	1.2		0.20	0.030	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	3.0		0.20	0.037	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	1.0		0.20	0.052	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.30		0.20	0.052	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.3		0.20	0.052	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.079	J	0.20	0.021	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.21		0.20	0.037	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.21		0.20	0.036	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	1.7		0.20	0.028	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	8.0		0.20	0.028	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	6.4		0.20	0.028	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	0.85		0.20	0.042	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.51		0.20	0.042	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	1.4		0.20	0.042	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.073	J	0.20	0.026	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Hol NE2-600=3 Soils — Lab Sample ID: 320-113899-11

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.11	J	0.19	0.043	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.16	J	0.19	0.029	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.52		0.19	0.036	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	1.7		0.19	0.050	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.20		0.19	0.050	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.9		0.19	0.050	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.30		0.19	0.021	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.048	J	0.19	0.036	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.37		0.19	0.027	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	3.5		0.19	0.027	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	3.1		0.19	0.027	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.098	J	0.19	0.046	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	3.3		0.19	0.040	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: Hol NE2-600=3 Soils (Continued)

Lab Sample ID: 320-113899-11

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Br-Perfluorooctanesulfonic acid	1.5		0.19	0.040	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	4.9		0.19	0.040	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.085	J	0.19	0.025	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Hol NE2-900=4 Soils

Lab Sample ID: 320-113899-12

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.15	J	0.19	0.045	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	0.15	J	0.19	0.040	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.97		0.19	0.030	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.79	F1	0.19	0.037	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	0.29		0.19	0.052	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.11	J	0.19	0.052	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.40		0.19	0.052	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.089	J I	0.19	0.021	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.28		0.19	0.037	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.37	F1	0.19	0.036	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.86		0.19	0.028	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	2.8	F1	0.19	0.028	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	1.9	F1	0.19	0.028	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	1.1	F1	0.19	0.042	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.60		0.19	0.042	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	1.7	F1	0.19	0.042	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.070	J	0.19	0.026	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Client Sample ID: Hol-North H2O

Date Collected: 07/15/24 08:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-1

Matrix: Water

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**25**		4.2	2.0	ng/L		07/19/24 12:30	08/09/24 15:58	1
Perfluoropentanoic acid (PFPeA)	**160**		1.7	0.41	ng/L		07/19/24 12:30	08/09/24 15:58	1
Perfluorohexanoic acid (PFHxA)	**110**		1.7	0.49	ng/L		07/19/24 12:30	08/09/24 15:58	1
Perfluoroheptanoic acid (PFHpA)	**21**		1.7	0.21	ng/L		07/19/24 12:30	08/09/24 15:58	1
L-Perfluorooctanoic acid	**23**		1.7	0.72	ng/L		07/19/24 12:30	08/09/24 15:58	1
Br-Perfluorooctanoic acid	**4.0**		1.7	0.72	ng/L		07/19/24 12:30	08/09/24 15:58	1
Total PFOA	**27**		1.7	0.72	ng/L		07/19/24 12:30	08/09/24 15:58	1
Perfluorononanoic acid (PFNA)	**1.3**	**J**	1.7	0.23	ng/L		07/19/24 12:30	08/09/24 15:58	1
Perfluorodecanoic acid (PFDA)	**0.66**	**J**	1.7	0.26	ng/L		07/19/24 12:30	08/09/24 15:58	1
Perfluoroundecanoic acid (PFUnA)	ND		1.7	0.93	ng/L		07/19/24 12:30	08/09/24 15:58	1
Perfluorobutanesulfonic acid (PFBS)	**20**		1.7	0.17	ng/L		07/19/24 12:30	08/09/24 15:58	1
Perfluoropentanesulfonic acid (PFPeS)	**15**		1.7	0.25	ng/L		07/19/24 12:30	08/09/24 15:58	1
Br-Perfluorohexanesulfonic acid	**18**		1.7	0.48	ng/L		07/19/24 12:30	08/09/24 15:58	1
Total PFHxS	**100**		1.7	0.48	ng/L		07/19/24 12:30	08/09/24 15:58	1
L-Perfluorohexanesulfonic acid	**82**		1.7	0.48	ng/L		07/19/24 12:30	08/09/24 15:58	1
Perfluoroheptanesulfonic acid (PFHpS)	**3.6**		1.7	0.16	ng/L		07/19/24 12:30	08/09/24 15:58	1
L-Perfluorooctanesulfonic acid	**87**		1.7	0.45	ng/L		07/19/24 12:30	08/09/24 15:58	1
Br-Perfluorooctanesulfonic acid	**60**		1.7	0.45	ng/L		07/19/24 12:30	08/09/24 15:58	1
Total PFOS	**150**		1.7	0.45	ng/L		07/19/24 12:30	08/09/24 15:58	1
4:2 FTS	ND		1.7	0.20	ng/L		07/19/24 12:30	08/09/24 15:58	1
6:2 FTS	**230**		4.2	2.1	ng/L		07/19/24 12:30	08/09/24 15:58	1
8:2 FTS	ND		1.7	0.39	ng/L		07/19/24 12:30	08/09/24 15:58	1
10:2 FTS	ND		1.7	0.56	ng/L		07/19/24 12:30	08/09/24 15:58	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*76*		*25 - 150*	*07/19/24 12:30*	*08/09/24 15:58*	*1*
13C5 PFPeA	*99*		*25 - 150*	*07/19/24 12:30*	*08/09/24 15:58*	*1*
13C2 PFHxA	*99*		*25 - 150*	*07/19/24 12:30*	*08/09/24 15:58*	*1*
13C4 PFHpA	*104*		*25 - 150*	*07/19/24 12:30*	*08/09/24 15:58*	*1*
13C4 PFOA	*99*		*25 - 150*	*07/19/24 12:30*	*08/09/24 15:58*	*1*
13C5 PFNA	*98*		*25 - 150*	*07/19/24 12:30*	*08/09/24 15:58*	*1*
13C2 PFDA	*92*		*25 - 150*	*07/19/24 12:30*	*08/09/24 15:58*	*1*
13C2 PFUnA	*82*		*25 - 150*	*07/19/24 12:30*	*08/09/24 15:58*	*1*
13C3 PFBS	*90*		*25 - 150*	*07/19/24 12:30*	*08/09/24 15:58*	*1*
18O2 PFHxS	*95*		*25 - 150*	*07/19/24 12:30*	*08/09/24 15:58*	*1*
13C4 PFOS	*92*		*25 - 150*	*07/19/24 12:30*	*08/09/24 15:58*	*1*
M2-4:2 FTS	*106*		*25 - 150*	*07/19/24 12:30*	*08/09/24 15:58*	*1*
M2-6:2 FTS	*103*		*25 - 150*	*07/19/24 12:30*	*08/09/24 15:58*	*1*
M2-8:2 FTS	*87*		*25 - 150*	*07/19/24 12:30*	*08/09/24 15:58*	*1*
13C2 10:2 FTS	*73*		*25 - 150*	*07/19/24 12:30*	*08/09/24 15:58*	*1*

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Client Sample ID: Hol-East H2O

Date Collected: 07/15/24 08:30
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-2

Matrix: Water

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	5500		200	96	ng/L		07/19/24 12:30	07/25/24 16:13	20
Perfluoroheptanoic acid (PFHpA)	4000		80	10	ng/L		07/19/24 12:30	07/25/24 16:13	20
L-Perfluorooctanoic acid	3200		80	34	ng/L		07/19/24 12:30	07/25/24 16:13	20
Br-Perfluorooctanoic acid	510		80	34	ng/L		07/19/24 12:30	07/25/24 16:13	20
Total PFOA	3700		80	34	ng/L		07/19/24 12:30	07/25/24 16:13	20
Perfluorononanoic acid (PFNA)	390		80	11	ng/L		07/19/24 12:30	07/25/24 16:13	20
Perfluorodecanoic acid (PFDA)	13	J	80	12	ng/L		07/19/24 12:30	07/25/24 16:13	20
Perfluoroundecanoic acid (PFUnA)	ND		80	44	ng/L		07/19/24 12:30	07/25/24 16:13	20
Perfluorobutanesulfonic acid (PFBS)	4100		80	8.0	ng/L		07/19/24 12:30	07/25/24 16:13	20
Perfluoropentanesulfonic acid (PFPeS)	2800		80	12	ng/L		07/19/24 12:30	07/25/24 16:13	20
Perfluoroheptanesulfonic acid (PFHpS)	620		80	7.6	ng/L		07/19/24 12:30	07/25/24 16:13	20
L-Perfluorooctanesulfonic acid	6800		80	22	ng/L		07/19/24 12:30	07/25/24 16:13	20
Br-Perfluorooctanesulfonic acid	8300		80	22	ng/L		07/19/24 12:30	07/25/24 16:13	20
Total PFOS	15000		80	22	ng/L		07/19/24 12:30	07/25/24 16:13	20
4:2 FTS	150		80	9.6	ng/L		07/19/24 12:30	07/25/24 16:13	20
6:2 FTS	13000		200	100	ng/L		07/19/24 12:30	07/25/24 16:13	20
8:2 FTS	45	J	80	18	ng/L		07/19/24 12:30	07/25/24 16:13	20
10:2 FTS	ND		80	27	ng/L		07/19/24 12:30	07/25/24 16:13	20

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*77*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:13*	*20*
13C4 PFHpA	*77*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:13*	*20*
13C4 PFOA	*96*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:13*	*20*
13C5 PFNA	*122*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:13*	*20*
13C2 PFDA	*129*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:13*	*20*
13C2 PFUnA	*95*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:13*	*20*
13C3 PFBS	*89*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:13*	*20*
13C4 PFOS	*103*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:13*	*20*
M2-4:2 FTS	*80*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:13*	*20*
M2-6:2 FTS	*168*	*5+	*25 - 150*	*07/19/24 12:30*	*07/25/24 16:13*	*20*
M2-8:2 FTS	*110*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:13*	*20*
13C2 10:2 FTS	*63*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:13*	*20*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoropentanoic acid (PFPeA)	23000		400	98	ng/L		07/19/24 12:30	07/24/24 17:53	100
Perfluorohexanoic acid (PFHxA)	27000		400	120	ng/L		07/19/24 12:30	07/24/24 17:53	100
Br-Perfluorohexanesulfonic acid	4900		400	110	ng/L		07/19/24 12:30	07/24/24 17:53	100
Total PFHxS	26000		400	110	ng/L		07/19/24 12:30	07/24/24 17:53	100
L-Perfluorohexanesulfonic acid	21000		400	110	ng/L		07/19/24 12:30	07/24/24 17:53	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFPeA	*70*		*25 - 150*	*07/19/24 12:30*	*07/24/24 17:53*	*100*
13C2 PFHxA	*94*		*25 - 150*	*07/19/24 12:30*	*07/24/24 17:53*	*100*
18O2 PFHxS	*88*		*25 - 150*	*07/19/24 12:30*	*07/24/24 17:53*	*100*

NMED Exhibits 65

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Client Sample ID: Hol-South H2O

Date Collected: 07/15/24 09:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-3

Matrix: Water

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**4200**		200	96	ng/L		07/19/24 12:30	07/25/24 16:32	20
Perfluoroheptanoic acid (PFHpA)	**2400**		80	10	ng/L		07/19/24 12:30	07/25/24 16:32	20
L-Perfluorooctanoic acid	**710**		80	34	ng/L		07/19/24 12:30	07/25/24 16:32	20
Br-Perfluorooctanoic acid	**110**		80	34	ng/L		07/19/24 12:30	07/25/24 16:32	20
Total PFOA	**830**		80	34	ng/L		07/19/24 12:30	07/25/24 16:32	20
Perfluorononanoic acid (PFNA)	**44**	**J I**	80	11	ng/L		07/19/24 12:30	07/25/24 16:32	20
Perfluorodecanoic acid (PFDA)	ND		80	12	ng/L		07/19/24 12:30	07/25/24 16:32	20
Perfluoroundecanoic acid (PFUnA)	ND		80	44	ng/L		07/19/24 12:30	07/25/24 16:32	20
Perfluorobutanesulfonic acid (PFBS)	**2800**		80	8.0	ng/L		07/19/24 12:30	07/25/24 16:32	20
Perfluoropentanesulfonic acid (PFPeS)	**1500**		80	12	ng/L		07/19/24 12:30	07/25/24 16:32	20
Br-Perfluorohexanesulfonic acid	**2000**		80	23	ng/L		07/19/24 12:30	07/25/24 16:32	20
Total PFHxS	**8400**		80	23	ng/L		07/19/24 12:30	07/25/24 16:32	20
L-Perfluorohexanesulfonic acid	**6400**		80	23	ng/L		07/19/24 12:30	07/25/24 16:32	20
Perfluoroheptanesulfonic acid (PFHpS)	**69**	**J**	80	7.6	ng/L		07/19/24 12:30	07/25/24 16:32	20
L-Perfluorooctanesulfonic acid	**620**		80	22	ng/L		07/19/24 12:30	07/25/24 16:32	20
Br-Perfluorooctanesulfonic acid	**610**		80	22	ng/L		07/19/24 12:30	07/25/24 16:32	20
Total PFOS	**1200**		80	22	ng/L		07/19/24 12:30	07/25/24 16:32	20
4:2 FTS	**120**		80	9.6	ng/L		07/19/24 12:30	07/25/24 16:32	20
6:2 FTS	**5900**		200	100	ng/L		07/19/24 12:30	07/25/24 16:32	20
8:2 FTS	ND		80	18	ng/L		07/19/24 12:30	07/25/24 16:32	20
10:2 FTS	ND		80	27	ng/L		07/19/24 12:30	07/25/24 16:32	20

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*68*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:32*	*20*
13C4 PFHpA	*71*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:32*	*20*
13C4 PFOA	*98*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:32*	*20*
13C5 PFNA	*125*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:32*	*20*
13C2 PFDA	*137*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:32*	*20*
13C2 PFUnA	*84*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:32*	*20*
13C3 PFBS	*100*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:32*	*20*
18O2 PFHxS	*87*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:32*	*20*
13C4 PFOS	*113*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:32*	*20*
M2-4:2 FTS	*71*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:32*	*20*
M2-6:2 FTS	*110*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:32*	*20*
M2-8:2 FTS	*104*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:32*	*20*
13C2 10:2 FTS	*46*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:32*	*20*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoropentanoic acid (PFPeA)	**18000**		400	98	ng/L		07/19/24 12:30	07/24/24 18:13	100
Perfluorohexanoic acid (PFHxA)	**19000**		400	120	ng/L		07/19/24 12:30	07/24/24 18:13	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFPeA	*70*		*25 - 150*	*07/19/24 12:30*	*07/24/24 18:13*	*100*
13C2 PFHxA	*97*		*25 - 150*	*07/19/24 12:30*	*07/24/24 18:13*	*100*

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Client Sample ID: Hol-West H2O

Date Collected: 07/15/24 10:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-4

Matrix: Water

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**4400**		200	96	ng/L		07/19/24 12:30	07/25/24 16:52	20
Perfluoroheptanoic acid (PFHpA)	**2400**		80	10	ng/L		07/19/24 12:30	07/25/24 16:52	20
L-Perfluorooctanoic acid	**850**		80	34	ng/L		07/19/24 12:30	07/25/24 16:52	20
Br-Perfluorooctanoic acid	**140**		80	34	ng/L		07/19/24 12:30	07/25/24 16:52	20
Total PFOA	**990**		80	34	ng/L		07/19/24 12:30	07/25/24 16:52	20
Perfluorononanoic acid (PFNA)	**57**	**J**	80	11	ng/L		07/19/24 12:30	07/25/24 16:52	20
Perfluorodecanoic acid (PFDA)	ND		80	12	ng/L		07/19/24 12:30	07/25/24 16:52	20
Perfluoroundecanoic acid (PFUnA)	ND		80	44	ng/L		07/19/24 12:30	07/25/24 16:52	20
Perfluorobutanesulfonic acid (PFBS)	**3000**		80	8.0	ng/L		07/19/24 12:30	07/25/24 16:52	20
Perfluoropentanesulfonic acid (PFPeS)	**1700**		80	12	ng/L		07/19/24 12:30	07/25/24 16:52	20
Br-Perfluorohexanesulfonic acid	**2100**		80	23	ng/L		07/19/24 12:30	07/25/24 16:52	20
Total PFHxS	**8600**		80	23	ng/L		07/19/24 12:30	07/25/24 16:52	20
L-Perfluorohexanesulfonic acid	**6600**		80	23	ng/L		07/19/24 12:30	07/25/24 16:52	20
Perfluoroheptanesulfonic acid (PFHpS)	**91**		80	7.6	ng/L		07/19/24 12:30	07/25/24 16:52	20
L-Perfluorooctanesulfonic acid	**1200**		80	22	ng/L		07/19/24 12:30	07/25/24 16:52	20
Br-Perfluorooctanesulfonic acid	**1100**		80	22	ng/L		07/19/24 12:30	07/25/24 16:52	20
Total PFOS	**2200**		80	22	ng/L		07/19/24 12:30	07/25/24 16:52	20
4:2 FTS	**130**		80	9.6	ng/L		07/19/24 12:30	07/25/24 16:52	20
6:2 FTS	**6000**		200	100	ng/L		07/19/24 12:30	07/25/24 16:52	20
8:2 FTS	ND		80	18	ng/L		07/19/24 12:30	07/25/24 16:52	20
10:2 FTS	ND		80	27	ng/L		07/19/24 12:30	07/25/24 16:52	20

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*56*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:52*	*20*
13C4 PFHpA	*66*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:52*	*20*
13C4 PFOA	*94*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:52*	*20*
13C5 PFNA	*119*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:52*	*20*
13C2 PFDA	*130*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:52*	*20*
13C2 PFUnA	*81*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:52*	*20*
13C3 PFBS	*94*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:52*	*20*
18O2 PFHxS	*89*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:52*	*20*
13C4 PFOS	*112*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:52*	*20*
M2-4:2 FTS	*81*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:52*	*20*
M2-6:2 FTS	*109*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:52*	*20*
M2-8:2 FTS	*100*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:52*	*20*
13C2 10:2 FTS	*43*		*25 - 150*	*07/19/24 12:30*	*07/25/24 16:52*	*20*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoropentanoic acid (PFPeA)	**17000**		400	98	ng/L		07/19/24 12:30	07/24/24 18:32	100
Perfluorohexanoic acid (PFHxA)	**21000**		400	120	ng/L		07/19/24 12:30	07/24/24 18:32	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFPeA	*69*		*25 - 150*	*07/19/24 12:30*	*07/24/24 18:32*	*100*
13C2 PFHxA	*88*		*25 - 150*	*07/19/24 12:30*	*07/24/24 18:32*	*100*

NMED Exhibits 65

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Client Sample ID: Hol NE4-0=1 Soils

Date Collected: 07/16/24 09:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-5

Matrix: Solid

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	2.3		0.20	0.046	ug/Kg		07/30/24 10:47	08/08/24 23:47	1
Perfluoropentanoic acid (PFPeA)	8.8		0.20	0.041	ug/Kg		07/30/24 10:47	08/08/24 23:47	1
Perfluorohexanoic acid (PFHxA)	14		0.20	0.031	ug/Kg		07/30/24 10:47	08/08/24 23:47	1
Perfluoroheptanoic acid (PFHpA)	3.0		0.20	0.038	ug/Kg		07/30/24 10:47	08/08/24 23:47	1
L-Perfluorooctanoic acid	7.0		0.20	0.053	ug/Kg		07/30/24 10:47	08/08/24 23:47	1
Br-Perfluorooctanoic acid	0.63		0.20	0.053	ug/Kg		07/30/24 10:47	08/08/24 23:47	1
Total PFOA	7.6		0.20	0.053	ug/Kg		07/30/24 10:47	08/08/24 23:47	1
Perfluorononanoic acid (PFNA)	4.8		0.20	0.022	ug/Kg		07/30/24 10:47	08/08/24 23:47	1
Perfluorodecanoic acid (PFDA)	1.1		0.20	0.048	ug/Kg		07/30/24 10:47	08/08/24 23:47	1
Perfluoroundecanoic acid (PFUnA)	0.086	J	0.20	0.042	ug/Kg		07/30/24 10:47	08/08/24 23:47	1
Perfluorobutanesulfonic acid (PFBS)	1.7		0.20	0.038	ug/Kg		07/30/24 10:47	08/08/24 23:47	1
Perfluoropentanesulfonic acid (PFPeS)	2.0		0.20	0.037	ug/Kg		07/30/24 10:47	08/08/24 23:47	1
Perfluoroheptanesulfonic acid (PFHpS)	5.0		0.20	0.049	ug/Kg		07/30/24 10:47	08/08/24 23:47	1
4:2 FTS	ND		0.20	0.051	ug/Kg		07/30/24 10:47	08/08/24 23:47	1
8:2 FTS	2.1		0.20	0.035	ug/Kg		07/30/24 10:47	08/08/24 23:47	1
10:2 FTS	ND		0.20	0.038	ug/Kg		07/30/24 10:47	08/08/24 23:47	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*74*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:47*	*1*
13C5 PFPeA	*79*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:47*	*1*
13C2 PFHxA	*91*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:47*	*1*
13C4 PFHpA	*74*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:47*	*1*
13C4 PFOA	*82*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:47*	*1*
13C5 PFNA	*77*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:47*	*1*
13C2 PFDA	*79*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:47*	*1*
13C2 PFUnA	*76*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:47*	*1*
13C3 PFBS	*67*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:47*	*1*
13C4 PFOS	*55*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:47*	*1*
M2-4:2 FTS	*88*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:47*	*1*
M2-8:2 FTS	*66*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:47*	*1*
13C2 10:2 FTS	*77*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:47*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	3.8	J	10	1.5	ug/Kg		07/30/24 10:47	08/12/24 16:46	50
Total PFHxS	29		10	1.5	ug/Kg		07/30/24 10:47	08/12/24 16:46	50
L-Perfluorohexanesulfonic acid	25		10	1.5	ug/Kg		07/30/24 10:47	08/12/24 16:46	50
L-Perfluorooctanesulfonic acid	350		10	2.2	ug/Kg		07/30/24 10:47	08/12/24 16:46	50
Br-Perfluorooctanesulfonic acid	160		10	2.2	ug/Kg		07/30/24 10:47	08/12/24 16:46	50
Total PFOS	500		10	2.2	ug/Kg		07/30/24 10:47	08/12/24 16:46	50
6:2 FTS	46		10	1.4	ug/Kg		07/30/24 10:47	08/12/24 16:46	50

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*83*		*25 - 150*	*07/30/24 10:47*	*08/12/24 16:46*	*50*
13C4 PFOS	*73*		*25 - 150*	*07/30/24 10:47*	*08/12/24 16:46*	*50*
M2-6:2 FTS	*74*		*25 - 150*	*07/30/24 10:47*	*08/12/24 16:46*	*50*

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Client Sample ID: Hol NE4-300=2 Soils

Date Collected: 07/16/24 08:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-6

Matrix: Solid

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**1.1**		0.19	0.044	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
Perfluoropentanoic acid (PFPeA)	**0.84**		0.19	0.039	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
Perfluorohexanoic acid (PFHxA)	**2.6**		0.19	0.030	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
Perfluoroheptanoic acid (PFHpA)	**3.4**		0.19	0.037	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
L-Perfluorooctanoic acid	**1.0**		0.19	0.051	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
Br-Perfluorooctanoic acid	**0.18**	**J**	0.19	0.051	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
Total PFOA	**1.2**		0.19	0.051	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
Perfluorononanoic acid (PFNA)	**0.14**	**J**	0.19	0.021	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
Perfluorodecanoic acid (PFDA)	ND		0.19	0.046	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
Perfluoroundecanoic acid (PFUnA)	ND		0.19	0.040	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
Perfluorobutanesulfonic acid (PFBS)	**0.38**		0.19	0.037	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
Perfluoropentanesulfonic acid (PFPeS)	**0.36**		0.19	0.036	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
Br-Perfluorohexanesulfonic acid	**2.1**		0.19	0.028	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
Total PFHxS	**8.0**		0.19	0.028	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
L-Perfluorohexanesulfonic acid	**5.9**		0.19	0.028	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.086**	**J**	0.19	0.047	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
L-Perfluorooctanesulfonic acid	**1.7**		0.19	0.041	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
Br-Perfluorooctanesulfonic acid	**1.2**		0.19	0.041	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
Total PFOS	**2.9**		0.19	0.041	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
4:2 FTS	ND		0.19	0.049	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
6:2 FTS	**0.17**	**J**	0.19	0.026	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
8:2 FTS	ND		0.19	0.034	ug/Kg		07/30/24 10:47	08/09/24 00:07	1
10:2 FTS	ND		0.19	0.037	ug/Kg		07/30/24 10:47	08/09/24 00:07	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*85*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:07*	*1*
13C5 PFPeA	*83*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:07*	*1*
13C2 PFHxA	*81*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:07*	*1*
13C4 PFHpA	*85*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:07*	*1*
13C4 PFOA	*82*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:07*	*1*
13C5 PFNA	*80*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:07*	*1*
13C2 PFDA	*77*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:07*	*1*
13C2 PFUnA	*77*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:07*	*1*
13C3 PFBS	*80*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:07*	*1*
18O2 PFHxS	*84*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:07*	*1*
13C4 PFOS	*78*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:07*	*1*
M2-4:2 FTS	*91*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:07*	*1*
M2-6:2 FTS	*86*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:07*	*1*
M2-8:2 FTS	*76*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:07*	*1*
13C2 10:2 FTS	*75*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:07*	*1*

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Client Sample ID: Hol NE4-600=3 Soils

Date Collected: 07/16/24 08:15
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-7

Matrix: Solid

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**1.2**		0.20	0.045	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
Perfluoropentanoic acid (PFPeA)	**0.20**		0.20	0.040	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
Perfluorohexanoic acid (PFHxA)	**0.41**		0.20	0.030	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
Perfluoroheptanoic acid (PFHpA)	**0.36**		0.20	0.037	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
L-Perfluorooctanoic acid	**0.20**		0.20	0.052	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
Br-Perfluorooctanoic acid	ND		0.20	0.052	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
Total PFOA	**0.20**		0.20	0.052	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
Perfluorononanoic acid (PFNA)	**0.058**	**J**	0.20	0.022	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
Perfluorodecanoic acid (PFDA)	ND		0.20	0.047	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
Perfluoroundecanoic acid (PFUnA)	ND		0.20	0.041	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
Perfluorobutanesulfonic acid (PFBS)	**0.079**	**J**	0.20	0.037	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.20	0.036	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
Br-Perfluorohexanesulfonic acid	**0.16**	**J**	0.20	0.028	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
Total PFHxS	**0.90**		0.20	0.028	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
L-Perfluorohexanesulfonic acid	**0.74**		0.20	0.028	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.20	0.048	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
L-Perfluorooctanesulfonic acid	**0.44**		0.20	0.042	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
Br-Perfluorooctanesulfonic acid	**0.30**		0.20	0.042	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
Total PFOS	**0.74**		0.20	0.042	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
4:2 FTS	ND		0.20	0.050	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
6:2 FTS	**0.14**	**J**	0.20	0.027	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
8:2 FTS	ND		0.20	0.034	ug/Kg		07/30/24 10:47	08/09/24 00:26	1
10:2 FTS	ND		0.20	0.037	ug/Kg		07/30/24 10:47	08/09/24 00:26	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*78*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:26*	*1*
13C5 PFPeA	*79*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:26*	*1*
13C2 PFHxA	*88*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:26*	*1*
13C4 PFHpA	*80*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:26*	*1*
13C4 PFOA	*80*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:26*	*1*
13C5 PFNA	*77*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:26*	*1*
13C2 PFDA	*77*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:26*	*1*
13C2 PFUnA	*65*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:26*	*1*
13C3 PFBS	*76*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:26*	*1*
18O2 PFHxS	*82*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:26*	*1*
13C4 PFOS	*75*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:26*	*1*
M2-4:2 FTS	*78*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:26*	*1*
M2-6:2 FTS	*75*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:26*	*1*
M2-8:2 FTS	*68*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:26*	*1*
13C2 10:2 FTS	*60*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:26*	*1*

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Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Client Sample ID: Hol NE4-900=4 Soils

Date Collected: 07/16/24 08:30
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-8

Matrix: Solid

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**1.1**		0.19	0.044	ug/Kg		07/30/24 10:47	08/09/24 00:45	1
Perfluoropentanoic acid (PFPeA)	**0.71**		0.19	0.039	ug/Kg		07/30/24 10:47	08/09/24 00:45	1
Perfluorohexanoic acid (PFHxA)	**2.6**		0.19	0.029	ug/Kg		07/30/24 10:47	08/09/24 00:45	1
Perfluoroheptanoic acid (PFHpA)	**5.0**		0.19	0.036	ug/Kg		07/30/24 10:47	08/09/24 00:45	1
Perfluorodecanoic acid (PFDA)	**0.80**		0.19	0.045	ug/Kg		07/30/24 10:47	08/09/24 00:45	1
Perfluoroundecanoic acid (PFUnA)	**0.22**		0.19	0.040	ug/Kg		07/30/24 10:47	08/09/24 00:45	1
Perfluorobutanesulfonic acid (PFBS)	**1.1**		0.19	0.036	ug/Kg		07/30/24 10:47	08/09/24 00:45	1
Perfluoropentanesulfonic acid (PFPeS)	**1.3**		0.19	0.035	ug/Kg		07/30/24 10:47	08/09/24 00:45	1
4:2 FTS	ND		0.19	0.048	ug/Kg		07/30/24 10:47	08/09/24 00:45	1
6:2 FTS	**0.59**		0.19	0.026	ug/Kg		07/30/24 10:47	08/09/24 00:45	1
8:2 FTS	**0.38**		0.19	0.033	ug/Kg		07/30/24 10:47	08/09/24 00:45	1
10:2 FTS	ND		0.19	0.036	ug/Kg		07/30/24 10:47	08/09/24 00:45	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*83*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:45*	*1*
13C5 PFPeA	*79*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:45*	*1*
13C2 PFHxA	*84*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:45*	*1*
13C4 PFHpA	*76*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:45*	*1*
13C2 PFDA	*74*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:45*	*1*
13C2 PFUnA	*75*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:45*	*1*
13C3 PFBS	*76*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:45*	*1*
M2-4:2 FTS	*105*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:45*	*1*
M2-6:2 FTS	*80*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:45*	*1*
M2-8:2 FTS	*80*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:45*	*1*
13C2 10:2 FTS	*70*		*25 - 150*	*07/30/24 10:47*	*08/09/24 00:45*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanoic acid	**47**		9.5	2.5	ug/Kg		07/30/24 10:47	08/12/24 17:05	50
Br-Perfluorooctanoic acid	**4.9**	**J**	9.5	2.5	ug/Kg		07/30/24 10:47	08/12/24 17:05	50
Total PFOA	**52**		9.5	2.5	ug/Kg		07/30/24 10:47	08/12/24 17:05	50
Perfluorononanoic acid (PFNA)	**21**		9.5	1.0	ug/Kg		07/30/24 10:47	08/12/24 17:05	50
Br-Perfluorohexanesulfonic acid	**18**		9.5	1.4	ug/Kg		07/30/24 10:47	08/12/24 17:05	50
Total PFHxS	**140**		9.5	1.4	ug/Kg		07/30/24 10:47	08/12/24 17:05	50
L-Perfluorohexanesulfonic acid	**120**		9.5	1.4	ug/Kg		07/30/24 10:47	08/12/24 17:05	50
Perfluoroheptanesulfonic acid (PFHpS)	**13**		9.5	2.3	ug/Kg		07/30/24 10:47	08/12/24 17:05	50
L-Perfluorooctanesulfonic acid	**470**		9.5	2.0	ug/Kg		07/30/24 10:47	08/12/24 17:05	50
Br-Perfluorooctanesulfonic acid	**240**		9.5	2.0	ug/Kg		07/30/24 10:47	08/12/24 17:05	50
Total PFOS	**710**		9.5	2.0	ug/Kg		07/30/24 10:47	08/12/24 17:05	50

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOA	*70*		*25 - 150*	*07/30/24 10:47*	*08/12/24 17:05*	*50*
13C5 PFNA	*73*		*25 - 150*	*07/30/24 10:47*	*08/12/24 17:05*	*50*
18O2 PFHxS	*73*		*25 - 150*	*07/30/24 10:47*	*08/12/24 17:05*	*50*
13C4 PFOS	*69*		*25 - 150*	*07/30/24 10:47*	*08/12/24 17:05*	*50*

Client Sample ID: Hol NE2-0=1 Soils

Date Collected: 07/16/24 09:10
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-9

Matrix: Solid

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	8.0		0.19	0.044	ug/Kg		07/30/24 10:47	08/09/24 01:05	1
Perfluorononanoic acid (PFNA)	14		0.19	0.021	ug/Kg		07/30/24 10:47	08/09/24 01:05	1
Perfluorodecanoic acid (PFDA)	1.8		0.19	0.046	ug/Kg		07/30/24 10:47	08/09/24 01:05	1
Perfluoroundecanoic acid (PFUnA)	0.19		0.19	0.040	ug/Kg		07/30/24 10:47	08/09/24 01:05	1
Perfluorobutanesulfonic acid (PFBS)	9.7		0.19	0.036	ug/Kg		07/30/24 10:47	08/09/24 01:05	1
4:2 FTS	0.23		0.19	0.049	ug/Kg		07/30/24 10:47	08/09/24 01:05	1
8:2 FTS	3.5		0.19	0.033	ug/Kg		07/30/24 10:47	08/09/24 01:05	1
10:2 FTS	0.055	J	0.19	0.036	ug/Kg		07/30/24 10:47	08/09/24 01:05	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*66*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:05*	*1*
13C4 PFHpA	*78*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:05*	*1*
13C5 PFNA	*73*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:05*	*1*
13C2 PFDA	*82*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:05*	*1*
13C2 PFUnA	*81*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:05*	*1*
13C3 PFBS	*78*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:05*	*1*
M2-4:2 FTS	*106*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:05*	*1*
M2-6:2 FTS	*92*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:05*	*1*
M2-8:2 FTS	*83*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:05*	*1*
13C2 10:2 FTS	*123*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:05*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoropentanoic acid (PFPeA)	39		19	3.9	ug/Kg		07/30/24 10:47	08/12/24 17:24	100
Perfluorohexanoic acid (PFHxA)	91		19	3.0	ug/Kg		07/30/24 10:47	08/12/24 17:24	100
Perfluoroheptanoic acid (PFHpA)	27		19	3.6	ug/Kg		07/30/24 10:47	08/12/24 17:24	100
L-Perfluorooctanoic acid	27		19	5.1	ug/Kg		07/30/24 10:47	08/12/24 17:24	100
Br-Perfluorooctanoic acid	5.1	J	19	5.1	ug/Kg		07/30/24 10:47	08/12/24 17:24	100
Total PFOA	32		19	5.1	ug/Kg		07/30/24 10:47	08/12/24 17:24	100
Perfluoropentanesulfonic acid (PFPeS)	14	J	19	3.5	ug/Kg		07/30/24 10:47	08/12/24 17:24	100
Br-Perfluorohexanesulfonic acid	23		19	2.8	ug/Kg		07/30/24 10:47	08/12/24 17:24	100
Total PFHxS	110		19	2.8	ug/Kg		07/30/24 10:47	08/12/24 17:24	100
L-Perfluorohexanesulfonic acid	90		19	2.8	ug/Kg		07/30/24 10:47	08/12/24 17:24	100
Perfluoroheptanesulfonic acid (PFHpS)	11	J	19	4.7	ug/Kg		07/30/24 10:47	08/12/24 17:24	100
L-Perfluorooctanesulfonic acid	670		19	4.1	ug/Kg		07/30/24 10:47	08/12/24 17:24	100
Br-Perfluorooctanesulfonic acid	350		19	4.1	ug/Kg		07/30/24 10:47	08/12/24 17:24	100
Total PFOS	1000		19	4.1	ug/Kg		07/30/24 10:47	08/12/24 17:24	100
6:2 FTS	120		19	2.6	ug/Kg		07/30/24 10:47	08/12/24 17:24	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFPeA	*74*		*25 - 150*	*07/30/24 10:47*	*08/12/24 17:24*	*100*
13C2 PFHxA	*92*		*25 - 150*	*07/30/24 10:47*	*08/12/24 17:24*	*100*
13C4 PFHpA	*75*		*25 - 150*	*07/30/24 10:47*	*08/12/24 17:24*	*100*
13C4 PFOA	*65*		*25 - 150*	*07/30/24 10:47*	*08/12/24 17:24*	*100*
13C5 PFNA	*71*		*25 - 150*	*07/30/24 10:47*	*08/12/24 17:24*	*100*
13C3 PFBS	*76*		*25 - 150*	*07/30/24 10:47*	*08/12/24 17:24*	*100*
18O2 PFHxS	*82*		*25 - 150*	*07/30/24 10:47*	*08/12/24 17:24*	*100*
13C4 PFOS	*71*		*25 - 150*	*07/30/24 10:47*	*08/12/24 17:24*	*100*

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Client Sample ID: Hol NE2-0=1 Soils
Date Collected: 07/16/24 09:10
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-9
Matrix: Solid

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL (Continued)

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
M2-6:2 FTS	97		25 - 150	07/30/24 10:47	08/12/24 17:24	100

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Client Sample ID: Hol NE2-300=2 Soils

Date Collected: 07/16/24 09:20
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-10

Matrix: Solid

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**0.66**		0.20	0.045	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
Perfluoropentanoic acid (PFPeA)	**0.18**	**J**	0.20	0.040	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
Perfluorohexanoic acid (PFHxA)	**1.2**		0.20	0.030	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
Perfluoroheptanoic acid (PFHpA)	**3.0**		0.20	0.037	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
L-Perfluorooctanoic acid	**1.0**		0.20	0.052	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
Br-Perfluorooctanoic acid	**0.30**		0.20	0.052	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
Total PFOA	**1.3**		0.20	0.052	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
Perfluorononanoic acid (PFNA)	**0.079**	**J**	0.20	0.021	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
Perfluorodecanoic acid (PFDA)	ND		0.20	0.047	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
Perfluoroundecanoic acid (PFUnA)	ND		0.20	0.041	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
Perfluorobutanesulfonic acid (PFBS)	**0.21**		0.20	0.037	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
Perfluoropentanesulfonic acid (PFPeS)	**0.21**		0.20	0.036	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
Br-Perfluorohexanesulfonic acid	**1.7**		0.20	0.028	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
Total PFHxS	**8.0**		0.20	0.028	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
L-Perfluorohexanesulfonic acid	**6.4**		0.20	0.028	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.20	0.048	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
L-Perfluorooctanesulfonic acid	**0.85**		0.20	0.042	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
Br-Perfluorooctanesulfonic acid	**0.51**		0.20	0.042	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
Total PFOS	**1.4**		0.20	0.042	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
4:2 FTS	ND		0.20	0.050	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
6:2 FTS	**0.073**	**J**	0.20	0.026	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
8:2 FTS	ND		0.20	0.034	ug/Kg		07/30/24 10:47	08/09/24 01:24	1
10:2 FTS	ND		0.20	0.037	ug/Kg		07/30/24 10:47	08/09/24 01:24	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*91*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:24*	*1*
13C5 PFPeA	*84*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:24*	*1*
13C2 PFHxA	*92*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:24*	*1*
13C4 PFHpA	*85*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:24*	*1*
13C4 PFOA	*83*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:24*	*1*
13C5 PFNA	*79*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:24*	*1*
13C2 PFDA	*79*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:24*	*1*
13C2 PFUnA	*80*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:24*	*1*
13C3 PFBS	*77*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:24*	*1*
18O2 PFHxS	*84*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:24*	*1*
13C4 PFOS	*79*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:24*	*1*
M2-4:2 FTS	*88*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:24*	*1*
M2-6:2 FTS	*82*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:24*	*1*
M2-8:2 FTS	*74*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:24*	*1*
13C2 10:2 FTS	*73*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:24*	*1*

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Client Sample ID: Hol NE2-600=3 Soils

Date Collected: 07/16/24 09:30
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-11

Matrix: Solid

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**0.11**	**J**	0.19	0.043	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
Perfluoropentanoic acid (PFPeA)	ND		0.19	0.038	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
Perfluorohexanoic acid (PFHxA)	**0.16**	**J**	0.19	0.029	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
Perfluoroheptanoic acid (PFHpA)	**0.52**		0.19	0.036	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
L-Perfluorooctanoic acid	**1.7**		0.19	0.050	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
Br-Perfluorooctanoic acid	**0.20**		0.19	0.050	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
Total PFOA	**1.9**		0.19	0.050	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
Perfluorononanoic acid (PFNA)	**0.30**		0.19	0.021	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
Perfluorodecanoic acid (PFDA)	ND		0.19	0.045	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
Perfluoroundecanoic acid (PFUnA)	ND		0.19	0.039	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
Perfluorobutanesulfonic acid (PFBS)	**0.048**	**J**	0.19	0.036	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.19	0.035	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
Br-Perfluorohexanesulfonic acid	**0.37**		0.19	0.027	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
Total PFHxS	**3.5**		0.19	0.027	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
L-Perfluorohexanesulfonic acid	**3.1**		0.19	0.027	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.098**	**J**	0.19	0.046	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
L-Perfluorooctanesulfonic acid	**3.3**		0.19	0.040	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
Br-Perfluorooctanesulfonic acid	**1.5**		0.19	0.040	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
Total PFOS	**4.9**		0.19	0.040	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
4:2 FTS	ND		0.19	0.048	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
6:2 FTS	**0.085**	**J**	0.19	0.025	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
8:2 FTS	ND		0.19	0.033	ug/Kg		07/30/24 10:47	08/09/24 01:44	1
10:2 FTS	ND		0.19	0.036	ug/Kg		07/30/24 10:47	08/09/24 01:44	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*79*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:44*	*1*
13C5 PFPeA	*80*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:44*	*1*
13C2 PFHxA	*89*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:44*	*1*
13C4 PFHpA	*85*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:44*	*1*
13C4 PFOA	*79*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:44*	*1*
13C5 PFNA	*76*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:44*	*1*
13C2 PFDA	*77*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:44*	*1*
13C2 PFUnA	*73*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:44*	*1*
13C3 PFBS	*65*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:44*	*1*
18O2 PFHxS	*72*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:44*	*1*
13C4 PFOS	*71*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:44*	*1*
M2-4:2 FTS	*75*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:44*	*1*
M2-6:2 FTS	*74*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:44*	*1*
M2-8:2 FTS	*68*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:44*	*1*
13C2 10:2 FTS	*72*		*25 - 150*	*07/30/24 10:47*	*08/09/24 01:44*	*1*

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Client Sample ID: Hol NE2-900=4 Soils

Date Collected: 07/16/24 09:45
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-12

Matrix: Solid

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**0.15**	**J**	0.19	0.045	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
Perfluoropentanoic acid (PFPeA)	**0.15**	**J**	0.19	0.040	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
Perfluorohexanoic acid (PFHxA)	**0.97**		0.19	0.030	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
Perfluoroheptanoic acid (PFHpA)	**0.79**	**F1**	0.19	0.037	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
L-Perfluorooctanoic acid	**0.29**		0.19	0.052	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
Br-Perfluorooctanoic acid	**0.11**	**J**	0.19	0.052	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
Total PFOA	**0.40**		0.19	0.052	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
Perfluorononanoic acid (PFNA)	**0.089**	**J I**	0.19	0.021	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
Perfluorodecanoic acid (PFDA)	ND		0.19	0.047	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
Perfluoroundecanoic acid (PFUnA)	ND		0.19	0.041	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
Perfluorobutanesulfonic acid (PFBS)	**0.28**		0.19	0.037	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
Perfluoropentanesulfonic acid (PFPeS)	**0.37**	**F1**	0.19	0.036	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
Br-Perfluorohexanesulfonic acid	**0.86**		0.19	0.028	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
Total PFHxS	**2.8**	**F1**	0.19	0.028	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
L-Perfluorohexanesulfonic acid	**1.9**	**F1**	0.19	0.028	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.19	0.048	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
L-Perfluorooctanesulfonic acid	**1.1**	**F1**	0.19	0.042	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
Br-Perfluorooctanesulfonic acid	**0.60**		0.19	0.042	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
Total PFOS	**1.7**	**F1**	0.19	0.042	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
4:2 FTS	ND		0.19	0.050	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
6:2 FTS	**0.070**	**J**	0.19	0.026	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
8:2 FTS	ND		0.19	0.034	ug/Kg		07/30/24 10:47	08/09/24 02:22	1
10:2 FTS	ND		0.19	0.037	ug/Kg		07/30/24 10:47	08/09/24 02:22	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*96*		*25 - 150*	*07/30/24 10:47*	*08/09/24 02:22*	*1*
13C5 PFPeA	*90*		*25 - 150*	*07/30/24 10:47*	*08/09/24 02:22*	*1*
13C2 PFHxA	*91*		*25 - 150*	*07/30/24 10:47*	*08/09/24 02:22*	*1*
13C4 PFHpA	*88*		*25 - 150*	*07/30/24 10:47*	*08/09/24 02:22*	*1*
13C4 PFOA	*85*		*25 - 150*	*07/30/24 10:47*	*08/09/24 02:22*	*1*
13C5 PFNA	*83*		*25 - 150*	*07/30/24 10:47*	*08/09/24 02:22*	*1*
13C2 PFDA	*83*		*25 - 150*	*07/30/24 10:47*	*08/09/24 02:22*	*1*
13C2 PFUnA	*82*		*25 - 150*	*07/30/24 10:47*	*08/09/24 02:22*	*1*
13C3 PFBS	*84*		*25 - 150*	*07/30/24 10:47*	*08/09/24 02:22*	*1*
18O2 PFHxS	*80*		*25 - 150*	*07/30/24 10:47*	*08/09/24 02:22*	*1*
13C4 PFOS	*80*		*25 - 150*	*07/30/24 10:47*	*08/09/24 02:22*	*1*
M2-4:2 FTS	*99*		*25 - 150*	*07/30/24 10:47*	*08/09/24 02:22*	*1*
M2-6:2 FTS	*78*		*25 - 150*	*07/30/24 10:47*	*08/09/24 02:22*	*1*
M2-8:2 FTS	*78*		*25 - 150*	*07/30/24 10:47*	*08/09/24 02:22*	*1*
13C2 10:2 FTS	*76*		*25 - 150*	*07/30/24 10:47*	*08/09/24 02:22*	*1*

Isotope Dilution Summary

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Solid

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-113899-5	Hol NE4-0=1 Soils	74	79	91	74	82	77	79	76
320-113899-5 - DL	Hol NE4-0=1 Soils								
320-113899-6	Hol NE4-300=2 Soils	85	83	81	85	82	80	77	77
320-113899-7	Hol NE4-600=3 Soils	78	79	88	80	80	77	77	65
320-113899-8	Hol NE4-900=4 Soils	83	79	84	76			74	75
320-113899-8 - DL	Hol NE4-900=4 Soils					70	73		
320-113899-9	Hol NE2-0=1 Soils	66			78		73	82	81
320-113899-9 - DL	Hol NE2-0=1 Soils		74	92	75	65	71		
320-113899-10	Hol NE2-300=2 Soils	91	84	92	85	83	79	79	80
320-113899-11	Hol NE2-600=3 Soils	79	80	89	85	79	76	77	73
320-113899-12	Hol NE2-900=4 Soils	96	90	91	88	85	83	83	82
320-113899-12 MS	Hol NE2-900=4 Soils	90	97	101	81	85	85	87	82
320-113899-12 MSD	Hol NE2-900=4 Soils	73	87	86	85	83	75	77	73
LCS 320-785917/2-A	Lab Control Sample	99	90	99	89	89	90	85	81
MB 320-785917/1-A	Method Blank	102	98	105	91	96	102	97	96

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
320-113899-5	Hol NE4-0=1 Soils	67		55	88		66	77
320-113899-5 - DL	Hol NE4-0=1 Soils		83	73		74		
320-113899-6	Hol NE4-300=2 Soils	80	84	78	91	86	76	75
320-113899-7	Hol NE4-600=3 Soils	76	82	75	78	75	68	60
320-113899-8	Hol NE4-900=4 Soils	76			105	80	80	70
320-113899-8 - DL	Hol NE4-900=4 Soils		73	69				
320-113899-9	Hol NE2-0=1 Soils	78			106	92	83	123
320-113899-9 - DL	Hol NE2-0=1 Soils	76	82	71		97		
320-113899-10	Hol NE2-300=2 Soils	77	84	79	88	82	74	73
320-113899-11	Hol NE2-600=3 Soils	65	72	71	75	74	68	72
320-113899-12	Hol NE2-900=4 Soils	84	80	80	99	78	78	76
320-113899-12 MS	Hol NE2-900=4 Soils	70	79	81	94	74	76	84
320-113899-12 MSD	Hol NE2-900=4 Soils	70	71	72	70	74	71	89
LCS 320-785917/2-A	Lab Control Sample	73	80	77	90	91	79	69
MB 320-785917/1-A	Method Blank	86	90	90	104	101	91	88

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
PFHxA = 13C2 PFHxA
C4PFHA = 13C4 PFHpA
PFOA = 13C4 PFOA
PFNA = 13C5 PFNA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS
PFHxS = 18O2 PFHxS
PFOS = 13C4 PFOS
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
M102FTS = 13C2 10:2 FTS

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Isotope Dilution Summary

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Water

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-113899-1	Hol-North H2O	76	99	99	104	99	98	92	82
320-113899-2 - DL	Hol-East H2O		70	94					
320-113899-2	Hol-East H2O	77			77	96	122	129	95
320-113899-3 - DL	Hol-South H2O		70	97					
320-113899-3	Hol-South H2O	68			71	98	125	137	84
320-113899-4 - DL	Hol-West H2O		69	88					
320-113899-4	Hol-West H2O	56			66	94	119	130	81
LCS 320-781606/2-A	Lab Control Sample	95	79	90	90	99	110	102	106
LCSD 320-781606/3-A	Lab Control Sample Dup	100	84	95	96	98	107	103	109
MB 320-781606/1-A	Method Blank	101	88	98	87	99	106	115	120

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)	
320-113899-1	Hol-North H2O	90	95	92	106	103	87	73	
320-113899-2 - DL	Hol-East H2O		88						
320-113899-2	Hol-East H2O	89		103	80	168 *5+	110	63	
320-113899-3 - DL	Hol-South H2O								
320-113899-3	Hol-South H2O	100	87	113	71	110	104	46	
320-113899-4 - DL	Hol-West H2O								
320-113899-4	Hol-West H2O	94	89	112	81	109	100	43	
LCS 320-781606/2-A	Lab Control Sample	88	94	109	79	101	98	93	
LCSD 320-781606/3-A	Lab Control Sample Dup	88	101	110	87	101	102	109	
MB 320-781606/1-A	Method Blank	96	98	113	76	101	106	113	

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
PFHxA = 13C2 PFHxA
C4PFHA = 13C4 PFHpA
PFOA = 13C4 PFOA
PFNA = 13C5 PFNA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS
PFHxS = 18O2 PFHxS
PFOS = 13C4 PFOS
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
M102FTS = 13C2 10:2 FTS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Lab Sample ID: MB 320-781606/1-A
Matrix: Water
Analysis Batch: 782324

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 781606

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		5.0	2.4	ng/L		07/19/24 12:30	07/22/24 14:15	1
Perfluoropentanoic acid (PFPeA)	ND		2.0	0.49	ng/L		07/19/24 12:30	07/22/24 14:15	1
Perfluorohexanoic acid (PFHxA)	ND		2.0	0.58	ng/L		07/19/24 12:30	07/22/24 14:15	1
Perfluoroheptanoic acid (PFHpA)	ND		2.0	0.25	ng/L		07/19/24 12:30	07/22/24 14:15	1
L-Perfluorooctanoic acid	ND		2.0	0.85	ng/L		07/19/24 12:30	07/22/24 14:15	1
Br-Perfluorooctanoic acid	ND		2.0	0.85	ng/L		07/19/24 12:30	07/22/24 14:15	1
Total PFOA	ND		2.0	0.85	ng/L		07/19/24 12:30	07/22/24 14:15	1
Perfluorononanoic acid (PFNA)	ND		2.0	0.27	ng/L		07/19/24 12:30	07/22/24 14:15	1
Perfluorodecanoic acid (PFDA)	ND		2.0	0.31	ng/L		07/19/24 12:30	07/22/24 14:15	1
Perfluoroundecanoic acid (PFUnA)	ND		2.0	1.1	ng/L		07/19/24 12:30	07/22/24 14:15	1
Perfluorobutanesulfonic acid (PFBS)	ND		2.0	0.20	ng/L		07/19/24 12:30	07/22/24 14:15	1
Perfluoropentanesulfonic acid (PFPeS)	ND		2.0	0.30	ng/L		07/19/24 12:30	07/22/24 14:15	1
Br-Perfluorohexanesulfonic acid	ND		2.0	0.57	ng/L		07/19/24 12:30	07/22/24 14:15	1
Total PFHxS	ND		2.0	0.57	ng/L		07/19/24 12:30	07/22/24 14:15	1
L-Perfluorohexanesulfonic acid	ND		2.0	0.57	ng/L		07/19/24 12:30	07/22/24 14:15	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		2.0	0.19	ng/L		07/19/24 12:30	07/22/24 14:15	1
L-Perfluorooctanesulfonic acid	ND		2.0	0.54	ng/L		07/19/24 12:30	07/22/24 14:15	1
Br-Perfluorooctanesulfonic acid	ND		2.0	0.54	ng/L		07/19/24 12:30	07/22/24 14:15	1
Total PFOS	ND		2.0	0.54	ng/L		07/19/24 12:30	07/22/24 14:15	1
4:2 FTS	ND		2.0	0.24	ng/L		07/19/24 12:30	07/22/24 14:15	1
6:2 FTS	ND		5.0	2.5	ng/L		07/19/24 12:30	07/22/24 14:15	1
8:2 FTS	ND		2.0	0.46	ng/L		07/19/24 12:30	07/22/24 14:15	1
10:2 FTS	ND		2.0	0.67	ng/L		07/19/24 12:30	07/22/24 14:15	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*101*		*25 - 150*	*07/19/24 12:30*	*07/22/24 14:15*	*1*
13C5 PFPeA	*88*		*25 - 150*	*07/19/24 12:30*	*07/22/24 14:15*	*1*
13C2 PFHxA	*98*		*25 - 150*	*07/19/24 12:30*	*07/22/24 14:15*	*1*
13C4 PFHpA	*87*		*25 - 150*	*07/19/24 12:30*	*07/22/24 14:15*	*1*
13C4 PFOA	*99*		*25 - 150*	*07/19/24 12:30*	*07/22/24 14:15*	*1*
13C5 PFNA	*106*		*25 - 150*	*07/19/24 12:30*	*07/22/24 14:15*	*1*
13C2 PFDA	*115*		*25 - 150*	*07/19/24 12:30*	*07/22/24 14:15*	*1*
13C2 PFUnA	*120*		*25 - 150*	*07/19/24 12:30*	*07/22/24 14:15*	*1*
13C3 PFBS	*96*		*25 - 150*	*07/19/24 12:30*	*07/22/24 14:15*	*1*
18O2 PFHxS	*98*		*25 - 150*	*07/19/24 12:30*	*07/22/24 14:15*	*1*
13C4 PFOS	*113*		*25 - 150*	*07/19/24 12:30*	*07/22/24 14:15*	*1*
M2-4:2 FTS	*76*		*25 - 150*	*07/19/24 12:30*	*07/22/24 14:15*	*1*
M2-6:2 FTS	*101*		*25 - 150*	*07/19/24 12:30*	*07/22/24 14:15*	*1*
M2-8:2 FTS	*106*		*25 - 150*	*07/19/24 12:30*	*07/22/24 14:15*	*1*
13C2 10:2 FTS	*113*		*25 - 150*	*07/19/24 12:30*	*07/22/24 14:15*	*1*

Lab Sample ID: LCS 320-781606/2-A
Matrix: Water
Analysis Batch: 782324

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 781606

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	40.0	37.5		ng/L		94	76 - 136

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-781606/2-A
Matrix: Water
Analysis Batch: 782324

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 781606

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluoropentanoic acid (PFPeA)	40.0	42.3		ng/L		106	71 - 131
Perfluorohexanoic acid (PFHxA)	40.0	44.2		ng/L		111	73 - 133
Perfluoroheptanoic acid (PFHpA)	40.0	42.8		ng/L		107	72 - 132
L-Perfluorooctanoic acid	30.3	37.9		ng/L		125	70 - 130
Total PFOA	38.4	44.2		ng/L		115	70 - 130
Perfluorononanoic acid (PFNA)	26.1	32.0		ng/L		123	75 - 135
Perfluorodecanoic acid (PFDA)	40.0	42.4		ng/L		106	76 - 136
Perfluoroundecanoic acid (PFUnA)	40.0	44.0		ng/L		110	68 - 128
Perfluorobutanesulfonic acid (PFBS)	35.5	40.6		ng/L		114	67 - 127
Perfluoropentanesulfonic acid (PFPeS)	37.6	39.4		ng/L		105	66 - 126
Total PFHxS	36.5	38.0		ng/L		104	59 - 119
L-Perfluorohexanesulfonic acid	36.5	38.0		ng/L		104	59 - 119
Perfluoroheptanesulfonic acid (PFHpS)	38.2	39.8		ng/L		104	76 - 136
L-Perfluorooctanesulfonic acid	37.2	38.3		ng/L		103	70 - 130
Total PFOS	37.2	38.3		ng/L		103	70 - 130
4:2 FTS	37.5	45.8		ng/L		122	79 - 139
6:2 FTS	38.1	45.1		ng/L		118	59 - 175
8:2 FTS	38.4	42.3		ng/L		110	75 - 135
10:2 FTS	38.6	38.1		ng/L		99	64 - 142

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*95*		*25 - 150*
13C5 PFPeA	*79*		*25 - 150*
13C2 PFHxA	*90*		*25 - 150*
13C4 PFHpA	*90*		*25 - 150*
13C4 PFOA	*99*		*25 - 150*
13C5 PFNA	*110*		*25 - 150*
13C2 PFDA	*102*		*25 - 150*
13C2 PFUnA	*106*		*25 - 150*
13C3 PFBS	*88*		*25 - 150*
18O2 PFHxS	*94*		*25 - 150*
13C4 PFOS	*109*		*25 - 150*
M2-4:2 FTS	*79*		*25 - 150*
M2-6:2 FTS	*101*		*25 - 150*
M2-8:2 FTS	*98*		*25 - 150*
13C2 10:2 FTS	*93*		*25 - 150*

Lab Sample ID: LCSD 320-781606/3-A
Matrix: Water
Analysis Batch: 782324

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 781606

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)	40.0	37.1		ng/L		93	76 - 136	1	30
Perfluoropentanoic acid (PFPeA)	40.0	39.4		ng/L		98	71 - 131	7	30
Perfluorohexanoic acid (PFHxA)	40.0	40.5		ng/L		101	73 - 133	9	30
Perfluoroheptanoic acid (PFHpA)	40.0	41.8		ng/L		105	72 - 132	2	30

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCSD 320-781606/3-A
Matrix: Water
Analysis Batch: 782324

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 781606

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
L-Perfluorooctanoic acid			30.3	38.8		ng/L		128	70 - 130	2	30
Total PFOA			38.4	46.5		ng/L		121	70 - 130	5	30
Perfluorononanoic acid (PFNA)			26.1	32.5		ng/L		125	75 - 135	2	30
Perfluorodecanoic acid (PFDA)			40.0	42.3		ng/L		106	76 - 136	0	30
Perfluoroundecanoic acid (PFUnA)			40.0	44.9		ng/L		112	68 - 128	2	30
Perfluorobutanesulfonic acid (PFBS)			35.5	39.0		ng/L		110	67 - 127	4	30
Perfluoropentanesulfonic acid (PFPeS)			37.6	43.0		ng/L		114	66 - 126	9	30
Total PFHxS			36.5	36.1		ng/L		99	59 - 119	5	30
L-Perfluorohexanesulfonic acid			36.5	36.1		ng/L		99	59 - 119	5	30
Perfluoroheptanesulfonic acid (PFHpS)			38.2	39.0		ng/L		102	76 - 136	2	30
L-Perfluorooctanesulfonic acid			37.2	37.7		ng/L		101	70 - 130	1	30
Total PFOS			37.2	37.7		ng/L		101	70 - 130	1	30
4:2 FTS			37.5	43.9		ng/L		117	79 - 139	4	30
6:2 FTS			38.1	45.6		ng/L		120	59 - 175	1	30
8:2 FTS			38.4	43.3		ng/L		113	75 - 135	2	30
10:2 FTS			38.6	37.7		ng/L		98	64 - 142	1	30

Isotope Dilution	*LCSD %Recovery*	*LCSD Qualifier*	*Limits*
13C4 PFBA	*100*		*25 - 150*
13C5 PFPeA	*84*		*25 - 150*
13C2 PFHxA	*95*		*25 - 150*
13C4 PFHpA	*96*		*25 - 150*
13C4 PFOA	*98*		*25 - 150*
13C5 PFNA	*107*		*25 - 150*
13C2 PFDA	*103*		*25 - 150*
13C2 PFUnA	*109*		*25 - 150*
13C3 PFBS	*88*		*25 - 150*
18O2 PFHxS	*101*		*25 - 150*
13C4 PFOS	*110*		*25 - 150*
M2-4:2 FTS	*87*		*25 - 150*
M2-6:2 FTS	*101*		*25 - 150*
M2-8:2 FTS	*102*		*25 - 150*
13C2 10:2 FTS	*109*		*25 - 150*

Lab Sample ID: MB 320-785917/1-A
Matrix: Solid
Analysis Batch: 789265

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 785917

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.20	0.046	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
Perfluoropentanoic acid (PFPeA)	ND		0.20	0.041	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
Perfluorohexanoic acid (PFHxA)	ND		0.20	0.031	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
Perfluoroheptanoic acid (PFHpA)	ND		0.20	0.038	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
L-Perfluorooctanoic acid	ND		0.20	0.053	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
Br-Perfluorooctanoic acid	ND		0.20	0.053	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
Total PFOA	ND		0.20	0.053	ug/Kg		07/30/24 10:47	08/08/24 23:08	1

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: MB 320-785917/1-A
Matrix: Solid
Analysis Batch: 789265

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 785917

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorononanoic acid (PFNA)	ND		0.20	0.022	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
Perfluorodecanoic acid (PFDA)	ND		0.20	0.048	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
Perfluoroundecanoic acid (PFUnA)	ND		0.20	0.042	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.20	0.038	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.20	0.037	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
Br-Perfluorohexanesulfonic acid	ND		0.20	0.029	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
Total PFHxS	ND		0.20	0.029	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
L-Perfluorohexanesulfonic acid	ND		0.20	0.029	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.20	0.049	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
L-Perfluorooctanesulfonic acid	ND		0.20	0.043	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
Br-Perfluorooctanesulfonic acid	ND		0.20	0.043	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
Total PFOS	ND		0.20	0.043	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
4:2 FTS	ND		0.20	0.051	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
6:2 FTS	ND		0.20	0.027	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
8:2 FTS	ND		0.20	0.035	ug/Kg		07/30/24 10:47	08/08/24 23:08	1
10:2 FTS	ND		0.20	0.038	ug/Kg		07/30/24 10:47	08/08/24 23:08	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*102*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:08*	*1*
13C5 PFPeA	*98*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:08*	*1*
13C2 PFHxA	*105*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:08*	*1*
13C4 PFHpA	*91*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:08*	*1*
13C4 PFOA	*96*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:08*	*1*
13C5 PFNA	*102*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:08*	*1*
13C2 PFDA	*97*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:08*	*1*
13C2 PFUnA	*96*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:08*	*1*
13C3 PFBS	*86*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:08*	*1*
18O2 PFHxS	*90*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:08*	*1*
13C4 PFOS	*90*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:08*	*1*
M2-4:2 FTS	*104*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:08*	*1*
M2-6:2 FTS	*101*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:08*	*1*
M2-8:2 FTS	*91*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:08*	*1*
13C2 10:2 FTS	*88*		*25 - 150*	*07/30/24 10:47*	*08/08/24 23:08*	*1*

Lab Sample ID: LCS 320-785917/2-A
Matrix: Solid
Analysis Batch: 789265

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 785917

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	2.00	1.89		ug/Kg		94	76 - 136
Perfluoropentanoic acid (PFPeA)	2.00	1.76		ug/Kg		88	69 - 129
Perfluorohexanoic acid (PFHxA)	2.00	1.85		ug/Kg		93	71 - 131
Perfluoroheptanoic acid (PFHpA)	2.00	1.99		ug/Kg		100	71 - 131
L-Perfluorooctanoic acid	2.00	1.79		ug/Kg		89	72 - 132
Total PFOA	2.00	1.79		ug/Kg		89	72 - 132
Perfluorononanoic acid (PFNA)	2.00	1.71		ug/Kg		85	73 - 133
Perfluorodecanoic acid (PFDA)	2.00	1.81		ug/Kg		90	72 - 132

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-785917/2-A
Matrix: Solid
Analysis Batch: 789265

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 785917

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluoroundecanoic acid (PFUnA)	2.00	1.92		ug/Kg		96	66 - 126
Perfluorobutanesulfonic acid (PFBS)	1.78	2.01		ug/Kg		113	69 - 129
Perfluoropentanesulfonic acid (PFPeS)	1.88	1.92		ug/Kg		102	66 - 126
Total PFHxS	1.82	1.73		ug/Kg		95	62 - 122
L-Perfluorohexanesulfonic acid	1.82	1.73		ug/Kg		95	62 - 122
Perfluoroheptanesulfonic acid (PFHpS)	1.91	2.01		ug/Kg		105	76 - 136
L-Perfluorooctanesulfonic acid	1.86	1.74		ug/Kg		93	68 - 141
Total PFOS	1.86	1.74		ug/Kg		93	68 - 141
4:2 FTS	1.88	1.72		ug/Kg		92	68 - 143
6:2 FTS	1.90	1.65		ug/Kg		87	73 - 139
8:2 FTS	1.92	2.03		ug/Kg		106	75 - 135
10:2 FTS	1.93	1.90		ug/Kg		98	69 - 145

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*99*		*25 - 150*
13C5 PFPeA	*90*		*25 - 150*
13C2 PFHxA	*99*		*25 - 150*
13C4 PFHpA	*89*		*25 - 150*
13C4 PFOA	*89*		*25 - 150*
13C5 PFNA	*90*		*25 - 150*
13C2 PFDA	*85*		*25 - 150*
13C2 PFUnA	*81*		*25 - 150*
13C3 PFBS	*73*		*25 - 150*
18O2 PFHxS	*80*		*25 - 150*
13C4 PFOS	*77*		*25 - 150*
M2-4:2 FTS	*90*		*25 - 150*
M2-6:2 FTS	*91*		*25 - 150*
M2-8:2 FTS	*79*		*25 - 150*
13C2 10:2 FTS	*69*		*25 - 150*

Lab Sample ID: 320-113899-12 MS
Matrix: Solid
Analysis Batch: 789265

Client Sample ID: Hol NE2-900=4 Soils
Prep Type: Total/NA
Prep Batch: 785917

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	0.15	J	1.85	2.03		ug/Kg		102	76 - 136
Perfluoropentanoic acid (PFPeA)	0.15	J	1.85	1.84		ug/Kg		92	69 - 129
Perfluorohexanoic acid (PFHxA)	0.97		1.85	2.91		ug/Kg		105	71 - 131
Perfluoroheptanoic acid (PFHpA)	0.79	F1	1.85	3.27	F1	ug/Kg		134	71 - 131
L-Perfluorooctanoic acid	0.29		1.85	2.28		ug/Kg		108	72 - 132
Total PFOA	0.40		1.85	2.28		ug/Kg		102	72 - 132
Perfluorononanoic acid (PFNA)	0.089	J I	1.85	1.83		ug/Kg		94	73 - 133
Perfluorodecanoic acid (PFDA)	ND		1.85	1.90		ug/Kg		103	72 - 132
Perfluoroundecanoic acid (PFUnA)	ND		1.85	1.86		ug/Kg		101	66 - 126

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: 320-113899-12 MS
Matrix: Solid
Analysis Batch: 789265

Client Sample ID: Hol NE2-900=4 Soils
Prep Type: Total/NA
Prep Batch: 785917

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanesulfonic acid (PFBS)	0.28		1.64	2.38		ug/Kg		128	69 - 129
Perfluoropentanesulfonic acid (PFPeS)	0.37	F1	1.73	3.22	F1	ug/Kg		164	66 - 126
Total PFHxS	2.8	F1	1.68	6.06	F1	ug/Kg		194	62 - 122
L-Perfluorohexanesulfonic acid	1.9	F1	1.68	6.06	F1	ug/Kg		245	62 - 122
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.76	1.93		ug/Kg		110	76 - 136
L-Perfluorooctanesulfonic acid	1.1	F1	1.72	3.58	F1	ug/Kg		146	68 - 141
Total PFOS	1.7	F1	1.72	3.58		ug/Kg		111	68 - 141
4:2 FTS	ND		1.73	1.90		ug/Kg		110	68 - 143
6:2 FTS	0.070	J	1.76	1.81		ug/Kg		99	73 - 139
8:2 FTS	ND		1.77	1.94		ug/Kg		109	75 - 135
10:2 FTS	ND		1.78	1.54		ug/Kg		87	69 - 145

Isotope Dilution	*MS %Recovery*	*MS Qualifier*	*Limits*
13C4 PFBA	*90*		*25 - 150*
13C5 PFPeA	*97*		*25 - 150*
13C2 PFHxA	*101*		*25 - 150*
13C4 PFHpA	*81*		*25 - 150*
13C4 PFOA	*85*		*25 - 150*
13C5 PFNA	*85*		*25 - 150*
13C2 PFDA	*87*		*25 - 150*
13C2 PFUnA	*82*		*25 - 150*
13C3 PFBS	*70*		*25 - 150*
18O2 PFHxS	*79*		*25 - 150*
13C4 PFOS	*81*		*25 - 150*
M2-4:2 FTS	*94*		*25 - 150*
M2-6:2 FTS	*74*		*25 - 150*
M2-8:2 FTS	*76*		*25 - 150*
13C2 10:2 FTS	*84*		*25 - 150*

Lab Sample ID: 320-113899-12 MSD
Matrix: Solid
Analysis Batch: 789265

Client Sample ID: Hol NE2-900=4 Soils
Prep Type: Total/NA
Prep Batch: 785917

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)	0.15	J	1.96	2.08		ug/Kg		98	76 - 136	3	30
Perfluoropentanoic acid (PFPeA)	0.15	J	1.96	2.00		ug/Kg		94	69 - 129	8	30
Perfluorohexanoic acid (PFHxA)	0.97		1.96	3.00		ug/Kg		104	71 - 131	3	30
Perfluoroheptanoic acid (PFHpA)	0.79	F1	1.96	2.69		ug/Kg		97	71 - 131	19	30
L-Perfluorooctanoic acid	0.29		1.96	2.19		ug/Kg		97	72 - 132	4	30
Total PFOA	0.40		1.96	2.19		ug/Kg		92	72 - 132	4	30
Perfluorononanoic acid (PFNA)	0.089	J I	1.96	2.09		ug/Kg		102	73 - 133	13	30
Perfluorodecanoic acid (PFDA)	ND		1.96	2.07		ug/Kg		106	72 - 132	9	30
Perfluoroundecanoic acid (PFUnA)	ND		1.96	2.12		ug/Kg		108	66 - 126	13	30
Perfluorobutanesulfonic acid (PFBS)	0.28		1.74	2.20		ug/Kg		110	69 - 129	8	30

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: 320-113899-12 MSD
Matrix: Solid
Analysis Batch: 789265

Client Sample ID: Hol NE2-900=4 Soils
Prep Type: Total/NA
Prep Batch: 785917

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluoropentanesulfonic acid (PFPeS)	0.37	F1	1.84	2.66		ug/Kg		124	66 - 126	19	30
Total PFHxS	2.8	F1	1.79	5.37	F1	ug/Kg		144	62 - 122	12	30
L-Perfluorohexanesulfonic acid	1.9	F1	1.79	5.37	F1	ug/Kg		192	62 - 122	12	30
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.87	2.20		ug/Kg		117	76 - 136	13	30
L-Perfluorooctanesulfonic acid	1.1	F1	1.82	4.76	F1	ug/Kg		202	68 - 141	28	30
Total PFOS	1.7	F1	1.82	4.76	F1	ug/Kg		169	68 - 141	28	30
4:2 FTS	ND		1.84	2.19		ug/Kg		119	68 - 143	14	30
6:2 FTS	0.070	J	1.87	1.79		ug/Kg		92	73 - 139	1	30
8:2 FTS	ND		1.88	2.14		ug/Kg		114	75 - 135	10	30
10:2 FTS	ND		1.89	1.96		ug/Kg		103	69 - 145	24	30

Isotope Dilution	*MSD %Recovery*	*MSD Qualifier*	*Limits*
13C4 PFBA	*73*		*25 - 150*
13C5 PFPeA	*87*		*25 - 150*
13C2 PFHxA	*86*		*25 - 150*
13C4 PFHpA	*85*		*25 - 150*
13C4 PFOA	*83*		*25 - 150*
13C5 PFNA	*75*		*25 - 150*
13C2 PFDA	*77*		*25 - 150*
13C2 PFUnA	*73*		*25 - 150*
13C3 PFBS	*70*		*25 - 150*
18O2 PFHxS	*71*		*25 - 150*
13C4 PFOS	*72*		*25 - 150*
M2-4:2 FTS	*70*		*25 - 150*
M2-6:2 FTS	*74*		*25 - 150*
M2-8:2 FTS	*71*		*25 - 150*
13C2 10:2 FTS	*89*		*25 - 150*

LCMS

Prep Batch: 781606

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113899-1	Hol-North H2O	Total/NA	Water	3535	
320-113899-2 - DL	Hol-East H2O	Total/NA	Water	3535	
320-113899-2	Hol-East H2O	Total/NA	Water	3535	
320-113899-3	Hol-South H2O	Total/NA	Water	3535	
320-113899-3 - DL	Hol-South H2O	Total/NA	Water	3535	
320-113899-4	Hol-West H2O	Total/NA	Water	3535	
320-113899-4 - DL	Hol-West H2O	Total/NA	Water	3535	
MB 320-781606/1-A	Method Blank	Total/NA	Water	3535	
LCS 320-781606/2-A	Lab Control Sample	Total/NA	Water	3535	
LCSD 320-781606/3-A	Lab Control Sample Dup	Total/NA	Water	3535	

Analysis Batch: 782324

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
MB 320-781606/1-A	Method Blank	Total/NA	Water	B/L/T PFAS	781606
LCS 320-781606/2-A	Lab Control Sample	Total/NA	Water	B/L/T PFAS	781606
LCSD 320-781606/3-A	Lab Control Sample Dup	Total/NA	Water	B/L/T PFAS	781606

Analysis Batch: 783718

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113899-2 - DL	Hol-East H2O	Total/NA	Water	B/L/T PFAS	781606
320-113899-3 - DL	Hol-South H2O	Total/NA	Water	B/L/T PFAS	781606
320-113899-4 - DL	Hol-West H2O	Total/NA	Water	B/L/T PFAS	781606

Analysis Batch: 784588

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113899-2	Hol-East H2O	Total/NA	Water	B/L/T PFAS	781606
320-113899-3	Hol-South H2O	Total/NA	Water	B/L/T PFAS	781606
320-113899-4	Hol-West H2O	Total/NA	Water	B/L/T PFAS	781606

Prep Batch: 785917

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113899-5 - DL	Hol NE4-0=1 Soils	Total/NA	Solid	SHAKE	
320-113899-5	Hol NE4-0=1 Soils	Total/NA	Solid	SHAKE	
320-113899-6	Hol NE4-300=2 Soils	Total/NA	Solid	SHAKE	
320-113899-7	Hol NE4-600=3 Soils	Total/NA	Solid	SHAKE	
320-113899-8	Hol NE4-900=4 Soils	Total/NA	Solid	SHAKE	
320-113899-8 - DL	Hol NE4-900=4 Soils	Total/NA	Solid	SHAKE	
320-113899-9	Hol NE2-0=1 Soils	Total/NA	Solid	SHAKE	
320-113899-9 - DL	Hol NE2-0=1 Soils	Total/NA	Solid	SHAKE	
320-113899-10	Hol NE2-300=2 Soils	Total/NA	Solid	SHAKE	
320-113899-11	Hol NE2-600=3 Soils	Total/NA	Solid	SHAKE	
320-113899-12	Hol NE2-900=4 Soils	Total/NA	Solid	SHAKE	
MB 320-785917/1-A	Method Blank	Total/NA	Solid	SHAKE	
LCS 320-785917/2-A	Lab Control Sample	Total/NA	Solid	SHAKE	
320-113899-12 MS	Hol NE2-900=4 Soils	Total/NA	Solid	SHAKE	
320-113899-12 MSD	Hol NE2-900=4 Soils	Total/NA	Solid	SHAKE	

Analysis Batch: 789265

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113899-5	Hol NE4-0=1 Soils	Total/NA	Solid	B/L/T PFAS	785917
320-113899-6	Hol NE4-300=2 Soils	Total/NA	Solid	B/L/T PFAS	785917

LCMS (Continued)

Analysis Batch: 789265 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113899-7	Hol NE4-600=3 Soils	Total/NA	Solid	B/L/T PFAS	785917
320-113899-8	Hol NE4-900=4 Soils	Total/NA	Solid	B/L/T PFAS	785917
320-113899-9	Hol NE2-0=1 Soils	Total/NA	Solid	B/L/T PFAS	785917
320-113899-10	Hol NE2-300=2 Soils	Total/NA	Solid	B/L/T PFAS	785917
320-113899-11	Hol NE2-600=3 Soils	Total/NA	Solid	B/L/T PFAS	785917
320-113899-12	Hol NE2-900=4 Soils	Total/NA	Solid	B/L/T PFAS	785917
MB 320-785917/1-A	Method Blank	Total/NA	Solid	B/L/T PFAS	785917
LCS 320-785917/2-A	Lab Control Sample	Total/NA	Solid	B/L/T PFAS	785917
320-113899-12 MS	Hol NE2-900=4 Soils	Total/NA	Solid	B/L/T PFAS	785917
320-113899-12 MSD	Hol NE2-900=4 Soils	Total/NA	Solid	B/L/T PFAS	785917

Analysis Batch: 789266

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113899-1	Hol-North H2O	Total/NA	Water	B/L/T PFAS	781606

Analysis Batch: 790534

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113899-5 - DL	Hol NE4-0=1 Soils	Total/NA	Solid	B/L/T PFAS	785917
320-113899-8 - DL	Hol NE4-900=4 Soils	Total/NA	Solid	B/L/T PFAS	785917
320-113899-9 - DL	Hol NE2-0=1 Soils	Total/NA	Solid	B/L/T PFAS	785917

Lab Chronicle

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Client Sample ID: Hol-North H2O
Lab Sample ID: 320-113899-1
Date Collected: 07/15/24 08:00
Matrix: Water
Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3535			297 mL	10.0 mL	781606	07/19/24 12:30	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 15:58	JTD	EET SAC

Client Sample ID: Hol-East H2O
Lab Sample ID: 320-113899-2
Date Collected: 07/15/24 08:30
Matrix: Water
Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3535	DL		125.0 mL	10.0 mL	781606	07/19/24 12:30	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	783718	07/24/24 17:53	S1C	EET SAC
Total/NA	Prep	3535			125.0 mL	10.0 mL	781606	07/19/24 12:30	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS		20	1 mL	1 mL	784588	07/25/24 16:13	S1C	EET SAC

Client Sample ID: Hol-South H2O
Lab Sample ID: 320-113899-3
Date Collected: 07/15/24 09:00
Matrix: Water
Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3535	DL		125.0 mL	10.0 mL	781606	07/19/24 12:30	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	783718	07/24/24 18:13	S1C	EET SAC
Total/NA	Prep	3535			125.0 mL	10.0 mL	781606	07/19/24 12:30	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS		20	1 mL	1 mL	784588	07/25/24 16:32	S1C	EET SAC

Client Sample ID: Hol-West H2O
Lab Sample ID: 320-113899-4
Date Collected: 07/15/24 10:00
Matrix: Water
Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3535	DL		125.0 mL	10.0 mL	781606	07/19/24 12:30	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	783718	07/24/24 18:32	S1C	EET SAC
Total/NA	Prep	3535			125.0 mL	10.0 mL	781606	07/19/24 12:30	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS		20	1 mL	1 mL	784588	07/25/24 16:52	S1C	EET SAC

Client Sample ID: Hol NE4-0=1 Soils
Lab Sample ID: 320-113899-5
Date Collected: 07/16/24 09:00
Matrix: Solid
Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			5.00 g	10.0 mL	785917	07/30/24 10:47	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789265	08/08/24 23:47	JTD	EET SAC
Total/NA	Prep	SHAKE	DL		5.00 g	10.0 mL	785917	07/30/24 10:47	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	50	1 mL	1 mL	790534	08/12/24 16:46	S1C	EET SAC

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Client Sample ID: Hol NE4-300=2 Soils
Date Collected: 07/16/24 08:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-6
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			5.19 g	10.0 mL	785917	07/30/24 10:47	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789265	08/09/24 00:07	JTD	EET SAC

Client Sample ID: Hol NE4-600=3 Soils
Date Collected: 07/16/24 08:15
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-7
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			5.09 g	10.0 mL	785917	07/30/24 10:47	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789265	08/09/24 00:26	JTD	EET SAC

Client Sample ID: Hol NE4-900=4 Soils
Date Collected: 07/16/24 08:30
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-8
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			5.28 g	10.0 mL	785917	07/30/24 10:47	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789265	08/09/24 00:45	JTD	EET SAC
Total/NA	Prep	SHAKE	DL		5.28 g	10.0 mL	785917	07/30/24 10:47	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	50	1 mL	1 mL	790534	08/12/24 17:05	S1C	EET SAC

Client Sample ID: Hol NE2-0=1 Soils
Date Collected: 07/16/24 09:10
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-9
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			5.23 g	10.0 mL	785917	07/30/24 10:47	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789265	08/09/24 01:05	JTD	EET SAC
Total/NA	Prep	SHAKE	DL		5.23 g	10.0 mL	785917	07/30/24 10:47	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	790534	08/12/24 17:24	S1C	EET SAC

Client Sample ID: Hol NE2-300=2 Soils
Date Collected: 07/16/24 09:20
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-10
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			5.12 g	10.0 mL	785917	07/30/24 10:47	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789265	08/09/24 01:24	JTD	EET SAC

Client Sample ID: Hol NE2-600=3 Soils
Date Collected: 07/16/24 09:30
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-11
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			5.33 g	10.0 mL	785917	07/30/24 10:47	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789265	08/09/24 01:44	JTD	EET SAC

Lab Chronicle

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Client Sample ID: HoI NE2-900=4 Soils

Date Collected: 07/16/24 09:45
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113899-12

Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			5.13 g	10.0 mL	785917	07/30/24 10:47	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789265	08/09/24 02:22	JTD	EET SAC

Laboratory References:

EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

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Accreditation/Certification Summary

Client: University of New Mexico
Job ID: 320-113899-1
Project/Site: Holloman Lake_Waters & Soils

Laboratory: Eurofins Sacramento

All accreditations/certifications held by this laboratory are listed. Not all accreditations/certifications are applicable to this report.

Authority	Program	Identification Number	Expiration Date
Alaska (UST)	State	17-020	02-20-27
ANAB	Dept. of Defense ELAP	L2468	01-20-27
ANAB	Dept. of Energy	L2468.01	01-20-27
ANAB	ISO/IEC 17025	L2468	01-20-27
Arizona	State	AZ0708	08-11-25
Arkansas DEQ	State	88-0691	05-18-25
California	State	2897	01-31-26
Colorado	State	CA00044	08-31-24
Florida	NELAP	E87570	06-30-25
Georgia	State	4040	01-29-25
Hawaii	State	Eurofins Sacramento	01-29-25
Illinois	NELAP	200060	03-31-25
Kansas	NELAP	E-10375	10-31-25
Louisiana	NELAP	01944	06-30-25
Louisiana (All)	NELAP	01944	06-30-25
Maine	State	CA00004	04-14-26
Michigan	State	9947	01-29-25
Nevada	State	CA00044	10-31-24
New Hampshire	NELAP	2997	04-19-25
New Jersey	NELAP	CA005	06-30-25
New York	NELAP	11666	04-01-25
Ohio	State	41252	01-29-25
Oregon	NELAP	4040	01-29-25
Texas	NELAP	T104704399-23-17	05-31-25
US Fish & Wildlife	US Federal Programs	A22139	04-30-25
USDA	US Federal Programs	P330-18-00239	02-28-26
Utah	NELAP	CA000442023-16	02-28-25
Virginia	NELAP	460278	03-14-25
Washington	State	C581	05-05-25
West Virginia (DW)	State	9930C	01-31-25
Wisconsin	State	998204680	08-31-25
Wyoming	State Program	8TMS-L	01-28-19 *

* Accreditation/Certification renewal pending - accreditation/certification considered valid.

Method Summary

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Method	Method Description	Protocol	Laboratory
B/L/T PFAS	Branched, Linear and Total PFAS	EPA	EET SAC
3535	Solid-Phase Extraction (SPE)	SW846	EET SAC
SHAKE	Shake Extraction with Ultrasonic Bath Extraction	SW846	EET SAC

Protocol References:

EPA = US Environmental Protection Agency

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

Sample Summary

Client: University of New Mexico
Project/Site: Holloman Lake_Waters & Soils

Job ID: 320-113899-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
320-113899-1	Hol-North H2O	Water	07/15/24 08:00	07/18/24 09:20
320-113899-2	Hol-East H2O	Water	07/15/24 08:30	07/18/24 09:20
320-113899-3	Hol-South H2O	Water	07/15/24 09:00	07/18/24 09:20
320-113899-4	Hol-West H2O	Water	07/15/24 10:00	07/18/24 09:20
320-113899-5	Hol NE4-0=1 Soils	Solid	07/16/24 09:00	07/18/24 09:20
320-113899-6	Hol NE4-300=2 Soils	Solid	07/16/24 08:00	07/18/24 09:20
320-113899-7	Hol NE4-600=3 Soils	Solid	07/16/24 08:15	07/18/24 09:20
320-113899-8	Hol NE4-900=4 Soils	Solid	07/16/24 08:30	07/18/24 09:20
320-113899-9	Hol NE2-0=1 Soils	Solid	07/16/24 09:10	07/18/24 09:20
320-113899-10	Hol NE2-300=2 Soils	Solid	07/16/24 09:20	07/18/24 09:20
320-113899-11	Hol NE2-600=3 Soils	Solid	07/16/24 09:30	07/18/24 09:20
320-113899-12	Hol NE2-900=4 Soils	Solid	07/16/24 09:45	07/18/24 09:20

Eurofins Env. Testing Northern California
880 Riverside Parkway
West Sacramento, CA 95605
Phone: 916.373.5600

Chain of Custody Record

eurofins Environment Testing America

Client Contact	Report To Jean-Luc Cartron	Site Contact:	Date: 7/17/2024	COC No
Daniel B Stephens & Associates	email: jcartron@geo-logic.com, jlec@unm.edu	Lab Contact: Linda Laver	Carrier: FedEx	____ of ____ COCs
6020 Academy Road NE, Suite 100	Analysis Turnaround Time			Job No
Albuquerque/NM/87109-3315	Business Days (BD) _____			
Phone 505-822-9400	TAT if different from Above _____			Field Sampler:
Tel.	☐ 2 weeks			
Project Name. Holloman Lake PFAS Research	☐ 1 week			
Site: Holloman Lake Otero Co New Mexico	☐ 2 days			
P O #	☐ 1 day			

Sample Identification	Sample Date	Sample Time	Sample Type	Matrix	# of Cont.	Filtered Sample	Enter requested analyses in these fields	Sample Specific Notes:
Hol-North H O	7/15/24	8:00am	Water		1			Surface water from Holloman Lake
Hol East H_2O	7/15/24	8.30am	Water		1			Surface water from Holloman Lake
Hol-South H O	7/15/24	9:00am	Water		1			Surface water from Holloman Lake
Hol-West H O	7/15/24	10:00am	Water		1			Surface water from Holloman Lake
Hol NE4-0=1 Soils	7/16/24	9:00 am	Soil		1			Topsoil along transect starting at shoreline
Hol NE4-300=2 Soils	7/16/24	8:00 am	Soil		1			Topsoil along transect starting at shoreline
Hol NE4-600=3 Soils	7/16/24	8 15 am	Soil		1			Topsoil along transect starting at shoreline
Hol NE4-900=4 Soils	7/16/24	8.30 am	Soil		1			Topsoil along transect starting at shoreline
Hol NE2-0=1 Soils	7/16/24	9 10 am	Soil		1			Topsoil along transect starting at shoreline
Hol NE2-300=2 Soils	7/16/24	9:20 am	Soil		1			Topsoil along transect starting at shoreline
Hol NE2-600=3 Soils	7/16/24	9.30 am	Soil		1			Topsoil along transect starting at shoreline
Hol NE2-900=4 Soils	7/16/24	9:45 am	Soil		1			Topsoil along transect starting at shoreline
					1			
					1			
					1			
					1			
					1			
					1			
					1			
					1			
					1			

320-113899 Chain of Custody

Preservation Used. 1= Ice, 2= HCl, 3= H2SO4, 4=HNO3 5=NaOH, 6= Other _____

Possible Hazard Identification
☒ *Non-Hazard* ☐ *Flammable* ☐ *Skin Irritant* *Poison B* ☐ *Unknown* ☐

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☐ *Return To Client* ☒ *Disposal By Lab* ☐ *Archive For _____ Months*

Special Instructions/QC Requirements & Comments:

2.3°C

Relinquished by: Jean-Luc Cartron	Company: DBS&A	Date/Time: 7/17/24	Received by: DSM	Company: EECSAC	Date/Time: 07/18/24 0920
Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:
Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time

8/16/2024

NMED Exhibits 65

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Loc. 320
113899

Sacramento Sample Receiving Notes (SSRN)

Tracking # 7774 5250 9628

Job _____

SO / PO / FO / SAT / 2-Day / Ground / UPS / CDO / Courier
GSL / OnTrac / Goldstreak / USPS / Other_____

Use this form to record Sample Custody Seal, Cooler Custody Seal, Temperature & corrected Temperature & other observations
File in the job folder with the COC

Therm. ID: L06 Corr Factor: (+ / -) NA °C

Ice ✓ Wet ✓ Gel _____ Other _____

Cooler Custody Seal: 2477839

Cooler ID _____

Temp Observed: 2.3 °C Corrected: 2.3 °C
From Temp Blank ☒ Sample ☐

Opening/Processing The Shipment	Yes	No	NA
Cooler compromised/tampered with?	☐	☒	☐
Cooler Temperature is acceptable?	☒	☐	☐
Frozen samples show signs of thaw?	☐	☐	☒

Initials DM Date 07/18/24

Unpacking/Labeling The Samples	Yes	No	NA
Containers are not broken or leaking?	☒	☐	☐
Samples compromised/tampered with?	☐	☒	☐
COC is complete w/o discrepancies	☒	☐	☐
Sample custody seal?	☐	☐	☒
Sample containers have legible labels?	☒	☐	☐
Sample date/times are provided?	☒	☐	☐
Appropriate containers are used?	☒	☐	☐
Sample bottles are completely filled?	☒	☐	☐
Sample preservatives verified?	☐	☐	☒
Is the Field Sampler's name on COC?	☐	☐	☒
Samples w/o discrepancies?	☒	☐	☐
Zero headspace?*	☐	☐	☒
Alkalinity has no headspace?	☐	☐	☒
Perchlorate has headspace? (Methods 314, 331, 6850)	☐	☐	☒
Multiphasic samples are not present?	☒	☐	☐

*Containers requiring zero headspace have no headspace, or bubble < 6 mm (1/4")

Initials _____ Date 7.18.24

Notes: Analyses not listed on the COC.

Trizma Lot #(s) _____

Ammonium Acetate Lot #(s) _____

Login Completion	Yes	No	NA
Receipt Temperature on COC?	☒	☐	☐
NCM Filed?	☒	☐	☐
Samples received within hold time?	☒	☐	☐
Log Release checked in TALS?	☒	☐	☐

Initials _____ Date 7.18.24

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ANALYTICAL REPORT

PREPARED FOR

Attn: Jean-Luc Cartron
University of New Mexico
Museum of Southwestern Biology
Division of Mammals
CERIA Bldg 83, Room 204
Albuquerque, New Mexico 87131

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JOB DESCRIPTION

Holloman bird/mammal

JOB NUMBER

320-113896-1

Eurofins Sacramento
880 Riverside Parkway
West Sacramento CA 95605

See page two for job notes and contact information.

NMED Exhibits 65

my EOL

Job Notes

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The test results in this report relate only to the samples as received by the laboratory and will meet all requirements of the methodology, with any exceptions noted. This report shall not be reproduced except in full, without the express written approval of the laboratory. All questions should be directed to the Eurofins Environment Testing Northern California, LLC Project Manager.

Authorization



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Authorized for release by
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Definitions/Glossary

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Qualifiers

LCMS

Qualifier	Qualifier Description
*5+	Isotope dilution analyte is outside acceptance limits, high biased.
B	Compound was found in the blank and sample.
E	Result exceeded calibration range.
I	Value is EMPC (estimated maximum possible concentration).
J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
¤	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CFU	Colony Forming Unit
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MCL	EPA recommended "Maximum Contaminant Level"
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
MPN	Most Probable Number
MQL	Method Quantitation Limit
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
NEG	Negative / Absent
POS	Positive / Present
PQL	Practical Quantitation Limit
PRES	Presumptive
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)
TNTC	Too Numerous To Count

Job ID: 320-113896-1 — Eurofins Sacramento

Job Narrative
320-113896-1

Receipt
The samples were received on 7/18/2024 9:20 AM. Unless otherwise noted below, the samples arrived in good condition, and where required, properly preserved and on ice. The temperature of the cooler at receipt was -36.9º C.

Receipt Exceptions
The Chain-of-Custody (COC) was incomplete as received and was not signed at the time samples were relinquished to the lab and does not list the requested analyses. Based on communications with the client, the samples were logged in for PFAS by 537 Mod.

The container label for each sample did not include a collection date or time. Samples were logged in and according to COC. Sample VDS 0 TEST (320-113896-23) was an empty vial intended to be tested as a blank. The COC does not list a collection date or time and this sample was logged in as 7/17/2024 @ 00:00. The COC does not list a collection time for sample NK284444 V24-20096 liner (320-113896-24) and was logged in as 00:00.

LCMS
Method B/L/T PFAS: Isotope Dilution Analyte (IDA) recoveries are above the method recommended limit for multiple samples due to matrix interferences common to tissue matrices. Quantitation by isotope dilution generally precludes any adverse effect on data quality due to elevated IDA recoveries.

Method B/L/T PFAS: The "I" qualifier means the transition mass ratio for the indicated analyte was outside the established ratio limits. The qualitative identification of the analyte has some degree of uncertainty. However, analyst judgment was used to positively identify the analyte. NK311145 femur (320-113896-6), ArtNE2 01 (320-113896-15) and NK284447 (320-113896-30)

Method B/L/T PFAS: The concentration of one or more analytes associated with the following samples exceeded the instrument calibration range in the diluted analysis. These analytes have been qualified (E); however, the peak(s) did not saturate the instrument detector. Historical data indicate that for the isotope dilution method, further dilution and re-analysis will not produce significantly different results from those reported above the calibration range. NK311145 liver (320-113896-5), NK311146 liver (320-113896-7), NK284439 (320-113896-35) and NK284442 V24-20096 liver (320-113896-37)

Method B/L/T PFAS: Results for multiple samples were reported from the analysis of a diluted extract due to high concentration of the target analyte and/or matrix interference in the analysis of the undiluted extract. The dilution factor was applied to the labeled internal standard area counts and these area counts were within acceptance limits.

Method B/L/T PFAS: Results for the following samples were reported from the analysis of a diluted extract due to high concentration of the target analyte in the analysis of the undiluted extract. The dilution factor was applied to the labeled internal standard area counts and these area counts were outside acceptance limits. The internal standard is not used to quantitate target analyte concentrations, therefore the data have been reported. NK311133 liver (320-113896-11), NK284442 (320-113896-25) and NK284444 (320-113896-27)

Method B/L/T PFAS: Internal standard (ISTD) response for the following sample was outside control limits in the undiluted extract. The sample was re-analyzed at a dilution and the ISTD was within control limits. The ISTD is not used to quantitate target analytes; therefore, the data has been reported. NK284442 V24-20096 liver (320-113896-37)

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Organic Prep
Method SHAKE: A matrix spike/matrix spike duplicate (MS/MSD) was not prepared for preparation batches 320-785621 and 320-320-788729.

Method SHAKE: Elevated reporting limits are provided for the following samples due to insufficient sample available for extraction: NK311142 liver (320-113896-3), NK311143 liver (320-113896-4), NK311145 femur (320-113896-6), NK311146 femur (320-113896-8), NK311129 liver (320-113896-9), NK311131 liver (320-113896-10), NK311133 liver (320-113896-11), Velvet ant NE2 03 (320-113896-14), ArtNE2 01 (320-113896-15), ArtNE2 02 (320-113896-16), ArtNE2 04 (320-113896-18), ArtNE4 01 (320-113896-19), ArtNE4 02 (320-113896-20), ArtNE4 03 (320-113896-21), ArtNE4 04 (320-113896-22), NK284449 (320-113896-32), NK284450 (320-113896-33) and NK284444 V24-20103 liver (320-113896-39).

Method SHAKE: The following samples were discolored following extraction: NK311140 liver (320-113896-1), NK311141 liver (320-113896-2), NK311145 liver (320-113896-5), NK311146 liver (320-113896-7), NK311131 liver (320-113896-10), NK311133 liver (320-113896-11), NK319511 muscle (320-113896-12), NK319092 liver (320-113896-13), ArtNE2 03 (320-113896-17) and NK284439 (320-113896-35).

Job ID: 320-113896-1 (Continued)

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Detection Summary

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK311140 liver — Lab Sample ID: 320-113896-1

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	7.8		0.99	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	6.5		0.99	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	5.4		0.99	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	2.1		0.99	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.35	J	0.99	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	2.7		0.99	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	2.4		0.99	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	8.2		0.99	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	1.0		0.99	0.099	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.14	J	0.99	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	1000		50	4.0	ug/Kg	20		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	820		50	4.0	ug/Kg	20		B/L/T PFAS	Total/NA
Total PFOS - DL	1800		50	4.0	ug/Kg	20		B/L/T PFAS	Total/NA

Client Sample ID: NK311141 liver — Lab Sample ID: 320-113896-2

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	17		0.75	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	26		0.75	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	18		0.75	0.077	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	8.0		0.75	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.20	J	0.75	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	4.0		0.75	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	3.8		0.75	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	6.8		0.75	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.64	J	0.75	0.075	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.083	J	0.75	0.075	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	1100		93	7.6	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	840		93	7.6	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS - DL	1900		93	7.6	ug/Kg	50		B/L/T PFAS	Total/NA

Client Sample ID: NK311142 liver — Lab Sample ID: 320-113896-3

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	3.8	J	14	2.9	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	3.8	J	14	2.9	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	24		14	2.5	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	3.3	J	14	1.5	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	34		14	2.1	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	34		14	2.1	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	6.7	J	14	2.6	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	1800		180	15	ug/Kg	5		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	340		180	15	ug/Kg	5		B/L/T PFAS	Total/NA
Total PFOS - DL	2200		180	15	ug/Kg	5		B/L/T PFAS	Total/NA

Client Sample ID: NK311143 liver — Lab Sample ID: 320-113896-4

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	5.4	J	7.1	1.7	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	6.9	J	7.1	1.3	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

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Client Sample ID: NK311143 liver (Continued) — Lab Sample ID: 320-113896-4

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorodecanoic acid (PFDA)	2.1	J	7.1	0.74	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	1.1	J	7.1	1.1	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	1.1	J	7.1	1.1	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	350		18	1.5	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	290		18	1.5	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	640		18	1.5	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK311145 liver — Lab Sample ID: 320-113896-5

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	15		0.69	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	0.34	J	0.69	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.10	J	0.69	0.080	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	1.2		0.69	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.2		0.69	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	56		0.69	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	31		0.69	0.071	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	2.6		0.69	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.52	J	0.69	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	8.9		0.69	0.069	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.20	J	0.69	0.070	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS - DL	130		69	10	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	130		69	10	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	320		69	13	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	31000	E	170	14	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	16000	E	170	14	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	47000		170	14	ug/Kg	100		B/L/T PFAS	Total/NA

Client Sample ID: NK311145 femur — Lab Sample ID: 320-113896-6

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	4.4	J	5.3	0.92	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.7	J	5.3	0.54	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	45		5.3	0.78	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	45		5.3	0.78	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	40		5.3	0.97	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	1600	I	130	11	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	570		130	11	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	2200		130	11	ug/Kg	10		B/L/T PFAS	Total/NA

Client Sample ID: NK311146 liver — Lab Sample ID: 320-113896-7

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	13		0.65	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	0.52	J	0.65	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.51	J	0.65	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.20	J	0.65	0.075	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	8.1		0.65	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.30	J	0.65	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	8.4		0.65	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	28		0.65	0.066	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK311146 liver (Continued)

Lab Sample ID: 320-113896-7

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroundecanoic acid (PFUnA)	5.3		0.65	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.34	J	0.65	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	3.0		0.65	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	32		0.65	0.065	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.35	J	0.65	0.065	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	72		65	11	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	110		65	9.5	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	110		65	9.5	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	110		65	12	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	19000	E	160	13	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	4500		160	13	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	24000		160	13	ug/Kg	100		B/L/T PFAS	Total/NA

Client Sample ID: NK311146 femur

Lab Sample ID: 320-113896-8

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	1.1	J	3.4	0.70	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.1	J	3.4	0.70	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	5.3		3.4	0.60	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.8	J	3.4	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.66	J	3.4	0.51	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	23		3.4	0.51	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	22		3.4	0.51	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	12		3.4	0.64	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	1.5	J	3.4	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	1500		86	7.0	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	300		86	7.0	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	1800		86	7.0	ug/Kg	10		B/L/T PFAS	Total/NA

Client Sample ID: NK311129 liver

Lab Sample ID: 320-113896-9

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	2.0	J	2.5	0.59	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.56	J	2.5	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	9.1		2.5	0.51	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	1.0	J	2.5	0.51	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	10		2.5	0.51	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	11		2.5	0.44	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.7	J	2.5	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	1.9	J	2.5	0.45	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	8.3		2.5	0.37	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	110		2.5	0.37	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	100		2.5	0.37	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	9.3		2.5	0.46	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	720		63	5.1	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	460		63	5.1	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	1200		63	5.1	ug/Kg	10		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Detection Summary

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK311131 liver — Lab Sample ID: 320-113896-10

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	2.4	J	3.3	0.79	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	2.0	J	3.3	0.39	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	120		3.3	0.67	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	13		3.3	0.67	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	140		3.3	0.67	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	160		3.3	0.58	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	16		3.3	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	6.0		3.3	0.60	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	15		3.3	1.4	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	14		3.3	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	110	J	330	49	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	2000		330	49	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	1900		330	49	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	170	J	330	62	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	12000		830	68	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	5600		830	68	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	17000		830	68	ug/Kg	100		B/L/T PFAS	Total/NA

Client Sample ID: NK311133 liver — Lab Sample ID: 320-113896-11

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	1.7	J	2.7	0.64	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.60	J	2.7	0.31	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	23		2.7	0.55	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	2.6	J	2.7	0.55	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	26		2.7	0.55	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	26		2.7	0.47	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	2.8		2.7	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	1.8	J	2.7	0.49	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	15		2.7	0.40	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	150		2.7	0.40	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	130		2.7	0.40	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	22		2.7	0.50	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.60	J	2.7	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	1700		140	11	ug/Kg	20		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	720		140	11	ug/Kg	20		B/L/T PFAS	Total/NA
Total PFOS - DL	2400		140	11	ug/Kg	20		B/L/T PFAS	Total/NA

Client Sample ID: NK319511 muscle — Lab Sample ID: 320-113896-12

No Detections.

Client Sample ID: NK319092 liver — Lab Sample ID: 320-113896-13

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorodecanoic acid (PFDA)	0.47	J	0.66	0.068	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.20	J	0.66	0.18	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

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Detection Summary

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: Velvet ant NE2 03 — Lab Sample ID: 320-113896-14

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	1.1	J	3.7	0.75	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.1	J	3.7	0.75	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	2.5	J	3.7	0.55	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	2.5	J	3.7	0.55	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	4.8	J	9.3	0.75	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	2.0	J	9.3	0.75	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	6.9	J	9.3	0.75	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: ArtNE2 01 — Lab Sample ID: 320-113896-15

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.91	J	1.2	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	5.0		1.2	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	14		1.2	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	5.2		1.2	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	13		1.2	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	1.1	J	1.2	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	14		1.2	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	10	I	1.2	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.69	J	1.2	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	1.5		1.2	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	2.2		1.2	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	8.9		1.2	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	63		1.2	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	54		1.2	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	9.2		1.2	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	49		1.2	0.52	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	1.3		1.2	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	390		30	2.5	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	240		30	2.5	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	630		30	2.5	ug/Kg	10		B/L/T PFAS	Total/NA

Client Sample ID: ArtNE2 02 — Lab Sample ID: 320-113896-16

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Br-Perfluorohexanesulfonic acid	8.7	J	20	3.0	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	17	J	20	3.0	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	8.7	J	20	3.0	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	75		50	4.1	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	22	J	50	4.1	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	98		50	4.1	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: ArtNE2 03 — Lab Sample ID: 320-113896-17

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanoic acid (PFHpA)	0.52	J	0.81	0.094	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	1.7		0.81	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.16	J	0.81	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.8		0.81	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.72	J	0.81	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.13	J	0.81	0.083	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

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Client Sample ID: ArtNE2 03 (Continued) — Lab Sample ID: 320-113896-17

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Br-Perfluorohexanesulfonic acid	0.37	J	0.81	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	3.1		0.81	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	2.7		0.81	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.25	J	0.81	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	18		2.0	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	7.4		2.0	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	25		2.0	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	1.3		0.81	0.34	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: ArtNE2 04 — Lab Sample ID: 320-113896-18

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	7.4		6.7	1.3	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	1.4	J	6.7	1.3	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	8.8		6.7	1.3	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	3.0	J	6.7	1.2	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	8.2		6.7	0.99	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	8.2		6.7	0.99	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	2.5	J	6.7	1.2	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	110		17	1.4	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	45		17	1.4	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	150		17	1.4	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: ArtNE4 01 — Lab Sample ID: 320-113896-19

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	1.1	J	1.2	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	2.9		1.2	0.32	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	1.8		1.2	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	6.7		1.2	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.58	J	1.2	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	7.3		1.2	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	5.3		1.2	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.64	J	1.2	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.20	J	1.2	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.67	J	1.2	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	4.3		1.2	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	33		1.2	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	29		1.2	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	6.4		1.2	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	42		1.2	0.50	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	1.8		1.2	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	320		29	2.4	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	180		29	2.4	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	500		29	2.4	ug/Kg	10		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Detection Summary

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: ArtNE4 02 — Lab Sample ID: 320-113896-20

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanoic acid (PFHpA)	0.84	J	2.3	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	2.3		2.3	0.47	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	2.3		2.3	0.47	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	1.3	J	2.3	0.41	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.99	J	2.3	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	7.7		2.3	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	6.7		2.3	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.81	J	2.3	0.43	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	54		5.8	0.47	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	29		5.8	0.47	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	83		5.8	0.47	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	1.5	J	2.3	0.99	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: ArtNE4 03 — Lab Sample ID: 320-113896-21

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Total PFHxS	0.74	J	4.0	0.59	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.74	J	4.0	0.59	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	6.1	J	10	0.81	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	2.7	J	10	0.81	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	8.9	J	10	0.81	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: ArtNE4 04 — Lab Sample ID: 320-113896-22

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	1.0	J	3.4	0.81	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	1.6	J	3.4	0.94	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.71	J	3.4	0.40	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	10		3.4	0.70	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.91	J	3.4	0.70	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	11		3.4	0.70	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	6.6		3.4	0.60	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.39	J	3.4	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	2.0	J	3.4	0.51	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	21		3.4	0.51	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	19		3.4	0.51	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	3.5		3.4	0.64	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	160		8.6	0.70	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	75		8.6	0.70	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	240		8.6	0.70	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: VDS 0 TEST — Lab Sample ID: 320-113896-23

No Detections.

Client Sample ID: NK284441 — Lab Sample ID: 320-113896-24

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	2.0		1.1	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	2.0		1.1	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	8.8		1.1	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	3.0		1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

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Client Sample ID: NK284441 (Continued) — Lab Sample ID: 320-113896-24

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroundecanoic acid (PFUnA)	1.4		1.1	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	1.5		1.1	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	58		1.1	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	56		1.1	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	22		1.1	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	16		1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	3.0	B	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	1600		130	11	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	370		130	11	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS - DL	2000		130	11	ug/Kg	50		B/L/T PFAS	Total/NA

Client Sample ID: NK284442 — Lab Sample ID: 320-113896-25

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanoic acid (PFHpA)	0.14	J	0.85	0.098	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	3.0		0.85	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	3.0		0.85	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	11		0.85	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	2.6		0.85	0.087	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	1.3		0.85	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.15	J	0.85	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	1.3		0.85	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	60		0.85	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	59		0.85	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	14		0.85	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	6.9		0.85	0.085	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.34	J B	0.85	0.086	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	470		21	1.7	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	130		21	1.7	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	590		21	1.7	ug/Kg	10		B/L/T PFAS	Total/NA

Client Sample ID: NK284443 — Lab Sample ID: 320-113896-26

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.14	J	0.50	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.21	J	0.50	0.058	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	14		0.50	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.47	J	0.50	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	14		0.50	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	22		0.50	0.088	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	2.3		0.50	0.052	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.42	J	0.50	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.72		0.50	0.091	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	36		0.50	0.093	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	5.6	J	25	3.7	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFHxS - DL	380		25	3.7	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	380		25	3.7	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	690		63	5.1	ug/Kg	50		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK284443 (Continued) — Lab Sample ID: 320-113896-26

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Br-Perfluorooctanesulfonic acid - DL	210		63	5.1	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS - DL	890		63	5.1	ug/Kg	50		B/L/T PFAS	Total/NA
8:2 FTS - DL	2.6	J	25	2.5	ug/Kg	50		B/L/T PFAS	Total/NA

Client Sample ID: NK284444 — Lab Sample ID: 320-113896-27

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.28	J	0.76	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.090	J	0.76	0.088	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	1.6		0.76	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.21	J	0.76	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.8		0.76	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	4.6		0.76	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.7		0.76	0.078	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.80		0.76	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.82		0.76	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	34		0.76	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	33		0.76	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	8.7		0.76	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	4.3		0.76	0.076	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.67	J B	0.76	0.077	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	510		19	1.5	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	120		19	1.5	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	640		19	1.5	ug/Kg	10		B/L/T PFAS	Total/NA

Client Sample ID: NK284445 — Lab Sample ID: 320-113896-28

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.33	J	1.0	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	0.19	J	1.0	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.35	J	1.0	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.47	J	1.0	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	6.4		1.0	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.50	J	1.0	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	6.9		1.0	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	6.6		1.0	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	2.1		1.0	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.86	J	1.0	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.56	J	1.0	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	3.0		1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	62		1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	59		1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	13		1.0	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	7.3		1.0	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	1.4	B	1.0	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	740		26	2.1	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	190		26	2.1	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	940		26	2.1	ug/Kg	10		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Detection Summary

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284446 — Lab Sample ID: 320-113896-29

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.50	J	0.70	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	0.31	J	0.70	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.68	J	0.70	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.74		0.70	0.082	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	8.1		0.70	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.51	J	0.70	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	8.6		0.70	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	6.8		0.70	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	2.4		0.70	0.073	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	1.3		0.70	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.37	J	0.70	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	18		0.70	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	5.3		0.70	0.070	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	1.2	B	0.70	0.071	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS - DL	84		35	5.2	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	84		35	5.2	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	820		88	7.1	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	200		88	7.1	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS - DL	1000		88	7.1	ug/Kg	50		B/L/T PFAS	Total/NA

Client Sample ID: NK284447 — Lab Sample ID: 320-113896-30

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Total PFHxS	0.92	J	1.1	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.92	J	1.1	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	7.9	I	2.8	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	1.3	J	2.8	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	9.2		2.8	0.23	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK284448 — Lab Sample ID: 320-113896-31

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanoic acid (PFHpA)	0.41	J	0.56	0.065	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	3.8		0.56	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.21	J	0.56	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	4.0		0.56	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	2.2		0.56	0.098	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.21	J	0.56	0.058	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.21	J	0.56	0.096	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	1.2		0.56	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	3.1		0.56	0.083	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	44		0.56	0.083	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	40		0.56	0.083	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	2.8		0.56	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.56		0.56	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.49	J	0.56	0.056	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.068	J B	0.56	0.057	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	130		14	1.1	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	35		14	1.1	ug/Kg	10		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

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Client Sample ID: NK284448 (Continued) — Lab Sample ID: 320-113896-31

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Total PFOS - DL	170		14	1.1	ug/Kg	10		B/L/T PFAS	Total/NA

Client Sample ID: NK284449 — Lab Sample ID: 320-113896-32

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanoic acid (PFHpA)	0.41	J	1.3	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	2.3		1.3	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	2.3		1.3	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	3.9		1.3	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.1	J	1.3	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	1.4		1.3	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.31	J	1.3	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	2.9		1.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	84		1.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	81		1.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	6.6		1.3	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	37		1.3	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	3.4	B	1.3	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	390		33	2.7	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	81		33	2.7	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	470		33	2.7	ug/Kg	10		B/L/T PFAS	Total/NA

Client Sample ID: NK284450 — Lab Sample ID: 320-113896-33

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanoic acid (PFHpA)	0.25	J	1.8	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	1.4	J	1.8	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.4	J	1.8	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	2.8		1.8	0.31	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.0	J	1.8	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	1.2	J	1.8	0.49	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.99	J	1.8	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	33		1.8	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	32		1.8	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	4.1		1.8	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	42		1.8	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	2.9	B	1.8	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	340		89	7.3	ug/Kg	20		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	51	J	89	7.3	ug/Kg	20		B/L/T PFAS	Total/NA
Total PFOS - DL	390		89	7.3	ug/Kg	20		B/L/T PFAS	Total/NA

Client Sample ID: NK284451 — Lab Sample ID: 320-113896-34

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanoic acid (PFHpA)	0.14	J	0.92	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	0.86	J	0.92	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.86	J	0.92	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	2.0		0.92	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.69	J	0.92	0.094	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.58	J	0.92	0.25	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK284451 (Continued) — Lab Sample ID: 320-113896-34

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Br-Perfluorohexanesulfonic acid	0.80	J	0.92	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	31		0.92	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	30		0.92	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	3.6		0.92	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	12		0.92	0.092	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	1.9	B	0.92	0.093	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	350		46	3.7	ug/Kg	20		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	55		46	3.7	ug/Kg	20		B/L/T PFAS	Total/NA
Total PFOS - DL	400		46	3.7	ug/Kg	20		B/L/T PFAS	Total/NA

Client Sample ID: NK284439 — Lab Sample ID: 320-113896-35

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	4.9		0.98	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	4.1		0.98	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	32		0.98	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	24		0.98	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	32		0.98	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	4.4		0.98	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	2.6		0.98	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	32		0.98	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	20		0.98	0.42	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	86		0.98	0.098	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	1.6	B	0.98	0.099	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	310		98	20	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOA - DL	310		98	20	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	300		98	17	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	210		98	15	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	3600		98	15	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	3400		98	15	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	790		98	18	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	32000	E	250	20	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	16000	E	250	20	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	48000		250	20	ug/Kg	100		B/L/T PFAS	Total/NA

Client Sample ID: NK284452 — Lab Sample ID: 320-113896-36

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	11		0.97	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.23	J	0.97	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	12		0.97	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	13		0.97	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	5.7		0.97	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	4.1		0.97	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	1.1		0.97	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	21		0.97	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	2.0		0.97	0.41	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	2.4	B	0.97	0.098	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK284452 (Continued) — Lab Sample ID: 320-113896-36

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Br-Perfluorohexanesulfonic acid - DL	7.3	J	49	7.2	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFHxS - DL	200		49	7.2	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	200		49	7.2	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	1300		120	9.9	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	210		120	9.9	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS - DL	1500		120	9.9	ug/Kg	50		B/L/T PFAS	Total/NA
8:2 FTS - DL	49		49	4.9	ug/Kg	50		B/L/T PFAS	Total/NA

Client Sample ID: NK284442 V24-20096 liver — Lab Sample ID: 320-113896-37

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanoic acid (PFHpA)	0.44	J	1.1	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	15		1.1	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.48	J	1.1	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	15		1.1	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	73		1.1	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	19		1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	8.0		1.1	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.67	J	1.1	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	51		1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	1.5	B	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS - DL	220		55	8.1	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	220		55	8.1	ug/Kg	50		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	71		55	10	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	5100	E	140	11	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	1200		140	11	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS - DL	6300		140	11	ug/Kg	50		B/L/T PFAS	Total/NA

Client Sample ID: NK284443 V24-20097 liver — Lab Sample ID: 320-113896-38

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanoic acid (PFHpA)	0.17	J	0.93	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	18		0.93	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.60	J	0.93	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	19		0.93	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	39		0.93	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	4.8		0.93	0.095	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.90	J	0.93	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.79	J	0.93	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	54		0.93	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	4.8		0.93	0.39	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	5.1		0.93	0.093	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.19	J B	0.93	0.094	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	6.9	J	46	6.9	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFHxS - DL	410		46	6.9	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	400		46	6.9	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	1800		120	9.4	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	380		120	9.4	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS - DL	2200		120	9.4	ug/Kg	50		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Detection Summary

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284444 V24-20103 liver

Lab Sample ID: 320-113896-39

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	8.9		3.1	0.63	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	1.5	J	3.1	0.63	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	10		3.1	0.63	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	33		3.1	0.55	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	11		3.1	0.32	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	4.5		3.1	0.85	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	5.7		3.1	0.46	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	170		3.1	0.46	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	170		3.1	0.46	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	60		3.1	0.58	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	29		3.1	0.31	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	3.5	B	3.1	0.32	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	4500		390	32	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	890		390	32	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS - DL	5400		390	32	ug/Kg	50		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK311140 liver

Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-1

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**7.8**		0.99	0.23	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
Perfluoropentanoic acid (PFPeA)	ND		0.99	0.17	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
Perfluorohexanoic acid (PFHxA)	ND		0.99	0.27	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
Perfluoroheptanoic acid (PFHpA)	ND		0.99	0.11	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
L-Perfluorooctanoic acid	ND		0.99	0.20	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
Br-Perfluorooctanoic acid	ND		0.99	0.20	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
Total PFOA	ND		0.99	0.20	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
Perfluorononanoic acid (PFNA)	**6.5**		0.99	0.17	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
Perfluorodecanoic acid (PFDA)	**5.4**		0.99	0.10	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
Perfluoroundecanoic acid (PFUnA)	**2.1**		0.99	0.27	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.99	0.17	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.99	0.18	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
Br-Perfluorohexanesulfonic acid	**0.35**	**J**	0.99	0.15	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
Total PFHxS	**2.7**		0.99	0.15	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
L-Perfluorohexanesulfonic acid	**2.4**		0.99	0.15	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
Perfluoroheptanesulfonic acid (PFHpS)	**8.2**		0.99	0.18	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
4:2 FTS	ND		0.99	0.26	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
6:2 FTS	ND		0.99	0.42	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
8:2 FTS	**1.0**		0.99	0.099	ug/Kg		07/29/24 11:09	08/09/24 04:58	1
10:2 FTS	**0.14**	**J**	0.99	0.10	ug/Kg		07/29/24 11:09	08/09/24 04:58	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*47*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:58*	*1*
13C5 PFPeA	*64*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:58*	*1*
13C2 PFHxA	*73*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:58*	*1*
13C4 PFHpA	*82*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:58*	*1*
13C4 PFOA	*79*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:58*	*1*
13C5 PFNA	*60*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:58*	*1*
13C2 PFDA	*91*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:58*	*1*
13C2 PFUnA	*98*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:58*	*1*
13C3 PFBS	*62*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:58*	*1*
18O2 PFHxS	*71*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:58*	*1*
13C4 PFOS	*61*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:58*	*1*
M2-4:2 FTS	*178*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 04:58*	*1*
M2-6:2 FTS	*172*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 04:58*	*1*
M2-8:2 FTS	*325*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 04:58*	*1*
13C2 10:2 FTS	*306*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 04:58*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**1000**		50	4.0	ug/Kg		07/29/24 11:09	08/15/24 10:59	20
Br-Perfluorooctanesulfonic acid	**820**		50	4.0	ug/Kg		07/29/24 11:09	08/15/24 10:59	20
Total PFOS	**1800**		50	4.0	ug/Kg		07/29/24 11:09	08/15/24 10:59	20

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*89*		*25 - 150*	*07/29/24 11:09*	*08/15/24 10:59*	*20*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK311141 liver

Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-2

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**17**		0.75	0.18	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
Perfluoropentanoic acid (PFPeA)	ND		0.75	0.13	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
Perfluorohexanoic acid (PFHxA)	ND		0.75	0.20	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
Perfluoroheptanoic acid (PFHpA)	ND		0.75	0.087	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
L-Perfluorooctanoic acid	ND		0.75	0.15	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
Br-Perfluorooctanoic acid	ND		0.75	0.15	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
Total PFOA	ND		0.75	0.15	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
Perfluorononanoic acid (PFNA)	**26**		0.75	0.13	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
Perfluorodecanoic acid (PFDA)	**18**		0.75	0.077	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
Perfluoroundecanoic acid (PFUnA)	**8.0**		0.75	0.20	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.75	0.13	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.75	0.14	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
Br-Perfluorohexanesulfonic acid	**0.20**	**J**	0.75	0.11	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
Total PFHxS	**4.0**		0.75	0.11	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
L-Perfluorohexanesulfonic acid	**3.8**		0.75	0.11	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
Perfluoroheptanesulfonic acid (PFHpS)	**6.8**		0.75	0.14	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
4:2 FTS	ND		0.75	0.20	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
6:2 FTS	ND		0.75	0.32	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
8:2 FTS	**0.64**	**J**	0.75	0.075	ug/Kg		07/29/24 11:09	08/09/24 05:17	1
10:2 FTS	**0.083**	**J**	0.75	0.075	ug/Kg		07/29/24 11:09	08/09/24 05:17	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*25*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:17*	*1*
13C5 PFPeA	*56*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:17*	*1*
13C2 PFHxA	*80*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:17*	*1*
13C4 PFHpA	*90*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:17*	*1*
13C4 PFOA	*82*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:17*	*1*
13C5 PFNA	*58*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:17*	*1*
13C2 PFDA	*100*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:17*	*1*
13C2 PFUnA	*110*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:17*	*1*
13C3 PFBS	*56*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:17*	*1*
18O2 PFHxS	*80*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:17*	*1*
13C4 PFOS	*68*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:17*	*1*
M2-4:2 FTS	*188*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 05:17*	*1*
M2-6:2 FTS	*139*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:17*	*1*
M2-8:2 FTS	*184*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 05:17*	*1*
13C2 10:2 FTS	*361*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 05:17*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**1100**		93	7.6	ug/Kg		07/29/24 11:09	08/15/24 11:18	50
Br-Perfluorooctanesulfonic acid	**840**		93	7.6	ug/Kg		07/29/24 11:09	08/15/24 11:18	50
Total PFOS	**1900**		93	7.6	ug/Kg		07/29/24 11:09	08/15/24 11:18	50

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*88*		*25 - 150*	*07/29/24 11:09*	*08/15/24 11:18*	*50*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK311142 liver

Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-3

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		14	3.4	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
Perfluoropentanoic acid (PFPeA)	ND		14	2.5	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
Perfluorohexanoic acid (PFHxA)	ND		14	3.9	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
Perfluoroheptanoic acid (PFHpA)	ND		14	1.7	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
L-Perfluorooctanoic acid	**3.8**	**J**	14	2.9	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
Br-Perfluorooctanoic acid	ND		14	2.9	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
Total PFOA	**3.8**	**J**	14	2.9	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
Perfluorononanoic acid (PFNA)	**24**		14	2.5	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
Perfluorodecanoic acid (PFDA)	**3.3**	**J**	14	1.5	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
Perfluoroundecanoic acid (PFUnA)	ND		14	3.9	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
Perfluorobutanesulfonic acid (PFBS)	ND		14	2.4	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
Perfluoropentanesulfonic acid (PFPeS)	ND		14	2.6	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
Br-Perfluorohexanesulfonic acid	ND		14	2.1	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
Total PFHxS	**34**		14	2.1	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
L-Perfluorohexanesulfonic acid	**34**		14	2.1	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
Perfluoroheptanesulfonic acid (PFHpS)	**6.7**	**J**	14	2.6	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
4:2 FTS	ND		14	3.8	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
6:2 FTS	ND		14	6.1	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
8:2 FTS	ND		14	1.4	ug/Kg		07/29/24 11:09	08/09/24 05:37	1
10:2 FTS	ND		14	1.4	ug/Kg		07/29/24 11:09	08/09/24 05:37	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*90*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:37*	*1*
13C5 PFPeA	*91*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:37*	*1*
13C2 PFHxA	*97*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:37*	*1*
13C4 PFHpA	*95*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:37*	*1*
13C4 PFOA	*95*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:37*	*1*
13C5 PFNA	*92*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:37*	*1*
13C2 PFDA	*98*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:37*	*1*
13C2 PFUnA	*112*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:37*	*1*
13C3 PFBS	*74*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:37*	*1*
18O2 PFHxS	*91*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:37*	*1*
13C4 PFOS	*78*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:37*	*1*
M2-4:2 FTS	*230*	*5+	*25 - 150*	*07/29/24 11:09*	*08/09/24 05:37*	*1*
M2-6:2 FTS	*139*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:37*	*1*
M2-8:2 FTS	*98*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:37*	*1*
13C2 10:2 FTS	*282*	*5+	*25 - 150*	*07/29/24 11:09*	*08/09/24 05:37*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**1800**		180	15	ug/Kg		07/29/24 11:09	08/15/24 11:38	5
Br-Perfluorooctanesulfonic acid	**340**		180	15	ug/Kg		07/29/24 11:09	08/15/24 11:38	5
Total PFOS	**2200**		180	15	ug/Kg		07/29/24 11:09	08/15/24 11:38	5

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*93*		*25 - 150*	*07/29/24 11:09*	*08/15/24 11:38*	*5*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK311143 liver
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-4
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**5.4**	**J**	7.1	1.7	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
Perfluoropentanoic acid (PFPeA)	ND		7.1	1.3	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
Perfluorohexanoic acid (PFHxA)	ND		7.1	2.0	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
Perfluoroheptanoic acid (PFHpA)	ND		7.1	0.83	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
L-Perfluorooctanoic acid	ND		7.1	1.4	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
Br-Perfluorooctanoic acid	ND		7.1	1.4	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
Total PFOA	ND		7.1	1.4	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
Perfluorononanoic acid (PFNA)	**6.9**	**J**	7.1	1.3	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
Perfluorodecanoic acid (PFDA)	**2.1**	**J**	7.1	0.74	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
Perfluoroundecanoic acid (PFUnA)	ND		7.1	1.9	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
Perfluorobutanesulfonic acid (PFBS)	ND		7.1	1.2	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
Perfluoropentanesulfonic acid (PFPeS)	ND		7.1	1.3	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
Br-Perfluorohexanesulfonic acid	ND		7.1	1.1	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
Total PFHxS	**1.1**	**J**	7.1	1.1	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
L-Perfluorohexanesulfonic acid	**1.1**	**J**	7.1	1.1	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		7.1	1.3	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
L-Perfluorooctanesulfonic acid	**350**		18	1.5	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
Br-Perfluorooctanesulfonic acid	**290**		18	1.5	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
Total PFOS	**640**		18	1.5	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
4:2 FTS	ND		7.1	1.9	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
6:2 FTS	ND		7.1	3.0	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
8:2 FTS	ND		7.1	0.71	ug/Kg		07/29/24 11:09	08/09/24 05:56	1
10:2 FTS	ND		7.1	0.72	ug/Kg		07/29/24 11:09	08/09/24 05:56	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*57*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:56*	*1*
13C5 PFPeA	*86*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:56*	*1*
13C2 PFHxA	*91*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:56*	*1*
13C4 PFHpA	*95*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:56*	*1*
13C4 PFOA	*87*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:56*	*1*
13C5 PFNA	*99*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:56*	*1*
13C2 PFDA	*96*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:56*	*1*
13C2 PFUnA	*95*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:56*	*1*
13C3 PFBS	*73*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:56*	*1*
18O2 PFHxS	*83*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:56*	*1*
13C4 PFOS	*84*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:56*	*1*
M2-4:2 FTS	*136*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:56*	*1*
M2-6:2 FTS	*158*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 05:56*	*1*
M2-8:2 FTS	*123*		*25 - 150*	*07/29/24 11:09*	*08/09/24 05:56*	*1*
13C2 10:2 FTS	*310*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 05:56*	*1*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK311145 liver

Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-5

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**15**		0.69	0.16	ug/Kg		07/29/24 11:09	08/09/24 06:15	1
Perfluoropentanoic acid (PFPeA)	**0.34**	**J**	0.69	0.12	ug/Kg		07/29/24 11:09	08/09/24 06:15	1
Perfluorohexanoic acid (PFHxA)	ND		0.69	0.19	ug/Kg		07/29/24 11:09	08/09/24 06:15	1
Perfluoroheptanoic acid (PFHpA)	**0.10**	**J**	0.69	0.080	ug/Kg		07/29/24 11:09	08/09/24 06:15	1
L-Perfluorooctanoic acid	**1.2**		0.69	0.14	ug/Kg		07/29/24 11:09	08/09/24 06:15	1
Br-Perfluorooctanoic acid	ND		0.69	0.14	ug/Kg		07/29/24 11:09	08/09/24 06:15	1
Total PFOA	**1.2**		0.69	0.14	ug/Kg		07/29/24 11:09	08/09/24 06:15	1
Perfluorononanoic acid (PFNA)	**56**		0.69	0.12	ug/Kg		07/29/24 11:09	08/09/24 06:15	1
Perfluorodecanoic acid (PFDA)	**31**		0.69	0.071	ug/Kg		07/29/24 11:09	08/09/24 06:15	1
Perfluoroundecanoic acid (PFUnA)	**2.6**		0.69	0.19	ug/Kg		07/29/24 11:09	08/09/24 06:15	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.69	0.12	ug/Kg		07/29/24 11:09	08/09/24 06:15	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.69	0.12	ug/Kg		07/29/24 11:09	08/09/24 06:15	1
4:2 FTS	ND		0.69	0.18	ug/Kg		07/29/24 11:09	08/09/24 06:15	1
6:2 FTS	**0.52**	**J**	0.69	0.29	ug/Kg		07/29/24 11:09	08/09/24 06:15	1
8:2 FTS	**8.9**		0.69	0.069	ug/Kg		07/29/24 11:09	08/09/24 06:15	1
10:2 FTS	**0.20**	**J**	0.69	0.070	ug/Kg		07/29/24 11:09	08/09/24 06:15	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*38*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:15*	*1*
13C5 PFPeA	*73*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:15*	*1*
13C2 PFHxA	*82*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:15*	*1*
13C4 PFHpA	*87*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:15*	*1*
13C4 PFOA	*84*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:15*	*1*
13C5 PFNA	*53*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:15*	*1*
13C2 PFDA	*94*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:15*	*1*
13C2 PFUnA	*116*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:15*	*1*
13C3 PFBS	*60*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:15*	*1*
M2-4:2 FTS	*182*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 06:15*	*1*
M2-6:2 FTS	*117*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:15*	*1*
M2-8:2 FTS	*140*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:15*	*1*
13C2 10:2 FTS	*266*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 06:15*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	ND		69	10	ug/Kg		07/29/24 11:09	08/15/24 16:10	100
Total PFHxS	**130**		69	10	ug/Kg		07/29/24 11:09	08/15/24 16:10	100
L-Perfluorohexanesulfonic acid	**130**		69	10	ug/Kg		07/29/24 11:09	08/15/24 16:10	100
Perfluoroheptanesulfonic acid (PFHpS)	**320**		69	13	ug/Kg		07/29/24 11:09	08/15/24 16:10	100
L-Perfluorooctanesulfonic acid	**31000**	**E**	170	14	ug/Kg		07/29/24 11:09	08/15/24 16:10	100
Br-Perfluorooctanesulfonic acid	**16000**	**E**	170	14	ug/Kg		07/29/24 11:09	08/15/24 16:10	100
Total PFOS	**47000**		170	14	ug/Kg		07/29/24 11:09	08/15/24 16:10	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*90*		*25 - 150*	*07/29/24 11:09*	*08/15/24 16:10*	*100*
13C4 PFOS	*70*		*25 - 150*	*07/29/24 11:09*	*08/15/24 16:10*	*100*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK311145 femur

Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-6

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		5.3	1.2	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
Perfluoropentanoic acid (PFPeA)	ND		5.3	0.92	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
Perfluorohexanoic acid (PFHxA)	ND		5.3	1.4	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
Perfluoroheptanoic acid (PFHpA)	ND		5.3	0.61	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
L-Perfluorooctanoic acid	ND		5.3	1.1	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
Br-Perfluorooctanoic acid	ND		5.3	1.1	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
Total PFOA	ND		5.3	1.1	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
Perfluorononanoic acid (PFNA)	**4.4**	**J**	5.3	0.92	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
Perfluorodecanoic acid (PFDA)	**1.7**	**J**	5.3	0.54	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
Perfluoroundecanoic acid (PFUnA)	ND		5.3	1.4	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
Perfluorobutanesulfonic acid (PFBS)	ND		5.3	0.89	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
Perfluoropentanesulfonic acid (PFPeS)	ND		5.3	0.95	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
Br-Perfluorohexanesulfonic acid	ND		5.3	0.78	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
Total PFHxS	**45**		5.3	0.78	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
L-Perfluorohexanesulfonic acid	**45**		5.3	0.78	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
Perfluoroheptanesulfonic acid (PFHpS)	**40**		5.3	0.97	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
4:2 FTS	ND		5.3	1.4	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
6:2 FTS	ND		5.3	2.2	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
8:2 FTS	ND		5.3	0.53	ug/Kg		07/29/24 11:09	08/09/24 06:35	1
10:2 FTS	ND		5.3	0.53	ug/Kg		07/29/24 11:09	08/09/24 06:35	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*84*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:35*	*1*
13C5 PFPeA	*91*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:35*	*1*
13C2 PFHxA	*86*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:35*	*1*
13C4 PFHpA	*81*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:35*	*1*
13C4 PFOA	*94*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:35*	*1*
13C5 PFNA	*82*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:35*	*1*
13C2 PFDA	*88*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:35*	*1*
13C2 PFUnA	*90*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:35*	*1*
13C3 PFBS	*85*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:35*	*1*
18O2 PFHxS	*83*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:35*	*1*
13C4 PFOS	*74*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:35*	*1*
M2-4:2 FTS	*170*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 06:35*	*1*
M2-6:2 FTS	*134*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:35*	*1*
M2-8:2 FTS	*134*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:35*	*1*
13C2 10:2 FTS	*225*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 06:35*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**1600**	**I**	130	11	ug/Kg		07/29/24 11:09	08/15/24 11:57	10
Br-Perfluorooctanesulfonic acid	**570**		130	11	ug/Kg		07/29/24 11:09	08/15/24 11:57	10
Total PFOS	**2200**		130	11	ug/Kg		07/29/24 11:09	08/15/24 11:57	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*94*		*25 - 150*	*07/29/24 11:09*	*08/15/24 11:57*	*10*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK311146 liver

Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-7

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**13**		0.65	0.15	ug/Kg		07/29/24 11:09	08/09/24 06:54	1
Perfluoropentanoic acid (PFPeA)	**0.52**	**J**	0.65	0.11	ug/Kg		07/29/24 11:09	08/09/24 06:54	1
Perfluorohexanoic acid (PFHxA)	**0.51**	**J**	0.65	0.18	ug/Kg		07/29/24 11:09	08/09/24 06:54	1
Perfluoroheptanoic acid (PFHpA)	**0.20**	**J**	0.65	0.075	ug/Kg		07/29/24 11:09	08/09/24 06:54	1
L-Perfluorooctanoic acid	**8.1**		0.65	0.13	ug/Kg		07/29/24 11:09	08/09/24 06:54	1
Br-Perfluorooctanoic acid	**0.30**	**J**	0.65	0.13	ug/Kg		07/29/24 11:09	08/09/24 06:54	1
Total PFOA	**8.4**		0.65	0.13	ug/Kg		07/29/24 11:09	08/09/24 06:54	1
Perfluorodecanoic acid (PFDA)	**28**		0.65	0.066	ug/Kg		07/29/24 11:09	08/09/24 06:54	1
Perfluoroundecanoic acid (PFUnA)	**5.3**		0.65	0.18	ug/Kg		07/29/24 11:09	08/09/24 06:54	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.65	0.11	ug/Kg		07/29/24 11:09	08/09/24 06:54	1
Perfluoropentanesulfonic acid (PFPeS)	**0.34**	**J**	0.65	0.12	ug/Kg		07/29/24 11:09	08/09/24 06:54	1
4:2 FTS	ND		0.65	0.17	ug/Kg		07/29/24 11:09	08/09/24 06:54	1
6:2 FTS	**3.0**		0.65	0.27	ug/Kg		07/29/24 11:09	08/09/24 06:54	1
8:2 FTS	**32**		0.65	0.065	ug/Kg		07/29/24 11:09	08/09/24 06:54	1
10:2 FTS	**0.35**	**J**	0.65	0.065	ug/Kg		07/29/24 11:09	08/09/24 06:54	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*36*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:54*	*1*
13C5 PFPeA	*72*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:54*	*1*
13C2 PFHxA	*89*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:54*	*1*
13C4 PFHpA	*97*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:54*	*1*
13C4 PFOA	*86*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:54*	*1*
13C2 PFDA	*108*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:54*	*1*
13C2 PFUnA	*117*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:54*	*1*
13C3 PFBS	*67*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:54*	*1*
M2-4:2 FTS	*157*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 06:54*	*1*
M2-6:2 FTS	*147*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:54*	*1*
M2-8:2 FTS	*147*		*25 - 150*	*07/29/24 11:09*	*08/09/24 06:54*	*1*
13C2 10:2 FTS	*213*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 06:54*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorononanoic acid (PFNA)	**72**		65	11	ug/Kg		07/29/24 11:09	08/15/24 16:29	100
Br-Perfluorohexanesulfonic acid	ND		65	9.5	ug/Kg		07/29/24 11:09	08/15/24 16:29	100
Total PFHxS	**110**		65	9.5	ug/Kg		07/29/24 11:09	08/15/24 16:29	100
L-Perfluorohexanesulfonic acid	**110**		65	9.5	ug/Kg		07/29/24 11:09	08/15/24 16:29	100
Perfluoroheptanesulfonic acid (PFHpS)	**110**		65	12	ug/Kg		07/29/24 11:09	08/15/24 16:29	100
L-Perfluorooctanesulfonic acid	**19000**	**E**	160	13	ug/Kg		07/29/24 11:09	08/15/24 16:29	100
Br-Perfluorooctanesulfonic acid	**4500**		160	13	ug/Kg		07/29/24 11:09	08/15/24 16:29	100
Total PFOS	**24000**		160	13	ug/Kg		07/29/24 11:09	08/15/24 16:29	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFNA	*83*		*25 - 150*	*07/29/24 11:09*	*08/15/24 16:29*	*100*
18O2 PFHxS	*87*		*25 - 150*	*07/29/24 11:09*	*08/15/24 16:29*	*100*
13C4 PFOS	*77*		*25 - 150*	*07/29/24 11:09*	*08/15/24 16:29*	*100*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK311146 femur
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-8
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		3.4	0.81	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
Perfluoropentanoic acid (PFPeA)	ND		3.4	0.60	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
Perfluorohexanoic acid (PFHxA)	ND		3.4	0.94	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
Perfluoroheptanoic acid (PFHpA)	ND		3.4	0.40	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
L-Perfluorooctanoic acid	**1.1**	**J**	3.4	0.70	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
Br-Perfluorooctanoic acid	ND		3.4	0.70	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
Total PFOA	**1.1**	**J**	3.4	0.70	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
Perfluorononanoic acid (PFNA)	**5.3**		3.4	0.60	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
Perfluorodecanoic acid (PFDA)	**1.8**	**J**	3.4	0.36	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
Perfluoroundecanoic acid (PFUnA)	ND		3.4	0.94	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
Perfluorobutanesulfonic acid (PFBS)	ND		3.4	0.59	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
Perfluoropentanesulfonic acid (PFPeS)	ND		3.4	0.62	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
Br-Perfluorohexanesulfonic acid	**0.66**	**J**	3.4	0.51	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
Total PFHxS	**23**		3.4	0.51	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
L-Perfluorohexanesulfonic acid	**22**		3.4	0.51	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
Perfluoroheptanesulfonic acid (PFHpS)	**12**		3.4	0.64	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
4:2 FTS	ND		3.4	0.92	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
6:2 FTS	ND		3.4	1.5	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
8:2 FTS	**1.5**	**J**	3.4	0.34	ug/Kg		07/29/24 11:09	08/09/24 07:33	1
10:2 FTS	ND		3.4	0.35	ug/Kg		07/29/24 11:09	08/09/24 07:33	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*82*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:33*	*1*
13C5 PFPeA	*86*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:33*	*1*
13C2 PFHxA	*88*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:33*	*1*
13C4 PFHpA	*88*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:33*	*1*
13C4 PFOA	*92*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:33*	*1*
13C5 PFNA	*85*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:33*	*1*
13C2 PFDA	*106*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:33*	*1*
13C2 PFUnA	*104*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:33*	*1*
13C3 PFBS	*82*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:33*	*1*
18O2 PFHxS	*86*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:33*	*1*
13C4 PFOS	*72*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:33*	*1*
M2-4:2 FTS	*174*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 07:33*	*1*
M2-6:2 FTS	*142*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:33*	*1*
M2-8:2 FTS	*121*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:33*	*1*
13C2 10:2 FTS	*406*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 07:33*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**1500**		86	7.0	ug/Kg		07/29/24 11:09	08/15/24 12:36	10
Br-Perfluorooctanesulfonic acid	**300**		86	7.0	ug/Kg		07/29/24 11:09	08/15/24 12:36	10
Total PFOS	**1800**		86	7.0	ug/Kg		07/29/24 11:09	08/15/24 12:36	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*99*		*25 - 150*	*07/29/24 11:09*	*08/15/24 12:36*	*10*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK311129 liver

Date Collected: 05/16/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-9

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**2.0**	**J**	2.5	0.59	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
Perfluoropentanoic acid (PFPeA)	ND		2.5	0.44	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
Perfluorohexanoic acid (PFHxA)	ND		2.5	0.68	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
Perfluoroheptanoic acid (PFHpA)	**0.56**	**J**	2.5	0.29	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
L-Perfluorooctanoic acid	**9.1**		2.5	0.51	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
Br-Perfluorooctanoic acid	**1.0**	**J**	2.5	0.51	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
Total PFOA	**10**		2.5	0.51	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
Perfluorononanoic acid (PFNA)	**11**		2.5	0.44	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
Perfluorodecanoic acid (PFDA)	**1.7**	**J**	2.5	0.26	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
Perfluoroundecanoic acid (PFUnA)	ND		2.5	0.68	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
Perfluorobutanesulfonic acid (PFBS)	ND		2.5	0.43	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
Perfluoropentanesulfonic acid (PFPeS)	**1.9**	**J**	2.5	0.45	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
Br-Perfluorohexanesulfonic acid	**8.3**		2.5	0.37	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
Total PFHxS	**110**		2.5	0.37	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
L-Perfluorohexanesulfonic acid	**100**		2.5	0.37	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
Perfluoroheptanesulfonic acid (PFHpS)	**9.3**		2.5	0.46	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
4:2 FTS	ND		2.5	0.67	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
6:2 FTS	ND		2.5	1.1	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
8:2 FTS	ND		2.5	0.25	ug/Kg		07/29/24 11:09	08/09/24 07:53	1
10:2 FTS	ND		2.5	0.25	ug/Kg		07/29/24 11:09	08/09/24 07:53	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*79*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:53*	*1*
13C5 PFPeA	*87*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:53*	*1*
13C2 PFHxA	*96*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:53*	*1*
13C4 PFHpA	*85*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:53*	*1*
13C4 PFOA	*87*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:53*	*1*
13C5 PFNA	*93*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:53*	*1*
13C2 PFDA	*98*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:53*	*1*
13C2 PFUnA	*99*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:53*	*1*
13C3 PFBS	*84*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:53*	*1*
18O2 PFHxS	*80*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:53*	*1*
13C4 PFOS	*74*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:53*	*1*
M2-4:2 FTS	*139*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:53*	*1*
M2-6:2 FTS	*124*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:53*	*1*
M2-8:2 FTS	*116*		*25 - 150*	*07/29/24 11:09*	*08/09/24 07:53*	*1*
13C2 10:2 FTS	*292*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 07:53*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**720**		63	5.1	ug/Kg		07/29/24 11:09	08/15/24 13:15	10
Br-Perfluorooctanesulfonic acid	**460**		63	5.1	ug/Kg		07/29/24 11:09	08/15/24 13:15	10
Total PFOS	**1200**		63	5.1	ug/Kg		07/29/24 11:09	08/15/24 13:15	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*93*		*25 - 150*	*07/29/24 11:09*	*08/15/24 13:15*	*10*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK311131 liver

Date Collected: 05/16/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-10

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**2.4**	**J**	3.3	0.79	ug/Kg		07/29/24 11:09	08/09/24 08:12	1
Perfluoropentanoic acid (PFPeA)	ND		3.3	0.58	ug/Kg		07/29/24 11:09	08/09/24 08:12	1
Perfluorohexanoic acid (PFHxA)	ND		3.3	0.91	ug/Kg		07/29/24 11:09	08/09/24 08:12	1
Perfluoroheptanoic acid (PFHpA)	**2.0**	**J**	3.3	0.39	ug/Kg		07/29/24 11:09	08/09/24 08:12	1
L-Perfluorooctanoic acid	**120**		3.3	0.67	ug/Kg		07/29/24 11:09	08/09/24 08:12	1
Br-Perfluorooctanoic acid	**13**		3.3	0.67	ug/Kg		07/29/24 11:09	08/09/24 08:12	1
Total PFOA	**140**		3.3	0.67	ug/Kg		07/29/24 11:09	08/09/24 08:12	1
Perfluorononanoic acid (PFNA)	**160**		3.3	0.58	ug/Kg		07/29/24 11:09	08/09/24 08:12	1
Perfluorodecanoic acid (PFDA)	**16**		3.3	0.34	ug/Kg		07/29/24 11:09	08/09/24 08:12	1
Perfluoroundecanoic acid (PFUnA)	ND		3.3	0.91	ug/Kg		07/29/24 11:09	08/09/24 08:12	1
Perfluorobutanesulfonic acid (PFBS)	ND		3.3	0.57	ug/Kg		07/29/24 11:09	08/09/24 08:12	1
Perfluoropentanesulfonic acid (PFPeS)	**6.0**		3.3	0.60	ug/Kg		07/29/24 11:09	08/09/24 08:12	1
4:2 FTS	ND		3.3	0.89	ug/Kg		07/29/24 11:09	08/09/24 08:12	1
6:2 FTS	**15**		3.3	1.4	ug/Kg		07/29/24 11:09	08/09/24 08:12	1
8:2 FTS	**14**		3.3	0.33	ug/Kg		07/29/24 11:09	08/09/24 08:12	1
10:2 FTS	ND		3.3	0.34	ug/Kg		07/29/24 11:09	08/09/24 08:12	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*84*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:12*	*1*
13C5 PFPeA	*108*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:12*	*1*
13C2 PFHxA	*103*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:12*	*1*
13C4 PFHpA	*94*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:12*	*1*
13C4 PFOA	*91*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:12*	*1*
13C5 PFNA	*90*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:12*	*1*
13C2 PFDA	*99*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:12*	*1*
13C2 PFUnA	*100*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:12*	*1*
13C3 PFBS	*90*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:12*	*1*
M2-4:2 FTS	*116*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:12*	*1*
M2-6:2 FTS	*147*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:12*	*1*
M2-8:2 FTS	*105*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:12*	*1*
13C2 10:2 FTS	*344*	*5+	*25 - 150*	*07/29/24 11:09*	*08/09/24 08:12*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	**110**	**J**	330	49	ug/Kg		07/29/24 11:09	08/15/24 15:50	100
Total PFHxS	**2000**		330	49	ug/Kg		07/29/24 11:09	08/15/24 15:50	100
L-Perfluorohexanesulfonic acid	**1900**		330	49	ug/Kg		07/29/24 11:09	08/15/24 15:50	100
Perfluoroheptanesulfonic acid (PFHpS)	**170**	**J**	330	62	ug/Kg		07/29/24 11:09	08/15/24 15:50	100
L-Perfluorooctanesulfonic acid	**12000**		830	68	ug/Kg		07/29/24 11:09	08/15/24 15:50	100
Br-Perfluorooctanesulfonic acid	**5600**		830	68	ug/Kg		07/29/24 11:09	08/15/24 15:50	100
Total PFOS	**17000**		830	68	ug/Kg		07/29/24 11:09	08/15/24 15:50	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*109*		*25 - 150*	*07/29/24 11:09*	*08/15/24 15:50*	*100*
13C4 PFOS	*100*		*25 - 150*	*07/29/24 11:09*	*08/15/24 15:50*	*100*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK311133 liver

Date Collected: 05/16/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-11

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**1.7**	**J**	2.7	0.64	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
Perfluoropentanoic acid (PFPeA)	ND		2.7	0.47	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
Perfluorohexanoic acid (PFHxA)	ND		2.7	0.74	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
Perfluoroheptanoic acid (PFHpA)	**0.60**	**J**	2.7	0.31	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
L-Perfluorooctanoic acid	**23**		2.7	0.55	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
Br-Perfluorooctanoic acid	**2.6**	**J**	2.7	0.55	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
Total PFOA	**26**		2.7	0.55	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
Perfluorononanoic acid (PFNA)	**26**		2.7	0.47	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
Perfluorodecanoic acid (PFDA)	**2.8**		2.7	0.28	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
Perfluoroundecanoic acid (PFUnA)	ND		2.7	0.74	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
Perfluorobutanesulfonic acid (PFBS)	ND		2.7	0.46	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
Perfluoropentanesulfonic acid (PFPeS)	**1.8**	**J**	2.7	0.49	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
Br-Perfluorohexanesulfonic acid	**15**		2.7	0.40	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
Total PFHxS	**150**		2.7	0.40	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
L-Perfluorohexanesulfonic acid	**130**		2.7	0.40	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
Perfluoroheptanesulfonic acid (PFHpS)	**22**		2.7	0.50	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
4:2 FTS	ND		2.7	0.72	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
6:2 FTS	ND		2.7	1.1	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
8:2 FTS	**0.60**	**J**	2.7	0.27	ug/Kg		07/29/24 11:09	08/09/24 08:31	1
10:2 FTS	ND		2.7	0.27	ug/Kg		07/29/24 11:09	08/09/24 08:31	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*74*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:31*	*1*
13C5 PFPeA	*89*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:31*	*1*
13C2 PFHxA	*97*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:31*	*1*
13C4 PFHpA	*97*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:31*	*1*
13C4 PFOA	*90*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:31*	*1*
13C5 PFNA	*98*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:31*	*1*
13C2 PFDA	*94*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:31*	*1*
13C2 PFUnA	*91*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:31*	*1*
13C3 PFBS	*85*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:31*	*1*
18O2 PFHxS	*85*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:31*	*1*
13C4 PFOS	*75*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:31*	*1*
M2-4:2 FTS	*134*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:31*	*1*
M2-6:2 FTS	*137*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:31*	*1*
M2-8:2 FTS	*118*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:31*	*1*
13C2 10:2 FTS	*220*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 08:31*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**1700**		140	11	ug/Kg		07/29/24 11:09	08/16/24 09:38	20
Br-Perfluorooctanesulfonic acid	**720**		140	11	ug/Kg		07/29/24 11:09	08/16/24 09:38	20
Total PFOS	**2400**		140	11	ug/Kg		07/29/24 11:09	08/16/24 09:38	20

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*92*		*25 - 150*	*07/29/24 11:09*	*08/16/24 09:38*	*20*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK319511 muscle

Date Collected: 02/10/24 10:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-12

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.53	0.12	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
Perfluoropentanoic acid (PFPeA)	ND		0.53	0.093	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
Perfluorohexanoic acid (PFHxA)	ND		0.53	0.14	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
Perfluoroheptanoic acid (PFHpA)	ND		0.53	0.061	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
L-Perfluorooctanoic acid	ND		0.53	0.11	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
Br-Perfluorooctanoic acid	ND		0.53	0.11	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
Total PFOA	ND		0.53	0.11	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
Perfluorononanoic acid (PFNA)	ND		0.53	0.093	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
Perfluorodecanoic acid (PFDA)	ND		0.53	0.054	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
Perfluoroundecanoic acid (PFUnA)	ND		0.53	0.14	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.53	0.090	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.53	0.096	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
Br-Perfluorohexanesulfonic acid	ND		0.53	0.078	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
Total PFHxS	ND		0.53	0.078	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
L-Perfluorohexanesulfonic acid	ND		0.53	0.078	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.53	0.098	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
L-Perfluorooctanesulfonic acid	ND		1.3	0.11	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
Br-Perfluorooctanesulfonic acid	ND		1.3	0.11	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
Total PFOS	ND		1.3	0.11	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
4:2 FTS	ND		0.53	0.14	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
6:2 FTS	ND		0.53	0.22	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
8:2 FTS	ND		0.53	0.053	ug/Kg		07/29/24 11:09	08/09/24 08:51	1
10:2 FTS	ND		0.53	0.053	ug/Kg		07/29/24 11:09	08/09/24 08:51	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*59*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:51*	*1*
13C5 PFPeA	*79*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:51*	*1*
13C2 PFHxA	*84*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:51*	*1*
13C4 PFHpA	*81*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:51*	*1*
13C4 PFOA	*88*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:51*	*1*
13C5 PFNA	*30*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:51*	*1*
13C2 PFDA	*108*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:51*	*1*
13C2 PFUnA	*93*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:51*	*1*
13C3 PFBS	*65*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:51*	*1*
18O2 PFHxS	*79*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:51*	*1*
13C4 PFOS	*71*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:51*	*1*
M2-4:2 FTS	*142*		*25 - 150*	*07/29/24 11:09*	*08/09/24 08:51*	*1*
M2-6:2 FTS	*180*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 08:51*	*1*
M2-8:2 FTS	*184*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 08:51*	*1*
13C2 10:2 FTS	*300*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 08:51*	*1*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK319092 liver

Date Collected: 02/10/24 10:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-13

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.66	0.16	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
Perfluoropentanoic acid (PFPeA)	ND		0.66	0.12	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
Perfluorohexanoic acid (PFHxA)	ND		0.66	0.18	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
Perfluoroheptanoic acid (PFHpA)	ND		0.66	0.077	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
L-Perfluorooctanoic acid	ND		0.66	0.13	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
Br-Perfluorooctanoic acid	ND		0.66	0.13	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
Total PFOA	ND		0.66	0.13	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
Perfluorononanoic acid (PFNA)	ND		0.66	0.12	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
Perfluorodecanoic acid (PFDA)	**0.47**	**J**	0.66	0.068	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
Perfluoroundecanoic acid (PFUnA)	**0.20**	**J**	0.66	0.18	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.66	0.11	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.66	0.12	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
Br-Perfluorohexanesulfonic acid	ND		0.66	0.098	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
Total PFHxS	ND		0.66	0.098	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
L-Perfluorohexanesulfonic acid	ND		0.66	0.098	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.66	0.12	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
L-Perfluorooctanesulfonic acid	ND		1.7	0.13	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
Br-Perfluorooctanesulfonic acid	ND		1.7	0.13	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
Total PFOS	ND		1.7	0.13	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
4:2 FTS	ND		0.66	0.18	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
6:2 FTS	ND		0.66	0.28	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
8:2 FTS	ND		0.66	0.066	ug/Kg		07/29/24 11:09	08/09/24 09:10	1
10:2 FTS	ND		0.66	0.067	ug/Kg		07/29/24 11:09	08/09/24 09:10	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*53*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:10*	*1*
13C5 PFPeA	*84*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:10*	*1*
13C2 PFHxA	*85*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:10*	*1*
13C4 PFHpA	*88*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:10*	*1*
13C4 PFOA	*87*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:10*	*1*
13C5 PFNA	*97*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:10*	*1*
13C2 PFDA	*111*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:10*	*1*
13C2 PFUnA	*106*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:10*	*1*
13C3 PFBS	*70*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:10*	*1*
18O2 PFHxS	*85*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:10*	*1*
13C4 PFOS	*81*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:10*	*1*
M2-4:2 FTS	*192*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 09:10*	*1*
M2-6:2 FTS	*76*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:10*	*1*
M2-8:2 FTS	*167*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 09:10*	*1*
13C2 10:2 FTS	*397*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 09:10*	*1*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: Velvet ant NE2 03
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-14
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		3.7	0.87	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
Perfluoropentanoic acid (PFPeA)	ND		3.7	0.65	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
Perfluorohexanoic acid (PFHxA)	ND		3.7	1.0	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
Perfluoroheptanoic acid (PFHpA)	ND		3.7	0.43	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
L-Perfluorooctanoic acid	**1.1**	**J**	3.7	0.75	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
Br-Perfluorooctanoic acid	ND		3.7	0.75	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
Total PFOA	**1.1**	**J**	3.7	0.75	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
Perfluorononanoic acid (PFNA)	ND		3.7	0.65	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
Perfluorodecanoic acid (PFDA)	ND		3.7	0.38	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
Perfluoroundecanoic acid (PFUnA)	ND		3.7	1.0	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
Perfluorobutanesulfonic acid (PFBS)	ND		3.7	0.63	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
Perfluoropentanesulfonic acid (PFPeS)	ND		3.7	0.67	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
Br-Perfluorohexanesulfonic acid	ND		3.7	0.55	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
Total PFHxS	**2.5**	**J**	3.7	0.55	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
L-Perfluorohexanesulfonic acid	**2.5**	**J**	3.7	0.55	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		3.7	0.69	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
L-Perfluorooctanesulfonic acid	**4.8**	**J**	9.3	0.75	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
Br-Perfluorooctanesulfonic acid	**2.0**	**J**	9.3	0.75	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
Total PFOS	**6.9**	**J**	9.3	0.75	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
4:2 FTS	ND		3.7	0.99	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
6:2 FTS	ND		3.7	1.6	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
8:2 FTS	ND		3.7	0.37	ug/Kg		07/29/24 11:09	08/09/24 09:30	1
10:2 FTS	ND		3.7	0.37	ug/Kg		07/29/24 11:09	08/09/24 09:30	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*92*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:30*	*1*
13C5 PFPeA	*96*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:30*	*1*
13C2 PFHxA	*100*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:30*	*1*
13C4 PFHpA	*91*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:30*	*1*
13C4 PFOA	*92*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:30*	*1*
13C5 PFNA	*93*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:30*	*1*
13C2 PFDA	*91*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:30*	*1*
13C2 PFUnA	*87*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:30*	*1*
13C3 PFBS	*83*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:30*	*1*
18O2 PFHxS	*89*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:30*	*1*
13C4 PFOS	*90*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:30*	*1*
M2-4:2 FTS	*95*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:30*	*1*
M2-6:2 FTS	*103*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:30*	*1*
M2-8:2 FTS	*103*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:30*	*1*
13C2 10:2 FTS	*133*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:30*	*1*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: ArtNE2 01

Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-15

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**0.91**	**J**	1.2	0.29	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
Perfluoropentanoic acid (PFPeA)	**5.0**		1.2	0.21	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
Perfluorohexanoic acid (PFHxA)	**14**		1.2	0.33	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
Perfluoroheptanoic acid (PFHpA)	**5.2**		1.2	0.14	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
L-Perfluorooctanoic acid	**13**		1.2	0.25	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
Br-Perfluorooctanoic acid	**1.1**	**J**	1.2	0.25	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
Total PFOA	**14**		1.2	0.25	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
Perfluorononanoic acid (PFNA)	**10**	**I**	1.2	0.21	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
Perfluorodecanoic acid (PFDA)	**0.69**	**J**	1.2	0.13	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
Perfluoroundecanoic acid (PFUnA)	ND		1.2	0.33	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
Perfluorobutanesulfonic acid (PFBS)	**1.5**		1.2	0.21	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
Perfluoropentanesulfonic acid (PFPeS)	**2.2**		1.2	0.22	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
Br-Perfluorohexanesulfonic acid	**8.9**		1.2	0.18	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
Total PFHxS	**63**		1.2	0.18	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
L-Perfluorohexanesulfonic acid	**54**		1.2	0.18	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
Perfluoroheptanesulfonic acid (PFHpS)	**9.2**		1.2	0.23	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
4:2 FTS	ND		1.2	0.32	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
6:2 FTS	**49**		1.2	0.52	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
8:2 FTS	**1.3**		1.2	0.12	ug/Kg		07/29/24 11:09	08/09/24 09:49	1
10:2 FTS	ND		1.2	0.12	ug/Kg		07/29/24 11:09	08/09/24 09:49	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*84*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:49*	*1*
13C5 PFPeA	*94*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:49*	*1*
13C2 PFHxA	*91*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:49*	*1*
13C4 PFHpA	*99*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:49*	*1*
13C4 PFOA	*91*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:49*	*1*
13C5 PFNA	*88*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:49*	*1*
13C2 PFDA	*89*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:49*	*1*
13C2 PFUnA	*96*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:49*	*1*
13C3 PFBS	*100*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:49*	*1*
18O2 PFHxS	*86*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:49*	*1*
13C4 PFOS	*78*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:49*	*1*
M2-4:2 FTS	*112*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:49*	*1*
M2-6:2 FTS	*96*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:49*	*1*
M2-8:2 FTS	*88*		*25 - 150*	*07/29/24 11:09*	*08/09/24 09:49*	*1*
13C2 10:2 FTS	*234*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 09:49*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**390**		30	2.5	ug/Kg		07/29/24 11:09	08/15/24 15:11	10
Br-Perfluorooctanesulfonic acid	**240**		30	2.5	ug/Kg		07/29/24 11:09	08/15/24 15:11	10
Total PFOS	**630**		30	2.5	ug/Kg		07/29/24 11:09	08/15/24 15:11	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*95*		*25 - 150*	*07/29/24 11:09*	*08/15/24 15:11*	*10*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: ArtNE2 02
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-16
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		20	4.7	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
Perfluoropentanoic acid (PFPeA)	ND		20	3.5	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
Perfluorohexanoic acid (PFHxA)	ND		20	5.5	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
Perfluoroheptanoic acid (PFHpA)	ND		20	2.3	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
L-Perfluorooctanoic acid	ND		20	4.0	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
Br-Perfluorooctanoic acid	ND		20	4.0	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
Total PFOA	ND		20	4.0	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
Perfluorononanoic acid (PFNA)	ND		20	3.5	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
Perfluorodecanoic acid (PFDA)	ND		20	2.1	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
Perfluoroundecanoic acid (PFUnA)	ND		20	5.4	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
Perfluorobutanesulfonic acid (PFBS)	ND		20	3.4	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
Perfluoropentanesulfonic acid (PFPeS)	ND		20	3.6	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
Br-Perfluorohexanesulfonic acid	**8.7**	**J**	20	3.0	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
Total PFHxS	**17**	**J**	20	3.0	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
L-Perfluorohexanesulfonic acid	**8.7**	**J**	20	3.0	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		20	3.7	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
L-Perfluorooctanesulfonic acid	**75**		50	4.1	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
Br-Perfluorooctanesulfonic acid	**22**	**J**	50	4.1	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
Total PFOS	**98**		50	4.1	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
4:2 FTS	ND		20	5.3	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
6:2 FTS	ND		20	8.5	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
8:2 FTS	ND		20	2.0	ug/Kg		07/29/24 11:09	08/09/24 10:08	1
10:2 FTS	ND		20	2.0	ug/Kg		07/29/24 11:09	08/09/24 10:08	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*95*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:08*	*1*
13C5 PFPeA	*91*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:08*	*1*
13C2 PFHxA	*98*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:08*	*1*
13C4 PFHpA	*97*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:08*	*1*
13C4 PFOA	*96*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:08*	*1*
13C5 PFNA	*95*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:08*	*1*
13C2 PFDA	*95*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:08*	*1*
13C2 PFUnA	*92*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:08*	*1*
13C3 PFBS	*87*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:08*	*1*
18O2 PFHxS	*94*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:08*	*1*
13C4 PFOS	*93*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:08*	*1*
M2-4:2 FTS	*119*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:08*	*1*
M2-6:2 FTS	*109*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:08*	*1*
M2-8:2 FTS	*100*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:08*	*1*
13C2 10:2 FTS	*134*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:08*	*1*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: ArtNE2 03
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-17
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.81	0.19	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
Perfluoropentanoic acid (PFPeA)	ND		0.81	0.14	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
Perfluorohexanoic acid (PFHxA)	ND		0.81	0.22	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
Perfluoroheptanoic acid (PFHpA)	**0.52**	**J**	0.81	0.094	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
L-Perfluorooctanoic acid	**1.7**		0.81	0.16	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
Br-Perfluorooctanoic acid	**0.16**	**J**	0.81	0.16	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
Total PFOA	**1.8**		0.81	0.16	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
Perfluorononanoic acid (PFNA)	**0.72**	**J**	0.81	0.14	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
Perfluorodecanoic acid (PFDA)	**0.13**	**J**	0.81	0.083	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
Perfluoroundecanoic acid (PFUnA)	ND		0.81	0.22	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.81	0.14	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.81	0.15	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
Br-Perfluorohexanesulfonic acid	**0.37**	**J**	0.81	0.12	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
Total PFHxS	**3.1**		0.81	0.12	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
L-Perfluorohexanesulfonic acid	**2.7**		0.81	0.12	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.25**	**J**	0.81	0.15	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
L-Perfluorooctanesulfonic acid	**18**		2.0	0.16	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
Br-Perfluorooctanesulfonic acid	**7.4**		2.0	0.16	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
Total PFOS	**25**		2.0	0.16	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
4:2 FTS	ND		0.81	0.21	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
6:2 FTS	**1.3**		0.81	0.34	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
8:2 FTS	ND		0.81	0.081	ug/Kg		07/29/24 11:09	08/09/24 10:28	1
10:2 FTS	ND		0.81	0.081	ug/Kg		07/29/24 11:09	08/09/24 10:28	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*42*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:28*	*1*
13C5 PFPeA	*76*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:28*	*1*
13C2 PFHxA	*89*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:28*	*1*
13C4 PFHpA	*89*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:28*	*1*
13C4 PFOA	*87*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:28*	*1*
13C5 PFNA	*92*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:28*	*1*
13C2 PFDA	*114*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:28*	*1*
13C2 PFUnA	*121*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:28*	*1*
13C3 PFBS	*81*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:28*	*1*
18O2 PFHxS	*92*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:28*	*1*
13C4 PFOS	*90*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:28*	*1*
M2-4:2 FTS	*150*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:28*	*1*
M2-6:2 FTS	*131*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:28*	*1*
M2-8:2 FTS	*146*		*25 - 150*	*07/29/24 11:09*	*08/09/24 10:28*	*1*
13C2 10:2 FTS	*447*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 10:28*	*1*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: ArtNE2 04
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-18
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		6.7	1.6	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
Perfluoropentanoic acid (PFPeA)	ND		6.7	1.2	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
Perfluorohexanoic acid (PFHxA)	ND		6.7	1.8	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
Perfluoroheptanoic acid (PFHpA)	ND		6.7	0.77	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
L-Perfluorooctanoic acid	**7.4**		6.7	1.3	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
Br-Perfluorooctanoic acid	**1.4**	**J**	6.7	1.3	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
Total PFOA	**8.8**		6.7	1.3	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
Perfluorononanoic acid (PFNA)	**3.0**	**J**	6.7	1.2	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
Perfluorodecanoic acid (PFDA)	ND		6.7	0.69	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
Perfluoroundecanoic acid (PFUnA)	ND		6.7	1.8	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
Perfluorobutanesulfonic acid (PFBS)	ND		6.7	1.1	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
Perfluoropentanesulfonic acid (PFPeS)	ND		6.7	1.2	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
Br-Perfluorohexanesulfonic acid	ND		6.7	0.99	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
Total PFHxS	**8.2**		6.7	0.99	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
L-Perfluorohexanesulfonic acid	**8.2**		6.7	0.99	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
Perfluoroheptanesulfonic acid (PFHpS)	**2.5**	**J**	6.7	1.2	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
L-Perfluorooctanesulfonic acid	**110**		17	1.4	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
Br-Perfluorooctanesulfonic acid	**45**		17	1.4	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
Total PFOS	**150**		17	1.4	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
4:2 FTS	ND		6.7	1.8	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
6:2 FTS	ND		6.7	2.8	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
8:2 FTS	ND		6.7	0.67	ug/Kg		07/29/24 11:09	08/09/24 14:21	1
10:2 FTS	ND		6.7	0.67	ug/Kg		07/29/24 11:09	08/09/24 14:21	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*99*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:21*	*1*
13C5 PFPeA	*104*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:21*	*1*
13C2 PFHxA	*100*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:21*	*1*
13C4 PFHpA	*93*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:21*	*1*
13C4 PFOA	*87*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:21*	*1*
13C5 PFNA	*95*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:21*	*1*
13C2 PFDA	*87*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:21*	*1*
13C2 PFUnA	*93*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:21*	*1*
13C3 PFBS	*94*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:21*	*1*
18O2 PFHxS	*93*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:21*	*1*
13C4 PFOS	*90*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:21*	*1*
M2-4:2 FTS	*108*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:21*	*1*
M2-6:2 FTS	*103*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:21*	*1*
M2-8:2 FTS	*89*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:21*	*1*
13C2 10:2 FTS	*132*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:21*	*1*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: ArtNE4 01

Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-19

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.2	0.28	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
Perfluoropentanoic acid (PFPeA)	**1.1**	**J**	1.2	0.21	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
Perfluorohexanoic acid (PFHxA)	**2.9**		1.2	0.32	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
Perfluoroheptanoic acid (PFHpA)	**1.8**		1.2	0.14	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
L-Perfluorooctanoic acid	**6.7**		1.2	0.24	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
Br-Perfluorooctanoic acid	**0.58**	**J**	1.2	0.24	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
Total PFOA	**7.3**		1.2	0.24	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
Perfluorononanoic acid (PFNA)	**5.3**		1.2	0.21	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
Perfluorodecanoic acid (PFDA)	**0.64**	**J**	1.2	0.12	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
Perfluoroundecanoic acid (PFUnA)	ND		1.2	0.32	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
Perfluorobutanesulfonic acid (PFBS)	**0.20**	**J**	1.2	0.20	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
Perfluoropentanesulfonic acid (PFPeS)	**0.67**	**J**	1.2	0.21	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
Br-Perfluorohexanesulfonic acid	**4.3**		1.2	0.17	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
Total PFHxS	**33**		1.2	0.17	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
L-Perfluorohexanesulfonic acid	**29**		1.2	0.17	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
Perfluoroheptanesulfonic acid (PFHpS)	**6.4**		1.2	0.22	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
4:2 FTS	ND		1.2	0.31	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
6:2 FTS	**42**		1.2	0.50	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
8:2 FTS	**1.8**		1.2	0.12	ug/Kg		07/29/24 11:09	08/09/24 14:40	1
10:2 FTS	ND		1.2	0.12	ug/Kg		07/29/24 11:09	08/09/24 14:40	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*92*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:40*	*1*
13C5 PFPeA	*91*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:40*	*1*
13C2 PFHxA	*92*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:40*	*1*
13C4 PFHpA	*92*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:40*	*1*
13C4 PFOA	*94*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:40*	*1*
13C5 PFNA	*93*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:40*	*1*
13C2 PFDA	*89*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:40*	*1*
13C2 PFUnA	*98*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:40*	*1*
13C3 PFBS	*96*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:40*	*1*
18O2 PFHxS	*91*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:40*	*1*
13C4 PFOS	*81*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:40*	*1*
M2-4:2 FTS	*97*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:40*	*1*
M2-6:2 FTS	*94*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:40*	*1*
M2-8:2 FTS	*93*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:40*	*1*
13C2 10:2 FTS	*89*		*25 - 150*	*07/29/24 11:09*	*08/09/24 14:40*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**320**		29	2.4	ug/Kg		07/29/24 11:09	08/16/24 09:57	10
Br-Perfluorooctanesulfonic acid	**180**		29	2.4	ug/Kg		07/29/24 11:09	08/16/24 09:57	10
Total PFOS	**500**		29	2.4	ug/Kg		07/29/24 11:09	08/16/24 09:57	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*105*		*25 - 150*	*07/29/24 11:09*	*08/16/24 09:57*	*10*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: ArtNE4 02

Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-20

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		2.3	0.55	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
Perfluoropentanoic acid (PFPeA)	ND		2.3	0.41	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
Perfluorohexanoic acid (PFHxA)	ND		2.3	0.63	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
Perfluoroheptanoic acid (PFHpA)	**0.84**	**J**	2.3	0.27	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
L-Perfluorooctanoic acid	**2.3**		2.3	0.47	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
Br-Perfluorooctanoic acid	ND		2.3	0.47	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
Total PFOA	**2.3**		2.3	0.47	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
Perfluorononanoic acid (PFNA)	**1.3**	**J**	2.3	0.41	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
Perfluorodecanoic acid (PFDA)	ND		2.3	0.24	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
Perfluoroundecanoic acid (PFUnA)	ND		2.3	0.63	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
Perfluorobutanesulfonic acid (PFBS)	ND		2.3	0.40	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
Perfluoropentanesulfonic acid (PFPeS)	ND		2.3	0.42	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
Br-Perfluorohexanesulfonic acid	**0.99**	**J**	2.3	0.34	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
Total PFHxS	**7.7**		2.3	0.34	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
L-Perfluorohexanesulfonic acid	**6.7**		2.3	0.34	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.81**	**J**	2.3	0.43	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
L-Perfluorooctanesulfonic acid	**54**		5.8	0.47	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
Br-Perfluorooctanesulfonic acid	**29**		5.8	0.47	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
Total PFOS	**83**		5.8	0.47	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
4:2 FTS	ND		2.3	0.62	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
6:2 FTS	**1.5**	**J**	2.3	0.99	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
8:2 FTS	ND		2.3	0.23	ug/Kg		07/29/24 11:09	08/09/24 15:00	1
10:2 FTS	ND		2.3	0.23	ug/Kg		07/29/24 11:09	08/09/24 15:00	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*112*		*25 - 150*	*07/29/24 11:09*	*08/09/24 15:00*	*1*
13C5 PFPeA	*107*		*25 - 150*	*07/29/24 11:09*	*08/09/24 15:00*	*1*
13C2 PFHxA	*103*		*25 - 150*	*07/29/24 11:09*	*08/09/24 15:00*	*1*
13C4 PFHpA	*105*		*25 - 150*	*07/29/24 11:09*	*08/09/24 15:00*	*1*
13C4 PFOA	*92*		*25 - 150*	*07/29/24 11:09*	*08/09/24 15:00*	*1*
13C5 PFNA	*96*		*25 - 150*	*07/29/24 11:09*	*08/09/24 15:00*	*1*
13C2 PFDA	*106*		*25 - 150*	*07/29/24 11:09*	*08/09/24 15:00*	*1*
13C2 PFUnA	*104*		*25 - 150*	*07/29/24 11:09*	*08/09/24 15:00*	*1*
13C3 PFBS	*97*		*25 - 150*	*07/29/24 11:09*	*08/09/24 15:00*	*1*
18O2 PFHxS	*109*		*25 - 150*	*07/29/24 11:09*	*08/09/24 15:00*	*1*
13C4 PFOS	*105*		*25 - 150*	*07/29/24 11:09*	*08/09/24 15:00*	*1*
M2-4:2 FTS	*94*		*25 - 150*	*07/29/24 11:09*	*08/09/24 15:00*	*1*
M2-6:2 FTS	*99*		*25 - 150*	*07/29/24 11:09*	*08/09/24 15:00*	*1*
M2-8:2 FTS	*96*		*25 - 150*	*07/29/24 11:09*	*08/09/24 15:00*	*1*
13C2 10:2 FTS	*142*		*25 - 150*	*07/29/24 11:09*	*08/09/24 15:00*	*1*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: ArtNE4 03
Date Collected: 05/16/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-21
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		4.0	0.94	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
Perfluoropentanoic acid (PFPeA)	ND		4.0	0.70	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
Perfluorohexanoic acid (PFHxA)	ND		4.0	1.1	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
Perfluoroheptanoic acid (PFHpA)	ND		4.0	0.46	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
L-Perfluorooctanoic acid	ND		4.0	0.81	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
Br-Perfluorooctanoic acid	ND		4.0	0.81	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
Total PFOA	ND		4.0	0.81	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
Perfluorononanoic acid (PFNA)	ND		4.0	0.70	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
Perfluorodecanoic acid (PFDA)	ND		4.0	0.41	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
Perfluoroundecanoic acid (PFUnA)	ND		4.0	1.1	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
Perfluorobutanesulfonic acid (PFBS)	ND		4.0	0.68	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
Perfluoropentanesulfonic acid (PFPeS)	ND		4.0	0.72	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
Br-Perfluorohexanesulfonic acid	ND		4.0	0.59	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
Total PFHxS	**0.74**	**J**	4.0	0.59	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
L-Perfluorohexanesulfonic acid	**0.74**	**J**	4.0	0.59	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		4.0	0.74	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
L-Perfluorooctanesulfonic acid	**6.1**	**J**	10	0.81	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
Br-Perfluorooctanesulfonic acid	**2.7**	**J**	10	0.81	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
Total PFOS	**8.9**	**J**	10	0.81	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
4:2 FTS	ND		4.0	1.1	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
6:2 FTS	ND		4.0	1.7	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
8:2 FTS	ND		4.0	0.40	ug/Kg		08/08/24 10:31	08/09/24 19:31	1
10:2 FTS	ND		4.0	0.40	ug/Kg		08/08/24 10:31	08/09/24 19:31	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*76*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:31*	*1*
13C5 PFPeA	*96*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:31*	*1*
13C2 PFHxA	*95*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:31*	*1*
13C4 PFHpA	*87*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:31*	*1*
13C4 PFOA	*92*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:31*	*1*
13C5 PFNA	*78*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:31*	*1*
13C2 PFDA	*89*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:31*	*1*
13C2 PFUnA	*86*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:31*	*1*
13C3 PFBS	*78*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:31*	*1*
18O2 PFHxS	*80*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:31*	*1*
13C4 PFOS	*78*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:31*	*1*
M2-4:2 FTS	*117*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:31*	*1*
M2-6:2 FTS	*94*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:31*	*1*
M2-8:2 FTS	*91*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:31*	*1*
13C2 10:2 FTS	*126*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:31*	*1*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: ArtNE4 04
Date Collected: 05/15/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-22
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**1.0**	**J**	3.4	0.81	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
Perfluoropentanoic acid (PFPeA)	ND		3.4	0.60	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
Perfluorohexanoic acid (PFHxA)	**1.6**	**J**	3.4	0.94	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
Perfluoroheptanoic acid (PFHpA)	**0.71**	**J**	3.4	0.40	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
L-Perfluorooctanoic acid	**10**		3.4	0.70	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
Br-Perfluorooctanoic acid	**0.91**	**J**	3.4	0.70	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
Total PFOA	**11**		3.4	0.70	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
Perfluorononanoic acid (PFNA)	**6.6**		3.4	0.60	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
Perfluorodecanoic acid (PFDA)	**0.39**	**J**	3.4	0.36	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
Perfluoroundecanoic acid (PFUnA)	ND		3.4	0.94	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
Perfluorobutanesulfonic acid (PFBS)	ND		3.4	0.59	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
Perfluoropentanesulfonic acid (PFPeS)	ND		3.4	0.62	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
Br-Perfluorohexanesulfonic acid	**2.0**	**J**	3.4	0.51	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
Total PFHxS	**21**		3.4	0.51	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
L-Perfluorohexanesulfonic acid	**19**		3.4	0.51	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
Perfluoroheptanesulfonic acid (PFHpS)	**3.5**		3.4	0.64	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
L-Perfluorooctanesulfonic acid	**160**		8.6	0.70	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
Br-Perfluorooctanesulfonic acid	**75**		8.6	0.70	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
Total PFOS	**240**		8.6	0.70	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
4:2 FTS	ND		3.4	0.92	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
6:2 FTS	ND		3.4	1.5	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
8:2 FTS	ND		3.4	0.34	ug/Kg		08/08/24 10:31	08/09/24 19:51	1
10:2 FTS	ND		3.4	0.35	ug/Kg		08/08/24 10:31	08/09/24 19:51	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*40*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:51*	*1*
13C5 PFPeA	*72*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:51*	*1*
13C2 PFHxA	*86*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:51*	*1*
13C4 PFHpA	*89*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:51*	*1*
13C4 PFOA	*96*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:51*	*1*
13C5 PFNA	*91*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:51*	*1*
13C2 PFDA	*114*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:51*	*1*
13C2 PFUnA	*117*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:51*	*1*
13C3 PFBS	*71*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:51*	*1*
18O2 PFHxS	*87*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:51*	*1*
13C4 PFOS	*84*		*25 - 150*	*08/08/24 10:31*	*08/09/24 19:51*	*1*
M2-4:2 FTS	*219*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 19:51*	*1*
M2-6:2 FTS	*225*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 19:51*	*1*
M2-8:2 FTS	*260*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 19:51*	*1*
13C2 10:2 FTS	*445*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 19:51*	*1*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: VDS 0 TEST
Date Collected: 07/17/24 00:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-23
Matrix: Water

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		310	150	ng/L		07/30/24 19:07	08/09/24 15:19	1
Perfluoropentanoic acid (PFPeA)	ND		130	31	ng/L		07/30/24 19:07	08/09/24 15:19	1
Perfluorohexanoic acid (PFHxA)	ND		130	36	ng/L		07/30/24 19:07	08/09/24 15:19	1
Perfluoroheptanoic acid (PFHpA)	ND		130	16	ng/L		07/30/24 19:07	08/09/24 15:19	1
L-Perfluorooctanoic acid	ND		130	53	ng/L		07/30/24 19:07	08/09/24 15:19	1
Br-Perfluorooctanoic acid	ND		130	53	ng/L		07/30/24 19:07	08/09/24 15:19	1
Total PFOA	ND		130	53	ng/L		07/30/24 19:07	08/09/24 15:19	1
Perfluorononanoic acid (PFNA)	ND		130	17	ng/L		07/30/24 19:07	08/09/24 15:19	1
Perfluorodecanoic acid (PFDA)	ND		130	19	ng/L		07/30/24 19:07	08/09/24 15:19	1
Perfluoroundecanoic acid (PFUnA)	ND		130	69	ng/L		07/30/24 19:07	08/09/24 15:19	1
Perfluorobutanesulfonic acid (PFBS)	ND		130	13	ng/L		07/30/24 19:07	08/09/24 15:19	1
Perfluoropentanesulfonic acid (PFPeS)	ND		130	19	ng/L		07/30/24 19:07	08/09/24 15:19	1
Br-Perfluorohexanesulfonic acid	ND		130	36	ng/L		07/30/24 19:07	08/09/24 15:19	1
Total PFHxS	ND		130	36	ng/L		07/30/24 19:07	08/09/24 15:19	1
L-Perfluorohexanesulfonic acid	ND		130	36	ng/L		07/30/24 19:07	08/09/24 15:19	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		130	12	ng/L		07/30/24 19:07	08/09/24 15:19	1
L-Perfluorooctanesulfonic acid	ND		130	34	ng/L		07/30/24 19:07	08/09/24 15:19	1
Br-Perfluorooctanesulfonic acid	ND		130	34	ng/L		07/30/24 19:07	08/09/24 15:19	1
Total PFOS	ND		130	34	ng/L		07/30/24 19:07	08/09/24 15:19	1
4:2 FTS	ND		130	15	ng/L		07/30/24 19:07	08/09/24 15:19	1
6:2 FTS	ND		310	160	ng/L		07/30/24 19:07	08/09/24 15:19	1
8:2 FTS	ND		130	29	ng/L		07/30/24 19:07	08/09/24 15:19	1
10:2 FTS	ND		130	42	ng/L		07/30/24 19:07	08/09/24 15:19	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*97*		*25 - 150*	*07/30/24 19:07*	*08/09/24 15:19*	*1*
13C5 PFPeA	*101*		*25 - 150*	*07/30/24 19:07*	*08/09/24 15:19*	*1*
13C2 PFHxA	*96*		*25 - 150*	*07/30/24 19:07*	*08/09/24 15:19*	*1*
13C4 PFHpA	*95*		*25 - 150*	*07/30/24 19:07*	*08/09/24 15:19*	*1*
13C4 PFOA	*101*		*25 - 150*	*07/30/24 19:07*	*08/09/24 15:19*	*1*
13C5 PFNA	*94*		*25 - 150*	*07/30/24 19:07*	*08/09/24 15:19*	*1*
13C2 PFDA	*95*		*25 - 150*	*07/30/24 19:07*	*08/09/24 15:19*	*1*
13C2 PFUnA	*97*		*25 - 150*	*07/30/24 19:07*	*08/09/24 15:19*	*1*
13C3 PFBS	*96*		*25 - 150*	*07/30/24 19:07*	*08/09/24 15:19*	*1*
18O2 PFHxS	*92*		*25 - 150*	*07/30/24 19:07*	*08/09/24 15:19*	*1*
13C4 PFOS	*93*		*25 - 150*	*07/30/24 19:07*	*08/09/24 15:19*	*1*
M2-4:2 FTS	*85*		*25 - 150*	*07/30/24 19:07*	*08/09/24 15:19*	*1*
M2-6:2 FTS	*88*		*25 - 150*	*07/30/24 19:07*	*08/09/24 15:19*	*1*
M2-8:2 FTS	*93*		*25 - 150*	*07/30/24 19:07*	*08/09/24 15:19*	*1*
13C2 10:2 FTS	*119*		*25 - 150*	*07/30/24 19:07*	*08/09/24 15:19*	*1*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284441
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-24
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.1	0.25	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
Perfluoropentanoic acid (PFPeA)	ND		1.1	0.19	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
Perfluorohexanoic acid (PFHxA)	ND		1.1	0.29	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
Perfluoroheptanoic acid (PFHpA)	ND		1.1	0.12	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
L-Perfluorooctanoic acid	**2.0**		1.1	0.21	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
Br-Perfluorooctanoic acid	ND		1.1	0.21	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
Total PFOA	**2.0**		1.1	0.21	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
Perfluorononanoic acid (PFNA)	**8.8**		1.1	0.19	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
Perfluorodecanoic acid (PFDA)	**3.0**		1.1	0.11	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
Perfluoroundecanoic acid (PFUnA)	**1.4**		1.1	0.29	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.1	0.18	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.1	0.19	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
Br-Perfluorohexanesulfonic acid	**1.5**		1.1	0.16	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
Total PFHxS	**58**		1.1	0.16	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
L-Perfluorohexanesulfonic acid	**56**		1.1	0.16	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
Perfluoroheptanesulfonic acid (PFHpS)	**22**		1.1	0.20	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
4:2 FTS	ND		1.1	0.28	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
6:2 FTS	ND		1.1	0.45	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
8:2 FTS	**16**		1.1	0.11	ug/Kg		08/08/24 10:31	08/09/24 20:10	1
10:2 FTS	**3.0**	**B**	1.1	0.11	ug/Kg		08/08/24 10:31	08/09/24 20:10	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*94*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:10*	*1*
13C5 PFPeA	*95*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:10*	*1*
13C2 PFHxA	*97*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:10*	*1*
13C4 PFHpA	*87*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:10*	*1*
13C4 PFOA	*87*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:10*	*1*
13C5 PFNA	*83*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:10*	*1*
13C2 PFDA	*97*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:10*	*1*
13C2 PFUnA	*112*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:10*	*1*
13C3 PFBS	*81*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:10*	*1*
18O2 PFHxS	*85*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:10*	*1*
13C4 PFOS	*63*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:10*	*1*
M2-4:2 FTS	*103*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:10*	*1*
M2-6:2 FTS	*110*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:10*	*1*
M2-8:2 FTS	*97*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:10*	*1*
13C2 10:2 FTS	*486*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 20:10*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**1600**		130	11	ug/Kg		08/08/24 10:31	08/12/24 20:19	50
Br-Perfluorooctanesulfonic acid	**370**		130	11	ug/Kg		08/08/24 10:31	08/12/24 20:19	50
Total PFOS	**2000**		130	11	ug/Kg		08/08/24 10:31	08/12/24 20:19	50

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*79*		*25 - 150*	*08/08/24 10:31*	*08/12/24 20:19*	*50*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284442
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-25
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.85	0.20	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
Perfluoropentanoic acid (PFPeA)	ND		0.85	0.15	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
Perfluorohexanoic acid (PFHxA)	ND		0.85	0.23	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
Perfluoroheptanoic acid (PFHpA)	**0.14**	**J**	0.85	0.098	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
L-Perfluorooctanoic acid	**3.0**		0.85	0.17	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
Br-Perfluorooctanoic acid	ND		0.85	0.17	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
Total PFOA	**3.0**		0.85	0.17	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
Perfluorononanoic acid (PFNA)	**11**		0.85	0.15	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
Perfluorodecanoic acid (PFDA)	**2.6**		0.85	0.087	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
Perfluoroundecanoic acid (PFUnA)	**1.3**		0.85	0.23	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.85	0.14	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
Perfluoropentanesulfonic acid (PFPeS)	**0.15**	**J**	0.85	0.15	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
Br-Perfluorohexanesulfonic acid	**1.3**		0.85	0.13	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
Total PFHxS	**60**		0.85	0.13	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
L-Perfluorohexanesulfonic acid	**59**		0.85	0.13	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
Perfluoroheptanesulfonic acid (PFHpS)	**14**		0.85	0.16	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
4:2 FTS	ND		0.85	0.23	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
6:2 FTS	ND		0.85	0.36	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
8:2 FTS	**6.9**		0.85	0.085	ug/Kg		08/08/24 10:31	08/09/24 20:30	1
10:2 FTS	**0.34**	**J B**	0.85	0.086	ug/Kg		08/08/24 10:31	08/09/24 20:30	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*82*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:30*	*1*
13C5 PFPeA	*86*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:30*	*1*
13C2 PFHxA	*96*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:30*	*1*
13C4 PFHpA	*94*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:30*	*1*
13C4 PFOA	*89*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:30*	*1*
13C5 PFNA	*91*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:30*	*1*
13C2 PFDA	*99*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:30*	*1*
13C2 PFUnA	*109*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:30*	*1*
13C3 PFBS	*77*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:30*	*1*
18O2 PFHxS	*84*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:30*	*1*
13C4 PFOS	*75*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:30*	*1*
M2-4:2 FTS	*130*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:30*	*1*
M2-6:2 FTS	*112*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:30*	*1*
M2-8:2 FTS	*104*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:30*	*1*
13C2 10:2 FTS	*566*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 20:30*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**470**		21	1.7	ug/Kg		08/08/24 10:31	08/12/24 20:58	10
Br-Perfluorooctanesulfonic acid	**130**		21	1.7	ug/Kg		08/08/24 10:31	08/12/24 20:58	10
Total PFOS	**590**		21	1.7	ug/Kg		08/08/24 10:31	08/12/24 20:58	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*91*		*25 - 150*	*08/08/24 10:31*	*08/12/24 20:58*	*10*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284443

Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-26

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**0.14**	**J**	0.50	0.12	ug/Kg		08/08/24 10:31	08/09/24 20:49	1
Perfluoropentanoic acid (PFPeA)	ND		0.50	0.088	ug/Kg		08/08/24 10:31	08/09/24 20:49	1
Perfluorohexanoic acid (PFHxA)	ND		0.50	0.14	ug/Kg		08/08/24 10:31	08/09/24 20:49	1
Perfluoroheptanoic acid (PFHpA)	**0.21**	**J**	0.50	0.058	ug/Kg		08/08/24 10:31	08/09/24 20:49	1
L-Perfluorooctanoic acid	**14**		0.50	0.10	ug/Kg		08/08/24 10:31	08/09/24 20:49	1
Br-Perfluorooctanoic acid	**0.47**	**J**	0.50	0.10	ug/Kg		08/08/24 10:31	08/09/24 20:49	1
Total PFOA	**14**		0.50	0.10	ug/Kg		08/08/24 10:31	08/09/24 20:49	1
Perfluorononanoic acid (PFNA)	**22**		0.50	0.088	ug/Kg		08/08/24 10:31	08/09/24 20:49	1
Perfluorodecanoic acid (PFDA)	**2.3**		0.50	0.052	ug/Kg		08/08/24 10:31	08/09/24 20:49	1
Perfluoroundecanoic acid (PFUnA)	**0.42**	**J**	0.50	0.14	ug/Kg		08/08/24 10:31	08/09/24 20:49	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.50	0.085	ug/Kg		08/08/24 10:31	08/09/24 20:49	1
Perfluoropentanesulfonic acid (PFPeS)	**0.72**		0.50	0.091	ug/Kg		08/08/24 10:31	08/09/24 20:49	1
Perfluoroheptanesulfonic acid (PFHpS)	**36**		0.50	0.093	ug/Kg		08/08/24 10:31	08/09/24 20:49	1
4:2 FTS	ND		0.50	0.13	ug/Kg		08/08/24 10:31	08/09/24 20:49	1
6:2 FTS	ND		0.50	0.21	ug/Kg		08/08/24 10:31	08/09/24 20:49	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*58*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:49*	*1*
13C5 PFPeA	*68*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:49*	*1*
13C2 PFHxA	*86*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:49*	*1*
13C4 PFHpA	*87*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:49*	*1*
13C4 PFOA	*83*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:49*	*1*
13C5 PFNA	*82*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:49*	*1*
13C2 PFDA	*115*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:49*	*1*
13C2 PFUnA	*125*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:49*	*1*
13C3 PFBS	*69*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:49*	*1*
13C4 PFOS	*65*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:49*	*1*
M2-4:2 FTS	*123*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:49*	*1*
M2-6:2 FTS	*129*		*25 - 150*	*08/08/24 10:31*	*08/09/24 20:49*	*1*
M2-8:2 FTS	*208*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 20:49*	*1*
13C2 10:2 FTS	*486*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 20:49*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	**5.6**	**J**	25	3.7	ug/Kg		08/08/24 10:31	08/12/24 21:17	50
Total PFHxS	**380**		25	3.7	ug/Kg		08/08/24 10:31	08/12/24 21:17	50
L-Perfluorohexanesulfonic acid	**380**		25	3.7	ug/Kg		08/08/24 10:31	08/12/24 21:17	50
L-Perfluorooctanesulfonic acid	**690**		63	5.1	ug/Kg		08/08/24 10:31	08/12/24 21:17	50
Br-Perfluorooctanesulfonic acid	**210**		63	5.1	ug/Kg		08/08/24 10:31	08/12/24 21:17	50
Total PFOS	**890**		63	5.1	ug/Kg		08/08/24 10:31	08/12/24 21:17	50
8:2 FTS	**2.6**	**J**	25	2.5	ug/Kg		08/08/24 10:31	08/12/24 21:17	50
10:2 FTS	ND		25	2.5	ug/Kg		08/08/24 10:31	08/12/24 21:17	50

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*84*		*25 - 150*	*08/08/24 10:31*	*08/12/24 21:17*	*50*
13C4 PFOS	*77*		*25 - 150*	*08/08/24 10:31*	*08/12/24 21:17*	*50*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284444
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-27
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**0.28**	**J**	0.76	0.18	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
Perfluoropentanoic acid (PFPeA)	ND		0.76	0.13	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
Perfluorohexanoic acid (PFHxA)	ND		0.76	0.21	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
Perfluoroheptanoic acid (PFHpA)	**0.090**	**J**	0.76	0.088	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
L-Perfluorooctanoic acid	**1.6**		0.76	0.15	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
Br-Perfluorooctanoic acid	**0.21**	**J**	0.76	0.15	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
Total PFOA	**1.8**		0.76	0.15	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
Perfluorononanoic acid (PFNA)	**4.6**		0.76	0.13	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
Perfluorodecanoic acid (PFDA)	**1.7**		0.76	0.078	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
Perfluoroundecanoic acid (PFUnA)	**0.80**		0.76	0.21	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.76	0.13	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.76	0.14	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
Br-Perfluorohexanesulfonic acid	**0.82**		0.76	0.11	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
Total PFHxS	**34**		0.76	0.11	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
L-Perfluorohexanesulfonic acid	**33**		0.76	0.11	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
Perfluoroheptanesulfonic acid (PFHpS)	**8.7**		0.76	0.14	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
4:2 FTS	ND		0.76	0.20	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
6:2 FTS	ND		0.76	0.32	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
8:2 FTS	**4.3**		0.76	0.076	ug/Kg		08/08/24 10:31	08/09/24 21:08	1
10:2 FTS	**0.67**	**J B**	0.76	0.077	ug/Kg		08/08/24 10:31	08/09/24 21:08	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*81*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:08*	*1*
13C5 PFPeA	*80*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:08*	*1*
13C2 PFHxA	*92*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:08*	*1*
13C4 PFHpA	*87*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:08*	*1*
13C4 PFOA	*85*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:08*	*1*
13C5 PFNA	*86*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:08*	*1*
13C2 PFDA	*89*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:08*	*1*
13C2 PFUnA	*107*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:08*	*1*
13C3 PFBS	*79*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:08*	*1*
18O2 PFHxS	*77*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:08*	*1*
13C4 PFOS	*73*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:08*	*1*
M2-4:2 FTS	*104*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:08*	*1*
M2-6:2 FTS	*106*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:08*	*1*
M2-8:2 FTS	*98*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:08*	*1*
13C2 10:2 FTS	*460*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 21:08*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**510**		19	1.5	ug/Kg		08/08/24 10:31	08/12/24 22:16	10
Br-Perfluorooctanesulfonic acid	**120**		19	1.5	ug/Kg		08/08/24 10:31	08/12/24 22:16	10
Total PFOS	**640**		19	1.5	ug/Kg		08/08/24 10:31	08/12/24 22:16	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*80*		*25 - 150*	*08/08/24 10:31*	*08/12/24 22:16*	*10*

Client Sample ID: NK284445

Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-28

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**0.33**	**J**	1.0	0.24	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
Perfluoropentanoic acid (PFPeA)	**0.19**	**J**	1.0	0.18	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
Perfluorohexanoic acid (PFHxA)	**0.35**	**J**	1.0	0.28	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
Perfluoroheptanoic acid (PFHpA)	**0.47**	**J**	1.0	0.12	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
L-Perfluorooctanoic acid	**6.4**		1.0	0.21	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
Br-Perfluorooctanoic acid	**0.50**	**J**	1.0	0.21	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
Total PFOA	**6.9**		1.0	0.21	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
Perfluorononanoic acid (PFNA)	**6.6**		1.0	0.18	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
Perfluorodecanoic acid (PFDA)	**2.1**		1.0	0.11	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
Perfluoroundecanoic acid (PFUnA)	**0.86**	**J**	1.0	0.28	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
Perfluoropentanesulfonic acid (PFPeS)	**0.56**	**J**	1.0	0.18	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
Br-Perfluorohexanesulfonic acid	**3.0**		1.0	0.15	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
Total PFHxS	**62**		1.0	0.15	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
L-Perfluorohexanesulfonic acid	**59**		1.0	0.15	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
Perfluoroheptanesulfonic acid (PFHpS)	**13**		1.0	0.19	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
4:2 FTS	ND		1.0	0.27	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
6:2 FTS	ND		1.0	0.43	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
8:2 FTS	**7.3**		1.0	0.10	ug/Kg		08/08/24 10:31	08/09/24 21:28	1
10:2 FTS	**1.4**	**B**	1.0	0.10	ug/Kg		08/08/24 10:31	08/09/24 21:28	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*81*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:28*	*1*
13C5 PFPeA	*94*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:28*	*1*
13C2 PFHxA	*92*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:28*	*1*
13C4 PFHpA	*86*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:28*	*1*
13C4 PFOA	*89*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:28*	*1*
13C5 PFNA	*91*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:28*	*1*
13C2 PFDA	*92*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:28*	*1*
13C2 PFUnA	*104*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:28*	*1*
13C3 PFBS	*79*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:28*	*1*
18O2 PFHxS	*85*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:28*	*1*
13C4 PFOS	*70*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:28*	*1*
M2-4:2 FTS	*110*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:28*	*1*
M2-6:2 FTS	*96*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:28*	*1*
M2-8:2 FTS	*101*		*25 - 150*	*08/08/24 10:31*	*08/09/24 21:28*	*1*
13C2 10:2 FTS	*406*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 21:28*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**740**		26	2.1	ug/Kg		08/08/24 10:31	08/14/24 09:51	10
Br-Perfluorooctanesulfonic acid	**190**		26	2.1	ug/Kg		08/08/24 10:31	08/14/24 09:51	10
Total PFOS	**940**		26	2.1	ug/Kg		08/08/24 10:31	08/14/24 09:51	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*97*		*25 - 150*	*08/08/24 10:31*	*08/14/24 09:51*	*10*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284446
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-29
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**0.50**	**J**	0.70	0.17	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
Perfluoropentanoic acid (PFPeA)	**0.31**	**J**	0.70	0.12	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
Perfluorohexanoic acid (PFHxA)	**0.68**	**J**	0.70	0.19	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
Perfluoroheptanoic acid (PFHpA)	**0.74**		0.70	0.082	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
L-Perfluorooctanoic acid	**8.1**		0.70	0.14	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
Br-Perfluorooctanoic acid	**0.51**	**J**	0.70	0.14	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
Total PFOA	**8.6**		0.70	0.14	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
Perfluorononanoic acid (PFNA)	**6.8**		0.70	0.12	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
Perfluorodecanoic acid (PFDA)	**2.4**		0.70	0.073	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
Perfluoroundecanoic acid (PFUnA)	**1.3**		0.70	0.19	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.70	0.12	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
Perfluoropentanesulfonic acid (PFPeS)	**0.37**	**J**	0.70	0.13	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
Perfluoroheptanesulfonic acid (PFHpS)	**18**		0.70	0.13	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
4:2 FTS	ND		0.70	0.19	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
6:2 FTS	ND		0.70	0.30	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
8:2 FTS	**5.3**		0.70	0.070	ug/Kg		08/08/24 10:31	08/09/24 22:07	1
10:2 FTS	**1.2**	**B**	0.70	0.071	ug/Kg		08/08/24 10:31	08/09/24 22:07	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*88*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:07*	*1*
13C5 PFPeA	*92*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:07*	*1*
13C2 PFHxA	*96*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:07*	*1*
13C4 PFHpA	*94*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:07*	*1*
13C4 PFOA	*91*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:07*	*1*
13C5 PFNA	*92*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:07*	*1*
13C2 PFDA	*100*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:07*	*1*
13C2 PFUnA	*114*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:07*	*1*
13C3 PFBS	*72*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:07*	*1*
13C4 PFOS	*66*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:07*	*1*
M2-4:2 FTS	*128*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:07*	*1*
M2-6:2 FTS	*126*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:07*	*1*
M2-8:2 FTS	*111*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:07*	*1*
13C2 10:2 FTS	*497*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 22:07*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	ND		35	5.2	ug/Kg		08/08/24 10:31	08/12/24 22:54	50
Total PFHxS	**84**		35	5.2	ug/Kg		08/08/24 10:31	08/12/24 22:54	50
L-Perfluorohexanesulfonic acid	**84**		35	5.2	ug/Kg		08/08/24 10:31	08/12/24 22:54	50
L-Perfluorooctanesulfonic acid	**820**		88	7.1	ug/Kg		08/08/24 10:31	08/12/24 22:54	50
Br-Perfluorooctanesulfonic acid	**200**		88	7.1	ug/Kg		08/08/24 10:31	08/12/24 22:54	50
Total PFOS	**1000**		88	7.1	ug/Kg		08/08/24 10:31	08/12/24 22:54	50

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*89*		*25 - 150*	*08/08/24 10:31*	*08/12/24 22:54*	*50*
13C4 PFOS	*96*		*25 - 150*	*08/08/24 10:31*	*08/12/24 22:54*	*50*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284447
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-30
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.1	0.27	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
Perfluoropentanoic acid (PFPeA)	ND		1.1	0.20	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
Perfluorohexanoic acid (PFHxA)	ND		1.1	0.31	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
Perfluoroheptanoic acid (PFHpA)	ND		1.1	0.13	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
L-Perfluorooctanoic acid	ND		1.1	0.23	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
Br-Perfluorooctanoic acid	ND		1.1	0.23	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
Total PFOA	ND		1.1	0.23	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
Perfluorononanoic acid (PFNA)	ND		1.1	0.20	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
Perfluorodecanoic acid (PFDA)	ND		1.1	0.12	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
Perfluoroundecanoic acid (PFUnA)	ND		1.1	0.31	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.1	0.19	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.1	0.21	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
Br-Perfluorohexanesulfonic acid	ND		1.1	0.17	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
Total PFHxS	**0.92**	**J**	1.1	0.17	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
L-Perfluorohexanesulfonic acid	**0.92**	**J**	1.1	0.17	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.1	0.21	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
L-Perfluorooctanesulfonic acid	**7.9**	**I**	2.8	0.23	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
Br-Perfluorooctanesulfonic acid	**1.3**	**J**	2.8	0.23	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
Total PFOS	**9.2**		2.8	0.23	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
4:2 FTS	ND		1.1	0.30	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
6:2 FTS	ND		1.1	0.48	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
8:2 FTS	ND		1.1	0.11	ug/Kg		08/08/24 10:31	08/09/24 22:26	1
10:2 FTS	ND		1.1	0.11	ug/Kg		08/08/24 10:31	08/09/24 22:26	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*77*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:26*	*1*
13C5 PFPeA	*95*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:26*	*1*
13C2 PFHxA	*104*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:26*	*1*
13C4 PFHpA	*90*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:26*	*1*
13C4 PFOA	*89*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:26*	*1*
13C5 PFNA	*88*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:26*	*1*
13C2 PFDA	*92*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:26*	*1*
13C2 PFUnA	*93*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:26*	*1*
13C3 PFBS	*78*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:26*	*1*
18O2 PFHxS	*76*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:26*	*1*
13C4 PFOS	*82*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:26*	*1*
M2-4:2 FTS	*97*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:26*	*1*
M2-6:2 FTS	*109*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:26*	*1*
M2-8:2 FTS	*92*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:26*	*1*
13C2 10:2 FTS	*414*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 22:26*	*1*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284448

Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-31

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.56	0.13	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
Perfluoropentanoic acid (PFPeA)	ND		0.56	0.098	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
Perfluorohexanoic acid (PFHxA)	ND		0.56	0.15	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
Perfluoroheptanoic acid (PFHpA)	**0.41**	**J**	0.56	0.065	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
L-Perfluorooctanoic acid	**3.8**		0.56	0.11	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
Br-Perfluorooctanoic acid	**0.21**	**J**	0.56	0.11	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
Total PFOA	**4.0**		0.56	0.11	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
Perfluorononanoic acid (PFNA)	**2.2**		0.56	0.098	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
Perfluorodecanoic acid (PFDA)	**0.21**	**J**	0.56	0.058	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
Perfluoroundecanoic acid (PFUnA)	ND		0.56	0.15	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
Perfluorobutanesulfonic acid (PFBS)	**0.21**	**J**	0.56	0.096	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
Perfluoropentanesulfonic acid (PFPeS)	**1.2**		0.56	0.10	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
Br-Perfluorohexanesulfonic acid	**3.1**		0.56	0.083	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
Total PFHxS	**44**		0.56	0.083	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
L-Perfluorohexanesulfonic acid	**40**		0.56	0.083	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
Perfluoroheptanesulfonic acid (PFHpS)	**2.8**		0.56	0.10	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
4:2 FTS	ND		0.56	0.15	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
6:2 FTS	**0.56**		0.56	0.24	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
8:2 FTS	**0.49**	**J**	0.56	0.056	ug/Kg		08/08/24 10:31	08/09/24 22:45	1
10:2 FTS	**0.068**	**J B**	0.56	0.057	ug/Kg		08/08/24 10:31	08/09/24 22:45	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*61*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:45*	*1*
13C5 PFPeA	*75*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:45*	*1*
13C2 PFHxA	*85*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:45*	*1*
13C4 PFHpA	*89*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:45*	*1*
13C4 PFOA	*84*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:45*	*1*
13C5 PFNA	*85*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:45*	*1*
13C2 PFDA	*92*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:45*	*1*
13C2 PFUnA	*98*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:45*	*1*
13C3 PFBS	*70*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:45*	*1*
18O2 PFHxS	*81*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:45*	*1*
13C4 PFOS	*79*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:45*	*1*
M2-4:2 FTS	*145*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:45*	*1*
M2-6:2 FTS	*107*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:45*	*1*
M2-8:2 FTS	*97*		*25 - 150*	*08/08/24 10:31*	*08/09/24 22:45*	*1*
13C2 10:2 FTS	*438*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 22:45*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**130**		14	1.1	ug/Kg		08/08/24 10:31	08/12/24 23:53	10
Br-Perfluorooctanesulfonic acid	**35**		14	1.1	ug/Kg		08/08/24 10:31	08/12/24 23:53	10
Total PFOS	**170**		14	1.1	ug/Kg		08/08/24 10:31	08/12/24 23:53	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*92*		*25 - 150*	*08/08/24 10:31*	*08/12/24 23:53*	*10*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284449
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-32
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.3	0.31	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
Perfluoropentanoic acid (PFPeA)	ND		1.3	0.23	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
Perfluorohexanoic acid (PFHxA)	ND		1.3	0.36	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
Perfluoroheptanoic acid (PFHpA)	**0.41**	**J**	1.3	0.15	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
L-Perfluorooctanoic acid	**2.3**		1.3	0.27	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
Br-Perfluorooctanoic acid	ND		1.3	0.27	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
Total PFOA	**2.3**		1.3	0.27	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
Perfluorononanoic acid (PFNA)	**3.9**		1.3	0.23	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
Perfluorodecanoic acid (PFDA)	**1.1**	**J**	1.3	0.14	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
Perfluoroundecanoic acid (PFUnA)	**1.4**		1.3	0.36	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.3	0.22	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
Perfluoropentanesulfonic acid (PFPeS)	**0.31**	**J**	1.3	0.24	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
Br-Perfluorohexanesulfonic acid	**2.9**		1.3	0.19	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
Total PFHxS	**84**		1.3	0.19	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
L-Perfluorohexanesulfonic acid	**81**		1.3	0.19	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
Perfluoroheptanesulfonic acid (PFHpS)	**6.6**		1.3	0.24	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
4:2 FTS	ND		1.3	0.35	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
6:2 FTS	ND		1.3	0.56	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
8:2 FTS	**37**		1.3	0.13	ug/Kg		08/08/24 10:31	08/09/24 23:05	1
10:2 FTS	**3.4**	**B**	1.3	0.13	ug/Kg		08/08/24 10:31	08/09/24 23:05	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*88*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:05*	*1*
13C5 PFPeA	*95*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:05*	*1*
13C2 PFHxA	*95*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:05*	*1*
13C4 PFHpA	*89*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:05*	*1*
13C4 PFOA	*90*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:05*	*1*
13C5 PFNA	*96*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:05*	*1*
13C2 PFDA	*101*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:05*	*1*
13C2 PFUnA	*96*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:05*	*1*
13C3 PFBS	*75*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:05*	*1*
18O2 PFHxS	*96*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:05*	*1*
13C4 PFOS	*78*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:05*	*1*
M2-4:2 FTS	*137*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:05*	*1*
M2-6:2 FTS	*132*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:05*	*1*
M2-8:2 FTS	*123*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:05*	*1*
13C2 10:2 FTS	*513*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 23:05*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**390**		33	2.7	ug/Kg		08/08/24 10:31	08/13/24 00:12	10
Br-Perfluorooctanesulfonic acid	**81**		33	2.7	ug/Kg		08/08/24 10:31	08/13/24 00:12	10
Total PFOS	**470**		33	2.7	ug/Kg		08/08/24 10:31	08/13/24 00:12	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*94*		*25 - 150*	*08/08/24 10:31*	*08/13/24 00:12*	*10*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284450

Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-33

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.8	0.42	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
Perfluoropentanoic acid (PFPeA)	ND		1.8	0.31	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
Perfluorohexanoic acid (PFHxA)	ND		1.8	0.49	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
Perfluoroheptanoic acid (PFHpA)	**0.25**	**J**	1.8	0.21	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
L-Perfluorooctanoic acid	**1.4**	**J**	1.8	0.36	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
Br-Perfluorooctanoic acid	ND		1.8	0.36	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
Total PFOA	**1.4**	**J**	1.8	0.36	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
Perfluorononanoic acid (PFNA)	**2.8**		1.8	0.31	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
Perfluorodecanoic acid (PFDA)	**1.0**	**J**	1.8	0.18	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
Perfluoroundecanoic acid (PFUnA)	**1.2**	**J**	1.8	0.49	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.8	0.30	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.8	0.32	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
Br-Perfluorohexanesulfonic acid	**0.99**	**J**	1.8	0.26	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
Total PFHxS	**33**		1.8	0.26	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
L-Perfluorohexanesulfonic acid	**32**		1.8	0.26	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
Perfluoroheptanesulfonic acid (PFHpS)	**4.1**		1.8	0.33	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
4:2 FTS	ND		1.8	0.48	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
6:2 FTS	ND		1.8	0.76	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
8:2 FTS	**42**		1.8	0.18	ug/Kg		08/08/24 10:31	08/09/24 23:24	1
10:2 FTS	**2.9**	**B**	1.8	0.18	ug/Kg		08/08/24 10:31	08/09/24 23:24	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*92*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:24*	*1*
13C5 PFPeA	*100*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:24*	*1*
13C2 PFHxA	*91*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:24*	*1*
13C4 PFHpA	*95*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:24*	*1*
13C4 PFOA	*87*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:24*	*1*
13C5 PFNA	*91*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:24*	*1*
13C2 PFDA	*89*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:24*	*1*
13C2 PFUnA	*100*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:24*	*1*
13C3 PFBS	*87*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:24*	*1*
18O2 PFHxS	*87*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:24*	*1*
13C4 PFOS	*86*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:24*	*1*
M2-4:2 FTS	*105*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:24*	*1*
M2-6:2 FTS	*113*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:24*	*1*
M2-8:2 FTS	*100*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:24*	*1*
13C2 10:2 FTS	*536*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 23:24*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**340**		89	7.3	ug/Kg		08/08/24 10:31	08/14/24 10:10	20
Br-Perfluorooctanesulfonic acid	**51**	**J**	89	7.3	ug/Kg		08/08/24 10:31	08/14/24 10:10	20
Total PFOS	**390**		89	7.3	ug/Kg		08/08/24 10:31	08/14/24 10:10	20

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*102*		*25 - 150*	*08/08/24 10:31*	*08/14/24 10:10*	*20*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284451

Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-34

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.92	0.22	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
Perfluoropentanoic acid (PFPeA)	ND		0.92	0.16	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
Perfluorohexanoic acid (PFHxA)	ND		0.92	0.25	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
Perfluoroheptanoic acid (PFHpA)	**0.14**	**J**	0.92	0.11	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
L-Perfluorooctanoic acid	**0.86**	**J**	0.92	0.19	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
Br-Perfluorooctanoic acid	ND		0.92	0.19	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
Total PFOA	**0.86**	**J**	0.92	0.19	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
Perfluorononanoic acid (PFNA)	**2.0**		0.92	0.16	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
Perfluorodecanoic acid (PFDA)	**0.69**	**J**	0.92	0.094	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
Perfluoroundecanoic acid (PFUnA)	**0.58**	**J**	0.92	0.25	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.92	0.16	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.92	0.17	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
Br-Perfluorohexanesulfonic acid	**0.80**	**J**	0.92	0.14	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
Total PFHxS	**31**		0.92	0.14	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
L-Perfluorohexanesulfonic acid	**30**		0.92	0.14	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
Perfluoroheptanesulfonic acid (PFHpS)	**3.6**		0.92	0.17	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
4:2 FTS	ND		0.92	0.24	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
6:2 FTS	ND		0.92	0.39	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
8:2 FTS	**12**		0.92	0.092	ug/Kg		08/08/24 10:31	08/09/24 23:44	1
10:2 FTS	**1.9**	**B**	0.92	0.093	ug/Kg		08/08/24 10:31	08/09/24 23:44	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*99*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:44*	*1*
13C5 PFPeA	*108*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:44*	*1*
13C2 PFHxA	*112*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:44*	*1*
13C4 PFHpA	*107*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:44*	*1*
13C4 PFOA	*85*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:44*	*1*
13C5 PFNA	*97*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:44*	*1*
13C2 PFDA	*104*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:44*	*1*
13C2 PFUnA	*104*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:44*	*1*
13C3 PFBS	*94*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:44*	*1*
18O2 PFHxS	*97*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:44*	*1*
13C4 PFOS	*87*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:44*	*1*
M2-4:2 FTS	*130*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:44*	*1*
M2-6:2 FTS	*123*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:44*	*1*
M2-8:2 FTS	*120*		*25 - 150*	*08/08/24 10:31*	*08/09/24 23:44*	*1*
13C2 10:2 FTS	*558*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 23:44*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**350**		46	3.7	ug/Kg		08/08/24 10:31	08/14/24 10:30	20
Br-Perfluorooctanesulfonic acid	**55**		46	3.7	ug/Kg		08/08/24 10:31	08/14/24 10:30	20
Total PFOS	**400**		46	3.7	ug/Kg		08/08/24 10:31	08/14/24 10:30	20

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*93*		*25 - 150*	*08/08/24 10:31*	*08/14/24 10:30*	*20*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284439
Date Collected: 07/11/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-35
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**4.9**		0.98	0.23	ug/Kg		08/08/24 10:31	08/10/24 00:03	1
Perfluoropentanoic acid (PFPeA)	**4.1**		0.98	0.17	ug/Kg		08/08/24 10:31	08/10/24 00:03	1
Perfluorohexanoic acid (PFHxA)	**32**		0.98	0.27	ug/Kg		08/08/24 10:31	08/10/24 00:03	1
Perfluoroheptanoic acid (PFHpA)	**24**		0.98	0.11	ug/Kg		08/08/24 10:31	08/10/24 00:03	1
Perfluorodecanoic acid (PFDA)	**32**		0.98	0.10	ug/Kg		08/08/24 10:31	08/10/24 00:03	1
Perfluoroundecanoic acid (PFUnA)	**4.4**		0.98	0.27	ug/Kg		08/08/24 10:31	08/10/24 00:03	1
Perfluorobutanesulfonic acid (PFBS)	**2.6**		0.98	0.17	ug/Kg		08/08/24 10:31	08/10/24 00:03	1
Perfluoropentanesulfonic acid (PFPeS)	**32**		0.98	0.18	ug/Kg		08/08/24 10:31	08/10/24 00:03	1
4:2 FTS	ND		0.98	0.26	ug/Kg		08/08/24 10:31	08/10/24 00:03	1
6:2 FTS	**20**		0.98	0.42	ug/Kg		08/08/24 10:31	08/10/24 00:03	1
8:2 FTS	**86**		0.98	0.098	ug/Kg		08/08/24 10:31	08/10/24 00:03	1
10:2 FTS	**1.6**	**B**	0.98	0.099	ug/Kg		08/08/24 10:31	08/10/24 00:03	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*63*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:03*	*1*
13C5 PFPeA	*86*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:03*	*1*
13C2 PFHxA	*105*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:03*	*1*
13C4 PFHpA	*98*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:03*	*1*
13C2 PFDA	*110*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:03*	*1*
13C2 PFUnA	*125*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:03*	*1*
13C3 PFBS	*90*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:03*	*1*
M2-4:2 FTS	*220*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 00:03*	*1*
M2-6:2 FTS	*177*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 00:03*	*1*
M2-8:2 FTS	*172*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 00:03*	*1*
13C2 10:2 FTS	*425*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 00:03*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanoic acid	**310**		98	20	ug/Kg		08/08/24 10:31	08/13/24 01:30	100
Br-Perfluorooctanoic acid	ND		98	20	ug/Kg		08/08/24 10:31	08/13/24 01:30	100
Total PFOA	**310**		98	20	ug/Kg		08/08/24 10:31	08/13/24 01:30	100
Perfluorononanoic acid (PFNA)	**300**		98	17	ug/Kg		08/08/24 10:31	08/13/24 01:30	100
Br-Perfluorohexanesulfonic acid	**210**		98	15	ug/Kg		08/08/24 10:31	08/13/24 01:30	100
Total PFHxS	**3600**		98	15	ug/Kg		08/08/24 10:31	08/13/24 01:30	100
L-Perfluorohexanesulfonic acid	**3400**		98	15	ug/Kg		08/08/24 10:31	08/13/24 01:30	100
Perfluoroheptanesulfonic acid (PFHpS)	**790**		98	18	ug/Kg		08/08/24 10:31	08/13/24 01:30	100
L-Perfluorooctanesulfonic acid	**32000**	**E**	250	20	ug/Kg		08/08/24 10:31	08/13/24 01:30	100
Br-Perfluorooctanesulfonic acid	**16000**	**E**	250	20	ug/Kg		08/08/24 10:31	08/13/24 01:30	100
Total PFOS	**48000**		250	20	ug/Kg		08/08/24 10:31	08/13/24 01:30	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOA	*91*		*25 - 150*	*08/08/24 10:31*	*08/13/24 01:30*	*100*
13C5 PFNA	*91*		*25 - 150*	*08/08/24 10:31*	*08/13/24 01:30*	*100*
18O2 PFHxS	*100*		*25 - 150*	*08/08/24 10:31*	*08/13/24 01:30*	*100*
13C4 PFOS	*75*		*25 - 150*	*08/08/24 10:31*	*08/13/24 01:30*	*100*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284452

Date Collected: 07/16/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-36

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.97	0.23	ug/Kg		08/08/24 10:31	08/10/24 00:22	1
Perfluoropentanoic acid (PFPeA)	ND		0.97	0.17	ug/Kg		08/08/24 10:31	08/10/24 00:22	1
Perfluorohexanoic acid (PFHxA)	ND		0.97	0.27	ug/Kg		08/08/24 10:31	08/10/24 00:22	1
Perfluoroheptanoic acid (PFHpA)	ND		0.97	0.11	ug/Kg		08/08/24 10:31	08/10/24 00:22	1
L-Perfluorooctanoic acid	**11**		0.97	0.20	ug/Kg		08/08/24 10:31	08/10/24 00:22	1
Br-Perfluorooctanoic acid	**0.23**	**J**	0.97	0.20	ug/Kg		08/08/24 10:31	08/10/24 00:22	1
Total PFOA	**12**		0.97	0.20	ug/Kg		08/08/24 10:31	08/10/24 00:22	1
Perfluorononanoic acid (PFNA)	**13**		0.97	0.17	ug/Kg		08/08/24 10:31	08/10/24 00:22	1
Perfluorodecanoic acid (PFDA)	**5.7**		0.97	0.10	ug/Kg		08/08/24 10:31	08/10/24 00:22	1
Perfluoroundecanoic acid (PFUnA)	**4.1**		0.97	0.26	ug/Kg		08/08/24 10:31	08/10/24 00:22	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.97	0.17	ug/Kg		08/08/24 10:31	08/10/24 00:22	1
Perfluoropentanesulfonic acid (PFPeS)	**1.1**		0.97	0.18	ug/Kg		08/08/24 10:31	08/10/24 00:22	1
Perfluoroheptanesulfonic acid (PFHpS)	**21**		0.97	0.18	ug/Kg		08/08/24 10:31	08/10/24 00:22	1
4:2 FTS	ND		0.97	0.26	ug/Kg		08/08/24 10:31	08/10/24 00:22	1
6:2 FTS	**2.0**		0.97	0.41	ug/Kg		08/08/24 10:31	08/10/24 00:22	1
10:2 FTS	**2.4**	**B**	0.97	0.098	ug/Kg		08/08/24 10:31	08/10/24 00:22	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*51*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:22*	*1*
13C5 PFPeA	*60*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:22*	*1*
13C2 PFHxA	*74*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:22*	*1*
13C4 PFHpA	*73*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:22*	*1*
13C4 PFOA	*85*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:22*	*1*
13C5 PFNA	*76*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:22*	*1*
13C2 PFDA	*103*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:22*	*1*
13C2 PFUnA	*98*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:22*	*1*
13C3 PFBS	*63*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:22*	*1*
18O2 PFHxS	*74*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:22*	*1*
13C4 PFOS	*65*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:22*	*1*
M2-4:2 FTS	*155*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 00:22*	*1*
M2-6:2 FTS	*186*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 00:22*	*1*
13C2 10:2 FTS	*392*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 00:22*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	**7.3**	**J**	49	7.2	ug/Kg		08/08/24 10:31	08/13/24 02:28	50
Total PFHxS	**200**		49	7.2	ug/Kg		08/08/24 10:31	08/13/24 02:28	50
L-Perfluorohexanesulfonic acid	**200**		49	7.2	ug/Kg		08/08/24 10:31	08/13/24 02:28	50
L-Perfluorooctanesulfonic acid	**1300**		120	9.9	ug/Kg		08/08/24 10:31	08/13/24 02:28	50
Br-Perfluorooctanesulfonic acid	**210**		120	9.9	ug/Kg		08/08/24 10:31	08/13/24 02:28	50
Total PFOS	**1500**		120	9.9	ug/Kg		08/08/24 10:31	08/13/24 02:28	50
8:2 FTS	**49**		49	4.9	ug/Kg		08/08/24 10:31	08/13/24 02:28	50

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*79*		*25 - 150*	*08/08/24 10:31*	*08/13/24 02:28*	*50*
13C4 PFOS	*88*		*25 - 150*	*08/08/24 10:31*	*08/13/24 02:28*	*50*
M2-8:2 FTS	*95*		*25 - 150*	*08/08/24 10:31*	*08/13/24 02:28*	*50*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284442 V24-20096 liver

Date Collected: 06/24/24 00:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-37

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.1	0.26	ug/Kg		08/08/24 10:31	08/10/24 00:42	1
Perfluoropentanoic acid (PFPeA)	ND		1.1	0.19	ug/Kg		08/08/24 10:31	08/10/24 00:42	1
Perfluorohexanoic acid (PFHxA)	ND		1.1	0.30	ug/Kg		08/08/24 10:31	08/10/24 00:42	1
Perfluoroheptanoic acid (PFHpA)	**0.44**	**J**	1.1	0.13	ug/Kg		08/08/24 10:31	08/10/24 00:42	1
L-Perfluorooctanoic acid	**15**		1.1	0.22	ug/Kg		08/08/24 10:31	08/10/24 00:42	1
Br-Perfluorooctanoic acid	**0.48**	**J**	1.1	0.22	ug/Kg		08/08/24 10:31	08/10/24 00:42	1
Total PFOA	**15**		1.1	0.22	ug/Kg		08/08/24 10:31	08/10/24 00:42	1
Perfluorononanoic acid (PFNA)	**73**		1.1	0.19	ug/Kg		08/08/24 10:31	08/10/24 00:42	1
Perfluorodecanoic acid (PFDA)	**19**		1.1	0.11	ug/Kg		08/08/24 10:31	08/10/24 00:42	1
Perfluoroundecanoic acid (PFUnA)	**8.0**		1.1	0.30	ug/Kg		08/08/24 10:31	08/10/24 00:42	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.1	0.19	ug/Kg		08/08/24 10:31	08/10/24 00:42	1
Perfluoropentanesulfonic acid (PFPeS)	**0.67**	**J**	1.1	0.20	ug/Kg		08/08/24 10:31	08/10/24 00:42	1
4:2 FTS	ND		1.1	0.29	ug/Kg		08/08/24 10:31	08/10/24 00:42	1
6:2 FTS	ND		1.1	0.47	ug/Kg		08/08/24 10:31	08/10/24 00:42	1
8:2 FTS	**51**		1.1	0.11	ug/Kg		08/08/24 10:31	08/10/24 00:42	1
10:2 FTS	**1.5**	**B**	1.1	0.11	ug/Kg		08/08/24 10:31	08/10/24 00:42	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*59*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:42*	*1*
13C5 PFPeA	*93*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:42*	*1*
13C2 PFHxA	*96*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:42*	*1*
13C4 PFHpA	*97*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:42*	*1*
13C4 PFOA	*83*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:42*	*1*
13C5 PFNA	*36*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:42*	*1*
13C2 PFDA	*103*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:42*	*1*
13C2 PFUnA	*124*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:42*	*1*
13C3 PFBS	*79*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:42*	*1*
13C4 PFOS	*52*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:42*	*1*
M2-4:2 FTS	*193*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 00:42*	*1*
M2-6:2 FTS	*87*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:42*	*1*
M2-8:2 FTS	*129*		*25 - 150*	*08/08/24 10:31*	*08/10/24 00:42*	*1*
13C2 10:2 FTS	*452*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 00:42*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	ND		55	8.1	ug/Kg		08/08/24 10:31	08/13/24 03:07	50
Total PFHxS	**220**		55	8.1	ug/Kg		08/08/24 10:31	08/13/24 03:07	50
L-Perfluorohexanesulfonic acid	**220**		55	8.1	ug/Kg		08/08/24 10:31	08/13/24 03:07	50
Perfluoroheptanesulfonic acid (PFHpS)	**71**		55	10	ug/Kg		08/08/24 10:31	08/13/24 03:07	50
L-Perfluorooctanesulfonic acid	**5100**	**E**	140	11	ug/Kg		08/08/24 10:31	08/13/24 03:07	50
Br-Perfluorooctanesulfonic acid	**1200**		140	11	ug/Kg		08/08/24 10:31	08/13/24 03:07	50
Total PFOS	**6300**		140	11	ug/Kg		08/08/24 10:31	08/13/24 03:07	50

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*91*		*25 - 150*	*08/08/24 10:31*	*08/13/24 03:07*	*50*
13C4 PFOS	*82*		*25 - 150*	*08/08/24 10:31*	*08/13/24 03:07*	*50*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284443 V24-20097 liver
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-38
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.93	0.22	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
Perfluoropentanoic acid (PFPeA)	ND		0.93	0.16	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
Perfluorohexanoic acid (PFHxA)	ND		0.93	0.25	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
Perfluoroheptanoic acid (PFHpA)	**0.17**	**J**	0.93	0.11	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
L-Perfluorooctanoic acid	**18**		0.93	0.19	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
Br-Perfluorooctanoic acid	**0.60**	**J**	0.93	0.19	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
Total PFOA	**19**		0.93	0.19	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
Perfluorononanoic acid (PFNA)	**39**		0.93	0.16	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
Perfluorodecanoic acid (PFDA)	**4.8**		0.93	0.095	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
Perfluoroundecanoic acid (PFUnA)	**0.90**	**J**	0.93	0.25	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.93	0.16	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
Perfluoropentanesulfonic acid (PFPeS)	**0.79**	**J**	0.93	0.17	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
Perfluoroheptanesulfonic acid (PFHpS)	**54**		0.93	0.17	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
4:2 FTS	ND		0.93	0.25	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
6:2 FTS	**4.8**		0.93	0.39	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
8:2 FTS	**5.1**		0.93	0.093	ug/Kg		08/08/24 10:31	08/10/24 01:01	1
10:2 FTS	**0.19**	**J B**	0.93	0.094	ug/Kg		08/08/24 10:31	08/10/24 01:01	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*42*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:01*	*1*
13C5 PFPeA	*67*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:01*	*1*
13C2 PFHxA	*79*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:01*	*1*
13C4 PFHpA	*81*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:01*	*1*
13C4 PFOA	*84*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:01*	*1*
13C5 PFNA	*76*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:01*	*1*
13C2 PFDA	*99*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:01*	*1*
13C2 PFUnA	*117*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:01*	*1*
13C3 PFBS	*74*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:01*	*1*
13C4 PFOS	*62*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:01*	*1*
M2-4:2 FTS	*173*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 01:01*	*1*
M2-6:2 FTS	*172*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 01:01*	*1*
M2-8:2 FTS	*265*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 01:01*	*1*
13C2 10:2 FTS	*433*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 01:01*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	**6.9**	**J**	46	6.9	ug/Kg		08/08/24 10:31	08/13/24 03:46	50
Total PFHxS	**410**		46	6.9	ug/Kg		08/08/24 10:31	08/13/24 03:46	50
L-Perfluorohexanesulfonic acid	**400**		46	6.9	ug/Kg		08/08/24 10:31	08/13/24 03:46	50
L-Perfluorooctanesulfonic acid	**1800**		120	9.4	ug/Kg		08/08/24 10:31	08/13/24 03:46	50
Br-Perfluorooctanesulfonic acid	**380**		120	9.4	ug/Kg		08/08/24 10:31	08/13/24 03:46	50
Total PFOS	**2200**		120	9.4	ug/Kg		08/08/24 10:31	08/13/24 03:46	50

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*92*		*25 - 150*	*08/08/24 10:31*	*08/13/24 03:46*	*50*

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284444 V24-20103 liver

Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-39

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		3.1	0.74	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
Perfluoropentanoic acid (PFPeA)	ND		3.1	0.55	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
Perfluorohexanoic acid (PFHxA)	ND		3.1	0.85	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
Perfluoroheptanoic acid (PFHpA)	ND		3.1	0.36	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
L-Perfluorooctanoic acid	**8.9**		3.1	0.63	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
Br-Perfluorooctanoic acid	**1.5**	**J**	3.1	0.63	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
Total PFOA	**10**		3.1	0.63	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
Perfluorononanoic acid (PFNA)	**33**		3.1	0.55	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
Perfluorodecanoic acid (PFDA)	**11**		3.1	0.32	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
Perfluoroundecanoic acid (PFUnA)	**4.5**		3.1	0.85	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
Perfluorobutanesulfonic acid (PFBS)	ND		3.1	0.53	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
Perfluoropentanesulfonic acid (PFPeS)	ND		3.1	0.57	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
Br-Perfluorohexanesulfonic acid	**5.7**		3.1	0.46	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
Total PFHxS	**170**		3.1	0.46	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
L-Perfluorohexanesulfonic acid	**170**		3.1	0.46	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
Perfluoroheptanesulfonic acid (PFHpS)	**60**		3.1	0.58	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
4:2 FTS	ND		3.1	0.83	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
6:2 FTS	ND		3.1	1.3	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
8:2 FTS	**29**		3.1	0.31	ug/Kg		08/08/24 10:31	08/10/24 01:40	1
10:2 FTS	**3.5**	**B**	3.1	0.32	ug/Kg		08/08/24 10:31	08/10/24 01:40	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*148*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:40*	*1*
13C5 PFPeA	*155*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 01:40*	*1*
13C2 PFHxA	*145*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:40*	*1*
13C4 PFHpA	*150*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:40*	*1*
13C4 PFOA	*89*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:40*	*1*
13C5 PFNA	*121*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:40*	*1*
13C2 PFDA	*146*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:40*	*1*
13C2 PFUnA	*168*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 01:40*	*1*
13C3 PFBS	*137*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:40*	*1*
18O2 PFHxS	*136*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:40*	*1*
13C4 PFOS	*111*		*25 - 150*	*08/08/24 10:31*	*08/10/24 01:40*	*1*
M2-4:2 FTS	*231*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 01:40*	*1*
M2-6:2 FTS	*152*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 01:40*	*1*
M2-8:2 FTS	*168*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 01:40*	*1*
13C2 10:2 FTS	*579*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/10/24 01:40*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**4500**		390	32	ug/Kg		08/08/24 10:31	08/13/24 04:24	50
Br-Perfluorooctanesulfonic acid	**890**		390	32	ug/Kg		08/08/24 10:31	08/13/24 04:24	50
Total PFOS	**5400**		390	32	ug/Kg		08/08/24 10:31	08/13/24 04:24	50

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*88*		*25 - 150*	*08/08/24 10:31*	*08/13/24 04:24*	*50*

Isotope Dilution Summary

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Tissue

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-113896-1	NK311140 liver	47	64	73	82	79	60	91	98
320-113896-1 - DL	NK311140 liver								
320-113896-2	NK311141 liver	25	56	80	90	82	58	100	110
320-113896-2 - DL	NK311141 liver								
320-113896-3	NK311142 liver	90	91	97	95	95	92	98	112
320-113896-3 - DL	NK311142 liver								
320-113896-4	NK311143 liver	57	86	91	95	87	99	96	95
320-113896-5	NK311145 liver	38	73	82	87	84	53	94	116
320-113896-5 - DL	NK311145 liver								
320-113896-6	NK311145 femur	84	91	86	81	94	82	88	90
320-113896-6 - DL	NK311145 femur								
320-113896-7	NK311146 liver	36	72	89	97	86		108	117
320-113896-7 - DL	NK311146 liver						83		
320-113896-8	NK311146 femur	82	86	88	88	92	85	106	104
320-113896-8 - DL	NK311146 femur								
320-113896-9	NK311129 liver	79	87	96	85	87	93	98	99
320-113896-9 - DL	NK311129 liver								
320-113896-10	NK311131 liver	84	108	103	94	91	90	99	100
320-113896-10 - DL	NK311131 liver								
320-113896-11	NK311133 liver	74	89	97	97	90	98	94	91
320-113896-11 - DL	NK311133 liver								
320-113896-12	NK319511 muscle	59	79	84	81	88	30	108	93
320-113896-13	NK319092 liver	53	84	85	88	87	97	111	106
320-113896-14	Velvet ant NE2 03	92	96	100	91	92	93	91	87
320-113896-15	ArtNE2 01	84	94	91	99	91	88	89	96
320-113896-15 - DL	ArtNE2 01								
320-113896-16	ArtNE2 02	95	91	98	97	96	95	95	92
320-113896-17	ArtNE2 03	42	76	89	89	87	92	114	121
320-113896-18	ArtNE2 04	99	104	100	93	87	95	87	93
320-113896-19	ArtNE4 01	92	91	92	92	94	93	89	98
320-113896-19 - DL	ArtNE4 01								
320-113896-20	ArtNE4 02	112	107	103	105	92	96	106	104
320-113896-21	ArtNE4 03	76	96	95	87	92	78	89	86
320-113896-22	ArtNE4 04	40	72	86	89	96	91	114	117
320-113896-24	NK284441	94	95	97	87	87	83	97	112
320-113896-24 - DL	NK284441								
320-113896-25	NK284442	82	86	96	94	89	91	99	109
320-113896-25 - DL	NK284442								
320-113896-26	NK284443	58	68	86	87	83	82	115	125
320-113896-26 - DL	NK284443								
320-113896-27	NK284444	81	80	92	87	85	86	89	107
320-113896-27 - DL	NK284444								
320-113896-28	NK284445	81	94	92	86	89	91	92	104
320-113896-28 - DL	NK284445								
320-113896-29	NK284446	88	92	96	94	91	92	100	114
320-113896-29 - DL	NK284446								
320-113896-30	NK284447	77	95	104	90	89	88	92	93
320-113896-31	NK284448	61	75	85	89	84	85	92	98
320-113896-31 - DL	NK284448								

Isotope Dilution Summary

Client: University of New Mexico
Job ID: 320-113896-1
Project/Site: Holloman bird/mammal

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Matrix: Tissue **Prep Type: Total/NA**

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-113896-32	NK284449	88	95	95	89	90	96	101	96
320-113896-32 - DL	NK284449								
320-113896-33	NK284450	92	100	91	95	87	91	89	100
320-113896-33 - DL	NK284450								
320-113896-34	NK284451	99	108	112	107	85	97	104	104
320-113896-34 - DL	NK284451								
320-113896-35	NK284439	63	86	105	98			110	125
320-113896-35 - DL	NK284439					91	91		
320-113896-36	NK284452	51	60	74	73	85	76	103	98
320-113896-36 - DL	NK284452								
320-113896-37	NK284442 V24-20096 liver	59	93	96	97	83	36	103	124
320-113896-37 - DL	NK284442 V24-20096 liver								
320-113896-38	NK284443 V24-20097 liver	42	67	79	81	84	76	99	117
320-113896-38 - DL	NK284443 V24-20097 liver								
320-113896-39	NK284444 V24-20103 liver	148	155 *5+	145	150	89	121	146	168 *5+
320-113896-39 - DL	NK284444 V24-20103 liver								
LCS 320-785621/2-A	Lab Control Sample	87	92	93	93	92	88	92	104
LCS 320-788729/2-A	Lab Control Sample	96	104	90	93	97	98	100	111
LCSD 320-785621/3-A	Lab Control Sample Dup	96	92	95	97	89	94	95	99
LCSD 320-788729/3-A	Lab Control Sample Dup	96	91	98	94	90	91	100	99
MB 320-785621/1-A	Method Blank	80	92	90	90	94	87	90	98
MB 320-788729/1-A	Method Blank	94	94	90	102	97	97	110	117

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
320-113896-1	NK311140 liver	62	71	61	178 *5+	172 *5+	325 *5+	306 *5+
320-113896-1 - DL	NK311140 liver			89				
320-113896-2	NK311141 liver	56	80	68	188 *5+	139	184 *5+	361 *5+
320-113896-2 - DL	NK311141 liver			88				
320-113896-3	NK311142 liver	74	91	78	230 *5+	139	98	282 *5+
320-113896-3 - DL	NK311142 liver			93				
320-113896-4	NK311143 liver	73	83	84	136	158 *5+	123	310 *5+
320-113896-5	NK311145 liver	60			182 *5+	117	140	266 *5+
320-113896-5 - DL	NK311145 liver		90	70				
320-113896-6	NK311145 femur	85	83	74	170 *5+	134	134	225 *5+
320-113896-6 - DL	NK311145 femur			94				
320-113896-7	NK311146 liver	67			157 *5+	147	147	213 *5+
320-113896-7 - DL	NK311146 liver		87	77				
320-113896-8	NK311146 femur	82	86	72	174 *5+	142	121	406 *5+
320-113896-8 - DL	NK311146 femur			99				
320-113896-9	NK311129 liver	84	80	74	139	124	116	292 *5+
320-113896-9 - DL	NK311129 liver			93				
320-113896-10	NK311131 liver	90			116	147	105	344 *5+
320-113896-10 - DL	NK311131 liver		109	100				
320-113896-11	NK311133 liver	85	85	75	134	137	118	220 *5+
320-113896-11 - DL	NK311133 liver			92				
320-113896-12	NK319511 muscle	65	79	71	142	180 *5+	184 *5+	300 *5+
320-113896-13	NK319092 liver	70	85	81	192 *5+	76	167 *5+	397 *5+
320-113896-14	Velvet ant NE2 03	83	89	90	95	103	103	133
320-113896-15	ArtNE2 01	100	86	78	112	96	88	234 *5+

Isotope Dilution Summary

Client: University of New Mexico
Job ID: 320-113896-1
Project/Site: Holloman bird/mammal

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Matrix: Tissue
Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
320-113896-15 - DL	ArtNE2 01			95				
320-113896-16	ArtNE2 02	87	94	93	119	109	100	134
320-113896-17	ArtNE2 03	81	92	90	150	131	146	447 *5+
320-113896-18	ArtNE2 04	94	93	90	108	103	89	132
320-113896-19	ArtNE4 01	96	91	81	97	94	93	89
320-113896-19 - DL	ArtNE4 01			105				
320-113896-20	ArtNE4 02	97	109	105	94	99	96	142
320-113896-21	ArtNE4 03	78	80	78	117	94	91	126
320-113896-22	ArtNE4 04	71	87	84	219 *5+	225 *5+	260 *5+	445 *5+
320-113896-24	NK284441	81	85	63	103	110	97	486 *5+
320-113896-24 - DL	NK284441			79				
320-113896-25	NK284442	77	84	75	130	112	104	566 *5+
320-113896-25 - DL	NK284442			91				
320-113896-26	NK284443	69		65	123	129	208 *5+	486 *5+
320-113896-26 - DL	NK284443		84	77				
320-113896-27	NK284444	79	77	73	104	106	98	460 *5+
320-113896-27 - DL	NK284444			80				
320-113896-28	NK284445	79	85	70	110	96	101	406 *5+
320-113896-28 - DL	NK284445			97				
320-113896-29	NK284446	72		66	128	126	111	497 *5+
320-113896-29 - DL	NK284446		89	96				
320-113896-30	NK284447	78	76	82	97	109	92	414 *5+
320-113896-31	NK284448	70	81	79	145	107	97	438 *5+
320-113896-31 - DL	NK284448			92				
320-113896-32	NK284449	75	96	78	137	132	123	513 *5+
320-113896-32 - DL	NK284449			94				
320-113896-33	NK284450	87	87	86	105	113	100	536 *5+
320-113896-33 - DL	NK284450			102				
320-113896-34	NK284451	94	97	87	130	123	120	558 *5+
320-113896-34 - DL	NK284451			93				
320-113896-35	NK284439	90			220 *5+	177 *5+	172 *5+	425 *5+
320-113896-35 - DL	NK284439		100	75				
320-113896-36	NK284452	63	74	65	155 *5+	186 *5+		392 *5+
320-113896-36 - DL	NK284452		79	88			95	
320-113896-37	NK284442 V24-20096 liver	79		52	193 *5+	87	129	452 *5+
320-113896-37 - DL	NK284442 V24-20096 liver		91	82				
320-113896-38	NK284443 V24-20097 liver	74		62	173 *5+	172 *5+	265 *5+	433 *5+
320-113896-38 - DL	NK284443 V24-20097 liver		92					
320-113896-39	NK284444 V24-20103 liver	137	136	111	231 *5+	152 *5+	168 *5+	579 *5+
320-113896-39 - DL	NK284444 V24-20103 liver			88				
LCS 320-785621/2-A	Lab Control Sample	95	87	87	97	113	102	403 *5+
LCS 320-788729/2-A	Lab Control Sample	92	104	95	95	104	113	357 *5+
LCSD 320-785621/3-A	Lab Control Sample Dup	86	88	96	95	115	105	396 *5+
LCSD 320-788729/3-A	Lab Control Sample Dup	91	86	90	94	105	92	346 *5+
MB 320-785621/1-A	Method Blank	89	88	86	109	106	99	388 *5+
MB 320-788729/1-A	Method Blank	95	98	95	99	115	113	374 *5+

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA

Client: University of New Mexico
Job ID: 320-113896-1
Project/Site: Holloman bird/mammal

PFHxA = 13C2 PFHxA
C4PFHA = 13C4 PFHpA
PFOA = 13C4 PFOA
PFNA = 13C5 PFNA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS
PFHxS = 18O2 PFHxS
PFOS = 13C4 PFOS
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
M102FTS = 13C2 10:2 FTS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Water **Prep Type: Total/NA**

		Percent Isotope Dilution Recovery (Acceptance Limits)							
		PFBA	PFPeA	PFHxA	C4PFHA	PFOA	PFNA	PFDA	PFUnA
Lab Sample ID	Client Sample ID	(25-150)	(25-150)	(25-150)	(25-150)	(25-150)	(25-150)	(25-150)	(25-150)
320-113896-23	VDS 0 TEST	97	101	96	95	101	94	95	97

		Percent Isotope Dilution Recovery (Acceptance Limits)							
		C3PFBS	PFHxS	PFOS	M242FTS	M262FTS	M282FTS	M102FTS	
Lab Sample ID	Client Sample ID	(25-150)	(25-150)	(25-150)	(25-150)	(25-150)	(25-150)	(25-150)	
320-113896-23	VDS 0 TEST	96	92	93	85	88	93	119	

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
PFHxA = 13C2 PFHxA
C4PFHA = 13C4 PFHpA
PFOA = 13C4 PFOA
PFNA = 13C5 PFNA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS
PFHxS = 18O2 PFHxS
PFOS = 13C4 PFOS
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
M102FTS = 13C2 10:2 FTS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Lab Sample ID: MB 320-785621/1-A
Matrix: Tissue
Analysis Batch: 789266

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 785621

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.27	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
L-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
Total PFOA	ND		1.0	0.20	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.10	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.27	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
Total PFHxS	ND		1.0	0.15	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
L-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
Br-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
Total PFOS	ND		2.5	0.20	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
4:2 FTS	ND		1.0	0.27	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
6:2 FTS	ND		1.0	0.42	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
8:2 FTS	ND		1.0	0.10	ug/Kg		07/29/24 11:09	08/09/24 04:00	1
10:2 FTS	ND		1.0	0.10	ug/Kg		07/29/24 11:09	08/09/24 04:00	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*80*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:00*	*1*
13C5 PFPeA	*92*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:00*	*1*
13C2 PFHxA	*90*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:00*	*1*
13C4 PFHpA	*90*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:00*	*1*
13C4 PFOA	*94*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:00*	*1*
13C5 PFNA	*87*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:00*	*1*
13C2 PFDA	*90*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:00*	*1*
13C2 PFUnA	*98*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:00*	*1*
13C3 PFBS	*89*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:00*	*1*
18O2 PFHxS	*88*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:00*	*1*
13C4 PFOS	*86*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:00*	*1*
M2-4:2 FTS	*109*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:00*	*1*
M2-6:2 FTS	*106*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:00*	*1*
M2-8:2 FTS	*99*		*25 - 150*	*07/29/24 11:09*	*08/09/24 04:00*	*1*
13C2 10:2 FTS	*388*	**5+*	*25 - 150*	*07/29/24 11:09*	*08/09/24 04:00*	*1*

Lab Sample ID: LCS 320-785621/2-A
Matrix: Tissue
Analysis Batch: 789266

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 785621

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	10.0	10.4		ug/Kg		104	76 - 136

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-785621/2-A
Matrix: Tissue
Analysis Batch: 789266

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 785621

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluoropentanoic acid (PFPeA)	10.0	10.2		ug/Kg		102	69 - 129
Perfluorohexanoic acid (PFHxA)	10.0	10.6		ug/Kg		106	71 - 131
Perfluoroheptanoic acid (PFHpA)	10.0	11.1		ug/Kg		111	71 - 131
L-Perfluorooctanoic acid	10.0	10.2		ug/Kg		102	72 - 132
Total PFOA	10.0	10.2		ug/Kg		102	
Perfluorononanoic acid (PFNA)	10.0	11.0		ug/Kg		110	73 - 133
Perfluorodecanoic acid (PFDA)	10.0	11.3		ug/Kg		113	72 - 132
Perfluoroundecanoic acid (PFUnA)	10.0	10.1		ug/Kg		101	66 - 126
Perfluorobutanesulfonic acid (PFBS)	8.88	9.17		ug/Kg		103	69 - 129
Perfluoropentanesulfonic acid (PFPeS)	9.40	9.82		ug/Kg		104	66 - 126
Total PFHxS	9.12	9.20		ug/Kg		101	
L-Perfluorohexanesulfonic acid	9.12	9.20		ug/Kg		101	62 - 122
Perfluoroheptanesulfonic acid (PFHpS)	9.54	10.9		ug/Kg		114	76 - 136
L-Perfluorooctanesulfonic acid	9.30	10.3		ug/Kg		111	68 - 141
Total PFOS	9.30	10.3		ug/Kg		111	
4:2 FTS	9.38	10.3		ug/Kg		110	68 - 143
6:2 FTS	9.52	9.05		ug/Kg		95	73 - 139
8:2 FTS	9.60	10.6		ug/Kg		110	75 - 135
10:2 FTS	9.66	11.1		ug/Kg		115	69 - 145

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*87*		*25 - 150*
13C5 PFPeA	*92*		*25 - 150*
13C2 PFHxA	*93*		*25 - 150*
13C4 PFHpA	*93*		*25 - 150*
13C4 PFOA	*92*		*25 - 150*
13C5 PFNA	*88*		*25 - 150*
13C2 PFDA	*92*		*25 - 150*
13C2 PFUnA	*104*		*25 - 150*
13C3 PFBS	*95*		*25 - 150*
18O2 PFHxS	*87*		*25 - 150*
13C4 PFOS	*87*		*25 - 150*
M2-4:2 FTS	*97*		*25 - 150*
M2-6:2 FTS	*113*		*25 - 150*
M2-8:2 FTS	*102*		*25 - 150*
13C2 10:2 FTS	*403*	*5+	*25 - 150*

Lab Sample ID: LCSD 320-785621/3-A
Matrix: Tissue
Analysis Batch: 789266

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 785621

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)	10.0	10.8		ug/Kg		108	76 - 136	4	30
Perfluoropentanoic acid (PFPeA)	10.0	11.0		ug/Kg		110	69 - 129	7	30
Perfluorohexanoic acid (PFHxA)	10.0	11.2		ug/Kg		112	71 - 131	6	30
Perfluoroheptanoic acid (PFHpA)	10.0	10.4		ug/Kg		104	71 - 131	6	30

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCSD 320-785621/3-A
Matrix: Tissue
Analysis Batch: 789266

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 785621

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
L-Perfluorooctanoic acid			10.0	11.0		ug/Kg		110	72 - 132	8	30
Total PFOA			10.0	11.0		ug/Kg		110		8	
Perfluorononanoic acid (PFNA)			10.0	10.6		ug/Kg		106	73 - 133	4	30
Perfluorodecanoic acid (PFDA)			10.0	11.0		ug/Kg		110	72 - 132	2	30
Perfluoroundecanoic acid (PFUnA)			10.0	10.5		ug/Kg		105	66 - 126	5	30
Perfluorobutanesulfonic acid (PFBS)			8.88	10.0		ug/Kg		113	69 - 129	9	30
Perfluoropentanesulfonic acid (PFPeS)			9.40	11.8		ug/Kg		126	66 - 126	18	30
Total PFHxS			9.12	9.21		ug/Kg		101		0	
L-Perfluorohexanesulfonic acid			9.12	9.21		ug/Kg		101	62 - 122	0	30
Perfluoroheptanesulfonic acid (PFHpS)			9.54	9.29		ug/Kg		97	76 - 136	16	30
L-Perfluorooctanesulfonic acid			9.30	9.37		ug/Kg		101	68 - 141	10	30
Total PFOS			9.30	9.37		ug/Kg		101		10	
4:2 FTS			9.38	10.9		ug/Kg		116	68 - 143	6	30
6:2 FTS			9.52	8.96		ug/Kg		94	73 - 139	1	30
8:2 FTS			9.60	10.6		ug/Kg		110	75 - 135	0	30
10:2 FTS			9.66	11.5		ug/Kg		119	69 - 145	4	30

Isotope Dilution	*LCSD %Recovery*	*LCSD Qualifier*	*Limits*
13C4 PFBA	*96*		*25 - 150*
13C5 PFPeA	*92*		*25 - 150*
13C2 PFHxA	*95*		*25 - 150*
13C4 PFHpA	*97*		*25 - 150*
13C4 PFOA	*89*		*25 - 150*
13C5 PFNA	*94*		*25 - 150*
13C2 PFDA	*95*		*25 - 150*
13C2 PFUnA	*99*		*25 - 150*
13C3 PFBS	*86*		*25 - 150*
18O2 PFHxS	*88*		*25 - 150*
13C4 PFOS	*96*		*25 - 150*
M2-4:2 FTS	*95*		*25 - 150*
M2-6:2 FTS	*115*		*25 - 150*
M2-8:2 FTS	*105*		*25 - 150*
13C2 10:2 FTS	*396*	*5+	*25 - 150*

Lab Sample ID: MB 320-788729/1-A
Matrix: Tissue
Analysis Batch: 789267

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 788729

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.27	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
L-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
Total PFOA	ND		1.0	0.20	ug/Kg		08/08/24 10:31	08/09/24 18:33	1

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: MB 320-788729/1-A
Matrix: Tissue
Analysis Batch: 789267

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 788729

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.10	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.27	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
Total PFHxS	ND		1.0	0.15	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
L-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
Br-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
Total PFOS	ND		2.5	0.20	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
4:2 FTS	ND		1.0	0.27	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
6:2 FTS	ND		1.0	0.42	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
8:2 FTS	ND		1.0	0.10	ug/Kg		08/08/24 10:31	08/09/24 18:33	1
10:2 FTS	0.103	J	1.0	0.10	ug/Kg		08/08/24 10:31	08/09/24 18:33	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*94*		*25 - 150*	*08/08/24 10:31*	*08/09/24 18:33*	*1*
13C5 PFPeA	*94*		*25 - 150*	*08/08/24 10:31*	*08/09/24 18:33*	*1*
13C2 PFHxA	*90*		*25 - 150*	*08/08/24 10:31*	*08/09/24 18:33*	*1*
13C4 PFHpA	*102*		*25 - 150*	*08/08/24 10:31*	*08/09/24 18:33*	*1*
13C4 PFOA	*97*		*25 - 150*	*08/08/24 10:31*	*08/09/24 18:33*	*1*
13C5 PFNA	*97*		*25 - 150*	*08/08/24 10:31*	*08/09/24 18:33*	*1*
13C2 PFDA	*110*		*25 - 150*	*08/08/24 10:31*	*08/09/24 18:33*	*1*
13C2 PFUnA	*117*		*25 - 150*	*08/08/24 10:31*	*08/09/24 18:33*	*1*
13C3 PFBS	*95*		*25 - 150*	*08/08/24 10:31*	*08/09/24 18:33*	*1*
18O2 PFHxS	*98*		*25 - 150*	*08/08/24 10:31*	*08/09/24 18:33*	*1*
13C4 PFOS	*95*		*25 - 150*	*08/08/24 10:31*	*08/09/24 18:33*	*1*
M2-4:2 FTS	*99*		*25 - 150*	*08/08/24 10:31*	*08/09/24 18:33*	*1*
M2-6:2 FTS	*115*		*25 - 150*	*08/08/24 10:31*	*08/09/24 18:33*	*1*
M2-8:2 FTS	*113*		*25 - 150*	*08/08/24 10:31*	*08/09/24 18:33*	*1*
13C2 10:2 FTS	*374*	**5+*	*25 - 150*	*08/08/24 10:31*	*08/09/24 18:33*	*1*

Lab Sample ID: LCS 320-788729/2-A
Matrix: Tissue
Analysis Batch: 789267

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 788729

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	10.0	10.3		ug/Kg		103	76 - 136
Perfluoropentanoic acid (PFPeA)	10.0	10.5		ug/Kg		105	69 - 129
Perfluorohexanoic acid (PFHxA)	10.0	11.1		ug/Kg		111	71 - 131
Perfluoroheptanoic acid (PFHpA)	10.0	10.9		ug/Kg		109	71 - 131
L-Perfluorooctanoic acid	10.0	9.85		ug/Kg		99	72 - 132
Total PFOA	10.0	9.85		ug/Kg		99	
Perfluorononanoic acid (PFNA)	10.0	10.6		ug/Kg		106	73 - 133
Perfluorodecanoic acid (PFDA)	10.0	10.9		ug/Kg		109	72 - 132

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-788729/2-A
Matrix: Tissue
Analysis Batch: 789267

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 788729

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits		
Perfluoroundecanoic acid (PFUnA)			10.0	9.93		ug/Kg		99	66 - 126		
Perfluorobutanesulfonic acid (PFBS)			8.88	10.7		ug/Kg		120	69 - 129		
Perfluoropentanesulfonic acid (PFPeS)			9.40	10.6		ug/Kg		113	66 - 126		
Total PFHxS			9.12	8.95		ug/Kg		98			
L-Perfluorohexanesulfonic acid			9.12	8.95		ug/Kg		98	62 - 122		
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.9		ug/Kg		114	76 - 136		
L-Perfluorooctanesulfonic acid			9.30	9.91		ug/Kg		107	68 - 141		
Total PFOS			9.30	9.91		ug/Kg		107			
4:2 FTS			9.38	10.9		ug/Kg		116	68 - 143		
6:2 FTS			9.52	9.74		ug/Kg		102	73 - 139		
8:2 FTS			9.60	9.57		ug/Kg		100	75 - 135		
10:2 FTS			9.66	9.37		ug/Kg		97	69 - 145		

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*96*		*25 - 150*
13C5 PFPeA	*104*		*25 - 150*
13C2 PFHxA	*90*		*25 - 150*
13C4 PFHpA	*93*		*25 - 150*
13C4 PFOA	*97*		*25 - 150*
13C5 PFNA	*98*		*25 - 150*
13C2 PFDA	*100*		*25 - 150*
13C2 PFUnA	*111*		*25 - 150*
13C3 PFBS	*92*		*25 - 150*
18O2 PFHxS	*104*		*25 - 150*
13C4 PFOS	*95*		*25 - 150*
M2-4:2 FTS	*95*		*25 - 150*
M2-6:2 FTS	*104*		*25 - 150*
M2-8:2 FTS	*113*		*25 - 150*
13C2 10:2 FTS	*357*	*5+	*25 - 150*

Lab Sample ID: LCSD 320-788729/3-A
Matrix: Tissue
Analysis Batch: 789267

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 788729

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)			10.0	10.1		ug/Kg		101	76 - 136	3	30
Perfluoropentanoic acid (PFPeA)			10.0	11.2		ug/Kg		112	69 - 129	7	30
Perfluorohexanoic acid (PFHxA)			10.0	9.76		ug/Kg		98	71 - 131	13	30
Perfluoroheptanoic acid (PFHpA)			10.0	10.9		ug/Kg		109	71 - 131	0	30
L-Perfluorooctanoic acid			10.0	10.5		ug/Kg		105	72 - 132	7	30
Total PFOA			10.0	10.5		ug/Kg		105		7	
Perfluorononanoic acid (PFNA)			10.0	11.0		ug/Kg		110	73 - 133	4	30
Perfluorodecanoic acid (PFDA)			10.0	10.2		ug/Kg		102	72 - 132	7	30
Perfluoroundecanoic acid (PFUnA)			10.0	10.9		ug/Kg		109	66 - 126	10	30

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCSD 320-788729/3-A
Matrix: Tissue
Analysis Batch: 789267

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 788729

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanesulfonic acid (PFBS)			8.88	10.1		ug/Kg		114	69 - 129	6	30
Perfluoropentanesulfonic acid (PFPeS)			9.40	10.1		ug/Kg		108	66 - 126	5	30
Total PFHxS			9.12	9.18		ug/Kg		101		3	
L-Perfluorohexanesulfonic acid			9.12	9.18		ug/Kg		101	62 - 122	3	30
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.2		ug/Kg		107	76 - 136	6	30
L-Perfluorooctanesulfonic acid			9.30	9.45		ug/Kg		102	68 - 141	5	30
Total PFOS			9.30	9.45		ug/Kg		102		5	
4:2 FTS			9.38	10.6		ug/Kg		113	68 - 143	2	30
6:2 FTS			9.52	9.55		ug/Kg		100	73 - 139	2	30
8:2 FTS			9.60	10.8		ug/Kg		112	75 - 135	12	30
10:2 FTS			9.66	9.08		ug/Kg		94	69 - 145	3	30

Isotope Dilution	*LCSD %Recovery*	*LCSD Qualifier*	*Limits*
13C4 PFBA	*96*		*25 - 150*
13C5 PFPeA	*91*		*25 - 150*
13C2 PFHxA	*98*		*25 - 150*
13C4 PFHpA	*94*		*25 - 150*
13C4 PFOA	*90*		*25 - 150*
13C5 PFNA	*91*		*25 - 150*
13C2 PFDA	*100*		*25 - 150*
13C2 PFUnA	*99*		*25 - 150*
13C3 PFBS	*91*		*25 - 150*
18O2 PFHxS	*86*		*25 - 150*
13C4 PFOS	*90*		*25 - 150*
M2-4:2 FTS	*94*		*25 - 150*
M2-6:2 FTS	*105*		*25 - 150*
M2-8:2 FTS	*92*		*25 - 150*
13C2 10:2 FTS	*346*	*5+	*25 - 150*

LCMS

Pre Prep Batch: 785620

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113896-1	NK311140 liver	Total/NA	Tissue	In-House	
320-113896-1 - DL	NK311140 liver	Total/NA	Tissue	In-House	
320-113896-2 - DL	NK311141 liver	Total/NA	Tissue	In-House	
320-113896-2	NK311141 liver	Total/NA	Tissue	In-House	
320-113896-3	NK311142 liver	Total/NA	Tissue	In-House	
320-113896-3 - DL	NK311142 liver	Total/NA	Tissue	In-House	
320-113896-4	NK311143 liver	Total/NA	Tissue	In-House	
320-113896-5 - DL	NK311145 liver	Total/NA	Tissue	In-House	
320-113896-5	NK311145 liver	Total/NA	Tissue	In-House	
320-113896-6	NK311145 femur	Total/NA	Tissue	In-House	
320-113896-6 - DL	NK311145 femur	Total/NA	Tissue	In-House	
320-113896-7 - DL	NK311146 liver	Total/NA	Tissue	In-House	
320-113896-7	NK311146 liver	Total/NA	Tissue	In-House	
320-113896-8 - DL	NK311146 femur	Total/NA	Tissue	In-House	
320-113896-8	NK311146 femur	Total/NA	Tissue	In-House	
320-113896-9	NK311129 liver	Total/NA	Tissue	In-House	
320-113896-9 - DL	NK311129 liver	Total/NA	Tissue	In-House	
320-113896-10 - DL	NK311131 liver	Total/NA	Tissue	In-House	
320-113896-10	NK311131 liver	Total/NA	Tissue	In-House	
320-113896-11 - DL	NK311133 liver	Total/NA	Tissue	In-House	
320-113896-11	NK311133 liver	Total/NA	Tissue	In-House	
320-113896-12	NK319511 muscle	Total/NA	Tissue	In-House	
320-113896-13	NK319092 liver	Total/NA	Tissue	In-House	
320-113896-14	Velvet ant NE2 03	Total/NA	Tissue	In-House	
320-113896-15 - DL	ArtNE2 01	Total/NA	Tissue	In-House	
320-113896-15	ArtNE2 01	Total/NA	Tissue	In-House	
320-113896-16	ArtNE2 02	Total/NA	Tissue	In-House	
320-113896-17	ArtNE2 03	Total/NA	Tissue	In-House	
320-113896-18	ArtNE2 04	Total/NA	Tissue	In-House	
320-113896-19 - DL	ArtNE4 01	Total/NA	Tissue	In-House	
320-113896-19	ArtNE4 01	Total/NA	Tissue	In-House	
320-113896-20	ArtNE4 02	Total/NA	Tissue	In-House	

Prep Batch: 785621

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113896-1	NK311140 liver	Total/NA	Tissue	SHAKE	785620
320-113896-1 - DL	NK311140 liver	Total/NA	Tissue	SHAKE	785620
320-113896-2 - DL	NK311141 liver	Total/NA	Tissue	SHAKE	785620
320-113896-2	NK311141 liver	Total/NA	Tissue	SHAKE	785620
320-113896-3 - DL	NK311142 liver	Total/NA	Tissue	SHAKE	785620
320-113896-3	NK311142 liver	Total/NA	Tissue	SHAKE	785620
320-113896-4	NK311143 liver	Total/NA	Tissue	SHAKE	785620
320-113896-5 - DL	NK311145 liver	Total/NA	Tissue	SHAKE	785620
320-113896-5	NK311145 liver	Total/NA	Tissue	SHAKE	785620
320-113896-6	NK311145 femur	Total/NA	Tissue	SHAKE	785620
320-113896-6 - DL	NK311145 femur	Total/NA	Tissue	SHAKE	785620
320-113896-7	NK311146 liver	Total/NA	Tissue	SHAKE	785620
320-113896-7 - DL	NK311146 liver	Total/NA	Tissue	SHAKE	785620
320-113896-8 - DL	NK311146 femur	Total/NA	Tissue	SHAKE	785620
320-113896-8	NK311146 femur	Total/NA	Tissue	SHAKE	785620
320-113896-9	NK311129 liver	Total/NA	Tissue	SHAKE	785620

LCMS (Continued)

Prep Batch: 785621 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113896-9 - DL	NK311129 liver	Total/NA	Tissue	SHAKE	785620
320-113896-10	NK311131 liver	Total/NA	Tissue	SHAKE	785620
320-113896-10 - DL	NK311131 liver	Total/NA	Tissue	SHAKE	785620
320-113896-11	NK311133 liver	Total/NA	Tissue	SHAKE	785620
320-113896-11 - DL	NK311133 liver	Total/NA	Tissue	SHAKE	785620
320-113896-12	NK319511 muscle	Total/NA	Tissue	SHAKE	785620
320-113896-13	NK319092 liver	Total/NA	Tissue	SHAKE	785620
320-113896-14	Velvet ant NE2 03	Total/NA	Tissue	SHAKE	785620
320-113896-15 - DL	ArtNE2 01	Total/NA	Tissue	SHAKE	785620
320-113896-15	ArtNE2 01	Total/NA	Tissue	SHAKE	785620
320-113896-16	ArtNE2 02	Total/NA	Tissue	SHAKE	785620
320-113896-17	ArtNE2 03	Total/NA	Tissue	SHAKE	785620
320-113896-18	ArtNE2 04	Total/NA	Tissue	SHAKE	785620
320-113896-19	ArtNE4 01	Total/NA	Tissue	SHAKE	785620
320-113896-19 - DL	ArtNE4 01	Total/NA	Tissue	SHAKE	785620
320-113896-20	ArtNE4 02	Total/NA	Tissue	SHAKE	785620
MB 320-785621/1-A	Method Blank	Total/NA	Tissue	SHAKE	
LCS 320-785621/2-A	Lab Control Sample	Total/NA	Tissue	SHAKE	
LCSD 320-785621/3-A	Lab Control Sample Dup	Total/NA	Tissue	SHAKE	

Prep Batch: 786204

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113896-23	VDS 0 TEST	Total/NA	Water	3535	

Pre Prep Batch: 788724

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113896-21	ArtNE4 03	Total/NA	Tissue	In-House	
320-113896-22	ArtNE4 04	Total/NA	Tissue	In-House	
320-113896-24 - DL	NK284441	Total/NA	Tissue	In-House	
320-113896-24	NK284441	Total/NA	Tissue	In-House	
320-113896-25	NK284442	Total/NA	Tissue	In-House	
320-113896-25 - DL	NK284442	Total/NA	Tissue	In-House	
320-113896-26	NK284443	Total/NA	Tissue	In-House	
320-113896-26 - DL	NK284443	Total/NA	Tissue	In-House	
320-113896-27	NK284444	Total/NA	Tissue	In-House	
320-113896-27 - DL	NK284444	Total/NA	Tissue	In-House	
320-113896-28 - DL	NK284445	Total/NA	Tissue	In-House	
320-113896-28	NK284445	Total/NA	Tissue	In-House	
320-113896-29 - DL	NK284446	Total/NA	Tissue	In-House	
320-113896-29	NK284446	Total/NA	Tissue	In-House	
320-113896-30	NK284447	Total/NA	Tissue	In-House	
320-113896-31 - DL	NK284448	Total/NA	Tissue	In-House	
320-113896-31	NK284448	Total/NA	Tissue	In-House	
320-113896-32	NK284449	Total/NA	Tissue	In-House	
320-113896-32 - DL	NK284449	Total/NA	Tissue	In-House	
320-113896-33 - DL	NK284450	Total/NA	Tissue	In-House	
320-113896-33	NK284450	Total/NA	Tissue	In-House	
320-113896-34	NK284451	Total/NA	Tissue	In-House	
320-113896-34 - DL	NK284451	Total/NA	Tissue	In-House	
320-113896-35	NK284439	Total/NA	Tissue	In-House	
320-113896-35 - DL	NK284439	Total/NA	Tissue	In-House	

LCMS (Continued)

Pre Prep Batch: 788724 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113896-36 - DL	NK284452	Total/NA	Tissue	In-House	
320-113896-36	NK284452	Total/NA	Tissue	In-House	
320-113896-37	NK284442 V24-20096 liver	Total/NA	Tissue	In-House	
320-113896-37 - DL	NK284442 V24-20096 liver	Total/NA	Tissue	In-House	
320-113896-38 - DL	NK284443 V24-20097 liver	Total/NA	Tissue	In-House	
320-113896-38	NK284443 V24-20097 liver	Total/NA	Tissue	In-House	
320-113896-39 - DL	NK284444 V24-20103 liver	Total/NA	Tissue	In-House	
320-113896-39	NK284444 V24-20103 liver	Total/NA	Tissue	In-House	

Prep Batch: 788729

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113896-21	ArtNE4 03	Total/NA	Tissue	SHAKE	788724
320-113896-22	ArtNE4 04	Total/NA	Tissue	SHAKE	788724
320-113896-24 - DL	NK284441	Total/NA	Tissue	SHAKE	788724
320-113896-24	NK284441	Total/NA	Tissue	SHAKE	788724
320-113896-25 - DL	NK284442	Total/NA	Tissue	SHAKE	788724
320-113896-25	NK284442	Total/NA	Tissue	SHAKE	788724
320-113896-26	NK284443	Total/NA	Tissue	SHAKE	788724
320-113896-26 - DL	NK284443	Total/NA	Tissue	SHAKE	788724
320-113896-27	NK284444	Total/NA	Tissue	SHAKE	788724
320-113896-27 - DL	NK284444	Total/NA	Tissue	SHAKE	788724
320-113896-28 - DL	NK284445	Total/NA	Tissue	SHAKE	788724
320-113896-28	NK284445	Total/NA	Tissue	SHAKE	788724
320-113896-29	NK284446	Total/NA	Tissue	SHAKE	788724
320-113896-29 - DL	NK284446	Total/NA	Tissue	SHAKE	788724
320-113896-30	NK284447	Total/NA	Tissue	SHAKE	788724
320-113896-31	NK284448	Total/NA	Tissue	SHAKE	788724
320-113896-31 - DL	NK284448	Total/NA	Tissue	SHAKE	788724
320-113896-32	NK284449	Total/NA	Tissue	SHAKE	788724
320-113896-32 - DL	NK284449	Total/NA	Tissue	SHAKE	788724
320-113896-33	NK284450	Total/NA	Tissue	SHAKE	788724
320-113896-33 - DL	NK284450	Total/NA	Tissue	SHAKE	788724
320-113896-34	NK284451	Total/NA	Tissue	SHAKE	788724
320-113896-34 - DL	NK284451	Total/NA	Tissue	SHAKE	788724
320-113896-35	NK284439	Total/NA	Tissue	SHAKE	788724
320-113896-35 - DL	NK284439	Total/NA	Tissue	SHAKE	788724
320-113896-36 - DL	NK284452	Total/NA	Tissue	SHAKE	788724
320-113896-36	NK284452	Total/NA	Tissue	SHAKE	788724
320-113896-37 - DL	NK284442 V24-20096 liver	Total/NA	Tissue	SHAKE	788724
320-113896-37	NK284442 V24-20096 liver	Total/NA	Tissue	SHAKE	788724
320-113896-38	NK284443 V24-20097 liver	Total/NA	Tissue	SHAKE	788724
320-113896-38 - DL	NK284443 V24-20097 liver	Total/NA	Tissue	SHAKE	788724
320-113896-39 - DL	NK284444 V24-20103 liver	Total/NA	Tissue	SHAKE	788724
320-113896-39	NK284444 V24-20103 liver	Total/NA	Tissue	SHAKE	788724
MB 320-788729/1-A	Method Blank	Total/NA	Tissue	SHAKE	
LCS 320-788729/2-A	Lab Control Sample	Total/NA	Tissue	SHAKE	
LCSD 320-788729/3-A	Lab Control Sample Dup	Total/NA	Tissue	SHAKE	

Analysis Batch: 789266

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113896-1	NK311140 liver	Total/NA	Tissue	B/L/T PFAS	785621

LCMS (Continued)

Analysis Batch: 789266 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113896-2	NK311141 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-3	NK311142 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-4	NK311143 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-5	NK311145 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-6	NK311145 femur	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-7	NK311146 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-8	NK311146 femur	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-9	NK311129 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-10	NK311131 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-11	NK311133 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-12	NK319511 muscle	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-13	NK319092 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-14	Velvet ant NE2 03	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-15	ArtNE2 01	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-16	ArtNE2 02	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-17	ArtNE2 03	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-18	ArtNE2 04	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-19	ArtNE4 01	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-20	ArtNE4 02	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-23	VDS 0 TEST	Total/NA	Water	B/L/T PFAS	786204
MB 320-785621/1-A	Method Blank	Total/NA	Tissue	B/L/T PFAS	785621
LCS 320-785621/2-A	Lab Control Sample	Total/NA	Tissue	B/L/T PFAS	785621
LCSD 320-785621/3-A	Lab Control Sample Dup	Total/NA	Tissue	B/L/T PFAS	785621

Analysis Batch: 789267

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113896-21	ArtNE4 03	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-22	ArtNE4 04	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-24	NK284441	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-25	NK284442	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-26	NK284443	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-27	NK284444	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-28	NK284445	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-29	NK284446	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-30	NK284447	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-31	NK284448	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-32	NK284449	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-33	NK284450	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-34	NK284451	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-35	NK284439	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-36	NK284452	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-37	NK284442 V24-20096 liver	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-38	NK284443 V24-20097 liver	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-39	NK284444 V24-20103 liver	Total/NA	Tissue	B/L/T PFAS	788729
MB 320-788729/1-A	Method Blank	Total/NA	Tissue	B/L/T PFAS	788729
LCS 320-788729/2-A	Lab Control Sample	Total/NA	Tissue	B/L/T PFAS	788729
LCSD 320-788729/3-A	Lab Control Sample Dup	Total/NA	Tissue	B/L/T PFAS	788729

Analysis Batch: 790560

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113896-24 - DL	NK284441	Total/NA	Tissue	B/L/T PFAS	788729

LCMS (Continued)

Analysis Batch: 790560 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113896-25 - DL	NK284442	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-26 - DL	NK284443	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-27 - DL	NK284444	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-29 - DL	NK284446	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-31 - DL	NK284448	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-32 - DL	NK284449	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-35 - DL	NK284439	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-36 - DL	NK284452	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-37 - DL	NK284442 V24-20096 liver	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-38 - DL	NK284443 V24-20097 liver	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-39 - DL	NK284444 V24-20103 liver	Total/NA	Tissue	B/L/T PFAS	788729

Analysis Batch: 791187

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113896-28 - DL	NK284445	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-33 - DL	NK284450	Total/NA	Tissue	B/L/T PFAS	788729
320-113896-34 - DL	NK284451	Total/NA	Tissue	B/L/T PFAS	788729

Analysis Batch: 791473

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113896-1 - DL	NK311140 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-2 - DL	NK311141 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-3 - DL	NK311142 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-5 - DL	NK311145 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-6 - DL	NK311145 femur	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-7 - DL	NK311146 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-8 - DL	NK311146 femur	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-9 - DL	NK311129 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-10 - DL	NK311131 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-15 - DL	ArtNE2 01	Total/NA	Tissue	B/L/T PFAS	785621

Analysis Batch: 791800

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-113896-11 - DL	NK311133 liver	Total/NA	Tissue	B/L/T PFAS	785621
320-113896-19 - DL	ArtNE4 01	Total/NA	Tissue	B/L/T PFAS	785621

Lab Chronicle

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK311140 liver
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-1
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			1.01 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 04:58	JTD	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE	DL		1.01 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	20	1 mL	1 mL	791473	08/15/24 10:59	C1P	EET SAC

Client Sample ID: NK311141 liver
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-2
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			1.34 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 05:17	JTD	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE	DL		1.34 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	50	1 mL	1 mL	791473	08/15/24 11:18	C1P	EET SAC

Client Sample ID: NK311142 liver
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-3
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			0.07 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 05:37	JTD	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE	DL		0.07 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	5	1 mL	1 mL	791473	08/15/24 11:38	C1P	EET SAC

Client Sample ID: NK311143 liver
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-4
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			0.14 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 05:56	JTD	EET SAC

Lab Chronicle

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK311145 liver

Lab Sample ID: 320-113896-5
Matrix: Tissue
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			1.45 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 06:15	JTD	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE	DL		1.45 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	791473	08/15/24 16:10	C1P	EET SAC

Client Sample ID: NK311145 femur

Lab Sample ID: 320-113896-6
Matrix: Tissue
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			0.19 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 06:35	JTD	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE	DL		0.19 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	791473	08/15/24 11:57	C1P	EET SAC

Client Sample ID: NK311146 liver

Lab Sample ID: 320-113896-7
Matrix: Tissue
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			1.55 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 06:54	JTD	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE	DL		1.55 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	791473	08/15/24 16:29	C1P	EET SAC

Client Sample ID: NK311146 femur

Lab Sample ID: 320-113896-8
Matrix: Tissue
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			0.29 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 07:33	JTD	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE	DL		0.29 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	791473	08/15/24 12:36	C1P	EET SAC

Lab Chronicle

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK311129 liver

Lab Sample ID: 320-113896-9
Matrix: Tissue
Date Collected: 05/16/24 07:00
Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			0.40 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 07:53	JTD	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE	DL		0.40 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	791473	08/15/24 13:15	C1P	EET SAC

Client Sample ID: NK311131 liver

Lab Sample ID: 320-113896-10
Matrix: Tissue
Date Collected: 05/16/24 07:00
Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			0.30 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 08:12	JTD	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE	DL		0.30 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	791473	08/15/24 15:50	C1P	EET SAC

Client Sample ID: NK311133 liver

Lab Sample ID: 320-113896-11
Matrix: Tissue
Date Collected: 05/16/24 07:00
Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			0.37 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 08:31	JTD	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE	DL		0.37 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	20	1 mL	1 mL	791800	08/16/24 09:38	S1C	EET SAC

Client Sample ID: NK319511 muscle

Lab Sample ID: 320-113896-12
Matrix: Tissue
Date Collected: 02/10/24 10:00
Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:06	AM	EET SAC
Total/NA	Prep	SHAKE			1.89 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 08:51	JTD	EET SAC

Client Sample ID: NK319092 liver

Lab Sample ID: 320-113896-13

Date Collected: 02/10/24 10:00

Matrix: Tissue

Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			1.51 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 09:10	JTD	EET SAC

Client Sample ID: Velvet ant NE2 03

Lab Sample ID: 320-113896-14

Date Collected: 07/03/24 07:00

Matrix: Tissue

Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			0.27 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 09:30	JTD	EET SAC

Client Sample ID: ArtNE2 01

Lab Sample ID: 320-113896-15

Date Collected: 07/03/24 07:00

Matrix: Tissue

Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			0.82 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 09:49	JTD	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE	DL		0.82 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	791473	08/15/24 15:11	C1P	EET SAC

Client Sample ID: ArtNE2 02

Lab Sample ID: 320-113896-16

Date Collected: 07/03/24 07:00

Matrix: Tissue

Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			0.05 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 10:08	JTD	EET SAC

Client Sample ID: ArtNE2 03

Lab Sample ID: 320-113896-17

Date Collected: 07/03/24 07:00

Matrix: Tissue

Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			1.24 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 10:28	JTD	EET SAC

Lab Chronicle

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: ArtNE2 04
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-18
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			0.15 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 14:21	JTD	EET SAC

Client Sample ID: ArtNE4 01
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-19
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			0.85 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 14:40	JTD	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE	DL		0.85 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	791800	08/16/24 09:57	S1C	EET SAC

Client Sample ID: ArtNE4 02
Date Collected: 07/03/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-20
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	785620	07/29/24 11:04	AM	EET SAC
Total/NA	Prep	SHAKE			0.43 g	10.0 mL	785621	07/29/24 11:09	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 15:00	JTD	EET SAC

Client Sample ID: ArtNE4 03
Date Collected: 05/16/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-21
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			0.25 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/09/24 19:31	C1P	EET SAC

Client Sample ID: ArtNE4 04
Date Collected: 05/15/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-22
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			0.29 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/09/24 19:51	C1P	EET SAC

Lab Chronicle

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: VDS 0 TEST
Date Collected: 07/17/24 00:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-23
Matrix: Water

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3535			4.0 mL	10.0 mL	786204	07/30/24 19:07	EWH	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789266	08/09/24 15:19	JTD	EET SAC

Client Sample ID: NK284441
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-24
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			0.94 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/09/24 20:10	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE	DL		0.94 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	50	1 mL	1 mL	790560	08/12/24 20:19	C1P	EET SAC

Client Sample ID: NK284442
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-25
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			1.18 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/09/24 20:30	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE	DL		1.18 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	790560	08/12/24 20:58	C1P	EET SAC

Client Sample ID: NK284443
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-26
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			1.99 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/09/24 20:49	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE	DL		1.99 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	50	1 mL	1 mL	790560	08/12/24 21:17	C1P	EET SAC

Client Sample ID: NK284444
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-27
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			1.32 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/09/24 21:08	C1P	EET SAC

Eurofins Sacramento

Lab Chronicle

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284444
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-27
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE	DL		1.32 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	790560	08/12/24 22:16	C1P	EET SAC

Client Sample ID: NK284445
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-28
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			0.98 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/09/24 21:28	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE	DL		0.98 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	791187	08/14/24 09:51	C1P	EET SAC

Client Sample ID: NK284446
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-29
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			1.42 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/09/24 22:07	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE	DL		1.42 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	50	1 mL	1 mL	790560	08/12/24 22:54	C1P	EET SAC

Client Sample ID: NK284447
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-30
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			0.88 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/09/24 22:26	C1P	EET SAC

Client Sample ID: NK284448
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-31
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			1.78 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/09/24 22:45	C1P	EET SAC

Lab Chronicle

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284448
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-31
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE	DL		1.78 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	790560	08/12/24 23:53	C1P	EET SAC

Client Sample ID: NK284449
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-32
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			0.76 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/09/24 23:05	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE	DL		0.76 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	790560	08/13/24 00:12	C1P	EET SAC

Client Sample ID: NK284450
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-33
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			0.56 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/09/24 23:24	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE	DL		0.56 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	20	1 mL	1 mL	791187	08/14/24 10:10	C1P	EET SAC

Client Sample ID: NK284451
Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-34
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			1.09 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/09/24 23:44	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE	DL		1.09 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	20	1 mL	1 mL	791187	08/14/24 10:30	C1P	EET SAC

Client Sample ID: NK284439

Lab Sample ID: 320-113896-35

Date Collected: 07/11/24 07:00

Matrix: Tissue

Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			1.02 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/10/24 00:03	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE	DL		1.02 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	790560	08/13/24 01:30	C1P	EET SAC

Client Sample ID: NK284452

Lab Sample ID: 320-113896-36

Date Collected: 07/16/24 07:00

Matrix: Tissue

Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			1.03 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/10/24 00:22	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE	DL		1.03 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	50	1 mL	1 mL	790560	08/13/24 02:28	C1P	EET SAC

Client Sample ID: NK284442 V24-20096 liver

Lab Sample ID: 320-113896-37

Date Collected: 06/24/24 00:00

Matrix: Tissue

Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			0.91 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/10/24 00:42	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE	DL		0.91 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	50	1 mL	1 mL	790560	08/13/24 03:07	C1P	EET SAC

Client Sample ID: NK284443 V24-20097 liver

Lab Sample ID: 320-113896-38

Date Collected: 06/24/24 07:00

Matrix: Tissue

Date Received: 07/18/24 09:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			1.08 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/10/24 01:01	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE	DL		1.08 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	50	1 mL	1 mL	790560	08/13/24 03:46	C1P	EET SAC

Lab Chronicle

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Client Sample ID: NK284444 V24-20103 liver

Date Collected: 06/24/24 07:00
Date Received: 07/18/24 09:20

Lab Sample ID: 320-113896-39

Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE			0.32 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	789267	08/10/24 01:40	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	788724	08/08/24 10:28	AM	EET SAC
Total/NA	Prep	SHAKE	DL		0.32 g	10.0 mL	788729	08/08/24 10:31	AM	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	50	1 mL	1 mL	790560	08/13/24 04:24	C1P	EET SAC

Laboratory References:

EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

Accreditation/Certification Summary

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Laboratory: Eurofins Sacramento

All accreditations/certifications held by this laboratory are listed. Not all accreditations/certifications are applicable to this report.

Authority	Program	Identification Number	Expiration Date
Alaska (UST)	State	17-020	02-20-27
ANAB	Dept. of Defense ELAP	L2468	01-20-27
ANAB	Dept. of Energy	L2468.01	01-20-27
ANAB	ISO/IEC 17025	L2468	01-20-27
Arizona	State	AZ0708	08-11-25
Arkansas DEQ	State	88-0691	05-18-25
California	State	2897	01-31-26
Colorado	State	CA00044	08-31-24
Florida	NELAP	E87570	06-30-25
Georgia	State	4040	01-29-25
Hawaii	State	Eurofins Sacramento	01-29-25
Illinois	NELAP	200060	03-31-25
Kansas	NELAP	E-10375	10-31-25
Louisiana	NELAP	01944	06-30-25
Louisiana (All)	NELAP	01944	06-30-25
Maine	State	CA00004	04-14-26
Michigan	State	9947	08-18-24
Nevada	State	CA00044	10-31-24
New Hampshire	NELAP	2997	04-19-25
New Jersey	NELAP	CA005	06-30-25
New York	NELAP	11666	04-01-25
Ohio	State	41252	01-29-25
Oregon	NELAP	4040	01-29-25
Texas	NELAP	T104704399-23-17	05-31-25
US Fish & Wildlife	US Federal Programs	A22139	04-30-25
USDA	US Federal Programs	P330-18-00239	02-28-26
Utah	NELAP	CA000442023-16	02-28-25
Virginia	NELAP	460278	03-14-25
Washington	State	C581	05-05-25
West Virginia (DW)	State	9930C	01-31-25
Wisconsin	State	998204680	08-31-25
Wyoming	State Program	8TMS-L	01-28-19 *

* Accreditation/Certification renewal pending - accreditation/certification considered valid.

Method Summary

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Method	Method Description	Protocol	Laboratory
B/L/T PFAS	Branched, Linear and Total PFAS	EPA	EET SAC
3535	Solid-Phase Extraction (SPE)	SW846	EET SAC
In-House	Tissue Preparation/Homgenization	NOAA	EET SAC
SHAKE	Shake Extraction with Ultrasonic Bath Extraction	SW846	EET SAC

Protocol References:

EPA = US Environmental Protection Agency

NOAA = National Marine Fisheries Service, National Oceanic And Atmospheric Administration, Seattle, WA, November 1988

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

Sample Summary

Client: University of New Mexico
Project/Site: Holloman bird/mammal

Job ID: 320-113896-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
320-113896-1	NK311140 liver	Tissue	07/03/24 07:00	07/18/24 09:20
320-113896-2	NK311141 liver	Tissue	07/03/24 07:00	07/18/24 09:20
320-113896-3	NK311142 liver	Tissue	07/03/24 07:00	07/18/24 09:20
320-113896-4	NK311143 liver	Tissue	07/03/24 07:00	07/18/24 09:20
320-113896-5	NK311145 liver	Tissue	07/03/24 07:00	07/18/24 09:20
320-113896-6	NK311145 femur	Tissue	07/03/24 07:00	07/18/24 09:20
320-113896-7	NK311146 liver	Tissue	07/03/24 07:00	07/18/24 09:20
320-113896-8	NK311146 femur	Tissue	07/03/24 07:00	07/18/24 09:20
320-113896-9	NK311129 liver	Tissue	05/16/24 07:00	07/18/24 09:20
320-113896-10	NK311131 liver	Tissue	05/16/24 07:00	07/18/24 09:20
320-113896-11	NK311133 liver	Tissue	05/16/24 07:00	07/18/24 09:20
320-113896-12	NK319511 muscle	Tissue	02/10/24 10:00	07/18/24 09:20
320-113896-13	NK319092 liver	Tissue	02/10/24 10:00	07/18/24 09:20
320-113896-14	Velvet ant NE2 03	Tissue	07/03/24 07:00	07/18/24 09:20
320-113896-15	ArtNE2 01	Tissue	07/03/24 07:00	07/18/24 09:20
320-113896-16	ArtNE2 02	Tissue	07/03/24 07:00	07/18/24 09:20
320-113896-17	ArtNE2 03	Tissue	07/03/24 07:00	07/18/24 09:20
320-113896-18	ArtNE2 04	Tissue	07/03/24 07:00	07/18/24 09:20
320-113896-19	ArtNE4 01	Tissue	07/03/24 07:00	07/18/24 09:20
320-113896-20	ArtNE4 02	Tissue	07/03/24 07:00	07/18/24 09:20
320-113896-21	ArtNE4 03	Tissue	05/16/24 07:00	07/18/24 09:20
320-113896-22	ArtNE4 04	Tissue	05/15/24 07:00	07/18/24 09:20
320-113896-23	VDS 0 TEST	Water	07/17/24 00:00	07/18/24 09:20
320-113896-24	NK284441	Tissue	06/24/24 07:00	07/18/24 09:20
320-113896-25	NK284442	Tissue	06/24/24 07:00	07/18/24 09:20
320-113896-26	NK284443	Tissue	06/24/24 07:00	07/18/24 09:20
320-113896-27	NK284444	Tissue	06/24/24 07:00	07/18/24 09:20
320-113896-28	NK284445	Tissue	06/24/24 07:00	07/18/24 09:20
320-113896-29	NK284446	Tissue	06/24/24 07:00	07/18/24 09:20
320-113896-30	NK284447	Tissue	06/24/24 07:00	07/18/24 09:20
320-113896-31	NK284448	Tissue	06/24/24 07:00	07/18/24 09:20
320-113896-32	NK284449	Tissue	06/24/24 07:00	07/18/24 09:20
320-113896-33	NK284450	Tissue	06/24/24 07:00	07/18/24 09:20
320-113896-34	NK284451	Tissue	06/24/24 07:00	07/18/24 09:20
320-113896-35	NK284439	Tissue	07/11/24 07:00	07/18/24 09:20
320-113896-36	NK284452	Tissue	07/16/24 07:00	07/18/24 09:20
320-113896-37	NK284442 V24-20096 liver	Tissue	06/24/24 00:00	07/18/24 09:20
320-113896-38	NK284443 V24-20097 liver	Tissue	06/24/24 07:00	07/18/24 09:20
320-113896-39	NK284444 V24-20103 liver	Tissue	06/24/24 07:00	07/18/24 09:20

Eurofins Environment Testing Northern California
880 Riverside Parkway
West Sacramento, CA 95605
Phone: 916.373.5600

Chain of Custody Record

eurofins

Client Contact	Report To Jean-Luc Cartron or Jon Dunnum	Site Contact:	16-Jul-24	COC No
Museum of Southwestern Biology University of New Mexico	Tel/Fax:505 277-9262; 505 977-7716	Lab Contact:	Carrier:	1 of 3 COCs
CERIA 83 rm 204 1 University of New Mexico	Analysis Turnaround Time			Job No
Albuquerque New Mexico 87131	Calendar (C) or Work Days (W) C			
505 277-9262 505 977-7716	TAT if different from Below			SDG No
FAX.	[x] 2 weeks			
Holloman bird/mammal PFAS Project	[ ] 1 week			
Site.	[ ] 2 days			
P O #	[ ] 1 day			

Sample Identification	Sample Date	Sample Time	Sample Type	Matrix	# of Cont.	Filtered Sample	Sample Specific Notes.
NK311140 liver	7/3/2024	7:00	liver				Dipodomys merriami
NK311141 liver	7/3/2024	7:00	liver				Dipodomys merriami
NK311142 liver	7/3/2024	7 00	liver				Perognathus flavus
NK311143 liver	7/3/2024	7:00	liver				Perognathus flavus
NK311145 liver	7/3/2024	7 00	liver				Dipodomys merriami
NK311145 femur	7/3/2024	7:00	bone				Dipodomys merriami
NK311146 liver	7/3/2024	7:00	liver				Xerospermophilus spilosoma
NK311146 femur	7/3/2024	7:00	bone				Xerospermophilus spilosoma
NK311129 liver	5/16/2024	7 00	liver				Chaetodipus eremicus
NK311131 liver	5/16/2024	7 00	liver				Chaetodipus eremicus
NK311133 liver	5/16/2024	7 00	liver				Chaetodipus eremicus
NK319511 muscle	2/10/2024	10:00	muscle				Oryz gazella

320-113896 Chain of Custody

Preservation Used: 1= Ice, 2= HCl; 3= H2SO4; 4=HNO3; 5=NaOH; 6= Other _____

Possible Hazard Identification
[ ] *Non-Hazard* [ ] *Flammable* [ ] *Skin Irritant* *Poison B* *Unknown* [ ]

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
[ ] *Return To Client* [x] *Disposal By Lab* [ ] *Archive For _____ Months*

Special Instructions/QC Requirements & Comments:

Relinquished by:	Company:	Date/Time	Received by:	Company:	Date/Time
				Eurofins	7/18/24 0920
Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time
Relinquished by:	Company	Date/Time.	Received by:	Company:	Date/Time

-36.9

NMED Exhibits 65

Eurofins Environment Testing Northern California
880 Riverside Parkway
West Sacramento CA 95605
Phone: 916.373 5600

Chain of Custody Record

eurofins

Client Contact	Report To Jean-Luc Cartron or Jon Dunnum	Site Contact:	16-Jul-24	COC No
Museum of Southwestern Biology University of New Mexico	Tel/Fax:505 277-9262, 505 977 7716	Lab Contact:	Carrier:	2 of 3 COCs
CERIA 83 rm 204 1 University of New Mexico	Analysis Turnaround Time			Job No
Albuquerque, New Mexico 87131	Calendar (C) or Work Days (W) C			
505 277-9262 505 977-7716	TAT if different from Below			
FAX.	[X] 2 weeks			SDG No
Holloman bird/mammal PFAS Project	[ ] 1 week			
Site.	[ ] 2 days			
P O #	[ ] 1 day			

Sample Identification	Sample Date	Sample Time	Sample Type	Matrix	# of Cont.	Filtered Sample	Sample Specific Notes
NK319092 liver	2/10/2024	10 00	liver				Oryz gazella
Velvet ant NE2 03	7/3/2024	7 00	arthropods				mixed arthropods
ArtNE2 01	7/3/2024	7 00	arthropods				mixed arthropods
ArtNE2 02	7/3/2024	7 00	arthropods				mixed arthropods
ArtNE2 03	7/3/2024	7:00	arthropods				mixed arthropods
ArtNE2 04	7/3/2024	7:00	arthropods				mixed arthropods
ArtNE4 01	7/3/2024	7 00	arthropods				mixed arthropods
ArtNE4 02	7/3/2024	7 00	arthropods				mixed arthropods
ArtNE4 03	5/16/2024	7:00	arthropods				mixed arthropods
ArtNE4 04	5/16/2024	7:00	arthropods				mixed arthropods
VDS 0 TEST			blank				to verify PFAS free vial

Preservation Used. 1= Ice, 2= HCl, 3= H_2SO_4, 4=HNO_3, 5=NaOH, 6= Other _____

Possible Hazard Identification
[ ] *Non-Hazard* [ ] *Flammable* [ ] *Skin Irritant* *Poison B* *Unknown* [ ]

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
[ ] *Return To Client* [X] *Disposal By Lab* [ ] *Archive For* _____ *Months*

Special Instructions/QC Requirements & Comments.

Relinquished by	Company	Date/Time	Received by	Company	Date/Time
				EETSac	7/19/2 0920
Relinquished by	Company	Date/Time	Received by	Company	Date/Time
Relinquished by	Company	Date/Time	Received by	Company	Date/Time

-36.9

NMED Exhibits 65

Eurofins Environment Testing Northern California
880 Riverside Parkway
West Sacramento, CA 95605
Phone: 916.373 5600

Chain of Custody Record

eurofins

Client Contact	Report To Jean-Luc Cartron or Jon Dunnum	Site Contact:	16-Jul-24	COC No:
Museum of Southwestern Biology University of New Mexico	Tel/Fax:505 277-9262, 505 977-7716	Lab Contact:	Carrier:	3 of 3 COCs
CERIA 83 rm 204 1 University of New Mexico	Analysis Turnaround Time			Job No
Albuquerque, New Mexico 87131	Calendar (C) or Work Days (W) C			
505 277-9262; 505 977-7716	TAT if different from Below			
FAX.	[X] 2 weeks			SDG No
Holloman bird/mammal PFAS Project	[ ] 1 week			
Site:	[ ] 2 days			
P O #	[ ] 1 day			

Sample Identification	Sample Date	Sample Time	Sample Type	Matrix	# of Cont.	Filtered Sample	Sample Specific Notes:
Nk284441	6/24/2024	7:00	muscle				Agelaius phoeniceus (muscle)
NK284442	6/24/2024	7:00	muscle				Charadrius vociferus (muscle)
NK284443	6/24/2024	7:00	muscle				Recurvirostra americana (muscle)
NK284444	6/24/2024	7:00	muscle				Agelaius phoeniceus (muscle)
NK284445	6/24/2024	7:00	muscle				Agelaius phoeniceus (muscle)
Nk284446	6/24/2024	7:00	muscle				Agelaius phoeniceus (muscle)
NK284447	6/24/2024	7:00	muscle				Tyrannus verticalis (muscle)
NK284448	6/24/2024	7:00	muscle				Tyrannus verticalis (muscle)
NK284449	6/24/2024	7:00	muscle				Geothlypis trichas (muscle)
NK284450	6/24/2024	7:00	muscle				Geothlypis trichas (muscle)
NK284451	6/24/2024	7:00	muscle				Geothlypis trichas (muscle)
NK284439	7/11/2024	7:00	tissue				Charadrius vociferus (tissue)
NK284452	7/16/2024	7:00	ground egg				Sayornus saya (egg)
NK284442 V24-20096 liver	6/24/2024		liver				Charadrius vociferus (liver)
NK284443 V24-20097 liver	6/24/2024	7:00	liver				Recurvirostra americana (liver)
NK284444 V24-20103 liver	6/24/2024	7:00	liver				Agelaius phoeniceus (liver)

Preservation Used. 1= Ice, 2= HCl, 3= H2SO4; 4=HNO3, 5=NaOH, 6= Other _____

Possible Hazard Identification
[ ] *Non-Hazard* [ ] *Flammable* [ ] *Skin Irritant* *Poison B* [ ] *Unknown* [ ]

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
[ ] *Return To Client* [x] *Disposal By Lab* [ ] *Archive For* _____ *Months*

Special Instructions/QC Requirements & Comments:

Relinquished by	Company	Date/Time:	Received by	Company	Date/Time:
				EETSac	7/15/24 0920
Relinquished by	Company	Date/Time:	Received by	Company	Date/Time:
Relinquished by	Company	Date/Time:	Received by	Company	Date/Time:

-36.6

NMED Exhibits 65

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Sacramento Sample Receiving Notes (SSRN)

Loc. 320
113896

Tracking # 777454148947

Job._____

SO / PO / FO / SAT / 2-Day / Ground / UPS / CDO / Courier
GSL / OnTrac / Goldstreak / USPS / Other_____

Use this form to record Sample Custody Seal, Cooler Custody Seal, Temperature & corrected Temperature & other observations.
File in the job folder with the COC

Therm. ID: IR7 Corr Factor: (+ / -) ____ °C

Ice____ Wet____ Gel____ Other ✓

Cooler Custody Seal —

Cooler ID: —

Temp Observed: −36.9°C Corrected: −36.9°C
From Temp Blank ☐ Sample ☒

Opening/Processing The Shipment	Yes	No	NA
Cooler compromised/tampered with?	☐	☒	☐
Cooler Temperature is acceptable?	☒	☐	☐
Frozen samples show signs of thaw?	☐	☐	☒

Initials: MA Date 7/19/24

Unpacking/Labeling The Samples	Yes	No	NA
Containers are not broken or leaking?	☒	☐	☐
Samples compromised/tampered with?	☐	☒	☐
COC is complete w/o discrepancies	☐	☒	☐
Sample custody seal?	☐	☐	☒
Sample containers have legible labels?	☒	☐	☐
Sample date/times are provided?	☒	☐	☐
Appropriate containers are used?	☒	☐	☐
Sample bottles are completely filled?	☒	☐	☐
Sample preservatives verified?	☐	☐	☒
Is the Field Sampler's name on COC?	☐	☒	☐
Samples w/o discrepancies?	☐	☒	☐
Zero headspace?*	☐	☐	☒
Alkalinity has no headspace?	☐	☐	☒
Perchlorate has headspace? (Methods 314, 331, 6850)	☐	☐	☒
Multiphasic samples are not present?	☒	☐	☐

*Containers requiring zero headspace have no headspace, or bubble < 6 mm (1/4")

Initials SO Date 7/18/24

Notes: Dry ice

Trizma Lot #(s) _____

Ammonium Acetate Lot #(s) _____

Login Completion	Yes	No	NA
Receipt Temperature on COC?	☒	☐	☐
NCM Filed?	☒	☐	☐
Samples received within hold time?	☒	☐	☐
Log Release checked in TALS?	☒	☐	☐

Initials SO Date 7/18/24

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ANALYTICAL REPORT

PREPARED FOR

Attn: Jean-Luc Cartron
University of New Mexico
Museum of Southwestern Biology
Division of Mammals
CERIA Bldg 83, Room 204
Albuquerque, New Mexico 87131

Generated 12/23/2024 8:48:15 AM

JOB DESCRIPTION

UNM_PFAS in Tissue, Plant & Soil, Holloman

JOB NUMBER

320-117195-1

Eurofins Sacramento
880 Riverside Parkway
West Sacramento CA 95605

See page two for job notes and contact information.

NMED Exhibits 60

Eurofins Sacramento

Job Notes

This report may not be reproduced except in full, and with written approval from the laboratory. The results relate only to the samples tested. For questions please contact the Project Manager at the e-mail address or telephone number listed on this page.

The test results in this report relate only to the samples as received by the laboratory and will meet all requirements of the methodology, with any exceptions noted. This report shall not be reproduced except in full, without the express written approval of the laboratory. All questions should be directed to the Eurofins Environment Testing Northern California, LLC Project Manager.

Authorization



Generated
12/23/2024 8:48:15 AM

Authorized for release by
Linda C. Laver, Senior Project Manager
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(916)374-4362

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Qualifiers

LCMS

Qualifier	Qualifier Description
*5-	Isotope dilution analyte is outside acceptance limits, low biased.
*5+	Isotope dilution analyte is outside acceptance limits, high biased.
E	Result exceeded calibration range.
H	Sample was prepped or analyzed beyond the specified holding time. This does not meet regulatory requirements.
H3	Sample was received and analyzed past holding time. This does not meet regulatory requirements.
I	Value is EMPC (estimated maximum possible concentration).
J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

General Chemistry

Qualifier	Qualifier Description
H	Sample was prepped or analyzed beyond the specified holding time. This does not meet regulatory requirements.
H3	Sample was received and analyzed past holding time. This does not meet regulatory requirements.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
☼	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CFU	Colony Forming Unit
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MCL	EPA recommended "Maximum Contaminant Level"
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
MPN	Most Probable Number
MQL	Method Quantitation Limit
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
NEG	Negative / Absent
POS	Positive / Present
PQL	Practical Quantitation Limit
PRES	Presumptive
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)
TNTC	Too Numerous To Count

Job ID: 320-117195-1 Eurofins Sacramento

Job Narrative
320-117195-1

Receipt
The samples were received on 11/21/2024 9:40 AM. Unless otherwise noted below, the samples arrived in good condition, and where required, properly preserved and on ice. The temperature of the cooler at receipt was -23.7º C.

Receipt Exceptions
Client emailed a Chain-of-Custody (COC) that was requested to be used for logging in the samples which had some revisions from the original COC shipped with the samples, Because the original COC was not signed at the time samples were relinquished, it was not included in this report.

Collection times were not provided. Samples were logged in with a default time of 00:00.

LCMS
Method B/L/T PFAS: Isotope Dilution Analyte (IDA) recovery is above the method recommended limit in most samples. Quantitation by isotope dilution generally precludes any adverse effect on data quality due to elevated IDA recoveries.

Method B/L/T PFAS: The Isotope Dilution Analyte (IDA) recovery associated with the following samples is below the method recommended limit: Cattail N wet 2 / MSB:DGR:3155_2 (320-117195-20) and Marsh fleabane / MSB:DGR:3153 (320-117195-22). Generally, data quality is not considered affected if the IDA signal-to-noise ratio is greater than 10:1, which is achieved for all IDA in the samples.

Method B/L/T PFAS: The "I" qualifier means the transition mass ratio for the indicated analyte was outside the established ratio limits. The qualitative identification of the analyte has some degree of uncertainty.

Method B/L/T PFAS: The concentration of one or more analytes associated with the following samples exceeded the instrument calibration range. These analytes have been qualified; however, the peak(s) did not saturate the instrument detector. Historical data indicate that for the isotope dilution method, dilution and re-analysis will not produce significantly different results from those reported above the calibration range. NK 10442 L / MSB:Mamm:89195 (320-117195-9), NK 180975 L / MSB:Mamm:1268357 (320-117195-13) and Gambusia Wet 1 / MSB:DGR:3154_1 (320-117195-16)

Method B/L/T PFAS: Some results for the following samples were reported from the analysis of a diluted extract due to high concentration of the target analyte in the analysis of the undiluted extract: holloman wetland / MSB:DGR:3158 (320-117195-23) and holloman S. Playa / MSB:DGR:3157 (320-117195-24) The dilution factor was applied to the labeled internal standard area counts and these area counts were within acceptance limits.

Method B/L/T PFAS: The internal standard recovery of 13C2 PFOA was outside control limits in sample Cattail N wet 2 / MSB:DGR:3155_2 (320-117195-20). The internal standard is not used to quantitate any target analytes, therefore, the data have been reported.

Method B/L/T PFAS: One or more continuing calibration verification (CCV) aliquots associated with analytical batch 320-820819 recovered above the uppercontrol limit for 8:2 FTS. The samples associated with these CCVs were non-detect (ND) for the affected analyte; therefore, the data have been reported.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

General Chemistry
Method D2216-92: The reference method does not list a specific holding time for the percent moisture analysis; therefore, the laboratory defaults to an in-house holding time of 14 days. The analysis for the following soil samples was performed outside this time period. holloman wetland / MSB:DGR:3158 (320-117195-23) and holloman S. Playa / MSB:DGR:3157 (320-117195-24)

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Organic Prep
Method SHAKE: Several samples were received after the preparation holding time had expired and are qualified accordingly.

Method SHAKE: Elevated reporting limits are provided for the following samples due to limited sample mass provided for extraction: NK 32079 L / MSB:Mamm:75616 (320-117195-2), NK 32043 L / MSB:Mamm:75617 (320-117195-3), NK 32074 L / MSB:Mamm:75618
(320-117195-4), NK 32071 L / MSB:Mamm:75619 (320-117195-5), NK 32039 L / MSB:Mamm:75620 (320-117195-6) and NK 40788 L / MSB:Mamm:89351 (320-117195-11), Dragonfly wetland / MSB:DGR:3159 (320-117195-18), Cattail N wet /

Job ID: 320-117195-1 (Continued) Eurofins Sacramento

MSB:DGR:3155_1 (320-117195-19), Cattail N wet 2 / MSB:DGR:3155_2 (320-117195-20), and saltceder NE4-4 / MSB:DGR:3156 (320-117195-21).

Method SHAKE: The following samples were discolored following extraction: saltceder NE4-4 / MSB:DGR:3156 (320-117195-21), Marsh fleabane / MSB:DGR:3153 (320-117195-22) and holloman wetland / MSB:DGR:3158 (320-117195-23)

Method SHAKE: Insufficient sample volume was available to perform a matrix spike/matrix spike duplicate (MS/MSD) associated with preparation batches 320-818866, 320-818987, 320-819252

Method SHAKE: The following samples were received after the preparation holding time had expired: NK 19893 L / MSB:Mamm:61848 (320-117195-1), NK 32079 L / MSB:Mamm:75616 (320-117195-2), NK 32043 L / MSB:Mamm:75617 (320-117195-3), NK 32074 L / MSB:Mamm:75618 (320-117195-4), NK 32071 L / MSB:Mamm:75619 (320-117195-5), NK 32039 L / MSB:Mamm:75620 (320-117195-6), NK 10447 L / MSB:Mamm:87701 (320-117195-7), NK 10444 L / MSB:Mamm:87702 (320-117195-8), NK 10442 L / MSB:Mamm:89195 (320-117195-9), NK 10446 L / MSB:Mamm:89187 (320-117195-10), NK 40788 L / MSB:Mamm:89351 (320-117195-11), NK 154469 M / MSB:Mamm:198472 (320-117195-12), NK 180975 L / MSB:Mamm:1268357 (320-117195-13), NK 303127 L / MSB:Mamm:326548 (320-117195-14) and NK 310003 L / MSB:Mamm:339709 (320-117195-15).

Method SHAKE: Insufficient sample volume was available to perform a matrix spike/matrix spike duplicate (MS/MSD) associated with preparation batches 320-818866, 320-818987, 320-819252

Method SHAKE: Elevated reporting limits are provided for the following sample due to limited sample provided for extraction: NK 32079 L / MSB:Mamm:75616 (320-117195-2), NK 32043 L / MSB:Mamm:75617 (320-117195-3), NK 32074 L / MSB:Mamm:75618 (320-117195-4), NK 32071 L / MSB:Mamm:75619 (320-117195-5), NK 32039 L / MSB:Mamm:75620 (320-117195-6) and NK 40788 L / MSB:Mamm:89351 (320-117195-11), Dragonfly wetland / MSB:DGR:3159 (320-117195-18), Cattail N wet / MSB:DGR:3155_1 (320-117195-19), Cattail N wet 2 / MSB:DGR:3155_2 (320-117195-20), and saltceder NE4-4 / MSB:DGR:3156 (320-117195-21).

Method SHAKE: The following samples were discolored following extraction: saltceder NE4-4 / MSB:DGR:3156 (320-117195-21), Marsh fleabane / MSB:DGR:3153 (320-117195-22) and holloman wetland / MSB:DGR:3158 (320-117195-23)

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Detection Summary

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: NK 19893 L / MSB:Mamm:61848 — Lab Sample ID: 320-117195-1

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorodecanoic acid (PFDA)	0.16	J H H3	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	16	H I H3	2.7	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.57	J H H3	2.7	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	17	H H3	2.7	0.22	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 32079 L / MSB:Mamm:75616 — Lab Sample ID: 320-117195-2

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	3.4	H H3	2.6	0.52	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	3.4	H H3	2.6	0.52	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.71	J H H3	2.6	0.45	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	3.9	H H3	2.6	0.38	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	3.9	H H3	2.6	0.38	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	26	I H H3	6.4	0.52	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	6.8	H H3	6.4	0.52	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	32	H H3	6.4	0.52	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.81	J H H3	2.6	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.37	J H H3	2.6	0.26	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 32043 L / MSB:Mamm:75617 — Lab Sample ID: 320-117195-3

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Total PFHxS	3.2	H H3	1.9	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	3.2	H H3	1.9	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.63	J H H3	1.9	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	140	I H H3	4.6	0.38	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	5.6	H H3	4.6	0.38	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	140	H H3	4.6	0.38	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 32074 L / MSB:Mamm:75618 — Lab Sample ID: 320-117195-4

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.97	J H H3	2.2	0.45	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.97	J H H3	2.2	0.45	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.60	J H H3	2.2	0.39	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.34	J H H3	2.2	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	5.1	H H3	2.2	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	4.8	H H3	2.2	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.58	J H H3	2.2	0.41	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	30	H H3	5.6	0.45	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	9.3	H H3	5.6	0.45	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	39	H H3	5.6	0.45	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 32071 L / MSB:Mamm:75619 — Lab Sample ID: 320-117195-5

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	9.4	J H H3	13	2.5	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	9.4	J H H3	13	2.5	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	10	J H H3	13	2.2	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	100	H H3	13	1.9	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	100	H H3	13	1.9	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Eurofins Sacramento

Client Sample ID: NK 32071 L / MSB:Mamm:75619 (Continued) — Lab Sample ID: 320-117195-5

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanesulfonic acid (PFHpS)	11	J H H3	13	2.3	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	210	I H H3	31	2.5	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	91	H H3	31	2.5	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	300	H H3	31	2.5	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	1.3	J H H3	13	1.3	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 32039 L / MSB:Mamm:75620 — Lab Sample ID: 320-117195-6

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	2.2	J H H3	4.8	0.83	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	1.3	J H H3	4.8	0.70	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	1.3	J H H3	4.8	0.70	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	12	H I H3	12	0.97	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	4.8	J H H3	12	0.97	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	17	H H3	12	0.97	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 10447 L / MSB:Mamm:87701 — Lab Sample ID: 320-117195-7

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorodecanoic acid (PFDA)	0.11	J H H3	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.18	J H H3	1.1	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.18	J H H3	1.1	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	5.9	H H3	2.7	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	3.3	H H3	2.7	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	9.2	H H3	2.7	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.12	J H H3	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 10444 L / MSB:Mamm:87702 — Lab Sample ID: 320-117195-8

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorohexanoic acid (PFHxA)	0.33	J H I H3	1.1	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.19	J H H3	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.18	J H H3	1.1	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.18	J H H3	1.1	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	23	H H3	2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	3.7	H H3	2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	27	H H3	2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.47	J H H3	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.11	J H H3	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 10442 L / MSB:Mamm:89195 — Lab Sample ID: 320-117195-9

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.31	J H H3	0.97	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.35	J H H3	0.97	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.38	J H H3	0.97	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.21	J H H3	0.97	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.21	J H H3	0.97	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	290	H E I H3	2.4	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	2.4	H H3	2.4	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	300	H H3	2.4	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.49	J H H3	0.97	0.41	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Detection Summary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Job ID: 320-117195-1

Client Sample ID: NK 10446 L / MSB:Mamm:89187 — Lab Sample ID: 320-117195-10

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.41	J H H3	0.98	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.48	J H H3	0.98	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.17	J H H3	0.98	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.22	J H H3	0.98	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.27	J H H3	0.98	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.27	J H H3	0.98	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	88	I H H3	2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	2.5	H H3	2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	90	H H3	2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.61	J H H3	0.98	0.42	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.11	J H H3	0.98	0.099	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 40788 L / MSB:Mamm:89351 — Lab Sample ID: 320-117195-11

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.84	J H H3	1.9	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	1.1	J H H3	1.9	0.52	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.45	J H H3	1.9	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.35	J H H3	1.9	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.35	J H H3	1.9	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	11	I H H3	4.8	0.39	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	11	H H3	4.8	0.39	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.90	J H H3	1.9	0.82	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 154469 M / MSB:Mamm:198472 — Lab Sample ID: 320-117195-12

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.49	J H H3	1.1	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	0.70	J H H3	1.1	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.73	J H H3	1.1	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.36	J H H3	1.1	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.22	J H H3	1.1	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.22	J H H3	1.1	0.16	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 180975 L / MSB:Mamm:1268357 — Lab Sample ID: 320-117195-13

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	1.3	H H3	0.95	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.99	H H3	0.95	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.11	J H H3	0.95	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	0.40	J H H3	0.95	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.40	J H H3	0.95	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.86	J H H3	0.95	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	2.0	H H3	0.95	0.098	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.49	J H H3	0.95	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.53	J H H3	0.95	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.69	J H H3	0.95	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.69	J H H3	0.95	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	220	H E I H3	2.4	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	4.3	H H3	2.4	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	220	H H3	2.4	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.38	J H H3	0.95	0.095	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK 180975 L / MSB:Mamm:1268357 (Continued)
Lab Sample ID: 320-117195-13

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
10:2 FTS	0.19	J H H3	0.95	0.096	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 303127 L / MSB:Mamm:326548
Lab Sample ID: 320-117195-14

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	0.59	J H H3	1.1	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	2.7	H H3	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.86	J H H3	1.1	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.58	J H H3	1.1	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.58	J H H3	1.1	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	94	H I H3	2.7	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	4.1	H H3	2.7	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	98	H H3	2.7	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.38	J H H3	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.28	J H H3	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 310003 L / MSB:Mamm:339709
Lab Sample ID: 320-117195-15

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.55	J H H3	1.0	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.55	J H H3	1.0	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	6.4	H H3	1.0	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	3.5	H H3	1.0	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.78	J H H3	1.0	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	3.0	H H3	1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	3.0	H H3	1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.44	J H H3	1.0	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	78	H I H3	2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	6.2	H H3	2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	84	H H3	2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Gambusia Wet 1 / MSB:DGR:3154_1
Lab Sample ID: 320-117195-16

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorodecanoic acid (PFDA)	0.90		0.90	0.093	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.92		0.90	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.51	J	0.90	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.51	J	0.90	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	110	E I	2.3	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	7.5		2.3	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	110		2.3	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.50	J	0.90	0.38	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.25	J	0.90	0.090	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.29	J	0.90	0.091	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Gambusia Wet 2 / MSB:DGR:3154_2
Lab Sample ID: 320-117195-17

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorodecanoic acid (PFDA)	0.54	J	1.0	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.53	J	1.0	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.75	J	1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: Gambusia Wet 2 / MSB:DGR:3154_2 (Continued)

Lab Sample ID: 320-117195-17

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorohexanesulfonic acid	0.61	J I	1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	42		2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	2.7		2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	44		2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.13	J	1.0	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.22	J	1.0	0.10	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Dragonfly wetland / MSB:DGR:3159

Lab Sample ID: 320-117195-18

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanesulfonic acid	1.1	J I	14	1.1	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	1.1	J	14	1.1	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Cattail N wet / MSB:DGR:3155_1

Lab Sample ID: 320-117195-19

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	12		2.6	0.61	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	57		2.6	0.45	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	7.8		2.6	0.70	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.56	J	2.6	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	1.8	J	2.6	0.38	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	1.8	J	2.6	0.38	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	3.8	J	6.4	0.52	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	1.3	J	6.4	0.52	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	5.2	J	6.4	0.52	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	3.2		2.6	1.1	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Cattail N wet 2 / MSB:DGR:3155_2

Lab Sample ID: 320-117195-20

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	18		1.4	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	35		1.4	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	3.3		1.4	0.39	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.65	J	1.4	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	0.85	J	1.4	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.85	J	1.4	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.29	J I	1.4	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.58	J	1.4	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	3.4		1.4	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	2.8		1.4	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	6.0		3.6	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	1.8	J	3.6	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	7.9		3.6	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	10		1.4	0.61	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: saltceder NE4-4 / MSB:DGR:3156

Lab Sample ID: 320-117195-21

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorohexanoic acid (PFHxA)	3.4		1.8	0.49	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.70	J	1.8	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	0.68	J	1.8	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.60	J	1.8	0.36	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: saltceder NE4-4 / MSB:DGR:3156 (Continued)

Lab Sample ID: 320-117195-21

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Total PFOA	1.3	J	1.8	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.41	J	1.8	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	2.6		1.8	0.32	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	2.7		1.8	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	24		1.8	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	22		1.8	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	3.9	J	4.5	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	1.8	J	4.5	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	5.8		4.5	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.18	J	1.8	0.18	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Marsh fleabane / MSB:DGR:3153

Lab Sample ID: 320-117195-22

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.81	J	0.87	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	6.6		0.87	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	1.2		0.87	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.16	J	0.87	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.53	J	0.87	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.53	J	0.87	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	0.65	J	2.2	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.37	J	2.2	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	1.0	J	2.2	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	2.3		0.87	0.37	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: holloman wetland / MSB:DGR:3158

Lab Sample ID: 320-117195-23

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	7.4		0.18	0.042	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	4.7		0.18	0.035	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	1.8		0.18	0.049	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.26		0.18	0.049	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	2.1		0.18	0.049	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.84		0.18	0.020	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.51		0.18	0.044	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.36		0.18	0.039	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	1.2		0.18	0.035	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	1.1		0.18	0.034	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	2.2		0.18	0.027	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	11		0.18	0.027	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	9.0		0.18	0.027	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.42		0.18	0.045	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	14		0.18	0.025	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.84		0.18	0.032	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.12	J	0.18	0.035	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA) - DL	53		3.7	0.76	ug/Kg	20		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA) - DL	25		3.7	0.57	ug/Kg	20		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	120		3.7	0.79	ug/Kg	20		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: holloman wetland / MSB:DGR:3158 (Continued)

Lab Sample ID: 320-117195-23

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Br-Perfluorooctanesulfonic acid - DL	23		3.7	0.79	ug/Kg	20		B/L/T PFAS	Total/NA
Total PFOS - DL	140		3.7	0.79	ug/Kg	20		B/L/T PFAS	Total/NA

Client Sample ID: holloman S. Playa / MSB:DGR:3157

Lab Sample ID: 320-117195-24

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	13		0.18	0.042	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	4.4		0.18	0.020	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.095	J	0.18	0.044	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.068	J	0.18	0.038	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	6.1		0.18	0.025	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.81		0.18	0.032	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA) - DL	59		18	3.7	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA) - DL	180		18	2.8	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA) - DL	83		18	3.5	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	110		18	4.8	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid - DL	19		18	4.8	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOA - DL	130		18	4.8	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS) - DL	23		18	3.5	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS) - DL	60		18	3.4	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	170		18	2.6	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	830		18	2.6	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	660		18	2.6	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	17	J	18	4.5	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	74		18	3.9	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	130		18	3.9	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	200		18	3.9	ug/Kg	100		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK 19893 L / MSB:Mamm:61848
Lab Sample ID: 320-117195-1
Date Collected: 05/11/89 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	1.1	0.26	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	1.1	0.19	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	1.1	0.30	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	1.1	0.13	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
L-Perfluorooctanoic acid	ND	H H3	1.1	0.22	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
Br-Perfluorooctanoic acid	ND	H H3	1.1	0.22	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
Total PFOA	ND	H H3	1.1	0.22	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
Perfluorononanoic acid (PFNA)	ND	H H3	1.1	0.19	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
Perfluorodecanoic acid (PFDA)	**0.16**	**J H H3**	1.1	0.11	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	1.1	0.30	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	1.1	0.19	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	1.1	0.20	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
Br-Perfluorohexanesulfonic acid	ND	H H3	1.1	0.16	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
Total PFHxS	ND	H H3	1.1	0.16	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
L-Perfluorohexanesulfonic acid	ND	H H3	1.1	0.16	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	1.1	0.20	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
L-Perfluorooctanesulfonic acid	**16**	**H I H3**	2.7	0.22	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
Br-Perfluorooctanesulfonic acid	**0.57**	**J H H3**	2.7	0.22	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
Total PFOS	**17**	**H H3**	2.7	0.22	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
4:2 FTS	ND	H H3	1.1	0.29	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
6:2 FTS	ND	H H3	1.1	0.47	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
8:2 FTS	ND	H H3	1.1	0.11	ug/Kg		12/03/24 04:26	12/09/24 16:44	1
10:2 FTS	ND	H H3	1.1	0.11	ug/Kg		12/03/24 04:26	12/09/24 16:44	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*82*		*25 - 150*	*12/03/24 04:26*	*12/09/24 16:44*	*1*
13C5 PFPeA	*87*		*25 - 150*	*12/03/24 04:26*	*12/09/24 16:44*	*1*
13C2 PFHxA	*106*		*25 - 150*	*12/03/24 04:26*	*12/09/24 16:44*	*1*
13C4 PFHpA	*105*		*25 - 150*	*12/03/24 04:26*	*12/09/24 16:44*	*1*
13C4 PFOA	*93*		*25 - 150*	*12/03/24 04:26*	*12/09/24 16:44*	*1*
13C5 PFNA	*114*		*25 - 150*	*12/03/24 04:26*	*12/09/24 16:44*	*1*
13C2 PFDA	*114*		*25 - 150*	*12/03/24 04:26*	*12/09/24 16:44*	*1*
13C2 PFUnA	*140*		*25 - 150*	*12/03/24 04:26*	*12/09/24 16:44*	*1*
13C3 PFBS	*97*		*25 - 150*	*12/03/24 04:26*	*12/09/24 16:44*	*1*
18O2 PFHxS	*116*		*25 - 150*	*12/03/24 04:26*	*12/09/24 16:44*	*1*
13C4 PFOS	*105*		*25 - 150*	*12/03/24 04:26*	*12/09/24 16:44*	*1*
M2-4:2 FTS	*102*		*25 - 150*	*12/03/24 04:26*	*12/09/24 16:44*	*1*
M2-6:2 FTS	*126*		*25 - 150*	*12/03/24 04:26*	*12/09/24 16:44*	*1*
M2-8:2 FTS	*121*		*25 - 150*	*12/03/24 04:26*	*12/09/24 16:44*	*1*
13C2 10:2 FTS	*731*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 16:44*	*1*

Client Sample ID: NK 32079 L / MSB:Mamm:75616
Lab Sample ID: 320-117195-2

Date Collected: 07/17/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	2.6	0.61	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	2.6	0.45	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	2.6	0.70	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	2.6	0.30	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
L-Perfluorooctanoic acid	**3.4**	**H H3**	2.6	0.52	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
Br-Perfluorooctanoic acid	ND	H H3	2.6	0.52	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
Total PFOA	**3.4**	**H H3**	2.6	0.52	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
Perfluorononanoic acid (PFNA)	**0.71**	**J H H3**	2.6	0.45	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
Perfluorodecanoic acid (PFDA)	ND	H H3	2.6	0.26	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	2.6	0.70	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	2.6	0.44	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	2.6	0.46	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
Br-Perfluorohexanesulfonic acid	ND	H H3	2.6	0.38	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
Total PFHxS	**3.9**	**H H3**	2.6	0.38	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
L-Perfluorohexanesulfonic acid	**3.9**	**H H3**	2.6	0.38	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	2.6	0.47	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
L-Perfluorooctanesulfonic acid	**26**	**I H H3**	6.4	0.52	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
Br-Perfluorooctanesulfonic acid	**6.8**	**H H3**	6.4	0.52	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
Total PFOS	**32**	**H H3**	6.4	0.52	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
4:2 FTS	ND	H H3	2.6	0.68	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
6:2 FTS	ND	H H3	2.6	1.1	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
8:2 FTS	**0.81**	**J H H3**	2.6	0.26	ug/Kg		12/03/24 04:26	12/09/24 17:03	1
10:2 FTS	**0.37**	**J H H3**	2.6	0.26	ug/Kg		12/03/24 04:26	12/09/24 17:03	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*107*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:03*	*1*
13C5 PFPeA	*88*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:03*	*1*
13C2 PFHxA	*116*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:03*	*1*
13C4 PFHpA	*118*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:03*	*1*
13C4 PFOA	*96*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:03*	*1*
13C5 PFNA	*113*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:03*	*1*
13C2 PFDA	*118*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:03*	*1*
13C2 PFUnA	*105*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:03*	*1*
13C3 PFBS	*102*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:03*	*1*
18O2 PFHxS	*119*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:03*	*1*
13C4 PFOS	*108*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:03*	*1*
M2-4:2 FTS	*147*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:03*	*1*
M2-6:2 FTS	*143*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:03*	*1*
M2-8:2 FTS	*113*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:03*	*1*
13C2 10:2 FTS	*608*	*5+	*25 - 150*	*12/03/24 04:26*	*12/09/24 17:03*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: NK 32043 L / MSB:Mamm:75617
Lab Sample ID: 320-117195-3
Date Collected: 06/12/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	1.9	0.44	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	1.9	0.32	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	1.9	0.51	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	1.9	0.21	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
L-Perfluorooctanoic acid	ND	H H3	1.9	0.37	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
Br-Perfluorooctanoic acid	ND	H H3	1.9	0.37	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
Total PFOA	ND	H H3	1.9	0.37	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
Perfluorononanoic acid (PFNA)	ND	H H3	1.9	0.32	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
Perfluorodecanoic acid (PFDA)	ND	H H3	1.9	0.19	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	1.9	0.50	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	1.9	0.31	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	1.9	0.34	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
Br-Perfluorohexanesulfonic acid	ND	H H3	1.9	0.27	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
Total PFHxS	**3.2**	**H H3**	1.9	0.27	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
L-Perfluorohexanesulfonic acid	**3.2**	**H H3**	1.9	0.27	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.63**	**J H H3**	1.9	0.34	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
L-Perfluorooctanesulfonic acid	**140**	**I H H3**	4.6	0.38	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
Br-Perfluorooctanesulfonic acid	**5.6**	**H H3**	4.6	0.38	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
Total PFOS	**140**	**H H3**	4.6	0.38	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
4:2 FTS	ND	H H3	1.9	0.49	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
6:2 FTS	ND	H H3	1.9	0.79	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
8:2 FTS	ND	H H3	1.9	0.19	ug/Kg		12/03/24 04:26	12/09/24 17:23	1
10:2 FTS	ND	H H3	1.9	0.19	ug/Kg		12/03/24 04:26	12/09/24 17:23	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*107*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:23*	*1*
13C5 PFPeA	*107*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:23*	*1*
13C2 PFHxA	*129*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:23*	*1*
13C4 PFHpA	*112*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:23*	*1*
13C4 PFOA	*91*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:23*	*1*
13C5 PFNA	*108*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:23*	*1*
13C2 PFDA	*117*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:23*	*1*
13C2 PFUnA	*121*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:23*	*1*
13C3 PFBS	*97*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:23*	*1*
18O2 PFHxS	*123*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:23*	*1*
13C4 PFOS	*113*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:23*	*1*
M2-4:2 FTS	*147*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:23*	*1*
M2-6:2 FTS	*73*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:23*	*1*
M2-8:2 FTS	*115*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:23*	*1*
13C2 10:2 FTS	*497*	*5+	*25 - 150*	*12/03/24 04:26*	*12/09/24 17:23*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: NK 32074 L / MSB:Mamm:75618
Lab Sample ID: 320-117195-4
Date Collected: 07/16/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	2.2	0.52	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	2.2	0.39	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	2.2	0.61	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	2.2	0.26	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
L-Perfluorooctanoic acid	**0.97**	**J H H3**	2.2	0.45	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
Br-Perfluorooctanoic acid	ND	H H3	2.2	0.45	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
Total PFOA	**0.97**	**J H H3**	2.2	0.45	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
Perfluorononanoic acid (PFNA)	**0.60**	**J H H3**	2.2	0.39	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
Perfluorodecanoic acid (PFDA)	ND	H H3	2.2	0.23	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	2.2	0.60	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	2.2	0.38	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	2.2	0.40	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
Br-Perfluorohexanesulfonic acid	**0.34**	**J H H3**	2.2	0.33	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
Total PFHxS	**5.1**	**H H3**	2.2	0.33	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
L-Perfluorohexanesulfonic acid	**4.8**	**H H3**	2.2	0.33	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.58**	**J H H3**	2.2	0.41	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
L-Perfluorooctanesulfonic acid	**30**	**H H3**	5.6	0.45	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
Br-Perfluorooctanesulfonic acid	**9.3**	**H H3**	5.6	0.45	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
Total PFOS	**39**	**H H3**	5.6	0.45	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
4:2 FTS	ND	H H3	2.2	0.59	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
6:2 FTS	ND	H H3	2.2	0.94	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
8:2 FTS	ND	H H3	2.2	0.22	ug/Kg		12/03/24 04:26	12/09/24 17:42	1
10:2 FTS	ND	H H3	2.2	0.22	ug/Kg		12/03/24 04:26	12/09/24 17:42	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*88*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:42*	*1*
13C5 PFPeA	*81*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:42*	*1*
13C2 PFHxA	*112*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:42*	*1*
13C4 PFHpA	*93*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:42*	*1*
13C4 PFOA	*93*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:42*	*1*
13C5 PFNA	*97*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:42*	*1*
13C2 PFDA	*95*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:42*	*1*
13C2 PFUnA	*90*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:42*	*1*
13C3 PFBS	*78*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:42*	*1*
18O2 PFHxS	*103*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:42*	*1*
13C4 PFOS	*90*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:42*	*1*
M2-4:2 FTS	*111*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:42*	*1*
M2-6:2 FTS	*132*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:42*	*1*
M2-8:2 FTS	*100*		*25 - 150*	*12/03/24 04:26*	*12/09/24 17:42*	*1*
13C2 10:2 FTS	*549*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 17:42*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: NK 32071 L / MSB:Mamm:75619
Lab Sample ID: 320-117195-5
Date Collected: 07/16/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	13	3.0	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	13	2.2	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	13	3.4	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	13	1.5	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
L-Perfluorooctanoic acid	**9.4**	**J H H3**	13	2.5	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
Br-Perfluorooctanoic acid	ND	H H3	13	2.5	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
Total PFOA	**9.4**	**J H H3**	13	2.5	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
Perfluorononanoic acid (PFNA)	**10**	**J H H3**	13	2.2	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
Perfluorodecanoic acid (PFDA)	ND	H H3	13	1.3	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	13	3.4	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	13	2.1	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	13	2.3	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
Br-Perfluorohexanesulfonic acid	ND	H H3	13	1.9	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
Total PFHxS	**100**	**H H3**	13	1.9	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
L-Perfluorohexanesulfonic acid	**100**	**H H3**	13	1.9	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
Perfluoroheptanesulfonic acid (PFHpS)	**11**	**J H H3**	13	2.3	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
L-Perfluorooctanesulfonic acid	**210**	**I H H3**	31	2.5	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
Br-Perfluorooctanesulfonic acid	**91**	**H H3**	31	2.5	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
Total PFOS	**300**	**H H3**	31	2.5	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
4:2 FTS	ND	H H3	13	3.3	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
6:2 FTS	ND	H H3	13	5.3	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
8:2 FTS	ND	H H3	13	1.3	ug/Kg		12/03/24 04:26	12/09/24 18:01	1
10:2 FTS	**1.3**	**J H H3**	13	1.3	ug/Kg		12/03/24 04:26	12/09/24 18:01	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*105*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:01*	*1*
13C5 PFPeA	*97*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:01*	*1*
13C2 PFHxA	*118*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:01*	*1*
13C4 PFHpA	*105*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:01*	*1*
13C4 PFOA	*94*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:01*	*1*
13C5 PFNA	*100*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:01*	*1*
13C2 PFDA	*104*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:01*	*1*
13C2 PFUnA	*91*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:01*	*1*
13C3 PFBS	*84*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:01*	*1*
18O2 PFHxS	*113*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:01*	*1*
13C4 PFOS	*96*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:01*	*1*
M2-4:2 FTS	*95*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:01*	*1*
M2-6:2 FTS	*139*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:01*	*1*
M2-8:2 FTS	*105*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:01*	*1*
13C2 10:2 FTS	*326*	*5+	*25 - 150*	*12/03/24 04:26*	*12/09/24 18:01*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: NK 32039 L / MSB:Mamm:75620
Lab Sample ID: 320-117195-6
Date Collected: 06/12/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	4.8	1.1	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	4.8	0.83	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	4.8	1.3	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	4.8	0.55	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
L-Perfluorooctanoic acid	ND	H H3	4.8	0.96	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
Br-Perfluorooctanoic acid	ND	H H3	4.8	0.96	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
Total PFOA	ND	H H3	4.8	0.96	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
Perfluorononanoic acid (PFNA)	**2.2**	**J H H3**	4.8	0.83	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
Perfluorodecanoic acid (PFDA)	ND	H H3	4.8	0.49	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	4.8	1.3	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	4.8	0.81	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	4.8	0.86	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
Br-Perfluorohexanesulfonic acid	ND	H H3	4.8	0.70	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
Total PFHxS	**1.3**	**J H H3**	4.8	0.70	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
L-Perfluorohexanesulfonic acid	**1.3**	**J H H3**	4.8	0.70	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	4.8	0.88	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
L-Perfluorooctanesulfonic acid	**12**	**H I H3**	12	0.97	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
Br-Perfluorooctanesulfonic acid	**4.8**	**J H H3**	12	0.97	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
Total PFOS	**17**	**H H3**	12	0.97	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
4:2 FTS	ND	H H3	4.8	1.3	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
6:2 FTS	ND	H H3	4.8	2.0	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
8:2 FTS	ND	H H3	4.8	0.48	ug/Kg		12/03/24 04:26	12/09/24 18:21	1
10:2 FTS	ND	H H3	4.8	0.48	ug/Kg		12/03/24 04:26	12/09/24 18:21	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*104*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:21*	*1*
13C5 PFPeA	*105*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:21*	*1*
13C2 PFHxA	*119*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:21*	*1*
13C4 PFHpA	*105*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:21*	*1*
13C4 PFOA	*92*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:21*	*1*
13C5 PFNA	*109*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:21*	*1*
13C2 PFDA	*110*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:21*	*1*
13C2 PFUnA	*91*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:21*	*1*
13C3 PFBS	*90*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:21*	*1*
18O2 PFHxS	*113*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:21*	*1*
13C4 PFOS	*109*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:21*	*1*
M2-4:2 FTS	*127*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:21*	*1*
M2-6:2 FTS	*156*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 18:21*	*1*
M2-8:2 FTS	*115*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:21*	*1*
13C2 10:2 FTS	*299*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 18:21*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: NK 10447 L / MSB:Mamm:87701
Lab Sample ID: 320-117195-7
Date Collected: 11/26/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	1.1	0.26	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	1.1	0.19	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	1.1	0.30	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	1.1	0.13	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
L-Perfluorooctanoic acid	ND	H H3	1.1	0.22	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
Br-Perfluorooctanoic acid	ND	H H3	1.1	0.22	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
Total PFOA	ND	H H3	1.1	0.22	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
Perfluorononanoic acid (PFNA)	ND	H H3	1.1	0.19	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
Perfluorodecanoic acid (PFDA)	**0.11**	**J H H3**	1.1	0.11	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	1.1	0.30	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	1.1	0.18	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	1.1	0.20	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
Br-Perfluorohexanesulfonic acid	ND	H H3	1.1	0.16	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
Total PFHxS	**0.18**	**J H H3**	1.1	0.16	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
L-Perfluorohexanesulfonic acid	**0.18**	**J H H3**	1.1	0.16	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	1.1	0.20	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
L-Perfluorooctanesulfonic acid	**5.9**	**H H3**	2.7	0.22	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
Br-Perfluorooctanesulfonic acid	**3.3**	**H H3**	2.7	0.22	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
Total PFOS	**9.2**	**H H3**	2.7	0.22	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
4:2 FTS	ND	H H3	1.1	0.29	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
6:2 FTS	ND	H H3	1.1	0.46	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
8:2 FTS	ND	H H3	1.1	0.11	ug/Kg		12/03/24 04:26	12/09/24 18:40	1
10:2 FTS	**0.12**	**J H H3**	1.1	0.11	ug/Kg		12/03/24 04:26	12/09/24 18:40	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*81*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:40*	*1*
13C5 PFPeA	*101*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:40*	*1*
13C2 PFHxA	*113*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:40*	*1*
13C4 PFHpA	*114*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:40*	*1*
13C4 PFOA	*97*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:40*	*1*
13C5 PFNA	*108*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:40*	*1*
13C2 PFDA	*139*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:40*	*1*
13C2 PFUnA	*127*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:40*	*1*
13C3 PFBS	*97*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:40*	*1*
18O2 PFHxS	*118*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:40*	*1*
13C4 PFOS	*106*		*25 - 150*	*12/03/24 04:26*	*12/09/24 18:40*	*1*
M2-4:2 FTS	*201*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 18:40*	*1*
M2-6:2 FTS	*184*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 18:40*	*1*
M2-8:2 FTS	*299*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 18:40*	*1*
13C2 10:2 FTS	*579*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 18:40*	*1*

Client Sample ID: NK 10444 L / MSB:Mamm:87702
Lab Sample ID: 320-117195-8

Date Collected: 11/26/94 00:00
Matrix: Tissue

Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	1.1	0.25	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	1.1	0.18	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
Perfluorohexanoic acid (PFHxA)	**0.33**	**J H I H3**	1.1	0.29	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	1.1	0.12	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
L-Perfluorooctanoic acid	ND	H H3	1.1	0.21	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
Br-Perfluorooctanoic acid	ND	H H3	1.1	0.21	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
Total PFOA	ND	H H3	1.1	0.21	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
Perfluorononanoic acid (PFNA)	ND	H H3	1.1	0.18	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
Perfluorodecanoic acid (PFDA)	**0.19**	**J H H3**	1.1	0.11	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	1.1	0.29	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	1.1	0.18	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	1.1	0.19	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
Br-Perfluorohexanesulfonic acid	ND	H H3	1.1	0.16	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
Total PFHxS	**0.18**	**J H H3**	1.1	0.16	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
L-Perfluorohexanesulfonic acid	**0.18**	**J H H3**	1.1	0.16	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	1.1	0.19	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
L-Perfluorooctanesulfonic acid	**23**	**H H3**	2.6	0.21	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
Br-Perfluorooctanesulfonic acid	**3.7**	**H H3**	2.6	0.21	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
Total PFOS	**27**	**H H3**	2.6	0.21	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
4:2 FTS	ND	H H3	1.1	0.28	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
6:2 FTS	ND	H H3	1.1	0.45	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
8:2 FTS	**0.47**	**J H H3**	1.1	0.11	ug/Kg		12/03/24 04:26	12/09/24 19:19	1
10:2 FTS	**0.11**	**J H H3**	1.1	0.11	ug/Kg		12/03/24 04:26	12/09/24 19:19	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*77*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:19*	*1*
13C5 PFPeA	*94*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:19*	*1*
13C2 PFHxA	*107*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:19*	*1*
13C4 PFHpA	*110*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:19*	*1*
13C4 PFOA	*93*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:19*	*1*
13C5 PFNA	*102*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:19*	*1*
13C2 PFDA	*128*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:19*	*1*
13C2 PFUnA	*115*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:19*	*1*
13C3 PFBS	*87*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:19*	*1*
18O2 PFHxS	*108*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:19*	*1*
13C4 PFOS	*94*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:19*	*1*
M2-4:2 FTS	*153*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 19:19*	*1*
M2-6:2 FTS	*136*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:19*	*1*
M2-8:2 FTS	*270*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 19:19*	*1*
13C2 10:2 FTS	*446*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 19:19*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: NK 10442 L / MSB:Mamm:89195
Lab Sample ID: 320-117195-9
Date Collected: 11/07/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	0.97	0.23	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
Perfluoropentanoic acid (PFPeA)	**0.31**	**J H H3**	0.97	0.17	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
Perfluorohexanoic acid (PFHxA)	**0.35**	**J H H3**	0.97	0.27	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	0.97	0.11	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
L-Perfluorooctanoic acid	ND	H H3	0.97	0.20	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
Br-Perfluorooctanoic acid	ND	H H3	0.97	0.20	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
Total PFOA	ND	H H3	0.97	0.20	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
Perfluorononanoic acid (PFNA)	ND	H H3	0.97	0.17	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
Perfluorodecanoic acid (PFDA)	**0.38**	**J H H3**	0.97	0.10	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	0.97	0.26	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	0.97	0.17	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	0.97	0.18	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
Br-Perfluorohexanesulfonic acid	ND	H H3	0.97	0.14	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
Total PFHxS	**0.21**	**J H H3**	0.97	0.14	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
L-Perfluorohexanesulfonic acid	**0.21**	**J H H3**	0.97	0.14	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	0.97	0.18	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
L-Perfluorooctanesulfonic acid	**290**	**H E I H3**	2.4	0.20	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
Br-Perfluorooctanesulfonic acid	**2.4**	**H H3**	2.4	0.20	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
Total PFOS	**300**	**H H3**	2.4	0.20	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
4:2 FTS	ND	H H3	0.97	0.26	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
6:2 FTS	**0.49**	**J H H3**	0.97	0.41	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
8:2 FTS	ND	H H3	0.97	0.097	ug/Kg		12/03/24 04:26	12/09/24 19:38	1
10:2 FTS	ND	H H3	0.97	0.098	ug/Kg		12/03/24 04:26	12/09/24 19:38	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*42*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:38*	*1*
13C5 PFPeA	*73*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:38*	*1*
13C2 PFHxA	*111*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:38*	*1*
13C4 PFHpA	*103*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:38*	*1*
13C4 PFOA	*91*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:38*	*1*
13C5 PFNA	*86*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:38*	*1*
13C2 PFDA	*100*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:38*	*1*
13C2 PFUnA	*104*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:38*	*1*
13C3 PFBS	*78*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:38*	*1*
18O2 PFHxS	*109*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:38*	*1*
13C4 PFOS	*99*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:38*	*1*
M2-4:2 FTS	*134*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:38*	*1*
M2-6:2 FTS	*125*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:38*	*1*
M2-8:2 FTS	*129*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:38*	*1*
13C2 10:2 FTS	*238*	*5+	*25 - 150*	*12/03/24 04:26*	*12/09/24 19:38*	*1*

Client Sample ID: NK 10446 L / MSB:Mamm:89187
Lab Sample ID: 320-117195-10

Date Collected: 11/25/94 00:00
Matrix: Tissue

Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	0.98	0.23	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
Perfluoropentanoic acid (PFPeA)	**0.41**	**J H H3**	0.98	0.17	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
Perfluorohexanoic acid (PFHxA)	**0.48**	**J H H3**	0.98	0.27	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	0.98	0.11	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
L-Perfluorooctanoic acid	ND	H H3	0.98	0.20	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
Br-Perfluorooctanoic acid	ND	H H3	0.98	0.20	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
Total PFOA	ND	H H3	0.98	0.20	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
Perfluorononanoic acid (PFNA)	ND	H H3	0.98	0.17	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
Perfluorodecanoic acid (PFDA)	**0.17**	**J H H3**	0.98	0.10	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	0.98	0.27	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
Perfluorobutanesulfonic acid (PFBS)	**0.22**	**J H H3**	0.98	0.17	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	0.98	0.18	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
Br-Perfluorohexanesulfonic acid	ND	H H3	0.98	0.15	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
Total PFHxS	**0.27**	**J H H3**	0.98	0.15	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
L-Perfluorohexanesulfonic acid	**0.27**	**J H H3**	0.98	0.15	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	0.98	0.18	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
L-Perfluorooctanesulfonic acid	**88**	**I H H3**	2.5	0.20	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
Br-Perfluorooctanesulfonic acid	**2.5**	**H H3**	2.5	0.20	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
Total PFOS	**90**	**H H3**	2.5	0.20	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
4:2 FTS	ND	H H3	0.98	0.26	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
6:2 FTS	**0.61**	**J H H3**	0.98	0.42	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
8:2 FTS	ND	H H3	0.98	0.098	ug/Kg		12/03/24 04:26	12/09/24 19:58	1
10:2 FTS	**0.11**	**J H H3**	0.98	0.099	ug/Kg		12/03/24 04:26	12/09/24 19:58	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*67*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:58*	*1*
13C5 PFPeA	*89*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:58*	*1*
13C2 PFHxA	*108*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:58*	*1*
13C4 PFHpA	*101*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:58*	*1*
13C4 PFOA	*89*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:58*	*1*
13C5 PFNA	*100*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:58*	*1*
13C2 PFDA	*112*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:58*	*1*
13C2 PFUnA	*103*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:58*	*1*
13C3 PFBS	*81*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:58*	*1*
18O2 PFHxS	*105*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:58*	*1*
13C4 PFOS	*103*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:58*	*1*
M2-4:2 FTS	*128*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:58*	*1*
M2-6:2 FTS	*151*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 19:58*	*1*
M2-8:2 FTS	*115*		*25 - 150*	*12/03/24 04:26*	*12/09/24 19:58*	*1*
13C2 10:2 FTS	*305*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 19:58*	*1*

Client Sample ID: NK 40788 L / MSB:Mamm:89351
Lab Sample ID: 320-117195-11

Date Collected: 06/18/97 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	1.9	0.45	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
Perfluoropentanoic acid (PFPeA)	**0.84**	**J H H3**	1.9	0.34	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
Perfluorohexanoic acid (PFHxA)	**1.1**	**J H H3**	1.9	0.52	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	1.9	0.22	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
L-Perfluorooctanoic acid	ND	H H3	1.9	0.39	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
Br-Perfluorooctanoic acid	ND	H H3	1.9	0.39	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
Total PFOA	ND	H H3	1.9	0.39	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
Perfluorononanoic acid (PFNA)	ND	H H3	1.9	0.34	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
Perfluorodecanoic acid (PFDA)	ND	H H3	1.9	0.20	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	1.9	0.52	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
Perfluorobutanesulfonic acid (PFBS)	**0.45**	**J H H3**	1.9	0.33	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	1.9	0.35	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
Br-Perfluorohexanesulfonic acid	ND	H H3	1.9	0.28	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
Total PFHxS	**0.35**	**J H H3**	1.9	0.28	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
L-Perfluorohexanesulfonic acid	**0.35**	**J H H3**	1.9	0.28	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	1.9	0.36	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
L-Perfluorooctanesulfonic acid	**11**	**I H H3**	4.8	0.39	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
Br-Perfluorooctanesulfonic acid	ND	H H3	4.8	0.39	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
Total PFOS	**11**	**H H3**	4.8	0.39	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
4:2 FTS	ND	H H3	1.9	0.51	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
6:2 FTS	**0.90**	**J H H3**	1.9	0.82	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
8:2 FTS	ND	H H3	1.9	0.19	ug/Kg		12/03/24 04:26	12/09/24 20:17	1
10:2 FTS	ND	H H3	1.9	0.19	ug/Kg		12/03/24 04:26	12/09/24 20:17	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*81*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:17*	*1*
13C5 PFPeA	*89*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:17*	*1*
13C2 PFHxA	*107*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:17*	*1*
13C4 PFHpA	*103*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:17*	*1*
13C4 PFOA	*100*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:17*	*1*
13C5 PFNA	*96*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:17*	*1*
13C2 PFDA	*102*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:17*	*1*
13C2 PFUnA	*95*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:17*	*1*
13C3 PFBS	*89*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:17*	*1*
18O2 PFHxS	*110*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:17*	*1*
13C4 PFOS	*102*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:17*	*1*
M2-4:2 FTS	*126*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:17*	*1*
M2-6:2 FTS	*146*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:17*	*1*
M2-8:2 FTS	*88*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:17*	*1*
13C2 10:2 FTS	*426*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 20:17*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: NK 154469 M / MSB:Mamm:198472
Lab Sample ID: 320-117195-12
Date Collected: 05/21/08 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**0.49**	**J H H3**	1.1	0.25	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
Perfluoropentanoic acid (PFPeA)	**0.70**	**J H H3**	1.1	0.19	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
Perfluorohexanoic acid (PFHxA)	**0.73**	**J H H3**	1.1	0.29	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	1.1	0.12	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
L-Perfluorooctanoic acid	ND	H H3	1.1	0.22	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
Br-Perfluorooctanoic acid	ND	H H3	1.1	0.22	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
Total PFOA	ND	H H3	1.1	0.22	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
Perfluorononanoic acid (PFNA)	ND	H H3	1.1	0.19	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
Perfluorodecanoic acid (PFDA)	ND	H H3	1.1	0.11	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	1.1	0.29	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
Perfluorobutanesulfonic acid (PFBS)	**0.36**	**J H H3**	1.1	0.18	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	1.1	0.19	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
Br-Perfluorohexanesulfonic acid	ND	H H3	1.1	0.16	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
Total PFHxS	**0.22**	**J H H3**	1.1	0.16	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
L-Perfluorohexanesulfonic acid	**0.22**	**J H H3**	1.1	0.16	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	1.1	0.20	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
L-Perfluorooctanesulfonic acid	ND	H H3	2.7	0.22	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
Br-Perfluorooctanesulfonic acid	ND	H H3	2.7	0.22	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
Total PFOS	ND	H H3	2.7	0.22	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
4:2 FTS	ND	H H3	1.1	0.29	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
6:2 FTS	ND	H H3	1.1	0.46	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
8:2 FTS	ND	H H3	1.1	0.11	ug/Kg		12/03/24 04:26	12/09/24 20:37	1
10:2 FTS	ND	H H3	1.1	0.11	ug/Kg		12/03/24 04:26	12/09/24 20:37	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*65*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:37*	*1*
13C5 PFPeA	*89*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:37*	*1*
13C2 PFHxA	*119*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:37*	*1*
13C4 PFHpA	*109*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:37*	*1*
13C4 PFOA	*94*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:37*	*1*
13C5 PFNA	*97*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:37*	*1*
13C2 PFDA	*109*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:37*	*1*
13C2 PFUnA	*87*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:37*	*1*
13C3 PFBS	*97*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:37*	*1*
18O2 PFHxS	*112*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:37*	*1*
13C4 PFOS	*99*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:37*	*1*
M2-4:2 FTS	*135*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:37*	*1*
M2-6:2 FTS	*110*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:37*	*1*
M2-8:2 FTS	*102*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:37*	*1*
13C2 10:2 FTS	*545*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 20:37*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: NK 180975 L / MSB:Mamm:1268357
Lab Sample ID: 320-117195-13
Date Collected: 02/27/13 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	0.95	0.22	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
Perfluoropentanoic acid (PFPeA)	**1.3**	**H H3**	0.95	0.17	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
Perfluorohexanoic acid (PFHxA)	**0.99**	**H H3**	0.95	0.26	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
Perfluoroheptanoic acid (PFHpA)	**0.11**	**J H H3**	0.95	0.11	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
L-Perfluorooctanoic acid	**0.40**	**J H H3**	0.95	0.19	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
Br-Perfluorooctanoic acid	ND	H H3	0.95	0.19	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
Total PFOA	**0.40**	**J H H3**	0.95	0.19	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
Perfluorononanoic acid (PFNA)	**0.86**	**J H H3**	0.95	0.17	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
Perfluorodecanoic acid (PFDA)	**2.0**	**H H3**	0.95	0.098	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
Perfluoroundecanoic acid (PFUnA)	**0.49**	**J H H3**	0.95	0.26	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
Perfluorobutanesulfonic acid (PFBS)	**0.53**	**J H H3**	0.95	0.16	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	0.95	0.17	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
Br-Perfluorohexanesulfonic acid	ND	H H3	0.95	0.14	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
Total PFHxS	**0.69**	**J H H3**	0.95	0.14	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
L-Perfluorohexanesulfonic acid	**0.69**	**J H H3**	0.95	0.14	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	0.95	0.18	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
L-Perfluorooctanesulfonic acid	**220**	**H E I H3**	2.4	0.19	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
Br-Perfluorooctanesulfonic acid	**4.3**	**H H3**	2.4	0.19	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
Total PFOS	**220**	**H H3**	2.4	0.19	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
4:2 FTS	ND	H H3	0.95	0.25	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
6:2 FTS	ND	H H3	0.95	0.40	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
8:2 FTS	**0.38**	**J H H3**	0.95	0.095	ug/Kg		12/03/24 04:26	12/09/24 20:56	1
10:2 FTS	**0.19**	**J H H3**	0.95	0.096	ug/Kg		12/03/24 04:26	12/09/24 20:56	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*43*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:56*	*1*
13C5 PFPeA	*86*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:56*	*1*
13C2 PFHxA	*122*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:56*	*1*
13C4 PFHpA	*121*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:56*	*1*
13C4 PFOA	*95*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:56*	*1*
13C5 PFNA	*102*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:56*	*1*
13C2 PFDA	*123*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:56*	*1*
13C2 PFUnA	*133*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:56*	*1*
13C3 PFBS	*105*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:56*	*1*
18O2 PFHxS	*122*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:56*	*1*
13C4 PFOS	*111*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:56*	*1*
M2-4:2 FTS	*199*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 20:56*	*1*
M2-6:2 FTS	*124*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:56*	*1*
M2-8:2 FTS	*142*		*25 - 150*	*12/03/24 04:26*	*12/09/24 20:56*	*1*
13C2 10:2 FTS	*448*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 20:56*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: NK 303127 L / MSB:Mamm:326548
Lab Sample ID: 320-117195-14
Date Collected: 08/02/17 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	1.1	0.25	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	1.1	0.19	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	1.1	0.29	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	1.1	0.12	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
L-Perfluorooctanoic acid	ND	H H3	1.1	0.22	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
Br-Perfluorooctanoic acid	ND	H H3	1.1	0.22	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
Total PFOA	ND	H H3	1.1	0.22	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
Perfluorononanoic acid (PFNA)	**0.59**	**J H H3**	1.1	0.19	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
Perfluorodecanoic acid (PFDA)	**2.7**	**H H3**	1.1	0.11	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
Perfluoroundecanoic acid (PFUnA)	**0.86**	**J H H3**	1.1	0.29	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	1.1	0.18	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	1.1	0.19	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
Br-Perfluorohexanesulfonic acid	ND	H H3	1.1	0.16	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
Total PFHxS	**0.58**	**J H H3**	1.1	0.16	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
L-Perfluorohexanesulfonic acid	**0.58**	**J H H3**	1.1	0.16	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	1.1	0.20	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
L-Perfluorooctanesulfonic acid	**94**	**H I H3**	2.7	0.22	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
Br-Perfluorooctanesulfonic acid	**4.1**	**H H3**	2.7	0.22	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
Total PFOS	**98**	**H H3**	2.7	0.22	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
4:2 FTS	ND	H H3	1.1	0.29	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
6:2 FTS	ND	H H3	1.1	0.46	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
8:2 FTS	**0.38**	**J H H3**	1.1	0.11	ug/Kg		12/03/24 04:26	12/09/24 21:15	1
10:2 FTS	**0.28**	**J H H3**	1.1	0.11	ug/Kg		12/03/24 04:26	12/09/24 21:15	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*88*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:15*	*1*
13C5 PFPeA	*106*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:15*	*1*
13C2 PFHxA	*119*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:15*	*1*
13C4 PFHpA	*114*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:15*	*1*
13C4 PFOA	*99*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:15*	*1*
13C5 PFNA	*114*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:15*	*1*
13C2 PFDA	*117*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:15*	*1*
13C2 PFUnA	*118*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:15*	*1*
13C3 PFBS	*115*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:15*	*1*
18O2 PFHxS	*126*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:15*	*1*
13C4 PFOS	*112*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:15*	*1*
M2-4:2 FTS	*136*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:15*	*1*
M2-6:2 FTS	*140*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:15*	*1*
M2-8:2 FTS	*119*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:15*	*1*
13C2 10:2 FTS	*580*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 21:15*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: NK 310003 L / MSB:Mamm:339709
Lab Sample ID: 320-117195-15
Date Collected: 06/13/19 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	1.0	0.25	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	1.0	0.18	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	1.0	0.28	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	1.0	0.12	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
L-Perfluorooctanoic acid	**0.55**	**J H H3**	1.0	0.21	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
Br-Perfluorooctanoic acid	ND	H H3	1.0	0.21	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
Total PFOA	**0.55**	**J H H3**	1.0	0.21	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
Perfluorononanoic acid (PFNA)	**6.4**	**H H3**	1.0	0.18	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
Perfluorodecanoic acid (PFDA)	**3.5**	**H H3**	1.0	0.11	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
Perfluoroundecanoic acid (PFUnA)	**0.78**	**J H H3**	1.0	0.28	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	1.0	0.18	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	1.0	0.19	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
Br-Perfluorohexanesulfonic acid	ND	H H3	1.0	0.15	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
Total PFHxS	**3.0**	**H H3**	1.0	0.15	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
L-Perfluorohexanesulfonic acid	**3.0**	**H H3**	1.0	0.15	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.44**	**J H H3**	1.0	0.19	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
L-Perfluorooctanesulfonic acid	**78**	**H I H3**	2.6	0.21	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
Br-Perfluorooctanesulfonic acid	**6.2**	**H H3**	2.6	0.21	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
Total PFOS	**84**	**H H3**	2.6	0.21	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
4:2 FTS	ND	H H3	1.0	0.28	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
6:2 FTS	ND	H H3	1.0	0.44	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
8:2 FTS	ND	H H3	1.0	0.10	ug/Kg		12/03/24 04:26	12/09/24 21:35	1
10:2 FTS	ND	H H3	1.0	0.11	ug/Kg		12/03/24 04:26	12/09/24 21:35	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*63*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:35*	*1*
13C5 PFPeA	*86*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:35*	*1*
13C2 PFHxA	*122*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:35*	*1*
13C4 PFHpA	*109*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:35*	*1*
13C4 PFOA	*94*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:35*	*1*
13C5 PFNA	*104*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:35*	*1*
13C2 PFDA	*108*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:35*	*1*
13C2 PFUnA	*114*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:35*	*1*
13C3 PFBS	*99*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:35*	*1*
18O2 PFHxS	*121*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:35*	*1*
13C4 PFOS	*103*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:35*	*1*
M2-4:2 FTS	*141*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:35*	*1*
M2-6:2 FTS	*109*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:35*	*1*
M2-8:2 FTS	*122*		*25 - 150*	*12/03/24 04:26*	*12/09/24 21:35*	*1*
13C2 10:2 FTS	*204*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 21:35*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: Gambusia Wet 1 / MSB:DGR:3154_1
Lab Sample ID: 320-117195-16
Date Collected: 10/02/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.90	0.21	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
Perfluoropentanoic acid (PFPeA)	ND		0.90	0.16	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
Perfluorohexanoic acid (PFHxA)	ND		0.90	0.25	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
Perfluoroheptanoic acid (PFHpA)	ND		0.90	0.10	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
L-Perfluorooctanoic acid	ND		0.90	0.18	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
Br-Perfluorooctanoic acid	ND		0.90	0.18	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
Total PFOA	ND		0.90	0.18	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
Perfluorononanoic acid (PFNA)	ND		0.90	0.16	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
Perfluorodecanoic acid (PFDA)	**0.90**		0.90	0.093	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
Perfluoroundecanoic acid (PFUnA)	**0.92**		0.90	0.25	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.90	0.15	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.90	0.16	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
Br-Perfluorohexanesulfonic acid	ND		0.90	0.13	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
Total PFHxS	**0.51**	**J**	0.90	0.13	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
L-Perfluorohexanesulfonic acid	**0.51**	**J**	0.90	0.13	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.90	0.17	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
L-Perfluorooctanesulfonic acid	**110**	**E I**	2.3	0.18	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
Br-Perfluorooctanesulfonic acid	**7.5**		2.3	0.18	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
Total PFOS	**110**		2.3	0.18	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
4:2 FTS	ND		0.90	0.24	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
6:2 FTS	**0.50**	**J**	0.90	0.38	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
8:2 FTS	**0.25**	**J**	0.90	0.090	ug/Kg		12/04/24 11:48	12/10/24 00:30	1
10:2 FTS	**0.29**	**J**	0.90	0.091	ug/Kg		12/04/24 11:48	12/10/24 00:30	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*46*		*25 - 150*	*12/04/24 11:48*	*12/10/24 00:30*	*1*
13C5 PFPeA	*73*		*25 - 150*	*12/04/24 11:48*	*12/10/24 00:30*	*1*
13C2 PFHxA	*84*		*25 - 150*	*12/04/24 11:48*	*12/10/24 00:30*	*1*
13C4 PFHpA	*86*		*25 - 150*	*12/04/24 11:48*	*12/10/24 00:30*	*1*
13C4 PFOA	*78*		*25 - 150*	*12/04/24 11:48*	*12/10/24 00:30*	*1*
13C5 PFNA	*84*		*25 - 150*	*12/04/24 11:48*	*12/10/24 00:30*	*1*
13C2 PFDA	*71*		*25 - 150*	*12/04/24 11:48*	*12/10/24 00:30*	*1*
13C2 PFUnA	*118*		*25 - 150*	*12/04/24 11:48*	*12/10/24 00:30*	*1*
13C3 PFBS	*75*		*25 - 150*	*12/04/24 11:48*	*12/10/24 00:30*	*1*
18O2 PFHxS	*101*		*25 - 150*	*12/04/24 11:48*	*12/10/24 00:30*	*1*
13C4 PFOS	*85*		*25 - 150*	*12/04/24 11:48*	*12/10/24 00:30*	*1*
M2-4:2 FTS	*86*		*25 - 150*	*12/04/24 11:48*	*12/10/24 00:30*	*1*
M2-6:2 FTS	*92*		*25 - 150*	*12/04/24 11:48*	*12/10/24 00:30*	*1*
M2-8:2 FTS	*98*		*25 - 150*	*12/04/24 11:48*	*12/10/24 00:30*	*1*
13C2 10:2 FTS	*467*	**5+*	*25 - 150*	*12/04/24 11:48*	*12/10/24 00:30*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: Gambusia Wet 2 / MSB:DGR:3154_2
Lab Sample ID: 320-117195-17
Date Collected: 10/02/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.28	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
L-Perfluorooctanoic acid	ND		1.0	0.21	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
Br-Perfluorooctanoic acid	ND		1.0	0.21	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
Total PFOA	ND		1.0	0.21	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
Perfluorodecanoic acid (PFDA)	**0.54**	**J**	1.0	0.11	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
Perfluoroundecanoic acid (PFUnA)	**0.53**	**J**	1.0	0.28	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.18	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.19	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
Total PFHxS	**0.75**	**J**	1.0	0.15	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
L-Perfluorohexanesulfonic acid	**0.61**	**J I**	1.0	0.15	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
L-Perfluorooctanesulfonic acid	**42**		2.6	0.21	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
Br-Perfluorooctanesulfonic acid	**2.7**		2.6	0.21	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
Total PFOS	**44**		2.6	0.21	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
4:2 FTS	ND		1.0	0.27	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
6:2 FTS	ND		1.0	0.44	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
8:2 FTS	**0.13**	**J**	1.0	0.10	ug/Kg		12/04/24 11:48	12/11/24 14:16	1
10:2 FTS	**0.22**	**J**	1.0	0.10	ug/Kg		12/04/24 11:48	12/11/24 14:16	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*63*		*25 - 150*	*12/04/24 11:48*	*12/11/24 14:16*	*1*
13C5 PFPeA	*77*		*25 - 150*	*12/04/24 11:48*	*12/11/24 14:16*	*1*
13C2 PFHxA	*106*		*25 - 150*	*12/04/24 11:48*	*12/11/24 14:16*	*1*
13C4 PFHpA	*100*		*25 - 150*	*12/04/24 11:48*	*12/11/24 14:16*	*1*
13C4 PFOA	*96*		*25 - 150*	*12/04/24 11:48*	*12/11/24 14:16*	*1*
13C5 PFNA	*108*		*25 - 150*	*12/04/24 11:48*	*12/11/24 14:16*	*1*
13C2 PFDA	*108*		*25 - 150*	*12/04/24 11:48*	*12/11/24 14:16*	*1*
13C2 PFUnA	*116*		*25 - 150*	*12/04/24 11:48*	*12/11/24 14:16*	*1*
13C3 PFBS	*93*		*25 - 150*	*12/04/24 11:48*	*12/11/24 14:16*	*1*
18O2 PFHxS	*116*		*25 - 150*	*12/04/24 11:48*	*12/11/24 14:16*	*1*
13C4 PFOS	*108*		*25 - 150*	*12/04/24 11:48*	*12/11/24 14:16*	*1*
M2-4:2 FTS	*108*		*25 - 150*	*12/04/24 11:48*	*12/11/24 14:16*	*1*
M2-6:2 FTS	*176*	**5+*	*25 - 150*	*12/04/24 11:48*	*12/11/24 14:16*	*1*
M2-8:2 FTS	*152*	**5+*	*25 - 150*	*12/04/24 11:48*	*12/11/24 14:16*	*1*
13C2 10:2 FTS	*418*	**5+*	*25 - 150*	*12/04/24 11:48*	*12/11/24 14:16*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: Dragonfly wetland / MSB:DGR:3159
Lab Sample ID: 320-117195-18
Date Collected: 10/02/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		5.6	1.3	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
Perfluoropentanoic acid (PFPeA)	ND		5.6	0.97	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
Perfluorohexanoic acid (PFHxA)	ND		5.6	1.5	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
Perfluoroheptanoic acid (PFHpA)	ND		5.6	0.64	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
L-Perfluorooctanoic acid	ND		5.6	1.1	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
Br-Perfluorooctanoic acid	ND		5.6	1.1	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
Total PFOA	ND		5.6	1.1	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
Perfluorononanoic acid (PFNA)	ND		5.6	0.97	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
Perfluorodecanoic acid (PFDA)	ND		5.6	0.57	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
Perfluoroundecanoic acid (PFUnA)	ND		5.6	1.5	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
Perfluorobutanesulfonic acid (PFBS)	ND		5.6	0.94	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
Perfluoropentanesulfonic acid (PFPeS)	ND		5.6	1.0	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
Br-Perfluorohexanesulfonic acid	ND		5.6	0.82	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
Total PFHxS	ND		5.6	0.82	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
L-Perfluorohexanesulfonic acid	ND		5.6	0.82	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		5.6	1.0	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
L-Perfluorooctanesulfonic acid	**1.1**	**J I**	14	1.1	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
Br-Perfluorooctanesulfonic acid	ND		14	1.1	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
Total PFOS	**1.1**	**J**	14	1.1	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
4:2 FTS	ND		5.6	1.5	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
6:2 FTS	ND		5.6	2.4	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
8:2 FTS	ND		5.6	0.56	ug/Kg		12/03/24 12:06	12/06/24 23:39	1
10:2 FTS	ND		5.6	0.56	ug/Kg		12/03/24 12:06	12/06/24 23:39	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*84*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:39*	*1*
13C5 PFPeA	*79*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:39*	*1*
13C2 PFHxA	*88*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:39*	*1*
13C4 PFHpA	*84*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:39*	*1*
13C4 PFOA	*74*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:39*	*1*
13C5 PFNA	*78*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:39*	*1*
13C2 PFDA	*78*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:39*	*1*
13C2 PFUnA	*73*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:39*	*1*
13C3 PFBS	*73*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:39*	*1*
18O2 PFHxS	*89*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:39*	*1*
13C4 PFOS	*76*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:39*	*1*
M2-4:2 FTS	*59*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:39*	*1*
M2-6:2 FTS	*54*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:39*	*1*
M2-8:2 FTS	*48*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:39*	*1*
13C2 10:2 FTS	*354*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 23:39*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: Cattail N wet / MSB:DGR:3155_1
Lab Sample ID: 320-117195-19
Date Collected: 10/02/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**12**		2.6	0.61	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
Perfluoropentanoic acid (PFPeA)	**57**		2.6	0.45	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
Perfluorohexanoic acid (PFHxA)	**7.8**		2.6	0.70	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
Perfluoroheptanoic acid (PFHpA)	**0.56**	**J**	2.6	0.30	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
L-Perfluorooctanoic acid	ND		2.6	0.52	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
Br-Perfluorooctanoic acid	ND		2.6	0.52	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
Total PFOA	ND		2.6	0.52	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
Perfluorononanoic acid (PFNA)	ND		2.6	0.45	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
Perfluorodecanoic acid (PFDA)	ND		2.6	0.26	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
Perfluoroundecanoic acid (PFUnA)	ND		2.6	0.70	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
Perfluorobutanesulfonic acid (PFBS)	ND		2.6	0.44	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
Perfluoropentanesulfonic acid (PFPeS)	ND		2.6	0.46	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
Br-Perfluorohexanesulfonic acid	ND		2.6	0.38	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
Total PFHxS	**1.8**	**J**	2.6	0.38	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
L-Perfluorohexanesulfonic acid	**1.8**	**J**	2.6	0.38	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		2.6	0.47	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
L-Perfluorooctanesulfonic acid	**3.8**	**J**	6.4	0.52	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
Br-Perfluorooctanesulfonic acid	**1.3**	**J**	6.4	0.52	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
Total PFOS	**5.2**	**J**	6.4	0.52	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
4:2 FTS	ND		2.6	0.68	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
6:2 FTS	**3.2**		2.6	1.1	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
8:2 FTS	ND		2.6	0.26	ug/Kg		12/03/24 12:06	12/06/24 23:00	1
10:2 FTS	ND		2.6	0.26	ug/Kg		12/03/24 12:06	12/06/24 23:00	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*40*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:00*	*1*
13C5 PFPeA	*86*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:00*	*1*
13C2 PFHxA	*89*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:00*	*1*
13C4 PFHpA	*80*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:00*	*1*
13C4 PFOA	*73*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:00*	*1*
13C5 PFNA	*72*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:00*	*1*
13C2 PFDA	*81*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:00*	*1*
13C2 PFUnA	*70*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:00*	*1*
13C3 PFBS	*74*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:00*	*1*
18O2 PFHxS	*84*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:00*	*1*
13C4 PFOS	*80*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:00*	*1*
M2-4:2 FTS	*78*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:00*	*1*
M2-6:2 FTS	*59*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:00*	*1*
M2-8:2 FTS	*48*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:00*	*1*
13C2 10:2 FTS	*316*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 23:00*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: Cattail N wet 2 / MSB:DGR:3155_2
Lab Sample ID: 320-117195-20
Date Collected: 10/02/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**18**		1.4	0.34	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
Perfluoropentanoic acid (PFPeA)	**35**		1.4	0.25	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
Perfluorohexanoic acid (PFHxA)	**3.3**		1.4	0.39	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
Perfluoroheptanoic acid (PFHpA)	**0.65**	**J**	1.4	0.17	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
L-Perfluorooctanoic acid	**0.85**	**J**	1.4	0.29	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
Br-Perfluorooctanoic acid	ND		1.4	0.29	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
Total PFOA	**0.85**	**J**	1.4	0.29	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
Perfluorononanoic acid (PFNA)	**0.29**	**J I**	1.4	0.25	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
Perfluorodecanoic acid (PFDA)	ND		1.4	0.15	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
Perfluoroundecanoic acid (PFUnA)	ND		1.4	0.39	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.4	0.24	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.4	0.26	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
Br-Perfluorohexanesulfonic acid	**0.58**	**J**	1.4	0.21	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
Total PFHxS	**3.4**		1.4	0.21	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
L-Perfluorohexanesulfonic acid	**2.8**		1.4	0.21	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.4	0.26	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
L-Perfluorooctanesulfonic acid	**6.0**		3.6	0.29	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
Br-Perfluorooctanesulfonic acid	**1.8**	**J**	3.6	0.29	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
Total PFOS	**7.9**		3.6	0.29	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
4:2 FTS	ND		1.4	0.38	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
6:2 FTS	**10**		1.4	0.61	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
8:2 FTS	ND		1.4	0.14	ug/Kg		12/03/24 12:06	12/06/24 23:19	1
10:2 FTS	ND		1.4	0.14	ug/Kg		12/03/24 12:06	12/06/24 23:19	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*17*	**5-*	*25 - 150*	*12/03/24 12:06*	*12/06/24 23:19*	*1*
13C5 PFPeA	*54*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:19*	*1*
13C2 PFHxA	*72*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:19*	*1*
13C4 PFHpA	*77*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:19*	*1*
13C4 PFOA	*63*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:19*	*1*
13C5 PFNA	*65*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:19*	*1*
13C2 PFDA	*70*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:19*	*1*
13C2 PFUnA	*62*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:19*	*1*
13C3 PFBS	*54*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:19*	*1*
18O2 PFHxS	*74*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:19*	*1*
13C4 PFOS	*69*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:19*	*1*
M2-4:2 FTS	*98*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:19*	*1*
M2-6:2 FTS	*73*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:19*	*1*
M2-8:2 FTS	*59*		*25 - 150*	*12/03/24 12:06*	*12/06/24 23:19*	*1*
13C2 10:2 FTS	*301*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 23:19*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: saltceder NE4-4 / MSB:DGR:3156
Lab Sample ID: 320-117195-21
Date Collected: 10/01/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.8	0.42	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
Perfluoropentanoic acid (PFPeA)	ND		1.8	0.31	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
Perfluorohexanoic acid (PFHxA)	**3.4**		1.8	0.49	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
Perfluoroheptanoic acid (PFHpA)	**0.70**	**J**	1.8	0.21	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
L-Perfluorooctanoic acid	**0.68**	**J**	1.8	0.36	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
Br-Perfluorooctanoic acid	**0.60**	**J**	1.8	0.36	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
Total PFOA	**1.3**	**J**	1.8	0.36	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
Perfluorononanoic acid (PFNA)	ND		1.8	0.31	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
Perfluorodecanoic acid (PFDA)	ND		1.8	0.18	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
Perfluoroundecanoic acid (PFUnA)	ND		1.8	0.49	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
Perfluorobutanesulfonic acid (PFBS)	**0.41**	**J**	1.8	0.30	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
Perfluoropentanesulfonic acid (PFPeS)	**2.6**		1.8	0.32	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
Br-Perfluorohexanesulfonic acid	**2.7**		1.8	0.26	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
Total PFHxS	**24**		1.8	0.26	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
L-Perfluorohexanesulfonic acid	**22**		1.8	0.26	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.8	0.33	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
L-Perfluorooctanesulfonic acid	**3.9**	**J**	4.5	0.36	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
Br-Perfluorooctanesulfonic acid	**1.8**	**J**	4.5	0.36	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
Total PFOS	**5.8**		4.5	0.36	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
4:2 FTS	ND		1.8	0.48	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
6:2 FTS	ND		1.8	0.76	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
8:2 FTS	ND		1.8	0.18	ug/Kg		12/04/24 11:48	12/10/24 01:08	1
10:2 FTS	**0.18**	**J**	1.8	0.18	ug/Kg		12/04/24 11:48	12/10/24 01:08	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*32*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:08*	*1*
13C5 PFPeA	*70*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:08*	*1*
13C2 PFHxA	*82*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:08*	*1*
13C4 PFHpA	*84*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:08*	*1*
13C4 PFOA	*71*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:08*	*1*
13C5 PFNA	*76*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:08*	*1*
13C2 PFDA	*72*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:08*	*1*
13C2 PFUnA	*64*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:08*	*1*
13C3 PFBS	*72*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:08*	*1*
18O2 PFHxS	*86*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:08*	*1*
13C4 PFOS	*79*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:08*	*1*
M2-4:2 FTS	*92*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:08*	*1*
M2-6:2 FTS	*81*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:08*	*1*
M2-8:2 FTS	*70*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:08*	*1*
13C2 10:2 FTS	*203*	**5+*	*25 - 150*	*12/04/24 11:48*	*12/10/24 01:08*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: Marsh fleabane / MSB:DGR:3153
Lab Sample ID: 320-117195-22
Date Collected: 10/02/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**0.81**	**J**	0.87	0.21	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
Perfluoropentanoic acid (PFPeA)	**6.6**		0.87	0.15	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
Perfluorohexanoic acid (PFHxA)	**1.2**		0.87	0.24	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
Perfluoroheptanoic acid (PFHpA)	**0.16**	**J**	0.87	0.10	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
L-Perfluorooctanoic acid	ND		0.87	0.18	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
Br-Perfluorooctanoic acid	ND		0.87	0.18	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
Total PFOA	ND		0.87	0.18	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
Perfluorononanoic acid (PFNA)	ND		0.87	0.15	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
Perfluorodecanoic acid (PFDA)	ND		0.87	0.090	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
Perfluoroundecanoic acid (PFUnA)	ND		0.87	0.24	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.87	0.15	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.87	0.16	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
Br-Perfluorohexanesulfonic acid	ND		0.87	0.13	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
Total PFHxS	**0.53**	**J**	0.87	0.13	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
L-Perfluorohexanesulfonic acid	**0.53**	**J**	0.87	0.13	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.87	0.16	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
L-Perfluorooctanesulfonic acid	**0.65**	**J**	2.2	0.18	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
Br-Perfluorooctanesulfonic acid	**0.37**	**J**	2.2	0.18	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
Total PFOS	**1.0**	**J**	2.2	0.18	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
4:2 FTS	ND		0.87	0.23	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
6:2 FTS	**2.3**		0.87	0.37	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
8:2 FTS	ND		0.87	0.087	ug/Kg		12/04/24 11:48	12/10/24 01:28	1
10:2 FTS	ND		0.87	0.088	ug/Kg		12/04/24 11:48	12/10/24 01:28	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*24*	*5-	*25 - 150*	*12/04/24 11:48*	*12/10/24 01:28*	*1*
13C5 PFPeA	*41*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:28*	*1*
13C2 PFHxA	*66*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:28*	*1*
13C4 PFHpA	*90*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:28*	*1*
13C4 PFOA	*64*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:28*	*1*
13C5 PFNA	*73*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:28*	*1*
13C2 PFDA	*75*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:28*	*1*
13C2 PFUnA	*67*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:28*	*1*
13C3 PFBS	*73*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:28*	*1*
18O2 PFHxS	*85*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:28*	*1*
13C4 PFOS	*75*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:28*	*1*
M2-4:2 FTS	*160*	*5+	*25 - 150*	*12/04/24 11:48*	*12/10/24 01:28*	*1*
M2-6:2 FTS	*82*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:28*	*1*
M2-8:2 FTS	*79*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:28*	*1*
13C2 10:2 FTS	*366*	*5+	*25 - 150*	*12/04/24 11:48*	*12/10/24 01:28*	*1*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: holloman wetland / MSB:DGR:3158
Lab Sample ID: 320-117195-23
Date Collected: 10/01/24 00:00
Matrix: Solid
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	7.4		0.18	0.042	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
Perfluoroheptanoic acid (PFHpA)	4.7		0.18	0.035	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
L-Perfluorooctanoic acid	1.8		0.18	0.049	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
Br-Perfluorooctanoic acid	0.26		0.18	0.049	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
Total PFOA	2.1		0.18	0.049	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
Perfluorononanoic acid (PFNA)	0.84		0.18	0.020	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
Perfluorodecanoic acid (PFDA)	0.51		0.18	0.044	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
Perfluoroundecanoic acid (PFUnA)	0.36		0.18	0.039	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
Perfluorobutanesulfonic acid (PFBS)	1.2		0.18	0.035	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
Perfluoropentanesulfonic acid (PFPeS)	1.1		0.18	0.034	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
Br-Perfluorohexanesulfonic acid	2.2		0.18	0.027	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
Total PFHxS	11		0.18	0.027	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
L-Perfluorohexanesulfonic acid	9.0		0.18	0.027	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
Perfluoroheptanesulfonic acid (PFHpS)	0.42		0.18	0.045	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
4:2 FTS	ND		0.18	0.047	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
6:2 FTS	14		0.18	0.025	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
8:2 FTS	0.84		0.18	0.032	ug/Kg		11/25/24 04:16	11/26/24 14:38	1
10:2 FTS	0.12	J	0.18	0.035	ug/Kg		11/25/24 04:16	11/26/24 14:38	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*85*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:38*	*1*
13C4 PFHpA	*88*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:38*	*1*
13C4 PFOA	*77*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:38*	*1*
13C5 PFNA	*89*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:38*	*1*
13C2 PFDA	*88*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:38*	*1*
13C2 PFUnA	*87*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:38*	*1*
13C3 PFBS	*97*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:38*	*1*
18O2 PFHxS	*93*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:38*	*1*
13C4 PFOS	*76*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:38*	*1*
M2-4:2 FTS	*95*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:38*	*1*
M2-6:2 FTS	*86*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:38*	*1*
M2-8:2 FTS	*82*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:38*	*1*
13C2 10:2 FTS	*196*	**5+*	*25 - 150*	*11/25/24 04:16*	*11/26/24 14:38*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoropentanoic acid (PFPeA)	53		3.7	0.76	ug/Kg		11/25/24 04:16	11/27/24 14:06	20
Perfluorohexanoic acid (PFHxA)	25		3.7	0.57	ug/Kg		11/25/24 04:16	11/27/24 14:06	20
L-Perfluorooctanesulfonic acid	120		3.7	0.79	ug/Kg		11/25/24 04:16	11/27/24 14:06	20
Br-Perfluorooctanesulfonic acid	23		3.7	0.79	ug/Kg		11/25/24 04:16	11/27/24 14:06	20
Total PFOS	140		3.7	0.79	ug/Kg		11/25/24 04:16	11/27/24 14:06	20

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFPeA	*70*		*25 - 150*	*11/25/24 04:16*	*11/27/24 14:06*	*20*
13C2 PFHxA	*85*		*25 - 150*	*11/25/24 04:16*	*11/27/24 14:06*	*20*
13C4 PFOS	*84*		*25 - 150*	*11/25/24 04:16*	*11/27/24 14:06*	*20*

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: holloman wetland / MSB:DGR:3158
Lab Sample ID: 320-117195-23
Date Collected: 10/01/24 00:00
Matrix: Solid
Date Received: 11/21/24 09:40

General Chemistry

Analyte	Result	Qualifier	RL	RL	Unit	D	Prepared	Analyzed	Dil Fac
Percent Moisture (ASTM D2216-92)	56	H H3	0.10	0.10	%			12/03/24 14:12	1
Percent Solids (ASTM D2216-92)	44	H H3	0.10	0.10	%			12/03/24 14:12	1

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: holloman S. Playa / MSB:DGR:3157
Lab Sample ID: 320-117195-24
Date Collected: 10/01/24 00:00
Matrix: Solid
Date Received: 11/21/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	13		0.18	0.042	ug/Kg		11/25/24 04:16	11/26/24 14:57	1
Perfluorononanoic acid (PFNA)	4.4		0.18	0.020	ug/Kg		11/25/24 04:16	11/26/24 14:57	1
Perfluorodecanoic acid (PFDA)	0.095	J	0.18	0.044	ug/Kg		11/25/24 04:16	11/26/24 14:57	1
Perfluoroundecanoic acid (PFUnA)	0.068	J	0.18	0.038	ug/Kg		11/25/24 04:16	11/26/24 14:57	1
4:2 FTS	ND		0.18	0.046	ug/Kg		11/25/24 04:16	11/26/24 14:57	1
6:2 FTS	6.1		0.18	0.025	ug/Kg		11/25/24 04:16	11/26/24 14:57	1
8:2 FTS	0.81		0.18	0.032	ug/Kg		11/25/24 04:16	11/26/24 14:57	1
10:2 FTS	ND		0.18	0.035	ug/Kg		11/25/24 04:16	11/26/24 14:57	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*37*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:57*	*1*
13C5 PFNA	*78*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:57*	*1*
13C2 PFDA	*86*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:57*	*1*
13C2 PFUnA	*76*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:57*	*1*
M2-4:2 FTS	*91*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:57*	*1*
M2-6:2 FTS	*71*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:57*	*1*
M2-8:2 FTS	*70*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:57*	*1*
13C2 10:2 FTS	*134*		*25 - 150*	*11/25/24 04:16*	*11/26/24 14:57*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoropentanoic acid (PFPeA)	59		18	3.7	ug/Kg		11/25/24 04:16	12/02/24 15:41	100
Perfluorohexanoic acid (PFHxA)	180		18	2.8	ug/Kg		11/25/24 04:16	12/02/24 15:41	100
Perfluoroheptanoic acid (PFHpA)	83		18	3.5	ug/Kg		11/25/24 04:16	12/02/24 15:41	100
L-Perfluorooctanoic acid	110		18	4.8	ug/Kg		11/25/24 04:16	12/02/24 15:41	100
Br-Perfluorooctanoic acid	19		18	4.8	ug/Kg		11/25/24 04:16	12/02/24 15:41	100
Total PFOA	130		18	4.8	ug/Kg		11/25/24 04:16	12/02/24 15:41	100
Perfluorobutanesulfonic acid (PFBS)	23		18	3.5	ug/Kg		11/25/24 04:16	12/02/24 15:41	100
Perfluoropentanesulfonic acid (PFPeS)	60		18	3.4	ug/Kg		11/25/24 04:16	12/02/24 15:41	100
Br-Perfluorohexanesulfonic acid	170		18	2.6	ug/Kg		11/25/24 04:16	12/02/24 15:41	100
Total PFHxS	830		18	2.6	ug/Kg		11/25/24 04:16	12/02/24 15:41	100
L-Perfluorohexanesulfonic acid	660		18	2.6	ug/Kg		11/25/24 04:16	12/02/24 15:41	100
Perfluoroheptanesulfonic acid (PFHpS)	17	J	18	4.5	ug/Kg		11/25/24 04:16	12/02/24 15:41	100
L-Perfluorooctanesulfonic acid	74		18	3.9	ug/Kg		11/25/24 04:16	12/02/24 15:41	100
Br-Perfluorooctanesulfonic acid	130		18	3.9	ug/Kg		11/25/24 04:16	12/02/24 15:41	100
Total PFOS	200		18	3.9	ug/Kg		11/25/24 04:16	12/02/24 15:41	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFPeA	*84*		*25 - 150*	*11/25/24 04:16*	*12/02/24 15:41*	*100*
13C2 PFHxA	*83*		*25 - 150*	*11/25/24 04:16*	*12/02/24 15:41*	*100*
13C4 PFHpA	*84*		*25 - 150*	*11/25/24 04:16*	*12/02/24 15:41*	*100*
13C4 PFOA	*73*		*25 - 150*	*11/25/24 04:16*	*12/02/24 15:41*	*100*
13C3 PFBS	*83*		*25 - 150*	*11/25/24 04:16*	*12/02/24 15:41*	*100*
18O2 PFHxS	*106*		*25 - 150*	*11/25/24 04:16*	*12/02/24 15:41*	*100*
13C4 PFOS	*79*		*25 - 150*	*11/25/24 04:16*	*12/02/24 15:41*	*100*

Client Sample Results

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: holloman S. Playa / MSB:DGR:3157
Lab Sample ID: 320-117195-24
Date Collected: 10/01/24 00:00
Matrix: Solid
Date Received: 11/21/24 09:40

General Chemistry

Analyte	Result	Qualifier	RL	RL	Unit	D	Prepared	Analyzed	Dil Fac
Percent Moisture (ASTM D2216-92)	32	H H3	0.10	0.10	%			12/03/24 14:12	1
Percent Solids (ASTM D2216-92)	68	H H3	0.10	0.10	%			12/03/24 14:12	1

Isotope Dilution Summary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Job ID: 320-117195-1

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Solid

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-117195-23	holloman wetland / MSB:DGR:3	85			88	77	89	88	87
320-117195-23 - DL	holloman wetland / MSB:DGR:3158		70	85					
320-117195-24	holloman S. Playa / MSB:DGR:3157	37					78	86	76
320-117195-24 - DL	holloman S. Playa / MSB:DGR:3157		84	83	84	73			
LCS 320-817586/2-A	Lab Control Sample	114	101	108	106	98	100	97	88
MB 320-817586/1-A	Method Blank	110	110	112	111	95	111	103	95

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
320-117195-23	holloman wetland / MSB:DGR:3	97	93	76	95	86	82	196 *5+
320-117195-23 - DL	holloman wetland / MSB:DGR:3158			84				
320-117195-24	holloman S. Playa / MSB:DGR:3157				91	71	70	134
320-117195-24 - DL	holloman S. Playa / MSB:DGR:3157	83	106	79				
LCS 320-817586/2-A	Lab Control Sample	113	105	100	98	84	80	115
MB 320-817586/1-A	Method Blank	112	110	102	87	91	88	134

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
PFHxA = 13C2 PFHxA
C4PFHA = 13C4 PFHpA
PFOA = 13C4 PFOA
PFNA = 13C5 PFNA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS
PFHxS = 18O2 PFHxS
PFOS = 13C4 PFOS
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
M102FTS = 13C2 10:2 FTS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Tissue

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-117195-1	NK 19893 L / MSB:Mamm:6184	82	87	106	105	93	114	114	140
320-117195-2	NK 32079 L / MSB:Mamm:75616	107	88	116	118	96	113	118	105
320-117195-3	NK 32043 L / MSB:Mamm:75617	107	107	129	112	91	108	117	121
320-117195-4	NK 32074 L / MSB:Mamm:75618	88	81	112	93	93	97	95	90

Isotope Dilution Summary

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Matrix: Tissue
Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-117195-5	NK 32071 L / MSB:Mamm:7561	105	97	118	105	94	100	104	91
320-117195-6	NK 32039 L / MSB:Mamm:75620	104	105	119	105	92	109	110	91
320-117195-7	NK 10447 L / MSB:Mamm:87701	81	101	113	114	97	108	139	127
320-117195-8	NK 10444 L / MSB:Mamm:87702	77	94	107	110	93	102	128	115
320-117195-9	NK 10442 L / MSB:Mamm:89195	42	73	111	103	91	86	100	104
320-117195-10	NK 10446 L / MSB:Mamm:89187	67	89	108	101	89	100	112	103
320-117195-11	NK 40788 L / MSB:Mamm:89351	81	89	107	103	100	96	102	95
320-117195-12	NK 154469 M / MSB:Mamm:198472	65	89	119	109	94	97	109	87
320-117195-13	NK 180975 L / MSB:Mamm:1268357	43	86	122	121	95	102	123	133
320-117195-14	NK 303127 L / MSB:Mamm:326548	88	106	119	114	99	114	117	118
320-117195-15	NK 310003 L / MSB:Mamm:339709	63	86	122	109	94	104	108	114
320-117195-16	Gambusia Wet 1 / MSB:DGR:3154_1	46	73	84	86	78	84	71	118
320-117195-17	Gambusia Wet 2 / MSB:DGR:3154_2	63	77	106	100	96	108	108	116
320-117195-18	Dragonfly wetland / MSB:DGR:3159	84	79	88	84	74	78	78	73
320-117195-19	Cattail N wet / MSB:DGR:3155_1	40	86	89	80	73	72	81	70
320-117195-20	Cattail N wet 2 / MSB:DGR:3155_2	17 *5-	54	72	77	63	65	70	62
320-117195-21	saltceder NE4-4 / MSB:DGR:3156	32	70	82	84	71	76	72	64
320-117195-22	Marsh fleabane / MSB:DGR:3153	24 *5-	41	66	90	64	73	75	67
LCS 320-818866/2-A	Lab Control Sample	104	94	111	103	94	100	102	96
LCS 320-818987/2-A	Lab Control Sample	76	65	74	75	64	72	70	65
LCS 320-819252/2-A	Lab Control Sample	87	82	87	91	77	87	87	82
LCSD 320-818866/3-A	Lab Control Sample Dup	117	103	122	112	100	110	111	97
LCSD 320-818987/3-A	Lab Control Sample Dup	87	87	91	87	81	89	85	86
LCSD 320-819252/3-A	Lab Control Sample Dup	95	82	100	86	85	88	89	83
MB 320-818866/1-A	Method Blank	106	93	113	109	96	102	107	95
MB 320-818987/1-A	Method Blank	83	72	75	84	84	84	86	79
MB 320-819252/1-A	Method Blank	95	79	112	94	87	92	96	89

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
320-117195-1	NK 19893 L / MSB:Mamm:6184	97	116	105	102	126	121	731 *5+
320-117195-2	NK 32079 L / MSB:Mamm:75616	102	119	108	147	143	113	608 *5+
320-117195-3	NK 32043 L / MSB:Mamm:75617	97	123	113	147	73	115	497 *5+
320-117195-4	NK 32074 L / MSB:Mamm:75618	78	103	90	111	132	100	549 *5+

Isotope Dilution Summary

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Matrix: Tissue
Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
320-117195-5	NK 32071 L / MSB:Mamm:7561	84	113	96	95	139	105	326 *5+
320-117195-6	NK 32039 L / MSB:Mamm:75620	90	113	109	127	156 *5+	115	299 *5+
320-117195-7	NK 10447 L / MSB:Mamm:87701	97	118	106	201 *5+	184 *5+	299 *5+	579 *5+
320-117195-8	NK 10444 L / MSB:Mamm:87702	87	108	94	153 *5+	136	270 *5+	446 *5+
320-117195-9	NK 10442 L / MSB:Mamm:89195	78	109	99	134	125	129	238 *5+
320-117195-10	NK 10446 L / MSB:Mamm:89187	81	105	103	128	151 *5+	115	305 *5+
320-117195-11	NK 40788 L / MSB:Mamm:89351	89	110	102	126	146	88	426 *5+
320-117195-12	NK 154469 M / MSB:Mamm:198472	97	112	99	135	110	102	545 *5+
320-117195-13	NK 180975 L / MSB:Mamm:1268357	105	122	111	199 *5+	124	142	448 *5+
320-117195-14	NK 303127 L / MSB:Mamm:326548	115	126	112	136	140	119	580 *5+
320-117195-15	NK 310003 L / MSB:Mamm:339709	99	121	103	141	109	122	204 *5+
320-117195-16	Gambusia Wet 1 / MSB:DGR:3154_1	75	101	85	86	92	98	467 *5+
320-117195-17	Gambusia Wet 2 / MSB:DGR:3154_2	93	116	108	108	176 *5+	152 *5+	418 *5+
320-117195-18	Dragonfly wetland / MSB:DGR:3159	73	89	76	59	54	48	354 *5+
320-117195-19	Cattail N wet / MSB:DGR:3155_1	74	84	80	78	59	48	316 *5+
320-117195-20	Cattail N wet 2 / MSB:DGR:3155_2	54	74	69	98	73	59	301 *5+
320-117195-21	saltceder NE4-4 / MSB:DGR:3156	72	86	79	92	81	70	203 *5+
320-117195-22	Marsh fleabane / MSB:DGR:3153	73	85	75	160 *5+	82	79	366 *5+
LCS 320-818866/2-A	Lab Control Sample	106	104	92	117	96	118	504 *5+
LCS 320-818987/2-A	Lab Control Sample	73	72	69	46	57	48	300 *5+
LCS 320-819252/2-A	Lab Control Sample	73	98	87	87	86	72	351 *5+
LCSD 320-818866/3-A	Lab Control Sample Dup	109	112	100	127	125	111	497 *5+
LCSD 320-818987/3-A	Lab Control Sample Dup	83	95	88	65	72	62	419 *5+
LCSD 320-819252/3-A	Lab Control Sample Dup	88	105	89	94	91	83	350 *5+
MB 320-818866/1-A	Method Blank	106	116	103	125	136	117	462 *5+
MB 320-818987/1-A	Method Blank	81	92	76	57	68	62	381 *5+
MB 320-819252/1-A	Method Blank	93	103	100	69	101	82	396 *5+

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
PFHxA = 13C2 PFHxA
C4PFHA = 13C4 PFHpA
PFOA = 13C4 PFOA
PFNA = 13C5 PFNA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS

Isotope Dilution Summary

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

PFHxS = 18O2 PFHxS
PFOS = 13C4 PFOS
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
M102FTS = 13C2 10:2 FTS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Lab Sample ID: MB 320-817586/1-A
Matrix: Solid
Analysis Batch: 817947

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 817586

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.20	0.046	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluoropentanoic acid (PFPeA)	ND		0.20	0.041	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluorohexanoic acid (PFHxA)	ND		0.20	0.031	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluoroheptanoic acid (PFHpA)	ND		0.20	0.038	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
L-Perfluorooctanoic acid	ND		0.20	0.053	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Br-Perfluorooctanoic acid	ND		0.20	0.053	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Total PFOA	ND		0.20	0.053	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluorononanoic acid (PFNA)	ND		0.20	0.022	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluorodecanoic acid (PFDA)	ND		0.20	0.048	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluoroundecanoic acid (PFUnA)	ND		0.20	0.042	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.20	0.038	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.20	0.037	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Br-Perfluorohexanesulfonic acid	ND		0.20	0.029	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Total PFHxS	ND		0.20	0.029	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
L-Perfluorohexanesulfonic acid	ND		0.20	0.029	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.20	0.049	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
L-Perfluorooctanesulfonic acid	ND		0.20	0.043	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Br-Perfluorooctanesulfonic acid	ND		0.20	0.043	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Total PFOS	ND		0.20	0.043	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
4:2 FTS	ND		0.20	0.051	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
6:2 FTS	ND		0.20	0.027	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
8:2 FTS	ND		0.20	0.035	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
10:2 FTS	ND		0.20	0.038	ug/Kg		11/25/24 04:16	11/26/24 13:59	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*110*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C5 PFPeA	*110*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C2 PFHxA	*112*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C4 PFHpA	*111*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C4 PFOA	*95*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C5 PFNA	*111*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C2 PFDA	*103*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C2 PFUnA	*95*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C3 PFBS	*112*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
18O2 PFHxS	*110*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C4 PFOS	*102*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
M2-4:2 FTS	*87*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
M2-6:2 FTS	*91*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
M2-8:2 FTS	*88*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C2 10:2 FTS	*134*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*

Lab Sample ID: LCS 320-817586/2-A
Matrix: Solid
Analysis Batch: 817947

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 817586

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	2.00	1.97		ug/Kg		98	76 - 136

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-817586/2-A
Matrix: Solid
Analysis Batch: 817947

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 817586

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluoropentanoic acid (PFPeA)	2.00	2.17		ug/Kg		108	74 - 134
Perfluorohexanoic acid (PFHxA)	2.00	1.91		ug/Kg		95	71 - 131
Perfluoroheptanoic acid (PFHpA)	2.00	1.98		ug/Kg		99	71 - 131
L-Perfluorooctanoic acid	2.00	1.83		ug/Kg		91	72 - 132
Total PFOA	2.00	1.83		ug/Kg		91	72 - 132
Perfluorononanoic acid (PFNA)	2.00	1.87		ug/Kg		94	73 - 133
Perfluorodecanoic acid (PFDA)	2.00	2.16		ug/Kg		108	72 - 132
Perfluoroundecanoic acid (PFUnA)	2.00	2.00		ug/Kg		100	75 - 135
Perfluorobutanesulfonic acid (PFBS)	1.78	1.65		ug/Kg		93	69 - 129
Perfluoropentanesulfonic acid (PFPeS)	1.88	1.61		ug/Kg		86	75 - 135
Total PFHxS	1.82	1.72		ug/Kg		95	62 - 122
L-Perfluorohexanesulfonic acid	1.82	1.72		ug/Kg		95	62 - 122
Perfluoroheptanesulfonic acid (PFHpS)	1.91	2.19		ug/Kg		115	76 - 136
L-Perfluorooctanesulfonic acid	1.86	1.83		ug/Kg		99	73 - 133
Total PFOS	1.86	1.83		ug/Kg		99	73 - 133
4:2 FTS	1.88	1.94		ug/Kg		104	71 - 131
6:2 FTS	1.90	1.78		ug/Kg		94	73 - 132
8:2 FTS	1.92	2.09		ug/Kg		109	75 - 135
10:2 FTS	1.93	1.84		ug/Kg		95	69 - 128

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*114*		*25 - 150*
13C5 PFPeA	*101*		*25 - 150*
13C2 PFHxA	*108*		*25 - 150*
13C4 PFHpA	*106*		*25 - 150*
13C4 PFOA	*98*		*25 - 150*
13C5 PFNA	*100*		*25 - 150*
13C2 PFDA	*97*		*25 - 150*
13C2 PFUnA	*88*		*25 - 150*
13C3 PFBS	*113*		*25 - 150*
18O2 PFHxS	*105*		*25 - 150*
13C4 PFOS	*100*		*25 - 150*
M2-4:2 FTS	*98*		*25 - 150*
M2-6:2 FTS	*84*		*25 - 150*
M2-8:2 FTS	*80*		*25 - 150*
13C2 10:2 FTS	*115*		*25 - 150*

Lab Sample ID: MB 320-818866/1-A
Matrix: Tissue
Analysis Batch: 820781

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 818866

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.27	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/03/24 04:26	12/09/24 15:46	1

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: MB 320-818866/1-A
Matrix: Tissue
Analysis Batch: 820781

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 818866

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
Total PFOA	ND		1.0	0.20	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.10	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.27	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
Total PFHxS	ND		1.0	0.15	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
L-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
Br-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
Total PFOS	ND		2.5	0.20	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
4:2 FTS	ND		1.0	0.27	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
6:2 FTS	ND		1.0	0.42	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
8:2 FTS	ND		1.0	0.10	ug/Kg		12/03/24 04:26	12/09/24 15:46	1
10:2 FTS	ND		1.0	0.10	ug/Kg		12/03/24 04:26	12/09/24 15:46	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*106*		*25 - 150*	*12/03/24 04:26*	*12/09/24 15:46*	*1*
13C5 PFPeA	*93*		*25 - 150*	*12/03/24 04:26*	*12/09/24 15:46*	*1*
13C2 PFHxA	*113*		*25 - 150*	*12/03/24 04:26*	*12/09/24 15:46*	*1*
13C4 PFHpA	*109*		*25 - 150*	*12/03/24 04:26*	*12/09/24 15:46*	*1*
13C4 PFOA	*96*		*25 - 150*	*12/03/24 04:26*	*12/09/24 15:46*	*1*
13C5 PFNA	*102*		*25 - 150*	*12/03/24 04:26*	*12/09/24 15:46*	*1*
13C2 PFDA	*107*		*25 - 150*	*12/03/24 04:26*	*12/09/24 15:46*	*1*
13C2 PFUnA	*95*		*25 - 150*	*12/03/24 04:26*	*12/09/24 15:46*	*1*
13C3 PFBS	*106*		*25 - 150*	*12/03/24 04:26*	*12/09/24 15:46*	*1*
18O2 PFHxS	*116*		*25 - 150*	*12/03/24 04:26*	*12/09/24 15:46*	*1*
13C4 PFOS	*103*		*25 - 150*	*12/03/24 04:26*	*12/09/24 15:46*	*1*
M2-4:2 FTS	*125*		*25 - 150*	*12/03/24 04:26*	*12/09/24 15:46*	*1*
M2-6:2 FTS	*136*		*25 - 150*	*12/03/24 04:26*	*12/09/24 15:46*	*1*
M2-8:2 FTS	*117*		*25 - 150*	*12/03/24 04:26*	*12/09/24 15:46*	*1*
13C2 10:2 FTS	*462*	**5+*	*25 - 150*	*12/03/24 04:26*	*12/09/24 15:46*	*1*

Lab Sample ID: LCS 320-818866/2-A
Matrix: Tissue
Analysis Batch: 820781

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 818866

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	10.0	10.3		ug/Kg		103	76 - 136
Perfluoropentanoic acid (PFPeA)	10.0	10.7		ug/Kg		107	69 - 129
Perfluorohexanoic acid (PFHxA)	10.0	9.88		ug/Kg		99	71 - 131
Perfluoroheptanoic acid (PFHpA)	10.0	10.2		ug/Kg		102	71 - 131
L-Perfluorooctanoic acid	10.0	9.61		ug/Kg		96	72 - 132

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-818866/2-A
Matrix: Tissue
Analysis Batch: 820781

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 818866

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits		
Total PFOA			10.0	9.61		ug/Kg		96			
Perfluorononanoic acid (PFNA)			10.0	9.22		ug/Kg		92	73 - 133		
Perfluorodecanoic acid (PFDA)			10.0	10.0		ug/Kg		100	72 - 132		
Perfluoroundecanoic acid (PFUnA)			10.0	8.81		ug/Kg		88	66 - 126		
Perfluorobutanesulfonic acid (PFBS)			8.88	8.43		ug/Kg		95	69 - 129		
Perfluoropentanesulfonic acid (PFPeS)			9.40	9.45		ug/Kg		101	66 - 126		
Total PFHxS			9.12	8.35		ug/Kg		92			
L-Perfluorohexanesulfonic acid			9.12	8.35		ug/Kg		92	62 - 122		
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.6		ug/Kg		111	76 - 136		
L-Perfluorooctanesulfonic acid			9.30	9.60		ug/Kg		103	68 - 141		
Total PFOS			9.30	9.60		ug/Kg		103			
4:2 FTS			9.38	10.0		ug/Kg		107	68 - 143		
6:2 FTS			9.52	10.5		ug/Kg		110	73 - 139		
8:2 FTS			9.60	9.36		ug/Kg		98	75 - 135		
10:2 FTS			9.66	8.93		ug/Kg		92	69 - 145		

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*104*		*25 - 150*
13C5 PFPeA	*94*		*25 - 150*
13C2 PFHxA	*111*		*25 - 150*
13C4 PFHpA	*103*		*25 - 150*
13C4 PFOA	*94*		*25 - 150*
13C5 PFNA	*100*		*25 - 150*
13C2 PFDA	*102*		*25 - 150*
13C2 PFUnA	*96*		*25 - 150*
13C3 PFBS	*106*		*25 - 150*
18O2 PFHxS	*104*		*25 - 150*
13C4 PFOS	*92*		*25 - 150*
M2-4:2 FTS	*117*		*25 - 150*
M2-6:2 FTS	*96*		*25 - 150*
M2-8:2 FTS	*118*		*25 - 150*
13C2 10:2 FTS	*504*	*5+	*25 - 150*

Lab Sample ID: LCSD 320-818866/3-A
Matrix: Tissue
Analysis Batch: 820781

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 818866

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)			10.0	9.41		ug/Kg		94	76 - 136	9	30
Perfluoropentanoic acid (PFPeA)			10.0	10.6		ug/Kg		106	69 - 129	1	30
Perfluorohexanoic acid (PFHxA)			10.0	9.52		ug/Kg		95	71 - 131	4	30
Perfluoroheptanoic acid (PFHpA)			10.0	9.90		ug/Kg		99	71 - 131	3	30
L-Perfluorooctanoic acid			10.0	9.48		ug/Kg		95	72 - 132	1	30
Total PFOA			10.0	9.48		ug/Kg		95		1	
Perfluorononanoic acid (PFNA)			10.0	9.21		ug/Kg		92	73 - 133	0	30
Perfluorodecanoic acid (PFDA)			10.0	9.98		ug/Kg		100	72 - 132	0	30

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCSD 320-818866/3-A
Matrix: Tissue
Analysis Batch: 820781

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 818866

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluoroundecanoic acid (PFUnA)			10.0	8.97		ug/Kg		90	66 - 126	2	30
Perfluorobutanesulfonic acid (PFBS)			8.88	8.79		ug/Kg		99	69 - 129	4	30
Perfluoropentanesulfonic acid (PFPeS)			9.40	8.80		ug/Kg		94	66 - 126	7	30
Total PFHxS			9.12	8.14		ug/Kg		89		3	
L-Perfluorohexanesulfonic acid			9.12	8.14		ug/Kg		89	62 - 122	3	30
Perfluoroheptanesulfonic acid (PFHpS)			9.54	11.2		ug/Kg		117	76 - 136	5	30
L-Perfluorooctanesulfonic acid			9.30	9.44		ug/Kg		101	68 - 141	2	30
Total PFOS			9.30	9.44		ug/Kg		101		2	
4:2 FTS			9.38	10.7		ug/Kg		114	68 - 143	6	30
6:2 FTS			9.52	8.58		ug/Kg		90	73 - 139	20	30
8:2 FTS			9.60	9.94		ug/Kg		104	75 - 135	6	30
10:2 FTS			9.66	9.46		ug/Kg		98	69 - 145	6	30

Isotope Dilution	*LCSD %Recovery*	*LCSD Qualifier*	*Limits*
13C4 PFBA	*117*		*25 - 150*
13C5 PFPeA	*103*		*25 - 150*
13C2 PFHxA	*122*		*25 - 150*
13C4 PFHpA	*112*		*25 - 150*
13C4 PFOA	*100*		*25 - 150*
13C5 PFNA	*110*		*25 - 150*
13C2 PFDA	*111*		*25 - 150*
13C2 PFUnA	*97*		*25 - 150*
13C3 PFBS	*109*		*25 - 150*
18O2 PFHxS	*112*		*25 - 150*
13C4 PFOS	*100*		*25 - 150*
M2-4:2 FTS	*127*		*25 - 150*
M2-6:2 FTS	*125*		*25 - 150*
M2-8:2 FTS	*111*		*25 - 150*
13C2 10:2 FTS	*497*	*5+	*25 - 150*

Lab Sample ID: MB 320-818987/1-A
Matrix: Tissue
Analysis Batch: 820056

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 818987

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.27	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
L-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Total PFOA	ND		1.0	0.20	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.10	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.27	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		12/03/24 12:06	12/06/24 15:53	1

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: MB 320-818987/1-A
Matrix: Tissue
Analysis Batch: 820056

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 818987

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Total PFHxS	ND		1.0	0.15	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
L-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Br-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Total PFOS	ND		2.5	0.20	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
4:2 FTS	ND		1.0	0.27	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
6:2 FTS	ND		1.0	0.42	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
8:2 FTS	ND		1.0	0.10	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
10:2 FTS	ND		1.0	0.10	ug/Kg		12/03/24 12:06	12/06/24 15:53	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*83*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C5 PFPeA	*72*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C2 PFHxA	*75*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C4 PFHpA	*84*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C4 PFOA	*84*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C5 PFNA	*84*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C2 PFDA	*86*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C2 PFUnA	*79*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C3 PFBS	*81*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
18O2 PFHxS	*92*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C4 PFOS	*76*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
M2-4:2 FTS	*57*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
M2-6:2 FTS	*68*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
M2-8:2 FTS	*62*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C2 10:2 FTS	*381*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*

Lab Sample ID: LCS 320-818987/2-A
Matrix: Tissue
Analysis Batch: 820056

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 818987

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	10.0	10.8		ug/Kg		108	76 - 136
Perfluoropentanoic acid (PFPeA)	10.0	8.77		ug/Kg		88	69 - 129
Perfluorohexanoic acid (PFHxA)	10.0	9.70		ug/Kg		97	71 - 131
Perfluoroheptanoic acid (PFHpA)	10.0	9.89		ug/Kg		99	71 - 131
L-Perfluorooctanoic acid	10.0	10.4		ug/Kg		104	72 - 132
Total PFOA	10.0	10.4		ug/Kg		104	
Perfluorononanoic acid (PFNA)	10.0	8.98		ug/Kg		90	73 - 133
Perfluorodecanoic acid (PFDA)	10.0	9.96		ug/Kg		100	72 - 132
Perfluoroundecanoic acid (PFUnA)	10.0	8.79		ug/Kg		88	66 - 126
Perfluorobutanesulfonic acid (PFBS)	8.88	8.84		ug/Kg		99	69 - 129

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-818987/2-A
Matrix: Tissue
Analysis Batch: 820056

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 818987

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits		
Perfluoropentanesulfonic acid (PFPeS)			9.40	8.32		ug/Kg		89	66 - 126		
Total PFHxS			9.12	8.45		ug/Kg		93			
L-Perfluorohexanesulfonic acid			9.12	8.45		ug/Kg		93	62 - 122		
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.2		ug/Kg		107	76 - 136		
L-Perfluorooctanesulfonic acid			9.30	9.10		ug/Kg		98	68 - 141		
Total PFOS			9.30	9.10		ug/Kg		98			
4:2 FTS			9.38	10.5		ug/Kg		112	68 - 143		
6:2 FTS			9.52	9.93		ug/Kg		104	73 - 139		
8:2 FTS			9.60	10.1		ug/Kg		105	75 - 135		
10:2 FTS			9.66	8.86		ug/Kg		92	69 - 145		

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*76*		*25 - 150*
13C5 PFPeA	*65*		*25 - 150*
13C2 PFHxA	*74*		*25 - 150*
13C4 PFHpA	*75*		*25 - 150*
13C4 PFOA	*64*		*25 - 150*
13C5 PFNA	*72*		*25 - 150*
13C2 PFDA	*70*		*25 - 150*
13C2 PFUnA	*65*		*25 - 150*
13C3 PFBS	*73*		*25 - 150*
18O2 PFHxS	*72*		*25 - 150*
13C4 PFOS	*69*		*25 - 150*
M2-4:2 FTS	*46*		*25 - 150*
M2-6:2 FTS	*57*		*25 - 150*
M2-8:2 FTS	*48*		*25 - 150*
13C2 10:2 FTS	*300*	**5+*	*25 - 150*

Lab Sample ID: LCSD 320-818987/3-A
Matrix: Tissue
Analysis Batch: 820056

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 818987

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)			10.0	10.9		ug/Kg		109	76 - 136	1	30
Perfluoropentanoic acid (PFPeA)			10.0	9.93		ug/Kg		99	69 - 129	12	30
Perfluorohexanoic acid (PFHxA)			10.0	10.0		ug/Kg		100	71 - 131	3	30
Perfluoroheptanoic acid (PFHpA)			10.0	10.9		ug/Kg		109	71 - 131	9	30
L-Perfluorooctanoic acid			10.0	10.7		ug/Kg		107	72 - 132	3	30
Total PFOA			10.0	10.7		ug/Kg		107		3	
Perfluorononanoic acid (PFNA)			10.0	9.79		ug/Kg		98	73 - 133	9	30
Perfluorodecanoic acid (PFDA)			10.0	11.0		ug/Kg		110	72 - 132	10	30
Perfluoroundecanoic acid (PFUnA)			10.0	9.40		ug/Kg		94	66 - 126	7	30
Perfluorobutanesulfonic acid (PFBS)			8.88	9.45		ug/Kg		106	69 - 129	7	30
Perfluoropentanesulfonic acid (PFPeS)			9.40	9.95		ug/Kg		106	66 - 126	18	30
Total PFHxS			9.12	8.51		ug/Kg		93		1	

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCSD 320-818987/3-A
Matrix: Tissue
Analysis Batch: 820056

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 818987

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
L-Perfluorohexanesulfonic acid			9.12	8.51		ug/Kg		93	62 - 122	1	30
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.9		ug/Kg		115	76 - 136	7	30
L-Perfluorooctanesulfonic acid			9.30	11.7		ug/Kg		126	68 - 141	25	30
Total PFOS			9.30	11.7		ug/Kg		126		25	
4:2 FTS			9.38	10.0		ug/Kg		107	68 - 143	4	30
6:2 FTS			9.52	10.1		ug/Kg		106	73 - 139	1	30
8:2 FTS			9.60	11.1		ug/Kg		115	75 - 135	9	30
10:2 FTS			9.66	10.0		ug/Kg		104	69 - 145	12	30

Isotope Dilution	*LCSD %Recovery*	*LCSD Qualifier*	*Limits*
13C4 PFBA	*87*		*25 - 150*
13C5 PFPeA	*87*		*25 - 150*
13C2 PFHxA	*91*		*25 - 150*
13C4 PFHpA	*87*		*25 - 150*
13C4 PFOA	*81*		*25 - 150*
13C5 PFNA	*89*		*25 - 150*
13C2 PFDA	*85*		*25 - 150*
13C2 PFUnA	*86*		*25 - 150*
13C3 PFBS	*83*		*25 - 150*
18O2 PFHxS	*95*		*25 - 150*
13C4 PFOS	*88*		*25 - 150*
M2-4:2 FTS	*65*		*25 - 150*
M2-6:2 FTS	*72*		*25 - 150*
M2-8:2 FTS	*62*		*25 - 150*
13C2 10:2 FTS	*419*	*5+	*25 - 150*

Lab Sample ID: MB 320-819252/1-A
Matrix: Tissue
Analysis Batch: 820782

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 819252

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.27	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
L-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Total PFOA	ND		1.0	0.20	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.10	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.27	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Total PFHxS	ND		1.0	0.15	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		12/04/24 11:48	12/09/24 23:31	1

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: MB 320-819252/1-A
Matrix: Tissue
Analysis Batch: 820782

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 819252

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Br-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Total PFOS	ND		2.5	0.20	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
4:2 FTS	ND		1.0	0.27	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
6:2 FTS	ND		1.0	0.42	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
8:2 FTS	ND		1.0	0.10	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
10:2 FTS	ND		1.0	0.10	ug/Kg		12/04/24 11:48	12/09/24 23:31	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*95*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C5 PFPeA	*79*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C2 PFHxA	*112*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C4 PFHpA	*94*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C4 PFOA	*87*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C5 PFNA	*92*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C2 PFDA	*96*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C2 PFUnA	*89*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C3 PFBS	*93*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
18O2 PFHxS	*103*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C4 PFOS	*100*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
M2-4:2 FTS	*69*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
M2-6:2 FTS	*101*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
M2-8:2 FTS	*82*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C2 10:2 FTS	*396*	**5+*	*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*

Lab Sample ID: LCS 320-819252/2-A
Matrix: Tissue
Analysis Batch: 820782

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 819252

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	10.0	10.0		ug/Kg		100	76 - 136
Perfluoropentanoic acid (PFPeA)	10.0	9.69		ug/Kg		97	69 - 129
Perfluorohexanoic acid (PFHxA)	10.0	9.60		ug/Kg		96	71 - 131
Perfluoroheptanoic acid (PFHpA)	10.0	10.1		ug/Kg		101	71 - 131
L-Perfluorooctanoic acid	10.0	10.4		ug/Kg		104	72 - 132
Total PFOA	10.0	10.4		ug/Kg		104	
Perfluorononanoic acid (PFNA)	10.0	8.90		ug/Kg		89	73 - 133
Perfluorodecanoic acid (PFDA)	10.0	9.88		ug/Kg		99	72 - 132
Perfluoroundecanoic acid (PFUnA)	10.0	8.72		ug/Kg		87	66 - 126
Perfluorobutanesulfonic acid (PFBS)	8.88	10.3		ug/Kg		116	69 - 129
Perfluoropentanesulfonic acid (PFPeS)	9.40	10.3		ug/Kg		109	66 - 126
Total PFHxS	9.12	8.09		ug/Kg		89	
L-Perfluorohexanesulfonic acid	9.12	8.09		ug/Kg		89	62 - 122
Perfluoroheptanesulfonic acid (PFHpS)	9.54	10.7		ug/Kg		112	76 - 136
L-Perfluorooctanesulfonic acid	9.30	9.35		ug/Kg		101	68 - 141
Total PFOS	9.30	9.35		ug/Kg		101	

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-819252/2-A
Matrix: Tissue
Analysis Batch: 820782

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 819252

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits		
4:2 FTS			9.38	9.41		ug/Kg		100	68 - 143		
6:2 FTS			9.52	9.13		ug/Kg		96	73 - 139		
8:2 FTS			9.60	10.7		ug/Kg		111	75 - 135		
10:2 FTS			9.66	8.51		ug/Kg		88	69 - 145		

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*87*		*25 - 150*
13C5 PFPeA	*82*		*25 - 150*
13C2 PFHxA	*87*		*25 - 150*
13C4 PFHpA	*91*		*25 - 150*
13C4 PFOA	*77*		*25 - 150*
13C5 PFNA	*87*		*25 - 150*
13C2 PFDA	*87*		*25 - 150*
13C2 PFUnA	*82*		*25 - 150*
13C3 PFBS	*73*		*25 - 150*
18O2 PFHxS	*98*		*25 - 150*
13C4 PFOS	*87*		*25 - 150*
M2-4:2 FTS	*87*		*25 - 150*
M2-6:2 FTS	*86*		*25 - 150*
M2-8:2 FTS	*72*		*25 - 150*
13C2 10:2 FTS	*351*	**5+*	*25 - 150*

Lab Sample ID: LCSD 320-819252/3-A
Matrix: Tissue
Analysis Batch: 820782

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 819252

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)			10.0	9.89		ug/Kg		99	76 - 136	1	30
Perfluoropentanoic acid (PFPeA)			10.0	10.1		ug/Kg		101	69 - 129	5	30
Perfluorohexanoic acid (PFHxA)			10.0	9.62		ug/Kg		96	71 - 131	0	30
Perfluoroheptanoic acid (PFHpA)			10.0	10.8		ug/Kg		108	71 - 131	7	30
L-Perfluorooctanoic acid			10.0	9.64		ug/Kg		96	72 - 132	7	30
Total PFOA			10.0	9.64		ug/Kg		96		7	
Perfluorononanoic acid (PFNA)			10.0	9.75		ug/Kg		98	73 - 133	9	30
Perfluorodecanoic acid (PFDA)			10.0	10.6		ug/Kg		106	72 - 132	7	30
Perfluoroundecanoic acid (PFUnA)			10.0	9.69		ug/Kg		97	66 - 126	11	30
Perfluorobutanesulfonic acid (PFBS)			8.88	9.07		ug/Kg		102	69 - 129	12	30
Perfluoropentanesulfonic acid (PFPeS)			9.40	10.1		ug/Kg		107	66 - 126	2	30
Total PFHxS			9.12	8.38		ug/Kg		92		4	
L-Perfluorohexanesulfonic acid			9.12	8.38		ug/Kg		92	62 - 122	4	30
Perfluoroheptanesulfonic acid (PFHpS)			9.54	11.0		ug/Kg		115	76 - 136	3	30
L-Perfluorooctanesulfonic acid			9.30	9.30		ug/Kg		100	68 - 141	1	30
Total PFOS			9.30	9.30		ug/Kg		100		1	
4:2 FTS			9.38	9.35		ug/Kg		100	68 - 143	1	30
6:2 FTS			9.52	9.42		ug/Kg		99	73 - 139	3	30
8:2 FTS			9.60	10.2		ug/Kg		106	75 - 135	5	30

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCSD 320-819252/3-A
Matrix: Tissue
Analysis Batch: 820782

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 819252

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
10:2 FTS			9.66	8.71		ug/Kg		90	69 - 145	2	30

Isotope Dilution	*LCSD %Recovery*	*LCSD Qualifier*	*Limits*
13C4 PFBA	*95*		*25 - 150*
13C5 PFPeA	*82*		*25 - 150*
13C2 PFHxA	*100*		*25 - 150*
13C4 PFHpA	*86*		*25 - 150*
13C4 PFOA	*85*		*25 - 150*
13C5 PFNA	*88*		*25 - 150*
13C2 PFDA	*89*		*25 - 150*
13C2 PFUnA	*83*		*25 - 150*
13C3 PFBS	*88*		*25 - 150*
18O2 PFHxS	*105*		*25 - 150*
13C4 PFOS	*89*		*25 - 150*
M2-4:2 FTS	*94*		*25 - 150*
M2-6:2 FTS	*91*		*25 - 150*
M2-8:2 FTS	*83*		*25 - 150*
13C2 10:2 FTS	*350*	*5+	*25 - 150*

Method: D2216-92 - Percent Moisture

Lab Sample ID: 320-117195-23 DU
Matrix: Solid
Analysis Batch: 819026

Client Sample ID: holloman wetland / MSB:DGR:3158
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier		DU Result	DU Qualifier	Unit	D			RPD	RPD Limit
Percent Moisture	56	H H3		57		%				0.4	20
Percent Solids	44	H H3		43		%				0.5	20

LCMS

Prep Batch: 817586

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-23	holloman wetland / MSB:DGR:3158	Total/NA	Solid	SHAKE	
320-117195-23 - DL	holloman wetland / MSB:DGR:3158	Total/NA	Solid	SHAKE	
320-117195-24	holloman S. Playa / MSB:DGR:3157	Total/NA	Solid	SHAKE	
320-117195-24 - DL	holloman S. Playa / MSB:DGR:3157	Total/NA	Solid	SHAKE	
MB 320-817586/1-A	Method Blank	Total/NA	Solid	SHAKE	
LCS 320-817586/2-A	Lab Control Sample	Total/NA	Solid	SHAKE	

Analysis Batch: 817947

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-23	holloman wetland / MSB:DGR:3158	Total/NA	Solid	B/L/T PFAS	817586
320-117195-24	holloman S. Playa / MSB:DGR:3157	Total/NA	Solid	B/L/T PFAS	817586
MB 320-817586/1-A	Method Blank	Total/NA	Solid	B/L/T PFAS	817586
LCS 320-817586/2-A	Lab Control Sample	Total/NA	Solid	B/L/T PFAS	817586

Analysis Batch: 818285

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-23 - DL	holloman wetland / MSB:DGR:3158	Total/NA	Solid	B/L/T PFAS	817586

Analysis Batch: 818692

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-24 - DL	holloman S. Playa / MSB:DGR:3157	Total/NA	Solid	B/L/T PFAS	817586

Pre Prep Batch: 818862

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-1	NK 19893 L / MSB:Mamm:61848	Total/NA	Tissue	In-House	
320-117195-2	NK 32079 L / MSB:Mamm:75616	Total/NA	Tissue	In-House	
320-117195-3	NK 32043 L / MSB:Mamm:75617	Total/NA	Tissue	In-House	
320-117195-4	NK 32074 L / MSB:Mamm:75618	Total/NA	Tissue	In-House	
320-117195-5	NK 32071 L / MSB:Mamm:75619	Total/NA	Tissue	In-House	
320-117195-6	NK 32039 L / MSB:Mamm:75620	Total/NA	Tissue	In-House	
320-117195-7	NK 10447 L / MSB:Mamm:87701	Total/NA	Tissue	In-House	
320-117195-8	NK 10444 L / MSB:Mamm:87702	Total/NA	Tissue	In-House	
320-117195-9	NK 10442 L / MSB:Mamm:89195	Total/NA	Tissue	In-House	
320-117195-10	NK 10446 L / MSB:Mamm:89187	Total/NA	Tissue	In-House	
320-117195-11	NK 40788 L / MSB:Mamm:89351	Total/NA	Tissue	In-House	
320-117195-12	NK 154469 M / MSB:Mamm:198472	Total/NA	Tissue	In-House	
320-117195-13	NK 180975 L / MSB:Mamm:1268357	Total/NA	Tissue	In-House	
320-117195-14	NK 303127 L / MSB:Mamm:326548	Total/NA	Tissue	In-House	
320-117195-15	NK 310003 L / MSB:Mamm:339709	Total/NA	Tissue	In-House	

Prep Batch: 818866

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-1	NK 19893 L / MSB:Mamm:61848	Total/NA	Tissue	SHAKE	818862
320-117195-2	NK 32079 L / MSB:Mamm:75616	Total/NA	Tissue	SHAKE	818862
320-117195-3	NK 32043 L / MSB:Mamm:75617	Total/NA	Tissue	SHAKE	818862
320-117195-4	NK 32074 L / MSB:Mamm:75618	Total/NA	Tissue	SHAKE	818862
320-117195-5	NK 32071 L / MSB:Mamm:75619	Total/NA	Tissue	SHAKE	818862
320-117195-6	NK 32039 L / MSB:Mamm:75620	Total/NA	Tissue	SHAKE	818862
320-117195-7	NK 10447 L / MSB:Mamm:87701	Total/NA	Tissue	SHAKE	818862
320-117195-8	NK 10444 L / MSB:Mamm:87702	Total/NA	Tissue	SHAKE	818862
320-117195-9	NK 10442 L / MSB:Mamm:89195	Total/NA	Tissue	SHAKE	818862

LCMS (Continued)

Prep Batch: 818866 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-10	NK 10446 L / MSB:Mamm:89187	Total/NA	Tissue	SHAKE	818862
320-117195-11	NK 40788 L / MSB:Mamm:89351	Total/NA	Tissue	SHAKE	818862
320-117195-12	NK 154469 M / MSB:Mamm:198472	Total/NA	Tissue	SHAKE	818862
320-117195-13	NK 180975 L / MSB:Mamm:1268357	Total/NA	Tissue	SHAKE	818862
320-117195-14	NK 303127 L / MSB:Mamm:326548	Total/NA	Tissue	SHAKE	818862
320-117195-15	NK 310003 L / MSB:Mamm:339709	Total/NA	Tissue	SHAKE	818862
MB 320-818866/1-A	Method Blank	Total/NA	Tissue	SHAKE	
LCS 320-818866/2-A	Lab Control Sample	Total/NA	Tissue	SHAKE	
LCSD 320-818866/3-A	Lab Control Sample Dup	Total/NA	Tissue	SHAKE	

Pre Prep Batch: 818986

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-16	Gambusia Wet 1 / MSB:DGR:3154_1	Total/NA	Tissue	In-House	
320-117195-17	Gambusia Wet 2 / MSB:DGR:3154_2	Total/NA	Tissue	In-House	
320-117195-18	Dragonfly wetland / MSB:DGR:3159	Total/NA	Tissue	In-House	

Prep Batch: 818987

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-18	Dragonfly wetland / MSB:DGR:3159	Total/NA	Tissue	SHAKE	818986
320-117195-19	Cattail N wet / MSB:DGR:3155_1	Total/NA	Tissue	SHAKE	819250
320-117195-20	Cattail N wet 2 / MSB:DGR:3155_2	Total/NA	Tissue	SHAKE	819250
MB 320-818987/1-A	Method Blank	Total/NA	Tissue	SHAKE	
LCS 320-818987/2-A	Lab Control Sample	Total/NA	Tissue	SHAKE	
LCSD 320-818987/3-A	Lab Control Sample Dup	Total/NA	Tissue	SHAKE	

Pre Prep Batch: 819250

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-19	Cattail N wet / MSB:DGR:3155_1	Total/NA	Tissue	In-House	
320-117195-20	Cattail N wet 2 / MSB:DGR:3155_2	Total/NA	Tissue	In-House	
320-117195-21	saltceder NE4-4 / MSB:DGR:3156	Total/NA	Tissue	In-House	
320-117195-22	Marsh fleabane / MSB:DGR:3153	Total/NA	Tissue	In-House	

Prep Batch: 819252

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-16	Gambusia Wet 1 / MSB:DGR:3154_1	Total/NA	Tissue	SHAKE	818986
320-117195-17	Gambusia Wet 2 / MSB:DGR:3154_2	Total/NA	Tissue	SHAKE	818986
320-117195-21	saltceder NE4-4 / MSB:DGR:3156	Total/NA	Tissue	SHAKE	819250
320-117195-22	Marsh fleabane / MSB:DGR:3153	Total/NA	Tissue	SHAKE	819250
MB 320-819252/1-A	Method Blank	Total/NA	Tissue	SHAKE	
LCS 320-819252/2-A	Lab Control Sample	Total/NA	Tissue	SHAKE	
LCSD 320-819252/3-A	Lab Control Sample Dup	Total/NA	Tissue	SHAKE	

Analysis Batch: 820056

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-18	Dragonfly wetland / MSB:DGR:3159	Total/NA	Tissue	B/L/T PFAS	818987
320-117195-19	Cattail N wet / MSB:DGR:3155_1	Total/NA	Tissue	B/L/T PFAS	818987
320-117195-20	Cattail N wet 2 / MSB:DGR:3155_2	Total/NA	Tissue	B/L/T PFAS	818987
MB 320-818987/1-A	Method Blank	Total/NA	Tissue	B/L/T PFAS	818987
LCS 320-818987/2-A	Lab Control Sample	Total/NA	Tissue	B/L/T PFAS	818987
LCSD 320-818987/3-A	Lab Control Sample Dup	Total/NA	Tissue	B/L/T PFAS	818987

LCMS

Analysis Batch: 820781

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-1	NK 19893 L / MSB:Mamm:61848	Total/NA	Tissue	B/L/T PFAS	818866
320-117195-2	NK 32079 L / MSB:Mamm:75616	Total/NA	Tissue	B/L/T PFAS	818866
320-117195-3	NK 32043 L / MSB:Mamm:75617	Total/NA	Tissue	B/L/T PFAS	818866
320-117195-4	NK 32074 L / MSB:Mamm:75618	Total/NA	Tissue	B/L/T PFAS	818866
320-117195-5	NK 32071 L / MSB:Mamm:75619	Total/NA	Tissue	B/L/T PFAS	818866
320-117195-6	NK 32039 L / MSB:Mamm:75620	Total/NA	Tissue	B/L/T PFAS	818866
320-117195-7	NK 10447 L / MSB:Mamm:87701	Total/NA	Tissue	B/L/T PFAS	818866
320-117195-8	NK 10444 L / MSB:Mamm:87702	Total/NA	Tissue	B/L/T PFAS	818866
320-117195-9	NK 10442 L / MSB:Mamm:89195	Total/NA	Tissue	B/L/T PFAS	818866
320-117195-10	NK 10446 L / MSB:Mamm:89187	Total/NA	Tissue	B/L/T PFAS	818866
320-117195-11	NK 40788 L / MSB:Mamm:89351	Total/NA	Tissue	B/L/T PFAS	818866
320-117195-12	NK 154469 M / MSB:Mamm:198472	Total/NA	Tissue	B/L/T PFAS	818866
320-117195-13	NK 180975 L / MSB:Mamm:1268357	Total/NA	Tissue	B/L/T PFAS	818866
320-117195-14	NK 303127 L / MSB:Mamm:326548	Total/NA	Tissue	B/L/T PFAS	818866
320-117195-15	NK 310003 L / MSB:Mamm:339709	Total/NA	Tissue	B/L/T PFAS	818866
MB 320-818866/1-A	Method Blank	Total/NA	Tissue	B/L/T PFAS	818866
LCS 320-818866/2-A	Lab Control Sample	Total/NA	Tissue	B/L/T PFAS	818866
LCSD 320-818866/3-A	Lab Control Sample Dup	Total/NA	Tissue	B/L/T PFAS	818866

Analysis Batch: 820782

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-16	Gambusia Wet 1 / MSB:DGR:3154_1	Total/NA	Tissue	B/L/T PFAS	819252
320-117195-21	saltceder NE4-4 / MSB:DGR:3156	Total/NA	Tissue	B/L/T PFAS	819252
320-117195-22	Marsh fleabane / MSB:DGR:3153	Total/NA	Tissue	B/L/T PFAS	819252
MB 320-819252/1-A	Method Blank	Total/NA	Tissue	B/L/T PFAS	819252
LCS 320-819252/2-A	Lab Control Sample	Total/NA	Tissue	B/L/T PFAS	819252
LCSD 320-819252/3-A	Lab Control Sample Dup	Total/NA	Tissue	B/L/T PFAS	819252

Analysis Batch: 821391

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-17	Gambusia Wet 2 / MSB:DGR:3154_2	Total/NA	Tissue	B/L/T PFAS	819252

General Chemistry

Analysis Batch: 819026

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117195-23	holloman wetland / MSB:DGR:3158	Total/NA	Solid	D2216-92	
320-117195-24	holloman S. Playa / MSB:DGR:3157	Total/NA	Solid	D2216-92	
320-117195-23 DU	holloman wetland / MSB:DGR:3158	Total/NA	Solid	D2216-92	

Lab Chronicle

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: NK 19893 L / MSB:Mamm:61848
Lab Sample ID: 320-117195-1
Date Collected: 05/11/89 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818862	12/03/24 04:16	R1T	EET SAC
Total/NA	Prep	SHAKE			0.91 g	10.0 mL	818866	12/03/24 04:26	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820781	12/09/24 16:44	S1C	EET SAC

Client Sample ID: NK 32079 L / MSB:Mamm:75616
Lab Sample ID: 320-117195-2
Date Collected: 07/17/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818862	12/03/24 04:16	R1T	EET SAC
Total/NA	Prep	SHAKE			0.39 g	10.0 mL	818866	12/03/24 04:26	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820781	12/09/24 17:03	S1C	EET SAC

Client Sample ID: NK 32043 L / MSB:Mamm:75617
Lab Sample ID: 320-117195-3
Date Collected: 06/12/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818862	12/03/24 04:16	R1T	EET SAC
Total/NA	Prep	SHAKE			0.54 g	10.0 mL	818866	12/03/24 04:26	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820781	12/09/24 17:23	S1C	EET SAC

Client Sample ID: NK 32074 L / MSB:Mamm:75618
Lab Sample ID: 320-117195-4
Date Collected: 07/16/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818862	12/03/24 04:16	R1T	EET SAC
Total/NA	Prep	SHAKE			0.45 g	10.0 mL	818866	12/03/24 04:26	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820781	12/09/24 17:42	S1C	EET SAC

Client Sample ID: NK 32071 L / MSB:Mamm:75619
Lab Sample ID: 320-117195-5
Date Collected: 07/16/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818862	12/03/24 04:16	R1T	EET SAC
Total/NA	Prep	SHAKE			0.08 g	10.0 mL	818866	12/03/24 04:26	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820781	12/09/24 18:01	S1C	EET SAC

Lab Chronicle

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: NK 32039 L / MSB:Mamm:75620
Lab Sample ID: 320-117195-6
Date Collected: 06/12/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818862	12/03/24 04:16	R1T	EET SAC
Total/NA	Prep	SHAKE			0.21 g	10.0 mL	818866	12/03/24 04:26	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820781	12/09/24 18:21	S1C	EET SAC

Client Sample ID: NK 10447 L / MSB:Mamm:87701
Lab Sample ID: 320-117195-7
Date Collected: 11/26/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818862	12/03/24 04:16	R1T	EET SAC
Total/NA	Prep	SHAKE			0.92 g	10.0 mL	818866	12/03/24 04:26	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820781	12/09/24 18:40	S1C	EET SAC

Client Sample ID: NK 10444 L / MSB:Mamm:87702
Lab Sample ID: 320-117195-8
Date Collected: 11/26/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818862	12/03/24 04:16	R1T	EET SAC
Total/NA	Prep	SHAKE			0.95 g	10.0 mL	818866	12/03/24 04:26	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820781	12/09/24 19:19	S1C	EET SAC

Client Sample ID: NK 10442 L / MSB:Mamm:89195
Lab Sample ID: 320-117195-9
Date Collected: 11/07/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818862	12/03/24 04:16	R1T	EET SAC
Total/NA	Prep	SHAKE			1.03 g	10.0 mL	818866	12/03/24 04:26	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820781	12/09/24 19:38	S1C	EET SAC

Client Sample ID: NK 10446 L / MSB:Mamm:89187
Lab Sample ID: 320-117195-10
Date Collected: 11/25/94 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818862	12/03/24 04:16	R1T	EET SAC
Total/NA	Prep	SHAKE			1.02 g	10.0 mL	818866	12/03/24 04:26	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820781	12/09/24 19:58	S1C	EET SAC

Lab Chronicle

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: NK 40788 L / MSB:Mamm:89351
Lab Sample ID: 320-117195-11
Date Collected: 06/18/97 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818862	12/03/24 04:16	R1T	EET SAC
Total/NA	Prep	SHAKE			0.52 g	10.0 mL	818866	12/03/24 04:26	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820781	12/09/24 20:17	S1C	EET SAC

Client Sample ID: NK 154469 M / MSB:Mamm:198472
Lab Sample ID: 320-117195-12
Date Collected: 05/21/08 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818862	12/03/24 04:16	R1T	EET SAC
Total/NA	Prep	SHAKE			0.93 g	10.0 mL	818866	12/03/24 04:26	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820781	12/09/24 20:37	S1C	EET SAC

Client Sample ID: NK 180975 L / MSB:Mamm:1268357
Lab Sample ID: 320-117195-13
Date Collected: 02/27/13 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818862	12/03/24 04:16	R1T	EET SAC
Total/NA	Prep	SHAKE			1.05 g	10.0 mL	818866	12/03/24 04:26	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820781	12/09/24 20:56	S1C	EET SAC

Client Sample ID: NK 303127 L / MSB:Mamm:326548
Lab Sample ID: 320-117195-14
Date Collected: 08/02/17 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818862	12/03/24 04:16	R1T	EET SAC
Total/NA	Prep	SHAKE			0.93 g	10.0 mL	818866	12/03/24 04:26	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820781	12/09/24 21:15	S1C	EET SAC

Client Sample ID: NK 310003 L / MSB:Mamm:339709
Lab Sample ID: 320-117195-15
Date Collected: 06/13/19 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818862	12/03/24 04:16	R1T	EET SAC
Total/NA	Prep	SHAKE			0.96 g	10.0 mL	818866	12/03/24 04:26	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820781	12/09/24 21:35	S1C	EET SAC

Client Sample ID: Gambusia Wet 1 / MSB:DGR:3154_1
Lab Sample ID: 320-117195-16

Date Collected: 10/02/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			1.11 g	10.0 mL	819252	12/04/24 11:48	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820782	12/10/24 00:30	P1P	EET SAC

Client Sample ID: Gambusia Wet 2 / MSB:DGR:3154_2
Lab Sample ID: 320-117195-17

Date Collected: 10/02/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.97 g	10.0 mL	819252	12/04/24 11:48	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821391	12/11/24 14:16	S1C	EET SAC

Client Sample ID: Dragonfly wetland / MSB:DGR:3159
Lab Sample ID: 320-117195-18

Date Collected: 10/02/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.18 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 23:39	P1R	EET SAC

Client Sample ID: Cattail N wet / MSB:DGR:3155_1
Lab Sample ID: 320-117195-19

Date Collected: 10/02/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	819250	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.39 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 23:00	P1R	EET SAC

Client Sample ID: Cattail N wet 2 / MSB:DGR:3155_2
Lab Sample ID: 320-117195-20

Date Collected: 10/02/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	819250	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.70 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 23:19	P1R	EET SAC

Lab Chronicle

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Client Sample ID: saltceder NE4-4 / MSB:DGR:3156
Lab Sample ID: 320-117195-21
Date Collected: 10/01/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	819250	12/04/24 11:42	ATB	EET SAC
Total/NA	Prep	SHAKE			0.56 g	10.0 mL	819252	12/04/24 11:48	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820782	12/10/24 01:08	P1P	EET SAC

Client Sample ID: Marsh fleabane / MSB:DGR:3153
Lab Sample ID: 320-117195-22
Date Collected: 10/02/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	819250	12/04/24 11:42	ATB	EET SAC
Total/NA	Prep	SHAKE			1.15 g	10.0 mL	819252	12/04/24 11:48	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820782	12/10/24 01:28	P1P	EET SAC

Client Sample ID: holloman wetland / MSB:DGR:3158
Lab Sample ID: 320-117195-23
Date Collected: 10/01/24 00:00
Matrix: Solid
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			5.43 g	10.0 mL	817586	11/25/24 04:16	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	817947	11/26/24 14:38	S1C	EET SAC
Total/NA	Prep	SHAKE	DL		5.43 g	10.0 mL	817586	11/25/24 04:16	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	20	1 mL	1 mL	818285	11/27/24 14:06	S1C	EET SAC
Total/NA	Analysis	D2216-92		1			819026	12/03/24 14:12	JCB	EET SAC

Client Sample ID: holloman S. Playa / MSB:DGR:3157
Lab Sample ID: 320-117195-24
Date Collected: 10/01/24 00:00
Matrix: Solid
Date Received: 11/21/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			5.49 g	10.0 mL	817586	11/25/24 04:16	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	817947	11/26/24 14:57	S1C	EET SAC
Total/NA	Prep	SHAKE	DL		5.49 g	10.0 mL	817586	11/25/24 04:16	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	818692	12/02/24 15:41	S1C	EET SAC
Total/NA	Analysis	D2216-92		1			819026	12/03/24 14:12	JCB	EET SAC

Laboratory References:
EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

Accreditation/Certification Summary

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Laboratory: Eurofins Sacramento

All accreditations/certifications held by this laboratory are listed. Not all accreditations/certifications are applicable to this report.

Authority	Program	Identification Number	Expiration Date
Alaska (UST)	State	17-020	02-20-27
ANAB	Dept. of Defense ELAP	L2468	01-20-27
ANAB	Dept. of Energy	L2468.01	01-20-27
ANAB	ISO/IEC 17025	L2468	01-20-27
Arizona	State	AZ0708	08-11-25
Arkansas DEQ	State	88-0691	05-18-25
California	State	2897	01-31-26
Colorado	State	CA00044	08-31-25
Florida	NELAP	E87570	06-30-25
Georgia	State	4040	01-29-25
Hawaii	State	Eurofins Sacramento	01-29-25
Illinois	NELAP	200060	03-31-25
Kansas	NELAP	E-10375	10-31-25
Louisiana	NELAP	01944	06-30-25
Louisiana (All)	NELAP	01944	06-30-25
Maine	State	CA00004	04-14-26
Michigan	State	9947	01-29-25
Minnesota	NELAP	2749448	12-31-25
Nevada	State	CA00044	07-31-25
New Hampshire	NELAP	2997	04-19-25
New Jersey	NELAP	CA005	06-30-25
New York	NELAP	11666	04-01-25
Ohio	State	41252	01-29-25
Oregon	NELAP	4040	01-29-25
Texas	NELAP	T104704399-23-17	05-31-25
US Fish & Wildlife	US Federal Programs	A22139	04-30-25
USDA	US Federal Programs	P330-18-00239	02-28-26
Utah	NELAP	CA000442023-16	02-28-25
Virginia	NELAP	460278	03-14-25
Washington	State	C581	05-05-25
West Virginia (DW)	State	9930C	01-31-25
Wisconsin	State	998204680	08-31-25
Wyoming	State Program	8TMS-L	01-28-19 *

* Accreditation/Certification renewal pending - accreditation/certification considered valid.

Method Summary

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Method	Method Description	Protocol	Laboratory
B/L/T PFAS	Branched, Linear and Total PFAS	EPA	EET SAC
D2216-92	Percent Moisture	ASTM	EET SAC
In-House	Tissue Preparation/Homgenization	NOAA	EET SAC
SHAKE	Shake Extraction with Ultrasonic Bath Extraction	SW846	EET SAC

Protocol References:

ASTM = ASTM International

EPA = US Environmental Protection Agency

NOAA = National Marine Fisheries Service, National Oceanic And Atmospheric Administration, Seattle, WA, November 1988

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

Sample Summary

Client: University of New Mexico
Job ID: 320-117195-1
Project/Site: UNM_PFAS in Tissue, Plant & Soil, Holloman

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
320-117195-1	NK 19893 L / MSB:Mamm:61848	Tissue	05/11/89 00:00	11/21/24 09:40
320-117195-2	NK 32079 L / MSB:Mamm:75616	Tissue	07/17/94 00:00	11/21/24 09:40
320-117195-3	NK 32043 L / MSB:Mamm:75617	Tissue	06/12/94 00:00	11/21/24 09:40
320-117195-4	NK 32074 L / MSB:Mamm:75618	Tissue	07/16/94 00:00	11/21/24 09:40
320-117195-5	NK 32071 L / MSB:Mamm:75619	Tissue	07/16/94 00:00	11/21/24 09:40
320-117195-6	NK 32039 L / MSB:Mamm:75620	Tissue	06/12/94 00:00	11/21/24 09:40
320-117195-7	NK 10447 L / MSB:Mamm:87701	Tissue	11/26/94 00:00	11/21/24 09:40
320-117195-8	NK 10444 L / MSB:Mamm:87702	Tissue	11/26/94 00:00	11/21/24 09:40
320-117195-9	NK 10442 L / MSB:Mamm:89195	Tissue	11/07/94 00:00	11/21/24 09:40
320-117195-10	NK 10446 L / MSB:Mamm:89187	Tissue	11/25/94 00:00	11/21/24 09:40
320-117195-11	NK 40788 L / MSB:Mamm:89351	Tissue	06/18/97 00:00	11/21/24 09:40
320-117195-12	NK 154469 M / MSB:Mamm:198472	Tissue	05/21/08 00:00	11/21/24 09:40
320-117195-13	NK 180975 L / MSB:Mamm:1268357	Tissue	02/27/13 00:00	11/21/24 09:40
320-117195-14	NK 303127 L / MSB:Mamm:326548	Tissue	08/02/17 00:00	11/21/24 09:40
320-117195-15	NK 310003 L / MSB:Mamm:339709	Tissue	06/13/19 00:00	11/21/24 09:40
320-117195-16	Gambusia Wet 1 / MSB:DGR:3154_1	Tissue	10/02/24 00:00	11/21/24 09:40
320-117195-17	Gambusia Wet 2 / MSB:DGR:3154_2	Tissue	10/02/24 00:00	11/21/24 09:40
320-117195-18	Dragonfly wetland / MSB:DGR:3159	Tissue	10/02/24 00:00	11/21/24 09:40
320-117195-19	Cattail N wet / MSB:DGR:3155_1	Tissue	10/02/24 00:00	11/21/24 09:40
320-117195-20	Cattail N wet 2 / MSB:DGR:3155_2	Tissue	10/02/24 00:00	11/21/24 09:40
320-117195-21	saltceder NE4-4 / MSB:DGR:3156	Tissue	10/01/24 00:00	11/21/24 09:40
320-117195-22	Marsh fleabane / MSB:DGR:3153	Tissue	10/02/24 00:00	11/21/24 09:40
320-117195-23	holloman wetland / MSB:DGR:3158	Solid	10/01/24 00:00	11/21/24 09:40
320-117195-24	holloman S. Playa / MSB:DGR:3157	Solid	10/01/24 00:00	11/21/24 09:40

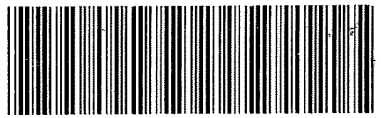
Eurofins Env. Testing Northern California
880 Riverside Parkway
West Sacramento, CA 95605
Phone: 916.373.5600

Chain of Custody Record

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Client Contact	Report To: Jean-Luc Cartron and Jon Dunnum	Site Contact:	Date: 11/18/2024	COC No:
	email: jlec@unm.edu, jldunnum@unm.edu	Lab Contact: Linda Laver	Carrier: FedEx	1 of 2 COCs
	Analysis Turnaround Time			Job No.
	Business Days (BD) _____			
	TAT if different from Above _____			Field Sampler
	☐ 2 weeks			
	☐ 1 week			
	☐ 2 days			
	☐ 1 day			

Sample Identification	Sample Date	Sample Time	Sample Type	Matrix	# of Cont.	Filtered Sample	Enter requested analyses in these fields	Sample Specific Notes:
NK 19893 L / MSB:Mamm:61848	11-May-89		Liver		1			Onychomys leucogaster 1989
NK 32079 L / MSB:Mamm:75616	17-Jul-94		Liver		1			Antrozous pallidus 1994
NK 32043 L / MSB:Mamm:75617	12-Jun-94		Liver		1			Antrozous pallidus 1994
NK 32074 L / MSB:Mamm:75618	16-Jul-94		Liver		1			Antrozous pallidus 1994
NK 32071 L / MSB:Mamm:75619	16-Jul-94		Liver		1			Myotis californicus - 1994
NK 32039 L / MSB:Mamm:75620	12-Jun-94		Liver		1			Myotis ciliolabrum - 1994
NK 10447 L /MSB:Mamm:87701	26-Nov-94		Liver		1			Neotoma micropus - 1994
NK 10444 L / MSB:Mamm:87702	26-Nov-94		Liver		1			Neotoma micropus 1994
NK 10442 L / MSB:Mamm:89195	7-Nov-94		Liver		1			Dipodomys merriami 1994
NK 10446 L / MSB:Mamm:89187	25-Nov-94		Liver		1			Dipodomys ordii- 1994
NK 40788 L / MSB:Mamm:89351	18-Jun-97		Liver		1			Sigmodon hispidus 1997
NK 154469 M / MSB:Mamm:198472	21-May-08		Liver		1			Canis latrans KAFB - 2008
NK 180975 L / MSB:Mamm:268357	27-Feb-13		Liver		1			Canis latrans KAFB 2013
NK 303127 L / MSB:Mamm:326548	2-Aug-17		Liver		1			Canis latrans KAFB 2017
NK 310003 L / MSB:Mamm:339709	13-Jun-19		Liver		1			Taxidea taxus KAFB 2019
Gambusia Wet 1 / MSB:DGR:3154_1	10/2/24		whole organism		1			Gambusia affinis
Gambusia Wet 2 / MSB:DGR:3154_2	10/2/24		whole organism		1			Gambusia affinis
Dragonfly wetland / MSB:DGR:3159	10/2/24		whole organism		1			Dragonfly (family Odonata)
Cattail N wet / MSB:DGR:3155_1	10/2/24		Plant tissue		1			Typha sp. (composite plant sample)
Cattail N wet 2 /MSB:DGR:3155_2	10/2/24		Plant tissue		1			Typha sp. (composite plant sample)
Saltcedar NE4-4 / MSB:DGR:3156	10/1/24		Plant tissue		1			Tamarix sp (composite plant sample)
Marsh fleabane / MSB:DGR:3153	10/2/24		Plant tissue		1			Pluchea odorata (composite plant sample)
Holloman wetland / MSB:DGR:3158	10/1/24		Soil/sediment		1			Soil at the edge of the wetland
Holloman S. Playa / MSB:DGR:3157	10/1/24		Soil/sediment		1			Soil sample from Playa downstream of Holloman Lake



Preservation Used: 1= Ice, 2= HCl; 3= H2SO4; 4=HNO3; 5=NaOH; 6= Other ___1=ice_____

Possible Hazard Identification
☒ Non-Hazard ☐ Flammable ☐ Skin Irritant Poison B Unknown ☐ ☐

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☐ Return To Client ☒ Disposal By Lab ☐ Archive For _____ Months

Special Instructions/QC Requirements & Comments:

Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:
				EUS	11/20/24 0942
Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:
Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:

Client emailed this CoC to be used to log in samples 11/20/24 (LCL)

12/23/2024

-23 9a

NMED Exhibits 65

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Sacramento Sample Receiving Notes (SSRN)

Loc: 320
117195

Tracking # 7700 8108 9118

Job _____

SO / (PO) / FO / SAT / 2-Day / Ground / UPS / CDO / Courier
GSL / OnTrac / Goldstreak / USPS / Other_____

Use this form to record Sample Custody Seal, Cooler Custody Seal, Temperature & corrected Temperature & other observations
File in the job folder with the COC

Therm ID C04 Corr Factor (+ / -) N/A °C

Ice_____ Wet_____ Gel _____ Other Dry Ice

Cooler Custody Seal: —

Cooler ID —

Temp Observed: -23.7 °C Corrected: -23.7 °C

From. Temp Blank ☐ Sandwich ☐ Sidewall ☐

Opening/Processing The Shipment	Yes	No	NA
Cooler compromised/tampered with?	☐	☒	☐
Cooler Temperature is acceptable?	☒	☐	☐
Frozen samples show signs of thaw?	☐	☒	☐

Initials SO Date 11/20/24

Unpacking/Labeling The Samples	Yes	No	NA
Containers are not broken or leaking?	☒	☐	☐
Samples compromised/tampered with?	☐	☒	☐
COC is complete w/o discrepancies	☒	☐	☐
Sample custody seal?	☐	☐	☒
Sample containers have legible labels?	☒	☐	☐
Sample date/times are provided?	☒	☐	☐
Appropriate containers are used?	☒	☐	☐
Sample bottles are completely filled?	☒	☐	☐
Sample preservatives verified?	☐	☐	☒
Is the Field Sampler's name on COC?	☐	☐	☒
Samples w/o discrepancies?	☒	☐	☐
Zero headspace?*	☐	☐	☒
Alkalinity has no headspace?	☐	☐	☒
Perchlorate has headspace? (Methods 314, 331, 6850)	☐	☐	☒
Multiphasic samples are not present?	☒	☐	☐

Containers requiring zero headspace have no headspace, or bubble < 6 mm (1/4")

Initials DM Date 11/21/24

Notes: _____

11/20/24

Trizma Lot #(s) _____

Ammonium Acetate Lot #(s) _____

Login Completion	Yes	No	NA
Receipt Temperature on COC?	☒	☐	☐
NCM Filed?	☒	☐	☐
Samples received within hold time?	☒	☐	☐
Log Release checked in TALS?	☒	☐	☐

Initials DM Date 11/21/24

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ANALYTICAL REPORT

PREPARED FOR

Attn: Jean-Luc Cartron
University of New Mexico
Museum of Southwestern Biology
Division of Mammals
CERIA Bldg 83, Room 204
Albuquerque, New Mexico 87131

Generated 12/23/2024 9:07:25 AM

JOB DESCRIPTION

UNM_PFAS in Tissue, Holloman

JOB NUMBER

320-117199-1

Eurofins Sacramento
880 Riverside Parkway
West Sacramento CA 95605

See page two for job notes and contact information.

NMED Exhibits 65

my EOL

Job Notes

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Authorization



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Definitions/Glossary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117199-1

Qualifiers

LCMS

Qualifier	Qualifier Description
*5+	Isotope dilution analyte is outside acceptance limits, high biased.
E	Result exceeded calibration range.
I	Value is EMPC (estimated maximum possible concentration).
J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
☼	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CFU	Colony Forming Unit
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MCL	EPA recommended "Maximum Contaminant Level"
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
MPN	Most Probable Number
MQL	Method Quantitation Limit
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
NEG	Negative / Absent
POS	Positive / Present
PQL	Practical Quantitation Limit
PRES	Presumptive
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)
TNTC	Too Numerous To Count

Job ID: 320-117199-1 — Eurofins Sacramento

Job Narrative
320-117199-1

Receipt
The samples were received on 11/20/2024 9:40 AM. Unless otherwise noted below, the samples arrived in good condition, and where required, properly preserved and on ice. The temperature of the cooler at receipt was -23.7º C.

Receipt Exceptions
Client emailed a Chain-of-Custody (COC) that was requested to be used for logging in the samples which had some revisions from the original COC shipped with the samples, Because the original COC was not signed at the time samples were relinquished, it was not included in this report.

Collection times were not provided. Samples were logged in with a default time of 00:00.

LCMS
Method B/L/T PFAS: Isotope Dilution Analyte (IDA) recovery is above the method recommended limit for some samples. Quantitation by isotope dilution generally precludes any adverse effect on data quality due to elevated IDA recoveries.

Method B/L/T PFAS: The "I" qualifier means the transition mass ratio for the indicated analyte was outside the established ratio limits. The qualitative identification of the analyte has some degree of uncertainty.

Method B/L/T PFAS: The concentration of one or more analytes associated with the following samples exceeded the instrument calibration range: NK 311147 liver (320-117199-1), NK 311147 (320-117199-2), NK 311147 bone (320-117199-3), NK 311148 liver (320-117199-4), NK 311148 (320-117199-5), NK 311148 bone (320-117199-6), NK 311149 liver (320-117199-7), NK 311149 (320-117199-8), NK 311149 bone (320-117199-9), NK 311150 liver (320-117199-10), NK 311150 (320-117199-11), NK 311152 liver (320-117199-13), NK 311153 (320-117199-15) and NK 311154 liver (320-117199-16) These analytes have been qualified; however, the peak(s) did not saturate the instrument detector. Historical data indicate that for the isotope dilution method, dilution and re-analysis will not produce significantly different results from those reported above the calibration range

Method B/L/T PFAS: Some results for the following samples were reported from the analysis of a diluted extract due to high concentration of the target analyte in the analysis of the undiluted extract. The dilution factor was applied to the labeled internal standard area counts and these area counts were within acceptance limits. NK 311147 liver (320-117199-1), NK 311148 liver (320-117199-4), NK 311149 liver (320-117199-7), NK 311150 liver (320-117199-10), NK 311150 (320-117199-11), NK 311151 (320-117199-12), NK 311152 liver (320-117199-13), NK 311154 liver (320-117199-16) and NK 311154 (320-117199-17)

Method B/L/T PFAS: Some results for the following sample were reported from the analysis of a diluted extract due to high concentration of the target analyte in the analysis of the undiluted extract. The dilution factor was applied to the labeled internal standard area counts and these area counts were outside acceptance limits. The internal standard is not used to quantitate any target analytes; therefore, the data have been reported. NK 311152 (320-117199-14)

Method B/L/T PFAS: The internal standard recovery of 13C2 PFOA was outside control limits in samples NK 311149 liver (320-117199-7) and NK 311150 liver (320-117199-10). Re-analysis confirms the out of control recovery. The internal standard is not used to quantitate any target analytes, therefore, the data have been reported NK 311149 liver (320-117199-7) and NK 311150 liver (320-117199-10)

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Organic Prep
Method SHAKE: Insufficient sample volume was available to perform a matrix spike/matrix spike duplicate (MS/MSD) associated with preparation batch 320-818987.

Method SHAKE: Elevated reporting limits are provided for the following sample due to limited sample provided for extraction: NK 311147 liver (320-117199-1), NK 311147 bone (320-117199-3), NK 311148 liver (320-117199-4), NK 311148 bone (320-117199-6), NK 311149 liver (320-117199-7), NK 311149 bone (320-117199-9), NK 311150 liver (320-117199-10), NK 311152 liver (320-117199-13), NK 311153 (320-117199-15) and NK 311154 liver (320-117199-16).

Method SHAKE: The following samples were discolored following extraction: NK 311147 liver (320-117199-1), NK 311148 liver (320-117199-4) and NK 311150 (320-117199-11).

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Detection Summary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117199-1

Client Sample ID: NK 311147 liver — Lab Sample ID: 320-117199-1

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.66	J	2.2	0.44	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.66	J	2.2	0.44	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	92		2.2	0.38	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	45		2.2	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	4.7		2.2	0.59	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	32		2.2	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS - DL	360		220	32	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	360		220	32	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	650		220	40	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	57000	E	540	44	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	37000	E	540	44	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	94000		540	44	ug/Kg	100		B/L/T PFAS	Total/NA
10:2 FTS - RA	0.35	J	2.2	0.22	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 311147 — Lab Sample ID: 320-117199-2

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.19	J	0.84	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.19	J	0.84	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	1.2		0.84	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.3		0.84	0.087	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	21		0.84	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	21		0.84	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	21		0.84	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	1600	E	2.1	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	540	E	2.1	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	2100		2.1	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.42	J	0.84	0.084	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 311147 bone — Lab Sample ID: 320-117199-3

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	0.79	J	3.4	0.60	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.64	J	3.4	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	22		3.4	0.51	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	22		3.4	0.51	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	16		3.4	0.64	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	810	E	8.6	0.70	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	260		8.6	0.70	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	1100		8.6	0.70	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 311148 liver — Lab Sample ID: 320-117199-4

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	26		1.9	0.32	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	37		1.9	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	4.1		1.9	0.50	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.96	J	1.9	0.79	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	31		1.9	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS - DL	220		190	27	ug/Kg	100		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Eurofins Sacramento

Client Sample ID: NK 311148 liver (Continued) — Lab Sample ID: 320-117199-4

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorohexanesulfonic acid - DL	220		190	27	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	330		190	34	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	44000	E	460	38	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	21000	E	460	38	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	65000		460	38	ug/Kg	100		B/L/T PFAS	Total/NA

Client Sample ID: NK 311148 — Lab Sample ID: 320-117199-5

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorohexanoic acid (PFHxA)	0.34	J I	0.92	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.92		0.92	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.1		0.92	0.094	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	38		0.92	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	38		0.92	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	23		0.92	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	1200	E	2.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	480	E	2.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	1700		2.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.48	J	0.92	0.092	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 311148 bone — Lab Sample ID: 320-117199-6

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	0.91	J	3.8	0.67	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.97	J	3.8	0.40	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	45		3.8	0.57	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	45		3.8	0.57	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	27		3.8	0.71	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	1000	E	9.6	0.78	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	360	E	9.6	0.78	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	1400		9.6	0.78	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 311149 liver — Lab Sample ID: 320-117199-7

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.53	J	2.3	0.47	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.53	J	2.3	0.47	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	45		2.3	0.41	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	34		2.3	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	3.9		2.3	0.63	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	150		2.3	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	150		2.3	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	250		230	43	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	31000	E	580	47	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	15000		580	47	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS	46000		580	47	ug/Kg	100		B/L/T PFAS	Total/NA
8:2 FTS	15		2.3	0.23	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Detection Summary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117199-1

Client Sample ID: NK 311149 — Lab Sample ID: 320-117199-8

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	2.2		0.93	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.0		0.93	0.095	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	36		0.93	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	36		0.93	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	38		0.93	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	1500	E	2.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	710	E	2.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	2200		2.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.42	J	0.93	0.39	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.55	J	0.93	0.093	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 311149 bone — Lab Sample ID: 320-117199-9

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	2.3	J	3.6	0.63	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.1	J	3.6	0.37	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	55		3.6	0.53	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	55		3.6	0.53	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	49		3.6	0.66	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	1300	E	8.9	0.73	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	630	E	8.9	0.73	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	1900		8.9	0.73	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.43	J	3.6	0.36	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 311150 liver — Lab Sample ID: 320-117199-10

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	1.4	J	1.9	0.37	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.4	J	1.9	0.37	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	79		1.9	0.32	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	34		1.9	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	1.7	J	1.9	0.50	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	11		1.9	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.20	J	1.9	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS - DL	600		190	27	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	600		190	27	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	1400		190	34	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	76000	E	460	38	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	45000	E	460	38	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	120000		460	38	ug/Kg	100		B/L/T PFAS	Total/NA

Client Sample ID: NK 311150 — Lab Sample ID: 320-117199-11

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	3.2		0.92	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.4		0.92	0.094	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.41	J	0.92	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	110		0.92	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	110	E	0.92	0.14	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK 311150 (Continued) — Lab Sample ID: 320-117199-11

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanesulfonic acid (PFHpS)	110		92	17	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	4900		230	19	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	1400		230	19	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS	6300		230	19	ug/Kg	100		B/L/T PFAS	Total/NA
6:2 FTS	0.81	J	0.92	0.39	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.35	J	0.92	0.092	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 311151 — Lab Sample ID: 320-117199-12

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	2.7		1.0	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	2.7		1.0	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	5.0		1.0	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.2		1.0	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.22	J	1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	70		1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	69		1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	29		1.0	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.34	J	1.0	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	1500		130	11	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	460		130	11	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS - DL	2000		130	11	ug/Kg	50		B/L/T PFAS	Total/NA

Client Sample ID: NK 311152 liver — Lab Sample ID: 320-117199-13

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.53	J	2.7	0.47	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	1.1	J	2.7	0.74	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	3.0		2.7	0.55	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	3.0		2.7	0.55	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	40		2.7	0.47	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	34		2.7	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	2.3	J	2.7	0.74	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	2.6	J	2.7	1.1	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	16		2.7	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS - DL	350		270	40	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	350		270	40	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	870		270	50	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	62000	E	680	55	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	44000	E	680	55	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	110000		680	55	ug/Kg	100		B/L/T PFAS	Total/NA

Client Sample ID: NK 311152 — Lab Sample ID: 320-117199-14

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.26	J	0.83	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.26	J	0.83	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	1.1		0.83	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.1		0.83	0.086	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.62	J	0.83	0.12	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK 311152 (Continued) — Lab Sample ID: 320-117199-14

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Total PFHxS	67		0.83	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	67		0.83	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	66		42	7.7	ug/Kg	50		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	3100		100	8.5	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	1000		100	8.5	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS	4100		100	8.5	ug/Kg	50		B/L/T PFAS	Total/NA
6:2 FTS	0.43	J	0.83	0.35	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.51	J	0.83	0.083	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 311153 — Lab Sample ID: 320-117199-15

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanoic acid (PFHpA)	0.50	J	1.6	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	21		1.6	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	21		1.6	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	6.1		1.6	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	2.4		1.6	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	25		1.6	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	610		1.6	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	580	E	1.6	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	61		1.6	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	570	E	4.0	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	580	E	4.0	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	1100		4.0	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.16	J	1.6	0.16	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK 311154 liver — Lab Sample ID: 320-117199-16

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.64	J	1.8	0.32	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	1.1	J	1.8	0.50	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.24	J	1.8	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	3.5		1.8	0.37	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	3.5		1.8	0.37	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	70		1.8	0.32	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	47		1.8	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	3.4		1.8	0.49	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.37	J	1.8	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	8.7		1.8	0.77	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	23		1.8	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS - DL	360		180	27	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	360		180	27	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	520		180	34	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	41000	E	450	37	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	25000	E	450	37	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	66000		450	37	ug/Kg	100		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Detection Summary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117199-1

Client Sample ID: NK 311154

Lab Sample ID: 320-117199-17

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.18	J	0.76	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	0.25	J	0.76	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.25	J	0.76	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	2.2		0.76	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.8		0.76	0.078	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	1.1		0.76	0.32	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.62	J	0.76	0.076	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS - DL	93		76	11	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	93		76	11	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	73	J	76	14	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	3600		190	15	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	1100		190	15	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	4700		190	15	ug/Kg	100		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK 311147 liver
Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-1
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		2.2	0.51	ug/Kg		12/03/24 12:06	12/06/24 16:51	1
Perfluoropentanoic acid (PFPeA)	ND		2.2	0.38	ug/Kg		12/03/24 12:06	12/06/24 16:51	1
Perfluorohexanoic acid (PFHxA)	ND		2.2	0.59	ug/Kg		12/03/24 12:06	12/06/24 16:51	1
Perfluoroheptanoic acid (PFHpA)	ND		2.2	0.25	ug/Kg		12/03/24 12:06	12/06/24 16:51	1
L-Perfluorooctanoic acid	**0.66**	**J**	2.2	0.44	ug/Kg		12/03/24 12:06	12/06/24 16:51	1
Br-Perfluorooctanoic acid	ND		2.2	0.44	ug/Kg		12/03/24 12:06	12/06/24 16:51	1
Total PFOA	**0.66**	**J**	2.2	0.44	ug/Kg		12/03/24 12:06	12/06/24 16:51	1
Perfluorononanoic acid (PFNA)	**92**		2.2	0.38	ug/Kg		12/03/24 12:06	12/06/24 16:51	1
Perfluorodecanoic acid (PFDA)	**45**		2.2	0.22	ug/Kg		12/03/24 12:06	12/06/24 16:51	1
Perfluoroundecanoic acid (PFUnA)	**4.7**		2.2	0.59	ug/Kg		12/03/24 12:06	12/06/24 16:51	1
Perfluorobutanesulfonic acid (PFBS)	ND		2.2	0.37	ug/Kg		12/03/24 12:06	12/06/24 16:51	1
Perfluoropentanesulfonic acid (PFPeS)	ND		2.2	0.39	ug/Kg		12/03/24 12:06	12/06/24 16:51	1
4:2 FTS	ND		2.2	0.58	ug/Kg		12/03/24 12:06	12/06/24 16:51	1
6:2 FTS	ND		2.2	0.92	ug/Kg		12/03/24 12:06	12/06/24 16:51	1
8:2 FTS	**32**		2.2	0.22	ug/Kg		12/03/24 12:06	12/06/24 16:51	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*78*		*25 - 150*	*12/03/24 12:06*	*12/06/24 16:51*	*1*
13C5 PFPeA	*85*		*25 - 150*	*12/03/24 12:06*	*12/06/24 16:51*	*1*
13C2 PFHxA	*98*		*25 - 150*	*12/03/24 12:06*	*12/06/24 16:51*	*1*
13C4 PFHpA	*84*		*25 - 150*	*12/03/24 12:06*	*12/06/24 16:51*	*1*
13C4 PFOA	*75*		*25 - 150*	*12/03/24 12:06*	*12/06/24 16:51*	*1*
13C5 PFNA	*67*		*25 - 150*	*12/03/24 12:06*	*12/06/24 16:51*	*1*
13C2 PFDA	*80*		*25 - 150*	*12/03/24 12:06*	*12/06/24 16:51*	*1*
13C2 PFUnA	*75*		*25 - 150*	*12/03/24 12:06*	*12/06/24 16:51*	*1*
13C3 PFBS	*84*		*25 - 150*	*12/03/24 12:06*	*12/06/24 16:51*	*1*
M2-4:2 FTS	*74*		*25 - 150*	*12/03/24 12:06*	*12/06/24 16:51*	*1*
M2-6:2 FTS	*127*		*25 - 150*	*12/03/24 12:06*	*12/06/24 16:51*	*1*
M2-8:2 FTS	*60*		*25 - 150*	*12/03/24 12:06*	*12/06/24 16:51*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	ND		220	32	ug/Kg		12/03/24 12:06	12/10/24 18:17	100
Total PFHxS	**360**		220	32	ug/Kg		12/03/24 12:06	12/10/24 18:17	100
L-Perfluorohexanesulfonic acid	**360**		220	32	ug/Kg		12/03/24 12:06	12/10/24 18:17	100
Perfluoroheptanesulfonic acid (PFHpS)	**650**		220	40	ug/Kg		12/03/24 12:06	12/10/24 18:17	100
L-Perfluorooctanesulfonic acid	**57000**	**E**	540	44	ug/Kg		12/03/24 12:06	12/10/24 18:17	100
Br-Perfluorooctanesulfonic acid	**37000**	**E**	540	44	ug/Kg		12/03/24 12:06	12/10/24 18:17	100
Total PFOS	**94000**		540	44	ug/Kg		12/03/24 12:06	12/10/24 18:17	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*89*		*25 - 150*	*12/03/24 12:06*	*12/10/24 18:17*	*100*
13C4 PFOS	*65*		*25 - 150*	*12/03/24 12:06*	*12/10/24 18:17*	*100*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
10:2 FTS	**0.35**	**J**	2.2	0.22	ug/Kg		12/03/24 12:06	12/10/24 18:37	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C2 10:2 FTS	*174*	*5+*	*25 - 150*	*12/03/24 12:06*	*12/10/24 18:37*	*1*

Client Sample ID: NK 311147
Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-2
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.84	0.20	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
Perfluoropentanoic acid (PFPeA)	ND		0.84	0.15	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
Perfluorohexanoic acid (PFHxA)	ND		0.84	0.23	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
Perfluoroheptanoic acid (PFHpA)	ND		0.84	0.097	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
L-Perfluorooctanoic acid	**0.19**	**J**	0.84	0.17	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
Br-Perfluorooctanoic acid	ND		0.84	0.17	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
Total PFOA	**0.19**	**J**	0.84	0.17	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
Perfluorononanoic acid (PFNA)	**1.2**		0.84	0.15	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
Perfluorodecanoic acid (PFDA)	**1.3**		0.84	0.087	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
Perfluoroundecanoic acid (PFUnA)	ND		0.84	0.23	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.84	0.14	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.84	0.15	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
Br-Perfluorohexanesulfonic acid	ND		0.84	0.12	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
Total PFHxS	**21**		0.84	0.12	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
L-Perfluorohexanesulfonic acid	**21**		0.84	0.12	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
Perfluoroheptanesulfonic acid (PFHpS)	**21**		0.84	0.16	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
L-Perfluorooctanesulfonic acid	**1600**	**E**	2.1	0.17	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
Br-Perfluorooctanesulfonic acid	**540**	**E**	2.1	0.17	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
Total PFOS	**2100**		2.1	0.17	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
4:2 FTS	ND		0.84	0.22	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
6:2 FTS	ND		0.84	0.36	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
8:2 FTS	**0.42**	**J**	0.84	0.084	ug/Kg		12/03/24 12:06	12/06/24 17:10	1
10:2 FTS	ND		0.84	0.085	ug/Kg		12/03/24 12:06	12/06/24 17:10	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*77*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:10*	*1*
13C5 PFPeA	*73*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:10*	*1*
13C2 PFHxA	*77*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:10*	*1*
13C4 PFHpA	*73*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:10*	*1*
13C4 PFOA	*63*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:10*	*1*
13C5 PFNA	*70*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:10*	*1*
13C2 PFDA	*72*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:10*	*1*
13C2 PFUnA	*70*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:10*	*1*
13C3 PFBS	*67*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:10*	*1*
18O2 PFHxS	*78*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:10*	*1*
13C4 PFOS	*51*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:10*	*1*
M2-4:2 FTS	*53*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:10*	*1*
M2-6:2 FTS	*62*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:10*	*1*
M2-8:2 FTS	*50*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:10*	*1*
13C2 10:2 FTS	*177*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 17:10*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117199-1

Client Sample ID: NK 311147 bone
Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-3
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		3.4	0.81	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
Perfluoropentanoic acid (PFPeA)	ND		3.4	0.60	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
Perfluorohexanoic acid (PFHxA)	ND		3.4	0.94	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
Perfluoroheptanoic acid (PFHpA)	ND		3.4	0.40	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
L-Perfluorooctanoic acid	ND		3.4	0.70	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
Br-Perfluorooctanoic acid	ND		3.4	0.70	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
Total PFOA	ND		3.4	0.70	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
Perfluorononanoic acid (PFNA)	**0.79**	**J**	3.4	0.60	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
Perfluorodecanoic acid (PFDA)	**0.64**	**J**	3.4	0.36	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
Perfluoroundecanoic acid (PFUnA)	ND		3.4	0.94	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
Perfluorobutanesulfonic acid (PFBS)	ND		3.4	0.59	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
Perfluoropentanesulfonic acid (PFPeS)	ND		3.4	0.62	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
Br-Perfluorohexanesulfonic acid	ND		3.4	0.51	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
Total PFHxS	**22**		3.4	0.51	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
L-Perfluorohexanesulfonic acid	**22**		3.4	0.51	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
Perfluoroheptanesulfonic acid (PFHpS)	**16**		3.4	0.64	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
L-Perfluorooctanesulfonic acid	**810**	**E**	8.6	0.70	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
Br-Perfluorooctanesulfonic acid	**260**		8.6	0.70	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
Total PFOS	**1100**		8.6	0.70	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
4:2 FTS	ND		3.4	0.92	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
6:2 FTS	ND		3.4	1.5	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
8:2 FTS	ND		3.4	0.34	ug/Kg		12/03/24 12:06	12/06/24 17:30	1
10:2 FTS	ND		3.4	0.35	ug/Kg		12/03/24 12:06	12/06/24 17:30	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*103*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:30*	*1*
13C5 PFPeA	*87*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:30*	*1*
13C2 PFHxA	*92*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:30*	*1*
13C4 PFHpA	*98*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:30*	*1*
13C4 PFOA	*84*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:30*	*1*
13C5 PFNA	*92*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:30*	*1*
13C2 PFDA	*88*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:30*	*1*
13C2 PFUnA	*75*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:30*	*1*
13C3 PFBS	*92*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:30*	*1*
18O2 PFHxS	*97*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:30*	*1*
13C4 PFOS	*79*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:30*	*1*
M2-4:2 FTS	*64*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:30*	*1*
M2-6:2 FTS	*71*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:30*	*1*
M2-8:2 FTS	*60*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:30*	*1*
13C2 10:2 FTS	*123*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:30*	*1*

Client Sample ID: NK 311148 liver
Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-4
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.9	0.44	ug/Kg		12/03/24 12:06	12/06/24 17:49	1
Perfluoropentanoic acid (PFPeA)	ND		1.9	0.32	ug/Kg		12/03/24 12:06	12/06/24 17:49	1
Perfluorohexanoic acid (PFHxA)	ND		1.9	0.51	ug/Kg		12/03/24 12:06	12/06/24 17:49	1
Perfluoroheptanoic acid (PFHpA)	ND		1.9	0.21	ug/Kg		12/03/24 12:06	12/06/24 17:49	1
L-Perfluorooctanoic acid	ND		1.9	0.37	ug/Kg		12/03/24 12:06	12/06/24 17:49	1
Br-Perfluorooctanoic acid	ND		1.9	0.37	ug/Kg		12/03/24 12:06	12/06/24 17:49	1
Total PFOA	ND		1.9	0.37	ug/Kg		12/03/24 12:06	12/06/24 17:49	1
Perfluorononanoic acid (PFNA)	**26**		1.9	0.32	ug/Kg		12/03/24 12:06	12/06/24 17:49	1
Perfluorodecanoic acid (PFDA)	**37**		1.9	0.19	ug/Kg		12/03/24 12:06	12/06/24 17:49	1
Perfluoroundecanoic acid (PFUnA)	**4.1**		1.9	0.50	ug/Kg		12/03/24 12:06	12/06/24 17:49	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.9	0.31	ug/Kg		12/03/24 12:06	12/06/24 17:49	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.9	0.34	ug/Kg		12/03/24 12:06	12/06/24 17:49	1
4:2 FTS	ND		1.9	0.49	ug/Kg		12/03/24 12:06	12/06/24 17:49	1
6:2 FTS	**0.96**	**J**	1.9	0.79	ug/Kg		12/03/24 12:06	12/06/24 17:49	1
8:2 FTS	**31**		1.9	0.19	ug/Kg		12/03/24 12:06	12/06/24 17:49	1
10:2 FTS	ND		1.9	0.19	ug/Kg		12/03/24 12:06	12/06/24 17:49	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*91*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:49*	*1*
13C5 PFPeA	*99*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:49*	*1*
13C2 PFHxA	*113*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:49*	*1*
13C4 PFHpA	*99*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:49*	*1*
13C4 PFOA	*94*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:49*	*1*
13C5 PFNA	*82*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:49*	*1*
13C2 PFDA	*99*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:49*	*1*
13C2 PFUnA	*94*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:49*	*1*
13C3 PFBS	*97*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:49*	*1*
M2-4:2 FTS	*76*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:49*	*1*
M2-6:2 FTS	*157*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 17:49*	*1*
M2-8:2 FTS	*68*		*25 - 150*	*12/03/24 12:06*	*12/06/24 17:49*	*1*
13C2 10:2 FTS	*247*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 17:49*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	ND		190	27	ug/Kg		12/03/24 12:06	12/10/24 19:35	100
Total PFHxS	**220**		190	27	ug/Kg		12/03/24 12:06	12/10/24 19:35	100
L-Perfluorohexanesulfonic acid	**220**		190	27	ug/Kg		12/03/24 12:06	12/10/24 19:35	100
Perfluoroheptanesulfonic acid (PFHpS)	**330**		190	34	ug/Kg		12/03/24 12:06	12/10/24 19:35	100
L-Perfluorooctanesulfonic acid	**44000**	**E**	460	38	ug/Kg		12/03/24 12:06	12/10/24 19:35	100
Br-Perfluorooctanesulfonic acid	**21000**	**E**	460	38	ug/Kg		12/03/24 12:06	12/10/24 19:35	100
Total PFOS	**65000**		460	38	ug/Kg		12/03/24 12:06	12/10/24 19:35	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*107*		*25 - 150*	*12/03/24 12:06*	*12/10/24 19:35*	*100*
13C4 PFOS	*85*		*25 - 150*	*12/03/24 12:06*	*12/10/24 19:35*	*100*

Client Sample ID: NK 311148
Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-5
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.92	0.22	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
Perfluoropentanoic acid (PFPeA)	ND		0.92	0.16	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
Perfluorohexanoic acid (PFHxA)	**0.34**	**J I**	0.92	0.25	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
Perfluoroheptanoic acid (PFHpA)	ND		0.92	0.11	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
L-Perfluorooctanoic acid	ND		0.92	0.19	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
Br-Perfluorooctanoic acid	ND		0.92	0.19	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
Total PFOA	ND		0.92	0.19	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
Perfluorononanoic acid (PFNA)	**0.92**		0.92	0.16	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
Perfluorodecanoic acid (PFDA)	**1.1**		0.92	0.094	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
Perfluoroundecanoic acid (PFUnA)	ND		0.92	0.25	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.92	0.16	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.92	0.17	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
Br-Perfluorohexanesulfonic acid	ND		0.92	0.14	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
Total PFHxS	**38**		0.92	0.14	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
L-Perfluorohexanesulfonic acid	**38**		0.92	0.14	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
Perfluoroheptanesulfonic acid (PFHpS)	**23**		0.92	0.17	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
L-Perfluorooctanesulfonic acid	**1200**	**E**	2.3	0.19	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
Br-Perfluorooctanesulfonic acid	**480**	**E**	2.3	0.19	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
Total PFOS	**1700**		2.3	0.19	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
4:2 FTS	ND		0.92	0.24	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
6:2 FTS	ND		0.92	0.39	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
8:2 FTS	**0.48**	**J**	0.92	0.092	ug/Kg		12/03/24 12:06	12/06/24 18:09	1
10:2 FTS	ND		0.92	0.093	ug/Kg		12/03/24 12:06	12/06/24 18:09	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*72*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:09*	*1*
13C5 PFPeA	*70*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:09*	*1*
13C2 PFHxA	*75*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:09*	*1*
13C4 PFHpA	*69*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:09*	*1*
13C4 PFOA	*64*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:09*	*1*
13C5 PFNA	*68*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:09*	*1*
13C2 PFDA	*68*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:09*	*1*
13C2 PFUnA	*63*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:09*	*1*
13C3 PFBS	*61*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:09*	*1*
18O2 PFHxS	*70*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:09*	*1*
13C4 PFOS	*52*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:09*	*1*
M2-4:2 FTS	*48*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:09*	*1*
M2-6:2 FTS	*66*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:09*	*1*
M2-8:2 FTS	*45*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:09*	*1*
13C2 10:2 FTS	*134*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:09*	*1*

Client Sample ID: NK 311148 bone

Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-6

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		3.8	0.91	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
Perfluoropentanoic acid (PFPeA)	ND		3.8	0.67	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
Perfluorohexanoic acid (PFHxA)	ND		3.8	1.1	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
Perfluoroheptanoic acid (PFHpA)	ND		3.8	0.45	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
L-Perfluorooctanoic acid	ND		3.8	0.78	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
Br-Perfluorooctanoic acid	ND		3.8	0.78	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
Total PFOA	ND		3.8	0.78	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
Perfluorononanoic acid (PFNA)	**0.91**	**J**	3.8	0.67	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
Perfluorodecanoic acid (PFDA)	**0.97**	**J**	3.8	0.40	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
Perfluoroundecanoic acid (PFUnA)	ND		3.8	1.0	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
Perfluorobutanesulfonic acid (PFBS)	ND		3.8	0.65	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
Perfluoropentanesulfonic acid (PFPeS)	ND		3.8	0.70	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
Br-Perfluorohexanesulfonic acid	ND		3.8	0.57	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
Total PFHxS	**45**		3.8	0.57	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
L-Perfluorohexanesulfonic acid	**45**		3.8	0.57	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
Perfluoroheptanesulfonic acid (PFHpS)	**27**		3.8	0.71	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
L-Perfluorooctanesulfonic acid	**1000**	**E**	9.6	0.78	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
Br-Perfluorooctanesulfonic acid	**360**	**E**	9.6	0.78	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
Total PFOS	**1400**		9.6	0.78	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
4:2 FTS	ND		3.8	1.0	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
6:2 FTS	ND		3.8	1.6	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
8:2 FTS	ND		3.8	0.38	ug/Kg		12/03/24 12:06	12/06/24 18:28	1
10:2 FTS	ND		3.8	0.39	ug/Kg		12/03/24 12:06	12/06/24 18:28	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*127*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:28*	*1*
13C5 PFPeA	*116*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:28*	*1*
13C2 PFHxA	*116*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:28*	*1*
13C4 PFHpA	*115*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:28*	*1*
13C4 PFOA	*95*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:28*	*1*
13C5 PFNA	*108*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:28*	*1*
13C2 PFDA	*100*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:28*	*1*
13C2 PFUnA	*91*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:28*	*1*
13C3 PFBS	*100*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:28*	*1*
18O2 PFHxS	*123*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:28*	*1*
13C4 PFOS	*93*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:28*	*1*
M2-4:2 FTS	*82*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:28*	*1*
M2-6:2 FTS	*79*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:28*	*1*
M2-8:2 FTS	*65*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:28*	*1*
13C2 10:2 FTS	*126*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:28*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117199-1

Client Sample ID: NK 311149 liver
Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-7
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		2.3	0.55	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
Perfluoropentanoic acid (PFPeA)	ND		2.3	0.41	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
Perfluorohexanoic acid (PFHxA)	ND		2.3	0.63	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
Perfluoroheptanoic acid (PFHpA)	ND		2.3	0.27	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
L-Perfluorooctanoic acid	**0.53**	**J**	2.3	0.47	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
Br-Perfluorooctanoic acid	ND		2.3	0.47	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
Total PFOA	**0.53**	**J**	2.3	0.47	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
Perfluorononanoic acid (PFNA)	**45**		2.3	0.41	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
Perfluorodecanoic acid (PFDA)	**34**		2.3	0.24	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
Perfluoroundecanoic acid (PFUnA)	**3.9**		2.3	0.63	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
Perfluorobutanesulfonic acid (PFBS)	ND		2.3	0.40	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
Perfluoropentanesulfonic acid (PFPeS)	ND		2.3	0.42	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
Br-Perfluorohexanesulfonic acid	ND		2.3	0.34	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
Total PFHxS	**150**		2.3	0.34	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
L-Perfluorohexanesulfonic acid	**150**		2.3	0.34	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
Perfluoroheptanesulfonic acid (PFHpS)	**250**		230	43	ug/Kg		12/03/24 12:06	12/10/24 20:33	100
L-Perfluorooctanesulfonic acid	**31000**	**E**	580	47	ug/Kg		12/03/24 12:06	12/10/24 20:33	100
Br-Perfluorooctanesulfonic acid	**15000**		580	47	ug/Kg		12/03/24 12:06	12/10/24 20:33	100
Total PFOS	**46000**		580	47	ug/Kg		12/03/24 12:06	12/10/24 20:33	100
4:2 FTS	ND		2.3	0.62	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
6:2 FTS	ND		2.3	0.99	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
8:2 FTS	**15**		2.3	0.23	ug/Kg		12/03/24 12:06	12/06/24 18:47	1
10:2 FTS	ND		2.3	0.23	ug/Kg		12/03/24 12:06	12/06/24 18:47	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*63*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:47*	*1*
13C5 PFPeA	*60*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:47*	*1*
13C2 PFHxA	*66*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:47*	*1*
13C4 PFHpA	*60*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:47*	*1*
13C4 PFOA	*56*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:47*	*1*
13C5 PFNA	*58*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:47*	*1*
13C2 PFDA	*64*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:47*	*1*
13C2 PFUnA	*58*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:47*	*1*
13C3 PFBS	*60*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:47*	*1*
18O2 PFHxS	*64*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:47*	*1*
13C4 PFOS	*49*		*25 - 150*	*12/03/24 12:06*	*12/10/24 20:33*	*100*
M2-4:2 FTS	*48*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:47*	*1*
M2-6:2 FTS	*100*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:47*	*1*
M2-8:2 FTS	*44*		*25 - 150*	*12/03/24 12:06*	*12/06/24 18:47*	*1*
13C2 10:2 FTS	*158*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 18:47*	*1*

Client Sample ID: NK 311149

Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-8

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.93	0.22	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
Perfluoropentanoic acid (PFPeA)	ND		0.93	0.16	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
Perfluorohexanoic acid (PFHxA)	ND		0.93	0.25	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
Perfluoroheptanoic acid (PFHpA)	ND		0.93	0.11	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
L-Perfluorooctanoic acid	ND		0.93	0.19	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
Br-Perfluorooctanoic acid	ND		0.93	0.19	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
Total PFOA	ND		0.93	0.19	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
Perfluorononanoic acid (PFNA)	**2.2**		0.93	0.16	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
Perfluorodecanoic acid (PFDA)	**1.0**		0.93	0.095	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
Perfluoroundecanoic acid (PFUnA)	ND		0.93	0.25	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.93	0.16	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.93	0.17	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
Br-Perfluorohexanesulfonic acid	ND		0.93	0.14	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
Total PFHxS	**36**		0.93	0.14	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
L-Perfluorohexanesulfonic acid	**36**		0.93	0.14	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
Perfluoroheptanesulfonic acid (PFHpS)	**38**		0.93	0.17	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
L-Perfluorooctanesulfonic acid	**1500**	**E**	2.3	0.19	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
Br-Perfluorooctanesulfonic acid	**710**	**E**	2.3	0.19	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
Total PFOS	**2200**		2.3	0.19	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
4:2 FTS	ND		0.93	0.25	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
6:2 FTS	**0.42**	**J**	0.93	0.39	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
8:2 FTS	**0.55**	**J**	0.93	0.093	ug/Kg		12/03/24 12:06	12/06/24 19:26	1
10:2 FTS	ND		0.93	0.094	ug/Kg		12/03/24 12:06	12/06/24 19:26	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*57*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:26*	*1*
13C5 PFPeA	*53*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:26*	*1*
13C2 PFHxA	*55*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:26*	*1*
13C4 PFHpA	*54*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:26*	*1*
13C4 PFOA	*49*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:26*	*1*
13C5 PFNA	*53*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:26*	*1*
13C2 PFDA	*54*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:26*	*1*
13C2 PFUnA	*50*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:26*	*1*
13C3 PFBS	*51*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:26*	*1*
18O2 PFHxS	*57*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:26*	*1*
13C4 PFOS	*37*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:26*	*1*
M2-4:2 FTS	*37*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:26*	*1*
M2-6:2 FTS	*39*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:26*	*1*
M2-8:2 FTS	*35*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:26*	*1*
13C2 10:2 FTS	*58*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:26*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117199-1

Client Sample ID: NK 311149 bone
Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-9
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		3.6	0.84	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
Perfluoropentanoic acid (PFPeA)	ND		3.6	0.63	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
Perfluorohexanoic acid (PFHxA)	ND		3.6	0.98	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
Perfluoroheptanoic acid (PFHpA)	ND		3.6	0.41	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
L-Perfluorooctanoic acid	ND		3.6	0.72	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
Br-Perfluorooctanoic acid	ND		3.6	0.72	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
Total PFOA	ND		3.6	0.72	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
Perfluorononanoic acid (PFNA)	**2.3**	**J**	3.6	0.63	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
Perfluorodecanoic acid (PFDA)	**1.1**	**J**	3.6	0.37	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
Perfluoroundecanoic acid (PFUnA)	ND		3.6	0.97	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
Perfluorobutanesulfonic acid (PFBS)	ND		3.6	0.61	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
Perfluoropentanesulfonic acid (PFPeS)	ND		3.6	0.65	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
Br-Perfluorohexanesulfonic acid	ND		3.6	0.53	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
Total PFHxS	**55**		3.6	0.53	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
L-Perfluorohexanesulfonic acid	**55**		3.6	0.53	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
Perfluoroheptanesulfonic acid (PFHpS)	**49**		3.6	0.66	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
L-Perfluorooctanesulfonic acid	**1300**	**E**	8.9	0.73	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
Br-Perfluorooctanesulfonic acid	**630**	**E**	8.9	0.73	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
Total PFOS	**1900**		8.9	0.73	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
4:2 FTS	ND		3.6	0.95	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
6:2 FTS	ND		3.6	1.5	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
8:2 FTS	**0.43**	**J**	3.6	0.36	ug/Kg		12/03/24 12:06	12/06/24 19:46	1
10:2 FTS	ND		3.6	0.36	ug/Kg		12/03/24 12:06	12/06/24 19:46	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*100*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:46*	*1*
13C5 PFPeA	*81*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:46*	*1*
13C2 PFHxA	*88*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:46*	*1*
13C4 PFHpA	*90*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:46*	*1*
13C4 PFOA	*78*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:46*	*1*
13C5 PFNA	*83*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:46*	*1*
13C2 PFDA	*81*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:46*	*1*
13C2 PFUnA	*74*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:46*	*1*
13C3 PFBS	*75*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:46*	*1*
18O2 PFHxS	*94*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:46*	*1*
13C4 PFOS	*69*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:46*	*1*
M2-4:2 FTS	*52*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:46*	*1*
M2-6:2 FTS	*56*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:46*	*1*
M2-8:2 FTS	*52*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:46*	*1*
13C2 10:2 FTS	*93*		*25 - 150*	*12/03/24 12:06*	*12/06/24 19:46*	*1*

Client Sample ID: NK 311150 liver

Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-10

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.9	0.44	ug/Kg		12/03/24 12:06	12/06/24 20:05	1
Perfluoropentanoic acid (PFPeA)	ND		1.9	0.32	ug/Kg		12/03/24 12:06	12/06/24 20:05	1
Perfluorohexanoic acid (PFHxA)	ND		1.9	0.51	ug/Kg		12/03/24 12:06	12/06/24 20:05	1
Perfluoroheptanoic acid (PFHpA)	ND		1.9	0.21	ug/Kg		12/03/24 12:06	12/06/24 20:05	1
L-Perfluorooctanoic acid	**1.4**	**J**	1.9	0.37	ug/Kg		12/03/24 12:06	12/06/24 20:05	1
Br-Perfluorooctanoic acid	ND		1.9	0.37	ug/Kg		12/03/24 12:06	12/06/24 20:05	1
Total PFOA	**1.4**	**J**	1.9	0.37	ug/Kg		12/03/24 12:06	12/06/24 20:05	1
Perfluorononanoic acid (PFNA)	**79**		1.9	0.32	ug/Kg		12/03/24 12:06	12/06/24 20:05	1
Perfluorodecanoic acid (PFDA)	**34**		1.9	0.19	ug/Kg		12/03/24 12:06	12/06/24 20:05	1
Perfluoroundecanoic acid (PFUnA)	**1.7**	**J**	1.9	0.50	ug/Kg		12/03/24 12:06	12/06/24 20:05	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.9	0.31	ug/Kg		12/03/24 12:06	12/06/24 20:05	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.9	0.34	ug/Kg		12/03/24 12:06	12/06/24 20:05	1
4:2 FTS	ND		1.9	0.49	ug/Kg		12/03/24 12:06	12/06/24 20:05	1
6:2 FTS	ND		1.9	0.79	ug/Kg		12/03/24 12:06	12/06/24 20:05	1
8:2 FTS	**11**		1.9	0.19	ug/Kg		12/03/24 12:06	12/06/24 20:05	1
10:2 FTS	**0.20**	**J**	1.9	0.19	ug/Kg		12/03/24 12:06	12/06/24 20:05	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*76*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:05*	*1*
13C5 PFPeA	*83*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:05*	*1*
13C2 PFHxA	*94*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:05*	*1*
13C4 PFHpA	*84*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:05*	*1*
13C4 PFOA	*75*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:05*	*1*
13C5 PFNA	*65*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:05*	*1*
13C2 PFDA	*85*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:05*	*1*
13C2 PFUnA	*85*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:05*	*1*
13C3 PFBS	*75*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:05*	*1*
M2-4:2 FTS	*58*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:05*	*1*
M2-6:2 FTS	*124*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:05*	*1*
M2-8:2 FTS	*54*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:05*	*1*
13C2 10:2 FTS	*359*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 20:05*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	ND		190	27	ug/Kg		12/03/24 12:06	12/10/24 22:10	100
Total PFHxS	**600**		190	27	ug/Kg		12/03/24 12:06	12/10/24 22:10	100
L-Perfluorohexanesulfonic acid	**600**		190	27	ug/Kg		12/03/24 12:06	12/10/24 22:10	100
Perfluoroheptanesulfonic acid (PFHpS)	**1400**		190	34	ug/Kg		12/03/24 12:06	12/10/24 22:10	100
L-Perfluorooctanesulfonic acid	**76000**	**E**	460	38	ug/Kg		12/03/24 12:06	12/10/24 22:10	100
Br-Perfluorooctanesulfonic acid	**45000**	**E**	460	38	ug/Kg		12/03/24 12:06	12/10/24 22:10	100
Total PFOS	**120000**		460	38	ug/Kg		12/03/24 12:06	12/10/24 22:10	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*88*		*25 - 150*	*12/03/24 12:06*	*12/10/24 22:10*	*100*
13C4 PFOS	*68*		*25 - 150*	*12/03/24 12:06*	*12/10/24 22:10*	*100*

Client Sample ID: NK 311150

Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-11

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.92	0.22	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
Perfluoropentanoic acid (PFPeA)	ND		0.92	0.16	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
Perfluorohexanoic acid (PFHxA)	ND		0.92	0.25	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
Perfluoroheptanoic acid (PFHpA)	ND		0.92	0.11	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
L-Perfluorooctanoic acid	ND		0.92	0.19	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
Br-Perfluorooctanoic acid	ND		0.92	0.19	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
Total PFOA	ND		0.92	0.19	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
Perfluorononanoic acid (PFNA)	**3.2**		0.92	0.16	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
Perfluorodecanoic acid (PFDA)	**1.4**		0.92	0.094	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
Perfluoroundecanoic acid (PFUnA)	ND		0.92	0.25	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.92	0.16	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.92	0.17	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
Br-Perfluorohexanesulfonic acid	**0.41**	**J**	0.92	0.14	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
Total PFHxS	**110**		0.92	0.14	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
L-Perfluorohexanesulfonic acid	**110**	**E**	0.92	0.14	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
Perfluoroheptanesulfonic acid (PFHpS)	**110**		92	17	ug/Kg		12/03/24 12:06	12/10/24 22:49	100
L-Perfluorooctanesulfonic acid	**4900**		230	19	ug/Kg		12/03/24 12:06	12/10/24 22:49	100
Br-Perfluorooctanesulfonic acid	**1400**		230	19	ug/Kg		12/03/24 12:06	12/10/24 22:49	100
Total PFOS	**6300**		230	19	ug/Kg		12/03/24 12:06	12/10/24 22:49	100
4:2 FTS	ND		0.92	0.24	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
6:2 FTS	**0.81**	**J**	0.92	0.39	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
8:2 FTS	**0.35**	**J**	0.92	0.092	ug/Kg		12/03/24 12:06	12/06/24 20:24	1
10:2 FTS	ND		0.92	0.093	ug/Kg		12/03/24 12:06	12/06/24 20:24	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*80*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:24*	*1*
13C5 PFPeA	*79*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:24*	*1*
13C2 PFHxA	*80*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:24*	*1*
13C4 PFHpA	*76*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:24*	*1*
13C4 PFOA	*71*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:24*	*1*
13C5 PFNA	*70*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:24*	*1*
13C2 PFDA	*78*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:24*	*1*
13C2 PFUnA	*67*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:24*	*1*
13C3 PFBS	*64*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:24*	*1*
18O2 PFHxS	*75*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:24*	*1*
13C4 PFOS	*67*		*25 - 150*	*12/03/24 12:06*	*12/10/24 22:49*	*100*
M2-4:2 FTS	*57*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:24*	*1*
M2-6:2 FTS	*55*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:24*	*1*
M2-8:2 FTS	*51*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:24*	*1*
13C2 10:2 FTS	*275*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 20:24*	*1*

Client Sample ID: NK 311151
Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-12
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.25	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.28	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
L-Perfluorooctanoic acid	**2.7**		1.0	0.21	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
Br-Perfluorooctanoic acid	ND		1.0	0.21	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
Total PFOA	**2.7**		1.0	0.21	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
Perfluorononanoic acid (PFNA)	**5.0**		1.0	0.18	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
Perfluorodecanoic acid (PFDA)	**1.2**		1.0	0.11	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.28	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.18	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.19	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
Br-Perfluorohexanesulfonic acid	**0.22**	**J**	1.0	0.15	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
Total PFHxS	**70**		1.0	0.15	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
L-Perfluorohexanesulfonic acid	**69**		1.0	0.15	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
Perfluoroheptanesulfonic acid (PFHpS)	**29**		1.0	0.19	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
4:2 FTS	ND		1.0	0.28	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
6:2 FTS	ND		1.0	0.44	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
8:2 FTS	**0.34**	**J**	1.0	0.10	ug/Kg		12/03/24 12:06	12/06/24 20:44	1
10:2 FTS	ND		1.0	0.11	ug/Kg		12/03/24 12:06	12/06/24 20:44	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*71*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:44*	*1*
13C5 PFPeA	*78*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:44*	*1*
13C2 PFHxA	*88*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:44*	*1*
13C4 PFHpA	*80*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:44*	*1*
13C4 PFOA	*72*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:44*	*1*
13C5 PFNA	*72*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:44*	*1*
13C2 PFDA	*80*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:44*	*1*
13C2 PFUnA	*74*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:44*	*1*
13C3 PFBS	*80*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:44*	*1*
18O2 PFHxS	*85*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:44*	*1*
13C4 PFOS	*60*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:44*	*1*
M2-4:2 FTS	*56*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:44*	*1*
M2-6:2 FTS	*116*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:44*	*1*
M2-8:2 FTS	*52*		*25 - 150*	*12/03/24 12:06*	*12/06/24 20:44*	*1*
13C2 10:2 FTS	*225*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 20:44*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**1500**		130	11	ug/Kg		12/03/24 12:06	12/10/24 23:08	50
Br-Perfluorooctanesulfonic acid	**460**		130	11	ug/Kg		12/03/24 12:06	12/10/24 23:08	50
Total PFOS	**2000**		130	11	ug/Kg		12/03/24 12:06	12/10/24 23:08	50

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*80*		*25 - 150*	*12/03/24 12:06*	*12/10/24 23:08*	*50*

Client Sample ID: NK 311152 liver

Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-13

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		2.7	0.64	ug/Kg		12/03/24 12:06	12/06/24 21:03	1
Perfluoropentanoic acid (PFPeA)	**0.53**	**J**	2.7	0.47	ug/Kg		12/03/24 12:06	12/06/24 21:03	1
Perfluorohexanoic acid (PFHxA)	**1.1**	**J**	2.7	0.74	ug/Kg		12/03/24 12:06	12/06/24 21:03	1
Perfluoroheptanoic acid (PFHpA)	ND		2.7	0.31	ug/Kg		12/03/24 12:06	12/06/24 21:03	1
L-Perfluorooctanoic acid	**3.0**		2.7	0.55	ug/Kg		12/03/24 12:06	12/06/24 21:03	1
Br-Perfluorooctanoic acid	ND		2.7	0.55	ug/Kg		12/03/24 12:06	12/06/24 21:03	1
Total PFOA	**3.0**		2.7	0.55	ug/Kg		12/03/24 12:06	12/06/24 21:03	1
Perfluorononanoic acid (PFNA)	**40**		2.7	0.47	ug/Kg		12/03/24 12:06	12/06/24 21:03	1
Perfluorodecanoic acid (PFDA)	**34**		2.7	0.28	ug/Kg		12/03/24 12:06	12/06/24 21:03	1
Perfluoroundecanoic acid (PFUnA)	**2.3**	**J**	2.7	0.74	ug/Kg		12/03/24 12:06	12/06/24 21:03	1
Perfluorobutanesulfonic acid (PFBS)	ND		2.7	0.46	ug/Kg		12/03/24 12:06	12/06/24 21:03	1
Perfluoropentanesulfonic acid (PFPeS)	ND		2.7	0.49	ug/Kg		12/03/24 12:06	12/06/24 21:03	1
4:2 FTS	ND		2.7	0.72	ug/Kg		12/03/24 12:06	12/06/24 21:03	1
6:2 FTS	**2.6**	**J**	2.7	1.1	ug/Kg		12/03/24 12:06	12/06/24 21:03	1
8:2 FTS	**16**		2.7	0.27	ug/Kg		12/03/24 12:06	12/06/24 21:03	1
10:2 FTS	ND		2.7	0.27	ug/Kg		12/03/24 12:06	12/06/24 21:03	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*84*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:03*	*1*
13C5 PFPeA	*87*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:03*	*1*
13C2 PFHxA	*106*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:03*	*1*
13C4 PFHpA	*97*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:03*	*1*
13C4 PFOA	*77*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:03*	*1*
13C5 PFNA	*79*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:03*	*1*
13C2 PFDA	*92*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:03*	*1*
13C2 PFUnA	*79*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:03*	*1*
13C3 PFBS	*91*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:03*	*1*
M2-4:2 FTS	*89*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:03*	*1*
M2-6:2 FTS	*150*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:03*	*1*
M2-8:2 FTS	*66*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:03*	*1*
13C2 10:2 FTS	*178*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 21:03*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	ND		270	40	ug/Kg		12/03/24 12:06	12/10/24 23:28	100
Total PFHxS	**350**		270	40	ug/Kg		12/03/24 12:06	12/10/24 23:28	100
L-Perfluorohexanesulfonic acid	**350**		270	40	ug/Kg		12/03/24 12:06	12/10/24 23:28	100
Perfluoroheptanesulfonic acid (PFHpS)	**870**		270	50	ug/Kg		12/03/24 12:06	12/10/24 23:28	100
L-Perfluorooctanesulfonic acid	**62000**	**E**	680	55	ug/Kg		12/03/24 12:06	12/10/24 23:28	100
Br-Perfluorooctanesulfonic acid	**44000**	**E**	680	55	ug/Kg		12/03/24 12:06	12/10/24 23:28	100
Total PFOS	**110000**		680	55	ug/Kg		12/03/24 12:06	12/10/24 23:28	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*87*		*25 - 150*	*12/03/24 12:06*	*12/10/24 23:28*	*100*
13C4 PFOS	*76*		*25 - 150*	*12/03/24 12:06*	*12/10/24 23:28*	*100*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117199-1

Client Sample ID: NK 311152
Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-14
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.83	0.20	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
Perfluoropentanoic acid (PFPeA)	ND		0.83	0.15	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
Perfluorohexanoic acid (PFHxA)	ND		0.83	0.23	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
Perfluoroheptanoic acid (PFHpA)	ND		0.83	0.097	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
L-Perfluorooctanoic acid	**0.26**	**J**	0.83	0.17	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
Br-Perfluorooctanoic acid	ND		0.83	0.17	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
Total PFOA	**0.26**	**J**	0.83	0.17	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
Perfluorononanoic acid (PFNA)	**1.1**		0.83	0.15	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
Perfluorodecanoic acid (PFDA)	**1.1**		0.83	0.086	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
Perfluoroundecanoic acid (PFUnA)	ND		0.83	0.23	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.83	0.14	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.83	0.15	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
Br-Perfluorohexanesulfonic acid	**0.62**	**J**	0.83	0.12	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
Total PFHxS	**67**		0.83	0.12	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
L-Perfluorohexanesulfonic acid	**67**		0.83	0.12	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
Perfluoroheptanesulfonic acid (PFHpS)	**66**		42	7.7	ug/Kg		12/03/24 12:06	12/10/24 23:47	50
L-Perfluorooctanesulfonic acid	**3100**		100	8.5	ug/Kg		12/03/24 12:06	12/10/24 23:47	50
Br-Perfluorooctanesulfonic acid	**1000**		100	8.5	ug/Kg		12/03/24 12:06	12/10/24 23:47	50
Total PFOS	**4100**		100	8.5	ug/Kg		12/03/24 12:06	12/10/24 23:47	50
4:2 FTS	ND		0.83	0.22	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
6:2 FTS	**0.43**	**J**	0.83	0.35	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
8:2 FTS	**0.51**	**J**	0.83	0.083	ug/Kg		12/03/24 12:06	12/06/24 21:23	1
10:2 FTS	ND		0.83	0.084	ug/Kg		12/03/24 12:06	12/06/24 21:23	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*72*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:23*	*1*
13C5 PFPeA	*62*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:23*	*1*
13C2 PFHxA	*60*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:23*	*1*
13C4 PFHpA	*69*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:23*	*1*
13C4 PFOA	*63*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:23*	*1*
13C5 PFNA	*61*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:23*	*1*
13C2 PFDA	*66*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:23*	*1*
13C2 PFUnA	*64*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:23*	*1*
13C3 PFBS	*63*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:23*	*1*
18O2 PFHxS	*69*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:23*	*1*
13C4 PFOS	*43*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:23*	*1*
13C4 PFOS	*66*		*25 - 150*	*12/03/24 12:06*	*12/10/24 23:47*	*50*
M2-4:2 FTS	*40*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:23*	*1*
M2-6:2 FTS	*55*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:23*	*1*
M2-8:2 FTS	*41*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:23*	*1*
13C2 10:2 FTS	*233*	*5+	*25 - 150*	*12/03/24 12:06*	*12/06/24 21:23*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117199-1

Client Sample ID: NK 311153
Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-15
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.6	0.38	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
Perfluoropentanoic acid (PFPeA)	ND		1.6	0.28	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
Perfluorohexanoic acid (PFHxA)	ND		1.6	0.44	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
Perfluoroheptanoic acid (PFHpA)	**0.50**	**J**	1.6	0.19	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
L-Perfluorooctanoic acid	**21**		1.6	0.33	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
Br-Perfluorooctanoic acid	ND		1.6	0.33	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
Total PFOA	**21**		1.6	0.33	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
Perfluorononanoic acid (PFNA)	**6.1**		1.6	0.28	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
Perfluorodecanoic acid (PFDA)	ND		1.6	0.17	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
Perfluoroundecanoic acid (PFUnA)	ND		1.6	0.44	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.6	0.27	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
Perfluoropentanesulfonic acid (PFPeS)	**2.4**		1.6	0.29	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
Br-Perfluorohexanesulfonic acid	**25**		1.6	0.24	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
Total PFHxS	**610**		1.6	0.24	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
L-Perfluorohexanesulfonic acid	**580**	**E**	1.6	0.24	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
Perfluoroheptanesulfonic acid (PFHpS)	**61**		1.6	0.30	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
L-Perfluorooctanesulfonic acid	**570**	**E**	4.0	0.33	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
Br-Perfluorooctanesulfonic acid	**580**	**E**	4.0	0.33	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
Total PFOS	**1100**		4.0	0.33	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
4:2 FTS	ND		1.6	0.43	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
6:2 FTS	ND		1.6	0.68	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
8:2 FTS	ND		1.6	0.16	ug/Kg		12/03/24 12:06	12/06/24 21:42	1
10:2 FTS	**0.16**	**J**	1.6	0.16	ug/Kg		12/03/24 12:06	12/06/24 21:42	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*109*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:42*	*1*
13C5 PFPeA	*90*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:42*	*1*
13C2 PFHxA	*104*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:42*	*1*
13C4 PFHpA	*100*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:42*	*1*
13C4 PFOA	*88*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:42*	*1*
13C5 PFNA	*95*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:42*	*1*
13C2 PFDA	*94*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:42*	*1*
13C2 PFUnA	*94*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:42*	*1*
13C3 PFBS	*91*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:42*	*1*
18O2 PFHxS	*95*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:42*	*1*
13C4 PFOS	*84*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:42*	*1*
M2-4:2 FTS	*57*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:42*	*1*
M2-6:2 FTS	*80*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:42*	*1*
M2-8:2 FTS	*63*		*25 - 150*	*12/03/24 12:06*	*12/06/24 21:42*	*1*
13C2 10:2 FTS	*182*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 21:42*	*1*

Client Sample ID: NK 311154 liver

Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-16

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.8	0.43	ug/Kg		12/03/24 12:06	12/06/24 22:01	1
Perfluoropentanoic acid (PFPeA)	**0.64**	**J**	1.8	0.32	ug/Kg		12/03/24 12:06	12/06/24 22:01	1
Perfluorohexanoic acid (PFHxA)	**1.1**	**J**	1.8	0.50	ug/Kg		12/03/24 12:06	12/06/24 22:01	1
Perfluoroheptanoic acid (PFHpA)	**0.24**	**J**	1.8	0.21	ug/Kg		12/03/24 12:06	12/06/24 22:01	1
L-Perfluorooctanoic acid	**3.5**		1.8	0.37	ug/Kg		12/03/24 12:06	12/06/24 22:01	1
Br-Perfluorooctanoic acid	ND		1.8	0.37	ug/Kg		12/03/24 12:06	12/06/24 22:01	1
Total PFOA	**3.5**		1.8	0.37	ug/Kg		12/03/24 12:06	12/06/24 22:01	1
Perfluorononanoic acid (PFNA)	**70**		1.8	0.32	ug/Kg		12/03/24 12:06	12/06/24 22:01	1
Perfluorodecanoic acid (PFDA)	**47**		1.8	0.19	ug/Kg		12/03/24 12:06	12/06/24 22:01	1
Perfluoroundecanoic acid (PFUnA)	**3.4**		1.8	0.49	ug/Kg		12/03/24 12:06	12/06/24 22:01	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.8	0.31	ug/Kg		12/03/24 12:06	12/06/24 22:01	1
Perfluoropentanesulfonic acid (PFPeS)	**0.37**	**J**	1.8	0.33	ug/Kg		12/03/24 12:06	12/06/24 22:01	1
4:2 FTS	ND		1.8	0.48	ug/Kg		12/03/24 12:06	12/06/24 22:01	1
6:2 FTS	**8.7**		1.8	0.77	ug/Kg		12/03/24 12:06	12/06/24 22:01	1
8:2 FTS	**23**		1.8	0.18	ug/Kg		12/03/24 12:06	12/06/24 22:01	1
10:2 FTS	ND		1.8	0.18	ug/Kg		12/03/24 12:06	12/06/24 22:01	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*61*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:01*	*1*
13C5 PFPeA	*62*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:01*	*1*
13C2 PFHxA	*72*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:01*	*1*
13C4 PFHpA	*59*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:01*	*1*
13C4 PFOA	*56*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:01*	*1*
13C5 PFNA	*58*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:01*	*1*
13C2 PFDA	*61*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:01*	*1*
13C2 PFUnA	*61*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:01*	*1*
13C3 PFBS	*60*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:01*	*1*
M2-4:2 FTS	*57*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:01*	*1*
M2-6:2 FTS	*51*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:01*	*1*
M2-8:2 FTS	*45*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:01*	*1*
13C2 10:2 FTS	*243*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 22:01*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	ND		180	27	ug/Kg		12/03/24 12:06	12/11/24 00:45	100
Total PFHxS	**360**		180	27	ug/Kg		12/03/24 12:06	12/11/24 00:45	100
L-Perfluorohexanesulfonic acid	**360**		180	27	ug/Kg		12/03/24 12:06	12/11/24 00:45	100
Perfluoroheptanesulfonic acid (PFHpS)	**520**		180	34	ug/Kg		12/03/24 12:06	12/11/24 00:45	100
L-Perfluorooctanesulfonic acid	**41000**	**E**	450	37	ug/Kg		12/03/24 12:06	12/11/24 00:45	100
Br-Perfluorooctanesulfonic acid	**25000**	**E**	450	37	ug/Kg		12/03/24 12:06	12/11/24 00:45	100
Total PFOS	**66000**		450	37	ug/Kg		12/03/24 12:06	12/11/24 00:45	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*70*		*25 - 150*	*12/03/24 12:06*	*12/11/24 00:45*	*100*
13C4 PFOS	*60*		*25 - 150*	*12/03/24 12:06*	*12/11/24 00:45*	*100*

Client Sample ID: NK 311154
Date Collected: 11/13/24 00:00
Date Received: 11/20/24 09:40

Lab Sample ID: 320-117199-17
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**0.18**	**J**	0.76	0.18	ug/Kg		12/03/24 12:06	12/06/24 22:21	1
Perfluoropentanoic acid (PFPeA)	ND		0.76	0.13	ug/Kg		12/03/24 12:06	12/06/24 22:21	1
Perfluorohexanoic acid (PFHxA)	ND		0.76	0.21	ug/Kg		12/03/24 12:06	12/06/24 22:21	1
Perfluoroheptanoic acid (PFHpA)	ND		0.76	0.088	ug/Kg		12/03/24 12:06	12/06/24 22:21	1
L-Perfluorooctanoic acid	**0.25**	**J**	0.76	0.15	ug/Kg		12/03/24 12:06	12/06/24 22:21	1
Br-Perfluorooctanoic acid	ND		0.76	0.15	ug/Kg		12/03/24 12:06	12/06/24 22:21	1
Total PFOA	**0.25**	**J**	0.76	0.15	ug/Kg		12/03/24 12:06	12/06/24 22:21	1
Perfluorononanoic acid (PFNA)	**2.2**		0.76	0.13	ug/Kg		12/03/24 12:06	12/06/24 22:21	1
Perfluorodecanoic acid (PFDA)	**1.8**		0.76	0.078	ug/Kg		12/03/24 12:06	12/06/24 22:21	1
Perfluoroundecanoic acid (PFUnA)	ND		0.76	0.21	ug/Kg		12/03/24 12:06	12/06/24 22:21	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.76	0.13	ug/Kg		12/03/24 12:06	12/06/24 22:21	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.76	0.14	ug/Kg		12/03/24 12:06	12/06/24 22:21	1
4:2 FTS	ND		0.76	0.20	ug/Kg		12/03/24 12:06	12/06/24 22:21	1
6:2 FTS	**1.1**		0.76	0.32	ug/Kg		12/03/24 12:06	12/06/24 22:21	1
8:2 FTS	**0.62**	**J**	0.76	0.076	ug/Kg		12/03/24 12:06	12/06/24 22:21	1
10:2 FTS	ND		0.76	0.077	ug/Kg		12/03/24 12:06	12/06/24 22:21	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*70*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:21*	*1*
13C5 PFPeA	*72*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:21*	*1*
13C2 PFHxA	*86*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:21*	*1*
13C4 PFHpA	*77*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:21*	*1*
13C4 PFOA	*77*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:21*	*1*
13C5 PFNA	*72*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:21*	*1*
13C2 PFDA	*80*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:21*	*1*
13C2 PFUnA	*79*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:21*	*1*
13C3 PFBS	*68*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:21*	*1*
M2-4:2 FTS	*67*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:21*	*1*
M2-6:2 FTS	*109*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:21*	*1*
M2-8:2 FTS	*53*		*25 - 150*	*12/03/24 12:06*	*12/06/24 22:21*	*1*
13C2 10:2 FTS	*320*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 22:21*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	ND		76	11	ug/Kg		12/03/24 12:06	12/11/24 01:24	100
Total PFHxS	**93**		76	11	ug/Kg		12/03/24 12:06	12/11/24 01:24	100
L-Perfluorohexanesulfonic acid	**93**		76	11	ug/Kg		12/03/24 12:06	12/11/24 01:24	100
Perfluoroheptanesulfonic acid (PFHpS)	**73**	**J**	76	14	ug/Kg		12/03/24 12:06	12/11/24 01:24	100
L-Perfluorooctanesulfonic acid	**3600**		190	15	ug/Kg		12/03/24 12:06	12/11/24 01:24	100
Br-Perfluorooctanesulfonic acid	**1100**		190	15	ug/Kg		12/03/24 12:06	12/11/24 01:24	100
Total PFOS	**4700**		190	15	ug/Kg		12/03/24 12:06	12/11/24 01:24	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*88*		*25 - 150*	*12/03/24 12:06*	*12/11/24 01:24*	*100*
13C4 PFOS	*80*		*25 - 150*	*12/03/24 12:06*	*12/11/24 01:24*	*100*

Isotope Dilution Summary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117199-1

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Tissue

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-117199-1	NK 311147 liver	78	85	98	84	75	67	80	75
320-117199-1 - RA	NK 311147 liver								

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)			
320-117199-1	NK 311147 liver	84	74	127	60				
320-117199-1 - RA	NK 311147 liver					174 *5+			

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
PFHxA = 13C2 PFHxA
C4PFHA = 13C4 PFHpA
PFOA = 13C4 PFOA
PFNA = 13C5 PFNA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
M102FTS = 13C2 10:2 FTS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Tissue

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFHxS (25-150)	PFOS (25-150)						
320-117199-1 - DL	NK 311147 liver	89	65						
320-117199-4 - DL	NK 311148 liver	107	85						
320-117199-10 - DL	NK 311150 liver	88	68						
320-117199-13 - DL	NK 311152 liver	87	76						
320-117199-16 - DL	NK 311154 liver	70	60						
320-117199-17 - DL	NK 311154	88	80						

Surrogate Legend

PFHxS = 18O2 PFHxS
PFOS = 13C4 PFOS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Tissue

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-117199-4	NK 311148 liver	91	99	113	99	94	82	99	94
320-117199-10	NK 311150 liver	76	83	94	84	75	65	85	85
320-117199-13	NK 311152 liver	84	87	106	97	77	79	92	79
320-117199-16	NK 311154 liver	61	62	72	59	56	58	61	61
320-117199-17	NK 311154	70	72	86	77	77	72	80	79

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Matrix: Tissue **Prep Type: Total/NA**

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)		
320-117199-4	NK 311148 liver	97		76	157 *5+	68	247 *5+		
320-117199-10	NK 311150 liver	75		58	124	54	359 *5+		
320-117199-13	NK 311152 liver	91		89	150	66	178 *5+		
320-117199-16	NK 311154 liver	60		57	51	45	243 *5+		
320-117199-17	NK 311154	68		67	109	53	320 *5+		

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
PFHxA = 13C2 PFHxA
C4PFHA = 13C4 PFHpA
PFOA = 13C4 PFOA
PFNA = 13C5 PFNA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
M102FTS = 13C2 10:2 FTS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Tissue **Prep Type: Total/NA**

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-117199-2	NK 311147	77	73	77	73	63	70	72	70
320-117199-3	NK 311147 bone	103	87	92	98	84	92	88	75
320-117199-5	NK 311148	72	70	75	69	64	68	68	63
320-117199-6	NK 311148 bone	127	116	116	115	95	108	100	91
320-117199-7	NK 311149 liver	63	60	66	60	56	58	64	58
320-117199-8	NK 311149	57	53	55	54	49	53	54	50
320-117199-9	NK 311149 bone	100	81	88	90	78	83	81	74
320-117199-11	NK 311150	80	79	80	76	71	70	78	67
320-117199-12	NK 311151	71	78	88	80	72	72	80	74
320-117199-14	NK 311152	72	62	60	69	63	61	66	64
320-117199-15	NK 311153	109	90	104	100	88	95	94	94
LCS 320-818987/2-A	Lab Control Sample	76	65	74	75	64	72	70	65
LCSD 320-818987/3-A	Lab Control Sample Dup	87	87	91	87	81	89	85	86
MB 320-818987/1-A	Method Blank	83	72	75	84	84	84	86	79

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
320-117199-2	NK 311147	67	78	51	53	62	50	177 *5+
320-117199-3	NK 311147 bone	92	97	79	64	71	60	123
320-117199-5	NK 311148	61	70	52	48	66	45	134
320-117199-6	NK 311148 bone	100	123	93	82	79	65	126
320-117199-7	NK 311149 liver	60	64		48	100	44	158 *5+
320-117199-8	NK 311149	51	57	37	37	39	35	58
320-117199-9	NK 311149 bone	75	94	69	52	56	52	93

Isotope Dilution Summary

Client: University of New Mexico
Job ID: 320-117199-1
Project/Site: UNM_PFAS in Tissue, Holloman

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Matrix: Tissue **Prep Type: Total/NA**

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
320-117199-11	NK 311150	64	75		57	55	51	275 *5+
320-117199-12	NK 311151	80	85	60	56	116	52	225 *5+
320-117199-14	NK 311152	63	69	43	40	55	41	233 *5+
320-117199-15	NK 311153	91	95	84	57	80	63	182 *5+
LCS 320-818987/2-A	Lab Control Sample	73	72	69	46	57	48	300 *5+
LCSD 320-818987/3-A	Lab Control Sample Dup	83	95	88	65	72	62	419 *5+
MB 320-818987/1-A	Method Blank	81	92	76	57	68	62	381 *5+

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
PFHxA = 13C2 PFHxA
C4PFHA = 13C4 PFHpA
PFOA = 13C4 PFOA
PFNA = 13C5 PFNA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS
PFHxS = 18O2 PFHxS
PFOS = 13C4 PFOS
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
M102FTS = 13C2 10:2 FTS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Tissue **Prep Type: Total/NA**

		Percent Isotope Dilution Recovery (Acceptance Limits)
Lab Sample ID	Client Sample ID	PFOS (25-150)
320-117199-7	NK 311149 liver	49
320-117199-11	NK 311150	67
320-117199-12 - DL	NK 311151	80
320-117199-14	NK 311152	66

Surrogate Legend

PFOS = 13C4 PFOS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Lab Sample ID: MB 320-818987/1-A
Matrix: Tissue
Analysis Batch: 820056

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 818987

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.27	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
L-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Total PFOA	ND		1.0	0.20	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.10	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.27	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Total PFHxS	ND		1.0	0.15	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
L-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Br-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
Total PFOS	ND		2.5	0.20	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
4:2 FTS	ND		1.0	0.27	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
6:2 FTS	ND		1.0	0.42	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
8:2 FTS	ND		1.0	0.10	ug/Kg		12/03/24 12:06	12/06/24 15:53	1
10:2 FTS	ND		1.0	0.10	ug/Kg		12/03/24 12:06	12/06/24 15:53	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*83*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C5 PFPeA	*72*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C2 PFHxA	*75*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C4 PFHpA	*84*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C4 PFOA	*84*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C5 PFNA	*84*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C2 PFDA	*86*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C2 PFUnA	*79*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C3 PFBS	*81*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
18O2 PFHxS	*92*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C4 PFOS	*76*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
M2-4:2 FTS	*57*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
M2-6:2 FTS	*68*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
M2-8:2 FTS	*62*		*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*
13C2 10:2 FTS	*381*	**5+*	*25 - 150*	*12/03/24 12:06*	*12/06/24 15:53*	*1*

Lab Sample ID: LCS 320-818987/2-A
Matrix: Tissue
Analysis Batch: 820056

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 818987

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	10.0	10.8		ug/Kg		108	76 - 136

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-818987/2-A
Matrix: Tissue
Analysis Batch: 820056

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 818987

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits		
Perfluoropentanoic acid (PFPeA)			10.0	8.77		ug/Kg		88	69 - 129		
Perfluorohexanoic acid (PFHxA)			10.0	9.70		ug/Kg		97	71 - 131		
Perfluoroheptanoic acid (PFHpA)			10.0	9.89		ug/Kg		99	71 - 131		
L-Perfluorooctanoic acid			10.0	10.4		ug/Kg		104	72 - 132		
Total PFOA			10.0	10.4		ug/Kg		104			
Perfluorononanoic acid (PFNA)			10.0	8.98		ug/Kg		90	73 - 133		
Perfluorodecanoic acid (PFDA)			10.0	9.96		ug/Kg		100	72 - 132		
Perfluoroundecanoic acid (PFUnA)			10.0	8.79		ug/Kg		88	66 - 126		
Perfluorobutanesulfonic acid (PFBS)			8.88	8.84		ug/Kg		99	69 - 129		
Perfluoropentanesulfonic acid (PFPeS)			9.40	8.32		ug/Kg		89	66 - 126		
Total PFHxS			9.12	8.45		ug/Kg		93			
L-Perfluorohexanesulfonic acid			9.12	8.45		ug/Kg		93	62 - 122		
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.2		ug/Kg		107	76 - 136		
L-Perfluorooctanesulfonic acid			9.30	9.10		ug/Kg		98	68 - 141		
Total PFOS			9.30	9.10		ug/Kg		98			
4:2 FTS			9.38	10.5		ug/Kg		112	68 - 143		
6:2 FTS			9.52	9.93		ug/Kg		104	73 - 139		
8:2 FTS			9.60	10.1		ug/Kg		105	75 - 135		
10:2 FTS			9.66	8.86		ug/Kg		92	69 - 145		

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*76*		*25 - 150*
13C5 PFPeA	*65*		*25 - 150*
13C2 PFHxA	*74*		*25 - 150*
13C4 PFHpA	*75*		*25 - 150*
13C4 PFOA	*64*		*25 - 150*
13C5 PFNA	*72*		*25 - 150*
13C2 PFDA	*70*		*25 - 150*
13C2 PFUnA	*65*		*25 - 150*
13C3 PFBS	*73*		*25 - 150*
18O2 PFHxS	*72*		*25 - 150*
13C4 PFOS	*69*		*25 - 150*
M2-4:2 FTS	*46*		*25 - 150*
M2-6:2 FTS	*57*		*25 - 150*
M2-8:2 FTS	*48*		*25 - 150*
13C2 10:2 FTS	*300*	**5+*	*25 - 150*

Lab Sample ID: LCSD 320-818987/3-A
Matrix: Tissue
Analysis Batch: 820056

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 818987

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)			10.0	10.9		ug/Kg		109	76 - 136	1	30
Perfluoropentanoic acid (PFPeA)			10.0	9.93		ug/Kg		99	69 - 129	12	30
Perfluorohexanoic acid (PFHxA)			10.0	10.0		ug/Kg		100	71 - 131	3	30
Perfluoroheptanoic acid (PFHpA)			10.0	10.9		ug/Kg		109	71 - 131	9	30

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCSD 320-818987/3-A
Matrix: Tissue
Analysis Batch: 820056

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 818987

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
L-Perfluorooctanoic acid			10.0	10.7		ug/Kg		107	72 - 132	3	30
Total PFOA			10.0	10.7		ug/Kg		107		3	
Perfluorononanoic acid (PFNA)			10.0	9.79		ug/Kg		98	73 - 133	9	30
Perfluorodecanoic acid (PFDA)			10.0	11.0		ug/Kg		110	72 - 132	10	30
Perfluoroundecanoic acid (PFUnA)			10.0	9.40		ug/Kg		94	66 - 126	7	30
Perfluorobutanesulfonic acid (PFBS)			8.88	9.45		ug/Kg		106	69 - 129	7	30
Perfluoropentanesulfonic acid (PFPeS)			9.40	9.95		ug/Kg		106	66 - 126	18	30
Total PFHxS			9.12	8.51		ug/Kg		93		1	
L-Perfluorohexanesulfonic acid			9.12	8.51		ug/Kg		93	62 - 122	1	30
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.9		ug/Kg		115	76 - 136	7	30
L-Perfluorooctanesulfonic acid			9.30	11.7		ug/Kg		126	68 - 141	25	30
Total PFOS			9.30	11.7		ug/Kg		126		25	
4:2 FTS			9.38	10.0		ug/Kg		107	68 - 143	4	30
6:2 FTS			9.52	10.1		ug/Kg		106	73 - 139	1	30
8:2 FTS			9.60	11.1		ug/Kg		115	75 - 135	9	30
10:2 FTS			9.66	10.0		ug/Kg		104	69 - 145	12	30

Isotope Dilution	*LCSD %Recovery*	*LCSD Qualifier*	*Limits*
13C4 PFBA	*87*		*25 - 150*
13C5 PFPeA	*87*		*25 - 150*
13C2 PFHxA	*91*		*25 - 150*
13C4 PFHpA	*87*		*25 - 150*
13C4 PFOA	*81*		*25 - 150*
13C5 PFNA	*89*		*25 - 150*
13C2 PFDA	*85*		*25 - 150*
13C2 PFUnA	*86*		*25 - 150*
13C3 PFBS	*83*		*25 - 150*
18O2 PFHxS	*95*		*25 - 150*
13C4 PFOS	*88*		*25 - 150*
M2-4:2 FTS	*65*		*25 - 150*
M2-6:2 FTS	*72*		*25 - 150*
M2-8:2 FTS	*62*		*25 - 150*
13C2 10:2 FTS	*419*	**5+*	*25 - 150*

LCMS

Pre Prep Batch: 818986

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117199-1 - RA	NK 311147 liver	Total/NA	Tissue	In-House	
320-117199-1 - DL	NK 311147 liver	Total/NA	Tissue	In-House	
320-117199-1	NK 311147 liver	Total/NA	Tissue	In-House	
320-117199-2	NK 311147	Total/NA	Tissue	In-House	
320-117199-3	NK 311147 bone	Total/NA	Tissue	In-House	
320-117199-4	NK 311148 liver	Total/NA	Tissue	In-House	
320-117199-4 - DL	NK 311148 liver	Total/NA	Tissue	In-House	
320-117199-5	NK 311148	Total/NA	Tissue	In-House	
320-117199-6	NK 311148 bone	Total/NA	Tissue	In-House	
320-117199-7	NK 311149 liver	Total/NA	Tissue	In-House	
320-117199-8	NK 311149	Total/NA	Tissue	In-House	
320-117199-9	NK 311149 bone	Total/NA	Tissue	In-House	
320-117199-10	NK 311150 liver	Total/NA	Tissue	In-House	
320-117199-10 - DL	NK 311150 liver	Total/NA	Tissue	In-House	
320-117199-11	NK 311150	Total/NA	Tissue	In-House	
320-117199-12 - DL	NK 311151	Total/NA	Tissue	In-House	
320-117199-12	NK 311151	Total/NA	Tissue	In-House	
320-117199-13 - DL	NK 311152 liver	Total/NA	Tissue	In-House	
320-117199-13	NK 311152 liver	Total/NA	Tissue	In-House	
320-117199-14	NK 311152	Total/NA	Tissue	In-House	
320-117199-15	NK 311153	Total/NA	Tissue	In-House	
320-117199-16 - DL	NK 311154 liver	Total/NA	Tissue	In-House	
320-117199-16	NK 311154 liver	Total/NA	Tissue	In-House	
320-117199-17	NK 311154	Total/NA	Tissue	In-House	
320-117199-17 - DL	NK 311154	Total/NA	Tissue	In-House	

Prep Batch: 818987

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117199-1 - DL	NK 311147 liver	Total/NA	Tissue	SHAKE	818986
320-117199-1 - RA	NK 311147 liver	Total/NA	Tissue	SHAKE	818986
320-117199-1	NK 311147 liver	Total/NA	Tissue	SHAKE	818986
320-117199-2	NK 311147	Total/NA	Tissue	SHAKE	818986
320-117199-3	NK 311147 bone	Total/NA	Tissue	SHAKE	818986
320-117199-4 - DL	NK 311148 liver	Total/NA	Tissue	SHAKE	818986
320-117199-4	NK 311148 liver	Total/NA	Tissue	SHAKE	818986
320-117199-5	NK 311148	Total/NA	Tissue	SHAKE	818986
320-117199-6	NK 311148 bone	Total/NA	Tissue	SHAKE	818986
320-117199-7	NK 311149 liver	Total/NA	Tissue	SHAKE	818986
320-117199-8	NK 311149	Total/NA	Tissue	SHAKE	818986
320-117199-9	NK 311149 bone	Total/NA	Tissue	SHAKE	818986
320-117199-10 - DL	NK 311150 liver	Total/NA	Tissue	SHAKE	818986
320-117199-10	NK 311150 liver	Total/NA	Tissue	SHAKE	818986
320-117199-11	NK 311150	Total/NA	Tissue	SHAKE	818986
320-117199-12 - DL	NK 311151	Total/NA	Tissue	SHAKE	818986
320-117199-12	NK 311151	Total/NA	Tissue	SHAKE	818986
320-117199-13	NK 311152 liver	Total/NA	Tissue	SHAKE	818986
320-117199-13 - DL	NK 311152 liver	Total/NA	Tissue	SHAKE	818986
320-117199-14	NK 311152	Total/NA	Tissue	SHAKE	818986
320-117199-15	NK 311153	Total/NA	Tissue	SHAKE	818986
320-117199-16 - DL	NK 311154 liver	Total/NA	Tissue	SHAKE	818986
320-117199-16	NK 311154 liver	Total/NA	Tissue	SHAKE	818986

LCMS (Continued)

Prep Batch: 818987 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117199-17 - DL	NK 311154	Total/NA	Tissue	SHAKE	818986
320-117199-17	NK 311154	Total/NA	Tissue	SHAKE	818986
MB 320-818987/1-A	Method Blank	Total/NA	Tissue	SHAKE	
LCS 320-818987/2-A	Lab Control Sample	Total/NA	Tissue	SHAKE	
LCSD 320-818987/3-A	Lab Control Sample Dup	Total/NA	Tissue	SHAKE	

Analysis Batch: 820056

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117199-1	NK 311147 liver	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-2	NK 311147	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-3	NK 311147 bone	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-4	NK 311148 liver	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-5	NK 311148	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-6	NK 311148 bone	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-7	NK 311149 liver	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-8	NK 311149	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-9	NK 311149 bone	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-10	NK 311150 liver	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-11	NK 311150	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-12	NK 311151	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-13	NK 311152 liver	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-14	NK 311152	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-15	NK 311153	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-16	NK 311154 liver	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-17	NK 311154	Total/NA	Tissue	B/L/T PFAS	818987
MB 320-818987/1-A	Method Blank	Total/NA	Tissue	B/L/T PFAS	818987
LCS 320-818987/2-A	Lab Control Sample	Total/NA	Tissue	B/L/T PFAS	818987
LCSD 320-818987/3-A	Lab Control Sample Dup	Total/NA	Tissue	B/L/T PFAS	818987

Analysis Batch: 821094

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117199-1 - DL	NK 311147 liver	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-1 - RA	NK 311147 liver	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-4 - DL	NK 311148 liver	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-7	NK 311149 liver	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-10 - DL	NK 311150 liver	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-11	NK 311150	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-12 - DL	NK 311151	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-13 - DL	NK 311152 liver	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-14	NK 311152	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-16 - DL	NK 311154 liver	Total/NA	Tissue	B/L/T PFAS	818987
320-117199-17 - DL	NK 311154	Total/NA	Tissue	B/L/T PFAS	818987

Client Sample ID: NK 311147 liver

Lab Sample ID: 320-117199-1

Date Collected: 11/13/24 00:00

Matrix: Tissue

Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.46 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 16:51	P1R	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE	DL		0.46 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	821094	12/10/24 18:17	P1R	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE	RA		0.46 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	821094	12/10/24 18:37	P1R	EET SAC

Client Sample ID: NK 311147

Lab Sample ID: 320-117199-2

Date Collected: 11/13/24 00:00

Matrix: Tissue

Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			1.19 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 17:10	P1R	EET SAC

Client Sample ID: NK 311147 bone

Lab Sample ID: 320-117199-3

Date Collected: 11/13/24 00:00

Matrix: Tissue

Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.29 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 17:30	P1R	EET SAC

Client Sample ID: NK 311148 liver

Lab Sample ID: 320-117199-4

Date Collected: 11/13/24 00:00

Matrix: Tissue

Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.54 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 17:49	P1R	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE	DL		0.54 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	821094	12/10/24 19:35	P1R	EET SAC

Lab Chronicle

Client: University of New Mexico
Job ID: 320-117199-1
Project/Site: UNM_PFAS in Tissue, Holloman

Client Sample ID: NK 311148
Lab Sample ID: 320-117199-5
Date Collected: 11/13/24 00:00
Matrix: Tissue
Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			1.09 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 18:09	P1R	EET SAC

Client Sample ID: NK 311148 bone
Lab Sample ID: 320-117199-6
Date Collected: 11/13/24 00:00
Matrix: Tissue
Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.26 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 18:28	P1R	EET SAC

Client Sample ID: NK 311149 liver
Lab Sample ID: 320-117199-7
Date Collected: 11/13/24 00:00
Matrix: Tissue
Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.43 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 18:47	P1R	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.43 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		100	1 mL	1 mL	821094	12/10/24 20:33	P1R	EET SAC

Client Sample ID: NK 311149
Lab Sample ID: 320-117199-8
Date Collected: 11/13/24 00:00
Matrix: Tissue
Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			1.08 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 19:26	P1R	EET SAC

Client Sample ID: NK 311149 bone
Lab Sample ID: 320-117199-9
Date Collected: 11/13/24 00:00
Matrix: Tissue
Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.28 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 19:46	P1R	EET SAC

Client Sample ID: NK 311150 liver

Lab Sample ID: 320-117199-10

Date Collected: 11/13/24 00:00

Matrix: Tissue

Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.54 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 20:05	P1R	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE	DL		0.54 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	821094	12/10/24 22:10	P1R	EET SAC

Client Sample ID: NK 311150

Lab Sample ID: 320-117199-11

Date Collected: 11/13/24 00:00

Matrix: Tissue

Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			1.09 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 20:24	P1R	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			1.09 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		100	1 mL	1 mL	821094	12/10/24 22:49	P1R	EET SAC

Client Sample ID: NK 311151

Lab Sample ID: 320-117199-12

Date Collected: 11/13/24 00:00

Matrix: Tissue

Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.96 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 20:44	P1R	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE	DL		0.96 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	50	1 mL	1 mL	821094	12/10/24 23:08	P1R	EET SAC

Client Sample ID: NK 311152 liver

Lab Sample ID: 320-117199-13

Date Collected: 11/13/24 00:00

Matrix: Tissue

Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.37 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 21:03	P1R	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE	DL		0.37 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	821094	12/10/24 23:28	P1R	EET SAC

Lab Chronicle

Client: University of New Mexico
Job ID: 320-117199-1
Project/Site: UNM_PFAS in Tissue, Holloman

Client Sample ID: NK 311152
Lab Sample ID: 320-117199-14
Date Collected: 11/13/24 00:00
Matrix: Tissue
Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			1.20 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 21:23	P1R	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			1.20 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		50	1 mL	1 mL	821094	12/10/24 23:47	P1R	EET SAC

Client Sample ID: NK 311153
Lab Sample ID: 320-117199-15
Date Collected: 11/13/24 00:00
Matrix: Tissue
Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.62 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 21:42	P1R	EET SAC

Client Sample ID: NK 311154 liver
Lab Sample ID: 320-117199-16
Date Collected: 11/13/24 00:00
Matrix: Tissue
Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			0.55 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 22:01	P1R	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE	DL		0.55 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	821094	12/11/24 00:45	P1R	EET SAC

Client Sample ID: NK 311154
Lab Sample ID: 320-117199-17
Date Collected: 11/13/24 00:00
Matrix: Tissue
Date Received: 11/20/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE			1.32 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820056	12/06/24 22:21	P1R	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	818986	12/03/24 12:04	ATB	EET SAC
Total/NA	Prep	SHAKE	DL		1.32 g	10.0 mL	818987	12/03/24 12:06	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	821094	12/11/24 01:24	P1R	EET SAC

Laboratory References:
EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

Accreditation/Certification Summary

Client: University of New Mexico
Job ID: 320-117199-1
Project/Site: UNM_PFAS in Tissue, Holloman

Laboratory: Eurofins Sacramento

All accreditations/certifications held by this laboratory are listed. Not all accreditations/certifications are applicable to this report.

Authority	Program	Identification Number	Expiration Date
Alaska (UST)	State	17-020	02-20-27
ANAB	Dept. of Defense ELAP	L2468	01-20-27
ANAB	Dept. of Energy	L2468.01	01-20-27
ANAB	ISO/IEC 17025	L2468	01-20-27
Arizona	State	AZ0708	08-11-25
Arkansas DEQ	State	88-0691	05-18-25
California	State	2897	01-31-26
Colorado	State	CA00044	08-31-25
Florida	NELAP	E87570	06-30-25
Georgia	State	4040	01-29-25
Hawaii	State	Eurofins Sacramento	01-29-25
Illinois	NELAP	200060	03-31-25
Kansas	NELAP	E-10375	10-31-25
Louisiana	NELAP	01944	06-30-25
Louisiana (All)	NELAP	01944	06-30-25
Maine	State	CA00004	04-14-26
Michigan	State	9947	01-29-25
Minnesota	NELAP	2749448	12-31-25
Nevada	State	CA00044	07-31-25
New Hampshire	NELAP	2997	04-19-25
New Jersey	NELAP	CA005	06-30-25
New York	NELAP	11666	04-01-25
Ohio	State	41252	01-29-25
Oregon	NELAP	4040	01-29-25
Texas	NELAP	T104704399-23-17	05-31-25
US Fish & Wildlife	US Federal Programs	A22139	04-30-25
USDA	US Federal Programs	P330-18-00239	02-28-26
Utah	NELAP	CA000442023-16	02-28-25
Virginia	NELAP	460278	03-14-25
Washington	State	C581	05-05-25
West Virginia (DW)	State	9930C	01-31-25
Wisconsin	State	998204680	08-31-25
Wyoming	State Program	8TMS-L	01-28-19 *

* Accreditation/Certification renewal pending - accreditation/certification considered valid.

Method Summary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117199-1

Method	Method Description	Protocol	Laboratory
B/L/T PFAS	Branched, Linear and Total PFAS	EPA	EET SAC
In-House	Tissue Preparation/Homgenization	NOAA	EET SAC
SHAKE	Shake Extraction with Ultrasonic Bath Extraction	SW846	EET SAC

Protocol References:

EPA = US Environmental Protection Agency

NOAA = National Marine Fisheries Service, National Oceanic And Atmospheric Administration, Seattle, WA, November 1988

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

Sample Summary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117199-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
320-117199-1	NK 311147 liver	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-2	NK 311147	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-3	NK 311147 bone	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-4	NK 311148 liver	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-5	NK 311148	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-6	NK 311148 bone	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-7	NK 311149 liver	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-8	NK 311149	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-9	NK 311149 bone	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-10	NK 311150 liver	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-11	NK 311150	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-12	NK 311151	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-13	NK 311152 liver	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-14	NK 311152	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-15	NK 311153	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-16	NK 311154 liver	Tissue	11/13/24 00:00	11/20/24 09:40
320-117199-17	NK 311154	Tissue	11/13/24 00:00	11/20/24 09:40

Eurofins Sacramento
NMED Exhibits 63
12/23/2024

Eurofins Env. Testing Northern California
880 Riverside Parkway
West Sacramento, CA 95605
Phone: 916.373.5600

Chain of Custody Record

eurofins | Environment Testing America

Client Contact	Report To: Jean-Luc Cartron and Jon Dunnum	Site Contact:	Date: 11/18/2024	COC No: This is a corrected CoC. Please ignore
Jean-Luc Cartron, UNM, jlec@unm.edu	email: jlec@unm.edu, jldunnum@unm.edu	Lab Contact: Linda Laver	Carrier: FedEx	2 of 2 COCs
Jon Dunnum, UNM, jldunnum@unm.edu	Analysis Turnaround Time			Job No.
	Business Days (BD)			
	TAT if different from Above			Field Sampler
	☐ 2 weeks			
	☐ 1 week			
	☐ 2 days			
	☐ 1 day			

Sample Identification	Sample Date	Sample Time	Sample Type	Matrix	# of Cont.	Filtered Sample	Enter requested analyses in these fields	Sample Specific Notes:
NK 311147 liver	13-Nov-24		liver		1			MSB.Mamm:353459 Dipodomys merriami
NK 311147	13-Nov-24		muscle		1			MSB.Mamm:353459 Dipodomys merriami
NK 311147 bone	13-Nov-24		bone		1			MSB.Mamm:353459 Dipodomys merriami
NK 311148 liver	13-Nov-24		liver		1			MSB.Mamm:353457 Dipodomys merriami
NK 311148	13-Nov-24		muscle		1			MSB:Mamm:353457 Dipodomys merriami
NK 311148 bone	13-Nov-24		bone		1			MSB:Mamm:353457 Dipodomys merriami
NK 311149 liver	13-Nov-24		liver		1			MSB:Mamm:353456 Dipodomys merriami
NK 311149	13-Nov-24		muscle		1			MSB:Mamm:353456 Dipodomys merriami
NK 311149 bone	13-Nov-24		bone		1			MSB.Mamm:353456 Dipodomys merriami
NK 311150 liver	13-Nov-24		liver		1			MSB.Mamm:353462 Dipodomys merriami
NK 311150	13-Nov-24		muscle		1			MSB.Mamm:353462 Dipodomys merriami
NK 311151	13-Nov-24		muscle		1			MSB.Mamm:353463 Peromyscus maniculatus
NK 311152 liver	13-Nov-24		liver		1			MSB:Mamm:353461 Dipodomys merriami
NK 311152	13-Nov-24		muscle		1			MSB.Mamm:353461 Dipodomys merriami
NK 311153	13-Nov-24		muscle		1			MSB:Mamm:353458 Chaetodipus eremicus
NK 311154 liver	13-Nov-24		liver		1			MSB:Mamm:353460 Dipodomys merriami
NK 311154	13-Nov-24		muscle		1			MSB:Mamm:353460 Dipodomys merriami
					1			
					1			
					1			
					1			
					1			
					1			

Client emailed this CoC to be used to log in samples 11/20/24 (LOL)

320-117199 Chain of Custody

Preservation Used: 1= Ice, 2= HCl; 3= H2SO4; 4=HNO3; 5=NaOH; 6= Other _____

Possible Hazard Identification
☒ Non-Hazard ☐ Flammable ☐ Skin Irritant Poison B ☐ Unknown ☐

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☐ Return To Client ☒ Disposal By Lab ☐ Archive For _____ Months

Special Instructions/QC Requirements & Comments:

Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:
				ECBe	11/20/24 0940
Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:
Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:

-23.7°C

12/23/2024

NMED Exhibits 65

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Loc: 320
117199

Sacramento Sample Receiving Notes (SSRN)

Tracking # 7700 8108 9118

Job _____

SO / (PO) FO / SAT / 2-Day / Ground / UPS / CDO / Courier
GSL / OnTrac / Goldstreak / USPS / Other _____

Use this form to record Sample Custody Seal, Cooler Custody Seal, Temperature & corrected Temperature & other observations
File in the job folder with the COC

Therm ID C04 Corr Factor (+/-) N/A °C

Ice _____ Wet _____ Gel _____ Other Dry Ice

Cooler Custody Seal —

Cooler ID —

Temp Observed -23.7 °C Corrected -23.7 °C
From Temp Blank ☐ Sandwich ☐ Sidewall ☐

Opening/Processing The Shipment	**Yes**	**No**	**NA**
Cooler compromised/tampered with?	☐	☒	☐
Cooler Temperature is acceptable?	☒	☐	☐
Frozen samples show signs of thaw?	☐	☒	☐

Initials SO Date 11/20/24

Unpacking/Labeling The Samples	**Yes**	**No**	**NA**
Containers are not broken or leaking?	☒	☐	☐
Samples compromised/tampered with?	☐	☒	☐
COC is complete w/o discrepancies	☐	☒	☐
Sample custody seal?	☐	☐	☒
Sample containers have legible labels?	☒	☐	☐
Sample date/times are provided?	☒	☐	☐
Appropriate containers are used?	☒	☐	☐
Sample bottles are completely filled?	☒	☐	☐
Sample preservatives verified?	☐	☐	☒
Is the Field Sampler's name on COC?	☐	☐	☒
Samples w/o discrepancies?	☒	☐	☐
Zero headspace?*	☐	☐	☒
Alkalinity has no headspace?	☐	☐	☒
Perchlorate has headspace? (Methods 314, 331, 6850)	☐	☐	☒
Multiphasic samples are not present?	☒	☐	☐

*Containers requiring zero headspace have no headspace, or bubble < 6 mm (1/4")

Initials DM Date 11/21/24

Notes: _____

Trizma Lot #(s) _____

Ammonium Acetate Lot #(s) _____

Login Completion	**Yes**	**No**	**NA**
Receipt Temperature on COC?	☒	☐	☐
NCM Filed?	☐	☐	☐
Samples received within hold time?	☒	☐	☐
Log Release checked in TALS?	☒	☐	☐

Initials DM Date 11/21/24

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ANALYTICAL REPORT

PREPARED FOR

Attn: Jean-Luc Cartron
University of New Mexico
Museum of Southwestern Biology
Division of Mammals
CERIA Bldg 83, Room 204
Albuquerque, New Mexico 87131

Generated 12/23/2024 9:22:18 AM

JOB DESCRIPTION

UNM_Soil & Snake Skin, Holloman

JOB NUMBER

320-117252-1

Eurofins Sacramento
880 Riverside Parkway
West Sacramento CA 95605

See page two for job notes and contact information.

my EOL

Job Notes

This report may not be reproduced except in full, and with written approval from the laboratory. The results relate only to the samples tested. For questions please contact the Project Manager at the e-mail address or telephone number listed on this page.

The test results in this report relate only to the samples as received by the laboratory and will meet all requirements of the methodology, with any exceptions noted. This report shall not be reproduced except in full, without the express written approval of the laboratory. All questions should be directed to the Eurofins Environment Testing Northern California, LLC Project Manager.

Authorization



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Authorized for release by
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NMED Exhibit 65

Definitions/Glossary

Client: University of New Mexico
Job ID: 320-117252-1
Project/Site: UNM_Soil & Snake Skin, Holloman

Qualifiers

LCMS

Qualifier	Qualifier Description
*5+	Isotope dilution analyte is outside acceptance limits, high biased.
4	MS, MSD: The analyte present in the original sample is greater than 4 times the matrix spike concentration; therefore, control limits are not applicable.
E	Result exceeded calibration range.
F1	MS and/or MSD recovery exceeds control limits.
J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
☼	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CFU	Colony Forming Unit
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MCL	EPA recommended "Maximum Contaminant Level"
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
MPN	Most Probable Number
MQL	Method Quantitation Limit
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
NEG	Negative / Absent
POS	Positive / Present
PQL	Practical Quantitation Limit
PRES	Presumptive
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)
TNTC	Too Numerous To Count

Job ID: 320-117252-1 — Eurofins Sacramento

Job Narrative
320-117252-1

Comments
This report contains data for samples requested for PFAS. Data for samples requested for TOC are included in the report for Job 320-117252-2.

Receipt
The samples were received on 11/21/2024 9:25 AM. Unless otherwise noted below, the samples arrived in good condition, and where required, properly preserved and on ice. The temperature of the cooler at receipt was 2.3º C.

Receipt Exceptions
Collection times were not provided. Samples were logged in with a default time of 00:00.

LCMS
Method B/L/T PFAS: Isotope Dilution Analyte (IDA) recovery is above the method recommended limit for some samples. Quantitation by isotope dilution generally precludes any adverse effect on data quality due to elevated IDA recoveries.

Method B/L/T PFAS: The concentration of one or more analytes associated with the following samples exceeded the instrument calibration range: NE-2-200- m (320-117252-5), NE-4-200- m (320-117252-6), (320-117252-A-6-B MS) and (320-117252-A-6-CMSD). These analytes have been qualified; however, the peak(s) did not saturate the instrument detector. Historical data indicate that for the isotope dilution method, dilution and re-analysis will not produce significantly different results from those reported above the calibration range.

Method B/L/T PFAS: Some results for sample C atrox skin (320-117252-7) were reported from the analysis of a diluted extract due to high concentration of the target analyte in the analysis of the undiluted extract. The dilution factor was applied to the labeled internal standard area counts and these area counts were within acceptance limits.

Method B/L/T PFAS: The matrix spike / matrix spike duplicate (MS/MSD) recoveries for preparation batch 320-817586 were outside control limits for one or more analytes. Sample matrix interference and/or non-homogeneity are suspected because the associated laboratory control sample (LCS) recovery is within acceptance limits .Due to the high concentration of L-Perfluorohexanesulfonic acid and L-Perfluorooctanesulfonic acid, the MS/MSD could not be evaluated for accuracy and precision for these analytes.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

General Chemistry
No analytical or quality issues were noted, other than those described in the Definitions/Glossary page.

Organic Prep
Method SHAKE: The following samples were discolored following extraction: NE-2-100- m (320-117252-3), NE-4-100- m (320-117252-4), NE-4-200- m (320-117252-6), (320-117252-6 MS) and (320-117252-6 MSD).

Method SHAKE: Insufficient sample volume was available to perform a matrix spike/matrix spike duplicate (MS/MSD) associated with preparation batch 320-819252.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Detection Summary

Client: University of New Mexico
Project/Site: UNM_Soil & Snake Skin, Holloman

Job ID: 320-117252-1

Client Sample ID: NE-2-100- m — Lab Sample ID: 320-117252-3

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorohexanoic acid (PFHxA)	0.56		0.19	0.030	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	1.1		0.19	0.037	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	0.69		0.19	0.052	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.12	J	0.19	0.052	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.81		0.19	0.052	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.094	J	0.19	0.021	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.095	J	0.19	0.036	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.54		0.19	0.028	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	3.4		0.19	0.028	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	2.8		0.19	0.028	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.081	J	0.19	0.048	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	2.4		0.19	0.042	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	1.6		0.19	0.042	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	4.1		0.19	0.042	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.74		0.19	0.026	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NE-4-100- m — Lab Sample ID: 320-117252-4

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorohexanoic acid (PFHxA)	0.30		0.18	0.029	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	3.1		0.18	0.035	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	0.97		0.18	0.049	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.27		0.18	0.049	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.2		0.18	0.049	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.15	J	0.18	0.020	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.22		0.18	0.034	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	4.2		0.18	0.027	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	20		0.18	0.027	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	16		0.18	0.027	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.15	J	0.18	0.045	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	3.6		0.18	0.040	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	2.5		0.18	0.040	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	6.1		0.18	0.040	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.50		0.18	0.025	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NE-2-200- m — Lab Sample ID: 320-117252-5

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorohexanoic acid (PFHxA)	0.051	J	0.20	0.031	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	1.0		0.20	0.038	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	3.7		0.20	0.053	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.94		0.20	0.053	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	4.6		0.20	0.053	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.45		0.20	0.022	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.038	J	0.20	0.037	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	3.0		0.20	0.029	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	32		0.20	0.029	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	29	E	0.20	0.029	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Eurofins Sacramento

Client Sample ID: NE-2-200- m (Continued)

Lab Sample ID: 320-117252-5

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanesulfonic acid (PFHpS)	0.39		0.20	0.049	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	11		0.20	0.043	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	5.6		0.20	0.043	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	17		0.20	0.043	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.38		0.20	0.027	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NE-4-200- m

Lab Sample ID: 320-117252-6

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.066	J	0.19	0.044	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	0.075	J	0.19	0.039	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	1.7		0.19	0.029	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	4.6	F1	0.19	0.036	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	3.8	F1	0.19	0.050	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.88		0.19	0.050	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	4.7	F1	0.19	0.050	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.72		0.19	0.021	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.094	J	0.19	0.045	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.076	J	0.19	0.040	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.091	J	0.19	0.036	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.39		0.19	0.035	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	4.9		0.19	0.027	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	26		0.19	0.027	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	21	E	0.19	0.027	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.62		0.19	0.046	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	15		0.19	0.041	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	12		0.19	0.041	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	27		0.19	0.041	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	1.1		0.19	0.026	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.044	J	0.19	0.033	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: C atrox skin

Lab Sample ID: 320-117252-7

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
8:2 FTS	66		0.85	0.085	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA) - DL	60	J	85	15	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA) - DL	93		85	23	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	220		85	17	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid - DL	19	J	85	17	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOA - DL	240		85	17	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	110		85	15	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	100		85	13	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	970		85	13	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	870		85	13	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	160		85	16	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	7200		210	17	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	3200		210	17	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	10000		210	17	ug/Kg	100		B/L/T PFAS	Total/NA
6:2 FTS - DL	1500		85	36	ug/Kg	100		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: C atrox skin (Continued)

Lab Sample ID: 320-117252-7

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA) - RA	12		0.85	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA) - RA	45		0.85	0.099	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA) - RA	12		0.85	0.088	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA) - RA	1.6		0.85	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS) - RA	12		0.85	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS) - RA	22		0.85	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS - RA	0.53	J	0.85	0.086	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client: University of New Mexico
Project/Site: UNM_Soil & Snake Skin, Holloman

Job ID: 320-117252-1

Client Sample ID: NE-2-100- m
Date Collected: 11/19/24 00:00
Date Received: 11/21/24 09:25

Lab Sample ID: 320-117252-3
Matrix: Solid

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.19	0.045	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
Perfluoropentanoic acid (PFPeA)	ND		0.19	0.040	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
Perfluorohexanoic acid (PFHxA)	**0.56**		0.19	0.030	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
Perfluoroheptanoic acid (PFHpA)	**1.1**		0.19	0.037	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
L-Perfluorooctanoic acid	**0.69**		0.19	0.052	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
Br-Perfluorooctanoic acid	**0.12**	**J**	0.19	0.052	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
Total PFOA	**0.81**		0.19	0.052	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
Perfluorononanoic acid (PFNA)	**0.094**	**J**	0.19	0.021	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
Perfluorodecanoic acid (PFDA)	ND		0.19	0.047	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
Perfluoroundecanoic acid (PFUnA)	ND		0.19	0.041	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.19	0.037	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
Perfluoropentanesulfonic acid (PFPeS)	**0.095**	**J**	0.19	0.036	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
Br-Perfluorohexanesulfonic acid	**0.54**		0.19	0.028	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
Total PFHxS	**3.4**		0.19	0.028	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
L-Perfluorohexanesulfonic acid	**2.8**		0.19	0.028	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.081**	**J**	0.19	0.048	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
L-Perfluorooctanesulfonic acid	**2.4**		0.19	0.042	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
Br-Perfluorooctanesulfonic acid	**1.6**		0.19	0.042	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
Total PFOS	**4.1**		0.19	0.042	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
4:2 FTS	ND		0.19	0.050	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
6:2 FTS	**0.74**		0.19	0.026	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
8:2 FTS	ND		0.19	0.034	ug/Kg		11/25/24 04:16	11/26/24 15:17	1
10:2 FTS	ND		0.19	0.037	ug/Kg		11/25/24 04:16	11/26/24 15:17	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*110*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:17*	*1*
13C5 PFPeA	*110*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:17*	*1*
13C2 PFHxA	*113*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:17*	*1*
13C4 PFHpA	*101*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:17*	*1*
13C4 PFOA	*91*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:17*	*1*
13C5 PFNA	*111*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:17*	*1*
13C2 PFDA	*101*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:17*	*1*
13C2 PFUnA	*96*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:17*	*1*
13C3 PFBS	*103*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:17*	*1*
18O2 PFHxS	*98*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:17*	*1*
13C4 PFOS	*97*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:17*	*1*
M2-4:2 FTS	*87*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:17*	*1*
M2-6:2 FTS	*97*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:17*	*1*
M2-8:2 FTS	*84*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:17*	*1*
13C2 10:2 FTS	*116*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:17*	*1*

General Chemistry

Analyte	Result	Qualifier	RL	RL	Unit	D	Prepared	Analyzed	Dil Fac
Percent Moisture (ASTM D2216-92)	**26**		0.10	0.10	%			12/03/24 14:12	1
Percent Solids (ASTM D2216-92)	**74**		0.10	0.10	%			12/03/24 14:12	1

Client Sample ID: NE-4-100- m

Date Collected: 11/19/24 00:00
Date Received: 11/21/24 09:25

Lab Sample ID: 320-117252-4

Matrix: Solid

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.18	0.043	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
Perfluoropentanoic acid (PFPeA)	ND		0.18	0.038	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
Perfluorohexanoic acid (PFHxA)	**0.30**		0.18	0.029	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
Perfluoroheptanoic acid (PFHpA)	**3.1**		0.18	0.035	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
L-Perfluorooctanoic acid	**0.97**		0.18	0.049	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
Br-Perfluorooctanoic acid	**0.27**		0.18	0.049	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
Total PFOA	**1.2**		0.18	0.049	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
Perfluorononanoic acid (PFNA)	**0.15**	**J**	0.18	0.020	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
Perfluorodecanoic acid (PFDA)	ND		0.18	0.044	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
Perfluoroundecanoic acid (PFUnA)	ND		0.18	0.039	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.18	0.035	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
Perfluoropentanesulfonic acid (PFPeS)	**0.22**		0.18	0.034	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
Br-Perfluorohexanesulfonic acid	**4.2**		0.18	0.027	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
Total PFHxS	**20**		0.18	0.027	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
L-Perfluorohexanesulfonic acid	**16**		0.18	0.027	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.15**	**J**	0.18	0.045	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
L-Perfluorooctanesulfonic acid	**3.6**		0.18	0.040	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
Br-Perfluorooctanesulfonic acid	**2.5**		0.18	0.040	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
Total PFOS	**6.1**		0.18	0.040	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
4:2 FTS	ND		0.18	0.047	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
6:2 FTS	**0.50**		0.18	0.025	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
8:2 FTS	ND		0.18	0.032	ug/Kg		11/25/24 04:16	11/26/24 15:36	1
10:2 FTS	ND		0.18	0.035	ug/Kg		11/25/24 04:16	11/26/24 15:36	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*99*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:36*	*1*
13C5 PFPeA	*107*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:36*	*1*
13C2 PFHxA	*108*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:36*	*1*
13C4 PFHpA	*105*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:36*	*1*
13C4 PFOA	*92*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:36*	*1*
13C5 PFNA	*100*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:36*	*1*
13C2 PFDA	*97*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:36*	*1*
13C2 PFUnA	*89*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:36*	*1*
13C3 PFBS	*104*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:36*	*1*
18O2 PFHxS	*97*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:36*	*1*
13C4 PFOS	*96*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:36*	*1*
M2-4:2 FTS	*106*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:36*	*1*
M2-6:2 FTS	*110*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:36*	*1*
M2-8:2 FTS	*76*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:36*	*1*
13C2 10:2 FTS	*135*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:36*	*1*

General Chemistry

Analyte	Result	Qualifier	RL	RL	Unit	D	Prepared	Analyzed	Dil Fac
Percent Moisture (ASTM D2216-92)	**15**		0.10	0.10	%			12/03/24 14:12	1
Percent Solids (ASTM D2216-92)	**85**		0.10	0.10	%			12/03/24 14:12	1

Client Sample ID: NE-2-200- m

Date Collected: 11/19/24 00:00
Date Received: 11/21/24 09:25

Lab Sample ID: 320-117252-5

Matrix: Solid

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.20	0.046	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
Perfluoropentanoic acid (PFPeA)	ND		0.20	0.041	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
Perfluorohexanoic acid (PFHxA)	**0.051**	**J**	0.20	0.031	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
Perfluoroheptanoic acid (PFHpA)	**1.0**		0.20	0.038	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
L-Perfluorooctanoic acid	**3.7**		0.20	0.053	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
Br-Perfluorooctanoic acid	**0.94**		0.20	0.053	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
Total PFOA	**4.6**		0.20	0.053	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
Perfluorononanoic acid (PFNA)	**0.45**		0.20	0.022	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
Perfluorodecanoic acid (PFDA)	ND		0.20	0.048	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
Perfluoroundecanoic acid (PFUnA)	ND		0.20	0.042	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.20	0.038	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
Perfluoropentanesulfonic acid (PFPeS)	**0.038**	**J**	0.20	0.037	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
Br-Perfluorohexanesulfonic acid	**3.0**		0.20	0.029	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
Total PFHxS	**32**		0.20	0.029	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
L-Perfluorohexanesulfonic acid	**29**	**E**	0.20	0.029	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.39**		0.20	0.049	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
L-Perfluorooctanesulfonic acid	**11**		0.20	0.043	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
Br-Perfluorooctanesulfonic acid	**5.6**		0.20	0.043	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
Total PFOS	**17**		0.20	0.043	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
4:2 FTS	ND		0.20	0.051	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
6:2 FTS	**0.38**		0.20	0.027	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
8:2 FTS	ND		0.20	0.035	ug/Kg		11/25/24 04:16	11/26/24 15:55	1
10:2 FTS	ND		0.20	0.038	ug/Kg		11/25/24 04:16	11/26/24 15:55	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*104*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:55*	*1*
13C5 PFPeA	*101*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:55*	*1*
13C2 PFHxA	*95*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:55*	*1*
13C4 PFHpA	*105*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:55*	*1*
13C4 PFOA	*85*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:55*	*1*
13C5 PFNA	*98*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:55*	*1*
13C2 PFDA	*99*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:55*	*1*
13C2 PFUnA	*93*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:55*	*1*
13C3 PFBS	*97*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:55*	*1*
18O2 PFHxS	*97*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:55*	*1*
13C4 PFOS	*92*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:55*	*1*
M2-4:2 FTS	*93*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:55*	*1*
M2-6:2 FTS	*83*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:55*	*1*
M2-8:2 FTS	*79*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:55*	*1*
13C2 10:2 FTS	*94*		*25 - 150*	*11/25/24 04:16*	*11/26/24 15:55*	*1*

General Chemistry

Analyte	Result	Qualifier	RL	RL	Unit	D	Prepared	Analyzed	Dil Fac
Percent Moisture (ASTM D2216-92)	**19**		0.10	0.10	%			12/03/24 14:12	1
Percent Solids (ASTM D2216-92)	**81**		0.10	0.10	%			12/03/24 14:12	1

Client: University of New Mexico
Project/Site: UNM_Soil & Snake Skin, Holloman

Job ID: 320-117252-1

Client Sample ID: NE-4-200- m

Date Collected: 11/19/24 00:00
Date Received: 11/21/24 09:25

Lab Sample ID: 320-117252-6

Matrix: Solid

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	0.066	J	0.19	0.044	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
Perfluoropentanoic acid (PFPeA)	0.075	J	0.19	0.039	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
Perfluorohexanoic acid (PFHxA)	1.7		0.19	0.029	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
Perfluoroheptanoic acid (PFHpA)	4.6	F1	0.19	0.036	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
L-Perfluorooctanoic acid	3.8	F1	0.19	0.050	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
Br-Perfluorooctanoic acid	0.88		0.19	0.050	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
Total PFOA	4.7	F1	0.19	0.050	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
Perfluorononanoic acid (PFNA)	0.72		0.19	0.021	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
Perfluorodecanoic acid (PFDA)	0.094	J	0.19	0.045	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
Perfluoroundecanoic acid (PFUnA)	0.076	J	0.19	0.040	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
Perfluorobutanesulfonic acid (PFBS)	0.091	J	0.19	0.036	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
Perfluoropentanesulfonic acid (PFPeS)	0.39		0.19	0.035	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
Br-Perfluorohexanesulfonic acid	4.9		0.19	0.027	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
Total PFHxS	26		0.19	0.027	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
L-Perfluorohexanesulfonic acid	21	E	0.19	0.027	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
Perfluoroheptanesulfonic acid (PFHpS)	0.62		0.19	0.046	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
L-Perfluorooctanesulfonic acid	15		0.19	0.041	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
Br-Perfluorooctanesulfonic acid	12		0.19	0.041	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
Total PFOS	27		0.19	0.041	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
4:2 FTS	ND		0.19	0.048	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
6:2 FTS	1.1		0.19	0.026	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
8:2 FTS	0.044	J	0.19	0.033	ug/Kg		11/25/24 04:16	11/26/24 16:15	1
10:2 FTS	ND		0.19	0.036	ug/Kg		11/25/24 04:16	11/26/24 16:15	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*89*		*25 - 150*	*11/25/24 04:16*	*11/26/24 16:15*	*1*
13C5 PFPeA	*110*		*25 - 150*	*11/25/24 04:16*	*11/26/24 16:15*	*1*
13C2 PFHxA	*103*		*25 - 150*	*11/25/24 04:16*	*11/26/24 16:15*	*1*
13C4 PFHpA	*95*		*25 - 150*	*11/25/24 04:16*	*11/26/24 16:15*	*1*
13C4 PFOA	*83*		*25 - 150*	*11/25/24 04:16*	*11/26/24 16:15*	*1*
13C5 PFNA	*94*		*25 - 150*	*11/25/24 04:16*	*11/26/24 16:15*	*1*
13C2 PFDA	*94*		*25 - 150*	*11/25/24 04:16*	*11/26/24 16:15*	*1*
13C2 PFUnA	*88*		*25 - 150*	*11/25/24 04:16*	*11/26/24 16:15*	*1*
13C3 PFBS	*105*		*25 - 150*	*11/25/24 04:16*	*11/26/24 16:15*	*1*
18O2 PFHxS	*96*		*25 - 150*	*11/25/24 04:16*	*11/26/24 16:15*	*1*
13C4 PFOS	*84*		*25 - 150*	*11/25/24 04:16*	*11/26/24 16:15*	*1*
M2-4:2 FTS	*122*		*25 - 150*	*11/25/24 04:16*	*11/26/24 16:15*	*1*
M2-6:2 FTS	*91*		*25 - 150*	*11/25/24 04:16*	*11/26/24 16:15*	*1*
M2-8:2 FTS	*82*		*25 - 150*	*11/25/24 04:16*	*11/26/24 16:15*	*1*
13C2 10:2 FTS	*149*		*25 - 150*	*11/25/24 04:16*	*11/26/24 16:15*	*1*

General Chemistry

Analyte	Result	Qualifier	RL	RL	Unit	D	Prepared	Analyzed	Dil Fac
Percent Moisture (ASTM D2216-92)	33		0.10	0.10	%			12/03/24 14:12	1
Percent Solids (ASTM D2216-92)	67		0.10	0.10	%			12/03/24 14:12	1

Client Sample ID: C atrox skin
Lab Sample ID: 320-117252-7

Date Collected: 11/19/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:25

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	66		0.85	0.085	ug/Kg		12/04/24 11:48	12/10/24 01:47	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
M2-8:2 FTS	*130*		*25 - 150*	*12/04/24 11:48*	*12/10/24 01:47*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoropentanoic acid (PFPeA)	60	J	85	15	ug/Kg		12/04/24 11:48	12/16/24 14:25	100
Perfluorohexanoic acid (PFHxA)	93		85	23	ug/Kg		12/04/24 11:48	12/16/24 14:25	100
L-Perfluorooctanoic acid	220		85	17	ug/Kg		12/04/24 11:48	12/16/24 14:25	100
Br-Perfluorooctanoic acid	19	J	85	17	ug/Kg		12/04/24 11:48	12/16/24 14:25	100
Total PFOA	240		85	17	ug/Kg		12/04/24 11:48	12/16/24 14:25	100
Perfluorononanoic acid (PFNA)	110		85	15	ug/Kg		12/04/24 11:48	12/16/24 14:25	100
Br-Perfluorohexanesulfonic acid	100		85	13	ug/Kg		12/04/24 11:48	12/16/24 14:25	100
Total PFHxS	970		85	13	ug/Kg		12/04/24 11:48	12/16/24 14:25	100
L-Perfluorohexanesulfonic acid	870		85	13	ug/Kg		12/04/24 11:48	12/16/24 14:25	100
Perfluoroheptanesulfonic acid (PFHpS)	160		85	16	ug/Kg		12/04/24 11:48	12/16/24 14:25	100
L-Perfluorooctanesulfonic acid	7200		210	17	ug/Kg		12/04/24 11:48	12/16/24 14:25	100
Br-Perfluorooctanesulfonic acid	3200		210	17	ug/Kg		12/04/24 11:48	12/16/24 14:25	100
Total PFOS	10000		210	17	ug/Kg		12/04/24 11:48	12/16/24 14:25	100
6:2 FTS	1500		85	36	ug/Kg		12/04/24 11:48	12/16/24 14:25	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFPeA	*59*		*25 - 150*	*12/04/24 11:48*	*12/16/24 14:25*	*100*
13C2 PFHxA	*71*		*25 - 150*	*12/04/24 11:48*	*12/16/24 14:25*	*100*
13C4 PFOA	*68*		*25 - 150*	*12/04/24 11:48*	*12/16/24 14:25*	*100*
13C5 PFNA	*68*		*25 - 150*	*12/04/24 11:48*	*12/16/24 14:25*	*100*
18O2 PFHxS	*86*		*25 - 150*	*12/04/24 11:48*	*12/16/24 14:25*	*100*
13C4 PFOS	*61*		*25 - 150*	*12/04/24 11:48*	*12/16/24 14:25*	*100*
M2-6:2 FTS	*99*		*25 - 150*	*12/04/24 11:48*	*12/16/24 14:25*	*100*
M2-8:2 FTS	*52*		*25 - 150*	*12/04/24 11:48*	*12/16/24 14:25*	*100*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	12		0.85	0.20	ug/Kg		12/04/24 11:48	12/11/24 03:40	1
Perfluoroheptanoic acid (PFHpA)	45		0.85	0.099	ug/Kg		12/04/24 11:48	12/11/24 03:40	1
Perfluorodecanoic acid (PFDA)	12		0.85	0.088	ug/Kg		12/04/24 11:48	12/11/24 03:40	1
Perfluoroundecanoic acid (PFUnA)	1.6		0.85	0.23	ug/Kg		12/04/24 11:48	12/11/24 03:40	1
Perfluorobutanesulfonic acid (PFBS)	12		0.85	0.15	ug/Kg		12/04/24 11:48	12/11/24 03:40	1
Perfluoropentanesulfonic acid (PFPeS)	22		0.85	0.15	ug/Kg		12/04/24 11:48	12/11/24 03:40	1
4:2 FTS	ND		0.85	0.23	ug/Kg		12/04/24 11:48	12/11/24 03:40	1
10:2 FTS	0.53	J	0.85	0.086	ug/Kg		12/04/24 11:48	12/11/24 03:40	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*78*		*25 - 150*	*12/04/24 11:48*	*12/11/24 03:40*	*1*
13C4 PFHpA	*85*		*25 - 150*	*12/04/24 11:48*	*12/11/24 03:40*	*1*
13C2 PFDA	*90*		*25 - 150*	*12/04/24 11:48*	*12/11/24 03:40*	*1*
13C2 PFUnA	*88*		*25 - 150*	*12/04/24 11:48*	*12/11/24 03:40*	*1*
13C3 PFBS	*95*		*25 - 150*	*12/04/24 11:48*	*12/11/24 03:40*	*1*

Client: University of New Mexico
Job ID: 320-117252-1
Project/Site: UNM_Soil & Snake Skin, Holloman

Client Sample ID: C atrox skin
Lab Sample ID: 320-117252-7
Date Collected: 11/19/24 00:00
Matrix: Tissue
Date Received: 11/21/24 09:25

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA (Continued)

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
M2-4:2 FTS	149		25 - 150	12/04/24 11:48	12/11/24 03:40	1
13C2 10:2 FTS	132		25 - 150	12/04/24 11:48	12/11/24 03:40	1

Isotope Dilution Summary

Client: University of New Mexico
Project/Site: UNM_Soil & Snake Skin, Holloman

Job ID: 320-117252-1

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Solid

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-117252-3	NE-2-100- m	110	110	113	101	91	111	101	96
320-117252-4	NE-4-100- m	99	107	108	105	92	100	97	89
320-117252-5	NE-2-200- m	104	101	95	105	85	98	99	93
320-117252-6	NE-4-200- m	89	110	103	95	83	94	94	88
320-117252-6 MS	NE-4-200- m	93	111	109	107	90	106	107	104
320-117252-6 MSD	NE-4-200- m	107	109	112	113	92	108	101	90
LCS 320-817586/2-A	Lab Control Sample	114	101	108	106	98	100	97	88
MB 320-817586/1-A	Method Blank	110	110	112	111	95	111	103	95

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)	
320-117252-3	NE-2-100- m	103	98	97	87	97	84	116	
320-117252-4	NE-4-100- m	104	97	96	106	110	76	135	
320-117252-5	NE-2-200- m	97	97	92	93	83	79	94	
320-117252-6	NE-4-200- m	105	96	84	122	91	82	149	
320-117252-6 MS	NE-4-200- m	101	106	95	141	107	101	188 *5+	
320-117252-6 MSD	NE-4-200- m	116	107	91	153 *5+	108	94	128	
LCS 320-817586/2-A	Lab Control Sample	113	105	100	98	84	80	115	
MB 320-817586/1-A	Method Blank	112	110	102	87	91	88	134	

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
PFHxA = 13C2 PFHxA
C4PFHA = 13C4 PFHpA
PFOA = 13C4 PFOA
PFNA = 13C5 PFNA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS
PFHxS = 18O2 PFHxS
PFOS = 13C4 PFOS
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
M102FTS = 13C2 10:2 FTS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Tissue

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	M282FTS (25-150)							
320-117252-7	C atrox skin	130							

Surrogate Legend

M282FTS = M2-8:2 FTS

Isotope Dilution Summary

Client: University of New Mexico
Job ID: 320-117252-1
Project/Site: UNM_Soil & Snake Skin, Holloman

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Tissue

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	PFBA (25-150)	C4PFHA (25-150)	PFDA (25-150)	PFUnA (25-150)	C3PFBS (25-150)	M242FTS (25-150)	M102FTS (25-150)
320-117252-7 - RA	C atrox skin	78	85	90	88	95	149	132

Surrogate Legend

PFBA = 13C4 PFBA
C4PFHA = 13C4 PFHpA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS
M242FTS = M2-4:2 FTS
M102FTS = 13C2 10:2 FTS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Tissue

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-117252-7 - DL	C atrox skin		59	71		68	68		
LCS 320-819252/2-A	Lab Control Sample	87	82	87	91	77	87	87	82
LCSD 320-819252/3-A	Lab Control Sample Dup	95	82	100	86	85	88	89	83
MB 320-819252/1-A	Method Blank	95	79	112	94	87	92	96	89

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
320-117252-7 - DL	C atrox skin		86	61		99	52	
LCS 320-819252/2-A	Lab Control Sample	73	98	87	87	86	72	351 *5+
LCSD 320-819252/3-A	Lab Control Sample Dup	88	105	89	94	91	83	350 *5+
MB 320-819252/1-A	Method Blank	93	103	100	69	101	82	396 *5+

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
PFHxA = 13C2 PFHxA
C4PFHA = 13C4 PFHpA
PFOA = 13C4 PFOA
PFNA = 13C5 PFNA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS
PFHxS = 18O2 PFHxS
PFOS = 13C4 PFOS
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
M102FTS = 13C2 10:2 FTS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Lab Sample ID: MB 320-817586/1-A
Matrix: Solid
Analysis Batch: 817947

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 817586

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.20	0.046	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluoropentanoic acid (PFPeA)	ND		0.20	0.041	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluorohexanoic acid (PFHxA)	ND		0.20	0.031	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluoroheptanoic acid (PFHpA)	ND		0.20	0.038	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
L-Perfluorooctanoic acid	ND		0.20	0.053	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Br-Perfluorooctanoic acid	ND		0.20	0.053	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Total PFOA	ND		0.20	0.053	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluorononanoic acid (PFNA)	ND		0.20	0.022	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluorodecanoic acid (PFDA)	ND		0.20	0.048	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluoroundecanoic acid (PFUnA)	ND		0.20	0.042	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.20	0.038	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.20	0.037	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Br-Perfluorohexanesulfonic acid	ND		0.20	0.029	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Total PFHxS	ND		0.20	0.029	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
L-Perfluorohexanesulfonic acid	ND		0.20	0.029	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.20	0.049	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
L-Perfluorooctanesulfonic acid	ND		0.20	0.043	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Br-Perfluorooctanesulfonic acid	ND		0.20	0.043	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
Total PFOS	ND		0.20	0.043	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
4:2 FTS	ND		0.20	0.051	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
6:2 FTS	ND		0.20	0.027	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
8:2 FTS	ND		0.20	0.035	ug/Kg		11/25/24 04:16	11/26/24 13:59	1
10:2 FTS	ND		0.20	0.038	ug/Kg		11/25/24 04:16	11/26/24 13:59	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*110*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C5 PFPeA	*110*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C2 PFHxA	*112*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C4 PFHpA	*111*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C4 PFOA	*95*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C5 PFNA	*111*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C2 PFDA	*103*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C2 PFUnA	*95*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C3 PFBS	*112*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
18O2 PFHxS	*110*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C4 PFOS	*102*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
M2-4:2 FTS	*87*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
M2-6:2 FTS	*91*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
M2-8:2 FTS	*88*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*
13C2 10:2 FTS	*134*		*25 - 150*	*11/25/24 04:16*	*11/26/24 13:59*	*1*

Lab Sample ID: LCS 320-817586/2-A
Matrix: Solid
Analysis Batch: 817947

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 817586

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	2.00	1.97		ug/Kg		98	76 - 136

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-817586/2-A
Matrix: Solid
Analysis Batch: 817947

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 817586

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluoropentanoic acid (PFPeA)	2.00	2.17		ug/Kg		108	74 - 134
Perfluorohexanoic acid (PFHxA)	2.00	1.91		ug/Kg		95	71 - 131
Perfluoroheptanoic acid (PFHpA)	2.00	1.98		ug/Kg		99	71 - 131
L-Perfluorooctanoic acid	2.00	1.83		ug/Kg		91	72 - 132
Total PFOA	2.00	1.83		ug/Kg		91	72 - 132
Perfluorononanoic acid (PFNA)	2.00	1.87		ug/Kg		94	73 - 133
Perfluorodecanoic acid (PFDA)	2.00	2.16		ug/Kg		108	72 - 132
Perfluoroundecanoic acid (PFUnA)	2.00	2.00		ug/Kg		100	75 - 135
Perfluorobutanesulfonic acid (PFBS)	1.78	1.65		ug/Kg		93	69 - 129
Perfluoropentanesulfonic acid (PFPeS)	1.88	1.61		ug/Kg		86	75 - 135
Total PFHxS	1.82	1.72		ug/Kg		95	62 - 122
L-Perfluorohexanesulfonic acid	1.82	1.72		ug/Kg		95	62 - 122
Perfluoroheptanesulfonic acid (PFHpS)	1.91	2.19		ug/Kg		115	76 - 136
L-Perfluorooctanesulfonic acid	1.86	1.83		ug/Kg		99	73 - 133
Total PFOS	1.86	1.83		ug/Kg		99	73 - 133
4:2 FTS	1.88	1.94		ug/Kg		104	71 - 131
6:2 FTS	1.90	1.78		ug/Kg		94	73 - 132
8:2 FTS	1.92	2.09		ug/Kg		109	75 - 135
10:2 FTS	1.93	1.84		ug/Kg		95	69 - 128

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*114*		*25 - 150*
13C5 PFPeA	*101*		*25 - 150*
13C2 PFHxA	*108*		*25 - 150*
13C4 PFHpA	*106*		*25 - 150*
13C4 PFOA	*98*		*25 - 150*
13C5 PFNA	*100*		*25 - 150*
13C2 PFDA	*97*		*25 - 150*
13C2 PFUnA	*88*		*25 - 150*
13C3 PFBS	*113*		*25 - 150*
18O2 PFHxS	*105*		*25 - 150*
13C4 PFOS	*100*		*25 - 150*
M2-4:2 FTS	*98*		*25 - 150*
M2-6:2 FTS	*84*		*25 - 150*
M2-8:2 FTS	*80*		*25 - 150*
13C2 10:2 FTS	*115*		*25 - 150*

Lab Sample ID: 320-117252-6 MS
Matrix: Solid
Analysis Batch: 817947

Client Sample ID: NE-4-200- m
Prep Type: Total/NA
Prep Batch: 817586

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	0.066	J	1.86	2.10		ug/Kg		109	76 - 136
Perfluoropentanoic acid (PFPeA)	0.075	J	1.86	1.88		ug/Kg		97	74 - 134
Perfluorohexanoic acid (PFHxA)	1.7		1.86	3.83		ug/Kg		113	71 - 131
Perfluoroheptanoic acid (PFHpA)	4.6	F1	1.86	6.89		ug/Kg		123	71 - 131

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: 320-117252-6 MS
Matrix: Solid
Analysis Batch: 817947

Client Sample ID: NE-4-200- m
Prep Type: Total/NA
Prep Batch: 817586

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec Limits
L-Perfluorooctanoic acid	3.8	F1	1.86	8.60	F1	ug/Kg		257	72 - 132
Total PFOA	4.7	F1	1.86	8.60	F1	ug/Kg		209	72 - 132
Perfluorononanoic acid (PFNA)	0.72		1.86	2.63		ug/Kg		103	73 - 133
Perfluorodecanoic acid (PFDA)	0.094	J	1.86	1.88		ug/Kg		96	72 - 132
Perfluoroundecanoic acid (PFUnA)	0.076	J	1.86	1.83		ug/Kg		94	75 - 135
Perfluorobutanesulfonic acid (PFBS)	0.091	J	1.65	1.91		ug/Kg		110	69 - 129
Perfluoropentanesulfonic acid (PFPeS)	0.39		1.75	2.18		ug/Kg		102	75 - 135
Total PFHxS	26		1.70	33.8	4	ug/Kg		489	62 - 122
L-Perfluorohexanesulfonic acid	21	E	1.70	33.8	E 4	ug/Kg		776	62 - 122
Perfluoroheptanesulfonic acid (PFHpS)	0.62		1.77	2.79		ug/Kg		123	76 - 136
L-Perfluorooctanesulfonic acid	15		1.73	33.9	E 4	ug/Kg		1101	73 - 133
Total PFOS	27		1.73	33.9	4	ug/Kg		421	73 - 133
4:2 FTS	ND		1.74	1.67		ug/Kg		96	71 - 131
6:2 FTS	1.1		1.77	2.81		ug/Kg		96	73 - 132
8:2 FTS	0.044	J	1.78	1.84		ug/Kg		101	75 - 135
10:2 FTS	ND		1.80	1.50		ug/Kg		83	69 - 128

Isotope Dilution	*MS %Recovery*	*MS Qualifier*	*Limits*
13C4 PFBA	*93*		*25 - 150*
13C5 PFPeA	*111*		*25 - 150*
13C2 PFHxA	*109*		*25 - 150*
13C4 PFHpA	*107*		*25 - 150*
13C4 PFOA	*90*		*25 - 150*
13C5 PFNA	*106*		*25 - 150*
13C2 PFDA	*107*		*25 - 150*
13C2 PFUnA	*104*		*25 - 150*
13C3 PFBS	*101*		*25 - 150*
18O2 PFHxS	*106*		*25 - 150*
13C4 PFOS	*95*		*25 - 150*
M2-4:2 FTS	*141*		*25 - 150*
M2-6:2 FTS	*107*		*25 - 150*
M2-8:2 FTS	*101*		*25 - 150*
13C2 10:2 FTS	*188*	*5+	*25 - 150*

Lab Sample ID: 320-117252-6 MSD
Matrix: Solid
Analysis Batch: 817947

Client Sample ID: NE-4-200- m
Prep Type: Total/NA
Prep Batch: 817586

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)	0.066	J	1.84	1.95		ug/Kg		103	76 - 136	7	30
Perfluoropentanoic acid (PFPeA)	0.075	J	1.84	1.81		ug/Kg		94	74 - 134	4	30
Perfluorohexanoic acid (PFHxA)	1.7		1.84	3.82		ug/Kg		114	71 - 131	0	30
Perfluoroheptanoic acid (PFHpA)	4.6	F1	1.84	5.75	F1	ug/Kg		63	71 - 131	18	30
L-Perfluorooctanoic acid	3.8	F1	1.84	7.66	F1	ug/Kg		209	72 - 132	11	30
Total PFOA	4.7	F1	1.84	7.66	F1	ug/Kg		161	72 - 132	11	30
Perfluorononanoic acid (PFNA)	0.72		1.84	2.39		ug/Kg		91	73 - 133	10	30

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: 320-117252-6 MSD — **Client Sample ID: NE-4-200- m**
Matrix: Solid — **Prep Type: Total/NA**
Analysis Batch: 817947 — **Prep Batch: 817586**

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorodecanoic acid (PFDA)	0.094	J	1.84	1.96		ug/Kg		101	72 - 132	4	30
Perfluoroundecanoic acid (PFUnA)	0.076	J	1.84	1.98		ug/Kg		104	75 - 135	8	30
Perfluorobutanesulfonic acid (PFBS)	0.091	J	1.63	1.68		ug/Kg		97	69 - 129	13	30
Perfluoropentanesulfonic acid (PFPeS)	0.39		1.73	1.98		ug/Kg		92	75 - 135	10	30
Total PFHxS	26		1.68	29.4	4	ug/Kg		231	62 - 122	14	30
L-Perfluorohexanesulfonic acid	21	E	1.68	29.4	E 4	ug/Kg		521	62 - 122	14	30
Perfluoroheptanesulfonic acid (PFHpS)	0.62		1.75	2.74		ug/Kg		121	76 - 136	2	30
L-Perfluorooctanesulfonic acid	15		1.71	31.5	E 4	ug/Kg		974	73 - 133	7	30
Total PFOS	27		1.71	31.5	4	ug/Kg		287	73 - 133	7	30
4:2 FTS	ND		1.72	1.50		ug/Kg		87	71 - 131	10	30
6:2 FTS	1.1		1.75	2.73		ug/Kg		92	73 - 132	3	30
8:2 FTS	0.044	J	1.76	1.77		ug/Kg		98	75 - 135	4	30
10:2 FTS	ND		1.78	1.66		ug/Kg		94	69 - 128	11	30

Isotope Dilution	*MSD %Recovery*	*MSD Qualifier*	*Limits*
13C4 PFBA	*107*		*25 - 150*
13C5 PFPeA	*109*		*25 - 150*
13C2 PFHxA	*112*		*25 - 150*
13C4 PFHpA	*113*		*25 - 150*
13C4 PFOA	*92*		*25 - 150*
13C5 PFNA	*108*		*25 - 150*
13C2 PFDA	*101*		*25 - 150*
13C2 PFUnA	*90*		*25 - 150*
13C3 PFBS	*116*		*25 - 150*
18O2 PFHxS	*107*		*25 - 150*
13C4 PFOS	*91*		*25 - 150*
M2-4:2 FTS	*153*	*5+	*25 - 150*
M2-6:2 FTS	*108*		*25 - 150*
M2-8:2 FTS	*94*		*25 - 150*
13C2 10:2 FTS	*128*		*25 - 150*

Lab Sample ID: MB 320-819252/1-A — **Client Sample ID: Method Blank**
Matrix: Tissue — **Prep Type: Total/NA**
Analysis Batch: 820782 — **Prep Batch: 819252**

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.27	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
L-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Total PFOA	ND		1.0	0.20	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.10	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.27	ug/Kg		12/04/24 11:48	12/09/24 23:31	1

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: MB 320-819252/1-A
Matrix: Tissue
Analysis Batch: 820782

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 819252

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Total PFHxS	ND		1.0	0.15	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
L-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Br-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
Total PFOS	ND		2.5	0.20	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
4:2 FTS	ND		1.0	0.27	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
6:2 FTS	ND		1.0	0.42	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
8:2 FTS	ND		1.0	0.10	ug/Kg		12/04/24 11:48	12/09/24 23:31	1
10:2 FTS	ND		1.0	0.10	ug/Kg		12/04/24 11:48	12/09/24 23:31	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*95*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C5 PFPeA	*79*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C2 PFHxA	*112*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C4 PFHpA	*94*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C4 PFOA	*87*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C5 PFNA	*92*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C2 PFDA	*96*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C2 PFUnA	*89*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C3 PFBS	*93*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
18O2 PFHxS	*103*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C4 PFOS	*100*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
M2-4:2 FTS	*69*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
M2-6:2 FTS	*101*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
M2-8:2 FTS	*82*		*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*
13C2 10:2 FTS	*396*	**5+*	*25 - 150*	*12/04/24 11:48*	*12/09/24 23:31*	*1*

Lab Sample ID: LCS 320-819252/2-A
Matrix: Tissue
Analysis Batch: 820782

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 819252

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	10.0	10.0		ug/Kg		100	76 - 136
Perfluoropentanoic acid (PFPeA)	10.0	9.69		ug/Kg		97	69 - 129
Perfluorohexanoic acid (PFHxA)	10.0	9.60		ug/Kg		96	71 - 131
Perfluoroheptanoic acid (PFHpA)	10.0	10.1		ug/Kg		101	71 - 131
L-Perfluorooctanoic acid	10.0	10.4		ug/Kg		104	72 - 132
Total PFOA	10.0	10.4		ug/Kg		104	
Perfluorononanoic acid (PFNA)	10.0	8.90		ug/Kg		89	73 - 133
Perfluorodecanoic acid (PFDA)	10.0	9.88		ug/Kg		99	72 - 132
Perfluoroundecanoic acid (PFUnA)	10.0	8.72		ug/Kg		87	66 - 126
Perfluorobutanesulfonic acid (PFBS)	8.88	10.3		ug/Kg		116	69 - 129

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-819252/2-A
Matrix: Tissue
Analysis Batch: 820782

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 819252

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits		
Perfluoropentanesulfonic acid (PFPeS)			9.40	10.3		ug/Kg		109	66 - 126		
Total PFHxS			9.12	8.09		ug/Kg		89			
L-Perfluorohexanesulfonic acid			9.12	8.09		ug/Kg		89	62 - 122		
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.7		ug/Kg		112	76 - 136		
L-Perfluorooctanesulfonic acid			9.30	9.35		ug/Kg		101	68 - 141		
Total PFOS			9.30	9.35		ug/Kg		101			
4:2 FTS			9.38	9.41		ug/Kg		100	68 - 143		
6:2 FTS			9.52	9.13		ug/Kg		96	73 - 139		
8:2 FTS			9.60	10.7		ug/Kg		111	75 - 135		
10:2 FTS			9.66	8.51		ug/Kg		88	69 - 145		

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*87*		*25 - 150*
13C5 PFPeA	*82*		*25 - 150*
13C2 PFHxA	*87*		*25 - 150*
13C4 PFHpA	*91*		*25 - 150*
13C4 PFOA	*77*		*25 - 150*
13C5 PFNA	*87*		*25 - 150*
13C2 PFDA	*87*		*25 - 150*
13C2 PFUnA	*82*		*25 - 150*
13C3 PFBS	*73*		*25 - 150*
18O2 PFHxS	*98*		*25 - 150*
13C4 PFOS	*87*		*25 - 150*
M2-4:2 FTS	*87*		*25 - 150*
M2-6:2 FTS	*86*		*25 - 150*
M2-8:2 FTS	*72*		*25 - 150*
13C2 10:2 FTS	*351*	**5+*	*25 - 150*

Lab Sample ID: LCSD 320-819252/3-A
Matrix: Tissue
Analysis Batch: 820782

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 819252

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)			10.0	9.89		ug/Kg		99	76 - 136	1	30
Perfluoropentanoic acid (PFPeA)			10.0	10.1		ug/Kg		101	69 - 129	5	30
Perfluorohexanoic acid (PFHxA)			10.0	9.62		ug/Kg		96	71 - 131	0	30
Perfluoroheptanoic acid (PFHpA)			10.0	10.8		ug/Kg		108	71 - 131	7	30
L-Perfluorooctanoic acid			10.0	9.64		ug/Kg		96	72 - 132	7	30
Total PFOA			10.0	9.64		ug/Kg		96		7	
Perfluorononanoic acid (PFNA)			10.0	9.75		ug/Kg		98	73 - 133	9	30
Perfluorodecanoic acid (PFDA)			10.0	10.6		ug/Kg		106	72 - 132	7	30
Perfluoroundecanoic acid (PFUnA)			10.0	9.69		ug/Kg		97	66 - 126	11	30
Perfluorobutanesulfonic acid (PFBS)			8.88	9.07		ug/Kg		102	69 - 129	12	30
Perfluoropentanesulfonic acid (PFPeS)			9.40	10.1		ug/Kg		107	66 - 126	2	30
Total PFHxS			9.12	8.38		ug/Kg		92		4	

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCSD 320-819252/3-A
Matrix: Tissue
Analysis Batch: 820782

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 819252

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
L-Perfluorohexanesulfonic acid			9.12	8.38		ug/Kg		92	62 - 122	4	30
Perfluoroheptanesulfonic acid (PFHpS)			9.54	11.0		ug/Kg		115	76 - 136	3	30
L-Perfluorooctanesulfonic acid			9.30	9.30		ug/Kg		100	68 - 141	1	30
Total PFOS			9.30	9.30		ug/Kg		100		1	
4:2 FTS			9.38	9.35		ug/Kg		100	68 - 143	1	30
6:2 FTS			9.52	9.42		ug/Kg		99	73 - 139	3	30
8:2 FTS			9.60	10.2		ug/Kg		106	75 - 135	5	30
10:2 FTS			9.66	8.71		ug/Kg		90	69 - 145	2	30

Isotope Dilution	*LCSD %Recovery*	*LCSD Qualifier*	*Limits*
13C4 PFBA	*95*		*25 - 150*
13C5 PFPeA	*82*		*25 - 150*
13C2 PFHxA	*100*		*25 - 150*
13C4 PFHpA	*86*		*25 - 150*
13C4 PFOA	*85*		*25 - 150*
13C5 PFNA	*88*		*25 - 150*
13C2 PFDA	*89*		*25 - 150*
13C2 PFUnA	*83*		*25 - 150*
13C3 PFBS	*88*		*25 - 150*
18O2 PFHxS	*105*		*25 - 150*
13C4 PFOS	*89*		*25 - 150*
M2-4:2 FTS	*94*		*25 - 150*
M2-6:2 FTS	*91*		*25 - 150*
M2-8:2 FTS	*83*		*25 - 150*
13C2 10:2 FTS	*350*	**5+*	*25 - 150*

LCMS

Prep Batch: 817586

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117252-3	NE-2-100- m	Total/NA	Solid	SHAKE	
320-117252-4	NE-4-100- m	Total/NA	Solid	SHAKE	
320-117252-5	NE-2-200- m	Total/NA	Solid	SHAKE	
320-117252-6	NE-4-200- m	Total/NA	Solid	SHAKE	
MB 320-817586/1-A	Method Blank	Total/NA	Solid	SHAKE	
LCS 320-817586/2-A	Lab Control Sample	Total/NA	Solid	SHAKE	
320-117252-6 MS	NE-4-200- m	Total/NA	Solid	SHAKE	
320-117252-6 MSD	NE-4-200- m	Total/NA	Solid	SHAKE	

Analysis Batch: 817947

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117252-3	NE-2-100- m	Total/NA	Solid	B/L/T PFAS	817586
320-117252-4	NE-4-100- m	Total/NA	Solid	B/L/T PFAS	817586
320-117252-5	NE-2-200- m	Total/NA	Solid	B/L/T PFAS	817586
320-117252-6	NE-4-200- m	Total/NA	Solid	B/L/T PFAS	817586
MB 320-817586/1-A	Method Blank	Total/NA	Solid	B/L/T PFAS	817586
LCS 320-817586/2-A	Lab Control Sample	Total/NA	Solid	B/L/T PFAS	817586
320-117252-6 MS	NE-4-200- m	Total/NA	Solid	B/L/T PFAS	817586
320-117252-6 MSD	NE-4-200- m	Total/NA	Solid	B/L/T PFAS	817586

Pre Prep Batch: 819250

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117252-7	C atrox skin	Total/NA	Tissue	In-House	
320-117252-7 - RA	C atrox skin	Total/NA	Tissue	In-House	
320-117252-7 - DL	C atrox skin	Total/NA	Tissue	In-House	

Prep Batch: 819252

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117252-7	C atrox skin	Total/NA	Tissue	SHAKE	819250
320-117252-7 - RA	C atrox skin	Total/NA	Tissue	SHAKE	819250
320-117252-7 - DL	C atrox skin	Total/NA	Tissue	SHAKE	819250
MB 320-819252/1-A	Method Blank	Total/NA	Tissue	SHAKE	
LCS 320-819252/2-A	Lab Control Sample	Total/NA	Tissue	SHAKE	
LCSD 320-819252/3-A	Lab Control Sample Dup	Total/NA	Tissue	SHAKE	

Analysis Batch: 820782

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117252-7	C atrox skin	Total/NA	Tissue	B/L/T PFAS	819252
MB 320-819252/1-A	Method Blank	Total/NA	Tissue	B/L/T PFAS	819252
LCS 320-819252/2-A	Lab Control Sample	Total/NA	Tissue	B/L/T PFAS	819252
LCSD 320-819252/3-A	Lab Control Sample Dup	Total/NA	Tissue	B/L/T PFAS	819252

Analysis Batch: 821097

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117252-7 - RA	C atrox skin	Total/NA	Tissue	B/L/T PFAS	819252

Analysis Batch: 822232

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117252-7 - DL	C atrox skin	Total/NA	Tissue	B/L/T PFAS	819252

QC Association Summary

Client: University of New Mexico
Job ID: 320-117252-1
Project/Site: UNM_Soil & Snake Skin, Holloman

General Chemistry

Analysis Batch: 819026

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117252-3	NE-2-100- m	Total/NA	Solid	D2216-92	
320-117252-4	NE-4-100- m	Total/NA	Solid	D2216-92	
320-117252-5	NE-2-200- m	Total/NA	Solid	D2216-92	
320-117252-6	NE-4-200- m	Total/NA	Solid	D2216-92	

Client Sample ID: NE-2-100- m
Date Collected: 11/19/24 00:00
Date Received: 11/21/24 09:25

Lab Sample ID: 320-117252-3
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			5.13 g	10.0 mL	817586	11/25/24 04:16	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	817947	11/26/24 15:17	S1C	EET SAC
Total/NA	Analysis	D2216-92		1			819026	12/03/24 14:12	JCB	EET SAC

Client Sample ID: NE-4-100- m
Date Collected: 11/19/24 00:00
Date Received: 11/21/24 09:25

Lab Sample ID: 320-117252-4
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			5.41 g	10.0 mL	817586	11/25/24 04:16	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	817947	11/26/24 15:36	S1C	EET SAC
Total/NA	Analysis	D2216-92		1			819026	12/03/24 14:12	JCB	EET SAC

Client Sample ID: NE-2-200- m
Date Collected: 11/19/24 00:00
Date Received: 11/21/24 09:25

Lab Sample ID: 320-117252-5
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			5.03 g	10.0 mL	817586	11/25/24 04:16	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	817947	11/26/24 15:55	S1C	EET SAC
Total/NA	Analysis	D2216-92		1			819026	12/03/24 14:12	JCB	EET SAC

Client Sample ID: NE-4-200- m
Date Collected: 11/19/24 00:00
Date Received: 11/21/24 09:25

Lab Sample ID: 320-117252-6
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			5.28 g	10.0 mL	817586	11/25/24 04:16	R1T	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	817947	11/26/24 16:15	S1C	EET SAC
Total/NA	Analysis	D2216-92		1			819026	12/03/24 14:12	JCB	EET SAC

Client Sample ID: C atrox skin
Date Collected: 11/19/24 00:00
Date Received: 11/21/24 09:25

Lab Sample ID: 320-117252-7
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	819250	12/04/24 11:42	ATB	EET SAC
Total/NA	Prep	SHAKE			1.17 g	10.0 mL	819252	12/04/24 11:48	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820782	12/10/24 01:47	P1P	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	819250	12/04/24 11:42	ATB	EET SAC
Total/NA	Prep	SHAKE	RA		1.17 g	10.0 mL	819252	12/04/24 11:48	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	821097	12/11/24 03:40	S1C	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	819250	12/04/24 11:42	ATB	EET SAC
Total/NA	Prep	SHAKE	DL		1.17 g	10.0 mL	819252	12/04/24 11:48	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	822232	12/16/24 14:25	JTD	EET SAC

Lab Chronicle

Client: University of New Mexico
Project/Site: UNM_Soil & Snake Skin, Holloman

Job ID: 320-117252-1

Laboratory References:

EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

Accreditation/Certification Summary

Client: University of New Mexico
Job ID: 320-117252-1
Project/Site: UNM_Soil & Snake Skin, Holloman

Laboratory: Eurofins Sacramento

All accreditations/certifications held by this laboratory are listed. Not all accreditations/certifications are applicable to this report.

Authority	Program	Identification Number	Expiration Date
Alaska (UST)	State	17-020	02-20-27
ANAB	Dept. of Defense ELAP	L2468	01-20-27
ANAB	Dept. of Energy	L2468.01	01-20-27
ANAB	ISO/IEC 17025	L2468	01-20-27
Arizona	State	AZ0708	08-11-25
Arkansas DEQ	State	88-0691	05-18-25
California	State	2897	01-31-26
Colorado	State	CA00044	08-31-25
Florida	NELAP	E87570	06-30-25
Georgia	State	4040	01-29-25
Hawaii	State	Eurofins Sacramento	01-29-25
Illinois	NELAP	200060	03-31-25
Kansas	NELAP	E-10375	10-31-25
Louisiana	NELAP	01944	06-30-25
Louisiana (All)	NELAP	01944	06-30-25
Maine	State	CA00004	04-14-26
Michigan	State	9947	01-29-25
Minnesota	NELAP	2749448	12-31-25
Nevada	State	CA00044	07-31-25
New Hampshire	NELAP	2997	04-19-25
New Jersey	NELAP	CA005	06-30-25
New York	NELAP	11666	04-01-25
Ohio	State	41252	01-29-25
Oregon	NELAP	4040	01-29-25
Texas	NELAP	T104704399-23-17	05-31-25
US Fish & Wildlife	US Federal Programs	A22139	04-30-25
USDA	US Federal Programs	P330-18-00239	02-28-26
Utah	NELAP	CA000442023-16	02-28-25
Virginia	NELAP	460278	03-14-25
Washington	State	C581	05-05-25
West Virginia (DW)	State	9930C	01-31-25
Wisconsin	State	998204680	08-31-25
Wyoming	State Program	8TMS-L	01-28-19 *

* Accreditation/Certification renewal pending - accreditation/certification considered valid.

Method Summary

Client: University of New Mexico
Project/Site: UNM_Soil & Snake Skin, Holloman

Job ID: 320-117252-1

Method	Method Description	Protocol	Laboratory
B/L/T PFAS	Branched, Linear and Total PFAS	EPA	EET SAC
D2216-92	Percent Moisture	ASTM	EET SAC
In-House	Tissue Preparation/Homgenization	NOAA	EET SAC
SHAKE	Shake Extraction with Ultrasonic Bath Extraction	SW846	EET SAC

Protocol References:

ASTM = ASTM International

EPA = US Environmental Protection Agency

NOAA = National Marine Fisheries Service, National Oceanic And Atmospheric Administration, Seattle, WA, November 1988

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

Sample Summary

Client: University of New Mexico
Project/Site: UNM_Soil & Snake Skin, Holloman

Job ID: 320-117252-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
320-117252-3	NE-2-100- m	Solid	11/19/24 00:00	11/21/24 09:25
320-117252-4	NE-4-100- m	Solid	11/19/24 00:00	11/21/24 09:25
320-117252-5	NE-2-200- m	Solid	11/19/24 00:00	11/21/24 09:25
320-117252-6	NE-4-200- m	Solid	11/19/24 00:00	11/21/24 09:25
320-117252-7	C atrox skin	Tissue	11/19/24 00:00	11/21/24 09:25

320-117252 Chain of Custody

Eurofins Env. Testing Northern California
880 Riverside Parkway
West Sacramento, CA 95605
Phone: 916.373.5600

Chain of Custody Record

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Client Contact	Report To Jean-Luc Cartron and Jon Dunnum	Site Contact:	Date: 11/20/2024	COC No
Jean-Luc Cartron	email. jlec@unm.edu, jldunnum@unm.edu	Lab Contact: Linda Laver	Carrier: FedEx	1 of 1 COCs
jcartron@geo-logic.com	Analysis Turnaround Time			Job No.
jlec@unm edu	Business Days (BD) _____			
	TAT if different from Above _____			Field Sampler
	☐ 2 weeks			
	☐ 1 week			
	☐ 2 days			
	☐ 1 day			

Sample Identification	Sample Date	Sample Time	Sample Type	Matrix	# of Cont.	Filtered Sample	Enter requested analyses in these fields	Sample Specific Notes:
NE-2-0 m	19-Nov-24		Soil		1		Soil Organic Content (soil carbon content)	ETERMINATION (NOT PFAS SCREENING) Surface soil coll
NE-4-0 m	19-Nov-24		Soil		1		Soil Organic Content (soil carbon content)	ETERMINATION (NOT PFAS SCREENING) Surface soil coll
NE-2-100 m	19-Nov-24		Soil		1		PFAS targeted analysis	GETED ANALYSIS Surface soil collected along NE-2 transect 10
NE-4-100 m	19-Nov-24		Soil		1		PFAS targeted analysis	GETED ANALYSIS Surface soil collected along NE-4 transect 10
NE-2-200 m	19-Nov-24		Soil				PFAS targeted analysis	GETED ANALYSIS Surface soil collected along NE-2 transect 10
NE-4-200 m	19-Nov-24		Soil		1		PFAS targeted analysis	GETED ANALYSIS Surface soil collected along NE-4 transect 20
C. atrox skin	19-Nov-24		Snake skin		1		PFAS targeted analysis	ALYSIS Snake skin collected along shoreline (please dry tissue as

Preservation Used. 1= Ice, 2= HCl, 3= H2SO4, 4=HNO3, 5=NaOH, 6= Other ___1=ice_____

Possible Hazard Identification
☒ *Non-Hazard* ☐ *Flammable* ☐ *Skin Irritant* *Poison B* *Unknown* ☐ ☐

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☐ *Return To Client* ☒ *Disposal By Lab* ☐ *Archive For _____ Months*

Special Instructions/QC Requirements & Comments: Note that 2 of the soil samples are for quantifying soil organic content, the other 5 samples are for PFAS targeted analyses. The snake skin was washed to remove dirt debris. To the extent possible, please dry the skin prior to analysis. *Thank you*

Relinquished by: Jean-Luc Cartron	Company: Daniel B. Stephens & Associates	Date/Time: 11/20	Received by:	Company: ESSgc	Date/Time: 11/21/24 0925
Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:
Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:

2 3°C

12/23/2024

NMED Exhibits 65

14 13 12 11 10 9 8 7 6 5 4 3 2 1

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Sacramento Sample Receiving Notes (SSRN)

Loc: 320
117252

Tracking # 7701 0222 0190

Job _____ _____

SO / PO / FO / SAT / 2-Day / Ground / UPS / CDO / Courier
GSL / OnTrac / Goldstreak / USPS / Other _____

Use this form to record Sample Custody Seal, Cooler Custody Seal, Temperature & corrected Temperature & other observations
File in the job folder with the COC

Therm ID 104 Corr Factor (+ / -) 0.0 °C

Ice ✓ Wet ✓ Gel _____ Other _____

Cooler Custody Seal —

Cooler ID: —

Temp Observed 2.3 °C Corrected 2.3 °C

From Temp Blank ☒ Sandwich ☐ Sidewall ☐

Opening/Processing The Shipment	Yes	No	NA
Cooler compromised/tampered with?	☐	☒	☐
Cooler Temperature is acceptable?	☒	☐	☐
Frozen samples show signs of thaw?	☐	☐	☒

Initials SO Date 11/21/24

Unpacking/Labeling The Samples	Yes	No	NA
Containers are not broken or leaking?	☒	☐	☐
Samples compromised/tampered with?	☐	☒	☐
COC is complete w/o discrepancies	☒	☐	☐
Sample custody seal?	☐	☐	☒
Sample containers have legible labels?	☒	☐	☐
Sample date/times are provided?	☒	☐	☐
Appropriate containers are used?	☒	☐	☐
Sample bottles are completely filled?	☒	☐	☐
Sample preservatives verified?	☐	☐	☒
Is the Field Sampler's name on COC?	☐	☒	☐
Samples w/o discrepancies?	☐	☒	☐
Zero headspace?*	☐	☐	☒
Alkalinity has no headspace?	☐	☐	☒
Perchlorate has headspace? (Methods 314, 331, 6850)	☐	☐	☒
Multiphasic samples are not present?	☒	☐	☐

*Containers requiring zero headspace have no headspace, or bubble < 6 mm (1/4")

Initials SO Date 11/21/24

Notes:
① · ② No Data

Trizma Lot #(s) _____

Ammonium Acetate Lot #(s) _____

Login Completion	Yes	No	NA
Receipt Temperature on COC?	☒	☐	☐
NCM Filed?	☒	☐	☐
Samples received within hold time?	☒	☐	☐
Log Release checked in TALS?	☒	☐	☐

Initials SO Date 11/21/24

Eurofins Sacramento
880 Riverside Parkway
West Sacramento, CA 95605
Phone: 916-373-5600 Fax: 916-372-1059

Chain of Custody Record

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12/23/2024

Client Information (Sub Contract Lab)	Sampler: N/A	Lab PM: Laver Linda C.	Carrier Tracking No(s): N/A	COC No: 320-355433.1
Client Contact: Shipping/Receiving	Phone: N/A	E-Mail: Linda.Laver@et.eurofinsus.com	State of Origin: New Mexico	Page: Page 1 of 1
Company: Eurofins Environment Testing South Centr		Accreditations Required (See note): N/A		Job #: 320-117252-1
Address: 4145 Greenbriar Dr	Due Date Requested: 12/16/2024			Preservation Codes:
City: Stafford	TAT Requested (days): N/A			
State, Zip: TX, 77477				
Phone: 281-240-4200(Tel)	PO #: N/A			
Email: N/A	WO #: N/A			
Project Name: UNM_Soil & Snake Skin, Holloman	Project #: 32019969			
Site: N/A	SSOW#: N/A			Other: N/A

Analysis Requested

Sample Identification Client ID (Lab ID)	Sample Date	Sample Time	Sample Type (C=comp, G=grab)	Matrix (W=water, S=solid, O=waste/oil, BT=Tissue, A=Air)	Field Filtered Sample (Yes or No)	Perform MS/MSD (Yes or No)	9060A_Soil_MOD	Total Number of containers	Special Instructions/Note:
			Preservation Code:						
NE-2-0- m (320-117252-1)	11/19/24	Mountain	G	Solid			X	1	
NE-4-0- m (320-117252-2)	11/19/24	Mountain	G	Solid			X	1	

Note: Since laboratory accreditations are subject to change, Eurofins Environment Testing Northern California, LLC places the ownership of method, analyte & accreditation compliance upon our subcontract laboratories. This sample shipment is forwarded under chain-of-custody. If the laboratory does not currently maintain accreditation in the State of Origin listed above for analysis/tests/matrix being analyzed, the samples must be shipped back to the Eurofins Environment Testing Northern California, LLC laboratory or other instructions will be provided. Any changes to accreditation status should be brought to Eurofins Environment Testing Northern California, LLC attention immediately. If all requested accreditations are current to date, return the signed Chain of Custody attesting to said compliance to Eurofins Environment Testing Northern California, LLC.

Possible Hazard Identification	Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
Unconfirmed	☐ Return To Client ☐ Disposal By Lab ☐ Archive For _____ Months
Deliverable Requested: I, II, III, IV Other (specify) Primary Deliverable Rank: 2	Special Instructions/QC Requirements:

Empty Kit Relinquished by:	Date:	Time:	Method of Shipment:

	Relinquished by:	Date/Time:	Company	Received by:	Date/Time:	Company
	Relinquished by:	11/22/24 1630	EETSac			
	Relinquished by:	Date/Time:	Company	Received by:	Date/Time:	Company
	Relinquished by:	Date/Time:	Company	Received by:	Date/Time: 11-22-24 0930	Company

Custody Seals Intact: Δ Yes Δ No	Custody Seal No.	Cooler Temperature(s) °C and Other Remarks: 12 7/8 37

Ver 10/10/2024

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ANALYTICAL REPORT

PREPARED FOR

Attn: Jean-Luc Cartron
University of New Mexico
Museum of Southwestern Biology
Division of Mammals
CERIA Bldg 83, Room 204
Albuquerque, New Mexico 87131

Generated 10/22/2024 11:34:33 AM

JOB DESCRIPTION

Holloman Lake PFAS Research

JOB NUMBER

320-115443-1

Eurofins Sacramento
880 Riverside Parkway
West Sacramento CA 95605

See page two for job notes and contact information.

NMED Exhibits 65

my EOL

Job Notes

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The test results in this report relate only to the samples as received by the laboratory and will meet all requirements of the methodology, with any exceptions noted. This report shall not be reproduced except in full, without the express written approval of the laboratory. All questions should be directed to the Eurofins Environment Testing Northern California, LLC Project Manager.

Authorization



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10/22/2024 11:34:33 AM

Authorized for release by
Linda C. Laver, Senior Project Manager
Linda.Laver@et.eurofinsus.com
(916)374-4362

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Definitions/Glossary

Client: University of New Mexico
Job ID: 320-115443-1
Project/Site: Holloman Lake PFAS Research

Qualifiers

LCMS

Qualifier	Qualifier Description
*5+	Isotope dilution analyte is outside acceptance limits, high biased.
B	Compound was found in the blank and sample.
E	Result exceeded calibration range.
H	Sample was prepped or analyzed beyond the specified holding time. This does not meet regulatory requirements.
H3	Sample was received and analyzed past holding time. This does not meet regulatory requirements.
I	Value is EMPC (estimated maximum possible concentration).
J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
☼	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CFU	Colony Forming Unit
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MCL	EPA recommended "Maximum Contaminant Level"
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
MPN	Most Probable Number
MQL	Method Quantitation Limit
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
NEG	Negative / Absent
POS	Positive / Present
PQL	Practical Quantitation Limit
PRES	Presumptive
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)
TNTC	Too Numerous To Count

Job ID: 320-115443-1 — Eurofins Sacramento

Job Narrative
320-115443-1

Receipt
The samples were received on 9/17/2024 9:40 AM. Unless otherwise noted below, the samples arrived in good condition, and where required, properly preserved and on ice. The temperature of the cooler at receipt was -34.2º C.

Receipt Exceptions
The Chain-of-Custody (COC) was incomplete as received and was not signed at the time samples were relinquished to the lab and does not list the requested analyses. Based on communications with the client, the samples were logged in for PFAS by 537 Mod.

The COC and container label for each sample did not include a collection time. Samples were logged with a default time as 00:00.

LCMS
Method B/L/T PFAS: Isotope Dilution Analyte (IDA) recovery is above the method recommended limit for the following samples. Quantitation by isotope dilution generally precludes any adverse effect on data quality due to elevated IDA recoveries. NK284441 liver (320-115443-1), NK284445 liver (320-115443-2), NK284446 liver (320-115443-3), NK284447 liver (320-115443-4), NK284448 liver (320-115443-5), NK284449 liver (320-115443-6), NK284450 liver (320-115443-7), NK284451 liver (320-115443-8), NK284458 liver (320-115443-9), African Rue East Intake (320-115443-11), Saltcedar East Intake (320-115443-12), Saltcedar NE 4-1 (320-115443-13), pickleweed NE 4-1 (320-115443-14), MSBHerp109299 muscle (320-115443-15), MSBHerp109299 liver (320-115443-16), NK319555 muscle (320-115443-17), NK319556 muscle (320-115443-18), NK319556 liver (320-115443-19), MSB89187 femur (320-115443-20), MSB89196 femur (320-115443-23), MSB87701 femur (320-115443-24), MSB87702 femur (320-115443-25), MSB89195 femur (320-115443-26), (MB 320-802924/1-A), (LCS 320-802924/2-A), (LCSD 320-802924/3-A), (MB 320-803280/1-A), (LCS 320-803280/2-A) and (LCSD 320-803280/3-A)

Method B/L/T PFAS: The "I" qualifier means the transition mass ratio for the indicated analyte was outside the established ratio limits. The qualitative identification of the analyte has some degree of uncertainty. However, analyst judgment was used to positively identify the analyte. NK284447 liver (320-115443-4).

Method B/L/T PFAS: Results for the following samples were reported from the analysis of a diluted extract due to high concentration of the target analyte in the analysis of the undiluted extract. The dilution factor was applied to the labeled internal standard area counts and these area counts were within acceptance limits. NK284441 liver (320-115443-1), NK284445 liver (320-115443-2), NK284446 liver (320-115443-3), NK284448 liver (320-115443-5), NK284449 liver (320-115443-6), NK284450 liver (320-115443-7), NK284451 liver (320-115443-8), NK284463 eggshell + contents (320-115443-10), Saltcedar East Intake (320-115443-12), Saltcedar NE 4-1 (320-115443-13), pickleweed NE 4-1 (320-115443-14), MSBHerp109299 muscle (320-115443-15), MSBHerp109299 liver (320-115443-16) and NK319555 muscle (320-115443-17)

Method B/L/T PFAS: The concentration of L-Perfluorooctanesulfonic acid associated with the following sample exceeded the instrument calibration range. The analyte has been qualified (E); however, the peaks did not saturate the instrument detector. The concentration was over calibration range at the laboratory's maximum possible dilution; therefore, no further corrective action was performed and the data have been reported. NK284463 eggshell + contents (320-115443-10)

Method B/L/T PFAS: The method blank for preparation batch 320-802924 had detections of some analytes above the method detection limit (J), but less than the reporting limit (RL); therefore, re-extraction of the associated samples was not performed.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Organic Prep
Method SHAKE: Several samples were received with less than 1 g of material and were processed at reduced mass. The reporting limits (RLs) have been elevated proportionately.

Method SHAKE: The following sample extract contained particulates which clogged the solid phase clean-up column: NK284463 eggshell + contents (320-115443-10).

Method SHAKE: The following samples were discolored following extraction. NK284441 liver (320-115443-1), NK284445 liver (320-115443-2), NK284446 liver (320-115443-3), NK284448 liver (320-115443-5), NK284458 liver (320-115443-9), NK284463 eggshell + contents (320-115443-10), African Rue East Intake (320-115443-11), Saltcedar East Intake (320-115443-12) and Saltcedar NE 4-1 (320-115443-13), pickleweed NE 4-1 (320-115443-14), MSBHerp109299 liver (320-115443-16), NK319555 muscle (320-115443-17), NK319556 liver (320-115443-19), MSB87701 femur (320-115443-24) and MSB87702 femur (320-115443-25).

Job ID: 320-115443-1 (Continued)

Method SHAKE: The following samples were received after the laboratory's default holding time from sample collection to sample preparation had expired: MSB89187 femur (320-115443-20), MSB92667 femur (320-115443-21), MSB61848 femur (320-115443-22), MSB89196 femur (320-115443-23), MSB87701 femur (320-115443-24), MSB87702 femur (320-115443-25), MSB89195 femur (320-115443-26) and MSB61849 femur (320-115443-27)

Method SHAKE: Insufficient sample volume was available to perform a matrix spike/matrix spike duplicate/sample duplicate (MS/MSD/DUP) associated with preparation batches 320-802924 and 320-803280.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Detection Summary

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: NK284441 liver — Lab Sample ID: 320-115443-1

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	9.1	J	13	2.5	ug/Kg	5		B/L/T PFAS	Total/NA
Total PFOA	9.1	J	13	2.5	ug/Kg	5		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	53		13	2.2	ug/Kg	5		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	19		13	1.3	ug/Kg	5		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	6.8	J	13	3.4	ug/Kg	5		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	11	J	13	1.9	ug/Kg	5		B/L/T PFAS	Total/NA
Total PFHxS	300		13	1.9	ug/Kg	5		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	290		13	1.9	ug/Kg	5		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	110		13	2.3	ug/Kg	5		B/L/T PFAS	Total/NA
8:2 FTS	80		13	1.3	ug/Kg	5		B/L/T PFAS	Total/NA
10:2 FTS	14		13	1.3	ug/Kg	5		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	9700	B	310	25	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	6800		310	25	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS - DL	17000	B	310	25	ug/Kg	50		B/L/T PFAS	Total/NA

Client Sample ID: NK284445 liver — Lab Sample ID: 320-115443-2

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorohexanoic acid (PFHxA)	2.8	J B	5.9	1.6	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	2.7	J	5.9	0.68	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	56		5.9	1.2	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	5.1	J	5.9	1.2	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	61		5.9	1.2	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	78		5.9	1.0	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	24		5.9	0.61	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	9.1		5.9	1.6	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	4.3	J	5.9	1.1	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	34		5.9	0.87	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	520		5.9	0.87	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	490		5.9	0.87	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	120		5.9	1.1	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	75		5.9	0.59	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	12		5.9	0.59	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	9300	B	740	60	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	2600		740	60	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS - DL	12000	B	740	60	ug/Kg	50		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA) - RA	1.3	J B	5.9	1.0	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK284446 liver — Lab Sample ID: 320-115443-3

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanoic acid (PFHpA)	3.0	J	22	2.6	ug/Kg	10		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	50		22	4.5	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOA	50		22	4.5	ug/Kg	10		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	48		22	3.9	ug/Kg	10		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	16	J	22	2.3	ug/Kg	10		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	7.8	J	22	6.0	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	23		22	3.3	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFHxS	530		22	3.3	ug/Kg	10		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	500		22	3.3	ug/Kg	10		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK284446 liver (Continued)

Lab Sample ID: 320-115443-3

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanesulfonic acid (PFHpS)	84		22	4.1	ug/Kg	10		B/L/T PFAS	Total/NA
8:2 FTS	36		22	2.2	ug/Kg	10		B/L/T PFAS	Total/NA
10:2 FTS	6.3	J	22	2.2	ug/Kg	10		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	6000	B	280	23	ug/Kg	50		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	4300		280	23	ug/Kg	50		B/L/T PFAS	Total/NA
Total PFOS - DL	10000	B	280	23	ug/Kg	50		B/L/T PFAS	Total/NA

Client Sample ID: NK284447 liver

Lab Sample ID: 320-115443-4

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	1.2	J	5.9	1.2	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.2	J	5.9	1.2	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	1.6	J	5.9	0.87	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	6.8		5.9	0.87	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	5.2	J	5.9	0.87	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - RA	78	I B	15	1.2	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - RA	19		15	1.2	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS - RA	96	B	15	1.2	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK284448 liver

Lab Sample ID: 320-115443-5

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanoic acid (PFHpA)	1.4	J	1.8	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	13		1.8	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.88	J	1.8	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	14		1.8	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	8.7		1.8	0.31	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.82	J	1.8	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.94	J B	1.8	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	5.4		1.8	0.32	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	37		1.8	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	200		1.8	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	160		1.8	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	9.4		1.8	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	3.9		1.8	0.76	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	1.8		1.8	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	660	B	89	7.3	ug/Kg	20		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	2600		89	7.3	ug/Kg	20		B/L/T PFAS	Total/NA
Total PFOS - DL	3200	B	89	7.3	ug/Kg	20		B/L/T PFAS	Total/NA

Client Sample ID: NK284449 liver

Lab Sample ID: 320-115443-6

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	9.1	J	13	2.5	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	9.1	J	13	2.5	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	31		13	2.2	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	8.0	J	13	1.3	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	8.1	J	13	3.4	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	23		13	1.9	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	370		13	1.9	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK284449 liver (Continued) — Lab Sample ID: 320-115443-6

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorohexanesulfonic acid	340		13	1.9	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	33		13	2.3	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	190		13	1.3	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	15		13	1.3	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	2600	B	310	25	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	1100		310	25	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	3700	B	310	25	ug/Kg	10		B/L/T PFAS	Total/NA

Client Sample ID: NK284450 liver — Lab Sample ID: 320-115443-7

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	2.9	J	6.3	1.3	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	2.9	J	6.3	1.3	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	11		6.3	1.1	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	3.9	J	6.3	0.64	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	3.9	J	6.3	1.7	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	5.1	J	6.3	0.93	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	92		6.3	0.93	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	87		6.3	0.93	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	13		6.3	1.2	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	120		6.3	0.63	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	8.0		6.3	0.63	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	1200	B	160	13	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	860		160	13	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	2000	B	160	13	ug/Kg	10		B/L/T PFAS	Total/NA

Client Sample ID: NK284451 liver — Lab Sample ID: 320-115443-8

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	5.1	J	17	3.4	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	5.1	J	17	3.4	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	27		17	2.9	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	7.5	J	17	1.7	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	4.6	J	17	4.5	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	12	J	17	2.5	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	170		17	2.5	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	160		17	2.5	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	25		17	3.1	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	84		17	1.7	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	13	J	17	1.7	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	3200	B	420	34	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	820		420	34	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	4000	B	420	34	ug/Kg	10		B/L/T PFAS	Total/NA

Client Sample ID: NK284458 liver — Lab Sample ID: 320-115443-9

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	0.42	J	0.79	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.48	J	0.79	0.081	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.38	J	0.79	0.21	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK284458 liver (Continued) — Lab Sample ID: 320-115443-9

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanesulfonic acid	3.0	B	2.0	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	1.2	J	2.0	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	4.2	B	2.0	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.14	J	0.79	0.080	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK284463 eggshell + contents — Lab Sample ID: 320-115443-10

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	2.7	B	0.98	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	13	B	0.98	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	8.0		0.98	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	75		0.98	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	12		0.98	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.68	J B	0.98	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	4.1		0.98	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	9.9		0.98	0.42	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	1.9		0.98	0.099	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	110		98	20	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOA - DL	110		98	20	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	340		98	17	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	37	J	98	15	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	1300		98	15	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	1300		98	15	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	270		98	18	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	26000	E B	250	20	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	8400		250	20	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	35000	B	250	20	ug/Kg	100		B/L/T PFAS	Total/NA
8:2 FTS - DL	180		98	9.8	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA) - RA	4.2	B	0.98	0.17	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: African Rue East Intake — Lab Sample ID: 320-115443-11

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	21	B	1.1	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	6.1	B	1.1	0.31	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	1.1		1.1	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	1.9		1.1	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.9		1.1	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	1.7		1.1	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	2.6	B	1.1	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	1.8		1.1	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	4.6		1.1	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	38		1.1	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	34		1.1	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	1.6		1.1	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	63	B	2.8	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	29		2.8	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	92	B	2.8	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	1.6		1.1	0.48	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: African Rue East Intake (Continued) — Lab Sample ID: 320-115443-11

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA) - RA	17	B	1.1	0.20	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Saltcedar East Intake — Lab Sample ID: 320-115443-12

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.43	J B	1.1	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	7.9	B	1.1	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	5.9		1.1	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	26		1.1	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	1.0	J	1.1	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	27		1.1	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	19		1.1	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.16	J	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	2.0	B	1.1	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	8.8		1.1	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	48		1.1	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	26		1.1	0.47	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.11	J	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	25		22	3.3	ug/Kg	20		B/L/T PFAS	Total/NA
Total PFHxS - DL	420		22	3.3	ug/Kg	20		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	400		22	3.3	ug/Kg	20		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	630	B	55	4.5	ug/Kg	20		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	600		55	4.5	ug/Kg	20		B/L/T PFAS	Total/NA
Total PFOS - DL	1200	B	55	4.5	ug/Kg	20		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA) - RA	1.5	B	1.1	0.19	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Saltcedar NE 4-1 — Lab Sample ID: 320-115443-13

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	1.5	J B	1.7	0.40	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	7.1	B	1.7	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	43	B	1.7	0.46	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	63		1.7	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	3.8		1.7	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	3.9	B	1.7	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	33		1.7	0.31	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	28		1.7	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	890		17	3.4	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid - DL	41		17	3.4	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOA - DL	930		17	3.4	ug/Kg	10		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	230		17	3.0	ug/Kg	10		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	1400		17	3.1	ug/Kg	10		B/L/T PFAS	Total/NA
6:2 FTS - DL	1300		17	7.2	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL2	210		170	25	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL2	6800		170	25	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL2	6500		170	25	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL2	15000	B	420	34	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL2	15000		420	34	ug/Kg	100		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: Saltcedar NE 4-1 (Continued) — Lab Sample ID: 320-115443-13

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Total PFOS - DL2	30000	B	420	34	ug/Kg	100		B/L/T PFAS	Total/NA

Client Sample ID: pickleweed NE 4-1 — Lab Sample ID: 320-115443-14

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	1.3	B	0.99	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	8.2	B	0.99	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	1.7		0.99	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	5.0		0.99	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.37	J	0.99	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	5.4		0.99	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	4.9		0.99	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.38	J	0.99	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	1.3	B	0.99	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	4.1		0.99	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	12		0.99	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	54		0.99	0.42	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	1.5		0.99	0.099	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	14	J	20	2.9	ug/Kg	20		B/L/T PFAS	Total/NA
Total PFHxS - DL	160		20	2.9	ug/Kg	20		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	140		20	2.9	ug/Kg	20		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	730	B	50	4.0	ug/Kg	20		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	290		50	4.0	ug/Kg	20		B/L/T PFAS	Total/NA
Total PFOS - DL	1000	B	50	4.0	ug/Kg	20		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA) - RA	3.6	B	0.99	0.17	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: MSBHerp109299 muscle — Lab Sample ID: 320-115443-15

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	4.8		1.1	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	4.8		1.1	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	7.1		1.1	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.0	J	1.1	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.40	J	1.1	0.31	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.52	J	1.1	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	15		1.1	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	2.4		1.1	0.48	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	13		1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	23		11	1.7	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFHxS - DL	200		11	1.7	ug/Kg	10		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	180		11	1.7	ug/Kg	10		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	700	B	28	2.3	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	240		28	2.3	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	940	B	28	2.3	ug/Kg	10		B/L/T PFAS	Total/NA

Client Sample ID: MSBHerp109299 liver — Lab Sample ID: 320-115443-16

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	32		5.6	1.1	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: MSBHerp109299 liver (Continued) — Lab Sample ID: 320-115443-16

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Br-Perfluorooctanoic acid	1.5	J	5.6	1.1	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	34		5.6	1.1	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	58		5.6	0.97	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	4.6	J	5.6	0.57	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	3.1	J	5.6	1.0	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	160		5.6	1.0	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	5.8		5.6	0.56	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.63	J	5.6	0.56	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	160		56	8.2	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFHxS - DL	1500		56	8.2	ug/Kg	10		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	1400		56	8.2	ug/Kg	10		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	4400		140	11	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	2300		140	11	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	6800		140	11	ug/Kg	10		B/L/T PFAS	Total/NA

Client Sample ID: NK319555 muscle — Lab Sample ID: 320-115443-17

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	1.3		1.1	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	0.31	J	1.1	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.40	J	1.1	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	15		1.1	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.46	J	1.1	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	15		1.1	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	9.5		1.1	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.0	J	1.1	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	1.6		1.1	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	22		1.1	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	1.3		1.1	0.48	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.31	J	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	350		11	1.7	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFHxS - DL	360		11	1.7	ug/Kg	10		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	8.5	J	11	1.7	ug/Kg	10		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	420		28	2.3	ug/Kg	10		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	220		28	2.3	ug/Kg	10		B/L/T PFAS	Total/NA
Total PFOS - DL	640		28	2.3	ug/Kg	10		B/L/T PFAS	Total/NA

Client Sample ID: NK319556 muscle — Lab Sample ID: 320-115443-18

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	0.78		0.76	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	0.15	J	0.76	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.15	J	0.76	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.16	J	0.76	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.16	J	0.76	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	0.31	J	1.9	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	0.31	J	1.9	0.15	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Detection Summary

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: NK319556 liver — Lab Sample ID: 320-115443-19

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	2.1		0.71	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.12	J	0.71	0.083	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	0.87		0.71	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.14	J	0.71	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.0		0.71	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	0.66	J	0.71	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.27	J	0.71	0.074	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.63	J	0.71	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.63	J	0.71	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	2.1		1.8	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.94	J	1.8	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	3.0		1.8	0.15	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: MSB89187 femur — Lab Sample ID: 320-115443-20

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
10:2 FTS	0.55	J H H3	4.8	0.48	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: MSB92667 femur — Lab Sample ID: 320-115443-21

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanesulfonic acid	310	H H3	83	6.8	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	61	J H H3	83	6.8	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	370	H H3	83	6.8	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	3.7	J H H3	33	3.4	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: MSB61848 femur — Lab Sample ID: 320-115443-22

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
10:2 FTS	2.7	J H H3	25	2.5	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: MSB89196 femur — Lab Sample ID: 320-115443-23

No Detections.

Client Sample ID: MSB87701 femur — Lab Sample ID: 320-115443-24

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.45	J H H3	2.1	0.36	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: MSB87702 femur — Lab Sample ID: 320-115443-25

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.56	J H H3	2.4	0.42	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	0.77	J H H3	6.0	0.48	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	0.77	J H H3	6.0	0.48	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.25	J H H3	2.4	0.24	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: MSB89195 femur — Lab Sample ID: 320-115443-26

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
10:2 FTS	1.2	J H H3	11	1.1	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Detection Summary

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: MSB61849 femur

Lab Sample ID: 320-115443-27

No Detections.

This Detection Summary does not include radiochemical test results.

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: NK284441 liver
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-1
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		13	3.0	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
Perfluoropentanoic acid (PFPeA)	ND		13	2.2	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
Perfluorohexanoic acid (PFHxA)	ND		13	3.4	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
Perfluoroheptanoic acid (PFHpA)	ND		13	1.5	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
L-Perfluorooctanoic acid	**9.1**	**J**	13	2.5	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
Br-Perfluorooctanoic acid	ND		13	2.5	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
Total PFOA	**9.1**	**J**	13	2.5	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
Perfluorononanoic acid (PFNA)	**53**		13	2.2	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
Perfluorodecanoic acid (PFDA)	**19**		13	1.3	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
Perfluoroundecanoic acid (PFUnA)	**6.8**	**J**	13	3.4	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
Perfluorobutanesulfonic acid (PFBS)	ND		13	2.1	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
Perfluoropentanesulfonic acid (PFPeS)	ND		13	2.3	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
Br-Perfluorohexanesulfonic acid	**11**	**J**	13	1.9	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
Total PFHxS	**300**		13	1.9	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
L-Perfluorohexanesulfonic acid	**290**		13	1.9	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
Perfluoroheptanesulfonic acid (PFHpS)	**110**		13	2.3	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
4:2 FTS	ND		13	3.3	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
6:2 FTS	ND		13	5.3	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
8:2 FTS	**80**		13	1.3	ug/Kg		09/28/24 06:38	10/14/24 16:23	5
10:2 FTS	**14**		13	1.3	ug/Kg		09/28/24 06:38	10/14/24 16:23	5

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*98*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:23*	*5*
13C5 PFPeA	*105*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:23*	*5*
13C2 PFHxA	*83*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:23*	*5*
13C4 PFHpA	*107*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:23*	*5*
13C4 PFOA	*101*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:23*	*5*
13C5 PFNA	*107*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:23*	*5*
13C2 PFDA	*108*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:23*	*5*
13C2 PFUnA	*113*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:23*	*5*
13C3 PFBS	*111*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:23*	*5*
18O2 PFHxS	*109*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:23*	*5*
13C4 PFOS	*92*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:23*	*5*
M2-4:2 FTS	*124*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:23*	*5*
M2-6:2 FTS	*177*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/14/24 16:23*	*5*
M2-8:2 FTS	*140*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:23*	*5*
13C2 10:2 FTS	*397*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/14/24 16:23*	*5*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**9700**	**B**	310	25	ug/Kg		09/28/24 06:38	10/10/24 21:12	50
Br-Perfluorooctanesulfonic acid	**6800**		310	25	ug/Kg		09/28/24 06:38	10/10/24 21:12	50
Total PFOS	**17000**	**B**	310	25	ug/Kg		09/28/24 06:38	10/10/24 21:12	50

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*89*		*25 - 150*	*09/28/24 06:38*	*10/10/24 21:12*	*50*

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: NK284445 liver
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-2
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		5.9	1.4	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
Perfluorohexanoic acid (PFHxA)	**2.8**	**J B**	5.9	1.6	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
Perfluoroheptanoic acid (PFHpA)	**2.7**	**J**	5.9	0.68	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
L-Perfluorooctanoic acid	**56**		5.9	1.2	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
Br-Perfluorooctanoic acid	**5.1**	**J**	5.9	1.2	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
Total PFOA	**61**		5.9	1.2	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
Perfluorononanoic acid (PFNA)	**78**		5.9	1.0	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
Perfluorodecanoic acid (PFDA)	**24**		5.9	0.61	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
Perfluoroundecanoic acid (PFUnA)	**9.1**		5.9	1.6	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
Perfluorobutanesulfonic acid (PFBS)	ND		5.9	1.0	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
Perfluoropentanesulfonic acid (PFPeS)	**4.3**	**J**	5.9	1.1	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
Br-Perfluorohexanesulfonic acid	**34**		5.9	0.87	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
Total PFHxS	**520**		5.9	0.87	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
L-Perfluorohexanesulfonic acid	**490**		5.9	0.87	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
Perfluoroheptanesulfonic acid (PFHpS)	**120**		5.9	1.1	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
4:2 FTS	ND		5.9	1.6	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
6:2 FTS	ND		5.9	2.5	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
8:2 FTS	**75**		5.9	0.59	ug/Kg		09/28/24 06:38	10/10/24 22:10	1
10:2 FTS	**12**		5.9	0.59	ug/Kg		09/28/24 06:38	10/10/24 22:10	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*101*		*25 - 150*	*09/28/24 06:38*	*10/10/24 22:10*	*1*
13C2 PFHxA	*99*		*25 - 150*	*09/28/24 06:38*	*10/10/24 22:10*	*1*
13C4 PFHpA	*100*		*25 - 150*	*09/28/24 06:38*	*10/10/24 22:10*	*1*
13C4 PFOA	*85*		*25 - 150*	*09/28/24 06:38*	*10/10/24 22:10*	*1*
13C5 PFNA	*113*		*25 - 150*	*09/28/24 06:38*	*10/10/24 22:10*	*1*
13C2 PFDA	*108*		*25 - 150*	*09/28/24 06:38*	*10/10/24 22:10*	*1*
13C2 PFUnA	*115*		*25 - 150*	*09/28/24 06:38*	*10/10/24 22:10*	*1*
13C3 PFBS	*106*		*25 - 150*	*09/28/24 06:38*	*10/10/24 22:10*	*1*
18O2 PFHxS	*103*		*25 - 150*	*09/28/24 06:38*	*10/10/24 22:10*	*1*
13C4 PFOS	*80*		*25 - 150*	*09/28/24 06:38*	*10/10/24 22:10*	*1*
M2-4:2 FTS	*125*		*25 - 150*	*09/28/24 06:38*	*10/10/24 22:10*	*1*
M2-6:2 FTS	*194*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/10/24 22:10*	*1*
M2-8:2 FTS	*120*		*25 - 150*	*09/28/24 06:38*	*10/10/24 22:10*	*1*
13C2 10:2 FTS	*470*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/10/24 22:10*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**9300**	**B**	740	60	ug/Kg		09/28/24 06:38	10/10/24 21:51	50
Br-Perfluorooctanesulfonic acid	**2600**		740	60	ug/Kg		09/28/24 06:38	10/10/24 21:51	50
Total PFOS	**12000**	**B**	740	60	ug/Kg		09/28/24 06:38	10/10/24 21:51	50

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*95*		*25 - 150*	*09/28/24 06:38*	*10/10/24 21:51*	*50*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoropentanoic acid (PFPeA)	**1.3**	**J B**	5.9	1.0	ug/Kg		09/28/24 06:38	10/04/24 23:03	1

Client: University of New Mexico
Job ID: 320-115443-1
Project/Site: Holloman Lake PFAS Research

Client Sample ID: NK284445 liver
Lab Sample ID: 320-115443-2
Date Collected: 07/11/24 00:00
Matrix: Tissue
Date Received: 09/17/24 09:40

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
13C5 PFPeA	81		25 - 150	09/28/24 06:38	10/04/24 23:03	1

Client Sample ID: NK284446 liver

Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-3

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		22	5.2	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
Perfluoropentanoic acid (PFPeA)	ND		22	3.9	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
Perfluorohexanoic acid (PFHxA)	ND		22	6.1	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
Perfluoroheptanoic acid (PFHpA)	**3.0**	**J**	22	2.6	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
L-Perfluorooctanoic acid	**50**		22	4.5	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
Br-Perfluorooctanoic acid	ND		22	4.5	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
Total PFOA	**50**		22	4.5	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
Perfluorononanoic acid (PFNA)	**48**		22	3.9	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
Perfluorodecanoic acid (PFDA)	**16**	**J**	22	2.3	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
Perfluoroundecanoic acid (PFUnA)	**7.8**	**J**	22	6.0	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
Perfluorobutanesulfonic acid (PFBS)	ND		22	3.8	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
Perfluoropentanesulfonic acid (PFPeS)	ND		22	4.0	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
Br-Perfluorohexanesulfonic acid	**23**		22	3.3	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
Total PFHxS	**530**		22	3.3	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
L-Perfluorohexanesulfonic acid	**500**		22	3.3	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
Perfluoroheptanesulfonic acid (PFHpS)	**84**		22	4.1	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
4:2 FTS	ND		22	5.9	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
6:2 FTS	ND		22	9.4	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
8:2 FTS	**36**		22	2.2	ug/Kg		09/28/24 06:38	10/14/24 16:42	10
10:2 FTS	**6.3**	**J**	22	2.2	ug/Kg		09/28/24 06:38	10/14/24 16:42	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*107*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:42*	*10*
13C5 PFPeA	*109*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:42*	*10*
13C2 PFHxA	*117*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:42*	*10*
13C4 PFHpA	*109*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:42*	*10*
13C4 PFOA	*106*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:42*	*10*
13C5 PFNA	*120*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:42*	*10*
13C2 PFDA	*118*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:42*	*10*
13C2 PFUnA	*106*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:42*	*10*
13C3 PFBS	*128*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:42*	*10*
18O2 PFHxS	*104*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:42*	*10*
13C4 PFOS	*107*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:42*	*10*
M2-4:2 FTS	*127*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:42*	*10*
M2-6:2 FTS	*214*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/14/24 16:42*	*10*
M2-8:2 FTS	*143*		*25 - 150*	*09/28/24 06:38*	*10/14/24 16:42*	*10*
13C2 10:2 FTS	*308*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/14/24 16:42*	*10*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**6000**	**B**	280	23	ug/Kg		09/28/24 06:38	10/10/24 22:30	50
Br-Perfluorooctanesulfonic acid	**4300**		280	23	ug/Kg		09/28/24 06:38	10/10/24 22:30	50
Total PFOS	**10000**	**B**	280	23	ug/Kg		09/28/24 06:38	10/10/24 22:30	50

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*95*		*25 - 150*	*09/28/24 06:38*	*10/10/24 22:30*	*50*

Client Sample ID: NK284447 liver

Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-4

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		5.9	1.4	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
Perfluoropentanoic acid (PFPeA)	ND		5.9	1.0	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
Perfluorohexanoic acid (PFHxA)	ND		5.9	1.6	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
Perfluoroheptanoic acid (PFHpA)	ND		5.9	0.68	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
L-Perfluorooctanoic acid	**1.2**	**J**	5.9	1.2	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
Br-Perfluorooctanoic acid	ND		5.9	1.2	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
Total PFOA	**1.2**	**J**	5.9	1.2	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
Perfluorononanoic acid (PFNA)	ND		5.9	1.0	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
Perfluorodecanoic acid (PFDA)	ND		5.9	0.61	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
Perfluoroundecanoic acid (PFUnA)	ND		5.9	1.6	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
Perfluorobutanesulfonic acid (PFBS)	ND		5.9	1.0	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
Perfluoropentanesulfonic acid (PFPeS)	ND		5.9	1.1	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
Br-Perfluorohexanesulfonic acid	**1.6**	**J**	5.9	0.87	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
Total PFHxS	**6.8**		5.9	0.87	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
L-Perfluorohexanesulfonic acid	**5.2**	**J**	5.9	0.87	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		5.9	1.1	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
4:2 FTS	ND		5.9	1.6	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
6:2 FTS	ND		5.9	2.5	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
8:2 FTS	ND		5.9	0.59	ug/Kg		09/28/24 06:38	10/10/24 23:47	1
10:2 FTS	ND		5.9	0.59	ug/Kg		09/28/24 06:38	10/10/24 23:47	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*96*		*25 - 150*	*09/28/24 06:38*	*10/10/24 23:47*	*1*
13C5 PFPeA	*90*		*25 - 150*	*09/28/24 06:38*	*10/10/24 23:47*	*1*
13C2 PFHxA	*100*		*25 - 150*	*09/28/24 06:38*	*10/10/24 23:47*	*1*
13C4 PFHpA	*99*		*25 - 150*	*09/28/24 06:38*	*10/10/24 23:47*	*1*
13C4 PFOA	*96*		*25 - 150*	*09/28/24 06:38*	*10/10/24 23:47*	*1*
13C5 PFNA	*72*		*25 - 150*	*09/28/24 06:38*	*10/10/24 23:47*	*1*
13C2 PFDA	*104*		*25 - 150*	*09/28/24 06:38*	*10/10/24 23:47*	*1*
13C2 PFUnA	*101*		*25 - 150*	*09/28/24 06:38*	*10/10/24 23:47*	*1*
13C3 PFBS	*103*		*25 - 150*	*09/28/24 06:38*	*10/10/24 23:47*	*1*
18O2 PFHxS	*100*		*25 - 150*	*09/28/24 06:38*	*10/10/24 23:47*	*1*
13C4 PFOS	*95*		*25 - 150*	*09/28/24 06:38*	*10/10/24 23:47*	*1*
M2-4:2 FTS	*196*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/10/24 23:47*	*1*
M2-6:2 FTS	*178*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/10/24 23:47*	*1*
M2-8:2 FTS	*126*		*25 - 150*	*09/28/24 06:38*	*10/10/24 23:47*	*1*
13C2 10:2 FTS	*205*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/10/24 23:47*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**78**	**I B**	15	1.2	ug/Kg		09/28/24 06:38	10/15/24 10:47	1
Br-Perfluorooctanesulfonic acid	**19**		15	1.2	ug/Kg		09/28/24 06:38	10/15/24 10:47	1
Total PFOS	**96**	**B**	15	1.2	ug/Kg		09/28/24 06:38	10/15/24 10:47	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*89*		*25 - 150*	*09/28/24 06:38*	*10/15/24 10:47*	*1*

Client Sample ID: NK284448 liver

Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-5

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.8	0.42	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
Perfluoropentanoic acid (PFPeA)	ND		1.8	0.31	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
Perfluorohexanoic acid (PFHxA)	ND		1.8	0.49	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
Perfluoroheptanoic acid (PFHpA)	**1.4**	**J**	1.8	0.21	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
L-Perfluorooctanoic acid	**13**		1.8	0.36	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
Br-Perfluorooctanoic acid	**0.88**	**J**	1.8	0.36	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
Total PFOA	**14**		1.8	0.36	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
Perfluorononanoic acid (PFNA)	**8.7**		1.8	0.31	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
Perfluorodecanoic acid (PFDA)	**0.82**	**J**	1.8	0.18	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
Perfluoroundecanoic acid (PFUnA)	ND		1.8	0.49	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
Perfluorobutanesulfonic acid (PFBS)	**0.94**	**J B**	1.8	0.30	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
Perfluoropentanesulfonic acid (PFPeS)	**5.4**		1.8	0.32	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
Br-Perfluorohexanesulfonic acid	**37**		1.8	0.26	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
Total PFHxS	**200**		1.8	0.26	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
L-Perfluorohexanesulfonic acid	**160**		1.8	0.26	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
Perfluoroheptanesulfonic acid (PFHpS)	**9.4**		1.8	0.33	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
4:2 FTS	ND		1.8	0.48	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
6:2 FTS	**3.9**		1.8	0.76	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
8:2 FTS	**1.8**		1.8	0.18	ug/Kg		09/28/24 06:38	10/11/24 00:26	1
10:2 FTS	ND		1.8	0.18	ug/Kg		09/28/24 06:38	10/11/24 00:26	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*88*		*25 - 150*	*09/28/24 06:38*	*10/11/24 00:26*	*1*
13C5 PFPeA	*89*		*25 - 150*	*09/28/24 06:38*	*10/11/24 00:26*	*1*
13C2 PFHxA	*96*		*25 - 150*	*09/28/24 06:38*	*10/11/24 00:26*	*1*
13C4 PFHpA	*86*		*25 - 150*	*09/28/24 06:38*	*10/11/24 00:26*	*1*
13C4 PFOA	*98*		*25 - 150*	*09/28/24 06:38*	*10/11/24 00:26*	*1*
13C5 PFNA	*53*		*25 - 150*	*09/28/24 06:38*	*10/11/24 00:26*	*1*
13C2 PFDA	*104*		*25 - 150*	*09/28/24 06:38*	*10/11/24 00:26*	*1*
13C2 PFUnA	*105*		*25 - 150*	*09/28/24 06:38*	*10/11/24 00:26*	*1*
13C3 PFBS	*104*		*25 - 150*	*09/28/24 06:38*	*10/11/24 00:26*	*1*
18O2 PFHxS	*96*		*25 - 150*	*09/28/24 06:38*	*10/11/24 00:26*	*1*
13C4 PFOS	*92*		*25 - 150*	*09/28/24 06:38*	*10/11/24 00:26*	*1*
M2-4:2 FTS	*172*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 00:26*	*1*
M2-6:2 FTS	*208*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 00:26*	*1*
M2-8:2 FTS	*153*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 00:26*	*1*
13C2 10:2 FTS	*388*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 00:26*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**660**	**B**	89	7.3	ug/Kg		09/28/24 06:38	10/14/24 17:21	20
Br-Perfluorooctanesulfonic acid	**2600**		89	7.3	ug/Kg		09/28/24 06:38	10/14/24 17:21	20
Total PFOS	**3200**	**B**	89	7.3	ug/Kg		09/28/24 06:38	10/14/24 17:21	20

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*97*		*25 - 150*	*09/28/24 06:38*	*10/14/24 17:21*	*20*

Client Sample ID: NK284449 liver

Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-6

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		13	3.0	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
Perfluoropentanoic acid (PFPeA)	ND		13	2.2	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
Perfluorohexanoic acid (PFHxA)	ND		13	3.4	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
Perfluoroheptanoic acid (PFHpA)	ND		13	1.5	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
L-Perfluorooctanoic acid	**9.1**	**J**	13	2.5	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
Br-Perfluorooctanoic acid	ND		13	2.5	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
Total PFOA	**9.1**	**J**	13	2.5	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
Perfluorononanoic acid (PFNA)	**31**		13	2.2	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
Perfluorodecanoic acid (PFDA)	**8.0**	**J**	13	1.3	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
Perfluoroundecanoic acid (PFUnA)	**8.1**	**J**	13	3.4	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
Perfluorobutanesulfonic acid (PFBS)	ND		13	2.1	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
Perfluoropentanesulfonic acid (PFPeS)	ND		13	2.3	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
Br-Perfluorohexanesulfonic acid	**23**		13	1.9	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
Total PFHxS	**370**		13	1.9	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
L-Perfluorohexanesulfonic acid	**340**		13	1.9	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
Perfluoroheptanesulfonic acid (PFHpS)	**33**		13	2.3	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
4:2 FTS	ND		13	3.3	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
6:2 FTS	ND		13	5.3	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
8:2 FTS	**190**		13	1.3	ug/Kg		09/28/24 06:38	10/11/24 01:05	1
10:2 FTS	**15**		13	1.3	ug/Kg		09/28/24 06:38	10/11/24 01:05	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*96*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:05*	*1*
13C5 PFPeA	*105*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:05*	*1*
13C2 PFHxA	*93*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:05*	*1*
13C4 PFHpA	*91*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:05*	*1*
13C4 PFOA	*98*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:05*	*1*
13C5 PFNA	*107*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:05*	*1*
13C2 PFDA	*98*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:05*	*1*
13C2 PFUnA	*100*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:05*	*1*
13C3 PFBS	*118*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:05*	*1*
18O2 PFHxS	*100*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:05*	*1*
13C4 PFOS	*90*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:05*	*1*
M2-4:2 FTS	*129*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:05*	*1*
M2-6:2 FTS	*191*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 01:05*	*1*
M2-8:2 FTS	*108*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:05*	*1*
13C2 10:2 FTS	*231*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 01:05*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**2600**	**B**	310	25	ug/Kg		09/28/24 06:38	10/14/24 17:40	10
Br-Perfluorooctanesulfonic acid	**1100**		310	25	ug/Kg		09/28/24 06:38	10/14/24 17:40	10
Total PFOS	**3700**	**B**	310	25	ug/Kg		09/28/24 06:38	10/14/24 17:40	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*97*		*25 - 150*	*09/28/24 06:38*	*10/14/24 17:40*	*10*

Client Sample ID: NK284450 liver

Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-7

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		6.3	1.5	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
Perfluoropentanoic acid (PFPeA)	ND		6.3	1.1	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
Perfluorohexanoic acid (PFHxA)	ND		6.3	1.7	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
Perfluoroheptanoic acid (PFHpA)	ND		6.3	0.73	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
L-Perfluorooctanoic acid	**2.9**	**J**	6.3	1.3	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
Br-Perfluorooctanoic acid	ND		6.3	1.3	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
Total PFOA	**2.9**	**J**	6.3	1.3	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
Perfluorononanoic acid (PFNA)	**11**		6.3	1.1	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
Perfluorodecanoic acid (PFDA)	**3.9**	**J**	6.3	0.64	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
Perfluoroundecanoic acid (PFUnA)	**3.9**	**J**	6.3	1.7	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
Perfluorobutanesulfonic acid (PFBS)	ND		6.3	1.1	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
Perfluoropentanesulfonic acid (PFPeS)	ND		6.3	1.1	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
Br-Perfluorohexanesulfonic acid	**5.1**	**J**	6.3	0.93	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
Total PFHxS	**92**		6.3	0.93	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
L-Perfluorohexanesulfonic acid	**87**		6.3	0.93	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
Perfluoroheptanesulfonic acid (PFHpS)	**13**		6.3	1.2	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
4:2 FTS	ND		6.3	1.7	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
6:2 FTS	ND		6.3	2.7	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
8:2 FTS	**120**		6.3	0.63	ug/Kg		09/28/24 06:38	10/11/24 01:44	1
10:2 FTS	**8.0**		6.3	0.63	ug/Kg		09/28/24 06:38	10/11/24 01:44	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*99*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:44*	*1*
13C5 PFPeA	*99*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:44*	*1*
13C2 PFHxA	*111*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:44*	*1*
13C4 PFHpA	*91*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:44*	*1*
13C4 PFOA	*107*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:44*	*1*
13C5 PFNA	*116*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:44*	*1*
13C2 PFDA	*106*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:44*	*1*
13C2 PFUnA	*109*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:44*	*1*
13C3 PFBS	*115*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:44*	*1*
18O2 PFHxS	*104*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:44*	*1*
13C4 PFOS	*101*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:44*	*1*
M2-4:2 FTS	*132*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:44*	*1*
M2-6:2 FTS	*201*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 01:44*	*1*
M2-8:2 FTS	*133*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:44*	*1*
13C2 10:2 FTS	*203*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 01:44*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**1200**	**B**	160	13	ug/Kg		09/28/24 06:38	10/11/24 01:24	10
Br-Perfluorooctanesulfonic acid	**860**		160	13	ug/Kg		09/28/24 06:38	10/11/24 01:24	10
Total PFOS	**2000**	**B**	160	13	ug/Kg		09/28/24 06:38	10/11/24 01:24	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*97*		*25 - 150*	*09/28/24 06:38*	*10/11/24 01:24*	*10*

Client Sample ID: NK284451 liver

Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-8

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		17	3.9	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
Perfluoropentanoic acid (PFPeA)	ND		17	2.9	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
Perfluorohexanoic acid (PFHxA)	ND		17	4.6	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
Perfluoroheptanoic acid (PFHpA)	ND		17	1.9	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
L-Perfluorooctanoic acid	**5.1**	**J**	17	3.4	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
Br-Perfluorooctanoic acid	ND		17	3.4	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
Total PFOA	**5.1**	**J**	17	3.4	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
Perfluorononanoic acid (PFNA)	**27**		17	2.9	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
Perfluorodecanoic acid (PFDA)	**7.5**	**J**	17	1.7	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
Perfluoroundecanoic acid (PFUnA)	**4.6**	**J**	17	4.5	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
Perfluorobutanesulfonic acid (PFBS)	ND		17	2.8	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
Perfluoropentanesulfonic acid (PFPeS)	ND		17	3.0	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
Br-Perfluorohexanesulfonic acid	**12**	**J**	17	2.5	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
Total PFHxS	**170**		17	2.5	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
L-Perfluorohexanesulfonic acid	**160**		17	2.5	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
Perfluoroheptanesulfonic acid (PFHpS)	**25**		17	3.1	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
4:2 FTS	ND		17	4.4	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
6:2 FTS	ND		17	7.1	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
8:2 FTS	**84**		17	1.7	ug/Kg		09/28/24 06:38	10/11/24 02:23	1
10:2 FTS	**13**	**J**	17	1.7	ug/Kg		09/28/24 06:38	10/11/24 02:23	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*89*		*25 - 150*	*09/28/24 06:38*	*10/11/24 02:23*	*1*
13C5 PFPeA	*102*		*25 - 150*	*09/28/24 06:38*	*10/11/24 02:23*	*1*
13C2 PFHxA	*101*		*25 - 150*	*09/28/24 06:38*	*10/11/24 02:23*	*1*
13C4 PFHpA	*92*		*25 - 150*	*09/28/24 06:38*	*10/11/24 02:23*	*1*
13C4 PFOA	*104*		*25 - 150*	*09/28/24 06:38*	*10/11/24 02:23*	*1*
13C5 PFNA	*99*		*25 - 150*	*09/28/24 06:38*	*10/11/24 02:23*	*1*
13C2 PFDA	*99*		*25 - 150*	*09/28/24 06:38*	*10/11/24 02:23*	*1*
13C2 PFUnA	*99*		*25 - 150*	*09/28/24 06:38*	*10/11/24 02:23*	*1*
13C3 PFBS	*118*		*25 - 150*	*09/28/24 06:38*	*10/11/24 02:23*	*1*
18O2 PFHxS	*101*		*25 - 150*	*09/28/24 06:38*	*10/11/24 02:23*	*1*
13C4 PFOS	*91*		*25 - 150*	*09/28/24 06:38*	*10/11/24 02:23*	*1*
M2-4:2 FTS	*132*		*25 - 150*	*09/28/24 06:38*	*10/11/24 02:23*	*1*
M2-6:2 FTS	*162*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 02:23*	*1*
M2-8:2 FTS	*116*		*25 - 150*	*09/28/24 06:38*	*10/11/24 02:23*	*1*
13C2 10:2 FTS	*149*		*25 - 150*	*09/28/24 06:38*	*10/11/24 02:23*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanesulfonic acid	**3200**	**B**	420	34	ug/Kg		09/28/24 06:38	10/14/24 18:00	10
Br-Perfluorooctanesulfonic acid	**820**		420	34	ug/Kg		09/28/24 06:38	10/14/24 18:00	10
Total PFOS	**4000**	**B**	420	34	ug/Kg		09/28/24 06:38	10/14/24 18:00	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOS	*102*		*25 - 150*	*09/28/24 06:38*	*10/14/24 18:00*	*10*

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: NK284458 liver
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-9
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.79	0.19	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
Perfluoropentanoic acid (PFPeA)	ND		0.79	0.14	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
Perfluorohexanoic acid (PFHxA)	ND		0.79	0.21	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
Perfluoroheptanoic acid (PFHpA)	ND		0.79	0.091	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
L-Perfluorooctanoic acid	ND		0.79	0.16	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
Br-Perfluorooctanoic acid	ND		0.79	0.16	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
Total PFOA	ND		0.79	0.16	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
Perfluorononanoic acid (PFNA)	**0.42**	**J**	0.79	0.14	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
Perfluorodecanoic acid (PFDA)	**0.48**	**J**	0.79	0.081	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
Perfluoroundecanoic acid (PFUnA)	**0.38**	**J**	0.79	0.21	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.79	0.13	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.79	0.14	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
Br-Perfluorohexanesulfonic acid	ND		0.79	0.12	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
Total PFHxS	ND		0.79	0.12	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
L-Perfluorohexanesulfonic acid	ND		0.79	0.12	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.79	0.15	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
L-Perfluorooctanesulfonic acid	**3.0**	**B**	2.0	0.16	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
Br-Perfluorooctanesulfonic acid	**1.2**	**J**	2.0	0.16	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
Total PFOS	**4.2**	**B**	2.0	0.16	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
4:2 FTS	ND		0.79	0.21	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
6:2 FTS	ND		0.79	0.33	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
8:2 FTS	ND		0.79	0.079	ug/Kg		09/28/24 06:38	10/11/24 03:21	1
10:2 FTS	**0.14**	**J**	0.79	0.080	ug/Kg		09/28/24 06:38	10/11/24 03:21	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*52*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:21*	*1*
13C5 PFPeA	*85*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:21*	*1*
13C2 PFHxA	*101*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:21*	*1*
13C4 PFHpA	*105*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:21*	*1*
13C4 PFOA	*102*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:21*	*1*
13C5 PFNA	*116*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:21*	*1*
13C2 PFDA	*121*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:21*	*1*
13C2 PFUnA	*142*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:21*	*1*
13C3 PFBS	*109*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:21*	*1*
18O2 PFHxS	*96*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:21*	*1*
13C4 PFOS	*100*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:21*	*1*
M2-4:2 FTS	*306*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 03:21*	*1*
M2-6:2 FTS	*270*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 03:21*	*1*
M2-8:2 FTS	*380*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 03:21*	*1*
13C2 10:2 FTS	*507*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 03:21*	*1*

Client Sample ID: NK284463 eggshell + contents

Lab Sample ID: 320-115443-10

Date Collected: 07/11/24 00:00

Matrix: Tissue

Date Received: 09/17/24 09:40

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	2.7	B	0.98	0.23	ug/Kg		09/28/24 06:38	10/11/24 04:00	1
Perfluorohexanoic acid (PFHxA)	13	B	0.98	0.27	ug/Kg		09/28/24 06:38	10/11/24 04:00	1
Perfluoroheptanoic acid (PFHpA)	8.0		0.98	0.11	ug/Kg		09/28/24 06:38	10/11/24 04:00	1
Perfluorodecanoic acid (PFDA)	75		0.98	0.10	ug/Kg		09/28/24 06:38	10/11/24 04:00	1
Perfluoroundecanoic acid (PFUnA)	12		0.98	0.27	ug/Kg		09/28/24 06:38	10/11/24 04:00	1
Perfluorobutanesulfonic acid (PFBS)	0.68	J B	0.98	0.17	ug/Kg		09/28/24 06:38	10/11/24 04:00	1
Perfluoropentanesulfonic acid (PFPeS)	4.1		0.98	0.18	ug/Kg		09/28/24 06:38	10/11/24 04:00	1
4:2 FTS	ND		0.98	0.26	ug/Kg		09/28/24 06:38	10/11/24 04:00	1
6:2 FTS	9.9		0.98	0.42	ug/Kg		09/28/24 06:38	10/11/24 04:00	1
10:2 FTS	1.9		0.98	0.099	ug/Kg		09/28/24 06:38	10/11/24 04:00	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*34*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:00*	*1*
13C2 PFHxA	*31*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:00*	*1*
13C4 PFHpA	*33*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:00*	*1*
13C2 PFDA	*30*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:00*	*1*
13C2 PFUnA	*36*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:00*	*1*
13C3 PFBS	*34*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:00*	*1*
M2-4:2 FTS	*49*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:00*	*1*
M2-6:2 FTS	*54*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:00*	*1*
13C2 10:2 FTS	*137*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:00*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanoic acid	110		98	20	ug/Kg		09/28/24 06:38	10/11/24 03:40	100
Br-Perfluorooctanoic acid	ND		98	20	ug/Kg		09/28/24 06:38	10/11/24 03:40	100
Total PFOA	110		98	20	ug/Kg		09/28/24 06:38	10/11/24 03:40	100
Perfluorononanoic acid (PFNA)	340		98	17	ug/Kg		09/28/24 06:38	10/11/24 03:40	100
Br-Perfluorohexanesulfonic acid	37	J	98	15	ug/Kg		09/28/24 06:38	10/11/24 03:40	100
Total PFHxS	1300		98	15	ug/Kg		09/28/24 06:38	10/11/24 03:40	100
L-Perfluorohexanesulfonic acid	1300		98	15	ug/Kg		09/28/24 06:38	10/11/24 03:40	100
Perfluoroheptanesulfonic acid (PFHpS)	270		98	18	ug/Kg		09/28/24 06:38	10/11/24 03:40	100
L-Perfluorooctanesulfonic acid	26000	E B	250	20	ug/Kg		09/28/24 06:38	10/11/24 03:40	100
Br-Perfluorooctanesulfonic acid	8400		250	20	ug/Kg		09/28/24 06:38	10/11/24 03:40	100
Total PFOS	35000	B	250	20	ug/Kg		09/28/24 06:38	10/11/24 03:40	100
8:2 FTS	180		98	9.8	ug/Kg		09/28/24 06:38	10/11/24 03:40	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOA	*38*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:40*	*100*
13C5 PFNA	*32*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:40*	*100*
18O2 PFHxS	*38*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:40*	*100*
13C4 PFOS	*29*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:40*	*100*
M2-8:2 FTS	*36*		*25 - 150*	*09/28/24 06:38*	*10/11/24 03:40*	*100*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoropentanoic acid (PFPeA)	4.2	B	0.98	0.17	ug/Kg		09/28/24 06:38	10/05/24 01:58	1

Client: University of New Mexico
Job ID: 320-115443-1
Project/Site: Holloman Lake PFAS Research

Client Sample ID: NK284463 eggshell + contents
Lab Sample ID: 320-115443-10
Date Collected: 07/11/24 00:00
Matrix: Tissue
Date Received: 09/17/24 09:40

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
13C5 PFPeA	33		25 - 150	09/28/24 06:38	10/05/24 01:58	1

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: African Rue East Intake
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-11
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	21	B	1.1	0.27	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
Perfluorohexanoic acid (PFHxA)	6.1	B	1.1	0.31	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
Perfluoroheptanoic acid (PFHpA)	1.1		1.1	0.13	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
L-Perfluorooctanoic acid	1.9		1.1	0.23	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
Br-Perfluorooctanoic acid	ND		1.1	0.23	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
Total PFOA	1.9		1.1	0.23	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
Perfluorononanoic acid (PFNA)	1.7		1.1	0.20	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
Perfluorodecanoic acid (PFDA)	ND		1.1	0.12	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
Perfluoroundecanoic acid (PFUnA)	ND		1.1	0.31	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
Perfluorobutanesulfonic acid (PFBS)	2.6	B	1.1	0.19	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
Perfluoropentanesulfonic acid (PFPeS)	1.8		1.1	0.20	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
Br-Perfluorohexanesulfonic acid	4.6		1.1	0.17	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
Total PFHxS	38		1.1	0.17	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
L-Perfluorohexanesulfonic acid	34		1.1	0.17	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
Perfluoroheptanesulfonic acid (PFHpS)	1.6		1.1	0.21	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
L-Perfluorooctanesulfonic acid	63	B	2.8	0.23	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
Br-Perfluorooctanesulfonic acid	29		2.8	0.23	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
Total PFOS	92	B	2.8	0.23	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
4:2 FTS	ND		1.1	0.30	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
6:2 FTS	1.6		1.1	0.48	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
8:2 FTS	ND		1.1	0.11	ug/Kg		09/28/24 06:38	10/11/24 04:39	1
10:2 FTS	ND		1.1	0.11	ug/Kg		09/28/24 06:38	10/11/24 04:39	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*50*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:39*	*1*
13C2 PFHxA	*102*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:39*	*1*
13C4 PFHpA	*97*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:39*	*1*
13C4 PFOA	*101*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:39*	*1*
13C5 PFNA	*99*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:39*	*1*
13C2 PFDA	*93*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:39*	*1*
13C2 PFUnA	*91*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:39*	*1*
13C3 PFBS	*110*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:39*	*1*
18O2 PFHxS	*106*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:39*	*1*
13C4 PFOS	*95*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:39*	*1*
M2-4:2 FTS	*209*	*5+	*25 - 150*	*09/28/24 06:38*	*10/11/24 04:39*	*1*
M2-6:2 FTS	*123*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:39*	*1*
M2-8:2 FTS	*111*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:39*	*1*
13C2 10:2 FTS	*364*	*5+	*25 - 150*	*09/28/24 06:38*	*10/11/24 04:39*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoropentanoic acid (PFPeA)	17	B	1.1	0.20	ug/Kg		09/28/24 06:38	10/05/24 02:17	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFPeA	*104*		*25 - 150*	*09/28/24 06:38*	*10/05/24 02:17*	*1*

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: Saltcedar East Intake

Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-12

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	0.43	J B	1.1	0.26	ug/Kg		09/28/24 06:38	10/11/24 05:17	1
Perfluorohexanoic acid (PFHxA)	7.9	B	1.1	0.30	ug/Kg		09/28/24 06:38	10/11/24 05:17	1
Perfluoroheptanoic acid (PFHpA)	5.9		1.1	0.13	ug/Kg		09/28/24 06:38	10/11/24 05:17	1
L-Perfluorooctanoic acid	26		1.1	0.22	ug/Kg		09/28/24 06:38	10/11/24 05:17	1
Br-Perfluorooctanoic acid	1.0	J	1.1	0.22	ug/Kg		09/28/24 06:38	10/11/24 05:17	1
Total PFOA	27		1.1	0.22	ug/Kg		09/28/24 06:38	10/11/24 05:17	1
Perfluorononanoic acid (PFNA)	19		1.1	0.19	ug/Kg		09/28/24 06:38	10/11/24 05:17	1
Perfluorodecanoic acid (PFDA)	0.16	J	1.1	0.11	ug/Kg		09/28/24 06:38	10/11/24 05:17	1
Perfluoroundecanoic acid (PFUnA)	ND		1.1	0.30	ug/Kg		09/28/24 06:38	10/11/24 05:17	1
Perfluorobutanesulfonic acid (PFBS)	2.0	B	1.1	0.19	ug/Kg		09/28/24 06:38	10/11/24 05:17	1
Perfluoropentanesulfonic acid (PFPeS)	8.8		1.1	0.20	ug/Kg		09/28/24 06:38	10/11/24 05:17	1
Perfluoroheptanesulfonic acid (PFHpS)	48		1.1	0.20	ug/Kg		09/28/24 06:38	10/11/24 05:17	1
4:2 FTS	ND		1.1	0.29	ug/Kg		09/28/24 06:38	10/11/24 05:17	1
6:2 FTS	26		1.1	0.47	ug/Kg		09/28/24 06:38	10/11/24 05:17	1
8:2 FTS	0.11	J	1.1	0.11	ug/Kg		09/28/24 06:38	10/11/24 05:17	1
10:2 FTS	ND		1.1	0.11	ug/Kg		09/28/24 06:38	10/11/24 05:17	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*28*		*25 - 150*	*09/28/24 06:38*	*10/11/24 05:17*	*1*
13C2 PFHxA	*99*		*25 - 150*	*09/28/24 06:38*	*10/11/24 05:17*	*1*
13C4 PFHpA	*95*		*25 - 150*	*09/28/24 06:38*	*10/11/24 05:17*	*1*
13C4 PFOA	*98*		*25 - 150*	*09/28/24 06:38*	*10/11/24 05:17*	*1*
13C5 PFNA	*103*		*25 - 150*	*09/28/24 06:38*	*10/11/24 05:17*	*1*
13C2 PFDA	*109*		*25 - 150*	*09/28/24 06:38*	*10/11/24 05:17*	*1*
13C2 PFUnA	*104*		*25 - 150*	*09/28/24 06:38*	*10/11/24 05:17*	*1*
13C3 PFBS	*103*		*25 - 150*	*09/28/24 06:38*	*10/11/24 05:17*	*1*
18O2 PFHxS	*106*		*25 - 150*	*09/28/24 06:38*	*10/11/24 05:17*	*1*
13C4 PFOS	*92*		*25 - 150*	*09/28/24 06:38*	*10/11/24 05:17*	*1*
M2-4:2 FTS	*292*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 05:17*	*1*
M2-6:2 FTS	*237*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 05:17*	*1*
M2-8:2 FTS	*162*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 05:17*	*1*
13C2 10:2 FTS	*447*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 05:17*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	25		22	3.3	ug/Kg		09/28/24 06:38	10/11/24 04:58	20
Total PFHxS	420		22	3.3	ug/Kg		09/28/24 06:38	10/11/24 04:58	20
L-Perfluorohexanesulfonic acid	400		22	3.3	ug/Kg		09/28/24 06:38	10/11/24 04:58	20
L-Perfluorooctanesulfonic acid	630	B	55	4.5	ug/Kg		09/28/24 06:38	10/11/24 04:58	20
Br-Perfluorooctanesulfonic acid	600		55	4.5	ug/Kg		09/28/24 06:38	10/11/24 04:58	20
Total PFOS	1200	B	55	4.5	ug/Kg		09/28/24 06:38	10/11/24 04:58	20

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*100*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:58*	*20*
13C4 PFOS	*96*		*25 - 150*	*09/28/24 06:38*	*10/11/24 04:58*	*20*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoropentanoic acid (PFPeA)	1.5	B	1.1	0.19	ug/Kg		09/28/24 06:38	10/05/24 02:37	1

Client: University of New Mexico
Job ID: 320-115443-1
Project/Site: Holloman Lake PFAS Research

Client Sample ID: Saltcedar East Intake
Lab Sample ID: 320-115443-12
Date Collected: 07/11/24 00:00
Matrix: Tissue
Date Received: 09/17/24 09:40

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
13C5 PFPeA	92		25 - 150	09/28/24 06:38	10/05/24 02:37	1

Client Sample ID: Saltcedar NE 4-1

Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-13

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	1.5	J B	1.7	0.40	ug/Kg		09/28/24 06:38	10/05/24 02:56	1
Perfluoropentanoic acid (PFPeA)	7.1	B	1.7	0.30	ug/Kg		09/28/24 06:38	10/05/24 02:56	1
Perfluorohexanoic acid (PFHxA)	43	B	1.7	0.46	ug/Kg		09/28/24 06:38	10/05/24 02:56	1
Perfluoroheptanoic acid (PFHpA)	63		1.7	0.20	ug/Kg		09/28/24 06:38	10/05/24 02:56	1
Perfluorodecanoic acid (PFDA)	3.8		1.7	0.17	ug/Kg		09/28/24 06:38	10/05/24 02:56	1
Perfluoroundecanoic acid (PFUnA)	ND		1.7	0.46	ug/Kg		09/28/24 06:38	10/05/24 02:56	1
Perfluorobutanesulfonic acid (PFBS)	3.9	B	1.7	0.29	ug/Kg		09/28/24 06:38	10/05/24 02:56	1
Perfluoropentanesulfonic acid (PFPeS)	33		1.7	0.31	ug/Kg		09/28/24 06:38	10/05/24 02:56	1
4:2 FTS	ND		1.7	0.45	ug/Kg		09/28/24 06:38	10/05/24 02:56	1
8:2 FTS	28		1.7	0.17	ug/Kg		09/28/24 06:38	10/05/24 02:56	1
10:2 FTS	ND		1.7	0.17	ug/Kg		09/28/24 06:38	10/05/24 02:56	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*55*		*25 - 150*	*09/28/24 06:38*	*10/05/24 02:56*	*1*
13C5 PFPeA	*115*		*25 - 150*	*09/28/24 06:38*	*10/05/24 02:56*	*1*
13C2 PFHxA	*112*		*25 - 150*	*09/28/24 06:38*	*10/05/24 02:56*	*1*
13C4 PFHpA	*96*		*25 - 150*	*09/28/24 06:38*	*10/05/24 02:56*	*1*
13C2 PFDA	*100*		*25 - 150*	*09/28/24 06:38*	*10/05/24 02:56*	*1*
13C2 PFUnA	*106*		*25 - 150*	*09/28/24 06:38*	*10/05/24 02:56*	*1*
13C3 PFBS	*113*		*25 - 150*	*09/28/24 06:38*	*10/05/24 02:56*	*1*
M2-4:2 FTS	*225*	*5+	*25 - 150*	*09/28/24 06:38*	*10/05/24 02:56*	*1*
M2-8:2 FTS	*125*		*25 - 150*	*09/28/24 06:38*	*10/05/24 02:56*	*1*
13C2 10:2 FTS	*460*	*5+	*25 - 150*	*09/28/24 06:38*	*10/05/24 02:56*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanoic acid	890		17	3.4	ug/Kg		09/28/24 06:38	10/11/24 05:56	10
Br-Perfluorooctanoic acid	41		17	3.4	ug/Kg		09/28/24 06:38	10/11/24 05:56	10
Total PFOA	930		17	3.4	ug/Kg		09/28/24 06:38	10/11/24 05:56	10
Perfluorononanoic acid (PFNA)	230		17	3.0	ug/Kg		09/28/24 06:38	10/11/24 05:56	10
Perfluoroheptanesulfonic acid (PFHpS)	1400		17	3.1	ug/Kg		09/28/24 06:38	10/11/24 05:56	10
6:2 FTS	1300		17	7.2	ug/Kg		09/28/24 06:38	10/11/24 05:56	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOA	*100*		*25 - 150*	*09/28/24 06:38*	*10/11/24 05:56*	*10*
13C5 PFNA	*102*		*25 - 150*	*09/28/24 06:38*	*10/11/24 05:56*	*10*
13C4 PFOS	*75*		*25 - 150*	*09/28/24 06:38*	*10/11/24 05:56*	*10*
M2-6:2 FTS	*146*		*25 - 150*	*09/28/24 06:38*	*10/11/24 05:56*	*10*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL2

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	210		170	25	ug/Kg		09/28/24 06:38	10/11/24 05:37	100
Total PFHxS	6800		170	25	ug/Kg		09/28/24 06:38	10/11/24 05:37	100
L-Perfluorohexanesulfonic acid	6500		170	25	ug/Kg		09/28/24 06:38	10/11/24 05:37	100
L-Perfluorooctanesulfonic acid	15000	B	420	34	ug/Kg		09/28/24 06:38	10/11/24 05:37	100
Br-Perfluorooctanesulfonic acid	15000		420	34	ug/Kg		09/28/24 06:38	10/11/24 05:37	100
Total PFOS	30000	B	420	34	ug/Kg		09/28/24 06:38	10/11/24 05:37	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*126*		*25 - 150*	*09/28/24 06:38*	*10/11/24 05:37*	*100*

Client Sample ID: Saltcedar NE 4-1
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-13
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL2 (Continued)

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
13C4 PFOS	97		25 - 150	09/28/24 06:38	10/11/24 05:37	100

Client Sample ID: pickleweed NE 4-1
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-14
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	1.3	B	0.99	0.23	ug/Kg		09/28/24 06:38	10/11/24 06:54	1
Perfluorohexanoic acid (PFHxA)	8.2	B	0.99	0.27	ug/Kg		09/28/24 06:38	10/11/24 06:54	1
Perfluoroheptanoic acid (PFHpA)	1.7		0.99	0.11	ug/Kg		09/28/24 06:38	10/11/24 06:54	1
L-Perfluorooctanoic acid	5.0		0.99	0.20	ug/Kg		09/28/24 06:38	10/11/24 06:54	1
Br-Perfluorooctanoic acid	0.37	J	0.99	0.20	ug/Kg		09/28/24 06:38	10/11/24 06:54	1
Total PFOA	5.4		0.99	0.20	ug/Kg		09/28/24 06:38	10/11/24 06:54	1
Perfluorononanoic acid (PFNA)	4.9		0.99	0.17	ug/Kg		09/28/24 06:38	10/11/24 06:54	1
Perfluorodecanoic acid (PFDA)	0.38	J	0.99	0.10	ug/Kg		09/28/24 06:38	10/11/24 06:54	1
Perfluoroundecanoic acid (PFUnA)	ND		0.99	0.27	ug/Kg		09/28/24 06:38	10/11/24 06:54	1
Perfluorobutanesulfonic acid (PFBS)	1.3	B	0.99	0.17	ug/Kg		09/28/24 06:38	10/11/24 06:54	1
Perfluoropentanesulfonic acid (PFPeS)	4.1		0.99	0.18	ug/Kg		09/28/24 06:38	10/11/24 06:54	1
Perfluoroheptanesulfonic acid (PFHpS)	12		0.99	0.18	ug/Kg		09/28/24 06:38	10/11/24 06:54	1
4:2 FTS	ND		0.99	0.26	ug/Kg		09/28/24 06:38	10/11/24 06:54	1
6:2 FTS	54		0.99	0.42	ug/Kg		09/28/24 06:38	10/11/24 06:54	1
8:2 FTS	1.5		0.99	0.099	ug/Kg		09/28/24 06:38	10/11/24 06:54	1
10:2 FTS	ND		0.99	0.10	ug/Kg		09/28/24 06:38	10/11/24 06:54	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*29*		*25 - 150*	*09/28/24 06:38*	*10/11/24 06:54*	*1*
13C2 PFHxA	*86*		*25 - 150*	*09/28/24 06:38*	*10/11/24 06:54*	*1*
13C4 PFHpA	*85*		*25 - 150*	*09/28/24 06:38*	*10/11/24 06:54*	*1*
13C4 PFOA	*92*		*25 - 150*	*09/28/24 06:38*	*10/11/24 06:54*	*1*
13C5 PFNA	*93*		*25 - 150*	*09/28/24 06:38*	*10/11/24 06:54*	*1*
13C2 PFDA	*105*		*25 - 150*	*09/28/24 06:38*	*10/11/24 06:54*	*1*
13C2 PFUnA	*108*		*25 - 150*	*09/28/24 06:38*	*10/11/24 06:54*	*1*
13C3 PFBS	*93*		*25 - 150*	*09/28/24 06:38*	*10/11/24 06:54*	*1*
13C4 PFOS	*76*		*25 - 150*	*09/28/24 06:38*	*10/11/24 06:54*	*1*
M2-4:2 FTS	*222*	*5+	*25 - 150*	*09/28/24 06:38*	*10/11/24 06:54*	*1*
M2-6:2 FTS	*328*	*5+	*25 - 150*	*09/28/24 06:38*	*10/11/24 06:54*	*1*
M2-8:2 FTS	*199*	*5+	*25 - 150*	*09/28/24 06:38*	*10/11/24 06:54*	*1*
13C2 10:2 FTS	*495*	*5+	*25 - 150*	*09/28/24 06:38*	*10/11/24 06:54*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	14	J	20	2.9	ug/Kg		09/28/24 06:38	10/14/24 18:38	20
Total PFHxS	160		20	2.9	ug/Kg		09/28/24 06:38	10/14/24 18:38	20
L-Perfluorohexanesulfonic acid	140		20	2.9	ug/Kg		09/28/24 06:38	10/14/24 18:38	20
L-Perfluorooctanesulfonic acid	730	B	50	4.0	ug/Kg		09/28/24 06:38	10/14/24 18:38	20
Br-Perfluorooctanesulfonic acid	290		50	4.0	ug/Kg		09/28/24 06:38	10/14/24 18:38	20
Total PFOS	1000	B	50	4.0	ug/Kg		09/28/24 06:38	10/14/24 18:38	20

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*92*		*25 - 150*	*09/28/24 06:38*	*10/14/24 18:38*	*20*
13C4 PFOS	*94*		*25 - 150*	*09/28/24 06:38*	*10/14/24 18:38*	*20*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluoropentanoic acid (PFPeA)	3.6	B	0.99	0.17	ug/Kg		09/28/24 06:38	10/05/24 03:15	1

Client: University of New Mexico
Job ID: 320-115443-1
Project/Site: Holloman Lake PFAS Research

Client Sample ID: pickleweed NE 4-1
Lab Sample ID: 320-115443-14
Date Collected: 07/11/24 00:00
Matrix: Tissue
Date Received: 09/17/24 09:40

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
13C5 PFPeA	62		25 - 150	09/28/24 06:38	10/05/24 03:15	1

Client Sample ID: MSBHerp109299 muscle

Date Collected: 09/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-15

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.1	0.27	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
Perfluoropentanoic acid (PFPeA)	ND		1.1	0.20	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
Perfluorohexanoic acid (PFHxA)	ND		1.1	0.31	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
Perfluoroheptanoic acid (PFHpA)	ND		1.1	0.13	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
L-Perfluorooctanoic acid	**4.8**		1.1	0.23	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
Br-Perfluorooctanoic acid	ND		1.1	0.23	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
Total PFOA	**4.8**		1.1	0.23	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
Perfluorononanoic acid (PFNA)	**7.1**		1.1	0.20	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
Perfluorodecanoic acid (PFDA)	**1.0**	**J**	1.1	0.12	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
Perfluoroundecanoic acid (PFUnA)	**0.40**	**J**	1.1	0.31	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.1	0.19	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
Perfluoropentanesulfonic acid (PFPeS)	**0.52**	**J**	1.1	0.21	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
Perfluoroheptanesulfonic acid (PFHpS)	**15**		1.1	0.21	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
4:2 FTS	ND		1.1	0.30	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
6:2 FTS	**2.4**		1.1	0.48	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
8:2 FTS	**13**		1.1	0.11	ug/Kg		09/28/24 06:38	10/11/24 07:33	1
10:2 FTS	ND		1.1	0.11	ug/Kg		09/28/24 06:38	10/11/24 07:33	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*94*		*25 - 150*	*09/28/24 06:38*	*10/11/24 07:33*	*1*
13C5 PFPeA	*101*		*25 - 150*	*09/28/24 06:38*	*10/11/24 07:33*	*1*
13C2 PFHxA	*86*		*25 - 150*	*09/28/24 06:38*	*10/11/24 07:33*	*1*
13C4 PFHpA	*84*		*25 - 150*	*09/28/24 06:38*	*10/11/24 07:33*	*1*
13C4 PFOA	*93*		*25 - 150*	*09/28/24 06:38*	*10/11/24 07:33*	*1*
13C5 PFNA	*101*		*25 - 150*	*09/28/24 06:38*	*10/11/24 07:33*	*1*
13C2 PFDA	*94*		*25 - 150*	*09/28/24 06:38*	*10/11/24 07:33*	*1*
13C2 PFUnA	*96*		*25 - 150*	*09/28/24 06:38*	*10/11/24 07:33*	*1*
13C3 PFBS	*98*		*25 - 150*	*09/28/24 06:38*	*10/11/24 07:33*	*1*
13C4 PFOS	*78*		*25 - 150*	*09/28/24 06:38*	*10/11/24 07:33*	*1*
M2-4:2 FTS	*106*		*25 - 150*	*09/28/24 06:38*	*10/11/24 07:33*	*1*
M2-6:2 FTS	*114*		*25 - 150*	*09/28/24 06:38*	*10/11/24 07:33*	*1*
M2-8:2 FTS	*109*		*25 - 150*	*09/28/24 06:38*	*10/11/24 07:33*	*1*
13C2 10:2 FTS	*186*	**5+*	*25 - 150*	*09/28/24 06:38*	*10/11/24 07:33*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	**23**		11	1.7	ug/Kg		09/28/24 06:38	10/11/24 07:14	10
Total PFHxS	**200**		11	1.7	ug/Kg		09/28/24 06:38	10/11/24 07:14	10
L-Perfluorohexanesulfonic acid	**180**		11	1.7	ug/Kg		09/28/24 06:38	10/11/24 07:14	10
L-Perfluorooctanesulfonic acid	**700**	**B**	28	2.3	ug/Kg		09/28/24 06:38	10/11/24 07:14	10
Br-Perfluorooctanesulfonic acid	**240**		28	2.3	ug/Kg		09/28/24 06:38	10/11/24 07:14	10
Total PFOS	**940**	**B**	28	2.3	ug/Kg		09/28/24 06:38	10/11/24 07:14	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*89*		*25 - 150*	*09/28/24 06:38*	*10/11/24 07:14*	*10*
13C4 PFOS	*88*		*25 - 150*	*09/28/24 06:38*	*10/11/24 07:14*	*10*

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: MSBHerp109299 liver
Date Collected: 09/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-16
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		5.6	1.3	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
Perfluoropentanoic acid (PFPeA)	ND		5.6	0.97	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
Perfluorohexanoic acid (PFHxA)	ND		5.6	1.5	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
Perfluoroheptanoic acid (PFHpA)	ND		5.6	0.64	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
L-Perfluorooctanoic acid	**32**		5.6	1.1	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
Br-Perfluorooctanoic acid	**1.5**	**J**	5.6	1.1	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
Total PFOA	**34**		5.6	1.1	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
Perfluorononanoic acid (PFNA)	**58**		5.6	0.97	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
Perfluorodecanoic acid (PFDA)	**4.6**	**J**	5.6	0.57	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
Perfluoroundecanoic acid (PFUnA)	ND		5.6	1.5	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
Perfluorobutanesulfonic acid (PFBS)	ND		5.6	0.94	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
Perfluoropentanesulfonic acid (PFPeS)	**3.1**	**J**	5.6	1.0	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
Perfluoroheptanesulfonic acid (PFHpS)	**160**		5.6	1.0	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
4:2 FTS	ND		5.6	1.5	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
6:2 FTS	ND		5.6	2.4	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
8:2 FTS	**5.8**		5.6	0.56	ug/Kg		09/30/24 13:29	10/03/24 05:49	1
10:2 FTS	**0.63**	**J**	5.6	0.56	ug/Kg		09/30/24 13:29	10/03/24 05:49	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*97*		*25 - 150*	*09/30/24 13:29*	*10/03/24 05:49*	*1*
13C5 PFPeA	*82*		*25 - 150*	*09/30/24 13:29*	*10/03/24 05:49*	*1*
13C2 PFHxA	*85*		*25 - 150*	*09/30/24 13:29*	*10/03/24 05:49*	*1*
13C4 PFHpA	*78*		*25 - 150*	*09/30/24 13:29*	*10/03/24 05:49*	*1*
13C4 PFOA	*95*		*25 - 150*	*09/30/24 13:29*	*10/03/24 05:49*	*1*
13C5 PFNA	*94*		*25 - 150*	*09/30/24 13:29*	*10/03/24 05:49*	*1*
13C2 PFDA	*90*		*25 - 150*	*09/30/24 13:29*	*10/03/24 05:49*	*1*
13C2 PFUnA	*89*		*25 - 150*	*09/30/24 13:29*	*10/03/24 05:49*	*1*
13C3 PFBS	*85*		*25 - 150*	*09/30/24 13:29*	*10/03/24 05:49*	*1*
13C4 PFOS	*70*		*25 - 150*	*09/30/24 13:29*	*10/03/24 05:49*	*1*
M2-4:2 FTS	*99*		*25 - 150*	*09/30/24 13:29*	*10/03/24 05:49*	*1*
M2-6:2 FTS	*133*		*25 - 150*	*09/30/24 13:29*	*10/03/24 05:49*	*1*
M2-8:2 FTS	*101*		*25 - 150*	*09/30/24 13:29*	*10/03/24 05:49*	*1*
13C2 10:2 FTS	*296*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 05:49*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	**160**		56	8.2	ug/Kg		09/30/24 13:29	10/05/24 05:12	10
Total PFHxS	**1500**		56	8.2	ug/Kg		09/30/24 13:29	10/05/24 05:12	10
L-Perfluorohexanesulfonic acid	**1400**		56	8.2	ug/Kg		09/30/24 13:29	10/05/24 05:12	10
L-Perfluorooctanesulfonic acid	**4400**		140	11	ug/Kg		09/30/24 13:29	10/05/24 05:12	10
Br-Perfluorooctanesulfonic acid	**2300**		140	11	ug/Kg		09/30/24 13:29	10/05/24 05:12	10
Total PFOS	**6800**		140	11	ug/Kg		09/30/24 13:29	10/05/24 05:12	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*88*		*25 - 150*	*09/30/24 13:29*	*10/05/24 05:12*	*10*
13C4 PFOS	*84*		*25 - 150*	*09/30/24 13:29*	*10/05/24 05:12*	*10*

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: NK319555 muscle
Date Collected: 09/12/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-17
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**1.3**		1.1	0.27	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
Perfluoropentanoic acid (PFPeA)	**0.31**	**J**	1.1	0.20	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
Perfluorohexanoic acid (PFHxA)	ND		1.1	0.31	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
Perfluoroheptanoic acid (PFHpA)	**0.40**	**J**	1.1	0.13	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
L-Perfluorooctanoic acid	**15**		1.1	0.23	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
Br-Perfluorooctanoic acid	**0.46**	**J**	1.1	0.23	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
Total PFOA	**15**		1.1	0.23	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
Perfluorononanoic acid (PFNA)	**9.5**		1.1	0.20	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
Perfluorodecanoic acid (PFDA)	**1.0**	**J**	1.1	0.12	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
Perfluoroundecanoic acid (PFUnA)	ND		1.1	0.31	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.1	0.19	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
Perfluoropentanesulfonic acid (PFPeS)	**1.6**		1.1	0.21	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
Perfluoroheptanesulfonic acid (PFHpS)	**22**		1.1	0.21	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
4:2 FTS	ND		1.1	0.30	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
6:2 FTS	**1.3**		1.1	0.48	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
8:2 FTS	**0.31**	**J**	1.1	0.11	ug/Kg		09/30/24 13:29	10/03/24 06:08	1
10:2 FTS	ND		1.1	0.11	ug/Kg		09/30/24 13:29	10/03/24 06:08	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*37*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:08*	*1*
13C5 PFPeA	*67*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:08*	*1*
13C2 PFHxA	*83*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:08*	*1*
13C4 PFHpA	*94*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:08*	*1*
13C4 PFOA	*96*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:08*	*1*
13C5 PFNA	*103*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:08*	*1*
13C2 PFDA	*120*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:08*	*1*
13C2 PFUnA	*112*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:08*	*1*
13C3 PFBS	*82*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:08*	*1*
13C4 PFOS	*81*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:08*	*1*
M2-4:2 FTS	*275*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 06:08*	*1*
M2-6:2 FTS	*156*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 06:08*	*1*
M2-8:2 FTS	*253*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 06:08*	*1*
13C2 10:2 FTS	*530*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 06:08*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	**350**		11	1.7	ug/Kg		09/30/24 13:29	10/05/24 05:31	10
Total PFHxS	**360**		11	1.7	ug/Kg		09/30/24 13:29	10/05/24 05:31	10
L-Perfluorohexanesulfonic acid	**8.5**	**J**	11	1.7	ug/Kg		09/30/24 13:29	10/05/24 05:31	10
L-Perfluorooctanesulfonic acid	**420**		28	2.3	ug/Kg		09/30/24 13:29	10/05/24 05:31	10
Br-Perfluorooctanesulfonic acid	**220**		28	2.3	ug/Kg		09/30/24 13:29	10/05/24 05:31	10
Total PFOS	**640**		28	2.3	ug/Kg		09/30/24 13:29	10/05/24 05:31	10

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*94*		*25 - 150*	*09/30/24 13:29*	*10/05/24 05:31*	*10*
13C4 PFOS	*89*		*25 - 150*	*09/30/24 13:29*	*10/05/24 05:31*	*10*

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: NK319556 muscle
Date Collected: 09/13/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-18
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**0.78**		0.76	0.18	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
Perfluoropentanoic acid (PFPeA)	ND		0.76	0.13	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
Perfluorohexanoic acid (PFHxA)	ND		0.76	0.21	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
Perfluoroheptanoic acid (PFHpA)	ND		0.76	0.089	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
L-Perfluorooctanoic acid	**0.15**	**J**	0.76	0.15	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
Br-Perfluorooctanoic acid	ND		0.76	0.15	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
Total PFOA	**0.15**	**J**	0.76	0.15	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
Perfluorononanoic acid (PFNA)	ND		0.76	0.13	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
Perfluorodecanoic acid (PFDA)	ND		0.76	0.079	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
Perfluoroundecanoic acid (PFUnA)	ND		0.76	0.21	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.76	0.13	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.76	0.14	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
Br-Perfluorohexanesulfonic acid	ND		0.76	0.11	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
Total PFHxS	**0.16**	**J**	0.76	0.11	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
L-Perfluorohexanesulfonic acid	**0.16**	**J**	0.76	0.11	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.76	0.14	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
L-Perfluorooctanesulfonic acid	**0.31**	**J**	1.9	0.15	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
Br-Perfluorooctanesulfonic acid	ND		1.9	0.15	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
Total PFOS	**0.31**	**J**	1.9	0.15	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
4:2 FTS	ND		0.76	0.20	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
6:2 FTS	ND		0.76	0.32	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
8:2 FTS	ND		0.76	0.076	ug/Kg		09/30/24 13:29	10/03/24 06:28	1
10:2 FTS	ND		0.76	0.077	ug/Kg		09/30/24 13:29	10/03/24 06:28	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*81*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:28*	*1*
13C5 PFPeA	*88*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:28*	*1*
13C2 PFHxA	*93*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:28*	*1*
13C4 PFHpA	*86*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:28*	*1*
13C4 PFOA	*96*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:28*	*1*
13C5 PFNA	*104*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:28*	*1*
13C2 PFDA	*99*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:28*	*1*
13C2 PFUnA	*99*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:28*	*1*
13C3 PFBS	*82*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:28*	*1*
18O2 PFHxS	*89*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:28*	*1*
13C4 PFOS	*94*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:28*	*1*
M2-4:2 FTS	*116*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:28*	*1*
M2-6:2 FTS	*116*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:28*	*1*
M2-8:2 FTS	*107*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:28*	*1*
13C2 10:2 FTS	*481*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 06:28*	*1*

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: NK319556 liver
Date Collected: 09/14/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-19
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**2.1**		0.71	0.17	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
Perfluoropentanoic acid (PFPeA)	ND		0.71	0.13	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
Perfluorohexanoic acid (PFHxA)	ND		0.71	0.20	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
Perfluoroheptanoic acid (PFHpA)	**0.12**	**J**	0.71	0.083	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
L-Perfluorooctanoic acid	**0.87**		0.71	0.14	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
Br-Perfluorooctanoic acid	**0.14**	**J**	0.71	0.14	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
Total PFOA	**1.0**		0.71	0.14	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
Perfluorononanoic acid (PFNA)	**0.66**	**J**	0.71	0.13	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
Perfluorodecanoic acid (PFDA)	**0.27**	**J**	0.71	0.074	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
Perfluoroundecanoic acid (PFUnA)	ND		0.71	0.19	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.71	0.12	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.71	0.13	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
Br-Perfluorohexanesulfonic acid	ND		0.71	0.11	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
Total PFHxS	**0.63**	**J**	0.71	0.11	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
L-Perfluorohexanesulfonic acid	**0.63**	**J**	0.71	0.11	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.71	0.13	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
L-Perfluorooctanesulfonic acid	**2.1**		1.8	0.15	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
Br-Perfluorooctanesulfonic acid	**0.94**	**J**	1.8	0.15	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
Total PFOS	**3.0**		1.8	0.15	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
4:2 FTS	ND		0.71	0.19	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
6:2 FTS	ND		0.71	0.30	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
8:2 FTS	ND		0.71	0.071	ug/Kg		09/30/24 13:29	10/03/24 06:47	1
10:2 FTS	ND		0.71	0.072	ug/Kg		09/30/24 13:29	10/03/24 06:47	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*78*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:47*	*1*
13C5 PFPeA	*91*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:47*	*1*
13C2 PFHxA	*90*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:47*	*1*
13C4 PFHpA	*89*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:47*	*1*
13C4 PFOA	*96*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:47*	*1*
13C5 PFNA	*113*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:47*	*1*
13C2 PFDA	*105*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:47*	*1*
13C2 PFUnA	*109*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:47*	*1*
13C3 PFBS	*96*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:47*	*1*
18O2 PFHxS	*101*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:47*	*1*
13C4 PFOS	*103*		*25 - 150*	*09/30/24 13:29*	*10/03/24 06:47*	*1*
M2-4:2 FTS	*217*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 06:47*	*1*
M2-6:2 FTS	*164*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 06:47*	*1*
M2-8:2 FTS	*163*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 06:47*	*1*
13C2 10:2 FTS	*514*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 06:47*	*1*

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: MSB89187 femur
Date Collected: 11/28/94 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-20
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	4.8	1.1	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	4.8	0.83	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	4.8	1.3	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	4.8	0.55	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
L-Perfluorooctanoic acid	ND	H H3	4.8	0.96	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
Br-Perfluorooctanoic acid	ND	H H3	4.8	0.96	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
Total PFOA	ND	H H3	4.8	0.96	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
Perfluorononanoic acid (PFNA)	ND	H H3	4.8	0.83	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
Perfluorodecanoic acid (PFDA)	ND	H H3	4.8	0.49	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	4.8	1.3	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	4.8	0.81	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	4.8	0.86	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
Br-Perfluorohexanesulfonic acid	ND	H H3	4.8	0.70	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
Total PFHxS	ND	H H3	4.8	0.70	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
L-Perfluorohexanesulfonic acid	ND	H H3	4.8	0.70	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	4.8	0.88	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
L-Perfluorooctanesulfonic acid	ND	H H3	12	0.97	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
Br-Perfluorooctanesulfonic acid	ND	H H3	12	0.97	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
Total PFOS	ND	H H3	12	0.97	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
4:2 FTS	ND	H H3	4.8	1.3	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
6:2 FTS	ND	H H3	4.8	2.0	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
8:2 FTS	ND	H H3	4.8	0.48	ug/Kg		09/30/24 13:29	10/03/24 07:07	1
10:2 FTS	**0.55**	**J H H3**	4.8	0.48	ug/Kg		09/30/24 13:29	10/03/24 07:07	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*94*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:07*	*1*
13C5 PFPeA	*92*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:07*	*1*
13C2 PFHxA	*93*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:07*	*1*
13C4 PFHpA	*86*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:07*	*1*
13C4 PFOA	*101*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:07*	*1*
13C5 PFNA	*101*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:07*	*1*
13C2 PFDA	*108*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:07*	*1*
13C2 PFUnA	*100*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:07*	*1*
13C3 PFBS	*89*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:07*	*1*
18O2 PFHxS	*100*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:07*	*1*
13C4 PFOS	*103*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:07*	*1*
M2-4:2 FTS	*247*	*5+	*25 - 150*	*09/30/24 13:29*	*10/03/24 07:07*	*1*
M2-6:2 FTS	*110*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:07*	*1*
M2-8:2 FTS	*123*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:07*	*1*
13C2 10:2 FTS	*155*	*5+	*25 - 150*	*09/30/24 13:29*	*10/03/24 07:07*	*1*

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: MSB92667 femur
Date Collected: 08/16/94 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-21
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	33	7.9	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	33	5.8	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	33	9.1	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	33	3.9	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
L-Perfluorooctanoic acid	ND	H H3	33	6.7	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
Br-Perfluorooctanoic acid	ND	H H3	33	6.7	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
Total PFOA	ND	H H3	33	6.7	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
Perfluorononanoic acid (PFNA)	ND	H H3	33	5.8	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
Perfluorodecanoic acid (PFDA)	ND	H H3	33	3.4	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	33	9.1	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	33	5.7	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	33	6.0	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
Br-Perfluorohexanesulfonic acid	ND	H H3	33	4.9	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
Total PFHxS	ND	H H3	33	4.9	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
L-Perfluorohexanesulfonic acid	ND	H H3	33	4.9	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	33	6.2	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
L-Perfluorooctanesulfonic acid	**310**	**H H3**	83	6.8	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
Br-Perfluorooctanesulfonic acid	**61**	**J H H3**	83	6.8	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
Total PFOS	**370**	**H H3**	83	6.8	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
4:2 FTS	ND	H H3	33	8.9	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
6:2 FTS	ND	H H3	33	14	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
8:2 FTS	ND	H H3	33	3.3	ug/Kg		09/30/24 13:29	10/03/24 07:26	1
10:2 FTS	**3.7**	**J H H3**	33	3.4	ug/Kg		09/30/24 13:29	10/03/24 07:26	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*104*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:26*	*1*
13C5 PFPeA	*104*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:26*	*1*
13C2 PFHxA	*96*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:26*	*1*
13C4 PFHpA	*87*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:26*	*1*
13C4 PFOA	*90*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:26*	*1*
13C5 PFNA	*99*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:26*	*1*
13C2 PFDA	*93*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:26*	*1*
13C2 PFUnA	*93*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:26*	*1*
13C3 PFBS	*94*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:26*	*1*
18O2 PFHxS	*99*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:26*	*1*
13C4 PFOS	*94*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:26*	*1*
M2-4:2 FTS	*145*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:26*	*1*
M2-6:2 FTS	*97*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:26*	*1*
M2-8:2 FTS	*98*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:26*	*1*
13C2 10:2 FTS	*113*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:26*	*1*

Client Sample ID: MSB61848 femur

Date Collected: 05/11/89 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-22

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	25	5.9	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	25	4.4	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	25	6.8	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	25	2.9	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
L-Perfluorooctanoic acid	ND	H H3	25	5.1	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
Br-Perfluorooctanoic acid	ND	H H3	25	5.1	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
Total PFOA	ND	H H3	25	5.1	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
Perfluorononanoic acid (PFNA)	ND	H H3	25	4.4	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
Perfluorodecanoic acid (PFDA)	ND	H H3	25	2.6	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	25	6.8	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	25	4.3	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	25	4.5	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
Br-Perfluorohexanesulfonic acid	ND	H H3	25	3.7	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
Total PFHxS	ND	H H3	25	3.7	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
L-Perfluorohexanesulfonic acid	ND	H H3	25	3.7	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	25	4.6	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
L-Perfluorooctanesulfonic acid	ND	H H3	63	5.1	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
Br-Perfluorooctanesulfonic acid	ND	H H3	63	5.1	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
Total PFOS	ND	H H3	63	5.1	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
4:2 FTS	ND	H H3	25	6.7	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
6:2 FTS	ND	H H3	25	11	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
8:2 FTS	ND	H H3	25	2.5	ug/Kg		09/30/24 13:29	10/03/24 07:45	1
10:2 FTS	**2.7**	**J H H3**	25	2.5	ug/Kg		09/30/24 13:29	10/03/24 07:45	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*106*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:45*	*1*
13C5 PFPeA	*98*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:45*	*1*
13C2 PFHxA	*94*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:45*	*1*
13C4 PFHpA	*88*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:45*	*1*
13C4 PFOA	*97*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:45*	*1*
13C5 PFNA	*96*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:45*	*1*
13C2 PFDA	*95*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:45*	*1*
13C2 PFUnA	*88*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:45*	*1*
13C3 PFBS	*97*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:45*	*1*
18O2 PFHxS	*89*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:45*	*1*
13C4 PFOS	*91*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:45*	*1*
M2-4:2 FTS	*137*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:45*	*1*
M2-6:2 FTS	*106*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:45*	*1*
M2-8:2 FTS	*98*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:45*	*1*
13C2 10:2 FTS	*116*		*25 - 150*	*09/30/24 13:29*	*10/03/24 07:45*	*1*

Client Sample ID: MSB89196 femur
Date Collected: 11/27/94 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-23
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	25	5.9	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	25	4.4	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	25	6.8	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	25	2.9	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
L-Perfluorooctanoic acid	ND	H H3	25	5.1	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
Br-Perfluorooctanoic acid	ND	H H3	25	5.1	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
Total PFOA	ND	H H3	25	5.1	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
Perfluorononanoic acid (PFNA)	ND	H H3	25	4.4	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
Perfluorodecanoic acid (PFDA)	ND	H H3	25	2.6	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	25	6.8	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	25	4.3	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	25	4.5	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
Br-Perfluorohexanesulfonic acid	ND	H H3	25	3.7	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
Total PFHxS	ND	H H3	25	3.7	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
L-Perfluorohexanesulfonic acid	ND	H H3	25	3.7	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	25	4.6	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
L-Perfluorooctanesulfonic acid	ND	H H3	63	5.1	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
Br-Perfluorooctanesulfonic acid	ND	H H3	63	5.1	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
Total PFOS	ND	H H3	63	5.1	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
4:2 FTS	ND	H H3	25	6.7	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
6:2 FTS	ND	H H3	25	11	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
8:2 FTS	ND	H H3	25	2.5	ug/Kg		09/30/24 13:29	10/03/24 08:24	1
10:2 FTS	ND	H H3	25	2.5	ug/Kg		09/30/24 13:29	10/03/24 08:24	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*93*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:24*	*1*
13C5 PFPeA	*98*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:24*	*1*
13C2 PFHxA	*98*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:24*	*1*
13C4 PFHpA	*86*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:24*	*1*
13C4 PFOA	*101*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:24*	*1*
13C5 PFNA	*103*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:24*	*1*
13C2 PFDA	*93*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:24*	*1*
13C2 PFUnA	*93*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:24*	*1*
13C3 PFBS	*98*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:24*	*1*
18O2 PFHxS	*101*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:24*	*1*
13C4 PFOS	*95*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:24*	*1*
M2-4:2 FTS	*204*	*5+	*25 - 150*	*09/30/24 13:29*	*10/03/24 08:24*	*1*
M2-6:2 FTS	*100*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:24*	*1*
M2-8:2 FTS	*106*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:24*	*1*
13C2 10:2 FTS	*125*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:24*	*1*

Client Sample ID: MSB87701 femur

Date Collected: 11/26/94 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-24

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	2.1	0.49	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
Perfluoropentanoic acid (PFPeA)	**0.45**	**J H H3**	2.1	0.36	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	2.1	0.57	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	2.1	0.24	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
L-Perfluorooctanoic acid	ND	H H3	2.1	0.42	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
Br-Perfluorooctanoic acid	ND	H H3	2.1	0.42	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
Total PFOA	ND	H H3	2.1	0.42	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
Perfluorononanoic acid (PFNA)	ND	H H3	2.1	0.36	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
Perfluorodecanoic acid (PFDA)	ND	H H3	2.1	0.21	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	2.1	0.57	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	2.1	0.35	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	2.1	0.38	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
Br-Perfluorohexanesulfonic acid	ND	H H3	2.1	0.31	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
Total PFHxS	ND	H H3	2.1	0.31	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
L-Perfluorohexanesulfonic acid	ND	H H3	2.1	0.31	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	2.1	0.39	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
L-Perfluorooctanesulfonic acid	ND	H H3	5.2	0.42	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
Br-Perfluorooctanesulfonic acid	ND	H H3	5.2	0.42	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
Total PFOS	ND	H H3	5.2	0.42	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
4:2 FTS	ND	H H3	2.1	0.55	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
6:2 FTS	ND	H H3	2.1	0.88	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
8:2 FTS	ND	H H3	2.1	0.21	ug/Kg		09/30/24 13:29	10/03/24 08:44	1
10:2 FTS	ND	H H3	2.1	0.21	ug/Kg		09/30/24 13:29	10/03/24 08:44	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*59*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:44*	*1*
13C5 PFPeA	*88*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:44*	*1*
13C2 PFHxA	*93*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:44*	*1*
13C4 PFHpA	*90*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:44*	*1*
13C4 PFOA	*96*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:44*	*1*
13C5 PFNA	*102*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:44*	*1*
13C2 PFDA	*107*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:44*	*1*
13C2 PFUnA	*109*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:44*	*1*
13C3 PFBS	*91*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:44*	*1*
18O2 PFHxS	*96*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:44*	*1*
13C4 PFOS	*97*		*25 - 150*	*09/30/24 13:29*	*10/03/24 08:44*	*1*
M2-4:2 FTS	*287*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 08:44*	*1*
M2-6:2 FTS	*160*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 08:44*	*1*
M2-8:2 FTS	*198*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 08:44*	*1*
13C2 10:2 FTS	*282*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 08:44*	*1*

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: MSB87702 femur
Date Collected: 11/27/94 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-25
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	2.4	0.56	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
Perfluoropentanoic acid (PFPeA)	**0.56**	**J H H3**	2.4	0.42	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	2.4	0.65	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	2.4	0.28	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
L-Perfluorooctanoic acid	ND	H H3	2.4	0.48	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
Br-Perfluorooctanoic acid	ND	H H3	2.4	0.48	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
Total PFOA	ND	H H3	2.4	0.48	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
Perfluorononanoic acid (PFNA)	ND	H H3	2.4	0.42	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
Perfluorodecanoic acid (PFDA)	ND	H H3	2.4	0.25	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	2.4	0.65	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	2.4	0.40	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	2.4	0.43	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
Br-Perfluorohexanesulfonic acid	ND	H H3	2.4	0.35	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
Total PFHxS	ND	H H3	2.4	0.35	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
L-Perfluorohexanesulfonic acid	ND	H H3	2.4	0.35	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	2.4	0.44	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
L-Perfluorooctanesulfonic acid	**0.77**	**J H H3**	6.0	0.48	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
Br-Perfluorooctanesulfonic acid	ND	H H3	6.0	0.48	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
Total PFOS	**0.77**	**J H H3**	6.0	0.48	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
4:2 FTS	ND	H H3	2.4	0.63	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
6:2 FTS	ND	H H3	2.4	1.0	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
8:2 FTS	ND	H H3	2.4	0.24	ug/Kg		09/30/24 13:29	10/03/24 09:03	1
10:2 FTS	**0.25**	**J H H3**	2.4	0.24	ug/Kg		09/30/24 13:29	10/03/24 09:03	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*65*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:03*	*1*
13C5 PFPeA	*91*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:03*	*1*
13C2 PFHxA	*84*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:03*	*1*
13C4 PFHpA	*100*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:03*	*1*
13C4 PFOA	*104*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:03*	*1*
13C5 PFNA	*116*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:03*	*1*
13C2 PFDA	*129*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:03*	*1*
13C2 PFUnA	*120*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:03*	*1*
13C3 PFBS	*94*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:03*	*1*
18O2 PFHxS	*103*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:03*	*1*
13C4 PFOS	*106*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:03*	*1*
M2-4:2 FTS	*306*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 09:03*	*1*
M2-6:2 FTS	*210*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 09:03*	*1*
M2-8:2 FTS	*273*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 09:03*	*1*
13C2 10:2 FTS	*345*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 09:03*	*1*

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: MSB89195 femur
Date Collected: 11/07/94 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-26
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	11	2.6	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	11	1.9	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	11	3.0	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	11	1.3	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
L-Perfluorooctanoic acid	ND	H H3	11	2.2	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
Br-Perfluorooctanoic acid	ND	H H3	11	2.2	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
Total PFOA	ND	H H3	11	2.2	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
Perfluorononanoic acid (PFNA)	ND	H H3	11	1.9	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
Perfluorodecanoic acid (PFDA)	ND	H H3	11	1.1	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	11	3.0	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	11	1.9	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	11	2.0	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
Br-Perfluorohexanesulfonic acid	ND	H H3	11	1.6	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
Total PFHxS	ND	H H3	11	1.6	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
L-Perfluorohexanesulfonic acid	ND	H H3	11	1.6	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	11	2.1	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
L-Perfluorooctanesulfonic acid	ND	H H3	28	2.3	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
Br-Perfluorooctanesulfonic acid	ND	H H3	28	2.3	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
Total PFOS	ND	H H3	28	2.3	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
4:2 FTS	ND	H H3	11	3.0	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
6:2 FTS	ND	H H3	11	4.7	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
8:2 FTS	ND	H H3	11	1.1	ug/Kg		09/30/24 13:29	10/03/24 09:23	1
10:2 FTS	**1.2**	**J H H3**	11	1.1	ug/Kg		09/30/24 13:29	10/03/24 09:23	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*97*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:23*	*1*
13C5 PFPeA	*93*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:23*	*1*
13C2 PFHxA	*92*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:23*	*1*
13C4 PFHpA	*86*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:23*	*1*
13C4 PFOA	*97*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:23*	*1*
13C5 PFNA	*100*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:23*	*1*
13C2 PFDA	*99*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:23*	*1*
13C2 PFUnA	*96*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:23*	*1*
13C3 PFBS	*92*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:23*	*1*
18O2 PFHxS	*90*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:23*	*1*
13C4 PFOS	*91*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:23*	*1*
M2-4:2 FTS	*159*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 09:23*	*1*
M2-6:2 FTS	*102*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:23*	*1*
M2-8:2 FTS	*104*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:23*	*1*
13C2 10:2 FTS	*122*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:23*	*1*

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Client Sample ID: MSB61849 femur
Date Collected: 05/11/89 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-27
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND	H H3	17	3.9	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
Perfluoropentanoic acid (PFPeA)	ND	H H3	17	2.9	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
Perfluorohexanoic acid (PFHxA)	ND	H H3	17	4.6	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
Perfluoroheptanoic acid (PFHpA)	ND	H H3	17	1.9	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
L-Perfluorooctanoic acid	ND	H H3	17	3.4	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
Br-Perfluorooctanoic acid	ND	H H3	17	3.4	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
Total PFOA	ND	H H3	17	3.4	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
Perfluorononanoic acid (PFNA)	ND	H H3	17	2.9	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
Perfluorodecanoic acid (PFDA)	ND	H H3	17	1.7	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
Perfluoroundecanoic acid (PFUnA)	ND	H H3	17	4.5	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
Perfluorobutanesulfonic acid (PFBS)	ND	H H3	17	2.8	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
Perfluoropentanesulfonic acid (PFPeS)	ND	H H3	17	3.0	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
Br-Perfluorohexanesulfonic acid	ND	H H3	17	2.5	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
Total PFHxS	ND	H H3	17	2.5	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
L-Perfluorohexanesulfonic acid	ND	H H3	17	2.5	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
Perfluoroheptanesulfonic acid (PFHpS)	ND	H H3	17	3.1	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
L-Perfluorooctanesulfonic acid	ND	H H3	42	3.4	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
Br-Perfluorooctanesulfonic acid	ND	H H3	42	3.4	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
Total PFOS	ND	H H3	42	3.4	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
4:2 FTS	ND	H H3	17	4.4	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
6:2 FTS	ND	H H3	17	7.1	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
8:2 FTS	ND	H H3	17	1.7	ug/Kg		09/30/24 13:29	10/03/24 09:42	1
10:2 FTS	ND	H H3	17	1.7	ug/Kg		09/30/24 13:29	10/03/24 09:42	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*92*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:42*	*1*
13C5 PFPeA	*95*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:42*	*1*
13C2 PFHxA	*101*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:42*	*1*
13C4 PFHpA	*86*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:42*	*1*
13C4 PFOA	*96*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:42*	*1*
13C5 PFNA	*98*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:42*	*1*
13C2 PFDA	*98*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:42*	*1*
13C2 PFUnA	*96*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:42*	*1*
13C3 PFBS	*85*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:42*	*1*
18O2 PFHxS	*90*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:42*	*1*
13C4 PFOS	*91*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:42*	*1*
M2-4:2 FTS	*129*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:42*	*1*
M2-6:2 FTS	*102*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:42*	*1*
M2-8:2 FTS	*97*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:42*	*1*
13C2 10:2 FTS	*132*		*25 - 150*	*09/30/24 13:29*	*10/03/24 09:42*	*1*

Isotope Dilution Summary

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Tissue

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-115443-1 - DL	NK284441 liver								
320-115443-1	NK284441 liver	98	105	83	107	101	107	108	113
320-115443-2 - RA	NK284445 liver		81						
320-115443-2 - DL	NK284445 liver								
320-115443-2	NK284445 liver	101		99	100	85	113	108	115
320-115443-3 - DL	NK284446 liver								
320-115443-3	NK284446 liver	107	109	117	109	106	120	118	106
320-115443-4	NK284447 liver	96	90	100	99	96	72	104	101
320-115443-4 - RA	NK284447 liver								
320-115443-5	NK284448 liver	88	89	96	86	98	53	104	105
320-115443-5 - DL	NK284448 liver								
320-115443-6	NK284449 liver	96	105	93	91	98	107	98	100
320-115443-6 - DL	NK284449 liver								
320-115443-7 - DL	NK284450 liver								
320-115443-7	NK284450 liver	99	99	111	91	107	116	106	109
320-115443-8	NK284451 liver	89	102	101	92	104	99	99	99
320-115443-8 - DL	NK284451 liver								
320-115443-9	NK284458 liver	52	85	101	105	102	116	121	142
320-115443-10 - RA	NK284463 eggshell + contents		33						
320-115443-10 - DL	NK284463 eggshell + contents					38	32		
320-115443-10	NK284463 eggshell + contents	34		31	33			30	36
320-115443-11 - RA	African Rue East Intake		104						
320-115443-11	African Rue East Intake	50		102	97	101	99	93	91
320-115443-12 - RA	Saltcedar East Intake		92						
320-115443-12 - DL	Saltcedar East Intake								
320-115443-12	Saltcedar East Intake	28		99	95	98	103	109	104
320-115443-13	Saltcedar NE 4-1	55	115	112	96			100	106
320-115443-13 - DL2	Saltcedar NE 4-1								
320-115443-13 - DL	Saltcedar NE 4-1					100	102		
320-115443-14 - RA	pickleweed NE 4-1		62						
320-115443-14	pickleweed NE 4-1	29		86	85	92	93	105	108
320-115443-14 - DL	pickleweed NE 4-1								
320-115443-15 - DL	MSBHerp109299 muscle								
320-115443-15	MSBHerp109299 muscle	94	101	86	84	93	101	94	96
320-115443-16	MSBHerp109299 liver	97	82	85	78	95	94	90	89
320-115443-16 - DL	MSBHerp109299 liver								
320-115443-17	NK319555 muscle	37	67	83	94	96	103	120	112
320-115443-17 - DL	NK319555 muscle								
320-115443-18	NK319556 muscle	81	88	93	86	96	104	99	99
320-115443-19	NK319556 liver	78	91	90	89	96	113	105	109
320-115443-20	MSB89187 femur	94	92	93	86	101	101	108	100
320-115443-21	MSB92667 femur	104	104	96	87	90	99	93	93
320-115443-22	MSB61848 femur	106	98	94	88	97	96	95	88
320-115443-23	MSB89196 femur	93	98	98	86	101	103	93	93
320-115443-24	MSB87701 femur	59	88	93	90	96	102	107	109
320-115443-25	MSB87702 femur	65	91	84	100	104	116	129	120
320-115443-26	MSB89195 femur	97	93	92	86	97	100	99	96
320-115443-27	MSB61849 femur	92	95	101	86	96	98	98	96
LCS 320-802924/2-A	Lab Control Sample	90	97	88	88	99	93	94	106

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Matrix: Tissue **Prep Type: Total/NA**

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
LCS 320-803280/2-A	Lab Control Sample	91	83	89	77	90	90	88	89
LCSD 320-802924/3-A	Lab Control Sample Dup	88	94	87	85	94	96	94	97
LCSD 320-803280/3-A	Lab Control Sample Dup	82	83	84	75	87	89	86	87
MB 320-802924/1-A	Method Blank	88	79	93	87	95	91	93	99
MB 320-803280/1-A	Method Blank	92	83	84	77	90	88	86	88

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)	
320-115443-1 - DL	NK284441 liver			89					
320-115443-1	NK284441 liver	111	109	92	124	177 *5+	140	397 *5+	
320-115443-2 - RA	NK284445 liver								
320-115443-2 - DL	NK284445 liver			95					
320-115443-2	NK284445 liver	106	103	80	125	194 *5+	120	470 *5+	
320-115443-3 - DL	NK284446 liver			95					
320-115443-3	NK284446 liver	128	104	107	127	214 *5+	143	308 *5+	
320-115443-4	NK284447 liver	103	100	95	196 *5+	178 *5+	126	205 *5+	
320-115443-4 - RA	NK284447 liver			89					
320-115443-5	NK284448 liver	104	96	92	172 *5+	208 *5+	153 *5+	388 *5+	
320-115443-5 - DL	NK284448 liver			97					
320-115443-6	NK284449 liver	118	100	90	129	191 *5+	108	231 *5+	
320-115443-6 - DL	NK284449 liver			97					
320-115443-7 - DL	NK284450 liver			97					
320-115443-7	NK284450 liver	115	104	101	132	201 *5+	133	203 *5+	
320-115443-8	NK284451 liver	118	101	91	132	162 *5+	116	149	
320-115443-8 - DL	NK284451 liver			102					
320-115443-9	NK284458 liver	109	96	100	306 *5+	270 *5+	380 *5+	507 *5+	
320-115443-10 - RA	NK284463 eggshell + contents								
320-115443-10 - DL	NK284463 eggshell + contents		38	29			36		
320-115443-10	NK284463 eggshell + contents	34			49	54		137	
320-115443-11 - RA	African Rue East Intake								
320-115443-11	African Rue East Intake	110	106	95	209 *5+	123	111	364 *5+	
320-115443-12 - RA	Saltcedar East Intake								
320-115443-12 - DL	Saltcedar East Intake		100	96					
320-115443-12	Saltcedar East Intake	103	106	92	292 *5+	237 *5+	162 *5+	447 *5+	
320-115443-13	Saltcedar NE 4-1	113			225 *5+		125	460 *5+	
320-115443-13 - DL2	Saltcedar NE 4-1		126	97					
320-115443-13 - DL	Saltcedar NE 4-1			75		146			
320-115443-14 - RA	pickleweed NE 4-1								
320-115443-14	pickleweed NE 4-1	93		76	222 *5+	328 *5+	199 *5+	495 *5+	
320-115443-14 - DL	pickleweed NE 4-1		92	94					
320-115443-15 - DL	MSBHerp109299 muscle		89	88					
320-115443-15	MSBHerp109299 muscle	98		78	106	114	109	186 *5+	
320-115443-16	MSBHerp109299 liver	85		70	99	133	101	296 *5+	
320-115443-16 - DL	MSBHerp109299 liver		88	84					
320-115443-17	NK319555 muscle	82		81	275 *5+	156 *5+	253 *5+	530 *5+	
320-115443-17 - DL	NK319555 muscle		94	89					
320-115443-18	NK319556 muscle	82	89	94	116	116	107	481 *5+	
320-115443-19	NK319556 liver	96	101	103	217 *5+	164 *5+	163 *5+	514 *5+	
320-115443-20	MSB89187 femur	89	100	103	247 *5+	110	123	155 *5+	
320-115443-21	MSB92667 femur	94	99	94	145	97	98	113	

Isotope Dilution Summary

Client: University of New Mexico
Job ID: 320-115443-1
Project/Site: Holloman Lake PFAS Research

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Matrix: Tissue
Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
320-115443-22	MSB61848 femur	97	89	91	137	106	98	116
320-115443-23	MSB89196 femur	98	101	95	204 *5+	100	106	125
320-115443-24	MSB87701 femur	91	96	97	287 *5+	160 *5+	198 *5+	282 *5+
320-115443-25	MSB87702 femur	94	103	106	306 *5+	210 *5+	273 *5+	345 *5+
320-115443-26	MSB89195 femur	92	90	91	159 *5+	102	104	122
320-115443-27	MSB61849 femur	85	90	91	129	102	97	132
LCS 320-802924/2-A	Lab Control Sample	93	97	98	99	93	116	437 *5+
LCS 320-803280/2-A	Lab Control Sample	85	89	86	94	102	96	380 *5+
LCSD 320-802924/3-A	Lab Control Sample Dup	97	90	95	88	100	103	427 *5+
LCSD 320-803280/3-A	Lab Control Sample Dup	76	83	83	92	99	93	361 *5+
MB 320-802924/1-A	Method Blank	102	85	89	100	93	103	404 *5+
MB 320-803280/1-A	Method Blank	76	82	80	103	105	95	352 *5+

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
PFHxA = 13C2 PFHxA
C4PFHA = 13C4 PFHpA
PFOA = 13C4 PFOA
PFNA = 13C5 PFNA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS
PFHxS = 18O2 PFHxS
PFOS = 13C4 PFOS
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
M102FTS = 13C2 10:2 FTS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Lab Sample ID: MB 320-802924/1-A
Matrix: Tissue
Analysis Batch: 806065

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 802924

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	0.437	J	1.0	0.24	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
Perfluoropentanoic acid (PFPeA)	0.710	J	1.0	0.18	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
Perfluorohexanoic acid (PFHxA)	0.287	J	1.0	0.27	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
L-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
Total PFOA	ND		1.0	0.20	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.10	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.27	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
Perfluorobutanesulfonic acid (PFBS)	0.227	J	1.0	0.17	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
Total PFHxS	ND		1.0	0.15	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
L-Perfluorooctanesulfonic acid	0.705	J	2.5	0.20	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
Br-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
Total PFOS	0.705	J	2.5	0.20	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
4:2 FTS	ND		1.0	0.27	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
6:2 FTS	ND		1.0	0.42	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
8:2 FTS	ND		1.0	0.10	ug/Kg		09/28/24 06:38	10/10/24 20:14	1
10:2 FTS	ND		1.0	0.10	ug/Kg		09/28/24 06:38	10/10/24 20:14	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*88*		*25 - 150*	*09/28/24 06:38*	*10/10/24 20:14*	*1*
13C5 PFPeA	*79*		*25 - 150*	*09/28/24 06:38*	*10/10/24 20:14*	*1*
13C2 PFHxA	*93*		*25 - 150*	*09/28/24 06:38*	*10/10/24 20:14*	*1*
13C4 PFHpA	*87*		*25 - 150*	*09/28/24 06:38*	*10/10/24 20:14*	*1*
13C4 PFOA	*95*		*25 - 150*	*09/28/24 06:38*	*10/10/24 20:14*	*1*
13C5 PFNA	*91*		*25 - 150*	*09/28/24 06:38*	*10/10/24 20:14*	*1*
13C2 PFDA	*93*		*25 - 150*	*09/28/24 06:38*	*10/10/24 20:14*	*1*
13C2 PFUnA	*99*		*25 - 150*	*09/28/24 06:38*	*10/10/24 20:14*	*1*
13C3 PFBS	*102*		*25 - 150*	*09/28/24 06:38*	*10/10/24 20:14*	*1*
18O2 PFHxS	*85*		*25 - 150*	*09/28/24 06:38*	*10/10/24 20:14*	*1*
13C4 PFOS	*89*		*25 - 150*	*09/28/24 06:38*	*10/10/24 20:14*	*1*
M2-4:2 FTS	*100*		*25 - 150*	*09/28/24 06:38*	*10/10/24 20:14*	*1*
M2-6:2 FTS	*93*		*25 - 150*	*09/28/24 06:38*	*10/10/24 20:14*	*1*
M2-8:2 FTS	*103*		*25 - 150*	*09/28/24 06:38*	*10/10/24 20:14*	*1*
13C2 10:2 FTS	*404*	*5+	*25 - 150*	*09/28/24 06:38*	*10/10/24 20:14*	*1*

Lab Sample ID: LCS 320-802924/2-A
Matrix: Tissue
Analysis Batch: 806065

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 802924

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	10.0	10.3		ug/Kg		103	76 - 136

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-802924/2-A
Matrix: Tissue
Analysis Batch: 806065

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 802924

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluoropentanoic acid (PFPeA)	10.0	10.5		ug/Kg		105	69 - 129
Perfluorohexanoic acid (PFHxA)	10.0	8.67		ug/Kg		87	71 - 131
Perfluoroheptanoic acid (PFHpA)	10.0	9.53		ug/Kg		95	71 - 131
L-Perfluorooctanoic acid	10.0	8.71		ug/Kg		87	72 - 132
Total PFOA	10.0	8.71		ug/Kg		87	
Perfluorononanoic acid (PFNA)	10.0	9.58		ug/Kg		96	73 - 133
Perfluorodecanoic acid (PFDA)	10.0	10.3		ug/Kg		103	72 - 132
Perfluoroundecanoic acid (PFUnA)	10.0	9.63		ug/Kg		96	66 - 126
Perfluorobutanesulfonic acid (PFBS)	8.88	9.71		ug/Kg		109	69 - 129
Perfluoropentanesulfonic acid (PFPeS)	9.40	8.63		ug/Kg		92	66 - 126
Total PFHxS	9.12	6.92		ug/Kg		76	
L-Perfluorohexanesulfonic acid	9.12	6.92		ug/Kg		76	62 - 122
Perfluoroheptanesulfonic acid (PFHpS)	9.54	8.37		ug/Kg		88	76 - 136
L-Perfluorooctanesulfonic acid	9.30	8.81		ug/Kg		95	68 - 141
Total PFOS	9.30	8.81		ug/Kg		95	
4:2 FTS	9.38	8.16		ug/Kg		87	68 - 143
6:2 FTS	9.52	8.00		ug/Kg		84	73 - 139
8:2 FTS	9.60	8.34		ug/Kg		87	75 - 135
10:2 FTS	9.66	8.93		ug/Kg		92	69 - 145

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*90*		*25 - 150*
13C5 PFPeA	*97*		*25 - 150*
13C2 PFHxA	*88*		*25 - 150*
13C4 PFHpA	*88*		*25 - 150*
13C4 PFOA	*99*		*25 - 150*
13C5 PFNA	*93*		*25 - 150*
13C2 PFDA	*94*		*25 - 150*
13C2 PFUnA	*106*		*25 - 150*
13C3 PFBS	*93*		*25 - 150*
18O2 PFHxS	*97*		*25 - 150*
13C4 PFOS	*98*		*25 - 150*
M2-4:2 FTS	*99*		*25 - 150*
M2-6:2 FTS	*93*		*25 - 150*
M2-8:2 FTS	*116*		*25 - 150*
13C2 10:2 FTS	*437*	*5+	*25 - 150*

Lab Sample ID: LCSD 320-802924/3-A
Matrix: Tissue
Analysis Batch: 806065

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 802924

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)	10.0	11.1		ug/Kg		111	76 - 136	8	30
Perfluoropentanoic acid (PFPeA)	10.0	10.7		ug/Kg		107	69 - 129	2	30
Perfluorohexanoic acid (PFHxA)	10.0	8.98		ug/Kg		90	71 - 131	4	30
Perfluoroheptanoic acid (PFHpA)	10.0	10.5		ug/Kg		105	71 - 131	9	30

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCSD 320-802924/3-A
Matrix: Tissue
Analysis Batch: 806065

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 802924

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
L-Perfluorooctanoic acid			10.0	9.76		ug/Kg		98	72 - 132	11	30
Total PFOA			10.0	9.76		ug/Kg		98		11	
Perfluorononanoic acid (PFNA)			10.0	9.94		ug/Kg		99	73 - 133	4	30
Perfluorodecanoic acid (PFDA)			10.0	10.9		ug/Kg		109	72 - 132	5	30
Perfluoroundecanoic acid (PFUnA)			10.0	10.9		ug/Kg		109	66 - 126	12	30
Perfluorobutanesulfonic acid (PFBS)			8.88	8.94		ug/Kg		101	69 - 129	8	30
Perfluoropentanesulfonic acid (PFPeS)			9.40	9.30		ug/Kg		99	66 - 126	8	30
Total PFHxS			9.12	7.60		ug/Kg		83		9	
L-Perfluorohexanesulfonic acid			9.12	7.60		ug/Kg		83	62 - 122	9	30
Perfluoroheptanesulfonic acid (PFHpS)			9.54	8.74		ug/Kg		92	76 - 136	4	30
L-Perfluorooctanesulfonic acid			9.30	9.85		ug/Kg		106	68 - 141	11	30
Total PFOS			9.30	9.85		ug/Kg		106		11	
4:2 FTS			9.38	8.49		ug/Kg		90	68 - 143	4	30
6:2 FTS			9.52	8.25		ug/Kg		87	73 - 139	3	30
8:2 FTS			9.60	8.84		ug/Kg		92	75 - 135	6	30
10:2 FTS			9.66	9.41		ug/Kg		97	69 - 145	5	30

Isotope Dilution	*LCSD %Recovery*	*LCSD Qualifier*	*Limits*
13C4 PFBA	*88*		*25 - 150*
13C5 PFPeA	*94*		*25 - 150*
13C2 PFHxA	*87*		*25 - 150*
13C4 PFHpA	*85*		*25 - 150*
13C4 PFOA	*94*		*25 - 150*
13C5 PFNA	*96*		*25 - 150*
13C2 PFDA	*94*		*25 - 150*
13C2 PFUnA	*97*		*25 - 150*
13C3 PFBS	*97*		*25 - 150*
18O2 PFHxS	*90*		*25 - 150*
13C4 PFOS	*95*		*25 - 150*
M2-4:2 FTS	*88*		*25 - 150*
M2-6:2 FTS	*100*		*25 - 150*
M2-8:2 FTS	*103*		*25 - 150*
13C2 10:2 FTS	*427*	*5+	*25 - 150*

Lab Sample ID: MB 320-803280/1-A
Matrix: Tissue
Analysis Batch: 803965

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 803280

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.27	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
L-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
Total PFOA	ND		1.0	0.20	ug/Kg		09/30/24 13:29	10/03/24 04:51	1

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: MB 320-803280/1-A
Matrix: Tissue
Analysis Batch: 803965

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 803280

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.10	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.27	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
Total PFHxS	ND		1.0	0.15	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
L-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
Br-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
Total PFOS	ND		2.5	0.20	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
4:2 FTS	ND		1.0	0.27	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
6:2 FTS	ND		1.0	0.42	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
8:2 FTS	ND		1.0	0.10	ug/Kg		09/30/24 13:29	10/03/24 04:51	1
10:2 FTS	ND		1.0	0.10	ug/Kg		09/30/24 13:29	10/03/24 04:51	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*92*		*25 - 150*	*09/30/24 13:29*	*10/03/24 04:51*	*1*
13C5 PFPeA	*83*		*25 - 150*	*09/30/24 13:29*	*10/03/24 04:51*	*1*
13C2 PFHxA	*84*		*25 - 150*	*09/30/24 13:29*	*10/03/24 04:51*	*1*
13C4 PFHpA	*77*		*25 - 150*	*09/30/24 13:29*	*10/03/24 04:51*	*1*
13C4 PFOA	*90*		*25 - 150*	*09/30/24 13:29*	*10/03/24 04:51*	*1*
13C5 PFNA	*88*		*25 - 150*	*09/30/24 13:29*	*10/03/24 04:51*	*1*
13C2 PFDA	*86*		*25 - 150*	*09/30/24 13:29*	*10/03/24 04:51*	*1*
13C2 PFUnA	*88*		*25 - 150*	*09/30/24 13:29*	*10/03/24 04:51*	*1*
13C3 PFBS	*76*		*25 - 150*	*09/30/24 13:29*	*10/03/24 04:51*	*1*
18O2 PFHxS	*82*		*25 - 150*	*09/30/24 13:29*	*10/03/24 04:51*	*1*
13C4 PFOS	*80*		*25 - 150*	*09/30/24 13:29*	*10/03/24 04:51*	*1*
M2-4:2 FTS	*103*		*25 - 150*	*09/30/24 13:29*	*10/03/24 04:51*	*1*
M2-6:2 FTS	*105*		*25 - 150*	*09/30/24 13:29*	*10/03/24 04:51*	*1*
M2-8:2 FTS	*95*		*25 - 150*	*09/30/24 13:29*	*10/03/24 04:51*	*1*
13C2 10:2 FTS	*352*	**5+*	*25 - 150*	*09/30/24 13:29*	*10/03/24 04:51*	*1*

Lab Sample ID: LCS 320-803280/2-A
Matrix: Tissue
Analysis Batch: 803965

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 803280

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	10.0	11.0		ug/Kg		110	76 - 136
Perfluoropentanoic acid (PFPeA)	10.0	11.2		ug/Kg		112	69 - 129
Perfluorohexanoic acid (PFHxA)	10.0	10.2		ug/Kg		102	71 - 131
Perfluoroheptanoic acid (PFHpA)	10.0	10.3		ug/Kg		103	71 - 131
L-Perfluorooctanoic acid	10.0	10.4		ug/Kg		104	72 - 132
Total PFOA	10.0	10.4		ug/Kg		104	
Perfluorononanoic acid (PFNA)	10.0	10.8		ug/Kg		108	73 - 133
Perfluorodecanoic acid (PFDA)	10.0	11.4		ug/Kg		114	72 - 132

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-803280/2-A
Matrix: Tissue
Analysis Batch: 803965

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 803280

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluoroundecanoic acid (PFUnA)	10.0	11.6		ug/Kg		116	66 - 126
Perfluorobutanesulfonic acid (PFBS)	8.88	10.3		ug/Kg		116	69 - 129
Perfluoropentanesulfonic acid (PFPeS)	9.40	10.2		ug/Kg		108	66 - 126
Total PFHxS	9.12	7.63		ug/Kg		84	
L-Perfluorohexanesulfonic acid	9.12	7.63		ug/Kg		84	62 - 122
Perfluoroheptanesulfonic acid (PFHpS)	9.54	11.0		ug/Kg		115	76 - 136
L-Perfluorooctanesulfonic acid	9.30	10.6		ug/Kg		114	68 - 141
Total PFOS	9.30	10.6		ug/Kg		114	
4:2 FTS	9.38	9.49		ug/Kg		101	68 - 143
6:2 FTS	9.52	9.33		ug/Kg		98	73 - 139
8:2 FTS	9.60	12.0		ug/Kg		125	75 - 135
10:2 FTS	9.66	12.7		ug/Kg		132	69 - 145

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*91*		*25 - 150*
13C5 PFPeA	*83*		*25 - 150*
13C2 PFHxA	*89*		*25 - 150*
13C4 PFHpA	*77*		*25 - 150*
13C4 PFOA	*90*		*25 - 150*
13C5 PFNA	*90*		*25 - 150*
13C2 PFDA	*88*		*25 - 150*
13C2 PFUnA	*89*		*25 - 150*
13C3 PFBS	*85*		*25 - 150*
18O2 PFHxS	*89*		*25 - 150*
13C4 PFOS	*86*		*25 - 150*
M2-4:2 FTS	*94*		*25 - 150*
M2-6:2 FTS	*102*		*25 - 150*
M2-8:2 FTS	*96*		*25 - 150*
13C2 10:2 FTS	*380*	*5+	*25 - 150*

Lab Sample ID: LCSD 320-803280/3-A
Matrix: Tissue
Analysis Batch: 803965

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 803280

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)	10.0	10.3		ug/Kg		103	76 - 136	7	30
Perfluoropentanoic acid (PFPeA)	10.0	10.8		ug/Kg		108	69 - 129	4	30
Perfluorohexanoic acid (PFHxA)	10.0	9.25		ug/Kg		93	71 - 131	10	30
Perfluoroheptanoic acid (PFHpA)	10.0	10.7		ug/Kg		107	71 - 131	4	30
L-Perfluorooctanoic acid	10.0	9.37		ug/Kg		94	72 - 132	10	30
Total PFOA	10.0	9.37		ug/Kg		94		10	
Perfluorononanoic acid (PFNA)	10.0	9.72		ug/Kg		97	73 - 133	11	30
Perfluorodecanoic acid (PFDA)	10.0	11.1		ug/Kg		111	72 - 132	3	30
Perfluoroundecanoic acid (PFUnA)	10.0	10.6		ug/Kg		106	66 - 126	9	30

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCSD 320-803280/3-A
Matrix: Tissue
Analysis Batch: 803965

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 803280

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanesulfonic acid (PFBS)			8.88	9.37		ug/Kg		105	69 - 129	10	30
Perfluoropentanesulfonic acid (PFPeS)			9.40	10.2		ug/Kg		109	66 - 126	0	30
Total PFHxS			9.12	7.97		ug/Kg		87		4	
L-Perfluorohexanesulfonic acid			9.12	7.97		ug/Kg		87	62 - 122	4	30
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.0		ug/Kg		105	76 - 136	9	30
L-Perfluorooctanesulfonic acid			9.30	9.98		ug/Kg		107	68 - 141	6	30
Total PFOS			9.30	9.98		ug/Kg		107		6	
4:2 FTS			9.38	10.1		ug/Kg		108	68 - 143	7	30
6:2 FTS			9.52	9.29		ug/Kg		98	73 - 139	1	30
8:2 FTS			9.60	11.9		ug/Kg		124	75 - 135	0	30
10:2 FTS			9.66	12.2		ug/Kg		127	69 - 145	4	30

Isotope Dilution	*LCSD %Recovery*	*LCSD Qualifier*	*Limits*
13C4 PFBA	*82*		*25 - 150*
13C5 PFPeA	*83*		*25 - 150*
13C2 PFHxA	*84*		*25 - 150*
13C4 PFHpA	*75*		*25 - 150*
13C4 PFOA	*87*		*25 - 150*
13C5 PFNA	*89*		*25 - 150*
13C2 PFDA	*86*		*25 - 150*
13C2 PFUnA	*87*		*25 - 150*
13C3 PFBS	*76*		*25 - 150*
18O2 PFHxS	*83*		*25 - 150*
13C4 PFOS	*83*		*25 - 150*
M2-4:2 FTS	*92*		*25 - 150*
M2-6:2 FTS	*99*		*25 - 150*
M2-8:2 FTS	*93*		*25 - 150*
13C2 10:2 FTS	*361*	*5+	*25 - 150*

LCMS

Pre Prep Batch: 802923

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-115443-10	NK284463 eggshell + contents	Total/NA	Tissue	In-House	
320-115443-10 - DL	NK284463 eggshell + contents	Total/NA	Tissue	In-House	
320-115443-10 - RA	NK284463 eggshell + contents	Total/NA	Tissue	In-House	
320-115443-16 - DL	MSBHerp109299 liver	Total/NA	Tissue	In-House	
320-115443-16	MSBHerp109299 liver	Total/NA	Tissue	In-House	
320-115443-17 - DL	NK319555 muscle	Total/NA	Tissue	In-House	
320-115443-17	NK319555 muscle	Total/NA	Tissue	In-House	
320-115443-18	NK319556 muscle	Total/NA	Tissue	In-House	
320-115443-19	NK319556 liver	Total/NA	Tissue	In-House	
320-115443-20	MSB89187 femur	Total/NA	Tissue	In-House	
320-115443-21	MSB92667 femur	Total/NA	Tissue	In-House	
320-115443-22	MSB61848 femur	Total/NA	Tissue	In-House	
320-115443-23	MSB89196 femur	Total/NA	Tissue	In-House	
320-115443-24	MSB87701 femur	Total/NA	Tissue	In-House	
320-115443-25	MSB87702 femur	Total/NA	Tissue	In-House	
320-115443-26	MSB89195 femur	Total/NA	Tissue	In-House	
320-115443-27	MSB61849 femur	Total/NA	Tissue	In-House	

Prep Batch: 802924

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-115443-1 - DL	NK284441 liver	Total/NA	Tissue	SHAKE	
320-115443-1	NK284441 liver	Total/NA	Tissue	SHAKE	
320-115443-2	NK284445 liver	Total/NA	Tissue	SHAKE	
320-115443-2 - DL	NK284445 liver	Total/NA	Tissue	SHAKE	
320-115443-2 - RA	NK284445 liver	Total/NA	Tissue	SHAKE	
320-115443-3	NK284446 liver	Total/NA	Tissue	SHAKE	
320-115443-3 - DL	NK284446 liver	Total/NA	Tissue	SHAKE	
320-115443-4 - RA	NK284447 liver	Total/NA	Tissue	SHAKE	
320-115443-4	NK284447 liver	Total/NA	Tissue	SHAKE	
320-115443-5 - DL	NK284448 liver	Total/NA	Tissue	SHAKE	
320-115443-5	NK284448 liver	Total/NA	Tissue	SHAKE	
320-115443-6	NK284449 liver	Total/NA	Tissue	SHAKE	
320-115443-6 - DL	NK284449 liver	Total/NA	Tissue	SHAKE	
320-115443-7	NK284450 liver	Total/NA	Tissue	SHAKE	
320-115443-7 - DL	NK284450 liver	Total/NA	Tissue	SHAKE	
320-115443-8 - DL	NK284451 liver	Total/NA	Tissue	SHAKE	
320-115443-8	NK284451 liver	Total/NA	Tissue	SHAKE	
320-115443-9	NK284458 liver	Total/NA	Tissue	SHAKE	
320-115443-10 - RA	NK284463 eggshell + contents	Total/NA	Tissue	SHAKE	802923
320-115443-10	NK284463 eggshell + contents	Total/NA	Tissue	SHAKE	802923
320-115443-10 - DL	NK284463 eggshell + contents	Total/NA	Tissue	SHAKE	802923
320-115443-11	African Rue East Intake	Total/NA	Tissue	SHAKE	
320-115443-11 - RA	African Rue East Intake	Total/NA	Tissue	SHAKE	
320-115443-12 - RA	Saltcedar East Intake	Total/NA	Tissue	SHAKE	
320-115443-12	Saltcedar East Intake	Total/NA	Tissue	SHAKE	
320-115443-12 - DL	Saltcedar East Intake	Total/NA	Tissue	SHAKE	
320-115443-13 - DL2	Saltcedar NE 4-1	Total/NA	Tissue	SHAKE	
320-115443-13	Saltcedar NE 4-1	Total/NA	Tissue	SHAKE	
320-115443-13 - DL	Saltcedar NE 4-1	Total/NA	Tissue	SHAKE	
320-115443-14 - DL	pickleweed NE 4-1	Total/NA	Tissue	SHAKE	
320-115443-14	pickleweed NE 4-1	Total/NA	Tissue	SHAKE	

LCMS (Continued)

Prep Batch: 802924 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-115443-14 - RA	pickleweed NE 4-1	Total/NA	Tissue	SHAKE	
320-115443-15 - DL	MSBHerp109299 muscle	Total/NA	Tissue	SHAKE	
320-115443-15	MSBHerp109299 muscle	Total/NA	Tissue	SHAKE	
MB 320-802924/1-A	Method Blank	Total/NA	Tissue	SHAKE	
LCS 320-802924/2-A	Lab Control Sample	Total/NA	Tissue	SHAKE	
LCSD 320-802924/3-A	Lab Control Sample Dup	Total/NA	Tissue	SHAKE	

Prep Batch: 803280

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-115443-16	MSBHerp109299 liver	Total/NA	Tissue	SHAKE	802923
320-115443-16 - DL	MSBHerp109299 liver	Total/NA	Tissue	SHAKE	802923
320-115443-17	NK319555 muscle	Total/NA	Tissue	SHAKE	802923
320-115443-17 - DL	NK319555 muscle	Total/NA	Tissue	SHAKE	802923
320-115443-18	NK319556 muscle	Total/NA	Tissue	SHAKE	802923
320-115443-19	NK319556 liver	Total/NA	Tissue	SHAKE	802923
320-115443-20	MSB89187 femur	Total/NA	Tissue	SHAKE	802923
320-115443-21	MSB92667 femur	Total/NA	Tissue	SHAKE	802923
320-115443-22	MSB61848 femur	Total/NA	Tissue	SHAKE	802923
320-115443-23	MSB89196 femur	Total/NA	Tissue	SHAKE	802923
320-115443-24	MSB87701 femur	Total/NA	Tissue	SHAKE	802923
320-115443-25	MSB87702 femur	Total/NA	Tissue	SHAKE	802923
320-115443-26	MSB89195 femur	Total/NA	Tissue	SHAKE	802923
320-115443-27	MSB61849 femur	Total/NA	Tissue	SHAKE	802923
MB 320-803280/1-A	Method Blank	Total/NA	Tissue	SHAKE	
LCS 320-803280/2-A	Lab Control Sample	Total/NA	Tissue	SHAKE	
LCSD 320-803280/3-A	Lab Control Sample Dup	Total/NA	Tissue	SHAKE	

Analysis Batch: 803965

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-115443-16	MSBHerp109299 liver	Total/NA	Tissue	B/L/T PFAS	803280
320-115443-17	NK319555 muscle	Total/NA	Tissue	B/L/T PFAS	803280
320-115443-18	NK319556 muscle	Total/NA	Tissue	B/L/T PFAS	803280
320-115443-19	NK319556 liver	Total/NA	Tissue	B/L/T PFAS	803280
320-115443-20	MSB89187 femur	Total/NA	Tissue	B/L/T PFAS	803280
320-115443-21	MSB92667 femur	Total/NA	Tissue	B/L/T PFAS	803280
320-115443-22	MSB61848 femur	Total/NA	Tissue	B/L/T PFAS	803280
320-115443-23	MSB89196 femur	Total/NA	Tissue	B/L/T PFAS	803280
320-115443-24	MSB87701 femur	Total/NA	Tissue	B/L/T PFAS	803280
320-115443-25	MSB87702 femur	Total/NA	Tissue	B/L/T PFAS	803280
320-115443-26	MSB89195 femur	Total/NA	Tissue	B/L/T PFAS	803280
320-115443-27	MSB61849 femur	Total/NA	Tissue	B/L/T PFAS	803280
MB 320-803280/1-A	Method Blank	Total/NA	Tissue	B/L/T PFAS	803280
LCS 320-803280/2-A	Lab Control Sample	Total/NA	Tissue	B/L/T PFAS	803280
LCSD 320-803280/3-A	Lab Control Sample Dup	Total/NA	Tissue	B/L/T PFAS	803280

Analysis Batch: 804303

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-115443-2 - RA	NK284445 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-10 - RA	NK284463 eggshell + contents	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-11 - RA	African Rue East Intake	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-12 - RA	Saltcedar East Intake	Total/NA	Tissue	B/L/T PFAS	802924

LCMS (Continued)

Analysis Batch: 804303 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-115443-13	Saltcedar NE 4-1	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-14 - RA	pickleweed NE 4-1	Total/NA	Tissue	B/L/T PFAS	802924

Analysis Batch: 804573

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-115443-16 - DL	MSBHerp109299 liver	Total/NA	Tissue	B/L/T PFAS	803280
320-115443-17 - DL	NK319555 muscle	Total/NA	Tissue	B/L/T PFAS	803280

Analysis Batch: 806065

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-115443-1 - DL	NK284441 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-2 - DL	NK284445 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-2	NK284445 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-3 - DL	NK284446 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-4	NK284447 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-5	NK284448 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-6	NK284449 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-7 - DL	NK284450 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-7	NK284450 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-8	NK284451 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-9	NK284458 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-10 - DL	NK284463 eggshell + contents	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-10	NK284463 eggshell + contents	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-11	African Rue East Intake	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-12 - DL	Saltcedar East Intake	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-12	Saltcedar East Intake	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-13 - DL2	Saltcedar NE 4-1	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-13 - DL	Saltcedar NE 4-1	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-14	pickleweed NE 4-1	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-15 - DL	MSBHerp109299 muscle	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-15	MSBHerp109299 muscle	Total/NA	Tissue	B/L/T PFAS	802924
MB 320-802924/1-A	Method Blank	Total/NA	Tissue	B/L/T PFAS	802924
LCS 320-802924/2-A	Lab Control Sample	Total/NA	Tissue	B/L/T PFAS	802924
LCSD 320-802924/3-A	Lab Control Sample Dup	Total/NA	Tissue	B/L/T PFAS	802924

Analysis Batch: 806827

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-115443-1	NK284441 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-3	NK284446 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-5 - DL	NK284448 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-6 - DL	NK284449 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-8 - DL	NK284451 liver	Total/NA	Tissue	B/L/T PFAS	802924
320-115443-14 - DL	pickleweed NE 4-1	Total/NA	Tissue	B/L/T PFAS	802924

Analysis Batch: 807049

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-115443-4 - RA	NK284447 liver	Total/NA	Tissue	B/L/T PFAS	802924

Client Sample ID: NK284441 liver
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-1
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE	DL		0.40 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	50	1 mL	1 mL	806065	10/10/24 21:12	S1C	EET SAC
Total/NA	Prep	SHAKE			0.40 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		5	1 mL	1 mL	806827	10/14/24 16:23	S1C	EET SAC

Client Sample ID: NK284445 liver
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-2
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE	RA		0.17 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	804303	10/04/24 23:03	S1C	EET SAC
Total/NA	Prep	SHAKE	DL		0.17 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	50	1 mL	1 mL	806065	10/10/24 21:51	S1C	EET SAC
Total/NA	Prep	SHAKE			0.17 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	806065	10/10/24 22:10	S1C	EET SAC

Client Sample ID: NK284446 liver
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-3
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE	DL		0.45 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	50	1 mL	1 mL	806065	10/10/24 22:30	S1C	EET SAC
Total/NA	Prep	SHAKE			0.45 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		10	1 mL	1 mL	806827	10/14/24 16:42	S1C	EET SAC

Client Sample ID: NK284447 liver
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-4
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE	RA		0.17 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	807049	10/15/24 10:47	GWO	EET SAC
Total/NA	Prep	SHAKE			0.17 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	806065	10/10/24 23:47	S1C	EET SAC

Client Sample ID: NK284448 liver
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-5
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			0.56 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	806065	10/11/24 00:26	S1C	EET SAC
Total/NA	Prep	SHAKE	DL		0.56 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	20	1 mL	1 mL	806827	10/14/24 17:21	S1C	EET SAC

Client Sample ID: NK284449 liver
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-6
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			0.08 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	806065	10/11/24 01:05	S1C	EET SAC
Total/NA	Prep	SHAKE	DL		0.08 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	806827	10/14/24 17:40	S1C	EET SAC

Client Sample ID: NK284450 liver
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-7
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE	DL		0.16 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	806065	10/11/24 01:24	S1C	EET SAC
Total/NA	Prep	SHAKE			0.16 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	806065	10/11/24 01:44	S1C	EET SAC

Client Sample ID: NK284451 liver
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-8
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			0.06 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	806065	10/11/24 02:23	S1C	EET SAC
Total/NA	Prep	SHAKE	DL		0.06 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	806827	10/14/24 18:00	S1C	EET SAC

Client Sample ID: NK284458 liver
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-9
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.27 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	806065	10/11/24 03:21	S1C	EET SAC

Client Sample ID: NK284463 eggshell + contents
Date Collected: 07/11/24 00:00
Date Received: 09/17/24 09:40

Lab Sample ID: 320-115443-10
Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	802923	09/28/24 06:34	ATB	EET SAC
Total/NA	Prep	SHAKE	RA		1.02 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	804303	10/05/24 01:58	S1C	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	802923	09/28/24 06:34	ATB	EET SAC
Total/NA	Prep	SHAKE	DL		1.02 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	806065	10/11/24 03:40	S1C	EET SAC

Client Sample ID: NK284463 eggshell + contents

Lab Sample ID: 320-115443-10
Date Collected: 07/11/24 00:00
Matrix: Tissue
Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	802923	09/28/24 06:34	ATB	EET SAC
Total/NA	Prep	SHAKE			1.02 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	806065	10/11/24 04:00	S1C	EET SAC

Client Sample ID: African Rue East Intake

Lab Sample ID: 320-115443-11
Date Collected: 07/11/24 00:00
Matrix: Tissue
Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE	RA		0.89 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	804303	10/05/24 02:17	S1C	EET SAC
Total/NA	Prep	SHAKE			0.89 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	806065	10/11/24 04:39	S1C	EET SAC

Client Sample ID: Saltcedar East Intake

Lab Sample ID: 320-115443-12
Date Collected: 07/11/24 00:00
Matrix: Tissue
Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE	RA		0.91 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	804303	10/05/24 02:37	S1C	EET SAC
Total/NA	Prep	SHAKE	DL		0.91 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	20	1 mL	1 mL	806065	10/11/24 04:58	S1C	EET SAC
Total/NA	Prep	SHAKE			0.91 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	806065	10/11/24 05:17	S1C	EET SAC

Client Sample ID: Saltcedar NE 4-1

Lab Sample ID: 320-115443-13
Date Collected: 07/11/24 00:00
Matrix: Tissue
Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			0.59 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	804303	10/05/24 02:56	S1C	EET SAC
Total/NA	Prep	SHAKE	DL2		0.59 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL2	100	1 mL	1 mL	806065	10/11/24 05:37	S1C	EET SAC
Total/NA	Prep	SHAKE	DL		0.59 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	806065	10/11/24 05:56	S1C	EET SAC

Client Sample ID: pickleweed NE 4-1

Lab Sample ID: 320-115443-14
Date Collected: 07/11/24 00:00
Matrix: Tissue
Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE	RA		1.01 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	804303	10/05/24 03:15	S1C	EET SAC

Client Sample ID: pickleweed NE 4-1

Lab Sample ID: 320-115443-14

Date Collected: 07/11/24 00:00

Matrix: Tissue

Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.01 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	806065	10/11/24 06:54	S1C	EET SAC
Total/NA	Prep	SHAKE	DL		1.01 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	20	1 mL	1 mL	806827	10/14/24 18:38	S1C	EET SAC

Client Sample ID: MSBHerp109299 muscle

Lab Sample ID: 320-115443-15

Date Collected: 09/11/24 00:00

Matrix: Tissue

Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE	DL		0.88 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	806065	10/11/24 07:14	S1C	EET SAC
Total/NA	Prep	SHAKE			0.88 g	10.0 mL	802924	09/28/24 06:38	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	806065	10/11/24 07:33	S1C	EET SAC

Client Sample ID: MSBHerp109299 liver

Lab Sample ID: 320-115443-16

Date Collected: 09/11/24 00:00

Matrix: Tissue

Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	802923	09/28/24 06:34	ATB	EET SAC
Total/NA	Prep	SHAKE			0.18 g	10.0 mL	803280	09/30/24 13:29	ERR	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	803965	10/03/24 05:49	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	802923	09/28/24 06:34	ATB	EET SAC
Total/NA	Prep	SHAKE	DL		0.18 g	10.0 mL	803280	09/30/24 13:29	ERR	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	804573	10/05/24 05:12	S1C	EET SAC

Client Sample ID: NK319555 muscle

Lab Sample ID: 320-115443-17

Date Collected: 09/12/24 00:00

Matrix: Tissue

Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	802923	09/28/24 06:34	ATB	EET SAC
Total/NA	Prep	SHAKE			0.88 g	10.0 mL	803280	09/30/24 13:29	ERR	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	803965	10/03/24 06:08	C1P	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	802923	09/28/24 06:34	ATB	EET SAC
Total/NA	Prep	SHAKE	DL		0.88 g	10.0 mL	803280	09/30/24 13:29	ERR	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	10	1 mL	1 mL	804573	10/05/24 05:31	S1C	EET SAC

Client Sample ID: NK319556 muscle

Lab Sample ID: 320-115443-18

Date Collected: 09/13/24 00:00

Matrix: Tissue

Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	802923	09/28/24 06:34	ATB	EET SAC
Total/NA	Prep	SHAKE			1.31 g	10.0 mL	803280	09/30/24 13:29	ERR	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	803965	10/03/24 06:28	C1P	EET SAC

Client Sample ID: NK319556 liver

Lab Sample ID: 320-115443-19

Date Collected: 09/14/24 00:00

Matrix: Tissue

Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	802923	09/28/24 06:43	ATB	EET SAC
Total/NA	Prep	SHAKE			1.40 g	10.0 mL	803280	09/30/24 13:29	ERR	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	803965	10/03/24 06:47	C1P	EET SAC

Client Sample ID: MSB89187 femur

Lab Sample ID: 320-115443-20

Date Collected: 11/28/94 00:00

Matrix: Tissue

Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	802923	09/28/24 06:43	ATB	EET SAC
Total/NA	Prep	SHAKE			0.21 g	10.0 mL	803280	09/30/24 13:29	ERR	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	803965	10/03/24 07:07	C1P	EET SAC

Client Sample ID: MSB92667 femur

Lab Sample ID: 320-115443-21

Date Collected: 08/16/94 00:00

Matrix: Tissue

Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	802923	09/28/24 06:43	ATB	EET SAC
Total/NA	Prep	SHAKE			0.03 g	10.0 mL	803280	09/30/24 13:29	ERR	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	803965	10/03/24 07:26	C1P	EET SAC

Client Sample ID: MSB61848 femur

Lab Sample ID: 320-115443-22

Date Collected: 05/11/89 00:00

Matrix: Tissue

Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	802923	09/28/24 06:43	ATB	EET SAC
Total/NA	Prep	SHAKE			0.04 g	10.0 mL	803280	09/30/24 13:29	ERR	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	803965	10/03/24 07:45	C1P	EET SAC

Client Sample ID: MSB89196 femur

Lab Sample ID: 320-115443-23

Date Collected: 11/27/94 00:00

Matrix: Tissue

Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	802923	09/28/24 06:43	ATB	EET SAC
Total/NA	Prep	SHAKE			0.04 g	10.0 mL	803280	09/30/24 13:29	ERR	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	803965	10/03/24 08:24	C1P	EET SAC

Client Sample ID: MSB87701 femur

Lab Sample ID: 320-115443-24

Date Collected: 11/26/94 00:00

Matrix: Tissue

Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	802923	09/28/24 06:43	ATB	EET SAC
Total/NA	Prep	SHAKE			0.48 g	10.0 mL	803280	09/30/24 13:29	ERR	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	803965	10/03/24 08:44	C1P	EET SAC

Client Sample ID: MSB87702 femur

Lab Sample ID: 320-115443-25

Date Collected: 11/27/94 00:00

Matrix: Tissue

Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	802923	09/28/24 06:43	ATB	EET SAC
Total/NA	Prep	SHAKE			0.42 g	10.0 mL	803280	09/30/24 13:29	ERR	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	803965	10/03/24 09:03	C1P	EET SAC

Client Sample ID: MSB89195 femur

Lab Sample ID: 320-115443-26

Date Collected: 11/07/94 00:00

Matrix: Tissue

Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	802923	09/28/24 06:43	ATB	EET SAC
Total/NA	Prep	SHAKE			0.09 g	10.0 mL	803280	09/30/24 13:29	ERR	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	803965	10/03/24 09:23	C1P	EET SAC

Client Sample ID: MSB61849 femur

Lab Sample ID: 320-115443-27

Date Collected: 05/11/89 00:00

Matrix: Tissue

Date Received: 09/17/24 09:40

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	802923	09/28/24 06:43	ATB	EET SAC
Total/NA	Prep	SHAKE			0.06 g	10.0 mL	803280	09/30/24 13:29	ERR	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	803965	10/03/24 09:42	C1P	EET SAC

Laboratory References:

EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

Accreditation/Certification Summary

Client: University of New Mexico
Job ID: 320-115443-1
Project/Site: Holloman Lake PFAS Research

Laboratory: Eurofins Sacramento

All accreditations/certifications held by this laboratory are listed. Not all accreditations/certifications are applicable to this report.

Authority	Program	Identification Number	Expiration Date
Alaska (UST)	State	17-020	02-20-27
ANAB	Dept. of Defense ELAP	L2468	01-20-27
ANAB	Dept. of Energy	L2468.01	01-20-27
ANAB	ISO/IEC 17025	L2468	01-20-27
Arizona	State	AZ0708	08-11-25
Arkansas DEQ	State	88-0691	05-18-25
California	State	2897	01-31-26
Colorado	State	CA00044	08-31-25
Florida	NELAP	E87570	06-30-25
Georgia	State	4040	01-29-25
Hawaii	State	Eurofins Sacramento	01-29-25
Illinois	NELAP	200060	03-31-25
Kansas	NELAP	E-10375	10-31-25
Louisiana	NELAP	01944	06-30-25
Louisiana (All)	NELAP	01944	06-30-25
Maine	State	CA00004	04-14-26
Michigan	State	9947	01-29-25
Minnesota	NELAP	2749448	12-31-24
Nevada	State	CA00044	07-31-25
New Hampshire	NELAP	2997	04-19-25
New Jersey	NELAP	CA005	06-30-25
New York	NELAP	11666	04-01-25
Ohio	State	41252	01-29-25
Oregon	NELAP	4040	01-29-25
Texas	NELAP	T104704399-23-17	05-31-25
US Fish & Wildlife	US Federal Programs	A22139	04-30-25
USDA	US Federal Programs	P330-18-00239	02-28-26
Utah	NELAP	CA000442023-16	02-28-25
Virginia	NELAP	460278	03-14-25
Washington	State	C581	05-05-25
West Virginia (DW)	State	9930C	01-31-25
Wisconsin	State	998204680	08-31-25
Wyoming	State Program	8TMS-L	01-28-19 *

* Accreditation/Certification renewal pending - accreditation/certification considered valid.

Method Summary

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Method	Method Description	Protocol	Laboratory
B/L/T PFAS	Branched, Linear and Total PFAS	EPA	EET SAC
In-House	Tissue Preparation/Homgenization	NOAA	EET SAC
SHAKE	Shake Extraction with Ultrasonic Bath Extraction	SW846	EET SAC

Protocol References:

EPA = US Environmental Protection Agency

NOAA = National Marine Fisheries Service, National Oceanic And Atmospheric Administration, Seattle, WA, November 1988

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

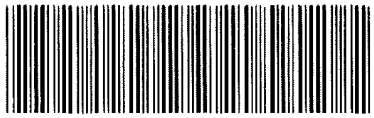
Sample Summary

Client: University of New Mexico
Project/Site: Holloman Lake PFAS Research

Job ID: 320-115443-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
320-115443-1	NK284441 liver	Tissue	07/11/24 00:00	09/17/24 09:40
320-115443-2	NK284445 liver	Tissue	07/11/24 00:00	09/17/24 09:40
320-115443-3	NK284446 liver	Tissue	07/11/24 00:00	09/17/24 09:40
320-115443-4	NK284447 liver	Tissue	07/11/24 00:00	09/17/24 09:40
320-115443-5	NK284448 liver	Tissue	07/11/24 00:00	09/17/24 09:40
320-115443-6	NK284449 liver	Tissue	07/11/24 00:00	09/17/24 09:40
320-115443-7	NK284450 liver	Tissue	07/11/24 00:00	09/17/24 09:40
320-115443-8	NK284451 liver	Tissue	07/11/24 00:00	09/17/24 09:40
320-115443-9	NK284458 liver	Tissue	07/11/24 00:00	09/17/24 09:40
320-115443-10	NK284463 eggshell + contents	Tissue	07/11/24 00:00	09/17/24 09:40
320-115443-11	African Rue East Intake	Tissue	07/11/24 00:00	09/17/24 09:40
320-115443-12	Saltcedar East Intake	Tissue	07/11/24 00:00	09/17/24 09:40
320-115443-13	Saltcedar NE 4-1	Tissue	07/11/24 00:00	09/17/24 09:40
320-115443-14	pickleweed NE 4-1	Tissue	07/11/24 00:00	09/17/24 09:40
320-115443-15	MSBHerp109299 muscle	Tissue	09/11/24 00:00	09/17/24 09:40
320-115443-16	MSBHerp109299 liver	Tissue	09/11/24 00:00	09/17/24 09:40
320-115443-17	NK319555 muscle	Tissue	09/12/24 00:00	09/17/24 09:40
320-115443-18	NK319556 muscle	Tissue	09/13/24 00:00	09/17/24 09:40
320-115443-19	NK319556 liver	Tissue	09/14/24 00:00	09/17/24 09:40
320-115443-20	MSB89187 femur	Tissue	11/28/94 00:00	09/17/24 09:40
320-115443-21	MSB92667 femur	Tissue	08/16/94 00:00	09/17/24 09:40
320-115443-22	MSB61848 femur	Tissue	05/11/89 00:00	09/17/24 09:40
320-115443-23	MSB89196 femur	Tissue	11/27/94 00:00	09/17/24 09:40
320-115443-24	MSB87701 femur	Tissue	11/26/94 00:00	09/17/24 09:40
320-115443-25	MSB87702 femur	Tissue	11/27/94 00:00	09/17/24 09:40
320-115443-26	MSB89195 femur	Tissue	11/07/94 00:00	09/17/24 09:40
320-115443-27	MSB61849 femur	Tissue	05/11/89 00:00	09/17/24 09:40

Eurofins Sacramento
NMED Exhibits 63
10/22/2024



320-115443 Chain of Custody

Eurofins Env Testing Northern California
880 Riverside Parkway
West Sacramento, CA 95605
Phone. 916 373 5600

Chain of Custody Record

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Client Contact	Report To Jean-Luc Cartron	Site Contact:	Date 9/13/2024	COC No:
Daniel B Stephens & Associates	email jeartron@geo-logic.com, jlcc@unm.edu	Lab Contact. Linda Laver	Carrier FedEx	____ of ____ COCs
6020 Academy Road NE, Suite 100	**Analysis Turnaround Time**			Job No
Albuquerque/NM/87109-3315	Business Days (BD) _____			
Phone 505-822-9400	TAT if diff. nt from Above _____			Field Sampler
Tel	☐ 2 weeks			
Project Name Holloman Lake PFAS Research	☐ 1 week			
Site Holloman Lake Otero Co New Mexico	☐ 2 days			
P O #	☐ 1 day			

Sample Identification	Sample Date	Sample Time	Sample Type	Matrix	# f Cont.	Filtered Sample	Enter requested analyses in these fields	Sample Specific Notes
NK284441 liver	7/11/24		liver		1			wetland directly north of Holloman
NK284445 liver	7/11/24		liver		1			wetland directly north of Holloman
NK284446 liver	7/11/24		liver		1			wetland directly north of Holloman
NK284447 liver	7/11/24		liver		1			wetland directly north of Holloman
NK284448 liver	7/11/24		liver		1			wetland directly north of Holloman
NK284449 liver	7/11/24		liver		1			wetland directly north of Holloman
NK284450 liver	7/11/24		liver		1			wetland directly north of Holloman
NK284451 liver	7/11/24		liver		1			wetland directly north of Holloman
NK284458 liver	7/11/24		liver		1			wetland directly north of Holloman
NK284463 eggshell + contents	7/11/24		egg		1			Holloman Lake
African Rue East Intake	7/11/24		plant		1			east intake
Saltcedar East Intake	7/11/24		plant		1			east intake
Saltcedar NE 4-1	7/11/24		plant		1			NE 4-1
pickleweed NE 4-1	7 11/24		plant		1			NE 4-1
MSBHerp109299 muscle	9/11/24		musel		1			US-70 by Holloman Lake turnoff
MSBHerp109299 liver	9/11/24		liver		1			US 70 by Holloman Lake turnoff
NK319555 muscle	9/12/24		muscle		1			0.64 km East of Holloman Lake access on highway 70
NK319556 muscle	9/13/24		muscle		1			12.66 km East of Holloman Lake access on highway 70.
NK319556 liver	9/14/24		liver		1			12.66 km East of Holloman Lake access on highway 70.
MSB89187 femur	11/28/94		femur		1			HOLLOMAN AFB S OF WSMR RNG RD 10 ALONG E DUNE EDGE
MSB92667 femur	8/16/94		femur		1			Holloman AFB lagoon G, 3 7 mi W of Main Gate on Hwy 70
MSB61848 femur	5/11/89		femur		1			WHITE SANDS MISSILE RANGE, 1 MI. N RITA SITE EXIT
MSB89196 femur	11/27/94		femur		1			HOLLOMAN AFB E OF MUNITIONS AREA, T16 S R8 E SEC36 SW4SW4
MSB87701 femur	11/26/94		femur		1			Holloman AFB, N of WSMR Rng. Rd. 10, along E dune edge T16S R8E sec 31
MSB87702 femur	11/27/94		femur		1			Holloman AFB, E of Munitions Area on Base; T16S R8E sec 36 SW 4 SW 4
MSB89195 femur	11/7/94		femur		1			HOLLOMAN AFB T15 S R8 E SEC23
MSB61849 femur	5/11/89		femur		1			WHITE SANDS MISSILE RANGE, 1 MI. N. RITA SITE EXIT

Preservation Used 1= Ice, 2= HCl; 3= H2SO4; 4=HNO3, 5=NaOH; 6= Other _____

Possible Hazard Identification
☒ Non-Hazard ☐ Flammable ☐ Skin Irritant ☐ Poison B ☐ Unknown ☐

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☐ Return To Client ☒ Disposal By Lab ☐ Archive For _____ Months

Special Instructions/QC Requirements & Comments

Relinquished by	Company	Date/Time	Received by	Company	Date/Time
Jean-Luc Cartron	DBS&A	7 17 24	DSM	EECSAC	09/17/24 0940
Relinquished by	Company	Date/Time	Received by	Company	Date/Time
Relinquished by	Company	Date/Time	Received by	Company	Date/Time

-34.2

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Sacramento Sample Receiving Notes (SSRN)

Loc: 320
115443

Tracking # 7786 1662 2334

Job _____ _____

SO (PO) / FO / SAT / 2-Day / Ground / UPS / CDO / Courier
GSL / OnTrac / Goldstreak / USPS / Other_____

Use this form to record Sample Custody Seal, Cooler Custody Seal, Temperature & corrected Temperature & other observations.
File in the job folder with the COC

Therm. ID: L016 Corr. Factor (+/-) NA °C

Ice_____ Wet_____ Gel _____ Other ✓

Cooler Custody Seal: _____

Cooler ID: _____

Temp Observed -34.2 °C Corrected -34.2 °C
From Temp Blank ☐ Sample ☑

Opening/Processing The Shipment	Yes	No	NA
Cooler compromised/tampered with?	☐	☑	☐
Cooler Temperature is acceptable?	☑	☐	☐
Frozen samples show signs of thaw?	☐	☐	☑

Initials DM Date 09/17/24

Unpacking/Labeling The Samples	Yes	No	NA
Containers are not broken or leaking?	☑	☐	☐
Samples compromised/tampered with?	☐	☑	☐
COC is complete w/o discrepancies	☐	☑	☐
Sample custody seal?	☐	☐	☑
Sample containers have legible labels?	☑	☐	☐
Sample date/times are provided?	☑	☐	☐
Appropriate containers are used?	☑	☐	☐
Sample bottles are completely filled?	☑	☐	☐
Sample preservatives verified?	☐	☐	☑
Is the Field Sampler's name on COC?	☐	☐	☑
Samples w/o discrepancies?	☑	☐	☐
Zero headspace?*	☐	☐	☑
Alkalinity has no headspace?	☐	☐	☑
Perchlorate has headspace? (Methods 314, 331, 6850)	☐	☐	☑
Multiphasic samples are not present?	☑	☐	☐

*Containers requiring zero headspace have no headspace, or bubble < 6 mm (1/4")

Initials DM Date 09/17/24

Notes: Dry Ice

Analysis not listed on the COC.

Trizma Lot #(s) _____

_____

_____

Ammonium
Acetate Lot #(s): _____

_____

_____

Login Completion	Yes	No	NA
Receipt Temperature on COC?	☑	☐	☐
NCM Filed?	☑	☐	☐
Samples received within hold time?	☑	☐	☐
Log Release checked in TALS?	☑	☐	☐

Initials DM Date 09/17/24

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ANALYTICAL REPORT

PREPARED FOR

Attn: Jean-Luc Cartron
University of New Mexico
Museum of Southwestern Biology
Division of Mammals
CERIA Bldg 83, Room 204
Albuquerque, New Mexico 87131

Generated 12/30/2024 8:57:42 AM

JOB DESCRIPTION

UNM_PFAS in Tissue, Holloman

JOB NUMBER

320-117508-1

Eurofins Sacramento
880 Riverside Parkway
West Sacramento CA 95605

See page two for job notes and contact information.

NMED Exhibits 65

my EOL

Job Notes

This report may not be reproduced except in full, and with written approval from the laboratory. The results relate only to the samples tested. For questions please contact the Project Manager at the e-mail address or telephone number listed on this page.

The test results in this report relate only to the samples as received by the laboratory and will meet all requirements of the methodology, with any exceptions noted. This report shall not be reproduced except in full, without the express written approval of the laboratory. All questions should be directed to the Eurofins Environment Testing Northern California, LLC Project Manager.

Authorization



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12/30/2024 8:57:42 AM

Authorized for release by
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(916)374-4362

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Definitions/Glossary

Client: University of New Mexico
Job ID: 320-117508-1
Project/Site: UNM_PFAS in Tissue, Holloman

Qualifiers

LCMS

Qualifier	Qualifier Description
*1	LCS/LCSD RPD exceeds control limits.
*5-	Isotope dilution analyte is outside acceptance limits, low biased.
*5+	Isotope dilution analyte is outside acceptance limits, high biased.
E	Result exceeded calibration range.
I	Value is EMPC (estimated maximum possible concentration).
J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
☼	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CFU	Colony Forming Unit
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MCL	EPA recommended "Maximum Contaminant Level"
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
MPN	Most Probable Number
MQL	Method Quantitation Limit
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
NEG	Negative / Absent
POS	Positive / Present
PQL	Practical Quantitation Limit
PRES	Presumptive
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)
TNTC	Too Numerous To Count

Job Narrative
320-117508-1

Receipt
The samples were received on 12/5/2024 9:35 AM. Unless otherwise noted below, the samples arrived in good condition, and where required, properly preserved and on ice. The temperature of the cooler at receipt was -12.3º C.

Receipt Exceptions
Collection times were not provided. Samples were logged in with a default time of 00:00.

The sample ID listed on the container label for the following sample did not match the information listed on the Chain-of-Custody (COC). The ID on the container was "NK283664" but the COC has "NK283644". The rest of the ID did match. The sample was logged in based on the COC. NK283644, S. clypeata, Liver, MSB1011744, P48 (320-117508-45)

LCMS
Method B/L/T PFAS: Isotope Dilution Analyte (IDA) recovery is above the method recommended limit for all samples. Quantitation by isotope dilution generally precludes any adverse effect on data quality due to elevated IDA recoveries.

Method B/L/T PFAS: Isotope Dilution Analyte (IDA) recovery associated with the following sample is below the method recommended limit: NK35935, MSB39605, P17 (320-117508-16). Generally, data quality is not considered affected if the signal-to-noise ratio is greater than 10:1, which is achieved for all IDA in the sample(s).

Method B/L/T PFAS: The "I" qualifier means the transition mass ratio for the indicated analyte was outside the established ratio limits. The qualitative identification of the analyte has some degree of uncertainty.

Method B/L/T PFAS: Internal standard (ISTD) response for sample NK35811, MSB30651, P8 (320-117508-8) in analytical batch 320-821391 was outside acceptance criteria. The internal standard is not used to quantitate any target analytes, therefore, the data have been reported

Method B/L/T PFAS: The concentration of one or more analytes associated with multiple samples exceeded the instrument calibration range. These analytes have been qualified (E); however, the peak(s) did not saturate the instrument detector. Historical data indicate that for the isotope dilution method, dilution and re-analysis will not produce significantly different results from those reported above the calibration range.

Method B/L/T PFAS: Some results for multiple samples were reported from the analysis of a diluted extract due to high concentration of the target analyte in the analysis of the undiluted extract. The dilution factor was applied to the labeled internal standard area counts and these area counts were within acceptance limits.

Method B/L/T PFAS: One or more continuing calibration verification (CCV) aliquots associated with analytical batches 320-820819 and 320-821645 recovered above the upper control limit for 8:2 FTS. The client samples associated with these CCVs were non-detect for the affected analyte; therefore, the data have been reported.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Organic Prep
Method SHAKE: Insufficient sample volume was available to perform a matrix spike/matrix spike duplicate (MS/MSD) associated with preparation batches 320-820080, 320-820824 and 320-820977.

Method SHAKE: Elevated reporting limits are provided for the following samples due to limited sample provided for extraction: Pool 25, Duck PFAS, P25 (320-117508-23), NK282630, MSB50169, P26 (320-117508-24), NK276851, MSB46239, P28 (320-117508-25), NK276660, MSB45963, P30 (320-117508-27), NK282696, MSB50223, P31 (320-117508-28) and NK283629, S. calypteata, Liver, MSB1011446, P44 (320-117508-41).

Method SHAKE: The following samples were discolored prior to and/or following extraction: NK14474, MSB18488, Pool1, P1 (320-117508-1), NK9098, Liver, P2 (320-117508-2), NK2445, Liver, AFP7B, P3 (320-117508-3), NK2444, Liver, AFP7A, P4 (320-117508-4), NK35660, MSB29117, P5 (320-117508-5), NK35661, MSB29140, P6 (320-117508-6), NK35655, MSB29134, P7 (320-117508-7), NK35811, MSB30651, P8 (320-117508-8), NK35643, MSB29100, P9 (320-117508-9), NK170946, P10 (320-117508-10), NK165232, MSB26431, P12 (320-117508-12), NK100328, Liver, AEPIR, P11 (320-117508-11), NK35676, MSB29118, P14 (320-117508-13), NK35678, MSB29131, P15 (320-117508-14), NK35669, MSB29093, P16 (320-117508-15), NK35935, MSB39605, P17 (320-117508-16), NK35958, MSB40165, P18 (320-117508-17), NK35816, MSB30670, P19 (320-117508-18), NK35804, MSB30716, P20 (320-117508-19), NK35876, MSB39746, P22 (320-117508-20), NK35910, MSB39349, P23(320-117508-21), NK282630, MSB50169, P26 (320-117508-24), NK282547, MSB49842, P29 (320-117508-26),

Job ID: 320-117508-1 (Continued)

NK282696, MSB50223, P31 (320-117508-28), NK283601, Spat. Cly, Liver, ABJ34298, MSB1011285, P32 (320-117508-29), NK283605, Liver, Spatula, MSB1011318, P34 (320-117508-31), NK283606, Spatula, Liver, MSB1011339, P35 (320-117508-32), NK283607, S. calypteata, Liver, MSB1011310, P36 (320-117508-33), NK283608, S. calypeata, L, MSB1011324, P37 (320-117508-34), NK283615, S. calypeata, L, MSB1011402, P38 (320-117508-35), NK283619, S. calypeata, L, MSB1011416, P39 (320-117508-36), NK283621, S. calypteata, L, MSB1011430, P40 (320-117508-37), NK283622, L, S. calypeata, MSB1011451, P41 (320-117508-38) and NK283626, S. calypeata, L, MSB1011466, P42 (320-117508-39).

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Detection Summary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK14474, MSB18488, Pool1, P1 — Lab Sample ID: 320-117508-1

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.58	J	1.0	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.58	J	1.0	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	3.5		1.0	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	4.1		1.0	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	1.0		1.0	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.16	J	1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	3.0		1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	2.9		1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	1.7		1.0	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	1000	E I	2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	28		2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	1100		2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.14	J	1.0	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS - RA	0.30	J	1.0	0.10	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK9098, Liver, P2 — Lab Sample ID: 320-117508-2

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanesulfonic acid	66	I	2.1	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.75	J	2.1	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	67		2.1	0.17	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK2445, Liver, AFP7B, P3 — Lab Sample ID: 320-117508-3

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	4.4		0.93	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.6		0.93	0.095	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	3.0		0.93	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	3.0		0.93	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	2.1		0.93	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	420	E I	2.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	17		2.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	440		2.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK2444, Liver, AFP7A, P4 — Lab Sample ID: 320-117508-4

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	0.67	J	0.96	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.30	J	0.96	0.099	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	530	E I	2.4	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	1.4	J	2.4	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	530		2.4	0.20	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK35660, MSB29117, P5 — Lab Sample ID: 320-117508-5

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	0.37	J	0.96	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.24	J	0.96	0.099	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.27	J	0.96	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.27	J	0.96	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	640	E I	2.4	0.20	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK35660, MSB29117, P5 (Continued) — Lab Sample ID: 320-117508-5

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Br-Perfluorooctanesulfonic acid	0.45	J	2.4	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	650		2.4	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.15	J	0.96	0.097	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK35661, MSB29140, P6 — Lab Sample ID: 320-117508-6

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.72	J	0.97	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.72	J	0.97	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	6.4		0.97	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	3.8		0.97	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	1.4		0.97	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.27	J	0.97	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	3.7		0.97	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	3.5		0.97	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	1.3		0.97	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	1000	E I	2.4	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	15		2.4	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	1000		2.4	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.35	J	0.97	0.098	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS - RA	0.43	J	0.97	0.097	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK35655, MSB29134, P7 — Lab Sample ID: 320-117508-7

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.46	J	0.99	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.46	J	0.99	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	15		0.99	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	20		0.99	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	9.5		0.99	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.35	J	0.99	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.35	J	0.99	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.43	J	0.99	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	570	E I	2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	7.5		2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	580		2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.72	J	0.99	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS - RA	0.41	J	0.99	0.099	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK35811, MSB30651, P8 — Lab Sample ID: 320-117508-8

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	7.8		0.94	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	9.5		0.94	0.097	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	4.3		0.94	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.18	J	0.94	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.18	J	0.94	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.23	J	0.94	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	250	E I	2.4	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	7.7		2.4	0.19	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK35811, MSB30651, P8 (Continued) — Lab Sample ID: 320-117508-8

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Total PFOS	250		2.4	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.21	J	0.94	0.095	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS - RA	0.095	J	0.94	0.094	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK35643, MSB29100, P9 — Lab Sample ID: 320-117508-9

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.33	J	0.93	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.33	J	0.93	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	16		0.93	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	9.6		0.93	0.095	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	1.5		0.93	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	1.1		0.93	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	1.1		0.93	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	1.3		0.93	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	330	E I	2.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	15		2.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	350		2.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.32	J	0.93	0.093	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.25	J	0.93	0.094	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK170946, P10 — Lab Sample ID: 320-117508-10

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanesulfonic acid	960	E I	2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.21	J	2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	960		2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK100328, Liver, AEPIR, P11 — Lab Sample ID: 320-117508-11

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanesulfonic acid	2.6	I	2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	2.6		2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK165232, MSB26431, P12 — Lab Sample ID: 320-117508-12

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	1.9		1.2	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	1.9		1.2	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	12		1.2	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	6.9		1.2	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	4.7		1.2	0.32	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.17	J	1.2	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	1.4		1.2	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	1.3		1.2	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.53	J	1.2	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	260	E I	2.9	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	14		2.9	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	280		2.9	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.12	J	1.2	0.12	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Detection Summary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK35676, MSB29118, P14 — Lab Sample ID: 320-117508-13

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.58	J	1.0	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.58	J	1.0	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	6.1		1.0	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	4.4		1.0	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.89	J	1.0	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	1.7		1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	1.7		1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.39	J	1.0	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	630	E I	2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	8.7		2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	640		2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.17	J	1.0	0.10	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK35678, MSB29131, P15 — Lab Sample ID: 320-117508-14

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	1.6		0.98	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.3		0.98	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.63	J	0.98	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.25	J	0.98	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.25	J	0.98	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	570	E I	2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	1.5	J	2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	570		2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.17	J	0.98	0.099	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS - RA	0.12	J	0.98	0.098	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK35669, MSB29093, P16 — Lab Sample ID: 320-117508-15

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.34	J	1.0	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.34	J	1.0	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	6.8		1.0	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	5.1		1.0	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	2.5		1.0	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.79	J	1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.79	J	1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.33	J	1.0	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	340	E I	2.5	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	4.3		2.5	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	340		2.5	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.27	J	1.0	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS - RA	0.14	J	1.0	0.10	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK35935, MSB39605, P17 — Lab Sample ID: 320-117508-16

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	15		0.99	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	54		0.99	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	19		0.99	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	1.8		0.99	0.15	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

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Client Sample ID: NK35935, MSB39605, P17 (Continued) — Lab Sample ID: 320-117508-16

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorohexanesulfonic acid	1.8		0.99	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	1.9		0.99	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	710	E	2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	38		2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	750		2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.12	J	0.99	0.10	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK35958, MSB40165, P18 — Lab Sample ID: 320-117508-17

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanesulfonic acid	260	E I	2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	260		2.5	0.20	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK35816, MSB30670, P19 — Lab Sample ID: 320-117508-18

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.20	J	0.51	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.20	J	0.51	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	5.2		0.51	0.089	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	4.6		0.51	0.053	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	1.4		0.51	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.22	J	0.51	0.076	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.22	J	0.51	0.076	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.27	J	0.51	0.094	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	330	E I	1.3	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	4.3		1.3	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	330		1.3	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.062	J	0.51	0.051	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.13	J	0.51	0.052	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK35804, MSB30716, P20 — Lab Sample ID: 320-117508-19

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.33	J	0.93	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.33	J	0.93	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	13		0.93	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	14		0.93	0.096	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	3.0		0.93	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.42	J	0.93	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	5.3		0.93	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	4.9		0.93	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	1.4		0.93	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	490	E I	2.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	26		2.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	510		2.3	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	0.58	J	0.93	0.093	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.34	J	0.93	0.094	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK35876, MSB39746, P22 — Lab Sample ID: 320-117508-20

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.27	J	1.0	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.27	J	1.0	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	3.9		1.0	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.0		1.0	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.34	J	1.0	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	620	E I	2.5	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.76	J	2.5	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	620		2.5	0.21	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK35910, MSB39349, P23 — Lab Sample ID: 320-117508-21

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	5.0		1.0	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	1.5		1.0	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.54	J	1.0	0.28	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	0.36	J	1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.47	J	1.0	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	350	E I	2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	1.6	J	2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	350		2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.10	J	1.0	0.10	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK35817, MSB30650, P24 — Lab Sample ID: 320-117508-22

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	2.9		1.1	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	2.9		1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.77	J	1.1	0.29	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFHxS	0.22	J	1.1	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	0.22	J	1.1	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	0.20	J	1.1	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	540	E I	2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	3.5		2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	540		2.6	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.13	J	1.1	0.11	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: Pool 25, Duck PFAS, P25 — Lab Sample ID: 320-117508-23

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	0.30	J	1.1	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.36	J	1.1	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	590	E I	2.8	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.30	J	2.8	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	590		2.8	0.23	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK282630, MSB50169, P26 — Lab Sample ID: 320-117508-24

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	0.68	J	1.5	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.29	J	1.5	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	6.2	I	3.7	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	6.2		3.7	0.30	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Eurofins Sacramento

Detection Summary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK276851, MSB46239, P28 — Lab Sample ID: 320-117508-25

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	0.76	J	1.3	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.80	J	1.3	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	300	E I	3.2	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.59	J	3.2	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	300		3.2	0.26	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK282547, MSB49842, P29 — Lab Sample ID: 320-117508-26

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanoic acid	0.22	J	0.91	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	0.22	J	0.91	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	6.6		0.91	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	2.3		0.91	0.094	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	2.2		0.91	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	380	E I	2.3	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.56	J	2.3	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	380		2.3	0.18	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK276660, MSB45963, P30 — Lab Sample ID: 320-117508-27

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
L-Perfluorooctanesulfonic acid	720	E I	4.3	0.35	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	720		4.3	0.35	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK282696, MSB50223, P31 — Lab Sample ID: 320-117508-28

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA)	0.33	J	1.8	0.31	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	0.90	J	1.8	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	350	E I	4.4	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	0.90	J	4.4	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOS	350		4.4	0.36	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK283601, Spat. Cly, Liver, ABJ34298, MSB1011285, P32 — Lab Sample ID: 320-117508-29

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.33	J	0.60	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.69		0.60	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	1.2		0.60	0.069	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	29		0.60	0.062	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	2.7		0.60	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.94		0.60	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	31		0.60	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.95		0.60	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.15	J	0.60	0.060	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	110		60	12	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOA - DL	110		60	12	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	340		60	10	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	140		60	8.9	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	3100		60	8.9	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	2900		60	8.9	ug/Kg	100		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK283601, Spat. Cly, Liver, ABJ34298, MSB1011285, P32 (Continued)

Lab Sample ID: 320-117508-29

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanesulfonic acid (PFHpS) - DL	330		60	11	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	11000	E	150	12	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	3300		150	12	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	15000		150	12	ug/Kg	100		B/L/T PFAS	Total/NA
8:2 FTS - RA	11		0.60	0.060	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK283602, JLW125, S. Calypeata, L, MSB1011279, P33

Lab Sample ID: 320-117508-30

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	1.9		0.98	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	0.38	J	0.98	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.59	J	0.98	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.53	J	0.98	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	120		98	20	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOA	120		98	20	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	200		98	17	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	19		0.98	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	1.4		0.98	0.27	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.69	J	0.98	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	21		0.98	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	140		98	15	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS	1800		98	15	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	1600		98	15	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	120		98	18	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	5400		250	20	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	1500		250	20	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS	6900		250	20	ug/Kg	100		B/L/T PFAS	Total/NA
6:2 FTS	0.42	J	0.98	0.42	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.13	J	0.98	0.099	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS - RA	6.2		0.98	0.098	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK283605, Liver, Spatula, MSB1011318, P34

Lab Sample ID: 320-117508-31

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	4.1		0.86	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	0.50	J	0.86	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.88		0.86	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	1.6		0.86	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	16		0.86	0.089	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	1.5		0.86	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	1.4		0.86	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	67		0.86	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.82	J	0.86	0.37	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.12	J I	0.86	0.087	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	130		86	17	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOA - DL	130		86	17	ug/Kg	100		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK283605, Liver, Spatula, MSB1011318, P34 (Continued)

Lab Sample ID: 320-117508-31

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorononanoic acid (PFNA) - DL	150		86	15	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	180		86	13	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	1800		86	13	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	1600		86	13	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	120		86	16	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	5900		220	18	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	1500		220	18	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	7400		220	18	ug/Kg	100		B/L/T PFAS	Total/NA
8:2 FTS - RA	4.8		0.86	0.086	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK283606, Spatula, Liver, MSB1011339, P35

Lab Sample ID: 320-117508-32

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.18	J	0.94	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.30	J	0.94	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.34	J	0.94	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	70		0.94	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	1.1		0.94	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	71		0.94	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	21		0.94	0.097	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	1.7		0.94	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.40	J	0.94	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	13		0.94	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.59	J	0.94	0.40	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.16	J	0.94	0.095	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	250		94	17	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	80	J	94	14	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	1700		94	14	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	1700		94	14	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	260		94	17	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	7900		240	19	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	2200		240	19	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	10000		240	19	ug/Kg	100		B/L/T PFAS	Total/NA
8:2 FTS - RA	6.0		0.94	0.094	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK283607, S. calypteata, Liver, MSB1011310, P36

Lab Sample ID: 320-117508-33

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.37	J	0.88	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.54	J	0.88	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.61	J	0.88	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	74		0.88	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.78	J	0.88	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	74		0.88	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	34		0.88	0.091	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	2.7		0.88	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	1.1		0.88	0.15	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK283607, S. calypteata, Liver, MSB1011310, P36 (Continued)

Lab Sample ID: 320-117508-33

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanesulfonic acid (PFPeS)	28		0.88	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.54	J	0.88	0.38	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.16	J I	0.88	0.089	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	440		88	15	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	110		88	13	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	3300		88	13	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	3200		88	13	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	340		88	16	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	12000	E	220	18	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	3800		220	18	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	16000		220	18	ug/Kg	100		B/L/T PFAS	Total/NA
8:2 FTS - RA	11		0.88	0.088	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK283608, S. calypeata, L, MSB1011324, P37

Lab Sample ID: 320-117508-34

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.59	J	0.76	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.81		0.76	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.94		0.76	0.088	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	34		0.76	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	0.82		0.76	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	35		0.76	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	24		0.76	0.078	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	1.7		0.76	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.95		0.76	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	23		0.76	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.95		0.76	0.32	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.14	J	0.76	0.077	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	330		76	13	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	55	J	76	11	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	2500		76	11	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	2500		76	11	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	330		76	14	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	9900	E	190	15	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	2700		190	15	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	13000		190	15	ug/Kg	100		B/L/T PFAS	Total/NA
8:2 FTS - RA	7.1		0.76	0.076	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK283615, S. calypeata, L, MSB1011402, P38

Lab Sample ID: 320-117508-35

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.70	J	0.94	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.81	J	0.94	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.72	J	0.94	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	35		0.94	0.097	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK283615, S. calypeata, L, MSB1011402, P38 (Continued)

Lab Sample ID: 320-117508-35

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroundecanoic acid (PFUnA)	2.6		0.94	0.26	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.79	J	0.94	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	30		0.94	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.17	J	0.94	0.095	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	170		94	19	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOA - DL	170		94	19	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	480		94	17	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	150		94	14	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	3000		94	14	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	2800		94	14	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	290		94	17	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	11000	E	240	19	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	3100		240	19	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	14000		240	19	ug/Kg	100		B/L/T PFAS	Total/NA
8:2 FTS - RA	11		0.94	0.094	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK283619, S. calypeata, L, MSB1011416, P39

Lab Sample ID: 320-117508-36

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	2.1		0.75	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	2.5		0.75	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	2.2		0.75	0.087	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	53		0.75	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	4.3		0.75	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	58		0.75	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	25		0.75	0.077	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	1.8		0.75	0.20	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	1.2		0.75	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	34		0.75	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.54	J	0.75	0.32	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.23	J	0.75	0.076	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	390		75	13	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	52	J	75	11	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	2600		75	11	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	2600		75	11	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	460		75	14	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	11000	E	190	15	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	3200		190	15	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	14000		190	15	ug/Kg	100		B/L/T PFAS	Total/NA
8:2 FTS - RA	5.1		0.75	0.075	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK283621, S. calypteata, L, MSB1011430, P40

Lab Sample ID: 320-117508-37

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.50	J	0.76	0.13	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK283621, S. calypteata, L, MSB1011430, P40 (Continued)

Lab Sample ID: 320-117508-37

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorohexanoic acid (PFHxA)	0.87		0.76	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	1.4		0.76	0.089	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	45		0.76	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	1.2		0.76	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	46		0.76	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	62		0.76	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	7.4		0.76	0.079	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	0.57	J	0.76	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.90		0.76	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	23		0.76	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid	53	J	76	11	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS	390		76	11	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid	340		76	11	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	43		0.76	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid	2600		190	15	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid	480		190	15	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS	3100		190	15	ug/Kg	100		B/L/T PFAS	Total/NA
6:2 FTS	0.48	J	0.76	0.32	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.19	J	0.76	0.077	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS - RA	1.3		0.76	0.076	ug/Kg	1		B/L/T PFAS	Total/NA

Client Sample ID: NK283622, L, S. calypeata, MSB1011451, P41

Lab Sample ID: 320-117508-38

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	2.2		0.78	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	3.0		0.78	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	3.0		0.78	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	52		0.78	0.080	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	3.9		0.78	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	0.36	J	0.78	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	21		0.78	0.078	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.20	J	0.78	0.078	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	730		78	14	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	1200		78	11	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	1200		78	11	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	610		78	14	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	19000	E	190	16	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	6000		190	16	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	25000		190	16	ug/Kg	100		B/L/T PFAS	Total/NA

Client Sample ID: NK283626, S. calypeata, L, MSB1011466, P42

Lab Sample ID: 320-117508-39

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.32	J	0.70	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.66	J	0.70	0.19	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK283626, S. calypeata, L, MSB1011466, P42 (Continued)

Lab Sample ID: 320-117508-39

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoroheptanoic acid (PFHpA)	2.5		0.70	0.082	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	55		0.70	0.073	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	3.7		0.70	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	1.1		0.70	0.12	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	62		0.70	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.34	J	0.70	0.30	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	18		0.70	0.070	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.19	J	0.70	0.071	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	410		70	14	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOA - DL	410		70	14	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	800		70	12	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	260		70	10	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	5800		70	10	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	5600		70	10	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	750		70	13	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	19000	E	180	14	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	6400		180	14	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	26000		180	14	ug/Kg	100		B/L/T PFAS	Total/NA

Client Sample ID: NK283627, S. calypeata, L, MSB1011473, P43

Lab Sample ID: 320-117508-40

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorobutanoic acid (PFBA)	6.5		0.79	0.19	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanoic acid (PFPeA)	0.64	J	0.79	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	1.0		0.79	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	2.0		0.79	0.091	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	43		0.79	0.081	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	3.2		0.79	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	1.9		0.79	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	60		0.79	0.14	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.41	J	0.79	0.33	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	14		0.79	0.079	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.16	J	0.79	0.080	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	350		79	16	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOA - DL	350		79	16	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	690		79	14	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	300		79	12	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	6800		79	12	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	6500		79	12	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	680		79	15	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	17000	E	200	16	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	5400		200	16	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	23000		200	16	ug/Kg	100		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK283629, S. calypteata, Liver, MSB1011446, P44

Lab Sample ID: 320-117508-41

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.36	J	1.3	0.22	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.81	J	1.3	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	1.2	J	1.3	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	47		1.3	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	3.7		1.3	0.34	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	1.0	J	1.3	0.21	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	47		1.3	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	14		1.3	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.26	J	1.3	0.13	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	390		130	25	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOA - DL	390		130	25	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	540		130	22	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	210		130	19	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	5200		130	19	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	5000		130	19	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	450		130	23	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	15000	E	310	25	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	4200		310	25	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	19000		310	25	ug/Kg	100		B/L/T PFAS	Total/NA

Client Sample ID: NK283631, L, A. americana, MSB1011511, P45

Lab Sample ID: 320-117508-42

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.70	J	0.91	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	1.2		0.91	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	2.5		0.91	0.11	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	60		0.91	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	2.5		0.91	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	63		0.91	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA)	65		0.91	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	8.1		0.91	0.094	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	1.5		0.91	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	1.3		0.91	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	37		0.91	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS)	44		0.91	0.17	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	2.1		0.91	0.091	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.19	J	0.91	0.092	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	93		91	13	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	190		91	13	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	93		91	13	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	3100		230	18	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	570		230	18	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	3700		230	18	ug/Kg	100		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK283633, L, S. clypteata, MSB1011525, P46 — Lab Sample ID: 320-117508-43

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.34	J	0.89	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.58	J	0.89	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.98		0.89	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	40		0.89	0.092	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	3.2		0.89	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.82	J	0.89	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	43		0.89	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	15		0.89	0.089	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.18	J	0.89	0.090	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	410		89	18	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOA - DL	410		89	18	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	590		89	16	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	200		89	13	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	4700		89	13	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	4500		89	13	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	490		89	17	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	17000	E	220	18	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	4300		220	18	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	21000		220	18	ug/Kg	100		B/L/T PFAS	Total/NA

Client Sample ID: NK283641, L, S. clypteata, MSB1011577, P47 — Lab Sample ID: 320-117508-44

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.39	J	0.90	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.79	J	0.90	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.81	J	0.90	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	88		0.90	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	2.2		0.90	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	90		0.90	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	32		0.90	0.093	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	2.6		0.90	0.25	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	1.2		0.90	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	54		0.90	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	11		0.90	0.090	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.16	J	0.90	0.091	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	370		90	16	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	220		90	13	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	2300		90	13	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	2100		90	13	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	210		90	17	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	9700	E	230	18	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	2900		230	18	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	13000		230	18	ug/Kg	100		B/L/T PFAS	Total/NA

Client Sample ID: NK283644, S. clypeata, Liver, MSB1011744, P48 — Lab Sample ID: 320-117508-45

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.19	J	0.87	0.15	ug/Kg	1		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client Sample ID: NK283644, S. clypeata, Liver, MSB1011744, P48 (Continued)

Lab Sample ID: 320-117508-45

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluorohexanoic acid (PFHxA)	0.35	J	0.87	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.57	J	0.87	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	45		0.87	0.090	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	3.2		0.87	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.69	J	0.87	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	26		0.87	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	14		0.87	0.087	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.19	J	0.87	0.088	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	140		87	18	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOA - DL	140		87	18	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	660		87	15	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	130		87	13	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	3500		87	13	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	3300		87	13	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	500		87	16	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	16000	E	220	18	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	5200		220	18	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	21000		220	18	ug/Kg	100		B/L/T PFAS	Total/NA

Client Sample ID: NK283669, S. clypteata, Liver, MSB1011800, P49

Lab Sample ID: 320-117508-46

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.20	J	0.88	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.33	J	0.88	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.56	J	0.88	0.10	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid	64		0.88	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Br-Perfluorooctanoic acid	1.9		0.88	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Total PFOA	65		0.88	0.18	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	35		0.88	0.091	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	3.0		0.88	0.24	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.56	J	0.88	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	18		0.88	0.16	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	12		0.88	0.088	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.18	J	0.88	0.089	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	460		88	15	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	97		88	13	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	1800		88	13	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	1700	I	88	13	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	400		88	16	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	15000	E	220	18	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	4300		220	18	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	19000		220	18	ug/Kg	100		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Detection Summary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK283674, S. clypeata, Liver, MSB1011812, P50

Lab Sample ID: 320-117508-47

Analyte	Result	Qualifier	RL	MDL	Unit	Dil Fac	D	Method	Prep Type
Perfluoropentanoic acid (PFPeA)	0.23	J	0.85	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorohexanoic acid (PFHxA)	0.37	J	0.85	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroheptanoic acid (PFHpA)	0.78	J	0.85	0.099	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorodecanoic acid (PFDA)	50		0.85	0.088	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoroundecanoic acid (PFUnA)	3.7		0.85	0.23	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluorobutanesulfonic acid (PFBS)	0.92		0.85	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
Perfluoropentanesulfonic acid (PFPeS)	34		0.85	0.15	ug/Kg	1		B/L/T PFAS	Total/NA
6:2 FTS	0.45	J	0.85	0.36	ug/Kg	1		B/L/T PFAS	Total/NA
8:2 FTS	24		0.85	0.085	ug/Kg	1		B/L/T PFAS	Total/NA
10:2 FTS	0.78	J	0.85	0.086	ug/Kg	1		B/L/T PFAS	Total/NA
L-Perfluorooctanoic acid - DL	91		85	17	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOA - DL	91		85	17	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluorononanoic acid (PFNA) - DL	670		85	15	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorohexanesulfonic acid - DL	140		85	13	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFHxS - DL	2600		85	13	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorohexanesulfonic acid - DL	2500		85	13	ug/Kg	100		B/L/T PFAS	Total/NA
Perfluoroheptanesulfonic acid (PFHpS) - DL	480		85	16	ug/Kg	100		B/L/T PFAS	Total/NA
L-Perfluorooctanesulfonic acid - DL	17000	E	210	17	ug/Kg	100		B/L/T PFAS	Total/NA
Br-Perfluorooctanesulfonic acid - DL	5200		210	17	ug/Kg	100		B/L/T PFAS	Total/NA
Total PFOS - DL	22000		210	17	ug/Kg	100		B/L/T PFAS	Total/NA

This Detection Summary does not include radiochemical test results.

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK14474, MSB18488, Pool1, P1
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-1
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.28	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
L-Perfluorooctanoic acid	**0.58**	**J**	1.0	0.21	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
Br-Perfluorooctanoic acid	ND		1.0	0.21	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
Total PFOA	**0.58**	**J**	1.0	0.21	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
Perfluorononanoic acid (PFNA)	**3.5**		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
Perfluorodecanoic acid (PFDA)	**4.1**		1.0	0.11	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
Perfluoroundecanoic acid (PFUnA)	**1.0**		1.0	0.28	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.19	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
Br-Perfluorohexanesulfonic acid	**0.16**	**J**	1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
Total PFHxS	**3.0**		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
L-Perfluorohexanesulfonic acid	**2.9**		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
Perfluoroheptanesulfonic acid (PFHpS)	**1.7**		1.0	0.19	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
L-Perfluorooctanesulfonic acid	**1000**	**E I**	2.6	0.21	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
Br-Perfluorooctanesulfonic acid	**28**		2.6	0.21	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
Total PFOS	**1100**		2.6	0.21	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
4:2 FTS	ND	*1	1.0	0.27	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
6:2 FTS	ND		1.0	0.44	ug/Kg		12/06/24 12:01	12/10/24 10:12	1
10:2 FTS	**0.14**	**J**	1.0	0.10	ug/Kg		12/06/24 12:01	12/10/24 10:12	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*70*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:12*	*1*
13C5 PFPeA	*87*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:12*	*1*
13C2 PFHxA	*99*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:12*	*1*
13C4 PFHpA	*99*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:12*	*1*
13C4 PFOA	*83*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:12*	*1*
13C5 PFNA	*55*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:12*	*1*
13C2 PFDA	*108*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:12*	*1*
13C2 PFUnA	*116*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:12*	*1*
13C3 PFBS	*87*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:12*	*1*
18O2 PFHxS	*112*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:12*	*1*
13C4 PFOS	*90*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:12*	*1*
M2-4:2 FTS	*153*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 10:12*	*1*
M2-6:2 FTS	*127*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:12*	*1*
13C2 10:2 FTS	*499*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 10:12*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	**0.30**	**J**	1.0	0.10	ug/Kg		12/06/24 12:01	12/11/24 14:35	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
M2-8:2 FTS	*153*	*5+	*25 - 150*	*12/06/24 12:01*	*12/11/24 14:35*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK9098, Liver, P2
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-2
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.84	0.20	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
Perfluoropentanoic acid (PFPeA)	ND		0.84	0.15	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
Perfluorohexanoic acid (PFHxA)	ND		0.84	0.23	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
Perfluoroheptanoic acid (PFHpA)	ND		0.84	0.097	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
L-Perfluorooctanoic acid	ND		0.84	0.17	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
Br-Perfluorooctanoic acid	ND		0.84	0.17	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
Total PFOA	ND		0.84	0.17	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
Perfluorononanoic acid (PFNA)	ND		0.84	0.15	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
Perfluorodecanoic acid (PFDA)	ND		0.84	0.087	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
Perfluoroundecanoic acid (PFUnA)	ND		0.84	0.23	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.84	0.14	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.84	0.15	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
Br-Perfluorohexanesulfonic acid	ND		0.84	0.12	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
Total PFHxS	ND		0.84	0.12	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
L-Perfluorohexanesulfonic acid	ND		0.84	0.12	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.84	0.16	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
L-Perfluorooctanesulfonic acid	**66**	**I**	2.1	0.17	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
Br-Perfluorooctanesulfonic acid	**0.75**	**J**	2.1	0.17	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
Total PFOS	**67**		2.1	0.17	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
4:2 FTS	ND	*1	0.84	0.22	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
6:2 FTS	ND		0.84	0.36	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
8:2 FTS	ND		0.84	0.084	ug/Kg		12/06/24 12:01	12/10/24 10:31	1
10:2 FTS	ND		0.84	0.085	ug/Kg		12/06/24 12:01	12/10/24 10:31	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*84*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:31*	*1*
13C5 PFPeA	*84*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:31*	*1*
13C2 PFHxA	*94*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:31*	*1*
13C4 PFHpA	*83*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:31*	*1*
13C4 PFOA	*79*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:31*	*1*
13C5 PFNA	*81*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:31*	*1*
13C2 PFDA	*87*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:31*	*1*
13C2 PFUnA	*78*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:31*	*1*
13C3 PFBS	*83*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:31*	*1*
18O2 PFHxS	*101*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:31*	*1*
13C4 PFOS	*84*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:31*	*1*
M2-4:2 FTS	*133*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:31*	*1*
M2-6:2 FTS	*101*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:31*	*1*
M2-8:2 FTS	*81*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:31*	*1*
13C2 10:2 FTS	*452*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 10:31*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK2445, Liver, AFP7B, P3
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-3
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.93	0.22	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
Perfluoropentanoic acid (PFPeA)	ND		0.93	0.16	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
Perfluorohexanoic acid (PFHxA)	ND		0.93	0.25	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
Perfluoroheptanoic acid (PFHpA)	ND		0.93	0.11	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
L-Perfluorooctanoic acid	ND		0.93	0.19	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
Br-Perfluorooctanoic acid	ND		0.93	0.19	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
Total PFOA	ND		0.93	0.19	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
Perfluorononanoic acid (PFNA)	**4.4**		0.93	0.16	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
Perfluorodecanoic acid (PFDA)	**1.6**		0.93	0.095	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
Perfluoroundecanoic acid (PFUnA)	ND		0.93	0.25	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.93	0.16	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.93	0.17	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
Br-Perfluorohexanesulfonic acid	ND		0.93	0.14	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
Total PFHxS	**3.0**		0.93	0.14	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
L-Perfluorohexanesulfonic acid	**3.0**		0.93	0.14	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
Perfluoroheptanesulfonic acid (PFHpS)	**2.1**		0.93	0.17	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
L-Perfluorooctanesulfonic acid	**420**	**E I**	2.3	0.19	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
Br-Perfluorooctanesulfonic acid	**17**		2.3	0.19	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
Total PFOS	**440**		2.3	0.19	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
4:2 FTS	ND	*1	0.93	0.25	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
6:2 FTS	ND		0.93	0.39	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
8:2 FTS	ND		0.93	0.093	ug/Kg		12/06/24 12:01	12/10/24 10:51	1
10:2 FTS	ND		0.93	0.094	ug/Kg		12/06/24 12:01	12/10/24 10:51	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*68*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:51*	*1*
13C5 PFPeA	*76*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:51*	*1*
13C2 PFHxA	*91*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:51*	*1*
13C4 PFHpA	*86*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:51*	*1*
13C4 PFOA	*77*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:51*	*1*
13C5 PFNA	*72*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:51*	*1*
13C2 PFDA	*89*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:51*	*1*
13C2 PFUnA	*78*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:51*	*1*
13C3 PFBS	*85*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:51*	*1*
18O2 PFHxS	*94*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:51*	*1*
13C4 PFOS	*84*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:51*	*1*
M2-4:2 FTS	*77*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:51*	*1*
M2-6:2 FTS	*78*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:51*	*1*
M2-8:2 FTS	*77*		*25 - 150*	*12/06/24 12:01*	*12/10/24 10:51*	*1*
13C2 10:2 FTS	*300*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 10:51*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK2444, Liver, AFP7A, P4
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-4
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.96	0.23	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
Perfluoropentanoic acid (PFPeA)	ND		0.96	0.17	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
Perfluorohexanoic acid (PFHxA)	ND		0.96	0.26	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
Perfluoroheptanoic acid (PFHpA)	ND		0.96	0.11	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
L-Perfluorooctanoic acid	ND		0.96	0.19	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
Br-Perfluorooctanoic acid	ND		0.96	0.19	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
Total PFOA	ND		0.96	0.19	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
Perfluorononanoic acid (PFNA)	**0.67**	**J**	0.96	0.17	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
Perfluorodecanoic acid (PFDA)	**0.30**	**J**	0.96	0.099	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
Perfluoroundecanoic acid (PFUnA)	ND		0.96	0.26	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.96	0.16	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.96	0.17	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
Br-Perfluorohexanesulfonic acid	ND		0.96	0.14	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
Total PFHxS	ND		0.96	0.14	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
L-Perfluorohexanesulfonic acid	ND		0.96	0.14	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.96	0.18	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
L-Perfluorooctanesulfonic acid	**530**	**E I**	2.4	0.20	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
Br-Perfluorooctanesulfonic acid	**1.4**	**J**	2.4	0.20	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
Total PFOS	**530**		2.4	0.20	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
4:2 FTS	ND	*1	0.96	0.26	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
6:2 FTS	ND		0.96	0.41	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
8:2 FTS	ND		0.96	0.096	ug/Kg		12/06/24 12:01	12/10/24 11:10	1
10:2 FTS	ND		0.96	0.097	ug/Kg		12/06/24 12:01	12/10/24 11:10	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*54*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:10*	*1*
13C5 PFPeA	*73*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:10*	*1*
13C2 PFHxA	*82*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:10*	*1*
13C4 PFHpA	*84*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:10*	*1*
13C4 PFOA	*72*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:10*	*1*
13C5 PFNA	*58*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:10*	*1*
13C2 PFDA	*117*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:10*	*1*
13C2 PFUnA	*97*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:10*	*1*
13C3 PFBS	*76*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:10*	*1*
18O2 PFHxS	*92*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:10*	*1*
13C4 PFOS	*80*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:10*	*1*
M2-4:2 FTS	*81*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:10*	*1*
M2-6:2 FTS	*112*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:10*	*1*
M2-8:2 FTS	*81*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:10*	*1*
13C2 10:2 FTS	*480*	**5+*	*25 - 150*	*12/06/24 12:01*	*12/10/24 11:10*	*1*

Client Sample ID: NK35660, MSB29117, P5

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-5

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.96	0.23	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
Perfluoropentanoic acid (PFPeA)	ND		0.96	0.17	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
Perfluorohexanoic acid (PFHxA)	ND		0.96	0.26	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
Perfluoroheptanoic acid (PFHpA)	ND		0.96	0.11	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
L-Perfluorooctanoic acid	ND		0.96	0.19	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
Br-Perfluorooctanoic acid	ND		0.96	0.19	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
Total PFOA	ND		0.96	0.19	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
Perfluorononanoic acid (PFNA)	**0.37**	**J**	0.96	0.17	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
Perfluorodecanoic acid (PFDA)	**0.24**	**J**	0.96	0.099	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
Perfluoroundecanoic acid (PFUnA)	ND		0.96	0.26	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.96	0.16	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.96	0.17	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
Br-Perfluorohexanesulfonic acid	ND		0.96	0.14	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
Total PFHxS	**0.27**	**J**	0.96	0.14	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
L-Perfluorohexanesulfonic acid	**0.27**	**J**	0.96	0.14	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.96	0.18	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
L-Perfluorooctanesulfonic acid	**640**	**E I**	2.4	0.20	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
Br-Perfluorooctanesulfonic acid	**0.45**	**J**	2.4	0.20	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
Total PFOS	**650**		2.4	0.20	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
4:2 FTS	ND	*1	0.96	0.26	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
6:2 FTS	ND		0.96	0.41	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
8:2 FTS	ND		0.96	0.096	ug/Kg		12/06/24 12:01	12/10/24 11:30	1
10:2 FTS	**0.15**	**J**	0.96	0.097	ug/Kg		12/06/24 12:01	12/10/24 11:30	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*57*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:30*	*1*
13C5 PFPeA	*69*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:30*	*1*
13C2 PFHxA	*90*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:30*	*1*
13C4 PFHpA	*91*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:30*	*1*
13C4 PFOA	*73*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:30*	*1*
13C5 PFNA	*57*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:30*	*1*
13C2 PFDA	*115*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:30*	*1*
13C2 PFUnA	*104*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:30*	*1*
13C3 PFBS	*86*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:30*	*1*
18O2 PFHxS	*98*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:30*	*1*
13C4 PFOS	*87*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:30*	*1*
M2-4:2 FTS	*142*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:30*	*1*
M2-6:2 FTS	*155*	**5+*	*25 - 150*	*12/06/24 12:01*	*12/10/24 11:30*	*1*
M2-8:2 FTS	*97*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:30*	*1*
13C2 10:2 FTS	*454*	**5+*	*25 - 150*	*12/06/24 12:01*	*12/10/24 11:30*	*1*

Client Sample ID: NK35661, MSB29140, P6

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-6

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.97	0.23	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
Perfluoropentanoic acid (PFPeA)	ND		0.97	0.17	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
Perfluorohexanoic acid (PFHxA)	ND		0.97	0.27	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
Perfluoroheptanoic acid (PFHpA)	ND		0.97	0.11	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
L-Perfluorooctanoic acid	**0.72**	**J**	0.97	0.20	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
Br-Perfluorooctanoic acid	ND		0.97	0.20	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
Total PFOA	**0.72**	**J**	0.97	0.20	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
Perfluorononanoic acid (PFNA)	**6.4**		0.97	0.17	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
Perfluorodecanoic acid (PFDA)	**3.8**		0.97	0.10	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
Perfluoroundecanoic acid (PFUnA)	**1.4**		0.97	0.26	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.97	0.17	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.97	0.18	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
Br-Perfluorohexanesulfonic acid	**0.27**	**J**	0.97	0.14	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
Total PFHxS	**3.7**		0.97	0.14	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
L-Perfluorohexanesulfonic acid	**3.5**		0.97	0.14	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
Perfluoroheptanesulfonic acid (PFHpS)	**1.3**		0.97	0.18	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
L-Perfluorooctanesulfonic acid	**1000**	**E I**	2.4	0.20	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
Br-Perfluorooctanesulfonic acid	**15**		2.4	0.20	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
Total PFOS	**1000**		2.4	0.20	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
4:2 FTS	ND	*1	0.97	0.26	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
6:2 FTS	ND		0.97	0.41	ug/Kg		12/06/24 12:01	12/10/24 11:49	1
10:2 FTS	**0.35**	**J**	0.97	0.098	ug/Kg		12/06/24 12:01	12/10/24 11:49	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*37*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:49*	*1*
13C5 PFPeA	*63*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:49*	*1*
13C2 PFHxA	*79*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:49*	*1*
13C4 PFHpA	*92*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:49*	*1*
13C4 PFOA	*72*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:49*	*1*
13C5 PFNA	*43*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:49*	*1*
13C2 PFDA	*101*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:49*	*1*
13C2 PFUnA	*109*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:49*	*1*
13C3 PFBS	*74*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:49*	*1*
18O2 PFHxS	*85*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:49*	*1*
13C4 PFOS	*78*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:49*	*1*
M2-4:2 FTS	*146*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:49*	*1*
M2-6:2 FTS	*140*		*25 - 150*	*12/06/24 12:01*	*12/10/24 11:49*	*1*
13C2 10:2 FTS	*323*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 11:49*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	**0.43**	**J**	0.97	0.097	ug/Kg		12/06/24 12:01	12/11/24 14:55	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
M2-8:2 FTS	*188*	*5+	*25 - 150*	*12/06/24 12:01*	*12/11/24 14:55*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK35655, MSB29134, P7
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-7
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.99	0.23	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
Perfluoropentanoic acid (PFPeA)	ND		0.99	0.17	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
Perfluorohexanoic acid (PFHxA)	ND		0.99	0.27	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
Perfluoroheptanoic acid (PFHpA)	ND		0.99	0.11	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
L-Perfluorooctanoic acid	**0.46**	**J**	0.99	0.20	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
Br-Perfluorooctanoic acid	ND		0.99	0.20	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
Total PFOA	**0.46**	**J**	0.99	0.20	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
Perfluorononanoic acid (PFNA)	**15**		0.99	0.17	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
Perfluorodecanoic acid (PFDA)	**20**		0.99	0.10	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
Perfluoroundecanoic acid (PFUnA)	**9.5**		0.99	0.27	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.99	0.17	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.99	0.18	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
Br-Perfluorohexanesulfonic acid	ND		0.99	0.15	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
Total PFHxS	**0.35**	**J**	0.99	0.15	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
L-Perfluorohexanesulfonic acid	**0.35**	**J**	0.99	0.15	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.43**	**J**	0.99	0.18	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
L-Perfluorooctanesulfonic acid	**570**	**E I**	2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
Br-Perfluorooctanesulfonic acid	**7.5**		2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
Total PFOS	**580**		2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
4:2 FTS	ND	*1	0.99	0.26	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
6:2 FTS	ND		0.99	0.42	ug/Kg		12/06/24 12:01	12/10/24 12:08	1
10:2 FTS	**0.72**	**J**	0.99	0.10	ug/Kg		12/06/24 12:01	12/10/24 12:08	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*53*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:08*	*1*
13C5 PFPeA	*64*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:08*	*1*
13C2 PFHxA	*80*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:08*	*1*
13C4 PFHpA	*84*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:08*	*1*
13C4 PFOA	*71*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:08*	*1*
13C5 PFNA	*54*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:08*	*1*
13C2 PFDA	*99*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:08*	*1*
13C2 PFUnA	*109*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:08*	*1*
13C3 PFBS	*73*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:08*	*1*
18O2 PFHxS	*82*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:08*	*1*
13C4 PFOS	*75*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:08*	*1*
M2-4:2 FTS	*169*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 12:08*	*1*
M2-6:2 FTS	*135*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:08*	*1*
13C2 10:2 FTS	*81*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:08*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	**0.41**	**J**	0.99	0.099	ug/Kg		12/06/24 12:01	12/11/24 15:14	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
M2-8:2 FTS	*158*	*5+	*25 - 150*	*12/06/24 12:01*	*12/11/24 15:14*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK35811, MSB30651, P8
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-8
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.94	0.22	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
Perfluoropentanoic acid (PFPeA)	ND		0.94	0.17	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
Perfluorohexanoic acid (PFHxA)	ND		0.94	0.26	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
Perfluoroheptanoic acid (PFHpA)	ND		0.94	0.11	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
L-Perfluorooctanoic acid	ND		0.94	0.19	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
Br-Perfluorooctanoic acid	ND		0.94	0.19	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
Total PFOA	ND		0.94	0.19	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
Perfluorononanoic acid (PFNA)	**7.8**		0.94	0.17	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
Perfluorodecanoic acid (PFDA)	**9.5**		0.94	0.097	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
Perfluoroundecanoic acid (PFUnA)	**4.3**		0.94	0.26	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.94	0.16	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.94	0.17	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
Br-Perfluorohexanesulfonic acid	ND		0.94	0.14	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
Total PFHxS	**0.18**	**J**	0.94	0.14	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
L-Perfluorohexanesulfonic acid	**0.18**	**J**	0.94	0.14	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.23**	**J**	0.94	0.17	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
L-Perfluorooctanesulfonic acid	**250**	**E I**	2.4	0.19	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
Br-Perfluorooctanesulfonic acid	**7.7**		2.4	0.19	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
Total PFOS	**250**		2.4	0.19	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
4:2 FTS	ND	*1	0.94	0.25	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
6:2 FTS	ND		0.94	0.40	ug/Kg		12/06/24 12:01	12/10/24 12:47	1
10:2 FTS	**0.21**	**J**	0.94	0.095	ug/Kg		12/06/24 12:01	12/10/24 12:47	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*48*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:47*	*1*
13C5 PFPeA	*59*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:47*	*1*
13C2 PFHxA	*73*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:47*	*1*
13C4 PFHpA	*79*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:47*	*1*
13C4 PFOA	*66*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:47*	*1*
13C5 PFNA	*61*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:47*	*1*
13C2 PFDA	*87*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:47*	*1*
13C2 PFUnA	*99*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:47*	*1*
13C3 PFBS	*67*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:47*	*1*
18O2 PFHxS	*82*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:47*	*1*
13C4 PFOS	*72*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:47*	*1*
M2-4:2 FTS	*140*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:47*	*1*
M2-6:2 FTS	*123*		*25 - 150*	*12/06/24 12:01*	*12/10/24 12:47*	*1*
13C2 10:2 FTS	*391*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 12:47*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	**0.095**	**J**	0.94	0.094	ug/Kg		12/06/24 12:01	12/11/24 15:34	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
M2-8:2 FTS	*111*		*25 - 150*	*12/06/24 12:01*	*12/11/24 15:34*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK35643, MSB29100, P9
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-9
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.93	0.22	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
Perfluoropentanoic acid (PFPeA)	ND		0.93	0.16	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
Perfluorohexanoic acid (PFHxA)	ND		0.93	0.25	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
Perfluoroheptanoic acid (PFHpA)	ND		0.93	0.11	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
L-Perfluorooctanoic acid	**0.33**	**J**	0.93	0.19	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
Br-Perfluorooctanoic acid	ND		0.93	0.19	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
Total PFOA	**0.33**	**J**	0.93	0.19	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
Perfluorononanoic acid (PFNA)	**16**		0.93	0.16	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
Perfluorodecanoic acid (PFDA)	**9.6**		0.93	0.095	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
Perfluoroundecanoic acid (PFUnA)	**1.5**		0.93	0.25	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.93	0.16	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.93	0.17	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
Br-Perfluorohexanesulfonic acid	ND		0.93	0.14	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
Total PFHxS	**1.1**		0.93	0.14	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
L-Perfluorohexanesulfonic acid	**1.1**		0.93	0.14	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
Perfluoroheptanesulfonic acid (PFHpS)	**1.3**		0.93	0.17	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
L-Perfluorooctanesulfonic acid	**330**	**E I**	2.3	0.19	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
Br-Perfluorooctanesulfonic acid	**15**		2.3	0.19	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
Total PFOS	**350**		2.3	0.19	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
4:2 FTS	ND	*1	0.93	0.25	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
6:2 FTS	ND		0.93	0.39	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
8:2 FTS	**0.32**	**J**	0.93	0.093	ug/Kg		12/06/24 12:01	12/11/24 15:53	1
10:2 FTS	**0.25**	**J**	0.93	0.094	ug/Kg		12/06/24 12:01	12/11/24 15:53	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*79*		*25 - 150*	*12/06/24 12:01*	*12/11/24 15:53*	*1*
13C5 PFPeA	*87*		*25 - 150*	*12/06/24 12:01*	*12/11/24 15:53*	*1*
13C2 PFHxA	*109*		*25 - 150*	*12/06/24 12:01*	*12/11/24 15:53*	*1*
13C4 PFHpA	*110*		*25 - 150*	*12/06/24 12:01*	*12/11/24 15:53*	*1*
13C4 PFOA	*95*		*25 - 150*	*12/06/24 12:01*	*12/11/24 15:53*	*1*
13C5 PFNA	*96*		*25 - 150*	*12/06/24 12:01*	*12/11/24 15:53*	*1*
13C2 PFDA	*124*		*25 - 150*	*12/06/24 12:01*	*12/11/24 15:53*	*1*
13C2 PFUnA	*129*		*25 - 150*	*12/06/24 12:01*	*12/11/24 15:53*	*1*
13C3 PFBS	*104*		*25 - 150*	*12/06/24 12:01*	*12/11/24 15:53*	*1*
18O2 PFHxS	*120*		*25 - 150*	*12/06/24 12:01*	*12/11/24 15:53*	*1*
13C4 PFOS	*104*		*25 - 150*	*12/06/24 12:01*	*12/11/24 15:53*	*1*
M2-4:2 FTS	*234*	*5+	*25 - 150*	*12/06/24 12:01*	*12/11/24 15:53*	*1*
M2-6:2 FTS	*192*	*5+	*25 - 150*	*12/06/24 12:01*	*12/11/24 15:53*	*1*
M2-8:2 FTS	*149*		*25 - 150*	*12/06/24 12:01*	*12/11/24 15:53*	*1*
13C2 10:2 FTS	*572*	*5+	*25 - 150*	*12/06/24 12:01*	*12/11/24 15:53*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK170946, P10
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-10
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.28	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
L-Perfluorooctanoic acid	ND		1.0	0.21	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
Br-Perfluorooctanoic acid	ND		1.0	0.21	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
Total PFOA	ND		1.0	0.21	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.11	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.28	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
Total PFHxS	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
L-Perfluorooctanesulfonic acid	**960**	**E I**	2.6	0.21	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
Br-Perfluorooctanesulfonic acid	**0.21**	**J**	2.6	0.21	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
Total PFOS	**960**		2.6	0.21	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
4:2 FTS	ND	*1	1.0	0.27	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
6:2 FTS	ND		1.0	0.43	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
8:2 FTS	ND		1.0	0.10	ug/Kg		12/06/24 12:01	12/10/24 13:26	1
10:2 FTS	ND		1.0	0.10	ug/Kg		12/06/24 12:01	12/10/24 13:26	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*63*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:26*	*1*
13C5 PFPeA	*62*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:26*	*1*
13C2 PFHxA	*78*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:26*	*1*
13C4 PFHpA	*77*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:26*	*1*
13C4 PFOA	*77*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:26*	*1*
13C5 PFNA	*37*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:26*	*1*
13C2 PFDA	*76*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:26*	*1*
13C2 PFUnA	*72*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:26*	*1*
13C3 PFBS	*64*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:26*	*1*
18O2 PFHxS	*89*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:26*	*1*
13C4 PFOS	*76*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:26*	*1*
M2-4:2 FTS	*97*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:26*	*1*
M2-6:2 FTS	*80*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:26*	*1*
M2-8:2 FTS	*72*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:26*	*1*
13C2 10:2 FTS	*367*	**5+*	*25 - 150*	*12/06/24 12:01*	*12/10/24 13:26*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK100328, Liver, AEPIR, P11
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-11
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.25	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.28	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
L-Perfluorooctanoic acid	ND		1.0	0.21	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
Br-Perfluorooctanoic acid	ND		1.0	0.21	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
Total PFOA	ND		1.0	0.21	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.11	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.28	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.19	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
Total PFHxS	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
L-Perfluorooctanesulfonic acid	**2.6**	**I**	2.6	0.21	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
Br-Perfluorooctanesulfonic acid	ND		2.6	0.21	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
Total PFOS	**2.6**		2.6	0.21	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
4:2 FTS	ND	*1	1.0	0.28	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
6:2 FTS	ND		1.0	0.44	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
8:2 FTS	ND		1.0	0.10	ug/Kg		12/06/24 12:01	12/10/24 13:45	1
10:2 FTS	ND		1.0	0.11	ug/Kg		12/06/24 12:01	12/10/24 13:45	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*60*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:45*	*1*
13C5 PFPeA	*66*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:45*	*1*
13C2 PFHxA	*87*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:45*	*1*
13C4 PFHpA	*84*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:45*	*1*
13C4 PFOA	*75*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:45*	*1*
13C5 PFNA	*78*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:45*	*1*
13C2 PFDA	*94*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:45*	*1*
13C2 PFUnA	*88*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:45*	*1*
13C3 PFBS	*82*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:45*	*1*
18O2 PFHxS	*88*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:45*	*1*
13C4 PFOS	*85*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:45*	*1*
M2-4:2 FTS	*121*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:45*	*1*
M2-6:2 FTS	*90*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:45*	*1*
M2-8:2 FTS	*113*		*25 - 150*	*12/06/24 12:01*	*12/10/24 13:45*	*1*
13C2 10:2 FTS	*431*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 13:45*	*1*

Client Sample ID: NK165232, MSB26431, P12

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-12

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.2	0.27	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
Perfluoropentanoic acid (PFPeA)	ND		1.2	0.20	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
Perfluorohexanoic acid (PFHxA)	ND		1.2	0.32	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
Perfluoroheptanoic acid (PFHpA)	ND		1.2	0.13	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
L-Perfluorooctanoic acid	**1.9**		1.2	0.23	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
Br-Perfluorooctanoic acid	ND		1.2	0.23	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
Total PFOA	**1.9**		1.2	0.23	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
Perfluorononanoic acid (PFNA)	**12**		1.2	0.20	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
Perfluorodecanoic acid (PFDA)	**6.9**		1.2	0.12	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
Perfluoroundecanoic acid (PFUnA)	**4.7**		1.2	0.32	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.2	0.20	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.2	0.21	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
Br-Perfluorohexanesulfonic acid	**0.17**	**J**	1.2	0.17	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
Total PFHxS	**1.4**		1.2	0.17	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
L-Perfluorohexanesulfonic acid	**1.3**		1.2	0.17	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.53**	**J**	1.2	0.22	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
L-Perfluorooctanesulfonic acid	**260**	**E I**	2.9	0.24	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
Br-Perfluorooctanesulfonic acid	**14**		2.9	0.24	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
Total PFOS	**280**		2.9	0.24	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
4:2 FTS	ND	*1	1.2	0.31	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
6:2 FTS	ND		1.2	0.49	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
8:2 FTS	ND		1.2	0.12	ug/Kg		12/06/24 12:01	12/10/24 14:05	1
10:2 FTS	**0.12**	**J**	1.2	0.12	ug/Kg		12/06/24 12:01	12/10/24 14:05	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*67*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:05*	*1*
13C5 PFPeA	*77*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:05*	*1*
13C2 PFHxA	*84*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:05*	*1*
13C4 PFHpA	*88*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:05*	*1*
13C4 PFOA	*71*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:05*	*1*
13C5 PFNA	*79*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:05*	*1*
13C2 PFDA	*92*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:05*	*1*
13C2 PFUnA	*109*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:05*	*1*
13C3 PFBS	*88*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:05*	*1*
18O2 PFHxS	*93*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:05*	*1*
13C4 PFOS	*84*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:05*	*1*
M2-4:2 FTS	*155*	**5+*	*25 - 150*	*12/06/24 12:01*	*12/10/24 14:05*	*1*
M2-6:2 FTS	*112*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:05*	*1*
M2-8:2 FTS	*123*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:05*	*1*
13C2 10:2 FTS	*400*	**5+*	*25 - 150*	*12/06/24 12:01*	*12/10/24 14:05*	*1*

Client Sample ID: NK35676, MSB29118, P14

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-13

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.27	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
L-Perfluorooctanoic acid	**0.58**	**J**	1.0	0.20	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
Total PFOA	**0.58**	**J**	1.0	0.20	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
Perfluorononanoic acid (PFNA)	**6.1**		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
Perfluorodecanoic acid (PFDA)	**4.4**		1.0	0.10	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
Perfluoroundecanoic acid (PFUnA)	**0.89**	**J**	1.0	0.27	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
Total PFHxS	**1.7**		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
L-Perfluorohexanesulfonic acid	**1.7**		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.39**	**J**	1.0	0.19	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
L-Perfluorooctanesulfonic acid	**630**	**E I**	2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
Br-Perfluorooctanesulfonic acid	**8.7**		2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
Total PFOS	**640**		2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
4:2 FTS	ND	*1	1.0	0.27	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
6:2 FTS	ND		1.0	0.42	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
8:2 FTS	ND		1.0	0.10	ug/Kg		12/06/24 12:01	12/10/24 14:24	1
10:2 FTS	**0.17**	**J**	1.0	0.10	ug/Kg		12/06/24 12:01	12/10/24 14:24	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*53*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:24*	*1*
13C5 PFPeA	*64*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:24*	*1*
13C2 PFHxA	*77*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:24*	*1*
13C4 PFHpA	*81*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:24*	*1*
13C4 PFOA	*64*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:24*	*1*
13C5 PFNA	*55*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:24*	*1*
13C2 PFDA	*91*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:24*	*1*
13C2 PFUnA	*85*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:24*	*1*
13C3 PFBS	*64*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:24*	*1*
18O2 PFHxS	*84*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:24*	*1*
13C4 PFOS	*75*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:24*	*1*
M2-4:2 FTS	*126*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:24*	*1*
M2-6:2 FTS	*93*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:24*	*1*
M2-8:2 FTS	*91*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:24*	*1*
13C2 10:2 FTS	*406*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 14:24*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK35678, MSB29131, P15
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-14
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.98	0.23	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
Perfluoropentanoic acid (PFPeA)	ND		0.98	0.17	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
Perfluorohexanoic acid (PFHxA)	ND		0.98	0.27	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
Perfluoroheptanoic acid (PFHpA)	ND		0.98	0.11	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
L-Perfluorooctanoic acid	ND		0.98	0.20	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
Br-Perfluorooctanoic acid	ND		0.98	0.20	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
Total PFOA	ND		0.98	0.20	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
Perfluorononanoic acid (PFNA)	**1.6**		0.98	0.17	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
Perfluorodecanoic acid (PFDA)	**1.3**		0.98	0.10	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
Perfluoroundecanoic acid (PFUnA)	**0.63**	**J**	0.98	0.27	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.98	0.17	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.98	0.18	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
Br-Perfluorohexanesulfonic acid	ND		0.98	0.15	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
Total PFHxS	**0.25**	**J**	0.98	0.15	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
L-Perfluorohexanesulfonic acid	**0.25**	**J**	0.98	0.15	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.98	0.18	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
L-Perfluorooctanesulfonic acid	**570**	**E I**	2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
Br-Perfluorooctanesulfonic acid	**1.5**	**J**	2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
Total PFOS	**570**		2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
4:2 FTS	ND	*1	0.98	0.26	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
6:2 FTS	ND		0.98	0.42	ug/Kg		12/06/24 12:01	12/10/24 14:44	1
10:2 FTS	**0.17**	**J**	0.98	0.099	ug/Kg		12/06/24 12:01	12/10/24 14:44	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*43*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:44*	*1*
13C5 PFPeA	*58*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:44*	*1*
13C2 PFHxA	*71*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:44*	*1*
13C4 PFHpA	*73*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:44*	*1*
13C4 PFOA	*61*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:44*	*1*
13C5 PFNA	*51*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:44*	*1*
13C2 PFDA	*80*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:44*	*1*
13C2 PFUnA	*83*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:44*	*1*
13C3 PFBS	*47*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:44*	*1*
18O2 PFHxS	*72*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:44*	*1*
13C4 PFOS	*73*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:44*	*1*
M2-4:2 FTS	*122*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:44*	*1*
M2-6:2 FTS	*91*		*25 - 150*	*12/06/24 12:01*	*12/10/24 14:44*	*1*
13C2 10:2 FTS	*286*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 14:44*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	**0.12**	**J**	0.98	0.098	ug/Kg		12/06/24 12:01	12/11/24 16:12	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
M2-8:2 FTS	*111*		*25 - 150*	*12/06/24 12:01*	*12/11/24 16:12*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK35669, MSB29093, P16
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-15
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.28	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
L-Perfluorooctanoic acid	**0.34**	**J**	1.0	0.20	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
Total PFOA	**0.34**	**J**	1.0	0.20	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
Perfluorononanoic acid (PFNA)	**6.8**		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
Perfluorodecanoic acid (PFDA)	**5.1**		1.0	0.10	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
Perfluoroundecanoic acid (PFUnA)	**2.5**		1.0	0.27	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
Total PFHxS	**0.79**	**J**	1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
L-Perfluorohexanesulfonic acid	**0.79**	**J**	1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.33**	**J**	1.0	0.19	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
L-Perfluorooctanesulfonic acid	**340**	**E I**	2.5	0.21	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
Br-Perfluorooctanesulfonic acid	**4.3**		2.5	0.21	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
Total PFOS	**340**		2.5	0.21	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
4:2 FTS	ND	*1	1.0	0.27	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
6:2 FTS	ND		1.0	0.43	ug/Kg		12/06/24 12:01	12/10/24 15:03	1
10:2 FTS	**0.27**	**J**	1.0	0.10	ug/Kg		12/06/24 12:01	12/10/24 15:03	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*54*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:03*	*1*
13C5 PFPeA	*81*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:03*	*1*
13C2 PFHxA	*107*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:03*	*1*
13C4 PFHpA	*101*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:03*	*1*
13C4 PFOA	*87*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:03*	*1*
13C5 PFNA	*80*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:03*	*1*
13C2 PFDA	*122*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:03*	*1*
13C2 PFUnA	*132*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:03*	*1*
13C3 PFBS	*90*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:03*	*1*
18O2 PFHxS	*107*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:03*	*1*
13C4 PFOS	*100*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:03*	*1*
M2-4:2 FTS	*183*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 15:03*	*1*
M2-6:2 FTS	*157*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 15:03*	*1*
13C2 10:2 FTS	*465*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 15:03*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	**0.14**	**J**	1.0	0.10	ug/Kg		12/06/24 12:01	12/11/24 16:32	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
M2-8:2 FTS	*189*	*5+	*25 - 150*	*12/06/24 12:01*	*12/11/24 16:32*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK35935, MSB39605, P17
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-16
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.99	0.23	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
Perfluoropentanoic acid (PFPeA)	ND		0.99	0.17	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
Perfluorohexanoic acid (PFHxA)	ND		0.99	0.27	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
Perfluoroheptanoic acid (PFHpA)	ND		0.99	0.11	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
L-Perfluorooctanoic acid	ND		0.99	0.20	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
Br-Perfluorooctanoic acid	ND		0.99	0.20	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
Total PFOA	ND		0.99	0.20	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
Perfluorononanoic acid (PFNA)	**15**		0.99	0.17	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
Perfluorodecanoic acid (PFDA)	**54**		0.99	0.10	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
Perfluoroundecanoic acid (PFUnA)	**19**		0.99	0.27	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.99	0.17	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.99	0.18	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
Br-Perfluorohexanesulfonic acid	ND		0.99	0.15	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
Total PFHxS	**1.8**		0.99	0.15	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
L-Perfluorohexanesulfonic acid	**1.8**		0.99	0.15	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
Perfluoroheptanesulfonic acid (PFHpS)	**1.9**		0.99	0.18	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
L-Perfluorooctanesulfonic acid	**710**	**E**	2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
Br-Perfluorooctanesulfonic acid	**38**		2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
Total PFOS	**750**		2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
4:2 FTS	ND	*1	0.99	0.26	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
6:2 FTS	ND		0.99	0.42	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
8:2 FTS	ND		0.99	0.099	ug/Kg		12/06/24 12:01	12/10/24 15:23	1
10:2 FTS	**0.12**	**J**	0.99	0.10	ug/Kg		12/06/24 12:01	12/10/24 15:23	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*22*	*5-	*25 - 150*	*12/06/24 12:01*	*12/10/24 15:23*	*1*
13C5 PFPeA	*52*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:23*	*1*
13C2 PFHxA	*80*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:23*	*1*
13C4 PFHpA	*93*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:23*	*1*
13C4 PFOA	*77*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:23*	*1*
13C5 PFNA	*75*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:23*	*1*
13C2 PFDA	*104*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:23*	*1*
13C2 PFUnA	*128*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:23*	*1*
13C3 PFBS	*64*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:23*	*1*
18O2 PFHxS	*95*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:23*	*1*
13C4 PFOS	*87*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:23*	*1*
M2-4:2 FTS	*143*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:23*	*1*
M2-6:2 FTS	*132*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:23*	*1*
M2-8:2 FTS	*162*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 15:23*	*1*
13C2 10:2 FTS	*311*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 15:23*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK35958, MSB40165, P18
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-17
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.27	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
L-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
Total PFOA	ND		1.0	0.20	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.10	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.27	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
Total PFHxS	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
L-Perfluorooctanesulfonic acid	**260**	**E I**	2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
Br-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
Total PFOS	**260**		2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
4:2 FTS	ND	*1	1.0	0.27	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
6:2 FTS	ND		1.0	0.42	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
8:2 FTS	ND		1.0	0.10	ug/Kg		12/06/24 12:01	12/10/24 15:42	1
10:2 FTS	ND		1.0	0.10	ug/Kg		12/06/24 12:01	12/10/24 15:42	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*46*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:42*	*1*
13C5 PFPeA	*72*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:42*	*1*
13C2 PFHxA	*91*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:42*	*1*
13C4 PFHpA	*97*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:42*	*1*
13C4 PFOA	*91*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:42*	*1*
13C5 PFNA	*85*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:42*	*1*
13C2 PFDA	*106*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:42*	*1*
13C2 PFUnA	*97*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:42*	*1*
13C3 PFBS	*86*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:42*	*1*
18O2 PFHxS	*106*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:42*	*1*
13C4 PFOS	*99*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:42*	*1*
M2-4:2 FTS	*141*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:42*	*1*
M2-6:2 FTS	*98*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:42*	*1*
M2-8:2 FTS	*108*		*25 - 150*	*12/06/24 12:01*	*12/10/24 15:42*	*1*
13C2 10:2 FTS	*448*	*5+	*25 - 150*	*12/06/24 12:01*	*12/10/24 15:42*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK35816, MSB30670, P19
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-18
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.51	0.12	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
Perfluoropentanoic acid (PFPeA)	ND		0.51	0.089	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
Perfluorohexanoic acid (PFHxA)	ND		0.51	0.14	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
Perfluoroheptanoic acid (PFHpA)	ND		0.51	0.059	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
L-Perfluorooctanoic acid	**0.20**	**J**	0.51	0.10	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
Br-Perfluorooctanoic acid	ND		0.51	0.10	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
Total PFOA	**0.20**	**J**	0.51	0.10	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
Perfluorononanoic acid (PFNA)	**5.2**		0.51	0.089	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
Perfluorodecanoic acid (PFDA)	**4.6**		0.51	0.053	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
Perfluoroundecanoic acid (PFUnA)	**1.4**		0.51	0.14	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.51	0.087	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.51	0.092	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
Br-Perfluorohexanesulfonic acid	ND		0.51	0.076	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
Total PFHxS	**0.22**	**J**	0.51	0.076	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
L-Perfluorohexanesulfonic acid	**0.22**	**J**	0.51	0.076	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.27**	**J**	0.51	0.094	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
L-Perfluorooctanesulfonic acid	**330**	**E I**	1.3	0.10	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
Br-Perfluorooctanesulfonic acid	**4.3**		1.3	0.10	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
Total PFOS	**330**		1.3	0.10	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
4:2 FTS	ND	*1	0.51	0.14	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
6:2 FTS	ND		0.51	0.22	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
8:2 FTS	**0.062**	**J**	0.51	0.051	ug/Kg		12/06/24 12:01	12/11/24 16:51	1
10:2 FTS	**0.13**	**J**	0.51	0.052	ug/Kg		12/06/24 12:01	12/11/24 16:51	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*55*		*25 - 150*	*12/06/24 12:01*	*12/11/24 16:51*	*1*
13C5 PFPeA	*84*		*25 - 150*	*12/06/24 12:01*	*12/11/24 16:51*	*1*
13C2 PFHxA	*90*		*25 - 150*	*12/06/24 12:01*	*12/11/24 16:51*	*1*
13C4 PFHpA	*107*		*25 - 150*	*12/06/24 12:01*	*12/11/24 16:51*	*1*
13C4 PFOA	*93*		*25 - 150*	*12/06/24 12:01*	*12/11/24 16:51*	*1*
13C5 PFNA	*69*		*25 - 150*	*12/06/24 12:01*	*12/11/24 16:51*	*1*
13C2 PFDA	*126*		*25 - 150*	*12/06/24 12:01*	*12/11/24 16:51*	*1*
13C2 PFUnA	*143*		*25 - 150*	*12/06/24 12:01*	*12/11/24 16:51*	*1*
13C3 PFBS	*88*		*25 - 150*	*12/06/24 12:01*	*12/11/24 16:51*	*1*
18O2 PFHxS	*111*		*25 - 150*	*12/06/24 12:01*	*12/11/24 16:51*	*1*
13C4 PFOS	*98*		*25 - 150*	*12/06/24 12:01*	*12/11/24 16:51*	*1*
M2-4:2 FTS	*171*	*5+	*25 - 150*	*12/06/24 12:01*	*12/11/24 16:51*	*1*
M2-6:2 FTS	*159*	*5+	*25 - 150*	*12/06/24 12:01*	*12/11/24 16:51*	*1*
M2-8:2 FTS	*141*		*25 - 150*	*12/06/24 12:01*	*12/11/24 16:51*	*1*
13C2 10:2 FTS	*479*	*5+	*25 - 150*	*12/06/24 12:01*	*12/11/24 16:51*	*1*

Client Sample ID: NK35804, MSB30716, P20

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-19

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.93	0.22	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
Perfluoropentanoic acid (PFPeA)	ND		0.93	0.16	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
Perfluorohexanoic acid (PFHxA)	ND		0.93	0.26	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
Perfluoroheptanoic acid (PFHpA)	ND		0.93	0.11	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
L-Perfluorooctanoic acid	**0.33**	**J**	0.93	0.19	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
Br-Perfluorooctanoic acid	ND		0.93	0.19	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
Total PFOA	**0.33**	**J**	0.93	0.19	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
Perfluorononanoic acid (PFNA)	**13**		0.93	0.16	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
Perfluorodecanoic acid (PFDA)	**14**		0.93	0.096	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
Perfluoroundecanoic acid (PFUnA)	**3.0**		0.93	0.25	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.93	0.16	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.93	0.17	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
Br-Perfluorohexanesulfonic acid	**0.42**	**J**	0.93	0.14	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
Total PFHxS	**5.3**		0.93	0.14	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
L-Perfluorohexanesulfonic acid	**4.9**		0.93	0.14	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
Perfluoroheptanesulfonic acid (PFHpS)	**1.4**		0.93	0.17	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
L-Perfluorooctanesulfonic acid	**490**	**E I**	2.3	0.19	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
Br-Perfluorooctanesulfonic acid	**26**		2.3	0.19	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
Total PFOS	**510**		2.3	0.19	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
4:2 FTS	ND	*1	0.93	0.25	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
6:2 FTS	ND		0.93	0.40	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
8:2 FTS	**0.58**	**J**	0.93	0.093	ug/Kg		12/06/24 12:01	12/11/24 17:11	1
10:2 FTS	**0.34**	**J**	0.93	0.094	ug/Kg		12/06/24 12:01	12/11/24 17:11	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*37*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:11*	*1*
13C5 PFPeA	*64*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:11*	*1*
13C2 PFHxA	*94*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:11*	*1*
13C4 PFHpA	*119*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:11*	*1*
13C4 PFOA	*94*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:11*	*1*
13C5 PFNA	*84*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:11*	*1*
13C2 PFDA	*124*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:11*	*1*
13C2 PFUnA	*140*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:11*	*1*
13C3 PFBS	*78*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:11*	*1*
18O2 PFHxS	*105*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:11*	*1*
13C4 PFOS	*97*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:11*	*1*
M2-4:2 FTS	*232*	**5+*	*25 - 150*	*12/06/24 12:01*	*12/11/24 17:11*	*1*
M2-6:2 FTS	*242*	**5+*	*25 - 150*	*12/06/24 12:01*	*12/11/24 17:11*	*1*
M2-8:2 FTS	*271*	**5+*	*25 - 150*	*12/06/24 12:01*	*12/11/24 17:11*	*1*
13C2 10:2 FTS	*451*	**5+*	*25 - 150*	*12/06/24 12:01*	*12/11/24 17:11*	*1*

Client Sample ID: NK35876, MSB39746, P22

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-20

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.28	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
L-Perfluorooctanoic acid	**0.27**	**J**	1.0	0.20	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
Total PFOA	**0.27**	**J**	1.0	0.20	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
Perfluorononanoic acid (PFNA)	**3.9**		1.0	0.18	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
Perfluorodecanoic acid (PFDA)	**1.0**		1.0	0.10	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
Perfluoroundecanoic acid (PFUnA)	**0.34**	**J**	1.0	0.27	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
Total PFHxS	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
L-Perfluorooctanesulfonic acid	**620**	**E I**	2.5	0.21	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
Br-Perfluorooctanesulfonic acid	**0.76**	**J**	2.5	0.21	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
Total PFOS	**620**		2.5	0.21	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
4:2 FTS	ND	*1	1.0	0.27	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
6:2 FTS	ND		1.0	0.43	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
8:2 FTS	ND		1.0	0.10	ug/Kg		12/06/24 12:01	12/11/24 17:49	1
10:2 FTS	ND		1.0	0.10	ug/Kg		12/06/24 12:01	12/11/24 17:49	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*58*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:49*	*1*
13C5 PFPeA	*86*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:49*	*1*
13C2 PFHxA	*119*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:49*	*1*
13C4 PFHpA	*104*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:49*	*1*
13C4 PFOA	*90*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:49*	*1*
13C5 PFNA	*70*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:49*	*1*
13C2 PFDA	*129*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:49*	*1*
13C2 PFUnA	*122*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:49*	*1*
13C3 PFBS	*101*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:49*	*1*
18O2 PFHxS	*118*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:49*	*1*
13C4 PFOS	*104*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:49*	*1*
M2-4:2 FTS	*160*	*5+	*25 - 150*	*12/06/24 12:01*	*12/11/24 17:49*	*1*
M2-6:2 FTS	*183*	*5+	*25 - 150*	*12/06/24 12:01*	*12/11/24 17:49*	*1*
M2-8:2 FTS	*146*		*25 - 150*	*12/06/24 12:01*	*12/11/24 17:49*	*1*
13C2 10:2 FTS	*442*	*5+	*25 - 150*	*12/06/24 12:01*	*12/11/24 17:49*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK35910, MSB39349, P23
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-21
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.28	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
L-Perfluorooctanoic acid	ND		1.0	0.21	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
Br-Perfluorooctanoic acid	ND		1.0	0.21	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
Total PFOA	ND		1.0	0.21	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
Perfluorononanoic acid (PFNA)	**5.0**		1.0	0.18	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
Perfluorodecanoic acid (PFDA)	**1.5**		1.0	0.11	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
Perfluoroundecanoic acid (PFUnA)	**0.54**	**J**	1.0	0.28	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.18	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.19	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
Br-Perfluorohexanesulfonic acid	**0.36**	**J**	1.0	0.15	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
Total PFHxS	**0.47**	**J**	1.0	0.15	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
L-Perfluorooctanesulfonic acid	**350**	**E I**	2.6	0.21	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
Br-Perfluorooctanesulfonic acid	**1.6**	**J**	2.6	0.21	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
Total PFOS	**350**		2.6	0.21	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
4:2 FTS	ND		1.0	0.27	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
6:2 FTS	ND		1.0	0.44	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
8:2 FTS	ND		1.0	0.10	ug/Kg		12/10/24 03:40	12/12/24 23:53	1
10:2 FTS	**0.10**	**J**	1.0	0.10	ug/Kg		12/10/24 03:40	12/12/24 23:53	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*49*		*25 - 150*	*12/10/24 03:40*	*12/12/24 23:53*	*1*
13C5 PFPeA	*64*		*25 - 150*	*12/10/24 03:40*	*12/12/24 23:53*	*1*
13C2 PFHxA	*93*		*25 - 150*	*12/10/24 03:40*	*12/12/24 23:53*	*1*
13C4 PFHpA	*91*		*25 - 150*	*12/10/24 03:40*	*12/12/24 23:53*	*1*
13C4 PFOA	*83*		*25 - 150*	*12/10/24 03:40*	*12/12/24 23:53*	*1*
13C5 PFNA	*84*		*25 - 150*	*12/10/24 03:40*	*12/12/24 23:53*	*1*
13C2 PFDA	*99*		*25 - 150*	*12/10/24 03:40*	*12/12/24 23:53*	*1*
13C2 PFUnA	*117*		*25 - 150*	*12/10/24 03:40*	*12/12/24 23:53*	*1*
13C3 PFBS	*80*		*25 - 150*	*12/10/24 03:40*	*12/12/24 23:53*	*1*
18O2 PFHxS	*106*		*25 - 150*	*12/10/24 03:40*	*12/12/24 23:53*	*1*
13C4 PFOS	*96*		*25 - 150*	*12/10/24 03:40*	*12/12/24 23:53*	*1*
M2-4:2 FTS	*213*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/12/24 23:53*	*1*
M2-6:2 FTS	*127*		*25 - 150*	*12/10/24 03:40*	*12/12/24 23:53*	*1*
M2-8:2 FTS	*140*		*25 - 150*	*12/10/24 03:40*	*12/12/24 23:53*	*1*
13C2 10:2 FTS	*559*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/12/24 23:53*	*1*

Client Sample ID: NK35817, MSB30650, P24

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-22

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.1	0.25	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
Perfluoropentanoic acid (PFPeA)	ND		1.1	0.18	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
Perfluorohexanoic acid (PFHxA)	ND		1.1	0.29	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
Perfluoroheptanoic acid (PFHpA)	ND		1.1	0.12	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
L-Perfluorooctanoic acid	ND		1.1	0.21	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
Br-Perfluorooctanoic acid	ND		1.1	0.21	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
Total PFOA	ND		1.1	0.21	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
Perfluorononanoic acid (PFNA)	**2.9**		1.1	0.18	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
Perfluorodecanoic acid (PFDA)	**2.9**		1.1	0.11	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
Perfluoroundecanoic acid (PFUnA)	**0.77**	**J**	1.1	0.29	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.1	0.18	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.1	0.19	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
Br-Perfluorohexanesulfonic acid	ND		1.1	0.16	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
Total PFHxS	**0.22**	**J**	1.1	0.16	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
L-Perfluorohexanesulfonic acid	**0.22**	**J**	1.1	0.16	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
Perfluoroheptanesulfonic acid (PFHpS)	**0.20**	**J**	1.1	0.19	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
L-Perfluorooctanesulfonic acid	**540**	**E I**	2.6	0.21	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
Br-Perfluorooctanesulfonic acid	**3.5**		2.6	0.21	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
Total PFOS	**540**		2.6	0.21	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
4:2 FTS	ND		1.1	0.28	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
6:2 FTS	ND		1.1	0.45	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
8:2 FTS	ND		1.1	0.11	ug/Kg		12/10/24 03:40	12/13/24 00:13	1
10:2 FTS	**0.13**	**J**	1.1	0.11	ug/Kg		12/10/24 03:40	12/13/24 00:13	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*67*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:13*	*1*
13C5 PFPeA	*75*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:13*	*1*
13C2 PFHxA	*104*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:13*	*1*
13C4 PFHpA	*98*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:13*	*1*
13C4 PFOA	*90*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:13*	*1*
13C5 PFNA	*82*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:13*	*1*
13C2 PFDA	*123*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:13*	*1*
13C2 PFUnA	*138*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:13*	*1*
13C3 PFBS	*95*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:13*	*1*
18O2 PFHxS	*106*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:13*	*1*
13C4 PFOS	*103*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:13*	*1*
M2-4:2 FTS	*162*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 00:13*	*1*
M2-6:2 FTS	*146*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:13*	*1*
M2-8:2 FTS	*138*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:13*	*1*
13C2 10:2 FTS	*605*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 00:13*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: Pool 25, Duck PFAS, P25
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-23
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.1	0.27	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
Perfluoropentanoic acid (PFPeA)	ND		1.1	0.20	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
Perfluorohexanoic acid (PFHxA)	ND		1.1	0.31	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
Perfluoroheptanoic acid (PFHpA)	ND		1.1	0.13	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
L-Perfluorooctanoic acid	ND		1.1	0.23	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
Br-Perfluorooctanoic acid	ND		1.1	0.23	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
Total PFOA	ND		1.1	0.23	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
Perfluorononanoic acid (PFNA)	**0.30**	**J**	1.1	0.20	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
Perfluorodecanoic acid (PFDA)	**0.36**	**J**	1.1	0.12	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
Perfluoroundecanoic acid (PFUnA)	ND		1.1	0.31	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.1	0.19	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.1	0.20	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
Br-Perfluorohexanesulfonic acid	ND		1.1	0.17	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
Total PFHxS	ND		1.1	0.17	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
L-Perfluorohexanesulfonic acid	ND		1.1	0.17	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.1	0.21	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
L-Perfluorooctanesulfonic acid	**590**	**E I**	2.8	0.23	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
Br-Perfluorooctanesulfonic acid	**0.30**	**J**	2.8	0.23	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
Total PFOS	**590**		2.8	0.23	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
4:2 FTS	ND		1.1	0.30	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
6:2 FTS	ND		1.1	0.48	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
8:2 FTS	ND		1.1	0.11	ug/Kg		12/10/24 03:40	12/13/24 00:32	1
10:2 FTS	ND		1.1	0.11	ug/Kg		12/10/24 03:40	12/13/24 00:32	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*70*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:32*	*1*
13C5 PFPeA	*89*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:32*	*1*
13C2 PFHxA	*106*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:32*	*1*
13C4 PFHpA	*108*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:32*	*1*
13C4 PFOA	*93*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:32*	*1*
13C5 PFNA	*74*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:32*	*1*
13C2 PFDA	*113*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:32*	*1*
13C2 PFUnA	*100*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:32*	*1*
13C3 PFBS	*88*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:32*	*1*
18O2 PFHxS	*110*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:32*	*1*
13C4 PFOS	*101*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:32*	*1*
M2-4:2 FTS	*172*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 00:32*	*1*
M2-6:2 FTS	*168*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 00:32*	*1*
M2-8:2 FTS	*136*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:32*	*1*
13C2 10:2 FTS	*581*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 00:32*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK282630, MSB50169, P26
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-24
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.5	0.35	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
Perfluoropentanoic acid (PFPeA)	ND		1.5	0.26	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
Perfluorohexanoic acid (PFHxA)	ND		1.5	0.40	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
Perfluoroheptanoic acid (PFHpA)	ND		1.5	0.17	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
L-Perfluorooctanoic acid	ND		1.5	0.30	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
Br-Perfluorooctanoic acid	ND		1.5	0.30	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
Total PFOA	ND		1.5	0.30	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
Perfluorononanoic acid (PFNA)	**0.68**	**J**	1.5	0.26	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
Perfluorodecanoic acid (PFDA)	**0.29**	**J**	1.5	0.15	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
Perfluoroundecanoic acid (PFUnA)	ND		1.5	0.40	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.5	0.25	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.5	0.27	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
Br-Perfluorohexanesulfonic acid	ND		1.5	0.22	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
Total PFHxS	ND		1.5	0.22	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
L-Perfluorohexanesulfonic acid	ND		1.5	0.22	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.5	0.27	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
L-Perfluorooctanesulfonic acid	**6.2**	**I**	3.7	0.30	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
Br-Perfluorooctanesulfonic acid	ND		3.7	0.30	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
Total PFOS	**6.2**		3.7	0.30	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
4:2 FTS	ND		1.5	0.39	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
6:2 FTS	ND		1.5	0.62	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
8:2 FTS	ND		1.5	0.15	ug/Kg		12/10/24 03:40	12/13/24 00:51	1
10:2 FTS	ND		1.5	0.15	ug/Kg		12/10/24 03:40	12/13/24 00:51	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*73*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:51*	*1*
13C5 PFPeA	*75*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:51*	*1*
13C2 PFHxA	*93*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:51*	*1*
13C4 PFHpA	*91*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:51*	*1*
13C4 PFOA	*85*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:51*	*1*
13C5 PFNA	*92*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:51*	*1*
13C2 PFDA	*103*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:51*	*1*
13C2 PFUnA	*86*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:51*	*1*
13C3 PFBS	*88*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:51*	*1*
18O2 PFHxS	*107*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:51*	*1*
13C4 PFOS	*99*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:51*	*1*
M2-4:2 FTS	*240*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 00:51*	*1*
M2-6:2 FTS	*141*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:51*	*1*
M2-8:2 FTS	*148*		*25 - 150*	*12/10/24 03:40*	*12/13/24 00:51*	*1*
13C2 10:2 FTS	*374*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 00:51*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK276851, MSB46239, P28
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-25
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.3	0.30	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
Perfluoropentanoic acid (PFPeA)	ND		1.3	0.22	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
Perfluorohexanoic acid (PFHxA)	ND		1.3	0.35	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
Perfluoroheptanoic acid (PFHpA)	ND		1.3	0.15	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
L-Perfluorooctanoic acid	ND		1.3	0.26	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
Br-Perfluorooctanoic acid	ND		1.3	0.26	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
Total PFOA	ND		1.3	0.26	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
Perfluorononanoic acid (PFNA)	**0.76**	**J**	1.3	0.22	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
Perfluorodecanoic acid (PFDA)	**0.80**	**J**	1.3	0.13	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
Perfluoroundecanoic acid (PFUnA)	ND		1.3	0.35	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.3	0.22	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.3	0.23	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
Br-Perfluorohexanesulfonic acid	ND		1.3	0.19	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
Total PFHxS	ND		1.3	0.19	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
L-Perfluorohexanesulfonic acid	ND		1.3	0.19	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.3	0.24	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
L-Perfluorooctanesulfonic acid	**300**	**E I**	3.2	0.26	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
Br-Perfluorooctanesulfonic acid	**0.59**	**J**	3.2	0.26	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
Total PFOS	**300**		3.2	0.26	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
4:2 FTS	ND		1.3	0.34	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
6:2 FTS	ND		1.3	0.54	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
8:2 FTS	ND		1.3	0.13	ug/Kg		12/10/24 03:40	12/13/24 01:11	1
10:2 FTS	ND		1.3	0.13	ug/Kg		12/10/24 03:40	12/13/24 01:11	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*61*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:11*	*1*
13C5 PFPeA	*71*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:11*	*1*
13C2 PFHxA	*90*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:11*	*1*
13C4 PFHpA	*85*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:11*	*1*
13C4 PFOA	*81*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:11*	*1*
13C5 PFNA	*85*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:11*	*1*
13C2 PFDA	*96*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:11*	*1*
13C2 PFUnA	*102*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:11*	*1*
13C3 PFBS	*80*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:11*	*1*
18O2 PFHxS	*97*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:11*	*1*
13C4 PFOS	*91*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:11*	*1*
M2-4:2 FTS	*124*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:11*	*1*
M2-6:2 FTS	*100*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:11*	*1*
M2-8:2 FTS	*96*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:11*	*1*
13C2 10:2 FTS	*403*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 01:11*	*1*

Client Sample ID: NK282547, MSB49842, P29

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-26

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.91	0.21	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
Perfluoropentanoic acid (PFPeA)	ND		0.91	0.16	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
Perfluorohexanoic acid (PFHxA)	ND		0.91	0.25	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
Perfluoroheptanoic acid (PFHpA)	ND		0.91	0.11	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
L-Perfluorooctanoic acid	**0.22**	**J**	0.91	0.18	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
Br-Perfluorooctanoic acid	ND		0.91	0.18	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
Total PFOA	**0.22**	**J**	0.91	0.18	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
Perfluorononanoic acid (PFNA)	**6.6**		0.91	0.16	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
Perfluorodecanoic acid (PFDA)	**2.3**		0.91	0.094	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
Perfluoroundecanoic acid (PFUnA)	**2.2**		0.91	0.25	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.91	0.15	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
Perfluoropentanesulfonic acid (PFPeS)	ND		0.91	0.16	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
Br-Perfluorohexanesulfonic acid	ND		0.91	0.13	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
Total PFHxS	ND		0.91	0.13	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
L-Perfluorohexanesulfonic acid	ND		0.91	0.13	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		0.91	0.17	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
L-Perfluorooctanesulfonic acid	**380**	**E I**	2.3	0.18	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
Br-Perfluorooctanesulfonic acid	**0.56**	**J**	2.3	0.18	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
Total PFOS	**380**		2.3	0.18	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
4:2 FTS	ND		0.91	0.24	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
6:2 FTS	ND		0.91	0.39	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
8:2 FTS	ND		0.91	0.091	ug/Kg		12/10/24 03:40	12/13/24 01:30	1
10:2 FTS	ND		0.91	0.092	ug/Kg		12/10/24 03:40	12/13/24 01:30	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*51*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:30*	*1*
13C5 PFPeA	*78*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:30*	*1*
13C2 PFHxA	*87*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:30*	*1*
13C4 PFHpA	*100*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:30*	*1*
13C4 PFOA	*91*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:30*	*1*
13C5 PFNA	*84*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:30*	*1*
13C2 PFDA	*104*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:30*	*1*
13C2 PFUnA	*104*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:30*	*1*
13C3 PFBS	*81*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:30*	*1*
18O2 PFHxS	*110*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:30*	*1*
13C4 PFOS	*104*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:30*	*1*
M2-4:2 FTS	*188*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 01:30*	*1*
M2-6:2 FTS	*151*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 01:30*	*1*
M2-8:2 FTS	*139*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:30*	*1*
13C2 10:2 FTS	*560*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 01:30*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK276660, MSB45963, P30
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-27
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.7	0.41	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
Perfluoropentanoic acid (PFPeA)	ND		1.7	0.30	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
Perfluorohexanoic acid (PFHxA)	ND		1.7	0.47	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
Perfluoroheptanoic acid (PFHpA)	ND		1.7	0.20	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
L-Perfluorooctanoic acid	ND		1.7	0.35	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
Br-Perfluorooctanoic acid	ND		1.7	0.35	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
Total PFOA	ND		1.7	0.35	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
Perfluorononanoic acid (PFNA)	ND		1.7	0.30	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
Perfluorodecanoic acid (PFDA)	ND		1.7	0.18	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
Perfluoroundecanoic acid (PFUnA)	ND		1.7	0.47	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.7	0.29	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.7	0.31	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
Br-Perfluorohexanesulfonic acid	ND		1.7	0.26	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
Total PFHxS	ND		1.7	0.26	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
L-Perfluorohexanesulfonic acid	ND		1.7	0.26	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.7	0.32	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
L-Perfluorooctanesulfonic acid	**720**	**E I**	4.3	0.35	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
Br-Perfluorooctanesulfonic acid	ND		4.3	0.35	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
Total PFOS	**720**		4.3	0.35	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
4:2 FTS	ND		1.7	0.46	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
6:2 FTS	ND		1.7	0.73	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
8:2 FTS	ND		1.7	0.17	ug/Kg		12/10/24 03:40	12/13/24 01:50	1
10:2 FTS	ND		1.7	0.17	ug/Kg		12/10/24 03:40	12/13/24 01:50	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*75*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:50*	*1*
13C5 PFPeA	*73*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:50*	*1*
13C2 PFHxA	*89*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:50*	*1*
13C4 PFHpA	*86*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:50*	*1*
13C4 PFOA	*85*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:50*	*1*
13C5 PFNA	*76*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:50*	*1*
13C2 PFDA	*93*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:50*	*1*
13C2 PFUnA	*92*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:50*	*1*
13C3 PFBS	*80*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:50*	*1*
18O2 PFHxS	*99*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:50*	*1*
13C4 PFOS	*91*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:50*	*1*
M2-4:2 FTS	*106*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:50*	*1*
M2-6:2 FTS	*127*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:50*	*1*
M2-8:2 FTS	*93*		*25 - 150*	*12/10/24 03:40*	*12/13/24 01:50*	*1*
13C2 10:2 FTS	*518*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 01:50*	*1*

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK282696, MSB50223, P31
Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Lab Sample ID: 320-117508-28
Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.8	0.41	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
Perfluoropentanoic acid (PFPeA)	ND		1.8	0.31	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
Perfluorohexanoic acid (PFHxA)	ND		1.8	0.48	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
Perfluoroheptanoic acid (PFHpA)	ND		1.8	0.20	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
L-Perfluorooctanoic acid	ND		1.8	0.35	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
Br-Perfluorooctanoic acid	ND		1.8	0.35	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
Total PFOA	ND		1.8	0.35	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
Perfluorononanoic acid (PFNA)	**0.33**	**J**	1.8	0.31	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
Perfluorodecanoic acid (PFDA)	**0.90**	**J**	1.8	0.18	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
Perfluoroundecanoic acid (PFUnA)	ND		1.8	0.48	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.8	0.30	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.8	0.32	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
Br-Perfluorohexanesulfonic acid	ND		1.8	0.26	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
Total PFHxS	ND		1.8	0.26	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
L-Perfluorohexanesulfonic acid	ND		1.8	0.26	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.8	0.32	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
L-Perfluorooctanesulfonic acid	**350**	**E I**	4.4	0.36	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
Br-Perfluorooctanesulfonic acid	**0.90**	**J**	4.4	0.36	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
Total PFOS	**350**		4.4	0.36	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
4:2 FTS	ND		1.8	0.47	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
6:2 FTS	ND		1.8	0.74	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
8:2 FTS	ND		1.8	0.18	ug/Kg		12/10/24 03:40	12/13/24 02:29	1
10:2 FTS	ND		1.8	0.18	ug/Kg		12/10/24 03:40	12/13/24 02:29	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*80*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:29*	*1*
13C5 PFPeA	*98*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:29*	*1*
13C2 PFHxA	*110*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:29*	*1*
13C4 PFHpA	*110*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:29*	*1*
13C4 PFOA	*97*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:29*	*1*
13C5 PFNA	*108*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:29*	*1*
13C2 PFDA	*121*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:29*	*1*
13C2 PFUnA	*120*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:29*	*1*
13C3 PFBS	*108*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:29*	*1*
18O2 PFHxS	*119*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:29*	*1*
13C4 PFOS	*109*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:29*	*1*
M2-4:2 FTS	*265*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 02:29*	*1*
M2-6:2 FTS	*207*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 02:29*	*1*
M2-8:2 FTS	*158*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 02:29*	*1*
13C2 10:2 FTS	*429*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 02:29*	*1*

Client Sample ID: NK283601, Spat. Cly, Liver, ABJ34298, MSB1011285, P32
Lab Sample ID: 320-117508-29
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.60	0.14	ug/Kg		12/10/24 03:40	12/13/24 02:48	1
Perfluoropentanoic acid (PFPeA)	**0.33**	**J**	0.60	0.10	ug/Kg		12/10/24 03:40	12/13/24 02:48	1
Perfluorohexanoic acid (PFHxA)	**0.69**		0.60	0.16	ug/Kg		12/10/24 03:40	12/13/24 02:48	1
Perfluoroheptanoic acid (PFHpA)	**1.2**		0.60	0.069	ug/Kg		12/10/24 03:40	12/13/24 02:48	1
Perfluorodecanoic acid (PFDA)	**29**		0.60	0.062	ug/Kg		12/10/24 03:40	12/13/24 02:48	1
Perfluoroundecanoic acid (PFUnA)	**2.7**		0.60	0.16	ug/Kg		12/10/24 03:40	12/13/24 02:48	1
Perfluorobutanesulfonic acid (PFBS)	**0.94**		0.60	0.10	ug/Kg		12/10/24 03:40	12/13/24 02:48	1
Perfluoropentanesulfonic acid (PFPeS)	**31**		0.60	0.11	ug/Kg		12/10/24 03:40	12/13/24 02:48	1
4:2 FTS	ND		0.60	0.16	ug/Kg		12/10/24 03:40	12/13/24 02:48	1
6:2 FTS	**0.95**		0.60	0.25	ug/Kg		12/10/24 03:40	12/13/24 02:48	1
10:2 FTS	**0.15**	**J**	0.60	0.060	ug/Kg		12/10/24 03:40	12/13/24 02:48	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*53*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:48*	*1*
13C5 PFPeA	*71*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:48*	*1*
13C2 PFHxA	*108*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:48*	*1*
13C4 PFHpA	*110*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:48*	*1*
13C2 PFDA	*112*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:48*	*1*
13C2 PFUnA	*153*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 02:48*	*1*
13C3 PFBS	*99*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:48*	*1*
M2-4:2 FTS	*147*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:48*	*1*
M2-6:2 FTS	*133*		*25 - 150*	*12/10/24 03:40*	*12/13/24 02:48*	*1*
13C2 10:2 FTS	*632*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 02:48*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanoic acid	**110**		60	12	ug/Kg		12/10/24 03:40	12/17/24 08:32	100
Br-Perfluorooctanoic acid	ND		60	12	ug/Kg		12/10/24 03:40	12/17/24 08:32	100
Total PFOA	**110**		60	12	ug/Kg		12/10/24 03:40	12/17/24 08:32	100
Perfluorononanoic acid (PFNA)	**340**		60	10	ug/Kg		12/10/24 03:40	12/17/24 08:32	100
Br-Perfluorohexanesulfonic acid	**140**		60	8.9	ug/Kg		12/10/24 03:40	12/17/24 08:32	100
Total PFHxS	**3100**		60	8.9	ug/Kg		12/10/24 03:40	12/17/24 08:32	100
L-Perfluorohexanesulfonic acid	**2900**		60	8.9	ug/Kg		12/10/24 03:40	12/17/24 08:32	100
Perfluoroheptanesulfonic acid (PFHpS)	**330**		60	11	ug/Kg		12/10/24 03:40	12/17/24 08:32	100
L-Perfluorooctanesulfonic acid	**11000**	**E**	150	12	ug/Kg		12/10/24 03:40	12/17/24 08:32	100
Br-Perfluorooctanesulfonic acid	**3300**		150	12	ug/Kg		12/10/24 03:40	12/17/24 08:32	100
Total PFOS	**15000**		150	12	ug/Kg		12/10/24 03:40	12/17/24 08:32	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOA	*95*		*25 - 150*	*12/10/24 03:40*	*12/17/24 08:32*	*100*
13C5 PFNA	*100*		*25 - 150*	*12/10/24 03:40*	*12/17/24 08:32*	*100*
18O2 PFHxS	*133*		*25 - 150*	*12/10/24 03:40*	*12/17/24 08:32*	*100*
13C4 PFOS	*95*		*25 - 150*	*12/10/24 03:40*	*12/17/24 08:32*	*100*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	**11**		0.60	0.060	ug/Kg		12/10/24 03:40	12/16/24 20:53	1

Client: University of New Mexico
Job ID: 320-117508-1
Project/Site: UNM_PFAS in Tissue, Holloman

Client Sample ID: NK283601, Spat. Cly, Liver, ABJ34298, MSB1011285, P32
Lab Sample ID: 320-117508-29
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
M2-8:2 FTS	123		25 - 150	12/10/24 03:40	12/16/24 20:53	1

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK283602, JLW125, S. Calypeata, L, MSB1011279, P33

Lab Sample ID: 320-117508-30

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	1.9		0.98	0.23	ug/Kg		12/10/24 03:40	12/13/24 03:07	1
Perfluoropentanoic acid (PFPeA)	0.38	J	0.98	0.17	ug/Kg		12/10/24 03:40	12/13/24 03:07	1
Perfluorohexanoic acid (PFHxA)	0.59	J	0.98	0.27	ug/Kg		12/10/24 03:40	12/13/24 03:07	1
Perfluoroheptanoic acid (PFHpA)	0.53	J	0.98	0.11	ug/Kg		12/10/24 03:40	12/13/24 03:07	1
L-Perfluorooctanoic acid	120		98	20	ug/Kg		12/10/24 03:40	12/21/24 00:33	100
Br-Perfluorooctanoic acid	ND		98	20	ug/Kg		12/10/24 03:40	12/21/24 00:33	100
Total PFOA	120		98	20	ug/Kg		12/10/24 03:40	12/21/24 00:33	100
Perfluorononanoic acid (PFNA)	200		98	17	ug/Kg		12/10/24 03:40	12/21/24 00:33	100
Perfluorodecanoic acid (PFDA)	19		0.98	0.10	ug/Kg		12/10/24 03:40	12/13/24 03:07	1
Perfluoroundecanoic acid (PFUnA)	1.4		0.98	0.27	ug/Kg		12/10/24 03:40	12/13/24 03:07	1
Perfluorobutanesulfonic acid (PFBS)	0.69	J	0.98	0.17	ug/Kg		12/10/24 03:40	12/13/24 03:07	1
Perfluoropentanesulfonic acid (PFPeS)	21		0.98	0.18	ug/Kg		12/10/24 03:40	12/13/24 03:07	1
Br-Perfluorohexanesulfonic acid	140		98	15	ug/Kg		12/10/24 03:40	12/21/24 00:33	100
Total PFHxS	1800		98	15	ug/Kg		12/10/24 03:40	12/21/24 00:33	100
L-Perfluorohexanesulfonic acid	1600		98	15	ug/Kg		12/10/24 03:40	12/21/24 00:33	100
Perfluoroheptanesulfonic acid (PFHpS)	120		98	18	ug/Kg		12/10/24 03:40	12/21/24 00:33	100
L-Perfluorooctanesulfonic acid	5400		250	20	ug/Kg		12/10/24 03:40	12/21/24 00:33	100
Br-Perfluorooctanesulfonic acid	1500		250	20	ug/Kg		12/10/24 03:40	12/21/24 00:33	100
Total PFOS	6900		250	20	ug/Kg		12/10/24 03:40	12/21/24 00:33	100
4:2 FTS	ND		0.98	0.26	ug/Kg		12/10/24 03:40	12/13/24 03:07	1
6:2 FTS	0.42	J	0.98	0.42	ug/Kg		12/10/24 03:40	12/13/24 03:07	1
10:2 FTS	0.13	J	0.98	0.099	ug/Kg		12/10/24 03:40	12/13/24 03:07	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*70*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:07*	*1*
13C5 PFPeA	*95*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:07*	*1*
13C2 PFHxA	*112*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:07*	*1*
13C4 PFHpA	*106*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:07*	*1*
13C4 PFOA	*80*		*25 - 150*	*12/10/24 03:40*	*12/21/24 00:33*	*100*
13C5 PFNA	*94*		*25 - 150*	*12/10/24 03:40*	*12/21/24 00:33*	*100*
13C2 PFDA	*120*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:07*	*1*
13C2 PFUnA	*135*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:07*	*1*
13C3 PFBS	*110*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:07*	*1*
18O2 PFHxS	*96*		*25 - 150*	*12/10/24 03:40*	*12/21/24 00:33*	*100*
13C4 PFOS	*66*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:07*	*1*
13C4 PFOS	*90*		*25 - 150*	*12/10/24 03:40*	*12/21/24 00:33*	*100*
M2-4:2 FTS	*165*	*5+	*25 - 150*	*12/10/24 03:40*	*12/13/24 03:07*	*1*
M2-6:2 FTS	*132*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:07*	*1*
13C2 10:2 FTS	*594*	*5+	*25 - 150*	*12/10/24 03:40*	*12/13/24 03:07*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	6.2		0.98	0.098	ug/Kg		12/10/24 03:40	12/16/24 16:21	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
M2-8:2 FTS	*107*		*25 - 150*	*12/10/24 03:40*	*12/16/24 16:21*	*1*

Client Sample ID: NK283605, Liver, Spatula, MSB1011318, P34

Lab Sample ID: 320-117508-31

Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**4.1**		0.86	0.20	ug/Kg		12/10/24 03:40	12/13/24 03:27	1
Perfluoropentanoic acid (PFPeA)	**0.50**	**J**	0.86	0.15	ug/Kg		12/10/24 03:40	12/13/24 03:27	1
Perfluorohexanoic acid (PFHxA)	**0.88**		0.86	0.24	ug/Kg		12/10/24 03:40	12/13/24 03:27	1
Perfluoroheptanoic acid (PFHpA)	**1.6**		0.86	0.10	ug/Kg		12/10/24 03:40	12/13/24 03:27	1
Perfluorodecanoic acid (PFDA)	**16**		0.86	0.089	ug/Kg		12/10/24 03:40	12/13/24 03:27	1
Perfluoroundecanoic acid (PFUnA)	**1.5**		0.86	0.23	ug/Kg		12/10/24 03:40	12/13/24 03:27	1
Perfluorobutanesulfonic acid (PFBS)	**1.4**		0.86	0.15	ug/Kg		12/10/24 03:40	12/13/24 03:27	1
Perfluoropentanesulfonic acid (PFPeS)	**67**		0.86	0.16	ug/Kg		12/10/24 03:40	12/13/24 03:27	1
4:2 FTS	ND		0.86	0.23	ug/Kg		12/10/24 03:40	12/13/24 03:27	1
6:2 FTS	**0.82**	**J**	0.86	0.37	ug/Kg		12/10/24 03:40	12/13/24 03:27	1
10:2 FTS	**0.12**	**J I**	0.86	0.087	ug/Kg		12/10/24 03:40	12/13/24 03:27	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*57*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:27*	*1*
13C5 PFPeA	*75*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:27*	*1*
13C2 PFHxA	*93*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:27*	*1*
13C4 PFHpA	*91*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:27*	*1*
13C2 PFDA	*103*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:27*	*1*
13C2 PFUnA	*139*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:27*	*1*
13C3 PFBS	*89*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:27*	*1*
M2-4:2 FTS	*125*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:27*	*1*
M2-6:2 FTS	*162*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 03:27*	*1*
13C2 10:2 FTS	*572*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 03:27*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanoic acid	**130**		86	17	ug/Kg		12/10/24 03:40	12/16/24 17:19	100
Br-Perfluorooctanoic acid	ND		86	17	ug/Kg		12/10/24 03:40	12/16/24 17:19	100
Total PFOA	**130**		86	17	ug/Kg		12/10/24 03:40	12/16/24 17:19	100
Perfluorononanoic acid (PFNA)	**150**		86	15	ug/Kg		12/10/24 03:40	12/16/24 17:19	100
Br-Perfluorohexanesulfonic acid	**180**		86	13	ug/Kg		12/10/24 03:40	12/16/24 17:19	100
Total PFHxS	**1800**		86	13	ug/Kg		12/10/24 03:40	12/16/24 17:19	100
L-Perfluorohexanesulfonic acid	**1600**		86	13	ug/Kg		12/10/24 03:40	12/16/24 17:19	100
Perfluoroheptanesulfonic acid (PFHpS)	**120**		86	16	ug/Kg		12/10/24 03:40	12/16/24 17:19	100
L-Perfluorooctanesulfonic acid	**5900**		220	18	ug/Kg		12/10/24 03:40	12/16/24 17:19	100
Br-Perfluorooctanesulfonic acid	**1500**		220	18	ug/Kg		12/10/24 03:40	12/16/24 17:19	100
Total PFOS	**7400**		220	18	ug/Kg		12/10/24 03:40	12/16/24 17:19	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOA	*84*		*25 - 150*	*12/10/24 03:40*	*12/16/24 17:19*	*100*
13C5 PFNA	*87*		*25 - 150*	*12/10/24 03:40*	*12/16/24 17:19*	*100*
18O2 PFHxS	*96*		*25 - 150*	*12/10/24 03:40*	*12/16/24 17:19*	*100*
13C4 PFOS	*88*		*25 - 150*	*12/10/24 03:40*	*12/16/24 17:19*	*100*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	**4.8**		0.86	0.086	ug/Kg		12/10/24 03:40	12/16/24 21:12	1

Client: University of New Mexico
Job ID: 320-117508-1
Project/Site: UNM_PFAS in Tissue, Holloman

Client Sample ID: NK283605, Liver, Spatula, MSB1011318, P34
Lab Sample ID: 320-117508-31
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
M2-8:2 FTS	104		25 - 150	12/10/24 03:40	12/16/24 21:12	1

Client Sample ID: NK283606, Spatula, Liver, MSB1011339, P35

Lab Sample ID: 320-117508-32
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.94	0.22	ug/Kg		12/10/24 03:40	12/13/24 03:46	1
Perfluoropentanoic acid (PFPeA)	**0.18**	**J**	0.94	0.17	ug/Kg		12/10/24 03:40	12/13/24 03:46	1
Perfluorohexanoic acid (PFHxA)	**0.30**	**J**	0.94	0.26	ug/Kg		12/10/24 03:40	12/13/24 03:46	1
Perfluoroheptanoic acid (PFHpA)	**0.34**	**J**	0.94	0.11	ug/Kg		12/10/24 03:40	12/13/24 03:46	1
L-Perfluorooctanoic acid	**70**		0.94	0.19	ug/Kg		12/10/24 03:40	12/13/24 03:46	1
Br-Perfluorooctanoic acid	**1.1**		0.94	0.19	ug/Kg		12/10/24 03:40	12/13/24 03:46	1
Total PFOA	**71**		0.94	0.19	ug/Kg		12/10/24 03:40	12/13/24 03:46	1
Perfluorodecanoic acid (PFDA)	**21**		0.94	0.097	ug/Kg		12/10/24 03:40	12/13/24 03:46	1
Perfluoroundecanoic acid (PFUnA)	**1.7**		0.94	0.26	ug/Kg		12/10/24 03:40	12/13/24 03:46	1
Perfluorobutanesulfonic acid (PFBS)	**0.40**	**J**	0.94	0.16	ug/Kg		12/10/24 03:40	12/13/24 03:46	1
Perfluoropentanesulfonic acid (PFPeS)	**13**		0.94	0.17	ug/Kg		12/10/24 03:40	12/13/24 03:46	1
4:2 FTS	ND		0.94	0.25	ug/Kg		12/10/24 03:40	12/13/24 03:46	1
6:2 FTS	**0.59**	**J**	0.94	0.40	ug/Kg		12/10/24 03:40	12/13/24 03:46	1
10:2 FTS	**0.16**	**J**	0.94	0.095	ug/Kg		12/10/24 03:40	12/13/24 03:46	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*44*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:46*	*1*
13C5 PFPeA	*67*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:46*	*1*
13C2 PFHxA	*95*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:46*	*1*
13C4 PFHpA	*90*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:46*	*1*
13C4 PFOA	*73*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:46*	*1*
13C2 PFDA	*90*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:46*	*1*
13C2 PFUnA	*124*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:46*	*1*
13C3 PFBS	*79*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:46*	*1*
M2-4:2 FTS	*116*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:46*	*1*
M2-6:2 FTS	*109*		*25 - 150*	*12/10/24 03:40*	*12/13/24 03:46*	*1*
13C2 10:2 FTS	*480*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 03:46*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorononanoic acid (PFNA)	**250**		94	17	ug/Kg		12/10/24 03:40	12/16/24 17:39	100
Br-Perfluorohexanesulfonic acid	**80**	**J**	94	14	ug/Kg		12/10/24 03:40	12/16/24 17:39	100
Total PFHxS	**1700**		94	14	ug/Kg		12/10/24 03:40	12/16/24 17:39	100
L-Perfluorohexanesulfonic acid	**1700**		94	14	ug/Kg		12/10/24 03:40	12/16/24 17:39	100
Perfluoroheptanesulfonic acid (PFHpS)	**260**		94	17	ug/Kg		12/10/24 03:40	12/16/24 17:39	100
L-Perfluorooctanesulfonic acid	**7900**		240	19	ug/Kg		12/10/24 03:40	12/16/24 17:39	100
Br-Perfluorooctanesulfonic acid	**2200**		240	19	ug/Kg		12/10/24 03:40	12/16/24 17:39	100
Total PFOS	**10000**		240	19	ug/Kg		12/10/24 03:40	12/16/24 17:39	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOA	*73*		*25 - 150*	*12/10/24 03:40*	*12/16/24 17:39*	*100*
13C5 PFNA	*80*		*25 - 150*	*12/10/24 03:40*	*12/16/24 17:39*	*100*
18O2 PFHxS	*88*		*25 - 150*	*12/10/24 03:40*	*12/16/24 17:39*	*100*
13C4 PFOS	*77*		*25 - 150*	*12/10/24 03:40*	*12/16/24 17:39*	*100*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	**6.0**		0.94	0.094	ug/Kg		12/10/24 03:40	12/16/24 21:32	1

Client: University of New Mexico
Job ID: 320-117508-1
Project/Site: UNM_PFAS in Tissue, Holloman

Client Sample ID: NK283606, Spatula, Liver, MSB1011339, P35
Lab Sample ID: 320-117508-32
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
M2-8:2 FTS	90		25 - 150	12/10/24 03:40	12/16/24 21:32	1

Client Sample ID: NK283607, S. calypteata, Liver, MSB1011310, P36
Lab Sample ID: 320-117508-33
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.88	0.21	ug/Kg		12/10/24 03:40	12/13/24 04:06	1
Perfluoropentanoic acid (PFPeA)	**0.37**	**J**	0.88	0.15	ug/Kg		12/10/24 03:40	12/13/24 04:06	1
Perfluorohexanoic acid (PFHxA)	**0.54**	**J**	0.88	0.24	ug/Kg		12/10/24 03:40	12/13/24 04:06	1
Perfluoroheptanoic acid (PFHpA)	**0.61**	**J**	0.88	0.10	ug/Kg		12/10/24 03:40	12/13/24 04:06	1
L-Perfluorooctanoic acid	**74**		0.88	0.18	ug/Kg		12/10/24 03:40	12/13/24 04:06	1
Br-Perfluorooctanoic acid	**0.78**	**J**	0.88	0.18	ug/Kg		12/10/24 03:40	12/13/24 04:06	1
Total PFOA	**74**		0.88	0.18	ug/Kg		12/10/24 03:40	12/13/24 04:06	1
Perfluorodecanoic acid (PFDA)	**34**		0.88	0.091	ug/Kg		12/10/24 03:40	12/13/24 04:06	1
Perfluoroundecanoic acid (PFUnA)	**2.7**		0.88	0.24	ug/Kg		12/10/24 03:40	12/13/24 04:06	1
Perfluorobutanesulfonic acid (PFBS)	**1.1**		0.88	0.15	ug/Kg		12/10/24 03:40	12/13/24 04:06	1
Perfluoropentanesulfonic acid (PFPeS)	**28**		0.88	0.16	ug/Kg		12/10/24 03:40	12/13/24 04:06	1
4:2 FTS	ND		0.88	0.24	ug/Kg		12/10/24 03:40	12/13/24 04:06	1
6:2 FTS	**0.54**	**J**	0.88	0.38	ug/Kg		12/10/24 03:40	12/13/24 04:06	1
10:2 FTS	**0.16**	**J I**	0.88	0.089	ug/Kg		12/10/24 03:40	12/13/24 04:06	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*50*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:06*	*1*
13C5 PFPeA	*71*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:06*	*1*
13C2 PFHxA	*97*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:06*	*1*
13C4 PFHpA	*96*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:06*	*1*
13C4 PFOA	*86*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:06*	*1*
13C2 PFDA	*102*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:06*	*1*
13C2 PFUnA	*146*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:06*	*1*
13C3 PFBS	*88*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:06*	*1*
M2-4:2 FTS	*141*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:06*	*1*
M2-6:2 FTS	*161*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 04:06*	*1*
13C2 10:2 FTS	*585*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 04:06*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorononanoic acid (PFNA)	**440**		88	15	ug/Kg		12/10/24 03:40	12/16/24 17:58	100
Br-Perfluorohexanesulfonic acid	**110**		88	13	ug/Kg		12/10/24 03:40	12/16/24 17:58	100
Total PFHxS	**3300**		88	13	ug/Kg		12/10/24 03:40	12/16/24 17:58	100
L-Perfluorohexanesulfonic acid	**3200**		88	13	ug/Kg		12/10/24 03:40	12/16/24 17:58	100
Perfluoroheptanesulfonic acid (PFHpS)	**340**		88	16	ug/Kg		12/10/24 03:40	12/16/24 17:58	100
L-Perfluorooctanesulfonic acid	**12000**	**E**	220	18	ug/Kg		12/10/24 03:40	12/16/24 17:58	100
Br-Perfluorooctanesulfonic acid	**3800**		220	18	ug/Kg		12/10/24 03:40	12/16/24 17:58	100
Total PFOS	**16000**		220	18	ug/Kg		12/10/24 03:40	12/16/24 17:58	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFNA	*96*		*25 - 150*	*12/10/24 03:40*	*12/16/24 17:58*	*100*
18O2 PFHxS	*116*		*25 - 150*	*12/10/24 03:40*	*12/16/24 17:58*	*100*
13C4 PFOS	*88*		*25 - 150*	*12/10/24 03:40*	*12/16/24 17:58*	*100*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	**11**		0.88	0.088	ug/Kg		12/10/24 03:40	12/16/24 21:51	1

Client: University of New Mexico
Job ID: 320-117508-1
Project/Site: UNM_PFAS in Tissue, Holloman

Client Sample ID: NK283607, S. calypteata, Liver, MSB1011310, P36
Lab Sample ID: 320-117508-33
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
M2-8:2 FTS	101		25 - 150	12/10/24 03:40	12/16/24 21:51	1

Client Sample ID: NK283608, S. calypeata, L, MSB1011324, P37

Lab Sample ID: 320-117508-34

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.76	0.18	ug/Kg		12/10/24 03:40	12/13/24 04:25	1
Perfluoropentanoic acid (PFPeA)	**0.59**	**J**	0.76	0.13	ug/Kg		12/10/24 03:40	12/13/24 04:25	1
Perfluorohexanoic acid (PFHxA)	**0.81**		0.76	0.21	ug/Kg		12/10/24 03:40	12/13/24 04:25	1
Perfluoroheptanoic acid (PFHpA)	**0.94**		0.76	0.088	ug/Kg		12/10/24 03:40	12/13/24 04:25	1
L-Perfluorooctanoic acid	**34**		0.76	0.15	ug/Kg		12/10/24 03:40	12/13/24 04:25	1
Br-Perfluorooctanoic acid	**0.82**		0.76	0.15	ug/Kg		12/10/24 03:40	12/13/24 04:25	1
Total PFOA	**35**		0.76	0.15	ug/Kg		12/10/24 03:40	12/13/24 04:25	1
Perfluorodecanoic acid (PFDA)	**24**		0.76	0.078	ug/Kg		12/10/24 03:40	12/13/24 04:25	1
Perfluoroundecanoic acid (PFUnA)	**1.7**		0.76	0.21	ug/Kg		12/10/24 03:40	12/13/24 04:25	1
Perfluorobutanesulfonic acid (PFBS)	**0.95**		0.76	0.13	ug/Kg		12/10/24 03:40	12/13/24 04:25	1
Perfluoropentanesulfonic acid (PFPeS)	**23**		0.76	0.14	ug/Kg		12/10/24 03:40	12/13/24 04:25	1
4:2 FTS	ND		0.76	0.20	ug/Kg		12/10/24 03:40	12/13/24 04:25	1
6:2 FTS	**0.95**		0.76	0.32	ug/Kg		12/10/24 03:40	12/13/24 04:25	1
10:2 FTS	**0.14**	**J**	0.76	0.077	ug/Kg		12/10/24 03:40	12/13/24 04:25	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*52*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:25*	*1*
13C5 PFPeA	*84*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:25*	*1*
13C2 PFHxA	*113*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:25*	*1*
13C4 PFHpA	*112*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:25*	*1*
13C4 PFOA	*94*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:25*	*1*
13C2 PFDA	*123*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:25*	*1*
13C2 PFUnA	*167*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 04:25*	*1*
13C3 PFBS	*99*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:25*	*1*
M2-4:2 FTS	*149*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:25*	*1*
M2-6:2 FTS	*151*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 04:25*	*1*
13C2 10:2 FTS	*661*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 04:25*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorononanoic acid (PFNA)	**330**		76	13	ug/Kg		12/10/24 03:40	12/16/24 18:18	100
Br-Perfluorohexanesulfonic acid	**55**	**J**	76	11	ug/Kg		12/10/24 03:40	12/16/24 18:18	100
Total PFHxS	**2500**		76	11	ug/Kg		12/10/24 03:40	12/16/24 18:18	100
L-Perfluorohexanesulfonic acid	**2500**		76	11	ug/Kg		12/10/24 03:40	12/16/24 18:18	100
Perfluoroheptanesulfonic acid (PFHpS)	**330**		76	14	ug/Kg		12/10/24 03:40	12/16/24 18:18	100
L-Perfluorooctanesulfonic acid	**9900**	**E**	190	15	ug/Kg		12/10/24 03:40	12/16/24 18:18	100
Br-Perfluorooctanesulfonic acid	**2700**		190	15	ug/Kg		12/10/24 03:40	12/16/24 18:18	100
Total PFOS	**13000**		190	15	ug/Kg		12/10/24 03:40	12/16/24 18:18	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFNA	*95*		*25 - 150*	*12/10/24 03:40*	*12/16/24 18:18*	*100*
18O2 PFHxS	*121*		*25 - 150*	*12/10/24 03:40*	*12/16/24 18:18*	*100*
13C4 PFOS	*82*		*25 - 150*	*12/10/24 03:40*	*12/16/24 18:18*	*100*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	**7.1**		0.76	0.076	ug/Kg		12/10/24 03:40	12/16/24 22:11	1

Client: University of New Mexico
Job ID: 320-117508-1
Project/Site: UNM_PFAS in Tissue, Holloman

Client Sample ID: NK283608, S. calypeata, L, MSB1011324, P37
Lab Sample ID: 320-117508-34
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
M2-8:2 FTS	151	*5+	25 - 150	12/10/24 03:40	12/16/24 22:11	1

Client Sample ID: NK283615, S. calypeata, L, MSB1011402, P38

Lab Sample ID: 320-117508-35

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.94	0.22	ug/Kg		12/10/24 03:40	12/13/24 04:44	1
Perfluoropentanoic acid (PFPeA)	**0.70**	**J**	0.94	0.17	ug/Kg		12/10/24 03:40	12/13/24 04:44	1
Perfluorohexanoic acid (PFHxA)	**0.81**	**J**	0.94	0.26	ug/Kg		12/10/24 03:40	12/13/24 04:44	1
Perfluoroheptanoic acid (PFHpA)	**0.72**	**J**	0.94	0.11	ug/Kg		12/10/24 03:40	12/13/24 04:44	1
Perfluorodecanoic acid (PFDA)	**35**		0.94	0.097	ug/Kg		12/10/24 03:40	12/13/24 04:44	1
Perfluoroundecanoic acid (PFUnA)	**2.6**		0.94	0.26	ug/Kg		12/10/24 03:40	12/13/24 04:44	1
Perfluorobutanesulfonic acid (PFBS)	**0.79**	**J**	0.94	0.16	ug/Kg		12/10/24 03:40	12/13/24 04:44	1
Perfluoropentanesulfonic acid (PFPeS)	**30**		0.94	0.17	ug/Kg		12/10/24 03:40	12/13/24 04:44	1
4:2 FTS	ND		0.94	0.25	ug/Kg		12/10/24 03:40	12/13/24 04:44	1
6:2 FTS	ND		0.94	0.40	ug/Kg		12/10/24 03:40	12/13/24 04:44	1
10:2 FTS	**0.17**	**J**	0.94	0.095	ug/Kg		12/10/24 03:40	12/13/24 04:44	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*66*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:44*	*1*
13C5 PFPeA	*75*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:44*	*1*
13C2 PFHxA	*115*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:44*	*1*
13C4 PFHpA	*106*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:44*	*1*
13C2 PFDA	*111*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:44*	*1*
13C2 PFUnA	*129*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:44*	*1*
13C3 PFBS	*102*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:44*	*1*
M2-4:2 FTS	*147*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:44*	*1*
M2-6:2 FTS	*122*		*25 - 150*	*12/10/24 03:40*	*12/13/24 04:44*	*1*
13C2 10:2 FTS	*490*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 04:44*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanoic acid	**170**		94	19	ug/Kg		12/10/24 03:40	12/16/24 18:56	100
Br-Perfluorooctanoic acid	ND		94	19	ug/Kg		12/10/24 03:40	12/16/24 18:56	100
Total PFOA	**170**		94	19	ug/Kg		12/10/24 03:40	12/16/24 18:56	100
Perfluorononanoic acid (PFNA)	**480**		94	17	ug/Kg		12/10/24 03:40	12/16/24 18:56	100
Br-Perfluorohexanesulfonic acid	**150**		94	14	ug/Kg		12/10/24 03:40	12/16/24 18:56	100
Total PFHxS	**3000**		94	14	ug/Kg		12/10/24 03:40	12/16/24 18:56	100
L-Perfluorohexanesulfonic acid	**2800**		94	14	ug/Kg		12/10/24 03:40	12/16/24 18:56	100
Perfluoroheptanesulfonic acid (PFHpS)	**290**		94	17	ug/Kg		12/10/24 03:40	12/16/24 18:56	100
L-Perfluorooctanesulfonic acid	**11000**	**E**	240	19	ug/Kg		12/10/24 03:40	12/16/24 18:56	100
Br-Perfluorooctanesulfonic acid	**3100**		240	19	ug/Kg		12/10/24 03:40	12/16/24 18:56	100
Total PFOS	**14000**		240	19	ug/Kg		12/10/24 03:40	12/16/24 18:56	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOA	*83*		*25 - 150*	*12/10/24 03:40*	*12/16/24 18:56*	*100*
13C5 PFNA	*85*		*25 - 150*	*12/10/24 03:40*	*12/16/24 18:56*	*100*
18O2 PFHxS	*100*		*25 - 150*	*12/10/24 03:40*	*12/16/24 18:56*	*100*
13C4 PFOS	*81*		*25 - 150*	*12/10/24 03:40*	*12/16/24 18:56*	*100*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	**11**		0.94	0.094	ug/Kg		12/10/24 03:40	12/16/24 22:30	1

Client: University of New Mexico
Job ID: 320-117508-1
Project/Site: UNM_PFAS in Tissue, Holloman

Client Sample ID: NK283615, S. calypeata, L, MSB1011402, P38
Lab Sample ID: 320-117508-35
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
M2-8:2 FTS	111		25 - 150	12/10/24 03:40	12/16/24 22:30	1

Client Sample ID: NK283619, S. calypeata, L, MSB1011416, P39

Lab Sample ID: 320-117508-36

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.75	0.18	ug/Kg		12/10/24 03:40	12/13/24 05:04	1
Perfluoropentanoic acid (PFPeA)	**2.1**		0.75	0.13	ug/Kg		12/10/24 03:40	12/13/24 05:04	1
Perfluorohexanoic acid (PFHxA)	**2.5**		0.75	0.21	ug/Kg		12/10/24 03:40	12/13/24 05:04	1
Perfluoroheptanoic acid (PFHpA)	**2.2**		0.75	0.087	ug/Kg		12/10/24 03:40	12/13/24 05:04	1
L-Perfluorooctanoic acid	**53**		0.75	0.15	ug/Kg		12/10/24 03:40	12/13/24 05:04	1
Br-Perfluorooctanoic acid	**4.3**		0.75	0.15	ug/Kg		12/10/24 03:40	12/13/24 05:04	1
Total PFOA	**58**		0.75	0.15	ug/Kg		12/10/24 03:40	12/13/24 05:04	1
Perfluorodecanoic acid (PFDA)	**25**		0.75	0.077	ug/Kg		12/10/24 03:40	12/13/24 05:04	1
Perfluoroundecanoic acid (PFUnA)	**1.8**		0.75	0.20	ug/Kg		12/10/24 03:40	12/13/24 05:04	1
Perfluorobutanesulfonic acid (PFBS)	**1.2**		0.75	0.13	ug/Kg		12/10/24 03:40	12/13/24 05:04	1
Perfluoropentanesulfonic acid (PFPeS)	**34**		0.75	0.14	ug/Kg		12/10/24 03:40	12/13/24 05:04	1
4:2 FTS	ND		0.75	0.20	ug/Kg		12/10/24 03:40	12/13/24 05:04	1
6:2 FTS	**0.54**	**J**	0.75	0.32	ug/Kg		12/10/24 03:40	12/13/24 05:04	1
10:2 FTS	**0.23**	**J**	0.75	0.076	ug/Kg		12/10/24 03:40	12/13/24 05:04	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*65*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:04*	*1*
13C5 PFPeA	*87*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:04*	*1*
13C2 PFHxA	*100*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:04*	*1*
13C4 PFHpA	*103*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:04*	*1*
13C4 PFOA	*90*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:04*	*1*
13C2 PFDA	*106*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:04*	*1*
13C2 PFUnA	*136*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:04*	*1*
13C3 PFBS	*97*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:04*	*1*
M2-4:2 FTS	*131*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:04*	*1*
M2-6:2 FTS	*130*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:04*	*1*
13C2 10:2 FTS	*534*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 05:04*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorononanoic acid (PFNA)	**390**		75	13	ug/Kg		12/10/24 03:40	12/16/24 19:16	100
Br-Perfluorohexanesulfonic acid	**52**	**J**	75	11	ug/Kg		12/10/24 03:40	12/16/24 19:16	100
Total PFHxS	**2600**		75	11	ug/Kg		12/10/24 03:40	12/16/24 19:16	100
L-Perfluorohexanesulfonic acid	**2600**		75	11	ug/Kg		12/10/24 03:40	12/16/24 19:16	100
Perfluoroheptanesulfonic acid (PFHpS)	**460**		75	14	ug/Kg		12/10/24 03:40	12/16/24 19:16	100
L-Perfluorooctanesulfonic acid	**11000**	**E**	190	15	ug/Kg		12/10/24 03:40	12/16/24 19:16	100
Br-Perfluorooctanesulfonic acid	**3200**		190	15	ug/Kg		12/10/24 03:40	12/16/24 19:16	100
Total PFOS	**14000**		190	15	ug/Kg		12/10/24 03:40	12/16/24 19:16	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFNA	*91*		*25 - 150*	*12/10/24 03:40*	*12/16/24 19:16*	*100*
18O2 PFHxS	*115*		*25 - 150*	*12/10/24 03:40*	*12/16/24 19:16*	*100*
13C4 PFOS	*73*		*25 - 150*	*12/10/24 03:40*	*12/16/24 19:16*	*100*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	**5.1**		0.75	0.075	ug/Kg		12/10/24 03:40	12/16/24 22:49	1

Client: University of New Mexico
Job ID: 320-117508-1
Project/Site: UNM_PFAS in Tissue, Holloman

Client Sample ID: NK283619, S. calypeata, L, MSB1011416, P39
Lab Sample ID: 320-117508-36
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Isotope Dilution	%Recovery	Qualifier	Limits	Prepared	Analyzed	Dil Fac
M2-8:2 FTS	105		25 - 150	12/10/24 03:40	12/16/24 22:49	1

Client Sample ID: NK283621, S. calypteata, L, MSB1011430, P40

Lab Sample ID: 320-117508-37

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.76	0.18	ug/Kg		12/10/24 03:40	12/13/24 05:23	1
Perfluoropentanoic acid (PFPeA)	**0.50**	**J**	0.76	0.13	ug/Kg		12/10/24 03:40	12/13/24 05:23	1
Perfluorohexanoic acid (PFHxA)	**0.87**		0.76	0.21	ug/Kg		12/10/24 03:40	12/13/24 05:23	1
Perfluoroheptanoic acid (PFHpA)	**1.4**		0.76	0.089	ug/Kg		12/10/24 03:40	12/13/24 05:23	1
L-Perfluorooctanoic acid	**45**		0.76	0.15	ug/Kg		12/10/24 03:40	12/13/24 05:23	1
Br-Perfluorooctanoic acid	**1.2**		0.76	0.15	ug/Kg		12/10/24 03:40	12/13/24 05:23	1
Total PFOA	**46**		0.76	0.15	ug/Kg		12/10/24 03:40	12/13/24 05:23	1
Perfluorononanoic acid (PFNA)	**62**		0.76	0.13	ug/Kg		12/10/24 03:40	12/13/24 05:23	1
Perfluorodecanoic acid (PFDA)	**7.4**		0.76	0.079	ug/Kg		12/10/24 03:40	12/13/24 05:23	1
Perfluoroundecanoic acid (PFUnA)	**0.57**	**J**	0.76	0.21	ug/Kg		12/10/24 03:40	12/13/24 05:23	1
Perfluorobutanesulfonic acid (PFBS)	**0.90**		0.76	0.13	ug/Kg		12/10/24 03:40	12/13/24 05:23	1
Perfluoropentanesulfonic acid (PFPeS)	**23**		0.76	0.14	ug/Kg		12/10/24 03:40	12/13/24 05:23	1
Br-Perfluorohexanesulfonic acid	**53**	**J**	76	11	ug/Kg		12/10/24 03:40	12/21/24 00:52	100
Total PFHxS	**390**		76	11	ug/Kg		12/10/24 03:40	12/21/24 00:52	100
L-Perfluorohexanesulfonic acid	**340**		76	11	ug/Kg		12/10/24 03:40	12/21/24 00:52	100
Perfluoroheptanesulfonic acid (PFHpS)	**43**		0.76	0.14	ug/Kg		12/10/24 03:40	12/13/24 05:23	1
L-Perfluorooctanesulfonic acid	**2600**		190	15	ug/Kg		12/10/24 03:40	12/21/24 00:52	100
Br-Perfluorooctanesulfonic acid	**480**		190	15	ug/Kg		12/10/24 03:40	12/21/24 00:52	100
Total PFOS	**3100**		190	15	ug/Kg		12/10/24 03:40	12/21/24 00:52	100
4:2 FTS	ND		0.76	0.20	ug/Kg		12/10/24 03:40	12/13/24 05:23	1
6:2 FTS	**0.48**	**J**	0.76	0.32	ug/Kg		12/10/24 03:40	12/13/24 05:23	1
10:2 FTS	**0.19**	**J**	0.76	0.077	ug/Kg		12/10/24 03:40	12/13/24 05:23	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*51*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:23*	*1*
13C5 PFPeA	*76*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:23*	*1*
13C2 PFHxA	*102*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:23*	*1*
13C4 PFHpA	*101*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:23*	*1*
13C4 PFOA	*85*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:23*	*1*
13C5 PFNA	*63*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:23*	*1*
13C2 PFDA	*105*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:23*	*1*
13C2 PFUnA	*131*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:23*	*1*
13C3 PFBS	*88*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:23*	*1*
18O2 PFHxS	*91*		*25 - 150*	*12/10/24 03:40*	*12/21/24 00:52*	*100*
13C4 PFOS	*86*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:23*	*1*
13C4 PFOS	*77*		*25 - 150*	*12/10/24 03:40*	*12/21/24 00:52*	*100*
M2-4:2 FTS	*139*		*25 - 150*	*12/10/24 03:40*	*12/13/24 05:23*	*1*
M2-6:2 FTS	*198*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 05:23*	*1*
13C2 10:2 FTS	*533*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 05:23*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - RA

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
8:2 FTS	**1.3**		0.76	0.076	ug/Kg		12/10/24 03:40	12/16/24 16:41	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
M2-8:2 FTS	*118*		*25 - 150*	*12/10/24 03:40*	*12/16/24 16:41*	*1*

Client Sample ID: NK283622, L, S. calypeata, MSB1011451, P41

Lab Sample ID: 320-117508-38

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**2.2**		0.78	0.18	ug/Kg		12/10/24 03:40	12/13/24 06:02	1
Perfluoropentanoic acid (PFPeA)	ND		0.78	0.14	ug/Kg		12/10/24 03:40	12/13/24 06:02	1
Perfluorohexanoic acid (PFHxA)	ND		0.78	0.21	ug/Kg		12/10/24 03:40	12/13/24 06:02	1
Perfluoroheptanoic acid (PFHpA)	ND		0.78	0.090	ug/Kg		12/10/24 03:40	12/13/24 06:02	1
L-Perfluorooctanoic acid	**3.0**		0.78	0.16	ug/Kg		12/10/24 03:40	12/13/24 06:02	1
Br-Perfluorooctanoic acid	ND		0.78	0.16	ug/Kg		12/10/24 03:40	12/13/24 06:02	1
Total PFOA	**3.0**		0.78	0.16	ug/Kg		12/10/24 03:40	12/13/24 06:02	1
Perfluorodecanoic acid (PFDA)	**52**		0.78	0.080	ug/Kg		12/10/24 03:40	12/13/24 06:02	1
Perfluoroundecanoic acid (PFUnA)	**3.9**		0.78	0.21	ug/Kg		12/10/24 03:40	12/13/24 06:02	1
Perfluorobutanesulfonic acid (PFBS)	ND		0.78	0.13	ug/Kg		12/10/24 03:40	12/13/24 06:02	1
Perfluoropentanesulfonic acid (PFPeS)	**0.36**	**J**	0.78	0.14	ug/Kg		12/10/24 03:40	12/13/24 06:02	1
4:2 FTS	ND		0.78	0.21	ug/Kg		12/10/24 03:40	12/13/24 06:02	1
6:2 FTS	ND		0.78	0.33	ug/Kg		12/10/24 03:40	12/13/24 06:02	1
8:2 FTS	**21**		0.78	0.078	ug/Kg		12/10/24 03:40	12/13/24 06:02	1
10:2 FTS	**0.20**	**J**	0.78	0.078	ug/Kg		12/10/24 03:40	12/13/24 06:02	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*54*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:02*	*1*
13C5 PFPeA	*84*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:02*	*1*
13C2 PFHxA	*94*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:02*	*1*
13C4 PFHpA	*96*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:02*	*1*
13C4 PFOA	*90*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:02*	*1*
13C2 PFDA	*93*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:02*	*1*
13C2 PFUnA	*88*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:02*	*1*
13C3 PFBS	*89*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:02*	*1*
M2-4:2 FTS	*130*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:02*	*1*
M2-6:2 FTS	*125*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:02*	*1*
M2-8:2 FTS	*92*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:02*	*1*
13C2 10:2 FTS	*359*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 06:02*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorononanoic acid (PFNA)	**730**		78	14	ug/Kg		12/10/24 03:40	12/16/24 19:35	100
Br-Perfluorohexanesulfonic acid	ND		78	11	ug/Kg		12/10/24 03:40	12/16/24 19:35	100
Total PFHxS	**1200**		78	11	ug/Kg		12/10/24 03:40	12/16/24 19:35	100
L-Perfluorohexanesulfonic acid	**1200**		78	11	ug/Kg		12/10/24 03:40	12/16/24 19:35	100
Perfluoroheptanesulfonic acid (PFHpS)	**610**		78	14	ug/Kg		12/10/24 03:40	12/16/24 19:35	100
L-Perfluorooctanesulfonic acid	**19000**	**E**	190	16	ug/Kg		12/10/24 03:40	12/16/24 19:35	100
Br-Perfluorooctanesulfonic acid	**6000**		190	16	ug/Kg		12/10/24 03:40	12/16/24 19:35	100
Total PFOS	**25000**		190	16	ug/Kg		12/10/24 03:40	12/16/24 19:35	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFNA	*95*		*25 - 150*	*12/10/24 03:40*	*12/16/24 19:35*	*100*
18O2 PFHxS	*102*		*25 - 150*	*12/10/24 03:40*	*12/16/24 19:35*	*100*
13C4 PFOS	*77*		*25 - 150*	*12/10/24 03:40*	*12/16/24 19:35*	*100*

Client Sample ID: NK283626, S. calypeata, L, MSB1011466, P42

Lab Sample ID: 320-117508-39

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.70	0.17	ug/Kg		12/10/24 03:40	12/13/24 06:21	1
Perfluoropentanoic acid (PFPeA)	**0.32**	**J**	0.70	0.12	ug/Kg		12/10/24 03:40	12/13/24 06:21	1
Perfluorohexanoic acid (PFHxA)	**0.66**	**J**	0.70	0.19	ug/Kg		12/10/24 03:40	12/13/24 06:21	1
Perfluoroheptanoic acid (PFHpA)	**2.5**		0.70	0.082	ug/Kg		12/10/24 03:40	12/13/24 06:21	1
Perfluorodecanoic acid (PFDA)	**55**		0.70	0.073	ug/Kg		12/10/24 03:40	12/13/24 06:21	1
Perfluoroundecanoic acid (PFUnA)	**3.7**		0.70	0.19	ug/Kg		12/10/24 03:40	12/13/24 06:21	1
Perfluorobutanesulfonic acid (PFBS)	**1.1**		0.70	0.12	ug/Kg		12/10/24 03:40	12/13/24 06:21	1
Perfluoropentanesulfonic acid (PFPeS)	**62**		0.70	0.13	ug/Kg		12/10/24 03:40	12/13/24 06:21	1
4:2 FTS	ND		0.70	0.19	ug/Kg		12/10/24 03:40	12/13/24 06:21	1
6:2 FTS	**0.34**	**J**	0.70	0.30	ug/Kg		12/10/24 03:40	12/13/24 06:21	1
8:2 FTS	**18**		0.70	0.070	ug/Kg		12/10/24 03:40	12/13/24 06:21	1
10:2 FTS	**0.19**	**J**	0.70	0.071	ug/Kg		12/10/24 03:40	12/13/24 06:21	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*52*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:21*	*1*
13C5 PFPeA	*81*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:21*	*1*
13C2 PFHxA	*98*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:21*	*1*
13C4 PFHpA	*103*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:21*	*1*
13C2 PFDA	*103*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:21*	*1*
13C2 PFUnA	*146*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:21*	*1*
13C3 PFBS	*87*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:21*	*1*
M2-4:2 FTS	*126*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:21*	*1*
M2-6:2 FTS	*172*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 06:21*	*1*
M2-8:2 FTS	*125*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:21*	*1*
13C2 10:2 FTS	*628*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 06:21*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanoic acid	**410**		70	14	ug/Kg		12/10/24 03:40	12/16/24 19:55	100
Br-Perfluorooctanoic acid	ND		70	14	ug/Kg		12/10/24 03:40	12/16/24 19:55	100
Total PFOA	**410**		70	14	ug/Kg		12/10/24 03:40	12/16/24 19:55	100
Perfluorononanoic acid (PFNA)	**800**		70	12	ug/Kg		12/10/24 03:40	12/16/24 19:55	100
Br-Perfluorohexanesulfonic acid	**260**		70	10	ug/Kg		12/10/24 03:40	12/16/24 19:55	100
Total PFHxS	**5800**		70	10	ug/Kg		12/10/24 03:40	12/16/24 19:55	100
L-Perfluorohexanesulfonic acid	**5600**		70	10	ug/Kg		12/10/24 03:40	12/16/24 19:55	100
Perfluoroheptanesulfonic acid (PFHpS)	**750**		70	13	ug/Kg		12/10/24 03:40	12/16/24 19:55	100
L-Perfluorooctanesulfonic acid	**19000**	**E**	180	14	ug/Kg		12/10/24 03:40	12/16/24 19:55	100
Br-Perfluorooctanesulfonic acid	**6400**		180	14	ug/Kg		12/10/24 03:40	12/16/24 19:55	100
Total PFOS	**26000**		180	14	ug/Kg		12/10/24 03:40	12/16/24 19:55	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOA	*83*		*25 - 150*	*12/10/24 03:40*	*12/16/24 19:55*	*100*
13C5 PFNA	*85*		*25 - 150*	*12/10/24 03:40*	*12/16/24 19:55*	*100*
18O2 PFHxS	*131*		*25 - 150*	*12/10/24 03:40*	*12/16/24 19:55*	*100*
13C4 PFOS	*76*		*25 - 150*	*12/10/24 03:40*	*12/16/24 19:55*	*100*

Client Sample ID: NK283627, S. calypeata, L, MSB1011473, P43

Lab Sample ID: 320-117508-40

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	**6.5**		0.79	0.19	ug/Kg		12/10/24 03:40	12/13/24 06:41	1
Perfluoropentanoic acid (PFPeA)	**0.64**	**J**	0.79	0.14	ug/Kg		12/10/24 03:40	12/13/24 06:41	1
Perfluorohexanoic acid (PFHxA)	**1.0**		0.79	0.21	ug/Kg		12/10/24 03:40	12/13/24 06:41	1
Perfluoroheptanoic acid (PFHpA)	**2.0**		0.79	0.091	ug/Kg		12/10/24 03:40	12/13/24 06:41	1
Perfluorodecanoic acid (PFDA)	**43**		0.79	0.081	ug/Kg		12/10/24 03:40	12/13/24 06:41	1
Perfluoroundecanoic acid (PFUnA)	**3.2**		0.79	0.21	ug/Kg		12/10/24 03:40	12/13/24 06:41	1
Perfluorobutanesulfonic acid (PFBS)	**1.9**		0.79	0.13	ug/Kg		12/10/24 03:40	12/13/24 06:41	1
Perfluoropentanesulfonic acid (PFPeS)	**60**		0.79	0.14	ug/Kg		12/10/24 03:40	12/13/24 06:41	1
4:2 FTS	ND		0.79	0.21	ug/Kg		12/10/24 03:40	12/13/24 06:41	1
6:2 FTS	**0.41**	**J**	0.79	0.33	ug/Kg		12/10/24 03:40	12/13/24 06:41	1
8:2 FTS	**14**		0.79	0.079	ug/Kg		12/10/24 03:40	12/13/24 06:41	1
10:2 FTS	**0.16**	**J**	0.79	0.080	ug/Kg		12/10/24 03:40	12/13/24 06:41	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*69*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:41*	*1*
13C5 PFPeA	*89*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:41*	*1*
13C2 PFHxA	*115*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:41*	*1*
13C4 PFHpA	*111*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:41*	*1*
13C2 PFDA	*112*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:41*	*1*
13C2 PFUnA	*140*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:41*	*1*
13C3 PFBS	*98*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:41*	*1*
M2-4:2 FTS	*156*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 06:41*	*1*
M2-6:2 FTS	*150*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:41*	*1*
M2-8:2 FTS	*118*		*25 - 150*	*12/10/24 03:40*	*12/13/24 06:41*	*1*
13C2 10:2 FTS	*619*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/13/24 06:41*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanoic acid	**350**		79	16	ug/Kg		12/10/24 03:40	12/16/24 20:14	100
Br-Perfluorooctanoic acid	ND		79	16	ug/Kg		12/10/24 03:40	12/16/24 20:14	100
Total PFOA	**350**		79	16	ug/Kg		12/10/24 03:40	12/16/24 20:14	100
Perfluorononanoic acid (PFNA)	**690**		79	14	ug/Kg		12/10/24 03:40	12/16/24 20:14	100
Br-Perfluorohexanesulfonic acid	**300**		79	12	ug/Kg		12/10/24 03:40	12/16/24 20:14	100
Total PFHxS	**6800**		79	12	ug/Kg		12/10/24 03:40	12/16/24 20:14	100
L-Perfluorohexanesulfonic acid	**6500**		79	12	ug/Kg		12/10/24 03:40	12/16/24 20:14	100
Perfluoroheptanesulfonic acid (PFHpS)	**680**		79	15	ug/Kg		12/10/24 03:40	12/16/24 20:14	100
L-Perfluorooctanesulfonic acid	**17000**	**E**	200	16	ug/Kg		12/10/24 03:40	12/16/24 20:14	100
Br-Perfluorooctanesulfonic acid	**5400**		200	16	ug/Kg		12/10/24 03:40	12/16/24 20:14	100
Total PFOS	**23000**		200	16	ug/Kg		12/10/24 03:40	12/16/24 20:14	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOA	*87*		*25 - 150*	*12/10/24 03:40*	*12/16/24 20:14*	*100*
13C5 PFNA	*86*		*25 - 150*	*12/10/24 03:40*	*12/16/24 20:14*	*100*
18O2 PFHxS	*128*		*25 - 150*	*12/10/24 03:40*	*12/16/24 20:14*	*100*
13C4 PFOS	*66*		*25 - 150*	*12/10/24 03:40*	*12/16/24 20:14*	*100*

Client Sample ID: NK283629, S. calypteata, Liver, MSB1011446, P44

Lab Sample ID: 320-117508-41

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.3	0.30	ug/Kg		12/10/24 13:20	12/11/24 20:05	1
Perfluoropentanoic acid (PFPeA)	**0.36**	**J**	1.3	0.22	ug/Kg		12/10/24 13:20	12/11/24 20:05	1
Perfluorohexanoic acid (PFHxA)	**0.81**	**J**	1.3	0.34	ug/Kg		12/10/24 13:20	12/11/24 20:05	1
Perfluoroheptanoic acid (PFHpA)	**1.2**	**J**	1.3	0.15	ug/Kg		12/10/24 13:20	12/11/24 20:05	1
Perfluorodecanoic acid (PFDA)	**47**		1.3	0.13	ug/Kg		12/10/24 13:20	12/11/24 20:05	1
Perfluoroundecanoic acid (PFUnA)	**3.7**		1.3	0.34	ug/Kg		12/10/24 13:20	12/11/24 20:05	1
Perfluorobutanesulfonic acid (PFBS)	**1.0**	**J**	1.3	0.21	ug/Kg		12/10/24 13:20	12/11/24 20:05	1
Perfluoropentanesulfonic acid (PFPeS)	**47**		1.3	0.23	ug/Kg		12/10/24 13:20	12/11/24 20:05	1
4:2 FTS	ND		1.3	0.33	ug/Kg		12/10/24 13:20	12/11/24 20:05	1
6:2 FTS	ND		1.3	0.53	ug/Kg		12/10/24 13:20	12/11/24 20:05	1
8:2 FTS	**14**		1.3	0.13	ug/Kg		12/10/24 13:20	12/11/24 20:05	1
10:2 FTS	**0.26**	**J**	1.3	0.13	ug/Kg		12/10/24 13:20	12/11/24 20:05	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*72*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:05*	*1*
13C5 PFPeA	*111*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:05*	*1*
13C2 PFHxA	*128*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:05*	*1*
13C4 PFHpA	*137*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:05*	*1*
13C2 PFDA	*125*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:05*	*1*
13C2 PFUnA	*155*	**5+*	*25 - 150*	*12/10/24 13:20*	*12/11/24 20:05*	*1*
13C3 PFBS	*106*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:05*	*1*
M2-4:2 FTS	*117*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:05*	*1*
M2-6:2 FTS	*119*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:05*	*1*
M2-8:2 FTS	*111*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:05*	*1*
13C2 10:2 FTS	*561*	**5+*	*25 - 150*	*12/10/24 13:20*	*12/11/24 20:05*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanoic acid	**390**		130	25	ug/Kg		12/10/24 13:20	12/12/24 17:44	100
Br-Perfluorooctanoic acid	ND		130	25	ug/Kg		12/10/24 13:20	12/12/24 17:44	100
Total PFOA	**390**		130	25	ug/Kg		12/10/24 13:20	12/12/24 17:44	100
Perfluorononanoic acid (PFNA)	**540**		130	22	ug/Kg		12/10/24 13:20	12/12/24 17:44	100
Br-Perfluorohexanesulfonic acid	**210**		130	19	ug/Kg		12/10/24 13:20	12/12/24 17:44	100
Total PFHxS	**5200**		130	19	ug/Kg		12/10/24 13:20	12/12/24 17:44	100
L-Perfluorohexanesulfonic acid	**5000**		130	19	ug/Kg		12/10/24 13:20	12/12/24 17:44	100
Perfluoroheptanesulfonic acid (PFHpS)	**450**		130	23	ug/Kg		12/10/24 13:20	12/12/24 17:44	100
L-Perfluorooctanesulfonic acid	**15000**	**E**	310	25	ug/Kg		12/10/24 13:20	12/12/24 17:44	100
Br-Perfluorooctanesulfonic acid	**4200**		310	25	ug/Kg		12/10/24 13:20	12/12/24 17:44	100
Total PFOS	**19000**		310	25	ug/Kg		12/10/24 13:20	12/12/24 17:44	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOA	*88*		*25 - 150*	*12/10/24 13:20*	*12/12/24 17:44*	*100*
13C5 PFNA	*90*		*25 - 150*	*12/10/24 13:20*	*12/12/24 17:44*	*100*
18O2 PFHxS	*117*		*25 - 150*	*12/10/24 13:20*	*12/12/24 17:44*	*100*
13C4 PFOS	*78*		*25 - 150*	*12/10/24 13:20*	*12/12/24 17:44*	*100*

Client Sample ID: NK283631, L, A. americana, MSB1011511, P45

Lab Sample ID: 320-117508-42

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.91	0.21	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
Perfluoropentanoic acid (PFPeA)	**0.70**	**J**	0.91	0.16	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
Perfluorohexanoic acid (PFHxA)	**1.2**		0.91	0.25	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
Perfluoroheptanoic acid (PFHpA)	**2.5**		0.91	0.11	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
L-Perfluorooctanoic acid	**60**		0.91	0.18	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
Br-Perfluorooctanoic acid	**2.5**		0.91	0.18	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
Total PFOA	**63**		0.91	0.18	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
Perfluorononanoic acid (PFNA)	**65**		0.91	0.16	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
Perfluorodecanoic acid (PFDA)	**8.1**		0.91	0.094	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
Perfluoroundecanoic acid (PFUnA)	**1.5**		0.91	0.25	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
Perfluorobutanesulfonic acid (PFBS)	**1.3**		0.91	0.15	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
Perfluoropentanesulfonic acid (PFPeS)	**37**		0.91	0.16	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
Perfluoroheptanesulfonic acid (PFHpS)	**44**		0.91	0.17	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
4:2 FTS	ND		0.91	0.24	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
6:2 FTS	ND		0.91	0.39	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
8:2 FTS	**2.1**		0.91	0.091	ug/Kg		12/10/24 13:20	12/11/24 20:25	1
10:2 FTS	**0.19**	**J**	0.91	0.092	ug/Kg		12/10/24 13:20	12/11/24 20:25	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*73*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:25*	*1*
13C5 PFPeA	*88*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:25*	*1*
13C2 PFHxA	*105*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:25*	*1*
13C4 PFHpA	*109*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:25*	*1*
13C4 PFOA	*89*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:25*	*1*
13C5 PFNA	*69*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:25*	*1*
13C2 PFDA	*107*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:25*	*1*
13C2 PFUnA	*134*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:25*	*1*
13C3 PFBS	*103*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:25*	*1*
13C4 PFOS	*80*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:25*	*1*
M2-4:2 FTS	*130*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:25*	*1*
M2-6:2 FTS	*151*	**5+*	*25 - 150*	*12/10/24 13:20*	*12/11/24 20:25*	*1*
M2-8:2 FTS	*84*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:25*	*1*
13C2 10:2 FTS	*578*	**5+*	*25 - 150*	*12/10/24 13:20*	*12/11/24 20:25*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	**93**		91	13	ug/Kg		12/10/24 13:20	12/17/24 00:26	100
Total PFHxS	**190**		91	13	ug/Kg		12/10/24 13:20	12/17/24 00:26	100
L-Perfluorohexanesulfonic acid	**93**		91	13	ug/Kg		12/10/24 13:20	12/17/24 00:26	100
L-Perfluorooctanesulfonic acid	**3100**		230	18	ug/Kg		12/10/24 13:20	12/17/24 00:26	100
Br-Perfluorooctanesulfonic acid	**570**		230	18	ug/Kg		12/10/24 13:20	12/17/24 00:26	100
Total PFOS	**3700**		230	18	ug/Kg		12/10/24 13:20	12/17/24 00:26	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
18O2 PFHxS	*102*		*25 - 150*	*12/10/24 13:20*	*12/17/24 00:26*	*100*
13C4 PFOS	*84*		*25 - 150*	*12/10/24 13:20*	*12/17/24 00:26*	*100*

Client Sample ID: NK283633, L, S. clypteata, MSB1011525, P46

Lab Sample ID: 320-117508-43

Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.89	0.21	ug/Kg		12/10/24 13:20	12/11/24 20:44	1
Perfluoropentanoic acid (PFPeA)	**0.34**	**J**	0.89	0.16	ug/Kg		12/10/24 13:20	12/11/24 20:44	1
Perfluorohexanoic acid (PFHxA)	**0.58**	**J**	0.89	0.24	ug/Kg		12/10/24 13:20	12/11/24 20:44	1
Perfluoroheptanoic acid (PFHpA)	**0.98**		0.89	0.10	ug/Kg		12/10/24 13:20	12/11/24 20:44	1
Perfluorodecanoic acid (PFDA)	**40**		0.89	0.092	ug/Kg		12/10/24 13:20	12/11/24 20:44	1
Perfluoroundecanoic acid (PFUnA)	**3.2**		0.89	0.24	ug/Kg		12/10/24 13:20	12/11/24 20:44	1
Perfluorobutanesulfonic acid (PFBS)	**0.82**	**J**	0.89	0.15	ug/Kg		12/10/24 13:20	12/11/24 20:44	1
Perfluoropentanesulfonic acid (PFPeS)	**43**		0.89	0.16	ug/Kg		12/10/24 13:20	12/11/24 20:44	1
4:2 FTS	ND		0.89	0.24	ug/Kg		12/10/24 13:20	12/11/24 20:44	1
6:2 FTS	ND		0.89	0.38	ug/Kg		12/10/24 13:20	12/11/24 20:44	1
8:2 FTS	**15**		0.89	0.089	ug/Kg		12/10/24 13:20	12/11/24 20:44	1
10:2 FTS	**0.18**	**J**	0.89	0.090	ug/Kg		12/10/24 13:20	12/11/24 20:44	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*76*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:44*	*1*
13C5 PFPeA	*94*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:44*	*1*
13C2 PFHxA	*125*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:44*	*1*
13C4 PFHpA	*114*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:44*	*1*
13C2 PFDA	*112*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:44*	*1*
13C2 PFUnA	*119*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:44*	*1*
13C3 PFBS	*103*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:44*	*1*
M2-4:2 FTS	*116*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:44*	*1*
M2-6:2 FTS	*125*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:44*	*1*
M2-8:2 FTS	*100*		*25 - 150*	*12/10/24 13:20*	*12/11/24 20:44*	*1*
13C2 10:2 FTS	*496*	**5+*	*25 - 150*	*12/10/24 13:20*	*12/11/24 20:44*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanoic acid	**410**		89	18	ug/Kg		12/10/24 13:20	12/12/24 18:04	100
Br-Perfluorooctanoic acid	ND		89	18	ug/Kg		12/10/24 13:20	12/12/24 18:04	100
Total PFOA	**410**		89	18	ug/Kg		12/10/24 13:20	12/12/24 18:04	100
Perfluorononanoic acid (PFNA)	**590**		89	16	ug/Kg		12/10/24 13:20	12/12/24 18:04	100
Br-Perfluorohexanesulfonic acid	**200**		89	13	ug/Kg		12/10/24 13:20	12/12/24 18:04	100
Total PFHxS	**4700**		89	13	ug/Kg		12/10/24 13:20	12/12/24 18:04	100
L-Perfluorohexanesulfonic acid	**4500**		89	13	ug/Kg		12/10/24 13:20	12/12/24 18:04	100
Perfluoroheptanesulfonic acid (PFHpS)	**490**		89	17	ug/Kg		12/10/24 13:20	12/12/24 18:04	100
L-Perfluorooctanesulfonic acid	**17000**	**E**	220	18	ug/Kg		12/10/24 13:20	12/12/24 18:04	100
Br-Perfluorooctanesulfonic acid	**4300**		220	18	ug/Kg		12/10/24 13:20	12/12/24 18:04	100
Total PFOS	**21000**		220	18	ug/Kg		12/10/24 13:20	12/12/24 18:04	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOA	*85*		*25 - 150*	*12/10/24 13:20*	*12/12/24 18:04*	*100*
13C5 PFNA	*100*		*25 - 150*	*12/10/24 13:20*	*12/12/24 18:04*	*100*
18O2 PFHxS	*128*		*25 - 150*	*12/10/24 13:20*	*12/12/24 18:04*	*100*
13C4 PFOS	*90*		*25 - 150*	*12/10/24 13:20*	*12/12/24 18:04*	*100*

Client Sample ID: NK283641, L, S. clypteata, MSB1011577, P47

Lab Sample ID: 320-117508-44

Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.90	0.21	ug/Kg		12/10/24 13:20	12/11/24 21:04	1
Perfluoropentanoic acid (PFPeA)	**0.39**	**J**	0.90	0.16	ug/Kg		12/10/24 13:20	12/11/24 21:04	1
Perfluorohexanoic acid (PFHxA)	**0.79**	**J**	0.90	0.25	ug/Kg		12/10/24 13:20	12/11/24 21:04	1
Perfluoroheptanoic acid (PFHpA)	**0.81**	**J**	0.90	0.10	ug/Kg		12/10/24 13:20	12/11/24 21:04	1
L-Perfluorooctanoic acid	**88**		0.90	0.18	ug/Kg		12/10/24 13:20	12/11/24 21:04	1
Br-Perfluorooctanoic acid	**2.2**		0.90	0.18	ug/Kg		12/10/24 13:20	12/11/24 21:04	1
Total PFOA	**90**		0.90	0.18	ug/Kg		12/10/24 13:20	12/11/24 21:04	1
Perfluorodecanoic acid (PFDA)	**32**		0.90	0.093	ug/Kg		12/10/24 13:20	12/11/24 21:04	1
Perfluoroundecanoic acid (PFUnA)	**2.6**		0.90	0.25	ug/Kg		12/10/24 13:20	12/11/24 21:04	1
Perfluorobutanesulfonic acid (PFBS)	**1.2**		0.90	0.15	ug/Kg		12/10/24 13:20	12/11/24 21:04	1
Perfluoropentanesulfonic acid (PFPeS)	**54**		0.90	0.16	ug/Kg		12/10/24 13:20	12/11/24 21:04	1
4:2 FTS	ND		0.90	0.24	ug/Kg		12/10/24 13:20	12/11/24 21:04	1
6:2 FTS	ND		0.90	0.38	ug/Kg		12/10/24 13:20	12/11/24 21:04	1
8:2 FTS	**11**		0.90	0.090	ug/Kg		12/10/24 13:20	12/11/24 21:04	1
10:2 FTS	**0.16**	**J**	0.90	0.091	ug/Kg		12/10/24 13:20	12/11/24 21:04	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*66*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:04*	*1*
13C5 PFPeA	*93*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:04*	*1*
13C2 PFHxA	*105*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:04*	*1*
13C4 PFHpA	*105*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:04*	*1*
13C4 PFOA	*92*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:04*	*1*
13C2 PFDA	*102*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:04*	*1*
13C2 PFUnA	*116*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:04*	*1*
13C3 PFBS	*89*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:04*	*1*
M2-4:2 FTS	*119*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:04*	*1*
M2-6:2 FTS	*98*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:04*	*1*
M2-8:2 FTS	*88*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:04*	*1*
13C2 10:2 FTS	*448*	**5+*	*25 - 150*	*12/10/24 13:20*	*12/11/24 21:04*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorononanoic acid (PFNA)	**370**		90	16	ug/Kg		12/10/24 13:20	12/12/24 18:23	100
Br-Perfluorohexanesulfonic acid	**220**		90	13	ug/Kg		12/10/24 13:20	12/12/24 18:23	100
Total PFHxS	**2300**		90	13	ug/Kg		12/10/24 13:20	12/12/24 18:23	100
L-Perfluorohexanesulfonic acid	**2100**		90	13	ug/Kg		12/10/24 13:20	12/12/24 18:23	100
Perfluoroheptanesulfonic acid (PFHpS)	**210**		90	17	ug/Kg		12/10/24 13:20	12/12/24 18:23	100
L-Perfluorooctanesulfonic acid	**9700**	**E**	230	18	ug/Kg		12/10/24 13:20	12/12/24 18:23	100
Br-Perfluorooctanesulfonic acid	**2900**		230	18	ug/Kg		12/10/24 13:20	12/12/24 18:23	100
Total PFOS	**13000**		230	18	ug/Kg		12/10/24 13:20	12/12/24 18:23	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFNA	*104*		*25 - 150*	*12/10/24 13:20*	*12/12/24 18:23*	*100*
18O2 PFHxS	*127*		*25 - 150*	*12/10/24 13:20*	*12/12/24 18:23*	*100*
13C4 PFOS	*95*		*25 - 150*	*12/10/24 13:20*	*12/12/24 18:23*	*100*

Client Sample ID: NK283644, S. clypeata, Liver, MSB1011744, P48

Lab Sample ID: 320-117508-45

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.87	0.21	ug/Kg		12/10/24 13:20	12/11/24 21:23	1
Perfluoropentanoic acid (PFPeA)	**0.19**	**J**	0.87	0.15	ug/Kg		12/10/24 13:20	12/11/24 21:23	1
Perfluorohexanoic acid (PFHxA)	**0.35**	**J**	0.87	0.24	ug/Kg		12/10/24 13:20	12/11/24 21:23	1
Perfluoroheptanoic acid (PFHpA)	**0.57**	**J**	0.87	0.10	ug/Kg		12/10/24 13:20	12/11/24 21:23	1
Perfluorodecanoic acid (PFDA)	**45**		0.87	0.090	ug/Kg		12/10/24 13:20	12/11/24 21:23	1
Perfluoroundecanoic acid (PFUnA)	**3.2**		0.87	0.24	ug/Kg		12/10/24 13:20	12/11/24 21:23	1
Perfluorobutanesulfonic acid (PFBS)	**0.69**	**J**	0.87	0.15	ug/Kg		12/10/24 13:20	12/11/24 21:23	1
Perfluoropentanesulfonic acid (PFPeS)	**26**		0.87	0.16	ug/Kg		12/10/24 13:20	12/11/24 21:23	1
4:2 FTS	ND		0.87	0.23	ug/Kg		12/10/24 13:20	12/11/24 21:23	1
6:2 FTS	ND		0.87	0.37	ug/Kg		12/10/24 13:20	12/11/24 21:23	1
8:2 FTS	**14**		0.87	0.087	ug/Kg		12/10/24 13:20	12/11/24 21:23	1
10:2 FTS	**0.19**	**J**	0.87	0.088	ug/Kg		12/10/24 13:20	12/11/24 21:23	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*80*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:23*	*1*
13C5 PFPeA	*109*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:23*	*1*
13C2 PFHxA	*124*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:23*	*1*
13C4 PFHpA	*108*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:23*	*1*
13C2 PFDA	*114*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:23*	*1*
13C2 PFUnA	*152*	**5+*	*25 - 150*	*12/10/24 13:20*	*12/11/24 21:23*	*1*
13C3 PFBS	*103*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:23*	*1*
M2-4:2 FTS	*120*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:23*	*1*
M2-6:2 FTS	*102*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:23*	*1*
M2-8:2 FTS	*96*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:23*	*1*
13C2 10:2 FTS	*597*	**5+*	*25 - 150*	*12/10/24 13:20*	*12/11/24 21:23*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanoic acid	**140**		87	18	ug/Kg		12/10/24 13:20	12/12/24 18:43	100
Br-Perfluorooctanoic acid	ND		87	18	ug/Kg		12/10/24 13:20	12/12/24 18:43	100
Total PFOA	**140**		87	18	ug/Kg		12/10/24 13:20	12/12/24 18:43	100
Perfluorononanoic acid (PFNA)	**660**		87	15	ug/Kg		12/10/24 13:20	12/12/24 18:43	100
Br-Perfluorohexanesulfonic acid	**130**		87	13	ug/Kg		12/10/24 13:20	12/12/24 18:43	100
Total PFHxS	**3500**		87	13	ug/Kg		12/10/24 13:20	12/12/24 18:43	100
L-Perfluorohexanesulfonic acid	**3300**		87	13	ug/Kg		12/10/24 13:20	12/12/24 18:43	100
Perfluoroheptanesulfonic acid (PFHpS)	**500**		87	16	ug/Kg		12/10/24 13:20	12/12/24 18:43	100
L-Perfluorooctanesulfonic acid	**16000**	**E**	220	18	ug/Kg		12/10/24 13:20	12/12/24 18:43	100
Br-Perfluorooctanesulfonic acid	**5200**		220	18	ug/Kg		12/10/24 13:20	12/12/24 18:43	100
Total PFOS	**21000**		220	18	ug/Kg		12/10/24 13:20	12/12/24 18:43	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOA	*90*		*25 - 150*	*12/10/24 13:20*	*12/12/24 18:43*	*100*
13C5 PFNA	*91*		*25 - 150*	*12/10/24 13:20*	*12/12/24 18:43*	*100*
18O2 PFHxS	*122*		*25 - 150*	*12/10/24 13:20*	*12/12/24 18:43*	*100*
13C4 PFOS	*83*		*25 - 150*	*12/10/24 13:20*	*12/12/24 18:43*	*100*

Client Sample ID: NK283669, S. clypteata, Liver, MSB1011800, P49

Lab Sample ID: 320-117508-46

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.88	0.21	ug/Kg		12/10/24 13:20	12/11/24 21:42	1
Perfluoropentanoic acid (PFPeA)	**0.20**	**J**	0.88	0.15	ug/Kg		12/10/24 13:20	12/11/24 21:42	1
Perfluorohexanoic acid (PFHxA)	**0.33**	**J**	0.88	0.24	ug/Kg		12/10/24 13:20	12/11/24 21:42	1
Perfluoroheptanoic acid (PFHpA)	**0.56**	**J**	0.88	0.10	ug/Kg		12/10/24 13:20	12/11/24 21:42	1
L-Perfluorooctanoic acid	**64**		0.88	0.18	ug/Kg		12/10/24 13:20	12/11/24 21:42	1
Br-Perfluorooctanoic acid	**1.9**		0.88	0.18	ug/Kg		12/10/24 13:20	12/11/24 21:42	1
Total PFOA	**65**		0.88	0.18	ug/Kg		12/10/24 13:20	12/11/24 21:42	1
Perfluorodecanoic acid (PFDA)	**35**		0.88	0.091	ug/Kg		12/10/24 13:20	12/11/24 21:42	1
Perfluoroundecanoic acid (PFUnA)	**3.0**		0.88	0.24	ug/Kg		12/10/24 13:20	12/11/24 21:42	1
Perfluorobutanesulfonic acid (PFBS)	**0.56**	**J**	0.88	0.15	ug/Kg		12/10/24 13:20	12/11/24 21:42	1
Perfluoropentanesulfonic acid (PFPeS)	**18**		0.88	0.16	ug/Kg		12/10/24 13:20	12/11/24 21:42	1
4:2 FTS	ND		0.88	0.24	ug/Kg		12/10/24 13:20	12/11/24 21:42	1
6:2 FTS	ND		0.88	0.38	ug/Kg		12/10/24 13:20	12/11/24 21:42	1
8:2 FTS	**12**		0.88	0.088	ug/Kg		12/10/24 13:20	12/11/24 21:42	1
10:2 FTS	**0.18**	**J**	0.88	0.089	ug/Kg		12/10/24 13:20	12/11/24 21:42	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*64*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:42*	*1*
13C5 PFPeA	*94*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:42*	*1*
13C2 PFHxA	*120*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:42*	*1*
13C4 PFHpA	*110*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:42*	*1*
13C4 PFOA	*91*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:42*	*1*
13C2 PFDA	*114*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:42*	*1*
13C2 PFUnA	*119*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:42*	*1*
13C3 PFBS	*114*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:42*	*1*
M2-4:2 FTS	*108*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:42*	*1*
M2-6:2 FTS	*91*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:42*	*1*
M2-8:2 FTS	*87*		*25 - 150*	*12/10/24 13:20*	*12/11/24 21:42*	*1*
13C2 10:2 FTS	*539*	**5+*	*25 - 150*	*12/10/24 13:20*	*12/11/24 21:42*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorononanoic acid (PFNA)	**460**		88	15	ug/Kg		12/10/24 13:20	12/12/24 19:02	100
Br-Perfluorohexanesulfonic acid	**97**		88	13	ug/Kg		12/10/24 13:20	12/12/24 19:02	100
Total PFHxS	**1800**		88	13	ug/Kg		12/10/24 13:20	12/12/24 19:02	100
L-Perfluorohexanesulfonic acid	**1700**	**I**	88	13	ug/Kg		12/10/24 13:20	12/12/24 19:02	100
Perfluoroheptanesulfonic acid (PFHpS)	**400**		88	16	ug/Kg		12/10/24 13:20	12/12/24 19:02	100
L-Perfluorooctanesulfonic acid	**15000**	**E**	220	18	ug/Kg		12/10/24 13:20	12/12/24 19:02	100
Br-Perfluorooctanesulfonic acid	**4300**		220	18	ug/Kg		12/10/24 13:20	12/12/24 19:02	100
Total PFOS	**19000**		220	18	ug/Kg		12/10/24 13:20	12/12/24 19:02	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C5 PFNA	*89*		*25 - 150*	*12/10/24 13:20*	*12/12/24 19:02*	*100*
18O2 PFHxS	*108*		*25 - 150*	*12/10/24 13:20*	*12/12/24 19:02*	*100*
13C4 PFOS	*75*		*25 - 150*	*12/10/24 13:20*	*12/12/24 19:02*	*100*

Client Sample ID: NK283674, S. clypeata, Liver, MSB1011812, P50

Lab Sample ID: 320-117508-47

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		0.85	0.20	ug/Kg		12/10/24 13:20	12/11/24 22:02	1
Perfluoropentanoic acid (PFPeA)	**0.23**	**J**	0.85	0.15	ug/Kg		12/10/24 13:20	12/11/24 22:02	1
Perfluorohexanoic acid (PFHxA)	**0.37**	**J**	0.85	0.23	ug/Kg		12/10/24 13:20	12/11/24 22:02	1
Perfluoroheptanoic acid (PFHpA)	**0.78**	**J**	0.85	0.099	ug/Kg		12/10/24 13:20	12/11/24 22:02	1
Perfluorodecanoic acid (PFDA)	**50**		0.85	0.088	ug/Kg		12/10/24 13:20	12/11/24 22:02	1
Perfluoroundecanoic acid (PFUnA)	**3.7**		0.85	0.23	ug/Kg		12/10/24 13:20	12/11/24 22:02	1
Perfluorobutanesulfonic acid (PFBS)	**0.92**		0.85	0.15	ug/Kg		12/10/24 13:20	12/11/24 22:02	1
Perfluoropentanesulfonic acid (PFPeS)	**34**		0.85	0.15	ug/Kg		12/10/24 13:20	12/11/24 22:02	1
4:2 FTS	ND		0.85	0.23	ug/Kg		12/10/24 13:20	12/11/24 22:02	1
6:2 FTS	**0.45**	**J**	0.85	0.36	ug/Kg		12/10/24 13:20	12/11/24 22:02	1
8:2 FTS	**24**		0.85	0.085	ug/Kg		12/10/24 13:20	12/11/24 22:02	1
10:2 FTS	**0.78**	**J**	0.85	0.086	ug/Kg		12/10/24 13:20	12/11/24 22:02	1

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*47*		*25 - 150*	*12/10/24 13:20*	*12/11/24 22:02*	*1*
13C5 PFPeA	*81*		*25 - 150*	*12/10/24 13:20*	*12/11/24 22:02*	*1*
13C2 PFHxA	*116*		*25 - 150*	*12/10/24 13:20*	*12/11/24 22:02*	*1*
13C4 PFHpA	*116*		*25 - 150*	*12/10/24 13:20*	*12/11/24 22:02*	*1*
13C2 PFDA	*117*		*25 - 150*	*12/10/24 13:20*	*12/11/24 22:02*	*1*
13C2 PFUnA	*160*	**5+*	*25 - 150*	*12/10/24 13:20*	*12/11/24 22:02*	*1*
13C3 PFBS	*94*		*25 - 150*	*12/10/24 13:20*	*12/11/24 22:02*	*1*
M2-4:2 FTS	*115*		*25 - 150*	*12/10/24 13:20*	*12/11/24 22:02*	*1*
M2-6:2 FTS	*133*		*25 - 150*	*12/10/24 13:20*	*12/11/24 22:02*	*1*
M2-8:2 FTS	*112*		*25 - 150*	*12/10/24 13:20*	*12/11/24 22:02*	*1*
13C2 10:2 FTS	*679*	**5+*	*25 - 150*	*12/10/24 13:20*	*12/11/24 22:02*	*1*

Method: EPA B/L/T PFAS - Branched, Linear and Total PFAS - DL

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
L-Perfluorooctanoic acid	**91**		85	17	ug/Kg		12/10/24 13:20	12/12/24 19:21	100
Br-Perfluorooctanoic acid	ND		85	17	ug/Kg		12/10/24 13:20	12/12/24 19:21	100
Total PFOA	**91**		85	17	ug/Kg		12/10/24 13:20	12/12/24 19:21	100
Perfluorononanoic acid (PFNA)	**670**		85	15	ug/Kg		12/10/24 13:20	12/12/24 19:21	100
Br-Perfluorohexanesulfonic acid	**140**		85	13	ug/Kg		12/10/24 13:20	12/12/24 19:21	100
Total PFHxS	**2600**		85	13	ug/Kg		12/10/24 13:20	12/12/24 19:21	100
L-Perfluorohexanesulfonic acid	**2500**		85	13	ug/Kg		12/10/24 13:20	12/12/24 19:21	100
Perfluoroheptanesulfonic acid (PFHpS)	**480**		85	16	ug/Kg		12/10/24 13:20	12/12/24 19:21	100
L-Perfluorooctanesulfonic acid	**17000**	**E**	210	17	ug/Kg		12/10/24 13:20	12/12/24 19:21	100
Br-Perfluorooctanesulfonic acid	**5200**		210	17	ug/Kg		12/10/24 13:20	12/12/24 19:21	100
Total PFOS	**22000**		210	17	ug/Kg		12/10/24 13:20	12/12/24 19:21	100

Isotope Dilution	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFOA	*86*		*25 - 150*	*12/10/24 13:20*	*12/12/24 19:21*	*100*
13C5 PFNA	*93*		*25 - 150*	*12/10/24 13:20*	*12/12/24 19:21*	*100*
18O2 PFHxS	*128*		*25 - 150*	*12/10/24 13:20*	*12/12/24 19:21*	*100*
13C4 PFOS	*88*		*25 - 150*	*12/10/24 13:20*	*12/12/24 19:21*	*100*

Isotope Dilution Summary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Matrix: Tissue

Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-117508-1	NK14474, MSB18488, Pool1, P	70	87	99	99	83	55	108	116
320-117508-1 - RA	NK14474, MSB18488, Pool1, P1								
320-117508-2	NK9098, Liver, P2	84	84	94	83	79	81	87	78
320-117508-3	NK2445, Liver, AFP7B, P3	68	76	91	86	77	72	89	78
320-117508-4	NK2444, Liver, AFP7A, P4	54	73	82	84	72	58	117	97
320-117508-5	NK35660, MSB29117, P5	57	69	90	91	73	57	115	104
320-117508-6	NK35661, MSB29140, P6	37	63	79	92	72	43	101	109
320-117508-6 - RA	NK35661, MSB29140, P6								
320-117508-7	NK35655, MSB29134, P7	53	64	80	84	71	54	99	109
320-117508-7 - RA	NK35655, MSB29134, P7								
320-117508-8	NK35811, MSB30651, P8	48	59	73	79	66	61	87	99
320-117508-8 - RA	NK35811, MSB30651, P8								
320-117508-9	NK35643, MSB29100, P9	79	87	109	110	95	96	124	129
320-117508-10	NK170946, P10	63	62	78	77	77	37	76	72
320-117508-11	NK100328, Liver, AEPIR, P11	60	66	87	84	75	78	94	88
320-117508-12	NK165232, MSB26431, P12	67	77	84	88	71	79	92	109
320-117508-13	NK35676, MSB29118, P14	53	64	77	81	64	55	91	85
320-117508-14	NK35678, MSB29131, P15	43	58	71	73	61	51	80	83
320-117508-14 - RA	NK35678, MSB29131, P15								
320-117508-15	NK35669, MSB29093, P16	54	81	107	101	87	80	122	132
320-117508-15 - RA	NK35669, MSB29093, P16								
320-117508-16	NK35935, MSB39605, P17	22 *5-	52	80	93	77	75	104	128
320-117508-17	NK35958, MSB40165, P18	46	72	91	97	91	85	106	97
320-117508-18	NK35816, MSB30670, P19	55	84	90	107	93	69	126	143
320-117508-19	NK35804, MSB30716, P20	37	64	94	119	94	84	124	140
320-117508-20	NK35876, MSB39746, P22	58	86	119	104	90	70	129	122
320-117508-21	NK35910, MSB39349, P23	49	64	93	91	83	84	99	117
320-117508-22	NK35817, MSB30650, P24	67	75	104	98	90	82	123	138
320-117508-23	Pool 25, Duck PFAS, P25	70	89	106	108	93	74	113	100
320-117508-24	NK282630, MSB50169, P26	73	75	93	91	85	92	103	86
320-117508-25	NK276851, MSB46239, P28	61	71	90	85	81	85	96	102
320-117508-26	NK282547, MSB49842, P29	51	78	87	100	91	84	104	104
320-117508-27	NK276660, MSB45963, P30	75	73	89	86	85	76	93	92
320-117508-28	NK282696, MSB50223, P31	80	98	110	110	97	108	121	120
320-117508-29	NK283601, Spat. Cly, Liver, ABJ34298, MSB1011285, P32	53	71	108	110			112	153 *5+
320-117508-29 - RA	NK283601, Spat. Cly, Liver, ABJ34298, MSB1011285, P32								
320-117508-29 - DL	NK283601, Spat. Cly, Liver, ABJ34298, MSB1011285, P32					95	100		
320-117508-30	NK283602, JLW125, S. Calypeata, L, MSB1011279, P33	70	95	112	106			120	135
320-117508-30 - RA	NK283602, JLW125, S. Calypeata, L, MSB1011279, P33								
320-117508-30	NK283602, JLW125, S. Calypeata, L, MSB1011279, P33					80	94		
320-117508-31	NK283605, Liver, Spatula, MSB1011318, P34	57	75	93	91			103	139

Isotope Dilution Summary

Client: University of New Mexico
Job ID: 320-117508-1
Project/Site: UNM_PFAS in Tissue, Holloman

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Matrix: Tissue
Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-117508-31 - RA	NK283605, Liver, Spatula, MSB								
320-117508-31 - DL	NK283605, Liver, Spatula, MSB1011318, P34					84	87		
320-117508-32	NK283606, Spatula, Liver, MSB1011339, P35	44	67	95	90	73		90	124
320-117508-32 - RA	NK283606, Spatula, Liver, MSB1011339, P35								
320-117508-32 - DL	NK283606, Spatula, Liver, MSB1011339, P35					73	80		
320-117508-33	NK283607, S. calypteata, Liver, MSB1011310, P36	50	71	97	96	86		102	146
320-117508-33 - DL	NK283607, S. calypteata, Liver, MSB1011310, P36						96		
320-117508-33 - RA	NK283607, S. calypteata, Liver, MSB1011310, P36								
320-117508-34	NK283608, S. calypeata, L, MSB1011324, P37	52	84	113	112	94		123	167 *5+
320-117508-34 - DL	NK283608, S. calypeata, L, MSB1011324, P37						95		
320-117508-34 - RA	NK283608, S. calypeata, L, MSB1011324, P37								
320-117508-35	NK283615, S. calypeata, L, MSB1011402, P38	66	75	115	106			111	129
320-117508-35 - DL	NK283615, S. calypeata, L, MSB1011402, P38					83	85		
320-117508-35 - RA	NK283615, S. calypeata, L, MSB1011402, P38								
320-117508-36	NK283619, S. calypeata, L, MSB1011416, P39	65	87	100	103	90		106	136
320-117508-36 - DL	NK283619, S. calypeata, L, MSB1011416, P39						91		
320-117508-36 - RA	NK283619, S. calypeata, L, MSB1011416, P39								
320-117508-37	NK283621, S. calypteata, L, MSB1011430, P40	51	76	102	101	85	63	105	131
320-117508-37 - RA	NK283621, S. calypteata, L, MSB1011430, P40								
320-117508-37	NK283621, S. calypteata, L, MSB1011430, P40								
320-117508-38	NK283622, L, S. calypeata, MSB1011451, P41	54	84	94	96	90		93	88
320-117508-38 - DL	NK283622, L, S. calypeata, MSB1011451, P41						95		
320-117508-39	NK283626, S. calypeata, L, MSB1011466, P42	52	81	98	103			103	146
320-117508-39 - DL	NK283626, S. calypeata, L, MSB1011466, P42					83	85		
320-117508-40	NK283627, S. calypeata, L, MSB1011473, P43	69	89	115	111			112	140
320-117508-40 - DL	NK283627, S. calypeata, L, MSB1011473, P43					87	86		
320-117508-41	NK283629, S. calypteata, Liver, MSB1011446, P44	72	111	128	137			125	155 *5+
320-117508-41 - DL	NK283629, S. calypteata, Liver, MSB1011446, P44					88	90		
320-117508-42	NK283631, L, A. americana, MSB1011511, P45	73	88	105	109	89	69	107	134

Isotope Dilution Summary

Client: University of New Mexico
Job ID: 320-117508-1
Project/Site: UNM_PFAS in Tissue, Holloman

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Matrix: Tissue
Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)							
Lab Sample ID	Client Sample ID	PFBA (25-150)	PFPeA (25-150)	PFHxA (25-150)	C4PFHA (25-150)	PFOA (25-150)	PFNA (25-150)	PFDA (25-150)	PFUnA (25-150)
320-117508-42 - DL	NK283631, L, A. americana, MS								
320-117508-43	NK283633, L, S. clypteata, MSB1011525, P46	76	94	125	114			112	119
320-117508-43 - DL	NK283633, L, S. clypteata, MSB1011525, P46					85	100		
320-117508-44	NK283641, L, S. clypteata, MSB1011577, P47	66	93	105	105	92		102	116
320-117508-44 - DL	NK283641, L, S. clypteata, MSB1011577, P47						104		
320-117508-45	NK283644, S. clypeata, Liver, MSB1011744, P48	80	109	124	108			114	152 *5+
320-117508-45 - DL	NK283644, S. clypeata, Liver, MSB1011744, P48					90	91		
320-117508-46	NK283669, S. clypteata, Liver, MSB1011800, P49	64	94	120	110	91		114	119
320-117508-46 - DL	NK283669, S. clypteata, Liver, MSB1011800, P49						89		
320-117508-47	NK283674, S. clypeata, Liver, MSB1011812, P50	47	81	116	116			117	160 *5+
320-117508-47 - DL	NK283674, S. clypeata, Liver, MSB1011812, P50					86	93		
LCS 320-820079/2-A	Lab Control Sample	67	68	73	67	64	63	66	64
LCS 320-820824/2-A	Lab Control Sample	83	94	97	99	89	95	102	96
LCS 320-820977/2-A	Lab Control Sample	104	96	107	105	97	101	110	98
LCSD 320-820079/3-A	Lab Control Sample Dup	91	77	98	86	86	87	91	86
LCSD 320-820824/3-A	Lab Control Sample Dup	78	88	99	90	90	89	102	92
LCSD 320-820977/3-A	Lab Control Sample Dup	86	89	114	96	99	101	105	95
MB 320-820079/1-A	Method Blank	75	80	83	80	68	71	79	72
MB 320-820824/1-A	Method Blank	89	76	99	88	88	88	99	91
MB 320-820977/1-A	Method Blank	90	85	88	93	91	92	98	91

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
320-117508-1	NK14474, MSB18488, Pool1, P	87	112	90	153 *5+	127		499 *5+
320-117508-1 - RA	NK14474, MSB18488, Pool1, P1						153 *5+	
320-117508-2	NK9098, Liver, P2	83	101	84	133	101	81	452 *5+
320-117508-3	NK2445, Liver, AFP7B, P3	85	94	84	77	78	77	300 *5+
320-117508-4	NK2444, Liver, AFP7A, P4	76	92	80	81	112	81	480 *5+
320-117508-5	NK35660, MSB29117, P5	86	98	87	142	155 *5+	97	454 *5+
320-117508-6	NK35661, MSB29140, P6	74	85	78	146	140		323 *5+
320-117508-6 - RA	NK35661, MSB29140, P6						188 *5+	
320-117508-7	NK35655, MSB29134, P7	73	82	75	169 *5+	135		81
320-117508-7 - RA	NK35655, MSB29134, P7						158 *5+	
320-117508-8	NK35811, MSB30651, P8	67	82	72	140	123		391 *5+
320-117508-8 - RA	NK35811, MSB30651, P8						111	
320-117508-9	NK35643, MSB29100, P9	104	120	104	234 *5+	192 *5+	149	572 *5+
320-117508-10	NK170946, P10	64	89	76	97	80	72	367 *5+
320-117508-11	NK100328, Liver, AEPIR, P11	82	88	85	121	90	113	431 *5+
320-117508-12	NK165232, MSB26431, P12	88	93	84	155 *5+	112	123	400 *5+
320-117508-13	NK35676, MSB29118, P14	64	84	75	126	93	91	406 *5+
320-117508-14	NK35678, MSB29131, P15	47	72	73	122	91		286 *5+

Isotope Dilution Summary

Client: University of New Mexico
Job ID: 320-117508-1
Project/Site: UNM_PFAS in Tissue, Holloman

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Matrix: Tissue
Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
320-117508-14 - RA	NK35678, MSB29131, P15						111	
320-117508-15	NK35669, MSB29093, P16	90	107	100	183 *5+	157 *5+		465 *5+
320-117508-15 - RA	NK35669, MSB29093, P16						189 *5+	
320-117508-16	NK35935, MSB39605, P17	64	95	87	143	132	162 *5+	311 *5+
320-117508-17	NK35958, MSB40165, P18	86	106	99	141	98	108	448 *5+
320-117508-18	NK35816, MSB30670, P19	88	111	98	171 *5+	159 *5+	141	479 *5+
320-117508-19	NK35804, MSB30716, P20	78	105	97	232 *5+	242 *5+	271 *5+	451 *5+
320-117508-20	NK35876, MSB39746, P22	101	118	104	160 *5+	183 *5+	146	442 *5+
320-117508-21	NK35910, MSB39349, P23	80	106	96	213 *5+	127	140	559 *5+
320-117508-22	NK35817, MSB30650, P24	95	106	103	162 *5+	146	138	605 *5+
320-117508-23	Pool 25, Duck PFAS, P25	88	110	101	172 *5+	168 *5+	136	581 *5+
320-117508-24	NK282630, MSB50169, P26	88	107	99	240 *5+	141	148	374 *5+
320-117508-25	NK276851, MSB46239, P28	80	97	91	124	100	96	403 *5+
320-117508-26	NK282547, MSB49842, P29	81	110	104	188 *5+	151 *5+	139	560 *5+
320-117508-27	NK276660, MSB45963, P30	80	99	91	106	127	93	518 *5+
320-117508-28	NK282696, MSB50223, P31	108	119	109	265 *5+	207 *5+	158 *5+	429 *5+
320-117508-29	NK283601, Spat. Cly, Liver, ABJ34298, MSB1011285, P32	99			147	133		632 *5+
320-117508-29 - RA	NK283601, Spat. Cly, Liver, ABJ34298, MSB1011285, P32						123	
320-117508-29 - DL	NK283601, Spat. Cly, Liver, ABJ34298, MSB1011285, P32		133	95				
320-117508-30	NK283602, JLW125, S. Calypeata, L, MSB1011279, P33	110		66	165 *5+	132		594 *5+
320-117508-30 - RA	NK283602, JLW125, S. Calypeata, L, MSB1011279, P33						107	
320-117508-30	NK283602, JLW125, S. Calypeata, L, MSB1011279, P33		96	90				
320-117508-31	NK283605, Liver, Spatula, MSB1011318, P34	89			125	162 *5+		572 *5+
320-117508-31 - RA	NK283605, Liver, Spatula, MSB1011318, P34						104	
320-117508-31 - DL	NK283605, Liver, Spatula, MSB1011318, P34		96	88				
320-117508-32	NK283606, Spatula, Liver, MSB1011339, P35	79			116	109		480 *5+
320-117508-32 - RA	NK283606, Spatula, Liver, MSB1011339, P35						90	
320-117508-32 - DL	NK283606, Spatula, Liver, MSB1011339, P35		88	77				
320-117508-33	NK283607, S. calypteata, Liver, MSB1011310, P36	88			141	161 *5+		585 *5+
320-117508-33 - DL	NK283607, S. calypteata, Liver, MSB1011310, P36		116	88				
320-117508-33 - RA	NK283607, S. calypteata, Liver, MSB1011310, P36						101	
320-117508-34	NK283608, S. calypeata, L, MSB1011324, P37	99			149	151 *5+		661 *5+
320-117508-34 - DL	NK283608, S. calypeata, L, MSB1011324, P37		121	82				
320-117508-34 - RA	NK283608, S. calypeata, L, MSB1011324, P37						151 *5+	

Isotope Dilution Summary

Client: University of New Mexico
Job ID: 320-117508-1
Project/Site: UNM_PFAS in Tissue, Holloman

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Matrix: Tissue
Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
320-117508-35	NK283615, S. calypeata, L, MSE	102			147	122		490 *5+
320-117508-35 - DL	NK283615, S. calypeata, L, MSB1011402, P38		100	81				
320-117508-35 - RA	NK283615, S. calypeata, L, MSB1011402, P38						111	
320-117508-36	NK283619, S. calypeata, L, MSB1011416, P39	97			131	130		534 *5+
320-117508-36 - DL	NK283619, S. calypeata, L, MSB1011416, P39		115	73				
320-117508-36 - RA	NK283619, S. calypeata, L, MSB1011416, P39						105	
320-117508-37	NK283621, S. calypteata, L, MSB1011430, P40	88		86	139	198 *5+		533 *5+
320-117508-37 - RA	NK283621, S. calypteata, L, MSB1011430, P40						118	
320-117508-37	NK283621, S. calypteata, L, MSB1011430, P40		91	77				
320-117508-38	NK283622, L, S. calypeata, MSB1011451, P41	89			130	125	92	359 *5+
320-117508-38 - DL	NK283622, L, S. calypeata, MSB1011451, P41		102	77				
320-117508-39	NK283626, S. calypeata, L, MSB1011466, P42	87			126	172 *5+	125	628 *5+
320-117508-39 - DL	NK283626, S. calypeata, L, MSB1011466, P42		131	76				
320-117508-40	NK283627, S. calypeata, L, MSB1011473, P43	98			156 *5+	150	118	619 *5+
320-117508-40 - DL	NK283627, S. calypeata, L, MSB1011473, P43		128	66				
320-117508-41	NK283629, S. calypteata, Liver, MSB1011446, P44	106			117	119	111	561 *5+
320-117508-41 - DL	NK283629, S. calypteata, Liver, MSB1011446, P44		117	78				
320-117508-42	NK283631, L, A. americana, MSB1011511, P45	103		80	130	151 *5+	84	578 *5+
320-117508-42 - DL	NK283631, L, A. americana, MSB1011511, P45		102	84				
320-117508-43	NK283633, L, S. clypteata, MSB1011525, P46	103			116	125	100	496 *5+
320-117508-43 - DL	NK283633, L, S. clypteata, MSB1011525, P46		128	90				
320-117508-44	NK283641, L, S. clypteata, MSB1011577, P47	89			119	98	88	448 *5+
320-117508-44 - DL	NK283641, L, S. clypteata, MSB1011577, P47		127	95				
320-117508-45	NK283644, S. clypeata, Liver, MSB1011744, P48	103			120	102	96	597 *5+
320-117508-45 - DL	NK283644, S. clypeata, Liver, MSB1011744, P48		122	83				
320-117508-46	NK283669, S. clypteata, Liver, MSB1011800, P49	114			108	91	87	539 *5+
320-117508-46 - DL	NK283669, S. clypteata, Liver, MSB1011800, P49		108	75				
320-117508-47	NK283674, S. clypeata, Liver, MSB1011812, P50	94			115	133	112	679 *5+
320-117508-47 - DL	NK283674, S. clypeata, Liver, MSB1011812, P50		128	88				

Isotope Dilution Summary

Client: University of New Mexico
Job ID: 320-117508-1
Project/Site: UNM_PFAS in Tissue, Holloman

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Matrix: Tissue
Prep Type: Total/NA

		Percent Isotope Dilution Recovery (Acceptance Limits)						
Lab Sample ID	Client Sample ID	C3PFBS (25-150)	PFHxS (25-150)	PFOS (25-150)	M242FTS (25-150)	M262FTS (25-150)	M282FTS (25-150)	M102FTS (25-150)
LCS 320-820079/2-A	Lab Control Sample	70	76	73	71	66	56	259 *5+
LCS 320-820824/2-A	Lab Control Sample	106	115	103	108	114	102	294 *5+
LCS 320-820977/2-A	Lab Control Sample	118	117	109	99	80	80	275 *5+
LCSD 320-820079/3-A	Lab Control Sample Dup	84	102	94	78	87	79	332 *5+
LCSD 320-820824/3-A	Lab Control Sample Dup	113	105	104	114	109	96	338 *5+
LCSD 320-820977/3-A	Lab Control Sample Dup	95	111	103	88	80	83	309 *5+
MB 320-820079/1-A	Method Blank	67	87	84	73	79	68	307 *5+
MB 320-820824/1-A	Method Blank	86	101	94	109	112	108	400 *5+
MB 320-820977/1-A	Method Blank	73	96	95	96	94	79	335 *5+

Surrogate Legend

PFBA = 13C4 PFBA
PFPeA = 13C5 PFPeA
PFHxA = 13C2 PFHxA
C4PFHA = 13C4 PFHpA
PFOA = 13C4 PFOA
PFNA = 13C5 PFNA
PFDA = 13C2 PFDA
PFUnA = 13C2 PFUnA
C3PFBS = 13C3 PFBS
PFHxS = 18O2 PFHxS
PFOS = 13C4 PFOS
M242FTS = M2-4:2 FTS
M262FTS = M2-6:2 FTS
M282FTS = M2-8:2 FTS
M102FTS = 13C2 10:2 FTS

Method: B/L/T PFAS - Branched, Linear and Total PFAS

Lab Sample ID: MB 320-820079/1-A
Matrix: Tissue
Analysis Batch: 820819

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 820079

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.27	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
L-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
Total PFOA	ND		1.0	0.20	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.10	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.27	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
Total PFHxS	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
L-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
Br-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
Total PFOS	ND		2.5	0.20	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
4:2 FTS	ND		1.0	0.27	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
6:2 FTS	ND		1.0	0.42	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
8:2 FTS	ND		1.0	0.10	ug/Kg		12/06/24 12:01	12/10/24 09:14	1
10:2 FTS	ND		1.0	0.10	ug/Kg		12/06/24 12:01	12/10/24 09:14	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*75*		*25 - 150*	*12/06/24 12:01*	*12/10/24 09:14*	*1*
13C5 PFPeA	*80*		*25 - 150*	*12/06/24 12:01*	*12/10/24 09:14*	*1*
13C2 PFHxA	*83*		*25 - 150*	*12/06/24 12:01*	*12/10/24 09:14*	*1*
13C4 PFHpA	*80*		*25 - 150*	*12/06/24 12:01*	*12/10/24 09:14*	*1*
13C4 PFOA	*68*		*25 - 150*	*12/06/24 12:01*	*12/10/24 09:14*	*1*
13C5 PFNA	*71*		*25 - 150*	*12/06/24 12:01*	*12/10/24 09:14*	*1*
13C2 PFDA	*79*		*25 - 150*	*12/06/24 12:01*	*12/10/24 09:14*	*1*
13C2 PFUnA	*72*		*25 - 150*	*12/06/24 12:01*	*12/10/24 09:14*	*1*
13C3 PFBS	*67*		*25 - 150*	*12/06/24 12:01*	*12/10/24 09:14*	*1*
18O2 PFHxS	*87*		*25 - 150*	*12/06/24 12:01*	*12/10/24 09:14*	*1*
13C4 PFOS	*84*		*25 - 150*	*12/06/24 12:01*	*12/10/24 09:14*	*1*
M2-4:2 FTS	*73*		*25 - 150*	*12/06/24 12:01*	*12/10/24 09:14*	*1*
M2-6:2 FTS	*79*		*25 - 150*	*12/06/24 12:01*	*12/10/24 09:14*	*1*
M2-8:2 FTS	*68*		*25 - 150*	*12/06/24 12:01*	*12/10/24 09:14*	*1*
13C2 10:2 FTS	*307*	**5+*	*25 - 150*	*12/06/24 12:01*	*12/10/24 09:14*	*1*

Lab Sample ID: LCS 320-820079/2-A
Matrix: Tissue
Analysis Batch: 820819

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 820079

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	10.0	10.4		ug/Kg		104	76 - 136

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-820079/2-A
Matrix: Tissue
Analysis Batch: 820819

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 820079

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluoropentanoic acid (PFPeA)	10.0	9.28		ug/Kg		93	69 - 129
Perfluorohexanoic acid (PFHxA)	10.0	9.11		ug/Kg		91	71 - 131
Perfluoroheptanoic acid (PFHpA)	10.0	10.6		ug/Kg		106	71 - 131
L-Perfluorooctanoic acid	10.0	10.8		ug/Kg		108	72 - 132
Total PFOA	10.0	10.8		ug/Kg		108	
Perfluorononanoic acid (PFNA)	10.0	10.2		ug/Kg		102	73 - 133
Perfluorodecanoic acid (PFDA)	10.0	10.9		ug/Kg		109	72 - 132
Perfluoroundecanoic acid (PFUnA)	10.0	9.34		ug/Kg		93	66 - 126
Perfluorobutanesulfonic acid (PFBS)	8.88	7.29		ug/Kg		82	69 - 129
Perfluoropentanesulfonic acid (PFPeS)	9.40	9.13		ug/Kg		97	66 - 126
Total PFHxS	9.12	8.53		ug/Kg		94	
L-Perfluorohexanesulfonic acid	9.12	8.53		ug/Kg		94	62 - 122
Perfluoroheptanesulfonic acid (PFHpS)	9.54	10.5		ug/Kg		110	76 - 136
L-Perfluorooctanesulfonic acid	9.30	9.33		ug/Kg		100	68 - 141
Total PFOS	9.30	9.33		ug/Kg		100	
4:2 FTS	9.38	9.46		ug/Kg		101	68 - 143
6:2 FTS	9.52	10.2		ug/Kg		107	73 - 139
8:2 FTS	9.60	11.1		ug/Kg		115	75 - 135
10:2 FTS	9.66	8.89		ug/Kg		92	69 - 145

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*67*		*25 - 150*
13C5 PFPeA	*68*		*25 - 150*
13C2 PFHxA	*73*		*25 - 150*
13C4 PFHpA	*67*		*25 - 150*
13C4 PFOA	*64*		*25 - 150*
13C5 PFNA	*63*		*25 - 150*
13C2 PFDA	*66*		*25 - 150*
13C2 PFUnA	*64*		*25 - 150*
13C3 PFBS	*70*		*25 - 150*
18O2 PFHxS	*76*		*25 - 150*
13C4 PFOS	*73*		*25 - 150*
M2-4:2 FTS	*71*		*25 - 150*
M2-6:2 FTS	*66*		*25 - 150*
M2-8:2 FTS	*56*		*25 - 150*
13C2 10:2 FTS	*259*	**5+*	*25 - 150*

Lab Sample ID: LCSD 320-820079/3-A
Matrix: Tissue
Analysis Batch: 820819

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 820079

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)	10.0	10.3		ug/Kg		103	76 - 136	1	30
Perfluoropentanoic acid (PFPeA)	10.0	10.9		ug/Kg		109	69 - 129	16	30
Perfluorohexanoic acid (PFHxA)	10.0	10.0		ug/Kg		100	71 - 131	9	30
Perfluoroheptanoic acid (PFHpA)	10.0	12.1		ug/Kg		121	71 - 131	13	30

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCSD 320-820079/3-A
Matrix: Tissue
Analysis Batch: 820819

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 820079

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
L-Perfluorooctanoic acid			10.0	10.2		ug/Kg		102	72 - 132	5	30
Total PFOA			10.0	10.2		ug/Kg		102		5	
Perfluorononanoic acid (PFNA)			10.0	10.6		ug/Kg		106	73 - 133	4	30
Perfluorodecanoic acid (PFDA)			10.0	11.1		ug/Kg		111	72 - 132	1	30
Perfluoroundecanoic acid (PFUnA)			10.0	9.86		ug/Kg		99	66 - 126	5	30
Perfluorobutanesulfonic acid (PFBS)			8.88	9.17		ug/Kg		103	69 - 129	23	30
Perfluoropentanesulfonic acid (PFPeS)			9.40	11.7		ug/Kg		124	66 - 126	24	30
Total PFHxS			9.12	8.62		ug/Kg		95		1	
L-Perfluorohexanesulfonic acid			9.12	8.62		ug/Kg		95	62 - 122	1	30
Perfluoroheptanesulfonic acid (PFHpS)			9.54	11.5		ug/Kg		121	76 - 136	10	30
L-Perfluorooctanesulfonic acid			9.30	10.2		ug/Kg		110	68 - 141	9	30
Total PFOS			9.30	10.2		ug/Kg		110		9	
4:2 FTS			9.38	13.0	*1	ug/Kg		139	68 - 143	32	30
6:2 FTS			9.52	10.2		ug/Kg		107	73 - 139	0	30
8:2 FTS			9.60	11.8		ug/Kg		122	75 - 135	6	30
10:2 FTS			9.66	9.87		ug/Kg		102	69 - 145	10	30

Isotope Dilution	*LCSD %Recovery*	*LCSD Qualifier*	*Limits*
13C4 PFBA	*91*		*25 - 150*
13C5 PFPeA	*77*		*25 - 150*
13C2 PFHxA	*98*		*25 - 150*
13C4 PFHpA	*86*		*25 - 150*
13C4 PFOA	*86*		*25 - 150*
13C5 PFNA	*87*		*25 - 150*
13C2 PFDA	*91*		*25 - 150*
13C2 PFUnA	*86*		*25 - 150*
13C3 PFBS	*84*		*25 - 150*
18O2 PFHxS	*102*		*25 - 150*
13C4 PFOS	*94*		*25 - 150*
M2-4:2 FTS	*78*		*25 - 150*
M2-6:2 FTS	*87*		*25 - 150*
M2-8:2 FTS	*79*		*25 - 150*
13C2 10:2 FTS	*332*	*5+	*25 - 150*

Lab Sample ID: MB 320-820824/1-A
Matrix: Tissue
Analysis Batch: 821645

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 820824

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.27	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
L-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
Total PFOA	ND		1.0	0.20	ug/Kg		12/10/24 03:40	12/12/24 22:55	1

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: MB 320-820824/1-A
Matrix: Tissue
Analysis Batch: 821645

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 820824

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.10	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.27	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
Total PFHxS	ND		1.0	0.15	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
L-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
Br-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
Total PFOS	ND		2.5	0.20	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
4:2 FTS	ND		1.0	0.27	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
6:2 FTS	ND		1.0	0.42	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
8:2 FTS	ND		1.0	0.10	ug/Kg		12/10/24 03:40	12/12/24 22:55	1
10:2 FTS	ND		1.0	0.10	ug/Kg		12/10/24 03:40	12/12/24 22:55	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*89*		*25 - 150*	*12/10/24 03:40*	*12/12/24 22:55*	*1*
13C5 PFPeA	*76*		*25 - 150*	*12/10/24 03:40*	*12/12/24 22:55*	*1*
13C2 PFHxA	*99*		*25 - 150*	*12/10/24 03:40*	*12/12/24 22:55*	*1*
13C4 PFHpA	*88*		*25 - 150*	*12/10/24 03:40*	*12/12/24 22:55*	*1*
13C4 PFOA	*88*		*25 - 150*	*12/10/24 03:40*	*12/12/24 22:55*	*1*
13C5 PFNA	*88*		*25 - 150*	*12/10/24 03:40*	*12/12/24 22:55*	*1*
13C2 PFDA	*99*		*25 - 150*	*12/10/24 03:40*	*12/12/24 22:55*	*1*
13C2 PFUnA	*91*		*25 - 150*	*12/10/24 03:40*	*12/12/24 22:55*	*1*
13C3 PFBS	*86*		*25 - 150*	*12/10/24 03:40*	*12/12/24 22:55*	*1*
18O2 PFHxS	*101*		*25 - 150*	*12/10/24 03:40*	*12/12/24 22:55*	*1*
13C4 PFOS	*94*		*25 - 150*	*12/10/24 03:40*	*12/12/24 22:55*	*1*
M2-4:2 FTS	*109*		*25 - 150*	*12/10/24 03:40*	*12/12/24 22:55*	*1*
M2-6:2 FTS	*112*		*25 - 150*	*12/10/24 03:40*	*12/12/24 22:55*	*1*
M2-8:2 FTS	*108*		*25 - 150*	*12/10/24 03:40*	*12/12/24 22:55*	*1*
13C2 10:2 FTS	*400*	**5+*	*25 - 150*	*12/10/24 03:40*	*12/12/24 22:55*	*1*

Lab Sample ID: LCS 320-820824/2-A
Matrix: Tissue
Analysis Batch: 821645

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 820824

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	10.0	8.85		ug/Kg		88	76 - 136
Perfluoropentanoic acid (PFPeA)	10.0	8.99		ug/Kg		90	69 - 129
Perfluorohexanoic acid (PFHxA)	10.0	8.95		ug/Kg		89	71 - 131
Perfluoroheptanoic acid (PFHpA)	10.0	9.55		ug/Kg		95	71 - 131
L-Perfluorooctanoic acid	10.0	9.58		ug/Kg		96	72 - 132
Total PFOA	10.0	9.58		ug/Kg		96	
Perfluorononanoic acid (PFNA)	10.0	9.04		ug/Kg		90	73 - 133
Perfluorodecanoic acid (PFDA)	10.0	9.67		ug/Kg		97	72 - 132

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-820824/2-A
Matrix: Tissue
Analysis Batch: 821645

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 820824

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluoroundecanoic acid (PFUnA)	10.0	9.29		ug/Kg		93	66 - 126
Perfluorobutanesulfonic acid (PFBS)	8.88	8.07		ug/Kg		91	69 - 129
Perfluoropentanesulfonic acid (PFPeS)	9.40	8.59		ug/Kg		91	66 - 126
Total PFHxS	9.12	7.53		ug/Kg		83	
L-Perfluorohexanesulfonic acid	9.12	7.53		ug/Kg		83	62 - 122
Perfluoroheptanesulfonic acid (PFHpS)	9.54	10.2		ug/Kg		107	76 - 136
L-Perfluorooctanesulfonic acid	9.30	8.87		ug/Kg		95	68 - 141
Total PFOS	9.30	8.87		ug/Kg		95	
4:2 FTS	9.38	9.63		ug/Kg		103	68 - 143
6:2 FTS	9.52	8.97		ug/Kg		94	73 - 139
8:2 FTS	9.60	9.72		ug/Kg		101	75 - 135
10:2 FTS	9.66	9.12		ug/Kg		94	69 - 145

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*83*		*25 - 150*
13C5 PFPeA	*94*		*25 - 150*
13C2 PFHxA	*97*		*25 - 150*
13C4 PFHpA	*99*		*25 - 150*
13C4 PFOA	*89*		*25 - 150*
13C5 PFNA	*95*		*25 - 150*
13C2 PFDA	*102*		*25 - 150*
13C2 PFUnA	*96*		*25 - 150*
13C3 PFBS	*106*		*25 - 150*
18O2 PFHxS	*115*		*25 - 150*
13C4 PFOS	*103*		*25 - 150*
M2-4:2 FTS	*108*		*25 - 150*
M2-6:2 FTS	*114*		*25 - 150*
M2-8:2 FTS	*102*		*25 - 150*
13C2 10:2 FTS	*294*	*5+	*25 - 150*

Lab Sample ID: LCSD 320-820824/3-A
Matrix: Tissue
Analysis Batch: 821645

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 820824

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)	10.0	10.5		ug/Kg		105	76 - 136	17	30
Perfluoropentanoic acid (PFPeA)	10.0	10.3		ug/Kg		103	69 - 129	14	30
Perfluorohexanoic acid (PFHxA)	10.0	9.15		ug/Kg		91	71 - 131	2	30
Perfluoroheptanoic acid (PFHpA)	10.0	10.8		ug/Kg		108	71 - 131	12	30
L-Perfluorooctanoic acid	10.0	9.98		ug/Kg		100	72 - 132	4	30
Total PFOA	10.0	9.98		ug/Kg		100		4	
Perfluorononanoic acid (PFNA)	10.0	9.88		ug/Kg		99	73 - 133	9	30
Perfluorodecanoic acid (PFDA)	10.0	9.60		ug/Kg		96	72 - 132	1	30
Perfluoroundecanoic acid (PFUnA)	10.0	9.56		ug/Kg		96	66 - 126	3	30

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCSD 320-820824/3-A
Matrix: Tissue
Analysis Batch: 821645

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 820824

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanesulfonic acid (PFBS)			8.88	8.19		ug/Kg		92	69 - 129	1	30
Perfluoropentanesulfonic acid (PFPeS)			9.40	8.17		ug/Kg		87	66 - 126	5	30
Total PFHxS			9.12	8.79		ug/Kg		96		15	
L-Perfluorohexanesulfonic acid			9.12	8.79		ug/Kg		96	62 - 122	15	30
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.7		ug/Kg		112	76 - 136	5	30
L-Perfluorooctanesulfonic acid			9.30	8.97		ug/Kg		96	68 - 141	1	30
Total PFOS			9.30	8.97		ug/Kg		96		1	
4:2 FTS			9.38	9.31		ug/Kg		99	68 - 143	3	30
6:2 FTS			9.52	10.0		ug/Kg		106	73 - 139	11	30
8:2 FTS			9.60	10.2		ug/Kg		107	75 - 135	5	30
10:2 FTS			9.66	8.84		ug/Kg		92	69 - 145	3	30

Isotope Dilution	*LCSD %Recovery*	*LCSD Qualifier*	*Limits*
13C4 PFBA	*78*		*25 - 150*
13C5 PFPeA	*88*		*25 - 150*
13C2 PFHxA	*99*		*25 - 150*
13C4 PFHpA	*90*		*25 - 150*
13C4 PFOA	*90*		*25 - 150*
13C5 PFNA	*89*		*25 - 150*
13C2 PFDA	*102*		*25 - 150*
13C2 PFUnA	*92*		*25 - 150*
13C3 PFBS	*113*		*25 - 150*
18O2 PFHxS	*105*		*25 - 150*
13C4 PFOS	*104*		*25 - 150*
M2-4:2 FTS	*114*		*25 - 150*
M2-6:2 FTS	*109*		*25 - 150*
M2-8:2 FTS	*96*		*25 - 150*
13C2 10:2 FTS	*338*	*5+	*25 - 150*

Lab Sample ID: MB 320-820977/1-A
Matrix: Tissue
Analysis Batch: 821394

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 820977

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perfluorobutanoic acid (PFBA)	ND		1.0	0.24	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
Perfluoropentanoic acid (PFPeA)	ND		1.0	0.18	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
Perfluorohexanoic acid (PFHxA)	ND		1.0	0.27	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
Perfluoroheptanoic acid (PFHpA)	ND		1.0	0.12	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
L-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
Br-Perfluorooctanoic acid	ND		1.0	0.20	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
Total PFOA	ND		1.0	0.20	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
Perfluorononanoic acid (PFNA)	ND		1.0	0.18	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
Perfluorodecanoic acid (PFDA)	ND		1.0	0.10	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
Perfluoroundecanoic acid (PFUnA)	ND		1.0	0.27	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
Perfluorobutanesulfonic acid (PFBS)	ND		1.0	0.17	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
Perfluoropentanesulfonic acid (PFPeS)	ND		1.0	0.18	ug/Kg		12/10/24 13:20	12/11/24 19:07	1

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: MB 320-820977/1-A
Matrix: Tissue
Analysis Batch: 821394

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 820977

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Br-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
Total PFHxS	ND		1.0	0.15	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
L-Perfluorohexanesulfonic acid	ND		1.0	0.15	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
Perfluoroheptanesulfonic acid (PFHpS)	ND		1.0	0.19	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
L-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
Br-Perfluorooctanesulfonic acid	ND		2.5	0.20	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
Total PFOS	ND		2.5	0.20	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
4:2 FTS	ND		1.0	0.27	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
6:2 FTS	ND		1.0	0.42	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
8:2 FTS	ND		1.0	0.10	ug/Kg		12/10/24 13:20	12/11/24 19:07	1
10:2 FTS	ND		1.0	0.10	ug/Kg		12/10/24 13:20	12/11/24 19:07	1

Isotope Dilution	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
13C4 PFBA	*90*		*25 - 150*	*12/10/24 13:20*	*12/11/24 19:07*	*1*
13C5 PFPeA	*85*		*25 - 150*	*12/10/24 13:20*	*12/11/24 19:07*	*1*
13C2 PFHxA	*88*		*25 - 150*	*12/10/24 13:20*	*12/11/24 19:07*	*1*
13C4 PFHpA	*93*		*25 - 150*	*12/10/24 13:20*	*12/11/24 19:07*	*1*
13C4 PFOA	*91*		*25 - 150*	*12/10/24 13:20*	*12/11/24 19:07*	*1*
13C5 PFNA	*92*		*25 - 150*	*12/10/24 13:20*	*12/11/24 19:07*	*1*
13C2 PFDA	*98*		*25 - 150*	*12/10/24 13:20*	*12/11/24 19:07*	*1*
13C2 PFUnA	*91*		*25 - 150*	*12/10/24 13:20*	*12/11/24 19:07*	*1*
13C3 PFBS	*73*		*25 - 150*	*12/10/24 13:20*	*12/11/24 19:07*	*1*
18O2 PFHxS	*96*		*25 - 150*	*12/10/24 13:20*	*12/11/24 19:07*	*1*
13C4 PFOS	*95*		*25 - 150*	*12/10/24 13:20*	*12/11/24 19:07*	*1*
M2-4:2 FTS	*96*		*25 - 150*	*12/10/24 13:20*	*12/11/24 19:07*	*1*
M2-6:2 FTS	*94*		*25 - 150*	*12/10/24 13:20*	*12/11/24 19:07*	*1*
M2-8:2 FTS	*79*		*25 - 150*	*12/10/24 13:20*	*12/11/24 19:07*	*1*
13C2 10:2 FTS	*335*	**5+*	*25 - 150*	*12/10/24 13:20*	*12/11/24 19:07*	*1*

Lab Sample ID: LCS 320-820977/2-A
Matrix: Tissue
Analysis Batch: 821394

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 820977

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits
Perfluorobutanoic acid (PFBA)	10.0	9.58		ug/Kg		96	76 - 136
Perfluoropentanoic acid (PFPeA)	10.0	10.1		ug/Kg		101	69 - 129
Perfluorohexanoic acid (PFHxA)	10.0	9.55		ug/Kg		95	71 - 131
Perfluoroheptanoic acid (PFHpA)	10.0	10.5		ug/Kg		105	71 - 131
L-Perfluorooctanoic acid	10.0	9.77		ug/Kg		98	72 - 132
Total PFOA	10.0	9.77		ug/Kg		98	
Perfluorononanoic acid (PFNA)	10.0	9.65		ug/Kg		97	73 - 133
Perfluorodecanoic acid (PFDA)	10.0	10.4		ug/Kg		104	72 - 132
Perfluoroundecanoic acid (PFUnA)	10.0	10.1		ug/Kg		101	66 - 126
Perfluorobutanesulfonic acid (PFBS)	8.88	8.41		ug/Kg		95	69 - 129
Perfluoropentanesulfonic acid (PFPeS)	9.40	8.78		ug/Kg		93	66 - 126
Total PFHxS	9.12	8.39		ug/Kg		92	

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCS 320-820977/2-A
Matrix: Tissue
Analysis Batch: 821394

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 820977

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec Limits		
L-Perfluorohexanesulfonic acid			9.12	8.39		ug/Kg		92	62 - 122		
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.4		ug/Kg		109	76 - 136		
L-Perfluorooctanesulfonic acid			9.30	9.38		ug/Kg		101	68 - 141		
Total PFOS			9.30	9.38		ug/Kg		101			
4:2 FTS			9.38	10.1		ug/Kg		107	68 - 143		
6:2 FTS			9.52	10.8		ug/Kg		113	73 - 139		
8:2 FTS			9.60	11.8		ug/Kg		123	75 - 135		
10:2 FTS			9.66	9.74		ug/Kg		101	69 - 145		

Isotope Dilution	*LCS %Recovery*	*LCS Qualifier*	*Limits*
13C4 PFBA	*104*		*25 - 150*
13C5 PFPeA	*96*		*25 - 150*
13C2 PFHxA	*107*		*25 - 150*
13C4 PFHpA	*105*		*25 - 150*
13C4 PFOA	*97*		*25 - 150*
13C5 PFNA	*101*		*25 - 150*
13C2 PFDA	*110*		*25 - 150*
13C2 PFUnA	*98*		*25 - 150*
13C3 PFBS	*118*		*25 - 150*
18O2 PFHxS	*117*		*25 - 150*
13C4 PFOS	*109*		*25 - 150*
M2-4:2 FTS	*99*		*25 - 150*
M2-6:2 FTS	*80*		*25 - 150*
M2-8:2 FTS	*80*		*25 - 150*
13C2 10:2 FTS	*275*	*5+	*25 - 150*

Lab Sample ID: LCSD 320-820977/3-A
Matrix: Tissue
Analysis Batch: 821394

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 820977

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
Perfluorobutanoic acid (PFBA)			10.0	11.2		ug/Kg		112	76 - 136	15	30
Perfluoropentanoic acid (PFPeA)			10.0	9.99		ug/Kg		100	69 - 129	1	30
Perfluorohexanoic acid (PFHxA)			10.0	9.29		ug/Kg		93	71 - 131	3	30
Perfluoroheptanoic acid (PFHpA)			10.0	10.8		ug/Kg		108	71 - 131	3	30
L-Perfluorooctanoic acid			10.0	9.73		ug/Kg		97	72 - 132	0	30
Total PFOA			10.0	9.73		ug/Kg		97		0	
Perfluorononanoic acid (PFNA)			10.0	9.27		ug/Kg		93	73 - 133	4	30
Perfluorodecanoic acid (PFDA)			10.0	10.5		ug/Kg		105	72 - 132	1	30
Perfluoroundecanoic acid (PFUnA)			10.0	10.1		ug/Kg		101	66 - 126	0	30
Perfluorobutanesulfonic acid (PFBS)			8.88	9.34		ug/Kg		105	69 - 129	10	30
Perfluoropentanesulfonic acid (PFPeS)			9.40	11.2		ug/Kg		120	66 - 126	24	30
Total PFHxS			9.12	8.55		ug/Kg		94		2	
L-Perfluorohexanesulfonic acid			9.12	8.55		ug/Kg		94	62 - 122	2	30
Perfluoroheptanesulfonic acid (PFHpS)			9.54	10.9		ug/Kg		114	76 - 136	5	30

Method: B/L/T PFAS - Branched, Linear and Total PFAS (Continued)

Lab Sample ID: LCSD 320-820977/3-A
Matrix: Tissue
Analysis Batch: 821394

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 820977

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec Limits	RPD	RPD Limit
L-Perfluorooctanesulfonic acid			9.30	9.47		ug/Kg		102	68 - 141	1	30
Total PFOS			9.30	9.47		ug/Kg		102		1	
4:2 FTS			9.38	9.88		ug/Kg		105	68 - 143	2	30
6:2 FTS			9.52	10.8		ug/Kg		113	73 - 139	0	30
8:2 FTS			9.60	10.7		ug/Kg		111	75 - 135	10	30
10:2 FTS			9.66	10.3		ug/Kg		106	69 - 145	5	30

Isotope Dilution	*LCSD %Recovery*	*LCSD Qualifier*	*Limits*
13C4 PFBA	*86*		*25 - 150*
13C5 PFPeA	*89*		*25 - 150*
13C2 PFHxA	*114*		*25 - 150*
13C4 PFHpA	*96*		*25 - 150*
13C4 PFOA	*99*		*25 - 150*
13C5 PFNA	*101*		*25 - 150*
13C2 PFDA	*105*		*25 - 150*
13C2 PFUnA	*95*		*25 - 150*
13C3 PFBS	*95*		*25 - 150*
18O2 PFHxS	*111*		*25 - 150*
13C4 PFOS	*103*		*25 - 150*
M2-4:2 FTS	*88*		*25 - 150*
M2-6:2 FTS	*80*		*25 - 150*
M2-8:2 FTS	*83*		*25 - 150*
13C2 10:2 FTS	*309*	*5+	*25 - 150*

LCMS

Prep Batch: 820079

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-1	NK14474, MSB18488, Pool1, P1	Total/NA	Tissue	SHAKE	820080
320-117508-1 - RA	NK14474, MSB18488, Pool1, P1	Total/NA	Tissue	SHAKE	820080
320-117508-2	NK9098, Liver, P2	Total/NA	Tissue	SHAKE	820080
320-117508-3	NK2445, Liver, AFP7B, P3	Total/NA	Tissue	SHAKE	820080
320-117508-4	NK2444, Liver, AFP7A, P4	Total/NA	Tissue	SHAKE	820080
320-117508-5	NK35660, MSB29117, P5	Total/NA	Tissue	SHAKE	820080
320-117508-6	NK35661, MSB29140, P6	Total/NA	Tissue	SHAKE	820080
320-117508-6 - RA	NK35661, MSB29140, P6	Total/NA	Tissue	SHAKE	820080
320-117508-7 - RA	NK35655, MSB29134, P7	Total/NA	Tissue	SHAKE	820080
320-117508-7	NK35655, MSB29134, P7	Total/NA	Tissue	SHAKE	820080
320-117508-8	NK35811, MSB30651, P8	Total/NA	Tissue	SHAKE	820080
320-117508-8 - RA	NK35811, MSB30651, P8	Total/NA	Tissue	SHAKE	820080
320-117508-9	NK35643, MSB29100, P9	Total/NA	Tissue	SHAKE	820080
320-117508-10	NK170946, P10	Total/NA	Tissue	SHAKE	820080
320-117508-11	NK100328, Liver, AEPIR, P11	Total/NA	Tissue	SHAKE	820080
320-117508-12	NK165232, MSB26431, P12	Total/NA	Tissue	SHAKE	820080
320-117508-13	NK35676, MSB29118, P14	Total/NA	Tissue	SHAKE	820080
320-117508-14	NK35678, MSB29131, P15	Total/NA	Tissue	SHAKE	820080
320-117508-14 - RA	NK35678, MSB29131, P15	Total/NA	Tissue	SHAKE	820080
320-117508-15 - RA	NK35669, MSB29093, P16	Total/NA	Tissue	SHAKE	820080
320-117508-15	NK35669, MSB29093, P16	Total/NA	Tissue	SHAKE	820080
320-117508-16	NK35935, MSB39605, P17	Total/NA	Tissue	SHAKE	820080
320-117508-17	NK35958, MSB40165, P18	Total/NA	Tissue	SHAKE	820080
320-117508-18	NK35816, MSB30670, P19	Total/NA	Tissue	SHAKE	820080
320-117508-19	NK35804, MSB30716, P20	Total/NA	Tissue	SHAKE	820080
320-117508-20	NK35876, MSB39746, P22	Total/NA	Tissue	SHAKE	820080
MB 320-820079/1-A	Method Blank	Total/NA	Tissue	SHAKE	
LCS 320-820079/2-A	Lab Control Sample	Total/NA	Tissue	SHAKE	
LCSD 320-820079/3-A	Lab Control Sample Dup	Total/NA	Tissue	SHAKE	

Pre Prep Batch: 820080

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-1	NK14474, MSB18488, Pool1, P1	Total/NA	Tissue	In-House	
320-117508-1 - RA	NK14474, MSB18488, Pool1, P1	Total/NA	Tissue	In-House	
320-117508-2	NK9098, Liver, P2	Total/NA	Tissue	In-House	
320-117508-3	NK2445, Liver, AFP7B, P3	Total/NA	Tissue	In-House	
320-117508-4	NK2444, Liver, AFP7A, P4	Total/NA	Tissue	In-House	
320-117508-5	NK35660, MSB29117, P5	Total/NA	Tissue	In-House	
320-117508-6 - RA	NK35661, MSB29140, P6	Total/NA	Tissue	In-House	
320-117508-6	NK35661, MSB29140, P6	Total/NA	Tissue	In-House	
320-117508-7	NK35655, MSB29134, P7	Total/NA	Tissue	In-House	
320-117508-7 - RA	NK35655, MSB29134, P7	Total/NA	Tissue	In-House	
320-117508-8	NK35811, MSB30651, P8	Total/NA	Tissue	In-House	
320-117508-8 - RA	NK35811, MSB30651, P8	Total/NA	Tissue	In-House	
320-117508-9	NK35643, MSB29100, P9	Total/NA	Tissue	In-House	
320-117508-10	NK170946, P10	Total/NA	Tissue	In-House	
320-117508-11	NK100328, Liver, AEPIR, P11	Total/NA	Tissue	In-House	
320-117508-12	NK165232, MSB26431, P12	Total/NA	Tissue	In-House	
320-117508-13	NK35676, MSB29118, P14	Total/NA	Tissue	In-House	
320-117508-14	NK35678, MSB29131, P15	Total/NA	Tissue	In-House	
320-117508-14 - RA	NK35678, MSB29131, P15	Total/NA	Tissue	In-House	

LCMS (Continued)

Pre Prep Batch: 820080 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-15 - RA	NK35669, MSB29093, P16	Total/NA	Tissue	In-House	
320-117508-15	NK35669, MSB29093, P16	Total/NA	Tissue	In-House	
320-117508-16	NK35935, MSB39605, P17	Total/NA	Tissue	In-House	
320-117508-17	NK35958, MSB40165, P18	Total/NA	Tissue	In-House	
320-117508-18	NK35816, MSB30670, P19	Total/NA	Tissue	In-House	
320-117508-19	NK35804, MSB30716, P20	Total/NA	Tissue	In-House	
320-117508-20	NK35876, MSB39746, P22	Total/NA	Tissue	In-House	

Analysis Batch: 820819

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-1	NK14474, MSB18488, Pool1, P1	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-2	NK9098, Liver, P2	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-3	NK2445, Liver, AFP7B, P3	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-4	NK2444, Liver, AFP7A, P4	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-5	NK35660, MSB29117, P5	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-6	NK35661, MSB29140, P6	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-7	NK35655, MSB29134, P7	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-8	NK35811, MSB30651, P8	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-10	NK170946, P10	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-11	NK100328, Liver, AEPIR, P11	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-12	NK165232, MSB26431, P12	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-13	NK35676, MSB29118, P14	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-14	NK35678, MSB29131, P15	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-15	NK35669, MSB29093, P16	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-16	NK35935, MSB39605, P17	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-17	NK35958, MSB40165, P18	Total/NA	Tissue	B/L/T PFAS	820079
MB 320-820079/1-A	Method Blank	Total/NA	Tissue	B/L/T PFAS	820079
LCS 320-820079/2-A	Lab Control Sample	Total/NA	Tissue	B/L/T PFAS	820079
LCSD 320-820079/3-A	Lab Control Sample Dup	Total/NA	Tissue	B/L/T PFAS	820079

Pre Prep Batch: 820822

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-21	NK35910, MSB39349, P23	Total/NA	Tissue	In-House	
320-117508-22	NK35817, MSB30650, P24	Total/NA	Tissue	In-House	
320-117508-23	Pool 25, Duck PFAS, P25	Total/NA	Tissue	In-House	
320-117508-24	NK282630, MSB50169, P26	Total/NA	Tissue	In-House	
320-117508-25	NK276851, MSB46239, P28	Total/NA	Tissue	In-House	
320-117508-26	NK282547, MSB49842, P29	Total/NA	Tissue	In-House	
320-117508-27	NK276660, MSB45963, P30	Total/NA	Tissue	In-House	
320-117508-28	NK282696, MSB50223, P31	Total/NA	Tissue	In-House	
320-117508-29 - RA	NK283601, Spat. Cly, Liver, ABJ34298, MSB101	Total/NA	Tissue	In-House	
320-117508-29 - DL	NK283601, Spat. Cly, Liver, ABJ34298, MSB101	Total/NA	Tissue	In-House	
320-117508-29	NK283601, Spat. Cly, Liver, ABJ34298, MSB101	Total/NA	Tissue	In-House	
320-117508-30	NK283602, JLW125, S. Calypeata, L, MSB10112	Total/NA	Tissue	In-House	
320-117508-30 - RA	NK283602, JLW125, S. Calypeata, L, MSB10112	Total/NA	Tissue	In-House	
320-117508-31 - DL	NK283605, Liver, Spatula, MSB1011318, P34	Total/NA	Tissue	In-House	
320-117508-31	NK283605, Liver, Spatula, MSB1011318, P34	Total/NA	Tissue	In-House	
320-117508-31 - RA	NK283605, Liver, Spatula, MSB1011318, P34	Total/NA	Tissue	In-House	
320-117508-32 - RA	NK283606, Spatula, Liver, MSB1011339, P35	Total/NA	Tissue	In-House	
320-117508-32 - DL	NK283606, Spatula, Liver, MSB1011339, P35	Total/NA	Tissue	In-House	
320-117508-32	NK283606, Spatula, Liver, MSB1011339, P35	Total/NA	Tissue	In-House	

LCMS (Continued)

Pre Prep Batch: 820822 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-33 - RA	NK283607, S. calypteata, Liver, MSB1011310, P3	Total/NA	Tissue	In-House	
320-117508-33	NK283607, S. calypteata, Liver, MSB1011310, P3	Total/NA	Tissue	In-House	
320-117508-33 - DL	NK283607, S. calypteata, Liver, MSB1011310, P3	Total/NA	Tissue	In-House	
320-117508-34 - DL	NK283608, S. calypeata, L, MSB1011324, P37	Total/NA	Tissue	In-House	
320-117508-34 - RA	NK283608, S. calypeata, L, MSB1011324, P37	Total/NA	Tissue	In-House	
320-117508-34	NK283608, S. calypeata, L, MSB1011324, P37	Total/NA	Tissue	In-House	
320-117508-35	NK283615, S. calypeata, L, MSB1011402, P38	Total/NA	Tissue	In-House	
320-117508-35 - DL	NK283615, S. calypeata, L, MSB1011402, P38	Total/NA	Tissue	In-House	
320-117508-35 - RA	NK283615, S. calypeata, L, MSB1011402, P38	Total/NA	Tissue	In-House	
320-117508-36	NK283619, S. calypeata, L, MSB1011416, P39	Total/NA	Tissue	In-House	
320-117508-36 - RA	NK283619, S. calypeata, L, MSB1011416, P39	Total/NA	Tissue	In-House	
320-117508-36 - DL	NK283619, S. calypeata, L, MSB1011416, P39	Total/NA	Tissue	In-House	
320-117508-37	NK283621, S. calypteata, L, MSB1011430, P40	Total/NA	Tissue	In-House	
320-117508-37 - RA	NK283621, S. calypteata, L, MSB1011430, P40	Total/NA	Tissue	In-House	
320-117508-38	NK283622, L, S. calypeata, MSB1011451, P41	Total/NA	Tissue	In-House	
320-117508-38 - DL	NK283622, L, S. calypeata, MSB1011451, P41	Total/NA	Tissue	In-House	
320-117508-39	NK283626, S. calypeata, L, MSB1011466, P42	Total/NA	Tissue	In-House	
320-117508-39 - DL	NK283626, S. calypeata, L, MSB1011466, P42	Total/NA	Tissue	In-House	
320-117508-40	NK283627, S. calypeata, L, MSB1011473, P43	Total/NA	Tissue	In-House	
320-117508-40 - DL	NK283627, S. calypeata, L, MSB1011473, P43	Total/NA	Tissue	In-House	

Prep Batch: 820824

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-21	NK35910, MSB39349, P23	Total/NA	Tissue	SHAKE	820822
320-117508-22	NK35817, MSB30650, P24	Total/NA	Tissue	SHAKE	820822
320-117508-23	Pool 25, Duck PFAS, P25	Total/NA	Tissue	SHAKE	820822
320-117508-24	NK282630, MSB50169, P26	Total/NA	Tissue	SHAKE	820822
320-117508-25	NK276851, MSB46239, P28	Total/NA	Tissue	SHAKE	820822
320-117508-26	NK282547, MSB49842, P29	Total/NA	Tissue	SHAKE	820822
320-117508-27	NK276660, MSB45963, P30	Total/NA	Tissue	SHAKE	820822
320-117508-28	NK282696, MSB50223, P31	Total/NA	Tissue	SHAKE	820822
320-117508-29 - DL	NK283601, Spat. Cly, Liver, ABJ34298, MSB101	Total/NA	Tissue	SHAKE	820822
320-117508-29	NK283601, Spat. Cly, Liver, ABJ34298, MSB101	Total/NA	Tissue	SHAKE	820822
320-117508-29 - RA	NK283601, Spat. Cly, Liver, ABJ34298, MSB101	Total/NA	Tissue	SHAKE	820822
320-117508-30	NK283602, JLW125, S. Calypeata, L, MSB10112	Total/NA	Tissue	SHAKE	820822
320-117508-30 - RA	NK283602, JLW125, S. Calypeata, L, MSB10112	Total/NA	Tissue	SHAKE	820822
320-117508-31 - DL	NK283605, Liver, Spatula, MSB1011318, P34	Total/NA	Tissue	SHAKE	820822
320-117508-31 - RA	NK283605, Liver, Spatula, MSB1011318, P34	Total/NA	Tissue	SHAKE	820822
320-117508-31	NK283605, Liver, Spatula, MSB1011318, P34	Total/NA	Tissue	SHAKE	820822
320-117508-32	NK283606, Spatula, Liver, MSB1011339, P35	Total/NA	Tissue	SHAKE	820822
320-117508-32 - RA	NK283606, Spatula, Liver, MSB1011339, P35	Total/NA	Tissue	SHAKE	820822
320-117508-32 - DL	NK283606, Spatula, Liver, MSB1011339, P35	Total/NA	Tissue	SHAKE	820822
320-117508-33 - RA	NK283607, S. calypteata, Liver, MSB1011310, P3	Total/NA	Tissue	SHAKE	820822
320-117508-33 - DL	NK283607, S. calypteata, Liver, MSB1011310, P3	Total/NA	Tissue	SHAKE	820822
320-117508-33	NK283607, S. calypteata, Liver, MSB1011310, P3	Total/NA	Tissue	SHAKE	820822
320-117508-34 - DL	NK283608, S. calypeata, L, MSB1011324, P37	Total/NA	Tissue	SHAKE	820822
320-117508-34 - RA	NK283608, S. calypeata, L, MSB1011324, P37	Total/NA	Tissue	SHAKE	820822
320-117508-34	NK283608, S. calypeata, L, MSB1011324, P37	Total/NA	Tissue	SHAKE	820822
320-117508-35 - RA	NK283615, S. calypeata, L, MSB1011402, P38	Total/NA	Tissue	SHAKE	820822
320-117508-35 - DL	NK283615, S. calypeata, L, MSB1011402, P38	Total/NA	Tissue	SHAKE	820822
320-117508-35	NK283615, S. calypeata, L, MSB1011402, P38	Total/NA	Tissue	SHAKE	820822

LCMS (Continued)

Prep Batch: 820824 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-36 - DL	NK283619, S. calypeata, L, MSB1011416, P39	Total/NA	Tissue	SHAKE	820822
320-117508-36	NK283619, S. calypeata, L, MSB1011416, P39	Total/NA	Tissue	SHAKE	820822
320-117508-36 - RA	NK283619, S. calypeata, L, MSB1011416, P39	Total/NA	Tissue	SHAKE	820822
320-117508-37 - RA	NK283621, S. calypteata, L, MSB1011430, P40	Total/NA	Tissue	SHAKE	820822
320-117508-37	NK283621, S. calypteata, L, MSB1011430, P40	Total/NA	Tissue	SHAKE	820822
320-117508-38	NK283622, L, S. calypeata, MSB1011451, P41	Total/NA	Tissue	SHAKE	820822
320-117508-38 - DL	NK283622, L, S. calypeata, MSB1011451, P41	Total/NA	Tissue	SHAKE	820822
320-117508-39 - DL	NK283626, S. calypeata, L, MSB1011466, P42	Total/NA	Tissue	SHAKE	820822
320-117508-39	NK283626, S. calypeata, L, MSB1011466, P42	Total/NA	Tissue	SHAKE	820822
320-117508-40	NK283627, S. calypeata, L, MSB1011473, P43	Total/NA	Tissue	SHAKE	820822
320-117508-40 - DL	NK283627, S. calypeata, L, MSB1011473, P43	Total/NA	Tissue	SHAKE	820822
MB 320-820824/1-A	Method Blank	Total/NA	Tissue	SHAKE	
LCS 320-820824/2-A	Lab Control Sample	Total/NA	Tissue	SHAKE	
LCSD 320-820824/3-A	Lab Control Sample Dup	Total/NA	Tissue	SHAKE	

Pre Prep Batch: 820939

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-41	NK283629, S. calypteata, Liver, MSB1011446, P4	Total/NA	Tissue	In-House	
320-117508-41 - DL	NK283629, S. calypteata, Liver, MSB1011446, P4	Total/NA	Tissue	In-House	
320-117508-42	NK283631, L, A. americana, MSB1011511, P45	Total/NA	Tissue	In-House	
320-117508-42 - DL	NK283631, L, A. americana, MSB1011511, P45	Total/NA	Tissue	In-House	
320-117508-43 - DL	NK283633, L, S. clypteata, MSB1011525, P46	Total/NA	Tissue	In-House	
320-117508-43	NK283633, L, S. clypteata, MSB1011525, P46	Total/NA	Tissue	In-House	
320-117508-44 - DL	NK283641, L, S. clypteata, MSB1011577, P47	Total/NA	Tissue	In-House	
320-117508-44	NK283641, L, S. clypteata, MSB1011577, P47	Total/NA	Tissue	In-House	
320-117508-45	NK283644, S. clypeata, Liver, MSB1011744, P48	Total/NA	Tissue	In-House	
320-117508-45 - DL	NK283644, S. clypeata, Liver, MSB1011744, P48	Total/NA	Tissue	In-House	
320-117508-46	NK283669, S. clypteata, Liver, MSB1011800, P4	Total/NA	Tissue	In-House	
320-117508-46 - DL	NK283669, S. clypteata, Liver, MSB1011800, P4	Total/NA	Tissue	In-House	
320-117508-47	NK283674, S. clypeata, Liver, MSB1011812, P50	Total/NA	Tissue	In-House	
320-117508-47 - DL	NK283674, S. clypeata, Liver, MSB1011812, P50	Total/NA	Tissue	In-House	

Prep Batch: 820977

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-41	NK283629, S. calypteata, Liver, MSB1011446, P4	Total/NA	Tissue	SHAKE	820939
320-117508-41 - DL	NK283629, S. calypteata, Liver, MSB1011446, P4	Total/NA	Tissue	SHAKE	820939
320-117508-42	NK283631, L, A. americana, MSB1011511, P45	Total/NA	Tissue	SHAKE	820939
320-117508-42 - DL	NK283631, L, A. americana, MSB1011511, P45	Total/NA	Tissue	SHAKE	820939
320-117508-43 - DL	NK283633, L, S. clypteata, MSB1011525, P46	Total/NA	Tissue	SHAKE	820939
320-117508-43	NK283633, L, S. clypteata, MSB1011525, P46	Total/NA	Tissue	SHAKE	820939
320-117508-44 - DL	NK283641, L, S. clypteata, MSB1011577, P47	Total/NA	Tissue	SHAKE	820939
320-117508-44	NK283641, L, S. clypteata, MSB1011577, P47	Total/NA	Tissue	SHAKE	820939
320-117508-45	NK283644, S. clypeata, Liver, MSB1011744, P48	Total/NA	Tissue	SHAKE	820939
320-117508-45 - DL	NK283644, S. clypeata, Liver, MSB1011744, P48	Total/NA	Tissue	SHAKE	820939
320-117508-46	NK283669, S. clypteata, Liver, MSB1011800, P4	Total/NA	Tissue	SHAKE	820939
320-117508-46 - DL	NK283669, S. clypteata, Liver, MSB1011800, P4	Total/NA	Tissue	SHAKE	820939
320-117508-47	NK283674, S. clypeata, Liver, MSB1011812, P50	Total/NA	Tissue	SHAKE	820939
320-117508-47 - DL	NK283674, S. clypeata, Liver, MSB1011812, P50	Total/NA	Tissue	SHAKE	820939
MB 320-820977/1-A	Method Blank	Total/NA	Tissue	SHAKE	
LCS 320-820977/2-A	Lab Control Sample	Total/NA	Tissue	SHAKE	
LCSD 320-820977/3-A	Lab Control Sample Dup	Total/NA	Tissue	SHAKE	

LCMS

Analysis Batch: 821391

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-1 - RA	NK14474, MSB18488, Pool1, P1	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-6 - RA	NK35661, MSB29140, P6	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-7 - RA	NK35655, MSB29134, P7	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-8 - RA	NK35811, MSB30651, P8	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-9	NK35643, MSB29100, P9	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-14 - RA	NK35678, MSB29131, P15	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-15 - RA	NK35669, MSB29093, P16	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-18	NK35816, MSB30670, P19	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-19	NK35804, MSB30716, P20	Total/NA	Tissue	B/L/T PFAS	820079
320-117508-20	NK35876, MSB39746, P22	Total/NA	Tissue	B/L/T PFAS	820079

Analysis Batch: 821394

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-41	NK283629, S. calypteata, Liver, MSB1011446, P4	Total/NA	Tissue	B/L/T PFAS	820977
320-117508-42	NK283631, L, A. americana, MSB1011511, P45	Total/NA	Tissue	B/L/T PFAS	820977
320-117508-43	NK283633, L, S. clypteata, MSB1011525, P46	Total/NA	Tissue	B/L/T PFAS	820977
320-117508-44	NK283641, L, S. clypteata, MSB1011577, P47	Total/NA	Tissue	B/L/T PFAS	820977
320-117508-45	NK283644, S. clypeata, Liver, MSB1011744, P48	Total/NA	Tissue	B/L/T PFAS	820977
320-117508-46	NK283669, S. clypteata, Liver, MSB1011800, P4	Total/NA	Tissue	B/L/T PFAS	820977
320-117508-47	NK283674, S. clypeata, Liver, MSB1011812, P50	Total/NA	Tissue	B/L/T PFAS	820977
MB 320-820977/1-A	Method Blank	Total/NA	Tissue	B/L/T PFAS	820977
LCS 320-820977/2-A	Lab Control Sample	Total/NA	Tissue	B/L/T PFAS	820977
LCSD 320-820977/3-A	Lab Control Sample Dup	Total/NA	Tissue	B/L/T PFAS	820977

Analysis Batch: 821644

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-41 - DL	NK283629, S. calypteata, Liver, MSB1011446, P4	Total/NA	Tissue	B/L/T PFAS	820977
320-117508-43 - DL	NK283633, L, S. clypteata, MSB1011525, P46	Total/NA	Tissue	B/L/T PFAS	820977
320-117508-44 - DL	NK283641, L, S. clypteata, MSB1011577, P47	Total/NA	Tissue	B/L/T PFAS	820977
320-117508-45 - DL	NK283644, S. clypeata, Liver, MSB1011744, P48	Total/NA	Tissue	B/L/T PFAS	820977
320-117508-46 - DL	NK283669, S. clypteata, Liver, MSB1011800, P4	Total/NA	Tissue	B/L/T PFAS	820977
320-117508-47 - DL	NK283674, S. clypeata, Liver, MSB1011812, P50	Total/NA	Tissue	B/L/T PFAS	820977

Analysis Batch: 821645

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-21	NK35910, MSB39349, P23	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-22	NK35817, MSB30650, P24	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-23	Pool 25, Duck PFAS, P25	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-24	NK282630, MSB50169, P26	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-25	NK276851, MSB46239, P28	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-26	NK282547, MSB49842, P29	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-27	NK276660, MSB45963, P30	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-28	NK282696, MSB50223, P31	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-29	NK283601, Spat. Cly, Liver, ABJ34298, MSB101	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-30	NK283602, JLW125, S. Calypeata, L, MSB10112	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-31	NK283605, Liver, Spatula, MSB1011318, P34	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-32	NK283606, Spatula, Liver, MSB1011339, P35	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-33	NK283607, S. calypteata, Liver, MSB1011310, P3	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-34	NK283608, S. calypeata, L, MSB1011324, P37	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-35	NK283615, S. calypeata, L, MSB1011402, P38	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-36	NK283619, S. calypeata, L, MSB1011416, P39	Total/NA	Tissue	B/L/T PFAS	820824

LCMS (Continued)

Analysis Batch: 821645 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-37	NK283621, S. calypteata, L, MSB1011430, P40	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-38	NK283622, L, S. calypeata, MSB1011451, P41	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-39	NK283626, S. calypeata, L, MSB1011466, P42	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-40	NK283627, S. calypeata, L, MSB1011473, P43	Total/NA	Tissue	B/L/T PFAS	820824
MB 320-820824/1-A	Method Blank	Total/NA	Tissue	B/L/T PFAS	820824
LCS 320-820824/2-A	Lab Control Sample	Total/NA	Tissue	B/L/T PFAS	820824
LCSD 320-820824/3-A	Lab Control Sample Dup	Total/NA	Tissue	B/L/T PFAS	820824

Analysis Batch: 822235

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-29 - RA	NK283601, Spat. Cly, Liver, ABJ34298, MSB101	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-30 - RA	NK283602, JLW125, S. Calypeata, L, MSB10112	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-31 - DL	NK283605, Liver, Spatula, MSB1011318, P34	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-31 - RA	NK283605, Liver, Spatula, MSB1011318, P34	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-32 - DL	NK283606, Spatula, Liver, MSB1011339, P35	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-32 - RA	NK283606, Spatula, Liver, MSB1011339, P35	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-33 - DL	NK283607, S. calypteata, Liver, MSB1011310, P	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-33 - RA	NK283607, S. calypteata, Liver, MSB1011310, P	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-34 - DL	NK283608, S. calypeata, L, MSB1011324, P37	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-34 - RA	NK283608, S. calypeata, L, MSB1011324, P37	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-35 - DL	NK283615, S. calypeata, L, MSB1011402, P38	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-35 - RA	NK283615, S. calypeata, L, MSB1011402, P38	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-36 - DL	NK283619, S. calypeata, L, MSB1011416, P39	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-36 - RA	NK283619, S. calypeata, L, MSB1011416, P39	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-37 - RA	NK283621, S. calypteata, L, MSB1011430, P40	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-38 - DL	NK283622, L, S. calypeata, MSB1011451, P41	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-39 - DL	NK283626, S. calypeata, L, MSB1011466, P42	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-40 - DL	NK283627, S. calypeata, L, MSB1011473, P43	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-42 - DL	NK283631, L, A. americana, MSB1011511, P45	Total/NA	Tissue	B/L/T PFAS	820977

Analysis Batch: 822525

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-29 - DL	NK283601, Spat. Cly, Liver, ABJ34298, MSB101	Total/NA	Tissue	B/L/T PFAS	820824

Analysis Batch: 823808

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
320-117508-30	NK283602, JLW125, S. Calypeata, L, MSB10112	Total/NA	Tissue	B/L/T PFAS	820824
320-117508-37	NK283621, S. calypteata, L, MSB1011430, P40	Total/NA	Tissue	B/L/T PFAS	820824

Lab Chronicle

Client: University of New Mexico
Job ID: 320-117508-1
Project/Site: UNM_PFAS in Tissue, Holloman

Client Sample ID: NK14474, MSB18488, Pool1, P1
Lab Sample ID: 320-117508-1
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			0.97 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 10:12	S1C	EET SAC
Total/NA	Prep	SHAKE	RA		0.97 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	821391	12/11/24 14:35	S1C	EET SAC

Client Sample ID: NK9098, Liver, P2
Lab Sample ID: 320-117508-2
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.19 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 10:31	S1C	EET SAC

Client Sample ID: NK2445, Liver, AFP7B, P3
Lab Sample ID: 320-117508-3
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.08 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 10:51	S1C	EET SAC

Client Sample ID: NK2444, Liver, AFP7A, P4
Lab Sample ID: 320-117508-4
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.04 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 11:10	S1C	EET SAC

Client Sample ID: NK35660, MSB29117, P5
Lab Sample ID: 320-117508-5
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.04 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 11:30	S1C	EET SAC

Lab Chronicle

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK35661, MSB29140, P6

Lab Sample ID: 320-117508-6
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.03 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 11:49	S1C	EET SAC
Total/NA	Prep	SHAKE	RA		1.03 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	821391	12/11/24 14:55	S1C	EET SAC

Client Sample ID: NK35655, MSB29134, P7

Lab Sample ID: 320-117508-7
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.01 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 12:08	S1C	EET SAC
Total/NA	Prep	SHAKE	RA		1.01 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	821391	12/11/24 15:14	S1C	EET SAC

Client Sample ID: NK35811, MSB30651, P8

Lab Sample ID: 320-117508-8
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.06 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 12:47	S1C	EET SAC
Total/NA	Prep	SHAKE	RA		1.06 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	821391	12/11/24 15:34	S1C	EET SAC

Client Sample ID: NK35643, MSB29100, P9

Lab Sample ID: 320-117508-9
Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.08 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821391	12/11/24 15:53	S1C	EET SAC

Client Sample ID: NK170946, P10

Lab Sample ID: 320-117508-10

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			0.98 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 13:26	S1C	EET SAC

Client Sample ID: NK100328, Liver, AEPIR, P11

Lab Sample ID: 320-117508-11

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			0.96 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 13:45	S1C	EET SAC

Client Sample ID: NK165232, MSB26431, P12

Lab Sample ID: 320-117508-12

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			0.86 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 14:05	S1C	EET SAC

Client Sample ID: NK35676, MSB29118, P14

Lab Sample ID: 320-117508-13

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.00 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 14:24	S1C	EET SAC

Client Sample ID: NK35678, MSB29131, P15

Lab Sample ID: 320-117508-14

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.02 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 14:44	S1C	EET SAC
Total/NA	Prep	SHAKE	RA		1.02 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	821391	12/11/24 16:12	S1C	EET SAC

Client Sample ID: NK35669, MSB29093, P16

Lab Sample ID: 320-117508-15

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			0.99 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 15:03	S1C	EET SAC
Total/NA	Prep	SHAKE	RA		0.99 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	821391	12/11/24 16:32	S1C	EET SAC

Client Sample ID: NK35935, MSB39605, P17

Lab Sample ID: 320-117508-16

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.01 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 15:23	S1C	EET SAC

Client Sample ID: NK35958, MSB40165, P18

Lab Sample ID: 320-117508-17

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.00 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	820819	12/10/24 15:42	S1C	EET SAC

Client Sample ID: NK35816, MSB30670, P19

Lab Sample ID: 320-117508-18

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.96 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821391	12/11/24 16:51	S1C	EET SAC

Client Sample ID: NK35804, MSB30716, P20

Lab Sample ID: 320-117508-19

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			1.07 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821391	12/11/24 17:11	S1C	EET SAC

Lab Chronicle

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK35876, MSB39746, P22

Lab Sample ID: 320-117508-20

Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	SHAKE			0.99 g	10.0 mL	820079	12/06/24 12:01	ATB	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820080	12/06/24 12:03	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821391	12/11/24 17:49	S1C	EET SAC

Client Sample ID: NK35910, MSB39349, P23

Lab Sample ID: 320-117508-21

Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			0.97 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/12/24 23:53	S1C	EET SAC

Client Sample ID: NK35817, MSB30650, P24

Lab Sample ID: 320-117508-22

Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			0.95 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 00:13	S1C	EET SAC

Client Sample ID: Pool 25, Duck PFAS, P25

Lab Sample ID: 320-117508-23

Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			0.89 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 00:32	S1C	EET SAC

Client Sample ID: NK282630, MSB50169, P26

Lab Sample ID: 320-117508-24

Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			0.68 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 00:51	S1C	EET SAC

Client Sample ID: NK276851, MSB46239, P28

Lab Sample ID: 320-117508-25

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			0.78 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 01:11	S1C	EET SAC

Client Sample ID: NK282547, MSB49842, P29

Lab Sample ID: 320-117508-26

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			1.10 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 01:30	S1C	EET SAC

Client Sample ID: NK276660, MSB45963, P30

Lab Sample ID: 320-117508-27

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			0.58 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 01:50	S1C	EET SAC

Client Sample ID: NK282696, MSB50223, P31

Lab Sample ID: 320-117508-28

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			0.57 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 02:29	S1C	EET SAC

Client Sample ID: NK283601, Spat. Cly, Liver, ABJ34298, MSB1011285, P32

Lab Sample ID: 320-117508-29

Date Collected: 12/04/24 00:00

Matrix: Tissue

Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			1.67 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 02:48	S1C	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	RA		1.67 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	822235	12/16/24 20:53	S1C	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	DL		1.67 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	822525	12/17/24 08:32	S1C	EET SAC

Client Sample ID: NK283602, JLW125, S. Calypeata, L, MSB1011279, P33

Lab Sample ID: 320-117508-30

Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			1.02 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 03:07	S1C	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	RA		1.02 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	822235	12/16/24 16:21	S1C	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			1.02 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		100	1 mL	1 mL	823808	12/21/24 00:33	S1C	EET SAC

Client Sample ID: NK283605, Liver, Spatula, MSB1011318, P34

Lab Sample ID: 320-117508-31

Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			1.16 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 03:27	S1C	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	DL		1.16 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	822235	12/16/24 17:19	S1C	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	RA		1.16 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	822235	12/16/24 21:12	S1C	EET SAC

Client Sample ID: NK283606, Spatula, Liver, MSB1011339, P35

Lab Sample ID: 320-117508-32

Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			1.06 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 03:46	S1C	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	DL		1.06 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	822235	12/16/24 17:39	S1C	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	RA		1.06 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	822235	12/16/24 21:32	S1C	EET SAC

Client Sample ID: NK283607, S. calypteata, Liver, MSB1011310, P36

Lab Sample ID: 320-117508-33

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			1.13 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 04:06	S1C	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	DL		1.13 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	822235	12/16/24 17:58	S1C	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	RA		1.13 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	822235	12/16/24 21:51	S1C	EET SAC

Client Sample ID: NK283608, S. calypeata, L, MSB1011324, P37

Lab Sample ID: 320-117508-34

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			1.32 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 04:25	S1C	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	DL		1.32 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	822235	12/16/24 18:18	S1C	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	RA		1.32 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	822235	12/16/24 22:11	S1C	EET SAC

Client Sample ID: NK283615, S. calypeata, L, MSB1011402, P38

Lab Sample ID: 320-117508-35

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			1.06 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 04:44	S1C	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	DL		1.06 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	822235	12/16/24 18:56	S1C	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	RA		1.06 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	822235	12/16/24 22:30	S1C	EET SAC

Client Sample ID: NK283619, S. calypeata, L, MSB1011416, P39

Lab Sample ID: 320-117508-36

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			1.33 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 05:04	S1C	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	DL		1.33 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	822235	12/16/24 19:16	S1C	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	RA		1.33 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	822235	12/16/24 22:49	S1C	EET SAC

Client Sample ID: NK283621, S. calypteata, L, MSB1011430, P40

Lab Sample ID: 320-117508-37

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			1.31 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 05:23	S1C	EET SAC
Total/NA	Pre Prep	In-House	RA		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	RA		1.31 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	RA	1	1 mL	1 mL	822235	12/16/24 16:41	S1C	EET SAC
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			1.31 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		100	1 mL	1 mL	823808	12/21/24 00:52	S1C	EET SAC

Client Sample ID: NK283622, L, S. calypeata, MSB1011451, P41

Lab Sample ID: 320-117508-38

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			1.29 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 06:02	S1C	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	DL		1.29 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	822235	12/16/24 19:35	S1C	EET SAC

Client Sample ID: NK283626, S. calypeata, L, MSB1011466, P42

Lab Sample ID: 320-117508-39

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			1.42 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 06:21	S1C	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	DL		1.42 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	822235	12/16/24 19:55	S1C	EET SAC

Client Sample ID: NK283627, S. calypeata, L, MSB1011473, P43

Lab Sample ID: 320-117508-40

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE			1.27 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821645	12/13/24 06:41	S1C	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820822	12/10/24 03:38	R1T	EET SAC
Total/NA	Prep	SHAKE	DL		1.27 g	10.0 mL	820824	12/10/24 03:40	ATB	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	822235	12/16/24 20:14	S1C	EET SAC

Client Sample ID: NK283629, S. calypteata, Liver, MSB1011446, P44

Lab Sample ID: 320-117508-41

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820939	12/10/24 11:38	MKC	EET SAC
Total/NA	Prep	SHAKE			0.80 g	10.0 mL	820977	12/10/24 13:20	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821394	12/11/24 20:05	P1R	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820939	12/10/24 11:38	MKC	EET SAC
Total/NA	Prep	SHAKE	DL		0.80 g	10.0 mL	820977	12/10/24 13:20	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	821644	12/12/24 17:44	P1R	EET SAC

Client Sample ID: NK283631, L, A. americana, MSB1011511, P45

Lab Sample ID: 320-117508-42

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820939	12/10/24 11:38	MKC	EET SAC
Total/NA	Prep	SHAKE			1.10 g	10.0 mL	820977	12/10/24 13:20	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821394	12/11/24 20:25	P1R	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820939	12/10/24 11:38	MKC	EET SAC
Total/NA	Prep	SHAKE	DL		1.10 g	10.0 mL	820977	12/10/24 13:20	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	822235	12/17/24 00:26	S1C	EET SAC

Client Sample ID: NK283633, L, S. clypeata, MSB1011525, P46

Lab Sample ID: 320-117508-43

Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820939	12/10/24 11:38	MKC	EET SAC
Total/NA	Prep	SHAKE			1.12 g	10.0 mL	820977	12/10/24 13:20	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821394	12/11/24 20:44	P1R	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820939	12/10/24 11:38	MKC	EET SAC
Total/NA	Prep	SHAKE	DL		1.12 g	10.0 mL	820977	12/10/24 13:20	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	821644	12/12/24 18:04	P1R	EET SAC

Client Sample ID: NK283641, L, S. clypeata, MSB1011577, P47

Lab Sample ID: 320-117508-44

Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820939	12/10/24 11:38	MKC	EET SAC
Total/NA	Prep	SHAKE			1.11 g	10.0 mL	820977	12/10/24 13:20	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821394	12/11/24 21:04	P1R	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820939	12/10/24 11:38	MKC	EET SAC
Total/NA	Prep	SHAKE	DL		1.11 g	10.0 mL	820977	12/10/24 13:20	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	821644	12/12/24 18:23	P1R	EET SAC

Client Sample ID: NK283644, S. clypeata, Liver, MSB1011744, P48

Lab Sample ID: 320-117508-45

Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820939	12/10/24 11:38	MKC	EET SAC
Total/NA	Prep	SHAKE			1.15 g	10.0 mL	820977	12/10/24 13:20	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821394	12/11/24 21:23	P1R	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820939	12/10/24 11:38	MKC	EET SAC
Total/NA	Prep	SHAKE	DL		1.15 g	10.0 mL	820977	12/10/24 13:20	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	821644	12/12/24 18:43	P1R	EET SAC

Client Sample ID: NK283669, S. clypeata, Liver, MSB1011800, P49

Lab Sample ID: 320-117508-46

Date Collected: 12/04/24 00:00
Matrix: Tissue
Date Received: 12/05/24 09:35

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820939	12/10/24 11:38	MKC	EET SAC
Total/NA	Prep	SHAKE			1.13 g	10.0 mL	820977	12/10/24 13:20	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821394	12/11/24 21:42	P1R	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820939	12/10/24 11:38	MKC	EET SAC
Total/NA	Prep	SHAKE	DL		1.13 g	10.0 mL	820977	12/10/24 13:20	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	821644	12/12/24 19:02	P1R	EET SAC

Lab Chronicle

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Client Sample ID: NK283674, S. clypeata, Liver, MSB1011812, P50

Lab Sample ID: 320-117508-47

Date Collected: 12/04/24 00:00
Date Received: 12/05/24 09:35

Matrix: Tissue

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Pre Prep	In-House			1.0 g	1.0 g	820939	12/10/24 11:38	MKC	EET SAC
Total/NA	Prep	SHAKE			1.17 g	10.0 mL	820977	12/10/24 13:20	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS		1	1 mL	1 mL	821394	12/11/24 22:02	P1R	EET SAC
Total/NA	Pre Prep	In-House	DL		1.0 g	1.0 g	820939	12/10/24 11:38	MKC	EET SAC
Total/NA	Prep	SHAKE	DL		1.17 g	10.0 mL	820977	12/10/24 13:20	MKC	EET SAC
Total/NA	Analysis	B/L/T PFAS	DL	100	1 mL	1 mL	821644	12/12/24 19:21	P1R	EET SAC

Laboratory References:

EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

Accreditation/Certification Summary

Client: University of New Mexico
Job ID: 320-117508-1
Project/Site: UNM_PFAS in Tissue, Holloman

Laboratory: Eurofins Sacramento

All accreditations/certifications held by this laboratory are listed. Not all accreditations/certifications are applicable to this report.

Authority	Program	Identification Number	Expiration Date
Alaska (UST)	State	17-020	02-20-27
ANAB	Dept. of Defense ELAP	L2468	01-20-27
ANAB	Dept. of Energy	L2468.01	01-20-27
ANAB	ISO/IEC 17025	L2468	01-20-27
Arizona	State	AZ0708	08-11-25
Arkansas DEQ	State	88-0691	05-18-25
California	State	2897	01-31-26
Colorado	State	CA00044	08-31-25
Florida	NELAP	E87570	06-30-25
Georgia	State	4040	01-29-25
Hawaii	State	Eurofins Sacramento	01-29-25
Illinois	NELAP	200060	03-31-25
Kansas	NELAP	E-10375	10-31-25
Louisiana	NELAP	01944	06-30-25
Louisiana (All)	NELAP	01944	06-30-25
Maine	State	CA00004	04-14-26
Michigan	State	9947	01-29-25
Minnesota	NELAP	2749448	12-31-25
Nevada	State	CA00044	07-31-25
New Hampshire	NELAP	2997	04-19-25
New Jersey	NELAP	CA005	06-30-25
New York	NELAP	11666	04-01-25
Ohio	State	41252	01-29-25
Oregon	NELAP	4040	01-29-25
Texas	NELAP	T104704399-23-17	05-31-25
US Fish & Wildlife	US Federal Programs	A22139	04-30-25
USDA	US Federal Programs	P330-18-00239	02-28-26
Utah	NELAP	CA000442023-16	02-28-25
Virginia	NELAP	460278	03-14-25
Washington	State	C581	05-05-25
West Virginia (DW)	State	9930C	01-31-25
Wisconsin	State	998204680	08-31-25
Wyoming	State Program	8TMS-L	01-28-19 *

* Accreditation/Certification renewal pending - accreditation/certification considered valid.

Method Summary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Method	Method Description	Protocol	Laboratory
B/L/T PFAS	Branched, Linear and Total PFAS	EPA	EET SAC
In-House	Tissue Preparation/Homgenization	NOAA	EET SAC
SHAKE	Shake Extraction with Ultrasonic Bath Extraction	SW846	EET SAC

Protocol References:

EPA = US Environmental Protection Agency

NOAA = National Marine Fisheries Service, National Oceanic And Atmospheric Administration, Seattle, WA, November 1988

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

EET SAC = Eurofins Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

Sample Summary

Client: University of New Mexico
Project/Site: UNM_PFAS in Tissue, Holloman

Job ID: 320-117508-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
320-117508-1	NK14474, MSB18488, Pool1, P1	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-2	NK9098, Liver, P2	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-3	NK2445, Liver, AFP7B, P3	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-4	NK2444, Liver, AFP7A, P4	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-5	NK35660, MSB29117, P5	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-6	NK35661, MSB29140, P6	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-7	NK35655, MSB29134, P7	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-8	NK35811, MSB30651, P8	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-9	NK35643, MSB29100, P9	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-10	NK170946, P10	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-11	NK100328, Liver, AEPIR, P11	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-12	NK165232, MSB26431, P12	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-13	NK35676, MSB29118, P14	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-14	NK35678, MSB29131, P15	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-15	NK35669, MSB29093, P16	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-16	NK35935, MSB39605, P17	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-17	NK35958, MSB40165, P18	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-18	NK35816, MSB30670, P19	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-19	NK35804, MSB30716, P20	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-20	NK35876, MSB39746, P22	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-21	NK35910, MSB39349, P23	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-22	NK35817, MSB30650, P24	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-23	Pool 25, Duck PFAS, P25	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-24	NK282630, MSB50169, P26	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-25	NK276851, MSB46239, P28	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-26	NK282547, MSB49842, P29	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-27	NK276660, MSB45963, P30	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-28	NK282696, MSB50223, P31	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-29	NK283601, Spat. Cly, Liver, ABJ34298, MSB1011285, P32	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-30	NK283602, JLW125, S. Calypeata, L, MSB1011279, P33	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-31	NK283605, Liver, Spatula, MSB1011318, P34	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-32	NK283606, Spatula, Liver, MSB1011339, P35	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-33	NK283607, S. calypteata, Liver, MSB1011310, P36	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-34	NK283608, S. calypeata, L, MSB1011324, P37	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-35	NK283615, S. calypeata, L, MSB1011402, P38	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-36	NK283619, S. calypeata, L, MSB1011416, P39	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-37	NK283621, S. calypteata, L, MSB1011430, P40	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-38	NK283622, L, S. calypeata, MSB1011451, P41	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-39	NK283626, S. calypeata, L, MSB1011466, P42	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-40	NK283627, S. calypeata, L, MSB1011473, P43	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-41	NK283629, S. calypteata, Liver, MSB1011446, P44	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-42	NK283631, L, A. americana, MSB1011511, P45	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-43	NK283633, L, S. clypteata, MSB1011525, P46	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-44	NK283641, L, S. clypteata, MSB1011577, P47	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-45	NK283644, S. clypeata, Liver, MSB1011744, P48	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-46	NK283669, S. clypteata, Liver, MSB1011800, P49	Tissue	12/04/24 00:00	12/05/24 09:35
320-117508-47	NK283674, S. clypeata, Liver, MSB1011812, P50	Tissue	12/04/24 00:00	12/05/24 09:35

Eurofins Env. Testing Northern California
880 Riverside Parkway
West Sacramento, CA 95605
Phone: 916.373.5600

Chain of Custody Record

eurofins

Client Contact	Report To: Jean-Luc Cartron and Christopher Wi	Site Contact:	Date: 12/04/2024	COC No:
Jean-Luc Cartron UNM jlec@unm edu	email: jlec@unm.edu,cwitt@unm.edu	Lab Contact: Linda Laver	Carrier: FedEx	1 of 2 COCs
Christopher Witt, UNM, cwitt@unm.edu	Analysis Turnaround Time			Job No.
Mariel Campbell, UNM, campmlc@unm.edu	Business Days (BD) _____			
	TAT if different from Above _____			pler
	☐ 2 weeks			
	☐ 1 week			
	☐ 2 days			
	☐ 1 day			

320-117508 Chain of Custody

Sample Identification	Sample Date	Sample Time	Sample Type	Matrix	# of Cont.	Filtered Sample	Enter requested analyses in these field	Sample Specific Notes:
NK14474, MSB18488, Pool1, P1	4-Dec-24		liver		1			Pool 1
NK9098, Liver, P2	4-Dec-24		liver		1			Pool 2
NK 2445, Liver, AFP7B, P3	4-Dec-24		liver		1			Pool 3
NK2444, Liver AFP7A, P4	4-Dec-24		liver		1			Pool 4
NK35660, MSB29117, P5	4-Dec-24		liver		1			Pool 5
NK35661, MSB29140, P6	4-Dec-24		liver		1			Pool 6
NK35655, MSB29134, P7	4-Dec-24		liver		1			Pool 7
NK35811, MSB30651, P8	4-Dec-24		liver		1			Pool 8
NK35643, MSB29100, P9	4-Dec-24		liver		1			Pool 9
NK170946, P10	4-Dec-24		liver		1			Pool 10
NK100328, Liver, AEP1R, P11	4-Dec-24		liver		1			Pool 11
NK165232, MSB26431, P12	4-Dec-24		liver		1			Pool 12
NK35676, MSB29118, P14	4-Dec-24		liver		1			Pool 14
NK35678, MSB29131, P15	4-Dec-24		liver		1			Pool 15
NK35669, MSB29093, P16	4-Dec-24		liver		1			Pool 16
NK35935, MSB39605, P17	4-Dec-24		liver		1			Pool 17
NK35958, MSB40165, P18	4-Dec-24		liver		1			Pool 18
NK35816, MSB30670, P19	4-Dec-24		liver		1			Pool 19
NK35804, MSB30716, P20	4-Dec-24		liver		1			Pool 20
NK35876, MSB39746, P22	4-Dec-24		liver		1			Pool 22
NK35910, MSB39349, P23	4-Dec-24		liver		1			Pool 23
NK35817 MSB30650, P24	4-Dec-24		liver		1			Pool 24
					1			
					1			

Preservation Used: 1= Ice, 2= HCl; 3= H2SO4; 4=HNO3; 5=NaOH, 6= Other ___ice_____

Possible Hazard Identification
☒ *Non-Hazard* ☐ *Flammable* ☐ *Skin Irritant* *Poison B* *Unknown* ☐

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☐ *Return To Client* ☒ *Disposal By Lab* ☐ *Archive For _____ Months*

Special Instructions/QC Requirements & Comments: Page 1 of 2 for same shipment and COC. Missing Pools 13 and 21 use Pool numbers for tracking and reporting

Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:
Mariel L. Campbell	Museum of SW Biology	12/4/2024		ECTSac	12/5/24 0935
Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:
					SCI USLA
Relinquished by	Company:	Date/Time:	Received by:	Company:	Date/Time:

-12.3°C

NMED Exhibits 65

Eurofins Env. Testing Northern California
880 Riverside Parkway
West Sacramento, CA 95605
Phone: 916.373.5600

Chain of Custody Record

eurofins

Client Contact	Report To: Jean-Luc Cartron and Christopher Wi	Site Contact:	Date: 12/04/2024	COC No:
Jean-Luc Cartron UNM jlec@unm.edu	email: jlec@unm.edu,cwitt@unm.edu	Lab Contact: Linda Laver	Carrier: FedEx	2 of 2 COCs
Christopher Witt, UNM cwitt@unm.edu	Analysis Turnaround Time			Job No.
Mariel Campbell, UNM, campmlc@unm.edu	Business Days (BD)			
	TAT if different from Above			Field Sampler:
	☐ 2 weeks			
	☐ 1 week			
	☐ 2 days			
	☐ 1 day			

Sample Identification	Sample Date	Sample Time	Sample Type	Matrix	# of Cont.	Filtered Sample	Enter requested analyses in these fields	Sample Specific Notes:
Pool 25, Duck PFAS, P25	4-Dec-24		liver		1			Pool 25
NK282630, MSB50169 P26	4-Dec-24		liver		1			Pool 26
NK276851 MSB46239 P28	4-Dec-24		liver		1			Pool 28
NK282547, MSB49842, P29	4-Dec-24		liver		1			Pool 29
NK276660, MSB45963, P30	4-Dec-24		liver		1			Pool 30
NK282696, MSB50223, P31	4-Dec-24		liver		1			Pool 31
NK283601 Spat. Cly Liver ABJ34298, MSB1011285, P32	4-Dec-24		liver		1			Pool 32
NK283602, JLW125, S. Calypeata, L, MSB1011279, P33	4-Dec-24		liver		1			Pool 33
NK283605, Liver, Spatula, MSB1011318, P34	4-Dec-24		liver		1			Pool 34
NK283606, Spatula, Liver, MSB1011339, P35	4-Dec-24		liver		1			Pool 35
NK283607, S. calypteata, Liver, MSB1011310, P36	4-Dec-24		liver		1			Pool 36
NK283608, S. calypeata, L, MSB1011324, P37	4-Dec-24		liver		1			Pool 37
NK283615, S. calypeata, L, MSB1011402, P38	4-Dec-24		liver		1			Pool 38
NK283619, S. calypeata, L, MSB1011416, P39	4-Dec-24		liver		1			Pool 39
NK283621 S. calypteata, L, MSB1011430, P40	4-Dec-24		liver		1			Pool 40
NK283622, L, S. calypeata, MSB1011451 P41	4-Dec-24		liver		1			Pool 41
NK283626, S. calypeata, L, MSB1011466, P42	4-Dec-24		liver		1			Pool 42
NK283627, S. calypeata, L, MSB1011473, P43	4-Dec-24		liver		1			Pool 43
NK283629 S. calypteata, Liver MSB1011446, P44	4-Dec-24		liver		1			Pool 44
NK283631, L, A. americana, MSB1011511, P45	4-Dec-24		liver		1			Pool 45
NK283633, L, S. clypteata, MSB1011525 P46	4-Dec-24		liver		1			Pool 46
NK283641 L, S. clypteata, MSB1011577 P47	4-Dec-24		liver					Pool 47
NK283644, S clypeata, Liver MSB1011744, P48	4-Dec-24		liver					Pool 48
NK283669 S clypteata, Liver, MSB1011800, P49	4-Dec-24		liver					Pool 49
NK283674, S. clypeata, Liver MSB1011812, P50	4-Dec-24		liver					Pool 50

Preservation Used. 1= Ice, 2= HCl; 3= H2SO4; 4=HNO3; 5=NaOH, 6= Other ice

Possible Hazard Identification
☐ *Non-Hazard* ☐ *Flammable* ☐ *Skin Irritant* *Poison B* *Unknown* ☐

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☐ *Return To Client* ☐ *Disposal By Lab* ☐ *Archive For* _____ *Months*

Special Instructions/QC Requirements & Comments. Page 2 of 2 for same shipment and COC: Missing Pool 27- use Pool numbers for tracking and reporting

Relinquished by	Company	Date/Time:	Received by	Company	Date/Time:
Mariel L. Campbell	Museum of SW Biology	12/4/2024		EETSac	12/5/24 0935
Relinquished by	Company	Date/Time:	Received by	Company	Date/Time: 12/5/24
Relinquished by	Company	Date/Time:	Received by	Company	Date/Time:

~ 12.3°C

NMED Exhibits 65

eurofins | Environment Testing

Sacramento Sample Receiving Notes (SSRN)

Loc: 320
117508

Tracking # 7704 9866 6565

Job _____

SO / PO / FO / SAT / 2-Day / Ground / UPS / CDO / Courier
GSL / OnTrac / Goldstreak / USPS / Other_____

Use this form to record Sample Custody Seal, Cooler Custody Seal, Temperature & corrected Temperature & other observations
File in the job folder with the COC

Therm ID: 104 Corr Factor (+/-): N/A °C

Ice_____ Wet_____ Gel _____ Other Dry Ice

Cooler Custody Seal —

Cooler ID —

Temp Observed: -12.3 °C Corrected -12.3 °C

From Temp Blank ☐ Sandwich ☑ Sidewall ☐

Opening/Processing The Shipment	Yes	No	NA
Cooler compromised/tampered with?	☐	☑	☐
Cooler Temperature is acceptable?	☑	☐	☐
Frozen samples show signs of thaw?	☐	☑	☐

SO 12/4/24

Initials DO Date 12/4/24
SO 12/5/24

Unpacking/Labeling The Samples	Yes	No	NA
Containers are not broken or leaking?	☑	☐	☐
Samples compromised/tampered with?	☐	☑	☐
COC is complete w/o discrepancies	☑	☐	☐
Sample custody seal?	☐	☐	☑
Sample containers have legible labels?	☑	☐	☐
Sample date/times are provided?	☑	☐	☐
Appropriate containers are used?	☑	☐	☐
Sample bottles are completely filled?	☑	☐	☐
Sample preservatives verified?	☐	☐	☑
Is the Field Sampler's name on COC?	☐	☐	☑
Samples w/o discrepancies?	☐	☑	☐
Zero headspace?*	☐	☐	☑
Alkalinity has no headspace?	☐	☐	☑
Perchlorate has headspace? (Methods 314, 331, 6850)	☐	☐	☑
Multiphasic samples are not present?	☑	☐	☐

*Containers requiring zero headspace have no headspace, or bubble < 6 mm (1/4")

Initials DM Date 12/05/24

Notes: Sample #45 and COC do not match:

COC: NK283644
COA: NK283664

Trizma Lot #(s) _____

_____

_____

Ammonium
Acetate Lot #(s) _____

_____

_____

Login Completion	Yes	No	NA
Receipt Temperature on COC?	☑	☐	☐
NCM Filed?	☐	☐	☐
Samples received within hold time?	☑	☐	☐
Log Release checked in TALS?	☑	☐	☐

Initials DM Date 12/05/24

Appendix B

Necropsy Results

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-20096
Owner: UNM Museum of Southwestern Bio
ID: NK284442
Species: Killdeer
Breed: Killdeer

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 07/11/24
Reported: 08/13/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 76 grams, male, *Charadrius vociferus* (killdeer) identified as "NK284442". The bird was in good body condition with minimal postmortem decomposition. The liver mass was 2.02 grams. The combined kidney mass was 0.75 grams. The testicles were 0.06 centimeters x 0.04 centimeters. There were no significant lesions in the trachea, esophagus, lungs, airsacs, heart, liver, spleen, proventriculus, ventriculus, small intestine, large intestine, pancreas, testicles, kidneys, skeletal muscle, or brain.

HISTOPATHOLOGY

There are rare perivascular infiltrates of small numbers of lymphocytes and plasma cells in the lung.

There are small numbers of perivascular infiltrates of small numbers of lymphocytes, plasma cells, and macrophages in the portal areas of the liver.

The lumen of the proventriculus contains two small degenerate helminths.

There are no significant microscopic lesions in the trachea, esophagus, thyroid tissue, heart, skeletal muscle, spleen, kidneys, ventriculus, small intestine, large intestine, pancreas, adrenal glands, testicles, or brain.

FINAL COMMENTS

The changes in the organs (mild perivascular inflammation in the lung and liver and endoparasitism in the proventriculus) are background lesions and likely of no clinical significance. There is no evidence of an infectious disease, neoplasia, or toxicosis.

CASE DIAGNOSIS

ENDOPARASITISM

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-20097
Owner: UNM Museum of Southwestern Bio
ID: NK284443
Species:
Breed:

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 07/11/24
Reported: 08/13/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 322 grams, male, *Recurvirostra americana* (American avocet) identified as "NK284443". The bird was in good body condition with minimal postmortem decomposition. The bird had been gunshot. The liver mass was 9.12 grams. The combined kidney mass was 2.9 grams. The testicles were 0.07 centimeters x 0.03 centimeters. The lumen of the small intestine contained at least one adult cestode (tapeworm). There were no significant lesions in the trachea, esophagus, lungs, airsacs, heart, liver, spleen, proventriculus, ventriculus, large intestine, pancreas, testicles, kidneys, skeletal muscle, or brain.

HISTOPATHOLOGY

The portal areas of the liver contain small numbers of lymphocytes and plasma cells.

The myofibers of the heart contain moderate amounts of perinuclear golden-brown pigment consistent with lipofuscin in the cytoplasm. There are rare perivascular infiltrates of small numbers of lymphocytes in the myocardium.

There are small numbers of myofibers in the skeletal muscle that contain small amounts of perimembrane golden-brown pigment consistent with lipofuscin in the cytoplasm. There are rare perivascular infiltrates of small numbers of lymphocytes.

The interstitium of the testicles contain infiltrates of moderate numbers of lymphocytes with lesser numbers of plasma cells and macrophages. The lymphocytes often extend into the seminiferous tubules where there is degeneration and necrosis of the spermatogenic epithelium and Sertoli cells and almost a complete absence of spermatozoa production.

The lumen of the small intestine contains an adult cestode (tapeworm). The lamina propria of the mucosal epithelium of the large intestine contains numerous lymphocytes, eosinophils, and lesser numbers of plasma cells. The mesentery contains perivascular infiltrates of moderate numbers of lymphocytes and plasma cells.

There are perivascular infiltrates of moderate numbers of lymphocytes and plasma cells on the serosa of the proventriculus.

There are perivascular infiltrates of moderate numbers of lymphocytes and plasma cells in the fat adjacent to the spleen.

The mucosal epithelium and submucosa of the ventriculus contain multiple eosinophilic granulomas characterized by a brightly eosinophilic center of necrotic debris surrounded by macrophages, multinucleated giant cells, eosinophils and small numbers of lymphocytes. One eosinophilic granuloma contains a degenerate nematode. There are large numbers of eosinophils in the lamina propria of the ventriculus. There are rare tangential segments of larval rhabditiform nematodes in the mucosal epithelium of the ventriculus one of which is associated with a large brightly eosinophilic focus of necrosis. The koilin layer contains small numbers of degenerate nematodes.

There are no significant microscopic lesions in the lung, trachea, esophagus, thymus, spleen, kidneys, large intestine, pancreas, adrenal glands, or brain.

FINAL COMMENTS

Most of the lesions in this bird are inflammatory lesions associated with endoparasitism in the small intestine and ventriculus. The inflammation in the mesentery, fat adjacent to the spleen, and in the liver are likely in response to endoparasitism. The bird has lipofuscin in the heart and skeletal muscle. Lipofuscin is considered a "wear-and-tear" pigment that accumulates as an animal ages. It is most commonly seen microscopically in older animals.

The bird also has moderate to severe lymphocytic orchitis (inflammation of the testicles) the cause of which could not be determined. There is degeneration and necrosis of the spermatogenic epithelium and Sertoli cells with almost complete absence of spermatozoa production associated with the orchitis. The orchitis is likely a sporadic event that only occurred in this bird.

CASE DIAGNOSIS

ENDOPARASITISM
ORCHITIS

John Ragsdale , DVM, PhD
Diplomate, ACVP

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-20098
Owner: UNM Museum of Southwestern Bio
ID: NK204441
Species: Red-winged Blackbird
Breed: Red-winged Blackbird

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 07/11/24
Reported: 08/13/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 37 grams, female, *Agelaius phoeniceus* (red-winged blackbird) identified as "NK284441". The bird was in good body condition with minimal postmortem decomposition. The liver mass was 1.33 grams. The combined kidney mass was 0.41 grams. The ovary was 0.06 centimeters x 0.04 centimeters with the largest ovum having a diameter of 0.015 centimeters. There were no significant lesions in the trachea, esophagus, lungs, airsacs, heart, liver, spleen, proventriculus, ventriculus, small intestine, large intestine, pancreas, testicles, kidneys, skeletal muscle, or brain.

HISTOPATHOLOGY

There are no significant microscopic lesions in the lung, trachea, esophagus, thyroid tissue, heart, liver, spleen, proventriculus, ventriculus, small intestine, large intestine, pancreas, ovary, oviduct, kidney, adrenal glands, skeletal muscle, or brain.

FINAL COMMENTS

There was no evidence of infectious disease, neoplasia, parasitism, or toxicosis.

CASE DIAGNOSIS

NORMAL TISSUE

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-20099
Owner: UNM Museum of Southwestern Bio
ID: NK284445
Species: Red-winged Blackbird
Breed: Red-winged Blackbird

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 07/11/24
Reported: 08/13/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 38 grams, female, *Agelaius phoeniceus* (red-winged blackbird) identified as "NK284445". The bird was in good body condition with minimal postmortem decomposition. The liver mass was 1.16 grams. The combined kidney mass was 0.51 grams. The ovary was 0.12 centimeters x 0.04 centimeters with largest ovum having a diameter of 0.015 centimeters. There were no significant lesions in the trachea, esophagus, lungs, airsacs, heart, liver, spleen, proventriculus, ventriculus, small intestine, large intestine, pancreas, testicles, kidneys, skeletal muscle, or brain.

HISTOPATHOLOGY

There are no significant microscopic lesions in the lung, trachea, esophagus, heart, liver, spleen, kidneys, adrenal glands, proventriculus, ventriculus, small intestine, large intestine, pancreas, ovary, oviduct, skeletal muscle, or brain.

FINAL COMMENTS

There is no evidence of an infectious disease, neoplasia, parasitism, or toxicosis.

CASE DIAGNOSIS

NORMAL TISSUE

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-20100
Owner: UNM Museum of Southwestern Bio
ID: NK204447
Species:
Breed:

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 07/11/24
Reported: 08/13/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 31 grams, female, *Tyrannus verticalis* (western kingbird) identified as "NK284447". The bird was in good body condition with minimal postmortem decomposition. The liver mass was 0.92 grams. The combined kidney mass was 0.45 grams. The ovary was 0.08 centimeters x 0.04 centimeters with the largest ovum having a diameter of 0.05 centimeters. There was an approximately 5 cm long thin white nematode in the right abdominal airsac. There were no significant lesions in the trachea, esophagus, lungs, heart, liver, spleen, proventriculus, ventriculus, small intestine, large intestine, pancreas, testicles, kidneys, skeletal muscle, or brain.

HISTOPATHOLOGY

The portal vein adjacent to the liver contains paired adult (female and male) flukes. The flukes are surrounded by fibrin and macrophages. There are small numbers or portal areas in the liver that contain flukes eggs surrounded by variable numbers of macrophages mixed with lesser numbers of lymphocytes and eosinophils. There are also small numbers of filamentous bacteria surrounded by and within the cytoplasm of macrophages in one portal area.

The lumen of the small intestine contained a cross-section of a single small nematode.

The kidneys contain small numbers of interstitial infiltrates of macrophages and lymphocytes that widely separate the tubules.

There are no significant microscopic lesions in the trachea, esophagus, lungs, heart, spleen, ovary, oviduct, proventriculus, ventriculus, large intestine, pancreas, skeletal muscle, or brain.

FINAL COMMENTS

The bird had an airsac nematode, nematodes in the small intestine (endoparasitism), and flukes within the portal vein (avian schistosomiasis). The mild lymphohistiocytic interstitial nephritis could have been the result of parasite migration through a kidney. There was no evidence of an infectious disease, neoplasia, or toxicosis.

CASE DIAGNOSIS

NEPHRITIS - INTERSTITIAL
PARASITISM - HELMINTH

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #:	24-20101
Owner:	UNM Museum of Southwestern Bio
ID:	NK284451
Species:	Bird NOS
Breed:	Bird NOS

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 07/11/24
Reported: 08/13/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 10 grams, male, *Geothlypis trichas* (common yellowthroat) identified as "NK284451". The bird was in good body condition with minimal postmortem decomposition. The liver mass was 0.27 grams. The combined kidney mass was 0.08 grams. The testicles were 0.09 centimeters x 0.06 centimeters. The pectoral muscles contained numerous approximately 0.4 cm x 0.1 cm white oblong foci with smaller numbers of similar foci in skeletal muscle throughout the body. There were no significant lesions in the trachea, esophagus, lungs, airsacs, heart, liver, spleen, proventriculus, ventriculus, small intestine, large intestine, pancreas, testicles, kidneys, or brain.

HISTOPATHOLOGY

The skeletal muscle contains multiple large ovoid protozoal cysts that measure up to 5,116 um x 1,387 um within an individual myofiber. The cysts contained numerous approximately 10 um long bradyzoites.

The dorsal aspect of a cerebral hemisphere has a small focus of perivascular to diffuse infiltrates of small numbers of microglia, lymphocytes, and rare hemosiderin-laden macrophages.

There are no significant microscopic lesions in the trachea, esophagus, lung, heart, liver, proventriculus, ventriculus, small intestine, large intestine, pancreas, kidneys, adrenal gland, or testicles.

FINAL COMMENTS

The bird had embedded *Sarcocystis* species protozoal cysts in the skeletal muscle (sarcocystosis, rice breast disease). It also had a small focus of nonsuppurative encephalitis that was likely associated with prior trauma to the area. The hemosiderin within macrophages in the focus indicates previous hemorrhage in the area. There were no other lesions to indicate an infectious disease, neoplasia, or toxicosis.

CASE DIAGNOSIS

SARCOCYSTIS
ENCEPHALITIS - NONSUPPURATIVE
PARASITISM - PROTOZOAN

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-20102
Owner: UNM Museum of Southwestern Bio
ID: NK284449
Species: Bird NOS
Breed: Bird NOS

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 07/11/24
Reported: 08/13/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 11 grams, male, *Geothlypis trichas* (common yellowthroat) identified as "NK284449". The bird was in good body condition with minimal postmortem decomposition. The liver mass was 0.28 grams. The combined kidney mass was 0.15 grams. The testicles were 0.08 centimeters x 0.06 centimeters. There were no significant lesions in the trachea, esophagus, lungs, airsacs, heart, liver, spleen, proventriculus, ventriculus, small intestine, large intestine, pancreas, testicles, kidneys, skeletal muscle, or brain.

HISTOPATHOLOGY

There are no significant microscopic lesions in the trachea, esophagus, thyroid tissue, lungs, heart, liver, kidneys, testicles, proventriculus, ventriculus, small intestine, large intestine, pancreas, skeletal muscle, or brain.

FINAL COMMENTS

There is no evidence of an infectious disease, parasitism, neoplasia, or toxicosis.

CASE DIAGNOSIS

NORMAL TISSUE

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-20103
Owner: UNM Museum of Southwestern Bio
ID: NK204444
Species: Red-winged Blackbird
Breed: Red-winged Blackbird

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 07/11/24
Reported: 08/13/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 36 grams, female, *Agelaius phoeniceus* (red-winged blackbird) identified as "NK284444". The bird was in good body condition with minimal postmortem decomposition. The liver mass was 1.10 grams. The combined kidney mass was 0.43 grams. The ovary was 0.06 centimeters x 0.04 centimeters with the largest ovum having a diameter of 0.01 centimeters. There were no significant lesions in the trachea, esophagus, lungs, airsacs, heart, liver, spleen, proventriculus, ventriculus, small intestine, large intestine, pancreas, testicles, kidneys, skeletal muscle, or brain.

HISTOPATHOLOGY

There are no significant microscopic lesions in the trachea, esophagus, lungs, heart, liver, spleen, kidney, adrenal glands, proventriculus, ventriculus, small intestine, large intestine, pancreas, ovary, oviduct, skeletal muscle, or brain.

FINAL COMMENTS

There is no evidence of an infectious disease, neoplasia, parasitism, or toxicosis.

CASE DIAGNOSIS

NORMAL TISSUE

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-20104
Owner: UNM Museum of Southwestern Bio
ID: NK284448
Species:
Breed:

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 07/11/24
Reported: 08/13/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 34 grams, male, *Tyrannus verticalis* (western kingbird) identified as "NK284448". The bird was in good body condition with minimal postmortem decomposition. The liver mass was 1.09 grams. The combined kidney mass was 0.50 grams. The testicles were 0.06 centimeters x 0.03 centimeters. There were no significant lesions in the trachea, esophagus, lungs, airsacs, heart, liver, spleen, proventriculus, ventriculus, small intestine, large intestine, pancreas, testicles, kidneys, skeletal muscle, or brain.

HISTOPATHOLOGY

The seminiferous tubules in the right and left testicles are shrunken and separated by a relative increased amount of interstitium. The seminiferous tubules are lined by a thin layer of mostly Sertoli cells with a few spermatogenic epithelial cells. There is no spermatozoa production in the seminiferous tubules or spermatozoa in the epididymis.

The lumen of the small intestine contains an adult cestode (tapeworm).

There are no significant microscopic lesions in the trachea, esophagus, lungs, heart, liver, spleen, kidneys, proventriculus, ventriculus, large intestine, pancreas, skeletal muscle, or brain.

FINAL COMMENTS

The bird had testicular atrophy that was most likely due to seasonal atrophy/testicular inactivity. However, comparison of the testicles of other adult male western kingbirds in mid-July would be necessary to confirm that suspicion. The bird also had an adult tapeworm in the small intestine. There was no evidence of an infectious disease, neoplasia, or toxicosis.

CASE DIAGNOSIS

ENDOPARASITISM
TESTICULAR ATROPHY

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-20105
Owner: UNM Museum of Southwestern Bio
ID: NK284450
Species: Bird NOS
Breed: Bird NOS

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 07/11/24
Reported: 08/13/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 9 grams, female, *Geothlypis trichas* (common yellowthroat) identified as "NK284450". The bird was in good body condition with minimal postmortem decomposition. The liver mass was 0338 grams. The combined kidney mass was 0.11 grams. The ovary was 0.06 centimeters x 0.06 centimeters with the largest ovum being 0.01 centimeters in diameter. There were no significant lesions in the trachea, esophagus, lungs, airsacs, heart, liver, spleen, proventriculus, ventriculus, small intestine, large intestine, pancreas, testicles, kidneys, skeletal muscle, or brain.

HISTOPATHOLOGY

There are no significant microscopic lesions in the trachea, esophagus, lungs, heart, liver, kidneys, proventriculus, ventriculus, small intestine, large intestine, pancreas, skeletal muscle, or brain.

FINAL COMMENTS

There is no evidence of infectious disease, neoplasia, parasitism, or toxicosis.

CASE DIAGNOSIS

NORMAL TISSUE

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-20106
Owner: UNM Museum of Southwestern Bio
ID: NK284446
Species: Red-winged Blackbird
Breed: Red-winged Blackbird

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 07/11/24
Reported: 08/13/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 37 grams, female, *Agelaius phoeniceus* (red-winged blackbird) identified as "NK284446". The bird was in good body condition with minimal postmortem decomposition. The liver mass was 1.30 grams. The combined kidney mass was 0.44 grams. The ovary was 0.06 centimeters x 0.04 centimeters with the largest ovum have a diameter of 0.015 centimeters. There were no significant lesions in the trachea, esophagus, lungs, airsacs, heart, liver, spleen, proventriculus, ventriculus, small intestine, large intestine, pancreas, testicles, kidneys, skeletal muscle, or brain.

HISTOPATHOLOGY

The liver contains a few portal areas that contain infiltrates of small numbers lymphocytes, macrophages and plasma cells.

There are no significant microscopic lesions in the trachea, esophagus, lungs, heart, spleen, kidneys, adrenal glands, ovary, oviduct, proventriculus, ventriculus, small intestine, large intestine, pancreas, skeletal muscle, or brain.

FINAL COMMENTS

The bird had very mild inflammation in the portal areas of the liver. This is common in many species, including domestic species, and is not clinically significant. There is no evidence of infectious disease, parasitism, neoplasia, or toxicosis.

CASE DIAGNOSIS

INFLAMMATION

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

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End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-15155
Owner: UNM MUSEUM OF SOUTHWESTERN BIO
ID: NK311130
Species:
Breed:

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 05/16/24
Reported: 06/20/24
Final Report

CASE HISTORY

Specimen collected at Holloman Lake in Otero County, New Mexico. High exposure to PFAS very likely based on recent published research. Goal of necropsy is to document pathology related to PFAS at the organ and tissue levels. Specimens should be returned to UNM MSB and 1g of muscle tissue needed for PFAS screening.

NECROPSY

This is the body of a 44 g, adult, male, *Dipodomys merriami* , with minimal autolysis (necropsy performed within hours of death). The liver weighs 1.5 g, and the kidneys both weigh 0.5 g. All organs are within normal limits grossly.

HISTOPATHOLOGY

1. and 2. Brain: Multiple levels of brain are examined. There are no significant findings.
3. Heart: There are no significant findings.
Trachea: There are no significant findings.
Esophagus: There are no significant findings.
Thyroid: There are no significant findings.
4. Trachea: There are no significant findings
Esophagus: There are no significant findings
Lung: There is diffuse vascular congestion. There are multifocal to coalescing areas of mild to moderate acute hemorrhage within alveolar spaces.
5. Liver: There is diffuse vascular congestion. There is mild intracytoplasmic vacuolation of hepatocytes; vacuoles are clear and indistinct (normal for post-prandial mouse).
6. Kidney: There is diffuse vascular congestion.
Liver: There are no new findings.
7. Pancreas: There are no significant findings.
Spleen: There are no significant findings
Favor urinary bladder: Portions of the mucosa appear sloughed (post-mortem change).
Adrenal gland- There are no significant findings.
Fat: There are no significant findings.
8. Stomach: There are no significant findings.
Small intestine: There are no significant findings.
Pancreas: There are no significant findings.
Large intestine: There are no significant findings.
9. Testicle: There are no significant findings.
Eye: There are no significant findings.
Skin: There are no significant findings.
Pancreas: There are no significant findings.
Small intestine: There are no significant findings.
10. Bone marrow (femur, ribs), bone, and surrounding skeletal muscle: There are no significant findings.

FINAL COMMENTS

****Please see addendum below ****

There were no significant findings in this animal on gross necropsy or microscopic exam. The acute hemorrhage in the lungs is interpreted as agonal or perimortem trauma. *Francisella tularensis* and *Yersinia pestis* were not cultured from this animal. PFAS analysis is pending.

Note: For thoroughness, I am seeking the opinions of other pathologists on the liver and adrenals in this case. When completed, the results will be included in an addendum.

ADDENDA COMMENTS

Addendum 06/20/24: The slides with liver and adrenals were shared with Dr. Donna Kusewitt for a formal consult. Dr. John Ragsdale also consulted on the liver, informally. I have copied Dr. Kusewitt's complete assessment below, including her interpretations. Note:

Some of the slides also had other organs, and she commented on them, as well.

In summary, Dr. Kusewitt notes the presence of occasional, small aggregates of enlarged hepatocytes. She notes that these are called "altered foci", and are not unusual -at least in *Mus musculus* – and can increase with age and exposure to some carcinogens. She thinks the liver vacuolation is within normal limits for a non-fasted mouse. Dr. Ragsdale thought that, while the liver vacuolation could be within normal limits for a post-prandial mouse, and he wouldn't call it a toxic hepatopathy, he can't rule out the vacuolation isn't due to a xenobiotic.

Overall, while the "altered foci" described above may just be a non-specific, age related change, and we cannot attribute them to PFAS with the informatino we have, this may be a change worth exploring in future animals.

PFAS analysis is pending for this animal.

Dr. Kusewitt's assessment:

Case Number: V24 15155 (Slides 5 and 7)
Animal Number: NK 311130
Species: *Dipodomys merriami*
Sex: Male

Organ: Liver
Post mortem condition: Good
Observations: Hepatic lobules are not as well-defined as in some other rodent species. There is moderate, diffuse vacuolation of hepatocytes; vacuoles are ragged. This vacuolar change is interpreted as glycogen accumulation. There is mild variation in the size of hepatocyte nuclei and small numbers of binucleate hepatocytes are present. At a few sites on the surface of the liver there are small poorly defined aggregates of enlarged hepatocytes. There is a single small focus of lymphocytes adjacent to a central vein. There is no evidence of neoplasia or infectious disease.

Organ: Pancreas
Post mortem condition: Good
Observations: Acini and islets are easily identified. There is no evidence of neoplasia or inflammation.

Organ: Spleen

Post mortem condition: Good
Observations: The spleen is somewhat contracted, as evidence by pleating of the organ capsule. Multiple lymphoid follicles are present; active germinal centers are not seen. In the centers of many follicles there are small aggregates of amorphous eosinophilic material interpreted as amyloid. Little evidence of extramedullary hematopoiesis is seen. There is no evidence of neoplasia or inflammation.

Organ: Urinary bladder
Post mortem condition: Moderate autolysis
Observations: The bladder is distended. No calculi are seen within the bladder and there is no evidence of neoplasia or inflammation.

Organ: Adrenals
Post mortem condition: Good
Observations: The adrenal surfaces are smooth. All layers of the cortices are present and symmetrical. The medullae are unexceptional. A muscular artery and ganglion adjacent to one adrenal are normal in appearance. There is no evidence of neoplasia or inflammation.

Interpretation: Liver vacuolation is within normal limits for an animal that is not fasting. Variation in the size of liver nuclei and the presence of binucleate hepatocytes are typical of rodents. The presence of lymphocytes adjacent to a blood vessel is considered an incidental finding. Foci of enlarged hepatocytes are called "altered foci" and are not an unusual finding at least in Mus musculus, and increase in number with age and with exposure to some carcinogens.

The low level of extramedullary hematopoiesis in the red pulp of the spleen indicates that the animal was not anemic. The absence of prominent germinal follicles in the white pulp suggests the absence of any marked antigenic stimulus. Amyloid within the spleen is not an unusual finding in the spleens of some species.

Pancreas, urinary bladder, and adrenals show no evidence of pathologic processes.

Donna F. Kusewitt, DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

CASE DIAGNOSIS

NO DIAGNOSIS

Teresa Garcia , DVM
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

New Mexico Department of Agriculture

Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

VDS LAB USE ONLY
Date Received: 5/16/24 Case No.: V24 15155

Veterinarian: TERESA GARCIA
Clinic: C300 VDS
Address:
City: **State:** **Zip:**
Phone: **Fax:**
Mobile: **Alternate:**
Email:
__ Phone __ Fax __ Email Report

TESTS REQUESTED

__ Bacteriology	__ Cytology
__ Bacteriology & Sensi.	__ Histopath . . . __ IHC
__ CBC/Chem Panel	X Necropsy
__ *CBC only . . __*Chem only	__ Parasitology
__ *CBC/Fibrinogen only	__ Mycology
__ Plague/Tularemia	__ Serology
__ PCR_____	__ Toxicology

Other_____

Date Shipped _____ **VIA**
____ DMC Courier ____ Owner ____ Vet ____ Mail
___ UPS ___ FedEx ___ Other _____

No. specimens _____ **Date taken** 05/16/24
No. in herd _____ **Date onset** _____
Sick _____ **Dead** _____
Necropsy disposal method _____

Owner Name UNM Museum of Southwestern Biology, Mammal Division
Male _____ Neutered _____ Female _____ Spayed _____

Animal Name/ID _____
Age _____ yrs _____ mths _____ wks _____ days _____ fetus

Species _____ **Breed** _____
Agent(s) suspected _____

SPECIMEN(S) SUBMITTED

____ Brain
____ Eye V24-15155
____ Heart
____ Lung
____ Trachea
____ Stomach V24-15156
____ Stomach Contents
____ Small Intestine
____ Large Intestine
____ Cecum
____ Liver V24-15157
____ Spleen
____ Kidney V24-15158
____ Urinary Bladder
____ Skin
____ EDTA Blood
____ Serum
____ Urine V24-15159
X Carcass

(1) NK 311130 Dipodomys merriami
(2) NK 311134 Peromyscus leucopus
(3) NK 311139 Peromyscus
(4) NK 311135 Mus musculus
(5) NK 311138 Peromyscus leucopus

HISTORY

specimen collected at Holloman Lake in Otero County New Mexico. High exposure to PFAS very likely based on recent published research. Goal of necropsy is to document any pathology to the organ related to PFAS at the organ and tissue levels

Specimen should be returned to UNM MSB and 1g of muscle tissue needed for PFAS screening.

VDS LAB USE ONLY
Specimens received
5 CARCASS

Referred to/Case Coordinator
VDS / TG

Received by AP
Entered by _____
NMDA/VDS Form: QS-006 (08/15)

Date: 5/16/2024

Accession: 15155 NK 311130

Merriam's kangaroo rat (Dipodomys merriami)

Male

dentition: ok

Animal weight: 44g

Muscle collected for PFAS: yes

Liver weight: 1.5g

Kidney L weight: 0.5g

Kidney R weight: 0.5g

Kidney collected for microplastics: No

Gross findings: all organs within normal limits (gall bladder not found)

Histology:

Skin (where):
Muscle (which):
Femur (bone marrow)
Spleen
Pancreas (around spleen)
Liver
Kidney (side):
Adrenal:
Lymph nodes (mesenteric):
Bladder
GI (stomach and intestines)
Reproductive tract
Tongue
Esophagus
Thyroid, trachea (en bloc):
Lung
Heart
Brain
Salivary gland

64731

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-15156
Owner: UNM MUSEUM OF SOUTHWESTERN BIO
ID: NK31134
Species:
Breed:

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 05/16/24
Reported: 06/20/24
Final Report

CASE HISTORY

Specimen collected at Holloman Lake in Otero County, New Mexico. High exposure to PFAS very likely based on recent published research. Goal of necropsy is to document pathology related to PFAS at the organ and tissue levels. Specimens should be returned to UNM MSB and 1g of muscle tissue needed for PFAS screening.

NECROPSY

This is the body of a 19 g, adult, male, *Peromyscus leucopus* . The liver weighs between 1 g and 1.5 g. The kidneys both weigh less than 0.5 g. There are no significant gross findings.

HISTOPATHOLOGY

1. Brain: There are no significant findings.
2. Tongue: In the skeletal muscle, there is a foreign material (plant matter) surrounded by a focal aggregate of macrophages, polymorphonuclear cells, with occasional multinucleated cells, lymphocytes, and plasma cells. There are occasional intracytoplasmic protozoal cysts (sarcocysts), with no associated inflammation.
Esophagus: In the submucosa, there is foreign material (plant matter) surrounded by a focal aggregate of macrophages, polymorphonuclear cells, with occasional multinucleated cells.
Thyroid: There are no significant findings.
Trachea: There is hemorrhage in the lumen, with no lesions in the mucosa or surrounding tissue (agonal or from the lungs).
Fat: There are no significant findings.
Heart: There are no significant findings.
Lungs: There is diffuse congestion and variable atelectasis.
Salivary gland: There are no significant findings.
3. Lungs: There are changes as described above. In addition, there are occasional areas of mild hemorrhage in the alveolar spaces. There are occasional interstitial aggregates of macrophages, polymorphonuclear cells, lymphocytes and plasma cells.
Heart: There are no significant findings.
Esophagus: There are no significant findings.
4. Liver: There is diffuse vascular congestion. There are occasional granulomas within the parenchyma, and one has an intralesional fluke. There are occasional pigment granulomas.
5. Kidney: There are rare aggregates of lymphocytes in the renal pelvis.
Liver : There are no new findings.
6. Pancreas: There are no significant findings.
Liver: There are no new findings.
Adrenal gland: There are no significant findings.
Spleen: Lymphoid follicles in the white pulp are expanded, and occasionally coalesce. There are mixed small mature lymphocytes, lymphoblasts, and macrophages, in these areas.
Bone marrow: There are no significant findings.
7. Stomach: There are no significant findings.
Pancreas: There are no significant findings.
Lymphoid tissue: Adjacent to the pancreas, is lymphoid tissue with germinal centers and sheets of plasma cells, lymphocytes, and macrophages.
Small intestine: There is moderate to severe autolysis of the mucosa. There are no overt significant findings.
8. Skin: There are occasional sarcocysts within underlying skeletal muscle.
Eye: There are no significant findings.
9. Testicle: There are no significant findings.
Urinary bladder: There are no significant findings.
10. Bone marrow, bone, and surrounding skeletal muscle: There are occasional sarcocysts within the skeletal muscle. There are no other significant findings.

FINAL COMMENTS

****Please note addendum below****

There are multiple inflammatory changes in this mouse, attributable to either foreign material (tongue and esophagus), parasites (liver), or other causes (lung). The inflammation in the lung is chronic and mild, and although the exact cause was not seen

histologically, I suspect it may be parasitic, or potentially environmental irritation (eg inorganic dust), but the exact cause is unknown. The mild hemorrhage is interpreted as agonal or perimortem trauma. The cause of the lymphoid hyperplasia in the spleen is not clear, but is likely due to chronic antigenic stimulus.

Regarding PFAS – While the exact cause of the inflammation in the lungs and hyperplasia in the spleen is not clear, I lean towards them not being related to PFAS. The changes documented in the peer-reviewed literature in the spleen are of atrophy, not hypertrophy of lymphoid cells.

Francisella tularensis and *Yersinia pestis* were not cultured from this animal. PFAS analysis is pending.

Note: For thoroughness, I am seeking the opinions of other pathologists in this case. When completed, the results will be included in an addendum.

Guo, H. (2021) Perfluorooctanoic acid (PFOA) exposure induces splenic atrophy via overactivation of macrophages in male mice, Journal of Hazardous Materials, Volume 407, 2021

Diagnoses

Tongue: Focal granulomatous glossitis with intralesional foreign material (plant material)
Liver: Mild to moderate, granulomatous hepatitis with intralesional trematodes
Spleen: Lymphofollicular hyperplasia
Lung: 1) Mild, chronic, interstitial pneumonia; 2) Mild acute hemorrhage (perimortem change)

Esophagus: Focal granulomatous esophagitis with intralesional foregin material (plant material)

ADDENDA COMMENTS

Addendum 06/20/24: The slides with liver and adrenals were shared with Dr. Donna Kusewitt for a formal consult. Dr. John Ragsdale also assessed a few of the slides, informally. I have copied Dr. Kusewitt's complete assessment below, including her interpretations. Note: Some of the slides also had other organs, and she commented on them, as well.

I note that in the cuts of tissue present on her slides, the liver flukes were not present – I saw them in the original slides, and Dr. Ragsdale agreed with this interpretation. Thus, the inflammation in the liver is interpreted as secondary to these parasites. He also noted a cestode within a lymph node adjacent to the pancreas.

PFAS analysis is pending for this animal.

Dr. Kusewitt's assessment:
Case Number: V24-15156 (Slides 4 and 6)
Animal Number: NK311134
Species: *Peromyscus leucopus*
Sex: Male

Organ: Liver
Post mortem condition: Good
Observations: Hepatic lobules are clearly defined. Most hepatocytes contain few vacuoles, although around some central veins there are small numbers of hepatocytes with clear vacuoles in the cytoplasm. These vacuoles are interpreted as fat droplets. Many hepatocytes throughout the hepatic lobules contain small amounts of finely granular brown pigment interpreted as bile. There is moderate variation in the size of hepatocyte nuclei and small numbers of binucleate hepatocytes are present. The hepatic parenchyma contains two granulomas of moderate size. Each granuloma is characterized by a central aggregate of macrophages, some of which have multiple nuclei, surrounded by a rim of lymphoid cells. No microorganisms are evident within granulomas. In one granuloma, many macrophages contain bile pigment. Small aggregates of lymphoid cells lie adjacent to a few bile ducts and one blood vessel. There is no evidence of neoplasia.

Organ: Spleen
Post mortem condition: Good
Observations: The spleen contains multiple lymphoid follicles, many of which have prominent germinal centers. The red pulp contains numerous cells of the erythropoietic series. There is no evidence of neoplasia.

Organ: Pancreas
Post mortem condition: Mild autolysis
Observations: Acini and islets are readily distinguished. There is no evidence of inflammation or neoplasia.

Organ: Adrenal
Post mortem condition: Good
Observations: The adrenal surface is smooth. All layers of the cortex are present and symmetrical. The medulla is unexceptional. There is no evidence of neoplasia or inflammation.

Organ: Bone marrow
Post mortem condition: Good

Observations: A small sample of bone marrow is present. The marrow is highly cellular and contains cells of all hematopoietic series. There is no evidence of neoplasia.

Interpretation: Liver vacuolation in rodents is highly variable, depending on the feeding status. In the present case, the extent and pattern of vacuolation are within normal limits. Variation in the size of liver nuclei and the presence of binucleate hepatocytes are typical of rodents. The liver granulomas do not appear to be associated with an infectious organism; their etiology is unclear. The cause of the bile droplet accumulation within hepatocytes is not apparent. The presence of lymphocytes adjacent to a few bile ducts and a blood vessel is considered an incidental finding.

The presence of prominent germinal centers in splenic white pulp suggests antigenic stimulation. Marked erythropoiesis in the splenic red pulp is consistent with response to anemia.

Pancreas, adrenal, and bone marrow show no evidence of pathologic processes.

Donna F. Kusewitt, DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Teresa Garcia , DVM
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

NEW MEXICO DEPARTMENT OF AGRICULTURE
VETERINARY DIAGNOSTIC SERVICES
PATHOLOGY TEST REQUEST FORM

V24 15156
Case #

** Return form to Receiving staff following procedure(s). **

☐ No Tests Required
☐ Add Insurance/Forensic Charge
☐ SLD Rabies case only
Decap performed:_____ (initials/date)

Submitter: GARCIA
Owner: UNM
Animal ID(s): NK31134

Date Received: 5/16/24
Pathologist: TG

Histopathology

NOTES:

☑ Various Tissues
☐ Single Tissue Source:_____

Bacteriology Pooled Cases ☐ No ☐ Yes Case #s Pooled_____ * Additional specific testing

Source(s)	Pooled	Specific Requests *	Anaerobic	Sensi
Lung, Liver, Spleen	☑	Clarens / Rhyne	☐	☐
	☐		☐	☐

Molecular Biology Pooled Cases ☐ No ☐ Yes Case #s Pooled_____ * Specify test method

* Test	Source(s)	Pooled	Referral Lab	Date Routed	Courier	Initials
~~Lung, Liver, Spleen~~ To 05/14/24		☐				
		☐				
		☐				

Virology / Other Pooled Cases ☐ No ☐ Yes Case #s Pooled_____ * Specify test method

* Test	Source(s)	Pooled	Referral Lab	Date Routed	Courier	Initials
PPRS	Skeletal muscle	☐				
		☐				
		☐				

Storage of specimens *Locations include: room temperature = RT, refrigerator = R, refrigerator freezer = RF, deep freeze = D, ultralow freezer = U

Date_____ Specimen(s)_____ Location*_____ Requested storage time_____

Date_____ Specimen(s)_____ Location*_____ Requested storage time_____

VDS FORM: PA-009

Form PA-009 - Pathology Test Request Form - Version 2.0, Index: Form PA-009 Printed: 06-Jun-2018 16:52
Authorised on: 06-Jun-2018 Authorised by: Kim Ethridgehill Unique Reference: 820-71508757 See iPassport for review timelines
Author(s): John Ragsdale Kim Ethridgehill

EB / Date:_____

Page 1 of 1

Form PA-009 - Pathology Test Request Form - Version 2.0, Index: Form PA-009 Printed: 06-Jun-2018 16:52

Date: 5/16/2024

Accession: V24-15156 NK 31134 Peromyscus leucopus

Animal weight: 19g Male

Muscle collected for PFAS: yes (femoral, tibial, pectoral) 0.5g

Liver weight: 1g-1.5g

Kidney L weight: <0.5g

Kidney R weight: <0.5g

Kidney collected for microplastics: no

Gross findings: every organ within normal limits

Histology:

Skin (where):
Muscle (which):
Femur (bone marrow)
Spleen
Pancreas (around spleen)
Liver
Kidney (side):
Adrenal:
Lymph nodes (mesenteric):
Bladder
GI (stomach and intestines)
Reproductive tract
Tongue
Esophagus
Thyroid, trachea (en bloc):
Lung
Heart
Brain
Salivary gland

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-15157
Owner: UNM MUSEUM OF SOUTHWESTERN BIO
ID: NK311139
Species:
Breed:

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 05/16/24
Reported: 06/20/24
Final Report

CASE HISTORY

Specimen collected at Holloman Lake in Otero County, New Mexico. High exposure to PFAS very likely based on recent published research. Goal of necropsy is to document pathology related to PFAS at the organ and tissue levels. Specimens should be returned to UNM MSB and 1g of muscle tissue needed for PFAS screening.

NECROPSY

This is the body of a 27.5 g, male, adult, *Peromyscus maniculatus*, with minimal autolysis (necropsied within hours of death). The liver weighs 1.5 g, and an enhanced reticular pattern is seen diffusely. The kidneys both weigh less than 0.5 g. The adrenal glands are symmetrical, but appear subjectively enlarged. The stomach is distended by ingested food.

HISTOPATHOLOGY

1. and 2. Brain: Multiple sections of brain are examined. There are no significant findings.
3. Esophagus: There are occasional intracytoplasmic protozoal cysts (sarcocysts) within skeletal muscle fibers in the wall of the esophagus, with no associated inflammation.
Trachea: There are no significant findings.
Thyroid: There are no significant findings.
Brain: There are no significant findings.
Brown fat: There are no significant findings.
Peripheral nerve: There are no significant findings.
4. Heart: There are no significant findings.
Lung: There are multifocal to coalescing areas of mild to moderate hemorrhage within alveolar spaces, occasionally disrupting alveolar septa; this affects approximately 15% of the pulmonary parenchyma in examined sections.
Trachea: There are no significant findings.
Esophagus: There are no significant findings.
5. and 6. Liver: There is diffuse vascular congestion.
7. Adrenal gland: There is diffuse hypertrophy of adrenocortical cells, with severe anisocytosis and anisokaryosis of adrenal cortical cells (zona fasciculata, potentially reticularis), and occasional multinucleation.
Kidney: There are no significant findings.
Spleen: There are no significant findings.
Pancreas: There are no significant findings.
8. Testicles: There are no significant findings.
Eye: There are no significant findings.
Skin: There are no significant findings.
9. Small intestine: Some sections have moderate to severe autolysis of the mucosa. There are no overt significant findings.
Large intestine: There are no overt significant findings.
Stomach: There are no significant findings.
Pancreas: There are no significant findings.
10. Bone marrow, bone, and surrounding skeletal muscle (femur and ribs): There are no significant findings

FINAL COMMENTS

****Please see addendum****

The findings with the most potential for significance in this case are in the adrenal gland, however, the exact significance of the findings is unclear. The adrenal glands were subjectively enlarged on gross necropsy, and, on microscopic exam, in the adrenal cortex, there were changes most consistent with hypertrophy (enlarged cells), with anisocytosis (differing cell size), anisokaryosis (differing nuclear size), and there were multinucleated cells. The portion of the cortex involved is the zona fasciculata, and potentially the zona reticularis (the zona reticularis is not delineated in mice on routine histology). The zona fasciculata secretes glucocorticoids – hormones involved in the stress response.

I shared this case with Dr. John Ragsdale. As far as we are aware, these changes are not normal findings in the mouse adrenal gland. However, I note that most of what is documented in the adrenal gland is from laboratory or captive mice. I am hestitant to say that these changes are definitively abnormal in a wild *Peromyscus maniculatus* without more information (eg could this be some kind of seasonal change?) I have ordered an article via interlibrary loan that details the adrenal gland in a wild mouse of the same

genus (*Peromyscus leucopus* - Costa 1968) – results will be released in an addendum.

Again, the exact diagnosis and significance of these change are not clear, but, using guidelines from the International Harmonization of Nomenclature and Diagnostic Criteria for Lesions in Rats and Mice, the changes are most consistent with diffuse cortical hypertrophy of the adrenal gland (Brändli-Baiocco et al. 2018). I note that the anisocytosis, anisokaryosis, and multinucleation seen in this case are not described in the context of hypertrophy in these guidelines. Diffuse adrenocortical hypertrophy is typically caused by increased ACTH – either due to stress or disease, or exogenously administered ACTH (Brändli-Baiocco et al. 2018). This guide notes that xenobiotics that inhibit steroid synthesis can cause hypertrophy, but typically they also cause increased vacuolation – I do not see overtly increased vacuolation in this case. Again, I am not sure if this is a normal change for a wild mouse of this genus and species, and hopefully the abovementioned paper will provide additional information.

Regarding potential links to PFAS - Without controlled studies detailing similar changes in mice, it is difficult to assign underlying cause to this change in the adrenal cortex. While I cannot say it is due to PFAS, at this time, I cannot rule out that it is due to PFAS. A brief literature review finds that various PFAS have been found to affect the production of glucocorticoids (Ying Y, et al. 2024; Pereiro, N et al. 2014; Pötzl B, et al 2024), and while some describe the general thickening of the zona fasciculata, I did not find any studies detailing the microscopic changes seen here. Note: I have one of these articles on ILL regarding morphologic changes, but I do not expect the changes to be similar to those seen here based on the abstract. I would also want to make sure muscle sampled from this animal had elevated PFAS (elevated PFAS are expected based on environmental levels).

If you are interested, I think it would be helpful to submit the slide with the adrenal gland to a veterinary pathologist with specialization in toxicology pathology and mice– please let me know if you are interested in doing so.

Other findings:

The liver change seen grossly (enhanced reticular pattern) was microscopically found to be diffuse congestion of vessels. This is a non-specific finding that is likely incidental, and likely occurred as the animal was dying. There were no changes in the heart to suggest it was due to heart failure, or other changes in the liver suggestive of hepatic pathology.

There was hemorrhage in the lung – both John and I agree this is likely an agonal change or due to trauma at the time of death. We did not see evidence of pneumonia or other lung pathology.

Francisella tularensis and *Yersenia pestis* were not cultured from this mouse.

I could not find an average and standard deviation for organ values for wild *Peromyscus maniculatus*, however, there is a paper with organ masses for captive *Peromyscus maniculatus*, with average values and standard error – see below.

Please contact me with any questions or concerns.

References:
Brändli-Baiocco et al. (2018) Nonproliferative and Proliferative Lesions of the Rat and Mouse Endocrine System. J Toxicol Pathol. 31(3 Suppl):1S-95S
Costa, J.L. (1968), Histological, histochemical, and cytological observations on the adrenal gland of the wild white-footed mouse, Peromyscus leucopus. Anat. Rec., 162: 275-287.
Hayssen, V. (2001) Body and organ mass in agouti and non-agouti deer mice (Peromyscus maniculatus), Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, Volume 130, Issue 2 Pages 311-321
Pereiro, N et al. (2014) Regulation of corticosterone secretion is modified by PFOS exposure at different levels of the hypothalamic–pituitary–adrenal axis in adult male rats, Toxicology Letters, Volume 230, Issue 2, 2014, Pages 252-262
Pötzl B, et al (2024) Endocrine Disruptors: Focus on the Adrenal Cortex. Horm Metab Res. Jan;56(1):78-90.
Ying Y, et al. (2024) Perfluorotetradecanoic acid exposure to adult male rats stimulates corticosterone biosynthesis but inhibits aldosterone production. Environmental Toxicology. 39(5): 2610-2622.

Diagnoses
Adrenal gland: Severe, adrenocortical hypertrophy with anisocytosis, anisokaryosis, and multinucleated cells
Lungs: Multifocal to coalescing, moderate, pulmonary hemorrhage

ADDENDA COMMENTS

Addendum 06/20/24: The slides with liver and adrenals were shared with Dr. Donna Kusewitt for a formal consult. Dr. John Ragsdale also assessed a few of the slides, informally. I have copied Dr. Kusewitt's complete assessment below, including her interpretations. Note: Some of the slides also had other organs, and she commented on them, as well.

Dr. Kusewitt thinks the adrenal is within normal limits, and in a personal communication told me the adrenals and male sex organs of *Peromyscus* can vary among populations, depending on living conditions, and time of year. Further, the changes in the paper referenced above note descriptions of changes in wild Peromyscus adrenals similar to the ones seen here. Thus, ultimately, it is most likely the changes in the adrenal are within normal variations for this genus.

PFAS analysis is pending for this animal.

Dr. Kusewitt's assessment:

Case Number: V24 15157 (slides 5 and 7)
Animal Number: NK 311139
Species: *Peromyscus maniculatus*
Sex: Male

Organ: Liver
Post mortem condition: Mild autolysis
Observations: Hepatic lobules are discernible. There is very slight diffuse ragged vacuolation of hepatocyte cytoplasm interpreted as glycogen accumulation. In some centrilobular areas, hepatocytes contain clear-edged vacuoles interpreted as fat droplets. There is mild variation in the size of hepatocyte nuclei and small numbers of binucleate hepatocytes are present. Multiple portal triads contain lymphoid cells; lymphoid cells are generally few in number. There is no evidence of neoplasia.

Organ: Spleen
Post mortem condition: Good
Observations: The spleen contains multiple lymphoid follicles, some of which contain evident germinal centers. There is moderate extramedullary hematopoiesis in the red pulp; most hematopoietic cells are of the erythroid lineage. There is no evidence of neoplasia disease.

Organ: Kidney
Post mortem condition: Moderate autolysis
Observations: Glomeruli are small and uniform in size and cellularity. Tubular lumina do not contain casts or proteinaceous fluid. No aggregates of inflammatory cells or interstitial fibrosis is seen. There is no evidence of neoplasia or infectious disease.

Organ: Adrenals
Post mortem condition: Good
Observations: The surfaces of the adrenals are smooth. Multiple layers of cells are seen in the cortex, but layers are not as well-defined as in some other animals examined, and there is more variation in nuclear size than in the adrenal of some other animals. The medulla is present in only one adrenal and it is unexceptional in appearance. There is no evidence of neoplasia or infectious disease.

Interpretation: Liver vacuolation in rodents is highly variable, depending on the feeding status. In the present case, the extent and pattern of vacuolation is within normal limits. Variation in the size of liver nuclei and the presence of binucleate hepatocytes are typical of rodents. The presence of lymphoid cells in multiple portal triads suggests a mild triaditis, likely an incidental lesion.

Changes in the white and red pulp of the spleen are mild and likely to be within normal limits.

There is no evidence of pathologic processes in kidneys or adrenals.

Donna F. Kusewitt, DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Teresa Garcia , DVM
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

NEW MEXICO DEPARTMENT OF AGRICULTURE
VETERINARY DIAGNOSTIC SERVICES
PATHOLOGY TEST REQUEST FORM

V24 15157
Case #

** Return form to Receiving staff following procedure(s). **

☐ No Tests Required
☐ Add Insurance/Forensic Charge
☐ SLD Rabies case only
Decap performed:_____ (initials/date)

Submitter: GARCIA
Owner: UNM
Animal ID(s): NK 311139

Date Received: 5/16/24
Pathologist: TG

Histopathology

☐ Various Tissues
☐ Single Tissue Source:_____

NOTES:

Bacteriology Pooled Cases ☐ No ☐ Yes Case #s Pooled_____ * Additional specific testing

Source(s)	Pooled	Specific Requests *	Anaerobic	Sensi
Lung, Liver, Spleen	☐	Intravenous Injection	☐	☐
	☐		☐	☐

Molecular Biology Pooled Cases ☐ No ☐ Yes Case #s Pooled_____ * Specify test method

* Test / Source(s)	Pooled	Referral Lab	Date Routed	Courier	Initials
* Test_____ Source(s)_____	☐				
* Test_____ Source(s)_____	☐				
* Test_____ Source(s)_____	☐				

Virology / Other Pooled Cases ☐ No ☐ Yes Case #s Pooled_____ * Specify test method

* Test / Source(s)	Pooled	Referral Lab	Date Routed	Courier	Initials
* Test RPBS Source(s) Skeletal muscle	☐				
* Test_____ Source(s)_____	☐				
* Test_____ Source(s)_____	☐				

Storage of specimens *Locations include: room temperature = RT, refrigerator = R, refrigerator freezer = RF, deep freeze = D, ultralow freezer = U

Date_____ Specimen(s)_____ Location*_____ Requested storage time_____

Date_____ Specimen(s)_____ Location*_____ Requested storage time_____

VDS FORM: PA-009

Form PA-009 - Pathology Test Request Form - Version: 2.0 Index: Form PA-009 Printed: 06-Jun-2018 16:52
Authorised on: 06-Jun-2018 Authorised by: Kim Ethridgehill Unique Reference: 820-71508757 See iPassport for review timelines
Author(s): John Ragsdale, Kim Ethridgehill

EB / Date:_____

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Date: 5/16/2024

Accession: V24-15157 NK311139 Peromyscus maniculatus male

Animal weight: 27.5g

Muscle collected for PFAS: femoral, tibial, pectoral : 1g

Liver weight: 1.5

Kidney L weight: < 0.5g

Kidney R weight: < 0.5g

Kidney collected for microplastics: no

Gross findings: enhanced reticular pattern (liver, more pronounced in the left lobe) - photo.
Adrenal gland, symetrical but subjectively larger than in other Peromyscus specimen (but ± species)
Full stomach, distended by digested food

Histology:

Skin (where):
Muscle (which):
Femur (bone marrow)
Spleen
Pancreas (around spleen)
Liver
Kidney (side):
Adrenal:
Lymph nodes (mesenteric):
Bladder
GI (stomach and intestines)
Reproductive tract
Tongue
Esophagus
Thyroid, trachea (en bloc):
Lung
Heart
Brain
Salivary gland

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-15158
Owner: UNM MUSEUM OF SOUTHWESTERN BIO
ID: NK311135
Species:
Breed:

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 05/16/24
Reported: 06/20/24
Final Report

CASE HISTORY

Specimen collected at Holloman Lake in Otero County, New Mexico. High exposure to PFAS very likely based on recent published research. Goal of necropsy is to document pathology related to PFAS at the organ and tissue levels. Specimens should be returned to UNM MSB and 1g of muscle tissue needed for PFAS screening.

NECROPSY

This is the body of a 13 g, adult, male *Mus musculus*, with minimal autolysis (necropsy within hours of death). The liver weighs between 0.5 g and 1.0 g. The kidneys are greater than 0 g but less than 0.5 g. Organs are within normal limits grossly.

HISTOPATHOLOGY

1. Brain: There are no significant findings.
Salivary gland: There are no significant findings.
Bone marrow: There are no significant findings.
2. Thyroid and parathyroid: There are no significant findings.
Trachea: There are no significant findings.
Esophagus: There are no significant findings.
Heart: There are no significant findings.
Lungs: There is diffuse vascular congestion, with variable atelectasis.
3. Liver: There is diffuse vascular congestion. Occasionally, there is mild intracytoplasmic vacuolation in hepatocytes (within normal limits for post-prandial mouse).
4. Pancreas: There are no significant findings.
Kidney: There are no significant findings.
Lymph node: There are no significant findings.
5. Testicle: There are no significant findings.
Fat: There are no significant findings.
Adrenal gland: There are no significant findings.
6. Small intestine: There is moderate to severe autolysis of the mucosa. There is increased mitotic activity/turnover in the crypts, but there are no increased chronic inflammatory cells at the base of the lamina propria.
7. Brain: There are no significant findings.
8. Bone marrow, bone, and surrounding skeletal muscle: There are no significant findings.

FINAL COMMENTS

****Please see addendum below****

There were no overt significant findings from this animal's gross necropsy and microscopic exam. There were some changes in the small intestine consistent with increased cell turnover, which can suggest enteritis. The villus tips of the intestine in this cause are autolyzed, which makes interpretation a bit difficult (this unfortunately can happen even with necropsy within hours of death, given the number of bacteria in the GI tract). While this may be an enteritis, I do not see changes suggestive of Inflammatory bowel disease (IBD), which has been described in rats treated with PFOS.

While I am not convinced there are any significant changes in the small intestine we can attribute to PFAS, because IBD like lesions have been found in relation to PFAS in rats, I will consult with another pathologist, with results released in an addendum when this is completed, to see if they would consider this an IBD like lesion. I note that, even if other pathologists disagree and think there is an IBD like enteritis, there are so many possible causes of enteritis in a wild animal that it would be difficult to attribute it to PFAS in this case.

Francisella tularensis and *Yersinia pestis* were not cultured from this animal. PFAS analysis is pending.

Liang H, Yang M, Zeng C, Wu W, Zhao L, Wang Y. Perfluorooctane sulfonate exerts inflammatory bowel disease-like intestinal injury in rats. PeerJ. 2021

ADDENDA COMMENTS

Addendum 06/20/24: The slides with liver, adrenals, and intestine were shared with Dr. Donna Kusewitt for a formal consult. Note: Some of the slides also had other organs, and she commented on them, as well. Dr. Kusewitt does not interpret an overt enteritis in

these slides, and liver and adrenals are within normal limits.

PFAS analysis is pending for this animal.

Dr. Kusewitt's assessment:

Case Number: V24 15158 (slides 3,5, and 6)
Animal Number: NK311135
Species: *Mus musculus*
Sex: Male

Organ: Liver
Post mortem condition: Mild autolysis
Observations: Hepatic lobules are discernible. There is very slight diffuse ragged vacuolation of hepatocyte cytoplasm interpreted as glycogen accumulation. In some centrilobular areas, hepatocytes contain clear-edged vacuoles interpreted as fat droplets. There is mild variation in the size of hepatocyte nuclei and small numbers of binucleate hepatocytes are present. A few portal triads contain small numbers of lymphoid cells. A few small, irregular foci of hemorrhage are seen; these are interpreted as artefactual. There is no evidence of neoplasia or infectious disease.

Organs: Testes
Post mortem condition: Good
Observations: Active spermatogenesis is evident in seminiferous tubules. There is no evidence of neoplasia or infectious disease.

Organ: Epididymis
Post mortem condition: Mild autolysis
Observations: Tubules are packed with mature sperm. There is no evidence of neoplasia or infectious disease.

Organ: Adrenal
Post mortem condition: Good
Observations: The adrenal surface is smooth. All layers of the cortex are present and symmetrical. The medulla is unexceptional. There is no evidence of neoplasia or inflammation.

Organ: Stomach
Post mortem condition: Moderate autolysis
Observations: Both glandular and non-glandular portions of the stomach are present. Mucosa in both areas of the stomach is entirely normal in appearance. Food is present in the stomach lumen. There is no evidence of neoplasia or inflammation.

Organ: Small intestine
Post mortem condition: Marked autolysis
Observations: Marked autolysis makes examination of the small intestine somewhat challenging. No shortening or fusion of villi is seen. There is no evidence of ulceration. The lamina propria contains numerous lymphoid cells, but these are uniformly distributed; the number of lymphoid cells is judged to be within normal limits. There is no evidence of neoplasia or inflammation.

Organ: Large intestine and cecum
Post mortem condition: Variable autolysis
Observations: The cecum is too autolytic to evaluate. Better preserved areas of the large intestine are unexceptional. There is no evidence of neoplasia or inflammation.

Interpretation: Liver vacuolation is within normal limits for an animal that is not fasting. Variation in the size of liver nuclei and the presence of binucleate hepatocytes are typical of rodents. The presence of lymphocytes adjacent to a few bile ducts is considered an incidental finding.

There is marked spermatogenesis in the testes, and the epididymis examined contains numerous mature sperm. This is compatible with active breeding.

No abnormalities are observed in the stomach or intestine, but post mortem autolysis may mask minor pathologic changes.

No abnormalities are seen in the adrenal.

Donna F. Kusewitt, DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

CASE DIAGNOSIS

NO DIAGNOSIS

Teresa Garcia , DVM
Diplomate, ACVP

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

NEW MEXICO DEPARTMENT OF AGRICULTURE
VETERINARY DIAGNOSTIC SERVICES
PATHOLOGY TEST REQUEST FORM

V24 15158
Case #

** Return form to Receiving staff following procedure(s). **

☐ No Tests Required
☐ Add Insurance/Forensic Charge
☐ SLD Rabies case only
Decap performed:_____ (initials/date)

Submitter: GARCIA
Owner: UNM
Animal ID(s): NK 311135

Date Received: 5/16/24
Pathologist: TG

Histopathology

NOTES:

☑ Various Tissues
☐ Single Tissue Source:_____

Bacteriology Pooled Cases ☐ No ☐ Yes Case #s Pooled_____ * Additional specific testing

Source(s)	Pooled	Specific Requests *	Anaerobic	Sensi
Lung, Liver, Spleen	☐	☑ Intestine / Urine	☐	☐
	☐		☐	☐

Molecular Biology Pooled Cases ☐ No ☐ Yes Case #s Pooled_____ * Specify test method

* Test / Source(s)	Pooled	Referral Lab	Date Routed	Courier	Initials
* Test_____ Source(s)_____	☐				
* Test_____ Source(s)_____	☐				
* Test_____ Source(s)_____	☐				

Virology / Other Pooled Cases ☐ No ☐ Yes Case #s Pooled_____ * Specify test method

* Test / Source(s)	Pooled	Referral Lab	Date Routed	Courier	Initials
* Test PPAS Source(s) Skeletal muscle	☐				
* Test_____ Source(s)_____	☐				
* Test_____ Source(s)_____	☐				

Storage of specimens *Locations include: room temperature = RT, refrigerator = R, refrigerator freezer = RF, deep freeze = D, ultralow freezer = U

Date_____ Specimen(s)_____ Location*_____ Requested storage time_____
Date_____ Specimen(s)_____ Location*_____ Requested storage time_____

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VDS FORM: PA-009

Form PA-009 - Pathology Test Request Form - Version: 2.0. Index: Form PA-009. Printed: 06-Jun-2018 15:52.
Authorised on: 06-Jun-2018. Authorised by: Kim Ethridgehill. Unique Reference: 820-71508757 See iPassport for review timelines.
Author(s): John Ragsdale, Kim Ethridgehill.

EB / Date:_____

Page 1 of 1

Date: 5/16/2024

Accession: V24-15158 NK 311135

House mouse
Mus musculus

Animal weight: 13 g

Muscle collected for PFAS: yes arm, legs, pectorals <0.5g

Male

Liver weight: 0.5g - 1g (close to 1g)

Kidney L weight: 0-0.5g

Kidney R weight: 0-0.5g

Kidney collected for microplastics: no

Gross findings: within normal limits

Histology:

Skin (where):
Muscle (which):
Femur (bone marrow)
Spleen
Pancreas (around spleen)
Liver
Kidney (side):
Adrenal:
Lymph nodes (mesenteric):
Bladder
GI (stomach and intestines)
Reproductive tract
Tongue
Esophagus
Thyroid, trachea (en bloc):
Lung
Heart
Brain
Salivary gland

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-15159
Owner: UNM MUSEUM OF SOUTHWESTERN BIO
ID: NK311138
Species:
Breed:

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 05/16/24
Reported: 06/20/24
Final Report

CASE HISTORY

Specimen collected at Holloman Lake in Otero County, New Mexico. High exposure to PFAS very likely based on recent published research. Goal of necropsy is to document pathology related to PFAS at the organ and tissue levels. Specimens should be returned to UNM MSB and 1g of muscle tissue needed for PFAS screening.

NECROPSY

This is the body of a 25.5 g, adult, female, *Peromyscus leucopus*, with minimal autolysis (necropsy performed within hours of death). The liver weighs 1.5 g. Each kidney weighs more than 0 g but less than 0.5 grams. All organs are grossly within normal limits.

HISTOPATHOLOGY

1. Brain: There are no significant findings.
2. Heart: There are no significant findings.
Esophagus: There are no significant findings
Lung: There is diffuse vascular congestion, with variable atelectasis. There is very mild hemorrhage within alveolar spaces.
Trachea: There are no significant findings
Fat: There are no significant findings
3. Esophagus: There are occasional protozoal cysts (sarcocysts) within the cytoplasm of skeletal muscle fibers in the wall of the esophagus, with no associated inflammatory response.
Tongue: There are occasional sarcocysts within skeletal muscle fibers, with no associated inflammatory response.
Liver: There is mild, intracytoplasmic, indistinct, clear vacuolation of hepatocytes, diffusely (within normal limits for a postprandial mouse).
4. Kidneys: There are no significant findings
Spleen: There are no significant findings
5. Liver: There are changes as described above. In addition, there are occasional pigment granulomas.
6. Uterus: There are no significant findings.
Ovaries: There are no significant findings.
7. Eye: There are no significant findings.
Skin: There are no significant findings
8. Stomach: There are no significant findings
Pancreas: There are no significant findings
Small intestine: There are no significant findings
Large intestine: There are no significant findings
9. Bone marrow, bone, and surrounding skeletal muscle: There are frequent sarcocysts within skeletal muscle fibers. There are no significant findings in the bone marrow or bone.

FINAL COMMENTS

****Please see addendum below****

There were no significant findings from this animals necropsy and microscopic exam. *Francisella tularensis* and *Yersinia pestis* were not cultured from this animal. PFAS analysis is pending. I am consulting with another pathologist on a few organs, and, when completed, results will be released in an addendum.

ADDENDA COMMENTS

Addendum 06/20/24: The slide with liver was shared with Dr. Donna Kusewitt for a formal consult. Dr. John Ragsdale also assessed the liver, informally. I have copied Dr. Kusewitt's complete assessment below, including her interpretations. Note: The slide also had other organs, and she commented on them, as well.

Dr. Kusewitt interpreted the liver as being within normal limits for a non-fasted rodent. Similar to the liver for V24-15155, Dr. Ragsdale thought that, while the liver vacuolation could be within normal limits for a post-prandial mouse, and he wouldn't call it a toxic hepatopathy, he can't rule out the vacuolation isn't due to a xenobiotic.

PFAS analysis is pending for this animal.

Dr. Kusewitt's assessment:

Case Number: V24 15159
Animal Number: NK311138
Species: *Peromyscus leucopus*
Sex: Female

Organ: Liver
Post mortem condition: Mild autolysis
Observations: Hepatic lobules are discernible. There is moderate diffuse ragged vacuolation of hepatocyte cytoplasm interpreted as glycogen accumulation. There is mild variation in the size of hepatocyte nuclei and small numbers of binucleate hepatocytes are present. A few portal triads contain small numbers of lymphoid cells. There is a single small focus of parenchymal necrosis. There is no evidence of neoplasia or infectious disease.

Organ: Gall bladder
Post mortem condition: Moderate autolysis
Observations: No abnormalities are seen.

Interpretation: Liver vacuolation in rodents is highly variable, depending on the feeding status. In the present case, the extent and pattern of vacuolation is within normal limits. Variation in the size of liver nuclei and the presence of binucleate hepatocytes are typical of rodents. Lymphoid cells surrounding a few bile ducts and a single small focus of necrosis in the liver are considered incidental findings.

Donna F. Kusewitt, DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

CASE DIAGNOSIS

NO DIAGNOSIS

Teresa Garcia , DVM
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.

End of Report

NEW MEXICO DEPARTMENT OF AGRICULTURE
VETERINARY DIAGNOSTIC SERVICES
PATHOLOGY TEST REQUEST FORM

V24 15159
Case #

** Return form to Receiving staff following procedure(s). **

☐ No Tests Required
☐ Add Insurance/Forensic Charge
☐ SLD Rabies case only
Decap performed:_____ (initials/date)

Submitter: GARCIA
Owner: UNM
Animal ID(s): NK311138

Date Received: 5/16/24
Pathologist: TG

Histopathology

NOTES:

☒ Various Tissues
☐ Single Tissue Source:_____

Bacteriology Pooled Cases ☐ No ☐ Yes Case #s Pooled_____ * Additional specific testing

Source(s)	Pooled	Specific Requests *	Anaerobic	Sensi
Leg, Liver, Spleen	☐	Cutaneous/ Plague	☐	☐
	☐		☐	☐

Molecular Biology Pooled Cases ☐ No ☐ Yes Case #s Pooled_____ * Specify test method

* Test	Source(s)	Pooled	Referral Lab	Date Routed	Courier	Initials
PFAs	Skeletal muscle (Submitted 5/16/24 TG 05/16/24 Client will Submit)	☐				
		☐				
		☐				

Virology / Other Pooled Cases ☐ No ☐ Yes Case #s Pooled_____ * Specify test method

* Test	Source(s)	Pooled	Referral Lab	Date Routed	Courier	Initials
		☐				
		☐				
		☐				

Storage of specimens *Locations include: room temperature = RT, refrigerator = R, refrigerator freezer = RF, deep freeze = D, ultralow freezer = U

Date_____ Specimen(s)_____ Location*_____ Requested storage time_____
Date_____ Specimen(s)_____ Location*_____ Requested storage time_____

VDS FORM: PA-009

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Authorised on: 06-Jun-2018 Authorised by: Kim Ethridgehill Unique Reference: 820-71508757 See iPassport for review timelines
Author(s): John Ragsdale, Kim Ethridgehill

EB / Date:_____

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Form PA-009 - Pathology Test Request Form - Version: 2.0 Index: Form PA-009 Printed: 06-Jun-2018 16:52

Date: 5/16/2024

Accession: V24-15159 NK 311138 Peromyscus leucopus

Animal weight: 25.5 g

Muscle collected for PFAS: femoral, tibial, and pectoral <0.5g

Liver weight: 1.5g

Female

Kidney L weight: <0.5g

Kidney R weight: <0.5g

Kidney collected for microplastics: no

Gross findings: within normal limits

Histology:

Skin (where):
Muscle (which):
Femur (bone marrow)
Spleen
Pancreas (around spleen)
Liver
Kidney (side):
Adrenal:
Lymph nodes (mesenteric):
Bladder
GI (stomach and intestines)
Reproductive tract
Tongue
Esophagus
Thyroid, trachea (en bloc):
Lung
Heart
Brain
Salivary gland

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-29669
Owner: UNM Museum of Southwest Biol
ID: AQ001 NK311147
Species:
Breed:

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 11/13/24
Reported: 12/14/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 39.06 grams, female, Merriam's kangaroo rat. The kangaroo rat was identified as "AQ 001" and "NK311147". The rat was in good body condition with minimal postmortem decomposition. The subcutis and organs were dry and tacky suggesting dehydration. The stomach, small intestine, and large intestine were filled with dark red to black digested blood. The liver mass 1.27 grams. The combined mass of the right and left kidneys was 0.54 grams. There were no other significant lesions.

HISTOPATHOLOGY

There is multifocal necrosis of the glandular epithelium of the mucosa of the stomach that varies in thickness. The foci of necrosis are filled with necrotic debris, fibrin, hemorrhage, and hemoglobin-breakdown pigments. The submucosa associated with the mucosal epithelial necrosis is edematous. The adjacent gastric glandular epithelium is degenerate with hemorrhage in the associated lamina propria.

There are rare random and multifocal small infiltrates of small numbers of macrophages and lesser numbers of lymphocytes in the liver that are occasionally associated with apoptotic hepatocytes.

There are no significant microscopic lesions in the tongue, larynx, esophagus, trachea, salivary gland, lymph nodes, lung, heart, spleen, kidneys, adrenal glands, small intestine, large intestine, pancreas, uterus, urinary bladder, skeletal muscle, or brain.

FINAL COMMENTS

The rat had multiple punctate gastric erosions/ulcers that resulted in blood loss into the gastrointestinal tract. The cause of the gastric ulcers could not be determined because there was no evidence of inflammation, infectious organisms, neoplasia, or parasites that could have caused the gastric ulcer. The relationship between the gastric ulcers and PFAS concentrations is not known.

There were rare microgranulomas in the liver of this rat. Microgranulomas are common in the livers of laboratory mice and rats in both control and study populations. The cause of the microgranulomas is not known, and they are typically considered to be nonspecific background changes. The significance of hepatic microgranulomas in wild rats is not known.

Thoolen B, Maronpot R, Harada T, Nyska A, Rousseaux C, Nolte T, *et al*. Proliferative and nonproliferative lesions of the rat and mouse hepatobiliary system. *Tox Pathol*. 2010;38: 5S-81S.

CASE DIAGNOSIS

GASTRIC ULCER

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-29669
Owner: UNM Museum of Southwest Biol
ID: AQ001 NK311147
Species:
Breed:

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 11/13/24
Reported: 12/14/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 39.06 grams, female, Merriam's kangaroo rat. The kangaroo rat was identified as "AQ 001" and "NK311147". The rat was in good body condition with minimal postmortem decomposition. The subcutis and organs were dry and tacky suggesting dehydration. The stomach, small intestine, and large intestine were filled with dark red to black digested blood. The liver mass 1.27 grams. The combined mass of the right and left kidneys was 0.54 grams. There were no other significant lesions.

HISTOPATHOLOGY

There is multifocal necrosis of the glandular epithelium of the mucosa of the stomach that varies in thickness. The foci of necrosis are filled with necrotic debris, fibrin, hemorrhage, and hemoglobin-breakdown pigments. The submucosa associated with the mucosal epithelial necrosis is edematous. The adjacent gastric glandular epithelium is degenerate with hemorrhage in the associated lamina propria.

There are rare random and multifocal small infiltrates of small numbers of macrophages and lesser numbers of lymphocytes in the liver that are occasionally associated with apoptotic hepatocytes.

There are no significant microscopic lesions in the tongue, larynx, esophagus, trachea, salivary gland, lymph nodes, lung, heart, spleen, kidneys, adrenal glands, small intestine, large intestine, pancreas, uterus, urinary bladder, skeletal muscle, or brain.

FINAL COMMENTS

The rat had multiple punctate gastric erosions/ulcers that resulted in blood loss into the gastrointestinal tract. The cause of the gastric ulcers could not be determined because there was no evidence of inflammation, infectious organisms, neoplasia, or parasites that could have caused the gastric ulcer. The relationship between the gastric ulcers and PFAS concentrations is not known.

There were rare microgranulomas in the liver of this rat. Microgranulomas are common in the livers of laboratory mice and rats in both control and study populations. The cause of the microgranulomas is not known, and they are typically considered to be nonspecific background changes. The significance of hepatic microgranulomas in wild rats is not known.

Thoolen B, Maronpot R, Harada T, Nyska A, Rousseaux C, Nolte T, *et al*. Proliferative and nonproliferative lesions of the rat and mouse hepatobiliary system. *Tox Pathol*. 2010;38: 5S-81S.

CASE DIAGNOSIS

GASTRIC ULCER

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

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End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-29670
Owner: UNM Museum of Southwest Biol
ID: AQ-002 NK311148
Species:
Breed:

DR. JEAN-LUC E. CARTRON
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6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 11/13/24
Reported: 12/14/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 41.61 grams, male, Merriam's kangaroo rat. The kangaroo rat was identified as "AQ 002" and "NK311148". The rat was in good body condition with minimal postmortem decomposition. The liver mass was 1.64 grams. The mass of the combined right and left kidneys was 0.58 grams. There were significant lesions in the thoracic viscera, abdominal viscera, skeletal muscle, or brain.

HISTOPATHOLOGY

There are rare random and multifocal small infiltrates of small numbers of macrophages and lesser numbers of lymphocytes in the liver that are occasionally associated with apoptotic hepatocytes.

The lumen of the small intestine contains small numbers of adult cestodes (tapeworms).

There are no significant microscopic lesions in the tongue, larynx, esophagus, thyroid gland, lymph nodes, lung, heart, spleen, kidneys, stomach, large intestine, pancreas, testicles, accessory sex glands, urinary bladder, skeletal muscle, or brain.

FINAL COMMENTS

The rat was mildly parasitized by tapeworms in the small intestine.

There were rare microgranulomas in the liver of this rat. Microgranulomas are common in the livers of laboratory mice and rats in both control and study populations. The cause of the microgranulomas is not known, and they are typically considered to be nonspecific background changes. The significance of hepatic microgranulomas in wild rats is not known.

Thoolen B, Maronpot R, Harada T, Nyska A, Rousseaux C, Nolte T, et al. Proliferative and nonproliferative lesions of the rat and mouse hepatobiliary system. Tox Pathol. 2010;38: 5S-81S.

CASE DIAGNOSIS

ENDOPARASITISM

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
(505) 383-9294 fax

Case #: 24-29671
Owner: UNM Museum of Southwest Biol
ID: AQ-003 NK311149
Species:
Breed:

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 11/13/24
Reported: 12/14/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 39.64 grams, male, Merriam's kangaroo rat. The kangaroo rat was identified as "AQ 003" and "NK311149". The rat was in good body condition with minimal postmortem decomposition. The liver mass 1.28 grams. The combined mass of the right and left kidneys was 0.47 grams. There were no significant lesions in the thoracic viscera, abdominal viscera, skeletal muscle, or brain.

HISTOPATHOLOGY

There is focally extensive necrosis of the lumenal aspect of the glandular epithelium of the mucosa of the stomach. The focus of necrosis is filled with necrotic debris, fibrin, hemorrhage, and hemoglobin-breakdown pigments. The submucosa associated with the mucosal epithelial necrosis is edematous. The adjacent gastric glandular epithelium is degenerate with hemorrhage in the associated lamina propria.

There are rare random and multifocal small infiltrates of small numbers of macrophages and lesser numbers of lymphocytes in the liver that are occasionally associated with apoptotic hepatocytes.

The lumen of the small intestine contains small numbers of adult nematodes.

There are no significant microscopic lesions in the tongue, larynx, esophagus, trachea, thyroid gland, lung, heart, spleen, kidneys, large intestine, pancreas, testicles, accessory sex glands, urinary bladder, skeletal muscle, or brain.

FINAL COMMENTS

The rat had a punctate gastric erosion/ulcer that resulted in small amounts of blood loss into the stomach. The cause of the gastric ulcer could not be determined because there was no evidence of inflammation, infectious organisms, neoplasia, or stomach parasites that could have caused the gastric ulcer. The relationship between the gastric ulcer and PFAS concentrations is not known.

The rat was parasitized by small numbers of adult nematodes in the small intestine.

There were rare microgranulomas in the liver of this rat. Microgranulomas are common in the livers of laboratory mice and rats in both control and study populations. The cause of the microgranulomas is not known, and they are typically considered to be nonspecific background changes. The significance of hepatic microgranulomas in wild rats is not known.

Thoolen B, Maronpot R, Harada T, Nyska A, Rousseaux C, Nolte T, et al. Proliferative and nonproliferative lesions of the rat and mouse hepatobiliary system. Tox Pathol. 2010;38: 5S-81S.

CASE DIAGNOSIS

ENDOPARASITISM
GASTRIC ULCER

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

New Mexico Department of Agriculture
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Albuquerque, New Mexico 87102
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Case #: 24-29672
Owner: UNM Museum of Southwest Biol
ID: AQ-004 NK311150
Species:
Breed:

DR. JEAN-LUC E. CARTRON
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ALBUQUERQUE, NM 87109

Received: 11/13/24
Reported: 12/14/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 31.34 grams, male, Merriam's kangaroo rat. The kangaroo rat was identified as "AQ 004" and "NK311150". The rat was in good body condition with minimal postmortem decomposition. The liver mass 1.10 grams. The combined mass of the right and left kidneys was 0.47 grams. There were no significant lesions in the thoracic viscera, abdominal viscera, skeletal muscle, or brain.

HISTOPATHOLOGY

There are rare random and multifocal small infiltrates of small numbers of macrophages and lesser numbers of lymphocytes in the liver that are occasionally associated with apoptotic hepatocytes.

There are no significant microscopic lesions in the tongue, larynx, esophagus, trachea, lymph nodes, lung, heart, spleen, kidneys, adrenal glands, stomach, small intestine, large intestine, pancreas, testicles, accessory sex glands, urinary bladder, skeletal muscle, or brain.

FINAL COMMENTS

There were rare microgranulomas in the liver of this rat. Microgranulomas are common in the livers of laboratory mice and rats in both control and study populations. The cause of the microgranulomas is not known, and they are typically considered to be nonspecific background changes. The significance of hepatic microgranulomas in wild rats is not known.

Thoolen B, Maronpot R, Harada T, Nyska A, Rousseaux C, Nolte T, et al. Proliferative and nonproliferative lesions of the rat and mouse hepatobiliary system. Tox Pathol. 2010;38: 5S-81S.

CASE DIAGNOSIS

NO SIGNIFICANT LESIONS

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

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End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
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Albuquerque, New Mexico 87102
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(505) 383-9294 fax

Case #: 24-29673
Owner: UNM Museum of Southwest Biol
ID: AQ-006 NK311152
Species:
Breed:

DR. JEAN-LUC E. CARTRON
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ALBUQUERQUE, NM 87109

Received: 11/13/24
Reported: 12/14/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 37.16 grams, female, Merriam's kangaroo rat. The kangaroo rat was identified as "AQ 006" and "NK311152". The rat was in good body condition with minimal postmortem decomposition. The liver mass 1.37 grams. The combined mass of the right and left kidneys was 0.58 grams. There were no significant lesions in the thoracic viscera, abdominal viscera, skeletal muscle, or brain.

HISTOPATHOLOGY

There are rare random and multifocal small infiltrates of small numbers of macrophages and lesser numbers of lymphocytes in the liver that are occasionally associated with apoptotic hepatocytes.

There are small numbers of myofibers in the skeletal muscle that contain variably sized protozoal cysts. The cysts are filled with numerous estimated 5 - 7 micron diameter crescent-shaped bradyzoites.

There are no significant microscopic lesions in the tongue, larynx, thyroid gland, trachea, esophagus, lungs, heart, spleen, kidneys, adrenal glands, stomach, small intestine, large intestine, pancreas, lymph nodes, urinary bladder, or brain.

FINAL COMMENTS

The rat had small numbers of sarcocysts in the skeletal muscle. Sarcocysts are the intermediate stage of *Sarcocystis* species. When a predator eats an animal with sarcocysts, the protozoa will mature within the predator to complete their life cycle.

There were rare microgranulomas in the liver of this rat. Microgranulomas are common in the livers of laboratory mice and rats in both control and study populations. The cause of the microgranulomas is not known, and they are typically considered to be nonspecific background changes. The significance of hepatic microgranulomas in wild rats is not known.

Thoolen B, Maronpot R, Harada T, Nyska A, Rousseaux C, Nolte T, et al. Proliferative and nonproliferative lesions of the rat and mouse hepatobiliary system. Tox Pathol. 2010;38: 5S-81S.

CASE DIAGNOSIS

SARCOCYST

John Ragsdale , DVM, PhD
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End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
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Albuquerque, New Mexico 87102
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Case #: 24-29674
Owner: UNM Museum of Southwest Biol
ID: AQ-08 NK311154
Species:
Breed:

DR. JEAN-LUC E. CARTRON
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ALBUQUERQUE, NM 87109

Received: 11/13/24
Reported: 12/14/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 38.93 grams, male, Merriam's kangaroo rat. The kangaroo rat was identified as "AQ 08" and "NK311154". The rat was in good body condition with minimal postmortem decomposition. The liver mass 1.31 grams. The combined mass of the right and left kidneys was 0.54 grams. There were no significant lesions in the thoracic viscera, abdominal viscera, skeletal muscle, or brain.

HISTOPATHOLOGY

There are rare random and multifocal small infiltrates of small numbers of macrophages and lesser numbers of lymphocytes in the liver that are occasionally associated with apoptotic hepatocytes.

The lumen of the small intestine contains small numbers of adult nematodes.

There are no significant microscopic lesions in the tongue, larynx, thyroid gland, esophagus, lung, heart, spleen, kidneys, adrenal glands, lymph nodes, stomach, small intestine, large intestine, pancreas, testicles, accessory sex glands, urinary bladder, or brain.

FINAL COMMENTS

The rat was mildly parasitized with small numbers of nematodes in the small intestine.

There were rare microgranulomas in the liver of this rat. Microgranulomas are common in the livers of laboratory mice and rats in both control and study populations. The cause of the microgranulomas is not known, and they are typically considered to be nonspecific background changes. The significance of hepatic microgranulomas in wild rats is not known.

Thoolen B, Maronpot R, Harada T, Nyska A, Rousseaux C, Nolte T, et al. Proliferative and nonproliferative lesions of the rat and mouse hepatobiliary system. Tox Pathol. 2010;38: 5S-81S.

CASE DIAGNOSIS

ENDOPARASITISM

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

NMED Exhibits 65

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
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Case #: 24-29675
Owner: UNM Museum of Southwest Biol
ID: AQ-007 NK311153
Species: Mouse NOS
Breed: Mouse NOS

DR. JEAN-LUC E. CARTRON
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6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 11/13/24
Reported: 12/14/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 11.39 grams, female, Chihuahuan pocket mouse. The pocket mouse was identified as "AQ 007" and "NK311153". The mouse was in good body condition with minimal postmortem decomposition. The liver mass 0.46 grams. The combined mass of the right and left kidneys was 0.20 grams. There were no significant lesions in the thoracic viscera, abdominal viscera, skeletal muscle, or brain.

HISTOPATHOLOGY

There are no significant microscopic lesions in the tongue, larynx, trachea, esophagus, thyroid gland, lungs, heart, liver, spleen, kidneys, adrenal glands, stomach, small intestine, large intestine, pancreas, uterus, skeletal muscle, brain, and a single cross section of the spinal cord.

FINAL COMMENTS

There are no significant lesion in the pocket mouse. There is no evidence of infectious disease, parasitism, neoplasia, or toxicosis.

CASE DIAGNOSIS

NO SIGNIFICANT LESIONS

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

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End of Report

New Mexico Department of Agriculture
Veterinary Diagnostic Services
1101 Camino de Salud, NE
Albuquerque, New Mexico 87102
(505) 383-9299 phone
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Case #: 24-29676
Owner: UNM Museum of Southwest Biol
ID: AQ-005 NK311151
Species:
Breed:

DR. JEAN-LUC E. CARTRON
Geologic Associates, Inc.
6020 Academy Road NE, Sui
ALBUQUERQUE, NM 87109

Received: 11/13/24
Reported: 12/14/24
Final Report

NECROPSY

The carcass presented for postmortem examination was an adult, 18.82 grams, male, deer mouse. The deer mouse was identified as "AQ 005" and "NK311151". The mouse was in good body condition with minimal postmortem decomposition. The liver mass 0.81 grams. The combined mass of the right and left kidneys was 0.40 grams. There were no significant lesions in the thoracic viscera, abdominal viscera, skeletal muscle, or brain.

HISTOPATHOLOGY

There are rare random and multifocal small infiltrates of small numbers of macrophages and lesser numbers of lymphocytes in the liver that are occasionally associated with apoptotic hepatocytes.

There are no significant microscopic lesions in the tongue, larynx, trachea, esophagus, thyroid gland, lungs, heart, spleen, kidneys, adrenal glands, lymph nodes, skeletal muscle, stomach, small intestine, large intestine, urinary bladder, testicles, accessory sex glands, or brain.

FINAL COMMENTS

There were rare microgranulomas in the liver of this mouse. Microgranulomas are common in the livers of laboratory mice and rats in both control and study populations. The cause of the microgranulomas is not known, and they are typically considered to be nonspecific background changes. The significance of hepatic microgranulomas in wild mice is not known.

Thoolen B, Maronpot R, Harada T, Nyska A, Rousseaux C, Nolte T, et al. Proliferative and nonproliferative lesions of the rat and mouse hepatobiliary system. Tox Pathol. 2010;38: 5S-81S.

CASE DIAGNOSIS

NO SIGNIFICANT LESIONS

John Ragsdale , DVM, PhD
Diplomate, ACVP
Veterinary Pathologist

Confidential report intended for individual/organization addressed. Results apply to samples as received.
End of Report

National Primary Drinking Water Regulations

The National Primary Drinking Water Regulations (NPDWR) (National Primary Drinking Water Regulations)are legally enforceable primary standards and treatment techniques that apply to public water systems. Primary standards and treatment techniques protect public health by limiting the levels of contaminants in drinking water.

- Microorganisms
- Disinfectants
- Disinfection Byproducts
- Inorganic Chemicals
- Organic Chemicals, except for PFAS
  - Selected Per- and poly-fluoroalkyl substances (PFAS)
- Radionuclides

Related Info

- Find out how EPA develops drinking water regulations <https://epa.gov/sdwa/sdwa-evaluation-and-rulemaking-process>
- Learn about existing EPA drinking water regulations <https://epa.gov/node/115533/>
- Read the drinking water section of the Code of Federal Regulations (40 CFR 141) <http://www.gpo.gov>
- Historical information Fact Sheet: Questions and Answers on Fluoride, January 2011 <https://19january2021snapshot.epa.gov/dwsixyearreview/fact-sheet-questions-and-answers-fluoride_.html>

Microorganisms

- **Surface Water Treatment Rules** <https://epa.gov/dwreginfo/surface-water-treatment-rules>
- **Ground Water Rule** <https://epa.gov/dwreginfo/ground-water-rule>
- **Revised Total Coliform Rule And Total Coliform Rule** <https://epa.gov/dwreginfo/revised-total-coliform-rule-and-total-coliform-rule>

Contaminant	MCLG (Maximum Contaminant Level Goal)[1]	MCL (Maximum Contaminant Level) or TT (Treatment Technique)[1]	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
Cryptosporidium	zero	TT (Treatment Technique)[3]	Gastrointestinal illness (such as diarrhea, vomiting, and cramps)	Human and animal fecal waste
Giardia lamblia	zero	TT (Treatment Technique)[3]	Gastrointestinal illness (such as diarrhea, vomiting, and cramps)	Human and animal fecal waste
Heterotrophic plate count (HPC (Heterotrophic plate count))	n/a	TT (Treatment Technique)[3]	HPC (Heterotrophic plate count) has no health effects; it is an analytic method used to measure the variety of bacteria that are common in water. The lower the concentration of bacteria in drinking water, the better maintained the water system is.	HPC (Heterotrophic plate count) measures a range of bacteria that are naturally present in the environment
Legionella <https://epa.gov/ground-water-and-drinking-water/legionella>	zero	TT (Treatment Technique)[3]	Legionnaire's Disease, a type of pneumonia	Found naturally in water; multiplies in heating systems

Contaminant	MCLG (Maximum Contaminant Level Goal)[1]	MCL (Maximum Contaminant Level) or TT (Treatment Technique)[1]	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
Total Coliforms (including fecal coliform and *E. Coli*) • Quick reference guide • Rule Summary <https://epa.gov/dwreginfo/revised-total-coliform-rule-and-total-coliform-rule>	zero	5.0%[4]	Not a health threat in itself; it is used to indicate whether other potentially harmful bacteria may be present[5]	Coliforms are naturally present in the environment; as well as feces; fecal coliforms and *E. coli* only come from human and animal fecal waste.
Turbidity	n/a	TT (Treatment Technique)[3]	Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (such as whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.	Soil runoff
Viruses (enteric)	zero	TT (Treatment Technique)[3]	Gastrointestinal illness (such as diarrhea, vomiting, and cramps)	Human and animal fecal waste

Disinfection Byproducts

- **Quick reference guide: Stage 1 and 2 Disinfectants and Disinfection Byproducts Rules**
- **Stage 1 and 2 Rules Summary** <https://epa.gov/dwreginfo/stage-1-and-stage-2-disinfectants-and-disinfection-byproducts-rules>

Contaminant	MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]	MCL (Maximum Contaminant Level) or TT (Treatment Technique)[1] (mg/L (Milligrams per Liter))[2]	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
Bromate	zero	0.010	Increased risk of cancer	Byproduct of drinking water disinfection
Chlorite	0.8	1.0	Anemia; infants and young children: nervous system effects	Byproduct of drinking water disinfection
Haloacetic acids (HAA5) (Haloacetic acids)	n/a[6]	0.060	Increased risk of cancer	Byproduct of drinking water disinfection

Contaminant	MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]	MCL (Maximum Contaminant Level) or TT (Treatment Technique)[1] (mg/L (Milligrams per Liter))[2]	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
Total Trihalomethanes (TTHMs (Total Trihalomethanes))	n/a[6]	0.080	Liver, kidney or central nervous system problems; increased risk of cancer	Byproduct of drinking water disinfection

Disinfectants

- **Quick reference guide: Stage 1 and 2 Disinfectants and Disinfection Byproducts Rules**
- **Stage 1 and 2 Rules Summary** <https://epa.gov/dwreginfo/stage-1-and-stage-2-disinfectants-and-disinfection-byproducts-rules>

Contaminant	MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]	MCL (Maximum Contaminant Level) or TT (Treatment Technique)[1] (mg/L (Milligrams per Liter))[2]	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
Chloramines (as Cl_2 (Chlorine)) <https://epa.gov/dwreginfo/chloramines-drinking-water>	MRDLG (Maximum Residual Disinfectant Level Goal)=4[1]	MRDL (Maximum Residual Disinfectant Level)=4.0[1]	Eye/nose irritation; stomach discomfort, anemia	Water additive used to control microbes
Chlorine (as Cl_2 (Chlorine))	MRDLG (Maximum Residual Disinfectant Level Goal)=4[1]	MRDL (Maximum Residual Disinfectant Level)=4.0[1]	Eye/nose irritation; stomach discomfort	Water additive used to control microbes
Chlorine dioxide (as ClO_2 (Chlorine dioxide))	MRDLG (Maximum Residual Disinfectant Level Goal)=0.8[1]	MRDL (Maximum Residual Disinfectant Level)=0.8[1]	Anemia; infants and young children: nervous system effects	Water additive used to control microbes

Inorganic Chemicals

- **Chemical Contaminant Rules Summary** <https://epa.gov/dwreginfo/chemical-contaminant-rules>

Contaminant	MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligram per Liter))[2]	MCL (Maximum Contaminant Level) or TT (Treatment Technique)[1] (mg/L (Milligrams per Liter))[2]	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
Antimony	0.006	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder
Arsenic • Quick reference guide • Consumer fact sheet	0	0.010 as of 01/23/06	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards, runoff from glass and electronics production wastes
Asbestos (fiber > 10 micrometers)	7 million fibers per liter (MFL (Million Fibers per Liter))	7 MFL (Million Fibers per Liter)	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits
Barium	2	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Beryllium	0.004	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries
Cadmium	0.005	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints
Chromium (total) <https://epa.gov/dwstandardsregulations/chromium-drinking-water>	0.1	0.1	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits

Contaminant	MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligram per Liter))[2]	MCL (Maximum Contaminant Level) or TT (Treatment Technique)[1] (mg/L (Milligrams per Liter))[2]	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
Copper	1.3	TT (Treatment Technique)[7]; Action Level=1.3	Short term exposure: Gastrointestinal distress Long term exposure: Liver or kidney damage People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; erosion of natural deposits
Cyanide (as free cyanide)	0.2	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories
Fluoride	4.0	4.0	Bone disease (pain and tenderness of the bones); Children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories
Lead <https://epa.gov/node/133825/> • Quick reference guide • Rule information <https://epa.gov/node/120819/>	zero	TT (Treatment Technique)[7]; Action Level=0.010	Infants and children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities Adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits
Mercury (inorganic)	0.002	0.002	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands
Nitrate (measured as Nitrogen)	10	10	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaking from septic tanks, sewage; erosion of natural deposits

Contaminant	MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligram per Liter))[2]	MCL (Maximum Contaminant Level) or TT (Treatment Technique)[1] (mg/L (Milligrams per Liter))[2]	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
Nitrite (measured as Nitrogen)	1	1	Infants below the age of six months who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaking from septic tanks, sewage; erosion of natural deposits
Selenium	0.05	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines
Thallium	0.0005	0.002	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories

Organic Chemicals, except for PFAS

- **Chemical Contaminant Rules Summary** <https://epa.gov/dwreginfo/chemical-contaminant-rules>

Contaminant	MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]	MCL (Maximum Contaminant Level) or TT (Treatment Technique)[1] (mg/L (Milligrams per Liter))[2]	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
Acrylamide	zero	TT (Treatment Technique)[8]	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/wastewater treatment
Alachlor	zero	0.002	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops
Atrazine	0.003	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops
Benzene	zero	0.005	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills

Contaminant	MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]	MCL (Maximum Contaminant Level) or TT (Treatment Technique)[1] (mg/L (Milligrams per Liter))[2]	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
Benzo(a)pyrene (PAHs)	zero	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines
Carbofuran	0.04	0.04	Problems with blood, nervous system, or reproductive system	Leaching of soil fumigant used on rice and alfalfa
Carbon tetrachloride	zero	0.005	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities
Chlordane	zero	0.002	Liver or nervous system problems; increased risk of cancer	Residue of banned termiticide
Chlorobenzene	0.1	0.1	Liver or kidney problems	Discharge from chemical and agricultural chemical factories
2,4-D	0.07	0.07	Kidney, liver, or adrenal gland problems	Runoff from herbicide used on row crops
Dalapon	0.2	0.2	Minor kidney changes	Runoff from herbicide used on rights of way
1,2-Dibromo-3-chloropropane (DBCP (1,2-Dibromo-3-chloropropane))	zero	0.0002	Reproductive difficulties; increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards
o-Dichlorobenzene	0.6	0.6	Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories
p-Dichlorobenzene	0.075	0.075	Anemia; liver, kidney or spleen damage; changes in blood	Discharge from industrial chemical factories
1,2-Dichloroethane	zero	0.005	Increased risk of cancer	Discharge from industrial chemical factories
1,1-Dichloroethylene	0.007	0.007	Liver problems	Discharge from industrial chemical factories
cis-1,2-Dichloroethylene	0.07	0.07	Liver problems	Discharge from industrial chemical factories

Contaminant	MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]	MCL (Maximum Contaminant Level) or TT (Treatment Technique)[1] (mg/L (Milligrams per Liter))[2]	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
trans-1,2-Dichloroethylene	0.1	0.1	Liver problems	Discharge from industrial chemical factories
Dichloromethane	zero	0.005	Liver problems; increased risk of cancer	Discharge from drug and chemical factories
1,2-Dichloropropane	zero	0.005	Increased risk of cancer	Discharge from industrial chemical factories
Di(2-ethylhexyl) adipate	0.4	0.4	Weight loss, liver problems, or possible reproductive difficulties.	Discharge from chemical factories
Di(2-ethylhexyl) phthalate	zero	0.006	Reproductive difficulties; liver problems; increased risk of cancer	Discharge from rubber and chemical factories
Dinoseb	0.007	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans and vegetables
Dioxin (2,3,7,8-TCDD (Dioxin))	zero	0.00000003	Reproductive difficulties; increased risk of cancer	Emissions from waste incineration and other combustion; discharge from chemical factories
Diquat	0.02	0.02	Cataracts	Runoff from herbicide use
Endothall	0.1	0.1	Stomach and intestinal problems	Runoff from herbicide use
Endrin	0.002	0.002	Liver problems	Residue of banned insecticide
Epichlorohydrin	zero	TT (Treatment Technique)[8]	Increased cancer risk, and over a long period of time, stomach problems	Discharge from industrial chemical factories; an impurity of some water treatment chemicals
Ethylbenzene	0.7	0.7	Liver or kidneys problems	Discharge from petroleum refineries
Ethylene dibromide	zero	0.00005	Problems with liver, stomach, reproductive system, or kidneys; increased risk of cancer	Discharge from petroleum refineries

Contaminant	MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]	MCL (Maximum Contaminant Level) or TT (Treatment Technique)[1] (mg/L (Milligrams per Liter))[2]	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
Glyphosate	0.7	0.7	Kidney problems; reproductive difficulties	Runoff from herbicide use
Heptachlor	zero	0.0004	Liver damage; increased risk of cancer	Residue of banned termiticide
Heptachlor epoxide	zero	0.0002	Liver damage; increased risk of cancer	Breakdown of heptachlor
Hexachlorobenzene	zero	0.001	Liver or kidney problems; reproductive difficulties; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories
Hexachlorocyclopentadiene	0.05	0.05	Kidney or stomach problems	Discharge from chemical factories
Lindane	0.0002	0.0002	Liver or kidney problems	Runoff/leaching from insecticide used on cattle, lumber, gardens
Methoxychlor	0.04	0.04	Reproductive difficulties	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, livestock
Oxamyl (Vydate)	0.2	0.2	Slight nervous system effects	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes
Polychlorinated biphenyls (PCBs (Polychlorinated biphenyls))	zero	0.0005	Skin changes; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer	Runoff from landfills; discharge of waste chemicals
Pentachlorophenol	zero	0.001	Liver or kidney problems; increased cancer risk	Discharge from wood preserving factories
Picloram	0.5	0.5	Liver problems	Herbicide runoff
Simazine	0.004	0.004	Problems with blood	Herbicide runoff
Styrene	0.1	0.1	Liver, kidney, or circulatory system problems	Discharge from rubber and plastic factories; leaching from landfills

Contaminant	MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]	MCL (Maximum Contaminant Level) or TT (Treatment Technique)[1] (mg/L (Milligrams per Liter))[2]	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
Tetrachloroethylene	zero	0.005	Liver problems; increased risk of cancer	Discharge from factories and dry cleaners
Toluene	1	1	Nervous system, kidney, or liver problems	Discharge from petroleum factories
Toxaphene	zero	0.003	Kidney, liver, or thyroid problems; increased risk of cancer	Runoff/leaching from insecticide used on cotton and cattle
2,4,5-TP (Silvex)	0.05	0.05	Liver problems	Residue of banned herbicide
1,2,4-Trichlorobenzene	0.07	0.07	Changes in adrenal glands	Discharge from textile finishing factories
1,1,1-Trichloroethane	0.20	0.2	Liver, nervous system, or circulatory problems	Discharge from metal degreasing sites and other factories
1,1,2-Trichloroethane	0.003	0.005	Liver, kidney, or immune system problems	Discharge from industrial chemical factories
Trichloroethylene	zero	0.005	Liver problems; increased risk of cancer	Discharge from metal degreasing sites and other factories
Vinyl chloride	zero	0.002	Increased risk of cancer	Leaching from PVC pipes; discharge from plastic factories
Xylenes (total)	10	10	Nervous system damage	Discharge from petroleum factories; discharge from chemical factories

Selected Per- and poly-fluoroalkyl substances (PFAS)

- **PFAS rule references** <https://epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas>

Contaminant	MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]	MCL (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]	HBWC[9] (mg/L)[2] for Hazard Index Calculation <https://epa.gov/system/files/documents/2024-04/pfas-npdwr_fact-sheet_hazard-index_4.8.24.pdf>	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
Hazard Index <https://epa.gov/system/files/documents/2024-04/pfas-npdwr_fact-sheet_hazard-index_4.8.24.pdf> PFAS (HFPO-DA, PFBS, PFHxS, and PFNA)	1(unitless)	1(unitless)	Not applicable	Low levels of multiple PFAS that individually would not likely result in increased risk of adverse health effects may result in adverse health effects when combined in a mixture. Increased health risks include liver, immune, and thyroid effects. Additionally, developmental and thyroid effects following repeated exposure during pregnancy and/or childhood.	Discharge from manufacturing and industrial chemical facilities, use of certain consumer products, occupational exposures, and certain firefighting activities.

Contaminant	**MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]**	**MCL (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]**	**HBWC[9] (mg/L)[2] for Hazard Index Calculation** <https://epa.gov/system/files/documents/2024-04/pfas-npdwr_fact-sheet_hazard-index_4.8.24.pdf>	**Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)**	**Sources of Contaminant in Drinking Water**
HFPO-DA (commonly knowns as GenX Chemicals)	0.00001	0.00001	0.00001	Immune, liver and kidney effects; potential concern for cancer Developmental effects following repeated exposure during pregnancy and/or childhood	Discharge from manufacturing and industrial chemical facilities, use of certain consumer products, occupational exposures, and certain firefighting activities.
PFBS	No individual MCLG	No individual MCL	0.002	See Hazard Index PFAS information	See Hazard Index PFAS information
PFHxS	0.00001	0.00001	0.00001	Immune, thyroid, and liver effects Developmental effects following repeated exposure during pregnancy and/or childhood	Discharge from manufacturing and industrial chemical facilities, use of certain consumer products, occupational exposures, and certain firefighting activities.

Contaminant	**MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]**	**MCL (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]**	**HBWC[9] (mg/L)[2] for Hazard Index Calculation** <https://epa.gov/system/files/documents/2024-04/pfas-npdwr_fact-sheet_hazard-index_4.8.24.pdf>	**Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)**	**Sources of Contaminant in Drinking Water**
PFNA	0.00001	0.00001	0.00001	Elevated cholesterol levels and immune and liver effects Developmental effects following repeated exposure during pregnancy and/or childhood	Discharge from manufacturing and industrial chemical facilities, use of certain consumer products, occupational exposures, and certain firefighting activities.
PFOA	zero	0.0000040	Not applicable	Cardiovascular, immune and liver effects; increased incidence of certain types of cancers including kidney and testicular Developmental and immune effects following repeated exposure during pregnancy and/or childhood	Discharge from manufacturing and industrial chemical facilities, use of certain consumer products, occupational exposures, and certain firefighting activities.

Contaminant	MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]	MCL (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]	HBWC[9] (mg/L)[2] for Hazard Index Calculation <https://epa.gov/system/files/documents/2024-04/pfas-npdwr_fact-sheet_hazard-index_4.8.24.pdf>	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
PFOS	zero	0.0000040	Not applicable	Cardiovascular, immune and liver effects; increased incidence of certain types of cancers including liver Developmental and immune effects following repeated exposure during pregnancy and/or childhood	Discharge from manufacturing and industrial chemical facilities, use of certain consumer products, occupational exposures, and certain firefighting activities.

Radionuclides

- **Quick Reference Guide**
- **Radionuclides Rule Information and Summary** <https://epa.gov/dwreginfo/radionuclides-rule>

Contaminant	MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]	MCL (Maximum Contaminant Level) or TT (Treatment Technique)[1] (mg/L (Milligrams per Liter))[2]	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
Alpha particles	none ---------- zero	15 picocuries per Liter (pCi/L (Picocuries per Liter))	Increased risk of cancer	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation
Beta particles and photon emitters	none ---------- zero	4 millirems per year	Increased risk of cancer	Decay of natural and man-made deposits of certain minerals that are radioactive and may emit forms of radiation known as photons and beta radiation

Contaminant	MCLG (Maximum Contaminant Level Goal)[1] (mg/L (Milligrams per Liter))[2]	MCL (Maximum Contaminant Level) or TT (Treatment Technique)[1] (mg/L (Milligrams per Liter))[2]	Potential Health Effects from Long-Term Exposure Above the MCL (Maximum Contaminant Level) (unless specified as short-term)	Sources of Contaminant in Drinking Water
Radium 226 and Radium 228 (combined)	none ---------- zero	5 pCi/L (Picocuries per Liter)	Increased risk of cancer	Erosion of natural deposits
Uranium	zero	30 ug/L (microgram per liter) as of 12/08/03	Increased risk of cancer, kidney toxicity	Erosion of natural deposits

Notes

[1]Definitions:

- Maximum Contaminant Level Goal (MCLG (Maximum Contaminant Level Goal)) - The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.
- Maximum Contaminant Level (MCL (Maximum Contaminant Level)) - The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.
- Maximum Residual Disinfectant Level Goal (MRDLG (Maximum Residual Disinfectant Level Goal)) - The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs (Maximum Residual Disinfectant Level Goal) do not reflect the benefits of the use of disinfectants to control microbial contaminants.
- Treatment Technique (TT (Treatment Technique)) - A required process intended to reduce the level of a contaminant in drinking water.
- Maximum Residual Disinfectant Level (MRDL (Maximum Residual Disinfectant Level)) - The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

[2] Units are in milligrams per liter (mg/L (Milligrams per Liter)) unless otherwise noted. Milligrams per liter are equivalent to parts per million (PPM (Parts per Million)).

[3] EPA's surface water treatment rules require systems using surface water or ground water under the direct influence of surface water to

a. Disinfect their water, and
b. Filter their water, or
c. Meet criteria for avoiding filtration so that the following contaminants are controlled at the following levels:

- *Cryptosporidium*: Unfiltered systems are required to include *Cryptosporidium* in their existing watershed control provisions
- *Giardia lamblia*: 99.9% removal/inactivation.
- Viruses: 99.99% removal/inactivation.
- *Legionella*: No limit, but EPA believes that if *Giardia* and viruses are removed/inactivated, according to the treatment techniques in the Surface Water Treatment Rule, *Legionella* will also be controlled.
- Turbidity: For systems that use conventional or direct filtration, at no time can turbidity (cloudiness of water) go higher than 1 Nephelometric Turbidity Unit (NTU) (Nephelometric Turbidity Unit), and samples for turbidity must be less than or equal to 0.3 NTUs (Nephelometric Turbidity Units) in at least 95 percent of the samples in any month. Systems that use filtration other than the conventional or direct filtration must follow state limits, which must include turbidity at no time exceeding 5 NTUs (Nephelometric Turbidity Units).
- Heterotrophic Plate Count (HPC) (Heterotrophic Plate Count): No more than 500 bacterial colonies per milliliter.
- Long Term 1 Enhanced Surface Water Treatment: Surface water systems or groundwater under the direct influence (GWUDI (Groundwater Under The Direct Influence)) systems serving fewer than 10,000 people must comply with the applicable Long Term 1 Enhanced Surface Water Treatment Rule provisions (such as turbidity standards, individual filter monitoring, *Cryptosporidium* removal requirements, updated watershed control requirements for unfiltered systems).

- Long Term 2 Enhanced Surface Water Treatment Rule: This rule applies to all surface water systems or ground water systems under the direct influence of surface water. The rule targets additional *Cryptosporidium* treatment requirements for higher risk systems and includes provisions to reduce risks from uncovered finished water storage facilities and to ensure that the systems maintain microbial protection as they take steps to reduce the formation of disinfection byproducts.
- Filter Backwash Recycling: This rule requires systems that recycle to return specific recycle flows through all processes of the system's existing conventional or direct filtration system or at an alternate location approved by the state.

[4] No more than 5.0% samples total coliform-positive (TC-positive (Total Coliform-positive)) in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month.) Every sample that has total coliform must be analyzed for either fecal coliforms or *E. coli* if two consecutive TC-positive (Total Coliform-positive) samples, and one is also positive for *E.coli* fecal coliforms, system has an acute MCL (Maximum Contaminant Level) violation.

[5] Fecal coliform and *E. coli* are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Disease-causing microbes (pathogens) in these wastes can cause diarrhea, cramps, nausea, headaches, or other symptoms. These pathogens may pose a special health risk for infants, young children, and people with severely compromised immune systems.

[6] Although there is no collective MCLG (Maximum Contaminant Level Goal) for this contaminant group, there are individual MCLGs (Maximum Contaminant Level Goals) for some of the individual contaminants:

- Trihalomethanes: bromodichloromethane (zero); bromoform (zero); dibromochloromethane (0.06 mg/L (Milligrams per Liter)): chloroform (0.07 mg/L (Milligrams per Liter).
- Haloacetic acids: dichloroacetic acid (zero); trichloroacetic acid (0.02 mg/L (Milligrams per Liter)); monochloroacetic acid (0.07mg/L (Milligrams per Liter)). Bromoacetic acid and dibromoacetic acid are regulated with this group but have no MCLGs.

[7] Lead and copper are regulated by a treatment technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level, water systems must take additional steps. For copper, the action level is 1.3 mg/L (Milligrams per Liter), and for lead is 0.010 mg/L (Milligrams per Liter).

[8] Each water system must certify, in writing, to the state (using third-party or manufacturer's certification) that when acrylamide and epichlorohydrin are used to treat water, the combination (or product) of dose and monomer level does not exceed the levels specified, as follows:

- Acrylamide = 0.05% dosed at 1 mg/L (Milligrams per Liter) (or equivalent)
- Epichlorohydrin = 0.01% dosed at 20 mg/L (Milligrams per Liter) (or equivalent)

[9] Health Based Water Concentration (HBWC) - To calculate the Hazard Index, a ratio is developed for each PFAS by dividing the measured level of the PFAS in drinking water by the level below which adverse health effects are not likely to occur (i.e., the Health Based Water Concentration).

Contact us about Ground Water and Drinking Water <https://epa.gov/ground-water-and-drinking-water/forms/contact-us-about-ground-water-and-drinking-water-0> to ask a question, provide feedback, or report a problem.

Last updated on December 1, 2025

pH

Overview | When to List | Ways to Measure | Conceptual Diagrams | Literature Reviews | References

Overview

- Low pH
  - Checklist of Sources, Site Evidence and Biological Effects
- High pH
  - Checklist of Sources, Site Evidence and Biological Effects

pH is an expression of hydrogen ion concentration in water. Specifically, pH is the negative logarithm of hydrogen ion (H^+) concentration (mol/L) in an aqueous solution:

$pH = -\log_{10}(H^+)$

The term is used to indicate basicity or acidity of a solution on a scale of 0 to 14, with pH 7 being neutral. As the concentration of H^+ ions in solution increases, acidity increases and pH gets lower, below 7 (see Figure 1). When pH is above 7, the solution is basic.

Because pH is a logarithmic function, one unit change in pH (e.g., 7 to 6) indicates a 10x change in H^+ concentration in that solution. However, what is actually measured is hydrogen ion activity, not concentration.

Note that although basic solutions are alkaline, “basicity” and “alkalinity” are not exactly the same thing. Basicity refers to the ratio of hydrogen and hydroxyl (OH^-) ions in solution, and is directly related to pH. Alkalinity is related to the acid-neutralizing capacity (ANC) of a solution. In aquatic ecosystems, processes that increase dissolved carbon dioxide or dissolved organic carbon (DOC) decrease pH but have no effect on ANC.

pH affects most chemical and biological processes in water. It is one of the most important environmental factors limiting species distributions in aquatic habitats. Different species flourish within different ranges of pH, with the optima for most aquatic organisms falling between pH 6.5-8. U.S. EPA water quality criteria for pH in freshwater suggest a range of 6.5 to 9.

Fluctuating pH or sustained pH outside this range physiologically stresses many species and can result in decreased reproduction, decreased growth, disease or death. This can ultimately lead to reduced biological diversity in streams.

Even small changes in pH can shift community composition in streams. This is because pH alters the chemical state of many pollutants (e.g., copper, ammonia), changing their solubility, transport and bioavailability. This can increase exposure to and toxicity of metals and nutrients to aquatic plants and animals.



Figure 1. Example of an acidic stream due to mine drainage. Courtesy of USGS Biology, Contaminant Biology Program

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Low pH

For a waterbody to be considered to have low pH, pH generally needs to be below 6 or 6.5, depending on the system. Low pH is addressed in this module as a proximate cause of effects on aquatic biota. It should be listed as a candidate cause when potential human sources and activities, site observations or observed biological effects support portions of the source-to-impairment pathways (see Figure 2).

This diagram and some of the other information also may be useful in Step 3: Evaluate Data from the Case.

Checklist of Sources, Site Evidence and Biological Effects

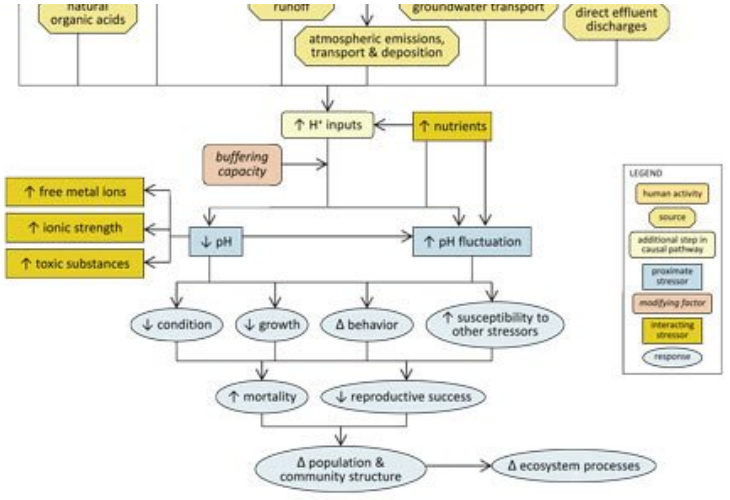
The checklist below will help you determine whether to include low pH among your candidate causes. The list is intended to guide you in collecting evidence to support, weaken or eliminate low pH as a candidate cause. For more information on specific entries, go to the When to List tab.

Consider listing low pH as a candidate cause when the following sources and activities, site evidence and biological effects are present:

Sources and Activities

- Mine wastes
- Historic mine sites
- Acid-generating rocks/soils
- Power plants and other sources of acidic gases
- Coal pile runoff
- Industrial effluents

<https://epa.gov/sites/default/files/2015-12/lowphcd_sim_500.jpg>



Simple conceptual model diagram for **LOW pH**

Figure 2. A simple conceptual diagram illustrating causal pathways, from sources to impairments, related to **low pH**. Click on the diagram to

- Landfill leachate
- Confined animal feeding operations, dairy runoff
- Instream oxidation or reduction processes
- Recent draining of naturally inundated wetlands or floodplains

view a larger version.

Site Evidence

- Low site pH data
- Acidic precipitation
- Geology or soil type (e.g., serpentine geology, soils)
- Mine drainage/overflows (current or historic)
- “Yellow-boy” (iron precipitates on rocks)
- Black or brown (tea colored) water
- Filamentous algae

Biological Effects

- Damage to gill epithelium
- Mucus on gills
- Decreased growth
- Reproductive failure
- Respiratory inhibition
- Ionoregulatory impacts
- Reduced number of species and individuals
- Mortality
- Replacement of acid-sensitive species with acid-tolerant species

Consider contributing, modifying and related factors when listing low pH as a candidate cause:

- **Metals**: Common interactions to consider with low pH involve metals (e.g., aluminum, copper, zinc). Acid rain mobilizes and leaches metals (e.g., aluminum) into groundwater and streams, resulting in higher dissolved metal concentrations combined with low pH. Metals such as aluminum become increasingly bioavailable with decreasing pH (<6.0) due to increases in the free ionic form. This results in greater toxic effects at low pH than at neutral or high pH (Howells et al. 1983, Playle et al. 1989). The direct cause of biological effects may be pH (with metals contributing), metals (with pH contributing), or both pH and metals combined (i.e., neither acting alone would have caused observed effects).
- **Ionic strength**: To a large extent, pH controls both the chemical form and solubility of ionic chemicals.

- **Unspecified toxic chemicals**: The toxicity of compounds (e.g., phenols, cyanides) may increase with decreasing pH. For example, six phenols were more toxic to the guppy *Poecilia reticulata* at pH 5 or 6 than at pH 7 or 8 (Saarikoski 1981). Also, hydrogen cyanide (HCN) predominates at low and middle pH values and is about twice as toxic as CN^-, which is found in appreciable amounts above pH 8.5 (Rand 1995).
- **Ammonia**: Concentration and toxicity of NH_3 increases as pH increases, although less NH_3 is required to produce toxic effects at lower pH (IPCS 1986, Wurts 2003).

High pH

A waterbody is considered to have a high pH if pH exceeds 9 for prolonged periods or with high frequency. High pH is less common than low pH as a candidate cause, because anthropogenic sources are acidic more often than basic.

High pH is addressed in this module as a proximate cause of effects on aquatic biota. It should be listed as a candidate cause when potential human sources and activities, site observations or observed biological effects support portions of the source-to-impairment pathways (Figure 3). This conceptual diagram and some of the other information also may be useful in Step 3: Evaluate Data from the Case.

Checklist of Sources, Site Evidence and Biological Effects

The checklist below will help you determine whether to include high pH among your candidate causes. The list is intended to guide you in collecting evidence to support, weaken or eliminate high pH as a candidate cause. For more information on specific entries, go to the When to List tab.

Consider listing high pH as a candidate cause when the following sources and activities, site evidence, and biological effects are present:

Sources and Activities

- Industrial discharges
- Alkaline geology and soils
- Asphalt production or disposal
- Agricultural lime
- Oil and gas brines
- Industrial landfills
- Cement manufacturing
- Soap manufacturing
- Limestone gravel roads

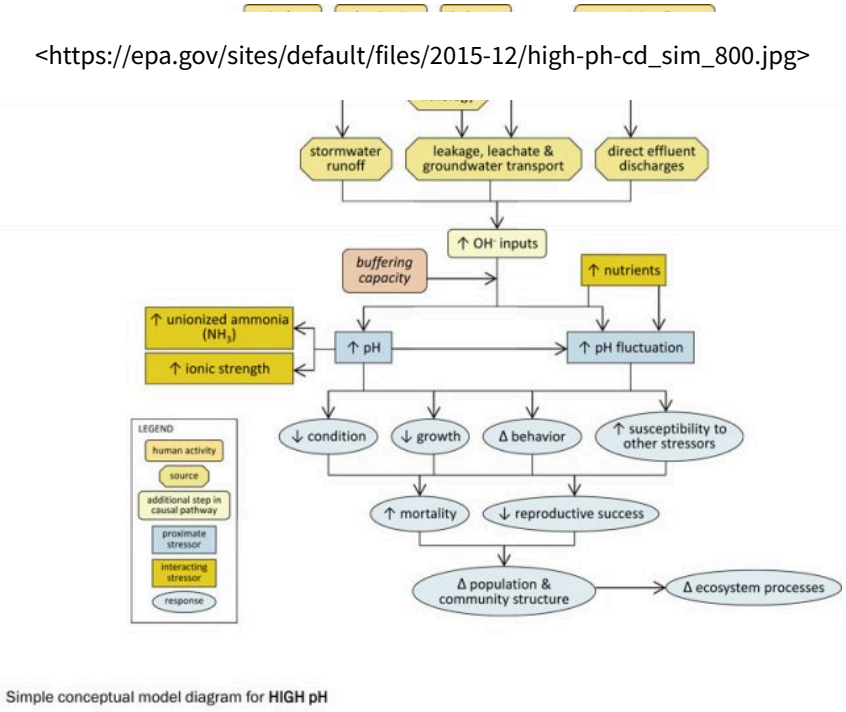
Site Evidence

- Abundant macrophytes, filamentous algae or algal mats
- High site pH data
- Mineral deposits
- Low nighttime or early morning dissolved oxygen concentration
- (e.g., <40% saturation)

Biological Effects

- Decreased reproduction
- Reduced biodiversity
- Decreased growth
- Damage to skin, gills, olfactory organs, eyes

<https://epa.gov/sites/default/files/2015-12/high-ph-cd_sim_800.jpg>



Simple conceptual model diagram for **HIGH pH**

Figure 3. A simple conceptual diagram illustrating causal pathways, from sources to impairments, related to **high pH**. Click on the diagram to view a larger version.

Consider contributing, modifying and related factors when high pH is selected as a candidate cause:

- **Dissolved oxygen**
- **Ionic strength**: To a large extent, pH controls both the chemical form and the solubility of ionic chemicals.
- **Ammonia**: Concentration and toxicity of NH_3 increases as pH increases, although less NH_3 is required to produce toxic effects at lower pH (IPCS 1986, Wurts 2003).

When to List

Low pH	High pH

Low pH

- Sources and Activities that Suggest Listing Low pH as a Candidate Cause
- Site Evidence that Suggests Listing Low pH as a Candidate Cause
- Biological Effects that Suggest Listing Low pH as a Candidate Cause
- Site Evidence that Supports Excluding Low pH as a Candidate Cause

Sources and Activities that Suggest Including Low pH as a Candidate Cause

Mine wastes/historic mine sites: Coal mining is a well known source of low pH, particularly where sulfur-bearing rock is present. Drainage from other mines and mine wastes can also be very acidic.

Acid generating rocks/soils: Interactions between rocks or soils and water (i.e., weathering) can generate acid. For example, andesite soils of the Great Basin region are derived from weathered volcanic rock and are strongly acidic.

Sources of acidic gasses: Acidic deposition is the transfer of acidic compounds via rain, snow, and dry deposition. This process acidifies waters. Sulfur and nitrogen oxides are emitted into the atmosphere from power plants, industrial sources (e.g., pulp mills), and internal combustion engines (where they are transformed into H_2SO_4 and HNO_3) (see Figure 4). When deposited into freshwater systems, these gasses increase SO_4^{2-}, NO_3^-, and H^+, which can decrease pH.



Figure 4. Gases emitted into the air contribute to acidic deposition.
Photo courtesy of The National Acid Precipitation Assessment Program (NAPAP)

Streams and lakes with relatively low buffering capacity or low flow (e.g., intermittent and first order streams) are particularly susceptible to low pH from acidic deposition. Acidic deposition has occurred in the northeastern United States. Numerous cities and industrial plants in the Midwest and New England emit pollutants to air, which are then transported and deposited in the northeastern U.S. Acid deposition stored in snow and ice at high elevations or in cold climates can be a pulsed source of low pH water to streams during spring melting.

Point and nonpoint discharges: Industrial effluents (e.g., from metal plating and other processes requiring acid) can be discharged at a low pH if not properly treated. Nonpoint sources such as confined animal feeding operations (CAFOs), dairies and concentrated poultry farms can generate acidic runoff from manure if not controlled adequately. Coal pile runoff, runoff from urban areas, and leachate from improperly functioning septic systems and landfills can be acidic as well.

Instream oxidation or reduction processes: Inputs of ammonium can contribute to acidification, because the nitrification of NH_4^+ produces H^+.

Recent draining of naturally inundated wetlands or floodplains: Under natural conditions, sulfur in permanently saturated soils is reduced. When those soils are drained and exposed to air, sulfuric acid can be generated and released to streams.

Site Evidence that Suggests Including Low pH as a Candidate Cause

pH changes are generally not directly observable in the field, and observers usually must measure pH to detect a change. Thus, site observations indicative of low pH are typically indirect and largely restricted to

observing one or more acid-producing sources (above).

Low pH may be indicated by the presence of metal precipitates on stream substrate. Common metal precipitates observed in streams under acidic conditions include iron, manganese, and aluminum which have a yellow (or orange or red), black, or white color, respectively (see Figure 5). Metal precipitates, notably iron, can result in a thick floc that smothers biota and degrades habitat quality to the point that many fauna are extirpated.

Black or brown (tea colored) water, common in southeastern U.S. swamps and bayous (e.g., Okefenokee Swamp, GA) are typically acidic due to humic and other natural organic acids derived from peat and dissolved vegetative material.



Figure 5. Example of acid mine drainage.
Photo courtesy of Peters Creek Watershed

Some filamentous algae are tolerant of low pH and may dominate acidified lakes and streams without heavy precipitates (Niyogi et al. 1999). They include the filamentous green algae *Klebsormidium*, *Microspora*, *Mougeotia*, *Ulotrix* and *Stigeoclonium* (Stevens et al. 2001).

Biological Effects that Suggest Including Low pH as a Candidate Cause

Low pH has both lethal and sublethal effects on organisms. For many stream species, prolonged periods of pH <5 are likely to be lethal, resulting in significant changes in species composition and diversity. At pHs between about 5 and 6.5, sublethal effects on many stream species result in reduced fecundity, growth and population size. Acid water also damages the skin and gills of fish, amphibians and invertebrates. Skin damage increases fish susceptibility to fungal infections, which may lead to diseases such as epizootic ulcerative syndrome. Gill and skin damage and associated mucus production reduce the ability of fish to take in oxygen or regulate salt and water intake.

Meyer and Barclay's (1990) fish kill manual states that acids (as well as heavy metals and trinitrophenols) can cause “white film on gills, skin, and mouth.” Meyer and Barclay (1990) also state that hyperexcitability and attempts by fish to swim onto shore may be observed. These effects are symptomatic of low pH, but they are not specific enough to be considered diagnostic.

The presence of stream species that are either especially sensitive to or especially tolerant of low pH may suggest whether to include low pH as a candidate cause. The generalizations about acid tolerance and pH effects thresholds presented in this section are imprecise because responses are heavily dependent on co-occurring toxic and nutrient ions (Baker et al. 1990). However, they can be helpful. For example, if the impairment is characterized by the loss of brook trout, the cause is more likely to be a stressor to which that species is sensitive (e.g., high temperature, low DO) than low pH.

Certain aquatic or semiaquatic plants are indicative of low pH conditions. These include certain spike rushes, water lilies and many insectivorous marsh plants (e.g., venus fly traps, pitcher plants and sundews).

Macroinvertebrate diversity, particularly for the commonly monitored EPT (Ephemeroptera, Plecoptera and Trichoptera) taxa, generally declines with declining pH. Of the EPT taxa, Ephemeroptera (mayflies) are generally most sensitive and Plecoptera (stoneflies) are generally most tolerant. Particularly sensitive species are found in the mayfly genera *Heptagenia* (Heptageniidae), *Ephemerella* (Ephemerellidae) and *Paraleptophlebia* (Leptophlebiidae) and the stonefly families Leuctridae and Perlidae.

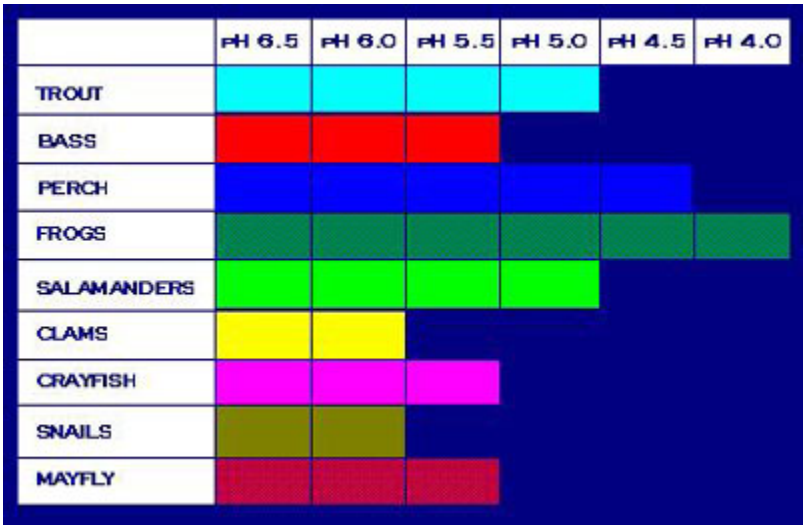


Figure 6. This table illustrates pH values that can be tolerated by different species.

These taxa are generally absent from streams with low pH. A few chironomids, including *Apsectrotanypus trifascipennis* and *Rheocricotopus fuscipes*, also are sensitive to acid and were only found in streams with pH >6 (Orendt, 1999). Invertebrates that require calcium carbonate for shell or cuticle development (e.g., clams, mussels, snails and amphipods) also are intolerant of low pH (<5) because acidic water dissolves calcium carbonate.

Other stream invertebrates are relatively tolerant of low pH (see Figure 6). These include Megaloptera (e.g., *Corydalus*) and craneflies (e.g., *Tipula*). Certain Chironomidae (midge) genera are also tolerant of low pH (e.g., some Orthocladiinae such as *Corynoneura*) and their dominance may indicate low pH (Orendt 1999). Also, northern pike (*Esox lucius*) can survive at pH 4-4.5 (Mackie 2001).

Low pH can cause reproductive failure and local extinction of fish populations due to low egg fertilization rates and failure of normal egg development (see Figure 7). In general, minnows (small members of the family Cyprinidae) are the first to disappear from acidifying streams. Blacknose dace may disappear at pH below 6.1 and common shiners experience embryo mortality below pH 6.0 (U.S. EPA 2008). Eggs of several fish species (e.g., striped bass, lake trout, fathead minnow) will not develop properly at pH less than approximately 5.5 (Howells et al. 1983, Baker et al. 1990). For most North American species, juvenile and adult fish are generally more tolerant of moderately low pH (5-6.5) (Baker et al. 1990). Brook trout is a relatively acid-tolerant species, not disappearing until pH is near 5 (U.S. EPA 2008).

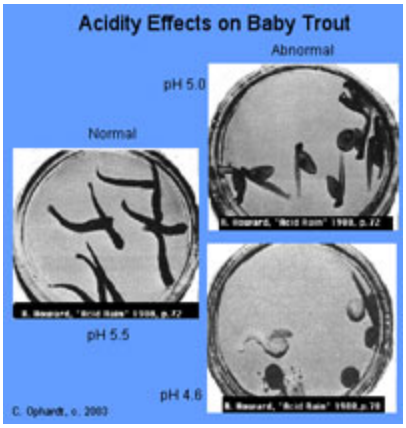


Figure 7. Examples of biological effects on reproduction. Courtesy of C. Ophardt

Low pH can have secondary effects on primary and secondary consumers due to pH stress on lower trophic levels. Low pH also can impede many ecosystem processes that depend on proper biological enzyme function (e.g., photosynthesis and decomposition). The sequence of direct and indirect effects of acidification is summarized in Table 1.

Table 1. General Summary of Biological Changes Anticipated with Surface Water Acidification, Expressed as a Decrease in Surface Water pH

pH Decrease	General Biological Effects
6.5 to 6.0	Small decreases in plankton and benthic invertebrate species richness resulting from loss of a few highly acid-sensitive species, but no measurable change in total community abundance or production.
	Some adverse effects (decreased reproductive success) may occur for highly acid-sensitive fish species (e.g., fathead minnow, striped bass).
6.0 to 5.5	Loss of sensitive species of minnows and dace (e.g., fathead minnow and blacknose dace); in some waters, decreased reproductive success of lake trout and walleye, which are important sport fish species in some areas.
	Visual accumulation of filamentous green algae in near-shore zone of many lakes and in some streams.
	Distinct decrease in species richness and change in species composition of plankton and benthic invertebrate communities, although little if any change in total community abundance or production.
	Loss of some common invertebrate species from zooplankton and benthic communities, including many species of snails, clams, mayflies, amphipods, and some crayfish.

pH Decrease	General Biological Effects
5.5 to 5.0	Loss of several important sport fish species, including lake trout, walleye, rainbow trout and smallmouth bass, as well as additional nongame species such as creek chub.
	Further increase in the extent and abundance of filamentous green algae in lake near-shore areas and streams.
	Continued shift in species composition and decline in species richness of plankton, periphyton and benthic invertebrate communities; decreases in total abundance and biomass of benthic invertebrates and zooplankton may occur in some waters.
	Loss of several additional invertebrate species common in surface waters, including all snails, most species of clams and many species of mayflies, stoneflies and other benthic invertebrates.
	Inhibition of nitrification.
5.0 to 4.5	Loss of most fish species, including most important sport fish species (e.g., brook trout and Atlantic salmon). A few fish species are able to survive and reproduce in water below pH 4.5 (e.g., central mudminnow, yellow perch).
	Measurable decline in whole-system rates of organic matter decomposition, potentially resulting in decreased rates of nutrient cycling.
	Substantial decrease in number plankton and benthic invertebrate species and further decline in plankton and periphyton species richness; measurable decrease in total community biomass of plankton and benthic invertebrates of most waters.
	Loss of additional plankton and benthic invertebrate species, including all clams and many insects and crustaceans.
	Reproductive failure of some acid-sensitive species of amphibians (e.g., spotted salamanders, Jefferson salamanders, leopard frogs).
From Baker et al. (1990).	

Site Evidence that Supports Excluding Low pH as a Candidate Cause

Low pH is buffered by minerals, such as calcium carbonate. If the stream is well buffered, or flows through soils and rocks high in alkaline minerals (e.g., limestone or dolomite), it is less likely that low pH is an appropriate candidate cause. The presence of acid-intolerant species such as ephemerellid mayflies, leuctrid

or perlid stoneflies or an abundance of clams or snails would also be evidence supporting exclusion of low pH as a candidate cause.

However, criteria or other benchmarks alone should not be used to exclude low pH as a cause. Different species have different pH requirements, different sites have different naturally occurring levels of pH, and other agents may enhance the effects of pH.

High pH

- Sources and Activities that Suggest Listing High pH as a Candidate Cause
- Site Evidence that Suggests Listing High pH as a Candidate Cause
- Biological Effects that Suggest Listing High pH as a Candidate Cause
- Site Evidence that Supports Excluding High pH as a Candidate Cause

Sources and Activities that Suggest Including High pH as a Candidate Cause

High pH can be caused by discharges from industries that use lime, lye or sodium hydroxide (NaOH); from agricultural runoff of fertilizers high in lime; or from industrial landfill leachates that contain solvents or lye. In particular, cement, asphalt and soap manufacturing may be sources of high pH due to the use of lime or lye. Runoff from limestone gravel roads also may increase pH.

In rare cases, high pH can be caused by natural conditions and mineralogy (e.g., weathering of chalk rock high in carbonates or olivine basalts). However, even in these cases, it is rare for stream pH to exceed 9.5. Leaching of naturally alkaline rocks and soils is exacerbated by physical disturbances such as tilling, mining and construction. An additional cause of elevated pH is high photosynthetic activity, which removes carbon dioxide from water and raises pH.

Site Evidence that Suggests Including High pH as a Candidate Cause

pH changes are not directly observable in typical field settings, and observers usually must measure pH to detect a change. However, high photosynthetic activity as evidenced by algal blooms or mats, or high macrophyte density, can cause pH to increase above tolerable levels (pH > 9), at least during daylight hours (Figure 8 and Figure 9). Certain species of *Microcystis* and *Coccochloris* algae grow optimally at pH 10 and do not grow below pH 8. *Cladophora glomerata* is only found in streams with pH greater than 8, whereas species such as *Oedogonium kurtzi* (green alga) and *Phaeospaera perforate* (yellow-green alga) are found in streams with pH less than 7 (Mackie 2001). High pH also may be indicated by certain mineral deposits in the stream, notably metal (e.g., nickel and cadmium) hydroxide precipitates that are insoluble above pH 9.

Biological Effects that Suggest Including High pH as a Candidate Cause



Figure 8. Stream with abundant aquatic plants and algae, which are sources of high pH.

As with low pH, effects of high pH usually are not specific enough to be considered symptomatic. Short-term exposures of fish to high pH (~9.5) are rarely lethal to most fish species. However, prolonged exposure to pH between 9.5 and 10 can damage outer surfaces such as gills, eyes, and skin. Cypriniformes (e.g., minnows) often are less sensitive to high pH than Perciformes (e.g., perch). High pH also can affect the sensory epithelium of the fish olfactory system, making it difficult for fish to detect food, sex hormones or pheromones, alarm substances from conspecifics or toxic chemicals.



Figure 9. Excessive *Cladophora* algal growth in a canal.

In addition to direct effects of high pH, an important indirect effect to consider is its interaction with ammonia. As pH increases, unionized ammonia (NH_3), which is more toxic to aquatic life than the ionized form (NH_4^+), becomes the dominant form. At pH > 9, the fraction of unionized ammonia is > 100 times the fraction at pH = 7 (> 90% of the total ammonia). This could result in ammonia toxicity if sufficient ammonia is present (e.g., >5 mg/L total ammonia at 25° C). Because ammonia toxicity can occur over relatively short exposure durations (hours to days depending on concentration), even short-term high pH events can contribute to biological effects. Therefore, when considering high pH as a candidate cause, bear in mind that it might be contributing to ammonia toxicity.

Site Evidence that Supports Excluding High pH as a Candidate Cause

There are no site observations that specifically provide evidence of the absence of high pH. We strongly caution against using benchmarks of effects (e.g., water quality criteria) as evidence for excluding high pH from your initial list of candidate causes. Different species have different pH requirements, different sites have different naturally occurring levels of pH, and other agents may enhance the effects of pH.

Ways to Measure

pH meter: A typical pH meter consists of a measuring probe connected to an electronic meter that measures and displays the pH reading. Because the meter measures hydrogen ion activity rather than concentration, it is affected by temperature and by other ions in solution. The influence of temperature on pH is usually automatically adjusted for by the meter.

Color comparator: Color comparators involve adding an indicator reagent to the sample that colors the sample water. Color intensity is proportional to pH of the sample. This color is then matched against a standard color chart to determine pH.

Conceptual Diagrams

- About Conceptual Diagrams
- Simple Conceptual Model Diagram (Low pH)
- Simple Conceptual Model Diagram (High pH)
- Detailed Conceptual Model Diagram (Low pH)
- Detailed Conceptual Model Diagram (High pH)

About Conceptual Diagrams

Conceptual diagrams are used to describe hypothesized relationships among sources, stressors and biotic responses within aquatic systems.

- More about Conceptual Diagrams <https://epa.gov/caddis/about-conceptual-diagrams>

Simple Conceptual Model Diagram (Low pH)

pH is a measure of hydrogen ion concentration in an aqueous solution. pH decreases as hydrogen ion concentration increases, and these acidic conditions can adversely affect aquatic biota.

Certain human activities can result in increased hydrogen ion inputs into aquatic systems, including sources associated with agriculture (e.g., animal feedlots), urbanization (e.g., vehicles), industry (e.g., coal-fired power plants) and mining (e.g., acid mine drainage). Natural sources of hydrogen ions include acid-generating geologies and lithologies subjected to weathering and natural organic acids (e.g., humic acids).

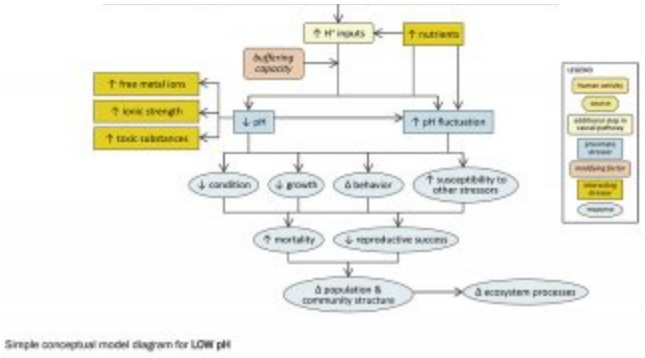
Hydrogen ions from these sources can be introduced into aquatic systems via four main transport pathways (or transport-defined sources) (see Figure 10): stormwater runoff, leakage or leachate into groundwater sources and subsequent transport, atmospheric emissions and deposition and direct effluent discharges. Each pathway can contribute to increased hydrogen ion inputs into surface waters.

Whether hydrogen ion inputs to aquatic systems lead to decreases in pH depends upon buffering capacity, or the system's ability to neutralize those inputs. Nutrient concentrations also play a significant role in pH dynamics, because nitrification and respiration both produce hydrogen ions. Decreases in pH can in turn affect other stressors, such as by increasing free metal ions, increasing bioavailability and toxicity of toxic substances, and increasing ionic strength.

Downloads

- Simple and Detailed Conceptual Model Diagrams (Low pH) <https://epa.gov/caddis/simple-and-detailed-conceptual-model-diagram-downloads#file-239927>
- Simple and Detailed Conceptual Model Diagrams (High pH) <https://epa.gov/caddis/simple-and-detailed-conceptual-model-diagram-downloads#file-239939>
- Simple Conceptual Diagram (Low and High pH) (PPT) (ppt) <https://www.epa.gov/sites/default/files/2016-11/low_high_ph_cd_sim_2016_11_22.ppt> (160 KB)
- Detailed Conceptual Diagram (Low and High pH) (PPT) (ppt) <https://www.epa.gov/sites/default/files/2016-11/low_high_ph_cd_det_2016_11_22.ppt> (290.5 KB)

<https://epa.gov/sites/default/files/2015-12/lowphcd_sim_large.jpg>



Simple conceptual model diagram for **LOW pH**

Figure 10. Example of a simple conceptual model diagram for **Low pH**. Click on the diagram to view a larger version.

Decreases in pH and associated increases in pH fluctuation can contribute to decreased condition, decreased growth, altered behavior and increased susceptibility to other stressors in affected biota.

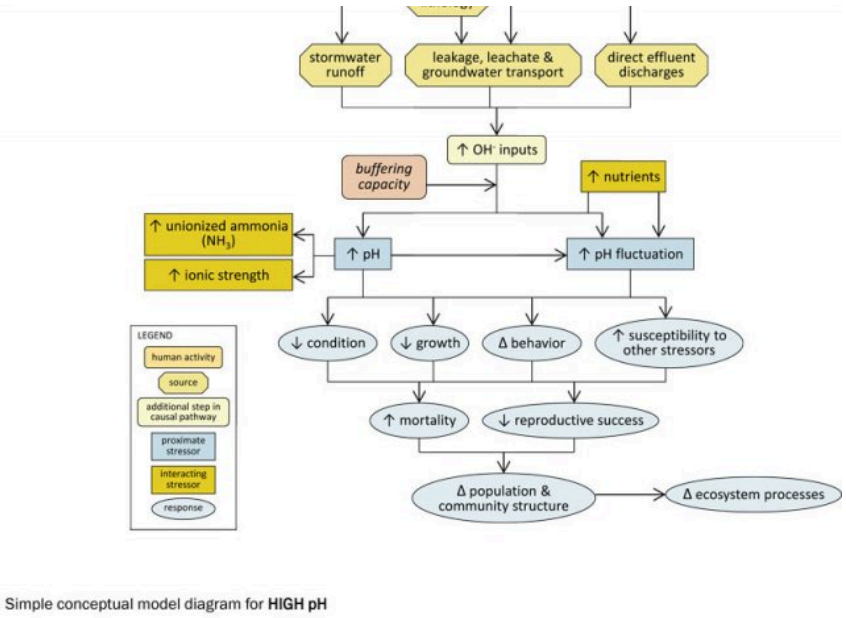
Ultimately, these effects may result in increased mortality, decreased reproductive success and changes in population and community structure and ecosystem function. For example, taxa sensitive to low pH (e.g., certain mayfly and stonefly taxa) may decrease, while more tolerant taxa such as tipulids (crane flies), megalopterans (alderflies, dobsonflies, fishflies and hellgrammites) and spike rushes may increase. Sensitive life stages (e.g., eggs in fish) also may decline.

Simple Conceptual Model Diagram (High pH)

High pH levels occur when hydroxide ion concentrations are high and hydrogen ions are scarce. Although acidic conditions more commonly result from human activities, alkaline conditions also can occur and adversely affect aquatic biota.

Certain human activities and associated sources can result in increased pH in aquatic systems (see Figure 11). These include stormwater runoff from sources associated with agriculture (e.g., lime-rich fertilizers) and urbanization (e.g., asphalt roads) and effluents and leachate from sources associated with industry (e.g., soap manufacturing plants) and mining (e.g., oil and gas brine mining wastes). Atmospheric emissions and deposition generally do not contribute to high pH conditions, a marked difference from low pH conditions.

<https://epa.gov/sites/default/files/2015-12/high-ph-cd_sim_800.jpg>



Simple conceptual model diagram for **HIGH pH**

Figure 3. A simple conceptual diagram illustrating causal pathways, from sources to impairments, related to **high pH**. Click on the diagram to view a larger version.

There also are natural sources which can result in high pH conditions, such as naturally alkaline geologies and lithologies and high levels of photosynthesis. Because photosynthesis produces hydroxide ions, elevated nutrient concentrations may contribute to pH increases.

High pH levels can affect other stressors, most notably by increasing the proportion of ammonia in its unionized, toxic form. Increases in pH and pH fluctuation may contribute to decreased condition, decreased growth, altered behavior and increased susceptibility to other stressors in affected biota.

Ultimately, these effects may result in increased mortality, decreased reproductive success and changes in population and community structure and ecosystem function. For example, taxa sensitive to high pH (e.g., perciform fishes) may decrease, while more tolerant taxa (e.g., cypriniform fishes, *Cladophora*) may increase. These changes may result in reduced taxa richness or diversity.

Detailed Conceptual Model Diagram (Low pH)

pH is a measure of hydrogen ion concentration in an aqueous solution. pH decreases as hydrogen ion concentration increases, and these acidic conditions can adversely affect aquatic biota.

This conceptual diagram (see Figure 12) illustrates linkages between low pH and associated pH fluctuations (middle of diagram), the human activities and sources that can contribute to low pH (top of diagram) and the biological responses that can result (bottom of diagram). In some cases, additional steps leading from sources to stressors, modes of action leading from stressors to responses and other modifying factors also are shown. This narrative generally follows the diagram top to bottom, left to right.

<https://epa.gov/sites/default/files/2015-12/lowphcd_det_1500.jpg>

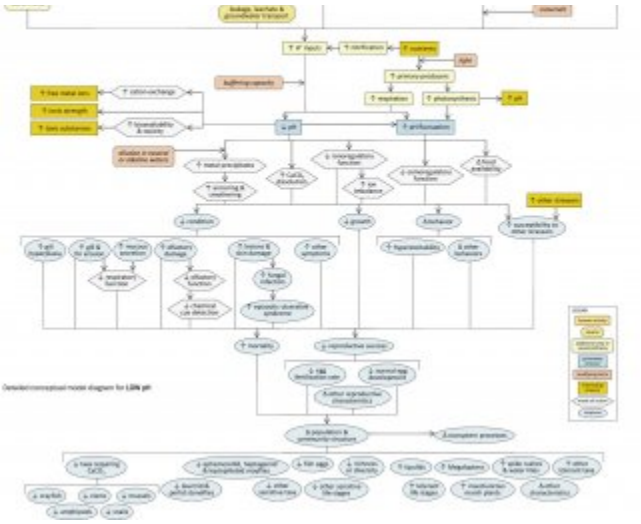


Figure 12. Example of a detailed conceptual model diagram for **Low pH**. Click on the diagram to view a larger version.

Linking Sources to Stressors

Certain human activities and land uses can result in increased input of hydrogen ions into aquatic systems. Land drainage can reduce soil saturation and lead to sulfur oxidation and the release of sulfuric acid. Other sources of hydrogen ions include acid mine drainage and other mining wastes from active and historical mines; natural, acid-generating geologies and lithologies subjected to weathering; natural organic acids (e.g., humic acids); animal wastes from CAFOs, dairies and aquaculture facilities; coal piles and landfills associated with residential, municipal, commercial and industrial facilities; and emissions and effluents from coal-fired power plants, metal plating plants and other industrial facilities.

Hydrogen ions from these sources can be introduced into aquatic systems via four main transport pathways (or transport-defined sources): stormwater runoff, leakage or leachate into groundwater sources and subsequent transport, atmospheric emissions and deposition or direct effluent discharges. Each of these transport-defined sources can contribute to increased hydrogen ion inputs into surface waters. When atmospheric deposition of hydrogen ions occurs in the form of snowfall, snowmelt can result in pulsed delivery of hydrogen ions to surface waters.

Whether hydrogen ion inputs to aquatic systems lead to decreases in pH depends upon buffering capacity, or the ability of the system to neutralize those inputs. Streams with high bicarbonate concentrations are highly buffered, and may not become acidic even with significant hydrogen ion inputs. Once buffering capacity is exceeded, however, pH will decrease.

Instream oxidation-reduction processes also may influence pH. For example, nitrification and respiration both produce hydrogen ions, so nutrient concentrations may play a significant role in pH dynamics. Decreases in pH also can affect other stressors, such as by increasing free metal ions, increasing the bioavailability and toxicity of toxic substances, and increasing ionic strength (see the Metals, Ionic Strength, and Unspecified Toxic Substances modules for more information on these pathways).

Linking Stressors to Biological Responses

Decreases in pH and associated increases in pH fluctuation can adversely affect aquatic organisms via many potential modes of action. Low pH can lead to dissolution of calcium carbonate shells, ultimately leading to decreases in taxa with calcium carbonate shells (e.g., mussels and snails).

When low pH solutions (e.g., acid mine drainage) are neutralized upon entering higher pH streams, metals in those solutions can precipitate and smother or armor stream bottoms. Low pH also can compromise ionoregulatory and osmoregulatory function, or lead to changes in food availability.

These different modes of action all may contribute to decreased condition, decreased growth, altered behavior and increased susceptibility to other stressors in affected biota. Possible decreases in condition include gill hyperplasia, gill and fin erosion, lesions and skin damage (increasing susceptibility to fungal infections) and increased mucous secretion. Possible changes in behavior include hyperexcitability.

Ultimately, these effects may result in increased mortality and decreased reproductive success, particularly in terms of impaired egg fertilization and development. This can lead to changes in population and community structure and ecosystem function. Taxa sensitive to low pH (e.g., certain mayfly and stonefly taxa) may decrease, while more tolerant taxa (e.g., tipulids, megalopterans, spike rushes) may increase. Sensitive life stages (e.g., eggs in fish) also may decline. These changes in community structure may in turn affect ecosystem functions such as leaf decomposition.

Detailed Conceptual Model Diagram (High pH)

High pH levels occur when hydroxide ion concentrations are high and hydrogen ions are scarce. Although acidic conditions more commonly result from human activities, alkaline conditions also can occur and adversely affect aquatic biota.

This conceptual diagram (see Figure 13) illustrates linkages between high pH and associated pH fluctuations (middle of diagram), the human activities and sources that can contribute to high pH (top of diagram) and the biological responses that can result (bottom of diagram). In some cases, additional steps leading from sources to stressors, modes of action leading from stressors to responses and other modifying factors also are shown. This narrative generally follows the diagram top to bottom, left to right.

Linking Sources to Stressors

Certain human activities and land uses can result in increased input of hydroxide ions into aquatic systems, leading to increases in pH. These sources include: runoff of lime-rich fertilizers applied to agricultural cropfields, golf courses and lawns; runoff from limestone gravel roads, asphalt roads and other asphalt waste; and effluents and leachate from oil and gas brine mining wastes or from industries that use lime, lye or sodium hydroxide (e.g., asphalt and cement manufacturing plants, soap manufacturing plants).

Atmospheric emissions and deposition are not significant transport sources for hydroxide ions and thus generally do not contribute to high pH conditions, a marked difference from low pH conditions. There also are natural sources which can result in high pH conditions, such as naturally alkaline geologies and lithologies and high levels of photosynthesis.

<https://epa.gov/sites/default/files/2015-12/high-ph-cd_det_1200.jpg>

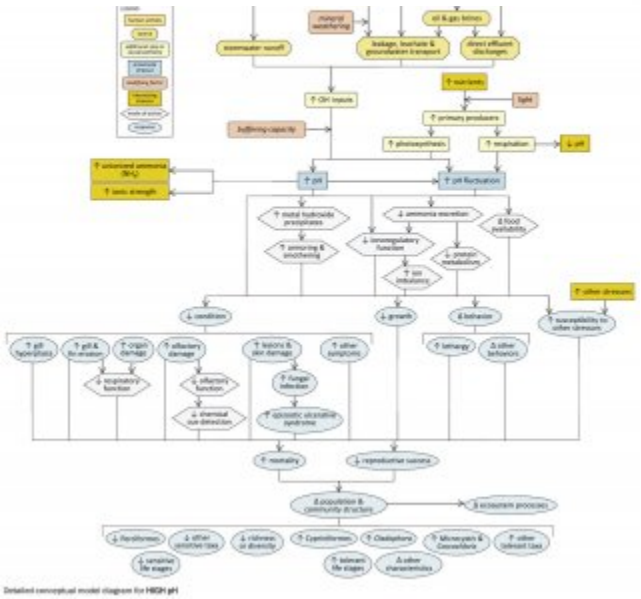


Figure 13. Example of a detailed conceptual model diagram for **High pH**. Click on the diagram to view a larger version.

Because photosynthesis produces hydroxide ions, elevated nutrient concentrations may contribute to pH increases. High pH levels also can affect other stressors, most notably by increasing the proportion of ammonia in its unionized, toxic form (see the ammonia and ionic strength modules for more information on these pathways).

Linking Stressors to Biological Response

Increases in pH and associated increases in pH fluctuation can adversely affect aquatic organisms via many potential modes of action. For example, metal hydroxides can form and precipitate, smothering or armoring stream bottoms. Ammonia excretion may be impaired, adversely affecting ionoregulatory function and protein metabolism. Indirect effects such as changes in food availability also may occur.

These different modes of action all may contribute to decreased condition, decreased growth, altered behavior and increased susceptibility to other stressors in affected biota. Possible decreases in condition include gill hyperplasia, gill and fin erosion, lesions and skin damage (increasing susceptibility to fungal infections) and increased olfactory damage; possible changes in behavior include lethargy.

Ultimately, these effects may result in increased mortality, decreased reproductive success and changes in population and community structure and ecosystem function. Taxa sensitive to high pH (e.g., perciform fishes) may decrease, while more tolerant taxa (e.g., cypriniform fishes, *Cladophora*) may increase. These changes may result in reduced taxa richness or diversity.

Literature Reviews

This section presents an annotated bibliography of references providing information on stressor-response relationships for pH, as well as general background information. This is not meant to be a comprehensive bibliography of references dealing with pH. Rather, it is meant to highlight a few references that may be especially useful.

- Baker JP, Bernard DP, Christensen SW, Sale MJ (1990) Biological effects of changes in surface water acid-base chemistry. National Acid Precipitation Assessment Program, Washington DC. NAPAP Report 13.

This report describes the effects of acidification on biological communities. The described effects include, but are not limited to, changes in taxonomic composition, biomass and density. Mechanisms of effect are also described. The report includes methods for regional assessments of fish community effects and some regional analyses.

- Driscoll CT, Lawrence GB, Bulger AJ, Butler TJ, Cronan SC, Eagar C, Lambert KF, Likens GE, Stoddard JL, Weathers KC (2001) Acidic deposition in the northeastern United States: sources and inputs, ecosystem effects, and management strategies. BioScience 51(3):180-198.

This article provides an excellent general review of effects of acidic deposition on soil, forest vegetation, surface waters and terrestrial and aquatic ecosystems.

- Hamelink JL, Landrum PF, Bergman HL, Benson WH (Eds.) (1994) Bioavailability: Physical, Chemical, and Biological Interactions. Lewis Publishers, Boca Raton FL.

This book discusses factors affecting bioavailability of different pollutant classes (e.g., metals, nonpolar organics). The section *Effects of Redox Processes on Acid-Producing Potential and Metal Mobility in Sediments* has particularly relevant pH information. This book is more technical than the other reviewed literature. A good discussion of buffering factors includes a list the major processes that consume H^+.

- Howells GG, Brown DJA, Sadler K (1983) Effects of acidity, calcium and aluminum on fish survival and productivity: a review. Journal of the Science of Food and Agriculture 34(6):559-570.

This article reviews studies of the effects of calcium and aluminum at low pH on survival. It also presents a section on modeling water quality effects on fish populations in an attempt to relate laboratory and field data.

- Mackie GL (2001) Applied Aquatic Ecosystem Concepts. Kendall/Hunt Publishing, Dubuque IA.

This textbook contains a section about acid precipitation that discusses the pH scale, geochemical influences, biological effects to several aquatic organisms, other atmospheric pollutants and mitigating lake acidification.

- Morris R, Taylor EW, Brown DJA, Brown JA (Eds.) (1989) Acid Toxicity and Aquatic Animals. Cambridge University Press, Cambridge UK.

This collection of papers describes a variety of biotic responses and modes of action in response to acid. The introduction *The Causes and Consequences of Surface Water Acidification* discusses acid precipitation and its effects at length. The rest of the book provides more specific and in-depth information regarding acid toxicity in aquatic systems.

- Orendt C (1999) Chironomids as bioindicators in acidified streams: a contribution to the acidity tolerance of chironomid species with a classification in sensitivity classes. International Review of Hydrobiology 84:439-449.

This study discusses the acid tolerance of chironomids based on their occurrence in a certain pH range.Twenty-five species are classified according to their acid sensitivity.

- Rand GM (Ed.) (1995) Fundamentals of Aquatic Toxicology: Effects, Environmental Fate, and Risk Assessment (2nd edition). Taylor and Francis, Washington DC.

Appendix C, *Factors that Modify Toxicity*, includes a section on hydrogen ion concentration. It contains information on how both low and high pH can modify pollutant toxicity.

- Robertson-Bryan, Inc. (2004) Technical Memorandum: pH Requirements of Freshwater Aquatic Life. California's Central Valley Water Quality Control Board.

This document is a review of many studies on pH requirements and effects on freshwater aquatic life. It reviews both fish and macroinvertebrates with respect to high and low pH.

- Scullion J, Edwards RW (1980) The effects of coal industry pollutants on the macroinvertebrate fauna of a small river in the South Wales coalfield. Freshwater Biology 10:141-162.

This paper is a case study that investigated the effects of coal industry pollutants on the macroinvertebrate fauna of a small river in a South Wales coalfield. It discusses the pH fluctuations due to drainage water from coal stockpiles and seasonal flows. The paper contains water quality data, arithmetic mean density of several species and a range of numbers of species and densities in relation to distance from the source. It contains a good discussion of low pH effects on specific species.

- U.S. EPA (2008) Integrated Science Assessment for Oxides of Nitrogen and Sulfur: Ecological Criteria. U.S. Environmental Protection Agency, Washington DC. EPA/600/R-08/082F.

This assessment reviews field and laboratory studies of the effects of acidification in aquatic and terrestrial ecosystems. Section B.6 contains 24 pages of tables summarizing effects by species and ecosystem.

References

- Baker JP, Bernard DP, Christensen SW, Sale MJ (1990) Biological effects of changes in surface water acid-base chemistry. National Acid Precipitation Assessment Program, Washington DC. NAPAP Report 13.
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- Rand GM (Ed.) (1995) Fundamentals of Aquatic Toxicology: Effects, Environmental Fate, and Risk Assessment (2nd edition). Taylor and Francis, Washington DC.
- Robertson-Bryan, Inc. (2004) Technical Memorandum: pH Requirements of Freshwater Aquatic Life. California's Central Valley Water Quality Control Board.
- Saarikoski J, Viluksela M (1981) Influence of pH on the toxicity of substituted phenols to fish. Archives of Environmental Contamination and Toxicology 10:747-753.

- Scullion J, Edwards RW (1980) The effects of coal industry pollutants on the macroinvertebrate fauna of a small river in the South Wales coalfield. Freshwater Biology 10:141-162.
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- U.S. EPA (2008) Integrated Science Assessment for Oxides of Nitrogen and Sulfur: Ecological Criteria. U.S. Environmental Protection Agency, Washington DC. EPA/600/R-08/082F.
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Last updated on February 7, 2025

United States
Environmental Protection
Agency

Office of Water
Regulations and Standards
Washington, DC 20460

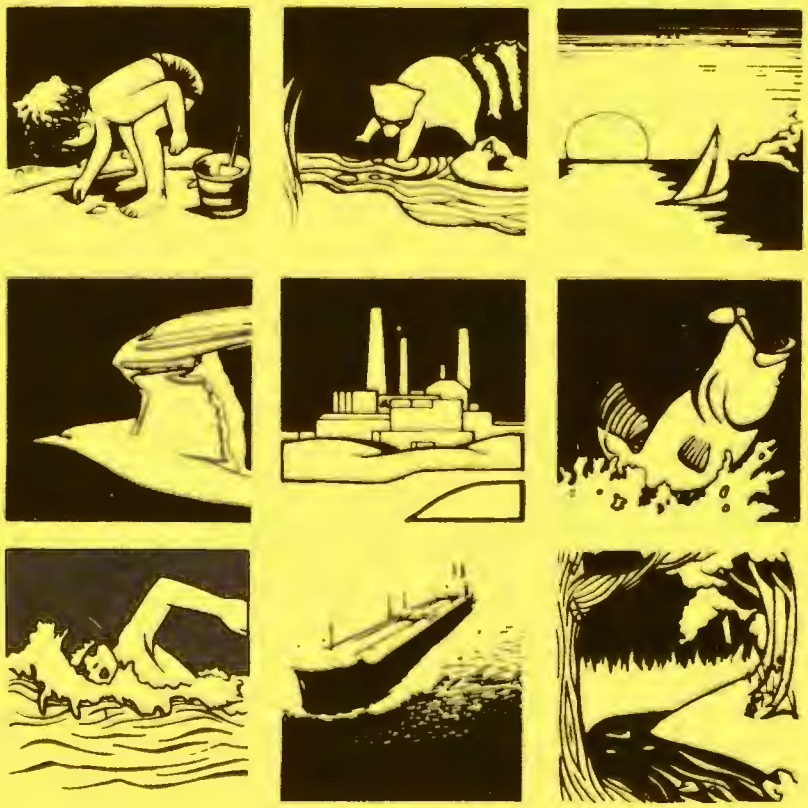
May 1, 1986

EPA

Water

EPA 440/5-86-001

QUALITY CRITERIA for WATER 1986



NMED Exhibit 68

TO INTERESTED PARTIES

Section 304(a)(1) of the Clean Water Act (33 U.S.C. 1314(a)(1) requires the Environmental Protection Agency (EPA) to publish and periodically update ambient water quality criteria. These criteria are to accurately reflect the latest scientific knowledge (a) on the kind and extent of all identifiable effects on health and welfare including, but not limited to, plankton, fish shellfish, wildlife, plant life, shorelines, beaches, aesthetics, and recreation which may be expected from the presence of pollutants in any body of water including ground water; (b) on the concentration and dispersal of pollutants, or their byproducts, through biological, physical, and chemical processes; and (c) on the effects of pollutants on biological community diversity, productivity, and stability, including information on the factors affecting rates of eutrophication and organic and inorganic sedimentation for varying types of receiving waters. These criteria are not rules and they do not have regulatory impact. Rather, these criteria present scientific data and guidance of the environmental effects of pollutants which can be useful to derive regulatory requirements based on considerations of water quality impacts. When additional data has become available, these summaries have been updated to reflect the latest Agency recommendations on acceptable limits for aquatic life and human health protection.

Periodically EPA and its predecessor agencies has issued ambient water quality criteria, beginning in 1968 with the "Green Book" followed by the 1973 publication of the "Blue Book" (Water Quality Criteria 1972). In 1976, the "Red Book" (Quality

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Washington, D.C. 20402

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Criteria for Water) was published. On November 28, 1980 (45 FR 79318), and February 15, 1984 (49 FR 5831), EPA announced through Federal Register notices, the publication of 65 individual ambient water quality criteria documents for pollutants listed as toxic under section 307(a)(1) of the Clean Water Act. On July 29, 1985 (50 FR 30784), EPA published additional water quality criteria documents.

The development and publication of ambient water quality criteria has been pursued over the past 10 years and is an ongoing process. EPA expects to publish about 10 final criteria documents each year. Some of these will update and revise existing criteria recommendations and others will be issued for the first time.

In a continuing effort to provide those who use EPA's water quality and human health criteria with up-to-date criteria values and associated information, this document Quality Criteria for Water 1986 was assembled. This document includes summaries of all the contaminants for which EPA has developed criteria recommendations (Appendix A-C). The appropriate appendix is identified at the end of each summary. A more detailed description of these procedures can be found in the appropriate Appendix. Copies of this document can be obtained by contacting the U.S. Government Printing Office at:

U.S. Government Printing Office
Superintendent of Documents
N. Capitol and H Street N.W.
Washington, D.C. 20401

A fee is charged for this document.

Copies of the complete background ambient water quality

criteria documents containing all the data used to develop the criteria recommendations summarized herein and the "Red Book", including complete bibliographies are available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

Telephone: (703) 487-4650

The NTIS order numbers for the criteria documents can be found in the Index. A fee is charged for copies of these documents.

As new criteria are developed and existing criteria revised, updated criteria summaries will be made available once a year to those who purchase this document through the U.S. Government Printing Office. You will automatically be placed on the mailing list to receive annual updates. The cost for receiving annual updates is included in the purchase price of the document.

Quality Criteria for Water, 1986 is designed to be easily updated to reflect EPA's continuing work to present the latest scientific information and practices. Our planned schedule for future criteria development in the next few years is attached for your information.

The Agency is currently developing Acceptable Daily Intake (ADI) or Verified Reference Dose (RfD) values on a number of chemicals for Agency-wide use. Based upon this new analysis the values have changed significantly for 5 chemicals from those used in the original human health criteria calculation done in 1980. The chemicals affected are as follows:

Chemical	1980 WQC	Draft RfD
1. Cyanide	200 ug/L	.02 mg/kg/day
2. Ethylbenzene	1.4 mg/L	.01 mg/kg/day
3. Nitrobenzene	19.8 mg/L	.0005 mg/kg/day
4. Phenol	3.5 mg/L	0.1 mg/kg/day
5. Toluene	14.3 mg/L	0.3 mg/kg/day

FOR FURTHER INFORMATION CONTACT:

Dr. Frank Gostomski at the above address or by phoning (202) 245-3030.

It is EPA's goal to continue to develop and make available ambient water quality criteria reflecting the latest scientific practices and information. In this way we can continue to improve and protect the quality of the Nation's waters.

James M. Conlon

James M Conlon

Acting Director,
Office of Water Regulations
and Standards

DRAFT CRITERIA DOCUMENTS TO BE PROPOSED

LATE FY 86/EARLY FY 87

Diethyhexylphthalate
1,2,4, Trichlorobenzene
Silver
Phenanthrene
2,4,5, Trichlorophenol
Organotins
Tributyltin
Selenium (no saltwater criteria)
Hexachlorobenzene
Antimony III
Acrolein (no saltwater criteria)

LATE FY 87/EARLY 88

Thallium (no saltwater criteria)
Tetrachloroethylene (no saltwater criteria)
Phenol
Toluene
Chloroform (no saltwater criteria)
Analine
Acrylontrile
Hexachlorocyclopentadiene (no saltwater criteria)
Dimethylphenol
Hexachlorobutadiene (no saltwater criteria)

- Both lists will incorporate aquatic and human health values.

- All above are toxic pollutants except for organotins and analine which are non-conventionals.

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Ammonia	PB 85-227114
Antimony	PB 81-117319
Arsenic	PB 85-227445
Asbestos	PB 81-117335
Bacteria	PB 86-158-045 & PB-263943
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Beryllium	PB 81-117350
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Thallium	PB 81-117848
Toluene	PB 81-117855
Toxaphene	PB 81-117863
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Zinc	PB 81-117897

APPENDIX A Methodology for Developing Criteria

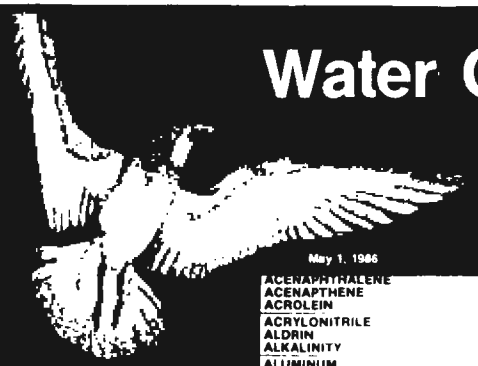
APPENDIX B Methodology for Developing Criteria

APPENDIX C Methodology for Developing Criteria

BIBLIOGRAPHY

SUMMARY CHART

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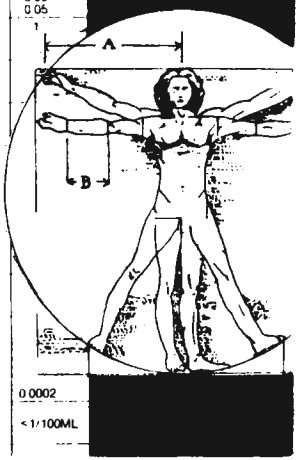


Water Quality Criteria Summary

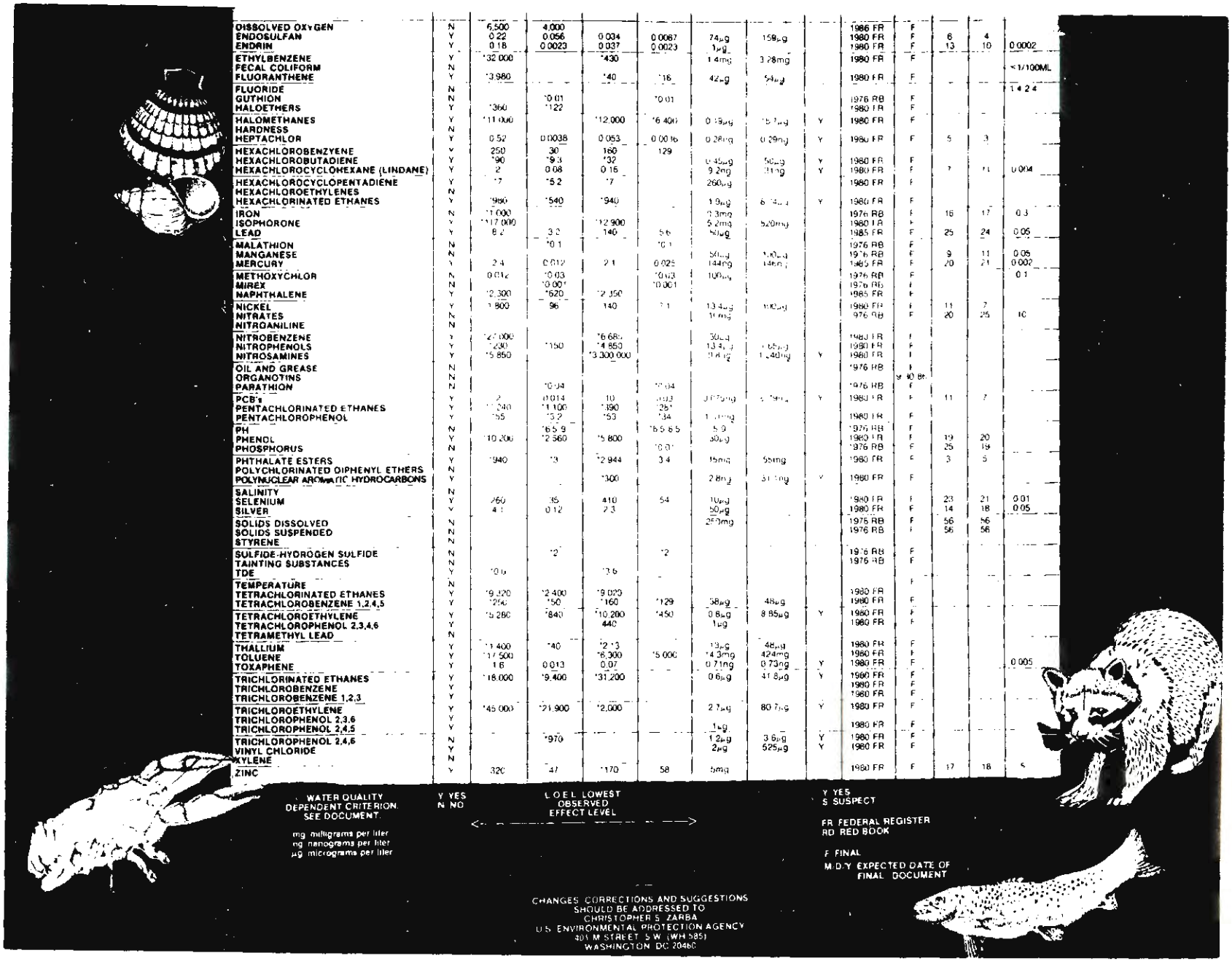
May 1, 1986

	Priority Pollutant	Fresh Acute Criteria *L.O.E.L.	Fresh Chronic Criteria *L.O.E.L.	Marine Acute Criteria *L.O.E.L.	Marine Chronic Criteria *L.O.E.L.	HUMAN HEALTH: Water and Fish Ingestion	HUMAN HEALTH: Fish Consumption Only	HUMAN HEALTH: Carcinogen	HUMAN HEALTH: Date/Reference	States Standard AQ·LI	States Standard HU·H	Drinking Water M.C.L.
CONCENTRATIONS IN ·												
ACENAPHTHALENE	N											
ACENAPTHENE	Y	*1,700	*520	*970	*500	20µg			1980 FR	F		
ACROLEIN	Y	*68	*21	*55		320µg	780µg		1980 FR	F		
ACRYLONITRILE	Y	*7,550	*2,600			0.058µg	0.65µg	Y	1980 FR	F		
ALDRIN	Y	3		1.3		0.074ng	0.079ng	Y	1980 FR	F	10	6
ALKALINITY	N		*20,000						1976 RB	F		
ALUMINUM	N									9/30/86		
AMMONIA TOTAL	N	15.7	3.9						1985 FR	F	23	20
AMMONIA UN-IONIZED	N	0.092	0.022						1985 FR	F	23	20
ANALINE	N									9/30/86		
ANTIMONY	Y	*9,000	*1,600			146µg	45,000µg		1980 FR	F		
ARSENIC	N	360	190	36	69	2.2ng	17.5ng	Y	1985 FR	F		0.05
ARSENIC(PENT)	N	*850	*48	*2,319	*5			Y	1985 FR	F	22	28
ARSENIC(TRI)	Y	4.4	48	69	36			Y	1985 FR	F	22	28
ASBESTOS	Y					30k f.1		Y	1980 FR	F		
BARIUM	N					1mg			1976 RB	F	13	25
BENZENE	Y	*5,300		*5,100	*700	0.66µg	40µg	Y	1980 FR	F		1
BENZIDINE	Y	2,500				0.12ng	0.53ng	Y	1980 FR	F	3	4
BERYLLIUM	Y	*130	*5.3			3.7ng	64.1ng	Y	1980 FR	F	7	4
BHC	Y	*100		*0.34					1980 FR	F		
BIS 2 CHLOROETHYOXY METHANE	N											
BORON	N								1976 RB	F	5	3
BOTYLBENZYLPTHALATE	N								1980 RB			
CADMIUM	Y	3.9	1.1	43	9.3	10µg			1985 FR	F	22	27
CARBAZOLE	N											
CARBON TETRACHLORIDE	Y	*35,200		*50,000		0.4µg	6.94µg	Y	1980 FR	F		
CHLORALKYL ETHERS	Y	*238,000				0.0038ng	1.84ng	Y	1980 FR			
CHLORDANE	Y	2.4	0.0043	0.004	0.07	0.46ng	0.48ng	Y	1980 FR	F		
CHLORINATED BENZENES	Y	*250	*50	*160	*129				1980 FR	F		
CHLORINATED ETHANES	Y							S	1980 FR	F		
CHLORINATED ETHERS	N											
CHLORINATED NAPHTHALENES	Y	*1,600		*7.5					1980 FR	F		
CHLORINATED PHENOLS	Y	*500,000	970	440					1980 FR	F		
CHLORINE	N	19	11	13	7.5				1985 FR	F		
CHLORO-4 METHYL-3 PHENOL	N	*30										
CHLOROFORM	Y	*28,900	*1,240			0.19µg	15.7µg	Y	1980 FR	F		
CHLOROPHENOL	N			*440								
CHLOROPHENOL 2	Y	*4,380	*2,000				0.1µg		1980 FR	F		
CHLOROPHENOL 4	N			*29,700								
CHLOROPHENOXY HERBICIDES	N								1976 RB	F		
CHROMIUM (HEX)	Y	16	11	1,100	50	50µg			1985 FR	F	2	24
CHROMIUM (TRI)	Y	1,700	210	10,300					1985 FR	F	2	24
COPPER	Y	18	12	2.9		170mg	3.433mg		1985 FR	F	20	22
CYANIDE	Y	22.	5.2	1		200µg			1985 FR	F	19	16
DDE	Y	*1,050		*14							10	11
DDT	Y	1.1	0.001	0.13	0.001	0.024ng	0.024ng	Y	1980 FR	F	10	11
DEHP	N									9/30/86		
DEMETON	N		*0.1		*0.1				1976 RB	F		
DIAMINO TOLUENE	N											
DIBENZOFURANS	N									9.30/86		
DICHLORINATED ETHANES	N	*11,800?	*20,000	*113,000								
DICHLOROBENZENES	Y	*1,120	*763	*1,970		400µg	2.6mg		1980 FR	F		
DICHLOROBENZIDINES	Y					0.0103µg	0.0204µg	Y	1980 FR	F		
DICHLOROETHYLENE	Y	*11,600		*224,000		0.033µg	1.85µg		1980 FR	F		
DICHLOROPHENOL 2 4	N	*2,020	*365				0.3µg		1980 FR	F		
DICHLOROPROPANE	Y	*23,000	*5,700	10,300	*3,040				1980 FR	F		
DICHLOROPROPENE	Y	*6,060	*244	*790		87µg	14.1mg		1980 FR	F		
DIELDRIN	Y	2.5	0.0019	0.71	0.0019	0.071ng	0.076ng	Y	1980 FR	F	12	10
DIMETHYL PHENOL	Y								1980 FR	F		
DIMETHYL PHENOL 2,4	Y	*2,120					400		1980 FR	F		
DIMETHYLSULFOXIDE	N											
DINITROBENZENE 1,3	N											
DINITROTULUENE 2,4	Y	*330	*230	*590	*370	0.11µg	9.1µg	Y	1980 FR	F		
DIOXANE P	N											
DIOXIN	Y	*0.01	*0.0056					Y	1984 FR	F		
DIPHENYLHYDRAZINE	Y	*270			Y	0.42ng	0.56ng		1980 FR	F		
DISSOLVED OXYGEN	N	6,500	4,000						1986 FR	F		
ENDOSULFAN	Y	0.22	0.056	0.034	0.0087	74µg	159µg		1980 FR	F	6	4
ENDRIN	Y	0.18	0.0023	0.037	0.0023	1µg			1980 FR	F	13	10
ETHYLBENZENE	Y	*32,000		*430		1.4mg	3.28mg		1980 FR	F		0.0002
FECAL COLIFORM	N											
FLUORANTHENE	Y	*3,980		*40	*16	42µg	54µg		1980 FR	F		<1/100ML





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DISSOLVED OXYGEN	N	6,500	4,000						1986 FR	F			
ENDOSULFAN	Y	0.22	0.056	0.034	0.0087	74µg	159µg		1980 FR	F	6	4	
ENDRIN	Y	0.18	0.0023	0.037	0.0023	1µg			1980 FR	F	13	10	0.0002
ETHYLBENZENE	Y	*32,000		*430		1.4mg	3.28mg		1980 FR	F			
FECAL COLIFORM	N												<1/100ML
FLUORANTHENE	Y	*3,980		*40	*16	42µg	54µg		1980 FR	F			
FLUORIDE	N												1.4 2.4
GUTHION	N		*0.01		*0.01				1976 RB	F			
HALOETHERS	Y	*360	*122						1980 FR	F			
HALOMETHANES	Y	*11,000		*12,000	*6,400	0.19µg	*5.7µg	Y	1980 FR	F			
HARDNESS	N												
HEPTACHLOR	Y	0.52	0.0038	0.053	0.0016	0.28ng	0.29ng	Y	1980 FR	F	5	3	
HEXACHLOROBENZYENE	Y	250	30	160	129								
HEXACHLOROBUTADIENE	Y	*90	*9.3	*32		0.45µg	90µg	Y	1980 FR	F			
HEXACHLOROCYCLOHEXANE (LINDANE)	Y	2	0.08	0.16		9.2mg	31mg	Y	1980 FR	F	7	11	0.004
HEXACHLOROCYCLOPENTADIENE	Y	*7	*5.2	*7		260µg			1980 FR	F			
HEXACHLOROETHYLENES	N												
HEXACHLORINATED ETHANES	Y	*980	*540	*940		1.9µg	6.4µg	Y	1980 FR	F			
IRON	N	*1,000				2.3mg			1976 RB	F	16	17	0.3
ISOPHORONE	Y	*117,000		*12,900		5.2mg	520mg		1980 FR	F			
LEAD	Y	8.2	3.2	140	5.6	50µg			1985 FR	F	25	24	0.05
MALATHION	N		*0.1		*0.1				1976 RB	F			
MANGANESE	N					50µg	1,100µg		1976 RB	F	9	11	0.05
MERCURY	Y	2.4	0.012	2.1	0.025	144ng	1,400ng		1985 FR	F	20	21	0.002
METHOXYCHLOR	N	0.03	*0.03		*0.03	100µg			1976 RB	F			0.1
MIREX	N		*0.001		*0.001				1976 RB	F			
NAPHTHALENE	Y	*2,300	*620	*2,350					1985 FR	F			
NICKEL	Y	1,800	96	140	7.1	13.4µg	100µg		1980 FR	F	11	7	
NITRATES	N					10mg			1976 RB	F	20	25	10
NITROANILINE	N												
NITROBENZENE	Y	*27,000		*6,680		30µg			1980 FR	F			
NITROPHENOLS	Y	*230	*150	*4,850		13.4µg	1,650µg		1980 FR	F			
NITROSAMINES	Y	*5,850		*3,300,000		31.4µg	1,240mg	Y	1980 FR	F			
OIL AND GREASE	N								*1976 RB	F			
ORGANOTINS	N												
PARATHION	N		*0.04		*0.04				1976 RB	F			
PCB's	Y	2	0.014	10	0.03	0.079ng	1.19µg	Y	1980 FR	F	11	7	
PENTACHLORINATED ETHANES	Y	*1,240	*1,100	*390	*25*								
PENTACHLOROPHENOL	Y	*55	*3.2	*53	*34	1.01mg			1980 FR	F			
PH	N		*6.5-9		*6.5-8.5	5.9			1976 RB	F			
PHENOL	Y	*10,200	*2,560	*5,800		30µg			1980 FR	F	19	20	
PHOSPHORUS	N				*0.01				1976 RB	F	25	19	
PHTHALATE ESTERS	Y	*940	*3	*2,944	3.4	15mg	55mg		1980 FR	F	3	5	
POLYCHLORINATED DIPHENYL ETHERS	N												
POLYNUCLEAR AROMATIC HYDROCARBONS	Y			*300		2.8ng	31.1ng	Y	1980 FR	F			
SALINITY	N												
SELENIUM	Y	*260	35	410	54	10µg			1980 FR	F	23	21	0.01
SILVER	Y	4.1	0.12	2.3		50µg			1980 FR	F	14	18	0.05
SOLIDS DISSOLVED	N					250mg			1976 RB	F	56	56	
SOLIDS SUSPENDED	N								1976 RB	F	56	56	
STYRENE	N												
SULFIDE-HYDROGEN SULFIDE	N		*2		*2				1976 RB	F			
TAINTING SUBSTANCES	N								1976 RB	F			
TDE	Y	*0.6		*3.6									
TEMPERATURE	N									F			
TETRACHLORINATED ETHANES	Y	*9,320	*2,400	*9,020					1980 FR				
TETRACHLOROBENZENE 1,2,4,5	Y	*250	*50	*160	*129	58µg	48µg		1980 FR	F			
TETRACHLOROETHYLENE	Y	*5,280	*840	*10,200	*450	0.8µg	8.85µg	Y	1980 FR	F			
TETRACHLOROPHENOL 2,3,4,6	Y			440		1µg			1980 FR	F			
TETRAMETHYL LEAD	N												
THALLIUM	Y	*1,400	*40	*2.13		13µg	48µg		1980 FR	F			
TOLUENE	Y	*17,500		*6,300	*5,000	14.3mg	424mg		1980 FR	F			
TOXAPHENE	Y	1.6	0.013	0.07		0.71ng	0.73ng	Y	1980 FR	F			0.005
TRICHLORINATED ETHANES	Y	*18,000	*9,400	*31,200		0.6µg	41.8µg	Y	1980 FR	F			
TRICHLOROBENZENE	Y								1980 FR	F			
TRICHLOROBENZENE 1,2,3	Y								1980 FR	F			
TRICHLOROETHYLENE	Y	*45,000	*21,900	*2,000		2.7µg	80.7µg	Y	1980 FR	F			
TRICHLOROPHENOL 2,3,6	Y												
TRICHLOROPHENOL 2,4,5	Y					1µg			1980 FR	F			
TRICHLOROPHENOL 2,4,6	Y		*970			1.2µg	3.6µg	Y	1980 FR	F			
VINYL CHLORIDE	N					2µg	525µg	Y	1980 FR	F			
XYLENE	Y												
ZINC	Y	320	47	*170	58	5mg			1980 FR	F	17	18	5

WATER QUALITY DEPENDENT CRITERION. SEE DOCUMENT.

mg milligrams per liter
ng nanograms per liter
µg micrograms per liter

Y YES
N NO

L O E L LOWEST OBSERVED EFFECT LEVEL

Y YES
S SUSPECT

FR FEDERAL REGISTER
RD RED BOOK

F FINAL
M.D.Y EXPECTED DATE OF FINAL DOCUMENT

CHANGES, CORRECTIONS AND SUGGESTIONS SHOULD BE ADDRESSED TO
CHRISTOPHER S. ZARBA
U.S. ENVIRONMENTAL PROTECTION AGENCY
401 M STREET S.W. (WH-585)
WASHINGTON, DC 20460

NMED Exhibit 68

ACENAPHTHENE

CRITERIA:

Aquatic Life

The available data for acenaphthene indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 1,700 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of acenaphthene to sensitive freshwater aquatic animals but toxicity to freshwater algae occur at concentrations as low as 520 ug/L.

The available data for acenaphthene indicate that acute and chronic toxicity to saltwater aquatic life occurs at concentrations as low as 970 and 710 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested. Toxicity to algae occurs at concentrations as low as 500 ug/L.

Human Health

Sufficient data are not available for acenaphthene to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, to control undesirable taste and odor quality of ambient water the estimated level is 0.02 mg/L. It should be recognized that organoleptic data, have limitations as a basis for establishing water quality criteria, and have no demonstrated relationship to potential adverse human health effects.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

ACROLEIN

CRITERIA:

Aquatic Life

The available data for acrolein indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 68 and 21 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

The available data for acrolein indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 55 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of acrolein to sensitive saltwater aquatic life.

Human Health

For the protection of human health from the toxic properties of acrolein ingested through contaminated aquatic organisms, the ambient water criterion is determined to be 320 ug/L.

For the protection of human health from the toxic properties of acrolein ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 780 ug/L.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

ACRYLONITRILE

CRITERIA:

Aquatic Life

The available data for acrylonitrile indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 7,550 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No definitive data are available concerning the chronic toxicity of acrylonitrile to sensitive freshwater aquatic life but mortality occurs at concentrations as low as 2,600 ug/L with a fish species exposed for 30 days.

Only one saltwater species has been tested with acrylonitrile and no statement can be made concerning acute or chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects resulting from exposure to acrylonitrile through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 0.58 ug/L, 0.058 ug/L, and 0.006 ug/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption

of water, the levels are 6.5 ug/L, 0.65 ug/L, and 0.065 ug/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

AESTHETIC QUALITIES

CRITERIA:

All waters free from substances attributable to wastewater or other discharges that:

(1) settle to form objectionable deposits;

(2) float as debris, scum, oil, or other matter to form nuisances;

(3) produce objectionable color, odor, taste, or turbidity;

(4) injure or are toxic or produce adverse physiological responses in humans, animals or plants; and,

(5) produce undesirable or nuisance aquatic life.

RATIONALE:

Aesthetic qualities of water address the general principles laid down in common law. They embody the beauty and quality of water and their concepts may vary within the minds of individuals encountering the waterway. A rationale for these qualities cannot be developed with quantifying definitions; however, decisions concerning such quality factors can portray the best in the public interest.

Aesthetic qualities provide the general rules to protect water against environmental insults: they provide minimal freedom requirements from pollution; they are essential properties to protect the Nation's waterways.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

ALKALINITY

CRITERION:

20 mg/L or more as $CaCO_3$ freshwater aquatic life except where natural concentrations are less.

INTRODUCTION:

Alkalinity is the sum total of components in the water that tend to elevate the pH of the water above a value of about 4.5. It is measured by titration with standardized acid to a pH value of about 4.5 and it is expressed commonly as milligrams per liter of calcium carbonate. Alkalinity, therefore, is a measure of the buffering capacity of the water, and since pH has a direct effect on organisms as well as an indirect effect on the toxicity of certain other pollutants in the water, the buffering capacity is important to water quality. Examples of commonly occurring materials in natural waters that increase the alkalinity are carbonates, bicarbonates, phosphates and hydroxides.

RATIONALE:

The alkalinity of water used for municipal water supplies is important because it affects the amounts of chemicals that need to be added to accomplish calculation, softening and control of corrosion in distribution systems. The alkalinity of water assists in the neutralization of excess acid produced during the addition of such materials as aluminum sulfate during chemical coagulation. Waters having sufficient alkalinity do not have to be supplemented with artificially added materials to increase the alkalinity. Alkalinity resulting from naturally occurring

materials such as carbonate and bicarbonate is not considered a health hazard in drinking water supplies, per se, and naturally occurring maximum levels up to approximately 400 mg/L as calcium carbonate are not considered a problem to human health (NAS, 1974).

Alkalinity is important for fish and other aquatic life in freshwater systems because it buffers pH changes that occur naturally as a result of photosynthetic activity of the chlorophyll-bearing vegetation. Components of alkalinity such as carbonate and biocarbonate will complex some toxic heavy metals and reduce their toxicity markedly. For these reasons, the National Technical Advisory Committee (NATC, 1968) recommended a minimum alkalinity of 20 mg/L and the subsequent NAS Report (1974) recommended that natural alkalinity not be reduced by more than 25 percent but did not place an absolute minimal value for it. The use of the 25 present reduction avoids the problem of establishing standards on waters where natural alkalinity is at or below 20 mg/L. For such waters, alkalinity should not be further reduced.

The NAS Report recommends that adequate amounts of alkalinity be maintained to buffer the pH within tolerable limits for marine waters. It has been noted as a correlation that productive waterfowl habitats are above 25 mg/L with higher alkalinities resulting in better waterfowl habitats (NATC, 1968).

Excessive alkalinity can cause problems for swimmers by altering the pH of the lacrimal fluid around the eye, causing irritation.

For industrial water supplies, high alkalinity can be damaging to industries involved in food production, especially those in which acidity accounts for flavor and stability, such as the carbonated beverages. In other instances, alkalinity is desirable because water with a high alkalinity is much less corrosive.

A brief summary of maximum alkalinities accepted as a source of raw water by industry is included in Table 1. The concentrations listed in the table are for water prior to treatment and thus are only desirable ranges and not critical ranges for industrial use.

The effect of alkalinity in water used for irrigation may be important in some instances because it may indirectly increase the relative proportion of sodium in soil water. As an example, when bicarbonate concentrations are high, calcium and magnesium ions that are in solution precipitate as carbonates in the soil water as the water becomes more concentrated through evaporation and transpiration. As the calcium and magnesium ions decrease in concentration, the percentage of sodium increases and results in soil and plant damage. Alkalinity may also lead to chlorosis in plants because it causes the iron to precipitate as a hydroxide (NAS, 1974). Hydroxyl ions react with available iron in the soil

TABLE I*

Maximum Alkalinity In Waters Used As A Source Of Supply Prior To Treatment

Industry	Alkalinity mg/L as $CaCO_3$
Steam generation boiler makeup.....	350
Steam generation cooling.....	500
Textile mill products.....	50-200
Paper and allied products.....	75-150
Chemical and Allied Products.....	500
Petroleum refining.....	500
Primary metals industries.....	200
Food canning industries.....	300
Bottled and canned soft drinks.....	85

* NAS, 1974

water and make the iron unavailable to plants. Such deficiencies induce chlorosis and further plant damage. Usually alkalinity must exceed 6 mg/L before such effects are noticed, however.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

*ALDRIN-DIELDRIN

CRITERIA:

Aquatic Life

Dieldrin

For dieldrin the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.0019 ug/L as a 24-hour average, and the concentration should not exceed 2.5 ug/L at any time.

For dieldrin the criterion to protect saltwater aquatic life as derived using the Guidelines is 0.0019 ug/L as a 24-hour average, and the concentration should not exceed 0.71 ug/L at any time.

Aldrin

For freshwater aquatic life the concentration of aldrin should not exceed 3.0 ug/L at any time. No data are available concerning the chronic toxicity of aldrin to sensitive freshwater aquatic life.

For saltwater aquatic life the concentration of aldrin should not exceed 1.3 ug/L at any time. No data are available concerning the chronic toxicity of aldrin to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to aldrin through ingestion of contaminated water and contaminated aquatic organisms, the

*Indicates suspended, canceled or restricted by U.S. EPA Office of Pesticides and Toxic Substances

ambient water concentration should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6} and 10^{-7} The corresponding recommended criteria are 0.74 ng/L, 0.074 ng/L, and 0.0074 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 0.79 ng/L, 0.079 ng/L, and 0.0079 ng/L, respectively.

For the maximum protection of human health from the potential carcinogenic effects of exposure to dieldrin through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6} and 10^{-7}. The corresponding recommended criteria are 0.71 ng/L, 0.071 ng/L, and 0.0071 ng/L, respectively. If these above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 0.76 ng/L, 0.076 ng/L, and 0.0076 ng/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

AMMONIA

SUMMARY:

All concentrations used herein are expressed as un-ionized ammonia (NH_3), because NH_3, not the ammonium ion (NH_4^+) has been demonstrated to be the principal toxic form of ammonia. The data used in deriving criteria are predominantly from flow through tests in which ammonia concentrations were measured. Ammonia was reported to be acutely toxic to freshwater organisms at concentrations (uncorrected for pH) ranging from 0.53 to 22.8 mg/L NH_3 for 19 invertebrate species representing 14 families and 16 genera and from 0.083 to 4.60 mg/L NH_3 for 29 fish species from 9 families and 18 genera. Among fish species, reported 96-hour LC50 ranged from 0.083 to 1.09 mg/L for salmonids and from 0.14 to 4.60 mg/L NH_3 for nonsalmonids. Reported data from chronic tests on ammonia with two freshwater invertebrate species, both daphnids, showed effects at concentrations (uncorrected for pH) ranging from 0.304 to 1.2 mg/L NH_3, and with nine freshwater fish species, from five families and seven genera, ranging from 0.0017 to 0.612 mg/L NH_3.

Concentrations of ammonia acutely toxic to fishes may cause loss of equilibrium, hyperexcitability, increased breathing, cardiac output and oxygen uptake, and, in extreme cases, convulsions, coma, and death. At lower concentrations ammonia has many effects on fishes, including a reduction in hatching success, reduction in growth rate and morphological development, and pathologic changes in tissues of gills, livers, and kidneys.

Several factors have been shown to modify acute NH_3 toxicity in fresh water. Some factors alter the concentration of un-ionized ammonia in the water by affecting the aqueous ammonia equilibrium, and some factors affect the toxicity of un-ionized ammonia itself, either ameliorating or exacerbating the effects of ammonia. Factors that have been shown to affect ammonia toxicity include dissolved oxygen concentration, temperature, pH, previous acclimation to ammonia, fluctuating or intermittent exposures, carbon dioxide concentration, salinity, and the presence of other toxicants.

The most well-studied of these is pH; the acute toxicity of NH_3 has been shown to increase as pH decreases. Sufficient data exist from toxicity tests conducted at different pH values to formulate a mathematical expression to describe pH-dependent acute NH_3 toxicity. The very limited amount of data regarding effects of pH on chronic NH_3 toxicity also indicates increasing NH_3 toxicity with decreasing pH, but the data are insufficient to derive a broadly applicable toxicity/pH relationship. Data on temperature effects on acute NH_3 toxicity are limited and somewhat variable, but indications are that NH_3 toxicity to fish is greater as temperature decreases. There is no information available regarding temperature effects on chronic NH_3 toxicity.

Examination of pH and temperature-corrected acute NH_3 toxicity values among species and genera of freshwater organisms showed that invertebrates are generally more tolerant than fishes, a notable exception being the fingernail clam. There is no clear trend among groups of fish; the several most sensitive

tested species and genera include representatives from diverse families (Salmonidae, Cyprinidae, Percidae, and Centrarchidae). Available chronic toxicity data for freshwater organisms also indicate invertebrates (cladocerans, one insect species) to be more tolerant than fishes, again with the exception of the fingernail clam. When corrected for the presumed effects of temperature and pH, there is also no clear trend among groups of fish for chronic toxicity values, the most sensitive species including representatives from five families (Salmonidae, Cyprinidae, Ictaluridae, Centrarchidae, and Catostomidae) and having chronic values ranging by not much more than a factor or two. The range of acute-chronic ratios for 10 species from 6 families was 3 to 43, and acute-chronic ratios were higher for the species having chronic tolerance below the median. Available data indicate that differences in sensitivities between warm and coldwater families of aquatic organisms are inadequate to warrant discrimination in the national ammonia criterion between bodies of water with "warm" and "coldwater" fishes; rather, effects of organism sensitivities on the criterion are most appropriately handled by site-specific criteria derivation procedures.

Data for concentrations of NH_3 toxic to freshwater phytoplankton and vascular plants, although limited, indicate that freshwater plant species are appreciably more tolerant to NH_3 than are invertebrates or fishes. The ammonia criterion appropriate for the protection of aquatic animals will therefore in all likelihood be sufficiently protective of plant life.

Available acute and chronic data for ammonia with saltwater organisms are very limited, and insufficient to derive a saltwater criterion. A few saltwater invertebrate species have been tested, and the prawn Macrobrachium rosenbergii was the most sensitive. The few saltwater fishes tested suggest greater sensitivity than freshwater fishes. Acute toxicity of NH_3 appears to be greater at low pH values, similar to findings in freshwater. Data for saltwater plant species are limited to diatoms, which appear to be more sensitive than the saltwater invertebrates for which data are available.

More quantitative information needs to be published on the toxicity of ammonia to aquatic life. Several key research needs must be addressed to provide a more complete assessment of ammonia toxicity. These are: (1) acute tests with additional saltwater fish species and saltwater invertebrate species; (2) life-cycle and early life-stage tests with representative freshwater and saltwater organisms from different families, with particular attention to trends of acute-chronic ratios; (3) fluctuating and intermittent exposure tests with a variety of species and exposure patterns; (4) more complete tests of the individual and combined effects of pH and temperature, especially for chronic toxicity; (5) more histopathological and histochemical research with fishes, which would provide a rapid means of identifying and quantifying sublethal ammonia effects; and (6) studies on effects of dissolved and suspended solids on acute and chronic toxicity.

NATIONAL CRITERIA:

The procedures described in the Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if:

(1) the 1-hour* average concentration of un-ionized ammonia (in mg/L NH_3) does not exceed, more often than once every 3 years on the average, the numerical value given by 0.52/FT/FPH/2,

where:

$$FT = 10^{0.03(20-TCAP)}; \quad TCAP \leq T \leq 30$$

$$10^{0.03(20-T)}; \quad 0 \leq T \leq TCAP$$

$$FPH = 1 \quad ; \quad 8 < pH < 9$$

$$\frac{1+10^{7.4-pH}}{1.25} \quad ; \quad 6.5 \leq pH \leq 7.7$$

TCAP = 20 C; Salmonids or other sensitive coldwater species present

= 25 C; Salmonids and other sensitive coldwater species absent

(*An averaging period of 1 hour may not be appropriate if excursions of concentrations to greater than 1.5 times the average occur during the hour; in such cases, a shorter averaging period may be needed.)

(2) the 4-day average concentration of un-ionized ammonia (in mg/L NH_3) does not exceed, more often than once every 3 years on the average, the average* numerical value given by 0.80/FT/FPH/RATIO, where FT and FPH are as above and:

$$\text{RATIO} = 16 \qquad ; \ 7.7 \leq \text{pH} \leq 9$$

$$= 24 \ \frac{10^{7.7-\text{pH}}}{1+10^{7.4\text{pH}}} \qquad ; 6.5 \leq \text{pH} \leq 7.7$$

TCAP = 15 C; Salmonids or other sensitive coldwater species present

= 20 C; Salmonids and other sensitive coldwater species absent

(*Because these formulas are nonlinear in pH and temperature, the criterion should be the average of separate evaluations of the formulas reflective of the fluctuations of flow, pH, and temperature within the averaging period; it is not appropriate in general to simply apply the formula to average pH, temperature, and flow.)

The extremes for temperature (0, 30) and pH (6.5, 9) given in the above formulas are absolute. It is not permissible with current data to conduct any extrapolations beyond these limits. In particular, there is reason to believe that appropriate criteria at pH > 9 will be lower than the plateau between pH 8 and 9 given above.

Criteria concentrations for the pH range 6.5 to 9.0 and the temperature range 0 C to 30 C are provided in the following tables. Total ammonia concentrations equivalent to each un-ionized ammonia concentration are also provided in these tables. There are limited data on the effect of temperature on chronic toxicity. EPA will be conducting additional research on the effects of temperature on ammonia toxicity in order to fill perceived data gaps. Because of this uncertainty, additional site-specific information should be developed before these

criteria are used in wasteload allocation modeling. For example, the chronic criteria tabulated for sites lacking salmonids are less certain at temperatures much below 20 C than those tabulated at temperatures near 20 C. Where the treatment levels needed to meet these criteria below 20 C may be substantial, use of site-specific criteria is strongly suggested. Development of such criteria should be based upon site-specific toxicity tests.

Data available for saltwater species are insufficient to derive a criterion for saltwater.

The recommended exceedence frequency of 3 years is the Agency's best scientific judgment of the average amount of time it will take an unstressed system to recover from a pollution event in which exposure to ammonia exceeds the criterion. A stressed system, for example, one in which several outfalls occur in a limited area, would be expected to require more time for recovery. The resilience of ecosystems and their ability to recover differ greatly, however, and site-specific criteria may be established if adequate justification is provided.

The use of criteria in designing waste treatment facilities requires the selection of an appropriate wasteload allocation model. Dynamic models are preferred for the application of these criteria. Limited data or other factors may make their use impractical, in which case one should rely on a steady-state model. The Agency recommends the interim use of 1Q5 or 1Q10 for Criterion Maximum Concentration design flow and 7Q5 or 7Q10 for the Criterion Continuous Concentration design flow in steady-state models for unstressed and stressed systems respectively.

(2) 4-day average concentrations for ammonia.*

pH	0 C	5 C	10 C	15 C	20 C	25 C	30 C
A. Salmonids or Other Sensitive Coldwater Species Present							
			Un-ionized Ammonia (mg/liter NH_3)				
6.50	0.0007	0.0009	0.0013	0.0019	0.0019	0.0019	0.0019
6.75	0.0012	0.0017	0.0023	0.0033	0.0033	0.0033	0.0033
7.00	0.0021	0.0029	0.0042	0.0059	0.0059	0.0059	0.0059
7.25	0.0037	0.0052	0.0074	0.0105	0.0105	0.0105	0.0105
7.50	0.0066	0.0093	0.0132	0.0186	0.0186	0.0186	0.0186
7.75	0.0109	0.0153	0.022	0.031	0.031	0.031	0.031
8.00	0.0126	0.0177	0.025	0.035	0.035	0.035	0.035
8.25	0.0126	0.0177	0.025	0.035	0.035	0.035	0.035
8.50	0.0126	0.0177	0.025	0.035	0.035	0.035	0.035
8.75	0.0126	0.0177	0.025	0.035	0.035	0.035	0.035
9.00	0.0126	0.0177	0.025	0.035	0.035	0.035	0.035
			Total Ammonia (mg/liter NH_3)				
6.50	2.5	2.4	2.2	2.2	1.49	1.04	0.73
6.75	2.5	2.4	2.2	2.2	1.49	1.04	0.73
7.00	2.5	2.4	2.2	2.2	1.49	1.04	0.74
7.25	2.5	2.4	2.2	2.2	1.50	1.04	0.74
7.50	2.5	2.4	2.2	2.2	1.50	1.05	0.74
7.75	2.3	2.2	2.1	2.0	1.40	0.99	0.71
8.00	1.53	1.44	1.37	1.33	0.93	0.66	0.47
8.25	0.87	0.82	0.78	0.76	0.54	0.39	0.28
8.50	0.49	0.47	0.45	0.44	0.32	0.23	0.17
8.75	0.28	0.27	0.26	0.27	0.19	0.15	0.11
9.00	0.16	0.16	0.16	0.16	0.13	0.10	0.08
B. Salmonids and Other Sensitive Coldwater Species Absent†							
			Un-ionized Ammonia (mg/liter NH_3)				
6.50	0.0007	0.0009	0.0013	0.0019	0.0026	0.0026	0.0026
6.75	0.0012	0.0017	0.0023	0.0033	0.0047	0.0047	0.0047
7.00	0.0021	0.0029	0.0042	0.0059	0.0083	0.0083	0.0083
7.25	0.0037	0.0052	0.0074	0.0105	0.0148	0.0148	0.0148
7.50	0.0066	0.0093	0.0132	0.0186	0.026	0.026	0.026
7.75	0.0109	0.0153	0.022	0.031	0.043	0.043	0.043
8.00	0.0126	0.0177	0.025	0.035	0.050	0.050	0.050
8.25	0.0126	0.0177	0.025	0.035	0.050	0.050	0.050
8.50	0.0126	0.0177	0.025	0.035	0.050	0.050	0.050
8.75	0.0126	0.0177	0.025	0.035	0.050	0.050	0.050
9.00	0.0126	0.0177	0.025	0.035	0.050	0.050	0.050
			Total Ammonia (mg/liter NH_3)				
6.50	2.5	2.4	2.2	2.2	2.1	1.46	1.03
6.75	2.5	2.4	2.2	2.2	2.1	1.47	1.04
7.00	2.5	2.4	2.2	2.2	2.1	1.47	1.04
7.25	2.5	2.4	2.2	2.2	2.1	1.48	1.05
7.50	2.5	2.4	2.2	2.2	2.1	1.49	1.06
7.75	2.3	2.2	2.1	2.0	1.98	1.39	1.00
8.00	1.53	1.44	1.37	1.33	1.31	0.93	0.67
8.25	0.87	0.82	0.78	0.76	0.76	0.54	0.40
8.50	0.49	0.47	0.45	0.44	0.45	0.33	0.25
8.75	0.28	0.27	0.26	0.27	0.27	0.21	0.16
9.00	0.16	0.16	0.16	0.16	0.17	0.14	0.11

* To convert these values to mg/liter N, multiply by 0.822.

† Site-specific criteria development is strongly suggested at temperatures above 20 C because of the limited data available to generate the criteria recommendation, and at temperatures below 20 C because of the limited data and because small changes in the criteria may have significant impact on the level of treatment required in meeting the recommended criteria.

(1) One-hour average concentrations for ammonia.*

pH	0 C	5 C	10 C	15 C	20 C	25 C	30 C
A. Salmonids or Other Sensitive Coldwater Species Present							
			Un-ionized Ammonia (mg/liter NH_3)				
6.50	0.0091	0.0129	0.0182	0.026	0.036	0.036	0.036
6.75	0.0149	0.021	0.030	0.042	0.059	0.059	0.059
7.00	0.023	0.033	0.046	0.066	0.093	0.093	0.093
7.25	0.034	0.048	0.068	0.095	0.135	0.135	0.135
7.50	0.045	0.064	0.091	0.128	0.181	0.181	0.181
7.75	0.056	0.080	0.113	0.159	0.22	0.22	0.22
8.00	0.065	0.092	0.130	0.184	0.26	0.26	0.26
8.25	0.065	0.092	0.130	0.184	0.26	0.26	0.26
8.50	0.065	0.092	0.130	0.184	0.26	0.26	0.26
8.75	0.065	0.092	0.130	0.184	0.26	0.26	0.26
9.00	0.065	0.092	0.130	0.184	0.26	0.26	0.26
			Total Ammonia (mg/liter NH_3)				
6.50	35	33	31	30	29	20	14.3
6.75	32	30	28	27	27	18.6	13.2
7.00	28	26	25	24	23	16.4	11.6
7.25	23	22	20	19.7	19.2	13.4	9.5
7.50	17.4	16.3	15.5	14.9	14.6	10.2	7.3
7.75	12.2	11.4	10.9	10.5	10.3	7.2	5.2
8.00	8.0	7.5	7.1	6.9	6.8	4.8	3.5
8.25	4.5	4.2	4.1	4.0	3.9	2.8	2.1
8.50	2.6	2.4	2.3	2.3	2.3	1.71	1.28
8.75	1.47	1.40	1.37	1.38	1.42	1.07	0.83
9.00	0.86	0.83	0.83	0.86	0.91	0.72	0.58
B. Salmonids and Other Sensitive Coldwater Species Absent							
			Un-ionized Ammonia (mg/liter NH_3)				
6.50	0.0091	0.0129	0.0182	0.026	0.036	0.051	0.051
6.75	0.0149	0.021	0.030	0.042	0.059	0.084	0.084
7.00	0.023	0.033	0.046	0.066	0.093	0.131	0.131
7.25	0.034	0.048	0.068	0.095	0.135	0.190	0.190
7.50	0.045	0.064	0.091	0.128	0.181	0.26	0.26
7.75	0.056	0.080	0.113	0.159	0.22	0.32	0.32
8.00	0.065	0.092	0.130	0.184	0.26	0.37	0.37
8.25	0.065	0.092	0.130	0.184	0.26	0.37	0.37
8.50	0.065	0.092	0.130	0.184	0.26	0.37	0.37
8.75	0.065	0.092	0.130	0.184	0.26	0.37	0.37
9.00	0.065	0.092	0.130	0.184	0.26	0.37	0.37
			Total Ammonia (mg/liter NH_3)				
6.50	35	33	31	30	29	29	20
6.75	32	30	28	27	27	26	18.6
7.00	28	26	25	24	23	23	16.4
7.25	23	22	20	19.7	19.2	19.0	13.5
7.50	17.4	16.3	15.5	14.9	14.6	14.5	10.3
7.75	12.2	11.4	10.9	10.5	10.3	10.2	7.3
8.00	8.0	7.5	7.1	6.9	6.8	6.8	4.9
8.25	4.5	4.2	4.1	4.0	3.9	4.0	2.9
8.50	2.6	2.4	2.3	2.3	2.3	2.4	1.81
8.75	1.47	1.40	1.37	1.38	1.42	1.52	1.18
9.00	0.86	0.83	0.83	0.86	0.91	1.01	0.82

* To convert these values to mg/liter N, multiply by 0.822.

The Agency acknowledges that the Criterion Continuous Concentration stream flow averaging period used for steady-state wasteload allocation modeling may be as long as 30 days in situations involving POTWs designed to remove ammonia where limited variability of effluent pollutant concentration and resultant concentrations in receiving waters can be demonstrated. In cases where low variability can be demonstrated, longer averaging periods for the ammonia Criterion Continuous Concentration (e.g., 30-day averaging periods) would be acceptable because the magnitude and duration of exceedences above the Criterion Continuous Concentration would be sufficiently limited. These matters are discussed in more detail in the Technical Support Document for Water Quality-Based Toxics Control (U.S. EPA, 1985a).

(50 F.R. 30784, July 29, 1985)
SEE APPENDIX A FOR METHODOLOGY

ANTIMONY

CRITERIA:

Aquatic Life

The available data for antimony indicate that acute and chronic toxicity to freshwater aquatic life occur at concentrations as low as 9,000 and 1,600 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested. Toxicity to algae occurs at concentrations as low as 610 ug/L.

No saltwater organisms have been adequately tested with antimony, and no statement can be made concerning acute or chronic toxicity.

Human Health

For the protection of human health from the toxic properties of antimony ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 146 ug/L.

For the protection of human health from the toxic properties of antimony ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 45 mg/L.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

ARSENIC

AQUATIC LIFE SUMMARY:

The chemistry of arsenic in water is complex and the form present in solution is dependent on such environmental conditions as Eh, pH, organic content, suspended solids, and sediment. The relative toxicities of the various forms of arsenic apparently vary from species to species. For inorganic arsenic(III) acute values for 16 freshwater animal species ranged from 812 ug/L for a cladoceran to 97,000 ug/L for a midge, but the three acute-chronic ratios only ranged from 4.660 to 4.862. The five acute values for inorganic arsenic(V) covered about the same range, but the single acute-chronic ratio was 28.71. The six acute values for MSMA ranged from 3,243 to 1,403,000 ug/L. The freshwater residue data indicated that arsenic is not bioconcentrated to a high degree but that lower forms of aquatic life may accumulate higher arsenic residues than fish. The low bioconcentration factor and short half-life of arsenic in fish tissue suggest that residues should not be a problem to predators of aquatic life.

The available data indicate that freshwater plants differ a great deal as to their sensitivity to arsenic(III) and arsenic(V). In comparable tests, the alga, Selenastrum capricornutum, was 45 times more sensitive to arsenic(V) than to arsenic(III), although other data present conflicting information on the sensitivity of this alga to arsenic(V). Many plant values for inorganic arsenic(III) were in the same range as the available chronic values for freshwater animals; several

plant values for arsenic(V) were lower than the one available chronic value.

The other toxicological data revealed a wide range of toxicity based on tests with a variety of freshwater species and endpoints. Tests with early life stages appeared to be the most sensitive indicator of arsenic toxicity. Values obtained from this type of test with inorganic arsenic(III) were lower than chronic values contained in Table 2. For example, an effect concentration of 40 ug/L was obtained in a test on inorganic arsenic(III) with embryos and larvae of a toad.

Twelve species of saltwater animals have acute values for inorganic arsenic(III) from 232 to 16,030 ug/L and the single acute-chronic ratio is 1.945. The only values available for inorganic arsenic(V) are for two invertebrate and are between 2,000 and 3,000 ug/L. Arsenic(III) and arsenic(V) are equally toxic to various species of saltwater algae, but the sensitivities of the species range from 19 ug/L to more than 1,000 ug/L. In a test with an oyster, a BCF of 350 was obtained for inorganic arsenic(III).

NATIONAL CRITERIA:

The procedures described in the Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of arsenic(III) does not exceed 190 ug/L more than once every 3 years on the

average and if the 1-hour average concentration does not exceed 360 ug/L more than once every 3 years on the average.

The procedures described in the Guidelines indicate that, except possibly where a locally important species is very sensitive, saltwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of arsenic(III) does not exceed 36 ug/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 69 ug/L more than once every 3 years on the average. This criterion might be too high wherever Skeletonema cosrarum or Thalassiosira aestivalis are ecologically important.

Not enough data are available to allow derivation of numerical national water quality criteria for freshwater aquatic life for inorganic arsenic(V) or any organic arsenic compound. Inorganic arsenic(V) is acutely toxic to freshwater aquatic animals at concentrations as low as 850 ug/L and an acute-chronic ratio of 28 was obtained with the fathead minnow. Arsenic(V) affected freshwater aquatic plants at concentrations as low as 48 ug/L. Monosodium methanearsenace (MSMA) is acutely toxic to aquatic animals at concentrations as low as 1,900 ug/L, but no data are available concerning chronic toxicity to animals or toxicity to plants.

Very few data are available concerning the toxicity of any form of arsenic other than inorganic arsenic(III) to saltwater aquatic life. The available data do show that inorganic arsenic(V) is acutely toxic to saltwater animals at concentrations as low as 2,319 ug/L and affected some saltwater

plants at 13 to 56 ug/L. No data are available concerning the chronic toxicity of any form of arsenic other than inorganic arsenic(III) to saltwater aquatic life.

EPA believes that a measurement such as "acid-soluble" would provide a more scientifically correct basis upon which to establish criteria for metals. The criteria were developed on this basis. However, at this time, no EPA approved methods for such a measurement are available to implement the criteria through the regulatory programs of the Agency and the States. The Agency is considering development and approval of methods for a measurement such as acid-soluble. Until available, however, EPA recommends applying the criteria using the total recoverable method. This has two impacts: (1) certain species of some metals cannot be analyzed directly because the total recoverable method does not distinguish between individual oxidation states, and (2) these criteria may be overly protective when based on the total recoverable method.

The recommended exceedence frequency of 3 years is the Agency's best scientific judgment of the average amount of time it will take an unstressed system to recover from a pollution event in which exposure to arsenic(III) exceeds the criterion. a stressed system, for example, one in which several outfalls occur in a limited area, would be expected to require more time for recovery. The resilience of ecosystems and their ability to recover differ greatly, however, and site-specific criteria may be established if adequate justification is provided.

The use of criteria in designing waste treatment facilities requires the selection of an appropriate wasteload allocation

model. Dynamic models are preferred for the application of these criteria. Limited data or other factors may make their use impractical, in which case one should rely on a steady-state model. The Agency recommends the interim use of 1Q5 or 1Q10 for Criterion Maximum Concentration design flow and 7Q5 or 7Q10 for the Criterion Continuous Concentration design flow in steady-state models for unstressed and stressed systems respectively. These matters are discussed in more detail in the Technical Support Document for Water Quality-Based Toxics Control (U.S. EPA, 1985).

HUMAN HEALTH CRITERIA:

For the maximum protection of human health from the potential carcinogenic effects due to exposure of arsenic through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-6}, and 10^{-7}. The corresponding criteria are 22 ng/L, 2.2 ng/L, and .22 ng/L, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 175 ng/L, 17.5 ng/L, and 1.75 ng/L, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purpoes and does not represent an Agency judgment on an "acceptable" risk level.

(45 F.R. 79318 Nov. 28,1980) (50 F.R. 30784, July 29, 1985)
SEE APPENDIX A FOR METHODOLOGY

ASBESTOS

CRITERIA:

Aquatic Life

No freshwater organisms have been tested with any asbestiform mineral and no statement can be made concerning acute or chronic toxicity

No saltwater organisms have been tested with any asbestiform mineral and no statement can be made concerning acute or chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to asbestos through ingestion of water and contaminated aquatic organisms, the ambient water concentration should be zero. The estimated levels which would result in increased lifetime cancer risks of 10^{-5}, 10^{-6}, and 10^{-7} are 300,000 fibers/L, 30,000 fibers/L, and 3,000 fibers/L, respectively. Estimates for consumption of aquatic organisms only, excluding the consumption of water cannot be made.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

BACTERIA

CRITERIA

Freshwater Bathing

Based on a statistically sufficient number of samples (generally not less than 5 samples equally spaced over a 30-day period), the geometric mean of the indicated bacterial densities should not exceed one or the other of the following:(1)

E. coli	126 per 100 ml; or
enterococci	33 per 100 ml;

no sample should exceed a one sided confidence limit (C.L.) calculated using the following as guidance:

designated bathing beach	75% C.L.
moderate use for bathing	82% C.L.
light use for bathing	90% C.L.
infrequent use for bathing	95% C.L.

based on a site-specific log standard deviation, or if site data are insufficient to establish a log standard deviation, then using 0.4 as the log standard deviation for both indicators.

Marine Water Bathing

Based on a statistically sufficient number of samples (generally not less than 5 samples equally spaced over a 30-day period), the geometric mean of the enterococci densities should not exceed 35 per 100 ml; no sample should exceed a one sided confidence limit using the following as guidance:

designated bathing beach	75% C.L.
moderate use for bathing	82% C.L.
light use for bathing	90% C.L.
infrequent use for bathing	95% C.L.

based on a site-specific log standard deviation, or if site data are insufficient to establish a log standard deviation, then using 0.7 as the log standard deviation.

Note (1) - Only one indicator should be used. The Regulatory agency should select the appropriate indicator for its conditions.

Shellfish Harvesting Waters

The median fecal coliform bacterial concentration should not exceed 14 MPN per 100 ml with not more than 10 percent of samples exceeding 43 MPN per 100 ml for the taking of shellfish.

RATIONALE

Bathing Waters

A recreational water quality criterion can be defined as a "quantifiable relationship between the density of an indicator in the water and the potential human health risks involved in the water's recreational use." From such a definition, a criterion can be adopted which establishes upper limits for densities of indicator bacteria in waters that are associated with acceptable health risks for swimmers.

The Environmental Protection Agency, in 1972, initiated a series of studies at marine and fresh water bathing beaches which were designed to determine if swimming in sewage-contaminated marine and fresh water carries a health risk for bathers; and, if so, to what type of illness. Additionally, the Agency wanted to determine which bacterial indicator is best correlated to swimming-associated health effects and if the relationship is strong enough to provide a criterion. (1)

The quantitative relationships between the rates of swimming-associated health effects and bacterial indicator densities were determined using regression analysis. Linear relationships were estimated from data grouped on the basis of summers or trials with similar indicator densities. The data for each summer were analyzed by pairing the geometric mean indicator density for a summer bathing season at each beach with the corresponding swimming-associated gastrointestinal illness rate for the same summer. The swimming-associated illness rate was determined by subtracting the gastrointestinal illness rate in nonswimmers from that for swimmers. Ihese two variables from multiple beach sites were used to calculate a regression coefficient, y-intercept and 95% confidence intervals for the paired data. In the marine studies the total number of points for use in regression analysis was increased by collecting trial days with similar indicator densities from each study location and placing them into groups. The swimming-associated illness rate was determined as before, by subtracting the nonswimmer illness rate of all the individuals included in the grouped trial days from the swimmer illness rate during these safe grouped trial days. The grouping by trial days with similar indicator densities approach was not possible with the freshwater data because the variation of bacterial indicator densities in freshwater samples was not larqe enouqh to allow such an adjustment to be made. For the saltwater studies the results of the regression analyses of illness rates against indicator density data was very similar using the "by summer" or "by grouped trial days" approaches.

The methods used to enumerate the bacterial indicator densities which showed the best relationship to swimming-associated gastroenteritis rates were specifically developed for the recreational water quality studies.

These membrane filter methods have successfully undergone precision and bias testing by the EPA Environmental Monitoring and Support Laboratory. (2)

Several monitoring situations to assess bacterial quality are encountered by regulatory agencies. The situation needing the most rigorous monitoring is the designated swimming beach. Such areas are frequently lifeguard protected, provide parking and other public access and are heavily used by the public. Public beaches of this type were used by EPA in developing the relationship described in this document.

Other recreational activities may involve bodies of water which are regulated by individual State water quality standards. These recreational resources may be natural wading ponds used by children or waters where incidential full body contact occurs because of water skiing or other similar activities.

EPA's evaluation of the bacteriological data indicated that using the fecal coliform indicator group at the maximum geometric mean of 200 per 100 ml, recommended in Quality Criteria for Water would cause an estimated 8 illness per 1,000 swimmers at fresh water beaches and 19 illness per 1,000 swimmers at marine beaches. These relationships are only approximate and are based on applying ratios of the geometric means of the various indicators from the EPA studies to the 200 per 100 ml fecal

coliform criterion. However, these are EPA's best estimates of the accepted illness rates for areas which apply the EPA fecal coliform criterion.

The E. coli and enterococci criteria presented in Table 1 were developed using these currently accepted illness rates. The equations developed by Dufour[3] and Cabelli[4] were used to calculate the geometric mean indicator densities corresponding to the accepted gastrointestinal illness rates. These densities are for steady state dry weather conditions. The beach is in noncompliance with the criteria if the geometric mean of several bacterial density samples exceeds the value listed in Table 1.

Noncompliance is also signaled by an unacceptably high value for any single bacterial sample. The maximum acceptable bacterial density for a single sample is set higher than that for the geometric mean, in order to avoid necessary beach closings based on single samples. In deciding whether a beach should be left open, it is the long term geometric mean bacterial density that is of interest. Because of day-to-day fluctuations around this mean, a decision based on a single sample (or even several samples) may be erroneous, i.e., the sample may exceed the recommended mean criteria even though the long-term geometric mean is protective, or may fall below the maximum even if this mean is in the nonprotective range.

To set the single sample maximum, it is necessary to specify the desired chance that the beach will be left open when the protection is adequate. This chance, or confidence level, was based on Agency judgment. For the simple decision rule considered here, a smaller confidence level corresponds to a more

stringent (i.e. lower) single sample maximum. Conversely, a greater confidence level corresponds to less stringent (i.e. higher) maximum values. This technique reduces the chances of single samples inappropriately indicating violations of the recommended criteria.

By using a control chart analogy [5] and the actual log standard deviations from the EPA studies, single sample maximum densities for various confidence levels were calculated. EPA then assigned qualitative use intensities to those confidence levels. A low confidence level (75%) was assigned to designated beach areas because a high degree of caution should be used to evaluate water quality for heavily used areas. Less intensively used areas would allow less restrictive single sample limits. Thus, 95% confidence might be appropriate for swimmable water in remote areas. Table 1 summarizes the results of these calculations. These single sample maximum levels should be recalculated for individual areas if significant differences in log standard deviations occur.

The levels displayed in Table 1 depend not only on the assumed standard deviation of log densities, but also on the chosen level of acceptable risk. While this level was based on the historically accepted risk, it is still arbitrary insofar as the historical risk was itself arbitrary.

Currently EPA is not recommending a change in the stringency of its bacterial criteria for recreational waters. Such a change does not appear warranted until more information based on greater experience with the new indicators can be accrued. EPA and the

State Agencies can then evaluate the impacts of change in terms of beach closures and other restricted uses.

Shellfish Harvesting Waters

The microbiological criterion for shellfish water quality has been accepted by international agreement to be 70 total coliforms per 100 ml, using a median MPN, with no more than 10 percent of the values exceeding 230 total coliforms. No evidence of disease outbreak from consumption of raw shellfish which were grown in waters meeting this bacteriological criterion has been demonstrated. This standard has proven to be a practical limit when supported by sanitary surveys of the growing waters, acceptable quality in shellfish meats, and good epidemiological evidence. However, evidence from field investigations suggests that not all total coliform occurrences can be associated with fecal pollution. Thus, attention has been directed toward the adoption of the fecal coliform test to measure more accurately the occurrence and magnitude of fecal pollution in shellfish-growing waters.

A series of studies was initiated by the National Shellfish Sanitation Program and data relating the occurrence of total coliforms to numbers of fecal coliforms were compiled. The data show that a 70 coliform MPN per 100 ml at the 50th percentile was equivalent to a fecal coliform MPN of 14 per 100 ml. The data, therefore, indicate that a median value for a fecal coliform standard is 15 and the 90th percentile should not exceed 43 for a 5-tube, 3-dilution method.

EPA is currently (1986) co-sponsoring, with the National

Oceanic and Atmospheric Administration, research into the application of the enterococci and E. coli indicators for assessing the quality of shellfish harvesting waters. The Food and Drug Administration is also reviewing the results of these studies. A change to the new indicators may be forthcoming if the studies show a correlation between gastrointestinal disease and the consumption of raw shellfish from waters with defined densities of the new indicators. However, these studies have not sufficiently progressed to justify any change at this time. Thus, evaluation of the microbiological suitability of waters for recreational taking of shellfish should be based upon the fecal coliform bacterial levels. (6)

CRITERIA FOR INDICATOR FOR BACTERIOLOGICAL DENSITIES

	Acceptable Swimming Associated Gastro-enteritis Rate per 1000 swimmers	Steady State Geometric Mean Indicator Density	Single Sample Maximum Allowable Density (4), (5)			
			Designated Beach Area (upper 75% C.L.)	Moderate Full Body Contact Recreation (upper 82% C.L.)	Lightly Used Full Body Contact Recreation (upper 90% C.L.)	Infrequently Used Full Body Contact Recreation (upper 95% C.L.)
Freshwater						
enterococci	8	33(1)	61	89	108	151
E. coli	8	126(2)	235	298	406	576
Marine Water						
enterococci	19	35(3)	104	124	276	500

Notes:

(1) Calculated to nearest whole number using equation:

$$\text{(mean enterococci density)} = \text{antilog}_{10} \frac{\text{illness rate/1000 people} + 6.28}{9.40}$$

(2) Calculated to nearest whole number using equation:

$$\text{(mean } \textit{E. coli} \text{ density)} = \text{antilog}_{10} \frac{\text{illness rate/1000 people} + 11.74}{9.40}$$

(3) Calculated to nearest whole number using equation:

$$\text{(mean enterococci density)} = \text{antilog}_{10} \frac{\text{illness rate/1000 people} - 0.20}{12.17}$$

(4) Single sample limit = antilog_{10} (Log_{10} indicator geometric mean density/100 ml) + Factor determined from areas under the Normal probability curve for the assumed level of probability x ($\log_{10}$ stand. deviation)

The appropriate factors for the indicated one sided confidence levels are:

75% C.L. - .675
82% C.L. - .935
90% C.L. - 1.28
95% C.L. - 1.65

(5) Based on the observed log standard deviations during the EPA studies: 0.4 for freshwater *E. coli* and enterococci; and 0.7 for marine water enterococci. Each jurisdiction should establish its own standard deviation for its conditions which would then vary the single sample limit.

References

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5. ASTM. 1951. Manual on Quality Control of Materials. Special Technical Publication 15-C, American Society for Testing and Materials, Philadelphia, PA.

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BARIUM

CRITERION:

1 mg/L for domestic water supply (health).

INTRODUCTION:

Barium is a yellowish-white metal of the alkaline earth group. It occurs in nature chiefly as barite, $BaSO_4$ and witherite, $BaCO_3$, both of which are highly insoluble salts. The metal is stable in dry air, but readily oxidized by humid air or water.

Many of the salts of barium are soluble in both water and acid, and soluble barium salts are reported to be poisonous (Lange, 1965; NAS, 1974). However, barium ions generally are thought to be rapidly precipitated or removed from solution by absorption and sedimentation (McKee and Wolf, 1963 NAS, 1974).

While barium is a malleable, ductile metal, its major commercial value is in its compounds. Barium compounds are used in a variety of industrial applications including the metallurgic, paint, glass and electronics industries, as well as for medicinal purposes.

RATIONALE:

Concentrations of barium drinking water supplies generally range from less than 0.6 ug/L to approximately 10 ug/L with upper limits in a few midwestern and western States ranging from 100 to 3,000 ug/L (PHS, 1962/1963; Katz, 1970; Little, 1971). Barium enters the body primarily through air and water, since appreciable amounts are not contained in foods (NAS, 1974).

The fatal dose of barium for man is reported to be 550 to 600 mg. Ingestion of soluble barium compounds may also result in effects on the gastrointestinal tract, causing vomiting and diarrhea, and on the central nervous system, causing violent tonic and clonic spasms followed in some cases by paralysis (Browning, 1961; Patty, 1962, cited in Preliminary Air Pollution Survey of Barium and Its Compounds, 1969). Barium salts are considered to be muscle stimulants, especially for the heart muscle (Sollman, 1957). By constricting blood vessels, barium may cause an increase in blood pressure. On the other hand, it is not likely that barium accumulates in the bone, muscle, kidney or other tissues because it is readily excreted (Browning, 1961; McKee and Wolf, 1963).

Stokinger and Woodward (1958) developed a safe concentration for barium in drinking water based on the limiting values for industrial atmospheres, an estimate of the amount absorbed into the blood stream, and daily consumption of 2 liters of water. From other factors they arrived at a limiting concentration of 2 mg/L for a healthy adult human population, to which a safety factor was applied to allow for any possible accumulation in the body. Since barium is not removed by conventional water treatment processes and because of the toxic effect on the heart and blood vessels, a limit of 1 mg/L is recommended for barium in domestic water supplies.

Experimental data indicate that the soluble barium concentration in fresh and marine water generally would have to exceed 50 mg/L before toxicity to aquatic life would be expected. In most natural waters, there is sufficient sulfate or carbonate

to precipitate the barium present in the water as a virtually insoluble, non-toxic compound. Recognizing that the physical and chemical properties of barium generally will preclude the existence of the toxic soluble form under usual marine and fresh water conditions, a restrictive criterion for aquatic life appears unwarranted.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

BENZENE

CRITERIA:

Aquatic Life

The available data for benzene indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 5,300 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of benzene to sensitive freshwater aquatic life.

The available data for benzene indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 5,100 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No definitive data are available concerning the chronic toxicity of benzene to sensitive saltwater aquatic life, but adverse effects occur at concentrations as low as 700 ug/L with a fish species exposed for 168 days.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to benzene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the non threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 6.6 ug/L, 0.66 ug/L, and

0.066 ug/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 400 ug/L, 40.0 ug/L, and 4.0 ug/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

BENZIDINE

CRITERIA:

Aquatic Life

The available data for benzidine indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 2,500 ug/L and would occur at lower concentrations among species that are more sensitive than those tested No data are available concerning the chronic toxicity of benzidine to sensitive freshwater aquatic life.

No saltwater organisms have been tested with benzidine and no statement can be made concerning acute and chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to benzidine through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 1.2 ng/L, 0.12 ng/L, and 0.01 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 5.3 ng/L, 0.53 ng/L, and 0.05 ng/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

BERYLLIUM

CRITERIA:

Aquatic Life

The available data for beryllium indicate that acute and chronic toxicity to freshwater aquatic life occur at concentrations as low as 130 and 5.3 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested. Hardness has a substantial effect on acute toxicity.

The limited saltwater data base available for beryllium does not permit any statement concerning acute or chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to beryllium through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero, based on the non threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 68 ng/L, 6.8 ng/L, and 0.68 ng/L, respectively. If these estimates are made for

consumption of aquatic organisms only, excluding consumption of water, the levels are 1170 ng/L, 117.0 ng/L, and 11.71 ng/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

BORON

CRITERION:

750 ug/L for long-term irrigation on sensitive crops.

INTRODUCTION:

Boron is not found in its elemental form in nature: it is usually found as a sodium or calcium borate salt. Boron salts are used in fire retardants, the production of glass, leather tanning and finishing industries, cosmetics, photographic materials, metallurgy and for high energy rocket fuels. Elemental boron also can be used in nuclear reactors for neutron absorption. Borates are used as "burnable" poisons.

RATIONALE:

Boron is an essential element for growth of plants but there is no evidence that it is required by animals. The maximum concentration found in 1,546 samples of river and lake waters from various parts of the United States was 5.0 mg/L; the mean value was 0.1 mg/L (Kopp and Kroner, 1967). Ground waters could contain substantially higher concentrations at certain places. The concentration in seawater is reported as 4.5 mg/L in the form of borate (NAS, 1974). Naturally occurring concentrations of boron should have no effects on aquatic life.

The minimum lethal dose for minnows exposed to boric acid at 20 ^{o}C for 6 hours was reported to be 18,000 to 19,000 mg/L in distilled water and 19,000 to 19,500 mg/L in hard water (Le Clerc and Devlaminck, 1955: Le Clerc, 1960).

In the dairy cow, 16 to 20 g/day of boric acid for 40 days

produced no ill effects (McKee and Wolf, 1963).

Sensitive crops have shown toxic effects at 1000 ug/L or less of boron (Richards, 1954). Bradford (1966), in a review of boron deficiencies and toxicities, stated that when the boron concentration in irrigation waters was greater than 0.75 ug/L, some sensitive plants such as citrus began to show injury. Biggar and Fireman (1960) showed that with neutral and alkaline soils of high absorption capacities, water containing 2 ug/L boron might be used for some time without injury to sensitive plants. The criterion of 750 ug/L is thought to protect sensitive crops during long-term irrigation.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

CADMIUM

AQUATIC LIFE SUMMARY:

Freshwater acute values for cadmium are available for species in 44 genera and range from 1.0 ug/L for rainbow trout to 28,000 ug/L for a mayfly. The antagonistic effect of hardness on acute toxicity has been demonstrated with five species. Chronic tests have been conducted on cadmium with 12 freshwater fish species and 4 invertebrate species with chronic values ranging from 0.15 ug/L for Daphnia magna to 156 ug/L for the Atlantic salmon. Acute-chronic ratios are available for eight species and range from 0.9021 for the chinook salmon to 433.8 for the flagfish.

Freshwater aquatic plants are affected by cadmium at concentrations ranging from 2 to 7,400 ug/L. These values are in the same range as the acute toxicity values for fish and invertebrate species, and are considerably above the chronic values. Bioconcentration factors (BCFs) for cadmium in fresh water range from 164 to 4,190 for invertebrates and from 3 to 2,213 for fishes.

Saltwater acute values for cadmium and five species of fishes range from 577 ug/L for larval Atlantic silverside to 114,000 ug/L for juvenile mummichog. Acute values for 30 species of invertebrates range from 15.5 ug/L for a mysid to 135,000 ug/L for an oligochaete worm. The acute toxicity of cadmium generally increases as salinity decreases. The effect of temperature seems to be species-specific. Two life-cycle tests with Mysidopsis bahia under different test conditions resulted in similar chronic values of 8.2 and 7.1 ug/L, but the acute-chronic ratios were 1.9 and 15, respectively. The acute values appear to

reflect effects of salinity and temperature, whereas the few available chronic values apparently do not. A life-cycle test with Mysidopsis bigelowi also resulted in a chronic value of 7.1 ug/L and an acute-chronic ratio of 15. Studies with microalgae and macroalgae revealed effects at 22.8 to 860 ug/L.

BCFs determined with a variety of saltwater invertebrates ranged from 5 to 3,160. BCFs for bivalve molluscs were above 1,000 in long exposures, with no indication that steady-state had been reached. Cadmium mortality is cumulative for exposure periods beyond 4 days. Chronic cadmium exposure resulted in significant effects on the growth of bay scallops at 78 ug/L and on reproduction of a copepod at 44 ug/L.

NATIONAL CRITERIA:

The procedures described in the Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration (in ug/L) of cadmium does not exceed the numerical value given by $e^{(0.7852[\ln(\text{hardness})]-3.490)}$ more than once every 3 years on the average and if the one-hour average concentration (in ug/L) does not exceed the numerical value given by $e^{(1.128[\ln(\text{hardness})]-3.828)}$ more than once every 3 years on the average. For example, at hardnesses of 50, 100, and 200 mg/L as $CaCO_3$ the 4-day average concentrations of cadmium are 0.66, 1.1, and 2.0 ug/L, respectively, and the 1-hour average concentrations are

1.8, 3.9 and 8.6 ug/L. If brook trout, brown trout, and striped bass are as sensitive as some data indicate, they might not be protected by this criterion.

The procedures described in the Guidelines indicate that, except possibly where a locally important species is very sensitive, saltwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of cadmium does not exceed 9.3 ug/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 43 ug/L more than once every 3 years on the average. The little information that is available concerning the sensitivity of the American lobster to cadmium indicates that this important species might not be protected by this criterion. In addition, data suggest that the acute toxicity of cadmium is salinity dependent; therefore, the 1-hour average concentration might be underprotective at low salinities and overprotective at high salinities.

EPA believes that a measurement such as "acid-soluble" would provide a more scientifically correct basis upon which to establish criteria for metals. The criteria were developed on this basis. However, at this time, no EPA-approved methods for such a measurement are available to implement the criteria through the regulatory programs of the Agency and the States. The Agency is considering development and approval of methods for a measurement such as acid-soluble. Until available, however, EPA recommends applying the criteria using the total recoverable method. This has two impacts: (1) certain species of some metals

cannot be analyzed directly because the total recoverable method does not distinguish between individual oxidation states, and (2) these criteria may be overly protective when based on the total recoverable method.

The recommended exceedence frequency of 3 years is the Agency's best scientific judgment of the average amount of time it will take an unstressed system to recover from a pollution event in which exposure to cadmium exceeds the criterion. A stressed system, for example, one in which several outfalls occur in a limited area, would be expected to require more time for recovery. The resilience of ecosystems and their ability to recover differ greatly, however, and site-specific criteria may be established if adequate justification is provided.

The use of criteria in designing waste treatment facilities requires the selection of an appropriate wasteload allocation model. Dynamic models are preferred for the application of these criteria. Limited data or other factors may make their use impractical, in which case one should rely on a steady-state model. The Agency recommends the interim use of 1Q5 or 1Q10 for Criterion Maximum Concentration design flow and 7Q5 or 7Q10 for the Criterion Continuous Concentration design flow in steady-state models for unstressed and stressed systems, respectively. These matters are discussed in more detail in the Technical Support Document for Water Quality-Based Toxics Control (U.S. EPA, 1985).

HUMAN HEALTH CRITERIA:

The ambient water quality criterion for cadmium is recommended to be identical to the existing drinking water

standard which is 10 ug/L. Analysis of the toxic effects data resulted in a calculated level which is protective of human health against the ingestion of contaminated water and contaminated aquatic organisms. The calculated value is comparable to the present standard. For this reason a selective criterion based on exposure solely from consumption of 6.5 grams of aquatic organisms was not derived.

(45 F.R. 79318 Nov. 28,1980) (50 F.R. 30784, July 29, 1985)
SEE APPENDIX A FOR METHODOLOGY

CARBON TETRACHLORIDE

CRITERIA:

Aquatic Life

The available data for carbon tetrachloride indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 35,200 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of carbon tetrachloride to sensitive freshwater aquatic life.

The available data for carbon tetrachloride indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 50,000 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of carbontetrachloride to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to carbon tetrachloride through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 4.0 ug/L, 0.40ug/L, and 0.04 ug/L, respectively. If these estimates are made for

consumption of aquatic organisms only, excluding consumption of water, the levels are 69.4 ug/L, 6.94 ug/L, and 0.69 ug/L respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

CHLORDANE

CRITERIA:

Aquatic Life

For chlordane the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.0043 ug/L as a 24-hour average, and the concentration should not exceed 2.4 ug/L at any time.

For chlordane the criterion to protect saltwater aquatic life as derived using the Guidelines is 0.0040 ug/L as a 24-hour average, and the concentration should not exceed 0.09 ug/L at any time.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to chlordane through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 4.6 ng/L, 0.46 ng/L, and 0.046 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 4.8 ng/L, 0.48 ng/L, and 0.048 ng/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

2-CHLOROPHENOL

CRITERIA:

Aquatic Life

The available data for 2-chlorophenol indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 4,380 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No definitive data are available concerning the chronic toxicity of 2-chlorophenol to sensitive freshwater aquatic life, but flavor impairment occurs in one species of fish at concentrations as low as 2,000 ug/L.

No saltwater organisms have been tested with 2-chlorophenol and therefore, no statement can be made concerning acute or chronic toxicity.

Human Health

Sufficient data are not available for 2-chlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, to control undesirable taste and odor qualities of ambient water the estimated level is 0.1 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have no demonstrated relationship to potential adverse human health effects.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

CHLORINATED BENZENES

CRITERIA

Aquatic Life

The available data for chlorinated benzenes indicate that acute toxicity to fresh water aquatic life at concentrations as low as 250 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of the more toxic of the chlorinated benzenes to sensitive freshwater aquatic life but toxicity occurs at concentrations as low as 50 ug/L for a fish species exposed for 7.5 days.

The available data for chlorinated benzenes indicate that acute and chronic toxicity to saltwater aquatic life occur at concentrations as low as 160 and 129 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Human Health

For comparison purposes, two approaches were used to derive criterion levels for monochlorobenzene. Based on available toxicity data, for the protection of public health, the derived level is 488 ug/L. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 20 ug/L. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

Trichlorobenzenes

Due to the insufficiency in the available information for the trichlorobenzenes, a criterion cannot be derived at this time using the present guidelines.

1,2,4,5-Tetrachlorobenzene

For the protection of human health from the toxic properties of 1,2,4,5-tetrachlorobenzene ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 38 ug/L.

For the protection of human health from the toxic properties of 1,2,4,5-tetrachlorobenzene ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 48 ug/L.

Pentachlorobenzene

For the protection of human health from the toxic properties of pentachlorobenzene ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 74 ug/L.

For the protection of human health from the toxic properties of pentachlorobenzene ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 85 ug/L.

Hexachlorobenzene

For the maximum protection of human health from the potential carcinogenic effects due to exposure of hexachlorobenzene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero

level may not be attainable at the present time. Therefor, the levels which may result in incramental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 7.2 ng/L, 0.72 ng/L, and 0.072 ng/L, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 7.4 ng/L, 0.74 ng/L and 0.074. ng/L respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

CHLORINATED ETHANES

CRITERIA:

Aquatic Life

The available freshwater data for chlorinated ethanes indicate that toxicity increases greatly with increasing chlorination, and that acute toxicity occurs at concentrations as low as 118,000 ug/L for 1,2-dichloroethane, 18,000 ug/L for two trichloroethanes, 9,320 ug/L for two tetrachloroethanes, 7,240 ug/L for pentachloroethane, and 980 ug/L for hexachloroethane. Chronic toxicity occurs at concentrations as low as 20,000 ug/L for 1,2-dichloroethane, 9,400 ug/L for 1,1,2-trichloroethane, 2,400 ug/L for 1,1,2,2-tetrachloroethane, 1,100 ug/L for pentachloroethane, and 540 ug/L for hexachloroethane. Acute and chronic toxicity would occur at lower concentrations among species that are more sensitive than those tested.

The available saltwater data for chlorinated ethanes indicate that toxicity increases greatly with increasing chlorination and that acute toxicity to fish and invertebrate species occurs at concentrations as low as 113,000 ug/L for 1,2-dichloroethane, 31,200 ug/L for 1,1,1-trichloroethane, 9,020 ug/L for 1,1,2,2-tetrachloroethane, 390 ug/L for pentachloroethane, and 940 ug/L for hexachloroethane. Chronic toxicity occurs at concentrations as low as 281 ug/L for pentachloroethane. Acute and chronic toxicity would occur at lower concentrations among species that are more sensitive than those tested.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to 1,2-dichloroethane through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 9.4 ug/L, 0.94 ug/L, and 0.094 ug/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 2,430 ug/L, 243 ug/L, and 24.3 ug/L, respectively.

For the maximum protection of human health from the potential carcinogenic effects of exposure to 1,1,2-trichloroethane through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 6.0 ug/L, 0.6 ug/L, and 0.06 ug/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 418 ug/L, 41.8 ug/L, and 4.18 ug/L, respectively.

For the maximum protection of human health from the potential carcinogenic effects of exposure to 1,1,2,2-tetrachloroethane through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 1.7 ug/L, 0.17 ug/L, and 0.017 ug/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 107 ug/L, 10.7 ug/L, and 1.07 ug/L, respectively.

For the maximum protection of human health from the potential carcinogenic effects of exposure to hexachloroethane through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 19 ug/L, 1.9 ug/L, and 0.19 ug/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 87.4 ug/L, 8.74 ug/L, and 0.87 ug/L, respectively.

For the protection of human health from the toxic properties of 1,1,1-trichloroethane ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 18.4 mg/L.

For the protection of human health from the toxic properties of 1,1,1-trichloroethane ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 1.03 ug/1.

Because of insufficient available data for monochloroethane, 1,1-dichloroethane, 1,1,1,2-tetrachloroethane, and pentachloroethane, satisfactory criteria cannot be derived at this time, using the present guidelines.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

CHLORINATED NAPHTHALENES

CRITERIA:

Aquatic Life

The available data for chlorinated naphthalenes indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 1,600 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of chlorinated naphthalenes to sensitive freshwater aquatic life.

The available data for chlorinated naphthalenes indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 7.5 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of chlorinated naphthalenes to sensitive saltwater aquatic life.

Human Health

Using the present guidelines, a satisfactory criterion cannot be derived at this time because of insufficient available data for chlorinated naphthalenes.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

CHLORINE

SUMMARY:

Thirty-three freshwater species in 28 genera have been exposed to TRC and the acute values range from 28 ug/L for Daphnia magna to 710 ug/L for the threespine stickleback. Fish and invertebrate species had similar ranges of sensitivity. Freshwater chronic tests have been conducted with two invertebrate and one fish species and the chronic values for these three species ranged from less than 3.4 to 26 ug/L, with acute-chronic ratios from 3.7 to greater than 78.

The acute sensitivities of 24 species of saltwater animals in 21 genera have been determined for CPO, and the LC50 range from 26 ug/L for the eastern oyster to 1,418 ug/L for a mixture of two shore crab species. This range is very similar to that observed with freshwater species, and fish and invertebrate species had similar sensitivities. Only one chronic test has been conducted with a saltwater species, Menidia peninsulae, and in this test the acute chronic ratio was 1.162.

The available data indicate that aquatic plants are more resistant to chlorine than fish and invertebrate species.

NATIONAL CRITERIA:

The procedures described in the Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected

unacceptably if the 4-day average concentration of total residual chlorine does not exceed 11 ug/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 19 ug/L more than once every 3 years on the average.

The procedures described in the Guidelines indicate that, except possibly where a locally important species is very sensitive, saltwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of chlorine-produced oxidants does not exceed 7.5 ug/L more than once every 3 years on the average and if the one-hour average concentration does not exceed 13 ug/L more than once every 3 years on the average.

The recommended exceedence frequency of 3 years is the Agency's best scientific judgment of the average amount of time it will take an unstressed system to recover from a pollution event in which exposure to chlorine exceeds the criterion. A stressed system, for example, one in which several outfalls occur in a limited area, would be expected to require more time for recovery. The resilience of ecosystems and their ability to recover differ greatly, however, and site-specific criteria may be established if adequate justification is provided.

The use of criteria in designing waste treatment facilities requires the selection of an appropriate wasteload allocation model. Dynamic models are preferred for the application of these criteria. Limited data or other factors may make their use impractical, in which case one should rely on a steady-state model. The Agency recommends the interim use of 1Q5 or 1Q10 for Criterion Maximum Concentration design flow and 7Q5 or 7Q10 for

the Criterion Continuous Concentration design flow in steady-state models for unstressed and stressed systems, respectively. These matters are discussed in more detail in the Technical Support Document for Water Quality-Based Toxics Control (U.S. EPA, 1985).

(50 F.R. 30784, July 29, 1985)
SEE APPENDIX A FOR METHODOLOGY

CHLORINATED PHENOLS

CRITERIA:

Aquatic Life

The available freshwater data for chlorinated phenols indicate that toxicity generally increases with increasing chlorination, and that acute toxicity occurs at concentrations as low as 30 ug/L for 4-chloro-3-methylphenol to greater than 500,000 ug/L for other compounds. Chronic toxicity occurs at concentrations as low as 970 ug/L for 2,4,6-trichlorophenol. Acute and chronic toxicity would occur at lower concentrations among species that are more sensitive than those tested.

The available saltwater data for chlorinated phenols indicate that toxicity generally increases with increasing chlorination and that acute toxicity occurs at concentrations as low as 440 ug/L for 2,3,5,6-tetrachlorophenol and 29,700 ug/L for 4-chlorophenol. Acute toxicity would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of chlorinated phenols to sensitive saltwater aquatic life.

Human Health

Sufficient data are not available for 3-chlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, to control undesirable taste and odor qualities of ambient water, the estimated level is 0.1 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have no demonstrated

relationship to potential adverse human health effects.

Sufficient data are not available for 4-chlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, to control undesirable taste and odor qualities of ambient water the estimated level is 0.1 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have no demonstrated relationship to potential adverse human health effects.

Sufficient data are not available for 2,3-dichlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, to control undesirable taste and odor qualities of ambient water the estimated level is 0.04 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have no demonstrated relationship to potential adverse human health effects.

Sufficient data are not available for 2,5-dichlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, to control undesirable taste and odor qualities of ambient water the estimated level is 0.5 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have no demonstrated relationship to potential adverse human health effects.

Sufficient data are not available for 2,6-dichlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, to control

undesirable taste and odor qualities of ambient water the estimated level is 0.2 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have no demonstrated relationship to potential adverse human health effects.

Sufficient data are not available for 3,4-dichlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, to control undesirable taste and odor qualities of ambient water the estimated level is 0.3 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have no demonstrated relationship to potential adverse human health effects.

For comparison purposes, two approaches were used to derive criterion levels for 2,4,5-trichlorophenol. Based on available toxicity data, to protect public health the derived level is 2.6 mg/L. Using available organoleptic data, to control undesirable taste and odor quality of ambient water the estimated level is 1.0 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have no demonstrated relationship to potential adverse human health effects.

For the maximum protection of human health from the potential carcinogenic effects of exposure to 2,4,6-trichlorophenol through the ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero, based on the nonthreshold assumption for this

chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 12 ug/L, 1.2 ug/L, and 0.12 ug/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 36 ug/L, 3.6 ug/L, and 0.36 ug/L, respectively. Using available organoleptic data, to control undesirable taste and odor qualities of ambient water the estimated level is 2 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing. a water quality criterion, and have no demonstrated relationship to potential adverse human health effects.

Sufficient data are not available for 2,3,4,6-tetrachlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, to control undesirable taste and odor qualities of ambient water the estimated level is 1.0 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have demonstrated relationship to potential adverse human health effects.

Sufficient data are not available for 2-methyl-4-chlorophenol to derive a criterion level which would protect against any potential toxicity of this compound. Using available organoleptic data, to control undesirable taste and odor qualities of ambient water the estimated level is 1,800 ug/L. It

should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion and have no demonstrated relationship to potential adverse human health effects.

Sufficient data are not available for 3-methyl-4-chlorophenol to derive a criterion level which would protect against any potential toxicity of this compound. Using available organoleptic data, to control undesirable taste and odor qualities of ambient water the estimated level is 3,000 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have no demonstrated relationship to potential adverse human health effects.

Sufficient data are not available for 3-methyl-6-chlorophenol to derive a criterion level which would protect against any potential toxicity of this compound. Using available organoleptic data, to control undesirable taste and odor qualities of ambient water the estimated level is 20 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have no demonstrated relationship to potential adverse human health effects.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

CHLOROALKYL ETHERS

CRITERIA:

Aquatic Life

The available data for chloroalkyl ethers indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 238,000 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No definitive data are available concerning the chronic toxicity of chloroalkyl ethers to sensitive freshwater aquatic life.

No saltwater organism has been tested with any chloroalkyl ether and therefore, no statement can be made concerning acute or chronic toxicity.

Human Health

For the protection of human health from the toxic properties of bis(2-chloroisopropyl) ether ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 34.7 ug/L.

For the protection of human health from the toxic properties of bis(2-chloroisopropyl) ether ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 4.36 mg/L.

For the maximum protection of human health from the potential carcinogenic effects of exposure to bis(chloromethyl) ether through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero

level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 37.6×10^{-6} ug/L, 3.76×10^{-6} ug/L, and 0.376×10^{-6} ug/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 18.4×10^{-3} ug/L, 1.84×10^{-3} ug/L, and 0.184×10^{-3} ug/L, respectively.

For the maximum protection of human health from the potential carcinogenic effects of exposure to bis(2-chloroethyl) ether through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 0.30 ug/L, 0.030 ug/L, and 0.003 ug/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 13.6 ug/L, 1.36 ug/L, and 0.136 ug/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

CHLOROFORM

CRITERIA:

Aquatic Life

The available data for chloroform indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 28,900 ug/L, and would occur at lower concentrations among species that are more sensitive than the three tested species Twenty-seven-day LC50 values indicate that chronic toxicity occurs at concentrations as low as 1,240 ug/L, and could occur at lower concentrations among species or other life stages that are more sensitive than the earliest life cycle stages of the rainbow trout. The data base for saltwater species is limited to one test and therefore, no statement can be made concerning acute or chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to chloroform through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 1.90 ug/L, 0.19 ug/L, and 0.019 ug/L, respectively. If these

estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 157 ug/L, 15.7 ug/L, and 1.57 ug/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

CHLOROPHENOXY HERBICIDES
2,4-D; 2,4,5-TP

CRITERIA:

2,4-D 100 ug/L for domestic water supply (health)

2,4,5-TP 10 ug/L for domestic water supply (health)

RATIONALE:

Two widely used herbicides are 2,4-D (2, 4-dichlorophenoxyacetic acid) and 2,4,5-TP (silvex) [2-(2,4, 5-trichlorophenoxy) propionic acid. Each of these compounds is formulated in a variety of salts and esters that may have a marked difference in herbicidal properties, but all are hydrolyzed rapidly to the corresponding acid in the body.

The subacute oral toxicity of chlorophenoxy herbicides has been investigated in a number of species of experimental animals (Palmer and Radeleff, 1964; Lehman, 1965). The dog was found to be sensitive and often displayed mild injury in response to doses of 10 mg/kg/day for 90 days, and serious effects from a dose of 20 mg/kg/day for 90 days. Lehman (1965) reported that the no-effect level of 2,4-D is 0.5 mg/kg/day in the rat, and 8.0 mg/kg/day in the dog.

Data are available on the toxicity of 2,4-D to man. A daily dosage of 500 mg (about 7 mg/kg) produced no apparent ill effects in a volunteer over a 21-day period (Kraus, 1946). When 2,4-D was investigated as a possible treatment for disseminated coccidioidomycosis, the patient had no side effects from 18 intravenous doses during 33 days; each of the last 12 doses in

the series was 800 mg (about 15 mg/kg) or more, the last being 2000 mg (about 37 mg/kg) (Seabury, 1963). A 19th and final dose of 3600 mg (67 mg/kg) produced mild symptoms.

The long-term no-effects levels (mg/kg/day) are listed for the rat and the dog. Those values are adjusted by a factor of 1/500 for 2,4-D and 2,4,5-TP. The safe levels are then readjusted to reflect total allowable intake per person. Since little 2,4-D or 2,4,5-TP is expected to occur in foods, 20 percent of the safe exposure level can reasonably be allocated to water without jeopardizing the health of the consumer.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

CHROMIUM (VI)

AQUATIC LIFE SUMMARY:

Acute toxicity values for chromium(VI) are available for freshwater animal species in 27 genera and range from 23.07 ug/L for a cladoceran to 1,870,000 ug/L for a stonefly. These species include a wide variety of animals that perform a wide spectrum of ecological functions. All five tested species of daphnids are especially sensitive. The few data that are available indicate that the acute toxicity of chromium(VI) decreases as hardness and pH increase.

The chronic value for both rainbow trout and brook trout is 264.6 ug/L, which is much lower than the chronic value of 1,987 ug/L for the fathead minnow. The acute-chronic ratios for these three fishes range from 18.55 to 260.8. In all three chronic tests a temporary reduction in growth occurred at low concentrations. Six chronic tests with five species of daphnids gave chronic values that range from <2.5 to 40 ug/L and the acute-chronic ratios range from 1.130 to >9.680. Except for the fathead minnow, all the chronic tests were conducted in soft water. Green algae are quite sensitive to chromium(VI). The bioconcentration factor obtained with rainbow trout is less than 3. Growth of chinook salmon was reduced at a measured concentration of 16 ug/L.

The acute toxicity of chromium (VI) to 23 saltwater vertebrate and invertebrate species ranges from 2,000 ug/L for a polychaete worm and a mysid to 105,000 ug/L for the mud snail. The chronic values for a polychaete range from <13 to 36.74 ug/L, whereas

that for a mysid is 132 ug/L. The acute-chronic ratios range from 15.38 to >238.5. Toxicity to macroalgae was reported at 1,000 and 5,000 ug/L. Bioconcentration factors for chromium(VI) range from 125 to 236 for bivalve molluscs and polychaetes.

CHROMIUM (III)

Acute values for chromium(III) are available for 20 freshwater animal species in 18 genera ranging from 2,221 ug/L for a mayfly to 71,060 ug/L for caddisfly. Hardness has a significant influence on toxicity, with chromium(III) being more toxic in soft water.

A life-cycle test with Daphnia magna in soft water gave a chronic value of 66 ug/L. In a comparable test in hard water the lowest test concentration of 44 ug/L inhibited reproduction of Daphnia magna, but this effect may have resulted from ingested precipitated chromium. In a life-cycle test with the fathead minnow in hard water the chronic value was 1,025 ug/L. Toxicity data are available for only two freshwater plant species. A concentration of 9,900 ug/L inhibited growth of roots of Eurasian watermilfoil. A freshwater green alga was affected by a concentration of 397 ug/L in soft water. No bioconcentration factor has been measured for chromium(III) with freshwater organisms.

Only two acute values are available for chromium (III) in saltwater 10,300 ug/L for the eastern oyster and 31,500 ug/L for the mummichog. In a chronic test effects were not observed on a polychaete worm at 50,400 ug/L at pH = 7.9, but acute lethality occurred when pH = 4.5. Bioconcentration factors for saltwater

organisms and chromium(III) range from 86 to 153, similar to the bioconcentration factors for chromium(VI) and saltwater species.

NATIONAL CRITERIA:

CHROMIUM(VI)

The procedures described in the Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of chromium(VI) does not exceed 11 ug/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 16 ug/L more than once every 3 years on the average.

The procedures described in the Guidelines indicate that, except possibly where a locally important species is very sensitive, saltwater aquatic organisms, and their uses should not be affected unacceptably if the 4-day average concentration of chromium(VI) does not exceed 50 ug/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 1,100 ug/L more than once every 3 years on the average. Data suggest that the acute toxicity of chromium (VI) is salinity dependent; therefore, the 1-hour average concentration might be underprotective at low salinities.

CHROMIUM(III)

The procedures described in the Guidelines indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not

be affected unacceptably if the 4-day average concentration (in ug/L) of chromium(III) does not exceed the numerical value given by $e^{(0.8190[\ln(\text{hardness})]+1.561)}$ more than once every 3 years on the average and if the 1-hour average concentration (in ug/L) does not exceed the numerical value given by $e^{(0.8190[\ln(\text{hardness})]+3.688)}$ more than once every 3 years on the average. For example, at hardnesses of 50, 100, and 200 mg/L as $CaCO_3$ the 4-day average concentrations of chromium(III) are 120, 210, and 370 ug/L, respectively, and the 1-hour average concentrations are 980, 1,700, and 3,100 ug/L.

No saltwater criterion can be derived for chromium(III), but 10,300 ug/L is the EC50 for eastern oyster embryos, whereas 50,400 ug/L did not affect a polychaete worm in a life-cycle test.

EPA believes that a measurement such as "acid-soluble" would provide a more scientifically correct basis upon which to establish criteria for minerals. The criteria were developed on this basis. However, at this time, no EPA-approved methods for such a measurement are available to implement the criteria through the regulatory programs of the Agency and the States. The Agency is considering development and approval of methods for a measurement such as acid-soluble. Until available, however, EPA recommends applying the criteria using the total recoverable method. This has two impacts: (1) certain species of some metals cannot be analyzed directly because the total recoverable method does not distinguish between individual

oxidation states, and (2) these criteria may be overly protective when based on the total recoverable method.

The recommended exceedence frequency of 3 years is the Agency's best scientific judgment of the average amount of time it will take an unstressed system to recover from a pollution event in which exposure to chromium exceeds the criterion. A stressed system, for example, one in which several outfalls occur in a limited area, would be expected or require more time for recovery. The resilience of ecosystems and their ability to recover differ greatly, however, and site-specific criteria may be established if adequate justification is provided.

The use of criteria in designing waste treatment facilities requires the selection of an appropriate wasteload allocation model. Dynamic models are preferred for the application of these criteria. Limited data or other factors may make their use impractical, in which case one should rely on a steady-state model. The Agency recommends the interim use of 1Q5 or 1Q10 for Criterion Maximum Concentration design flow and 7Q5 or 7Q10 or the Criterion Continuous Concentration design flow in steady-state models for unstressed and stressed systems, respectively. These matters are discussed in more detail in the Technical Support Document for water Quality-Based Toxics Control (U.S. EPA, 1985).

HUMAN HEALTH CRITERIA:

For the protection of human health from the toxic properties of Chromium III ingested through water and contaminated aquatic

organisms, the ambient water criterion is determined to be 170 mg/L.

For the protection of human health from the toxic properties of Chromium III ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 3433 mg/L.

The ambient water quality criterion for total Chromium VI is recommended to be identical to the existing drinking water standard which is 50 ug/L. Analysis of the toxic effects data resulted in a calculated level which is protective of human health against the ingestion of contaminated water and contaminated aquatic organisms. The calculated value is comparable to the present standard. For this reason a selective criterion based on exposure solely from consumption of 6.5 grams of aquatic organisms was not derived.

(45 F.R. 79318 Nov. 28,1980) (50 F.R. 30784, July 29, 1985)
SEE APPENDIX A FOR METHODOLOGY

COLOR

CRITERIA:

Waters shall be virtually free from substances producing objectionable color for aesthetic purposes;

the source of supply should not exceed 75 color units on the platinum-cobalt scale for domestic water supplies; and

increased color (in combination with turbidity) should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life.

INTRODUCTION:

Color in water principally results from degradation processes in the natural environment. Although colloidal forms of iron and manganese occasionally are the cause of color in water, the most common causes are complex organic compounds originating from the decomposition of naturally occurring organic matter (AWWA, 1971). Sources of organic material include human materials from the soil such as tannins, human acid and humates; decaying plankton; and other decaying aquatic plants. Industrial discharges may contribute similar compounds: for example, those from the pulp and paper and tanning industries. Other industrial discharges may contain brightly colored substances such as those from certain processes in textile and chemical industries.

Surface waters may appear colored because of suspended matter which comprises turbidity. Such color is referred to as apparent color and is differentiated from true color caused by colloidal human materials (Sawyer, 1960). Natural color is reported in

color "units" which generally are determined by use of the platinum-cobalt method (Standard Methods, 1971).

There is no general agreement as to the chemical composition of natural color, and in fact the composition may vary chemically from place to place (AWWA, 1971). Black and Christman (1963a) characterized color-causing colloids examined as aromatic, polyhydroxy, methoxy carboxylic acids. Shapiro (1964) characterized color-causing constituents as being dialyzable and composed of aliphatic, polyhydroxyl carboxylic acids with molecular weights varying from less than 200 to approximately 400. The colloidal fraction of color exists in the 3.5 to 10 mu diameter range (Black and Christman, 1963b). These same authors summarized other characteristics of color observed in laboratory studies of natural waters: color is caused by light scattering and fluorescence rather than absorption of light energy, and pH affects both particle size of the color-causing colloids and the intensity of color itself.

RATIONALE:

Color in water is an important constituent in terms of aesthetic considerations. To be aesthetically pleasing, water should be virtually free from substances introduced by man's activities which produce objectionable color. "Objectionable color" is defined to be a significant increase over natural background levels. Non-natural colors such as dyes should not be perceptible by the human eye as such colors are especially objectionable to those who receive pleasure by viewing water in its natural state. Because of the extreme variations in the

natural background amount of color, it is meaningless to attempt numerical limits. The aesthetic attributes of water depend on one's appreciation of the water setting.

The effects of color on public water supplies also are principally aesthetic. The 1962 Drinking Water Standards (PHS, 1962) recommended that color in finished waters should not exceed 15 units on the platinum-cobalt scale. Water consistently can be treated using standard coagulation, sedimentation and filtration processes to reduce color to substantially less than 15 color units when the source water does not exceed 75 color units AWWA, 1971; NAS, 1974).

The effects of color in water on aquatic life principally are to reduce light penetration and thereby generally reduce photosynthesis by phytoplankton and to restrict the zone for aquatic vascular plant growth.

The light supply necessary to support plant life is dependent on both intensity and effective wave lengths (Welch, 1952). In general, the rate of photosynthesis increases with the intensity of the incident light. Photosynthetic rates are most affected in the red region and least affected in the blue-violet region of incident light (Welch, 1952). It has been found that in colored waters the red spectrum is not a region of high absorption so that the effective penetration, and therefore the intensity for photosynthesis, is not as restricted as are other wave lengths. It should be emphasized that transmission of all parts of the spectrum is affected by color, but the greatest effect is on the standard or blue end of the spectrum (Birge and Juday, 1930). In

TABLE 2.

Maximum color of surface waters that have been used as sources for industrial water supplies.

Industry or Industrial Use	Color units
Boiler make up	1,200
Cooling water	1,200
Pulp and paper	360
Chemical and allied products	500
Petroleum	25

highly colored waters (45 to 132 color units) Birge and Juday (1930) measured the light transmission as a percentage of the incident level and found very little blue, 50 percent or less yellow, and 100 to 120 percent red.

The light intensity required for some aquatic vascular plants to photosynthetically balance the oxygen used in respiration may be 5 percent of full sunlight during maximum summer illumination periods (NTAC, 1968). As much as 10 percent of the incident light may be required for plankton to likewise photosynthetically produce sufficient oxygen to balance their respiration requirements (NTAC, 1968). The depth at which such a compensation point is reached, calledthe compensation depth, delineates the zone of effective photosynthetic oxygen production. To maintain satisfactory biological conditions, this depth cannot be substantially reduced.

Industrial requirements as related to water color have been standardized (NAS, 1974). Table 2 lists the maximum value used as a source of water for various industries and industrial uses. Through treatment, such waters can be made to meet almost any industrial requirement.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

*COPPER

AQUATIC LIFE SUMMARY:

Acute toxicity data are available for species in 41 genera of freshwater animals. At a hardness of 50 mg/L the genera range in sensitivity from 16.74 ug/L for Ptychocheilus to 10,240 ug/L for Acroneuria. Data for eight species indicate that acute toxicity decreases as hardness increases. Additional data for several species indicate that toxicity also decreases with increases in alkalinity and total organic carbon.

Chronic values are available for 15 freshwater species and range from 3.873 ug/L for brook trout to 60.36 ug/L for northern pike. Fish and invertebrate species seem to be about equally sensitive to the chronic toxicity of copper.

Toxicity tests have been conducted on copper with a wide range of freshwater plants and the sensitivities are similar to those of animals. Complexing effects of the test media and a lack of good analytical data make interpretation and application of these results difficult. Protection of animal species, however, appears to offer adequate protection of plants. Copper does not appear to bioconcentrate very much in the edible portion of freshwater aquatic species.

The acute sensitivities of saltwater animals to copper range from 5.8 ug/L for the blue mussel to 600 ug/L for the green crab. A chronic life-cycle test has been conducted with a mysid, and adverse effects were observed at 77 ug/L but not at 38 ug/L, which resulted in an acute-chronic ratio of 3.346. Several

*Indicates suspended, canceled or restricted by U.S.EPA Office of Pesticides and Toxic Substances

saltwater algal species have been tested, and effects were observed between 5 and 100 ug/L. Oysters can bioaccumulate copper up to 28,200 times, and become bluish-green, apparently without significant mortality. In long-term exposures, the bay scallop was killed at 5 ug/L.

NATIONAL CRITERIA:

The procedures described in the Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Uses indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration (in ug/L) of copper does not exceed the numerical value given by $e^{(0.8545[\ln(\text{hardness})]-1.465)}$ more than once every 3 years on the average and if the 1-hour average concentration (in ug/L) does not exceed the numerical value given by $e^{(0.9422[\ln(\text{hardness})]-1.464)}$ more than once every 3 years on the average. For example, at hardnesses of 50, 100, and 200 mg/L as $CaCO_3$ the 4-day average concentrations of copper are 6.5, 12, and 21 ug/L, respectively, and the 1-hour average concentrations are 9.2, 18, and 34 ug/L.

The procedures described in the Guidelines indicate that, except possibly where a locally important species is very sensitive, saltwater aquatic organisms and their uses should not be affected unacceptably if the 1-hour average concentration of copper does not exceed 2.9 ug/L more than once every 3 years on the average.

EPA believes that a measurement such as "acid-soluble" would

provide a more scientifically correct basis upon which to establish criteria for metals. The criteria were developed on this basis. However, at this time, no EPA approved methods for such a measurement are available to implement the criteria through the regulatory programs of the Agency and the States. The Agency is considering development and approval of methods for a measurement such as acid-soluble. Until available, however, EPA recommends applying the criteria using the total recoverable method. This has two impacts: (1) certain species of some metals cannot be analyzed directly because the total recoverable method does not distinguish between individual oxidation states, and (2) these criteria may be overly protective when based on the total recoverable method.

The recommended exceedence frequency of 3 years is the Agency's best scientific judgment of the average amount of time it will take an unstressed system to recover from a pollution event in which exposure to copper exceeds the criterion. A stressed system, for example, one in which several outfalls occur in a limited area, would be expected to require more time for recovery. The resilience of ecosystems and their ability to recover differ greatly, however, and site-specific criteria may be established if adequate justification is provided.

The use of criteria in developing waste treatment facilities requires the selection of an appropriate wasteload allocation model. Dynamic models are preferred for the application of these criteria. Limited data or other factors may make their use impractical, in which case one should rely on a steady-state model. The Agency recommends the interim use of 1Q5 or 1Q10 for

Criterion Maximum Concentration design flow and 7Q5 or 7Q10 for the Criterion Continuous Concentration (CCC) design flow in steady-state models for unstressed and stressed systems respectively. These matters are discussed in more detail in the Technical Support Document for Water Quality-Based Toxics Control (U.S. EPA, 1985).

HUMAN HEALTH CRITERIA:

Sufficient data is not available for copper to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 1 mg/L. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

(45 F.R. 79318 Nov. 28,1980) (50 F.R. 30784, July 29, 1985)
SEE APPENDIX A FOR METHODOLOGY

CYANIDE

AQUATIC LIFE SUMMARY:

Data on the acute toxicity of free cyanide (the sum of cyanide present as HCN and CN-, expressed as CN) are available for a wide variety of freshwater species that are involved in diverse community functions. The acute sensitivities ranged from 44.73 ug/L to 2,490 ug/L, but all of the species with acute sensitivities above 400 ug/L were invertebrates. A long-term survival, and a partial and life-cycle test with fish gave chronic values of 13.57, 7.849, and 16.39 ug/L, respectively. Chronic values for two freshwater invertebrate species were 18.33 and 34.06 ug/L. Freshwater plants were affected at cyanide concentrations ranging from 30 ug/L to 26,000 ug/L.

The acute toxicity of free cyanide to saltwater species ranged from 4.893 ug/L to >10,000 ug/L and invertebrates were both the most and least sensitive species. Long-term survival in an early life-stage test with the sheepshead minnow gave a chronic value of 36.12 ug/L. Long-term survival in a mysid life-cycle test resulted in a chronic value of 69.71 ug/L. Tests with the red macroalga, Champia parvula, showed cyanide toxicity at 11 to 25 ug/L, but other species were affected at concentrations up to 3,000 ug/L.

NATIONAL CRITERIA:

The procedures described in the Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected

unacceptably if the 4-day average concentration of cyanide does not exceed 5.2 ug/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 22 ug/L more than once every 3 years on the average.

The procedures described in the Guidelines indicate that, except possibly where a locally important species is very sensitive, saltwater aquatic organisms and their uses should not be affected unacceptably if the 1-hour average concentration of cyanide does not exceed 1.0 ug/L more than once every 3 years on the average.

EPA believes that a measurement such as "acid soluble" would provide a more scientifically correct basis upon which to establish criteria for cyanide. The criteria were developed on this basis. However, at this time, no EPA-approved methods for such a measurement are available to implement the criteria through the regulatory programs of the Agency and the States.

The Agency is considering development and approval of methods for a measurement such as acid soluble. Until available, however, EPA recommends applying the criteria using the total recoverable method. These criteria may be overly protective when based on the total recoverable method.

The recommended exceedence frequency of 3 years is the Agency's best scientific judgment of the average amount of time it will take an unstressed system to recover from a pollution event in which exposure to cyanide exceeds the criterion. A stressed system, for example, one in which several outfalls occur in a limited area, would be expected to require more time for recovery. The resilience of ecosystems and their ability to

recover differ greatly, however, and site-specific criteria may be established if adequate justification is provided.

The use of criteria in designing waste treatment facilities requires the selection of an appropriate wasteload allocation model. Dynamic models are preferred for the application of these criteria. Limited data or other factors may make their use impractical, in which case one should rely on a steady-state model. The Agency recommends the interim use of 1Q5 or 1Q10 for Criterion Maximum Concentration design flow and 7Q5 or 7Q10 for the Criterion Continuous Concentration design flow in steady-state models for unstressed and stressed systems respectively. These matters are discussed in more detail in the Technical Support Document for Water Quality-Based Toxics Control (U.S. EPA, 1985).

HUMAN HEALTH CRITERIA

The ambient water quality criterion for cyanide is recommended to be identical to the existing drinking water standard which is 200 ug/L. Analysis of the toxic effects data resulted in a calculated level which is protective of human health against the ingestion of contaminated water and contaminated aquatic organisms. The calculated value is comparable to the present standard. For this reason a selective criterion based on exposure solely from consumption of 6.5 grams of aquatic organisms was not derived.

NOTE: The U.S. EPA is currently developing Acceptable Daily Intake (ADI) or Verified Reference Dose (RfD) values for Agency-wide use for this chemical. The new value should be substituted when it becomes available. The January, 1986, draft Verified Reference Dose document cites an RfD of .02 mg/kg/day for free cyanide.

DDT AND METABOLITES

CRITERIA:

Aquatic Life

DDT

For DDT and its metabolites the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.0010 ug/L as a 24-hour average and the concentration should not exceed 1.1 ug/L at any time.

For DDT and its metabolites the criterion to protect saltwater aquatic life as derived using the Guidelines is 0.0010 ug/L as a 24-hour average and the concentration should not exceed 0.13 ug/L at any time.

TDE

The available data for TDE indicate that acute toxicity to freswater aquatic life occurs at concentrations as low as 0.6 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of TDE to sensitive freshwater aquatic life.

The available data for TDE indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 3.6 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of TDE to sensitive saltwater aquatic life.

DDE

The available data for DDE indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as

1,050 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of DDE to sensitive freshwater aquatic life.

The available data for DDE indicate that acute toxicity to saltwater aquatic life occurs in concentrations as low as 14 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of DDE to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to DDT through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6} and 10^{-7}. The corresponding recommended criteria are 0.24 ng/L, 0.024 ng/L, and 0.0024 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 0.24 ng/L, 0.024 ng/L, and 0.0024 ng/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

DEMETON

CRITERION:

0.1 ug/L for freshwater and marine aquatic life

RATIONALE:

Static LC50 bioassays yielded toxicity values for the organophosphorus pesticide demeton for carp, goldfish, fathead minnow, channel catfish, guppy, rainbow, trout and bluegill, ranging from 70 ug/L to 15,000 ug/L (Henderson and Pickering, 1958; Ludemann and Neumann, 1982; Macek and McAllister, 1970; McCann and Jasper, 1972; Pickering et al. 1962). Results of these tests demonstrate an apparent sharp division in species sensitivity, with bluegill (Lepomis macrochirus), rainbow trout (Salmo gairdneri) and guppy, (Poecilia reticulata), being susceptible to lower concentrations while the remaining species were comparatively resistant. In the 96-hour exposures toxicity did not increase significantly with time, indicating that concentrations close to nominal may not have been maintained for more than a few hours. Bluegills with a 24-hour LC50 of 70 ug/L were the most sensitive fish (McCann and Jasper, 1972).

When fish were exposed to acutely toxic levels of demeton for 12 hours by Weiss (1959, 1961) the maximum inhibition of brain acetiylcholinesterase (AChE) was not reached. The lowest levels of AChE occurred after 24 to 48 hours. It was demonstrated that maximum inhibition could last as long as two weeks after exposure, and subsequent recovery to levels approaching normal took many more weeks. Weiss (1958) reported a significant increase in mortality of fathead minnows exposed for a second

time to the organophosphate, Sarin, before the fish had recovered normal brain AChE levels. The resistance of fully recovered fish was equal to that of previously unexposed controls. Weiss and Gakstatter (1964a) reported no significant inhibition of brain AChE in bluegills, goldfish and shiners (Notemigonus crysoleucas), following 15-day exposures to demeton at continuously replenished, nominal concentrations of 1 ug/L.

Acute toxicity values reported for invertebrates range from 10 to 100,000 ug/L (Ludemann and Neumann, 1962; Sanders, 1972). In general, molluscs and tubifex worms were very resistant while the smaller crustaceans and insect larvae were susceptible. Ludemann and Neumann (1962) reported that Chironomus plumosus larvae were the most sensitive species they tested. A 24-hour exposure at 10 ug/L produced undefined effects while 100 percent were killed at 1000 ug/L. Calculated LC50 data for invertebrates apparently are limited to a single, nominal concentration static exposure of Gammarus fasciatus (Sanders, 1972). These 24- and 96-hour LC50 values are reported as 500 and 27 ug/L, indicating a time-related effect not observed in the bioassays with fishes. As only a few of the sensitive species have been tested and great variance in response can result with different test methods, caution must be exercised in estimating the sub-acute concentration for aquatic fauna in general. It appears that no study has been made of possible residual effects other than AChE inhibition, which might result from short exposures to subacute concentrations of organophosphates.

There are few data on the toxicity of demeton to marine organisms. Butler (1964) reported a 48-hour EC50 of 63 ug/L for

the pink shrimp, Peneaus duorarum, and a 24-hour LC50 of 550 ug/L for the spot, Leiostomus xanthurus.

Chronic demeton toxicity data for freshwater organism are not currently available. Since no data are available at this time to indicate long-term no-effect levels for aquatic organisms, a criterion must be derived based partly on the fact that all organophosphates inhibit the production of the AChE enzyme. Demeton is unique, however, in that the persistence of its AChE-inhibiting ability is greater than that of 10 other common organophosphates, even though its acute toxicity is apparently less. The effective "half-life" of AChE inhibition for demeton is greater than one year (Weiss and Gakstatter, 1964b). Because such inhibition may be additive with repeated exposures and may be compounded by any of the organophosphates, it is recommended that a criterion for demeton be based primarily on its enzyme-inhibiting potential. A criterion of 0.1 ug/L demeton for freshwater and marine aquatic life is recommended since it will not be expected to significantly inhibit AChE over a prolonged period of time. In addition, the criteria recommendation is in close agreement with the criteria for the other organophosphates.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

DICHLOROBENZENES

CRITERIA:

Aquatic Life

The available data for dichlorobenzenes indicate that acute and chronic toxicity to freshwater aquatic life occur at concentrations as low as 1,120 and 763 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

The available data for dichlorobenzenes indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 1,970 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of dichlorobenzenes to sensitive saltwater aquatic life.

Human Health

For the protection of human health from the toxic properties of dichlorobenzene ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 400 ug/L.

For the protection of human health from the toxic properties of dichlorobenzenes ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 2.6 mg/L.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

DICHLOROBENZIDINE

CRITERIA:

Aquatic Life

The data base available for dichlorobenzidines and freshwater organisms is limited to one test on bioconcentration of 3,3-dichlorobenzidine, and therefore, no statement can be made concerning acute or chronic toxicity.

No saltwater organisms have been tested with any dichlorobenzidine, and therefore, no statement can be made concerning acute or chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to dichlorobenzidine through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 0.103 ug/L, 0.010 ug/L, and 0.001 ug/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 0.204 ug/L, 0.020 ug/L, and 0.002 ug/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

DICHLOROETHYLENES

CRITERIA:

Aquatic Life

The available data for dichloroethylenes indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 11,600 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No definitive data are available concerning the chronic toxicity of dichloroethylenes to sensitive freshwater aquatic life.

The available data for dichloroethylenes indicate that acute and chronic toxicity to saltwater aquatic life occurs at concentrations as low as 224,000 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of dichloroethylenes to sensitive saltwater aquatic life.

Human Health

1,1-Dichloroethylene

For the maximum protection of human health from the potential carcinogenic effects of exposure to 1,1 dichloroethylene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the non threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 0.33 ug/L, 0.033 ug/L, and 0.003 ug/L, respectively. If

these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 18.5 ug/L, 1.85 ug/L, and 0.185 ug/L, respectively.

1,2-Dichloroethylene

Using the present guidelines, a satisfactory criterion cannot be derived at this time because of insufficient available data for 1,2-dichloroethylene.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

2,4-DICHLOROPHENOL

CRITERIA:

Aquatic Life

The available data for 2,4-dichlorophenol indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 2,020 and 365 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested. Mortality to early life stages of one species of fish occurs at concentrations as low as 70 ug/L.

Only one test has been conducted with saltwater organisms and 2,4-dichlorophenol and therefore, no statement can be made concerning acute or chronic toxicity.

Human Health

For comparison purposes, two approaches were used to derive criterion levels for 2,4-dichlorophenol. Based on available toxicity data, to protect public health the derived level is 3.09 mg/L. Using available organoleptic data, to control undesirable taste and odor qualities of ambient water the estimated level is 0.3 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have no demonstrated relationship to potential adverse human health effects.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

DICHLOROPROPANES/DICHLOROPROPENES

CRITERIA:

Aquatic Life

The available data for dichloropropanes indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 23,000 and 5,700 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

The available data for dichloropropene indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 6,060 and 244 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

The available data for dichloropropane indicate that acute and chronic toxicity to saltwater aquatic life occur at concentrations as low as 10,300 and 3,040 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

The available data for dichloropropene indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 790 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of dichloropropene to sensitive saltwater aquatic life.

Human Health

Using the present guidelines, a satisfactory criterion cannot be derived at this time because of insufficient available data for dichloropropanes.

For the protection of human health from the toxic properties of dichloropropenes ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 87 ug/L.

For the protection of human health from the toxic properties of dichloropropenes ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 14.1 mg/L.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

2,4-DIMETHYLPHENOL

CRITERIA

Aquatic Life

The available data for 2,4-dimethylphenol indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 2,120 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of dimethylphenol to sensitive freshwater aquatic life.

No saltwater organisms have been tested with 2,4-dimethyl-phenol and therefore, no statement can be made concerning acute or chronic toxicity.

Human Health

Sufficient data are not available for 2,4-dimethylphenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, to control undesirable taste and odor quality of ambient water the estimated level is 400 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have no demonstrated relationship to potential adverse human health effects.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

DINITROTOLUENE

CRITERIA:

Aquatic Life

The available data for dinitrotoluenes indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 330 and 230 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

The available data for dinitrotoluenes indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 590 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of dinitrotoluenes to sensitive saltwater aquatic life but a decrease in algal cell numbers occurs at concentrations as low as 370 ug/L.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to 2,4-dinitrotoluene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6} and 10^{-7}. The corresponding recommended criteria are 1.1 ug/L, 0.11 ug/L, and 0.011 ug/L, respectively. If these estimates are made for consumption of aquatic organ-isms only, excluding consumption

of water, the levels are 91 ug/L, 9.1 ug/L, and 0.91 ug/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

DIPHENYLHYDRAZINE

CRITERIA:

Aquatic Life

The available data for 1,2-diphenylhydrazine indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 270 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of 1,2-diphenylhydrazine to sensitive freshwater aquatic life.

No saltwater organisms have been tested with 1,2-diphenylhydrazine and therefore, no statement can be made concerning acute or chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to diphenylhydrazine through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 422 ng/L, 42 ng/L, and 4 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 5.6 ug/L, 0.56 ug/L, and 0.056 ug/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

ENDOSULFAN

CRITERIA:

Aquatic Life

For endosulfan the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.056 ug/L as a 24-hour average and the concentration should not exceed 0.22 ug/L at any time.

For endosulfan the criterion to protect saltwater aquatic life as derived using the Guidelines is 0.0087 ug/L as a 24-hour average and the concentration should not exceed 0.034 ug/L at any time.

Human Health

For the protection of human health from the toxic properties of endosulfan ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 74 ug/L.

For the protection of human health from the toxic properties of endosulfan ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 159 ug/L.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

*ENDRIN

CRITERIA:

Aquatic Life

For endrin the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.0023 ug/L as a 24-hour average, and the concentration should not exceed 0.18 ug/L at any time.

For endrin the criterion to protect saltwater aquatic life as derived using the Guidelines is 0.0023 ug/L as a 24-hour average, and the concentration should not exceed 0.037 ug/L at any time.

Human Health

The ambient water quality criterion for endrin is recommended to be identical to the existing water standard which is 1.0 ug/L. Analysis of the toxic effects data resulted in a calculated level which is protective of human health against the ingestion of contaminated water and contaminated aquatic organisms. The calculated value is comparable to the present standard. For this reason a selective criterion based on exposure solely from consumption of 6.5 g of aquatic organisms was not derived.

*Indicates suspended, canceled or restricted by U.S. EPA Office of Pesticides and Toxic Substances

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

ETHYLBENZENE

CRITERIA:

Aquatic Life

The available data for ethylbenzene indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 32,000 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No definitive data are available concerning the chronic toxicity of ethylbenzene to sensitive freshwater aquatic life.

The available data for ethylbenzene indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 430 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of ethylbenzene to sensitive saltwater aquatic life.

Human Health

For the protection of human health from the toxic properties of ethylbenzene ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 1.4 mg/L.

For the protection of human health from the toxic properties of ethylbenzene ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 3.28 mg/L.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

NOTE: The U.S. EPA is currently developing Acceptable Daily Intake (ADI) or Verified Reference Dose (RfD) values for Agency-wide use for this chemical. The new value should be substituted when it becomes available. The January, 1986, draft Verified Reference Dose document cites an RfD of 0.1 mg/kg/day for ethylbenzene.

FLUORANTHENE

CRITERIA:

Aquatic Life

The available data for fluoranthene indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 3,980 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of fluoranthene to sensitive freshwater aquatic life.

The available data for fluoranthene indicate that acute and chronic toxicity to saltwater aquatic life occur at concentrations as low as 40 and 16 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Human Health

For the protection of human health from the toxic properties of fluoranthene ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 42 ug/L.

For the protection of human health from the toxic properties of fluoranthene ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 54 ug/L.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

GASES, TOTAL DISSOLVED

CRITERION:

To protect freshwater and marine aquatic life, the total dissolved gas concentrations in water should not exceed 110 percent of the saturation value for gases at the existing atmospheric and hydrostatic pressures.

RATIONALE:

Fish in water containing excessive dissolved gas pressure or tension are killed when dissolved gases in their circulatory system come out of solution to form bubbles (emboli) which block the flow of blood through the capillary vessels. In aquatic organisms this is commonly referred to as "gas bubble disease". External bubbles (emphysema) also appear in the fins, on the opercula, in the skin and in other body tissues. Aquatic invertebrates are also affected by gas bubble disease, but usually at supersaturation levels higher than those lethal to fish.

The standard method of analyzing for gases in solutions has been the Van Slyke method (Van Slyke et al. 1934); now, gas chromatography also is used for determination of individual and total gases. For determination of total gas pressure, Weiss has developed the saturometer, a device based upon a thin-wall silicone rubber tube that is permeable to gases but impermeable to water. Gases pass from the water through the tube, thus raising the internal gas pressure which is measured by a

manometer or pressure gauge connected to the tube (NAS, 1974). This method alone does not separate the total gas pressure into the separate components, but Winkler oxygen determinations can be run simultaneously, and gas concentrations can be calculated.

Total dissolved gas concentrations must be determined because analysis of individual gases may not determine with certainty that gas supersaturation exists. For example, water could be highly supersaturated with oxygen, but if nitrogen were at less than saturation, the saturation as measured by total gas pressure might not exceed 100 percent. Also, if the water was highly supersaturated with dissolved oxygen, the oxygen alone might be sufficient to create gas pressures or tensions greater than the criterion limits, but one would not know the total gas pressure or tension, or by how much the criterion was exceeded. The rare and inert gases such as argon, neon and helium are not usually involved in causing gas bubble disease as their contribution to total gas pressures is very low. Dissolved nitrogen (N_2), which comprises roughly 80 percent of the earth's atmosphere, is nearly inert biologically and is the most significant cause of gas bubble disease in aquatic animals. Dissolved oxygen, which is extremely bioactive, is consumed by the metabolic processes of the organism and is less important in causing serious gas bubble disease though it may be involved in initiating emboli formation in the blood (Nebeker et al. 1976a).

Percent saturation of water containing a given amount of gas varies with the absolute temperature and with the pressure. Because of the pressure changes, percent saturation with a given

amount of gas changes with depth of the water. Gas supersaturation decreases by 10 percent per meter of increase in water depth because of hydrostatic pressure; a gas that is at 130 percent saturation at the surface would be at 100 percent saturation at 3 meters' depth. Compensation for altitude may be needed because a reduction in atmospheric pressure changes the water/gas equilibria, resulting in changes in solubility of dissolved gases.

There are several ways that total dissolved gas supersaturation can occur:

1. Excessive biological activity--dissolved oxygen concentrations often reach supersaturation because of excessive algal photosynthesis. Renfro (1963) reported gas bubble disease in fishes resulting, in part, from algal blooms. Algal blooms often accompany an increase in water temperature and this higher temperature further contributes to supersaturation.

2. Lindroff (1957) reported that water spillage at hydropower dams caused supersaturation. When excess water is spilled over the face of a dam it entrains air as it plunges to the stilling or plunge pool at the base of the dam. The momentum of the fall carries the water and entrained gases to great depths in the pool; and, under increased hydrostatic pressure, the entrained gases are driven into solution, causing supersaturation of dissolved gases.

3. Gas bubble disease may be induced by discharges from power-generating and other thermal sources (Marcello et al. 1975). Cool, gas-saturated water is heated as it passes through the condenser or heat exchanger. As the temperature of the water

rises, percent saturation increases because of the reduced solubility of gases at higher temperatures. Thus, the discharged water becomes supersaturated with gases and fish or other organisms living in the heated water may exhibit gas bubble disease (DeMont and Miller, 1972: Malouf et al. 1972; Keup, 1975).

In recent years, gas bubble disease has been identified as a major problem affecting valuable stocks of salmon and trout in the Columbia River system (Rulifson and Abel, 1971). The disease is caused by high concentrations of dissolved atmospheric gas which enter the river's water during heavy spilling at hydroelectric dams. A report by Ebel et al. (1975) presents results from field and laboratory studies on the lethal, sublethal and physiological effects of gas on fish, depth distribution of fish in the river (fish can compensate for some high concentrations of gas by moving deeper into the water column), detection and avoidance of gas concentrations by fish, intermittent exposure of fish to gas concentrations, and bioassays of many species of fish exposed to different concentrations of gas. Several conclusions resulting from these studies are:

1. When either juvenile or adult salmonids are confined to shallow water (1 m), substantial mortality occurs at and above 115 percent total dissolved gas saturation.

2. When either juvenile or adult salmonids are free to sound and obtain hydrostatic compensation either in the laboratory or in the field, substantial mortality still occurs when saturation

levels (of total dissolved gases) exceed 120 percent saturation.

3. On the basis of survival estimates made in the Snake River from 1966 to 1975, it is concluded that juvenile fish losses ranging from 40 to 95 percent do occur and a major portion of this mortality can be attributed to fish exposure to supersaturation by atmospheric gases during years of high flow.

4. Juvenile salmonids subjected to sublethal periods of exposure to supersaturation can recover when returned to normally saturated water, but adults do not recover and generally die from direct and indirect effects of the exposure.

5. Some species of salmon and trout can detect and avoid supersaturated water; others may not.

6. Higher survival was observed during periods of intermittent exposure than during continuous exposure.

7. In general, in acute bioassays, salmon and trout were less tolerant than the nonsalmonids.

Dawley and Ebel (1975) found that exposure of juvenile spring chinook salmon, Oncorhynchus tshawytscha, and steelhead trout, Salmo gairdneri, to 120 percent saturation for 1.5 days resulted in over 50 percent mortality; 100 percent mortality occurred in less than 3 days. They also determined that the threshold level where significant mortalities begin occurring is at 115 percent nitrogen saturation (111 percent total gas saturation in this test).

Rucker (1974), using juvenile coho salmon, Oncorhynchus kisutch, determined the effect of individual ratios of oxygen and nitrogen and established that a decrease in lethal effect occurred when the nitrogen content fell below 109 percent

saturation even though total gas saturation remained at 119 percent saturation, indicating the importance of determining the concentration of the individual components (O_2 and N_2) of the atmospheric supersaturation. Nebeker et al. (1976a), using juvenile sockeye salmon, Oncorhynchus nerka, also showed that there was a significant increase in fish mortality when the nitrogen concentration was increased while holding the total percent saturation constant. They also showed that there was no significant difference in fish mortality at different CO_2 concentrations.

Research collected by Bouck et al. (1975) showed that gas supersaturated water at and above 115 percent total gas saturation is acutely lethal to most species of salmonids, with 120 percent saturation and above rapidly lethal to all salmonids tested. Levels as low as 110 percent will produce emphysema in most species. Steelhead trout were most sensitive to gas-supersaturated water followed by sockeye salmon, Oncorhyncnus nerka. Chinook salmon, Oncorhynchus tshawytscha, were intermediate in sensitivity. Coho salmon, Oncorhyncnus kisutch, were significantly the more tolerant of the salmonids though still much more susceptible than non-salmonids like bass or carp.

Dapnnia magna exhibited a sensitivity to supersaturation similar to that of the salmonids (Nebeker et al. 1975), with 115 percent saturation lethal within a few days. Stoneflies exhibited an intermediate sensitivity similar to bass with mortality at 130 percent saturation. Crayfish were very tolerant, with levels near 140 percent total gas saturation resulting in mortality.

No differences are proposed in the criteria for freshwater and marine aquatic life as the data available indicate that there probably is little difference in overall tolerances between marine and freshwater species.

The development of gas bubble disease in menhaden, Brevoortia sp., and their tolerance to gas saturation in laboratory bioassays and in the field (Pilgrim Nuclear Power Station Discharge Canal) are discussed by Clay et al. (1975) and Marcello et al. (1975). At 100 percent and 105 percent nitrogen saturation, no gas bubbles developed externally or in any of the internal organs of menhaden. At 105 percent nitrogen saturation, however, certain behavioral changes became apparent. Fish sloughed off mucus, swam erratically, were more excitable, and became darker in color. Menhaden behavioral changes observed at 110 percent nitrogen saturation were similar to those noted at 105 percent. In addition, at 110 percent gas emboli were found in the intestines, the pyloric caeca, and occasionally the operculum. The behavioral changes described were also observed at 115 percent, and clearly defined subcutaneous emphysema was observed in the fins and occasionally in the eye. At 120 percent and 130 percent nitrogen saturation, menhaden developed within a few hours classic symptoms of gas bubble disease. Externally, emboli were evident in all fins, the operculum and within the oral cavity.

Exophthalmia also occurred and emboli developed in internal organs. The bulbous arteriosis and swim bladder were severely distended, and emboli were found along the length of the gill arterioles, resulting in hemostasis. At water temperatures of 30

°C, menhaden did not survive, regardless of gas saturation level. At water temperatures of 15 , 22 , and 25 °C 100 percent of the menhaden died within 24 hours at 120 percent and 130 percent gas saturation. Fifty percent died after 96 hours at 115 percent (22 °C) Menhaden survival after 96 hours at 110 percent nitrogen saturation ranged from 92 percent at 22° and 25° to 83 percent at 15 °C. Observations on the relationship between the mortality rate of menhaden and gas saturation levels at Pilgrim Station during the April 1975, incident suggest that the fish may tolerate somewhat higher gas saturation levels in nature.

It has been shown by Bouck et al. (1975) and Dawley et al. (1975) that survival of salmon and steelhead smolts in seawater is not affected by prior exposure to gas supersaturation while in fresh water. No significant mortality of juvenile coho and sockeye salmon occurred when they were exposed to sublethal concentrations of supersaturated water and then transferred to seawater (Nebeker et al. 1976b).

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

GUTHION

CRITERION:

.01 ug/L for freshwater and marine aquatic life.

RATIONALE:

Ninety-six-hour LC50 values for fish exposed to the organophosphorus pesticide guthion range from 4 to 4270 ug/L (Katz, 1961; Pickering et al. 1962; Lahav and Sarig, 1969; Macek et al. 1969; Macek and McAllister, 1970). The only long-term fish exposure data available are those obtained recently by Adelman and Smith (unpublished data). Decreased spawning (eggs produced per female) was observed in fathead minnows, Pimephales promelas, exposed during a complete life cycle. An estimated "safe" long-term exposure concentration for fathead minnows lies between 0.3 and 0.5 ug/L. Survival of larvae was reduced at approximately 0.7 ug/L.

An investigation of the persistence of guthion in fish revealed that 50 percent of the chemical was lost in less than one week (Meyer, 1965). Analysis of plankton and pond water in the same study indicated a 50 percent loss of guthion in about 48 hours. Flint et al. (1970) determined the half-life of guthion at 30C in pond water and in a phosphate buffer protected from light in the laboratory. The half-life in pond water was 1.2 days whereas that in the laboratory solution was 10 days. The more rapid degradation in pond water was attributed to the effect of sunlight and microorganisms.

Organophosphate pesticides are toxic because they inhibit the

enzyme acetylcholinesterase (AChE) which is essential to nerve impulse conduction and transmission (Holland et al. 1967). Weiss (1958, 1959, 1961) demonstrated that a 40 to 70 percent inhibition of fish brain AChE usually is lethal. Centrarchids generally are considered one of the more sensitive groups of fish to guthion (Pickering et al. 1962; Weiss and Gakstatter, 1964; Meyer, 1965). Weiss and Gakskatter (1964) found that over a 15-day period bluegills, Lepomis macrochirus, exhibited AChE inhibition at 1.0 ug/L guthion but not at 0.1 ug/L. Exposure at 0.05 ug/L for 30 days also failed to produce inhibition below the range of normal variation, but the authors stated that it appeared there was a downward trend in brain enzyme activity and that if exposure was continued a definite reduction might develop. Weiss (1961) found that about 30 days were required for fathead minnow and bluegill brain AChE levels to recover after 8 to 24 hours exposure to 10 ug/L guthion.

Benke and Murphy (1974) showed that repetitive injection of fish with guthion caused cumulative inhibition of brain AChE and mortality. After substantial inhibition by guthion exposure, it takes several weeks for brain AChE of fishes to return to normal even though exposure is discontinued (Weiss, 1959, 1960; Carter, 1971). Inhibition of brain AChE of fishes by 46 percent or more has been associated with harmful effects in exposures to there organophosphate pesticides for a life cycle (Eaton, 1970) and for shorter periods (Carter, 1971; Coppage and Duke, 1971; Coppage, 1972; Coppage and Matthews, 1974; Post and Leasure, 1974; Coppage et al. in press). In static tests, similar inhibition of AChE and mortality were caused in the sheepshead minnow, Cyprinodon

variegatus, in 2, 24, 48 and 72 hours at concentrations of 50, 7, 3.5 and 3 ug/L, respectively (Coppage, 1972). These data indicate that reduction of brain AChE activity of marine fishes by 70 to 80 percent or more in short-term exposures to guthion may be associated with some deaths.

There is no evidence to indicate that guthion would cause adverse effects through the food chain. Tissue residue accumulation for whole fish calculated from the data of Meyer (1965) indicate no more than a twentyfold accumulation. LC50 toxicity values for birds are relatively high and range from 70 to 2,000 mg/kg (Tucker and Crabtree, 1970).

Ninety-six-hour LC50 values for aquatic invertebrates range from 0.10 to 22.0 ug/L (Nebeker and Gaufin, 1964; Gaufin et al. 1965: Jensen and Gaufin, 1966: Sanders and Cope, 1968; Sanders, 1969, 1972). Sanders (1972) exposed the grass shrimp, Paleomonetes kadiakensis, to guthion in a continuous flow bioassay for up to 20 days and found that the 5- and 20-day LC50 values were 1.2 and 0.16 ug/L, respectively. He found that the amphipod, Gammarus fasciatus, was the most sensitive aquatic organism tested, with a 96-hour LC50 of 0.10 ug/L. Jensen and Gaufin (1966), also using a continuous flow system, exposed two species of stonefly naiads in 4- and 30-day studies. They observed 96-hour and 30-day LC50 values for Acroneuria pacifica of 2.0 and 0.24 ug/L, respectively, whereas for Pteronarcys californica the values were 4.6 and 1.3 ug/L, respectively.

Results of other toxicity studies on marine organisms have been reported. The 24-hour LC50 for the white mullet, Mugil

curema, was found to be 5.5 ug/L guthion (Butler, 1963). The 96-hour LC50 for the striped mullet, Mugil cephalus, was determined by Lahav and Sarig (1969) to be 8 ug/L guthion. Portman (1972) reported the 48-hour LC50 for the fish, Pleuronectes limanda, to be 10 to 30 ug/L. The 48-hour LC50 for the European shrimp, Crangon crangon, was found to be 0.33 ug/L guthion (Portman, 1972). Butler (1963) found that the 24-hour EC50 for blue crab, Callinectes sapidus, was 550 ug/L and the 48-hour EC50 for pink shrimp, Penaeus duorarum, was 4.4 ug/L guthion. The 48-hour TLm was estimated to be 620 ug/L for fertilized oyster eggs, Crassostrea virginica, and 860 ug/L for fertilized clam eggs, Mercenaria mercenaria (Davis and Hidu, 1969).

A criterion level of .01 ug/L for guthion is based upon use of an 0.1 application factor applied to the 96-hour LC50 of 0.1 ug/L for Gammarus and a similar value of 0.3 ug/L for the European shrimp.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

HALOETHERS

CRITERIA:

Aquatic Life

The available data for haloethers indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 360 and 122 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

No saltwater organisms have been tested with any haloether and therefore, no statement can be made concerning acute or chronic toxicity.

Human Health

Using the present guidelines, a satisfactory criterion cannot be derived at this time because of insufficient available data for haloethers.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

HALOMETHANES

CRITERIA:

Aquatic Life

The available data for halomethanes indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low a 11,000 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of halomethanes to sensitive freshwater aquatic life.

The available data for halomethanes indicate that acute and chronic toxicity to saltwater aquatic life occurs at concentrations as low as 12,000 and 6,400 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested. A decrease in algal cell numbers occurs at concentrations as low as 11,500 ug/L.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to chloromethane, bromomethane, dichloromethane, bromodichloromethane, tribromomethane, dichlorodifluoromethane, trichlorofluoromethane, or combinations of these chemicals through ingestion of contaminated water and aquatic organisms, the ambient water concentration should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime

are estimated at 10^{-5}, 10^{-6} and 10^{-7}. The corresponding recommended criteria are 1.9 ug/L, 0.19 ug/L, and 0.019 ug/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 157 ug/L, 15.7 ug/L, and 1.57 ug/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

HARDNESS

INTRODUCTION:

Water hardness is caused by the polyvalent metallic ions disolved in water. In fresh water these are primarily calcium and magnesium although other metals such as iron, strontium and manganese contribute to the extent that appreciable concentrations are present. Hardness commonly is reported as an equivalent concentration of calcium carborate ($CaCO_3$).

The concept of hardness comes from water supply practice. It is measured by soap requirements for adequate lather formation and as an indicator of the rate of scale formation in hot water heaters and low pressure boilers. A commonly used classification is given in the following table (Sawyer, 1960).

TABLE 3.

Classification of Water by Hardness Content

Conc. mg/L $CaCO_3$	Description
0 - 75	soft
75 - 150	moderately hard
150 - 300	hard
300 and up	very hard

Natural sources of hardness principally are limestones which are dissolved by percolating rainwater made acid by dissolved carbon dioxide. Industrial and industrially related sources include the inorganic chemical industry and discharges from operating and abandoned mines.

Hardness in fresh water frequently is distinguished in carbonate and non-carbonate fractions. The carbonate fraction is chemically equivalent to the bicarbonates present in water.

Since bicarbonates generally are measured as alkalinity, the carbonate hardness usually is considered equal to the alkalinity.

RATIONALE:

The determination of hardness in raw waters subsequently treated and used for domestic water supplies is useful as a parameter to characterize the total dissolved solids present and for calculating dosages where lime-soda softening is practiced. Because hardness concentrations in water have not been proven health related, the final level achieved principally is a function of economics. Since hardness in water can be removed with treatment by such processes as lime-soda softening and zeolite or ion exchange systems, a criterion for raw waters used for public water supply is not practical.

The effects of hardness on freshwater fish and other aquatic life appear to be related to the ions causing the hardness rather than hardness. Both the NTAC (1968) and NAS (1974) panels have recommended against the use of the term hardness but suggest the inclusion of the concentrations of the specific ions. This procedure should avoid confusion in future studies but is not helpful in evaluating previous studies. For most existing data, it is difficult to determine whether toxicity of various metal ions is reduced because of the formation of metallic hydroxides and carbonates caused by the associated increases in alkalinity, or because of an antagonistic effect of one of the principal cations contributing to hardness, e.g., calcium, or a combination of both effects. Stiff (1971) presented a theory (without proof)

that if cupric ions were the toxic form of copper whereas copper carbonate complexes were relatively non-toxic, then the observed difference in toxicity of copper between hard and soft waters can be explained by the difference in alkalinity rather than hardness. Doudoroff and Katz (1953), in their review of the literature on toxicity, presented data showing that increasing calcium in particular reduced the toxicity of other heavy metals. Under usual conditions in fresh water and assuming that other bivalent metals behave similarly to copper, it is reasonable to assume that both effects occur simultaneously and explain the observed reduction of toxicity of metals in waters containing carbonate hardness. The amount of reduced toxicity related to hardness, as measured by a 40-hour LC50 for rainbow trout, has been estimated to be about four times for copper and zinc when the hardness was increased from 10 to 100 mg/L as $CaCO_3$ (NAS, 1974).

Limits on hardness for industrial uses are quite variable. Table 4 lists maximum values that have been accepted by various industries as a source of raw water (NAS, 1974). Subsequent treatment generally can reduce hardness to tolerable limits although costs of such treatment are an important factor in determining its desirability for a particular water source.

Hardness is not a determination of concern for irrigation use of water. The concentrations of the cations calcium and magnesium, which comprise hardness, are important in determining the exchangeable sodium in a given water. This particular calculation will be discussed under total dissolved solids rather

TABLE 4.

Maximum Hardness Levels Accepted
By Industry as a Raw Water Source*

Industry	Maximum Concentration mg/L as $CaCO_3$
Electric utilities	5,000
Textile	120
Pulp and paper	475
Chemical	1,000
Petroleum	900
Primary metals	1,000

* Requirements for final use within a process may be essentially zero, which requires treatment for concentration reductions.

than hardness.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

HEPTACHLOR

CRITERIA:

Aquatic Life

For heptachlor the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.0038 ug/L as a 24-hour average, and the concentration should not exceed 0.52 ug/L at any time.

For heptachlor the criterion to protect saltwater aquatic life as derived using the Guidelines is 0.0036 ug/L as a 24-hour average, and the concentration should not exceed 0.053 ug/L at any time.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to heptachlor through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero, based on the non threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 2.78 ng/L, 0.28 ng/L, and 0.028 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 2.85 ng/L, 0.29 ng/L, and 0.029 ng/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

HEXACHLOROBUTADIENE

CRITERIA:

Aquatic Life

The available data for hexachlorobutadiene indicate that acute and chronic toxicity to freshwater aquatic life occur at concentrations as low as 90 and 9.3 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

The available data for hexachlorobutadiene indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 32 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of hexachlorobutadiene to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to hexachlorobutadiene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 4.47 ug/L, 0.45 ug/L, and 0.045 ug/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding

consumption of water, the levels are 500 ug/L, 50 ug/L, and 5.0 ug/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

CRITERIA:

Aquatic Life

Lindane

For lindane the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.080 ug/L as a 24-hour average and the concentration should not exceed 2.0 ug/L at any time.

For saltwater aquatic life the concentration of lindane should not exceed 0.16 ug/L at any time. No data are available concerning the chronic toxicity of lindane to sensitive saltwater aquatic life.

BHC

The available data for a mixture of isomers of BHC indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 100 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of a mixture of isomers of BHC to sensitive freshwater aquatic life.

The available data for a mixture of isomers of BHC indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 0.34 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of a mixture of isomers of BHC to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to alpha-hexachlorocyclohexane through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 92 ng/L, 9.2 ng/L, and .92 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 310 ng/L, 31.0 ng/L, and 3.10 ng/L, respectively.

For the maximum protection of human health from the potential carcinogenic effects of exposure to beta-hexachlorocyclohexane through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 163 ng/L, 16.3 ng/L, and 1.63 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 547 ng/L, 54.7 ng/L, and 5.47 ng/L, respectively.

For the maximum protection of human health from the potential carcinogenic effects due to exposure of gama-hexachlorocyclohexane through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 186 ng/L, 18.6 ng/L, and 1.86 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 625 ng/L, 62.5 ng/L, and 6.25 ng/L, respectively.

For the maximum protection of human health from the potential carcinogenic effects of exposure to technical-hexachlorocyclohexane through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 123 ng/L, 12.3 ng/L, and 1.23 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 414 ng/L, 41.4 ng/L, and 4.14 ng/L, respectively.

Using the present guidelines, satisfactory criteria cannot be derived at this time for delta and epsilon hexachlorocyclohexane because of insufficient available data.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

HEXACHLOROCYCLOPENTADIENE

CRITERIA:

Aquatic Life

The available data for hexachlorocyclopentadiene indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 7.0 and 5.2 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

The available data for hexachlorocyclopentadiene indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 7.0 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of hexachlorocyclopentadiene to sensitive saltwater aquatic life.

Human Health

For comparison purposes, two approaches were used to derive criterion levels for hexachlorocyclopentadiene. Based on available toxicity data, to protect public health the derived level is 206 ug/L. Using available organoleptic data, to control undersirable taste and odor quality of ambient water the estimated level is 1 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing water quality criteria, and have no demonstrated relationship to potential adverse human health effects.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

IRON

CRITERIA:

0.3 mg/L for domestic water supplies (welfare).

1.0 mg/L for freshwater aquatic life.

INTRODUCTION:

Iron is the fourth most abundant, by weight, of the elements that make up the earth's crust. Common in many rocks, it is an important component of many soils, especially the clay soils where usually it is a major constituent. Iron in water may be present in varying quantities dependent upon the geology of the area and other chemical components of the waterway.

Iron is an essential trace element required by both plants and animals. In some waters it may be a limiting factor for the growth of algae and other plants; this is true especially in some marl lakes where it is precipitated by the highly alkaline conditions. It is a vital oxygen transport mechanism in the blood of all vertebrate and some invertebrate animals.

The ferrous, or bivalent (Fe^{++}), and the ferric, or trivalent (Fe^{+++}) irons, are the primary forms of concern in the aquatic environment, although other forms may be in organic and inorganic wastewater streams. The ferrous (Fe^{++}) form can persist in waters void of dissolved oxygen and originates usually from groundwaters or mines when these are pumped or drained. For practical purposes the ferric (Fe^{+++}) form is insoluble. Iron can exist in natural organometallic or humic compounds and colloidal forms. Black or brown swamp waters may contain iron concentrations of several mg/L in the presence or absence of dissolved oxygen, but this iron form has little effect on aquatic

life.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

ISOPHORONE

CRITERIA:

Aquatic Life

The available data for isophorone indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 117,000 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of isophorone to sensitive freshwater aquatic life.

The available data for isophorone indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 12,900 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of isophorone to sensitive saltwater aquatic life.

Human Health

For the protection of human health from the toxic properties of isophorone ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 5.2 mg/L.

For the protection of human health from the toxic properties of isophorone ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 520 mg/L.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

LEAD

AQUATIC LIFE SUMMARY:

The acute toxicity of lead to several species of freshwater animals has been shown to decrease as the hardness of water increases. At a hardness of 50 mg/L the acute sensitivities of 10 species range from 142.5 ug/L for an amphipod to 235,900 ug/L for a midge. Data on the chronic effects of lead on freshwater animals are available for two fish and two invertebrate species. The chronic toxicity of lead also decreases as hardness increases and the lowest and highest available chronic values (12.26 and 128.1 ug/L) are both for a cladoceran, but in soft and hard water, respectively. Acute-chronic ratios are available for three species and range from 18 to 62. Freshwater algae are affected by concentrations of lead above 500 ug/L, based on data for four species. Bioconcentration factors are available for four invertebrate and two fish species and range from 42 to 1,700.

Acute values are available for 13 saltwater animal species and range from 315 ug/L for the mummichog to 27,000 ug/L for the soft shell clam. A chronic toxicity test was conducted with a mysid; unacceptable effects were observed at 37 ug/L but not at 17 ug/L and the acute-chronic ratio for this species is 124.8. A species of macroalgae was affected at 20 ug/L. Available bioconcentration factors range from 17.5 to 2,570.

NATIONAL CRITERIA:

The procedures described in the Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of

Aquatic Organisms and Their Uses indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration (in ug/L) of lead does not exceed the numerical value given by $_{e}$(1.273[ln(hardness)]-4.705) more than once every 3 years on the average and if the 1-hour average concentration (in ug/L) does not exceed the numerical value given by $_{e}$(1.273[ln(hardness)]-1.460) more than once every 3 years on the average. For example, at hardnesses of 50, 100, and 200 mg/L as $CaCO_3$ the 4-day average concentrations of lead are 1.3, 3.2, and 7.7 ug/L, respectively, and the 1-hour average concentrations are 34, 82, and 200 ug/L.

The procedures described in the Guidelines indicate that, except possibly where a locally important species is very sensitive, saltwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of lead does not exceed 5.6 ug/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 140 ug/L more than once every three years on the average.

EPA believes that a measurement such as "acid-soluble" would provide a more scientifically correct basis upon which to establish criteria for metals. The criteria were developed on this basis. However, at this time, no EPA-approved methods for such a measurement are available to implement the criteria through the regulatory programs of the Agency and the States. The Agency is considering development and approval of methods for a measurement such as acid-soluble. Until available, however, EPA recommends applying the criteria using the total recoverable.

method. This has two impacts: (1) Certain species of some metals cannot be analyzed directly because the total recoverable method does not distinguish between individual oxidation states, and (2) these criteria may be overly protective when based on the total recoverable method.

The recommended exceedence frequency of 3 years is the Agency's best scientific judgment of the average amount of time it will take an unstressed system to recover from a pollution event in which exposure to lead exceeds the criterion. A stressed system, for example, one in which several outfalls occur in a limited area, would be expected to require more time for recovery. The resilience of ecosystems and their ability to recover differ greatly, however, and site-specific criteria may be established if adequate justification is provided.

The use of criteria in designing waste treatment facilities requires the selection of an appropriate wasteload allocation model. Dynamic models are preferred for the application of these criteria. Limited data or other factors may make their use impractical, in which case one should rely on a steady-state model. The Agency recommends the interim use of 1Q5 or 1Q10 for Criterion Maximum Concentration design flow and 7Q5 or 7Q10 for the Criterion Continuous Concentration design flow in steady-state models for unstressed and stressed systems, respectively. These matters are discussed in more detail in the Technical Support Document for Water Quality-Based Toxics Control (U.S. EPA, 1985).

HUMAN HEALTH CRITERIA:

The ambient water quality criterion for lead is recommended to be identical to the existing drinking water standard which is 50 ug/L. Analysis of the toxic effects data resulted in a calculated level whic is protective to human health against the ingestion of contaminated water and contaminated aquatic organisms. The calculated value is comparable to the present standard. For this reason a selective criterion based on exposure soley from consumption of 6.5 grams of aquatic organisms was not derived.

(45 F.R. 79318 Nov. 28,1980) (50 F.R. 30784, July 29, 1985)
SEE APPENDIX A FOR METHODOLOGY

MALATHION

CRITERION:

0.1 ug/L for freshwater and marine aquatic life.

RATIONALE:

The freshwater fish most sensitive to malathion, an organophosphorus pesticide, appear to be the salmonids and centrarchids. Post and Schroeder (1971) report a 96-hour LC50 between 120 and 265 ug/L for 4 species of salmonids. Macek and McAllister (1970) found a 96-hour LC50 range between 101 and 285 ug/L for 3 species of centrarchids and 3 species of salmonids. Other 96-hour LC50's are: rainbow trout, Salmo gairdneri, 68 ug/L (Cope, 1965); largemouth bass, Micropterus salmoides, 50 ug/L (Pickering et al. 1962); and chinook salmon, Oncorhynchus tshawytscha, 23 ug/L (Katz, 1961). All of the above tests were in static systems. Eaton (1970) determined a 96-hour LC50 for bluegill, Lepomis macrochirus, in a flow-through system at 110 ug/L. Macek and McAllister (1970) reported a similar 96-hour LC50 for the bluegill in a static exposure. Static 96-hour LC50s of 120 and 160 ug/L were reported by Post and Schroeder (1971) for brook trout, Salvelinus fontinalis. Bender (1969) indicated that the acute toxicity to fathead minnows, Pimephales promelas, is slightly greater (about 2.0 times) in a static system than in a flow-through system. The flow-through acute toxicity to fathead minnows reported by Mount and Stephan (1967) approximated the static acute toxicity reported by Henderson and Pickering (1958) and Bender (1969).

Many aquatic invertebrates appear to be more sensitive than fish to malathion. The 96-hour LC50 for Gammarus lacustris was 1.0 ug/L (Sanders, 1969); for Pteronarcella badia, 1.1 ug/L (Sanders and Cope, 1968); and for Gammarus fasciatus, 0.76 ug/L (Sanders, 1972). The 48-hour LC50 for Simocephalus serrulatus was 3.5 ug/L and for Daphnia pulex, 1.8 ug/L (Sanders and Cope, 1966). Daphnia were immobilized in 50 hours in 0.9 ug/L (Anderson, 1960). The 24-hour LC50s for two species of midge larvae were 2.1 ug/L (Mulla and Khasawinah, 1969) and 2.0 ug/L (Karnak and Collins, 1974).

Safe life cycle exposure concentrations for the more sensitive invertebrates are not known. The most sensitive aquatic organisms probably have not yet been tested; safe concentrations for the most sensitive invertebrates exposed through a complete life cycle have not been determined; and effects of low concentrations on invertebrate behavior are unknown.

The stability of malathion in water is dependent on the chemical and biological conditions of the water (Paris et al. 1975). Weiss and Gakstatter (1964) have shown that the half-life of malathion was reduced from about 5 months at pH 6 to 1 to 2 weeks at pH 8. Eichelberger and Lichtenberg (1971) found that only 10 percent remained in the Little Miami River (pH 7.3-8.0) after 2 weeks. Bender (1969) states that one of the malathion breakdown products may be more toxic than the parent compound.

It has been shown that a measured concentration of 575 ug/L malathion in flowing seawater kills 40 to 60 percent of the

marine fish, Lagodon rhomboides, in 3.5 hours and causes about 75 percent brain acetylcholinesterase (AChE) inhibition (Coppage et al. 1975). Similar inhibition of AChE and mortality were caused in pinfish in 24, 48, and 72 hours at measured concentrations of 142, 92 and 58 ug/L, respectively. A concentration of 31 ug/L caused 34 percent AChE inhibition in pinfish but no deaths in 72 hours. Coppage and Matthews (1974) demonstrated that death may be associated with reductions of brain AChE activity of four marine fishes by 70 to 80 percent or more in short-term exposures to malathion. Coppage and Duke (1971) found that moribund mullet, Mugil cephalus, in an estuary sprayed with malathion (3 oz./acre) during a large-scale mosquito control operation had about 98 percent inhibition of brain AChE. This is in agreement with 70 to 80 percent or more inhibition of brain AChE levels at and below which some deaths are likely to occur in short-term exposure. Spot, Leiostomus xanthurus, and Atlantic croaker, Micropogon undulatus, also had substantial inhibition of brain during the spray operation (70 percent or more inhibition).

Toxicity studies have been made on a number of marine animals. Eisler (1970) studied the 96-hour LC50 for several marine fishes at 20 ^{o}C in static, aerated seawater. The 96-hour LC50 values (in ug/L) were: Menidia menidia, 125; Mugil cephalus, 550; Fundulus majalis, 250; Fundulus heteroclitus, 240; Sphaeroides maculatus, 3250; Anguilla rostrata, 82; and Thalassoma bifasciatum, 27. Katz (1961) reported the static 24-hour LC50 for Gasterosteus aculeatus in 25 o/oo saltwater as 76.9 ug/L active ingredient. The 96-hour LC50 for striped bass,

Morone saxatilis, in intermittent flowing seawater has been reported as 14 ug/L (U.S. BSFW, 1970).

Reporting on studies of the toxicity of malathion on marine invertebrates, Eisler (1969) found the 96-hour LC50 (static, 24 o/oo salinity aerated) to be 33 ug/L for sand shrimp, Crangon septemspinosa; 82 ug/L for grass shrimp, Palaemonetes vulgaris; and 83 ug/L for hermit crab, Pagurus longicarpus. Growth of oyster, Crassostrea virginica, was reduced 32 percent by 96-hour exposure to 1 mg/L (Butler, 1963). The 48-hour LC50 for fertilized eggs of oysters was estimated by Davis and Hidu (1969) to be 9.07 mg/L and the 14-day LC50 for larvae, 2.66 mg/L.

Malathion enters the aquatic environment primarily as a result of its application as an insecticide. Because it degrades quite rapidly in most waters, depending on pH, its occurrence is sporadic rather than continuous. Because the toxicity is exerted through inhibition of AChE and because such inhibition may be additive with repeated exposures and may be caused by any of the organophosphorus insecticides, inhibition of AChE by more than 35 percent may be expected to result in damage to aquatic organisms.

An application factor of 0.1 is applied to the 96-hour LC50 data for Gammarus lacustris, G. fasciatis and Daphnia, which are all approximately 1.0 ug/L, yielding a criterion of 0.1 ug/L.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

MANGANESE

CRITERIA:

50 ug/L for domestic water supplies (welfare);

100 ug/L for protection of consumers of marine molluscs.

INTRODUCTION:

Manganese does not occur naturally as a metal but is found in various salts and minerals, frequently in association with iron compounds. The principal manganese-containing substances are manganese dioxide (MnO_2), pyrolusite, manganese carbonate (rhodocrosite) and manganese silicate (rhodonite). The oxides are the only important minerals mined. Manganese is not mined in the United States except when manganese is contained in iron ores that are deliberately used to form ferro-manganese alloys.

The primary uses of manganese are in metal alloys, dry cell batteries, micro-nutrient fertilizer additives, organic compounds used in paint driers and as chemical reagents. Permanganates are very strong oxidizing agents of organic materials.

Manganese is a vital micro-nutrient for both plants and animals. When manganese is not present in sufficient quantities, plants exhibit chlorosis (a yellowing of the leaves) or failure of the leaves to develop properly. Inadequate quantities of manganese in domestic animal food results in reduced reproductive capabilities and deformed or poorly maturing young. Livestock feeds usually have sufficient manganese, but beef cattle on a high corn diet may require a supplement.

RATIONALE:

Although inhaled manganese dusts have been reported to be toxic to humans, manganese normally is ingested as a trace nutrient in food. The average human intake is approximately 10 mg/day (Sollman, 1957). Very large doses of ingested manganese can cause some disease and liver damage but these are not known to occur in the United States. Only a few manganese toxicity problems have been found throughout the world and these have occurred under unique circumstances, i.e., a well in Japan near a deposit of buried batteries (McKee and Wolf, 1963).

It is possible to partially sequester manganese with special treatment but manganese is not removed in the conventional treatment of domestic waters (Riddick et al. 1958; Illig, 1960). Consumer complaints arise when manganese exceeds a concentration of 150 ug/L in water supplies (Griffin, 1960). These complaints are concerned primarily with the brownish staining of laundry and objectionable tastes in beverages. It is possible that the presence of low concentrations of iron may intensify the adverse effects of manganese. Manganese at concentrations of about 10 to 20 ug/L is acceptable to most consumers. A criterion for domestic water supplies of 50 ug/L should minimize the objectionable qualities.

McKee and Wolf (1963) summarized data on toxicity of manganese to freshwater aquatic life. Ions of manganese are found rarely at concentrations above 1 mg/L. The tolerance values reported range from 1.5 mg/L to over 1000 mg/L. Thus, manganese is not considered to be a problem in fresh waters. Permanganates have been reported to kill fish in 8 to 18 hours at

concentrations of 2.2 to 4.1 mg/L, but permanganates are not persistent because they rapidly oxidize organic materials and are thereby reduced and rendered nontoxic.

Few data are available on the toxicity of manganese to marine organisms. The ambient concentration of manganese is about 2 ug/L (Fairbridge, 1966). The material is rapidly assimilated and bioconcentrated into nodules that are deposited on the sea floor. The major problem with manganese may be concentration in the edible portions of molluscs, as bioaccumulation factors as high as 12,000 have been reported (NAS, 1974). In order to protect against a possible health hazard to humans by manganese accumulation in shellfish, a criterion of 100 ug/L is recommended for marine water.

Manganese is not known to be a problem in water consumed by livestock. At concentrations of slightly less than 1 mg/L to a few milligrams per liter, manganese nay be toxic to plants from irrigation water applied to soils with pH values lower than 6.0. The problem may be rectified by liming soils to increase the pH. Problems may develop with long-term (20 year) continuous irrigation on other soils with water containing about 10 mg/L of manganese (NAS, 1974). But, as stated above, manganese is rarely found in surface waters at concentrations greater than 1 mg/L. Thus, no specific criterion for manganese in agricultural waters is proposed. In select areas, and where acidophilic crops are cultivated and irrigated, a criterion of 200 ug/L is suggested for consideration.

Most industrial users of water can operate successfully where the criterion proposed for public water supplies is observed. Examples of industrial tolerance of manganese in water are summarized for industries such as dyeing, milk processing, paper, textiles, photography and plastics (McKee and Wolf, 1963). A more restrictive criterion may be needed to protect or ensure product quality.

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SEE APPENDIX C FOR METHODOLOGY

*MERCURY

AQUATIC LIFE SUMMARY:

Data are available on the acute toxicity of mercury(II) to 28 genera of freshwater animals. Acute values for invertebrate species range from 2.2 ug/L for Daphnia pulex to 2,000 ug/L for three insects. Acute values for fishes range from 30 ug/L for the guppy to 1,000 ug/L for the Mozambique tilapia. Few data are available for various organomercury compounds and mercurous nitrate, and they all appear to be 4 to 31 times more acutely toxic than mercury(II).

Available chronic data indicate that methylmercury is the most chronically toxic of the tested mercury compounds. Tests on methylmercury with Daphnia magna and brook trout produced chronic values less than 0.07 ug/L. For mercury(II) the chronic value obtained with Daphnia magna was about 1.1 ug/L and the acute-chronic ratio was 4.5. In both a life-cycle test and an early life-stage test on mercuric chloride with the fathead minnow, the chronic value was less than 0.26 ug/L and the acute-chronic ratio was over 600.

Freshwater plants show a wide range of sensitivities to mercury, but the most sensitive plants appear to be less sensitive than the most sensitive freshwater animals to both mercury(II) and methylmercury. A bioconcentration factor of 4,994 is available for mercury(II), but the bioconcentration factors for methylmercury range from 4,000 to 85,000.

*Indicates suspended, canceled or restricted by U.S. EPA Office of Pesticides and Toxic Substances

Data on the acute toxicity of mercuric chloride are available for 29 genera of saltwater animals, including annelids, molluscs, crustaceans, echinoderms, and fishes. Acute values range from 3.5 ug/L for a mysid to 1,678 ug/L for winter flounder. Fishes tend to be more resistant and molluscs and crustaceans tend to be more sensitive to the acute toxic effects of mercury(II). Results of a life-cycle test with the mysid show that mercury(II) at a concentration of 1.6 ug/L significantly affected time of first spawn and productivity; the resulting acute-chronic ratio was 3.1.

Concentrations of mercury that affected growth and photosynthetic activity of one saltwater diatom and six species of brown algae range from 10 to 160 ug/L. Bioconcentration factors of 10,000 and 40,000 have been obtained for mercuric chloride and methylmercury with an oyster.

NATIONAL CRITERIA:

Derivation of a water quality criterion for mercury is more complex than for most metals because of methylation of mercury in sediment, in fish, and in the food chain of fish. Apparently almost all mercury currently being discharged is mercury(II). Thus mercury(II) should be the only important possible cause of acute toxicity and the Criterion Maximum Concentrations can be based on the acute values for mercury(II).

The best available data concerning long-term exposure of fish to mercury(II) indicates that concentrations above 0.23 ug/L caused statistically significant effects on the fathead minnow and caused the concentration of total mercury in the whole body

to exceed 1.0 mg/kg. Although it is not known what percent of the mercury in the fish was methylmercury, it is also not known whether uptake from food would increase the concentration in the fish in natural situations. Species such as rainbow trout, coho salmon, and especially the bluegill, might suffer chronic effects and accumulate high residues of mercury about the same as the fathead minnow.

With regard to long-term exposure to methylmercury, McKim et al. (1976) found that brook trout can exceed the FDA action level without suffering statistically significant adverse effects on survival, growth, or reproduction. Thus for methylmercury the Final Residue Value would be substantially lower than the Final Chronic Value.

Basing a freshwater criterion on the Final Residue Value of 0.012 ug/L derived from the bioconcentration factor of 81,700 for methylmercury with the fathead minnow (Olson et al. 1975) essentially assumes that all discharged mercury is methylmercury. On the other hand, there is the possibility that in field situations uptake from food might add to the uptake from water. Similar considerations apply to the derivation of the saltwater criterion of 0.025 ug/L using the BCF of 40,000 obtained for methylmercury with the Eastern oyster (Kopfler, 1974). Because the Final Residue Values for methylmercury are substantially below the Final Chronic Values for mercury(II), it is probably not too important that many fishes, including the rainbow trout, coho salmon, bluegill, and haddock might not be adequately protected by the freshwater and saltwater Final Chronic Values for mercury(II).

In contrast to all the complexities of deriving numerical criteria for mercury, monitoring for unacceptable environmental effects should be relatively straightforward. The most sensitive adverse effect will probably be exceedence of the FDA action level. Therefore, existing discharges should be acceptable if the concentration of methylmercury in the edible portion of exposed consumed species does not exceed the FDA action level.

The procedures described in the Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of mercury does not exceed 0.012 ug/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 2.4 ug/L more than once every 3 years on the average. If the 4-day average concentration exceeds 0.012 ug/L more than once in a 3-year period, the edible portion of consumed species should be analyzed to determine whether the concentration of methylmercury exceeds the FDA action level.

The procedures described in the Guidelines indicate that, except possibly where a localy important species is very sensitive, saltwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of mercury does not exceed 0.025 ug/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 2.1 ug/L more than once every 3 years on the average. If the 4-day average concentration exceeds 0.025 ug/L more than once

in a 3-year period, the edible protion of consumed species should be analyzed to determine whether the concentration of mathylmercury exceeds the FDA action level.

EPA believes that a measurement such as "acid-soluble" would provide a more scientifically correct basis upon which to establish criteria for metals. The criteria were developed on this basis. However, at this time, no EPA approved-methods for such a measurement are available to implement the criteria through the regulatory programs of the Agency and the States. The Agency is considering development and approval of methods for a measurement such as acid-soluble. Until available, however, EPA recommends applying the criteria using the total recoverable method. This has two impacts: (1) certain species of some metals cannot be analyzed directly because the total recoverable method does not distinguish between individual oxidation states, and (2) these criteria may be overly protective when based on the total recoverable method.

The recommended exceedence frequency of 3 years is the Agency's best scientific judgment of the average amount of time it will take an unstressed system to recover from a pollution event in which exposure to mercury exceeds the criterion. A stressed system, for example, one in which several outfalls occur in a limited area, would be expected to require more time for recovery. The resilience of ecosystems and their ability to recover differ greatly, however, and site-specific criteria may be established if adequate justification is provided.

The use of criteria in designing waste treatment facilities requires the selection of an appropriate wasteload allocation model. Dynamic models are preferred for the application of these criteria. Limited data or other factors may make their use impractical, in which case one should rely on a steady-state model. The Agency recommends the interim use of 1Q5 or 1Q10 for Criterion Maximum Concentration design flow and 7Q5 or 7Q10 for the Criterion Continuous Concentration design flow in steady-state models for unstressed and stressed systems respectively. These matters are discussed in more detail in the Technical Support Document for Water Quality-Based Toxics Control (U.S EPA, 1985).

HUMAN HEALTH CRITERIA

For the protection of human health from the toxic properties of mercury ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 144 ng/L.

For the protection of human health from the toxic properties of mercury ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 146 ng/L.

NOTE: These values include the consumption of freshwater, estuarine, and marine species.

(45 F.R. 79318 Nov. 28,1980) (50 F.R. 30784, July 29, 1985)
SEE APPENDIX A FOR METHODOLOGY

METHOXYCHLOR

CRITERIA:

100 ug/L for domestic water supply (health);

0.03 ug/L for freshwater and marine aquatic life.

RATIONALE:

The highest level of methoxychlor found to have minimal or no long-term effects in man is 2.0 mg/kg of body weight/day (Lehman, 1965). Where adequate human data are available for corroboration of the animal results, the total "safe" drinking water intake level is assumed to be 1/100 of the no-effect or minimal effect level reported for the most sensitive animal tested, in this case, man.

Applying the available data and based upon the assumptions that 20 percent of the total intake of methoxychlor is from drinking water, and that the average person weighs 70 kg and consumes 2 liters of water per day, the formula for calculating a criterion is 2.0 mg/kg x 0.2 x 70 kg x 1/100 x 1/2 = 0.14 mg/L. A criterion level for domestic water supply of 100 ug/L is recommended.

Few data are available on acute and chronic effects of methoxychlor on freshwater fish. Merna and Eisele (1973) observed reduced hatchability of fathead minnow (Pimephales promelas) embryos at 0.125 ug/L and lack of spawning at 2.0 ug/L. Yellow perch, Perca flavescens, exposed to 0.6 ug/L for 8 months exhibited reduced growth. The 96-hour LC50 concentration was 7.5 and 22 ug/L for the fathead minnow and yellow perch, respectively. Korn and Earnest (1974) obtained a 96-hour LC50

of 3.3 ug/L with juvenile stripped bass, Morone saxatilis, exposed to methoxychlor in a flowing-water bioassay.

Sanders (1972) determined a 96-hour LC50 value of 0.5 ug/L for the crayfish, Orconectes nais. Merna and Eisele (1973) obtained a 96-hour LC50 value of 0.61 ug/L for the scud, Gammarus pseudolimnaeus and 96-hour LC50's ranging from 1.59 to 7.05 ug/L for the crayfish, Orconectes nais, and three aquatic insect larvae. In 28-day exposures, reduction in emergence of mayflies, Stenonema sp., and in pupation of caddisflies, Cheumatospsyche sp., were observed at 0.5 and 0.25 ug/L concentrations, respectively. They also found methoxychlor to be degraded in a few weeks or less in natural waters.

Eisele (1974) conducted a study in which a section of a natural stream was dosed at 0.2 ug/L methoxychlor for 1 year. The near extinction of one species of scud, Hyallella azteca, and reductions in populations of other sensitive species, as well as biomass, were observed. Residue accumulation of up to 1,000 times the level in the stream was observed in first-year crayfish, Orconectes nais. Metcalf et al. (1971) traced the rapid conversion of methoxychlor to water soluble compounds and elimination from the tissues of snails, mosquito larvae and mosquitofish. Thus, methoxychlor appears to be considerably less bioaccumlative in aquatic organisms than some of the other chlorinated pesticides.

Methoxyhlor has a very low accumulation rate in birds and mammals (Stickel, 1973), and relatively low avian (Heath et al. 1972) and mammalian (Hodge et al. 1950) toxicities. No administrative guidelines for acceptable levels in edible fish

tissues have been established by the U.S. Food and Drug Administration.

The above data indicate that 0.1 ug/L methoxychlor would be just below chronic effect level for the fathead minnow and one-fifth the acute toxicity level in a crayfish species. Therefore, a criterion level of 0.03 ug/L is recommended. This criterion should protect fish as sensitive as striped bass and is 10 times lower than the level causing effects on some invertebrate populations in a 1-year dosing of a natural stream.

Bahner and Nimmo (1974) found the 96-hour LC50 of methoxychlor for the pink shrimp, Penaeus duorarum, to be 3.5 ug/L and the 30-day LC50 to be 1.3 ug/L. Using an application factor of 0.01 with the pink shrimp's acute toxicity of 3.5 ug/L, the recommended criterion for the marine environment is 0.03 ug/L.

Butler (1971) found accumulation factors of 470 and 1,500 for the molluscs, Mercenaria mercenaria and Mya arenaria, respectively, when exposed to 1 ug/L methoxychlor for 5 days. Using the 1,500 accumulation factor as a basis, a water concentration of 0.2 ug/L would be required to meet the U.S. Food and Drug Administration's guideline for methoxychlor in meat products. Thus, the recommended marine criterion of 0.03 ug/L is an order of magnitude lower than this concentration.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

MIREX

CRITERION:

0.001 ug/L for freshwater and marine aquatic life.

RATIONALE:

Mirex is used to control the imported fire ant Solenopsis saevissima richteri in the southeastern United States. Its use is essentially limited to the control of this insect and it is always presented in bait. In the most common formulation, technical grade mirex is dissolved in soybean oil and sprayed on corncob grits. The bait produced in this manner consists of 0.3 percent mirex, 14.7 percent soybean oil and 85 percent corncob grits. The mirex bait often is applied at a rate of 1.4 kg/ha, equivalent to 4.2 grams of toxicant per hectare.

Relatively few studies have been made of the effects of mirex on freshwater invertebrates of these, only Ludke et al. (1971) report chemical analyses of mirex in the water. Their study reported effects on two crayfish species exposed to mirex by three techniques. First, field-collected crayfish were exposed to several sublethal concentrations of technical grade mirex solutions for various periods of time; second, crayfish were exposed to mirex leached from bait (0.3 percent active ingredient); and third, the crayfish were fed mirex bait.

Procambarus blandingi juveniles were exposed to 1 or 5 ug/L for 6 to 144 hours, transferred to clean water and observed for 10 days. After 5 days in clean water, 95 percent of the animals exposed to 1 ug/L for 144 hours were dead. Exposure to 5 ug/L for 6, 24, and 58 hours resulted in 26, 50, and 98 percent mortality 10 days after transfer to clean water. Crayfish,

Procambarus hayi, were exposed to 0.1 and 0.5 ug/L for 48 hours. Four days after transfer to clean water, 65 percent of the animals exposed to 0.1 ug/L were dead. At the 0.5 ug/L concentration, 71 percent of the animals were dead after 4 days in clean water. Tissue residue accumulations (wet weight basis) ranged from 940- to 27,210-fold above water concentrations. In leached bait experiments, 10 bait particles were placed in 2 liters of water but isolated from 20 juvenile crayfish. Thirty percent of the crayfish were dead in 4 days and 95 percent were dead in 7 days. Water analysis indicated mirex concentrations of 0.86 ug/L. In feeding experiments, 108 crayfish each were fed one bait particle. Mortality was noticed on the first day after feeding, and by the sixth day 77 percent were dead. In another experiment, all crayfish were dead 4 days after having been fed 2 bait particles each. From this report it is obvious that mirex is extremely toxic to these species of crayfish. Mortality and accumulation increase with time of exposure to the insecticide. Concentrations as low as 0.1 ug/L or the ingestion of one particle resulted in death.

Research to determine effects of mirex on fish has been concentrated on species which have economic and sport fishery importance. Hyde et al. (1974) applied mirex bait (0.3 percent mirex) at the standard rate (1.4 kg/ha) in four ponds containing channel catfish, Ictalurus punctatus. Three applications were made over an 8-month period with the first application 8 days after fingerling (average weight 18.4 g) catfish were placed in the ponds. Fish were collected at each subsequent application

(approximately 4-month intervals). Two and one half months after the final application, the ponds were drained, all fish were measured and weighed, and the percent survival was calculated. Mirex residues in the fish at termination of the experiment ranged from 0.015 ug/g (ppm) in the fillet to 0.255 ug/g in the fat.

In another study, Van Valin et al. (1968) exposed bluegills, Lepomis macrochirus, and the goldfish, Carassius auratus, to mirex by feeding a mirex-treated diet (1, 3, and 5 mg mirex per kg body weight) or by treating holding ponds with mirex bait (1.3, 100, and 1000 ug/L computed water concentration). They reported no mortality or tissue pathology for the bluegills; however, after 56 days of exposure, gill breakdown in goldfish was found in the 100 and 1000 ug/L contact exposure ponds, and kidney breakdown was occurring in the 1000 ug/L ponds. Mortality in the feeding experiments was not related to the level of exposure, although growth of the bluegills fed 5 ug/L mirex was reduced.

In laboratory and field test systems, reported concentrations of mirex usually are between 0.5 and 1.0 ug/L (Van Valin et al. 1968: Ludke et al. 1971). Although mirex seldom is found above 1 ug/L in the aquatic environment, several field studies have shown that the insecticide is accumulated through the food chain. Borthwick et al. (1973) reported the accumulation of mirex in South Carolina estuaries. Their data revealed that mirex was transported from treated land and marsh to the estuary animals and that accumulation, especially in predators, occurred. In the test area, water samples consistently were less than 0.01 ug/L.

Residues in fish varied from non-detectable to 0.8 ug/g with 15 percent of the samples containing residues. The amount of mirex and the percent of samples containing mirex increased at higher trophic levels. Fifty-four percent of the raccoons sampled contained mirex residues up to 4.4 ug/g and 78 percent of the birds contained residues up to 17 ug/g. Nagvi and de la Cruz (1973) reported average residues for molluscs (0.15 ug/g), fish (0.26 ug/g), insects (0.29 ug/g), crustaceans (0.44 ug/g) and annelids (0.63 ug/g). They also reported that mirex was found in areas not treated with mirex which suggests movement of the pesticide in the environment. Wolfe and Norment (1973) sampled an area for one year following an aerial application of mirex bait (2.1 g mirex/ha). Crayfish residues ranged from 0.04 to 0.16 ug/g. Fish residues were about 2 to 20 times greater than the controls and averaged from 0.01 to 0.76 ug/g. Kaiser (1974), reported the presence of mirex in fish from the Bay of Quinte, Lake Ontario, Canada. Concentrations range from 0.02 ug/g in the gonads of the northern long nose gar, Lepistosteus osseus, to 0.05 ug/g in the post-anal fin of the northern pike, Esox lucius. Mirex has never been registered for use in Canada.

Mirex does not appear to be greatly toxic to birds, with LC50's for the young of four species ranging from 547 to greater than 1667 ug/g (Heath et al. 1972). Long-term dietary dosages caused no adverse effect at 3 ug/g with mallards and 13 ug/g with pheasants (Heath and Spann, 1973). However, it has been reported (Stickel et al. 1973) that the persistence of mirex in bird tissue exceeds that of all organochlorine compounds tested except

for DDE. Delayed mortality occurred among birds subjected to doses above expected environmental concentration.

A summary examination of the data available at this time shows a mosaic of effects. Crayfish and channel catfish survival is affected by mirex in the water or by ingestion of the bait particles. Bioaccumulation is well established for a wide variety of organisms but the effect of this bioaccumulation on the aquatic ecosystem is unknown. There is evidence that mirex is very persistent in bird tissue. Considering the extreme toxicity and potential for bioaccumulation, every effort should be made to keep mirex bait particles out of water containing aquatic organisms and water concentrations should not exceed 0.001 ug/L mirex. This value is based upon an application factor of 0.01 applied to the lowest levels at which effects on crayfish have been observed.

Data upon which to base a marine criterion involve several estuarine and marine crustaceans. A concentration of 0.1 ug/L technical grade mirex in flowing seawater was lethal to juvenile pink shrimp, Penaeus durorarum, in a 3-week exposure (Lowe et al. 1971). In static tests with larval stages (megalopal) of the mud crab, Rhithropanopeus harrisii, reduced survival was observed in 0.1-ug/L mirex (Bookhout et al. 1972). In three of four 28-day seasonal flow-through experiments, Tagatz et al. (1975) found reduced survival of Callinectes sapidus, Penaeus durorarum, and grass shrimp, Palaemonetes pugio, at levels of 0.12 ug/L in summer, 0.06 ug/L in fall and 0.09 ug/L in winter.

Since two reports, Lowe et al. (1971) and Bookhout et al. (1972), stated that effects of mirex on estuarine and marine

crustaceans were observed only after considerable time had elapsed, it seems reasonable that length of exposure is an important consideration for this chemical. This may not be the case in fresh water since the crayfish were affected within 48 hours. Therefore, a 3- to 4-week exposure might be considered "acute" and by applying an application factor of 0.01 to a reasonable average of toxic-effect levels as summarized above, a recommended marine criterion of 0.001 ug/L results.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

NAPHTHALENE

CRITERIA:

Aquatic Life

The available data for naphthalene indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 2,300 and 620 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

The available data for naphthalene indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 2,350 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of naphthalene to sensitive saltwater aquatic life.

Human Health

Using the present guidelines, a satisfactory criterion cannot be derived at this time because of insufficient available data for naphthalene.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

NICKEL

CRITERIA:

Aquatic Life

For total recoverable nickel the criterion (in ug/L) to protect freshwater aquatic life as derived using the Guidelines is the numerical value given by $e^{(0.76[\ln(\text{hardness})]+1.06)}$ as a 24-hour average, and the concentration (in ug/L) should not exceed the numerical value given by $e^{(0.76[\ln(\text{hardness})]+4.02)}$ at any time. For example, at hardnesses of 50, 100, and 200 mg/L as $CaCO_3$ the criteria are 56, 96, and 160 ug/L, respectively, as 24-hour averages, and the concentrations should not exceed 1,100, 1,800, and 3,100 ug/L, respectively, at any time.

For total recoverable nickel the criterion to protect saltwater aquatic life as derived using the Guidelines is 7.1 ug/L as a 24-hour average, and the concentration should not exceed 140 ug/L at any time.

Human Health

For the protection of human health from the toxic properties of nickel ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 13.4 ug/L.

For the protection of human health from the toxic properties of nickel ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 100. ug/L.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

NITRATES/NITRITES

CRITERION:

10 mg/L nitrate nitrogen (N) for domestic water supply (health).

INTRODUCTION:

Two gases (molecular nitrogen and nitrous oxide) and five forms of nongaseous, combined nitrogen (amino and amide groups, ammonium, nitrite, and nitrate) are important in the nitrogen cycle. The amino and amide groups are found in soil organic matter and as constituents of plant and animal protein. The ammonium ion either is released from proteinaceous organic matter and urea, or is synthesized in industrial processes involving atmospheric nitrogen fixation. The nitrite ion is formed from the nitrate or the ammonium ions by certain microorganisms found in soil, water, sewage, and the digestive tract. The nitrate ion is formed by the complete oxidation of ammonium ions by soil or water microorganisms; nitrite is an intermediate product of this nitrification process. In oxygenated natural water systems nitrite is rapidly oxidized to nitrate. Growing plants assimilate nitrate or ammonium ions and convert them to protein. A process known as denitrification takes place when nitrate-containing soils become anaerobic and the conversion to nitrite, molecular nitrogen, or nitrous oxide occurs. Ammonium ions may also be produced in some circumstances.

Among the major point sources of nitrogen entry into water bodies are municipal and industrial wastewaters, septic tanks, and feed lot discharges. Diffuse sources of nitrogen include farm-site fertilizer and animal wastes, lawn fertilizer, leachate

from waste disposal in dumps or sanitary landfills, atmospheric fallout, nitric oxide and nitrite discharges from automobile exhausts and other combustion processes, and losses from natural sources such as mineralization of soil organic matter (NAS, 1972). Water reuse systems in some fish hatcheries employ a nitrification process for ammonia reduction; this may result in exposure of the hatchery fish to elevated levels of nitrite (Russo et al. 1974).

RATIONALE:

In quantities normally found in food or feed, nitrates become toxic only under conditions in which they are, or may be, reduced to nitrites. Otherwise, at "reasonable" concentration nitrates are rapidly excreted in the urine. High intake of nitrates constitutes a hazard primarily to warmblooded animals under conditions that are favorable to reduction to nitrite. Under certain circumstances, nitrate can be reduced to nitrite in the gastrointestinal tract which then reaches the bloodstream and reacts directly with hemoglobin to produce methemoglobin, consequently impairing transport.

The reaction of nitrite with hemoglobin can be hazardous in infants under 3 months of age. Serious and occasionally fatal poisonings in infants have occurred following ingestion of untreated well waters shown to contain nitrate at concentrations greater than 10 mg/L nitrate nitrogen (N) (NAS, 1974). High nitrate concentrations frequently are found in shallow farm and rural community wells, often as the result of inadequate protection from barnyard drainage or from septic tanks (USPHS,

1961; Stewart et al. 1967). Increased concentrations of nitrates also have been found in streams from farm tile drainage in areas of intense fertilization and farm crop production (Harmeson et al. 1971). Approximately 2,000 cases of infant methemoglobinemia have been reported in Europe and North America since 1945; 7 to 8 percent of the affected infants died (Walton, 1951; Sattelmacher, 1962). Many infants have drunk water in which the nitrate nitrogen content was greater than 10 mg/L without developing methemoglobinemia. Many public water supplies in the United States contain levels that routinely exceed this amount, but only one U.S. case of infant methemoglobinemia associated with a public water supply has ever been reported (Virgil et al. 1965). The differences in susceptibility to methemoglobinemia are not yet understood but appear to be related to a combination of factors including nitrate concentration, enteric bacteria, and the lower acidity characteristic of the digestive systems of baby mammals. Methemoglobinemia systems and other toxic effects were observed when high nitrate well waters containing pathogenic bacteria were fed to laboratory mammals (Wolff et al. 1972). Conventional water treatment has no significant effect on nitrate removal from water (NAS, 1974).

Because of the potential risk of methemoglobinemia to bottle-fed infants, and in view of the absence of substantiated physiological effects at nitrate concentrations below 10 mg/L nitrate nitrogen, this level is the criterion for domestic water supplies. Waters with nitrite nitrogen concentrations over 1

mg/L should not be used for infant feeding. Waters with a significant nitrite concentration usually would be heavily polluted and probably bacteriologically unacceptable.

Westin (1974) determined that the respective 96-hour and 7-day LC50 values for chinook salmon, Oncorhynchus tshawytscha, were 1,310 and 1,080 mg/L nitrate nitrogen in fresh water and 990 and 900 mg/L nitrate nitrogen in 15 o/oo saline water. For fingerling rainbow trout, Salmo gairdneri, the respective 96-hour and 7-day LC50 values were 1,360 and 1,060 mg/L nitrate nitrogen in fresh water, and 1,050 and 900 mg/L nitrate nitrogen in 15 o/oo saline water. Trama (1954) reported that the 96-hour LC50 for bluegills, Lepomis macrochirus, at 20°C was 2,000 mg/L nitrate nitrogen (sodium nitrate) and 420 mg/L nitrate nitrogen (potassium nitrate). Knepp and Arkin (1973) observed that largemouth bass, Micropterus salmoides, and channel catfish, Ictalurus punctatus, could be maintained at concentrations up to 400 mg/L nitrate (90 mg/L nitrate nitrogen) without significant effect upon their growth and feeding activities.

The 96-hour and 7-day LC50 values for chinook salmon, Oncorhynchus tshawytscha, were found to be 0.9 and 0.7 mg/L nitrite nitrogen in fresh water (Westin, 1974). Smith and Williams (1974) tested the effects of nitrite nitrogen and observed that yearling rainbow trout, Salmo gairdneri, suffered a 55 percent mortality after 24 hours at 0.55 mg/L; fingerling rainbow trout suffered a 50 percent mortality after 24 hours of exposure at 1.6 mg/L; and chinook salmon, Oncorhynchus tshawytscha, suffered a 40 percent mortality within 24 hours at

0.5 mg/L. There were no mortalities among rainbow trout exposed to 0.15 mg/L nitrite nitrogen for 48 hours. These data indicate that salmonids are more sensitive to nitrite toxicity than are other fish species, e.g., minnows, Phoxinus laevis, that suffered a 50 percent mortality within 1.5 hours of exposure to 2,030 mg/L nitrite nitrogen, but required 14 days of exposure for mortality to occur at 10 mg/L (Klingler, 1957), and carp, Cyprinus carpio, when raised in a water reuse system, tolerated up to 1.8 mg/L nitrite nitrogen (Saeki, 1965).

Gillette, et al. (1952) observed that the critical range for creek chub, Semotilus atromaculatus, was 80 to 400 mg/L nitrite nitrogen. Wallen et al. (1957) reported a 24-hour LC50 of 1.6 mg/L nitrite nitrogen, and 48- and 96-hour LC50 values of 1.5 mg/L nitrite nitrogen for mosquitofish, Gambusia affinis. McCoy (1972) tested the nitrite susceptibility of 13 fish species and found that logperch, Percina caprodes, were the most sensitive species tested (mortality at 5 mg/L nitrite nitrogen in less than 3 hours of exposure) whereas carp, Cyprinus carpio, and black bullheads, Ictalurus melas, survived 40 mg/L nitrite nitrogen for a 48-hour exposure period; the common white sucker, Catostomus commersoni, and the quillback, Carpiodes cyprinus, survived 100 mg/L for 48 and 36 hours, respectively.

Russo et al. (1974) performed flow-through nitrite bioassays in hard water (hardness = 199 mg/L $CaCO_3$; alkalinity = 176 mg/L $CaCO_3$; pH = 7.9) on rainbow trout, Salmo gairdneri, of four different sizes, and obtained 96-hour LC50 values ranging from 0.19 to 0.39 mg/L nitrite nitrogen. Duplicate bioassays on 12-gram rainbow trout were continued long enough for their toxicity

curves to level off, and asymptotic LC50 concentrations of 0.14 and 0.15 mg/L were reached in 8 days; on day 19, additional mortalities occurred. For 2-gram rainbow trout, the minimum tested level of nitrite nitrogen at which no mortalities were observed after 10 days was 0.14 mg/L; for the 235-gram trout, the minimum level with no mortality after 10 days was 0.06 mg/L.

It is concluded that (1) levels of nitrate nitrogen at or below 90 mg/L would have no adverse effects on warmwater fish (Knepp and Arkin, 1973); (2) nitrite nitrogen at or below 5 mg/L should be protective of most warmwater fish (McCoy, 1972); and (3) nitrite nitrogen at or below 0.06 mg/L should be protective of salmonid fishes (Russo et al. 1974; Russo and Thurston, 1975). These levels either are not known to occur or would be unlikely to occur in natural surface waters.

Recognizing that concentrations of nitrate or nitrite that would exhibit toxic effects on warm- or coldwater fish could rarely occur in nature, restrictive criteria are not recommended.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

NITROBENZENE

CRITERIA:

Aquatic Life

The available data for nitrobenzene indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 27,000 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No definitive data are available concerning the chronic toxicity of nitrobenzene to sensitive freshwater aquatic life.

The available data for nitrobenzene indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 6,680 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No definitive data are available concerning the chronic toxicity of nitrobenzene to sensitive saltwater aquatic life.

Human Health

For comparison purposes, two approaches were used to derive criterion levels for nitrobenzene. Based on available toxicity data, to protect public health the derived level is 19.8 mg/L. Using available organoleptic data, to control undesirable taste and odor qualities of ambient water the estimated level is 30 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have no demonstrated relationship to potential adverse human health effects.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

NOTE: The U.S. EPA is currently developing Acceptable Daily Intake (ADI) or Verified Reference Dose (RfD) values for Agency-wide use for this chemical. The new value should

be substituted when it becomes available. The January, 1986, draft Verified Reference Dose document cites an RfD of .0005 mg/kg/day for nitrobenzene.

NITROPHENOLS

CRITERIA:

Aquatic Life

The available data for nitrophenols indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 230 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of nitrophenols to sensitive freshwater aquatic life but toxicity to one species of algae occurs at concentrations as low as 150 ug/L.

The available data for nitrophenols indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 4,850 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of nitrophenols to sensitive saltwater aquatic life.

Human Health

Because of insufficient available data for mono- and trinitrophenols, satisfactory criteria cannot be derived at this time, using the present guidelines.

For the protection of human health from the toxic properties of dinitrophenols and 2,4-dinitro-o-cresol ingested through water and contaminated aquatic organisms, the ambient water criteria are determined to be 70 ug/L and 13.4 ug/L, respectively.

For the protection of human health from the toxic properties of dinitrophenols and 2,4-dinitro-o-cresol ingested through contaminated aquatic organisms alone, the ambient water criteria

are determined to be 14.3 mg/L and 765 ug/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

NITROSAMINES

CRITERIA:

Aquatic Life

The available data for nitrosamines indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 5,850 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of nitrosamines to sensitive freshwater aquatic life.

The available data for nitrosamines indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 3,300,000 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of nitrosamines to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to N-nitrosodiethylamine and all other nitrosamines except those listed below, through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the non threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 8.0 ng/L, 0.8 ng/L, and 0.08 ng/L, respectively. If these estimates are made for

consumption of aquatic organisms only, excluding consumption of water, the levels are 12,400 ng/L, 1,240 ng/L, and 124 ng/L, respectively.

For the maximum protection of human health from the potential carcinoqenic effects of exposure to N-nitrosodimethylamine through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10-6, and 10^{-7} The corresponding recommended criteria are 14 ng/L, 1.4 ng/L, and 0.14 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 160,000 ng/L, 16,000 ng/L, and 1,600 ng/L, respectively.

For the maximum protection of human health from the potential carcinogenic effects of exposure to N-nitrosodibutylamine through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10-6, and 10^{-7}. The corresponding recommended criteria are 64 ng/L, 6.4 ng/L, and 0.64 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 5,868 ng/L, 587

ng/L, and 58.7 ng/L, respectively.

For the maximum protection of human health from the potential carcinogenic effects of exposure to N-nitrosopyrrolidine through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 160 ng/L, 16 ng/L, and 1.6 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 919,000 ng/L, 91,900 ng/L, and 9,190 ng/L, respectively.

For the maximum protection of human health from the potential carcinogenic effects of exposure to N-nitrosodiphenylamine through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 49,000 ng/L, 4,900 ng/L, and 490 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 161,000 ng/L, 16,100 ng/L, and 1,610 ng/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

OIL AND GREASE

CRITERIA:

For domestic water supply: Virtually free from oil and grease, particularly from the tastes and odors that emanate from petroleum products.

For aquatic life:

(1) 0.01 of the lowest continuous flow 96-hour LC50 to several important freshwater and marine species, each having a demonstrated high susceptibility to oils and petrochemicals.

(2) Levels of oils or petrochemicals in the sediment which cause deleterious effects to the biota should not be allowed.

(3) Surface waters shall be virtually free from floating nonpetroleum oils of vegetable or animal origin, as well as petroleum-derived oils.

INTRODUCTION:

It has been estimated that between 5 and 10 million metric tons of oil enter the marine environment annually (Blumer, 1970). A major difficulty encountered in the setting of criteria for oil and grease is that these are not definitive chemical categories, but include thousands of organic compounds with varying physical, chemical, and toxicological properties. They may be volatile or nonvolatile, soluble or insoluble, persistent or easily degraded.

RATIONALE:

Field and laboratory evidence have demonstrated both acute lethal toxicity and long-term sublethal toxicity of oils to aquatic organisms. Events such as the Tampico Maru wreck of 1957 in Baja, California, (Diaz-Piferrer, 1962), and the No. 2 fuel oil spill in West Falmouth, Massachusetts, in 1969

(Hampson and Sanders, 1969), both of which caused immediate death to a wide variety of organisms, are illustrative of the lethal toxicity that may be attributed to oil pollution. Similarly, a gasoline spill in South Dakota in November 1969 (Bugbee and Walter, 1973) was reported to have caused immediate death to the majority of freshwater invertebrates and 2,500 fish, 30 percent of which were native species of trout. Because of the wide range of compounds included in the category of oil, it is impossible to establish meaningful 96-hour LC50 values for oil and grease without specifying the product involved. However, as the data in Table 6 show, the most susceptible category of organisms, the marine larvae, appear to be intolerant of petroleum pollutants, particularly the water soluble compounds, at concentrations as low as 0.1 mg/L.

The long-term sublethal effects of oil pollution refer to interferences with cellular and physiological processes such as feeding and reproduction and do not lead to immediate death of the organism. Disruption of such behavior apparently can result from petroleum product concentrations as low as 10 to 100 ug/L (see Table 7).

Table 7 summarizes some of the sublethal toxicities for various petroleum pollutants and aquatic species. In addition to sublethal effects reported at the 10 to 100 ug/L level, it has been shown that petroleum products can harm aquatic life at concentrations as low as 1 ug/L (Jacobson and Boylan, 1973).

Bioaccumulation of petroleum products presents two especially important public health problems: (1) the tainting of edible,

aquatic species, and (2) the possibility of edible marine organisms incorporating the high boiling, carcinogenic polycyclic aromatics in their tissues. Nelson-Smith (1971) reported that 0.01 mg/L of crude oil caused tainting in oysters. Moore et al. (1973) reported that concentrations as low as 1 to 10 ug/L could lead to tainting within very short periods of time. It has been shown that chemicals responsible for cancer in animals and man (such as 3,4-benzopyrene) occur in crude oil (Blumer, 1970). It also has been shown that marine organisms are capable of incorporating potentially carcinogenic compounds into their body fat where the compounds remain unchanged (Blumer, 1970).

Oil pollutants may also be incorporated into sediments. There is evidence that once this occurs in the sediments below the aerobic surface layer, petroleum oil can remain unchanged and toxic for long periods, since its rate of bacterial degradation is slow. For example, Blumer (1970) reported that No. 2 fuel oil incorporated into the sediments after the West Falmouth spill persisted for over a year, and even began spreading in the form of oil-laden sediments to more distant areas that had remained unpolluted immediately after the spill. The persistence of unweathered oil within the sediment could have a long-term effect on the structure of the benthic community or cause the demise of specific sensitive important species. Moore et al. (1973) reported concentrations of 5 mg/L for the carcinogen 3, 4-benzopyrene in marine sediments.

Mironov (1967) reported that 0.01 mg/L oil produced deformed and inactive flatfish larvae. Mironov (1970) also reported inhibition or delay of cellular division in algae by oil

concentrations of 10^{-4} to 10^{-1} mg/L. Jacobson and Boylan (1973) reported a reduction in the chemotactic perception of food by the snail, Nassarius obsoletus, at kerosene concentrations of 0.001 to 0.004 mg/L. Bellen et al. (1972) reported decreased survival and fecundity in worms at concentrations of 0.01 to 10 mg/L of detergent.

Because of the great variability in the toxic properties of oil, it is difficult to establish a numerical criterion which would be applicable to all types of oil. Thus, an application factor of 0.01 of the 96-hour LC50 as determined by using continuous flow with a sensitive resident species should be employed for individual petrochemical components.

There is a paucity of toxicological data on the ingestion of the components of refinery wastewaters by humans or by test animals. It is apparent that any tolerable health concentrations for petroleum-derived substances far exceed the limits of taste and odor. Since petroleum derivatives become organoleptically objectionable at concentrations far below the human chronic toxicity, it appears that hazards to humans will not arise from drinking oil-polluted waters (Johns Hopkins Univ., 1956; Mckee and Wolf, 1963). Oils of animal or vegetable origin generally are nontoxic to humans and aquatic life.

In view of the problem of petroleum oil incorporation in sediments, its persistence and chronic toxic potential, and the present lack of sufficient toxicity data to support specific criteria, concentrations of oils in sediments should not approach levels that cause deleterious effects to important species or the

bottom community as a whole.

Petroleum and nonpetroleum oils share some similar physical and chemical properties. Because they share common properties, they may cause similar harmful effects in the aquatic environment by forming a sheen, film, or discoloration on the surface of the water. Like petroleum oils, nonpetroleum oils may occur at four levels of the aquatic environment: (a) floating on the surface, (b) emulsified in the water column, (c) solubilized, and (d) settled on the bottom as a sludge. Analogous to the grease balls from vegetable oil and animal fats are the tar balls of petroleum origin which have been found in the marine environment or washed ashore on beaches.

Oils of any kind can cause (a) drowning of waterfowl because of loss of buoyancy, exposure because of loss of insulating capacity of feathers, and starvation and vulnerability to predators because of lack of mobility; (b) lethal effects on fish by coating epithelial surfaces of gills, thus preventing respiration; (c) potential fishkills resulting from biochemical oxygen demand; (d) asphyxiation of benthic life forms when floating masses become engaged with surface debris and settle on the bottom; and (e) adverse aesthetic effects of fouled shorelines and beaches. These and other effects have been documented in the U.S. Department of Health, Education and Welfare report on Oil Spills Affecting the Minnesota and Mississippi Rivers and the 1975 Proceedings of the Joint Conference on Prevention and Control of Oil Spills.

Oils of animal or vegetable origin generally are chemically nontoxic to humans or aquatic life; however, floating sheens of

such oils result in deleterious environmental effects described in this criterion. Thus, it is recommended that surface waters shall be virtually free from floating nonpetroleum oils of vegetable or animal origin. This same recommendation applies to floating oils of petroleum origin since they too may produce similar effects.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

DISSOLVED OXYGEN

NATIONAL CRITERIA:

The national criteria for ambient dissolved oxygen concentrations for the protection of freshwater aquatic life are presented in Table 1. The criteria are derived from the production impairment estimates which are based primarily upon growth data and information on temperature, disease, and pollutant stresses. The average dissolved oxygen concentrations selected are values 0.5 mg/L above the slight production impairment values and represent values between no production impairment and slight production impairment. Each criterion may thus be viewed as an estimate of the threshold concentration below which detrimental effects are expected.

Criteria for coldwater fish are intended to apply to waters containing a population of one or more species in the family Salmonidae (Bailey et al., 1970) or to waters containing other coldwater or coolwater fish deemed by the user to be closer to salmonids in sensitivity than to most warmwater species. Although the acute lethal limit for salmonids is at or below 3 mg/L, the coldwater minimum has been established at 4 mg/L because a significant proportion of the insect species common to salmonid habitats are less tolerant of acute exposures to low dissolved oxygen than are salmonids. Some coolwater species may require more protection than that afforded by the other life stage criteria for warmwater fish and it may be desirable to protect sensitive coolwater species with the coldwater criteria. Many states have more stringent dissolved oxygen standards for cooler waters, waters that contain either

salmonids, nonsalmonid coolwater fish, or the sensitive centrachid, the smallmouth bass The warmwater criteria are necessary to protect early life stages of warmwater fish as sensitive as as channel catfish and to protect other life stages of fish as sensitive as largemouth bass. Criteria for early life stages are intended to apply only where and when these stages occur. These criteria represent dissolved oxygen concentrations which EPA believes provide a reasonable and adequate degree of protection for freshwater aquatic life.

The criteria do not represent assured no-effect levels. However, because the criteria represent worst case conditions (i.e. for wasteload allocation and waste treatment plant design), conditions will be better than the criteria nearly all of the time at most sites. In situations where criteria conditions are just maintained for considerable periods the proposed criteria represent some risk of production impairment. This impairment would depend on innumerable other factors. If slight production impairment or a small but undefinable risk of moderate impairment is unacceptable, than one should use the "no production impairment" values given in the document as means and the "slight production impairment" values as minima. The table which presents these concentrations is reproduced here as table 2.

The criteria do represent dissolved oxygen concentrations believed to protect the more sensitive populations of organisms against potentially damaging production impairment. The dissolved oxygen concentrations in the criteria are intended to be protective at typically high seasonal environmental temperatures for the appropriate taxonomic and life stage classi-

Table 1. Water quality criteria for ambient dissolved oxygen concentration.

	Coldwater Criteria		Warmwater Criteria	
	Early Life Stages[1,2]	Other Life Stages	Early Life Stages[2]	Other Life Stages
30 Day Mean	NA[3]	6.5	NA	5.5
7 Day Mean	9.5 (6.5)	NA	6.0	NA
7 Day Mean Minimum	NA	5.0	NA	4.0
1 Day Minimum [4,5]	8.0 (5.0)	4.0	5.0	3.0

1 These are water column concentrations recommended to achieve the required intergravel dissolved oxygen concentrations shown in parentheses. The 3 mg/L differential is discussed in the criteria document. For species that have early life stages exposed directly to the water column, the figures in parentheses apply.

2 Includes all embryonic and larval stages and all juvenile forms to 30-days following hatching.

3 NA (not applicable).

4 For highly manipulatable discharges, further restrictions apply (see page 37)

5 All minima should be considered as instantaneous concentrations to be achieved at all times.

fications, temperatures which are often higher than those used in the research from which the criteria were generated, especially for other than early life stages.

Where natural conditions alone create dissolved oxygen concentrations less than 110 percent of the applicable criteria means or minima or both, the minimum acceptable concentration is

90 percent of the natural concentration. These values are similar to those presented graphically by Doudoroff and Shumway (1970) and those calculated from Water Quality Criteria 1972 (NAS/NAE, 1973). Absolutely no anthropogenic dissolved oxygen depression in the potentially lethal area below the 1-day minima should be allowed unless special care is taken to ascertain the tolerance of resident species to low dissolved oxygen.

If daily cycles of dissolved oxygen are essentially sinusoidal, a reasonable daily average is calculated from the day's high and low dissolved oxygen values. A time-weighted average may be required if the dissolved oxygen cycles are decidedly non-sinusoidal. Determining the magnitude of daily dissolved oxygen cycles requires at least two appropriately timed measurements daily, and characterizing the shape of the cycle requires several more appropriately spaced measurements.

Once a series of daily mean dissolved oxygen concentrations are calculated, an average of these daily means can be calculated (Table 3). For embryonic, larval, and early life stages, the averaging period should not exceed 7 days. This short time is needed to adequately protect these often short duration, most sensitive life stages. Other life stages can probably be adequately protected by 30-day averages. Regardless of the averaging period, the average should be considered a moving average rather than a calendar-week or calendar-month average.

Table 2. Dissolved Oxygen Concentrations (mg/L) Versus Quantitative Level of Effect.

1. Salmonid Waters

a. Embryo and Larval Stages

No Production Impairment	= 11* (8)
Slight Production Impairment	= 9* (6)
Moderate Production Impairment	= 8* (5)
Severe Production Impairment	= 7* (4)
Limit to Avoid Acute Mortality	= 6* (3)

(* Note: These are water column concentrations recommended to achieve the required intergravel dissolved oxygen concentrations shown in parentheses. The 3 mg/L difference is discussed in the criteria document.)

b. Other Life Stages

No Production Impairment	= 8
light Production Impairment	= 6
Moderate Production Impairment	= 5
Severe Production Impairment	= 4
Limit to Avoid Acute Mortality	= 3

2. Nonsalmonid Waters

a. Early Life Stages

No Production Impairment	= 6.5
Slight Production Impairment	= 5.5
Moderate Production Impairment	= 5
Severe Production Impairment	= 4.5
Limit to Avoid Acute Mortality	= 4

b. Other Life Stages

No Production Impairment	= 6
Slight Production Impairment	= 5
Moderate Production Impairment	= 4
Severe Production Impairment	= 3.5
Limit to Avoid Acute Mortality	= 3

3. Invertebrates

No Production Impairment	= 8
Some Production Impairment	= 5
Acute Mortality Limit	= 4

Table 3. Sample calculations for determining daily means and 7-day mean dissolved oxygen concentrations (30-day averages are calculated in a similar fashion using 30 days data).

Dissolved Oxygen (mg/L)

Day	Daily Max.	Daily Min.	Daily Mean
1	9.0	7.0	8.0
2	10.0	7.0	8.5
3	11.0	8.0	9.5[b]
4	12.0[a]	8.0	9.5
5	10.0	8.0	9.0
6	11.0	9 0	10.0
7	12.0[a]	10.0	10.5[c]
		57.0	65.0
1-day Minimum		7.0	
7-day Mean Minimum		8.1	
7-day Mean			9.3

a Above air saturation concentration (assumed to be 11.0 mg/L for this example).

b (11.0 + 8.0)2.

c (11 0 +10.0)2.

The criteria have been established on the basis that the maximum dissolved oxygen value actually used in calculating any daily mean should not exceed the air saturation value. This consideration is based primarily on analysis of studies of cycling dissolved oxygen and the growth of largemouth bass (Stewart et al., 1967), which indicated that high dissolved oxygen levels (> 6 mg/L) had no beneficial effect on growth.

During periodic cycles of dissolved oxygen concentrations, minima lower than acceptable constant exposure levels are tolerable so long as:

1. the average concentration attained meets or exceeds the criterion;

2. the average dissolved oxygen concentration is calculated as recommended in Table 3; and

3. the minima are not unduly stressful and clearly are not lethal.

A daily minimum has been included to make certain that no acute mortality of sensitive species occurs as a result of lack of oxygen. Because repeated exposure to dissolved oxygen concentrations at or near the acute lethal threshold will be stressful and because stress can indirectly produce mortality or other adverse effects (e.g., through disease), the criteria are designed to prevent significant episodes of continuous or regularly recurring exposures to dissolved oxygen concentrations at or near the lethal threshold. This protection has been achieved by setting the daily minimum for early life stages at the subacute lethality threshold, by the use of a 7-day averaging period for early life stages, by stipulating a 7-day mean minimum value for other life stages, and by recommending additional limits for manipulatable discharges.

The previous EPA criterion for dissolved oxygen published in Quality Criteria for Water (USEPA, 1976) was a minimum of 5 mg/L (usually applied as a 7Q10) which is similar to the current criterion minimum except for other life stages of warmwater fish which now allows a 7-day mean minimum of 4 mg/L. The new criteria are similar to those contained in the 1968 "Green Book" of the Federal Water Pollution Control Federation (FWPCA, 1968).

A. The Criteria and Monitoring and Design Conditions

The acceptable mean concentrations should be attained most of the time, but some deviation below these values would probably not cause significant harm. Deviations below the mean will probably be serially correlated and hence apt to occur on consecutive days. The significance of deviations below the mean will depend on whether they occur continuously or in daily cycles, the former being more adverse than the latter. Current knowledge regarding such deviations is limited primarily to laboratory growth experiments and by extrapolation to other activity-related phenomena.

Under conditions where large daily cycles of dissolved oxygen occur, it is possible to meet the criteria mean values and consistently violate the mean minimum criteria. Under these conditions the mean minimum criteria will clearly be the limiting regulation unless alternatives such as nutrient control can dampen the daily cycles.

The significance of conditions which fail to meet the recommended dissolved oxygen criteria depend largely upon five factors: (1) the duration of the event; (2) the magnitude of the dissolved oxygen depression; (3) the frequency of recurrence; (4) the proportional area of the site failing to meet the criteria, and (5) the biological significance of the site where the event occurs. Evaluation of an event's significance must be largely case- and site-specific. Common sense would dictate that the magnitude of the depression would be the single most important factor in general, especially if the acute value is violated. A

logical extension of these considerations is that the event must be considered in the context of the level of resolution of the monitoring or modeling effort. Evaluating the extent, duration, and magnitude of an event must be a function of the spatial and temporal frequency of the data. Thus, a single deviation below the criterion takes on considerably less significance where continuous monitoring occurs than where sampling is comprised of once-a-week grab samples. This is so because based on continuous monitoring the event is provably small, but with the much less frequent sampling the event is not provably small and can be considerably worse than indicated by the sample. The frequency of recurrence is of considerable interest to those modeling dissolved oxygen concentrations because the return period, or period between recurrences, is a primary modeling consideration contingent upon probabilities of receiving water volumes, waste loads, temperatures, etc. It should be apparent that return period cannot be isolated from the other four factors discussed above. Ultimately, the question of return period may be decided on a site-specific basis taking into account the other factors (duration, magnitude, areal extent, and biological significance) mentioned above. Future studies of temporal patterns of dissolved oxygen concentrations, both within and between years, must be conducted to provide a better basis for selection of the appropriate return period.

In conducting wasteload allocation and treatment plant design computations, the choice of temperature in the models will be important. Probably the best option would be to use temperatures consistent with those expected in the receiving water over the

critical dissolved oxygen period for the biota.

B. The Criteria and Manipulatable Discharges

If daily minimum DOs are perfectly serially correlated, i.e, if the annual lowest daily minimum dissolved oxygen concentration is adjacent in time to the next lower daily minimum dissolved oxygen concentration and one of these two minima is adjacent to the third lowest daily minimum dissolved oxygen concentration, etc., then in order to meet the 7-day mean minimum criterion it is unlikely that there will be more than three or four consecutive daily minimum values below the acceptable 7-day mean minimum. Unless the dissolved oxygen pattern is extremely erratic, it is also unlikely that the lowest dissolved oxygen concentration will be appreciably below the acceptable 7-day mean minimum or that daily minimum values below the 7-day mean minimum will occur in more than one or two weeks each year. For some discharges, the distribution of dissolved oxygen concentrations can be manipulated to varying degrees. Applying the daily minimum to manipulatable discharges would allow repeated weekly cycles of minimum acutely acceptable dissolved oxygen values, a condition of unacceptable stress and possible adverse biological effect. For this reason, the application of the one day minimum criterion to manipulatable discharges must limit either the frequency of occurrence of values below the acceptable 7-day mean minimum or must impose further limits on the extent of excursions below the 7-day mean minimum. For such controlled discharges, it is recommended that the occurrence of daily minima below the acceptable 7-day mean

minimum be limited to 3 weeks per year or that the acceptable one-day minimum be increased to 4.5 mg/L for coldwater fish and 3.5 mg/L for warmwater fish. Such decisions could be site-specific based upon the extent of control and serial correlation.

NMED Exhibit 68

PARATHION

CRITERION:

0.04 ug/L for freshwater and marine aquatic life.

RATIONALE:

Acute static LC50 values of the organophosphorus pesticide, parathion, for freshwater fish have ranged generally from about 50 ug/L for more sensiitive species such as bluegills, Lepomis macrochirus, to about 2.5 mg/L for the more resistant species such as minnows (U.S. Environ. Prot. Agency, 1975). In flowing water exposures, Spacie (1975) obtained 96-hour LC50 values of 0.5 mg/L, 1.6 mg/L, and 1.76 mg/L for bluegills, Lepomis macrochirus, fathead minnows, Pimephales promelas, and brook trout, Salvelinus fontinalis, respectively. Korn and Earnest (1974) found a 96-hour LC50 of 18 ug/L for juvenile freshwater and estuarine striped bass, Morone saxatilis, in a flowing water system.

Few chronic exposure data are available for aquatic organisms. Brown bullheads, Ictalurus nebulosus, exposed to 30 ug/L parathion for 30 days exhibited tremors; at 60 ug/L they convulsed and were found to have developed a deformed vertebral column (Mount and Boyle, 1969). In a 23-month exposure of bluegills, Spacie (1975) observed deformities (scoliosis and a characteristic protrusion in the throat region) at 0.34 ug/L, but not at 0.16 ug/L. Tremors, convulsions, hypersensitivity, and hemorrhages also were evident at higher concentrations.

Reproductive impairment and deformities were observed in fathead minnows exposed to 4.0 ug/L for 8 1/2 months.

Development of brook trout, S. fontinalis embryos exposed to 32 ug/L was abnormal and mortalities associated with premature hatching were observed. Embryos at 10 ug/L appeared normal. No adverse effects on juveniles and adults was evident during 9 months' exposure to 7 ug/L.

Inhibition of cholinesterase enzymes is the well-established mode of physiological action of parathion and other organic phosphorus pesticides (Weiss, 1958). The degree of inhibition of brain acetylcholinesterase (AChE) activity has been the most frequently used measure of effect of these pesticides. Various studies (Weiss, 1958, 1959, 1961; Murphy et al., 1968; Gibson et al. 1969) have shown the degree of inhibition to be dependent upon toxicant concentration, length of exposure, and species sensitivity. The results of these studies have also indicated that death results from AChE inhibition ranging from 25 to 90 percent of normal. Weiss (1959) also showed that susceptibility depended upon the extent of recovery of AChE activity following prior exposure and that the recovery period for fish exposed to parathion was relatively long. In bluegills, AChE activity was only 50 percent recovered 30 days after exposure to 1 mg/L for 6 to 7 hours (Weiss, 1961).

Some of the other physiological effects observed to result from exposure of fish to parathion have been inhibition of spermatogenesis in guppies, Poecilia reticulata, at 10 ug/L (Billard and deKinkelin, 1970), alternation of oxygen consumption rate in bluegills, Lepomis macrochirus, at 100 ug/L (Dowden, 1966), and liver enlargement associated with increased pesticide-hydrolizing capability in mosquitofish, Gambusia

affinis (Ludke, 1970).

Parathion has been found acutely toxic to aquatic invertebrates at under 1 ug/L e.g., a 50-hour LC50 of 0.8 ug/L for Daphnia magna; 48-hour LC50 of 0.6 ug/L for Daphnia pulex; 48-hour LC50 of 0.37 for Simocephalus serrulatus (a daphnid) (Sanders and Cope, 1966); a 5-day LC50 of 0.93 ug/L for the larval stonefly, Acroneuria pacifica (Jensen and Gaufin, 1964); and a 96-hour LC50 of 0.43 ug/L for the larval caddisfly Hydropsyche californica (Gaufin et al. 1965). Mulla and Khasawinah (1969) obtained a 24-hour LC50 of 0.5 ug/L for 4th instar larvae of the midge Tanypus grodhausi. Spacie (1975) obtained 96-hour LC50's in flow-through bioassays of 0.62 ug/L for Daphnia magna, 0.40 ug/L for the scud, Gammarus fasciatus, and 31.0 ug/L for 4th instar of Chironomous tentans, a midge. Other invertebrates have been found acutely sensitive to parathion in concentrations of from 1 to 30 ug/L in water (U.S. Environ. Prot. Agency, 1975).

Few longer exposures have been conducted. Jensen and Gaufin (1964) obtained 30-day LC50's for Pteronarcys californica and Acroneuria pacifica of 2.2 and 0.44 ug/L, respectively. Spacie (1975) found the 3-week LC50 for Daphnia magna to be 0.14 ug/L. Statistically significant reproductive impairment occurred at concentrations above 0.08 ug/L. A 43-day LC50 of 0.07 ug/L was reported for Gammarus fasciatus and a concentration of 0.04 ug/L produced significantly greater mortality than among controls.

Limited information is available on persistence of parathion in water. Eichelberger and Lichtenberg (1971) determined the

half-life in river water (pH 7.3 - 8.0) to be 1 week. Using AChE inhibitory capacity as the indicator, Weiss and Gakstatter (1964) found the half-life of parathion or its active breakdown products to be 40, 35, and 20 days in "natural" waters having a pH of 5.1. 7.0, and 8.4, respectively. The possibility of breakdown resulting in compounds more toxic than parathion was suggested by Burke and Ferguson (1969) who determined that the toxicity of this pesticide to mosquitofish, Gambusia affinis, was greater in static than in flowing water test systems. Sanders (1972), in 96-hour bioassays with the scud, Gammarus fasciatus, and glass shrimp, Palaemonetes kadiakensis, also observed greater toxicity under static than in flow-through conditions.

Tissue accumulations of parathion by exposed aquatic organisms are not great and do not appear to be very persistent. Mount and Boyle (1969) observed concentrations in the blood of bullhead, Ictalurus melas, up to about 50 times water concentrations. Spacie (1975) found muscle concentrations in chronically exposed brook trout, S. fontinalis, to be several hundred times water concentrations; bluegills, Lepomis macrochirus, had about 25 times water concentrations in their bodies. Leland (1968) demonstrated a biological half-life of parathion in rainbow trout, Salmo gairdneri, exposed and then placed in fresh water to be only 30 to 40 hours. It is not expected that parathion residues in aquatic organisms exposed to the recommended criterion concentrations will be a hazard to consumer organisms.

Weiss and Gakstatter (1964) have shown that 15-day continuous exposure to parathion (1.0 ug/L) can produce progressively greater (i.e., cumulative) brain AChE inhibition in a fish species. After substantial inhibition by parathion exposure, it takes several weeks for brain AChE of exposed fishes to return to normal even though exposure is discontinued (Weiss, 1959, 1961). Inhibition of brain AChE of fishes by 46 percent or more has been associated with harmful effects in exposures to organophosphate pesticides for one life cycle (Eaton, 1970) and for short periods (Carter, 1971; Coppage and Duke, 1971; Coppage, 1972; Coppage and Matthews, 1974; Post and Leasure, 1974; Coppage et al. 1975). It has been shown that a concentration of 10 ug parathion/L of flowing seawater kills 40 to 60 percent of the marine fishes Lagodon rhomboides (pinfish) and Leostomus xanthurus (spot) in 24 hours and causes about 87 to 92 percent brain AChE inhibition (Coppage and Matthews, 1974.) Similar inhibition of AChE and mortality were caused in sheepshead minnows, Cyprinodon variegatus, in 2, 24, 48, and 72 hours at concentrations of 5,000, 2,000, 100, and 10 ug/L, respectively in static tests (Coppage, 1972). These data indicate that reductions of brain AChE activity of marine fishes by 70 to 80 percent or more in short-term exposures to parathion may be associated with some deaths.

Other estimates of parathion toxicity to marine organisms follow. The 48-hour EC50 for parathion to Penaeus duorarum was found to be 0.2 ug/L (Lowe et al. 1970). Lahav and Sarig (1969) reported the 96-hour LC50 for mullet, Mugil cephalus to be 125 ug/L. The shell growth of the oyster, Crassostrea virginica, was found by Lowe et al. (1970) to be decreased by 22 percent after 96 hours in 1.0 mg/L.

An application factor of 0.1 is applied to the 96-hour LC50 data for invertebrates which range upward from 0.4 ug/L. A criteria of 0.04 ug/L is recommended for marine and freshwater aquatic life.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

PENTACHLOROPHENOL

CRITERIA:

Aquatic Life

The available data for pentachlorophenol indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 55 and 3.2 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

The available data for pentachlorophenol indicate that acute and chronic toxicity to saltwater aquatic life occur at concentrations as low as 53 and 34 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Human Health

For comparison purposes, two approaches were used to derive criterion levels for pentachlorophenol. Based on available toxicity data, to protect public health the derived level is 1.01 mg/L. Using available organoleptic data, to control undesirable taste and odor qualities of ambient water the estimated level is 30 ug/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have no demonstrated relationship to potential adverse human health effects.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

pH

CRITERIA:

Range	
5 - 9	Domestic water supplies (welfare)
6.5 - 9.0	Freshwater aquatic life
6.5 - 8.5	Marine aquatic life (but not more than 0.2 units outside of normallyoccurring range.)

INTRODUCTION:

"pH" is a measure of the hydrogen ion activity in a water sample. It is mathematically related to hydrogen ion activity according to the expression: pH = -log 10 (H^+), where (H^+) is the hydrogen ion activity.

The pH of natural waters is a measure of acid-base equilibrium achieved by the various dissolved compounds, salts, and gases. The principal system regulating pH in natural waters is the carbonate system which is composed of carbon dioxide (CO_2), carbonic acid, (H_2CO_3), bicarbonate ion (HCO_3) and carbonate ions (CO_3). The interactions and kinetics of this system have been described by Stumm and Morgan (1970).

pH is an important factor in the chemical and biological systems of natural waters. The degree of dissociation of weak acids or bases is affected by changes in pH. This effect is important because the toxicity of many compounds is affected by the degree of dissociation. One such example is hydrogen cyanide (HCN). Cyanide toxicity to fish increases as the pH is lowered because the chemical equlibrium is shifted toward an increased concentration of HCN. Similar results have been shown for hydrogen sulfide (H_2S) (Jones, 1964).

The solubility of metal compounds contained in bottom sediments or as suspended material also is affected by pH. For example, laboratory equilibrium studies under anaerobic conditions indicated that pH was an important parameter involved in releasing manganese from bottom sediments (Delfino and Lee, 1971).

The pH of a water does not indicate ability to neutralize additions of acids or bases without appreciable change. This characteristic, termed "buffering capacity," is controlled by the amounts of alkalinity and acidity present.

RATIONALE:

Knowledge of pH in the raw water used for public water supplies is important because without adjustment to a suitable level, such waters may be corrosive and adversely affect treatment processes including coagulation and chlorination.

Coagulation for removal of colloidal color by use of aluminum or iron salts generally has an optimum pH range of 5.0 to 6.5 (Sawyer, 1960). Such optima are predicated upon the availability of sufficient alkalinity to complete the chemical reactions.

The effect of pH on chlorine in water principally is on the equilibrium between hypochlorous acid (HOCl) and the hypochlorite ion (OCl^-) according to the reaction:

$$HOCl = H^+ + OCl^-$$

Butterfield (1984) has shown that chlorine disinfection is more effective at values less than pH 7. Another study (Reid and Carlson, 1974) has indicated, however, that in natural waters no significant difference in the kill rate for Escherichia coli was

observed between pH 6 and pH 8.

Corrosion of plant equipment and piping in the distribution system can lead to expensive replacement as well as the introduction of metal ions such as copper, lead, zinc, and cadmium. Langelier (1936) developed a method to calculate and control water corrosive activity that employs calcium carbonate saturation theory and predicts whether the water would tend to dissolve or deposit calcium carbonate. By maintaining the pH at the proper level, the distribution system can be provided with a protective calcium carbonate lining which prevents metal pipe corrosion. Generally, this level is above pH 7 and frequently approaches pH 8.3, the point of maximum bicarbonate/carbonate buffering.

Since pH is relatively easily adjusted prior to and during water treatment, a rather wide range is acceptable for waters serving as a source of public water supply. A range of pH from 5.0 to 9.0 would provide a water treatable by typical (coagulation, sedimentation, filtration, and chlorination) treatment plant processes. As the range is extended, the cost of neutralizing chemicals increases.

A review of the effects of pH on fresh water fish has been published by the European Inland Fisheries Advisory Commission (1969). The commission concluded:

> There is no definite pH range within which a fishery is unharmed and outside which it is damaged, but rather, there is a gradual deterioration as the pH values are further removed from the normal range. The pH range which is not directly lethal to fish is 5 - 9; however, the toxicity of several common pollutants is markedly affected by pH changes within this range, and increasing acidity or alkalinity may make these poisons more toxic. Also, an acid discharge may liberate sufficient CO_2 from bicarbonate in the water either

to be directly toxic, or to cause the pH range 5 - 6 to become lethal.

Mount (1973) performed bioassays on the fathead minnow, Pimephales promelas, for a 13-month, one generation time period to determine chronic pH effects. Tests were run at pH levels of 4.5, 5.2.

pH Range	Effect on Fish*
5.0 - 6.0	Unlikely to be harmful to any species unless either the concentration of free CO_2 is greater than 20 ppm, or the water contains iron salts which are precipitated as ferric hydroxide, the toxicity of which is not known.
6.0 - 6.5	Unlikely to be harmful to fish unless free carbon dioxide is present in excess of 100 ppm.
6.5 - 9.0	Harmless to fish, although the toxicity of other poisons may be affected by changes within this range.

EIFAC, 1969

5.9, 6.6, and a control of 7.5. At the two lowest pH values (4.5 and 5.2) behavior was abnormal and the fish were deformed. At pH values less than 6.6, egg production and hatchability were reduced when compared with the control. It was concluded that a pH of 6.6 was marginal for vital life functions.

Bell (1971) performed bioassays with nymphs of caddisflies (two species) stoneflies (four species), dragonflies (two species), and mayflies (one species). All are important fish food organisms. The 30-day TL50 values ranged from 2.45 to 5.38 with the caddisflies being the most tolerant and the mayflies being the least tolerant. The pH values at which 50 percent of the organisms emerged ranged from 4.0 to 6.6 with increasing percentage emergence occurring with the increasing pH values.

Based on present evidence, a pH range of 6.5 to 9.0 appears to provide adequate protection for the life of freshwater fish and bottom dwelling invertebrates fish food organisms. Outside of this range, fish suffer adverse physiological effects increasing in severity as the degree of deviation increases until lethal levels are reached.

Conversely, rapid increases in pH can cause increased NH_3 concentrations that are also toxic. Ammonia has been shown to be 10 times as toxic at pH 8.0 as at pH 7.0 (EIFAC, 1969).

The chemistry of marine waters differs from that of fresh water because of the large concentration of salts present. In addition to alkalinity based on the carbonate system, there is also alkalinity from other weak acid salts such as borate. Because of the buffering system present in seawater, the

naturally occurring variability of pH is less than in fresh water. Some marine communities are more sensitive to pH change than others (NAS, 1974). Normal pH values in seawater are 8.0 to 8.2 at the surface, decreasing to 7.7 to 7.8 with increasing depth (Capurro, 1970). The NAS Committee's review (NAS, 1974) indicated that plankton and benthic invertebrates are probably more sensitive than fish to changes in pH and that mature forms and larvae of oysters are adversely affected at the extremes of the pH range of 6.5 to 9.0. However, in the shallow, biologically active waters in tropical or subtropical areas, large diurnal pH changes occur naturally because of photosynthesis. pH values may range from 9.5 in the daytime to 7.3 in the early morning before dawn. Apparently, these communities are adapted to such variations or intolerant species are able to avoid extremes by moving out of the area.

For open ocean waters where the depth is substantially greater than the euphotic zone, the pH should not be changed more than 0.2 units outside of the naturally occurring variation or in any case outside the range of 6.5 to 8.5. For shallow, highly productive coastal and estuarine areas where naturally occurring variations approach the lethal limits for some species, changes in pH should be avoided, but in any case not exceed the limits established for fresh water, i.e., pH of 6.5 to 9.0. As with freshwater criteria, rapid pH fluctuations that are caused by waste discharges should be avoided. Additional support for these limits is provided by Zirino and Yamamoto (1972). These investigators developed a model which illustrates the effects of variable pH on copper, zinc, cadmium, and lead; small changes in

pH cause large shifts in these metallic complexes. Such changes may affect toxicity of these metals.

For the industrial classifications considered, the NAS report (NAS, 1974) tabulated the range of pH values used by industry for various process and cooling purposes. In general, process waters used varied from pH 3.0 to 11.7, while cooling waters used varied from 5.0 to 8.9. Desirable pH values are undoubtedly closer to neutral to avoid corrosion and other deleterious chemical reactions. Waters with pH values outside these ranges are considered unusable for industrial purposes.

The pH of water applied for irrigation purposes is not normally a critical parameter. Compared with the large buffering capacity of the soil matrix, the pH of applied water is rapidly changed to approximately that of the soil. The greatest danger in acid soils is that metallic ions such as iron, manganese, or aluminum may be dissolved in concentrations which are subsequently directly toxic to plants. Under alkaline conditions, the danger to plants is the toxicity of sodium carbonates and bicarbonates either directly or indirectly (NAS, 1974).

To avoid undesirable effects in irrigation waters, the pH should not exceed a range of 4.5 to 9.0.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

PHENOL

CRITERIA:

Aquatic Life

The available data for phenol indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 10,200 and 2,560 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

The available data for phenol indicate that toxicity to saltwater aquatic life occurs at concentrations as low as 5,800 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of phenol to sensitive saltwater aquatic life.

Human Health

For comparison purposes, two approaches were used to derive criterion levels for phenol. Based on available toxicity data, to protect public health the derived level is 3.5 mg/L.

Using available organoleptic data, to control undesirable taste and odor qualities of ambient water the estimated level is 0.3 mg/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criterion, and have no demonstrated relationship to potential adverse human health effects.

NOTE: The U.S. EPA is currently developing Acceptable Daily Intake (ADI) or Verified Reference Dose (RfD) values for Agency-wide use for this chemical. The new value should be substituted when it becomes available. The January, 1986, draft Verified Reference Dose document cites an RfD of 0.1 mg/kg/day for phenol.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

PHOSPHORUS

CRITERION::

0.10 ug/L yellow (elemental) phosphorus for marine or estuarine water.

INTRODUCTION:

Phosphorus in the elemental form is particularly toxic and is subject to bioaccumulation in much the same way as mercury. Phosphorus as phosphate is one of the major nutrients required for plant nutrition and is essential for life. In excess of a critical concentration, phosphates stimulate plant growths. During the past 30 years, a formidable case has developed for the belief that increasing standing crops of aquatic plants, which often interfere with water uses and are nuisances to man, frequently are caused by increasing supplies of phosphorus. Such phenomena are associated with a condition of accelerated eutrophication or aging of waters. Generally, it is recognized that phosphorus is not the sole cause of eutrophication but there is substantiating evidence that frequently it is the key element of all of the elements required by freshwater plants, and generally, it is present in the least amount relative to need. Therefore, an increase in phosphorus allows use of other already present nutrients for plant growth. Further, of all of the elements required for plant growth in the water environment, phosphorus is the most easily controlled by man.

Large deposits of phosphate rock are found near the western shore of Central Florida, as well as in a number of other States. Deposits in Florida are found in the form of pebbles which vary

in size from fine sand to about the size of a human foot. These pebbles are embedded in a matrix of clay and sand. The phosphate rock beds lie within a few feet of the surface and mining is accomplished by using hydraulic water jets and a washing operation that separates the phosphates from waste materials. The process is similar to that of strip-mining. Florida, Idaho, Montana, North Carolina, South Carolina, Tennessee, Utah, Virginia, and Wyoming share phosphate mining activities.

Phosphates enter waterways from several different sources. The human body excretes about one pound per year of phosphorus expressed as "P". The use of phosphate detergents and other domestic phosphates increases the per capita contribution to about 3.5 pounds per year of phosphorus as P. Some industries, such as potato processing, have wastewaters high in phosphates. Crop, forest, idle, and urban land contribute varying amounts of phosphorus-diffused sources in drainage to watercourses. This drainage may be surface runoff of rainfall, effluent from tile lines, or return flow from irrigation. Cattle feedlots, concentrations of domestic duck or wild duck populations, tree leaves, and fallout from the atmosphere all are contributing sources.

Evidence indicates that: (1) high phosphorus concentrations are associated with accelerated eutrophication of waters, when other growth-promoting factors are present; (2) aquatic plant problems develop in reservoirs and other standing waters at phosphorus values lower than those critical in flowing streams; (3) reservoirs and lakes collect phosphates from influent streams

and store a portion of them within consolidated sediments, thus serving as a phosphate sink; and (4) phosphorus concentrations critical to noxious plant growth vary and nuisance growths may result from a particular concentration of phosphate in one geographical area but not in another. The amount or percentage of inflowing nutrients that may be retained by a lake or reservoir is variable and will depend upon: (1) the nutrient loading to the lake or resevoir; (2) the volume of the euphotic zone; (3) the extent of biological activities; (4) the detention time within a lake basin or the time available for biological activities; and (5) the level of discharge from the lake or of the penstock from the reservoir.

Once nutrients are combined within the aquatic ecosystem, their removal is tedious and expensive. Phosphates are used by algae and higher aquatic plants and may be stored in excess of use within the plant cell. With decomposition of the plant cell, some phosphorus may be released immediately through bacterial action for recycling within the biotic community, while the remainder may be deposited with sediments. Much of the material that combines with the consolidated sediments within the lake bottom is bound permanently and will not be recycled into the system.

RATIONALE:

Elemental Phosphorus

Isom (1960) reported an LC50 of 0.105 mg/L at 48 hours and 0.025 mg/L at 160 hours for bluegill sunfish, Lepomis macrochirus, exposed to yellow phosphorus in distilled water at

26 °C and pH 7. The 125-and 195-hour LC50's of yellow phosphorus to Atlantic cod, Gadus morhua, and Atlantic salmon, Salmo salar, smolts in continuous-exposure experiments were 1.89 and 0.79 ug/L, respectively (Fletcher and Hoyle, 1972). No evidence of an incipient lethal level was observed since the lowest concentration of P_4 tested was 0.79 ug/L. Salmon that were exposed to elemental phosphorus concentrations of 40 ug/L or less developed a distinct external red color and showed signs of extensive hemolysis. The predominant features of P_4 poisoning in salmon were external redness, hemolysis, and reduced hematocrits.

Following the opening of an elemental phosphorus production plant in Long Harbour, Placentia Bay, Newfoundland, divers observed dead fish upon the bottom throughout the Harbour (Peer, 1972). Mortalities were confined to a water depth of less than 18 meters. There was visual evidence of selective mortality among benthos. Live mussels were found within 300 meters of the effluent pipe, while all scallops within this area were dead.

Fish will concentrate elemental phosphorus from water containing as little as 1 ug/L (Idler, 1969). In one set of experiments, a cod swimming in water containing 1 ug/L elemental phosphorus for 18 hours concentrated phosphorus to 50 ug/kg in muscle, 150 ug/kg in fatty tissue, and 25,000 ug/kg in the liver (Idler, 1969; Jangaard, 1970). The experimental findings showed that phosphorus is quite stable in the fish tissues.

The criterion of 0.10 ug/L elemental phosphorus for marine or estuarine waters is .1 of demonstrated lethal levels to important marine organisms and of levels that have been found to result in significant bioaccumulation.

Phosphate Phosphorus

Although a total phosphorus criterion to control nuisance aquatic growths is not presented, it is believed that the following rationale to support such a criterion, which currently is evolving, should be considered.

Total phosphate phosphorus concentrations in excess of 100 ug/L P may interfere with coagulation in water treatment plants. When such concentrations exceed 25 ug/L at the time of the spring turnover on a volume-weighted basis in lakes or reservoirs, they may occasionally stimulate excessive or nuisance growths of algae and other aquatic plants. Algal growths inpart undesirable tastes and odors to water, interfere with water treatment, become aesthetically unpleasant, and alter the chemistry of the water supply. They contribute to the phenomenon of cultural eutrophication.

To prevent the development of biological nuisances and to control accelerated or cultural eutrophication, total phosphates as phosphorus (P) should not exceed 50 ug/L in any stream at the point where it enters any lake or reservoir, nor 25 ug/L within the lake or reservoir. A desired goal for the prevention of plant nuisances in streams or other flowing waters not discharging directly to lakes or impoundments is 100 ug/L total P (Mackenthun, 1973). Most relatively uncontaminated lake districts are known to have surface waters that contain from 10 to 30 ug/L total phosphorus as P (Hutchinson, 1957).

The majority of the Nation's eutrophication problems are associated with lakes or reservoirs and currently there are more

data to support the establishment of a limiting phosphorus level in those waters than in streams or rivers that do not directly impact such water. There are natural conditions, also, that would dictate the consideration of either a more or less stringent phosphorus level. Eutrophication problems may occur in waters where the phosphorus concentration is less than that indicated above and, obviously, such waters would need more stringent nutrient limits. Likewise, there are those waters within the Nation where phosphorus is not now a limiting nutrient and where the need for phosphorus limits is substantially diminished. Such conditions are described in the last paragraph of this rationale.

There are two basic needs in establishing a phosphorus criterion for flowing waters: one is to control the development of plant nuisances within the flowing water and, in turn, to control and prevent animal pests that may become associated with such plants; the other is to protect the downstream receiving waterway, regardless of its proximity in linear distance. It is evident that a portion of that phosphorus that enters a stream or other flowing waterway eventually will reach a receiving lake or estuary either as a component of the fluid mass, as bed load sediments that are carried downstream, or as floating organic materials that may drift just above the stream's bed or float on its water's surface. Superimposed on the loading from the inflowing waterway, a lake or estuary may receive additional phosphorus as fallout from the air shed or as a direct introduction from shoreline areas.

Another method to control the inflow of nutrients, particularly phosphates, into a lake is that of prescribing an annual loading to the receiving water. Vollenweider (1973) suggests total phosphorus (P) loadings in grams per square meter of surface area per year that will be a critical level for eutrophic conditions within the receiving waterway for a particular water volume where the mean depth of the lake in meters is divided by the hydraulic detention time in years. Vollenweider's data suggest a range of loading values that should result in oligotrophic lake water quality.

Mean Depth/Hydraulic Detention Time	Oligotrophic or Permissible Loading	Eutrophic or Critical Loading
(meters/year)	(grams/meter^2/year)	(grams/meter^2/year)
0.5	0.07	0.14
1.0	0.10	0.20
2.5	0.16	0.32
5.0	0.22	0.45
7.5	0.27	0.55
10.0	0.32	0.63
25.0	0.50	1.00
50.0	0.71	1.41
75.0	0.87	1.73
100.0	1.00	2.00

There may be waterways wherein higher concentrations or loadings of total phosphorus do not produce eutrophy, as well as those waterways wherein lower concentrations or loadings of total

phosphorus may be associated with populations of nuisance organisms. Waters now containing less than the specified amounts of phosphorus should not be degraded by the introduction of additional phosphates.

It should be recognized that a number of specific exceptions can occur to reduce the threat of phosphorus as a contributor to lake eutrophy: 1. Naturally occurring phenomena may limit the development of plant nuisances. 2. Technological or cost-effective limitations may help control introduced pollutants. 3. Waters may be highly laden with natural silts or colors which reduce the penetration of sunlight needed for plant photosynthesis. 4. Some waters morphometric features of steep banks, great depth, and substantial flows contribute to a history of no plant problems. 5. Waters may be managed primarily for waterfowl or other wildlife. 7. In some waters nutrient other than phosphorus is limiting to plant growth; the level and nature of such limiting nutrient would not be expected to increase to an extent that would influence eutrophication. 6. In some waters phosphorus control cannot be sufficiently effective under present technology to make phosphorus the limiting nutrient.

No national criterion is presented for phosphate phosphorus for the control of eutrophication.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

PHTHALATE ESTERS

CRITERIA:

Aquatic Life

The available data for phthalate esters indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 940 and 3 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

The available data for phthalate esters indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 2,944 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of phthalate esters to sensitive saltwater aquatic life but toxicity to one species of algae occurs at concentrations as low as 3.4 ug/L.

Human Health

For the protection of human health from the toxic properties of dimethyl phthalate ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 313 mg/L.

For the protection of human health from the toxic properties of dimethyl phthalate ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 2.9 g/l.

For the protection of human health from the toxic properties of diethyl phthalate ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 350 mg/L.

For the protection of human health from the toxic properties of diethyl phthalate ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 1.8 g/l.

For the protection of human health from the toxic properties of dibutyl phthalate ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 34 mg/L.

For the protection of human health from the toxic properties of dibutyl phthalate ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 154 mg/L.

For the protection of human health from the toxic properties of di-2-ethylhexyl phthalate ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 15 mg/L.

For the protection of human health from the toxic properties of di-2-ethylhexyl phthalate ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 50 mg/L.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

POLYCHLORINATED BIPHENYLS

CRITERIA:

Aquatic Life

For polychlorinated biphenyls the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.014 ug/L as a 24-hour average. The concentration of 0.014 ug/L is probably too high because it is based on bioconcentration factors measured in laboratory studies, but field studies apparently produce factors at least 10 times higher for fishes. The available data indicate that acute toxicity to freshwater aquatic life probably will occur only at concentrations above 2.0 ug/L and that the 24-hour average should provide adequate protection against acute toxicity.

For polychlorinated biphenyls the criterion to protect saltwater aquatic life as derived using the Guidelines is 0.030 ug/L as a 24-hour average. The concentration of 0.030 ug/L is probably too high because it is based on bioconcentration factors measured in laboratory studies, but field studies apparently produce factors at least 10 times higher for fishes. The available data indicate that acute toxicity to saltwater aquatic life probably will only occur at concentrations above 10 ug/L and that the 24-hour average criterion should provide adequate protection against acute toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to polychlorinated biphenyls through ingestion of contaminated water and contaminated aquatic

organisms, the ambient water concentration should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 0.79 ng/L, 0.079 ng/L, and 0.0079 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 0.79 ng/L, 0.079 ng/L, and 0.0079 ng/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

POLYNUCLEAR AROMATIC HYDROCARBONS

CRITERIA:

Aquatic Life

The limited freshwater data base available for polynuclear aromatic hydrocarbons, mostly from short-term bioconcentration studies with two compounds, does not permit a statement concerning acute or chronic toxicity.

The available data for polynuclear aromatic hydrocarbons indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 300 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of polynuclear aromatic hydrocarbons to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to polynuclear aromatic hydrocarbons through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 28.0 ng/L, 2.8 ng/L, and 0.28 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 311.0 ng/L,

31.1 ng/L, and 3.11 ng/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

SELENIUM

CRITERIA:

Aquatic Life

For total recoverable inorganic selenite the criterion to protect freshwater aquatic life as derived using the Guidelines is 35 ug/L as a 24-hour average, and the concentration should not exceed 260 ug/L at any time.

For total recoverable inorganic selenite the criterion to protect saltwater aquatic life as derived using the Guidelines is 54 ug/L as a 24-hour average, and the concentration should not exceed 410 ug/L at any time.

The available data for inorganic selenate indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 760 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of inorganic selenate to sensitive freshwater aquatic life.

No data are available concerning the toxicity of inorganic selenate to saltwater aquatic life.

Human Health

The ambient water quality criterion for selenium is recommended to be identical to the existing water standard which is 10 ug/L. Analysis of the toxic effects data resulted in a calculated level which is protective of human health against the ingestion of contaminated water and contaminated aquatic organisms. The calculated value is comparable to the present

standard. For this reason a selective criterion based on exposure solely from consumption of 6.5 grams of aquatic organisms was not derived.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

SILVER

CRITERIA:

Aquatic Life

For freshwater aquatic life the concentration (in ug/L) of total recoverable silver should not exceed the numerical value given by $^{e}(1.72[\ln(\text{hardness})]-6.52)$ at any time. For example, at hardnesses of 50, 100, and 200 mg/L as $CaCO^3$, the concentration of total recoverable silver should not exceed 1.2, 4.1, and 13 ug/L, respectively, at any time. The available data indicate that chronic toxicity to freshwater aquatic life may occur at concentrations as low as 0.12 ug/L.

For saltwater aquatic life the concentration of total recoverable silver should not exceed 2.3 ug/L at any time. No data are available concerning the chronic toxicity of silver to sensitive saltwater aquatic life.

Human Health

The ambient water quality criterion for silver is recommended to be identical to the existing water standard, which is 50 ug/L. Analysis of the toxic effects data resulted in a calculated level which is protective of human health against the ingestion of contaminated water and contaminated aquatic organisms. The calculated value is comparable to the present standard. For this reason a selective criterion based on exposure solely from consumption of 6.5 grams of aquatic organisms was not derived.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

SOLIDS (DISSOLVED) AND SALINITY

CRITERION:

250 mg/L for chlorides and sulfates
in domestic water supplies (welfare).

INTRODUCTION:

Dissolved solids and total dissolved solids are terms generally associated with freshwater systems and consist of inorganic salts, small amounts of organic matter, and dissolved materials (Sawyer, 1960). The equivalent terminology in Standard Methods is filtrable residue (Standard Methods, 1971). Salinity is an oceanographic term, and although not precisely equivalent to the total dissolved salt content it is related to it (Capurro, 1970). For most purposes, the terms total dissolved salt content and salinity are equivalent. The principal inorganic anions dissolved in water include the carbonates, chlorides, sulfates, and nitrates (principally in ground waters); the principal cations are sodium, potassium, calcium, and magnesium.

RATIONALE:

Excess dissolved solids are objectionable in drinking water because of possible physiological effects, unpalatable mineral tastes, and higher costs because of corrosion or the necessity for additional treatment.

The physiological effects directly related to dissolved solids include laxative effects principally from sodium sulfate and magnesium sulfate and the adverse effect of sodium on certain patients afflicted with cardiac disease and women with toxemia associated with pregnancy. One study was made using data

collected from wells in North Dakota. Results from a questionnaire showed that with wells in which sulfates ranged from 1,000 to 1,500 mg/L, 62 percent of the respondents indicated laxative effects associated with consumption of the water. However, nearly one-quarter of the respondents to the questionnaire reported difficulties when concentrations ranged from 200 to 500 mg/L (Moore, 1952). To protect transients to an area, a sulfate level of 250 mg/L should afford reasonable protection from laxative effects.

As indicated, sodium frequently is the principal component of dissolved solids. Persons on restricted sodium diets may have an intake restricted from 500 to 1,000 mg/day (Nat. Res. Coun., 1954). That portion ingested in water must be compensated by reduced levels in food ingested so that the total does not exceed the allowable intake. Using certain assumptions of water intake (e.g., 2 liters of water consumed per day) and sodium content of food, it has been calculated that for very restricted sodium diets, 20 mg/L in water would be the maximum, while for moderately restricted diets, 270 mg/L would be maximum. Specific sodium levels for entire water supplies have not been recommended but various restricted sodium intakes are recommended because: (1) the general population is not adversely affected by sodium, but various restricted sodium intakes are recommended by physicians for a significant portion of the population, and (2) 270 mg/L of sodium is representative of mineralized waters that may be aesthetically unacceptable, but many domestic water supplies exceed this level. Treatment for removal of sodium in

water supplies is costly (NAS, 1974).

A study based on consumer surveys in 29 California water systems was made to measure the taste threshold of dissolved salts in water (Bruvold et al., 1969). Systems were selected to eliminate possible interferences from other taste-causing substances than dissolved salts. The study revealed that consumers rated waters with 319 to 397 mg/L dissolved solids as "excellent" while those with 1,283 to 1,333 mg/L dissolved solids were "unacceptable" depending on the rating system used. A "good" rating was registered for dissolved solids less than 658 to 755 mg/L. The 1962 PHS Drinking Water Standards recommended a maximum dissolved solids concentration of 500 mg/L unless more suitable supplies were unavailable.

Specific constituents included in the dissolved solids in water may cause mineral tastes at lower concentrations than other constituents. Chloride ions have frequently been cited as having a low taste threshold in water. Data from Ricter and MacLean (1939) on a taste panel of 53 adults indicated that 61 mg/L NaCl was the median level for detecting a difference from distilled water. At a median concentration of 395 mg/L chloride a salty taste was distinguishable, although the range was from 120 to 1,215 mg/L. Lockhart, et al. 1955) evaluated the effect of chlorides on water used for brewing coffee indicated threshold concentrations for chloride ranging from 210 mg/L to 310 mg/L depending on the associated cation. These data indicate that a level of 250 mg/L chlorides is a reasonable maximum level to protect consumers of drinking water.

The causation of corrosion and encrustation of metallic surfaces by water containing dissolved solids is well known. In water distribution systems corrosion is controlled by insulating dissimilar metal connections by nonmetallic materials, using pH control and corrosion inhibitors, or some form of galvanic or impressed electrical current systems (Lehmann, 1964). In household systems water piping, wastewater piping, water heaters, faucets, toilet flushing mechanisms, garbage grinders and both clothes and dishwashing machines incure damage.

By using water with 1,750 mg/L dissolved solids as compared with 250 mg/L, service life was reduced from 70 percent for toilet flushing mechanisms to 30 percent for washing equipment. Such increased corrosion was calculated in 1968 to cost the consumer an additional $0.50 per 1,000 gallons used.

All species of fish and other aquatic life must tolerate a range of dissolved solids concentrations in order to survive under natural conditions. Based on studies in Saskatchewan it has been indicated that several common freshwater species survived 10,000 mg/L dissolved solids, that whitefish and pike-perch survived 15,000 mg/L, but only the stickleback survived 20,000 mg/L dissolved solids. It was concluded that lakes with dissolved solids in excess of 15,000 mg/L were unsuitable for most freshwater fishes (Rawson and Moore, 1944). The 1968 NTAC Report also recommended maintaining osmotic pressure levels of less than that caused by a 15,000 mg/L solution of sodium chloride.

Marine fishes also exhibit variance in ability to tolerate salinity changes. However, fishkills in Laguna Madre off the Texas coast have occurred with salinities in the range of 75 to 100 o/oo. Such concentrated seawater is caused by evaporation and lack of exchange with the Gulf of Mexico (Rounsafell and Everhart, 1953).

Estuarine species of fish are tolerant of salinity changes ranging from fresh to brackish to seawater. Anadromous species likewise are tolerant although evidence indicates that the young cannot tolerate the change until the normal time of migration (Rounsefell and Everhart, 1953). Other aquatic species are more dependent on salinity for protection from predators or require certain minimal salinities for successful hatching of eggs. The oyster drill cannot tolerate salinities less than 12.5 o/oo. Therefore, estuarine segments containing salinities below about 12.5 o/oo produce most of the seed oysters for planting (Rounsefell and Everhart, 1953). Based on similar examples, the 1968 NTAC Report recommended that to protect fish and other marine animals no changes in hydrography or stream flow should be allowed that permanently change isohaline patterns in the estuary by more than 10 percent from natural variation.

Many of the recommended game bird levels for dissolved solids concentrations in drinking water have been extrapolated from data collected on domestic species such as chickens. However, young ducklings were reported poisoned in Suisan Marsh by salt when maximum summer salinities varied from 0.55 to 1.74 o/oo with means as high as 1.26 o/oo (Griffith, 1963).

Indirect effects of excess dissolved solids are primarily the elimination of desirable food plants and other habitat-forming plants. Rapid salinity changes cause plasmolysis of tender leaves and stems because of changes in osmotic pressure. The 1968 NTAC Report recommended the following limits in salinity variation from natural to protect wildlife habitats:

Natural Salinity (o/oo)	Variation Permitted (o/oo)
0 to 3.5	1
3.5 to 13.5	2
13.5 to 35	4

Agricultural uses of water are also limited by excessive dissolved solids concentrations. Studies have indicated that chickens, swine, cattle, and sheep can survive on saline waters up to 15,000 mg/L of salts of sodium and calcium combined with bicarbonates, chlorides, and sulfates but only 10,000 mg/L of corresponding salts of potassium and magnesium. The approximate limit for highly alkaline waters containing sodium and calcium carbonates is 5,000 mg/L (NTAC, 1968).

Irrigation use of water depends not only upon the osmotic effect of dissolved solids, but also on the ratio of the various cations present. In arid and semiarid areas general classification of salinity hazards has been prepared (NTAC, 1968) (see Table 9).

Table 9.-Dissolved Solids Hazard for Irrigation Water (mg/L).

water from which no detrimental effects will usually be noticed----------	500

water which can have detrimental effects on sensitive crops----------	500-1,000
water that may have adverse effects on many crops and requires careful management Practices----------	1,000-2,000
water that can be used for tolerant plants on permeable soils with careful management practices----------	2,000-5,000

The amount of sodium and the percentage of sodium in relation to other cations are often important. In addition to contributing to osmotic pressure, sodium is toxic to certain plants, especially fruits, and frequently causes problems in soil structure, infiltration, and permeability rates (Agriculture Handbook #60, 1954). A high percentage of exchangeable sodium in soils containing clays that swell when wet can cause a soil condition adverse to water movement and plant growth. The exchangeable-sodium percentage (ESP)* is an index of the sodium status of soils. An ESP of 10 to 15 percent is considered excessive if a high percentage of swelling clay minerals is present (Agricultural Handbook #60, 1954).

For sensitive fruits, the tolerance for sodium for irrigation water is for a sodium adsorption ratio (SAR)** of about 4, whereas for general crops and forages a range of 8 to 18 is generally considered usable (NTAC, 1968). It is emphasized that application of these factors must be interpreted in relation to specific soil conditions existing in a given locale and therefore frequently requires field investigation.

Industrial requirements regarding the dissolved solids content of raw waters is quite variable. Table 10 indicates

Table 10.-Total Dissolved Solids Concentrations of Surface Waters That Have Been Used as Sources for Industrial Water Supplies

Industry/Use	Maximum Concentration (mg/L)
Textile	150
Pulp and Paper	1,080
Chemical	2,500
Petroleum	3,500
Primary Metals	1,500
Boiler Make-up	35,000

maximum values accepted by various industries for process requirements (NAS, 1974). Since water of almost any dissolved solids concentration can be de-ionized to meet the most stringent requirements, the economics of such treatment are the limiting factor for industry.

$$*ESP = \frac{100\ [a + b(SAR)]}{1\ \ [a + b(SAR)]}$$

where: a = intercept respresenting experimental error (ranges from -0.06 to 0.01)
b = slope of regression line (ranges from 0.014 to 0.016)

$$**SAR = \text{sodium adsorption ratio} = \frac{Na}{[0.5(Ca + Mg)]^{0.5}}$$

SAR is expressed as milliequivalents

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

SOLIDS (SUSPENDED, SETTLEABLE) AND TURBIDITY

CRITERIA

Freshwater fish and other aquatic life:

Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life.

INTRODUCTION:

The term "suspended and settleable solids" is descriptive of the organic and inorganic particulate matter in water. The equivalent terminology used for solids in Standard Methods (APHA, 1971) is total suspended matter for suspended solids, settleable matter for settleable solids, volatile suspended matter for volatile solids and fixed suspended matter for fixed suspended solids. The term "solids" is used in this discussion because of its more common use in the water pollution control literature.

RATIONALE:

Suspended solids and turbidity are important parameters in both municipal and industrial water supply practices. Finished drinking waters have a maximum limit of 1 turbidity unit where the water enters the distribution system. This limit is based on health considerations as it relates to effective chlorine disinfection. Suspended matter provides areas where microorganisms do not come into contact with the chlorine disinfectant (NAS,1974). The ability of common water treatment processes (i.e., coagulation, sedimentation, filtration, and chlorination) to remove suspended matter to achieve acceptable final turbidities is a function of the composition of the material as well as its concentration. Because of the variability

of such removal efficiency, it is not possible to delineate a general raw water criterion for these uses.

Turbid water interferes with recreational use and aesthetic enjoyment of water. Turbid waters can be dangerous for swimming, especially if diving facilities are provided, because ofthe possibility of unseen submerged hazards and the difficulty in locating swimmers in danger of drowning (NAS, 1974). The less turbid the water the more desirable it becomes for swimming and other water contact sports. Other recreational pursuits such as boating and fishing will be adequately protected by suspended solids criteria developed for protection of fish and other aquatic life.

Fish and other aquatic life requirements concerning suspended solids can be divided into those whose effect occurs in the water column and those whose effect occurs following sedimentation to the bottom of the water body. Noted effects are similar for both fresh and marine waters.

The effects of suspended solids on fish have been reviewed by the European Inland Fisheries Advisory Commission (EIFAC, 1965). This review in 1965 identified four effects on the fish and fish food populations, namely:

(1) by acting directly on the fish swimming in water in which solids are suspended, and either killing them or reducing their growth rate, resistance to disease, etc.;

(2) by preventing the successful development of fish eggs and larvae;

(3) by modifying natural movements and migrations of fish;

(4) by reducing the abundance of food available to the fish;...

Settleable materials which blanket the bottom of water bodies damage the invertebrate populations, block gravel spawning beds, and if organic, remove dissolved oxygen from overlying waters (ElFAC, 1965; Edberg and Hofsten, 1973). In a study downstream from the discharge of a rock quarry where inert suspended solids were increased to 80 mg/L, the density of macroinvertebrates decreased by 60 percent while in areas of sediment accumulation benthic invertebrate populations also decreased by 60 percent regardless of the suspended solid concantrations (Gammon, 1970). Similar effects have been reported downstream from an area which was intensively logged. Major increases in stream suspended solids (25 ppm turbidity upstream versus 390 ppm downstream) caused smothering of bottom invertebrates, reducing organism density to only 7.3 per square foot versus 25.5 per square foot upstraam (Tebo, 1955).

When settleable solids block gravel spawning beds which contain eggs, high mortalities result although there is evidence that some species of salmonids will not spawn in such areas (EIFAC, 1965).

It has been postulated that silt attached to the eggs prevents sufficient exchange of oxygen and carbon dioxide between the egg and the overlying water. The important variables are particle size, stream velocity, and degree of turbulence (EIFAC, 1965).

Deposition of organic materials to the bottom sediments can cause imbalances in stream biota by increasing bottom animal density principally worm populations, and diversity is reduced as pollution-sensitive forms disappear (Mackenthun, 1973). Algae likewise flourish in such nutrient-rich areas although forms may become less desirable (Tarzwell and Gaufin, 1953).

Plankton and inorganic suspended materials reduce light penetration into the water body, reducing the depth of thephotic zone. This reduces primary production and decreases fish food. The NAS commitee in 1974 recommended that the depth of light penetration not be reduced by more than 10 percent (NAS, 1974). Additionally, the near surface waters are heated because of the greater heat absorbency of the particulate material which tends to stabilize the water column and prevents vertical mixing (NAS, 1974). Such mixing reductions decrease the dispersion of dissolved oxygen and nutrients to lower portions of the water body.

One partially offsetting benefit of suspended inorganic material in water is the sorption of organic materials such as pesticides. Following this sorption process subsequent sedimentation may remove these materials from the water column into the sediments (NAS, 1974).

Identifiable effects of suspended solids on irrigation use of water include the formation of crusts on top of the soil which inhibits water infiltration and plant emergence, and impedes soil aeration; the formation of films on plant leaves which blocks sunlight and impedes photosynthesis and which may reduce the

marketability of some leafy crops like lettuce, and finally the adverse effect on irrigation reservoir capacity, delivery canals, and other distribution equipment (NAS, 1974).

The criterion for freshwater fish and other aquatic lifeare essentially that proposed by the National Academy of Sciences and the Great Lakes Water Quality Board.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

SULFIDE - HYDROGEN SULFIDE

CRITERION:

2 ug/L undissociated H_2S for fish and other aquatic life, fresh and marine water.

INTRODUCTION:

Hydrogen sulfide is a soluble, highly poisonous, gaseous compound having the characteristic odor of rotten eggs. It is detectable in air by humans at a dilution of 0.002 ppm. It will dissolve in water at 4,000 mg/L at 20° C and one atmosphere of pressure. Hydrogen sulfide biologically is an active compound that is found primarily as an anaerobic degradation product of both organic sulfur compounds and inorganic sulfates. Sulfides are constituents of many industrial wastes such as those from tanneries, paper mills, chemical plants, and gas works. The anaerobic decomposition of sewage, sludge beds, algae, and other naturally deposited organic material is a major source of hydrogen sulfide.

When soluble sulfides are added to water they react with hydrogen ions to form HS or H_2S, the proportion of each depending on the pH. The toxicity of sulfides derives primarily from H_2S rather than from the hydrosulfide (HS^-) or sulfide ($S^{=}$) ions. When hydrogen sulfide dissolves in water it dissociates according to the reactions:

$$H_2S \quad HS_- + H_+ \quad \text{and} \quad HS_- \quad S_= + H_+$$

At pH 9 about 99 percent of the sulfide is in the form of HS_-, at pH 7 the sulfide is equally divided between HS_- and H_2S; and at pH 5 about 99 percent of the sulfide is present as H_2S (NAS

1974). The fact that H_2S is oxidized in well-aerated water by natural biological systems to sulfates or is biologically oxidized to elemental sulfur has caused investigators to minimize the toxic effects of H_2S on fish and other aquatic life.

RATIONALE:

The degree of hazard exhibited by sulfide to aquatic animal life is dependent on the temperature, pH, and dissolved oxygen. At lower pH values a greater proportion is in the form of the toxic undissociated H_2S. In winter when the pH is neutral or below or when dissolved oxygen levels are low but not lethal to fish, the hazard from sulfides is exacerbated. Fish exhibit a strong avoidance reaction to sulfide. Based on data from experiments with the stickleback, Jones (1964) hypothesized that if fish encounter a lethal concentration of sulfide there is a reasonable chance they will be repelled by it before they are harmed. This, of course, assumes that an escape route is open.

Many past data on the toxicity of hydrogen sulfide to fish and other aquatic life have been based on extremely short exposure periods. Consequently, these early data have indicated that concentrations between 0.3 and 0.4 mg/L permit fish to survive (Van Horn 1958, Boon and Follis 1967, Theede et al., 1969). Recent long-term data, both in field situations and under controlled laboratory conditions, demonstrate hydrogen sulfide toxicity at lower concentrations.

Colby and Smith (1967) found that concentrations as high as 0.7 mg/L have been found within 20 mm of the bottom of sludge beds, and the levels of 0.1 to 0.02 mg/L were common within the

first 20 mm of water above this layer. Walleye (Stizostedion vitreum) eggs held in trays in this zone did not hatch. Adelman and Smith (1970) reported that the hatchability of northern pike (Esox lucius) eggs was substantially reduced at 25 ug/L H_2S; at 47 ug/L mortality was almost complete. Northern pike fry had 96-hour LC50 values that varied from 17 to 32 ug/L at normal oxygen levels of 6.0 mg/L. The highest concentration of hydrogen sulfide that had no observable effect on eggs and fry was 14 and 4 ug/L, respectively. Smith and Oseid (1972), working on eggs, fry and juveniles of walleyes and white suckers (Catostomus commersoni) and Smith (1971), Safe levels in working on walleyes and fathead minnows, Pimephales promelas, were found to vary from 2.9 ug/L to 12 ug/L with eggs being the least sensitive and juveniles being the most sensitive in short-term tests. In 96-hour bioassays, fathead minnows and goldfish, Carassius auratus, varied greatly in tolerance to hydrogen sulfide with changes in temperature. They were more tolerant at low temperatures (6 to 10_o C). Holland, et al. (1960) reported that 1.0 mg/L sulfide caused 100 percent mortality in 72 hours with Pacific salmon.

On the basis of chronic tests evaluating growth and survival, the safe H_2S level for bluegill (Lepomis macrochirus) juveniles and adults was 2 ug/L. Egg deposition in bluegills was reduced after 46 days in 1.4 ug/L H_2S (Smith and Oseid, 1974). White sucker eggs were hatched at 15 ug/L, but juveniles showed growth reductions at 1 ug/L. Safe level for fathead minnows were between 2 and 3 ug/L. Studies showed that safe levels for Gammarus Pseudolimnaeus and Hexagenia limbata were 2 and 15 ug/L, respectively (Oseid and Smith, 1974a, 1974b). Some species

typical of normally stressed habitats, Asellus spp., were much more resistant (Oseid and Smith, 1974c).

Sulfide criteria for domestic or livestock use have not been established because the unpleasant odor and taste would preclude such use at hazardous concentrations.

It is recognized that the hazard from hydrogen sulfide to aquatic life is often localized and transient. Available data indicate that water containing concentrations of 2.0 ug/L undissociated H_2S would not be hazardous to most fish and other aquatic wildlife, but concentrations in excess of 2.0 ug/L would constitute a long-term hazard.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

TAINTING SUBSTANCES

CRITERION:

Materials should not be present in concentrations that individually or in combination produce undesirable flavors which are detectable by organoleptic tests performed on the edible portions of aquatic organisms.

RATIONALE:

Fish or shellfish with abnormal flavors, colors, tastes or odors are either not marketable or will result in consumer complaints and possible rejection of the food source even though subsequent lots of organisms may be acceptable. Poor product quality can and has seriously affected or eliminated the commercial fishing industry in some areas. Recreational fishing also can be affected adversely by off-flavored fish. For the majority of sport fishermen, the consumption of their catch is part of their recreation and off-flavored catches can result in diversion of the sportsmen to other water bodies. This can have serious economic impact on the established recreation industries such as tackle and bait sales and boat and cottage rental.

Water Quality Criteria, 1972 (NAS, 1974) lists a number of wastewaters and chemical compounds that have been found to lower the palatability of fish flesh. Implicated wastewaters included those from 2,4-D manufacturing plants, kraft and neutral sulfite pulping processes, municipal wastewater treatment plants, oily wastes, refinery wastes, phenolic wastes, and wastes from slaughterhouses. The list of implicated chemical compounds is long: it includes cresol and phenol compounds, kerosene, naphthol, styrene, toluene, and exhaust outboard motor fuel. As little as 0.1 ug/L o-chlorophenol was reported to cause tainting

of fish flesh.

Shumway and Palensky 1973) determined estimated threshold concentrations for 22 organic compounds. The values ranged from 0.4 ug/L (2,4-dichlorophenol) to 95,000 ug/L (formaldehyde). An additional 12 compounds were tested, 7 of which were not found to impair flavor at or near lethal levels.

Thomas (1973) reviewed the literature review on tainting substances revealed serious problems that have occurred. Detailed studies and methodology used to evaluate the palatability of fishes in the Ohio River as affected by various waste discharges showed that the susceptibility of fishes to the accumulation of tainting substances is variable and dependent upon the species, length of exposure, and the pollutant. As little as 5 ug/L of gasoline can impart off-flavors to fish (Boyle, 1967).

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

TEMPERATURE

CRITERIA:

Freshwater Aquatic Life

For any time of year, there are two upper limiting temperatures for a location (based on the important sensitive species found there at that time):

1. One limit consists of a maximum temperature for short exposures that is time dependent and is given by the species-specific equation:

$$\text{Temperature}_{(C_o)} = (1/b)(\log_{10}[\text{time}_{(\text{min})}] - a) - 2_o\,C$$

where: $\log_{10}$ = logarithm to base 10 (common logarithm)

a = intercept on the "y" or logarithmic axis of the line fitted to experimental data and which is available for some species from Appendix II-C, National Academy of Sciences 1974 document.

b = slope of the line fitted to experimental data and available for some species from Appendix II-C, of the National Academy of Sciences document.

and

2. The second value is a limit on the weekly average temperature that:

a. In the cooler months (mid-October to mid-April in the north and December to February in the south) will protect against mortality of importr to mid-April in the north and December to February in the south) will protect against mortality of important species if the elevated plume temperature is suddenly dropped to the ambient temperature, with the limit being the

acclimation temperature minus 2Pto C when the lower lethal threshold temperature equals the ambient water temperature (in some regions this limitation may also be applicable in summer).

or

b. In the warmer months (April through October in the north and March through November in the south) is determined by adding to the physiological optimum temperature (usually for growth) a factor calculated as one-third of the difference between the ultimate upper incipient lethal temperature and the optimum temperature for the most sensitive important species (and appropriate life state) that normally is found at that location and time.

or

c. During reproductive seasons (generally April through June and September through October in the north and March through May and October through November in the south) the limit is that temperature that meets site-specific requirements for successful migration, spawning, egg incubation, fry rearing, and other reproductive functions of important species. These local requirements should supersede all other requirements when they are applicable.

or

d. There is a site-specific limit that is found necessary to preserve normal species diversity or prevent appearance of nuisance organisms.

Marine Aquatic Life

In order to assure protection of the characteristic indigenous marine community of a water body segment from adverse thermal effects:

a. the maximum acceptable increase in the weekly average temperature resulting from artificial sources is 1^{o} C (1.8 F) during all seasonsofthe year, providing the summer maxima are not exceeded; and

b. daily temperature cycles characteristic of the water body segment should not be altered in either amplitude or frequency.

Summer thermal maxima, which define the upper thermal limits for the communities of the discharge area, should be established on a site-specific basis. Existing studies suggest the following regional limits:

	Short-term Maximum	Maximum True Daily Mean*
Sub tropical regions (south of Cape Canaveral and Tampa Bay, Florida, and Hawaii	32.2° C (90° F)	29.4° C (85° F)
Cape Hatteras, N.C., to Cape Canaveral, Fla.	32.2° C (90° F)	29.4° C (85° F)
Long Island (south shore) to Cape Hatteras, N.C.	30.6° C (87° F)	27.8° C (82° F)

(* True Daily Mean = average of 24 hourly temperature readings.)

Baseline thermal conditions should be measured at a site where there is no unnatural thermal addition from any source, which is in reasonable proximity to the thermal discharge (within 5 miles) and which has similar hydrography to that of the receiving waters at the discharge.

INTRODUCTION:

The uses of water by man in and out of its natural situs in the environment are affected by its temperature. Offstream domestic uses and instream recreation are both partially temperature dependent. Likewise, the life associated with the aquatic environment in any location has its species composition and activity regulated by water temperature. Since essentially all of these organisms are so-called "cold blooded" or poikilotherms, the temperature of the water regulates their metabolism and ability to survive and reproduce effectively. Industrial uses for process water and for coolingare likewise regulated by the water's temperature. Temperature, therefore, is an important physical parameter which to some extent regulates many of the beneficial uses of water. The Federal Water Pollution Control Administration in 1967 called temperature a

catalyst, a depressant, an activator, a restrictor, a stimulator, a controller, a killer, one of the most important and most influential water quality characteristics to life in water."

RATIONALE:

The suitability of water for total body immersion is greatly affected by temperature. In temperate climates, dangers from exposure to low temperatures is more prevalent than exposure to elevated water temperatures. Depending on the amount of activity by the swimmer, comfortable temperatures range from 20° C to 30° C. Short durations of lower and higher temperatures can be tolerated by most individuals. For example, for a 30-minute period, temperatures of 10° C or 35° C can be tolerated without harm by most individuals (NAS, 1974).

Temperature also affects the self-purification phenomenon in water bodies and therefore the aesthetic and sanitary qualities that exist. Increased temperatures accelerate the biodegradation of organic material both in the overlying water and in bottom deposits which makes increased demands on the dissolved oxygen resources of a given system. The typical situation is exacerbated by the fact that oxygen becomes less soluble as water temperature increases. Thus, greater demands are exerted on an increasingly scarce resource which may lead to total oxygen depletion and obnoxious septic conditions. These effects have been described by Phelps (1944), Carp (1963), and Velz (1970).

Indicator enteric bacteria, and presumably enteric pathogens, are likewise affected by temperature. It has been shown that both total and fecal coliform bacteria die away more rapidly in the environment with increasing temperatures (Ballentine and

Kittrell, 1968).

Temperature effects have been shown for water treatment processes. Lower temperatures reduce the effectiveness of coagulation with alum and subsequent rapid sand filtration. In one study, difficulty was especially pronounced below 5° C (Hannah, et al., 1967). Decreased temperature also decreases the effectiveness of chlorination. Based on studies relating chlorine dosage to temperature, and with a 30-minute contact time, dosages required for equivalent disinfective effect increased by as much as a factor of 3 when temperatures were decreased from 20° C to 10° C (Reid and Carlson, 1974). Increased temperature may increase the odor of water because of the increased volatility of odor-causing compounds (Bumson, 1938). Odor problems associated with plankton may also be aggravated.

The effects of temperature on aquatic organisms have been the subject of comprehensive literature reviews (Brett, 1956; Fry, 1967; FWPCA, 1967; Kine, 1970) and annual literature reviews published by the Water Pollution Control Federation (Coutant, 1968, 1969, 1970, 1971; Coutant and Goodyear, 1972; Coutant and Pfuderer, 1973, 1974). Only highlights from the thermal effects on aquatic life are presented here.

Temperature changes in water bodies can alter the existing aquatic community. The dominance of various phytoplankton groups in specific temperature ranges has been shown. For example, from 20° C to 25° C, diatoms predominated; green algae predominated from 30° C; to 35° C and blue-greens predominated above 35° C

(Cairns, 1956). Likewise, changes from a coldwater fishery to a warm-water fishery can occur because temperature may be directly lethal to adults or fry cause a reduction of activity or limit reproduction (Brett, 1960).

Upper and lower limits for temperature have been established for many aquatic organisms. Considerably more data exist for upper as opposed to lower limits. Tabulations of lethal temperatures for fish and other organisms are available (Jones, 1964: FWPCA, 1967 NAS, 1974). Factors such as diet, activity, age, general health, osmotic stress, and even weather contribute to the lethality of temperature. The aquatic species, thermal accumulation state and exposure time are considered the critical factors (Parker and Krenkel, 1969).

The effects of sublethal temperatures on metabolism, respiration, behavior, distribution and migration, feeding rate, growth, and reproduction have been summarized by De Sylva (1969). Another study has illustrated that inside the tolerance zone there is encompassed a more restrictive temperature range in which normal activity and growth occur and yet an even more restrictive zone inside that in which normal reproduction will occur (Brett, 1960).

De Sylva (1969) has summarized available data on the combined effects of increased temperature and toxic materials on fish indicate that toxicity generally increases with increased temperature and that organisms subjected to stress from toxic materials are less tolerant of temperature extremes.

The tolerance of organisms to extremes of temperature is a function of their genetic ability to adapt to thermal changes

within their characteristic temperature range, the acclimation temperature prior to exposure, and the time of exposure to the elevated temperature (Coutant, 1972). The upper incipient lethal temperature or the highest temperature that 50 percent of a sample of organisms can survive is determined on the organism at the highest sustainable acclimation temperature. The lowest temperature that 50 percent of the warm acclimated organisms can survive in is the ultimate lower incipient lethal temperature. True acclimation to changing temperatures requires several days (Brett, 1941). The lower end of the temperature accommodation range for aquatic life is 0^{o} C in fresh water and somewhat less for saline waters. However, organisms acclimated to relatively warm water, when subjected to reduced temperatures that under other conditions of acclimation would not be detrimental, may suffer a significant mortality caused by thermal shock (Coutant, 1972).

Through the natural changes in climatic conditions, the temperatures of water bodies fluctuate daily, as well as seasonally. These changes do not eliminate indigenous aquatic populations, but affect the existing community structure and the geographic distribution of species. Such temperature changes are necessary to induce the reproductive cycles of aquatic organisms and to regulate other life factors (Mount, 1969).

Artificially induced changes such as the return of cooling water or the release of cool hypolimnetic waters from impoundments may alter indigenous aquatic ecosystems (Coutant, 1972). Entrained organisms may be damaged by temperature

increases across cooling water condensers if the increase is sufficiently great or the exposure period sufficiently long. Impingement upon condenser screens, chlorination for slime control, or other physical insults damage aquatic life (Raney, 1969: Patrick, 1969 (b)). However, Patrick (1969(a)) has shown that algae passing through condensers are not injured if the temperature of the outflowing water does not exceed 345° C.

In open waters elevated temperatures may affect periphyton, benthic invertebrates, and fish, in addition to causing shifts in algal dominance. Trembley (1960) studies of the Delaware River downstream from a power plant concluded that the periphyton population was considerably altered by the discharge.

The number and distribution of bottom organisms decrease as water temperatures increase. The upper tolerance limit for a balanced benthic population structure is approximately 32° C. A large number of these invertebrate species are able to tolerate higher temperatures than those required for reproduction (FWPCA, 1967).

In order to define criteria for fresh waters, Coutant (1972) cited the following was cited as currently definable requirements:

1. Maximum sustained temperatures that are consistent with maintaining desirable levels of productivity,

2. maximum levels of metabolic acclimation to warm temperatures that will permit return to ambient winter temperatures should artificial sources of heat cease,

3. Time-dependent temperature limitations for survival of brief exposures to temperature extremes, both upper and lower,

4. Restricted temperature ranges for various states of reproduction, including (for fish) gametogenesis, spawning migration, release of gametes, development of the embryo, commencement of independent feeding (and other activities) by juveniles, and temperatures required for metamorphosis, emergence, or other activities of lower forms,

5. Thermal limits for diverse species compositions of aquatic communities, particularly where reduction in diversity creates nuisance growths of certain organisms, or where important food sources (food chains) are altered,

6. Thermal requirements of downstream aquatic life (in rivers) where upstream diminution of a coldwater resource will adversely affect downstream temperature requirements.

The major portion of such information that is available, however, is for freshwater fish species rather than lower forms of marine aquatic life.

The temperature-time duration for short-term exposures such that 50 percent of a given population will survive an extreme temperature frequently is expressed mathematically by fitting experimental data with a staright line on a semi-logarithmic plot with time on the logarithmic scale and temperature on the linear scale (see fig. 1). In equation form this 50 percent mortality relationship is:

$$\log^{10} (\text{time}^{(\text{minutes})}) = a + b\,(\text{Temperature } (^{\circ}\text{C}))$$

where: $\log^{10}$ = logarithm to base 10 (common logarithm)

a = intercept on the "y" or logarithmic axis of the line fitted to experimental data and which is available for some species from Appendix II-C, of the National Academy of Sciences document.

b = slope of the line fitted to experimental data and which is available for some species from Appendix II-C, of the National Academy of Sciences document.

To provide a safety factor so that none or only a few organisms will perish, it has been found experimentally that a

criterion of 2° C below maximum temperature is usually sufficient (Black, 1953). To provide safety for all the organisms, the temperature causing a median mortality for 50 percent of the population would be calculated and reduced by 2° C in the case of an elevated temperature. Available scientific information includes upper and lower incipient lethal temperatures, coefficients "a" and "b" for the thermal resistance equation, and information of size, life stage, and geographic source of the particular test species (Appendix II-C, NAS, 1974).

Maximum temperatures for an extensive exposure (e.g., more than 1 week) must be divided into those for warmer periods and winter. Other than for reproduction, the most temperature-sensitive life function appears to be growth (Coutant, 1972). Coutant (1972) has suggested that a satisfactory estimate of a limiting maximum weekly mean temperature may be an average of the optimum temperature for growth and the temperature for zero net growth.

Because of the difficulty in determining the temperature of zero net growth, essentially the same temperature can be derived by adding to the optimum essentially to temperature (for growth or other physiological functions) a factor calculated as one-third of the difference between the ultimate upper incipient lethal temperature and the optimum temperature (NAS, 1974). In equation form:

Maximum weekly average = temperature	optimum + 1/3	(ultimate upper optimum) (incipient lethal - temperature) (temperature)

Since temperature tolerance varies with various states of development of a particular species, the criterion for a

particular location would be calculated for the most important life form likely to be present during a particular month. One caveat in using the maximum weekly mean temperature is that the limit for short-term exposure must not be exceeded. Example calculations for predicting the summer maximum temperatures for short-term survival and for extensive exposure for various fish species are presented in Table 11. These calculations use the above equations and data from EPA's Environmental Research Laboratory in Duluth.

The winter maximum temperature must not exceed the ambient water temperature by more than the amount of change a specimen acclimated to the plume temperature can tolerate. Such a change could occur by a cessation of the source of heat or by the specimen being driven from an area by addition of biocides or other factors. However, there are inadequate data to estimate a safety factor for the "no stress" level from cold shocks (NAS, 1974). Figure 2 was developed from available data in the literature (ERL-Duluth, 1976) and can be used for estimating allowable winter temperature increases.

Coutant (1972) has reviewed the effects of temperature on aquatic life reproduction and development. Reproductive events are noted as perhaps the most thermally restricted of all life phases assuming other factors are at or near optimum levels. Natural short-term temperature fluctuations appear to cause reduced reproduction of fish and invertebrates.

TABLE 11.-Example Calculated Values for Maximum Weekly Average Temperatures for Growth and Short-Term Maxima for Survival for Juveniles and Adults During the Summer (Centigrade and Fahrenheit).

Species	Growth[a]		Maxima[b]	
Atlantic salmon	20	(68)	23	(73)
Bigmouth buffalo				
Black crappie	27	(81)		
Bluegill	32	(90)	35	(95)
Brook trout	19	(66)	24	(75)
Carp				
Channel catfish	32	(90)	35	(95)
Coho salmon	18	(64)	24	(75)
Emerald shiner	30	(86)		
Freshwater drum				
Lake herring (Cisco)	17	(63)	25	(77)
Largemouth bass	32	(90)	34	(93)
Northern pike	28	(82)	30	(86)
Rainbow trout	19	(66)	24	(75)
Sauger	25	(77)		
Smallmouth bass	29	(84)		
Smallmouth buffalo				
Sockeye salmon	18	(64)	22	(72)
Striped bass				
Threadfin shad				
White bass				
White crappie	28	(82)		
White sucker	28	(82)		
Yellow perch	29	(84)		

a - Calculated according to the equation (using optimum temperature for growth)

maximum weekly average temperature for growth = optimum temperature + 1/3 (ultimate incipient lethal temperature-optimum temperature.

b - Based on temperature (^{o}C) = $1/b\ (\log^{10} time_{(min.)} - a)$ 2^{o} C, acclimation at the maximum weekly average temperature for summer growth, and data in Appendix II-C of Water Quality Criteria, published by National Academy of Sciences.

c - Based on data for larvae (ERL-Duluth, 1976).

There are indadequate data available quantitating the most temperature-sensitive life stages among various aquatic species. Uniform elevation of temperature a few degrees but still within the spawning range may lead to advanced spawning for spring spawning species and delays for fall spawners. Such changes may not be detrimental unless asynchrony occurs between newly hatched juveniles and their normal food source. Such asynchrony may be most pronounced among anadromous species or other migrants who pass from the warmed area to a normally chilled, unproductive area. Reported temperature data on maximum temperatures for spawning and embryo survival have been summarized in Table 12 (from ERL-Duluth 1976).

Although the limiting effects of thermal addition to estuarine and marine waters are not as conspicuous in the fall, winter, and spring as during the summer season of maximum heat stress, nonetheless crucial thermal limitations do exist. Hence, it is important that the thermal additions to the receiving waters be minimized during all seasons of the year. Size of harvestable stocks of commercial fish and shellfish, particularly near geographic limits of the fishery, appear to be markedly influenced by slight changes in the long-term temperature regime (Dow, 1973).

Jefferies and Johnson (1974) studied the relationship between temperature and annual variation in 7-year catch data for winter flounder, Pseudopleuronectes americanus, in Narragansett Bay, Rhode Island, revealed that a 78 percent decrease in annual catch correlated closely with a 0.5°C increase in the average

temperature over the 30-month period between spawning and recruitment into the fishery. Sissenwine's 1974 model predicts a 68 percent reduction of recruitment in yellowtail flounder, Limanda ferruginea, with a 1°C long-term elevation in southern New England waters.

TABLE 12.

Summary of Reported Values for Maximum Weekly Average Temperature for Spawning and Short-Term Maxima for Embryo Survival During the Spawning Season (Centigrade and Fahrenheit)

Species	Spawning[a]		Embryo Survival[b]	
Atlantic Salmon	5	(41)	7	(45)
Bigmouth Buffalo	17	(63)	27	(81)c
Black Crappie				
Bluegill	25	(77)	34	(93)
Brook Trout	9	(48)	13	(55)
Carp	21	(70)	33	(91)
Channel Catfish	27	(81)	29	(84)
Coho Salmon	10	(50)	13	(55)
Emerald Shiner	24	(75)	28	(82)c
Freshwater Drum	21	(70)	26	(79)
Lake Herring (Cisco)	3	(37)	8	(46)
Largemouth Bass	21	(70)	27	(81)
Northern Pike	11	(52)	19	(66)
Rainbow Trout	9	(48)	13	(55)
Sauger	10	(50)	21	(70)
Smallmouth Bass	17	(63)		
Smallmouth Buffalo	17	(63)	21	(70)
Sockeye Salmon	10	(50)	13	(55)
Striped Bass	18	(64)	24	(75)
Threadfin Shad	18	(64)	34	(93)
White Bass	17	(63)	26	(79)
White Crappie	18	(64)	23	(73)
White Sucker	10	(50)	20	(68)
Yellow Perch	12	(54)	20	(68)

a - the optimum or mean of the range of spawning temperatures reported for the species (ERL-Duluth, 1976).

b - the upper temperature for successful incubation and hatching reported for the species (ERL-Duluth, 1976).

c - upper temperature for spawning.

Community balance can be influenced strongly by such temperature-dependent factors as rates of reproduction, recruitment, and growth of each component population. A few degrees elevation in average monthly temperature can appreciably alter a community through changes in interspecies relationships. A 50 percent reduction in the softshell clam fishery in Maine by the green crab, Carcinus maenus, illustrates how an increase in winter temperatures can establish new predator-prey relationships. Over a period of 4 years, there was a natural amelioration of temperature and the monthly mean for the coldest month of each year did not fall below 2°C. This apparently precluded appreciable ice formation and winter cold kill of the green crab and permitted a major expansion of its population, with increased predation of the softshell clam resulting (Glude, 1954; Welch, 1968).

Temperature is a primary factor controlling reproduction and can influence many events of the reproductive cycle from gametogenesis to spawning. Among marine invertebrates, initiation of reproduction (gametogenesis) is often triggered during late winter by attainment of a minimum environmental threshold temperature. In some species, availability of adequate food is also a requisite (Pearse, 1970; Sastry, 1975: deVlaming, 1971). Elevated temperature can limit gametogenesis by preventing accumulation of nutrients in the gonads. This problem could be acute during the winter if food availability and feeding activity is reduced. Most marine organisms spawn during the spring and summer; gametogenesis is usually initiated during the

previous fall. It should also be noted that some species spawn only during the fall (herrinhg),while others during the winter and very early spring. At the higher latitudes, winter breeders include such estuarine community dominants as acorn barnacles, Balanus balanus and B. balanoides, the edible blue mussel Mytilus edulis, sea urchin, Strongylocentrotus drobachiensis, sculpin, and the winter flounder, Pseudopleuronectes americanus. The two boreal barnacles require temperatures below 10°C before egg production will be initiated (Crisp, 1957). It is clear that adaptations for reproduction exist which are dependent on temperature conditions close to the natural cycle.

Juvenile and adult fish usually thermoregulate behaviorally by moving to water having temperatures closest to their thermal preference. This provides a thermal environment which approximates the optimal temperature for many physiological functions, including growth (Neill and Magnuson. 1974). As a consequence, fishes usually are attracted to heated water during the fall, winter, and spring. Avoidance will occur as warmer temperature exceeds the preferendum by 1 to 3°C (Coutant, 1975). This response precludes problems of heat stress for juvenile and adult fishes during the summer, but several potential problems exist during the other seasons. The possibility of cold shock and death of plume-entrained fish resulting from winter plant shutdown is well recognized. Also, increased incidence of disease and a deterioration of physiological condition has been observed among plume-entrained fishes, perhaps because of insufficient food (Massengill, 1973). A weight loss of approximately 10 percent for each 1° C rise in water temperature

has been observed in fish when food is absent. (Phillips et al., 1960) There may also be indirect adverse effects on the indigenous community because of increased predation pressure if thermal addition leads to a concentration of fish which are dependent on this community for their food.

Fish migration is often linked to natural environmental temperature cycles. In early spring, fish employ temperature as their environmental cue to migrate northward (e.g., menhaden, bluefish) or to move inshore (winter flounder). Likewise, water temperature strongly influences timing of spawning runs ofanadromous fish into rivers (Leggett and Whitney, 1972). In the autumn, a number of juvenile marine fishes and shrimp are dependent on a drop in temperature to trigger their migration from estuarine nursery grounds for oceanic dispersal or southward migration (Lund and Maltezos, 1970; Talbot, 1966).

Thermal discharges should not alter diurnal and tidal temperature variations normally experienced by marine communities. Laboratory studies show thermal tolerance to be enhanced when animals are maintained under a diurnally fluctuating temperature regime rather than at a constant temperature (Costlow and Bookhout, 1971; Furch, 1972; Hoss, et al.,). A daily cyclic regime can be protective additionally as it reduces duration of exposure to extreme temperatures (Pearce, 1969; Gonzalez, 1972).

Summer thermal maxima should be established to protect the various marine communities within each biogeographic region. During the summer, naturally elevated temperatures may be of

sufficent magnitude to cause death or emigration (Glynn, 1968; Vaughn, 1961). This more commonly occurs in tropical and warm temperate zone waters, but has been reported for enclosed bays and shallow waters in other regions as well (Nichols, 1918). Summer heat stress also can contribute to increased incidence of disease or parasitism (Sinderman, 1965); reduce or block sexual maturation (Thorhaug, et al., 1971: deVlaming, 1972); inhibit or block embryonic cleavage of larval development (Calabrese, 1969); reduce feeding and growth of juveniles and adults (Olla and Studholme, 1971); result in increased predation (Gonzalez, 1972); and reduce productivity of macroalgae and seagrasses (South and Hill, 1970; Zieman, 1970). The general ceilings set forth here are derived from studies delineating limiting temperatures for the more thermally sensitive species or communities of a biogeographic region.

Thermal effects data are presently insufficient to set general temperature limits for all coastal biogeographic regions. The data enumerated in the Appendix, plus any additional data subsequently generated, should be used to develop thermal limits which specifically consider communities relevant to given water bodies.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

CRITERIA:

Aquatic Life

Not enough data are available concerning the effects of 2,3,7,8-TCDD on aquatic life and its uses to allow derivation of national criteria. The available information indicates that acute values for some freshwater animal species are >1.0 ug/L; some chronic values are <0.01 ug/L; and the chronic value for rainbow trout is <0.001 ug/L. Because exposures of some species of fishes to 0.01 ug/L for <6 days resulted in substantial mortality several weeks later, derivation of aquatic life criteria for 2,3,7,8-TCDD may require special consideration. Predicted bioconcentration factors (BCFs) for 2,3,7,8-TCDD range from 3,000 to 900,000, but the available measured BCFs range from 390 to 13,000. If the BCF is 5,000, concentrations >0.00001 ug/L should result in concentrations in edible freshwater and saltwater fish and shellfish that exceed levels identified in a U.S. FDA health advisory. If the BCF is >5,000 or if uptake in a field situation is greater than that in laboratory tests, the value of 0.00001 ug/L will be too high.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of 2,3,7,8-TCDD exposure through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero. This criterion is

based on the nonthreshold assumption for 2,3,7,8-TCDD. However, zero may not be an attainable level at this time. Therefore, the levels that may result in an increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 1.3×10^{-7}, 1.3×10^{-8} and 1.3×10^{-9} ug/L, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 1.4×10^{-7}, 1.4×10^{-8} and 1.4×10^{-9} ug/L, respectively. If these estimates are made for comsumption of water only, the levels are 2.2×10^{-6}, 2.2×10^{-7} and 2.2×10^{-8} ug/L, respectively.

(49 F.R. 5831, February 15, 1984)
SEE APPENDIX B FOR METHODOLOGY

TETRACHLOROETHYLENE

CRITERIA:

Aquatic Life

The available data for tetrachloroethylene indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 5,280 and 840 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

The available data for tetrachloroethylene indicate that acute and chronic toxicity to saltwater aquatic life occurs at concentrations as low as 10,200 and 450 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to tetrachloroethylene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 8.0 ug/L, 0.80 ug/L, and 0.08 ug/L, respectively. If these estimates are made for

consumption of aquatic organisms only, excluding consumption of water, the levels are 88.5 ug/L, 8.85 ug/L, and 0.88 ug/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

THALLIUM

CRITERIA:

Aquatic Life

The available data for thallium indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 1,400 and 40 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested. Toxicity to one species of fish occurs at concentrations as low as 20 ug/L after 2,600 hours of exposure.

The available data for thallium indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 2,130 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of thallium to sensitive saltwater aquatic life.

Human Health

For the protection of human health from the toxic properties of thallium ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 13 ug/L.

For the protection of human health from the toxic properties of thallium ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 48 ug/L.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

TOLUENE

CRITERIA:

Aquatic Life

The available data for toluene indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 17,500 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of toluene to sensitive freshwater aquatic life.

The available data for toluene indicate that acute and chronic toxicity to saltwater aquatic life occurs at concentrations as low as 6,300 and 5,000 ug/L, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Human Health

For the protection of human health from the toxic properties of toluene ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 14.3 mg/L.

For the protection of human health from the toxic properties of toluene ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 424 mg/L.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

NOTE: The U.S. EPA is currently developing Acceptable Daily Intake (ADI) or Verified Reference Dose (RfD) values for Agency-wide use for this chemical. The new value should be substituted when it becomes available. The January, 1986, draft Verified Reference Dose document cites an RfD of 0.3 mg/kg/day for toluene.

TOXAPHENE

CRITERIA:

Aquatic Life

For toxaphene the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.013 ug/L as a 24-hour average, and the concentration should not exceed 1.6 ug/L at any time.

For saltwater aquatic life the concentration of toxaphene should not exceed 0.070 ug/L at any time. No data are available concerning the chronic toxicity of toxaphene to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to toxaphene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero, based on the non threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 7.1 ng/L, 0.71 ng/L, and 0.07 ng/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 7.3 ng/L, 0.73 ng/L, and 0.07 ng/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

TRICHLOROETHYLENE

CRITERIA:

Aquatic Life

The available data for trichloroethylene indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 45,000 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of trichloroethylene to sensitive freshwater aquatic life but the behavior of one species is adversely affected at concentrations as low as 21,900 ug/L.

The available data for trichloroethylene indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 2,000 ug/L and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of trichloroethylene to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to trichloroethylene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 27 ug/L, 2.7 ug/L, and 0.27 ug/L, respectively. If these estimates are made for

consumption of aquatic organisms only, excluding consumption of water, the levels are 807 ug/L, 80.7 ug/L, and 8.07 ug/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

VINYL CHLORIDE

CRITERIA:

Aquatic Life

No freshwater organisms have been tested with vinyl chloride and no statement can be made concerning acute or chronic toxicity.

No saltwater organisms have been tested with vinyl chloride and no statement can be made concerning acute or chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects of exposure to vinyl chloride through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero, based on the nonthreshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 20 ug/L, 2.0 ug/L, and 0.2 ug/L, respectively. If these estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 5,246 ug/L, 525 ug/L, and 52.5 ug/L, respectively.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

ZINC

CRITERIA:

Aquatic Life

For total recoverable zinc the criterion to protect freshwater aquatic life as derived using the Guidelines is 47 ug/L as a 24-hour average and the concentration (in ug/L) should not exceed the numerical value given by $e^{(0.83[\ln(\text{hardness})]+1.95)}$ at any time. For example, at hardnesses of 50, 100, and 200 mg/L as $CaCO_3$ the concentration of total recoverable zinc should not exceed 180, 320, and 570 ug/L at any time.

For total recoverable zinc the criterion to protect saltwater aquatic life as derived using the Guidelines is 58 ug/L as a 24-hour average and the concentration should not exceed 170 ug/L at any time.

Human Health

Sufficient data are not available for zinc to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, to control undesirable taste and odor quality of ambient water the estimated level is 5 mg/L. It should be recognized that organoleptic data have limitations as a basis for establishing a water quality criteria, and have no demonstrated relationship to potential adverse human health effects.

(45 F.R. 79318, November 28, 1980)
SEE APPENDIX B FOR METHODOLOGY

APPENDIX A

DERIVATION OF THE 1985 CRITERION

Derivation of numerical national water quality criteria for the protection of aquatic organisms and their uses is a complex process that uses information from many areas of aquatic toxicology. After a decision is made that a national criterion is needed for a particular material, all available information concerning toxicity to, and bioaccumulation by, aquatic organisms is collected, reviewed for acceptability, and sorted. If enough acceptable data on acute toxicity to aquatic animals are available, they are used to estimate the highest 1-hour average concentration that should not result in unacceptable effects on aquatic organisms and their uses. If justified, this concentration is made a function of a water quality characteristic such as pH, salinity, or hardness. Similarly, data on the chronic toxicity of the material to aquatic animals are used to estimate the highest 4-day average concentration that should not cause unacceptable toxicity during a long-term exposure. If appropriate, this concentration is also related to a water quality characteristic.

Data on toxicity to aquatic plants are examined to determine whether plants are likely to be unacceptably affected by concentrations that should not cause unacceptable effects on animals. Data on bioaccumulation by aquatic organisms are used to determine if residues might subject edible species to restrictions by the U.S. Food and Drug Administration or if such residues might harm some wildlife consumers of aquatic life. All other available data are examined for adverse effects that might

be biologically important.

If a thorough review of the pertinent information indicates that enough acceptable data are available, numerical national water quality criteria are derived for fresh water or saltwater or both to protect aquatic organisms and their uses from unacceptable effects due to exposures to high concentrations for short periods of time, lower concentrations for longer periods of time, and combinations of the two.

I. Collection of Data

A. Collect all available data on the material concerning (a) toxicity to, and bioaccumulation by, aquatic animals and plants, (b) FDA action levels [12], and (c) chronic feeding studies and long-term field studies with wildlife species that regularly consume aquatic organisms.

B. All data that are used should be available in typed, dated, and signed hard copy (publication, manuscript, letter, memorandum, etc.) with enough supporting information to indicate that acceptable test procedures were used and that the results are probably reliable. In some cases it may be appropriate to obtain additional written information from the investigator, if possible. Information that is confidential or privileged or otherwise not available for distribution should not be used.

C. Questionable data, whether published or

unpublished, should not be used. For example, data should usually be rejected if they are from tests that did not contain a control treatment, tests in which too many organisms in the control treatment died or showed signs of stress or disease, and tests in which distilled or deionized water was used as the dilution water without addition of appropriate salts.

D. Data on technical grade materials may be used if appropriate, but data on formulated mixtures and emulsifiable concentrates of the material of concern should not be used.

E. For some highly volatile, hydrolyzable, or degradable materials it is probably appropriate to use only results of flow-through tests in which the concentrations of test material in the test solutions were measured often enough using acceptable analytical methods.

F. Data should be rejected if they were obtained using:

1. Brine shrimp, because they usually occur naturally only in water with salinity greater than 35 g/kg.
2. Species that do not have reproducing wild populations in North America (See Appendix 1).
3. Organisms that were previously exposed to substantial concentrations of the test material or other contaminants.

G. Questionable data, data on formulated mixtures and emulsifiable concentrates, and data obtained with nonresident species or previously exposed organisms may be used to provide auxiliary information but should not be used in the derivation of criteria.

II. Required Data

A. Certain data should be available to help ensure that each of the four major kinds of possible adverse effects receives adequate consideration. Results of acute and chronic toxicity tests with representative species of aquatic animals are necessary so that data available for tested species can be considered a useful indication of the sensitivities of appropriate untested species. Fewer data concerning toxicity to aquatic plants are required because procedures for conducting tests with plants and interpreting the results of such tests are not as well developed. Data concerning bioaccumulation by aquatic organisms are required only if relevant data are available concerning the significance of residues in aquatic organisms.

B. To derive a criterion for freshwater aquatic organisms and their uses, the following should be available:

1. Results of acceptable acute tests (see Section

IV) with at least one species of freshwater animal in at least eight different families such that all of the following are included:

a. the family Salmonidae in the class Osteichthyes

b. a second family in the class Osteichthyes, preferably a commercially or recreationally important warmwater species (e.g., bluegill, channel catfish, etc.)

c. a third family in the phylum Chordata (may be in the class Osteichthyes or may be an amphibian, etc.)

d. a planktonic crustacean (e.g., cladoceran, copepod, etc.)

e. a benthic crustacean (e.g., ostracod, isopod, amphipod, crayfish, etc.)

f. an insect (e.g., mayfly, dragonfly, damselfly, stonefly, caddisfly, mosquito, midge, etc.)

g. a family in a phylum other than Arthropoda or Chordata (e.g., Rotifera, Annelida, Mollusca, etc.)

h. a family in any order of insect or any phylum not already represented.

2. Acute-chronic ratios (see Section VI) with species of aquatic animals in at least three different families provided that of the three species:

a. at least one is a fish

b. at least one is an invertebrate

c. at least one is an acutely sensitive freshwater species (the other two may be saltwater species).

3. Results of at least one acceptable test with a freshwater alga or vascular plant (see Section VIII). If plants are among the aquatic organisms that are most sensitive to the material, results of a test with a plant in another phylum (division) should also be available.

4. At least one acceptable bioconcentration factor determined with an appropriate freshwater species, if a maximum permissible tissue concentration is available (see Section IX).

C. To derive a criterion for saltwater aquatic organisms and their uses, the following should be available:

1. Results of acceptable acute tests (see Section IV) with at least one species of saltwater animal in at least eight different families such that all of the following are included:

a. two families in the phylum Chordata

b. a family in a phylum other than Arthropoda or Chordata

c. either the Mysidae or Penaeidae family

d. three other families not in the phylum Chordata (may include Mysidae or Penaeidae, whichever was not used above)

e. any other family.

2. Acute-chronic ratios (see section VI) with species of aquatic animals in at least three different families provided that of the three species:

a. at least one is a fish

b. at least one is an invertebrate

c. at least one is an acutely sensitive saltwater species (the other one may be a freshwater species).

3. Results of at least one acceptable test with a saltwater alga or vascular plant (see Section VIII. If plants are among the aquatic organisms most sensitive to the material, results of a test with a plant in another phylum (division) should also be available.

4. At least one acceptable bioconcentration factor determined with an appropriate saltwater species, if a maximum permissible tissue concentration is available (see Section IX).

D. If all the required data are available, a numerical criterion can usually be derived, except in special cases. For example, derivation of a criterion

might not be possible if the available acute-chronic ratios vary by more than a factor of 10 with no apparent pattern. Also, if a criterion is to be related to a water quality characteristic T (see Sections V and VII), more data will be necessary.

Similarly, if all required data are not available, a numerical criterion should not be derived except in special cases. For example, even if not enough acute and chronic data are available, it might be possible to derive a criterion if the available data clearly indicate that the Final Residue Value should be much lower than either the Final Chronic Value or the Final Plant Value.

E. Confidence in a criterion usually increases as the amount of available pertinent data increases. Thus, additional data are usually desirable.

III. Final Acute Value

A. Appropriate measures of the acute (short-term) toxicity of the material to a variety of species of aquatic animals are used to calculate the Final Acute Value. The Final Acute Value is an estimate of the concentration of the material corresponding to a cumulative probability of 0.05 in the acute toxicity values for the genera with which acceptable acute tests have been conducted on the material. However, in some cases, if the Species

Mean Acute Value of a commercially or recreationally important species is lower than the calculated Final Acute Value, then that Species Mean Acute Value replaces the calculated Final Acute Value in order to provide protection for that important species.

B. Acute toxicity tests should have been conducted using acceptable procedures [13].

C. Except for tests with saltwater annelids and mysids, results of acute tests during which the test organisms were fed should not be used, unless data indicate that the food did not affect the toxicity of the test material.

D. Results of acute tests conducted in unusual dilution water, e.g., dilution water in which total organic carbon or particulate matter exceeded 5 mg/L, should not be used, unless a relationship is developed between acute toxicity and organic carbon or particulate matter or unless data show that organic carbon, particulate matter, etc., do not affect toxicity.

E. Acute values should be based on endpoints which reflect the total severe acute adverse impact of the test material on the organisms used in the test. Therefore, only the following kinds of data on acute toxicity to aquatic animals should be used:

1. Tests with daphnids and other cladocerans should be started with organisms less than 24 hours old and tests with midges should be stressed with second- or third-instar larvae. The result should be the 48-hr EC50 based on percentage of organisms immobilized plus percentage of organisms killed. If such an EC50 is not available from a test, the 48-hr LC50 should be used in place of the desired 48-hr EC50. An EC50 or LC50 of longer than 48 hours can be used as long as the animals were not fed and the control animals were acceptable at the end of the test.
2. The result of a test with embryos and larvae of barnacles, bivalve molluscs (clams, mussels, oysters, and scallops), sea urchins, lobsters, crabs, shrimp, and abalones should be the 96-hr EC50 based on the percentage of organisms with incompletely developed shells plus the percentage of organisms killed. If such an EC50 is not available from a test, the lower of the 96-hr EC50 based on the percentage of organisms with incompletely developed shells and the 96-hr LC50 should be used in place of the desired 96-hr EC50. If the duration of the test was between 48 and 96 hours, the EC50 or LC50 at the end of the test should be used.

3. The acute values from tests with all other freshwater and saltwater animal species and older life stages of barnacles, bivalve molluscs, sea urchins, lobsters, crabs, shrimps, and abalones should be the 96-hr EC50 based on the percentage of organisms exhibiting loss of equilibrium plus the percentage of organisms immobilized plus the percentage of organisms killed. If such an EC50 is not available from a test, the 96-hr LC50 should be used in place of the desired 96-hr EC50.

4. Tests with single-celled organisms are not considered acute tests, even if the duration was 96 hours or less.

5. If the tests were conducted properly, acute values reported as "greater than" values and those which are above the solubility of the test material should be used, because rejection of such acute values would unnecessarily lower the Final Acute Value by eliminating acute values for resistant species.

F. If the acute toxicity of the material to aquatic animals apparently has been shown to be related to a water quality characteristic such as hardness or particulate matter for freshwater animals or

salinity or particulate matter for saltwater animals, a Final Acute Equation should be derived based on that water quality characteristic. Go to Section V.

G. If the available data indicate that one or more life stages are at least a factor of 2 more resistant than one or more other life stages of the same species, the data for the more resistant life stages should not be used in the calculation of the Species Mean Acute Value (SMAV) because a species can only be considered protected from acute toxicity if all life stages are protected.

H. The agreement of the data within and between species should be considered. Acute values that appear to be questionable in comparison with other acute and chronic data for the same species and for other species in the same genus probably should not be used in calculation of a Species Mean Acute Value. For example, if the acute values available for a species or genus differ by more than a factor of 10, some or all of the values probably should not be used in calculations.

I. For each species for which at least one acute value is available, the Species Mean Acute Value should be calculated as the geometric mean of the results of all flow-through tests in which the concentrations of test material were measured. For a species for which no such result is available,

the Species Mean Acute Value should be calculated as the geometric mean of all available acute values, i.e., results of flow-through tests in which the concentrations were not measured and results of static and renewal tests based on initial concentrations of test material (nominal concentrations are acceptable for most test materials if measured concentrations are not available).

NOTE: Data reported by original investigators should not be rounded off. Results of all intermediate calculations should be rounded [14] to four significant digits.

NOTE: The geometric mean of N numbers is the N^{th} root of the product of the N numbers. Alternatively, the geometric mean can be calculated by adding the logarithms of the N numbers, dividing the sum by N, and taking the antilog of the quotient. The geometric mean of two numbers is the square root of the product of the two numbers, and the geometric mean of one number is that number. Either natural (base 0) or common (base 10) logarithms can be used to calculate geometric means as long as they are used consistently within each set of data, i.e., the antilog used must match the logarithm used.

NOTE: Geometric means, rather than arithmetic means, are used here because the distributions of sensitivities of individual organisms in toxicity tests on most materials and the distributions of sensitivities of species within a genus are more likely to be lognormal than normal. Similarly, geometric means are used for acute-chronic ratios and bioconcentration factors because quotients are likely to be closer to lognormal than normal distributions. In addition, division of the geometric mean of a set of numerators by the geometric mean of the set of corresponding denominators will result in the geometric mean of the set of corresponding quotients.

J. For each genus for which one or more Species Mean Acute Values are available, the Genus Mean Acute Value should be calculated as the geometric mean of the Species Mean Acute Values available for the genus.

K. Order the Genus Mean Acute Value from high to low.

L. Assign ranks, R, to the Genus Mean Acute Value from "1" for the lowest to "N" for the highest. If two or more Genus Mean Acute Values are identical, arbitrarily assign them successive ranks.

M. Calculate the cumulative probability, P, for each Genus Mean Acute Value as R/(N+1).

N. Select the four Genus Mean Acute Value which have cumulative probabilities closest to 0.05 (if there are less than 59 Genus Mean Acute Value, these will always be the four lowest Genus Mean Acute Values).

O. Using the selected Genus Mean Acute Values and Ps, calculate:

$$S_2 = \frac{E(\ln GMAV)_2 - ((E\ln GMAV))_2/4)}{(P) - ((E\ /\hat{}p))_2/4)}$$

$$L = (E(\ln GMAV) - S(E(/\hat{}p)))/4$$

$$A = S(/\hat{}0.05) + L$$

$$FAV = e^A$$

(See [11] for development of the calculation procedure and Appendix 2 for example calculation and computer program.)

NOTE: Natural logarithms (logarithms to base e, denoted as ln) are used herein merely because they are easier to use on some hand calculators and computers than common (base 10) logarithms. Consistent use of either will produce the same result.

P. If for a commercially or recreationally important species the geometric mean of the acute values from flow-through tests in which the concentrations of test material were measured is lower than the calculated Final Acute Value, then that geometric mean should be used as the Final Acute Value instead of the calculated Final Acute

Value.

Q. Go to Section VI.

IV. Final Acute Equation

A. When enough data are available to show that acute toxicity to two or more species is similarly related to a water quality characteristic, the relationship should be taken into account as described in Sections B-G below or using analysis of covariance [15,16]. The two methods are equivalent and produce identical results. The manual method described below provides an understanding of this application of covariance analysis, but computerized versions of covariance analysis are much more convenient for analyzing large data tests. If two or more factors affect toxicity, multiple regression analysis should be used.

B. For each species for which comparable acute toxicity values are available at two or more different values of the water quality characteristic, perform a least squares regression of the acute toxicity values on the corresponding values of the water quality characteristic to obtain the slope and its 95 percent confidence limits for each species.

NOTE: Because the best documented relationship fitting these data is that between hardness and acute toxicity of metals in fresh water and a log-log

relationship, geometric means and natural logarithms of both toxicity and water quality are used in the rest of this section. For relationships based on other water quality characteristics such as pH, temperature, or salinity, no transformation or a different transformation might fit the data better, and appropriate changes will be necessary throughout this section.

C. Decide whether the data for eachspecies are useful, taking into account the range and number of the tested values of the water quality characteristic and the degree of agreement within and between species. For example, a slope based on six data points might be of limited value if it is based only on data for a very narrow range of values of the water quality characteristic. A slope based on only two data points, however, might be useful if it is consistent with other information and if the two points cover a broad enough range of the water quality characteristic. In addition, acute values that appear to be questionable in comparison with other acute and chronic data available for the same species and for other species in the same genus probably should not be used. For example, if after adjustment for the water quality characteristic, the acute values available for a species or genus

differ by more than a factor of 10, probably some or all of the values should be rejected. If useful slopes are not available for at least one fish and one invertebrate or if the available slopes are too dissimilar or if too few data are available to adequately define the relationship between acute toxicity and the water quality characteristic, return to Section IV.G, using the results of tests conducted under conditions and in waters similar to those commonly used for toxicity tests with the species.

D. Individually for each species calculate the geometric mean of the available acute values and then divide each of the acute values for species by the mean for the species. This normalizes the values so that the geometric mean of the normalized values for each species individually and for any combination of species is 1.0.

E. Similarly normalize the values of the water quality characteristic for each species individually.

F. Individually for each species perform a least squares regression of the normalized acute toxicity values on the corresponding normalized values of the water quality characteristic. The resulting slopes and 95 percent confidence limits will be identical to those obtained in Section B.

Now, however, if the data are actually plotted, the line of best fit for each individual species will go through the point 1,1 in the center of the graph.

G. Treat all the normalized data as if they were all for the same species and perform a least squares regression of all the normalized acute values on the corresponding normalized values of the water quality characteristic to obtain the pooled acute slope, V, and its 95 percent confidence limits. If all the normalized data are actually plotted, the line of best fit will go through the point 1,1 in the center of the graph.

H. For each species calculate the geometric mean, W, of the acute toxicity values and the geometric mean, X, of the values of the water quality characteristic. (These were calculated in steps D and E.)

I. For each species calculate the logarithm, Y, of the Species Mean Acute Value at a selected value, Z, of the water quality characteristic using the equation:

$$Y = \ln W - V(\ln X - \ln Z).$$

J. For each species calculate the SMAV at Z using the equation: $SMAV = e^{Y}$.

NOTE: Alternatively, the Species Mean Acute Values at Z can be obtained by skipping step H using the

equations in steps I and J to adjust each acute value individually to Z, and then calculating the geometric mean of the adjusted values for each species individually. This alternative procedure allows an examination of the range of the adjusted acute values for each species.

K. Obtain the Final Acute Value at Z by using the procedure described in Section IV.J-O.

L. If the Species Mean Acute Value at Z of a commercially or recreationally important species is lower than the calculated Final Acute Value at Z, then that Species Mean Acute Value should be used as the Final Acute Value at Z instead of the calculated Final Acute Value.

M. The Final Acute Equation is written as: Final Acute Value = $e^{(V[\ln(\text{water quality characteristic})] + \ln A - V[\ln Z])}$, where V = pooled acute slope and A = Final Acute Value at Z. Because V, A, and Z are known, the Final Acute Value can be calculated for any selected value of the water quality characteristic.

V. Final Chronic Value

A. Depending on the data that are available concerning chronic toxicity to aquatic animals, the Final Chronic Value might be calculated in the same manner as the Final Acute Value or by dividing the Final Acute Value by the Final Acute-

Chronic Ratio. In some cases it may not be possible to calculate a Final Chronic Value.

NOTE: As the name implies, the acute-chronic ratio is a way of relating acute and chronic toxicities. The acute-chronic ratio is basically the inverse of the application factor, but this new name is better because it is more descriptive and should help prevent confusion between "application factors" and "safety factors." Acute-chronic ratios and application factors are ways of relating the acute and chronic toxicities of a material to aquatic organisms. Safety factors are used to provide an extra margin of safety beyond the known or estimated sensitivities of aquatic organisms. Another advantage of the acute-chronic ratio is that it will usually be greater than 1; this should avoid the confusion as to whether a large application factor is one that is close to unity or one that has a denominator that is much greater than the numerator.

B. Chronic values should be based on results of flow-through (except renewal is acceptable for daphnids) chronic tests in which the concentrations of test material in the test solutions were properly measured at appropriate times during the test.

C. Results of chronic tests in which survival,

growth, or reproduction in the control treatment was unacceptably low should not be used. The limits of acceptability will depend on the species.

D. Results of chronic tests conducted in unusual dilution water, e.g., dilution water in which total organic carbon or particulate matter exceeded 5 mg/L, should not be used, unless a relationship is developed between chronic toxicity and organic carbon or particulate matter or unless data show that organic carbon, particulate matter, etc., do not affect toxicity.

E. Chronic values should be based on endpoints and lengths of exposure appropriate to the species. Therefore, only results of the following kinds of chronic toxicity tests should be used:

1. Life-cycle toxicity tests consisting of exposures of each of two or more groups of individuals of a species to a different concentration of the test material throughout a life cycle. To ensure that all life stages and life processes are exposed, tests with fish should begin with embryos or newly hatched young less than 48 hours old, continue through maturation and reproduction, and should end not less than 24 days (90 days for salmonids) after the hatching of the next generation. Tests with daphnids should begin

with young less than 24 hours old and last for not less than 21 days. Tests with mysids should begin with young less than 24 hours old and continue until 7 days past the median time of first brood release in the controls. For fish, data should be obtained and analyzed on survival and growth of adults and young, maturation of males and females, eggs spawned per female, embryo viability (salmonids only), and hatchability. For daphnids, data should be obtained and analyzed on survival and young per female. For mysids, data should be obtained and analyzed on survival, growth, and young per female.

2. Partial life-cycle toxicity tests consisting of exposures of each of two or more groups of individuals of a species of fish to a concentration of the test material through most portions of a life cycle. Partial life-cycle tests are allowed with fish species that require more than a year to reach sexual maturity, so that all major life stages can be exposed to the test material in less than 15 months. Exposure to the test material should begin with immature juveniles at least 2 months prior to active gonad development, continue through maturation and reproduction,

and end not less than 24 days (90 days for salmonids) after the hatching of the next generation. Data should be obtained and analyzed on survival and growth of adults and young, maturation of males and females, eggs spawned per female, embryo viability (salmonids only), and hatchability.

3. Early life-stage toxicity tests consisting of 28- to 32-day (60 days post hatch for salmonids) exposures of the early life stages of a species of fish from shortly after fertilization through embryonic, larval, and early juvenile development. Data should be obtained and analyzed on survival and growth.

NOTE: Results of an early life-stage test are used as predictions of results of life-cycle and partial life-cycle tests with the same species. Therefore, when results of a life-cycle or partial life-cycle test are available, results of an early life-stage test with the same species should not be used. Also, results of early life-stage tests in which the incidence of mortalities or abnormalities increased substantially near the end of the test should not be used because results of such tests are possibly not good predictions of the results of comparable life-cycle or partial life-cycle tests.

F. A chronic value may be obtained by calculating the geometric mean of the lower and upper chronic limits from a chronic test or by analyzing chronic data using regression analysis. A lower chronic limit is the highest tested concentration (a) in an acceptable chronic test, (b) which did not cause an unacceptable amount of adverse effect on any of the specified biological measurements, and (c) below which no tested concentration caused an unacceptable effect. An upper chronic limit is the lowest tested concentration (a) in an acceptable chronic test, (b) which did cause an unacceptable amount of adverse effect on one or more of the specified biological measurements, and (c) above which all tested concentrations also caused such an effect.

NOTE: Because various authors have used a variety of terms and definitions to interpret and report results of chronic tests, reported results should be reviewed carefully. The amount of effect that is considered unacceptable is often based on a statistical hypothesis test, but might also be defined in terms of a specified percent reduction from the controls. A small percent reduction (e.g., 3 percent) might be considered acceptable even if it is statistically significantly different from the control, whereas a large

percent reduction (e.g., 30 percent) might be considered unacceptable even if it is not statistically significant.

G. If the chronic toxicity of the material to aquatic animals apparently has been shown to be related to a water quality characteristic such as hardness or particulate matter for freshwater animals or salinity or particulate matter for saltwater animals, a Final Chronic Equation should be derived based on that water quality characteristic. Go to Section VII.

H. If chronic values are available for species in eight families as described in Sections III.B.1 or III.C.1, a Species Mean Chronic Value (SMCV) should be calculated for each species for which at least one chronic value is available by calculating the geometric mean of all chronic values available for the species, and appropriate Genus Mean Chronic Values should be calculated. The Final Chronic Value should then be obtained using the procedure described in Section IV.J-0. Then go to Section VI.M.

I. For each chronic value for which at least one corresponding appropriate acute value is available, calculate an acute-chronic ratio, using for the numerator the geometric mean of the results of all acceptable flow-through (except static is acceptable for daphnids) acute tests in

the same dilution water and in which the concentrations were measured. For fish, the acute test(s) should have been conducted with juveniles. The acute test(s) should have been part of the same study as the chronic test. If acute tests were not conducted as part of the same study, acute tests conducted in the same laboratory and dilution water, but in a different study, may be used. If no such acute tests are available, results of acute tests conducted in the same dilution water in a different laboratory may be used. If no such acute tests are available, an acute-chronic ratio should not be calculated.

J. For each species, calculate the species mean acute-chronic ratio as the geometric mean of all acute-chronic ratios available for that species.

K. For some materials the acute-chronic ratio seems to be the same for all species, but for other materials the ratio seems to increase or decrease as the Species Mean Acute Value (SMAV) increases. Thus the Final Acute-Chronic Ratio can be obtained in four ways, depending on the data available:

1. If the Species Mean Acute-Chronic ratio seems to increase or decrease as the Species Mean Acute Value increases, the Final Acute-Chronic Ratio should be calculated as the geometric mean of the acute-chronic ratios for species

whose Species Mean Acute Values are close to the Final Acute Value.

2. If no major trend is apparent and the acute-chronic ratios for a number of species are within a factor of 10, the Final Acute-Chronic Ratio should be calculated as the geometric mean of all the Species Mean Acute-Chronic Ratios available for both freshwater and saltwater species.

3. For acute tests conducted on metals and possibly other substances with embryos and larvae of barnacles, bivalve molluscs, sea urchins, lobsters, crabs, shrimp, and abalones (see Section IV.E.2), it is probably appropriate to assume that the acute-chronic ratio is 2. Chronic tests are very difficult to conduct with most such species, but it is likely that the sensitivities of embryos and larvae would determine the results of life-cycle tests. Thus, if the lowest available Species Mean Acute Values were determined with embryos and larvae of such species, the Final Acute-Chronic Ratio should probably be assumed to be 2, so that the Final Chronic Value is equal to the Criterion Maximum Concentration (see Section XI.B)

4. If the most appropriate Species Mean Acute-Chronic Ratios are less than 2.0, and especially if they are less than 1.0, acclimation has probably occurred during the chronic test. Because continuous exposure and acclimation cannot be assured to provide adequate protection in field situations, the Final Acute-Chronic Ratio should be assumed to be 2, so that the Final Chronic Value is equal to the Criterion Maximum Concentration (see Section XI.B).

   If the available Species Mean Acute-Chronic Ratios do not fit one of these cases, a Final Acute-Chronic Ratio probably cannot be obtained, and a Final Chronic Value probably cannot be calculated.

L. Calculate the Final Chronic Value by dividing the Final Acute Value by the Final Acute-Chronic Ratio. If there was a Final Acute Equation rather than a Final Acute Value, see also Section VII.A.

M. If the Species Mean Chronic Value of a commercially or recreationally important species is lower than the calculated Final Chronic Value, then that Species Mean Chronic Value should be used as the Final Chronic Value instead of the calculated Final Chronic Value.

N. Go to Section VIII.

VI. Final Chronic Equation

A. A Final Chronic Equation can be derived in two ways. The procedure described here in Section A will result in the chronic slope being the same as the acute slope. The procedure described in Sections B-N usually will result in the chronic slope being different from the acute slope.

1. If acute-chronic ratios are available for enough species at enough values of the water quality characteristic to indicate that the acute-chronic ratio is probably the same for all species and is probably independent of the water quality characteristic, calculate the Final Acute-Chronic Ratio as the geometric mean of the available Species Mean Acute-Chronic Ratios.
2. Calculate the Final Chronic Value at the selected value Z of the water quality characteristic by dividing the Final Acute Value at Z (see Section V.M) by the Final Acute-Chronic Ratio.
3. Use V = pooled acute slope (see section V.M) as L = pooled chronic slope.
4. Go to Section VII.M.

B. When enough data are available to show that chronic toxicity to at least one species is related to a water quality characteristic, the

relationship should be taken into account as described in Sections B-G or using analysis of covariance [15,16]. The two methods are equivalent and produce identical results. The manual method described below provides an understanding of this application of covariance analysis, but computerized versions of covariance analysis are much more convenient for analyzing large data sets. If two or more factors affect toxicity, multiple regression analysis should be used.

For each species for which comparable chronic toxicity values are available at two or more different values of the water quality characteristic, perform a least squares regression of the chronic toxicity values on the corresponding values of the water quality characteristic to obtain the slope and its 95 percent confidence limits for each species.

NOTE: Because the best documented relationship fitting these data is that between hardness and acute toxicity of metals in freshwater and a log-log relationship, geometric means and natural logarithms of both toxicity and water quality are used in the rest of this section. For relationships based on other water quality characteristics such as pH, temperature, or

salinity, no transformation or a different transformation might fit the data better, and appropriate changes will be necessary throughout this section. It is probably preferable, but not necessary, to use the same transformation that was used with the acute values in Section V.

D. Decide whether the data for each species are useful, taking into account the range and number of the tested values of the water quality characteristic and the degree of agreement within and between species. For example, a slope based on six data points might be of limited value if it is based only on data for a very narrow range of values of the water quality characteristic. A slope based on only two data points, however, might be useful if it is consistent with other information and if the two points cover a broad enough range of the water quality characteristic. In addition, chronic values that appear to be questionable in comparison with other acute and chronic data available for the same species and for other species in the same genus probably should not be used. For example, if after adjustment for the water quality characteristic, the chronic values available for a species or genus differ by more than a factor of 10, probably some or all of the values should be rejected. If

a useful chronic slope is not available for at least one species or if the available slopes are too dissimilar or if too few data are available to adequately define the relationship between chronic toxicity and the water quality characteristic, it might be appropriate to assume that the chronic slope is the same as the acute slope, which is equivalent to assuming that the acute-chronic ratio is independent of the water quality characteristic. Alternatively, return to Section VI.H, using the results of tests conducted under conditions and in waters similar to those commonly used for toxicity tests with the species.

E. Individually for each species calculate the geometric mean of the available chronic values and then divide each chronic value for a species by the mean for the species. This normalizes the chronic values so that the geometric mean of the normalized values for each species individually and for any combination of species is 1.0.

F. Similarly normalize the values of the water quality characteristic for each species individually.

G. Individually for each species perform a least squares regression of the normalized chronic toxicity values on the corresponding normalized values of the water quality characteristic. The resulting slopes and the 95 percent confidence

limits will be identical to those obtained in Section B. Now, however, if the data are actually plotted, the line of best fit for each individual species will go through the point 1,1 in the center of the graph.

H. Treat all the normalized data as if they were all for the same species and perform a least squares regression of all the normalized chronic values on the corresponding normalized values of the water quality characteristic to obtain the pooled chronic slope, L, and its 95 percent confidence limits. If all the normalized data are actually plotted, the line of best fit will go through the point 1,1 in the center of the graph.

I. For each species calculate the geometric mean, M, of the toxicity values and the geometric mean, P, of the values of the water quality characteristic. (These were calculated in steps E and F.)

J. For each species calculate the logarithm, Q, of the Species Mean Chronic Value at a selected value, Z, of the water quality characteristic using the equation: $Q = \ln M - L(\ln P - \ln Z)$.

NOTE: Although it is not necessary, it will usually be best to use the same value of the water quality characteristic here as was used in section V.I.

K. For each species calculate a Species Mean Chronic Value at Z using the equation: $SMCV = e^{Q}$.

NOTE: Alternatively, the Species Mean Chronic Values at Z can be obtained by skipping step J, using the equations in steps J and K to adjust each acute value individually to Z, and then calculating the geometric means of the adjusted values for each species individually. This alternative procedure allows an examination of the range of the adjusted chronic values for each species.

L. Obtain the Final Chronic Value at Z by using the procedure described in Section IV.J-O.

M. If the Species Mean Chronic Value at Z of a commercially or recreationally important species is lower than the calculated Final Chronic Value at Z, then that Species Mean Chronic Value should be used as the Final Chronic Value at Z instead of the calculated Final Chronic Value.

N. The Final Chronic Equation is written as: Final Chronic Value = $e^{(L[\ln(\text{water quality characteristic})] + \ln S - L[\ln Z])}$, where L = pooled chronic slope and S = Final Chronic Value at Z. Because L, S and Z are known, the Final Chronic Value can be calculated for any selected value of the water quality characteristic.

VII. Final Plant Value

A. Appropriate measures of the toxicity of the material to aquatic plants are used to compare the relative sensitivities of aquatic plants and animals. Although procedures for conducting and interpreting the results of toxicity tests with plants are not well developed, results of tests with plants usually indicate that criteria which adequately protect aquatic animals and their uses will probably also protect aquatic plants and their uses.

B. A plant value is the result of a 96-hr test conducted with an alga or a chronic test conducted with an aquatic vascular plant.

NOTE: A test of the toxicity of a metal to a plant usually should not be used if the medium contained an excessive amount of a complexing agent, such as EDTA, that might affect the toxicity of the metal. Concentrations of EDTA above about 200 ug/L should probably be considered excessive.

C. The Final Plant Value should be obtained by selecting the lowest result from a test with an important aquatic plant species in which the concentrations of test material were measured and the endpoint was biologically important.

VIII. Final Residue Value

A. The Final Residue Value is intended to (a) prevent concentrations in commercially or recreationally important aquatic species from affecting marketability because of exceedence of applicable FDA action levels and (b) protect wildlife, including fishes and birds, that consume aquatic organisms from demonstrated unacceptable effects. The Final Residue Value is the lowest of the residue values that are obtained by dividing maximum permissible tissue concentrations by appropriate bioconcentration or bioaccumulation factors. A maximum permissible tissue concentration is either (a) an FDA action level [12] for fish oil or for the edible portion of fish or shellfish, or (b) a maximum acceptable dietary intake based on observations on survival, growth, or reproduction in a chronic wildlife feeding study or a long-term wildlife field study. If no maximum permissible tissue concentration is available, go to Section X because no Final Residue Value can be derived.

B. Bioconcentration Factors (BCFs) and bioaccumulation factors (BAFs) are quotients of the concentration of a material in one or more tissues of an aquatic organism divided by the average concentration in the solution in which the organism had been living. A BCF is intended to account only for net uptake directly from water, and thus almost has to be measured in a laboratory test. Some uptake during the bioconcentration test might not be directly from water if the food sorbs some of the test material before it is eaten by the test organisms. A BAF is intended to account for net uptake from both food and water in a real-world situation. A BAF almost has to be measured in a field situation in which predators accumulate the material directly from water and by consuming prey that itself could have accumulated the material from both food and water. The BCF and BAF are probably similar for a material with a low BCF, but the BAF is probably higher than the BCF for materials with high BCFs. Although BCFs are not too difficult to determine, very few BAFs have been measured acceptably because it is necessary to make enough measurements of the concentration of the material in water to show that it was reasonably constant for a long enough period of time over the range of territory inhabited by the

organisms. Because so few acceptable BAFs are available, only BCFs will be discussed further. However, if an acceptable BAF is available for a material, it should be used instead of any available BCFs.

C. If a maximum permissible tissue concentration is available for a substance (e.g., parent material, parent material plus metabolites, etc.), the tissue concentration used in the calculation of the BCF should be for the same substance. Otherwise the tissue concentration used in the calculation of the BCF should be that of the material and its metabolites which are structurally similar and are not much more soluble in water than the parent material.

D. 1. A BCF should be used only if the test was flow-through, the BCF was calculated based on measured concentrations of the test material in tissue and in the test solution, and the exposure continued at least until either apparent steady-state or 28 days was reached. Steady-state is reached when the BCF does not change significantly over a period of time, such a 2 days or 16 percent of the length of the exposure, whichever is longer. The BCF used from a test should be the highest of (a) the apparent steady-state BCF, if apparent steady-state was reached, (b) the highest BCF

obtained, if apparent steady-state was not reached, and (c) the projected steady-state BCF, if calculated.

2. Whenever a BCF is determined for a lipophilic material, the percent lipids should also be determined in the tissue(s) for which the BCF was calculated.

3. A BCF obtained from an exposure that adversely affected the test organisms may be used only if it is similar to a BCF obtained with unaffected organisms of the same species at lower concentrations that did not cause adverse effects.

4. Because maximum permissible tissue concentrations are almost never based on dry weights, a BCF calculated using dry tissue weights must be converted to a wet tissue weight basis. If no conversion factor is reported with the BCF, multiply the dry weight BCF by 0.1 for plankton and by 0.2 for individual species of fishes and invertebrates [17].

5. If more than one acceptable BCF is available for a species, the geometric mean of the available values should be used, except that if the BCFs are from different lengths of exposure and the BCF increases with length of

exposure, the BCF for the longest exposure should be used.

E. If enough pertinent data exist, several residue values can be calculated by dividing maximum permissible tissue concentrations by appropriate BCFs:

1. For each available maximum acceptable dietary intake derived from a chronic feeding study or a long-term field study with wildlife, including birds and aquatic organisms, the appropriate BCF is based on the whole body of aquatic species which constitute or represent a major portion of the diet of the tested wildlife species.

2. For an FDA action level for fish or shellfish, the appropriate BCF is the highest geometric mean species BCF for the edible portion (muscle for decapods, muscle with or without skin for fishes, adductor muscle for scallops, and total soft tissue for other bivalve molluscs) of a consumed species. The highest species BCF is used because FDA action levels are applied on a species-by-species basis.

F. For lipophilic materials, it might be possible to calculate additional residue values. Because the steady-state BCF for a lipophilic material seems to be proportional to percent lipids from one tissue to another and from one species to another

[18-20], extrapolations can be made from tested tissues or species to untested tissues or species on the basis of percent lipids.

1. For each BCF for which the percent lipids is known for the same tissue for which the BCF was measured, normalize the BCF to a 1 percent lipid basis by dividing the BCF by the percent lipids. This adjustment to a 1 percent lipid basis is intended to make all the measured BCFs for a material comparable regardless of the species or tissue with which the BCF was measured.

2. Calculate the geometric mean normalized BCF. Data for both saltwater and freshwater species should be used to determine the mean normalized BCF, unless the data show that the normalized BCFs are probably not similar.

3. Calculate all possible residue values by dividing the available maximum permissible tissue concentrations by the mean normalized BCF and by the percent lipids values appropriate to the maximum permissible tissue concentrations, i.e.,

$$\text{Residue value} = \frac{(\text{maximum permissible tissue concentration})}{(\text{mean normalized BCF})(\text{appropriate percent lipids})}$$

tissue concentration) Residue value = (mean normalized BCF) (appropriate percent lipids)

a. For an FDA action level for fish oil, the

appropriate percent lipids value is 100.

b. For an FDA action level for fish, the appropriate percent lipids value is 11 for freshwater criteria and 10 for saltwater criteria because FDA action levels are applied on a species-by-species basis to commonly consumed species. The highest lipid contents in the edible portions of important consumed species are about 11 percent for both the freshwater chinook salmon and lake trout and about 10 percent for the saltwater Atlantic herring [21].

c. For a maximum acceptable dietary intake derived from a chronic feeding study or a long-term field study with wildlife, the appropriate percent lipids is that of an aquatic species or group of aquatic species which constitute a major portion of the diet of the wildlife species.

G. The Final Residue Value is obtained by selecting the lowest of the available residue values.

NOTE: In some cases the Final Residue Value will not be low enough. For example, a residue value calculated from an FDA action level will probably result in an average concentration in the edible portion of a fatty species that is at the action level. Some individual organisms, and possibly some species, will have residue concentrations higher than the mean value but no mechanism has been devised to provide appropriate additional protection. Also, some chronic feeding studies and long-term field studies with wildlife identify concentrations that cause adverse effects but do not identify concentrations which do not cause adverse effects; again, no mechanism has been devised to provide appropriate additional protection. These are some of the species and uses that are not protected at all times in all places.

X. Other Data

Pertinent information that could not be used in earlier sections might be available concerning adverse effects on aquatic organisms and their uses. The most important of these are data on cumulative and delayed toxicity, flavor impairment, reduction in survival, growth, or reproduction, or any other adverse effect that has been shown to be biologically important. Especially important are data for species for which no

other data are available. Data from behavioral, biochemical, physiological, microcosm, and field studies might also be available. Data might be available from tests conducted in unusual dilution water (see IV.D and VI.D), from chronic tests in which the concentrations were not measured (see VI.B), from tests with previously exposed organisms (see II.F), and from tests on formulated mixtures or emulsifiable concentrates (see II.D). Such data might affect a criterion if the data were obtained with an important species, the test concentrations were measured, and the endpoint was biologically important.

XI. Criterion

A. A criterion consists of two concentrations: the Criterion Maximum Concentration and the Criterion Continuous Concentration.

B. The Criterion Maximum Concentration (CMC) is equal to one-half the Final Acute Value.

C. The Criterion Continuous Concentration (CCC) is equal to the lowest of the Final Chronic Value, the Final Plant Value, and the Final Residue Value, unless other data (see Section X) show that a lower value should be used. If toxicity is related to a water quality characteristic, the Criterion Continuous Concentration is obtained from the Final Chronic Equation, the Final Plant Value, and the Final Residue Value by selecting

the one, or the combination, that results in the lowest concentrations in the usual range of the water quality characteristic, unless other data (see Section X) show that a lower value should be used.

D. Round [14] both the Criterion Maximum Concentration and the Criterion Continuous Concentration to two significant digits.

E. The criterion is stated as:

The procedures described in the Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses indicate that, except possibly where a locally important species is very sensitive, (1) aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of (2) does not exceed (3) ug/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed (4) ug/L more than once every 3 years on the average.

where (1) = insert "freshwater" or "saltwater"

(2) = insert name of material

(3) = insert the Criterion Continuous Concentration

(4) = insert the Criterion Maximum Concentration.

XII. Final Review

A. The derivation of the criterion should be carefully reviewed by rechecking each step of the Guidelines. Items that should be especially checked are:

1. If unpublished data are used, are they well documented?
2. Are all required data available?
3. Is the range of acute values for any species greater than a factor of 10?
4. Is the range of Species Mean Acute Values for any genus greater than a factor of 10?
5. Is there more than a factor of 10 difference between the four lowest Genus Mean Acute Values?
6. Are any of the four lowest Genus Mean Acute Values questionable?
7. Is the Final Acute Value reasonable in comparison with the Species Mean Acute Values and Genus Mean Acute Values?
8. For any commercially or recreationally important species, is the geometric mean of the acute values from flow-through tests in which the concentrations of test material were measured lower than the Final Acute Value?
9. Are any of the chronic values questionable?

10. Are chronic values available for acutely sensitive species?

11. Is the range of acute-chronic ratios greater than a factor of 10?

12. Is the Final Chronic Value reasonable in comparison with the available acute and chronic data?

13. Is the measured or predicted chronic value for any commercially or recreationally important species below the Final Chronic Value?

14. Are any of the other data important?

15. Do any data look like they might be outliers?

16. Are there any deviations from the Guidelines? Are they acceptable?

B. On the basis of all available pertinent laboratory and field information, determine if the criterion is consistent with sound scientific evidence. If it is not, another criterion, either higher or lower, should be derived using appropriate modifications of these Guidelines.

APPENDIX B

SUMMARY OF THE 1980 AQUATIC LIFE GUIDELINES

The Guidelines for Deriving Water Quality Criteria for the Protection of Aquatic Life and its Uses were developed to describe an objective, internally consistent, and appropriate way of ensuring that water quality criteria for aquatic life would provide, on the average, a reasonable amount of protection. The resulting criteria are not intended to provide 100 percent protection of all species and all uses of aquatic life all of the time, but they are intended to protect most species in a balanced, healthy aquatic community.

Minimum data requirements are identified in four areas: acute toxicity to animals (eight data points), chronic toxicity to animals (three data points), toxicity to plants, and residues. Data on acute toxicity are needed for a variety of fish and invertebrate species and are used to derive a Final Acute Value. By taking into account the number and relative sensitivities of the tested species, the Final Acute Value is designed to protect most, but not necessarily all, of the tested and untested species.

Data on chronic toxicity to animals can be used to derive a Final Chronic Value by two different means. If chronic values are available for a specified number and array of species, a Final Chronic Value can be calculated directly. If not, an acute-chronic ratio is derived and then used with the Final Acute Value to obtain the Final Chronic Value.

The Final Plant Value is obtained by selecting the lowest plant toxicity value based on measured concentrations.

The Final Residue Value is intended to protect wildlife which consume aquatic organisms and the marketability of aquatic organisms. Protection of the marketability of aquatic organisms is, in actuality, protection of a use of that water body (commercial fishery). Two kinds of data are necessary to calculate the Final Residue Value: a bioconcentration factor (BCF) and a maximum permissible tissue concentration, which can be an FDA action level or can be the result of a chronic wildlife feeding study. For lipid-soluble pollutants, the BCF is normalized for percent lipids and then the Final Residue Value is calculated by dividing the maximum permissible tissue concentration by the normalized BCF and by an appropriate percent lipid value. BCFs are normalized for percent lipids since the BCF measured for any individual aquatic species is generally proportional to the percent lipids in that species.

If sufficient data are available to demonstrate that one or more of the final values should be related to a water quality characteristic, such as salinity, hardness, or suspended solids, the final value(s) are expressed as a function of that characteristic.

After the four final values (Final Acute Value, Final Chronic Value, Final Plant Value, and Final Residue Value) have been obtained, the criterion is established with the Final Acute Value becoming the maximum value and the lowest of the other three values becoming the 24-hour average value. All of the data used to calculate the four final values and any additional pertinent information are then reviewed to determine if the criterion is reasonable. If sound scientific evidence indicates that the

criterion should be raised or lowered, appropriate changes are made as necessary.

The November 28, 1980, Guidelines have been revised from the earlier published versions (43 FR 21506, May 18, 1978; 43 FR 29028, July 5, 1978; 44 FR 15926, March 15, 1979). Details have been added in many places and the concept of a minimum data base has been incorporated. In addition, three adjustment factors and the species sensitivity factor have been deleted. These modifications were the result of the Agency's analysis of public comments and comments received from the Science Advisory Board on earlier versions of the Guidelines. These comments and the Resultant modifications are addressed fully in Appendix D to this notice.

Criteria for the Protection of Human Health

Interpretation of the Human Health Criteria

The human health criteria issued today are summarized in Appendix A of this Federal Register notice. Criteria for the protection of human health are based on their carcinogenic, toxic, or organoleptic (taste and odor) properties. The meanings and practical uses of the criteria values are distinctly different depending on the properties on which they are based.

The objective of the health assessment portions of the criteria documents is to estimate ambient water concentrations which, in the case of noncarcinogens, prevent adverse health effects in humans, and in the case of suspect or proven carcinogens, represent various levels of incremental cancer risk.

Health assessments typically contain discussions of four elements: exposure, pharmacokinetics, toxic effects, and criterion formulation.

The exposure section summarizes information on exposure routes: ingestion directly from water, indirectly from consumption of aquatic organisms found in ambient water, other dietary sources, inhalation, and dermal contact. Exposure assumptions are used to derive human health criteria. Most criteria are based solely on exposure from consumption of water containing a specified concentration of a toxic pollutant and through consumption of aquatic organisms which are assumed to have bioconcentrated pollutants from the water in which they live. Other multimedia routes of exposure such as air, nonaquatic diet, or dermal are not factored into the criterion formulation for the vast majority of pollutants because of lack of data. The criteria are calculated using the combined aquatic exposure pathway and also using the aquatic organism ingestion exposure route alone. In criteria reflecting both the water consumption and aquatic organism ingestion routes of exposure, the relative exposure contribution varies with the propensity of a pollutant to bioconcentrate, with the consumption of aquatic organisms becoming more important as the bioconcentration factor (BCF) increases. As additional information on total exposure is assembled for pollutants for which criteria reflect only the two specified aquatic exposure routes, adjustments in water concentration values may be made. The demonstration of significantly different exposure patterns will become an element

of a process to adapt/modify human health-based criteria to local conditions, somewhat analogous to the aquatic life criteria modification process discussed previously. It is anticipated that States at their discretion will be able to set appropriate human health criteria based on this process.

Specific health-based criteria are developed only if a weight of evidence supports the occurrence of the toxic effect and if dose/response data exist from which criteria can be estimated. The pharmacokinteics section reviews data on absorption, distribution, metabolism, and excretion to assess the biochemical fate of the compounds in the human and animal system. The toxic effects section reviews data on acute, subacute, and chronic toxicity, synergistic and antagonistic effects, and specific information on mutagenicity, teratogenicity, and carcinogenicity. From this review, the toxic effect to be protected against is identified taking into account the quality, quantity, and weight of evidence characteristic of the data. The criterion formulation section reviews the highlights of the text and specifies a rationale for criterion development and the mathematical derivation of the criterion number.

Within the limitations of time and resources, current published information of significance was incorporated into the human health assessments. Review articles nad reports were used for data evaluation and synthesis. Scientific judgment was exercised in reviewing and evaluating the data in each criteria document and in identifying the adverse effects for which protective criteria were published.

Criteria for suspect or proven carcinogens are presented as concentrations in water associated with a range of incremental cancer risks to man. Criteria for noncarcinogens represent levels at which exposure to a single chemical is not anticipated to produce adverse effects in man. In a few cases, organoleptic (taste and odor) data form the basis for the criterion. While this type of criterion does not represent a value which directly affects human health, it is presented as an estimate of the level of a pollutant that will not produce unpleasant taste or odor either directly from water consumption or indirectly by consumption of aquatic organisms found in ambient waters. A criterion developed in this manner is judged to be as useful as other types of criteria in protecting designated water uses. In addition, where data are available, toxicity-based criteria are also presented for pollutants with derived organoleptic criteria. The choice of criteria used in water quality standards for these pollutants will depend upon the designated use to be protected. In the case of a multiple use water body, the criterion protecting the most sensitive use will be applied. Finally, for several pollutants no criteria are recommended because insufficient information is available for quantitative criterion formulation.

Risk Extrapolation

Because methods do not exist to establish the presence of a threshold for carcinogenic effects, EPA's policy is that there is no scientific basis for estimating "safe" levels for carcinogens. The criteria for carcinogens, therefore, state that the

recommended concentration for maximum protection of human health is zero. In addition, the Agency has presented a range of concentrations corresponding to incremental cancer risks of 10_{-7} to 10_{-5} (one additional case of cancer in populations ranging from 10 million to 100,000, respectively). Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on a "acceptable" risk level.

Summary of the Human Health Guidelines

The health assessments and corresponding criteria were derived based on Guidelines and Methodology Used in the Preparation of Health Effect Assessment Chapters of the Consent Decree Water Criteria Documents (the Guidelines) developed by EPA'S Office of Research and Development. The estimation of health risk associated with human exposure to environmental pollutants requires predicting the effect of low doses for up to a lifetime in duration. A combination of epidemiological and animal dose/response data is considered the preferred basis for quantitative criterion derivation.

No-effect (noncarcinogen) or specified risk (carcinogen) concentrations were estimated by extrapolation from animal toxicity or human epidemiology studies using the following basic exposure assumptions: a 70-kilogram male person (Report of the Task Group on Reference Man, International Commission for Radiation Protection, November 23, 1957) as the exposed individual; the average daily consumption of freshwater and

estuarine fish and shellfish products equal to 6.5 grams/day; and the average ingestion of 2 liters/day of water (Drinking Water and Health, National Academy of Sciences, National Research Council, 1977). Criteria based on these assumptions are estimated to be protective of an adult male who experiences average exposure conditions.

Two basic methods were used to formulate health criteria, depending on whether the prominent adverse effect was cancer or other toxic manifestations. The following sections detail these methods.

Carcinogens

Extrapolation of cancer responses from high to low doses and subsequent risk estimation from animal data are performed using a linearized multi-stage model. This procedure is flexible enough to fit all monotonically-increasing dose response data, since it incorporates several adjustable parameters. The multi-stage model is a linear nonthreshold model as was the "one-hit" model originally used in the proposed criteria documents. The linear nonthreshold concept has been endorsed by the four agencies in the Interagency Regulatory Liaison Group and is less likely to underestimate risk at the low doses typical of environmental exposure than other models that could be used. Because of the uncertainties associated with dose response, animal-to-human extrapolation, and other unknown factors; because of the use of average consumptions; and because of the serious public health consequences that could result if risks were underestimated, EPA believes that it is prudent to use conservative methods to

estimate risk in the water quality criteria program. The linearized multistage model is more systematic and invokes fewer arbitrary assumptions than the "one-hit" procedure previously used.

It should be noted that extrapolation models provide estimates of risk since a variety of assumptions are built into any model. Models using widely different assumptions may produce estimates ranging over several orders of magnitude. Since there is at present no way to demonstrate the scientific validity of any model, the use of risk extrapolation models is a subject of debate in the scientific community. However, risk extrapolation is generally recognized as the only tool available at this time for estimating the magnitude of health hazards associated with nonthreshold toxicants and has been endorsed by numerous Federal agencies and scientific organizations, including EPA's Carcinogen Assessment Group, the National Academy of Sciences, and the Interagency Regulatory Liaison Group, as a useful means of assessing the risks of exposure to various carcinogenic pollutants.

Noncarcinogens

Health criteria based on toxic effects of pollutants other than carcinogenicity are estimates of concentrations which are not expected to produce adverse effects in humans. They are based upon Acceptable Daily Intake (ADI) levels and are generally derived using no-observed-adverse-effect-level data from animal studies although human data are used wherever available. The ADI is calculated using safety factors to account for uncertainties

inherent in extrapolation from animal to man. In accordance with the National Research Council recommendations (Drinking Water and Health, National Academy of Sciences, National Research Council, 1977), safety factors of 10, 100, or 1,000 are used, depending on the quality and quantity of data. In some instances extrapolations are made from inhalation studies or limits to approximate a human response from ingestion using the Stokinger-Woodward model (Journal of American Water Works Association, 1958). Calculations of criteria from ADIs are made using the standard exposure assumptions (2 liters of water, 6.5 grams of edible aquatic products, and an average body weight of 70 kg).

APPENDIX C

THE PHILOSOPHY OF THE 1976 WATER QUALITY CRITERIA

Water quality criteria specify concentrations of water constituents which, if not exceeded, are expected to support an organic ecosystem suitable for the higher uses of water. Such criteria are derived from scientific facts obtained from experimental or *in situ* observations that depict organic responses to a defined stimulus or material under identifiable or regulated environmental conditions for a specified time period.

Water quality criteria are not intended to offer the same degree of strategy for survival and propagation at all times to all organisms within a given ecosystem. They are intended not only to protect essential and significant life in water and the direct users of water, but also to protect life that is dependent on life in water for its existence, or that may consume intentionally or unintentionally any edible portion of such life.

The criteria levels for domestic water supply incorporate available data for human health protection. Such values are different from the criteria levels necessary for protection of aquatic life. The Agency's interim primary drinking water regulations (40 Federal Register 59566 December 24, 1975), as required by the Safe Drinking Water Act (42 U.S.C. 300f, et seq.), incorporate applicable domestic water supply criteria. Where pollutants are identified in both the quality criteria for domestic water supply and the Drinking Water Standards, the concentration levels are identical. Water treatment may not significantly affect the removal of certain pollutants.

What is essential and significant life in water? Do Daphnia or stonefly nymphs qualify as such life? Why does 1/100th of a concentration that is lethal to 50 percent of the test organisms (LC50) constitute a criterion in some instances, whereas 1/2 or 1/10th of some effect levels constitutes a criterion in other instances? These are questions that often are asked of those who undertake the task of criteria formulation.

The universe of organisms composing life in water is great in both kinds and numbers. As in the human population, physiological variability exists among individuals of the same species in response to a given stimulus. A much greater response variation exists among species of aquatic organisms. Thus, aquatic organisms do not exhibit the same degree of harm, individually or by species, from a given concentration of a toxicant or potential toxicant within the environment. In establishing a level or concentration of a quality constituent as a criterion it is necessary to ensure a reasonable degree of safety for those more sensitive species that are important to the functioning of the aquatic ecosystem even though data on the response of such species to the quality constituent under consideration may not be available. The aquatic food web is an intricate relationship of predator and prey organisms. A water constituent that may in some way destroy or eliminate an important segment of that food web would, in all likelihood, destroy or seriously impair other organisms associated with it.

Although experimentation relating to the effects of particular substances under controlled conditions began in the

early 1900's, the effects of any substance on more than a few of the vast number of aquatic organisms have not been investigated. Certain test animals have been selected by investigators for intensive investigation because of their importance to man, their availability to the researcher, and their physiological responses to the laboratory environment. As general indicators of organism responses such test organisms are representative of the expected results for other associated organisms. In this context Daphnia or stoneflies or other associated organisms indicate the general levels of toxicity to be expected among untested species. In addition, test organisms are themselves vital links within the food web that results in the fish population in a particular waterway.

The ideal data base for criteria development would consist of information on a large percentage of aquatic species and would show the community response to a range of concentrations for a tested constituent during a long time period. This information is not available but investigators are beginning to derive such information for a few water constituents. Where only 96-hour bioassay data are available, judgmental prudence dictates that a substantial safety factor be employed to protect all life stages of the test organism in waters of varying quality, as well as associated organisms within the aquatic environment that have not been tested and that may be more sensitive to the test constituent. Application factors have been used to provide the degree of protection required. Safe levels for certain chlorinated hydrocarbons and certain heavy metals were estimated by applying an 0.01 application factor to the 96-hour LC50 value

for sensitive aquatic organisms. Flow-through bioassays have been conducted for some test indicator organisms over a substantial period of their life history. In a few other cases, information is available for the organism's natural life or for more than one generation of the species. Such data may indicate a minimal effect level, as well as a no-effect level.

The word "criterion" should not be used interchangeably with or as a synonym for the word "standard." The word "criterion" represents a constituent concentration or level associated with a degree of environmental effect upon which scientific judgment may be based. As it is currently associated with the water environment it has come to mean a designated concentration of a constituent that, when not exceeded, will protect an organism, an organism community, or a prescribed water use or quality with an adequate degree of safety. A criterion, in some cases, may be a narrative statement instead of a constituent concentration. On the other hand, a standard connotes a legal entity for a particular reach of waterway or for an effluent. A water quality standard may use a water quality criterion as a basis for regulation or enforcement, but the standard may differ from a criterion because of prevailing local natural conditions, such as naturally occurring organic acids, or because of the importance of a particular waterway, economic considerations, or the degree of safety to a particular ecosystem that may be desired.

Toxicity to aquatic life generally is expressed in terms of acute (short term) or chronic (long-term) effects. Acute toxicity refers to effects occurring in a short time period:

often death is the end point. Acute toxicity can be expressed as the lethal concentration for a stated percentage of organisms tested, or the reciprocal, which is the tolerance limit of a percentage of surviving organisms. Acute toxicity for aquatic organisms generally has been expressed for 24 to 96-hour exposures.

Chronic toxicity refers to effects through an extended time period. Chronic toxicity may be expressed in terms of an observation period equal to the lifetime of an organism or to the time span of more than one generation. Some chronic effects may be reversible, but most are not.

Chronic effects often occur in the species population rather than in the individual. If eggs fail to develop or the sperm does not remain viable, the species would be eliminated from an ecosystem because of reproductive failure. Physiological stress may make a species less competitive with others and may result in a gradual population decline or absence from an area. The elimination of a microcrustacean that serves as a vital food during the larval period of a fish's life could result ultimately in the elimination of the fish from an area. The phenomenon of bioaccumulation of certain materials may result in chronic toxicity to the ultimate consumer in a food chain. Thus, fish may mobilize lethal toxicants from their fatty tissues during periods of physiological stress. Egg shells of predatory birds may be weakened to a point of destruction in the nest. Bird chick embryos may have increased mortality rates. There may be a hazard to the health of man if aquatic organisms with toxic residues are consumed.

The fact that living systems, i.e., individuals, populations, species, and ecosystems, can take up, accumulate, and bioconcentrate manmade and natural toxicants is well documented. In aquatic systems biota are exposed directly to pollutant toxicants through submersion in a relatively efficient solvent (water) and are exposed indirectly through food webs and other biological, chemical, and physical interactions. Initial toxicant levels, if not immediately toxic and damaging, may accumulate in the biota or sediment over time and increase to levels that are lethal or sublethally damaging to aquatic organisms or to consumers of these organisms. Water quality criteria reflect a knowledge of the capacity for environmental accumulation, persistence, and effects of specific toxicants in specific aquatic systems.

Ions of toxic materials frequently cause adverse effects because they pass through the semipermeable membranes of an organism. Molecular diffusion through membranes may occur for some compounds such as pesticides, polychlorinated biphenyls, and other toxicants. Some materials may not pass through membranes in their natural or waste-discharged state, but in water they may be converted to states that have increased ability to affect organisms. For example, certain microorganisms can methylate mercury, thus producing a material that more readily enters physiological systems. Some materials may have multiple effects: for example, an iron salt may not be toxic; an iron floc or gel may be an irritant or clog fish gills to effect asphyxiation; iron at low concentrations can be a trace nutrient

but at high concentrations it can be a toxicant. Materials also can affect organisms if their metabolic byproducts cannot be excreted. Unless otherwise stated, criteria are based on the total concentration of the substance because an ecosystem can produce chemical, physical, and biological changes that may be detrimental to organisms living in or using the water.

In prescribing water quality criteria, certain fundamental principles dominate the reasoning process. In establishing a level or concentration as a criterion for a given constituent it was assumed that other factors within the aquatic environment are acceptable to maintain the integrity of the water. Interrelationships and interactions among organisms and their environment, as well as the interrelationships of sediments and the constituents they contain to the water above, are recognized as fact.

Antagonistic and synergistic reactions among many quality constituents in water also are recognized as fact. The precise definition of such reactions and their relative effects on particular segments of aquatic life have not been identified with scientific precision. Historically much of the data to support criteria development was of an ambient concentration-organism response nature. Recently, data are becoming available on long-term chronic effects on particular species. Studies now determine carcinogenic, teratogenic, and other insidious effects of toxic materials.

Some unpolluted waters in the Nation may exceed designated criteria for particular constituents. There is variability in the natural quality of water and certain organisms become adapted

to that quality, which may be considered extreme in other areas. Likewise, it is recognized that a single criterion cannot identify minimal quality for the protection of the integrity of water for every aquatic ecosystem in the Nation. To provide an adequate degree of safety to protect against long-term effects may result in a criterion that cannot be detected with present analytical tools. In some cases, a mass balance calculation can provide a means of assurance that the integrity of the waterway is not being degraded.

Water quality criteria do not have direct regulatory impact, but they form the basis for judgment in several Environmental Protection Agency programs that are derived from water quality considerations. For example, water quality standards developed by the States under section 303 of the Act and approved by EPA are to be based on the water quality criteria, appropriately modified to take account of local conditions. The local conditions to be considered include actual and projected uses of the water, natural background levels of particular constituents, the presence or absence of sensitive important species, characteristics of the local biological community, temperature and weather, flow characteristics, and synergistic or antagonistic effects of combinations of pollutants.

Similarly, by providing a judgment on desirable levels of ambient water quality, water quality criteria are the starting point in deriving toxic pollutant effluent standards pursuant to section 307(a) of the Act. Other EPA programs that use water quality criteria involve drinking water standards, the ocean

dumping program, designation of hazardous substances, dredge spoil criteria development, removal of in-place toxic materials, thermal pollution, and pesticide registration.

To provide the water resource protection for which they are designed, quality criteria should apply to virtually all of the Nation's navigable waters with modifications for local conditions as needed. To violate quality criteria for any substantial length of time or in any substantial portion of a waterway may result in an adverse affect on aquatic life and perhaps a hazard to man or other consumers of aquatic life.

Quality criteria have been designed to provide long-term protection. Thus, they may provide a basis for effluent standards, but it is not intended that criteria values become effluent standards. It is recognized that certain substances may be applied to the aquatic environment with the concurrence of a governmental agency for the precise purpose of controlling or managing a portion of the aquatic ecosystem; aquatic herbicides and piscicides are examples of such substances. For such occurrences, criteria obviously do not apply. It is recognized further that pesticides applied according to official label instructions to agricultural and forest lands may be washed to a receiving waterway by a torrential rainstorm. Under such conditions it is believed that such diffuse source inflows should receive consideration similar to that of a discrete effluent discharge and that in such instances the criteria should be applied to the principal portion of the waterway rather than to that peripheral portion receiving the diffuse inflow.

The format for presenting water quality criteria includes a concise statement of the dominant criterion or criteria for a particular constituent followed by a narrative introduction, a rationale that includes justification for the designated criterion or criteria, and a listing of the references cited within the rationale. An effort has been made to restrict supporting data to those which either have been published or are in press awaiting publication. A particular constituent may have more than one criterion to ensure more than one water use or condition, i.e., hard or soft water where applicable, suitability as a drinking water supply source, protection of human health when edible portions of selected biota are consumed, provision for recreational bathing or waterskiing, and permitting an appropriate factor of safety to ensure protection for essential warm-or coldwater associated biota.

Criteria are presented for those substances that may occur in water where data indicate the potential for harm to aquatic life, or to water users, or to the consumers of the water or aquatic life. Presented criteria do not represent an all-inclusive list of constituent contaminants. Omissions from criteria should not be construed to mean that an omitted quality constituent is either unimportant or non-hazardous.

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NMED Exhibit 68



Technical Memorandum

PH REQUIREMENTS OF FRESHWATER AQUATIC LIFE

Prepared by:

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Specializing in Water and Power Resources

May 2004

NMED Exhibit 69



Technical Memorandum

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The pH of surface waters is important to aquatic life because pH affects the ability of fish and other aquatic organisms to regulate basic life-sustaining processes, primarily the exchanges of respiratory gasses and salts with the water in which they live. Failure to adequately regulate these processes can result in numerous sub-lethal effects (e.g., diminished growth rates) and even mortality in cases when ambient pH exceeds the range physiologically tolerated by aquatic organisms.

DIRECT EFFECTS OF pH ON AQUATIC LIFE

The effects of pH on fish and other freshwater aquatic life have been reviewed in detail (e.g., Doudoroff and Katz 1950; McKee and Wolf 1963; EIFAC 1969; Katz 1969; NAS 1972; AFS 1979; Alabaster and Lloyd 1980). The pH of water affects the normal physiological functions of aquatic organisms, including the exchange of ions with the water and respiration. Such important physiological processes operate normally in most aquatic biota under a relatively wide pH range (e.g., 6-9 pH units). There is no definitive pH range within which all freshwater aquatic life is unharmed and outside which adverse impacts occur. Rather, there is a gradual "deterioration" in acceptability as pH values become further removed from the normal range (EIFAC 1969; AFS 1979; Alabaster and Lloyd 1980). The acceptable range of pH to aquatic life, particularly fish, depends on numerous other factors, including prior pH acclimatization, water temperature, dissolved oxygen concentration, and the concentrations and ratios of various cations and anions (McKee and Wolf 1963).

Alabaster and Lloyd (1980) identified the pH range that is not directly lethal to freshwater fish as 5.0-9.0. With few exceptions, pH values between 6.5 and 9.0 are satisfactory, on a long-term basis, for fish and other freshwater aquatic life. The pH of most inland fresh waters containing fish ranges from about 6 to 9 (Ellis 1937), with most waters, particularly those with healthy, diverse, and productive fish and macroinvertebrates communities having a pH between approximately 6.5 and 8.5 units (Ellis 1937; McKee and Wolf 1963; NTAC1968; NAS 1972). In establishing water quality criteria for pH, ORVWSC (1955) stated that, although fish had been found at pH values from 4-10, the safe range was 5-9 and for maximum productivity the pH should be maintained between 6.5 and 8.5. Some aquatic organisms (e.g., certain species of algae) have been found to live at pH 2 and lower, and others at pH 10 and higher (NAS 1972). However, there are few such organisms, and their extreme tolerances are not reflective of the pH tolerated by the majority of organisms occurring in a given aquatic ecosystem.

Limiting pH Values			
Minimum	*Maximum*	*Remarks*	*References*
3.3	10.7	Trout survived without adverse effects	1467
3.6	---	Tench survived two weeks but carp died	1302
3.6	10.5	96-hour TL_m range for bluegill sunfish	2934
3.8	10.0	Fish eggs could be hatched, but abnormal young were produced of extreme pH's	1468
4.0	10.0	The most resistant fish can tolerate such extreme pH values indefinitely after acclimatization	1460
4.0	10.1	Limits for the most resistant species	361
4.0	10.4	Limits for bluegill sunfish with HCl and NaOH	3606
4.1	8.5	Range tolerated by speckled trout in nature	1467
4.1	9.5	Range tolerated by trout	862
4.3	---	Carp died in 5 days	1303
4.4	8.7	Toxic limits for trout	3609
4.5	8–9	Trout eggs and larvae develop normally	1636
4.6	9.5	Toxic limits for perch	3609
4.6	---	Tench died in two days	2977
4.8	---	Lower limit for trout	1304
4.8	---	Illness and early death for carp	2977
4.8	9.2	Toxic limits for fish	1305
5.0	---	Toxic limit for sticklebacks	2941
5.0	9.0	Tolerable range for most fish	361, 2409, 3609
---	8.7	Upper limit for good fishing water	717
5.4	---	Lower limit for carp and tench	1306
---	9.2	Upper limit for trout and perch	2977
5.5	---	Lower limit for general fish protection	1307
5.4	11.4	Fish avoided waters beyond these limits	1046
6.0	11.0	Fish did not avoid waters in this range	1046
6.0	7.2	Optimum range for fish eggs	1468
6.5	8.4	Range tolerated by most freshwater fish	1466
For other aquatic organisms, ranges were reported as follows:			
1.0	---	Mosquito larvae destroyed at this value	1308
2.5	---	Tolerated by *Chlamydomonas, Fragilaria, Asterionella, Aphanizomenon*	2168
3.3	4.7	Mosquito larvae thrived in this range	1309
4.0	---	Toxic for *Paramecium, Volvox, Asplanchna*	2977
7.5	8.4	Good range for plankton production	1021
---	8.5	Algae are destroyed above this value	

Source: McKee and Wolf (1963).

A Summary of Some Effects of pH on Freshwater Fish and Other Aquatic Organisms

pH	Known effects
11.5–12.0....	Some caddis flies (Trichoptera) survive but emergence reduced.
11.0–11.5....	Rapidly lethal to all species of fish.
10.5–11.0....	Rapidly lethal to salmonids. The upper limit is lethal to carp (Cyprinus carpio), goldfish (Carassius auratus), and pike. Lethal to some stoneflies (Plecoptera) and dragonflies (Odonata). Caddis fly emergence reduced.
10.0–10.5....	Withstood by salmonids for short periods but eventually lethal. Exceeds tolerance of bluegills (Lepomis macrochirus) and probably goldfish. Some typical stoneflies and mayflies (Ephemera) survive with reduced emergence.
9.5–10.0....	Lethal to salmonids over a prolonged period of time and no viable fishery for coldwater species. Reduces populations of warmwater fish and may be harmful to development stages. Causes reduced emergence of some stoneflies.
9.0–9.5.....	Likely to be harmful to salmonids and perch (Perca) if present for a considerable length of time and no viable fishery for coldwater species. Reduced populations of warmwater fish. Carp avoid these levels.
8.5–9.0.....	Approaches tolerance limit of some salmonids, whitefish (Coregonus), catfish (Ictaluridae), and perch. Avoided by goldfish. No apparent effects on invertebrates.
8.0–8.5.....	Motility of carp sperm reduced. Partial mortality of burbot (Lota lota) eggs.
7.0–8.0....	Full fish production. No known harmful effects on adult or immature fish, but 7.0 is near low limit for Gammarus reproduction and perhaps for some other crustaceans.
6.5–7.0.....	Not lethal to fish unless heavy metals or cyanides that are more toxic at low pH are present. Generally full fish production, but for fathead minnow (Pimephales promelas), frequency of spawning and number of eggs are somewhat reduced. Invertebrates except crustaceans relatively normal, including common occurrence of mollusks. Microorganisms, algae, and higher plants essentially normal.
6.0–6.5.....	Unlikely to be toxic to fish unless free carbon dioxide is present in excess of 100 ppm. Good aquatic populations with varied species can exist with some exceptions. Reproduction of Gammarus and Daphnia prevented, perhaps other crustaceans. Aquatic plants and microorganisms relatively normal except fungi frequent.
5.5–6.0.....	Eastern brook trout (Salvelinus fontinalis) survive at over pH 5.5. Rainbow trout (Salmo gairdneri) do not occur. In natural situations, small populations of relatively few species of fish can be found. Growth rate of carp reduced. Spawning of fathead minnow significantly reduced. Mollusks rare.
5.0–5.5.....	Very restricted fish populations but not lethal to any fish species unless CO_2 is high (over 25 ppm), or water contains iron salts. May be lethal to eggs and larvae of sensitive fish species. Prevents spawning of fathead minnow. Benthic invertebrates moderately diverse, with certain black flies (Simuliidae), mayflies (Ephemerella), stoneflies, and midges (Chironomidae) present in numbers. Lethal to other invertebrates such as the mayfly. Bacterial species diversity decreased; yeasts and sulfur and iron bacteria (Thiobacillus-Ferrobacillus) common. Algae reasonably diverse and higher plants will grow.
4.5–5.0.....	No viable fishery can be maintained. Likely to be lethal to eggs and fry of salmonids. A salmonid population could not reproduce. Harmful, but not necessarily lethal to carp. Adult brown trout (Salmo trutta) can survive in peat waters. Benthic fauna restricted, mayflies reduced. Lethal to several typical stoneflies. Inhibits emergence of certain caddis fly, stonefly, and midge larvae. Diatoms are dominant algae.
4.0–4.5.....	Fish populations limited; only a few species survive. Perch, some coarse fish, and pike can acclimate to this pH, but only pike reproduce. Lethal to fathead minnow. Some caddis flies and dragonflies found in such habitats; certain midges dominant. Flora restricted.
3.5–4.0.....	Lethal to salmonids and bluegills. Limit of tolerance of pumkinseed (Lepomis gibbosus), perch, pike, and some coarse fish. All flora and fauna severely restricted in number of species. Cattail (Typha) is only common higher plant.
3.0–3.5.....	Unlikely that any fish can survive for more than a few hours. A few kinds of invertebrates such as certain midges and alderflies, and a few species of algae may be found at this pH range and lower

Source: USEPA (1973). Table incorporates information presented by Alabaster and Lloyd (1980).

In response to the acid rain problems occurring in the eastern United States and Canada, the physiological effects of acid stress on fish and other aquatic life have been well documented (e.g., see Alabaster and Lloyd 1980; AFS 1982). A number of researchers have proposed that the toxic action of hydrogen ions on fish under acidic conditions involves production of mucus on the gill epithelium, which interferes with the exchange of respiratory gasses and ions across the gill; precipitation of proteins within the epithelial cells; and/or acidosis of the blood (also affecting oxygen uptake) (Ellis 1937; Westfall 1945; Leivestad, in AFS 1982; Boyd 1990). Hence, respiratory distress and osmotic imbalance are the primary physiological symptoms of acid stress in fish. Less research has been conducted on the effects of acid stress on macroinvertebrates. However, those species that exchange respiratory gasses and regulate ions through their gills (e.g., mayflies and stoneflies) and/or species affected by blood acid-base balance may experience effects similar to fish.

Below a pH of 5.0, mortality occurs in some life stages of certain fish species, although some fishes can be acclimated to pH levels below 4.0. Certain species of macroinvertebrates can tolerate very low pH values. Lackey (1938) found Gammarus spp. in two streams with pH values of 2.2 and 3.2, mosquito larvae in a stream at pH 2.4, and caddis fly larvae (Trichoptera) at pH 2.4. Nevertheless, the primary productivity of freshwater aquatic ecosystems is reduced considerably below pH 5.0, which, in turn, reduces the food supply for higher organisms. Hence, fish that remain present would likely experience reduced numbers and/or growth rates (Alabaster and Lloyd 1980).

The physiological effects on aquatic life induced by high pH (>9) have been studied less than those at low pH. This is likely because high pH waters are less common (Doudoroff and Katz 1950; Alabaster and Lloyd 1980). Several researchers concluded that the toxic mode of action of hydroxyl ions (i.e., high pH values) is hypertrophy of mucus cells at the base of the gill filaments and destruction of gill and skin epithelium, with effects on the eye lens and cornea (Alabaster and Lloyd 1980; Boyd 1990).

Studies have shown that pH values of between 9 and 10 can result in partial mortality for bluegill sunfish (Lepomis macrochirus), rainbow trout (Oncorhynchus mykiss), brown trout (Salmo trutta), salmon, and perch. The majority of freshwater fishes and macroinvertebrates experience harmful effects (lethal or sublethal) at one or more life stages at pH values above 10 (Weibe 1931; AFS 1979; Alabaster and Lloyd 1980). Where high pH is caused by aquatic plant photosynthesis, high water temperatures and supersaturation of dissolved gasses may also occur and may contribute to physiological effects experienced by aquatic organisms, making it difficult to correlate mortality with laboratory data on pH alone. Based on their review of the literature,

Alabaster and Lloyd (1980) stated that chronic exposure to pH values above 10 was harmful to all species studied, while salmonids and some other species were harmed at pH values above 9.

The USEPA has concluded that a pH range of 6.5 to 9.0 provides adequate protection for the life of freshwater fish and bottom-dwelling macroinvertebrates. Outside this range, fish suffer adverse physiological effects that increase in severity as the degree of deviation increases until lethal levels are reached (USEPA 1976, 1986).

EFFECTS OF DIURNAL FLUCTUATIONS AND RAPID PH CHANGES ON AQUATIC LIFE

The pH of lakes and streams often changes during the day in response to photosynthetic activity. In ponds having poorly buffered (low alkalinity) waters, the pH may fall to approximately 7 in the early morning and increase to 9 or more in the afternoon (Boyd 1990). Good fish production usually can be maintained in spite of these daily fluctuations. In most lakes and ponds, diurnal pH fluctuations during the summer, when photosynthetic activity peaks, are generally less than 2 pH units, while in streams are generally less (e.g., 0.5-1.0 units). Unless diurnal fluctuations result in ambient pH falling below 6 or being elevated above 9, they generally have no adverse impact on aquatic life. This is supported by the study findings discussed below.

Although it was once believed that fish could not tolerate sudden pH changes, studies conducted by Brown and Jewell (1926) and Wiebe (1931) showed that certain fish species could tolerate such rapid changes, within the normal pH range. Brown and Jewell (1926) observed catfish and perch living in a bog lake having a pH of 4.4-6.4, and also in a nearby glacial lake having a pH of 8.2-8.7. These researchers demonstrated that the fish from both lakes survived transfer from one lake to another.

Wiebe (1931) reported that sunfish (Lepomis spp.) and goldfish (Carassius auratus) survived rapid changes from pH 7.2 to 9.6 (2.4 units); largemouth bass (Micropterus salmoides) from pH 6.1 to 9.6 (3.5 units); and smallmouth bass (Micropterus dolomieui) from pH 6.6 to 9.3 (2.7 units). Witschi and Ziebell (1979) transferred rainbow trout from water of pH 7.2 to waters of pH 8.5, 9.0, 9.5, and 10.0. Survival after 48 hours was 100% for fish transferred to pH 7.2 and 8.5, 88% for those transferred to pH 9.0, 68% for pH 9.5, with complete mortality occurring for fish transferred to pH 10.0. This study clearly demonstrated that rainbow trout could handle rapid pH changes of 1.3 units (from 7.2 to 8.5) without experiencing acute mortality. The acute mortality that occurred when transferred to pH 9.0, 9.5, and 10.0 water was more likely due to being transferred to a pH outside the acceptable range for the species than due to the pH change itself (Modin, pers. comm., 1998). If no acute mortality occurs, no chronic effects would be expected because of physiological acclimation to the new pH, which occurs within a short period of time (i.e., hours to days).

This work demonstrated that the fish species studied tolerated rapid pH changes of 1.3 to 3.5 units when these changes occurred within the physiological-tolerance pH range. When the pH changed to a value that approached the species' normal upper tolerance level (i.e., 9.0) or exceeded their upper tolerance limit (9.5 and 10.0), mortality occurred (Witschi and Ziebell 1979). Based on findings from these studies and personal communications with CDFG fish pathologists (Modin, pers. comm., 1998), it is concluded that neither acute mortality nor chronic sub-lethal effects would be expected in fish experiencing rapid pH changes when all pH levels to which fish are exposed remain within the range of 6.5 to 8.5. Conversely, these studies suggest that small pH changes (e.g., 1 unit) could have adverse impacts when the resulting pH value falls outside the physiologically acceptable range for a given species. For example, rainbow trout acclimated to pH 9.0, which is at or near the species' upper limit, would be expected to experience high mortality if transferred to pH 10.0 and, in fact, would be expected to experience mortality if transferred to pH 9.5 – a change of just 0.5 units (Witschi and Ziebell 1979; Modin, pers. comm., 1998).

The ability of fish to rapidly acclimate to waters having substantially different pH values is further demonstrated by hatchery stocking programs and the freshwater tropical fish (aquarium) industry, where it is common to move fish from one water body or aquarium to another that differ by at least 0.5 pH units, and often by more than 1.0 pH unit. However, it should be noted that this "stocking" of fish typically involves waters with pH values in the range of 6.5 to 8.5 units so that the fish are transferred to waters with pH values well within the range that is physiologically acceptable to them. Available data regarding pH values tolerated by macroinvertebrates suggest that, like fish, they can rapidly adapt to changes in ambient pH levels within their natural pH range (Alabaster and Lloyd 1980; Boyd 1990).

A technical review of the effects of rapid pH changes on benthic macroinvertebrates revealed evidence indicating that macroinvertebrates rapidly exposed to pH changes of one unit or more, when pH is maintained within the 6.5 to 8.5 range, would not experience mortality, or other long-term adverse effects. Information supporting this finding is discussed further below.

The available scientific literature on the effects of rapid pH reductions on benthic macroinvertebrates provides evidence to suggest that rapid pH reductions of one unit or more, when pH is maintained between 6.5 and 8.5, would not cause chronic, adverse effect on individual macroinvertebrates or their populations. A thorough review of the scientific literature was conducted to identify studies that investigated the effects of rapid pH changes on macroinvertebrates, when pH was maintained between 6.5 and 8.5. No such studies were found. The fact that no studies of this nature could be found in the literature further supports the contention that rapid pH changes within the 6.5 to 8.5 range are not problematic to benthic

macroinvertebrates. Based on the commonality of their experimental approaches, the acidification studies that are available in the scientific literature suggest that significant adverse effects to individual macroinvertebrates and their communities would not be expected to occur upon experiencing a rapid pH reduction unless the ending pH is below 6.0. Several studies that investigated the effects of stream acidification on benthic macroinvertebrate communities, where ending pH was below 6.0, shed additional light on how a pH gradient within a point source discharge mixing zone would affect benthic macroinvertebrates drifting through the zone; hence, findings from these studies are briefly summarized below.

Bernard et al. (1990) acidified experimental reaches of a British Columbia stream from pH 7.0 to 5.9 within 30 minutes to assess the effect of mild acidification on short-term invertebrate drift. They reported that small Ephemeroptera showed no initial response to pH reductions from 7.0 to 5.9, but that their drift increased after about 6 hours. Increased drift was observed for Chironomid and Trichoptera within an hour of reaching pH 5.9. Harpactacoid copepods, Hydrcarina, simulid Diptera, Plecoptera, and large Ephemeroptera did not respond. Lack of a drift response induced by rapid pH reduction in certain taxa demonstrates that the organisms were not adversely affected enough to move, and consequently, would not be affected enough to experience mortality. Kratz et al. (1994) reported that Simuliids (black flies) did not respond to rapid depressions of 1 pH unit below ambient, with an ending pH of below 6.0. Also, Hall et al. (1987) reported no effect on daytime drift rates in acidic Norris Brook, where pH was reduced from 6.4 to 5.2-5.5. Bernard et al. (1990) surmised that the rapid, large increases in drift exhibited by chironomids were avoidance behavior. Sensitive organisms may escape by drift to more suitable conditions downstream. Bernard (1985) (cited in Bernard et al. 1990) supported this hypothesis by showing that rapidly responding mayflies collected in a stream rapidly acidified to pH 5.7 had greater than 95% survival when subsequently held in circumneutral water for 24 hours. Kratz et al. (1994) concurred with these findings, suggesting that mild pH reductions (i.e., those with an ending pH near 6.0 or above) would likely elicit increased drift in some species due to behavioral responses rather than from causing pH-related mortality, whereas mortality-induced drift would increase as ending pH decreases, and reached lethal levels (e.g., 5.5 or lower).

To determine the direct effects of water chemistry on invertebrates sensitive to pH reductions, Rosemond et al. (1992) transplanted three mayfly species (i.e., *Drunella conestee (*Family Ephemerellidae) and *Stenonema* sp. and *Epeorus pleuralis* (Family Heptageniidae)) from a stream having pH of 6.6-6.8 to: 1) the stream from which they were collected (i.e., back into pH 6.6-6.8), and 2) a stream of pH 5.0 (a rapid pH change of 1.6-1.8 units). In the first *in situ* transplant experiment, there was no significant difference in mortality among the individuals of *Drunella conestee* transplanted into the two sites through 9 days post transplant. Mortality rates were 32% for organisms transplanted back into the same pH, and 28% for those transplanted into

pH 5.0. In the second *in situ* experiment, using *Stenonema* sp., and *Epeorus pleuralis*, both species transplanted into the pH 5.0 stream experienced significantly higher mortality that those transplanted back into the original stream. In addition, the ultimate mortality experienced by these two species transplanted into the pH 5.0 stream differed significantly. These researchers concluded that the different sensitivities of the three species was due to differences in sensitivities to ending pH and acquired body burdens of aluminum, rather than to the initially-experienced rapid change in pH. This was supported by the fact that it took 2-6 days for mortality rates to differ between transplant groups for the same species. An inability to tolerate the initial pH shock (an acute phenomenon) would be expected to become apparent within a matter of hours rather than days. This is of particular relevance because macroinvertebrates drifting through a mixing zone would typically pass through the zone in a matter of minutes to hours.

Bell and Nebeker (1969) investigated the tolerance of aquatic insects to low pH. In this study, caddisfly, stonefly, dragonfly, and mayfly nymphs were exposed to a range of pH levels for 96 hours (4 days) to determine the pH levels at which 50% of the test organisms died (96-hr TL_{50}). Field-collected nymphs were acclimated to the laboratory for one week at pH 7.8. However, no gradual acclimation to test pH levels was reported. In fact the methods stated: "*If the test pH deviated by more than 0.25 pH units from the desired pH, the test was terminated*." Hence, test organisms were taken directly from their laboratory acclimation tank (pH 7.8), and placed directly into test tanks maintained at pH 1.0-7.0. The 96-hr TL_{50} values reported for the 10 species tested (from the families identified above) ranged from a low of 1.5 (the caddisfly *Brachycentrus americanus*) to a high of 4.65 (the mayfly *Ephemerella subvaria*) pH units. All 10 species tested showed 100% survival at pH 6.0, a 1.8 unit change from their acclimated pH of 7.8. The mayfly *Ephemerella subvaria* began to experience some mortality at test pH levels below 6.0. However, the caddisfly *Hydropsyche betteni*, stonefly *Acroneuria lycorias*, dragonfly *Boyeria vinosa*, and mayfly *Stenonema rubrum* all showed 100% survival at test pH levels as low as 5.5. Hence, these species showed no mortality when transferred from the acclimation tank at pH 7.8 to test tanks at pH 5.5, thereby experiencing a rapid pH change of 2.3 pH units. The caddisfly *Brachycentrus americanus* showed 100% survival to pH levels of 4.5, thereby experiencing a rapid pH change of 3.3 pH units.

In a follow-up study, Bell (1970) performed similar experiments with the same species of benthic macroinvertebrates, but extended the test period from 96 hours to 30 days. Findings were similar to the 96-hr study, except that the 30-day TL_{50}s were somewhat higher (i.e., higher pH levels) than those reported for the 96-exposure. These studies' findings concur with those of the studies discussed above, indicating that the ending pH is more important in determining mortality than the magnitude and rate of initial pH change.

These studies showed that rapid pH reductions of up to 1.6 pH units, with an ending pH below 6.0, did not cause elevated mortality in mayflies, a taxa of benthic macroinvertebrates shown through numerous studies (e.g., Kratz et al. 1994; Feldman and Connor 1992; Rosemond et al. 1992) to be the most sensitive taxa to pH reductions. Mortality was not shown to occur in sensitive mayfly species, or other macroinvertebrate taxa, when the ending pH was maintained at or above 6.5, as would always occur under compliance with the proposed pH objective.

Personal communications with several macroinvertebrate experts provide evidence in support of the conclusions pertaining to rapid pH changes stated above. S. Cooper (U.C. Santa Barbra, pers. comm., 1999), R. Haro (U.W. LaCrosse, pers. comm., 1999), and J. Harrington (CDFG, pers. comm., 1999) all concurred that the lack of studies in the scientific literature addressing pH changes within the 6.5 to 8.5 range suggest that rapid changes within this range are unlikely to adversely affect macroinvertebrates. Moreover, none of these experts were aware of any studies reported in the literature that document mortality to macroinvertebrates resulting from rapid pH changes with in the 6.5 to 8.5 range.

When asked to give their professional opinion regarding potential effects of rapid pH changes on benthic macroinvertebrates within the context of what can occur across the mixing zone associated with a municipal effluent discharge, the following statements were made.

A pH change from 8.5 to 7.0 would not be expected to have a lethal effect, but could have a sublethal (e.g., behavioral) effect. Nevertheless, sublethal effects would be expected to cease when the macroinvertebrates acclimated to the new pH. One would not expect to see lethal effects until the ending pH fell outside the normal pH range, perhaps 5.5 or 5.0 pH units (Cooper, pers. comm., 1999). S. Cooper is considered to be the leading expert on the West Coast regarding the effects of acid pulses on stream benthic macroinvertebrates.

As long as pH remained within the 6.5 to 8.5 range (referred to as circumneutral), there generally would not be any substantial adverse effects to macroinvertebrates drifting downstream into the effluent-dominated portion of the creek, where pH could be 1-2 units lower. Short-term sublethal (e.g., behavioral) effects could occur in some species (Haro, pers. comm., 1999).

In discussions with Jim Harrington of CDFG, regarding ranges of pH acceptable to aquatic life, he stated the following, *"The pH range of 6.5 to 8.5 is accepted to represent safe levels, and this is probably why there is not much literature on its effects to the aquatic system. When I write biological significance reports on pH-related spill events, I would conclude that there would be no deleterious effects within this range."* (Harrington, pers. comm., 1999).

The USEPA's past and current national pH criteria for the protection of aquatic life provide evidence to suggest that rapid pH changes, when pH is maintained within the 6.5 to 8.5 range, would not cause adverse impacts to benthic macroinvertebrates or their communities. Based on the language used by the NAS in its 1972 criteria referring to pH changes above or below the "…natural seasonal", it is clear that the 0.5 unit of change allowed under the "nearly maximum level of protection" was defined to limit the ambient pH range, not the magnitude of rapid change within this range. In fact, no quantitative criterion was assigned to limit rapid pH changes within the preferred pH range of 6.5 to 8.5. Similarly, the USEPA's current pH criterion for the protection of freshwater aquatic life (USEPA 1986, 1999a) simply defines an acceptable ambient pH range (i.e., 6.5-9.0), but does not quantitatively limit the magnitude of rapid change that organisms can be exposed to within this range (e.g., during movement through mixing zones associated with point-source discharges). Because the magnitude of rapid change to which freshwater aquatic life are exposed, within acceptable ambient pH ranges, has never been regulated as part of any national pH criterion, it can be reasonably concluded that all available scientific data on this issue indicate that the effects of rapid pH changes are insignificant when pH is maintained within the acceptable ambient range (e.g., 6.5-8.5).

Based on the above discussion, the proposed pH amendment is strongly supported by the current science regarding pH requirements of freshwater aquatic life and would be consistent with, but somewhat more restrictive than, USEPA's current national recommended criteria for the protection of freshwater aquatic life.

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U.S. Environmental Protection Agency

NPDES Permit Writers' Manual



U.S. Environmental Protection Agency
Office of Wastewater Management, Water Permits Division
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United States
Environmental Protection
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Office of Water
Washington, DC

United States
Environmental Protection Agency

National Pollutant Discharge Elimination System (NPDES) Permit Writers' Manual

This guidance was developed by staff within the U.S. Environmental Protection Agency's (EPA's) Office of Wastewater Management and addresses development of wastewater discharge permits under the National Pollutant Discharge Elimination System (NPDES). NPDES permit development is governed by existing requirements of the Clean Water Act (CWA) and the EPA NPDES implementing regulations. CWA provisions and regulations contain legally binding requirements. This document does not substitute for those provisions or regulations. Recommendations in this guidance are not binding; the permitting authority may consider other approaches consistent with the CWA and EPA regulations. When EPA makes a permitting decision, it will make each decision on a case-by-case basis and will be guided by the applicable requirements of the CWA and implementing regulations, taking into account comments and information presented at that time by interested persons regarding the appropriateness of applying these recommendations to the situation. This guidance incorporates, and does not modify, existing EPA policy and guidance on developing NPDES permits. EPA may change this guidance in the future.

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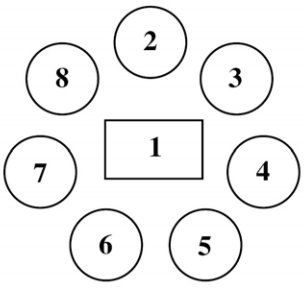
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6. Non-Municipal (Industrial)—EPA
7. Construction Stormwater—Barry Tonning, Tetra Tech, Inc.
8. Combined Sewer Overflow—EPA



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Introduction to the Manual

This manual reviews the statutory and regulatory framework of the National Pollutant Discharge Elimination System (NPDES) program and examines technical considerations for developing NPDES permits for wastewater discharges. The manual is designed, primarily, for new permit writers becoming acquainted with the NPDES program and the process of permit writing, but can also serve as a reference for experienced permit writers or anyone interested in learning about the legal and technical aspects of developing NPDES permits. This manual replaces the *1996 U.S. EPA NPDES Permit Writers' Manual*[1] <www.epa.gov/npdes/pubs/owm0243.pdf>, which updated the *1993 Training Manual for NPDES Permit Writers*[2] <www.epa.gov/npdes/pubs/owm0339.pdf>.

To assist the reader, acronyms and abbreviations are defined for the first use in each chapter and in Appendix A of the manual. Endnotes are provided at the end of each chapter.

Purpose of this Manual

The purpose of this *NPDES Permit Writers' Manual* (manual) is to provide a general reference for permitting authorities that outlines and explains the core elements of the NPDES permit program. The core elements form the foundation of the NPDES program on which guidance for specific areas of the program (e.g., stormwater, concentrated animal feeding operations) can be built. While the guidance for these core program areas will be applicable in many cases, the U.S. Environmental Protection Agency (EPA) recognizes that each EPA Regional Office or authorized state, territory, or tribe (hereafter *state*) will tailor specific aspects of its NPDES permitting procedures to address state and local laws and site-specific concerns and conditions.

The specific objectives and functions of this manual are as follows:

- Provide an overview of the scope and the statutory and regulatory framework of the NPDES program.
- Describe the essential components of a permit and provide an overview of the permitting process.
- Describe the different types of effluent limitations and the legal and technical considerations involved in developing effluent limitations.
- Describe the legal and technical considerations involved in developing other permit conditions including
  - Monitoring and reporting requirements.
  - Special conditions.
  - Standard conditions.
- Describe other permitting considerations including
  - Variances.
  - Anti-backsliding.
  - Other applicable statutes.

- Explain the administrative process for issuing, modifying, revoking and terminating NPDES permits.

This manual is not intended to be a standalone reference document. Rather, it establishes the framework for NPDES permit development and should be supplemented, where necessary, by additional EPA and state regulations, policy, and detailed guidance applicable to specific types of dischargers and circumstances. To that end, this manual identifies and references relevant regulations, policy, and other guidance documents throughout the text.

Publications Referenced

This manual provides links to publications available online that supplement the information in the manual. All documents available electronically were accessed and available as of the date of this manual's publication. Some documents are not available in an electronic format. In those instances, readers should check the following sources to determine the availability of and to obtain printed copies of the documents:

- Office of Water Resource Center (OWRC) <www.epa.gov/safewater/resource/>
  OWRC is a contractor-operated facility providing document delivery, information/referral, and reference services to public users and EPA staff interested in Office of Water Program information
  phone: 202-566-1729 or 800-832-7828, fax: 202-566-1736, e-mail: <center.water-resource@epa.gov>.
- EPA Library Services and Repositories <www.epa.gov/natlibra/libraries.htm>
  EPA's library services and repositories provide access to information about the environment and related scientific, technical, management, and policy information. Library services <www.epa.gov/natlibra/library_services.html> are delivered through the National Library Network <www.epa.gov/natlibra/index.html>.
- National Service Center for Environmental Publications (NSCEP) <www.epa.gov/ncepihom/>
  NSCEP, formerly NCEPI, maintains and distributes EPA publications in hardcopy, CD ROM and other multimedia formats. The publication inventory includes more than 7,000 titles
  phone: 513-489-8190 or 800-490-9198, fax: 513-489-8695, e-mail: ncepimal@one.net.
- National Technical Information Service (NTIS) <www.ntis.gov/>
  NTIS is the largest central resource for government-funded scientific, technical, engineering, and business related information covering more than 350 subject areas from more than 200 federal agencies
  phone: 703-605-6050 or 888-584-8332, fax: 703-605-6900, e-mail: customerservice@ntis.gov.

Legislative and Regulatory Citations

There are a number of different conventions used to cite legislation and regulations. In this manual, the following conventions have been used:

- When citing the *United States Code*, the abbreviation U.S.C. is used. The abbreviation is preceded by the Title of the U.S.C. and then followed by the section number.
  Example: 16 U.S.C. 1531 *et seq*. and 33 U.S.C. §§ 1251-1387.

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- When citing the Clean Water Act, the abbreviation CWA is used. The abbreviation is followed by the word *section* and then the section number.
  Example: CWA section 402 and CWA section 402(o).
- When citing the *Code of Federal Regulations* (CFR), the convention depends on the location of the reference. For first references, the abbreviation CFR is preceded by the title number of the CFR and followed either by the word *Part* (if it is a part—a whole number) or the number of the subsection (if it is a subpart/subsection). For subsequent references, the title and CFR are omitted and just the word *Part* or the section symbol (§) is used.
  Example: First citation: 40 CFR Part 136 or 40 CFR 122.44
  Subsequent citations: Part 136 or § 122.44.

Almost all the regulatory citations in this manual are for Title 40 of the CFR (with the exception of the other federal laws referenced in section 11.1 of this manual). Any other Titles are explicitly referenced and in the format for the first regulatory citation (e.g., 50 CFR Part 402).

Electronic NPDES Information

Websites and electronically stored publications and data are available to help permit writers draft NPDES permits. Tools have been created to assist permit writers with specific aspects of permit development and are discussed in their respective sections. The electronic tools listed below apply to all aspects of permit development and serve as valuable references for the permit writer.

NPDES Website and Resources

The Water Permits Division (WPD) within the EPA Office of Water (OW), Office of Wastewater Management, has developed a comprehensive NPDES Website <www.epa.gov/npdes> with technical and regulatory information about the NPDES permit program, information on related programs and initiatives, and documents published by WPD. Where applicable, this manual references the NPDES Website and provides links to relevant documents on that site. This manual also references other EPA and non-EPA websites that contain information that might be helpful to NPDES permit writers. Note, however, that EPA is not responsible for information provided on websites outside the EPA Website <www.epa.gov>.

WPD also has prepared several websites and other resources to help permit writers draft permits. This manual references those websites and resources in the appropriate section of this manual.

Electronic Permitting Tools

Many EPA Regions and authorized states have developed tools to help them manage the permit issuance process. Electronic permitting tools range from spreadsheets and word processing applications to sophisticated Web-based systems that enable permitting authorities to manage their entire environmental program. For example, some states have built systems that enable dischargers to electronically sign and submit discharge reports; create, track, and store permit documents; and manage enforcement, compliance, and inspections related to permits. As technologies continue to evolve, many permitting authorities are likely to begin using more information technology applications to manage the process of permitting.

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ICIS-NPDES

Together with OW, the Office of Enforcement and Compliance Assurance (OECA) is responsible for oversight of implementation of the NPDES program. OW is responsible for the NPDES implementing regulations and oversight of permit issuance by states and EPA Regions. OECA, along with its regional, state, tribal and local counterparts, is responsible for tracking and maintaining enforcement and compliance activities, monitoring and enforcement and compliance status of the regulated community, and reviewing and evaluating program performance. OECA also maintains national data systems to support program management and oversight of the NPDES program.

The Permit Compliance System (PCS), one of two national NPDES electronic databases, supports the management and oversight of the NPDES program. Since the last modernization of PCS in 1985, the NPDES program has evolved significantly to include additional program requirements, such as the NPDES program for stormwater and implementation of the Combined Sewer Overflow Control Policy. Because of limitations to PCS, OECA is working to phase out this system and move to a more modern data management system described below.

The Integrated Compliance Information System for NPDES permits (ICIS-NPDES) <https://icis.epa.gov/icis>, the successor to PCS, provides an updated system that enables national program management and oversight activities such as

- Permit tracking and management.
- Compliance monitoring.
- NPDES program management.
- Enforcement actions.

ICIS-NPDES is a Web-based system with an electronic database capable of handling the large amount of data generated by and about the NPDES program. Section 11.5.1.1 of this manual provides more information on ICIS-NPDES as it relates to NPDES permit compliance.

Hyperlinks in this Document

Where a website provides supplementary information or is referenced in this manual, the actual site or higher level site address appears in the symbols < > so that readers will have a reference to the address even in a printed version of this document. In the electronic version of the manual, the text in carats is also the hyperlink to the referenced website. Care has been taken to provide the correct Web addresses and hyperlinks; however, these references can change or become outdated after this manual's publication.

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[1] U.S. Environmental Protection Agency. 1996. *U.S. EPA NPDES Permit Writers' Manual*. EPA-833-B-96-003. U.S. Environmental Protection Agency, Office of Water, Washington, DC. <www.epa.gov/npdes/pubs/owm0243.pdf>. Separate sections of this document are also available on the NPDES Website by going to <www.epa.gov/npdes>, clicking on Publications and entering NPDES Permit Writers' Manual in the Search box.

[2] U.S. Environmental Protection Agency. 1993. *Training Manual for NPDES Permit Writers*. EPA-833-B-93-003. U.S. Environmental Protection Agency, Office of Wastewater Management, Washington, DC. <www.epa.gov/npdes/pubs/owm0339.pdf>.

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CHAPTER 1. Development of the Clean Water Act and the NPDES Program

This chapter presents an overview of the history of water pollution control in the United States and the evolution and accomplishments of the National Pollutant Discharge Elimination System (NPDES) Program.

1.1 History of Water Pollution Control in the United States

Major water pollution control legislation in the United States dates back to the end of the 19th century. Exhibit 1-1 presents a summary of key legislative and executive actions in the history of clean water program development in the United States.

Exhibit 1-1 Important milestones of clean water program development

1899 Rivers and Harbors Act
1948 Federal Water Pollution Control Act (FWPCA)
1965 Water Quality Act
1970 Executive Order–U.S. Environmental Protection Agency (EPA) established
1970 Refuse Act Permit Program (RAPP)
1972 FWPCA Amendments
1977 Clean Water Act (CWA)
1987 Water Quality Act (WQA)

The first major water pollution control statute was the **1899 Rivers and Harbors Act**, which established permit requirements to prevent unauthorized obstruction or alteration of any navigable water of the United States. That act focused on navigation rather than water quality.

The **1948 Federal Water Pollution Control Act (FWPCA)** initiated the federal government's involvement in water pollution control for public health protection. The act allotted funds to state and local governments for water pollution control and emphasized the states' role in controlling and protecting water resources with few federal limitations or guidelines. The act, however, did charge the U.S. Surgeon General with developing comprehensive programs to eliminate or reduce the pollution of interstate waters.

Over the next two decades, Congress became increasingly interested in the problem of water quality degradation. From 1956 through 1966, it enacted four major laws to strengthen the federal role in water pollution control, including the FWPCA Amendments of 1956 and the FWPCA Amendments of 1961. Those statutes focused primarily on providing funding to municipalities to construct wastewater treatment plants.

Just a few years later, Congress further strengthened federal water pollution control laws by enacting the **1965 Water Quality Act**. This law created the Federal Water Pollution Control Administration and

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represented a major regulatory advancement in water pollution control by requiring states to develop water quality standards for interstate waters by 1967. The Water Quality Act also called for states to quantify the amount of pollutants that each discharger could release without exceeding the water quality standards (i.e., pollutant loadings). Despite escalating public concern and increased public spending, only about half of the states developed water quality standards by 1971. Furthermore, enforcement of the federal statute was minimal because the regulatory agencies had to demonstrate a direct link between a discharge and a health or water quality problem, and the scientific data to make such demonstrations were often lacking. Finally, there were no criminal or civil penalties for violations of statutory requirements.

Growing concern about the environment prompted President Nixon to form the **U.S. Environmental Protection Agency (EPA**) in 1970 to enforce environmental compliance and consolidate federal pollution control activities. That year, the President also created the **Refuse Act Permit Program (RAPP)** through Executive Order 11574 and under the authority of section 13 of the 1899 Rivers and Harbors Act (a section also known as the Refuse Act). This new permitting program was focused on controlling industrial water pollution. EPA and the U.S. Army Corps of Engineers (Corps) would prepare the program requirements and the Corps would administer the program. EPA was tasked with developing *guidelines on effluent quality* for 22 different categories of sources. A discharger would apply for a permit, and the Corps would ask EPA if the proposed effluent levels were consonant with state water quality standards and with the newly developed guidelines on effluent quality. States would be asked to examine permit applications and advise EPA whether existing or proposed treatment processes would ensure that established water quality standards would be met. EPA would review the state's response for interstate waters and instruct the Corps whether to issue the permit. However, the U.S. District Court for the District of Columbia struck down RAPP (*Kalur v. Resor*, Civ. Action No. 1331-71 [D.D.C. Dec. 21, 1971]) because the program would allow the issuance of permits to discharge refuse to non-navigable tributaries of navigable waterways, which the Court said exceeded the authority given in the Act, and because the regulations implementing the program did not require compliance with certain procedural requirements of the National Environmental Policy Act.

Because of the perceived need for a discharge permit program, and to rectify the problems encountered in earlier water pollution control legislation, Congress enacted the **FWPCA Amendments of 1972**. This legislation, which was passed over a Presidential veto in November 1972, provided a comprehensive re-codification and revision of past federal water pollution control law. The 1972 amendments marked a distinct change in the philosophy of water pollution control in the United States and marked the beginning of the present water programs, including the NPDES permit program. Under those amendments, the federal government assumed a major role in directing and defining water pollution control programs. In establishing the basis for clean water programs, Congress sought a balance between economics (considering both the costs and benefits of cleanup) and ecology (setting deadlines and ambitious requirements for reducing discharges and restoring water quality).

The FWPCA Amendments of 1972 established a series of goals in section 101. Perhaps the most notable goal was that the discharge of pollutants into navigable waters be eliminated by 1985. Although that goal remains unmet, it underlies the CWA approach to establishing the technology standards that are implemented through technology-based effluent limitations (TBELs) in NPDES permits. The FWPCA Amendments of 1972 also set an interim goal of achieving, "water quality [that] provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water" by July 1, 1983. That goal is commonly referred to as the *fishable, swimmable* goal of the act and is one

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of the factors that states must consider in the development of their water quality standards. The water quality standards are implemented in NPDES permits through water quality-based effluent limitations (WQBELs). By prohibiting the discharge of a pollutant or pollutants from a point source to waters of the United States—except as in compliance with the statute, the FWPCA Amendments of 1972 also established the important principle that the discharge of pollutants to navigable waters is not a right.

Since 1972, the FWPCA has been further amended on several occasions, including the **1977 Clean Water Act** (CWA), which is now the name for the statute, and the **1987 Water Quality Act** (WQA). Both of these statutes are discussed further in section 1.2 below with regard to their impact on the evolution of the NPDES program. Exhibit B-1, Index to Sections of the CWA, in Appendix B of this document matches the key sections of the CWA to their appropriate reference in the *United States Code* (U.S.C.). This information is at U.S.C., Title 33 (Navigation and Navigable Waters), Chapter 26 (Water Pollution Prevention and Control), 1251-1387 (33 U.S.C. §§ 1251-1387) <www.epa.gov/lawsregs/laws/cwa.html>.

1.2 Evolution of the NPDES Program

Section 402 of Title IV of the FWPCA, Permits and Licenses, created today's system for permitting wastewater discharges, known as the NPDES program. Under the requirements of the program, a point source may be authorized to discharge pollutants into waters of the United States by obtaining a permit. Section 1.3 below discusses this basic statutory framework in detail. A permit provides two types of control: technology-based limitations (based on the technological and economic ability of dischargers in the same category to control the discharge of pollutants in wastewater) and water quality-based limitations (to protect the quality of the specific waterbody receiving the discharge).

The FWPCA Amendments of 1972 established several important requirements and deadlines. Municipal facilities were required to meet secondary treatment standards by July 1, 1977. Industrial facilities were required to meet two levels of technology standards: *Best Practicable Control Technology Currently Available* (BPT) and *Best Available Technology Economically Achievable* (BAT), which would bring them further toward the goal of eliminating the discharge of all pollutants. [CWA section 301 (b)(2)(A)]. Compliance deadlines for BPT and BAT were established as of July 1, 1977, and July 1, 1983, respectively.

In addition to BPT and BAT requirements for industrial categories, the 1972 FWPCA Amendments established *new source performance standards* (NSPS) or best available demonstrated control technology including where practicable a standard permitting no discharge of pollutants [CWA section 306(a)]. The Legislative History indicates that Congress believed that technologies would be more affordable for new dischargers who could plan control technologies at the design phase. The standards represent state-of-the-art control technologies for new sources because the permittees have the opportunity to install the most efficient production processes and the latest in treatment technologies during construction. NSPS are effective on the date the facility begins operation, and the facility must demonstrate compliance within 90 days of start-up.

EPA tried to set national, uniform effluent limitations guidelines and standards (effluent guidelines) as a basis for technology-based limitations; however, most effluent guidelines were not in place when the first set of permits was issued between 1973 and 1976. About 75 percent of the first round permits were issued

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under a section of the act that allows a permit writer to use his or her best professional judgment to establish case-by-case limitations. Using that approach, a single permit writer developed effluent limitations for a specific facility using his or her knowledge of the industry and the specific discharge, rather than using a set of national standards and limitations developed by EPA for the entire industry.

This first round of permitting focused on *conventional pollutants*, which generally are found in sanitary waste from households, businesses, and industries. CWA section 304(a)(4) and Title 40 of the *Code of Federal Regulations* (CFR) 401.16 designate the conventional pollutants with oil and grease added to § 401.16 in 1979. The following are formally designated as conventional pollutants:

- Five-day Biochemical Oxygen Demand (BOD_5).
- Total Suspended Solids (TSS).
- pH.
- Fecal Coliform.
- Oil and Grease.

The 1972 FWPCA Amendments, however, also required that EPA publish a list of toxic pollutants within 90 days and propose effluent standards for those pollutants 6 months later. EPA was not able to meet those requirements because of the lack of information on treatability. The Natural Resources Defense Council (NRDC) sued EPA, resulting in a court supervised *consent decree* (*NRDC et al. v. Train, 8 E.R.C. 2120*, DDC 1976) that identified the following:

- Toxic (priority) pollutants to be controlled.
- Primary industries for technology-based control.
- Methods for regulating toxic discharges through the authorities of the FWPCA Amendments.

The provisions of the consent decree were incorporated into the framework of the 1977 FWPCA Amendments, formally known as the CWA. This statute shifted the emphasis of the NPDES program from controlling conventional pollutants to controlling toxic pollutant discharges. CWA section 307(a)(1) required EPA to publish a list of toxic pollutants or combination of pollutants. Those pollutants often are called the priority pollutants and are listed in § 401.15. The terms *toxic pollutant* and *priority pollutant* are used interchangeably throughout this document.

CWA section 307(a) originally identified 65 toxic pollutants and classes of pollutants for 21 major categories of industries (known as *primary industries*). That list was later further defined as the current list of 126 toxic pollutants. The priority pollutants are listed in Appendix C of this document and in Appendix A of Part 423. Note that the list goes up to 129; however, there are only 126 priority pollutants because 017, 049, and 050 were deleted.

The 1977 CWA adjusted technology standards to reflect the shift toward control of toxics, clarified and expanded the concept of BAT controls, created a new level of control for conventional pollutants, and made changes to strengthen the industrial pretreatment program. The 1977 law created a new pollutant category, nonconventional pollutants, that included pollutants (such as chlorine and ammonia) not specifically categorized as conventional or toxic. The CWA clarified that BAT covers both toxic and nonconventional pollutants, extended the compliance deadline for BAT for toxic pollutants to July 1, 1984, established a three-year deadline for compliance with BAT for newly listed toxics, and gave industries until as late as July 1, 1987 to meet BAT requirements for nonconventional pollutants. In addition, conventional pollutants, controlled by BPT and BAT in the first round of permitting, were now

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subject to a new level of control termed *Best Conventional Pollutant Control Technology* (BCT). The CWA established a compliance deadline for BCT of July 1, 1984. BCT was not an additional performance standard, but replaced BAT for the control of conventional pollutants. Finally, among other changes, the 1977 CWA authorized EPA to approve local pretreatment programs and required authorized states to modify their programs to provide for local pretreatment program oversight.

The 1977 CWA recognized that the technology-based limitations were not able to prevent the discharge of toxic substances in toxic amounts in all waterways. To complement its work on technology-based limitations, EPA initiated a national policy in February 1984 to control toxics using a water quality approach. On February 4, 1987, Congress amended the CWA with the 1987 WQA that outlined a strategy to accomplish the goal of meeting state water quality standards. The 1987 WQA required all states to identify waters that were not expected to meet water quality standards after technology-based controls on point source were imposed. Each state then had to prepare individual control strategies to reduce toxics from point and nonpoint sources to meet the water quality standards. Among other measures, those plans were expected to address control of pollutants beyond technology-based levels.

The 1987 WQA further extended the compliance deadline for BAT- and BCT-based effluent limitations, this time to a new deadline of March 31, 1989. The 1987 WQA also established new schedules for issuing NPDES permits to industrial and municipal stormwater dischargers. In addition to meeting water quality-based standards, industrial stormwater discharges must meet the equivalent of BAT and BCT effluent quality standards. *Municipal separate storm sewer systems* (MS4s) were required to have controls to reduce pollutant discharges to the *maximum extent practicable* (MEP), including management practices, control techniques and system design and engineering methods, and such other provisions as the Administrator deems appropriate for the control of such pollutants [CWA section 402(p)(3)(B)]. The 1987 WQA also required EPA to identify toxics in sewage sludge and establish numeric limitations to control such toxics. A statutory *anti-backsliding* requirement in the WQA specified the circumstances under which an existing permit can be modified or reissued with less stringent effluent limitations, standards, or conditions than those already imposed.

Since 1987, there have been minor revisions to the CWA (e.g., Combined Sewer Overflow program requirements). However, the basic structure of the NPDES program remains unchanged from the framework established in the 1972 FWPCA Amendments.

1.3 NPDES Statutory Framework

As noted in section 1.2 above, under the NPDES program any point source that discharges or proposes to discharge pollutants into waters of the United States is required to obtain an NPDES permit. Understanding how each of these terms (i.e., permit, pollutant, waters of the United States, and point source) is defined is the key to defining the scope of the NPDES program.

1.3.1 Permit

A permit is a license, issued by the government to a person or persons granting permission to do something that would otherwise be illegal without the permit. An NPDES permit typically is a license for a facility to discharge a specified amount of a pollutant into a receiving water under certain conditions; however, NPDES permits can also authorize facilities to process, incinerate, landfill, or beneficially use

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biosolids (sewage sludge). A discharger does not have a right to receive a permit, and permits may be revoked for cause such as noncompliance with the conditions of the permit.

1.3.2 Pollutant

The term *pollutant* is defined in CWA section 502(6) and § 122.2. The statute defines pollutant very broadly and includes any type of industrial, municipal, or agricultural waste (including heat) discharged into water. For regulatory purposes, pollutants are grouped into three categories under the NPDES program: conventional, toxic, and nonconventional.

- **Conventional** pollutants are those defined in CWA section 304(a)(4) and § 401.16 (BOD_5, TSS, fecal coliform, pH, and oil and grease).
- **Toxic (priority)** pollutants are those defined in CWA section 307(a)(1) (and listed in § 401.15 and Appendix A of Part 423) and include 126 metals and manmade organic compounds (see Exhibit C-1 in Appendix C of this document).
- **Nonconventional** pollutants are those that do not fall under either of the above categories (conventional or toxic pollutants) and include parameters such as chlorine, ammonia, nitrogen, phosphorus, chemical oxygen demand (COD), and whole effluent toxicity (WET).

Sewage from vessels and, under certain conditions, water, gas, or other material injected into wells to facilitate production of oil or gas or water derived in association with oil and gas production and disposed of in a well are specifically excluded from the definition of pollutant under the NPDES program.

1.3.3 Waters of the United States

The CWA regulates discharges to *navigable waters*. CWA section 502(7) defines navigable waters as "waters of the United States, including the territorial seas." NPDES regulations define *waters of the United States* to mean,

- Waters that are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including waters subject to the ebb and flow of the tide.
- Interstate waters including interstate *wetlands*.
- Other waters that could affect interstate or foreign commerce.
- Impoundments of waters of the United States.
- Tributaries of the above categories of waters.
- Territorial seas.
- Wetlands adjacent to other waters (except wetlands themselves) in the above categories.

Wetlands are further defined in § 122.2. In addition, the definition of waters of the United States contains exclusions for waste treatment systems (other than certain cooling ponds) designed to meet the requirements of the CWA and also for *prior converted croplands*, which is mostly relevant to the CWA section 404 permitting program administered by the Corps.

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Waters of the United States covers a broad range of surface waters. The CWA does not give EPA the authority to regulate ground water quality through NPDES permits. If a discharge of pollutants to ground water reaches waters of the United States, however, it could be a discharge to the surface water (albeit indirectly via a direct hydrological connection, i.e., the ground water) that needs an NPDES permit.

The scope of waters of the United States has been the subject of several U.S. Supreme Court cases (the most recent as of the time of publication of this manual being a decision from 2006 in the combined Rapanos/Carabell wetland cases) and numerous lower court cases. The court cases often have been difficult to interpret, resulting in much litigation and an evolving understanding of the exact scope of waters subject to CWA jurisdiction. Also, permit writers should keep in mind that discharges through non-jurisdictional features that reach waters of the United States may need a permit even if the discharge is not directly to a jurisdictional waterbody. EPA Regional wetlands staff have significant expertise in jurisdictional issues related to the scope of waters of the United States. Some Regions have interoffice teams to address jurisdictional issues that come up in the different CWA programs. In addition, guidance on waters of the United States is on EPA's Office of Wetlands, Oceans, and Watersheds Website <www.epa.gov/wetlands/guidance/CWAwaters.html>.

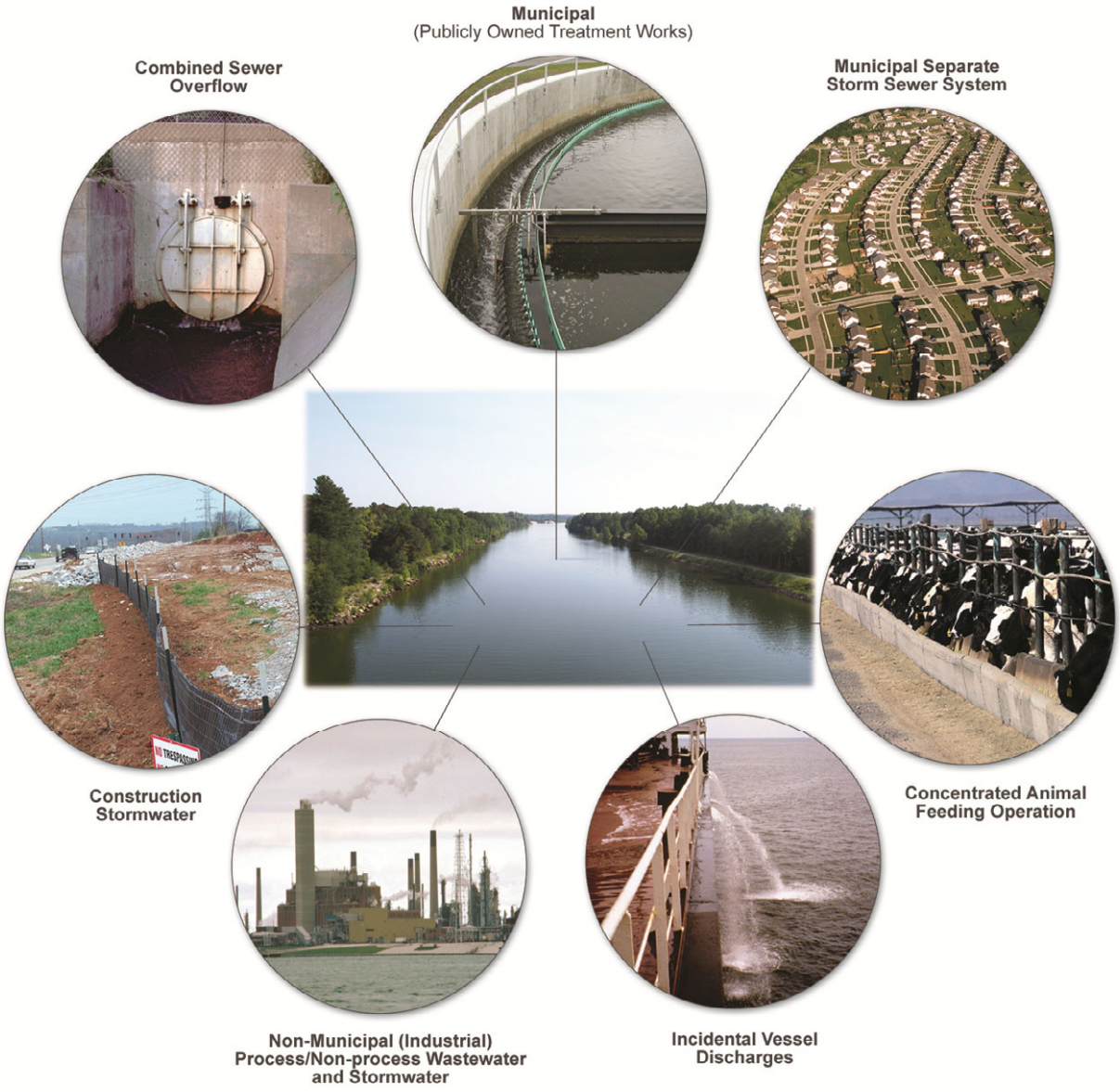
1.3.4 Point Source

Pollutants can enter water via a variety of pathways including agricultural, domestic and industrial sources. For regulatory purposes, these sources generally are categorized as either point sources or nonpoint sources. The term *point source* is defined in CWA section 502(14) and § 122.2 to include any discernible, confined, and discrete conveyance from which pollutants are or may be discharged. Point source discharges include discharges from publicly owned treatment works (POTWs), industrial process wastewater discharges, runoff conveyed through a storm sewer system, and discharges from concentrated animal feeding operations (CAFOs), among others (see Exhibit 1-2). Return flows from irrigated agriculture and agricultural stormwater runoff specifically are excluded from the definition of a point source.

Pollutant contributions to waters of the United States may come from both direct and indirect discharges. Direct discharge (which is synonymous with *discharge of a pollutant*) is defined by the NPDES regulations at § 122.2 to include any addition of any pollutant or combination of pollutants to a water of the United States from any point source. An *indirect discharger* is defined as, "a nondomestic discharger introducing pollutants to a POTW." Under the national program, NPDES permits are issued only to direct dischargers. The National Pretreatment Program controls industrial and commercial indirect dischargers (for more on pretreatment, see section 2.3.1.2 of this manual).

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Exhibit 1-2 Common point source discharges of pollutants to waters of the United States



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CHAPTER 2. Regulatory Framework and Program Areas of the NPDES Program

This chapter discusses the regulatory framework of the National Pollutant Discharge Elimination System (NPDES) program, identifies the types of activities regulated under the NPDES program, describes the roles and responsibilities of federal and state governments, and presents the program areas that address the various types of regulated activities.

2.1 Regulatory Framework of the NPDES Program

Chapter 1 discussed how Congress, in Clean Water Act (CWA) section 402, required the U.S. Environmental Protection Agency (EPA) to develop and implement the NPDES permit program. While Congress' intent was established in the CWA, EPA was required to develop specific regulations to carry out the congressional mandate. The regulations developed by EPA to implement and administer the NPDES program primarily are in Title 40 of the *Code of Federal Regulations* (CFR) Part 122 <www.epa.gov/lawsregs/search/40cfr.html>.

The CFR is an annual codification of the general and permanent rules published in the *Federal Register* (FR) by the executive departments and agencies of the federal government. The CFR is divided into 50 titles that represent broad areas subject to federal regulation. Title 40 covers protection of the environment. The FR is a legal publication that contains federal agency regulations; proposed rules and notices; and executive orders, proclamations and other presidential documents. The National Archives and Records Administration, an independent federal agency responsible for managing all federal records, publishes the FR and CFR. The text of all final regulations is found in the CFR. The background and implementation information related to these regulations, however, are found in the preamble to the regulations contained in the FR. This information is important to permit writers because it explains the legal, technical, and scientific bases on which regulatory decisions are made.

Exhibit 2-1 lists regulations in 40 CFR that are related to the NPDES program, and Exhibit 2-2 is an outline of the federal NPDES regulations from Part 122. The regulations at § 123.25 should be referenced for information applicable to state NPDES programs. Exhibit B-2 in Appendix B of this document is an Index to NPDES Regulations that provides regulatory citations by topic area.

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Exhibit 2-1 Regulations related to the NPDES program

Regulation (40 CFR)	Subject
Part 121	State certification
Part 122	The federal NPDES permit program
Part 123	State program requirements
Part 124	Procedures for decision making
Part 125	Technology standards
Part 129	Toxic pollutant effluent standards
Part 130	Water quality planning and management
Part 131	Water quality standards
Part 133	Secondary treatment regulations
Part 135	Citizen suits
Part 136	Analytical procedures
Part 257	State sludge disposal regulations
Part 401	General provisions for effluent limitations guidelines and standards (effluent guidelines)
Part 403	General pretreatment regulations
Parts 405-471	Effluent guidelines
Part 501	State sewage sludge management program requirements
Part 503	Standards for use or disposal of sewage sludge

2.2 Federal and State Responsibilities

This section discusses the relationship between federal and state governments in the administration of the NPDES program and the process by which a state can become *authorized*.

2.2.1 State NPDES Program Authority

EPA may authorize qualified state, territorial, or tribal government agencies to implement all or parts of the NPDES program. States, territories, or tribes (hereafter *states*) are authorized through a process defined by the CWA section 402(b) and NPDES regulations Part 123. A state wanting to be authorized to administer the NPDES program submits to EPA a letter from the governor requesting review and approval of its program submission, a Memorandum of Agreement (MOA), a Program Description, a Statement of Legal Authority (also known as an *Attorney General's Statement* or *AG Statement*), and the underlying state laws and regulations. EPA determines whether the package is complete within 30 days of receipt. Within 90 days of receipt, EPA renders a decision to approve or disapprove the program. The time for review can be extended by agreement. The process of authorization includes a public review and comment period, and a public hearing.

States may apply for the authority to issue one or more of the following five types of NPDES authorization:

- NPDES Base Program for individual municipal and industrial facilities.
- General Permit Program.
- Pretreatment Program.
- Federal Facilities Program.
- Biosolids (Sewage Sludge) Program.

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Exhibit 2-2 Federal NPDES regulations (40 CFR Part 122)

Subpart A–Definitions and General Program Requirements

§ 122.1 Purpose and scope
§ 122.2 Definitions
§ 122.3 Exclusions
§ 122.4 Prohibitions
§ 122.5 Effect of a permit
§ 122.6 Continuation of expiring permits
§ 122.7 Confidentiality of information

Subpart B–Permit Application and Special NPDES Program Requirements

§ 122.21 Applications
§ 122.22 Signatories to permit applications and reports
§ 122.23 Concentrated animal feeding operations
§ 122.24 Concentrated aquatic animal production
§ 122.25 Aquaculture projects
§ 122.26 Stormwater discharges
§ 122.27 Silviculture activities
§ 122.28 General permits
§ 122.29 New sources and new dischargers
§ 122.30-122.37 MS4s

Subpart C–Permit Conditions

§ 122.41 Standard conditions applicable to all permits
§ 122.42 Standard conditions applicable to specified categories of permits
§ 122.43 Establishing permit conditions
§ 122.44 Establishing limitations, standards, and other permit conditions

(a) Technology basis
(b) Other basis (not WQ)
(c) Reopeners
(d) Water quality basis
(e) Toxic (priority) pollutants
(f) Notification levels
(g) 24 Hour reporting
(h) Duration of permits
(i) Monitoring
(j) Pretreatment program
(k) Best management practices (BMPs)
(l) Anti-backsliding
(m) Privately owned treatment works
(n) Grants
(o) Sewage sludge
(p) Coast Guard
(q) Navigation
(r) Great Lakes
(s) Qualifying programs

§ 122.45 Calculating limitations

(a) Outfalls and discharge points
(b) Production basis
(c) Metals
(d) Continuous discharges
(e) Non-continuous discharges
(f) Mass limitations
(g) Pollutants in intake water
(h) Internal waste streams
(i) Discharge into wells, into publicly owned treatment works or by land application

§ 122.46 Duration of permits
§ 122.47 Schedules of compliance
§ 122.48 Requirements for recording and reporting of monitoring results
§ 122.49 Consideration under federal law
§ 122.50 Disposal into wells, into publicly owned treatment works or by land application

Subpart D–Transfer, Modification, Revocation and Reissuance, and Termination of Permit

§ 122.61 Transfer of permits
§ 122.62 Modification or revocation and reissuance of permits
§ 122.63 Minor modifications of permits
§ 122.64 Termination of permits

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A state can receive authorization for one or more of the NPDES program components. For example, a state might receive authorization for the NPDES Base Program, General Permit Program, and Pretreatment Program, but not the Federal Facilities Program or Biosolids Program. In such a case, EPA continues to issue permits to federal facilities (e.g., facilities on military installations, federal lands) for discharges originating within the state and continues to implement the Biosolids Program. (Section 2.2.2 below provides additional discussion of Biosolids Program implementation.)

If EPA approves a program, the state assumes permitting authority in lieu of EPA. All new permit applications would then be submitted to the state agency for NPDES permit issuance. Certain permits issued before authorization might continue under EPA administration as set forth in the MOA. Even after a state receives NPDES authorization, EPA continues to issue NPDES permits on tribal lands within the boundaries of the state (if the tribe is not administering its own approved NPDES program). Following authorization, EPA also continues its national program management responsibilities by ensuring that state programs meet applicable federal requirements. If EPA disapproves the program, EPA remains the permitting authority for that state.

The State Program Status Website <www.epa.gov/npdes/authorization> provides the current authorization status for the states.

2.2.2 Roles and Responsibilities of the Federal and State Authorities

Until a state program is authorized, EPA is the permitting authority that issues all permits, conducts all compliance and monitoring activities, and enforces all program requirements.

As noted above, if a state has only partial authority, EPA will implement the other program activities. For example, where a state has an approved NPDES program but has not received EPA approval of its state sewage sludge management program, the EPA Region is responsible for including conditions to implement the Part 503 Standards for the Use or Disposal of Sewage Sludge in permits issued to treatment works treating domestic sewage (TWTDS) in that state. EPA could issue a separate permit with the applicable sewage sludge standards and requirements, or collaborate with the state on joint issuance of NPDES permits containing the Part 503 sewage sludge standards. The same process also applies where a state has not received approval of its pretreatment program or federal facilities program. One exception to that process is where an NPDES-authorized state is not approved to implement the general permit program. In such cases, EPA may not issue a general permit in that state as clarified in the memorandum *EPA's Authority to Issue NPDES General Permits in Approved NPDES States*[1] <www.epa.gov/npdes/pubs/owm0444.pdf>.

Once a state is authorized to issue permits, EPA generally is precluded from issuing permits in the state; however, EPA must be provided with an opportunity to review certain permits and may formally object to elements that conflict with federal requirements. If the permitting agency does not satisfactorily address the points of objection, EPA will issue the permit directly. Once a permit is issued through a government agency, it is enforceable by the approved state and federal agencies (including EPA) with legal authority to implement and enforce the permit. Private citizens may also bring a civil action in federal court against an alleged violator or against the EPA Administrator for alleged failure to enforce NPDES permit requirements. Exhibit 2-3 presents a summary of federal and state roles before and after program authorization.

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Exhibit 2-3 Summary of federal and state/territorial/tribal roles in the NPDES permitting program

Before state/territorial/tribal program approval:

- EPA issues permits
- EPA conducts compliance and monitoring activities
- EPA enforces
- State/territory/tribe reviews permits and grants CWA section 401 certification

After state/territorial/tribal program approval:

- State/territory/tribe issues permits
- State/territory/tribe conducts compliance and monitoring activities
- State/territory/tribe enforces
- EPA provides administrative, technical and legal support
- EPA ensures state program meets federal requirements
- EPA offers NPDES program training
- EPA oversees grants to states (e.g., CWA section 106)
- EPA reviews permits and, as necessary, comments or objects
- EPA oversees and, as necessary, assumes enforcement of permits

2.3 NPDES Program Areas

NPDES permittees can be broadly classified as municipal (publicly owned treatment works [POTWs] and related discharges) and non-municipal facilities. Federal facilities fall into the broader category of non-municipal facilities. Within those broad categories, there might also be specific types of activities that are subject to unique programmatic requirements in the NPDES regulations. Exhibit 2-4 provides an overview of the different activities related to municipal and non-municipal sources; identifies the NPDES program areas that address these activities; and identifies the applicable regulations for each NPDES program area.

2.3.1 NPDES Program Areas Applicable to Municipal Sources

The NPDES regulations establish technology-based effluent requirements applicable to discharges from POTWs. In addition to effluent requirements, the NPDES regulations establish other programmatic requirements applicable to other POTW activities (e.g., sewage sludge disposal and management, stormwater discharges from the treatment plant site) or activities that may be conducted by a municipality (e.g., municipal separate storm sewer systems, combined sewer overflows). A description of those programs and how they relate to NPDES permits is provided in the following sections.

2.3.1.1 Publicly Owned Treatment Works (POTWs)

The federal regulations at § 403.3 define a POTW as a treatment works (as defined in CWA section 212) that is owned by a state or municipality [as defined in CWA section 502(4)]. The definition includes any devices and systems used in the storage, treatment, recycling, and reclamation of municipal sewage or industrial wastes of a liquid nature. It also includes sewers, pipes, and other conveyances only if they convey wastewater to a POTW. Finally, the term also means the municipality that has the jurisdiction over the indirect discharges to and the discharges from the treatment works. Federally owned treatment works, privately owned treatment works, and other treatment plants not owned by a state or municipality are not considered POTWs.

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Exhibit 2-4 NPDES program areas and applicable regulations

Source	Program areas	Applicable regulations (40 CFR)
Municipal	Municipal (POTWs) effluent discharges	Part 122 Part 125 Part 133
	Indirect non-municipal discharges (Pretreatment)	Part 122 Part 403 Parts 405-471
	Biosolids (sewage sludge) use and disposal	Part 122 Part 257 Part 501 Part 503
	Combined sewer overflow (CSO) discharges	Part 122 Part 125
	Sanitary sewer overflow (SSO) discharges	Part 122
	Municipal separate storm sewer systems (MS4s) discharges	Part 122 Part 125
Non-municipal (Industrial)	Process wastewater discharges	Part 122 Part 125 Parts 405-471
	Non-process wastewater discharges	Part 122 Part 125
	Stormwater discharges associated with industrial activity	Part 122 Part 125
	Stormwater discharges from construction activities*	Part 122 Part 125
	Cooling water intake structures (CWIS)	Part 122 Part 125 Part 401
	Concentrated animal feeding operations (CAFOs)	Part 122 Part 123 Part 125 Part 412
	Concentrated aquatic animal production (CAAP) facilities	Part 122 Part 125 Part 451
	Vessel Discharges	Part 122

* Though stormwater discharges from construction activity resulting in disturbance of 5 or more acres of total land area technically are considered, "stormwater discharges associated with industrial activity" as defined by §122.26(b)(14)(x), these discharges are commonly referred to as stormwater discharges from *large* construction activities.

POTWs receive, primarily, domestic sewage from residential and commercial customers. Larger POTWs also typically receive and treat wastewater from industrial facilities (indirect dischargers) connected to the collection system. The types of pollutants treated by a POTW always include conventional pollutants and may include nonconventional and toxic pollutants, depending on the characteristics of the sources discharging to the POTW. The treatment provided by a POTW typically produces a treated effluent and a biosolids (sewage sludge) residual.

2.3.1.2 The National Pretreatment Program

The National Pretreatment Program <www.epa.gov/npdes/pretreatment> regulates the introduction of nondomestic (i.e., industrial and commercial) wastewater to POTWs. Because such discharges are treated by the POTW before release to a water of the United States, they are termed *indirect discharges*. The

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pretreatment program prohibits industrial and commercial indirect dischargers from discharging pollutants to a POTW that will pass through the POTW to receiving waters or interfering with POTW treatment processes or contaminating sewage sludge. The federal program also requires certain indirect dischargers to meet technology-based requirements developed specifically for such POTW users that are similar to those for direct dischargers.

EPA's pretreatment regulations require certain POTWs to develop a pretreatment program, the requirements of which are generally included as conditions of a POTW's NPDES permit. The federal regulations specifying which POTWs must have pretreatment programs, and the authorities and procedures that must be developed by the POTW before program approval, are in Part 403. The requirement to develop and implement a local pretreatment program typically is included as a special condition in the POTW's NPDES permit. Section 9.2.1 of this manual includes a discussion on incorporating pretreatment special conditions into permits.

2.3.1.3 Biosolids (Sewage Sludge)

In 1987 Congress amended CWA section 405 to establish a comprehensive sewage sludge program <www.epa.gov/OW-OWM.html/mtb/biosolids/index.htm>. The program regulates the use and disposal of sewage sludge by POTWs and by other TWTDS. TWTDS include facilities that generate sewage sludge, provide commercial treatment of sewage sludge, manufacture a product derived from sewage sludge, or provide disposal of sewage sludge. CWA section 405 required EPA to develop technical standards that establish sewage sludge management practices and acceptable levels of toxic pollutants in sewage sludge. The terms *biosolids*, *sewage sludge*, and *municipal sludge* are used interchangeably throughout this document.

Regulations for state sewage sludge program approval are at Part 123 or Part 501 (depending on whether the state wishes to administer the sewage sludge program under its NPDES program or under another program, e.g., a solid waste program). The technical standards governing sewage sludge use and disposal are in Part 503. TWTDS not otherwise subject to the NPDES permit requirements under CWA section 402 must apply for and receive a permit addressing standards for use and disposal of sewage sludge in Part 503. Details of this rule are described in *A Plain English Guide to the EPA Part 503 Biosolids Rule*[2] <www.epa.gov/owm/mtb/biosolids/503pe/>. Where applicable, sewage sludge management requirements may be included as a special condition in permits issued to POTWs. Section 9.2.2 of this manual includes a discussion on incorporating special conditions that address sewage sludge requirements.

2.3.1.4 Combined Sewer Overflows (CSOs)

An additional concern for some older POTWs may be combined *sewer systems* (CSS), which are wastewater collection systems owned by a state or municipality [as defined by CWA section 502(4)] that convey sanitary wastewater (domestic, commercial and industrial wastewaters) and stormwater through a single-pipe system to a POTW [as defined by § 403.3(q)]. EPA estimates that CSSs serve about 40 million people in 772 communities nationwide <www.epa.gov/npdes/cso/csodem>. During dry weather, CSSs collect and convey domestic, commercial, and industrial wastewater to a POTW; however, during periods of rainfall, snowmelt, and other forms of precipitation, the systems can become overloaded. When that overloading occurs, the CSS can overflow at designed relief points and discharge a combination of untreated sanitary wastewater and stormwater directly to a surface waterbody.

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A combined sewer overflow (CSO) <www.epa.gov/npdes/cso> is the discharge from a CSS at a point before the POTW. CSOs can be a major source of water pollution in communities served by CSSs. CSOs often contain high levels of suspended solids (SS), pathogenic microorganisms, toxic pollutants, floatables, nutrients, oxygen-demanding organic compounds, oil and grease, and other pollutants, causing water quality standards to be exceeded.

To address CSOs, EPA issued the National CSO Control Strategy (54 FR 37370, September 8, 1989). While implementation of the 1989 strategy has resulted in progress toward controlling CSOs, significant public health and water quality risks remain. To expedite compliance with the CWA, and to elaborate on the 1989 strategy, EPA, after collaboration with other CSO stakeholders (communities with CSSs, state water quality authorities, and environmental groups), published the CSO Control Policy <www.epa.gov/npdes/cso/controlpolicy> (59 FR 18688, April 19, 1994). The 1994 CSO policy represents a comprehensive national strategy to ensure that municipalities, permitting authorities, water quality standards authorities, and the public engage in a comprehensive and coordinated planning effort to achieve cost-effective CSO controls that ultimately meet appropriate health and environmental objectives. The Wet Weather Water Quality Act of 2000 stipulates that NDPES permits, enforcement orders, or decrees must conform to the 1994 CSO Policy [CWA section 402(q)].

Before issuing a permit with conditions that address CSOs, permit writers should consult the CSO Control Policy and associated guidance. Section 9.2.3 of this manual includes a discussion on incorporating appropriate CSO permit conditions.

2.3.1.5 Sanitary Sewer Overflows (SSOs)

Properly designed, operated, and maintained sanitary sewer systems are meant to collect and transport all the sewage that flows into them to a POTW; however, occasional, unintentional spills of raw sewage from municipal sanitary sewers occur in almost every system. Such types of releases are called sanitary sewer overflows (SSOs) <www.epa.gov/npdes/sso>.

SSOs have a variety of causes including severe weather, improper system operation and maintenance, and vandalism. EPA estimates that over 40.000 SSO events occur per year in the United States (excluding basement backups). Overflows of untreated wastewater can present risks of human exposure when released to certain areas, such as streets, private property, basements, and receiving waters used for drinking water, fishing and shellfishing, or contact recreation. A description of the extent of human health and environmental impacts caused by releases of untreated sewage, along with other information, is provided in the *Report to Congress on the Impacts and Control of CSOs and SSOs*[3] <www.epa.gov/npdes/csossoreport2004>. That 2004 report shows that NPDES permit requirements establishing clear reporting, record keeping, third party notification of overflows from municipal sewage collection systems, and clear requirements to properly operate and maintain the collection system, are critical to effective program implementation.

EPA has developed a draft fact sheet <www.epa.gov/npdes/pubs/sso_fact_sheet_model_permit_cond.pdf> and draft model permit conditions <www.epa.gov/npdes/pubs/sso_model_permit_conditions.pdf> that explain how NPDES permitting authorities can better address SSOs and sanitary sewer collection systems. Section 9.2.4 of this manual discusses incorporation of conditions to address SSOs in NPDES permits.

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2.3.1.6 Municipal Separate Storm Sewer Systems (MS4s)

Stormwater from major metropolitan areas is a significant source of pollutants discharged to waters of the United States. While rainfall and snow are natural events, the nature of stormwater discharges and their impact on receiving waters are greatly affected by human activities and land use. Stormwater from lands modified by human activities, such as metropolitan areas and urban streets, can affect surface water resources by modifying natural flow patterns or by elevating pollution concentrations and loadings.

To address such concerns, the 1987 amendments to the CWA added section 402(p), a provision that directed EPA to establish phased NPDES requirements for stormwater discharges. Phase I of the stormwater program addresses permits for discharges from medium and large MS4s serving a population of 100,000 or more, as well as certain categories of industrial activity, including construction activity disturbing greater than 5 acres. Phase II expanded the stormwater program to include small MS4s and construction activity disturbing between 1–5 acres.

The MS4 stormwater application regulations (Phase I) established requirements for a two-part permit application that allowed large and medium local governments to help define priority pollutant sources in the municipality and to develop and implement appropriate controls for such discharges to MS4s (55 FR 47990, November 16, 1990). Part II of the application requires municipal applicants to propose municipal stormwater management programs to control pollutants to the *maximum extent practicable* (MEP) and to effectively prohibit non-stormwater discharges to the municipal system. Medium and large MS4 operators are required to submit comprehensive permit applications and are issued individual permits.

Phase II of the stormwater program extended the NPDES permitting program to small MS4s in urbanized areas (64 FR 68722, December 8, 1999). The Phase II MS4 regulations require small MS4s to develop a program to address six *minimum control measures* that include BMPs and measurable goals for each BMP. Permit writers have the option of permitting regulated small MS4 operators using an individual permit, a general permit, or a modification of an existing Phase I MS4's individual permit (although the vast majority of small MS4s have been covered under general permits).

Municipal stormwater management programs combine source controls and management practices that address targeted sources in the boundaries of the municipal system. For example, a municipality that expects significant new development may focus more on proposing requirements for new development and construction. On the other hand, a municipality that does not expect significant new development could focus more on municipal activities that affect stormwater quality such as: maintenance of leaking sanitary sewers, road de-icing and maintenance, operation of municipal landfills, flood control efforts, and control of industrial contributions of stormwater.

MEP is not precisely defined so as to allow maximum flexibility in MS4 permitting to optimize reductions in stormwater pollutants on a location-by-location basis (64 FR 68754, December 8, 1999). Therefore, permit writers must rely on application requirements specified in the regulations and the applicant's proposed management program when developing appropriate permit conditions. The stormwater Phase II rule was challenged in the courts, with the U.S. Court of Appeals for the Ninth Circuit generally upholding the Phase II rule but remanding three issues back to EPA. EPA issued guidance on April 16, 2004 for how new general permits should address the remanded issues of public availability of notices of intent (NOIs), opportunity for public hearings, and permitting authority reviews of NOIs titled *Implementing the Partial Remand of the Stormwater Phase II Regulations Regarding*

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Notices of Intent & NPDES General Permitting for Phase II MS4s[4] <www.epa.gov/npdes/pubs/hanlonphase2apr14signed.pdf>.

In addition to information on the Stormwater Discharges From Municipal Separate Storm Sewer Systems (MS4s) Website <www.epa.gov/npdes/stormwater/municipal>, EPA has developed the following guidance documents and memoranda to help permit writers and permittees implement the municipal stormwater program:

- *Guidance Manual for the Preparation of Part 2 of the NPDES Permit Applications for Discharge from Municipal Separate Storm Sewer Systems*[5] <www.epa.gov/npdes/pubs/owm0246.pdf>.
- *Interim Permitting Approach for Water Quality-Based Effluent Limitations in Stormwater Permits*[6] <www.epa.gov/npdes/pubs/swpol.pdf>.
- *Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs*[7] <www.epa.gov/npdes/pubs/final-wwtmdl.pdf>.
- *MS4 Program Evaluation Guidance*[8] <www.epa.gov/npdes/pubs/ms4guide_withappendixa.pdf>.
- *MS4 Permit Improvement Guide*[9] <www.epa.gov/npdes/pubs/ms4permit_improvement_guide.pdf>.

The application requirements for stormwater discharges from MS4s serving a population greater than 100,000 and for stormwater discharges from small MS4s are discussed in sections 4.3.10 and 4.3.11 of this manual.

2.3.2 NPDES Program Areas Applicable to Non-Municipal Sources

Non-municipal sources include industrial and commercial facilities, industrial stormwater (including large construction activities), and discharges from small construction activity, concentrated animal feeding operations (CAFOs) and concentrated aquatic animal production (CAAP) facilities. Unlike municipal sources, the types of raw materials, production processes, treatment technologies used and pollutants discharged at industrial facilities vary widely and are dependent on the type of industry and specific facility characteristics. The operations, however, generally are carried out within a more clearly defined area; thus, the collection systems are less complex than POTW collection systems. In addition, unlike biosolids at POTWs, the NPDES program does not regulate residuals (sludge) generated by non-municipal facilities.

Non-municipal facilities can have discharges of stormwater that might be contaminated through contact with manufacturing activities or raw material and product storage, or they can have non-process wastewater discharges such as non-contact cooling water. In addition, some non-municipal facilities take in cooling water. Those discharges and intakes may be regulated under an NPDES permit in addition to any process wastewater.

2.3.2.1 Process Wastewater

Industrial and commercial facilities often use water in the manufacture and processing of products. The regulations at § 122.2 define process wastewater as, "[a]ny water which, during manufacturing or processing, comes into direct contact with, or results from the production or use of any raw material, intermediate product, finished product, byproduct, or waste product."

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Process wastewater can contain pollutants at levels that could affect the quality of receiving waters. The NPDES permit program establishes specific requirements for discharges of process wastewater from industrial and commercial sources. If a facility discharges directly to surface water, it would require an individual or general NPDES permit. An industrial or commercial facility also may discharge wastewater to a municipal sewer system, which would be covered under the NPDES pretreatment program. Many types of industrial facilities, whether they discharge directly to surface water or to a municipal sewer system, are covered by effluent guidelines and standards (see section 5.2 of this manual). The stormwater that runs off the property of an industrial or commercial facility or from a construction site might require an NPDES permit under the industrial stormwater program (see section 2.3.2.3 below).

2.3.2.2 Non-Process Wastewater

Industrial and commercial facilities often use water for purposes other than processing products, such as using non-contact cooling water for heat exchange, and may discharge wastewater from sources such as sanitary or cafeteria wastes. Like process wastewater, non-process wastewater is regulated under the NPDES program. Non-process wastewater might also be important to the permit writer when drafting monitoring conditions for facilities where the non-process wastewater dilutes the concentration of pollutants of concern in process wastewater. The permit writer must ensure that specified monitoring locations ensure accurate measurement for compliance with all effluent limitations.

2.3.2.3 Stormwater Associated with Industrial Activity

To minimize the impact of stormwater discharges from industrial facilities, the NPDES program includes an industrial stormwater permitting component. Operators of industrial facilities included in 1 of the 11 categories of stormwater discharges associated with industrial activity that discharge or propose to discharge stormwater to an MS4 or directly to waters of the United States require authorization under an NPDES industrial stormwater permit. EPA published permit regulations and permit application requirements for stormwater discharges associated with industrial activity in 55 FR 48063, November 16, 1990.

Permit Regulations for Stormwater Associated with Industrial Activity

The regulations define stormwater discharges associated with industrial activity as discharges from any conveyance used for collecting and conveying stormwater and that is directly related to manufacturing, processing, or raw materials storage areas at an industrial plant. The regulations at § 122.26(b)(14)(i - xi) identify the following 11 industrial categories required to apply for NPDES permits for stormwater discharges:

- Facilities subject to stormwater effluent guidelines, new source performance standards, or toxic pollutant effluent standards under Parts 400-471 (Subchapter N).
- Certain heavy manufacturing facilities (lumber, paper, chemicals, petroleum refining, leather tanning, stone, clay, glass, concrete, ship construction).
- Active and inactive mining operations and oil and gas operations with contaminated stormwater.
- Hazardous waste treatment, storage, or disposal facilities, including Resource Conservation and Recovery Act (RCRA) Subtitle C facilities.
- Landfills, land application sites, open dumps, and RCRA Subtitle D facilities.

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- Recycling facilities, including metal scrap yards, battery reclaimers, salvage yards, and automotive junkyards.
- Steam electric power generating facilities, including coal-handling sites.
- Transportation facilities that have vehicle maintenance shops, equipment cleaning operations, or airport deicing operations.
- Major POTW sludge handling facilities, including on-site application of sewage sludge.
- Construction activities that disturb five acres or more (see subsection below).
- Light industrial manufacturing facilities.

Operators of industrial facilities that are federally, state- or municipally owned or operated that meet the above descriptions must also submit applications.

EPA issued a final rule for Phase II of the stormwater program in 64 FR 68722, December 8, 1999. That rule clarified that stormwater discharges from industrial facilities that have *no exposure* of industrial activities or materials to stormwater may be conditionally excluded from the stormwater permitting program. To qualify for the no exposure exclusion, the industrial operator must complete a no exposure certification form and submit this to EPA once every 5 years. For more information, see the Conditional No Exposure Exclusion Website <www.epa.gov/npdes/stormwater/noexposure>.

Generally, EPA- or state-issued general permits regulate stormwater discharges from industrial, construction and Phase II municipal sources, while Phase I municipal sources usually are issued individual permits. In some cases, stormwater conditions may be incorporated into a comprehensive individual NPDES permit for a facility or a stormwater-specific individual NPDES permit. Incorporating permit conditions to address stormwater discharges associated with industrial and construction activities into an individual facility permit is discussed in the subsections below. For more information regarding the scope of the NPDES stormwater program, see the NPDES Stormwater Program Website <www.epa.gov/npdes/stormwater>.

Permit Conditions for Stormwater Discharges Associated with Industrial Activity

All stormwater discharges associated with industrial activity that discharge stormwater through a separate MS4 or discharge directly to waters of the United States are required to obtain an NPDES permit. Because of the large number of facilities requiring permits, EPA and most NPDES-authorized states choose to issue general permits to regulate stormwater discharges. The Phase I rule in 1990 established the concept of a permitting exemption for industrial facilities with little or no likelihood of discharging contaminated stormwater; however, this exemption was not well-defined or required to be submitted to the NPDES permitting authority. The Phase II rule in December 1999 clarified and expanded the no exposure certification requirement to require industrial facilities with no exposure of industrial processes to stormwater to submit a written certification notifying EPA or the authorized state that the facility wishes to be excluded from the NPDES program.

Each industrial facility covered under an EPA-issued stormwater general permit must meet the numeric and non-numeric effluent limitations established in the general permit. Industrial facilities can meet those effluent limitations by implementing control measures, including BMPs, that control the discharge of stormwater associated with industrial activity.

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The EPA- and state-issued stormwater general permits generally require the facility to develop and implement a site-specific *stormwater pollution prevention plan* (SWPPP). The SWPPP describes the control measures, whether structural or nonstructural, which are used for controlling stormwater discharges from the industrial facility. The special conditions component of EPA's stormwater general permits identifies the requirements that must be documented in the SWPPP, including the following:

- A description of potential pollutant sources at the facility, including the following:
  - A map of the facility indicating the drainage areas of the site and the industrial activities that occur in each drainage area.
  - An inventory of materials that could be exposed to stormwater.
  - A description of the likely sources of pollutants from the site and a prediction of the pollutants likely to be present in the stormwater.
  - The history of spills and leaks of toxic and hazardous materials over the past 3 years.
- The measures and controls that will be implemented to prevent or minimize pollution of stormwater, including the following:
  - Good housekeeping or upkeep of industrial areas exposed to stormwater.
  - Preventive maintenance of stormwater controls and other facility equipment.
  - Spill prevention and response procedures.
  - Testing of outfalls to ensure that there are no illicit discharges.
  - Employee training on pollution prevention measure and controls, and record keeping.

A permit writer's best sources of information for developing appropriate special conditions for stormwater control measures are other stormwater general permits. Using existing general permits as the basis for special conditions is encouraged because doing so will reduce duplication of effort. A listing of individual and general permits (stormwater and non-stormwater) issued by EPA and authorized states is on the View NPDES Individual and General Permits Website <www.epa.gov/npdes/permitsearch>. In addition to the Stormwater Discharge From Industrial Facilities Website <www.epa.gov/npdes/stormwater/indust>, EPA published *Developing Your Stormwater Pollution Prevention Plan: A Guide for Industrial Operators*[10] <www.epa.gov/npdes/pubs/industrial_swppp_guide.pdf> to help permit writers identify components of SWPPPs and BMPs and to help permittees develop their own plans. Section 4.3.8 of this manual discusses Form 2F and individual permit requirements for stormwater discharges associated with industrial activity.

Permit Conditions for Stormwater Discharges associated with Construction Activities

EPA and most NPDES-authorized states have issued NPDES general stormwater permits for discharges associated with construction activity that are separate from the industrial stormwater general permits. The Phase I stormwater regulations require permit coverage for all construction activity that results in the disturbance of five acres or greater of the total land area. This includes disturbance of less than five acres of total land area that is part of larger common plan of development or sale if the larger common plan will ultimately disturb five acres of more. The Phase II stormwater regulations require permit coverage for all construction activity that result in land disturbance of equal to or greater than one acre and less than five acres. This includes the disturbance of less than one acre of total land area that is part of a larger common plan of development or sale if the larger common plan will ultimately disturb equal to or greater than one and less than five acres. Since March 2003, most construction activity disturbing one to five acres has been required to comply with the conditions of the relevant NPDES permit (typically under the relevant construction general permit for stormwater discharges), though states have the option of not requiring the submittal of NOIs for stormwater discharges associated with small construction activity.

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EPA and NPDES-authorized state permitting authorities may include permit conditions that incorporate qualifying state or local erosion and sediment control program requirements by reference. A qualifying state or local erosion and sediment control program is one that includes the requirements at § 122.44(s). Once EPA or an NPDES authorized state identifies and incorporates a qualifying local program in their NPDES construction general permit, operators can follow the erosion and sediment control requirements of the qualifying local program. By incorporating the qualifying local program by reference the permitting authority can avoid duplicative or conflicting erosion and sediment control requirements between the local program requirements and the NPDES general permit control requirements addressing stormwater discharges associated with construction activity. Operators that are engaged in construction activity within a qualifying program must still submit an NOI under the appropriate construction general permit and comply with all other permit conditions.

The permit requirements in a construction general permit may be similar to those in an industrial general permit, including the development of a SWPPP. In addition to the Stormwater Discharges from Construction Activities Website <www.epa.gov/npdes/stormwater/construction>, EPA also developed the Stormwater Pollution Prevention Plans for Construction Activities Website <www.epa.gov/npdes/swpppguide>. Section 4.3.9 of this manual discusses individual permit requirements for stormwater discharges associated with construction activity.

2.3.2.4 Cooling Water Intake Structures

CWA section 316(b) provides that any standard established pursuant to CWA sections 301 or 306 and applicable to a point source will require that the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact. This CWA provision is unique because it addresses the *intake* of water, in contrast to other provisions that regulate the discharge of pollutants into waters of the United States. EPA has established national performance standards under CWA section 316(b) designed to reduce the impingement and entrainment of fish and other aquatic organisms as they are drawn into a facility's cooling water intake structure(s). Impingement occurs when organisms are trapped against cooling water intake structures by the force of water being drawn through the intake structure. Entrainment occurs when organisms are drawn through a cooling water intake structure into a cooling system, through the heat exchanger, and then pumped back out into the waterbody. For more information, see section 4.3.12 of this manual.

In April 1976, EPA published regulations at Part 402 to address cooling water intake structures. Fifty-eight electric utility companies challenged the final rule. The U.S. Court of Appeals for the Fourth Circuit remanded the rule in 1977, and in 1979, EPA withdrew Part 402. Beginning in 1977, NPDES permit authorities made decisions implementing CWA section 316(b) on a case-by-case basis using best professional judgment (BPJ) (§§ 125.90(b) and 401.14).

In the 1990s, EPA began developing CWA section 316(b) regulations establishing national standards. EPA divided the rulemaking into three phases:

- Phase I addressed new facilities and was completed in December 2001 (Part 125, Subpart I).
- Phase II addressed existing electric generating plants that use at least 50 million gallons per day (mgd) of cooling water was completed in July 2004 (Part 125, Subpart J).

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- Phase III addressed other existing facilities, including small existing electric generating plants that use less than 50 mgd of cooling water, manufacturers, and new offshore and coastal oil and gas extraction facilities.

The Phase III regulations, finalized in June 2006, establish national standards only for new offshore and coastal oil and gas extraction facilities (Part 125, Subpart N). EPA decided that other Phase III industrial facilities withdrawing water for cooling purposes would not be covered by national standards but would continue to be subject to CWA section 316(b) requirements set by the NPDES Permitting Director on a case-by-case, BPJ basis (§§ 125.90(b) and 401.14).

All three regulations were subject to judicial challenges. While the Phase I rule was largely upheld, the court reviewing the Phase II regulation rejected a number of its provisions. Under remands from the reviewing courts, EPA is reevaluating the Phase II regulation and the decision in the Phase III regulation not to establish national standards for existing Phase III facilities. In the interim, as noted above, NPDES permits must include CWA section 316(b) conditions developed on a case-by-case basis. For the most current information on regulatory requirements, see the Cooling Water Intake Structure Program Website <www.epa.gov/waterscience/316b/>, and for additional Cooling Water Intake Structures regulatory requirements, see section 4.3.12 of this manual.

2.3.2.5 Concentrated Animal Feeding Operations (CAFOs)

Animal feeding operations (AFOs) are agricultural facilities where animals are kept and raised in confined situations. AFOs typically maintain animals, feed, and manure and have production operations in a limited land area. Manure and wastewater from AFOs have the potential to contribute pollutants such as nitrogen and phosphorus, organic matter, sediments, pathogens, heavy metals, hormones, antibiotics, and ammonia to the environment. An AFO is a lot or facility (other than an aquatic animal production facility) where the following conditions are met:

- Animals have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period.
- Crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.

AFOs that meet the regulatory definition of a CAFO, or that are designated as CAFOs by the permitting authority, and that discharge or propose to discharge are required to be permitted under the NPDES permitting program.

An animal operation must meet the definition of an AFO [§ 122.23(b)(1)] before it can be considered a CAFO. To be defined as a CAFO, an AFO must meet the regulatory definition [§§ 122.23(b)(4) or 122.23(b)(6)] of a large or medium CAFO or must be designated by the permitting authority [§ 122.23(c)]. Only CAFOs that discharge or propose to discharge are subject to NPDES permitting requirements.

CAFOs are subject to requirements that limit discharges from the production area and requirements applicable to land application areas under the control of the CAFO operator. Large CAFOs are subject to a no discharge requirement for production areas, whereas other CAFOs are subject to BPJ requirements for their production areas. One of the principal substantive pollution control conditions in any CAFO

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permit is the requirement to implement the terms of the nutrient management plan (NMP) incorporated into the permit when permit authorization is granted. For more information, see the Animal Feeding Operations Website <www.epa.gov/npdes/cafo>. In addition, section 4.3.4 of this manual discusses application requirements for CAFOs.

2.3.2.6 Concentrated Aquatic Animal Production (CAAP) Facilities

CAAP facilities also are regulated under the NPDES program. In 2004 EPA promulgated new effluent guidelines that address CAAP facilities. The effluent guidelines apply to CAAP facilities (flow-through, recirculating, and net pen) that directly discharge wastewater and have annual production equal to or greater than 100,000 pounds of aquatic animals. The rule requires a BMP plan and implementation of measures, including recordkeeping and reporting requirements, to minimize discharges of solids, to prevent spills of drugs, feed, and chemicals that could result in discharges to waters of the United States, and to ensure proper maintenance of the facility. A facility that does not meet the effluent guideline threshold might still need an NPDES permit if it meets the CAAP facilities thresholds established in the NPDES regulations at § 122.24(b) or if it is designated as a CAAP facility under the designation authority in § 122.24(c). For more information, see the Aquatic Animal Production Industry Effluent Guidelines Website <www.epa.gov/guide/aquaculture/>.

2.3.2.7 Vessel Discharges

On March 30, 2005, the U.S. District Court for the Northern District of California (in *Northwest Environmental Advocates et al. v. EPA*) ruled that the EPA regulation excluding discharges incidental to the normal operation of a vessel from NPDES permitting exceeded the Agency's authority under the CWA. On September 18, 2006, the Court issued an order revoking this regulation [40 CFR 122.3(a)] as of September 30, 2008. EPA appealed the District Court's decision, and on July 23, 2008, the Ninth Circuit upheld the decision, leaving the September 30, 2008, *vacatur* date in effect. In response to the Court order, EPA developed two proposed permits to regulate discharges from vessels. The district court ultimately extended the date of *vacatur* to February 6, 2009.

In July 2008, Congress amended the CWA (P.L. No. 110-288) to add a new section 402(r), which excludes discharges incidental to the normal operation of a recreational vessel from NPDES permitting. Instead, it directs EPA to regulate those discharges under a newly created CWA section 312(o). As a result of the law, EPA did not finalize the previously proposed Recreational Vessel General Permit and is instead undertaking rulemaking to develop BMPs for these vessels under the authority of CWA section 312(o).

In July 2010 P.L. 111-215 (Senate Bill S. 3372) was signed into law. This law amends P.L. 110-299 (Senate Bill S. 3298), which generally imposes a moratorium during which time neither EPA nor states may require NPDES permits for discharges incidental to the normal operation of commercial fishing vessels and other non-recreational vessels less than 79 feet. As a result, of P.L. 110-299, the Vessel General Permit (VGP) does not cover vessels less than 79 feet, or commercial fishing vessels, unless they have ballast water discharges. P.L. 111-215 extended the expiration date of the moratorium from July 31, 2010, to December 18, 2013.

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As a result of the court ruling, EPA issued the VGP on December 18, 2008. The 2008 VGP regulates discharges incidental to the normal operation of vessels operating in a capacity as a means of transportation. The VGP includes the following:

- general effluent limits applicable to all discharges.
- general effluent limits applicable to 26 specific discharge streams.
- narrative water-quality based effluent limits.
- inspection, monitoring, recordkeeping, and reporting requirements.
- additional requirements applicable to certain vessel types.

EPA estimates that approximately 61,000 domestically flagged commercial vessels and approximately 8,000 foreign flagged vessels could be affected by this permit.

Because this area of the NPDES permit program is relatively new and continues to evolve, for the most current information, see EPA's Vessel Discharges Website <www.epa.gov/npdes/vessels>.

2.4 Major/Minor Facility Designation

In addition to categorizing facilities as municipal and non-municipal, EPA has also developed criteria to determine which of the sources should be considered *major facilities*. The distinction was made initially to assist EPA and states in setting priorities for permit issuance and reissuance. The regulations at § 122.2 define major facility as, "any NPDES *facility or activity* classified as such by the Regional Administrator, or in the case of *approved state programs*, the Regional Administrator in conjunction with the [s]tate Director." All facilities that are not designated as *majors* are considered *minor* facilities.

Through policy, including the memoranda *Procedures for Revising the Major Permit List*[11] <www.epa.gov/npdes/pubs/owm0364.pdf> and *Delegation of Updates to Major/Minor Lists*[12] <www.epa.gov/npdes/pubs/owm0142.pdf>, EPA has established working definitions for POTW and non-municipal major facilities. For POTWs, major facilities are those that have a design flow of one million gallons per day or greater or serve a population of 10,000 or more or cause significant water quality impacts. Non-POTW discharges are classified as major facilities on the basis of the number of points accumulated using the NPDES Permit Rating Work Sheet <www.epa.gov/npdes/pubs/owm0116.pdf>. The worksheet evaluates the significance of a facility using several criteria, including toxic pollutant potential, flow volume, and water quality factors such as impairment of the receiving water or proximity of the discharge to coastal waters.

2.5 Growth and Change in the NPDES Program

The basic structure of the NPDES program has remained the same since the 1972 Federal Water Pollution Control Act amendments, but as EPA develops new regulations, policies, and guidance or modifies existing program requirements and guidance, the existing program is refined and new aspects of the program can emerge. To stay informed about the most recent program developments, permit writers should visit EPA's NPDES Program Website <www.epa.gov/npdes/> frequently.

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[2] U.S. Environmental Protection Agency. 1994. *A Plain English Guide to the EPA Part 503 Biosolids Rule.* EPA/832/R-93/003. U.S. Environmental Protection Agency, Office of Wastewater Management, Washington, DC. <www.epa.gov/owm/mtb/biosolids/503pe/>.

[3] U.S. Environmental Protection Agency. 2004. *Report to Congress on the Impacts and Control of CSOs and SSOs.* EPA 833-R-04-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. <www.epa.gov/npdes/csossoreport2004>.

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[9] U.S. Environmental Protection Agency. 2010. *MS4 Permit Improvement Guide*. EPA833-R-10-001. U.S. Environmental Protection Agency. Office of Water, Washington, DC. <www.epa.gov/npdes/pubs/ms4permit_improvement_guide.pdf>

[10] U.S. Environmental Protection Agency. 2009. *Developing Your Stormwater Pollution Prevention Plan: A Guide for Industrial Operators*. EPA 833-B-09-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC. <www.epa.gov/npdes/pubs/industrial_swppp_guide.pdf>.

[11] Dougherty, Cynthia. 1988. *Procedures for Revising the Major Permit List.* U.S. Environmental Protection Agency, Permits Division. Memorandum, December 28, 1988. <www.epa.gov/npdes/pubs/owm0364.pdf>.

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CHAPTER 3. Overview of the NPDES Permitting Process

This chapter presents an overview of the different types of National Pollutant Discharge Elimination System (NPDES) permits, the major permit components, and the permit development and issuance process. The permit process is illustrated by flow charts. The tasks identified within the flow charts are described in detail in subsequent chapters.

3.1 Types of Permits

The two basic types of NPDES permits are individual and general permits. These permit types share the same components but are used under different circumstances and involve different permit issuance processes.

3.1.1 Individual Permits

An individual permit is a permit specifically tailored to an individual facility. Upon receiving the appropriate application form(s), the permitting authority develops a permit for that facility on the basis of information from the permit application and other sources (e.g., previous permit requirements, discharge monitoring reports, technology and water quality standards, total maximum daily loads, ambient water quality data, special studies). The permitting authority then issues the permit to the facility for a specific period not to exceed 5 years, with a requirement to reapply before the expiration date.

3.1.2 General Permits

A permitting authority develops and issues a general permit to cover multiple facilities in a specific category of discharges or of sludge use or disposal practices. General permits can be a cost-effective option for agencies because of the large number of facilities that can be covered under a single permit. According to Title 40 of the *Code of Federal Regulations* (CFR) 122.28(a)(2), general permits may be written to cover stormwater point sources or other categories of point sources having the following common elements:

- Sources that involve the same or substantially similar types of operations.
- Sources that discharge the same types of wastes or engage in the same types of sludge use or disposal.
- Sources that require the same effluent limitations or operating conditions, or standards for sewage sludge use or disposal.
- Sources that require the same monitoring where tiered conditions may be used for minor differences within a class (e.g., size or seasonal activity).
- Sources that are more appropriately regulated by a general permit.

The regulations at § 122.28(a)(1) provide for general permits to cover dischargers within an area corresponding to specific geographic or political boundaries such as the following:

- Designated planning area.
- Sewer district.
- City, county, or state boundary.

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- State highway system.
- Standard metropolitan statistical area.
- Urbanized area.

The regulation also allows a general permit to cover any other appropriate division or combination of such boundaries. For example, EPA has issued general permits that cover multiple states, territories, and tribes where EPA is the permitting authority.

Where a large number of similar facilities require permits, a general permit allows the permitting authority to allocate resources in a more efficient manner and to provide more timely permit coverage than issuing an individual permit to each facility. In addition, using a general permit ensures consistent permit conditions for comparable facilities.

3.2 Major Components of a Permit

All NPDES permits consist, at a minimum, of five sections:

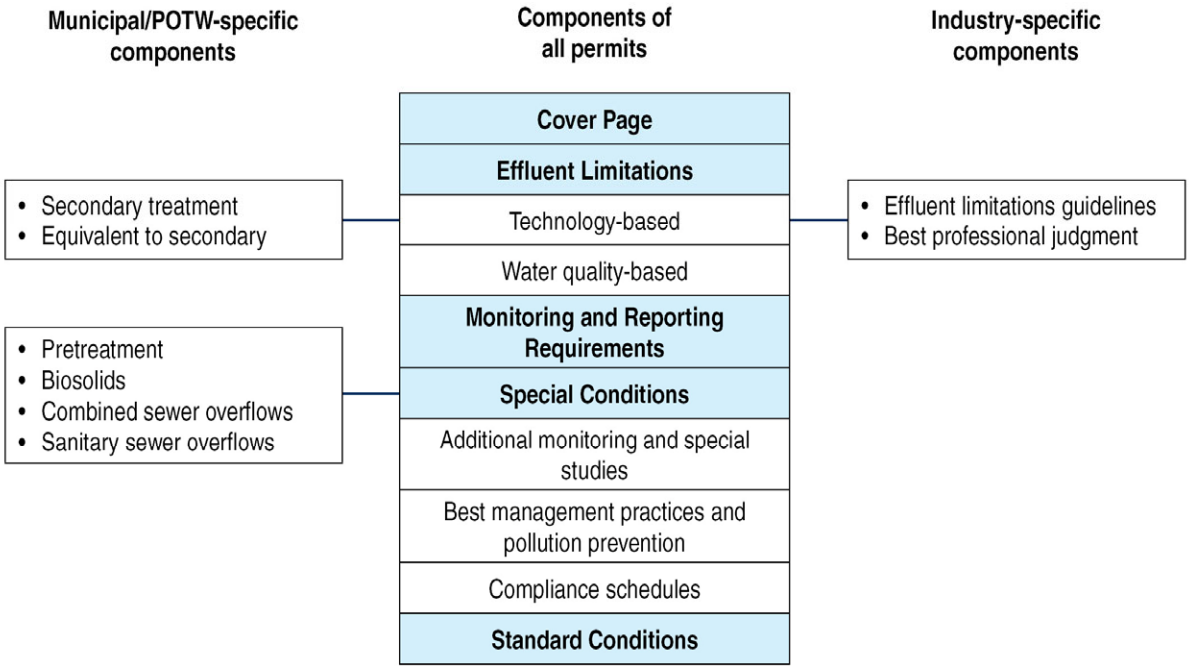
- **Cover Page:** Contains the name and location of the permittee, a statement authorizing the discharge, and a listing of the specific locations for which a discharge is authorized.
- **Effluent Limitations:** The primary mechanism for controlling discharges of pollutants to receiving waters. A permit writer spends the majority of his or her time, when drafting a permit, deriving appropriate effluent limitations on the basis of applicable technology and water quality standards.
- **Monitoring and Reporting Requirements:** Used to characterize wastestreams and receiving waters, evaluate wastewater treatment efficiency, and determine compliance with permit conditions.
- **Special Conditions:** Conditions developed to supplement numeric effluent limitations. Examples include additional monitoring activities, special studies, best management practices (BMPs), and compliance schedules.
- **Standard Conditions:** Pre-established conditions that apply to all NPDES permits and delineate the legal, administrative, and procedural requirements of the NPDES permit.

In addition to the components of the permit, a fact sheet or statement of basis explaining the rationale for permit conditions makes up part of the documentation that supports a draft permit. Section 11.2 of this manual includes additional discussion of permit documentation and the required elements of a fact sheet or statement of basis.

Although the major sections of a permit listed above are part of all permits, the contents of some sections vary depending on the nature of the discharge (e.g., municipal effluent, industrial process wastewater, stormwater, vessel discharges) and whether the permit is issued to an individual facility or to multiple dischargers (i.e., a general permit). Exhibit 3-1 shows the components of a permit and highlights some distinctions between the contents of NPDES permits for municipal (i.e., POTW) and industrial facilities. Permit writers should note that it is common for different permitting authorities to use different names for each section of a permit.

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Exhibit 3-1 Permit components



3.3 Overview of the Development and Issuance Process for NPDES Individual Permits

While the limitations and conditions in NPDES individual permits are unique to each permittee, the process used to develop the limitations and conditions and issue each permit generally follows a common set of steps. Exhibit 3-2 illustrates the major steps to develop and issue NPDES individual permits and also serves as an index for the subsequent chapters of this manual by identifying which chapter presents more detailed information on each step.

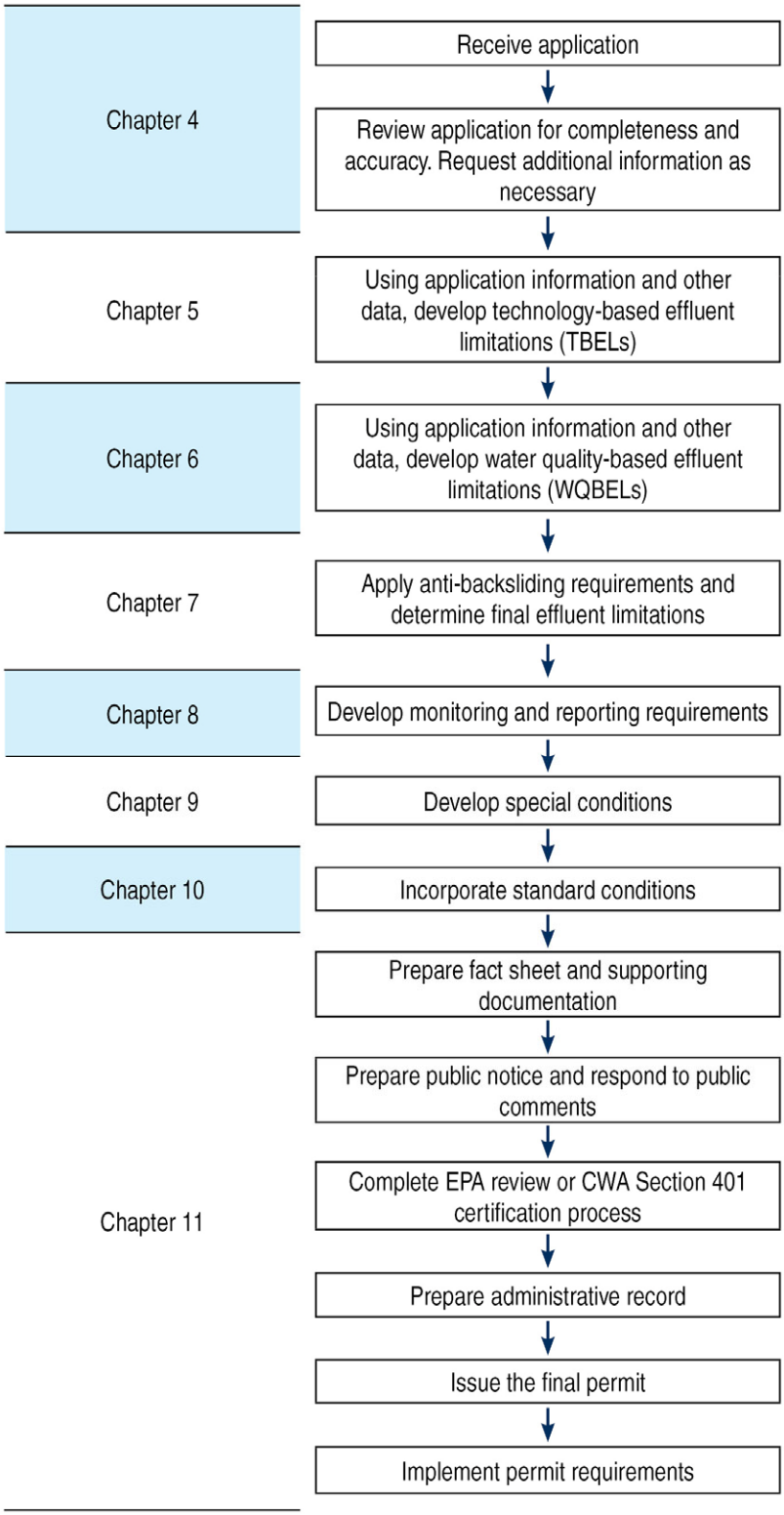
For individual permits, the permitting process generally begins when a facility operator submits an application. After receiving the application and making a decision to proceed with the permit, the permit writer reviews the application for completeness and accuracy. When the permit writer determines that the application is complete and has any additional information needed to draft the permit, the permit writer develops the draft permit and the justification for the permit conditions (i.e., the fact sheet or statement of basis).

The first major step in the permit development process is deriving technology-based effluent limitations (TBELs). Following that step, the permit writer derives effluent limitations that are protective of state water quality standards (i.e., water quality-based effluent limitations [WQBELs]) as needed. The permit writer then compares the TBELs with the WQBELs and, after conducting an anti-backsliding analysis if necessary, applies the final limitations in the NPDES permit. The permit writer must document the decision-making process for deriving limitations in the permit fact sheet. It is quite possible that a permit will have limitations that are technology-based for some parameters and water quality-based for others. For example, a permit could contain effluent limitations for total suspended solids (TSS) based on national effluent limitations guidelines and standards (effluent guidelines) (technology-based), limitations for ammonia based on preventing toxicity to aquatic life (water quality-based), and limitations for 5-day

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biochemical oxygen demand (BOD_5) that have different bases, such as an average monthly limitation based on effluent guidelines and a maximum daily limitation based on water quality standards.

Exhibit 3-2 Major steps to develop and issue NPDES individual permits



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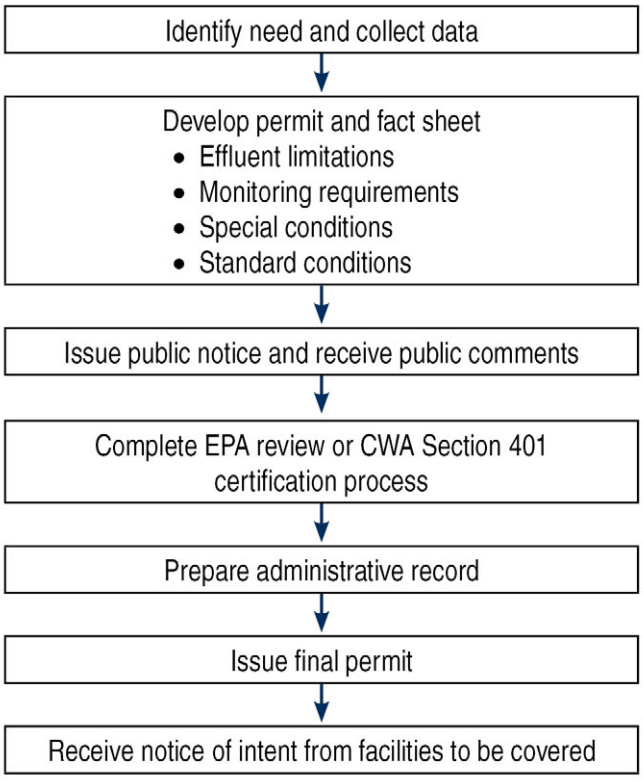
After effluent limitation development, the permit writer develops appropriate monitoring and reporting requirements and facility-specific special conditions. The permit writer then adds standard conditions, which are the same for all permits.

The next step is to provide an opportunity for public participation in the permit process and EPA review of the permit or, in the case of an EPA-issued permit, certification under CWA section 401 by the state with jurisdiction over the receiving water that the permit will comply with its water quality standards. The permitting authority issues a public notice announcing the draft permit and inviting interested parties to submit comments. If there is significant public interest, the permitting authority can hold a public hearing. Taking into consideration the public comments, the permitting authority then produces a final permit, with careful attention to documenting the process and decisions for the administrative record, and issues the final permit to the facility. The permitting authority might decide to make significant changes to the draft permit according to public comment and then provide another opportunity for public review and comment on the revised permit. Section 11.3 of this manual discusses items to address before final permit issuance in more detail.

3.4 Overview of the Development and Issuance Process for NPDES General Permits

The process for developing and issuing NPDES general permits is similar to the process for individual permits; however, there are some differences in the sequence of events. Exhibit 3-3 illustrates the major steps to develop and issue NPDES general permits.

Exhibit 3-3 Major steps to develop and issue NPDES general permits



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For general permits, the permitting authority first identifies the need for a general permit and collects data that demonstrate that a group or category of dischargers has similarities that warrant a general permit. In deciding whether to develop a general permit, permitting authorities consider whether

- A large number of facilities will be covered.
- The facilities have similar production processes or activities.
- The facilities generate similar pollutants.
- Whether uniform WQBELs (where necessary) will appropriately implement water quality standards.

The remaining steps of the permit process are the same as for individual permits. The permitting authority develops a draft permit that includes effluent limitations, monitoring conditions, special conditions, and standard conditions. The permitting authority then issues a public notice and addresses public comments, completes the EPA review or CWA section 401 certification process, develops the administrative record, and issues the final permit. The final permit will also establish the requirements for the specific information that must be submitted by a facility that wishes to be covered under the general permit.

After the final general permit has been issued, facilities that wish to be covered under the general permit typically submit a Notice of Intent (NOI) to the permitting authority. After receiving the NOI, the permitting authority can request additional information describing the facility, notify the facility that it is covered by the general permit, or require the facility to apply for an individual permit.

The following chapters in this manual describe steps in the permitting process in detail. In general, the chapters focus on the steps necessary to develop and issue an individual permit, but much of the technical discussion applies equally to general permit development.

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CHAPTER 4. NPDES Permit Application Process

This chapter describes the National Pollutant Discharge Elimination System (NPDES) permit application process, including the permit writer's role in reviewing the application and evaluating background information about the applicant. Through this process the permit writer gains an understanding of the circumstances of the discharge and the characteristics of the proposed effluent, which is necessary to develop appropriate permit limitations and conditions.

4.1 Who Applies for an NPDES Permit?

The NPDES regulations at Title 40 of the *Code of Federal Regulations* (CFR) 122.21(a) require that any person, except persons covered by general permits under § 122.28, who discharges pollutants or proposes to discharge pollutants to waters of the United States must apply for a permit. Further, § 122.21(e) prohibits the permitting authority from issuing an individual permit until and unless a prospective discharger provided a complete application. This regulation is broadly inclusive and ties back to the Clean Water Act (CWA) section 301(a) provision that, except as in compliance with the act, "…the discharge of any pollutant by any person shall be unlawful."

In most instances, the permit applicant will be the owner (e.g., corporate officer) of the facility. However, the regulations at § 122.21(b) require that when a facility or activity is owned by one person but is operated by another person, it is the operator's duty to obtain a permit. The regulations also require the application to be signed and certified by a high-ranking official of the business or activity. The signatory and certification requirements are at § 122.22.

Permits (and applications) are required for most discharges or proposed discharges to waters of the United States; however, NPDES permits are not required for some activities as specified under the *Exclusions* provision in § 122.3. Exceptions include the following:

- Discharge of dredged or fill materials into waters of the United States which are regulated under CWA section 404.
- The introduction of sewage, industrial wastes or other pollutants into publicly owned treatment works (POTWs) by indirect dischargers.
- Any discharge in compliance with the instructions of an On-Scene Coordinator pursuant to Part 300 (The National Oil and Hazardous Substances Pollution Contingency Plan) or 33 CFR 153.10(e) (Pollution by Oil and Hazardous Substances).
- Any introduction of pollutants from nonpoint source agricultural and silvicultural activities, including stormwater runoff from orchards, cultivated crops, pastures, range lands, and forest lands, but not discharges from concentrated animal feeding operations as defined in § 122.23, discharges from concentrated aquatic animal production facilities as defined in § 122.24, discharges to aquaculture projects as defined in § 122.25, and discharges from silvicultural point sources as defined in § 122.27.
- Return flows from irrigated agriculture.

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- Discharges into a privately owned treatment works, except as the Director may otherwise require under § 122.44(m).

While those types of discharges have been excluded from permitting requirements under the NPDES program, they might be subject to controls under other federal or state regulatory programs.

As of the date of this manual's publication, the exclusion for certain discharges incidental to the normal operation of a vessel is still in the CFR. Similarly, discharges from the application of pesticides consistent with all relevant requirements under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) (i.e., those relevant to protecting water quality) are excluded from NPDES permit coverage in the following two circumstances: (1) the application of pesticides directly to waters of the United States to control pests, and (2) the application of pesticides to control pests that are present over waters of the United States, including near such waters, where a portion of the pesticides will unavoidably be deposited to waters of the United States to target the pests effectively. However, because of court decisions, the exclusions for vessels and pesticides are vacated as of February 6, 2009, and April 9, 2011, respectively. The effect of the *vacaturs* on the exclusions in § 122.3 is presented in Exhibit 4-1.

Exhibit 4-1 Effect of court decisions on § 122.3

Exclusion	Issue
Vessel Discharges (www.epa.gov/npdes/vessels)	The Court's ruling does not affect vessel discharge exemptions from permitting that are specifically provided for in the CWA itself. For example, § 502(6)(A) excludes from the act's definition of *pollutant* sewage from vessels (including graywater in the case of commercial vessels operating on the Great Lakes) and discharges incidental to the normal operation of a vessel of the Armed Forces within the meaning of CWA section 312. As another example, the CWA section 502(12)(B) provides that discharges from vessels (i.e., discharges other than those when the vessel is operating in a capacity other than as a means of transportation) do not constitute the, "discharge of a pollutant" when such discharges occur beyond the limit of the 3-mile territorial sea. Because both *a pollutant* and a *discharge of a pollutant* are prerequisites to the requirement to obtain an NPDES permit, those two statutory provisions have the effect of exempting the vessel discharges they address from the requirement to obtain an NPDES permit. In addition, in July 2008, Congress amended the CWA to add a new section 402(r) to the act, which excludes discharges incidental to the normal operation of a recreational vessel from NPDES permitting. For more information, see section 2.3.2.7 of this manual.
Pesticides (www.epa.gov/npdes/aquaticpesticides)	On January 7, 2009, the 6th Circuit Court vacated the final rule in *The National Cotton Council of America et al. v. United States Environmental Protection Agency*. The court held that while an NPDES permit is not required for chemical pesticide applications that leave no residuals, an NPDES permit is required for discharges (1) from chemical pesticide applications to or over, including near water, where there is a residual, or excess pesticide, in the water following the application, and (2) from all biological pesticide applications regardless of whether a residual is left. On June 8, 2009, the court granted a request from the U.S. Department of Justice for a 2-year stay of its decision, until April 9, 2011, to provide time for EPA and the states to develop and issue NPDES general permits for the discharge of pollutants from the application of pesticides. Before April 9, 2011, permits are not required for discharges from these applications when applied in accordance with the product's FIFRA label. Certain related activities continue to be exempt from permitting under the CWA (i.e., irrigation return flow and agricultural stormwater runoff).

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4.2 Application Deadlines

The regulations at § 122.21(c) and (d) specify the time to apply for NPDES permits. Exhibit 4-2 summarizes the application deadline requirements for dischargers to be covered by an NPDES permit.

Exhibit 4-2 When to apply for an NPDES permit

Type of permit	Type of discharge	Schedule*
Individual	New	At least 180 days before the date on which the discharge is to commence
	Existing	At least 180 days before expiration date of existing permit
	Construction Stormwater	At least 90 days before the date on which construction is to commence
General	New	Specified in general permit
	Existing	X number of days following issuance of permit (specified in the general permit)

* Authorized states may use more stringent deadlines.

Anyone proposing a new discharge must apply to the permitting authority no later than 180 days before the expected commencement of the discharge if applying for an individual permit. Any person with an currently effective individual permit must submit an application to the permitting authority at least 180 days before the expiration of its existing individual permit unless permission for a later date has been granted in accordance with § 122.21(d). For general permits, the deadline for new dischargers to apply is specified in the general permit. A general permit also may specify a number of days after the general permit's issuance that operators of existing facilities are given to apply for coverage. Authorized states may have different schedules for permit applications, but their schedules may be no less stringent than the federal deadlines. The State Director or the Regional Administrator may allow an individual application to be submitted at dates later than those specified in the regulations, but not later than the expiration date of the existing permit.

Note that, according to § 122.6, the conditions of an expired NPDES permit remain in effect until the new permit is issued, as long as the discharger submitted a complete application in accordance with the timeframes prescribed in the regulations (or in accordance with state law, in the case of state-administered NPDES programs). If state law does not allow expired permits to remain in effect until a permit is reissued, or if the permit application is not on time and complete, the facility may be considered to be discharging without a permit from the time the permit expired until the effective date of the new permit.

4.3 Application Forms and Requirements for Individual Permits

When a facility needs an individual NPDES permit, it must submit a permit application. Application forms and requirements are specific to the type of facility and discharge. NPDES permit application requirements are in Part 122, Subpart B and identified on forms developed by the U.S. Environmental Protection Agency (EPA). Authorized states are not required to use the EPA application forms; however, any alternative form used by an authorized state must include the federal requirements at a minimum.

Exhibit 4-3 provides an overview of the types of dischargers required to submit NPDES application forms, identifies the forms that must be submitted, and references the corresponding NPDES regulatory citation. In some cases, a facility might need to file more than one application form. For example, an

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existing industrial facility (i.e., renewal) discharging stormwater combined with process and non-process wastewater might need to submit Form 1, Form 2C, and Form 2F. Section 2.3 of this manual discusses the NPDES program areas that have application requirements presented below.

Exhibit 4-3 EPA application requirements for NPDES individual permits

Type of facility or program area	Status	Forms	Regulatory citations and additional application requirements (40 CFR)
Municipal facilities • POTWs with design flows greater than or equal to 0.1 million gallons per day (mgd)	New and existing	**Form 2A**, Parts A, B and C; Parts D, E, F, or G as applicable	• § 122.21(a)(2)(i)(B) • § 122.21(j)
• POTWs with design flows less than 0.1 mgd	New and existing	**Form 2A**, Parts A and C; Parts D, E, F, or G as applicable	• § 122.21(a)(2)(i)(B) • § 122.21(j)
TWTDS (sewage sludge)	New and existing	**Form 2S**	• § 122.21(a)(2)(i)(H) • § 122.21(q)
Concentrated animal production facilities • Concentrated animal feeding operations • Concentrated aquatic animal production facilities	New and existing	**Form 1** and **Form 2B**	• § 122.21(a)(2)(i)(A) and (C) • § 122.21(f) and (i)
Industrial facilities • Manufacturing facilities • Commercial facilities • Mining activities • Silvicultural activities	Existing	**Form 1** and **Form 2C**	• § 122.21(a)(2)(i)(A) and (D) • § 122.21(f) and (g)
	New (process wastewater)	**Form 1** and **Form 2D**	• § 122.21(a)(2)(i)(A) and (E) • § 122.21(f) and (k)
	New and existing (non-process wastewater)	**Form 1** and **Form 2E**	• § 122.21(a)(2)(i)(A) and (F) • § 122.21(f) and (h)
Stormwater discharges associated with industrial activities (except stormwater discharges associated with construction activity)	New and existing	**Form 1** and **Form 2F**	• § 122.21(a)(2)(i)(A) and (G) • § 122.21(f) • § 122.26(c)
Stormwater discharges associated with construction activity	New and existing	**Form 1**	• § 122.21(a)(2)(i)(A) • § 122.21(f) • § 122.26(c)(1)(ii)
Stormwater discharges from MS4s serving a population greater than 100,000	New and existing	None	• § 122.26(d)
Stormwater discharges from small MS4s	New and existing	None	• § 122.33 • § 122.21(f)
Cooling water intake structures	New and existing	None	• § 122.21(r)

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4.3.1 Form 1: General Information

All facilities applying for an individual NPDES permit, with the exception of POTWs, treatment works treating domestic sewage (TWTDS), and municipal separate storm sewer systems (MS4s) applying for a municipal stormwater permit, must submit Form 1 <www.epa.gov/npdes/pubs/form_1.pdf>. The type of general facility information required by Form 1 is specified in §§ 122.21(a)(2)(i)(A) and 122.21(f) and includes the following:

- Name, mailing address, facility contact, and facility location.
- Standard industrial classification (SIC) code and a brief description of the nature of the business.
- Topographic map showing the location of the existing or proposed intake and discharge structures.

4.3.2 Form 2A: New and Existing POTWs

All new and existing POTWs must submit Form 2A <www.epa.gov/npdes/pubs/final2a.pdf>. EPA issued a final rule amending permit application requirements and application forms for POTWs and other TWTDS (64 FR 42433, August 4, 1999). The rule consolidated POTW application requirements, expanded toxic monitoring requirements for POTWs, and revised the forms used to submit permit applications. POTWs must also submit the form for permit renewals. Form 2A replaces Standard Form A and Short Form A.

POTWs with design influent flows equal to or greater than 100,000 gallons per day (gpd) (0.1 mgd) must submit Parts A, B, and C of Form 2A. POTWs with design flows of less than 100,000 gpd must submit Parts A and C of Form 2A. Parts A, B and C are referred to as Basic Application Information:

- Part A of Form 2A contains basic application information for all applicants:
  - Facility and applicant information.
  - Collection system type, areas served, and total population served.
  - Discharges and other disposal methods.
  - If the treatment works discharges effluent to waters of the United States, a description of outfalls, receiving waters, and treatment and effluent testing information.
- Part B of Form 2A collects additional information for applicants with a design flow greater than or equal to 0.1 mgd, including inflow and infiltration estimates, a topographic map, process flow diagram, and effluent testing data for additional parameters.
- Part C is a certification that all applicants must complete.

Form 2A also includes Supplemental Application Information (Parts D–G). POTWs complete these additional forms, as applicable, depending on the characteristics of the municipal discharge:

- Part D requests expanded effluent testing data for metals, volatile organic compounds, acid-extractable compounds, and base-neutral compounds. A POTW that discharges effluent to waters of the United States and meets one or more of the following criteria must complete Part D:
  - Has a design flow rate greater than or equal to 1 mgd.
  - Is required to have a pretreatment program (or has one in place).
  - Is otherwise required by the permitting authority to provide the information.

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- A POTW that meets one or more of the following criteria must complete Part E (Toxicity Testing Data):
  - Has a design flow greater than or equal to 1 mgd.
  - Is required to have a pretreatment program (or has one in place).
  - Is otherwise required by the permitting authority to submit results of toxicity testing.
- A POTW that accepts process wastewater from any significant industrial users (SIUs) or receives Resource Conservation and Recovery Act (RCRA) or Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or other remedial wastes must complete Part F. SIUs are defined as:
  - All industrial users subject to Categorical Pretreatment Standards under § 403.6 and 40 CFR Chapter I, Subchapter N.
  - Any other industrial user for which any of the following is true
    - Discharges an average of 25,000 gpd or more of process wastewater to the POTW (excluding sanitary, non-contact cooling, and boiler blowdown wastewater).
    - Contributes a process wastestream that makes up 5 percent or more of the average dry-weather hydraulic or organic capacity of the treatment plant.
    - Is designated an SIU by the control authority on the basis that it has a reasonable potential for adversely affecting the POTWs operation or for violating any pretreatment standard or requirement.
  - The control authority can determine that an industrial user subject to categorical pretreatment standards is a nonsignificant categorical industrial user, rather than an SIU, on a finding that it never discharges more than 100 gpd of total categorical wastewater and if:
    - Before that finding, the industrial user has consistently complied with all applicable categorical pretreatment standards and requirements.
    - The industrial user annually submits a certification statement required in § 403.12(q) and any information necessary to support the certification statement.
    - The industrial user never discharges any untreated concentrated wastewater.
  - If an industrial user meets one of the other criteria for determining that it is an SIU (i.e., discharges an average of 25,000 gpd of process wastewater), but the control authority finds that it has no reasonable potential for adversely affecting the POTW's operation or for violating any pretreatment standards or requirement, the control authority can determine that the industrial user is not an SIU.
- A POTW that has a combined sewer system must complete Part G. Information that must be provided in the section includes a system map and diagram, and descriptions of outfalls, combined sewer overflow (CSO) events, receiving waters, and operations.

4.3.3 Form 2S: New and Existing TWTDS

New TWTDS and TWTDS with effective NPDES permits must submit a new or renewal permit application, respectively, using new Form 2S <www.epa.gov/npdes/pubs/final2s.pdf>. Part 1 of Form 2S is to be completed by *sludge-only* facilities; that is, facilities that do not have, and are not applying for, an NPDES permit for a direct discharge to surface water. Part 1 collects background information on the facility, including identification information, quantities of sewage sludge handled, pollutant concentrations, treatment methods, and use and disposal information.

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Part 2 is used by facilities that already have or are applying for an NPDES permit. It includes five sections:

- All applicants using Part 2 must complete the general information collected by **section A**.
- Applicants who either generate sewage sludge or derive a material from sewage sludge must complete **section B**.
- Applicants who either apply sewage sludge to the land or generate sewage sludge that is applied to the land by others (unless the sludge from the facility meets certain exemption criteria) must complete **section C**.
- Applicants who own or operate a surface disposal site must complete **section D**.
- Applicants who own or operate a sewage sludge incinerator must complete **section E**.

4.3.4 Form 2B: New and Existing Concentrated Animal Feeding Operations (CAFOs) and Concentrated Aquatic Animal Production (CAAP) Facilities

In addition to Form 1, owners of new and existing CAFOs (defined in § 122.23) and CAAP facilities (defined in § 122.24) must submit Form 2B <www.epa.gov/ne/npdes/2010RevisedCafoFedRegstrForm2b.pdf>. Form 2B was significantly modified as part of the final CAFO Rules (68 FR 7176, February 12, 2003, and 73 FR 70418, November 20, 2008). The type of information required by Form 2B consists of the following:

- For CAFOs
  - The name of the owner or operator.
  - The facility location and mailing addresses.
  - Latitude and longitude of the production area.
  - A topographic map of the geographic area in which the CAFO is located.
  - Specific information about the number and type of animals.
  - The type of containment and total capacity for storage (tons/gallons).
  - The total number of acres under control of the applicant available for land application.
  - Estimated amounts of manure, litter, and process wastewater generated and amounts transferred to other persons per year.
  - A nutrient management plan (NMP) that satisfies the requirements of § 122.42(e).
- For CAAP facilities
  - The maximum daily and average monthly flow from each outfall.
  - The number of ponds, raceways, and similar structures.
  - The name of the receiving water and the source of intake water.
  - For each species of aquatic animals, the total yearly and maximum harvestable weight.
  - The calendar month of maximum feeding and the total mass of food fed during that month.

Note that recent revisions to the NPDES regulations require that a CAFO seeking coverage under a permit submit its NMP with its application for an individual permit or notice of intent (NOI) to be authorized under a general permit. Permitting authorities are required to review the plan and provide the public with an opportunity for meaningful public review and comment. Permitting authorities also are required to incorporate terms of the NMP as NPDES permit conditions. For more information on the revisions to the CAFO regulations, see the Animal Feeding Operations Website <www.epa.gov/npdes/cafo>.

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Sections 2.3.2.5 and 2.3.2.6 of this manual provide additional information on CAFOs and CAAP facilities, respectively.

4.3.5 Form 2C: Existing Manufacturing, Commercial, Mining, and Silvicultural Discharges

In addition to Form 1, operators of existing (i.e., currently permitted) manufacturing, commercial, mining, and silvicultural discharges must submit Form 2C <www.epa.gov/npdes/pubs/3510-2C.pdf>. The type of information required in Form 2C includes:

- Outfall locations.
- A line drawing of the water flow through the facility.
- Flow characteristics, sources of pollution, treatment technologies.
- Production information (if applicable).
- Improvements (if applicable).
- Intake and effluent characteristics for conventional, nonconventional and toxic (priority) pollutants.
- Potential discharges not covered by analysis.
- Biological testing data.
- Contract laboratory information.
- Certification and signature.

Quantitative effluent data requirements for existing industrial dischargers vary depending on the industrial category of the facility, the facility's discharge characteristics and the types of pollutants expected to be present in the discharge.

4.3.6 Form 2D: New Manufacturing, Commercial, Mining, and Silvicultural Discharges of Process Wastewater

In addition to Form 1, operators of new manufacturing, commercial, mining, and silvicultural discharges of process wastewater must submit Form 2D <www.epa.gov/npdes/pubs/3510-2D.pdf>. *New* dischargers are those that have not previously obtained permits for a discharge and have not commenced operation. The type of information required in Form 2D includes the following:

- Expected outfall locations.
- Date of expected commencement of discharge.
- Expected flow characteristics.
- Sources of pollutants.
- Treatment technologies.
- Production information (if applicable).
- Expected intake and effluent characteristics.

4.3.7 Form 2E: Manufacturing, Commercial, Mining, and Silvicultural Facilities that Discharge Only Non-Process Wastewater

In addition to Form 1, operators applying for an individual NPDES permit for manufacturing, commercial, mining, and silvicultural facilities that are not regulated by effluent limitations guidelines and standards (effluent guidelines) or new source performance standard, and that discharge only

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non-process wastewaters, must submit Form 2E <www.epa.gov/npdes/pubs/3510-2E.pdf>. *Non-process wastewater* includes sanitary wastes, restaurant or cafeteria wastes, and non-contact cooling water, but it does not include stormwater. Stormwater is specifically excluded from the definition of non-process wastewater. Form 2E also may not be used for discharges by educational, medical, or commercial chemical laboratories or by POTWs. The type of information required in Form 2E includes the following:

- Outfall locations.
- Type of waste discharged.
- Effluent characteristics, including quantitative data for selected parameters.
- Flow characteristics.
- Treatment technologies.

4.3.8 Form 2F: Stormwater Discharges Associated with Industrial Activities

In addition to Form 1, operators applying for an individual NPDES permit for discharges composed entirely of stormwater associated with industrial activity must submit Form 2F <www.epa.gov/npdes/pubs/3510-2F.pdf>. Applicants whose discharge is composed of stormwater and non-stormwater must also submit Form 2C, 2D, or 2E as appropriate. The type of information required in Form 2F includes the following:

- A topographic map and estimates of impervious surface area.
- Descriptions of material management practices and control measures.
- A certification that outfalls have been evaluated for non-stormwater discharges.
- Descriptions of past leaks and spills.
- Analytical data from each outfall for several specified parameters.

EPA developed the *Guidance Manual For the Preparation of NPDES Permit Applications For Stormwater Discharges Associated With Industrial Activity*[1] <www.epa.gov/npdes/pubs/owm0241.pdf> to assist operators of facilities that discharge stormwater associated with industrial activity in complying with the requirements for applying for an NPDES permit.

4.3.9 Stormwater Discharges Associated with Construction Activity

Most stormwater discharges associated with construction activities that result in the disturbance of one acre or more are covered under a general permit issued by EPA or the authorized state. In cases that a general permit does not cover the discharge or the discharger decides that an individual permit is necessary for stormwater discharges associated with construction activity, the discharger is required to submit Form 1, along with a narrative description of the following:

- The location (including a map) and the nature of the construction activity.
- The total area of the site and the area of the site that is expected to undergo excavation during the life of the permit.
- Proposed measures, including best management practices (BMPs), to control pollutants in stormwater discharges during construction, including a brief description of applicable state and local erosion and sediment control requirements.

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- Proposed measures to control pollutants in stormwater discharges that will occur after construction operations have been completed, including a brief description of applicable state or local erosion and sediment control requirements.
- An estimate of the runoff coefficient of the site and the increase in impervious area after the construction addressed in the permit application is completed, the nature of fill material and existing data describing the soil or the quality of the discharge.
- The name of the receiving water.

4.3.10 Stormwater Discharges from MS4s Serving a Population Greater than 100,000

The stormwater application regulations (55 FR 47990, November 16, 1990) require operators of large or medium MS4s to submit two-part applications. Part 1 application information was required to be submitted by large MS4s (serving a population greater than 250,000) by November 18, 1991, and by medium MS4s (serving a population greater than 100,000 but less than or equal to 250,000) by May 18, 1992. Part 2 application information was required to be submitted by large MS4s by November 16, 1992, and by medium MS4s by May 17, 1993. Those applications could be submitted on a system- or jurisdiction-wide basis. Key requirements of each part of the application include [and are further addressed in § 122.26(d)] the following:

- Part 1
  - General information (e.g., name, address).
  - Existing legal authorities to control discharges to the storm sewer system and any additional authority that might be required.
  - Source identification information (e.g., storm sewer outfalls, land use information).
  - Discharge characterization, including monthly precipitation estimates, average number of storm events, and results from dry-weather flow screening.
  - Characterization plan, including identification of 5 to 10 representative outfalls for stormwater sampling.
  - Description of existing stormwater management practices.
  - Descriptions of existing budget and resources available to complete Part 2 of the application and implement the stormwater program.
- Part 2
  - Demonstration of adequate legal authority.
  - Identification of any major storm sewer outfalls not included in Part 1 of the application.
  - Discharge characterization data from three representative storm events.
  - Proposed stormwater management program.
  - Assessment of controls, including expected reductions in pollutant loadings.
  - Fiscal analysis, including necessary capital and operation and maintenance expenditures for each year of the permit.

Under the NPDES regulations, permittees are required to reapply for a new NPDES permit before the expiration of their existing permit; however, in the case of stormwater permits for MS4s, Part 1 and Part 2 application requirements described above were intended only for the initial issuance of an MS4 permit and specific requirements for reapplication have not been defined in the regulations. On May 17, 1996, EPA issued a policy that sets forth a streamlined approach for reapplication requirements for operators of

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MS4s (61 FR 41698, August 9, 1996) that allows municipalities to use recommended changes submitted in their fourth year annual report required under § 122.42(c)(2), as the principal component of their reapplication package. It also encourages changes to monitoring programs to make them appropriate and useful to stormwater management decisions. With the policy, EPA seeks to improve municipal stormwater management efforts by allowing municipalities to target their resources for the greatest environmental benefit.

4.3.11 Stormwater Discharges from Small MS4s

The application requirements for small MS4s are addressed in § 122.33. Most states have issued general permits for small MS4s; however, regulated small MS4s may seek authorization to discharge under an individual permit. The application requirements are different depending on whether the MS4 will implement a program under § 122.34 (i.e., a program that follows EPA's six minimum control measures) or a program that varies from § 122.34. EPA anticipates that most MS4s will follow the § 122.34 requirements.

Regulated small MS4s seeking an individual permit and wishing to implement a program under § 122.34 (the six minimum control measures) must submit an application to their NPDES permitting authority that includes the following:

- The information required under §§ 122.21(f) and 122.34(d).
- An estimate of square mileage served by the small MS4.
- Any additional information that the NPDES permitting authority requests.

A storm sewer map that satisfies the requirement of § 122.34(b)(3)(i) will also satisfy the map requirement in § 122.21(f)(7).

Regulated small MS4s seeking an individual permit and wishing to implement a program that is different from the program under § 122.34 must comply with the permit application requirements of § 122.26(d) (for additional information, see section 4.3.10 above). Under § 122.33, the regulated small MS4 is required to submit both parts of the application requirements in §§ 122.26(d)(1) and (2) by March 10, 2003. Small MS4s are not required to submit the information required by §§ 122.26(d)(1)(ii) and (d)(2) regarding their legal authority, unless they intend for the permit writer to take such information into account when developing their other permit conditions. Regulated small MS4s may jointly apply with another regulated entity consistent with the same requirements.

Additionally, another regulated entity may seek a modification of an existing MS4 permit to include a regulated small MS4 as a co-permittee. In such a case, the regulated small MS4 must apply consistent with § 122.26 rather than § 122.34. Application requirements of §§ 122.26(d)(1)(iii) and (iv) and (d)(2)(iii) do not apply and compliance with §§ 122.26(d)(1)(v) and (d)(2)(iv) can be met by referring to the other MS4's stormwater management program.

4.3.12 Cooling Water Intake Structures

Phase I of the CWA section 316(b) rule was finalized on December 18, 2001, in 66 FR 65256. The Phase I Rule (Part 125, Subpart I) implements CWA section 316(b) for most new facilities. The rule applies to new facilities that use cooling water intake structures to withdraw water from waters of the United States and that have or require an NPDES permit. This rule includes new facilities that have a design intake flow of greater than 2 mgd and that use at least 25 percent of water withdrawn for cooling purposes. For other

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new facilities that have or require an NPDES permit but do not meet the 2-mgd intake flow threshold or use less than 25 percent of their water for cooling water purposes, the permit authority must implement CWA section 316(b) on a case-by-case basis, using best professional judgment (BPJ) (§§ 125.90(b) and 401.14).

Phase II of the CWA section 316(b) rule was finalized on July 9, 2004, in 69 FR 41576. In 2007 EPA suspended the rule following remand of a number of its provisions by the U.S. Court of Appeals for the Second Circuit. CWA section 316(b) requirements for such facilities must be developed on a case-by-case basis.

Phase III of the CWA section 316(b) rule was finalized on June 16, 2006, in 71 FR 35006. The Phase III rule (Part 125, Subpart N) implements CWA section 316(b) for new offshore oil and gas extraction facilities that use cooling water intake structures to withdraw water from waters of the United States and that have or require an NPDES permit. The rule includes facilities with a design intake flow of greater than 2 mgd and that use at least 25 percent of water withdrawn for cooling purposes.

EPA has not established national standards for existing Phase III facilities and is reevaluating its decisions in both Phase II and Phase III because of court remands. In the interim, for Phase III facilities not regulated under national categorical standards, the permitting authority must implement CWA section 316(b) on a case-by-case basis, using BPJ (§§ 125.90(b) and 401.14). For the most current information on regulatory requirements, see the Cooling Water Intake Structure Program Website <www.epa.gov/waterscience/316b/>.

4.4 Requirements for NPDES General Permits

As previously discussed in section 3.1.2 of this manual, general permits (§ 122.28) are permits developed for a specific category of dischargers within a specified geographic or political boundary. Using a general permit could simplify the permitting process for both EPA and the discharger. Owners/operators may seek coverage under a general permit only if one has been issued that is applicable to the type of facility for which coverage is sought and the permit covers the facility's activities. In addition, the permitting authority may determine that a general permit is not appropriate for a facility seeking coverage under the general permit and can require the facility to apply for an individual permit. Furthermore, a facility that otherwise qualifies for a general permit may opt to apply for an individual permit.

In most cases, a facility or activity seeking coverage under a general permit must seek coverage by submitting an NOI. The information that must be provided by the facility or activity in the NOI is specified in the general permit and must include, at a minimum, the following:

- Legal name and address of the owner or operator.
- Name and address of the facility.
- Type of facility or discharges.
- The receiving stream(s).

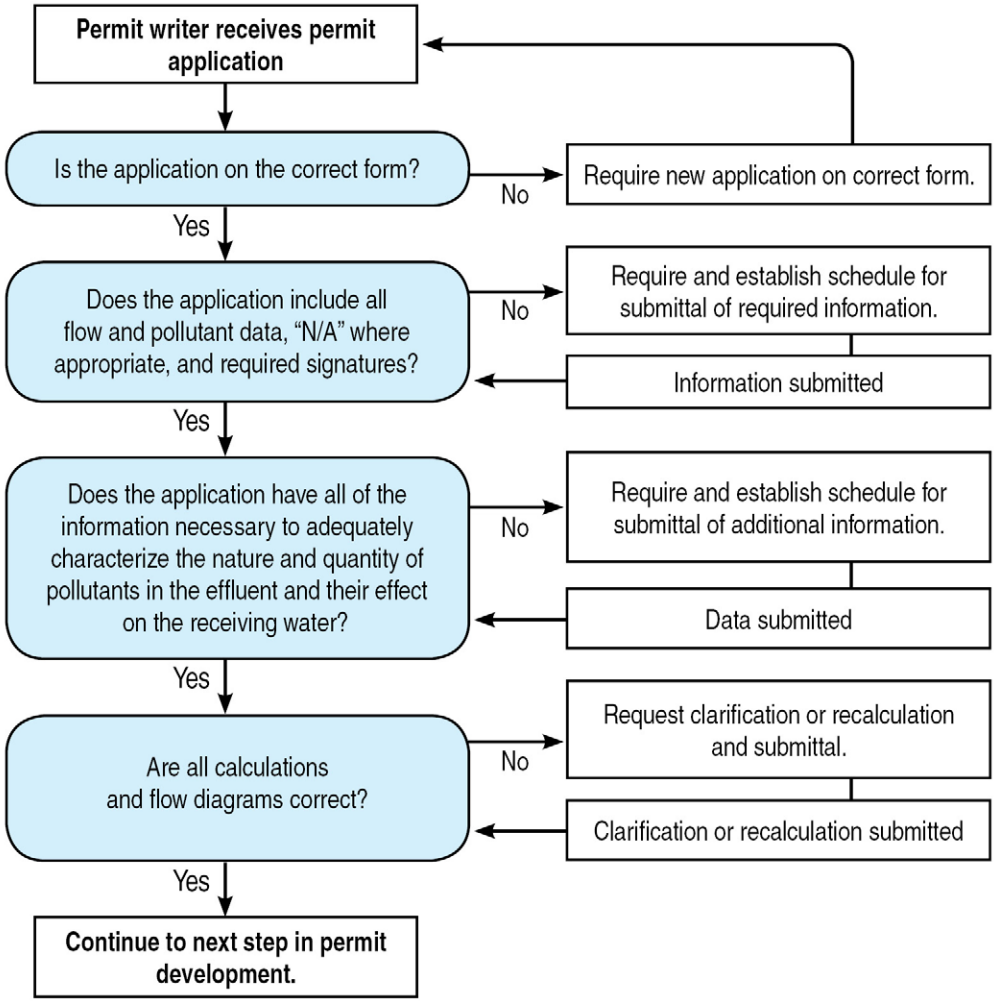
EPA has developed the Electronic NOI (eNOI) for construction sites and industrial facilities that need to apply for coverage under EPA's Construction General Permit (CGP) or Multi-Sector General Permit (MSGP), respectively. EPA's Electronic Stormwater Notice of Intent (eNOI) Website <www.epa.gov/npdes/stormwater/enoi> presents additional information about eNOI.

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4.5 Application Review

The contents of individual NPDES permits are based, in part, on the information included in the application. Thus, the application must be complete and accurate before a permit writer can properly develop a permit. Exhibit 4-4 depicts the general process for reviewing a permit application, based on a chart provided in the *Washington Department of Ecology's Permit Writers' Manual*[2].

Exhibit 4-4 Permit application review process



After the initial application review, the permit writer may request that an applicant submit other information needed to decide whether to issue a permit and for permit development. The requested information could include the following:

- Additional information, quantitative data, or recalculated data.
- Submission of a new form (if an inappropriate form was used).
- Resubmission of the application (if incomplete or outdated information was initially submitted).

In some situations, a considerable amount of correspondence might be required before the permit writer obtains all the information that he or she believes is necessary to draft the permit.

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4.5.1 The Complete Application

The regulations at § 122.21(e) state that the Director, "[must] not issue a permit before receiving a complete application..." At a minimum, the application form must have all applicable spaces filled in. Instructions for the application form state that all items must be completed and that applicants use the statement *not applicable* (N/A) to indicate that the item had been considered. Blanks on a form can occur for a number of reasons, such as the following:

- The response was inadvertently omitted.
- The applicant had difficulty determining the correct response and rather than provide misleading or incorrect information, left the space blank.
- The applicant was unwilling to provide the response.

A permit writer must obtain a response to the blank items by contacting the facility in writing or, in some cases, by telephone. Only minor changes should be handled by telephone and even minor items should be documented in writing in the permit file. Under no circumstances should a permit writer edit or modify the application, which is a legal document that has been signed and certified by the applicant. The original application, any subsequent clarifications, and any supplemental information provided by the applicant should be clearly identified in the file. The information will become part of the administrative record (§ 124.9) for the permit (see section 11.2.1 of this manual), which is critical if any legal challenges regarding permit decisions arise. If the changes or corrections to any application are extensive, the permit writer may require the permit applicant to submit a new application.

The permit writer may also require supplementary information, such as more detailed production information or maintenance and operating data for a treatment system, to process the permit. According to § 122.21(e), an application is considered complete when the permitting authority is satisfied that all required information has been submitted. Supplementary information also can be obtained later when the permit writer is actually drafting the permit. The applicant may submit additional information voluntarily or be required to do so under CWA section 308 or under a similar provision of state law.

4.5.2 Common Omissions in Applications

This section identifies some of the most common omissions and errors found in NPDES permit applications and provides examples of ways to identify missing information and verify the accuracy of certain data.

One of the most commonly omitted items from NPDES permit applications is a topographic map of the area around the discharge, which is required as an attachment to Form 1, Form 2A, and Form 2S. Other industry- or municipality-specific information is also often omitted. For example, industrial applicants sometimes fail to submit a line drawing of the water flow through the facility required by Part II-A of Form 2C. The line drawing is important for ensuring that the location and description of the outfalls and the description of processes (Parts I and II-B of Form 2C) provided by the applicant are accurate.

Sometimes applicants do not properly submit the effluent data necessary to characterize the facility. Below are some required data elements that are commonly omitted from permit applications:

- Valid whole effluent toxicity (WET) testing data, required from POTWs with design flows greater than 1 mgd or those with a pretreatment program. This requirement may be satisfied if the

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expiring permit contains a requirement for effluent characterization of WET. The permit writer should note the use of this option on the fact sheet.

- Biosolids (sewage sludge) monitoring data; a description of biosolids use and disposal procedures; annual biosolids production volumes; and information on the suitability of the site and a description of the site management for land application sites from POTWs and other TWTDS. A land application plan is required for any sites not identified in the application.
- Expected toxics and other pollutants. Non-municipal dischargers categorized as *primary industries* have some mandatory testing requirements for toxic pollutants (see § 122.21, Appendix D, Table I and Table II and also listed in Application Form 2C).
- Production rates and flow data from industrial facilities that are subject to production- or flow-based effluent guidelines. Applicants must use units of measure corresponding to applicable effluent guidelines to allow calculation of effluent limitations.
- Appropriate sample types for all required pollutants and parameters being analyzed (Part 136) (see sections 8.1.4 and 8.3 of this manual for more information). For example, only grab samples or continuous monitoring may be used for pH, total residual chlorine, and temperature, and only grab samples may be used for total phenols and volatile organics.

Exhibit 4-5 presents three examples of the types of questions that the permit writer should consider to determine whether an application is complete.

Exhibit 4-5 Considerations for an application to be complete

Example 1:

A plastics processor submits Form 1 and Form 2C but fails to indicate *testing required* for any gas chromatograph/mass spectrometer (GC/MS) fractions in section V.C. of Form 2C and does not provide any data for these pollutants.

Question:
Did the applicant provide all the required data for the toxic organic pollutants in Form 2C?

Answer:
No. The plastics processor is required to indicate *testing required* (in the check box) and provide data from at least one sample for each pollutant in the volatile GC/MS fraction (Table 2C-2 in the application form instructions and § 122.21(g)(7)(v)(A) of the NPDES regulations).

Example 2:

A soap and detergent manufacturing facility in the liquid detergents subcategory submits Form 1 and Form 2C but marks thallium and beryllium as *believed absent* in section V.C. of Form 2C and did not provide any data for these pollutants.

Question:
Is it appropriate for this applicant to mark *believed absent* in this section of Form 2C?

Answer:
No. Although an applicant that manufactures liquid detergents is not expected to discharge thallium and beryllium, page 2C-3 of the application form instructions and § 122.21(g)(7)(v)(B) require testing for all listed metals by all applicants in a primary industry category, such as soap and detergent manufacturers. The indication of *believed absent* is incorrect. The applicant should have indicated *testing required* and provided the results of at least one sample per pollutant. Occasionally, unexpected contaminants could be present in a wastestream.

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Exhibit 4-5 Considerations for an application to be complete (continued)

Example 3:
An integrated slaughterhouse and meat processing facility submits Form 1 and Form 2C and indicates that zinc is *believed absent* from its wastewater.

Question:
Is *believed absent* a proper indication for zinc for this wastewater?

Answer:
Possibly. After consulting the effluent guidelines development documents for the Meat and Poultry Products Point Source Category, the permit writer determines that metals, including zinc, are often used as feed additives and in sanitation products and might be present in the effluent, even though there are no effluent limitations specified for zinc in the applicable effluent guideline. The permit writer should contact the applicant and clarify whether zinc would be expected to be present in the discharge.

The comprehensive testing requirements that apply to the various categories of industry are designed to determine whether any contaminants (some expected, some unexpected) are present in significant quantities and to determine levels of pollutants that are known to be present. Exhibit 4-6 presents an example of how a permit writer makes the determination of pollutant data required in the application.

Exhibit 4-6 Example of required testing during application review

Consider the plastics processor and the liquid detergents manufacturer mentioned above, and answer the following questions:

Question:
What pollutant data are needed to characterize the industries above?
- For which toxic organic pollutants are they required to test?
- For which heavy metals are they required to test?
- Which metals would you expect to find in their wastewaters regardless of whether testing is required?

Answer:
The application form in Table 2C-2 and § 122.21(g)(7)(ii)(A) of the NPDES regulations require testing of the volatile GC/MS fraction by the plastics processor and the volatile, acid, and base/neutral fractions by the liquid detergent manufacturer. Page 2C-3 of the application instructions and § 122.21(g)(7)(ii)(B) require testing of all the metals listed in item V, Part C1 of the application form as well as cyanide and total phenols by both of these primary industry facilities. For information on which, if any, metals might be expected in wastewater discharged by these applicants, see the effluent guidelines development documents.

4.5.3 The Accurate Application

All information submitted on a permit application must be accurate. Although it might be difficult to detect certain inaccuracies, a number of common mistakes can be readily detected. When mistakes are detected, they must be corrected. Generally, any correction or edit to the application should be obtained from the applicant in writing and will become a part of the administrative record for the permit.

In most cases, errors in the application will be inadvertent because of the length and complexity of the form. Note, however, that the application certification statement indicates, "…that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations." If the permit writer believes that falsification has occurred, he or she should refer the findings to the agency's enforcement staff.

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Some of the most common mistakes on permit applications include failing to provide the correct long-term average and daily maximum values, reporting quantified values below known detection limits, and using misplaced decimal points or incorrect concentration units. Exhibit 4-7 presents three examples of the types of questions that the permit writer should consider while reviewing the permit application for accuracy. Additional guidance from EPA might be available to assist permit writers in reviewing applications for some of these common errors. For example, an August 23, 2007, memorandum *Analytical Methods for Mercury in National Pollutant Discharge Elimination System (NPDES) Permits*[3] <www.epa.gov/npdes/pubs/mercurymemo_analyticalmethods.pdf> describes when a method for mercury is sufficiently sensitive for purposes of permit applications and monitoring under a permit. In the memorandum, EPA strongly recommends that a permitting authority determine that a permit application that lacks effluent data analyzed with a sufficiently sensitive EPA-approved method (such as Method 1631E) is incomplete unless and until the facility supplements the original application with data analyzed with such a method.

4.6 Facility Information Review

In addition to the submitted application form, the permit writer should assemble other information that could be used to develop permit limitations and conditions.

4.6.1 Permit File Review

Before developing the draft permit and fact sheet, the permit writer should assemble and review any additional background information on the facility. If the permit writer is reissuing an existing permit, much of the information should be available in the permit file. Such information would typically include

- The current permit.
- The fact sheet or statement of basis for the current permit.
- Discharge monitoring reports (DMRs).
- Compliance inspection reports.
- Engineering reports.
- Correspondence or information on changes in plant conditions, problems, and compliance issues.

Much of this information, particularly DMR data, is stored in automated data tracking systems such as

- Permit Compliance System (PCS) or state databases.
- Integrated Compliance Information System (ICIS)-NPDES <https://icis.epa.gov>.
- Online Tracking Information System (OTIS) <www.epa.gov/idea/otis/>.
- Envirofacts Warehouse <www.epa.gov/enviro/>.

The permit writer can check with other permit writers who have permitted similar types of facilities to see if there are any special considerations related to the type of facility to be permitted. A permit writer might also wish to discuss compliance issues, changes, or history of complaints with compliance personnel who conducted previous inspections of the facility or with permit writers for other media (e.g., air, solid waste). Examples of some other sources of information that the permit writer could use for permit development include the following:

- Receiving water quality data from databases such as the EPA STOrage and RETrieval database (STORET) <www.epa.gov/STORET/>.

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Exhibit 4-7 Considerations for an application to be accurate

Example 1:

An industrial applicant provides a daily maximum effluent flow value of 50,000 gpd in its permit application Form 2C. However, a review of historical water usage records and an old permit application indicate estimated wastewater flows ranged from 100,000 to 150,000 gpd. The applicant had not instituted any water use reduction measures, significantly changed its process operations, or decreased its number of employees.

Question:
Are reported values consistent with historical information?

Answer:
No. An inspection of the facility revealed two separate water meters (one for sanitary and one for process water); the applicant had overlooked the sanitary meter. Further, the process water meter was found to be defective. Subsequent flow monitoring of the actual total wastestream recorded a flow of 125,000 gpd. A new water meter was installed, and concurrent wastestream flow monitoring and water meter readings resulted in the following water balances:

- **Water In** (based on both water meter readings):
  148,000 gpd (131,000 gpd process line and 17,000 gpd sanitary line).
- **Water Out** (based on effluent flow monitoring):
  125,000 gpd total treated effluent discharged to the receiving water.
  Evaporative and consumption losses were estimated at 23,000 gpd (15% of total water usage).

The permit writer should require the applicant to submit a signed and certified letter with the revised flow estimates and a new water balance diagram or submit a revised application.

Example 2:

An applicant reported its maximum daily flow as 1.2 mgd, the maximum daily suspended solids concentration as 23 milligrams per liter (mg/L), and the maximum daily mass discharge as 690 pounds per day (lbs/day).

Question:
Do the concentration, mass, and flow values correspond?

Discussion:
No. Even in the unlikely event that the maximum daily flow and the maximum daily concentration occurred on the same day, the mass discharged would be well below the reported value of 690 lbs/day. Using the calculation below, the mass discharge that corresponds to the solids concentration (23 mg/L) and flow (1.2 mgd) would be 230 lbs/day:

$$23 \text{ mg/L} \times 1.2 \text{ mgd} \times \underbrace{8.34 \text{ (lbs)(L)/(mg)(millions of gallons)}}_{\text{(conversion factor)}} = 230 \text{ lbs/day}$$

Because the applicant reported a maximum mass discharge of 690 lbs/day, a significant discrepancy is indicated. The permit writer should contact the applicant to resolve the discrepancy. The applicant should submit a signed and certified letter clarifying the correct maximum daily mass discharge of suspended solids or submit a revised application.

Example 3:

The results submitted in the application for total cyanide are all reported as < 1,000 micrograms per liter (µg/L). When asked, the applicant indicated that total cyanide was analyzed using EPA Method 335.3 (Color, Auto).

Question:
Do concentration values correspond with published method detection limits for the method used?

Answer:
No. EPA Method 335.3 for total cyanide has a published method detection limit (MDL) of 5 µg/L. The applicant should be able to quantify results for total cyanide at values well below 1,000 µg/L using this method. The applicant has most likely used Standard Method 4500-CN (titrimetric) for total cyanide, rather than the testing procedure indicated. If total cyanide is expected to be present in the discharge and would be of concern at effluent concentrations below 1,000 µg/L, the permit writer should require the applicant to retest for total cyanide using the more sensitive method and to submit the results in a signed, certified letter.

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- Supporting documentation collected by EPA for effluent guidelines and categorical pretreatment standards for a variety of industrial categories.
- Reference textbooks and technical documents that provide information about manufacturing processes and wastestreams for specific industry categories, which are available from libraries such as
  - National Technical Information Service (NTIS) <www.ntis.gov>.
  - EPA libraries <www.epa.gov/natlibra/libraries.htm>.
  - Office of Water Resource Center (OWRC) <www.epa.gov/safewater/resource/>.
  - National Service Center for Environmental Publications (NSCEP) <www.epa.gov/ncepihom/>.
- Related environmental permits that could provide site-specific background information about the types of pollutants and wastestreams at a facility, including, for example
  - RCRA permits, which regulate the management of hazardous waste by owners and operators of treatment, storage, and disposal facilities.
  - Clean Air Act permits, which regulate the discharge of atmospheric pollutants.
- EPA's *Treatability Manual*[4], which is a five-volume guidance manual that provides detailed descriptions of industrial processes, potential pollutants from each process, appropriate treatment technologies, and cost estimating procedures.
- The Toxic Release Inventory (TRI) <www.epa.gov/tri/>, which is accessible on EPA's mainframe and through a public online service. The TRI contains information on more than 300 listed toxic chemicals released by specific facilities, including chemical identification, quantity of chemicals released to various environmental media, off-site waste transfer, and waste treatment and minimization information.

If the permit writer must address special conditions in a permit for a municipal discharger to develop or implement a pretreatment program or to address discharges other than the wastewater treatment plant discharge, he or she should obtain the information needed to develop these special conditions. For example, the permit writer might need information on pretreatment program implementation, combined sewer overflows (CSOs), sanitary sewer overflows (SSOs), sewage sludge use or disposal, or stormwater discharges relevant to the facility. Such information is in

- Annual pretreatment reports, pretreatment compliance inspections and audits.
- CSO reports.
- Bypass notifications or SSO reports.
- Stormwater discharge applications or NOIs for a general permit.

4.6.2 Facility Site Visits

Facility site visits are an invaluable way to update information on manufacturing processes; obtain information about the facility's operations, equipment or management; and verify application information. A site visit also acquaints the permit writer with the people who will be operating under the permit and participating in the permit development process.

Site visits can also allow the permit writer to gain a better understanding of more complex facilities. Site visits are especially warranted if significant pollution control or treatment improvements will be required, if there have been frequent problems in complying with the existing permit, if there are known problems

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with spills or leaks or with contaminated surface runoff, or if there are other unique on-site activities that could affect the characteristics of the discharge from the facility.

The site visit should include a detailed review of production processes to evaluate the types of toxic or hazardous substances that might be present in raw materials, products, and by-products. The permit writer should review the water uses, the resulting wastewater streams, and any in-process pollution controls. This review is needed to assist in selecting toxic and other pollutants to be limited and in evaluating possible in-process control improvements.

In addition, the site visit should include a review of the performance and operation and maintenance practices of wastewater treatment facilities. The review is useful in evaluating the adequacy of existing treatment performance and assessing the feasibility of improvements in performance. The permit writer should examine effluent monitoring points, sampling methods, and analytical techniques to identify any needed changes to monitoring requirements and to evaluate the quality of DMR data.

Raw material and product storage and loading areas, sludge storage and disposal areas, hazardous waste management facilities, including on-site disposal areas, and all process areas should be observed to determine the need for controls on surface runoff and specific BMPs. Information from other environmental programs (e.g., CERCLA or RCRA) might be important in this regard.

While on-site, the permit writer should note any housekeeping problems or the need for spill prevention actions, which are not usually detectable from permit applications. If allowed, photographs of problem areas should be taken for future use during permit preparation. If necessary, the permit writer should meet with management to ask questions or clarify information provided on the permit application. If any inaccuracies in the application were found because of the site visit, that is the time for the permit writer to request corrected information.

The time required to conduct a site visit will vary according to the complexity of the facility. For facilities with only a few basic processes, one main waste treatment system, limited in-process controls, few surface runoff outfalls, and limited on-site management of sludge or hazardous wastes, an adequate site visit can most likely be completed in one day. Visits to complex, larger plants with several treatment systems, numerous outfalls, and extensive ancillary activities may require several days.

Time spent on site visits often results in time savings during permit preparation. However, time and travel resources might not be adequate to allow visits to all facilities to be permitted. In such cases, the permit writer might be able to obtain much of the desired information from facility compliance inspections and should try to coordinate the timing of compliance inspections with the timing of permit development.

Aerial photographs may provide much of the needed information on the potential for contamination of surface runoff and on ancillary activities without a site visit or inspection. In addition, comparing aerial photographs with site and process diagrams provided with the application can provide the permit writer with a complete visual description of the facility. Aerial photographs are available from a variety of sources, including the U.S. Geological Survey Earth Resources Observation and Science Center <eros.usgs.gov/#/Find_Data>; TerraServer <www.terraserver.com>; Google Earth <earth.google.com>; and other private contractors.

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4.7 Confidential Information

In accordance with Part 2, information submitted to EPA pursuant to the NPDES permitting regulations under Part 122 may be claimed as confidential; however, EPA has determined that the following information will not be held confidential (§ 122.7):

- Name and address of the applicant.
- Permit applications and information submitted with applications.
- Permits.
- Effluent data.

Information that may be claimed as confidential includes material related to manufacturing processes unique to the applicant, or information that might adversely affect the competitive position of the applicant if released to the public. Under such circumstances, the permit writer will be required to treat the information as confidential in accordance with the requirements in Part 2. Any claims of confidentiality must be made at the time of submission or the information will not be considered confidential.

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[1] U.S. Environmental Protection Agency. 1991. *Guidance Manual For the Preparation of NPDES Permit Applications For Stormwater Discharges Associated With Industrial Activity.* EPA-505/8-91-002. U.S. Environmental Protection Agency, Office of Water, Washington DC, <www.epa.gov/npdes/pubs/owm0241.pdf>.

[2] Bailey, Gary. 2008. *Water Quality Program Permit Writer's Manual*. Publication Number 92-109. Washington State Department of Ecology, Water Quality Program, Olympia, WA. <www.ecy.wa.gov/pubs/92109.pdf>

[3] Hanlon, James A. 2007. *Analytical Methods for Mercury in National Pollutant Discharge Elimination System (NPDES) Permits.* U.S. Environmental Protection Agency, Office of Wastewater Management. Memorandum, August 23, 2007. <www.epa.gov/npdes/pubs/mercurymemo_analyticalmethods.pdf>.

[4] U.S. Environmental Protection Agency. 1980. *Treatability Manual: Vol. I. Treatability Data* (EPA-600/8-80-042a) publications available on NEPIS Website <www.epa.gov/nscep/> as document 600880042A*; Vol. II. Industrial Descriptions* (EPA-600/8-80-042b) as document 600880024B*; Vol. III. Technologies* (EPA-600/8-80-042c) as document 600880024C*; Vol. IV. Cost Estimating* (EPA-600/8-80-042d) as document 600880042d; *Vol. V. Summary* (EPA-600/8-80-042e) as document 600880024E. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.

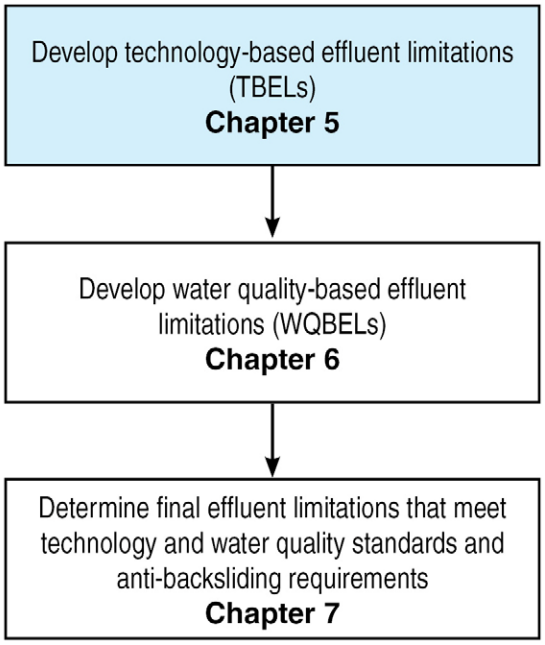
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CHAPTER 5. Technology-Based Effluent Limitations

One of the major strategies of the Clean Water Act (CWA) in making "reasonable further progress toward the national goal of eliminating the discharge of all pollutants" is to require effluent limitations based on the capabilities of the technologies available to control those discharges. Technology-based effluent limitations (TBELs) aim to prevent pollution by requiring a minimum level of effluent quality that is attainable using demonstrated technologies for reducing discharges of pollutants or pollution into the waters of the United States. TBELs are developed independently of the potential impact of a discharge on the receiving water, which is addressed through water quality standards and water quality-based effluent limitations (WQBELs). The NPDES regulations at Title 40 of the *Code of Federal Regulations* (CFR) 125.3(a) require NPDES permit writers to develop technology-based treatment requirements, consistent with CWA section 301(b), that represent the minimum level of control that must be imposed in a permit. The regulation also indicates that permit writers must include in permits additional or more stringent effluent limitations and conditions, including those necessary to protect water quality. As described in Chapter 7 of this manual, the permit writer might also need to apply anti-backsliding requirements to determine the final effluent limitations for the NPDES permit.

This chapter discusses development of TBELs for publicly owned treatment works (POTWs) and industrial (non-POTW) dischargers. Chapter 6 discusses development of WQBELs. Exhibit 5-1 illustrates the relationship between TBELs and WQBELs in an NPDES permit and the determination of final effluent limitations.

Exhibit 5-1 Developing effluent limitations



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5.1 Technology-based Effluent Limitations for POTWs

The largest category of dischargers requiring individual NPDES permits is POTWs. The federal regulations at § 403.3(q) define a POTW as a treatment works (as defined in CWA section 212) that is owned by a state or municipality [as defined in CWA section 502(4)]. Under § 403.3(q), that definition includes "any devices and systems used in the storage, treatment, recycling and reclamation of municipal sewage or industrial wastes of a liquid nature." The definition also includes "sewers, pipes, and other conveyances only if they convey wastewater to a POTW Treatment Plant," as defined in § 403.3(r). Under § 403.3(q), the term POTW "also means the municipality as defined in section 502(4) of the Act, which has jurisdiction over the Indirect Discharges to and the discharges from such a treatment works."

CWA section 304(d) required the U.S. Environmental Protection Agency (EPA) to publish information on the degree of effluent reduction attainable through the application of secondary treatment. Under CWA section 301(b)(1)(B), in general, POTWs in existence on July 1, 1977, were required to meet discharge limitations based on secondary treatment (or any more stringent limitations established under state law, including those necessary to meet state water quality standards). On the basis of those statutory provisions, EPA developed secondary treatment regulations, which are specified in Part 133. Later amendments to CWA section 304(d) called for EPA to develop alternative standards for certain types of POTWs. Those standards are referred to as "equivalent to secondary treatment" standards.

5.1.1 Secondary and Equivalent to Secondary Treatment Standards

Several regulations implement the statutory requirements for developing standards and discharge limitations based on secondary treatment. EPA has promulgated regulations in Part 133 establishing secondary treatment standards, equivalent to secondary treatment standards, and a number of special considerations applied on a case-by-case basis. In addition, § 122.44(a)(1) requires that NPDES permits include applicable technology-based limitations and standards, while regulations at § 125.3(a)(1) state that TBELs for POTWs must be based on secondary treatment standards (which includes the "equivalent to secondary treatment standards") specified in Part 133.

5.1.1.1 Secondary Treatment Standards

In Part 133, EPA published secondary treatment standards based on an evaluation of performance data for POTWs practicing a combination of physical and biological treatment to remove biodegradable organics and suspended solids. The regulation applies to all POTWs and identifies the technology-based performance standards achievable based on secondary treatment for 5-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), and pH. Exhibit 5-2 summarizes the standards.

Exhibit 5-2 Secondary treatment standards

Parameter	30-day average	7-day average
BOD_5	30 mg/L (or 25 mg/L $CBOD_5$)	45 mg/L (or 40 mg/L $CBOD_5$)
TSS	30 mg/L	45 mg/L
BOD_5 and TSS removal (concentration)	not less than 85%	--
pH	within the limits of 6.0–9.0*	

* unless the POTW demonstrates that: (1) inorganic chemicals are not added to the waste stream as part of the treatment process; and (2) contributions from industrial sources do not cause the pH of the effluent to be less than 6.0 or greater than 9.0

mg/L = milligrams per liter

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The regulation also includes an alternate set of standards that apply to certain facilities employing waste stabilization ponds or trickling filters as the principal process. Those standards are called equivalent to secondary treatment standards.

5.1.1.2 Equivalent to Secondary Treatment

Some biological treatment technologies, such as trickling filters or waste stabilization ponds, are capable of achieving significant reductions in BOD_5 and TSS but might not consistently achieve the secondary treatment standards for these parameters. Congress recognized that unless alternate limitations were set for facilities with trickling filters or waste stabilization ponds, which often are in small communities, such facilities could be required to construct costly new treatment systems to meet the secondary treatment standards even though their existing treatment technologies could achieve significant biological treatment. To prevent requiring upgrades where facilities were achieving their original design performance levels, Congress included provisions in the 1981 amendments to the Clean Water Act Construction Grants program (*Public Law 97-117, Section 23*) that required EPA to make allowances for alternative biological treatment technologies, such as a trickling filters or waste stabilization ponds. In response to that requirement, in 1984, EPA promulgated regulations at § 133.105 that include alternative standards that apply to facilities using "equivalent to secondary treatment." A facility must meet the criteria in § 133.101(g) to qualify for application of those alternative standards.

Equivalent to Secondary Standards

The equivalent to secondary treatment standards, as specified in § 133.105, are shown in Exhibit 5-3.

Exhibit 5-3 Equivalent to secondary treatment standards

Parameter	30-day average	7-day average
BOD_5	not to exceed 45 mg/L (or not to exceed 40 mg/L $CBOD_5$)	not to exceed 65 mg/L (or not to exceed 60 mg/L $CBOD_5$)
TSS	not to exceed 45 mg/L	not to exceed 65 mg/L
BOD_5 and TSS removal (concentration)	not less than 65%	--
pH	within the limits of 6.0–9.0*	

* unless the POTW demonstrates that: (1) inorganic chemicals are not added to the waste stream as part of the treatment process; and (2) contributions from industrial sources do not cause the pH of the effluent to be less than 6.0 or greater than 9.0

Criteria to Qualify for Equivalent to Secondary Standards

To be eligible for discharge limitations based on equivalent to secondary standards, a POTW must meet all three of the following criteria:

Criterion #1—Consistently Exceeds Secondary Treatment Standards: The first criterion that must be satisfied to qualify for the equivalent to secondary standards is demonstrating that the BOD_5 and TSS effluent concentrations consistently achievable through proper operation and maintenance of the treatment works exceed the secondary treatment standards set forth in §§ 133.102(a) and (b). The regulations at § 133.101(f) define "effluent concentrations consistently achievable through proper operation and maintenance" as

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- (f)(1): For a given pollutant parameter, the 95th percentile value for the 30-day average effluent quality achieved by a treatment works in a period of at least 2 years, excluding values attributable to upsets, bypasses, operational errors, or other unusual conditions.
- (f)(2): A 7-day average value equal to 1.5 times the value derived under paragraph (f)(1).

Some facilities might meet this criterion only for the BOD_5 limitations or only for the TSS limitations. EPA believes that it is acceptable for the permit writer to adjust the limitations for only one parameter (BOD_5 or TSS) if the effluent concentration of only one of the parameters is demonstrated to consistently exceed the secondary treatment standards.

Criterion #2—Principal Treatment Process: The second criterion that a facility must meet to be eligible for equivalent to secondary standards is that its principal treatment process must be a trickling filter or waste stabilization pond (i.e., the largest percentage of BOD and TSS removal is from a trickling filter or waste stabilization pond system).

Criterion #3—Provides Significant Biological Treatment: The third criterion for applying equivalent to secondary standards is that the treatment works provides significant biological treatment of municipal wastewater. The regulations at § 133.101(k) define *significant biological treatment* as using an aerobic or anaerobic biological treatment process in a treatment works to consistently achieve a 30-day average of at least 65 percent removal of BOD_5.

A permit writer should consider each facility on a case-by-case basis to determine whether it meets those three criteria. To apply the criteria, the permit writer should assemble enough influent, effluent, and flow data from the facility to adequately characterize the facility's performance or require the discharger to provide an appropriate analysis. If the facility has made substantial changes in its operations or treatment processes during the current permit term, the permit writer, using his or her best professional judgment (BPJ), may elect to use data for a period that is representative of the discharge at the time the permit is being drafted. Facilities that do not meet all three criteria do not qualify as equivalent to secondary treatment facilities. For such facilities, the secondary treatment standards apply. EPA noted in its December 1985 *Draft Guidance for NPDES Permits and Compliance Personnel—Secondary Treatment Redefinition*[1] that a treatment works operating beyond its design hydraulic or organic loading limit is not eligible for application of equivalent to secondary standards. If overloading or structural failure is causing poor performance, the solution to the problem is construction, not effluent limitations adjustment.

5.1.2 Adjustments to Equivalent to Secondary Standards

In addition to providing secondary treatment standards and equivalent to secondary treatment standards, the federal regulations allow states to make adjustments to the standards and to apply those adjusted standards on a case-by-case basis.

5.1.2.1 Adjusted TSS Requirements for Waste Stabilization Ponds

In accordance with regulations adopted by EPA in 1977 and revised in 1984, states can adjust the maximum allowable TSS concentration for waste stabilization ponds upward from those specified in the equivalent to secondary treatment standards to conform to TSS concentrations achievable with waste stabilization ponds. The regulation, found at § 133.103(c), defines "SS concentrations achievable with waste stabilization ponds" as the effluent concentration achieved 90 percent of the time within a state or

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appropriate contiguous geographical area by waste stabilization ponds that are achieving the levels of effluent quality for BOD_5 specified in § 133.105(a)(1) (45 milligrams per liter [mg/L] as a 30-day average). To qualify for an adjustment up to as high as the maximum concentration allowed, a facility must use a waste stabilization pond as its principal process for secondary treatment and its operations and maintenance data must indicate that it cannot achieve the equivalent to secondary standards. EPA has published approved alternate TSS requirements in 49 *Federal Register* (FR) 37005, September 20, 1984. Exhibit 5-4 is a summary from the FR notice of the adjusted TSS requirements for each state.

Exhibit 5-4 State-specific adjusted TSS requirements*

Location	Alternate TSS limitation (30-day average) (mg/L)	Location	Alternate TSS limitation (30-day average) (mg/L)
Alabama	90	Nebraska	80
Alaska	70	North Carolina	90
Arizona	90	North Dakota	
Arkansas	90	• North and east of Missouri R.	60
California	95	• South and west of Missouri R.	100
Colorado		Nevada	90
• Aerated ponds	75	New Hampshire	45
• All others	105	New Jersey	None
Connecticut	None	New Mexico	90
Delaware	None	New York	70
District of Columbia	None	Ohio	65
Florida	None	Oklahoma	90
Georgia	90	Oregon	
Guam	None	• East of Cascade Mountains	85
Hawaii	None	• West of Cascade Mountains	50
Idaho	None	Pennsylvania	None
Illinois	37	Puerto Rico	None
Indiana	70	Rhode Island	45
Iowa		South Carolina	90
• Controlled discharge, 3 cell	Case-by-case but not greater than 80	South Dakota	120
• All others	80	Tennessee	100
Kansas	80	Texas	90
Kentucky	None	Utah	None
Louisiana	90	Vermont	55
Maine	45	Virginia	
Maryland	90	• East of Blue Ridge Mountains	60
Massachusetts	None	• West of Blue Ridge Mountains	78
Michigan: Controlled seasonal discharge		• East slope counties: Loudoun, Fauquier, Rappahannock, Madison, Green, Albemarle, Nelson, Amherst, Bedford, Franklin, Patrick.	Case-by-case application of 60/78 limits
• Summer	70	Virgin Islands	None
• Winter	40	Washington	75
Minnesota	40	West Virginia	80
Mississippi	None	Wisconsin	80
Missouri	80	Wyoming	100
Montana	100	Trust Territories and N. Marianas	None

* (49 FR 37005, September 20, 1984)

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5.1.2.2 Alternative State Requirements (ASRs)

To further address the potential variations in facility performance arising from geographic, weather, or seasonal conditions in different states, the revised secondary treatment regulations (adopted in 1984) also included provisions in § 133.105(d) for ASRs. The ASR provisions give states flexibility to modify the maximum allowable concentrations of both BOD_5 and TSS for trickling filter facilities and for BOD_5 for waste stabilization pond facilities. ASRs are set at levels consistently achievable through proper operation and maintenance [§ 133.101(f)] by the median facility in a representative sample of facilities within a state or appropriate continuous geographical area that meet the definition of facilities eligible for treatment equivalent to secondary treatment. Qualifying facilities are eligible to receive limitations up to the concentrations specified by the ASRs.

5.1.3 Applying Secondary Treatment Standards, Equivalent to Secondary Treatment Standards, and Adjusted Standards

Determining whether secondary treatment standards or equivalent to secondary standards apply to a POTW and determining the specific discharge limitations for the facility based on either set of standards and any other special considerations that might apply can be a complex process. Permit writers should remember that compliance with limitations must be measurable and percent removal limitations require influent monitoring (for more on establishing monitoring conditions, see section 8.1 of this manual). This section presents a step-by-step procedure to establishing technology-based effluent limitations for POTWs as shown in Exhibit 5-5.

Exhibit 5-5 Steps to establish technology-based discharge limitations for POTWs

Step 1.	Determine whether secondary treatment standards or equivalent to secondary treatment standards or adjusted standards apply
Step 2.	Calculate effluent limitations based on secondary treatment standards or
Step 3.	Calculate effluent limitations based on equivalent to secondary standards or
Step 4.	Calculate effluent limitations based on adjusted standards
Step 5.	Apply special considerations for further adjustments
Step 6.	Document the application of secondary or equivalent to secondary treatment standards or adjusted standards and all special considerations in the fact sheet

5.1.3.1 Step 1: Determine Whether Secondary Treatment Standards or Equivalent to Secondary Treatment Standards or Adjusted Standards Apply

The first step for permit writers to develop TBELs for municipal dischargers is to determine whether secondary treatment standards (discussed in section 5.1.1 above), equivalent to secondary standards (discussed in section 5.1.1.2 above), or some adjustments to the equivalent to secondary standards (discussed in section 5.1.2 above) apply to the POTW.

An important consideration for permitting authorities is how to treat new POTW discharges that use a waste stabilization pond or trickling filter, or a combination of the two. New facilities or new discharges from trickling filters or waste stabilization ponds often are capable of achieving secondary treatment standards. In the preamble to the secondary treatment regulation (49 FR 37002, September 20, 1984) and in § 133.105(f)(2), EPA noted that when developing permits for new trickling filter and waste

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stabilization pond facilities, permitting authorities should consider the ultimate design capability of the treatment process, geographical and weather conditions, and the performance capabilities of recently constructed facilities in similar situations.

After determining whether secondary treatment standards or equivalent to secondary treatment standards apply to a facility or a discharge, the permit writer applies the appropriate standards to develop effluent limitations. Section 5.1.3.2 below (Step 2) details development of effluent limitations for facilities or discharges where secondary treatment standards apply; section 5.1.3.3 below (Step 3) details development of limitations for facilities that qualify for equivalent to secondary standards; and section 5.1.3.4 below (Step 4) details development of limitations for facilities where adjusted standards apply. It is possible that a facility with multiple biological treatment processes could have limitations based on a combination of the standards (see section 5.1.3.5 below [Step 5]); therefore, those sections are presented as separate steps.

5.1.3.2 Step 2: Calculate Effluent Limitations Based on Secondary Treatment Standards

If the facility being permitted is subject to the secondary treatment standards, the permit writer should complete Step 2. Otherwise, he or she should move to Step 3 in section 5.1.3.3 below.

Applying the secondary treatment standards in NPDES permits is straightforward. Where secondary treatment standards apply, the permit should include effluent limitations in the permit as presented in Exhibit 5-6 below, consistent with the secondary treatment standards and the regulatory requirements in § 122.45(d)(2).

Exhibit 5-6 Effluent limitations calculated from secondary treatment standards

Parameter	Average monthly limitation	Average weekly limitation
BOD_5	30 mg/L (or 25 mg/L $CBOD_5$)	45 mg/L (or 40 mg/L $CBOD_5$)
TSS	30 mg/L	45 mg/L
BOD_5 and TSS removal (concentration)	not less than 85%	N/A
pH	Within the range of 6.0–9.0 standard units at all times (or expressed as instantaneous minimum and maximum limitations)*	

* unless the POTW demonstrates that: (1) inorganic chemicals are not added to the waste stream as part of the treatment process; and (2) contributions from industrial sources do not cause the pH of the effluent to be less than 6.0 or greater than 9.0

Certain provisions in the EPA regulations warrant some clarification.

First, the secondary treatment standards are stated as 30-day and 7-day averages, whereas § 122.45(d)(2) requires that effluent limitations for POTWs be expressed, unless impracticable, as average monthly and average weekly limitations. The NPDES regulations in § 122.2 define average monthly and average weekly limitations on a calendar period basis. Therefore, EPA recommends that permit writers apply the 30-day and 7-day average secondary treatment standards directly as average monthly (calendar month) and average weekly (calendar week) discharge limitations.

Second, § 122.45(f)(1) requires that all permit limitations, standards, or prohibitions be expressed in terms of mass except in any of the following cases:

- For pH, temperature, radiation or other pollutants that cannot appropriately be expressed by mass limitations.

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- When applicable standards and limitations are expressed in terms of other units of measure.
- If in establishing permit limitations on a case-by-case basis under § 125.3, limitations expressed in terms of mass are infeasible because the mass of the pollutant discharged cannot be related to a measure of operation, and permit conditions ensure that dilution will not be used as a substitute for treatment.

The first condition applies to pH requirements established by secondary treatment standards. In addition, because the 30-day and 7-day average requirements for BOD_5 and TSS, including percent removal, are expressed in terms of concentration, the second condition applies to the standards. Thus, mass-based discharge limitations are not specifically required to implement secondary treatment standards; however, permit writers can choose to include mass-based limitations in a permit. In general, regulations at § 122.45(b)(1) require using the design flow rate of the POTW to calculate limitations. To calculate a mass-based limitation for a POTW (in pounds per day [lbs/day]) a permit writer would use the equation and follow the example calculations in Exhibit 5-7.

Exhibit 5-7 POTW mass based limitation calculation equation and example calculations

POTW design flow in million gallons per day (mgd)	x	**Concentration-based limitation** in milligrams per liter (mg/L)	x	**Conversion factor** 8.34 with units of (lbs)(L) / (mg)(millions of gallons)

A POTW with a design flow of 2.0 mgd would have mass-based limitations calculated from secondary treatment standards as follows:

Mass-based limitation*	=	**POTW design flow** x **Concentration-based limitation** x **Conversion factor**		
BOD_5				
Average monthly	=	2.0 mgd x 30 mg/L x 8.34 (lbs)(L) / (mg)(millions of gallons)	=	**500 lbs/day**
Average weekly	=	2.0 mgd x 45 mg/L x 8.34 (lbs)(L) / (mg)(millions of gallons)	=	**750 lbs/day**
TSS				
Average monthly	=	2.0 mgd x 30mg/L x 8.34 (lbs)(L) / (mg)(millions of gallons)	=	**500 lbs/day**
Average weekly	=	2.0 mgd x 45mg/L x 8.34 (lbs)(L) / (mg)(millions of gallons)	=	**750 lbs/day**

* calculated to 2 significant figures

5.1.3.3 Step 3: Calculate Effluent Limitations Based on Equivalent to Secondary Standards

If a facility being permitted is subject to the equivalent to secondary standards without any further adjustments by the state (e.g., ASRs), the permit writer should complete Step 3. Otherwise, he or she should move to Step 4 in section 5.1.3.4 below.

For facilities that qualify for equivalent to secondary standards, effluent limitations must meet the requirements specified in § 133.105 and summarized above in Exhibit 5-3 (not accounting for any further approved adjustments). It is important to note that the equivalent to secondary standards specify the maximum allowable discharge concentration of BOD_5 and TSS and a minimum percent removal requirement for qualified facilities. The regulations at § 133.105(f) require a permitting authority to include more stringent limitations when it determines that the 30-day average and 7-day average BOD_5 and TSS concentrations are achievable through proper operation and maintenance of the treatment works

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(based on an analysis of the past performance for an existing facility or considering the design capability of the treatment process and geographical and weather conditions for a new facility) would enable the treatment works to achieve more stringent limitations than the least stringent effluent quality allowed by the equivalent to secondary standards. As noted above, the regulations at § 133.101(f) define, "effluent concentrations consistently achievable through proper operation and maintenance" as the 95th percentile value for the 30-day average effluent quality achieved by a treatment works in a period of at least 2 years, excluding values attributable to upsets, bypasses, operational errors, or other unusual conditions. The 7-day average value is set equal to 1.5 times the 30-day average value.

If an existing facility does not have sufficient data to establish past performance, the permit writer could include the limitations from the previous permit in the new permit and require monitoring to generate the necessary data. In addition, the permit writer could choose to include a provision allowing the permitting authority to reopen and, if necessary, modify the permit after reviewing the additional data collected by the discharger.

As with limitations based on secondary treatment standards (shown in Exhibit 5-6 above), limitations based on equivalent to secondary standards are expressed as average monthly (calendar month) and average weekly (calendar week) limitations. Mass-based limitations can be calculated using the procedures outlined above.

5.1.3.4 Step 4: Calculate Effluent Limitations Based on Adjusted Standards

If a facility being permitted is subject to the adjusted standards as described in section 5.1.2 above, the permit writer should complete Step 4. Otherwise, he or she should move to section 5.1.3.5 below (Step 5).

As discussed in sections 5.1.2.1 and 5.1.2.2 above, the federal regulations at § 133.103(c) allow states to adjust the maximum allowable discharge concentration of TSS for waste stabilization ponds upward from what would otherwise be required by the equivalent to secondary standards, and the regulations at § 133.105(d) give states flexibility to adopt ASRs that modify equivalent to secondary requirements for both BOD_5 and TSS for trickling filter facilities and BOD_5 requirements for waste stabilization pond facilities. Where one or more of the adjusted standards apply, average monthly limitation(s) generally should be set at the lower of the following:

- The 30-day average concentration of the pollutant that could be achievable through proper operation and maintenance of the treatment works.
- The maximum concentration of the pollutant that would be allowed under the adjusted standard.

Permit writers should note, however, that if the state has developed an adjusted TSS standard for waste stabilization ponds consistent with § 133.103(c), the regulations would allow uniform application of that standard to POTWs where waste stabilization ponds are the principal process used for secondary treatment and operation and maintenance data indicate that the equivalent to secondary treatment standards for TSS cannot be achieved.

The average weekly limitation can be set equal to 1.5 times the average monthly limitation and mass-based limitations may be calculated using the procedures outlined above.

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5.1.3.5 Step 5: Apply Special Considerations for Further Adjustments

Part 133 allows a permit writer to make further adjustments when calculating effluent limitations derived from secondary treatment standards or equivalent to secondary standards based on several special considerations. The permit writer should determine whether any of the special considerations outlined in this section apply and, as appropriate, make any further adjustments to the concentration limitations or percent removal requirements. The calculated limitations, after making such adjustments, are the final technology-based effluent limitations for the POTW.

Substitution of $CBOD_5$ for BOD_5

Wastewater contains carbonaceous oxygen demanding substances and nitrogenous oxygen demanding substances. A $CBOD_5$ test measures the 5-day carbonaceous biochemical oxygen demand while the BOD_5 test measures the both carbonaceous biochemical oxygen demand and nitrogenous biochemical oxygen demand. During nitrification, nitrifying bacteria use a large amount of oxygen to consume nitrogenous oxygen demanding substances (unoxidized nitrogen and ammonia-nitrogen) and convert these to oxidized nitrate. For wastewaters with significant nitrogen content, basing permit limitations on $CBOD_5$ instead of BOD_5 eliminates the impact of nitrification on discharge limitations and compliance determinations. EPA recognizes that the $CBOD_5$ test can provide accurate information on treatment plant performance in many cases and, in Part 133, allows permit writers to use $CBOD_5$ limitations in place of BOD_5 limitations to minimize false indications of poor facility performance as a result of nitrogenous oxygen demand.

EPA has established $CBOD_5$ standards for cases where secondary treatment standards or equivalent to secondary treatment standards are applied:

- **Secondary Treatment:** The $CBOD_5$ secondary treatment performance standards specified by the regulations are as follows:
  - 25 mg/L as a 30-day average.
  - 40 mg/L as a 7-day average.
- The EPA-approved test procedures in Part 136 include a $CBOD_5$ (nitrogen inhibited) test procedure. Subject to any state-specific requirements, a permit writer can specify these $CBOD_5$ limitations along with $CBOD_5$ monitoring requirements in any POTW permit requiring performance based on secondary treatment standards [§ 133.102(a)(4)].
- **Equivalent to Secondary Treatment:** The $CBOD_5$ equivalent to secondary treatment performance standards specified by the regulations are as follows:
  - No greater than 40 mg/L as a 30-day average.
  - No greater than 60 mg/L as a 7-day average.
- Where data are available to establish $CBOD_5$ limitations, and subject to any state-specific requirements, a permit writer may substitute $CBOD_5$ for BOD_5 and specify $CBOD_5$ limitations and monitoring requirements when applying equivalent to secondary standards.

Substitution of COD or TOC for BOD_5

Chemical oxygen demand (COD) and total organic carbon (TOC) laboratory tests can provide an accurate measure of the organic content of wastewater in a shorter time frame than a BOD_5 test (i.e., several hours versus five days). The regulations at § 133.104(b) allow a permit writer to set limitations for COD or TOC instead of BOD_5 if a long-term BOD_5:COD or BOD_5:TOC correlation has been demonstrated.

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Adjustments for Industrial Contributions

Under § 133.103(b), treatment works receiving wastes from industrial categories with effluent limitations guidelines and standards (effluent guidelines) requirements or new source performance standards for BOD_5 or TSS, which are less stringent than the secondary treatment standards or, if applicable, the equivalent to secondary treatment standards in Part 133, can qualify to have their 30-day BOD_5 or TSS limitations adjusted upward provided that the following are true:

- The adjusted 30-day limitations are not greater than the limitations in effluent guidelines or new source performance standards, as applicable, for the industrial category.
- The flow or loading of BOD_5 or TSS introduced by the industrial category exceeds 10 percent of the design flow or loading to the POTW.

When making this adjustment, the Part 133 values for BOD_5 and TSS should be adjusted proportionately. Accordingly, a permit writer should make the adjustment using a flow-weighted or loading-weighted average of the two concentration limitations (i.e., the limitations developed from effluent guidelines for the industrial facility and the secondary or equivalent to secondary limitations).

Adjustments to Percent Removal Requirements

The 85 percent removal requirement (for a 30-day average) in secondary treatment standards was originally established to achieve two basic objectives:

- To encourage municipalities to remove high quantities of infiltration and inflow (I/I) from their sanitary sewer systems.
- To prevent intentional dilution of influent wastewater.

In facilities with dilute influent that is not attributable to high quantities of I/I or intentional dilution, the percent removal requirement could result in forcing *advanced treatment* rather than the intended secondary treatment. Advanced treatment generally refers to treatment processes following secondary treatment (e.g., filtration, chemical addition, or two-stage biological treatment). Advanced treatment can achieve significantly greater pollutant removals than secondary treatment processes but at a higher cost.

The regulations at §§ 133.103(a), (d) and (e) provide that, under certain circumstances, permit writers may set less stringent limitations for BOD_5 and TSS percent removal. The specific circumstances and the potential adjustments to the percent removal requirement are as follows:

- **Treatment works that receive less concentrated wastes from combined sewer systems** are eligible to have less stringent monthly percent removal limitations during wet-weather events [§ 133.103 (a)] and, under certain conditions, less stringent percent removal requirements or a mass loading limitation instead of a percent removal requirement during dry weather [§ 133.103 (e)]. The permit writer must determine on a case-by-case basis whether any attainable percentage removal level can be defined during wet weather and, if so, what the level should be. To qualify for a less stringent percent removal requirement or substitution of a mass limitation during dry weather, the discharger must satisfactorily demonstrate the following:

  1. The facility is consistently meeting, or will consistently meet, its permit effluent concentration limitations, but cannot meet its percent removal limitations because of less concentrated influent. A permitting authority should consider establishing criteria for

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documenting what constitutes consistently meeting concentration limitations and what constitutes being unable to meet percent removal limitations because of less concentrated influent.

2. To meet the percent removal requirements, the facility would have to achieve significantly more stringent effluent concentrations than would otherwise be required by the concentration-based standards. Each permitting authority also should consider establishing criteria for demonstrating that this condition is met (e.g., because of dilute influent, X percent of the time a discharger would be forced to meet concentration requirements that are X percent more stringent than the concentration limitations otherwise applicable to satisfy the percent removal requirements).

3. The less concentrated influent wastewater does not result from either excessive infiltration or clear water industrial discharges during dry weather periods. The determination of whether the less concentrated wastewater results from excessive infiltration is discussed in regulations at § 35.2005(b)(28). This regulation defines nonexcessive infiltration as the quantity of flow that is less than 120 gallons per capita per day (domestic base flow and infiltration) or the quantity of infiltration that cannot be economically and effectively eliminated from a sewer system as determined in a cost-effectiveness analysis. The regulations at § 133.103(e) include the additional criterion that either 40 gallons per capita per day or 1,500 gallons per inch diameter per mile of sewer may be used as the threshold value for that portion of dry-weather base flow attributed to infiltration. If the less concentrated influent wastewater is the result of clear water industrial discharges, then the treatment works must control such discharges pursuant to Part 403.

- **Treatment works that receive less concentrated wastes from separate sewer systems** can qualify to have less stringent percent removal requirement or receive a mass loading limitation instead of the percent removal requirement provided the treatment plant demonstrates all of the following [§ 133.103(d)]:

  1. The facility is consistently meeting or will consistently meet its permit effluent concentration limitations but cannot meet its percent removal limitations because of less concentrated influent wastewater. For additional detail on this criterion, see discussion above for combined sewers during dry weather.

  2. To meet the percent removal requirements, the facility would have to achieve significantly more stringent limitations than would otherwise be required by the concentration-based standards. For additional detail on this criterion, see the discussion above for combined sewers during dry weather.

  3. The less concentrated influent wastewater does not result from excessive infiltration and inflow (I/I). The regulation indicates that the determination of whether the less concentrated wastewater is the result of excessive I/I will use the definition of excessive I/I at § 35.2005(b)(16), plus the additional criterion that flow is nonexcessive if the total flow to the POTW (i.e., wastewater plus inflow plus infiltration) is less than 275 gallons per capita per day. The regulation at § 35.2005(b)(16) defines excessive I/I as the quantities of I/I that can be economically eliminated from a sewer system as determined in a cost-effectiveness analysis that compares the costs for correcting the I/I conditions to the total costs for

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transportation and treatment of the I/I. This regulation also refers to definitions of nonexcessive I/I in §§ 35.2005(b)(28) and 35.2005(b)(29).

Secondary Treatment Variance for Ocean Discharge—CWA Section 301(h) Variance

CWA section 301(h) provides for variances from secondary treatment standards for POTWs that discharge into ocean waters if the modified requirements do not interfere with attainment or maintenance of water quality. Permit writers should note that the deadline to apply for a CWA section 301(h) variance (December 29, 1982) has passed, thus no new facilities may apply for this variance.

Eligible POTW applicants meeting the set of environmentally stringent criteria in CWA section 301(h) receive a modified NPDES permit waiving the secondary treatment requirements for the conventional pollutants of BOD_5, TSS, and pH. EPA issued regulations, developed the *Amended Section 301(h) Technical Support Document*[2], and prepared a website titled Amendments to Regulations Issued, the Clean Water Act Section 301 (h) Program <www.epa.gov/owow/oceans/discharges/301h.html>. EPA has promulgated specific regulations pertaining to CWA section 301(h) that are provided in Part 125, Subpart G.

All CWA section 301(h) variance modified permits must contain the following specific permit conditions:

- Effluent limitations and mass loadings that will assure compliance with Part 125, Subpart G.
- Requirements for pretreatment program development, a nonindustrial toxics control program, and control of combined sewer overflows.
- Monitoring program requirements that include biomonitoring, water quality, and effluent monitoring.
- Reporting requirements that include the results of the monitoring programs.

No new or substantially increased discharges from the point source of the affected pollutant can be released above that volume of discharge specified in the permit.

5.1.3.6 Step 6: Document the Application of Secondary or Equivalent to Secondary Treatment Standards and all Adjustments and Considerations in the Fact Sheet

Permit writers need to document their application of secondary or equivalent to secondary treatment standards in the NPDES permit fact sheet for municipal facilities. The permit writer should clearly identify the data and information used to determine whether secondary treatment standards or equivalent to secondary treatment standards or adjusted standards apply and how that information was used to derive effluent limitations for the permit. The permit writer should also note all adjustments and special considerations in the fact sheet. The information in the fact sheet should provide the NPDES permit applicant and the public a transparent, reproducible, and defensible description of how the NPDES permit properly incorporates secondary treatment standards.

5.2 Technology-Based Effluent Limitations for Industrial (Non-POTW) Dischargers

EPA is required to promulgate technology-based limitations and standards that reflect pollutant reductions that can be achieved by categories, or subcategories, of industrial point sources using specific

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technologies (including process changes) that EPA identifies as meeting the statutorily prescribed level of control under the authority of CWA sections 301, 304, 306, 307, 308, 402, and 501 (33 *United States Code* [U.S.C.] 1311, 1314, 1316, 1318, 1342, and 1361). Those national industrial wastewater controls are called effluent limitations guidelines and standards (effluent guidelines). Unlike other CWA tools, such as water quality standards, effluent guidelines are national in scope and establish performance standards for all facilities within an industrial category or subcategory.

For point sources that introduce pollutants directly into the waters of the United States (direct dischargers), the effluent guidelines promulgated by EPA are implemented through NPDES permits as authorized in CWA sections 301(a), 301(b), and 402. For sources that discharge to POTWs (indirect dischargers), EPA promulgates pretreatment standards that apply directly to those sources and are enforced by POTWs and state and federal authorities as authorized in CWA sections 307(b) and (c).

When developing TBELs for industrial (non-POTW) facilities, the permit writer must consider all applicable technology standards and requirements for all pollutants discharged. Without applicable effluent guidelines for the discharge or pollutant, permit writers must identify any needed TBELs on a case-by-case basis, in accordance with the statutory factors specified in CWA sections 301(b)(2) and 304(b). The site-specific TBELs reflect the BPJ of the permit writer, taking into account the same statutory factors EPA would use in promulgating a national effluent guideline regulation, but they are applied to the circumstances relating to the applicant. The permit writer also should identify whether state laws or regulations govern TBELs and might require more stringent performance standards than those required by federal regulations. In some cases, a single permit could have TBELs based on effluent guidelines, BPJ, and state law, as well as WQBELs based on water quality standards.

Sections 5.2.1 and 5.2.2 below provide an overview of effluent guidelines and development of TBELs in NPDES permits using the effluent guidelines. Section 5.2.3 below discusses the development of TBELs in the absence of effluent guidelines (i.e., case-by-case limitations developed using BPJ).

5.2.1 Effluent Guidelines

Congress saw the creation of a single national pollution control requirement for each industrial category, based on the best technology the industry could afford, as a way to reduce the potential creation of *pollution havens* and to attain a high-level water quality in the nation's waters. Consequently, EPA's goal in establishing effluent guidelines is to ensure that industrial facilities with similar characteristics will meet similar effluent limitations representing the best pollution control technologies or pollution prevention practices regardless of their location or the nature of the receiving water into which the discharge is made. In establishing the effluent guidelines, EPA must consider the industry-wide economic achievability of implementing the technology and the incremental costs in relation to the pollutant-reduction benefits.

Effluent guidelines can include numeric and narrative limitations, including best management practices (BMPs), to control the discharge of pollutants from categories of point sources. The limitations are based on data characterizing the performance of technologies available and, in some cases, from modifying process equipment or the use of raw materials. Although the regulations do not require the use of any particular treatment technology, they do require facilities to achieve effluent limitations that reflect the proper operation of the *model* technologies selected as the basis for the effluent guidelines and from which the performance data were obtained to generate the limitations. Therefore, each facility has the

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discretion to select any technology design and process changes necessary to meet the performance-based discharge limitations and standards specified by the effluent guidelines.

As of the date of this manual's publication, EPA has issued effluent guidelines for 56 industrial categories, which apply to between 35,000 and 45,000 facilities that discharge directly to waters of the United States and another 12,000 facilities that discharge into POTWs. The regulations prevent the discharge of more than 1.2 billion pounds of toxic (priority) and nonconventional pollutants each year. EPA's Effluent Guidelines Program Website <www.epa.gov/guide/> provides information on existing effluent guidelines, current effluent guidelines rulemaking, and the effluent guidelines planning process.

5.2.1.1 Statutory Foundation for Effluent Guidelines

The CWA directs EPA to promulgate effluent guidelines reflecting pollutant reductions that can be achieved by existing facilities in categories or subcategories of industrial point sources using specific control technologies. In addition, EPA is required to develop effluent guidelines for new sources. Those levels of control are summarized below and in Exhibit 5-8.

Exhibit 5-8 Summary of CWA technology levels of control

Type of sites regulated	BPT	BCT	BAT	NSPS	PSES	PSNS
Existing Direct Dischargers	X	X	X			
New Direct Dischargers				X		
Existing Indirect Dischargers					X	
New Indirect Dischargers						X
Pollutants regulated	**BPT**	**BCT**	**BAT**	**NSPS**	**PSES**	**PSNS**
Conventional Pollutants	X	X		X		
Nonconventional Pollutants	X		X	X	X	X
Toxic (Priority) Pollutants	X		X	X	X	X

Best Practicable Control Technology Currently Available (BPT)

BPT is the first level of technology-based effluent controls for direct dischargers and it applies to all types of pollutants (conventional, nonconventional, and toxic). The Federal Water Pollution Control Act (FWPCA) amendments of 1972 require that when EPA establishes BPT standards, it must consider the industry-wide cost of implementing the technology in relation to the pollutant-reduction benefits. EPA also must consider the age of the equipment and facilities, the processes employed, process changes, engineering aspects of the control technologies, non-water quality environmental impacts (including energy requirements), and such other factors as the EPA Administrator deems appropriate [CWA section 304(b)(1)(B)]. Traditionally, EPA establishes BPT effluent limitations on the basis of the average of the best performance of well-operated facilities in each industrial category or subcategory. Where existing performance is uniformly inadequate, BPT may reflect higher levels of control than currently in place in an industrial category if the Agency determines that the technology can be practically applied. See CWA sections 301(b)(1)(A) and 304(b)(1)(B).

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Best Conventional Pollutant Control Technology (BCT)

The 1977 CWA requires EPA to identify effluent reduction levels for conventional pollutants associated with BCT for direct discharges from existing industrial point sources. As with BPT, when establishing BCT the Agency considers the age of the equipment and facilities, the processes employed, process changes, engineering aspects of the control technologies, non-water quality environmental impacts (including energy requirements), and such other factors as the EPA Administrator deems appropriate [CWA section 304(b)(4)(B)]. In addition, EPA also considers a two-part *cost reasonableness* test, as required by CWA section 304(b)(4)(B), which includes (1) consideration of the reasonableness of the relationship between the costs of attaining a reduction in effluent and the effluent reduction benefits derived and (2) a comparison of the cost and level of reduction of such pollutants from the discharge from POTWs to the cost and level of reduction of such pollutants from a class or category of industrial sources. EPA explained its methodology for developing BCT limitations in detail in 51 FR 24974, July 9, 1986 <www.epa.gov/npdes/pubs/fr_bct_1986.pdf>. See CWA sections 301(b)(2)(E) and 304(b)(4).

Best Available Technology Economically Achievable (BAT)

For the direct discharge of toxic and non-conventional pollutants, EPA promulgates effluent guidelines based on BAT. The FWPCA amendments of 1972 require EPA to consider the cost of achieving effluent reductions when defining BAT; however, they do not specifically require EPA to balance the cost of implementation against the pollution reduction benefit. The technology selected for BAT must be economically achievable [CWA section 301(b)(2)(A)]. EPA generally defines BAT on the basis of the performance associated with the best control and treatment measures that facilities in an industrial category are capable of achieving. Like BPT and BCT, other factors EPA must consider in assessing BAT include the age of equipment and facilities involved, the process employed, process changes, non-water quality environmental impacts, including energy requirements, and other such factors as the EPA Administrator deems appropriate [CWA section 304(b)(2)(B)]. The Agency retains considerable discretion in assigning the weight accorded to these factors. BAT limitations may be based on effluent reductions attainable through changes in a facility's processes and operations. Where existing performance is uniformly inadequate, BAT may reflect a higher level of performance than is currently being achieved within a subcategory on the basis of technology transferred from a different subcategory or category. BAT may be based on process changes or internal controls, even when those technologies are not common industry practice. See CWA sections 301(b)(2)(A), (C), (D) and (F) and 304(b)(2).

New Source Performance Standards (NSPS)

NSPS reflect effluent reductions that are achievable by direct dischargers based on the best available demonstrated control technology. New sources have the opportunity to install the best and most efficient production processes and wastewater treatment technologies at the time of construction. As a result, NSPS should represent the most stringent controls attainable through the application of the best available demonstrated control technology for all pollutants (i.e., conventional, nonconventional, and toxic pollutants). In establishing NSPS, EPA is directed to take into consideration the cost of achieving the effluent reduction and any non-water quality environmental impacts and energy requirements. See CWA section 306.

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Pretreatment Standards for Existing Sources (PSES)

PSES are designed to prevent the discharge of pollutants that pass through, interfere with, or are otherwise incompatible with the operation of POTWs, including incompatibility with the POTW's chosen biosolids (sewage sludge) disposal methods. The categorical pretreatment standards for existing indirect dischargers are technology-based and are analogous to BAT. The general pretreatment regulations, which set forth the framework for the implementation of national pretreatment standards, are at Part 403. See CWA section 307(b).

Pretreatment Standards for New Sources (PSNS)

Like PSES, PSNS are designed to prevent the discharges of pollutants that pass through, interfere with, or are otherwise incompatible with the operation of POTWs. PSNS are to be issued at the same time as NSPS. New indirect dischargers have the opportunity to incorporate into their facilities the best available demonstrated technologies at the time of construction. The Agency considers the same factors in promulgating PSNS as it considers in promulgating NSPS. See CWA section 307(c).

EPA typically does not establish pretreatment standards for conventional pollutants (e.g., BOD_5, TSS, oil and grease) because POTWs are designed to treat such pollutants, but EPA has exercised its authority to establish categorical pretreatment standards for conventional pollutants as surrogates for toxic or nonconventional pollutants or to prevent interference. For example, EPA established categorical pretreatment standards for new and existing sources with a one-day maximum concentration of 100 mg/L oil and grease in the Petroleum Refining Point Source Category in Part 419 based on "the necessity to minimize [the] possibility of slug loadings of oil and grease being discharged to POTWs."[3]

The final statutory deadline for meeting BPT requirements was July 1, 1977, and the final statutory deadline for meeting BCT and BAT requirements was March 31, 1989. When applying applicable effluent guidelines, permit writers should note that they do not have the authority to extend the statutory deadlines in an NPDES permit; thus, all applicable technology-based requirements (i.e., effluent guidelines and case-by-case limitations based on BPJ) must be applied in NPDES permits without the benefit of a compliance schedule. In addition, though NSPS do not have specific dates as compliance deadlines, they are effective on the date the new source begins discharging. The facility must demonstrate compliance with NSPS within 90 days of discharge [see § 122.29(d)]. For more information on determining whether a discharge is subject to NSPS, see Appendix D of this manual. For additional information on the statutory and regulatory history of the NPDES program, see section 1.2 of this manual.

5.2.1.2 EPA's Development of Effluent Guidelines

EPA establishes national effluent guidelines for a specific industrial sector by regulation after considering an in-depth engineering and economic analysis of the industrial sector. EPA's Industrial Regulations Website <www.epa.gov/guide/industry.html> provides development documents for some specific industry categories (e.g., Iron and Steel Manufacturing and Metal Products and Machinery). Those documents contain additional information on how EPA develops effluent guidelines.

For each industrial sector, EPA assesses the performance and availability of the best pollution control technologies and pollution prevention practices that are available for an industrial category or subcategory. The effluent guidelines are promulgated for various industrial categories in 40 CFR, Chapter I, Subchapter N - Effluent Guidelines and Standards - Parts 400-471 <www.epa.gov/lawsregs/search/40cfr.html>.

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In promulgating effluent guidelines, EPA may divide an industrial point source category into groupings of subcategories to provide a method for addressing variations between products, raw materials, processes, and other factors that result in distinctly different characteristics. Regulation of an industrial category using subcategories allows each subcategory to have a uniform set of requirements that take into account technological achievability and economic impacts unique to that subcategory. Grouping similar facilities into subcategories increases the likelihood that the regulations are practicable and diminishes the need to address variations between facilities within a category through a variance process. For more on variances, see section 5.2.2.7 below. EPA considers a number of different subcategorization factors during an effluent guidelines rulemaking, including the following:

- Manufacturing products and processes.
- Raw materials.
- Wastewater characteristics.
- Facility size.
- Geographical location.
- Age of facility and equipment.
- Wastewater treatability.

For each possible treatment technology option for an industry, EPA conducts an analysis of industry-wide incremental compliance costs, pollutant loadings and removals, and related non-water quality effects. The Agency also performs an economic analysis to assess the financial impact on the industry of implementing each option. That entire process involves data collection, rigorous data review, engineering analysis, and public comment. EPA selects a technology to serve as the *model* technology for pollutant removal for each required level of control (i.e., BPT, BCT, BAT, NSPS, PSES, and PSNS). Limitations and other requirements in the effluent guidelines for each level of control are based on application of the model technology to the category or subcategory of facilities.

Effluent guidelines are not always established for every pollutant present in a point source discharge. In many instances, EPA promulgates effluent guidelines for an *indicator* pollutant. Industrial facilities that comply with the effluent guidelines for the indicator pollutant will also control other pollutants (e.g., pollutants with a similar chemical structure). For example, EPA may choose to regulate only one of several metals present in the effluent from an industrial category, and compliance with the effluent guidelines will ensure that similar metals present in the discharge are adequately controlled. Additionally, for each industry sector EPA typically considers whether a pollutant is present in the process wastewater at treatable concentrations and whether the model technology for effluent guidelines effectively treats the pollutant. For example, see Figure 6-1 Pollutant of Concern Methodology <www.epa.gov/guide/cwt/final/develop/ch6.pdf> on page 6-4 of the *Centralized Waste Treatment category Technical Development Document*.

The CWA requires EPA to annually review existing effluent guidelines for both direct and indirect dischargers. CWA section 304(m) also requires EPA to publish an effluent guidelines program plan every 2 years. As part of the development of the biennial plan, the public is provided an opportunity to comment on a *preliminary* plan before it is finalized. The preliminary plan is published in odd-numbered years, and the final plan is published in even-numbered years. EPA encourages permit writers to participate in the effluent guidelines planning process and comment on the preliminary effluent guidelines program plans presented on the Effluent Guidelines Biennial Plan Website <www.epa.gov/guide/304m/index.html>.

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5.2.1.3 Types of Limitations in Effluent Guidelines

Although the requirements in effluent guidelines generally are numeric limitations on the mass or concentration of a pollutant that can be discharged directly into waters of the United States, CWA section 502(11) defines *effluent limitation* broadly. This section describes several types of possible expressions for the limitations found in effluent guidelines. The permit writer should note that the limitations in effluent guidelines might need to be translated into an appropriate form to be included as effluent limitations in an NPDES permit. That process is discussed further in section 5.2.2 below.

Mass- or Concentration-based Numeric Limitations

Limitations in effluent guidelines generally are expressed as numeric values, which are upper bounds of the amount of pollutant that may be discharged. For most pollutants, these limitations are mass-based or concentration-based values. They are, in effect, measures of how well the production, wastewater treatment, and pollution prevention processes must be operated. In the course of developing effluent guidelines regulations, EPA uses data on a number of different pollutants from facilities with the selected model technologies to determine the appropriate numeric limitations. The limitations generally consist of upper bounds (maximum values) established for both the daily discharge and for the average monthly discharge.

In developing numeric limitations in effluent guidelines, EPA first determines an average performance level (the *long-term average*) that a facility with well-designed and operated model technologies reflecting the appropriate level of control is capable of achieving. That long-term average is calculated from data taken from facilities using the model technologies that were selected as a basis for the limitations. EPA expects that all facilities subject to the limitations will design and operate their treatment systems to achieve the long-term average performance level consistently because facilities with well-designed and operated model technologies have demonstrated that it can be done. The technical development document for the effluent guidelines usually identifies the long-term average for the model technologies; however, they generally are not part of the limitations in the effluent guidelines or TBELs in the permit. The limitations generally are expressed as *maximum daily* and *average monthly limitations* (see definitions in Exhibit A-2 in Appendix A of this document) that include an allowance for variability around the long-term average.

EPA acknowledges that process and treatment systems have inherent variability and, therefore, incorporates an allowance for this variation into the limitations specified in the effluent guidelines. That allowance is based on statistical analysis of the data from facilities using the model technologies. The limitations included in effluent guidelines incorporate all components of variability including shipping, sampling, storage, and analytical variability. By accounting for those reasonable excursions above the long-term average, the limitations in effluent guidelines generally are well above the actual long-term averages. If a facility operates its treatment system to meet the long-term average, EPA expects the facility will be able to meet the limitations specified in the effluent guidelines based on that long-term average.

EPA has different objectives in establishing maximum daily and average monthly limitations in effluent guidelines. In establishing maximum daily limitations, EPA's objective is to restrict the discharges on a daily basis at a level that is achievable for a facility that targets its treatment at the long-term average. In establishing average monthly limitations, EPA's objective is to provide an additional restriction to help

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ensure that facilities target their average discharges in a manner that will achieve the long-term average. The average monthly limitation requires continuous dischargers to provide ongoing control on a monthly basis that complements controls imposed by the maximum daily limitation. To meet the average monthly limitation, a facility must counterbalance a value near the maximum daily limitation with one or more values well below the maximum daily limitation. To achieve compliance, the values must result in an average monthly value at or below the average monthly limitation. As explained below, EPA uses a smaller percentile basis for the average monthly limitation than the maximum daily limitation to encourage facilities to target their systems to a value closer to the long-term average.

EPA generally uses statistical procedures to determine the values of the limitations specified in the effluent guidelines. Those procedures involve fitting effluent data to distributions and using estimated upper percentiles of the distributions. EPA defines the maximum daily limitation as an estimate of the 99th percentile of the distribution of the daily measurements. The average monthly limitation is an estimate of the 95th percentile of the distribution of the monthly averages of the daily measurements. EPA bases its limitations on percentiles chosen with the intention that they be high enough above the long-term average to accommodate reasonably anticipated variability within control of the facility. In conjunction with the statistical methods, EPA performs an engineering review to verify that the limitations are reasonable on the basis of the design and expected operation of the control technologies and the facility process conditions. Such limitations are translated into effluent limitations in a facility's NPDES permit. Facilities must comply with the effluent limitations in their permits at all times. EPA has prevailed in several judicial challenges to its selection of percentiles and on other issues related to limitations specified in effluent guidelines. [See, for example, *Chemical Manufacturers Association v. U.S. Environmental Protection Agency*, 870 F.2d 177, 230 (5th Cir. 1989) and *National Wildlife Federation, et al v. Environmental Protection Agency*, 286 F.3d 554 (D.C. Cir. 2002)]

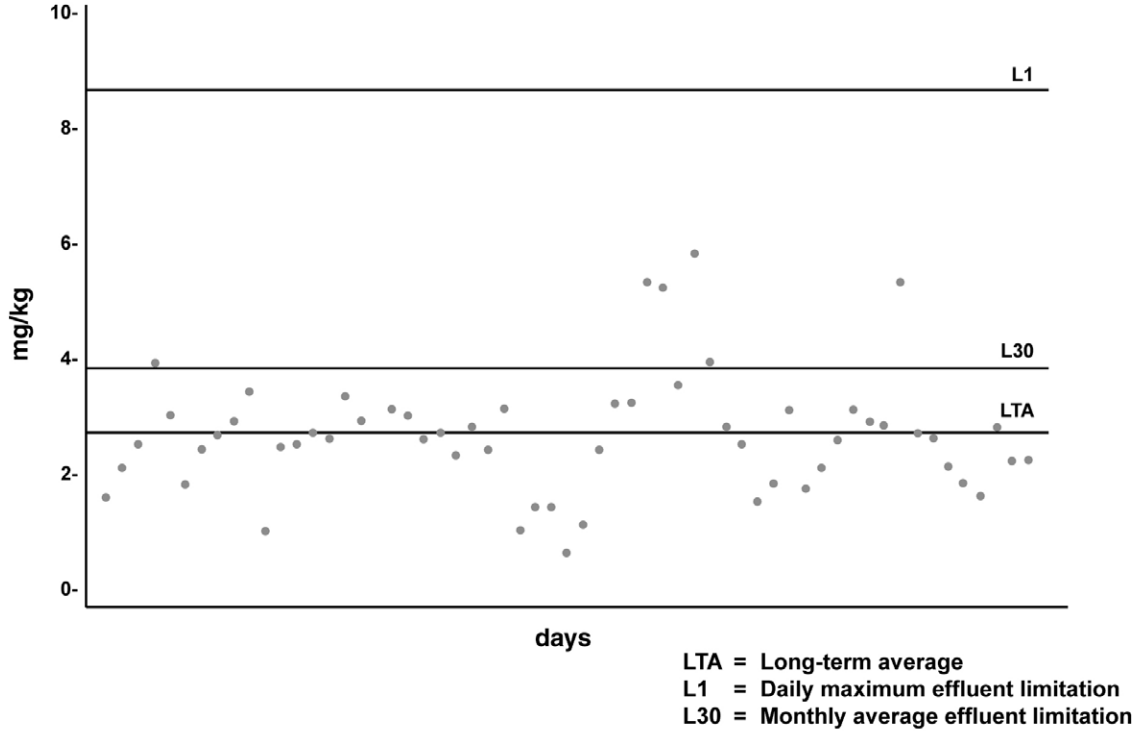
Exhibit 5-9 depicts an example of TSS data for a facility that is operating around a required long-term average level for TSS. The dots represent daily measurements, and the reference lines show the values for the long-term average (LTA), the maximum daily limitation (L1), and the average monthly limitation (L30). The facility has demonstrated compliance with both the maximum daily and average monthly limitations. Daily measurements include values both above and below the long-term average; however, all the data values are below the maximum daily limitation. Some individual daily values exceed the average monthly limitation; however, within each month, the average of the daily values is less than the average monthly limitation.

EPA generally exercises four basic alternatives in setting mass- or concentration-based numeric limitations specified in effluent guidelines:

- Mass-based, production-normalized limitations (e.g., the pollutant discharge is not to exceed 1 pound per 1,000 pounds of production).
- Mass-based, flow-normalized limitations (e.g., the pollutant discharge is not to exceed the mass determined by multiplying the process wastewater flow subject to the effluent guideline by the concentration requirement in the guideline).
- Concentration-based limitations (e.g., the pollutant discharge is not to exceed 1 mg of pollutant per liter of wastewater).
- Limitations requiring *zero discharge* of specific pollutants or all pollutants.

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Exhibit 5-9 Visual example of TSS LTA, maximum daily limitation and average monthly limitation



Except where a limitation requiring *zero discharge* of pollutants is applicable, EPA generally prefers setting production-normalized, mass-based limitations specified in effluent guidelines, where feasible, because production normalized limitations can reflect some expectation that the facility will conserve water and can reduce any potential for substituting dilution for treatment. EPA generally establishes concentration-based effluent guidelines when production and achievable wastewater flow cannot be correlated nationally. For example, in the Metal Finishing point source Category (Part 433), the Agency considered but decided against expressing the effluent guidelines as production-normalized mass-based effluent guidelines, "With the wide range of operations, product quality requirements, existing process configurations, and difficulties in measuring production, no consistent production normalizing relationship could be found. Concentration-based limits, however, can be consistently attained throughout the industry." [See 47 FR 38465, 31 August 1982.]

Numeric Limitations Established at Minimum Levels

Using percentile estimates to set limitations in effluent guidelines is not a requirement under the CWA. In some cases, the model technology for treating a pollutant might be capable of removing that pollutant to levels that cannot be reliably measured with existing analytical methods. EPA sometimes sets a requirement in the effluent guidelines that the concentration of a pollutant in the discharge must be below a *minimum level* or ML. The ML is the lowest level at which the entire analytical system must give a recognizable signal and an acceptable calibration point for the pollutant being analyzed. Where a limitation in the effluent guidelines is set at *less than the ML*, the value of the ML is specified in the effluent guidelines regulation on the basis of the analytical methods that EPA used to chemically analyze wastewaters in developing the regulation. For example, in the Pulp, Paper, and Paperboard point source

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category (Part 430) the Daily Maximum BAT effluent guideline for the Tetrachlorodibenzofuran (TCDF) congener of dioxin is expressed as <*ML* for papergrade sulfite (Subpart E) mills, which means "less than the minimum level specified in part 430.01(i)" (i.e., 10 picograms/liter for TCDF). If, in the future, analytical methods become more sensitive with lower MLs, EPA would determine whether the technologies for reducing the amount of the pollutant in the discharge are capable of achieving more stringent limitations and, thus, whether it would be appropriate to modify the requirements of the effluent guideline.

EPA has not established average monthly limitations in effluent guidelines when the maximum daily limitation is an ML limitation. The purpose of an average monthly limitation is to require continuous dischargers to provide better control, on a monthly basis, than required by the maximum daily limitation. However, for these pollutants, the data were determined by analytical methods that could not measure below the ML specified in the regulations. Thus, even if a permitting authority requires monitoring for the pollutants more frequently than once a month, average monthly limitations would still be expressed as *less than the ML* or < *ML*.

Other Expressions for Numeric Limitations

EPA also promulgates effluent guidelines for pollutants that cannot be expressed in terms of mass or concentration (e.g., pH, temperature, radiation) or are better expressed through other means (e.g., unitless ratios). For example, pH is generally expressed as an acceptable range (e.g., 6.0–9.0 standard pH units).

Nonnumeric Effluent Limitations

In some cases, EPA includes nonnumeric or narrative effluent limitations rather than, or in addition to, numeric limitations in effluent guidelines. Nonnumeric effluent limitations might include specific BMPs or requirements to minimize or eliminate discharges. CWA sections 304(e), 308(a), 402(a), and 501(a) authorize the Administrator to prescribe BMPs as part of effluent guidelines and as part of an NPDES permit. CWA section 304(e) authorizes EPA to include supplemental BMPs in effluent guidelines for toxic or hazardous pollutants for the purpose of controlling "plant site runoff, spillage or leaks, sludge or waste disposal, and drainage from raw material storage." Several effluent guidelines include BMPs as requirements. Some effluent guidelines, such as the Concentrated Aquatic Animal Production point source category (Part 451), include the BMPs requirement exclusively. Section 9.1.2 of this manual further discusses BMPs.

CWA section 402(a)(1) and (2) and the NPDES regulations at § 122.44(k) also authorize BMPs in NPDES permits to control or abate the discharge of pollutants when numeric effluent limitations are infeasible, or when the practices are reasonably necessary to achieve effluent limitations and standards or to carry out the purposes and intent of the CWA.

Once EPA establishes effluent guidelines, the permit writer is responsible for translating the limitations and other requirements of the effluent guidelines into TBELs and other conditions appropriate for inclusion in an NPDES permit. Section 5.2.2 below discusses a step-by-step approach for applying effluent guidelines through NPDES permits.

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5.2.2 Applying Effluent Guidelines through NPDES Permits

Permit writers need to have a detailed knowledge of the industrial facility applying for a new or reissued NPDES permit to identify applicable effluent guidelines and know how to use them to derive TBELs. This section provides a step-by-step procedure for applying effluent guidelines to direct discharges through NPDES permits as shown in Exhibit 5-10.

Exhibit 5-10 Steps for applying effluent guidelines to direct discharges

Step 1.	Learn about the industrial discharger
Step 2.	Identify the applicable effluent guidelines category(ies)
Step 3.	Identify the applicable effluent guidelines subcategory(ies)
Step 4.	Determine whether existing or new source standards apply
Step 5.	Calculate TBELs from the effluent guidelines
Step 6.	Account for overlapping or multiple effluent guidelines requirements
Step 7.	Apply additional regulatory considerations in calculating TBELs
Step 8.	Apply additional effluent guidelines requirements
Step 9.	Document the application of effluent guidelines in the fact sheet

5.2.2.1 Step 1: Learn About the Industrial Discharger

To write a defensible permit, the permit writer should have a solid understanding of the facility's operations. The permit writer should gather sufficient information to identify applicable effluent guidelines and derive TBELs. Facility-specific information the permit writer is likely to need includes the following:

- Industrial processes and raw materials.
- Products and services.
- Amount of manufacturing production or servicing.
- Number of production and non-production days.
- Current pollution prevention practices and wastewater treatment technology(ies).
- Discharge location of the wastewater pollutants and potential compliance sampling points.
- The source and characteristics of the wastewaters (including flow) and pollutants that are being discharged or have the potential to be discharged from the facility.

Sources of information include the facility's permit application, the current permit and fact sheet (if the facility is permitted), discharge monitoring reports, site visits, site inspections (such as compliance evaluation inspections for an existing permit), and other information submitted by the facility. The permit writer also should identify any information that would assist in determining whether the facility or part of the facility is considered a new source (e.g., age of facility and equipment).

5.2.2.2 Step 2: Identify the Applicable Effluent Guidelines Category(ies)

As noted above, EPA's effluent guidelines are at 40 CFR, Chapter I, Subchapter N - Effluent Guidelines and Standards, Parts 400–471 <www.epa.gov/lawsregs/search/40cfr.html>. A summary of promulgated effluent guidelines is presented on EPA's Industrial Regulations Website <www.epa.gov/guide/industry.html> and in Exhibit 5-11 below.

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Exhibit 5-11 Table of existing point source categories (June 2010)

Industry category (listed alphabetically)	40 CFR Part	Industry category (listed alphabetically)	40 CFR Part
Aluminum Forming	467	Meat and Poultry Products	432
Asbestos Manufacturing	427	Metal Finishing	433
Battery Manufacturing	461	Metal Molding and Casting	464
Canned and Preserved Fruits and Vegetable Processing	407	Metal Products and Machinery	438
Canned and Preserved Seafood Processing	408	Mineral Mining and Processing	436
Carbon Black Manufacturing	458	Nonferrous Metals Forming and Metal Powders	471
Cement Manufacturing	411	Nonferrous Metals Manufacturing	421
Centralized Waste Treatment	437	Oil and Gas Extraction	435
Coal Mining	434	Ore Mining and Dressing	440
Coil Coating	465	Organic Chemicals, Plastics, and Synthetic Fibers	414
Concentrated Animal Feeding Operations (CAFOs)	412	Paint Formulating	446
Concentrated Aquatic Animal Production	451	Paving and Roofing Materials (Tars and Asphalt)	443
Copper Forming	468	Pesticide Chemicals	455
Dairy Products Processing	405	Petroleum Refining	419
Electrical and Electronic Components	469	Pharmaceutical Manufacturing	439
Electroplating*	413	Phosphate Manufacturing	422
Explosives Manufacturing	457	Photographic	459
Ferroalloy Manufacturing	424	Plastic Molding and Forming	463
Fertilizer Manufacturing	418	Porcelain Enameling	466
Glass Manufacturing	426	Pulp, Paper, and Paperboard	430
Grain Mills	406	Rubber Manufacturing	428
Gum and Wood Chemicals	454	Soaps and Detergents Manufacturing	417
Hospitals	460	Steam Electric Power Generating	423
Ink Formulating	447	Sugar Processing	409
Inorganic Chemicals	415	Textile Mills	410
Iron and Steel Manufacturing	420	Timber Products Processing	429
Landfills	445	Transportation Equipment Cleaning	442
Leather Tanning and Finishing	425	Waste Combustors	444

* This category contains only categorical pretreatment standards (no effluent guidelines for direct dischargers).

The following sources of information might be helpful in identifying applicable effluent guidelines for a facility:

- **CFR titles and applicability section of the effluent guidelines**. This is first place to look for information for identifying applicable effluent guidelines. Each effluent guidelines regulation includes an applicability section for the category or each subcategory of the industry. The applicability section gives a general description of the types of facilities regulated by the effluent guidelines. The applicability sections often define certain industrial operations or other criteria (e.g., production or process wastewater flow thresholds) that identify whether a facility is regulated by the effluent guidelines.

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- **North American Industry Classification System (NAICS) and Standard Industrial Classification (SIC)**. The current NAICS <www.census.gov/epcd/www/naics.html> and former SIC codes <www.census.gov/epcd/www/naicstab.htm> could be helpful to determine the appropriate industrial category(ies) for a facility. NAICS and SIC codes were developed and are maintained by the federal government as a way to classify establishments by type of activity for comparing economic and other types of facility-specific data. Although SIC codes provide a helpful starting point for categorizing a facility, permit writers should be cautious of relying exclusively on SIC codes for determining the appropriate industrial category. SIC codes were not developed using EPA's industrial classification scheme, or vice versa, and, therefore, the codes might not always correspond exactly with the categorization process. In addition, more than one SIC code might apply to a single facility. Item V-II of NPDES Application Form l requires that the applicant provide the SIC code for the activity covered by the permit application. In some instances, the SIC code will identify both the industrial category and the subcategory of a facility. Sometimes the SIC code might identify the appropriate industrial category but not the subcategory. Exhibit 5-12 presents two examples of how a permit writer might identify the applicable effluent guidelines using the facilities SIC codes.

Exhibit 5-12 Examples of identifying applicable effluent guidelines using SIC codes

Example 1

A facility that performs the primary smelting and refining of copper reports SIC code 3331 in its NPDES permit application. By scanning the list of industrial point source categories, the permit writer can determine that the facility is regulated by effluent guidelines in the Nonferrous Metals Manufacturing point source category (Part 421). In this case, the SIC code also indicates that the facility is likely regulated by effluent guidelines in the Primary Copper Smelting Subcategory.

Example 2

A facility that manufactures ethyl acrylate and 2-ethylhexyl acrylate (acrylic acid esters) reports the SIC code 2869 (Industrial Organic Chemicals, Not Elsewhere Classified) in its NPDES permit application. By scanning the list of industrial point source categories, the permit writer can determine that facility is likely regulated by effluent guidelines in the Organic Chemicals, Plastics, and Synthetic Fibers (OCPSF) category (Part 414).

- **EPA's Development Documents and Compliance Guides**. EPA produces a number of documents that will aid permit writers in identifying applicable effluent guidelines and incorporating them into NPDES permits. In particular, development documents summarize the data and information EPA used to develop the effluent guidelines. Such documents are extremely useful in identifying the applicability of the effluent guidelines and how to incorporate the effluent guidelines into NPDES permits. EPA may also publish a compliance guide for permit writers and industry. EPA's Effluent Guidelines Website <www.epa.gov/guide/> provides available documents for specific industrial categories.

- **FR Notices**. The preamble text to the FR notices containing the proposed and final effluent guidelines rulemakings also provide additional insight into applicability of the effluent guidelines. EPA's Effluent Guidelines Website <www.epa.gov/guide/> provides FR notices for specific industrial categories. For example, the preambles to recently promulgated effluent guidelines typically list the SIC and NAICS codes for the potentially regulated facilities. Each Part in the CFR identifies the relevant FR notices. For example, § 419.11 (i.e., specialized definitions for

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Subpart [subcategory] A for the Petroleum Refining point source category) identifies 47 FR 46446, October 18, 1982, as amended at 50 FR 28522, July 12, 1985, as its source.

- **EPA Industry Experts**. EPA has a number of subject matter experts <www.epa.gov/guide/contacts.html> at its headquarters office in Washington, D.C. that are available to answer questions on specific effluent guidelines. EPA's NPDES Contacts in Regional Offices <www.epa.gov/npdes/regionalcontacts> also offer assistance in sorting through the different effluent guidelines and NPDES regulations.

- **EPA's Effluent Guidelines Planning Support Documents.** EPA's Effluent Guidelines Biennial Plan Website <http://water.epa.gov/lawsregs/lawsguidance/cwa/304m/> provides technical support documents and other information supporting EPA's biennial effluent guidelines program plans.

- **EPA's Sector Notebooks.** EPA's Sector Notebooks <www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/index.html> describe specific U.S. industries and governments and provide a holistic approach by integrating processes, applicable regulations, and other relevant environment information.

- **Other Sources**. Other sources of information include resources identified below in Exhibit 5-23, BPJ Permitting Tools. Permit and fact sheet and information from similar facilities might aid in identifying applicable effluent guidelines. However, the permit writer should not assume that a similar facility was correctly categorized in its permit and should examine the rationale for how the other permit writer identified any applicable effluent guidelines before relying on another permit to identify the applicable category.

Permit writers should be aware that effluent guidelines from two or more industrial point source categories might apply to a single facility. Step 6 below, provides additional information on overlapping or multiple effluent guidelines requirements.

5.2.2.3 Step 3: Identify the Applicable Effluent Guidelines Subcategory(ies)

In promulgating effluent guidelines, EPA may divide an industrial point source category into groupings called *subcategories* to provide a method for addressing variations between products, raw materials, processes, and other factors that result in distinctly different effluent characteristics or treatment options. Some effluent guidelines categories cover a variety of industrial sectors (e.g., the Nonferrous Metals Manufacturing point source category has 31 subcategories). It is important for the permit writer to correctly identify the applicable subcategory to derive TBELs.

The process of identifying the applicable effluent guidelines requires close review and comparison of information obtained from Step 1 and Step 2 above. Just as effluent guidelines from two or more industrial categories can apply to a single facility, it also is true that requirements from two or more subcategories could apply to a single facility.

Exhibit 5-13 presents two examples of how a permit writer can identify the subcategory containing the applicable effluent guidelines using information from the NPDES permit application.

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Exhibit 5-13 Examples of identifying the subcategory with the applicable effluent guidelines

Example 1

A permit writer has identified the facility from Example 2 in Exhibit 5-12 above as potentially regulated by the effluent guidelines in the OCPSF point source category (Part 414) <www.epa.gov/guide/ocpsf/>. The permit writer can determine from a further review of the industrial categorization discussion in the *OCPSF Development Document* and the guidance document that the facility is likely subject to effluent guidelines in Subpart G (Bulk Organic Chemicals). Specifically, the applicability criteria section in Subpart G (§ 414.70) states, "The provisions of this subpart are applicable to the process wastewater discharges resulting from the manufacture of the following: SIC 2865 and 2869 bulk organic chemicals and bulk organic chemical groups." Further, acrylic acid esters are listed in § 414.70 as an OCPSF product group.

Example 2

A large poultry slaughterhouse annually produces 200 million pounds of whole, halved, quarter or smaller meat cuts and reports SIC Code 2015 in its NPDES permit application. The permit writer reviewed the list of effluent guidelines and identified that the facility is likely regulated by effluent guidelines in the Meat and Poultry Products point source category (Part 432) <www.epa.gov/guide/mpp/>. The permit writer reviewed the preamble to the final effluent guidelines rule and the rule's development document. In that effluent guidelines regulation, EPA used NAICS codes to assist in applicability decisions. See 69 FR 54475, September 8, 2004. The permit writer used the U.S. Census Bureau's SIC to NAICS crosswalk website <www.census.gov/epcd/www/naicstab.htm> to identify the NAICS code (311615). Using the NAICS code, the permit writer can narrow the list of potentially applicable subcategories to the Poultry First Processing (Subpart K) or the Poultry Further Processing (Subpart L) subcategories. After reviewing the applicability criteria of both subcategories, the permit writer determined that only the effluent guidelines in Subpart K are likely applicable because the facility performs slaughtering operations, which are not regulated by Subpart L. Finally, the permit writer also needed to compare the average annual production of the facility (200 million pounds) with the production threshold in the effluent guidelines (100 million pounds per year). Because the facility produces more than the production threshold, the effluent guidelines in Subpart K are applicable to this facility. See §§ 432.112 and 432.113. In this example the permit writer would use the effluent guidelines for ammonia (as N), BOD_5, fecal coliform, oil and grease (as HEM), TSS, and total nitrogen to derive effluent limitations as detailed in section 5.2.2.5 below.

5.2.2.4 Step 4: Determine whether Existing or New Source Standards Apply

Section 5.2.1.1 above defines the different control technologies that apply to direct dischargers: BPT, BCT, BAT, and NSPS. The first three apply to existing direct dischargers, and the fourth to new sources. To determine whether existing source standards (i.e., BPT, BCT, and BAT) or NSPS apply to the facility, the permit writer must determine whether the facility or any part of the facility is a new source. A new source is defined in § 122.2 as a building, structure, facility, or installation that discharges pollutants or could discharge pollutants and for which construction began after promulgation of the applicable effluent guidelines or after proposal of the applicable effluent guidelines, but only if the effluent guidelines are promulgated within 120 days. Thus, the discharger's entire facility could be subject to new source standards (e.g., a brand new facility). Permit writers should note that the new source date for indirect dischargers is the date on which the pretreatment standard for new sources is proposed. See §403.3(m)(1).

Additional criteria for determining whether a discharge is a new source are defined in § 122.29(b) to cover situations where a facility is adding a new building or process line that results in a discharge to the waters of the United States. Such an addition would result in a new source if any of the following is true for the source:

- Is constructed at a site at which no other source is located.
- Totally replaces the process causing the discharge from an existing source.
- Has processes that are substantially independent of an existing source at the same site.

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Furthermore, some effluent guidelines, such as the effluent guidelines for the Pulp, Paper, and Paperboard Point Source Category in Part 430, include additional criteria for making new source determinations. See § 430.01(j).

Appendix D of this manual provides the applicable new source dates used in making new source determinations by effluent guideline category as provided in Appendix B of the EPA memorandum *New Source Dates for Direct and Indirect Dischargers*[4] <www.epa.gov/npdes/pubs/newsource_dates.pdf> sent by the directors of the Water Permits Division and the Engineering and Analysis Division to the Regional Water Division Directors. Permit writers can use Appendix D of this manual to find the date for determining whether a facility or part of a facility is subject to NSPS.

Where a new source is the result of a new installation of process equipment at an existing facility, part of the facility might be subject to existing source standards and other parts of the facility subject to new source standards. Permit writers should identify whether the facility has installed any process equipment after the last issuance of the NPDES permit and apply the criteria from § 122.29(b) on a case-by-case basis to new construction or new processes, while applying existing source requirements to the existing portions of the facility. Sometimes it can be difficult to distinguish between a new source and a modification or alteration of an existing source, especially when modifications have occurred slowly over time. The permit writer should consult the effluent guidelines regulation to determine if it defines more specifically what constitutes a new source.

It is important to remember that after the effective date of a new source standard, the CWA stipulates that it is unlawful for any owner or operator to operate such a source in violation of those standards. See 33 U.S.C. 1316(e) and 1317(d). EPA's regulations specify that a new source "[must] install and have in operating condition, and [must] *start up* all pollution control equipment" required to meet applicable standards before beginning to discharge. The regulations also indicate that the owner or operator of a new source must meet all applicable standards within "the shortest feasible time (not to exceed 90 days)." See § 122.29(d)(4).

In addition to the requirement to meet NSPS upon beginning to discharge, an EPA-issued NPDES permit for a new source is a federal action subject to the requirements of the National Environmental Policy Act (NEPA), 33 U.S.C. 1371(c)(1). For more information on NEPA and the NPDES program, see section 11.1.2 of this manual.

For existing facilities and existing sources (where NSPS do not apply), existing source standards (i.e., BPT, BCT, BAT) apply. The permit writer would use the more stringent technology level of control for each pollutant. For example, the BPT level of control in the Veneer Subcategory of the Timber Products Processing category (Part 429, Subpart B) allows a discharge of process wastewater and identifies effluent guidelines for BOD_5 and pH, while the BAT level of control bans the direct discharge of process wastewater. Consequently, the NPDES permit for a facility regulated by the Veneer Subcategory must use the more stringent BAT requirements and prohibit the direct discharge of process wastewater. The effluent guidelines for the Renderers subcategory of the Meat and Poultry Products point source category (Subpart J, Part 432) provide another example. In those effluent guidelines, the BCT requirements for BOD_5, oil and grease, and TSS are more stringent than the corresponding BPT requirements. Accordingly, the permit writer would use the more stringent BCT requirements, rather than the BPT requirements, to derive numeric permit limitations for an existing renderer.

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5.2.2.5 Step 5: Calculate TBELs from the Effluent Guidelines

Once a permit writer has identified the effluent guidelines that apply to a facility, he or she then uses those effluent guidelines to calculate applicable TBELs.

EPA's regulations at § 122.45(f)(1) stipulate that all pollutants limited in permits must have limitations, standards or prohibitions expressed in terms of mass except under any of the following conditions:

- For pH, temperature, radiation, or other pollutants that cannot appropriately be expressed by mass limitations.
- When applicable standards or limitations are expressed in terms of other units of measure.
- If in establishing technology-based permit limitations on a case-by-case basis, limitations based on mass are infeasible because the mass or pollutant cannot be related to a measure of production (e.g., discharges of TSS from certain mining operations). The permit conditions must ensure that dilution will not be used as a substitute for treatment.

Thus, the type of limitation (i.e., mass, concentration, or other units) calculated for a specific pollutant at a facility will depend on the type of pollutant and the way limitations are expressed in the applicable effluent guideline. Generally, effluent guidelines include both maximum daily and monthly average limitations for most pollutants. Though the effluent guidelines use different terms for monthly effluent limitations (e.g., monthly average, maximum for monthly average, average of daily values for 30 consecutive days), the requirements are expressed in NPDES permits as average monthly limitations as defined in § 122.2.

As stated in Steps 1 and 2 above, the permit writer would use many sources of information to calculate TBELs. From those sources, the permit writer should identify the source and characteristics of the wastewaters (including flow) and pollutants being discharged, or that have the potential to be discharged, and whether and how those pollutants are regulated by effluent guidelines. In particular, the permit writer should identify the following:

- The appropriate permit compliance point(s) (which might be specified in the effluent guidelines).
- Wastewaters subject to the applicable effluent guidelines and whether they are commingled with other wastewaters not regulated by effluent guidelines (e.g., sanitary wastewaters before the permit compliance point).
- Reasonable measure of the facility's actual long-term daily production and average number of production days per year regulated by effluent guidelines (necessary for derived effluent limitations from production-normalized effluent guidelines).
- Average daily facility flows at the compliance point(s) regulated by effluent guidelines.
- Average daily facility flows at the compliance point(s) not regulated by effluent guidelines.

That information is used in conjunction with the effluent guidelines for TBEL calculations as discussed below.

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Calculating Mass-based TBELs from Production-Normalized Effluent Guidelines

Most effluent guidelines requirements are mass-based and expressed in terms of allowable pollutant discharge per unit of production or some other measure of production (i.e., production normalized). Permit writers incorporate such production-normalized effluent guidelines into NPDES permits as mass-based TBELs by using a reasonable measure of the permittee's actual long-term daily production. The objective in determining the production for a facility is to develop a single estimate of the long-term average daily production that can reasonably be expected to prevail during the next term of the permit (i.e., not the design production rate). Permit writers may establish such a production rate using the past 3 to 5 years of facility data. For example, the permit writer might wish to use the average daily production rate calculated using the highest annual production from the previous 3 to 5 years. Whatever value is selected, the permit writer should ensure that the production rate used in deriving mass-based effluent limitations is representative of the actual production likely to prevail during the next term of the permit.

The examples in Exhibit 5-14 illustrate the application of production-based effluent guidelines using the approach where annual production data are available. In Example 1 in Exhibit 5-14, the highest annual production rate during the past 5 years was used as the estimate of production. If historical trends, market forces, company plans to decrease production, or plant designs and capital expenditures for an increase in production indicated that a different level of production would prevail during the permit term, the permit writer could consider a different basis for estimating production or establish tiered discharge limitations, as discussed in section 5.2.2.7 below.

Calculating Mass-based TBELs from Flow-Normalized Effluent Guidelines

In some cases, permit writers are directed to calculate mass-based TBELs from flow-normalized effluent guidelines that are expressed as concentrations. For example, the Organic Chemicals, Plastics, and Synthetic Fibers (OCPSF) effluent guidelines <www.epa.gov/waterscience/guide/ocpsf/> in Part 414 state that facilities "must achieve discharges not exceeding the quantity (mass) determined by multiplying the process wastewater flow subject to [the effluent guideline] times the concentration listed in the [effluent guideline]…" The *Development Document for Effluent Limitations Guidelines and Standards for the Organic Chemicals, Plastics and Synthetic Fibers Point Source Category*[5] <www.epa.gov/waterscience/guide/ocpsf/#guidance> directs the permit writer to "use a reasonable estimate of process wastewater discharges and the concentration limitations [in the effluent guideline] to develop mass limitations for the NPDES permit." Thus, the process for calculating the TBELs is similar to the process used with production-normalized effluent guidelines, but rather than using a reasonable measure of the actual daily production, the permit writer would use a reasonable measure of the actual daily flow rate as the basis for calculating the TBELs.

As with estimating production to calculate TBELs, the objective in determining a flow estimate for a facility is to develop a single estimate of the actual daily flow rate (in terms of volume of process wastewater per day), which can reasonably be expected to prevail during the next term of the permit (i.e., not the design flow rate). Permit writers can establish that flow rate using the past 3 to 5 years of facility data in a manner similar to the method used to determine production. For example, the permit writer might wish to use the highest average daily flow rate from the average daily flows calculated for each of the past 3 to 5 years. The value selected should be representative of the actual flow likely to prevail during the next term of the permit.

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Exhibit 5-14 Example of calculating mass-based effluent limitation from production-normalized effluent guidelines[6]

Example 1

Facility A has produced 331,000 tons, 301,500 tons, 321,500 tons, 330,000 tons, and 331,500 tons of product per year for the previous 5 years operating 255 days per year.

Question:
What would be a reasonable measure of production for permitting purposes?

Answer:
Using the highest year of production (331,500 tons per year) might be an appropriate and reasonable measure of production, if this figure is representative of the actual production expected to occur over the next term of the permit. Permit writers also should check to see if the maximum yearly value is within a certain percentage (e.g., 20 percent–see section 5.2.2.7 below) of the average value. In evaluating gross production figures, the number of production days should be considered. If the number of production days per year is not comparable, the permit writer would need to convert the numbers to production per day before comparing them. In this example, all the yearly production figures were based on 255 days per year of production, so they may be compared directly. The 331,500 tons per year figure is the maximum for the past 5 years, which is only 2.6 percent above the average annual production of 323,100 tons. Therefore, 331,500 tons is a reasonable measure of the annual production for the facility.

Example 2

For the same facility in Example 1 above with an annual production of 331,500 tons, the production-normalized effluent guidelines for zinc are 0.1 lbs/1,000 lbs as monthly average and 0.15 lbs/1,000 lbs as daily maximum.

Question:
What are the resulting zinc technology-based effluent limitations for the NPDES permit?

Answer:
The annual production would be converted to an average daily production rate to apply the effluent guidelines. To convert from the annual production rate to an average daily rate, divide the annual production rate by the number of production days per year. To determine the number of production days, subtract the total number of normally scheduled non-production days from the total days in a year. Because Company A normally has 255 production days per year, the annual production rate of 331,500 tons per year would yield an average production daily rate of 1,300 tons per day.

Monthly average discharge limitation for zinc*:

1,300 tons/day	x	2,000 lbs/ton	x	0.10 lbs/1,000 lbs	=	**260 lbs/day**

Daily maximum discharge limitation for zinc*:

1,300 tons/day	x	2,000 lbs/ton	x	0.15 lbs/1,000 lbs	=	**390 lbs/day**

* calculated to 2 significant figures

Calculating TBELs from Concentration-based Effluent Guidelines

Permit writers might want to develop mass-based limitations for facilities with concentration-based effluent guidelines (e.g., for a facility does not have adequate water conservation practices). Mass-based permit effluent limitations encourage water conservation (e.g., minimize the potential for diluting process wastewaters by non-process wastewater, more efficient use of water) and pollution prevention (e.g., reduce waste loads to wastewater treatment facilities by physically collecting solid materials before using water to clean equipment and facilities). Additionally, for facilities with on-site wastewater treatment systems, the combination of water-reduction technologies and practices and well-operated wastewater treatment will reduce the volume and mass of discharged wastewater pollution (i.e., after treatment). Another benefit of mass-based permit effluent limitations is that they provide the permittee with more flexibility. Permittees may elect to control their wastewater discharges through more efficient wastewater control technologies and pollution-prevention practices that result in lower pollutant concentrations in the

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discharged wastewater, or more efficient water conservation practices that result in less wastewater volume discharged from industrial operations), or both.

"EPA strongly supports water conservation and encourages all sectors, including municipal, industrial, and agricultural, to achieve efficient water use. EPA does not intend for its regulations to present a barrier to efficient water use in any industrial sector." See final 2006 Effluent Guidelines Program Plan in 71 FR 76655, December 21, 2006.

When calculating mass-based effluent limitations, the permit writer should use a conversion factor and document in the fact sheet the conversion factors used to calculate the permit limitations (e.g., concentration [mg/L] × flow [mgd] × 8.34 [conversion factor] = permit limitation [lbs/day]).

Additionally, guidance for implementing concentration-based limitations in effluent guidelines may direct permit writers to develop mass-based TBELs. For example, the *Permit Guidance Document Transportation Equipment Cleaning Point Source Category (40 CFR 442)*[7] industry states:

> The effluent limitations guidelines and standards for the TEC industry are concentration-based and adhere to the *building block* concept. Each regulated wastestream in an outfall is typically assigned a mass-based discharge allowance based on a calculation of its applicable concentration-based limitation and annual average flow. The sum of the allowances is the total mass discharge allowance for the outfall. In other words, the applicable permit limitations for facilities in more than one subcategory is the sum of the mass loadings based upon production in each subcategory and the respective subcategory effluent limitations guidelines. Mass-based limitations for unregulated or dilution wastewater streams at direct discharging facilities are established using [BPJ].

Where a permit writer cannot determine a reasonable measure of actual flow for a regulated discharge, concentration-based TBELs may be determined by directly applying the concentration-based limitations in effluent guidelines to the regulated flow and accounting for non-regulated flows at the point of compliance for the TBELs.

Supplementing Mass-based TBELs with Concentration Limitations

Even where effluent guidelines require permit writers to calculate mass-based TBELs, a permit writer may determine that it is beneficial to include concentration-based limitations to supplement the mass-based limitations. Where effluent limitations are expressed in terms of mass, a provision at § 122.45(f)(2) allows the permit writer, at his or her discretion, to express limitations in additional units (e.g., concentration units). Where limitations are expressed in more than one unit, the permittee must comply with both. The permit writer may determine that expressing limitations in terms of both concentration and mass encourages the proper operation of a treatment facility at all times.

Supplementing mass-based limitations with concentration-based limitations may be especially appropriate where the requirements in the effluent guidelines are flow-normalized (i.e., the effluent guidelines includes a concentration requirement but directs the permit writer to calculate a mass-based TBEL using the concentration requirement and the wastewater flow). The permit writer may determine that if the permit includes only mass-based limitations derived from the concentration-based limitations in the effluent guidelines, a permittee could increase its effluent pollutant concentrations above the applicable concentration requirements during low flow periods (i.e., reduce the efficiency of the wastewater

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treatment) and still meet its mass-based permit limitations. Supplementing the mass-based TBELs with concentration limitations would discourage the reduction in treatment efficiency during low-flow periods and require proper operation of treatment units at all times.

Incorporating Narrative Requirements from Effluent Guidelines

The permit writer should also ensure that any applicable narrative effluent guidelines controls or requirements are included in the permit. For example, the effluent guidelines for Concentrated Aquatic Animal Production facilities (Part 451) consist of narrative requirements implemented through BMPs. Another example, related to monitoring and compliance rather than effluent limitations, is found in the Metal Finishing effluent guidelines. The effluent guidelines allow a facility to make a statement regarding total toxic organics (TTO) in lieu of monitoring for toxic organics. Exhibit 5-15 provides an example narrative requirement representing BPT performance standards for Concentrated Aquatic Animal Production facilities, Subpart A (flow through and recirculating systems) § 455.11(a).

Exhibit 5-15 Example narrative requirement from the Concentrated Aquatic Animal Production effluent guideline—Subpart A [§ 455.11(a)]

Except as provided in [§§] 125.30 through 125.32, any existing point source subject to this subpart must meet the following requirements, expressed as practices (or any modification to these requirements as determined by the permitting authority based on its exercise of its best professional judgment) representing the application of BPT:

(a) Solids control. The permittee must:

(1) Employ efficient feed management and feeding strategies that limit feed input to the minimum amount reasonably necessary to achieve production goals and sustain targeted rates of aquatic animal growth in order to minimize potential discharges of uneaten feed and waste products to waters of the [United States]

(2) In order to minimize the discharge of accumulated solids from settling ponds and basins and production systems, identify and implement procedures for routine cleaning of rearing units and off-line settling basins, and procedures to minimize any discharge of accumulated solids during the inventorying, grading and harvesting aquatic animals in the production system.

(3) Remove and dispose of aquatic animal mortalities properly on a regular basis to prevent discharge to waters of the [United States], except in cases where the permitting authority authorizes such discharge in order to benefit the aquatic environment.

5.2.2.6 Step 6: Account for Overlapping or Multiple Effluent Guidelines Requirements

There are instances when one facility includes both new and existing sources, produces multiple products or services, or includes production or services belonging to more than one category or subcategory. In such cases, the permit writer must examine the applicable effluent guidelines closely to ensure that (1) one guideline does not supersede another; and (2) the effluent guidelines are properly applied.

Superseding Effluent Guidelines

EPA tries to minimize the overlap of different effluent guidelines by providing exclusions in the applicability sections. The effluent guidelines in the Metal Finishing point source category (Part 433) are an example of where EPA has tried to minimize the overlap of multiple effluent guidelines for certain wastewater discharges. Exhibit 5-16 presents the applicability section in Part 433 [§ 433.10(b)], which specifically excludes certain wastewaters from the Metal Finishing effluent guidelines. Another example

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is the preamble to the OCPSF effluent guidelines. The preamble identifies numerous circumstances where the OCPSF regulations are superseded by effluent guidelines for other industrial categories. Exhibit 5-17 presents excerpts from the preamble (52 FR 42523, November 5, 1987) to illustrate the point.

Exhibit 5-16 Exclusion of wastewaters in metal finishing effluent guidelines

In some cases, effluent limitations and standards for the following industrial categories might be effective and applicable to wastewater discharges from the metal finishing operations listed above [in paragraph (a)]. In such cases these Part 433 limitations shall not apply and the following regulations shall apply: [emphasis added]

- Nonferrous metal smelting and refining (40 CFR part 421)
- Coil coating (40 CFR Part 465)
- Porcelain enameling (40 CFR Part 466)
- Battery manufacturing (40 CFR Part 461)
- Iron and steel (40 CFR Part 420)
- Metal casting foundries (40 CFR Part 464)
- Aluminum forming (40 CFR Part 467)
- Copper forming (40 CFR Part 468)
- Plastic molding and forming (40 CFR Part 463)
- Nonferrous forming (40 CFR Part 471)
- Electrical and electronic components (40 CFR Part 469)

Exhibit 5-17 Excerpts from preamble to OCPSF effluent guidelines regarding applicability of effluent guidelines

- For the purposes of this regulation, OCPSF process wastewater discharges are defined as discharges from all establishments or portions of establishments that manufacture products or product groups listed in the applicability sections of this regulation, and are included within the following U.S. Department of Commerce Bureau of the Census Standard Industrial Classification (SIC) major groups:
  - SIC 2865: Cyclic Crudes and Intermediates, Dyes, and Organic Pigments.
  - SIC 2869: Industrial Organic Chemicals, not Elsewhere Classified.
  - SIC 2821: Plastic Materials, Synthetic Resins, and Nonvulcanizable Elastomers.
  - SIC 2823: Cellulosic Man-Made Fibers.
  - SIC 2824: Synthetic Organic Fibers, Except Cellulosic.

  The OCPSF regulation does not apply to process wastewater discharges from the manufacture of organic chemical compounds solely by extraction from plant and animal raw materials or by fermentation processes.
- The OCPSF regulation does not apply to discharges from OCPSF product/process operations [that] are covered by the provisions of other categorical industry effluent limitations guidelines and standards if the wastewater is treated in combination with the non-OCPSF industrial category regulated wastewater. (Different processes manufacture some products or product groups and some processes with slight operation condition variations give different products. EPA uses the term *product/process* to mean different variations of the same basic process to manufacture different products as well as to manufacture the same product using different processes.)
- The process wastewater discharges by petroleum refineries and pharmaceutical manufacturers from production of organic chemical products specifically covered by 40 CFR Part 419 Subparts C and E and Part 439 Subpart C, respectively, that are treated in combination with other petroleum refinery or pharmaceutical manufacturing wastewater, respectively, are not subject to the OCPSF regulation no matter what SIC code they use to report their products.
- Today's OCPSF category regulation applies to plastics molding and forming processes when plastic resin manufacturers mold or form crude intermediate plastic material for shipment off-site. The regulation also applies to the extrusion of fibers. Plastics molding and forming processes, other than those described above are regulated by the Plastics Molding and Forming effluent guidelines and standards (40 CFR Part 463).

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Exhibit 5-17 Excerpts from preamble to OCPSF effluent guidelines regarding applicability of effluent guidelines (continued)

- Public comments requested guidance relating to the coverage of OCPSF research and development facilities, standalone OCPSF research and development, pilot plant, technical service, and laboratory bench scale-operations are not covered by the OCSPF regulation. However, wastewater from such operations conducted in conjunction with and related to existing OCPSF manufacturing operations at OCPSF facilities is covered by the OCPSF regulation because these operations would most likely generate wastewater with characteristics similar to the commercial manufacturing facility. Research and development, pilot plant technical service, and laboratory operations [that] are unrelated to existing OCPSF plant operations, even though conducted on-site, are not covered by the OCPSF regulation because they may generate wastewater with characteristic dissimilar to that from the commercial OCPSF manufacturing facility.
- Finally, as described in the following paragraphs, this regulation does not cover certain production that has historically been reported to the Bureau of Census under a non-OCPSF SIC subgroup heading, even if such production could be reported under one of the five SIC code groups covered by today's regulation.

Multiple Effluent Guidelines Requirements

NPDES permit writers often find that a facility employs multiple processes each with its own effluent guidelines requirement. In addition, sometimes effluent guidelines from multiple categories and subcategories apply to wastewaters for a single facility. When a facility is subject to effluent guidelines for two or more processes in a subcategory or to effluent guidelines from two or more categories or subcategories, the permit writer must apply each of the applicable effluent guidelines to derive TBELs. In applying multiple effluent guidelines, the permit writer should use measures of actual production or flow that are reasonable with respect to operation of multiple processes at the same time. For example, if maximum production for one process can occur only when there is reduced production for a second process, it might not be reasonable to assume maximum production levels for both processes at the same time when applying the effluent guidelines. If all wastewaters regulated by effluent guidelines are treated separately but are combined before the discharge, the permit writer may establish internal outfalls and separately apply the effluent guidelines at the respective internal outfall as discussed in § 122.45(h) and in Step 7 below.

More commonly, wastewater streams regulated by effluent guidelines are combined during or before treatment. In such a case, the permit writer combines the allowable pollutant loadings from each set of requirements or from each set of effluent guidelines to arrive at a single TBEL for the facility using a *building block* approach. The building block approach as applied to a facility with multiple processes in the Primary Tungsten subcategory of the Primary Nonferrous Metals Manufacturing point source category (Part 421, Subpart J) is presented in Exhibit 5-18. The same principles illustrated in the exhibit would apply to a facility with processes subject to requirements from multiple subcategories or categories that are combined before or during treatment.

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Exhibit 5-18 Building block approach for applying effluent guidelines

A facility is subject to Part 421, Subpart J (Primary Tungsten). The facility uses a tungstic acid rinse, an acid leach wet air pollution control system, and an alkali leach wash in its manufacturing process.

The Maximum daily production rate for the facility is:
4.7 million pounds per day of Tungstic Acid (as W)
3.5 million pounds per day of Sodium Tungstate (as W)

Question:
What is the technology-based effluent limit for lead at the facility?

Answer:
BPT calculation for lead (§ 421.102):

a) **Tungstic acid rinse:**
(4.7 million lbs/day) × (17.230 lbs/million lbs) = 80.981 lbs/day

b) **Acid leach wet air pollution control:**
(4.7 million lbs/day) × (15.040 lbs/million lbs) = 70.688 lbs/day

c) **Alkali leach wash:**
(3.5 million lbs/day) × (0.000 lbs/million lbs) = 0.000 lbs/day

d) **Total allowable discharge** = 80.981 + 70.688 + 0.000 = 151.669 = **152 lbs/day**

BAT calculation for lead (§ 421.103):

a) **Tungstic acid rinse:**
(4.7 million lbs/day) × (11.490 lbs/million lbs) = 54.003 lbs/day

b) **Acid leach wet air pollution control:**
(4.7 million lbs/day) × (1.003 lbs/million lbs) = 4.7141 lbs/day

c) **Alkali leach wash:**
(3.5 million lbs/day) × (0.000 lbs/million lbs) = 0.000 lbs/day

d) **Total allowable discharge** = 54.003 + 4.7141 + 0.000 = 58.7171 = **59 lbs/day***

The technology-based maximum daily limitation for lead at the facility is the BAT limitation of **59 lbs/day**. That value is compared with the water quality-based effluent limitation for lead, to ensure that all applicable standards are implemented through the final effluent limitations.

* calculated to 2 significant figures

The building block approach is applied in other circumstances as well, such as

- **Mixture of mass-based and concentration-based requirements:** The limitations in effluent guidelines for some pollutants are mass-based, production-normalized limitations in some subparts and concentration-based limitations in other subparts. When all the wastewater streams go to the same treatment system, the permit writer would need to convert the concentration-based limitations to mass-based limitations so they could be combined with the mass-based, production-normalized limitations and applied to the combined wastewater streams.
- **Mixture of different concentration-based requirements:** Some facilities could have multiple operations that are each subject to different concentration-based requirements for the same pollutant but with wastewater streams that combine before treatment. In such a case, the permit writer can establish a flow-weighted concentration-based limitation as the TBEL for the combined wastewater streams or convert the concentration-based requirements to equivalent mass-based requirements using flow data and then combine the mass-based requirements into a single limitation for the combined wastewater streams.

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- **Mixture of regulated and unregulated wastewater streams:** In some cases, wastewater streams containing a pollutant regulated by the applicable effluent guidelines requirements can combine with other wastewater streams that do not have effluent guidelines requirements that regulate the pollutant. In such a case, the permit writer could use BPJ to establish a TBEL for the unregulated wastewater stream(s) (see section 5.2.3 below) and, as appropriate, calculate a final TBEL for the combined wastewater streams. For example, if one of the wastewater streams contributing to an industrial facility's discharge is sanitary wastewater, the permit writer might use BPJ to apply the treatment standards for domestic wastewater and calculate BOD_5 limitations for that wastewater stream. The secondary treatment standards, discussed in section 5.1 above, could be used to calculate mass-based limits for the sanitary wastewater using the concentration-based requirements and an estimate of flow rate that is expected to represent the flow rate during the proposed permit term. A final TBEL for BOD_5 could be calculated for the combined sanitary and process wastewater streams by combining the two mass limitations using the building block approach.
- **Mixture of wastewater streams containing a pollutant with wastewater streams not containing the pollutant:** If a wastewater stream that does not contain a pollutant is combined with another wastewater stream that contains the pollutant (and has applicable requirements in the effluent guidelines or requirements determined by the permit writer using BPJ), the permit writer must ensure that the non-regulated waste stream does not dilute the regulated waste stream to the point where the pollutant is not analytically detectable. If that occurs, the permit writer will most likely need to establish internal outfalls, as allowed under § 122.45(h) and in Step 7 below.

For examples of addressing combined wastewater streams, see section 15.3.3 on page 15-10 of EPA's *Technical Development Document for the Final Effluent Limitations Guidelines and Standards for the Meat and Poultry Products Point Source Category (40 CFR 432)*[8] <www.epa.gov/waterscience/guide/mpp/final/tdd15.pdf>.

Facilities with Both New and Existing Sources

Finally, as noted above, if effluent guidelines are applicable to an existing facility, and that facility adds a new production line, which becomes a *new source*, the permit writer should calculate TBELs for the subsequent permit using BPT, BCT, and BAT standards for the existing production line and NSPS for the new production line, as discussed in section 5.2.2.4 above.

5.2.2.7 Step 7: Apply Additional Regulatory Considerations in Calculating TBELs

The permit writer must consider several additional requirements when deriving TBELs from effluent guidelines. Those additional requirements consist of evaluating or accounting for the following:

- Expected significant increases or decreases in production during the permit term for tiered discharger limitations.
- Internal outfalls.
- Requests for a variance from effluent guidelines.

The following sections provide an overview of those topics.

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Tiered Discharge Limitations

If production rates are expected to change significantly during the life of the permit, the permit writer can include tiered (alternate) TBELs as allowed by § 122.45(b)(2)(ii)(A)(i). Tiered TBELs would apply to mass-based effluent limitations and would become effective when production or flow (or some other measure of production) exceeded a threshold value, such as during seasonal production variations. Generally, up to a 20 percent fluctuation in production is considered to be within the range of normal variability, while changes in production higher than 20 percent could warrant consideration of tiered limitations. Exhibit 5-19 illustrates application of tiered limitations.

Exhibit 5-19 Example of tiered discharge limitations

Plant B produced approximately 40 tons per day of product during spring and summer months (i.e., March through August) and 280 tons per day during fall and winter months during the previous 5 years. Production during the fall and winter months is significantly higher than during the off-season, and the discharger has made a plausible argument that production is expected to continue at that level. The effluent guidelines requirements for Pollutant Z are 0.08 lbs/1,000 lbs for the average monthly limitation and 0.14 lbs/1,000 lbs for the maximum daily limitation.

Question:
What are appropriate tiered effluent limitations for Plant B?

Answer:
The first tier or lower limitations would be based on a production rate of 40 tons per day. The limitations would apply between March and August.

Monthly average limitation:
40 tons/day × 2,000 lbs/ton x 0.08 lbs/1,000 lbs = **6.4 lbs/day***

Daily maximum limitation:
40 tons/day × 2,000 lbs/ton x 0.14 lbs/1,000 lbs = 11.2 lbs/day = **11 lbs/day***

The second tier or higher limitations would be based on a production rate of 280 tons per day. Those limitations would apply between September and February.

Monthly average limitation:
280 tons/day × 2,000 lbs/ton x 0.08 lbs/1,000 lbs = 44.8 lbs/day = **45 lbs/day***

Daily maximum limitation
280 tons/day × 2,000 lbs/ton x 0.14 lbs/1,000 lbs = 78.4 lbs/day = **78 lbs/day***

* calculated to 2 significant figures

Permit writers should include tiered limitations in a permit only after careful consideration of production data and only when a substantial increase or decrease in production is likely to occur. In the example above, the lower limitations would be in effect when production was at low levels (March through August). During periods of significantly higher production (September through February), the higher limitations would be in effect. In addition, a tiered or alternate set of limitations might be appropriate in the case of special processes or product lines that operate during certain times only.

Permit writers could base thresholds for tiered limitations on an expected increase in production during the term of the permit that will continue through the duration of the permit term. For example, if a facility plans to add a process line and significantly expand production in year 3 of the permit term, the permit could specify a higher tier of limitations that go into effect when the facility reports reaching a production level specified in the permit.

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Permit writers must detail in the permit the thresholds and time frames when each tier applies, measures of production, and special reporting requirements. Special reporting requirements include provisions such as the following:

- The facility notifying the permitting authority a specified number of business days before the month it expects to be operating at a higher level of production and the duration this level of production is expected to continue.
- The facility reporting, in the discharge monitoring report, the level of production and the limitation and standards applicable to that level.

A detailed discussion of the rationale and requirements for any tiered limitations should be provided in the fact sheet for the permit.

Internal Outfalls

The NPDES regulations at § 122.45(h) give NPDES permit writers the authority to identify internal outfalls when effluent limitations at the final outfall are impractical or infeasible. These internal compliance points might be necessary to ensure proper treatment of persistent, bioaccumulative, and toxic pollutants that are discharged in concentrations below analytic detection levels at the final effluent outfall or other pollutants that may be diluted by flows (e.g., cooling water) not containing the pollutant. Some effluent guidelines may *require* the use of internal outfalls unless the effluent limitations are adjusted based on the dilution ratio of the process wastewater to the wastewater flow at the compliance point. Examples of effluent guidelines with required internal compliance points include the Metal Finishing effluent guidelines (Part 433) and the Pulp, Paper, and Paperboard effluent guidelines (Part 430). Accordingly, the permit writer should identify any internal outfall monitoring that might be required by the applicable effluent guidelines and include monitoring requirements in the final permit.

Effluent Guidelines Variances

The CWA and federal regulations provide limited mechanisms for variances from requirements in effluent guidelines. An NPDES permit applicant must meet very specific data and variance application deadline requirements before a variance may be granted. A variance provides a unique exception to a particular requirement, and the permit writer should not expect to routinely receive variance requests. Nevertheless, the permit writer should be aware of the major types of variances and the basic requirements for each, because the permit writer will most likely be the person to conduct the initial reviews of such requests before submitting them for review to the State Director (if applicable) or to EPA.

Variance applications are submitted by the NPDES permit applicant and must be submitted before the close of the public comment period of the permit, except for Fundamentally Different Factors (FDF) variance requests, which must be requested by the NPDES permit applicant within 180 days of the effluent guidelines publication. The permit writer should consult § 124.62 for the specific procedures for decisions regarding various types of variances. Exhibit 5-20 lists the available variances from effluent guidelines.

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Exhibit 5-20 Variances from effluent guidelines

Legislation (CWA section)	Type	Regulation (40 CFR)	Approval authority	Application deadline
301(g)	Nonconventional Pollutant	Part 125, Subpart F (Reserved)	EPA Region HQ delegated authority	During permit comment period
301(n)	Fundamentally Different Factors (FDF)	Part 125, Subpart D	EPA Region HQ delegated authority	180 days from the date the limitation or standard is published in the FR
—	Net Intake or Net/Gross	§ 122.45(g)	NPDES state or EPA Region in absence of approved state NPDES program	During permit comment period

The following paragraphs further discuss the variances listed in Exhibit 5-20 and the factors that are considered in a technical review of a variance request.

Nonconventional Pollutant—CWA Section 301(g) Variance

CWA section 301(g) and the regulations at § 122.21(m)(2) provide for a variance from new or revised BAT effluent guidelines for certain nonconventional pollutants because of local environmental factors, so long as the discharger demonstrates that it is meeting BPT and that the discharge does not prevent attainment of water quality standards and would not result in additional requirements on other point or nonpoint sources. The pollutants for which a facility may request a CWA section 301(g) variance are ammonia, chlorine, color, iron, and phenols (as measured by the colorimetric 4-aminoantipyrine [4AAP] method). The CWA also provides a process to petition to include additional pollutants on this list. Industries with facilities that have applied for CWA section 301(g) variances include Iron and Steel Manufacturing (Part 420), Steam Electric Power Generating (Part 423), Inorganic Chemicals Manufacturing (Part 415), Nonferrous Metals Manufacturing (Part 421), Aluminum Forming (Part 467), and Pesticides Chemicals (Part 455) facilities.

In addition to meeting the application deadline, the discharger must file a variance application that meets the following requirements:

- The proposed modified requirements must result in compliance with BPT and water quality standards of the receiving stream.
- No additional treatment will be required of other point or nonpoint source dischargers as a result of the variance approval.
- The modified requirements will not interfere with attainment or maintenance of water quality to protect public water supplies, or with protection and propagation of a balanced population of shellfish, fish, and wildfowl, and will allow recreational activities in and on the water.
- The modified requirements will not result in quantities of pollutants that can reasonably be anticipated to pose an unacceptable risk to human health or the environment, cause acute or chronic toxicity, or promote synergistic properties.

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The permit writer should review the request to ensure that it complies with each of the requirements for this type of variance. This variance request can involve a great deal of water quality assessment, including aquatic toxicity, mixing zone and dilution model analysis, and possible site-specific criterion development. In addition, it might be necessary to assess many complex human health effects, including carcinogenicity, teratogenicity, mutagenicity, bioaccumulation, and synergistic propensities. Permit writers may use EPA's *Draft Technical Guidance Manual for the Regulations Promulgated Pursuant to Section 301(g) of the Clean Water Act of 1977 40 CFR Part 125 (Subpart F)* <www.epa.gov/npdes/pubs/owm0008.pdf> to assess a completed variance request.

Fundamentally Different Factors—FDF Variance

Alternative effluent limitations or standards different from the otherwise applicable requirements in effluent guidelines may be authorized by EPA if an individual facility is fundamentally different with respect to factors considered in establishing the limitations or standards otherwise applicable to that facility's industrial category. Such a modification is known as a *fundamentally different factors* (FDF) variance.

Facilities must submit all FDF variance applications to the appropriate Director, as defined at § 122.2, no later than 180 days from the date the limitations or standards are published in the FR [see CWA section 301(n)(2) and § 122.21(m)(1)(i)(B)(2)]. An FDF variance is not available to a new source subject to NSPS.

EPA regulations at Part 125, Subpart D, authorizing the EPA Regional Administrators to establish alternative limitations and standards, further detail the substantive criteria used to evaluate FDF variance requests for direct dischargers. The regulations at § 125.31(d) identify six factors that may be considered in determining if a facility is fundamentally different:

- Nature or quality of pollutants contained in the raw process wastewater.
- Volume of the process wastewater and effluent discharged.
- Non-water quality environmental impact of control and treatment of the raw wasteload.
- Energy requirements of the application of control and treatment technology.
- Age, size, land availability, and configurations of discharger's equipment or facilities as well as processes employed, process changes, and engineering aspects of the application of control technology.
- Cost of compliance with required control technology.

The Agency must determine whether, on the basis of one or more of those six factors, the facility in question is fundamentally different from the facilities and factors considered by EPA in developing the nationally applicable effluent guidelines. The regulation also lists four other factors that may not provide a basis for an FDF variance:

- Infeasibility of installation within the time allowed by the CWA.
- Assertion that the national limitations cannot be achieved with the appropriate waste treatment facilities installed (if the assertion is not based on one or more of the six FDF factors above).
- A discharger's ability to pay for the required water treatment.

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- The impact of a discharge on local receiving water quality.

In addition, under § 125.31(b)(3), a request for limitations less stringent than the national limitation may be approved only if compliance with the national limitations would result in either of the following:

- Removal cost wholly out of proportion to the removal cost considered during development of the national limitations.
- Non-water quality environmental impact (including energy requirements) fundamentally more adverse than the impact considered during development of the national limitations.

The conditions for approval of a request to modify applicable pretreatment standards and factors considered are the same as those for direct dischargers.

The legislative history of CWA section 301(n) underscores the necessity for the FDF variance applicant to establish eligibility for the variance. EPA's regulations at § 125.32(b)(1) are explicit in imposing that burden on the applicant. The applicant must show that the factors relating to the discharge controlled by the applicant's permit, which are claimed to be fundamentally different are, in fact, fundamentally different from those factors considered by the EPA in establishing the applicable effluent guidelines. The pretreatment regulations incorporate a similar requirement at § 403.13(h)(9).

Intake Allowance or Net/Gross Variance

Some facilities might be unable to comply with effluent guidelines because of pollutants in their intake water. Under certain circumstances, the NPDES regulations allow credit for pollutants in intake water. Specifically, permit writers are authorized to grant net credits for the quantity of pollutants in the intake water where (1) the applicable effluent guidelines specify that the guidelines are to be applied on a net basis; or (2) the pollution control technology would, if properly installed and operated, meet applicable effluent guidelines without the pollutants in the intake waters. The following requirements are included in § 122.45(g) for establishing net limitations:

- Credit for conventional pollutants, such as BOD_5 or TSS, are only authorized where the constituents resulting in the effluent BOD_5 and the TSS are similar between the intake water and the discharge.
- Credit is authorized only up to the extent necessary to meet the applicable limitation or standard, with a maximum value equal to the influent concentration.
- Intake water must be taken from the same body of water into which the discharge is made.
- Net credits do not apply to the discharge of raw water clarifier sludge generated during the treatment of intake water.

Permit writers must include influent monitoring in the permit when this type of variance is granted.

Thermal Discharge—CWA Section 316(a) Variance

CWA section 316(a) and the regulations at § 122.21(m)(6) provide for variances from thermal effluent limitations in NPDES permits. EPA has only promulgated thermal limitations in effluent guidelines for two industrial sectors: Beet Sugar Processing Subcategory of the Sugar Processing Point Source Category (Part 409 Subpart A) and the Cement Manufacturing Point Source Category (Part 411, Subparts A and B).

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Most thermal limitations are based on water quality standards, so most thermal variances actually are not true *technology-based* variances. Dischargers must apply for a thermal discharge variance with its permit application if the thermal effluent limitation is based on an effluent guideline or during the permit comment period if the thermal effluent limitation is based on a WQBEL.

Regulations for submitting and reviewing thermal discharge variance requests are promulgated at Part 125, Subpart H. The approval authority for a thermal discharge variance request is the state permitting authority or the EPA Region if there is no approved state NPDES program. Less stringent alternative thermal effluent limitations may be included in permits if the discharger properly demonstrates that such effluent limitations are more stringent than necessary to assure the protection and propagation of a balanced, indigenous community of shellfish, fish and wildlife in and on the body of water into which the discharge is made, taking into account the cumulative impact of its thermal discharge together with all other significant impacts on the species affected. Once a variance is granted, the discharger must still reapply for the variance each permit term. The majority of thermal variance requests are from power plants seeking relief from water-quality based effluent limitations.

Ambient Water Temperature Considerations

Evaluation of requests for variances under CWA section 316(a) requires consideration of the change to the ambient water temperature because of an effluent discharge. The studies provided by applicants to support their requests frequently include historical thermal data for the receiving water. Permitting authorities should be aware that the effects of global weather patterns could alter the thermal profile of some receiving waters making the historical record of thermal conditions less representative of future conditions. Where appropriate, water quality models should take these potential changes into account.

5.2.2.8 Step 8: Apply Additional Requirements in Effluent Guidelines

The effluent guidelines could provide additional requirements for permit writers to consider when applying them in NPDES permits.

Industrial Stormwater

Industrial stormwater is sometimes regulated by effluent guidelines. In particular, effluent guidelines often regulate stormwater for industrial activities that are unsheltered (e.g., mining, outdoor processing, outside storage of product materials). Examples of contaminated stormwater regulated by effluent guidelines include the Concentrated Animal Feeding Operations (Part 412), Fertilizer Manufacturing (Part 418), Petroleum Refining (Part 419), Iron and Steel Manufacturing (Part 420), Pulp, Paper, and Paperboard (Part 430), Metal Products and Machinery (Part 438), and Ore Mining and Dressing (Part 440) point source categories. The permit writer should identify any specific stormwater controls that may be required by the applicable effluent guidelines accordingly.

Stormwater not regulated by effluent guidelines that is commingled with process wastewater will require the adjustment of the effluent limitations as discussed in Step 6 above. Section 2.3.2.3 of this manual provides additional information about stormwater discharges associated with industrial activities.

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Identify the Analytical Methods for Measuring Compliance with TBELs

The permit writer should ensure that the permit specifies the use of the correct analytical methods for demonstrating compliance with TBELs derived from effluent guidelines. The effluent guidelines often require specific analytical methods. For example, the *General Definitions* section of the Meat and Poultry Products effluent guidelines [§ 432.2(l)] states, "The approved methods of analysis for the following six parameters [Ammonia (as N), BOD_5, Oil and Grease (O&G), O&G as hexane extractable material (HEM), Total Nitrogen, TSS] are found in Table 1B in [§] 136.3. The nitrate/nitrite part of total nitrogen may also be measured by EPA Method 300.0 (incorporated by reference, see § 432.5)." Section 8.3 of this manual provides additional information on analytical methods in the NPDES permitting process.

Documentation and Recordkeeping Requirements

Specific documentation and recordkeeping requirements (e.g., solvent management plans, BMP plans, alternative monitoring requirements) may be included in the applicable effluent guidelines. The permit writer should ensure that the documentation and recordkeeping requirements are included in the NPDES permit. For example, to use the alternative monitoring compliance method for controlling toxic organics in the Metal Finishing effluent guidelines, the NPDES permit applicant must not only make a certification statement (see Exhibit 5-15), but must also "submit a solvent management plan that specifies to the satisfaction of the permitting authority (or, in the case of indirect dischargers, the control authority) the toxic organic compounds used; the method of disposal used instead of dumping, such as reclamation, contract hauling, or incineration; and procedures for ensuring that toxic organics do not routinely spill or leak into the wastewater" as required by § 433.12(b). Other examples of such documentation and recordkeeping requirements include the BMP Plans used in the Oil and Gas Extraction (Part 435) and the Concentrated Aquatic Animal Production effluent guidelines (Part 451), the pollution prevention alternative in the Pesticide Chemicals effluent guidelines (Part 455), and alternative monitoring requirements (e.g., certification in lieu of monitoring for chloroform, in the Pulp, Paper, and Paperboard effluent guidelines (Part 430).

5.2.2.9 Step 9: Document the Application of Effluent Guidelines in the Fact Sheet

Permit writers need to document their application of effluent guidelines in the NPDES permit fact sheet. The permit writer should clearly identify the data and information used to determine the applicable effluent guidelines and how that information was used to derive effluent limitations for the permit. The information in the fact sheet should provide the NPDES permit applicant and the public a transparent, reproducible, and defensible description of how the NPDES permit properly incorporates effluent guidelines.

Similarly, permit writer should also document the rationale for concluding that there are no applicable effluent guidelines for a discharge or pollutant. In such cases, TBELs may be determined by the permit writer on a case-by-case basis as discussed in section 5.2.3 below.

5.2.3 Case-by-Case TBELs for Industrial Dischargers

As previously stated, § 125.3(a) indicates that technology-based treatment requirements under CWA section 301(b) represent the minimum level of control that must be imposed in an NPDES permit.

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Where EPA-promulgated effluent guidelines are not applicable to a non-POTW discharge, such requirements are established on a case-by-case basis using BPJ.

5.2.3.1 Legal Authority to Establish Case-by-Case TBELs

Case-by-case TBELs are developed pursuant to CWA section 402(a)(1), which authorizes the EPA Administrator to issue a permit that will meet either all applicable requirements developed under the authority of other sections of the CWA (e.g., technology-based treatment standards, water quality standards, ocean discharge criteria) or, before taking the necessary implementing actions related to those requirements, "such conditions as the Administrator determines are necessary to carry out the provisions of this Act." The regulation at § 125.3(c)(2) specifically cites this section of the CWA, stating that technology-based treatment requirements may be imposed in a permit "on a case-by-case basis under section 402(a)(1) of the Act, to the extent that EPA-promulgated effluent limitations are inapplicable." Further, § 125.3(c)(3) indicates that "where promulgated effluent limitations guidelines only apply to certain aspects of the discharger's operation, or to certain pollutants, other aspects or activities are subject to regulation on a case-by-case basis to carry out the provisions of the Act." When establishing case-by-case effluent limitations using BPJ, the permit writer should cite in the fact sheet or statement of basis both the approach used to develop the limitations, which is discussed further below, and how the limitations carry out the intent and requirements of the CWA and the NPDES regulations.

5.2.3.2 Identifying the Need for Case-by-Case TBELs

As noted above, case-by-case TBELs are established in situations where EPA promulgated effluent guidelines are inapplicable. That includes situations such as the following:

- When EPA has not yet promulgated effluent guidelines for the point source category to which a facility belongs (e.g., a facility that produced distilled and blended liquors [SIC code 2085] and is part of the miscellaneous foods and beverages category, which does not now have any applicable effluent guidelines).
- When effluent guidelines are available for the industry category, but no effluent guidelines are available for the facility subcategory (e.g., discharges from coalbed methane wells are not now regulated by effluent guidelines; however, EPA considers the coalbed methane industrial sector as a potential new subcategory of the existing Oil and Gas Extraction point source category [Part 435] because of the similar industrial operations performed [i.e., drilling for natural gas extraction]).
- When effluent guidelines are available for the industry category but are not applicable to the NPDES permit applicant (e.g., facilities that do not perform the industrial operation triggering applicability of the effluent guidelines or do not meet the production or wastewater flow cutoff applicability thresholds of the effluent guidelines). For example, assume that the poultry slaughterhouse in Example 2 of Exhibit 5-13 above produces 50 million pounds of whole, halved, quarter or smaller meat cuts annually. In that case, any TBELs for the facility would be case-by-case limitations developed using BPJ because the facility is below the annual production threshold of 100 million pounds listed in the effluent guideline (Part 432, Subpart K).
- When effluent guidelines are available for the industry category, but no effluent guidelines requirements are available for the pollutant of concern (e.g., a facility is regulated by the effluent guidelines for Pesticide Chemicals [Part 455] but discharges a pesticide that is not regulated by

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these effluent guidelines). The permit writer should make sure that the pollutant of concern is not already controlled by the effluent guidelines and was not considered by EPA when the Agency developed the effluent guidelines.

Generally, case-by-case limitations are appropriate when at least one of the conditions listed above applies and the pollutant is present, or expected to be present, in the discharge in amounts that can be treated or otherwise removed (e.g., implementation of pollution prevention measures). The resources listed in sections 5.2.2.2 above and 5.2.3.4 below will help the permit writer in making such determinations. For example, EPA's effluent guidelines planning support documents on EPA's Effluent Guidelines Biennial Plan Website <http://water.epa.gov/lawsregs/lawsguidance/cwa/304m/> identify facilities and industrial sectors that currently are not regulated by effluent guidelines.

5.2.3.3 Factors Considered When Developing Case-by-Case TBELs

The NPDES regulations at § 125.3(c)(2) require that permit writers developing case-by-case effluent limitations consider the following:

- The appropriate technology for the category class of point sources of which the applicant is a member, based on all available information.
- Any unique factors relating to the applicant.

The regulations also require that, in setting case-by-case limitations, the permit writer consider several specific factors established in § 125.3(d) to select a model treatment technology and derive effluent limitations on the basis of that treatment technology. That process and the factors considered by the permit writer are the same factors required to be considered by EPA in developing effluent guidelines and, therefore, are often referred to as the CWA section 304(b) factors. The factors are summarized below in Exhibit 5-21. The permit writer evaluates case-by-case limitations based on BPT, BCT, and BAT and uses the more stringent technology level of control for each pollutant of concern.

Exhibit 5-21 Summary of factors considered when developing case-by-case TBELs

For BPT requirements (all pollutants)
- The age of equipment and facilities involved*
- The process(es) employed*
- The engineering aspects of the application of various types of control techniques*
- Process changes*
- Non-water quality environmental impact including energy requirements*
- The total cost of application of technology in relation to the effluent reduction benefits to be achieved from such application

For BCT requirements (conventional pollutants)
- All items in the BPT requirements indicated by an asterisk (*) above
- The reasonableness of the relationship between the costs of attaining a reduction in effluent and the derived effluent reduction benefits
- The comparison of the cost and level of reduction of such pollutants from the discharge of POTWs to the cost and level of reduction of such pollutants from a class or category of industrial sources

For BAT requirements (toxic and non-conventional pollutants)
- All items in the BPT requirements indicated by an asterisk (*) above
- The cost of achieving such effluent reduction

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The CWA also gives the permit writer the authority to consider process changes to evaluate case-by-case limitations. As previously stated, technology-based controls in NPDES permits are performance-based measures. EPA incorporates technology-based controls in NPDES permits that correspond to the application of an identified technology (including process changes) but does not require dischargers to install the identified technology. Therefore, EPA leaves to each facility the discretion to select the technology design or process changes necessary to meet the TBELs specified in the NPDES permit.

The permit writer might need to establish a monitoring-only requirement in the current NPDES permit to identify pollutants of concern and potential case-by-case limitations for the subsequent NPDES permit renewal.

5.2.3.4 Resources for Developing Case-by-Case TBELs

There are numerous resources for identifying candidates for model technologies or process changes and developing case-by-case TBELs using BPJ. Exhibit 5-22 lists some example references that permit writers can use to derive such limitations.

5.2.3.5 Statistical Considerations When Establishing Case-by-Case TBELs

The quality of the effluent from a treatment facility will normally vary over time. If, for example, BOD_5 data for a typical treatment plant were plotted against time, one would observe day-to-day variations of effluent concentrations. Some of that behavior can be described by constructing a frequency-concentration plot. From the plot, one could observe that for most of the time, BOD_5 concentrations are near some average value. Any treatment system can be described using the mean concentration of the parameter of interest (i.e., the long-term average) and the variance (or coefficient of variation) and by assuming a particular statistical distribution (usually lognormal).

When developing a case-by-case limitation, permit writers can use an approach consistent with the statistical approach EPA has used to develop effluent guidelines. Specifically, the maximum daily limitation could be calculated by multiplying the long-term average achievable by implementation of the model technology or process change by a daily variability factor determined from the statistical properties of a lognormal distribution. The average monthly limitation can be calculated similarly except that the variability factor corresponds to the distribution of monthly averages instead of daily concentration measurements. The daily variability factor is a statistical factor defined as the ratio of the estimated 99th percentile of a distribution of daily values divided by the mean of the distribution. Similarly, the monthly variability factor is typically defined as the estimated 95th percentile of the distribution of monthly averages divided by the mean of the distribution of monthly averages.

A modified delta-lognormal distribution could be fit to concentration data and variability factors computed for the facility distribution. The modified delta-lognormal distribution models the data as a mixture of measured values and observations recorded as values less than the detectable level. This distribution often is selected because the data for many analytes consist of such a mixture of measured values and results below the detectable level. The modified delta-lognormal distribution assumes that all non-detected results have a value equal to the detection limitations and that the detected values follow a lognormal distribution.

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Exhibit 5-22 Tools for developing case-by-case TBELs using BPJ

Permit file information
- Current and previous NPDES application forms.
- Previous NPDES permit and fact sheet.
- Discharge monitoring reports.
- Compliance inspection reports.

Information from existing facilities and permits
- NPDES Individual and General Permits for other NPDES permits issued to facilities in the same region or state, or that include case-by-case limitations for the same pollutants.
- Toxicity reduction evaluations for selected industries.
- Other media permit files (e.g., Resource Conservation and Recovery Act [RCRA] permit applications and Spill Prevention Countermeasure and Control [SPCC] plans.
- ICIS-NPDES <https://icis.epa.gov/icis> data.
- Literature (e.g., technical journals and books).

Effluent guidelines development and planning information
- Industry experts within EPA headquarters, EPA Regions, and states <www.epa.gov/guide/contacts.html>.
- Development Documents, CWA section 308 questionnaires, screening and verification data, proposed and final regulations, contractor's reports, and project officer contacts <www.epa.gov/guide>.
- EPA's Technical Support Documents <http://water.epa.gov/lawsregs/lawsguidance/cwa/304m/> and records supporting EPA's biennial effluent guidelines program plans also provide additional useful information. In particular, such resources provide a sample of the current limitation and latest developments in industrial pollutant prevention, water conservation, and wastewater treatment. The Technical Support Documents also identify industrial sectors not currently regulated by effluent guidelines.

Statistical guidance
- Effluent Guidelines Technical Development Support Documents, such as the Development Document for Final Effluent Limitations Guidelines and Standards for the Iron and Steel Manufacturing Point Source Category <www.epa.gov/guide/>.

Economics guidance
- *Protocol and Workbook for Determining Economic Achievability for NPDES Permits*[9] <www.epa.gov/npdes/pubs/protocol_npdespermits.pdf> and <www.epa.gov/npdes/pubs/workbook_econ_permits.pdf>.
- *BCT Cost Test Guidance* <www.epa.gov/npdes/pubs/owm0009.pdf>.

Guidance for BMP-based limitations
- *Guidance Manual for Developing Best Management Practices (BMPs)*[10] <www.epa.gov/npdes/pubs/owm0274.pdf>.
- *Storm Water Management for Industrial Activities: Developing Pollution Prevention Plans and BMPs*[11] <www.epa.gov/npdes/pubs/contents_indguide.pdf>.
- National Menu of Stormwater Best Management Practices <www.epa.gov/npdes/stormwater/menuofbmps>.

For more details on EPA's use of statistical methods for developing effluent guidelines, refer to *Development Document for Final Effluent Limitations Guidelines and Standards for the Iron and Steel Manufacturing Point Source Category* <www.epa.gov/guide/ironsteel/reg/tdd.htm>.

5.2.3.6 Documenting Case-by-Case TBELs in the Permit Fact Sheet

Permit writers will need to document the development of case-by-case limitations in the NPDES permit fact sheet. The permit writer should clearly identify the data and information used in developing these effluent limitations and how that information was used. The permit writer also should document the rationale for concluding that there are no applicable effluent guidelines for the industrial wastewater or pollutant discharge. The information in the fact sheet should provide the NPDES permit applicant and the public a transparent, reproducible, and defensible description of how the BPJ limitations comply with the CWA and EPA regulations.

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[1] U.S. Environmental Protection Agency. 1985. *Draft Guidance for NPDES Permits and Compliance Personnel—Secondary Treatment Redefinition.* U.S. Environmental Protection Agency. Office of Water Enforcement and Permits. Washington, DC.

[2] U.S. Environmental Protection Agency. 1994. *Amended Section 301(h) Technical Support Document*. EPA-842-B-94-007. U.S. Environmental Protection Agency. Office of Wetlands Oceans and Watersheds, Washington, DC.

[3] U.S. Environmental Protection Agency. 1977. *Interim Final Supplement for Pretreatment to the Development Document for the Petroleum Refining Industry Existing Point Source Category*, EPA-440-1-76-083A. Page 92. U.S. Environmental Protection Agency, Office of Water and Hazardous Materials, Washington, DC. Publication available on NEPIS Website <www.epa.gov/nscep/> as document 440176083A.

[4] Boornazian, Linda and Mary Smith. 2006. *New Source Dates for Direct and Indirect Dischargers*. U.S. Environmental Protection Agency, Office of Water Memorandum. September 28, 2006. <www.epa.gov/npdes/pubs/newsource_dates.pdf>.

[5] U.S. Environmental Protection Agency. 1987. *Development Document for Effluent Limitations Guidelines and Standards for the Organic Chemicals, Plastics and Synthetic Fibers Point Source Category*. EPA 440-1-87-009. Page IX-9. <www.epa.gov/waterscience/guide/ocpsf/#guidance>.

[6] Jordan, J.W. 1984. *Calculations of Production-Based Effluent Limits*. U.S. Environmental Protection Agency, Office of Water, Washington, DC. Memorandum, December 18, 1984. <www.epa.gov/npdes/pubs/owm0427.pdf>.

[7] U.S. Environmental Protection Agency. 2001. *Permit Guidance Document: Transportation Equipment Cleaning Point Source Category (40 CFR 442)*, p. 30. EPA-821-R-01-021. U.S. Environmental Protection Agency, Office of Water, Washington, DC. <www.epa.gov/waterscience/guide/teci/tecguid.pdf>.

[8] U.S. Environmental Protection Agency. 2004. *Technical Development Document for the Final Effluent Limitations Guidelines and Standards for the Meat and Poultry Products Point Source Category (40 CFR 432),* EPA-821-R-04-011. U.S. Environmental Protection Agency, Office of Water, Washington, DC. <www.epa.gov/waterscience/guide/mpp/final/tdd15.pdf>.

[9] Putnam, Hayes and Bartlett, Inc. 1982. *Protocol and Workbook for Determining Economic Achievability for National Pollutant Discharge Elimination System Permits*. U.S. Environmental Protection Agency, Permits Division, Washington, DC. <www.epa.gov/npdes/pubs/protocol_npdespermits.pdf.> and <www.epa.gov/npdes/pubs/workbook_econ_permits.pdf>

[10] U.S. Environmental Protection Agency. 1993. *Guidance Manual for Developing Best Management Practices (BMP)*. EPA 833-B-93-004. U.S. Environmental Protection Agency, Office of Water, Washington, DC. <www.epa.gov/npdes/pubs/owm0274.pdf>.

[11] U.S. Environmental Protection Agency. 1992. *Storm Water Management for Industrial Activities: Developing Pollution Prevention Plans and BMPs*. EPA 832-R-92-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC. <www.epa.gov/npdes/pubs/contents_indguide.pdf>.

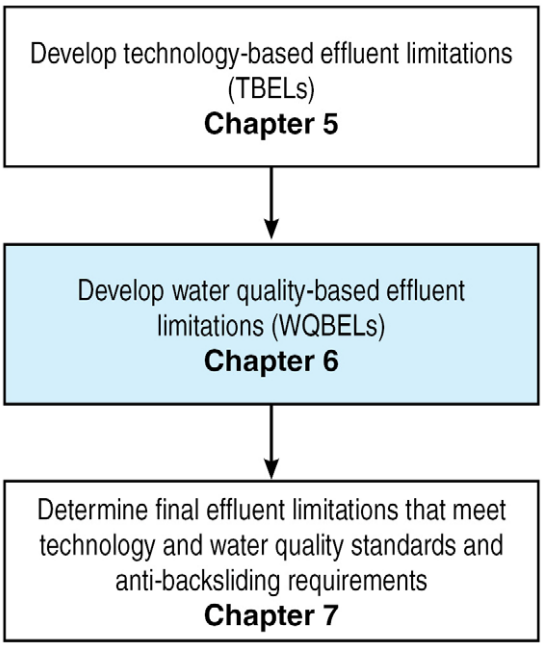
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CHAPTER 6. Water Quality-Based Effluent Limitations

When drafting a National Pollutant Discharge Elimination System (NPDES) permit, a permit writer must consider the impact of the proposed discharge on the quality of the receiving water. Water quality goals for a waterbody are defined by state water quality standards. By analyzing the effect of a discharge on the receiving water, a permit writer could find that technology-based effluent limitations (TBELs) alone will not achieve the applicable water quality standards. In such cases, the Clean Water Act (CWA) and its implementing regulations require development of water quality-based effluent limitations (WQBELs). WQBELs help meet the CWA objective of restoring and maintaining the chemical, physical, and biological integrity of the nation's waters and the goal of water quality that provides for the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water (*fishable/swimmable*).

WQBELs are designed to protect water quality by ensuring that water quality standards are met in the receiving water. On the basis of the requirements of Title 40 of the *Code of Federal Regulations* (CFR) 125.3(a), additional or more stringent effluent limitations and conditions, such as WQBELs, are imposed when TBELs are not sufficient to protect water quality. Exhibit 6-1 illustrates the relationship between TBELs and WQBELs in an NPDES permit, as well as the determination of final effluent limitations.

Exhibit 6-1 Developing effluent limitations

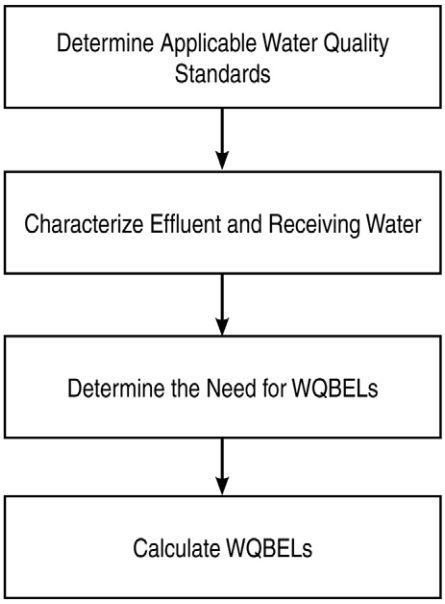


CWA section 301(b)(1)(C) requires that permits include any effluent limitations necessary to meet water quality standards. As illustrated above, to satisfy that requirement, permit writers implement a process to determine when existing effluent limitations (e.g., TBELs) and existing effluent quality are not sufficient to comply with water quality standards and to, where necessary, develop WQBELs. Exhibit 6-2 illustrates the four basic parts of the *standards-to-permits* process used to assess the need for and develop WQBELs.

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After completing that process, the permit writer determines the final effluent limitations, includes any compliance schedules and interim effluent limitations, as appropriate, and documents all his or her decisions and calculations.

Exhibit 6-2 Standards-to-permits process



This chapter provides basic information on the standards-to-permits process. For more detailed information on water quality standards and water quality-based permitting, and some of the specific topics discussed in this chapter, refer to the NPDES Website <www.epa.gov/npdes> and Water Quality Standards Website <www.epa.gov/waterscience/standards>.

6.1 Determine Applicable Water Quality Standards

CWA section 303(c) and Part 131 establish the framework for water quality standards. The CWA and implementing regulations require states to develop and, from time to time, revise water quality standards applicable to waters of the United States, or segments of such waterbodies, that are in the jurisdiction of the state. States must review their water quality standards at least once every 3 years and revise them as appropriate. Wherever attainable, water quality standards should protect water quality that provides for the protection and propagation of fish, shellfish and wildlife, and recreation in and on the water (i.e., the CWA section 101(a)(2) *fishable/swimmable* goal). In establishing standards, states must consider the use and value of their waters for public water supplies, propagation of fish and wildlife, recreation, agriculture and industrial purposes, and navigation. The U.S. Environmental Protection Agency (EPA) has provided information regarding procedures for developing water quality standards in the Water Quality Standards Regulation at Part 131 and EPA's *Water Quality Standards Handbook: Second Edition*[1] <www.epa.gov/waterscience/library/wqstandards/handbook.pdf.> (hereafter *WQS Handbook*). Under CWA section 510, states may develop water quality standards that are more stringent than those required by the CWA.

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EPA Regions review and approve or disapprove new and revised water quality standards adopted by states. The purpose of EPA's review is to ensure that the new and revised water quality standards meet the requirements of the CWA and the Water Quality Standards Regulation. Water quality standards adopted and submitted to EPA after May 30, 2000, must be approved by EPA before they may be used to implement the CWA (e.g., used in NPDES permitting). If an EPA Region disapproves a submitted new or revised state water quality standard, and the state does not adopt the necessary changes within 90 days of notification of the disapproval, EPA must promptly propose and promulgate a replacement standard [see § 131.22(a)].

When writing an NPDES permit, the permit writer must identify and use the state water quality standards in effect for CWA purposes. EPA maintains a compilation of current state water quality standards on the Water Quality Standards: State, Tribal, & Territorial Standards Website <www.epa.gov/waterscience/standards/wqslibrary/>. In addition, EPA's Water Quality Standards: Laws and Regulations Website <www.epa.gov/waterscience/standards/rules/> provides federally promulgated standards applicable to specific states. The remainder of this section provides permit writers with a general overview of water quality standards and how they are implemented in NPDES permits.

6.1.1 Components of Water Quality Standards

Water quality standards comprise three parts:

- Designated uses.
- Numeric and/or narrative water quality criteria.
- Antidegradation policy.

Each of those three components, along with general policies that also may be included in state water quality standards, is described below.

6.1.1.1 Designated Uses (§ 131.10)

The first part of a state's water quality standards is a classification system for waterbodies based on the expected uses of those waterbodies. The uses in this system are called *designated uses*. The regulations at § 131.10(a) describe various uses of waters that are considered desirable and that must be considered when establishing water quality standards. Those uses include public water supplies, propagation of fish, shellfish, and wildlife, recreation in and on the water, agricultural, industrial, and other purposes including navigation. The regulations allow states to designate more specific uses (e.g., cold water aquatic life) [see § 131.10(c)] or uses not specifically mentioned in the CWA, with the exception of waste transport and assimilation, which are not acceptable designated uses [see § 131.10(a)]. States must also consider and ensure the attainment and maintenance of the water quality standards of downstream waters when establishing designated uses [see § 131.10(b)].

The regulations in § 131.10(j) effectively establish a *rebuttable presumption* that the uses in CWA section 101(a)(2) (fishable/swimmable) are attainable. If a state fails to designate a given waterbody for such uses, or wishes to remove such uses, it must provide appropriate documentation demonstrating why such uses are not attainable. This analysis is commonly called a *Use Attainability Analysis* (UAA) (see § 131.3(g) and section 6.1.2.1 below).

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6.1.1.2 Water Quality Criteria (§ 131.11)

The second part of a state's water quality standards is the set of water quality criteria sufficient to support the designated uses of each waterbody. EPA's Water Quality Standards Regulation at § 131.11(a) requires states to adopt water quality criteria using sound scientific rationale and to include sufficient parameters or constituents to protect the designated use. If a waterbody has multiple use designations, the criteria must support the most sensitive use. The regulation at § 131.11(b) allows states to adopt both numeric and narrative water quality criteria. Numeric water quality criteria are developed for specific parameters to protect aquatic life and human health and, in some cases, wildlife from the deleterious effects of pollutants. States establish narrative criteria where numeric criteria cannot be established, or to supplement numeric criteria. Criteria newly adopted or revised on or after May 30, 2000, do not become effective for purposes of the CWA until approved by EPA [see § 131.21(c)].

CWA section 304(a) directs EPA to develop, publish, and, from time to time, revise criteria for water quality accurately reflecting the latest scientific knowledge on the following:

- The kind and extent of all identifiable effects on health and welfare, including effects on aquatic life and recreational uses, that may be expected from the presence of pollutants in any body of water.
- The concentration and dispersal of pollutants or their byproducts through biological, physical, and chemical processes.
- The effects of pollutants on biological community diversity, productivity, and stability.

EPA's recommended criteria developed under CWA section 304(a) assist states in developing their water quality standards. EPA's numeric criteria are ambient levels of individual pollutants or parameters or they describe conditions of a waterbody that, if met, generally will protect the CWA section 101(a)(2) fishable and swimmable uses. EPA's recommended criteria developed under CWA section 304(a) do not reflect consideration of economic impacts or the technological feasibility of meeting the chemical concentrations in ambient water. EPA provides a table of the nationally recommended CWA section 304(a) criteria on the National Recommended Water Quality Criteria Website <www.epa.gov/waterscience/criteria/wqctable/>. The regulation at § 131.11(b)(1) indicates that, in establishing numeric criteria, states may (1) adopt EPA's recommended criteria published under CWA section 304(a), (2) adopt those criteria modified to reflect site-specific conditions, or (3) adopt criteria based on other scientifically defensible methods.

CWA section 303(c)(2)(B) specifically requires states to adopt numeric criteria for CWA section 307(a) toxic (priority) pollutants for which EPA has published recommended criteria if the discharge or presence of the pollutant can reasonably be expected to interfere with designated uses. Furthermore, § 131.11(a)(2) requires states to review water quality data and information on discharges to identify specific water bodies where toxic pollutants might be adversely affecting water quality or attainment of designated uses or where levels of toxic pollutants would warrant concern and to adopt criteria for such toxic pollutants applicable to the waterbody that are sufficient to protect the designated use. As discussed in section 1.2 and presented in Exhibit C-1 in Appendix C of this manual, the CWA section 307(a) list contains 65 compounds and families of compounds, which EPA has interpreted to include 126 toxic (priority) pollutants.

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Numeric Criteria—Aquatic Life

Numeric criteria for the protection of aquatic life are designed to protect aquatic organisms, including both plants and animals. EPA's aquatic life criteria address both short-term (acute) and long-term (chronic) effects on both freshwater and saltwater species. Each of those criteria generally consists of three components:

- **Magnitude:** The level of pollutant (or pollutant parameter), usually expressed as a concentration, that is allowable.
- **Duration:** The period (averaging period) over which the in-stream concentration is averaged for comparison with criteria concentrations.
- **Frequency:** How often criteria may be exceeded.

Are criteria and effluent limitations expressed in the same terms?

Generally, criteria and effluent limitations are not expressed in the same terms. As discussed above, criteria are generally expressed as a magnitude, duration and frequency. Effluent limitations in NPDES permits are generally expressed as a magnitude (e.g., milligrams per liter, micrograms per liter) and an averaging period (e.g., maximum daily, average weekly, average monthly). A permit writer should be aware of the procedures used by his or her permitting authority to appropriately reflect the magnitude, duration, and frequency components of aquatic life criteria when determining the need for and calculating effluent limitations for NPDES permits. Typically, the components of the criteria are addressed in water quality models through the use of statistically derived receiving water and effluent flow values that ensure that criteria are met under *critical conditions* (see section 6.2 below).

Exhibit 6-3 is an example of freshwater aquatic life criteria for cadmium from the National Recommended Water Quality Criteria Website <www.epa.gov/waterscience/criteria/wqctable/> and at 66 FR 18935, April 12, 2001, Notice of Availability of 2001 Update: Aquatic Life Criteria Document for Cadmium <www.epa.gov/EPA-WATER/2001/April/Day-12/w9056.htm>.

Exhibit 6-3 Aquatic life criteria example: Cadmium (dissolved)

Except possibly where a locally important species is unusually sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if

Chronic criterion:
The 4-day average concentration (in micrograms per liter [µg/L]) does not exceed the numerical value given by $e^{(0.7409[\ln(\text{hardness})]-4.719)}$ (1.101672 – [(ln hardness)(0.041838)]) more than once every 3 years on average.

Acute criterion:
The 24-hour average concentration (in µg/L) does not exceed the numerical value given by $e^{(1.0166[\ln(\text{hardness})]-3.924)}$ (1.136672 – [(ln hardness)(0.041838)]) more than once every 3 years on average.

It is apparent that the acute and chronic aquatic life criteria for cadmium are not simply single numbers. Rather, they are expressed as a magnitude, a duration (4-day average or 24-hour average), and a frequency (not more than once every 3 years). Furthermore, the magnitude is expressed by a formula that is hardness-dependent, as is the case for most criteria for metals.

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The magnitude of other aquatic life criteria can vary according to other conditions in the water or even based on the presence or absence of certain aquatic life. For example, EPA's 1999 recommended ammonia criteria vary according to pH, temperature, the presence or absence of salmonid species, and the presence or absence of early life stages of fish. A permit writer must be aware of the applicable criteria and any state regulations, policies, and procedures for interpreting numeric criteria and for implementing the criteria in NPDES permits. The durations of aquatic life criteria vary as well. For example, EPA's criteria recommendations for ammonia include a 30-day average chronic criterion. Also, many acute criteria for toxic pollutants are expressed as a 1-hour average. The frequency component of most aquatic life criteria specifies that they should be exceeded no more than once every three years.

Some states have adopted numeric criteria for nutrients as part of their water quality standards. EPA has developed nutrient criteria recommendations that are numeric values for both causative (phosphorus and nitrogen) and response (chlorophyll *a* and turbidity) variables associated with the prevention and assessment of eutrophic conditions. EPA's recommended nutrient criteria are different from most of its other recommended criteria, such as the criteria for cadmium and ammonia. First, EPA's recommended nutrient criteria are *ecoregional* rather than nationally applicable criteria, and they can be refined and localized using nutrient criteria technical guidance manuals. Second, the recommended nutrient criteria represent conditions of surface waters that have minimal impacts caused by human activities rather than values derived from laboratory toxicity testing. Third, the recommended nutrient criteria are do not include specific duration or frequency components; however, the ecoregional nutrient criteria documents indicate that states may adopt seasonal or annual averaging periods for nutrient criteria instead of the 1-hour, 24-hour, or 4-day average durations typical of aquatic life criteria for toxic pollutants. The ecoregional nutrient criteria documents, technical guidance manuals, and other information on EPA's nutrient criteria recommendations, are available on the Water Quality Criteria for Nitrogen and Phosphorus Pollution Website <www.epa.gov/waterscience/criteria/nutrient/>.

Water quality standards also typically include aquatic life criteria for parameters such as temperature and pH that are not chemical constituents. Criteria for pH generally are expressed as an acceptable pH range in the waterbody. Temperature criteria might be expressed as both *absolute temperature values* (e.g., temperature may not exceed 18 degrees Celsius [°C]) and restrictions on causing *changes in temperature* in the waterbody (e.g., discharges may not warm receiving waters by more than 0.5 °C).

In addition to criteria for individual pollutants or pollutant parameters, many states include in their water quality standards criteria for dissolved oxygen. Often, criteria for dissolved oxygen are addressed by modeling and limiting discharges of oxygen-demanding pollutants such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), and nutrients (phosphorus and nitrogen).

Finally, states could also include in their water quality standards numeric criteria to address the effect of mixtures of pollutants. For example, whole effluent toxicity (WET) criteria protect the waterbody from the aggregate and synergistic toxic effects of a mixture of pollutants. WET is discussed in detail later in this chapter.

Numeric Criteria—Human Health

Human health criteria for toxic pollutants are designed to protect people from exposure resulting from consumption of fish or other aquatic organisms (e.g., mussels, crayfish) or from consumption of both water and aquatic organisms. These criteria express the highest concentrations of a pollutant that are not

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expected to pose significant long-term risk to human health. Exhibit 6-4 is an example of human health criteria for dichlorobromomethane.

Exhibit 6-4 Human health criteria example: Dichlorobromomethane

For the protection of human health from the potential carcinogenic effects of dichlorobromomethane through ingestion of water and contaminated aquatic organisms, the ambient water criterion is determined to be 0.55 µg/L.
For the protection of human health from the potential carcinogenic effects of dichlorobromomethane through ingestion contaminated aquatic organisms alone, the ambient water criterion is determined to be 17 µg/L.
These values were calculated based on a national default freshwater/estuarine fish consumption rate of 17.5 grams per day.

Other criteria for protection of human health (e.g., bacteria criteria) consider a shorter-term exposure through uses of the waterbody such as contact recreation. EPA's current bacteria criteria recommendations use enterococci and *Escherichia coli* bacteria as indicators and include two components: a geometric mean value and a single sample maximum value. EPA has developed information on implementing those criteria in water quality standards on the Microbial (Pathogen) Water Quality Criteria Website <www.epa.gov/waterscience/criteria/humanhealth/microbial/>.

Other Numeric Criteria

In addition to aquatic life and human health criteria, some state water quality standards include other forms of numeric criteria, such as wildlife, sediment, and biocriteria.

Wildlife criteria are derived to establish ambient concentrations of chemicals that, if not exceeded, will protect mammals and birds from adverse impacts resulting from exposure to those chemicals through consumption of aquatic organisms and water. EPA established four numeric criteria to protect wildlife in the Great Lakes system in its *Final Water Quality Guidance for the Great Lakes System* <www.epa.gov/EPA-WATER/1995/March/Day-23/pr-82.html> (60 FR 15387, March 23, 1995).

In a healthy aquatic community, sediments provide a habitat for many living organisms. Controlling the concentration of pollutants in the sediment helps to protect bottom-dwelling species and prevents harmful toxins from moving up the food chain and accumulating in the tissue of animals at progressively higher levels. For more information on this topic, see EPA's Suspended and Bedded Sediments Website <www.epa.gov/waterscience/criteria/sediment/>.

The presence, condition and numbers of types of fish, insects, algae, plants, and other organisms are data that, together, provide direct, accurate information about the health of specific bodies of water. Biological criteria (biocriteria) are narrative or numeric expressions that describe the reference biological integrity (structure and function) of aquatic communities inhabiting waters of a given designated aquatic life use. Biocriteria are based on the numbers and kinds of organisms present and are regulatory-based biological measurements. They are used as a way of describing the qualities that must be present to support a desired condition in a waterbody, and they serve as the standard against which biological assessment results are compared. EPA's Biocriteria: Uses of Data in NPDES Permits Website <www.epa.gov/waterscience/biocriteria/watershed/npdes.html> provides more information on the use of bioassessment information.

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Narrative Criteria

All states have adopted narrative water quality criteria to supplement numeric criteria. Narrative criteria are statements that describe the desired water quality goal for a waterbody. Narrative criteria, for example, might require that discharges be "free from toxics in toxic amounts" or be "free of objectionable color, odor, taste, and turbidity." Narrative criteria can be the basis for limiting specific pollutants for which the state does not have numeric criteria [§ 122.44(d)(1)(vi)] or they can be used as the basis for limiting toxicity using WET requirements where the toxicity has not yet been traced to a specific pollutant or pollutants [§ 122.44(d)(1)(v)]. For toxic pollutants, EPA's Water Quality Standards Regulation at § 131.11(a)(2) requires states to develop implementation procedures for toxics narrative criteria that address how the state intends to regulate point source discharges of toxic pollutants to water quality limited segments.

6.1.1.3 Antidegradation Policy (§ 131.12)

The third part of a state's water quality standards is its antidegradation policy. Each state is required to adopt an antidegradation policy consistent with EPA's antidegradation regulations at § 131.12. A state's antidegradation policy specifies the framework to be used in making decisions about proposed activities that will result in changes in water quality. Antidegradation policies can play a critical role in helping states protect the public resource of water whose quality is better than established criteria levels and ensure that decisions to allow reductions in water quality are made in a public manner and serve the public good. Along with developing an antidegradation policy, each state must identify the method it will use to implement the policy. It is important for permit writers to be familiar with their state's antidegradation policy and how that policy is to be implemented in NPDES permits.

A state's antidegradation policy provides three levels of protection from degradation of existing water quality:

- **Tier 1:** This tier requires that existing uses, and the level of water quality necessary to protect the existing uses, be maintained and protected.
- **Tier 2:** Where the quality of waters exceeds levels necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water (sometimes referred to as *high-quality waters*), Tier 2 requires that this level of water quality be maintained and protected unless the state finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the state's continuing planning process, that allowing lower water quality is necessary to accommodate important economic or social development in the area where the waters are located. In allowing any such degradation or lower water quality, the state must assure water quality adequate to protect existing uses fully and must assure that there will be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable best management practices for nonpoint source control.
- **Tier 3:** This tier requires that the water quality of *outstanding national resources waters* (ONRWs) be maintained and protected.

States take a variety of approaches to implementing antidegradation policies. Some states designate their waters as Tier 1, Tier 2 (high-quality water) or Tier 3 waters in their antidegradation implementation methods, while others designate a waterbody as a Tier 2 or high-quality water only when activities that would degrade water quality are proposed. In some cases, states may have classified the waterbody as

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receiving a tier of protection for all pollutant-related parameters, whereas in other cases, tiers of protection have been determined on a parameter-by-parameter basis.

6.1.1.4 General Policies (§ 131.13)

In addition to the three required components of water quality standards, states may, at their discretion, include in their standards policies that generally affect how the standards are applied or implemented. Examples of such policies include mixing zone policies, critical low flows at which criteria must be achieved, and the availability of variances. Some general policies are discussed in more detail later in this chapter. As with the other components of water quality standards, general policies are subject to EPA review and approval if they are deemed to be new or revised water quality standards (i.e., if they constitute a change to designated use(s), water quality criteria, antidegradation requirements, or any combination).

Additional and more detailed information on water quality standards is available in the WQS Handbook.

6.1.2 Water Quality Standards Modifications

Permit writers should be aware of several types of modifications to water quality standards that could permanently or temporarily change the standards and, thus, change the fundamental basis of WQBELs. Those modifications, described below, are as follows:

- Designated use reclassification.
- Site-specific water quality criteria modification.
- Water quality standard variance.

6.1.2.1 Designated Use Reclassification

Once a use has been designated for a particular waterbody or segment, that use may not be removed from the water quality standards except under specific conditions. To remove a designated use, the state demonstrates that attaining that use is not feasible because of any one of the six factors listed in § 131.10(g). The regulations at § 131.10(j) specifically require a state to conduct a UAA if the designated uses for a waterbody do not include the uses in CWA section 101(a)(2) (i.e., fishable/swimmable uses); if the state wishes to remove designated uses included in CWA section 101(a)(2) from its water quality standards; or if the state wishes to adopt subcategories of CWA section 101(a)(2) uses with less stringent criteria. The WQS Handbook discusses UAAs and removing designated uses in detail. Reclassifying a waterbody's designated uses, as supported by a UAA, is a permanent change to both the designated use(s) and the water quality criteria associated with that (those) use(s).

States may conduct a UAA and remove a designated use but not if it is an existing use. Existing uses are defined in § 131.3 as those uses actually attained in the waterbody on or after November 28, 1975 (the date of EPA's initial water quality standards regulation at 40 *Federal Register* 55334, November 28, 1975). At a minimum, uses are deemed attainable if they can be achieved by the implementing effluent limits required under CWA sections 301(b) and 306 and by implementing cost effective and reasonable best management practices (BMPs) for nonpoint source control. EPA's Water Quality Standards: UAA Website <www.epa.gov/waterscience/standards/uses/uaa/index.htm> provides additional information and some example UAAs.

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6.1.2.2 Site-Specific Water Quality Criteria Modification

As noted above, CWA sections 303(a)–(c) require states to adopt water quality criteria sufficient to protect applicable designated uses. In some cases, a state might find that the criteria it has adopted to protect a waterbody or segment of a waterbody do not adequately account for site-specific conditions. In such cases, states have the option of modifying water quality criteria on a site-specific basis. Setting site-specific criteria might be appropriate where, for example, a state has adopted EPA's CWA section 304(a) criteria recommendations and finds that physical or chemical properties of the water at a site affect the bioavailability or toxicity of a chemical, or the types of local aquatic organisms differ significantly from those actually tested in developing the EPA-recommended criteria. Site-specific criteria modifications change water quality criteria permanently while continuing to support the current designated uses.

Development of site-specific criteria for aquatic life is discussed in section 3.7 of the WQS Handbook for cases when (1) there might be relevant differences in the toxicity of the chemical in the water at the site and laboratory dilution water (Water-Effect Ratio Procedure) and (2). the species at the site are more or less sensitive than those used in developing the natural criteria (Species Recalculation Procedure). EPA's Office of Science and Technology (OST) has developed the Interim Guidance on Determination and Use of Water-Effect Ratios for Metals <www.epa.gov/waterscience/standards/handbook/handbookappxL.pdf> in Appendix L of the WQS Handbook and the *Streamlined Water-Effect Ratio Procedure for Discharges of Copper*[2] <www.epa.gov/waterscience/criteria/copper/copper.pdf>. In addition, pages 90-97 of Appendix L provide guidance for using the Species Recalculation Procedure. States may also consider establishing aquatic life criteria based on *natural background* conditions. Further information can be found in the memo *Establishing Site Specific Aquatic Life Criteria Equal to Natural Background*[3] <www.epa.gov/waterscience/library/wqcriteria/naturalback.pdf>.

6.1.2.3 Water Quality Standard Variance

Water quality standard variances are changes to water quality standards and have similar substantive and procedural requirements as what are required to remove a designated use. Unlike use removal, variances are time-limited and do not permanently remove the current designated use of a waterbody. Variances are usually discharger- and pollutant-specific, though some states have adopted *general variances*. Where a state has adopted a general variance, the analyses necessary for the variance have been completed on a watershed-wide or statewide basis and, therefore, the process of obtaining a variance is simplified for individual dischargers in that watershed or state.

A variance might be appropriate where the state believes that the existing standards are ultimately attainable and that, by retaining the existing standards rather than changing them, the state would ensure that further progress is made in improving the water quality toward attaining the designated uses while the variance is in effect. State-adopted variances have been approved by EPA where, among other things, the state's standards allow variances and the state demonstrates that meeting the applicable criteria is not feasible on the basis of one or more of the factors outlined in § 131.10(g). A variance typically is granted for a specified period and must be reevaluated at least once every 3 years as reasonable progress is made toward meeting the standards [see section 5.3 of the WQS Handbook and § 131.20(a)].

Modifications of water quality standards could affect effluent limitations in permits in several ways. Specifically, the modifications can change the fundamental basis for WQBELs, potentially affecting an assessment of the need for WQBELs and possibly resulting in either more or less stringent WQBELs than

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would otherwise be required. It is the permit writer's responsibility to ensure that any EPA-approved modification of water quality standards is properly reflected in an affected NPDES permit.

6.1.3 Water Quality Standards Implementation

As previously noted, CWA section 301(b)(1)(C) requires NPDES permits to establish effluent limitations as necessary to meet water quality standards. Effluent limitations and other conditions in NPDES permits may be based on a parameter-specific approach or a WET testing approach to implementing water quality standards. A third approach to implementing water quality standards, using biocriteria or bioassessment, is not directly accomplished through NPDES permit effluent limitations but can lead to effluent limitations for specific parameters or for WET. Each of those approaches to implementing water quality standards is discussed briefly below.

What procedures should permit writers use to implement water quality standards?

The terminology used and procedures described in this manual when discussing both assessing the need for and calculating WQBELs are based on the procedures in EPA's *Technical Support Document for Water Quality-Based Toxics Control*[4] <www.epa.gov/npdes/pubs/owm0264.pdf> (hereafter *TSD*). Those procedures were developed specifically to address toxic pollutants but have been appropriately used to address a number of conventional and nonconventional pollutants as well. Permit writers should be aware that most permitting authorities have developed their own terminology and procedures for water quality-based permitting, often derived from, but with variations on, EPA's guidance. For example, EPA itself promulgated *Final Water Quality Guidance for the Great Lakes System* (60 FR 15387, March 23, 1995) with minimum water quality criteria, antidegradation policies, and implementation procedures, including permitting procedures based on the TSD. Under the CWA, Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin were required to adopt procedures for the Great Lakes system that are consistent with that guidance. Permit writers should always consult the applicable permitting regulations, policy, and guidance for the approved water quality-based permitting procedures in their state.

6.1.3.1 Parameter-Specific Approach

The parameter-specific approach uses parameter-specific criteria for protection of aquatic life, human health, wildlife, and sediments, as well as any other parameter-specific criteria adopted into a state's water quality standards. The criteria are the basis for analyzing an effluent, deciding which parameters need controls, and deriving effluent limitations that will control those parameters to the extent necessary to achieve water quality standards in the receiving water. Parameter-specific WQBELs in NPDES permits involve a site-specific evaluation of the discharge (or proposed discharge) and its potential effect on the receiving water or an evaluation of the effects of multiple sources of a pollutant on the receiving water (e.g., through a total maximum daily load [TMDL] analysis). The parameter-specific approach allows for controlling individual parameters, (e.g., copper, BOD, total phosphorus) before a water quality impact has occurred or for helping return water quality to a level that will meet designated uses.

6.1.3.2 Whole Effluent Toxicity (WET) Approach

WET requirements in NPDES permits protect aquatic life from the aggregate toxic effect of a mixture of pollutants in the effluent. WET tests measure the degree of response of exposed aquatic test organisms to an effluent. The WET approach is useful for complex effluents where it might be infeasible to identify

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and regulate all toxic pollutants in the effluent or where parameter-specific effluent limitations are set, but the combined effects of multiple pollutants are suspected to be problematic. The WET approach allows a permit writer to implement numeric criteria for toxicity included in a state's water quality standards or to be protective of a narrative "no toxics in toxic amounts" criterion. Like the parameter-specific approach, the WET approach allows permitting authorities to control toxicity in effluents before toxic impacts occur or may be used to help return water quality to a level that will meet designated uses.

6.1.3.3 Bioassessment Approach

The biocriteria approach is used to assess the overall biological integrity of an aquatic community. As discussed in section 6.1.1.2 above, biocriteria are numeric values or narrative statements that describe the biological integrity of aquatic communities inhabiting waters of a given designated aquatic life use. When incorporated into state water quality standards, biocriteria and aquatic life use designations serve as direct endpoints for determining aquatic life use attainment. Once biocriteria are developed, the biological condition of a waterbody can be measured through a biological assessment, or bioassessment.

A bioassessment is an evaluation of the biological condition of a waterbody using biological surveys and other direct measurements of resident biota in surface waters. A biological survey, or biosurvey, consists of collecting, processing, and analyzing representative portions of a resident aquatic community to determine the community structure and function. The results of biosurveys can be compared to the reference waterbody to determine if the biocriteria for the designated use of the waterbody are being met. EPA issued guidance on this approach in *Biological Criteria: National Program Guidance for Surface Waters*[5] <www.epa.gov/bioindicators/html/biolcont.html>. As previously discussed, biocriteria generally are not directly implemented through NPDES permits but could be used in assessing whether a waterbody is attaining water quality standards. Nonattainment of biocriteria could lead to parameter-specific effluent limitations where the permitting authority is able to identify specific pollutant(s) and source(s) contributing to that nonattainment (see EPA's Biocriteria: Uses of Data – Identify Stressors to a Waterbody Website <www.epa.gov/waterscience/biocriteria/uses/stressors.html>) or could lead to WET limitations where the permitting authority identifies sources of toxicity to aquatic life. EPA's Biocriteria: Uses of Data - NPDES <www.epa.gov/waterscience/biocriteria/watershed/npdes.html> provides examples on the use of bioassessment information in the NPDES permitting process.

Sections 6.2–6.4 below discuss, in detail, implementing water quality standards using the parameter-specific approach to assess the need for and develop effluent limitations in NPDES permits. Section 6.5 below provides additional detail on WET requirements in NPDES permits.

6.2 Characterize the Effluent and the Receiving Water

After identifying the most current, approved, water quality standards that apply to a waterbody, a permit writer should characterize both the effluent discharged by the facility being permitted and the receiving water for that discharge. The permit writer uses the information from those characterizations to determine whether WQBELs are required (section 6.3 below) and, if so, to calculate WQBELs (section 6.4 below). Characterizing the effluent and receiving water can be divided into five steps as shown in Exhibit 6-5 and discussed in detail below.

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Exhibit 6-5 Steps for characterizing the effluent and receiving water

Step 1.	Identify pollutants of concern in the effluent
Step 2.	Determine whether water quality standards provide for consideration of a dilution allowance or mixing zone
Step 3.	Select an approach to model effluent and receiving water interactions
Step 4.	Identify effluent and receiving water critical conditions
Step 5.	Establish an appropriate dilution allowance or mixing zone

6.2.1 Step 1: Identify Pollutants of Concern in the Effluent

There are several sources of information for and methods of identifying pollutants of concern for WQBEL development. For some pollutants of concern, the permit writer might not need to conduct any further analysis and could, after characterizing the effluent and receiving water, proceed directly to developing WQBELs (section 6.4 below). For other pollutants of concern, the permit writer uses the information from the effluent and receiving water characterization to assess the need for WQBELs (section 6.3 below). The following subsections identify five categories of pollutants of concern for WQBEL development.

6.2.1.1 Pollutants with Applicable TBELs

One category of pollutants of concern includes those pollutants for which the permit writer has developed TBELs based on national or state technology standards or on a case-by-case basis using best professional judgment. By developing TBELs for a pollutant, the permit writer has already determined that there will be some type of final limitations for that pollutant in the permit and must then determine whether more stringent limitations than the applicable TBELs are needed to prevent an excursion above water quality standards in the receiving water (see Exhibit 6-1 above). A permit writer can determine whether the TBELs are sufficiently protective by either proceeding to calculate WQBELs as described in section 6.4 below and comparing them to the TBELs or by assuming that the maximum daily TBEL calculated is the maximum discharge concentration in the water quality assessments described in section 6.3 below.

6.2.1.2 Pollutants with a Wasteload Allocation from a TMDL

Pollutants of concern include those pollutants for which a *wasteload allocation* (WLA) has been assigned to the discharge through a TMDL. Under CWA section 303(d), states are required to develop lists of impaired waters. Impaired waters are those that do not meet the water quality standards set for them, even after point sources of pollution have installed the minimum required levels of pollution control technology. The law requires that those jurisdictions establish priority rankings for waters on their CWA section 303(d) list and develop TMDLs for those waters.

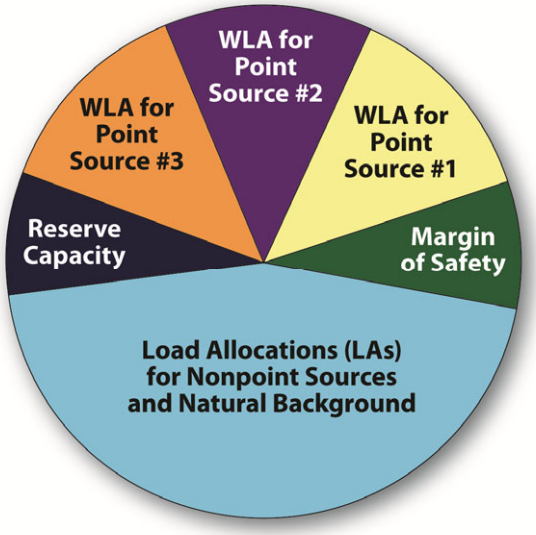
What is a WLA?

The term WLA refers to the portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution [see § 130.2(h)]. The WLA could be allocated through an EPA-approved TMDL, an EPA or state watershed loading analysis, or a facility-specific water quality modeling analysis.

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A TMDL is a calculation of the maximum amount of a single pollutant that a waterbody can receive and still meet water quality standards and an allocation of that amount to the pollutant's sources. The portions of the TMDL assigned to point sources are WLAs, and the portions assigned to nonpoint sources and background concentrations of the pollutant are called *load allocations* (LAs). The calculation must include a margin of safety to ensure that the waterbody can be used for the purposes designated in the water quality standards, to provide for the uncertainty in predicting how well pollutant reduction will result in meeting water quality standards, and to account for seasonal variations. A TMDL might also include a reserve capacity to accommodate expanded or new discharges in the future. Exhibit 6-6 depicts the parts of a TMDL.

Exhibit 6-6 Parts of a TMDL



TMDL = ΣWLA + ΣLA + Margin of Safety + Reserve Capacity

The NPDES regulations at § 122.44(d)(1)(vii)(B) require that NPDES permits include effluent limitations developed consistent with the assumptions and requirements of any WLA that has been assigned to the discharge as part of an approved TMDL. Thus, any pollutant for which a WLA has been assigned to the permitted facility through a TMDL is a pollutant of concern.

Permit writers might also choose to consider any pollutant associated with an impairment of the receiving water a pollutant of concern, regardless of whether an approved TMDL has been developed for that pollutant, a WLA has been assigned to the permitted facility, or the permitted facility has demonstrated that the pollutant is present in its effluent. Permitting authorities might consider monitoring requirements to collect additional data related to the presence or absence of the impairing pollutant in a specific discharge to provide information for further analyses.

6.2.1.3 Pollutants Identified as Needing WQBELs in the Previous Permit

Another category of pollutants of concern includes those pollutants that were identified as needing WQBELs in the discharger's previous permit. Permit writers must determine whether the conditions leading to a decision to include WQBELs for the pollutant in the previous permit continue to apply. Where those conditions no longer apply, the permit writer would need to complete an anti-backsliding

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analysis to determine whether to remove the WQBELs from the reissued permit. Chapter 7 of this manual provides additional information on anti-backsliding requirements of the CWA and NPDES regulations. In addition, the permit writer might need to conduct an antidegradation analysis if the revised limitation would allow degradation of the quality of the receiving water.

6.2.1.4 Pollutants Identified as Present in the Effluent through Monitoring

Pollutants of concern also include any pollutants identified as present in the effluent through effluent monitoring. Effluent monitoring data are reported in the discharger's NPDES permit application, discharge monitoring reports and special studies. In addition, the permitting authority might collect data itself through compliance inspection monitoring or other special study. Permit writers can match information on which pollutants are present in the effluent to the applicable water quality standards to identify parameters that are candidates for WQBELs.

6.2.1.5 Pollutants Otherwise Expected to be Present in the Discharge

A final category of pollutants of concern includes those pollutants that are not in one of the other categories but are otherwise expected to be present in the discharge. There might be pollutants for which neither the discharger nor the permitting authority have monitoring data but, because of the raw materials stored or used, products or by-products of the facility operation, or available data and information on similar facilities, the permit writer has a strong basis for expecting that the pollutant could be present in the discharge. Because there are no analytical data to verify the concentrations of these pollutants in the effluent, the permit writer must either postpone a quantitative analysis of the need for WQBELs and generate, or require the discharger to generate, effluent monitoring data, or base a determination of the need for WQBELs on other information, such as the effluent characteristics of a similar discharge. A discussion on determining the need for WQBELs without effluent monitoring data is provided in section 6.3.3 below.

6.2.2 Step 2: Determine Whether Water Quality Standards Provide for Consideration of a Dilution Allowance or Mixing Zone

Many state water quality standards have general provisions allowing some consideration of mixing of effluent and receiving water when determining the need for and calculating WQBELs. Depending on the state's water quality standards and implementation policy, such a mixing consideration could be expressed in the form of a *dilution allowance* or *regulatory mixing zone*. A dilution allowance typically is expressed as the flow of a river or stream, or a portion thereof. A regulatory mixing zone generally is expressed as a limited area or volume of water in any type of waterbody where initial dilution of a discharge takes place and within which the water quality standards allow certain water quality criteria to be exceeded. Section 6.2.5 below discusses dilution allowances and mixing zones in greater detail.

State water quality standards or implementation policies might indicate specific locations or conditions (e.g., breeding grounds for aquatic species or bathing beaches) or water quality criteria (e.g., pathogens, pH, bioaccumulative pollutants, or narrative criteria) for which consideration of a dilution allowance or mixing zone is not allowed or is otherwise considered inappropriate.

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6.2.3 Step 3: Select an Approach to Model Effluent and Receiving Water Interactions

Where consideration of a dilution allowance or mixing zone is not permitted by the water quality standards or is not appropriate, the relevant water quality criterion must be attained at the point of discharge. In such cases, there is no need for a water quality model to characterize the interaction between the effluent and receiving water. In this situation effluent limitations are based on attaining water quality criteria at the "end of the pipe."

Where a dilution allowance or mixing zone is permitted, however, characterizing the interaction between the effluent and receiving water generally requires using a water quality model. In the majority of situations, and in all of the examples provided in this manual, permit writers will use a steady-state water quality model to assess the impact of a discharge on its receiving water. Steady-state means that the model projects the impact of the effluent on the receiving water under a single or *steady* set of design conditions. Because the model is run under a single set of conditions, those conditions generally are set at *critical conditions* for protection of receiving water quality as discussed in section 6.2.4 below. The permit writer would determine the amount of the dilution allowance or the size of the mixing zone that is available under these critical conditions as provided in section 6.2.5 below.

6.2.4 Step 4: Identify Effluent and Receiving Water Critical Conditions

Where steady-state models are used for water quality-based permitting, an important part of characterizing the effluent and receiving water is identifying the critical conditions needed as inputs to the water quality model. Permit writers should discuss selection of critical conditions with water quality modelers or other water quality specialists. Identifying the right critical conditions is important for appropriately applying a water quality model to assess the need for WQBELs and to calculate WQBELs. Some key effluent and receiving water critical conditions are summarized below.

What if I am not a water quality modeler?

Permit writers are not always water quality modelers, nor do they necessarily need to be experts in this field. Many permitting authorities have a team of water quality specialists who model point source discharges to provide data required for permit writers to assess the need for and develop WQBELs. In some cases, this team might even calculate WQBELs directly for the permit writers, who then only need to compare them to TBELs and determine the final effluent limitations for the NPDES permit. Permit writers should, at a minimum, familiarize themselves with water quality modeling concepts presented in this manual, particularly the identification of critical conditions input to a steady-state water quality model, and should consult water quality modelers or other water quality specialists as needed in the process of NPDES permit development.

6.2.4.1 Effluent Critical Conditions

In most any steady-state water quality model there will be at least two basic critical conditions related to the effluent: flow and pollutant concentration.

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Effluent Flow

Effluent flow (designated Q_d in the water quality modeling equations used in this manual) is a critical design condition used when modeling the impact of an effluent discharge on its receiving water. A permit writer should be able to obtain effluent flow data from discharge monitoring reports or a permit application. Permitting authority policy or procedures might specify which flow measurement to use as the critical effluent flow value(s) in various water quality-based permitting calculations (e.g., the maximum daily flow reported on the permit application, the maximum of the monthly average flows from discharge monitoring reports for the past three years, the facility design flow). Permit writers should follow existing policy or procedures for determining critical effluent flow or, if the permitting authority does not specify how to determine this value, look at past permitting practices and strive for consistency.

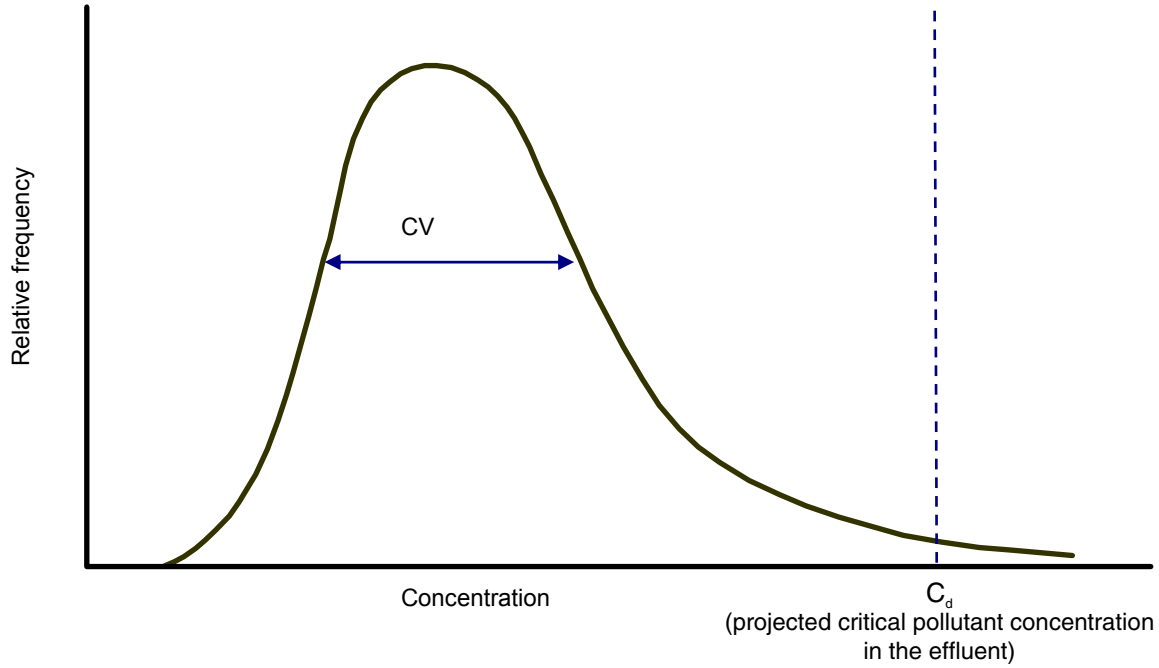
Effluent Pollutant Concentration

Permit writers can determine the critical effluent concentration of the pollutant of concern (designated C_d) by gathering effluent data representative of the discharge. To establish the critical effluent pollutant concentration from the available data, EPA has recommended considering a concentration that represents something close to the maximum concentration of the pollutant that would be expected over time. In most cases, permit writers have a limited effluent data set and, therefore, would not have a high degree of certainty that the limited data would actually include the maximum potential effluent concentration of the pollutant of concern. In addition, the NPDES regulations at § 122.44(d)(1)(ii) require that permit writers consider the variability of the pollutant in the effluent when determining the need for WQBELs. To address those concerns, EPA developed guidance for permit writers on how to characterize effluent concentrations of certain types of pollutants using a limited data set and accounting for variability. This guidance is detailed in EPA's TSD.

By studying effluent data for numerous facilities, EPA determined that daily pollutant measurements of many pollutants follow a *lognormal distribution*. The TSD procedures allow permit writers to project a critical effluent concentration (e.g., the 99th or 95th percentile of a lognormal distribution of effluent concentrations) from a limited data set using statistical procedures based on the characteristics of the lognormal distribution. These procedures use the number of available effluent data points for the measured concentration of the pollutant and the coefficient of variation (or CV) of the data set, which is a measure of the variability of data around the average, to predict the critical pollutant concentration in the effluent. Exhibit 6-7 provides an example of a lognormal distribution of effluent pollutant concentrations and projection of a critical effluent pollutant concentration (C_d). For additional details regarding EPA's guidance, see Chapter 3 of the TSD. Many permitting authorities have developed procedures for estimating a critical effluent pollutant concentration that are based on or derived from those procedures. For pollutants with effluent concentrations that *do not* follow a lognormal distribution, permit writers would rely on alternative procedures developed by their permitting authority for determining the critical effluent pollutant concentration.

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Exhibit 6-7 Example of lognormal distribution of effluent pollutant concentrations and projection of critical concentration (C_d)



6.2.4.2 Receiving Water Critical Conditions

As with the effluent, flow (for rivers and streams) and pollutant concentration are receiving water critical conditions used in steady-state water quality models. In addition, depending on the waterbody and pollutant of concern, there could be additional receiving water characteristics that permit writers need to consider in a water quality model.

Receiving Water Upstream Flow

For rivers and streams, an important critical condition is the stream flow upstream of the discharge (designated Q_s). That critical condition generally is specified in the applicable water quality standards and reflects the duration and frequency components of the water quality criterion that is being addressed. For most pollutants and criteria, the critical flow in rivers and streams is some measure of the low flow of that river or stream; however, the critical condition could be different (for example, a high flow, where wet weather sources are a major problem). If a discharge is controlled so that it does not cause water quality criteria to be exceeded in the receiving water at the critical flow condition, the discharge controls should be protective and ensure that water quality criteria, and thus designated uses, are attained under all receiving water flow conditions.

Examples of typical critical hydrologically based low flows found in water quality standards include the 7Q10 (7-day average, once in 10 years) low flow for chronic aquatic life criteria, the 1Q10 low flow for acute aquatic life criteria, and the harmonic mean flow for human health criteria for toxic organic pollutants. The permit writer might examine stream flow data from the state or the U.S. Geological

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Survey to determine the critical flow at a point upstream of the discharge. The permit writer might also account for any additional sources of flow or diversions between the point where a critical low flow has been calculated and the point of discharge. EPA also has developed a biologically based flow method that directly uses the durations and frequencies specified in the water quality criteria.

Receiving Water Flow Considerations

As noted in this section, the receiving water upstream flow is an important factor in modeling the interaction between the effluent discharge and a river or stream. In most instances, state water quality standards or implementation policies establish the critical low flows that should be used in modeling this interaction. The most common source of upstream flow data for water quality modelers is historical flow gage data available through the U.S. Geological Survey. Modelers should be aware that the effects of global weather patterns could alter historical flow patterns in rivers and streams, making these historical flow records less accurate in predicting current and future critical flows. Where appropriate, water quality modelers should consider alternate approaches to establishing critical low flow conditions that account for these changes.

Receiving Water Background Pollutant Concentration

In addition to determining the critical effluent concentration of the pollutant of concern, the permit writer also should determine the critical background concentration of the pollutant of concern in the receiving water before the discharge (designated C_s) to ensure that any pollutant limitations derived are protective of the designated uses. Permitting authority policies or procedures often address how to determine that critical background concentration value for the pollutant. For example, using ambient data or working with the discharger to obtain reliable ambient data, the permit writer might use the maximum measured background pollutant concentration or, perhaps, an average of measured concentrations as the critical condition. Ambient data will provide the most reliable characterization of receiving water background pollutant concentration. EPA encourages permitting authorities to collect and use actual ambient data, where possible. Where data are not available, however, the state might have other procedures, such as establishing that without valid and representative ambient data, no dilution or mixing will be allowed (i.e., criteria end-of-pipe), or using a percentage of an applicable water quality criterion or a detection, quantitation, or other reporting level. The permit writer should consult the permitting authority's policies and procedures or, if there are no policies or procedures available, look at past permitting practices and maintain consistency with those practices when determining the critical receiving water background concentrations.

Other Receiving Water Characteristics

For waterbodies other than free-flowing rivers and streams, there might be critical environmental conditions that apply rather than flow (e.g., tidal flux, temperature). In addition, depending on the pollutant of concern, the effects of biological activity and reaction chemistry might be important in assessing the impact of a discharge on the receiving water. In such situations, additional critical receiving water conditions that might be used in a steady-state water quality model include conditions such as pH, temperature, hardness, or reaction rates, and the presence or absence of certain fish species or life stages of aquatic organisms, to name a few.

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Sections 6.3 and 6.4 below provide further discussion of how critical conditions are applied in a water quality model to determine the need for and calculate WQBELs.

6.2.5 Step 5: Establish an Appropriate Dilution Allowance or Mixing Zone

Following verification of whether the applicable water quality standards allow any consideration of effluent and receiving water mixing and, for a steady-state modeling approach, the critical conditions that apply to the effluent and receiving water, permit writers can determine how the effluent and the receiving water mix under critical conditions. Based on this determination, permit writers can then establish the maximum dilution allowance or mixing zone allowed by the water quality standards for each pollutant of concern.

6.2.5.1 Type of Mixing Under Critical Conditions

On the basis of requirements in the water quality standards, the dilution allowance or mixing zone used in water quality models and calculations are likely to vary depending on whether there is rapid and complete mixing or incomplete mixing of the effluent and receiving water under critical conditions. Thus, the permit writer needs to understand something about *how* the effluent and receiving water mix under critical conditions.

Rapid and complete mixing is mixing that occurs when the lateral variation in the concentration of a pollutant in the direct vicinity of the outfall is small. The applicable water quality standards might specify certain conditions under which a permit writer could *assume* that rapid and complete mixing is occurring, such as the presence of a diffuser. Some standards may also allow a *demonstration* of rapid and complete mixing in cases where the conditions for simply assuming rapid and complete mixing are not met. For example, the applicable water quality standards might specify a distance downstream of a discharge point by which the pollutant concentration across the stream width must vary by less than a certain percentage to assume that there is rapid and complete mixing.

If the permit writer cannot assume rapid and complete mixing and there has been no demonstration of rapid and complete mixing, the permit writer should assume that there is incomplete mixing. Under incomplete mix conditions, mixing occurs more slowly and higher concentrations of pollutants are present in-stream near the discharge as compared to rapid and complete mixing. Thus, an assumption of incomplete mixing is more conservative than an assumption of rapid and complete mixing. For waterbodies other than rivers and streams (e.g., lakes, bays, and the open ocean) the permit writer usually would assume incomplete mixing.

6.2.5.2 Maximum Dilution Allowance or Mixing Zone Size

Once a permit writer determines whether the applicable water quality standards allow consideration of some ambient dilution or mixing and determines the type of mixing taking place (rapid and complete mixing versus incomplete mixing), he or she would again consult the water quality standards to determine the maximum size of the dilution allowance or mixing zone that may be considered in water quality modeling calculations.

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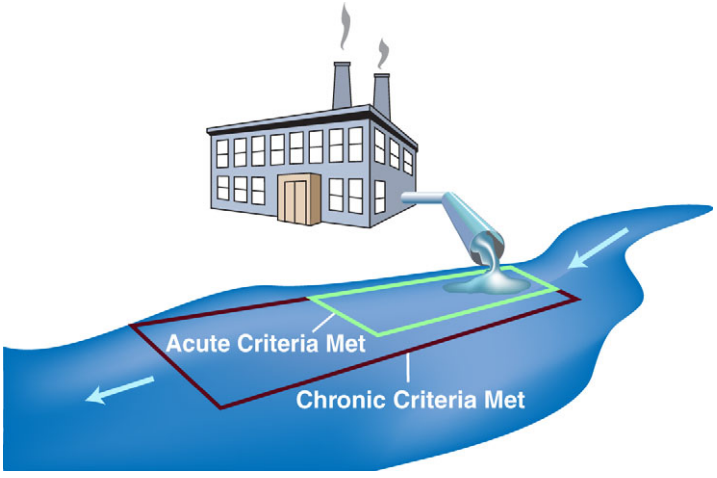
Dilution Allowances in Rapid and Complete Mix Situations

The maximum permissible dilution allowance for rivers and streams under conditions of rapid and complete mixing should be indicated in the water quality standards or standards implementation policy. For example, some water quality standards allow a permit writer to use up to 100 percent of the critical low flow of a river or stream as a dilution allowance in water quality models and calculations when there is rapid and complete mixing. In some cases, water quality standards implement a factor of safety by permitting only a percentage of the critical low flow to be used as a dilution allowance, even when there is rapid and complete mixing under critical conditions. Water quality standards might incorporate such a factor of safety to account for any uncertainty related to other conditions in the waterbody or to ensure that some assimilative capacity is retained downstream of the discharge being permitted. Recall as well that for some pollutants (e.g., pathogens in waters designated for primary contact recreation, bioaccumulative pollutants), the water quality standards or implementing procedures might not authorize any dilution allowance, even where the effluent and receiving water mix rapidly and completely.

Dilution Allowances and Regulatory Mixing Zones in Incomplete Mix Situations

In an incomplete mixing situation, the water quality standards or implementation policies might allow some consideration of ambient dilution. Rather than permitting as much as 100 percent of the critical low flow as a dilution allowance, however, they will likely specify either a limited dilution allowance (such as a percentage of the critical low flow) or the maximum size of a regulatory mixing zone. A regulatory *mixing zone* is a limited area or volume of water where initial dilution of a discharge takes place and within which the water quality standards allow certain water quality criteria to be exceeded. While the criteria may be exceeded within the mixing zone, the use and size of the mixing zone must be limited such that the waterbody as a whole will not be impaired and such that all designated uses are maintained as discussed in section 6.2.5.3 below. Exhibit 6-8 is a diagram illustrating the concept of a regulatory mixing zone. The mixing zone often is a simple geometric shape inside of which a water quality criterion may be exceeded. The geometric shape does not characterize how mixing actually occurs. Actual mixing is described using field studies and a water quality model.

Exhibit 6-8 Regulatory mixing zones for aquatic life criteria



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Note that Exhibit 6-8 above illustrates two different mixing zones, one for an acute aquatic life criterion and one for a chronic aquatic life criterion. The water quality standards could specify different maximum mixing zones sizes for different pollutants, different types of criteria, and different waterbody types. Exhibit 6-9 provides examples of different maximum mixing zone sizes and dilution allowances.

Exhibit 6-9 Examples of maximum mixing zone sizes or dilution allowances under incomplete mixing conditions by waterbody type*

For rivers and streams:
- Mixing zones cannot be larger than 1/4 of the stream width and 1/4 mile downstream
- Mixing must be less than 1/2 stream width with a longitudinal limit of 5 times the stream width
- Dilution cannot be greater than 1/3 of the critical low flow

For lakes and the ocean:
- Mixing zones for lakes cannot be larger than 5% of the lake surface
- A maximum of 4:1 dilution is available for lake discharges
- A maximum of 10:1 dilution is available for ocean discharges
- The maximum size mixing zone for the ocean is a 100-foot radius from the point of discharge

* Examples were adapted from state standards and procedures and do not reflect EPA guidance or recommendations.

Permit writers should always check the applicable water quality standards to see if mixing zones are permitted and determine the maximum mixing zone size for the waterbody type, pollutant of concern, and specific criterion being considered.

6.2.5.3 Restrictions on Dilution Allowance or Mixing Zone Size

In addition to specifying the maximum dilution allowance or mixing zone size allowed under both rapid and complete mixing conditions and incomplete mixing conditions, the water quality standards or implementation policies generally include constraints that could further limit the available dilution allowance or mixing zone size to something less than the absolute maximum allowed. For example, one restriction on the size of the acute mixing zone could be that it must be small enough to ensure that the potential time of exposure of aquatic organisms to a pollutant concentration above the acute criterion is very short, and organisms passing through that acute mixing zone will not die from exposure to the pollutant. Such a restriction might lead the permitting authority to give a discharger an acute mixing zone for a specific pollutant that is smaller than the maximum size allowed by the water quality standards or to not allow any acute mixing zone at all. Other possible restrictions on dilution and mixing zone size include preventing impairment of the integrity of the waterbody as a whole and preventing significant risks to human health. For example, a permitting authority might restrict the size of a mixing zone for a human health criterion to prevent the mixing zone from overlapping a drinking water intake.

6.3 Determine the Need for WQBELs

After determining the applicable water quality standards and characterizing the effluent and receiving water, a permit writer determines whether WQBELs are needed. This section provides an overview of that process.

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6.3.1 Defining Reasonable Potential

EPA regulations at § 122.44(d)(1)(i) state, "Limitations must control all pollutants or pollutant parameters (either conventional, nonconventional, or toxic pollutants) which the Director determines are or may be discharged at a level that will *cause*, have the *reasonable potential to cause*, or *contribute* to an excursion above any [s]tate water quality standard, including [s]tate narrative criteria for water quality." [emphasis added] Because of that regulation, EPA and many authorized NPDES states refer to the process that a permit writer uses to determine whether a WQBEL is required in an NPDES permit as a *reasonable potential analysis*. Wording the requirements of the regulation another way, a reasonable potential analysis is used to determine whether a discharge, alone or in combination with other sources of pollutants to a waterbody and under a set of conditions arrived at by making a series of reasonable assumptions, could lead to an excursion above an applicable water quality standard. The regulation also specifies that the reasonable potential determination must apply not only to numeric criteria, but also to narrative criteria (e.g., *no toxics in toxic amounts*, *presence of pollutants or pollutant parameters in amounts that would result in nuisance algal blooms*). A permit writer can conduct a reasonable potential analysis using effluent and receiving water data and modeling techniques, as described above, or using a non-quantitative approach. Both approaches are discussed below.

6.3.2 Conducting a Reasonable Potential Analysis Using Data

When determining the need for a WQBEL, a permit writer should use any available effluent and receiving water data as well as other information pertaining to the discharge and receiving water (e.g., type of industry, existing TBELs, compliance history, stream surveys), as the basis for a decision. The permit writer might already have data available from previous monitoring or he or she could decide to work with the permittee to generate data before permit issuance or as a condition of the new permit. EPA recommends that monitoring data be generated before effluent limitation development whenever possible. Monitoring should begin far enough in advance of permit development to allow sufficient time to conduct chemical analyses. Where data are generated as a condition of the permit (for example for a new permittee), it might be appropriate for the permit writer to include a reopener condition in the permit to allow the incorporation of a WQBEL if the monitoring data indicate that a WQBEL is required.

A reasonable potential analysis conducted with available data can be divided into four steps as shown in Exhibit 6-10 and discussed in detail below.

Exhibit 6-10 Steps of a reasonable potential analysis with available data

Step 1.	Determine the appropriate water quality model
Step 2.	Determine the expected receiving water concentration under critical conditions
Step 3.	Answer the question, "Is there reasonable potential?"
Step 4.	Document the reasonable potential determination in the fact sheet

6.3.2.1 Step 1: Determine the Appropriate Water Quality Model

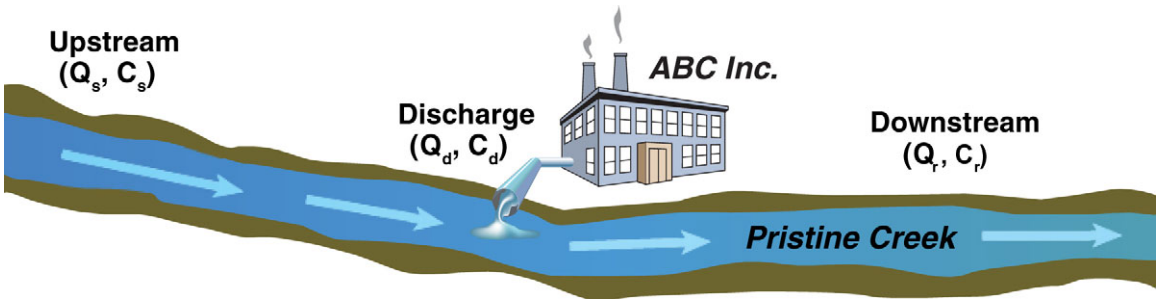
Steady-state or dynamic water quality modeling techniques can be used in NPDES permitting. As discussed in section 6.2.3 above, the examples in this manual consider only steady-state modeling techniques, which consider the impact of a discharge on the receiving water modeled under a single set of critical conditions.

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The specific steady-state model used will depend on the pollutant or parameter of concern and whether there is rapid and complete mixing or incomplete mixing of the effluent and the receiving water under critical conditions. For example, to model dissolved oxygen in a river, the permit writer might choose the Streeter-Phelps equation. For modeling heavy metals in an incomplete mix situation, the permit writer might choose the CORMIX model. For pollutants such as BOD, nutrients, or non-conservative parameters, the effects of biological activity and reaction chemistry should be modeled, in addition to the effects of dilution, to assess possible impacts on the receiving water. This manual focuses only on dilution of a pollutant discharged to the receiving water and does not address modeling biological activity or reaction chemistry in receiving waters. For additional information, permit writers should discuss modeling that accounts for biological activity or reaction chemistry with water quality modelers or other water quality specialists as needed and consult EPA's Water Quality Models and Tools Website <www.epa.gov/waterscience/models/>.

For many pollutants such as most toxic (priority) pollutants, conservative pollutants, and pollutants that can be treated as conservative pollutants when near-field effects are of concern, if there is rapid and complete mixing in a river or stream, the permit writer could use a simple mass-balance equation to model the effluent and receiving water. The simple mass-balance equation as applied to a hypothetical facility, ABC, Inc., discharging Pollutant Z to a free-flowing stream called Pristine Creek is presented in Exhibit 6-11 below.

Exhibit 6-11 Simple mass-balance equation



Mass = **Flow** (Q) in million gallons per day (mgd) or cubic feet per second (cfs) X **Pollutant concentration** (C) in milligrams per liter (mg/L)

$$Q_sC_s + Q_dC_d = Q_rC_r$$

where

Q_s	=	stream flow in mgd or cfs above point of discharge
C_s	=	background in-stream pollutant concentration in mg/L
Q_d	=	effluent flow in mgd or cfs
C_d	=	effluent pollutant concentration in mg/L
Q_r	=	resultant in-stream flow, after discharge in mgd or cfs
C_r	=	resultant in-stream pollutant concentration in mg/L (after complete mixing occurs)

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6.3.2.2 Step 2: Determine the Expected Receiving Water Concentration under Critical Conditions

When using a steady-state model, the permit writer, or water quality modeler, determines the impact of the effluent discharge on the receiving water under critical conditions. This step examines how this steady-state analysis is conducted in situations where there is incomplete mixing and then provides a detailed discussion of this analysis for situations where there is rapid and complete mixing.

How are *critical conditions* defined?

When using a steady-state water quality model, permit writers generally input values that reflect critical conditions. State permitting procedures should guide permit writers in this task. When characterizing the effluent and receiving water for water quality-based permitting, the permit writer should follow the permitting authority's policies and procedures for selecting the critical conditions to use in a steady-state model. The discussion in section 6.2.4 above provides a discussion of how those values might be selected.

Permit writers generally would input into a steady-state model for a reasonable potential analysis the critical conditions identified in the effluent and receiving water characterization discussed in section 6.2.4 above. Recall that critical conditions include the following:

- Effluent critical conditions
  - Flow.
  - Pollutant concentration.
- Receiving water critical conditions
  - Flow (for rivers and streams).
  - Pollutant concentration.
  - Other receiving water characteristics such as tidal flux, temperature, pH, or hardness (depending on the waterbody and pollutant of concern)

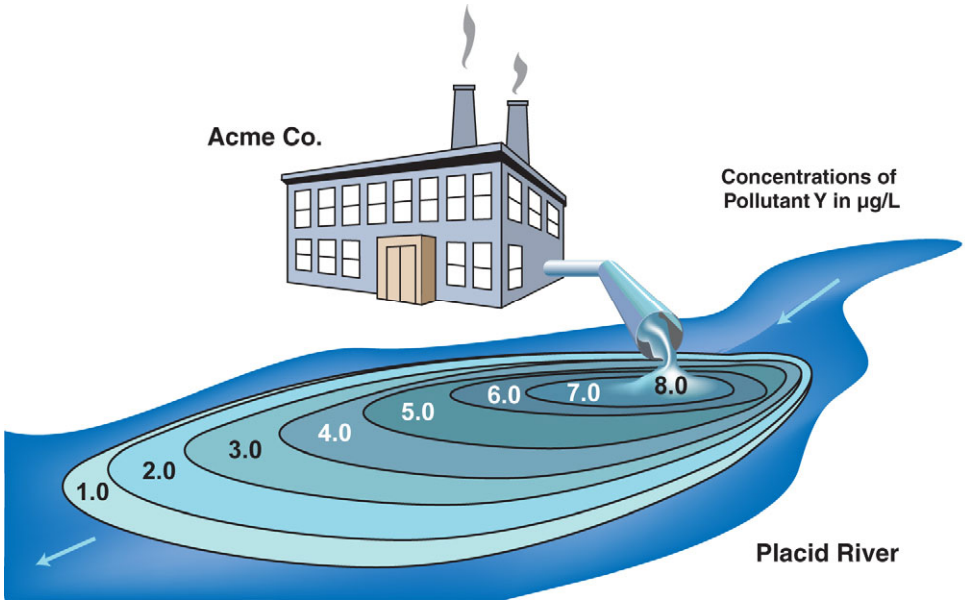
As discussed in section 6.2.4.1 above, EPA and other permitting authorities have developed guidance for determining those critical conditions. Permit writers should rely on their permit authority's policies and procedures or past practices to determine values for all other critical conditions.

Expected Receiving Water Concentration in an Incomplete Mixing Situation

Exhibit 6-12 illustrates a situation where there is incomplete mixing of a discharge from a hypothetical facility, Acme Co., with the receiving water, the Placid River. The concentration of the pollutant of concern discharged by Acme Co. (Pollutant Y) is highest nearest the point of discharge and gradually decreases until the pollutant is completely mixed with the receiving water. To determine expected receiving water concentrations resulting from the Acme Co.'s discharge of Pollutant Y to the Placid River, the permit writer, or water quality modeler, would use the appropriate incomplete mixing model, calibrated to actual observations from field studies or dye studies, to simulate mixing under critical conditions. In Step 3 below, the concentrations of the pollutant of concern in the receiving water, as predicted by the water quality model, will be overlaid by a regulatory mixing zone established by the applicable water quality standard to determine whether WQBELs are needed.

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Exhibit 6-12 Example of receiving water concentrations in an incomplete mixing situation determined using an incomplete mixing water quality model



Expected Receiving Water Concentration in Rapid and Complete Mixing Situation

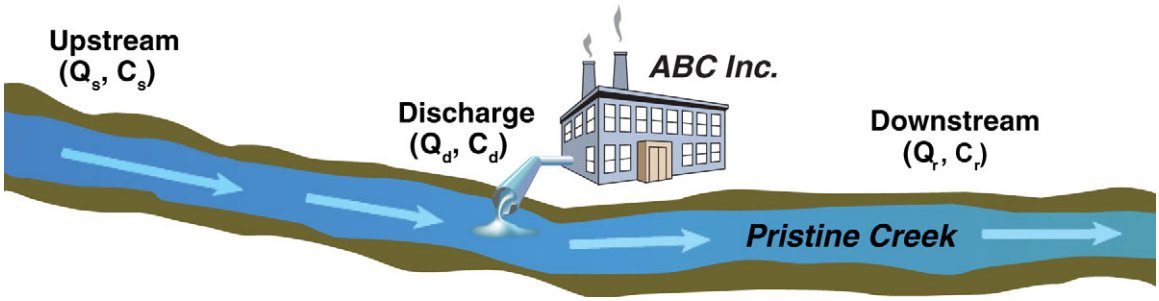
For many pollutants, if there is rapid and complete mixing in a river or stream, the permit writer could use the simple mass-balance equation presented in Exhibit 6-11 above to determine the expected receiving water concentration of the pollutant of concern under critical conditions. As noted previously, the simple mass-balance equation is a very basic steady-state model that can be used for most toxic pollutants, conservative pollutants, and other pollutants for which near-field effects are the primary concern. In Exhibit 6-13, that equation is applied to ABC Inc.'s, discharge of Pollutant Z (a conservative pollutant) to Pristine Creek under conditions of rapid and complete mixing. The mass-balance equation is rearranged to show how it would be used in a reasonable potential analysis.

To use the simple mass-balance equation to predict receiving water impacts for a reasonable potential analysis, the permit writer needs to input one value for each variable and solve the equation for C_r, the downstream concentration of the pollutant. Because this model, like other steady-state models, uses a single value for each variable, the permit writer should be sure that the values selected reflect critical conditions for the discharge and the receiving water. In Exhibit 6-14, those critical conditions have been identified and the equation has been solved for C_r.

It is important for permit writers to remember that, in some situations, the selected steady-state model could be more complex than the simple mass-balance equation shown. For example, there could be other pollutant sources along the stream segment; the pollutant might not be conservative (e.g., BOD); or the parameter to be modeled might be affected by multiple pollutants (e.g., dissolved oxygen affected by BOD and nutrients). For illustrative purposes, this example focuses on a situation where using a simple mass-balance equation is sufficient (i.e., rapid and complete mixing of a conservative pollutant in a river or stream under steady-state conditions).

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Exhibit 6-13 Mass-balance equation for reasonable potential analysis for conservative pollutant under conditions of rapid and complete mixing



The mass-balance equation can be used to determine whether the discharge from ABC Inc., would cause, have the reasonable potential to cause, or contribute to an excursion above the water quality standards applicable to Pristine Creek. The equation is used to predict the concentration of Pollutant Z, a conservative pollutant, in Pristine Creek under critical conditions. The predicted concentration can be compared to the applicable water quality criteria for Pollutant Z. Assume the discharge mixes rapidly and completely with Pristine Creek.

Mass	=	**Flow** (Q) in million gallons per day (mgd) or cubic feet per second (cfs)	X	**Pollutant concentration** (C) in milligrams per liter (mg/L)

$$Q_sC_s + Q_dC_d = Q_rC_r$$

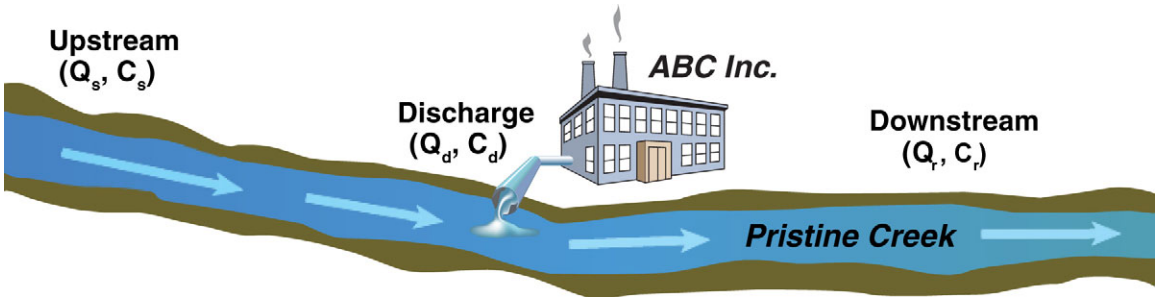
where

Q_s	=	critical stream flow in mgd or cfs above point of discharge
C_s	=	critical background in-stream pollutant concentration in mg/L
Q_d	=	critical effluent flow in mgd or cfs
C_d	=	critical effluent pollutant concentration in mg/L
Q_r	=	resultant in-stream flow, after discharge in mgd or cfs ($Q_r = Q_s + Q_d$)
C_r	=	resultant in-stream pollutant concentration in mg/L (after complete mixing occurs)

Rearrange the equation to determine the concentration of Pollutant Z in the waterbody downstream of a discharge under critical conditions:

$$C_r = \frac{(Q_d)(C_d) + (Q_s)(C_s)}{Q_r}$$

Exhibit 6-14 Example of applying mass-balance equation to conduct reasonable potential analysis for conservative pollutant under conditions of rapid and complete mixing



Mass-Balance Equation: $Q_sC_s + Q_dC_d = Q_rC_r$

Dividing both sides of the mass-balance equation by Q_r gives the following:

$$C_r = \frac{(Q_d)(C_d) + (Q_s)(C_s)}{Q_r}$$

where C_r is the receiving water concentration downstream of the discharge

The following values are known for ABC Inc. and Pristine Creek:

Q_s = critical upstream flow (water quality standards allow a dilution allowance of up to 100% of 1Q10 low flow for rapid and complete mixing)	= 1.20 cfs
C_s = critical upstream concentration of Pollutant Z in Pristine Creek	= 0.75 mg/L
Q_d = critical discharge flow	= 0.55 cfs
C_d = statistically projected critical discharge concentration of Pollutant Z	= 2.20 mg/L
Q_r = downstream flow = Q_d + Q_s	= 0.55 + 1.20 = 1.75 cfs
Acute aquatic life water quality criterion for Pollutant Z in Pristine Creek	= 1.0 mg/L

Find the projected downstream concentration (C_r) by inserting the given values into the equation as follows:

$$C_r = \frac{(0.55\,\text{cfs})(2.20\,\text{mg/L}) + (1.20\,\text{cfs})(0.75\,\text{mg/L})}{(1.75\,\text{cfs})}$$

C_r = 1.2 mg/L of Pollutant Z*

* calculated to 2 significant figures

6.3.2.3 Step 3: Answer the Question, Is There Reasonable Potential?

The next step in the reasonable potential analysis is to consider the results of water quality modeling to answer the question, *Is there reasonable potential?*

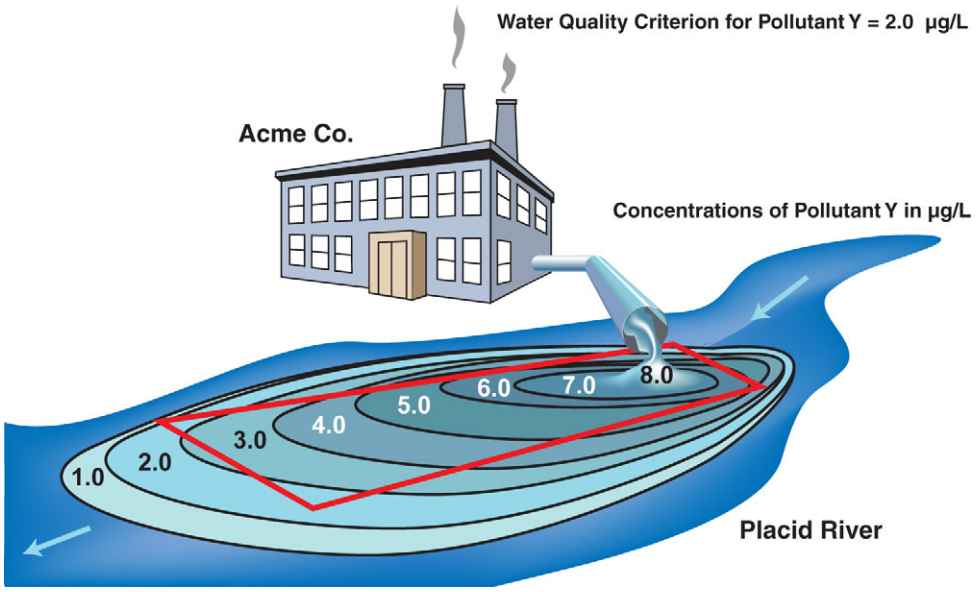
- For most pollutants, if the receiving water pollutant concentration projected by a steady-state model (e.g., a simple mass-balance equation or a more complex model) exceeds the applicable water quality criterion, there is *reasonable potential*, and the permit writer must calculate WQBELs. (Note that for dissolved oxygen, reasonable potential would occur if the water quality model indicates that the projected effluent concentration of the oxygen-demanding pollutants would result in depletion of dissolved oxygen below acceptable values in the receiving water).
- If the projected concentration is equal to or less than the applicable criterion, there is no reasonable potential and, thus far, there is no demonstrated need to calculate WQBELs.

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Reasonable Potential Determination in an Incomplete Mixing Situation

To determine whether there is reasonable potential in an incomplete mixing situation, the permit writer would compare the projected concentration of the pollutant of concern at the edge of the regulatory mixing zone or after accounting for the available dilution allowance, with the applicable water quality criterion. Exhibit 6-15 illustrates the reasonable potential determination for Acme Co. in a situation where the regulatory mixing zone is described by a geometric shape. In the example, the water quality criterion for Pollutant Y being considered is 2.0 micrograms per liter (µg/L). The illustration shows that at many points along the edge of the regulatory mixing zone specified by the water quality standards, which is represented by the rectangle, the concentration of Pollutant Y exceeds 2.0 µg/L. Therefore, there is reasonable potential, and the permit writer must calculate WQBELs for Pollutant Y for Acme Co.

Exhibit 6-15 Reasonable potential determination in an incomplete mixing situation



Reasonable Potential Determination in a Rapid and Complete Mixing Situation

In the rapid and complete mixing example for ABC, Inc., shown in Exhibit 6-14 above, a projected downstream concentration (C_r) of 1.2 mg/L of Pollutant Z was calculated. The permit writer would compare the calculated concentration to the acute aquatic life water quality criterion of 1.0 mg/L for Pollutant Z in Pristine Creek presented in Exhibit 6-14. Because 1.2 mg/L > 1.0 mg/L, the projected downstream concentration exceeds the water quality criterion; therefore, there is a reasonable potential for the water quality criterion to be exceeded, and the permit writer must calculate WQBELs for Pollutant Z.

A permit writer should repeat the reasonable potential analysis for all applicable criteria for the pollutant of concern and must remember that the critical conditions could differ depending on the criterion being evaluated. For example, the critical stream flow used when considering the acute aquatic life criterion might be the 1Q10 low flow, whereas the critical stream flow used when considering the chronic aquatic life criterion might be the 7Q10 low flow. If calculations demonstrate that the discharge of a pollutant of concern would cause, have the reasonable potential to cause, or contribute to an excursion of *any one* of the applicable criteria for that pollutant, the permit writer must develop WQBELs for that pollutant.

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In addition, it is important for permit writers to remember that they must repeat the reasonable potential analysis for each pollutant of concern and calculate WQBELs where there is reasonable potential. For each pollutant for which there is no reasonable potential, the permit writer should consider whether there are any existing WQBELs in the previous permit and whether they should be retained. The permit writer would complete an anti-backsliding analysis (see Chapter 7 of this manual) to determine whether it is possible to remove any existing WQBELs from the reissued permit.

6.3.2.4 Step 4: Document the Reasonable Potential Determination in the Fact Sheet

As a final step, permit writers need to document the details of the reasonable potential analysis in the NPDES permit fact sheet. The permit writer should clearly identify the information and procedures used to determine the need for WQBELs. The goal of that documentation is to provide the NPDES permit applicant and the public a transparent, reproducible, and defensible description of how each pollutant was evaluated, including the basis (i.e., reasonable potential analysis) for including or not including a WQBEL for any pollutant of concern.

6.3.3 Conducting a Reasonable Potential Analysis without Data

State implementation procedures might allow, or even require, a permit writer to determine reasonable potential through a qualitative assessment process without using available facility-specific effluent monitoring data or when such data are not available. For example, as noted in section 6.2.1.2 above, where there is a pollutant with a WLA from a TMDL, a permit writer must develop WQBELs or other permit requirements consistent with the assumptions of the TMDL. Even without a TMDL, a permitting authority could, at its own discretion, determine that WQBELs are needed for any pollutant associated with impairment of a waterbody. A permitting authority might also determine that WQBELs are required for specific pollutants for all facilities that exhibit certain operational or discharge characteristics (e.g., WQBELs for pathogens in all permits for POTWs discharging to contact recreational waters).

Types of information that the permit writer might find useful in a qualitative approach to determining reasonable potential include the following:

- Effluent variability information such as history of compliance problems and toxic impacts.
- Point and nonpoint source controls such as existing treatment technology, the type of industry, POTW treatment system, or BMPs in place.
- Species sensitivity data including in-stream data, adopted water quality criteria, or designated uses.
- Dilution information such as critical receiving water flows or mixing zones.

The permit writer should always provide justification for the decision to require WQBELs in the permit fact sheet or statement of basis and *must* do so where required by federal and state regulations. A thorough rationale is particularly important when the decision to include WQBELs is not based on an analysis of effluent data for the pollutant of concern.

After evaluating all available information characterizing the nature of the discharge without effluent monitoring data for the pollutant of concern, if the permit writer is not able to decide whether the discharge causes, has the reasonable potential to cause, or contributes to an excursion above a water

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quality criterion, he or she may determine that effluent monitoring should be required to gather additional data. The permit writer might work with the permittee to obtain data before permit issuance, if sufficient time exists, or could require the monitoring as a condition of the newly issued or reissued permit. The permit writer might also include a clause in the permit that would allow the permitting authority to reopen the permit and impose an effluent limitation if the required monitoring establishes that there is reasonable potential that the discharge will cause or contribute to an excursion above a water quality criterion.

6.4 Calculate Parameter-specific WQBELs

If a permit writer has determined that a pollutant or pollutant parameter is discharged at a level that will cause, have reasonable potential to cause, or contribute to an excursion above any state water quality standard, the permit writer must develop WQBELs for that pollutant parameter. This manual presents the approach recommended by EPA's TSD for calculating WQBELs for toxic (priority) pollutants. Many permitting authorities apply those or similar procedures to calculate WQBELs for toxic pollutants and for a number of conventional or nonconventional pollutants with effluent concentrations that tend to follow a lognormal distribution. Permit writers should consult permitting authority policies and procedures to determine the methodology specific to their authorized NPDES permitting program, including the approach for pollutants with effluent concentrations that do not follow a lognormal distribution.

6.4.1 Calculating Parameter-specific WQBELs from Aquatic Life Criteria

The TSD process for calculating WQBELs from aquatic life criteria follows five steps as shown in Exhibit 6-16 and discussed in detail below.

Exhibit 6-16 Calculating parameter-specific WQBELs from aquatic life criteria

Step 1.	Determine acute and chronic WLAs
Step 2.	Calculate long-term average (LTA) concentrations for each WLA
Step 3.	Select the lowest LTA as the performance basis for the permitted discharger
Step 4.	Calculate an average monthly limitation (AML) and a maximum daily limitation (MDL)
Step 5.	Document the calculation of WQBELs in the fact sheet.

6.4.1.1 Step 1: Determine Acute and Chronic WLAs

Before calculating a WQBEL, the permit writer will first need to determine the appropriate WLAs for the point source discharge based on both the acute and chronic criteria. A WLA may be determined from a TMDL or calculated for an individual point source directly. Where an EPA-approved TMDL has been developed for a particular pollutant, the WLA for a specific point source discharger is the portion of that TMDL that is allocated to that point source, as discussed in section 6.2.1.2 above. Where no TMDL is available, a water quality model generally is used to calculate a WLA for the specific point source discharger. The WLA is the loading or concentration of pollutant that the specific point source may discharge while still allowing the water quality criterion to be attained downstream of that discharge. Of course, the WLA calculation should take into account any reserve capacity, safety factor, and contributions from other point and nonpoint sources as might be required by the applicable water quality standards regulations or implementation policies.

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When a WLA is not given as part of a TMDL or where a separate WLA is needed to address the near-field effects of a discharge on water quality criteria, permit writers will, in many situations, use a steady-state water quality model to determine the appropriate WLA for a discharge. As discussed in section 6.3 above, steady-state models generally are run under a single set of critical conditions for protection of receiving water quality. If a permit writer uses a steady-state model with a specific set of critical conditions to assess reasonable potential, he or she generally may use the same model and critical conditions to calculate a WLA for the same discharge and pollutant of concern.

As with the reasonable potential assessment, the type of steady-state model used to determine a WLA depends on the type of mixing that occurs in the receiving water and the type of pollutant or parameter being modeled. As discussed in section 6.3.2 above, permit writers can use the mass-balance equation as a simple steady-state model for many pollutants, such as most toxic (priority) pollutants or any pollutant that can be treated as a conservative pollutant when considering near-field effects, if there is rapid and complete mixing in the receiving water. For pollutants or discharge situations that do not have those characteristics (e.g., non-conservative pollutants, concern about effects on a downstream waterbody), a water quality model other than the mass-balance equation would likely be more appropriate.

The mass-balance equation is presented again in Exhibit 6-17. In the exhibit, the equation is rearranged to show how it would be used to calculate a WLA for a conservative pollutant discharged to a river or stream under conditions of rapid and complete mixing.

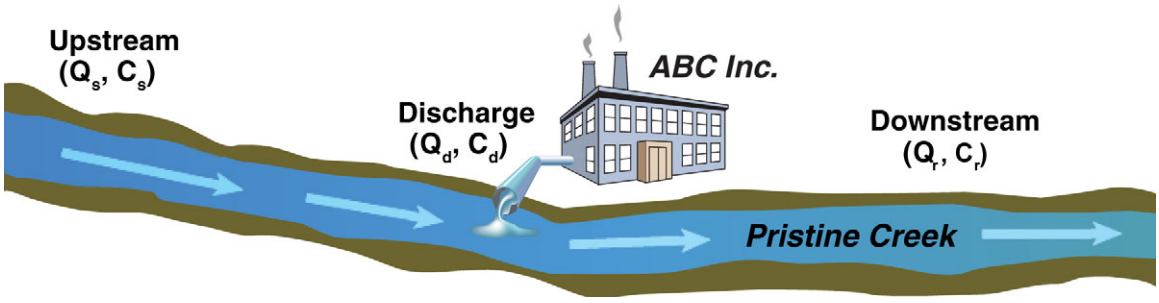
6.4.1.2 Step 2: Calculate LTA Concentrations for Each WLA

The requirements of a WLA generally must be interpreted in some way to be expressed as an effluent limitation. The goal of the permit writer is to derive effluent limitations that are enforceable, adequately account for effluent variability, consider available receiving water dilution, protect against acute and chronic impacts, account for compliance monitoring sampling frequency, and assure attainment of the WLA and water quality standards. In developing WQBELs, the permit writer develops limitations that require a facility to perform in such a way that the concentration of the pollutant of concern in the effluent discharged is nearly always below the WLA.

To accomplish that goal, EPA has developed a statistical permit limitation derivation procedure to translate WLAs into effluent limitations *for pollutants with effluent concentration measurements that tend to follow a lognormal distribution*. EPA believes that this procedure, discussed in Chapter 5 of the TSD, results in defensible, enforceable, and protective WQBELs for such pollutants. In addition, a number of states have adopted procedures based on, but not identical to, EPA's guidance that also provide defensible, enforceable, and protective WQBELs. Permit writers should always use the procedures adopted by their permitting authority. In addition, permit writers should recognize that alternative procedures would be used to calculate effluent limitations for pollutants with effluent concentrations that cannot generally be described using a lognormal distribution.

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Exhibit 6-17 Example of applying mass-balance equation to calculate WLAs for conservative pollutant under conditions of rapid and complete mixing



Mass Balance Equation: $Q_sC_s + Q_dC_d = Q_rC_r$

where

Q_s	=	background stream flow in mgd or cfs above point of discharge
C_s	=	background in-stream pollutant concentration in mg/L
Q_d	=	effluent flow in mgd or cfs
C_d	=	effluent pollutant concentration in mg/L **= WLA**
Q_r	=	resultant in-stream flow, after discharge in mgd or cfs
C_r	=	resultant in-stream pollutant concentration in mg/L (after complete mixing occurs)

Rearrange the equation to determine the WLA (C_d) for ABC Inc., necessary to achieve the acute water quality criterion for Pollutant Z in Pristine Creek (C_r) downstream of the discharge:

$$C_d = \frac{Q_rC_r - Q_sC_s}{Q_d}$$

The following values are known for ABC Inc., and Pristine Creek:

Q_s = critical upstream flow (water quality standards allow a dilution allowance of up to 100% of 1Q10 low flow for rapid and complete mixing)	= 1.20 cfs
C_s = upstream concentration of Pollutant Z in Pristine Creek	= 0.75 mg/L
Q_d =discharge flow	= 0.55 cfs
Q_r = downstream flow = $Q_d + Q_s$	= 0.55 + 1.20 = 1.75 cfs
C_r = acute water quality criterion for Pollutant Z in Pristine Creek	= 1.0 mg/L

Determine the WLA for ABC Inc., by inserting the given values into the equation as follows:

$$\text{WLA for ABC Inc.} = C_d = \frac{(1.75\ \text{cfs})(1.0\ \text{mg/L}) - (1.20\ \text{cfs})(0.75\ \text{mg/L})}{(0.55\ \text{cfs})}$$

C_d = 1.5 mg/L of Pollutant Z*

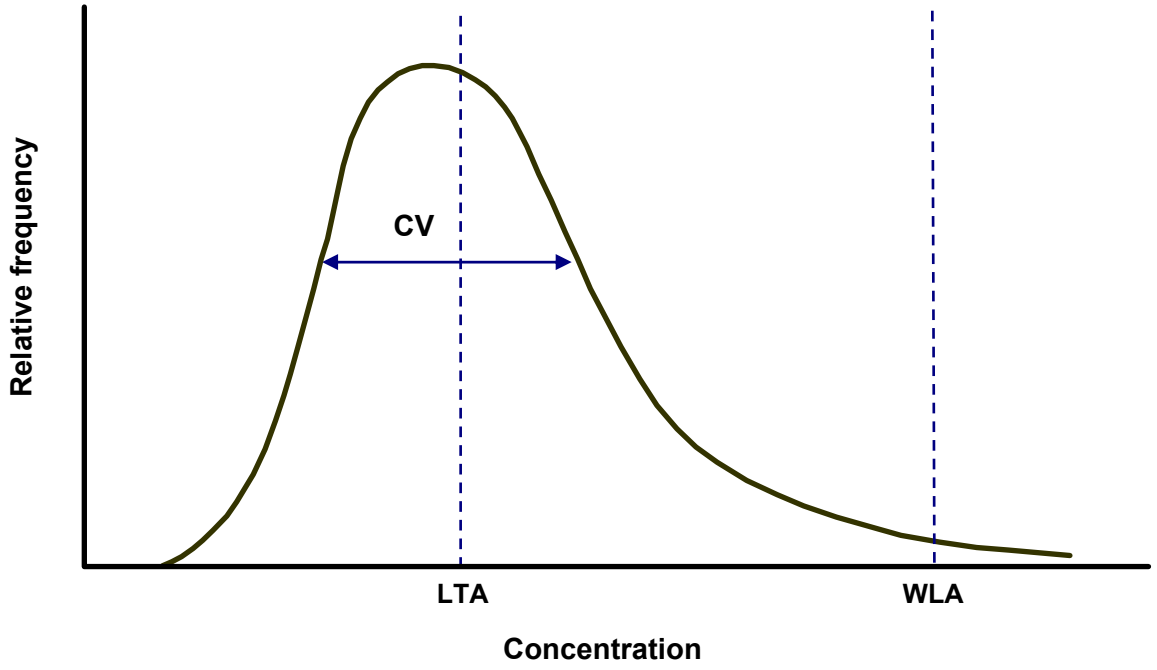
* calculated to 2 significant figures

For those pollutants with effluent concentrations that do follow a lognormal distribution, the distribution can be described by determining a long-term average (or LTA) that ensures that the effluent pollutant concentration remains nearly always below the WLA and by the CV, a measure of the variability of data around the LTA. Exhibit 6-18 illustrates a lognormal distribution with the LTA, CV, and WLA highlighted.

When applying aquatic life criteria, a permit writer generally establishes a WLA based on the acute aquatic life criterion and a WLA based on the chronic aquatic life criterion. Thus, the permit writer determines two LTAs—one that would ensure that an effluent concentration is nearly always below the acute WLA and one that would ensure that an effluent concentration nearly always below the chronic WLA. Each LTA, acute and chronic, would represent a different performance expectation for the discharger.

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Exhibit 6-18 Example of lognormal distribution of effluent pollutant concentrations and calculation of LTA



6.4.1.3 Step 3: Select the Lowest LTA as the Performance Basis for the Permitted Discharger

EPA recommends that WQBELs be based on a single performance expectation for a facility; therefore, once a permit writer has calculated LTA values for each WLA, he or she would select only one of those LTAs to define the required performance of the facility and serve as the basis for WQBELs. Because WQBELs must assure attainment of all applicable water quality criteria, the permit writer would select the lowest LTA as the basis for calculating effluent limitations. Selecting the lowest LTA would ensure that the facility's effluent pollutant concentration remains below all the calculated WLAs nearly all the time. Further, because WLAs are calculated using critical receiving water conditions, the limiting LTA would also ensure that water quality criteria are fully protected under nearly all conditions.

6.4.1.4 Step 4: Calculate an Average Monthly Limitation (AML) and a Maximum Daily Limitation (MDL)

The NPDES regulations at § 122.45(d) require that all effluent limitations be expressed, unless impracticable, as both AMLs and MDLs for all discharges other than POTWs and as both AMLs and average weekly limitations (AWLs) for POTWs. The AML is the highest allowable value for the average of daily discharges over a calendar month. The MDL is the highest allowable daily discharge measured during a calendar day or 24-hour period representing a calendar day. The AWL is the highest allowable value for the average of daily discharges over a calendar week. For pollutants with limitations expressed in units of mass, the daily discharge is the total mass discharged over the day. For limitations expressed in other units, the daily discharge is the average measurement of the pollutant over the period of a day.

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In the TSD, EPA recommends establishing an MDL, rather than an AWL, for discharges of toxic pollutants from POTWs. That approach is appropriate for at least two reasons. First, the basis for the AWL for POTWs is the secondary treatment requirements discussed in section 5.1.1.1 of this manual and is not related to the need for assuring attainment of water quality standards. Second, an AWL, which could be the average of up to seven daily discharges, could average out peak toxic concentrations and, therefore, the discharge's potential for causing acute toxic effects might be missed. An MDL would be more likely to identify potential acutely toxic impacts.

Chapter 5 of the TSD includes statistical tools for calculating MDLs and AMLs from the LTA value selected in Step 3 above. Again, note that those procedures apply to *pollutants with effluent concentration measurements that tend to follow a lognormal distribution*. EPA has not developed guidance on procedures for calculating effluent limitations for pollutants with effluent concentrations that generally cannot be described using a lognormal distribution. For such pollutants, permit writers should use other procedures as recommended by their permitting authority in its policies, procedures, or guidance.

Whether using the TSD procedures or other procedures for calculating WQBELs, the objective is to establish limitations calculated to require treatment plant performance levels that, after considering acceptable effluent variability, would have a very low statistical probability of exceeding the WLA and, therefore, would comply with the applicable water quality standards under most foreseeable conditions.

6.4.1.5 Step 5: Document Calculation of WQBELs in the Fact Sheet

Permit writers should document in the NPDES permit fact sheet the process used to develop WQBELs. The permit writer should clearly identify the data and information used to determine the applicable water quality standards and how that information, or any applicable TMDL, was used to derive WQBELs and explain how the state's antidegradation policy was applied as part of the process. The information in the fact sheet should provide the NPDES permit applicant and the public a transparent, reproducible, and defensible description of how the permit writer properly derived WQBELs for the NPDES permit.

6.4.2 Calculating Chemical-specific WQBELs based on Human Health Criteria for Toxic Pollutants

Developing WQBELs for toxic pollutants affecting human health is somewhat different from calculating WQBELs for other pollutants because (1) the exposure period of concern is generally longer (e.g., often a lifetime exposure) and (2) usually the average exposure, rather than the maximum exposure, is of concern. EPA's recommended approach for setting WQBELs for toxic pollutants for human health protection is to set the AML equal to the WLA calculated from the human health toxic pollutant criterion and calculate the MDL from the AML. Section 5.4.4 of the TSD describes statistical procedures used for such calculations for pollutants with effluent concentrations that follow a lognormal distribution. Once again, for pollutants with effluent concentrations that do not follow a lognormal distribution, permit writers should use other procedures as specified by their permitting authority.

If the permit writer calculates chemical-specific WQBELs from human health criteria, he or she should compare the limitations to any other calculated WQBELs (e.g., WQBELs based on aquatic life criteria) and TBELs and apply antidegradation and anti-backsliding requirements to determine the final limitations that meet all technology and water quality standards. As discussed above, that process should be documented in the fact sheet for the NPDES permit.

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6.5 Calculate Reasonable Potential and WQBELs for WET

WET tests measure the degree of response of exposed aquatic test organisms to an effluent mixed in some proportion with control water (e.g., laboratory water or a non-toxic receiving water sample). WET testing is used as a second approach, in addition to the chemical-specific approach, to implementing water quality standards in NPDES permits. This section provides a brief introduction to WET testing and WET limitations.

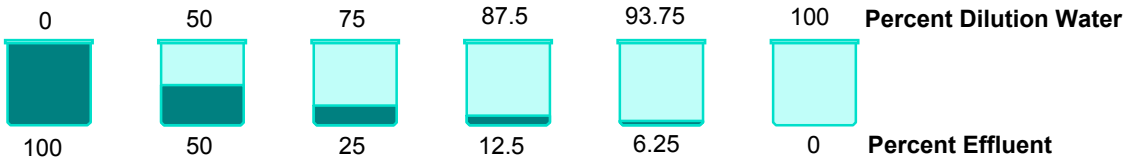
Test of Significant Toxicity (TST)

At the time of the writing of this guidance manual, EPA had recently published a new statistical approach that assesses the whole effluent toxicity (WET) measurement of wastewater effects on specific test organisms' ability to survive, grow, and reproduce. This new approach is called the Test of Significant Toxicity (TST) and is a statistical method that uses hypothesis testing techniques based on research and peer-reviewed publications. The hypothesis test under the TST approach examines whether an effluent, at the critical concentration (e.g., in-stream waste concentration [IWC]), and the control within a WET test differ by an unacceptable amount (the amount that would have a measured detrimental effect on the ability of aquatic organisms to thrive and survive). The TST implementation document and the TST technical document are available at the NPDES WET Website <www.epa.gov/npdes/wet>.

6.5.1 Types of WET Tests

In many WET tests, the effluent and control water are mixed in varying proportions to create a dilution series. Exhibit 6-19 is an example of a typical dilution series used in WET testing.

Exhibit 6-19 Example of typical dilution series



There are two types of WET tests: acute and chronic. An acute toxicity test usually is conducted over a short time, generally 96 hours or less, and the endpoint measured is mortality. The endpoint for an acute test is often expressed as an LC_{50} (i.e., the percent of effluent that is lethal to 50 percent of the exposed test organisms). A chronic toxicity test is usually conducted during a critical life phase of the organism and the endpoints measured are mortality and sub-lethal effects, such as changes in reproduction and growth. A chronic test can occur over a matter of hours or days, depending on the species tested and test endpoint. The endpoint of a chronic toxicity test often is expressed in one of the following ways:

- No observed effect concentration (NOEC), the highest concentration of effluent (i.e., highest percent effluent) at which no adverse effects are observed on the aquatic test organisms.
- Lowest observed effect concentration (LOEC), the lowest concentration of effluent that causes observable adverse effects in exposed test organisms.

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- Inhibition concentration (IC), a point estimate of the effluent concentration that would cause a given percent reduction in a biological measurement of the test organisms.
- Effect concentration (EC), a point estimate of the effluent concentration that would cause an observable adverse effect in a given percentage of test organisms.

For additional information on WET monitoring and WET test methods, see section 8.2.4 of this manual.

6.5.2 Expressing WET Limitations or Test Results

There are two options for expressing WET limitations or test results. First, WET limitations or test results can be expressed directly in terms of the WET test endpoints discussed above (e.g., LC_{50}, NOEC, and IC_{25}). Alternatively, the limitations or test results can be expressed in terms of *toxic units* (TUs). A TU is the inverse of the sample fraction, calculated as 100 divided by the percent effluent. Exhibit 6-20 presents example TUs for expressing acute and chronic test results.

Exhibit 6-20 Example of toxic units

If an **acute test** result is a LC_{50} of 60 percent, that result can be expressed as

$$\frac{100}{60} = 1.7 \text{ acute toxic units} = 1.7 \text{ TU}_a$$

If a **chronic test** result is an IC_{25} of 40 percent effluent, that result can be expressed as

$$\frac{100}{40} = 2.5 \text{ chronic toxic units} = 2.5 \text{ TU}_c$$

It is important to distinguish acute TUs (TU_a) from chronic TUs (TU_c). The difference between TU_a and TU_c can be likened to the difference between miles and kilometers. Both miles and kilometers are used to measure distance, but a distance of 1.0 mile is not the same as a distance of 1.0 kilometer. Likewise, both TU_a and TU_c are expressions of the toxicity of an effluent, but 1.0 TU_a is not the same as 1.0 TU_c. It is possible, however, to determine the relationship between the acute toxicity of an effluent and the chronic toxicity of that same effluent, just as it is possible to determine the relationship between miles and kilometers (i.e., through a conversion factor). Unlike the conversion between miles and kilometers that remains constant, the conversion factor between acute and chronic toxic units varies from effluent to effluent.

For an effluent, the permit writer could develop a conversion factor that would allow conversion of TU_a into equivalent TU_c or vice versa. This conversion factor is known as an acute-to-chronic ratio (ACR) for that effluent. The ACR for an effluent may be calculated where there are at least 10 sets of paired acute and chronic WET test data available. The ACR is determined by calculating the mean of the individual ACRs for each pair of acute and chronic WET tests. Where there are not sufficient data to calculate an ACR for an effluent (i.e., less than 10 paired sets of acute and chronic WET test data), EPA recommends a default value of ACR = 10. Exhibit 6-21 presents examples showing how the ACR converts TU_a into TU_c, how to calculate an ACR from existing data, and how, once an ACR is calculated, a permit writer could estimate the chronic toxicity of an effluent sample from its measured acute toxicity or vice versa.

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Exhibit 6-21 Using the ACR

The ACR is expressed

$$ACR = \frac{\text{Acute Endpoint}}{\text{Chronic Endpoint}} = \frac{LC_{50}}{IC_{25}}$$

A TU is the inverse of the sample fraction. Therefore, by definition

$$TU_a = \frac{100}{LC_{50}} \qquad TU_c == \frac{100}{IC_{25}}$$

Consequently, toxicity as percent sample, may be expressed

$$LC_{50} = \frac{100}{TU_a} \qquad IC_{25} = \frac{100}{TU_c}$$

Substituting into the original equation gives

$$ACR = \frac{LC_{50}}{IC_{25}} = \frac{\frac{100}{TU_a}}{\frac{100}{TU_c}} = \frac{TU_c}{TU_a}$$

Example 1
Given: LC_{50} = 28%, IC_{25} = 10%

$$ACR = \frac{LC_{50}}{IC_{25}} = \frac{28\%}{10\%} = 2.8$$

Example 2
Given: TU_a = 3.6, TU_c = 10.0

$$ACR = \frac{TU_c}{TU_a} = \frac{10.0}{3.6} = 2.8$$

Example 3
Given: Toxicity data for a facility's effluent for *C. dubia*. as presented in the table to the right.

The ACR in the third column is calculated using the following equation:

$$ACR = \frac{LC_{50}}{IC_{25}}$$

LC_{50} (% effluent)	IC_{25} (% effluent)	ACR
62	10	6.2
18	10	1.8
68	25	2.7
61	10	6.1
63	25	2.5
70	25	2.8
17	5	3.4
35	10	3.5
35	10	3.5
35	25	1.4
47	10	4.7
Mean		**3.5**

Example 4
Given: TU_a = 1.8, ACR = 3.5

$$ACR = \frac{TU_c}{TU_a} \qquad TU_c = ACR \times TU_a$$

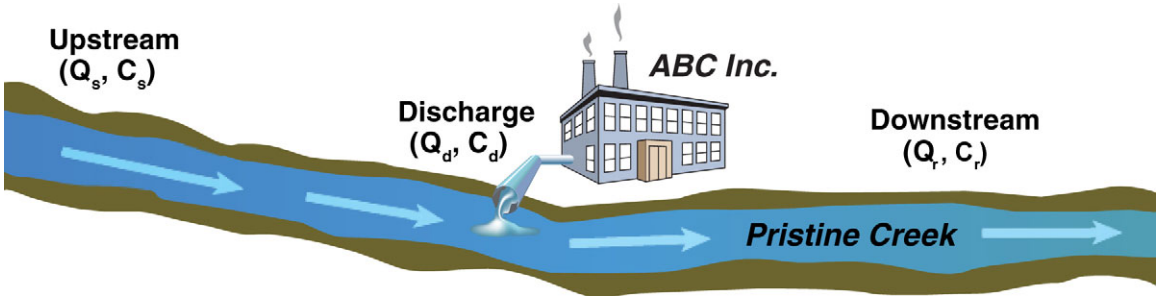
$$\text{Estimated } TU_c = ACR \times TU_a = 3.5 \frac{TU_c}{TU_a} \times 1.8\ TU_a = 6.3\ TU_c$$

6.5.3 Determining the Need for WET Limitations

If a state has numeric criteria for WET, a permit writer could use the results of WET tests to project acute or chronic toxicity in the receiving water after accounting for the applicable dilution allowance or mixing zone made available in the water quality standards. The permit writer would compare the projected toxicity of the receiving water to the applicable water quality criterion for WET. If the projected toxicity exceeds the applicable numeric water quality criterion for WET, the discharge would cause, have the reasonable potential to cause, or contribute to an excursion above the applicable water quality standards, and the permit writer must develop a WQBEL for WET [see § 122.44(d)(1)(iv)]. In that way, numeric criteria for WET can be treated similarly to chemical-specific criteria. Exhibit 6-22 provides an example of how the mass-balance equation is used to conduct a reasonable potential analysis for WET.

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Exhibit 6-22 Example of mass-balance equation for a WET reasonable potential analysis



The mass-balance equation can be used to determine whether the discharge from ABC Inc. would cause, have the reasonable potential to cause, or contribute to toxicity in Pristine Creek that exceeds the numeric water quality criteria for acute or chronic toxicity. Assume the discharge mixes rapidly and completely with Pristine Creek.

Mass-Balance Equation: $Q_sC_s + Q_dC_d = Q_rC_r$

Dividing both sides of the mass-balance equation by Q_r gives the following:

$$C_r = \frac{(Q_d)(C_d) + (Q_s)(C_s)}{Q_r}$$

The following values are known for ABC Inc. and Pristine Creek:

Q_s = Critical upstream flow (1Q10 for acute protection)	= 23.6 cfs
(7Q10 for chronic protection)	= 70.9 cfs
C_s = Upstream toxicity in Pristine Creek (acute)	= 0 TU_a
(chronic)	= 0 TU_c
Q_d = Discharge flow	= 7.06 cfs
C_d = Discharge toxicity (acute)	= 2.50 TU_a
(chronic)	= 8.00 TU_c
Q_r = Downstream flow	= Q_d + Q_s
Acute Water Quality Criterion in Pristine Creek	= 0.3 TU_a
Chronic Water Quality Criterion in Pristine Creek	= 1.0 TU_c

Find the downstream concentration (C_r) by inserting the given values into the equation as follows:

For acute toxicity:

$$C_r = \frac{(7.06\ \text{cfs})(2.5\ TU_a) + (23.6\ \text{cfs})(0\ TU_a)}{7.06\ \text{cfs} + 23.6\ \text{cfs}} = 0.58\ TU_a$$

The downstream concentration (C_r) exceeds the water quality criterion for acute toxicity of 0.3 TU_a.

For chronic toxicity:

$$C_r = \frac{(7.06\ \text{cfs})(8.00\ TU_c) + (70.9\ \text{cfs})(0\ TU_c)}{7.06\ \text{cfs} + 70.9\ \text{cfs}} = 0.72\ TU_c$$

The downstream concentration (C_r) does not exceed the water quality criterion for chronic toxicity of 1.0 TU_c.

In Exhibit 6-22 above, the downstream concentration under critical conditions for the acute water quality criterion (C_r = 0.58 TU_a) exceeds the water quality criterion for acute toxicity (0.3 TU_a); therefore there is reasonable potential and WET limitations are required. WET limitations would be calculated in much the same way as limitations on specific chemicals. The limitations would be calculated to ensure that WET criteria are not exceeded after any available dilution or at the edge of the applicable mixing zone.

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Where state water quality standards do not include numeric criteria for WET, a permit writer could evaluate the need for WQBELs for WET on the basis of narrative criteria; specifically, a narrative criterion stating that waterbodies must be free from *toxics in toxic amounts*. To make it easier for a permit writer to readily establish WET limitations in this situation, the permitting authority should have a policy for implementing the narrative criterion. Following the permitting authority's policy, if the permit writer determines that a discharge causes, has the reasonable potential to cause, or contributes to an in-stream excursion above a narrative criterion, the regulations at § 122.44(d)(1)(v) require that the permit include WQBELs for WET unless the permit writer demonstrates that parameter-specific limitations for the effluent are sufficient to attain and maintain applicable numeric and narrative water quality criteria. In other words, the permit must include WET limitations unless the permit writer is able to determine the specific pollutants that are the source of toxicity and include parameter-specific limitations for those pollutants that assure, and will continue to assure, attainment of water quality standards. If there are no criteria in the state water quality standards for the specific parameters causing the toxicity, the permit writer can establish WQBELs using one of three approaches outlined in § 122.44(d)(1)(vi):

- Use EPA's national recommended criteria.
- Calculate a numeric criterion that will attain and maintain the applicable narrative criterion.
- Control the pollutant using an indicator parameter for the pollutant of concern.

A permit also could include a requirement to conduct a toxicity identification evaluation and toxicity reduction evaluation (TIE/TRE) as a special condition in an NPDES permit. (Chapter 9 of this manual presents more information on special conditions.) A TIE/TRE is a site-specific study designed to systematically investigate and identify the causes of effluent toxicity problems, isolate the sources of that toxicity, identify and implement appropriate toxicity control options, and confirm the effectiveness of those control options and the reduction in toxicity. The permit writer might require a TIE/TRE when WET limitations are exceeded or, if there are no WET limitations in the permit, where WET testing demonstrates an unacceptable level of effluent toxicity. Because WET testing indicates the degree of toxicity of an effluent, but does not specifically identify the cause of that toxicity or ways to reduce toxicity, a TIE/TRE is necessary to achieve compliance with effluent limitations or other effluent toxicity requirements in NPDES permits. If a TIE/TRE is not required through the special conditions section of the permit, it could be required via a CWA section 308 letter, a CWA section 309 administrative order, or a consent decree.

6.6 Antidegradation Review

Early in the permit development process, a permit writer should check the state's antidegradation policy and implementation methods to determine what tier(s) of protection, if any, the state has assigned to the proposed receiving water for the parameter(s) of concern. The regulations concerning antidegradation and each of the tiers are described above in section 6.1.1.3. The tier of antidegradation protection is important for determining the required process for developing the water quality-based permit limits and conditions. In some cases, where a waterbody is classified as Tier 3 for antidegradation purposes, the permit writer might find that it is not possible to issue a permit for the proposed activity.

If the state has not specified the tier, the permit writer will need to evaluate, in accordance with the state's implementation procedures, whether the receiving waterbody is of high water quality for the parameters of concern, and thus will require Tier 2 protection. After identifying the tier(s) of protection for the

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proposed receiving waterbody and parameter(s) of concern, the permit writer should consult the state's antidegradation implementation procedures relevant to the tier(s).

The following sections provide methods permit writers should consider for implementing, through the WQBEL development process, the three levels of protection typically found in a state's antidegradation policy. Implementation of the state's antidegradation policy could have a significant effect on the calculation of WQBELs.

6.6.1 Tier 1 Implementation

All waterbodies receive at least Tier 1 protection. Tier 1 protection means that the permit writer must include limits in the permit sufficient to maintain and protect water quality necessary to protect existing uses. In practice, for a Tier 1 receiving waterbody, the permit writer typically calculates the WQBELs on the basis of the applicable criteria because the state's designated uses and criteria to protect those uses must be sufficient to protect the existing uses. If a Tier 1 waterbody is impaired for a parameter that would be present in the proposed discharge, the permit writer should identify and consult any relevant TMDLs to determine what quantity of pollutant (if any) is appropriate.

6.6.2 Tier 2 Implementation

For new or increased discharges that could potentially lower water quality in high-quality waters, Tier 2 protection provides the state with a framework for making decisions regarding the degree to which it will protect and maintain the high water quality. A new or expanded discharge permit application typically triggers a Tier 2 antidegradation review. Depending on the outcome of the review, the permit could be written to maintain the existing high water quality or could be written to allow some degradation.

Each state's antidegradation policy or implementation procedures should describe the Tier 2 antidegradation review process. Though the process varies among states, EPA's antidegradation regulation at § 131.12 outlines the common elements of the process. To permit a new or increased discharge that would lower water quality, the state is required to make a finding on the basis of the following:

- The state must find that allowing lower water quality is necessary for important social or economic development in the area in which the waters are located.
  - The state would perform an alternatives analysis to evaluate whether the proposed discharge is actually *necessary* (i.e., whether there are less degrading feasible alternatives) and that might include consideration of a wide range of alternatives (e.g. non-discharging options, relocation of discharge, alternative processes, and innovative treatments).
  - The state should provide a justification of important social or economic development (or both) that would occur as a result of permitting the proposed discharge.
- The state's finding must be made after full satisfaction of its own intergovernmental coordination and public participation provisions.
- The state must assure that the highest statutory and regulatory requirements for all new and existing point sources will be achieved.
- The state must assure that all cost-effective and reasonable BMPs for nonpoint source control will be achieved.

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- The state must assure that water quality will still protect existing uses.

If, after fulfilling the above conditions of the Tier 2 antidegradation review process, the state makes a determination to allow a new or increased discharge that would lower water quality, the permit writer may include such limitations in the NPDES permit for that discharge provided the limitations meet all other applicable technology and water quality standards.

6.6.3 Tier 3 Implementation

States identify their own ONRWs for Tier 3 protection, which requires that the water quality be maintained and protected. This is the most stringent level of protection. ONRWs often include waters in national or state parks, wildlife refuges, and waters of exceptional recreational or ecological significance. Waterbodies can be given Tier 3 protection regardless of their existing level of water quality. Some states implement Tier 3 by prohibiting any new or increased discharges to ONRWs or their tributaries that would result in lower water quality, with the exception of some limited activities such as those that would result in temporary changes in water quality ultimately resulting in restoration. Some states allow increased discharges as long as they are offset by equivalent or greater reductions elsewhere in the waterbody.

In addition to Tiers 1, 2, and 3, some states have a class of waters considered outstanding to the state and for which the state might have specific antidegradation requirements. Such waterbodies are sometimes referred to as *Tier 2 ½* waters because implementation of the antidegradation policy for them affords a greater degree of protection than Tier 2 but more flexibility than Tier 3.

Chapter 4 of EPA's WQS Handbook and the *Water Quality Standards Regulation Advance Notice of Proposed Rulemaking* (64 FR 36742, July 7, 1998) include additional information on implementing antidegradation policies. The permit writer should clearly explain the antidegradation analysis and how it affects calculation of WQBELs in the fact sheet or statement of basis for the permit.

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[1] U.S. Environmental Protection Agency. 1994. *Water Quality Standards Handbook: Second Edition* (WQS Handbook). EPA 823-B-94-005a. U.S. Environmental Protection Agency, Office of Water, Washington DC. <www.epa.gov/waterscience/standards/handbook/>.

[2] U.S. Environmental Protection Agency. 2001. *Streamlined Water-Effect Ratio Procedure for Discharges of Copper*. EPA-822-R-01-005. U.S. Environmental Protection Agency, Office of Science and Technology, Washington, DC. <www.epa.gov/waterscience/criteria/copper/copper.pdf>.

[3] Davies, Tudor T. 1997. *Establishing Site Specific Aquatic Life Criteria Equal to Natural Background.* U.S. Environmental Protection Agency, Office of Science and Technology, Washington, DC. <www.epa.gov/waterscience/library/wqcriteria/naturalback.pdf>.

[4] U.S. Environmental Protection Agency. 1991. *Technical Support Document for Water Quality-Based Toxics Control* (TSD). EPA-505/2-90-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. <www.epa.gov/npdes/pubs/owm0264.pdf>.

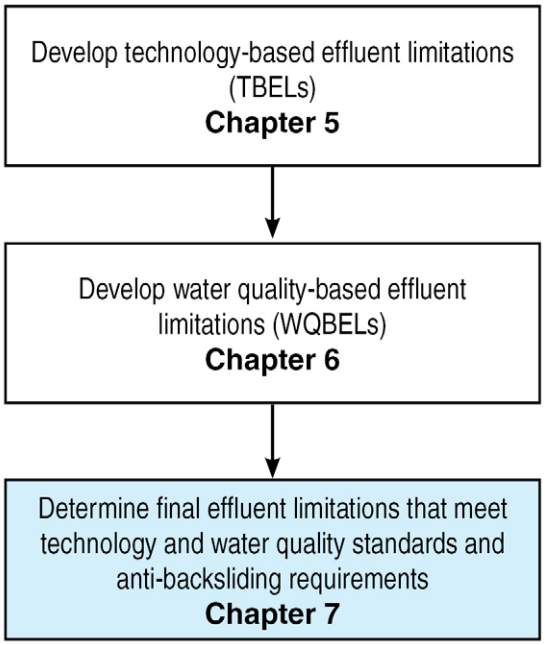
[5] U.S. Environmental Protection Agency. 1990. *Biological Criteria: National Program Guidance for Surface Waters*. EPA-440/5-91-004. U.S. Environmental Protection Agency, Office of Science and Technology, Washington, DC. <www.epa.gov/bioindicators/html/biolcont.html>.

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CHAPTER 7. Final Effluent Limitations and Anti-backsliding

As illustrated in Exhibit 7.1, after calculating applicable technology-based effluent limitations (TBELs) and water quality-based effluent limitations (WQBELs), the permit writer must determine the final effluent limitations that will be included in the National Pollutant Discharge Elimination System (NPDES) permit for each pollutant or pollutant parameter. For reissued permits, that determination must also include an assessment of whether the revised effluent limitations are consistent with the Clean Water Act (CWA) requirements and NPDES regulations related to anti-backsliding.

Exhibit 7-1 Developing effluent limitations



7.1 Determining Final Effluent Limitations

When determining the final effluent limitations, the permit writer must ensure that all applicable statutory and regulatory requirements, including technology and water quality standards, are fully implemented.

- The permit writer determines the calculated limitations (TBELs, WQBELs, or some combination of the calculated limitations) that will ensure that all applicable CWA standards are met.
- As noted above, for reissued permits, if any of the limitations are less stringent than limitations on the same pollutant in the previous NPDES permit, the permit writer then conducts an anti-backsliding analysis and, if necessary, revises the limitations accordingly. A detailed discussion of the anti-backsliding provisions of the CWA and the NPDES regulations is included below in Section 7.2.

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In addition, the permit writer should clearly explain in the fact sheet for the permit how the final limitations in the permit were determined and how those limitations meet both technology and water quality standards (including antidegradation) and, where appropriate, how an anti-backsliding analysis was applied to the final effluent limitations.

7.2 Applying Anti-backsliding Requirements

As noted in Section 7.1, after selecting the calculated effluent limitations for a pollutant that ensure that all CWA standards are met, the permit writer applies anti-backsliding requirements, as necessary, to determine the final effluent limitations. In general, the term anti-backsliding refers to statutory and regulatory provisions that prohibit the renewal, reissuance, or modification of an existing NPDES permit that contains effluent limitations, permit conditions, or standards less stringent than those established in the previous permit. There are, however, exceptions to the prohibition, and determining the applicability and circumstances of the exceptions requires familiarity with both the statutory and regulatory provisions that address anti-backsliding.

7.2.1 Anti-backsliding Statutory Provisions

Clean Water Act (CWA) section 402(o) expressly prohibits backsliding from certain existing effluent limitations. CWA section 402(o) consists of three main parts: (1) a prohibition on specific forms of backsliding, (2) exceptions to the prohibition, and (3) a *safety clause* that provides an absolute limitation on backsliding.

7.2.1.1 Statutory Prohibition Against Backsliding

First, CWA section 402(o)(1) prohibits the relaxation of effluent limitations for two situations:

- To revise an existing TBEL that was developed on a case-by-case basis using best professional judgment (BPJ) to reflect subsequently promulgated effluent limitations guidelines and standards (effluent guidelines) that would result in a less stringent effluent limitation.
- Relaxation of an effluent limitation that is based on state standards, such as water quality standards or treatment standards, unless the change is consistent with CWA section 303(d)(4). Section 303(d)(4) may be applied independently of section 402(o).

The prohibition against relaxation of effluent limitations is subject to the exceptions in CWA section 402(o)(2) and, for limitations based on state standards, the provisions of CWA section 303(d)(4). Those exceptions are outlined further in the following sections.

7.2.1.2 Exceptions for Case-by-Case TBELs

CWA section 402(o)(2) outlines specific exceptions to the general prohibition against revising an existing TBEL that was developed on a case-by-case basis using BPJ to reflect subsequently promulgated, less stringent effluent guidelines in a renewed, reissued, or modified permit. CWA section 402(o)(2) provides that relaxed limitations may be allowed where

- There have been material and substantial alternations or additions to the permitted facility that justify the relaxation.

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- New information (other than revised regulations, guidance, or test methods) is available that was not available at the time of permit issuance and that would have justified a less stringent effluent limitation. If the effluent limitation was based on water quality standards, any changes must result in a decrease in pollutants discharged.
- Technical mistakes or mistaken interpretations of the law were made in issuing the permit under CWA section 402(a)(1)(b).
- Good cause exists because of events beyond the permittee's control (e.g., natural disasters) and for which there is no reasonably available remedy.
- The permit has been modified under CWA sections 301(c), 301(g), 301(h), 310(i), 301(k), 301(n), or 316(a).
- The permittee has installed and properly operated and maintained required treatment facilities but still has been unable to meet the effluent limitations (relaxation may be allowed only to the treatment levels actually achieved).

7.2.1.3 Exceptions for Limitations Based on State Standards

EPA has consistently interpreted CWA section 402(o)(1) to allow relaxation of WQBELs and effluent limitations based on state standards if the relaxation is consistent with the provisions of CWA section 303(d)(4) or if one of the exceptions in CWA section 402(o)(2) is met. The two provisions constitute independent exceptions to the prohibition against relaxation of effluent limitations. If either is met, relaxation is permissible.

CWA section 303(d)(4) has two parts: paragraph (A), which applies to *nonattainment waters*, and paragraph (B), which applies to *attainment waters*.

- **Nonattainment water:** CWA section 303(d)(4)(A) allows the establishment of a less stringent effluent limitation when the receiving water has been identified as not meeting applicable water quality standards (i.e., a *nonattainment water*) if the permittee meets two conditions. First, the existing effluent limitation must have been based on a total maximum daily load (TMDL) or other wasteload allocation (WLA) established under CWA section 303. Second, relaxation of the effluent limitation is only allowed if attainment of water quality standards will be ensured or the designated use not being attained is removed in accordance with the water quality standards regulations. This subsection does not provide an exception for establishing less stringent limitations where the original limitation was based on state permitting standards (e.g., state treatment standards) and was not based on a TMDL or WLA.
- **Attainment water:** CWA section 303(d)(4)(B) applies to waters where the water quality equals or exceeds levels necessary to protect the designated use, or to otherwise meet applicable water quality standards (i.e., an *attainment water*). Under CWA section 303(d)(4)(B), a limitation based on a TMDL, WLA, other water quality standard, or any other permitting standard may only be relaxed where the action is consistent with state's antidegradation policy.

Although the statute also identifies six exceptions in section 402(o)(2) where effluent limitations otherwise subject to the prohibition in section 402(o)(1) may be relaxed, the exceptions for technical mistakes or mistaken interpretations and permit modification, which are described above, would not apply to WQBELs.

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7.2.1.4 Exception Safety Clause

CWA section 402(o)(3) is a *safety clause* that provides an absolute limitation on backsliding. This section of the CWA prohibits the relaxation of effluent limitations in all cases if the revised effluent limitation would result in a violation of applicable effluent guidelines or water quality standards, including antidegradation requirements. Thus, even if one or more of the backsliding exceptions outlined in the statute is applicable and met, CWA section 402(o)(3) acts as a floor and restricts the extent to which effluent limitations may be relaxed. The requirement affirms existing provisions of the CWA that require effluent limitations, standards, and conditions to ensure compliance with applicable technology and water quality standards.

7.2.2 Anti-backsliding Regulatory Provisions

Anti-backsliding regulations are found at Title 40 of the *Code of Federal Regulations* (CFR) 122.44(l). The regulations do not specifically address backsliding where a permittee seeks relaxation of an effluent limitation that is based on a state treatment standard or water quality standard [i.e., based on CWA section 301(b)(1)(C), 303(d) or 303(e)]. They do, however, address all other forms of backsliding.

First, the regulations at § 122.44(l)(1) restrict the relaxation of *final effluent limitations* and the relaxation of *standards or conditions* contained in existing permits. Thus, this regulation, in effect, addresses all types of backsliding not addressed in the CWA provisions (e.g., backsliding from limitations derived from effluent guidelines, from new source performance standards, from existing case-by-case limitations to new case-by-case limitations, and from conditions such as monitoring requirements that are not effluent limitations). Under the regulation, a permittee must meet one of the causes for modification under § 122.62 for the reissued permit to allow relaxation of such limitations, standards, or conditions.

Second, the regulations at § 122.44(l)(2)(i) directly reflect the specific prohibition imposed by CWA section 402(o) on backsliding where a permittee seeks to revise an existing case-by-case TBEL developed using BPJ to reflect a subsequently promulgated effluent guideline that is less stringent than the case-by-case requirement. The regulations include the same exceptions to this prohibition that are in CWA section 402(o)(2) and the same *safety clause* in CWA section 402(o)(3).

Thus, if the permit condition being considered for relaxation is either a case-by-case effluent limitation developed using BPJ or is any other limitation, standard, or condition other than an effluent limitation based on a state standard, the permit writer can apply the requirements in § 122.44(l). For effluent limitations based on state standards, the permit writer should apply the provisions of CWA sections 402(o) and 303(d)(4) directly. Exhibit 7-2 illustrates the process of applying the statutory and regulatory provisions addressing anti-backsliding.

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Exhibit 7-2 Application of anti-backsliding requirements

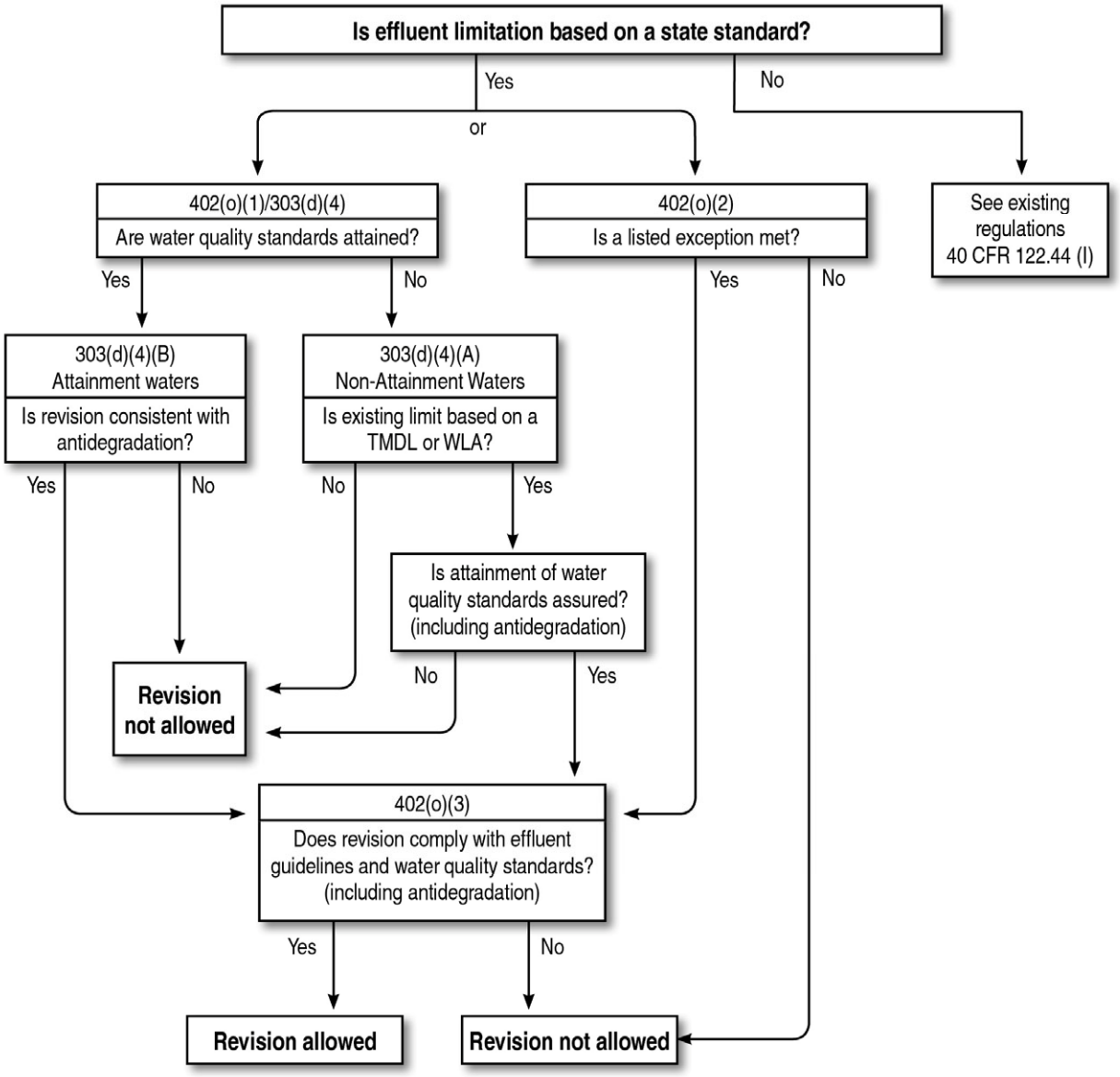


Exhibit 7-3 presents some examples of situations when backsliding might be a factor in effluent limitation development.

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Exhibit 7-3 Backsliding examples

Example 1

- A publicly owned treatment works (POTW) seeks to relax its WQBEL for Pollutant X
- The current effluent limitation for Pollutant X is based on a TMDL and WLA for the POTW developed in accordance with § 130.7.
- The POTW is in compliance with its existing effluent limitation, and the applicable water quality standards for Pollutant X are attained.
- The POTW has developed new models with new river flow information. The models indicate that the water quality standards for Pollutant X would be maintained with a relaxed permit limitation.

Question:
May the effluent limitation for Pollutant X be relaxed?

Answer:
Possibly. Under the interpretation discussed above, WQBELs may be relaxed where one of the exceptions in CWA sections 402(o)(1) or (2) are met. In this case, although the new information from the models might meet the exception requirements criteria under CWA section 402(o)(2)(B)(i), CWA section 402(o)(2) will not justify the request unless the state reduces the pollutant loadings from other point sources or nonpoint sources of pollution. That is because, as discussed in Section 7.1 above, CWA section 402(o)(2) restricts the use of new information to cases where there is a decrease in the amount of pollutants being discharged.

The CWA section 402(o)(1) exceptions, on the other hand, might justify the request. In this case, the reference to CWA section 303(d)(4)(B) in CWA section 402(o)(1) is the relevant exception. CWA section 303(d)(4)(B) provides that, for receiving waters that meet water quality standards, permit limitations based on a TMDL or other WLA or other permit standard may be relaxed if the state's antidegradation policy requirements are met.

Example 2

- The state has established a technology-based treatment standard for fecal coliform pursuant to CWA section 301(b)(1)(C).
- The state later relaxes the standard in a revised regulation.
- A POTW, which has been in violation of its effluent limitation for fecal coliform based on the old standard, requests a revision of the limitation to reflect the new standard.
- Water quality standards for fecal coliform are not being attained.
- There was no TMDL or WLA developed. The basis of the effluent limitation was a state technology-based treatment standard.

Question:
May the fecal coliform effluent limitation be relaxed?

Answer:
No. Under CWA section 402(o)(1), the applicable provision is CWA section 303(d)(4)(A). This subsection does not authorize backsliding in this case (i.e., nonattainment waters) because it applies only to permit limitations based on a TMDL or other WLA. Here, the limitation in question is based on a state technology-based treatment standard.

Furthermore, if the permit sought to apply the exceptions in CWA section 402(o)(2), the new information provision would not allow the revision. For purposes of this section of the CWA, new information does not include *revised regulations*.

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Exhibit 7-3 Backsliding examples (continued)

Example 3

- The state has a narrative water quality criterion of *no toxics in toxic amounts*.
- On the basis of WET testing data or other information, the state found that the discharge would cause, have the reasonable potential to cause, or contribute to an excursion of the water quality standards in the receiving water—specifically the narrative water quality criterion.
- The permitting authority imposed a WET limitation under § 122.44(d)(1)(v).
- The permittee determines that Pollutant Z is the cause of WET measured in its discharge.
- The permittee can demonstrate through sufficient data (including WET testing data) that an effluent limitation for Pollutant Z will assure compliance with the narrative water quality criterion as well as the state's numeric criteria for Pollutant Z, as required by § 122.44(d)(1)(v).

Question:
May the state modify the permit to delete the WET limitation and to add the effluent limitation for Pollutant Z?

Answer:
Possibly. CWA section 303(d)(4) might justify the action. The applicable provision is CWA section 303(d)(4)(B) because the narrative water quality criterion is currently attained. The permittee is complying with the existing WET limitation to attain and maintain the criterion. Under CWA section 303(d)(4)(B), the existing effluent limitation may be relaxed as long as antidegradation requirements are met and the relaxed limitation will not cause a violation of any effluent guidelines or water quality standards applicable to the discharge. In this case, it appears likely that a relaxation would be permissible because the permittee can demonstrate that the new limitation for Pollutant Z will assure compliance with both the narrative and numeric water quality criteria; however, the permit writer might consider continuing WET monitoring to identify other potential sources of toxicity in the future.

Example 4

- An industrial permittee seeks to revise its WQBEL of 60 mg/L for total suspended solids (TSS) to 100 mg/L, which is its actual discharge level.
- The current effluent limitation is based on a WLA from a TMDL developed in accordance with § 130.7.
- The water quality standards are not being attained. The ambient concentration of TSS exceeds the applicable water quality criteria.
- An effluent limitation of 100 mg/L is consistent with applicable effluent guidelines.
- New modeling information shows that the water quality standards will be attained with an effluent limitation of 75 mg/L TSS.

Question:
May the effluent limitation for TSS be revised from 60 mg/L to 100 mg/L?

Answer:
No; however, the effluent limitation could be relaxed to 75 mg/L under either CWA sections 402(o)(1) or (2) exceptions.

The water quality standards are not being attained because of TSS. Therefore, under CWA section 402(o)(1), the applicable exception is CWA section 303(d)(4)(A). In this case, the permitting authority may allow backsliding to 75 mg/L because the existing effluent limitation is based on a WLA from a TMDL, and the data show that attainment of the water quality standards is assured with an effluent limitation of 75 mg/L (but not with a limitation of 100 mg/L).

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CHAPTER 8. Monitoring and Reporting Conditions

This chapter describes the monitoring and reporting conditions that a permit writer establishes in a National Pollutant Discharge Elimination System (NPDES) permit. The monitoring and reporting conditions require the permittee to conduct routine or episodic self-monitoring of permitted discharges and internal operations (where applicable) and report the analytical results to the permitting authority with the information necessary to evaluate discharge characteristics and compliance status. Periodic monitoring and reporting establish an ongoing record of the permittee's compliance status and, where violations are detected, create a basis for any necessary enforcement actions.

The monitoring and reporting conditions section of an NPDES permit generally includes specific requirements for the following items:

- Monitoring locations.
- Monitoring frequencies.
- Sample collection methods.
- Analytical methods.
- Reporting and recordkeeping requirements.

The following sections provide an overview of the considerations involved in determining appropriate monitoring, reporting, and recordkeeping requirements, and how to properly incorporate the appropriate requirements in an NPDES permit.

8.1 Establishing Monitoring Conditions

The NPDES regulations require facilities discharging pollutants to waters of the United States to periodically evaluate compliance with the effluent limitations established in their permits and provide the results to the permitting authority. A permit writer should consider several factors when determining the specific requirements to be included in the NPDES permit. Inappropriate or incomplete monitoring requirements can lead to inaccurate compliance determinations. Factors that could affect sampling location, sampling method, and sampling frequency include the following:

- Applicability of effluent limitations guidelines and standards (effluent guidelines).
- Wastestream and process variability.
- Access to sample locations.
- Pollutants discharged.
- Effluent limitations.
- Discharge frequencies (e.g., continuous versus intermittent).
- Effect of flow or pollutant load or both on the receiving water.
- Characteristics of the pollutants discharged.
- Permittee's compliance history.

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8.1.1 Purposes of Monitoring

Monitoring is performed to determine compliance with effluent limitations established in NPDES permits, establish a basis for enforcement actions, assess treatment efficiency, characterize effluents and characterize receiving water.

Regulations requiring the establishment of monitoring and reporting conditions in NPDES permits are at Title 40 of the *Code of Federal Regulations* (CFR) 122.44(i) and 122.48. Regulations at § 122.44(i) require permittees to monitor pollutant mass (or other applicable unit of measure) and effluent volume and to provide other measurements (as appropriate) using the test methods established at Part 136. That subpart also establishes that NPDES permits (with certain specific exceptions as discussed in section 8.1.3 below) must require permittees to monitor for all limited pollutants and report data at least once per year.

Regulations at § 122.48 stipulate that all permits must specify requirements concerning the proper use, maintenance, and installation of monitoring equipment or methods (including biological monitoring methods when appropriate). NPDES permits must also specify the monitoring type, intervals, and frequency sufficient to yield data that are representative of the activity. The following sections focus on developing permit monitoring conditions that properly address these regulatory requirements.

8.1.2 Monitoring Location

The permit writer should specify the appropriate monitoring location in an NPDES permit to ensure compliance with the permit limitations and provide the necessary data to determine the effects of an effluent on the receiving water. The NPDES regulations do not prescribe exact monitoring locations; rather, the permit writer is responsible for determining the most appropriate monitoring location(s) and indicating the location(s) in the permit. Ultimately, the permittee is responsible for providing a safe and accessible sampling point that is representative of the discharge [§ 122.41(j)(1)].

The permit writer should consider the following questions when selecting a monitoring location:

- Is the monitoring location on the facility's property?
- Is the monitoring location accessible to the permittee and the permitting authority?
- Will the results be representative of the targeted wastestream?
- Is monitoring at internal points needed?

Permit writers should establish monitoring locations where the wastewater is well mixed, such as near a Parshall flume or at a location in a sewer with hydraulic turbulence. Weirs tend to enhance the settling of solids immediately upstream and the accumulation of floating oil or grease immediately downstream. Such locations should be avoided for sampling.

The permit writer can specify monitoring locations with either a narrative description or a diagram of the permittee's facility. Exhibit 8-1 provides examples of how to specify monitoring locations in a permit either by narrative or by diagram.

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Exhibit 8-1 Examples of specifying monitoring locations in permits

Narrative

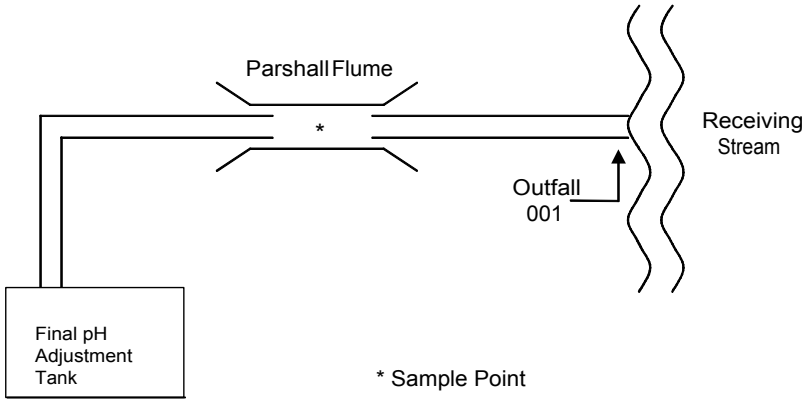
A. Monitoring Locations

1. Discharge from the Chemistry-Fine Arts Building must be sampled at the Parshall flume before the discharge point for Outfall 001.
2. Discharge from the Physics Building must be sampled at the Parshall flume before the discharge point for Outfall 002.
3. Discharge from the Research Lab No. 1 must be sampled at the Parshall flume before the discharge point for Outfall 003.

Diagram

A. Monitoring Locations

Outfall	Description
001	Discharge Pipe: Discharge of wastewater generated by all regulated metal finishing processes at the facility. Samples must be collected at the point indicated on the diagram below.



The monitoring location will vary depending on the type of monitoring required. The following sections discuss monitoring location considerations for each monitoring type.

8.1.2.1 Influent and source water monitoring locations

Influent monitoring is monitoring of a wastestream before that wastestream receives treatment. The permit writer should require influent monitoring when a characterization of the influent is needed to determine compliance with a permit condition, such as the 5-day biochemical oxygen demand (BOD_5) and total suspended solids (TSS) percent removal limitations required by the secondary treatment standards for publicly owned treatment works (POTWs).

Source water monitoring is the monitoring of source water before use as process water (e.g., river water used as contact cooling water). The permit writer should require source water monitoring if intake credits are established as specified in § 122.45(g).

Influent and source water monitoring locations should ensure a representative sample of raw intake water before any processes or treatment that could alter the properties of the intake water.

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8.1.2.2 Internal monitoring locations

Internal monitoring is the monitoring of wastestreams at a location within the facility before discharge to waters of the United States. The NPDES regulations at § 122.45(h) allow internal monitoring points to be established when needed to determine compliance with a standard and in cases where setting an external monitoring location is not feasible. The permit writer may require internal monitoring to determine compliance with technology-based effluent limitations (TBELs) for a wastestream before commingling with other process or non-process wastestreams. Internal monitoring is generally not appropriate for determining compliance with water quality-based effluent limitations (WQBELs) unless final effluent monitoring is impractical (e.g., the final discharge point is submerged or inaccessible).

Examples of reasons for requiring designation of internal monitoring locations include the following:

- **Ensuring compliance with effluent guidelines (at non-POTW facilities):** When non-process wastewaters dilute process wastewaters subject to effluent guidelines, monitoring the combined discharge might not accurately allow determination of whether the facility is complying with the effluent guidelines. Under such circumstances, the permit writer might consider requiring monitoring for compliance with TBELs before the process wastewater is combined with non-process wastewater.
- **Ensuring compliance with secondary treatment standards (for POTWs only):** Some POTWs include treatment processes that do not address pollutants regulated by secondary treatment standards and that could interfere with the ability to accurately monitor for compliance with secondary treatment standards. Under such circumstances, the permit writer could consider requiring monitoring for compliance with limitations derived from secondary treatment standards before such processes. For example, the permit could require effluent monitoring for compliance with limitations derived from secondary treatment standards after secondary clarification but before disinfection.
- **Allowing detection of a pollutant:** Instances could arise where the combination of process and non-process wastewaters result in dilution of a pollutant of concern such that it would not be detectable using approved analytical methods. Internal monitoring would enable characterization of the pollutant before dilution with other wastewaters.

Where the permit writer determines that internal monitoring is necessary, § 122.45(h)(2) states that limitations on internal wastestreams may be imposed only where the permit fact sheet sets forth the exceptional circumstances requiring application of limitations at those locations.

8.1.2.3 Effluent monitoring locations

Effluent monitoring is monitoring of the final effluent after all treatment processes. The permit writer should require effluent monitoring to determine compliance with final effluent limitations established in the permit. Effluent monitoring also can be used to provide data to assess the possible impact of the discharge on the receiving water.

Effluent monitoring locations should provide a representative sample of the effluent being discharged into the receiving water. Effluent monitoring locations should be established after all industrial uses and treatment processes. Most importantly, the point where a final effluent limitation applies and the point

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where monitoring is required must be the same. A logical effluent monitoring point is just before discharge to the receiving water. This is particularly true for ensuring compliance with WQBELs.

8.1.3 Monitoring Frequency

The permit writer should establish monitoring frequencies sufficient to characterize the effluent quality and to detect events of noncompliance, considering the need for data and, as appropriate, the potential cost to the permittee. Monitoring frequency should be determined on a case-by-case basis, and decisions for setting monitoring frequency should be described in the fact sheet. Some states have their own monitoring guidelines that can help a permit writer determine an appropriate monitoring frequency.

To establish a monitoring frequency, the permit writer should consider the variability of the concentration of various parameters by reviewing effluent data for the facility (e.g., from discharge monitoring reports [DMRs]) or, without actual data, information from similar dischargers. A highly variable discharge should require more frequent monitoring than a discharge that is relatively consistent over time (particularly in terms of flow and pollutant concentration). Other factors that should be considered when establishing appropriate monitoring frequencies include the following:

- **Design capacity of the treatment facility.** The monitoring frequency might need to be increased at facilities where the treatment facility is nearing design capacity. For example, at equivalent average flow rates, a large lagoon system that is not susceptible to bypasses would require less frequent monitoring than an overloaded treatment facility that experiences fluctuating flow rates from infiltration or large batch discharges from an industrial user system. The lagoon should have a relatively low variability compared to the facility receiving batch discharges.
- **Treatment method used.** The monitoring frequency will be similar for similar treatment processes. The type of wastewater treatment used by the facility might affect the frequency of effluent monitoring. An industrial facility employing biological treatment would have a similar monitoring frequency as a secondary treatment plant with the same units used for wastewater treatment. If the treatment method is appropriate and achieving high pollutant removals on a consistent basis, monitoring could be less frequent than for a plant with little or insufficient treatment.
- **Compliance history.** The monitoring frequency might need to be adjusted to reflect the compliance history of the facility. A facility with problems achieving compliance generally should be required to perform more frequent monitoring to characterize the source or cause of the problems or to detect noncompliance.
- **Cost of monitoring relative to permittee's capabilities.** The monitoring frequency should not be excessive and should be what is necessary to provide sufficient information about the discharge.
- **Location of the discharge.** The monitoring frequency could be increased if the discharge is to sensitive waters or is near a public water supply.
- **Nature of the pollutants.** To accurately characterize the discharge, the monitoring frequency might be increased for wastewaters with highly toxic pollutants or where the nature of the pollutants varies.

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- **Frequency of the discharge.** The monitoring frequency for a wastewater discharged in batches infrequently should differ from that for a continuous discharge of highly concentrated wastewater or a wastewater containing a pollutant that is found infrequently and at very low concentrations. The production schedule of the facility (e.g., seasonal, daily), the plant washdown schedule, and other similar factors should be considered.
- **Number of monthly samples used in developing effluent limitations.** When establishing monitoring frequency, the permit writer should consider the number of monthly samples used in developing average monthly WQBELs. If the discharger monitors less frequently than the monthly monitoring frequency assumed when developing applicable effluent guidelines or in calculating a WQBEL, it could be more difficult for the discharger to comply with its average monthly effluent limitations. For example, if an average monthly limitation is established assuming a monitoring frequency of four times per month (i.e., the limit is the expected average of four samples taken during a month), a discharger taking only one sample per month would statistically have a greater chance of exceeding its average monthly limit than if it sampled at least four times per month.
- **Tiered limitations.** The monitoring frequency requirements should correspond to the applicable tiers in cases where the permit writer has included tiered limitations. If a facility has seasonal discharge limitations, it might be appropriate to increase the monitoring frequency during the higher production season, and reduce the frequency during the off-season.
- **Other Considerations.** To ensure representative monitoring, permit conditions could be included to require monitoring on the same day, week, or month for parameters that might be correlated in some way. For example, coordinating the monitoring requirements for parameters such as pathogens and chlorine or metals and pH can provide information for both compliance assessment and determination of treatment efficacy.

A permit writer could also establish a tiered monitoring schedule that reduces or increases the monitoring frequency during a permit cycle. Tiered monitoring might be appropriate for discharges where the initial sampling shows compliance with effluent limitations, justifying a reduction in monitoring frequency over time. Conversely, if problems are found during the initial sampling, more frequent sampling and more comprehensive monitoring can be applied. This step-wise approach could lead to lower monitoring costs for permittees while still providing the data needed to demonstrate compliance with effluent limitations.

In 1996 EPA issued *Interim Guidance for Performance-Based Reductions of NPDES Permit Monitoring Frequencies* <www.epa.gov/npdes/pubs/perf-red.pdf>. Under the guidance, NPDES reporting and monitoring requirements may be reduced on the basis of a demonstration of excellent historical performance. Facilities can demonstrate that historical performance by meeting a set of compliance and enforcement criteria and by demonstrating their ability to consistently discharge pollutants below the levels necessary to meet their existing NPDES permit limitations. Reductions are determined parameter-by-parameter, on the basis of the existing monitoring frequency and the percentage below the limitation at which the parameter is being discharged. The reductions are incorporated when the permit is reissued. To remain eligible for the reductions, permittees are expected to maintain the parameter performance levels and good compliance on which the reductions were based.

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8.1.4 Sample Collection

The permit writer must specify the sample collection method for all parameters required to be monitored in the permit. The permit writer should determine the sample collection method on the basis of the characteristics of each specific discharge. Certain sample collection and storage requirements are identified as part of the analytical methods specified in Part 136. (Section 8.3 below presents more on analytical methods.) The two most frequently used sampling methods are grab and composite. For more detailed information on sample collection methods, permit writers should refer to Chapter 5 (Sampling) of the NPDES Compliance Inspection Manual[1] <www.epa.gov/compliance/resources/publications/monitoring/cwa/inspections/npdesinspect/npdesmanual.html>.

8.1.4.1 Grab Samples

Grab samples are individual samples collected over a period not exceeding 15 minutes and that are representative of conditions at the time the sample is collected. Grab samples are appropriate when the flow and characteristics of the wastestream being sampled are relatively constant. The sample volume depends on the type and number of analyses to be performed. A grab sample is appropriate when a sample is needed to

- Monitor an effluent that does not discharge on a continuous basis.
- Provide information about instantaneous concentrations of pollutants at a specific time.
- Allow collection of a variable sample volume.
- Corroborate composite samples.
- Monitor parameters not amenable to compositing (e.g., temperature).

Grab samples can also be used to determine the spatial variability of a parameter or information on variability over a short period. They also are useful for monitoring intermittent wastewater flows from well-mixed batch process tanks.

8.1.4.2 Composite Samples

Composite samples are collected over time, either by continuous sampling or by mixing discrete samples, and represent the average characteristics of the wastestream during the sample period. Composite samples might provide a more representative measure of the discharge of pollutants over a given period than grab samples, and are used when any of the following is true:

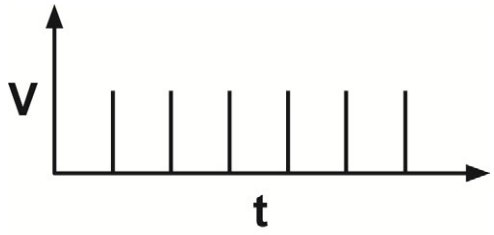
- A measure of the average pollutant concentration during the compositing period is needed.
- A measure of mass loadings per unit of time is needed.
- Wastewater characteristics are highly variable.

Composite samples can be discrete samples (see discussion of sequential sampling in section 8.1.4.3 below) or a single combined sample and are collected either manually or with automatic samplers. There are two general types of composite sampling: time-proportional and flow-proportional. The permit writer should clearly express which type is required in the permit.

Time-proportional composite sample: This method collects a fixed volume (V) of discrete sample aliquots in one container at constant time intervals (t) as shown in Exhibit 8-2.

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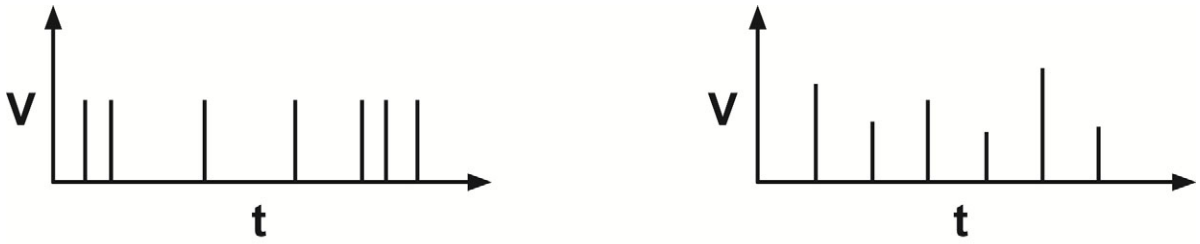
Exhibit 8-2 Visual interpretation of time-proportional composite monitoring



Time-proportional composite monitoring is appropriate when the flow of the sampled stream is constant (flow rate does not vary more than ±10 percent of the average flow rate) or when flow-monitoring equipment is not available. Automatically timed composited samples are usually preferred over manually collected composites. Composite samples collected by hand are appropriate for infrequent analyses and screening or if the subsamples have a fixed volume at equal time intervals.

Flow-proportional composite sample: There are two methods used for this type of sample: constant-volume when the interval time varies between samples, or constant-time when the interval volume collected varies between samples as shown in Exhibit 8-3.

Exhibit 8-3 Visual interpretation of flow-proportional composite monitoring



The constant-volume, flow-proportional, composite monitoring method collects a constant sample volume at varying time intervals proportional to stream flow (e.g., 200 milliliters sample collected for every 5,000 gallons of flow). The constant-time, flow-proportional, composite monitoring method collects the sample by adjusting the volume of each aliquot as the flow varies, while maintaining a constant time interval between the aliquots.

Flow-proportional composite sampling is usually preferred over time-proportional composite sampling when the effluent flow volume varies appreciably over time. If there is no flow-measuring device, effluent samples can be manually composited using the influent flow measurement without any correction for time lag. The error in the influent and effluent flow measurement is insignificant except in those cases where large volumes of water are impounded, as in equalization basins.

If a sampling protocol is not specified in the regulations, the permit writer should establish the duration of the compositing period and frequency of aliquot collection. The permit writer should also establish the time frame within which the sample is to be collected and the number of individual aliquots in the composite.

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There are instances where composite samples are inappropriate. For example, the permit application regulations at § 122.21(g)(7) indicate that grab samples must be used for sampling several parameters that may change during the time it takes to composite the sample. Composite samples can be used for whole effluent toxicity (WET) testing; however, if there is concern that there are toxicity spikes or that the toxicant is a parameter for which composite sampling is not appropriate, grab samples for WET testing could be specified in the permit.

8.1.4.3 Sequential and Continuous Monitoring

Sequential monitoring refers to collecting discrete samples in individual containers in regular succession, such as timed intervals or discharge increments. Sequential grab samples provide a characteristic of the wastestream over a given time. Automatic sequential monitoring may be done with a special type of automatic sampling device that collects relatively small amounts of a sampled wastestream with the interval between sampling proportioned based on either time or effluent flow. Unlike a combined composite sampler, the sequential sampling device automatically retrieves a sample and holds it in a bottle separate from other automatically retrieved samples. Many individual samples can be stored separately in the unit rather than combining aliquots in a common bottle.

Continuous monitoring is another option for a limited number of parameters such as flow, total organic carbon (TOC), temperature, pH, conductivity, residual chlorine, fluoride, and dissolved oxygen. When establishing continuous monitoring requirements, the permit writer should be aware that the NPDES regulations concerning pH limitations allow for a period of excursion when the effluent is being continuously monitored (§ 401.17). The reliability, accuracy, and cost of continuous monitoring vary with the parameter monitored. The permit writer should consider the environmental significance of the variation of any of these parameters in the effluent and the cost of continuous monitoring before establishing continuous monitoring requirements in the permit.

8.2 Additional Monitoring Requirements and WET Testing

A variety of discharges other than traditional POTW or industrial wastewater discharges, including biosolids (sewage sludge), combined sewer and sanitary sewer overflows, and stormwater, are regulated under the NPDES permit program. In addition, many permits include requirements for WET testing. As discussed in this section, a permit writer should account for such unique discharges and testing requirements in establishing monitoring requirements.

8.2.1 Biosolids (Sewage Sludge)

The purpose of monitoring sewage sludge is to ensure safe use or disposal of the sludge. Sewage sludge regulations specified in Part 503 require monitoring of sewage sludge that is applied to land, placed on a surface disposal site, or incinerated. The frequency of monitoring is based on the annual amount of sewage sludge that is used or disposed of by those methods. POTWs that provide the sewage sludge to another party for further treatment (such as composting) must provide that party with the information necessary to comply with regulations at Part 503. Sewage sludge disposed of in a municipal solid waste landfill unit must meet the criteria for municipal solid waste landfills in the regulations at Part 258.

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Exhibit 8-4 shows the minimum monitoring requirements established in Part 503 for sewage sludge before use and disposal. More frequent monitoring for any of the required or recommended parameters is appropriate when the POTW has any of the following:

- A highly variable influent load of toxics or organic solids.
- A significant industrial load.
- A history of process upsets due to toxics, or of adverse environmental impacts due to sludge use or disposal activities.

Exhibit 8-4 Minimum requirements for sewage sludge monitoring, based on method of sludge use or disposal

Method	Monitoring requirements	Frequency	Citation (40 CFR)
Land application	• Sludge weight and percent total solids • Metals: As, Cd, Cu, Pb, Hg, Mo, Ni, Se, and Zn • Pathogen Density • Vector Attraction Reduction	Based on dry weight of sludge in metric tons per year: • > zero but < 290: annually • = or > 290 but < 1,500: quarterly • = or > 1,500 but < 15,000: bimonthly • = or > 15,000: monthly	§ 503.16
Co-disposal in municipal solid waste landfill	• Sludge weight and percent total solids • Passes Paint-Filter Liquid Test • Suitability of sludge used as cover • Characterize in accordance with hazardous waste rules	Monitoring requirements or frequency not specified by Part 503. Determined by local health authority or landfill owner/operator.	Part 258
Surface disposal: lined sites with leachate collection and unlined sites	• Sludge weight and percent total solids • Metals: As, Cr, Ni (Unlined sites only) • Pathogen Density • Vector Attraction Reduction	Based on dry weight of sludge in metric tons per year: • > zero but < 290: annually • = or > 290 but < 1,500: quarterly • = or > 1,500 but < 15,000: bimonthly • = or > 15,000: monthly	§ 503.26
	• Methane gas	• Continuously	
Incineration	• Sludge weight and percent total solids • Metals: As, Cd, Cr, Pb, and Ni	Based on dry weight of sludge in metric tons per year: • > zero but < 290: annually • = or > 290 but < 1,500: quarterly • = or > 1,500 but < 15,000: bimonthly • = or > 15,000: monthly	§ 503.46
	• Be and Hg (National Emissions Standards)	• As required by permitting authority (local air authority)	
	• THC or O_2, moisture, combustion temperatures	• Continuously	
	• Air pollution control device operating parameters	• As required by permitting authority	

Notes:
Monitoring frequencies required by Part 503 may be reduced after 2 years of monitoring, but in no case may be less than once per year.
A successful land application program could necessitate sampling for other constituents of concern (such as nitrogen) in determining appropriate agronomic rates. The permit writer will determine additional monitoring requirements.

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The sampling and analysis methods specified in § 503.8 and Part 136 should be followed for monitoring the required parameters. Without any specific methods in Part 503, guidance on appropriate methods is in the following documents:

- *Part 503 Implementation Guidance*[2] <www.epa.gov/npdes/pubs/owm0237.pdf>.
- *POTW Sludge Sampling and Analysis Guidance Document*[3] <www.epa.gov/npdes/pubs/owm012.pdf>.
- *Control of Pathogens and Vector Attraction in Sewage Sludge*[4] <www.epa.gov/ORD/NRMRL/pubs/625r92013/625r92013.htm>.

8.2.2 Combined Sewer Overflows (CSOs) and Sanitary Sewer Overflows (SSOs)

EPA's Combined Sewer Overflow (CSO) Control Policy (59 FR 18688, April 19, 1994) requires monitoring to characterize the combined sewer system, assist in developing a Long-Term Control Plan (LTCP), and show compliance with permit requirements. The permit writer should ensure the following:

- Monitoring is done to develop an initial system characterization as part of the nine minimum controls to reduce CSOs and their effect on receiving water quality. Such monitoring includes analyzing existing data on precipitation events, on the combined sewer system and CSOs, on water quality, and conducting field inspections.
- As part of the LTCP, a permittee is required to develop a more complete characterization of the sewer system through monitoring and modeling.
- To show compliance with the permit requirements and ultimately the attainment of water quality standards, the permittee is required to conduct a post-construction compliance monitoring program. Specific monitoring requirements of the post-construction compliance monitoring program will be unique to each permittee's LTCP and should be established as specific monitoring conditions in the individual NPDES permit.

These monitoring conditions should require monitoring of certain key parameters during a representative number of CSOs from a representative number of wet-weather events along with ambient water quality monitoring to ascertain attainment of water quality standards. EPA has prepared a guidance manual on monitoring entitled *Combined Sewer Overflows: Guidance for Monitoring and Modeling*[5] <www.epa.gov/npdes/pubs/sewer.pdf>.

A facility's permit might also contain monitoring requirements for sanitary sewer overflows (SSOs). SSO monitoring requirements would be developed on a case-by-case basis.

8.2.3 Stormwater Monitoring Considerations

Stormwater monitoring requirements vary according to the type of permit regulating the stormwater discharge and the activity. Municipal separate storm sewer systems (MS4s) serving more than 100,000 people (and some serving less than 100,000) are typically issued individual NPDES permits with monitoring requirements that are specific to the MS4. Smaller MS4s regulated under the stormwater Phase II rule are typically not required to conduct water quality monitoring as a condition in their NPDES general permit, though evaluation of measurable goals may include monitoring. EPA's multi-sector general permit (MSGP) for stormwater discharges from industrial facilities includes analytical monitoring requirements based on the type of industrial activity. Finally, operators of construction activity regulated under the

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construction general permit are typically not required to conduct water quality monitoring; however, some states and EPA Regions do require monitoring if the construction activity will discharge to a water impaired by sediment.

Specific monitoring conditions for the federal general stormwater permits are detailed in the most recent Construction General Permit or MSGP issued by EPA (available on the EPA Stormwater Program Website <www.epa.gov/npdes/stormwater>). Additional documents on stormwater monitoring are:

- *Urban Stormwater BMP Performance: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements*[6] <www.epa.gov/npdes/pubs/montcomplete.pdf>.
- *Guidance Manual for the Monitoring and Reporting Requirements of the NPDES Stormwater Multi-Sector General Permit (MSGP)*[7] <www.epa.gov/npdes/pubs/dmr-fin.pdf>.

8.2.4 WET Monitoring

The use of WET testing to evaluate the toxicity in a receiving stream is discussed in section 6.4 of this manual and on the NPDES WET Website <www.epa.gov/npdes/wet>. The WET (or biomonitoring) test procedures were promulgated in § 136.3 (60 FR 53529, October 16, 1995). EPA revised the WET methods in 67 FR 69951, November 19, 2002. WET monitoring conditions included in permits should specify the particular biomonitoring test to be used, the test species, required test endpoints, and quality assurance/quality control procedures.

To support permitting agencies in implementing WET methods, EPA has revised and published manuals for toxicity test protocols:

- *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms*. 5th ed.[8] <www.epa.gov/waterscience/WET/disk2/atx.pdf>.
- *Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms*. 4th ed.[9] <www.epa.gov/waterscience/WET/disk3/ctf.pdf>.
- *Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Marine and Estuarine Organisms*. 3rd ed.[10] <www.epa.gov/waterscience/WET/disk1/ctm.pdf>.
- *NPDES Compliance Monitoring Inspector Training: Biomonitoring*[11] (No Link).

WET testing samples could be composite or grab samples. Twenty-four hour composite samples are suggested except when any of the following are true:

- The effluent is expected to be more toxic at a certain time of day.
- Toxicity may be diluted during compositing.
- The size of the sample needed exceeds the composite sampler volume.

WET tests are relatively expensive compared to single parameter tests. Therefore, a permit writer should carefully consider the appropriate frequency for WET testing. A discharge with highly variable flow or observed toxicity should have more frequent monitoring than a discharge that is relatively consistent over time. As with other parameters, factors that a permit writer should consider when establishing appropriate WET monitoring frequencies include the following:

- Type of treatment process.

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- Environmental significance and nature of the toxicity.
- Past compliance record or history.
- Cost of monitoring relative to financial capabilities.
- Number of monthly samples used in developing the permit limitation.
- The frequency of intermittent discharges.

Samples should be evenly spaced throughout the year so that seasonal variability can be ascertained.

8.3 Analytical Methods

The permit writer must specify the analytical methods to be used for monitoring. EPA's Office of Science and Technology's Clean Water Act Analytical Methods Website <www.epa.gov/waterscience/methods/> contains information about analytical methods.

The standard conditions of the permit [§§ 122.41(j)(4) and 122.44(i)] require that, when available, permittees use test procedures specified in Part 136 <www.epa.gov/waterscience/methods/basic.htm>. The analytical methods contained in Part 136 are established for conventional, toxic (priority), and some nonconventional pollutants. Without analytical methods for a parameter, the permit writer should specify the analytical method to be used. There are also procedures to apply for approval of alternative test methods in accordance with § 136.4.

While Part 136 identifies the analytical methods approved for use in the NPDES program, additional methods information is available through the National Environmental Methods Index (NEMI) <www.nemi.gov/>. NEMI is a Web-based, searchable clearinghouse of methods supported by the U.S. Geological Survey and EPA's Office of Water. NEMI contains summaries of more than 1,100 methods and describes them by their performance characteristics and their regulatory status, relative cost, detection level, detection level type, accuracy, precision, spiking level, instrumentation, lab equipment, and the *greenness* of analytic methods. Permit writers might find that information useful in comparing the features of Part 136 methods that will be used for assessing compliance with the calculated effluent limitations.

When establishing effluent limitations for a specific parameter (based on technology or water quality regulatory requirements), it is possible for the value of the calculated limit to fall below the method detection limit (MDL) and the minimum level (ML) established by the approved analytical method(s). Regardless of whether current analytical methods are available to detect and quantify the parameter at the concentration of the calculated limitation, the limitation must be included in the permit as calculated.

In some instances, there might be two or more approved Part 136 analytical methods available for the analysis of a parameter. In such cases, the permit should determine whether there is a need to select one of the approved methods and to include a requirement in the permit mandating the use of only the selected method. That approach might be necessary where an effluent limit is established at a level that is quantifiable by one approved method but is below the ML of another approved method.

Such a situation often occurs where a permit contains a WQBEL for mercury. To clarify the EPA's position with respect to effluent monitoring for mercury, EPA developed a memo *Analytical Methods for Mercury in National Pollutant Discharge Elimination System (NPDES) Permits*[12] <www.epa.gov/npdes/pubs/mercurymemo_analyticalmethods.pdf>.

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***Sufficiently Sensitive* Methods**

At the time of the writing of this manual, EPA had proposed regulations at §§ 122.21(e), 122.44(i), and Part 136, to require the use of sufficiently sensitive methods for analyses conducted for NPDES permit applications and for compliance monitoring (75 FR 35712, June 23, 2010). To ensure that appropriate analytical methods are required and performed, see the most current version of these federal regulations and applicable state analytical method regulations and policy.

8.4 Reporting Monitoring Results

The NPDES regulations require the permittee to maintain records and periodically report on monitoring activities. The regulations at § 122.41(l)(4)(i) require that monitoring results must be reported on a DMR <www.epa.gov/npdes/pubs/dmr.pdf>. Data reported include both data required by the permit and any additional data the permittee has collected consistent with permit requirements. All facilities must submit reports (on discharges and sludge use or disposal) at least annually, as required by § 122.44(i)(2). POTWs with pretreatment programs must submit a pretreatment report at least annually as required by § 403.12(i). However, the NPDES regulation states that monitoring frequency and reporting should be dependent on the nature and effect of the discharge or sludge use or disposal. Thus, the permit writer can require reporting more frequent than annually.

8.5 Recordkeeping Requirements

Generally, the permit writer is required by § 122.41(j) to include in the permit the requirement to retain records for at least three years, subject to extension by the State Director. Recordkeeping requirements for sewage sludge [§ 122.41(j)] and the CAFO program [§ 122.42(e)(2)] require records be kept five years or longer if required by the State Director. The permit writer should designate in the permit where records should be kept.

Monitoring records must include the following:

- Date, place, time of sampling.
- Name of sampler.
- Date of analysis.
- Name of analyst.
- Analytical methods used.
- Analytical results.

According to § 122.41(j), monitoring records must be representative of the discharge. Monitoring records, which must be retained, include continuous strip chart recordings, calibration data, copies of all reports for the permit, and copies of all data used to compile reports and applications.

Sewage sludge regulations under §§ 503.17, 503.27, and 503.47 establish recordkeeping requirements that vary depending on the use and disposal method for the sewage sludge. The same recordkeeping requirements should be applied to other sludge monitoring parameters not regulated by the Part 503 rule.

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[1] U.S. Environmental Protection Agency. 2004. *NPDES Compliance Inspection Manual*. EPA-305-X-03-001. U.S. Environmental Protection Agency, Office of Enforcement and Compliance Assurance, Washington, DC. <www.epa.gov/compliance/resources/publications/monitoring/cwa/inspections/npdesinspect/npdesinspect.pdf>.

[2] U.S. Environmental Protection Agency. 1995. *Part 503 Implementation Guidance*. EPA 833-R-95-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. <www.epa.gov/npdes/pubs/owm0237.pdf>.

[3] U.S. Environmental Protection Agency. 1989. *POTW Sludge Sampling and Analysis Guidance Document*. EPA-833-B-89-100. U.S. Environmental Protection Agency, Office of Water, Washington, DC. <www.epa.gov/npdes/pubs/owm012.pdf>.

[4] U.S. Environmental Protection Agency. 1992. *Control of Pathogens and Vector Attraction in Sewage Sludge*. EPA-625/R-92-013. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC. <www.epa.gov/ORD/NRMRL/pubs/625r92013/625r92013.htm>.

[5] U.S. Environmental Protection Agency. 1999. *Combined Sewer Overflows–Guidance for Monitoring and Modeling*. EPA-832-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC. <www.epa.gov/npdes/pubs/sewer.pdf>.

[6] U.S. Environmental Protection Agency. 2002. *Urban Stormwater BMP Performance: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements*. EPA-821-B-02-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. <www.epa.gov/npdes/pubs/montcomplete.pdf>.

[7] U.S. Environmental Protection Agency. 1999. *Guidance Manual for the Monitoring and Reporting Requirements of the NPDES Stormwater Multi-Sector General Permit (MSGP).* U.S. Environmental Protection Agency, Office of Water, NPDES Program Branch, Washington, DC. <www.epa.gov/npdes/pubs/dmr-fin.pdf>.

[8] U.S. Environmental Protection Agency. 2002. *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms, Fifth Edition.* EPA-821-R-02-012. U.S. Environmental Protection Agency, Office of Water, Washington, DC <www.epa.gov/waterscience/WET/disk2/atx.pdf>.

[9] U.S. Environmental Protection Agency. 2002. *Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms, Fourth Edition*. EPA-821-R-02-013. U.S. Environmental Protection Agency, Office of Water, Washington, DC. <www.epa.gov/waterscience/WET/disk3/ctf.pdf>.

[10] U.S. Environmental Protection Agency. 1994. *Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Marine and Estuarine Organisms, Third Edition*. EPA821-R-02-014. U.S. Environmental Protection Agency, Office of Water, Washington, DC. <www.epa.gov/waterscience/WET/disk1/ctm.pdf>.

[11] U.S. Environmental Protection Agency. 1990. *NPDES Compliance Monitoring Inspector Training: Biomonitoring.* U.S. Environmental Protection Agency, Office of Water Enforcement and Permits, Washington, DC. NTIS # PB91-145854. (No Link)

[12] Hanlon, James A. 2007. *Analytical Methods for Mercury in National Pollutant Discharge Elimination System (NPDES) Permits.* U.S. Environmental Protection Agency, Office of Wastewater Management. Memorandum, August 23, 2007. <www.epa.gov/npdes/pubs/mercurymemo_analyticalmethods.pdf>.

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CHAPTER 9. Special Conditions

Special conditions in National Pollutant Discharge Elimination System (NPDES) permits supplement numeric effluent limitations and require the permittee to undertake activities designed to reduce the overall quantity of pollutants being discharged to waters of the United States, to reduce the potential for discharges of pollutants, or to collect information that could be used in determining future permit requirements.

There are many different reasons to incorporate special conditions into a permit including:

- To address unique situations, such as facilities discharging pollutants for which data are absent or limited, making development of technology- or water quality-based effluent limitations (TBELs or WQBELs) more difficult or impossible.
- To incorporate preventive requirements, such as requirements to install process control alarms, containment structures, good housekeeping practices, and the like.
- To address foreseeable changes to discharges, such as planned changes to process, products, or raw materials that could affect discharge characteristics.
- To incorporate compliance schedules to provide the time necessary to comply with permit conditions.
- To incorporate other NPDES programmatic requirements (e.g., pretreatment, sewage sludge).
- To impose additional monitoring requirements that provide the permit writer with data to evaluate the need for changes in permit limitations.
- To increase or decrease monitoring requirements, depending on monitoring results or changes in processes or products.
- To impose requirements for special studies such as ambient stream surveys, toxicity identification evaluations (TIEs) and toxicity reduction evaluations (TREs), bioaccumulation studies, sediment studies, mixing or mixing zone studies, pollutant reduction evaluations, or other such information-gathering studies.

Section 9.1 below addresses several types of special conditions that apply to both municipal and non-municipal facilities. Section 9.2 addresses special conditions unique to municipal facilities.

9.1 Special Conditions Potentially Applicable to Any Type of Discharger

This section discusses several types of special conditions that could be included in any NPDES permit (i.e., municipal or non-municipal). Those special conditions can be thought of as the *ABCs* of special conditions and include the following:

- **A**dditional monitoring and special studies.
- **B**est management practices (BMPs).
- **C**ompliance schedules.

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A summary of the use of those special conditions follows.

9.1.1 Additional Monitoring and Special Studies

Additional monitoring requirements, beyond those required under the effluent limitations section of the permit, and special studies are useful for collecting data that were not available to the permit writer for consideration during permit development. Additional monitoring requirements and special studies generally are used to supplement numeric effluent limitations or support future permit development activities. Examples of the types of special studies that could be required in an NPDES permit include the following:

- **Treatability studies:** Might be required in a permit when insufficient treatability information for a pollutant or pollutants would hinder a permit writer from developing defensible TBELs. Treatability studies can also be required when the permit writer suspects that a facility might not be able to comply with an effluent limitation.
- **Toxicity identification evaluation/toxicity reduction evaluation (TIE/TRE):** Could be required in a permit when wastewater discharges are found to be toxic using whole effluent toxicity (WET) tests. The purpose of those evaluations is to identify and control the sources of toxicity in an effluent. Further guidance related to U.S. Environmental Protection Agency (EPA) recommended TIE/TRE procedures and requirements is found in the following guidance manuals:
  - *Toxicity Reduction Evaluation Guidance for Municipal Wastewater Treatment Plants*[1] <www.epa.gov/npdes/pubs/tre.pdf>.
  - *Clarifications Regarding Toxicity Reduction and Identification Evaluations in the National Pollutant Discharge Elimination System Program*[2] <www.epa.gov/npdes/pubs/owmfinaltretie.pdf>.
  - *Generalized Methodology for Conducting Industrial Toxicity Reduction Evaluations*[3] (No link—see the endnote for ordering instructions).
  - *Methods for Aquatic Toxicity Identification Evaluations: Phase I Toxicity Characterization Procedures*. 2nd ed[4] <www.epa.gov/npdes/pubs/owm0330.pdf>.
  - *Toxicity Identification Evaluation: Characterization of Chronically Toxic Effluents, Phase I*[5] <www.epa.gov/npdes/pubs/owm0255.pdf>.
  - *Methods for Aquatic Toxicity Identification Evaluations: Phase II Toxicity Identification Procedures for Samples Exhibiting Acute and Chronic Toxicity*[6] <www.epa.gov/npdes/pubs/owm0343.pdf>.
  - *Methods for Aquatic Toxicity Identification Evaluations: Phase III Confirmation Procedures for Samples Exhibiting Acute and Chronic Toxicity*[7] <www.epa.gov/npdes/pubs/owm0341.pdf>.
- **Mixing or mixing zone studies:** Might be required in a permit to assist in determining how effluent and receiving water mix and in establishing a regulatory mixing zone that can be applied when developing WQBELs.
- **Sediment monitoring:** Could be included in a permit if a permit writer suspects that pollutants contained in wastewater discharges accumulate in the sediments of the receiving water.
- **Bioaccumulation studies:** Might be required in a permit to determine whether pollutants contained in wastewater discharges bioaccumulate in aquatic organisms (e.g., fish, invertebrates). Such studies could be required when water quality criteria are expressed in terms of fish tissue levels. Additional guidance related to evaluating the bioaccumulation potential of a pollutant can

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be found in the *EPA Great Lakes Water Quality Initiative Technical Support Document for the Procedure to Determine Bioaccumulation Factors*[8] (No link—see the endnote for ordering instructions).

When establishing additional monitoring or special studies, permit writers must ensure that any requirements related to the study (e.g., special sampling or analytical procedures) are specified in the appropriate permit condition. In addition, permit writers should establish a reasonable schedule for completion and submission of the study or monitoring program. If the anticipated timeline is longer than one year, an interim progress report during the study is advisable.

9.1.2 Best Management Practices (BMPs)

In general, BMPs are actions or procedures to prevent or reduce the discharge of pollution to waters of the United States. Title 40 of the *Code of Federal Regulations* (CFR) section 122.2 includes the following in the definition of BMPs:

- Schedules of activities.
- Prohibitions of practices.
- Maintenance procedures.
- Treatment requirements.
- Operating procedures and practices to control
  - Plant site runoff.
  - Spillage or leaks.
  - Sludge or waste disposal.
  - Drainage from raw material storage areas.

9.1.2.1 When to Use BMPs

Clean Water Act (CWA) section 304(e) authorizes EPA to require BMPs as part of effluent limitations guidelines and standards (effluent guidelines) to control plant site runoff, spillage or leaks, sludge or waste disposal, and drainage from raw material storage that it determines are associated with or ancillary to the industrial manufacturing or treatment process and can contribute significant amounts of pollutants to navigable waters. Where effluent guidelines require specific control measures, including BMPs or development of a BMP plan, permit writers must include such requirements in permits. In addition, CWA section 402(p)(3)(B)(iii) states that permits for discharges from municipal storm sewers must require controls, including management practices, to reduce the discharge of pollutants. Finally, CWA sections 402(a)(1) and (2) give the permitting authority the ability to include BMPs in permits on a case-by-case basis to carry out the provisions of the CWA.

The NPDES regulations at § 122.44(k) track the statutory provisions cited above. This section of the regulations provides that permits must contain BMPs (when applicable) to control or abate the discharge of pollutants when any of the following are true:

- They are authorized under CWA section 304(e).
- They are authorized under CWA section 402(p) for the control of stormwater discharges.
- Numeric effluent limitations are infeasible.
- The practices are necessary to achieve effluent limitations and standards or carry out the purpose and intent of the CWA.

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Circumstances under which numeric effluent limitations might be infeasible include the following:

- Regulating a pollutant for which limited treatability or aquatic impact data are available to allow development of numeric TBELs or WQBELs.
- Regulating discharges when the types of pollutants vary greatly over time.

In addition, a permit writer should consider using BMPs under any of the following circumstances:

- When chemical analyses are inappropriate or impossible.
- When there is a history of leaks and spills or when housekeeping is sloppy.
- When a complex facility lacks data for a pollutant or pollutants.

9.1.2.2 BMPs in NPDES Permits

Permit writers include BMP requirements in permits using two approaches: (1) site-, process-, or pollutant-specific BMPs, or (2) a requirement to develop a BMP plan. Site-, process-, or pollutant-specific BMPs might be appropriate in the case of an individual permit where a permit writer has the opportunity to review the circumstances at the facility. On the other hand, it might not be appropriate to include site-, process-, or pollutant-specific BMPs as conditions in a general permit, a permit for a particularly complex facility, or a permit for a facility with operations not familiar to the permit writer. Instead, complicated facilities and discharges covered under a general permit could be required to develop a BMP plan that requires the permittee to determine appropriate BMPs on the basis of circumstances at its facility.

Specific BMPs

Specific BMPs are designed to address conditions particular to a type of facility or to a specific site, process, or pollutant. Specific BMPs might be used in a permit when

- They are needed to address ancillary activities that could result in the discharge of pollutants to waters of the United States.
- Numeric effluent limitations for a specific process are otherwise infeasible and BMPs serve as effluent limitations for that process.
- They are required to supplement and ensure compliance with effluent limitations in the permit.

To select a specific BMP, the permit writer could

- Review the industry profiles or the specific facility to determine the applicable and appropriate management practices.
- Evaluate whether the BMP would help to achieve effluent limitations or other environmental objectives for that facility.
- Use information from other permits, pollution prevention sources, and EPA guidance documents to identify applicable and appropriate BMPs.

Specific BMPs frequently are required for certain types of dischargers such as concentrated animal feeding operations (CAFOs), combined sewer overflows (CSOs), and stormwater discharges.

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BMP Plans

The *Guidance Manual for Developing Best Management Practices*[9] <www.epa.gov/npdes/pubs/owm0274.pdf> describes the activities and materials at an industrial or municipal facility that are best addressed by BMPs. The manual also describes how BMPs work and gives examples of types of BMPs.

If a permit writer requires a BMP plan, it is the facility's responsibility to develop, implement, and evaluate the success or shortfalls of its own plan. Often, a BMP committee (i.e., a group of individuals within the plant organization) is responsible for developing the BMP plan and assisting the plant management in implementing and updating the BMP plan.

EPA has identified several recommended components of effective BMP plans and detailed each component in the *Guidance Manual for Developing Best Management Practices*. The minimum suggested components of a general BMP plan are presented below:

- General Provisions
  - Name and location of facility.
  - Statement of BMP policy and objective.
  - Review by plant manager.
- Specific Provisions
  - BMP committee.
  - Risk identification and assessment.
  - Reporting of BMP incidents.
  - Materials compatibility.
  - Good housekeeping.
  - Preventive maintenance.
  - Inspections and records.
  - Security.
  - Employee training.

BMP plans used to supplement effluent limitations or to describe how the discharger plans to meet effluent limitations can be submitted to the regulatory agency or be kept on-site and made available to the permitting authority upon request. A general schedule for BMP plan development can be included in the permit (e.g., complete and submit the plan within six months of permit issuance and begin implementing the plan within nine months of permit issuance).

Exhibit 9-1 presents example permit text for a requirement to develop and implement a BMP plan and should be adapted as necessary to reflect conditions at the individual facility.

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Exhibit 9-1 Example BMP plan requirement

The following is example text for requiring development and implementation of a BMP plan through an NPDES permit. The text should be crafted and changed as necessary to meet the individual facility's needs and the permitting authority's goals. The bracketed text should be updated to be specific to the permit.

1. Implementation.

[IF A BMP PLAN DOES NOT EXIST:]

The permittee, must develop and implement a best management practices (BMP) plan that achieves the objectives and the specific requirements listed below. A copy of the plan must be submitted to the U.S. Environmental Protection Agency (EPA) **[AND/OR STATE AGENCY]** within six months of the effective date of this permit. The plan must be implemented as soon as possible but no later than nine months from the effective date of the permit. The permittee must update and amend the plan as needed.

[IF A BMP PLAN ALREADY EXISTS:]

The permittee must during the term of this permit operate the facility in accordance with the BMP plan **[CITE EXISTING PLAN]** and in accordance with subsequent amendments to the plan. The permittee must amend the plan to incorporate practices to achieve the objectives and specific requirements listed below, and a copy of the amended plan must be submitted to the U.S. Environmental Protection Agency (EPA) **[AND/OR STATE AGENCY]** within three months of the effective date of this permit. The amended plan must be implemented as soon as possible but not later than six months from the effective date of the permit.

2. Purpose

Through implementation of the BMP plan the permittee must prevent or minimize the generation and the potential for the release of pollutants from the facility to the waters of the United States through normal operations and ancillary activities.

3. Objectives

The permittee must develop and amend the BMP plan consistent with the following objectives for the control of pollutants.

a. The number and quantity of pollutants and the toxicity of effluent generated, discharged, or potentially discharged at the facility must be minimized by the permittee to the extent feasible by managing each influent waste stream in the most appropriate manner.
b. Under the BMP plan, and any Standard Operating Procedures (SOPs) included in the plan, the permittee must ensure proper operation and maintenance of the treatment facility as required by § 122.41(e).
c. The permittee must establish specific objectives for the control of pollutants by conducting the following evaluations.
    1. Each facility component or system must be examined for its waste minimization opportunities and its potential for causing a release of significant amounts of pollutants to waters of the United States because of equipment failure, improper operation, and natural phenomena such as rain or snowfall, etc. The examination must include all normal operations and ancillary activities including material storage areas, plant site runoff, in-plant transfer, process and material handling areas, loading or unloading operations, spillage or leaks, sludge and waste disposal, or drainage from raw material storage. **[NOTE THAT ONLY THE APPLICABLE AREAS SHOULD BE INCLUDED IN THE PREVIOUS LIST.]**
    2. Where experience indicates a reasonable potential for equipment failure (e.g., a tank overflow or leakage), natural condition (e.g., precipitation), or other circumstances that may result in significant amounts of pollutants reaching surface waters, the program should include a prediction of the direction, rate of flow and total quantity of pollutants that could be discharged from the facility as a result of each condition or circumstance.

4. Requirements

The BMP Plan must be consistent with the objectives in the Objectives section above and the general guidance contained in the publication entitled *Guidance Manual for Developing Best Management Practices (BMPs)*, EPA 833-B-93-004, <www.epa.gov/npdes/pubs/owm0274.pdf> or any subsequent revisions to the guidance document. The BMP plan must

a. Be documented in narrative form, must include any necessary plot plans, drawings or maps, and must be developed in accordance with good engineering practices. The BMP plan must be organized and written with the following structure:
    1. Name and location of the facility.
    2. Statement of BMP policy.
    3. Structure, functions, and procedures of the BMP Committee.
    4. Specific management practices and standard operating procedures to achieve the above objectives, including the following:

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Exhibit 9-1 Example BMP plan requirement (continued)

a. Modification of equipment, facilities, technology, processes, and procedures.
b. Reformulation or redesign of products.
c. Substitution of materials.
d. Improvement in management, inventory control, materials handling or general operational phases of the facility.

5. Risk identification and assessment.
6. Reporting of BMP incidents.
7. Materials compatibility.
8. Good housekeeping.
9. Preventative maintenance.
10. Inspections and records.
11. Security.
12. Employee training.

b. Include the following provisions concerning BMP plan review:
   1. Review by plant engineering staff and the plant manager.
   2. Review and endorsement by the permittee's BMP Committee.
   3. A statement that the above reviews have been completed and that the BMP plan fulfills the requirements set forth in this permit. The statement must include the dated signatures of each BMP Committee member as certification of the reviews.

c. Establish specific BMPs to meet the objectives identified in the Objectives section above, addressing each component or system capable of generating or causing a release of significant amounts of pollutants, and identifying specific preventive or remedial measures to be implemented.

d. Establish specific BMPs or other measures that ensure that the following specific requirements are met:
   1. Ensure proper management of solid and hazardous waste in accordance with regulations promulgated under the Resource Conservation and Recovery Act (RCRA). Management practices required under RCRA regulations must be referenced in the BMP plan.
   2. Reflect requirements for Spill Prevention, Control, and Countermeasure (SPCC) plans under Clean Water Act (CWA) section 311 and 40 CFR Part 112 and may incorporate any part of such plans into the BMP plan by reference.
   3. Reflect requirements for stormwater control under CWA section 402(p) and the regulations at 40 CFR 122.26 and 122.44, and otherwise eliminate to the extent practicable, contamination of stormwater runoff.

   etc.

[NOTE: SECTION d. ABOVE COULD BE TAILORED TO EACH FACILITY BY THE PERMIT WRITER AND MAY INCLUDE PROCESSES OR AREAS OF THE FACILITY WITH HOUSEKEEPING PROBLEMS, NONCOMPLIANCE, SPILLS/LEAKS, OR OTHER PROBLEMS THAT COULD BE REMEDIED THROUGH A BMP. IF THERE IS A KNOWN SOLUTION TO THE PROBLEM (E.G., MORE FREQUENT INSPECTIONS, PREVENTIVE MAINTENANCE, ETC.), THIS REMEDY COULD ALSO BE INCLUDED AS A PART OF THE BMP PLAN REQUIREMENTS. TO GATHER IDEAS FOR SUCH REQUIREMENTS, THE PERMIT WRITER MAY WANT TO CONTACT THE PERMITTEE, COMPLIANCE PERSONNEL, FACILITY INSPECTORS, OPERATIONS OFFICE PERSONNEL, AND STATE AGENCY COUNTERPARTS. THE PERMIT WRITER MIGHT ALSO WANT TO CHECK REQUIREMENTS IN OTHER PERMITS AND BMP PLANS FOR SIMILAR FACILITIES.]

5. Documentation

The permittee must maintain a copy of the BMP plan at the facility and must make the plan available to EPA **[AND/OR STATE AGENCY]** upon request. All offices of the permittee, which are required to maintain a copy of the NPDES permit, must also maintain a copy of the BMP plan.

6. BMP Plan Modification

The permittee must amend the BMP plan whenever there is a change in the facility, or in the operation of the facility, that materially increases the generation of pollutants or their release or potential release to the receiving waters. The permittee must also amend the plan, as appropriate, when plant operations covered by the BMP plan change. Any such changes to the BMP plan must be consistent with the objectives and specific requirements listed above. All changes in the BMP plan must be reported to EPA **[AND/OR STATE AGENCY]** in writing.

7. Modification for Ineffectiveness

If at any time the BMP plan proves to be ineffective in achieving the general objective of preventing and minimizing the generation of pollutants and their release and potential release to the receiving waters and/or the specific requirements above, the permit and/or the BMP plan must be subject to modification to incorporate revised BMP requirements.

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9.1.2.3 Pollution Prevention in BMPs

BMPs are, by their nature, pollution prevention practices. Traditionally, BMPs have focused on good housekeeping measures and good management techniques that attempt to avoid contact between pollutants and water as a result of leaks, spills, and improper waste disposal. However, on the basis of the authority granted under the regulations, BMPs may include a range of pollution prevention options, including production modifications, operational changes, materials substitution, and materials and water conservation.

When developing BMPs, permit writers should be familiar with the fundamental principles of pollution prevention:

- Pollution should be prevented or reduced at the source, whenever feasible (*Reduce*).
- Pollution that cannot be prevented should be reused or recycled in an environmentally safe manner, whenever feasible (*Reuse-Recycle*).
- Pollution that cannot be prevented or recycled should be treated in an environmentally safe manner, whenever feasible (*Treat*).
- Disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner (*Dispose of*).

When writing an NPDES permit, a permit writer who has familiarity with a certain type of processes might identify pollution prevention practices that are not used at a facility and that would help that facility achieve its pollution prevention goals. Where the pollution prevention practices are necessary to carry out the purposes and intent of the CWA, the permit writer may develop BMPs to implement those practices.

9.1.3 Compliance Schedules

The NPDES regulations at § 122.47 allow permit writers to establish schedules of compliance to give permittees additional time to achieve compliance with the CWA and applicable regulations. Schedules developed under this provision must require compliance by the permittee *as soon as possible*, but may not extend the date for final compliance beyond compliance dates established by the CWA. Thus, compliance schedules in permits are not appropriate for every type of permit requirement. Specifically, a permit writer may not establish a compliance schedule in a permit for TBELs because the statutory deadlines for meeting technology standards (i.e., secondary treatment standards and effluent guidelines) have passed. This restriction applies to both existing and new dischargers. Permit writers should note, however, that § 122.29(d)(4) allows a new source or new discharger up to 90 days to *start-up* its pollution control equipment and achieve compliance with its permit conditions (i.e., provides for up to a 90-day period to achieve compliance).

Examples of requirements for which a compliance schedule in an NPDES permit might be appropriate include:

- Pretreatment program development.
- Sludge use and disposal program development and implementation.
- BMP plan development and implementation.
- Effluent limitations derived from new or revised water quality standards.

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An EPA Administrator's decision specifically addresses compliance schedules for effluent limitations derived from new or revised water quality standards. In the decision *In the Matter of Star-Kist Caribe, Inc*., documented in the memorandum *Order Denying Modification Request With Respect to the Administrator's 1990 Decision in Star-Kist Caribe, Inc. (NPDES Appeal No. 88-5)*[10] <www.epa.gov/npdes/pubs/owm0121.pdf>, the EPA Administrator interpreted CWA section 301(b)(1)(C) to mean that 1) after July 1, 1977, permits may not contain compliance schedules for effluent limitations based on water quality standards adopted before July 1, 1977, and 2) compliance schedules are allowed for effluent limitations based on standards adopted after that date *only* if the state has clearly indicated in its water quality standards or implementing regulations that it intends to allow them.

In May 2007, the Director of EPA's Office of Wastewater Management issued a memorandum to EPA Region 9 that clarified the requirements of § 122.47 as they relate to WQBELs [see *Compliance Schedules for Water Quality-Based Effluent Limitations in NPDES Permits*[11] <www.epa.gov/npdes/pubs/memo_complianceschedules_may07.pdf>. Permit writers should consider the principles outlined in this memo when assessing whether a compliance schedule for achieving a WQBEL is consistent with the CWA and its implementing regulations and when documenting the basis for a compliance schedule in a permit. Considerations outlined in the memo include the following:

- Demonstrate that the permittee cannot immediately comply with the new effluent limitation on the effective date of the permit.
- Include an enforceable *final* effluent limitation and a date for achievement in the permit.
- Justify and document the *appropriateness* of the compliance schedule; factors relevant to a determination that a compliance schedule is appropriate include how much time the discharger had to meet the WQBEL under prior permit(s), whether there is any need for modifications to treatment facilities, operations, or other measures and, if so, how long it would take to implement such modifications.
- Justify and demonstrate that compliance with the final WQBEL is required *as soon as possible*; factors relevant to a determination that a compliance is required as soon as possible include the steps needed to modify or install treatment facilities, operations, or other measures and the time those steps would take.
- Include an enforceable sequence of events leading to compliance with interim milestones for schedules longer than one year.
- Recognize that a schedule solely to provide time to develop a total maximum daily load (TMDL) or to conduct a use attainability analysis (UAA) is not appropriate.

Many of the principles outlined in the memo could be more generally applied to compliance schedules for requirements other than WQBELs.

9.2 Special Conditions for Municipal Facilities

This section explains several common special conditions that are applicable only to municipal facilities. These conditions reflect requirements for publicly owned treatment works (POTWs) to implement and enforce local pretreatment programs for their industrial users; biosolids (sewage sludge) disposal requirements; CSO requirements; SSO requirements; and municipal separate storm sewer system (MS4) requirements.

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9.2.1 The National Pretreatment Program

CWA section 402(b)(8) requires that certain POTWs receiving pollutants from significant industrial sources (subject to CWA section 307(b) standards) establish a pretreatment program to ensure compliance with these standards. The implementing regulations at § 403.8(a) state that:

> Any POTW (or combination of POTWs operated by the same authority) with a total design flow greater than 5 million gallons per day (mgd) and receiving from industrial users pollutants which pass through or interfere with the operation of the POTW or are otherwise subject to pretreatment standards will be required to establish a POTW pretreatment program unless the NPDES state exercises its option to assume local responsibilities as provided in § 403.10(e).

As specified in § 403.8(a), the Regional Administrator or Director of an authorized state may require a POTW with a design flow of 5 mgd or less to develop a POTW pretreatment program. Program development could be determined to be necessary to prevent interference with or pass through of the POTW based on the nature, or volume, of the industrial influent, a history of treatment process upsets and violations of POTW effluent limitation(s), and contamination of municipal sludge.

Since 1978, approximately 1,500 POTWs have been required to develop and implement pretreatment programs through special conditions of NPDES permits. The pretreatment program was developed to control industrial discharges to POTWs and to meet the following objectives:

- To prevent pass through of pollutants.
- To prevent interference with POTW processes, including interference with the use or disposal of municipal sludge.
- To improve opportunities to recycle and reclaim municipal and industrial wastewater and sludges.

The pretreatment program also helps ensure POTW personnel health and safety.

As authorized by the pretreatment regulations at §§ 403.8(c), 403.8(d) and 403.8(e) and the NPDES regulations at § 122.44(j)(2), the requirements to develop and implement a POTW pretreatment program are included as enforceable conditions in the POTW's NPDES permit. NPDES permits drive the development and implementation of pretreatment programs by requiring the following:

- Adequate legal authority.
- Maintenance of an industrial user inventory.
- Development and implementation of local limits.
- Control mechanisms issued to significant industrial users (SIUs).
- Compliance monitoring activities.
- Swift and effective enforcement.
- Data management and recordkeeping.
- Reporting to the approval authority (EPA or state).
- Public participation.

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Through the NPDES permit, the POTW is required to develop and implement a pretreatment program. The POTW is required to submit an approvable program that meets the requirements in § 403.9(b). A more detailed description of these required program elements is in § 403.8(f). The POTW must have the legal authority enabling it to do the following:

- Deny or condition new or increased contributions of pollutants, or changes in nature of pollutants, to the POTW by industrial users.
- Require compliance with applicable pretreatment standards and requirements by industrial users.
- Control through a permit, order, or similar means the contribution to the POTW by each industrial user to ensure compliance with applicable pretreatment standards and requirements. These control mechanisms must have certain conditions as laid out in § 403.8(f)(1)(iii) and be enforceable.
- Require the development of compliance schedules where necessary by each industrial user for the installation of technology required to meet applicable pretreatment standards and requirements, and submission of all notices and self-monitoring reports to assess and ensure compliance.
- Carry out all inspection, surveillance, and monitoring procedures necessary to determine compliance with applicable pretreatment standards and requirements independent of information submitted by the industrial user (including the authority to enter the premises of the industrial user).
- Obtain remedies for noncompliance (e.g., injunctive relief, penalties).
- Comply with confidentiality requirements.

Further, at a minimum, the POTW must have procedures to do the following:

- Identify and locate all possible industrial users that might be subject to the POTW pretreatment program.
- Identify the character and volume of pollutants contributed to the POTW by the industrial users.
- Notify industrial users of applicable pretreatment standards and applicable requirements under CWA sections 204(b) and 405 and RCRA Subtitles C and D.
- Receive and analyze self-monitoring reports.
- Conduct sampling, inspections and other surveillance activities to determine compliance with applicable pretreatment standards and requirements independent of information supplied by the industrial user.
- Investigate instances of noncompliance.
- Comply with public participation requirements, including annual public notice of industrial users determined to be in significant noncompliance during the previous 12-month period.

Also, as part of the POTW pretreatment program, POTWs must have adequate resources and funding to implement the program, evaluate the need for and, as necessary, develop local limits and develop an enforcement response plan.

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The NPDES permit should include the conditions specified in § 403.9, including that the POTW be required to submit the program documentation, detailing the authority and procedures to be implemented, along with other information about the program. The permit will allow the POTW up to one year, from the time when written notification from the approval authority determined the need for a pretreatment program, to develop and submit a program for approval as stated in § 403.8(b). Once the permitting authority reviews and approves the program, the requirement to implement the approved program is then incorporated into the permit.

The permit writer generally incorporates the requirement to develop a pretreatment program at the time of permit reissuance. The requirement, however, may also be incorporated through a modification of the permit if there is *cause*, as defined in detail in § 403.8(e), to make such a modification. The permit writer must follow procedures outlined by § 122.62 related to modifications when including the requirement to develop a pretreatment program in an NPDES permit

During the life of the permit, it might be necessary for the POTW to modify its approved pretreatment program (changes to local limits, changes to the ordinance, and such). The changes can be brought about by the POTW's desire to change the way the program operates, or they can be the result of changes that are necessary to address deficiencies in the program found during inspections or audits done by the permitting authority. Whatever the reason for the modification, the permitting authority must review and approve any modification to the approved program that is considered substantial, as required by § 403.18. All substantial program modifications to the POTW's approved pretreatment program require minor modifications to the NPDES permit and are subject to the procedural requirements in §§ 122.63(g) and 403.18. In addition, incorporating the requirement for a previously approved pretreatment program for the purpose of making the implementation of the program an enforceable part of the permit is also considered a minor modification to the NPDES permit.

The majority of POTWs that need pretreatment program requirements in their permits currently have them in place. In addition, an NPDES state or an EPA region will often designate a pretreatment coordinator to serve as the pretreatment expert to review the annual report from the POTW and recommend any action to be taken. The state or EPA regional pretreatment coordinator is a key resource on pretreatment issues, particularly at the time of NPDES permit reissuance. EPA regions and approved states have developed standard pretreatment development or implementation conditions (with minor modifications made to tailor the conditions to the specific discharger) that are placed in all applicable NPDES permits in that region or state. The permit writer can usually obtain examples of these NPDES pretreatment conditions from the EPA or state pretreatment coordinators. The permit writer might need to update or modify pretreatment implementation language or initiate corrective action related to the pretreatment program.

EPA has developed the Pretreatment Program Website <www.epa.gov/npdes/pretreatment> and prepared a number of guidance manuals for POTWs on how to implement their local pretreatment programs that are accessible through this website. In addition, EPA prepared the *Introduction to the National Pretreatment Program*[12] <www.epa.gov/npdes/pubs/final99.pdf> as a reference for anyone interested in understanding the basics of pretreatment program requirements and to provide a roadmap to additional and more detailed guidance materials for those trying to implement specific elements of the pretreatment program.

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Pretreatment program information and monitoring data obtained through the POTW's pretreatment program are useful to the permit writer in identifying possible modifications to the pretreatment program's local limits or procedures, or the need for water quality-based controls. The permit writer should obtain such data with the aid of the pretreatment coordinator. Permits must include conditions requiring a POTW to provide a written technical evaluation of the need to revise local limits under § 403.5(c)(1) following permit issuance or reissuance [§ 122.44(j)(2)(ii)]. In addition, POTWs with a design flow greater than or equal to one mgd and with an approved pretreatment program or required to develop a pretreatment program must sample and analyze their effluent for priority (toxic) pollutants listed in Part 122, Appendix J, Table 2 as part of the permit application process [see § 122.21(j)(4)(iv)]. Those data and information also are useful for determining the need for WQBELs.

9.2.2 Biosolids (Sewage Sludge)

CWA section 405(d) requires that EPA regulate the use and disposal of sewage sludge to protect public health and the environment from any reasonably anticipated adverse effects of these practices. In the CWA, Congress directed EPA to develop technical standards for municipal sludge use and disposal options and enacted strict deadlines for compliance with these standards. Within one year of promulgation of the standards, compliance was required unless construction of new pollution control facilities was necessary, in which case compliance was required within two years.

EPA promulgated Part 503, Standards for the Use or Disposal of Sewage Sludge in 58 *Federal Register* (FR) 9248, February 19, 1993, with amendments in 59 FR 9095, February 19, 1994 and 60 FR 54764, October 25, 1995. These regulations address four sludge use and disposal practices: land application, surface disposal, incineration, and disposal in a municipal solid waste landfill. The standards for each end use and disposal method consist of general requirements, numeric effluent limitations, operational standards, and management practices, as well as monitoring, recordkeeping, and reporting requirements. Unlike technology standards, which are based on the ability of treatment technologies to reduce the level of pollutants, EPA's sewage sludge standards are based on health and environmental risks. Part 503 imposes requirements on four groups:

- Persons who prepare sewage sludge or material derived from sewage sludge.
- Land appliers of sewage sludge.
- Owners/operators of sewage sludge surface disposal sites.
- Owners/operators of sewage sludge incinerators.

Details of that rule are described in *A Plain English Guide to the EPA Part 503 Biosolids Rule*[13] <www.epa.gov/owm/mtb/biosolids/503pe/>.

The risk assessment for the Part 503 rule that governs the land application of biosolids took nearly 10 years to complete and had extensive rigorous review and comment. The risk assessment evaluated and established limitations for a number of pollutants. These limitations are in chapter 4 of *A Guide to the Biosolids Risk Assessments for the EPA Part 503 Rule*[14] <www.epa.gov/owm/mtb/biosolids/503rule/>.

The regulation is largely self-implementing, and anyone who engages in activities covered by the regulation must comply with the appropriate requirements on or before the compliance deadlines. A person who violates Part 503 requirements is subject to administrative, civil, and criminal enforcement actions.

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CWA section 405(f) requires the inclusion of sewage sludge use or disposal requirements in any NPDES permit issued to a Treatment Works Treating Domestic Sewage (TWTDS) and authorizes the issuance of sewage sludge-only permits to non-discharging TWTDS. In response, EPA promulgated revisions to the NPDES permit regulations at Parts 122 and 124 in 54 FR 18716, May 2, 1989, to address inclusion of sewage sludge use and disposal standards in NPDES permits and NPDES permit issuance to treatment works that do not have an effluent discharge to waters of the United States, but are involved in sewage sludge use or disposal as preparers, appliers, or owners/operators. TWTDS includes all sewage sludge generators and facilities, such as blenders, that change the quality of sewage sludge.

EPA recognizes that implementation of Part 503 requirements is a source of confusion for permit writers and permittees who might already have NPDES permits with special conditions addressing sewage sludge requirements. EPA has provided several guidance documents to help clarify NPDES permitting expectations, and explain the requirements of Part 503:

- *Part 503 Implementation Guidance*[15] <www.epa.gov/npdes/pubs/owm0237.pdf>.
- *Land Application of Sewage Sludge—A Guide for Land Appliers on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge Management in 40 CFR Part 503*[16] <www.epa.gov/npdes/pubs/sludge.pdf>.
- *Surface Disposal of Sewage Sludge—A Guide for Owners/Operators of Surface Disposal Facilities on the Monitoring, Recordkeeping, and Reporting Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge in 40 CFR Part 503*[17] <No Link–see the endnote for ordering instructions>.
- *Preparing Sewage Sludge for Land Application or Surface Disposal—A Guide for Preparers of Sewage Sludge on the Monitoring, Record Keeping, and Reporting Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge in 40 CFR Part 503*[18] <No Link–see the endnote for ordering instructions>.
- *Domestic Septage Regulatory Guidance, A Guide to the EPA 503 Rule*[19] <www.epa.gov/npdes/pubs/owm0026.pdf>.
- *Control of Pathogens and Vector Attraction in Sewage Sludge*[20] <www.epa.gov/nrmrl/pubs/625r92013/625R92013.pdf>.

The permit writer should refer to the *Part 503 Implementation Guidance* and EPA Region and state guidelines or policies for instructions on how to implement the applicable Part 503 standards into the permit. The permit writer will need to determine the type of sewage sludge use or disposal practice(s) used by the discharger and apply the appropriate Part 503 standards. In general, conditions will need to be established to address the following:

- Pollutant concentrations or loading rates.
- Operational standards (such as pathogen and vector attraction reduction requirements for land application and surface disposal and total hydrocarbons (THC) concentrations for incinerators).
- Management practices (e.g., siting restrictions, design requirements, operating practices).
- Monitoring requirements (e.g., pollutants to be monitored, sampling locations, frequency, and sample collection and analytical methods).

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- Recordkeeping requirements.
- Reporting requirements (e.g., contents of reports and frequency or due dates for submission of reports).
- General requirements (e.g., specific notification requirements before land application, submission of closure and post closure plan for surface disposal sites).

In addition to any specific applicable Part 503 standards, three boilerplate conditions must be written in the NPDES permit where applicable. These consist of the following:

- Text requiring the POTW/TWTDS to comply with all existing requirements for sewage sludge use and disposal, including the Part 503 standards [see § 122.44(b)(2)].
- A reopener clause, which authorizes reopening a permit to include technical standards if the technical standards are more stringent or more comprehensive than the conditions in the permit [see § 122.44(c)].
- A notification provision requiring the permittee to give notice to the permitting authority when a significant change in the sewage sludge use or disposal practice occurs (or is planned) [see standard conditions in § 122.41(l)(1)(iii)].

If permit conditions based on existing regulations are insufficient to protect public health and the environment from adverse effects that could occur from toxic pollutants in sewage sludge, permit conditions should be developed on a case-by-case basis using best professional judgment (BPJ) to fulfill the statutory requirement. The *Part 503 Implementation Guidance* contains information to assist permit writers in developing effluent limitations and management practice requirements on a case-by-case basis to protect public health and the environment from adverse effects that could occur from toxic pollutants in sewage sludge. For more information on biosolids, see section 2.3.1.3 of this manual and the Biosolids Website <www.epa.gov/owm/mtb/biosolids/index.htm>

9.2.3 Combined Sewer Overflows (CSOs)

Combined sewer systems were designed and built in the 19th and early 20th centuries to collect sanitary and industrial wastewater and stormwater runoff. During dry weather, combined sewers carry sanitary wastes and industrial wastewater to a treatment plant. In periods of heavy rainfall, however, stormwater is combined with untreated wastewater, which can overflow and discharge directly to a waterbody without being treated. These overflows are called combined sewer overflows (CSOs).

EPA published a CSO Control Policy in 59 FR 18688, April 19, 1994. That policy represents a comprehensive national strategy to ensure that municipalities, permitting authorities, water quality standards authorities, and the public engage in a comprehensive and coordinated planning effort to achieve cost-effective CSO controls that ultimately meet appropriate health and environmental objectives.

The CSO Control Policy includes expectations for NPDES permitting authorities. In general, EPA envisioned a phased permit approach, including initial requirements to implement Nine Minimum CSO Controls (NMC) and develop a Long-Term CSO Control Plan (LTCP), followed by requirements to implement the controls in the approved LTCP. The Wet Weather Water Quality Act of 2000 amended the CWA to add section 402(q), which required that CSO permits be issued in conformance with the CSO Control Policy.

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CSOs are point source discharges subject to both the technology-based requirements of the CWA and applicable state water quality standards. Under the CWA, CSOs must comply with Best Available Technology Economically Achievable (BAT) for nonconventional and toxic pollutants and Best Conventional Technology (BCT) for conventional pollutants. However, there are no promulgated BAT or BCT limitations in effluent guidelines for CSOs. As a result, permit writers must use BPJ in developing technology-based permit requirements for controlling CSOs. Permit conditions also must achieve compliance with applicable water quality standards.

The 1994 CSO Control Policy contains the recommended approach for developing and issuing NPDES permits to control CSOs. In addition, EPA has developed the following CSO guidance documents to help permit writers and permittees implement the CSO Control Policy:

- *Combined Sewer Overflows–Guidance for Long-Term Control Plan*[21] <www.epa.gov/npdes/pubs/owm0272.pdf>.
- *Combined Sewer Overflows–Guidance for Nine Minimum Controls*[22] <www.epa.gov/npdes/pubs/owm0030.pdf>.
- *Combined Sewer Overflows–Guidance for Screening and Ranking*[23] <www.epa.gov/npdes/cso>.
- *Combined Sewer Overflows–Guidance for Monitoring and Modeling*[24] <www.epa.gov/npdes/pubs/sewer.pdf>.
- *Combined Sewer Overflows–Guidance for Financial Capability Assessment and Schedule Development*[25] <www.epa.gov/npdes/pubs/csofc.pdf>.
- *Combined Sewer Overflows–Guidance for Funding Options*[26] <www.epa.gov/npdes/pubs/owm0249.pdf>.
- *Combined Sewer Overflows–Guidance for Permit Writers*[27] <www.epa.gov/npdes/cso>.
- *Combined Sewer Overflows–Guidance: Coordinating Combined Sewer Overflow Long-Term Planning with Water Quality Standards Reviews*[28] <www.epa.gov/npdes/pubs/wqs_guide_final.pdf>.

Combined Sewer Overflows–Guidance for Permit Writers[24] contains guidance and example permit language that permit writers can use. Controlling CSOs typically requires substantial long-term planning, construction, financing and continuous reassessment; therefore, the implementation of CSO controls will probably occur over several permit cycles. The guidance explains a phased permitting approach to CSOs. Exhibit 9-2 depicts this phased permitting approach and the types of permit conditions that should be developed for each phase.

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Exhibit 9-2 Categories of CSO permitting conditions

NPDES permit	Phase I	Phase II	Post phase II
A. Technology-based	• NMC, at a minimum	• NMC, at a minimum	• NMC, at a minimum
B. Water Quality-based	• Narrative	• Narrative + performance-based standards	• Narrative + performance-based standards + numeric WQBELs (as appropriate)
C. Monitoring	• Characterization, monitoring, and modeling of CSS	• Monitoring to evaluate water quality impacts • Monitoring to determine effectiveness of CSO controls	• Post-construction compliance monitoring
D. Reporting	• Documentation of NMC implementation • Interim LTCP deliverables	• Implementation of CSO controls (both NMC and long-term controls)	• Report results of post-construction compliance monitoring
E. Special conditions	• Prohibition of dry weather overflows (DWO) • Development of LTCP	• Prohibition of DWO • Implementation of LTCP • Reopener clause for water quality standards violations • Sensitive area reassessment	• Prohibition of DWO • Reopener clause for water quality standards violations

Depending on the permittee's situation, a permit may contain both Phase I and Phase II elements. Phase I permits require demonstration of implementation of the NMC, shown in Exhibit 9-3.

Exhibit 9-3 Nine minimum CSO controls

1. Proper operation and regular maintenance programs for the sewer system and the CSOs
2. Maximum use of the collection system for storage
3. Review and modification of pretreatment requirements to ensure that CSO impacts are minimized
4. Maximization of flow to the POTW for treatment
5. Prohibition of CSOs during dry weather
6. Control of solid and floatable materials in CSOs
7. Establishment of pollution prevention programs
8. Public notification to ensure that the public receives adequate notification of CSO occurrences and CSO impacts
9. Monitoring to effectively characterize CSO impacts and the efficacy of CSO controls

In the Phase I permit issued/modified to reflect the CSO Control Policy, the NPDES authority should at least require permittees to

- Immediately implement BAT/BCT, which at a minimum includes the NMC, as determined on a BPJ basis by the permitting authority.
- Develop and submit a report documenting the implementation of the NMC within 2 years of permit issuance/modification.

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- Comply with applicable water quality standards, no later than the date allowed under the state's water quality standards expressed in the form of a narrative limitation.
- Develop and submit, consistent with the CSO Control Policy and based on a schedule in an appropriate enforceable mechanism, an LTCP, as soon as practicable, but generally within 2 years after the effective date of the permit issuance/modification. Permitting authorities may establish a longer timetable for completion of the long-term CSO control plan on a case-by-case basis to account for site-specific factors that could influence the complexity of the planning process. Exhibit 9-4 shows the minimum elements of the LTCP.

Exhibit 9-4 Elements of the long-term CSO control plan

1. Characterization, monitoring, and modeling of the combined sewer system
2. Public participation
3. Consideration of sensitive areas
4. Evaluation of alternatives
5. Cost/performance considerations
6. Operational plan
7. Maximizing treatment at the existing POTW treatment plant
8. Implementation schedule
9. Post-construction compliance monitoring program

Phase II permits require the implementation of an LTCP. The Phase II permit should contain the following:

- Requirements to implement the technology-based controls including the NMC determined on a BPJ basis.
- Narrative requirements that ensure that the selected CSO controls are implemented, operated and maintained as described in the LTCP.
- Water quality-based effluent limits under §§ 122.44(d)(1) and 122.44(k), requiring, at a minimum, compliance with, no later than the date allowed under the state's water quality standards, the numeric performance standards for the selected CSO controls, based on average design conditions specifying at least one of the following:
  - A maximum number of overflow events per year for specified design conditions consistent with II.C.4.a.i of the CSO Control Policy.
  - A minimum percentage capture of combined sewage by volume for treatment under specified design conditions consistent with II.C.4.a.ii of the CSO Control Policy.
  - A minimum removal of the mass of pollutants discharged for specified design conditions consistent with II.C.4.a.iii of CSO Control Policy.
  - Performance standards and requirements that are consistent with II.C.4.b of the CSO Control Policy.
- A requirement to implement, with an established schedule, the approved post-construction water quality assessment program including requirements to monitor and collect sufficient information to demonstrate compliance with water quality standards and protection of designated uses as well as to determine the effectiveness of CSO controls.

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- A requirement to reassess overflows to sensitive areas in those cases where elimination or relocation of the overflow is not physically possible and economically achievable.
- Conditions establishing requirements for maximizing the treatment of wet-weather flows at the POTW, as appropriate, consistent with section II.C.7. of the CSO Policy.
- A reopener clause authorizing the NPDES authority to reopen and modify the permit upon determination that the CSO controls fail to meet water quality standards or protect designated uses.

Reviewing the permittee's LTCP and consultations with other staff involved in the CSO control process and the permittee are important steps in the process of determining the appropriate Phase II permit conditions. Water quality-based controls in Phase II generally are expressed as narrative requirements and performance standards for the combined sewer system. Finally, post Phase II permit conditions would address continued implementation of the NMC, long-term CSO controls, and post-construction compliance monitoring. There may also be numeric WQBELs when there are sufficient data to support their development.

LTCP implementation schedules were expected to include project milestones and a financing plan for design and construction of necessary controls as soon as practicable. The CSO Control Policy expected permitting authorities to undertake the following:

- Review and revise, as appropriate, state CSO permitting strategies developed in response to the National CSO Control Strategy.
- Develop and issue permits requiring CSO communities to immediately implement the NMC and document their implementation and develop and implement an LTCP.
- Promote coordination among the CSO community, the water quality standards authority, and the general public through LTCP development and implementation.
- Evaluate water pollution control needs on a watershed basis and coordinate CSO control with the control of other point and nonpoint sources of pollution.
- Recognize that it might be difficult for some small communities to meet all the formal elements of LTCP development, and that compliance with the NMC and a reduced scope LTCP might be sufficient.
- Consider sensitive areas, use impairment, and a CSO community's financial capability in the review and approval of implementation schedules.

Communities must develop and implement LTCPs to meet water quality standards, including the designated uses and criteria to protect those uses for waterbodies that receive CSO discharges. The CSO Control Policy recognized that substantial coordination and agreement among the permitting authority, the water quality standards authority, the public, and the CSO community would be required to accomplish this objective. The CSO Control Policy also recognized that the development of the LTCP should be coordinated with the review and appropriate revision of water quality standards and their implementation procedures.

In developing permit requirements to meet technology-based requirements and applicable state water quality standards, the permit writer, in conjunction with staff involved in water quality standards and the

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permittee, should identify the appropriate site-specific considerations that will determine the CSO conditions to be established in the permit. EPA believes that the following information will be particularly relevant in developing the appropriate conditions:

- CSO Discharge
  - Flow, frequency, and duration of the CSO discharge.
  - Available effluent characterization data on the CSO discharge.
  - Available information and data on the impacts of the CSO discharge(s) (e.g., CWA section 305(b) reports, ambient survey data, fish kills, CWA section 303(d) lists of impaired waters).
  - Compliance history of the CSO owner, including performance and reliability of any existing CSO controls.
  - Current NPDES permit and NPDES permit application.
  - Facility planning information from the permittee that addresses CSOs.
- Technologies
  - Performance data (either from the manufacturer or from other applications) for various CSO technologies that may be employed, including equipment efficiency and reliability.
  - Cost information associated with the installation, operation and maintenance of CSO technologies.
  - Reference materials on various types of CSO.

For more information on CSOs, see section 2.3.1.4 of this manual and the Combined Sewer Overflows Website <www.epa.gov/npdes/cso>.

9.2.4 Sanitary Sewer Overflows (SSOs)

EPA's *Report to Congress on the Impacts and Control of CSOs and SSOs*[29] <www.epa.gov/npdes/csossoreport2004> shows that NPDES permit requirements establishing clear reporting, recordkeeping and third party notification of overflows from municipal sewage collection systems, as well as clear requirements to properly operate and maintain the collection system, are critical to effective program implementation. NPDES authorities should be improving NPDES permit requirements for SSOs and sanitary sewer collection systems, which could lead to improved performance of municipal sanitary sewer collection systems and improved public notice for SSO events.

The NPDES regulations provide standard conditions that are to be in NPDES permits for POTWs as discussed in Chapter 10 of this manual. Standard conditions in a permit for a POTW apply to portions of the collection system for which the permittee has ownership or has operational control. When reissued, permits for POTW discharges should clarify how key standard permit conditions apply to SSOs and sanitary sewer collection systems. On August 20, 2007, EPA circulated a draft fact sheet, NPDES Permit Requirements for Municipal Sanitary Sewer Collection Systems and SSOs <www.epa.gov/npdes/pubs/sso_fact_sheet_model_permit_cond.pdf>, which explains the ways NPDES permitting authorities should be improving implementation of NPDES permit requirements to address SSOs and sanitary sewer collection systems.

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The draft fact sheet indicates that clarifications should address the particular application of standard permit conditions to SSOs and municipal sanitary sewer collection systems as discussed below.

- **Immediate reporting.** Permits should clarify that the permittee is required to notify the NPDES authority of an overflow that could endanger health or the environment from portions of the collection system over which the permittee has ownership or operational control as soon as practicable but within 24 hours of the time the permittee becomes aware of the overflow. [See § 122.41(l)(6)].
- **Written reports**. Permits should clarify that the permittee is required to provide the NPDES authority a written report within 5 days of the time it became aware of any overflow that is subject to the immediate reporting provision. [See § 122.41(l)(6)(i).] In addition, permits should clarify that any overflow that is not immediately reported as indicated above, should be reported in the discharge monitoring report. [See § 122.41(l)(7)].
- **Third party notice.** Permits should establish a process for requiring the permittee or the NPDES authority to notify specified third parties of overflows that could endanger health because of a likelihood of human exposure; or unanticipated bypass and upset that exceeds any effluent limitation in the permit or that could endanger health because of a likelihood of human exposure. Permits should clarify that the permittee is required to develop, in consultation with appropriate authorities at the local, county, or state level (or any combination), a plan that describes how, under various overflow (and unanticipated bypass and upset) scenarios, the public, and other entities, would be notified of overflows that may endanger health. The plan should identify all overflows that would be reported, to whom they should be reported, the specific information that would be reported, a description of lines of communication, and the identities of responsible officials. [See § 122.41(l)(6)].
- **Recordkeeping**. Permits should clarify that the permittee is required to keep records of overflows. Clarified permit language for recordkeeping should require the permittee to retain the reports submitted to the NPDES authority and other appropriate reports that could include work orders associated with investigation of system problems related to an overflow, that describes the steps taken or planned to reduce, eliminate, and prevent reoccurrence of the overflow. [See § 122.41(j)].
- **Capacity, management, operation and maintenance programs.** Permits should clarify requirements for proper operation and maintenance of the collection system. [See §§ 122.41(d) and 122.41(e)]. This may include requiring the development and implementation of capacity, management, operation and maintenance (CMOM) programs. EPA's Region 4 has developed materials and guidance that can help a municipality with its CMOM program on the Management, Operation and Maintenance (MOM) Programs Project Website <www.epa.gov/region4/water/wpeb/momproject/>. The CMOM program may use a process for self-assessment and information management techniques for ongoing program improvement and may develop and implement emergency response procedures to overflows. In addition, the CMOM permit condition may specify appropriate documentation requirements, including the following:
  - CMOM program summary. Permittees may be required to develop a written summary of their CMOM programs, which would be available to the NPDES authority and public on request. The program summary would give an overview of the management program and summarize major implementation activities.

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- Program audit report. Permittees may be required to conduct comprehensive audits of their programs during the permit cycle, and submit a copy of the audit report to the NPDES authority with the application for permit renewal. EPA's Sanitary Sewer Overflow Toolbox Website <www.epa.gov/npdes/sso/ssotoolbox> provides information on CMOM.
- System evaluation and capacity assurance plan. Capacity assurance refers to a process to identify, characterize and address hydraulic deficiencies in a sanitary sewer collection system. The permit may require the permittee to implement a program to assess the current capacity of the collection system and treatment facilities that they own or over which they have operational control to ensure that discharges from unauthorized locations do not occur. Where peak flow conditions contribute to an SSO discharge or to noncompliance at a treatment plant, the permittee may be required to prepare and implement a system evaluation and capacity assurance plan. In some instances, the permittee may already be under an enforceable obligation and schedule, in which case this permit provision would be redundant and, thus, unnecessary.

Section 2.3.1.5 of this manual and EPA's Sanitary Sewer Overflows Website <www.epa.gov/npdes/sso> provide more information on SSOs.

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CHAPTER 10. Standard Conditions of NPDES Permits

This chapter describes standard conditions, sometimes called *boilerplate* conditions, that must be incorporated in National Pollutant Discharge Elimination System (NPDES) permits. Standard conditions, specified in Title 40 of the *Code of Federal Regulations* (CFR) 122.41 and 122.42, play an important supporting role to effluent limitations, monitoring and reporting requirements, and special conditions because they delineate various legal, administrative, and procedural requirements of the permit. Standard conditions cover various topics, including definitions, testing procedures, records retention, notification requirements, penalties for noncompliance, and other permittee responsibilities. The conditions provided in § 122.41 apply to all types and categories of NPDES permits and must be included in all permits (see § 123.25 for applicability to state NPDES permits). The conditions provided in § 122.42 apply only to certain categories of NPDES facilities. Any permit issued to a facility in one of the categories listed in § 122.42 must contain the additional conditions, as applicable.

The use of standard conditions helps ensure uniformity and consistency of all NPDES permits issued by authorized states or the U.S. Environmental Protection Agency (EPA) Regional Offices. Permit writers need to be aware of the contents of the standard conditions because it might be necessary to explain portions of the conditions to a discharger. The permit writer should keep abreast of any changes in EPA's standard conditions set out in §§ 122.41 and 122.42. According to § 122.41, standard conditions may be incorporated into a permit either expressly (verbatim from the regulations) or by reference to the regulations. It generally is preferable for permit writers to attach the standard conditions expressly because permittees might not have easy access to the regulations. Some states have developed an attachment for NPDES permits that includes the federal standard conditions.

10.1 Types of Standard Conditions

A brief summary of the § 122.41 standard conditions that must be included in all types of NPDES permits follows:

- **Duty to Comply** § 122.41(a): The permittee must comply with all conditions of the permit. Noncompliance is a violation of the Clean Water Act (CWA) and is grounds for enforcement action, changes to or termination of the permit, or denial of a permit renewal application.
- **Duty to Reapply** § 122.41(b): A permittee wishing to continue permitted activities after the permit expiration date must reapply for and obtain a new permit.
- **Need to Halt or Reduce Activity not a Defense** § 122.41(c): The permittee may not use as a defense in an enforcement action the reasoning that halting or reducing the permitted activity is the only way to maintain compliance.
- **Duty to Mitigate** § 122.41(d): The permittee is required to take all reasonable steps to prevent any discharge or sludge use or disposal in violation of the permit that has a reasonable likelihood of adversely affecting human health or the environment.
- **Proper Operation and Maintenance** § 122.41(e): The permittee must properly operate and maintain all equipment and treatment systems used for compliance with the terms of the permit.

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The permittee must provide appropriate laboratory controls and quality assurance procedures. Operation of backup systems is required only when needed to ensure compliance.

- **Permit Actions** § 122.41(f): The permit may be modified, revoked and reissued, or terminated for cause. A request by the permittee for a permit modification, revocation or reissuance, termination, or a notification of planned changes or anticipated noncompliance does not suspend the permittee's obligation to comply with all permit conditions.
- **Property Rights** § 122.41(g): The permit does not convey any property rights of any sort, or any exclusive privilege.
- **Duty to Provide Information** § 122.41(h): The permittee must furnish, within a reasonable time, any information needed to determine compliance with the permit or to determine whether there is cause to modify, revoke and reissue, or terminate the permit. The permittee also must furnish, on request, copies of records that must be kept as required by the permit.
- **Inspection and Entry** § 122.41(i): The permittee must, upon presentation of valid credentials by the Director or his or her representative, allow entry into the premises where the regulated activity or records are present. The Director must have access to and be able to make copies of any required records; inspect facilities, practices, operations, and equipment; and sample or monitor at reasonable times.
- **Monitoring and Records** § 122.41(j): Samples must be representative of the monitored activity. The permittee must retain records for 3 years (5 years for sewage sludge activities) subject to extension by the Director. Monitoring records must identify the sampling dates and personnel, the sample location and time, and the analytical techniques used and corresponding results. Wastewater and sludge measurements must be conducted in accordance with Parts 136 or 503 or other specified procedures. Falsification of results is a violation under the CWA.
- **Signatory Requirement** § 122.41(k): The permittee must sign and certify applications, reports, or information submitted to the Director in accordance with the requirements in § 122.22. Knowingly making false statements, representations, or certifications is punishable by fines or imprisonment.
- **Planned Changes** § 122.41(l)(1): Notice must be given to the Director as soon as possible of planned physical alterations or additions to the facility (or both) that could meet the criteria for determining whether the facility is a new source under § 122.29(b); result in changes in the nature or quantity of pollutants discharged; or significantly change sludge use or disposal practices.
- **Anticipated Noncompliance** § 122.41(l)(2): The permittee must give advance notice of any planned changes that could result in noncompliance.
- **Permit Transfers** § 122.41(l)(3): The permit is not transferable except after written notice to the Director. The Director may require modification or revocation and reissuance, as necessary.
- **Monitoring Reports** § 122.41(l)(4): Monitoring results must be reported at the frequency specified in the permit and be reported on a discharge monitoring report (DMR) or forms provided or specified by the Director for reporting results of monitoring sludge use or disposal practices. Monitoring for any pollutant that occurs more frequently than is required by the permit and uses approved test procedures or test procedures specified in the permit must also be reported. Calculations requiring averaging must use an arithmetic mean unless otherwise specified in the permit.

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- **Compliance Schedules** § 122.41(l)(5): Reports of compliance or noncompliance or any progress report must be submitted no later than 14 days following the interim or final compliance date specified in a compliance schedule.
- **Twenty-Four Hour Reporting** § 122.41(l)(6): The permittee must orally report any noncompliance that might endanger human health or the environment within 24 hours after becoming aware of the circumstances. Within 5 days of becoming aware of the circumstances, the permittee must provide a written submission including a description of the noncompliance and its cause; the period of noncompliance, including exact dates and times; the anticipated time the noncompliance is expected to continue (if not already corrected); and steps taken to reduce, eliminate, or prevent reoccurrence unless the Director waives the requirement. In addition, 24-hour reporting is required for an unanticipated bypass exceeding effluent limits; an upset exceeding effluent limits; and a violation of a maximum daily effluent limitation for pollutants listed in the permit for 24-hour reporting.
- **Other Noncompliance** § 122.41(l)(7): The permittee must report all instances of noncompliance not reported under other specific reporting requirements at the time monitoring reports are submitted.
- **Other Information** § 122.41(l)(8): If the permittee becomes aware that it failed to submit any relevant facts in its application, or submitted incorrect information in its application or other reports, it must promptly submit such facts or information.
- **Bypass** § 122.41(m): The intentional diversion of wastestreams from any portion of a treatment facility. Bypass is prohibited unless the bypass does not cause the effluent to exceed limits and is for essential maintenance to assure efficient operation (no notice or 24-hour reporting is required in such a case). All other bypasses are prohibited, and the Director of the NPDES program may take enforcement action against a permittee for a bypass, unless the bypass was unavoidable to prevent loss of life, personal injury, or severe property damage, there was no feasible alternative, and the proper notification was submitted.
- **Upset** § 122.41(n): An upset (i.e., an exceptional incident in which there is unintentional and temporary noncompliance with technology-based effluent limits because of factors beyond the permittee's control) can be used as an affirmative defense in actions brought against the permittee for noncompliance. An upset does not include noncompliance to the extent caused by operational error, improperly designed or inadequate treatment facilities, lack of preventative maintenance, or careless or improper operation. The permittee (who has the burden of proof to demonstrate that an upset has occurred) must have operational logs or other evidence that shows
  - When the upset occurred and its causes.
  - The facility was being operated properly.
  - Proper notification was made.
  - Remedial measures were taken.

10.2 Other Standard Conditions

In addition to standard conditions specified in § 122.41 that are applicable to all permittees, § 122.42 includes additional conditions applicable to certain categories of NPDES permits. Below are summaries of these additional standard conditions applicable to various types of NPDES permits.

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Non-Municipal (Industrial) Permits: Additional standard conditions applicable to non-municipal permits are found in § 122.42(a) and specify that the permittee must notify the Director as soon as it knows or has reason to believe that the discharge has or will exceed certain notification levels specified in §§ 122.42(a)(1) and (2). In addition, § 122.44(f) allows the Director to establish alternate notification levels upon petition by the permittee or by his or her own initiative.

Publicly Owned Treatment Work (POTW) Permits: Additional standard conditions applicable to POTWs are found in § 122.42(b). The standard conditions specify that the permittee must provide adequate notice to the Director of the new introduction of certain pollutants into the POTW from an indirect discharger and of substantial changes in the volume or character of pollutants introduced into the POTW. That notice must include information on the quality and quantity of effluent introduced to the POTW and information on the impact to the quality and quantity of the POTW's effluent.

Municipal Separate Storm Sewer Systems: Additional standard conditions applicable to large, medium or EPA-designated municipal separate storm sewer systems are in § 122.42(c). Those standard conditions require that the permittee submit an annual report addressing the status, and changes to, the stormwater management program, water quality data and other information specified in §§ 122.42(c)(1)-(6).

Individual Stormwater Permits: Initial permits for discharges composed entirely of stormwater and permitted under § 122.26(e)(7) must require compliance no later than 3 years after permit issuance.

Concentrated Animal Feeding Operations (CAFO) Permits: The regulations at § 122.42(e) specify conditions that must be included in all permits for CAFOs.

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CHAPTER 11. NPDES Permit Administration

Previous discussions in this manual focused on the process of developing National Pollutant Discharge Elimination System (NPDES) permit conditions and effluent limitations. This chapter describes the administrative process associated with the issuance of an NPDES permit including a discussion of the other federal laws that might affect the development or issuance of NPDES permits.

11.1 Other Federal Laws Applicable to NPDES Permits

This section addresses other federal laws, besides the Clean Water Act (CWA), that permit writers should consider when drafting an NPDES permit. The requirements imposed under these statutes only apply to federal actions (i.e., U.S. Environmental Protection Agency [EPA] issuance of permits). Permits issued by states authorized to administer the NPDES program are not subject to the requirements of these statutes. However, many states may have enacted state legislation that is modeled on federal law and, therefore, it is prudent to review state law in these areas before preparing an NPDES permit.

The following sections briefly discuss the other federal laws and contain links to other websites for more information. Because these laws are implemented by other federal agencies, many of the links provided below are to websites outside EPA, and EPA is not responsible for the information provided on those websites. The NPDES regulations at Title 40 of the *Code of Federal Regulations* (CFR) 122.49 also include a discussion of how some of the laws relate to the federal NPDES program. Exhibit 11-1 presents the other federal laws that are applicable to NPDES permits and includes the legislative citations from the *United States Code* (U.S.C.) and the implementing regulations in the CFR.

Exhibit 11-1 Other federal laws applicable to NPDES permits

Federal law	Year	Federal agency	Legislative citations	Implementing regulations
Endangered Species Act (ESA)	1973	FWS, NMFS	16 U.S.C. 1531 et seq.	50 CFR Part 402
National Environmental Policy Act (NEPA)	1969	CEQ	42 U.S.C. 4321 et seq.	40 CFR Part 6
National Historic Preservation Act (NHPA)	1992	ACHP	16 U.S.C. 470 et seq.	36 CFR Part 800
Coastal Zone Management Act (CZMA)	1972	NOAA	16 U.S.C. 1451 et seq.	15 CFR Part 930
Wild and Scenic Rivers Act	1968	Various	16 U.S.C. 1271 et seq.	36 CFR Part 297
Fish and Wildlife Coordination Act (FWCA)	1934	FWS	16 U.S.C. 661 et seq.	--
Essential Fish Habitat Provisions (EFH)	1996	NOAA	16 U.S.C. 1855(b)(2)	50 CFR Part 600

11.1.1 Endangered Species Act

This section discusses procedures intended to protect endangered species that apply only to permits issued by EPA. The 1973 Endangered Species Act (ESA) <www.fws.gov/endangered/esa-library/pdf/ESAall.pdf>, 16 U.S.C. 1531 *et seq.*, was enacted to protect and conserve endangered and threatened species and critical habitat. The Fish and Wildlife Service (FWS) <www.fws.gov/endangered/> of the Department of the Interior and the National Marine Fisheries Service (NMFS) <www.nmfs.noaa.gov/pr/> of the National

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Oceanic and Atmospheric Administration (NOAA) within the Department of Commerce (collectively *the Services*) share primary responsibility for administration of the ESA.

ESA section 7 requires that federal agencies consult with the Services to ensure that any action authorized, funded, or carried out by the agencies that could affect a listed species or critical habitat and to ensure that their actions are not likely to jeopardize the continued existence of any endangered species or threatened species, or result in the destruction or adverse modification of critical habitat of such species. The ESA section 7 regulations are in 50 CFR Part 402. FWS/NMFS published the ESA Section 7 Consultation Handbook <www.fws.gov/endangered/esa-library/pdf/TOC-GLOS.PDF> to address the major consultation processes pursuant to ESA section 7.

Consultation may be either informal or formal. An informal consultation determines if an action is or is not likely to adversely affect the species. A formal consultation is required if the findings from the informal consultation show that there is a likelihood for adverse impacts and evaluates whether the proposed action is likely to jeopardize the continued existence of the species. It is EPA's responsibility to ensure that consultation occurs; however, a nonfederal representative (i.e., the discharger) may be designated for the informal consultation.

On February 22, 2001, EPA entered into a National Memorandum of Agreement (*National MOA*) <www.epa.gov/fedrgstr/EPA-SPECIES/2001/February/Day-22/e2170.pdf> with the Services that outlines the process for consulting on federally issued NPDES permits. In addition, because consultation is not required for state-issued permits, the National MOA includes a process for coordinating with the Services on state-issued permits. EPA permit writers should review the ESA consultation regulations and the ESA section 7 Consultation Handbook, and coordinate with the Region's ESA coordinator (if such a position has been established in a Region) and the Service office(s) nearest to the site.

11.1.2 National Environmental Policy Act

This section discusses environmental review procedures that apply only when EPA issues permits to *new sources* (dischargers subject to New Source Performance Standards). The 1969 National Environmental Policy Act (NEPA) <www.epa.gov/compliance/basics/nepa.html>, 42 U.S.C. 4321 *et seq*., requires that agencies perform environmental impact reviews and prepare an *Environmental Impact Statement* (EIS) for major federal actions significantly affecting the quality of the human environment [see section 102(2)(C)]. The President's Council on Environmental Quality (CEQ) <www.whitehouse.gov/ceq/> coordinates federal environmental efforts to comply with NEPA.

Within EPA, the Office of Federal Activities under the Office of Enforcement and Compliance Assurance (OECA) is responsible for EPA's implementation of NEPA <www.epa.gov/compliance/nepa/>. EPA's NEPA regulations are at 40 CFR Part 6. With respect to NPDES permits, CWA section 511 establishes that only EPA-issued permits to new sources are subject to NEPA's environmental review procedures before permit issuance. States may have their own state law versions of NEPA. Federal permit writers should coordinate efforts with the Office of Federal Activities and document all NEPA activities in the permit file and fact sheet.

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11.1.3 National Historic Preservation Act Amendments

Section 106 of the 1992 National Historic Preservation Act (NHPA) <www.achp.gov/nhpa.html>, 16 U.S.C. 470 *et seq.*, as amended, and implementing regulations 36 CFR Part 800 require the Regional Administrator, before issuing a license (permit), to identify the area of potential effect of a permitted discharge and, if historic or cultural resources within that area would be adversely affected by the discharge, to adopt measures when feasible to mitigate potential adverse effects of the licensed activity and properties listed or eligible for listing in the National Register of Historic Places.

The Act's requirements are to be implemented in cooperation with State Historic Preservation Officers <www.achp.gov/shpo.html>, and upon notice to, and when appropriate, in consultation with the Advisory Council on Historic Preservation <www.achp.gov/>, which provides national oversight for the NHPA. A decision by the D.C. Circuit in 2003 concluded that NHPA consultation is not required for state-issued permits (*National Mining Ass'n v. Fowler*, 324 F.3d 752 (D.C. Cir. 2003) <caselaw.findlaw.com/us-dc-circuit/1169695.html>).

Federal permit writers should evaluate potential effects of NHPA and submit written documentation of the evaluation to the State Historic Preservation Office and to the permit file.

11.1.4 Coastal Zone Management Act

The 1972 Coastal Zone Management Act (CZMA) <www.coastalmanagement.noaa.gov/czm/czm_act.html>, 16 U.S.C. 1451 *et seq.*, was enacted to manage the nation's coastal zone and is implemented through a state-federal partnership. Section 307 of the CZMA (16 U.S.C. 1456 and 15 CFR Part 930) prohibits the issuance of federal NPDES permits for activities affecting land or water use in coastal zones unless the permit applicant certifies that the proposed activity complies with the state Coastal Zone Management Program and the relevant state either concurs with the applicant's certification or the state's concurrence is conclusively presumed as a result of the state's failure to concur or non-concur. *Coastal States*, according to the CZMA, include those states and territories adjacent to the Atlantic, Pacific, or Arctic oceans; the Gulf of Mexico; or one or more of the Great Lakes. Any of those states that have completed the development of its management program is required, as a condition of receipt of federal grant money under the CZMA, to adopt coastal management plans, which designate boundaries, identify areas of particular concern, and establish inventories of permitted uses and enforcement policies. Beach access, emergency planning, and erosion control also must be addressed in such plans.

The Office of Ocean and Coastal Resource Management <www.coastalmanagement.noaa.gov/>, which is part of NOAA within the Department of Commerce, oversees the CZMA. The CZMA implementing regulations are at 15 CFR Part 930. EPA and other federal agencies must coordinate their activities on coastal lands with state CZMA plans. Federal permit writers should document all activities relating to CZMA in the permit file.

11.1.5 Wild and Scenic Rivers Act

The 1968 Wild and Scenic Rivers Act (WSRA) <www.rivers.gov/publications/wsr-act.pdf>, 16 U.S.C. 1271 *et seq.*, established a National Wild and Scenic Rivers System (System) and prescribed the process by which additional rivers may be added to this System. Rivers may be added by act of Congress [WSRA section 2(a)(i)] or by the Secretary of the Interior at the initiative of a state governor [WSRA section 2(a)(ii)]. Under WSRA section 7(a), EPA is prohibited from assisting, by license or otherwise, in the construction

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of any water resources project that would have a direct and adverse effect on the values for which a national wild and scenic river was established. The WSRA regulations are codified at 36 CFR Part 297.

Federal permit writers should verify whether the receiving water is part of the System and document all activities related to the Act in the permit file and fact sheet. For detailed explanation of WSRA section 7, refer to Wild and Scenic Rivers Act: Section 7 <www.rivers.gov/publications/section-7.pdf>, a technical report of the Interagency Wild and Scenic Rivers Coordinating Council. Permit writers may also refer to Water Quantity and Quality as Related to the Management of Wild and Scenic Rivers <www.rivers.gov/publications/water.pdf>, a technical report of the Interagency Wild and Scenic Rivers Coordinating Council.

11.1.6 Fish and Wildlife Coordination Act

The 1934 Fish and Wildlife Coordination Act (FWCA) <www.fws.gov/habitatconservation/fwca.html>, 16 U.S.C. 661 *et seq.*, requires mitigation for the loss of wildlife habitat due to the construction of federal water resources projects. The FWCA requires designers of federal dams, reservoirs, and irrigation works to include the costs and benefits to fish and wildlife when determining the benefit/cost ratio of a project and requires that EPA and other federal agencies consult with state and federal wildlife and fisheries agencies to minimize the impacts of the activity on fish and wildlife. The FWCA specifically calls for ongoing studies by the U.S. Department of the Interior on the effects of domestic sewage and industrial wastes on fish and wildlife (16 U.S.C. 665).

No implementing regulations directly related to the FWCA and NPDES permits exist. However, the FWCA describes actions taken or compelled by the affected federal agencies. The Water Resources Development under the Fish and Wildlife Coordination Act manual <www.fws.gov/habitatconservation/fwca.pdf> provides the FWS guidance on implementing the FWCA. Federal permit writers should note any FWCA consultation activities in the permit file.

11.1.7 Essential Fish Habitat Provisions

The 1996 Essential Fish Habitat (EFH) provisions of the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act or MSA) promote the protection of essential fish habitat in any federal action authorized, funded, or undertaken, or proposed to be authorized, funded, or undertaken, by such agency that might adversely affect such habitat identified under the MSA [16 U.S.C. 1855(b)(2)]. The MSA requires that federal agencies, such as EPA, consult with the NMFS for any EPA-issued permits that might adversely affect essential fish habitat identified under the MSA. The regulations applicable to federal agencies' coordination and consultation under the MSA are codified at 50 CFR 600.905 through 600.930, and other EFH information can be found on the NMFS EFH Website <www.habitat.noaa.gov/protection/efh/index.html>. Federal permit writers should note any EFH determinations and consultation activities in the permit file.

11.2 Documentation for Development of the Draft Permit

EPA regulations at 40 CFR 124.2 define a draft permit as a document that indicates the Director's tentative decision to issue or deny, modify, revoke and reissue, terminate, or reissue a permit. After the permit is issued, the fact sheet and supporting documentation (administrative record) are the primary support for defending the permit in the administrative appeals process. Documenting the permit requires

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the permit writer to be organized and logical throughout the permit development process. Some of the content of the fact sheet and administrative record is specified by federal and state regulation, and the remainder is dictated by good project management. Permit writers should recognize the importance of

- Developing a thorough permit in a logical fashion.
- Meeting legal requirements for preparation of an administrative record, fact sheet, and statement of basis.
- Substantiating permit decisions and providing a sound basis for the derivation of permit terms, conditions, and limitations if challenges are made.
- Establishing a permanent record of the basis of the permit for use in future permit actions.

Exhibit 11-2 presents reasons for good documentation in the permit file and fact sheet.

Exhibit 11-2 Reasons for good documentation

- Streamlines the permit reissuance/ compliance monitoring process
- Establishes a permanent record of the basis for the permit
- Explains the legal and technical basis of the permit
- Provides a sound basis for future modifications and permits
- Requires the permit writer to be organized and logical throughout permit development process

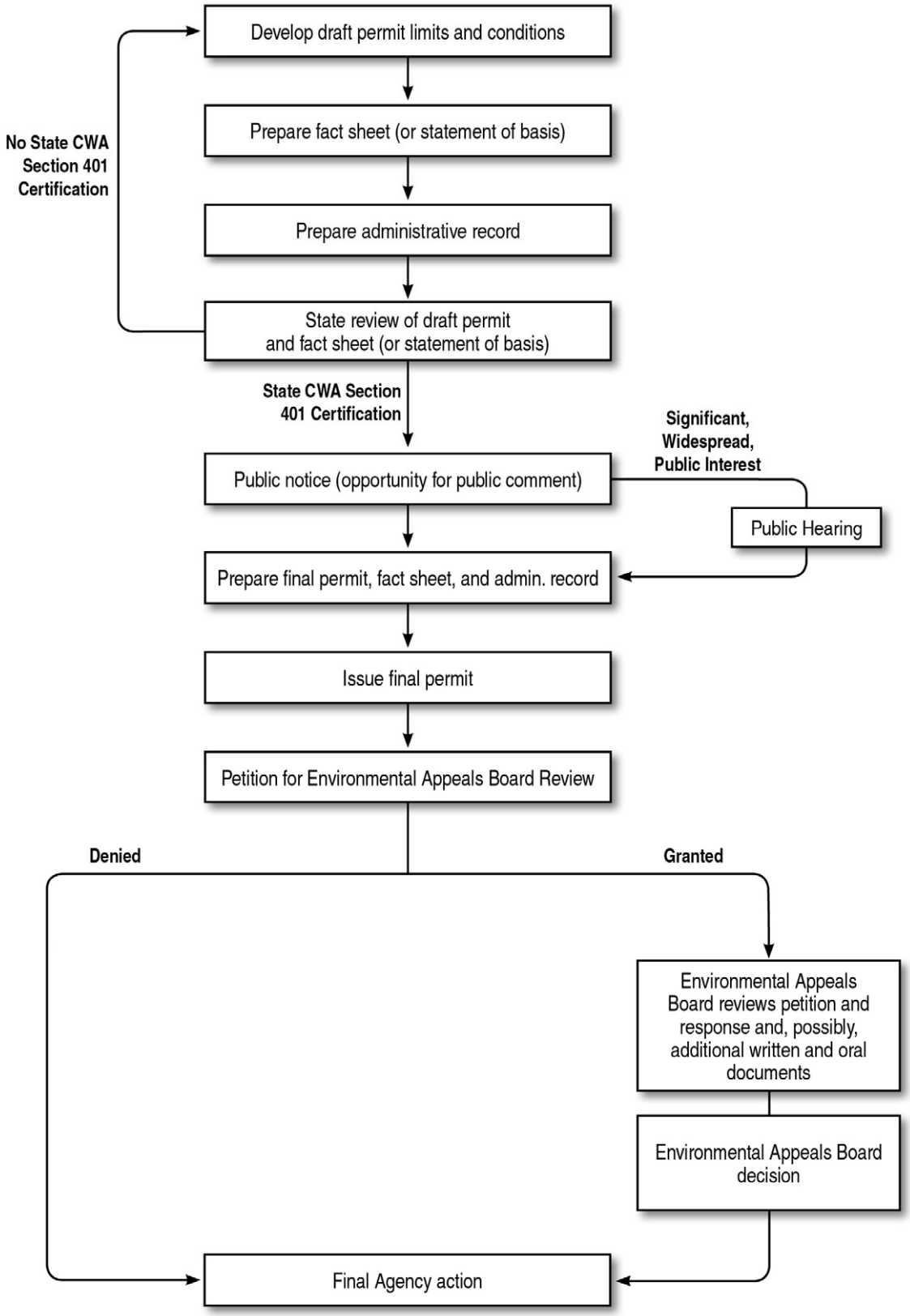
Exhibits 11-3 and 11-4 provide flow diagrams of the NPDES permit administrative process. In general, the administrative process includes the following:

- Documenting all permit decisions.
- Coordinating EPA and state review of the draft (or proposed) permit.
- Providing public notice, conducting hearings (if appropriate), and responding to public comments.
- Defending the permit and modifying it (if necessary) after issuance.

Note that Exhibit 11-3 provides the general framework for the administrative process where EPA is the NPDES permitting authority and Exhibit 11-4 provides a typical framework for the administrative process where a state is the permitting authority. State requirements need not be identical to federal regulatory requirements, provided they are at least as stringent. Some authorized states have slightly different processes for developing and issuing NPDES permits. The same holds true for the appeal process. This manual presents EPA's procedure; state procedures for NPDES permit hearings and appeals vary according to state law.

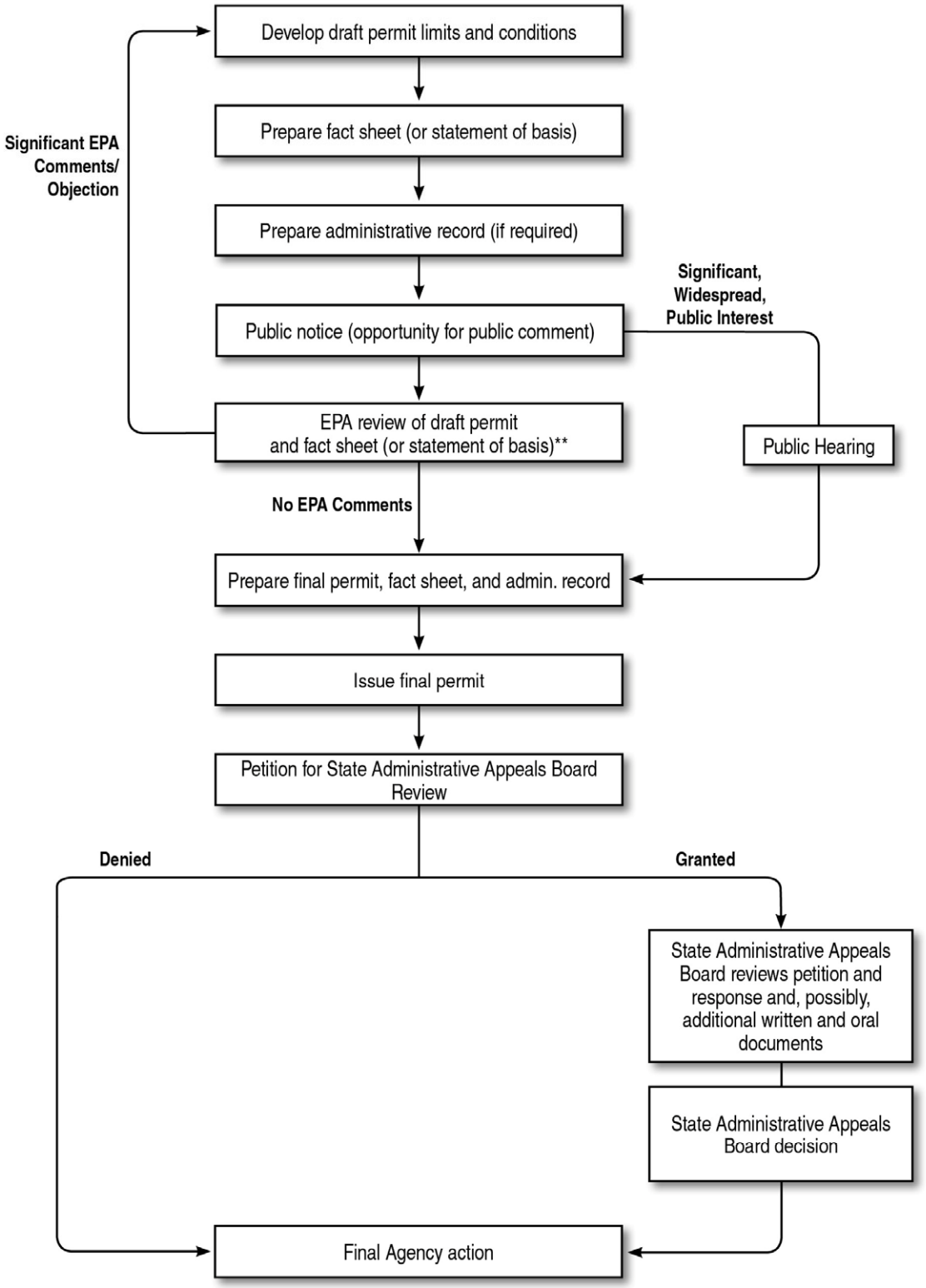
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Exhibit 11-3 Administrative process for EPA-issued NPDES permits



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Exhibit 11-4 Typical administrative process for state-issued NPDES permits*



* State statutes and regulations govern the specific steps of the state administrative process, which may differ from the process outlined in this exhibit.
** Under State/EPA MOA, EPA may review draft or proposed permit.

11.2.1 Administrative Record

The administrative record should be considered the foundation that supports the NPDES permit. If EPA issues the permit, the contents of the administrative record are prescribed by regulation, with § 124.9 identifying the required content of the administrative record for a draft permit and § 124.18 describing the requirements for final permits. Regardless of whether a state or EPA issues the permit, all supporting materials must be made available to the public at any time and may be examined during the public comment period and any subsequent public hearing. The importance of maintaining the permit records in a neat, orderly, complete, and retrievable form cannot be over emphasized. The record allows personnel from the permitting agency to reconstruct the justification for a given permit and defend the permit during any legal proceedings regarding the permit.

The administrative record for a draft permit consists, at a minimum, of the specific documents shown in Exhibit 11-5. Materials that are readily available in the permit issuing office or published material that is generally available do not need to be physically included with the record as long as they are specifically referred to in the fact sheet or statement of basis. If EPA issues a draft permit for a new source, the administrative record should include any EISs or *Environmental Assessments* (EAs) performed in accordance with § 122.29(c).

Exhibit 11-5 Elements of the administrative records for a draft permit

- Permit application and supporting data
- Draft permit
- Statement of basis or fact sheet
- All items cited in the statement of basis or fact sheet, including calculations used to derive the permit limitations
- Meeting reports
- Correspondence with the applicant and regulatory personnel
- All other items in the supporting file
- For new sources, any EA, draft/final EIS, or other such background information, such as a Finding of No Significant Impact (only applies if EPA issues the permit)

The administrative record should include all meeting reports and correspondence with the applicant and other regulatory agency personnel, trip reports, and records of telephone conversations. All correspondence, notes, and calculations should be dated and indicate the name of the writer and all other persons involved. Because correspondence is subject to public scrutiny, references or comments that do not serve an objective purpose should be avoided. Finally, the presentation of calculations and documentation of decisions should be organized in such a way that they can be reconstructed and the logic supporting the calculation or decisions can easily be found.

11.2.2 Fact Sheets and Statements of Basis

A fact sheet is a document that briefly sets forth the principal facts and the significant factual, legal, methodological, and policy questions considered in preparing the draft permit. When the permit is in the draft stage, the fact sheet and supporting documentation serve to explain the rationale and assumptions used in deriving the limitations to the discharger, the public, and other interested parties.

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The NPDES regulations at § 124.8(a) stipulate that every EPA and state-issued permit must be accompanied by a fact sheet if the permit

- Involves a major facility or activity.
- Incorporates a variance or requires an explanation under § 124.56(b) (toxic pollutants, internal waste stream, and indicator pollutants and for privately owned waste treatment facilities).
- Is an NPDES general permit.
- Is subject to widespread public interest.
- Is a Class I sludge management facility.
- Includes a sewage sludge land application plan.

A well-documented rationale for all permit decisions reduces the work necessary to reissue a permit by eliminating conjecture concerning the development of those permit conditions that are being carried forward to the next permit. That is also true if a modification is initiated during the life of the permit. The required contents of a fact sheet, as specified in §§ 124.8 and 124.56, are listed in Exhibit 11-6.

Exhibit 11-6 Required elements of a fact sheet

Required element	Regulatory citation (40 CFR)
General facility information • Description of the facility or activity • Sketches or a detailed description of the discharge location • Type and quantity of waste/pollutants discharged	 § 124.8 § 124.56 § 124.8
Summary rationale of permit conditions • Summary of the basis for the draft permit conditions • References to the applicable statutory or regulatory provisions • References to the administrative record	§ 124.8
Detailed rationale of permit conditions • Explanation and calculation of effluent limitations and conditions • Specific explanations of – Toxic pollutant limitations – Limitations on internal wastestreams – Limitations on indicator pollutants – Case-by-case requirements – Decisions to regulate non-publicly owned treatment works (POTWs) under a separate permit • For EPA-issued permits, the requirements of any state certification • For permits with a sewage sludge land application plan, a description of how all required elements of the land application plan are addressed in the permit • Reasons why any requested variances do not appear justified, if applicable	 § 124.56 § 124.8
Administrative Requirements • A description of the procedures for reaching a final decision on the draft permit, including – Public comment period beginning and ending dates – Procedures for requesting a hearing – Other procedures for public participation • Name and telephone number of the person to contact for additional information	 § 124.8

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The fact sheet should include detailed discussions of the development of permit limitations for each pollutant, including the following:

- Calculations and assumptions related to production and flow.
- Type of limitations (i.e., limitations based on secondary treatment standards, effluent limitations guidelines and standards (effluent guidelines), case-by-case determinations, or water quality standards).
- Whether the effluent guidelines used were Best Practicable Control Technology Currently Available (BPT), Best Available Technology Economically Achievable (BAT), Best Conventional Pollutant Control Technology (BCT), or New Source Performance Standards (NSPS).
- The water quality standards or criteria used.
- Whether any parameters were used as indicators for other pollutants.
- Citations to appropriate wasteload allocation or total maximum daily load studies, guidance documents, other references.

Often, decisions to include certain requirements lead to a decision to exclude other requirements. It is just as important to keep a thorough record of items that were not included in the draft permit as it is to keep a record of included items. Such records might include the following:

- Why were secondary treatment standards, case-by-case determinations, or effluent guidelines used as the basis for final effluent limitations rather than water quality standards (i.e., demonstrate that the limitations checked to see that water quality standards would be attained)?
- Why was biomonitoring not included?
- Why were pollutants that were reported as present in the permit application not specifically limited in the permit?
- Why is a previously limited pollutant no longer limited in the draft permit?

Finally, the fact sheet should address the logistics of the permit issuance process, including the beginning and ending dates of the public comment period, procedures for requesting a hearing, and other means of public involvement in the final decision.

A statement of basis, as described in § 124.7, is required for EPA-issued permits that are not required to have a fact sheet. A statement of basis describes the derivation of the effluent limitations and the reasons for special conditions. However, a prudent permit writer will develop the detailed rationale required in a fact sheet for any permit that includes complex calculations or special conditions (e.g., case-by-case effluent limitations based on best professional judgment [BPJ]) even if a fact sheet is not required by regulation.

11.3 Items to Address before Issuing a Final Permit

This section describes the public participation activities that must be conducted in the permit issuance process. These include providing public notices, collecting and responding to public comments, and holding public hearings as necessary.

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11.3.1 Public Notice

The public notice is the vehicle for informing all interested parties and members of the general public of the contents of a draft NPDES permit or other significant actions with respect to an NPDES permit or permit application. The basic intent of this requirement is to ensure that all interested parties have an opportunity to comment on significant actions of the permitting agency with respect to NPDES permits. The exact scope, required contents, and methods for effecting public notices are found in § 124.10. The NPDES permit-related actions for which public notice is required are shown in Exhibit 11-7.

Exhibit 11-7 Actions for which public notice is required

- Tentative denial of an NPDES permit application (not necessarily applicable to state programs)
- Preparation of a draft NPDES permit, including a proposal to terminate a permit
- Scheduling of a public hearing
- An appeal has been granted by the Environmental Appeals Board
- Major permit modifications (after permit issuance)
- New Source determinations (EPA only)

The permit writer should be particularly concerned with the first three items in Exhibit 11-7. It is important to note that no public notice is required when a request for a permit modification, revocation, reissuance, or termination is denied.

Public notice of NPDES permit-related activities should be provided using the following methods:

- For major permits, publication of a notice in daily or weekly newspaper within the area affected by the facility or activity.
- For general permits issued by EPA, publication in the FR.
- For all permits, direct mailing to various interested parties. This mailing list should include the following:
  - The applicant.
  - Any interested parties on the mailing list.
  - Any other agency that has issued or is required to issue a Resource Conservation and Recovery Act (RCRA), Underground Injection Control (UIC), Prevention of Significant Deterioration (PSD) (or other permit under the Clean Air Act), NPDES, CWA section 404, sludge management, or ocean dumping permit under the Marine Research Protection and Sanctuaries Act for the same facility or activity.
  - Federal and state agencies with jurisdiction over fish, shellfish, and wildlife resources and over coastal zone management plans, the Advisory Council on Historic Preservation, State Historic Preservation Officers, including any affected states and tribes.
  - State agencies conducting area-wide and continuing planning under CWA sections 208(b)(2), 208(b)(4) or 303(e) and the FWS, NMFS, and the U.S. Army Corps of Engineers.
  - Users identified in the permit application of a privately owned treatment work.
  - Persons on any mailing lists developed by including those who request inclusion in writing and persons solicited for *area lists* from participants in past permit proceedings in the area.
  - Any local government having jurisdiction over the locality of the facility.

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A public notice must contain the information shown in Exhibit 11-8.

Exhibit 11-8 Contents of the public notice

- Name and address of the office processing the permit action
- Name and address of the permittee or applicant and, if different, of the facility or activity regulated by the permit
- A brief description of the business conducted at the facility or activity described in the permit
- Name, address, and telephone number of a contact from whom interested persons can obtain additional information
- A brief description of the comment procedures required, the time and place of any hearing to be held including procedures to request a hearing
- For EPA-issued permits, the location and availability of the administrative record and the times at which the record will be open for public inspection and a statement that all data submitted by the applicant is available as part of the administrative record
- A description of the location of each existing or proposed discharge point and the name of the receiving water and the sludge use and disposal practice(s) and the location of each sludge treatment works treating domestic sewage and use or disposal sites known at the time of permit application
- Requirements applicable to a thermal variance under CWA section 316(a)
- Requirements applicable to cooling water intake structures under CWA section 316(b)
- Any additional information considered necessary

The regulatory agency preparing the permit must provide public notice of the draft permit (including a notice of intent to deny a permit application), and it must provide at least 30 days for public comment. The draft permit is usually submitted for public notice after it has undergone internal review by the regulatory agency that is issuing the permit. State-issued permits typically undergo public notice after EPA has reviewed and commented on the draft permit. In the special case of those EPA-issued permits that require an EIS, public notice is not given until after a draft EIS is issued.

11.3.2 Public Comments

Public notice of a draft permit might elicit comments from concerned individuals or agencies. Frequently, such comments are simply requests for additional information. However, some comments are of a substantive nature and suggest modifications to the draft permit or indicate that the draft permit is inappropriate for various reasons. In such cases, commenters must submit all reasonable arguments and factual material in support of their positions and comments by the close of the public comment period, and the permitting authority must consider those comments in making final decisions. If the approach is technically correct and clearly stated in the fact sheet, it will be difficult for commenters to find fault with the permit. Commenters can always suggest alternatives, however. In addition, an interested party may also request a public hearing.

To the extent possible, it is desirable to respond to all public comments as quickly as possible. In some cases, it might be possible to diffuse a potentially controversial situation by providing further explanation of permit terms and conditions. Additionally, permit writers should also consider notifying commenters that their comments have been received and are being considered.

The permitting agency must respond to all significant comments, in accordance with § 124.17, at the time a final permit decision is reached (in the case of EPA-issued permits) or at the same time a final permit is

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actually issued (in the case of state-issued permits). The response should incorporate the following elements:

- Changes in any of the provisions of the draft permit and the reasons for the changes.
- Description and response to all significant comments on the draft permit or the permit application raised during the public comment period or during any hearing.

If any information is submitted during the public comment period raises substantial new questions about the draft permit, one of the following actions can occur:

- A new draft permit with a revised fact sheet or statement of basis is prepared.
- A revised statement of basis, a fact sheet, or revised fact sheet is prepared, and the comment period is reopened.
- The comment period is reopened but is limited to new findings only.

If any of those actions is taken, a new public notice, as described earlier, must be given.

For EPA-issued permits, any documents cited in the response to comments must be included in the administrative record. If new points are raised or new material is supplied during the public comment period, EPA may document its response to these new materials by adding new materials to the administrative record.

11.3.3 Public Hearings

Any interested party may request a public hearing. The request should be in writing and should state the nature of the issues proposed to be raised during the hearing. However, a request for a hearing does not automatically necessitate that a hearing be held. A public hearing should be held when there is a significant amount of interest expressed during the public comment period or when it is necessary to clarify the issues involved in the permit decision.

Thus, the decision of whether to hold a public hearing is actually a judgment call. Such decisions are usually made by someone other than the permit writer. However, the permit writer will be responsible for ensuring that all the factual information in support of the draft permit is well documented.

Public notice of a public hearing must be given at least 30 days before the public meeting. Public notice of the hearing may be given at the same time as public notice of the draft permit, and the two notices may be combined. The public notice of the hearing should contain the following information:

- Brief description of the nature and purpose of the hearing, including the applicable rules and procedures.
- Reference to the dates of any other public notices relating to the permit.
- Date, time, and place of the hearing.

Scheduling a hearing automatically extends the comment period until at least the close of the hearing [§ 124.12(c)] and the public comment period may be extended by request during the hearing. Anyone may submit written or oral comments concerning the draft permit at the hearing. A presiding officer is responsible for scheduling the hearing and maintaining orderly conduct, including setting reasonable time

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limitations for oral statements. Note that a transcript or recording of the hearing must be available to interested persons.

11.3.4 Reserved

11.3.5 EPA and State/Tribal Roles in Reviewing Draft Permits

The CWA and the NPDES regulations include review roles for EPA and for states, tribes, and territories (states) depending on whether EPA or a state is issuing an NPDES permit.

11.3.5.1 State-issued Permits

Each authorized state administering an NPDES program must transmit to the EPA Region copies of permit applications received and copies of draft or proposed permits [§ 123.43(a)]. The state and the EPA Region execute a Memorandum of Agreement (MOA) under § 123.24 that addresses administration and enforcement of the state's regulatory program. The MOA may specify that EPA will review draft permits rather than proposed permits [§ 123.44(j)] and specify the classes or categories of permit applications and draft or proposed permits that the state will send to the EPA Region for review, comment, and, where applicable, objection. In addition, the MOA specifies classes or categories of permits for which EPA will waive its right to review the draft or proposed permit. EPA cannot waive its right to review classes or categories of permits for the following:

- Discharges into the territorial seas.
- Discharges that could affect waters of a state other than the one in which the discharge originates.
- Discharges proposed to be regulated by general permits.
- Discharges from a POTW with a daily average discharge exceeding 1 million gallons per day.
- Discharges of uncontaminated cooling water with a daily average discharge exceeding 500 million gallons per day.
- Discharges from any major discharger or from any NPDES primary industry category.
- Discharges from other sources with a daily average discharge exceeding 500,000 gallons per day (however, EPA may waive review for non-process wastewater).

The MOA provides a period up to 90 days from receipt of a permit during which the EPA Region can make general comments on, objections to, or recommendations with respect to the permit. If the EPA

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Region objects to a permit, within 90 days of receiving the permit it must transmit to the state a statement of the reasons for the objection and the actions that the state must take to eliminate the objection [§ 123.44(a)-(b)]. Specific causes for objection are outlined in the regulations at § 123.44(c). Any interested party can request a public hearing on an objection by the EPA Region. After such a hearing, the Region can affirm the objection, modify the terms of the objection, or withdraw the objection and notify the state of that decision. If the EPA Region does not withdraw the objection, the state then has 30 days to resubmit a permit revised to meet the objection. If the state does not do so, exclusive authority to issue the permit passes to the EPA Region. If no public hearing on the objection is held, the time frame for the state to resubmit a revised permit is 90 days from receipt of the objection.

11.3.5.2 EPA-issued Permits

Permits issued by EPA require an opportunity for state review and certification under CWA section 401. The state in which a discharge originates or will originate is provided the opportunity to review an application or a draft permit and certify that the discharge will comply with the applicable water quality standards. This process also has the benefits of ensuring that state initiatives or policies are addressed in EPA-issued NPDES permits and promoting consistency between state-issued and EPA-issued permits where not all permits within the state are issued by the same agency.

Regulations at §§ 124.53 (State Certification) and 124.54 (Special provisions for state certification and concurrence on applications for CWA section 301(h) variances) describe procedures an EPA permit writer should follow to obtain state certification. Under CWA section 401(a)(1), EPA may not issue a permit until a certification is granted or waived. If EPA is preparing the draft permit, state certification can be accomplished by allowing states to review and certify the application before draft permit preparation. Under § 124.53, if EPA has not received a state certification by the time the draft permit is prepared, EPA must send the state a copy of the draft permit along with a notice requesting state certification.

If the state does not respond within a specified reasonable time, which cannot exceed 60 days, it is deemed to have waived its right to certify. If the state chooses to certify the draft permit, it may include any conditions more stringent than those in the draft permit necessary to ensure compliance with the applicable provisions of the CWA or state law, and must cite the CWA or state law references that support the changes. In addition, the state is required to include a statement of the extent to which each condition of the draft permit can be made less stringent without violating the requirements of state law, including water quality standards. Failure to provide this statement for any condition waives the right to certify or object to any less stringent condition that might be established during the EPA permit issuance process. When a permit applicant requests a CWA section 301(h) variance (§ 124.54), the state certification process is very similar to the process described above. For more on CWA section 301(h) variances, see section 5.1.3.5 of this manual.

11.3.6 Schedule for Final Permit Issuance

The final permit may be issued after the close of the public notice period and after state certification has been received (for permits issued by EPA). The public notice period consists of the following:

- A 30-day period that gives notice of intent to issue or deny the permit.
- A 30-day period advertising a public hearing (if applicable).
- Any extensions or reopening of the comment period.

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Final EPA permit decisions are effective immediately upon issuance unless comment were received on the draft permit, in which case, the effective date of the permit is 30 days after issuance (or a later date if specified in the permit). In addition, permit decisions will not be immediately effective if review is requested on the permit under § 124.19. As discussed earlier, any comments that are received must be answered at the time of final permit issuance (in the case of NPDES states or tribes) or after a final decision is reached (in the case of EPA). The administrative record for the final permit consists of the items in Exhibit 11-9.

Exhibit 11-9 Elements of the administrative records for a final permit

- All elements for the draft permit administrative record (see Exhibit 11-5)
- All comments received during the comment period
- The tape or transcript of any public hearing
- Any materials submitted at a hearing
- Responses to comments
- For NPDES new source permits, the draft or final EIS
- The final permit

11.4 Administrative Actions after Final Permit Issuance

Once the final permit has been issued, the issuing authority should enter the permit limitations and any special conditions into the Integrated Compliance Information System for the NPDES program (ICIS-NPDES) (for more on ICIS-NPDES, see the introduction to this manual and section 11.5.1.1 below). Entering permit information into ICIS-NPDES will ensure that the facility's performance will be tracked and the permitting agency will be alerted to the need for corrective action if violations of permit limitations, terms, or conditions occur.

After final permit issuance, interested parties have opportunities to change the permit through permit appeals, major/minor permit modifications, termination and revocation, or transfer. Those administrative procedures are described below.

11.4.1 Permit Appeals

Throughout the process of developing a permit and during the public notice period, the permit writer should carefully consider all legitimate concerns of the applicant/permittee and any other interested party. Nevertheless, there will inevitably be situations in which a permit is issued in spite of the objections of the permittee or a third party. In such instances, the permittee or interested party can choose to legally contest or appeal the NPDES permit, as provided in § 124.19. Permit appeals are the process by which any person that filed comments on the draft permit may contest the final limitations and conditions in a permit.

Appeals of EPA-issued permits consist of petitioning the Environmental Appeals Board (EAB) for review. Such review must be requested within 30 days of issuance of the final permit, and challenges must be limited to issues raised during the draft permit's public comment or hearing processes, although persons not participating in these processes may seek review of changes in the permit from draft to final permit. During the appeals process, only those conditions of an existing permit that are being contested

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are stayed. Within a reasonable time following the filing of the petition for review, the EAB must grant or deny the petition. Only individual permits may be appealed to the EAB; general permits may be challenged in court or an individual permit may be sought and appealed.

Many states have similar administrative appeal procedures designed to resolve challenges to the conditions of a permit. For the sake of convenience, such procedures, which could be known by different names (e.g., evidentiary hearing, administrative appeal), are hereafter *permit appeals*. Permit writers will, from time to time, be involved in permit appeals and will need to address the types of issues discussed below.

Aside from preparing the administrative record and notices, the permit writer might not be involved in the procedural matters relating to permit appeals. All requests for permit appeals are coordinated through the office of the EPA Regional Counsel or the appropriate state legal counsel. The permit writer's first involvement with the appeals process will likely come as a result of designation of the appeals staff, and his or her role will be limited to that of a technical advisor to legal counsel and, where a state uses an evidentiary hearing procedure, possibly a witness.

11.4.1.1 Deposition and Testimony

In a state hearing procedure, a permit writer might be required to give a deposition during which the appellant attorney conducts the questioning that would otherwise occur in the hearing. The deposition is transcribed and presented as evidence. The appellant attorney may ask some of the same questions at the hearing.

To prepare for a deposition and testimony, the permit writer should first consult with his or her general counsel to become familiar with laws, regulations, and policies that could affect the permit. The permit writer should also be thoroughly familiar with the technical basis for the permit conditions. For example, if final effluent limitations are based on water quality standards, the permit writer should thoroughly study the applicable water quality standards, water quality models, and procedures used to develop the effluent limitations and be prepared to defend all assumptions and decisions made in the effluent limitation calculations. For case-by-case limitations based on BPJ, the permit writer should carefully review all applicable data and procedures used to calculate the effluent limitations and should be sure that the information on which case-by-case limitations are based is unimpeachable, the limitations were derived from the data in a logical manner in accordance with established procedures, and the limitations are technically sound and meet applicable standards for economic reasonableness.

A permit appeal before the EAB relies on the information presented in the petitions and briefs, and possibly includes oral argument, but typically does not use depositions and direct testimony.

11.4.1.2 The Permit Writer's Role in the Appeals Process

As technical advisor to legal counsel, the permit writer's most important function is to develop support for contested permit conditions. A permit writer should not attempt to support technically indefensible conditions. Contested permit conditions that are not technically defensible and are not based on any legal requirement should be brought to counsel's attention, with advice that EPA or the state withdraw those conditions.

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The second most important advisory function of the permit writer is assisting counsel in identifying weaknesses in the appellant's arguments. That process could include developing questions for cross-examination of opposing witnesses in a state permit appeal that involves a hearing. Questions should be restricted to the subject material covered by the witness' direct testimony and should be designed to elicit an affirmative or negative response, rather than an essay-type response.

Finally, the permit writer should remember that when a person petitions for EAB review or requests a hearing for a state-issued permit, the permit writer should refrain from any discussion about the case without first consulting with legal counsel.

In the role of technical advisor or witness, the permit writer should do the following:

- Cultivate credibility.
- Never imply or admit weakness in his or her area of expertise.
- Never attempt to testify about subjects outside his or her area of expertise.
- Always maintain good communication with counsel.

The EAB generally will attempt to resolve permit appeals in the initial stage of granting review. If that is not possible, the EAB conducts formal review of the contested conditions and publishes a written opinion (an Environmental Administrative Decision). The result of an EAB or state permit appeal might be relief from certain permit conditions, validation or strengthening of contested permit conditions, or a combination of these two outcomes. Under certain circumstances, decisions of the EAB can be appealed in federal court. Authorized state's permit appeal procedures typically provide for further appeal of administrative decisions regarding contested permit conditions in state court when all administrative steps have been fulfilled.

11.4.2 Modification or Revocation and Reissuance of Permits

In most cases, a permit will not need to be modified (or revoked and reissued) during the term of the permit if the facility can fully comply with permit conditions. However, under certain circumstances, it might be necessary to modify the permit before its expiration date. A permit modification could be triggered in several ways. For example, a representative of the regulatory agency might inspect the facility and identify a need for the modification (i.e., the improper classification of an industry), or information submitted by the permittee might suggest the need for a change. Of course, any interested person may make a request for a permit modification.

Modifications differ from revocations and reissuance. In a permit modification, only the conditions subject to change are reconsidered while all other permit conditions remain in effect. Conversely, the entire permit could be reconsidered when it is revoked and reissued.

Except where the permittee requests or agrees, permit modifications are limited to specific *causes* identified in §§ 122.62(a) and 122.62(b) and summarized in Exhibit 11-10. Most NPDES permit modifications require EPA or the state to conduct the public notice and participation activities of Part 124, similar to the issuance or reissuance of the permit; however, only those specific conditions being modified are open to review and comment. The permitting authority may revoke and reissue a permit during its term for the causes identified in § 122.62(b) (i.e., the final two bulleted items in Exhibit 11-10).

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Exhibit 11-10 Causes for permit modification

- **Alterations**: When there are material and substantial alterations or changes to the permitted facility or activity occur that justify new conditions that are different from the existing permit.
- **New information**: When information is received that was not available at the time of permit issuance.
- **New regulations**: Under limited circumstances, when standards or regulations on which the permit was based have been changed by the modification, withdrawal or promulgation of amended standards or regulations or by judicial decision.
- **Compliance schedules**: To modify the compliance schedule when good cause exists, such as an act of God, strike, or flood.
- **Variance requests**: When requests for variances or fundamentally different factors are filed within the specified time but not granted until after permit issuance.
- **Toxics**: To insert CWA section 307(a) toxic effluent standard or prohibition.
- **Reopener**: Conditions in the permit that require it to be reopened under certain circumstances.
- **Net limits**: Upon request of a permittee who qualifies for effluent limitations on a net basis under § 122.45(g) or when a permittee is no longer eligible for net limitations, as provided in § 122.45(g)(1)(ii).
- **Pretreatment**: As necessary under § 403.8 (e) to put a compliance schedule in place for the development of a pretreatment program or to change the schedule for program development.
- **Failure to notify**: Upon failure of an approved state to notify another state whose waters may be affected by a discharge from the approved state.
- **Non-limited pollutants**: When the level of any pollutant that is not limited in the permit exceeds the level that can be achieved by the technology-based treatment requirements appropriate to the permit.
- **Notification levels**: To establish notification levels for toxic pollutants as provided in §122.44(f).
- **Compliance schedules for innovative or alternative facilities**: To modify the compliance schedule in light of the additional time that might be required to construct such a facility.
- **Small municipal separate storm sewer system (MS4) minimum control measures**: For a small MS4 to include required minimum control measures when the permit does not include such measure(s) based on the determination that another entity was responsible for implementation and the other entity fails to fulfill its responsibility to implement such measure(s).
- **Technical mistakes**: To correct technical mistakes or mistaken interpretations of law made in developing the permit conditions.
- **Failed BPJ compliance**: When BPJ technology is installed and properly operated and maintained but the permittee is unable to meet its limitations, the limitations may be reduced to reflect actual removal; however, they may not be less than the limitations in the effluent guidelines. If BPJ operation and maintenance costs are extremely disproportionate to the costs considered in a subsequent effluent guideline, the permittee may be allowed to backslide to the limitations in the effluent guideline.
- **Land application plans**: When required by a permit condition to incorporate a land application plan for beneficial reuse of sewage sludge, to revise an existing land application plan, or to add a land application plan.
- **Cause exists for termination**: Cause exists under § 122.64, and the Director determines that modification is appropriate.
- **Notification of proposed transfer**: Director may modify the permit upon receipt of ownership transfer notification.

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There are certain minor modifications that, upon consent of the permittee, may be processed by the permitting authority without following the procedures for public notice in Part 124. Minor modifications are generally non-substantive changes (e.g., typographical errors) and are exempt from the administrative procedures; that is, a draft permit and public review are not required. The specific permit changes that can be processed as minor modifications, described in § 122.63, are to

- Correct typographical errors.
- Incorporate more frequent monitoring or reporting.
- Revise an interim compliance date in the schedule of compliance, provided the new date is not more than 120 days after the date specified in the permit and does not interfere with attainment of the final compliance date requirement.
- Allow for a change of ownership, provided no other change is necessary (see section 11.4.4 below).
- Change the construction schedule for a new source discharger.
- Delete a point source outfall when that outfall is terminated and does not result in discharge of pollutants from other outfalls except in accordance with permit limits.
- Incorporate an approved local pretreatment program.

11.4.3 Permit Termination

Situations could arise during the life of the permit that are causes for termination of the permit. Such circumstances, described in § 122.64(a), include the following:

- Noncompliance by the permittee with any condition of the permit.
- Misrepresentation or omission of relevant facts by the permittee.
- Determination that the permitted activity endangers human health or the environment, and can be regulated to acceptable levels only by permit modification or termination.
- A change in any condition that requires either a temporary or permanent reduction or elimination of a discharge (e.g., plant closure).

Terminations are used to retract a permittee's privileges to discharge during the permit term. A notice of intent to terminate a permit is a type of draft permit that follows the same procedures as any draft permit prepared under § 124.6. Administrative procedures, such as public notice, must be followed in permit termination proceedings. If a facility with a terminated permit wishes to obtain permit coverage, it would have to submit an application and apply for a new permit.

The regulations at § 122.64(b) do provide one exception to the more formal permit termination process described above. Where the entire discharge is permanently terminated by elimination of the flow or by connection to a POTW (but not by land application or disposal into a well) the permit can be terminated by notice to the permittee, and the Part 124 administrative process is not required. However, if the permittee objects to such an expedited termination, the Permitting Authority must then proceed in accordance with the administrative procedures described above.

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11.4.4 Permit Transfer

Regulatory agencies occasionally receive notification of a change in ownership of a facility covered by an NPDES permit. Such changes require that a permit be transferred by one of two provisions:

- **Transfer by modification or revocation**: The transfer may be made during the process of a major or minor permit modification. It may also be addressed by revoking and subsequently reissuing the permit.
- **Automatic transfer**: A permit may automatically be transferred to a new permittee if three conditions are met:
  - The current permittee notifies the Director 30 days in advance of the transfer date.
  - The notice includes a written agreement between the old and new owner that contains the specific date for transfer of permit responsibility, coverage, and liability between them.
  - The Director of the regulatory agency does not notify the old permittee and the proposed new permittee that the subject permit will be modified or revoked and reissued.

11.5 Permit Compliance and Enforcement

EPA's OECA is responsible for nationally managing EPA's compliance and enforcement programs for all media including the CWA and NPDES. EPA uses a mix of tools including compliance assistance, incentives, and monitoring and enforcement. EPA and state environmental agencies authorized to administer the NPDES program seek to achieve and maintain a high level of compliance with environmental laws and regulations. Enforcement provides a powerful incentive for NPDES permittees to comply, and the way in which an NPDES permit is written directly affects its enforceability. Each permit must be written clearly and unambiguously so that compliance can be tracked effectively and the permit can be enforced if violations occur.

The permit writer could become actively involved with the compliance monitoring and enforcement of the terms and conditions of the NPDES permits that he or she has written. The extent of the permit writer's involvement will usually depend on the organizational structure of the regulatory agency. Larger, centrally organized agencies typically have separate personnel responsible for enforcing the terms of NPDES permits. In other organizations, the individual who writes the permit will also be responsible for such enforcement activities as discharge monitoring report (DMR) tracking, facility inspections, and enforcement recommendations. If a civil judicial enforcement action occurs, the permit writer might be called on to testify regarding the specific requirements of the permit or its basis.

Regardless of a regulatory agency's organizational structure, the permit writer should have an appreciation for the various aspects of a meaningful NPDES compliance enforcement program. The following sections address compliance monitoring reviews and inspections and data in the national ICIS-NPDES (formerly the Permit Compliance System or PCS) database, which provides the basis for evaluating compliance. This section concludes with a brief description of the enforcement actions available to facilitate permit compliance. For more information about CWA enforcement, see OECA's Clean Water Act Enforcement Website <www.epa.gov/compliance/civil/cwa/index.html>.

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11.5.1 Compliance Monitoring

Compliance monitoring is a broad term that includes all activities that federal or state regulatory agencies take to ascertain a permittee's compliance with the conditions specified in an NPDES permit. Compliance monitoring data collected as part of the NPDES program are used to evaluate compliance and support enforcement actions. The process includes receiving, reviewing, and entering data into the ICIS-NPDES database, conducting on-site inspections, identifying violators, and determining an appropriate response.

A primary function of the compliance monitoring program is to verify compliance with permit conditions, including effluent limitations and compliance schedules. Compliance verification is achieved through

- **Compliance review**: A review of all written reports and other material relating to the status of a permittee's compliance.
- **Compliance inspections**: Field-related regulatory activities (i.e., facility inspections, effluent sampling) to determine compliance.

11.5.1.1 Compliance Review

Compliance and enforcement personnel use two primary sources of information to carry out compliance reviews:

- Permit/compliance files.
- The ICIS-NPDES database.

Permit/compliance files include the permit, application, fact sheet, compliance schedule reports, compliance inspection reports, DMRs, enforcement actions, and correspondence (e.g., summaries of telephone calls, copies of warning letters). Compliance personnel periodically review that information and use it to determine if enforcement is necessary and, if so, what level of enforcement is appropriate.

The ICIS-NPDES database <https://icis.epa.gov/icis> is the national database for tracking compliance with NPDES requirements and is discussed further in this manual's introduction. Information in ICIS-NPDES includes facility and discharge characteristics, self-monitoring data, compliance schedules, permit conditions, inspections, and enforcement actions. Permittees are required to submit effluent monitoring data, and compliance and status information, via Compliance Schedule Reports and DMRs. EPA Regions and NPDES states enter such information into ICIS-NPDES and evaluate permittees on compliance with NPDES permit requirements. Inspection and enforcement information is collected and entered by Regions or authorized states or both. Quarterly, EPA reviews the ICIS-NPDES system data and generates a *quarterly noncompliance report* (QNCR) for all major facilities following the requirements of § 123.45.

ICIS-NPDES supports compliance and enforcement actions and assists EPA staff in evaluation and oversight of the NPDES program. The database also promotes national consistency and uniformity in permit and compliance evaluations. NPDES permits must be written so that compliance can be tracked using ICIS-NPDES. Situations might arise in which permit limitations and monitoring conditions are not initially compatible with ICIS-NPDES entry and tracking. In such cases, the permit writer should alert the state or EPA Regional staff responsible for entering ICIS-NPDES codes and work with them to resolve any coding issues. To assist ICIS-NPDES coders in accurately interpreting and entering the permit into ICIS-NPDES and to assist enforcement personnel in reviewing permittee's self-monitoring data and

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reports in a timely manner, permit writers should follow the compliance inspection procedures discussed in the next section.

11.5.1.2 Compliance Inspections

Compliance inspections refer to all field-related regulatory activities conducted to determine permit compliance. Such field activities can include compliance evaluation inspections (non-sampling), sampling inspections, other specialized inspections, and remote sensing. Certain inspections, such as diagnostic inspections and performance audit inspections, aid the regulatory agency in evaluating the facility's problems in addition to providing information to support enforcement action. Biomonitoring inspections are specifically targeted at facilities with effluent suspected or identified as causing toxicity problems that threaten the ecological balance of the receiving waters.

Compliance inspections are undertaken to fulfill one or more of the following purposes:

- Establish a regulatory presence to deter noncompliance.
- Ensure that permit requirements are being met or determine if permit conditions are adequate.
- Check the completeness and accuracy of a permittee's performance and compliance records.
- Assess the adequacy of the permittee's self-monitoring and reporting program including on-site laboratory functions.
- Determine the progress or completion of corrective action.
- Obtain independent compliance data on a facility's discharge.
- Evaluate the permittee's operation and maintenance activities.
- Observe the status of construction required by the permit.

11.5.2 Quarterly Noncompliance Reports

EPA Regional offices and NPDES states are required by the regulations at § 123.45 to report quarterly on major facilities that are not in compliance with the terms and conditions of their permit or enforcement order (i.e., that meet the criteria for *reportable noncompliance* [RNC] for effluent limitation, schedules, and reporting violations).

The regulations in § 123.45 establish requirements for listing facility violations and resulting regulatory enforcement action on QNCRs. The regulation establishes reporting requirements for violations that meet specific, quantifiable reporting criteria, as well as for violations that are more difficult to quantify but are of sufficient concern to be considered reportable. The regulation also specifies the format that the reports must follow and the schedule for their submission.

Only major facilities that meet RNC criteria must be reported on the QNCR. RNC consists of several general types of violations as established in § 123.45:

- Effluent limitations
  - Monthly average effluent limitations (see below for more).
  - Other effluent limitations with water quality or health impacts.

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- Schedule: Violations of compliance schedule milestones by 90 days or more.
- Reporting: Reports late by 30 days or more.

A violation of any monthly average limitation should be evaluated for magnitude by comparing the measured amount in the DMR to the product of the monthly average limitation times the Technical Review Criteria (TRC) for that pollutant or parameter. The TRC is 1.4 for Group I (conventional) pollutants and 1.2 for Group II (generally toxic) pollutants. Appendix A to Part 123 contains a list of pollutants in each Group. RNC includes violations of a given Group I or Group II pollutant or parameter that equals or exceeds the product of the TRC times the monthly average limitation for any 2 or more months during a 6-month reporting period. RNC also includes violations of a Group I or Group II parameter by any amount (not necessarily TRC times the limitation or greater) for 4 months during the 6-month reporting period.

A subset of instances of RNC that appear on the QNCR could be noted as *significant noncompliance* (SNC). This distinction is used solely for management accountability purposes as a means of tracking trends in compliance and evaluating the relative timeliness of enforcement response toward priority violations.

The definition of SNC is not regulatory and can change as the NPDES program evolves to encompass new enforcement priorities. For example, in September 1995, EPA revised the definition of SNC to include violations of non-monthly average permit limitations by major facilities. Many permits for NPDES major facilities lacked required monthly average limitations and, thus, were not evaluated for SNC violations and follow-up formal enforcement action. The new definition became effective as of October 1, 1996. EPA's SNC policy is described in the memorandum Revision of NPDES Significant Noncompliance (SNC) Criteria to Address Violations of Non-Monthly Average Limits[1] <www.epa.gov/compliance/resources/policies/civil/cwa/revisedsncmemo.pdf>.

Generally, the designation of SNC indicates a violation is of sufficient magnitude or duration or both to be considered among EPA's priorities for regulatory review or response. The categories of SNC are

- Effluent limitations: The effluent limitation SNC criteria are the same as for QNCR discussed above.
- Schedule: The schedule SNC criteria are the same as for QNCR discussed above.
- Reporting: The reporting SNC criteria are the same as for QNCR discussed above.
- Order requirements: Violation of requirements in administrative or judicial orders.

The instance of SNC is considered resolved when the SNC criteria are no longer met during the review period, or when the permittee formerly in SNC exhibits compliance for all 3 months of the most recent 3-month reporting period. A permittee with SNC violations under a compliance schedule that is meeting its deadlines for corrective actions is in *resolved pending* status.

Any major permittee that is listed on the QNCR for two consecutive 3-month reporting periods for the same instance of SNC (e.g., same outfall point, same parameter, same category of violation) is expected to return to compliance or to be addressed with an appropriate enforcement action before the reporting deadline for the second QNCR. If the facility is in SNC after the second QNCR, and no enforcement

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action has been taken, the facility is placed on the Watch List. The Watch List is a management tool that identifies and tracks facilities with serious violations and no apparent formal enforcement response.

11.5.3 Enforcement

EPA's NPDES compliance and enforcement principles and recommendations are described in the NPDES Enforcement Management System (EMS)[2] <www.epa.gov/compliance/resources/policies/civil/cwa/emscwa-jensen-rpt.pdf>. By choosing an appropriate enforcement response to CWA violations, EPA tries to achieve several goals:

- Correction of the violation as soon as possible.
- Deterrence of future violations by the same permittee or other permittees.
- Equal treatment of the regulated community through use of a uniform approach to selecting enforcement responses (i.e., similar violations are treated similarly).
- Assessment of an appropriate penalty.
- Protection of human health and the environment.

Once a facility has been identified as having potential CWA violations, EPA or the NPDES state reviews the facility's compliance history. The review includes an assessment of the magnitude, frequency, and duration of violations. The permitting authority identifies significant violations and makes a determination of the appropriate enforcement response. CWA section 309 authorizes the Agency to bring civil or criminal action against facilities that discharge pollutants without a permit or discharge in violation of NPDES permit conditions and judicial penalties up to $32,500 per day per violation.

EPA Regions and authorized states have specific procedures for reviewing self-monitoring and inspection data and for deciding what type of enforcement action is warranted. EPA recommends an escalating response to continuing noncompliance. The range of enforcement responses includes the following:

- Informal action (e.g., *notice of violation* [NOV]).
- Formal action.
- Administrative compliance order.
- Administrative order with or without an administrative penalty order (up to $157,500).
- Civil judicial action that imposes injunctive relief seeking compliance or penalty or both.
- Criminal prosecution.

Considerations when making determinations on the level of the enforcement response include the following:

- The duration of the violation.
- The severity of the violation.
- The degree of economic benefit obtained through the violation.
- Compliance history and previous enforcement actions taken against the violator.
- The degree of culpability.
- The deterrent effect of the response on similarly situated permittees.

Equally important considerations may include fairness and equity, national consistency, and the integrity of the NPDES program.

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Citizens can participate in the enforcement process in a number of ways. Under the Freedom of Information Act, citizens have the right to request certain facility-specific compliance information from EPA's ICIS-NPDES database. In addition, under NPDES regulations, interested citizens can intervene in any federal civil judicial action to enjoin any threatened or continuing violation of program requirements or permit conditions, and to recover civil penalties in court. Citizens also have the opportunity to review and comment on any proposed consent decree to resolve a state or federal civil judicial enforcement action.

CWA section 505 allows any citizen to begin a civil judicial enforcement action on his or her own behalf. In certain circumstances, citizens may not begin suit if EPA or the state is diligently prosecuting a civil or criminal judicial action or an administrative action to obtain a penalty under CWA section 309(g) or a comparable provision of state law. Citizens must also give EPA, the state, and the alleged violator 60 days' notice of the alleged violation before beginning a citizen suit.

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[1] Herman, S.A. 1995. *Revision of NPDES Significant Noncompliance (SNC) Criteria to Address Violations of Non-Monthly Average Limits.* U.S. Environmental Protection Agency, Office of Enforcement and Compliance Assurance. Memorandum, September 21, 1995. <www.epa.gov/compliance/resources/policies/civil/cwa/revisedsncmemo.pdf>.

[2] U.S. Environmental Protection Agency. 1989. *The Enforcement Management System: National Pollutant Discharge Elimination System (Clean Water Act)*. EC-G-1998-11b. U.S. Environmental Protection Agency, Office of Water, Washington, DC. <www.epa.gov/compliance/resources/policies/civil/cwa/emscwa-jensen-rpt.pdf>.

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Appendix A. Acronyms, Abbreviations and Glossary

This appendix contains two tables for permit writers to more easily navigate through the acronyms and the terms that are mentioned throughout this manual. The first table, *Acronyms and Abbreviations*, provides the full text of the acronyms and abbreviations used throughout and indicates whether they are defined in the *Glossary* (the second table), which provides definitions of terms used in the Clean Water Act and NPDES permit program. It provides a reference to the source of the definitions, where available.

A.1 Acronyms and Abbreviations

Exhibit A-1 presents the abbreviations used in the *NPDES Permit Writers' Manual*.

Exhibit A-1 Acronyms and abbreviations

Acronym or abbreviation	Full phrase	Glossary
1Q10	1-day, 10-year Low Flow	
7Q10	7-day, 10-year Low Flow	
4AAP	4-Aminoantipyrine (used for detecting phenolic compounds colorimetrically)	
ACHP	Advisory Council on Historic Preservation	
ACR	Acute-to-Chronic Ratio	
AFO	Animal Feeding Operation	x
AML	Average Monthly Limitation	x
ASR	Alternative State Requirement	
AWL	Average Weekly Limitation	x
BA	Biological Assessment	
BAT	Best Available Technology Economically Achievable	x
BCT	Best Conventional Pollutant Control Technology	x
BE	Biological Evaluation	
BMP	Best Management Practice	x
BOD	Biochemical Oxygen Demand	x
BOD_5	5-day Biochemical Oxygen Demand	
BPJ	Best Professional Judgment	x
BPT	Best Practicable Control Technology Currently Available	x
CAAP	Concentrated Aquatic Animal Production	
CAFO	Concentrated Animal Feeding Operation	x
CBOD	Carbonaceous Biochemical Oxygen Demand	x
$CBOD_5$	5-day Carbonaceous Biochemical Oxygen Demand	
CEQ	Council on Environmental Quality	
CERCLA	Comprehensive Environmental Response, Compensation and Liabilities Act	
CFR	*Code of Federal Regulations*	x
cfs	Cubic Feet per Second	
CGP	Construction General Permit	
CMOM	Capacity, Management, Operation and Maintenance	

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Exhibit A-1 Acronyms and abbreviations (continued)

Acronym or abbreviation	Full phrase	Glossary
COD	Chemical Oxygen Demand	x
CSO	Combined Sewer Overflow	x
CSS	Combined Sewer System	x
CV	Coefficient of Variation	
CWA	Clean Water Act	x
CWIS	Cooling Water Intake Structure	
CZMA	Coastal Zone Management Act	
DMR	Discharge Monitoring Report	x
DWO	Dry Weather Overflow	
EA	Environmental Assessment	
EAB	Environmental Appeals Board	
EC	Effect Concentration	
EFH	Essential Fish Habitat	
EIS	Environmental Impact Statement	
ELG	Effluent Limitations Guidelines or Effluent Guidelines	x
EMS	Enforcement Management System	
eNOI	Electronic Notice of Intent	
EPA	U.S. Environmental Protection Agency	
ESA	Endangered Species Act	
FDF	Fundamentally Different Factors	x
FR	*Federal Register*	
FWCA	Fish and Wildlife Coordination Act	
FWPCA	Federal Water Pollution Control Act	
FWS	U.S. Fish and Wildlife Service	
GC/MS	Gas Chromatography/Mass Spectroscopy	
gpd	Gallons per Day	
HEM	Hexane Extractable Material	
IC	Inhibition Concentration	
ICIS	Integrated Compliance Information System	
I/I	Infiltration/Inflow	
LA	Load Allocation	
lbs/day	Pounds per Day	
LC_{50}	Lethal Concentration to 50% of test organisms	
LOEC	Lowest Observed Effect Concentration	
LTA	Long-Term Average	
LTCP	Long-Term Control Plan	
MDL	Method Detection Limit	x
MDL	Maximum Daily Effluent Limitation	x
MEP	Maximum Extent Practicable	
µg/L	Micrograms per Liter	
mg/L	Milligrams per Liter	
mgd	Million Gallons per Day	x
ML	Minimum Level	x

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Exhibit A-1 Acronyms and abbreviations (continued)

Acronym or abbreviation	Full phrase	Glossary
MOA	Memorandum of Agreement	
MS4	Municipal Separate Storm Sewer System	x
MSA	Magnuson-Stevens Act	
MSGP	Multi-Sector General Permit	
N/A	Not Applicable	
NAICS	North American Industrial Classification System	x
NEMI	National Environmental Methods Index	
NEPA	National Environmental Policy Act	
NHPA	National Historic Preservation Act	
NMC	Nine Minimum CSO Controls	
NMFS	National Marine Fisheries Service	
NMP	Nutrient Management Plan	
NOAA	National Oceanic and Atmospheric Administration	
NOEC	No Observable Effect Concentration	
NOI	Notice of Intent	
NOV	Notice of Violation	
NPDES	National Pollutant Discharge Elimination System	x
NRDC	Natural Resources Defense Council	
NSCEP	National Service Center for Environmental Publications	
NSPS	New Source Performance Standards	
NTIS	National Technical Information Service	
O&G	Oil and Grease	
OCPSF	Organic Chemicals, Plastics, and Synthetic Fibers Point Source Category	
OECA	EPA Office of Enforcement and Compliance Assurance	
ONRW	Outstanding National Resources Waters	
OTIS	Online Tracking Information System	
OW	Office of Water	
OWRC	Office of Water Resource Center	
PCS	Permit Compliance System	
POTW	Publicly Owned Treatment Works	x
PSD	Prevention of Significant Deterioration	
PSES	Pretreatment Standards for Existing Sources	
PSNS	Pretreatment Standards for New Sources	
QNCR	Quarterly Noncompliance Report	
RAPP	Refuse Act Permit Program	
RCRA	Resource Conservation and Recovery Act	
RNC	Reportable Noncompliance	
SIC	Standard Industrial Classification	x
SIU	Significant Industrial User	x
SNC	Significant Noncompliance	
SOP	Standard Operating Procedure	
SPCC	Spill Prevention Control and Countermeasure	x
SS	Suspended Solids	x

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Exhibit A-1 Acronyms and abbreviations (continued)

Acronym or abbreviation	Full phrase	Glossary
SSO	Sanitary Sewer Overflow	x
STORET	EPA Storage and Retrieval Database	x
SWPPP	Stormwater Pollution Prevention Plan	
TBEL	Technology-Based Effluent Limit(s)	x
TCDF	Tetrachlorodibenzofuran	
TEC	Transportation Equipment Cleaning Point Source Category	
THC	Total Hydrocarbons	
TIE	Toxicity Identification Evaluation	
TMDL	Total Maximum Daily Load	x
TOC	Total Organic Carbon	x
TRC	Technical Review Criteria	
TRE	Toxicity Reduction Evaluation	x
TRI	Toxic Release Inventory	
TSD	Technical Support Document [for Water Quality-based Toxics Control]	
TSS	Total Suspended Solids	x
TTO	Total Toxic Organics	
TU	Toxic Units	
TUa	Toxic Units – Acute	
TUc	Toxic Units – Chronic	
TWTDS	Treatment Works Treating Domestic Sewage	x
UAA	Use Attainability Analysis	
UIC	Underground Injection Control	
U.S.C.	*United States Code*	
WET	Whole Effluent Toxicity	x
VGP	Vessel General Permit	
WLA	Waste Load Allocation	x
WPD	EPA Water Permits Division	
WQA	Water Quality Act of 1987	
WQBEL	Water Quality-Based Effluent Limit(s)	x
WQS	Water Quality Standard(s)	x
WSRA	Wild and Scenic Rivers Act	

A.2 Glossary

Exhibit A-2 includes definitions of terms used in the *NPDES Permit Writers' Manual*. For terms that have a definition in the federal regulations, that definition is included with an appropriate citation. The citations also indicate where this guidance manual has paraphrased or modified the regulatory definitions for consistency with the format of the glossary. For terms that do not have a regulatory definition, but that are defined in another published EPA document, the citation to the relevant EPA document is provided.

Note that the definitions provided in the Glossary do not constitute EPA's official use of terms and phrases for regulatory purposes, and nothing in this document should be construed to alter or supplant any

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other federal document. Official terminology is in the laws and related regulations as published in such sources as the Congressional Record, *Federal Register*, and elsewhere.

Exhibit A-2 Glossary

Term	Definition	Citation
401(a) Certification	A requirement of CWA section 401(a) that all federally issued permits be certified by the state in which the discharge occurs. The state certifies that the proposed permit will comply with state water quality standards and other state requirements.	1996 U.S. EPA NPDES Permit Writers' Manual (1996 PWM) <www.epa.gov/npdes/pubs/owm0243.pdf>
Acute Effect	The effect of a stimulus severe enough to rapidly induce an effect; in aquatic toxicity tests, an effect generally observed in 96 hours or less is typically considered acute. When referring to aquatic toxicology or human health, an acute effect is not always measured in terms of lethality.	1996 PWM
Animal Feeding Operation (AFO)	Lot or facility (other than an aquatic animal production facility) where the following conditions are met: • Animals (other than aquatic animals) have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period. • Crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.	§ 122.23(b)(1)
Anti-backsliding	In general, a statutory provision that prohibits the renewal, reissuance, or modification of an existing NPDES permit that contains effluent limitations, permit conditions, or standards that are less stringent than those established in the previous permit. For more information on anti-backsliding, see Chapter 7 of this manual.	CWA section 402(o)
Antidegradation	A policy developed and adopted as part of a state's water quality standards that ensures protection of existing uses and maintains the existing level of water quality where that water quality exceeds levels necessary to protect fish and wildlife propagation and recreation on and in the water. This policy also includes special protection of water designated as Outstanding National Resource Waters.	Adapted from 1996 PWM
Authorized Program or Authorized State	A state, territorial, tribal, or interstate NPDES program that has been approved or authorized by EPA under Part 123.	1996 PWM
Average Monthly Discharge Limitation	The highest allowable average of daily discharges over a calendar month, calculated as the sum of all daily discharges measured during that month divided by the number of daily discharges measured during that month.	§ 122.2
Average Weekly Discharge Limitation	The highest allowable average of daily discharges over a calendar week, calculated as the sum of all daily discharges measured during a calendar week divided by the number of daily discharges measured during that week.	§ 122.2
Best Available Technology Economically Achievable (BAT)	Technology standard established by the CWA as the most appropriate means available on a national basis for controlling the direct discharge of toxic and nonconventional pollutants to navigable waters. BAT limitations in effluent guidelines, in general, represent the best existing performance of treatment technologies that are economically achievable within an industrial point source category or subcategory.	Adapted from 1996 PWM

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Exhibit A-2 Glossary (continued)

Term	Definition	Citation
Best Conventional Pollutant Control Technology (BCT)	Technology-based standard for the discharge from existing industrial point sources of conventional pollutants including BOD, TSS, fecal coliform, pH, oil and grease. The BCT is established in light of a two-part cost reasonableness test, which compares the cost for an industry to reduce its pollutant discharge with the cost to a POTW for similar levels of reduction of a pollutant loading. The second test examines the cost-effectiveness of additional industrial treatment beyond BPT. EPA must find limits which are reasonable under both tests before establishing them as BCT.	1996 PWM
Best Management Practice (BMP)	Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of *waters of the United States*. BMPs also include treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.	§ 122.2
Best Practicable Control Technology Currently Available (BPT)	The first level of technology standards established by the CWA to control pollutants discharged to waters of the U.S. BPT limitations in effluent guidelines are generally based on the average of the best existing performance by plants within an industrial category or subcategory.	Adapted from 1996 PWM
Best Professional Judgment (BPJ)	The method used by permit writers to develop technology-based NPDES permit conditions on a case-by-case basis using all reasonably available and relevant data.	1996 PWM
Bioassay	A test used to evaluate the relative potency of a chemical or a mixture of chemicals by comparing its effect on a living organism with the effect of a standard preparation on the same type of organism.	1996 PWM
Biochemical Oxygen Demand (BOD)	A measurement of the amount of oxygen used by the decomposition of organic material, over a specified time (usually 5 days) in a wastewater sample; it is used as a measurement of the readily decomposable organic content of a wastewater.	1996 PWM
Biosolids	See *Sewage Sludge*.	--
Bypass	The intentional diversion of waste streams from any portion of a treatment facility. This definition applies to both direct and indirect discharges.	§ 122.41(m)(1)(i) and § 403.17
Carbonaceous Biochemical Oxygen Demand (CBOD)	The biochemical oxygen demand of carbonaceous sources. This differs from BOD in that BOD measures both nitrogenous and carbonaceous sources, whereas CBOD excludes nitrogenous sources (e.g., nitrifying bacteria) from determination through the addition of a nitrification inhibitor.	--
Categorical Industrial User (CIU)	An industrial user subject to national categorical pretreatment standards.	1996 PWM
Categorical Pretreatment Standards	National pretreatment standards , expressed as Pretreatment Standards for Existing Sources (PSES) or Pretreatment Standards for New Sources (PSNS), specifying quantities or concentrations of pollutants or pollutant properties that may be discharged to a POTW by existing or new industrial users in specific industrial subcategories established as separate regulations under the appropriate subpart of 40 CFR chapter I, subchapter N.	Adapted from § 403.6

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Exhibit A-2 Glossary (continued)

Term	Definition	Citation
Chemical Oxygen Demand (COD)	A measure of the oxygen-consuming capacity of inorganic and organic matter present in wastewater. COD is expressed as the amount of oxygen consumed in mg/L. Results do not necessarily correlate to the biochemical oxygen demand (BOD) because the chemical oxidant can react with substances that bacteria do not stabilize.	Adapted from 1996 PWM
Chronic Effect	The effect of a stimulus that lingers or continues for a relatively long period, often one-tenth of the life span or more. The measurement of a chronic effect can be reduced growth, reduced reproduction, and such, in addition to lethality.	1996 PWM
Clean Water Act (CWA)	The Clean Water Act is a statute passed by the U.S. Congress to control water pollution. It was formerly referred to as the Federal Water Pollution Control Act of 1972 or Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500), 33 U.S.C. 1251 *et seq.*, as amended by: Public Law 96-483; Public Law 97-117; Public Laws 95-217, 97-117, 97-440, and 100-04.	1996 PWM
Code of Federal Regulations (CFR)	A codification of the final rules published daily in the *Federal Register*. Title 40 of the CFR contains regulations for the protection of the environment.	1996 PWM
Combined Sewer Overflow (CSO)	A discharge of untreated wastewater from a combined sewer system at a point before the headworks of a publicly owned treatment works. CSOs generally occur during wet weather (rainfall or snowmelt). During periods of wet weather, these systems become overloaded, bypass treatment works, and discharge directly to receiving waters at designed overflow points.	1996 PWM
Combined Sewer System (CSS)	A wastewater collection system that conveys sanitary wastewaters (domestic, commercial and industrial wastewaters) and stormwater through a single pipe to a publicly owned treatment works for treatment before discharge to surface waters.	1996 PWM
Compliance Schedule (or Schedule of Compliance)	A schedule of remedial measures included in a permit, including an enforceable sequence of interim requirements (for example, actions, operations, or milestone events) leading to compliance with the CWA and regulations.	§ 122.2
Composite Sample	Sample composed of two or more discrete aliquots (samples). The aggregate sample will reflect the average water quality of the compositing or sample period.	--
Conventional Pollutants	Pollutants typical of municipal sewage, and for which publicly owned treatment works typically are designed to remove; defined by Federal Regulation (§ 401.16) as BOD, TSS, fecal coliform bacteria, oil and grease, and pH.	1996 PWM
Daily Discharge	The *discharge of a pollutant* measured during a calendar day or any 24-hour period that reasonably represents the calendar day for purposes of sampling. For pollutants with limitations expressed in units of mass, the daily discharge is calculated as the total mass of the pollutant discharged over the day. For pollutants with limitations expressed in other units of measurement, the daily discharge is calculated as the average measurement of the pollutant over the day.	§ 122.2

Exhibit A-2 Glossary (continued)

Term	Definition	Citation
Designated Uses	Those uses specified in water quality standards for each waterbody or segment whether they are being attained (§ 131.3). Examples of designated uses include cold and warm water fisheries, public water supply, and irrigation.	Adapted from EPA. Terms of Environment: Glossary, Abbreviations, Acronyms. <www.epa.gov/OCEPAterms/dterms.html>
Development Document	A report prepared during development of an effluent guideline by EPA that provides the data and methodology used to develop effluent guidelines and categorical pretreatment standards for an industrial category.	Adapted from 1996 PWM
Director	The Regional Administrator or the State Director, as the context requires, or an authorized representative. When there is no *approved state program*, and there is an EPA-administered program, *Director* means the Regional Administrator. When there is an approved state program, Director normally means the State Director. In some circumstances, however, EPA retains the authority to take certain actions even when there is an approved state program. (For example, when EPA has issued an NPDES permit before the approval of a state program, EPA may retain jurisdiction over that permit after program approval, see § 123.1.) In such cases, Director means the Regional Administrator and not the State Director.	§ 122.2
Discharge Monitoring Report (DMR)	The EPA uniform national form, including any subsequent additions, revisions, or modifications for the reporting of self-monitoring results by permittees. DMRs must be used by *approved states* as well as by EPA. EPA will supply DMRs to any approved state upon request. The EPA national forms may be modified to substitute the state agency name, address, logo, and other similar information, as appropriate, in place of EPA's.	§ 122.2
Draft Permit	A document prepared under § 124.6 indicating the Director's tentative decision to issue, deny, modify, revoke and reissue, terminate, or reissue a *permit.* A notice of intent to terminate a permit, and a notice of intent to deny a permit, as discussed in § 124.5, are types of *draft permits*. A denial of a request for modification, revocation and reissuance, or termination, as discussed in § 124.5, is not a draft permit. A *proposed permit* is not a draft permit.	§ 122.2
Effluent Limitation	Any restriction imposed by the Director on quantities, discharge rates, and concentrations of *pollutants* which are *discharged* from *point sources* into waters of the United States, the waters of the *contiguous zone*, or the ocean.	§ 122.2
Effluent Limitations Guidelines (Effluent Guidelines or ELG)	A regulation published by the Administrator under CWA section 304(b) to adopt or revise *effluent limitations*.	§ 122.2
Existing Uses	Those uses actually attained in the waterbody on or after November 28, 1975, whether they are included in the water quality standards.	§ 131.3

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Exhibit A-2 Glossary (continued)

Term	Definition	Citation
Fact Sheet	A document that must be prepared for all draft individual permits for NPDES major dischargers, NPDES general permits, NPDES permits that contain variances, NPDES permits that contain sewage sludge land application plans and several other classes of dischargers. The document summarizes the principal facts and the significant factual, legal, methodological and policy questions considered in preparing the draft permit and explains how the public may comment (§§ 124.8 and 124.56). Where a fact sheet is not required, a statement of basis must be prepared (§ 124.7).	1996 PWM
Fundamentally Different Factors (FDF)	Those components of a petitioner's facility that are determined to be so unlike those components considered by EPA during the effluent guidelines and pretreatment standards rulemaking that the facility is worthy of a variance from the effluent guidelines or categorical pretreatment standards that would otherwise apply.	Adapted from 1996 PWM
General Permit	An NPDES permit issued under § 122.28 that authorizes a category of discharges under the CWA within a geographical area. A general permit is not specifically tailored for an individual discharger.	1996 PWM
Grab Sample	A sample taken from a wastestream on a one-time basis without consideration of the flow rate of the wastestream and without consideration of time.	Adapted from 1996 PWM
Hazardous Substance	Any substance—as designated under Part 116 pursuant to CWA section 311—that presents an imminent and substantial danger to the public health or welfare, including fish, shellfish, wildlife, shorelines, and beaches, upon discharge to navigable waters of the United States.	Adapted from § 122.2 and CWA section 311(b)(2)(A)
Indirect Discharger	A nondomestic discharger introducing *pollutants* to a publicly owned treatment works.	40 CFR 122.2
Instantaneous Maximum Limit	The maximum allowable concentration or other measure of a pollutant determined from the analysis of any discrete or composite sample collected, independent of the flow rate and the duration of the sampling event.	1996 PWM
Instantaneous Minimum Limit	The minimum allowable concentration or other measure of a pollutant determined from the analysis of any discrete or composite sample collected, independent of the flow rate and the duration of the sampling event.	--
Load Allocation	The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished.	§ 130.2
Local Limits	Where specific prohibitions or limits on pollutants or pollutant parameters are developed by a POTW in accordance with § 403.4(c), such limits must be deemed Pretreatment Standards for the purposes of CWA section 307(d).	Adapted from § 403.4(d)

Exhibit A-2 Glossary (continued)

Term	Definition	Citation
Major Facility	Any NPDES facility or activity classified as such by the Regional Administrator, or in the case of approved state programs, the Regional Administrator in conjunction with the State Director (§ 122.2). Major municipal dischargers include all facilities with design flows of greater than one million gallons per day and facilities with EPA/state approved industrial pretreatment programs. Major industrial facilities are determined based on specific ratings criteria developed by EPA or are classified as such by EPA in conjunction with the state.	1996 PWM
Method Detection Limit (MDL)	The minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero and is determined from analysis of a sample in a given matrix containing the analyte.	§ 136 - Appendix B
Maximum Daily Effluent Limitation (MDL)	The highest allowable daily discharge of a pollutant. (Chapter 6)	--
Million Gallons per Day (or mgd)	A unit of flow commonly used for wastewater discharges. One million gallon per day is equivalent to 1.547 cubic feet per second.	1996 PWM
Minimum Level (ML)	The level at which the entire analytical system must give a recognizable signal and acceptable calibration point. It is equivalent to the concentration of the lowest calibration standard, assuming that all method-specified sample weights, volumes, and cleanup procedures have been employed.	§ 136 - Appendix A
Mixing Zone	An area where an effluent discharge undergoes initial dilution and is extended to cover the secondary mixing in the ambient waterbody. A mixing zone is an allocated impact zone where water quality criteria can be exceeded as long as acutely toxic conditions are prevented.	Technical Support Document for Water Quality-based Toxics Control <www.epa.gov/npdes/pubs/owm0264.pdf>
Municipal Separate Storm Sewer System (MS4)	A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains): a. Owned or operated by a state, city, town, borough, county, parish, district, association, or other public body (created by or pursuant to state law) having jurisdiction over disposal of sewage, industrial wastes, stormwater, or other wastes, including special districts under state law such as a sewer district, flood control district or drainage district, or similar entity, or an Indian tribe or an authorized Indian tribal organization, or a designated and approved management agency under CWA section 208 that discharges to waters of the United States. b. Designed or used for collecting or conveying stormwater. c. [That] is not a combined sewer. d. [That] is not part of a Publicly Owned Treatment Works (POTW) as defined at § 122.2.	§ 122.26(b)(8)
Municipal Sludge	See *Sewage Sludge*.	--

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Exhibit A-2 Glossary (continued)

Term	Definition	Citation
National Pollutant Discharge Elimination System (NPDES)	The national program for issuing, modifying, revoking and reissuing, terminating, monitoring and enforcing permits, and imposing and enforcing pretreatment requirements, under CWA sections 307, 318, 402, and 405. The term includes *approved program*. NPDES permits regulate discharges of pollutants from point sources to waters of the United States. Such discharges are illegal unless authorized by an NPDES permit.	Adapted from § 122.2
National Pretreatment Standard or Pretreatment Standard	Any regulation promulgated by EPA in accordance with CWA sections 307(b) and 307(c) that applies to a specific category of industrial users and provides limitations on the introduction of pollutants into publicly owned treatment works. The term includes the prohibited discharge standards under § 403.5.	Adapted from § 403.3(l)
New Discharger	Any building, structure, facility, or installation: a. From which there is or may be a discharge of pollutants. b. That did not begin the discharge of pollutants at that site before August 13, 1979. c. That is not a new source. d. That has never received a finally effective NPDES permit for discharges at that site. This definition includes an *indirect discharger* that begins discharging into waters of the United States after August 13, 1979. It also includes any existing mobile point source (other than an offshore or coastal oil and gas exploratory drilling rig or a coastal oil and gas developmental drilling rig) such as a seafood processing rig, seafood processing vessel, or aggregate plant, that begins discharging at a *site* for which it does not have a permit; and any offshore or coastal mobile oil and gas exploratory drilling rig or coastal mobile oil and gas developmental drilling rig that commences the discharge of pollutants after August 13, 1979, at a site under EPA's permitting jurisdiction for which it is not covered by an individual or general permit and which is in an area determined by the Regional Administrator in the issuance of a final permit to be an area or biological concern. In determining whether an area is an area of biological concern, the Regional Administrator must consider the factors specified in §§ 125.122(a)(1) - 125.122(a)(10). An offshore or coastal mobile exploratory drilling rig or coastal mobile developmental drilling rig will be considered a *new discharger* only for the duration of its discharge in an area of biological concern.	Adapted from § 122.2

Exhibit A-2 Glossary (continued)

Term	Definition	Citation
New Source	Any building, structure, facility, or installation from which there is or could be a discharge of pollutants, the construction of which commenced: a. After promulgation of standards of performance under CWA section 306, which are applicable to such source; or b. After proposal of standards of performance in accordance with CWA section 306, which are applicable to such source but only if the standards are promulgated in accordance with CWA section 306 within 120 days of their proposal. Additional Criteria: Except as otherwise provided in an applicable new source performance standard, a source is a *new source* if it meets the definition in § 122.2; and i. It is constructed at a site at which no other source is located; or ii. It totally replaces the process or production equipment that causes the discharge of pollutants at an existing source; or iii. Its processes are substantially independent of an existing source at the same site. In determining whether these processes are substantially independent, the Director shall consider such factors as the extent to which the new facility is integrated with the existing plant; and the extent to which the new facility is engaged in the same general type of activity as the existing source.	Adapted from § 122.2 and § 122.29(b)(1)
New Source Performance Standards (NSPS)	Technology standards for facilities that qualify as new sources under § 122.2 and § 122.29. Standards consider that the new source facility has an opportunity to design operations to more effectively control pollutant discharges.	1996 PWM
Nonconventional Pollutants	All pollutants that are not included in the list of conventional or toxic pollutants in Part 401. Includes pollutants such as chemical oxygen demand (COD), total organic carbon (TOC), nitrogen, and phosphorus.	1996 PWM
Nonpoint Source	Diffuse pollution sources (i.e., without a single point of origin or not introduced into a receiving stream from a specific outlet). The pollutants are generally carried off the land by stormwater. Atmospheric deposition and hydromodification are also sources of nonpoint source pollution.	--
North American Industrial Classification System (NAICS)	The North American Industry Classification System (NAICS) is the standard used by federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy.	Retrieved from <www.census.gov/epcd/www/naics.html>
Nutrients	Chemical elements and compounds found in the environment that plants and animals need to grow and survive. Nutrients include compounds of nitrogen (nitrate, nitrite, ammonia, organic nitrogen) and phosphorus (orthophosphate and others), both natural and man-made.	--
Permitting Authority	The agency authorized to issue and enforce specific requirements of the NPDES permit program. The permitting authority may be EPA, or a state, territorial, or tribal agency that has been authorized under CWA section 402(b) to administer the NPDES program within its jurisdiction.	--

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Exhibit A-2 Glossary (continued)

Term	Definition	Citation
pH	A measure of the hydrogen ion concentration of water or wastewater; expressed as the negative log of the hydrogen ion concentration in mg/L. A pH of 7 is neutral. A pH less than 7 is acidic, and a pH greater than 7 is basic.	1996 PWM
Point Source	Any discernible, confined, and discrete conveyance, including any pipe, ditch, channel, tunnel, conduit, well, discrete fixture, container, rolling stock, concentrated animal feeding operation, landfill leachate collection system, vessel or other floating craft from which pollutants are or may be discharged. The term does not include return flows from irrigated agriculture or agricultural stormwater runoff.	Adapted from § 122.2
Pollutant	Dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials (except those regulated under the Atomic Energy Act of 1954, as amended [42 U.S.C. 2011 *et seq.*)], heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water. It does not mean a. Sewage from vessels. b. Water, gas, or other material that is injected into a well to facilitate production of oil or gas, or water derived in association with oil and gas production and disposed of in a well, if the well used either to facilitate production or for disposal purposes is approved by authority of the state in which the well is located, and if the state determines that the injection or disposal will not result in the degradation of ground or surface water resources.	§ 122.2
Pollutant, Conservative	Pollutants that do not readily degrade in the environment and that are mitigated primarily by dilution after entering receiving waters (e.g., metals, total suspended solids).	Adapted from 1996 PWM
Pollutant, Non-Conservative	Pollutants that are mitigated by natural biodegradation or other environmental decay or removal processes in the receiving water after mixing and dilution have occurred (e.g., biochemical oxygen demand, pH, volatile organic compounds).	Adapted from 1996 PWM
Pretreatment	The reduction of the amount of pollutants, the elimination of pollutants, or the alteration of the nature of pollutant properties in wastewater prior to or in lieu of discharging or otherwise introducing such pollutants into a POTW.	§ 403.3(s)
Primary Industry Category	Any industry category listed in the NRDC settlement agreement (*Natural Resources Defense Council et al. v. Train,* 8 E.R.C. 2120 [D.D.C. 1976], modified 12 E.R.C. 1833 [D.D.C. 1979]); also listed in Appendix A of Part 122.	§ 122.2
Primary Treatment	The practice of removing some portion of the suspended solids and organic matter in wastewater through sedimentation. Common usage of this term also includes preliminary treatment to remove wastewater constituents that may cause maintenance or operational problems in the system (i.e., grit removal, screening for rags and debris, oil and grease removal, etc.).	1996 PWM
Priority Pollutants	Those pollutants considered to be of principal importance for control under the CWA based on the NRDC Consent Decree (*NRDC et al. v. Train,* 8 E.R.C. 2120 [D.D.C. 1976], modified 12 E.R.C. 1833 [D.D.C. 1979]); a list of the pollutants is provided as Appendix A to 40 CFR Part 423.	1996 PWM

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Exhibit A-2 Glossary (continued)

Term	Definition	Citation
Process Wastewater	Any water [that], during manufacturing or processing, comes into direct contact with, or results from the production or use of any raw material, intermediate product, finished product, by-product, or waste product.	§ 122.2
Production-Based Standard	A discharge standard expressed in terms of pollutant mass allowed per unit of product manufactured or some other measure of production.	1996 PWM
Proposed Permit	A state NPDES *permit* prepared after the close of the public comment period (and when applicable, any public hearing and administrative appeals) [that] is sent to EPA for review before final issuance by the state. A *proposed permit* is not a *draft permit*.	§ 122.2
Publicly Owned Treatment Works (POTW)	A treatment works as defined by CWA section 212, which is owned by a state or municipality [as defined by CWA section 502(4)]. This definition includes any devices and systems used in the storage, treatment, recycling, and reclamation of municipal sewage or industrial wastes of a liquid nature. It also includes sewers, pipes, and other conveyances only if they convey wastewater to a POTW. The term also means the municipality as defined in CWA section 502(4), which has jurisdiction over the indirect discharges to and the discharges from such a treatment works.	§ 403.3(q)
Sanitary Sewer	A pipe or conduit (sewer) intended to carry wastewater or water-borne wastes from homes, businesses, and industries to the POTW.	1996 PWM
Sanitary Sewer Overflows (SSO)	Untreated or partially treated sewage overflows from a sanitary sewer collection system.	1996 PWM
Secondary Industry Category	Any industry category, which is not a *primary industry category*.	§ 122.2
Secondary Treatment	Technology-based requirements for direct discharging POTWs. Standard is based on the expected performance of a combination of physical and biological processes typical for the treatment of pollutants in municipal sewage. Standards are expressed as a minimum level of effluent quality in terms of: BOD_5, total suspended solids (TSS), and pH (except as provided by treatment equivalent to secondary treatment and other special considerations).	Adapted from 1996 PWM
Section 304(a) Criteria	Developed by EPA under authority of CWA section 304(a) based on the latest scientific information on the relationship that the effect of a constituent concentration has on particular aquatic species and/or human health. This information is issued periodically to the states as guidance for use in developing criteria.	§ 131.3(c)
Self-Monitoring	Sampling and analyses performed by a facility to determine compliance with effluent limitations or other regulatory requirements.	1996 PWM

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Exhibit A-2 Glossary (continued)

Term	Definition	Citation
Sewage Sludge	Any solid, semi-solid, or liquid residue removed during the treatment of municipal waste water or domestic sewage. Sewage sludge includes solids removed during primary, secondary, or advanced wastewater treatment, scum, septage, portable toilet pumpings, type III marine sanitation device pumpings (33 CFR Part 159), and sewage sludge products. Sewage sludge does not include ash generated during the firing of sewage sludge in a sewage sludge incinerator or grit and screenings generated during preliminary treatment of domestic sewage in a treatment works.	Adapted from § 122.2 and Part 503
Significant Industrial User (SIU)	An indirect discharger that is the focus of control efforts under the National Pretreatment Program. SIUs include [with exceptions provided under § 403.3(v)]: i. All Industrial Users subject to Categorical Pretreatment Standards under § 403.6 and Chapter 1, Subchapter N. ii. Any other Industrial User that: discharges an average of 25,000 gallons per day or more of process wastewater to the POTW (excluding sanitary, noncontact cooling and boiler blowdown wastewater); contributes a process wastestream that makes up 5 percent or more of the average dry weather hydraulic or organic capacity of the POTW; or is designated as such by the Control Authority on the basis that the Industrial User has a reasonable potential for adversely affecting the POTW's operation or for violating any Pretreatment Standard or requirement [in accordance with § 403.8(f)(6)].	Adapted from § 403.3(v)
Spill Prevention Control and Countermeasure Plan (SPCC)	A plan prepared by a facility to minimize the likelihood of a spill and to expedite control and cleanup activities if a spill occurs. Such plans are required for certain facilities under the Oil Pollution Prevention Regulations at 40 CFR Part 112.	Adapted from 1996 PWM
Standard Industrial Classification (SIC) Code	A code number system used to identify various types of industries. A particular industry may have more than one SIC code if it conducts several types of commercial or manufacturing activities onsite. An online version of the 1987 SIC Manual <www.osha.gov/pls/imis/sic_manual.html> is available courtesy of the Occupational Safety & Health Administration (OSHA).	Adapted from 1996 PWM
Statement of Basis	A document prepared for every draft NPDES permit for which a fact sheet is not required. A statement of basis briefly describes how permit conditions were derived and the reasons the conditions are necessary for the permit.	1996 PWM
STORET	EPA's computerized STOrage and RETrieval water quality data base that includes physical, chemical, and biological data measured in waterbodies throughout the United States.	1996 PWM
Storm Water (or Stormwater)	Stormwater runoff, snow melt runoff, and surface runoff and drainage.	§ 122.26(b)(13)
Technology-Based Effluent Limitation (TBEL)	An effluent limit for a pollutant that is based on the capability of a treatment method to reduce the pollutant to a certain concentration or mass loading level. TBELs for POTWs are derived from the secondary treatment regulations in Part 133 or state treatment standards. TBELs for non-POTWs are derived from effluent guidelines, state treatment standards, or by the permit writer on a case-by-case basis using best professional judgment.	Adapted from 1996 PWM

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Exhibit A-2 Glossary (continued)

Term	Definition	Citation
Tiered Permit Limits	Permit limits that apply to the discharge only when a certain threshold (e.g., production level), specific circumstance (e.g., batch discharge), or time frame (e.g., after 6 months, during the months of May through October) triggers their use.	Adapted from 1996 PWM
Total Maximum Daily Load (TMDL)	The sum of the individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and natural background. If a receiving water has only one point source discharger, the TMDL is the sum of that point source WLA plus the LAs for any nonpoint sources of pollution and natural background sources, tributaries, or adjacent segments. TMDLs can be expressed in terms of either mass per time, toxicity, or other appropriate measure. If best management practices (BMPs) or other nonpoint source pollution controls make more stringent load allocations practicable, then wasteload allocations can be made less stringent. Thus, the TMDL process provides for nonpoint source control tradeoffs.	40 CFR § 130.2(i)
Total Suspended Solids (TSS)	A measure of the filterable solids present in a sample, as determined by the method specified in Part 136.	1996 PWM
Toxic Pollutant	Any pollutant listed as toxic under CWA section 307(a)(1) or, in the case of *sludge use or disposal practices*, any pollutant identified in regulations implementing CWA section 405(d).	§ 122.2
Toxicity Reduction Evaluation (TRE)	A site-specific study conducted in a step-wise process designed to identify the causative agent(s) of effluent toxicity, isolate the sources of toxicity, evaluate the effectiveness of toxicity control options, and then confirm the reduction in effluent toxicity.	1996 PWM
Toxicity Test	A procedure to determine the toxicity of a chemical or an effluent using living organisms. A toxicity test measures the degree of effect on exposed test organisms of a specific chemical or effluent.	1996 PWM
Trading (or Water Quality Trading)	An innovative approach to achieve water quality goals more efficiently. Trading is based on the fact that sources in a watershed can face very different costs to control the same pollutant. Trading programs allow facilities facing higher pollution control costs to meet their regulatory obligations by purchasing environmentally equivalent (or superior) pollution reductions from another source at lower cost, thus achieving the same water quality improvement at lower overall cost.	Water Quality Trading Fact Sheet: <www.epa.gov/owow/watershed/trading/handbook/factsheet.html>
Treatability Manual	Five-set library of EPA guidance manuals that contain information related to the treatability of many pollutants. The manual may be used in developing effluent limitations for facilities and pollutants, which, at the time of permit issuance, are not subject to industry-specific effluent guidelines. The five volumes that comprise this series consist of Vol. I – Treatability Data (EPA-600/8-80-042a); Vol. II – Industrial Descriptions (EPA-600/8-80-042b); Vol. III – Technologies (EPA-600/8-80-042c); Vol. IV – Cost Estimating (EPA-600/8-80-042d); and Vol. V – Summary (EPA-600/8-80-042e).	1996 PWM
Treatment Works Treating Domestic Sewage (TWTDS)	A POTW or any other sewage sludge or waste water treatment devices or systems, regardless of ownership (including federal facilities), used in the storage, treatment, recycling, and reclamation of municipal or domestic sewage, including land dedicated for the disposal of sewage sludge. This definition does not include septic tanks or similar devices. For purposes of this definition, *domestic sewage* includes waste and waste water from humans or household operations that are discharged to or otherwise enter a treatment works.	Adapted from § 122.2

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Exhibit A-2 Glossary (continued)

Term	Definition	Citation
Upset	An exceptional incident in which there is unintentional and temporary noncompliance with technology-based permit effluent limitations because of factors beyond the reasonable control of the permittee. An upset does not include noncompliance to the extent caused by operational error, improperly designed treatment facilities, inadequate treatment facilities, lack of preventive maintenance, or careless or improper operation.	§ 122.41(n)
Use Attainability Analysis	A structured scientific assessment of the factors affecting the attainment of the use that [can] include physical, chemical, biological, and economic factors as described in § 131.10(g).	§ 131.3
Variance	Any mechanism or provision under CWA sections 301 or 316 or under 40 CFR Part 125, or in the applicable *effluent limitations guidelines*, which allows modification to or waiver of the generally applicable effluent limitation requirements or time deadlines of the CWA. This includes provisions, [that] allow the establishment of alternative limitations based on fundamentally different factors or on CWA sections 301(c), 301(g), 301(h), 301(i), or 316(a).	§ 122.2
Wasteload Allocation (WLA)	The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution.	Adapted from § 130.2(h)
Water Quality Criteria	Elements of state water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use.	§ 131.3(b)
Water Quality Limited Segment	Any segment where it is known that water quality does not meet applicable water quality standards, and/or is not expected to meet applicable water quality standards, even after the application of the technology-based effluent limitations required by CWA sections 301(b) and 306.	§ 131.3
Water Quality Standards (WQS)	Provisions of state or federal law that consist of a designated use or uses for the waters of the United States and water quality criteria for such waters based on such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water, and serve the purposes of the CWA.	Adapted from §131.3
Water Quality-Based Effluent Limitation (WQBEL)	An effluent limitation determined by selecting the most stringent of the effluent limits calculated using all applicable water quality criteria (e.g., aquatic life, human health, wildlife, translation of narrative criteria) for a specific point source to a specific receiving water.	Adapted from 1996 PWM

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Exhibit A-2 Glossary (continued)

Term	Definition	Citation
Waters of the United States	Means a. All waters [that] are currently used, were used in the past, or [could] be susceptible to use in interstate or foreign commerce, including all waters [that] are subject to the ebb and flow of the tide. b. All interstate waters, including interstate *wetlands*. c. All other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, *wetlands*, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds the use, degradation, or destruction of which would affect or could affect interstate or foreign commerce including any such waters 1. [That] are or could be used by interstate or foreign travelers for recreational or other purposes. 2. From which fish or shellfish are or could be taken and sold in interstate or foreign commerce or 3. [That] are used or could be used for industrial purposes by industries in interstate commerce. d. All impoundments of waters otherwise defined as waters of the United States under this definition. e. Tributaries of waters identified in paragraphs (a) through (d) of this definition. f. The territorial sea and g. Wetlands adjacent to waters (other than waters that are themselves wetlands) identified in paragraphs (a) through (f) of this definition. [see additional notes in § 122.2]	§ 122.2
Whole Effluent Toxicity (WET)	The aggregate toxic effect of an effluent measured directly by a toxicity test.	§ 122.2

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Appendix B. Index to the CWA and NPDES Regulations

This appendix provides two tables to help permit writers navigate Clean Water Act (CWA) legislation and National Pollutant Discharge Elimination System (NPDES) regulations. The first table provides key sections of the CWA and the second table provides an index to NPDES regulations.

B.1 Index to Sections of the CWA

Title 33 of the *United States Code* (U.S.C.) includes the statutes and amendments to the CWA. Exhibit B-1 matches key sections of the CWA to the appropriate reference in the U.S.C. This latest version, dated December 20, 2004, was provided by the New England Interstate Water Pollution Control Commission.

Exhibit B-1 Index to sections of the CWA

33 U.S.C. section	Section title	CWA section
	Subchapter I Research and Related Programs	
1251	Congressional declaration of goals and policy	**101**
1252	Comprehensive programs for water pollution control	**102**
1253	Interstate cooperation and uniform laws	**103**
1254	Research, investigations, training and information	**104**
1255	Grants for research and development	**105**
1256	Grants for pollution control programs	**106**
1257	Mine water pollution demonstrations	**107**
1258	Pollution control in the Great Lakes	**108**
1259	Training grants and contracts	**109**
1260	Applications for training grants and contracts; allocations	**110**
1261	Scholarships	**111**
1262	Definitions and authorization	**112**
1263	Alaska village demonstration project	**113**
1265	In-place toxic pollutants	**115**
1266	Hudson River reclamation demonstration project	**116**
1267	Chesapeake Bay	**117**
1268	Great Lakes	**118**
1269	Long Island Sound	**119**
1270	Lake Champlain management conference	**120**
1273	Lake Pontchartrain Basin	**121**
1274	Wet weather watershed pilot projects	**121**
	Subchapter II Grants for Construction of Treatment Works	
1281	Congressional declaration of purpose	**201**
1282	Federal share	**202**
1283	Plans, specifications, estimates, and payments	**203**
1284	Limitations and conditions	**204**
1285	Allotment of grant funds	**205**
1286	Reimbursement and advanced construction	**206**
1287	Authorization of appropriations	**207**
1288	Area wide waste treatment management	**208**
1289	Basin planning	**209**

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Exhibit B-1 Index to sections of the CWA (continued)

33 U.S.C. section	Section title	CWA section
1290	Annual survey	**210**
1291	Sewage collection system	**211**
1292	Definitions	**212**
1293	Loan guarantees	**213**
1294	Wastewater recycling and reuse information and education	**214**
1295	Requirements for American materials	**215**
1296	Determination of priority	**216**
1297	Guidelines for cost-effective analysis	**217**
1298	Cost effectiveness	**218**
1299	State certification of projects	**219**
1300	Pilot program for alternative water source projects	**220**
1301	Sewer overflow control grants	**221**
	Subchapter III Standards and Enforcement	
1311	Effluent Limitations	**301**
1312	Water quality-related effluent limitations	**302**
1313	Water quality standards and implementation plans	**303**
1314	Information and guidelines	**304**
1315	Water quality inventory	**305**
1316	National standards of performance	**306**
1317	Toxic and pretreatment effluent standards	**307**
1318	Records and reports, inspections	**308**
1319	Enforcement	**309**
1320	International pollution abatement	**310**
1321	Oil and hazardous substance liability	**311**
1322	Marine sanitation devices	**312**
1323	Federal facility pollution control	**313**
1324	Clean lakes	**314**
1325	National study commission	**315**
1326	Thermal discharges	**316**
1328	Aquaculture	**318**
1329	Nonpoint source management program	**319**
1330	National estuary study	**320**
	Subchapter IV Permits and Licenses	
1341	Certification	**401**
1342	National pollutant discharge elimination system	**402**
1343	Ocean discharge criteria	**403**
1344	Permits for dredge and fill materials	**404**
1345	Disposal or use of sewage sludge	**405**
1346	Coastal recreation water quality monitoring and notification	**406**
	Subchapter V General Provisions	
1361	Administration	**501**
1362	Definitions	**502**
1363	Water pollution control advisory board	**503**
1364	Emergency powers	**504**
1365	Citizen suits	**505**
1366	Appearance	**506**
1367	Employee protection	**507**
1368	Federal procurement	**508**
1369	Administrative procedure and judicial review	**509**
1370	State authority	**510**

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Exhibit B-1 Index to sections of the CWA (continued)

33 U.S.C. section	Section title	CWA section
1371	Authority under other laws and regulations	**511**
1251 Note	Separability	**512**
1372	Labor standards	**513**
1373	Public health agency coordination	**514**
1374	Effluent standards and water quality information advisory committee	**515**
1375	Reports to Congress	**516**
1376	Authorization of appropriations	**517**
1377	Indian tribes	**518**
1251 Note	Short Title	**519**
Subchapter VI State Water Pollution Control Revolving Funds		
1381	Grants to States for establishment of revolving funds	**601**
1382	Capitalization grant agreements	**602**
1383	Water pollution control revolving loan funds	**603**
1384	Allotment of funds	**604**
1385	Corrective actions	**605**
1386	Audits, reports, fiscal controls, intended use plan	**606**
1387	Authorization of appropriations	**607**

B.2 Index to NPDES Regulations

The index to NPDES regulations table presented in Exhibit B-2 was created by Sylvia Kawabata of EPA Region 10 on February 1, 1986, and is maintained by Doug Corb of EPA Region 1.

Exhibit B-2 Index to NPDES regulations

Subject	40 CFR section number
Selected CWA sections	
CWA section 301(c) – Modification of Timetable	§ 122.21(m)(2) Part 125, Subpart E (reserved)
CWA section 301(g) – Modifications for Certain Nonconventional Pollutants	§ 122.21(m)(2) Part 125, Subpart F (reserved) *Technical Guidance Manual for the Regulations Promulgated Pursuant to section 301(g) of the Clean Water Act of 1977 and 40 CFR Part 125 (Subpart F); August 22, 1984.* <www.epa.gov/npdes/pubs/owm0008.pdf>
CWA section 301(h) – Secondary Treatment Waiver	§ 122.21(n)(1) Part 125, Subpart G
CWA section 301(n) – Timetable for Achievement of Objectives	See Fundamentally Different Factors
CWA section 316(a) – Thermal Discharges	§ 122.21(m)(6) Part 125, Subpart H § 124.57 § 124.62(a)(2) § 124.66
NPDES permit subjects	
Administrative Procedures Act Permit Continuance	§ 122.6
Administrative Record	§ 124.9 § 124.18

Exhibit B-2 Index to NPDES regulations (continued)

Subject	40 CFR section number
Alternate Test Procedures • Application • Approval	 • § 136.4 • § 136.5
Ambient Monitoring (for Indicator Parameters)	§ 122.44(d)(1)(vi)(C)(3)
Anti-backsliding	See Backsliding
Antidegradation Policy	§ 131.12
Applicability to State NPDES Programs	See General Conditions for All Permits (State Programs)
Application • Submittal Deadline (Time to Apply) • Permit May Not Be Issued Without Complete Application • Completeness	§ 122.21 • § 122.21(c) • § 122.21(e) • §§ 124.3(c) – 124.3(g)
Aquaculture	§ 122.25 Part 125, Subpart B
Aquatic Animal Production Facilities • Application • Definition Criteria for Determination • General Permit	§ 122.24 • § 122.21(i)(2) • § 122.24 Part 122, Appendix C • § 122.28
Average Monthly (Definition) • Requirements for use in Non-POTWs • Requirements for use in POTWs	§ 122.2 • § 122.45(d)(1) • § 122.45(d)(2)
Average Weekly (Definition) • Requirements for use in POTWs	§ 122.2 • § 122.45(d)(2)
Biochemical Oxygen Demand (BOD_5)	§ 133.101(d)
Backsliding • From Water Quality and Technology Based Limits • From Water Quality	§ 122.44(l) § 122.62(a)(15) § 122.62(a)(17) • CWA section 402(o) • CWA section 303(d)(4)
Best Management Practices • Definition • In Effluent Limitation Guidelines • Case-by-Case Authority	 • § 122.2 § 122.44(k) § 130.2(m) • CWA section 304(e) • CWA section 402(a)(1)
Best Professional Judgment (BPJ) • Case-by-Case Authority • Appropriate Factors	 • §125.3(a)(1) • §§125.3(c) and 125.3(d)
BMP	See Best Management Practices
Boilerplate Permit Conditions	§§ 122.41 - 122.42
BPJ	See Best Professional Judgment
Bypasses	§ 122.41(m)
CAFO	See Concentrated Animal Feeding Operations
Calculating NPDES Permit Conditions	§ 122.45
Carbonaceous Biochemical Oxygen Demand ($CBOD_5$)	§ 133.101(e)
Case-by-Case Limitations	See also BPJ § 122.44(a) § 125.3
Case-by-Case Permits	See also BPJ § 124.52

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Exhibit B-2 Index to NPDES regulations (continued)

Subject	40 CFR section number
Clean Water Act (CWA)	(Public Law 92-500), 33 U.S.C. 1251 *et seq.*, as amended by Public Laws 96-483; 97-117; 95-217, 97-117, 97-440, and 100-04
Coast Guard (Discharges from Transportation Over Water)	§ 122.44(p)
Coastal Zone Management Act	§ 122.49(d)
Combined Sewer Overflow Policy	59 FR 18688, April 19, 1994 <www.epa.gov/npdes/pubs/owm0111.pdf>
Comments Received During Public Notice Period	§ 124.13
Compliance Schedules (in permits) • Allowance by State Water Quality Standards	§ 122.41(l)(5) § 122.47 §§ 122.62(a)(4), (a)(9), (a)(13) • Star-kist Caribe, Inc., NPDES Appeal No. 88-5 <www.epa.gov/npdes/pubs/owm0121.pdf> (EAB, May 25, 1992)
Computation of Time	§ 124.20
Concentrated Animal Feeding Operations	§ 122.23
Concentrated Aquatic Animal Production	See Aquatic Animal Production
Conditions Applicable to Specified Categories	§ 122.42
Confidentiality of Information	§ 122.7 Part 2
Consolidation of Permit Processing	§ 124.4
Continuation of Expired Permits	§ 122.6
Continuous Discharge	§ 122.45(d)
Conventional Pollutants	§ 401.16
Cooling Water Intake Structures [CWA section 316(b)]	Part 125, Subparts I, J and N § 122.21(r) § 401.14
DMR	See Discharge Monitoring Report
Daily Average	See Average Monthly
Daily Maximum	See Maximum Daily
Definitions	§ 122.2 § 124.2 § 401.11
Denial of Permit • Public Notice of Denial	§ 124.6(b) • § 124.10(a)(1)(i)
Design Flow (POTWs)	§ 122.45(b)(1)
Dilution, Not A Substitute For Treatment	§ 122.45(f)(1)(iii) § 125.3(f)
Discharge Monitoring Report (DMR)	§ 122.41(l)(4)
Discharge of a Pollutant (Definition)	§ 122.2
Disposal into Wells, into POTWs, or by Land Application	§ 122.50 § 122.45(i)
Draft Permit	§ 124.6
Dredged Materials (Discharge to Waters of the United States)	CWA section 404
Duration of Permits • Computation of time	§ 122.46 • § 124.20
Duty to Comply	§ 122.41(a)
Duty to Mitigate	§ 122.41(d)
Duty to Provide Information	§ 122.41(h)
Duty to Reapply	§ 122.41(b)
Effect of a Permit	§ 122.5

Exhibit B-2 Index to NPDES regulations (continued)

Subject	40 CFR section number
Effective Date	§ 124.15
Effluent Limitations Guidelines (Effluent Guidelines or ELG)	Parts 405-471
Endangered Species Act	§ 122.49(c)
Enforcement Authority	§ 123.27
Environmental Impact Statement (EIS) • EIS Public Notice of a New Source • Final EIS • New Source • NEPA	 • § 124.10(b)(1) • § 124.61 • § 122.29(c) • Part 6
Equivalent To Secondary Treatment (for POTWs)	§ 133.105
Establishing Limitations, Standards	§ 122.44
Establishing Permit Conditions	§ 122.43
Evidentiary Hearing Procedures (Eliminated)	§§ 124.21 (b) - (c)
Exclusions	§ 122.3
Existing Source (Definition)	§ 122.29(a)(3)
Expiration Dates	See Duration of Permits
Extension of Public Notice Comment Period	§ 124.12(c)
FDF	See Fundamentally Different Factors
Fact Sheets	§ 124.8 § 124.56
Feedlots	See Concentrated Animal Feeding Operations
Filter Backwash	§ 125.3(g)
Fish and Wildlife Coordination Act	§ 122.49(e)
Fish Farms	See Aquatic Animal Production Facilities
Flow Augmentation	§ 125.3(f)
Flow Limits (POTW - Design Flow)	§ 122.45(b)
Flow Monitoring Requirement	§ 122.44(i)(1)(ii)
Fundamentally Different Factors (FDF)	§ 122.21(m)(1) § 122.44(d)(8) Part 125, Subpart D
Frequency of Sampling (Not less than once per year)	§ 122.44(i)(2)
General Conditions Applicable to All Permits	§ 122.41
General Conditions for All Permits (State Programs)	§ 123.25
General Permits • Public Notice • Individual Permit Required	§ 122.28 • § 124.10(c)(2)(i) • § 122.28(b)(3)
Great Lakes Water Quality Guidance	Part 132
Indian Tribe (Definition)	§ 124.2
Innovative Technology	See CWA section 301(k) – Innovative Technology
Inspection and Entry	§ 122.41(i)
Internal Waste Streams	§ 122.45(h)
Interim Dates for Schedules of Compliance	§ 122.47(a)(3)
Introduction of New Pollutants (POTW)	§ 122.42(b)
Issuance and Effective Date	§ 124.15 § 124.60
Mass Limitations	§ 122.45(f) § 122.44(i)(1)(i)
Maximum Daily (Definition) • Requirements for Non-POTWs	§ 122.2 • § 122.45(d)(1)
Metals (To Be Expressed as Total Recoverable)	§ 122.45(c)

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Exhibit B-2 Index to NPDES regulations (continued)

Subject	40 CFR section number
Method Detection Limit	Part 136, Appendix B
Minor Modifications	§ 122.63
Mixing Zones	§ 131.13
Modifications	§ 122.62 § 124.5
Monitoring Results, Requirements for Recording and Reporting	§ 122.48
Monitoring and Records • Monitoring Reports • Requirements • Recordkeeping	§ 122.41(j) • § 122.41(l)(4) • § 122.44(h) • § 122.21(p)
Municipal Separate Storm Sewer Systems (MS4) • When Permit Required • Definitions	 • §§ 122.26(a)(3), (4), and (5) • § 122.26(b)
• Large and Medium MS4s Application Requirements • Small MS4 Requirements	• § 122.26(d) • §§ 122.30 and 122.32 - 122.37
• Tribes	• § 122.31
NPDES (Definition)	§ 122.2
National Environmental Policy Act (NEPA)	§ 122.49(g)
National Historic Preservation Act	§ 122.49(b)
Navigable Waters (Definition)	§ 110.1
Navigation	§ 122.44(q)
Need to Halt or Reduce Activity, Not a Defense	§ 122.41(c)
Net/Gross - Intake Credits	§ 122.45(g)
New Discharger (Definition)	§ 122.2
New Source • Definition • Application Requirements • Program Requirements • Determination • Mitigation Measures • Prohibited discharges • Public Notice	 • § 122.2 • § 122.21(k) • § 122.29 • § 122.29(b) • § 122.44(d)(9) • § 122.4(i) • § 124.10(a)(1)(vi)
Non-Attainment Waters	§ 130.10(d)
Non-Continuous Discharges	§ 122.45(e)
Noncompliance • Anticipated • Other	 • § 122.41(l)(2) • § 122.41(l)(7)
Notification Levels • General • For Existing Manufacturing, Commercial, Mining, and Silvicultural Dischargers	 • § 122.62(a)(12) • § 122.42(a) • § 122.44(f)
Ocean Discharge Criteria	Part 125, Subpart M
Offshore Oil and Gas Facilities • Requirements Applicable to Cooling Water Intake Structures for New Offshore Oil and Gas Extraction Facilities under CWA section 316(b) • General Permit Requirements & Application	 • Part 125, Subpart N • § 122.28(c)
Effluent Guidelines and Standards	Part 435, Subpart A
Stormwater Exemption	§ 122.26(a)(2)
Oil Pollution Prevention	Part 112

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Exhibit B-2 Index to NPDES regulations (continued)

Subject	40 CFR section number
On-Site Construction (New Source)	§ 122.29(b)(4)
Operation and Maintenance	§ 122.41(e)
pH Limits with Continuous Monitoring	§ 401.17
Planned Changes	§ 122.41(l)(1)
Pollutant (Definition)	§ 122.2
POTWs, Applications for New and Existing	§ 122.21(j)
Pretreatment	§ 122.44(j) Part 403
Primary Industry Categories	Part 122, Appendix A
Prior Notice of Citizen Suits (Under CWA)	Part 135
Priority Pollutants	Part 423, Appendix A
Privately Owned Treatment Works	§ 122.44(m)
Production-based Limitations	§ 122.45(b)
Prohibitions	§ 122.4
Proper Operation and Maintenance	§ 122.41(e)
Property Rights	§ 122.41(g)
Public Hearing • Public Notice for Public Hearings	§ 124.12 • § 124.10(b)(2) § 124.10(d)(2)
Public Notice • Specific Procedures Applicable to NPDES Permits	§ 124.10 • § 124.57
Reapplication	§ 122.21(d)
Recordkeeping and Reporting	§ 122.21(p) § 122.41(j)(2) § 122.48
Reopener Clause • Treatment Works Treating Domestic Sewage • Other	 • § 122.44(c) • § 122.62(a)(7)
Reopening of Public Comment Period	§ 124.14
Response to Comments	§ 124.17
Reasonable Potential (RP) - Need For A Limit • Chemical Specific • Whole Effluent Toxicity (WET)	§ 122.44(d)(1) • § 122.44(d)(1)(vi) • § 122.44(d)(1)(v)
Retention of Records	§ 122.41(j)(2)
Revocation and Reissuance	§ 122.62
Sample Type (Composite/Grab)	§ 122.21(g)(7)(i)
Sample Holding Times, Containers, and Preservation	§ 136.3
Sample, Representative	§ 122.41(j)
Schedule of Compliance (Definition)	See also Compliance Schedule § 124.2
Secondary Treatment Regulation (POTW) • Definitions • Secondary Treatment • Special Considerations • Treatment Equivalent to Secondary Treatment	Part 133 • § 133.101 • § 133.102 • § 133.103 • § 133.105
Signatory Requirements	§ 122.22
Silviculture	§ 122.27

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Exhibit B-2 Index to NPDES regulations (continued)

Subject	40 CFR section number
Sludge (Definition) • Sludge Standards • Land Application • Surface Disposal • Pathogens and Vector Attraction Reduction • Incineration	§ 122.44(o) • Part 503 • Part 503, Subpart B • Part 503, Subpart C • Part 503, Subpart D • Part 503, Subpart E
Sludge, Municipal Co-Disposal Landfills	Part 258
Sludge-Only Facilities (Handlers)	§ 122.1(b)(3)
Small Business Exemption	§ 122.21(g)(8)
Solid Waste Facilities, Classification of	Part 257
Spill Prevention, Control, and Countermeasures (SPCC)	§ 112.3
Standard Conditions	§§ 122.41 and 122.42
State Certification • Applications for CWA section 301(h) Variances • Effect of State Certification	§ 124.53 • § 124.54 • § 124.55
State Program Requirements	Part 123
Statutory Deadlines • For POTWs • For Non-POTWs	 • § 125.3(a)(1) • § 125.3(a)(2)
Statutory Variances and Extensions	§ 125.3(b)
Stays of Contested Permit Conditions	§ 124.16
Stormwater • Discharge Associated with Industrial Activity	§ 122.26 • § 122.26(b)(14)
Test Methods, EPA Approved	Part 136
Ten-Year Protection Period	See also New Sources and Dischargers § 122.29
Termination of a Permit	§ 122.64
Thermal Discharge Variance	See CWA section 316(a) – Thermal Discharges
Total Maximum Daily Load (TMDL) • Definition • Which Waterbodies Need TMDLs	 • § 130.2 • § 130.7
Toxics – Application and Testing	§ 122.21(g)(7) § 122.21(g)(9) § 122.21(g)(11)
Toxic Pollutants (Definition) • Technology-based Controls	§ 122.2 • § 122.44(e)
Toxic Pollutant List	§ 401.15
Toxicity Based Permit Limits	§ 125.3(c)(4)
Transfer of Permit	§ 122.61
Treatment Works Treating Domestic Sewage Sludge (TWTDS) (Definition)	§ 122.2
Twenty-four Hour Reporting	§ 122.41(l)(6)
Upset	§ 122.41(n)
Variances for • Non-POTWs • POTWs • Appeals of variances • Decisions on variances • Expedited variance procedures and time extensions • Procedures for variances when EPA is the permitting authority	 • § 122.21(m) • § 122.21(n) • § 124.64 • § 124.62 • § 122.21(o) • § 124.63

Exhibit B-2 Index to NPDES regulations (continued)

Subject	40 CFR section number
Vessel (Definition)	§ 112.2
Waste Stabilization Ponds (POTW)	§ 133.103(c)
Water Quality Report – CWA section 305(b)	§ 130.8
Water Quality Standards (WQS) • Scope • Purpose • Definitions • State Authority • EPA Authority • Submission, Minimum Requirements • Dispute Resolution • Establishment of Standards • Criteria • Antidegradation Policy • General Policies on Establishing WQS • State Review and Revision of WQS • EPA Review and Approval of WQS • EPA Promulgation of WQS • Federally Promulgated Standards (State-By-State List)	Part 131 • § 131.1 • § 131.2 • § 131.3 • § 131.4 • § 131.5 • § 131.6 • § 131.7 • § 131.10 • § 131.11 • § 131.12 • § 131.13 • § 131.20 • § 131.21 • § 131.22 • Part 131, Subpart D
Waters of the United States (Definition)	§ 122.2
Wetlands	See Waters of the U.S. § 122.2
Whole Effluent Toxicity (WET) Limits	§ 122.44(d)(1)(iv) § 125.3(c)(4)
WET Testing With Permit Application (POTWs)	§ 122.21(j)
Wild and Scenic Rivers Act	§ 122.49(a)
Withdrawal Of State Program	§§ 123.63 - 123.64

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Appendix C. Priority Pollutants

Exhibit C-1 presents the list of 126 priority (toxic) pollutants from 40 CFR Part 423 Appendix A, which are further discussed in sections 1.2 and 6.1.1.2 of this manual. Note that the list goes up to 129 because numbers 017, 049, and 050 were deleted.

Exhibit C-1 Priority pollutants from 40 CFR Part 423, Appendix A

#	Pollutant name	#	Pollutant name
001	Acenaphthene	067	Butyl benzyl phthalate
002	Acrolein	068	Di-N-Butyl Phthalate
003	Acrylonitrile	069	Di-n-octyl phthalate
004	Benzene	070	Diethyl Phthalate
005	Benzidine	071	Dimethyl phthalate
006	Carbon tetrachloride (tetrachloromethane)	072	1,2-benzanthracene (benzo(a) anthracene
007	Chlorobenzene	073	Benzo(a)pyrene (3,4-benzo-pyrene)
008	1,2,4-trichlorobenzene	074	3,4-Benzofluoranthene (benzo(b) fluoranthene)
009	Hexachlorobenzene	075	11,12-benzofluoranthene (benzo(b) fluoranthene)
010	1,2-dichloroethane	076	Chrysene
011	1,1,1-trichloreothane	077	Acenaphthylene
012	Hexachloroethane	078	Anthracene
013	1,1-dichloroethane	079	1,12-benzoperylene (benzo(ghi) perylene)
014	1,1,2-trichloroethane	080	Fluorene
015	1,1,2,2-tetrachloroethane	081	Phenanthrene
016	Chloroethane	082	1,2,5,6-dibenzanthracene (dibenzo(,h) anthracene)
018	Bis(2-chloroethyl) ether	083	Indeno (,1,2,3-cd) pyrene (2,3-o-pheynylene pyrene)
019	2-chloroethyl vinyl ether (mixed)	084	Pyrene
020	2-chloronaphthalene	085	Tetrachloroethylene
021	2,4, 6-trichlorophenol	086	Toluene
022	Parachlorometa cresol	087	Trichloroethylene
023	Chloroform (trichloromethane)	088	Vinyl chloride (chloroethylene)
024	2-chlorophenol	089	Aldrin
025	1,2-dichlorobenzene	090	Dieldrin
026	1,3-dichlorobenzene	091	Chlordane (technical mixture and metabolites)
027	1,4-dichlorobenzene	092	4,4-DDT
028	3,3-dichlorobenzidine	093	4,4-DDE (p,p-DDX)
029	1,1-dichloroethylene	094	4,4-DDD (p,p-TDE)
030	1,2-trans-dichloroethylene	095	Alpha-endosulfan
031	2,4-dichlorophenol	096	Beta-endosulfan
032	1,2-dichloropropane	097	Endosulfan sulfate
033	1,2-dichloropropylene (1,3-dichloropropene)	098	Endrin
034	2,4-dimethylphenol	099	Endrin aldehyde
035	2,4-dinitrotoluene	100	Heptachlor
036	2,6-dinitrotoluene	101	Heptachlor epoxide (BHC-hexachlorocyclohexane)
037	1,2-diphenylhydrazine	102	Alpha-BHC
038	Ethylbenzene	103	Beta-BHC
039	Fluoranthene	104	Gamma-BHC (lindane)
040	4-chlorophenyl phenyl ether	105	Delta-BHC (PCB-polychlorinated biphenyls)

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Exhibit C-1 Priority pollutants from 40 CFR Part 423, Appendix A (continued)

#	Pollutant name	#	Pollutant name
041	4-bromophenyl phenyl ether	106	PCB-1242 (Arochlor 1242)
042	Bis(2-chloroisopropyl) ether	107	PCB-1254 (Arochlor 1254)
043	Bis(2-chloroethoxy) methane	108	PCB-1221 (Arochlor 1221)
044	Methylene chloride (dichloromethane)	109	PCB-1232 (Arochlor 1232)
045	Methyl chloride (dichloromethane)	110	PCB-1248 (Arochlor 1248)
046	Methyl bromide (bromomethane)	111	PCB-1260 (Arochlor 1260)
047	Bromoform (tribromomethane)	112	PCB-1016 (Arochlor 1016)
048	Dichlorobromomethane	113	Toxaphene
051	Chlorodibromomethane	114	Antimony
052	Hexachlorobutadiene	115	Arsenic
053	Hexachloromyclopentadiene	116	Asbestos
054	Isophorone	117	Beryllium
055	Naphthalene	118	Cadmium
056	Nitrobenzene	119	Chromium
057	2-nitrophenol	120	Copper
058	4-nitrophenol	121	Cyanide, Total
059	2,4-dinitrophenol	122	Lead
060	4,6-dinitro-o-cresol	123	Mercury
061	N-nitrosodimethylamine	124	Nickel
062	N-nitrosodiphenylamine	125	Selenium
063	N-nitrosodi-n-propylamin	126	Silver
064	Pentachlorophenol	127	Thallium
065	Phenol	128	Zinc
066	Bis(2-ethylhexyl) phthalate	129	2,3,7,8-tetrachloro-dibenzo-p-dioxin (TCDD)

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Appendix D. New Source Dates by Effluent Guideline Category

This appendix provides the applicable new source dates used in making new source determinations by effluent guideline category as provided in Appendix B of the U.S. Environmental Protection Agency (EPA) memorandum *New Source Dates for Direct and Indirect Dischargers*[1] <www.epa.gov/npdes/pubs/newsource_dates.pdf> sent by the directors of EPA's Water Permits Division and the Engineering and Analysis Division to the Regional Water Division Directors on September 28, 2006. Section 5.2.2.4 of this manual discusses the determination of whether existing or new source standards apply.

EPA has promulgated regulations under the Clean Water Act (CWA) that establish effluent limitations guidelines for existing sources, standards of performance for new sources and pretreatment standards for new and existing sources. EPA has codified these regulations at Title 40 of the *Code of Federal Regulations* (CFR) Subchapter N. As discussed in section 5.2.1 of this manual, EPA has published effluent guidelines for 56 major industrial categories (over 450 subcategories) since the passage of the 1972 CWA. Those regulations limit the discharge of pollutants to surface waters by point source dischargers (*direct dischargers*). The regulations also limit the introduction of pollutants into publicly owned treatment works (POTWs) by industrial users (*indirect dischargers*). The CWA and EPA regulations define when a source is a *new source*. A discharger is defined as a new source in CWA sections 306(a)(2) and 307(c) and §§ 122.2 (for direct dischargers) and 403.3(m) (for indirect dischargers). In general, a facility is a new source if it begins construction after either the date of promulgation of new source performance standards applicable to the direct dischargers or the date of publication of a proposed new source performance standard applicable to an indirect discharger.

Exhibit D-1 lists new source dates for direct or indirect dischargers based on regulatory definitions. In some cases, effluent guidelines in 40 CFR Chapter I, Subchapter N, specify New Source Dates, and these dates are reported in the table below. If dates are not specified in the rule language, EPA based the date on the regulatory definitions of new source, which are cited above. EPA's General Pretreatment Regulations provide that an indirect source is a new source if construction of the source began after the publication of proposed pretreatment standards for new sources if the proposed standard is later finalized [§ 403.3(m)]. For direct dischargers, § 122.2 states that the New Source date is the proposal date if the standard is finalized within 120 days after its proposal; otherwise, the New Source date is the *promulgation date*. EPA's regulations establish the time and date of EPA's actions for purposes of determining when the action is subject to judicial review. The regulations, in the case of the CWA, define the date of an EPA promulgation action as two weeks after the rule appears in the *Federal Register* (see § 23.2). Before February 1985, the date on which the final rule was published was considered the promulgation date.

This document is not a regulation itself, nor does it substitute for any requirements under the CWA or EPA's regulations. Thus, it does not impose legally binding requirements on EPA, states or the regulated community. While EPA has made every effort to ensure the accuracy of this table, dischargers' obligations are determined, in the case of direct dischargers, by the terms of their NPDES permit and the CWA and EPA's regulations, and, in the case of indirect dischargers, by permits or equivalent control

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mechanisms issued to POTW industrial users and the CWA and EPA regulations. Nothing in this document changes any statutory or regulatory requirement. If the discussion in this memorandum conflicts with any permit or regulation, this document would not be controlling.

Exhibit D-1 New source dates by effluent category

40 CFR Part	Category	New source date for direct dischargers		New source date for indirect dischargers	
467	Aluminum Forming	Subparts A-F:	10/24/83	Subparts A-F:	11/22/82
427	Asbestos Manufacturing	Subparts A-K:	10/30/73[2]	Not Applicable	
461	Battery Manufacturing	Subparts A-G:	03/09/84	Subparts A-G	11/10/82
407	Canned and Preserved Fruits and Vegetables Processing	Subparts A-H:	03/21/74	Not Applicable	
408	Canned and Preserved Seafood Processing	Subparts A-J, N: Subparts O-AG:	06/26/74 12/01/75	Not Applicable	
458	Carbon Black Manufacturing	Subparts A-D:	01/09/78	Subparts A-D:	05/18/76
411	Cement Manufacturing	Subparts A-C:	02/20/74	Not Applicable	
437	Centralized Waste Treatment (CWT)	Subparts A-D:	01/05/01	Subparts A-D:	01/13/99
434	Coal Mining	Subparts B-E, H: Subpart G:	05/04/84[3] 02/22/02[4]	Not Applicable	
465	Coil Coating	Subparts A-C: Subpart D:	12/01/82 11/17/83	Subparts A-C: Subpart D:	01/12/81 02/10/83
412	Concentrated Animal Feeding Operations (CAFO)	Subparts A-B: Subparts C-D:	02/14/74 04/14/03[5]	Subpart B:	09/07/73
451	Concentrated Aquatic Animal Production	Subparts A-B:	09/07/04	Not Applicable	
468	Copper Forming	Subpart A:	08/15/83	Subpart A:	11/12/82
405	Dairy Products Processing	Subparts A-L:	05/28/74	Not Applicable	
469	Electrical and Electronic Components	Subparts A-B: Subparts C-D:	04/08/83 12/14/83	Subparts A-B: Subparts C-D:	08/24/82 03/09/83
413	Electroplating	Not Applicable[6]		See Metal Finishing[7]	
457	Explosives Manufacturing	Not Applicable		Not Applicable	
424	Ferroalloy Manufacturing	Subparts A-C:	02/22/74	Not Applicable	
418	Fertilizer Manufacturing	Subparts A-D: Subpart E: Subparts F-G:	04/08/74 01/16/76 10/07/74[8]	Subparts A-D[9]: Subpart E: Subparts F-G:	12/07/73 01/16/76 10/07/74
426	Glass Manufacturing	Subpart A: Subparts B-D: Subparts E-G: Subparts H, J-M:	01/22/74 02/14/74 02/14/74 01/16/75	Subparts H, K-M:	08/21/74
406	Grain Mills	Subparts A-J:	12/04/73[10]	Subpart A:	12/04/73
454	Gum and Wood Chemicals	Not Applicable		Not Applicable	
460	Hospitals	Not Applicable		Not Applicable	
447	Ink Formulating	Subpart A:	07/28/75	Subpart A:	02/26/75

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Exhibit D-1 New source dates by effluent category (continued)

40 CFR Part	Category	New source date for direct dischargers		New source date for indirect dischargers	
415	Inorganic Chemicals	Subparts B-F, H, K-N, P, Q, T, V, W, AJ [$CuSO_4$ manufacturing], AH, AP, AU [$NiSO_4$ manufacturing], BB: Subparts AJ [except $CuSO_4$ manufacturing], AU [except $NiSO_4$ manufacturing], BL - BO:	06/29/82 08/22/84	Subparts B-F, H, K-N, P, Q, V, AH, AJ [$CuSO_4$ manufacturing], AP, AU [$NiSO_4$ manufacturing], BB: Subparts T, AA, AC, AE, AI, AJ [except $CuSO_4$ manufacturing], AL, AN, AQ, AR, AU [except $NiSO_4$ manufacturing], AX, BC, BH, BK-BO:	07/24/80 10/25/83
420	Iron and Steel Manufacturing	Subparts A-B: Subpart C: Subpart D, Semi-Wet: Subpart D, Other: Subparts E-L: Subpart M:	11/18/02[11] 05/27/82 10/31/02 05/27/82 05/27/82 10/31/02	Subparts A-B: Subpart C: Subpart D, Semi-Wet: Subpart D, Other: Subparts E-F, H-J,L: Subpart M:	11/18/02[12] 01/07/81 12/27/00 01/07/81 01/07/81 12/27/00
445	Landfills	Subparts A-B:	02/02/00	Not Applicable	
425	Leather Tanning and Finishing	Subparts A, B, D-I: Subpart C:	11/23/82 04/04/88	Subpart A, B, D-I: Subpart C:	07/02/79 01/21/87
432	Meat and Poultry Products	Subparts A-D, Small Facilities: Subparts A-D, Other: Subparts E-I, Small Facilities: Subparts E-I, Other: Subpart J-L:	02/28/74[13] 09/22/04 01/03/75[14] 09/22/04 09/22/04	Not Applicable	
433	Metal Finishing	Subpart A:	07/15/83	Subpart A:	08/31/82
464	Metal Molding and Casting	Subparts A-D:	11/13/85	Subparts A-D:	11/15/82
438	Metal Products and Machinery	Subpart A:	06/12/03[15]	Not Applicable	
436	Mineral Mining and Processing	Not Applicable		Not Applicable	
471	Nonferrous Metals Forming and Metal Powders	Subparts A-J:	09/06/85	Subparts A-J:	03/05/84
421	Nonferrous Metal Manufacturing	Subparts B-I (except molybdenum acid plants), K-M: Subparts N-AE, molybdenum acid plants in subpart I: Subpart J:	03/08/84 10/04/85 02/04/88	Subparts B-I (except molybdenum acid plants), K-M: Subparts N-AE, molybdenum acid plants in subpart I: Subpart J:	02/17/83 06/27/84 01/22/87
435	Oil and Gas Extraction[16]	Subparts C (Onshore), D (Coastal), and E (Agriculture & Wildlife): Subparts A and D (Synthetic-Based Drilling Fluids):	03/04/93 02/05/01	Subpart D:	02/17/95
440	Ore Mining and Dressing	Subparts A-F, J, M:	12/03/82	Not Applicable	

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Exhibit D-1 New source dates by effluent category (continued)

40 CFR Part	Category	New source date for direct dischargers		New source date for indirect dischargers	
414	Organic Chemicals, Plastics, and Synthetic Fibers	Subparts B-H:	11/19/87	Subparts B-H:	03/21/83
446	Paint Formulating	Subpart A:	07/28/75	Subpart A:	02/26/75
443	Paving and Roofing Materials (Tars and Asphalt)	Subparts A-D:	07/28/75	Subparts A-D:	01/10/75
455	Pesticide Chemicals	Subparts A-B: Subparts C, E:	10/12/93 11/20/96	Subparts A-B: Subparts C, E:	04/10/92 04/14/94
419	Petroleum Refining	Subparts A-E:	10/18/82	Subparts A-E:	12/21/79
439	Pharmaceutical Manufacturing	Subparts A-D:	11/20/98[17]	Subparts A-D:	05/02/95
422	Phosphate Manufacturing	Subparts D-F:	06/23/76	Not Applicable	
459	Photographic	Not Applicable		Not Applicable	
463	Plastics Molding and Forming	Subparts A-C:	12/17/84	Not Applicable	
466	Porcelain Enameling	Subparts A-D:	11/24/82	Subparts A-D:	01/27/81
430	Pulp, Paper, and Paperboard	Subparts B, E: Subparts A, C, D, F, G, I-L:	06/15/98[18] 11/18/82	Subparts B, E: Subparts A, C, D, F, G, I-L:	12/17/93 01/06/81
428	Rubber Manufacturing	Subparts A-D: Subparts E-J:	02/21/74 01/10/75	Subparts E-K:	08/23/74
417	Soap and Detergents Manufacturing	Subparts A-S:	4/12/74	Subpart Q: Subparts O, P, R:	12/26/73 02/20/75
423	Steam Electric Power Generation		11/19/82[19]		10/14/80
409	Sugar Processing	Subpart A: Subparts B, C:	1/31/74 12/07/73[20]	Not Applicable	

[1] Boornazian, Linda and Mary Smith. 2006. *New Source Dates for Direct and Indirect Dischargers*. U.S. Environmental Protection Agency, Office of Water Memorandum. September 28, 2006. <www.epa.gov/npdes/pubs/newsource_dates.pdf>.

[2] The rule was finalized within 120 days of its October 30, 1973, proposal (38 FR 22606).

[3] The New Source date is specified in 40 CFR 434.11(j)(1).

[4] The New Source date is specified in 40 CFR 434.11(j)(1).

[5] New Source date derived from the 10-year protection period [see 40 CFR 412.35(d) and 412.43(d)].

[6] Direct dischargers formerly regulated under Part 413 are now regulated under Part 433 (metal finishing).

[7] Pretreatment categorical standards in Part 413 currently apply only to job shop electroplaters and independent printed circuit board manufacturers that were in existence before the New Source date for Part 433 (metal finishing). Job shop electroplaters and independent printed circuit board manufacturers that are "New Sources" must comply with PSNS in Part 433. Except for these "existing" job shop electroplaters and independent printed circuit board manufacturers, all other operations formerly subject to Part 413 are now subject to Part 433.

[8] The rule was finalized within 120 days of its October 7, 1974, proposal.

[9] Section 41 8.46 (the PSNS under Subpart D) was suspended until further notice, at 40 FR 26275, June 23, 1975, effective July 20, 1975.

[10] The rule was finalized within 120 days of its December 4, 1973, proposal (38 FR 33438).

Endnotes for this chapter continued on the next page.

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[11] Date specified in 40 CFR 420.14(a)(2), 420.16(a)(2), 420.24(b), and 420.26(a)(2).

[12] See previous footnote.

[13] The 2004 Amendment did not revise NSPSs for small meat products facilities in Subparts A-I, so the 2004 New Source date does not affect these facilities.

[14] See previous footnote.

[15] Date specified in 40 CFR 438.15.

[16] See promulgated standards at 40 CFR 58 FR 12505 and 66 FR 6850 for complete information on the applicability of New Source standards.

[17] New Source date derived from the 10-year protection period [see 40 CFR 439.15(c), 439.35(c), and 439.45(b)].

[18] Date specified in 40 CFR 430.25(b) and 430.55(b). Refer to these sections for additional information regarding the applicability of NSPSs.

[19] NSPS promulgated were not removed via the 1982 regulation; therefore wastewaters generated by Part 423-applicable sources that were New Sources under the 1974 regulations are subject to the 1974 NSPS. The New Source date for the 1974 regulations was 10/8/1974.

[20] The rule was finalized within 120 days of its December 7, 1973, proposal (38 FR 33846).

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An official website of the United States Government Here's how you know

PBT - Persistent Bioaccumulative Toxic Chemicals

Substance List Details

Type	Ad Hoc
Number of Entries	72
Description	EPA has finalized enhanced reporting requirements that focus on toxic chemicals which persist and bioaccumulate in the environment. These are known as persistent bioaccumulative toxic (PBT) chemicals. EPA is increasing the utility of the Toxic Release Inventory (TRI) to the public by adding PBT chemicals to the TRI list and by lowering the reporting thresholds for some of these chemicals. Toxic chemicals that persist and bioaccumulate are of particular concern because they remain in the environment for significant periods of time and concentrate in the organisms exposed to them. These PBT chemicals have the potential to cause serious human health and environmental effects resulting from low levels of release and exposure that would not be reported under the thresholds that apply to other toxic chemicals under Section 313.
Metadata Last Updated	Sep 20 2024
Last Synonym Update	Jun 16 2023
Admin Last Reviewed	

Search

- Substance Search
- Multiple Entry Search
- Advanced Search
- PMN & Accession Numbers Search

SRS Information

- About SRS
- Automated Services (Web Services/APIs)
- SRS FAQs

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List Steward(s)

Michael Hart |
hart.michael@epa.gov

List Export Options

Browse Substances

View the Substances on this List

Adjust Columns

1 – 72 of 72

Filter Synonyms

Synonym (+4 others)

Reset

Type text to filter the table.

Items per page: 100

Synonym	CAS	EPA ID	Molecular Formula	Active Status
1,2,3,4,6,7,8,9-Octachlorodibenzodioxin	3268-87-9		C12Cl8O2	Active
1,2,3,4,6,7,8,9-Octachlorodibenzofuran	39001-02-0		C12Cl8O	Active
1,2,3,4,6,7,8-Heptachlorodibenzodioxin	35822-46-9		C12HCl7O2	Active
1,2,3,4,6,7,8-Heptachlorodibenzofuran	67562-39-4		C12HCl7O	Active
1,2,3,4,7,8,9-Heptachlorodibenzofuran	55673-89-7		C12HCl7O	Active
1,2,3,4,7,8-Hexachlorodibenzodioxin	39227-28-6		C12H2Cl6O2	Active
1,2,3,4,7,8-Hexachlorodibenzofuran	70648-26-9		C12H2Cl6O	Active
1,2,3,6,7,8-Hexachlorodibenzodioxin	57653-85-7		C12H2Cl6O2	Active
1,2,3,6,7,8-Hexachlorodibenzofuran	57117-44-9		C12H2Cl6O	Active
1,2,3,7,8,9-Hexachlorodibenzodioxin	19408-74-3		C12H2Cl6O2	Active
1,2,3,7,8,9-Hexachlorodibenzofuran	72918-21-9		C12H2Cl6O	Active

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Synonym	CAS	EPA ID	Molecular Formula	Active Status
1,2,3,7,8-Pentachlorodibenzodioxin	40321-76-4		C12H3Cl5O2	Active
1,2,3,7,8-Pentachlorodibenzofuran	57117-41-6		C12H3Cl5O	Active
1-Nitropyrene	5522-43-0		C16H9NO2	Active
2,3,3',4,4',5,5'-Heptachlorobiphenyl	39635-31-9		C12H3Cl7	Active
2,3,3',4,4',5-Hexachlorobiphenyl	38380-08-4		C12H4Cl6	Active
2,3,3',4,4',5'-Hexachlorobiphenyl	69782-90-7		C12H4Cl6	Active
2,3,3',4,4'-Pentachlorobiphenyl	32598-14-4		C12H5Cl5	Active
2,3',4,4',5,5'-Hexachlorobiphenyl	52663-72-6		C12H4Cl6	Active
2,3,4,4',5-Pentachlorobiphenyl	74472-37-0		C12H5Cl5	Active
2,3',4,4',5-Pentachlorobiphenyl	31508-00-6		C12H5Cl5	Active
2,3',4,4',5'-Pentachlorobiphenyl	65510-44-3		C12H5Cl5	Active
2,3,4,6,7,8-Hexachlorodibenzofuran	60851-34-5		C12H2Cl6O	Active
2,3,4,7,8-Pentachlorodibenzofuran	57117-31-4		C12H3Cl5O	Active
2,3,7,8-Tetrachlorodibenzodioxin	1746-01-6		C12H4Cl4O2	Active
2,3,7,8-Tetrachlorodibenzofuran	51207-31-9		C12H4Cl4O	Active
3,3',4,4',5,5'-Hexachlorobiphenyl	32774-16-6		C12H4Cl6	Active
3,3',4,4',5-Pentachlorobiphenyl	57465-28-8		C12H5Cl5	Active
3,3',4,4'-Tetrachlorobiphenyl	32598-13-3		C12H6Cl4	Active
3-Methylcholanthrene	56-49-5		C21H16	Active
5-Methylchrysene	3697-24-3		C19H14	Active
7,12-Dimethylbenz(a)anthracene	57-97-6		C20H16	Active
7H-Dibenzo(c,g)carbazole	194-59-2		C20H13N	Active
Aldrin	309-00-2		C12H8Cl6	Active
Benzo(a)anthracene	56-55-3		C18H12	Active
Benzo(a)phenanthrene	218-01-9		C18H12	Active

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Synonym	CAS	EPA ID	Molecular Formula	Active Status
Benzo(a)pyrene	50-32-8		C20H12	Active
Benzo(b)fluoranthene	205-99-2		C20H12	Active
Benzo(g,h,i)perylene	191-24-2		C22H12	Active
Benzo(j)fluoranthene	205-82-3		C20H12	Active
Benzo(j,k)fluorene	206-44-0		C16H10	Active
Benzo(k)fluoranthene	207-08-9		C20H12	Active
Benzo(r,s,t)pentaphene	189-55-9		C24H14	Active
Chlordane	57-74-9		C10H6Cl8	Active
Dibenz(a,h)acridine	226-36-8		C21H13N	Active
Dibenz(a,j)acridine	224-42-0		C21H13N	Active
Dibenzo(a,e)fluoranthene	5385-75-1		C24H14	Active
Dibenzo(a,e)pyrene	192-65-4		C24H14	Active
Dibenzo(a,h)anthracene	53-70-3		C22H14	Active
Dibenzo(a,h)pyrene	189-64-0		C24H14	Active
Dibenzo(a,l)pyrene	191-30-0		C24H14	Active
Dioxin and dioxin-like compounds		E755371		Active
Fluoranthene	206-44-0		C16H10	Active
Heptachlor	76-44-8		C10H5Cl7	Active
Hexachlorobenzene	118-74-1		C6Cl6	Active
Indeno(1,2,3-cd)pyrene	193-39-5		C22H12	Active
Isodrin	465-73-6		C12H8Cl6	Active
Mercury	7439-97-6		Hg	Active
Mercury compounds		E650028		Active
Methoxychlor	72-43-5		C16H15Cl3O2	Active
Octachlorostyrene	29082-74-4		C8Cl8	Active

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Synonym	CAS	EPA ID	Molecular Formula	Active Status
PCBs	1336-36-3		Unspecified	Active
Pendimethalin	40487-42-1		C13H19N3O4	Active
Pentachlorobenzene	608-93-5		C6HCl5	Active
Polychlorinated biphenyls	1336-36-3		Unspecified	Active
Polycyclic aromatic compounds		E649749		Active
TBBPA	79-94-7		C15H12Br4O2	Active
Tetrabromobisphenol A	79-94-7		C15H12Br4O2	Active
Toxaphene	8001-35-2		Unspecified	Active
Trifluralin	1582-09-8		C13H16F3N3O4	Active
Vanadium compounds		E755389		Active
Vanadium (except alloys)	7440-62-2		V	Active

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ENVIRONMENTAL PROTECTION AGENCY

40 CFR Part 372

[OPPTS–400132C; FRL–6389–11]

RIN 2070–AD09

Persistent Bioaccumulative Toxic (PBT) Chemicals; Lowering of Reporting Thresholds for Certain PBT Chemicals; Addition of Certain PBT Chemicals; Community Right-to-Know Toxic Chemical Reporting

AGENCY: Environmental Protection Agency (EPA).

ACTION: Final rule.

SUMMARY: EPA is lowering the reporting thresholds for certain persistent bioaccumulative toxic (PBT) chemicals that are subject to reporting under section 313 of the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA) and section 6607 of the Pollution Prevention Act of 1990 (PPA). EPA is also adding a category of dioxin and dioxin-like compounds to the EPCRA section 313 list of toxic chemicals and establishing a 0.1 gram reporting threshold for the category. In addition, EPA is adding certain other PBT chemicals to the EPCRA section 313 list of toxic chemicals and establishing lower reporting thresholds for these chemicals. EPA is removing the fume or dust qualifier from vanadium and adding all forms of vanadium with the exception of vanadium when contained in alloys. EPA is also adding vanadium compounds to the EPCRA section 313 list of toxic chemicals. However, EPA is not lowering the reporting thresholds for either vanadium or vanadium compounds. EPA is taking these actions pursuant to its authority under EPCRA section 313(f)(2) to revise reporting thresholds and pursuant to its authority to add chemicals and chemical categories that meet the EPCRA section 313(d)(2) toxicity criteria. The additions of these chemicals are based on their carcinogenicity or other chronic human health effects and/or their significant adverse effects on the environment. Today's actions also include modifications to certain reporting exemptions and requirements for those toxic chemicals that are subject to the lower reporting thresholds. This document also announces the effective date of § 372.27 of the Code of Federal Regulations, which contained information collection requirements and which was originally published in the **Federal Register** on November 30, 1994.

DATES: 40 CFR 372.27 became effective on March 17, 1995, when the Office of Management and Budget approved its information collection requirements. This rule shall take effect on December 31, 1999. For purposes of EPCRA section 313(d)(4), the chemical additions shall be considered made as of November 30, 1999, and shall apply for the reporting year beginning January 1, 2000.

FOR FURTHER INFORMATION CONTACT: For technical information on this final rule contact: Daniel R. Bushman, Petitions Coordinator, Environmental Protection Agency, Mail Code 7408, 401 M St., SW., Washington, DC 20460; telephone number 202–260–3882, e-mail address: bushman.daniel@epa.gov. For general information on EPCRA section 313, contact the Emergency Planning and Community Right-to-Know Hotline, Environmental Protection Agency, Mail Code 5101, 401 M St., SW., Washington, DC 20460, Toll free: 1–800–535–0202, in Virginia and Alaska: 703–412–9877 or Toll free TDD: 1–800–553–7672.

SUPPLEMENTARY INFORMATION:

I. General Information

A. Does this Action Apply to Me?

You may be affected by this action if you manufacture, process, or otherwise use aldrin, chlordane, dioxin and certain dioxin-like compounds, heptachlor, hexachlorobenzene, isodrin, mercury, mercury compounds, methoxychlor, octachlorostyrene, pendimethalin, pentachlorobenzene, polychlorinated biphenyls, certain polycyclic aromatic compounds, tetrabromobisphenol A, toxaphene, trifluralin, and vanadium (except alloys) or vanadium compounds. See Table 1 in Unit V.C. for a more detailed listing. Potentially affected categories and entities may include, but are not limited to:

Category	Examples of Potentially Affected Entities
Industry	SIC major group codes 10 (except 1011, 1081, and 1094), 12 (except 1241), or 20 through 39; industry codes 4911 (limited to facilities that combust coal and/or oil for the purpose of generating power for distribution in commerce); 4931 (limited to facilities that combust coal and/or oil for the purpose of generating power for distribution in commerce); or 4939 (limited to facilities that combust coal and/or oil for the purpose of generating power for distribution in commerce); or 4953 (limited to facilities regulated under the Resource Conservation and Recovery Act, subtitle C, 42 U.S.C. section 6921 *et seq.*), or 5169, or 5171, or 7389 (limited to facilities primarily engaged in solvent recovery services on a contract or fee basis)
Federal Government	Federal facilities

This table is not intended to be exhaustive, but rather provides a guide for readers regarding entities likely to be affected by this action. Other types of entities not listed in the table could also be affected. To determine whether your facility would be affected by this action, you should carefully examine the applicability criteria in part 372, subpart B of Title 40 of the Code of Federal Regulations. If you have questions regarding the applicability of this action to a particular entity, consult the person listed in the ''FOR FURTHER INFORMATION CONTACT'' section.

B. How Can I Get Additional Information or Copies of this Document or Other Support Documents?

1. *Electronically*. You may obtain electronic copies of this document from the EPA Internet Home Page at http://www.epa.gov/. On the Home Page select ''Laws and Regulations'' and then look up the entry for this document under the ''**Federal Register**--Environmental Documents.'' You can also go directly to the ''**Federal Register**'' listings at http://www.epa.gov/fedrgstr/.

2. *In person*. The Agency has established an official record for this action under docket control number OPPTS–400132. The official record consists of the documents specifically referenced in this action, any public comments received during an applicable comment period, and any other information related to this action, including any information claimed as confidential business information (CBI). This official record includes the

documents that are physically located in the docket, as well as the documents that are referenced in those documents. The public version of the official record does not include any information claimed as CBI. The public version of the official record, which includes printed, paper versions of any electronic comments submitted during an applicable comment period, is available for inspection in the TSCA Nonconfidential Information Center, North East Mall Rm. B–607, Waterside Mall, 401 M St., SW., Washington, DC. The Center is open from noon to 4 p.m., Monday through Friday, excluding legal holidays. The telephone number for the Center is (202) 260–7099.

II. Statutory Authority

EPA is finalizing these actions under sections 313(d)(1) and (2), 313(f)(2), 313(g), 313(h), and 328 of EPCRA, 42 U.S.C. 11023(d)(1)-(2), 11023(f)(2), 11023(g), 11023(h) and 11048; PPA section 6607, 42 U.S.C. 13106.

Section 313 of EPCRA requires certain facilities manufacturing, processing, or otherwise using a listed toxic chemical in amounts above reporting threshold levels, to report certain facility specific information about such chemicals, including the annual quantity entering each environmental medium. These reports must be filed by July 1 of each year for the previous calendar year. Such facilities also must report pollution prevention and recycling data for these chemicals, pursuant to section 6607 of PPA.

A. What is the Authority for the Addition of Chemicals?

Section 313 established an initial list of toxic chemicals comprised of more than 300 chemicals and 20 chemical categories. Section 313(d) authorizes EPA to add or delete chemicals from the list, and sets forth criteria for these actions. EPA has added and deleted chemicals from the original statutory list on the basis of the criteria in subparagraph (A), (B) and/or (C) of subsection (d)(2) of EPCRA section 313. Under section 313(e)(1), any person may petition EPA to add chemicals to, or delete chemicals from, the list on the grounds that it does or does not meet the criteria at 313(d)(2)(A) or (B). Pursuant to EPCRA section 313(e)(1), EPA must respond to petitions within 180 days, either by initiating a rulemaking or by publishing an explanation of why the petition is denied. EPCRA section 313(d)(2) states that a chemical may be added to the list if any of the three listing criteria set forth there are met. Therefore, in order to add a chemical, EPA must find that at least one criterion is met, but does not need to examine whether all other criteria are also met. EPA has published a statement elaborating its interpretation of the section 313(d)(2) and (3) criteria for adding and deleting chemicals from the section 313 list (at 59 FR 61432, November 30, 1994) (FRL–4922–2).

B. What is the Authority for the Lowering of Reporting Thresholds?

EPA is finalizing these actions pursuant to its authority under EPCRA section 313(f)(2) to revise reporting thresholds. EPCRA section 313 establishes default reporting thresholds, which are set forth in section 313(f)(1). Section 313(f)(2), however, provides that EPA:

> may establish a threshold amount for a toxic chemical different from the amount established by paragraph (1). Such revised threshold shall obtain reporting on a substantial majority of total releases of the chemical at all facilities subject to the requirements of this section. The amounts established by EPA may, at the Administrator's discretion, be based on classes of chemicals or categories of facilities.

This provision provides EPA with broad, but not unlimited, authority to establish thresholds for particular chemicals, classes of chemicals, or categories of facilities, and commits to EPA's discretion the determination that a different threshold is warranted. Congress also committed the determination of the levels at which to establish any alternate thresholds to EPA's discretion, requiring only that any ''revised threshold shall obtain reporting on a substantial majority of total releases of the chemical at all facilities subject to the requirements'' of section 313. 42 U.S.C. 11023(f)(2).

For purposes of determining what constitutes a ''substantial majority of total releases,'' EPA interprets the language in section 313(f)(2), ''facilities subject to the requirements of [section 313],'' to refer to those facilities that fall within the category of facilities described by sections 313(a) and (b), i.e., the facilities currently reporting. Subsection (a) lays out the general requirement that ''the owner or operator of facilities subject to the requirements of this section shall'' file a report under EPCRA section 313. Subsection (b) then defines the facilities subject to the requirements of this section:

> [t]he requirements of this section shall apply to owners and operators of facilities that have 10 or more full-time employees and that are in Standard Industrial Classification Codes 20-39, . . . and that manufactured, processed, or otherwise used a toxic chemical listed under subsection (c) of this section in excess of the quantity of that toxic chemical established under subsection (f) of this section during the calendar year for which a toxic chemical release form is required under this section.

Thus, in revising the reporting thresholds, EPA must ensure that, under the new thresholds, a substantial majority of releases currently being reported will continue to be reported. No further prerequisites for exercising this authority appears in the statute.

C. What is the Authority for Modifications to Other EPCRA Section 313 Reporting Requirements?

Today's actions also include modifications to certain reporting exemptions and requirements for those toxic chemicals that are subject to the lower reporting thresholds. Congress granted EPA rulemaking authority to allow the Agency to fully implement the statute. EPCRA section 328 provides that the ''Administrator may prescribe such regulations as may be necessary to carry out this chapter'' (28 U.S.C. 11048).

III. Background Information

A. What is the General Background for this Action?

Under EPCRA section 313, Congress set the initial parameters of the Toxic Release Inventory, but also gave EPA clear authority to modify reporting in various ways, including authority to change the toxic chemicals subject to reporting, the facilities required to report, and the threshold quantities that trigger reporting. By providing this authority, Congress recognized that the TRI program would need to evolve to meet the needs of a better informed public and to refine existing information. EPA has, therefore, undertaken a number of actions to expand and enhance TRI. These actions include expanding the number of reportable toxic chemicals by adding 286 toxic chemicals and chemical categories to the EPCRA section 313 list in 1994. Further, a new category of facilities was added to EPCRA section 313 on August 3, 1993, through Executive Order 12856, which requires Federal facilities meeting threshold requirements to file annual EPCRA section 313 reports. In addition, in 1997 EPA expanded the number of private sector facilities that are required to report under EPCRA section 313 by adding seven new industrial groups to the list of covered facilities. At the same time, EPA has sought to reduce the burden of EPCRA section 313 reporting by actions such as delisting chemicals it has determined do not meet the statutory listing criteria and establishing

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an alternate reporting threshold of 1 million pounds for facilities with 500 pounds or less of production-related releases and other wastes. Facilities meeting the requirements of this alternate threshold may file a certification statement (Form A) instead of reporting on the standard EPCRA section 313 form, the Form R.

In today's actions, EPA is finalizing enhanced reporting requirements that focus on a unique group of toxic chemicals. These toxic chemicals which persist and bioaccumulate in the environment are commonly referred to as persistent bioaccumulative toxic chemicals or PBT chemicals. To date, with the exception of the alternate threshold certification on Form A, EPA has not altered the statutory reporting threshold for any listed chemicals. However, as the TRI program has evolved over time and as communities identify areas of special concern, thresholds and other aspects of the EPCRA section 313 reporting requirements may need to be modified to assure the collection and dissemination of relevant, topical information and data. Towards that end, EPA is increasing the utility of TRI to the public by adding a number of chemicals to the section 313 list of toxic chemicals that persist and bioaccumulate in the environment and by lowering the reporting thresholds for a number of toxic chemicals that have these properties. Toxic chemicals that persist and bioaccumulate are of particular concern because they remain in the environment for significant periods of time and concentrate in the organisms exposed to them. EPA believes that the public understands that these PBT chemicals have the potential to cause serious human health and environmental effects resulting from low levels of release and exposure (Refs. 75 and 76). Lowering the reporting thresholds for PBT chemicals will ensure that the public has important information on the quantities of these chemicals released or otherwise managed as waste, that would not be reported under the 10,000 and 25,000 pound/year thresholds that apply to other toxic chemicals.

B. What Outreach Has EPA Conducted?

EPA has engaged in a comprehensive outreach effort. This outreach served to inform interested parties, including industry groups affected by the rule, state regulatory officials, environmental organizations, labor unions, community groups, and the general public of EPA's intention to add certain PBT chemicals to the list of toxic chemicals under EPCRA section 313 and lower the applicable reporting thresholds for a subset of PBT chemicals. For all interested parties, EPA held three public meetings (in Chicago, IL (February 23, 1999); San Francisco, CA (March 5, 1999); and Washington, DC (February 16, 1999)) during the comment period for the proposal. Participants included a range of industry representatives, trade associations (representing both small and large businesses), law firms representing industry groups, environmental groups, the general public, plus other groups and organizations. For state and tribal governments, EPA attended the regularly-held public meetings of the Forum on State and Tribal Toxics Action (FOSTTA) to discuss the PBT proposal. EPA also received substantial public comment on this proposal, to which EPA is responding in this Final Rule and the Response to Comments document (Ref. 69). In response to the strong interest by the public, and to allow more individuals and groups to submit their comments, EPA extended the public comment period to April 7, 1999 (at 64 FR 9957, March 1, 1999) (FRL–6066–1). Additional information regarding EPA's outreach may be found in supporting documents included in the public version of the official record.

IV. Summary of Proposal

A. What Chemicals Did EPA Propose to Add to the EPCRA Section 313 List of Toxic Chemicals?

In an initial screening of PBT chemicals that appear on the list of chemicals of concern in the various chemical initiatives, EPA identified seven chemicals and one category of chemicals that persist and bioaccumulate in the environment but that were not on the list of EPCRA section 313 toxic chemicals. Although identification of these chemicals for initial consideration prior to this rulemaking was based on their status as PBT chemicals, their proposed addition in this rulemaking was based solely on the determination that they meet the EPCRA section 313(d)(2) listing criteria. All of the chemicals proposed for addition were found to be reasonably anticipated to cause serious or irreversible chronic human health effects at relatively low doses or ecotoxicity at relatively low concentrations, and thus are considered to have moderately high to high chronic toxicity or high ecotoxicity. The chemicals and chemicals categories EPA proposed to add to the list of EPCRA section 313 toxic chemicals include: Dioxin and dioxin-like compounds category, benzo(g,h,i)perylene, benzo(j,k)fluorene (fluoranthene), 3-methylcholanthrene, octachlorostyrene, pentachlorobenzene, tetrabromobisphenol A (TBBPA), vanadium (except alloys) and vanadium compounds.

B. What Persistence and Bioaccumulation Issues Did EPA Consider?

As noted above, for purposes of the proposed rule, EPA conducted its first, limited review of chemicals for their persistence and bioaccumulation properties under EPCRA section 313. EPA first established criteria to be used under section 313 for determining if a chemical persists or bioaccumulates in the environment. These criteria were then applied to determine whether the chemicals included in the review have the potential to persist and bioaccumulate in the environment. The initial group of chemicals reviewed were the result of EPA's screening assessment of two lists of persistent and bioaccumulative chemicals: (1) The Great Lakes Binational Level 1 list (Ref. 24); and (2) chemicals that received high scores for persistence and bioaccumulation in the initial version of the Waste Minimization Prioritization Tool (WMPT) developed by EPA's Office of Solid Waste (Ref. 74). Finally, included in this initial review were the chemicals included in the dioxin and dioxin-like compounds category that EPA had proposed for addition to the section 313 list in 1997 (at 62 FR 24887, May 7, 1997) (FRL–5590–1).

1. *Persistence*. A chemical's persistence refers to the length of time the chemical can exist in the environment before being destroyed (i.e., transformed) by natural processes. The proposal discussed those aspects of persistence that are important to consider in determining a chemical's persistence in the environment and set forth the criteria that EPA used for determining whether a chemical is persistent for purposes of reporting under EPCRA section 313. Numerous organizations and internationally negotiated agreements have set numerical criteria for environmental persistence, many of which have been developed through consensus processes (Ref. 68). Of those reviewed, the criteria for persistence in water, soil, and sediment tend to cluster around two half-lifes, 1 to 2 months and 6 months while the persistence criterion for air was either a half-life of 2 or 5 days. A half-life of 6 months for water, soil, and sediment and half-lifes of either 2 or 5 days for air were chosen by the international organizations as criteria for chemicals that are being banned or

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severely restricted. However, EPCRA section 313 is an information collection and dissemination program. EPA believes that persistence criteria consistent with the criteria applied to chemicals that are of global or regional (e.g., Europe and the Great Lakes) concern and that are targeted for ban, restriction, or phase-out are inappropriate for such a program. Chemicals that meet the persistence criteria used in the international agreements are the extremely persistent chemicals. Applying these strict criteria to EPCRA section 313 would result in a very narrow list of chemicals that would focus on only extremely persistent chemicals. This is inconsistent with one of the fundamental tenets of right-to-know which is to provide the public with information on toxic chemicals that have the potential to cause adverse effects in their community. Further, persistence criteria of half-lifes of 6 months and 5 days have not been used to establish whether a chemical is a PBT chemical but rather whether a chemical should have restrictions on its uses. The Agency stated in the proposal its belief that half-life criteria of 2 months for water, sediment, and soil and 2 days for air will include a better representative sample of chemicals that persist in the environment. Therefore, EPA used a half-life criterion of 2 months for water, sediment, and soil and a half-life of 2 days for air for the purposes of determining under EPCRA section 313 whether a toxic chemical is persistent in the environment. Under these criteria, if a toxic chemical meets any one of the media-specific criteria, it is considered to be persistent.

2. *Bioaccumulation*. Bioaccumulation is a general term that is used to describe the process by which organisms may accumulate chemical substances in their bodies. The term refers to both uptake of chemicals from water (bioconcentration) and from ingested food and sediment residues. The discussions and data on bioaccumulation in the proposed rule dealt strictly with aquatic organisms because most of the bioaccumulation data are from aquatic studies. The proposal also discussed, in detail, those aspects of determining bioaccumulation that are important to consider in assessing whether a particular chemical will bioaccumulate in the environment.

A chemical's potential to bioaccumulate can be quantified by measuring or predicting a chemical's bioaccumulation factor (BAF) or a chemical's bioconcentration factor (BCF). Sources of BAF and BCF data for the chemicals included in the proposed rule included a mixture of both predicted and measured BAF and BCF values. The record for the proposed rule includes a document that explains the origin of the BAF or BCF value selected for each PBT chemical (Ref. 71). Most data were retrieved from the U.S. EPA's AQUIRE data base (Ref. 58) and the Japanese Chemicals Inspection and Testing Institute (CITI) data base (Ref. 18a).

As with persistence, a number of organizations and internationally negotiated agreements have set numerical criteria for bioaccumulation, many of which have been developed through a consensus processes. Of those reviewed, the criteria used for bioaccumulation was a BAF/BCF numerical value of either 5,000 or 1,000 or, in some cases, 500. The bioaccumulation criteria chosen by the international organizations as criteria for chemicals that are being banned or severely restricted was 5,000. However, for the same reasons discussed in Unit IV.B.1., EPA stated that the criteria used by the international organizations would not be appropriate for purposes of EPCRA section 313. Therefore, EPA used a BAF/BCF numerical criterion of 1,000 for determining if a chemical is bioaccumulative for purposes of EPCRA section 313.

3. *Persistence and bioaccumulation data*. In the proposal, EPA presented the bioaccumulation and persistence data for the PBT chemicals being considered. More detailed discussions of the sources of these data are provided in the support documents (Refs. 7 and 71). When considering the bioaccumulation and persistence potential of chemical categories, EPA reviewed the individual bioaccumulation and persistence data for the category members and determined in which tier the entire chemical category should be placed. For chemicals that had half-life ranges that bracketed the persistence tiers, EPA considered the types of studies supporting the half-life ranges and determined the most appropriate tier for each chemical.

C. How Did EPA Propose to Address Dioxin and Dioxin-Like Compounds?

In response to a petition from Communities For A Better Environment, EPA issued a proposed rule (at 62 FR 24887) to add a category of dioxin and dioxin-like compounds to the EPCRA section 313 list of toxic chemicals. As part of that action, EPA proposed to move 11 co-planar polychlorinated biphenyls (PCBs) from their listing under Chemicals Abstract Service Registry (CAS) Number 1336–36–3 to the dioxin and dioxin-like compounds category. However, since PCBs persist and bioaccumulate, EPA stated its belief in the proposed rule that PCBs should be subject to lower reporting thresholds. Thus EPA believed there was no need to move the 11 co-planar PCBs to the proposed dioxin and dioxin-like compounds category. Therefore, EPA withdrew its original proposal to modify the listing for PCBs and instead proposed to lower the reporting thresholds for the current PCB listing which covers all PCBs (at 64 FR 710). Because of this change, the proposed dioxin and dioxin-like compounds category included only the 7 polychlorinated dibenzo-*p*-dioxins and the 10 polychlorinated dibenzofurans identified in the proposed rule. In order to focus reporting on those facilities that actually add to the environmental loading of the dioxin and dioxin-like compounds and to reduce reporting burden, EPA proposed to add the activity qualifier ''manufacture only'' to the category. This qualifier would have limited reporting to those dioxin and dioxin-like compounds that are manufactured at the facility, including those coincidentally manufactured.

D. What Proposed Changes to Reporting Requirements for PBT Chemicals Did EPA Consider?

1. *Changes to reporting thresholds*. In evaluating potential lower reporting thresholds for PBT chemicals, EPA considered not only their persistence and bioaccumulation and the purposes of EPCRA section 313, but also the potential burden that might be imposed on the regulated community. Because all PBT chemicals persist and bioaccumulate in the environment, they have the potential to pose greater exposure to humans and the environment over a longer period of time (Refs. 75 and 76). The nature of PBT chemicals indicates that small quantities of such chemicals are of concern, which provides strong support for setting lower reporting thresholds than the current section 313 thresholds of 10,000 and 25,000 pounds. For determining the levels at which reporting thresholds should be set for these chemicals, EPA adopted a two-tiered approach. EPA made a distinction between persistent bioaccumulative toxic chemicals and highly persistent, highly bioaccumulative toxic chemicals by proposing to set lower reporting thresholds based on two levels of persistence and bioaccumulation potential. EPA proposed to set a manufacture, process and otherwise use threshold of 100 pounds for PBT chemicals and a threshold of 10 pounds for that subset of PBT chemicals that are highly persistent and highly

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bioaccumulative toxic chemicals. One exception to this is the reporting threshold for the dioxin and dioxin-like compounds category, see the discussion in Unit IV.D.2.

In determining the appropriate reporting thresholds to propose for PBT chemicals, EPA started with the premise that low or very low reporting thresholds may be appropriate for these chemicals based on their persistence and bioaccumulation potentials only. EPA then considered the burden that would be imposed by lower reporting thresholds and the distribution of reporting across covered facilities. Considering the factors described above, in addition to the purposes of EPCRA section 313, EPA proposed to lower the manufacture, process, and otherwise use thresholds to 100 pounds for PBT chemicals and to 10 pounds for that subset of PBT chemicals that are highly persistent and highly bioaccumulative. EPA presented the proposed section 313 reporting thresholds for each of the PBT chemicals considered. For purposes of section 313 reporting, threshold determinations for chemical categories are based on the total of all toxic chemicals in the category (see 40 CFR 372.25(d)).

2. *Special reporting threshold for dioxin and dioxin-like compounds.* The category of dioxin and dioxin-like compounds are highly persistent and highly bioaccumulative toxic chemicals. However, this category of chemicals poses unique problems with regard to setting section 313 reporting thresholds because these chemicals are generally produced in extremely small amounts compared to other section 313 chemicals. In response to EPA's original proposal to add dioxin and dioxin-like compounds, EPA received numerous comments suggesting that the reporting threshold for this category be set at zero. EPA stated its belief that rather than setting a zero reporting threshold it would be better to set a very low threshold that provides facilities with a clear indicator of when they are required to report. EPA proposed a manufacture threshold of 0.1 gram for the category. EPA expressed its intent to develop reporting guidance for industries that may fall within this reporting category. In addition to the proposed lower reporting threshold for the dioxin and dioxin-like compounds category, EPA requested comment on an alternative way of reporting release and other waste management data for this category. This alternative included reporting release and other waste management data for the dioxin and dioxin-like compounds category in terms of grams of toxicity equivalents (TEQs).

E. What Other Reporting Issues Did EPA Consider for PBT Chemicals?

1. *De minimis exemption.* In 1988, EPA promulgated the *de minimis* exemption because: (1) The Agency believed that facilities newly covered by EPCRA section 313 would have limited access to information regarding low concentrations of toxic chemicals in mixtures that are imported, processed, otherwise used or manufactured as impurities; (2) the Agency did not believe that these low concentrations would result in quantities that would significantly contribute to threshold determinations and release calculations at the facility (53 FR 4509, February 16, 1988); and (3) the exemption was consistent with information collected by the Occupational Safety and Health Administration's (OSHA) Hazard Communication Standard (HCS). However, given that: (1) Covered facilities currently have several sources of information available to them regarding the concentration of PBT chemicals in mixtures; (2) even minimal releases of persistent bioaccumulative chemicals may result in significant adverse effects and can reasonably be expected to significantly contribute to exceeding the proposed lower thresholds; and (3) the concentration levels chosen, in part, to be consistent with the OSHA HCS are inappropriately high for PBT chemicals, EPA's original rationale for the *de minimis* exemption does not apply to PBT chemicals. EPA therefore proposed to eliminate the *de minimis* exemption for PBT chemicals. EPA did not propose, however, to modify the applicability of the *de minimis* exemption to the supplier notification requirements (40 CFR 372.45(d)(1)) because the Agency believed there was sufficient information available.

2. *Use of the alternative threshold and Form A.* EPA stated its belief that use of the existing alternate threshold and reportable quantity for Form A would be inconsistent with the intent of expanded PBT chemical reporting. The general information provided in the Form A on the quantities of the chemical that the facility manages as waste is insufficient for conducting analyses on PBT chemicals and would be virtually useless for communities interested in assessing risk from releases and other waste management of PBT chemicals. EPA, therefore, proposed excluding all PBT chemicals from the alternate threshold of 1 million pounds.

3. *Proposed changes to the use of range reporting.* EPA stated its belief that use of ranges could misrepresent data accuracy for PBT chemicals because the low or the high end range numbers may not really be that close to the estimated value, even taking into account its inherent error (i.e., errors in measurements and developing estimates). EPA believed this uncertainty would severely limit the applicability of release information where the majority of releases, particularly for PBT chemicals, are expected to be within the amounts eligible for range reporting. Given EPA's belief that the large uncertainty that would be part of these data would severely limit their utility, EPA proposed to eliminate range reporting for PBT chemicals.

4. *Proposed changes to the use of the half-pound rule and whole numbers.* EPA currently allows facilities to report whole numbers and to round releases of 0.5 pound or less to zero. EPA explained its concern that the combination of requiring the reporting of whole numbers and allowing rounding to zero would result in a significant number of facilities reporting their releases of some PBT chemicals as zero. EPA, therefore, proposed that all releases or other waste management quantities greater than 1/10 of a pound of PBT chemicals (except dioxins) be reported, provided that the appropriate activity threshold has been exceeded. For the category of dioxin and dioxin-like compounds, which have a proposed reporting threshold of 0.1 gram, EPA proposed that facilities report all releases and other waste management activities greater than 100 micrograms (ug) (i.e., 0.0001 gram).

5. *Proposed changes to other EPCRA section 313 reporting requirements.* The alkyl lead compounds tetraethyl lead (CAS No. 78–00–2) and tetramethyl lead (CAS No. 75–74–1) are currently reportable under the EPCRA section 313 category listing for lead compounds. However, these two chemicals specifically appear on the Binational Level 1 list of chemicals that have been identified for virtual elimination from the Great Lakes and thus are of special concern. EPA, therefore, proposed that separate reports be filed for these two members of the lead compounds category, which would allow better tracking of these specific lead compounds. In addition, EPA proposed to list ''vanadium'' and ''vanadium compounds'' and delete the EPCRA section 313 listing for ''vanadium (fume or dust).'' Since vanadium without the fume or dust qualifier would be a new section 313 listing, EPA did not propose to include additional reporting on alloys containing vanadium. In the proposal, EPA deferred making a final decision on

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vanadium contained in alloys until the Agency could complete a scientific review of issues pertinent to some alloys. EPA proposed to include the qualifier ''except when contained in an alloy'' in the vanadium listing. EPA also requested comment on the adequacy of existing studies for determining the bioaccumulation potential of cobalt and cobalt compounds.

V. Summary of the Final Rule

A. Which Chemicals is EPA Adding to the List of Toxic Chemicals Under EPCRA Section 313?

In this action, EPA is adding seven chemicals and two chemical compound categories to the list of toxic chemicals subject to reporting under EPCRA section 313. These chemicals include: benzo(g,h,i)perylene, benzo(j,k)fluorene (fluoranthene), 3-methylcholanthrene, octochlorostyrene, pentachlorobenzene, TBBPA, vanadium (except when in an alloy), vanadium compounds, and a category consisting of 17 specified dioxin and dioxin-like compounds. EPA has determined that each of these chemicals and chemical compound categories meets the listing criteria under EPCRA section 313(d)(2). Two of these chemicals, 3-methylchloanthrene and benzo(j,k)fluorene (fluoranthene), are being added as members of the polycyclic aromatic compounds (PACs) category. Vanadium, with the qualifier ''fume or dust,'' has been on the list of toxic chemicals since the program's inception in 1987. In today's action, however, the Agency is removing the ''fume or dust'' qualifier from the vanadium listing. However, EPA is not including reporting on vanadium when contained in alloys. EPA is finalizing the proposed qualifier ''except when contained in an alloy'' to the vanadium listing. Therefore all elemental vanadium, unless it is in an alloy, is now reportable under EPCRA section 313. In addition to modifying the qualifier, EPA is also adding a new vanadium compounds category. Thus, all chemical compounds that contain vanadium are reportable under this listing. Further, EPA is finalizing its proposal (62 FR 24887) to add dioxins and 16 dioxin-like compounds. However, the Agency is modifying the qualifier that it originally included with this listing. In the PBT proposed rule, EPA proposed to add the dioxin and dioxin-like compounds category with the qualifier ''manufacturing only.'' However, based on comments the Agency received, EPA is changing this qualifier to include: Manufacturing; and the processing or otherwise use of dioxin and dioxin-like compounds if the dioxin and dioxin-like compounds are present as contaminants in a chemical and if they were created during the manufacturing of that chemical.

B. Which Chemicals is EPA Including as PBT Chemicals Under EPCRA Section 313?

EPA has made the final determination that 18 of the chemicals and chemical categories proposed meet the EPCRA section 313 criteria for persistence and bioaccumulation. Thus EPA is lowering the reporting threshold for all of these toxic chemicals. These chemicals and their final thresholds are listed in Table 1 below:

Table 1.—Reporting Thresholds for EPCRA Section 313 Listed PBT Chemicals

Chemical Name or Chemical Category Name	CASRN	Section 313 Reporting Threshold (in pounds unless noted otherwise)
Aldrin	309-00-2	100
Benzo(g,h,i)perylene	191-24-2	10
Chlordane	57-74-9	10
Dioxin and dioxin-like compounds category (manufacturing; and the processing or otherwise use of dioxin and dioxin-like compounds if the dioxin and dioxin-like compounds are present as contaminants in a chemical and if they were created during the manufacturing of that chemical)	NA	0.1 grams
Heptachlor	76-44-8	10
Hexachlorobenzene	118-74-1	10
Isodrin	465-73-6	10
Methoxychlor	72-43-5	100
Octachlorostyrene	29082-74-4	10
Pendimethalin	40487-42-1	100
Pentachlorobenzene	608-93-5	10
Polycyclic aromatic compounds category	NA	100
Polychlorinated biphenyl (PCBs)	1336-36-3	10
Tetrabromobisphenol A	79-94-7	100
Toxaphene	8001-35-2	10
Trifluralin	1582-09-8	100
Mercury	7439-97-6	10

Table 1.—Reporting Thresholds for EPCRA Section 313 Listed PBT Chemicals—Continued

Chemical Name or Chemical Category Name	CASRN	Section 313 Reporting Threshold (in pounds unless noted otherwise)
Mercury compounds	NA	10

EPA is deferring its decision for two chemicals and one chemical category. Specifically, EPA is deferring a determination on dicofol while the Agency continues to review the available persistence data. EPA is also deferring its decision on cobalt and cobalt compounds because it needs to further investigate the bioaccumulative potential of these chemicals.

C. What Thresholds Has EPA Established for PBT chemicals?

EPA is finalizing the thresholds it proposed for PBT chemicals in the January 5, 1999 (64 FR 688) **Federal Register**. Specifically, EPA is finalizing two thresholds based on the chemicals' potential to persist and bioaccumulate in the environment. The two levels include setting section 313 manufacture, process, and otherwise use thresholds at 100 pounds for PBT chemicals and at 10 pounds for that subset of PBT chemicals that are highly persistent and highly bioaccumulative. One exception is the dioxin and dioxin-like compounds category. The dioxin and dioxin-like compounds category threshold determination required special consideration because these highly persistent and highly bioaccumulative compounds are manufactured in extremely small amounts compared to other section 313 chemicals. In order to capture release and other waste management data, EPA is setting the threshold for the dioxin and dioxin-like compound category at 0.1 gram.

D. What Exemptions and Other Reporting Issues is EPA Addressing?

EPA is eliminating the *de minimis* exemption for the PBT chemicals included in today's final rule. However, this action will not affect the applicability of the *de minimis* exemption to the supplier notification requirements (40 CFR 372.45(d)(1)). During the inter-agency review process, it was suggested that EPA consider constructing an exemption for facilities in SIC code 5171, i.e., Petroleum Bulk Plants and Terminals. Specifically, it was suggested that EPA exempt the processing of PBT chemicals in petroleum products. Before EPA can consider this exemption, EPA must determine that these facilities process and release and otherwise manage as waste very small aggregate quantities of PBT chemicals. The Agency is soliciting comments and information on this suggestion, particularly any information that could provide a factual basis for such an exemption. Please send your comments to the person listed in the ''FOR FURTHER INFORMATION CONTACT'' section within the next 60 days. EPA will evaluate this suggestion, and provide a response within approximately 180 days.

In today's action, EPA is also excluding all PBT chemicals from eligibility for the alternate threshold of 1 million pounds and eliminating for PBT chemicals range reporting for on-site releases and transfers off-site for further waste management. This will not affect the applicability of the range reporting of the maximum amount on-site as required by EPCRA section 313(g). EPA is addressing the alkyl lead compounds, tetraethyl lead (CAS No. 78–00–2), and tetramethyl lead (CAS No. 75–74–1), in a separate rulemaking for lead and lead compounds (64 FR 42222, August 3, 1999) (FRL–6081–4). Therefore, EPA is not finalizing any action with respect to these two lead compounds in today's action.

EPA proposed to require reporting of all releases and other waste management quantities greater than 1/10 of a pound of PBT chemicals (except dioxin), provided that the accuracy in the underlying data on which the estimate is based supports this level of precision. Also, EPA stated that releases and other waste management quantities would continue to be reported to two significant digits. In addition, EPA stated that for quantities of 10 pounds or greater, only whole numbers would be required to be reported. For the category of dioxin and dioxin-like compounds, which have a proposed reporting threshold of 0.1 gram, EPA proposed that facilities report all releases and other waste management activities greater than 100 µg (i.e., 0.0001 gram). After reviewing all the comments on this issue, EPA is providing additional guidance on the level of precision at which facilities should report their releases and other waste management quantities of PBT chemicals. Facilities should still report releases and other waste management quantities greater than 0.1 pound (except dioxins) provided the accuracy and the underlying data on which the estimate is based supports this level of precision. Rather than reporting in whole numbers and to two significant digits, if a facility's release or other waste management estimates support reporting an amount that is more precise than whole numbers and two significant digits, then the facility should report that more precise amount. The Agency believes that, particularly for PBT chemicals, facilities may be able to calculate their estimates of releases and other waste management quantities to 1/10 of a pound and believes that such guidance is consistent with the reporting requirements of sections 313(g) and (h).

E. What is the Relationship Between This Rule and the Clean Air Act Mercury Information Collection Request?

Throughout calendar year 1999, EPA has been using authority under section 114 of the Clean Air Act to require all coal-fired power plants over 25 mega watts to submit to EPA the results of analyses of the mercury content of their coal. A representative sample of these plants, stratified by type of plant and type of coal burned, have been required to perform stack testing to determine the amount (and species) of mercury emitted. The stack testing will allow EPA to develop a set of emissions factors that can be applied to the mercury in coal analysis to generate mercury emissions estimates for each coal-fired plant. EPA does not intend to continue to require plants to submit either the coal analysis or the stack testing beyond the current requirement. Therefore for the purpose of reporting mercury releases to the TRI, EPA expects coal-fired power plants that do not have monitoring or stack test data for the reporting year to use the emissions factors that EPA will develop and make available to the public in the summer of 2000.

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VI. Summary of Public Comments and EPA Responses

A. What Comments Did EPA Receive on its Statutory Authority to Add Chemicals and Lower the Reporting Threshold and What is EPA's Response?

Several commenters assert that EPCRA section 313(f)(2) only grants EPA the authority to raise the statutory thresholds, but not to lower them. They agree that the substantial majority test is met ''as a matter of logical necessity'' when EPA lowers the reporting threshold, and argue that this makes the ''substantial majority'' test essentially meaningless when thresholds are lowered. They argue that this demonstrates that Congress did not intend for EPA to lower reporting thresholds, only to raise them.

These commenters also rely on the language of other provisions of EPCRA section 313 to support their argument that Congress did not grant EPA authority to lower thresholds. They rely on the fact that section 313(f)(2) does not provide that EPA can ''raise or lower'' thresholds, unlike section 313(d), under which EPA can ''add or delete'' chemicals from the list, and section 313(b), under which EPA can ''add or delete'' industry sectors. In addition, the commenters argue that section 313(f)(2) is analogous to section 313(l), where, despite the use of the otherwise neutral term ''modify,'' Congress clearly meant for EPA only to make the reporting requirements less frequent (i.e., less stringent). Based on these provisions, they also argue that, where Congress intended EPA to have the authority to both expand and restrict reporting, the statute explicitly provides the authority, but where Congress only intended to authorize EPA to reduce the reporting burden, it provided a neutral term, and then restricted it. The commenters argue that in section 313(f)(2), Congress qualified EPA's authority with a substantial majority restriction that only makes sense if EPA raises the thresholds.

EPA disagrees with the commenters' interpretations. Section 313(f)(2) clearly authorizes EPA to lower thresholds, as well as to raise them. The plain language of this provision provides that ''the Administrator may establish a threshold different from the amount established by paragraph (1).'' It clearly does not state that the Administrator may only establish a higher threshold than the amount established by paragraph (1), which appears to be the commenters' interpretation. Moreover, in the House debate on the conference report, Representative Edgar, one of EPCRA's sponsors, noted:

> The EPA is authorized to revise these thresholds, but only if such revised thresholds obtain reporting on a substantial majority of total releases, *especially if such revised thresholds raise the statutory levels*,. . . (A Legislative History of the Superfund Amendments and Reauthorization Act of 1986, Committee Print, vol. 6, 5315) (emphasis added).

The clear implication of this statement is that Congress intended EPA to have the authority to lower, as well as to raise, the statutory thresholds.

The commenters' interpretation that EPA lacks the authority to lower the thresholds conflicts with Congressional intent in other ways. During debate on the Conference Report, Representative Edgar noted that ''This act is intended to provide a *comprehensive view of toxic chemical exposure* and, hopefully, provide a basis for more sensible and effective local, State, and national policies.'' *Legislative History* at 5316. See, also, *Legislative History* at 5313 and 5338. And yet without the authority to lower the thresholds, EPA cannot ensure that this objective is achieved. For example, Congress included PCBs on the original list of EPCRA section 313 chemicals, thereby indicating an intent to provide the public with a ''comprehensive view of exposure'' to PCBs; but under the original reporting requirements, EPA only received 6 reports. Under no interpretation can six reports be characterized as obtaining ''a comprehensive view of toxic chemical exposure.'' *Legislative History* at 5315.

EPA also disagrees with the comment that the Agency's interpretation has rendered this provision meaningless. This argument is based on a logical fallacy; a standard need not constrain agency action to the same degree in all circumstances to be meaningful. Congress may impose a standard that constrains actions to varying degrees in different circumstances. In this case, the Congressional debate on this provision indicates that Congress was most concerned with the loss of publicly available information that may result from raising the thresholds. See, e.g., *Legislative History* at 5315-16. It is therefore reasonable to assume that Congress chose to impose a standard that presented a greater constraint on the Agency's ability to raise thresholds, and therefore created a ceiling beyond which the Agency was not authorized to modify thresholds.

Further, notwithstanding the fact that under EPA's interpretation of section 313(f)(2), the Agency can meet the statutory standard without the need for quantitative support when it lowers the threshold, EPA does not believe that Congress has granted it unfettered discretion to establish a different threshold. As discussed at length in Unit VI.E., Congress provided significant guidance in other provisions of the statute and the legislative history, to guide the Agency's exercise of discretion under this provision. Moreover, as noted above, the substantial majority requirement establishes a ceiling beyond which the Agency is not authorized to modify thresholds.

EPA also disagrees with the commenters' interpretation of other provisions of EPCRA section 313. In general, Congress established the basic framework of right-to-know reporting in EPCRA section 313, and selectively granted EPA carefully qualified authority to adjust individual parameters as appropriate. For example, EPA is authorized to modify the chemicals on the EPCRA section 313 list, the SIC codes and facilities covered by section 313, the reporting frequency, and the reporting thresholds, but each grant of authority is constrained to varying degrees by the standards contained in each respective provision. As the commenters have correctly noted, where Congress intended to restrict the Agency's authority to modify the original requirements, it did so explicitly. For example section 313(l) specifically limits EPA's authority to modify the reporting frequency: ''. . .but the Administrator may not modify the frequency to be any more often than annually.'' Similarly Congress included no provision authorizing any amendments to the generally applicable employee threshold. It is therefore reasonable to assume that had Congress intended to only permit EPA to raise the thresholds, they would have included such an explicit restriction in the provision. Moreover, as noted earlier in this unit, the little legislative history that exists on this provision indicates that Congress intended EPA to have the discretion to both raise and lower the reporting thresholds. Further, EPA disagrees with the commenters' interpretation that Congress relied on different statutory construction to indicate its decision not to grant the Agency authority to decrease reporting thresholds, rather than relying on an explicit restriction in the plain language of the statute. EPA is aware of no indication of such Congressional intent in the legislative history, nor have the commenters cited to any. More to the point, the commenters' interpretation is clearly refuted by the inclusion in section 313(l) of an explicit restriction, demonstrating that where Congress

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intended to restrict EPA's authority, it did so explicitly.

One commenter argues that EPA lacks authority to lower the thresholds based on a comparison of the language in EPCRA sections 311 and 312 authorizing EPA to revise the section 311 and section 312 thresholds, with the language of section 313(f)(2). The commenter states that Congress could have used this same broad and simple language in section 313, and argues that because it did not, but instead chose to impose the ''substantial majority'' requirement, this demonstrates that Congress did not intend EPA to have the authority to lower the thresholds. Instead, the commenter argues, Congress was concerned with reporting burden when it crafted section 313, and so declined to grant EPA authority to lower the thresholds.

EPA disagrees. There is no significant difference between the language in sections 311, 312, and 313 that supports the commenter's interpretation. Unlike section 313, Congress did not establish thresholds in sections 311 and 312, but granted the Administrator broad discretion to determine whether a threshold was even appropriate; at what level to establish the threshold; and to modify it as appropriate. The language with which Congress conferred this authority provides that ''the Administrator may establish threshold quantities. . . .'' This is almost identical to the language of section 313(f)(2), which simply provides that ''the Administrator may establish a threshold amount for a toxic chemical different from the amount established by paragraph (1).'' The commenter's argument turns wholly on the inclusion of the ''substantial majority'' requirement, and as explained above, EPA does not believe that this standard either precludes EPA from lowering thresholds or demonstrates Congressional intent to do so.

Several commenters challenged EPA's finding that its alternate thresholds would capture a substantial majority of total releases, contending that the Agency had impermissibly relied on an increase in the number of reports submitted. The commenters assert that EPA is required to estimate releases at these facilities and determine, on a percentage basis, whether a ''substantial majority'' of all releases of each chemical, from all facilities subject to EPCRA section 313, will be captured. One commenter noted that, even if lowering the threshold for an EPCRA section 313 chemical results in an increase in the number of reports on the chemical, this does not necessarily mean that the additional reports will capture a substantial majority of the total releases from all facilities subject to EPCRA section 313 reporting. In order for the lower threshold to meet the statutory test, the threshold must result in capturing at least two thirds of all releases of the chemical at covered facilities. The commenter contended that the number of reports is irrelevant to the percentage of releases captured by the reports. If a certain chemical were present at only one facility in the country subject to EPCRA section 313, the submission of one report on the chemical accounting for at least 66% of the releases from that facility would satisfy the ''substantial majority'' test. By contrast, if a lower threshold generated 1,000 new reports on a EPCRA section 313 chemical, the ''substantial majority'' test would not be met if those reports did not account for at least 66% of the total releases from all facilities subject to EPCRA section 313. This may be the case, for example, if a large percentage of releases of the EPCRA section 313 chemical occurred at facilities otherwise subject to EPCRA section 313 that do not meet the threshold for that particular chemical that triggers the obligation to report the releases.

EPA disagrees with the commenter's interpretation. As noted in the proposed rule, EPA interprets the language in 313(f)(2), ''facilities subject to the requirements of [section 313],'' to refer to those facilities that fall within the category of facilities described by sections 313(a) and (b). Subsection (a) lays out the general requirement that ''the owner or operator of facilities subject to the requirements of this section'' file an EPCRA section 313 report. Subsection (b) then further defines the facilities subject to the requirements of this section:

> [t]he requirements of this section shall apply to owners and operators of facilities that have 10 or more full-time employees and that are in Standard Industrial Classification Codes 20-39, . . . and that manufactured, processed, or otherwise used a toxic chemical listed under subsection (c) of this section in excess of the quantity of that toxic chemical established under subsection (f) of this section during the calendar year for which a toxic chemical release form is required under this section.

Thus, to be subject to the requirements, a facility must meet all three of the requirements laid out in subsection (b). This means that the class of facilities subject to reporting under section 313 will vary according to the individual chemical. Moreover, facilities that have not exceeded a threshold for a particular chemical are not ''subject to the requirements'' of EPCRA section 313 for that chemical.

To determine whether a particular threshold, either higher or lower, for an individual chemical meets the substantial majority test, one would compare the total national aggregate of releases of the chemical by covered facilities at the existing thresholds with the estimated total national aggregate of releases at the proposed alternate threshold, and determine whether a substantial majority of releases reported under the original thresholds would be reported. Logically, the universe of facilities subject to the requirements under a lower threshold will always be either equivalent to, or greater, than the universe of facilities that are subject to the requirements under the existing thresholds. Moreover, because facilities subject to the requirements of section 313 must report ''the annual quantity of the toxic chemical entering each environmental medium,'' EPA can meet the substantial majority standard when lowering the thresholds, without the need for quantitative support; i.e., facilities that report, must report their releases and other waste management quantities. In this instance, the number of reports serves as an adequate surrogate for releases because essentially all releases (and other waste management quantities) will be reported by facilities subject to the requirements of this section.

In other words, facilities ''subject to the requirements of this section'' are those that must file EPCRA section 313 reports. Thus, the baseline against which the ''substantial majority of total releases'' is measured is the category of facilities that currently submit reports. Consequently, if quantitative support for its finding were necessary, EPA would be justified in relying on the number of reports to make its finding.

By contrast, although it is not clear exactly how the commenters interpret the phrase ''facilities subject to the requirements of this section,'' it is clear that they do so without reference to all of the requirements in subsections (a) and (b). And essentially, any interpretation that ignores any portion of subsection (b), results in an interpretation of EPCRA section 313(f)(2) as ''facilities *otherwise* or *potentially* subject to the requirements of this section.'' This is inconsistent with the plain language of section 313(f)(2). The commenters can only support their argument that EPA has not met the ''substantial majority'' test by assuming that all facilities, irrespective of whether they are in a covered SIC code or they exceed the existing thresholds, are subject to EPCRA section

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313, and that EPA must ensure that it captures a substantial majority of releases from the universe of those facilities. If this were correct, the addition of certain SIC codes could be a prerequisite to lowering thresholds for certain chemicals. Such a requirement is not currently included in section 313. The commenters have provided no support in either the statute or legislative history for these interpretations. Nor have the commenters provided any support for the interpretation that ''substantial majority'' equates to a particular percentage, such as 66%.

Finally, EPA notes, as it noted in the proposed rule, that, for several reasons, it does not believe that it has the necessary information to develop even reasonably accurate estimates of the potential releases that would be reported at an average facility at each of the identified options for a lowered threshold. Specifically, EPA believes that: (1) Sufficient information is not currently available for these chemicals, and (2) there is insufficient information on the numerous processes employed by all the sectors involved to calculate a comprehensive release estimate for each sector. While there are some data available, comprehensive data are not available for all sectors and chemicals. EPA further notes that none of the commenters provided either any information or methodology to address this issue, notwithstanding EPA's specific request.

Two commenters rely on excerpts from the debate on the Conference Report with respect to section 313(f)(2) to argue that EPA is only authorized to revise the thresholds if EPA presents a convincing analysis that revisions to the threshold will capture a substantial majority of the releases while also ensuring that it is not placing undue burdens on facilities which contribute little to such releases. The commenters argue that EPA has not satisfied the substantial majority requirement, and to do so, must conduct a more thorough assessment of the burden imposed on industry focused on the volume of releases that will be captured, not the number of reports. Another commenter compares the legislative history of sections 311 and 312 with 313, and concludes that Congress clearly intended EPA to factor burden into section 313 threshold questions.

EPA disagrees. Ultimately, EPA must comply with the statutory language, and section 313(f)(2) does not impose any requirement on the Agency to rely on the type of analyses described by the commenter. In addition, the commenters' reliance on the statements made during the Conference Report debate are misplaced. The commenter only quotes part of Representative Edgar's statement; the full quotation indicates only that EPA must present a convincing case, ''based on verifiable, historical data'' that the statutory thresholds warrant revision. As discussed below in Unit VI.E., EPA believes it has presented a convincing case that the thresholds should be lowered for PBT chemicals. The commenter also failed to include the portion of Representative Edgar's statement explaining that a convincing case was particularly necessary if the effect of the modification was to raise the thresholds. See, *Legislative History* at 5315.

Nonetheless, as discussed in greater detail in Unit VI.E., EPA considered the burden that lower thresholds would impose on industry in selecting the PBT thresholds. EPA believes that the levels it has adopted will capture significantly more information about PBT chemicals than current thresholds, but will not be unduly burdensome on industry. In addition, as discussed in the Response to Comments document (Ref. 69), EPA believes that the number of reports filed is a more accurate measure of burden than the volume of releases.

A commenter alleges that EPA's interpretation of section 313(f)(2) contradicts its prior statements regarding threshold changes. The commenterstates that EPA was clear in the original EPCRA section 313 rulemaking that the statute requires a substantial majority finding supported by actual data. For example, in the June 1987 proposed rule, EPA stated: ''The Agency is interested in data that would support the necessary finding that a modified threshold would still generate reporting on a substantial majority of total releases, as the statute requires.'' And in the February 16, 1988 final rule promulgating EPCRA section 313 requirements, EPA stated

> . . .the first few years' data should be evaluated to determine whether modifications of the threshold would meet the statutory test of obtaining reporting on a substantial majority of the releases (i.e., pounds released per year) of each chemical from subject facilities. EPA may consider changing the reporting thresholds based on several years of data collection.

The commenter also notes that in neither the proposed nor final rule establishing EPCRA section 313 requirements did EPA specifically assert that it had the authority to lower thresholds.

EPA disagrees that its statements in this rulemaking contradict its prior statements in the 1988 rulemaking. As a preliminary matter, EPA has never denied that the requirement that a revised threshold obtain reporting on a substantial majority of total releases applies to any action lowering the reporting thresholds. Specifically, EPA's discussion in the 1987 proposed rule was in the context of a response to proposals from the Small Business Administration (SBA) that the Agency raise the thresholds to capture only larger facilities. EPA's statements in the 1988 final rule also need to be evaluated with SBA's proposals in mind. Moreover, while it is true that the discussion to which the commenter cited did not distinguish between lowering and raising the thresholds (it was intended as a response to comments on both sides of the issue), EPA notes that the majority of the comment summary focuses on requests to raise the thresholds. Finally, while it is true that EPA did not specifically assert its authority to lower the thresholds in either rule, neither did EPA deny that EPCRA section 313(f)(2) grants it this authority. However, it is worth noting that in the final rule, EPA responded to comments from environmental and public interest groups requesting that the Agency lower the thresholds, and that EPA never stated or implied that it lacked the authority to lower thresholds.

One commenter states that EPA's authority to lower reporting thresholds is not limitless. The commenter argues that a decision to lower the thresholds must be tied to the overall purpose of the Act, namely, to inform the public of potential health risks posed by the presence of toxic chemicals released to the environment in their communities. A regulatory decision to capture more reports under EPCRA section 313 must be based on the need to inform the public of health risks associated with the releases captured in those reports. Otherwise, the usefulness of the TRI data base begins to diminish. EPA needs to demonstrate that the releases of the PBTs at such small amounts pose a meaningful risk to the public health. Another commenter asserts that EPA is relying on the purposes of EPCRA to support its interpretation of section 313(f), and argues that, although section 313(h) does describe intended uses for TRI data, section 313(h) itself does not describe the purposes or intention of section 313. The commenter instead relies on several provisions of section 313 and argues that the purpose and intention of Congress to make information available to the public was balanced by concerns about the potential burden of the TRI program. The commenter also states that the uses

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Congress anticipated for TRI data do not outweigh the balance that Congress intended between generating information and minimizing burden, and do not grant EPA blanket authority to expand the reporting requirements.

EPA agrees with the commenter that its authority to lower reporting thresholds is not limitless, and that its decision to lower the thresholds must be tied to EPCRA's overall purposes. However, EPA believes that Congress granted the Agency broad, but not unfettered, discretion to determine when it is appropriate to lower thresholds, and to determine the specific thresholds that are appropriate. As discussed in greater detail in Unit VI.E., EPA believes that its decision to lower the thresholds, and the thresholds it has chosen, reflect these principles.

However, EPA generally disagrees with the remainder of the commenter's conclusions. As discussed in more detail in Unit VI.F., EPA is not required to base its decisions under EPCRA section 313 on the need to inform the public of health risks associated with reported releases and other waste management quantities. And as discussed elsewhere in this preamble and the Response to Comments document (Ref. 69), EPA believes that the information that will be reported as a result of this rulemaking will provide useful information to the public.

In large measure, the issues raised in the second comment closely relate to the specific thresholds and EPA's rationale for choosing them, and this issue is discussed in more detail in Unit VI.E. However, to the extent it relates to EPA's interpretation of section 313(f)(2), some response is also provided here.

As a preliminary matter, while it is true that EPCRA section 313 does not explicitly identify the purposes of the section, the Conference Report makes clear that subsection (h) of section 313:

> Describes the intended uses of the toxic chemical release forms required to be submitted by this section and expresses the purposes of this section. The information collected under this section is intended to inform the general public and the communities surrounding covered facilities about releases of toxic chemicals, to assist in research, to aid in development of regulations, guidelines, and standards, and for other similar purposes. (Conference Report at 299).

Contrary to the commenter's assertion, the Agency never indicated that it was relying on section 313(h) to expand its authority under section 313(f)(2). Rather, EPA noted that it was relying on the purposes of section 313 as an additional source of Congressional direction to guide the Agency's exercise of discretion under this provision. EPA relied on section 313(h), in part, because the Agency believes that its implementation of EPCRA generally should be guided by EPCRA section 313's purposes. In addition, section 313(h) shares certain elements with the Congressional guidance on section 313(f)(2) in the legislative history. As discussed in greater detail in Unit VI.E., EPA has distilled those common elements, and relied on them to guide its discretion in establishing the specific thresholds under section 313(f)(2).

EPA also disagrees with the commenter's assertion that the purpose of EPCRA is to achieve a balance between the public's right to information about their potential exposures to toxic chemicals and the reporting burden imposed on industry. EPCRA section 313(f)(2) does not require EPA to consider burden in establishing revised thresholds. Although EPA has included the reporting burdens imposed on industry as one consideration in determining the appropriate thresholds, the Agency is also mindful that the authors of EPCRA, while sensitive to the burdens EPCRA section 313 reporting placed on industry, never intended this consideration to outweigh the public's need for access to information concerning release and waste management, and thus their potential exposure to toxic chemicals. See, e.g., *Legislative History* at 5315–16 and 5338–39. And with respect to the assertion that the general purposes of section 313 are to balance the public's right-to-know about toxic chemical releases and other waste management in their communities against the reporting burdens EPCRA section 313 imposes, EPA notes that reporting burden is not included anywhere in section 313(h). Nor does the strong policy directive underlying EPA's overall implementation of EPCRA section 313 support such an interpretation. Representative Edgar, one of the bill's primary architects noted:

> The heart of the Federal Right-to-Know Program is its reporting requirements, which are intended to provide a comprehensive picture of the community's and the Nation's exposure to toxic chemicals. As the Environmental Protection Agency, the States, and localities implement this program, they should be guided by several general principles.
>
> First, Congress recognizes a compelling need for more information about the Nation's exposure to toxic chemicals. Until now, the success of such regulatory programs such as the Clean Air Act, the Resource Conservation and Recovery Act, and the Clean Water Act has been impossible to measure because no broad-based national information has been compiled to indicate increases or decreases in the amounts of toxic pollutants entering our environment. As a result, the reporting provision in this legislation should be construed expansively to require the collection of the most information permitted under the statutory language. Any discretion to limit the amount of information reported should be exercised only for compelling reasons. . . . *Legislative History* at 5313.

Significantly, Representative Edgar did not include reporting burden as one of the general principles that should guide the Agency's implementation of EPCRA section 313. Rather, he stated:

> This is a new Federal initiative, and I recognize the desire of some of my colleagues to move ahead cautiously to ensure that burdens imposed on industry are not excessive. Frankly, my concerns rest with the families that live in the shadows of these chemical and manufacturing plants. I have put myself in their shoes and have fought for a program that looks after their needs. This legislation gets us well on the path to the full disclosure they deserve. *Id* at 5316.

Nonetheless, EPA has considered the legislative history on section 313(f)(2), including the excerpts cited by the commenter, and determined it would be reasonable to include some consideration of the reporting burdens in selecting its revised thresholds. The degree to which EPA included burden in its selection of the thresholds established in this rulemaking is discussed at length in Unit VI.E. and the Response to Comments document (Ref. 69).

EPA agrees that section 313(h) does not grant EPA unfettered discretion to expand EPCRA's reporting requirements; as noted in a previous response, Congress established the basic parameters of the EPCRA section 313 reporting requirements, and selectively granted EPA carefully qualified authority to modify certain of them. In this action, for example, EPA is only affecting the activity thresholds, but Congress established other limitations that govern whether a facility is subject to reporting. For example, facilities with fewer than 10 employees are not subject to reporting under subsection 313(b)(1).

B. What Comments Did EPA Receive on Persistence Criteria, Bioaccumulation Criteria, and Toxicity Criteria, and What Are EPA's Responses?

1. *Comments on EPA's general approach.* Several commenters contend that only chemicals which are globally recognized as persistent bioaccumulative toxic chemicals should form the foundation of the EPCRA section 313 PBT chemical list and criteria. The application of the criteria in this manner is consistent with several existing international agreements and

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programs, such as the Great Lakes Binational Strategy, the North American Commission on Environmental Cooperation (NACEC), the United Nations Economic Commission for Europe's (UNECE) agreement to address persistent organic pollutants (POPs), and the United Nations Environmental Programme (UNEP). These programs have prompted widely accepted numerical values for persistence and bioaccumulation and defined parameters for assessing toxicity. These criteria have also been adopted with U.S. support and leadership and the commenters contend that it is not clear why EPA is now taking a vastly different approach to identifying PBT criteria in the proposed rule. The commenters suggest that EPA conform the criteria for PBT chemicals on EPCRA section 313 with the criteria and chemicals that are part of the programs being implemented by the NACEC, UNECE, and UNEP. By doing so, EPA would harmonize the U.S. program with similar international programs that focus on a narrow set of PBT chemicals.

EPA believes that it would be inappropriate to merely adopt the criteria and list of chemicals managed under the international programs cited because the purposes of the TRI program are different than the purposes of the cited international programs. The TRI was established by Congress under EPCRA section 313 in response to public demand for information on toxic chemicals being released in their communities. The TRI program is national in scope, but a significant part of its overriding goal is to provide information on releases to local communities so that they can determine if the releases result in potential risks. The entire concept of TRI, and indeed other, similar Pollutant Release and Transfer Registries (PRTRs) since established in several nations, is founded on the belief that the public has the right to know about chemical use, release, and other waste management in the areas in which they live, as well as the hazards associated with these chemicals. This emphasis is fundamentally different from the global focus of the UNEP negotiation and its concept of residual risk. It is EPA's position that the domestic, community-based purposes of EPCRA section 313 have important implications with regard to the criteria used to identify toxic chemicals as persistent and/or bioaccumulative, as well as the methods and models used to evaluate persistence and/or bioaccumulation.

EPCRA section 313 charges EPA with collecting and disseminating information on releases, among other waste management data, so that communities can estimate local exposure and local risks. One intent of EPCRA section 313 is to provide information to the public so that they can take an active role in determining what risks resulting from toxic chemical releases in their community are acceptable. This basic local empowerment is a cornerstone of the right-to-know program.

EPCRA section 313(h) states that:

> The release forms required under this section are intended to provide information to the Federal, State, and local governments and the public, including citizens of communities surrounding covered facilities. The release form shall be available, consistent with section 11044(a) of this title, to inform persons about releases of toxic chemicals to the environment; to assist governmental agencies, researchers, and other persons in the conduct of research and data gathering; to aid in the development of appropriate regulations, guidelines, and standards; and for other similar purposes.

EPCRA section 313 establishes an information collection and dissemination program. EPA interprets EPCRA section 313(g)(2) to require facilities to use readily available information to prepare each chemical-specific EPCRA section 313 report. The statute does not require that the facility conduct additional monitoring or emissions measurements to determine these quantities. A facility must only use readily available data or reasonable estimation methods in preparing the quantitative information it reports.

The purpose of EPCRA section 313 is not to ban the manufacture or use of a chemical, to restrict releases of the chemical, or to dictate how it should be used or released. As a result, the burden and control EPCRA section 313 imposes is significantly less than that imposed by a statute that controls the manufacture, use, and/or release of a chemical. The focus of EPCRA section 313 is not equivalent to the focus of a statute or international agreements in which chemicals are to be banned, phased-out, or restricted.

In contrast, the international agreements cited by the commenters are intended to ban, restrict, or phase-out the manufacture, use and/or release of a limited set of persistent organic pollutants and certain heavy metals that are highly persistent and highly bioaccumulative. Descriptions of the purposes of the Protocol on Persistent Organic Pollutants (POPs); Convention on Long-Range Transboundary Air Pollution (LRTAP), UNECE, UNEP on POPs, North American Commission for Environmental Cooperation's Sound Management of Chemicals (NACEC SMOC), as well as the International Council of Chemical Associations' (ICCA) position on POPs are presented below. The following quotes clearly illustrate that the intent of the international agreements is to narrowly focus on that subset of toxic chemicals which are of regional (e.g., North America and Europe) or global concern.

UNECE LRTAP

> The ultimate objective is to eliminate any discharges, emissions and losses of POPs. The Protocol bans the production and use of some products outright (aldrin, chlordane, chlordecone, dieldrin, endrin, hexabromobiphenyl, mirex and toxaphene). Others are scheduled for elimination at a later stage (DDT, heptachlor, hexachlorobenzene, PCBs). Finally, the Protocol severely restricts the use of DDT, HCH (including lindane) and PCBs. The Protocol includes provisions for dealing with the wastes of products that will be banned. (The 1998 Aarhus Protocol on Persistent Organic Pollutants (POPs); Convention on Long-Range Transboundary Air Pollution, United Nations Economic Commission for Europe (UNECE) at http://www.unece.org/env/lrtap) (Ref. 54)

UNEP

> International action to protect health and the environment through measures which will reduce and/or eliminate emissions and discharges of persistent organic pollutants, including the development of an international legally binding instrument. (Governing Council Decisions 20/24, 1999; United Nations Environmental Programme at http://irptc.unep.ch/pops/newlayout/negotiations.htm) (Ref. 57)

NACEC SMOC

> NACEC SMOC has developed action plans for PCBs, DDT, chlordane, and mercury. The action plans include 1) for PCBs ''work toward the virtual elimination of PCBs in the environment, which the task force is interpreting as no measurable release to the environment'', 2) for DDT ''gradual reduction of DDT use for malaria control'' and ''additional reductions,'' 3) for chlordane ''phase-out of chlordane use'', and 4) for mercury ''reduce sources of anthropogenic mercury pollution.'' The longer-term goal of the plan is to reduce the presence of mercury in the environment to achieve naturally occurring levels.'' (North American Cooperation for the Sound Management of Chemicals (June 1998); North American Commission for Environmental Cooperation at http://www.cec.org/english/profile/coop/Pollute—f.cfm?format=1) (Ref. 40)

ICCA

> *ICCA Position*: ICCA member associations have demonstrated their commitment to sound chemicals management, and to the goal of reducing the potential human health and environmental risks that may be associated with POPs. Many POPs are already subject to considerable voluntary risk management by chemical companies, and the uses of most substances identified as POPs has been discontinued or extremely limited

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by chemical companies within the countries represented by ICCA member associations. (International Council of Chemical Associations (ICCA) Briefing Note on Persistent Organic Pollutants (POPs) (April 21, 1998) at http://www.icca-chem.org/issues.htm) (Ref. 26)

In addition, as directed under EPCRA section 313(h), EPA makes the TRI data available to various groups, including international organizations, that, in turn, use the information to decide whether to ban, restrict, or phase-out chemicals.

For the same reasons, EPA also disagrees that only substances globally recognized as POPs should provide the basis of persistence criteria for this rulemaking. POPs are organic chemicals whose characteristics of persistence in the environment, accumulation in biological organisms and toxicity make them priority pollutants that cause significant environmental risks to humans and ecosystems. The substances or substance categories being considered for implementation of global controls through the UNEP negotiations (UNEP/GC.18/32, 1995: aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, mirex, toxaphene, hexachlorobenzene, PCBs, polychlorinated dibenzo-*p*-dioxins and furans) (Refs. 44 and 45) were selected largely because they or their degradation products pose risks that may occur far from their sites of initial entry into the environment. The UNEP action is the global counterpart to similar, regional negotiations, most notably the UNECE Convention on Long-Range Transboundary Air Pollution (LRTAP) (Ref. 54); the North American Free Trade Agreement (NAFTA) CEC Initiative on the Sound Management of Chemicals (Ref. 39); and the bilateral US/Canada agreement to control discharge or release of POPs in the Great Lakes basin (Ref. 23). A central theme of the UNEP action, consistent with its global scope, is the notion of residual risk, meaning specifically that to be subject to the negotiations, it is not sufficient for a substance to pose risks within a nation or regionally, rather it must pose risks to populations and nations distant from release sites.

2. *Comments on EPA's individual criteria.* The same commenters state that EPA should use the international criteria being applied by UNEP, UNECE LRTAP, NACEC SMOC, for persistence, bioaccumulation, and toxicity. Some of these commenters also include the criteria developed by CMA (CMA, PTB Policy Implementation Guidance: Product Risk Management Guidance for PTBs (February 1996)). One commenter includes the criteria developed by the ICCA for POPs. Another commenter states that there is no reason to adopt criteria that are significantly more stringent than those used in other programs. One commenter states that EPA should consider the degree of toxicity and focus on the most toxic chemicals. Some commenters state that EPA should couple the persistence and bioaccumulation criteria to each other. They believe that these criteria should not be considered independently. The numerical criteria presented by some of the commenters are provided below:

Table 2.—Numerical Persistence and Bioaccumulation Criteria Suggested by Commenters

	CMA PTB Policy	NACEC SMOC	UNECE (LRTAP) POPs	UNEP POPs/CEG FRAMEWORK	Environment Canada Toxic Substances Management Policy (June 1995)	ICCA
Persistence	Half-life = 6 months in water or 1 year in soil	Half-life > = 2 days air; 6 months water/soil; or 1 year sediment	Half-life> 2 months water or 6 months soils/sediment; or otherwise sufficiently persistent to be of concern	Half-life > [2 or 6] months soil/sediment; or other evidence that substance is sufficiently persistent to be of concern	Half-life > = 2 days air; 6 months water/soil; 1 year sediment	Half-life = 6 months water, 1 year soil sediments, or 5 days air
Bioaccumulation	BAF/BCF > = 5,000 or estimation techniques	BAF/BCF >= 5,000 or Log K_{ow} > = 5	BAF/BCF > 5,000 or Log K_{ow} > 5 or factors such as high toxicity	BCF/BAF > 5,000 or Log K_{ow}> [4 or 5]; evidence that substance with significantly lower BCF/BAF is of concern, e.g., due to high toxicity/ecotoxicity; or monitoring data in biota indicating sufficient bioaccumulation to be of concern	Half-life > 2 months water or 6 months soils/sediment (or otherwise sufficiently persistent to be of concern)	BCF > 5,000 or log Log K_{ow} > 5 and <7.5, MW<700 and substance is not metabolized

Table 2.—Numerical Persistence and Bioaccumulation Criteria Suggested by Commenters—Continued

	CMA PTB Policy	NACEC SMOC	UNECE (LRTAP) POPs	UNEP POPs/CEG FRAMEWORK	Environment Canada Toxic Substances Management Policy (June 1995)	ICCA
Toxicity	Professional judgment in evaluation of aquatic toxicity, wildlife toxicity, oral/dermal/inhalation toxicity (mammals and birds), reproductive toxicity, neurological toxicity; carcinogenicity, mutagenicity, and/or teratogenicity	Acute and chronic (including toxicity of breakdown products, if appropriate)	Potential to affect human health and/or the environment adversely	Evidence that (chronic) toxicity or ecotoxicity data indicate a potential for damage to human health or the environment caused by the substance resulting or anticipated from long-range transport	CEPA - toxic	Expert judgment that acute aquatic lethality, subchronic and chronic aquatic toxicity, acute wildlife toxicity, oral/dermal/inhalation toxicity in mammals and birds, carcinogenicity, mutagenicity, teratogenicity, reproductive toxicity, neurological toxicity, and immune system effects must be demonstrated or expected to occur at the concentrations observed in the environment

EPA is establishing criteria in this rulemaking for the TRI program for persistence and bioaccumulation. EPCRA section 313(d)(2) already provides toxicity criteria for the TRI program. While EPA chose in this rulemaking to focus on chemicals that are toxic and persistent and bioaccumulative, EPA did not state that the persistence criterion could only be applied in conjunction with the bioaccumulation criterion and vice versa. EPA has not tied the criteria together because there is no scientific rationale to define persistence criteria in terms of both bioaccumulation and persistence and to define bioaccumulation both in terms of persistence and bioaccumulation. As illustrated by the descriptions of persistence and bioaccumulation provided in the proposed rule, persistence and bioaccumulation are separate chemical and/or biological processes. They are not by definition dependent upon the other.

A chemical's persistence refers to the length of time the chemical can exist in the environment before being destroyed. (at 64 FR 698)

and

Bioaccumulation is a general term that is used to describe the process by which organisms may accumulate chemical substances in their bodies. (at 64 FR 703)

A chemical is not considered to be persistent if it is only bioaccumulative. For example, a chemical may be extremely persistent and yet not bioaccumulate appreciably. For example, metals cannot be destroyed in the environment and thus are extremely persistent. Some metals bioaccumulate appreciably while others do not. However, the degree to which a metal can bioaccumulate does not affect the metal's persistence in the environment. The connection suggested by the commenters is not scientifically justified. Thus, EPA does not believe that persistence criteria can be applied only in conjunction with the bioaccumulation criteria. EPA reiterates that in this rulemaking the Agency chose to focus on those toxic chemicals that meet both the persistence and bioaccumulation criteria proposed for EPCRA section 313. In the future, the Agency may focus on toxic chemicals that are either persistent or bioaccumulative.

A discussion of the individual criteria is presented in the remainder of this unit.

a. *Persistence*. EPA proposed persistence criteria for the TRI program of half-lifes of 2 months in water, soil, and sediment and 2 days in air. As discussed in Unit VI.B.1., EPA disagrees that it must choose persistence criteria for EPCRA section 313, an information collection and dissemination program, consistent with the international criteria being applied to chemicals that are of global or regional (e.g., Europe and the Great Lakes) concern and that are being targeted for ban, restriction, or phase-out. Chemicals that meet the persistence criteria used in the international agreements are extremely persistent chemicals. Applying these criteria to EPCRA section 313 would result in a very narrow list of chemicals that would focus on only extremely persistent chemicals. This is inconsistent with both the purposes of EPCRA section 313 and with EPA's technical judgment. There is no ''bright line'' that separates what is persistent from what is not persistent. The degree of persistence is a continuum. Chemicals with a half-life of 2 to 6 months are not non-persistent. They are less than chemicals with a half-life of greater than 6 months. The degree of persistence that should be used as criteria is not an absolute scientific determination. Rather it is a combination of science and policy. As discussed in the proposed rule and the remainder of this section, organizations have generally used as persistence criteria half-lifes of 2 months and/or 6 months for water, soil, and sediment.

The determination of which set of numerical criteria to apply will depend on the final intent: for example, providing communities with information on persistent chemicals that can build up in their environment versus banning the manufacture and use and eliminating releases of a chemical that has global impacts. For EPCRA section 313, which provides information on toxic chemicals to communities, researchers, and governments, the criteria should be in keeping with both science and the intent of the statute.

Long-range transport (LRT) and residual risk are relevant domestically, since chemical substances may be transported regionally and transcontinentally, resulting in exposures at sites distant from releases but still within U.S. borders. Nevertheless, as a general rule, the closer the sources and receptor are, the more likely it is that released material will reach that receptor. The 12 UNEP POPs or their degradation products all meet or exceed the half-life criterion of 6 months for soil, water, or sediment, often by large margins (Refs. 44 and 45), and the 6 months criterion thus acts to isolate these substances for international attention aimed at limiting LRT. But a shorter half-life criterion is necessary to protect communities from bioaccumulative toxicants derived from sources closer to home, since, all other things being equal, a pollutant reaches nearby populations in less time than distant ones.

An article by Wania and Mackay (Ref. 81) is often cited in discussions of ''global distillation'' of relatively mobile POPs such as hexachlorobenzene and lindane, which tend to have inverted concentration profiles such that concentrations increase with distance from the source (i.e., from temperate to polar regions) rather than the reverse. What may be less obvious is that the converse is also true; namely, that less volatile substances show no significant latitudinal dependence; that low-mobility POPs such as mirex and the more highly chlorinated PCBs tend to undergo *rapid deposition and retention* close to their sources; and that all but high or relatively high mobility chemicals are expected to show ''normal'' concentration profiles, such that concentrations decline with distance from warmer sources to colder remote regions (Ref. 81). A recent study of organochlorine contaminants in sea otters illustrates this point. Although the levels of total DDTs observed were not considered toxicologically significant, Bacon *et al.* (Ref. 8) found the highest levels in California sea otters (ca. 850 micrograms per kilogram (µg/kg)) but much lower levels in Aleutian otters (40 µg/kg) and southeast Alaska otters (1 µg/kg), and attributed the higher levels in the California otters to extensive DDT use and production in this region from the 1950s to the 1970s. Even UNEP's Criteria Expert Group (CEG), which is charged with developing criteria and procedures for addition of substances beyond the original 12 POPs, has highlighted the importance of ''near-field'' exposures:

> In warmer climates exposures may occur closer to the source; e.g., occupational exposure during use, or local exposure caused by runoff from use or leaking from stockpiles. Food, such as fish, may be a major route of intake also in warmer climates [in contrast to Arctic and sub-Arctic regions] and POPs may accumulate in the food chain and reach high levels in predatory species in these conditions. (UNEP/POPS/INC/CEG/1/2: 1998) (Ref. 56)

An additional factor that argues for adopting the more protective persistence criterion is the need for communities with vulnerable populations to have access to data on release and other waste management quantities. Examples of such populations include toddlers who play in contaminated soil, local farmers who consume their own produce, and subsistence as well as sport fishers, who often consume large quantities of what they catch. The relative importance of any of these pathways depends on the properties of the substance, rates and media of release and other factors, but ingestion of bioaccumulating substances may occur by all of these routes. The Organization for Economic Cooperation and Development (OECD) guidance on the assessment of indirect human exposure to chemical toxicants is consistent with EPA policy, and states that in the case of local, site-specific emissions, one or more of these subgroups may be particularly endangered (Ref. 53).

From a scientific perspective there is no one best persistence criterion. However, it is simply not accurate to state that there is no precedent or basis for using a persistence criterion of 2 months. As outlined in the proposed rule (64 FR 701), similar values have been proposed by several authorities, including the Ontario, Canada Ministry of Environment and Energy (MOEE) for its Candidate Substances List for Bans or Phaseouts (Ref. 36); the Canadian initiative for Accelerated Reduction/Elimination of Toxics (ARET) (Refs. 1 and 2); the International Joint Commission's (IJC) Great Lakes Water Quality Agreement (GLWQA) (Ref. 27); and the UNECE's LRTAP Convention, which did adopt 2 months as the persistence criterion of record for water (Ref. 54). In each of these programs the focus was on persistent, bioaccumulative and toxic substances, and it is noteworthy that all are national or regional, not global, in scope. Thus, a trend exists in which authorities with domestic or regional mandates to take action to reduce risks from indirect exposure to PBT chemicals have recommended half-life criteria substantially lower than 6 months.

EPA's Office of Water maintains a Listing of Fish and Wildlife Advisories (LFWA) for the U.S. and territories, which listed 2,299 advisories in 1997 (Ref. 29). U.S. states and territories and Native American tribes have primary responsibility for issuing advisories for the general population, which include recommendations to limit or avoid consumption of certain fish and wildlife from specific water bodies. The overwhelming majority of the advisories are for well recognized PBT chemicals (chlordane, mercury, PCBs, etc.), but many less familiar substances are also represented. The number and content of advisories in LFWA clearly indicate that toxicologically significant levels of chemical contaminants, specifically PBT chemicals, are often found in fish and wildlife that are caught noncommercially and consumed by the U.S. population. It is generally impossible to determine the exact source(s) of exposure for the species and locations included in any given advisory, but it seems highly unlikely that the majority of listed contaminants in U.S. waters could be derived from non-U.S. (i.e., geographically distant) sources. The LFWA thus lends further support to the contention that concern for exposure to PBT chemicals is not limited to situations where the exposure results primarily from LRT. It should be noted that the fact that no advisories have been issued for a particular chemical does not mean that it does not persist. Not all species of aquatic organisms are tested nor are all water bodies, in addition, each state determines what it will use as the level of concern for issuing an advisory.

A series of Toxic Substances Control Act (TSCA) section 5 Premanufacture Notifications (PMNs) submitted to EPA in 1990 also illustrates that exposure to PBT chemicals is not limited to LRT (Refs. 37 and 38), and also demonstrates: (i) Why EPA believes that the persistence criterion for bioaccumulating substances in soil, water, or sediment should be set substantially lower than 6 months; and (ii) that for purposes of EPCRA section 313, concern for potential exposures to persistent and bioaccumulative toxics

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must extend beyond the UNEP's 12 widely acknowledged POPs. The substances in question were alkylated diphenyls for use as solvents, and for which EPA expected discharge to receiving streams and rivers. The submitter supplied data on use and disposal, aquatic toxicity, and biodegradability. The submitted environmental fate data and EPA estimates of biodegradability based on structural analogs suggested that half-lifes in water would be well below 6 months, but not necessarily lower than 2 months. As a result of concerns expressed by EPA, use was limited to sites where resulting water concentrations could be limited to 1 microgram per liter (µg/L) or less; concomitantly, the submitter was also informed of EPA's belief that a potential for *long-term risk* existed, but that EPA could not quantify this risk since assessments typically evaluated releases over only 1 year. In 1998, results of monitoring were announced by the State EPA and revealed that the alkylated biphenyls had been found in fish fillets and sediment samples from the receiving stream.

One commenter contends that the persistence criteria of half-lifes of 2 months for water, soil, and sediment and 2 days for air may not be sufficiently protective (i.e., the criteria may be too high).

EPA disagrees with the comment. EPA believes that it should adopt criteria that focus on toxic chemicals that will build up in the environment, while at the same time not limiting the list of persistent toxic chemicals to only those that are of global concern. As discussed earlier in this section, EPA believes that 2 months is a reasonable half-life criterion given the purposes of EPCRA section 313. EPA believes that application of lower criteria would include so many substances as to be impractical. Further, given the uncertainties that often exist regarding physical properties and environmental behavior of chemicals, caution is especially appropriate for substances with shorter half-lifes, since they are (all other things being equal) less likely to build up in the environment than more persistent substances. EPA believes that the adoption of criteria of half-lifes of 2 months in water, soil, and sediment and a half-life of 2 days in air allows EPA to balance the need to provide communities and other data users with information on toxic chemicals that persist in their environment without being overly inclusive or restrictive.

One commenter contends that a half-life criterion for air of 2 days should be considered sufficient in and of itself for designating substances as persistent.

EPA agrees with the comment. EPA made the following statements in the proposed rule regarding the 2–day air half-life criterion and its use in the determination as to whether a chemical was a PBT under EPCRA section 313:

> For the purposes of determining whether a toxic chemical is persistent in the environment under section 313, EPA used a half-life criterion of 2 months for water/sediment and soil and a half-life of 2 days for air. Given the above discussions, EPA believes that, for purposes of reporting under section 313, these values are appropriate for determining whether a toxic chemical is persistent in the environment and will persist long enough in the environment to bioaccumulate or be transported to remote locations. Under these criteria, if a toxic chemical meets any one of the media specific criteria, then it is considered to be persistent. Thus if a toxic chemical's half-life in water or sediment or soil is equal to or greater than 2 months or greater than 2 days for air then the toxic chemical is considered to be persistent for purposes of section 313. Note that when considering persistence in connection with the potential for a toxic chemical to bioaccumulate, meeting the air half-life criteria alone would not be sufficient, since a chemical's potential to bioaccumulate is usually dependent on it being persistent in either water, sediment, or soil. In determining whether the chemicals in this proposal were persistent, EPA did not rely solely on the persistence in air. (at 64 FR 702)

It is clear from the discussion above that EPA agrees with the commenter that when considering persistence alone an air half-life of 2 days would be considered sufficient to classify a chemical as persistent under EPCRA section 313. However, for the reasons explained above, if a chemical only meets the 2–day air half-life persistence criteria, EPA does not believe that would be sufficient for classifying a chemical as a PBT under EPCRA section 313.

Some commenters contend that EPA's two-tiered approach to the persistence criteria is confusing.

EPA notes that it proposed only one set of persistence criteria for EPCRA section 313, half-lifes of 2 months or greater in water, soil, and sediment and 2 days in air. The Agency did not propose to use half-lifes of 6 months or greater in water, soil, and sediment and 2 days in air as a second set of persistence criteria for EPCRA section 313. However, for purposes of setting reporting thresholds in this rulemaking, the Agency did choose to focus on the subset of PBT chemicals that have half-lifes of 6 months or greater in water, soil, or sediment (and BCF/BAFs greater than 5,000) by proposing a 10 pound reporting threshold.

For the reasons given above, EPA reaffirms its intention to use a half-life of 2 months as the criterion for persistence in water, soil, and sediment and a half-life of 2 days as the criterion for air when characterizing a chemical as persistent for purposes of EPCRA section 313.

b. *Bioaccumulation*. EPA proposed as bioaccumulation criteria for the TRI program bioaccumulation/bioconcentration factors of 1,000. As discussed in Unit VI.B.1., EPA disagrees that it must choose for EPCRA section 313, bioaccumulation criteria consistent with the international criteria. Applying these strict criteria to EPCRA section 313 would result in a very narrow list of chemicals that would focus on only extremely bioaccumulative chemicals. This is inconsistent with the purposes of EPCRA section 313 and with EPA's technical judgment. There is no ''bright line'' that separates what is bioaccumulative from what is not bioaccumulative. The degree of bioaccumulation is a continuum. Chemicals with BCFs or BAFs of 1,000 to 5,000 are not non-bioaccumulative. They are less bioaccumulative than chemicals with BCFs or BAFs greater than 5,000. The degree of bioaccumulation that should be used as a criterion is not an absolute scientific determination. Rather it is a combination of science and policy. As discussed in the proposed rule and below, organizations have generally used as bioaccumulation criteria BAFs/BCFs of 1,000 and 5,000. The determination of which numerical criterion to apply will depend on the final intent: for example, providing communities with information on bioaccumulative chemicals that can accumulate in organisms versus banning the manufacture and use and eliminating releases of a chemical that has global impacts. For EPCRA section 313 which provides information on toxic chemicals to communities, researchers, and governments, the criteria should be in keeping with both the Agency's scientific judgment and the intent of the statute.

From a scientific perspective there is no one bioaccumulation criterion. However, it is simply not accurate to state that there is no precedent or basis for using a bioaccumulation criterion of 1,000. As noted in the proposed rule, for a number of years EPA scientists and programs have used a BCF of 1,000 or more to indicate a high level of concern for bioaccumulation. In addition, this value has been used in some Canadian projects, many dealing with the Great

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Lakes basin. Also, Germany proposed a BAF/BCF criterion of 1,000 during negotiation of the LRTAP Protocol. Support for a BAF criterion of 1,000 also comes from the Final Water Quality Guidance for the Great Lakes System (FWQGGLS) (60 FR 15366, March 23, 1995) (FRL–5173–7). In this document, EPA stated that bioaccumulation of persistent pollutants is a serious environmental threat to the Great Lakes Basin Ecosystem and that chemicals identified as bioaccumulative chemicals of concern (BCCs) (i.e., with BAF values greater than 1,000) would receive increased attention and more stringent controls. The final guidance designated as BCCs those chemicals with human health BAFs greater than 1,000 that were derived from certain field-measured BAFs. One commenter believed that the BAF criteria used in the FWQGGLS did not provide support for the use of a BAF of 1,000 since a more strenuous methodology taking more factors into account was used. However, EPA believes that this does provide support for the criteria established for the purposes of EPCRA section 313 because, although the underlying technical assessments may be more stringent, the bioaccumulation level of concern is still a BAF of 1,000. Also, as noted by some commenters, EPA has proposed to use a BCF/BAF of 1,000 to trigger testing under TSCA section 5(e) (63 FR 53417). Specifically, for chemicals subject to TSCA section 5 that have a BAF of 1,000 or greater and that meet certain toxicity and persistence criteria (similar to the EPCRA section 313 persistence criteria) testing would be ''triggered'' by specific production limits. While the manufacturer of the chemical would be allowed to commercialize the substance, certain controls could be stipulated, including specific limits on exposures, releases, or uses. EPA notes that in the same **Federal Register** document, the Agency has proposed that chemicals that have a bioaccumulation factor of 5,000 and that meet certain toxicity and persistence criteria (e.g., half-life of 6 months or greater in soil) be placed in a ''Ban Pending Testing,'' bin. Chemicals meeting these criteria could be subject to more stringent control up to a ban on commercial production.

Not only is there precedent for the use a BCF/BAF of 1,000, but EPA believes that the purposes of the statute argue for the use of the more expansive criterion. Data on PBT chemicals are the type of information that will be of particular use to specific communities such as those that consist of subsistence fishers. Subsistence fishers (as well as sports fishers) are more highly exposed to PBT chemicals than the general population. Subsistence fishers consume large quantities of what they catch. In addition, children are affected by lower doses of certain PBTs than are adults. Children of both subsistence fishers and sport fishers will consume larger quantities of lake food and seafood than children in other communities. As discussed in Unit VI.B.2., EPA's Office of Water maintains a Listing of Fish and Wildlife Advisories (LFWA) for the U.S. and its territories, which listed 2,299 advisories in 1997 (Ref. 29). The overwhelming majority of the advisories are for well-recognized PBT chemicals (chlordane, mercury, PCBs, etc.), but many less familiar substances are also represented. The number and content of advisories in LFWA clearly indicate that toxicologically significant levels of chemical contaminants, specifically PBTs, are often found in fish and wildlife that are caught noncommercially and consumed by the U.S. population. It should be noted that the fact that no advisories have been issued for a particular chemical does not mean that the chemical does not bioaccumulate. Not all species of aquatic organisms are tested nor are all water bodies. In addition, each state determines what it will use as the level of concern for issuing an advisory. EPA believes that it would be inconsistent with the intent of EPCRA section 313 to limit the information on bioaccumulative toxic chemicals to only information for the most bioaccumulative.

One commenter contends that EPA did not provide scientific justification for its choice of the bioaccumulation criterion of a BCF/BAF of 1,000. The commenter states the EPA's discussion of the origin of the 1,000 BCF/BAF value at a 1976 meeting sponsored by the American Society of Testing and Materials, and its reaffirmation in 1995 in a research article by two of the original authors, the use of the value by scientists in EPA's Office of Research and Development's Duluth Laboratories, by EPA's Office of Pollution Prevention and Toxics in the review of chemicals under TSCA sections 4 and 5, by EPA's Office of Water in the Final Water Quality Guidance for the Great Lakes System, and the use by other authorities, such as the German government, to identify chemicals of high concern for bioaccumulation do not provide a technical basis for choosing a value of 1,000 as a criterion for bioaccumulation. The commenter contends that a criterion of 5,000 is scientifically supportable because chemicals with a BCF/BAF of 5,000 have a high potential to biomagnify.

As discussed above, there is no scientifically ''best'' bioaccumulation criterion. The degree of bioaccumulation is a continuum. A chemical does not bioaccumulate only if it has a BCF that is 5,000 or greater. A chemical that has a BCF of 1,000 will bioaccumulate, specifically the chemical will be present in an organism at a concentration that is 1,000 times greater than its concentration in the surrounding aqueous environment. Rather the choice of a value along the bioaccumulation spectrum is based to a large degree on how the criterion is to be used, e.g., to track chemicals entering a particular environment, or to restrict the use of chemicals, etc. As such the choice of a bioaccumulation criterion is a combination of science and policy.

The commenter did not provide support for the contention that 5,000 was scientifically the ''best'' bioaccumulation criterion. Specifically, the commenter did not indicate why as a scientific matter a BCF of 5,000 was preferable to a BCF of, for example 4,000 or a BCF of 15,500. While the commenter did note that chemicals that have a BCF of 5,000 tend to have a high potential to biomagnify, the commenter did not indicate in what way this factored into his determination that a BCF of 5,000 is the scientifically ''best'' bioaccumulation criterion. In addition, EPA does not agree that a BAF or BCF of 5,000 indicates that a chemical will be more likely to biomagnify since biomagnification is a much more complex process. Biomagnification is not a separate process from bioaccumulation or bioconcentration, but is instead a specific example or subset of both. Biomagnification has been defined as: The result of the processes of bioconcentration and bioaccumulation by which tissue concentrations of bioaccumulated chemicals increase as the chemical passes up through two or more trophic levels (Ref. 43). The difference between bioaccumulation and biomagnification is that for a chemical to biomagnify its level of bioaccumulation must increase as it moves up the food chain. The whole concept of biomagnification can be viewed as controversial (Ref. 9) and biomagnification has been studied for only a few chemicals. Most importantly, biomagnification is not required in order to have a concern for chemicals that bioaccumulate. This is because bioaccumulation in even one species can have a serious impact on that species or any other species that feeds on it. For example, if a chemical only bioaccumulates in fish then the fish will

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be exposed to higher concentrations of the chemical as will anything that eats the fish. Therefore, EPA believes that there is no reason to establish biomagnification as a criterion for PBT chemicals since bioaccumulation is of more than sufficient concern in and of itself.

None of the other commenters who believe that the bioaccumulation criterion of 1,000 is too expansive suggested that EPA adopt another value, other than the 5,000 value used in international agreements, addressed in previous responses in this unit. At most, several commenters took issue with the fact that the EPCRA section 313 bioaccumulation criterion (BCF/BAF of 1,000) is 5 fold less than the international bioaccumulation criterion of a BCF/BAF or 5,000. Given that for each of these programs the focus was on PBT chemicals that are of global concern, EPA believes that as a matter of public policy, it is more appropriate for a reporting program to use a more protective criterion than that used in international agreements that seek to ban or severely restrict the use and/or release of chemicals.

One commenter believes that EPA should not adopt a bioaccumulation criterion (BCF/BAF of 1,000) for EPCRA section 313 that is more stringent than the criterion for a Great Lakes BCCs (a human health BAF of 1,000). EPA notes that BCCs will receive stringent controls which is not the case for toxic chemicals identified as bioaccumulative (and persistent) under EPCRA section 313.

Many commenters supported the proposed bioaccumulation criterion of a BCF/BAF or 1,000. However, one of these commenters believes that 1,000 should be the criterion only if the BCF or BAF is a measured value. If the BCF is an estimated value, then the criterion should be 500.

EPA believes that such a two-tiered approach will add confusion. Further, estimated or predicted BCFs are often based on measured data and equations that have been found to correlate well with measured data. In addition, EPA believes that a BCF of 500 is overly expansive. EPA believes that expanding the criteria to include estimated BCFs of 500 would label so many chemicals as bioaccumulative as to be impractical. EPA believes that the adoption of the criterion of BCF/BAF of 1,000 allows EPA to balance the need to provide communities with information on toxic chemicals that bioaccumulate without being overly inclusive or restrictive.

Some commenters contend that EPA's two-tiered approach to the bioaccumulation criteria is confusing. EPA notes that it proposed only one bioaccumulation criterion for EPCRA section 313, a BCF/BAF of 1,000. The Agency did not propose to use a BCF/BAF of greater 5,000 as a second bioaccumulation criterion for EPCRA section 313. However, for purposes of setting reporting thresholds in this rulemaking, the Agency did choose to focus on the subset of PBT chemicals that have a BCF/BAF greater than 5,000 (and half-lifes greater than 6 months) by proposing an even lower reporting threshold.

For the reasons given above, EPA reaffirms its intention to use a BCF/BAF of 1,000 as the criterion for characterizing a chemical as bioaccumulative under EPCRA section 313.

c. *Toxicity*. A number of commenters contend that EPA should set a separate toxicity criteria for PBT chemicals. EPA disagrees. EPCRA section 313 provides toxicity criteria at section 313(d)(2) to be used in adding a chemical to or deleting a chemical from the EPCRA section 313 list of toxic chemicals. These criteria are:

(A) The chemical is known to cause or can reasonably be anticipated to cause significant adverse acute human health effects at concentration levels that are reasonably likely to exist beyond facility site boundaries as a result of continuous, or frequently recurring, releases.

(B) The chemical is known to cause or can reasonably be anticipated to cause in humans-

(i) cancer or teratogenic effects, or

(ii) serious or irreversible-

(I) reproductive dysfunctions,

(II) neurological disorders,

(III) heritable genetic mutations, or

(IV) other chronic health effects.

(C) The chemical is known to cause or can reasonably be anticipated to cause, because of-

(i) its toxicity,

(ii) its toxicity and persistence in the environment, or

(iii) its toxicity and tendency to bioaccumulate in the environment, a significant adverse effect on the environment of sufficient seriousness, in the judgment of the Administrator, to warrant reporting under this section.

Given that Congress has provided EPA with specific toxicity criteria, and that listed chemicals are statutorily defined as ''toxic chemicals,'' the Agency does not believe that additional ''toxicity'' criteria would be appropriate. One reason is that the Agency is concerned that this would imply that TRI data on the toxic chemicals that meet the statutory toxicity criteria are of less value than TRI data that meet both the statutory toxicity criteria and some additional toxicity criteria that would be developed by EPA. EPA believes that bifurcating the list with an additional, non-statutory toxicity criteria would be inconsistent with the intent of Congress. In addition, it is worth noting that some of the toxicity criteria presented by the commenters are fundamentally consistent with the toxicity criteria outlined in the statute. However, EPA notes that some of the criteria provided by the commenters are risk criteria rather than hazard criteria. For example, see ICCA Briefing Note on POPs (April 21, 1998) (Ref. 26). As discussed at length in the final rule adding 286 chemicals to the EPCRA section 313 list (59 FR 61432), the EPCRA section 313(d)(2)(B) toxicity criteria (chronic toxicity) are hazard criteria, not risk criteria. The EPCRA section 313(d)(2)(C) criteria are primarily hazard based with only a limited exposure component. To impose additional toxicity criteria for purposes of defining a PBT or a PT or BT chemical based on risk rather than hazard would be inconsistent with EPCRA section 313. See, e.g., *Legislative History* at 5186. Risk assessment may be appropriate for use under statutes that control the manufacture, use and/or release of a chemical. However, EPCRA section 313 is an information collection provision that is fundamentally different from other environmental statutes that control or restrict chemical activities. For these reasons, EPA believes that it is inappropriate to add toxicity criteria, beyond the criteria provided by Congress at EPCRA section 313(d)(2).

3. *Persistence and bioaccumulation consideration under EPCRA section 313(d)(2)(C)(ii) and (iii).* The criteria that EPA has laid out in this rule for determining if a chemical is a persistent and/or bioaccumulative chemical are not the same criteria EPA uses when conducting assessments for listing chemicals pursuant to EPCRA section 313(d)(2)(C)(ii) and (iii). These sections of EPCRA allow EPA to consider whether a chemical meets the listing criteria based on ''its toxicity and persistence in the environment'' or ''its toxicity and tendency to bioaccumulate in the environment.'' Including consideration of persistence and/or bioaccumulation modifies the way in which EPA assesses a chemical's toxicity for purposes of listing. EPA interprets the results of the toxicity data in light of a chemical's persistence and/or bioaccumulation, and adjusts its concerns for the chemical's toxicity in accordance with the degree to which a chemical persists or bioaccumulates. For example, standard aquatic toxicity tests provide toxicity results in time frames that range from hours to a few weeks. For aquatic toxicity that results

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from such short exposure times, a chemical with a persistence half-life of even 2 weeks will result in a greater potential for exposure and therefore increased concern for the concentration at which toxicity is expressed. In this case, EPA would be concerned about the chemical's persistence at levels well below a half-life of 2 months or more. Because EPA's concern under these provisions is with the interrelationship between two chemical properties and how that affects whether the chemical can reasonably be anticipated to cause a significant adverse effect on the environment, EPA believes that it needs to be able to consider a broader range of values. By contrast, the persistence and bioaccumulation criteria established in today's rulemaking serve a different purpose; they are intended to operate independent of a chemical's toxicity, to identify a fixed class of chemicals. EPA has provided this explanation to clarify the different purposes of the persistence and bioaccumulation criteria established in this rule, and the use of persistence and bioaccumulation in assessments pursuant to EPCRA section 313(d)(2)(C)(ii) and (iii).

C. Criteria as they Apply to Metals

Many commenters contend that the persistence criteria proposed by EPA were developed for organic chemicals and cannot be applied to metals, or if applied, are not useful in screening for hazard. The critical parameter in determining risk is bioavailability, not persistence. This has been recognized by international organizations of which EPA is a member, so it is unclear why it is now necessary for EPA to deviate from these policies. Metals are not harmful if they are not in a bioavailable form. Moreover, metals are natural components of the earth's crust and many are accumulated by living organisms because they are essential nutrients. Two of the commenters state that because persistence is defined as ''the failure of a substance to readily biodegrade,'' this concept has no relevance for metals.

EPA disagrees. The scientific literature contains many definitions of persistence which vary in detail, but center on a common theme: persistence is the *ability of a chemical substance to remain in a particular environment in an unchanged form*. This definition makes no mention whatsoever of any specific processes that may impact a substance's environmental fate, such as biodegradation. According to this definition, specific metal compounds may or may not be persistent depending on the form of the metal and environmental conditions, but the elemental metal itself obviously meets the definition, and this was acknowledged in the majority of comments received.

That elemental metals are persistent by definition is widely accepted. While they may take different oxidation states that can be interconverted, the elemental metal itself cannot be destroyed. For example, chromium (VI) may convert to chromium (III). Both are simply different forms of chromium. All elemental metals therefore meet the 2 months half-life criterion automatically. Given this, it is obviously false to assert, as did the majority of commenters on this issue, that EPA's proposed persistence criteria *cannot be applied* to metals. The position of many commenters was that in determining whether a metal or metal compound may actually pose a risk if released to the environment, bioavailability is much more important than the fact that a substance meets the formal ''definition'' of persistence. EPA agrees that bioavailability is important in determining the potential for the metal to be accumulated in organisms, but parent metals do have the potential to become available from metal compounds under common environmental conditions. Availability of the metal ion may be the result of biotic or abiotic processes. There are a number of environmental factors which EPA considers in determining the availability of the metal ion. These include hydrolysis, pH effects on solubility, photolysis, aerobic and anaerobic transformations, and *in vivo* transformations. As outlined in the remainder of this section, it is realistic to expect that, in general, metals when released into the environment can encounter conditions in which they are available at levels sufficient to exert toxicity and bioaccumulate.

EPA also disagrees with the commenters' claims, direct or implied, that metals released to the environment as a result of human activity must be of negligible concern because they:

- Cannot be converted to bioavailable forms; or even if initially bioavailable are rapidly sequestered in such a way that subsequent exposure is impossible; or
- If bioavailable, are naturally wholesome and good because organisms need them to function.

EPA disagrees with this simplistic view. Metals can enter the environment in bioavailable forms or can be converted in the environment into bioavailable forms. As shown below, metals and metal compounds may be available to bioaccumulate under many realistic and common environmental conditions.

The commenters are correct in stating that metals released to the environment from anthropogenic sources are affected by prevailing environmental conditions, meaning broadly the wide variety of physical, chemical and biological processes that act upon them, and these collectively determine the form in which the metal ultimately exists.

According to Klein (Ref. 28), interconversion of inorganic metal compounds can be quite rapid, especially for ionic forms, and as a result the chemical form in which an elemental metal is released may not be the predominant form post-release. Generally, the ionic forms of inorganic metals are the most available. Availability is affected by many factors and its determination is complex. For metals environmental conditions can affect their availability. A detailed scientific discussion of the environmental fate of lead, which is representative of other metals, and that is illustrative of many of the more important environmental variables that affect availability is provided in Refs. 14, 28, 30, 50, 66a, 72, and 84. See also the preamble to EPA's recent proposal to lower the EPCRA section 313 reporting thresholds for lead and lead compounds (64 FR 42222). The same basic chemical properties and environmental variables will affect the degree of availability of a metal in the environment regardless of the specific metal. There is no metal that is unavailable under all conditions.

EPA recognizes that lead and lead compounds are the subject of an EPA proposal under EPCRA section 313 (64 FR 42222). The inclusion of the discussion of the environmental fate of lead and lead compounds does not predetermine EPA's decision on the appropriate thresholds that should be set for lead and lead compounds. That determination will be based on a number of factors, including the bioaccumulation of lead.

Microbial transformations in soil, water, and sediment are often important in determining the overall fate of metals and metal compounds, and therefore the potential for formation of bioavailable forms. Metals known to undergo microbial oxidation/reduction processes include, antimony, arsenic, iron, mercury, selenium, and tellurium (Ref. 11). Arsenic microbiology illustrates the importance of environmental conditions in the interconversion of inorganic forms of arsenic. Microbial populations in activated sludge can oxidize arsenite to arsenate under aerobic conditions, but under anaerobic conditions such as often predominate in sediments, arsenate can be reduced to arsenite and

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beyond. Both arsenites and arsenates can be available in the environment (Ref. 11). Microorganisms can reduce mercury in the form of mercuric chloride to elemental mercury, and are also capable of producing elemental mercury from organomercurials such as phenylmercuric acetate and methylmercuric chloride. Although the reduction of Hg^{2+} to elemental mercury can be regarded as decreasing availability, the elemental mercury formed is volatile and more likely to enter the global atmospheric circulation.

Mercury is perhaps better known for its potential to be biomethylated by bacteria in the environment (Ref. 11). Mercury has very high stability constants with organic ligands and can form true organometallic compounds (Ref. 6). As indicated by Stumm and Morgan (Ref. 49), metals and metalloids that form stable alkyl compounds are of special concern because they may be volatile; may accumulate in cells; and are toxic to the central nervous system of higher organisms. Methylmercury is highly bioaccumulative and is by far the best studied example of microbial bioalkylation. However, methylation of arsenic is also fairly well-characterized, involves the replacement of substituent oxygen atoms by methyl groups (e.g., arsenate is biomethylated to form dimethylarsine), and is important in the transfer of arsenic from sediment to the atmosphere (Ref. 11). Lead, germanium, selenium, tellurium, tin, and several other metals can also be biomethylated (Ref. 49).

Many of the commenters noted that certain metals are indeed micronutrients (e.g., cobalt, copper, and iron), and are accumulated precisely because they are required for certain cellular functions. It does not follow, however, that any amount of the same metal is acceptable or desirable. Accumulation of essential elements is usually governed by homeostatic mechanisms that control uptake (Ref. 28), but excessive uptake is possible and can be toxic to an organism. For example, selenium which is a micronutrient can cause selenosis at doses as low as 0.023 milligrams per kilogram per day (mg/kg/day). Clinical signs of selenosis include the characteristic ''garlic odor'' of excess selenium excretion in the breath and urine, thickened and brittle nails, hair and nail loss, lowered hemoglobin levels, mottled teeth, skin lesions, and central nervous system (CNS) abnormalities (peripheral anesthesia, acroparesthesia, and pain in the extremities) (Ref. 61). Similarly, copper, which is an essential nutrient, at high doses can cause vascular injury and hemolytic anemia. It should also be noted that copper exhibits high acute and chronic toxicity to aquatic organisms that results in the death of the organism (61 FR 54381, October 18, 1996) (FRL–5396–9), and inhalation of hexavalent chromium is known to cause cancer in humans (Ref. 60), even though chromium in very small oral doses is a micronutrient (Ref. 25). Moreover, the commenters freely cite Allen (Ref. 4), Chapman (Ref. 18) and other authors to the effect that metals are accumulated ''deliberately'' depending on the physiological needs of the organism, but it is clear that this applies only to metals that are essential nutrients. Metals are generally taken into cells by nutrient metal transport systems, and these are not sufficiently specific to completely exclude nonessential metals, some of which may be toxic and/or bioaccumulative. In this situation nutrient metals can be displaced from their binding sites by undesirable, toxic metals, which then gain access to the cell interior with concomitant exclusion of the essential metal (Ref. 49). Toxic metal ions are then free to react with critical enzymes or otherwise disrupt cellular functions if they reach certain levels. Often this toxicity occurs at relatively low doses. For example, inorganic arsenic is a known human carcinogen and causes chronic toxicity at doses as low as 0.014 mg/kg/day (Ref. 59). Lead has no known biological function in humans but is readily absorbed and has been shown to cause various toxic effects. For example, children can suffer permanent damage from lead poisoning, resulting in lowered intelligence, learning disabilities, hearing loss, reduced attention span, and behavioral abnormalities (Ref. 66).

EPA concludes that under many environmental conditions, metals and metal compounds may be available to express toxicity and to bioaccumulate, and that these effects are not necessarily limited to metals that are not essential nutrients. It is appropriate, therefore, to be concerned about the potential adverse effects, and one step in this direction is to more accurately assess emissions from anthropogenic activities. EPCRA section 313 provides that opportunity. Precedent for this concern exists at the international level in the form of a protocol for heavy metals under the UNECE LRTAP, which is currently being negotiated. The draft protocol expresses concern ''. . .that emissions of certain heavy metals are transported across national boundaries and may cause damage to ecosystems. . .and may have harmful effects on human health. . .,'' and specifically advocates assessing and controlling emissions caused by human activities (Ref. 54).

Several commenters raised the issue of EPA participation in various international organizations, claiming that any attempt to apply EPA's proposed persistence and bioaccumulation criteria and/or assessment approach to metals would violate the policies of these organizations, whose positions EPA has previously endorsed. These claims are false because the commenters either misunderstand or misstate the aforementioned policies. The main focus of the commenter's attention is two documents, the OECD's *Harmonized Integrated Hazard Classification System for Human Health and Environmental Effects of Chemical Substances* (Ref. 41), and the North American Agreement on Environmental Cooperation (NAAEC)'s *Process for Identifying Candidate Substances for Regional Action under the Sound Management of Chemicals Initiative* (Ref. 39). A report from a joint Canada/European Union Technical Workshop on metals (Ref. 17) was also cited by commenters and reached similar conclusions.

The OECD document's pronouncements on metals are contained in paragraphs 22 and 23 of that document. Paragraph 22 reads as follows:

> For inorganic compounds and metals, the concept of degradability as applied to organic compounds has limited or no meaning. Rather the substance may be transformed by normal environmental processes to either increase or decrease the bioavailability of the toxic species. Equally, the use of bioaccumulation data should be treated with care. Specific guidance will be [but has not yet been] provided on how these data for such materials may be used in meeting the requirements of the classification criteria. (Ref. 41)

By ''degradability as applied to organic compounds'' OECD means molecular degradation, most often by microbial degradation and/or hydrolysis or other abiotic processes, to progressively simpler organic chemical structures, leading eventually to inorganic substances like carbon dioxide and water. But, note, paragraph 22 does not in any way suggest that metals are not persistent. Moreover, it does not suggest that OECD hazard classification criteria cannot be applied, only that ''care'' (i.e., professional judgment) is required in the interpretation of data relative to the classification criteria. In fact, EPA agrees that bioavailability is important in determining the potential for the metal to be accumulated in organisms.

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The Agency has analyzed information on the environmental fate of metals, and, as noted above, asserts its professional judgment that the parent metals do have the potential to become available from metal compounds under commonly encountered environmental conditions. Therefore, the Agency's treatment of metals is consistent with the OECD's intent.

The same holds with respect to NAAEC's pronouncements under the SMOC (Ref. 39). The focus of NAAEC/SMOC (Ref. 39) is the development of North American Regional Action Plans (NARAPs) for substances that pose significant risk to human health and the environment in all three member countries (namely, Mexico, Canada, and the United States). To date, NARAPs have been established for DDT/chlordane, PCBs, and mercury (note: a metal). NAAEC/SMOC (Ref. 39) acknowledges the persistence of metals, but highlights the role of expert judgment in assessing potential bioavailability of metals and metal compounds:

> For naturally occurring substances such as metals and minerals, the Task Force understands that the direct application of the persistence and bioaccumulation criteria proves very difficult.....Organometals can behave like other persistent organic pollutants in their metallic form, and as certain compounds, metals tend to be infinitely persistent though not necessarily in a form that is bioavailable, and in some cases, they naturally bioaccumulate for beneficial purposes in organisms (i.e., essential elements). Expert judgment is essential for a meaningful evaluation of these substances.

Further, an earlier section of the document (Ref. 39) states,

> It is understood that expert scientific judgment plays a significant role in acknowledging and addressing the difficulties posed by quantitative criteria for persistence and bioaccumulation, particularly in relation to naturally-occurring substances like metals and minerals where the potential for transformation to complexes or metallic species which are more or less bioavailable, are emerging as important considerations.

It is difficult to read into the preceding any intention to *exclude* metals and metal compounds from consideration, as many commenters imply, and more specifically, to declare that these substances have no potential to pose risk because they are never released in bioavailable forms; cannot be converted to bioavailable forms under any foreseeable circumstances, etc. On the contrary, it is clear from the preceding language as well as the inclusion of mercury among the NARAPs developed to date that any substance judged to be potentially bioavailable and that otherwise meets the SMOC criteria, whether organic or inorganic, should not be excluded as a candidate for action. As outlined above, it is realistic to expect that, in general, released metals can encounter conditions in which they are available at levels sufficient to exert toxicity and bioaccumulate. Therefore, the Agency's treatment of metals is consistent with international policy under NAAEC/SMOC (Ref. 39).

Finally, EPA reminds commenters that a mechanism already exists to address concerns for any metal compound for which the data show that the metal cannot become available. The issue of bioavailability was addressed previously for EPCRA section 313 chemical assessments through EPA's policy and guidance concerning petitions to delist individual members of the metal compound categories listed under EPCRA section 313 (56 FR 23703, May 23, 1991). This policy states that if the metal in a metal compound cannot become available as a result of biotic or abiotic processes, then the metal will not be available to express its toxicity, and by extension, to bioaccumulate. If the intact metal compound is not toxic and the metal is not available from the metal compound, then such a chemical is a potential candidate for delisting. EPA has received fewer than 10 petitions to delete individual metal compounds because the petitioner contended that the metal portion of the metal compound would not be available under environmental conditions or *in vivo*.

D. Multimedia Modeling

One commenter contends that EPA should clarify how and when multimedia models will be used in the evaluation of PBT chemicals. EPA should not use the EQC model or other multimedia models as the sole determinant of potential risk. If exposure and use information is available, a detailed technical evaluation based on these data is preferred over modeling based on hypothetical exposure and loading scenarios.

The purpose of this rulemaking is to lower reporting thresholds for certain EPCRA section 313 substances that are being designated as persistent and bioaccumulative, and to list several additional substances that meet EPCRA section 313 listing criteria and are also persistent and bioaccumulative. Although neither quantitative risk nor exposure assessments have been performed, nor are they required under EPCRA, designation as a PBT does imply the existence of *potential* risk. However, contrary to the comment, EPA has not proposed that multimedia models be used as the sole factor in determining persistence. As clearly stated in the proposed rule, EPA intends to use such modeling ''as an additional factor, in conjunction with reaction half-lifes for individual media, bioaccumulation/bioconcentration factors, etc., in justifying [the] actions proposed.''

In the proposed rule EPA did explain in a general way (at 64 FR 703) how models would be used in PBT evaluation, and stated that results of multimedia modeling may be used to override compartment (medium)-specific degradation half-lifes, but only if all model inputs are judged sufficiently accurate. This leaves unspecified what specific value(s) might be used for overall environmental persistence *criteria* (expressed either as an overall residence time or overall half-life). To date no international scientific or regulatory authority has proposed any such criterion for POPs/PBT chemicals, and the complex relationship between compartment-specific and overall persistence criteria is in fact a major topic of current research.

One commenter raises concerns regarding the modification EPA made to the EQC III model that deleted advective losses and sediment burial.

EPA modified the model to exclude advective losses and sediment burial because if these processes are included the persistence based on destruction will be underestimated. In multimedia modeling, advection can be viewed as the flow into or out of the evaluative environment or ''box.'' These include processes such as downstream flow in surface waters, dispersion downwind in air, and burial in sediments. The model considers these non-destructive processes to result in loss from the evaluative environment in the same way that destruction does. However, these processes simply result in the transport of a chemical to another part of the environment downwind or downstream from where it is released, or its deposition into sediments, but not the destruction of the chemical.

The persistence of a chemical calculated when the model is run considering advective losses include non-destructive transport processes which remove the chemical from the evaluative environment. For example, the environmental persistence of a chemical released to water which does not significantly partition to sediments, degrade, or volatilize will reflect the rate at which the water to which it is released flows out of the evaluative environment. In this example, the

relative rate of non-destructive transport out of the evaluative environment may be more rapid than the processes which result in the destruction of the chemical. Thus, the persistence calculated by the model will be less than if advective transport from the evaluative environment was not considered.

EPA used the model to evaluate persistence based on destruction in a multimedia environment. This is consistent with EPCRA section 313 persistence criteria in that the criteria are based on destruction, not transport of the chemical. The Level III (non-equilibrium partitioning, steady state mass balance) models are preferred for developing qualitative and quantitative predictions of chemical distribution, pathways, and relative concentrations (Ref. 16). Level III models can also be used to assess persistence (Ref. 33). At steady state (level III) conditions the amount of chemical is unchanging with time and the input and output rates for a compartment are equal. The overall residence time of the chemical is the mass of the chemical in the compartment divided by the input or output rates. This represents the average time the chemical will reside in the compartment. Output may be by reactions that result in the destruction of the chemical or by advective flow (non-destructive) usually in air or water. When the model is modified to eliminate advective flow, the persistence of a chemical based on the rates of reactions that result in the destruction of the chemical can be assessed. Webster et al (Ref. 82) used this approach in evaluating the environmental persistence of chemicals using a multimedia fate model and noted that if advective loss is included, the residence time is reduced and can give a misleading impression of a short persistence. It was also noted that these advective losses ''. . .merely relocate the chemical; they do not destroy it.'' EPA also used a modified version of the EQC level III model as a tool to assist on the characterization of the persistence of the chemicals subject to this rule. In this version of the model only irreversible transformation contributes to net loss of a chemical. In other words, the model was modified to represent a ''closed box'' in which the effect of processes that serve only to move the chemical from within the evaluative environment to outside of it, primarily in air and water (advective losses) were nullified. Sediment processes responsible for transport of the chemical from the evaluative environment such as sediment burial were similarly treated. The intent of this modification was to make sure that only processes responsible for the destruction of the chemical were considered in evaluating its persistence in a multimedia environment. EPA supports the use of level III multimedia models modified, as described, for their ability to simultaneously consider reaction rates and partitioning so as to give a reasonable assessment of the persistence of chemicals in the multimedia environment.

However, EPA notes that its reliance on the multimedia modeling was limited. As discussed in the proposed rule (at 64 FR 703) and in Unit VI.B.2., EPA primarily considered media-specific data and made a case-by-case determination about the persistence of each chemical.

E. Thresholds

The issue most frequently raised by commenters was the Agency's choice of thresholds and the factors that EPA considered in lowering the thresholds. Many commenters contended that EPA should not consider burden in choosing thresholds. They believe that EPA should set a threshold of 10 pounds for PBT chemicals and 1 pound for that subset of PBT chemicals that are both highly persistent and highly bioaccumulative. Some commenters believe that EPA should set a threshold of 1 pound for all chemicals that are PBT chemicals. Numerous commenters believe that the threshold for reporting should be zero. Other commenters believe that burden should have been a greater consideration in EPA's choice of reporting thresholds. Many of these commenters believe that EPA should set thresholds based on some percentage of releases that would be reported.

EPA disagrees with these commenters. As explained in the proposal, the Agency considered a number of factors to determine the appropriate thresholds that should be established for these chemicals. EPA relied on the language of EPCRA sections 313(f)(2) and (h), and the legislative history to elicit the following principles to guide its exercise of discretion in lowering the thresholds, and in selecting the specific thresholds for PBT chemicals: (1) The purposes of EPCRA section 313; (2) the ''verifiable, historical data'' that convinces EPA of the need to lower the thresholds; (3) the chemical properties shared by the members of the class of toxic chemicals for which EPA is lowering the thresholds i.e., the degree of persistence and bioaccumulation; and (4) the reporting burden imposed by revised thresholds to the extent that such consideration would not deny the public significant information from a range of covered industry sectors. Further, EPA believes that in the language of EPCRA section 313, and its legislative history, Congress provided direction on the appropriate weight to allocate to each of these considerations in implementing EPCRA section 313(f)(2). These considerations underlay the entire process by which EPA determined the appropriate thresholds. But, as noted below, the Agency's choice of revised thresholds was governed, and ultimately constrained, by EPCRA section 313's overriding purpose, which is to provide government agencies, researchers, and local communities, with a comprehensive picture of toxic chemical releases and potential exposures to humans and ecosystems.

In general, EPA's implementation of EPCRA section 313 is guided by the statutory purposes described by EPCRA section 313(h), which provides:

> The release forms required under this section are intended to provide information to the Federal, State, and local governments and the public, including citizens of communities surrounding covered facilities. The release form shall be available. . .to inform persons about releases of toxic chemicals to the environment; to assist governmental agencies, researchers, and other persons in the conduct of research and data gathering; to aid in the development of appropriate regulations, guidelines, and standards; and for other similar purposes.

In addition to section 313(h), EPA was also guided by several statements on the principles intended to guide EPA's implementation of EPCRA section 313 made by Representative Edgar, one of EPCRA section 313's principal architects, during debate on the Conference Report. See, *Legislative History* at 5313–16. In the course of his statement, Representative Edgar also articulated EPCRA section 313's overriding purpose, which is:

> to provide a *comprehensive view of toxic chemical exposure* and, hopefully, provide a basis for more sensible and effective local, State, and national policies. *Legislative History* at 5316 (emphasis added).

Based on the existing reporting requirements, the Agency believes that there are still significant gaps in the picture the TRI data provides local communities, government agencies, and researchers. One of the most significant of these gaps is a comprehensive picture of the releases and potential exposure of PBT chemicals to humans and the environment. Currently, only a very limited picture of releases and other waste management of PBT chemicals is available from the TRI data, in part, as a result of the current thresholds. For

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example, under the current reporting thresholds, in 1997, EPA received only 29 reports on mercury and mercury compounds, and 6 reports on PCBs. This does not present a ''comprehensive view of toxic chemical exposure.'' In addition, information on the releases and other waste management of PBT chemicals is particularly significant because these chemicals both persist and bioaccumulate. Individually, each of these attributes has the potential to pose increased exposures to humans and the environment. Toxic chemicals possessing both attributes have the potential to pose *significant* exposures to humans and ecosystems over a longer period of time; even small amounts of PBT chemicals that enter the environment can accumulate to elevated concentrations in the environment and in organisms, and therefore have a greater potential to result in adverse effects on human health and the environment.

As a first step in addressing the significant gap of information on PBT chemical releases and waste management, EPA considered whether to lower the reporting thresholds for PBT chemicals. EPA then looked to section 313(f)(2) for further guidance on how to proceed. Since lowering the thresholds ensures that ''all facilities subject to the requirements of [section 313]'' will continue to report, the requirement in section 313(f)(2) that a revised threshold obtain a ''substantial majority of total releases of each chemical at all facilities subject to the requirements of this section'' can be met without the need for quantitative support. Consequently, EPA looked to other sources of Congressional direction in the statute and legislative history to guide its exercise of discretion in establishing revised thresholds.

Given that there is no guidance on implementing section 313(f)(2) in the Conference Report, EPA looked to the debate on the Conference Report. In this context, Representative Edgar, stated:

> It is also important to clarify the intent of Congress in establishing thresholds for reporting under this section. . . .These thresholds were designed to obtain reporting on both *a substantial majority of the Nation's toxic chemical releases and to obtain reporting from a large number of firms.* These thresholds reflect Congress' judgement that such thresholds appropriately balance the need for information against the burden on facilities required to provide such information. The EPA is authorized to revise these thresholds, but only if such revised thresholds continue to obtain reporting on a substantial majority of total releases. Any determination by the EPA regarding the ability of revised thresholds to obtain reporting on a substantial majority of releases, especially if such revised thresholds raise the statutory levels, *must be based on verifiable, historical data which presents a convincing case that the statutory levels must be revised. Legislative History* at 5313 (emphasis added).

And during the House debate, Representative Swift noted that any revised threshold ''should be *designed to improve the usefulness of the reports.* It must be structured to obtain reporting on a substantial majority of the *total nationwide releases* of the toxic chemical at *all facilities covered by section 313.*'' *Id.* at 5338 (emphasis added).

In determining how to structure its threshold revisions, and particularly how it would improve the usefulness of the reports, EPA also consulted EPCRA's purposes, laid out in subsection (h). In this context, EPA also considered the statements made by Senator Stafford during debate on the Conference Report:

> This section also requires the Administrator to computerize the data reported on the required forms and to make these data public by various means. Successful implementation of this requirement is vital to the basic purpose of the program. *The data should be managed in the computer in such a way as to allow a wide variety of analyses. For example, it should be possible to retrieve data, not only about individual facilities, but also aggregate data organized by type of chemical, type of effect, geographic location, company name, etc. as well as combinations of these parameters. . . . Legislative History* at 5186 (emphasis added).

Based on this Congressional guidance, EPA reached several conclusions. First, ample ''verifiable, historical data'' exists to support EPA's conclusions that PBT chemicals persist for long periods of time in the environment and bioaccumulate in organisms, including humans; that this persistence and bioaccumulation can result in higher exposures to humans and the environment; and that to ''obtain a substantial majority of the Nation's toxic chemical releases,'' lower thresholds for PBT chemicals are warranted. For example, PCBs have been found throughout the Great Lakes in sediments, water, and aquatic organisms. Multimedia analyses indicate that the majority (80–90%) of human exposure to chlorinated organic compounds, such as PCBs comes from the food pathway, a lesser amount (5–10%) from air, and minute amounts (less than 1%) from water. Most of the data available on human exposure to PCBs in the Great Lakes come from the analyses of contaminant levels in drinking water and sport fish. The consumption of contaminated sport fish and wildlife can significantly increase human exposure to the Great Lakes critical pollutants, such as PCBs. The sport fish are exposed to PCBs by consumption of sediments and through water (Ref. 76). See also Refs. 75 and 77.

Further, EPA strongly believes that increased reporting on PBT chemicals will improve the usefulness of the data on these chemicals. There are currently very few reports for some of the PBT chemicals, such as mercury, mercury compounds and PCBs. The currently available data provide a distorted picture of potential exposures to humans and the environment, because at the current thresholds only a fraction of the releases from facilities otherwise subject to EPCRA section 313 are reported. This limited reporting results in a significant underestimation of the releases from the industry sectors covered by EPCRA section 313. As such, the current data are of limited use for evaluating the potential exposures to humans and the environment of toxic chemicals that persist and bioaccumulate. Expanding the picture of releases, and therefore potential exposures, will increase the utility of all the TRI data on these chemicals. See, e.g., Economic Analysis, Chapter 6.4 (Ref. 67).

On these bases, EPA determined that revising the thresholds would be an important first step in closing the information gap on PBT chemicals. The Agency then began the process of determining the appropriate levels at which to establish the revised thresholds. For a number of technical and policy reasons, EPA chose an approach focused on two classes of PBT chemicals: (1) Toxic chemicals that meet the EPCRA section 313 persistence and bioaccumulation criteria discussed in Unit VI.B., i.e., those toxic chemicals that have half-lifes of 2 months or greater in water/sediment or soil and that have bioaccumulation or bioconcentration factors of 1,000 and (2) the subset of PBT chemicals that are highly persistent and highly bioaccumulative, i.e., those toxic chemicals that have half-lifes of 6 months or greater in water/sediment or soil and that have bioaccumulation or bioconcentration factors of 5,000 or greater.

First, for the most persistent and bioaccumulative toxic chemicals any release will lead to elevated concentrations in the environment and in organisms. EPA believes that such highly persistent and highly bioaccumulative toxic chemicals are of international, as well as national concern, because of the extent of their

persistence and bioaccumulation. As discussed elsewhere in this preamble, these facts have been widely recognized; there are a number of international agreements that ban, restrict, or phase out the manufacture, use and/or release of highly persistent and highly bioaccumulative toxic chemicals.

Similarly, toxic chemicals that are persistent and bioaccumulative are of national, regional, and local concern. As discussed elsewhere in this preamble, toxic chemicals that are persistent and bioaccumulative present a significant concern to many local communities due to the proximity of the communities to industrial sources. All other things being equal, a pollutant reaches nearby populations in less time than distant ones. Thus, toxic chemicals that persist and bioaccumulate can pose significant exposures to communities and ecosystems that immediately surround industrial sources as well as those communities that are subject to regional transport.

Given the international support for the extreme limitations on the use and release of toxic chemicals that are highly persistent and highly bioaccumulative, and the significant exposures that persistent and bioaccumulative toxic chemicals can pose to both local communities and broader regions of the United States and North America, EPA believes that it is appropriate to lower the reporting thresholds for *both* (1) Persistent and bioaccumulative toxic chemicals and (2) for highly persistent and highly bioaccumulative toxic chemicals. In addition, EPA believes this information is important to the public, government agencies, and researchers; for example, the information reported by facilities under the lower thresholds will help these groups assess the loading of the PBT chemicals in both local and regional ecosystems, e.g., a small lake or river or a larger ecosystem such as the Great Lakes or the Chesapeake Bay. See also, Economic Analysis at Chapter 6, pages 32–50 for examples of other uses of TRI data (Ref. 67).

Second, EPA considered how the revised thresholds would provide the information on PBT chemicals needed to assist the public to obtain ''a comprehensive view of toxic chemical exposure,'' as well as to assist government agencies, researchers, and other persons to conduct research and to establish appropriate regulations, guidelines and standards, in accordance with the directives laid out in subsection (h). EPA determined that providing greater information on two identifiable classes of chemicals best achieved these ends. It is consistent with the actions of a significant number of the groups that would use this information; for example, as discussed in Unit VI.B., UNEP is in the process of negotiating an international agreement on the class of persistent organic pollutants with half-lifes of 6 months and BCF/BAF values of 5,000. See also Economic Analysis at Chapter 6, pages 46–48 for examples of how TRI data will be used (Ref. 67). Moreover, EPA determined that data on members within the same class are more easily comparable; the members of the classes EPA established in this rulemaking share a qualitatively comparable level of concern based on their potential for increased exposure. The Agency believed that creating two distinct classes of comparable chemicals would significantly enhance the ability of researchers, government agencies, and other similar persons, to use the reports. Establishing distinct classes of comparable chemicals normalizes the subsequent years' data, providing a baseline against which data users can ascertain trends over time. Consequently researchers can more easily distinguish, and therefore track, the releases and other waste management of highly PBT chemicals, to evaluate the efficacy and progress of the policy strategies intended to address the risks of PBT chemicals, such as the Binational Great Lakes Water Quality Initiative. Finally, administrative convenience argued for establishing a limited number of alternate thresholds. As a practical matter, it would be burdensome for both the Agency and the regulated community to track a variety of individual thresholds for separate chemicals. In addition, because this was only the Agency's initial rulemaking to lower thresholds for certain PBT chemicals, EPA intended that the revised thresholds establish a set of categories that would be generally applicable to future designated PBT chemicals. All of these considerations led the Agency to conclude that it should establish two sets of revised thresholds based on two classes of PBT chemicals.

Thus, having concluded it was appropriate to focus the rulemaking on two classes of chemicals, persistent and bioaccumulative toxic chemicals and that subset of PBT chemicals that are highly persistent and highly bioaccumulative, EPA began the process of determining the specific thresholds that would achieve the purposes of subsections (f)(2) and (h). The intrinsic properties of PBT chemicals argue for very low thresholds. The subset of PBT chemicals that are highly persistent and highly bioaccumulative warrant, in the absence of other considerations, a threshold approaching zero. Any release of these toxic chemicals is of global concern because they can persist for long periods of time, can maintain their identity even after undergoing long range transport, and can bioaccumulate to a significant degree. As discussed above, and at length in Unit VI.B., the potential impacts that can result from any release of toxic chemicals that are highly persistent and highly bioaccumulative have been widely recognized. There are a number of international agreements that ban, restrict, or phase out the manufacture, use and/or release of the most persistent and bioaccumulative toxic chemicals.

However, EPA believes that a zero threshold would be impractical. Attempting to require facilities to determine if they manufacture, process, or otherwise use any amount whatsoever of these chemicals would be extremely burdensome and perhaps technically impossible. Without an actual numerical threshold, many facilities might report some amount of these chemicals in a misguided attempt to assure compliance. This could lead to misleading and inaccurate data on the actual sources of these chemicals. EPA believes that rather than setting a zero reporting threshold it would be better to set a very low threshold that provides facilities with a clear indicator of when they are required to report. In general for purposes of EPCRA section 313, 1 pound is the practical equivalent of zero for these chemicals. EPA explained these considerations in the proposed rule (64 FR 712) and has received no information from commenters that convinces the Agency to pursue a different approach.

EPA then considered the relative degree of persistence and bioaccumulation between the two classes of chemicals. EPA wanted to establish two sets of revised thresholds with the same approximate relationship to each other, as the relative exposure potentials of PBT chemicals to that subset of highly persistent and highly bioaccumulative PBT chemicals. Simply stated, chemicals with half-lifes of 6 months or greater and a BAF/BCF of 5,000 or greater have a higher exposure potential than chemicals with half-lifes of 2 months or greater and a BAF/BCF of 1,000 or greater. However, although, as discussed below, EPA could establish a qualitative relationship, the Agency could not reliably quantify the relative exposure potential across the board for all of the members of both classes. Therefore, in attempting to translate the qualitative exposure potential of PBT

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chemicals to that subset of PBT chemicals that are highly persistent and highly bioaccumulative into a qualitative threshold relationship, EPA considered both the attributes of these chemicals and factors specific to thresholds.

The manufacture, process, and otherwise use thresholds are not equivalent to release thresholds although, in many cases, the quantity manufactured or otherwise used will be very similar to the quantity released. Thus, even if EPA were able to quantify the relative exposure potential of PBT chemicals and that subset of PBT chemicals that are highly persistent and highly bioaccumulative, based on their degrees of persistence and bioaccumulation, and their interrelationship, the Agency would not rely solely on this to select a quantitative threshold relationship between these two classes of chemicals because: (1) The manufacturing, processing, and otherwise use thresholds are not equivalent to release thresholds, and (2) the quantity released, not the quantity manufactured, processed or otherwise used, is a critical factor in determining exposure.

Nonetheless, EPA believes that the relative reporting thresholds should be based to some extent upon the qualitative differential between the potential exposures that may result from releases of PBT chemicals and that subset of PBT chemicals that are highly persistent and highly bioaccumulative.

There is not a direct quantifiable relationship between the potential exposures that can result from equivalent releases of a toxic chemical that persists in the environment with a half-life of 6 months and that has a bioaccumulation factor of 5,000 and releases of a toxic chemical that persists in the environment with a half-life of 2 months and that has a bioaccumulation factor of 1,000. The potential exposure to humans and the environment will depend upon a number of factors, including release patterns, environment variables such as soil type, surface water chemistry, the types and distribution of flora and fauna, and fish consumption patterns. However, EPA did consider the relative differences in the potential exposures between these two classes. For example, after 1 year, there will be more than 15 times as much of a highly persistent chemical that remains in the environment than of a persistent chemical, all other things being equal. Similarly, fish will accumulate more than 5 times as much of the highly bioaccumulative chemical than of the bioaccumulative chemical, all other things being equal. While EPA believes that it can qualitatively describe the relative relationship of highly persistent chemicals to persistent chemicals and the relative relationship of highly bioaccumulative chemicals to bioaccumulative chemicals, the Agency cannot at the present time, define the relative relationship of persistence and bioaccumulation between the two classes of chemicals. This is in large part due to the many variables that must be considered in determining the potential exposures both due to the interaction of these chemical attributes and the large number of environmental factors that must be considered when evaluating persistence and bioaccumulation together.

Although EPA could not develop an exact quantitative threshold relationship between the two classes of chemicals, the Agency did consider the factors discussed above and did rely to some extent on the numerical relationships between the highly persistent and persistent chemicals and the highly bioaccumulative and bioaccumulative chemicals. Therefore, given that: (1) Highly bioaccumulative toxic chemicals will accumulate approximately 5 times greater than bioaccumulative toxic chemicals, (2) highly persistent toxic chemicals will remain in the environment after 1 year, at a level about 15 times greater than persistent toxic chemicals, (3) the fact that the EPCRA section 313 reporting thresholds are not release thresholds but that in some instances the quantities manufactured or otherwise used will be very similar to the quantity released, and (4) toxic chemicals that persist in the environment with half-lifes of 2 months and bioaccumulation factors of 1,000 or greater can be of both local and regional concern, EPA believes that the threshold for PBT chemicals should be a factor of 10 greater than the threshold for that subset of PBT chemicals that are highly persistent and highly bioaccumulative. EPA believes that this ratio balances the uncertainties and factors, including numerical factors, that the Agency considered. Therefore, based on the chemicals' intrinsic characteristics, EPA would establish thresholds of 1 pound for that subset of PBT chemicals that are highly persistent and highly bioaccumulative and 10 pounds for PBT chemicals.

However, the legislative history of section 313(f)(2) indicates that in establishing the original thresholds, Congress recognized the burden imposed on the regulated community. Lowering thresholds necessarily will increase that burden. Therefore, EPA determined it would be reasonable to include some consideration of reporting burden in selecting thresholds for PBT chemicals. But EPA accorded less weight to burden than to the other considerations discussed above. First, neither section 313(f)(2), section 313(h), nor any other provision of EPCRA requires EPA to consider burden. Second, EPA was mindful of the fact that in several places in the legislative history Congress made clear it never intended impacts on reporting facilities to outweigh the public's right-to-know about their potential exposures to toxic chemicals. For example, although Representative Edgar recognized that Congress had considered burden in establishing the statutory thresholds, he did not include reporting burden as one of the general principles that should guide the Agency's implementation of EPCRA section 313 as a whole. Rather, he stated:

> This is a new Federal initiative, and I recognize the desire of some of my colleagues to move ahead cautiously to ensure that burdens imposed on industry are not excessive. Frankly, my concern rest with the families that live in the shadows of these chemical and manufacturing plants. I have put myself in their shoes and have fought for a program that looks after their needs. This legislation gets us well on the path to the full disclosure they deserve. *Legislative History* at 5316. See also, *Legislative History* at 5185–86 (Senate debate on the Conference Report).

As noted in Unit VI.A, one of the major pieces of Congressional guidance on the establishment of alternate thresholds was to obtain a comprehensive picture of ''total nationwide releases of the toxic chemical at all facilities covered by section 313.'' This language, plus other Congressional directives on implementing section 313 generally, such as section 313(h), reflect an interest in obtaining information from a broadly representative range of sources. Consequently, EPA determined that the Agency should consider burden only to the extent that it would not deny the public significant information from a range of covered industry sectors.

Therefore, EPA estimated the number of reports that would be submitted by each industry sector for four groups of thresholds, 1 and 10 pounds, 10 and 100 pounds, 100 and 1,000 pounds, and 1,000 pounds for both classes of chemicals. These options were selected for the following reasons. EPA needed a reasonable but finite number of options to evaluate, and the options described above represent a reasonable picture of the entire range of potential revised thresholds. Data limitations on the manufacturing, processing, and otherwise use of PBT chemicals in the numerous industries, processes, and uses covered by EPCRA section 313

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constrained EPA's ability to make meaningful and reliable distinctions between threshold options that are less than an order of magnitude apart. For example, while EPA believes it can reliably estimate the difference in the number of reports from a 10 pound reporting threshold and a 100 pound reporting threshold, EPA believes that the data are insufficient to allow it to make a meaningful and reliable distinction in estimates of options that are closer than an order of magnitude such as 35 pounds and 50 pounds. EPA explained its data limitations in the proposal, and commenters provided no information that would allow the Agency to increase the resolution of its analysis. Consequently, for the final rule, EPA analyzed options that were orders of magnitude apart from the two thresholds identified through its technical review: 1 pound for highly persistent and highly bioaccumulative chemicals, and 10 pounds for persistent and bioaccumulative chemicals.

Based on information provided in the economic analysis for this rulemaking, at the technical reporting thresholds EPA would obtain information from a broad range of facilities (Ref. 67a). The analysis showed that at a threshold of 1 pound, the public would obtain information from all industry sectors that are currently subject to EPCRA section 313, and that have been identified as manufacturing, processing, or otherwise using those highly persistent highly bioaccumulative toxic chemicals that are part of this rulemaking (except dioxin and dioxin-like compounds which are discussed below). At a threshold of 10 pounds, the public would obtain information from all industry sectors that are currently subject to EPCRA section 313, and that have been identified as manufacturing, processing, or otherwise using those PBT chemicals that are part of this rulemaking. At the technical reporting thresholds, the estimated costs of the additional reports filed would have totaled $355 million in the first year, and $193 million in subsequent years (Ref. 67). EPA considered these costs, even though it cannot quantify the value of the information obtained or lost at the various thresholds, and cannot quantify the relationship between the reporting costs and the value of the information reported, or lost, at a particular threshold.

At thresholds of 10 pounds for highly persistent and highly bioaccumulative chemicals and 100 pounds for persistent and bioaccumulative chemicals, EPA is still able to obtain a significant amount of information on both classes of PBT chemicals from a wide range of industry sectors and sources. For example, no reporting on TBBPA would be lost from any sources or industry sectors at 100 pounds, and some information on octachlorostyrene would be potentially lost from only one industry sector, pesticide manufacturing facilities. At these thresholds, EPA does, however, lose information significant to local communities; for example, EPA loses considerable reporting on mercury and mercury compounds at 10 pounds, but the loss of information is localized in a limited number of industry sectors, and the public will still obtain some reporting from all of the currently covered industry sectors (Ref. 67a). For this threshold option, EPA estimated the total burden at these thresholds to be $191 million for the first year, and $105 million for subsequent years (Ref. 67).

At thresholds of 100 and 1,000 pounds and higher, EPA's analysis indicated that the public, government agencies, and researchers would lose information on many of the PBT chemicals from certain industry sectors and sources. For example, at a threshold of 100 pounds for toxic chemicals that are highly persistent and highly bioaccumulative, the Agency would not obtain reporting on mercury and mercury compounds generated in boilers in the manufacturing sector or information on octachlorostyrene from the primary metal industries (Ref. 67a). However, at these thresholds, EPA estimated the total first year costs to be $99 million and $55 million in subsequent years (Ref. 67).

These analyses led EPA to several conclusions. First, thresholds of 10 pounds for highly persistent and highly bioaccumulative chemicals and 100 pounds for persistent and bioaccumulative chemicals, achieve a significant reduction in reporting burden. Second, at these thresholds EPA obtains information from a broad distribution of industry sectors. Although EPA also loses information significant to local communities at these thresholds, it maintains the overall distribution of reporting from a broad range of industry sectors nationally. EPA could have attempted to compensate for the community-level loss of information on individual members of the classes of PBT chemicals (i.e., by establishing separate thresholds of 1 pound or 10 pounds for individual chemicals), but only by failing to take reporting burden into account for those individual chemicals. As explained previously, the availability of the data limited EPA's ability to distinguish meaningfully between thresholds separated by less than an order of magnitude. In addition, establishing separate thresholds would sacrifice many of the benefits of receiving information from comparable facilities using comparable chemicals, discussed earlier in this unit. Thus greater information for local communities would be achieved at the expense of the increased utility of the reports for other purposes established under EPCRA section 313(h)--e.g., assisting governmental agencies, researchers, agencies and other persons in the conduct of research and data gathering; and aiding in the development of appropriate regulations, guidelines, and standards. EPA believes that, to be consistent with the overriding policy directive in subsection (h), it must achieve a balance between improving the utility of the reports for all of the groups that rely on TRI data. Finally, as noted earlier in this Unit, administrative convenience argues against the establishment of individual thresholds. Among other issues, it would be burdensome on both EPA and the regulated community to track a variety of separate thresholds. Moreover, EPA intends the revised thresholds established in this rulemaking for the two classes of PBT chemicals to be generally applicable to future members of the two classes; absent a strong technical or policy concern to the contrary, it would ultimately be inconsistent with the purposes of EPCRA section 313 for chemicals that share such common characteristics to have vastly different thresholds.

Therefore, EPA believes its selection of thresholds of 100 pounds for PBT chemicals and 10 pounds for that subset of PBT chemicals that are highly persistent and highly bioaccumulative, balances the purposes of EPCRA section 313 and the Agency's desire to provide a comprehensive picture on releases and potential exposures of PBT chemicals, while factoring in an appropriate degree of the consequent impact on the regulated community.

Dioxin and dioxin-like compounds are highly persistent and highly bioaccumulative toxic chemicals. As discussed above, toxic chemicals that are highly persistent and highly bioaccumulative warrant, in the absence of other considerations, a threshold approaching zero. But, for the reasons discussed previously in this section, EPA does not believe that a zero threshold would be practical. However, because the dioxin and dioxin-like compounds are manufactured in extremely small amounts, EPA needed to select a threshold lower than that for the other highly persistent and highly

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bioaccumulative chemicals in order to obtain any reporting.

In choosing reporting thresholds for these chemicals, the Agency considered the extent of the information on dioxin and dioxin-like compounds that would be made available to the public, government agencies and researchers. EPA considered whether this level of information would provide them with ''a comprehensive view of toxic chemical exposure,'' given the attributes of dioxin and dioxin-like compounds, and with ''broad-based national information.'' At a threshold of 0.1 gram, the public would obtain information from all industry sectors that are subject to EPCRA section 313 and that have been identified in the *Inventory of Sources of Dioxin in the United States* (Ref. 3). EPA does not believe that a higher threshold, i.e., 1.0 grams, would provide the public with broad-based national information because there would be no information on the manufacture and release and other waste management of certain sectors. For example, at a higher threshold, EPA anticipates that there would be no reporting from hazardous waste incinerators, pulp mills, non high ferrous foundry industries, and secondary lead smelters (Ref. 67a). At thresholds lower than 0.1 gram, there is greater coverage *within* certain industry sectors, with a concomitant significant increase in burden. EPA believes its selection of a threshold of 0.1 gram for dioxin and dioxin-like compounds balances the purposes of EPCRA section 313 and the Agency's desire to provide a comprehensive picture on releases and exposures of dioxin and dioxin-like compounds while factoring in an appropriate degree of the resultant impact on the regulated community.

F. What Comments Did EPA Receive on Exposure and Risk Considerations and What Are EPA's Responses?

One of the most significant issues raised by commenters relates to the Agency's lack of consideration of quantitative risk in modifying the section 313(f) reporting thresholds. Specifically, a number of commenters believe that EPA should use quantitative risk as a criterion in determining whether to lower the reporting thresholds and in choosing a particular reporting threshold for each PBT chemical. The commenters contend that EPA should conduct risk assessments and make a formal determination that at a particular threshold releases of the PBT chemical pose a risk before lowering the reporting threshold. While the majority of commenters who commented on the issue believe that EPA should make a risk determination before modifying the reporting thresholds, the rationale for their conclusions varied. Some commenters state that a risk determination is required by EPCRA because the intent of EPCRA is to provide information to the public of potential risks posed by the presence of toxic chemicals released to the environment in their communities. Some commenters state that in addition to addressing the substantial majority test, EPCRA section 313(f)(2) requires EPA to use the degree of risk that releases will pose to communities as a determinant in choosing new thresholds. Other commenters state that consideration of risk is a required component of any action under EPCRA section 313. In support of this position, one of the commenters cites two D.C. Circuit Court decisions. Other commenters contend that it would be good public policy to choose a threshold based on risks. Some commenters contend that EPA should lower the reporting thresholds only for those chemicals that present the highest risks to the public. One commenter, however, believes that the Agency should not consider the degree of risk in making a determination to lower the reporting thresholds for PBT chemicals because the consideration of risk in past actions taken by EPA under other environmental statutes have not resulted in a decrease of human health or environmental risks due to PBT chemicals. The commenter states that the increasing number of fish advisories and the lingering and, in some cases, increasing levels of PBT chemicals in the environment and in fish, wildlife, and human tissue demonstrates the magnitude of the failure of the ''risk management strategy.''

EPA disagrees with the commenters' assertion that evidence of risk is required prior to lowering the threshold for any EPCRA section 313 chemical. Section 313(f)(2) addresses revisions to the reporting thresholds. It does not require EPA to establish, prior to the lowering of reporting thresholds, that releases at a particular threshold will result in specific quantitative risks. That section expressly provides that the Administrator may establish a threshold amount for a toxic chemical different from the 25,000 pound threshold for manufacturing and processing activities and the 10,000 pound threshold for otherwise use activities. The only prerequisite for revising the reporting threshold for a toxic chemical is that the revised threshold obtain reporting on a substantial majority of total releases of the chemical at all facilities subject to the requirements of EPCRA section 313. As discussed in Units II.B. and VI.A., EPA believes that it has satisfied the requirements of EPCRA section 313(f)(2) without the need for quantitative support.

EPA believes that the commenters attribute a purpose to EPCRA that is inconsistent with that clearly intended by Congress. Specifically, Congress stated in EPCRA section 313(h) that:

> The release forms required under this section are intended to provide information to the Federal, State, and local governments and the public, including citizens of communities surrounding covered facilities. The release form shall be available,. . .to inform persons about releases of toxic chemicals to the environment; to assist government agencies, researchers, and other persons in the conduct of research and data gathering; to aid in the development of appropriate regulations, guidelines, and standards; and for other similar purposes. 42 U.S.C. section 11023(h).

Neither EPCRA section 313(h) nor its legislative history directs EPA to limit the collection of information on releases to those releases that, from the Federal government's perspective, pose significant local human and environmental exposure and human health and environmental risks. See, e.g., *Legislative History* at 5186.

Federal and local perspectives on what may be an acceptable risk are likely to be very different. The roles of local government and the Federal government differ significantly in terms of ensuring environmental quality. In passing EPCRA, Congress determined that it is for the public to take the information reported on the use and releases and other waste management of toxic chemicals, and to determine whether these releases result in potential risks that the community determines warrant further action given other factors, such as economic and environmental conditions, or particularly vulnerable human or ecological populations. Congress did not intend the Federal government to consider these specific local factors prior to determining whether certain information should be made public or prior to determining whether a different threshold should be established for one or more toxic chemicals.

The intent of EPCRA section 313 is to move the determination of what risks are acceptable from EPA to the communities in which the releases occur. This basic local empowerment is a cornerstone of the right-to-know program. EPCRA section 313 establishes an information collection and dissemination program. The burden it imposes is significantly less than the

burden imposed by a statute which controls the manufacture, use, and/or disposal of a chemical. EPCRA section 313 requires that a facility use readily available data, or if such data are not available, reasonable estimates to prepare each chemical-specific report. The statute does not require that the facility conduct monitoring or emissions measurements to determine these quantities. This is in contrast to other environmental statutes that may require a facility to monitor releases, change its manufacturing process, install a specific waste treatment technology, or dispose of wastes in a certain manner. As such, the Agency believes that as a matter of policy the standard that must be met to require information pursuant to EPCRA section 313 is less than that required to regulate a chemical under a statute such as the Clean Air Act. See, e.g., *Legislative History* at 5186.

Further, contrary to assertions by some commenters, EPCRA section 313 does not require the collection of quantitative risk data nor does the statute require that risk data be disseminated to the public. Rather TRI data provide communities with information on releases and other waste management quantities. TRI data cannot, in themselves, provide information on quantitative risks to individual communities. A determination of the potential risk that a chemical release may pose is dependent upon a number of factors, including the toxicity of the chemical, the physical chemical properties of the chemical, the specific media to which the chemical is released, and site-specific information that will determine the estimated exposures. While TRI data are not in themselves measures of risk, they are an important input that local communities can use along with the factors described in this section to determine potential risks to themselves, their children, their communities, and their environment that may result from releases of toxic chemicals.

EPA's decision to lower the reporting threshold for PBT chemicals is rationally related to the EPCRA section 313 goals of informing communities, assisting research and data gathering, and aiding the development of regulations and guidelines. Because PBT chemicals persist in the environment for a significant period of time and bioaccumulate in animal tissues, PBT chemicals have the potential to be pervasive in the environment, in the food chain, and often in humans. In short, for PBT chemicals, releases and other waste management activities for relatively small amounts of PBT chemicals are of concern. Accordingly, pursuant to the intended purposes of EPCRA, even relatively small releases and other waste management activities for PBT chemicals need to be reported in order to inform communities, assist those engaged in research and data gathering, and to aid the development of regulations and guidelines. Lowered reporting thresholds for PBT chemicals are needed to obtain reporting on these relatively small releases and other waste management activities for PBT chemicals. Consequently, EPA believes that including consideration of the quantitative risk in establishing the thresholds would be poor public policy that would be inconsistent with the overall principles of EPCRA.

Finally, the reference by one of the commenters to two D.C. Circuit Court decisions is misplaced. In support of its position that EPA must undertake a risk assessment of any toxic chemical it is considering for lower reporting thresholds, the commenter cites *American Petroleum Institute* v. *Costle*, 665 F.2d 1176, 1187 (D.C. Cir. 1981), *cert. denied*, 455 U.S. 1034 (1982), and *Milwaukee Metropolitan Sewerage District* v. *EPA*, 40 F.3d 392 (D.C. Cir. 1994). Neither case cited by the commenter addresses EPCRA. Nor do these cases establish a generally applicable principle of law that risk assessments are required prior to any government action. In *Milwaukee Metropolitan Sewerage* the court reviewed standards adopted by EPA in a Clean Water Act regulation. In *American Petroleum Institute* the court reviewed the primary and secondary national ambient air quality standards for ozone promulgated by EPA under the Clean Air Act. Both the Clean Air Act and the Clean Water Act have no bearing on EPCRA section 313. Unlike the statutes at issue in the cases cited by the commenter, consideration of risk is not a requirement of section 313(f)(2) for modifying the reporting thresholds for EPCRA section 313 listed chemicals, and, in fact, the consideration of risk is generally not required for any rulemaking under section 313. *Troy Corporation* v. *EPA*, 120 F.3d 277 (D.C. Cir. 1997).

Some commenters further state that in proposing to change EPCRA section 313 reporting thresholds, EPA has not addressed any of the factors the Agency mentioned when it originally promulgated EPCRA section 313 regulations. In the February 16, 1988 final rule, EPA stated:

> EPA may consider a number of factors for threshold modification including exposure factors such as population density, the distance of population from covered facilities, and the types of releases. Threshold modifications could also take into account the relative potency of the chemical or class of chemicals and effects of concern. (53 FR 4508).

In this statement, the commenters contend that EPA correctly mentions factors that relate to risk (i.e., exposure and relative toxicity). The current proposal to change reporting thresholds under EPCRA section 313 fails to address these factors.

As is clearly evident in the quote from the February 16, 1988 final rule, EPA stated that these were things that it ''may consider'' or that could be taken into account. These statements do not require that the possible factors mentioned above be a basis for any change in the reporting thresholds nor do they preclude the consideration of factors such as the persistence and/or bioaccumulation of toxic chemicals in modifying the reporting thresholds. This statement was not a commitment that EPA would consider risk in any decision to modify reporting thresholds. It merely provided examples of things that the Agency may consider.

As explained in previous responses, EPA does not believe that it would be good public policy to consider factors related to quantitative risk with respect to establishing thresholds for PBT chemicals. Given the degree of persistence and bioaccumulation that these toxic chemicals exhibit, EPA believes that the value of this information to the public outweighs the policy considerations presented in favor of considering risk factors in establishing revised thresholds. Any other decision would be inconsistent with the legislative intent underlying EPCRA section 313.

Finally, EPA notes that this decision is consistent with the approach adopted in modifying the thresholds to establish a 1 million pound manufacture, process, or otherwise use threshold for facilities that have 500 pounds or less of production-related waste (59 FR 61488, November 30, 1994) (FRL–4920–5). Any decision to include risk considerations in establishing modified thresholds under section 313(f)(2) would compel the Agency to re-examine the thresholds established for facilities with less than 500 pounds of production-related waste.

Several commenters contend that a chemical's degree of persistence and bioaccumulation are unrelated to the chemical's exposure potential. They disagree that persistence and bioaccumulation are necessarily indicators of exposure or exposure potential. As an example, the commenter states that many of the compounds EPA is targeting are highly lipophilic, non-water soluble

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compounds, and the greatest potential for bioaccumulative effects is through uptake from the water column. EPA should evaluate how these compounds partition in the environment. Those that are not bioavailable have limited exposure potential, and therefore limited risk. Thus, the commenter believes that EPA must consider exposure in conjunction with persistence and bioaccumulation.

EPA disagrees with the commenters. All other things being equal, the chemical with a higher degree of persistence and bioaccumulation will have a greater exposure potential than the chemical with a lower degree of persistence and bioaccumulation. For example, all other things being equal, a chemical that has a half-life in water of 4 months will have a higher exposure potential to aquatic organisms than a chemical with a half-life in water of 1 month. Fifty percent of the first chemical will remain in the water after 4 months while only 12.5% of the second chemical will remain in the water after 4 months. After 4 months, aquatic organisms will be exposed to 4 times more of the first chemical than the second chemical. Clearly the chemical with the greater persistence has the higher exposure potential.

EPA does not believe that the commenter's example supports their contention that persistence and bioaccumulation are unrelated to exposure potential. As EPA understands the commenter's example, chemicals that have the greatest bioaccumulation potential will not be bioavailable in water because they are highly lipophilic and non-water soluble. Thus, because they are not bioavailable in water, they cannot bioaccumulate in aquatic organisms. A well-studied example that clearly contradicts the commenter's claim is the bioaccumulation of polychorinated biphenyls (PCBs) in the Great Lakes. PCBs have BAFs as high as 141,000,000 (Table 1, at 64 FR 707–8) and very, very low water solubility. PCBs have been found throughout the Great Lakes in sediments, water, and aquatic organisms. Multimedia analyses indicate that the majority (80–90%) of human exposure to chlorinated organic compounds, such as PCBs comes from the food pathway, a lesser amount (5–10%) from air, and minute amounts (less than 1%) from water. Most of the data available on human exposure to toxic substances in the Great Lakes come from the analyses of contaminant levels in drinking water and sport fish. The consumption of contaminated sport fish and wildlife can significantly increase human exposure to the Great Lakes critical pollutants. The sport fish are exposed to PCBs by consumption of sediments and in water, from which they bioaccumulate the PCBs (Ref. 62).

Some commenters contend that EPCRA requires that EPA consider the risks that a chemical may pose when making determinations to add a chemical to the EPCRA section 313 list of toxic chemicals. In support of this position, one commenter cites two D.C. Circuit Court decisions.

As discussed in detail in the final rule adding 286 chemicals to EPCRA section 313 (59 FR 61432), EPA disagrees with commenters that the Agency must include a risk assessment component to EPCRA section 313 determinations. While the Agency believes that there are limited circumstances where it may be appropriate to consider risk in making listing determinations, e.g., acute human health effects, EPA does not believe that the intent of EPCRA, the EPCRA section 313 toxicity criteria, or the legislative history support the contention that risk assessment is a required component of all EPCRA section 313 listing determinations.

The EPCRA section 313 toxicity criteria require that exposure and risk factors be considered only when determining if the toxic chemical should be listed on EPCRA section 313 based on its acute human health effects, but even then in only a very limited manner. The statute mandates that EPA consider whether ''a chemical is known to cause or can reasonably be anticipated to cause significant adverse acute human health effects at concentration levels that are reasonably likely to exist beyond facility site boundaries.'' EPA has, and will continue to look at exposures reasonably likely to exist beyond facility site boundaries when making a listing determination pursuant to EPCRA section 313(d)(2)(A). However, EPA notes that none of the toxic chemicals added in today's action were added pursuant to paragraph (A) of that section.

The statute is silent on the issue of exposure considerations for the section 313(d)(2)(B) and (C) criteria. The language of section 313 does not prohibit EPA from considering exposure factors when making a finding under either section 313(d)(2)(B) or section 313(d)(2)(C). However, the language of sections 313(d)(2)(B) and (C) does not require the type of exposure assessment and/or risk assessment argued by the commenters. EPA believes that it has the discretion under both section 313(d)(2)(B) and section 313(d)(2)(C) to consider, where appropriate, those exposure factors that may call into question the validity of listing of any specific chemical on EPCRA section 313.

EPA believes that its position regarding the limited use of risk in listing decisions is consistent with the purpose and legislative history of EPCRA section 313, as illustrated in the following passage from the Conference report:

> The Administrator, in determining to list a chemical under any of the above criteria, may, but is not required to, conduct new studies or risk assessments or perform site-specific analyses to establish actual ambient concentrations or to document adverse effects at any particular location. (H. Rep. 99-962, 99th Cong., 2nd Sess., p. 295 (October 3, 1986)). See also *Legislative History* at 5186.

This passage indicates that Congress did not intend to require EPA to conduct new studies, such as exposure studies, or to perform risk assessments. Therefore, Congress did not consider these activities to be mandatory components of all section 313 decisions. EPA believes that this statement combined with the plain language of the statutory criteria clearly indicate that Congress intended that the decision of whether and how to consider exposure under EPCRA section 313(d)(2)(B) and (C) should be left to the Agency's discretion. EPA has carefully considered when and how to use exposure to fully implement the right-to-know provisions of EPCRA. The Agency believes that exposure should be considered only in very limited circumstances when adding a chemical to EPCRA section 313(d)(2)(B) or (C). The Agency's interpretation of the section 313(d)(2) and (d)(3) criteria for modifying the section 313 list of toxic chemicals is discussed in the final rule adding 286 chemicals to EPCRA section 313 (at 59 FR 61440–2). And in fact, EPA's interpretation was upheld by the D.C. Circuit in *Troy* v. *EPA*, 120 F.3d 277. The addition of chemicals pursuant to EPCRA section 313(d)(2)(B) and (C) in today's rulemaking is consistent with this interpretation.

The intent of EPCRA section 313 is to move the determination of which risks are acceptable from EPA to the communities in which the releases occur. This basic, local empowerment is a cornerstone of the right-to-know program. EPCRA section 313 establishes an information collection and dissemination program. It provides the public with information that can be used with other site-specific factors to determine if releases into their communities result in risks that the community determines warrant further action given other factors, such as economic and environmental

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conditions, or particularly vulnerable human or ecological populations.

In addition, the reference by one of the commenters to two D.C. Circuit Court decisions is misplaced. In support of its position that EPA must undertake a risk assessment of any toxic chemical it is considering to add to EPCRA section 313, the commenter cites *American Petroleum Institute* v. *Costle*, 665 F.2d 1176, 1187 (D.C. Cir, 1981), *cert. denied*, 455 U.S. 1034 (1982), and *Milwaukee Metropolitan Sewerage District* v. *EPA*, 40 F.3d 392 (D.C. Cir. 1994). As discussed in a previous response in this unit, neither case cited by the commenter addresses EPCRA. In addition, since both cases were decided prior to *Troy*, by the same court, that decided the specific issue raised by the commenter, nothing in the two earlier cases cited by the commenter can overrule that decision.

G. Which Chemicals is EPA Adding to the List of EPCRA Section 313 Toxic Chemicals?

EPA is adding the following chemicals to the EPCRA section 313 list of toxic chemicals: dioxin and dioxin-like compounds, benzo(g,h,i)perylene, benzo(j,k)fluorene (fluoranthene), 3-methylcholanthrene, octachlorostyrene, pentachlorobenzene, tetrabromobisphenol A, vanadium (except alloys) and vanadium compounds. EPA conducted a hazard assessment on each chemical being added to the EPCRA section 313 list of toxic chemicals today. This assessment was separate and independent from the review conducted to determine each chemical's persistence and bioaccumulation potential, although EPA considered some of the same data in certain of its hazard assessments. EPA finds that each chemical being added today meets the criteria for chronic human toxicity and/or environmental toxicity, as set forth at EPCRA sections 313(d)(2)(B) and (C). A summary discussion of the basis for listing each of these chemicals as well as other related issue are presented in the remainder of this unit. A more extensive discussion of these issues is included in the Response to Comments document (Ref. 69) and supporting documents.

1. *Dioxin and dioxin-like compounds category*. There were a number of comments received on the addition of the dioxin and dioxin-like compounds category and these are addressed in detail in the Response to Comments document (Ref. 69). Most of the comments on the toxicity data that EPA presented in support of the addition of the category concern the dioxin-like compounds since most commenters seemed to agree that 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (dioxin or 2,3,7,8-TCDD) meets the criteria for listing under EPCRA section 313(d)(2)(B). A number of commenters did not believe that there was sufficient information to add any of the dioxin-like compounds while several commenters argue that the data on the octa- and heptachlorodibenzo-*p*-dioxins in particular were not sufficient. Commenters also argue that reliance on established toxicity equivalence factors (TEFs) does not provide sufficient support for determining that the dioxin-like compounds meet the EPCRA section 313(d)(2)(B) criteria.

EPA disagrees with the commenters that contend that there are not sufficient data to add the dioxin-like compounds pursuant to EPCRA section 313(d)(2)(B). 2,3,7,8-TCDD is generally recognized as one of the most studied toxic compounds found in the environment. To require the degree of documentation supporting toxicological classification of 2,3,7,8 -TCDD as a necessary criterion for determining that other dioxin-like compounds exhibit dioxin-like toxicity or for listing under EPCRA section 313 is an arbitrary and unrealistic criteria. As discussed in more detail in the Response to Comments document (Ref. 69), a more scientifically supportable set of criteria for determining if compounds exhibit dioxin-like toxicity was proposed by the World Health Organization European Centre for Environmental Health (WHO-ECEH) and the International Programme on Chemical Safety (IPCS) consultation group. These criteria include: (1) A compound must show a structural relationship to TCDD; (2) a compound must bind to the Ah receptor; (3) a compound must elicit Ah receptor-mediated biochemical and toxic responses; and (4) a compound must be persistent and accumulate in the food chain. Each of the 2,3,7,8 substitute dioxins and furans included in the dioxin TEQ approach meet these criteria (Ref. 3).

The commenters often quoted from the EPA Science Advisory Board (SAB) review of EPA's draft dioxin reassessment, to help support the claim that dioxin-like compounds other than 2,3,7,8-TCDD should not be included in the toxic release inventory. The SAB report is a complex document containing a number of contrasting observations. Care must be taken to accurately capture the SAB's concerns. For example, in their Executive Summary, the SAB concluded that, ''The use of the TEFs as a basis for developing an overall index of public health risk is clearly justified''; they caution, however, ''that practical application depends on the reliability of the TEFs and the availability of representative and reliable data.'' In their summary conclusions, the SAB stated:

> The document (EPA Draft Reassessment) represents a departure from the earlier EPA risk assessment for dioxin, which dealt primarily with 2,3,7,8-TCDD. In addressing a broad range of dioxin-like compounds having the common property of binding to the Ah receptor and producing related responses in cells and whole animals, it creates opportunities for a holistic assessment of the cumulative impacts of these broadly distributed anthropogenic pollutants. Thus, while the environmental concentrations of each compound alone may be too low to produce effects of concern, the combined exposure may be producing effects that warrant concern. The use of the concept of TEFs and the concentrations of the compounds in foods and environmental media to produce an overall index of public health risk is clearly justifiable.

The character and thrust of these statements made by the SAB are significantly different from those selectively chosen by many of the commenters opposing the addition of some or all of the dioxin-like compounds. The apparent contradiction between these broad concluding statements by the SAB and those cited by several commenters is due, in part, to commenters confusing the SAB criticisms of the text of the draft reassessment with statements about the general state of scientific knowledge. The SAB clearly felt that EPA needed to do a more rigorous job of discriminating between the inferences it drew about the toxicity of 2,3,7,8-TCDD, other 2,3,7,8 substitute dioxins and furans, and dioxin-like PCBs. Many of the comments cited were intended to help EPA generate a more rigorous scientific discussion in its final reassessment document rather than to represent substantive conclusions reached by the SAB on the nature of dioxin toxicology. Fully taking these concerns into consideration it was still the SAB's overall judgment, as stated above, that ''the use of the TEFs as a basis for developing an overall index of public health risk is clearly justified.''

Some commenters argue that there are qualitative differences in the toxicity of the different 2,3,7,8-substituted isomers of polychlorinated dioxins (PCDDs) and furans (PCDFs). Specifically, there are structural differences between the more toxic, lower chlorinated isomeric PCDDs and PCDFs and the higher chlorinated cogeners to the extent that the octa- and hepta-PCDDs and PCDFs should not be added to the list of EPCRA section 313

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toxic chemicals. These arguments are not valid for several reasons. First, there are data from subchronic studies for both octa- and hepta-PCDDS and PCDFs which demonstrate dioxin-like effects (Refs. 19, 21, 79, and 80). The new WHO TEFs are based on these subchronic studies (Ref. 78). While short-term studies indicate limited dioxin-like effects of these chemicals, these contrasting results are readily explained by the structural differences between the octa- and hepta-PCDDS and PCDFs compared to the lower chlorinated PCDDs and PCDFs. The relative potency of the dioxin-like compounds is related to both their ability to bind to the Ah receptor and their pharmacokinetic properties (Ref. 20). The water solubility of PCDDs and PCDFs decrease with increasing chlorine substitution. Hence the octa- and hepta-PCDDS and PCDFs are significantly less soluble in aqueous solutions compared to the lower chlorinated PCDDs and PCDFs. These solubility problems limit the amount of chemical that can be absorbed in high dose acute toxicity studies. The lack of effect observed in the high dose acute studies is consistent with the limited aqueous solubility of these compounds. However, low dose subchronic studies allow the chemicals to be better absorbed and bioaccumulate to concentrations which produce biochemical and toxic effects (Refs. 19, 21, 79, and 80). Once again this is consistent with the evidence of dioxin-like effects of these chemicals observed in the low-dose subchronic studies. Although not legally required to determine that a chemical meets the listing criteria under EPCRA section 313(d)(2)(B), it should be noted that human exposure to octa- and hepta-PCDDs and PCDFs are subchronic low dose exposures, similar to the experimental studies which demonstrate dioxin-like effects of these chemicals (Refs. 19, 21, 79, and 80).

While there are structural differences between the octa- and hepta- PCDDs and PCDFs compared to the lower chlorinated PCDDs and PCDFs, these differences result in quantitative not qualitative differences in the toxicity of these chemicals. The quantitative differences are demonstrated by the lower potency of the octa- and hepta-congeners compared to TCDD. In addition, the TEFs reflect these quantitative differences by assigning lower TEF values to the octa- and hepta-PCDDS and PCDFs. While there is limited evidence that the shape of the dose-response curve for induction of CYP1A1 activity *in vitro* for octachlorodibenzo-*p*-dioxin (OCDD) is different from TCDD, *in vivo* evidence indicates that the dose response for CYP1A1 induction by octachlorodibenzofuran (OCDF) in three tissues is equivalent to TCDD (Ref. 20). However, it should be noted that these are quantitative not qualitative differences.

Commenters also argue that octa- and hepta-PCDDs and PCDFs should not be listed because ''there is a growing consensus in the scientific community that the potential risks posed by dioxins are largely driven by a limited number of dioxin and dioxin-like compounds (tetra-, penta-, and hexa-PCDDs and PCDFs and certain coplanar PCBs).'' It is important to remember that, as discussed in Unit VI.F., EPCRA section 313 is primarily a hazard-based rather than a risk-based statute. The ''growing consensus'' on dioxin toxicity is probably best captured by the revised TEFs recently established by the WHO (Ref. 78). In this review the scientific evidence for ascribing values of relative toxicity to octa- and hepta-PCDDs and PCDFs was specifically reviewed, as evidenced by the lowering of the TEF for OCDD and OCDF by a factor of 10. In the course of the deliberations by the WHO panel of internationally distinguished scientists, there was the opportunity to remove both octa- and hepta-PCDDs and PCDFs from the TEF listings. However, the WHO panel concluded that the best scientific interpretation of the data available was to leave hepta-PCDDs and PCDFs unchanged and reduce but not eliminate OCDD from TEQ calculations. Even with this reduced toxicity, OCDD and OCDF clearly meet the listing criteria of EPCRA section 313(d)(2)(B).

EPA disagrees with the commenters that contend that TEFs are not adequate support for listing chemicals under EPCRA section 313. The development of TEFs has been a rigorous scientific effort involving a number of international panels of scientific experts and has involved the careful review of all relevant scientific literature. EPA believes that the development and review processes used for the generation of the TEFs was sound and represents a reasoned and reliable judgment on the dioxin toxicity of each of the 17 dioxin and dioxin-like compounds. The Response to Comments document (Ref. 69) includes an extensive discussion of the history of the development of dioxin TEFs which demonstrates why EPA believes that the TEFs are well supported scientifically and consequently have been openly adopted by the international scientific and regulatory community. In addition, as EPA has previously explained (59 FR 61432), the Agency believes that EPCRA section 313 allows a chemical category to be added to the list, where EPA identifies the toxic effects of concern for at least one member of the category and then shows why those effects can reasonably be expected to be caused by all other members of the category. Here, individual toxicity data are not available for all members of the category; however, there is sufficient information to conclude based on generally accepted scientific principles, that all of these chemicals are highly toxic based on structural and physical/chemical property similarities to those members of the category for which data are available.

Thus, EPA reaffirms that there is sufficient evidence for adding dioxin and dioxin-like compounds on EPCRA section 313 pursuant to EPCRA section 313(d)(2)(B) based on the available cancer and other serious chronic health effects data for these compounds. Therefore, EPA is finalizing the listing of dioxin and dioxin-like compounds on the EPCRA section 313 list.

a. *Manufacturing only qualifier for dioxins and dioxin-like compound category*. Comments were mixed with regard to EPA's proposal to add a manufacture only qualifier to the dioxin and dioxin-like compounds category. Some commenters agree with EPA's statements in the proposed rule concerning the burden reduction aspects of the qualifier and the fact that as a result, the dioxin reporting would focus on facilities that manufacture dioxin and dioxin-like compounds rather than those that process or otherwise use raw materials containing dioxin and dioxin-like compounds that have accumulated in those raw materials. Some commenters state that the qualifier would avoid duplicative testing and administrative costs among many processing and using industries which do not necessarily discharge dioxins or furans into the environment. Some commenters state that all releases of dioxin and dioxin-like compounds must be reported, not just those resulting from the manufacture of these chemicals. Other commenters note that a significant gap is created by the manufacture only qualifier because it would exclude the processing and otherwise use of chemicals than contain dioxin and dioxin-like compounds as a result of the processes used to manufacture them. Commenters specifically cite pentachlorophenol as an example of a chemical that is contaminated with dioxin and dioxin-like compounds from its manufacturing process. Commenters state that the processing and use of such chemicals

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result in the release of dioxin and dioxin-like compounds that would go unreported under the manufacture only qualifier. One commenter states that if the qualifier is finalized the commenter would like to see language that requires facilities to report if the background levels of dioxin are modified, concentrated, or somehow added to in the manufacturing process. Another commenter states that if the Agency wants to exempt animal sources of dioxin, such as dioxin contained in meat and other animal products, it should craft the rule to do so and not cut out other significant sources of dioxin in the environment by exempting all facilities that process material containing dioxin.

EPA believes that in order to obtain any reporting on dioxin and dioxin-like compounds a very low threshold is required, which is several orders of magnitude lower than the thresholds for other PBT chemicals. At such a low reporting threshold it is estimated that thousands of reports could potentially be filed by facilities, mainly food processing facilities, due to the amount of dioxins in the raw materials they process. The dioxins found in the meat and dairy products that food processors handle have been previously released, circulated in the environment, and bioaccumulated in animals; thus these are not additional loadings to the environment but loadings that have already occurred and cycled through the environment due to the persistence and bioaccumulative properties of these compounds. The unique combination of very low thresholds, the number of food processors that would be required to file, and the fact that they would be filing because of the bioaccumulation of previously released material, led EPA to add the manufacture only qualifier to the dioxins category. The qualifier was added in response to the unique set of conditions that apply to the reporting of dioxin and dioxin-like compounds. The manufacture only qualifier was added to reduce reporting burden on facilities, mainly in the food processing industry, that results from the unique combination of circumstances related to the reporting for these chemicals and to focus on those activities that add to the loading of dioxins in the environment rather than on activities dealing with previously released and bioaccumulated chemicals.

However, EPA acknowledges that the commenters who noted that the processing and otherwise use of chemicals contaminated with dioxin and dioxin-like compounds as a result of their manufacturing process, are correct that these would be newly created and thus any releases of dioxin and dioxin-like compounds that are due to the processing and otherwise use of such chemicals would be new loadings on the environment. In addition, EPA agrees, and has never stated otherwise, that the processing or use of chemicals contaminated with dioxin and dioxin-like compounds could result in the release of these chemicals to the environment. Given the fact that the manufacture of certain chemicals also results in the manufacture of dioxin and dioxin-like compounds that remain with those chemicals as impurities, EPA believes that releases and other waste management quantities for the dioxin and dioxin-like compounds found as impurities with those chemicals should be reported under the dioxin and dioxin-like compounds category. Thus, EPA's original proposal would have created an exemption that was too broad. Consequently, EPA is modifying the qualifier to read as follows:

> Dioxin and dioxin-like compounds (Manufacturing; and the processing or otherwise use of dioxin and dioxin-like compounds if the dioxin and dioxin-like compounds are present as contaminants in a chemical and if they were created during the manufacturing of that chemical)

EPA believes that narrowing its proposal in this fashion is consistent with EPA's intention to focus on new loadings to the environment for dioxin and dioxin-like compounds.

One commenter states that the activity qualifier for dioxin and dioxin-like compounds is intended to minimize the burden of reporting on naturally-occurring constituents of raw materials and that this qualifier would be consistent with the PBT criteria set forth by Canada's Department of the Environment in their Toxic Substances Management Policy. The commenter states that the Canadian policy requires a chemical to be ''predominantly anthropogenic'' to be considered a PBT chemical. The commenter states that EPA's assumption that these compounds are ubiquitous in raw materials may be incorrect. The commenter further states that these compounds may be formed in combustion processes due to the ubiquitous presence of *precursor* chemicals in coal, such as natural hydrocarbons and chlorine. The commenter argues that it is not reasonable to expect the hydrocarbon nor the chlorine to be removed from the raw material prior to combustion. Thus, the ''incidental manufacture'' of extremely minute amounts of these chemicals may be unavoidable.

EPA disagrees that the sole basis for its qualifier was to minimize the burden of reporting. The qualifier was added in response to the unique set of conditions that apply to the reporting of dioxin and dioxin-like compounds. As noted above, EPA was, and remains, concerned that, because dioxin is ubiquitous in the environment, the reporting be focused on those facilities that actually add to the environmental loading of these chemicals. EPA did not state that dioxin and dioxin-like compounds would be ubiquitous in all raw material and did not intend to imply that all raw materials contain these compounds. EPA stated that these compounds are ubiquitous in the environment and, thus, facilities that process raw materials containing these compounds might have to report because of the very low reporting threshold necessary to obtain reports from any sources, including those facilities that coincidentally manufacture them. In addition, although the qualifier may be consistent with Canada's Toxic Substances Management Policy, EPA has not proposed any requirement that a chemical must be ''predominantly anthropogenic'' to be considered a PBT chemical under EPCRA section 313. The commenter is correct that dioxin and dioxin-like compounds may be manufactured in combustion processes due to the ''ubiquitous presence of precursor chemicals'' and that such ''incidental manufacture'' may be unavoidable. However, the mere presence of the dioxin precursors will not guarantee dioxin production. There are well documented conditions that favor the formation of dioxins during combustion, and in some cases it may be possible to stringently control fuel composition, flow times, temperature, and other conditions in order to substantially reduce or even eliminate the incidental manufacture of dioxins during combustion processes.

b. *Withdrawal of the proposal to include dioxin-like PCBs in the dioxin category*. Several commenters support EPA's decision to withdraw the proposal to modify the current PCB listing and move the 11 co-planar PCBs to the proposed dioxin and dioxin-like compounds category and retain the co-planar PCBs as part of the current PCB listing. Two commenters support EPA's decision to leave co-planar PCBs out of the dioxin and dioxin-like compounds category since the structure, metabolism, gene regulation, and toxicities of PCBs are substantially different from those of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin. One commenter takes exception to the use of the term ''dioxin-like'' as a way of describing PCBs and other chlorinated

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compounds and agrees that the PCBs should be kept out of the ''dioxin-like'' class. Other commenters also argue that PCBs are more appropriately classified as PCBs, not dioxin-like compounds.

One commenter contends that since these chemicals are no longer allowed to be distributed in commerce, maintaining a separate EPCRA section 313 chemical category for these chemicals will streamline data management. This approach will also enable EPCRA section 313 reporting for this category of chemicals to be more consistent with existing data already collected for the purposes of complying with TSCA. Further the commenter asserts that approach is also consistent with EPA's Reinvention Policy and will enable ''one-stop'' reporting.

Another commenter asserts that it is unclear just how many grams of dioxin-like compounds would be excluded from this reporting since there are conflicting Agency proposals at work: the first is a much lower threshold for dioxins. The second includes only dioxins manufactured on site. Since PCBs are not generally manufactured on site, these 11 dioxin-like compounds would not be reported under the proposal if they were included as dioxins. On the other hand, if all dioxins (manufactured, processed, and otherwise used) are included in the EPCRA section 313 threshold determination, these 11 PCBs could make the difference between a facility's reporting or not reporting dioxins. If the dioxin threshold remains as proposed, then the 11 PCBs should remain with the PCB category. Further the commenter argues that if the threshold is expanded to include sources other than those that manufacture dioxin on-site, then the PCBs should be part of the dioxin-like compounds category. If EPA does not modify the dioxin threshold to include all dioxin uses, the 11 dioxin-like PCBs should remain with the PCB category.

While EPA agrees with the commenters that the co-planar PCBs should remain as part of the current PCB listing, the Agency does not agree with all of the reasons the commenters have presented. As EPA stated in the proposed rule:

> . . .EPA has determined that all PCBs persist and bioaccumulate. Since PCBs persist and bioaccumulate, EPA believes that they should be subject to lower reporting thresholds, and thus there is no need to move the 11 co-planar PCBs to the proposed dioxin and dioxin-like compounds category. Therefore, EPA has decided to withdraw its proposal to modify the current listing for PCBs and instead proposes to lower the reporting thresholds for the current PCB listing which covers all PCBs. EPA believes that, since all PCBs persist and bioaccumulate, it is appropriate to lower the reporting threshold for this class of chemicals and that this proposal is less burdensome than requiring separate reporting on the dioxin-like PCBs as part of the proposed dioxin and dioxin-like compounds category (at 64 FR 710).

EPA did not base its decision on a determination that co-planar PCBs were not ''dioxin-like'' and keeping them under the current PCB listing should not be interpreted as such a determination. Also, since EPA is not expanding the qualifier for the dioxin and dioxin-like compounds category to include all processing and otherwise use activities, the amounts of co-planar PCBs that might be reportable under the category would not be expected to contribute significantly to threshold determinations for the category at most facilities.

Four commenters specifically do not support EPA's decision to withdraw the proposal to modify the current PCB listing. Commenters assert that the aggregation of dioxin-like PCBs together with other PCBs will fail to provide reporting of useful information on dioxin-like PCBs. The commenters either contend that the PCBs should be included in the dioxin-like compounds category or the PCBs and all dioxin-like compounds should be reported separately. One commenter argues that the aggregate reporting of dioxin-like PCBs and other PCBs fails to provide any information on the release of dioxin-like PCBs to meet the research, regulatory, or public information goals of EPA's proposal. This commenter raises several points. The commenter contends that specifically, even if some facilities releasing dioxin-like PCBs reported these releases as a portion of their total PCBs production of 10 pounds annually or greater, information on dioxin-like PCBs releases would still be unobtainable. The commenter asserts that aside from the food chain, where some dioxin-like PCBs tend to concentrate disproportionately, available measurements indicate that these dioxin compounds are only a small portion of the mass of all PCB compounds. The commenter further argues that some of these dioxin compounds such as PCB-126 are far more toxic than other dioxin-like and non dioxin-like PCBs. Thus, the commenter asserts that in addition to all of the problems of dioxin-like chemical aggregate reporting, one would not know what, if any, portion of the total PCBs reported were dioxin-like. The commenter contends that the dioxin-like co-planar PCBs also should be reported individually so that a TEQ for all 28 dioxin and dioxin-like compounds can be calculated. Another commenter argues that based on information about current body burdens of co-planar PCBs, they compose as much or an even greater percentage of one's overall exposure than the 17 dioxin and dioxin-like compounds. This commenter cites an EPA document that stated that: ''[e]stimates of exposure to dioxin-like CDDs and CDFs based on dietary intake are in the range of 1-3 pg TEQ/kg/day. Estimates based on the contribution of dioxin-like PCBs to toxicity equivalents raise the total to 3-6 pg TEQ/kg/day.'' Some commenters contend that reporting the co-planar PCBs differently from the 17 dioxin and dioxin-like compounds would make any assessment of the overall release and potential health impact of these types of compounds difficult. One commenter argues that PCBs are currently contaminating sediments and industrial sites nationally and have ruined fish as a natural resource for human consumption across the nation and that the distinction between dioxin-like PCBs and dioxin-like compounds made under this rule is a distinction without a difference. This commenter urges EPA to include all dioxin-like compounds, including PCBs, in the dioxin-like compounds category and to require strict accounting from all sources which release these compounds and which manufacture them, incidentally or by design.

One commenter contends that the failure to report dioxin-like PCBs as a distinct entity separate from other PBT chemicals may hold back information on a significant portion of the total dioxin-like hazard from releases by facilities that report under EPCRA section 313, even if all dioxin and furan releases were reported. The commenter argues that environmental exposure measurements, such as those from fish in San Francisco Bay and from human tissues nationally, indicate that dioxin-like PCBs contribute a very significant portion of the total toxicity hazard from exposure to all dioxin-like chemicals. The commenter also asserts that PCB releases might in some cases represent an inadequately measured yet significant portion of the ongoing dioxin release hazard. If, for example, PCB-126 comprises even 1/10 of the PCBs release measured from San Francisco Bay Area sources, it would contribute substantially to total dioxin-like toxicity emission from some of these facilities. The commenter contends that the failure to provide release information on dioxin-like PCBs under EPA's proposal

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may result in failure to inform the public about a significant portion of the total dioxin toxicity that is still released.

EPA agrees that PCBs are toxic chemicals of concern that have caused significant contamination of the environment and that co-planar PCBs may have dioxin-like health effects. However, this does not, in itself, create a requirement that the co-planar PCBs must be moved from their current PCB listing to the dioxin and dioxin-like compounds category. EPA does not believe that the co-planar PCBs must be reported separately from the non co-planar PCBs because they may be more toxic than other PCBs. In general, chemical categories consist of chemicals that vary in their level of toxicity but this variability alone does not mean that release information must be reported separately for each chemical in the category. EPA believes that all PCBs are of concern and that leaving the co-planar PCBs under the current PCB listing will still provide the public with useful and important information. In deciding not to move the co-planar PCBs to the dioxin category, EPA also considered any potential additional burden associated with splitting the reporting for PCBs into two different listings, as well as the fact that facilities are not likely to be able to determine quantities of the specific co-planar PCBs in question. Specifically, EPA considered the lack of readily available estimation techniques for determining quantities of co-planar PCBs, as opposed to other PBT chemicals and the PCB listing as a whole (co-planar PCBs will be included in the estimation of PCBs). EPA determined that since all PCBs are of concern and since the reporting threshold for all of the PCBs under the PCB listing would be lowered substantially, that requiring separate reporting on the co-planar PCBs was not warranted.

One commenter contends that the failure to report dioxin-like PCBs would fail to provide information on that subgroup of dioxin-like compounds for which there is the greatest need for additional information. The commenter argues that EPA's evaluation of the emission of dioxin-like chemicals nationwide shows that there is less information on releases of dioxin-like PCBs than there is for other dioxin compounds. The commenter asserts that similarly, their survey of source information in the San Francisco Bay Area shows that, despite many measurements of dioxin and furan releases, and despite a handful of source measurements confirming PCBs, there are few or no source measurements for dioxin-like PCBs. The commenter argues that the information on releases from facilities is even less available for the dioxin-like PCBs than it is for the other dioxin-like chemicals and that EPA's analysis in the proposed rule fails to consider adequately this extreme need for source release information.

EPA agrees that there is far less information available on co-planar PCBs than for dioxin and other dioxin-like compounds. Much less testing and analysis has been conducted for these chemicals. This would pose an additional problem for reporting on the co-planar PCBs separately from the other PCBs. EPA considered the ability to estimate quantities of specific co-planar PCBs and determined that there is a lack of readily available estimation techniques for co-planar PCBs. In fact, at this time, the Agency would not be able to provide guidance for making a reasonable estimate of quantities of co-planar PCBs that may be manufactured in certain processes. In addition, EPCRA section 313 does not require any additional monitoring beyond that required by other provisions of law so listing the co-planar PCBs separately would not mean that additional source measurements would be developed. Thus, listing under EPCRA section 313 will not require the development of additional monitoring data that could be used to make reasonable estimations of thresholds or releases and other waste management quantities. Given the lack of information available for estimating quantities of co-planar PCBs and the potential additional burden associated with splitting the reporting for PCBs into two different listings, EPA decided to leave the co-planar PCBs under the current PCB listing.

One commenter asserts that the burden on industrial producers of dioxin-like PCBs is not an appropriate reason for excluding dioxin-like PCBs from the dioxin and dioxin-like compounds category because this will not meet EPCRA's right-to-know goal for dioxin-like PCBs. The commenter contends that EPA's cost analysis does not address dioxin-like PCBs specifically and thus, EPA's rationale in Unit VI. of the preamble of the proposed rule (64 FR 688) that ''this proposal is less burdensome than requiring separate reporting on the dioxin-like PCBs'' is not based on any cost analysis in EPA's proposal. The commenter argues further that in any case, aggregate reporting of dioxin-like PCBs with a 10 pound threshold will fail to obtain the required reporting on a substantial majority of dioxin-like PCBs or to provide needed information about dioxin-like PCB releases and therefore, EPA's perceptions regarding reporting burden cannot properly outweigh the public's need for the information which is denied under EPA's new proposal. The commenter refers to the proposal to retain dioxin-like PCBs under the PCB listing as the ''less than 10 pounds exemption.'' The commenter asserts that existing evidence demonstrates that many dioxin producing processes such as waste incinerators, oil-fired boilers, and other processes also produce potentially significant amounts of PCBs which are released to the environment from these facilities. The commenter argues that this evidence suggests that at least some facilities reporting under EPCRA section 313 are likely to be releasing dioxin-like PCBs as a portion of these PCB releases. The commenter contends that the evidence also suggests that most or all releases of dioxin-like PCBs at these facilities may be associated with total annual PCB production of less than 10 pounds per facility and thus, EPA may not meet the requirement that a substantial majority of dioxin-like PCBs be reported under this exemption.

Reporting burden was not the sole or even most important factor in EPA's decision not to move the co-planar PCBs to the dioxin and dioxin-like compounds category. In reaching its final decision, EPA considered the fact that additional information would be collected on all PCBs by lowering the threshold for the PCB listing and that the additional information that would be collected was sufficient for EPCRA section 313 purposes, as well as less burdensome. Even in its proposal EPA did not conclude that reporting burden alone outweighed the public's right-to-know about chemical releases. As stated in other responses to this issue, EPA is also concerned about the ability to estimate quantities of specific co-planar PCBs since there is a lack of readily available estimation techniques for co-planar PCBs. It is correct that EPA did not attempt to quantify the reduction in burden that would result from not including the co-planar PCBs in the dioxin and dioxin-like compounds category. However, EPA believes that it would be inherently less burdensome since facilities would not have to attempt to determine if they can estimate co-planar PCBs separately and filing one form would obviously be easier and less confusing than attempting to track and adjust the amounts that must be applied to two different listings and filing two reports. With regard to the issue of obtaining reporting on a substantial majority of ''dioxin-like PCB'' releases, as stated in EPCRA section 313(f)(2), the

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determination of whether a revised threshold meets the ''substantial majority'' standard is measured against the ''total releases of the chemical at all facilities subject to the requirements of this section.'' As EPA stated in the proposed rule:

> For purposes of determining what constitutes a ''substantial majority of total releases'', EPA interprets ''facilities subject to the requirements'' of section 313 as the facilities currently reporting, ... (at 64 FR 689).

Currently, facilities required to report on PCBs must report on all PCBs, not just the co-planar PCBs or any other individual PCBs. The current listing includes all PCBs. Consequently EPA does not believe that the requirements of section 313(f)(2) function as an impediment to its decision to withdraw its proposal to include the co-planar PCBs in the dioxin and dioxin-like compounds category. As discussed in Units II.B. and VI.A., EPA believes that it has satisfied the requirements of EPCRA section 313(f)(2), without the need for quantitative support.

c. *Listing dioxin and dioxin-like compounds as a category versus individual listing of each chemical.* Some commenters contend that reporting dioxin and dioxin-like compounds as one category would not provide useful information and asked that the individual compounds be reported. One commenter recommends that reporting on individual chemical species should be required when the information is available. One commenter who supports the individual reporting of all of the dioxin and dioxin-like compounds, states that the amounts of individual dioxin compounds released from facilities is part of the important public information needed to assist research and policy development. The commenter claims that reporting as a category will not provide the public with the information to assess the relative hazards of releases since one dioxin-like compound can have a relative hazard several orders of magnitude less than 2,3,7,8-tetrachlorodibenzo-*p*-dioxin. This commenter also states that different sources often emit a different mix of dioxin compounds and that this information is widely used to trace dioxin contamination to specific root causes. The commenter states that the relative amounts of the many different dioxin-like chemicals in a sample are compared to create a ''profile'' which might match the profile created by emission from a particular source. The commenter did not support the reporting of the category based on toxic equivalents (TEQs) but thought it important for the users of the data to be able to determine TEQs. Some other commenters make the same general argument that individual isomer reporting is needed to facilitate risk characterization including transport and fate of the different isomers.

Some commenters contend that certain dioxin-like compounds such as octachlorodibenzo-*p*-dioxin and octachlorodibenzofuran should not be reported since they are ubiquitous in the environment and are the least toxic under the toxic equivalent factors (TEFs). One commenter states that EPA should require reporting only for the most toxic congeners: the tetra-, penta-, and hexa-congeners and not the hepta- and octa-congeners which are less toxic and less relevant from a risk standpoint. Other commenters state that only 2,3,7,8-tetrachlorodibenzo-*p*-dioxin should be reported. Some commenters contend that reporting for these compounds should not be required at the same reporting threshold as the other dioxin and dioxin-like compounds. Most commenters who would like to exclude certain dioxin-like compounds did not indicate that they wanted individual reporting of the remaining compounds. Some commenters support the reporting of dioxin and dioxin-like compounds as a category, as EPA proposed. One commenter states that if reporting is not limited to just 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, then the commeter supports EPA's proposal to limit the category to only the 7 dioxins and 10 furans listed in the proposed rule.

After consideration of all of the comments on this issue, EPA has decided that the best way to report on dioxin and dioxin-like compounds is to report them as a category. This is consistent with the way EPA has addressed other groups of chemicals that share the same toxic effect and in this case are also generated as complex mixtures. As discussed in Units VI.G.1.d. and e., reporting as a category and based on TEQs would not provide users of the data with information on which compounds contribute the most to the TEQ total. In addition, requiring facilities to report each compound individually would impose an additional burden on the industries that will be required to report. However, EPA agrees that being able to determine the amounts of the individual dioxin and dioxin-like compounds would make the data more useful. Therefore EPA will add a section to the Form R that will require the reporting facility to provide the distribution of dioxin and each dioxin-like compound for the total quantity that the facility is reporting. If a facility has information on the distribution of the dioxin and dioxin-like compounds, the facility must report either the distribution that best represents the distribution of the total quantity of dioxin and dioxin-like compounds released to all media from the facility; or its one best media-specific distribution. This information is only required if it is available from the data used to calculate thresholds, releases, and other waste management quantities, no additional analysis is required. As with all other reporting under EPCRA section 313, this information will only be required if the facility has information that can be used to make a reasonable estimate of the distribution from the available data. With the distribution of congeners reported on each Form R, the user of the data can determine the grams of dioxin and each individual dioxin-like compound that makes up the total quantity reported on the Form R. Under this reporting mechanism, all of the information that the commenters have stated is important to determining the significance of quantities reported under this category will be provided to the public but the reporting facilities will still only have to file one report. Any of the other possible options, such as reporting in terms of TEQs or reporting each individual compound separately, either do not provide all of the information the commenters would like to have, or impose too great an additional reporting burden without providing the public with significant additional information.

d. *Using mass versus TEQs for reporting releases and other waste management quantities.* Most of the commenters on this issue suggest that EPA should require that release and other waste management data for the dioxin and dioxin-like compounds category be reported in terms of TEQs rather than in terms of absolute grams. The following list is a summary of the various reasons provided by the commenters in support of reporting dioxin and dioxin-like compounds in terms of TEQs: (1) All dioxin data reported under other EPA programs as well as other Federal and state regulatory programs are reported in terms of toxicity equivalents; (2) the public is familiar with dioxin data reported in terms of TEQs and reporting in other units would cause confusion and be misleading; (3) TEQs provide more meaningful information than total weights since they take into account the relative toxicities of the various dioxin-

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like compounds; (4) facilities that report under other regulatory programs are likely to rely upon TEQ data that they already have; (5) use of absolute mass may cause misleading comparisons between grams and grams TEQ; (6) releases reported in absolute mass make it difficult to assess the impacts these compounds may have on the environment due to the differences in their toxicities; and (7) reports based on TEQs would provide far more useful information about potential community risks than reports based on the total mass of compounds in the category since more risk information would be provided.

One commenter argues that EPA's justification for adding the category is based on assumptions about the toxicity of the other dioxin-like compounds relative to dioxin itself and that given these assumptions the reporting of TEQs makes sense. The commenter states that under current TEQ schemes, these dioxin-like compounds are all less toxic than dioxin, as much as 1,000 times less, and that facilities should not simply sum emissions on the Form R for compounds with such drastically different toxicities. One commenter suggests that EPA require the reporting of both grams and TEQs and if not both, then just grams. This commenter asserts that if only grams are reported, the data will be somewhat difficult to interpret without any further information, but if only TEQs are required to be reported, then there are uncertainties about what and how much is discharged.

Another commenter states that if EPA is going to require dioxin reporting as a group and not by specific chemicals, TEQ reporting is an unnecessary complication. The commenter states that the TEFs used to formulate the TEQs are constantly reviewed and changed, which would necessitate EPA review and possible reissuance of new TEFs each year. The commenter argues that this would make previous years' TRI data impossible to compare once the changes were made.

While EPA recognizes that TEQs are a common way of expressing quantities of dioxin-like compounds, EPA does not believe that reporting in these units would be the best or most appropriate way to report for the dioxin and dioxin-like compounds category under EPCRA section 313. Although some commenters believe that TEQ reporting should be used since not all of the dioxin-like compounds are as toxic as dioxin itself, EPA has determined that all of the dioxin-like compounds meet the listing criteria of EPCRA section 313. Since all of these compounds meet the listing criteria, the actual mass of each member of the category should be reported. To do otherwise would deny the public information on the actual quantities of toxic chemicals entering the environment. It would also be inconsistent with all other reporting of EPCRA section 313 toxic chemicals since none of them are reported based on relative toxicities. In addition, this would be inconsistent with EPCRA section 313(g)(1)(C)(iv) which requires that ''the annual quantity of the toxic chemical entering each environmental medium'' be reported.

Some of the commenters state that TEQs should be used because they provide more risk information to the public than just reporting mass. While TEQs do provide information on relative toxicity, EPA does not believe that increasing the amount of risk information is a basis for changing the EPCRA section 313 method for reporting from mass-based to relative toxicity-based. As discussed in Unit VI.F., EPCRA section 313 is not a risk-based program, and reporting is not intended to communicate information about relative risks. Rather it provides local communities with data on release and other waste management quantities on listed toxic chemicals, so that they may use the data in conjunction with information on chemical properties (e.g., persistence and bioaccumulation) and site-specific information to determine if releases present a potential risk. It is also not clear, as some commenters state, that the public is more familiar with dioxin data reported in terms of TEQs or that they will understand TEQs any better than grams.

EPA does not believe that the fact that other programs require reporting in TEQs and that facilities will already have TEQ information is a significant reason to require TEQ reporting under EPCRA section 313. Since the first piece of information that is required to determine TEQs is the grams of dioxin and each dioxin-like compound, these facilities should already have the gram-based information they would need. In addition, as stated above, EPCRA section 313 reporting serves the purposes of EPCRA section 313; other programs, e.g., the CWA, are risk-based command and control programs.

Several commenters also disagree with the concerns that EPA raised in the proposed rule, which were:

> . . .there are three significant disadvantages to reporting in TEQs. First, revisions in TEF factors for individual dioxin-like compounds in future years would require changes to the calculations in the reported release and other waste management quantities, thus making year to year comparisons more difficult, unless the particular dioxin-like compounds are identified. Second, some facilities may not be able to report in TEQs, since, although they may be able to estimate a mass quantity for the category as a whole, they may not have enough information to estimate the relative distribution of all category members. Third, TEQ reporting would be different from all other TRI reporting, which is mass-based, and may cause additional confusion. (at 64 FR 712-713)

Some commenters contend that EPA's first concern is not valid since the EPCRA section 313 reporting requirements have been changed several times in the past in spite of difficulties in comparing future reports to past performance. Two commenters state that this same logic could be applied to the use of AP–42 factors which EPA acknowledges have been revised and refined over the years, and that this also diminishes the value of year-to-year reporting comparisons. One commenter suggests that EPA could minimize any confusion that might be caused by a subsequent change in one or more TEFs by each year specifically publishing or cross referencing the TEFs that must be used for that reporting period.

One commenter contends that EPA's second and third concerns appeared weak in light of the much greater risk information provided by a TEQ approach. Some commenters contend that EPA's third concern is not valid since the reporting requirement being proposed for dioxin and dioxin-like compounds is different whether TEQs are used or not. One commenter states that the third concern is clearly dwarfed by the confusion that would ensue if all dioxin-like compounds were reported as equivalent, when the hazards vary by a factor of 500. One commenter states that reporting dioxin on a TEQ basis will cause more rather than less confusion if the public mistakenly compares data in grams with data presented in grams TEQ. Some commenters agreed with the concerns EPA expressed in the preamble. One commenter states that it agreed with these concerns but that the concern about year-to-year comparisons being more difficult also applies to the reporting of a single mass value for the entire category. The commenter contends that since the amounts of the individual dioxin-like compounds would not be known, if TEFs change, one cannot adjust previously reported values to reflect the changes in TEFs. This commenter suggests that in order to make the information reported of greatest use, the mass of dioxin and each of the dioxin-like compounds should be reported once a TEQ threshold is exceeded.

One commenter argues that while TEQs are a valid and scientifically

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sound metric for reporting the likely health hazard of a compound, that was not the intended purpose of the EPCRA section 313 reporting requirement. The commenter claims that reporting dioxin and dioxin-like compounds in TEQs will cause confusion, since all other reporting under EPCRA is done in terms of mass and does not take toxicity into account.

EPA believes, as do some of the commenters, that the concerns that were expressed in the proposed rule for reporting dioxin and dioxin-like compounds in terms of TEQs under EPCRA section 313 are valid. EPA disagrees with those commenters who claim that since other changes in reporting have occurred, such as revisions to AP-42 emission factors, there should be no concern for the changes that might occur in TEFs and the resulting TEQs. The fact that certain changes have occurred in reporting requirements or methods of estimation and that those changes may make certain year-to-year comparisons more difficult does not reduce the concern for knowingly selecting reporting units, based on relative toxicity as opposed to emission factors, that have changed in the past and may well change in the future. Also, EPA would be required to choose a particular set of TEFs (i.e., as of 1999) and would need to amend them by rulemaking each time the TEFs were revised. Changes in TEFs and the resulting TEQs would be unlike any of the past changes in EPCRA section 313 reporting since none of these reporting changes were related to the relative toxicity of chemicals that meet the listing criteria of EPCRA section 313. The cross referencing or publishing of the TEFs that must be used for each reporting period would still not allow year-to-year comparisons since without knowing a facility's distribution of each of the category members the TEQ cannot be recalculated. EPA's concerns that some facilities may not be able to report in terms of TEQs are also valid. Although most facilities that will be able to make reasonable estimations for the dioxin and dioxin-like compounds category should be able to report in terms of TEQs, there may be some that can only report in actual mass units and they should not be exempt from reporting. EPA is also still concerned that TEQs would be different than other EPCRA section 313 reporting units, since they are not based on absolute mass, and that this could cause confusion. EPA does not agree with the commenters that state that this does not matter since the reporting for the dioxin and dioxin-like compounds category is going to be different anyway. The only real reporting difference for the dioxin and dioxin-like compounds category is that the reporting units are in grams rather than pounds. To determine the amounts in pounds all that one would have to do is multiply the grams by 0.002204. However, TEQ reporting would be much different since in order to understand the reported value one would need to understand the basis for TEFs, what they are, how they relate to dioxin, and how TEQs are calculated from the individual TEFs. This obviously requires more knowledge on the part of the data user than simply understanding different units of mass and does have the potential to cause some confusion.

One commenter contends that neither total mass nor TEQ reporting provides sufficient information on reduction in potential exposure and risk. The commenter asserts that it is possible that a facility could reduce its dioxin TEQ while releasing a greater mass of dioxin-like compounds, but neither total mass nor TEQ reporting would really provide a good picture of what a facility was doing. The commenter suggests that if EPA wants to provide TEQ information to the public, it should also require facilities to report dioxins by individual chemical, rather than as a group.

Another commenter that favors the reporting of dioxin and dioxin-like compounds as individual chemicals claims that reporting as a category but in TEQs would still fail to reveal the amounts of individual dioxin compounds released. The commenter argues that this alternative would provide no information on individual compounds for use in tracing dioxin source profiles. The commenter contends that reporting in TEQs would provide better information on the relative toxicity hazard based upon today's toxicity information but that information on the relative toxicity of the many dioxin-like chemicals is improving and thus toxicity factors for some of these compounds will change in the future. The commenter claims that in future years the Inventory would have to choose between keeping the old toxicity calculation (and becoming irrelevant in comparison with other research data), or changing the toxicity calculation (and becoming irrelevant for tracking changes in dioxin release rates over time). The commenter contends that the need to aid research and policy development based on current science and the need to track release rates over time are fundamental to the Inventory's purpose and that this alternative must be rejected as just another ill-advised aggregate reporting scheme. The commenter recommends that EPA require the reporting of dioxin and dioxin-like compounds in the way these compounds are measured and analyzed by scientists and government agencies, as individual chemicals, and consider an additional service by EPA to calculate and report dioxin toxicity as TEQ for the year-to-year data using the most recent toxicity information which becomes available.

Several commenters make the point that for dioxin and dioxin-like compounds neither reporting total mass nor reporting in terms of TEQs provides sufficient information on potential exposures and risks, and that neither would allow for the tracing of dioxin source profiles. EPA agrees that neither approach would provide all of the data that the commenters would like to have reported and that being able to determine TEQs would provide additional useful information. A common solution to the TEQ issue that the commenters suggest, was to report dioxin and each individual dioxin-like compound separately rather than as a category. However, EPA believes that this approach would be overly burdensome and unnecessary to get the kind of data that would be the most useful. As discussed in the previous section of this unit, many other commenters requested that dioxin and dioxin-like compounds be reported separately rather than as a category. After consideration of all of the comments on this issue, EPA has determined that the best way to report for the dioxin and dioxin-like compounds category is to report in terms of absolute grams for the entire category. This is consistent with all other reporting under EPCRA section 313 and will provide the most consistent information from year-to-year. However, EPA agrees with most of the commenters that being able to determine TEQs from the reported data and being able to determine which individual chemicals are include in a facilities report would make the data more useful to the public. Therefore, as discussed in the previous section of this unit, EPA will add a section to the Form R that will require the reporting facility to provide the distribution of dioxin and each dioxin-like compound for the total quantity that the facility is reporting. If a facility has information on the distribution of the dioxin and dioxin-like compounds, the facility must report either the distribution that best represents the distribution of the total quantity of dioxin and dioxin-like compounds released to all media from the facility; or its one best media-

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specific distribution. This information is only required if it is available from the data used to calculate thresholds, releases, and other waste management quantities, no additional analysis is required. As with all other reporting under EPCRA section 313, this information will only be required if the facility has information that can be used to make a reasonable estimate of the distribution from the available data. With the distribution of the individual members of the category reported on each Form R, the user of the data can determine the grams TEQ that correspond to the absolute grams reported and can adjust the grams TEQ as TEF values change over time. Under this reporting mechanism, all of the information that the commenters state is important to determining the significance of quantities reported for this category will be provided to the public on one Form R. This way all parties can express the data in whichever format they believe is best, and since the first thing that must be determined under any reporting method is the mass of each member of the category, there should be little, if any, additional burden associated with including the distribution.

e. *Using TEQs as the basis for reporting thresholds.* All of the commenters on this issue requested that the reporting threshold for the dioxin and dioxin-like compounds be set in terms of TEQs. Most of the commenters indicate that the reasons they support a TEQ-based threshold were the same as the reasons they support reporting release and other waste management quantities in terms of TEQs (see the first paragraph of the preceding section of this unit). Two commenters argue that since EPA proposed to use TEQs for reporting release and other waste management quantities, that not basing the reporting threshold on TEQs would be inconsistent. The commenters contend that a facility may trigger reporting by having emissions that exceed the threshold (in terms of absolute weight) but have no significant reporting quantity (in terms of TEQ equivalent weight) and, therefore, no significant health risk. The commenters recommend the use of a consistent approach where TEQs are used for both threshold determinations and release and other waste management quantities. The commenters state that such an approach would be consistent with the health risk rationale for EPCRA reporting, yet not rely on site-specific risk approaches that may evolve over time. Another commenter had similar concerns suggesting that it would be extremely burdensome and unnecessarily complex to have thresholds based on absolute grams and release and other waste management quantities reported in TEQs and recommends that EPA should use TEQs for both.

One commenter claims that it may ease the reporting burden somewhat to base the EPCRA section 313 reporting threshold on a TEQ basis rather than attempting to develop mass-based estimates. Another commenter contends that in order to determine the sum of the mass of the 17 dioxin and dioxin-like compounds, one already will have determined the mass of each compound individually and that with data reported by compound, a TEQ can easily be calculated. The commenter also suggests that there are short-term screening bioassays for determining the TEQ of a sample that are less expensive, more sensitive, and can be done more rapidly than traditional analytical chemistry methods. The commenter states that rather than facilities trying to guess what their releases may be, in an attempt to avoid spending money on expensive analytical chemistry methods, if the reporting threshold were based on TEQs, a facility can readily and more inexpensively screen its releases. The commenter argues that having a reporting threshold based on TEQ is more representative of potential health risks and recommends that EPA consider using some amount of TEQs as the reporting threshold. Another commenter suggests that one option would be to report releases of each dioxin-like compound if the total, in TEQ, exceeds some chosen threshold.

One commenter that suggests that TEQs should be used for thresholds, notes that reporting dioxin on a mass basis is quite different from reporting on a TEQ basis. The commenter asserts that since some of the dioxin-like compounds have TEFs of 0.001 then the 0.1 gram threshold could require facilities that produce 0.0001 gram TEQ of dioxin to report. The commenter claims that when compared to the estimate that there are 2,973 grams TEQ of U.S. dioxin emissions such amounts are insignificant and meaningless. The commenter maintains that using TEQs instead of the mass of each compound for determining whether an EPCRA reporting threshold for dioxin and dioxin-like compounds is exceeded would not deprive EPA or the public of information regarding meaningful releases of dioxin. The commenter also recommends that whatever units EPA decides to use should be the same for thresholds and for release and other waste management quantities.

One commenter suggests that EPA should require sources to use toxicity factors in calculating the manufacturing threshold for dioxin and dioxin-like compounds to avoid triggering the threshold based solely on non-detection. The commenter states that the 17 dioxin-like compounds to which the 0.1 gram proposed reporting threshold would apply vary in toxicity by a factor of 1,000 but that EPA does not take this variation in toxicity into consideration for the purpose of determining the manufacturing threshold.

EPA did not propose to use TEQs as the units of measurement for the EPCRA section 313 reporting threshold for dioxin and dioxin-like compounds. EPA has the same concerns for using TEQs for EPCRA section 313 thresholds as it does for reporting releases and other waste management quantities in terms of TEQs, and most of the issues raised here have been addressed in the preceding section of this unit. Most importantly, since EPA has determined that each of the dioxin-like compounds meets the listing criteria of EPCRA section 313, the actual mass of each member of the category should be included in threshold determinations. Also, the fact that the TEFs and thus the TEQs can change over time, is even more important for thresholds since TEF changes would in effect change the threshold, because for example, the same mass quantity that would have exceeded the threshold before the change may not exceed the threshold after the change.

As one of the commenters pointed out, using TEQs as the units for the reporting threshold is much different than using actual mass. The commenter showed how a 0.1 gram threshold for a dioxin-like compound with a TEF of 0.001 would be equivalent to a 0.0001 gram TEQ threshold. The opposite of this is that if the 0.1 gram threshold were in units of TEQ, then for dioxin-like compounds with a 0.001 TEF, it would take 100 grams to reach the reporting threshold. Using TEQs as the units for the reporting threshold would thus be equivalent to establishing separate thresholds for each member of the dioxin and dioxin-like compounds category based on their relative toxicity. EPA does not believe that any of the reporting requirements of EPCRA section 313 should be based on relative toxicities since, as discussed in Unit VI.F., EPCRA section 313 is not a risk-based program and reporting is not intended to communicate information about the Federal government's risk determinations for individual chemicals. Rather it provides local communities with data on release and

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other waste management quantities on listed toxic chemicals, so that they may use the data in conjunction with information on chemical properties (e.g. persistence and bioaccumulation) and site-specific information to determine if releases present a potential risk.

Several commenters express concern about consistency between the units of measurement for the threshold for the dioxin and dioxin-like compounds category and the units of measurement used to report releases and other waste management quantities. While EPA is not adopting the use of TEQ as some commenters requested, EPA is being consistent since absolute gram quantities will be used for both thresholds and the reporting of releases and other waste management quantities.

EPA does not agree with those commenters who state that the information collected under a 0.1 gram threshold would, in some cases, represent such a small portion of the estimated national amount of dioxin TEQs that the data would not be useful. On a facility-by-facility basis, the amounts reported may be a small percentage of the national total, but that does not mean that it will not be useful or meaningful to the public. One of the purposes of EPCRA section 313 is to provide information to communities about releases into their community. A small percentage of national releases may pose potential risks to local communities. Further, even information that shows little or no releases helps communities to understand what risks may be or may not be present in their communities and helps government agencies to target resources. In addition, since not all of the sources of dioxin and dioxin-like compounds will be reporting under EPCRA section 313, the amount reported will be a larger portion of the total amount reported under EPCRA section 313 than it will be on a national basis. The issue of how many sources of dioxin and dioxin-like compounds are captured by EPCRA section 313 are addressed in the Response to Comments document (Ref. 69) for this rulemaking.

EPA does not agree that reporting in terms of TEQs would necessarily be less burdensome. As one commenter states, in order to determine the sum of the mass of the 17 dioxin and dioxin-like compounds, one already will have determined the mass of each compounds individually and that with data reported by compound, a TEQ can easily be calculated. Since the TEQs are calculated from the relative amounts of dioxin and each dioxin-like compound that is present, it is an additional step to present the data in terms of TEQs and therefore it should not be less burdensome.

f. *Reporting guidance for dioxin and dioxin-like compounds.* A number of commenters requested that EPA develop reporting guidance for the dioxin and dioxin-like compounds category.

EPA agrees that guidance should be provided to assist facilities in determining threshold and release quantities for the dioxin and dioxin-like compounds category. As EPA stated in the proposed rule:

> EPA intends to develop reporting guidance for industries that may fall within this reporting category. The guidance developed will be consistent with the methods and procedures that EPA has developed for determining if dioxin and dioxin-like compounds are present in various industrial processes, including Method 23 (Ref. 77) developed for electric utilities. In developing the reporting guidance for the dioxin and dioxin-like compounds category EPA will work with interested parties to provide the best possible guidance for reporting facilities (at 64 FR 712).

EPA will provide a guidance document to assist certain facilities in making thresholds and release determinations for the dioxin and dioxin-like compounds category. The guidance document will be consistent with EPA established methods of measuring or estimating quantities of dioxin and dioxin-like compounds, including Method 23.

2. *Benzo(g,h,i)perylene (CAS No. 191-24-2) (Ref. 70).* EPA proposed to add benzo(g,h,i)perylene to EPCRA section 313 pursuant to EPCRA section 313 (d)(2)(C). One commenter states that EPA should not add benzo(g,h,i)perylene to the EPCRA section 313 list of toxic chemicals because there are insufficient data to support the EPCRA section 313(d)(2)(C) determination. The commenter states that EPA used predicted aquatic toxicity values based on quantitative structure activity relationship (QSAR) analysis but did not provide any toxicity data. The commenter contends that EPA did not provide any evidence to support the statement that aquatic QSAR equations show a high correlation between predicted and measured toxicity values, and did not provide any other information to support use of QSAR for this type of chemical.

EPA disagrees with the commenter's statements. EPA provided the following discussion in the proposed rule:

> Three of the chemicals being proposed for listing (benzo(g,h,i)perylene, 3-methylcholanthene, and octachlorostyrene) have been found to meet the EPCRA section 313(d)(2)(C) criteria for ecotoxicity based on predicted aquatic toxicity values generated from quantitative structure activity relationship (QSAR) equations and other predictive techniques. As previously stated (58 FR 63500, December 1, 1993), EPA believes that, where no or insufficient actual measured aquatic toxicity data exist upon which to base a decision, toxicity predictions generated by QSARs and other predictive techniques may constitute sufficient evidence that a chemical meets the section 313 listing criteria. EPA's authority to use such predictive techniques derives from section 313(d)(2) of the statute, which states that EPA shall base its listing determinations on, inter alia, ''generally accepted scientific principles.'' EPA believes that the aquatic QSAR equations that are in widespread use and show a high correlation between predicted and measured aquatic toxicity values can be considered to be ''generally accepted scientific principles'' and can appropriately form the basis of a listing determination (Ref. 70). (at 64 FR 693)

EPA believes that QSAR data is valid predicted aquatic toxicity data and the fact that no actual toxicity studies were provided does not mean that the available data were insufficient to determine that benzo(g,h,i)perylene met the listing criteria of EPCRA section 313(d)(2)(C). In addition, EPA did provide support for the statement that aquatic QSAR equations are in widespread use and show a high correlation between predicted and measured aquatic toxicity values. The docket for the proposed rule contained a document titled ''SAR/QSAR in the Office of Pollution Prevention and Toxics'' In: Environmental Toxicology and Risk Assessment: 2nd Volume, STP 1216. One of the articles in this reference was titled *Validation of Structure Activity Relationships Used By the USEPA's Office of Pollution Prevention and Toxics for the Environmental Hazard Assessment of Industrial Chemical.* This includes the methods of SAR for the class of neutral organic chemicals which, as discussed in the support document, was used for benzo(g,h,i)perylene since it is a neutral organic chemical. Thus, EPA did provide support for its conclusions about QSAR analysis and for the use of QSAR for benzo(g,h,i)perylene.

This commenter also states that EPA uses an estimated Log K_{ow} in its aquatic toxicity prediction and argues that Log K_{ow} is an inaccurate predictor for many chemicals particularly if it is estimated rather than measured. The commenter contends that EPA's basis for the listing of benzo(g,h,i)perylene is a prediction based upon a prediction, with no actual data and that this is not a sufficient basis for listing under EPCRA section 313 and it does not meet the statutory requirements for listing that a chemical is ''known to cause or can reasonably be

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anticipated to cause'' a significant adverse effect.

EPA disagrees with the commenter's conclusions. The majority of the SAR calculations in the ECOSAR Class Program are based upon the octanol/water partition coefficient (K_{ow} or Log P) since there is a correlation between Log P and toxicity. Using the measured aquatic toxicity values and estimated Log P values, regression equations can be developed for a class of chemicals. Toxicity values for a chemical within that class may then be calculated by inserting the estimated K_{ow} into the class regression equation and correcting the resultant value for the molecular weight of the compound. The ecological assessment guidelines for predicting the toxicity of chemicals with limited measured aquatic toxicity data have been used for over a decade (Ref. 35). The commenter has not provided the Agency with any concrete information or data indicating that this approach either is not a generally accepted scientific approach or is unreliable, and the Agency finds no reasonable basis to change these techniques at this time. In addition, the commenter did not provide any data to indicate that the predicted Log K_{ow} for benzo(g,h,i)perylene was inaccurate.

This commenter also contends that EPA's failure to consider exposure in this proposed rule is particularly important for benzo(g,h,i)perylene. The commenter argues that given the properties of benzo(g,h,i)perylene, any release into water will result in the vast majority (more than 99%) of the compound being partitioned to sediment or adsorbed onto suspended particulates and organics in the water column and thus the potential for this chemical to be in a toxic form and pose risk in natural systems is low.

EPA disagrees with the commenters' contention that EPA should consider exposure in its determination that benzo(g,h,i)perylene meets the EPCRA section 313(d)(2)(C) listing criteria. As discussed in Unit VI.F., EPA is only required to consider exposure under a limited set of circumstances. In the final chemical expansion rule (59 FR 61432), EPA further explained its policy on the use of exposure considerations under EPCRA section 313(d)(2)(C) and the fact that the Agency does not consider exposure for chemicals that are highly ecotoxic. As EPA explained in the final rule:

> The Agency believes that exposure considerations are not appropriate in making determinations (1) under section 313(d)(2)(B) for chemicals that exhibit moderately high to high human toxicity (These terms, which do not directly correlate to the numerical screening values reflected in the Draft Hazard Assessment Guidelines, are defined in unit II.) based on a hazard assessment, and (2) under section 313(d)(2)(C) for chemicals that are highly ecotoxic or induce well-established adverse environmental effects (at 59 FR 61441).

Although EPA does not believe that it would be appropriate to consider exposure, EPA also disagrees with the commenter's characterization of the fate of benzo(g,h,i) perylene. Environmental fate models show that the chemical will only partition about 60% to the sediment. Also, the Agency cannot rely on the environment to serve as a sink for this chemical. Other environmental conditions such as turbidity, biological activity, or the chemical activity in water could cause redistribution of the chemical into the water column again.

Based upon QSAR equations and other predictive techniques, EPA has concluded that benzo(g,h,i)perylene is toxic. It has the potential to kill fish, daphnia, and algae, among other adverse effects, based on chemical and/or biological interactions. Benzo(g,h,i)perylene can cause these toxic effects at relatively low concentrations. The predicted aquatic toxicity values for benzo(g,h,i)perylene, based upon QSAR analysis using the equation for neutral organics and an estimated Log K_{ow} of 6.7, included calculated values of 0.030 milligrams per liter (mg/L) for the fish 96–hour LC_{50} (i.e., the concentration that is lethal to 50% of test organisms) and 0.0002 mg/L for fish chronic toxicity; 0.012 mg/L for daphnia 48–hour LC_{50} and 0.027 mg/L for the daphnid 16–day chronic LC_{50}; and 0.03 mg/L for the algae 96–hour EC_{50} (i.e., the concentration that is effective in producing a sublethal response in 50% of tests organisms) with an algal chronic toxicity of 0.012 mg/L.

Benzo(g,h,i)perylene can cause its toxic effects at relatively low concentrations, therefore EPA considers it to be highly toxic. Since benzo(g,h,i) perylene is toxic at relatively low concentrations EPA believes that it causes or can reasonably be anticipated to cause a significant adverse effect on the environment. In addition, because of the nature of the potential significant adverse effects, e.g., fish, daphnia, and algae kills, and the impacts such effects can have on ecological communities and ecosystems, EPA has determined that they are of sufficient seriousness to warrant reporting.

EPA reaffirms that there is sufficient evidence for listing benzo(g,h,i)perylene on the EPCRA section 313 list of toxic chemicals pursuant to EPCRA section 313(d)(2)(C)(i) based on the available ecotoxicity information for this chemical. Therefore, EPA is finalizing the addition of benzo(g,h,i)perylene on the EPCRA section 313 list.

3. *Benzo(j,k)fluorene (fluoranthene) (CAS No. 206–44–0) (Ref 70).* EPA proposed to add fluoranthene to EPCRA section 313 pursuant to EPCRA sections 313 (d)(2)(B) and (C). EPA received no comments specific to the carcinogenicity data that EPA presented in the proposed rule in support of the addition of fluoranthene to the EPCRA section 313 list of toxic chemicals. Thus, EPA reaffirms that there is sufficient evidence for adding fluoranthene to this list of EPCRA section 313 toxic chemicals pursuant to EPCRA section 313(d)(2)(B) based on the available carcinogenicity data for this chemical.

One commenter argues that EPA should refrain from listing fluoranthene pending additional assessment of the data. The commenter contends that EPA's reported toxicity values for fluoranthene span a range of about two orders of magnitude and that for such a wide range, it is necessary to evaluate potential exposure to determine which scenarios, and therefore which types of data, are most relevant to this compound following a release. The commenter argues that fluoranthene is a highly lipophilic compound that will bind primarily to sediment and suspended organics, so it is not clear whether the reported toxicity values on which EPA relies for the listing are applicable to this compound in the environment. EPA assumes the commenter was referring to data used to support EPA's proposal to list fluoranthene pursuant to EPCRA section 313(d)(2)(C).

As discussed in Unit VI.F., EPA does not believe that it is appropriate to consider exposure for chemicals that are highly ecotoxic as the data for fluoranthene clearly shows it is. However, even if EPA were to consider exposure, the commenter provided no data to support the assumption that fluoranthene will bind primarily to sediments and suspended organics, and EPA believes that fluoranthene will partition to water as well as sediment. While the ecotoxicity data for fluoranthene does range over about two orders of magnitude that does not, in itself, form a basis for conducting an exposure assessment. There are data that clearly show that fluoranthene is highly ecotoxic. Thus, an exposure assessment is not required. While it does not impact EPA's assessment, EPA notes that of the ecotoxicity values presented in the proposed rule, 9 were within the same order of magnitude, 4

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were one order of magnitude higher, and 2 were two orders of magnitude higher. Thus, 60% are within the same order of magnitude and 87% are within one order of magnitude. EPA does not believe that this represents a very wide distribution as the commenter implies.

Based on the available toxicity data, EPA has concluded that fluoranthene is toxic. It has the potential to kill mysid shrimp, a variety of freshwater benthic species and various saltwater species and it can also cause other adverse effects on fish and mysids, based on chemical and/or biological interactions. Fluoranthene can cause these toxic effects at relatively low concentrations. Ecotoxicity values for fluoranthene include a calculated 96–hour LC_{50} of 0.04 mg/L for mysid shrimp. Using standard acute toxicity tests, fluoranthene has been tested in 12 freshwater species from 11 genera. For freshwater benthic species, the acute 96–hour LC_{50} calculated values are 0.032 mg/L for an amphipod (*Gammarus minus*), 0.070 mg/L for a hydra (*Hydra americana*), 0.17 mg/L for an annelid (*Lumbriculus variegatus*), and 0.17 mg/L for a snail (*Physella virgata*). For saltwater species, the 96–hour LC_{50} values are 0.051 mg/L for a mysid (*Mysidopsis bahia*), 0.066 mg/L for an amphipod (*Ampelisca abdita*), 0.14 mg/L for a grass shrimp (*Palaemonetes pugio*), and 0.50 mg/L for an annelid (*Neanthes arenaceodentata*). Fathead minnows exposed to fluoranthene at a concentration of 0.0217 mg/L for 28 days in a chronic early life-stage test showed a reduction of 67% in survival and a 50.2% reduction in growth relative to the controls. In a 28–day chronic study, mysids exposed to 0.021 mg/L of fluoranthene showed a 26.7% reduction in survival and a 91.7% reduction in reproduction; at 0.043 mg/L all mysids died. In a 31–day study, mysids showed a reduction of 30% in survival, 12% in growth, and 100% in reproduction relative to controls at a concentration of 0.018 mg/L of fluoranthene.

Fluoranthene can cause its toxic effects at these relatively low concentrations, therefore EPA considers it to be highly toxic. Since fluoranthene is toxic at relatively low concentrations, EPA believes that it causes or can reasonably be anticipated to cause a significant adverse effect on the environment. In addition, because of the nature of the potential significant adverse effects, e.g., kills of mysid shrimp, a variety of freshwater benthic species, and various saltwater species, and the impacts such effects can have on ecological communities and ecosystems, EPA has determined that they are of sufficient seriousness to warrant reporting.

Thus, EPA reaffirms that there is sufficient evidence for adding fluoranthene on the EPCRA section 313 list of toxic chemicals pursuant to EPCRA section 313(d)(2)(C)(i) based on the available ecotoxicity information for this chemical.

Therefore, EPA is finalizing the listing of fluoranthene on the EPCRA section 313 list.

4. *3-Methylcholanthrene (CAS No. 56–49–5) (Ref. 70).* EPA proposed to add 3-methylcholanthrene to EPCRA section 313 pursuant to EPCRA sections 313(d)(2)(B) and (C). EPA received no comments on the carcinogenicity data that EPA presented in the proposed rule in support of the addition of 3-methylcholanthrene to the EPCRA section 313 list of toxic chemicals. Thus, EPA reaffirms that there is sufficient evidence for adding 3-methylcholanthrene to the list of EPCRA section 313 toxic chemicals pursuant to EPCRA section 313(d)(2)(B) based on the available carcinogenicity data for this chemical.

No comments were received concerning the ecotoxicity data that EPA presented for 3-methylcholanthrene in the proposed rule. Based upon quantitative structure activity relationship (QSAR) equations and other predictive techniques, EPA has concluded that 3-methylcholanthrene is toxic. It has the potential to kill fish and daphnia as well as cause other adverse effects on fish, daphnia, and algae based on chemical and/or biological interactions. 3-Methylcholanthrene can cause these toxic effects at relatively low concentrations. The predicted aquatic toxicity values for 3-methylcholanthrene, based on QSAR analysis using the equation for neutral organics and an estimated Log K_{ow} of 7.05, include a calculated fish 96–hour LC_{50} of 0.009 mg/L and a chronic fish toxicity value of 0.003 mg/L, a daphnia 48–hour LC_{50} of 0.005 mg/L and a 16–day chronic LC_{50} of 0.015 mg/L, and an algae 96–hour EC_{50} of 0.0105 mg/L with a calculated chronic toxicity value of 0.014 mg/L.

3-Methylcholanthrene can cause its toxic effects at these relatively low concentrations; therefore, EPA considers it to be highly toxic. Since 3-methylcholanthrene is toxic at relatively low concentrations, EPA believes that it causes or can reasonably be anticipated to cause a significant adverse effect on the environment. In addition, because of the nature of the potential significant adverse effects, e.g., fish and daphnia kills, and the impacts such effects can have on ecological communities and ecosystems, EPA has determined that they are of sufficient seriousness to warrant reporting.

Thus, EPA reaffirms that there is sufficient evidence for listing 3-methylcholanthrene on the EPCRA section 313 list of toxic chemicals pursuant to EPCRA section 313(d)(2)(C)(i) based on the available ecotoxicity information for this chemical.

Therefore, EPA is finalizing the listing of 3-methylcholanthrene on the EPCRA section 313 list.

5. *Octachlorostyrene (CAS No. 29082–74–4) (Ref. 70).* EPA proposed to add octachlorostyrene to EPCRA section 313 pursuant to EPCRA sections 313(d)(2)(B) and (C). One commenter argues that octachlorostyrene (OCS) should not be included in the EPCRA section 313 PBT chemicals list. The commenter contends that OCS was included as a PBT chemical simply because it appears on several lists of persistent and bioaccumulative chemicals and not based on a thorough evaluation of its toxicity. The commenter argues that there is limited toxicity data for OCS and cited two statements that were in EPA's support document for the addition of OCS and the other chemicals being added in this rulemaking. The two statements the commenter cited were:

> The health hazard data which support TRI listing are very limited. Human health data were not located. (Ref. 70 p. 48)

EPA disagrees with the commenters' conclusions. The commenter did not comment on the actual toxicity data that EPA provided as the basis for listing OCS pursuant to EPCRA section 313(d)(2)(B). Rather the commenter takes two statements that were contained in the support document out of context to support their apparent contention that there are insufficient data to list OCS under EPCRA section 313(d)(2)(B). The fact that the commenter has taken these statements out of context is demonstrated by the content of the rest of the paragraph that contained the statements the commenter cited:

> Laboratory studies on rats suggest OCS may have acute and chronic effects on the liver, kidneys, and thyroid. In a long-term study (one year) of rats a LOAEL of 0.31 mg/kg/day was determined based on significant histological effects on these organs. (Ref. 70)

The statements the commenter cited only acknowledged that there was not a vast amount of toxicity data for OCS and specifically, that there were no human studies; they do not support the commenters' conclusion that OCS does not meet listing criteria of EPCRA

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section 313(d)(2)(B). In addition, these statements were from the summary section of the discussion on OCS, more detailed discussion of the toxicity data for OCS was contained in the other sections on OCS toxicity but the commenter provided no comments on this information.

EPA reaffirms that there is sufficient evidence for adding OCS to the EPCRA section 313 list of toxic chemicals pursuant to EPCRA section 313(d)(2)(B) based on the available hepatic, nephric, and thyroid toxicity data for this chemical.

The same commenter also claims that the toxicity comparisons to hexachlorobenzene are not supported and that no references or rationale are provided to support basing the aquatic toxicity of OCS on that of hexachlorobenzene. As with the human health data, the commenter argues that there are limited environmental toxicity data for OCS and cited some statements that were in EPA's support document. The statements the commenter cited were:

> So far as is known, after a search of former EEB chemical files, the ecological hazard of OCS has never been formally reviewed under TSCA section 4 or in the OPPT Risk Management (RM) process. OCS was briefly reviewed for aquatic toxicity in August 1986, as part of an OTS (now OPPT) chemical scoring project. Thus, available information on OCS is very limited. (Ref. 70, p. 52)

EPA disagrees with the commenter's conclusions. The commenter has not commented on the actual toxicity data but rather states that the data are limited and that hexachlorobenzene is not an appropriate analogue for predicting the aquatic toxicity data for OCS. The statements the commenter cited only acknowledged that there was not a vast amount of toxicity data for OCS, they do not support the commenter's conclusion that OCS does not meet the listing criteria of EPCRA section 313(d)(2)(C). Contrary to the commenter's statement, EPA did provide a reference to the use of hexachlorobenzene as an appropriate analogue for OCS. As EPA stated in the same section of the support document the commenter cited:

> OCS is one of 7 compounds in this chemical class (chlorinated styrenes) with the generic formula $C_8H_{8-x}Cl_x$, where x equals 8 for OCS. This class is analogous to the chlorinated benzenes; for example hexachlorobenzene (HCB), is considered to be an appropriate analogue chemical for OCS (2). (Ref. 70, page 52).

The reference EPA cited is a previous EPA analysis of this class of chemicals that also used hexachlorobenzene as an appropriate analogue for OCS. EPA believes that since OCS and hexachlorobenzene are both highly chlorinated derivatives of benzene they can reasonably be anticipated to have similar toxicities. However, in addition to aquatic toxicity data on hexachlorobenzene, EPA provided the results of a QSAR analysis of OCS, using a measured Log K_{ow} of 7.7, that gave a predicted 14–day LC_{50} value of 6 µg/L for guppies.

Based upon QSAR equations and analogue data, EPA has concluded that OCS is toxic. It has the potential to kill fish and inhibit photosynthesis in algae, among other adverse effects, based on chemical and/or biological interactions. OCS can cause these toxic effects at relatively low concentrations. The predicted aquatic toxicity value for OCS, based upon QSAR analysis using a measured Log K_{ow} of 7.7, is an estimated 14–day LC_{50} of 6 µg/L for guppies. Based on the chemical analogue hexachlorobenzene, OCS can reasonably be anticipated to inhibit photosynthesis in algae at a concentration of 30 µg/L and have a calculated subchronic EC_{50} value of 16 µg/L for daphnids.

OCS can cause its toxic effects at these relatively low concentrations; therefore, EPA considers it to be highly toxic. Since OCS is toxic at relatively low concentrations, EPA believes that it causes or can reasonably be anticipated to cause a significant adverse effect on the environment. In addition, because of the nature of the potential significant adverse effects, e.g., fish kills, and inhibition of photosynthesis in algae and the impacts such effects can have on ecological communities and ecosystems, EPA has determined that they are of sufficient seriousness to warrant reporting.

EPA reaffirms that there is sufficient evidence for listing OCS on the EPCRA section 313 list of toxic chemicals pursuant to EPCRA section 313(d)(2)(C)(i) based on the available ecotoxicity information for this chemical.

Therefore, EPA is finalizing the addition of OCS on the EPCRA section 313 list.

6. *Pentachlorobenzene (CAS No. 609–93–5) (Ref. 70).* EPA proposed to add pentachlorobenzene to EPCRA section 313 pursuant to EPCRA sections 313(d)(2)(B) and (C). No comments were received concerning the human health toxicity data that EPA presented in the proposed rule. Thus, EPA reaffirms that there is sufficient evidence for adding pentachlorobenzene on EPCRA section 313 pursuant to EPCRA section 313(d)(2)(B) based on the available hepatic, nephric, hematological, and developmental toxicity data for this chemical.

No comments were received concerning the ecotoxicity data that EPA presented for pentachlorobenzene in the proposed rule. Based on the available toxicity data, EPA has concluded that pentachlorobenzene is toxic. It has the potential to kill fish and mysid shrimp as well as cause other adverse effects on algae and daphnia, based on chemical and/or biological interactions. Pentachlorobenzene can cause these toxic effects at relatively low concentrations. Aquatic acute toxicity calculated values for pentachlorobenzene include a sheepshead minnow 96–hour LC_{50} of 0.83 mg/L, bluegill sunfish 96–hour LC_{50}s of 0.25 mg/L and 0.3 mg/L, a guppy 96–hour LC_{50} of 0.54 mg/L, and a mysid shrimp 96–hour LC_{50} of 0.16 mg/L. Because pentachlorobenzene can cause these toxic effects at these relatively low concentrations, EPA considers it to be highly toxic. Additional acute toxicity calculated values include algae 96–hour EC_{50}s of 1.98 mg/L and 6.78 mg/L, and daphnia 48–hour EC_{50}s of 1.3 mg/L and 5.28 mg/L. Considering pentachlorobenzene's persistence and bioaccumulation potential pentachlorobenzene is considered highly toxic to aquatic organism at these higher concentrations.

As discussed above, pentachlorobenzene is highly toxic. Because pentachlorobenzene is highly toxic at relatively low concentrations, EPA believes that it causes or can reasonably be anticipated to cause a significant adverse effect on the environment. In addition, because of the nature of the potential significant adverse effects, e.g., fish and mysid shrimp kills as well as other adverse effects on algae and daphnia, and the impacts such effects can have on ecological communities and ecosystems, EPA has determined that they are of sufficient seriousness to warrant reporting.

Thus, EPA reaffirms that there is sufficient evidence for adding pentachlorobenzene on the EPCRA section 313 list of toxic chemicals pursuant to EPCRA section 313(d)(2)(C)(i), (ii), and (iii) based on the available ecotoxicity information for this chemical.

Therefore, EPA is finalizing the listing of pentachlorobenzene on the EPCRA section 313 list.

7. *Tetrabromobisphenol A (CAS No. 79–94–7) (Ref. 70).* EPA proposed to add TBBPA to EPCRA section 313 pursuant to EPCRA sections 313(d)(2)(B) and (C). One commenter claims that the study cited by EPA in support of its

conclusion that TBBPA meets the EPCRA section 313(d)(2)(B) criteria for listing based on developmental toxicity was not a study on TBBPA. The study in question was submitted to EPA by ICI Americas Inc. with a cover letter identifying Saytex 111, the product tested, as being TBBPA. The product was identified as TBBPA by both name and CAS number.

EPA has determined that the product tested was not TBBPA as claimed by the submitter but has been unable to determine why it was misidentified by the submitter. ICI Americas is now Zeneca at the Delaware location that submitted the study. A Zeneca staff member researched the submission and found that the report was originally from Ethyl Corporation and that no other report on TBBPA was submitted to EPA on that date. Without the misidentified developmental study, no adequate toxicology studies or other data were located by EPA that support the addition of TBBPA pursuant to EPCRA section 313(d)(2)(B). Thus, EPA is not adding TBBPA based on concerns for developmental toxicity or any other human health effects.

The same commenter provides comments on the persistence and bioaccumulation of TBBPA and contends that there are insufficient data to conclude that TBBPA meets the listing criteria of EPCRA section 313(d)(2)(C)(ii) and 313(d)(2)(C)(iii). These two sections deal with EPA's authority to add a chemical based on its ''toxicity and persistence in the environment'' and its ''toxicity and tendency to bioaccumulate in the environment'' respectively. However, the commenter does not contend that TBBPA does not meet the listing criteria of EPCRA section 313(d)(2)(C)(i) which addresses EPA's authority to add a chemical based on its ''toxicity'' without consideration of persistence and bioaccumulation. EPA believes that TBBPA is persistent and bioaccumulative as discussed in Unit VI.H. However, EPA did not propose to add TBBPA to the EPCRA section 313 list of toxic chemicals based on its persistence or bioaccumulation data, and neither of these properties were mentioned in the toxicity discussion of TBBPA in the proposed rule. Rather, EPA based its listing decision on the ecotoxicity data alone which indicated that TBBPA was highly toxic even without consideration of persistence or bioaccumulation.

Based the available toxicity data, EPA has concluded that TBBPA is toxic. It has the potential to kill fish, daphnid, and mysid shrimp, among other adverse effects, based on chemical and/or biological interactions. TBBPA can cause these toxic effects at relatively low concentrations. Aquatic acute toxicity calculated values for TBBPA include a fathead minnow 96–hour LC_{50} of 0.54 mg/L, a rainbow trout 96–hour LC_{50} of 0.40 mg/L, a bluegill sunfish 96–hour LC_{50} of 0.51 mg/L, and a daphnid 48–hour LC_{50} of 0.96 mg/L; mysid shrimp 96–hour LC_{50} values ranged from 0.86 to 1.2 mg/L depending on the age of the shrimp. Aquatic chronic toxicity calculated values from a daphnia 21–day study resulted in a Maximum Acceptable Toxicant Concentration (MATC) that was between 0.30 and 0.98 mg/L (geometric mean 0.54 mg/L) based on a significant reduction in reproduction rates; a fathead minnow 35–day study resulted in a MATC that was calculated to be between 0.16 and 0.31 mg/L (geometric mean 0.22 mg/L) based on adverse effects on embryo and larval survival.

TBBPA can cause its toxic effects at these relatively low concentrations; therefore, EPA considers it to be highly toxic. Since TBBPA is toxic at relatively low concentrations, EPA believes that it causes or can reasonably be anticipated to cause a significant adverse effect on the environment. In addition, because of the nature of the potential significant adverse effects, e.g., fish, daphnid, and mysid shrimp kills, and the impacts such effects can have on ecological communities and ecosystems, EPA has determined that they are of sufficient seriousness to warrant reporting.

EPA reaffirms that there is sufficient evidence for listing TBBPA on the EPCRA section 313 list of toxic chemicals pursuant to EPCRA section 313(d)(2)(C)(i) based on the available ecotoxicity information for this chemical. Therefore, EPA is finalizing the addition of TBBPA on the EPCRA section 313 list.

8. *Vanadium and vanadium compounds.* EPA proposed to add vanadium and vanadium compounds to EPCRA section 313 pursuant to EPCRA sections 313(d)(2)(C). One commenter cited the following statement from the proposed rule, ''However, very few toxicity tests have been conducted with invertebrates.'' The commenter argues that, beyond vanadium pentoxide, the Agency appears to have very little toxicity data on vanadium compounds. The commenter contends that the paucity of toxicity data on many different forms of vanadium compounds in the proposal, as well as in the literature, does not appear to support the Agency's belief that ''the evidence is sufficient to list vanadium and vanadium compounds on EPCRA section 313 pursuant to EPCRA section 313(d)(2)(C) based on the available ecotoxicity information on vanadium and vanadium compounds'' (at 64 FR 698).

EPA disagrees with the commenters' conclusions. Although there is limited information on vanadium's toxicity on invertebrates, data that were available for invertebrates shows that vanadium is toxic to these species. Furthermore, EPA's assessment of vanadium's toxicity included algae and vertebrates, and showed that the chemical is highly toxic to aquatic organisms. The data on vanadium are not limited to vanadium pentoxide, the ecological data provided in the proposed rule for vanadium evaluates vanadium toxicity based on data for other vanadium compounds including: sodium metavanadate, sodium orthovanadate, vanadyl sulfate, and ammonium vanadate. In assessing the ecological toxicity of vanadium and vanadium compounds, EPA evaluated the parent metal (vanadium) and determined that it is highly toxic to some aquatic species and anticipated to cause a significant adverse effect on the environment of sufficient seriousness to warrant reporting. Thus, vanadium, the parent metal in vanadium compounds, is the concern, not the other components of each vanadium compound. Many metals are tested in the salt form because these forms are readily soluble in aqueous solutions. The toxicity data for vanadium shows that the metal is highly toxic (aquatic toxicity < 1 mg/L) to the most sensitive species. This evaluation of vanadium's toxicity is acceptable according to traditional guidelines for the assessment of toxic substances as conducted by the Agency for over 2 decades. In addition, when consideration is given to vanadium's persistence it is also considered highly toxic at higher concentrations.

Three commenters contend that since most vanadium compounds are practically insoluble, they consequently have very low bioavailability, and thus it is likely that they could qualify for delisting. The commenters argue that the delisting process is extremely cumbersome, time-consuming and costly. One of these commenters contends that it is inappropriate to list all of vanadium compounds based on aquatic toxicity of the few compounds cited in the proposed rule. The bioavailability of metals such as vanadium was also raised as an issue at the public meetings held for this rulemaking. It was suggested that the parent metal will not be bioavailable from certain metal compounds that may be released into the environment and that therefore the compounds cannot be

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properly characterized as a PBT chemicals.

EPA disagrees with these comments. First, it should be noted that EPA has not addressed whether vanadium and vanadium compounds can properly be classified as PBT chemicals in this rulemaking. The sole issue, therefore, is whether vanadium and vanadium compounds meet the EPCRA section 313(d)(2)(C) listing criteria. EPA's analysis of the environmental fate of vanadium and vanadium compounds shows that under many environmental conditions vanadium will be available and thus is able to express its toxicity. The commenters have not provided EPA with any data or acceptable scientific studies indicating that vanadium in any particular compound will not become available in the environment. In fact, at least one commenter appears to indicate that these vanadium compounds may merely have low solubility. In these compounds, the parent metal vanadium can become available. While water soluble vanadium compounds would obviously provide vanadium in an immediately bioavailable form, solubility is not the only factor to consider in determining the bioavailability of vanadium from a vanadium compound. In addition to solubility, processes such as: hydrolysis at various pHs; solubilization in the environment at various pHs; photolysis; aerobic transformations (both abiotic and biotic); anaerobic transformation (both abiotic and biotic); and bioavailability when the compounds are ingested (solubilization in and/or absorption from the gastrointestinal tract and solubilization in various organs) need to be considered. In Unit VI.C., EPA discusses in detail the persistence and bioavailability of metals in general.

The issue of bioavailability has been addressed for EPCRA section 313 chemical assessments through EPA's policy and guidance concerning petitions to delist individual members of the metal compound categories on the EPCRA section 313 toxic chemical list (56 FR 23703). This policy states that if the metal in a metal compound cannot become available as a result of biotic or abiotic processes then the metal will not be available to express its toxicity. If the intact metal compound is not toxic and the metal is not available from the metal compound then such a chemical is a potential candidate for delisting.

One commenter argued that the lowest toxicity value cited by EPA for a marine algal species was for *Dunaliella marina* with a 9–day LC_{50} of 0.5 mg/L but that EPA omitted a study which tested the same species and reported no significant adverse effects at a concentration of 50 mg/L.

EPA believes that the study that reported the 9–day LC_{50} of 0.5 parts per million (ppm) on *Dunaliella marina,* is accurate and was acceptably conducted within the guidelines for ecological assessments of hazardous chemicals. This study shows the most sensitive species' response to the chemical. There are differences in the two studies that could explain the range of toxicity between the two. They are: (1) Differences in the exposure times, (2) the species used in the experiments, and (3) the form of vanadium that was exposed to the organisms. The exposure time in the study EPA cited reported a 9–day LC_{50} of 0.5 mg/L. However, the study the commenter cites did not report an LC_{50} duration. Also, the species for the study EPA cited reported the test species to be *Dunaliella marina* (*salina*), but the study the commenter cited only reported the genus name for this organism. Furthermore, the study EPA cited reported the form of vanadium as sodium vanadate, but the study the commenter cites only reported using the vanadium compound without reporting the specific salt form. It is clear that any one of the three factors mentioned, or some combination of these factors, likely accounts for the variation in toxicity between the two studies.

One commenter argues that a study, omitted in EPA's review of vanadium toxicity, on nine algal species showed no significant reduction in productivity (as measured by chlorophyll synthesis) at vanadium concentrations in excess of 10 mg/L. The commenter also contends that the authors of the study also demonstrated that phosphate concentrations were critical in the toxicity of vanadium to algae.

The Agency has not neglected to review the study cited by the commenter. However, EPA interprets the study cited by the commenter as describing the competition uptake between vanadium and phosphorus in an algal medium containing two different kinds of phosphorus concentrations (i.e., phosphorus deficient and phosphorus sufficient). Also, this study was performed only on freshwater algae and one form of vanadium (orthovanadate) which only exists in a pH range of 3 to 6. This study did report a moderately high toxicity value for *Scenedesmus acutus* between 5 and 177 M, which continues to support EPA's findings that vanadium is toxic to algae. Furthermore, EPA is aware that there are studies that were not included in the assessment that showed that the chemical was more toxic than the values reported in EPA's assessment. However, each study was carefully reviewed based on EPA's extensive evaluation process which reviews studies for conformance with generally accepted scientific standards and tests. The studies that were reported in EPA's assessment used generally accepted, validated scientific methods for evaluating aquatic toxicity. The toxicity values that were reported in the ecological assessment of vanadium toxicity were from well-conducted studies.

One commenter argues that it appears from a review of the data that the contention that vanadium is highly toxic to algae has no basis. The commenter contends that with the exception of one study on a single species, *Ceratium hirundinella,* none of the studies on freshwater algae showed significant toxicity at concentrations below 10 mg/L. The commenter states that the lowest level of toxicity reported for a marine species (*Dunaliella marina*) was an LC_{50} of 0.5 mg/L, but that there is conflicting evidence that the threshold of toxicity for this species may be higher than 50 mg/L. The commenter concludes that there appears to be little evidence that vanadium is a highly toxic agent to algae. The commenter also argues that evaluating the toxicity of a compound based on the response of individual algal species can be misleading. The commenter contends that algae never exist within either marine or freshwater environments as monocultures, but rather as dynamic mixed populations. The commenter concludes that unless a compound can be shown to have a broad effect over an entire assemblage or over numerous species of either freshwater or marine species, it is not likely to have a significant effect within the natural environment.

EPA's assessment on algae toxicity shows that vanadium is highly toxic based on the most sensitive species' response to the chemical. There is no conflict in the threshold of toxicity of *Dunaliella marina*. As stated above, there are three factors that most probably account for the differences between the study EPA cited and the study the commenter cites. After careful review of the available data, it is EPA's professional judgment that the study EPA cited provides accurate and valid data.

Algae studies have been included in ecological risk assessments for over 2 decades. Several guidelines on different species have been written to show that these genera are important in the environment and show sensitivity in how chemicals affect the biota. EPA

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agrees that algae usually do not exist in monocultures in the marine or freshwater environment. However, testing monocultures species is the most accurate method to determine whether a chemical is directly harmful to that species. Therefore, if a compound is highly toxic to a particular species of algae or any species, its effects can be extrapolated to represent other species exposed to that chemical. This evaluation process has been used by the Agency and accepted by OECD for over two decades, and used on thousands of chemicals. Vanadium's toxicity ranges from highly toxic to moderately toxic for algae in EPA's assessment. It is reasonable from the evidence in EPA's assessment of vanadium that the species that is the most sensitive to the chemical can represent the toxicity for all other species based on this narrow range. EPA's final evaluation of any chemical's toxicity is based on the most sensitive species' response.

One commenter contends that the study EPA cited that reported the 144–hour LC_{50} of 0.4 and 0.5 mg/L for vanadyl sulfate ($VOSO_4$) and ammonium metavanadate (NH_4VO_3), respectively, were actually values for $VOSO_4$ and sodium metavanadate ($NaVO_3$) respectively. The commenter contends that the 144–hour LC_{50} for NH_4VO_3 was l.5 mg/L. The commenter also argues that EPA neglected to report from the same study a 144–hour LC_{50} of 1.1 mg/L for vanadate pentoxide (V_2O_5) for this species. The commenter also contends that the findings of 144–hour LC_{50}s of 2.5 to 8.1 mg/L in goldfish (*Carassius auratus*) for the same four vanadium species were also omitted.

The comment concerning the vanadium compounds for the 144–hour LC_{50}s of 0.4 and 0.5 mg/L is correct. EPA inadvertently cited to the incorrect compound in the study. The correct vanadium compounds will be reflected in an update to the support document. However, sodium metavanadate, is still a vanadium compound and the study therefore continues to support EPA's findings that vanadium is highly toxic to fish. The other values of 2.5 and 8.1 mg/L merely provide further support for EPA's finding that the vanadium is moderately toxic to fish. However, considering vanadium's persistence in the environment, EPA believes that it is highly toxic at concentrations between 1 and 10 mg/L. Thus the goldfish values provide further support to EPA's finding that vanadium is highly toxic to some aquatic organisms.

One commenter contends that in assessing the toxicity of vanadium to fish, EPA neglected to review the following studies: (1) Hamilton and Buhl (1997), who reported a 96–hour LC_{50} for the flannelmouth sucker (*Catostomus latipinnis*) of 11.7 mg/L; (2) Taylor et al. (1985), who reported a 96–hour LC_{50} for English sole (*Limanda limanda*) of 26.8 mg/L; (3) Ernst and Garside (1987), who reported a 96–hour LC_{50} for the brook trout (*Salvelinus fontinaliis*) alevins of 24 mg/L and for yearlings of 7–15 mg/L (the authors also reported that the method by which stock solutions are formulated could have a dramatic effect on the toxicity of vanadium through its effects on the polymeric form of the metal in the test study); and (4) Hamilton and Buhl (1990), who reported a 96–hour LC_{50} for chinook salmon (*Oncorhynchus tshawytscha*) fry of 16.5 mg/L.

EPA undertook an exhaustive review of vanadium toxicity. The studies the commenter has listed show that vanadium compounds are moderately toxic to fish, which further support EPA's findings on the toxicity of vanadium. EPA's review of the studies cited in the proposed rule are not contradicted or undermined by the studies provided by the commenter, and continue to support the Agency's conclusion that vanadium and vanadium compounds are highly toxic to some aquatic species.

One commenter states that the background document to support EPA's proposal to list vanadium and vanadium compounds indicates that the proposed listing is based on data for five vanadium compounds: vanadium pentoxide, sodium metavanadate, sodium orthovanadate, vanadyl sulfate, and ammonium vanadate. The commenter contends that EPA may consider listing under EPCRA section 313 for the individual compounds for which the Agency has data, but EPA is not justified in listing a broad ''vanadium and vanadium compounds'' category based on data for only five compounds. The commenter suggests that EPA consider individual listings for these compounds, or a category consisting only of the compounds for which the Agency has data.

EPA disagrees with the commenter's characterization of the Agency's assessment of vanadium and vanadium compounds. In assessing the ecological toxicity of vanadium and vanadium compounds, EPA evaluated the parent metal (vanadium) and determined that it is highly toxic to some aquatic organisms and can reasonably be anticipated to cause a significant adverse effect on the environment of sufficient seriousness to warrant reporting pursuant to EPCRA section 313(d)(2)(C). Thus, vanadium, the parent metal in vanadium compounds, is the concern, not the other components of each compound. Many metals are tested in the salt form because they are readily soluble in aqueous solutions. The toxicity data for vanadium shows that the metal is highly toxic (aquatic toxicity < 1 mg/L) to the most sensitive species. In addition, because vanadium is persistent, EPA considers any toxicity values between 1 and 10 mg/L as indicating high ecotoxicity. This evaluation of vanadium's toxicity is acceptable according to traditional guidelines for the assessment of toxic substances conducted by the Agency for over two decades.

EPA has also provided sufficient basis for the inclusion of all vanadium compounds in the category. As EPA stated in the 1994 chemical expansion final rule:

> The Agency believes it satisfies the statutory criteria to add a category to the list by identifying the toxic effect of concern for at least one member of the category and then showing why that effect may reasonably be expected to be caused by all other members of the category. (at 59 FR 61442) See also, *Troy, supra* at 277.

EPA developed a hazard assessment for vanadium which reviewed the toxicity data for several vanadium compounds. The assessment indicated that the vanadium from these compounds is highly toxic to aquatic organisms. Since it is the vanadium from these compounds that is highly toxic rather than the intact chemical compound, EPA believes that all chemicals that are a source of vanadium meet the EPCRA section 313(d)(2)(C) listing criteria. Thus, EPA has established the toxic effect of concern, the chemical species that causes the effect, and the basis for why it may reasonably be expected that all members of the vanadium compounds category can cause the effects of concern.

Based on the available toxicity data, EPA has concluded that vanadium and vanadium compounds are toxic. They have the potential to kill fish, algae, and invertebrates as well as causing a range of other adverse effects on fish, algae, and invertebrates, based on chemical and/or biological interactions. Vanadium and vanadium compounds can cause these toxic effects at relatively low concentrations. Toxicity data for vanadium and vanadium compounds include for algae, a 9–day LC_{50} of 0.5 mg/L, a 15–day LC_{50} of 0.5 mg/L, inhibition of growth at 0.1 ppm, adverse effects on cell division at 3 ppb, 20 ppb, and 0.5 ppm; and for fish, a 96–hour LC_{50} of 0.62 ppm, and growth and survival depression of larvae at 0.17 ppm. Because vanadium and vanadium

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compounds can cause these toxic effects at these relatively low concentrations, EPA considers these chemicals to be highly toxic. Additional toxicity values include for algae, 9–day LC_{50}s of 2 and 3 ppm, and a 15–day LC_{50} of 2 mg/L; for invertebrates, a 9–day LC_{50} of 10 ppm; and for fish, 96–hour LC_{50}s of 6.4 ppm, 10 ppm, and 7 mg/L, an LC_{50} of 5.6 mg/L, an 11–day LC_{50} of 1.99 mg/L, 14–day LC_{50}s from 1.95 to 4.34 mg/L, and 7–day LC_{50}s from 1.9 to 6.0 ppm. Considering vanadium's persistence, vanadium and vanadium compounds are considered highly toxic to aquatic organism at these higher concentrations.

As discussed above, vanadium and vanadium compounds are highly toxic. Because vanadium and vanadium compounds are toxic at relatively low concentrations, EPA believes that they cause or can reasonably be anticipated to cause a significant adverse effect on the environment. In addition, because of the nature of the potential significant adverse effects, e.g., fish, algae, and invertebrate kills as well as a range of other adverse effects on fish, algae, and invertebrates, and the impacts such effects can have on ecological communities and ecosystems, EPA has determined that they are of sufficient seriousness to warrant reporting.

Thus, EPA reaffirms that there is sufficient evidence for adding vanadium and vanadium compounds on the EPCRA section 313 list of toxic chemicals pursuant to EPCRA section 313(d)(2)(C)(i) and (ii), based on the available ecotoxicity information for vanadium and vanadium compounds.

Therefore, EPA is finalizing the listing of vanadium and vanadium compounds on the EPCRA section 313 list.

a. *Reporting limitation of alloys.* A number of commenters support EPA's proposed determination to defer the reporting of vanadium when contained in alloys (64 FR 717). Many commenters also suggest that the Agency adopt a reporting limitation for the other metals such as chromium, copper, manganese, and nickel which are commonly found in alloys. The commenters assert that alloys have significantly different bioavailability, bioaccumulation, and toxicity characteristics than other forms of metals, and thus should be treated separately. The commenters argue that alloys are inherently more stable than unalloyed materials, do not enter the environment as readily as unalloyed materials and hence do not interact as greatly with organisms, and should be considered safer from an environmental and human health perspective. The commenters suggested that alloys should be treated separately not only for threshold changes, but also for EPCRA section 313 listings in general and recommend excluding alloys from general EPCRA section 313 listings for metals.

One commenter states in regard to the reporting of metals in alloys that it makes little or no sense to require the reporting of such ''useless'' information, since the information does not serve the purpose of informing the community. The commenter contends that not adding vanadium when contained in alloys would help to achieve EPCRA section 313's underlying purpose, i.e., to provide the public with meaningful information, while at the same time reducing the burden on reporting facilities. Another commenter argues that the proposed alloys exemption correctly recognizes that metals in alloys are not generally available for exposure or for toxic effects. The commenter argues that expansion of the exemption would improve the TRI data base by reporting only releases that may pose risks to human health and the environment, thereby providing the public with more meaningful data.

Two commenters state that the definition of vanadium alloys should include ''fused alloy slag'' in the qualifier as well. The commenters contend that the state of the vanadium in a ferroalloy form is one of intimate chemical combination on the atomic level, not a simple mixture of individual components and it is inherently stable and cannot be dissociated by ordinary means. The commenters argue that likewise, the fused alloy slag formed represents an intimate chemical combination of materials as a result of the smelting operation. The commenters assert that these elemental materials may include various components such as gangue or ore, ash of fuel, refractory lining, or other stable oxides with the ultimate characterization resting upon the chemical stability of the resultant fused alloy bearing slag. Thus, the commenters argue, vanadium contained in either alloy or alloy slag form is fused in a stable compound and therefore, no releases of vanadium into the environment would occur from either substance. The commenters state that the true environmental issue to consider in the formulation of an activity qualifier is the leachability of the material in that state, and since in both of the aforementioned cases the vanadium is in a stable compound, leaching would not be expected. The commenters assert that without allowing an exemption for fused alloy slag, large volumes of steelmaking and ferroalloy slag will unnecessarily fall under this reporting requirement. The commenters request that EPA reconsider its position and expand the definition of alloy to include both vanadium alloys and vanadium alloy slags.

EPA agrees with those commenters that support EPA's belief that it would be inappropriate, at this time, to change the status quo regarding reporting vanadium when contained in an alloy. As EPA stated in the proposed rule, the Agency is reviewing the issue of whether there should be any changes to the reporting requirements for metals contained in alloys.

In the proposed rule, EPA did not state, and did not intend to imply, that EPA considers alloys to be ''safe,'' or as some commenters suggested, that EPA had ''correctly'' recognized that metals in alloys are not generally available for exposure or to express their toxic effects. EPA has not completed its review of the alloys issue and has made no conclusions regarding whether there should or should not be any type of limitation or exemption for any metals contained in alloys. EPA's proposal merely recognized that while this issue was under review, it would not be appropriate to add alloy forms of vanadium.

The commenters contend that alloys have significantly different bioavailability, bioaccumulation, toxicity characteristics than other forms of metals and are inherently more stable than unalloyed materials and do not enter the environment as readily as unalloyed materials. EPA believes that the issue with alloys is primarily bioavailability, i.e., do the metals contained in alloys become available. This issue is the focus of EPA's current review. At this point in time, while EPA is in the process of a scientific review of the issues pertinent to alloys, the Agency is not prepared to make a final determination on whether vanadium in vanadium alloys meet the EPCRA section 313(d)(2) toxicity criteria.

The commenters did not provide any data to support their contention. The Agency does not believe that a metal compound in a slag necessarily will be environmentally unavailable; rather, the Agency's experience with a previous EPCRA section 313(d) review of manganese slags, indicates that at least in some cases the metal will be available (60 FR 44000, August 24, 1995) (FRL–4954–6).

Some commenters suggested that EPA create an alloys reporting limitation for all metals contained in alloys. However, as EPA has stated, the review of whether any kind of exemption or reporting limitation should be granted for certain metals in alloys is still under review and until the Agency has thoroughly reviewed the available data, EPA is not

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prepared to extend the reporting limitation to any other metals. For example, EPA is not lowering the reporting threshold for cobalt and cobalt compounds, and therefore the Agency is taking no action with respect to a reporting limitation for cobalt when contained in alloys.

One commenter asserts that for reasons of consistency--which helps ensure data quality--with existing EPCRA section 313 metal compound categories, they oppose adding the qualifier ''except when contained in an alloy'' in any new listing for vanadium.

EPA has not completed its review of the alloys issue and has made no conclusions regarding whether there should be any type of general limitation or exemption for any metals contained in alloys. EPA merely recognized that while this issue was under review it would not be appropriate to increase the reporting requirements for those facilities that would otherwise submit reports for vanadium contained in alloys. Therefore, as discussed earlier in this section, EPA has expanded the EPCRA section 313 listing for vanadium by removing the ''fume or dust'' qualifier for vanadium, but has not added the alloy forms of vanadium. Until EPA has the opportunity to fully evaluate the available data, the Agency is not prepared to make a final determination whether vanadium contained in alloys meets the EPCRA section 313(d)(2) listing criteria and should therefore be added. EPA believes that consistency, in this context, does not provide a sufficient basis to require reporting of vanadium contained in alloys.

H. Persistence and Bioaccumulation

The persistence and bioaccumulation data for the PBT chemicals covered by this final rule are listed in Table 3. A discussion of these data follows Table 3.

Table 3.—Persistence and Bioaccumulation Data

Chemical Category/Chemical Name	CASRN	BCF	BAF	Air Half-life	Surface Water Half-life	Soil Half-life
Dioxin/Dioxin-Like Compounds						
Polychlorinated dibenzo-p-dioxins						
1,2,3,4,6,7,8-heptachlorodibenzo-*p*-dioxin	35822–46–9	1,466		12.2–4.2 hrs		~20 yrs
1,2,3,4,7,8-hexachlorodibenzo-*p*-dioxin	39227–28–6	5,176		12.4–2.7 hrs		~20 yrs
1,2,3,6,7,8-hexachlorodibenzo-*p*-dioxin	57653–85–7	3,981		12.4–2.7 hrs		~20 yrs
1,2,3,7,8,9-hexachlorodibenzo-*p*-dioxin	19408–74–3	1,426		12.4–2.7 hrs		~20 yrs
1,2,3,4,6,7,8,9-octachlorodibenzo-*p*-dioxin	3268–87–9	2,239		20.4–4.8 hrs		~20 yrs
1,2,3,7,8-pentachlorodibenzo-*p*-dioxin	40321–76–4	10,890		14.8–2.0 hrs		~20 yrs
2,3,7,8-tetrachlorodibenzo-*p*-dioxin	1746–01–6	5,755		9.6–1.2 hrs		20–1.5 yrs
Polychlorinated dibenzofurans						
1,2,3,4,6,7,8-heptachlorodibenzofuran	67562–39–4	3,545		25.0–4.3 hrs		~20 yrs
1,2,3,4,7,8,9-heptachlorodibenzofuran	55673–89–7	3,545		25.0–4.3 hrs		~20 yrs
1,2,3,4,7,8-hexachlorodibenzofuran	70648–26–9	3,586		13.3–3 hrs		~20 yrs
1,2,3,6,7,8-hexachlorodibenzofuran	57117–44–9	3,586		13.3–3 hrs		~20 yrs
1,2,3,7,8,9-hexachlorodibenzofuran	72918–21–9	10,300		13.3–3 hrs		~20 yrs
2,3,4,6,7,8-hexachlorodibenzofuran	60851–34–5	3,586		13.3–3 hrs		~20 yrs
1,2,3,4,6,7,8,9-octachlorodibenzofuran	39001–02–0	1,259		29.4–13.7 hrs		~20 yrs
1,2,3,7,8-pentachlorodibenzofuran	57117–41–6	33,750		11.6–1.2 hrs		~20 yrs
2,3,4,7,8-pentachlorodibenzofuran	57117–31–4	42,500		11.6–1.2 hrs		~20 yrs
2,3,7,8-tetrachlorodibenzofuran	51207–31–9	2,042		11.5–2.1 hrs		~20 yrs
Pesticides						
Aldrin	309–00–2	3,715		10 hrs–1 hr	24 days[1]	9 yrs–291 days
Chlordane	57–74–9	11,050	>6,000,000[2]	5 days–12 hrs	239 days	8-0.4 yrs
Heptachlor	76–44–8	19,953		10.5 hrs–1 hr	129.4–23.1 hrs	4 yrs–8 days
Isodrin	465–73–6	20,180		10 hrs–1 hr		5 yrs–180 days
Methoxychlor	72–43–5	8,128		12 hrs–1 hr	15.2–5 days	136–81 days
Pendimethalin	40487–42–1	1,944		21–2 hrs		1300–54 days
Toxaphene	8001–35–2	34,050		16 days–19 hrs	5 yrs–1 yr	11–1 yrs
Trifluralin	1582–09–8	5,674		3.2–0.42 hrs	36.5–4.5 days[1]	394–99 days
Polycyclic Aromatic Compounds						

Table 3.—Persistence and Bioaccumulation Data—Continued

Chemical Category/Chemical Name	CASRN	BCF	BAF	Air Half-life	Surface Water Half-life	Soil Half-life
Benzo(a)pyrene	50–32–8	912		2.4 hrs	17.3–5.4 yrs	14.6 yrs–151 days
Benzo(b)fluoranthene	205–99–2	5,631		1.4 days–3.4 hrs	≥100 days	14.2 yrs–87 days
Benzo(r,s,t)pentaphene	189–55–9	26,280		13 hrs–1 hr		371–232 days
Benzo(a)anthracene	56–55–3	800		13 hrs–1 hr	3-1.2 yrs	2.0 yrs–240 days
7,12-Dimethylbenz(a)anthracene	57–97–6	5,834		4–0.4 hrs	6 yrs–1 yr	28–20 days
Dibenzo(a,h)anthracene	53–70–3	31,440		13 hrs–1 hr	≥100 days	2 yrs–240 days
3-Methylcholanthrene	56–49–5	17,510		3–0.3 hrs	3.8–1.7 yrs	
7H-Dibenzo(c,g)carbazole	194–59–2	16,900		23–2 hrs		>160 days
Benzo(k)fluoranthene	207–08–9	10,090		12 hrs–1 hr		11 yrs–139 days
Benzo(j)fluoranthene	205–82–3	10,090		12 hrs–1 hr		10.5 yrs
Dibenzo(a,e)pyrene	192–65–4	6,875		13 hrs–1 hr		371–232 days
Dibenzo(a,h)pyrene	189–64–4	26,280		13 hrs–1 hr		371–232 days
Indeno(1,2,3-cd)pyrene	193–39–5	28,620		7.6–0.34 hrs		730–58 days
Dibenz(a,h)acridine	226–36–8	3,500		13 hrs–1 hr		>160 days
Dibenz(a,j)acridine	224–42–0	18,470		23–2 hrs		>160 days
Benzo(g,h,i)perylene	191–24–2	25,420		10.0–0.31 hrs	≥100 days	1.8 yrs–173 days
Dibenzo(a,e)fluoranthene	5385–75–1	26,280		10 hrs–1 hr		371–232 days[3]
5-Methylchrysene	3697–24–3	9,388		5–0.5 hrs	3.8 yrs–79 days[4]	2.7 yrs–255 days[4]
Dibenzo(a,l)pyrene	191–30–0	6,875		13 hrs–1 hr		371–232 days
Benzo(a)phenanthrene	218–01–9	800		13 hrs–1 hr	3.8 yrs–79 days	2.7 yrs–255 days
1-Nitropyrene	5522–43–0	908		4 days–10 hrs	44 yrs–16 yrs	
Benzo(j,k)fluorene (fluoranthene)	206–44–0	5,100		20–2 hrs		13 yrs–110 days
Metals/Metal Compounds Mercury[5] and Mercury compounds	7439–97–6	7,000-36,000		see footnote 5	see footnote 5	see footnote 5
Polychlorinated Biphenyl (PCBs)	1336–36–3		>200,000[2,6]			
2,3,3′,4,4′,5,5′-heptachlorobiphenyl	39635–31–9	4,922		191–19 days	>56 days	>5–3.92 yrs
2,3,3′,4,4′,5-hexachlorobiphenyl	38380–08–4	37,590		127–13 days	>56 days	>5–3.42 yrs
2,3,3′,4,4′,5′-hexachlorobiphenyl	69782–90–7	37,590		114–11 days	>56 days	>5–3.42 yrs

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Table 3.—Persistence and Bioaccumulation Data—Continued

Chemical Category/Chemical Name	CASRN	BCF	BAF	Air Half-life	Surface Water Half-life	Soil Half-life
2,3′,4,4′,5,5′-hexachlorobiphenyl	52663–72–6	37,590		114–11 days	>56 days	>5–3.42 yrs
3,3′,4,4′,5,5′-hexachlorobiphenyl	32774–16–6	73,840		88–9 days	>56 days	>5–3.42 yrs
2,3,3′,4,4′-pentachlorobiphenyl	32598–14–4	196,900	>134,000,000[2]	80-8 days	>56 days	7.25–0.91 yrs
2,3,4,4′,5-pentachlorobiphenyl	74472–37–0	196,900		67–7 days	>56 days	7.25–0.91 yrs
2,3′,4,4′,5-pentachlorobiphenyl	31508–00–6	184,300	>141,000,000[2]	80–8 days	>56 days	7.25–0.91 yrs
2′,3,4,4′,5-pentachlorobiphenyl	65510–44–3	196,900		50–5 days	>56 days	7.25–0.91 yrs
3,3′,4,4′,5-pentachlorobiphenyl	57465–28–8	196,900		57–6 days	>56 days	7.25–0.91 yrs
3,3′,4,4′-tetrachlorobiphenyl	32598–13–3	105,900		37–4 days	>98 days	4.83–0.91 yrs
Other Chemicals						
Hexachlorobenzene	118–74–1	29,600-66,000	>2,500,000[2]	1,582–158 days		5.7–2.7 yrs
Octachlorostyrene	29082–74–4	33,113	>117,000,000[2]	10 hrs–1 hr		5.7–2.7 yrs7
Pentachlorobenzene	608–93–5	8,318	>640,000[2]	460–46 days		194 days–>22 yrs
Tetrabromobisphenol A	79–94–7	780; 1,200; 3,200		9 days–1 day	84–48 days	44–179 days

[1]The reported half-life data for water are suspected to include significant removal from the medium by processes other than degradation (e.g., volatilization).
[2]Values are for Piscivorous Fish.
[3]Since data could not be found for this chemical, the data for the dibenzopyrenes (192–65–4; 189–64–0; 191–30–0), which are structural analogues, was used.
[4]Since data could not be found for this chemical, the data for benzo(a)phenanthrene (218–01–9), a structural analogue was used.
[5]The bioaccumulation potential for the parent metals is assumed to be equivalent to the associated metal compounds since in the environment the parent metals may be converted to a metal compound. Since metals are not destroyed in the environment they persist longer than 6 months.
[6]Lowest value reported for a dichlorinated PCB.
[7]Since no data could be found for this chemical, the data for the structural analogues hexachlorobenzene (118–74–1) and pentachlorobenzene (608–93–5) was used.

1. *Persistence*—a. *Dioxin and dioxin-like compounds*. In the proposal, EPA preliminarily determined that dioxin and dioxin-like compounds have persistence half-life values in soil that ranged from 1.5 years to more than 20 with all but one chemical having a soil half-life of more than 20 years. EPA has reviewed information and all comments received on dioxin and dioxin-like compounds' persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that dioxin and dioxin-like compounds persist in the environment with half-lives of 2 months or greater and therefore meet the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical category can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 7). In addition, dioxin and dioxin-like compounds persist in the environment with a half-life of greater than 6 months making it highly persistent. This, plus other factors, supports EPA's decision to lower the threshold to 0.1 gram.

b. *Aldrin*. In the proposal, EPA preliminarily determined that aldrin has persistence half-life values in soil of 291 days to 9 years and a persistence half-life value in water of 24 days. EPA has reviewed information and all comments received on aldrin's persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that aldrin persists in the environment with a half-life of 2 months or greater and therefore meets the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 7).

c. *Chlordane*. In the proposal, EPA preliminarily determined that chlordane has persistence half-life values in soil of 0.4–8 years and a persistence half-life value in water of 239 days. EPA has reviewed information and all comments received on chlordane's persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that chlordane persists in the environment with a half-life of 2 months or greater and therefore meets the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69)

and/or in EPA's support documents for this rulemaking (Ref. 7). In addition, chlordane persists in the environment with a half-life of greater than 6 months which supports EPA's decision to lower the threshold to 10 pounds.

d. *Heptachlor*. In the proposal, EPA preliminarily determined that heptachlor has persistence half-life values in soil of 8 days to 4 years and a persistence half-life value in water of 23.1–129.4 hours. EPA has reviewed information and all comments received on heptachlor's persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that heptachlor persists in the environment with a half-life of 2 months or greater and therefore meets the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 7). In addition, heptachlor persists in the environment with a half-life of greater than 6 months which supports EPA's decision to lower the threshold to 10 pounds.

e. *Isodrin*. In the proposal, EPA preliminarily determined that isodrin has persistence half-life values in soil of 180 days to 5 years. EPA has reviewed information and all comments received on isodrin's persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that isodrin persists in the environment with a half-life of 2 months or greater and therefore meets the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 7). In addition, isodrin persists in the environment with a half-life of greater than 6 months which supports EPA's decision to lower the threshold to 10 pounds.

f. *Methoxychlor*. In the proposal, EPA preliminarily determined that methoxychlor has persistence half-life values in soil of 81 to 136 days and a persistence half-life value in water of 5 to 15.2 days. EPA has reviewed information and all comments received on methoxychlor's persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that methoxychlor persists in the environment with a half-life of 2 months or greater and therefore meets the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 7).

g. *Pendimethalin*. In the proposal, EPA preliminarily determined that pendimethalin has a persistence half-life value in soil of 54 to 1,300 days. EPA received several significant comments addressing pendimethalin's persistence potential which are addressed below. EPA has reviewed information and all comments received on pendimethalin's persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that pendimethalin persists in the environment with a half-life of 2 months or greater and therefore meets the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 7).

One commenter contends that EPA has miscategorized pendimethalin as a PBT chemical based on limited screening data which conflicts with conclusions reached by EPA in its risk assessment under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). The commenter believes that the characterization of pendimethalin is inaccurate and will lead to misplaced effort and misplaced focus on listed chemicals, and that there will be no benefit to the public or the environment in lowering the reporting threshold for pendimethalin.

EPA disagrees with the commenter. EPA did not base its determination that pendimethalin meets the EPCRA section 313 persistence criteria, nor that pendimethalin is highly persistent on ''screening'' data. EPA's conclusion that pendimethalin persists with a half-life greater than 6 months is based on a well-conducted study in which pendimethalin degrades in soil with a half-life of 1,322 days. Further, even if these data were discounted, there are numerous data submitted in support of reregistration of pendimethalin under FIFRA that provide strong evidence that pendimethalin meets the EPCRA section 313 persistence criteria, i.e., a half-life greater than 2 months. A more detailed discussion of these data is presented in the following responses. Contrary to the assertion by the commenter, the categorization of pendimethalin as a PBT chemical as described in the proposed rule is not in conflict with the conclusions reached by EPA during the FIFRA assessment. In addition, EPA disagrees that there will be no benefits to the public or the environment from lowering the thresholds for pendimethalin. EPA believes that pendimethalin, like all PBT chemicals, is of special concern because it has the potential to cause adverse effects even when released to the environment in small quantities because it can bioaccumulate in organisms to levels much greater than those present in the environment. EPA believes that lowering the reporting threshold for pendimethalin will provide information to the public that will increase their awareness of low levels of releases to the environment which have the potential to concentrate in organisms and cause adverse effects, which is fully consistent with the purposes of EPCRA section 313.

The commenter states that EPA has ignored bioavailability in designating pendimethalin as a PBT chemical and argues that the true bioaccumulation potential for pendimethalin is greatly overestimated based on the results of the standard laboratory fish bioconcentration study. The commenter asserts that when data on bioavailability, degradation, and depuration are all considered, the ''real world'' bioconcentration potential for pendimethalin is low and, therefore pendimethalin should not be mischaracterized as a PBT chemical.

The bioavailability data the commenter refers to was not specifically identified. Bioavailability of a chemical will vary from environment to environment and soil type to soil type. Caution must be taken, however, not to draw the erroneous conclusion that because a chemical has been shown to have a high affinity to sorb to sediments in aquatic environments that it will not be available for uptake by aquatic organisms. Examples like the PCBs (see Unit VI.F. for a further discussion on this issue) indicate that although some of these compounds have sorption coefficients much greater than pendimethalin, they are still widely found in the tissues of aquatic organisms in contaminated waters. Further, it would be erroneous to state that pendimethalin is not bioavailable because if it were not bioavailable it could not function as an herbicide.

The commenter claims that using EPA's own criteria (half-lifes longer than 2 months in water, sediment, or soil, or a half-life longer than 2 days in air) pendimethalin cannot be classified as persistent. Rather the commenter contends that pendimethalin has ''low'' or ''low to moderate'' persistence.

The commenter is incorrect. The Agency has set persistence criteria of half-lifes for soil, sediment, and water

greater than 2 months and a half-life in air of greater than 2 days. Chemicals meeting these criteria are considered persistent for purposes of EPCRA section 313. There are, in fact, no qualifiers such as ''low,'' ''moderate,'' or ''high'' associated with the persistence criteria. The commenter's characterization of the persistence of pendimethalin as ''low'' or ''low to moderate'' is thus not particularly relevant. It appears, based on the comments, that the commenter defines low to moderate persistence as a half-life of greater than 2 days in air and greater than 2 months in soil, sediment, or water. If this is the case, then the commenter in fact concurs with EPA's assessment of pendimethalin as persistent (half-life greater than 2 months in soil or water and greater than 2 days in air).

If the commenter, instead, meant that pendimethalin has half-lifes of less than 2 months in soil or water, and 2 days in air, EPA notes that the commenter has failed to provide data to support that assertion, and that EPA's review of the data support the Agency's conclusion.

A commenter cites numerous laboratory and field dissipation studies in support of the claim that pendimethalin does not meet the persistence criteria.

EPA disagrees that the degree of persistence of pendimethalin can be characterized by the field dissipation studies cited by the commenter. Field dissipation studies are not equivalent to the studies which measure the half-life for destruction of a chemical in a specific medium (i.e., soil, water, or air). Field dissipation studies are designed to measure the rate or extent of chemical loss from the medium after application of the chemical. The processes by which the chemical is lost may include not only those that result in destruction of the chemical, but those which only transport the chemical from one medium to another such as volatilization. The studies cited by the commenter measure the dissipation of pendimethalin from soil. For a relatively volatile chemical such as pendimethalin, field dissipation studies are of limited use in assessing persistence because an unknown amount of pendimethalin will be transported from soil to air, resulting in a measured loss from that medium, but not destruction. Thus, the field dissipation studies cited by the commenter will underestimate the persistence of pendimethalin in soil.

The commenter cites several laboratory experiments on the degradation of pendimethalin in soil to support the argument that pendimethalin does not meet the persistence criteria. For example, they state that laboratory aerobic soil degradation studies have been conducted in which pendimethalin was applied to soil grab samples and incubated under controlled conditions. Pendimethalin degraded in laboratory soil studies with half-lifes ranging from 31 to 1,322 days. In the *Reregistration Eligibility Decision (RED) for Pendimethalin* (Ref 63) document, EPA explained that 172 days was used instead of 1,322 days because:

> The half-lifes for aerobic soil metabolism ranged from 42-563 days in the literature studies referenced below with a guideline study reporting a half-life of 1,322 days for a total of 27 total observations. Because of the range of half-life values, statistical analyses of the available data were performed. The mean, median, and modal half-lifes are 126, 122, and 122 days, respectively, with a standard deviation of 66 days (n=24). The half-life values of 409, 563, and 1,322 days were not included in the final statistical analyses because they were greater than three standard deviations from the mean. Based on soils and crops that are normally treated with pendimethalin, the reviewer assumed that temperatures would likely range from 20–30 °C and soil moisture contents from 50-75% Field Capacity (FC). The range of observed half-lifes in the above experimental conditions was 72–172 days.

The commenter contends that the 1,322–day half-life value is assumed to be an outlier (Ref. 5), the range was 31 to 172 days. Thus, it is claimed that laboratory studies also indicate that pendimethalin has a low to moderate persistence according to the EPCRA section 313 persistence criteria.

EPA believes that the guideline study that reported a half-life of 1,322 days represents an accurate and representative value for the assessment of the persistence of pendimethalin in the environment. In situations where multiple values for half-lifes are submitted under FIFRA to EPA's Office of Pesticide Program (OPP), statistical analysis may be conducted to determine mean values and standard deviations. The analysis permits the use of a value for exposure assessment modeling that takes into account the variability in data, and allows the exclusion of values more than three standard deviations outside the mean as ''outliers.'' The designation as an outlier does not invalidate the study, and in fact, EPA maintains that even a study designated as an ''outlier,'' if valid, gives useful half-life information.

In their assessment of the persistence of chemicals in soils, OPP focuses on studies using soil types, soil moisture contents, and temperatures consistent with the field application of the chemical in its intended use. In the OPP review of the studies, the reviewer assumed that in the field application of the chemical, temperatures would likely range from 20-30 °C and that soil moisture would range from 50 to 75% field capacity. The consideration of data from studies conducted under these conditions resulted in a half-life range of 72 to 172 days for pendimethalin. It should be noted that even after the elimination of outliers and consideration of studies relevant to normal field application, the entire half-life range is above 2 months, clearly meeting the criteria for persistence in soil, i.e., a half-life of 2 months.

The releases of pendimethalin subject to EPCRA section 313 reporting, in many cases, will not be to agricultural soils under typical application scenarios. EPA, therefore, contends that even though some soil half-life values were not considered by OPP, either because they were derived using studies that did not represent the desired field conditions, or because they were labeled as statistical outliers, the study conditions still represent realistic scenarios for releases reported under EPCRA section 313 and are valid for use in the determination of persistence.

The commenter cites studies conducted using flooded soils to support the argument that pendimethalin does not meet the persistence criteria. The commenter asserts that the studies involved the use of pendimethalin spiked into soil grab samples covered with a shallow layer of water and incubated in the laboratory under controlled conditions. In laboratory flooded soil studies, pendimethalin degradation half-lifes ranged from seven to 104 days with the majority of studies giving half-lifes of less than 2 months. Degradation of pendimethalin was more rapid in flooded soils than in nonflooded soils in most instances. The commenter asserts that these results demonstrate that pendimethalin has a low to moderate persistence in flooded soils according to the EPCRA section 313 persistence criteria.

EPA agrees that the reported degradation half-lifes in laboratory flooded soils studies range from 7 to 104 days. The studies were reviewed for quality and preferred methodologies. Of the studies that are of acceptable quality, EPA chose the highest value (most protective) of the range to determine if the chemical meets the EPCRA section 313 persistence criteria. In this case, the value of 104 days would be used to characterize pendimethalin as persistent in flooded soils. However,

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there is not a separate persistence criterion for flooded soils, nor are data on flooded soils preferable to other soil data. EPA notes that other soil studies, as discussed above in this section, indicate a half-life of 1,322 days in soils.

The commenter states that while pendimethalin is stable to hydrolysis, it will degrade in natural water and water/sediment systems under laboratory conditions with degradation half-lifes ranging from 4 to 22 days. Photodegradation is also rapid with half-lifes of approximately 3.5 days. The commenter concludes that these results indicate that pendimethalin has a low persistence in both water and its underlying sediment according to the EPCRA section 313 persistence criteria.

Two of the aerobic aquatic degradation studies cited by the commenter were not provided to the Agency or are not publicly available, (i.e., they are internal American Cyanamid studies). It is unclear from the summary provided whether the cited studies measured destruction of pendimethalin or its loss from the medium by non-destructive water to air transport processes. If the latter is the case, the ''dissipation half-lifes'' cited cannot be used to characterize persistence. EPA agrees that if the half-lifes reported for aerobic aquatic degradation represent half-lifes for destruction of the chemical, they do not meet the criteria for persistence in water. However, as noted, the full studies were not available for review and as such, EPA cannot assume that the studies followed destruction of pendimethalin, or that the studies meet the quality criteria outlined in this rule.

The commenter cites a half-life range of 6 to 22 days derived from an anaerobic aquatic degradation study to support the argument that pendimethalin has a low persistence in both water and its underlying sediment according to the EPCRA section 313 persistence criteria. EPA agrees that the persistence half-life values cited by the commenter do not meet the EPCRA section 313 persistence criteria, but points out that additional data submitted in support of the reregistration of pendimethalin indicated that half-lifes in aquatic environments could be longer. OPP used flooded soil degradation studies to assess the persistence of pendimethalin under anaerobic aquatic conditions. Half-lifes in these studies ranged from 6 to 105 days. In its discussion of the potential impact of pendimethalin on water resources, OPP in the RED notes that pendimethalin has an anaerobic aquatic metabolism half-life of 60 days. EPA believes that after review of the available data on its persistence in water pendimethalin meets the EPCRA section 313 persistence criteria.

EPA agrees that rapid aqueous photodegradation under laboratory studies has been reported for pendimethalin. However, the photolysis screening tests used are designed to allow the determination of rates of photolysis at shallow depths in pure water as a function of lattitude and season. EPA believes that the environmental relevence of these tests should be considered in their use to determine persistence, and that the results are most applicable to shallow, clear waters. EPA believes that the application of the results beyond these environments is tenuous due to the attenuation of light by suspended matter and increasing depth in the aquatic environment. EPA believes that pendimethalin's tendency to sorb to soil and sediments may result, under some circumstances, in its deposition in benthic environments beyond the effects of aqueous photolysis. Therefore, EPA does not believe that the half-life for pendimethalin in water should be based on aqueous photolysis.

The commenter claims pendimethalin will not persist in air according to the EPCRA section 313 persistence criteria for air since it has a half-life of less than 2 days. The commenter discusses the estimation of pendimethalin's atmospheric half-life and a study on its photodegradation in air. The commenter cites the results of a calculation according to the method of Atkinson performed to determine the rate constant for reaction of pendimethalin with OH radicals in the gas phase (Ref 42). A tropospheric half-life of 3.4 hours was calculated using the method. The photolysis of pendimethalin was investigated by Bossan, *et al.*, 1995 (Ref. 15), who reported on the photoreactivity of pendimethalin on airborne fly ash and kaolin using simulated sunlight. Approximately 70% of applied pendimethalin degraded within 30 minutes when adsorbed to fly ash but little degradation was observed after 100 minutes when pendimethalin was bound to kaolin.

EPA agrees that pendimethalin does not meet the persistence half-life criteria for air of greater than 2 days, but because it meets the persistence criteria for soil and water, this does not affect EPA's conclusion. As noted in the proposed final rule (at 64 FR 702), a chemical need only meet one of the media-specific criteria to be considered persistent.

The commenter cites EPA's pendimethalin RED document and cites its conclusion in support of the argument that pendimethalin does not meet the persistence criteria. The commenter describes the RED conclusions as follows:

> Pendimethalin dissipates in the environment by binding to soil, microbially-mediated metabolism and volatilization. It is essentially immobile in soil.
>
> Based on laboratory studies and limited field study information, pendimethalin is slightly to moderately persistent in aerobic soil environments. Persistence decreases with increased temperature, increased moisture and decreased soil organic carbon.

EPA disagrees with the commenters' suggestion that the OPP RED for pendimethalin concludes that it does not meet the EPCRA 313 persistence criteria. As stated in an earlier response, ''moderate'' persistence has no relevance in the context of the proposed rule. A chemical is considered persistent if it has half-lifes of 2 days in air or 2 months in soil, sediment, or water, respectively.

The commenter implies that OPP has concluded that pendimethalin does not meet the persistence criteria by selectively citing the OPP RED while failing to acknowledge other information OPP discussed in the document confirming the persistence of pendimethalin. OPP did not make any formal summary conclusions regarding the overall environmental persistence of pendimethalin. The commenter has selectively cited from the RED by taking a few comments out of context while ignoring additional findings which demonstrate that pendimethalin meets the persistence criteria.

The first statement cited by the commenter addresses dissipation in the environment. Two of the three processes (soil binding and volatilization) responsible for dissipation do not result in the destruction of the chemical and cannot be directly related to persistence. Volatilization results in the relocation of the chemical to the atmosphere. Binding to soil does not destroy pendimethalin and under some soil conditions has been shown to increase persistence. While microbial metabolism of pendimethalin can result in its destruction, it has been shown to be a slow process under many environmental conditions.

The commenter cites OPP's qualitative description of the persistence of pendimethalin in aerobic soil environments as slight to moderate. This does not serve as, nor did OPP intend for this statement to represent, a quantitative description of pendimethalin's persistence in soil. OPP does not attempt to relate this characterization to a numeric range of persistence values in the RED, and the

commenter does not provide a rationale for concluding that OPP's language indicates that pendimethalin does not meet the EPCRA section 313 persistence criteria.

The final sentence of the citation points out factors that decrease persistence, but a more detailed reading of the RED on the subject of pendimethalin persistence in aerobic soils reveals that its persistence increases as temperature and soil moisture decrease, and soil organic carbon increase.

The commenter performed a Level III EQC Multimedia Modeling assessment for pendimethalin assuming ''best case, reasonable case, and worst case'' scenarios. The calculated overall environmental persistence was determined for pendimethalin to be 5 days, 58 days, and 142 days under the ''best, reasonable, and worst case'' scenarios, respectively. The results of the multimedia model indicated that pendimethalin will have a persistence in the environment of less than 2 months, assuming a reasonable case scenario. The commenter claims that multimedia modeling results indicate that pendimethalin will not be persistent according to the EPCRA section 313 persistence criteria.

The commenter notes that the values it calculated using the EQC model are much lower than the 30 days and 487 days calculated for EPA (Ref. 51) assuming best case and worst case scenarios. The commenter alleges that EPA assumed that half-lifes in soil, sediment and water were identical, 54 days and 1,322 days, respectively (Ref. 7). The data presented above, however, indicate that these were erroneous assumptions. The half-lifes for pendimethalin dissipation in water, soil, and sediment are not identical, and the 1,322 day half-life is an outlier.

The commenter concludes that pendimethalin will have a low to moderate persistence whether found in the air, water, soil, or sediment compartments of the environment. The commenter asserts that this is supported by field and laboratory degradation studies, multimedia modeling, and EPA's FIFRA registration environmental assessment of pendimethalin. Therefore, pendimethalin should not be classified as persistent for purposes of inclusion on the EPCRA section 313 list of PBT chemicals.

EPA disagrees that pendimethalin will have low persistence in the environment whether laboratory and field studies or multimedia modeling are considered. Multimedia mass balance models offer the most convenient means to estimate overall environmental persistence from information on sources and loadings, chemical properties and transformation processes, and intermedia partitioning. For the chemicals included in the proposed rule, EPA used a modified version of the EQC model (Ref. 33) to estimate overall environmental persistence. Overall persistence estimated in this way is used as an additional factor, in conjunction with reaction half-lifes for individual media, bioaccumulation/bioconcentration factors, in justifying the determination made by EPA in this rule.

The EQC model is based on the fugacity approach first delineated by Mackay (Ref. 31) and subsequently applied to numerous environmental processes (Ref. 32). It uses an ''evaluative environment'' in which environmental parameters such as bulk compartment dimensions and volumes (e.g., total area, volume of soil and sediment, etc.) are standardized, so that overall persistence for chemicals with different properties and rates of transformation may be compared on an equal basis (Ref. 15). EPA used a version of the EQC level III model (Ref. 33) which was modified to focus on net losses by deleting model terms for advective losses (movement out of the evaluative environment of air and water potentially containing a chemical) and sediment burial (Ref. 82). In this version of the model only irreversible transformation contributes to net loss of a chemical.

The overall persistence obtained from this model is calculated as the total amount in the evaluative environment when steady state is achieved, divided by the total loss rate. The results thus obtained are neither an overall environmental half-life nor a compartment (or transformation)-specific half-life; rather they are equivalent to an environmental residence time. When only irreversible transformation contributes to net loss--i.e., under the conditions of this version of the EQC model--overall environmental persistence times can be converted to half-lifes by multiplying the former by ln 2 (i.e., 0.693). The overall half-life calculated in this way is for dissipation in the environment as a whole and cannot be related directly to any individual compartment.

The commenter selected media-specific environmental half-lifes for use as input to the EQC model. The values were characterized as ''best,'' ''reasonable'' and ''worst'' case. No justification was given for this classification. It appeared that the shortest half-lives were categorized as ''best case.'' Based on the information provided by the commenter, it was not always possible to determine whether the half-lifes for soil or water selected by the commenter for use as input to the EQC model were for destruction of chemical, or its dissipation from the medium. As noted previously, dissipation half-lifes do not necessarily represent destruction of the chemical since non-destructive transport processes such as volatilization can be responsible for loss from the medium. Their use in multimedia modeling could potentially underestimate overall environmental persistence. This is particularly important since the modified EQC model predicted that greater than 90% of the pendimethalin would partition to soil at steady state. If a soil half-life based on loss from soil by nondestructive processes was used rather than one based on the destruction of pendimethalin, its persistence would have been underestimated.

In its modeling of the overall environmental persistence of pendimethalin EPA used the highest, lowest and mean values for the ranges of media-specific half-lifes from valid studies as inputs to the modified EQC model, not the highest and lowest as stated by the commenter. These included a half-life for pendimethalin in soil of 1,322 days. EPA determined that the study was properly conducted and chose the half-life value of 1,322 days for soil because it represented the most environmentally protective half-life derived from a valid study. The calculated overall environmental persistence half-lifes were 1 month, 8 months, and 16 months based on the highest, mean, and lowest half-lifes, respectively. For chemicals in this rulemaking, EPA considered the multi-media modeling EQC results in characterizing persistence in the overall environment. EPA only intended to use multimedia modeling results to override the medium-specific persistence data in limited circumstances, e.g., only if all model inputs are judged to be accurate (and, as noted above, the commenter's inputs cannot be determined to be accurate). But even if EPA were to use the EQC model to assess persistence, pendimethalin would be considered persistent because, with the EPA inputs described above, EQC overall environmental persistence half-lifes were calculated to be greater than 6 months using the mean and maximum air, soil, and water half-lifes calculated.

In response to this comment (even though it was unclear whether the commenter was basing its assertion on degradation data or dissipation data), EPA conducted a new EQC assessment for pendimethalin using the same half-

life inputs selected by the commenter. The calculated overall environmental persistence half-life was greater than 2 months using the longest half-lifes provided by the commenter for air, soil, water, and sediment. These results support EPA's assertion that the persistence of pendimethalin in the environment meets the EPCRA section 313 persistence criteria.

The commenter argues that the scientifically-based risk assessments conducted on pendimethalin as a part of the pesticide registration process should not be ignored, and that EPA should review pesticide PBT chemical classifications with EPA registration information to ensure an accurate analysis has been performed.

The commenter notes that EPA has determined through the review of a complete set of studies that this material used at an approximate rate of 1.0 to 2.0 pounds of active ingredient per acre does not present an unreasonable risk to human health or the environment, that low levels of pendimethalin in manufacturing wastewater releases do not pose an unacceptable risk to the environment, and that reported EPCRA section 313 air releases do not pose a significant risk to human health or the environment.

The commenter concludes that based on the weight of evidence it is clear that releases of pendimethalin from manufacturing do not pose a significant threat to human health and the environment and that pendimethalin should not be branded as having a high potential for harm as indicated by the proposed listing as a PBT chemical and lowering of the reporting threshold.

EPA disagrees that the risk assessments cited by the commenter are relevant to the characterization of pendimethalin as a PBT chemical. The characterization of chemicals as PBT chemicals for the purpose of this rule are based on intrinsic physical-chemical properties. Risk is not an intrinsic property of a substance, but rather the result of the combination of intrinsic hazard (toxicity) a substance possesses and the exposure to a target organism under a defined set of circumstances. It is possible for a substance to present a risk under one set of exposure conditions, but not another. In contrast, a substance characterized as a PBT chemical will remain a PBT chemical, regardless of the exposure to it or its levels in the environment. (See Unit VI.C.)

Toxic chemicals that persist and bioaccumulate are of particular concern because they remain in the environment for significant periods of time and concentrate in the organisms exposed to them. Furthermore, these PBT chemicals can have serious human health and environmental effects resulting from low levels of release and exposure.

EPA believes that the substances subject to this rule have been characterized as PBT chemicals using scientifically sound indicators based on the intrinsic properties of the substances. The PBT characterization is independent of the risk the substance may pose under a given set of circumstances. These substances have been characterized as persistent, bioaccumulative and toxic and, therefore, meet the criteria for lowered reporting thresholds.

Further, FIFRA requires the Agency to determine that pesticidal uses of a chemical do not cause ''unreasonable adverse effects on the environment,'' which is defined in FIFRA section 2(bb) as ''any unreasonable risk to man or the environment taking into account the economic, social, and environmental costs and benefits of the use of pesticides'' (7 U.S.C. section 136(bb)). FIFRA is a regulatory statute, and the impacts of regulation can be immediate and direct (e.g., banning of a chemical), and as such EPA examines not only the hazards presented by the chemical, but also the specific exposure scenarios, and weighs the risks against the benefits of the chemical. The ''unreasonable adverse effects'' determination under FIFRA is specific to the intentional use of the chemical as a pesticide and does not address other uses or releases of the chemical that may result from manufacture, processing, or other use. Furthermore, a determination under FIFRA that the use of a chemical will not result in an ''unreasonable adverse effect'' is not a determination that the chemical is not hazardous or persistent or that the use of the chemical is without risk, but merely that the benefits of agricultural use as a pesticide outweigh its risks as an agricultural pesticide or that the pesticide chemical residues on food or feed meet the standards of section 408 of the Federal Food, Drug, and Cosmetic Act. EPCRA section 313 was not enacted to serve the same purpose as FIFRA. Listing on EPCRA section 313 provides communities with some of the information required to determine what risks may result from the manufacture, processing, and use of a chemical, and to allow local communities to determine for themselves whether such risks are acceptable, information not provided under FIFRA.

h. *Toxaphene*. In the proposal, EPA preliminarily determined that toxaphene has persistence half-life values in soil of 1 to 11 years and a persistence half-life value in water of 1 to 5 years. EPA has reviewed information and all comments received on toxaphene's persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that toxaphene persists in the environment with a half-life of 2 months or greater and therefore meets the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking. (Ref. 7). In addition, toxaphene persists in the environment with a half-life of greater than 6 months which supports EPA's decision to lower the threshold to 10 pounds.

i. *Trifluralin*. In the proposal, EPA preliminarily determined that trifluralin has persistence half-life values in soil of 99 to 394 days and a persistence half-life value in water of 5 to 37 days. EPA has reviewed information and all comments received on trifluralin's persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that trifluralin persists in the environment with a half-life of 2 months or greater and therefore meets the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 7).

j. *Polycyclic aromatic compounds*. In the proposal, EPA preliminarily determined that PACs have persistence half-life values in soil that ranged from 20 days to 13 years. All but a few had half-lifes well in excess of 6 months. These chemicals had persistence half-life values in water that ranged from 79 days to 44 years. EPA received one significant comment addressing the persistence potential of PACs, which is discussed below. EPA has reviewed information and all comments received on PACs' persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that PACs persist in the environment with half-lives of 2 months or greater and therefore meet the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical category can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 7).

One commenter contends that EPA has incorrectly ignored biotreatment

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studies in evaluating persistence for PACs. EPA has also ignored a large body of recent research on sequestration and other phenomena that collectively act to reduce the bioavailability of soil contaminants, such as PACs.

Biotreatment studies include activated sludge or other wastewater treatment studies. As EPA stated in the proposed rule (at 64 FR 700), the reason for excluding such studies is that wastewater treatment in general and activated sludge in particular represent conditions that are far removed from ambient (surface) waters, soils, and sediments. Data on environmental fate and persistence of substances in wastewater and activated sludge normally cannot be extrapolated to the other conditions. The commenter seems most concerned about land biotreatment (bioremediation) studies, but in fact goes well beyond the concept of treatability, appearing to infer that EPA has ignored all biodegradation studies of PACs. However, this is incorrect because all mixed-culture biodegradation studies other than activated sludge tests--i.e., field tests as well as lab studies that used authentic soil, water and/or sediment grab samples--were considered in determining persistence for all of the listed substances.

The commenter also discusses recent research indicating that bioavailability of a substance may decline with time of incubation in soil, and suggests that EPA should include ''reasonable bioavailability factors'' in its determination of persistence. As an example of why this is relevant, there has been a concern that Superfund site remediation actions may be mistargeted if they are based on residues released from the soils by vigorous extraction procedures, since chemical substances in soil may become nonbioavailable yet still be extractable for analytical purposes. Additionally, bioremediation may fail to destroy all of a substance that such analysis shows is present, if some portion is sequestered in a non-bioavailable state. Further, the commenter contends that chemicals (including many PACs) are not bioavailable if the bioavailability is considerably less than 100%. The commenter does further specify a numerical bioavailability criteria.

The commenter over-generalizes from the research findings, using selective citation and quotation from the literature to give the impression that all is now known and any substance released to soil is as good as gone toxicologically speaking. Other reports can be quoted to the effect that the many factors determining bioavailability, sequestration, etc. are far from completely resolved, and deserve much further research. Moreover, sequestration does not necessarily imply non-bioavailability. For example, in a study of PAC sequestration and bioremediation, Tang et al. (Ref. 51a) state that:

> The results of the present study suggest that extensive biodegradation by microorganisms does not necessarily remove all of the fraction of an aged compound that is bioavailable since some uptake by worms occurred even after the laboratory-scale bioremediation. . . .it is also possible that a portion of a compound that is sequestered is available to different degrees to dissimilar organisms. . . .It may be that the mass of material that becomes sequestered should be considered as existing in two forms. One form may be unavailable to all organisms because it is physically remote and thus inaccessible. The second form may be differentially available, and its assimilation, toxicity, and/or biodegradation may depend on the properties of the species and its ability to mobilize the molecules from this non-remote location.
>
> [There is] danger if it is assumed that the disappearance of lethality denotes the absence of bioavailability....The point is reinforced by the case of DDT, which is sequestered in soil (13) and whose lethality to insects totally disappears as a result of such sequestration (5), yet a portion of that insecticide was still assimilated by earthworms introduced into soil that was treated in the field with DDT *more than 40 years before the bioassay was performed*. . . .(emphasis added)

And in a similar paper on DDT and dieldrin, Robertson and Alexander (Ref. 43a) state that:

> The significance of soil properties in controlling sequestration is evident in the early observation that the degree of sequestration of lindane after 22 months was greatest in a muck, intermediate in extent in a loam, and least in a sandy loam (11). Thus, *soil properties must be considered in attempting to predict the bioavailability of persistent compounds*. It is also evident from the data presented herein that the bioavailability of a sequestered toxicant varies with the exposed species. Thus, the declines in toxicity of aged DDT and dieldrin to the three test insects were quite different; whereas the lethality of the sequestered compound to one species had almost disappeared, it still was effective against a second. (emphasis added)

The conclusion is manifest: it is that although chemical substances released to soil may become sequestered over time, it cannot be assumed that this process necessarily leads to nonbioavailability even when the time horizon is years. Site- and species-specific factors, as well as substance properties, are important in determining bioavailability. Therefore, it is appropriate to be concerned about the bioavailability in soil and sediment of PACs and other substances that meet the PBT criteria established for this rulemaking.

Further, there is no scientific reason why a chemical can only be considered bioavailable if its bioavailability approaches 100%. The degree of bioavailability will vary depending upon the environmental conditions. In addition, as noted above the degree of bioavailability will also be species dependent. Therefore, EPA believes that the commenter's approach is overly simplistic.

k. *Benzo(g,h,i)perylene*. In the proposal, EPA preliminarily determined that benzo(g,h,i)perylene has persistence half-life values in soil of 173 days to 1.8 years and persistence half-life values in water of greater than 100 days. EPA has reviewed information and all comments received on benzo(g,h,i)perylene's persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that benzo(g,h,i)perylene persists in the environment with a half-life of 2 months or greater and therefore meets the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking. (Ref. 7). In addition, benzo(g,h,i)perylene persists in the environment with a half-life of greater than 6 months which supports EPA's decision to lower the threshold to 10 pounds.

1. *Mercury and mercury compounds*. Because metals may convert to different oxidation states but can never be destroyed, all metals meet the 6 months half-life criterion automatically. EPA received a few significant comments addressing mercury and mercury compounds' persistence. These are discussed below. EPA has reviewed information and all comments received on mercury and mercury compounds' persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that mercury and mercury compounds persist in the environment with half-lives of 2 months or greater and therefore meet the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical category can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and in EPA's support documents for this rulemaking (Ref. 7). In addition, mercury and mercury compounds persist in the environment with a half-life of greater

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than 6 months which supports EPA's decision to lower the threshold to 10 pounds.

One commenter asserts that EPA should not classify all forms of mercury as persistent. The commenter agrees that Hg (0) is properly characterized as persistent. However, the commenter contends that EPA is incorrect in characterizing Hg (II) as persistent because it is removed rapidly from the atmosphere via wet and dry deposition.

EPA believes that the commenter confuses residence time with half-life; these terms do not represent equivalent processes. There is a distinction between atmospheric ''half-life,'' which is the amount of time necessary for half of the chemical present to be destroyed in the medium, and atmospheric ''residence time'' which is the length of time a chemical resides in a particular environmental medium. For the purposes of this rule ''half-life'' includes only irreversible chemical transformations resulting in the destruction of chemical whereas ''residence time'' includes factors such as transport of the substance to another medium, for example, wet and dry deposition, sorption, complexation or sequestration; and reversible changes in speciation (i.e., oxidation reduction reactions). EPA agrees that Hg (0) has an average ''residence time'' in the atmosphere of about 1 year and that Hg (II) may be deposited relatively quickly by wet and dry deposition processes, leading to a ''residence time'' of hours to months (Ref. 42a). But the shorter residence times noted for Hg (II) are due to physical transport from the medium, rather than irreversible transformations resulting in the destruction of chemical. Hg (0) released to the atmosphere is rapidly converted to Hg (II) through ozone-mediated oxidation. However, this is not an irreversible reaction, nor does it result in the destruction of the substance since the Hg (II) produced from oxidation of Hg (0) by ozone can be reduced back to Hg (0) by sulfite (Ref. 28a). The persistence of mercury will not be mitigated simply by redox reactions of Hg (0) to and from Hg (II). Whether as Hg (0) or as Hg (II), mercury persists in the environment. Environmental processes may cause it to change oxidation states or to be transported from one environmental medium to another; however, these processes will not destroy it.

EPA agrees that the report cited provides reasonable estimates of the fraction of mercury emissions from each source category that is likely to be in the form of Hg (II) versus the fraction as Hg (0). However, this information is not relevant to the assessment of the persistence of mercury and mercury compounds because persistence considers destruction only.

m. *Polychlorinated biphenyls*. In the proposal, EPA preliminarily determined that polychlorinated biphenyls (PCBs) have persistence half-life values in soil that ranged from 1 to 7 years and persistence half-life values in water that ranged from 56 to 98 days. EPA has reviewed information and all comments received on PCBs' persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that PCBs persist in the environment with half-lifes of 2 months or greater and therefore meet the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical listing can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 7). In addition, all of the PCBs persist in the environment with a half-life of greater than 6 months which supports EPA's decision to lower the threshold to 10 pounds.

n. *Hexachlorobenzene*. In the proposal, EPA preliminarily determined that hexachlorobenzene has persistence half-life values in soil of 3 to 6 years. EPA has reviewed information and all comments received on hexachlorobenzene's persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that hexachlorobenzene persists in the environment with a half-life of 2 months or greater and therefore meets the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and in EPA's support documents for this rulemaking (Ref. 7). In addition, hexachlorobenzene persists in the environment with a half-life of greater than 6 months which supports EPA's decision to lower the threshold to 10 pounds.

o. *Octachlorostyrene*. In the proposal, EPA preliminarily determined that OCS has persistence half-life values in soil of 3 to 6 years. EPA received one significant comment addressing OCS's persistence potential which is discussed below. EPA has reviewed information and all comments received on OCS's persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that OCS persists in the environment with a half-life of 2 months or greater and therefore meets the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 7). In addition, OCS persists in the environment with a half-life of greater than 6 months which supports EPA's decision to lower the threshold to 10 pounds.

One commenter believes that OCS should not be considered to be a PBT chemical. The commenter admits that OCS has the potential to bioaccumulate and may theoretically persist in the environment, but cites falling environmental levels of OCS and the lack of evidence of human and environmental toxicity as justification for why OCS should not be considered to be a persistent, bioaccumulative and toxic chemical. The commenters contend that pentachlorobenzene and hexachlorobenzene are not good analogs for OCS.

EPA disagrees. As discussed in Unit VI.G., EPA believes that OCS meets the EPCRA section 313 toxicity criteria. Further, EPA believes that OCS is highly persistent. No measured half-life data for soil or water that met the standards for data acceptability could be located for octachlorostyrene (CAS No. 29082–74–4). Therefore, EPA used half-lifes for the structural analogs pentachlorobenzene (CAS No. 608–93–5) and hexachlorobenzene (CAS No. 118–74–1) for estimating half-lifes for OCS. EPA believes that pentachlorobenzene and hexachlorobenzene are good analogs for OCS because they, like OCS, are highly chlorinated benzene derivatives, which are structurally very similar. By analogy, OCS is expected to have a half-life in soil of greater than 6 months and greater than 2 days in air (Ref. 7). These half-lifes are sufficient to designate OCS as persistent using the criteria described in the proposed rule. EPA believes that its use of analog data is scientifically supportable because like OCS both analogs are highly chlorinated monocyclic aromatics.

EPA believes that the degree of toxicity as well as the degree of persistence and bioaccumulation are inherent to a chemical. The absolute level of a chemical in the environment does not affect its degree of persistence, bioaccumulation, or whether or not it has been shown to cause adverse effects to aquatic organisms. The absolute level in the environment is a factor of both how much is entering the environment and the persistence of the chemical in the environment. The degree to which a chemical is present in aquatic organisms is not only a measure of the BAF, but also inputs into the environment and

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persistence. The assertions made by the commenter do not support their contentions concerning the toxicity, persistence, or bioaccumulation of OCS.

p. *Pentachlorobenzene*. In the proposal, EPA preliminarily determined that pentachlorobenzene has persistence half-life values in soil of 194 days to more than 22 years. EPA received no significant comments addressing pentachlorobenzene's persistence potential. EPA has reviewed information and all comments on pentachlorobenzene's persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that pentachlorobenzene persists in the environment with a half-life of 2 months or greater and therefore meets the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 7). In addition, pentachlorobenzene persist in the environment with a half-life of greater than 6 months which supports EPA's decision to lower the threshold to 10 pounds.

q. *Tetrabromobisphenol A*. In the proposal, EPA preliminarily determined that TBBPA has persistence half-life values in soil of 44 to 179 days and persistence half-life values in water of 48 to 84 days. EPA received several significant comments addressing TBBPA's persistence and discusses them below. EPA has reviewed information and all comments received on TBBPA's persistence characteristics. Taking into account this information, as indicated in Table 3, EPA finds that TBBPA persists in the environment with a half-life of 2 months or greater and therefore meets the persistence criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 7).

One commenter states that EPA's determination that TBBPA is persistent in the environment appears to be based upon a model which uses default data, that it is difficult to interpret EPA's methodology for applying its *EQC Model Output for Toxics Release Inventory PBT Rule Chemicals*, and it therefore is not clear how EPA arrived at the conclusion that TBBPA is persistent.

EPA disagrees that it is unclear how the EQC model was used in the assessment of chemical persistence and that EPA used only default data. EPA provided discussion on the conduct of the multimedia modeling in the document titled *EQC Model Output for Toxics Release Inventory PBT Rule Chemicals* (Ref. 33). EPA used chemical-specific input data (i.e., half-lifes in air, soil, water, and sediment and chemical properties) where available in all multimedia modeling runs. No default data were used in lieu of chemical-specific inputs. All chemical-specific inputs for each chemical were listed in this document. Further, EPA explained its use of the modified EQC model not only in the support document identified earlier, but also in the preamble to the proposed rule. In its description of the modeling EPA stated:

> Multimedia mass balance models offer the most convenient means to estimate overall environmental persistence from information on sources and loadings, chemical properties and transformation processes, and intermedia partitioning. For the chemicals included in this proposed rule EPA used the [modified] EQC model. . .to estimate overall environmental persistence. Overall persistence estimated in this way is used as an additional factor, in conjunction with reaction half-lifes for individual media, bioaccumulation/ bioconcentration factors, etc., in justifying actions proposed in this rule.

The EQC model is based on the fugacity approach first delineated by Mackay (Ref. 31) and subsequently applied to numerous environmental processes (Ref. 32). It uses an ''evaluative environment'' in which environmental parameters such as bulk compartment dimensions and volumes (e.g., total area, volume of soil and sediment) are standardized, so that overall persistence for chemicals with different properties and rates of transformation may be compared on an equal basis (Ref. 15). EPA used a version of the EQC level III model (Ref. 33) which was modified to focus on net losses by deleting model terms for advective losses (movement out of the evaluative environment of air and water potentially containing a chemical) and sediment burial (Ref. 82). In this version of the model only irreversible transformation contributes to net loss of a chemical.

The overall persistence obtained from this model is calculated as the total amount in the evaluative environment when steady state is achieved, divided by the total loss rate. The results thus obtained are neither an overall environmental half-life nor a compartment (or transformation)-specific half-life; rather they are equivalent to an environmental residence time. When only irreversible transformation contributes to net loss--i.e., under the conditions of this version of the EQC model--overall environmental persistence times can be converted to half-lifes by multiplying the former by ln 2 (i.e., 0.693). The overall half-life calculated in this way is for dissipation in the environment as a whole and cannot be related directly to any individual compartment.

In the analysis EPA used the highest, lowest and mean values for the ranges of half-lifes for soil, air, and water as inputs to the model. These half-lifes were collected from the literature from scientifically sound studies and were subject to data quality standards. The overall environmental persistence half-life for TBBPA calculated based on the EQC model was greater than 2 months but less than 6 months using the longest half-lifes for air, soil, water, and sediment. These results support EPA's assertion that the persistence of TBBPA in the environment will meet the EPCRA section 313 persistence criteria.

The commenter believes that TBBPA does not meet the persistence criteria for air. To support this contention the commenter refers to a study cited in a World Health Organization (WHO) document (Ref. 83). Specifically the commenter cites photodegradation studies that demonstrated that the half-life of TBBPA absorbed onto silica gel exposed to ultraviolet (UV) radiation was 0.12 day in air. In addition, the commenter contends that studies of the photolysis of TBBPA in the presence of UV light and hydroxyl radicals show that TBBPA was totally degraded within 5 to 6 days with an estimated 33–hour half-life. The commenter did not provide these studies or provide references to the original studies.

Further, the same commenter cites WHO EHC 172 (Ref. 83) for data on photodegradation to support the claim that TBBPA does not meet the persistence criteria for air. A review of the citation provided by the commenter reveals that it is a secondary reference taken from unpublished data from Bayer (Ref. 10). EPA was unable to review the full unpublished study to determine the quality of the data, only the summary found in the WHO document was available. In the WHO summary of the Bayer study TBBPA adsorbed onto silica gel and was exposed to ultraviolet irradiation at the 254 nanometer (nm) wavelength. Eight metabolites were detected and a half-life value of 0.12 days obtained. WHO noted that ''[i]t is difficult to derive environmental conclusions from the results of these experiments.''

EPA believes that the environmental relevance of the test results is doubtful.

While the experiment may demonstrate the potential for TBBPA to undergo photodegradation under laboratory conditions, the experimental conditions, to the extent they could be determined from the short summary provided, were not environmentally relevant.

In order for a molecule to undergo photochemical change it must absorb light. It is well known that only the transitions corresponding to ultraviolet/visible light absorption are inherently energetic enough to lead to chemical reactions. The wavelengths of importance for photochemical transformations is thus ultraviolet/visible light with a wavelength of 110 - 750 nm. When environmental photochemistry at or near the earth's surface is considered, the wavelengths of light of importance are further narrowed because the stratospheric ozone layer effectively prevents UV irradiation of less than 290 nm from reaching the earth's surface. Thus, only the light of the 290-750 nm wavelength absorbed by a molecule can potentially lead to photochemical changes of that molecule in the environment near the earth's surface. EPA believes that because the subject study utilized UV irradiation at the 254 nm wavelength, a wavelength that does not reach the earth's surface due to mitigation by stratospheric ozone, the half-life derived is not relevant and, therefore, cannot be used to determine the persistence of TBBPA in air.

The commenter also refers to studies of the photolysis of TBBPA in the presence of UV light and hydroxyl radicals in which TBBPA was shown to totally degrade within 5 to 6 days with an estimated 33–hour half-life. No additional information or references were provided to enable EPA to evaluate these findings for use in the characterization of the atmospheric half-life TBBPA.

The commenter contends that TBBPA's molecular structure makes it inherently biodegradable. The hydroxyl moiety on the TBBPA molecule can be readily transformed by organisms in the environment. The parent TBBPA molecule is no longer present once this biotransformation takes place. Therefore, based on TBBPA's structure alone, the Agency should consider TBBPA as unlikely to be environmentally persistent.

EPA disagrees with the statement that based on structure alone, the Agency should consider TBBPA as unlikely to be environmentally persistent. While EPA generally believes that measured values from well conducted studies are preferable to structure activity relationships (SAR) as an indicator of persistence, the Agency believes that it is possible to make some general statements about the biodegradability of TBBPA based on its structure.

Current knowledge of structure biodegradability relationships suggests that the presence of multiple bromines on an aromatic molecule adversely effects biodegradation. In fact, when the biodegradability of TBBPA is assessed with EPA structure activity relationship tools for predicting biodegradation from structure (Refs. 46 and 47), the presence of multiple aromatic bromines, a carbon with four single bonds, and the molecular weight of TBBPA are all structural features that reduce biodegradability. Therefore, even if EPA were to base its assessment of the persistence of TBBPA on its molecular structure, the Agency would conclude that it is not readily biodegradable.

The commenter contends that TBBPA will not meet the persistence criteria for water, soil, and sediment because TBBPA will biodegrade in these media. The commenter cites the results of several biodegradation studies as demonstrating that TBBPA is not persistent in these media. The commenter states that even though degradation studies have shown that TBBPA is not ''readily biodegradable'' (i.e., TBBPA is not mineralized to a significant extent by sewage sludge within 28 days) there are studies that indicate it is not persistent. Specifically, in studies submitted to EPA in 1989, TBBPA has been shown to be subject to biodegradation both in soil and sediment under aerobic or anaerobic conditions; TBBPA's estimated half-life derived from these studies is 50 days. In studies submitted by the Brominated Flame Retardants Industry Panel to EPA, TBBPA also was shown to undergo degradation in a sediment/water system with an estimated half-life of 48 to 84 days. (These data were reported under the Agency's TSCA Section 4 test rule.) The commenter argues that these data demonstrate that TBBPA does not meet most widely (and internationally) accepted criteria for persistence in soil or sediments (See Unit VI.B.) Therefore, TBBPA should not be considered to be persistent for purposes of EPCRA Section 313.

The commenter cites additional research conducted on the biodegradation of TBBPA under aerobic and anaerobic conditions in soil (Refs. 47) and asserts that the data indicate that ''TBBPA does not meet the most widely and internationally accepted criteria.'' EPA discusses its assessment of the Springborn soil biodegradation studies elsewhere in the Response to Comments document (Ref. 69). As explained earlier, the international persistence criteria are not relevant to the classification of persistence under the criteria adopted by the Agency, and EPA disagrees that TBBPA should not be considered persistent because it does not meet the ''most widely (and internationally) accepted'' criteria. (See Unit VI.B.)

The commenter makes the argument that TBBPA has been shown to be subject to biodegradation in soil and sediment under aerobic and anaerobic conditions with ''estimated'' half-lifes of 50 days. Although the commenter derived a biodegradation half-life, the method used to do so and the validity of the value could not be determined because no supporting information was provided. EPA questions the validity of the 50–day half-lifes estimated by the commenter on those grounds.

The commenter refers to two soil grab sample studies and a sediment/water microbial system study. These studies investigated the biodegradation of TBBPA in three different soil types in the presence (aerobic) and absence (anaerobic) of oxygen, and the biodegradation of TBBPA in a system containing sediment and river water in the presence of oxygen. In the aerobic soil studies less than 6% ultimate biodegradation (complete biodegradation to CO_2) was observed over the 64–day test period. The major portion of TBBPA remained in the soil. Analysis showed after 64 days 74 to 82% TBBPA remained in a Massachusetts sandy loam soil, 36 to 40% remained in an Arkansas silt loam, and 41 to 43% remained in a California clay loam soil. Over the course of the experiments, TBBPA either remained in soil undegraded, underwent minor structural changes (primary biodegradation), or to a very small extent (<6%), underwent complete biodegradation to CO_2. Individual values for evolved CO_2 in each soil type over time were not reported and biodegradation half-life values were not calculated. If it is assumed in the absence of values for CO_2 evolution at sampling times spaced evenly over the test period reported data, that TBBPA underwent a steady rate of degradation over the duration of the experiments, approximate half-lifes of 44 to 179 days can be estimated (Ref. 7).

Biodegradation half-lifes from the aerobic soil biodegradation experiments can be approximated. The half-life is defined as the amount of time necessary for the destruction of half of the chemical present in the medium. Given that the duration of the soil biodegradation test is 64 days (equivalent to greater than 2 months), a

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chemical that undergoes less than 50% biodegradation by the end of the test period would have a half-life of greater than 2 months and meet the EPCRA 313 persistence criteria for soil. In one of the soils in which TBBPA was tested (a Massachusetts sandy loam soil) 74 to 82% of the original TBBPA applied remained in the soil unchanged at the end of the 64–day test period. Thus, in this study, TBBPA was shown to have a half-life in soil of greater than 2 months since less than 50% degradation of TBBPA occurred in 64 days.

The biodegradation of TBBPA in the same three soils as above under anaerobic conditions in a 64–day test has also been studied. The results showed that 44 to 57% of the TBBPA applied to soil remained undegraded in the Massachusetts sandy loam soil after a 64–day test period, 53–65% in an Arkansas silt loam soil, and 90% in a California clay loam soil. Less than 50% destruction of the test chemical occurred over a 64–day (> 2 month) test period in all soils tested. Thus, in this study, TBBPA was shown to have a half-life in soil of greater than 2 months since less than 50% degradation of TBBPA occurred in 64 days.

Aerobic sediment water microbial test systems containing natural sediments and river water were used to measure degradation half-lifes for TBBPA in 56–day experiments. Half-lifes calculated for the biodegradation of TBBPA ranged from 48 to 84 days. Researchers found an apparent correlation between half-lifes and TBBPA concentration, and half-lifes and microbial concentrations. Thus, in this study, TBBPA was shown to have a half-life in sediment water systems of greater than 2 months when either the larger value or the mean of the two values is considered.

Further, the commenter claims that abiotic degradation of TBBPA in water also is expected. The calculated half-life of decomposition of TBBPA by UV radiation in water was 10.2 days in spring, 6.6 in summer, 25.9 in autumn, and 80.7 days in winter. Therefore, TBBPA is not expected to be persistent in water. No other information was provided.

The commenter cites WHO EHC 172 (Ref. 83) for data on photodegradation to support the claim that TBBPA does not meet the persistence criteria for water. In its review of the literature to evaluate the persistence of TBBPA, EPA found no information on its photodegradation in water. A review of the citation provided by the commenter reveals that it is a secondary reference taken from an unpublished study from Bayer (Ref. 10). EPA was unable to review the full unpublished study to determine the quality of the data. Only the summary found in the WHO document was available. The Bayer study on photodegradation in water yielded calculated half-lifes ranging from 6.6 days to 80.7 days with the longest half-life calculated during the winter, when solar irradiation is least intense and the shortest half-life occurring in the summer, when the solar irradiation is most intense. The commenter did not include the fact that the effect of cloud cover lengthened the calculated half-life by a factor of 2. Water depth was also found to influence the direct photodegradation of TBBPA. At the surface of a water body, solar irradiation is fairly uniform; however, as depth increases, both the water itself and materials in it can attenuate the transmission of solar energy through the water column. Irradiance has been shown to decrease by greater than 90% for both ultraviolet and visible light at a depth of 5 meters in a eutrophic lake (Ref. 52). EPA disagrees with the commenter's conclusion that TBBPA photodegradation in water will be sufficiently rapid that it will not meet the persistence criteria. Based on the study cited by the commenter which includes an 80–day (> 2 month) half-life for photodegradation of TBBPA in winter, and the mitigating effects of water depth and cloud cover on rates of photodegradation, EPA believes that a half-life of greater than 2 months in water is supported. EPA, therefore asserts that based on these findings, TBBPA meets the EPCRA section 313 persistence criteria of greater than 2 months in soil and water.

2. *Bioaccumulation*—a. *Dioxin and dioxin-like compounds*. In the proposal, EPA preliminarily determined that dioxin and dioxin-like compounds have BCF values that range from 1,259–42,500 with 6 chemicals over 5,000 and 6 chemicals between 3,500 and 5,000. EPA has reviewed information and all comments received on dioxin and dioxin-like compounds' bioaccumulation characteristics. As indicated in Table 3, EPA finds that dioxin and dioxin-like compounds bioaccumulate in the environment with BAF/BCF values greater than 1,000 and therefore meet the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical category can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 71). In addition, most of the members of the dioxin and dioxin-like compounds category bioaccumulate in the environment with a value close to, or well above, 5,000, which supports EPA's decision to lower the threshold to 0.1 gram.

b. *Aldrin*. In the proposal, EPA preliminarily determined that aldrin has a BCF value of 3,715. EPA has reviewed information and all comments received on aldrin's bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that aldrin bioaccumulates in the environment with a BAF/BCF value greater than 1,000 and therefore meets the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 71).

c. *Chlordane*. In the proposal, EPA preliminarily determined that chlordane has a BCF value of 11,050. EPA has reviewed information and all comments received on chlordane's bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that chlordane bioaccumulates in the environment with a BAF/BCF value greater than 1,000 and therefore meets the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 71). In addition, chlordane bioaccumulates in the environment with a BCF value greater than 5,000 which supports EPA's decision to lower the threshold to 10 pounds.

d. *Heptachlor*. In the proposal, EPA preliminarily determined that heptachlor has a BCF value of 19,953. EPA has reviewed information and all comments received on heptachlor's bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that heptachlor bioaccumulates in the environment with a BAF/BCF value greater than 1,000 and therefore meets the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and in EPA's support documents for this rulemaking (Ref. 71). In addition, heptachlor bioaccumulates in the environment with a BAF/BCF value greater than 5,000 which supports EPA's decision to lower the threshold to 10 pounds.

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e. *Isodrin*. In the proposal, EPA preliminarily determined that isodrin has a BCF value of 20,180. EPA has reviewed information and all comments received on isodrin's bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that isodrin bioaccumulates in the environment with a BAF/BCF value greater than1,000 and therefore meets the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 71). In addition, isodrin bioaccumulates in the environment with a BAF/BCF value greater than 5,000 which supports EPA's decision to lower the threshold to 10 pounds.

f. *Methoxychlor*. In the proposal, EPA preliminarily determined that methoxychlor has a BCF value of 8,128. EPA has reviewed information and all comments received on methoxychlor's bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that methoxychlor bioaccumulates in the environment with a BAF/BCF value greater than 1,000 and therefore meets the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 71).

g. *Pendimethalin*. In the proposal, EPA preliminarily determined that pendimethalin has a BCF value of 1,944. EPA has reviewed information and all comments received on pendimethalin's bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that pendimethalin bioaccumulates in the environment with a BAF/BCF value greater than 1,000 and therefore meets the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 71).

h. *Toxaphene*. In the proposal, EPA preliminarily determined that toxaphene has a BCF value of 34,050. EPA has reviewed information and all comments received on toxaphene's bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that toxaphene bioaccumulates in the environment with a BAF/BCF value greater than 1,000 and therefore meets the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 71). In addition, toxaphene bioaccumulates in the environment with a BAF/BCF value greater than 5,000 which supports EPA's decision to lower the threshold to 10 pounds.

i. *Trifluralin*. In the proposal, EPA preliminarily determined that trifluralin has a BCF value of 5,674. EPA has reviewed information and all comments received on trifluralin's bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that trifluralin bioaccumulates in the environment with a BAF/BCF value greater than 1,000 and therefore meets the bioaccumulation criterion. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 71).

j. *Polycyclic aromatic compounds*. In the proposal, EPA preliminarily determined that PACs have BCF values that ranged from 800 to 31,440 with 16 of the 21 members of the category having BCF values greater than 5,000. EPA received several comments concerning the PACs category listing and the bioaccumulation data which are addressed below. EPA has reviewed information and all comments received on PACs' bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that PACs bioaccumulate in the environment with BAF/BCF values greater than 1,000 and therefore meet the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical category can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 71).

Three of the commenters support the retention of a single PACs category while one commenter believes that splitting the category into two categories would be the most appropriate option. Additional specific comments were as follows. One commenter stated that PACs are typically found as mixtures in incoming natural organic raw materials, such as coal and that it would be difficult to separate information into two reporting categories. Another commenter stated that reporting as one category is also more consistent with the Great Lakes Binational Toxics Strategy Level 2 listing for these chemicals. A commenter stated that the alternate proposal to create two PAC categories would be unnecessarily burdensome for the regulated community since reporting facilities would be required to speciate their PAC releases, and, if chemicals from both categories exceeded reporting thresholds, file two Form R reports, instead of one. One commenter stated that use of a single PACs category will simplify the reporting requirements; thus, it will reduce reporting burden. Several commenters stated that according to the proposed rule, 16 of the 21 members of the category had BCF values greater than 5,000 and that one proposal would regard the entire PACs category to be highly persistent and bioaccumulative, regardless of each individual PAC's actual persistence and bioaccumulative properties. Several commenters stated that they believed that splitting the category into two categories would be the most appropriate course. Another commenter stated that no chemical should be added to the highly persistent/bioaccumulative category when it does not fit the criteria and that in order to gain the most accurate information, two separate categories would be the superior solution. The commenter stated that lowering the reporting threshold for the PACs category to 10 pounds is unjustified considering that, according to EPA data, many of the individual PACs within the category do not meet the PBT criteria.

EPA considered splitting the PACs category into two or three categories or listings, but EPA believes, as do most of the commenters, that the most appropriate option is to retain a single PACs category. The PACs category was created because the members of the category are chemically and structurally very similar, share the same toxicological effect (carcinogenicity), and typically are produced, released, and otherwise managed as waste as complex mixtures rather than individual chemicals. As such it would be more difficult to estimate releases if the category were split into two or three categories based on the currently available bioaccumulation data. These reasons support retaining a single PACs category. EPA agrees with those commenters that stated that the retention of a single PACs category would be the simpler and less burdensome option. EPA also

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recognizes that, based on currently available information, not all members of the PACs category meet the highly persistence and highly bioaccumulative criteria. Of the 21 chemicals in the PACs category proposed for a lower threshold, 5 have BCF values that nominally do not meet the highly bioaccumulative criteria, while the rest exceed the highly bioaccumulative criteria. Given the structural similarities of the members of this category and the higher bioaccumulation values for 16 of the 21 PACs, the 5 BCF values below 5,000 may underestimate, to some extent, the bioaccumulation potential of these compounds. For purposes of this rulemaking, EPA is classifying the PACs category as persistent and bioaccumulative rather than highly persistent and highly bioaccumulative. Thus, the PACs category will have a reporting threshold of 100 pounds. However, the Agency will continue to assess the bioaccumulation potential of this category and specifically whether the lower bioaccumulation values for 5 members of the category are appropriate.

k. *Benzo(g,h,i)perylene*. In the proposal, EPA preliminarily determined that benzo(g,h,i)perylene has a BCF value of 25,420. EPA has reviewed information and all comments received on benzo(g,h,i)perylene's bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that benzo(g,h,i)perylene bioaccumulates in the environment with a BAF/BCF value greater than 1,000 and therefore meets the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 71). In addition, benzo(g,h,i)perylene bioaccumulates in the environment with a BCF value greater than 5,000 which supports EPA's decision to lower the threshold to 10 pounds.

l. *Mercury and mercury compounds*. In the proposal, EPA preliminarily determined that mercury and mercury compounds have BCF values that ranged from 7,000 to 36,000. EPA has reviewed information and all comments received on mercury and mercury compounds' bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that mercury and mercury compounds bioaccumulate in the environment with BAF/BCF values greater than 1,000 and therefore meet the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical category can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 71). In addition, mercury and mercury compounds bioaccumulate in the environment with a value above 5,000, which supports EPA's decision to lower the threshold to 10 pounds.

m. *Polychlorinated biphenyls*. In the proposal, EPA preliminarily determined that PCBs have BCF values that ranged from 4,922 to 196,900. All of the PCBs, except one, had BCF values far exceeding 5,000. The one exception, 2,3,3',4,4',5,5' heptachlorobiphenyl, had a BCF value of 4,922. EPA has reviewed information and all comments received on PCBs' bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that PCBs bioaccumulate in the environment with BAF/BCF values greater than 1,000 and therefore meet the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical listing can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 71). In addition, with one exception, all of the PCBs listed bioaccumulate in the environment with a value far exceeding 5,000, which supports EPA's decision to lower the threshold to 10 pounds.

n. *Hexachlorobenzene*. In the proposal, EPA preliminarily determined that hexachlorobenzene has a BCF value of 29,600 to 66,000. EPA has reviewed information and all comments received on hexachlorobenzene's bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that hexachlorobenzene bioaccumulates in the environment with a BAF/BCF value greater than 1,000 and therefore meets the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 71). In addition, hexachlorobenzene bioaccumulates in the environment with a BAF/BCF value greater than 5,000 which supports EPA's decision to lower the threshold to 10 pounds.

o. *Octochlorostyrene*. In the proposal, EPA preliminarily determined that OCS has a BCF value of 33,113. EPA received one significant comment addressing OCS's bioaccumulation potential which is discussed below. EPA has reviewed this comment and information on OCS's bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that OCS bioaccumulates in the environment with a BAF/BCF value greater than 1,000 and therefore meets the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking. (Ref. 71). In addition, OCS bioaccumulates in the environment with a BAF/BCF value greater than 5,000 which supports EPA's decision to lower the threshold to 10 pounds.

One commenter argued that OCS should not be included in the EPCRA section 313 PBT chemicals list. The commenter contends that OCS was included as a PBT chemical simply because it appears on several lists of persistent and bioaccumulative chemicals and not based on a thorough evaluation of its bioaccumulation. The commenter states that OCS has the potential to bioaccumulate, but nonetheless, OCS levels in fish and aquatic species in the Great Lakes continue to decline. The commenter provides a report on the Great Lakes region and argues that OCS should not be considered a PBT chemical since environmental concentration data show OCS levels in the environment are decreasing at a rate of 8% to 30% per year.

EPA disagrees with the commenter's conclusions. The commenter does not dispute the bioaccumulation values EPA presented in the proposed rule. Rather the commenter agrees that OCS has the potential to bioaccumulate but contends that since environmental concentrations are declining in the Great Lakes region OCS should not be considered a PBT chemical. The fact that OCS levels in the Great Lakes region may be declining is not a basis for concluding that OCS is not a PBT chemical or that it cannot bioaccumulate. There are a number of reasons that could explain a decrease in environmental concentrations of OCS but they do not change the fact that OCS has been shown to be highly bioaccumulative. OCS was included as a PBT chemical because it meets the EPCRA section 313 criterion for bioaccumulation laid out in the proposed rule, not simply because it has appeared on several other lists of PBT chemicals.

p. *Pentachlorobenzene*. In the proposal, EPA preliminarily determined

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that pentachlorobenzene has a BCF value of 8,318. EPA has reviewed information and all comments received on pentachlorobenzene's bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that pentachlorobenzene bioaccumulates in the environment with a BAF/BCF value greater than 1,000 and therefore meets the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 71). In addition, pentachlorobenzene bioaccumulates in the environment with a BAF/BCF value greater than 5,000 which supports EPA's decision to lower the threshold to 10 pounds.

q. *Tetrabromobisphenol A*. In the proposal, EPA preliminarily determined that TBBPA was found to have BCF values of 780; 1,200; and 3,200. EPA received one significant comment addressing TBBPA's bioaccumulation which is discussed below. EPA has reviewed the comments and information on TBBPA's bioaccumulation characteristics. Taking into account this information, as indicated in Table 3, EPA finds that TBBPA bioaccumulates in the environment with a BAF/BCF value greater than 1,000 and therefore meets the bioaccumulation criterion established in this rulemaking. A complete discussion of EPA's findings on this chemical can be found in EPA's Response to Comments document for this rulemaking (Ref. 69) and/or in EPA's support documents for this rulemaking (Ref. 71).

One commenter contends that the available data on TBBPA do not support its classification as a PBT chemical. The commenter argues that the oyster BCF value of 780 does not support the proposed criterion of 1,000. The commenter also notes that EPA fails to consider that TBBPA is not retained in the body once dosing stops in a BCF test and that TBBPA is rapidly eliminated. The commenter states that rapid elimination limits any potential for biomagnification. The commenter notes that only the highest chironomid BCF value (3,200) was cited by EPA and not the fact that this is from a range of 650–3,200.

EPA believes that the available data do support classification of TBBPA as a PBT chemical. Measured BCF values of 780, 1,200, and 3,200 were obtained from TSCA section 4 tests with oysters, fish and chironomids, respectively. The measured BCF values of 1,200 and 3,200 for fish and chironomids respectively, clearly satisfy the EPCRA section 313 bioaccumulatioin criterion of 1,000. EPA is aware that TBBPA will be eliminated from the body eventually once exposure to the chemical is halted; however, continuous or intermittent exposures of TBBPA to organisms may result in significant tissue residues depending on the exposure or release scenarios. The issue of biomagnification of TBBPA is not relevant to determining if TBBPA is a PBT chemical. As discussed in Unit VI.B.3., biomagnification is not required in order to have a concern for chemicals that bioaccumulate. The highest chironomid BCF value was listed because it is considered as a worst case indication of bioaccumulation in sediment-dwelling invertebrates.

I. Exemptions and Other Reporting Requirements

1. *De minimis exemption*. Many of the commenters assert that the initial reasons for adopting the *de minimis* exemption are still valid and that this exemption should be maintained for PBT chemicals. Specifically, several commenters contend that the *de minimis* exemption was initially adopted to alleviate undue burden on reporting facilities and that the elimination of this exemption for PBT chemicals will significantly increase the reporting burden for this rulemaking.

EPA disagrees with the commenters' contention that the initial reasons for adopting the *de minimis* exemption are valid for PBT chemicals. As originally explained in the 1988 final rule implementing the reporting provisions of EPCRA section 313, reiterated in the 1997 final rule adding seven new industry sectors, and discussed in the proposal to this final rule, EPA promulgated the *de minimis* exemption for several reasons, of which burden was only one. In addition to burden reduction, EPA promulgated the *de minimis* exemption because: (1) The Agency believed that facilities newly covered by EPCRA section 313 would have limited access to information regarding low concentrations of toxic chemicals in mixtures that are imported, processed, otherwise used or manufactured as impurities; (2) the Agency did not believe that these low concentrations would result in quantities that would significantly contribute to threshold determinations and release calculations at the facility (53 FR 4509); and (3) the exemption was consistent with information collected under the Occupational Safety and Health Administration's (OSHA) Hazard Communication Standard (HCS). If EPA had adopted the exemption only to reduce burden, the exemption would have covered all uses of *de minimis* quantities of the toxic chemical in mixtures. The exemption, however, includes only limited uses of the toxic chemical in mixtures (i.e., importing, processing, otherwise use, and manufacturing impurities) that were roughly tailored to whether EPA expected that facilities were reasonably likely to have information that would allow them to determine thresholds and make release calculations.

The purpose of the PBT rulemaking, however, is different from past rulemakings in that it is intended to capture information on significantly smaller quantities of releases and other waste management associated with these chemicals. Most of the PBT chemicals addressed in this rule have been shown to cause adverse effects at concentrations far less than the *de minimis* levels. For example, dioxins have been shown to cause adverse effects at levels in the parts per trillion. In addition, after 10 years of experience with the program, the Agency believes there are many sources of information in addition to material safety data sheets (MSDSs), readily available to reporters to use in making EPCRA section 313 determinations. Some of these sources of information include EPA guidance documents (e.g., *EPCRA Section 313 Industry Guidance: Electricity Generating Facilities* (EPA 745–B–99–003)) and trade association guidance documents (e.g., National Council of the Paper Industry for Air and Stream Improvement (NCASI) Technical Bulletins and NCASI's *Handbook of Chemical Specific Information for SARA Title III Section 313 Form R Reporting*). In addition, relevant information has become much more accessible to covered facilities over the past 10 years. For example, although the United States Geological Survey's U.S. Coal Quality Database has been in existence since the mid 1970s, only more recently has it been made available on the Internet. (http://energy.er.usgs.gov/products/databases/UScoal/index.htm). Further, the Agency believes that it underestimated how much information covered facilities had available to them in 1988 regarding small concentrations of toxic chemicals in mixtures. Therefore, given that: (1) Covered facilities have several sources of information available to them regarding the concentration of PBT chemicals in mixtures; (2) even minimal releases of persistent bioaccumulative chemicals may result in significant adverse effects and these small

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quantities can reasonably be expected to significantly contribute to the lower thresholds; and (3) the concentration levels originally chosen, in part, to be consistent with the OSHA HCS are inappropriately high for PBT chemicals, EPA believes that the reasons for the *de minimis* exemption that the Agency held for previous rulemakings do not apply to PBT chemicals.

A few commenters assert that reviewing each MSDS, when a facility may have many MSDSs for mixtures used on-site, to see if it includes trace quantities of PBT chemicals will be very time consuming. They contend that they do not have the manpower to track products on an individual basis looking for trace quantities of PBT chemicals and that these activities will be very burdensome.

EPA disagrees that eliminating the *de minimis* exemption for PBT chemicals will greatly increase burden under EPCRA section 313. Covered facilities are not required to report on toxic chemicals in mixtures and trade name products for which they have no concentration information or such information that is not reasonably known. However, if facilities do have information concerning the concentration of PBT chemicals in mixtures, such as on MSDSs, EPA does not believe it is more burdensome for facilities to identify and evaluate process streams containing relatively small quantities of PBT chemicals than for larger quantities of chemicals. Although some burden is associated with the identification and evaluation of process streams, EPA disagrees that the elimination of the *de minimis* exemption would vastly increase the extent of this required effort. Covered facilities will need to identify and evaluate process streams when considering a PBT chemical in concentrations below the *de minimis* level in the same manner they already do for toxic chemicals found in process streams in concentrations above the *de minimis* level. The additional burden can be attributed to resources spent considering and reporting on information they currently are allowed to disregard. Further, as explained above, EPA adopted the *de minimis* exemption for several reasons, of which burden reduction was only one, and EPA does not believe that these original reasons apply to this PBT rulemaking.

Some commenters assert that it is unrealistic for EPA to assume that industry will report only on what they know without making an effort to fill the data gaps and that enforcement actions could arise from reports based on only what is known to a facility.

EPA disagrees, however, because covered facilities are expected to have reasonable knowledge of the toxic chemicals present at their site and need only document their considerations concerning threshold determinations and release and other waste management calculations. As stated in EPCRA section 313(g)(2):

> [i]n order to provide the information required under this section, the owner or operator of a facility may use readily available data (including monitoring data) collected pursuant to other provisions of law, or, where such data are not readily available, reasonable estimates of the amounts involved. *Nothing in this section requires the monitoring or measurement of the quantities, concentration, or frequency of any toxic chemical released into the environment beyond that monitoring and measurement required under other provisions of law or regulation.* . . . (emphasis added)

Further, as stated previously, covered facilities are not required to report on toxic chemicals in mixtures and trade name products for which they have no concentration information, or for which such information is not readily available. Therefore, it is unlikely that facilities will have additional enforcement concerns.

Several commenters argue that the need to be consistent with the OSHA HCS that EPA cited in the 1988 final rule continues to be relevant with regards to collecting information on very small quantities.

EPA disagrees that the need to be consistent with OSHA to reduce burden is sufficient to justify retaining the *de minimis* exemption for PBT chemicals. EPA is not required to be consistent with the OSHA HCS. In 1988, EPA chose to be consistent with the OSHA HCS as part of its rationale for the exemption, because the Agency expected facilities to be familiar with these levels and thought that covered facilities might only have access to MSDSs for information on the content and percentage composition of toxic chemicals in mixtures. (See 53 FR 4509) However, EPA has never instructed facilities to stop looking if information concerning a toxic chemical is not on an MSDS. Rather, EPA has consistently instructed facilities to use their best readily available data in determining compliance with EPCRA section 313. As EPA explained earlier, given 10 years of experience with the program, the Agency believes that facilities may have other sources of information, in addition to MSDSs, available to them. Therefore, if a facility has better information regarding the concentration of a toxic chemical in a mixture, for example, that the chemical is above the *de minimis* level, the facility should be using that information to comply with EPCRA section 313. Further, EPA is consistent in some respects because under the OSHA HCS, if an employer has reason to believe that a permissible exposure limit for a component may be exceeded under the mixture's normal circumstances of use, the HCS also requires employers to list chemicals that are below the 1.0% and 0.1% thresholds. Therefore, OSHA adopted exceptions to the 1.0% and 0.1% limits under the HCS. Similarly, PBT chemicals are different from other toxic chemicals in that they may pose a more significant concern to the environment in much smaller quantities than other toxic chemicals. Furthermore, as explained in other responses in this unit, EPA believes the remainder of its rationale for the *de minimis* exemption is not applicable to PBT chemicals. For example, contrary to the commenter's statement, the small concentrations subject to the *de minimis* exemption are not necessarily small quantities and may contribute significantly to exceeding the lowered reporting thresholds.

Some commenters argue that the Agency has not justified why the exemption will result in increased health risk to the public or the environment. One commenter specifically argues that given the extremely low levels of these PBT chemicals in coal, the risk to the general public from these releases, which they believe is the original purpose of the legislation, is not apparent. Another commenter asserts that EPA must demonstrate that the removal of the exemption for specific PBT chemicals will have a public health or environmental benefit. Yet another commenter argues that the concentration of toxic chemicals contained in mixtures is irrelevant to public health concerns when the compounds of concern remain chemically bound within benign compounds.

EPA strongly disagrees with those commenters who indicated that EPA must consider risk to the general public when determining whether to eliminate the *de minimis* exemption. A primary purpose of the TRI program is to provide data on the releases (and other waste management activities) of listed toxic chemicals to communities so that they may use these data in conjunction with toxicity information for the chemical and site-specific information to determine if releases present a potential risk. They can also use TRI data in other ways. For example, an individual can use TRI data as a factor

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in choosing a neighborhood in which to live. The purpose of TRI, however, is not to make a national determination of risk, nor did EPA consider risk in its original adoption of the *de minimis* exemption under EPCRA section 313.

Moreover, as previously explained, EPA originally promulgated the *de minimis* exemption based on several considerations that are inapplicable to PBT chemicals. Where, as here, the rationale and factual bases underlying an exemption no longer exist with respect to a particular class, the Agency believes it cannot justify retaining the exemption for that class. Further, the Agency has received no information from any commenters that contradicts the Agency's factual and legal conclusions, or that would otherwise present a basis for retention of the *de minimis* exemption.

EPA also disagrees with the comment that because there are very low levels of PBT chemicals (e.g., mercury) in coal that the risk to the general public is not apparent. EPA believes that the commenter misunderstands the concept of risk. Because a chemical is in a low concentration in coal does not in itself control the level of risk that can result when coal is combusted. For example, mercury compounds are found in very low concentrations in coal. When coal is combusted, mercury compounds are either converted into mercury chloride or reduced to elemental mercury. Some of the mercury/mercury chloride is released to air and some remains in the bottom ash. The concentration of the mercury/mercury chloride in the air wastestream will not be the same as the concentration originally present in the coal. Once the mercury/mercury chloride is released, it will be carried varying distances before it is deposited. Mercury can be transported over large distances, while mercury chloride may be deposited relatively rapidly by wet and dry deposition processes. The amount of mercury in a community or ecosystem will depend upon sources both local and distant. Once mercury has been deposited, it will bioaccumulate in organisms and will also persist in the environment as a sink for exposure and bioaccumulation. The amount of mercury that a human, animal, or plant will be exposed to is related more closely to exposure pathways and the quantity that is present in an ecosystem rather than the concentration in the coal that is combusted. Thus, EPA believes that the commenter is incorrect.

One commenter asserts that the elimination of the *de minimis* thresholds would not yield meaningful additional information. The commenter argues that the proposed rule vastly overstates the significance of TRI data and therefore incorrectly concludes that the *de minimis* thresholds would ''deprive communities of important information on PBT chemicals'' (at 64 FR 714). Instead, the commenter contends, TRI data only provide a snapshot view of releases from the chemical industry and the few other industry sectors subject to TRI reporting and that many potential release sources are not subject to TRI reporting. The commenter argues that these sources overwhelm the limited additional information that will be reported by eliminating the *de minimis* exemption.

EPA disagrees that the proposed rule vastly overstates the significance of the TRI data. The public, all levels of government, and the regulated community have come to rely on TRI data in improving decision-making, measuring pollution prevention, and understanding the environmental and health consequences of toxic chemical releases and other waste management activities. Although the Toxics Release Inventory does not contain a complete inventory of every release, EPA believes it does provide one of the most comprehensive and accessible sources of release and other waste management information available. EPA also disagrees with the commenter's assertion that the data base only contains information from the chemical industry and a few others. In fact, all 20 manufacturing industry groups as well as an additional 7 other industries including metal and coal mining facilities and hazardous waste management facilities are subject to EPCRA section 313. Further, with the addition of these 7 newly covered industries, EPA expects over 27,500 facilities to submit over 110,000 reports on more than 630 toxic chemicals to the TRI for the 1998 reporting year. Currently no other sources of information can provide releases and information on other waste management quantities and qualitative source reduction data with the scope, level of detail, and chemical coverage as data currently included in TRI.

Further, as EPA has previously explained, PBT chemicals can remain in the environment for a significant amount of time and can bioaccumulate in animal tissues. Even relatively small releases of such chemicals have the potential to accumulate over time and cause significant adverse impacts on human health and the environment. Therefore, EPA believes it is particularly important to gather and disseminate to the public relevant information on even relatively small amounts of releases and other waste management of PBT chemicals. Under the 10,000 and 25,000 pound/year reporting thresholds, a significant amount of the releases and other waste management activities involving PBT chemicals are not being captured and thus the public does not have the information needed to determine if these chemicals are present in their communities at levels that may pose a significant risk.

Several commenters argue that the *de minimis* exemption already does not apply to the manufacture of a toxic chemical unless the toxic chemical is manufactured as an impurity or is imported. Therefore, any incidental manufacturing of a PBT chemical as a by-product would not be eligible for the *de minimis* exemption and would be subject to reporting. Thus, they argue, the elimination of the exemption will provide little additional information and will not provide added value.

The commenters are correct in stating that there are instances where PBT chemicals are manufactured as by-products and would, therefore, not be affected by the elimination of the *de minimis* exemption. However, as EPA explained in the PBT proposal, there are also many instances where a PBT chemical may exist in a mixture or trade name product at a concentration below the 1% or 0.1% *de minimis* limit but where the processing or otherwise use of the PBT chemical in that mixture would otherwise contribute significantly to or in itself exceed the reporting thresholds (at 64 FR 714). For example, mercury can be found at very low concentrations in steel. A resmelting facility could process and release more than 100 pounds of mercury a year from its resmelting activities. However, although this total quantity is greater than the 10 pound proposed threshold for mercury, if the concentration of mercury in the steel is less than the *de minimis* limit, none of the mercury would be reportable if the *de minimis* level is retained for PBT chemicals. Releases and other waste management associated with these exempt activities would be absent from the TRI data base. Because even minimal releases of PBT chemicals may result in elevated concentrations in the environment or in an organism and can have the potential to cause an adverse effect, EPA believes that all releases of these chemicals are of concern and that such information is significant and of value to the public.

a. *Readily available data.* Some commenters assert that the elimination of the *de minimis* exemption will conflict with the condition that reporters obtain data from readily

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available sources. They argue that because concentrations below 1% (and 0.1% for carcinogens) are not required on MSDSs, reporters will no longer be able to use MSDSs to screen for products containing PBT chemicals below these concentrations. They further contend that AP-42 guidance, Air CHIEF CD-ROM, TANKS, CHEMDAT8 and WATER8 would provide additional assistance in estimating the amount of a PBT coincidentally manufactured in wastestreams or released; however, these tools will not help quantify the amount of chemical in materials which are distributed in commerce or used as feedstock. They assert that there are no other consistent sources of information on whether a product contains a PBT chemical below *de minimis* levels. They also assert that the elimination of the *de minimis* exemption will cause additional burden for the regulated community because covered facilities will struggle with how to comply in the absence of information.

The Agency believes that since reporting first began in 1988, new sources of information have become available to covered facilities to use to determine concentrations of toxic chemicals in mixtures. In addition to the data bases and information sources cited by the commenter, EPA believes there are other sources of data that can and should be used in making threshold determinations and release and other waste management calculations for PBT chemicals. Examples of these sources of information include EPA guidance documents (e.g., *EPCRA Section 313 Industry Guidance: Electricity Generating Facilities* (EPA 745–B–99–003)) and trade association guidance documents (e.g., National Council of the Paper Industry for Air and Stream Improvement (NCASI) Technical Bulletins and NCASI's *Handbook of Chemical Specific Information for SARA Title III Section 313 Form R Reporting*). In addition, relevant information has become much more accessible to covered facilities over the past 10 years. For example, the United States Geological Survey's U.S. Coal Quality Database has been in existence since the mid 1970s, but only more recently has it been made available on the Internet. (http://energy.er.usgs.gov/products/databases/UScoal/index.htm) EPA believes that these tools, in addition to the ones cited by the commenter, will help covered facilities quantify the amount of chemical in materials which are distributed in commerce or used as feedstock and will allow covered facilities to make reasonable calculations to comply with EPCRA section 313. Further, the Agency believes that it underestimated how much information covered facilities had available to them in 1988 regarding small concentrations of toxic chemicals in mixtures. Therefore, EPA believes that facilities have sufficient information to make threshold determinations and release and other waste management calculations for PBT chemicals below *de minimis* concentrations. However, as EPA explained above, if a covered facility has no information, including no reasonable estimates or other reasonably known information, on the concentration of the toxic chemical in the mixture, they need not consider the chemical in that mixture for threshold determinations and release and other waste management calculations (at 53 FR 4511). Therefore if the only source of information on a toxic chemical in a mixture is from an MSDS, and the MSDS does not indicate if the chemical is contained in the mixture, the facility is not required to consider the toxic chemical towards threshold determinations or release and other waste management calculations.

Because some facilities covered under EPCRA section 313 have more extensive information available to them than they did in 1988, or EPA underestimated how much information they had available in 1988, and because these facilities are not required to report if they have no information on the concentration of the toxic chemical, the Agency believes that in these cases retention of the *de minimis* exemption would allow facilities to avoid reporting when information is available to them that would otherwise permit them to report.

Some commenters assert that facilities will have to begin monitoring for trace quantities of chemicals in mixtures if the *de minimis* exemption is eliminated for PBT chemicals. One commenter argues that the only way facilities would be able to estimate the levels of dioxin in combustion products and wastewater treatment ''would be to undertake the costly burden of monitoring what comes off at a series of concentrations and temperatures.'' Another commenter asserts that if the *de minimis* level is eliminated, industry would be subject to increased enforcement action because exhaustive testing may be insufficient to detect the chemicals.

EPA disagrees with the commenters because, as stated previously, EPCRA section 313(g)(2) limits monitoring requirements under EPCRA section 313. Under this section, facilities are not required to perform any additional monitoring or analysis of production, process or use other than that already collected under other requirements. However, if a facility is required to monitor toxic chemicals under another statute, this data must be considered in determining thresholds and release and other waste management calculations under EPCRA section 313. EPCRA section 313(g)(2) requires that facilities use readily available data, or in absence of such data, facilities are required to use reasonable estimates. If no monitoring data are available, the facility should use other readily available information in making threshold determinations and release and other waste management calculations. Further, if the facility believes that it has other, more representative data than its monitoring data, the facility should use that information instead.

As to specifically tracking PBT chemicals in wastewater, the commenter does not specify whether the toxic chemicals discussed in the comment are manufactured as by-products, are processed, or otherwise used. As discussed above, the *de minimis* exemption does not apply to toxic chemicals manufactured as by-products. Therefore, if PBT chemicals are coincidentally manufactured during on-site wastewater treatment, covered facilities would be required to consider those PBT toxic chemicals for threshold determinations and release and other waste management calculations even if the *de minimis* exemption were retained for PBT chemicals. Similarly, PBT chemicals manufactured as a result of burning fuel would not be exempt even if the *de minimis* exemption were retained because manufactured by-products are not eligible for this exemption. PBT chemicals in below *de minimis* concentrations in mixtures that are imported, processed, or otherwise used will be affected by the elimination of the *de minimis* exemption. Covered facilities will need to consider these quantities towards threshold determinations and release and other waste management calculations. These calculations would include the amounts contained in combustion by-products and wastewater treatment units. Additional monitoring of these quantities, however, would not be required under EPCRA section 313. Finally, EPA has limited the dioxin listing with the qualifier ''manufacturing; and the processing or otherwise use of dioxin and dioxin-like compounds if the dioxin and dioxin-like compounds are present as contaminants in a chemical and if they were created

during the manufacturing of that chemical.'' Therefore, not all processing or otherwise use activities of the dioxin and dioxin-like compounds category must be considered towards a facility's threshold determinations.

Some commenters assert that EPA should maintain the *de minimis* exemption for PBT chemicals present as impurities. They argue that information on PBT chemicals present as impurities is not readily available and that obtaining the relevant data, conducting the initial reviews to determine what information is available, and identifying data gaps would impose a huge burden on industry. They argue that even developing estimates with any accuracy entails a significant amount of time. In the instance of impurities, they assert that the absence of data and the difficulty in developing estimates will result in a heavy burden with little information of value being reported. These commenters believe that the elimination of the *de minimis* level is a requirement to provide new data when utilizing the *de minimis* exemption.

EPA disagrees with these commenters. Although there are burdens associated with obtaining relevant data, determining available information and identifying data gaps, EPA disagrees that the elimination of the *de minimis* exemption for PBT chemicals present as impurities would vastly increase the extent of this required effort. From the comment, it is unclear why requiring facilities to identify and evaluate process streams containing small quantities of PBT chemicals as impurities is more burdensome than for larger quantities of these chemicals manufactured, processed, or otherwise used at a covered facility in excess of the activity thresholds. For example, a facility monitors for chemical A at a concentration of greater than 0.001% and monitors for chemical B at a concentration of greater than 1.5%. The monitoring is done for the same wastestream and the same frequency. There is no differential in effort or burden. Currently, the only difference is that facilities can ignore available data when utilizing the *de minimis* exemption.

One commenter asserts that the *de minimis* exemption should be retained for PBT chemicals present at mining facilities. The commenter argues that the burden upon the mining industry is even greater in the context of the low thresholds proposed for PBT chemicals. Further, the commenter asserts that although EPCRA does not require covered facilities to conduct tests concerning the amount of listed chemicals processed, most reporters rely upon their knowledge of their manufacturing processes and raw materials to produce meaningful data for EPCRA section 313 reporting purposes. The commenter contends that this is not true of the mining industry. Due to the volume of materials moved in the extraction process and the heterogeneous nature of the materials mined, process knowledge often is inadequate to produce a meaningful picture of the minute levels of PBT chemicals that may be present in mining operations. The commenter asserts that inadequate process knowledge combined with the enormous expense of constantly testing the processed materials makes the elimination of the *de minimis* exemption for PBT chemicals unworkable as applied to mining operations.

EPA disagrees with the commenter. As the commenter points out, under EPCRA section 313(g)(2), facilities are not required to perform any additional monitoring or analysis of production, process, or use other than that already collected under other statutory or regulatory requirements. Therefore, there should be no added cost due to testing to comply with EPCRA section 313. However, EPA believes that in many cases mining facilities have the information needed to make reasonable estimates regarding small concentrations of PBT chemicals in the ores mined. In addition, as EPA explained in the 1988 final rule, if a covered facility has no information on the concentration of the toxic chemical in the mixture, including no reasonable estimates, the facility need not consider the chemical in that mixture for threshold determinations and release and other waste management calculations. If a mining facility does have information regarding the concentration of a toxic chemical in a mixture or trade name product, the facility must consider all non-exempted sources of the chemical for threshold determinations. If an activity threshold is exceeded for the chemical, the facility must then calculate release and other waste management quantities. Covered mining facilities will need to identify and evaluate process streams when considering a PBT chemical in concentrations below the *de minimis* level just as they already do for toxic chemicals found in process streams in concentrations above the *de minimis* level. Therefore, given that covered facilities: (1) Are not required to perform additional monitoring; (2) are not required to consider concentrations of toxic chemicals for which they have no information; and (3) need only consider readily available data, EPA disagrees that identifying and evaluating mining activities involving mixtures containing less than 1.0% or 0.1% concentrations of PBT chemicals will be more burdensome than for larger quantities of these chemicals manufactured, processed, or otherwise used at a mining facility in excess of the activity thresholds.

b. *Alternate de minimis level.* Several commenters argue that in lieu of eliminating the *de minimis* exemption for PBT chemicals, it would make more sense to change the level for the *de minimis* exemption for these chemicals. Some commenters argue that a more appropriate approach would be to compare the current thresholds and the current *de minimis* levels and use the same ratio to create a new *de minimis* level for the lowered PBT chemical thresholds. Therefore, they argue, the existing level is 1% for a threshold of 10,000 pounds, so an analogous reduction of the *de minimis* level would be 0.01% for the new proposed threshold of 100 pounds and 0.001% for the new proposed threshold of 10 pounds per year and 1 ppb for dioxins. One commenter argues that the current *de minimis* level of 0.1% for known or suspected carcinogens is not appropriate for dioxins. They suggest that EPA lower the *de minimis* exemption for dioxins proportionally to the lower reporting threshold EPA sets in the final rule. They assert that a reporting threshold for dioxins of 0.002 pound TEQ (not the threshold in the PBT proposal nor the one that EPA is finalizing today), is approximately seven orders of magnitude less than the current 10,000 pound threshold. Therefore, they argue, the 0.1% *de minimis* exemption should be lowered proportionally to 1×10^{-8}%. This translates to a concentration of 100 parts per trillion.

EPA disagrees with these commenters. As explained previously, EPA adopted the *de minimis* exemption for several reasons including the desire to be consistent with information mandated by the OSHA HCS. This OSHA standard requires the listing of hazardous chemicals on MSDSs but allows chemical suppliers to omit from the MSDSs hazardous chemicals that are below certain concentrations: Specifically, levels of 0.1% for OSHA carcinogens and 1.0% for other hazardous chemicals. However, the rationale for the OSHA HCS *de minimis* exemption is not relevant to PBT chemicals and therefore, is insufficient by itself to support an alternative *de minimis* exemption for PBT chemicals.

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As explained in the 1983 final rule, OSHA chose the 1.0% concentration limit based on comments that this level seemed to be sufficiently protective of workers and was considered to be reasonable by a number of commenters (48 FR 53280, at 53290, November 25, 1983). OSHA was also persuaded by comments that in some instances the 1.0% cut-off levels may not be protective enough with respect to certain health hazards and adopted the 0.1% level for carcinogens (at 48 FR 53292). Specifically, PBT chemicals are of concern because they persist and bioaccumulate in the environment. Persistence and bioaccumulation were not considered as a part of the OSHA rulemaking. In addition, as explained in other responses in this unit, EPA's original rationale for this exemption is inapplicable to PBT chemials, and the commenters have provided no alternate rationale to support an exemption based on extrapolating new *de minimis* levels from the proposed thresholds. Therefore, given the different intents between the OSHA HCS and EPCRA section 313, EPA does not believe that creating alternative *de minimis* levels for PBT chemicals based on a ratio between the lowered threshold and the OSHA HCS levels is appropriate.

Several commenters support EPA's elimination of the *de minimis* exemption for PBT chemicals. They assert that retention of the *de minimis* exemption would undermine the changes to the reporting threshold and would allow an unnecessary loophole from reporting. They assert that the rule does not require any additional testing for impurities and that the only additional reporting would be for those facilities that use sufficient quantities of mixtures or trade name products containing PBT chemicals as impurities. One commenter asserts that one of the original reasons for the *de minimis* exemption levels, that it was based on OSHA HCS thresholds of 1.0% for hazardous chemicals in mixtures and 0.1% for carcinogens in mixtures, does not apply to raw materials that are not manufactured chemicals, such as crude oil, coal, and mining inputs.

EPA agrees with these commenters and is eliminating the *de minimis* exemption for PBT chemicals addressed in today's rule. As discussed above, the reasons EPA indicated for originally adopting the *de minimis* exemption are not applicable to PBT chemicals. In addition, EPA has received no compelling arguments from commenters to extend the *de minimis* exemption to PBT chemicals. Because the purpose of today's rulemaking is different from past rulemakings in that it is intended to capture information on significantly smaller quantities of releases and other waste management associated with these chemicals, the *de minimis* exemption could significantly limit the amount of reporting on PBT chemicals. Therefore, given that: (1) Covered facilities have several sources of information available to them regarding the concentration of PBT chemicals in mixtures; (2) even minimal releases of persistent bioaccumulative chemicals may result in significant adverse effects and can reasonably be expected to significantly contribute to the proposed lower thresholds; and (3) the concentration levels chosen, in part, to be consistent with the OSHA HCS are inappropriately high for PBT chemicals, EPA believes that the reasons for the *de minimis* exemption that the Agency held for previous rulemakings do not apply to PBT chemicals. EPA is therefore eliminating the *de minimis* exemption for PBT chemicals.

c. *Supplier notification*. Several commenters were confused by EPA's failure to modify the *de minimis* exemption for PBT chemicals under the supplier notification requirements. As explained in the PBT proposal, the Agency believes that covered facilities have sufficient information available to them on PBT chemicals. The requirement of additional information under the supplier notification requirements would result in redundancies. Commenters that correctly understood EPA's inaction on this topic support the retention of the *de minimis* exemption for purposes of Subpart C Supplier Notification Requirements under 40 CFR 372.45(d)(1). EPA agrees with these commenters and has therefore taken no action on the supplier notification requirements for PBT chemicals.

2. *Other exemptions*. Although the Agency received several comments regarding the existing exemptions, EPA is not modifying any of these exemptions in this rule. Any changes to these exemptions would require additional rulemaking, and any comments submitted to EPA during this rulemaking will be considered as part of EPA's evaluation of these exemptions.

3. *Use of alternate threshold and Form A*. One issue that commenters raise relates to EPA's proposal to exclude all PBT chemicals from the alternate threshold of 1 million pounds for PBT chemicals. Several commenters argue that EPA should retain the alternate threshold of 1 million pounds for PBT chemicals. EPA disagrees. As stated in detail in the proposal, EPA believes that use of the existing alternate threshold and reportable quantity for Form A would be inconsistent with the intent of expanded PBT chemical reporting. The general information provided on the Form A, on the quantities of the chemical that the facility manages as waste is insufficient for conducting meaningful analyses on PBT chemicals.

A commenter states that because PACs in fuel are destroyed during combustion, EPA should retain the alternate threshold or provide a new alternate threshold. First, the commenter did not provide any information to support the contention that PACs in fuel are destroyed during combustion. And, to the contrary, EPA believes that, even if some or all of the PACs in fuel are destroyed during combustion, additional PACs may be created during the combustion process. Consequently, absent any information to support the basis for such an option, or the need for an alternate threshold, EPA does not believe it would be appropriate at this time to provide a new alternate Form A threshold. Although EPA solicited comments on this issue in the proposal, at this time, the Agency believes that it is appropriate to collect and analyze several years worth of data at the lowered thresholds before EPA considers developing a new alternate threshold and reportable quantity appropriate for PBT chemicals.

In addition, the commenter also appears to be raising a broader issue than just the destruction of PACs during combustion. The commenter implies that when a facility estimates its releases to be zero, the facility should be eligible to use the Form A. However, the commenter appears to misunderstand how to calculate the amounts required to determine eligibility for the Form A. Facilities may use the Form A provided that they do not exceed 500 pounds for the total annual reportable amount for a chemical, and that their amounts manufactured or processed or otherwise used do not exceed 1 million pounds. The annual reportable amount is equal to the combined total quantities released at the facility, treated at the facility, recovered at the facility as a result of recycle operations, combusted for the purpose of energy recovery at the facility, and amounts transferred from the facility to off-site locations for the purpose of recycle, energy recovery, treatment, and/or disposal. The commenter only appears to consider their releases as reportable amounts and does not appear to consider quantities generated from their other waste management activities as reportable amounts. This additional waste management information on PBT chemicals is very important to

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communities because it helps them understand the quantities of EPCRA section 313 chemicals that are being transported through their communities, the destination of these EPCRA section 313 chemicals, as well as the reported waste management activity at the receiving facility. In conclusion, EPA has not proposed to disregard this waste management information in calculating the annual reportable amount, therefore the commenter's approach is not consistent with current reporting under Form A or appropriate as an approach for reporting on PBT chemicals.

The commenter also states that the alternate threshold should be retained in order to ensure that only meaningful amounts of substances are reported under EPCRA section 313. EPA disagrees that retention of the alternate threshold would ensure that only meaningful information is reported under EPCRA section 313. The 500 pound waste eligibility could be interpreted by some data users, as a worst case, to mean that greater than 500 pounds of the chemical has been released into the environment (i.e., 500 pounds of production-related waste as release and some quantity of catastrophic release). Other data users may assume that the facility had no catastrophic releases and all of the toxic chemical in waste was managed in a manner other than as a release, e.g., the toxic chemical in waste was recycled. For PBT chemicals where any release is a concern, an uncertainty level of 500 pounds may result in data that is virtually unusable. As a result, EPA does not agree with the commenter that the alternate threshold will ensure that only meaningful amounts of substances will be reported under EPCRA section 313.

In addition, the commenter argues elimination of the alternate threshold for PBT chemicals will cause reporting burdens to increase while failing to provide for the collection of substantial additional release information. EPA's economic analysis used reporting costs for the Form R to estimate the costs to those facilities that would not be able to use the alternate threshold. The economic analysis also evaluated the benefits of the collection of additional release and other waste management of PBT chemicals (Ref. 67). The commenter does not dispute those estimates. As a result, EPA sees no compelling argument to revise its decision to exclude all PBT chemicals from the alternate threshold of 1 million pounds.

A number of commenters argue that EPA should eliminate the alternate threshold of 1 million pounds for all PBT chemicals on the EPCRA section 313 list. One commenter asserts that in light of the relatively small quantities of concern for PBT chemicals, particularly those with no deliberate commercial manufacture, it makes little sense to retain the Form A. The commenter further states that it believes that a modified Form A would be inappropriate due to the concern over releases of these chemicals at low levels. Another commenter adds that the Form A is clearly inappropriate for chemicals that will now have thresholds significantly lower than the 500 pound waste generation level. The commenter further contends that it is not appropriate for EPA to set a new Form A threshold for PBT chemicals, given the need to collect more information on these substances.

EPA agrees with the commenters that all PBT chemicals should be excluded from the alternate threshold of 1 million pounds. As stated in detail in the proposal, EPA believes that use of the existing alternate threshold and reportable quantity for Form A would be inconsistent with the intent of expanded PBT chemical reporting (at 64 FR 715–716). The general information provided in the Form A on the quantities of the chemical that the facility manages as waste is insufficient for conducting meaningful analyses on PBT chemicals.

EPA also agrees that a new alternate threshold for PBT chemicals would be inappropriate due to the concern over releases and other waste management of these chemicals at low levels. As stated in the proposal, even small quantities of persistent bioaccumulative chemicals may cause elevated concentrations in the environment and organisms that may cause significant adverse effects. Given the persistent and bioaccumulative nature of these chemicals and the need for the public to have information about smaller amounts of these PBT chemicals, EPA believes it would be inappropriate at this time to allow an option that would exclude significant information on some releases and other waste management of these chemicals.

In response to EPA's proposal to exclude all PBT chemicals from the alternate threshold of 1 million pounds, one commenter argues that EPA should consider establishing a new alternate reporting threshold for these chemicals. The commenter states that, at a minimum, an alternate reporting threshold of 10 to 100 pounds would be consistent with the throughput-reporting threshold proposed for all PBT chemicals except dioxins. The commenter further states that the SBA's analysis suggests significant reductions in burden associated with alternate reporting thresholds of 50 pounds for PBT chemicals. The commenter states that, based on an SBA study commissioned of petroleum bulk plants, which it estimates will be the largest group of reporters under this proposal, it finds that most of the reports avoided by this alternate threshold would reflect zero releases.

EPA disagrees with the comment suggesting that a new alternate threshold be established for PBT chemicals. As stated in the proposal, even small quantities of persistent bioaccumulative chemicals may cause elevated concentrations in the environment and organisms that may cause significant adverse effects. Given the persistent and bioaccumulative nature of these chemicals and the need for the public to have information about smaller amounts of these PBT chemicals, EPA believes it would be inappropriate at this time to allow an option that would exclude significant information on some releases and other waste management of these chemicals. The general information provided in the Form A on the quantities of the chemical that the facility manages as waste is insufficient for conducting meaningful analyses on PBT chemicals. Therefore, EPA does not agree that a new alternate threshold for PBT chemicals should be established.

The commenter also suggests that reporting burdens will increase while failing to provide for the collection of substantial additional release information. EPA's economic analysis used reporting costs for the Form R to estimate the costs to those facilities that would not be able to use the alternate threshold. The economic analysis also evaluated the benefits of the collection of additional release and other waste management of PBT chemicals (Ref. 67). The commenter does not dispute those estimates. As a result, EPA sees no compelling argument to revise its decision to exclude all PBT chemicals from the alternate threshold of 1 million pounds.

4. *Data precision issues*—a. *Use of significant digits, half pound and whole numbers*. EPA proposed to require reporting of all releases and other waste management quantities of PBT chemicals (except dioxin) that are greater than 1/10 of a pound, provided that the accuracy in the underlying data on which the estimate is based supports this level of precision. EPA further stated that releases and other waste management quantities would continue to be reported to two significant digits. In addition, EPA stated that for quantities of 10 pounds or greater, only

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whole numbers would be required to be reported. For the category of dioxin and dioxin-like compounds, which have a proposed reporting threshold of 0.1 gram, EPA proposed that facilities report all releases and other waste management activities greater than 100 µg (i.e., 0.0001 gram).

After reviewing all comments on this issue, EPA is providing the following guidance on the level of precision covered facilities should use to report their releases and other waste management quantities of PBT chemicals. Facilities should continue to report releases and other waste management amounts greater than 1/10 of a pound (except dioxin), at a level of precision supported by the accuracy of the underlying data and the estimation techniques on which the estimate is based.

This approach is consistent with the statutory reporting requirements when estimating reportable amounts. The statute requires facilities to, among other things, report ''[t]he annual quantity of the toxic chemical entering each environmental medium.'' (42 U.S.C. 11023(g)(1)(C)(iv)). To determine this ''annual quantity,'' the statute directs facilities to use readily available data (including monitoring data). When such data are not readily available, the statute directs facilities to use reasonable estimates. (42 U.S.C. 11023(g)(2)). However, while the statute allows for some level of imprecision regarding reportable amounts, it does not create an exemption or exception that would allow facilities to report less precisely than provided for by their data or estimation techniques. Therefore, facilities should report PBT chemicals as precisely as their estimation techniques or readily available data allow. If a facility's release or other management calculations support reporting an amount that is more precise than two significant digits, then the facility should report that more precise amount.

b. *Use of range reporting.* In the preamble to the proposed rule, EPA requested comments on its proposal to eliminate the use of range reporting in Form Rs for PBT chemicals. Commenters disagree with the proposal for a number of reasons outlined below.

Commenters argue that applying different reporting conventions for PBT chemicals would complicate EPCRA section 313 reporting, cause compliance difficulty, and introduce data inconsistencies (i.e., ranges for some chemicals but not for others). Commenters also argue that eliminating the use of range reporting for PBT chemicals has the potential to mislead the public and divert attention from actual risks.

EPA disagrees that the elimination of the use of range reporting for PBT chemicals will cause insurmountable obstacles to EPCRA section 313 reporting and cause compliance difficulties and data inconsistencies. There are already many different industries that report to EPA for 643 chemicals. EPA provides numerous guidance documents and training opportunities to reporting industries. With the finalization of the PBT rule, EPA will provide updated guidance documents, will prepare and provide, in those cases where it is appropriate, chemical-specific guidance documents, and will continue to offer training in order to assist facilities in reporting under EPCRA section 313. EPA also believes that the Agency will be able to adequately explain to the public the different reporting requirements for PBT chemicals so that they are put in context of other TRI data. EPA currently does this for other types of chemicals on the EPCRA section 313 list such as metals and pesticides.

Additionally, EPA believes that the elimination of range reporting is a critical part of this rulemaking, of which the ultimate intent is to provide useful information on PBT chemicals to assist communities in determining if PBT chemicals are present in their communities at levels that may pose an unacceptable risk. This information on PBT chemicals can also be used by government agencies and others to identify problems, set priorities, and take appropriate steps to reduce any potential risks to human health and the environment. Consequently, the information collected about these PBT chemicals will inform the public rather than mislead the public and will actually assist the public in determining the risk of PBT chemicals in their communities.

Commenters also argue that reporting numerical values for PBT chemicals assumes a level of accuracy that generally does not exist in the measurement of releases. In addition, commenters state that estimating numerical values would require the use of material balances, which are difficult to apply and essentially inaccurate for chemicals used in low concentrations. Commenters contend that, especially where reports are estimates, ranges may in fact provide more information than point estimates. Commenters argue that, for these reasons, elimination of range reporting will result in inaccurate estimates. Commenters also state that eliminating the use of range reporting for PBT chemicals would give the false impression of precise data, where uncertainty inherently exists.

As stated in the proposal, EPA believes that the use of ranges could misrepresent data accuracy because the low or the high end range numbers may not really be that close to the estimated value, even taking into account its inherent error (i.e., error in measurements and developing estimates) (at 64 FR 716). The user of the data must make a determination on whether to use the low end of the range, the mid-point, or the upper end. For example, a release of 501 pounds could be misinterpreted as 999 pounds if reported as a range of 500–999. This represents nearly a 100% error. This uncertainty severely limits the applicability of release information where the majority of releases, particularly for PBT chemicals, are expected to be within the amounts eligible for range reporting. The utility of these data would be severely limited given the uncertainty associated with data reported using ranges. Therefore, due to this uncertainty, EPA believes that facilities should report numerical values, not ranges, for PBT chemicals.

In addition, EPA believes that the information available to the typical EPCRA section 313 reporter is generally greater and/or more accessible than it was 10 years ago. Because of this improved information availability, EPA believes that many facilities will be able to accurately estimate releases and off-site transfers for further waste management of PBT chemicals in quantities of less than 1,000 pounds without the use of range codes. Although it may be true that some facilities will be better able to make those estimates than others, EPA does not believe this justifies not collecting the more specific and useful information from those facilities that can provide it.

Further, the Form R and Instructions and annual TRI data release provide information on the methods used to generate information reported and characterize many of the limitations that may apply to the data. This aids the data user in understanding the overall nature of the information available under EPCRA section 313. Facilities are required, for each release or transfer amount, to indicate on the the principal method used to determine the amount of release reported. There are codes which allow the facility to indicate whether the estimate is based on monitoring data, mass balance calculations, published emission factors, or other approaches such as engineering calculations or best engineering judgment. By looking at the

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information provided through the use of these codes, users of the data can gain an understanding of the degree of accuracy or uncertainty in any particular number reported by a facility. Thus, EPA believes that false impressions will not be communicated to the data user about the accuracy of the information filed.

Finally, EPCRA permits facilities to use reasonable estimates in the absence of readily available data to calculate reportable amounts. Compliance with EPCRA section 313 does not require that additional monitoring or sampling be done. Thus, the statute contemplates some level of imprecision in the data that may be filed, yet, by authorizing reporting based on reasonable estimates, affirms the community right-to-know purposes relative to information based on such reasonable estimates. Reporting releases of low volumes of PBT chemicals based on such reasonable estimates is no different than reporting on other toxic chemicals based on the same kind of information. The TRI data that has been reported since 1987 is a blend of estimates based on monitoring data, mass balance calculations, published emissions factors, and engineering calculations or engineering judgment.

The commenters contend that eliminating the use of range reporting for PBT chemicals would be extremely burdensome to facilities. EPA explained in the proposal that the original intent of providing the range reporting option was primarily as a burden reducing measure focused on small businesses. In past expansion activities, EPA has tried to retain burden reducing options wherever feasible. However, EPA does not expect the elimination of range reporting to significantly affect the unit cost of reporting because many facilities that could use range reporting are not choosing to do so. An analysis of the 1997 data reported under EPCRA section 313 reveals that the number of instances in which a range code was used for reporting quantities in sections 5 and 6 of the Form R was 37,168. These 37,168 instances included 7,605,305 pounds of releases and transfers using the median of the range code reported. However, there were 66,842 instances in which range reporting could have been used (i.e., the amounts reported where below 1,000 pounds), but the reporting facility chose instead to report a number rather than a range. These 66,842 instances included 13,662,758 pounds of releases and transfers. Thus, in 64% of the instances where range reporting could have been used facilities reported a number instead. The fact that in a majority of the instances in which range reporting could have been used facilities opted to report specific numbers would appear to indicate that the elimination of range reporting for PBT chemicals is unlikely to impose any significant additional burden on facilities. Therefore, EPA does not expect the elimination of range reporting to have any significant effect on unit reporting costs.

Commenters also argue that the elimination of the use of range reporting for PBT chemicals could result in an increase in the threat to confidential information and a possible increase in trade secret claims. Commenters maintain that Congress considered the need to protect trade secret information in the discussion of reporting chemical use and presence in ranges for EPCRA section 313:

> The conference substitute provides for reporting categories of use and ranges of chemicals present because the exact use of an identified chemical at a facility or the exact amount present may disclose secret processes. In some circumstances, this information may need to be reported in terms of broad 43 categories of use or amount ranges. . . . (H.R. Report No. 99–962, 298)

However, EPA believes that the conference report language cited by the commenter clearly refers only to the use of range reporting for the data element entitled ''maximum amount of the toxic chemical on-site at any time during the calendar year.'' EPA is not precluding range reporting for maximum amounts on-site. Contrary to the notion expressed by the commenter, Congress did not expressly direct EPA to allow range reporting for the reporting of releases and transfers off-site for further waste management. Additionally, in the statute, Congress provided the only means and mechanism for facilities to protect confidential business information (CBI) through the statute's trade secret provisions. If the commenter believes that any report filed might reveal confidential information as to the identity of the chemical, the commenter may choose to file a CBI claim by following the procedures as outlined in 40 CFR part 350. In addition, the statute is clear that trade secret claims may only be made for the identity of the chemical. Therefore, EPA believes that Congress adequately provided procedures for the protection of CBI and that a possible increase in CBI claims does not outweigh the need for increased information on releases and other waste management of PBT chemicals. See, *Legislative History* at 5185.

Commenters also argue that eliminating the use of range reporting for PBT chemicals will not result in the collection of substantial additional release information. EPA disagrees. The issue of range reporting is closely tied to the lowering of the reporting thresholds for PBT chemicals. As EPA noted in the proposal,

> Since PBT chemicals can remain in the environment for a significant amount of time and can bioaccumulate in animal tissues, even relatively small releases of such chemicals from individual facilities have the potential to accumulate over time to higher levels and cause significant adverse impacts on human health and the environment.

EPA also noted in the proposal that,

> Under current reporting thresholds, a significant amount of the releases and other waste management activities involving PBT chemicals are not being captured and thus the public does not have the information needed to determine if PBT chemicals are present in their communities and at levels that may pose a significant risk.

Therefore, by the lowering of reporting thresholds, EPA will receive important information on the quantities of PBT chemicals being released or otherwise managed as waste. Given the lowering of the reporting thresholds, continued use of ranges could misrepresent data accuracy because the low or the high end range numbers may not really be that close to the estimated value, even taking into account any inherent error (i.e., errors in measurements and developing estimates). The user of the data must make a determination on whether to use the low end of the range, the mid-point, or the upper end. For example, a release of 501 pounds could be misinterpreted as 999 pounds if reported as a range of 500–999. This represents a nearly 100% error. This uncertainty severely limits the applicability of release information where the majority of releases, particularly for PBT chemicals, are expected to be within the amounts eligible for range reporting. Given that the large uncertainty would be part of these data and would severely limit their utility, EPA has concluded that facilities must report numerical values, not ranges, for PBT chemicals.

In addition to the above comments, several commenters recommend the use of multiple ranges rather than total elimination of ranges just for PBT chemicals. One commenter generally agrees with EPA's position that reporting ranges ''B'' (11 to 499 pounds) and ''C'' (500 to 999 pounds), as they currently exist, may be too broad to provide meaningful information for PBT chemicals. Because the proposal does not impose any new obligation to measure or test beyond what is currently required, however, the commenter believes it is still

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appropriate to retain the ''A'' reporting range of 1 to 10 pounds for PBT chemicals. The commenter contends that the use of a specific number conveys a sense of precision that may not actually exist. The commenter argues that the retention of the ''A'' reporting range in its current form, coupled with the new reporting range of ''greater than zero, but less than 1 pound,'' will provide meaningful and valuable information to the public on PBT chemical transfers or releases.

Another commenter agrees with the purpose underlying the EPA's proposal to prohibit the use of range reporting for PBT chemicals and believes the ranges authorized under the current rules are too broad to be useful for PBT chemicals. However, the commenter believes that EPA should recognize that reporting in ranges is often necessary because uncertainty makes the selection of a single number arbitrary.

Another commenter argues that EPA should retain range reporting for PBT chemicals, even if the ranges are lower than those allowed for non-PBT chemicals. The commenter further contends that they believe that range reporting helps to correct some of the error introduced to EPCRA section 313 reporting through the use of estimates.

EPA disagrees that the Agency should retain the ''A'' reporting range of 1 to 10 pounds for PBT chemicals or that the Agency should retain some form of range reporting for PBT chemicals. As stated in the proposal, EPA believes that the use of ranges could misrepresent data accuracy because the low or the high end range numbers may not really be that close to the estimated value, even taking into account its inherent error (i.e., error in measurements and developing estimates). The user of the data must make a determination on whether to use the low end of the range, the mid-point, or the upper end. For example, a release of 501 pounds could be misinterpreted as 999 pounds if reported as a range of 500–999. This represents a nearly 100% error. Even with a lower range such as 1 to 10 pounds, the uncertainty associated with range reporting could severely limit the applicability of release information for PBT chemicals. Numerical values are particularly important since PBT chemicals can remain in the environment for a significant amount of time and can bioaccumulate in animal tissues. This means that even relatively small releases of such chemicals from individual facilities have the potential to accumulate over time to higher levels and cause adverse impacts on the environment and organisms. The utility of these data would be limited given the uncertainty associated with data reported using ranges. Therefore, due to this uncertainty, EPA is requiring that facilities report numerical values, not ranges, for PBT chemicals.

In addition, EPA believes that the information available to the typical EPCRA section 313 reporter is generally greater and more accessible than it was 10 years ago. Because of this improved information availability, EPA believes that facilities will be able to accurately estimate releases and off-site transfers for further waste management of PBT chemicals in quantities of less than 1,000 pounds without the use of range codes. Although it may be true that some facilities will be better able to make those estimates than others, EPA does not believe this justifies not collecting the more specific and useful information from those facilities that can provide it. Further, in the Form R, facilities are required, for each release or transfer amount, to indicate the principal method used to determine the amount of release reported. There are codes which allow the facility to indicate whether the estimate is based on monitoring data, mass balance calculations, published emission factors, or other approaches such as engineering calculations or best engineering judgment. By looking at the information provided through the use of these codes, users of the data can gain an understanding of the degree of accuracy or uncertainty in any particular number reported by a facility. Thus, EPA does not believe that false impressions will be communicated to the data user about the accuracy of the information filed.

Finally, as noted earlier EPCRA permits facilities to use reasonable estimates in the absence of readily available data to calculate reportable amounts. EPCRA does not require that additional monitoring or sampling be done in order to report. Thus, the statute contemplates some level of imprecision in the data that may be filed, yet, by authorizing reporting based on reasonable estimates, affirms the community right-to-know purposes relative to information based on such reasonable estimates.

A number of commenters agreed with EPA's proposal that range reporting be eliminated for all PBT chemicals on the EPCRA section 313 list. The commenters agreed with EPA's belief that the use of ranges could misrepresent data accuracy and significantly impact the usefulness of the data.

J. Other Issues

1. *Placing reported data into context.* Several commenters make the same general comment that EPCRA section 313 does not capture all sources of PBT chemical releases and therefore will not provide a complete or accurate picture of the releases of these chemicals. Commenters criticize the proposal for not putting the PBT releases from EPCRA section 313 covered facilities into context, in terms of either risk or the amount of PBT releases expected from non-covered facilities or sources. EPA disagrees with the implication by several commenters that simply because EPCRA section 313 may not capture all the sources of releases of PBT chemicals EPA should not attempt to capture more information from the facilities that do report under EPCRA section 313. This comment has been voiced in every major rulemaking under EPCRA section 313 but, as EPA has stated in the past, this is not an argument that EPA believes should restrict any efforts to collect additional data under EPCRA section 313. The mere fact that for some chemicals significant release sources are not captured does not in any way diminish the importance of the information that can be provided by those facilities that are required to report under EPCRA section 313. There is currently no one single reporting requirement that captures all of the releases of PBT chemicals and makes that information available to the public. For those chemicals that do have large release sources not captured under EPCRA section 313, EPA will use all available data to aid its actions and those of other international and national organizations and the public in efforts to address concerns on PBT chemicals. For example, all data will be considered to aid EPA's PBT strategy or other EPA PBT related programs; EPA will not rely solely on the data collected under EPCRA section 313. In addition, if there are significant sources of PBT chemicals that are not reported under EPCRA section 313, EPA will attempt to let the public know that some sources are not captured. In fact, in the most recent TRI data release documents, EPA has been providing information to the pubic on other sources of releases for certain EPCRA section 313 chemicals. In addition, EPA will continue to improve and augment public information materials so that users of the data will have information available to put in context the releases and other waste management of PBT chemicals by industries reporting under EPCRA section 313 versus those industries that do not report under EPCRA section 313.

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In fact, rather than an argument against lowering the reporting thresholds for PBT chemicals, EPA believes that the argument the commenters are making is one that supports expanding the types of facilities that should be required to report under EPCRA section 313 and not an argument that supports denying the public the right-to-know about PBT chemical releases from EPCRA section 313 covered facilities.

Some commenters stated that since EPA did not use exposure or risk considerations, the data on PBT chemical releases will be misleading to the public by indicating risks where none exist. EPCRA section 313 is not a risk-based reporting system, and, as discussed in Unit VI.F., EPA believes that a risk-based approach to EPCRA section 313 reporting is at odds with the overriding policy of EPCRA section 313, which is to get information about the use, disposition, and management of toxic chemicals into the public domain, enabling the users of this information to evaluate the information and draw their own conclusions about risk. The intent of EPCRA section 313 is to move the determination of which risks are acceptable from EPA to the communities in which the releases occur. This basic, local empowerment is a cornerstone of the right-to-know program. In addition, EPA will continue to improve its annual public data release as well as its outreach and education efforts to assist users in understanding the data. Consequently, EPA disagrees with the commenters that the information reported on releases and other waste management of PBT chemicals will be misleading to the public.

Another commenter states that the quantities of PBT chemicals reported in the TRI will be far smaller than the quantities of other chemicals which pose far less significant health risks. The commenter is concerned that the small quantities could lead members of the public to overlook the data on PBT chemicals. Therefore, the commenter argues that EPA should present PBT data in a way that draws the public's attention to it. The commenter states that it sees a danger that without sufficient education and guidance, the public may either overestimate or underestimate the health risks from PBT chemicals. The commenter believes that EPA should make a commitment to ensuring that the public is given the necessary education and guidance. EPA understands that the quantities of PBT chemicals may be reported in smaller quantities than other chemicals under EPCRA section 313 and that these quantities have the potential to be overlooked. EPA is also sensitive to the issue that data on PBT chemicals must be presented clearly to assist data users in understanding how the information on PBT chemicals is different from that reported on other chemicals under EPCRA section 313. EPA will continue to improve its annual public data release as well as its outreach and education efforts to assist users in understanding the data. Despite the concerns voiced by the commenters, EPA still believes that it is important to collect and disseminate this information so that communities can use the information with other site-specific factors to determine if releases into their communities result in risks that the community determines warrant further action given other factors, such as economic and environmental conditions, or particularly vulnerable human or ecological populations.

Another commenter expresses concern that release numbers for PBT chemical will not be comparable to those for other chemicals with higher reporting thresholds or to releases of the PBT chemical in previous years. The commenter adds that the lower thresholds may mislead the public into thinking that releases are rising or that a new chemical has been introduced at a facility. EPA understands the commenter's concern but does not believe this is a justification for not collecting additional information about PBT chemicals. EPA believes that it will be able to adequately explain to the public the different reporting requirements for PBT chemicals so that they are put in context of other TRI data. EPA will make clear which PBT chemicals were reportable prior to the finalization of this rule and what the reporting threshold was for these chemicals. Finally, EPA will continue to improve its annual public data release as well as its outreach and education efforts to assist users in understanding the data.

2. *Manufacture only qualifier for chemicals other than dioxin.* Many commenters request that EPA add a ''manufacture only'' qualifier to all PBT chemicals, not just the dioxin and dioxin-like compounds category. The commenters assert that the addition of the manufacture only qualifier to all PBT chemicals would greatly reduce the burden of the rule. Some commenters suggest that at a minimum the manufacture only qualifier should apply to polychlorinated biphenyls (PCBs), since EPA's rationale for applying the qualifier to dioxin and dioxin-like compounds is equally applicable to PCBs. One commenter contends that EPA's statement that the manufacture qualifier is appropriate for chemicals that are ''ubiquitous in the environment'' because otherwise many facilities would be required to report simply due to background levels in raw materials applies to PCBs as well. Some commenters suggest that unintentionally manufactured by-products such as hexachlorobenzene and octachlorostyrene should also have the manufacture only qualifier. Some commenters argue that the burden of the rule could be significantly reduced if EPA focused the reporting effort on the manufacturing sector, which should help concentrate EPA's pollution prevention efforts on the sector most likely to be able to make reductions. Some commenters contend that the primary source for PBT chemicals within the EPCRA section 313 reporting sectors is from manufacturing, and these are the sources that should be focused on for tracking PBT chemicals. Some commenters assert that EPA has acknowledged that many chemicals identified as persistent and bioaccumulative are not imported, processed, or otherwise used, but are manufactured as by-products (at 64 FR 715). Some commenters assert that they agree that manufacturing is the primary source for environmental loading of PBT chemicals from EPCRA section 313 facilities, and thus the effort for reporting should be concentrated on the sources where PBT chemicals are generated and data can be gathered. Some commenters argue that concentration on the manufacturing of PBT chemicals provides an efficient focus for meaningful pollution prevention efforts. Some commenters assert that they are concerned that data from importing, processing, or otherwise use of PBT chemicals will be inaccurate and misleading since processors and users may not have the resources to conduct the analyses required to provide accurate estimates. One commenter contends that the fear of enforcement might motivate those importing, processing, or otherwise using PBT chemicals to report ''some amount'' and that such information is likely to be inaccurate, and will not accurately reflect the true level of concern. Some commenters assert that instead of requiring reports from the many sources where effective emissions reductions may not be possible, that the addition of a manufacture only activity qualifier for all PBT chemicals will provide the public with the most accurate information on PBT chemical emissions and the best opportunity to monitor EPCRA section 313-related

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environmental loading of these chemicals.

EPA believes that in order to obtain any reporting on dioxin and dioxin-like compounds a very low threshold is required, which is several orders of magnitude lower than the thresholds for other PBT chemicals. At such a low reporting threshold it is estimated that thousands of reports could potentially be filed by facilities, mainly food processing facilities, due to the amount of dioxins in the raw materials they process. The dioxins found in the meat and dairy products that food processors handle have been previously released, circulated in the environment, and bioaccumulated in animals, thus these are not additional loadings to the environment but loadings that have already occurred and cycled through the environment due to the persistence and bioaccumulative properties of these compounds. The unique combination of very low thresholds, the number of food processors that would be required to file, and the fact that they would be filing because of the bioaccumulation of previously released material led EPA to propose to add only dioxin and dioxin-like compounds that are manufactured. EPA is finalizing the addition of dioxin with a revised qualifier in response to the unique set of conditions that apply to the reporting of dioxin and dioxin-like compounds. EPA proposed and is finalizing the addition of dioxin with a qualifier to reduce reporting burden on facilities, mainly in the food processing industry, that results from the unique combination of circumstances related to the reporting for these chemicals and to focus on those activities that add to the loading of dioxins in the environment rather than on activities dealing with previously released and bioaccumulated chemicals.

EPA did not conclude and does not believe that the manufacturing activity is the only important source of PBT chemical releases to the environment and believes that other activities such as processing or use can result in significant releases of PBT chemicals, including chemicals released to the environment for the first time. As discussed in Unit VI.G., EPA has modified the dioxin qualifier to reflect this. The unique combination of circumstances that exists for dioxin and dioxin-like compounds does not exists for any of the other PBT chemicals being added by this rule. EPA did not conclude that the manufacture qualifier is generally appropriate for other chemicals that are being added and that are ''ubiquitous in the environment.'' The full statement in the proposal was ''These dioxin and dioxin-like compounds are ubiquitous in the environment and thus under the very low reporting thresholds necessary to get reports from any sources (see discussion in Unit VII.A.2.), facilities that process raw materials would be required to report simply because the raw material contains background levels of these chemicals'' (at 64 FR 710). Clearly EPA made this statement in the context of the ''very low reporting thresholds necessary to get reports [for the dioxin and dioxin-like compounds category] from any sources.'' This statement is consistent with the unique combination of circumstances that exists for dioxin and dioxin-like compounds and was not intended to apply to all PBT chemicals.

Neither did EPA conclude that the manufacturing activity is the activity for which facilities would be most likely to be able to make reductions or that EPA's pollution prevention efforts should focus solely on the manufacturing of PBT chemicals. Commenters provided no basis for such a conclusion and EPA believes that processors and users of PBT chemicals also have the opportunity to make effective emissions reductions by using less of a PBT chemical, by not using materials that contain PBT chemicals as contaminants, etc. In addition, the purposes of reporting under EPCRA section 313 are not limited to the collection of information from sources where effective reductions in release and other waste management quantities are possible. Data collected under EPCRA section 313 can serve a variety of information purposes that do not depend on how easy it is for the source to achieve reduction in releases and other waste management. The commenter statement that EPA has acknowledged that many chemicals identified as persistent and bioaccumulative are not imported, processed, or otherwise used, but are manufactured as by-products, is incorrect. The actual statement was: ''[m]any of the chemicals identified as persistent and bioaccumulative in today's action are not imported, processed, or otherwise used but are manufactured as by-products'' (at 64 FR 715). As the words ''today's action'' clearly demonstrate, this statement was not a broad statement about all PBT chemicals but simply an acknowledgment that many of the PBT chemicals in the proposed rule were by-products. In addition, this statement was made in the context of the discussion on the *de minimis* exemption about how removing the exemption for PBT chemicals would affect the chemicals in the proposed rule; it was not a statement made in connection with the discussion on the manufacture only qualifier. EPA also did not state that manufacturing is the primary source for environmental loading of PBT chemicals from facilities covered under EPCRA section 313. The discussion on the loading of chemicals in the environment from manufacturing was in relation to the reporting of dioxin which, as discussed above, presents a unique combination of circumstances that EPA considered to determine how to focus its listing decision and does not apply to all PBT chemicals. EPA disagrees with the statements that data from facilities that import, process, or otherwise use PBT chemicals will be inaccurate and misleading or that such facilities will report some quantity out of fear of enforcement and that such information is likely to be inaccurate, and will not accurately reflect the true level of concern. EPA believes that facilities that import, process, or otherwise use PBT chemicals will be just as able to report as facilities that manufacture PBT chemicals. It is no more difficult to do calculations regarding small numbers than it is to do calculations on larger numbers, so if a facility that imports, processes, or otherwise uses PBT chemicals has information that allows them to make a reasonable estimation of quantities then they should be just as able to report as any manufacturing facility would be able to report on small quantities manufactured as by-products. If facilities that import, process, or otherwise use PBT chemicals do not have data available that allows them to make a reasonable estimation of quantities then they are not required to report. As for fear of enforcement, EPA can take enforcement actions both for under reporting and over reporting so facilities should not report an amount of a PBT chemical in order to avoid an enforcement action.

EPA does not believe that the unique combination of circumstances that exists for dioxin and dioxin-like compounds exists for any of the other PBT chemicals being added by this rule nor does EPA believe that reduced burden or any of the other reasons suggested by the commenters provide a sufficient reason to focus on manufacturing activity only for the other PBT chemicals in this rule. Therefore, EPA does not believe that it is appropriate to add a manufacture only qualifier to any of the other PBT chemicals in this rule.

3. *Waste management issues.* Some commenters contend that because activities such as recycling, approved

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waste disposal, and treatment are incorporated into reported volumes, the EPCRA section 313 reported releases will be substantial overestimates of the actual quantities released to the ambient environment. They further argue that although this information may be useful to source reduction efforts, merging of reporting requirements under section 313 of EPCRA and section 6607 of PPA has resulted in information which is misleading to the public's desire to know the actual exposures that are occurring. Another commenter asserts that by requiring electricity generating facilities to report transfers off-site for treatment and disposal of PCBs from transformers, EPA has established a disincentive to properly dispose of PCB transformers and remove them from use because most PCB wastes transferred to off-site facilities are destroyed in regulated units which destroy at least 99.9999% of the PCBs. They are concerned that because the casual reader may conclude additional releases of PCBs to the environment have occurred, companies would have a disincentive to voluntarily remove PCBs.

The commenters are incorrect in stating that EPCRA section 313 release quantities include recycling and treatment amounts. Under EPCRA section 313, if a chemical activity threshold is met for the chemical, covered facilities are required to report the quantity of the toxic chemical entering each environmental medium; this includes ''releases.'' The definition of release pursuant to EPCRA section 329(8) means:

> any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment (including the abandonment or discarding of barrels, containers, and other closed receptacles) of any hazardous chemical, extremely hazardous substance, or toxic chemical.

There is no language in this definition, any other provision of EPCRA, or in the regulations promulgated pursuant to EPCRA section 313, that limit this definition to ambient releases to the environment which may result in public exposure. In fact the definition specifically includes disposing of toxic chemicals as well as the abandonment of closed receptacles. In addition, neither the statute nor the regulations limit this definition to on-site releases. Therefore, the statutory definition of release under EPCRA section 313 is significantly broader than the commenter seems to believe.

In addition to release reporting, under section 6607(b)(1) of the PPA, if a covered facility meets the reporting thresholds under EPCRA section 313, the facility is required to report the ''quantity of the chemical entering any wastestream (or otherwise released to the environment). . . .'' This quantity includes amounts of the toxic chemical released, treated, and recycled. However, this quantity does not include:

> [t]he amount of any toxic chemical released into the environment which resulted from a catastrophic event, remedial action, or other one time event, *and is not associated with production processes during the reporting year*. (PPA 6607 (b)(7)) (emphasis added)

Therefore, the quantity of the toxic chemical entering the wastestream as collected under section 6607(b)(1) of the PPA, is the amount of the toxic chemical in production related waste. Covered facilities currently report the amount of the toxic chemical in production related waste as quantities of the toxic chemical released, treated, combusted for energy recovery and recycled. These quantities are collected as separate data elements in section 8 of the Form R. Further, facilities report the ultimate disposition of toxic chemicals in waste such that these quantities (i.e., amounts released, treated, combusted for energy recovery, and recycled) are mutually exclusive. Collectively, then, these quantities are the amount entering the waste stream or the quantity of the toxic chemical in production related waste. For example, a covered facility transfers 1,000,000 pounds of PCBs to an incinerator for treatment. The covered facility knows that 999,999 pounds are destroyed in the incinerator and the remaining 1 pound is disposed in a landfill. The facility reports 999,999 pounds as transferred off-site for treatment and 1 pound as transferred off-site for disposal. These two quantities are reported as separate data elements on the Form R. The quantity reported as disposed off-site is considered released because, as explained previously, disposal is a type of release. The entire quantity (1,000,000 pounds) is the amount of production related waste.

Once collected, EPA presents the TRI data to the public in a number of formats. In its annual data release documents, EPA highlights different aspects of the quantities of toxic chemicals released and otherwise managed as waste. For example, EPA presents total on-site releases and, as subsets, presents the quantities released to air, surface water, underground injection and on-site land releases. (See *1997 Toxics Release Inventory* (EPA 745–R–99–003) Figure 2-3 ''TRI On-site Releases'') EPA also presents the quantity of total releases in the public data release. As discussed earlier, under EPCRA section 313, release quantities are not limited to quantities released to the ambient environment. Therefore, total releases, as presented in the public data release include both on and off-site releases as well as a variety of disposal methods. For example, in Table 2-20A of the 1997 public data release, EPA presents TRI on-site and off-site releases by chemical and type of release (e.g., air emissions, underground injection, etc.) (*1997 Toxics Release Inventory*; EPA 745–R–99–003).

In addition to TRI release data, EPA presents production related waste quantities in the public data release. Because production related waste includes releases, EPA includes release quantities with other waste management quantities. However, in this document, the Agency generally distinguishes quantities of the toxic chemical released from other types of waste management. EPA does not count the quantities of toxic chemicals treated, combusted for energy recovery or recycled as quantities released. (See, for example, 1997 Toxics Release Inventory (EPA 745-R-99-003) Table 2-20A ''TRI On-site and Off-site Releases, by Chemical, 1997'' and Table 2-20B ''TRI Chemicals in Waste, by Chemical, 1997'')

Further, EPA does not believe that the TRI program provides a disincentive for the proper and safe handling of PCBs in transformers managed as waste. As explained earlier, covered facilities are required under EPCRA section 313 and section 6607 of the PPA to report quantities of toxic chemicals released or otherwise managed as waste if they meet a chemical activity threshold. Quantities of toxic chemicals sent off-site for treatment are described as such. These transfers are not included as releases. In addition, EPA disagrees that quantities of PCBs sent off-site for treatment will be misunderstood by the public because these quantities are accurately represented in the TRI data base and in the public data release as a separate type of waste management.

Another commenter asserts that the proposed rule will not encourage waste minimization because facilities will not be able to modify process designs to accomodate such minimization simply on the basis of data generated from guidance documents or reasonable estimates. The commenter asserts that although industry has made substantial minimization gains, the technology is not available to treat or remove chemicals of concern from manufactured products or waste (prior to generation) at such low

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concentrations and that any future improvements will be enormously expensive due to the low concentrations that would likely be involved.

EPA disagrees with the commenter. In the preamble to the proposed rule, EPA did not assert that covered facilities will begin performing waste minimization activities as a direct result of this rulemaking. Rather, the Agency stated that the PBT chemical rulemaking will provide data on PBT chemicals to EPA, industry, and the public. For example, several EPA offices have ongoing projects and programs that deal with issues concerning PBT chemicals. EPA has established the PBT planning group which is a coordinating body consisting of representatives from various program offices throughout EPA that are dealing with PBT chemicals. This group has developed a strategy to reduce pollution from PBT chemicals through the application of regulatory and nonregulatory authorities, with a strong emphasis on pollution prevention. The availability of that data, in turn, can allow all parties to identify and track releases of PBT chemicals and monitor the progress of the programs designed to reduce the amount of PBT chemicals entering the environment. The data will also allow EPA and others to design prevention strategies that are focused and effective.

In addition, EPA disagrees with the commenter's last assertion concerning the available technology and its costs. Although there are some processes that might not, at present, be amenable to source reduction in terms of PBT chemicals, some processes may be. For example, it may be possible to stringently control fuel composition, flow times, temperature, and other conditions in order to substantially reduce or even eliminate the incidental manufacture of dioxins during combustion processes. Therefore, EPA continues to believe that in some cases, opportunities for pollution prevention will present themselves resulting from information reported under EPCRA section 313 and section 6607 of the PPA.

4. *Modulated reporting thresholds.* The majority of commenters contend that modulating thresholds for reporting so that lower reporting thresholds are used every other year (with current thresholds used in alternate years) would introduce confusion for the regulated community and data users and would not significantly reduce burden. Further it could discourage facilities from establishing common standard procedures for data collection. Modulation will also result in data gaps, undermining data consistency and tracking. Many commenters believe that annual reporting is a fundamental attribute of TRI.

EPA agrees that modulating the reporting thresholds would introduce confusion for both the regulated community and data users. For data users, EPA believes that modulating the reporting thresholds would limit the usefulness of the TRI data because there would be poor data consistency and poorer data quality. For the regulated community, EPA believes that the burden reduction would not be significant and would possibly be offset by the confusion that would be introduced by different thresholds in alternate years.

VII. What Were the Results of EPA's Economic Analysis?

EPA has prepared an economic analysis of the impact of this action, which is contained in a document entitled *Economic Analysis of the Final Rule to Modify Reporting of Persistent Bioaccumulative Toxic Chemicals under EPCRA Section 313* (Ref. 67). This document is available in the public docket for this rulemaking. The analysis assesses the costs, benefits, and associated impacts of the rule, including potential effects on small entities. The major findings of the analysis are briefly summarized here.

A. What is the Need for the Rule?

Federal regulations exist, in part, to address significant market failures. Markets fail to achieve socially efficient outcomes when differences exist between market values and social values. Two causes of market failure are externalities and information asymmetries. In the case of negative externalities, the actions of one economic entity impose costs on parties that are ''external'' to any market transaction. For example, a facility may release toxic chemicals without accounting for the consequences to other parties, such as the surrounding community, and the prices of that facility's goods or services thus will fail to reflect those costs. The market may also fail to efficiently allocate resources in cases where consumers lack information. For example, where information is insufficient regarding toxic releases, individuals' choices regarding where to live and work may not be the same as if they had more complete information. Since firms ordinarily have little or no incentive to provide information on their releases and other waste management activities involving toxic chemicals, the market fails to allocate society's resources in the most efficient manner.

This rule is intended to address the market failures arising from private choices about PBT chemicals that have societal costs, and the market failures created by the limited information available to the public about the release and other waste management activities involving PBT chemicals. Through the collection and distribution of facility-specific data on toxic chemicals, TRI overcomes firms' lack of incentive to provide certain information, and thereby serves to inform the public of releases and other waste management of PBT chemicals. This information enables individuals to make choices that enhance their overall well-being. Choices made by a more informed public, including consumers, corporate lenders, and communities, may lead firms to internalize into their business decisions at least some of the costs to society relating to their releases and other waste management activities involving PBT chemicals. In addition, by helping to identify areas of concern, set priorities and monitor trends, TRI data can also be used to make more informed decisions regarding the design of more efficient regulations and voluntary programs, which also moves society towards an optimal allocation of resources.

If EPA were not to take this action adding certain PBT chemicals to EPCRA section 313 and lowering reporting thresholds, the market failure (and the associated social costs) resulting from the limited information on the release and other waste management of PBT chemicals would continue. EPA believes that today's action will improve the scope of multi-media data on the release and other waste management of PBT chemicals. This, in turn, will provide information to the public, empower communities to play a meaningful role in environmental decision-making, and improve the quality of environmental decision-making by government officials. In addition, this action will serve to generate information that reporting facilities themselves may find useful in such areas as highlighting opportunities to reduce chemical use or release or other waste management and thereby lower costs of production and/or waste management. EPA believes that these are sound rationales for adding chemicals to the EPCRA section 313 list of toxic chemicals and lowering reporting thresholds for PBT chemicals.

B. What Are the Costs Associated With This Rule?

This action will result in the expenditure of resources that, in the absence of the regulation, could be used

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for other purposes. The cost of the rule is the value of these resources in their best alternative use. Most of the costs of the rule result from requirements on industry. Approximately 11,300 facilities are expected to submit approximately 20,000 additional Form R reports annually. The estimated composition of this reporting, by chemical, is shown in Table 4.

Table 4.—Summary of Chemical Reporting as Estimated for Proposed and Final Rules

Chemical or Chemical Category	Estimated Number of Reports (Annual)	
	Proposed Rule	Final Rule
Alkyl lead (tetraethyl lead and tetramethyl lead)	134	N/A
Benzo(g,h,i)perylene	353	909
Dioxin and dioxin-like compounds category	1,863	1,475
Hexachlorobenzene	778	778
Mercury; mercury compounds category	5,230	5,346
Octachlorostyrene	230	230
Pentachlorobenzene	707	707
Pesticides (aldrin, chlordane, heptachlor, isodrin, methoxychlor, pendimethalin, toxaphene, trifluralin)	264	264
Polycyclic aromatic compounds (PACs) category	4,699	7,166
Polychlorinated biphenyls (PCBs)	2,267	2,310
Tetrabromobisphenol A	150	150
Vanadium; vanadium compounds category	654	655
Total	17,329	19,990

Table 5 displays the industry costs for this action based on the estimated number of facilities affected and the estimated number of additional reports. Aggregate industry costs in the first year for the rule are estimated to be $145 million; in subsequent years they are estimated to be $80 million per year. Industry costs are lower after the first year because facilities will be familiar with the reporting requirements, and many will be able to update or modify information from the previous year's report. EPA is expected to expend $2.0 million in the first year, and $1.6 million in subsequent years as a result of the rule.

Table 5.—Summary of Reporting and Associated Costs as Estimated for Proposed and Final Rules

	Proposed Rule	Final Rule
Number of new facilities	2,600	3,114
Total number of facilities	9,515	11,257
Number of Form Rs submitted	17,329	19,990
First year industry costs	$126 million	$145 million
Subsequent year industry costs	$70 million	$80 million
EPA costs	$1.4 million	$1.6 million

The estimated cost of the final rule differs from the estimated cost of the proposed rule as shown in Table 5. There are six major reasons for this change. First, EPA received new data during the comment period on the concentrations of PACs and benzo(g,h,i)perylene in distillate fuel oil. Since approximately 18,000 manufacturing facilities subject to EPCRA 313 reporting use distillate fuel oil, this change had a significant positive effect on the estimated number of reports for PACs and benzo(g,h,i)perylene as shown in Table 4. Second, the methodology for estimating reporting from facilities in SIC 5171 (Bulk Petroleum Stations and Terminals) was revised to account for the mix of products containing PBT chemicals that are processed at these facilities. This revision also had a positive effect on the estimated number of reports. Third, because facility-level dioxin emission factors for coal- and oil-burning manufacturing facilities have not been developed, the estimated number of reporting facilities was reduced. Fourth, the reporting qualifier for dioxin was changed from

''manufacture only'' to ''manufacturing; and the processing or otherwise use of dioxin and dioxin-like compounds if the dioxin and dioxin-like compounds are present as contaminants in a chemical and if they were created during the manufacturing of that chemical'' in the final rule. This resulted in additional expected reporting from facilities that process or otherwise use chemicals with dioxin impurities. Fifth, the Agency is not lowering EPCRA section 313 reporting thresholds for alkyl leads as part of this rulemaking. Therefore, no additional EPCRA section 313 reporting on alkyl leads is expected at this time. Sixth, the threshold for the PACs category was changed from 10 pounds in the proposed rule to 100 pounds in the final rule.

C. What Are the Benefits of This Rule?

In enacting EPCRA and PPA, Congress recognized the significant benefits of providing the public with information on toxic chemical releases and other waste management practices. EPCRA section 313 has empowered the Federal government, State governments, industry, environmental groups, and the general public to fully participate in an informed dialogue about the environmental impacts of toxic chemicals in the United States. EPCRA section 313's publicly available data base provides quantitative information on toxic chemical releases and other waste management practices. Since the TRI program's inception in 1987, the public, government, and the regulated community have had the ability to understand the magnitude of chemical releases in the United States, and to assess the need to reduce the uses, releases and other waste management of toxic chemicals. TRI enables all interested parties to establish credible baselines, to set realistic goals for environmental progress over time, and to measure progress in meeting these goals over time. The TRI program is a neutral yardstick by which progress can be measured by all stakeholders.

The information reported under EPCRA section 313 increases knowledge of the amount of toxic chemicals released and waste management practices, and thus aids in the evaluation of the potential pathways of exposure, improves scientific understanding of the health and environmental risks of toxic chemicals; allows the public to make informed decisions on where to work and live; enhances the ability of corporate leaders and purchasers to more accurately gauge a facility's potential environmental liabilities; provides reporting facilities with information that can be used to save money as well as reduce emissions; and assists Federal, State, and local authorities in making better decisions on acceptable levels of toxic chemicals in the environment.

There are two types of benefits associated with EPCRA section 313 reporting, those resulting from the actions required by the rule (such as reporting and recordkeeping), and those derived from follow-on activities that are not required by the rule. Benefits of activities required by the rule include the value of improved knowledge about the release and waste management of toxic chemicals, which leads to improvements in understanding, awareness, and decision-making. It is expected that this rule will generate such benefits by providing readily accessible information that otherwise would not be available to the public. The rule will benefit ongoing research efforts to understand the risks posed by PBT chemicals and to evaluate policy strategies that address the risks.

The second type of benefits derive from changes in behavior that may result from the information reported under EPCRA section 313. These changes in behavior, including reductions in releases of and changes in the waste management practices for toxic chemicals may yield health and environmental benefits. These changes in behavior come at some cost, and the net benefits of the follow-on activities are the difference between the benefits of decreased chemical releases and transfers and the costs of the actions needed to achieve the decreases.

Because the state of knowledge about the economics of information is not highly developed, EPA has not attempted to quantify the benefits of adding chemicals to EPCRA section 313 or changing reporting thresholds. Furthermore, because of the inherent uncertainty in the subsequent chain of events, EPA has also not attempted to predict the changes in behavior that result from the information, or the resultant net benefits (i.e., the difference between benefits and costs). EPA does not believe that there are adequate methodologies to make reasonable monetary estimates of either the benefits of the activities required by the rule, or the follow-on activities. The economic analysis of the rule, however, does provide illustrative examples of how the rule will improve the availability of information on PBT chemicals (Ref. 67).

A number of commenters asserted that information on the magnitude of PBT chemical releases that would be reported as a result of this rule is required for EPA and commenters to evaluate the benefit of EPA's proposed alternatives. EPA disagrees with these commenters for the following reasons.

Existing data do not support estimates of releases to multiple environmental media from the full range of facilities that may be affected by the rule because most of the data required for the analysis would only be available after the rule is in place. For most PBT chemicals and industry sectors, up-to-date multi-media release and other waste management estimates for affected facilities do not exist. Even where release estimates are available for an industry sector, most are derived from national activity levels rather than from facility-level information. To the extent that release estimates are available, they tend to cover only a single medium such as air. EPA does not believe that there is sufficient information to make reasonable predictions of the multi-media releases and other waste management information that will be reported as a result of EPCRA section 313 rulemakings.

Some commenters note that EPA has estimated releases of certain PBT chemicals in recent reports such as the Mercury Study Report to Congress (Ref. 65) and the Inventory of Source of Dioxin in the United States (Ref. 73). In fact, EPA reported the results of these reports in its economic analysis for this proposal. These studies do not provide community- or facility-level release estimates. The estimates in these studies are derived using a ''top-down'' methodology in which emission factors are applied to activity levels for entire industries. While having an estimate of multi-media PBT releases for a specific industry sector is a first step, other information would also be required to estimate the releases that would be reported as a result of each proposed alternative. Assuming that multi-media release estimates were available for an entire industry sector, these releases would still have to be divided among individual facilities according to some currently unknown distribution. In addition, there is the complication that EPCRA section 313 reporting thresholds are based on chemical throughput (manufacture, process, or use) rather than chemical release. The relationship between a chemical throughput that triggers the submission of a report, and the releases reported will vary in some currently unknown manner among industries, as well as among facilities within an industry.

Therefore, EPA does not believe that there is sufficient information to make reliable release estimates for this rule, when considering all the affected chemicals and industries. The

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uncertainties in the estimated values that go into such a calculation make predictions of facility level reporting extremely imprecise. Historical attempts to estimate the releases expected to be reported under EPCRA section 313 would have been imprecise to the point of being misleading, particularly in respect to estimates of releases per report or per facility (which some commenters have suggested that EPA should make). Further information on the feasibility of *ex ante* release estimates is available in the Response to Comments document (Ref. 69).

Aside from the general issue of uncertainty in the estimates of aggregate releases, predictions of releases per facility or per report (or dollars of reporting cost per pound of releases reported) are likely to be misleading due to the biases built into the estimates. The predicted number of reports (and thus costs) is generally an overestimate, since EPA's economic analyses use conservative estimates to avoid underestimating true costs. On the other hand, predictions of releases will tend to underestimate emissions, because while there may be information available on releases of some chemicals from some sectors, such estimates will not include other sources where releases are not identified until more detailed data (such as TRI data) are collected. Combining the two sets of estimates compounds the problem. Since estimated pounds of releases are underestimated and reports are overestimated, pounds per report would be biased significantly downward. Likewise, estimates of dollars of reporting cost per pound of releases (which varies as the inverse of pounds per report) would be biased significantly upward.

EPA notes that there were various reports and studies about air emissions of toxic chemicals prior to EPCRA section 313, but the collection of facility-level data provided significant new information on releases as well as other waste management. EPA cannot predict, at this stage, the quantity of releases and other waste management that will be reported as the result of this action any more accurately than it could have predicted when it proposed the original EPCRA section 313 rule.

Aside from the issue of whether EPA can predict releases and other waste management quantities prior to TRI reporting, EPA notes that pounds of releases (even if known) are not a reasonable proxy for the benefits of the information being provided. This is because the benefits of an informational regulation are not a linear function of the magnitude of the information being reported. EPA disagrees with the implicit assumption by commenters that the benefits of information from different facilities is strictly and systematically related to the quantity reported as being released. Calculations such as the commenters have suggested presume that the benefit to the public of knowing about a release of 20,000 pounds is twice as large as the benefit of knowing about a release of 10,000 pounds; and that the benefit of knowing about a 40,000 pound release is twice the benefit of knowing about a 20,000 pound release and four times the benefit of knowing about a 10,000 pound release. EPA does not believe this characterization to be accurate.

One of the central purposes of TRI data is to inform the public about releases and other waste management of EPCRA section 313 listed toxic chemicals in their community so that the public can form its own conclusions about risks. The amount of releases and waste management quantities that a community may find relevant or useful will vary depending on numerous factors specific to that community, such as the toxicity of the various chemicals, potential exposure to these toxic chemicals, and the number of other facilities in the area that release EPCRA section 313 listed toxic chemicals. Section 313(h) of EPCRA states that the data are ''to inform persons about releases of toxic chemicals to the environment; to assist governmental agencies, researchers, and other persons in the conduct of research and data gathering; to aid in the development of appropriate regulations, guidelines, and standards; and for other similar purposes'' (See Unit VI.E. for a more detailed discussion on the purposes of EPCRA section 313). Pounds of releases reported does not measure how the data perform these functions, and thus is not a measure of benefits.

Finally, EPA notes that commenters on this rule did not provide information on approaches or methodologies for estimating releases and/or throughput, or on estimating releases from throughput data, for the spectrum of industries, chemicals, and facilities covered by the rule. Instead, some commenters submitted data from EPA studies (that EPA had already reviewed in the context of this rule and used as references for the economic analysis of the proposed rule) for very narrow slices of the regulated universe (for example, estimated mercury releases from electric utilities or estimated dioxin releases from the vinyl industry). EPA considered these data and determined that they are not sufficient to predict the releases and/or throughput that will be reported as a result of this rule. Other commenters simply stated that EPA should consider releases without referencing any data. None of the commenters suggested new methodologies or approaches, or provided information from any sources that EPA had not already reviewed and considered. As a result, EPA continues to conclude that while there are data available to estimate national releases for some chemicals for some sectors, comprehensive, reliable data for all sectors and chemicals are unavailable, resulting in an incomplete data set. Furthermore, as stated previously, the quantity of releases reported are not a measure of the benefits of the rule. EPA does not believe that inaccurate or incomplete estimates of releases would aid the decision-making process for the rule. Therefore, EPA has not estimated the releases that would be reported as a result of the rule.

D. What are the Potential Impacts on Small Entities?

In accordance with the Regulatory Flexibility Act (RFA) and the Agency's longstanding policy of always considering whether there may be a potential for adverse impacts on small entities, the Agency has evaluated the potential impacts of this rule on small entities. The Agency's analysis of potentially adverse economic impacts is included in the Economic Analysis for this rule (Ref. 67). The following is a brief overview of EPA's findings.

1. *Overall methodology*. This rule may affect both small businesses and small governments. For the purpose of its analysis for the rule, EPA defined a small business using the small business size standards established by the Small Business Administration (SBA) at 13 CFR part 121. EPA defined small governments using the RFA definition of jurisdictions with a population of less than 50,000. No small organizations are expected to be affected by the rule.

Only those small entities that are expected to submit at least one report are considered to be affected for the purpose of the small entity analysis, although EPA recognizes that other small entities will conduct compliance determinations under lower thresholds. The number of affected entities will be smaller than the number of affected facilities, because many entities operate more than one facility. Impacts were calculated for both the first year of reporting and subsequent years. First year costs are typically higher than continuing costs because firms must familiarize themselves with the requirements. Once firms have become familiar with how the reporting

requirements apply to their operations, costs fall. EPA believes that subsequent year impacts present the best measure to judge the impact on small entities because these continuing costs are more representative of the costs firms face to comply with the rule.

EPA analyzed the potential cost impact of the rule on small businesses and governments for the manufacturing sector and in each of the recently added industry sectors separately in order to obtain the most accurate assessment for each. EPA then aggregated the analyses for the purpose of determining whether it could certify that the rule will not, if promulgated, have a ''significant economic impact on a substantial number of small entities.'' RFA section 605(b) provides an exemption from the requirement to prepare a regulatory flexibility analysis for a rule where an agency makes and supports the certification statement quoted above. EPA believes that the statutory test for certifying a rule and the statutory consequences of not certifying a rule all indicate that certification determinations may be based on an aggregated analysis of the rule's impact on all of the small entities subject to it.

2. *Small businesses*. EPA used annual compliance costs as a percentage of annual company sales to assess the potential impacts on small businesses of this rule. EPA believes that this is a good measure of a firm's ability to afford the costs attributable to a regulatory requirement, because comparing compliance costs to revenues provides a reasonable indication of the magnitude of the regulatory burden relative to a commonly available measure of a company's business volume. Where regulatory costs represent a small fraction of a typical firm's revenue (for example, less than 1%, but not greater than 3%), EPA believes that the financial impacts of the regulation may be considered not significant. As discussed above, EPA also believes that it is appropriate to apply this measure to subsequent year impacts.

Based on its estimates of additional reporting as a result of the rule, the Agency estimates that approximately 6,300 businesses will be affected by the rule, and that approximately 4,400 of these businesses are classified as small based on the applicable SBA size standards. For the first reporting year, EPA estimates that approximately 17 small businesses may bear compliance costs between 1% and 3% of revenues, and that no small businesses will bear costs greater than 3%. In subsequent years, EPA estimates that approximately 5 small businesses may bear compliance costs between 1% and 3% of revenues, and that no small businesses will bear costs greater than 3%. As stated above, EPA believes that subsequent-year impacts are the appropriate measure of small business impacts.

3. *Small governments*. To assess the potential impacts on small governments, EPA used annual compliance costs as a percentage of annual government revenues to measure potential impacts. Similar to the methodology for small businesses, this measure was used because EPA believes it provides a reasonable indication of the magnitude of the regulatory burden relative to a government's ability to pay for the costs, and is based on readily available data.

EPA estimates that 39 municipalities operate 49 publicly owned electric utility facilities. Of these facilities, 44 are expected to file additional reports as a result of this action. Of these affected facilities, 15 are operated by 15 small governments (i.e., those with populations under 50,000). It is estimated that none of these small governments will bear annual costs greater than 1% of annual government revenues.

4. *All small entities*. As discussed above, approximately 5 small businesses are expected to bear annual costs between 1% and 3% of annual revenues after the first year of reporting. None of the affected small governments are estimated to bear annual costs greater than 1% of annual revenues. No small organizations are expected to be affected by the rule. Thus, the total number of small entities with impacts above 1% of revenues does not change when the results are aggregated for all small entities (i.e., small businesses, small governments, and small organizations).

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IX. Which Regulatory Assessment Requirements Apply to This Action?

A. What is the Determination under Executive Order 12866

Under Executive Order 12866, entitled *Regulatory Planning and Review* (58 FR 51735, October 4, 1993), this is an economically ''significant regulatory action'' because it is likely to have an annual effect of $100 million or more. This action was submitted to the Office of Management and Budget (OMB) for review, and any substantive comments or changes made during that review have been documented in the public version of the official record.

EPA has prepared an economic analysis of the impact of this action, which is contained in a document entitled *Economic Analysis of the Final Rule to Modify Reporting of Persistent Bioaccumulative Toxic Chemicals under EPCRA Section 313* (Ref. 67). This document is available as a part of the public version of the official record for this action (instructions for accessing this document are contained in Unit I.B.) and is discussed in Unit VII.

B. What is the Determination under the Regulatory Flexibility Act?

Pursuant to section 605(b) of the Regulatory Flexibility Act (RFA) (5 U.S.C. 601 *et seq.*), the EPA Administrator hereby certifies that this final rule will not have a significant economic impact on a substantial number of small entities. The factual basis for this determination is presented in the small entity impact analysis prepared as part of the Economic Analysis for this final rule (Ref. 67), which is also discussed in detail in Unit VII. and contained in the public version of the official record for this rule. The following is a brief summary of the Agency's factual basis for this certification.

For the purpose of analyzing potential impacts on small entities, EPA used the RFA definition of small entities in section 601(6) of the RFA. Under this section, small entities include small governments, small non-profit organizations, and small businesses. No small organizations are expected to be affected by this final rule. EPA defined small governments using the RFA definition of jurisdictions with a population of less than 50,000, and defined a small business using the small business size standards established by the Small Business Administration (SBA), which are generally based on the number of employees or annual sales/revenue a business in a particular industrial sector has.

Based on EPA's economic analysis, approximately 11,300 facilities are expected to submit approximately 20,000 additional Form R reports annually. Of these facilities, approximately 3,100 are expected to file TRI reports for the first time as a result of today's action. EPA estimates that the cost for collecting this information averages $5,079 per Form R in the first reporting year, and $3,557 in subsequent years. EPA estimates that there are 15 small governments that may be affected by the rule (i.e., EPA analysis estimates that these entities may have to file one or more reports under the final rule). EPA estimates that none of these small governments will bear annual costs greater than 1% of annual government revenues. EPA estimates that 5 small businesses of the approximately 4,400 small businesses potentially affected by the rule will experience annual compliance costs between 1% and 3% of annual sales after the first year of reporting. Given the relatively small estimated impacts on small entities, EPA believes that the rule will not have a significant economic impact on a substantial number of small entities. This determination is for the entire population of small entities potentially affected by this rule, since the test for certification is whether the rule as a whole has a significant economic impact on a substantial number of small entities.

Notwithstanding the Agency's certification of this rule under section 605(b) of the RFA, EPA remains committed to minimizing real impacts

on small entities where this does not unacceptably compromise the informational benefits of the rule. Although not required, EPA intends to prepare guidance for reporting on dioxin that will assist facilities in determining their compliance needs and in properly completing the form, which will help ensure that small entities receive assistance to ease their burden of compliance. EPA has prepared such documents for current reporters and has received positive feedback on their utility from the targeted facilities. In addition, the Agency is always interested in any comments regarding the economic impacts that this regulatory action would impose on small entities, particularly suggestions for minimizing that impact. Such comments may be submitted to the Agency at any time, to the address listed in Unit I.B.

Information relating to this determination has been provided to the Chief Counsel for Advocacy of the Small Business Administration, and is included in the public version of the official record for this rulemaking.

C. What is the Determination under the Paperwork Reduction Act?

The information collection requirements contained in this final rule have been submitted to OMB under the Paperwork Reduction Act (PRA), 44 U.S.C. 3501 *et seq*., and in accordance with the procedures at 5 CFR 1320.11. OMB has approved the existing reporting and recordkeeping requirements EPA Toxic Chemical Release Inventory Form R (EPA Form No. 9350-1), supplier notification, and petitions under OMB Control No. 2070–0093 (EPA ICR No. 1363). An Information Collection Request (ICR) document has been prepared by EPA (EPA ICR No. 1363.10) to amend the existing ICR to include the burden associated with the lower reporting thresholds, and a copy may be obtained from Sandy Farmer, Office of Information Collections (OIC); U.S. Environmental Protection Agency (2137), 401 M St., SW., Washington, DC 20460, by calling (202) 260–2740, or electronically by sending an e-mail message to ''farmer.sandy@epa.gov.'' An electronic copy has also been posted with this **Federal Register** document on EPA's Homepage with other information related to this action as described in Unit I.B., and may also be downloaded from the Internet at http://www.epa.gov.icr/.

An Agency may not conduct or sponsor, and a person is not required to respond to a collection of information subject to OMB approval under the PRA unless it displays a currently valid OMB control number. The OMB control numbers for EPA's regulations, after initial publication in the **Federal Register**, are maintained in a list at 40 CFR part 9. The information requirements contained in this final rule are not effective until OMB approves them.

EPCRA section 313 requires owners or operators of certain facilities manufacturing, processing, or otherwise using any of over 600 listed toxic chemicals and chemical categories in excess of the applicable threshold quantities, and meeting certain requirements (i.e., at least 10 Full Time Employees or the equivalent), to report environmental on-site releases and transfers off-site for release and treatment. Under section 6607 of the PPA, facilities must also provide information on the quantities of the toxic chemicals in certain waste streams, and the efforts made to manage those waste quantities. The regulations codifying the EPCRA section 313 reporting requirements appear at 40 CFR part 372. Respondents may designate the specific chemical identity of a substance as a trade secret, pursuant to EPCRA section 322 (42 U.S.C. 11042). Regulations codifying the trade secret provisions can be found at 40 CFR part 350. Under the final rule, all facilities reporting under EPCRA section 313 on PBT chemicals would have to use the Form R (EPA Form No. 9350-1), which is currently approved by OMB.

For Form R, EPA estimates the industry reporting burden for collecting this information (including recordkeeping) to average 74 hours per report in the first year, at an estimated cost of $5,079 per Form R. In subsequent years, the burden is estimated to average 52.1 hours per report, at an estimated cost of $3,557 per Form R. These estimates include the time needed to review instructions; search existing data sources; gather and maintain the data needed; complete and review the collection of information; and transmit or otherwise disclose the information. The actual burden on any specific facility may be different from this estimate depending on the complexity of the facility's operations and the profile of the releases at the facility.

This final rule is estimated to result in reports from 11,300 respondents. Of these, 3,100 facilities are estimated to be reporting under EPCRA section 313 for the first time as a result of the rule, while 8,200 are currently reporting facilities that will be submitting additional reports. These facilities will submit an estimated additional 20,000 Form Rs. This rule therefore results in an estimated total burden of 2.1 million hours in the first year, and 1.2 million hours in subsequent years, at a total estimated industry cost of $145 million in the first year and $80 million in subsequent years. The existing ICR will be amended to include an additional annual burden of 1.5 million hours (annual average burden for the first 3 years of ICR approval).

Under the PRA, ''burden'' means the total time, effort, or financial resources expended by persons to generate, maintain, retain, or disclose or provide information to or for a Federal agency. This includes, where applicable, the time needed to review instructions; develop, acquire, install, and utilize technology and systems for the purposes of collecting, validating, and verifying information, processing and maintaining information, and disclosing and providing information; adjust the existing ways to comply with any previously applicable instructions and requirements; train personnel to be able to respond to a collection of information; search data sources; complete and review the collection of information; and transmit or otherwise disclose the information. EPA's burden estimates for the rule take into account all of the above elements, considering that under section 313, no additional measurement or monitoring may be imposed for purposes of reporting.

D. What are the Determinations under the Unfunded Mandates Reform Act and Executive Orders 12875 and 13084?

Pursuant to Title II of the Unfunded Mandates Reform Act of 1995 (UMRA) (Public Law 104–4), EPA has determined that this action contains a Federal mandate that may result in expenditures of $100 million or more for the private sector in any 1 year, but that it will not result in such expenditures for State, local, and tribal governments, in the aggregate. Accordingly, EPA has prepared a written statement for this rule pursuant to section 202 of UMRA, and that statement is available in the public version of the official record for this rulemaking (Ref. 71a). The costs associated with this action are estimated in the economic analysis prepared for this rule (Ref. 67), which is also included in the public version of the official record and summarized in Unit VII. The following is a brief summary of the UMRA statement for the rule.

This rule is being promulgated pursuant to sections 313(d)(1) and (2), 313(f)(2), 313(g), 313(h), and 328 of EPCRA, 42 U.S.C. 11023(d)(1)–(2), 11023(f)(2), 11023(g), 11023(h) and

11048; PPA section 6607, 42 U.S.C. 13106. The economic analysis contains an analysis of the benefits and costs of this rule, which estimates that the total industry costs of the rule will be $145 million in the first year and $80 million per year thereafter, and concludes that the benefits will be significant but cannot be assigned a dollar value due to the lack of adequate methodologies. EPA believes that the benefits provided by the information to be reported under this rule will significantly outweigh the costs imposed by today's action. The benefits of the information will in turn have positive effects on health, safety, and the natural environment through the behavioral changes that may result from that information.

EPA has not identified any Federal financial resources that are available to cover the costs of this rule. As set forth in the economic analysis, EPA has estimated the future industry compliance costs (after the first year) of this rule to be $80 million annually. Of those entities affected by today's action, EPA has not identified any disproportionate budgetary impact on any particular region, government, or community, or on any segment of the private sector. Based on the economic analysis, EPA has concluded that it is highly unlikely that this rule will have an appreciable effect on the national economy.

EPA has determined that it is not required to develop a small government agency plan as specified by section 203 of UMRA or to conduct prior consultation with State, local, or tribal governments under section 204 of UMRA, because the rule will not significantly or uniquely affect small governments and does not contain a significant Federal intergovernmental mandate.

Finally, EPA believes this rule complies with section 205(a) of UMRA. The objective of this rule is to expand the public benefits of the TRI program by exercising EPA's discretionary authority to add chemicals to the program and to lower reporting thresholds, thereby increasing the amount of information available to the public regarding the use, management, and disposition of PBT chemicals and enabling a more comprehensive view of PBT chemical exposures. In making additional information available through TRI, the Agency increases the utility of TRI data as an effective tool for empowering local communities, the public sector, industry, other agencies, and State and local governments to better evaluate risks to public health and the environment.

As described in Unit IV.D., EPA considered burden in the threshold selection. Existing burden-reducing measures (e.g., the laboratory exemption and the otherwise use exemptions, which include the routine janitorial or facility grounds maintenance exemption, motor vehicle maintenance exemption, structural component exemption, intake air and water exemption and the personal use exemption) will continue to apply to the facilities that file new reports as a result of this rule. EPA also will be assisting small entities subject to the rule, by such means as providing meetings, training, and compliance guides in the future, which also will ease the burdens of compliance. Many steps have been and will be taken to further reduce the burden associated with this rule, and to EPA's knowledge there is no available alternative to the rule that would obtain the equivalent information in a less burdensome manner. For all of these reasons, EPA believes the rule complies with UMRA section 205(a).

In addition, today's rule does not create an unfunded Federal mandate on State, local or tribal governments, nor does it significantly or uniquely affect the communities of Indian tribal governments. Accordingly, the requirements of section 1(a) of Executive Order 12875, entitled *Enhancing the Intergovernmental Partnership* (58 FR 58093, October 28, 1993), and section 3(b) of Executive Order 13084, entitled *Consultation and Coordination with Indian Tribal Governments* (63 FR 27655, May 19, 1998), do not apply to this proposed rule.

E. What are the Determinations under Executive Orders 12898 and 13045?

Pursuant to Executive Order 12898, entitled *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations* (59 FR 7629, February 16, 1994), the Agency must consider environmental justice related issues with regard to the potential impacts of this action on environmental and health conditions in low-income populations and minority populations. Pursuant to Executive Order 13045, entitled *Protection of Children from Environmental Health Risks and Safety Risks* (62 FR 19885, April 23, 1997), if an action is economically significant under Executive Order 12866, the Agency must, to the extent permitted by law and consistent with the Agency's mission, identify and assess the environmental health risks and safety risks that may disproportionately affect children.

By lowering the section 313 reporting thresholds for PBT chemicals, EPA will provide communities across the United States (including low-income populations and minority populations) with access to data that may assist them in lowering exposures and consequently reducing chemical risks for themselves and their children. This information can also be used by government agencies and others to identify potential problems, set priorities, and take appropriate steps to reduce any potential risks to human health and the environment. Therefore, the informational benefits of the rule will have a positive impact on the human health and environmental impacts of minority populations, low-income populations, and children.

F. What are the Determinations under Executive Orders 13132 and 12612?

On August 4, 1999, President Clinton issued a new executive order on federalism, Executive Order 13132, entitled *Federalism* (64 FR 43255, August 10, 1999), which will take effect on November 2, 1999. In the interim, the current Executive Order 12612, entitled *Federalism* (52 FR 41685, October 30, 1987) still applies. This action is expected to have a limited impact on municipal governments which operate electric utilities. EPA estimates that 39 municipalities operate 49 publicly owned electric utility facilities. Of these facilities, 44 are expected to file additional reports as a result of this action. Therefore EPA concludes that this rule will not have a substantial direct effect on States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government, as specified in Executive Order 12612.

G. What are the Determinations under the National Technology Transfer and Advancement Act?

Section 12(d) of the National Technology Transfer and Advancement Act of 1995 (NTTAA) (15 U.S.C. 272 note) directs EPA to use voluntary consensus standards in its regulatory activities unless doing so would be inconsistent with applicable law or impractical. Voluntary consensus standards are technical standards (e.g., materials specifications, test methods, sampling procedures, etc.) that are developed or adopted by voluntary consensus standards bodies. The NTTAA directs EPA to provide Congress, through OMB, explanations when the Agency decides not to use

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available and applicable voluntary consensus standards.

This action does not involve technical standards, nor did EPA consider the use of any voluntary consensus standards. In general, EPCRA does not prescribe technical standards to be used for threshold determinations or completion of EPCRA section 313 reports. EPCRA section 313(g)(2) states that ''In order to provide the information required under this section, the owner or operator of a facility may use readily available data (including monitoring data) collected pursuant to other provisions of law, or, where such data are not readily available, reasonable estimates of the amounts involved. Nothing in this section requires the monitoring or measurement of the quantities, concentration, or frequency of any toxic chemical released into the environment beyond that monitoring and measurement required under other provisions of law or regulation.''

H. What are the Determinations under the Congressional Review Act?

The Congressional Review Act, 5 U.S.C. 801 *et seq.*, as added by the Small Business Regulatory Enforcement Fairness Act of 1996, generally provides that before a rule may take effect, the agency promulgating the rule must submit a rule report, which includes a copy of the rule, to each House of the Congress and to the Comptroller General of the United States. EPA will submit a report containing this rule and other required information to the U.S. Senate, the U.S. House of Representatives, and the Comptroller General of the United States prior to publication of the rule in the **Federal Register**. A major rule cannot take effect until 60 days after it is published in the **Federal Register**. This action is a ''major rule'' as defined by 5 U.S.C. 804(2). This rule will be effective December 31, 1999.

List of Subjects in 40 CFR Part 372

Environmental protection, Community right-to-know, Hazardous substances, Intergovernmental relations, Reporting and recordkeeping requirements, Superfund.

Dated: October 25, 1999.

Carol M. Browner,

Administrator.

Therefore, 40 CFR part 372 is amended as follows:

PART 372—[AMENDED]

1. The authority citation for part 372 continues to read as follows:

Authority: 42 U.S.C. 11023 and 11048.

§ 372.22 [Amended]

2. In § 372.22(c), remove the phrase ''§ 372.25 or § 372.27.'' and add in its place ''§ 372.25, § 372.27, or § 372.28.''.

§ 372.25 [Amended]

3. Section 372.25 is amended as follows:

i. In the introductory text of § 372.25, remove the first clause ''Except as provided in § 372.27,'' and add in its place ''Except as provided in §§ 372.27 and 372.28,''.

ii. In paragraphs (f), (g), and (h), remove the reference ''§ 372.25'' and add in its place ''§ 372.25, § 372.27, or § 372.28''.

4. In § 372.27, add a new paragraph (e) to read as follows:

§ 372.27 Alternate threshold and certification.

* * * * *

(e) The provisions of this section do not apply to any chemicals listed in § 372.28.

5. Add a new § 372.28 to subpart B to read as follows:

§ 372.28 Lower thresholds for chemicals of special concern.

(a) Notwithstanding § 372.25 or § 372.27, for the toxic chemicals set forth in this section, the threshold amounts for manufacturing (including importing), processing, and otherwise using such toxic chemicals are as set forth in this section.

(1) Chemical listing in alphabetic order.

Chemical name	CAS No.	Reporting threshold
Aldrin	00309–00–2	100
Benzo(g,h,i)perylene	00191–24–2	10
Chlordane	00057–74–9	10
Heptachlor	00076–44–8	10
Hexachlorobenzene	00118–74–1	10
Isodrin	00465–73–6	10
Mercury	07439–97–6	10
Methoxychlor	00072–43–5	100
Octachlorostyrene	29082–74–4	10
Pendimethalin	40487–42–1	100
Pentachlorobenzene	00608–93–5	10
Polychlorinated biphenyl (PCBs)	01336–36–3	10
Tetrabromobisphenol A	00079–94–7	100
Toxaphene	08001–35–2	10
Trifluralin	01582–09–8	100

(2) Chemical categories in alphabetic order.

Category name	Reporting threshold
Dioxin and dioxin-like compounds (Manufacturing; and the processing or otherwise use of dioxin and dioxin-like compounds if the dioxin and dioxin-like compounds are present as contaminants in a chemical and if they were created during the manufacturing of that chemical) (This category includes only those chemicals listed below).	0.1 grams
67562–39–4 1,2,3,4,6,7,8-Heptachlorodibenzofuran	

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Category name		Reporting threshold
55673–89–7	1,2,3,4,7,8,9-Heptachlorodibenzofuran	
70648–26–9	1,2,3,4,7,8-Hexachlorodibenzofuran	
57117–44–9	1,2,3,6,7,8-Hexachlorodibenzofuran	
72918–21–9	1,2,3,7,8,9-Hexachlorodibenzofuran	
60851–34–5	2,3,4,6,7,8-Hexachlorodibenzofuran	
39227–28–6	1,2,3,4,7,8-Hexachlorodibenzo-*p*-dioxin	
57653–85–7	1,2,3,6,7,8-Hexachlorodibenzo-*p*-dioxin	
19408–74–3	1,2,3,7,8,9-Hexachlorodibenzo-*p*-dioxin	
35822–46–9	1,2,3,4,6,7,8-Heptachlorodibenzo-*p*-dioxin	
39001–02–0	1,2,3,4,6,7,8,9-Octachlorodibenzofuran	
03268–87–9	1,2,3,4,6,7,8,9-Octachlorodibenzo-*p*-dioxin	
57117–41–6	1,2,3,7,8-Pentachlorodibenzofuran	
57117–31–4	2,3,4,7,8-Pentachlorodibenzofuran	
40321–76–4	1,2,3,7,8-Pentachlorodibenzo-*p*-dioxin	
51207–31–9	2,3,7,8-Tetrachlorodibenzofuran	
01746–01–6	2,3,7,8 Tetrachlorodibenzo-*p*-dioxin	
Mercury compounds		10
Polycyclic aromatic compounds (PACs) (This category includes only those chemicals listed below).		100
00056–55–3	Benz(a)anthracene	
00205–99–2	Benzo(b)fluoranthene	
00205–82–3	Benzo(j)fluoranthene	
00207–08–9	Benzo(k)fluoranthene	
00206–44–0	Benzo(j,k)fluorene	
00189–55–9	Benzo(r,s,t)pentaphene	
00218–01–9	Benzo(a)phenanthrene	
00050–32–8	Benzo(a)pyrene	
00226–36–8	Dibenz(a,h)acridine	
00224–42–0	Dibenz(a,j)acridine	
00053–70–3	Dibenzo(a,h)anthracene	
00194–59–2	7H-Dibenzo(c,g)carbazole	
05385–75–1	Dibenzo(a,e)fluoranthene	
00192–65–4	Dibenzo(a,e)pyrene	
00189–64–0	Dibenzo(a,h)pyrene	
00191–30–0	Dibenzo(a,l)pyrene	
00057–97–6	7,12-Dimethylbenz(a)anthracene	
00193–39–5	Indeno[1,2,3-cd]pyrene	
00056–49–5	3-Methylcholanthrene	
03697–24–3	5-Methylchrysene	
05522–43–0	1-Nitropyrene	

(b) The threshold determination provisions under § 372.25(c) through (h) and the exemptions under § 372.38(b) through (h) are applicable to the toxic chemicals listed in paragraph (a) of this section.

§ 372.30 [Amended]

6. Section 372.30 is amended as follows:

i. In paragraph (a), remove the phrase ''in § 372.25 at'' and add in its place ''in § 372.25, § 372.27, or § 372.28 at''.

ii. In paragraphs (b)(1), the introductory text of (b)(3), (b)(3)(i), and (b)(3)(iv), remove the reference ''§ 372.25'' and add in its place ''§ 372.25, § 372.27, or § 372.28''.

§ 372.38 [Amended]

7. Section 372.38 is amended as follows:

i. In paragraph (a), add the following sentence at the end of the paragraph to read as follows: ''This exemption does not apply to toxic chemicals listed in § 372.28, except for purposes of § 372.45(d)(1).''.

ii. In paragraphs (b), (c) introductory text, (d) introductory text, and (f), remove the reference ''§ 372.25'' and add in its place ''§ 372.25, § 372.27, or § 372.28''.

iii. In paragraphs (g) and (h), remove the phrase ''§ 372.25 or § 372.27'' and add in its place ''§ 372.25, § 372.27, or § 372.28''.

8. Section 372.65 is amended as follows:

i. In the table in paragraph (a), revise the entry for ''Vanadium'' and alphabetically add four chemicals.

ii. In the table in paragraph (b), revise the CAS no. entry ''7440–62–2'' and add four chemicals in numerical CAS no. sequence.

iii. In the table in paragraph (c), alphabetically add two categories, ''dioxin and dioxin-like compounds'' and ''vanadium'', and alphabetically add two chemicals, ''benzo(j,k)fluorene'' and ''3-methylcholanthrene'', under the polycyclic aromatic compounds (PACs) category.

The revisions and additions read as follows:

§ 372.65 Chemicals and chemical categories to which the part applies.

* * * * *

(a) * * *

Chemical name	CAS No.	Effective date
* * * *	* * *	
Benzo(g,h,i)perylene	00191–24–2	1/00
* * * *	* * *	
Octachlorostyrene	29082–74–4	1/00
* * * *	* * *	
Pentachlorobenzene	00608–93–5	1/00
* * * *	* * *	
Tetrabromobisphenol A	00079–94–7	1/00
* * * *	* * *	
Vanadium (except when contained in an alloy)	7440–62–2	1/00
* * * *	* * *	

(b) * * *

CAS No.	Chemical name	Effective date
* * * * * * *		
7440–62–2	Vanadium (except when contained in an alloy)	1/00
* * * * * * *		
00079–94–7	Tetrabromobisphenol A	1/00
00191–24–2	Benzo(g,h,i)perylene	1/00
00608–93–5	Pentachlorobenzene	1/00
* * * * * * *		
29082–74–4	Octachlorostyrene	1/00
* * * * * * *		

(c) * * *

Category name	Effective date
* * * * * * *	
Dioxin and dioxin-like compounds (Manufacturing; and the processing or otherwise use of dioxin and dioxin-like compounds if the dioxin and dioxin-like compounds are present as contaminants in a chemical and if they were created during the manufacturing of that chemical)	
(This category includes only those chemicals listed below)	1/00
67562–39–4 1,2,3,4,6,7,8-Heptachlorodibenzofuran	
55673–89–7 1,2,3,4,7,8,9-Heptachlorodibenzofuran	
70648–26–9 1,2,3,4,7,8-Hexachlorodibenzofuran	
57117–44–9 1,2,3,6,7,8-Hexachlorodibenzofuran	
72918–21–9 1,2,3,7,8,9-Hexachlorodibenzofuran	
60851–34–5 2,3,4,6,7,8-Hexachlorodibenzofuran	
39227–28–6 1,2,3,4,7,8-Hexachlorodibenzo-*p*-dioxin	
57653–85–7 1,2,3,6,7,8-Hexachlorodibenzo-*p*-dioxin	
19408–74–3 1,2,3,7,8,9-Hexachlorodibenzo-*p*-dioxin	
35822–46–9 1,2,3,4,6,7,8-Heptachlorodibenzo-*p*-dioxin	
39001–02–0 1,2,3,4,6,7,8,9-Octachlorodibenzofuran	
03268–87–9 1,2,3,4,6,7,8,9-Octachlorodibenzo-*p*-dioxin	
57117–41–6 1,2,3,7,8-Pentachlorodibenzofuran	
57117–31–4 2,3,4,7,8-Pentachlorodibenzofuran	
40321–76–4 1,2,3,7,8-Pentachlorodibenzo-*p*-dioxin	
51207–31–9 2,3,7,8-Tetrachlorodibenzofuran	
01746–01–6 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin	

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Category name		Effective date
* * * * * * *		
Polycyclic aromatic compounds (PACs): This category includes only those chemicals listed below).		
* * * * * * *		
00206–44–0	Benzo(j,k)fluorene	1/00
* * * * * * *		
00056–49–5	3-Methylcholanthrene	1/00
* * * * * * *		
Vanadium compounds		1/00

9. In § 372.85, revise the introductory text of paragraph (b)(15)(i), add a new paragraph (b)(15)(ii), and revise paragraphs (b)(16)(i)(B) and (b)(16)(ii)(B) to read as follows:

§ 372.85 Toxic chemical release reporting form and instructions.

* * * * *

(b) * * *

(15) * * *

(i) An estimate of total releases in pounds (except for dioxin and dioxin-like compounds, which shall be reported in grams) per year (releases of less than 1,000 pounds per year may be indicated in ranges, except for chemicals set forth in § 372.28) from the facility plus an indication of the basis of estimate for the following:

* * * * *

(ii) Report a distribution of the chemicals included in the dioxin and dioxin-like compounds category. Such distribution shall either represent the distribution of the total quantity of dioxin and dioxin-like compounds released to all media from the facility; or its one best media-specific distribution.

(16) * * *

(i) * * *

(B) An estimate of the amount of the chemical transferred in pounds (except for dioxin and dioxin-like compounds, which shall be reported in grams) per year (transfers of less than 1,000 pounds per year may be indicated as a range, except for chemicals set forth in § 372.28) and an indication of the basis of the estimate.

* * * * *

(ii) * * *

(B) An estimate of the amount of the chemical in waste transferred in pounds (except for dioxin and dioxin-like compounds, which shall be reported in grams) per year (transfers of less than 1,000 pounds may be indicated in ranges, except for chemicals set forth in § 372.28) to each off-site location, and an indication of the basis for the estimate and an indication of the type of treatment or disposal used.

* * * * *

[FR Doc. 99–28169 Filed 10–28–99; 8:45 am]

BILLING CODE 6560–50–F

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STOCKHOLM CONVENTION

ON PERSISTENT ORGANIC POLLUTANTS (POPS)

TEXT AND ANNEXES

REVISED IN 2025



UN environment programme

STOCKHOLM CONVENTION

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STOCKHOLM CONVENTION

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TEXT AND ANNEXES

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STOCKHOLM CONVENTION

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INTRODUCTION

The Stockholm Convention on Persistent Organic Pollutants was adopted at a Conference of Plenipotentiaries on 22 May 2001 in Stockholm, Sweden. The Convention entered into force on 17 May 2004.

Since its adoption, the Stockholm Convention has seen the addition of Annex G on arbitration and conciliation procedures for settlement of disputes as well as a number of amendments to its Annexes A, B and C to eliminate and restrict additional persistent organic pollutants.

The version of the Stockholm Convention contained in this booklet does not substitute the original authentic texts of the Convention and amendments thereto as deposited with the Secretary-General in New York. Should you wish to access the authentic texts of the Convention, obtain a certified true copy of the Convention or, more generally, have access to amendments and modifications to the certified true copies, rectifications of authentic texts or any other relevant formalities circulated under the cover of depositary notifications (CNs), you are advised to visit the United Nations Treaty Section online (https://treaties.un.org) or kindly contact the Treaty Section for further assistance.

The Secretariat of the Stockholm Convention, 2025.

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STOCKHOLM CONVENTION ON PERSISTENT ORGANIC POLLUTANTS

The Parties to this Convention,

Recognizing that persistent organic pollutants possess toxic properties, resist degradation, bioaccumulate and are transported, through air, water and migratory species, across international boundaries and deposited far from their place of release, where they accumulate in terrestrial and aquatic ecosystems,

Aware of the health concerns, especially in developing countries, resulting from local exposure to persistent organic pollutants, in particular impacts upon women and, through them, upon future generations,

Acknowledging that the Arctic ecosystems and indigenous communities are particularly at risk because of the biomagnification of persistent organic pollutants and that contamination of their traditional foods is a public health issue,

Conscious of the need for global action on persistent organic pollutants,

Mindful of decision 19/13 C of 7 February 1997 of the Governing Council of the United Nations Environment Programme to initiate international action to protect human health and the environment through measures which will reduce and/or eliminate emissions and discharges of persistent organic pollutants,

Recalling the pertinent provisions of the relevant international environmental conventions, especially the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, and the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal including the regional agreements developed within the framework of its Article 11,

Recalling also the pertinent provisions of the Rio Declaration on Environment and Development and Agenda 21,

Acknowledging that precaution underlies the concerns of all the Parties and is embedded within this Convention,

Recognizing that this Convention and other international agreements in the field of trade and the environment are mutually supportive,

Reaffirming that States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources

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pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction,

Taking into account the circumstances and particular requirements of developing countries, in particular the least developed among them, and countries with economies in transition, especially the need to strengthen their national capabilities for the management of chemicals, including through the transfer of technology, the provision of financial and technical assistance and the promotion of cooperation among the Parties,

Taking full account of the Programme of Action for the Sustainable Development of Small Island Developing States, adopted in Barbados on 6 May 1994,

Noting the respective capabilities of developed and developing countries, as well as the common but differentiated responsibilities of States as set forth in Principle 7 of the Rio Declaration on Environment and Development,

Recognizing the important contribution that the private sector and non-governmental organizations can make to achieving the reduction and/or elimination of emissions and discharges of persistent organic pollutants,

Underlining the importance of manufacturers of persistent organic pollutants taking responsibility for reducing adverse effects caused by their products and for providing information to users, Governments and the public on the hazardous properties of those chemicals,

Conscious of the need to take measures to prevent adverse effects caused by persistent organic pollutants at all stages of their life cycle,

Reaffirming Principle 16 of the Rio Declaration on Environment and Development which states that national authorities should endeavour to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment,

Encouraging Parties not having regulatory and assessment schemes for pesticides and industrial chemicals to develop such schemes,

Recognizing the importance of developing and using environmentally sound alternative processes and chemicals,

Determined to protect human health and the environment from the harmful impacts of persistent organic pollutants,

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Have agreed as follows:

ARTICLE 1
Objective

Mindful of the precautionary approach as set forth in Principle 15 of the Rio Declaration on Environment and Development, the objective of this Convention is to protect human health and the environment from persistent organic pollutants.

ARTICLE 2
Definitions

For the purposes of this Convention:

a) "Party" means a State or regional economic integration organization that has consented to be bound by this Convention and for which the Convention is in force;

b) "Regional economic integration organization" means an organization constituted by sovereign States of a given region to which its member States have transferred competence in respect of matters governed by this Convention and which has been duly authorized, in accordance with its internal procedures, to sign, ratify, accept, approve or accede to this Convention;

c) "Parties present and voting" means Parties present and casting an affirmative or negative vote.

ARTICLE 3
Measures to reduce or eliminate releases from intentional production and use

1. Each Party shall:

   a) Prohibit and/or take the legal and administrative measures necessary to eliminate:

      i. Its production and use of the chemicals listed in Annex A subject to the provisions of that Annex; and

      ii. Its import and export of the chemicals listed in Annex A in accordance with the provisions of paragraph 2; and

   b) Restrict its production and use of the chemicals listed in Annex B in accordance with the provisions of that Annex.

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2. Each Party shall take measures to ensure:

    a) That a chemical listed in Annex A or Annex B is imported only:

        i. For the purpose of environmentally sound disposal as set forth in paragraph 1 (d) of Article 6; or

        ii. For a use or purpose which is permitted for that Party under Annex A or Annex B;

    b) That a chemical listed in Annex A for which any production or use specific exemption is in effect or a chemical listed in Annex B for which any production or use specific exemption or acceptable purpose is in effect, taking into account any relevant provisions in existing international prior informed consent instruments, is exported only:

        i. For the purpose of environmentally sound disposal as set forth in paragraph 1 (d) of Article 6;

        ii. To a Party which is permitted to use that chemical under Annex A or Annex B; or

        iii. To a State not Party to this Convention which has provided an annual certification to the exporting Party. Such certification shall specify the intended use of the chemical and include a statement that, with respect to that chemical, the importing State is committed to:

            a. Protect human health and the environment by taking the necessary measures to minimize or prevent releases;

            b. Comply with the provisions of paragraph 1 of Article 6; and

            c. Comply, where appropriate, with the provisions of paragraph 2 of Part II of Annex B.

The certification shall also include any appropriate supporting documentation, such as legislation, regulatory instruments, or administrative or policy guidelines. The exporting Party shall transmit the certification to the Secretariat within sixty days of receipt.

    c) That a chemical listed in Annex A, for which production and use specific exemptions are no longer in effect for any Party, is not exported from it except for the purpose of environmentally sound disposal as set forth in paragraph 1 (d) of Article 6;

    d) For the purposes of this paragraph, the term "State not Party to this Convention" shall include, with respect to a particular chemical, a State or regional economic integration organization that has not agreed to be bound by the Convention with respect to that chemical.

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3. Each Party that has one or more regulatory and assessment schemes for new pesticides or new industrial chemicals shall take measures to regulate with the aim of preventing the production and use of new pesticides or new industrial chemicals which, taking into consideration the criteria in paragraph 1 of Annex D, exhibit the characteristics of persistent organic pollutants.

4. Each Party that has one or more regulatory and assessment schemes for pesticides or industrial chemicals shall, where appropriate, take into consideration within these schemes the criteria in paragraph 1 of Annex D when conducting assessments of pesticides or industrial chemicals currently in use.

5. Except as otherwise provided in this Convention, paragraphs 1 and 2 shall not apply to quantities of a chemical to be used for laboratory-scale research or as a reference standard.

6. Any Party that has a specific exemption in accordance with Annex A or a specific exemption or an acceptable purpose in accordance with Annex B shall take appropriate measures to ensure that any production or use under such exemption or purpose is carried out in a manner that prevents or minimizes human exposure and release into the environment. For exempted uses or acceptable purposes that involve intentional release into the environment under conditions of normal use, such release shall be to the minimum extent necessary, taking into account any applicable standards and guidelines.

ARTICLE 4
Register of specific exemptions

1. A Register is hereby established for the purpose of identifying the Parties that have specific exemptions listed in Annex A or Annex B. It shall not identify Parties that make use of the provisions in Annex A or Annex B that may be exercised by all Parties. The Register shall be maintained by the Secretariat and shall be available to the public.

2. The Register shall include:

   a) A list of the types of specific exemptions reproduced from Annex A and Annex B;

   b) A list of the Parties that have a specific exemption listed under Annex A or Annex B; and

   c) A list of the expiry dates for each registered specific exemption.

3. Any State may, on becoming a Party, by means of a notification in writing to the Secretariat, register for one or more types of specific exemptions listed in Annex A or Annex B.

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4. Unless an earlier date is indicated in the Register by a Party, or an extension is granted pursuant to paragraph 7, all registrations of specific exemptions shall expire five years after the date of entry into force of this Convention with respect to a particular chemical.

5. At its first meeting, the Conference of the Parties shall decide upon its review process for the entries in the Register.

6. Prior to a review of an entry in the Register, the Party concerned shall submit a report to the Secretariat justifying its continuing need for registration of that exemption. The report shall be circulated by the Secretariat to all Parties. The review of a registration shall be carried out on the basis of all available information. Thereupon, the Conference of the Parties may make such recommendations to the Party concerned as it deems appropriate.

7. The Conference of the Parties may, upon request from the Party concerned, decide to extend the expiry date of a specific exemption for a period of up to five years. In making its decision, the Conference of the Parties shall take due account of the special circumstances of the developing country Parties and Parties with economies in transition.

8. A Party may, at any time, withdraw an entry from the Register for a specific exemption upon written notification to the Secretariat. The withdrawal shall take effect on the date specified in the notification.

9. When there are no longer any Parties registered for a particular type of specific exemption, no new registrations may be made with respect to it.

ARTICLE 5
Measures to reduce or eliminate releases from unintentional production

Each Party shall at a minimum take the following measures to reduce the total releases derived from anthropogenic sources of each of the chemicals listed in Annex C, with the goal of their continuing minimization and, where feasible, ultimate elimination:

a) Develop an action plan or, where appropriate, a regional or subregional action plan within two years of the date of entry into force of this Convention for it, and subsequently implement it as part of its implementation plan specified in Article 7, designed to identify, characterize and address the release of the chemicals listed in Annex C and to facilitate implementation of subparagraphs (b) to (e). The action plan shall include the following elements:

   i. An evaluation of current and projected releases, including the development and maintenance of source inventories and release estimates, taking into consideration the source categories identified in Annex C;

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ii. An evaluation of the efficacy of the laws and policies of the Party relating to the management of such releases;

iii. Strategies to meet the obligations of this paragraph, taking into account the evaluations in (i) and (ii);

iv. Steps to promote education and training with regard to, and awareness of, those strategies;

v. A review every five years of those strategies and of their success in meeting the obligations of this paragraph; such reviews shall be included in reports submitted pursuant to Article 15;

vi. A schedule for implementation of the action plan, including for the strategies and measures identified therein;

b) Promote the application of available, feasible and practical measures that can expeditiously achieve a realistic and meaningful level of release reduction or source elimination;

c) Promote the development and, where it deems appropriate, require the use of substitute or modified materials, products and processes to prevent the formation and release of the chemicals listed in Annex C, taking into consideration the general guidance on prevention and release reduction measures in Annex C and guidelines to be adopted by decision of the Conference of the Parties;

d) Promote and, in accordance with the implementation schedule of its action plan, require the use of best available techniques for new sources within source categories which a Party has identified as warranting such action in its action plan, with a particular initial focus on source categories identified in Part II of Annex C. In any case, the requirement to use best available techniques for new sources in the categories listed in Part II of that Annex shall be phased in as soon as practicable but no later than four years after the entry into force of the Convention for that Party. For the identified categories, Parties shall promote the use of best environmental practices. When applying best available techniques and best environmental practices, Parties should take into consideration the general guidance on prevention and release reduction measures in that Annex and guidelines on best available techniques and best environmental practices to be adopted by decision of the Conference of the Parties;

e) Promote, in accordance with its action plan, the use of best available techniques and best environmental practices:

i. For existing sources, within the source categories listed in Part II of Annex C and within source categories such as those in Part III of that Annex; and

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ii. For new sources, within source categories such as those listed in Part III of Annex C which a Party has not addressed under subparagraph (d).

When applying best available techniques and best environmental practices, Parties should take into consideration the general guidance on prevention and release reduction measures in Annex C and guidelines on best available techniques and best environmental practices to be adopted by decision of the Conference of the Parties;

f) For the purposes of this paragraph and Annex C:

i. "Best available techniques" means the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for release limitations designed to prevent and, where that is not practicable, generally to reduce releases of chemicals listed in Part I of Annex C and their impact on the environment as a whole. In this regard:

ii. "Techniques" includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;

iii. "Available" techniques means those techniques that are accessible to the operator and that are developed on a scale that allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages; and

iv. "Best" means most effective in achieving a high general level of protection of the environment as a whole;

v. "Best environmental practices" means the application of the most appropriate combination of environmental control measures and strategies;

vi. "New source" means any source of which the construction or substantial modification is commenced at least one year after the date of:

a) Entry into force of this Convention for the Party concerned; or

b) Entry into force for the Party concerned of an amendment to Annex C where the source becomes subject to the provisions of this Convention only by virtue of that amendment.

g) Release limit values or performance standards may be used by a Party to fulfil its commitments for best available techniques under this paragraph.

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ARTICLE 6
Measures to reduce or eliminate releases from stockpiles and wastes

1. In order to ensure that stockpiles consisting of or containing chemicals listed either in Annex A or Annex B and wastes, including products and articles upon becoming wastes, consisting of, containing or contaminated with a chemical listed in Annex A, B or C, are managed in a manner protective of human health and the environment, each Party shall:

    a) Develop appropriate strategies for identifying:

        i. Stockpiles consisting of or containing chemicals listed either in Annex A or Annex B; and

        ii. Products and articles in use and wastes consisting of, containing or contaminated with a chemical listed in Annex A, B or C;

    b) Identify, to the extent practicable, stockpiles consisting of or containing chemicals listed either in Annex A or Annex B on the basis of the strategies referred to in subparagraph (a);

    c) Manage stockpiles, as appropriate, in a safe, efficient and environmentally sound manner. Stockpiles of chemicals listed either in Annex A or Annex B, after they are no longer allowed to be used according to any specific exemption specified in Annex A or any specific exemption or acceptable purpose specified in Annex B, except stockpiles which are allowed to be exported according to paragraph 2 of Article 3, shall be deemed to be waste and shall be managed in accordance with subparagraph (d);

    d) Take appropriate measures so that such wastes, including products and articles upon becoming wastes, are:

        i. Handled, collected, transported and stored in an environmentally sound manner;

        ii. Disposed of in such a way that the persistent organic pollutant content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of persistent organic pollutants or otherwise disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option or the persistent organic pollutant content is low, taking into account international rules, standards, and guidelines, including those that may be developed pursuant to paragraph 2, and relevant global and regional regimes governing the management of hazardous wastes;

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iii. Not permitted to be subjected to disposal operations that may lead to recovery, recycling, reclamation, direct reuse or alternative uses of persistent organic pollutants; and

iv. Not transported across international boundaries without taking into account relevant international rules, standards and guidelines;

e) Endeavour to develop appropriate strategies for identifying sites contaminated by chemicals listed in Annex A, B or C; if remediation of those sites is undertaken it shall be performed in an environmentally sound manner.

2. The Conference of the Parties shall cooperate closely with the appropriate bodies of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal to, inter alia:

a) Establish levels of destruction and irreversible transformation necessary to ensure that the characteristics of persistent organic pollutants as specified in paragraph 1 of Annex D are not exhibited;

b) Determine what they consider to be the methods that constitute environmentally sound disposal referred to above; and

c) Work to establish, as appropriate, the concentration levels of the chemicals listed in Annexes A, B and C in order to define the low persistent organic pollutant content referred to in paragraph 1 (d) (ii).

ARTICLE 7
Implementation plans

1. Each Party shall:

a) Develop and endeavour to implement a plan for the implementation of its obligations under this Convention;

b) Transmit its implementation plan to the Conference of the Parties within two years of the date on which this Convention enters into force for it; and

c) Review and update, as appropriate, its implementation plan on a periodic basis and in a manner to be specified by a decision of the Conference of the Parties.

2. The Parties shall, where appropriate, cooperate directly or through global, regional and subregional organizations, and consult their national stakeholders, including women's groups and groups involved in the health of children, in order to facilitate the development, implementation and updating of their implementation plans.

3. The Parties shall endeavour to utilize and, where necessary, establish the means to integrate national implementation plans for persistent organic pollutants in their sustainable development strategies where appropriate.

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ARTICLE 8
Listing of chemicals in Annexes A, B and C

1. A Party may submit a proposal to the Secretariat for listing a chemical in Annexes A, B and/or C. The proposal shall contain the information specified in Annex D. In developing a proposal, a Party may be assisted by other Parties and/or by the Secretariat.

2. The Secretariat shall verify whether the proposal contains the information specified in Annex D. If the Secretariat is satisfied that the proposal contains the information so specified, it shall forward the proposal to the Persistent Organic Pollutants Review Committee.

3. The Committee shall examine the proposal and apply the screening criteria specified in Annex D in a flexible and transparent way, taking all information provided into account in an integrative and balanced manner.

4. If the Committee decides that:

   a) It is satisfied that the screening criteria have been fulfilled, it shall, through the Secretariat, make the proposal and the evaluation of the Committee available to all Parties and observers and invite them to submit the information specified in Annex E; or

   b) It is not satisfied that the screening criteria have been fulfilled, it shall, through the Secretariat, inform all Parties and observers and make the proposal and the evaluation of the Committee available to all Parties and the proposal shall be set aside.

5. Any Party may resubmit a proposal to the Committee that has been set aside by the Committee pursuant to paragraph 4. The resubmission may include any concerns of the Party as well as a justification for additional consideration by the Committee. If, following this procedure, the Committee again sets the proposal aside, the Party may challenge the decision of the Committee and the Conference of the Parties shall consider the matter at its next session. The Conference of the Parties may decide, based on the screening criteria in Annex D and taking into account the evaluation of the Committee and any additional information provided by any Party or observer, that the proposal should proceed.

6. Where the Committee has decided that the screening criteria have been fulfilled, or the Conference of the Parties has decided that the proposal should proceed, the Committee shall further review the proposal, taking into account any relevant additional information received, and shall prepare a draft risk profile in accordance with Annex E. It shall, through the Secretariat, make that draft

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available to all Parties and observers, collect technical comments from them and, taking those comments into account, complete the risk profile.

7. If, on the basis of the risk profile conducted in accordance with Annex E, the Committee decides:

   a) That the chemical is likely as a result of its long-range environmental transport to lead to significant adverse human health and/or environmental effects such that global action is warranted, the proposal shall proceed. Lack of full scientific certainty shall not prevent the proposal from proceeding. The Committee shall, through the Secretariat, invite information from all Parties and observers relating to the considerations specified in Annex F. It shall then prepare a risk management evaluation that includes an analysis of possible control measures for the chemical in accordance with that Annex; or

   b) That the proposal should not proceed, it shall, through the Secretariat, make the risk profile available to all Parties and observers and set the proposal aside.

8. For any proposal set aside pursuant to paragraph 7 (b), a Party may request the Conference of the Parties to consider instructing the Committee to invite additional information from the proposing Party and other Parties during a period not to exceed one year. After that period and on the basis of any information received, the Committee shall reconsider the proposal pursuant to paragraph 6 with a priority to be decided by the Conference of the Parties. If, following this procedure, the Committee again sets the proposal aside, the Party may challenge the decision of the Committee and the Conference of the Parties shall consider the matter at its next session. The Conference of the Parties may decide, based on the risk profile prepared in accordance with Annex E and taking into account the evaluation of the Committee and any additional information provided by any Party or observer, that the proposal should proceed. If the Conference of the Parties decides that the proposal shall proceed, the Committee shall then prepare the risk management evaluation.

9. The Committee shall, based on the risk profile referred to in paragraph 6 and the risk management evaluation referred to in paragraph 7 (a) or paragraph 8, recommend whether the chemical should be considered by the Conference of the Parties for listing in Annexes A, B and/or C. The Conference of the Parties, taking due account of the recommendations of the Committee, including any scientific uncertainty, shall decide, in a precautionary manner, whether to list the chemical, and specify its related control measures, in Annexes A, B and/or C.

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ARTICLE 9
Information exchange

1. Each Party shall facilitate or undertake the exchange of information relevant to:

    a) The reduction or elimination of the production, use and release of persistent organic pollutants; and

    b) Alternatives to persistent organic pollutants, including information relating to their risks as well as to their economic and social costs.

2. The Parties shall exchange the information referred to in paragraph 1 directly or through the Secretariat.

3. Each Party shall designate a national focal point for the exchange of such information.

4. The Secretariat shall serve as a clearing-house mechanism for information on persistent organic pollutants, including information provided by Parties, intergovernmental organizations and non-governmental organizations.

5. For the purposes of this Convention, information on health and safety of humans and the environment shall not be regarded as confidential. Parties that exchange other information pursuant to this Convention shall protect any confidential information as mutually agreed.

ARTICLE 10
Public information, awareness and education

1. Each Party shall, within its capabilities, promote and facilitate:

    a) Awareness among its policy and decision makers with regard to persistent organic pollutants;

    b) Provision to the public of all available information on persistent organic pollutants, taking into account paragraph 5 of Article 9;

    c) Development and implementation, especially for women, children and the least educated, of educational and public awareness programmes on persistent organic pollutants, as well as on their health and environmental effects and on their alternatives;

    d) Public participation in addressing persistent organic pollutants and their health and environmental effects and in developing adequate responses, including opportunities for providing input at the national level regarding implementation of this Convention;

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e) Training of workers, scientists, educators and technical and managerial personnel;

f) Development and exchange of educational and public awareness materials at the national and international levels; and

g) Development and implementation of education and training programmes at the national and international levels.

2. Each Party shall, within its capabilities, ensure that the public has access to the public information referred to in paragraph 1 and that the information is kept up-to-date.

3. Each Party shall, within its capabilities, encourage industry and professional users to promote and facilitate the provision of the information referred to in paragraph 1 at the national level and, as appropriate, subregional, regional and global levels.

4. In providing information on persistent organic pollutants and their alternatives, Parties may use safety data sheets, reports, mass media and other means of communication, and may establish information centres at national and regional levels.

5. Each Party shall give sympathetic consideration to developing mechanisms, such as pollutant release and transfer registers, for the collection and dissemination of information on estimates of the annual quantities of the chemicals listed in Annex A, B or C that are released or disposed of.

ARTICLE 11
Research, development and monitoring

1. The Parties shall, within their capabilities, at the national and international levels, encourage and/or undertake appropriate research, development, monitoring and cooperation pertaining to persistent organic pollutants and, where relevant, to their alternatives and to candidate persistent organic pollutants, including on their:

a) Sources and releases into the environment;

b) Presence, levels and trends in humans and the environment;

c) Environmental transport, fate and transformation;

d) Effects on human health and the environment;

e) Socio-economic and cultural impacts;

f) Release reduction and/or elimination; and

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g) Harmonized methodologies for making inventories of generating sources and analytical techniques for the measurement of releases.

2. In undertaking action under paragraph 1, the Parties shall, within their capabilities:

   a) Support and further develop, as appropriate, international programmes, networks and organizations aimed at defining, conducting, assessing and financing research, data collection and monitoring, taking into account the need to minimize duplication of effort;

   b) Support national and international efforts to strengthen national scientific and technical research capabilities, particularly in developing countries and countries with economies in transition, and to promote access to, and the exchange of, data and analyses;

   c) Take into account the concerns and needs, particularly in the field of financial and technical resources, of developing countries and countries with economies in transition and cooperate in improving their capability to participate in the efforts referred to in subparagraphs (a) and (b);

   d) Undertake research work geared towards alleviating the effects of persistent organic pollutants on reproductive health;

   e) Make the results of their research, development and monitoring activities referred to in this paragraph accessible to the public on a timely and regular basis; and

   f) Encourage and/or undertake cooperation with regard to storage and maintenance of information generated from research, development and monitoring.

ARTICLE 12
Technical assistance

1. The Parties recognize that rendering of timely and appropriate technical assistance in response to requests from developing country Parties and Parties with economies in transition is essential to the successful implementation of this Convention.

2. The Parties shall cooperate to provide timely and appropriate technical assistance to developing country Parties and Parties with economies in transition, to assist them, taking into account their particular needs, to develop and strengthen their capacity to implement their obligations under this Convention.

3. In this regard, technical assistance to be provided by developed country Parties, and other Parties in accordance with their capabilities, shall include, as

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appropriate and as mutually agreed, technical assistance for capacity-building relating to implementation of the obligations under this Convention. Further guidance in this regard shall be provided by the Conference of the Parties.

4. The Parties shall establish, as appropriate, arrangements for the purpose of providing technical assistance and promoting the transfer of technology to developing country Parties and Parties with economies in transition relating to the implementation of this Convention. These arrangements shall include regional and subregional centres for capacity-building and transfer of technology to assist developing country Parties and Parties with economies in transition to fulfil their obligations under this Convention. Further guidance in this regard shall be provided by the Conference of the Parties.

5. The Parties shall, in the context of this Article, take full account of the specific needs and special situation of least developed countries and small island developing states in their actions with regard to technical assistance.

ARTICLE 13
Financial resources and mechanisms

1. Each Party undertakes to provide, within its capabilities, financial support and incentives in respect of those national activities that are intended to achieve the objective of this Convention in accordance with its national plans, priorities and programmes.

2. The developed country Parties shall provide new and additional financial resources to enable developing country Parties and Parties with economies in transition to meet the agreed full incremental costs of implementing measures which fulfil their obligations under this Convention as agreed between a recipient Party and an entity participating in the mechanism described in paragraph 6. Other Parties may also on a voluntary basis and in accordance with their capabilities provide such financial resources. Contributions from other sources should also be encouraged. The implementation of these commitments shall take into account the need for adequacy, predictability, the timely flow of funds and the importance of burden sharing among the contributing Parties.

3. Developed country Parties, and other Parties in accordance with their capabilities and in accordance with their national plans, priorities and programmes, may also provide and developing country Parties and Parties with economies in transition avail themselves of financial resources to assist in their implementation of this Convention through other bilateral, regional and multilateral sources or channels.

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4. The extent to which the developing country Parties will effectively implement their commitments under this Convention will depend on the effective implementation by developed country Parties of their commitments under this Convention relating to financial resources, technical assistance and technology transfer. The fact that sustainable economic and social development and eradication of poverty are the first and overriding priorities of the developing country Parties will be taken fully into account, giving due consideration to the need for the protection of human health and the environment.

5. The Parties shall take full account of the specific needs and special situation of the least developed countries and the small island developing states in their actions with regard to funding.

6. A mechanism for the provision of adequate and sustainable financial resources to developing country Parties and Parties with economies in transition on a grant or concessional basis to assist in their implementation of the Convention is hereby defined. The mechanism shall function under the authority, as appropriate, and guidance of, and be accountable to the Conference of the Parties for the purposes of this Convention. Its operation shall be entrusted to one or more entities, including existing international entities, as may be decided upon by the Conference of the Parties. The mechanism may also include other entities providing multilateral, regional and bilateral financial and technical assistance. Contributions to the mechanism shall be additional to other financial transfers to developing country Parties and Parties with economies in transition as reflected in, and in accordance with, paragraph 2.

7. Pursuant to the objectives of this Convention and paragraph 6, the Conference of the Parties shall at its first meeting adopt appropriate guidance to be provided to the mechanism and shall agree with the entity or entities participating in the financial mechanism upon arrangements to give effect thereto. The guidance shall address, inter alia:

    a) The determination of the policy, strategy and programme priorities, as well as clear and detailed criteria and guidelines regarding eligibility for access to and utilization of financial resources including monitoring and evaluation on a regular basis of such utilization;

    b) The provision by the entity or entities of regular reports to the Conference of the Parties on adequacy and sustainability of funding for activities relevant to the implementation of this Convention;

    c) The promotion of multiple-source funding approaches, mechanisms and arrangements;

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d) The modalities for the determination in a predictable and identifiable manner of the amount of funding necessary and available for the implementation of this Convention, keeping in mind that the phasing out of persistent organic pollutants might require sustained funding, and the conditions under which that amount shall be periodically reviewed; and

e) The modalities for the provision to interested Parties of assistance with needs assessment, information on available sources of funds and on funding patterns in order to facilitate coordination among them.

8. The Conference of the Parties shall review, not later than its second meeting and thereafter on a regular basis, the effectiveness of the mechanism established under this Article, its ability to address the changing needs of the developing country Parties and Parties with economies in transition, the criteria and guidance referred to in paragraph 7, the level of funding as well as the effectiveness of the performance of the institutional entities entrusted to operate the financial mechanism. It shall, based on such review, take appropriate action, if necessary, to improve the effectiveness of the mechanism, including by means of recommendations and guidance on measures to ensure adequate and sustainable funding to meet the needs of the Parties.

ARTICLE 14
Interim financial arrangements

The institutional structure of the Global Environment Facility, operated in accordance with the Instrument for the Establishment of the Restructured Global Environment Facility, shall, on an interim basis, be the principal entity entrusted with the operations of the financial mechanism referred to in Article 13, for the period between the date of entry into force of this Convention and the first meeting of the Conference of the Parties, or until such time as the Conference of the Parties decides which institutional structure will be designated in accordance with Article 13. The institutional structure of the Global Environment Facility should fulfil this function through operational measures related specifically to persistent organic pollutants taking into account that new arrangements for this area may be needed.

ARTICLE 15
Reporting

1. Each Party shall report to the Conference of the Parties on the measures it has taken to implement the provisions of this Convention and on the effectiveness of such measures in meeting the objectives of the Convention.

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2. Each Party shall provide to the Secretariat:

   a) Statistical data on its total quantities of production, import and export of each of the chemicals listed in Annex A and Annex B or a reasonable estimate of such data; and

   b) To the extent practicable, a list of the States from which it has imported each such substance and the States to which it has exported each such substance.

3. Such reporting shall be at periodic intervals and in a format to be decided by the Conference of the Parties at its first meeting.

ARTICLE 16
Effectiveness evaluation

1. Commencing four years after the date of entry into force of this Convention, and periodically thereafter at intervals to be decided by the Conference of the Parties, the Conference shall evaluate the effectiveness of this Convention.

2. In order to facilitate such evaluation, the Conference of the Parties shall, at its first meeting, initiate the establishment of arrangements to provide itself with comparable monitoring data on the presence of the chemicals listed in Annexes A, B and C as well as their regional and global environmental transport. These arrangements:

   a) Should be implemented by the Parties on a regional basis when appropriate, in accordance with their technical and financial capabilities, using existing monitoring programmes and mechanisms to the extent possible and promoting harmonization of approaches;

   b) May be supplemented where necessary, taking into account the differences between regions and their capabilities to implement monitoring activities; and

   c) Shall include reports to the Conference of the Parties on the results of the monitoring activities on a regional and global basis at intervals to be specified by the Conference of the Parties.

3. The evaluation described in paragraph 1 shall be conducted on the basis of available scientific, environmental, technical and economic information, including:

   a) Reports and other monitoring information provided pursuant to paragraph 2;

   b) National reports submitted pursuant to Article 15; and

   c) Non-compliance information provided pursuant to the procedures established under Article 17.

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ARTICLE 17
Non-compliance

The Conference of the Parties shall, as soon as practicable, develop and approve procedures and institutional mechanisms for determining non-compliance with the provisions of this Convention and for the treatment of Parties found to be in non-compliance.

ARTICLE 18
Settlement of disputes

1. Parties shall settle any dispute between them concerning the interpretation or application of this Convention through negotiation or other peaceful means of their own choice.

2. When ratifying, accepting, approving or acceding to the Convention, or at any time thereafter, a Party that is not a regional economic integration organization may declare in a written instrument submitted to the depositary that, with respect to any dispute concerning the interpretation or application of the Convention, it recognizes one or both of the following means of dispute settlement as compulsory in relation to any Party accepting the same obligation:

   a) Arbitration in accordance with procedures to be adopted by the Conference of the Parties in an annex as soon as practicable;

   b) Submission of the dispute to the International Court of Justice.

3. A Party that is a regional economic integration organization may make a declaration with like effect in relation to arbitration in accordance with the procedure referred to in paragraph 2 (a).

4. A declaration made pursuant to paragraph 2 or paragraph 3 shall remain in force until it expires in accordance with its terms or until three months after written notice of its revocation has been deposited with the depositary.

5. The expiry of a declaration, a notice of revocation or a new declaration shall not in any way affect proceedings pending before an arbitral tribunal or the International Court of Justice unless the parties to the dispute otherwise agree.

6. If the parties to a dispute have not accepted the same or any procedure pursuant to paragraph 2, and if they have not been able to settle their dispute within twelve months following notification by one party to another that a dispute exists between them, the dispute shall be submitted to a conciliation commission at the request of any party to the dispute. The conciliation commission shall render a

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report with recommendations. Additional procedures relating to the conciliation commission shall be included in an annex to be adopted by the Conference of the Parties no later than at its second meeting.

ARTICLE 19
Conference of the Parties

1. A Conference of the Parties is hereby established.

2. The first meeting of the Conference of the Parties shall be convened by the Executive Director of the United Nations Environment Programme no later than one year after the entry into force of this Convention. Thereafter, ordinary meetings of the Conference of the Parties shall be held at regular intervals to be decided by the Conference.

3. Extraordinary meetings of the Conference of the Parties shall be held at such other times as may be deemed necessary by the Conference, or at the written request of any Party provided that it is supported by at least one third of the Parties.

4. The Conference of the Parties shall by consensus agree upon and adopt at its first meeting rules of procedure and financial rules for itself and any subsidiary bodies, as well as financial provisions governing the functioning of the Secretariat.

5. The Conference of the Parties shall keep under continuous review and evaluation the implementation of this Convention. It shall perform the functions assigned to it by the Convention and, to this end, shall:

   a) Establish, further to the requirements of paragraph 6, such subsidiary bodies as it considers necessary for the implementation of the Convention;

   b) Cooperate, where appropriate, with competent international organizations and intergovernmental and non-governmental bodies; and

   c) Regularly review all information made available to the Parties pursuant to Article 15, including consideration of the effectiveness of paragraph 2 (b) (iii) of Article 3;

   d) Consider and undertake any additional action that may be required for the achievement of the objectives of the Convention.

6. The Conference of the Parties shall, at its first meeting, establish a subsidiary body to be called the Persistent Organic Pollutants Review Committee for the purposes of performing the functions assigned to that Committee by this Convention. In this regard:

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a) The members of the Persistent Organic Pollutants Review Committee shall be appointed by the Conference of the Parties. Membership of the Committee shall consist of government-designated experts in chemical assessment or management. The members of the Committee shall be appointed on the basis of equitable geographical distribution;

b) The Conference of the Parties shall decide on the terms of reference, organization and operation of the Committee; and

c) The Committee shall make every effort to adopt its recommendations by consensus. If all efforts at consensus have been exhausted, and no consensus reached, such recommendation shall as a last resort be adopted by a two-thirds majority vote of the members present and voting.

7. The Conference of the Parties shall, at its third meeting, evaluate the continued need for the procedure contained in paragraph 2 (b) of Article 3, including consideration of its effectiveness.

8. The United Nations, its specialized agencies and the International Atomic Energy Agency, as well as any State not Party to this Convention, may be represented at meetings of the Conference of the Parties as observers. Anybody or agency, whether national or international, governmental or non-governmental, qualified in matters covered by the Convention, and which has informed the Secretariat of its wish to be represented at a meeting of the Conference of the Parties as an observer may be admitted unless at least one third of the Parties present object. The admission and participation of observers shall be subject to the rules of procedure adopted by the Conference of the Parties.

ARTICLE 20
Secretariat

1. A Secretariat is hereby established.

2. The functions of the Secretariat shall be:

a) To make arrangements for meetings of the Conference of the Parties and its subsidiary bodies and to provide them with services as required;

b) To facilitate assistance to the Parties, particularly developing country Parties and Parties with economies in transition, on request, in the implementation of this Convention;

c) To ensure the necessary coordination with the secretariats of other relevant international bodies;

d) To prepare and make available to the Parties periodic reports based on information received pursuant to Article 15 and other available information;

e) To enter, under the overall guidance of the Conference of the Parties, into such administrative and contractual arrangements as may be required for the effective discharge of its functions; and

f) To perform the other secretariat functions specified in this Convention and such other functions as may be determined by the Conference of the Parties.

3. The secretariat functions for this Convention shall be performed by the Executive Director of the United Nations Environment Programme, unless the Conference of the Parties decides, by a three-fourths majority of the Parties present and voting, to entrust the secretariat functions to one or more other international organizations.

ARTICLE 21
Amendments to the Convention

1. Amendments to this Convention may be proposed by any Party.

2. Amendments to this Convention shall be adopted at a meeting of the Conference of the Parties. The text of any proposed amendment shall be communicated to the Parties by the Secretariat at least six months before the meeting at which it is proposed for adoption. The Secretariat shall also communicate proposed amendments to the signatories to this Convention and, for information, to the depositary.

3. The Parties shall make every effort to reach agreement on any proposed amendment to this Convention by consensus. If all efforts at consensus have been exhausted, and no agreement reached, the amendment shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting.

4. The amendment shall be communicated by the depositary to all Parties for ratification, acceptance or approval.

5. Ratification, acceptance or approval of an amendment shall be notified to the depositary in writing. An amendment adopted in accordance with paragraph 3 shall enter into force for the Parties having accepted it on the ninetieth day after the date of deposit of instruments of ratification, acceptance or approval by at least three-fourths of the Parties. Thereafter, the amendment shall enter into force for any other Party on the ninetieth day after the date on which that Party deposits its instrument of ratification, acceptance or approval of the amendment.

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ARTICLE 22
Adoption and amendment of annexes

1. Annexes to this Convention shall form an integral part thereof and, unless expressly provided otherwise, a reference to this Convention constitutes at the same time a reference to any annexes thereto.

2. Any additional annexes shall be restricted to procedural, scientific, technical or administrative matters.

3. The following procedure shall apply to the proposal, adoption and entry into force of additional annexes to this Convention:

   a) Additional annexes shall be proposed and adopted according to the procedure laid down in paragraphs 1, 2 and 3 of Article 21;

   b) Any Party that is unable to accept an additional annex shall so notify the depositary, in writing, within one year from the date of communication by the depositary of the adoption of the additional annex. The depositary shall without delay notify all Parties of any such notification received. A Party may at any time withdraw a previous notification of non-acceptance in respect of any additional annex, and the annex shall thereupon enter into force for that Party subject to subparagraph (c); and

   c) On the expiry of one year from the date of the communication by the depositary of the adoption of an additional annex, the annex shall enter into force for all Parties that have not submitted a notification in accordance with the provisions of subparagraph (b).

4. The proposal, adoption and entry into force of amendments to Annex A, B or C shall be subject to the same procedures as for the proposal, adoption and entry into force of additional annexes to this Convention, except that an amendment to Annex A, B or C shall not enter into force with respect to any Party that has made a declaration with respect to amendment to those Annexes in accordance with paragraph 4 of Article 25, in which case any such amendment shall enter into force for such a Party on the ninetieth day after the date of deposit with the depositary of its instrument of ratification, acceptance, approval or accession with respect to such amendment.

5. The following procedure shall apply to the proposal, adoption and entry into force of an amendment to Annex D, E or F:

   a) Amendments shall be proposed according to the procedure in paragraphs 1 and 2 of Article 21;

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b) The Parties shall take decisions on an amendment to Annex D, E or F by consensus; and

c) A decision to amend Annex D, E or F shall forthwith be communicated to the Parties by the depositary. The amendment shall enter into force for all Parties on a date to be specified in the decision.

6. If an additional annex or an amendment to an annex is related to an amendment to this Convention, the additional annex or amendment shall not enter into force until such time as the amendment to the Convention enters into force.

ARTICLE 23
Right to vote

1. Each Party to this Convention shall have one vote, except as provided for in paragraph 2.

2. A regional economic integration organization, on matters within its competence, shall exercise its right to vote with a number of votes equal to the number of its member States that are Parties to this Convention. Such an organization shall not exercise its right to vote if any of its member States exercises its right to vote, and vice versa.

ARTICLE 24
Signature

This Convention shall be open for signature at Stockholm by all States and regional economic integration organizations on 23 May 2001, and at the United Nations Headquarters in New York from 24 May 2001 to 22 May 2002.

ARTICLE 25
Ratification, acceptance, approval or accession

1. This Convention shall be subject to ratification, acceptance or approval by States and by regional economic integration organizations. It shall be open for accession by States and by regional economic integration organizations from the day after the date on which the Convention is closed for signature. Instruments of ratification, acceptance, approval or accession shall be deposited with the depositary.

2. Any regional economic integration organization that becomes a Party to this Convention without any of its member States being a Party shall be bound by all the obligations under the Convention. In the case of such organizations, one or more of whose member States is a Party to this Convention, the organization

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and its member States shall decide on their respective responsibilities for the performance of their obligations under the Convention. In such cases, the organization and the member States shall not be entitled to exercise rights under the Convention concurrently.

3. In its instrument of ratification, acceptance, approval or accession, a regional economic integration organization shall declare the extent of its competence in respect of the matters governed by this Convention. Any such organization shall also inform the depositary, who shall in turn inform the Parties, of any relevant modification in the extent of its competence.

4. In its instrument of ratification, acceptance, approval or accession, any Party may declare that, with respect to it, any amendment to Annex A, B or C shall enter into force only upon the deposit of its instrument of ratification, acceptance, approval or accession with respect thereto.

ARTICLE 26
Entry into force

1. This Convention shall enter into force on the ninetieth day after the date of deposit of the fiftieth instrument of ratification, acceptance, approval or accession.

2. For each State or regional economic integration organization that ratifies, accepts or approves this Convention or accedes thereto after the deposit of the fiftieth instrument of ratification, acceptance, approval or accession, the Convention shall enter into force on the ninetieth day after the date of deposit by such State or regional economic integration organization of its instrument of ratification, acceptance, approval or accession.

3. For the purpose of paragraphs 1 and 2, any instrument deposited by a regional economic integration organization shall not be counted as additional to those deposited by member States of that organization.

ARTICLE 27
Reservations

No reservations may be made to this Convention.

ARTICLE 28
Withdrawal

1. At any time after three years from the date on which this Convention has entered into force for a Party, that Party may withdraw from the Convention by giving written notification to the depositary.

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2. Any such withdrawal shall take effect upon the expiry of one year from the date of receipt by the depositary of the notification of withdrawal, or on such later date as may be specified in the notification of withdrawal.

ARTICLE 29
Depositary

The Secretary-General of the United Nations shall be the depositary of this Convention.

ARTICLE 30
Authentic texts

The original of this Convention, of which the Arabic, Chinese, English, French, Russian and Spanish texts are equally authentic, shall be deposited with the Secretary General of the United Nations.

IN WITNESS WHEREOF the undersigned, being duly authorized to that effect, have signed this Convention.

Done at Stockholm on this twenty-second day of May, two thousand and one.

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ANNEXES

ANNEX A[1]
ELIMINATION

Part I
Procedure

Chemical	Activity	Specific exemption[2]
Aldrin* CAS No: 309-00-2	Production	None
	Use	Local ectoparasiticide Insecticide
Alpha hexachlorocyclohexane* CAS No: 319-84-6	Production	None
	Use	None
Beta hexachlorocyclohexane* CAS No: 319-85-7	Production	None
	Use	None
Chlordane* CAS No: 57-74-9	Production	As allowed for the Parties listed in the Register
	Use	Local ectoparasiticide Insecticide Termiticide Termiticide in buildings and dams Termiticide in roads Additive in plywood adhesives
Chlordecone* CAS No: 143-50-0	Production	None
	Use	None

[1] *Secretariat note: As amended by decisions SC-4/10 to SC-4/18 of 8 May 2009; SC-5/3 of 29 April 2011; SC-6/13 of 10 May 2013; SC-7/12 to SC-7/14 of 15 May 2015; and SC-8/10 to SC-8/12 of 5 May 2017; and SC-9/4, SC-9/11 and SC-9/12 of 10 May 2019; SC-10/13 of 17 June 2022; SC-11/9, SC-11/10 and SC-11/11 of 12 May 2023; and SC-12/9, SC-12/10, SC-12/12, and SC-12/14 of 9 May 2025.*

[2] *Secretariat note: Please note that, in accordance with paragraph 9 of Article 4 of the Convention, when there are no longer any Parties registered for a particular type of specific exemption no new registrations may be made with respect to such exemptions, which appear in grey text in the table.*

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Chlorpyrifos* **CAS No. 2921-88-2**	Production	As allowed for the Parties listed in the Register
	Use	• Crop-pest complexes as listed in accordance with the provisions of part XV of this Annex • Control of leaf-cutting ants (*Atta* spp. and *Acromyrmex* spp.) for agricultural use only • Control of locusts for agricultural use only • Control of ticks in cattle • Wood preservation against borers and termites in building foundations
Decabromodiphenyl ether (BDE-209) present in commercial decabromodiphenyl ether (CAS No: 1163-19-5)	Production	As allowed for the Parties listed in the Register
	Use	In accordance with Part IX of this Annex: • Parts for use in vehicles specified in paragraph 2 of Part IX of this Annex • Aircraft for which type approval has been applied for before December 2018 and has been received before December 2022 and spare parts for those aircraft • Textile products that require anti-flammable characteristics, excluding clothing and toys • Additives in plastic housings and parts used for heating home appliances, irons, fans, immersion heaters that contain or are in direct contact with electrical parts or are required to comply with fire retardancy standards, at concentrations lower than 10 per cent by weight of the part • Polyurethane foam for building insulation

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Dechlorane Plus **CAS No: 13560-89-9** **"Dechlorane Plus" includes its syn-isomer (CAS No: 135821-03-3) and its anti-isomer (CAS No: 135821-74-8)**	Production	None
	Use	In accordance with part XI of this Annex: • Aerospace • Space and defence applications • Medical imaging and radiotherapy devices and installations • Replacement parts for, and repair of, articles in applications in accordance with the provisions of paragraphs 2 and 3 of part XI of this Annex
Dicofol **CAS No: 115-32-2** **CAS No: 10606-46-9**	Production	None
	Use	None
Dieldrin* **CAS No: 60-57-1**	Production	None
	Use	In agricultural operations
Endrin* **CAS No: 72-20-8**	Production	None
	Use	None
Heptachlor* **CAS No: 76-44-8**	Production	None
	Use	Termiticide Termiticide in structures of houses Termiticide (subterranean) Wood treatment In use in underground cable boxes
Hexabromobiphenyl * **CAS No: 36355-01-8**	Production	None
	Use	None
Hexabromocyclododecane	Production	As allowed for the Parties listed in the Register in accordance with the provisions of Part VII of this Annex
	Use	Expanded polystyrene and extruded polystyrene in buildings in accordance with the provisions of Part VII of this Annex

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Hexabromodiphenyl ether* and heptabromodiphenyl ether*	Production	None
	Use	Articles in accordance with the provisions of Part IV of this Annex
Hexachlorobenzene CAS No: 118-74-1	Production	As allowed for the Parties listed in the Register
	Use	Intermediate Solvent in pesticide Closed system site limited intermediate
Hexachlorobutadiene CAS No: 87-68-3	Production	None
	Use	None
Lindane* CAS No: 58-89-9	Production	None
	Use	Human health pharmaceutical for control of head lice and scabies as second line treatment
Long-chain perfluorocarboxylic acids, their salts and related compounds **"Long-chain perfluorocarboxylic acids, their salts and related compounds" means the following:** **(i) Long-chain perfluorocarboxylic acids or their salts, for the purposes of the Convention, are a homologous series of substances with the molecular formula of $C_nF_{2n+1}COOH$ (where $8 \leq n \leq 20$);**	Production	As allowed for the Parties listed in the Register in accordance with the provisions of Part XIV of this Annex
	Use	In accordance with Part XIV of this Annex: • Semiconductors designed for replacement parts not covered in paragraphs 2 (a) and (b) of Part XIV of this Annex • Semiconductors designed for replacement parts for combustion-engine-powered vessels in accordance with the provisions of paragraph 2 of Part XIV of this Annex • Replacement parts for motor vehicles that have ceased mass production in accordance with the provisions of paragraph 2 of Part XIV of this Annex

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(ii) Compounds related to long-chain perfluorocarboxylic acids, for the purposes of the Convention, are any substance that is a precursor and may transform to long-chain perfluorocarboxylic acids, where the perfluorinated alkyl moiety has the formula C_nF_{2n+1} (where 8 ≤ n ≤ 20) and is directly bonded to any chemical moiety other than a fluorine, chlorine or bromine atom. **The following compounds are not included as long-chain perfluorocarboxylic acids, their salts and related compounds: perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds as listed in Annex A to the Convention.**		
Medium-chain chlorinated paraffins (MCCPs) **For the purposes of this Convention, substances or mixtures are considered as "Medium-chain chlorinated paraffins (MCCPs)" when they meet the definition in (i), (ii), or both (i) and (ii):**	Production	As allowed for the Parties listed in the Register in accordance with the provisions of Part XIII of this Annex
	Use	In accordance with Part XIII of this Annex: • Flexible polyvinyl chloride (PVC), limited to the following uses:

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(i) Substances or mixtures that contain linear chloroalkanes with carbon chain lengths in the range $C_{14–17}$ and chlorination levels at or exceeding 45 per cent chlorine by weight; **(ii) Substances or mixtures that contain linear $C_{14–17}$ chloroalkanes of the following molecular formulae:** **$C_{14}H_{(30–y)}Cl_y$ where y ≥ 5; $C_{15}H_{(32–y)}Cl_y$ where y ≥ 5; $C_{16}H_{(34–y)}Cl_y$ where y ≥ 6; $C_{17}H_{(36–y)}Cl_y$ where y ≥ 6.**		◦ Construction sector, including maintenance of buildings and other structures, for uses other than flooring in indoor spaces that are not used for commercial purposes ◦ Wires and cables in the construction sector ◦ Wires and cables in medical devices and in-vitro diagnostic devices ◦ Calendered films in the packaging field, excluding food packaging • Solid woven conveyor belts used in underground coal mines • Flexible elastomeric foam for thermal insulation • Adhesives and sealants, limited to the following uses: ◦ Polysulfide sealant and one-component polyurethane foam used in sealing for doors and windows ◦ Waterproof coatings and anticorrosion coatings ◦ Aerospace and defence applications (e.g., polyurethane adhesives and tamper-proof putty) • Tape used for non-structural bonding in aerospace and defence products • Fatliquoring component in leather, except in children's products • Emergency response pyrotechnic devices

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		• Paints and coatings for ammunition and ammunition markings • Metalworking fluids, in accordance with the provisions of paragraphs 5 and 6 of Part XIII of this Annex • Polymers and rubbers (including PVC, ethylene propylene diene monomer (EPDM) rubber, chloroprene (CR), nitrile butadiene rubber (NBR) and chlorinated polyethylene (CPE)) used in repair and replacement parts, in accordance with the provisions of paragraph 7 of Part XIII of this Annex • Ammunition pyrotechnic defence devices to achieve specific effects (e.g., sound, smoke, light), in accordance with the provisions of paragraphs 8 and 12 of Part XIII of this Annex • Intumescent coating and paint for space and defence equipment and its packaging to protect against extreme temperature, in accordance with the provisions of paragraphs 9 and 12 of Part XIII of this Annex • Coating and paint for the repair of, and use in replacement parts for, space and defence equipment, in accordance with the provisions of paragraphs 10 and 11 of Part XIII of this Annex

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Methoxychlor*	Production	None
"Methoxychlor" refers to any possible isomer of dimethoxydiphenyl-trichloroethane or any combination thereof.	Use	None
For example:		
CAS No: 72-43-5;		
CAS No: 30667-99-3;		
CAS No: 76733-77-2;		
CAS No: 255065-25-9;		
CAS No: 255065-26-0;		
CAS No: 59424-81-6;		
CAS No: 1348358-72-4.		
Mirex* **CAS No: 2385-85-5**	Production	As allowed for the Parties listed in the Register
	Use	Termiticide
Pentachlorobenzene* **CAS No: 608-93-5**	Production	None
	Use	None
Pentachlorophenol and its salts and esters	Production	As allowed for the Parties listed in the Register in accordance with the provisions of Part VIII of this Annex
	Use	Pentachlorophenol for utility poles and cross-arms in accordance with the provisions of Part VIII of this Annex
Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds	Production	None
"Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds" means the following:	Use	None

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(i) Perfluorohexane sulfonic acid (CAS No: 355-46-4, PFHxS), including branched isomers; **(ii) Its salts;** **(iii) Any substance that contains the chemical moiety $C_6F_{13}SO_2$- as one of its structural elements and that potentially degrades to PFHxS.**		
Perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds **"Perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds" means the following:** **(i) Perfluorooctanoic acid (PFOA; CAS No. 335-67-1), including any of its branched isomers;** **(ii) Its salts;** **(iii) PFOA-related compounds which, for the purposes of the Convention, are any substances that degrade to PFOA, including any substances (including salts and polymers) having a linear or branched**	Production	• Fire-fighting foam: None • For other production, as allowed for the Parties listed in the Register in accordance with the provisions of part X of this Annex
	Use	In accordance with the provisions of part X of this Annex: • Photolithography or etch processes in semiconductor manufacturing • Photographic coatings applied to films • Textiles for oil and water repellency for the protection of workers from dangerous liquids that comprise risks to their health and safety • Invasive and implantable medical devices • Fire-fighting foam for liquid fuel vapour suppression and liquid fuel fires (Class B fires) in installed systems, including both mobile and fixed systems, in accordance with paragraph 2 of part X of this Annex

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perfluoroheptyl group with the moiety (C_7F_{15}) C as one of the structural elements;
The following compounds are not included as PFOA-related compounds:
(iv) C_8F_{17}-X, where X= F, Cl, Br;
(v) Fluoropolymers that are covered by CF_3 $[CF_2]_n$-R', where R'=any group, n>16;
(vi) Perfluoroalkyl carboxylic and phosphonic acids (including their salts, esters, halides and anhydrides) with ≥8 perfluorinated carbons;
(vii) Perfluoroalkane sulfonic acids (including their salts, esters, halides and anhydrides) with ≥9 perfluorinated carbons;
(viii) Perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOSF), as listed in Annex B to the Convention.
		• Use of perfluorooctyl iodide for the production of perfluorooctyl bromide for the purpose of producing pharmaceutical products, in accordance with the provisions of paragraph 3 of part X of this Annex
		• Manufacture of polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF) for the production of:
		  ◦ High-performance, corrosion-resistant gas filter membranes, water filter membranes and membranes for medical textiles
		  ◦ Industrial waste heat exchanger equipment
		  ◦ Industrial sealants capable of preventing leakage of volatile organic compounds and PM2.5 particulates
		• Manufacture of polyfluoroethylene propylene (FEP) for the production of high-voltage electrical wire and cables for power transmission
		• Manufacture of fluoroelastomers for the production of O-rings, v-belts and plastic accessories for car interiors

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Polychlorinated Biphenyls (PCB)*	Production	None
	Use	Articles in use in accordance with the provisions of Part II of this Annex
Polychlorinated naphthalenes, including dichlorinated naphthalenes, trichlorinated naphthalenes, tetrachlorinated naphthalenes, pentachlorinated naphthalenes, hexachlorinated naphthalenes, heptachlorinated naphthalenes, octachlorinated naphthalene	Production	Intermediates in production of polyfluorinated naphthalenes, including octafluoronaphthalene
	Use	Production of polyfluorinated naphthalenes, including octafluoronaphthalene
Short-chain chlorinated paraffins (Alkanes, C_{10-13}, chloro)+ : straight-chain chlorinated hydrocarbons with chain lengths ranging from C_{10} to C_{13} and a content of chlorine greater than 48 per cent by weight **For example, the substances with the following CAS numbers may contain short-chain chlorinated paraffins:** **CAS No. 85535-84-8; CAS No. 68920-70-7; CAS No. 71011-12-6; CAS No. 85536-22-7; CAS No. 85681-73-8; CAS No. 108171-26-2.**	Production	As allowed for the Parties listed in the Register
	Use	• Additives in the production of transmission belts in the natural and synthetic rubber industry • Spare parts of rubber conveyor belts in the mining and forestry industries • Leather industry, in particular fatliquoring in leather • Lubricant additives, in particular for engines of automobiles, electric generators and wind power facilities, and for drilling in oil and gas exploration, petroleum refinery to produce diesel oil • Tubes for outdoor decoration bulbs

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		• Waterproofing and fire-retardant paints • Adhesives • Metal processing • Secondary plasticizers in flexible polyvinyl chloride, except in toys and children's products
Technical endosulfan* (CAS No: 115-29-7) and its related isomers* (CAS No: 959-98-8 and CAS No: 33213-65-9)	Production	As allowed for the Parties listed in the Register
	Use	Crop-pest complexes as listed in accordance with the provisions of part VI of this Annex
Tetrabromodiphenyl ether* and pentabromodiphenyl ether*	Production	None
	Use	Articles in accordance with the provisions of Part V of this Annex
Toxaphene* CAS No: 8001-35-2	Production	None
	Use	None
UV-328 CAS No. 25973-55-1	Production	As allowed for the Parties listed in the Register in accordance with the provisions of part XII of this Annex
	Use	In accordance with part XII of this Annex: • Parts of motor vehicles (covering all land-based vehicles, such as cars, motorcycles, agricultural and construction vehicles and industrial trucks), such as bumper systems, radiator grills, spoilers, car garnish, roof modules, soft/hard tops, trunk lids and rear window wipers • Industrial coating applications for motor vehicles, engineering machines, rail transportation vehicles, and heavy-duty coatings for large steel structures

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		• Mechanical separators in blood collection tubes • Triacetyl cellulose (TAC) film in polarizers • Photographic paper • Replacement parts for articles in applications in accordance with the provisions of paragraphs 2 and 3 of part XII of this Annex • Water-seal tape for insulation blankets and decking on aircraft; and polyurethane and polyamide adhesives, and polyurethane coatings, for structural, mechanical, interior and electrical assemblies, and emergency, propulsion, environmental control, and flight control systems, on aircraft.

Notes:

(i) Except as otherwise specified in this Convention, quantities of a chemical occurring as unintentional trace contaminants in products and articles shall not be considered to be listed in this Annex;

(ii) This note shall not be considered as a production and use specific exemption for purposes of paragraph 2 of Article 3. Quantities of a chemical occurring as constituents of articles manufactured or already in use before or on the date of entry into force of the relevant obligation with respect to that chemical, shall not be considered as listed in this Annex, provided that a Party has notified the Secretariat that a particular type of article remains in use within that Party. The Secretariat shall make such notifications publicly available;

(iii) This note, which does not apply to a chemical that has an asterisk following its name in the Chemical column in Part I of this Annex, shall not be considered as a production and use specific exemption for purposes of paragraph 2 of Article 3. Given that no significant quantities of the chemical are expected to reach humans and the environment during the production and use of a closed-system site-limited intermediate, a Party, upon notification to the Secretariat, may allow the production and use of quantities of a chemical listed in this Annex as a closed-system site-limited intermediate that is chemically transformed in the manufacture of other chemicals that, taking into consideration the criteria in paragraph 1 of Annex D, do not exhibit the characteristics of persistent organic pollutants. This notification shall include information on total production and use of such chemical or a reasonable estimate of such information and information regarding the nature of the closed-system site-limited process including the amount of any non-transformed and unintentional trace contamination of the persistent organic pollutant-starting material in the final product. This procedure applies except as otherwise specified in this Annex. The Secretariat shall make such notifications available to the Conference of the Parties and to the public. Such production or use shall not be considered a production or use specific exemption. Such production and use shall cease after a ten-year period, unless the Party concerned submits a new notification to the Secretariat, in which case the period will be extended for an additional ten years

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unless the Conference of the Parties, after a review of the production and use decides otherwise. The notification procedure can be repeated;

(iv) All the specific exemptions in this Annex may be exercised by Parties that have registered exemptions in respect of them in accordance with Article 4 with the exception of the use of polychlorinated biphenyls in articles in use in accordance with the provisions of Part II, and the use of hexabromodiphenyl ether and heptabromodiphenyl ether in accordance with the provisions of Part IV of this Annex, and the use of tetrabromodiphenyl ether and pentabromodiphenyl ether in accordance with the provisions of Part V of this Annex, which may be exercised by all Parties.

(v) Technical endosulfan (CAS No: 115-29-7), its related isomers (CAS No: 959-98-8 and CAS No: 33213-65-9) and endosulfan sulfate (CAS No: 1031-07-8) were assessed and identified as persistent organic pollutants.

(vi) Pentachlorophenol (CAS No: 87-86-5), sodium pentachlorophenate (CAS No: 131-52-2 and 27735-64-4 (as monohydrate)) and pentachlorophenyl laurate (CAS No: 3772-94-9), when considered together with their transformation product pentachloroanisole (CAS No: 1825-21-4), were identified as persistent organic pollutants.

(vii) Note (i) does not apply to quantities of a chemical that has a plus sign ("+") following its name in the "Chemical" column in Part I of this Annex that occurs in mixtures at concentrations greater than or equal to 1 per cent by weight.

Part II
Polychlorinated biphenyls

Each Party shall:

a) With regard to the elimination of the use of polychlorinated biphenyls in equipment (e.g. transformers, capacitors or other receptacles containing liquid stocks) by 2025, subject to review by the Conference of the Parties, take action in accordance with the following priorities:

   i. Make determined efforts to identify, label and remove from use equipment containing greater than 10 per cent polychlorinated biphenyls and volumes greater than 5 litres;

   ii. Make determined efforts to identify, label and remove from use equipment containing greater than 0.05 per cent polychlorinated biphenyls and volumes greater than 5 litres;

   iii. Endeavour to identify and remove from use equipment containing greater than 0.005 percent polychlorinated biphenyls and volumes greater than 0.05 litres;

b) Consistent with the priorities in subparagraph (a), promote the following measures to reduce exposures and risk to control the use of polychlorinated biphenyls:

   i. Use only in intact and non-leaking equipment and only in areas where the risk from environmental release can be minimised and quickly remedied;

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ii. Not use in equipment in areas associated with the production or processing of food or feed;

iii. When used in populated areas, including schools and hospitals, all reasonable measures to protect from electrical failure which could result in a fire, and regular inspection of equipment for leaks;

c) Notwithstanding paragraph 2 of Article 3, ensure that equipment containing polychlorinated biphenyls, as described in subparagraph (a), shall not be exported or imported except for the purpose of environmentally sound waste management;

d) Except for maintenance and servicing operations, not allow recovery for the purpose of reuse in other equipment of liquids with polychlorinated biphenyls content above 0.005 per cent;

e) Make determined efforts designed to lead to environmentally sound waste management of liquids containing polychlorinated biphenyls and equipment contaminated with polychlorinated biphenyls having a polychlorinated biphenyls content above 0.005 per cent, in accordance with paragraph 1 of Article 6, as soon as possible but no later than 2028, subject to review by the Conference of the Parties;

f) In lieu of note (ii) in Part I of this Annex, endeavour to identify other articles containing more than 0.005 per cent polychlorinated biphenyls (e.g. cable-sheaths, cured caulk and painted objects) and manage them in accordance with paragraph 1 of Article 6;

g) Provide a report every five years on progress in eliminating polychlorinated biphenyls and submit it to the Conference of the Parties pursuant to Article 15;

h) The reports described in subparagraph (g) shall, as appropriate, be considered by the Conference of the Parties in its reviews relating to polychlorinated biphenyls. The Conference of the Parties shall review progress towards elimination of polychlorinated biphenyls at five year intervals or other period, as appropriate, taking into account such reports.

Part III
Definitions

For the purpose of this Annex:

a) "Hexabromodiphenyl ether and heptabromodiphenyl ether" mean 2,2',4,4',5,5'-hexabromodiphenyl ether (BDE-153, CAS No: 68631-49-2), 2,2',4,4',5,6'-hexabromodiphenyl ether (BDE-154, CAS No: 207122-15-4), 2,2',3,3',4,5',6-heptabromodiphenyl ether (BDE-175, CAS No: 446255-22-7),

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2,2',3,4,4',5',6-heptabromodiphenyl ether (BDE-183, CAS No: 207122-16-5) and other hexa- and heptabromodiphenyl ethers present in commercial octabromodiphenyl ether.

b) "Tetrabromodiphenyl ether and pentabromodiphenyl ether" means 2,2',4,4'-tetrabromodiphenyl ether (BDE-47, CAS No: 5436-43-1) and 2,2',4,4',5-pentabromodiphenyl ether (BDE-99, CAS No: 60348-60-9) and other tetra- and pentabromodiphenyl ethers present in commercial pentabromodiphenyl ether.

c) "Hexabromocyclododecane" means hexabromocyclododecane (CAS No: 25637-99-4), 1, 2, 5, 6, 9, 10-hexabromocyclododecane (CAS No: 3194-55-6) and its main diastereoisomers: alpha-hexabromocyclododecane (CAS No: 134237-50-6); beta-hexabromocyclododecane (CAS No: 134237-51-7); and gamma-hexabromocyclododecane (CAS No: 134237-52-8).

Part IV
Hexabromodiphenyl ether and heptabromodiphenyl ether

1. A Party may allow recycling of articles that contain or may contain hexabromodiphenyl ether and heptabromodiphenyl ether, and the use and final disposal of articles manufactured from recycled materials that contain or may contain hexabromodiphenyl ether and heptabromodiphenyl ether, provided that:

   a) The recycling and final disposal is carried out in an environmentally sound manner and does not lead to recovery of hexabromodiphenyl ether and heptabromodiphenyl ether for the purpose of their reuse;

   b) The Party takes steps to prevent exports of such articles that contain levels/concentrations of hexabromodiphenyl ether and heptabromodiphenyl ether exceeding those permitted for the sale, use, import or manufacture of those articles within the territory of the Party; and

   c) The Party has notified the Secretariat of its intention to make use of this exemption.

2. At its sixth ordinary meeting and at every second ordinary meeting thereafter the Conference of the Parties shall evaluate the progress that Parties have made towards achieving their ultimate objective of elimination of hexabromodiphenyl ether and heptabromodiphenyl ether contained in articles and review the continued need for this specific exemption. This specific exemption shall in any case expire at the latest in 2030.

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Part V
Tetrabromodiphenyl ether and pentabromodiphenyl ether

1. A Party may allow recycling of articles that contain or may contain tetrabromodiphenyl ether and pentabromodiphenyl ether, and the use and final disposal of articles manufactured from recycled materials that contain or may contain tetrabromodiphenyl ether and pentabromodiphenyl ether, provided that:

    a) The recycling and final disposal is carried out in an environmentally sound manner and does not lead to recovery of tetrabromodiphenyl ether and pentabromodiphenyl ether for the purpose of their reuse;

    b) The Party does not allow this exemption to lead to the export of articles containing levels/concentrations of tetrabromodiphenyl ether and pentabromodiphenyl ether that exceed those permitted to be sold the within the territory of the Party; and

    c) The Party has notified the Secretariat of its intention to make use of this exemption.

2. At its sixth ordinary meeting and at every second ordinary meeting thereafter the Conference of the Parties shall evaluate the progress that Parties have made towards achieving their ultimate objective of elimination of tetrabromodiphenyl ether and pentabromodiphenyl ether contained in articles and review the continued need for this specific exemption. This specific exemption shall in any case expire at the latest in 2030.

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Part VI
Technical endosulfan and its related isomers (endosulfan)

1. The production and use of endosulfan shall be eliminated except for Parties that have notified the Secretariat of their intention to produce and/or use it in accordance with Article 4 of the Convention. Specific exemptions may be available for the use of endosulfan for the following crop-pest complexes:

Crop	Pest
Apple	Aphids
Arhar, gram	Aphids, caterpillars, pea semilooper, pod borer
Bean, cowpea	Aphids, leaf miner, whiteflies
Chilli, onion, potato	Aphids, jassids
Coffee	Berry borer, stem borers
Cotton	Aphids, cotton bollworm, jassids, leaf rollers, pink bollworm, thrips, whiteflies
Eggplant, okra	Aphids, diamondback moth, jassids, shoot and fruit borer
Groundnut	Aphids
Jute	Bihar hairy caterpillar, yellow mite
Maize	Aphids, pink borer, stem borers
Mango	Fruit flies, hoppers
Mustard	Aphids, gall midges
Rice	Gall midges, rice hispa, stem borers, white jassid
Tea	Aphids, caterpillars, flushworm, mealybugs, scale insects, smaller green leafhopper, tea geometrid, tea mosquito bug, thrips
Tobacco	Aphids, oriental tobacco budworm
Tomato	Aphids, diamondback moth, jassids, leaf miner, shoot and fruit borer, whiteflies
Wheat	Aphids, pink borer, termites

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Part VII
Hexabromocyclododecane

Each Party that has registered for the exemption pursuant to Article 4 for the production and use of hexabromocyclododecane for expanded polystyrene and extruded polystyrene in buildings shall take necessary measures to ensure that expanded polystyrene and extruded polystyrene containing hexabromocyclododecane can be easily identified by labelling or other means throughout its life cycle.

Part VIII
Pentachlorophenol and its salts and esters

Each Party that has registered for the exemption, pursuant to Article 4 for the production and use of pentachlorophenol for utility poles and cross-arms shall take the necessary measures to ensure that utility poles and cross-arms containing pentachlorophenol can be easily identified by labelling or other means throughout their life cycles. Articles treated with pentachlorophenol should not be reused for purposes other than those exempted.

Part IX
Decabromodiphenyl ether

1. The production and use of decabromodiphenyl ether shall be eliminated except for Parties that have notified the Secretariat of their intention to produce and/or use it in accordance with Article 4.

2. Specific exemptions for parts for use in vehicles may be available for the production and use of commercial decabromodiphenyl ether limited to the following:

    a) Parts for use in legacy vehicles, defined as vehicles that have ceased mass production, and with such parts falling into one or more of the following categories:

        i. Powertrain and under-hood applications such as battery mass wires, battery interconnection wires, mobile air-conditioning (MAC) pipes, powertrains, exhaust manifold bushings, under-hood insulation, wiring and harness under hood (engine wiring, etc.), speed sensors, hoses, fan modules and knock sensors;

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ii. Fuel system applications such as fuel hoses, fuel tanks and fuel tanks under body;

iii. Pyrotechnical devices and applications affected by pyrotechnical devices such as air bag ignition cables, seat covers/fabrics (only if airbag relevant) and airbags (front and side);

iv. Suspension and interior applications such as trim components, acoustic material and seat belts.

b) Parts in vehicles specified in paragraphs 2 (a) (i)–(iv) above and those falling into one or more of the following categories:

i. Reinforced plastics (instrument panels and interior trim);

ii. Under the hood or dash (terminal/fuse blocks, higher-amperage wires and cable jacketing (spark plug wires));

iii. Electric and electronic equipment (battery cases and battery trays, engine control electrical connectors, components of radio disks, navigation satellite systems, global positioning systems and computer systems);

iv. Fabric such as rear decks, upholstery, headliners, automobile seats, head rests, sun visors, trim panels, carpets.

3. The specific exemptions for parts specified in paragraph 2 (a) above shall expire at the end of the service life of legacy vehicles or in 2036, whichever comes earlier.

4. The specific exemptions for parts specified in paragraph 2 (b) above shall expire at the end of the service life of vehicles or in 2036, whichever comes earlier.

5. The specific exemptions for spare parts for aircraft for which type approval has been applied for before December 2018 and has been received before December 2022 shall expire at the end of the service life of those aircraft.

Part X
Perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds

1. The production and use of perfluorooctanoic acid (PFOA), its salts and PFOA related compounds shall be eliminated except for Parties that have notified the Secretariat of their intention to produce and/or use them in accordance with Article 4 of the Convention.

2. Each Party that has registered for a specific exemption pursuant to Article 4 for the use of PFOA, its salts and PFOA-related compounds for fire-fighting foam shall:

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a) Notwithstanding paragraph 2 of Article 3, ensure that fire-fighting foam that contains or may contain PFOA, its salts and PFOA-related compounds shall not be exported or imported except for the purpose of environmentally sound disposal as set forth in paragraph 1 (d) of Article 6;

b) Not use fire-fighting foam that contains or may contain PFOA, its salts and PFOA-related compounds for training;

c) Not use fire-fighting foam that contains or may contain PFOA, its salts and PFOA-related compounds for testing unless all releases are contained;

d) By the end of 2022, if it has the capacity to do so, but no later than 2025, restrict uses of fire-fighting foam that contains or may contain PFOA, its salts and PFOA-related compounds to sites where all releases can be contained;

e) Make determined efforts designed to lead to the environmentally sound management of fire-fighting foam stockpiles and wastes that contain or may contain PFOA, its salts and PFOA-related compounds, in accordance with paragraph 1 of Article 6, as soon as possible;

3. With regard to the specific exemption for the use of perfluorooctyl iodide for the production of perfluorooctyl bromide for the purpose of producing pharmaceutical products, at its thirteenth ordinary meeting and at every second ordinary meeting thereafter, the Conference of the Parties shall review the continued need for this specific exemption. This specific exemption shall in any case expire at the latest in 2036.

Part XI
Dechlorane Plus

1. The use of Dechlorane Plus shall be eliminated except for Parties that have notified the Secretariat of their intention to use it in accordance with Article 4.

2. Specific exemptions for the use of Dechlorane Plus for replacement parts for, and repair of, articles shall apply where Dechlorane Plus was originally used in the manufacture of those articles and may be available, limited to the following applications, until the end of the service life of the articles or 2044, whichever comes earlier:

   a) Aerospace (such as aircraft engine fan case rub strip products and void-filling and edge-sealing products, aircraft engine manufacturing repairs, electrical items, structural panels and aircraft cabin interiors);

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b) Space (such as satellites, probes and other exploration equipment, manned cabins and laboratories, heat-insulating materials for rocket motors and ground support equipment);

c) Defence (such as naval vessels, missiles, launch platforms, ordnance, communication equipment, radar and lidar systems and support equipment);

d) Motor vehicles (covering all land-based vehicles, such as cars, motorcycles, agricultural and construction vehicles and industrial trucks; applications include cables, wire harnesses, connectors and insulation tapes);

e) Stationary industrial machines (such as tower cranes, concrete plants and hydraulic crushers; applications include cables, wire harnesses, connectors and insulation tapes) for use in agriculture, forestry and construction;

f) Marine, garden, forestry and outdoor power equipment;

g) Instruments for analysis, measurements, control, monitoring, testing, production and inspection.

3. Specific exemptions for the use of Dechlorane Plus for replacement parts for, and repair of, articles shall apply where Dechlorane Plus was originally used in the manufacture of those articles and may be available, limited to the following applications, until the end of the service life of those articles, subject to review by the Conference of the Parties no later than 2041:

a) Medical devices (such as ultrasound diagnostic devices, magnetic resonance imaging systems, X-ray imaging systems, flexible endoscopes and radiotherapy devices and installations);

b) In-vitro diagnostic devices (such as immunoassay analysers, haematology analysers, polymerase chain reaction (PCR) testing systems, genetic analysers, clinical chemistry analysers, blood coagulation analysers and urinalysis analysers).

Part XII
UV-328

1. The production and use of UV-328 shall be eliminated except for Parties that have notified the Secretariat of their intention to produce and/or use it in accordance with Article 4.

2. Specific exemptions for the production and use of UV-328 for replacement parts for articles shall apply where UV-328 was originally used in the manufacture of those articles and may be available, limited to the following applications, until the end of the service life of the articles or 2044, whichever comes earlier:

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a) Motor vehicles (covering all land-based vehicles, such as cars, motorcycles, agricultural and construction vehicles and industrial trucks);

b) Stationary industrial machines (such as tower cranes, concrete plants and hydraulic crushers) for use in agriculture, forestry and construction;

c) Liquid crystal displays in instruments for analysis, measurements, control, monitoring, testing, production and inspection (such as recorders, infrared radiation thermometers, digital storage oscilloscopes and radiographic testing instruments) other than for medical applications.

3. Specific exemptions for the use of UV-328 for replacement parts for articles for the following applications for medical purposes shall apply where UV-328 was originally used in the manufacture of those articles and may be available until the end of the service life of those articles, subject to review by the Conference of the Parties no later than 2041:

a) Liquid crystal displays in medical and in-vitro diagnostic devices (such as ultrasound diagnostic devices, flexible endoscopes, immunoassay analysers, clinical chemistry analysers and blood coagulation analysers);

b) Liquid crystal displays in instruments for analysis, measurements, control, monitoring, testing, production and inspection (such as recorders, infrared radiation thermometers, digital storage oscilloscopes and radiographic testing instruments).

4. Regarding the specific exemption for "water-seal tape for insulation blankets and decking on aircraft; and polyurethane and polyamide adhesives, and polyurethane coatings, for structural, mechanical, interior and electrical assemblies, and emergency, propulsion, environmental control, and flight control systems, on aircraft", it is limited to use only. This exemption shall in any case expire by the end of 2030.

Part XIII
Medium-chain chlorinated paraffins

1. The production and use of medium-chain chlorinated paraffins shall be eliminated except for Parties that have notified the Secretariat of their intention to produce and/or use them in accordance with Article 4.

2. Note (i) of Annex A does not apply when the summed concentration of the following C_{14-17} chloroalkanes ($C_{14}H_{(30-y)}Cl_y$ where $y \geq 5$; $C_{15}H_{(32-y)}Cl_y$ where $y \geq 5$; $C_{16}H_{(34-y)}Cl_y$ where $y \geq 6$; $C_{17}H_{(36-y)}Cl_y$ where $y \geq 6$) in substances or mixtures occurs at a concentrations greater than 3 per cent by weight, subject to review by the

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Conference of the Parties at its fourteenth ordinary meeting and every second ordinary meeting thereafter, with the aim to reduce this limit over time.

3. Each Party is encouraged to require that manufacturers of chlorinated paraffins within their jurisdiction disclose information, including to others in the supply chain, on the summed concentration of the following linear C_{14-17} chloroalkanes in those chlorinated paraffins:

   a) $\Sigma C_{14}H_{(30-y)}Cl_y$ where $y \geq 5$;

   b) $\Sigma C_{15}H_{(32-y)}Cl_y$ where $y \geq 5$;

   c) $\Sigma C_{16}H_{(34-y)}Cl_y$ where $y \geq 6$;

   d) $\Sigma C_{17}H_{(36-y)}Cl_y$ where $y \geq 6$.

Alternatively, manufacturers of chlorinated paraffins can provide information, including to others in the supply chain, on the concentration of linear C_{14-17} alkanes present in the feedstock used to produce the corresponding chlorinated paraffins.

4. For mixtures containing more than one chlorinated paraffin product, or containing chlorinated paraffin products and other substances, Parties are encouraged to require that the information on the concentrations specified in paragraph 3 above be provided for all chlorinated paraffin products present in the mixture.

5. Specific exemptions for the production and use of medium-chain chlorinated paraffins for metalworking fluids shall apply where they are used in professional or industrial settings with collection systems, and may be available until 2036, limited to use as extreme temperature and pressure additives for metalworking fluids used in "heavy-duty" processes (including deep drawing, broaching and fine blanking, drawing with ironing, precision metalworking (cutting/punching/drilling), tapping, cold drawing, cold rolling (pilgering), stamping, forging, and grinding) for the production and repair of metals and metal alloy components (including steel, titanium, nickel, aluminium, copper, magnesium and beryllium) such as those used in the following applications and sectors:

   a) Aerospace;

   b) Defence;

   c) Motor vehicles covering all land-based vehicles, such as cars, motorcycles, agriculture and construction vehicles, and industrial trucks;

   d) Electrical and electronic equipment (EEE) used in medical devices, in-vitro diagnostics devices, and instruments for measurement, analysis, manufacturing, control, monitoring, testing and inspection;

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e) Machinery and tools used in agriculture, building/construction, forestry and landscaping;

f) Energy and power generation;

g) Oil and gas extraction;

h) Chemical production and refining;

i) Nuclear power facilities;

j) Low-carbon and renewable energy technologies;

k) Non-EEE medical devices;

6. Each Party that has registered for a specific exemption pursuant to Article 4 for the use of medium-chain chlorinated paraffins for metalworking fluids in professional or industrial settings with collection systems shall take measures to ensure protection of workers from risks associated with these uses.

7. Specific exemptions for the production and use of medium-chain chlorinated paraffins for polymers and rubbers (including PVC, ethylene propylene diene monomer (EPDM) rubber, chloroprene (CR), nitrile butadiene rubber (NBR) and chlorinated polyethylene (CPE)), used in replacement parts for, and repair of, articles shall apply where the substances were originally used in the manufacture of those articles, and may be available, limited to use in the following applications, until the end of service life of the articles or 2041, whichever comes earlier:

   a) Parts for land-based motor vehicles and machinery used in agriculture, construction, forestry, and landscaping (including powertrain and under-hood applications such as powertrains: wiring and under-hood harnesses (engine wiring, etc.); hoses, caps, tubes, filters; fuel system applications such as fuel hoses, fuel tanks, caps and underbodies; suspension and interior applications such as trim components, acoustic material and seat belts; exterior vehicle applications such as foam pads, sealers, gaskets, fasteners and windows; pyrotechnical devices and applications affected by pyrotechnical devices such as airbag ignition cables, seat covers/fabrics (only if airbag-relevant) and airbags);

   b) EEE used for medical devices, in-vitro diagnostics devices, and instruments for measurement, analysis, manufacturing, control, monitoring, testing and inspection;

   c) Aerospace and defence applications.

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8. Specific exemptions for the production and use of medium-chain chlorinated paraffins for ammunition pyrotechnic defence devices to achieve specific effects (e.g. sound, smoke, light) may be available until 2041.

9. Specific exemptions for the production and use of medium-chain chlorinated paraffins for intumescent coating and paint for space and defence equipment and its packaging to protect against extreme temperature may be available until 2041.

10. Specific exemptions for the production and use of medium-chain chlorinated paraffins in coating and paint for the repair of, and use in replacement parts for, space and defence equipment shall apply where medium-chain chlorinated paraffins were originally used in the manufacture of that equipment and may remain available until the end of service life of that equipment for its repair and maintenance, subject to review by the Conference of the Parties no later than 2041.

11. Each Party that has registered for a specific exemption pursuant to Article 4 for the use of medium-chain chlorinated paraffins in coating and paint for the repair of, and use in replacement parts for, space and defence equipment shall take measures to ensure the protection of workers from risks associated with this use.

12. With regard to the specific exemptions for the production and use of medium chain chlorinated paraffins for the applications referred to in paragraphs 8 and 9, at its fifteenth ordinary meeting and at every second ordinary meeting thereafter, the Conference of the Parties shall review the continued need for these specific exemptions.

Part XIV
Long-chain perfluorocarboxylic acids, their salts and related compounds

1. The production and use of long-chain perfluorocarboxylic acids, their salts and related compounds shall be eliminated except for Parties that have notified the Secretariat of their intention to produce and/or use them in accordance with Article 4.

2. Specific exemptions for the production and use of long-chain perfluorocarboxylic acids, their salts and related compounds, limited to the following applications, may be available until the end of the service life of articles being repaired or until 2041, whichever comes earlier:

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a) Semiconductors designed for replacement parts for combustion-engine-powered vessels;

b) Replacement parts for motor vehicles that have ceased mass production, covering all land-based vehicles, such as cars, motorcycles, agricultural and construction vehicles, and industrial trucks. Applications include semiconductors, coatings, cables, electronics, engines and under-hood applications, modules, hydraulic system components and relay assemblies.

Part XV
Chlorpyrifos

1. The production and use of chlorpyrifos shall be eliminated except for Parties that have notified the Secretariat of their intention to produce and/or use it in accordance with Article 4 of the Convention.

2. Specific exemptions for chlorpyrifos may be available for agricultural use only for the following crop pest complexes:

Crop	Pest
Barley	Termites
Cabbage	Diamondback moth *(Plutella xylostella)*
Cacao	Cacao-mosquitos *(Helopeltis spp.)*, cacao pod borer *(Conopomorpha cramerella)*
Chickpea	Cutworms
Citrus	Scale insects
Cotton, cotton seed	Aphids, carpophagous caterpillars, cutworms, spider mites, cotton leaf roller *(Syllepte derogata)*, whitefly larvae, whitefly adults
Eggplant	Shoot and fruit borer *(Leucinodes orbonalis)*
Maize	Armyworms *(Spodoptera cosmioides and Spodoptera frugiperda)*, lesser cornstalk borer *(Elasmopalpus lignosellus)*, variegated cutworm *(Peridroma saucia)*, corn earworm *(Helicoverpa armigera)*, sugarcane white grub *(Lepidiota stigma)*, seedling flies *(Atherigona spp.)*, stem borer *(Ostrinia furnacalis)*, green stink bug *(Nezara viridula)*

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Onion	Root grubs
Peanut	White grubs
Pineapple	Mealybug *(Dysmicoccus brevipes)*, pineapple weevil *(Metamasius dimidiatipennis)*, glasshouse symphylid *(Scutigerella immaculata)*
Rapeseed	Crucifer flea beetle, turnip sawfly, common pollen beetle, turnip gall weevil
Rice	Rice planthoppers, rice stemborers, rice leaf rollers
Sorghum	Armyworms *(Spodoptera cosmioides* and *Spodoptera frugiperda)*, lesser cornstalk borer *(Elasmopalpus lignosellus)*
Soya bean	Armyworm *(Spodoptera litura)*, soybean pod borer *(Etiella zinckenella)*, soybean seed fly *(Ophiomyia phaseoli)*, soybean leaf beetle *(Phaedonia inclusa stall)*, tobacco whitefly *(Bemisia tabaci)*, soybean aphid *(Aphis glycines)*, spiraling whitefly *(Aleurodicus dispersus)*, green stink bug *(Nezara viridula)*, brown stink bug *(Riptortus linearis)*, spider mite *(Tetranychus cinnabarinus)*
Sugar cane	Termites, beetles, sugarcane white grub *(Lepidiota stigma)*, sugarcane top borer *(Triporyza vinella)*, sugarcane stem borer *(Proceras sacchariphagus)*
Teff	Termites
Wheat	Termites, corn bugs, wheat chafers, leaf beetles, aphids, thrips

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ANNEX B[3]
RESTRICTION

Part I

Chemical	Activity	Acceptable purpose or specific exemption[4]
DDT (1,1,1-trichloro-2,2-bis (4-chlorophenyl)ethane) CAS No: 50-29-3	Production	Acceptable purpose: Disease vector control use in accordance with Part II of this Annex Specific exemption: Intermediate in production of dicofol Intermediate
	Use	Acceptable purpose: Disease vector control in accordance with Part II of this Annex Specific exemption: Production of dicofol Intermediate
Perfluorooctane sulfonic acid (CAS No. 1763-23-1), its salts[a] and perfluorooctane sulfonyl fluoride (CAS No. 307-35-7) **[a] For example: potassium perfluorooctane sulfonate (CAS No. 2795-39-3);**	Production	Acceptable purpose: In accordance with Part III of this Annex, production of other chemicals to be used solely for the use below. Production for uses listed below. Specific exemption: None

[3] *Secretariat note: As amended by decision SC-4/17 of 8 May 2009 and SC-9/4 of 10 May 2019*

[4] *Secretariat note: Please note that, in accordance with paragraph 9 of Article 4 of the Convention, when there are no longer any Parties registered for a particular type of specific exemption no new registrations may be made with respect to such exemptions, which appear in grey text in the table.*

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lithium perfluorooctane sulfonate (CAS No. 29457-72-5); ammonium perfluorooctane sulfonate (CAS No. 29081-56-9); diethanolammonium perfluorooctane sulfonate (CAS No. 70225-14-8); tetraethylammonium perfluorooctane sulfonate (CAS No. 56773-42-3); didecyldimethylammonium perfluorooctane sulfonate (CAS No. 251099-16-8)	Use	Acceptable purpose: In accordance with Part III of this Annex for the following acceptable purpose, or as an intermediate in the production of chemicals with the following acceptable purpose: • Insect baits with sulfluramid (CAS No. 4151-50-2) as an active ingredient for control of leaf-cutting ants from *Atta* spp. and *Acromyrmex* spp. for agricultural use only Specific exemption: • Metal plating (hard-metal plating) only in closed-loop systems • Fire-fighting foam for liquid fuel vapour suppression and liquid fuel fires (Class B fires) in installed systems, including both mobile and fixed systems, in accordance with paragraph 10 of part III of this Annex

Notes:

(i) Except as otherwise specified in this Convention, quantities of a chemical occurring as unintentional trace contaminants in products and articles shall not be considered to be listed in this Annex;

(ii) This note shall not be considered as a production and use acceptable purpose or specific exemption for purposes of paragraph 2 of Article 3. Quantities of a chemical occurring as constituents of articles manufactured or already in use before or on the date of entry into force of the relevant obligation with respect to that chemical, shall not be considered as listed in this Annex, provided that a Party has notified the Secretariat that a particular type of article remains in use within that Party. The Secretariat shall make such notifications publicly available;

(iii) This note shall not be considered as a production and use specific exemption for purposes of paragraph 2 of Article 3. Given that no significant quantities of the chemical are expected to reach humans and the environment during the production and use of a closed-system site-limited intermediate, a Party, upon notification to the Secretariat, may allow the production and use of quantities of a chemical listed in this Annex as a closed-system site-limited intermediate that is chemically transformed in the manufacture of other chemicals that, taking into consideration the criteria in paragraph 1 of Annex D, do not exhibit the characteristics of persistent organic pollutants. This notification shall include information on total production and use of such chemical or a reasonable estimate of such information and information regarding the nature of the closed-system site-limited process including the amount of any non-transformed and unintentional trace contamination of the persistent organic pollutant-starting material in the final product. This procedure applies except as otherwise specified in this Annex. The Secretariat

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shall make such notifications available to the Conference of the Parties and to the public. Such production or use shall not be considered a production or use specific exemption. Such production and use shall cease after a ten-year period, unless the Party concerned submits a new notification to the Secretariat, in which case the period will be extended for an additional ten years unless the Conference of the Parties, after a review of the production and use decides otherwise. The notification procedure can be repeated;

(iv) All the specific exemptions in this Annex may be exercised by Parties that have registered in respect of them in accordance with Article 4.

Part II
DDT (1,1,1-trichloro-2,2-bis (4-chlorophenyl)ethane)

1. The production and use of DDT shall be eliminated except for Parties that have notified the Secretariat of their intention to produce and/or use it. A DDT Register is hereby established and shall be available to the public. The Secretariat shall maintain the DDT Register.

2. Each Party that produces and/or uses DDT shall restrict such production and/ or use for disease vector control in accordance with the World Health Organization recommendations and guidelines on the use of DDT and when locally safe, effective and affordable alternatives are not available to the Party in question.

3. In the event that a Party not listed in the DDT Register determines that it requires DDT for disease vector control, it shall notify the Secretariat as soon as possible in order to have its name added forthwith to the DDT Register. It shall at the same time notify the World Health Organization.

4. Every three years, each Party that uses DDT shall provide to the Secretariat and the World Health Organization information on the amount used, the conditions of such use and its relevance to that Party's disease management strategy, in a format to be decided by the Conference of the Parties in consultation with the World Health Organization.

5. With the goal of reducing and ultimately eliminating the use of DDT, the Conference of the Parties shall encourage:

    a) Each Party using DDT to develop and implement an action plan as part of the implementation plan specified in Article 7. That action plan shall include:

        i. Development of regulatory and other mechanisms to ensure that DDT use is restricted to disease vector control;

        ii. Implementation of suitable alternative products, methods and strategies, including resistance management strategies to ensure the continuing effectiveness of these alternatives;

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iii. Measures to strengthen health care and to reduce the incidence of the disease.

b) The Parties, within their capabilities, to promote research and development of safe alternative chemical and non-chemical products, methods and strategies for Parties using DDT, relevant to the conditions of those countries and with the goal of decreasing the human and economic burden of disease. Factors to be promoted when considering alternatives or combinations of alternatives shall include the human health risks and environmental implications of such alternatives. Viable alternatives to DDT shall pose less risk to human health and the environment, be suitable for disease control based on conditions in the Parties in question and be supported with monitoring data.

6. Commencing at its first meeting, and at least every three years thereafter, the Conference of the Parties shall, in consultation with the World Health Organization, evaluate the continued need for DDT for disease vector control on the basis of available scientific, technical, environmental and economic information, including:

   a) The production and use of DDT and the conditions set out in paragraph 2;

   b) The availability, suitability and implementation of the alternatives to DDT; and

   c) Progress in strengthening the capacity of countries to transfer safely to reliance on such alternatives.

7. A Party may, at any time, withdraw its name from the DDT Registry upon written notification to the Secretariat. The withdrawal shall take effect on the date specified in the notification.

Part III
Perfluorooctane sulfonic acid, its salts, and perfluorooctane sulfonyl fluoride

1. The production and use of perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOSF) shall be eliminated by all Parties except as provided in Part I of this Annex for Parties that have notified the Secretariat of their intention to produce and/or use them for acceptable purposes. A Register of Acceptable Purposes is hereby established and shall be available to the public. The Secretariat shall maintain the Register of Acceptable Purposes. In the event that a Party not listed in the Register determines that it requires the use of PFOS, its salts or PFOSF for the acceptable purposes listed in Part I of this Annex it shall notify the Secretariat as soon as possible in order to have its name added forthwith to the Register.

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2. Parties that produce and/or use these chemicals shall take into account, as appropriate, guidance such as that given in the relevant parts of the general guidance on best available techniques and best environmental practices given in Part V of Annex C of the Convention.

3. Every four years, each Party that uses and/or produces these chemicals shall report on progress made to eliminate PFOS, its salts and PFOSF and submit information on such progress to the Conference of the Parties pursuant to and in the process of reporting under Article 15 of the Convention.

4. With the goal of reducing and ultimately eliminating the production and/or use of these chemicals, the Conference of the Parties shall encourage:

    a) Each Party using these chemicals to take action to phase out uses when suitable alternatives substances or methods are available;

    b) Each Party using and/or producing these chemicals to develop and implement an action plan as part of the implementation plan specified in Article 7 of the Convention;

    c) The Parties, within their capabilities, to promote research on and development of safe alternative chemical and non-chemical products and processes, methods and strategies for Parties using these chemicals, relevant to the conditions of those Parties. Factors to be promoted when considering alternatives or combinations of alternatives shall include the human health risks and environmental implications of such alternatives.

5. The Conference of the Parties shall evaluate the continued need for these chemicals for the various acceptable purposes and specific exemptions on the basis of available scientific, technical, environmental and economic information, including:

    a) Information provided in the reports described in paragraph 3;

    b) Information on the production and use of these chemicals;

    c) Information on the availability, suitability and implementation of alternatives to these chemicals;

    d) Information on progress in building the capacity of countries to transfer safely to reliance on such alternatives.

6. The evaluation referred to in the preceding paragraph shall take place no later than in 2015 and every four years thereafter, in conjunction with a regular meeting of the Conference of the Parties.

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7. Due to the complexity of the use and the many sectors of society involved in the use of these chemicals, there might be other uses of these chemicals of which countries are not presently aware. Parties which become aware of other uses are encouraged to inform the Secretariat as soon as possible.

8. A Party may, at any time, withdraw its name from the Register of acceptable purposes upon written notification to the Secretariat. The withdrawal shall take effect on the date specified in the notification.

9. The provisions of note (iii) of Part I of Annex B shall not apply to these chemicals.

10. Each Party that has registered for an exemption pursuant to Article 4 for the use of PFOS, its salts and PFOSF for fire-fighting foam shall:

    a) Notwithstanding paragraph 2 of Article 3, ensure that fire-fighting foam that contains or may contain PFOS, its salts and PFOSF shall not be exported or imported except for the purpose of environmentally sound disposal as set forth in paragraph 1 (d) of Article 6;

    b) Not use fire-fighting foam that contains or may contain PFOS, its salts and PFOSF for training;

    c) Not use fire-fighting foam that contains or may contain PFOS, its salts and PFOSF for testing unless all releases are contained;

    d) By the end of 2022, if it has the capacity to do so, restrict uses of fire-fighting foam that contains or may contain PFOS, its salts and PFOSF to sites where all releases can be contained;

    e) Make determined efforts designed to lead to the environmentally sound management of fire-fighting foam stockpiles and wastes that contain or may contain PFOS, its salts and PFOSF, in accordance with paragraph 1 of Article 6, as soon as possible.

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ANNEX C[5]
UNINTENTIONAL PRODUCTION

Part I
Persistent organic pollutants subject to the requirements of Article 5

This Annex applies to the following persistent organic pollutants when formed and released unintentionally from anthropogenic sources:

Chemical
Hexachlorobenzene (HCB) (CAS No: 118-74-1)
Hexachlorobutadiene (CAS No: 87-68-3)
Pentachlorobenzene (PeCB) (CAS No: 608-93-5)
Polychlorinated biphenyls (PCB)
Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/PCDF)
Polychlorinated naphthalenes, including dichlorinated naphthalenes, trichlorinated naphthalenes, tetrachlorinated naphthalenes, pentachlorinated naphthalenes, hexachlorinated naphthalenes, heptachlorinated naphthalenes, octachlorinated naphthalene

Part II
Source categories

Hexachlorobenzene, hexachlorobutadiene, pentachlorobenzene, polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins and dibenzofurans, polychlorinated naphthalenes, including dichlorinated naphthalenes, trichlorinated naphthalenes, tetrachlorinated naphthalenes, pentachlorinated naphthalenes, hexachlorinated naphthalenes, heptachlorinated naphthalenes, octachlorinated naphthalene are unintentionally formed and released from thermal processes involving organic matter and chlorine as a result of incomplete combustion or chemical reactions.

The following industrial source categories have the potential for comparatively high formation and release of these chemicals to the environment:

[5] *Secretariat note: As amended by decisions SC-4/16 and SC-4/18 of 8 May 2009; SC-7/14 of 15 May 2015; and SC-8/12 of 5 May 2017.*

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a) Waste incinerators, including co-incinerators of municipal, hazardous or medical waste or of sewage sludge;
b) Cement kilns firing hazardous waste;
c) Production of pulp using elemental chlorine or chemicals generating elemental chlorine for bleaching;
d) The following thermal processes in the metallurgical industry:
    i. Secondary copper production;
    ii. Sinter plants in the iron and steel industry;
    iii. Secondary aluminium production;
    iv. Secondary zinc production.

Part III
Source categories

Hexachlorobenzene, hexachlorobutadiene, pentachlorobenzene, polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins and dibenzofurans, polychlorinated naphthalenes, including dichlorinated naphthalenes, trichlorinated naphthalenes, tetrachlorinated naphthalenes, pentachlorinated naphthalenes, hexachlorinated naphthalenes, heptachlorinated naphthalenes, octachlorinated naphthalene may also be unintentionally formed and released from the following source categories, including:

a) Open burning of waste, including burning of landfill sites;
b) Thermal processes in the metallurgical industry not mentioned in Part II;
c) Residential combustion sources;
d) Fossil fuel-fired utility and industrial boilers;
e) Firing installations for wood and other biomass fuels;
f) Specific chemical production processes releasing unintentionally formed persistent organic pollutants, especially production of chlorophenols and chloranil;
g) Crematoria;
h) Motor vehicles, particularly those burning leaded gasoline;
i) Destruction of animal carcasses;
j) Textile and leather dyeing (with chloranil) and finishing (with alkaline extraction);
k) Shredder plants for the treatment of end-of-life vehicles;
l) Smouldering of copper cables;
m) Waste oil refineries.

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Part IV
Definitions

1. For the purposes of this Annex:

    a) "Polychlorinated biphenyls" means aromatic compounds formed in such a manner that the hydrogen atoms on the biphenyl molecule (two benzene rings bonded together by a single carbon-carbon bond) may be replaced by up to ten chlorine atoms; and

    b) "Polychlorinated dibenzo-p-dioxins" and "polychlorinated dibenzofurans" are tricyclic, aromatic compounds formed by two benzene rings connected by two oxygen atoms in polychlorinated dibenzo-p-dioxins and by one oxygen atom and one carbon-carbon bond in polychlorinated dibenzofurans and the hydrogen atoms of which may be replaced by up to eight chlorine atoms.

2. In this Annex, the toxicity of polychlorinated dibenzo-p-dioxins and dibenzofurans is expressed using the concept of toxic equivalency which measures the relative dioxin-like toxic activity of different congeners of polychlorinated dibenzo-p-dioxins and dibenzofurans and coplanar polychlorinated biphenyls in comparison to 2,3,7,8-tetrachlorodibenzo-p-dioxin. The toxic equivalent factor values to be used for the purposes of this Convention shall be consistent with accepted international standards, commencing with the World Health Organization 1998 mammalian toxic equivalent factor values for polychlorinated dibenzo-p-dioxins and dibenzofurans and coplanar polychlorinated biphenyls. Concentrations are expressed in toxic equivalents.

Part V
General guidance on best available techniques and best environmental practices

This Part provides general guidance to Parties on preventing or reducing releases of the chemicals listed in Part I.

A. General prevention measures relating to both best available techniques and best environmental practices

Priority should be given to the consideration of approaches to prevent the formation and release of the chemicals listed in Part I. Useful measures could include:

a) The use of low-waste technology;

b) The use of less hazardous substances;

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c) The promotion of the recovery and recycling of waste and of substances generated and used in a process;

d) Replacement of feed materials which are persistent organic pollutants or where there is a direct link between the materials and releases of persistent organic pollutants from the source;

e) Good housekeeping and preventive maintenance programmes;

f) Improvements in waste management with the aim of the cessation of open and other uncontrolled burning of wastes, including the burning of landfill sites. When considering proposals to construct new waste disposal facilities, consideration should be given to alternatives such as activities to minimize the generation of municipal and medical waste, including resource recovery, reuse, recycling, waste separation and promoting products that generate less waste. Under this approach, public health concerns should be carefully considered;

g) Minimization of these chemicals as contaminants in products;

h) Avoiding elemental chlorine or chemicals generating elemental chlorine for bleaching.

B. Best available techniques

The concept of best available techniques is not aimed at the prescription of any specific technique or technology, but at taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. Appropriate control techniques to reduce releases of the chemicals listed in Part I are in general the same. In determining best available techniques, special consideration should be given, generally or in specific cases, to the following factors, bearing in mind the likely costs and benefits of a measure and consideration of precaution and prevention:

a) General considerations:

   i. The nature, effects and mass of the releases concerned: techniques may vary depending on source size;

   ii. The commissioning dates for new or existing installations;

   iii. The time needed to introduce the best available technique;

   iv. The consumption and nature of raw materials used in the process and its energy efficiency;

   v. The need to prevent or reduce to a minimum the overall impact of the releases to the environment and the risks to it;

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vi. The need to prevent accidents and to minimize their consequences for the environment;

vii. The need to ensure occupational health and safety at workplaces;

viii. Comparable processes, facilities or methods of operation which have been tried with success on an industrial scale;

ix. Technological advances and changes in scientific knowledge and understanding.

b) General release reduction measures: When considering proposals to construct new facilities or significantly modify existing facilities using processes that release chemicals listed in this Annex, priority consideration should be given to alternative processes, techniques or practices that have similar usefulness but which avoid the formation and release of such chemicals. In cases where such facilities will be constructed or significantly modified, in addition to the prevention measures outlined in section A of Part V the following reduction measures could also be considered in determining best available techniques:

i. Use of improved methods for flue-gas cleaning such as thermal or catalytic oxidation, dust precipitation, or adsorption;

ii. Treatment of residuals, wastewater, wastes and sewage sludge by, for example, thermal treatment or rendering them inert or chemical processes that detoxify them;

iii. Process changes that lead to the reduction or elimination of releases, such as moving to closed systems;

iv. Modification of process designs to improve combustion and prevent formation of the chemicals listed in this Annex, through the control of parameters such as incineration temperature or residence time.

C. Best environmental practices

The Conference of the Parties may develop guidance with regard to best environmental practices.

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ANNEX D
INFORMATION REQUIREMENTS AND SCREENING CRITERIA

1. A Party submitting a proposal to list a chemical in Annexes A, B and/or C shall identify the chemical in the manner described in subparagraph (a) and provide the information on the chemical, and its transformation products where relevant, relating to the screening criteria set out in subparagraphs (b) to (e):

   a) Chemical identity:

      i. Names, including trade name or names, commercial name or names and synonyms, Chemical Abstracts Service (CAS) Registry number, International Union of Pure and Applied Chemistry (IUPAC) name; and

      ii. Structure, including specification of isomers, where applicable, and the structure of the chemical class;

   b) Persistence:

      i. Evidence that the half-life of the chemical in water is greater than two months, or that its half-life in soil is greater than six months, or that its half-life in sediment is greater than six months; or

      ii. Evidence that the chemical is otherwise sufficiently persistent to justify its consideration within the scope of this Convention;

   c) Bio-accumulation:

      i. Evidence that the bio-concentration factor or bio-accumulation factor in aquatic species for the chemical is greater than 5,000 or, in the absence of such data, that the log Kow is greater than 5;

      ii. Evidence that a chemical presents other reasons for concern, such as high bio-accumulation in other species, high toxicity or ecotoxicity; or

      iii. Monitoring data in biota indicating that the bio-accumulation potential of the chemical is sufficient to justify its consideration within the scope of this Convention;

   d) Potential for long-range environmental transport:

      i. Measured levels of the chemical in locations distant from the sources of its release that are of potential concern;

      ii. Monitoring data showing that long-range environmental transport of the chemical, with the potential for transfer to a receiving environment, may have occurred via air, water or migratory species; or

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iii. Environmental fate properties and/or model results that demonstrate that the chemical has a potential for long-range environmental transport through air, water or migratory species, with the potential for transfer to a receiving environment in locations distant from the sources of its release. For a chemical that migrates significantly through the air, its half-life in air should be greater than two days; and

e) Adverse effects:

i. Evidence of adverse effects to human health or to the environment that justifies consideration of the chemical within the scope of this Convention; or

ii. Toxicity or ecotoxicity data that indicate the potential for damage to human health or to the environment.

2. The proposing Party shall provide a statement of the reasons for concern including, where possible, a comparison of toxicity or ecotoxicity data with detected or predicted levels of a chemical resulting or anticipated from its long-range environmental transport, and a short statement indicating the need for global control.

3. The proposing Party shall, to the extent possible and taking into account its capabilities, provide additional information to support the review of the proposal referred to in paragraph 6 of Article 8. In developing such a proposal, a Party may draw on technical expertise from any source.

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ANNEX E
INFORMATION REQUIREMENTS FOR THE RISK PROFILE

The purpose of the review is to evaluate whether the chemical is likely, as a result of its long-range environmental transport, to lead to significant adverse human health and/or environmental effects, such that global action is warranted. For this purpose, a risk profile shall be developed that further elaborates on, and evaluates, the information referred to in Annex D and includes, as far as possible, the following types of information:

a) Sources, including as appropriate:

   i. Production data, including quantity and location;

   ii. Uses; and

   iii. Releases, such as discharges, losses and emissions;

b) Hazard assessment for the endpoint or endpoints of concern, including a consideration of toxicological interactions involving multiple chemicals;

c) Environmental fate, including data and information on the chemical and physical properties of a chemical as well as its persistence and how they are linked to its environmental transport, transfer within and between environmental compartments, degradation and transformation to other chemicals. A determination of the bio-concentration factor or bio-accumulation factor, based on measured values, shall be available, except when monitoring data are judged to meet this need;

d) Monitoring data;

e) Exposure in local areas and, in particular, as a result of long-range environmental transport, and including information regarding bio-availability;

f) National and international risk evaluations, assessments or profiles and labelling information and hazard classifications, as available; and

g) Status of the chemical under international conventions.

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ANNEX F
INFORMATION ON SOCIO-ECONOMIC CONSIDERATIONS

An evaluation should be undertaken regarding possible control measures for chemicals under consideration for inclusion in this Convention, encompassing the full range of options, including management and elimination. For this purpose, relevant information should be provided relating to socio-economic considerations associated with possible control measures to enable a decision to be taken by the Conference of the Parties. Such information should reflect due regard for the differing capabilities and conditions among the Parties and should include consideration of the following indicative list of items:

a) Efficacy and efficiency of possible control measures in meeting risk reduction goals:
    i. Technical feasibility; and
    ii. Costs, including environmental and health costs;
b) Alternatives (products and processes):
    i. Technical feasibility;
    ii. Costs, including environmental and health costs;
    iii. Efficacy;
    iv. Risk;
    v. Availability; and
    vi. Accessibility;
c) Positive and/or negative impacts on society of implementing possible control measures:
    i. Health, including public, environmental and occupational health;
    ii. Agriculture, including aquaculture and forestry;
    iii. Biota (biodiversity);
    iv. Economic aspects;
    v. Movement towards sustainable development; and
    vi. Social costs;
d) Waste and disposal implications (in particular, obsolete stocks of pesticides and clean-up of contaminated sites):
    i. Technical feasibility; and
    ii. Cost;
e) Access to information and public education;
f) Status of control and monitoring capacity; and
g) Any national or regional control actions taken, including information on alternatives, and other relevant risk management information.

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ANNEX G[6]
ARBITRATION AND CONCILIATION PROCEDURES FOR SETTLEMENT OF DISPUTES

Part I
Arbitration procedure

The arbitration procedure for purposes of paragraph 2 (a) of Article 18 of the Convention shall be as follows:

Article 1

1. A Party may initiate recourse to arbitration in accordance with Article 18 of the Convention by written notification addressed to the other party to the dispute. The notification shall be accompanied by a statement of the claim, together with any supporting documents, and state the subject-matter of arbitration and include, in particular, the articles of the Convention the interpretation or application of which are at issue.

2. The claimant party shall notify the Secretariat that the parties are referring a dispute to arbitration pursuant to Article 18. The notification shall be accompanied by the written notification of the claimant party, the statement of claim and the supporting documents referred to in paragraph 1 above. The Secretariat shall forward the information thus received to all Parties.

Article 2

1. If a dispute is referred to arbitration in accordance with Article 1 above, an arbitral tribunal shall be established. It shall consist of three members.

2. Each of the parties to the dispute shall appoint an arbitrator and the two arbitrators so appointed shall designate by common agreement the third arbitrator, who shall be the President of the tribunal. The President of the tribunal shall not be a national of one of the parties to the dispute, nor have his or her usual place of residence in the territory of one of those parties, nor be employed by any of them, nor have dealt with the case in any other capacity.

3. In disputes between more than two parties, parties in the same interest shall appoint one arbitrator jointly by agreement.

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[6] *Secretariat note: Annex G was adopted by the first meeting of the Conference of the Parties in its decision SC-1/2 of 6 May 2005*

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4. Any vacancy shall be filled in the manner prescribed for the initial appointment.

5. If the parties do not agree on the subject-matter of the dispute before the President of the arbitral tribunal is designated, the arbitral tribunal shall determine the subject-matter.

Article 3

1. If one of the parties to the dispute does not appoint an arbitrator within two months of the date on which the respondent party receives the notification of the arbitration, the other party may inform the Secretary-General of the United Nations, who shall make the designation within a further two-month period.

2. If the President of the arbitral tribunal has not been designated within two months of the date of the appointment of the second arbitrator, the Secretary-General of the United Nations shall, at the request of a party, designate the President within a further two-month period.

Article 4

The arbitral tribunal shall render its decisions in accordance with the provisions of the Convention and international law.

Article 5

Unless the parties to the dispute otherwise agree, the arbitral tribunal shall determine its own rules of procedure.

Article 6

The arbitral tribunal may, at the request of one of the parties, indicate essential interim measures of protection.

Article 7

The parties to the dispute shall facilitate the work of the arbitral tribunal and, in particular, using all means at their disposal, shall:

a) Provide it with all relevant documents, information and facilities; and

b) Enable it, when necessary, to call witnesses or experts and receive their evidence.

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Article 8

The parties and the arbitrators are under an obligation to protect the confidentiality of any information they receive in confidence during the proceedings of the arbitral tribunal.

Article 9

Unless the arbitral tribunal determines otherwise because of the particular circumstances of the case, the costs of the tribunal shall be borne by the parties to the dispute in equal shares. The tribunal shall keep a record of all its costs, and shall furnish a final statement thereof to the parties.

Article 10

A party that has an interest of a legal nature in the subject matter of the dispute which may be affected by the decision in the case may intervene in the proceedings with the consent of the tribunal.

Article 11

The tribunal may hear and determine counterclaims arising directly out of the subject matter of the dispute.

Article 12

Decisions both on procedure and substance of the arbitral tribunal shall be taken by a majority vote of its members.

Article 13

1. If one of the parties to the dispute does not appear before the arbitral tribunal or fails to defend its case, the other party may request the tribunal to continue the proceedings and to make its award. Absence of a party or a failure of a party to defend its case shall not constitute a bar to the proceedings.

2. Before rendering its final decision, the arbitral tribunal must satisfy itself that the claim is well founded in fact and law.

Article 14

The tribunal shall render its final decision within five months of the date on which it is fully constituted unless it finds it necessary to extend the time limit for a period which should not exceed five more months.

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Article 15

The final decision of the arbitral tribunal shall be confined to the subject matter of the dispute and shall state the reasons on which it is based. It shall contain the names of the members who have participated and the date of the final decision. Any member of the tribunal may attach a separate or dissenting opinion to the final decision.

Article 16

The award shall be binding on the parties to the dispute. The interpretation of the Convention given by the award shall also be binding upon a Party intervening under Article 10 above insofar as it relates to matters in respect of which that Party intervened. The award shall be without appeal unless the parties to the dispute have agreed in advance to an appellate procedure.

Article 17

Any controversy which may arise between those bound by the final decision in accordance with Article 16 above, as regards the interpretation or manner of implementation of that decision, may be submitted by any of them for decision to the arbitral tribunal which rendered it.

Part II
Conciliation procedure

The conciliation procedure for purposes of paragraph 6 of Article 18 of the Convention shall be as follows:

Article 1

1. A request by a party to a dispute to establish a conciliation commission in consequence of paragraph 6 of Article 18 shall be addressed in writing to the Secretariat. The Secretariat shall forthwith inform all Parties to the Convention accordingly.

2. The conciliation commission shall, unless the parties otherwise agree, be composed of three members, one appointed by each party concerned and a President chosen jointly by those members.

Article 2

In disputes between more than two parties, parties in the same interest shall appoint their members of the commission jointly by agreement.

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Article 3

If any appointments by the parties are not made within two months of the date of receipt by the Secretariat of the written request referred to in Article 1, the Secretary-General of the United Nations shall, upon request by a party, make those appointments within a further two-month period.

Article 4

If the President of the conciliation commission has not been chosen within two months of the second member of the commission being appointed, the Secretary General of the United Nations shall, upon request by a party, designate the President within a further two-month period.

Article 5

1. The conciliation commission shall, unless the parties to the dispute otherwise agree, determine its own rules of procedure.

2. The parties and members of the commission are under an obligation to protect the confidentiality of any information they receive in confidence during the proceedings of the commission.

Article 6

The conciliation commission shall take its decisions by a majority vote of its members.

Article 7

The conciliation commission shall render a report with recommendations for resolution of the dispute within twelve months of being established, which the parties shall consider in good faith.

Article 8

Any disagreement as to whether the conciliation commission has competence to consider a matter referred to it shall be decided by the commission.

Article 9

The costs of the commission shall be borne by the parties to the dispute in shares agreed by them. The commission shall keep the record of all its costs and shall furnish a final statement thereof to the parties.

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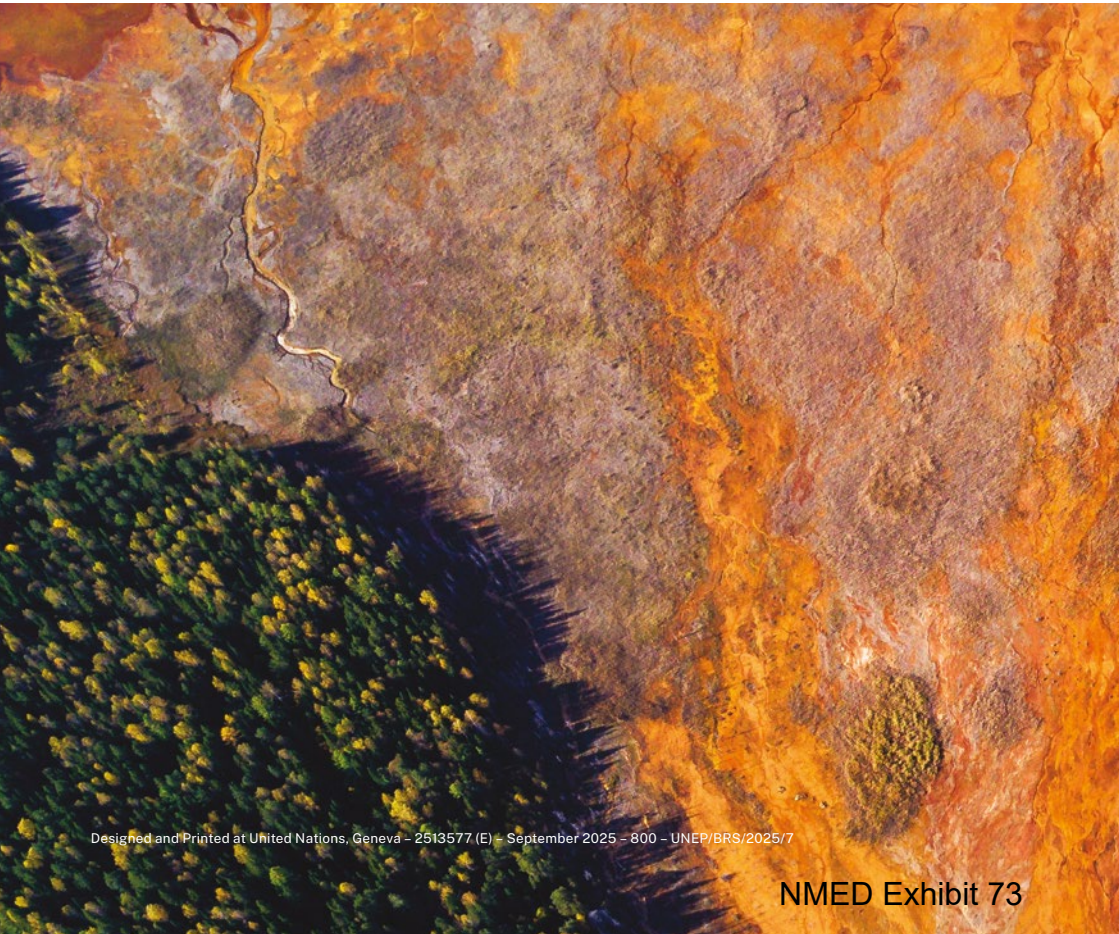
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NEW MEXICO WATER QUALITY CONTROL COMMISSION

IN THE MATTER OF PROPOSED AMENDMENTS TO SECTIONS 10, 11, 12, 113 AND 900 OF THE COMMISSION'S STANDARDS FOR INTERSTATE AND INTRASTATE SURFACE WATERS, 20 NMAC 6.4.

TRANSCRIPT OF PROCEEDINGS

VOLUME 1

BE IT REMEMBERED that on the 13th day of March, 2002, this matter came on for hearing before the Water Quality Control Commission, at the Bataan Memorial Building, Santa Fe, New Mexico, at the hour of 1:50 PM.

A P P E A R A N C E S

FOR THE WATER QUALITY CONTROL COMMISSION:

MR. PETER MAGGIORE, Chairman
MR. STEVE GLASS
MR. HOWARD HUTCHINSON
MR. CONRAD KEYES, JR.
MS. LYNN BRANDVOLD
MR. DAVID JOHNSON
MR. BILL OLSON
MS. JULIE MAITLAND
MR. JOHN WHIPPLE
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MR. MAGGIORE: Good afternoon everybody. My name is Pete Maggiore. I'm the Chairman of the Water Quality Control Commission. I've been designated by the Water Quality Control Commission to act as Hearing Officer at this hearing.

It's being held to consider proposed amendments to Section -- as I was saying, thank you -- amendments to Sections 10, 11, 12, 113 and 900 of the New Mexico Water Quality Control Commission's Standards for Interstate and Intrastate Surface Waters, 20 NMAC 6.4.

Timely notice of this hearing was published in the Albuquerque Journal, the Newsline for the Blind, and the New Mexico Register.

The amendments are proposed by the Surface Water Bureau of the Environment Department. The proposed amendments would adopt human health and aquatic life criteria for Environmental Protection Agency priority toxic pollutants.

The Commission may make a decision on the proposed amendments at the conclusion of this hearing, and if the regulations are approved, the regulations will be reformatted for consistency with the New Mexico Administrative Code.

The record in this matter includes the petition to amend the regulations and to request this hearing, the

notice of public hearing and evidence of publications, and several notices of intent to provide technical testimony.

This hearing will be conducted in accordance with the Commission's Guidelines for Regulation Hearings. Pursuant to Section 401 of these guidelines, I will conduct the hearing so as to provide a reasonable opportunity for all persons to be heard without making the hearing unreasonably lengthy or cumbersome.

The Rules of Civil Procedure and the Rules of Evidence do not apply, but I will make whatever orders are necessary to preserve the decorum and to protect the orderly hearing process.

All testimony will be given under oath and all persons giving testimony will be subject to cross-examination by any other person in attendance on the subject matter of their testimony and on matters affecting their credibility. I may limit cross-examination, if necessary, to avoid harassment, intimidation or repetition.

This hearing is being transcribed. Transcription services are provided by Kathy Townsend Court Reporters. Please contact them directly if you wish to purchase a transcript.

We will first proceed by hearing the technical

case. The order of presentation will be as follows: the Surface Water Bureau, as proponents of the amendments, shall present its case first. Those generally supporting the petition will go next, and I have listed there Larry Webb, the New Mexico Municipal Environmental Quality Association, the US Department of Interior, the Fish & Wildlife Service, and the Board of Regents of the University of California. Then we'll proceed with those who are generally opposed to the petition, which include the San Juan Water Commission.

The Commission's secretary received no other notices of intent to present technical testimony, so we will then go to nontechnical testimony, which will be taken in the order in which the attendees signed in. If you have not previously signed in, please do so now regardless of whether you wish to present testimony.

Are there any questions from any of the Commissioners or members of the audience regarding the hearing format?

MS. HUGHES: Mr. Chairman, there are no questions regarding the format. I just bring up a preliminary procedural matter.

Prior to the hearing, you got a letter from the San Juan Water Commission requesting that this hearing be postponed or delayed and held during the regular

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triennial review. It was your position that you didn't have authority --

MR. MAGGIORE: That's right.

MS. HUGHES: -- on behalf of the Commission to -- after the Commission had decided to hear this matter, that you didn't have authority to postpone or delay the hearing unilaterally.

MR. MAGGIORE: Right.

MS. HUGHES: So I just bring that up as a preliminary procedural matter.

MR. MAGGIORE: I did correspond, I think -- or you corresponded on my behalf -- with the San Juan Water Commission precisely that, that I did not have unilateral authority given to me by the Commission to summarily change or postpone the hearing.

I guess, Commissioners, there was that correspondence, though, and if there is any -- is there any need to discuss that?

Do you have some concerns, ma'am?

MS. MC CALEB: My name is Jolene L. McCaleb. I'm the attorney for the San Juan Water Commission.

What I would like to do at this point in time is -- I'm not certain whether it's correct to call it still a pending motion, given your letter, or whether I need to make a -- I need to move to renew --

MS. HUGHES: I would renew your motion.

Go ahead.

MS. MC CALEB: What I would like to do is I would like to renew the San Juan Water Commission's motion that this hearing be postponed.

The grounds for the motion are twofold: One is based on policy reasons why the subject matter of this hearing should be considered during the next triennial review. Also, we now have some procedural grounds based on concerns about the procedural fairness of this proceeding.

So I would propose that Mr. Kirkpatrick be permitted to present the policy concerns of San Juan Water Commission, and then I can make the legal arguments about the procedure.

MR. MAGGIORE: Any objections, Commissioners? If not, please proceed.

MS. MC CALEB: Thank you.

We'll try asking questions of Mr. Kirkpatrick from up here, if that works, so everyone doesn't need to move.

MR. MAGGIORE: Do we have a witness table?

MS. HUGHES: Let me just ask you, are you making argument? All you're making is argument, or is Mr. Kirkpatrick going to present testimony regarding -- I

mean, your motion is really a procedural motion, it sounds like, or a --

MS. MC CALEB: It's twofold.

MS. HUGHES: Okay.

MS. MC CALEB: The first portion of the motion is that for public policy reasons, it is not appropriate to consider this petition until the triennial review.

MS. HUGHES: Can you argue that? Can't you, as counsel, argue that motion?

MS. MC CALEB: I could argue that, if you would prefer.

MS. HUGHES: I think we would, because I think this is a motion for just -- that the lawyers should argue on that behalf, and then the Commission could make a decision.

MS. MC CALEB: Sure.

MS. HUGHES: Rather than having the witness be sworn in, et cetera, I think you should argue it.

MS. MC CALEB: Since I have people behind me, is it all right if I sit and make my argument?

MR. MAGGIORE: Do you have a microphone that she could use?

MR. PIERCE: We don't have a speaker.

MS. MC CALEB: You know what --

MR. MAGGIORE: Why don't you come down to the

front.

MS. MC CALEB: Thank you. Mr. Hearing Officer, Members of the Commission.

By letter of January 31st, Mr. Kirkpatrick, on behalf of the San Juan Water Commission, sent a letter to the Water Quality Control Commission requesting that this hearing be postponed for various policy reasons.

The primary policy reason is the scope of the Environment Department's proposal. The petition that we are here to discuss today essentially proposes the adoption of 113 new water quality standards.

It is the position of the San Juan Water Commission that such a broad proposal would more appropriately be considered during the next triennial review, so that it could be considered in context with the review of all other water quality issues at that time.

With regard to procedural issues and concerns, the New Mexico Environment Department, in our opinion, has made several substantive changes to its original petition, and, therefore, that requires a renoticing of this hearing.

For example, the Environment Department has submitted a revised petition that creates, for example, a new subset of, quote, persistent toxic pollutants, and

there have been various other changes that we believe are substantive and not just fine-tuning.

In addition, with regard to the fairness of the current procedure, I would like to bring to the Commission's attention that it was not possible to obtain copies of notices of intent that were filed, including the one filed by the Department, until six days after they were actually filed, because the Commission office was closed. We left several phone messages, and I guess because of the transition in the administrative secretary's position, no one was minding the shop, and that worked a disadvantage for my client.

In addition, we have a concern about the procedure under which the Environment Department listed its written technical testimony as an exhibit to potentially be filed in its notice of intent and then ten days later actually filed significant written testimony.

Other parties who actually intended to make an exhibit of written technical testimony provided it with their notice of intent, and I think that that is an unfair procedure for the Environment Department to be able to do that.

In addition, if you have the guidelines in front of you, I'm not sure whether you do, for Commission

hearings, Guideline 303, with regard to the submission of the notice of intent to present technical testimony states that the notice of intent shall either summarize or include a copy of the direct testimony.

It's our position that the Environment Department's notice of intent did neither of those things.

If you will look at the Department's notice of intent with regard to each witness, they indicate the topic that a witness will testify about, but in no way summarize or indicate what that testimony will be, and for the Department to then later file their written direct ten days after everyone else is an unfair procedure.

So for these various policies reasons and procedural reasons, we request that this hearing be postponed.

MR. MAGGIORE: Okay.

Thank you.

MS. MC CALEB: Thank you.

MR. MAGGIORE: Counsel?

MR. AMES: Yes. Thank you, Mr. Chairman, Members of the Commission.

My name is Eric Ames. I'm an attorney in the Office of General Counsel at the New Mexico Environment

Department, and I'm here today on behalf of the Surface Water Quality Bureau.

The Department opposes San Juan's request for a delay in this hearing. There are a number of reasons, in our estimation, why a delay is neither warranted nor prudent.

First, there is no defect in public notice. None has been mentioned here. Second, there would be prejudice to both the Department and the other parties who have prepared and sat and waited for this hearing for the past two days. Third, there is some urgency in having this hearing and proceeding to a decision on the petition. Finally, this is a regular Commission hearing on a proposal to amend these water quality standards. It's subject to the exact same procedural safeguards as any proceeding this Commission holds to amend the water quality standards, including the triennial review.

Before discussing these reasons in more detail, however, I'd like to provide a little context for the motion you just heard.

As Chairman Maggiore and Ms. McCaleb said, there was a letter on January 31st from the Commission -- the San Juan Water Commission requesting a delay. That was the first request for a delay that was made by a letter, as was said.

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The San Juan Water Commission never sent a copy to the Department -- a copy of that letter to the Department. They never called us before sending the letter to tell us they were going to ask for a delay, and they never called us after the letter to tell us they had asked for a delay. In fact, we only learned about the request for a delay on February 25th when I went down to the hearing clerk's office to obtain copies of the other parties' notices of intent.

More troubling, the letter is essentially an argument on the merits. I thought the whole matter had been resolved, because the Chairman, as he said, sent a letter to the Commission on February 20th telling them that the request for a delay had been denied, and on February 26th, San Juan sent a letter to the Commission Chairman telling him that, in fact, they were withdrawing their request for a delay -- or at least that's how we understood the letter.

So we're a bit surprised to hear the request raised for a second time here.

With that said, we'll wait until our case in chief to argue the merits of the so-called policy reasons for San Juan's request for a delay. At this time I'll explain in a little more detail our reasons for opposing the delay on procedural grounds.

First, as I said, there is no defect in the legitimacy of this hearing. There has been no claim that the public notice was improper or this hearing was improperly scheduled.

Second, the delay would be prejudicial to the Department and to the other parties. A petitioner generally has a right to a prompt hearing on its petition. It shouldn't be strung along for months by repeated requests for a delay.

Finally, the Department and other parties have expended a significant amount of time and resources to prepare for this hearing and to be here today.

The final reason is one which I would not have intended to offer in response to a motion, but since it was raised earlier by Dr. Davis, I will say, again, that Mr. Pierce will not be here after the 21st of March, and Mr. Pierce is an important part of the Department's case in chief, and it would work a severe hardship on the Department if this hearing were not held today or at least before March 21st.

San Juan did not make a proposal for how long a delay they would like. I presume they are asking for more than a week, based on the grounds for stay identified as the basis for their request.

Third, as I said, there is some urgency in

hearing this petition. The Department has filed this petition to address deficiencies in the triennial review identified by the EPA. The EPA has said that it will initiate federal promulgation for numeric criteria for the State of New Mexico unless the Commission acts. It's the Commission's decision whether to act, but we don't even get to that point unless we have a hearing, and we need to move promptly to get this done.

Second, there is a risk that an ongoing federal lawsuit could be amended to include a claim against the EPA, and that would only make the matter -- make matters much worse. It would thrust the state -- well, it would raise the stakes for the state in a matter in which it has already decided to intervene.

Lastly, I'd like to respond to the arguments that were made by Ms. McCaleb. Basically, in my view, San Juan has not made a convincing argument for delay.

First, they've had ample notice and time to prepare for this hearing. This hearing was petitioned when we -- let me rephrase. The petition was filed three-and-a-half months ago. A hearing was scheduled three months ago. The Department met with San Juan to discuss the proposal that's currently before you two months ago.

Since this petition was filed three-and-

one-half months ago, San Juan has made only one request for information. The Department responded promptly to that request, and we've heard nothing since. Nowhere in San Juan's written testimony is there a challenge to any specific criterion that the Department has proposed. They haven't even brought an expert witness to testify in this hearing or to listen to the testimony that's about to be offered.

I would submit that this is not a function of insufficient time to prepare for the hearing, but a function of having no evidence.

As to the argument that this proceeding should be delayed until the next triennial review, I would submit that this is still the triennial review. New Mexico has not completed the triennial review that it began in 1997. This is the last item.

Second, the next triennial review is not due until January of 2003. Under EPA guidance -- EPA -- the way EPA interprets the requirements, the next triennial review must begin three years after the submittal of the prior. This hearing excluded, we interpret that as January of 2000, meaning the next hearing would need to be initiated by January of 2003. Holding off on this hearing that long does raise the stakes with regard to this hearing.

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If this hearing is delayed, I would suggest there is a significant risk that EPA would act in the interim. There is nothing to be gained with respect to procedural safeguards. This is an identical public notice and procedure as the regular triennial review that was held in '97 and that will be held again in January of 2003. This hearing and the triennial review are conducted under the same Commission guidelines, and they must comply with the same EPA requirements for amending water quality standards.

Further, there is the same opportunity for public participation as the triennial review. The Department, in fact, conducted a wide -- talked to a wide number of people in getting ready for this hearing, consulted with a wide range of people after it initiated its petition.

San Juan, in its written submittal, acknowledges the Department addressed many of its concerns. In some it's hard to see what the Department could have done more or should have done more prior to this hearing.

As for the argument that the Department made additional changes to its petition after November 21st -- November 29th, that, in fact, is true; the Department, on February 1st, revised its petition and sent copies to

everyone who attended any of the meetings, including San Juan, as well as all people on the Commission mailing list and all members of the Commission.

These changes were in direct response to concerns raised at the meetings the Department held in January with a wide range of interest groups, including San Juan.

There is no need to renotice this petition in order for the Commission to proceed. The Water Quality Control Commission guidelines allow a party -- or allow a petitioner, as well as any party -- to submit modifications to the petition with its notice of intent.

The Department decided that it would be in the best interests of everyone if it did it sooner than the notice of intent. Notices of intent weren't due until February 22nd. The Department decided to do it immediately, and, therefore, within days of concluding the meetings, it submitted the revisions to everyone so they could prepare their written testimony and prepare their notices of intent.

I submit the Department did more than it was required to do by the Commission guidelines. It seems strange the Department now would be punished for it.

As to the one item which the Department did change that was addressed in San Juan's motion, the list

regarding persistent toxins, I would suggest that's a red herring.

The Department had already proposed to apply the human health criteria, all of them, to ephemeral waters, and, more appropriately, to tributaries of water with designated or existing attainable fishery use.

In the parlance you'll hear today, we're talking about them as ephemeral waters because they are waters that are not themselves designated as fisheries, but are a tributary to fisheries, so I will call them ephemeral waters.

Our original proposal was to apply the human health criteria to all tributaries, all ephemeral waters. In our proposal we restricted that list, we actually backed off from our broader proposal and limited it to those pollutants which the Department termed are persistent bioaccumulative toxic pollutants.

So to the extent that San Juan didn't have notice that we were going to restrict the list, that's a bit of a red herring, since we'd already said we were going to apply the -- apply the criteria -- all the criteria to these waters.

San Juan's next argument is that the Department violated the Commission guidelines regarding notices of intent. Their argument is essentially the Department did

not submit its written testimony with the notice of intent; and that, secondly, the Department's summary of its testimony in the notice of intent was not sufficient to meet that requirement.

The requirement is to submit a summary; that's it. There is no requirement to submit all your written testimony. San Juan chose to do so; Los Alamos National Laboratory chose to do so. Dr. Hernandez, I believe, did not choose to do so, he submitted an outline. The Department submitted a summary.

The fact that the Department listed its written testimony as an exhibit and then provided it ten days later does not create a violation of the Commission guidelines.

As to the argument that the summary is not sufficient, that is for the Commission to decide. The Department's notice of intent in this case is fundamentally no different than the Department's notices of intent that it filed in the primary contact designation hearing in Las Cruces in October or in the hearing on the changes to the surface water definition that it did, oh, last spring. In fact, I don't think it's much different than the notice of intent the Department filed in the triennial review in 1997.

The Commission has never established a standard

for what constitutes a summary. So there is very little for the Department to do in that context, but the Department believes that what it did provided a broad enough outline to put other parties on notice of the scope of its testimony and that that meets the requirement.

San Juan's final argument is that it was unable to obtain the notices of intent until six days after the filing deadline, and that, therefore, it was prejudiced in its ability to prepare for this hearing. Six days seems like a fairly short time in the scope of the -- of this matter to allege a prejudice, particularly since San Juan had already prepared its full position at the time it filed its notice of intent.

At the time it filed its notice of intent, it was prepared to go to hearing. It had already written down and announced to the public and to this Commission what it was going to say. What was left for it to prepare was to review everyone else's notice of intent.

It had a delay of six days. That's not the Surface Water Quality Bureau's fault, but that said, it's hard to see how a delay of six days can require this entire hearing be rescheduled for some undefined period of time in order to correct it.

In conclusion, the Department sees no need and

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no good reason for a delay. The hearing is required to give the state a chance to avoid federal imposition of numeric criteria. A delay increases the risk that this will occur.

The hearing was properly noticed and scheduled. There is going to be significant prejudice to the Department, as well as other parties, if a delay is granted.

In this light, the Department urges the Commission to proceed with this hearing today.

Thank you.

MR. MAGGIORE: Thank you, Counselor.

Any other parties wishing to argue this motion?

MS. MC CALEB: If I may, I would like to respond to the Environment Department.

MR. MAGGIORE: Please proceed.

MS. MC CALEB: Thank you.

The first comment I would like to make, before I get into the substance of what Mr. Ames said, is that I believe it is entirely inappropriate, the derogatory remarks he made to this Commission concerning the type of San Juan -- the type of testimony that San Juan Water Commission may be presenting and his interpretation that because we do not have a technical expert here that there are no -- essentially, there is nothing important to hear

from the San Juan Water Commission.

I believe that that was the shadow that was cast over what we are here to do, and I think that was entirely inappropriate on Mr. Ames' part.

With regard to the prejudice issue, and specifically, again, with Mr. Ames' concern that we are not here with an expert witness, that is because of circumstances outside our control and the date that this hearing was scheduled for, and so we have done our best to prepare Mr. Kirkpatrick in place of Mr. Pitts.

However, I would like to point out that in our attempts to get assistance from our technical expert, we were prejudiced in the fact that the Environment Department did not even send us a copy of its notice of intent, and I had to wait to try to get that from the Commission secretary.

Mr. Ames did provide the information to me on February 28th, when I had not been able to get ahold of the Commission secretary, but the Environment Department, even though they had our notice of intent and knew we would be participating, did not voluntarily provide their notice of intent to us.

With regard to Mr. Kirkpatrick's letter to the Commission to postpone this hearing, I have no proof that a copy of the letter was sent to Mr. Davis, because,

unfortunately, Mr. Kirkpatrick's secretary did not include the copy list on her letter; however, she was instructed to send a copy of that letter to Mr. Davis, and it's my belief that it was sent, and we certainly had no intention to not notify the Environment Department of our request to the Commission.

With regard to Mr. Ames' statement that he believes that San Juan Water Commission withdrew its motion based on Mr. Kirkpatrick's February 26th letter, Mr. Maggiore's letter and Mr. Kirkpatrick's letters passed in the mail.

In his letter, Mr. Kirkpatrick essentially said, "We haven't heard from the Water Quality Control Commission, and, therefore, do we need to assume that our motion has been denied?"

So in no way did we withdrew our motion; we just indicated that we hadn't heard anything, because the letters crossed in the mail.

With regard to our motion and when we would request that this hearing be rescheduled, we would request that it be part of the next triennial review, and that is for this Commission to set.

With regard to the severe hardship that would be imposed on the Department, I'd first like to point out that I realize everyone is here today prepared to go to a

hearing, but there is no other procedure available for an interested party to request that a motion -- that a hearing be postponed other than the way we attempted to do it. That's the best way we thought we could do it, first to send a letter to the Commission, after you had scheduled the hearing, requesting a postponement; and then if the Water Quality Control Commission does not consider that at that time, this is our first opportunity to present our motion.

And while we do understand that Mr. Pierce will be retiring, and we will miss him greatly, we mean that wholeheartedly, he's always been very helpful to us, I don't believe that the fact that the Department may be losing an employee is a sufficient reason to fail to postpone a hearing of this magnitude that requires more consideration and should appropriately be heard during the triennial review.

Thank you.

MR. MAGGIORE: Thank you.

Commissioners, any thoughts on the preliminary motion?

I'll entertain a motion.

MR. GLASS: One second before the motion, please.

MR. MAGGIORE: Commissioner Glass.

MR. GLASS: When Mr. Ames testified that the hearing we have scheduled today is really an extension of or a completion of the 1997 triennial review, I guess that brings to me -- brings up for me a question of what constitutes the conclusion of the triennial review.

Is it the final full approval by EPA of the standards, or is it some other measure of conclusion?

In fact, is this a continuation, or can it be classified as that?

MR. AMES: Mr. Glass, my understanding is that the Department's position is that the triennial review that was initiated in '97 will conclude when the Department -- when this Commission has considered all remaining issues left from EPA's record of decision issued in January of 2001. This is the last issue.

MR. GLASS: So it's predicated on Commission consideration of -- not so much EPA approval of the water quality --

MR. AMES: That's correct.

MR. GLASS: Okay.

MR. AMES: If this Commission were to decide to take no action on the Department's petition, or deny the petition, I suppose that would be the end of the triennial review, and from the Department's perspective, the ball would then be in EPA's court to decide how to

respond, but in the record of decision, EPA clearly left open for the Commission the opportunity to address issues which it considered problematic, and among those were the priority contact designation for the lower Rio Grande, a few involving the definition of surface waters, and this big issue of numeric criteria for toxic pollutants.

EPA said it would consider making a finding that the Department's -- or that the state's standards were inadequate, essentially giving us the opportunity to address that concern before EPA did it for us, and it's in that light that the Department has come back with this petition as an effort to close out all remaining open issues which EPA has given us an opportunity to address.

So it's the Department's position that this is the last piece of the 1997 triennial review.

MR. GLASS: In my view, a denial to even consider the petition would not constitute a Commission hearing or consideration of the issue brought up by EPA, just a -- if we were to deny to hear any of the petition today, we would not have considered it, and you've stated that our denial would bring the triennial review to a close, but I don't think that's true.

MR. AMES: Mr. Glass, I think you may have misunderstood me. I meant a denial of the petition after a hearing.

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MR. GLASS: Oh, okay. So we're considering --

MR. AMES: I think one could also argue that if the Commission refused to even consider the petition, that would be a final action by this Commission that the EPA could look at and say, "Well, the Commission has decided -- the State of New Mexico has decided that it's not going to deal with this issue, so now the ball is now in our court."

So I think we come to the same place, yes.

MR. GLASS: Okay. Thanks.

MR. MAGGIORE: Commissioner Hutchinson.

MR. HUTCHINSON: I just have a question for our legal counsel. Well, I guess Mr. Ames could answer it as well.

It's my understanding that regardless of a triennial review taking place that any person can request a change to the standards or a new standard at any time. So -- is that correct?

MR. AMES: Mr. Hutchinson, I'd be pleased to answer that.

I half expected that issue to be raised in San Juan's motion. It was not.

It is entirely appropriate for this Commission to hold separate hearings on a distinct issue -- on any issue. Anyone can petition this Commission for a change

in the water quality standards, and this Commission would decide whether to have a hearing and would have a hearing and decide on the matter. This is particularly true when there may be some urgency to the matter.

From a different perspective, the Commission might want to consider whether it's really a good idea to postpone hearing issues, particularly issues of some magnitude, until the triennial review, which then makes the triennial review quite an unwieldy and potentially unproductive forum.

Many of us sat through the -- or participated in the eight-and-a-half days that that triennial review required, and it led to a number of problems both for the Commissioners and for the parties themselves in terms of participating and gathering the necessary information to make a decision.

So not only do the guidelines allow -- not only does the act allow the Commission to have hearings when it deems it appropriate, but from a policy perspective, it makes sense for the Commission to have hearing when they -- on issues as they arise.

MR. GLASS: I move that we proceed with the hearing.

MR. JOHNSON: Second.

MR. MAGGIORE: A motion from Commissioner

Glass; a second from John the very end.

MR. MAGGIORE: The very end, Commissioner Johnson.

Any further discussion?

Seeing none, all in favor please signify by saying aye.

(Vote taken.)

MR. MAGGIORE: Motion carries.

We'll proceed.

Thank you, Counselors.

Please proceed with your case in chief.

MR. AMES: Thank you, Mr. Chairman.

As I stated at the beginning, my name is Eric Ames. I'm representing the Department here today.

The Department in this proceeding proposes the adoption of numeric criteria for priority toxic pollutants. There are 23 criteria for the protection of aquatic life, 11 are acute and 10 are chronic and 92 criteria are for the protection of human health based on fish consumption.

These criteria are the values recommended by EPA pursuant to the Clean Water Act, adjusted for the cancer-causing pollutants to reflect the Commission's preferred risk level.

The Department also proposes a procedure for

setting or deriving numeric criteria for the protection of human health in the future. The procedure would allow EPA, which issues NPDES permits in the State of New Mexico, to write and issue these permits for toxic pollutants in effluent discharges where the Commission has not adopted a numeric criteria for a specific priority toxic pollutant.

In addition, the Department proposes a special requirement that it return to the Commission for hearing on any such criterion. In other words, when EPA derives a criterion pursuant to the procedure, the Department will come back to this Commission and ask that it consider and adopt that criterion into the standards themselves.

Finally, the Department proposes to apply these human health criteria to all waters with a designated, existing or attainable fishery use and their tributaries.

With me today to present the Department's proposal are four members of the Surface Water Quality Bureau. The first to my right is Dr. James Davis, chief of the Bureau; to his right, Mr. Saums, manager of the Point Source Regulation Section; next to him is Mr. John Montgomery, who is the water quality standards coordinator for the Department, or will be upon Steve's retirement, I'm not sure of the precise timing of the

transition; and, lastly, Mr. Pierce, who is the manager of the Surveillance and Standards Section, which has traditionally been the section within the Bureau responsible for maintaining and updating the water quality standards.

I'll give you a very brief outline of our testimony.

Dr. Davis will begin by explaining the purpose of the Department's petition and explaining how it responds to EPA's identification of deficiencies in the last triennial review and why it is necessary for this Commission to take action to avert federal promulgation.

He will describe how the Department solicited public input during meetings with groups, and he will explain why the Department modified the petition on February 1st.

Mr. Montgomery will go next. He'll explain the legal and regulatory framework for the requirement to adopt numeric criteria for toxic pollutants. His discussion will include the relevant provisions of the Clean Water Act, including the specific requirement for states to adopt numeric criteria, and EPA's process for developing and updating its recommended criteria upon which the Department relies today.

Mr. Pierce will pick up John's thread. He'll

describe the evolution of the national policy for the control of toxic pollutants in surface waters of the United States, New Mexico's response to that national policy or strategy, and EPA's decision in January of 2001 which started this whole petition rolling.

He will describe the options for adopting numeric criteria to comply with the Clean Water Act and avoid federal promulgation, and he will describe the Department's preferred alternative for doing so.

He will then proceed with a section-by-section analysis of the Department's proposal, beginning with the numeric criteria and their bases on EPA's values. He will explain why numeric criteria should be generally applicable to fishery waters and why certain criteria, specifically those for persistent toxic pollutants, those that are persistent and bioaccumulative, to be more specific, should be applied to tributaries of fishery waters, even when those tributaries do not have water and do not have fish at the point of discharge.

He will describe why other approaches to controlling these kinds of discharges are not effective. He will explain why the Department is proposing the harmonic mean flow, why it is consistent with EPA's policy and practice, and why the Department has agreed to support LANL's -- or Los Alamos National Laboratory's

proposal for a modified harmonic mean flow formula for tributary waters which are ephemeral.

Mr. Saums will be next. He will testify regarding the effect of these criteria and the translation procedure on the development and issuance of NPDES permits in the State of New Mexico, to explain how the Department's proposal promotes consistency in the development of permits, and, in fact, will have a minimal impact on NPDES permittees, at least in the near term, and he will finally explain why the Commission's adoption of the Department's proposal provides the greatest opportunity for state control of numeric criteria within the EPA regulatory framework.

Finally, Dr. Davis will close out. He will testify about the effect of these criteria on the 303(d) program, specifically the impaired listings, and the TMDL program, as well as nonpoint sources.

The Department's testimony is accompanied, as you can tell, by a PowerPoint presentation. Copies of the presentation have been distributed to everyone in the audience, at least as of the beginning of the hearing. If anyone needs a copy, there are some more in the box at the front of this box here. Feel free to come down and get a copy.

The Department has already submitted its full

written testimony. That, too, has been distributed. Therefore, the Department will make every effort to abbreviate its oral testimony using the PowerPoint slides as guideposts.

You may note some changes in the Department's oral testimony from the written testimony. Those changes were made to reflect the testimony of other parties. The Department read and reviewed and discussed everyone else's testimony and decided that in some cases changes were warranted, and we will indicate what those changes are during our oral presentation.

Finally, the Department has submitted 21 exhibits in support of the petition. NMED Exhibits 1 through 20 were filed with the notice of intent. They were supplied on the compact disk for all Commissioners. I assume they were -- that most Commissioners, or all the Commissioners, received it. The CD was also available to anyone who asked, as indicated in the notice of intent, and the CDs were sent to counsel for Los Alamos and San Juan Water Commission.

NMED Exhibit 21, which is the Department's written testimony, was filed on March 4th, about -- what's that? -- about ten days after the notice of intent.

The testimony was sent electronically and by

mail to all Commissioners, as well as to all parties or their counsel.

In addition, there are nine paper copies of the entire set of the Department's exhibits, including the written testimony available here in this box. If anyone needs one, feel free to take one. As you can tell by the volume of the exhibits, we were attempting to save paper and state resources by not simply sending full copies, but as Mr. Olson knows, we made copies available when people needed them.

One point with respect to the CD approach to distributing exhibits and testimony. When this hearing is all over, if you had some problem with this approach, or you'd like it in a different way, or you think the way we did it can be improved, we would welcome some input. This may be the first time that a party to a proceeding for the Commission has tried to do everything -- or a large portion of their proposal electronically, and we'd like to know how it worked for you.

All these exhibits, including the testimony, are already in the record, but I will still move for their introduction at the close of the Department's case in chief.

That concludes my opening statement, and now I ask that the Hearing Officer swear the witnesses.

(Oath administered to James Davis, John Montgomery, Steven Pierce and Glenn Saums.)

JAMES DAVIS

after having been first duly sworn under oath, was questioned and testified as follows:

DIRECT EXAMINATION

BY MR. AMES:

Q. Please state your name for the record.

A. James Davis.

Q. Where do you work, Dr. Davis?

A. I work in Santa Fe, at the New Mexico Environment Department, Surface Water Quality Bureau.

Q. What is your position there?

A. I'm Bureau chief.

Q. How long have you been Bureau chief?

A. A little over four years.

Q. Is your resume accurately reflected in the Department's notice of intent?

A. I believe so, yes.

Q. Then we'll proceed directly to your testimony. What is the purpose of the Department's petition today?

A. The purpose of the Department's petition, as has been alluded to in introductory comments, is to complete the triennial review process that began in 1997,

or was initiated in 1997, and that was heard by this Commission during September of 1998.

This Commission deliberated on the record that resulted from that hearing -- do I need this? I'll simply speak up. I have never -- there was a witness yesterday who indicated that they'd never been accused of having a soft voice, and in this very similar manner, I have never been accused of having a soft voice; however, if there is anyone in the audience that has difficulty hearing me, I would be pleased to use the microphone. I don't believe it's necessary, however.

MS. VIGIL: Excuse me. Some people in the back can't hear. Maybe if you can face your voice that way.

MR. AMES: That seems to indicate the microphone is probably necessary.

MR. DAVIS: Okay.

Hopefully, there will come -- it's worse.

I'll speak up, and if anybody can't hear me, let me know.

This Commission deliberated on the record that was generated during that eight-and-a-half day hearing in September of 1998. Following that deliberation, this Commission issued a decision concerning the items discussed in the triennial review, revised the water quality standards accordingly, and submitted that to the

USEPA in January of 2000.

EPA responded to that submittal on January 23rd of 2001. In their response, they included what's known as a record of decision, or ROD, R-O-D. In that record of decision, they approved most of the revisions to New Mexico's Water Quality Standards, they disapproved some revisions, and they advised that they would consider recommending disapproval of other revisions unless New Mexico took certain actions.

Now, these various documents, I believe, are found in Exhibit NMED 12.

Since that time, since January of 2001, both the Water Quality Control Commission and the New Mexico Environment Department have worked to address those various revisions that were either disapproved or provisionally disapproved by EPA.

Again, as has been alluded to in introductory comments, the Water Quality Control Commission clarified the exemption that applies to five numeric standards, the violation of which may arise from the reasonable operation of irrigation and flood control facilities.

In addition, the Department petitioned the Water Quality Control Commission to revise the definition of surface waters of the state. Also, as many of the Commissioners know, last October, the Commission held a

hearing in Las Cruces to consider more stringent fecal coliform criteria for the lower Rio Grande.

Q. (BY MR. AMES) What does the Department propose today?

A. Specifically, today, the Department is proposing for the Commission's consideration the adoption of numeric criteria for priority toxic pollutants.

As you can see on the slide, these consist primarily of numeric criteria to protect human health, and this addresses the last pending issue for completion of the triennial review process initiated in 1997.

Specifically, the Department proposes 11 acute and 10 chronic numeric criteria for priority toxic pollutants to protect various fishery designated uses. The Department also proposes 92 numeric criteria for priority toxic pollutants to protect human health.

We propose a procedure for selecting or deriving numeric criteria when there are no criteria in the water quality standards, and a method of determining compliance with the human health criteria.

The Department also is proposing to apply these human health criteria to waters with an existing, designated, or attainable fishery use and tributaries for those waters.

Today, the Department will provide to the Water

Quality Control Commission information that is both necessary and sufficient to support a decision to adopt these criteria.

Q. Dr. Davis, what might happen if the Commission does not adopt the criteria?

A. Again, as was heard in introductory remarks, if the Commission does not adopt criteria today -- that are being proposed today, there is a risk that the US Environmental Protection Agency will impose more stringent criteria that would be broadly based on national concerns.

Specifically, EPA stated in their record of decision in January of last year that New Mexico's failure to address these issues could result in a finding that new water quality standards are needed to comply with the federal Clean Water Act, specifically Section 303(c)(4)(B) of the federal Clean Water Act.

Again, I would refer you to Exhibits NMED 1 and 12 in this regard. Specifically, that section of the Clean Water Act requires EPA to promulgate water quality standards whenever it finds that such standards are required to meet the requirements of the federal Clean Water Act.

On the slide in front of you now, you'll see examples where EPA has already taken such action for many

states.

In 1992, EPA promulgated the National Toxics Rule, which imposed priority toxic pollutant criteria on 11 states. I do not have an exhaustive list in front of me, but these included Nevada, Alaska and Florida, the District of Columbia, the territory of Puerto Rico and one recognized Indian reservation, the Colville Indian Reservation. This list is found in NMED Exhibit 2.

Additionally, EPA promulgated what is known as the Great Lakes Initiative in 1995. The Great Lakes Initiative imposed priority toxic pollutant criteria on the several states and Indian tribes which border the Great Lakes.

Most recently, EPA promulgated what is known as the California Toxics Rule in 2000, which imposed priority toxic pollutant criteria on the State of California.

In short, EPA has a well-developed procedure and a successful track record for imposing priority pollutant criteria on states which do not act for themselves.

Q. Does EPA have any other incentive for imposing the priority criteria?

A. Yes.

Again, as was mentioned in introductory

remarks, there is a suit -- a federal lawsuit pending. EPA has been sued over the New Mexico standards.

In December of last year, 2001, two New Mexico environmental groups filed a notice of intent to sue EPA for several alleged failures relating to New Mexico's surface water quality standards. Included in that was EPA's failure to promulgate priority toxic pollutant criteria for the State of New Mexico in the NOI.

The complaint, which was filed last month, does not repeat this particular claim, and it is our presumption that that is because the Commission seems poised to consider and decide this matter.

Q. If the EPA is not sued, what might it do, or what will it do with regard to numeric criteria?

A. As you'll hear in much more detail later in the testimony, EPA will continue to apply numeric criteria equivalent to the National Toxics Rule.

In fact, this has been occurring, and you'll hear much more detail about that later in the testimony.

The additional witnesses from the Department will explain the reasons, but, again, in summary, if New Mexico does not adopt numeric criteria, by default, EPA will impose its own.

Q. It has been argued that the Commission should only adopt limited criteria for toxic pollutants now.

What is the Department's response to that?

A. We believe that it's a very straightforward thing to do it now. If there is any need in the future to revise numeric criteria, we have well-established procedures to allow that before this Commission. There is really no benefit in delaying adoption.

Again, as I stated just a moment ago, EPA already uses criteria at a more stringent level, and it could very easily continue to do that, and there is -- there is no cost -- no additional cost right now in adopting all of these criterion; however, any future effort to do so would incur the costs of another hearing and all of the ancillary activities associated with it.

Q. How do the Department's proposed numeric criteria compare to the criteria EPA is using right now?

A. EPA's criteria are more stringent, at least with respect to the risk factor for cancer-causing pollutants. We believe they are less responsive to New Mexico water quality issues than those proposed by the Department.

The principal difference is the risk level for cancer-causing pollutants. The Department is proposing a risk level of ten to the minus fifth. Interpreting that,

that would be the risk of one additional cancer in 100,000 exposed persons, and this is consistent with this Commission's policy.

EPA, on the other hand, would impose criteria using a risk level of ten to the minus sixth, which would be the risk of one additional cancer in one million exposed persons.

There is a potential, a real potential, that EPA's more stringent criteria could affect NPDES permittees in New Mexico -- NPDES stands for National Pollutant Discharge Elimination System -- including municipalities with treatment works discharging into waters of the US.

In this light, we recommend that the WQCC, the Commission, should carefully consider this issue in adopting numeric criteria for priority toxic pollutants.

Q. The Department will explain in its testimony why it's proposing ten to the minus five as opposed to ten to the minus six as the risk level, correct?

A. That's correct.

Q. Why don't we skip a little bit.

A. Yes.

Q. What has the Department done to solicit public input?

A. We made a fairly substantial effort in this

regard. As the Commission knows, on November 29th of last year, the Department submitted the original petition to the Water Quality Control Commission, and that's found in Exhibit NMED 16.

On December 11th of last year, at the regularly scheduled meeting of the Commission, the Commission considered the petition and granted the public hearing, set it for this meeting.

Following the Commission's decision, the Department published the petition and notice of public hearing on its web page and in the Albuquerque Journal. We gave specific notice to all persons on the Commission's mailing list, and to other persons who had expressed interest or would likely be interested in the matter, and this is found in Exhibits NMED 17 and 18; and then the Bureau initiated a dialogue with several organizations and persons known to be interested in the triennial review and surface water quality standards.

Specifically, we met with a list of entities during the month of January, and that's on the slide in front of you.

On January 11th, we met with the Municipal League, Environmental Quality Association. On January 15th, we met with Los Alamos National Laboratory. That same day, January 15th, we met with the Dairy Producers

of New Mexico. On January 16th, we met with Forest Guardians and Amigos Bravos. On January 18th, we met with the Middle Rio Grande Conservancy District, the Elephant Butte Irrigation District, the Carlsbad Irrigation District, the San Juan Water Commission and representatives from the City of Farmington. On January 31st, we met with the US Fish & Wildlife Service. Exhibit NMED 19 contains the sign-in sheets from these several meetings.

We also attempted to meet with the New Mexico Acequia Commission, the New Mexico Cattle Growers Association, and the New Mexico Department of Agriculture. We were not successful in that. Scheduling difficulties for those various organizations prevented that.

Q. Did these meetings prompt any changes to the Department's proposal?

A. Yes, in fact, they did.

Our purpose in holding these meetings was to engage in dialogue with interested parties and persons, hoping to obtain their insights into this petition. We specifically selected these persons or parties because they had participated in previous hearings before the Water Quality Control Commission, they had demonstrated a continued interest in the Commission's work and in the

protection of the state's waters, and we felt that they were knowledgeable about the petition, about the issues at hand, and were affected by the petition.

Speaking very personally, I am pleased in the outcome of this effort. This required a fair amount of time and commitment on the part of the persons who met with us. We appreciate that.

It's also important to state that information was presented in these meetings that helped to clarify both our objective and intent with respect to the several sections of the petition.

So this was an effort that I believe very strongly benefited the Department, and I would hope also benefited the participants in the meeting -- meetings.

MR. AMES: Okay. We'll now move on to Mr. Montgomery.

JOHN MONTGOMERY

after having been first duly sworn under oath, was questioned and testified as follows:

DIRECT EXAMINATION

BY MR. AMES:

Q. Please state your name for the record.

A. John Montgomery.

Unlike Dr. Davis, I have been accused of having a soft voice. The microphones are gone, so I'll do my

best.

Q. Okay. Mr. Montgomery, where do you work?

A. I work in the Surveillance and Standards Section of the Surface Water Quality Bureau, New Mexico Environment Department.

Q. What is your job there?

A. I'm the surface water quality standards coordinator.

Q. How long have you done that?

A. A little over six months.

Q. What did you do before coming to the Department?

A. For about 14-and-a-half years, I worked for the Wyoming State Engineer's Office. I was in the Groundwater Section for nine years as a geologist. I worked another four-and-a-half years as the hydrographic commissioner on the Upper Green River, basically administering water rights.

I then attended law school. After graduation, I practiced law for about five years. I then took a position as the county planning director in Laramie, Wyoming, until the time I moved down here to take this position.

Q. Is your biography accurately reflected in the notice of intent?

A. I believe it is.

Q. Let's move on to your testimony.

What is the subject of your testimony?

A. I'll be testifying regarding the interrelated provisions of federal and state law and the regulations that combine to form the legal framework of regulating toxic pollutants in the surface water.

First, I'll describe the provisions of the federal Clean Water Act that establish the requirements for states to regulate toxic pollutants in surface water.

Second, I will identify the EPA regulations implementing these requirements.

Finally, I will discuss the provisions of state law that authorize the Commission to adopt the narrative and numeric criteria necessary to comply with the federal Clean Water Act.

Q. Please continue.

A. If it pleases the Commission, I won't read the statutes verbatim, in the interest of time.

First, we start with Section 101 of the Clean Water Act, which states the policy of Congress with regard to toxic pollutants -- that being that it is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited.

Congress then set forth a method by which this goal should be achieved in Section 303(c)(2)(B), which requires states to adopt toxic pollutant criteria to protect designated uses. The state must adopt numeric criteria if they are available; and if not, the state must adopt criteria based on biological monitoring or assessment methods.

Next, Section 307(a)(1) establishes the preliminary list of toxic pollutants and authorizes EPA to revise the list and add to or remove pollutants after consideration of specified factors. EPA has exercised this authority, adding and removing pollutants on a number of occasions. Initially, there was a list of 65 chemicals and families of chemicals that was expanded to a list of 129, and three have been delisted, bringing the current list to 126 toxic pollutants in the National Recommended Water Quality Criteria.

Finally, Section 304(a)(1) requires EPA to develop and publish numeric criteria for the toxic pollutants that are listed in Section 307(a)(1). These values are commonly known as the Section 304(a) criteria for toxic pollutants.

We have some examples on this slide of some of the substances, certainly not a full list of the 92, but perhaps gives an idea of the types of substances that are

involved.

EPA has published numeric criteria for many, but not all, of the priority toxic pollutants. These criteria are compiled in 40 CFR 131.36(b)(1). This is contained in NMED Exhibit 2 and in related EPA documents, such as the National Recommended Water Quality Criteria - Correction of April of 1999, which is available as Exhibit NMED 5.

Most of the criteria were originally published in 1980. Those were a series of documents for demonstration purposes. They look like this. They take up about two-and-a-half to three feet of shelf space.

Okay. Many of these documents are available from the EPA website. There are a number that have not been put onto the site, but a large number of them are. The documents can also be found in most federal repository libraries.

The basis for each criterion, and a full list of references on which the criterion is based, is set forth in these formal criteria documents.

Q. Are these criteria subject to ongoing review by EPA?

A. Yes. The criteria are subject to ongoing review.

Section 304(a)(1) requires EPA to revise its

criteria to accurately reflect the latest scientific knowledge. Accordingly, EPA has, from time to time, updated criteria based on the new information. In addition, EPA derives new criteria for listed pollutants through a routine process.

In my written testimony, there may be a small amount of confusion. I believe I stated in there that EPA would routinely revise their criteria. In fact, it is not something that happens that frequently, but when it does happen, it happens through a routine process.

That process begins with a comprehensive review by EPA of available data and information. EPA then publishes a notice in the Federal Register and on the Internet announcing its intent to evaluate an existing criterion, or to derive a new one, identifying the available data and information and inviting the submission of new data and information relative to criteria development.

After reviewing any responses, EPA develops a draft recommended water quality criterion and publishes notice in the Federal Register and on the Internet announcing the availability of the draft criterion and inviting public comment and scientific review.

Concurrently with the notice, EPA initiates an agency peer review. This review is conducted by a panel

of experts who produce a report of their findings. The peer review process is itself subject to public scrutiny. EPA's peer review practices are published in the Science Policy Council's Peer Review Handbook, which is EPA Document 100-B-98-001, and it may be viewed at the EPA website.

At the conclusion of the public comment and peer review processes, EPA evaluates the public comments and the panel's report and publishes its response in the record. EPA then revises the draft criterion, if necessary, and again publishes notice in the Federal Register and on the Internet announcing the availability of the final water quality criterion. At this point, the EPA's decision is subject to judicial review.

Q. John, how does the EPA reflect to the public how -- that it's actually conducting this ongoing review?

A. If I understand your question correctly, it is through publication, through notice in the Federal Register and on the Internet. Is that --

Q. And is the IRIS a part of this?

A. Oh, okay. Well, yes.

EPA maintains a record of its ongoing review of scientific knowledge relating to water quality criteria by posting new data and information on the Integrated Risk Information System, or IRIS, database. A detailed

description of IRIS is contained in Exhibit NMED 4, Appendix N.

On the screen we have, for demonstration purposes, a slide of the introductory IRIS web page. IRIS is a publicly available electronic database that provides chemical-specific risk information on the relationship between exposure and human health effects.

The next slide shows a drop-down list where you can click on a particular substance of interest. The next slide is a sample of one of the -- at least the beginning of one of the pages. This one happens to be for PCBs. The next screen shows a later portion of one of these that shows where the cancer risk information is published.

EPA originally developed the IRIS to assist federal government agencies in responding to the growing demand for consistent chemical-specific information for risk assessments, standard-setting, and other regulatory activities. Information is posted on IRIS only after a consensus has been reached by an interdisciplinary team of scientists representing EPA's various program offices that information -- after a consensus that the information is credible.

Consequently, the IRIS represents an agency-wide consensus regarding the latest scientific

knowledge about the chemical. The EPA updates this IRIS list on a monthly basis.

In addition to chemical-specific information, the IRIS database also identifies the most significant and recent references on which EPA's risk assessment is based. To be added to the IRIS database, each reference must have been peer reviewed.

Exhibit NMED 6 contains a compilation of references for each of the toxic pollutant numeric criteria adopted by EPA under Section 304(a)(1). The compilation includes references in the original 1980 criterion documents, as well as references considered by EPA in its ongoing review of those criteria. These latter references were obtained from the IRIS database.

Q. Would it be correct to say that the listings of references in Exhibit 6 are the scientific basis for the numeric criteria that EPA has adopted pursuant -- or recommended pursuant to Section 304(a)(1) of the Clean Water Act?

A. Yes.

In my discussions with personnel of EPA and other research I've done, I found that the references listed in the 1980 documents -- well, let me rephrase.

The 1980 documents are the criteria guidance, and the references in there are the references that were

cited by EPA in the development of those documents, and then, as they are revised, as new information is made available, that information appears on the IRIS database and its list of references.

Q. You've compiled all the references, as you said, for all of the pollutants for which the Department is proposing to correct here today, or all the criteria the Department is proposing today; correct?

A. That's correct.

Q. How long is that document?

A. The document, including some chemical synonyms lists, is approximately 750 pages. There are 683 pages of actual references.

Q. Do you know how many references are actually there?

A. I calculated that once. I don't recall the number, but it seems like it's in excess of 10,000 references. Some of those references do duplicate between different substances, so the actual count will be less than that.

Q. How has EPA implemented Section 303(c)(2)(B) of the Clean Water Act?

A. EPA has established and published regulations to implement the statutory requirements in Section 303(c)(2)(B). These regulations are set forth in 40 CFR,

Part 131, Water Quality Standards.

Of particular relevance is Section 131.11(a)(2), which requires the state to adopt criteria for toxic pollutants which may adversely affect water quality or the attainment of the designated water use or which warrant concern.

The criteria must be set at levels sufficient to protect the designated use, and 40 CFR 131.11(a)(1) requires the criteria must be based on sound, scientific rationale.

The EPA regulations also establish the acceptable form of criteria. 40 CFR 131.11(b) states a presumption that numeric criteria will be adopted. However, the states are authorized to adopt narrative criteria when numeric criteria cannot be established or to supplement numeric criteria.

This Commission long ago adopted, and EPA approved, a general narrative criteria for toxic pollutants. More recently, the Commission has adopted numeric criteria for certain chemicals and heavy metals. Steve Pierce will describe the Commission's historical approach to toxic pollutants during his testimony, as well as the basis for the Department's proposal to add numeric criteria and a procedure for selecting and deriving new criteria.

With respect to numeric criteria, Section 131.11(b) authorizes the state to use one of three approaches. First, the state may rely on EPA's published Section 304(a) criteria for priority toxic pollutants. As I previously described, these criteria are developed and published by EPA pursuant to the Clean Water Act and only after scientific peer review process and subject to judicial review.

As Steve Pierce will explain, these criteria, with one exception, are the numeric values which the Department proposes today.

Second, the state may adopt EPA's Section 304(a) criteria for priority toxic pollutants with modifications to reflect site-specific conditions. This approach requires substantial information about a water body, and if applied state-wide, will quickly exhaust the Department's resources. However, it may be possible to use this approach to adjust the numeric criteria, after their adoption by the Commission, to account for surface waters with substantially different physical, chemical, or biological characteristics.

Finally, the state may use other scientifically defensible methods. However, the Department is reluctant to develop its own method for deriving new values for all of the priority toxic pollutants in Sections 307(a)(1)

due to the cost and uncertainty whether EPA would accept those methods.

Q. Mr. Montgomery, does the New Mexico Water Quality Act authorize the Commission to adopt numeric and narrative criteria for priority toxic pollutants?

A. Yes.

The New Mexico Water Quality Act establishes the Commission and its powers and duties regarding the water quality in the State of New Mexico.

First, the New Mexico Water Quality Act designates the Commission as the state water pollution control agency, quote, for all purposes of the federal act, unquote, and directs the Commission to take all action necessary and appropriate to secure the state -- to secure to this state the benefits of the federal Clean Water Act and its programs.

One such benefit is the opportunity, under Section 303(c)(2)(B), for the state to adopt toxic pollutant criteria for itself under its own terms, rather than having the criteria imposed upon it by the federal government.

Second, the New Mexico Water Quality Act expressly authorizes the Commission to adopt water quality standards that shall, at a minimum, protect the public health and welfare, including water quality

criteria to protect designated uses.

The scope of this power is broad enough to authorize numeric and narrative criteria, and, in practice, the Commission has interpreted and applied this power to adopt both types of criteria as necessary to secure to this state the benefits of the federal act.

MR. AMES: Thank you, Mr. Montgomery.

Now, I'll move to Mr. Pierce.

STEVEN PIERCE

after having been first duly sworn under oath, was questioned and testified as follows:

DIRECT EXAMINATION

BY MR. AMES:

Q. Mr. Pierce, please state your name for the record.

A. My name is Steven Pierce.

Q. And, Mr. Pierce, where do you work?

A. I work at the Environment Department, Surface Water Quality Bureau, in the Surveillance and Standards Section.

Q. What do you do there?

A. I'm the program manager of the section.

Q. Is your biography accurately reflected in the notice of intent?

A. It is.

MR. AMES: At this point I'd like to interject a statement. Mr. Pierce is a bit under the weather and is not going to be able to present all of his testimony as planned.

The written testimony had already been previously provided to all the Commissioners, and I hope the Commission has had a chance to look it over, so we're actually going to skip substantial portions of Mr. Pierce's testimony, both to preserve time, move this proceeding to a conclusion, and also to preserve Mr. Pierce's voice for cross -- at least when we get there.

Q. So with your indulgence, Mr. Pierce, we're going to skip through the national -- the discussion about the national experience, which is background information for you all to understand how the United States got to this point, or how we got to the point of 303(c)(2)(B) of the Clean Water Act, which is the driver behind this particular petition. We're going to hit some questions along the way.

In particular, I'd like to ask Mr. Pierce what EPA has done to enforce the requirement for numeric criteria.

A. EPA has taken two steps to accelerate compliance with the requirement to adopt numeric

criteria.

First, while the states take the necessary steps to adopt --

MR. AMES: I think we're actually going to interrupt Mr. Pierce at this point, because I don't know how productive this is going to be for anyone, particularly Mr. Pierce.

I think we'll let Mr. Davis -- Dr. Davis present his testimony, if that's acceptable. It is Mr. Pierce's testimony, he's available for cross on that testimony. I don't believe that there have been, in the section that Dr. Davis is going to do, any changes from the written testimony itself.

With the Hearing Officer's indulgence, could we proceed in that manner?

In the Hearing Officer's absence, can we proceed?

MR. JOHNSON: Proceed.

MR. KEYES: We could take a five-minute break.

MR. AMES: That would be fine. I'd sure appreciate that.

(Recess held.)

MR. MAGGIORE: Let's go ahead and return from our recess.

I apologize for -- I was powdering my nose when

I guess Commissioner Keyes made an executive decision to go on break, which is excellent judgment.

I believe you were going to proceed with the direct testimony from Mr. Pierce?

MR. AMES: Yes, we are --

MR. MAGGIORE: Okay.

MR. AMES: -- Mr. Chairman.

Thank you.

MR. MAGGIORE: Please proceed.

Q. (BY MR. AMES) Mr. Pierce, what has EPA done to enforce the requirement for numeric criteria in the Clean Water Act?

A. EPA has taken two steps to accelerate compliance with the criteria.

First, while the states take the necessary steps to adopt numeric criteria, EPA adopted an interim measure to provide numeric criteria for NPDES permitting. The measure authorizes three alternatives for translating narrative toxic criterion, which is no toxics in toxic amounts, into chemical-specific applicable numeric criteria.

One alternative is to use the EPA's numeric criteria for priority toxic pollutants. Another alternative is to use the state-approved translation procedure.

The second step taken by EPA is to begin federal promulgation of numeric criteria. Rather than rely on permit writers, state and federal, to comply with the interim measure, EPA has imposed numeric criteria through the National Toxics Rule, the California Toxics Rule, and the Great Lakes Initiative.

It's in the context of these federal promulgations that EPA has demanded that New Mexico adopt numeric criteria for itself.

Q. What has New Mexico done to regulate toxic pollutants in surface water?

A. Well, for many years the State of New Mexico has relied on the narrative toxics criteria to satisfy its obligation under the Clean Water Act. In 1991, at the Department's request, the Commission supplemented this narrative criterion with numeric criteria for 13 priority toxic pollutants, but only for the protection of aquatic life.

EPA approved the new criteria, although it cautioned that additional criteria would be required in the future.

In 1992, EPA promulgated the National Toxics Rule. The Department responded by expanding its sampling program to include the entire list of priority toxic pollutants. The Department collected these samples

during all major water quality surveys at each location that was deemed to pose the highest probability of detecting priority toxic pollutants. The Department entered all these results into EPA's STORET water quality database. After considerable data evaluation, the Department determined that two organic priority toxic pollutants were present in state waters -- DDE, a breakdown of DDT, and gamma BHC, also known as lindane.

These priority toxic pollutants were detected in samples collected and analyzed by USGS -- DDE in two tributary drains of the Rio Grande, and lindane in the Santa Fe River. However, the measured concentrations were far below EPA's 304(a) criteria for these pollutants.

Accordingly, the Department determined that no priority toxic pollutants could reasonably be expected to interfere with the designated use of any water covered by the Clean Water Act, and it did not propose that the Commission adopt any numeric criteria for priority toxic pollutants during the 1998 triennial review.

Q. What was EPA's response?

A. On January 23rd, 2001, EPA issued its record of decision on New Mexico's 1998 triennial review. The ROD stated that EPA would consider recommending that the administrator make a finding that New Mexico water

quality standards did not comply with the Clean Water Act because they do not contain human health and aquatic life criteria for all priority toxic pollutants listed pursuant to Section 307(a)(1).

EPA gave two options for avoiding this result: we could adopt aquatic life and human health criteria for the remaining priority pollutants, or we could provide data analysis demonstrating these criteria are not needed because the pollutants are not present in concentrations that threaten aquatic life and human health.

Q. Now, in response to the ROD, the Department sought data from EPA and then they got back some effluent discharge screening data.

In addition to that data, you mentioned the ambient data we had on the tributaries to the Rio Grande and the Santa Fe River.

After the Department reviewed all this information, what position did it take and what position is it taking now regarding EPA's demand for numeric criteria?

A. Well, the Department has pretty well concluded that it might be most prudent to adopt all the remaining priority pollutant criteria. We have no data to prove that the presence of priority toxic pollutants in various effluent discharges and in the ambient waters of Los

Alamos National Laboratory and the Santa Fe River will not interfere with designated uses in affected waters of the United States.

Indeed, the levels of priority toxic pollutants in the ambient waters at Los Alamos National Laboratory indicate a threat to aquatic life and human health downstream in the Rio Grande. Moreover, it must be acknowledged that EPA's interpretation of the Clean Water Act, which it's charged with implementing, may be entitled to substantial deference.

Indeed, having stated its position that the Clean Water Act requires New Mexico to adopt numeric criteria for all priority toxic pollutants, EPA may have a difficult time evading the obligation to promulgate such criteria in the face of state inaction. In this light, the Department recommends that the Commission take the opportunity to adopt the numeric criteria it deems most appropriate and advantageous to the interests of the State of New Mexico.

Q. Assuming the Commission accepts the Department's recommendation, what options does it have?

A. EPA recognizes three options for complying with these requirements. The options are explained in more detail in the Water Quality Standards Handbook, which is

Exhibit NMED 4.

Option one is to adopt numeric criteria for all priority pollutants for which EPA has developed Section 304(a) recommended criteria, which are applicable to all state waters without regard to whether the pollutants are known to be present in those waters.

Most states exercise this option, and use EPA's Section 304(a) recommended criteria, because it achieves comprehensive coverage with scientifically defensible criteria, therefore, avoiding the need to conduct resource-intensive evaluations of numerous waters.

Option two. The state could adopt numeric criteria only for those priority toxic pollutants which are discharged or present in a state water and which could reasonably be expected to interfere with designated uses, and only to the extent necessary to protect those uses.

Functionally, this option requires the development of site-specific criteria. While the option comports with the statutory requirement and only requires criteria in response to a specific problem, in practice this option is difficult to implement. It is time- and resource-intensive to determine if, and which, priority pollutants are interfering with a designated use.

Moreover, the time and resources required to

develop and defend site-specific criterion on a recurring basis pose substantial problems for the Department, for the Commission, and for other interested parties.

In this regard, the option suffers from the same flaws that doomed the pre-1972 approach to water pollution control.

Option three. Adopt a procedure for translating a general narrative toxic criterion, no toxics in toxic amounts, into chemical-specific numeric criteria. At a minimum, this procedure must be used to derive numeric criteria for priority toxic pollutants whose discharge or presence could reasonably be expected to interfere with a designated use.

This option provides the flexibility of calculating numeric criteria on an as-needed basis, reducing the time and cost of adoption and allowing the immediate use of the latest scientific information.

And then there is option four that EPA didn't state, and that's that no action is taken. The result of this is it's possible EPA could promulgate these standards, these criteria, for the State of New Mexico.

The Water Quality Standards Handbook indicates that the most appropriate use of option three is to supplement option one or two. This would provide numeric criteria for priority toxic pollutants with statewide

applicability to ensure precision in the calculation of effluent limitations for NPDES permits and total maximum daily loads, backed up by a predictable method for developing additional numeric criteria as needed.

Q. What option has the Department been implementing for the past decade?

A. Since 1990, the Department has followed option two. It selected this option because it called for a more limited collection of samples for analysis during some water quality surveys and therefore was less expensive.

However, since EPA issued the ROD in January, 2001, the Department has been collecting and analyzing more extensive samples for all priority toxic pollutants during all water quality surveys. Accordingly, the principal argument against option one, which was the expense of sampling and analyzing for all priority toxic pollutants during all water quality surveys, is no longer applicable because we're already doing that.

Q. What is the Department's preferred option today?

A. The Department recommends that the Commission adopt a combination of option one and option three. With respect to option one, the Department recommends the adoption of numeric criteria for all priority toxic

pollutants for which EPA has published Section 304(a) criteria for the consumption of organisms.

With respect to option three, the Department recommends the adoption of a translation procedure for the existing general toxic standard to allow EPA to derive a numeric criterion for priority toxic pollutants in NPDES-regulated discharges but for which the Commission has not yet adopted numeric criteria.

The translation procedure has many advantages for New Mexico. First, it would allow the Department to certify NPDES permits with a reasonable assurance that designated uses are being protected. The translation procedure requires the use of the IRIS data, which is consistent with the federal requirement to use the most current risk information in calculating criteria for the protection of human health. It also requires the Department to incorporate the appropriate EPA-approved formulae for calculating numeric criteria into the Water Quality Management Plan.

These formulae, recently revised by EPA, are established in EPA's Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health. That's Exhibit NMED 7, and also shown on the slide.

Second, the translation procedure ensures that

EPA will implement the Commission's policy choice regarding the appropriate risk level for cancer-causing priority toxic pollutants.

In this petition, the Department proposes a cancer risk level of ten to the minus fifth. That's one additional cancer in 100,000 exposed persons.

The proposal reflects the Commission's previous endorsements of this risk level. They have endorsed this specifically in the water quality standards under the section of domestic water supply and also in the regulations at 20.6.2.7.UU, which is the definition of a toxic pollutant as one that would cause a risk level of ten to the minus fifth.

Third, the translation procedure tells EPA how to calculate numeric criteria when none is provided in the state water quality standards.

Finally, as I'll explain later in my testimony, the translation procedure requires the Commission to review and approve the numeric criterion itself. Notwithstanding the advantages of the translation procedure, it should be noted that the approach is not new. The Commission already employs a similar translation procedure for calculating aquatic life chronic numeric criterion, and it's the Department's practice to petition the Commission to review and approve

criteria that have been derived through this process.

Q. How are you doing?

A. I'm fine.

Q. We're now going to go on and talk about the petition itself section by section. We'll try and focus on the primary sections. There are a number of changes in the petition that probably don't warrant a discussion.

So why don't we start with Section 10, one of the primary changes.

Can you please explain what the Department has proposed with respect to Section 10 of the water quality standards?

A. Yes, I can.

The Department proposes a new flow value for evaluating compliance with human health criteria. The new value, which is known as the harmonic mean flow, is defined in EPA's Water Quality Standards Handbook, which is Exhibit NMED 4.

This definition says, "Harmonic mean flow is the number of daily flow measurements divided by the sum of the reciprocals of the flows," and it restates it as it is the reciprocal of the mean of reciprocals.

The Department initially did not propose a definition for this term because the Commission had

indicated during the 1998 triennial review and deliberations that standard statistical terms should not be defined in the standards. However, during the Department's January meetings with interested groups, several persons recommended that a common reference be provided. In response, the Department selected the EPA Water Quality Standards Handbook, which is publicly available in hard copy and also electronically on the Internet.

Nonetheless, LANL has suggested that actual language from the Water Quality Standards Handbook be added. The Department supports this proposal on the condition that the definition be contained in Section 20.6.4.10, which is the section that would have the reference to the harmonic mean flow, and that's because in the public notification, we did not notify that there would be any changes to Section 7, which is where definitions would be contained.

If this is the case, we could recommend a definition be adopted in that section during the triennial review.

The Department's specification of the harmonic mean flow and the proposed reference to the EPA definition ensures that the application of water quality standards complies with federal requirements. Since

1992, EPA has developed a Section 304(a) criteria for cancer-causing pollutants using exposure assumptions which are best reflected by the harmonic mean flow.

Specifically, EPA's model for human health effects assumes long-term exposures to low concentrations. Recently, EPA amended its implementation procedures to require the use of harmonic mean flow for noncancer-causing pollutants as well. As a result, EPA now requires the use of harmonic mean flow to implement all human health criterion.

The Department's proposing to retain the existing flow value, the critical low flow, for all other criteria. This value is used to calculate the NPDES effluent limitations to ensure that discharges comply with the criteria during most flow regimes -- that is, during all flow regimes above a specified low point, the critical low flow.

The specification of this low point is important, because, without it, a discharge would have to comply with the applicable numeric criteria at the end of the pipe. The standard would become the effluent limit.

The current critical low flow is the 4Q3, the lowest four-day flow which has a return frequency of three years. The Commission adopted this value in 1991 in order to implement new aquatic life criteria for heavy

metals, which are a subset of the priority toxic pollutants listed pursuant to Section 307(a)(1) of the Clean Water Act.

Before 1991, the Commission had specified this low point, the critical low flow, as the 7Q10, the lowest consecutive seven-day flow which recurs once in a ten-year period.

The difference between the harmonic mean flow, the 4Q3 and the 7Q10 is illustrated by the graphs shown in Exhibit NMED 11, which is shown on the screen.

Generally speaking, for a given stream, the harmonic mean flow is higher than the 4Q3, and both are higher than the 7Q10.

Originally, EPA took their use of the harmonic mean flow from an article that was published in the Journal of Hydraulic Engineering, which gives more information on the harmonic mean flow. In here, they state flows for 60 different watersheds throughout the country, and in every single case, the harmonic mean flow is lower than the average. The shorter the term, the closer the two are together.

If you look at the average on the seven-day period, the two terms are no more than two percent apart. As the time length grows longer, the harmonic mean flow starts diverging from the average, but it's always less

than the average.

The graphs show these flows for two different streams. The first graph shown here represents data for the free-flowing Rio Chama at La Puente, which is near Tierra Amarilla. The flow shown for each day shows the average for all flows for that day from 1956 to 1997, as measured by USGS. The total average flow for all days in the entire period is 364 cfs. The harmonic mean flow is 62.6 cfs. The 4Q3 flow, which is used for all other standards now, is 17.5 cfs. The 7Q10 that we used to use is 7.4 cfs.

So you can see that the harmonic mean flow is a less stringent way of applying standards.

The second and third graphs present the data for the Rio Grande at Albuquerque. Since 1973, the flow of the Rio Grande at Albuquerque has been controlled by Cochiti Dam, dams on the Rio Chama, Willow Creek, Jemez River, Galisteo Creek, and also the irrigation diversion at Angostura. For this stretch of river, the total average flow from 1975 to 1999 is 1,489 cfs.

In order to get a clearer picture of the others, we have to enlarge that section that's there, and it shows the harmonic mean flow would be 161 cfs, the 4Q3 flow is down toward the bottom at 32.2 cfs, and the 7Q10 flow is right at the baseline at 7.8 cfs.

So the harmonic mean flow here, again, is a lot less stringent way of implementing these standards.

One recurring issue regarding the use of harmonic mean flow concerns the application of human health criteria to ephemeral waters. The Department's proposing to apply human health criteria for a small number of the priority toxic pollutants to ephemeral waters which are tributaries of those waters with existing, designated or attainable fishery uses.

Specifically, the Department seeks to prevent persistent toxic pollutants, such as dioxin, DDT, PCBs, and various heavy metals, from reaching waters which contain fisheries used by New Mexico residents.

In a moment, I'll explain the Department's rationale for this proposal. It's been pointed out that it's not possible to calculate the harmonic mean flow for ephemeral waters, and, therefore, it's not possible to apply the human health criteria to these waters except at the end-of-pipe basis.

LANL has proposed in these procedures using the modified harmonic mean formula currently used by the State of Texas, which accommodates ephemeral waters that have periods of zero flow. The original formula could not take zero flows because it has to have the reciprocal of the flow, which is a nondefined term.

The Department believes that LANL's proposal has merit and supports the use of this formula for those waters that are ephemeral.

Finally, San Juan Water Commission argues that the Department should have evaluated whether harmonic mean flow represents the long-term average flow on which the human health criteria are based and adopt a long-term average flow if it reflects the appropriate flow conditions.

EPA stated in the California Toxics Rule, which is their most recent promulgation of human health criteria, that it believes that the harmonic mean flow is the correct statistic to use in computing such design flows rather than any other averaging techniques. Since EPA has conducted extensive studies into this matter, the Department sees no reason to invest its resources and reinvent the wheel.

Q. Mr. Pierce, the Department has proposed a new subparagraph in Section 10 regarding the applicability of the human health criteria.

Can you please explain what the Department's proposal is?

A. Yes, I can.

The Department proposes this new section to identify the waters that are subject to the numeric

criteria for the protection of human health. Specifically, these criteria would apply to all waters with a designated, existing or attainable fishery use.

There is little dispute about the application of the criteria to this. This language was adopted at public meetings for our proposal.

The Department's proposed human health criteria were developed to protect humans consuming fish, so it's appropriate to apply these criteria to waters with a designated, existing or attainable fishery use. The Department also proposes to apply a small subset of these criteria to waters which are tributary to waters with a designated, existing or attainable fishery use. This application is more contentious, because some of these tributaries are ephemeral or have ephemeral reaches. Many of these waters may have aquatic organisms, but they do not generally have fish which are consumed by humans.

The Department believes that it's appropriate to apply the criteria for persistent toxic pollutants to these ephemeral waters in order to protect downstream waters which do have fish communities. As I previously stated, the purpose of the human health criteria is to protect human health from the consumption of fish with

toxic pollutants in their flesh.

For most of the toxic pollutants, this goal can be accomplished by protecting the water in which the fish live from direct discharges of these pollutants. These pollutants degrade into less toxic compounds in a relatively short period of time, a matter of days or weeks.

Other toxic pollutants are more persistent, or else they degrade to equally toxic components, such as DDT. These pollutants pose a substantial risk in the environment over a period of many lifetimes. In many cases, they adhere to sediments and are mobilized during runoff events and transported downstream to live waters. These pollutants are bioaccumulative. They accumulate in fish, which absorb them from the water and the aquatic organisms which they eat, who in turn have absorbed them from the water column and from the sediments. Over time, these pollutants bioaccumulate to concentrations which are dangerous to humans which consume the fish.

This problem is real and it exists currently in New Mexico. The table in Exhibit NMED 10 indicates high levels of PCBs and dioxin in ephemeral storm waters at Los Alamos National Laboratory. These data were collected by the NMED-DOE Oversight Bureau, and they were analyzed by the Access Analytical Laboratories in

Vancouver.

There also is evidence that these pollutants are being transported downstream into waters containing fish consumed by New Mexicans. Exhibit NMED 9 contains a February, 2002, data review which reveals high levels of PCBs and dioxin in fish that were caught in Cochiti Reservoir.

This is only an example, and it's not my intent to single out LANL. These are very hard-to-detect pollutants. They may be found in other locations of the state if these same precise sampling and analytical procedures, which are very expensive, are conducted. But the example illustrates a larger point. For persistent toxic pollutants in ephemeral waters, the most common control strategies in place do not work.

For persistent toxic pollutants, a different strategy is needed. To protect downstream fisheries, the pollutant load discharged to the ephemeral water must be controlled. To achieve this objective, the numeric criteria for persistent toxic pollutants must be applied to the tributary itself, even if it does not have fish or a designated fishery use.

Q. LANL opposes the applicability of human health criteria to ephemeral waters. What arguments does it make in this regard?

A. LANL argues that ephemeral waters do not contain fisheries, and that is true. However, the Department's proposal is designed to ensure that loads of certain highly persistent toxics do not reach fishery waters.

LANL argues that applying criteria to ephemeral waters is not the best way to protect the downstream uses. They talk about the Rio Grande, and if a domestic water supply use were designated, that every tributary upstream of that segment would be required to be designated as a domestic water supply. This is really a straw-man argument. Standards are set on upstream waters to protect downstream uses. Natural free-flowing streams have the ability to attenuate levels of pollutants. They clean themselves up over distance and time. That's why not all waters upstream from primary contact waters have to be designated as primary contact. In those cases, the standards that are in place in upstream waters do protect the primary contact use downstream. However, that would not be the case for these highly persistent subsets of contaminants. These will stay in the environment for generations and will bioaccumulate.

Under LANL's proposal, these persistent contaminants would not be regulated in ephemeral streams. The Department's proposal only applies to 15 -- the very

worst of the worst of the toxic chemicals -- to ephemeral tributaries. These substances persist in the environment and bioaccumulate to dangerous levels in fish. There is no good reason to release any of these 15 persistent toxic chemicals into the watersheds of the state.

LANL argues that existing approaches are effective. The current application of standards to effluent-dependent reaches only applies when discharges routinely reach classified waters downstream, and it excludes all those discharges which reach those classified waters during runoff events. This is a very large loophole in the standards.

The LANL proposal is a blank check for discharges which add loading of persistent toxics to waters of the state. Water flows downhill and it carries sediments with it, and the sediments -- the smallest sediments have the largest surface water area and tend to pick up the greatest number of those contaminants. It's these fine sediments that get moved most easily downstream.

Any of these persistent priority toxic pollutants that are allowed to enter ephemeral waters will move downstream over time. Allowing these contaminants to enter ephemeral waters is the same as allowing them to enter waters that have fish in them.

Q. Mr. Pierce, in its written testimony the San Juan Water Commission argues that the Department intends to apply the criteria to private waters.

What is the Department's response?

A. There is absolutely nothing in the Department's proposal that says this. Jim Davis did not say this during the public outreach meetings.

If the San Juan Water Commission believes that this was said, why did they not question this at that meeting at that time? The meetings were set up for the purpose of openly exchanging information in a non-confrontational situation and to arrive at the very best proposal for all parties.

Private waters are and will continue to be exempt under the New Mexico Water Quality Act. That's simply not a prerogative of the Surface Water Quality Bureau.

Q. Mr. Pierce, what method will the Department use to determine compliance with the human health standards?

A. The Department proposes to add this section in order to specify the method for determining compliance with human health criteria.

The single grab sample approach is consistent with the compliance method adopted by the Commission for

all the other numeric criteria, except for compliance with chronic aquatic life criteria, which is based on the arithmetic mean of analytical results using appropriate protocol.

Now, in practice, the Department doesn't make compliance determinations on fewer than two samples, even if the method does allow for a single grab sample. When the Department detects an exceedence of a numeric criteria in an analytical result, after all QA/QC requirements have been investigated and found to be in effect, it goes out and collects at least one second sample from the same location. Only if the Department confirms this exceedence in the second sample does it conclude that an exceedence has occurred. It doesn't even consider a violation at that point. For a full assessment of attainment of the use, our protocol requires seven sample results are needed, and this includes all the standards for which the Commission has specified that compliance is based on a single grab sample.

Q. Steve, let's move on to Section 12.F. This is the heart of the Department's proposal.

Could you please explain how the Department proposes to use the Section 304(a), recommended values that EPA has developed and as well the translation

mechanism, to derive such a criteria when the Commission has not adopted them?

A. Okay. The Department proposes to amend Section 12.F to establish a procedure for using new EPA Section 304(a) criteria for priority toxic pollutants to protect aquatic life and human health. The Department also proposes a procedure for deriving numeric criteria for those priority toxic pollutants when EPA has not published Section 304(a) recommendations.

The Department's proposal regarding human health criteria is new, but the proposed language regarding aquatic life criteria follows the existing Commission procedures and language in the standards. It's important to retain this procedure because new toxic pollutants are occasionally detected in our aquatic ecosystems.

EPA, the Department, the regulated community, the public, and the environment are served by the availability of a readily identifiable, Commission-approved procedure for calculating these numeric criteria. Without the procedure, the Department would have to request a hearing every time a new toxic pollutant is detected in ambient water, delaying protection of the environment, and taxing the resources of the Department and other interested persons.

I'm going to go through the Section 12.F paragraph by paragraph.

The first paragraph, we propose to amend paragraph one to clarify the general toxic standard, no toxics in toxic amounts, applies to all sources except natural causes.

Deletion of the term "attributable to discharges" is necessary to ensure the general toxic standard applies to the full range of activities which contribute toxic pollutants to state waters. Specifically, the word "discharge" substantially narrowed the scope of the standard. The state water quality standards do not define "discharge," but the EPA, at 40 CFR Section 122.2, excludes pollutants deposited in dry channels and upland areas which may be mobilized into state waters from this definition. The exception for natural causes was added to clarify the Department recognizes the concept of natural background for evaluating the conditions of state waters.

Finally, the Department proposes to amend paragraph one to clarify the general toxic standard applies to toxicity affecting humans, livestock and to other animals, as well as fish and other aquatic organisms.

The Department proposes to amend paragraph two

to establish the procedure be followed when the Section 900.M table, which we are proposing for inclusion in the back part of the standards, does not contain a human health criterion for a priority toxic pollutant.

First, under paragraph 2(a), the human health criteria would be the recommended human health criterion for the category "consumption of organisms only" published by the US Environmental Protection Agency pursuant to Section 304(a) of the Clean Water Act. Of particular importance, the procedure specifies the category of organisms only and the ten to the minus fifth risk level for cancer-causing pollutants.

The Department proposes the organisms only category because it believes these criteria adequately protect human health in New Mexico. EPA publishes two categories of recommended human health criteria. The first category is consumption of water and organisms together, and the second is the consumption of organisms only.

The difference between the categories is the exposure route. The first category assures that the public -- I'm sorry, assumes that the public is consuming raw, untreated surface water and consuming fish caught in that same water. Because conventional drinking water treatment methods can remove the priority toxic

pollutants that might be found in surface waters of New Mexico, the Department does not consider the criteria based on the consumption of untreated surface water is necessary to protect human health in New Mexico.

The second category assumes that the public is exposed only through the consumption of fish, and other aquatic organisms, if appropriate. It assumes that the public obtains drinking water from a source which meets the requirements of the Federal Safe Drinking Water Act, which would limit the level of these priority toxic pollutants.

The Department concludes that this second category of criteria would adequately protect public health in New Mexico.

The Department proposes the ten to the minus fifth risk level because, as I've said previously, it's consistent with existing Commission policy. In at least two places, the Commission has endorsed this risk level.

When EPA has not published a Section 304(a) recommended criteria, under paragraph 2(b), the criterion would be derived using the appropriate formulae specified in the Water Quality Management Plan -- the New Mexico Water Quality Standards Management Plan.

These formulae were published by EPA in October of 2000 and are included in NMED Exhibit 7.

EPA has stated that the states may adopt Section 304(a) recommended criteria or criteria which have been calculated according to this formulae. Accordingly, in the absence of a Section 304(a) criterion, these formulae provide a method for deriving valid criteria.

Q. Does the Department address Los Alamos National Laboratory's concern by including these formulae by reference in its proposal?

A. Yes.

LANL argues that the formula implementing translation procedure should be included in the CPP and proposes language for such a formula.

The Department agrees with the thrust of these comments and of this proposal. We've modified the proposal in the notice of intent to present technical testimony to include the formulae in the Water Quality Management Plan instead of the CPP. We feel that the Water Quality Management Plan is the appropriate document in which to include this formula. We would also include the formulae that EPA published in October of 2000, which they state are the only supported formulae to be used now. So there would be no need for the recommended. It's there.

These again are the formulae -- these are the

new formulae that were revised by EPA. The difference is fairly slight, but EPA has stated that when they published the new formulae that they wouldn't accept criteria derived after that point by the old formulae.

Q. What other requirement does paragraph 2(b) impose on the translation procedure?

A. Paragraph 2(b) also requires the use of data available on the IRIS database. This requirement ensures that the latest information concerning reference doses for noncancer-causing pollutants and cancer potency slopes for cancer-causing pollutants is used.

As John Montgomery explained, EPA publishes these values on IRIS only after extensive peer review, and these numbers don't jump around. They are based on 20 years of data that have been in IRIS, and so at the most, there are very, very slight changes when new studies come out.

In most cases, the criteria that would be developed using these formulae, from IRIS figures, wouldn't show any change to any significant level that would affect a standard.

The Department does not expect that EPA, as the NPDES permitting authority for New Mexico, will invoke this procedure very often. Currently, there are only 17 priority toxic pollutants for which human health criteria

have not been published. EPA may add more toxic pollutants to the priority list under its Section 307(a)(1) authority. The Department is not aware of any pending proposals. Even if the EPA added more pollutants, the procedure would only apply if EPA also did not adopt human health criteria for those pollutants.

It's important to note that this procedure takes advantage of the confluence between EPA regulations authorizing a narrative criterion when numeric criteria cannot be established and another EPA regulation requiring EPA, as the NPDES permitting authority, to derive criteria from a state regulation interpreting the narrative criteria.

In this case, the Commission has adopted a narrative toxic criterion in Section 12.F(1) which prohibits toxic pollutants in toxic amounts, and it's adopted a procedure in paragraph F.2(b) which tells the EPA how to derive criteria to achieve that standard when EPA Section 304(a) criteria are not available.

In the absence of the procedure in Section F.2(b), EPA would have to calculate its own criterion without any guidance from the state regarding the category of protection -- i.e., water plus organisms versus organisms only -- and the risk level. By dictating the procedure and these categories, the

Commission constrains EPA's discretion to calculate and impose numeric criteria not consistent with the Commission's policy and practice. In other words, the Commission gets to say how EPA will develop those permit limits.

Nevertheless, some persons have questioned whether the procedure would result in the adoption of criteria without Commission review and approval.

Q. What is the Department's response to those arguments?

A. In the Department's view, the risk is no greater under paragraph 2(b) than under any of the other paragraphs in 12.F. The Department also questions whether EPA's use of the procedure to develop a numeric criterion for developing NPDES permit effluent limits constitutes, quote, adoption, unquote, under state law.

The real argument here seems to be that the Water Quality Control Commission has seen not to be able to adopt narrative criteria, and this is not true. Adoption of narrative criteria and the translation procedures to translate those narrative criteria are well within the scope of the authority.

The Commission has already adopted a narrative criteria, no toxics in toxic amounts, and this standard

has to be translated by someone. The numeric criteria that's derived would be subsequently presented to the WQCC for their adoption only after public notice and public hearing and all full notification requirements.

EPA already uses a translator to derive criteria for the statement no toxics in toxic amounts. However, they use the risk levels that they deem to be the best for New Mexico.

The Commission has the choice of specifying the translation used. The proposed procedure only clarifies how the narrative standard is to be applied. It specifies the procedure and the formula. It directs EPA to interpret a narrative standard in a specific way, rather than allowing the EPA to interpret the narrative standard as it wishes. The translator makes this narrative standard more understandable and its application throughout waters of New Mexico more consistent.

The WQCC has the authority to clarify this narrative standard and is doing so after public notice and during a public hearing.

Q. Now, Mr. Pierce, you earlier said that the numeric criteria that's derived from these, subsequently adopted by the Commission after public notice and hearing, or would be offered to the Commission for such

adoption.

Are you actually referring to paragraph 2(c), which is the Department's response to this concern?

A. Yes. This concern was voiced during our public outreach activities.

One of the suggestions that came from Mr. Hernandez was to have the Department petition the Commission after any kind of standard -- to petition the Commission after any numeric criteria have been calculated by EPA and implemented into any kind of effluent limits.

The section proposed as 2(c) would require the Department to do so within 90 days of the issuance of a final NPDES permit by EPA which contains numeric criteria that were calculated under paragraph 2(b).

So if EPA uses paragraph 2(b), that NPDES permit, we would then step forward within 90 days and request a hearing.

The petition would propose the adoption of the new criteria and would afford interested persons an opportunity for comment and the Commission an opportunity to thoroughly review and then to approve or disapprove the new criterion during a public hearing.

Q. Mr. Pierce, the Department proposed this new paragraph (c) in its notice of intent, is that correct?

A. Yes. This was included in the Department's notice of intent to present technical testimony filed on February 21st.

Q. Let's move on to paragraphs three and four of the Department's proposal. There are no changes in paragraph five, as I understand it, so why don't you just address three and four at this point.

A. Okay. Paragraph three would reflect the existing provisions that are in the standards right now for determining chronic criteria for the protection of aquatic life.

Only minor modifications have been made to the original language, primarily to parallel the language and format of paragraph two. The original language was moved in Section F, the no toxics in toxic amounts, which was at the end of Section F, and so in order to put it at this particular place in Section F, we had to strike it all out and show it as new language at this place in Section F.

As you may have remembered, over the last three or four years, Section F went from a very small paragraph to about a page long.

The Department proposes to amend paragraph four to specify the acute aquatic life criterion published by EPA may be used under the New Mexico Water Quality

Standards. This approach parallels the paragraph 3(a) for chronic aquatic life criteria, except for the calculation method that is afforded to the chronic criteria.

Although chronic criteria are almost always much lower than the acute criteria, and, therefore, are more protective, acute criteria may be important to determine the concentration of a toxic pollutant that would be immediately toxic to aquatic life. For example, in storm water runoff for which it may only be possible to get a single grab sample, but which could have very toxic impacts to the aquatic life.

Paragraph five just has minor changes.

Q. Those are simply -- I said no changes earlier, but those changes are very minor and simply intended to accommodate the changes that occur before it?

A. That is correct.

Q. Nothing substantive?

A. That's right.

Q. We've now reached Section 900, which is the last big section which changes -- in which changes are proposed.

Let's start with the cold-water fishery section. The Department has proposed some changes here. Would you explain them?

A. The Department proposes to amend this section to update references and to identify the specific parts of the new criterion table in Section 900.M which apply to this designated use, including the human health criteria.

The new heading for the criteria table in Section 900.M is "Aquatic Life." The term has caused great confusion, because it's not clear how aquatic life is related to the designated use of fisheries. In fact, the Department is not proposing any change in the designated uses. The designated uses refer to aquatic life, which is a shorthand term for the column in the table containing most of the numeric criteria.

The general standards refer to aquatic life because this is the EPA term of art that's been used ever since the Clean Water Act was first passed for the type of criteria used by New Mexico for the fishery designated uses.

When the Commission adopted numeric acute and chronic criteria to protect the fishery designated uses, it used EPA's aquatic life criteria and was fulfilling a federal requirement to protect aquatic life uses.

Q. Mr. Pierce, you mentioned that the use of the term aquatic life was confusing to some people. Can you explain why?

A. Some confusion may be caused by a misperception about the meaning of the term "fisheries." In some circles, the term has been read narrowly to exclude all other aquatic organisms. Such reading is contrary to the Clean Water Act, which requires the protection of fish and other aquatic organisms. It is also contrary to the Commission's history of designated uses.

In 1973, the Commission selected the term "fisheries" to identify the designated use commonly referred to by EPA as aquatic life. New Mexico's fishery designated uses are designed to protect both fish communities and the other aquatic organisms in a particular type of ecosystem. For instance, a cold-water fishery designated use was adapted from the 1967 water quality standards, in which these waters were called trout-producing waters, but the intent was to protect the entire aquatic life of such waters.

The warm-water fishery designated uses evolved from the earlier warm-water fish-producing waters designated use, which was an aquatic life use.

Q. There are some changes to this section on domestic water supply. I think these are accurately reflected in Mr. Pierce's written testimony, and none of them, as I understand it, are controversial, so we'll skip them for a moment and come back to them if we need

to on rebuttal, if necessary.

The same applies, I think, to high-quality cold-water fishery, in which the Department proposes to strike the criterion for total organic carbon. We'll skip that for the moment and move on to irrigation.

Mr. Pierce, what changes are proposed in the designated use of irrigation?

A. The Department proposes changes to this section to include irrigation storage in the title and direct users to the new criteria table in Section 900.M where the criteria that had been deleted here in this paragraph have been moved.

The title change is intended to clarify the long-standing assumption that these criteria apply to waters used directly for irrigation, but for the waters that are stored for that use as well.

The Department has consistently applied these criteria to irrigation storage designated uses when conducting water quality surveys, and irrigation storage facilities, reservoirs, and these are already subject to the far more stringent numeric criteria for fishery designated uses.

Accordingly, the title change does not substantively change the designated use. The relocated criteria values have not changed, but the units have been

converted from milligrams per liter to micrograms per liter to achieve consistency in the table. The one exception is selenium. Selenium will remain in this section because it requires explanatory information, and under the NMAC 2.0 rules, you can have no footnotes to any tables. They don't like tables themselves, you have to kind to beg them to put a table in, but they draw the line at footnotes.

Finally, the Commission should consider converting the selenium criteria that remain in this particular paragraph to micrograms per liter just to ensure consistency, but we did not indicate that change.

Q. Mr. Pierce, Los Alamos National Laboratories suggested the term "irrigation storage" should be defined.

What is your response?

A. Well, it appears to me that the term is pretty self-evident. "Irrigation storage" is the storage of water for irrigation. The definitions section of the standards again was not included in our public notice, and probably cannot be legally modified at this time, although I'm not one to speak on whether or not that would be legal.

Also, LANL has not proposed a definition for

this term at this time. In that light, these proposals could be brought up at the upcoming triennial review when all sections may be open for modification.

Q. Now, Mr. Pierce, I think we'll skip right through marginal cold-water fishery, warm-water fishery and limited warm-water fishery, as well as Section 900.J, livestock watering and wildlife habitat.

Those changes, as far as I'm aware, are not controversial and we can address any concerns people have later in this hearing.

Why don't we move on to Section 900.M. This is the table to which you refer. It contains many of the numeric -- or most of the numeric criteria which the Department is proposing. Let me rephrase that, it includes all of the numeric criteria which the Department is proposing. It includes many of the criteria from other parts of the Section 900.

Can you describe for the Commission the table and how it's organized?

A. Yes. This table, which we're calling Section M, is a table of all numeric criteria for priority toxic pollutants, except for those pollutants for specific uses which requires some type of explanation, but generally we would require a footnote to make it more understandable.

In those situations, this table includes a

reference to the subsection where the criteria and explanation can be found. This reference responds to LANL's concern that a person using the table might overlook some criteria applicable to a designated use.

The table contains most of the criteria for the priority toxic pollutants for easier reference. For each pollutant, the table identifies the Chemical Abstract System, shorthand is CAS, registry number assigned by the American Chemical Society. This doesn't make a lot of difference in a term such as mercury, but when you get to some of the long organic chemicals that can be stated by any of 150 different names, the CAS number becomes fairly important. Even in EPA documents, in some cases, they have recommended criteria under one name for one of these chemicals and IRIS has it under a different name.

MR. AMES: Steve, can you pause for us for a moment?

Is there some difficulty finding the table? I notice some Commissioners looking around frantically.

MS. BRANDVOLD: It's not in the testimony, but it is in Exhibit 20.

MR. AMES: Yes. It is in the Department's original proposal of November 29th and the revised one dated February 1st. It's toward the very end. It is at the very end, I believe. We did not include the table in

our written testimony itself.

MR. PIERCE: I have some extras.

MR. AMES: Mr. Secretary, are you looking for your copy?

MR. MAGGIORE: No, I'm looking for the adapter for my laptop. I've only got it for about ten more seconds.

MR. AMES: Okay.

MS. BRANDVOLD: Here, you can look at this copy.

MR. KEYES: There is no security on the Secretary's laptop.

MR. PIERCE: There are more copies of the February 1st proposal.

MR. AMES: Does anyone need a copy of our proposal so they can locate the table?

MR. JOHNSON: Yes. It's somewhere in this pile of stuff.

MR. AMES: Anybody?

MS. HUGHES: Give me one. Thanks.

MR. AMES: Okay.

MS. BRANDVOLD: Okay.

MR. PIERCE: If everybody can see the table now.

MR. KEYES: I don't see how anybody caught that

one mistake.

MR. AMES: There is another one we'll get to in a second.

MR. PIERCE: The table is composed of two alphabetical lists, and the way we propose it, the first alphabetical list is comprised of the first 24 priority toxic pollutants. They are all contained on the first page of these tables.

These pollutants are the inorganic compounds, and these inorganic compounds have the greatest number of criteria across all of the designated uses. For instance, the metal chromium has five numeric criteria for four different designated uses. By moving all of these pollutants to the first page of the table, the Department sought to make it easier to find these commonly applicable criteria. The remainder of the table, the next three pages, contains criteria for those organic priority toxic pollutants. The table also expresses all criteria in micrograms per liter. To achieve this consistency, the Department has proposed to convert the criteria for domestic water supply, irrigation and livestock watering designated uses from their current milligrams per liter to micrograms per liter. In converting these units, the Department did not intend to change any values. Any change in values that

might be detected would be corrected immediately.

The table contains all the new priority toxic pollutant criteria being proposed today. Most of the criteria, 92, are for the protection of human health, through the fish consumption pathway, while 21 are for the fishery designated uses. In the table, the fishery designated uses appear under the title "Aquatic Life," as they do under EPA recommended criteria tables.

The table contains 11 new acute and 10 new chronic criteria for priority toxic pollutants for the fishery designated uses.

The remainder of the new criteria are designated to protect human health based on fish consumption. In all, new human health criteria for 92 priority toxic pollutants are proposed. Of these 92 pollutants, the Department proposes to designate 56 of them as either carcinogens or persistent. The last column in the table indicates whether the pollutant is carcinogenic by a C or persistent by a P. Some pollutants are both carcinogenic and persistent.

Q. Mr. Pierce, Los Alamos National Laboratories suggested the term "human health" be defined. What is your response to that suggestion?

A. Here again, the term seems to be self-evident, and the Commission had indicated that self-evident

matters didn't need to be defined. However, it's been used at the federal level for about 25 years.

LANL has not proposed a definition at this time. If a definition appears warranted, it can certainly be proposed during the upcoming triennial review.

Q. What is the Department's basis for identifying certain pollutants as carcinogenic?

A. The Department based its determination of carcinogenicity on designations included in the 1999 EPA National Recommended Criteria, which is NMED Exhibit 5.

The designation is important because different formulae are used to derive human health criteria for carcinogens and noncarcinogens under Section 12.F. By providing this information in the table, the Department allows interested persons to use the appropriate formula to calculate criteria for their own purposes.

The Department based its determination of persistence on the EPA's identification of pollutants which are persistent, bioaccumulative and toxic, and which are the subject of an enhanced effort by EPA to eliminate all occurrences of these from the environment. This is Exhibit NMED 8.

The list of persistent toxic pollutants includes aldrin/dieldrin, benzopyrene, chlordane, DDT,

hexachlorobenzene, alkyl-lead, mercury, mirex, octachlorostyrene, PCBs, dioxins and furans, toxaphenes, and probably a few more that I couldn't even pronounce right now.

The designation of any new persistent toxic pollutants would require a hearing and rule-making before the Commission.

Q. Before we talk about the persistent toxics some more, is there a change to the list of carcinogenic pollutants identified by the Department?

A. Yes.

It was pointed out by LANL that for antimony, we had in our table a C and a P. It should have just been P; it was not a C.

Once again, it was not our intention to change any of the recommended designations that EPA had supplied in the recommended criteria. We thank them for finding that, and we do propose to change that.

Q. Now, in its testimony, Los Alamos National Laboratory suggested that there are some discrepancies between the Department's list of persistent toxic pollutants and the list published by the Environmental Protection Agency for the Great Lakes and Michigan.

What is the Department's response to that testimony?

A. We based our list of persistent toxics on the EPA list of toxics that's published on the Internet and is included as Exhibit Number 8. This is the list of priority PBTs, persistent, bioaccumulative and toxic compounds, currently being addressed by the PBT initiative by the EPA.

The New Mexico list also includes the toxic metals, which by their very nature are persistent.

The EPA Great Lakes Initiative list differs from the official EPA recommended list. This slide shows the GLI list. It might be very hard for you to see, and it's hard to see, but a number of these we put a black line through, and they indicate those that are also found on the Commission's list.

That's the next slide.

Then, also, delta-hexachlorohexane, which is indicated by a red line on the next slide, has no EPA recommended criterion at this time. Mercury, in the next slide, is indicated by a green line, and it's not been proposed, for reasons that I'll explain in a minute.

Q. Go ahead.

A. The three substances indicated with a yellow line, in the next slide, are not contained in the IRIS database and are not priority toxic pollutants. These were selected based on known problems in the Great Lakes

area.

The substances indicated by blue lines, which includes the rest of them on the GLI list, are nonpriority toxic pollutants, and New Mexico is not required to adopt criteria for these compounds.

That covers all the criteria that are in the Great Lakes Initiative list.

Q. Now, this is a little different -- that's much better. Before it was almost impossible to read.

Does the Commission want a summation of the differences between the two lists? We can perhaps do that.

Steve, do you think you can point to -- identify which pollutants on the GLI list are not included on ours, or vice versa, or would you need a moment to do that?

A. Okay. Which ones are not?

Q. Why don't we -- let's put that aside for a minute. I don't want to belabor the point. We'll go back and try and come up with an oral presentation that will supplement this, because this is a little difficult to read. We apologize. Let's just move on.

Mr. Pierce, where did the Department get the numeric criteria in table 900.M?

A. All new recommended numeric criteria in the

table were taken from the EPA 304(a) recommended values for priority toxic pollutants, with the exception of the recommended criterion for arsenic. EPA published these values in the National Recommended Water Quality Criteria, Corrected Version, that was published in April, 1999, and is NMED Exhibit 5.

There are many similarities between these values and the human health criteria for organisms only imposed by federal promulgation in the National Toxics Rule and the California Toxics Rules.

Q. Has EPA indicated whether it would approve these criteria?

A. EPA has indicated that it would approve these criteria. However, I note for the record that EPA is in the process of revising the criteria for human health based on a methodology that they published in October of 2000. This methodology takes into account the scientific knowledge gained since EPA developed the 1980 methodology on which the current criteria are based. In particular, the new methodology uses a bioaccumulation factor, a BAF, rather than the bioconcentration factor, BCF, that was used earlier.

The BAF considers the entire exposure of an organism to the toxic pollutant from water, sediment and food. However, EPA has not yet published peer review BAF

values for the priority toxic pollutants and has not said when it will do so, so it's not possible at this time, using the methodology, to calculate numeric criteria.

Q. Mr. Pierce, you said the Department deviated from EPA's Section 304(a) recommended values for one pollutant and you also said that the Department has not proposed a criterion for another pollutant.

Let's start with the deviation. Which pollutant are we referring to and what is the reason for the deviation?

A. The Department reviewed EPA's Section 304(a) recommended value for arsenic, and we believe that EPA's recommended value of 1.4 micrograms per liter, which is what their value would be expressed at ten to the minus fifth, is unreasonably stringent in light of natural background levels in New Mexico, which generally range from three to five and can at times be much higher.

On the other hand, the Department believes that Region 6's alternate recommendation of 20.5 micrograms per liter at ten to the minus sixth, which would be translated to 205 micrograms per liter at ten to the minus fifth, is not adequate to protect human health and would probably be disapproved by EPA.

Given the range between these EPA recommended values, 1.4 all the way up to 205, the Department sought

to derive a more appropriate criteria for arsenic for New Mexico. A recent federal study provided the basis for the Department's proposed criterion.

In 1997, USGS published a study of arsenic and other metals in the Rio Grande in the vicinity of Albuquerque. The study, conducted in conjunction with EPA, NMED, Isleta Pueblo, the City of Albuquerque, yielded some numbers that could be used to calculate an arsenic criteria.

The Department believes that this criterion protects human health and is realistic for New Mexico waters. The calculation uses a New Mexico-specific derived BAF for arsenic and the percentage of inorganic-to-total arsenic in fish tissue, 65 percent, which accounts for the toxic form of arsenic. Most arsenic criteria are developed to measure total arsenic because inorganic arsenic, the toxic form, is difficult and very expensive to detect through laboratory processes.

Q. Does the Department have any -- well, first of all, how much did this federal study cost?

A. The federal study went about $300,000.

Q. Is the Department aware of any similar studies for other pollutants in New Mexico -- other toxic pollutants and priority toxic pollutants, specifically,

in New Mexico?

A. No.

Q. The Department has not proposed one numeric criteria, you said earlier. Which metals or which pollutant is that?

A. That pollutant would be mercury. The Department has not proposed a numeric human health criterion for mercury. At this time it's simply not possible to do so.

On January 8th of 2001, EPA withdrew all Section 304(a) recommended human health criteria applied to the water column for mercury. In its place, EPA substituted a fish-tissue-based criterion that would require the calculation of watershed specific criteria.

To implement the standard, EPA stated that it would publish a guidance before the end of 2001. However, no guidance has been published at the time of this hearing. My staff says that it will be impossible at this time to implement that mercury criterion without the implementation guidance.

When EPA publishes the guidance, the Department will review the propriety of recommending a new criterion for mercury.

EPA's failure to publish the implementation guidance for its new criterion does not leave the state

without protection for mercury. The Commission adopted a chronic mercury criterion for aquatic life of 0.012 micrograms per liter in 1991. This was intended, at that time, to protect humans consuming fish in New Mexico. In other words, the Commission did adopt a human health criterion, but under a different label.

EPA has informed us that this criterion complies with federal requirements that were in place at that time, since the value is based on then-current EPA recommendations that were adopted to protect human health, and it was approved at that time by EPA. In other words, the water quality standards already contain the criterion to protect human health from the bioaccumulative effects of mercury in fish.

Q. Now, for the last question of Mr. Pierce.

How does the surface water quality in New Mexico compare to the Department's proposed human health criteria?

A. At this point, I'd like to describe how current water quality compares with our proposed criteria priority pollutants.

The data which I will present -- it's slide 79 -- are contained in the table labeled NMED 10. This table compares the Department's proposed human health criterion to information obtained from Section 308

effluent monitoring reports and ambient data collected by the Department and Los Alamos National Laboratory for all priority toxic pollutants detected in effluents or ambient water in New Mexico.

In all, 23 priority toxic pollutants are listed. 20 pollutants were found in effluent discharges from municipal wastewater treatment facilities. These were the data that the Commission and the Department had a long battle with the EPA to obtain during most of 2001.

The remaining three pollutants, gamma-BHC, PCBs and dioxin, were detected in ambient waters in New Mexico. For each of the 23 pollutants, the table identifies the Department's proposed criterion, the number of effluents containing that pollutant, the range of concentrations found in those effluents, the location of the highest concentration and the date of the sampling for the highest concentration, and then finally the magnitude of this concentration as a percentage relative to the Department's proposed criterion, whereas the same figure as the Department's criterion would be a hundred percent.

The table shows that most of the priority toxic pollutants detected currently in New Mexico are a very small fraction of the Department's proposed criterion. In fact, the majority, 13 out of 23 of these, are only a

fraction of one percent of the proposed criterion.

On the other hand, six priority toxic pollutants have been detected at levels which exceed the criterion. Arsenic was detected at 11 facilities, with the highest concentration in the effluent discharge at Jemez Springs, where the concentration was 364 percent of the proposed criterion. Two pesticides, chlordane and DDT, were detected in the effluent discharge at Cuba at concentrations greater than 40 times the proposed criteria.

Two persistent priority toxic pollutants, PCBs and dioxin, were detected at Los Alamos National Laboratory in ambient storm waters at concentrations that are hundreds of times higher than the proposed criterion. Thallium, a heavy metal, was detected in an effluent discharge from Los Alamos Bayo wastewater treatment facility at a level that's 190 percent of the proposed criterion.

It's important to note that the proposed human health criteria for ambient water quality -- are for ambient water quality and not effluent limits. So even though we're showing effluent data as a percentage of the standard, that would not be a direct relationship, because the standard would not apply to effluents, it would apply to the ambient waters after a dilution

factor.

The NPDES permittee might exceed the ambient water quality standard for a priority toxic pollutant in its effluent as long as the resulting in-stream concentration does not exceed the criteria. This in-stream concentration is a calculated value, taking into account ambient concentrations of the pollution, available dilution from the critical low flow, and other factors.

In the case of priority toxic pollutants, NPDES effluent limits would be calculated based on the harmonic mean flow dilution. For example, tetrachloroethylene, one of the priority toxic pollutants, was detected in the effluent discharge at Farmington's wastewater treatment facility in samples collected by Farmington at concentrations of 12 micrograms per liter. This exceeds EPA's Section 304(a) criteria at a ten to the minus sixth risk level, and, therefore, an effluent limitation would be required if the effluent caused a violation of the in-stream concentration. By comparison, the Farmington effluent discharge of tetrachloroethylene is only 13.6 percent of the Department's proposed numeric criterion and would not require an effluent limit under the Department's proposal.

That concludes my proposed testimony.

MR. AMES: Thank you, Mr. Pierce.

The Department has about 20 more minutes of testimony, ten minutes for Mr. Saums and ten minutes for Dr. Davis.

What is the Commission's pleasure?

MR. MAGGIORE: Commissioners, I suggest we get through the direct testimony and then we can decide if we want to go straight into cross or take a break.

Does that sound okay?

Please proceed, Mr. Ames.

MR. AMES: Okay.

GLENN SAUMS

after having been first duly sworn under oath, was questioned and testified as follows:

DIRECT EXAMINATION

BY MR. AMES:

Q. Mr. Saums, please state your full name for the record.

A. My name is Glenn Saums, S-a-u-m-s.

Q. Where do you work, Mr. Saums?

A. I work for the Surface Water Quality Bureau of the Environment Department.

Q. What do you do there?

A. I'm the program manager of the Point Source Regulation Section.

Q. How long have you done that?
A. I've been program manager of the section since 1985.
Q. What are your responsibilities there?
A. My responsibilities include preparing certifications of NPDES permits, under Section 401 of the Clean Water Act, and reviewing permits. Part of that review is to ensure that the permits are protective of state water quality standards and are consistent with the appropriate requirements of state law.
Q. Perhaps a little bit closer.
What is the subject of your testimony, Mr. Saums?
A. The subject of my testimony today will be a discussion of the EPA's approach for calculating numeric effluent limits for priority pollutants in NPDES permits in New Mexico, and the effect of the Department's modified petition on this approach.
Just for clarification and reminder, NPDES stands for National Pollutant Discharge Elimination System, which is the permitting program under the federal Clean Water Act.
Q. Let's move on to the legal framework.
How does EPA regulate toxic pollutants in NPDES permits?

A. Currently, Region 6 of the EPA must prepare the NPDES permits in accordance with all requirements of federal law, regulations, as well as EPA policy and guidelines.

To accomplish the Clean Water Act's goal of no discharge of toxic pollutants in toxic amounts, which was mentioned earlier in testimony, the EPA published a national policy which is applicable to NPDES permits being issued today.

The policy ensures that NPDES permits protect state narrative criteria for toxic pollutants, as well as chemical-specific numeric criteria.

Five years after EPA adopted that policy, they adopted regulations to implement this policy. In 40 CFR, Section 122.44(d)(1), the EPA required all permitting authorities to evaluate each NPDES-regulated discharge for the potential to exceed state narrative criteria for a toxic pollutant. You can refer to NMED Exhibit 3.

Discharges which might exceed these narrative criteria must have effluent limitations imposed in their NPDES permits. These effluent limitations should be chemical specific, but if the permitting authority determines that such limits are not sufficient, it must also impose effluent limitations based on whole effluent toxicity, also known as biomonitoring.

Q. Mr. Saums, these regulations established a process for translating state narrative criteria for toxic pollutants into chemical-specific numeric criteria, as necessary to evaluate discharges and write limits.

What are the four approaches that this regulation authorized for doing that?

A. I believe the four approaches are up on the slide being projected.

The first approach is to use the proposed state criterion or use a proposed state criterion.

The second approach would be to derive the criterion from an explicit state policy or regulation interpreting the narrative criterion.

The third option would be to use EPA's Section -- Clean Water Act Section 304(a) criteria for priority pollutants.

Last, the fourth option, would be the utilization of an indicator or surrogate parameter for monitoring, subject to several conditions which are stated in the regulation, which include reopening the permit if the monitoring no longer satisfies the narrative criterion.

Q. Mr. Saums, which approach has Region 6 adopted?

A. The EPA has described, in 40 CFR, 122.44(d)(1) --

Q. I think you can skip by that for the moment and just move on and describe the procedure that EPA Region 6 has adopted under this regulation.

A. Okay. Under this regulation, EPA has been reviewing NPDES permits on the basis of the national criteria of the -- as expressed in the National Toxics Rule. The EPA has expressed its intent to rely on Section 304(a) criteria when the state has not adopted a numeric criterion for the toxic pollutants or expressed a policy choice regarding derivation of the applicable values.

Region 6 also prohibited any regulated discharge which could endanger a drinking water supply, cause aquatic bioaccumulation which threatens human health, causes in-stream acute or chronic toxicity, causes a violation of a numeric water quality criterion.

The EPA Region 6, in order to accomplish these objectives, has stated that it would identify and address sources which may exceed the EPA water quality criteria for human health protection.

Q. What risk level is Region 6 using now to evaluate effluent discharges in New Mexico?

A. Currently, and for a number of years, the EPA has used the ten to the minus sixth risk level for carcinogenic pollutants.

Q. And that's applied to the EPA's Section 304 recommended values, correct?

A. That is correct.

Q. So give us a little more detail how EPA has actually implemented this approach for NPDES permits, some specific examples to put this in context.

A. EPA Region 6 has implemented the approach consistently in New Mexico. Between 1999 and the year 2001, Region 6 proposed to issue or reissue approximately 100 NPDES permits in New Mexico.

In the fact sheets that accompany these proposed permits, Region 6 stated that the criteria for the National Toxics Rule, which are identical to the Section 304(a) criteria, were used to evaluate the effluent discharge.

Region 6 also stated that it evaluated cancer-causing pollutants at the ten to the minus sixth risk level. In the majority of cases, there was no effect or result to the human health stream -- that is, no additional requirements were added to a permit.

For two NPDES permits, this practice could have resulted in more stringent effluent limitations. For example, in the case of Molycorp, Region 6 found a reasonable potential that the discharge would exceed the Section 304(a) criterion for arsenic, but ultimately the

more stringent technology-based effluent limitation was imposed in the permit.

In the case of the City of Roswell, Region 6 also found a reasonable potential that the discharge might exceed a 304(a) criterion for mercury, but later obtained additional data which controverted this finding.

The matter is still not settled with regard to a third NPDES permit. In this case, which is the case of the City of Rio Rancho -- in that case, Region 6 found a reasonable potential that the discharge would exceed the Section 304(a) criteria for pollutant, but the permit -- since the permit has not been issued at this time, it's unresolved, but it appears at this time, also, that it's likely that the issue will be resolved without the imposition of an effluent limitation based on the Section 304(a) criteria.

At this point in time, Region 6 has not imposed an effluent limitation in an NPDES permit based on Section 304(a) criteria using the ten to the minus sixth risk level; however, the possibility that that could happen concerns NPDES permittees who recognize the Commission has indicated a preference in previous actions for a lower risk level -- that is, ten to the minus fifth.

NMED Exhibit 74

Q. Now, Mr. Glenn, you've said that EPA Region 6 uses the ten to the minus sixth risk level for carcinogens.

Does Region 6 also use the harmonic mean flow?

A. Yes, they do.

Q. What effect will the Department's proposal have on EPA's current practice?

A. The EPA would begin to evaluate NPDES permits -- NPDES-regulated discharges differently if the Commission adopts the Department's proposal. That is that they would cease using their protocol and start using the Commission's.

First, the Department's proposed numeric criteria for priority toxic pollutants uses a risk level of carcinogens one order of magnitude less stringent than the EPA.

Second, the Department's proposal establishes a procedure for directing the EPA how to select or derive a numeric criterion in the absence of a value in the state water quality standards. Please refer to Section 20.6.4.12.F.2 of the water quality standards.

This procedure ensures that the EPA will use a consistent approach to selecting or deriving any numeric criteria for priority pollutant toxic -- priority toxic pollutants in the absence of approved values and is

expressly authorized by 40 CFR 122.44(d)(1)(vi), which also requires the EPA to select or derive missing criteria from Section 304(a) recommended criteria or a regulation interpreting the narrative criteria. Please refer to NMED Exhibit 4.

MR. AMES: Thank you, Mr. Saums.

Now, we will conclude with Dr. Davis.

JAMES DAVIS

after having been previously duly sworn under oath, was questioned and testified further as follows:

FURTHER DIRECT EXAMINATION

BY MR. AMES:

Q. Dr. Davis, what will be the effect of the numeric criteria on the TMDL program?

A. Minor, at best.

As the Commission knows, Section 303(d) of the Clean Water Act requires that the state survey state waters, anything that is found to be not in compliance with applicable standards is listed, and then a TMDL is developed.

As Mr. Pierce indicated in his testimony, we've been doing this on a routine basis. We simply don't think that this will have much of an impact on 303 lists, nor on the TMDL program.

Q. What effect will the Department's proposed

numeric criteria have on nonpoint sources?

A. We will survey all state waters regardless of source of pollution, as is our normal and current practice.

Mr. Pierce, in his testimony, indicated that we propose to delete the clause "attributable to discharges" from Section 12.F of the standards. Accordingly, these -- these -- I'm multi-tasking, excuse me -- these -- and I'm not doing it very well -- these criteria would apply to those waters, and we would -- we would survey them for the purpose of determining whether or not they are in compliance with these criteria.

It makes no distinction between point sources or nonpoint sources.

Q. And, finally, could you please sum up the Department's proposal one last time so it's fresh in the Commission's mind?

A. That's the slide that is currently up. We are asking -- we are proposing that numeric criteria for priority toxic pollutants be adopted, they consist primarily of numeric criteria for the protection of human health.

Again, to reiterate, this addresses the last pending issue for completion in the triennial review initiated in 1997. Specifically, as the slide indicates,

we propose 11 acute and 10 chronic numeric criteria for priority toxic pollutants to protect various fisheries designated uses and 92 numeric criteria for priority toxic pollutants to protect human health.

We propose a procedure for selecting and deriving numeric criteria when there are no such criteria in the water quality standards and a method of determining compliance.

We're also proposing to apply these human health criteria to waters with existing, designated or attainable fishery use and their tributaries, as explained by Mr. Pierce in his testimony.

Today, we've provided to the Water Quality Control Commission information that is both necessary and sufficient to support the decision to adopt these criteria.

MR. AMES: Thank you, Dr. Davis.

That concludes the Department's direct testimony.

I would now move the admission of the Department's exhibits, NMED 1 through 21, as well as the PowerPoint presentation, which is mostly for demonstrative purposes, but I'd move its admission now, too.

MR. MAGGIORE: Any objections for admission of

Environment Department Exhibits 1 through 21, and I guess we can go ahead and label the PowerPoint presentation Exhibit 22?

MR. AMES: Please.

Thank you.

MR. MAGGIORE: Can you take care of labeling that exhibit, Carolyn?

Seeing no objections, those exhibits have been entered.

(NMED Exhibits 1 through 22 admitted.)

MR. MAGGIORE: Thank you, Mr. Ames.

MR. AMES: Thank you, Mr. Chairman. That concludes the Department's case in chief.

MR. MAGGIORE: Commissioners, do we want to proceed with cross? Do we want to take a five-minute break? Do you want to take a supper break? What's the pleasure of the Commission?

MR. GLASS: At least a five-minute break.

MR. MAGGIORE: Five minutes for right now. Let's do a five-minute leg stretch and we'll move into cross.

(Recess held.)

MR. MAGGIORE: It's about 5:35. We're back on the record.

We will proceed with cross-examination of the

Department's witnesses.

I'll ask the Commissioners first, any cross-examination of the witnesses?

Do you wish to be crossed as a panel?

MR. AMES: Please.

MR. MAGGIORE: Okay.

MS. BRANDVOLD: This would be for whoever can answer, but adding all of these extra chemicals onto the list, what does that do to a dischargers' costs?

Does that increase their costs, or are those covered already in, say, a biomonitoring?

MR. SAUMS: Currently, EPA is -- when they are reissuing NPDES permits, they require -- they require the applicant to scan their effluent by sampling. So they are already sampling for all of these pollutants.

When EPA, we call it, screens the effluent against the standards, they only develop effluent limitations for those parameters for which there is a potential exceedence of a water quality standard.

So if for pollutant A, they screen it, and they determine that there is no reasonable potential that a water quality standard -- any water quality standard, whether it's human health based, or some other use -- if there is no reasonable potential, there is no effluent limitation.

Conversely, if there is a reasonable potential, then they would write an effluent limit, but since EPA is already scanning all effluent discharges against their human health criteria, our adoption of the same number of parameters is --

MS. BRANDVOLD: Doesn't matter?

MR. SAUMS: -- it comes out equal.

MS. BRANDVOLD: Thank you.

MR. GLASS: Except that, if I might --

MR. MAGGIORE: Commissioner Glass.

MR. GLASS: -- if I might add to that, in the process of obtaining an NPDES permit, there is a certain amount of effluent monitoring that has to be assembled by the municipality or dischargers, so to speak.

With this additional list of chemicals, is that cost going to increase? I mean, these are not inexpensive chemicals to test for.

So on whatever cycle it is, you know, ideally five years, more like 15 years, but, whatever, there is a time period during which you do have to possibly spend more money to do it.

MR. SAUMS: That's correct.

The EPA has already been asking permittees to run these pollutant scans as part of their reapplication. So since they are already doing that, and then they are

taking that data from those scans and running it against their numbers, they would continue to do that process, so it's not an increase, it would remain constant with what they are doing now in terms of asking for the data in advance.

Dr. Davis was just refreshing my memory that where there possibly was an increase is where there are now very few NPDES permits that are extremely old in terms of their expiration date, such as the City of Bernalillo, which was last issued by the EPA in 1988, and so there might be an increase for them because they haven't had a permit reissued in a long time.

There are other administrative and legal reasons that that's not happened, which are kind of outside of today's hearing.

Right now, the percentage of NPDES permits that are current has increased dramatically -- I don't have the numbers at my fingertips, I apologize for that, but EPA has, in the last three years, worked very diligently with the Department to update NPDES permits and bring them to be current -- current being within the five-year expiration date of a permit.

MR. GLASS: I guess from that you can conclude that -- we're on the third, is that true, the third round? Is that -- of NPDES?

MR. SAUMS: Third round, yes.

Third-round permits is a term that EPA uses to refer to NPDES permits where they are seeking to protect the -- particularly with regard to the discharge -- no discharge of toxics in toxic amounts.

MR. GLASS: So third-round permits will include the requirement for this?

MR. SAUMS: Most facilities in New Mexico are already into their third-round permit, and, arguably, I guess you could call it the fourth round.

MR. KEYES: May I ask a question --

MS. HUGHES: Commissioner Keyes.

MR. KEYES: -- along this line?

In your testimony on Exhibit Number 10, where you had the list of the dates when some of the items were, in fact, exceeded, some of the suggested levels, what are the termination -- or expiration dates of some of those communities that were listed in there?

Are their expiration dates way earlier than when these actually were collected?

MR. SAUMS: Most of the permits in NMED Exhibit 10 have been reissued within probably the last four or five years. I don't have the precise expiration dates in front of me, but my recollection is that we've gone through the effort to update NPDES permits, particularly,

in the last three years.

These all look familiar to me as having -- we've seen these in the last three or four years.

MR. KEYES: Thank you.

MR. MAGGIORE: Commissioner Hutchinson.

MR. HUTCHINSON: Just one quick question.

Dr. Davis, you said that there would be a negligible impact on TMDLs or 303(d) listings. Is that what I heard?

MR. DAVIS: Yes.

Mr. Chairman, Commissioner Hutchinson, I didn't use the word "negligible," but I said that I thought it would be, you know, a very small impact. I don't think it's significant.

MR. HUTCHINSON: So in that arena, we're proposing to apply these to ephemeral stretches.

Would that result in ephemeral stretches showing up on the 303(d) list that are not present there now because we don't classify them in that regard?

MR. DAVIS: Mr. Chairman, Commissioner Hutchinson, I don't know that it's correct to say that no ephemerals appear on the 303(d) list.

Wildlife habitat and livestock watering standards apply. When water is present, we measure it. It also depends on how the standards are actually

written. Some sections of the standards refer to perennial tributaries and other sections refer to all tributaries. Perennial tributaries, obviously, is self-explanatory. Ephemeral reaches, therefore, are not in that classified segment.

Where it says all tributaries, then ephemeral reaches are, by definition, included in that classified segment.

MR. HUTCHINSON: So it would just depend on the description of the reach?

MR. DAVIS: Yes, I think so.

Again, these chemicals that are in our proposal, typically, I think you would expect to not find them in most areas of the state that we're talking about, higher portions of a watershed or ephemeral tributaries to a -- you just typically would not expect to find them. That doesn't mean that we might not find them, but I would not expect it to occur very frequently.

MR. HUTCHINSON: That's what I was expecting. I just wanted to get a clarification on that.

Thank you.

MR. MAGGIORE: Thank you.

Any other cross-examination of the Department witnesses from the Commission?

Commissioner Whipple and then Commissioner

Keyes.

MR. WHIPPLE: Thank you, Mr. Chairman.

I have some questions for Mr. Pierce about his testimony.

One thing that I'm curious about that I don't understand is what does the harmonic mean flow have -- relate to anything physically?

Like the 4Q3 flow, I can visualize what that relates to physically.

MR. PIERCE: We do have the article in which the Journal of Hydraulic Engineering explained a little bit more about it and why they felt that it more accurately described long-term flow, kind of moderating out the highs and lows and a lot of the other methods, but, no, it doesn't -- there is nothing that you can visualize, like a 4Q3 or a 7Q10.

MR. WHIPPLE: So how would you describe how the exposure assumption used by EPA are best reflected by the harmonic mean flow?

MR. PIERCE: When they applied them to waters, they used the harmonic mean flow of those waters.

MR. WHIPPLE: So that's just the tie? Anything physically?

MR. PIERCE: Anything that was found based on the harmonic mean. It's like when they developed for the

chronic, they used four-day averages, and so most of the states, including New Mexico, went to a 4Q3, because that came closer to what EPA was using to determine those criteria.

MR. KEYES: Is that your question?

MR. MAGGIORE: Is this a friendly amendment to Mr. Whipple's question?

No problem.

MR. KEYES: When did Texas accept the harmonic mean flow and particularly in relation to the common reach? Do you know what year they accepted it in their review process?

MR. PIERCE: I don't know that answer, but it's possible that Mr. Meyerhoff from LANL would know that.

MR. MAGGIORE: Do you want to defer to -- is there someone that could help with the response to this question?

MR. MEYERHOFF: I do not have any answer to that question.

MR. MAGGIORE: Okay.

MR. AMES: That makes it easy.

MR. WHIPPLE: Mr. Chairman, I have a few more questions.

MR. MAGGIORE: Please.

MR. WHIPPLE: Mr. Pierce, on page 11 of your testimony, of your written testimony, in the second complete paragraph, it talks about high levels of PCBs and dioxin in ephemeral storm waters at Los Alamos National Laboratory, and then a February of 2002 analysis indicating high levels of PCBs and dioxin in fish caught in Cochiti Reservoir.

Are there other potential sources of those PCBs and dioxins other than from streams off the laboratory property?

MR. PIERCE: Mr. Chairman, Commissioner Whipple, certainly, particularly with the fire up in that area, there are lots of other potential sources than the lab itself.

We found elevated levels in Cochiti. We found elevated, but not nearly as high levels, in Abiquiu and in Navajo, but these are only places we've looked so far in the state.

We're looking a lot of other places, but the funding is quite low for us, unfortunately. We have a lot of fish that have already exceeded holding times that we're trying to get these kind of analyses on.

The PCB sampling, I believe, currently costs $1,200 a sample, and it doesn't take too many of those to go through a budget pretty quick, particularly when you

have to do QA, and you don't base it on one sample.

Yes, we're just starting to find these. EPA is looking for these contaminants in fish throughout the country. We're a part of that study. That's how Navajo Lake got -- our samples got analyzed for Navajo Lake.

The chemicals of concern that they are finding everywhere are mercury, of course, and dioxins and PCBs. So these are being found in other places, and, obviously, LANL is not at all those other places around the country, so, yes, there must be other sources.

MR. WHIPPLE: Okay. I have a question about the proposed changes to Section 20.6.4.900, Subsection D, in particular.

Is there a definition for irrigation storage?

MR. PIERCE: No, there is not.

MR. WHIPPLE: The reason why I ask is, I guess, I have a couple of concerns about the applicability to the standards, for example, where somebody may pump groundwater into an irrigation pond, where then it would become irrigation storage, or other instances where you might have a reservoir with no dedicated irrigation storage, per se, even though water flowing to the dam might be used for irrigation.

So I was wondering about the applicability of this standard to those types of surface waters.

MR. PIERCE: Mr. Chairman, Commissioner Whipple, irrigation storage is a designated use that this Commission has designated on 15 different waters of the state. Among those waters are Elephant Butte, Abiquiu, El Vado, Heron, Brantley, Sumner, Storrie, Avalon, Conchas and Navajo. These have been designated as irrigation storage for many years.

MR. WHIPPLE: So that's -- okay. Got you.

MR. PIERCE: So, I mean, there hasn't been a definition, but there hasn't been a definition for many years, either.

MR. WHIPPLE: Another question.

On ephemeral streams, would the human -- what I'm thinking of is a small reservoir that might be up along an ephemeral stream that might be supplied by diversions from a river or from groundwater, might have some surface water storage that could potentially spill during times of large rainfall runoff, but that would be the only times.

Would the criteria for the persistent toxic substances apply, I assume, to such a water body, as long as that was a tributary drainage to a stream segment that was designated fishery use?

MR. PIERCE: Mr. Chairman, Commissioner Whipple, that's correct, but currently also the livestock

watering and wildlife habitat all do apply to that.

Now, to be realistic, most of these little ponds aren't going to have dioxin, PCBs, or any of these priority toxic pollutants in them, so -- but those are currently subject to the standards. Unless there is a problem, probably nobody will go out and look at it, but they are -- they are already -- several of these are applicable if they happen to be in one of those segments for which the Commission has said that this stretch and all tributaries and they are also subject to fishery uses.

MR. WHIPPLE: Thank you.

MR. MAGGIORE: Dr. Davis.

MR. DAVIS: Thank you, Mr. Chairman.

To make sure I understand your question, Commissioner Whipple, are you referring to what could perhaps in common parlance be called a dirt tank, where a berm of dirt is placed in an arroyo to intercept intermittent or ephemeral flows and accumulate water for the purposes of livestock?

Is that the kind of thing you're referring to?

MR. WHIPPLE: No. But now that you've raised it --

MR. DAVIS: Okay. If you would, please,

explain in more detail what it is you're referring to.

MR. WHIPPLE: For instance, Morgan Lake, where PNM's water supply reservoir -- that are fed by the diversions off the San Juan River, but don't necessarily release water back into the system -- into the stream system.

MR. DAVIS: In any case, Mr. Pierce's answer is still a good one. I just -- I was visualizing, when you were describing -- when you described this, I was visualizing what -- what are known as dirt tanks, of which there are 30,000, 50,000, 100,000 of them around this state. I have no idea.

Nevertheless, in waters impounded like that, wildlife habitat and livestock watering standards apply. You don't expect to find these sorts of things in them, obviously.

Just a point of clarification. Thank you, Mr. Chairman.

MR. WHIPPLE: Thank you.

That's all I have.

MR. MAGGIORE: Any other cross-examination of Department witnesses from the Commission?

Commissioner Glass.

MR. GLASS: With apologies, I have a few questions, actually. I'm trying to trim them down.

The first issue that comes to mind is that your slide indicates that you have, for aquatic life, 11 acute and 10 chronic criteria being proposed. Those are new criteria, I suppose.

When I look at the table, I see many more than 10 acute and 11 chronic, and I just -- I assume that some of these existed prior and they've just been moved into the table.

Is there some way they could be -- the new ones could be highlighted so that the reader would know which are the new ones being proposed?

MR. PIERCE: Yes, Commissioner.

After the first 24, I believe everything is new.

MR. GLASS: Okay. The first 24 are old, just moved in from the textual tables, and then the ones --

MR. PIERCE: Except for the ones for human health, but for -- it's all the alphabet compounds that are on the next three pages that are new.

MR. GLASS: Okay.

MR. PIERCE: Except for chlordane and PCB, which we have existing standards, and DDT under wildlife habitat.

MR. GLASS: So everything in number 25 and after -- except for chlordane and DDT --

MR. PIERCE: And PCB.

MR. GLASS: Okay. I see the proposal is to include the formula, or the formulae -- there are several formulae for calculating criteria from the IRIS database -- to include those in the Water Quality Management Plan, and I guess I have kind of a timing problem with that in that one would publish -- we would adopt these standards when the formula isn't in the Water Quality Management Plan. Is that a problem? Do we have to revise the Water Quality Management Plan before these -- you see my point?

MR. DAVIS: Mr. Chairman, Commissioner Glass, yes, and we specifically thought about that, because as this Commission is very aware, we are undergoing a major update of the Water Quality Management Plan.

We looked at a calendar and anticipated a sequence of events, recognizing that in order to do this, we would need to modify the Draft Water Quality Management Plan that is currently in its 60-day public comment period.

This, obviously, is simply a proposed calendar. We anticipate that the Water Quality Management Plan -- see, this isn't going to work anymore. We do have a timing issue.

MR. GLASS: Maybe you can ask -- I was going to

ask counsel about that, but it's empty over there. Maybe I can ask their counsel.

MR. MAGGIORE: Is the question the concern that we will be adopting regulations that contain a formula which the Water Quality Management Plan is yet to --

MR. GLASS: Exactly.

MR. MAGGIORE: -- provide for?

MR. GLASS: The standards say that the formula will be used and give a reference to the location of the formula where it cannot be found.

MR. DAVIS: We would be -- Commissioner Glass, we would be able -- I believe we could approach the Commission in a very timely manner to make the change in the Water Quality Management Plan, such that action on this proposal would not be in effect yet, have no procedure specified in the plan, we would simply change the plan.

If the Commission adopts this approach that we're proposing and approves the inclusion into the Water Quality Management Plan, we would simply then move forward and make that change in the Water Quality Management Plan and approach the Commission at its next meeting to debate, discuss and adopt that change in the management plan.

I don't believe we can put something into the

management plan that references the standards if the standards have not yet been adopted by the Commission. So we have to -- we have to allow the Commission to act on the standards, and then following that, we would immediately act on the management plan.

MR. AMES: If I might add, Mr. Glass, if you recall, the EPA will either look to a state -- explicit state policy or a state regulation in deciding how to make the translation mechanism work, and I would suggest that if the Commission were to adopt this language into section 12.F.2(b) that the Department would point the EPA toward the transcript of the proceeding for evidence of the Commission's policy regarding the formula to use in the absence of those formulae in the management plan yet.

So there may be a gap in time, but EPA is not going to like run out and use whatever formula they want. After all, the formulae we're proposing for inclusion in the Water Quality Management Plan are EPA's current formulae, so the likelihood that we're going to hit the wall here, because the plan has not yet been amended to reflect what the standards require, I think, is extremely unlikely in these circumstances.

MR. DAVIS: And practically speaking, Commissioner Glass, it would be perhaps one month,

at the most two months, before we were able to do this. So, as a practical matter, I don't think it would be a problem.

It is very -- it is correct that it is a hypothetical problem, but I don't think it would be practical.

Glenn just pointed out that there is no prohibition for updating the Water Quality Management Plan more frequently than we have done in the past, and, accordingly, we would propose that the management plan be amended accordingly in a timely manner.

MR. GLASS: And I personally wouldn't have a problem with the approach here. I was just thinking more of a procedural or -- or something beyond my knowledge, if you will, just an issue.

But on the same page there, on the notice of intent, page five -- and I've flagged it elsewhere, too -- is the statement that -- actually you added it, I think, in response to a -- I forgot who expressed the concern, but it's on page five of your notice of intent to present technical testimony where you say that within 90 days of the issuance of an NPDES permit containing a numeric criterion calculated pursuant to, the Department shall petition the Commission to adopt such criterion into these standards.

My question is that if EPA establishes -- well, I guess that would be -- you're talking here about EPA establishing a stream criterion, right, a stream standard?

I mean EPA issues final permits, right, and it would be they that calculate the criterion? Is that true?

MR. SAUMS: Commissioner Glass, I think we're not talking about establishing a stream standard.

What we're talking about is them deriving a criterion for scanning in the permit issuance. When they are drafting the permit, if they don't have a number to scan the data against, as they review the permit, they would come up with a number according to that, and they would pursue their permitting action, and then upon the finalization of the permit, we would take that and come to the Commission to establish as a stream standard.

MR. GLASS: To propose a stream standard?

MR. SAUMS: As a stream standard, going through the full public participation process.

MR. GLASS: That was my concern, that we may be establishing here a mechanism to establish stream standards without the required public hearing, but that obviously is not the case, because the criterion that EPA would use for a permit is not tantamount to a standard.

It is a starting point for a standard, it would be proposed as a standard, but is not actually a standard?

MR. DAVIS: That's correct.

MR. SAUMS: I think that's correct, Commissioner Glass.

MR. GLASS: Okay. Got that. Thank you.

I guess just a last question. I did trim them down pretty well. There were 30 or 40.

In Mr. Pierce's testimony, on page 27, when discussing the issue of arsenic, as much as I hesitate to make Steve try to talk, you stated that you believed that Region -- it's in Pierce's testimony, page 27 -- you stated that the Department believes that Region 6's alternate recommendation of 20.5 micrograms per liter is not adequate to protect human health and would be disapproved by EPA.

I guess my question is that if EPA recommends it, why would EPA disapprove it, or is it a national or regional problem?

MR. PIERCE: That's part of it, Commissioner Glass.

Region 6 saw that there is a problem with arsenic -- as you're very aware, with the arsenic standard. National EPA is waiting for a study that's

being conducted to be finalized, which is already overdue.

Region 6 felt that they couldn't wait, so they put out what they called an interim recommended criterion of 20.5.

When you look at the basis, they based it on ten to the minus sixth. They don't say that this standard would be good if you went ahead and translated it to ten to the minus fifth. The standard they recommended was 20.5. So if we take it and change it to ten to the minus fifth, we kick it all the way up to 205, which is well above drinking levels, et cetera. So I'm pretty sure they would not approve that.

What they want people to do in the interim is to adopt the 20.5, but that wouldn't have the same basis as our other criterion, and so if we took it and changed it to 205, they wouldn't approve it at that level.

MR. GLASS: So it's the level of risk difference that really has the impact here?

MR. PIERCE: That's correct.

MR. GLASS: I understand that.

MR. PIERCE: Our calculated level is real close to that 20.5 at 24.2.

MR. GLASS: I noticed that. Yeah.

Thank you.

MS. BRANDVOLD: Is that your last question?
MR. GLASS: Yes.
MS. BRANDVOLD: Mr. Olson, you had some questions.
MR. OLSON: Just a couple.
I guess it's Mr. Pierce. I guess this is on the toxic pollutants, 20.6.4.12.F.
On removing that language "attributable to discharges," it sounds like that's going to be making nonpoint source activities and problems mandatory. Do you have any comment on that?
MR. PIERCE: Commissioner Olson, I don't believe that's the case.
Nonpoint sources aren't addressed by our standards and neither are point sources. Standards apply to the ambient water. So to the extent that there have been problems for nonpoint sources, they still need to be addressed, even though there is no mechanism except voluntary within the state, or the mechanism is they get a much higher priority rate when it comes to issuing 319 grants, but by removing that, it doesn't mean that nonpoint sources would be a mandatory enforcement.
It would just mean, you know, that we're applying the standard to the ambient stream.
MR. OLSON: Okay.

MR. PIERCE: And it wouldn't allow the loophole of being able to put large quantities out there that aren't coming specifically out of a pipe today that would get into the waters.

Did that answer your question?

MR. OLSON: Yes.

MR. DAVIS: Commissioner Olson, if I could, I'd like to expand a little bit on Steve's answer.

MR. OLSON: Yes.

MR. DAVIS: The logic of this is precisely the same logic that the Commission used when it clarified the exemption for irrigation flood control facilities of five numeric standards, and that is that the standards, as Steve pointed out, apply to the ambient water. They do not address the source of the pollutant. They establish the criteria against which ambient water is measured.

That logic, as it applies to the irrigation and flood control facility exemption, is correct. Equally, it would be correct under this circumstance, and that is that these standards are applicable to the water and they do not restrict themselves vis-a-vis the source of the pollutant.

MR. OLSON: Thank you.

I just have two others.

Mr. Pierce, on page 16 of your testimony, you

talked about a logic for not putting in drinking water -- or because of conventional drinking water treatment methods can remove the priority toxic pollutants, the Department doesn't consider those criteria based on the consumption of untreated surface water are necessary to protect public health.

If that's the case, why would we have -- we have some other domestic standards in the table M that we had currently. Is there some conflict with that, with what you're saying there, and the inclusion of those other domestic standards, because those things could be removed by treatment? Should they be in table M?

MR. PIERCE: The statement that conventional treatment could remove those was our way of thinking about whether or not, in a few years when Albuquerque is drinking river, would they be at a higher risk of eating fish and getting that through their drinking water, and the answer was no, based on that, because it would be treated and be removed, but also the water quality standards -- the drinking water standards would apply to Albuquerque.

We were looking to see if there was any significant risk of people who are drinking raw water and eating fish out of the same water, and in that that doesn't seem to be a very widespread situation in the

state; however, if it is determined to be occurring somewhere, then we would be quite willing to come back and propose a different basis for a site-specific standard for someplace where people are consuming the water and eating fish out of that same water.

MR. OLSON: But we do have some standards then for domestic water supply?

MR. PIERCE: That's correct.

These are drinking water standards from the Safe Drinking Water Act that would apply to surface water that people would use after filtration and disinfection.

Since the drinking water standards represent the level that is found to be healthful for people consuming two liters of water over 70 years, the Commission has always adopted those standards in those stretches of water that are recognized to be used directly for people to drink without any treatment beyond filtration or disinfection.

MR. OLSON: So is that the rationale that these ones that are in here wouldn't be removed by the conventional treatment and why there would be a standard, say, for, you know, barium, arsenic?

MR. PIERCE: Those standards do not apply to a municipal water supply. They only apply to a domestic water supply. The assumption under the domestic water

supply is that people use the water, disinfecting it and filtering it, and no other treatment.

MR. OLSON: Okay.

MR. PIERCE: Municipal water supply carries no standards whatsoever at the moment. The municipal water supply designated use carries no standards with it specifically at the moment.

MR. OLSON: Okay.

MR. PIERCE: If there was something that somebody was found not to be able to remove in treatment, then they might request such a site-specific standard for a stream to try to prevent that from going into the water.

Currently, all the items we're looking at now are removed by conventional treatment common in New Mexico.

MR. OLSON: Okay. This is just a question on table M.

Most of the aquatic life calculations that you have here, you have some -- most of them have acute and chronic, but you have a couple that have acute and no chronic criteria calculated.

Why is that? Is there --

MR. PIERCE: Commissioner Olson, these are directly out of the EPA guidelines, so they must have

found some problem with the calculation of a chronic or of acute for certain things.

It may be that some things have an effect over a long period of time -- i.e., the chronic standard can be developed, but the higher level doesn't cause immediate toxicity. So they may have been able to develop a chronic for some things, and it may be that some things that have an acute impact don't have any effect over a long period of time, but if they get it right away, it could kill them.

So I'm surmising there. My straight answer is EPA had no recommended criteria for those particular ones. Beyond that, I think what I'm saying is what I think the reason is.

MR. OLSON: Okay. It just seemed like every one had a -- except for a couple that had an acute standard also had a chronic. That didn't --

MR. PIERCE: For a few of these, they originally had proposed acute and chronic, and due to some problem, they removed one or the other.

For an example of one we had, the Commissioners will remember, we had acute and chronic standards for silver, and it was determined, after further experimentation, that the chronic standards for silver really was not necessary, that there wasn't a chronic

toxicity being shown, so that the Commission dropped its chronic standard and we just have an acute standard for silver.

MR. OLSON: Okay. I think that's all I have. Thank you.

MR. MAGGIORE: Any other cross-examination questions from the Commissioners?

Commissioner Keyes.

MR. KEYES: Mr. Chairman.

Mr. Pierce, I'm curious to know what the history is on the definition of grab sample, and is there a reason that the Commission has not defined that and whether it should be a split grab sample or use the protocol that you all have on the second sample only being used if, in fact, it's an exceedence of the criteria or the standard.

MR. PIERCE: Mr. Chairman, Commissioner Keyes, there is a theory that I've been around since before God, but it's not true. There are people around that have been here a lot longer. In fact, Commissioner Johnson has been on the Commission now for 26 years, so he may have more information.

I'm not aware of why the term was not defined. The protocol we used to determine the assessment were borne out of necessity when all at once the 303(d) list

became a very important document, and in what projects had highest priority, what TMDL developments had to be, and at that time we developed the assessment protocol, which were based on other states' assessment protocols and were based on a more logical look at the overall data.

We still have problems now on large data sets. We may go out and in a single season get 20,000 readings for temperature, and the way the standards read, if one of those 20,000 exceeded, we would consider it at least an exceedence.

So what we've done through the protocol is determined what we would use to determine whether or not the use is actually being nonattained. These are still undergoing tweaking, and I'm sure that they will be proposed to be part of the standards or part of the management plan when they are fully tweaked.

Currently, they are approved as part of our standards by EPA, and they have been tweaked almost yearly, and we're working on several of the large data set protocols, but, no, I do not know why the term grab sample has not been defined, or even if a definition has been kicked around at some point in the past.

MR. KEYES: Mr. Chair, I would like to make a comment off the record, if I may, to Mr. Pierce.

MR. MAGGIORE: Sure. We can go off the record for a minute.

(Off-the-record discussion.)

MR. MAGGIORE: We can go back on the record.

MR. KEYES: That's all I have.

MR. GLASS: I have a follow-up to that, if I might.

The proposed compliance with water quality standards for the protection of human health that shall be determined from the analytical result of a single grab sample, that is your proposed changes, you stated that that never actually really happens, that you don't -- that there is a confirmation, and I think, in fact, that your protocol requires seven samples.

I mean, you've got a couple of them, a second sample, you get an exceedence -- seven samples, I think you said substantiates a violation. Do I remember that right? Is that the QAPD, Q-A-P-D?

MR. DAVIS: Mr. Chairman, Commissioner Glass, let me try to answer that.

As Steve correctly points out, we have a data assessment protocol that the Bureau has developed that addresses a number of these types of issues. A single grab sample is in the standards.

My interpretation, not a definition of it, but

the interpretation that we use practically is that that means there is no averaging or weighting or other kind of statistical manipulation of the result, rather it is the result that derives from a single sample.

However, given that there is uncertainty associated with any analytical result, it is not, in my estimation, prudent to rely on a single number that only occurs -- that you only have one occurrence of. So we sample multiple times to achieve a level of confidence that the number, in fact, is correct, but we do not average cross those multiple samples, we simply use one numeric value to estimate or to determine whether or not a standard has been exceeded.

So, practically, we find ourselves taking multiple samples, but we apply no statistical methodology across those multiple samples, rather we use the result of a single sample, as is specified in the standards.

We simply can't go out and say, "Well, if we have one hit, is that real?" There has to be some repeatability to that, and so we sample multiple times to achieve that repeatability.

Does that help?

MR. GLASS: No, but that sounds very scientifically valid, absolutely, that -- but I guess my concern, or my suggestion is, or my wish is, that that

process could somehow be incorporated here so that we would -- you know, that the dischargers wouldn't be subject or feel subject to just sort of that single instance and then all of a sudden it's $25,000 a day.

MR. DAVIS: Right.

Commissioner Glass, the protocols that I speak of that the Bureau has developed over the last three-and-a-half years or so are currently in the Quality Assurance Project Plan that the Bureau develops every year and submits to EPA. This is a requirement of the federal act -- the various regulations under the federal act.

EPA reviews the procedures that any state is using. We have developed these with both internal and external review, again, to pick up on the -- one of the examples that Steve used is that we have a temperature protocol. We may, in fact, accumulate 20,000 or more temperature readings of a particular segment of stream in the state. We've worked with US Fish & Wildlife Service, New Mexico Department of Game and Fish and EPA to understand what a 15-minute, one-degree Celsius exceedence of the standard might mean, as opposed to a 45-minute, one-and-a-half-degree Celsius exceedence of the standard. Those are different for the biological community.

Accordingly, we developed a protocol that specifies -- I don't have it memorized, but, say, a two-degree Celsius exceedence of the standard for two hours is not acceptable, but a .5-degree Celsius exceedence of the standard for 15 minutes is.

Now, this is something that the Bureau has done to help us understand -- help us interpret the language in the standards that is absolute; where it says, for example, in a high-quality cold-water fishery the temperature is 20-degrees Celsius, shall not exceed.

These protocols are on our website, and they have been -- they are available for review by any interested party. They have been since they were developed. They do undergo routine and ongoing review, or tweaking, as the term of art is, and we're constantly interested in making these things better.

They are not codified anywhere, but we do anticipate, in the rewrite of the CPP, that we will be addressing these protocols through that document, which would then bring into play a review by the Commission. This is -- in any case --

MR. GLASS: But there is no hope, I don't suppose, for these interpretative -- interpretative criteria, if you will, or these methods of interpretation ever to translate themselves into a more -- a

less-limiting compliance scenario for the standards themselves.

I mean, couldn't this sentence say, for instance, compliance with water quality standards can be determined from the analytical results of a single grab sample after confirmation with a second sample?

MR. DAVIS: Mr. Chairman, Commissioner Glass, yes, that kind of thing would be very imaginable.

In fact, some states in the country do precisely that, they place into their standards these interpretative phrases to provide guidance or very clear examples of how the standards apply.

We've not had the opportunity to do that, quite frankly, with the Commission. It would be a very major undertaking in the standards, as you can well imagine, but something like that is, obviously, an option and it would be something we'd be -- we'd be happy to consider.

MR. GLASS: Then are you saying it's your opinion that we couldn't do it with this set of revisions for human health standards because of the potential impact to other parts of the standards?

MR. DAVIS: Mr. Chairman, Commissioner Glass, as a practical matter, no one has proposed it. We do not have any -- we do not have a proposal in front of us to

do that, but as a -- again, speaking, if you will, hypothetically, I see no -- I see no absolute barrier to that at all. I think that approach could be used in the standards.

MR. GLASS: I take it that the Bureau would have no objection to inserting "as confirmed by a second grab sample" in that 20.6.4.11(d)?

Is that a reasonable --

MR. DAVIS: Mr. Chairman, Commissioner Glass, I would ask that we take a careful -- that we give ourselves time to carefully think through the ramifications of it.

Again, as a practical matter, if you're basing -- I mean, I'm speaking simply off the top of my head right now, but if you're basing your estimation of compliance with the standards on a single grab sample that you can take multiple times, do you simply take samples until you find the result that you want, and that would not be appropriate. What would it mean to a permitted discharger?

Again, I don't think that there is any barrier to this approach, hypothetically, but I would like to take the time to think it through carefully.

I do know that I have seen examples of temperature standards in other states where they have

some graduated scale. You know, in discussions with this Commission in other forums, we've recognized this particular problem with the Gila River and San Francisco River Basins in the southwestern portion of the state that are typically exposed to higher ambient temperatures than the mountain streams in the Sangre de Christo Mountains at the border of Colorado.

Accordingly, you might expect a different temperature regime to occur in those waters, yet we have an absolute standard that applies everywhere in the state of 20-degrees Celsius for the designated use of high-quality cold-water or warm-water fishery.

It may in fact be that we need to capture some of that natural variation in the standards, but the way to do that is the difficult part, and so I would -- like I say, I would request that we take our time and think it through very carefully before we do it.

MR. GLASS: Okay. Thanks.

MS. HUGHES: Do you want me to take over?

MS. BRANDVOLD: Are there any more questions from the Commission?

MR. WHIPPLE: One more question.

Mr. Pierce, what is the fish consumption rate under these water quality standards?

MR. PIERCE: The consumption rate used in these

calculations by EPA is six-and-a-half grams of fish a day.

MR. WHIPPLE: Is that like a nationwide average, or is that a considerably high number that EPA has just assumed?

MR. PIERCE: That was developed as a nationwide number on an average of people that eat fish and people that don't eat fish.

Part of the risk level -- EPA has stated that you cannot go below a ten to the minus fourth risk level, and one of the assumptions they have is that you'll have an exposed population that eats a lot more fish.

So our proposal, even somebody who eats a lot of fish, would be protected at least by ten to the minus fourth level -- risk level.

Yes, they used six-and-a-half grams per day per person. There has been some talk of them changing that to 17-and-a-half grams a day, which I feel might be too high for New Mexico, and it might behoove us at that point to try to develop some local guidance to fish consumption.

Right now, we felt the six-and-a-half grams was a valid assumption to start with for New Mexico residents.

MR. WHIPPLE: Thank you.

MR. MAGGIORE: Any other cross-examination from the Commission?

If not, I'll open it up to cross-examination from the public.

If you're cross-examining, please rise and state your name slowly and clearly for the record and then proceed.

Mr. Rose.

MR. ROSE: Thank you, Mr. Chairman.

MR. MAGGIORE: Before you begin, can you estimate how long your cross might be?

MR. ROSE: Depending on the questions, hopefully, not more than ten minutes --

MR. MAGGIORE: Thank you.

MR. ROSE: -- but you never know. It depends on the questions.

For the record, my name is Louis Rose, I'm with Montgomery & Andrews in Santa Fe, and I'm here representing the University of California Board of Regents.

CROSS EXAMINATION BY MR. ROSE

MR. ROSE: It's a question for whoever wants to answer it. It's a toss-up question here.

With respect to -- I'm referring to Section 12.F.2(c) -- I think that's the proposed language that

the Department had in their notice of intent concerning petitioning the Commission for review of the standards.

I was curious, you've chosen 90 days from the final NPDES permit containing the numeric criteria. As I understand it, there would be an interim process where you would be required to certify a number in a proposed NPDES permit.

I wondered why you chose from the date the final permit was issued rather than from the date you certify compliance with the state requirements of the 401 certification?

MR. SAUMS: Mr. Rose, I guess I received the toss-up on that question.

MR. ROSE: I noticed Jim pointed to you.

MR. SAUMS: I think the answer to that is simply that a permit isn't final until it's final, and when EPA makes its final decision, that would be the time to act.

Well, in the case of the Molycorp permit that I referred to in my testimony, while EPA calculated that a number -- that their effluent might cause a water quality -- a human health standard violation, ultimately, a technology-based effluent limit prevailed, and, therefore, the issue of the human health criterion became moot.

So I think in that case it's prudent to wait until a permit is finalized by EPA before we go petitioning the Commission and approaching them with something, that if we were to go earlier than that, we might be premature.

MR. ROSE: In terms of the final number in an individual permit -- but would, for example, the calculation of what was appropriate to be the new -- the narrative standard, would that then be -- would that process be -- could it be replicated later, and in essence, the same analysis be done on a later permit?

Wouldn't it be more prudent to have the Commission review that analysis sooner than later in the process or even in a subsequent permit?

MR. SAUMS: I think that's a suggestion worthy of consideration.

MR. ROSE: When you reference "final NPDES permit," I assume you include storm water permits as well as point source, normal point source discharge permits, do you not?

MR. SAUMS: I think we're referring to all NPDES permits, whether they are individual permits or general permits.

MR. ROSE: Okay. I understand your reference to petition the Commission to be a petition under the

Commission's guidelines for rule-making.

Is that what you understood your testimony to be?

MR. SAUMS: Mr. Rose, I think that we would always adhere to the Commission's guidelines or preferences as they saw fit.

MR. ROSE: While the requirement obligates you to petition the Commission, there is no statement about what happens subsequent to the petition.

I was curious, say, for example, if the Commission were to either not go to hearing on a petition or not accept the number and adopt a different number in the standards, what would be the process?

Would you go back, and if it were a less stringent number, would you be amending or seek to amend the NPDES permit, or what would be the result of this if the Commission were not to agree with analysis of what the appropriate numeric translation of the narrative standard would be?

MR. DAVIS: My turn.

I think at that time, as the Commission deliberated and made its decision known, both to us and to the affected public, we would then probably seek guidance on what the next step should be, and that debate would occur -- the Commission would engage in that debate

and it would occur in the full view of the public.

I don't know that we can anticipate -- I mean, your question is interesting, but it's hypothetical, and I don't know that we can -- that we can speculate in a particularly beneficial manner on what the Commission may or may not do.

MR. ROSE: And I take it that the translation of narrative standards to numeric standards in F.2 is not the only place where that analysis takes place, is it not?

Wouldn't a similar sort of analysis take place under F.3, or could it not, where you translate a narrative into a numeric number? Particularly in F.3 -- I think it's F.3(b) -- or F.3.

Actually, it talks about how you calculate if there is a number in 900, then what you do, and what you apply in sequential order.

MR. AMES: Did you hear the question, Mr. Pierce?

Could you rephrase the question?

MR. PIERCE: I'm sorry, if you could rephrase it.

MR. ROSE: I was curious, as I was reading this -- we've been talking about F.2 and translating a narrative into a numeric standard, and it was my reading

that that's not the only place where that could take place, it could also take place under F.3.

I was curious -- I mean, that's the way I read them, and I wasn't sure if I was correct. I was asking for confirmation of that.

MR. PIERCE: You are correct. It does occur under F.3, which is existing language, and it has occurred at least once since 1995 when the Commission adopted these standards.

MR. ROSE: And I was curious, since you're proposing a process to deal with those narrative standards, which are calculated based on standards under F.2, why the Department did not consider a similar process under F.3 for Commission confirmation of those standards?

MR. DAVIS: That question or that idea was simply not raised. We didn't think of it, and neither did anyone else.

MR. ROSE: Would you object to similar language being interposed as to that process as well?

MR. DAVIS: I don't believe so, but I would prefer to have the opportunity to think about it a little longer.

MR. KEYES: You've got five minutes.

MR. DAVIS: I don't --

MR. MAGGIORE: You can handle that on rebuttal. You could address that, Dr. Davis, on rebuttal if you don't want to --

MR. DAVIS: Yes. That's fine.

MR. AMES: Thank you.

MR. ROSE: That's fine. I have no further questions.

MR. MAGGIORE: Thank you, Mr. Rose.

Any other cross-examination?

Ma'am.

MS. MC CALEB: Yes, Jolene McCaleb on behalf of San Juan Water Commission.

MR. MAGGIORE: Just quickly an estimate on time.

MS. MC CALEB: I'm guessing 45 minutes to an hour.

MR. MAGGIORE: Okay. That's why I asked, I guess.

Let me just ask the members from the public that had indicated they cannot return tomorrow -- there were two folks.

Ma'am, you had indicated earlier and you had already signed in and been sworn in --

MS. GNATKOWSKI: Yes.

MR. MAGGIORE: -- and you had said your

testimony will be relatively brief.

MS. GNATKOWSKI: Yes, it will be very short.

MR. MAGGIORE: Mr. Shields, yourself?

MR. SHIELDS: Yes, it will be very short.

MR. MAGGIORE: Short.

Okay. Commission, what do you want to do? Do you want to hear the public stuff and then call it a night or -- I'm seeing a lot of head shaking.

Okay. Let's go ahead and do that.

If I can ask you two individuals who want to provide some public comment -- ma'am, we will get to you first thing in the morning with cross-examination.

Mr. Shields.

MR. SHIELDS: Mr. Chairman, I had a couple of questions that I have for cross-examination. If I may address those first.

MR. MAGGIORE: I'm sorry?

MS. BRANDVOLD: If he can't come back tomorrow --

MR. MAGGIORE: Yes. Okay. I'm assuming -- I don't mean to inconvenience you, but you have apparently some robust questioning, and you will be back tomorrow; is that right?

MS. MC CALEB: Absolutely.

MR. MAGGIORE: All right.

Having heard that, then, Mr. Shields, why don't you proceed then with cross-examination of the Department, and then we'll move to public comment, and then we'll call it a night.

MR. SHIELDS: Thank you, Mr. Chairman.

MR. MAGGIORE: If you wouldn't mind coming up to the front, Mr. Shields, and stating your name and affiliation clearly for the record.

MR. SHIELDS: My name is Brian Shields. I'm the executive director of Amigos Bravos.

I just had a couple of questions that I wanted to ask.

CROSS EXAMINATION BY MR. SHIELDS

MR. SHIELDS: I guess I'm kind of curious to know how many communities in New Mexico actually use water for domestic purposes at this point. Use surface water, right. Sorry. A little technicality.

MR. MAGGIORE: Hopefully, Mr. Shields, but I think we --

MR. KEYES: Every one of them.

MR. SHIELDS: I was trying to save words. I can just use my voice.

MR. PIERCE: Mr. Chairman, Mr. Shields, right now we don't know -- I don't know that there are any -- any communities that use it. These would be mostly

individuals.

There are houses in Northern New Mexico that run pipes out to a stream for the drinking water. We had at least one of our NMED employees who carries water up from the river and pours it through a sand filter for his household. We know people do take water from the acequias.

I don't think that any communities draw it. If they do, then they would come under the Safe Drinking Water Act as a municipal system, and that's not the same as domestic water supply.

MR. SHIELDS: Okay. I'm aware that there are some -- like the community of Llano, I know that they depend on their water from the acequias, because many people don't have wells there, domestic wells.

So, I was wondering, in terms of that, I noticed that you used the criteria developed for consumption of organisms only, and I assume that the criteria for the consumption of water and organisms would be more protective of human health.

MR. PIERCE: It is a more stringent standard, yes.

MR. SHIELDS: It is a more stringent standard.

Can you tell me how it would relate to, for instance, the arsenic standard?

MR. PIERCE: Under the current recommendations, the arsenic standard for organisms only is 0.14 micrograms per liter. Water plus organisms is 0.018, which is a standard that some of the pueblos have adopted.

It isn't as great a difference in arsenic as it is in some of the highly bioaccumulative organic biocontaminants. So there it's an order of magnitude.

MR. SHIELDS: So I'm wondering, both with this -- using this criteria and also looking at the numbers that were used for risk -- for assessing risk criteria at ten to the minus five, as opposed to ten to the minus six, I'm just wondering, in terms of downstream receiving waters, like the pueblos, for instance, or other states, does -- how that affects what kind of -- what water we're delivering to those people.

MR. PIERCE: Mr. Chairman, Mr. Shields, currently, all of these are at real low levels, so there is probably not a current problem.

There could be a problem, as there could be with a lot of other aspects of water quality standards, because there are so many different sets of standards that apply to different areas of New Mexico.

I believe that the Rio Grande alone goes in and out of eight different jurisdictions and a lot of those

standards are quite different.

These standards were not chosen to be protective of any particular tribal standards. We don't know that they aren't protective, but they are not the same standards as some of the tribes have adopted.

MR. SHIELDS: So do we know, in terms of how many of our neighboring states have used the ten to the minus sixth criteria or -- I mean, I don't know how the pueblo standards are developed, but are they developed in the same manner, so how many pueblos adopted this, the more stringent criteria?

MR. PIERCE: I believe three of the pueblos have adopted human health, the others have not, and those three all adopted at ten to the minus sixth.

There is an exhibit that's being submitted by San Juan Water Commission that shows that Colorado uses ten to the minus sixth, Montana uses the same, Nevada uses the same, Texas is ten to the minus fifth. I can't make it out what it says for Utah. It looks like it's ten to the minus sixth. So they've gone back and forth.

MR. SHIELDS: Okay.

MR. AMES: Point of clarification, this document actually was prepared by the Department; correct?

MR. PIERCE: Originally, it was prepared by the Department in draft form, yes, but we did not introduce it as an exhibit.

MR. AMES: Okay.

MR. SHIELDS: I'm just curious whether adopting ten to the minus five places the state in a situation where they might be liable for not meeting -- not delivering water quality sufficient -- at a sufficient level for those downstream recipients?

MR. DAVIS: Mr. Chairman, Mr. Shields, in the interests of time, in the closing part of my testimony, we were moving quite rapidly, however, I --

MR. AMES: From our perspective.

MR. DAVIS: -- have a protocol for that that we've developed -- no, this is in my written testimony, but I can say it now.

Let me find it. I want to make sure that I say it correctly.

Okay. I say in my written testimony that the Department's proposal is squarely within the range of values authorized by federal law and regulation and would be acceptable to EPA. That's on page four of my written testimony, the last paragraph.

I thought I had a bullet in my notes to that effect, but I can't find it.

So your question of whether or not we would -- the state would be liable, I think -- I think what we're proposing is completely within what EPA would find acceptable, that doesn't go to, you know, hypothetical liability, but I believe it addresses what the federal agency --

MR. SHIELDS: At least it sounds like we don't have to worry about Texas on this one.

Mr. Chairman and Members of the Commission, that brings to a conclusion my cross-examination.

MR. MAGGIORE: Okay. Thank you, Mr. Shields.

Do you want to go straight into your public comment and then we'll have public comment from the Cattle Growers and we'll recess for the evening?

(Oath administered to Brian Shields.)

BRIAN SHIELDS

after having been first duly sworn under oath, was questioned and testified as follows:

DIRECT TESTIMONY

MR. SHIELDS: Mr. Chairman and Members of the Commission, thank you for providing this opportunity for me to make a brief presentation.

As many of you know, Amigos Bravos is a New Mexico river conservation advocacy organization. We have offices in both Taos and in Albuquerque, and we have a

membership of 1,500 members. We have a track record of working on water quality issues, having formally participated in the last triennial review of water quality standards and having helped to secure the NPDES and state water quality permits to control acid mine drainage from the Molycorp Mine in Questa, among other things.

On behalf of our members, who are mainly in New Mexico, we would like to offer support for the Bureau's present petition for the following reasons.

First, many of the priority pollutants in the petition are synthetic, often chlorinated, compounds which do not break down in nature and which, because of their unnaturalness, cause severe problems in natural systems ranging from ecosystems to human bodies. They include many of the worst, most persistent poisons on the planet. Many are known or suspected carcinogens and/or cause human reproduction or nervous system damage.

Second, the Bureau's present effort to prevent toxic bioaccumulations in fish is very valuable. Moreover, there are many other pathways through which these substances can potentially affect the environment and human beings through the use of river water for domestic supplies, for instance, which are being planned for Albuquerque, Santa Fe and other New Mexico cities in

the near future.

We believe that this is a good proactive measure to take at this time.

Third, we're only now finding out exactly where the substances exist in New Mexico surface waters. It seems that the more you look, the more you find. So we think it's important to be looking in order to protect human health.

In conclusion, Amigos Bravos believes that the precautionary principle is highly appropriate for regulating priority pollutants in New Mexico, because of their extreme toxicity, persistence, and uncertain systemic effects. This means that there should be strong efforts to locate and monitor these substances, to determine their extent and sources, and means minimizing the quantities that are allowed to enter the environment, preferably preventing their discharge completely at the source.

We believe that the present petition, as a whole, goes a considerable way towards this by helping to put the monitoring and control of these dangerous substances on a formal, transparent and systematic basis, and for those reasons, Amigos Bravos supports the petition.

Thank you for taking these comments into

consideration.

MR. MAGGIORE: Thank you, Mr. Shields.

Appreciate that.

I believe we have one more.

MS. BRANDVOLD: And cross.

MR. MAGGIORE: I'm sorry, any cross-examination of the witness by the Commission?

Seeing none, any cross-examination from the audience?

MR. AMES: No.

MR. MAGGIORE: None.

Thank you, Mr. Shields. Appreciate that.

(Oath administered to Callie Gnatkowski.)

CALLIE GNATKOWSKI

after having been first duly sworn under oath, was questioned and testified as follows:

DIRECT TESTIMONY

MS. GNATKOWSKI: Mr. Chairman, Members of the Commission, my name is Callie Gnatkowski. I'm here today representing the New Mexico Cattle Growers and the New Mexico Wool Growers Associations.

Caren Cowan, who was here yesterday with the Cattle Growers, wasn't able to come today.

Both organizations would support the San Juan Water Commission's position that the standards, since

they are of this magnitude and could have such impacts, should be considered during the next triennial review process when other standards, such as these, are considered.

Both associations are very interested in issues like this because of the impacts they can have on our membership and would be -- and would like to be involved in the process.

The Wool Growers Association was never notified about the process. I hadn't heard anything about it until I read an article in the New Mexico -- The New Mexican a couple of days ago.

The Cattle Growers were -- Caren asked me to say that the Cattle Growers were contacted by the Department in December about the potential for meeting with them, and she did say that she would like to meet with them, but then never heard back from them again. So that's really all I have to say.

MR. MAGGIORE: Okay. Thank you.

MS. GNATKOWSKI: Thank you.

MR. MAGGIORE: Thank you very much, and thank you for sticking around to share that with us.

Any cross-examination of the witness from the members of the Commission?

Seeing none, any cross-examination of the

witness from the audience?

Seeing none, thank you.

You're excused.

MS. GNATKOWSKI: Thanks.

MR. MAGGIORE: I think we can go off the record now and recess until 8:00 tomorrow morning, where we will pick up with the cross-examination of the Department's witnesses by San Juan.

I will not be able to be here tomorrow, and if it's the Commission's pleasure, I would like to -- since I was voted to be the Hearing Officer for this matter, I would ask the Commission's counsel, Tracy Hughes, to do that.

Is that okay with the fellow Commissioners?

Tracy, is that okay with you?

MS. HUGHES: I will do longer lunches, I promise.

MR. MAGGIORE: I'll give you a lot of work to work with there, Counsel.

(Hearing recessed at 6:54 PM.)

STATE OF NEW MEXICO)
)ss.
COUNTY OF BERNALILLO)

I, Kathy Townsend, the officer before whom the foregoing hearing was taken, do hereby certify that the witnesses whose testimony appears in the foregoing transcript were duly sworn by me; that I personally recorded the testimony by machine shorthand; that said transcript is a true record of the testimony given by said witnesses; that I am neither attorney nor counsel for, nor related to or employed by any of the parties to the action in which this matter is taken, and that I am not a relative or employee of any attorney or counsel employed by the parties hereto or financially interested in the action.

_____
NOTARY PUBLIC
CCR License Number: 23
Expires: 12/31/02

My Commission Expires: 9/12/05

United States
Environmental Protection
Agency

Office of Water
4304T

EPA-822-R-18-001
December 2018

FINAL
AQUATIC LIFE AMBIENT WATER QUALITY CRITERIA FOR ALUMINUM
2018

NMED Exhibit 75

EPA-822-R-18-001

FINAL

AQUATIC LIFE

AMBIENT WATER QUALITY CRITERIA FOR

ALUMINUM - 2018

(CAS Registry Number 7429-90-05)

December 2018

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER
OFFICE OF SCIENCE AND TECHNOLOGY
HEALTH AND ECOLOGICAL CRITERIA DIVISION
WASHINGTON, D.C.

NMED Exhibit 75

NOTICES

This document provides information to states and tribes authorized to establish water quality standards under the Clean Water Act (CWA), to protect aquatic life from toxic effects of aluminum. Under the CWA, states and tribes are to establish water quality criteria to protect designated uses. State and tribal decision makers retain the discretion to adopt approaches that are scientifically defensible that differ from these criteria to reflect site-specific conditions. While this document contains the Environmental Protection Agency's (EPA) scientific recommendations regarding ambient concentrations of aluminum that protect aquatic life, the Aluminum Criteria Document does not substitute for the CWA or the EPA's regulations; nor is it a regulation itself. Thus, the document does not impose legally binding requirements on the EPA, states, tribes, or the regulated community, and might not apply to a particular situation based upon the circumstances. The EPA may update this document in the future. This document has been approved for publication by the Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use. This document can be downloaded from: https://www.epa.gov/wqc/aquatic-life-criteria-and-methods-toxics.

NMED Exhibit 75

FOREWORD

The Clean Water Act (CWA) Section 304(a)(l) (P.L. 95-217) directs the Administrator of the Environmental Protection Agency (EPA) to publish water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water, including groundwater. This document is a final ambient water quality criteria (AWQC) document for the protection of aquatic life based upon consideration of all available information relating to effects of aluminum on aquatic organisms.

The term Water Quality Criteria is used in two sections of the CWA, Section 304(a)(l) and Section 303(c)(2). The term has different meanings in each section. In Section 304, the term represents a non-regulatory, scientific assessment of ecological and human health effects. Criteria presented in this document are such a scientific assessment of ecological effects. In section 303, if water quality criteria associated with specific surface water uses are adopted by a state or the EPA as water quality standards, they become the CWA water quality standards applicable in ambient waters within that state or authorized tribe. Water quality criteria adopted in state water quality standards could have the same numerical values as recommended criteria developed under section 304. However, in some situations states might want to adjust water quality criteria developed under section 304 to reflect local water chemistry or ecological conditions. Alternatively, states and authorized tribes may develop numeric criteria based on other scientifically defensible methods, but the criteria must be protective of designated uses. It is not until their adoption as part of state water quality standards, and subsequent approval by the EPA under section 303(c), that criteria become CWA applicable water quality standards. Guidelines to assist the states and authorized tribes in modifying the criteria presented in this document are contained in the Water Quality Standards Handbook (U.S. EPA 2014).

This document presents recommendations only. It does not establish or affect legal rights or obligations. It does not establish a binding requirement and cannot be finally determinative of the issues addressed. The EPA will make decisions in any particular situation by applying the CWA and the EPA regulations on the basis of specific facts presented and scientific information then available.

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ACRONYMS

ACR	Acute to Chronic Ratio
AIC	Akaike Information Criterion
AVS	Acid Volatile Sulfide
AWQC	Ambient Water Quality Criteria
BAF	Bioaccumulation Factor
BCF	Bioconcentration Factor
BIC	Bayesian Information Criterion
CCC	Criterion Continuous Concentration
CMC	Criterion Maximum Concentration
CV	Chronic Value (expressed in this document as an EC_{20})
CWA	Clean Water Act
DOC	Dissolved Organic Carbon
ECOTOX	Ecotoxicology Database
EC_x	Effect Concentration at X Percent Effect Level
ELS	Early-Life Stage
EPA	Environmental Protection Agency
EU	European Union
FACR	Final Acute-to-Chronic Ratio
FAV	Final Acute Value
FCV	Final Chronic Value
FDA	US Food and Drug Administration
GMAV	Genus Mean Acute Value
GMCV	Genus Mean Chronic Value
IC_x	Inhibitory Concentration at X Percent Level
LC_x	Lethal Concentration at X Percent Survival Level
LOEC	Lowest Observed Effect Concentration
MATC	Maximum Acceptable Toxicant Concentration (expressed mathematically as the geometric mean of the NOEC and LOEC)
MDR	Minimum Data Requirement
MLR	Multiple Linear Regression
NAWQA	USGS National Water Quality Assessment Program
NOAA	National Oceanic and Atmospheric Administration
NOEC	No Observed Effect Concentration
NPDES	National Pollutant Discharge Elimination System
QA/QC	Quality Assurance and Quality Control
SMAV	Species Mean Acute Value
SMCV	Species Mean Chronic Value
TMDL	Total Maximum Daily Load
TRAP	Toxicity Relationship Analysis Program
US	United States
USGS	United States Geological Survey
WQC	Water Quality Criteria
WQS	Water Quality Standards

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EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) is updating its aquatic life ambient water quality criteria (AWQC) recommendation for aluminum, in accordance with the provisions of section 304(a) directing the EPA to revise AWQC from time to time to reflect the latest scientific knowledge. The recommended aluminum aquatic life AWQC were developed using peer reviewed methods and data that are acceptable for the derivation of criteria, as described in the EPA's 1985 "*Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*" (Stephan et al. 1985, referred to herein as "1985 Guidelines"). The previous aquatic life AWQC for aluminum were developed in 1988 (EPA 440/5-86-008). These 2018 final recommended aquatic life AWQC for aluminum supersedes the 1988 recommended criteria.

The 2017 draft aquatic life AWQC for aluminum were posted to the Federal Register (Docket ID: EPA-HQ-OW-2017-0260) in late July 2017 for public comment. The public comment period was open for 90 days and closed in late October 2017. Public comments received were incorporated and addressed in these final AWQC, where applicable. The EPA responses to all of the public comments can be found on the website for the aluminum criteria (https://www.epa.gov/wqc/aquatic-life-criteria-aluminum).

Literature searches for laboratory tests published from 1988 to 2017 identified new studies describing the toxicity of aluminum to aquatic life. The EPA supplemented these studies with additional data made available by researchers in late-2017 and 2018. The EPA conducted a full evaluation of available data to determine test acceptability for criteria development. Appendix A of "*Quality Criteria for Water 1986*" (U.S. EPA 1986) provides an in-depth discussion of the minimum requirements for data quality needed to develop AWQC for aquatic life.

This update to the recommended aluminum aquatic life AWQC establishes freshwater criteria magnitude values resulting from the interactions of aluminum and three water chemistry parameters: pH, total hardness, and dissolved organic carbon (DOC). It also expands the toxicity database to include those studies conducted in waters with pH values below 6.5. There were insufficient data to establish an estuarine/marine aluminum criteria.

Multiple linear regression (MLR) models were developed to characterize the bioavailability of aluminum in aquatic systems, based on the effects of pH, total hardness and

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DOC on aluminum toxicity (DeForest et al. 2018a,b). These authors used a dataset comprised of 22 chronic tests with the fathead minnow (*Pimephales promelas*), and 23 chronic tests with an invertebrate (*Ceriodaphnia dubia*) to evaluate the ability of MLR models to predict chronic toxicity of aluminum as a function of pH, total hardness and DOC water chemistry conditions. These three parameters are considered to be the most influential for aluminum bioavailability and can be used to explain the range of differences in the observed toxicity values. These datasets were supplemented in 2018 with an additional nine *C. dubia* toxicity tests and nine *P. promelas* toxicity tests to expand the range of water chemistry conditions for model development (OSU 2018a,b,d). All of the toxicity test data used in the model were subjected to independent external expert peer review.

Two models, one for invertebrates and one for vertebrates, were used to normalize freshwater aluminum toxicity values. These separate models correspond to effects on invertebrates and vertebrates due to differing effects of pH, total hardness and DOC on aluminum bioavailability and toxicity, and therefore enable the criteria magnitudes to be calculated as a function of the unique chemistry conditions at a given site. The EPA conducted both independent external expert peer review and internal reviews of these models, published by DeForest et al. (2018a,b), to verify the results. The updated aluminum criteria were derived using these MLR models to normalize the freshwater acute and chronic toxicity data. The MLR equations applied to the acute toxicity data were those developed using chronic tests, with the expectation that the effect of water chemistry on bioavailability remains consistent across exposure duration.

Freshwater Criteria Update

The 1988 aluminum freshwater criteria (U.S. EPA 1988) are expressed as total recoverable aluminum. Acid soluble aluminum was considered but not used because the methods were not developed. These updated 2018 criteria are also based on total recoverable aluminum concentrations.

The 1988 criteria did not consider the variable effects of water chemistry on aluminum toxicity, but simply specified that the recommended criteria only applied to a pH range of 6.5 to 9.0. The 2018 final aluminum recommended AWQC take into account the effects of pH, total hardness and DOC on aluminum toxicity.

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The 1988 freshwater acute criterion was based on data from eight species of invertebrates and seven species of fish for a total of 15 species grouped into 14 genera. This 2018 freshwater acute criterion update is based on data from 13 species of invertebrates, eight species of fish, and one species of frog for a total of 22 species grouped into 20 genera.

The freshwater acute criterion represents the concentration of aluminum at which approximately 95% of genera in a freshwater aquatic ecosystem should be protected if the one-hour average (duration) concentration of total aluminum is not exceeded more than once in three years (frequency). The magnitude of the criterion depends on the water chemistry conditions in the waterbody, using the MLR models to normalize the freshwater acute toxicity data. As a result, the acute criterion will vary with water chemistry conditions. Example acute criteria values for various water chemistry conditions are presented in **Appendix K** (*Recommended Criteria for Various Water Chemistry Conditions*) and can also be calculated with the Aluminum Criteria Calculator V.2.0[1].

The 1988 aluminum freshwater chronic dataset included two species of invertebrates and one fish species grouped into three genera. This 2018 criteria update includes new chronic data for an additional nine species, and consists of eight invertebrate and four fish species grouped into 12 genera. With the addition of one study from **Appendix H** (*Other Data on Effects of Aluminum to Freshwater Aquatic Organisms*), the Minimum Data Requirements (MDRs) for direct calculation (using a sensitivity distribution, as described in the 1985 Guidelines) of the Final Chronic Value (FCV) were fulfilled. This method does not require the use of an acute to chronic ratio (ACR).

Like the acute criterion, the freshwater chronic criterion is also dependent on the water chemistry of the waterbody. Therefore, it is also a function of the MLR models used to normalize the chronic toxicity data. Example chronic criteria (CCC) for various water chemistry conditions are presented in **Appendix K** (*Recommended Criteria for Various Water Chemistry Conditions*) and can also be calculated with the Aluminum Criteria Calculator V.2.0.

The empirical toxicity test data used to develop the MLR models were developed under a range of water chemistry conditions (for more detail, see **Section 4** of this document). The MLRs were then used to normalize all of the toxicity data used in the criteria calculations. MLR models

[1] https://www.epa.gov/wqc/aquatic-life-criteria-aluminum

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are useful for characterizing trends in data, but should be used with caution when extrapolating beyond the range of data used for model development.

The bounds for pH of the models ranged from 6.0-8.7. The EPA criteria calculator is designed to allow the user to extrapolate beyond the pH values used to generate the MLR models. The criteria calculator can be used to address all waters within a pH range of 5.0 to 10.5. This is reflected in the criteria lookup tables in **Appendix K**. The EPA took this approach so that the recommended criteria can be calculated for, and will be protective of, a broader range of natural waters found in the U.S. Extrapolated criteria values outside of the empirical pH data tend to be more conservative (i.e., lower values) and will be more protective of the aquatic environment in situations where pH plays a critical role in aluminum toxicity. Criteria values generated outside of the range of the pH conditions of the toxicity tests underlying the MLR models are more uncertain than values within the pH conditions of the MLR toxicity tests, and thus should be considered carefully and used with caution.

The bounds for total hardness of the models ranged from 9.8 to 428 mg/L. Since a decrease in total hardness tends to increase aluminum toxicity, the EPA concludes that it is reasonable to extrapolate below the lower bound of the empirical hardness data of 9.8 mg/L to enable generation of more stringent criteria at low hardnesses. This is consistent with existing EPA approaches to address low end hardness values (U.S. EPA 2002). Therefore, hardness input values in the criteria calculator can be entered that are less than 9.8 mg/L down to a limit of 0.01 mg/L. However, hardness input values into the criteria calculator will be bounded at the approximate upper limit of the empirical MLR models' underlying hardness data, at a maximum of 430 mg/L total hardness (as $CaCO_3$). The user can input hardness values greater than 430 mg/L for total hardness into the criteria calculator, but the criteria magnitude will reach its maximum value at 430 mg/L total hardness (as $CaCO_3$), and criteria magnitudes will not increase or decrease by increasing the hardness above 430 mg/L total hardness (as $CaCO_3$). This is also consistent with existing EPA guidance on high end hardness caps (U.S. EPA 2002). This recommendation is reflected in the criteria lookup tables provided in **Appendix K**. The EPA took this approach to ensure that the recommended criteria are protective of a broader range of natural waters found in the U.S. Criteria values generated beyond the lower bound of the hardness conditions of the toxicity tests underlying the MLR models are more uncertain than values within the hardness bounds of the MLR toxicity test data.

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The bounds for DOC of the models ranged from 0.08 to 12.3 mg/L. Since most natural waters contain some DOC, the lower bound of the empirical toxicity test data (0.08 mg/L) is the lowest value that can be entered into the criteria calculator; thus no extrapolation below the lowest empirical DOC of 0.08 mg/L is provided. Similar to hardness, the criteria values generated will be bounded at the upper limit of the empirical MLR models' underlying DOC data, at a maximum 12.0 mg/L DOC in the criteria calculator. The user can input DOC values greater than 12.0 mg/L into the calculator, but the criteria magnitude will reach its maximum value at 12.0 mg/L DOC, and criteria magnitudes will not increase or decrease by increasing the DOC above 12.0 mg/L. This limitation on the maximum DOC value is also reflected in the criteria lookup tables provided in **Appendix K**. This is consistent with the existing approach for hardness (U.S. EPA 2002) to provide for protection of aquatic organisms through the use of protective, conservative values under water chemistry conditions beyond the upper limits of the empirical toxicity test data.

In addition to **Appendix K** look-up tables, the EPA created a user-friendly **Aluminum Criteria Calculator V.2.0** (Aluminum Criteria Calculator V.2.0.xlsm) that allows users to enter site-specific values for pH, total hardness and DOC to calculate the appropriate recommended freshwater acute and chronic criteria magnitudes for site-specific parameters and will generate criteria magnitude values based on the bounds described above.

2018 Recommended Aluminum Aquatic Life AWQC and the 1988 Criteria[a]

Version	**Freshwater Acute** (1-hour, total aluminum)	**Freshwater Chronic** (4-day, total aluminum)
2018 AWQC (vary as a function of a site's pH, DOC and total hardness)	1-4,800 µg/L[b]	0.63-3,200 µg/L[b]
1988 AWQC (pH 6.5 – 9.0, across all total hardness and DOC ranges)	750 µg/L	87 µg/L

[a] Values are recommended not to be exceeded more than once every three years on average.
[b] Criteria values will be different under differing water chemistry conditions as identified in this document, as described in Appendix K and applied in the Aluminum Criteria Calculator.

Estuarine/Marine Criteria Update

As with the 1988 AWQC for aluminum, there are still insufficient data on estuarine and marine species to fulfill the MDRs as specified in the 1985 Guidelines. As a result, the EPA cannot recommend criteria for estuarine/marine waters at this time. The 1985 Guidelines require

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that data from a minimum of eight families are needed to calculate an estuarine/marine Final Acute Value (FAV). New acute toxicity data for five families representing five species of estuarine/marine organisms are available for aluminum; no data were previously available. The most sensitive species was the polychaete worm (*Ctenodrilus serratus*) with a Species Mean Acute Value (SMAV) of 97.15 µg/L total aluminum, and the most tolerant species was a copepod (*Nitokra spinipes*) with a SMAV of 10,000 µg/L. No acceptable acute tests on estuarine/marine fish species were available. There are no estuarine/marine chronic toxicity data for fish or other genera that meet the test acceptability and quality assurance and quality control (QA/QC) principles as outlined in the 1985 Guidelines. Thus acute and chronic aluminum toxicity data for estuarine and marine species remain a data gap.

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1 INTRODUCTION AND BACKGROUND

The United States Environmental Protection Agency (EPA) establishes national recommended Ambient Water Quality Criteria (AWQC) as authorized under section 304(a)(1) of the Clean Water Act (CWA). Section 304(a)(1) aquatic life criteria serve as recommendations to states and authorized tribes by defining ambient water concentrations that will protect against unacceptable adverse ecological effects to aquatic life resulting from exposure to pollutants found in water, consistent with the 1985 Guidelines. Section 304(a) recommended aquatic life criteria are developed to provide for the protection and propagation of fish and shellfish. Once the EPA publishes final section 304(a) recommended water quality criteria, states and authorized tribes may adopt these criteria into their water quality standards to protect designated uses of water bodies. States and authorized tribes may adopt water quality criteria that reflect adjustments to the EPA's recommended section 304(a) criteria to reflect local environmental conditions and human exposure patterns. Alternatively, states and authorized tribes may derive numeric criteria based on other scientifically defensible methods that protect the designated use. After adoption, states and authorized tribes submit new and revised water quality standards (WQS) to the EPA for review and approval or disapproval under CWA section 303(c). When approved by the EPA, the state or authorized tribe's WQS become the applicable WQS for CWA purposes. Such purposes include identification of impaired waters and establishment of Total Maximum Daily Loads (TMDLs) under CWA section 303(d) and derivation of water quality-based effluent limitations in permits issued under the CWA Section 402 National Pollutant Discharge Elimination System (NPDES) permit program.

As required by the CWA, the EPA periodically reviews and revises section 304(a) AWQC to ensure the criteria accurately reflect the latest scientific knowledge. The EPA previously published AWQC recommendations for aluminum in 1988 (EPA-440/5-86-008[2]), and is updating these criteria through its authority under CWA section 304(a). Water quality criteria are developed following the guidance outlined in the EPA's "*Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*" (Stephan et al. 1985) (herein referred to as the "1985 Guidelines"). This document describes

[2] https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table

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scientifically defensible water quality criteria values for aluminum pursuant to CWA section 304(a), derived utilizing best available data in a manner consistent with the 1985 Guidelines.

2 PROBLEM FORMULATION

Problem formulation provides a strategic framework to develop water quality criteria by providing an overview of a chemical's sources and occurrence, fate and transport in the environment, and toxicological characteristics and factors affecting toxicity. A problem formulation uses this information to develop a conceptual model and identify the most relevant chemical properties and endpoints for evaluation. The structure of this effects assessment for aluminum is consistent with the EPA's *Guidelines for Ecological Risk Assessment* (U.S. EPA 1998a). This ecological effects assessment describes scientifically defensible water quality criteria values for aluminum under CWA section 304(a)(1).

2.1 Overview of Aluminum Sources and Occurrence

This section provides an overview of available reliable information from the peer-reviewed literature that characterizes sources and occurrence of aluminum in the environment. Aluminum is the third most abundant element and the most common metal in the Earth's crust, comprising about eight percent of the lithosphere (CRC 2000). It is typically found in complexation with oxygen (as oxides) and silica (as silicates), but rarely in the elemental state (Greenwood and Earnshaw 1997). Aluminum is found in most rocks, particularly igneous rocks, containing aluminosilicate minerals (Staley and Haupin 1992), and associated with clays and soil/sediments. Different water column forms include monomeric, polymeric, particulate (suspended) and colloidal forms of aluminum. Ions such as chloride, fluoride, nitrate, phosphate and sulfate form soluble complexes with aluminum, as do fulvic and humic acids (U.S. EPA 1988).

Aluminum enters the aquatic environment from both natural and anthropogenic sources, with natural sources typically dominating occurrence (Lantzy and MacKenzie 1979). This is due to the abundance of aluminum in rocks and minerals released by weathering (Lee and Von Lehmden 1973; Sorenson et al. 1974). Other natural aluminum sources include volcanic activity and acidic spring waters (USGS 1993; Varrica et al. 2000).

Anthropogenic releases are primarily associated with industrial processes and include air emissions, wastewater effluent and solid waste (ATSDR 2008). Anthropogenic sources include

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fossil fuel combustion, aluminum production (mining and smelting) and aluminum present in fertilizers used in agriculture (Lantzy and MacKenzie 1979; Lee and Von Lehmden 1973; Ondov et al. 1982; Que Hee et al. 1982). Alum (potassium aluminum sulfate), used as a coagulant to clarify drinking water and wastewater, can also be a source of aluminum if this water is discharged to aquatic systems (Gidde et al. 2012).

A common source of aluminum in freshwater systems is from the mobilization of aluminum from rocks and soils by acid precipitation, heavy rains, or snow melt (Bjerknes et al. 2003). For estuaries and oceans, the primary source of aluminum is from riverine discharges, with the majority of the introduced aluminum sorbed to the surface of clay particles in estuarine sediments (Hydes and Liss 1977). However, aluminum that is either bound to clays or complexed to dissolved organic carbon can be converted to the reactive species upon mixing with high pH and high salinity ocean waters (Bjerknes et al. 2003; Rosseland et al. 1998; Teien et al. 2006a). The mechanism of this conversion is not well understood.

Aluminum is still actively mined in the U.S. from bauxite, the primary aluminum ore (mainly in Arkansas), with approximately 2 million metric tons produced in 2014. This raw domestic feedstock, plus imported bauxite and recycled aluminum, are currently processed at nine U.S. smelters into refined products (Bray 2015; USGS 2013). Because of aluminum's properties (light weight, resistance to corrosion, electrical conductivity, and durability), it has many diverse uses including: the transportation industry (automobiles, airplanes, trucks, railcars, marine vessels, etc.); packaging (cans, foil, etc.); construction (windows, doors, siding, etc.); consumer durables (appliances, cooking utensils, etc.); electrical transmission lines; and machinery (USGS 2013). Aluminum is also used in wastewater treatment to reduce effluent phosphorus levels (Tchobanoglous et al. 2003) and in the pharmaceutical industry in antacids and as a food additive (Government of Canada 1998).

The Water Quality Data Portal (https://www.waterqualitydata.us/) is an extensive database of environmental measurements available to identify concentrations of chemical contaminants, including aluminum, in surface waters such as rivers and streams. The results are reported in filtered and unfiltered categories. The terms filtered, dissolved, unfiltered, and total and their relationships, as defined by the U.S. Geological Survey (USGS), are presented below. "Dissolved" refers to constituents that exist in chemical solution in a water sample. "Filtered" pertains to constituents in a water sample passed through a filter membrane of specified pore

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diameter, most commonly 0.45 micrometer or less for inorganic analytes. Therefore, for interpretation, the filtered samples (prior to acidification) will be assumed to be dissolved aluminum. "Total" pertains to the constituents in an unfiltered, representative water-suspended-sediment sample. This term is used only when the analytical procedure includes an acid digestion procedure that ensures measurement of at least 95 percent of the constituent present in both the dissolved and suspended phases of the sample. Therefore, for interpretation, the unfiltered samples are assumed to be total recoverable aluminum.

Aluminum data for freshwater systems were obtained from the Water Quality Data Portal (accessed 2/16/17) for data representing years 1991 to 2017. A total of 7,483 surface water samples were collected (4,991 filtered samples and 2,492 unfiltered samples) in that timeframe and analyzed for dissolved and total aluminum, respectively. The range of concentrations reported for dissolved aluminum was 0.8 µg/L to a maximum concentration reported of 20,600 µg/L. The range of total aluminum concentrations across all sites was a minimum of 0.9 µg/L, with a maximum reported total concentration of 210,000 µg/L. Groundwater concentrations of dissolved aluminum (filtered using a 0.45 micrometer filter) from the USGS National Water Quality Assessment Program (NAWQA) database collected during 1992-2003 are presented in **Figure 1**, and had a 90^{th} percentile concentration of dissolved aluminum concentrations of 11 µg/L.

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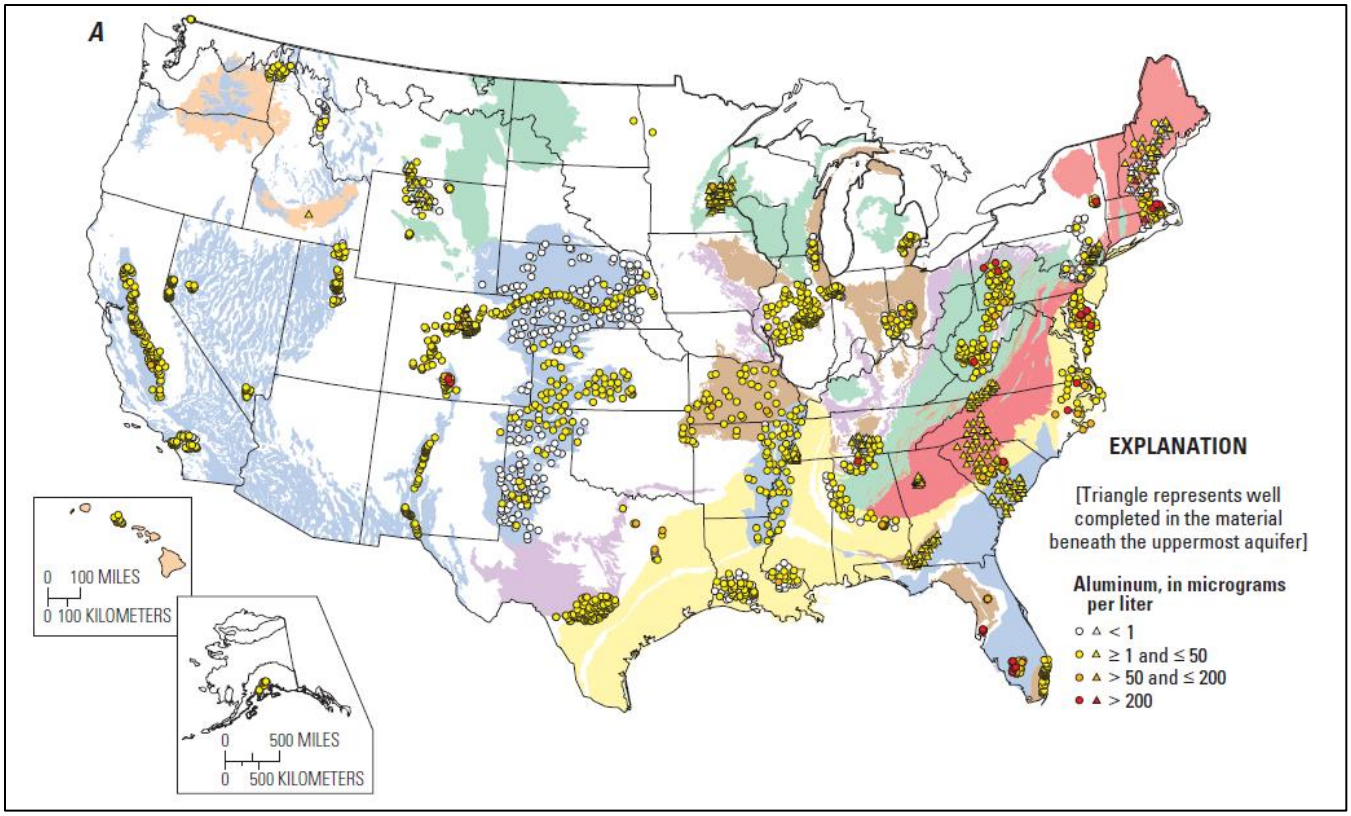


Figure 1. Geographic Distribution of Dissolved Aluminum Concentrations in Groundwater Collected from Wells as Part of the National Water-Quality Assessment Program, 1992–2003.
(Ayotte et al. 2011, used with permission.)

Aluminum concentrations in marine and estuarine waters are generally lower than levels found in freshwater systems, especially compared to acid-impacted areas (Gensemer and Playle 1999). Data for dissolved aluminum in coastal and marine waters were compiled from the scientific literature by Angel et al. (2016) and indicate that concentrations range from 0.5 to 2 µg/L in coastal waters, and from 0.008 to 0.68 µg/L in the open ocean. Other researchers have also reported that values are generally ≤1 µg/L in ocean waters (Brown et al. 2010; Hydes and Liss 1977; Tria et al. 2007). At the typical ocean pH of 8.0-8.3, aluminum forms complexes with hydroxide ion, primarily as $Al(OH)_4$, which precipitates out of solution. This largely explains the low concentrations in marine waters.

Much of the early to mid-1970s metals data in samples from natural waters are considered erroneously high due to contamination from sampling methods or containers. These flaws were corrected with the implementation of clean sampling techniques and guidance provided by U.S. EPA's Method 1669: Sampling Ambient Water for Trace Metals at EPA Water

Quality Criteria Levels (U.S. EPA. 2004). This method was designed to support water quality monitoring programs authorized under the Clean Water Act, specifically created for measuring toxic metals at the low part-per-trillion to low part-per-billion range (U.S. EPA 1996).

Average concentrations of total aluminum in the atmosphere were observed to range from 0.005 to 0.18 μg/m^3 (Hoffman et al. 1969; Potzl 1970; Sorenson et al. 1974). These concentrations are dependent on the location, weather conditions and industrial activity in the area with most of the airborne aluminum present in the form of small suspended particles of soil (dust) (ATSDR 2008). It should be noted that aluminum concentrations in air samples are often dependent upon the aluminum levels of the entrained soil particles, especially if measured as total aluminum. Goncharuk et al. (2012) sampled sea aerosols from the lower portion of the troposphere in the Black Sea (2002-2008), the Caspian Sea (2002-2006), the Baltic Sea (2001-2008), the White, Barents and Kara Seas (2005-2007) and high-altitude arctic regions in the Arctic and South Atlantic Oceans. Air samples were collected by aerosol filters for 3 to 5 hours during headwind conditions in the direction of atmospheric phenomenon. Most reported atmospheric total aluminum concentrations were less than 1 μg/m^3. The authors noted that the lowest concentrations were found at the high-altitude northern arctic regions, with increasing levels observed for the Western Arctic seas, and the highest concentrations reported for the most southerly located Black and Caspian Seas. They suggested that this northern to southern increasing concentration trend could be due to differential anthropogenic loading to the respective water bodies, and also with the increasing emissions of domestic and industrial wastes, wastewater, and emergency discharges of toxicants. Urban and industrial areas can have higher atmospheric total aluminum concentrations with levels reported from 0.4 to 8.0 μg/m^3 (Cooper et al. 1979; Dzubay 1980; Kowalczyk et al. 1982; Lewis and Macias 1980; Moyers et al. 1977; Ondov et al. 1982; Pillay and Thomas 1971; Sorenson et al. 1974; Stevens et al. 1978).

Total aluminum concentrations in North Atlantic precipitation collected in 1988 ranged from 6.1 to 827 μg/L (Lim and Jickells 1990). This is similar to a recent study that collected rainfall from two Mexico locations: a rural forested region 80 km south and downwind of Mexico City and Mexico City itself (Garcia et al. 2009). Average total aluminum precipitation concentrations reported in the rural area (107.2 μg/L, range of 28.8-222.7 μg/L) were higher than observed in the urban area (83.9 μg/L, range 35.8-125.4 μg/L). Samples of wet deposition collected in semi-rural Dexter, Michigan, had an average total aluminum concentration of 57

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µg/L (Landis and Keeler 1997). Much lower levels of total aluminum were found in rainfall samples collected in Japan during 2000 and 2002 where average concentrations ranged from 2.71 to 6.06 µg/L (Takeda et al. 2000; Vuai and Tokuyama 2011). Atmospheric precipitation (i.e., rain and snow) samples collected in the U.S. have contained up to 1,200 µg/L total aluminum (Dantzman and Breland 1970; DOI 1971; Fisher et al. 1968; USGS 1964). No available information was found reporting concentrations of aluminum in fog.

Due to the abundance of aluminum in the earth's crust, soil concentrations can range widely from approximately 700 mg/kg to over 100,000 mg/kg (Shacklette and Boerngen 1984; Sorenson et al. 1974), averaging 71,000 mg/kg (Frink 1996). These concentrations are generally dependent on local geology and associated vegetation types and can vary within the same area, often strongly correlated with its clay content (Ma et al. 1997). Total aluminum concentrations in 1,903 soil samples collected from the continental U.S., Hawaii, Virgin Islands, Guam and Puerto Rico ranged from 500 to 142,000 mg/kg (Burt et al. 2003). In streambed sediment samples collected from locations in the conterminous U.S. from 1992 to 1996, aluminum concentrations ranged from 1.4 to 14% (by weight) (Rice 1999). Marsh/estuarine sediment samples collected from nine sampling sites within or along Georgia's Cockspur Island and McQueen's Island at Fort Pulaski's National Monument, a salt marsh ecosystem, had aluminum concentrations ranging from 17 to 820 mg/kg dry weight (Kumar et al. 2008).

Aluminum may form a precipitate when aluminum-rich water meets less acidic water. This precipitate mix, referred to as a floc, may include other co-precipitated ions, as well as nutrients, suspended materials and microorganisms. Removal of phosphorus from water has been observed in laboratory studies (Auvraya et al. 2006; Gilmore 2009; Matheson 1975; Minzoni 1984; Peterson et al. 1974; Westholm 2006) and in lake field studies (Knapp and Soltero 1983; Pilgrim and Brezonik 2005; Reitzel et al. 2005). Turbidity due to clay has been removed from pond waters using aluminum sulfate (Boyd 1979). Unz and Davis (1975) hypothesized that aluminum floc might coalesce bacteria and concentrate organic matter in effluents, thus assisting the biological sorption of nutrients. Aluminum sulfate (or alum) has been used to flocculate algae from water (McGarry 1970; Minzoni 1984; Zarini et al. 1983).

2.2 Environmental Fate and Transport of Aluminum in the Aquatic Environment

Aluminum (CAS Number 7429-90-05) is a silver white, malleable, and ductile metal that is odorless, and has a molecular weight of 26.98 g/mole (HSDB 2008). It has a density of 2.70

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g/cm^3, a melting point of 660°C, a boiling point of 2,327°C, a vapor pressure of 1 mm Hg at 1,284°C, and is insoluble in water (CRC 2000; HSDB 2008). The n-octanol/water partitioning coefficient (K_{ow}), organic-carbon normalized partition coefficient (K_{oc}), and Henry's law constant for aluminum are unknown.

The chemistry of aluminum in surface water is complex because of the following properties: 1) it is amphoteric, meaning it is more soluble in acidic solutions and in basic solutions than in circumneutral solutions; 2) specific ions such as chloride, fluoride, nitrate, phosphate and sulfate form soluble complexes with aluminum; 3) it can form strong complexes with fulvic and humic acids; 4) hydroxide ions can connect aluminum ions to form soluble and insoluble polymers (e.g. gibbsite, corundum); and 5) under at least some conditions, solutions of aluminum in water approach chemical equilibrium rather slowly, with monomeric species of aluminum transforming into insoluble polymers which precipitate out of solution over time (Angel et al. 2016; Campbell et al. 1983; Hem 1968a,b; Hem and Roberson 1967; Hsu 1968; Roberson and Hem 1969; Smith and Hem 1972).

Aluminum exists as inorganic, monomeric species (Al^{3+}, $Al(OH)^{2+}$, $Al(OH)_2^+$, $Al(OH)_3$, and $Al(OH)_4^-$), as amorphous $Al(OH)_3$ leading to gibbsite formation and precipitation, and as polynuclear species such as the tridecameric Al_{13} polynuclear species (Gensemer and Playle 1999). The chemistry of aluminum in aquatic environments is complex, and several comprehensive reviews on its biological effects have been published (e.g., Driscoll and Schecher 1988; Gensemer and Playle 1999; Gostomski 1990; Havas 1986a,b; Havas and Jaworski 1986; Howells et al. 1990; Lewis 1989; Lydersen and Lofgren 2002; Rosseland et al. 1990; Scheuhammer 1991; Sigel and Sigel 1988; Sparling and Lowe 1996a; Sposito 1989, 1996; Wilson 2012; Yokel and Golub 1997). Effects on the aquatic community and considerations for criteria development are addressed below.

Aluminum from both natural and anthropogenic sources is transported by several means. Natural aluminum transport mechanisms include rock and mineral weathering, volcanic activity and acidic spring waters (USGS 1993; Varrica et al. 2000). Anthropogenic releases include air emissions, effluent dischargers and solid waste leaching. Aluminum is transported through the atmosphere as windblown particulate matter and is deposited onto land and water by wet and dry deposition. Atmospheric loading rates of aluminum to Lake Michigan have been estimated at 5

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million kg/year (Eisenreich 1980), and at 0.1 g/m^2-year on Massachusetts Bay (Golomb et al. 1997).

Factors such as pH, temperature, and presence of complexing ions influence the fate and transport of aluminum in the environment. Of primary importance to understanding aluminum fate and behavior are its interactions with pH (see **Figure 2**). At neutral pH, aluminum is nearly insoluble, but its solubility increases exponentially as the pH reaches either acidic (pH<6) or basic (pH>8) conditions (Gensemer and Playle 1999). At pH values between 6.5 and 9.0 in fresh water, aluminum occurs predominantly in solution as monomeric, dimeric, and polymeric hydroxides and as complexes with fulvic and humic acids, chloride, phosphate, sulfate, and less common anions. The K_{sp} (solubility product) of aluminum hydroxide (gibbsite) ranges from 1.06×10^{-33} (Gayer et al. 1958) to 3.7×10^{-15} at 25°C (CRC 2000). Thus, aluminum hydroxide is insoluble compared to the more soluble salts used to determine aluminum toxic effect levels to aquatic species (aluminum chloride $K_{sp} = 2.04 \times 10^{4}$, aluminum nitrate $K_{sp} = 2.16 \times 10^{3}$, and aluminum sulfate $K_{sp} = 6.92 \times 10^{1}$) (CRC 2000).

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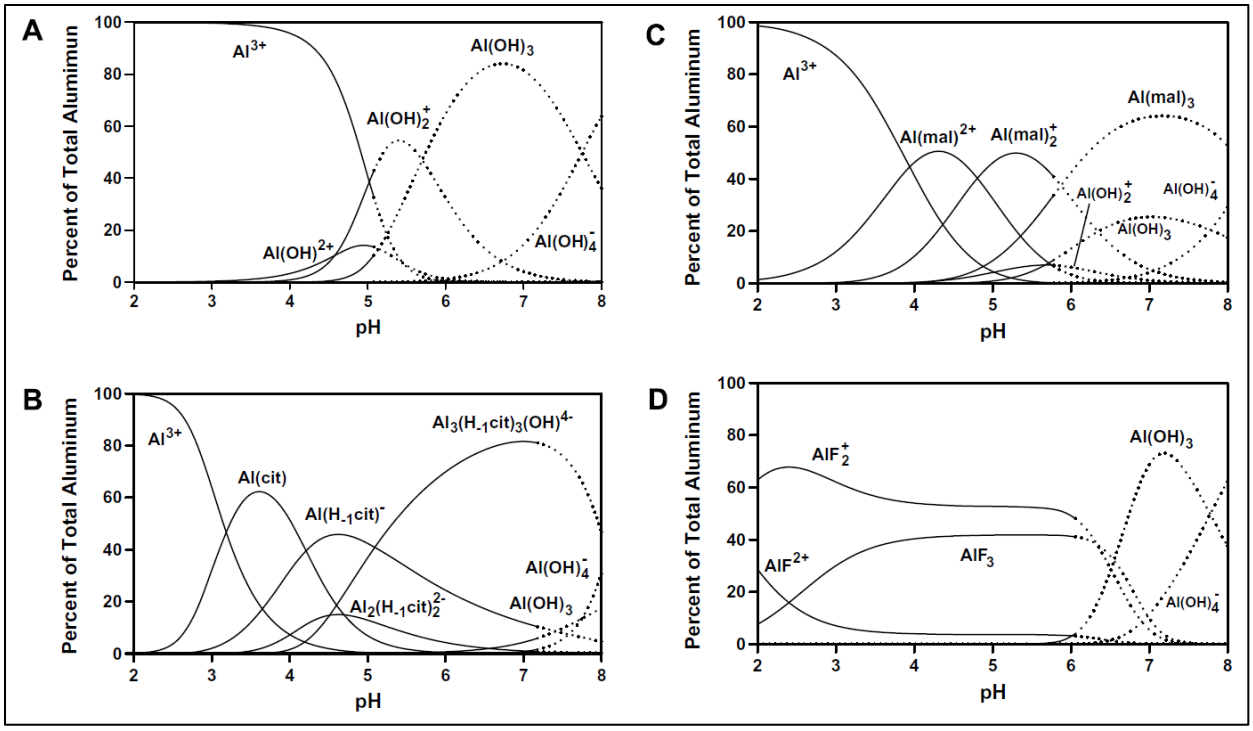


Figure 2. Results of Al Speciation Calculations at a Total of 65 µM Al in the Absence of Ligands (panel A) and in the Presence of Citrate (65 µM) (panel B), Maltolate (195 µM) (panel C), and Fluoride (260 µM) (panel D) in the pH Range 2 to 8.
The dotted lines indicate solutions that would be supersaturated with respect to freshly prepared $Al(OH)_3$. (Zhou et al. 2008, Figure 1, used with permission.)

Aluminum solubility increases at lower temperatures and in the presence of complexing ligands (both inorganic and organic) (ATSDR 2008; Lydersen, 1990; Wilson 2012). These two characteristics are significant because episodic acidic pulses in streams, for example during winter snowmelt, maximize the solubility of aluminum if pH drops to 5.5 or lower (Schofield 1977; Wilson 2012), and therefore may mobilize aluminum.

In the early 1980s the impacts of acid rain and aluminum toxicity were observed in aquatic and terrestrial environments in specific regions of the U.S., most notably in the northeastern part of the country where aquatic systems had limited buffering capacity to prevent pH changes. Researchers observed that aluminum can be a major factor responsible for the demise of biotic communities since the toxicant becomes more soluble and potentially more toxic to aquatic biota at acidic pH (Gensemer and Playle 1999).

2.3 Mode of Action and Toxicity

Aluminum has no biologically important functions or beneficial properties to aquatic life, and is therefore considered a non-essential metal (Eichenberger 1986; Exley 2003; Tchounwou

et al. 2012; Williams 1999; Wood 1984, 1985). It has been identified as the cause of harmful effects on fish and wildlife, but is not a known teratogen, carcinogen or mutagen (Leonard and Gerber 1988). The specific mechanisms of aluminum toxicity to aquatic organisms have been investigated extensively for fish and to a lesser extent for aquatic invertebrates.

For invertebrates, it is postulated that aluminum disrupts concentrations of specific ions, primarily resulting in a loss of sodium (Hornstrom et al. 1984). Elevated levels of aluminum affect ion regulation and the respiratory efficiency of sensitive species (Sparling and Lowe 1996a). Havas (1985) found that aluminum interfered with salt regulation in *Daphnia magna*, which caused a reduction in whole body sodium and chloride concentrations, resulting in death. In addition, aluminum has been shown to increase respiration, and thereby energy demands among mayfly species (Herrmann and Andersson 1986).

For fish, the gill is the primary site of aluminum toxic action, resulting in ionoregulatory, osmoregulatory and respiratory dysfunction. The gill is the primary site of aluminum toxicity under either acidic or alkaline conditions (Wilson 2012). Under acidic conditions, aluminum disrupts the barrier properties of the gill epithelium by binding with functional groups at both the apical gill surface and intracellularly within the lamellar epithelial cells (Exley et al. 1991). At reduced pH (<6.5), aluminum will accumulate on the gill surface resulting in physical damage to the epithelial cells that subsequently causes a loss of plasma ions (Na^+, Cl^-), reduced ion uptake and gas exchange. At alkaline pH (>8), the negatively charged aluminate anion dominates which also disrupts gill function, but to a lesser degree due to the lack of binding of the aluminate anion to the negatively charged gill surface. The subsequent necrosis of the epithelial cells causes a loss of plasma ions (Na^+, Cl^-), reduced osmolality and gas exchange, and if severe enough, the death of the fish (Dietrich 1988; Dietrich and Schlatter 1989a,b; Leivestad et al. 1980; Mallatt 1985; Muniz and Leivestad 1980a,b; Rosseland and Skogheim 1984, 1987). Mitigation of these toxic effects was observed with moderate concentrations of calcium (Brown 1981b), high concentrations of humic acids (Baker and Schofield 1982; Driscoll et al. 1980), and high concentrations of silica (Birchall et al. 1989). Fish in low pH waters with high aluminum concentrations will accumulate aluminum on the gill surface (Rosseland et al. 1990). Bjerknes et al. (2003) observed elevated aluminum concentrations in the gills of dead and "sluggish" Atlantic salmon (*Salmo salar*) associated with ruptured atria, which the authors suggested may have resulted from hypercapnia (abnormally elevated carbon dioxide levels in the blood) caused

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by circulatory distress from the clogging of gills with aluminum. The specific mechanisms of aluminum toxicity at alkaline pH are not well understood.

In laboratory toxicity tests, organisms are exposed to a mixture of dissolved and particulate aluminum depending on how long the acidic aluminum stock solution has been allowed to equilibrate prior to dosing the organisms (Angel et al. 2016). Over time (minutes) as the aluminum from the stock solution equilibrates with the test water and the pH increases, the monomeric species of aluminum transform to the newly-formed insoluble polymeric hydroxide species, which are more toxic (Cardwell et al. 2018). Thus, soon after test initiation, there is a transformation period of rapid speciation changes from short-lived transient amorphous and colloidal forms of aluminum (from minutes to a few hours) to more stable crystalline forms that can take days to form (Gensemer et al. 2018). Aged stock solutions (aluminum solutions that have been given sufficient time (i.e., hours to days) to form more stable forms of aluminum) have been shown to be less toxic than those that are not aged (Exley et al. 1996; Witters et al. 1996). Unfortunately, many studies included for criteria derivation did not describe stock solution age prior to test initiation, and this variable therefore cannot be factored into the toxicity assessment.

Several investigators have found different trends in the toxicity of aluminum under different pH conditions, and toxicity of aluminum appears to be lowest at neutral pH (approximately 7), with toxicity tending to increase with either increasing or decreasing pH (above and below neutral pH). Freeman and Everhart (1971) found that the lethal time to 50% of the rainbow trout decreased (i.e., was more toxic) as the pH increased from 6.8 to 8.99 when rainbow trout were exposed in flow-through tests to the same nominal (unmeasured) aluminum concentration. They concluded that soluble aluminum was the toxic form. Hunter et al. (1980) observed the same relationship of increasing toxicity with rainbow trout over a pH range of 7.0 to 9.0 in chronic static renewal toxicity studies (also nominal aluminum exposures). Call (1984) conducted measured static acute toxicity studies with fathead minnows at pH of 7.61 and 8.05 and showed a slight increase in toxicity at increased pH. However, in another measured static acute toxicity study with a different species, rainbow trout, Call (1984) found a decrease in toxicity as pH increased for the studies conducted at pH 7.31 and 8.17. Thus, generally, most studies show that aluminum toxicity increases as pH increases in the range of approximately 7.0 to 9.0.

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Regarding toxicity at low pH, Freeman and Everhart (1971) also observed the greater toxicity at acidic pH 6.52 in static renewal tests with rainbow trout. In a measured static acute toxicity study with rainbow trout by Call (1984), tests were conducted with pH measurements of 6.59, 7.31 and 8.17. The greatest toxicity was observed at the acidic pH of 6.59. The tests conducted by Freeman and Everhart (1971) and Hunter et al. (1980) were static renewal or flow-through and showed the lowest acute values. The flow-through and renewal tests are considered to be a more reliable way to conduct toxicity tests for aluminum because the dosed chemical is more likely to remain in solution at the desired concentration, and less likely to drop below nominal levels due to precipitation and/or adherence to test vessel surfaces. In addition, because the polymerization of aluminum hydroxide is a relatively slow process, the chemical form of aluminum might have differed from test to test due to the amount of time the aluminum was in stock and test solutions.

The influence of pH on aluminum speciation and associated toxicity to aquatic organisms is readily apparent and highlights the importance of pH control during toxicity tests. Depending on the pH at test initiation, the greatest potential for pH drift would be static exposures, followed by static-renewal and finally flow-through studies. All of the studies evaluated for criteria derivation reported pH, and most included the standard deviation of the measurements, thus providing a rough estimate of pH drift during the exposure. Only selected studies, however, described pH drift for individual tests (e.g., ENSR 1992c,d; European Aluminum Association 2009).

Driscoll et al. (1980) tested postlarvae of brook trout and white suckers under slightly acidic conditions and concluded that only inorganic forms of aluminum were toxic to fish. Hunter et al. (1980) reported that the toxicity of test solutions was directly related to the concentration of dissolved aluminum that passed through a 0.45 μm membrane filter.

In dilute aluminum solutions, formation of particles and the large insoluble polynuclear complexes known as floc is primarily a function of the concentration of organic acids and the hydroxide ion. Time for particle formation varies from less than one minute to several days depending upon the source of aluminum (i.e., aluminum chloride, aluminum nitrate), the pH and the presence of electrolytes and organic acids (Snodgrass et al. 1984). When particles form an aggregate large enough to become visible, the floc is white in color, and tends to settle. Mats of aluminum floc have been reported blanketing a stream bed (Hunter et al. 1980). Laboratory

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studies conducted at alkaline pH levels have reported floc in the exposure chambers (Brooke 1985; Call 1984; Lamb and Bailey 1981; Zarini et al. 1983). The floc did not appear to affect most aquatic species. However, the swimming ability of *Daphnia magna* was impeded by "fibers" of flocculated aluminum trailing from the carapaces. Additionally, the mobility and feeding of midges also was affected, ultimately resulting in death (Lamb and Bailey 1981). Bottom-dwelling organisms may be impacted more by aluminum floc in the field than in the laboratory due to the greater floc layer thickness observed in the field relative to laboratory exposures (U.S. EPA 1988), but this will also depend on the water velocity and mixing in both the field and the laboratory.

Aquatic plant toxicity to aluminum can be dependent on the speciation of aluminum which is controlled by pH. In a study of cell growth rate of the green alga, *Chlorella pyrenoidosa*, to aluminum, Helliwell et al. (1983) found that decreased cell growth occurred in the pH range of 5.8 to 6.2. This is near the pH of minimum solubility of aluminum and maximum concentration of $Al(OH)_2^+$. They found that the toxicity of aluminum decreased as pH increased from 6.2 to 7 or as pH decreased from 5.8 to 4.7, and they hypothesized that the monovalent hydroxide is the most toxic form. Seip et al. (1984) stated that "the simple hydroxides ($Al(OH)^{+2}$ and $Al(OH)_2^+$) are regarded as the most dangerous forms, while organically bound aluminum and polymeric forms are less toxic or essentially harmless." However, one study found algae productivity and biomass were seldom affected if the pH is above 3.0 (Sparling and Lowe 1996a). Aluminum and acid toxicity tend to be additive to some algae when the pH is less than 4.5. Because aluminum binds with inorganic phosphorus, it may reduce the availability of this nutrient thereby reducing productivity (Sparling and Lowe 1996a). As shown in **Appendix E** and **Appendix H**, the effects of aluminum on algae productivity and biomass are dependent on the pH, total hardness and DOC of the exposure solutions.

2.3.1 Water Quality Parameters Affecting Toxicity

Bioavailability of aluminum is affected by water chemistry parameters such as pH, total hardness and DOC, and to a lesser extent fluoride. The pH of waters affects aluminum speciation and solubility. Aluminum can sorb to dissolved organic carbon (DOC), such as humic and fulvic acids, and form organic aluminum complexes. An increase in DOC in waters reduces the bioavailability of aluminum to aquatic organisms as a result of this binding (Wilson 2012). Hardness also has an effect on the toxicity of aluminum, as the cation Al^{+3} competes with other

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cations present in water such as calcium (Ca^{+2}) for uptake (Gensemer and Playle 1999). The observed effect of total hardness may be due to one or more of a number of usually interrelated ions, such as hydroxide, carbonate, calcium, and magnesium. Acute tests were conducted at four different levels of water total hardness with *Ceriodaphnia dubia* (ENSR 1992d), demonstrating that daphnids were more than 138 times more sensitive to aluminum in soft water than in hard water (**Appendix A** *Acceptable Acute Toxicity Data of Aluminum to Freshwater Aquatic Animals*). Data in **Appendix A** also indicate that aluminum was more toxic to *Daphnia magna*, brook trout, and fathead minnows in soft water than in hard water. In contrast, no apparent total hardness-toxicity relationship was observed for rainbow trout exposed to three different total hardness levels at a controlled pH of 8.3 (Gundersen et al. 1994). This is consistent with data recently published by DeForest et al. (2018a) and Gensemer et al. (2018) demonstrating that there is a reduced effect of total hardness at elevated pH levels.

Development of the Biotic Ligand Model (BLM - formerly the "gill model") and multi-parameter linear regression models in recent years were intended to better account for the water chemistry parameters that most strongly affect the bioavailability, and hence toxicity, of metals to aquatic life. The BLM, a mechanistic model that uses a series of submodels to quantify the capacity of metals to accumulate or bind to active sites on the gills of aquatic organisms, estimates the bioavailable portion of dissolved metals in the water column based on site-specific water quality parameters such as pH, hardness, and DOC (McGeer et al. 2000; Meyer et al. 1999; Pagenkopf 1983; Paquin et al. 1999; U.S. EPA 1999a, 2000). Multiple linear regression (MLR) models are statistical in nature and can also take into account pH, total hardness and DOC. While MLR models are less complex than BLM models, they also estimate the bioavailability of aluminum to aquatic species. The EPA evaluated the use of empirical, non-mechanistic MLR models for aluminum (DeForest et al. 2018a) as a bioavailability-based approach for deriving water quality criteria as well as a BLM model for aluminum (Santore et al. 2018). Note that the aluminum BLM developed by Santore et al. (2018) differs from earlier BLMs for other metals, because the aluminum BLM accounts for the dissolved and precipitated fraction of aluminum. Previous BLMs for other metals only account for the dissolved fraction of the metal.

The EPA decided to use an empirical MLR approach in this aluminum criteria update rather than a BLM model due to: 1) the relative simplicity and transparency of the model, 2) the relative similarity to the available BLM model outputs, and 3) the decreased number of input

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data on water chemistry needed to derive criteria at different sites. An external peer review of an approach using a pH and total hardness equation-based criteria, an MLR approach, and a BLM approach for aluminum criteria development was conducted in 2015 and peer-reviewers' comments were considered in the selection of the MLR-based criteria approach. The EPA independently examined and verified the quality and fit of the DeForest et al. (2018a,b) MLR models before applying them in this criteria document.

2.4 Conceptual Model

Conceptual models consist of a written description and diagram (U.S. EPA 1998a) that illustrate the relationships between human activities, stressors, and ecological effects on assessment endpoints. The conceptual model links exposure characteristics with the ecological endpoints important for management goals.

2.4.1 Conceptual Diagram

Aluminum can originate from both natural and anthropogenic sources (Lantzy and MacKenzie 1979). The environmental fate properties of aluminum indicate that weathering/erosion, volcanic activity, runoff/leaching, groundwater recharge, spray drift from aluminum-containing pesticides, and atmospheric deposition represent potential transport mechanisms of aluminum to surface water habitats for aquatic organisms (ATSDR 2008). These transport mechanisms are depicted in the conceptual model below for natural (i.e., weathering and erosion, volcanic activity) and anthropogenic sources of aluminum to the environment (i.e., wastewater treatment, resource extraction, smelting/manufacturing operations, agricultural uses and fossil fuel combustion) (**Figure 3**). The model also depicts exposure pathways for biological receptors of concern (e.g., aquatic animals) and the potential attribute changes (i.e., effects such as reduced survival, growth and reproduction) in the receptors due to aluminum exposure. A solid line indicates a major pathway and a dashed line indicates a minor pathway. Aquatic assessments address exposure primarily through anthropogenic releases, runoff and atmospheric deposition.

The conceptual model provides a broad overview of how aquatic organisms can potentially be exposed to aluminum. Derivation of criteria focuses on effects on survival, growth and reproduction of aquatic organisms. However, the pathways, receptors, and attribute changes depicted in **Figure 3** may be helpful for states and authorized tribes as they adopt criteria into standards and need to evaluate potential exposure pathways affecting designated uses.

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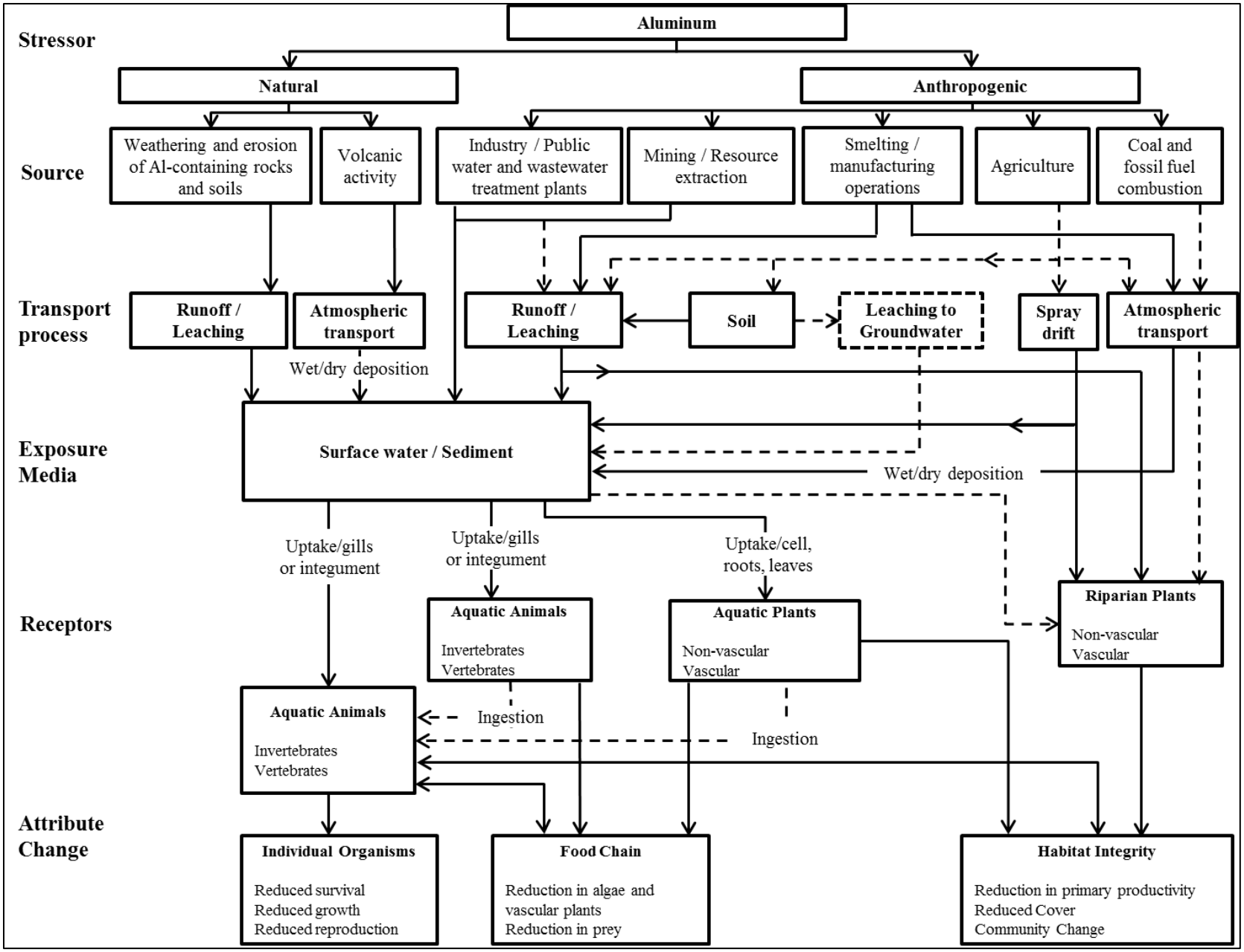


Figure 3. Conceptual Model for Aluminum Effects on Aquatic Organisms.
(Dotted lines indicate exposure pathways that have a lower likelihood of contributing to ecological effects).

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2.5 Assessment Endpoints

Assessment endpoints are defined as the explicit expressions of the environmental values to be protected and are comprised of both the ecological entity (e.g., a species, community, or other entity) and the attributes or characteristics of the entity to be protected (U.S. EPA 1998a). Assessment endpoints may be identified at any level of organization (e.g., individual, population, community). In the context of the CWA, aquatic life criteria for toxic substances are typically determined based on the results of toxicity tests with aquatic organisms, for which adverse effects on growth, reproduction, or survival are measured. This information is aggregated into a genus sensitivity analysis that characterizes an impact to the aquatic community. Criteria are designed to be protective of the vast majority of aquatic animal taxa in an aquatic community (i.e., approximately the 95^{th} percentile of genera based on tested aquatic animals representing the aquatic community per the 1985 Guidelines recommendations (Stephan et al 1985). Assessment endpoints consistent with the criteria developed in this document are summarized in **Table 1**.

The concept of using laboratory toxicity tests to protect North American bodies of water and resident aquatic species is based on the theory that effects occurring to a species in controlled laboratory tests will generally occur to the same species in comparable field situations. Since aquatic ecosystems are complex and diversified, the 1985 Guidelines require acceptable data be available for at least eight genera with a specified taxonomic diversity (the standard eight-family minimum data requirement, or MDR). The intent of the eight-family MDR is to serve as a typical surrogate sample community representative of the larger and generally much more diverse natural aquatic community, not necessarily the most sensitive species in a given environment. For many aquatic life criteria, enough data are available to describe a sensitivity distribution to represent the distribution of sensitivities in natural ecosystems. In addition, since aquatic ecosystems can tolerate some stress and occasional adverse effects, protection of all species at all times and places is not deemed necessary. The intent is to protect approximately 95 percent of a group of diverse taxa, with special consideration given to any commercially and recreationally important species (Stephan et al 1985). Thus, if properly derived and used, the combination of a freshwater or estuarine/marine acute and chronic aquatic life criteria should provide an appropriate degree of protection of aquatic organisms and their uses from acute and

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chronic toxicity to animals, toxicity to plants, and bioaccumulation by aquatic organisms (Stephan et al. 1985).

Table 1. Summary of Assessment Endpoints and Measures of Effect Used in Criteria Derivation.

Assessment Endpoints for the Aquatic Community	Measures of Effect
Survival, growth, and reproduction of freshwater fish, other freshwater vertebrates, and invertebrates	For acute effects: LC_{50}, EC_{50} For chronic effects: EC_{20}, MATC (only used when an EC_{20} could not be calculated for the genus), EC_{10} (for bioaccumulative compounds)
Survival, growth, and reproduction of estuarine/marine fish and invertebrates	For acute effects: LC_{50}, EC_{50} For chronic effects: EC_{20}, MATC (only used when an EC_{20} could not be calculated for the genus), EC_{10} (for bioaccumulative compounds)
Maintenance and growth of aquatic plants from standing crop or biomass (freshwater and estuarine/marine)	LOEC, EC_{20}, EC_{50}, IC_{50}, reduced growth rate, cell viability, calculated MATC

MATC = Maximum acceptable toxicant concentration (geometric mean of NOEC and LOEC)
NOEC = No observed effect concentration
LOEC = Lowest observed effect concentration
LC_{50} = Lethal concentration to 50% of the test population
$EC_{50}/EC_{20}/EC_{10}$ = Effect concentration to 50%/20%/10% of the test population
IC_{50} = Concentration of aluminum at which growth is inhibited 50% compared to control organism growth

2.6 Measurement Endpoints

Measurement endpoints (**Table 1**) are the measures of ecological effect used to characterize or quantify changes in the attributes of an assessment endpoint or changes in a surrogate entity or attribute, in this case a response to chemical exposure (U.S. EPA 1998a). Toxicity data are used as measures of direct and indirect effects on representative biological receptors. The selected measures of effects for the development of aquatic life criteria encompass changes in the growth, reproduction, and survival of aquatic organisms (Stephan et al. 1985).

The toxicity data used for the development of aquatic life criteria depend on the availability of applicable toxicity test outcomes, the acceptability of test methodologies, and an in-depth evaluation of the acceptability of each specific test, as performed by the EPA. Measurement endpoints for the development of aquatic life criteria are derived using acute and chronic toxicity studies for representative test species, which are then quantitatively and qualitatively analyzed, as described in the Analysis Plan below. Measurement endpoints

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considered for each assessment endpoint in this criteria document are summarized in **Table 1**. The following sections discuss toxicity data requirements for the fulfillment of these measurement endpoints.

2.6.1 Overview of Toxicity Data Requirements

The EPA has specific data requirements to assess the potential effects of a stressor on an aquatic ecosystem and develop CWA section 304(a) aquatic life criteria as described in the 1985 Guidelines (Stephan et al 1985). Acute toxicity test data (short term effects on survival) for species from a minimum of eight diverse taxonomic groups are required for the development of acute criteria to ensure the protection of various components of an aquatic ecosystem.

- Acute toxicity test data for species from a minimum of eight diverse taxonomic groups. The diversity of tested species is intended to ensure protection of various components of an aquatic ecosystem.
    - The acute freshwater requirement is fulfilled with the following eight minimum data requirements:
        - the family Salmonidae in the class Osteichthyes
        - a second family in the class Osteichthyes, preferably a commercially or recreationally important warmwater species (e.g., bluegill, channel catfish, etc.)
        - a third family in the phylum Chordata (may be in the class Osteichthyes or may be an amphibian, etc.)
        - a planktonic crustacean (e.g., cladoceran, copepod, etc.)
        - a benthic crustacean (e.g., ostracod, isopod, amphipod, crayfish, etc.)
        - an insect (e.g., mayfly, dragonfly, damselfly, stonefly, caddisfly, mosquito, midge, etc.)
        - a family in a phylum other than Arthropoda or Chordata (e.g., Rotifera, Annelida, Mollusca, etc.)
        - a family in any order of insect or any phylum not already represented
    - The acute estuarine/marine requirement is fulfilled with the following eight minimum data requirements:
        - two families in the phylum Chordata
        - a family in a phylum other than Arthropoda or Chordata
        - either the Mysidae or Penaeidae family
        - three other families not in the phylum Chordata (may include Mysidae or Penaeidae, whichever was not used above)
        - one from any other family
- Chronic toxicity test data (longer-term survival, growth, or reproduction) are required for a minimum of three taxa, with at least one chronic test being from an acutely-sensitive species.

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- Acute-chronic ratios (ACRs) can be calculated with data from species of aquatic animals from at least three different families if the following data requirements are met:
    - at least one is a fish
    - at least one is an invertebrate
    - for freshwater chronic criterion: at least one is an acutely sensitive freshwater species (the other two may be estuarine/marine species) or for estuarine/marine chronic criterion: at least one is an acutely sensitive estuarine/marine species (the other two may be freshwater species).

The 1985 Guidelines also require at least one acceptable test with a freshwater alga or vascular plant. If plants are among the aquatic organisms most sensitive to the chemical, results of a plant in another phylum should also be available. Data on toxicity to aquatic plants are examined to determine whether plants are likely to be unacceptably affected by concentrations below those expected to cause unacceptable effects on aquatic animals. As discussed in **Section 3.4** and **Section 5.2**, based on available data the relative sensitivity of fresh and estuarine/marine algae and plants to aluminum (**Appendix E** *Acceptable Toxicity Data of Aluminum to Freshwater Aquatic Plants* and **Appendix F** *Acceptable Toxicity Data of Aluminum to Estuarine/Marine Aquatic Plants*) is less than vertebrates and invertebrates, so plant criteria were not developed. This trend was apparent for all conditions, as vertebrate and invertebrate generated criteria values were always less than alga EC_{20}s (DeForest et al. 2018a), except at unrealistically high pH and very high total hardness.

2.6.2 Measures of Effect

The assessment endpoints for aquatic life criteria are based on survival, growth and reproduction of the assessed taxa per the 1985 Guidelines (Stephan et al 1985). The measures of effect are provided by the acute and chronic toxicity data. These toxicity endpoints (expressed as genus mean values) are used in the sensitivity distribution of the aquatic community at the genus level to derive the aquatic life criteria. Endpoints used in this assessment are listed in **Table 1**. Studies that had unacceptable control survival were not used (i.e., studies where acute and chronic control mortality was >10% and >20%, respectively), regardless of test conditions.

Measure of Aluminum Exposure Concentration

Only data from toxicity tests conducted using chloride, nitrate and sulfate salts (either anhydrous or hydrated) are used in this effects assessment. This is consistent with the EPA's

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previous 1988 aluminum aquatic life AWQC document. This document addresses the toxicity of total aluminum to freshwater organisms in the pH range of 5.0 to 10.5. The 1988 AWQC addressed waters with a pH between 6.5 and 9.0 (U.S. EPA 1988) to be consistent with the recommended aquatic life pH criteria (U.S. EPA 1986). The pH range for freshwater was expanded, in part, because of the complex chemistry of aluminum in surface waters, the available toxicity data demonstrated an increased sensitivity of freshwater aquatic species in low pH (i.e., pH<6.5), and the expanded range represents a fuller range of pH conditions in natural waters. Tests conducted in pH water less than 5 were deemed too low to be used quantitatively due to a mixture effect from the combined stress of both low pH and aluminum on the test organisms, and the inability to discern a particular effect level to either low pH or elevated aluminum concentration.

Aluminum chemistry in surface waters is extremely complex, and so measurement uncertainty can be high if only one form of aluminum is taken into account. A thorough understanding of aluminum toxicity is complicated by the need to distinguish between aqueous and particulate aluminum, and between inorganic and organic forms of aluminum (Driscoll and Postek 1996; Gensemer and Playle 1999). Laboratory dilution waters do not contain suspended solids, clays or particulate matter where aluminum may be bound (unless specifically investigated). Therefore, a distinction needs to be made in how the EPA interprets the measurements of aluminum in water, so that extrapolating laboratory data to natural waters is better understood. There is also a complication as the available measurement methods (i.e., total, total recoverable, acid soluble, pH 4 extractable and dissolved) present different challenges when applied to natural and laboratory waters. In application to natural waters, total, total recoverable, and acid soluble methods may be confounded by measuring aluminum in aluminum silicate (i.e., clay).

Laboratory Exposures

The 1988 AWQC considered using dissolved aluminum concentrations to set aquatic life criteria, however not enough data were available to allow derivation of a criterion based on dissolved aluminum. The EPA also noted at the time that organisms would be exposed to both dissolved and undissolved aluminum from laboratory exposures. The lack of data prevented any definitive analysis.

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Data are now available to compare toxicity of aluminum using total aluminum (unfiltered test samples that were acidified) and dissolved aluminum (operationally defined as filtered with typically a 0.45 µm filter before acidification). The total aluminum concentrations in laboratory test solutions will contain dissolved monomeric and precipitated forms (e.g., aluminum hydroxides) of aluminum. Dissolved concentrations will not contain these precipitated forms.

In tests with brook trout at low pH and total hardness, toxic effects increased with increasing concentrations of total aluminum even though the corresponding concentration of dissolved aluminum was relatively constant (Cleveland et al. 1989). This phenomenon was also observed in several chronic studies with widely varying test concentrations and conditions (renewal and flow-through exposures) at pH 6 conducted by the Oregon State University (e.g., 2012a,e), where toxic effects increased with increasing total aluminum concentrations, while measured concentrations of dissolved and monomeric aluminum changed very little with increasing total aluminum concentrations.

In filtration studies at pH 8 with the fathead minnow, both acute and chronic toxicity tests indicated no toxicity when the test water was 0.2 µm filtered prior to exposure (Gensemer et al. 2018). Toxicity was only observed when the test solutions were unfiltered. Furthermore, dose-response relationships were only observed using total aluminum; relationships were not observed using measurements of dissolved or monomeric forms (Gensemer et al. 2018). This same effect was observed in 7-day exposures at pH 7 and 8 with the daphnid (*Ceriodaphnia dubia*) where filtered test solutions were less toxic than unfiltered solutions (Gensemer et al. 2018).

Therefore, because measurements of dissolved aluminum do not reflect the full spectrum of forms of aluminum that results in toxicity, all laboratory exposure data used for criteria derivation will be based on measurements of total aluminum. Measurements with methods using lesser degrees of acidification (that is, acid soluble and pH 4 extractable) are generally not available. If aluminum criteria are based on dissolved concentrations, toxicity will be underestimated, because aluminum hydroxide precipitates that contribute to toxicity would not be measured (GEI Consultants, Inc. 2010; U.S. EPA 1988). All concentrations from toxicity tests are expressed as total aluminum in this document (unless otherwise specified).

Natural Waters

Researchers rely on operationally defined procedures to evaluate the concentration and forms of aluminum in natural waters, and the accuracy of these methods is difficult to evaluate,

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resulting in uncertainty regarding the actual amount of aluminum present in various forms (Driscoll and Postek 1996). Total aluminum concentrations in natural waters are determined using a wide variety of digestion procedures at varied extraction times, resulting in a range of operational methods and uncertainty in measured values (Driscoll and Postek 1996). Furthermore, particulate material comprises a continual size distribution making measurement of dissolved concentrations dependent on the filter-pore size used (Driscoll and Postek 1996).

A major complication for extrapolating total aluminum concentrations measured in laboratory waters to natural waters is the test method used. The 1988 AWQC for aluminum were based on acid-soluble concentrations (operationally defined as the aluminum that passes through a 0.45 µm filter after the sample has been acidified with nitric acid to a pH between 1.5 and 2.0). In the early 1990s, the EPA converted most metals criteria (excluding aluminum) to the dissolved measurement. With the acid-soluble method seldom used and insufficiently different from total, (U.S. EPA 1999c) the EPA expressed the aluminum criterion as total recoverable aluminum, with a caution that a Water-Effect Ratio would often be needed. The EPA uses the terms "total" and "total recoverable" synonymously for effluent guidelines and permitting under NPDES programs (U.S. EPA 1988b). The current EPA Test Method for measuring total recoverable aluminum in ambient water and wastewater uses inductively coupled plasma-atomic emission spectrometry and inductively-coupled plasma-mass spectrometry (U.S. EPA 1994a,b). The methods recommend that the sample first be solubilized by gentle refluxing with nitric and hydrochloric acids (i.e., digestion to pH<2) when an aqueous sample contains undissolved material. After cooling, the sample is made up to volume, then mixed and either centrifuged or allowed to settle overnight prior to analysis. This process dissolves the monomeric and polymeric forms of aluminum, in addition to colloidal, particulate and clay-bound aluminum. Applying the aluminum criteria to total recoverable aluminum is considered conservative because it includes monomeric (both organic and inorganic) forms, polymeric and colloidal forms, as well as particulate forms and aluminum sorbed to clays (Wilson 2012). However, under natural conditions not all of these forms would be biologically available to aquatic species (e.g., clay-bound aluminum).

EPA Methods 200.7 and 200.8 are the only currently approved methods for measuring aluminum in natural waters and wastewater for NPDES permits (U.S. EPA 1994a,b). Research on new analytical methods is ongoing to address concerns with including aluminum bound to

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particulate matter (i.e., clay) in the total recoverable aluminum concentrations (OSU 2018c). One approach would not acidify the sample to pH less than 2 but rather to pH 4 (pH 4 extracted method) to better capture the bioavailable fraction of aluminum (CIMM 2016, OSU 2018c). In the pH 4 extraction method, sodium acetate buffer is added to the sample to reach the desired pH, followed by sample agitation for a specified period of time, and finally 0.45 µm sample filtration. The sample is then acidified with nitric acid before inductively coupled plasma-optical emission spectrometry analysis.

To further explore this issue, researchers conducted an aluminum analysis of 12 natural freshwater sources throughout the United States with various concentrations of total suspended solids using four different aluminum methods (i.e., total, acid-soluble, pH 4 extracted and dissolved) (OSU 2018c). The total method (consistent with EPA methods 200.7 and 200.8) acidified the sample to pH 2 before analysis; the acid soluble method acidified the sample to pH<2, held the sample for 16 hours and then filtered the sample with a 0.45 µm filter; the pH extraction method acidified the sample to pH 4.0-4.2, held the sample for three hours, and then filtered the sample with a 0.45 µm filter; and lastly, the dissolved method filtered the sample before acidification. As expected, the total method typically had elevated measured aluminum concentrations compared to the levels quantified by the three other test methodologies. This trend was most evident with natural waters that had high total suspended solids. The validation of the pH 4 extraction method is still on-going, with the expectation that this approach will better estimate the bioavailable fraction of aluminum in natural waters.

Acute Measures of Effect

The acute measures of effect on aquatic organisms are the LC_{50}, EC_{50}, and IC_{50}. LC stands for "Lethal Concentration," and a LC_{50} is the concentration of a chemical that is estimated to kill 50 percent of the test organisms. EC stands for "Effect Concentration," and the EC_{50} is the concentration of a chemical that is estimated to produce a specific effect in 50 percent of the test organisms. IC stands for "Inhibitory Concentration," and the IC_{50} is the concentration of a chemical that is estimated to inhibit some biological process (e.g., growth) in 50 percent of the test organisms. Acute data that were determined to have acceptable quality and to be useable in the derivation of water quality criteria as described in the 1985 Guidelines for the derivation of a freshwater and estuarine/marine criteria are presented in **Appendix A** (*Acceptable Acute Toxicity*

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Data of Aluminum to Freshwater Aquatic Animals) and **Appendix B** (*Acceptable Acute Toxicity Data of Aluminum to Estuarine/Marine Aquatic Animals*), respectively.

Chronic Measures of Effect

The endpoint for chronic exposure for aluminum is the EC_{20}, which represents a 20 percent effect/inhibition concentration. This is in contrast to a concentration that causes a low level of reduction in response, such as an EC_5, which is rarely statistically significantly different from the control treatment. A major reduction, such as 50 percent, is not consistent with the intent of establishing chronic criteria to protect populations from long-term effects. The EPA selected an EC_{20} to estimate a low level of effect for aluminum that would typically be statistically different from control effects, but not severe enough to cause chronic effects at the population level (see U.S. EPA 1999b). Reported NOECs (No Observed Effect Concentrations) and LOECs (Lowest Observed Effect Concentrations) were only used for the derivation of a chronic criterion when an EC_{20} could not be calculated for the genus. A NOEC is the highest test concentration at which none of the observed effects are statistically different from the control. A LOEC is the lowest test concentration at which the observed effects are statistically different from the control. When LOECs and NOECs are used, a Maximum Acceptable Toxicant Concentration (MATC) is calculated, which is the geometric mean of the NOEC and LOEC.

Regression analysis was used to characterize a concentration-effect relationship and to estimate concentrations at which chronic effects are expected to occur. For the calculation of the chronic criterion, point estimates (e.g., EC_{20}s) were selected for use as the measure of effect rather than MATCs, as MATCs are highly dependent on the concentrations tested (as are the NOECs and LOECs from which they are derived). Point estimates also provide additional information that is difficult to determine with an MATC, such as a measure of magnitude of effect across a range of tested concentrations. Author reported EC_{20}s were used when provided, otherwise point estimates were calculated from raw toxicity data using the EPA's Toxicity Relationship Analysis Program (TRAP). Chronic toxicity data that met the test acceptability and quality assurance and quality control (QA/QC) criteria in the 1985 Guidelines for the derivation of freshwater and estuarine/marine criteria are presented in **Appendix C** (*Acceptable Chronic Toxicity Data of Aluminum to Freshwater Aquatic Animals*) and **Appendix D** (*Acceptable Chronic Toxicity Data of Aluminum to Estuarine/Marine Aquatic Animals*), respectively.

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2.7 Analysis Plan

During CWA section 304(a) criteria development, the EPA reviews and considers all relevant toxicity test data. Information available for all relevant species and genera are reviewed to identify whether: 1) data from acceptable tests meet data quality standards; and 2) the acceptable data meet the minimum data requirements (MDRs) as outlined in the 1985 Guidelines (Stephan et al. 1985; U.S. EPA 1986). The taxa represented by the different MDR groups represent taxa with different ecological, trophic, taxonomic and functional characteristics in aquatic ecosystems, and are intended to be a representative subset of the diversity within a typical aquatic community. In most cases, data on freshwater and estuarine/marine species are grouped separately to develop separate freshwater and estuarine/marine criteria. Thus, where data allow, four criteria are developed (acute freshwater, acute estuarine/marine, chronic freshwater, and chronic estuarine/marine). If plants are more sensitive than vertebrates and invertebrates, plant criteria are developed.

Table 2 provides a summary of the toxicity data used to fulfill the MDRs for calculation of acute and chronic criteria for both freshwater and estuarine/marine organisms. For aluminum, there are acceptable toxicity data for derivation of a freshwater acute criterion with all of the freshwater MDRs being met. The acceptable acute toxicity data encompass four phyla, 14 families, 20 genera and 22 species (**Table 2**). Acceptable estuarine/marine acute toxicity data are only available for three phyla, five families, five genera and five species. Consequently, only five of the eight MDRs are met for the estuarine/marine acute criterion; and no acceptable acute test data on fish species were available. Therefore, the EPA cannot develop an acute estuarine/marine criterion at this time. The chronic toxicity data for direct calculation of the FCV for the freshwater criterion consisted of seven of the eight freshwater MDRs (the missing MDR was the "other chordate"). However, the 1985 Guidelines still allow derivation of a chronic criterion (see **Section 2.6.1**). Because derivation of a chronic freshwater criterion is important for environmental protection, the EPA examined qualitative data for the Chordate MDR from **Appendix H** (*Other Data on Effects of Aluminum to Freshwater Aquatic Organisms*) and selected an amphibian test to fulfill that MDR. The species did not rank in the lowest four normalized Genus Mean Chronic Values (GMCVs) (the numeric-criteria-driving portion of the sensitivity distribution), and thus its use to fulfill the missing MDR is considered justified (U.S. EPA 2008). There are not enough chronic toxicity data for direct calculation of the FCV for the

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estuarine/marine criteria (no acceptable estuarine/marine chronic studies), thus the EPA did not derive chronic estuarine/marine criterion. Aluminum toxicity data on estuarine/marine species remain a data gap; additional acute and chronic toxicity testing on estuarine/marine taxa would be needed in order to derive estuarine/marine criteria for aluminum.

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Table 2. Summary of Acceptable Toxicity Data Used to Fulfill the Minimum Data Requirements in the 1985 Guidelines for Aluminum.

Family Minimum Data Requirement (Freshwater)	Acute (Phylum / Family / Genus)	Chronic (Phylum / Family / Genus)
Family Salmonidae in the class Osteichthyes	Chordata / Salmonidae / Oncorhynchus	Chordata / Salmonidae / Salvelinus
Second family in the class Osteichthyes	Chordata / Centrarchidae / Lepomis	Chordata / Cyprinidae / Pimephales
Third family in the phylum Chordata	Chordata / Cyprinidae / Pimephales	Chordata / Ranidae / Rana*
Planktonic Crustacean	Arthropoda / Daphniidae / Ceriodaphnia	Arthropoda / Daphniidae / Ceriodaphnia
Benthic Crustacean	Arthropoda / Crangonyctidae / Crangonyx	Arthropoda / Hyalellidae / Hyalella
Insect	Arthropoda/ Chironomidae/ Chironomus	Arthropoda / Chironomidae / Chironomus
Family in a phylum other than Arthropoda or Chordata	Mollusca / Physidae / Physa	Mollusca / Lymnaeidae / Lymnaea
Family in any order of insect or any phylum not already represented	Annelida / Naididae / Nais	Annelida / Aeolosomatidae / Aeolosoma
Family Minimum Data Requirement (Estuarine/Marine)	**Acute (Phylum / Family / Genus)**	**Chronic (Phylum / Family / Genus)**
Family in the phylum Chordata	No acceptable data	No acceptable data
Family in the phylum Chordata	No acceptable data	No acceptable data
Either the Mysidae or Penaeidae family	No acceptable data	No acceptable data
Family in a phylum other than Arthropoda or Chordata	Mollusca / Ostreidae / Crassostrea	No acceptable data
Family in a phylum other than Chordata	Annelida / Nereididae / Neanthes	No acceptable data
Family in a phylum other than Chordata	Annelida / Capitellidae / Capitella	No acceptable data
Family in a phylum other than Chordata	Annelida / Ctenodrilidae / Ctenodrilus	No acceptable data
Any other family	Arthropoda / Ameiridae / Nitokra	No acceptable data

* Data used qualitatively, see Section 3.2.1.

	Freshwater Acute			Freshwater Chronic			Estuarine/Marine Acute			Estuarine/Marine Chronic		
Phylum	**Families**	**GMAVs**	**SMAVs**	**Families**	**GMCVs**	**SMCVs**	**Families**	**GMAVs**	**SMAVs**	**Families**	**GMCVs**	**SMCVs**
Annelida	1	1	1	1	1	1	3	3	3	-	-	-
Arthropoda	5	7	9	3	4	4	1	1	1	-	-	-
Chordata	5	9	9	2	4	4	-	-	-	-	-	-
Mollusca	3	3	3	2	2	2	1	1	1	-	-	-
Rotifera	-	-	-	1	1	1	-	-	-	-	-	-
Total	**14**	**20**	**22**	**9**	**12**	**12**	**5**	**5**	**5**	**0**	**0**	**0**

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2.7.1 pH, Total Hardness and DOC Normalization

Although many factors might affect the results of toxicity tests of aluminum to aquatic organisms (Sprague 1985), water quality criteria can quantitatively take into account only factors for which enough data are available to show that the factor similarly affects the results of tests with a variety of species. A variety of approaches were evaluated for the development of the freshwater aluminum criteria due to aluminum's unique chemistry and geochemical effects on its bioavailability. These included empirical models that directly relate water chemistry conditions to metal bioavailability and include single parameter regression models (e.g., hardness adjustment equations) and a variety of MLRs. The mechanistic models evaluated included an aluminum BLM model and a simplified aluminum BLM model. For further discussion, see **Section 5.3.5**.

A recent publication by Gensemer et al. (2018) summarized short-term aluminum chronic toxicity data across a range of pH, total hardness, and DOC values. Three-day toxicity tests measuring growth with the green alga (*Pseudokirchneriella subcapitata*), 7-day reproduction tests with the cladoceran (*Ceriodaphnia dubia*), and 7-day mean biomass tests with the fathead minnow (*Pimephales promelas*) were compiled to evaluate how the effect of pH, total hardness, and DOC alters aluminum bioavailability. The *P. subcapitata* data consisted of 27 tests with dilution water parameters that ranged from 6.14-8.0 for pH, 22-121 mg/L total hardness and 0.3-4.0 mg/L DOC (DeForest et al. 2018a). The *C. dubia* data consisted of 23 tests with test parameters that ranged from 6.3-8.1 for pH, 9.8-123 mg/L total hardness and 0.1-4 mg/L DOC (DeForest et al. 2018a). The fathead minnow data consisted of 22 tests with test parameters that ranged from 6.0-8.0 for pH, 10.2-127 mg/L total hardness and 0.08-5.0 mg/L DOC (DeForest et al. 2018a). DeForest et al. (2018a) used these data to evaluate the ability of MLR models to predict chronic toxicity of aluminum as a function of multiple combinations of pH, total hardness, and DOC conditions. These three parameters are thought to be the most influential for aluminum bioavailability and can be used to explain the scale of differences in the observed toxicity values (Cardwell et al. 2018; Gensemer et al. 2018). As a result of the public comments on the draft of this document released into the Federal Register, data on an additional nine *C. dubia* and nine *P. promelas toxicity* tests were obtained in order to expand the ranges of water chemistry conditions for model development. The new toxicity data expanded the DOC range up to 12.3 mg/L for *C. dubia* and 11.6 mg/L for *P. promelas* and the hardness range up to 428 mg/L

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and 422 mg/L, respectively. These new data were subjected to an independent, external expert peer review, and an EPA quality review, prior to their use in the aluminum criteria. The external expert peer review comments on these new data obtained by the EPA in 2018 and the EPA's response to the external expert peer reviews can be found on the EPA website for the aluminum criteria (https://www.epa.gov/wqc/aquatic-life-criteria-aluminum).

The approach described by DeForest et al. (2018a,b) incorporated pH, total hardness, and DOC into MLR models to determine if the estimation of aluminum bioavailability to animals in freshwater aquatic systems could be applicable in the development of aluminum water quality criteria. The approach resulted in the creation of multiple MLR models that could be used for the development of aluminum water quality criteria following European Union (EU) (ECB 2003) and the EPA methodologies (Stephan et al. 1985). Only the MLR model development for the fathead minnow and *C. dubia* using EC_{20} effects concentrations is described below. Note that while a 7-day survival and growth test for *P. promelas* is not defined as an early-life stage (ELS) test per the 1985 Guidelines, testing demonstrated that it produced sensitivity values for total aluminum comparable to those generated via an acceptable ELS test (DeForest et al. 2018a, Table S1), and therefore, is considered appropriate to use for MLR model development.

MLR models for each species were developed using a multi-step process and the general approach is briefly described below. For more detailed information, figures, tables, and statistical results, please see DeForest et al. (2018a,b) and Brix et al. (2017). The authors first examined if any of the relationships between the dependent variable (total aluminum effect concentrations) and the three main effect terms (pH, total hardness and DOC; all independent variables) were non-linear. Effect concentrations (EC_{20}s) for each species were plotted against each independent variable using data where the other two parameters were held constant. Overall, EC_{20}s increased with each independent variable. However, there was some evidence of a unimodal relationship with pH, with increased EC_{20}s around pH 7 and decreasing EC_{20}s at low and high pH, as well as potential differences regarding the effects of total hardness at low and high pH (DeForest et al. 2018a). To account for these potential nonlinearities, the three potential two-way interactions (i.e., pH:hardness, DOC:hardness and pH:hardness) for each of the three main effect terms were added. Finally, a squared pH term was included in the initial models to account for the potential unimodal relationship between pH and aluminum bioavailability (DeForest et al. 2018a).

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Beginning with a seven-parameter model consisting of the three main effect terms (pH, total hardness and DOC), the three two-way interactions for the main effects, and a squared pH term, a final model was developed for each species using a step-wise procedure. In this procedure, the original model was compared to a series of simpler models by removing one or more of the four "higher-level" terms (i.e., the three interaction terms and the squared pH term), until the most parsimonious model was developed. Each potential model was evaluated using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The overall goodness of fit of a model increases with each additional model term. AIC and BIC penalize a model's goodness-of-fit by a factor related to the number of parameters in the model (DeForest et al. 2018a). AIC and BIC are minimized for the model that best balances overall goodness-of-fit and model complexity, as too many terms in the model may over extrapolate from the dataset making it less useful, whereas too few terms reduces its precision.

DeForest et al. (2018b) re-evaluated the original published models supplemented with the new data and developed a pooled MLR model based on the combined *C. dubia* and *P. promelas* datasets. A pooled model approach is described in Brix et al. (2017) for copper. In a pooled MLR model approach, species-specific intercepts are used to account for the differences in species sensitivity. The same procedures were used to develop a pooled model as was done for the individual species MLR models.

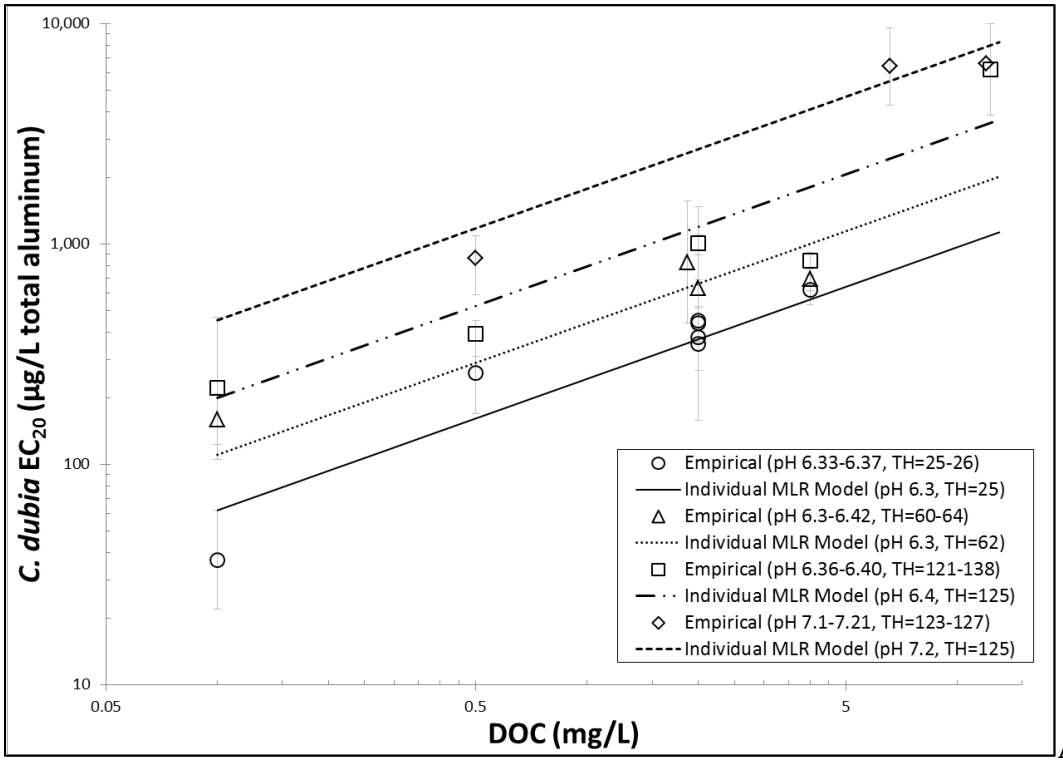
For *C. dubia*, the final individual MLR model, based on AIC and BIC, included both the pH:hardness interaction and the squared pH term (DeForest et al. 2018b). The negative pH^2 term accounts for the fact that aluminum bioavailability decreases from pH 6 to pH 7 and then increases from pH 7 to pH 8, which is expected given the unique solubility chemistry of aluminum (DeForest et al. 2018a). The negative pH:hardness term is reflective of the decreasing effects of total hardness mitigating toxicity as pH increases (DeForest et al. 2018a). The adjusted R^2 for the final model was 0.880, compared to an R^2 of 0.67 for the model consisting of the three main independent variables [pH, ln(total hardness), and ln(DOC)]. In the final MLR model, predicted EC_{20}s were within a factor of two of observed values used to create the model for 97% of the tests (DeForest et al. 2018b). The comparison of MLR predicted versus observed *C. dubia* values where one water chemistry parameter was varied is seen in **Figure 4** and **Figure 5**. No clear pattern was observed in the residuals over a wide range of water chemistry conditions or

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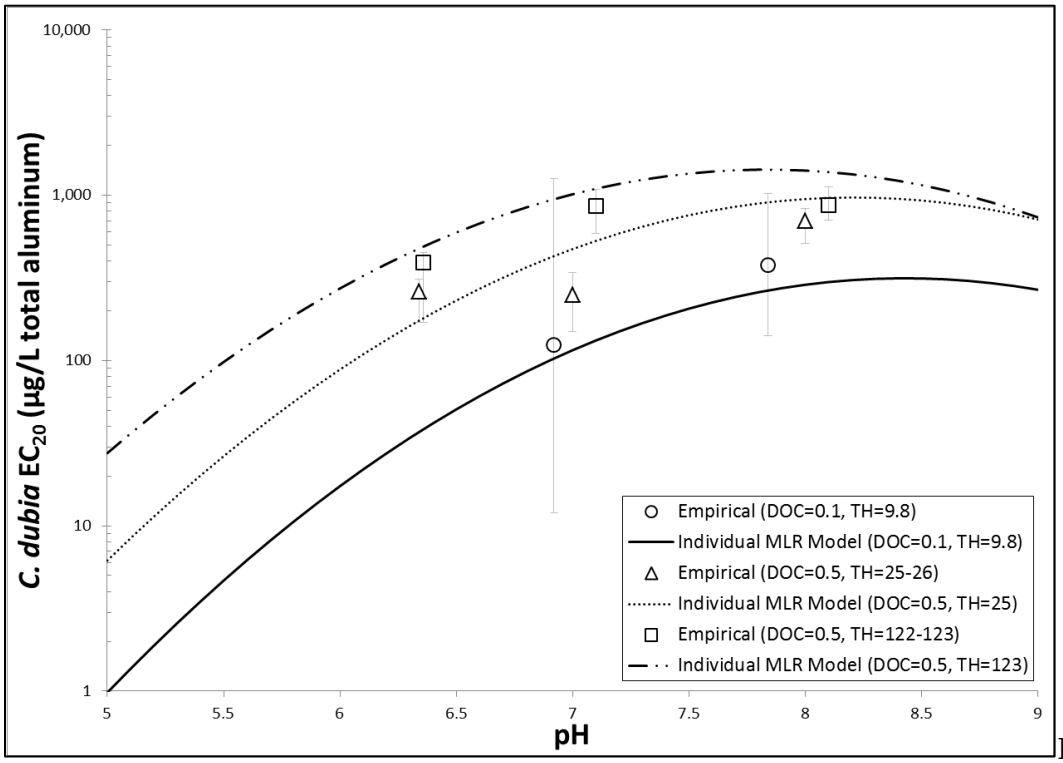
relative to single independent variables (Figure S3-Figure S6, DeForest et al. 2018a). The final individual MLR model for *C. dubia* is:

$$C.dubia\ EC_{20} = e^{\left[-32.523+[0.597\times\ln(DOC)]+[2.089\times\ln(hard)]+(8.802\times pH)-(0.491\times pH^2)-[0.230\times pH:\ln(hard)]\right]}$$

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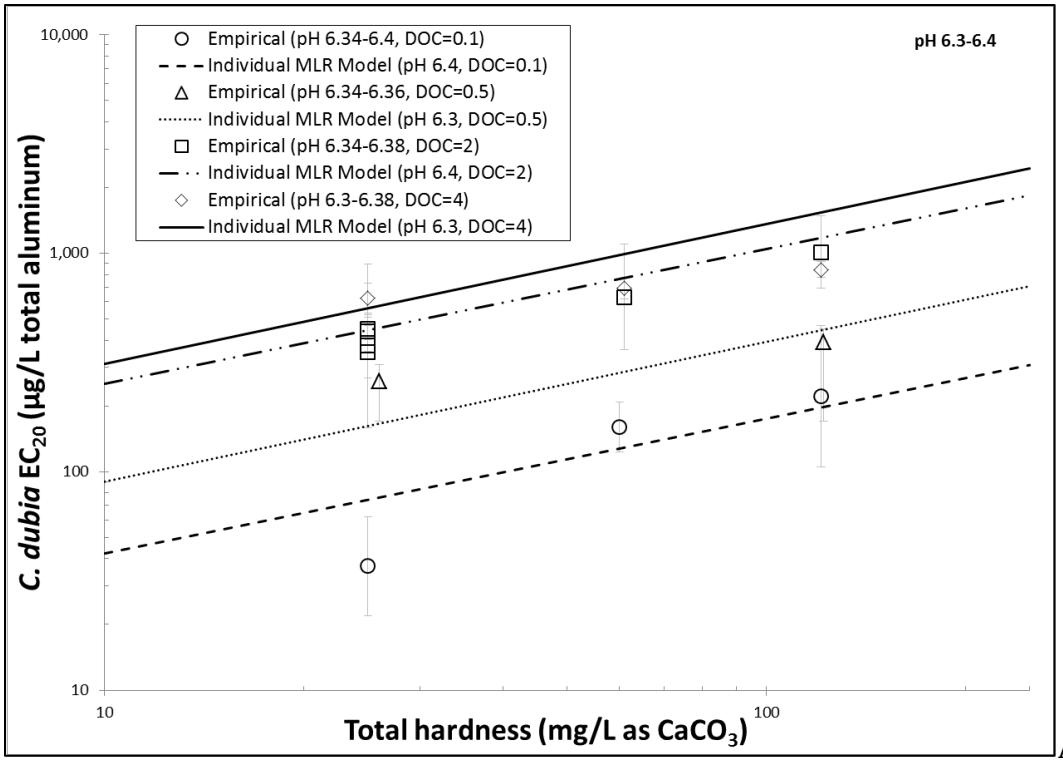


A

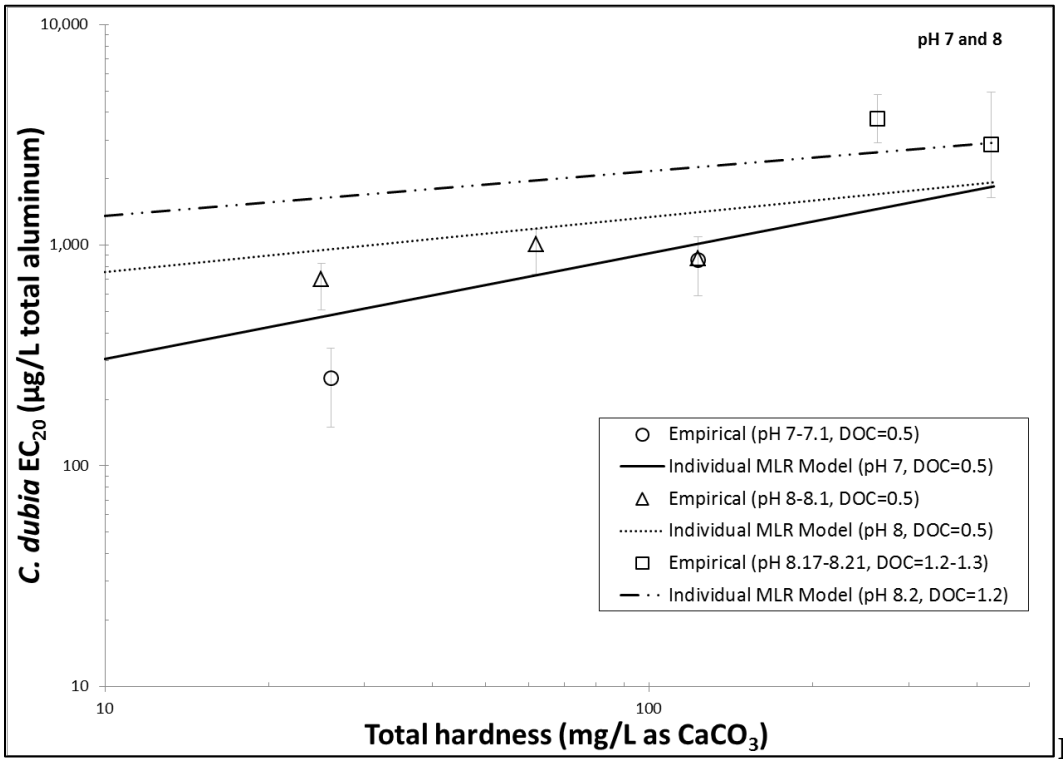


B

Figure 4. Observed and Individual MLR-Predicted Aluminum EC_{20}s (±95% CLs) for *C. dubia* where DOC or pH was Varied.
(Panel A: DOC is varied; Panel B: pH is varied; Adapted from Figure 2, from DeForest et al. 2018a, used with permission).



A



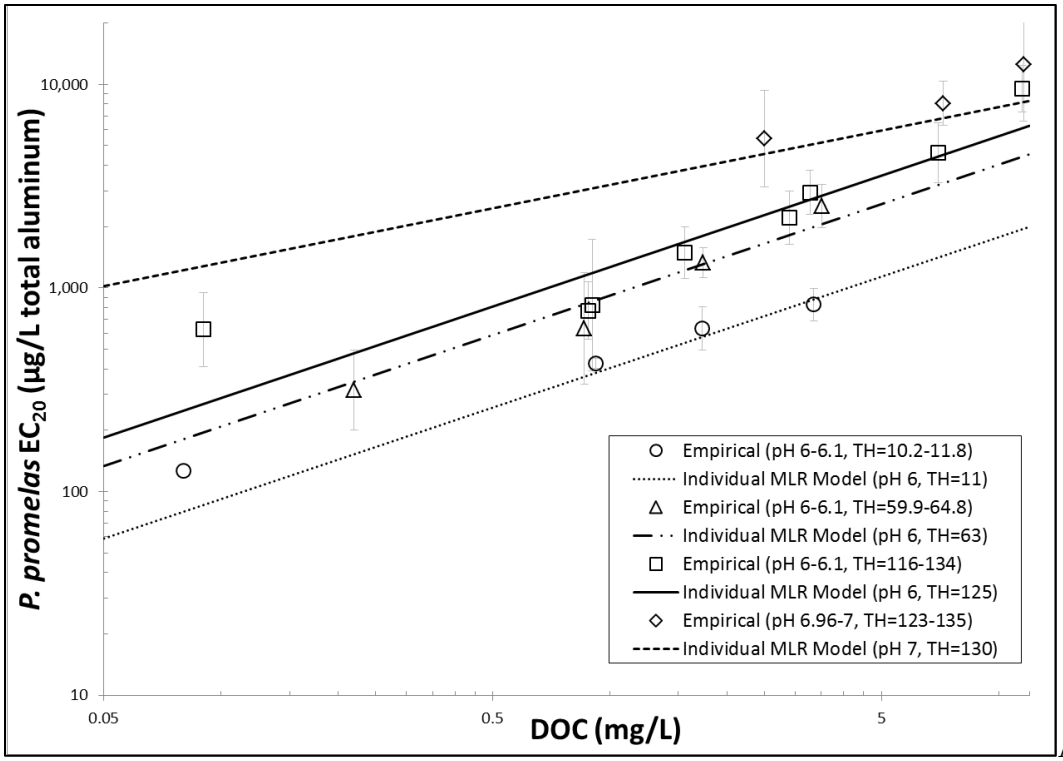
B

Figure 5. Observed and Individual MLR-Predicted Aluminum EC_{20}s (±95% CLs) for *C. dubia* where Total Hardness was Varied.
(Panel A: pH 6.3-6.4, Panel B: pH 7 and 8; Adapted from Figure 2, from DeForest et al. 2018a, used with permission).

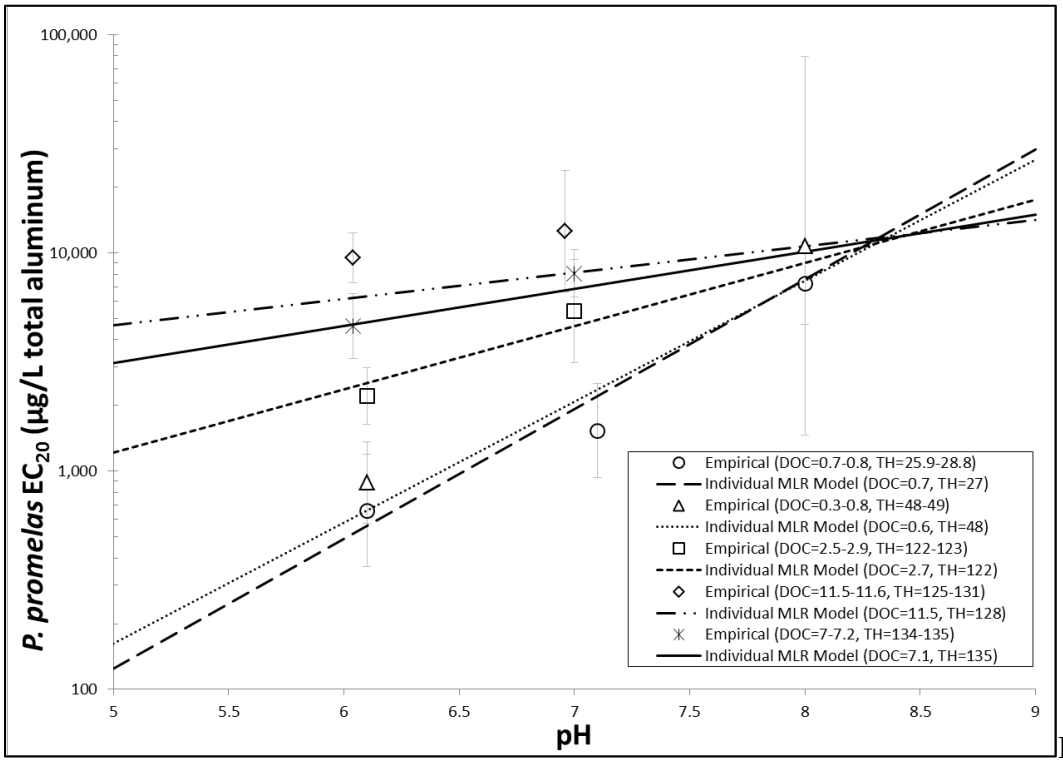
For *P. promelas*, the final individual model, based on AIC and BIC, included the pH:hardness and pH:DOC interaction terms (DeForest et al. 2018b). The pH:hardness interaction term was retained because of the unique chemistry of aluminum where total hardness has less of a mitigating effect on bioavailability at higher pH levels (DeForest et al. 2018a; Gensemer et al. 2018). The adjusted R^2 for the final model was 0.923, compared to an R^2 of 0.85 for the model consisting of the three main independent variables [ln(DOC), pH, and ln(hardness)]. In the final MLR model, predicted EC_{20}s were within a factor of two of observed values used to create the model for 97% of the tests (DeForest et al. 2018b). The comparison of MLR predicted versus observed *P. promelas* values where one water chemistry parameter was varied is provided in **Figure 6** and **Figure 7**. Again, no clear pattern was observed in the residuals over a wide range of water chemistry conditions or relative to single independent variables (Figure S3-Figure S6, DeForest et al. 2018a). The final individual MLR model for *P. promelas* is:

$$P.promelas\ EC_{20} = e^{[-7.371+[2.209\times\ln(DOC)]+[1.862\times\ln(hard)]+(2.041\times pH)-[0.232\times pH:\ln(hard)]-[0.261\times pH:\ln(DOC)]]}$$

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A



B

Figure 6. Observed and Individual MLR-Predicted Aluminum EC_{20}s (±95% CLs) for *P. promelas* where DOC or pH was Varied.
(Panel A: DOC, Panel B: pH; Adapted from Figure 3, from DeForest et al. 2018a, used with permission).

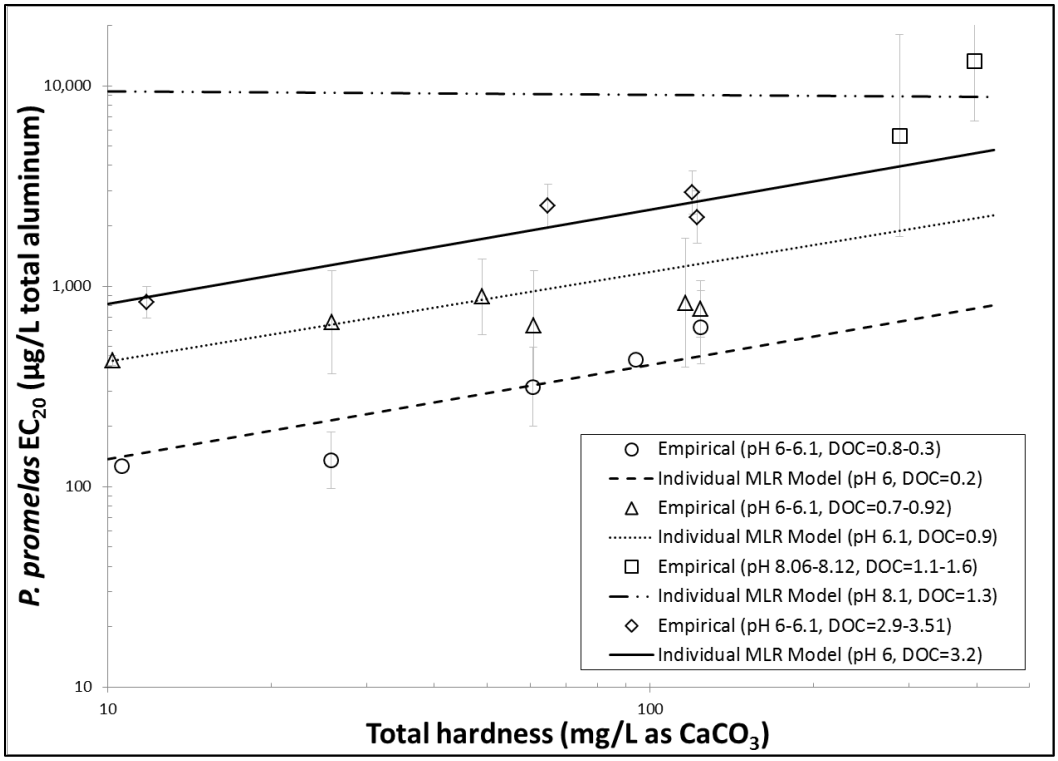


Figure 7. Observed and Individual MLR-Predicted Aluminum EC_{20}s (±95% CLs) for *P. promelas* where Total Hardness was Varied.
(Adapted from Figure 3, from DeForest et al. 2018a, used with permission).

The pooled MLR model performed similarly as the individual (fish and invertebrate) MLR models (DeForest et al. 2018b). The adjusted R^2 value, based on the BIC, was 0.882 and includes the pH:hardness interaction term. The pooled MLR model had a similar to identical level of accuracy as the individual MLR models with 97% of *C. dubia* and 94% of *P. promelas* predicted EC_{20}s within a factor of two of observed values (DeForest et al. 2018b). However, a comparison of the residuals between the observed and predicted values for the two models (individual vs. pooled MLR) showed that the individual models' residuals had smaller standard deviations. Additionally, the pooled model had some patterns in the residuals of the predictions relative to the independent variables (e.g., pH). There were no patterns in the residuals for either the *C. dubia* or *P. promelas* individual MLR models. The EPA elected to use the individual fish and invertebrate models in the final recommended aluminum aquatic life AWQC, instead of a pooled model for the above reasons. This modeling approach is also consistent with the approach in the draft 2017 aluminum criteria document. Additional analysis comparing the performance to the two model approaches (individual vs. pooled MLR) is presented in **Appendix L** (*EPA's MLR Model Comparison of DeForest et al. (2018b) Pooled and Individual-Species Model Options*).

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The models developed followed the trends seen in the empirical data, 1) at pH 6 predicted effects concentrations increased with both total hardness and DOC concentrations, 2) at pH 7 predicted effect concentrations increased with DOC concentrations, but not total hardness, and 3) at pH 8 predicted effect concentrations increased with DOC concentrations, but predicted effect concentrations decreased with increased total hardness concentrations (DeForest et al. 2018a). The individual species models developed by DeForest et al. (2018b) were used to normalize the freshwater acute and chronic data in **Appendix A** and **Appendix C**, respectively. Invertebrate data were normalized using the individual MLR model for *C. dubia*, and vertebrate data were normalized using the individual MLR model for *P. promelas*. Invertebrate and vertebrate freshwater aluminum toxicity data were normalized with the following equations:

$$Invertebrate\ Normalized\ EC_{20}/LC_{50}$$

$$= e^{\left[\begin{array}{c}(\ln EC_{20,test}/LC_{50,test})-[0.597\times(\ln DOC_{test}-\ln DOC_{target})]-[8.802\times(pH_{test}-pH_{target})]-[2.089\times(\ln hard_{test}-\ln hard_{target})]\\ +[0.491\times(pH_{test}^2-pH_{target}^2)]+[0.230\times[(pH_{test}\times\ln hard_{test})-(pH_{target}\times\ln hard_{target})]]\end{array}\right]}$$

$$Vertebrate\ Normalized\ EC_{20}/LC_{50}$$

$$= e^{\left[\begin{array}{c}\left(\ln\frac{EC_{20,test}}{LC_{50,test}}\right)-[2.209\times(\ln DOC_{test}-\ln DOC_{target})]-[2.041\times(pH_{test}-pH_{target})]-[1.862\times(\ln hard_{test}-\ln hard_{target})]\\ +[0.261\times[(pH_{test}\times\ln DOC_{test})-(pH_{target}\times\ln DOC_{target})]]\\ +[0.232\times[(pH_{test}\times\ln hard_{test})-(pH_{target}\times\ln hard_{target})]]\end{array}\right]}$$

where:

$EC_{20,test}$	=	reported chronic total aluminum effect concentration in µg/L
$LC_{50,test}$	=	reported acute total aluminum effect concentration in µg/L
DOC_{test}	=	reported test DOC concentration in mg/L
pH_{test}	=	reported test pH
$hard_{test}$	=	reported test total hardness concentration in mg/L as $CaCO_3$
DOC_{target}	=	DOC value to normalize to in mg/L
pH_{target}	=	pH value to normalize to
$hard_{target}$	=	total hardness value to normalize to in mg/L as $CaCO_3$

Throughout this document, unless otherwise stated, effect concentrations were normalized to pH 7, total hardness of 100 mg/L and DOC of 1 mg/L. This example scenario is illustrative only and

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is not meant to represent water quality characteristics typical of U.S. natural waters. Normalized values will be different under differing water chemistry conditions as identified in this document.

2.7.2 Acute Criterion

Acute criteria are derived from the sensitivity distribution of compiled genus mean acute values (GMAVs), calculated from species mean acute values (SMAVs) of acceptable data. SMAVs are calculated using the geometric mean for all acceptable toxicity tests within a given species (e.g., all tests for *Daphnia magna*). If only one test is available, the SMAV is that test value by default. As stated in the 1985 Guidelines, flow-through measured test data are normally given preference over other test exposure types (i.e., renewal, static, unmeasured) for a species, when available. When relationships are apparent between life-stage and sensitivity, only values for the most sensitive life-stage are considered. GMAVs are then calculated using the geometric means of all SMAVs within a given genus (e.g., all SMAVs for genus *Daphnia* - *Daphnia pulex*, *Daphnia magna*). If only one SMAV is available for a genus, then the GMAV is represented by that value. GMAVs are then rank-ordered by sensitivity from most sensitive to least sensitive.

Acute criteria are based on the Final Acute Value (FAV). The FAV is determined by regression analysis based on the four most sensitive genera (reflected as GMAVs) in the data set to interpolate or extrapolate (as appropriate) to the 5^{th} percentile of the sensitivity distribution represented by the tested genera. The intent of the eight MDRs is to serve as a representative sample of the aquatic community. These MDRs represent different ecological, trophic, taxonomic and functional differences observed in the natural aquatic ecosystem. Use of a sensitivity distribution where the criteria values are based on the four most sensitive taxa in a triangular distribution represents a censored statistical approach that improves estimation of the lower tail (where most sensitive taxa are) when the shape of the whole distribution is uncertain, while accounting for the total number of genera within the whole distribution.

The acute criterion, defined as the Criterion Maximum Concentration (CMC), is the FAV divided by two, which is intended to provide an acute criterion protective of nearly all individuals in such a genus. The use of the factor of two to reduce the FAV to the criterion magnitude is based on analysis of 219 acute toxicity tests on a range of chemicals, as described in the *Federal Register* on May 18, 1978 (43 FR 21506-18). For each of these tests, mortality data were used to determine the highest test concentration that did not cause mortality greater than that observed in the control for that particular test (which would be between 0 and 10% for

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an acceptable acute test). Thus, dividing the LC_{50}-based FAV by two decreases potential acute effects to a level comparable to control mortality levels. Therefore, the acute criterion is expected to protect 95% of species in a representative aquatic community from acute effects.

2.7.3 Chronic Criterion

The chronic criterion, defined as the Criterion Continuous Concentration (CCC), may be determined by one of two methods. If all eight MDRs are met with acceptable chronic test data, then the chronic criterion is derived using the same method used for the acute criterion, employing chronic values (e.g., EC_{20}) estimated from acceptable toxicity tests. In cases where fewer chronic data are available (i.e., must have at least three chronic tests from taxa that also have appropriate acute toxicity data), the chronic criterion can be derived by determining an appropriate acute-chronic ratio (ACR).

The criteria presented are the EPA's estimate of maximum concentrations of aluminum to protect most aquatic organisms from any unacceptable short- or long-term effects. Results of such intermediate calculations such as Species Mean Acute Values (**Appendix A** and **Appendix B**) and chronic values (**Appendix C** and **Appendix D**) are specified to four significant figures to prevent round-off error in subsequent calculations; the number of places beyond the decimal point does not reflect the precision of the value. The acute and chronic criteria are rounded to two significant figures.

3 EFFECTS ANALYSES

Data for aluminum were obtained from studies published in the open literature and identified in a literature search using the ECOTOXicology database (ECOTOX) as meeting data quality standards. ECOTOX is a source of high quality toxicity data for aquatic life, terrestrial plants, and wildlife. The database was created and is maintained by the EPA, Office of Research and Development, and the National Health and Environmental Effects Research Laboratory's Mid-Continent Ecology Division. The latest comprehensive literature search for this document via ECOTOX was conducted in 2017 and supplemented by additional data researchers made available to the EPA in 2018.

A further evaluation of the quality of the available data was performed by the EPA to determine test acceptability for criteria development. Appendix A of *Quality Criteria for Water*

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1986 (U.S. EPA 1986) provides an in-depth discussion of the minimum data requirements and data quality requirements for aquatic life criteria development.

3.1 Acute Toxicity to Aquatic Animals

All available reliable data relating to the acute effects of total aluminum on aquatic animals were considered in deriving the aluminum criteria. Data suitable (in terms of test acceptability and quality in a manner consistent with the 1985 Guidelines) for the derivation of a freshwater and an estuarine/marine FAV are presented in **Appendix A** (*Acceptable Acute Toxicity Data of Aluminum to Freshwater Aquatic Animals*) and **Appendix B** (*Acceptable Acute Toxicity Data of Aluminum to Estuarine/Marine Aquatic Animals*), respectively. Most fish and invertebrate data are LC_{50} measures from acute toxicity tests that were 96 hours in duration, except the tests for cladocerans, midges, mysids and certain embryos and larvae of specific estuarine/marine groups, which were 48 hours in duration and typically EC_{50} endpoints (per the 1985 Guidelines).

3.1.1 Freshwater

Twenty-two freshwater species encompassing 20 genera are represented in the dataset of acceptable data for acute toxicity to aluminum. The water quality conditions for these 118 toxicity tests ranged from 5.0-8.3 for pH, 2-220 mg/L as $CaCO_3$ for total hardness, and 0.48-4.0 mg/L for DOC. Since these three parameters affect the bioavailability, and hence toxicity of aluminum, all of the acceptable acute toxicity data presented in **Appendix A** were normalized to standardized water quality conditions using the MLR equations described in the Analysis Plan (**Section 2.7.1**). However, the dilution water DOC concentration was not reported for a number of acute studies presented in **Appendix A**. In this situation, where only the DOC was lacking, default values were used for several different dilution waters using a methodology documented in the 2007 freshwater copper AWQC document (see Appendix C, U.S. EPA 2007b). Specifically, the default DOC value for: 1) laboratory prepared reconstituted water is 0.5 mg/L, 2) Lake Superior water is 1.1 mg/L, 3) city tap and well water is 1.6 mg/L, and 4) Liberty Lake, Washington water is 2.8 mg/L. These values were determined from empirical data obtained for each source water.

Once normalized, the toxicity data were compiled (i.e., based on the geometric mean for each species and genus) and ranked by GMAV into a sensitivity distribution. Normalizing the toxicity data to the same pH, total hardness and DOC levels allows comparisons to be made

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because the MLR derived equations address the differences seen in the magnitude of effects when comparing across conditions. However, because the 118 toxicity tests were each conducted at different water quality conditions, the MLR derived equations may have either a minor or major effect on the magnitude of the observed reported effects depending on the set of conditions to which the tests are normalized. Thus, the relative sensitivity rankings can change depending on what pH, hardness and DOC concentrations are selected for normalization (see **Appendix K** for examples).

All values reported in this section are normalized to pH 7, total hardness of 100 mg/L as $CaCO_3$, and DOC of 1.0 mg/L (see **Section 2.7.1** for more information). Several species tested were not exposed to aluminum concentrations high enough or low enough to allow calculation of an LC_{50} (i.e., the LC_{50} is a "greater than" or "less than" value). The decision rule for using these non-definitive LC_{50}s to calculate SMAVs is consistent with methods used previously in criteria development. The freshwater ammonia AWQC document explains how chronic values (e.g., EC_{20}s) can be evaluated for potential use in deriving SMCVs (U.S. EPA 2013). The methodology is based on the finding that "greater than" values for concentrations of low magnitude, and "less than" values for concentrations of high magnitude do not generally add significant information to the toxicity analysis. The decision rule was applied as follows: "greater than" (>) low chronic values and "less than" (<) high chronic values were not used in the calculation of the SMCV; but "less than" (<) low chronic values and a "greater than" (>) high chronic values were included in the SMCV (U.S. EPA 2013). This approach was also followed for acute SMAV calculations.

While non-definitive SMAVs were ranked in **Table 3** according to the highest concentration used in the test, the value does not necessarily imply a accurate ranking of sensitivities. Again, in this section and below, the relative rankings are presented for comparative purposes and only apply when the set of chemistry conditions are pH 7, total hardness of 100 mg/L and DOC of 1.0 mg/L. SMAVs ranged from 1,836 µg/L for the cladoceran, *Daphnia pulex*, to 119,427 µg/L for the snail, *Melanoides tuberculata*. There is no apparent trend between freshwater taxon and acute sensitivity to aluminum (**Table 3**). The smallmouth bass, *Micropterus dolomieu*, represents the second most sensitive genus; cladocerans represent the first and fourth most sensitive genera; fish genera rank second, third, sixth and seventh in the sensitivity distribution; and an ostracod (*Stenocypris*) ranks fifth.

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Other fish species were less sensitive with SMAVs of 18,913 µg/L for the brook trout, *Salvelinus fontinalis*, greater than 22,095 µg/L for the fathead minnow, *Pimephales promelas*, greater than 31,087 µg/L for the green sunfish, *Lepomis cyanellus*, and greater than 21,779 µg/L for the Rio Grande silvery minnow, *Hybognathus amarus.* The midge (*Chironomus plumosus*, SMAV = 25,216 µg/L), the aquatic air-breathing snail (*Physa sp.*, SMAV = 41,858 µg/L), and the freshwater juvenile mussel (*Lampsilis siliquoidea*, SMAV = >29,492 µg/L) were comparatively insensitive to aluminum.

Summary of Studies Used in Acute Freshwater Determination

The taxa used in calculating the acute criterion (the lowest four ranked GMAVs) depends on the set of water quality conditions for which the criterion is being derived. Based on the analysis in **Appendix K** (*Recommended Criteria for Various Water Chemistry Conditions*), a combination of several genera will rank in the lowest four. Those acute studies used to calculate the GMAVs are summarized below. The normalized values mentioned below are for pH of 7, total hardness of 100 mg/L as $CaCO_3$ and DOC of 1.0 mg/L.

Invertebrates

Cladoceran, *Daphnia*

The pH/total hardness/DOC-normalized GMAV of 2,325 µg/L aluminum for *Daphnia* is based on the SMAVs for two cladoceran species, *Daphnia magna* and *D. pulex*. The *D. magna* normalized SMAV (2,944 µg/L) is based on the geometric mean of five 48-hr EC_{50}s (ranged from 713.2 to 15,625 µg/L aluminum) as reported by Biesinger and Christensen (1972), European Aluminum Association (2009), Kimball (1978) and Shephard (1983). All tests were static that exposed <24-hr old neonates, and only the Kimball (1978) test measured aluminum concentrations and did not use nominal concentrations. The *D. pulex* normalized SMAV (1,836 µg/L) is based on only one static-renewal unmeasured toxicity test conducted by Griffitt et al. (2008).

Cladoceran, *Ceriodaphnia*

Two species of *Ceriodaphnia, C. dubia* and *C. reticulata,* are used to derive the pH/total hardness/DOC-normalized GMAV of 7,771 µg/L aluminum. The *C. dubia* SMAV of 5,863 µg/L aluminum is calculated from 52 normalized EC_{50} values that ranged from 322.4 to greater than 88,933 µg/L aluminum (ENSR 1992d; European Aluminum Association 2009, 2010; Fort and Stover 1995; Gensemer et al. 2018; Griffitt et al. 2008; McCauley et al. 1986; Soucek et al.

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2001). The tests were a mix of static or renewal exposures with either measured or unmeasured aluminum concentrations. The *C. reticulata* normalized SMAV of 10,299 µg/L aluminum is based on the two flow-through measured test results reported by Shephard (1983).

Ostracod, *Stenocypris major*

Shuhaimi-Othman et al. (2011a, 2013) reported a 96-hr LC_{50} of 3,102 µg/L aluminum for the ostracod, *S. major*, which equates to a pH/total hardness/DOC-normalized LC_{50}/SMAV/GMAV of 8,000 µg/L total aluminum. The adult organisms were exposed to static-renewal conditions and the test solutions were measured.

Worm, *Nais elinguis*

Shuhaimi-Othman et al. (2012a, 2013) reported a 96-hr LC_{50} of 3,874 µg/L aluminum for the worm, *Nais elinguis* which equates to a pH/total hardness/DOC-normalized LC_{50}/SMAV/GMAV of 9,224 µg/L total aluminum. Adult worms were exposed to aluminum sulfate under static-renewal conditions and the test solutions were measured.

Vertebrates

Rainbow trout, *Oncorhynchus mykiss*

Eight acute toxicity tests for the rainbow trout (*O. mykiss*) were used to calculate the pH/total hardness/DOC-normalized SMAV of 3,312 µg/L aluminum reported by Gundersen et al. (1994). The eight flow-through measured normalized LC_{50}s ranged from 1,680 to 7,216 µg/L aluminum.

Atlantic salmon, *Salmo salar*

Two acceptable acute values reported by Hamilton and Haines (1995) were used to calculate the SMAV/GMAV for the Atlantic salmon, *S. salar*. The sac fry were exposed in static, unmeasured chambers at a total hardness of 6.8 mg/L (as $CaCO_3$) and two different pH levels. The 96-hr LC_{50} values were 584 and 599 µg/L total aluminum conducted at pH levels of 5.5 and 6.5, respectively. The corresponding pH/total hardness/DOC-normalized values are 20,749 and 3,599 and the resulting normalized SMAV/GMAV for the species is 8,642 µg/L total aluminum.

Smallmouth bass, *Micropterus dolomieu*

Three acceptable acute values from one study (reported in both Kane 1984; Kane and Rabeni 1987) are available for the smallmouth bass, *M. dolomieu*. The 48-hr post hatch larva were exposed in static, measured concentration chambers at a total hardness of ~12 mg/L (as $CaCO_3$) and three different pH levels. The LC_{50} values were 130, greater than 978.4 and greater

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than 216.8 µg/L total aluminum conducted at pH levels of 5.05, 6.25 and 7.5, respectively. The corresponding pH/total hardness/DOC-normalized values are 2,442, greater than 3,655 and greater than 153.4 µg/L. The SMAV/GMAV of 2,988 µg/L for the species/genus is based on the geometric mean of the normalized LC_{50} of 2,442 and greater than 3,655 µg/L total aluminum since the other value (greater than 153.4) is unbounded (i.e., greater than value), and is considered a "greater than" (>) low acute value.

GMAVs for 20 freshwater genera are provided in **Table 3**, and the four most sensitive genera were within a factor of 3.3 of each other. The freshwater FAV (the 5^{th} percentile of the genus sensitivity distribution, intended to protect 95 percent of the genera) for aluminum normalized to a pH 7, total hardness of 100 mg/L and DOC of 1.0 mg/L is 1,961 µg/L, calculated using the procedures described in the 1985 Guidelines. The FAV is an estimate of the concentration of aluminum corresponding to a cumulative probability of 0.05 in the acute toxicity values for the genera with which acceptable acute tests have been conducted (**Table 4**). The FAV is lower than all of the GMAVs for the tested species. The FAV is then divided by two for reasons described above (see **Section 2.7.2**). Based on the above, the FAV/2, which is the freshwater continuous maximum concentration (CMC), for aluminum normalized to a pH 7, total hardness of 100 mg/L and DOC of 1.0 mg/L is 980 µg/L total aluminum (rounded to two significant figures) and is expected to be protective of 95% of freshwater genera potentially exposed to aluminum under short-term conditions (**Figure 8**). However, the freshwater acute toxicity data are normalized using MLR equations that predict the bioavailability and hence toxicity of aluminum under different water chemistry conditions. Thus, the value of the criterion for a given site will depend on the specific pH, total hardness, and DOC concentrations at the site (see **Appendix K** *Recommended Criteria for Various Water Chemistry Conditions* for additional criteria values and four most sensitive genera for each set of conditions).

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Table 3. Ranked Freshwater Genus Mean Acute Values at pH 7, Total Hardness of 100 mg/L, and DOC of 1.0 mg/L.

(Note: Values will be different under differing water chemistry conditions as identified in this document).

Rank[a]	GMAV (µg/L total Al)	Genus	Species	SMAV[b] (µg/L total Al)
20	119,427	Melanoides	Snail, *Melanoides tuberculata*	119,427
19	>70,647	Paratanytarsus	Midge, *Paratanytarsus dissimilis*	>70,647
18	41,858	Physa	Snail, *Physa sp.*	41,858
17	>31,087	Lepomis	Green sunfish, *Lepomis cyanellus*	>31,087
16	>29,492	Lampsilis	Fatmucket, *Lampsilis siliquoidea*	>29,492
15	>27,766	Hyalella	Amphipod, *Hyalella azteca*	>27,766
14	25,216	Chironomus	Midge, *Chironomus plumosus*	25,216
13	>22,095	Pimephales	Fathead minnow, *Pimephales promelas*	>22,095
12	>21,779	Hybognathus	Rio Grande silvery minnow, *Hybognathus amarus*	>21,779
11	18,913	Salvelinus	Brook trout, *Salvelinus fontinalis*	18,913
10	>18,563	Hyla	Green tree frog, *Hyla cinerea*	>18,563
9	12,901	Crangonyx	Amphipod, *Crangonyx pseudogracilis*	12,901
8	9,224	Nais	Worm, *Nais elinguis*	9,224
7	9,061	Poecilia	Guppy, *Poecilia reticulata*	9,061
6	8,642	Salmo	Atlantic salmon, *Salmo salar*	8,642
5	8,000	Stenocypris	Ostracod, *Stenocypris major*	8,000
4	7,771	Ceriodaphnia	Cladoceran, *Ceriodaphnia dubia*	5,863
			Cladoceran, *Ceriodaphnia reticulata*	10,299
3	3,312	Oncorhynchus	Rainbow trout, *Oncorhynchus mykiss*	3,312
2	2,988	Micropterus	Smallmouth bass, *Micropterus dolomieu*	2,988
1	2,325	Daphnia	Cladoceran, *Daphnia magna*	2,944
			Cladoceran, *Daphnia pulex*	1,836

[a] Ranked from the most resistant to the most sensitive based on Genus Mean Acute Value.

[b] From Appendix A: Acceptable Acute Toxicity Data of Aluminum to Freshwater Aquatic Animals (all values normalized to pH 7, total hardness of 100 mg/L as $CaCO_3$, and DOC of 1.0 mg/L).

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Table 4. Freshwater Final Acute Value and Criterion Maximum Concentration (normalized to pH 7, total hardness of 100 mg/L and DOC of 1.0 mg/L).

(See Appendix K for acute criterion under different water chemistry conditions).

Calculated Freshwater FAV based on 4 lowest values: Total Number of GMAVs in Data Set = 20

Rank	Genus	GMAV (µg/L)	lnGMAV	(lnGMAV)^2	P=R/(n+1)	SQRT(P)
4	Ceriodaphnia	7,771	8.96	80.25	0.190	0.436
3	Oncorhynchus	3,312	8.11	65.70	0.143	0.378
2	Micropterus	2,988	8.00	64.04	0.095	0.309
1	Daphnia	2,325	7.75	60.08	0.048	0.218
		Σ (Sum):	**32.82**	**270.1**	**0.476**	**1.34**

S^2 = 31.13 **S = slope**

L = 6.334 **L = X-axis intercept**

A = 7.581 **A = lnFAV**

P = cumulative probability

FAV = 1,961 µg/L total aluminum

CMC (acute criterion) = 980 µg/L total aluminum (rounded to two significant figures)

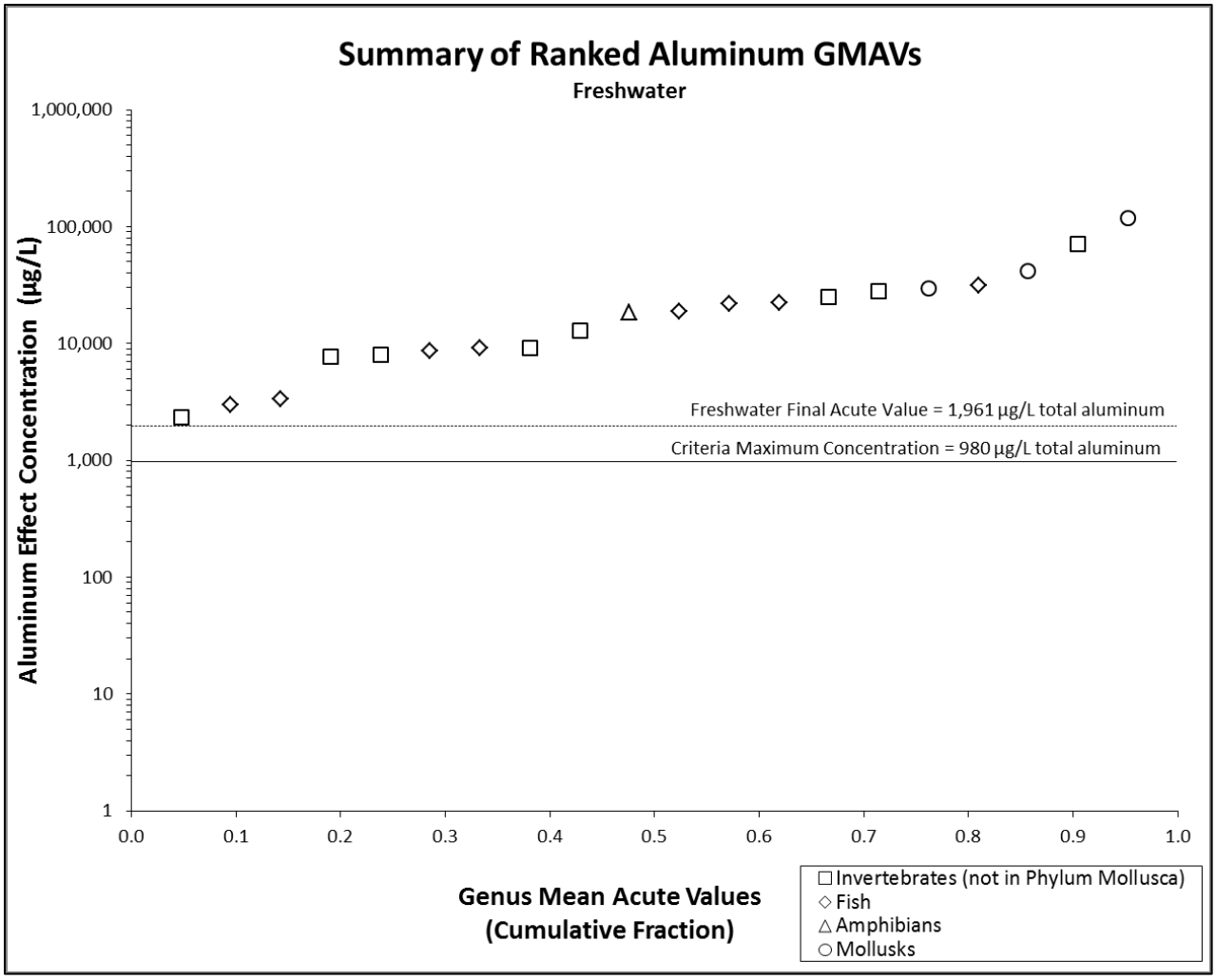


Figure 8. Ranked Summary of Total Aluminum Genus Mean Acute Values (GMAVs) - Freshwater at pH 7, Total Hardness of 100 mg/L, and DOC of 1.0 mg/L.

3.1.2 Estuarine/Marine

The 1985 Guidelines require that data from a minimum of eight families are needed to calculate an estuarine/marine FAV. Notably, no acceptable test data on fish species were available (**Figure 9**). Since data are available for only five families, an estuarine/marine FAV (and consequently the EPA cannot derive an estuarine/marine acute criterion).

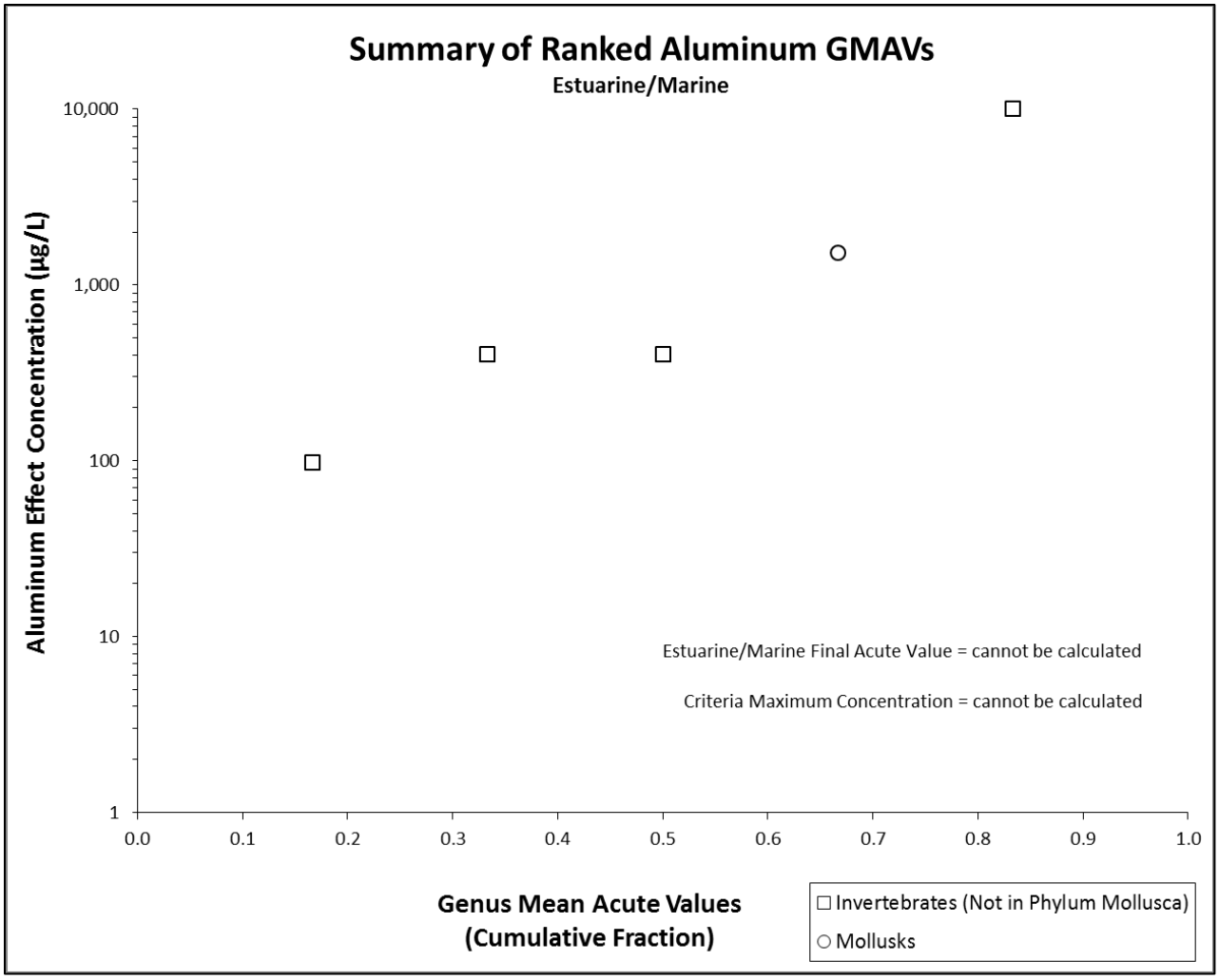


Figure 9. Ranked Summary of Total Aluminum Genus Mean Acute Values (GMAVs) - Estuarine/Marine.

3.2 Chronic Toxicity to Aquatic Animals

3.2.1 Freshwater

Freshwater chronic toxicity data that meet the test acceptability and quality assurance/control criteria (in a manner consistent with the 1985 Guidelines) are presented in **Appendix C** (*Acceptable Chronic Toxicity Data of Aluminum to Freshwater Aquatic Animals*). All tests were conducted with measured concentrations of total aluminum and measurement endpoints are EC_{20}s for all but one test where an EC_{20} could not be calculated. Details on chronic tests are described below. As with the freshwater acute SMAVs/GMAVs, the relative SMCV/GMCV rankings will change depending on the specific pH, total hardness and DOC values selected for data normalization. And as also described for the acute studies, the same

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DOC default values were used for select chronic tests where the DOC concentration was lacking for specific dilution waters as provided by U.S. EPA (2007b). In addition, the DOC value reported by Cleveland et al. (1989) was applied to the studies by McKee et al. (1989), Palawski et al. (1989) and Buckler et al. (1995). All four studies used the same dilution water preparation, a mixture of well water and reverse osmosis-treated well water to obtain a low hardness (~13 mg/L as $CaCO_3$), and all four studies reported using the same dilution water preparation from Cleveland et al. (1986).

Aluminum chronic toxicity data are available for twelve species of freshwater organisms: two mollusks (a freshwater mussel and a snail), five other invertebrate species (a rotifer, two cladocerans, a midge, an oligochaete and an amphipod) and four fish species (fathead minnow, zebrafish, Atlantic salmon and brook trout). The water quality conditions for these 59 toxicity tests ranged from 5.1-8.7 for pH, 11.8-428 mg/L as $CaCO_3$ for total hardness, and 0.33-12.3 mg/L for DOC. All chronic values were normalized using the same MLR derived equations as the acute data (see **Section 2.7.1**). If aluminum reduced survival and growth, the product of these variables (biomass) was analyzed (when possible), rather than analyzing them separately (U.S. EPA 2013).

In this section and below, the relative rankings only apply when the set of chemistry conditions are pH 7, total hardness of 100 mg/L and DOC of 1.0 mg/L. Ranked GMCVs are provided in **Table 5**. The fish genus *Salmo*, represented by Atlantic salmon, was the most sensitive genus, and the least sensitive genus was represented by an oligochaete. There is no apparent trend between freshwater taxon and chronic sensitivity to aluminum.

Invertebrates

The chronic toxicity of aluminum to the freshwater unionid mussel, *Lampsilis siliquoidea*, was evaluated by Wang et al. (2016, 2018). Six-week old juvenile mussels were exposed under flow-through measured conditions for 28 days to five aluminum nitrate concentrations and dilution water control composed of a well water/deionized water mix adjusted to a nominal pH of 6.0 and total hardness of 100 mg/L as $CaCO_3$. The calculated biomass EC_{20} of 169 µg/L was reported in the study, with a corresponding normalized EC_{20} of 1,026 µg/L (normalized to pH 7, total hardness = 100 mg/L as $CaCO_3$ and DOC = 1.0 mg/L).

Several chronic aluminum studies were conducted in separate laboratories with the cladoceran, *Ceriodaphnia dubia* (CECM 2014; ENSR 1992b; European Al Association 2010;

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Gensemer et al. 2018; McCauley et al. 1986; OSU 2018a). Aluminum chloride was evaluated by McCauley et al. (1986) at the University of Wisconsin-Superior using life cycle studies (*C. dubia* neonates, ≤16-hr old) in Lake Superior water (both raw and treated dechlorinated city water) to determine ACRs at near neutral pH. Five test concentrations plus a dilution water control were renewed three times over seven days, and the number of young per surviving adult was found to be significantly inhibited at 2,600 and 2,400 µg total aluminum/L in each respective dilution water. The EC_{20} and MATC were estimated to be 1,780 and <1,100 µg/L, respectively, or 2,031 and <925.5 µg/L after normalization. Poor dose response in the treated dechlorinated city water exposure prevented calculation of an EC_{20}.

Three-brood, 6-day static-renewal toxicity tests were conducted with aluminum chloride at four hardness levels using <24-hr old *C. dubia* neonates (ENSR 1992b). Reconstituted dilution water was prepared at nominal 25, 50, 100 and 200 mg/L total hardness as $CaCO_3$ and pH of 7.65, 7.7, 8.2 and 8.45, respectively. The mean number of young produced per female was the most sensitive endpoint with normalized (to pH 7, total hardness = 100 mg/L as $CaCO_3$ and DOC = 1.0 mg/L) EC_{20}s of 2,602, 1,077, 708.8 and 746.8 µg/L, respectively (**Appendix C**).

The Center for the Ecotoxicology and Chemistry of Metals (CECM 2014) and the European Al Association (2010) also evaluated the effect of aluminum on the survival and reproduction of *C. dubia* at different pH and total hardness levels. Less than 24-hr old neonates were exposed to aluminum nitrate for seven days using reconstituted laboratory water established at different nominal total hardness (25, 60 or 120 mg/L as $CaCO_3$), DOC (0.5, 2 or 4 mg/L) and pH (6.3, 7.0 or 8.0) levels. Test solutions were renewed daily and the pH was maintained with synthetic buffers (as summarized in Gensemer et al. 2018). Reproduction was the most sensitive endpoint, with EC_{20}s ranging from 36.6 to 1,011.6 µg/L aluminum, and corresponding normalized (to pH 7, total hardness = 100 mg/L as $CaCO_3$ and DOC = 1.0 mg/L) EC_{20}s ranging from 291.7 to 2,072 µg/L (**Appendix C**). A similar experiment was run with another cladoceran, *Daphnia magna*, except water chemistry parameters were not varied (European Al Association 2010; Gensemer et al. 2018). Less than 24-hr old neonates were exposed to aluminum nitrate for 21 days at a total hardness of 140 mg/L as $CaCO_3$, pH 6.3 and DOC of 2 mg/L. Again, reproduction (young per female) was the most sensitive endpoint with a reported EC_{20} of 791.0 µg/L total aluminum. The normalized SMCV/GMCV for the species is 985.3 µg/L.

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Oregon State University researchers conducted nine additional aluminum toxicity studies with *Ceriodaphnia dubia* in 2018. The results of these tests allowed the EPA to expand on the bounds of the MLR model. Less than 24-hr old neonates were exposed to one of five aluminum nitrate concentrations for seven days using reconstituted laboratory water established at different nominal total hardness (60-400 mg/L as $CaCO_3$), DOC (1.0-14.0 mg/L) and pH (6.3-8.8) levels (OSU 2018a). Reproduction was the most sensitive endpoint with effect concentrations ranging from 828.6 to 6,612 µg/L total aluminum (1,170 to 2,308 µg/L when normalized using the MLR equation).

Two acceptable *Hyalella azteca* chronic studies are available for aluminum based on recently recommended culture and control conditions (Mount and Hockett 2015; U.S. EPA 2012). Researchers at Oregon State University exposed 7-9 day old juvenile amphipods to five aluminum nitrate concentrations diluted with a well water/reverse osmosis water mix for 42 days under flow-through conditions and a nominal pH of 6 (Cardwell et al. 2018; OSU 2012h). A small amount of artificially-formulated sediment was provided as substrate during the test. Biomass was the most sensitive endpoint, with a 28-day EC_{20} of 199.3 µg/L and a normalized EC_{20} of 665.9 µg/L aluminum (the 28-day results were used since the 79 percent control survival after 42 days was slightly below the 80 percent minimum requirement).

Wang et al. (2016, 2018) also conducted a *H. azteca* chronic test where 7-day old juvenile amphipods were exposed under flow-through measured conditions for 28 days to five aluminum nitrate concentrations and dilution water control composed of a well water/deionized water mix adjusted to a nominal pH of 6.0 and total hardness of 100 mg/L as $CaCO_3$. Silica sand was provided as a substrate. The calculated biomass EC_{20} was 425 µg/L, with a corresponding normalized EC_{20} of 2,890 µg/L (normalized to pH 7, total hardness = 100 mg/L as $CaCO_3$ and DOC = 1.0 mg/L).

Oregon State University (2012f) conducted a 28-day life cycle test with the midge, *Chironomus riparius*, in a mixture of well water and reverse osmosis water (pH range of 6.3-6.9). The authors reported an EC_{20} for the number of eggs per case to be 3,387 µg/L, or 8,181 µg total aluminum/L when normalized to pH 7, total hardness of 100 mg/L as $CaCO_3$ and DOC of 1.0 mg/L. Palawski et al. (1989) also exposed *C. riparius*, but for 30 days at two pH levels (5.6 and 5.0). Larval midge (<24-hr) were exposed to five aluminum sulfate concentrations with a control under flow-through conditions. Adult midge emergence was significantly inhibited at

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61.4 and 235.2 µg/L aluminum, at pH 5.6 and 5.0, with calculated EC_{20}s of 29.55 and 84.42 µg/L and normalized EC_{20}s of 1,075 and 15,069 µg/L, respectively. The resultant normalized SMCV of 5,099 µg/L is calculated from all three test results.

Oregon State University also conducted chronic studies for three invertebrate species: an oligochaete, *Aeolosoma sp.*; a rotifer, *Brachionus calyciflorus*; and the great pond snail, *Lymnaea stagnalis* (Cardwell et al. 2018; OSU 2012b,c,e). All tests were conducted with aluminum nitrate, and at a nominal pH of 6.0. The normalized EC_{20}s from the aforementioned studies are 20,514 (oligochaete 17-day population count), 1,845 (48-hr rotifer population count) and 5,945 (pond snail 30-day biomass) µg/L, respectively (**Appendix C**). The researchers also conducted a series of validation studies in 2018 with the rotifer and great pond snail at nominal pH 6.3, with various hardness and DOC levels (OSU 2018e,f). The normalized EC_{20}s ranged from 2,132 to 6,653 µg/L for *Brachionus calyciflorus* and 1,812 to 3,902 µg/L for *Lymnaea stagnalis*.

Vertebrates

Kimball (1978) conducted an early life stage test using fathead minnow (*Pimephales. promelas*) fertilized eggs (16 to 40-hr old) in flowing hard well water. Six treatments of aluminum sulfate plus control replicated four times were used to expose fish for 28 days post-hatch, and aluminum concentrations were measured three times per week during the study. Biomass was more sensitive to the aluminum exposures than percent hatchability, growth and survival, with a resulting EC_{20} of 6,194 µg/L, or 2,690 µg/L when normalized.

The chronic toxicity of aluminum to fathead minnows and zebrafish (*Danio rerio*) was also evaluated by OSU (2012g, 2013) and summarized in Cardwell et al. (2018). Fish were exposed under flow-through conditions in the same dilution water and pH as described above for the amphipod and midge tests (OSU 2012f,h). Less than 24-hr old fertilized fathead minnow eggs and less than 36-hr post fertilization zebrafish were exposed to aluminum nitrate for 33 days. Fathead minnow fry survival was the most sensitive endpoint with a calculated EC_{20} of 428.6 µg/L, and normalized EC_{20} of 2,154 µg/L. Zebrafish biomass was the most sensitive endpoint with a calculated EC_{20} of 234.4 µg/L (1,342 µg/L when normalized).

An early life cycle test was also conducted with brook trout (*Salvelinus fontinalis*). Brook trout eyed eggs were exposed to four aluminum sulfate concentrations at pH 5.7 and 6.5 for 60 days (Cleveland et al. 1989). Both exposures were conducted using flow-through conditions and soft water (total hardness = 12.5 mg/L as $CaCO_3$). The survival and hatching of eyed eggs and

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the survival, growth, behavioral and biochemical responses of the resultant larvae and juveniles were measured during the exposure. The incomplete hatch endpoint reported in the study was not used after further analysis and communication with the authors because the incomplete hatch endpoint may or may not be a transient effect. The incompletely hatched larvae (based on chorion attachment) were removed daily from the study and not fully evaluated further for survivability. In addition, exposure to acidic waters increased the percentage of incomplete hatched larvae (Cleveland et al. 1986; Ingersoll et al. 1990c), and therefore it is difficult to distinguish between the effects of pH versus aluminum. Therefore, the lack of information and uncertainty with the endpoint led to the decision to not use the data from the study to develop the criteria document. The biomass EC_{20} for the test conducted at pH 5.7 was 143.5 µg/L, and at pH 6.5 the biomass EC_{20} was 164.4 µg/L. The normalized EC_{20}s at pH 5.7 and 6.5 were 1,076 µg/L and 378.7 µg/L, respectively.

Atlantic salmon eyed eggs were exposed to flow-through conditions for 60 days at pH 5.7 and a total hardness of 12.7 mg/L as $CaCO_3$ in reconstituted water (McKee et al. 1989). Salmon weight and survival NOEC and LOEC were 71 and 124 µg aluminum/L, respectively. The calculated biomass EC_{20} for the study was 61.56 µg/L (**Appendix C**). Buckler et al. (1995) also reported a chronic *Salmo salar* study initiated with eyed eggs in reconstituted water (total hardness of 12.7 mg/L as $CaCO_3$) that continued for 60 days post-hatch under flow-through exposure conditions. Time to hatch was not significantly affected at pH 5.7 and 264 µg/L, the highest test concentration evaluated. Survival at 60 days post hatch was reduced at 124 µg/L, with an estimated EC_{20} of 154.2 µg/L (normalized EC_{20} = 1,088 µg/L).

When calculating the Atlantic salmon EC_{20}s for the two studies (Buckler et al. 1995 and McKee et al. 1989), it was observed that the studies listed the same test concentrations and similar dose response for the same test measurements, but reported different endpoints between the two studies. It appears that the Buckler et al. (1995) study was a republication of the previous study performed by McKee et al. (1989), and therefore, only the most sensitive EC_{20} was used in the calculation of the SMCV. The most sensitive EC_{20} of 61.56 µg/L (or 434.4 µg/L when normalized to pH 7, total hardness of 100 mg/L as $CaCO_3$ and DOC of 1.0 mg/L), was based on a 60-day reduction in fish biomass.

Only seven of the eight MDRs are met for direct calculation of the FCV, with the third family in the phylum Chordata missing. Because derivation of a chronic freshwater criterion is

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important for environmental protection, the EPA examined qualitative data in **Appendix H** (*Other Data on Effects of Aluminum to Freshwater Aquatic Organisms*) to determine if any "Other Data" can be used to fulfill the missing MDR group, and selected an amphibian test to fulfill that MDR.

The MDR for the third family in the phylum Chordata was fulfilled using results of an abbreviated life cycle test initiated with wood frog (*Rana sylvatica*) larvae (Gosner stage 25) and continued through metamorphosis (Peles 2013). The NOEC for survival and growth normalized to a pH 7, total hardness of 100 mg/L and DOC of 1.0 mg/L was 10,684 µg/L, with a chronic value of greater than 10,684 µg/L. The study was not included in **Appendix C** because the test pH (4.68-4.70) was lower than 5. If not for the marginally lower pH (Peles 2013), this study would have been an acceptable chronic test for criterion derivation. The addition of this other chronic test does not directly affect the calculation of the FCV as the species does not rank in the lowest four GMCVs (the numeric-criteria-driving portion of the sensitivity distribution). The species was the most sensitive value from the qualitative data that could be used to fulfill the MDR and the test had a minor deviation in pH. After adding this additional study, the chronic dataset consists of 13 freshwater species representing 13 freshwater genera (**Table 5**).

The four most sensitive GMCVs are from the core quantitative chronic dataset and represent taxa which have been determined to be the most sensitive to aluminum. Based on these rankings, the resultant chronic criterion is 380 µg/L total aluminum at pH 7, total hardness of 100 mg/L (as $CaCO_3$) and DOC of 1.0 mg/L (**Table 6**). The chronic toxicity data are normalized using the MLR equations described in the Analysis Plan that account for the effects of pH, total hardness, and DOC on bioavailability and hence toxicity of aluminum. Thus, the value of the criterion for a given site will depend on the specific pH, total hardness, and DOC concentrations at the site (see **Appendix K** *Recommended Criteria for Various Water Chemistry Conditions* for additional criteria values and four most sensitive genera for each set of conditions). The EPA is confident that the criteria values generated using the MLR models are protective of approximately 95% of freshwater genera in an ecosystem that are potentially exposed to aluminum under long-term conditions (**Figure 10**).

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Table 5. Ranked Genus Mean Chronic Values at pH 7, Total Hardness of 100 mg/L, and DOC of 1.0 mg/L.

(Note: Values will be different under differing water chemistry conditions as identified in this document).

Rank[a]	GMCV (µg/L total Al)	Genus	Species	SMCV[b] (µg/L total Al)
13	20,514	Aeolosoma	Oligochaete, *Aeolosoma sp.*	20,514
12	>10,684	Rana	Wood frog,[c] *Rana sylvatica*	>10,684
11	5,099	Chironomus	Midge, *Chironomus riparius*	5,099
10	3,539	Brachionus	Rotifer, *Brachionus calyciflorus*	3,539
9	3,119	Lymnaea	Great pond snail, *Lymnaea stagnalis*	3,119
8	2,407	Pimephales	Fathead minnow, *Pimephales promelas*	2,407
7	1,387	Hyalella	Amphipod, *Hyalella azteca*	1,387
6	1,342	Danio	Zebrafish, *Danio rerio*	1,342
5	1,181	Ceriodaphnia	Cladoceran, *Ceriodaphnia dubia*	1,181
4	1,026	Lampsilis	Fatmucket, *Lampsilis siliquoidea*	1,026
3	985.3	Daphnia	Cladoceran, *Daphnia magna*	985.3
2	638.2	Salvelinus	Brook trout, *Salvelinus fontinalis*	638.2
1	434.4	Salmo	Atlantic salmon, *Salmo salar*	434.4

[a] Ranked from the most resistant to the most sensitive based on Genus Mean Chronic Value.

[b] From Appendix C: Acceptable Chronic Toxicity Data of Aluminum to Freshwater Aquatic Animals (all values normalized to pH 7, total hardness of 100 mg/L as $CaCO_3$, and DOC of 1.0 mg/L).

[c] Fulfills MDR for third family in phylum Chordata, used only qualitatively.

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Table 6. Freshwater Final Chronic Value and Criterion Continuous Concentration (normalized to pH 7, total hardness of 100 mg/L and DOC of 1.0 mg/L).

(See Appendix K for chronic criterion under different water chemistry conditions).

Calculated Freshwater FCV based on 4 lowest values: Total Number of GMCVs in Data Set = 13

Rank	Genus	GMCV (µg/L)	lnGMCV	$(lnGMCV)^2$	P=R/(n+1)	SQRT(P)
4	Lampsilis	1,026	6.93	48.07	0.286	0.535
3	Daphnia	985.3	6.89	47.51	0.214	0.463
2	Salvelinus	638.2	6.46	41.71	0.143	0.378
1	Salmo	434.4	6.07	36.89	0.071	0.267
		Σ (Sum):	**26.36**	**174.2**	**0.714**	**1.64**

S^2 =	12.423	**S = slope**
L =	5.142	**L = X-axis intercept**
A =	5.930	**A = lnFCV**
		P = cumulative probability

FCV = 376.3 µg/L total aluminum

CCC (chronic criterion) = 380 µg/L total aluminum (rounded to two significant figures)

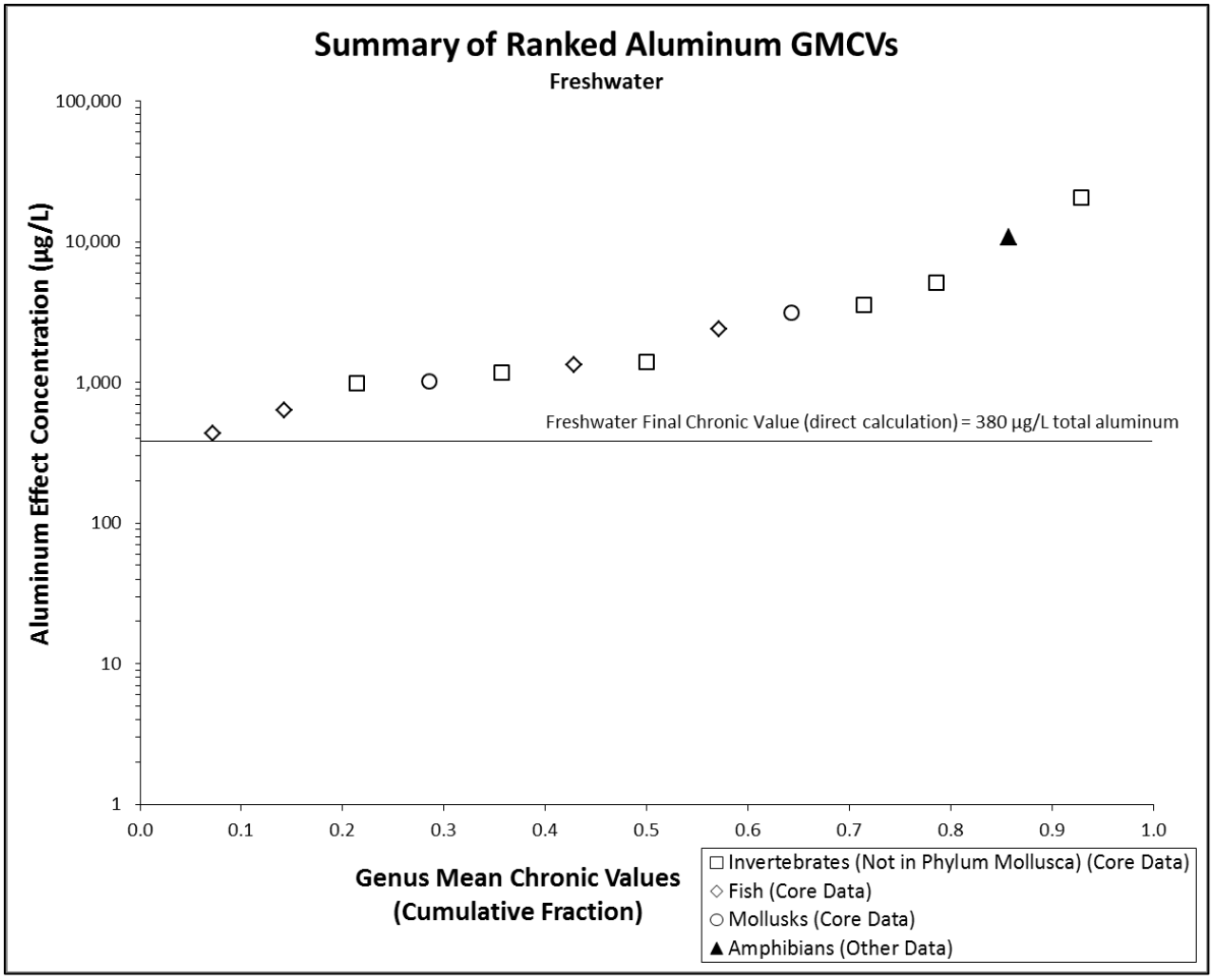


Figure 10. Ranked Summary of Total Aluminum Genus Mean Chronic Values (GMCVs) – Freshwater Supplemented with Other Data to Fulfill Missing MDRs at pH 7, Total Hardness of 100 mg/L, and DOC of 1.0 mg/L.

3.2.2 Estuarine/Marine

There are no estuarine/marine chronic toxicity data that meet the test acceptability and quality assurance/control criteria in a manner consistent with the 1985 Guidelines in **Appendix D** (*Acceptable Chronic Toxicity Data of Aluminum to Estuarine/Marine Aquatic Animals*).

3.3 Bioaccumulation

Aluminum bioaccumulates in aquatic organisms, although increased accumulation through trophic levels in aquatic food chains (i.e., biomagnification) is not usually observed (Suedel et al. 1994, U.S. EPA 2007a). Total uptake generally depends on the environmental aluminum concentration, exposure route and the duration of exposure (McGeer et al. 2003).

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Desouky et al. (2002) reported that the bioavailability of aluminum to a grazing invertebrate is influenced by both oligomeric silica and humic acid, and that aluminum bound to humic acid may still be bioavailable via grazing. Bioconcentration Factors (BCFs) and bioaccumulation factors (BAFs) typically vary with the bioavailable concentration of metals in water, with higher BCFs occurring at lower metal concentrations (McGeer et al. 2003). In marine sediments, metal bioavailability is altered by increased acid volatile sulfide (AVS) content (Casas and Crecelius 1994), and ligand concentration (Skrabal et al. 2000). Bioaccumulation and toxicity via the diet are considered unlikely relative to direct waterborne aluminum toxicity (Handy 1993; Poston 1991). This conclusion is also supported by the lack of any biomagnification within freshwater invertebrates that are likely to be prey of fish in acidic, aluminum-rich rivers (Herrmann and Frick 1995; Otto and Svensson 1983; Wren and Stephenson 1991). The opposite phenomena, trophic dilution up the food chain, has been suggested (King et al. 1992). A more detailed discussion of bioaccumulation factors is provided in the Effects Characterization section (**Section 5.1.6**).

No U.S. Food and Drug Administration (FDA) action level or other maximum acceptable concentration in tissue, as defined in the 1985 Guidelines, is available for aluminum. Therefore, a Final Residue Value cannot be calculated for fish tissue.

3.4 Toxicity to Aquatic Plants

No aluminum toxicity tests with important aquatic plant species in which the concentrations of test material were measured and the endpoint was biologically important are available in the literature. Therefore, the EPA could not determine a Final Plant Value. However, analysis of plant data provides evidence that criteria magnitudes that are protective of aquatic animals will also be protective of aquatic plants. Effects on aquatic plants are discussed qualitatively in the Effects Characterization section (**Section 5.2**).

4 SUMMARY OF NATIONAL CRITERIA

4.1 Freshwater

The 2018 final aluminum criteria are derived using multiple linear regression (MLR) models that incorporate pH, total hardness, and DOC as input parameters to normalize the acute and chronic toxicity data to a set of predetermined water quality conditions. The MLR equations account for the effects of pH, total hardness and DOC on the bioavailability, and hence toxicity

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of aluminum. The numeric magnitude of the criteria (acute or chronic criterion) for a given set of conditions, therefore, will depend on the specific pH, total hardness and DOC concentrations used for normalization. The relative GMAVs/GMCVs rankings and subsequent four most sensitive genera used to calculate the criteria will depend on the data normalization conditions selected. The acute and chronic criteria for a given set of input conditions (pH, total hardness and DOC) are numeric magnitude values that are protective for that set of input conditions. The recommended criteria for aluminum can be calculated in two different ways: 1) use the lookup tables provided (see **Appendix K** *Recommended Criteria for Various Water Chemistry Conditions*) to find the numeric aluminum acute and chronic criteria corresponding to the pH, total hardness and DOC conditions of interest, or 2) use the Aluminum Criteria Calculator V.2.0 (*Aluminum Criteria Calculator V.2.0.xlsm*) to enter the pH, total hardness and DOC conditions of interest.

For the purposes of illustration, the following criteria magnitude values are provided at pH 7, total hardness 100 mg/L and DOC of 1.0 mg/L. The resulting numeric values represent the concentrations at which freshwater aquatic organisms would have an appropriate level of protection if the one-hour average concentration of total aluminum does not exceed (in µg/L):

Criterion Maximum Concentration (CMC) =
980 µg/L total aluminum at a pH 7, total hardness of 100 mg/L as $CaCO_3$ and DOC of 1.0 mg/L;

and if the four-day average concentration of total aluminum does not exceed (in µg/L):

Criterion Continuous Concentration (CCC) =
380 µg/L total aluminum at pH 7, total hardness of 100 mg/L as $CaCO_3$ and DOC of 1.0 mg/L.

The criteria value for the specific water chemistry conditions of interest are recommended not to be exceeded more than once every three years on average.

The above illustrative criteria values would vary under other water chemistry conditions for the three water quality parameters (pH, total hardness and DOC) that affect the expression of aluminum toxicity (see **Appendix K** *Recommended Criteria for Various Water Chemistry Conditions*). **Table 7** provides a detailed break-down of the freshwater acute (CMC) and chronic

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(CCC) criteria across different pH and total hardness levels when the DOC = 1.0 mg/L. **Appendix K** provides additional criteria values across pH and total hardness levels when DOC = 0.1, 0.5, 2.5, 5, 10 and 12 mg/L, and provides the four most sensitive genera for both the acute and chronic criteria. The empirical toxicity test data that the EPA used to develop the MLR models were developed under a specific range of water chemistry conditions as described below.

The pH of toxicity test waters ranged from 6.0-8.7. Specifically, *Ceriodaphnia dubia* toxicity test data ranged 6.3-8.7 for pH (only one *C. dubia* toxicity test was conducted at pH 8.7; the majority of tests were conducted at pH less than 8.3); *Pimephales promelas* toxicity test data ranged 6.0-8.12 for pH. The EPA has determined that for pH it is reasonable to allow the user to extrapolate beyond these values for criteria derivations. The criteria calculator can be used to address all waters within a pH range of 5.0 to 10.5. Thus, criteria values for pH input values beyond the range of the underlying empirical pH data used for model development (pH 6.0 to 8.2) can be generated using the criteria calculator. This is also reflected in the criteria lookup tables in **Appendix K**. The EPA took this approach for pH so that the recommended criteria can be provided for, and thus are protective of, a broader range of U.S. natural waters. Extrapolated criteria values outside of the empirical pH data tend to be more protective of the aquatic environment (i.e., lower criteria values) in situations where pH plays a critical role in aluminum toxicity. However, criteria values generated outside of the range of the pH conditions of the toxicity tests underlying the MLR models are more uncertain than values within the pH conditions of the MLR toxicity tests, and thus should be considered carefully and used with caution. Although the EPA has provided model predictions of criteria values outside the empirical range for pH, these values may warrant further exploration and consideration for site-specific criteria. Additional information regarding the uncertainty associated with the MLR models is provided in **Section 5.3.6** and **Appendix L**.

The total hardness of toxicity test waters ranged from 9.8 to 428 mg/L. More specifically, total hardness (as $CaCO_3$) ranged from 9.8-428 mg/L for *Ceriodaphnia dubia* toxicity tests and from 10.2-422 mg/L for *Pimephales promelas* toxicity tests. Since a decrease in total hardness tends to increase aluminum toxicity, the EPA has determined it is reasonable to extrapolate on the lower bound of the hardness data to enable generation of more stringent criteria at low hardnesses beyond the limit of the empirical data. Thus, hardness input values in the criteria calculator can be entered that are less than 9.8 mg/L down to a limit of 0.01 mg/L. This is

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consistent with existing EPA approaches to low end hardness (U.S. EPA 2002). However, criteria values are bounded at the approximate upper limit of the empirical MLR models' underlying hardness data, at a maximum of 430 mg/L total hardness (as $CaCO_3$). The user can input hardness values into the criteria calculator that are greater than 430 mg/L for total hardness, but the criteria magnitude will reach its maximum value at 430 mg/L total hardness (as $CaCO_3$), and criteria magnitudes will not increase or decrease by increasing the hardness above 430 mg/L total hardness (as $CaCO_3$). This is also consistent with existing EPA guidance on high end hardness "caps" (U.S. EPA 2002). These total hardness bound approaches are also reflected in the criteria lookup tables in **Appendix K**. The EPA took this approach so that the recommended criteria can be provided for, and will be protective of, a broader range of natural waters found in the U.S. Criteria values generated beyond the lower bound of the hardness conditions of the toxicity tests underlying the MLR models are more uncertain than values within the hardness bounds of the MLR toxicity test data.

The DOC of toxicity test waters ranged from 0.08 to 12.3 mg/L. More specifically DOC ranged from 0.1-12.3 mg/L for *Ceriodaphnia dubia* toxicity tests and 0.08-11.6 mg/L for *Pimephales promelas* toxicity tests. Since most natural waters contain some DOC, the lower bound of the empirical toxicity test data (0.08 mg/L) is the lowest value that can be entered into the criteria calculator; thus no extrapolation below the lowest empirical DOC of 0.08 mg/L is provided. The criteria values generated with the criteria calculator are bounded at the upper limit of the empirical MLR models' underlying DOC data, at a maximum 12.0 mg/L DOC. The user can input DOC values greater than 12.0 mg/L into the calculator, but the criteria magnitude will reach its maximum value at 12.0 mg/L DOC, and criteria magnitudes will not increase or decrease by increasing the DOC above 12.0 mg/L. This is also reflected in the criteria lookup tables in **Appendix K**. This is consistent with the existing approach for hardness (U.S. EPA 2002) to provide for protection of aquatic organisms through the use of protective, conservative values when water chemistry conditions are beyond the upper limits of the empirical toxicity test data.

The EPA created the Aluminum Criteria Calculator V.2.0 (*Aluminum Criteria Calculator V.2.0.xlsm*) that allows users to enter the pH, total hardness and DOC based on water sampling and automatically calculates freshwater criteria for these site-specific parameters based on the bounds described above. Existing data on these water chemistry parameters may be helpful in

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determining criteria calculator input values. The criteria calculator gives a warning when any of the water quality parameters entered are "outside MLR model inputs," to alert end users. As noted above, total hardness and DOC concentrations entered into the calculator that are greater than the bounds recommended will automatically default to a maximum limit; pH values that are outside the bounds recommended (i.e., pH<6, pH>8.2) can be used, but should be considered carefully and used with caution. As displayed in **Table 7** and **Appendix K**, total hardness and DOC are bounded at a maximum of 430 mg/L as $CaCO_3$ and 12.0 mg/L, respectively. **Table 7** shows example freshwater acute (CMC) and chronic (CCC) criteria at DOC of 1.0 mg/L and various water total hardness levels and pH, with additional tables for other DOC values are provided in **Appendix K**.

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Table 7. Freshwater Acute and Chronic Criteria at Example Conditions of DOC of 1.0 mg/L and Various Water Total Hardness Levels and pH.

(Italicized and underlined values are outside the pH limits of the empirical data used to generate the MLR models and should be used with caution).

Total Hardness	Acute Criteria (µg/L total aluminum)												
	pH												
	5.0	**5.5**	**6.0**	**6.5**	**7.0**	**7.5**	**8.0**	**8.2**	**8.5**	**9.0**	**9.5**	**10.0**	**10.5**
10	*4.0*	*19*	70	190	430	810	1,200	1,200	*1,300*	*1,100*	*720*	*370*	*150*
25	*9.5*	*40*	130	310	620	1,100	1,400	1,500	*1,400*	*1,100*	*660*	*310*	*110*
50	*18*	*72*	210	430	790	1,300	1,700	1,700	*1,600*	*1,100*	*610*	*270*	*90*
75	*27*	*100*	260	520	900	1,400	1,800	1,800	*1,700*	*1,100*	*590*	*240*	*79*
100	*35*	*130*	320	590	980	1,500	1,900	1,900	*1,700*	*1,100*	*570*	*230*	*72*
150	*51*	*170*	400	700	1,100	1,600	2,100	2,100	*1,800*	*1,100*	*550*	*210*	*63*
200	*67*	*220*	470	790	1,200	1,700	2,200	2,200	*1,900*	*1,100*	*540*	*200*	*57*
250	*82*	*260*	540	870	1,300	1,800	2,200	2,200	*1,900*	*1,100*	*530*	*190*	*53*
300	*98*	*300*	600	950	1,400	1,900	2,300	2,300	*2,000*	*1,100*	*520*	*180*	*50*
350	*110*	*340*	650	1,000	1,500	1,900	2,300	2,300	*2,000*	*1,200*	*510*	*180*	*48*
400	*130*	*380*	700	1,100	1,600	2,000	2,400	2,400	*2,100*	*1,200*	*500*	*170*	*46*
430	*140*	*400*	730	1,100	1,600	2,000	2,400	2,400	*2,100*	*1,200*	*500*	*170*	*45*

Total Hardness	Chronic Criteria (µg/L total aluminum)												
	pH												
	5.0	**5.5**	**6.0**	**6.5**	**7.0**	**7.5**	**8.0**	**8.2**	**8.5**	**9.0**	**9.5**	**10.0**	**10.5**
10	*2.5*	*12*	47	110	240	500	730	770	*790*	*670*	*450*	*230*	*95*
25	*5.9*	*25*	81	160	300	580	970	930	*890*	*680*	*410*	*190*	*71*
50	*11*	*46*	110	200	340	620	1,100	1,100	*980*	*690*	*380*	*170*	*56*
75	*17*	*66*	140	220	360	640	1,100	1,200	*1,000*	*700*	*370*	*150*	*49*
100	*22*	*85*	160	240	380	650	1,100	1,300	*1,100*	*700*	*360*	*140*	*45*
150	*32*	*120*	190	260	400	660	1,100	1,300	*1,100*	*710*	*350*	*130*	*39*
200	*42*	*140*	210	290	420	670	1,100	1,300	*1,200*	*710*	*340*	*120*	*36*
250	*51*	*160*	230	300	430	670	1,100	1,300	*1,300*	*720*	*330*	*120*	*33*
300	*61*	*180*	250	320	440	680	1,100	1,300	*1,300*	*720*	*320*	*110*	*31*
350	*71*	*200*	260	330	450	680	1,100	1,300	*1,400*	*720*	*320*	*110*	*30*
400	*80*	*220*	280	340	470	680	1,100	1,300	*1,400*	*720*	*310*	*110*	*29*
430	*86*	*230*	290	350	470	680	1,100	1,300	*1,400*	*720*	*310*	*110*	*28*

4.2 Estuarine/Marine

Insufficient data are available to fulfill the MDRs for estuarine/marine criteria development, therefore no criteria are recommended at this time.

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5 EFFECTS CHARACTERIZATION

This section characterizes the potential effects of aluminum on aquatic life based on available test data and describes additional lines of evidence not used directly in the criteria calculations, but which support the 2018 criteria values. This section also provides a summary of the uncertainties and assumptions associated with the criteria derivation and explanations for the decisions the EPA made regarding data acceptability and usage in the effects assessment. Finally, this section describes substantive differences between the 1988 aluminum AWQC and the 2018 update.

5.1 Effects on Aquatic Animals

5.1.1 Freshwater Acute Toxicity

The EPA identifies several acute studies that did not meet data quality screening guidelines for inclusion in criterion calculations (**Appendix H** *Other Data on Effects of Aluminum to Freshwater Aquatic Organisms*), but showed similar ranges of toxicity and are presented here to provide additional supporting evidence of the observed toxicity of aluminum to aquatic organisms.

Among Mollusca studies where the pH was greater than or equal to 5, Harry and Aldrich (1963) observed adverse 24-hr effects to the snail *Taphius glabratus* exposed to aluminum at concentrations between 1,000-5,000 µg/L in distilled water (**Appendix J** *List of Aluminum Studies Not Used in Document Along with Reasons*). In contrast, the 24-hr LC_{50} of 130,500 µg/L (65,415 µg/L when normalized to conditions in **Appendix A**) for the zebra mussel *Dreissena polymorpha* (Mackie and Kilgour 1995) was insensitive, similar to the mollusk *Physa sp.* (**Appendix A**). In a series of 96-hr tests conducted at low pH and total hardness (15.3 mg/L as $CaCO_3$) levels, Mackie (1989) found that *Pisidium casertanum* and *Pisidium compressum* did not reach 50% mortality at 1,000 µg/L when pH was 3.5, and 400 µg/L when pH was 4.0 and 4.5; the highest concentrations tested. When these concentrations are normalized to the conditions in **Appendix A**, LC_{50}s for the species would be greater than 412,645 to greater than 72,075,634 µg/L.

Among cladocerans, Call et al. (1984) observed an unidentified *Ceriodaphnia* species to be similarly acutely sensitive to identified *Ceriodaphnia* species in acceptable tests, with pH/total hardness/DOC-normalized 48-hr LC_{50} values of 2,277 µg/L and 3,083 µg/L. Also

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similar to results observed among acceptable tests and supporting studies, *Daphnia sp.* was more acutely sensitive than *Ceriodaphnia sp.* For example, Havas and Likens (1985b) observed reduced survival in *Daphnia catawba* for a test with a non-standard test duration (72 hours) at a pH/total hardness/DOC-normalized concentration of 4,341 µg/L; Khangarot and Ray (1989) observed a normalized 48-hr LC_{50} of 23,665 µg/L for *Daphnia magna* exposed to an unacceptable form of aluminum (aluminum ammonium sulfate); and Havas (1985) observed a normalized 48-hr LOEC based on survival of 1,343 µg/L in *Daphnia magna* using lake water as dilution water.

Although no data from benthic crustaceans were used to calculate the freshwater acute criterion (not one of the four most sensitive genera), evidence suggests they are somewhat acutely sensitive to aluminum. The isopod *Asellus aquaticus* was found to be somewhat sensitive to aluminum, with a pH/total hardness/DOC-normalized 72-hr LC_{50} of 12,284 µg/L that was not included because of the test duration (Martin and Holdich 1986). The isopod values would fall 8th out of 20 in relative acute sensitivity to aluminum, despite the decreased length of the acute test over standard acute invertebrate test durations. Both Borgmann et al. (2005) and Mackie (1989) conducted acute toxicity tests with the amphipod *Hyalella azteca*. Seven-day LC_{50}s from the two Borgmann et al. (2005) studies comparing soft reconstituted water and dechlorinated tap water were 212.7 and greater than 2,978 µg/L, respectively (values normalized to **Appendix A** conditions), but these data were not included because of both test length and unacceptable control mortality. Three (pH/total hardness/DOC) adjusted unbounded *H. azteca* LC_{50} values reported by Mackie (1989) ranged from greater than 4,455 to greater than 178,365 µg/L, the highest concentrations tested. The lowest of these values would rank this taxon 4th in the acute genus sensitivity. These data were included in **Appendix H** because of uncertainty regarding whether bromide and chloride concentrations in dilution water met the recently established testing requirements for *H. azteca* (Mount and Hockett 2015; U.S. EPA 2012). The author was not able to provide details regarding bromide and chloride water concentrations, but noted that there was 100% survival in the experiment, suggesting that conditions were met (Gerry Mackie, personal communication, March 2013). In addition, no substrate was provided for the test organisms. Although some substrate is recommended for water only tests with *H. azteca*, the absence of substrate does not invalidate a test result (Mount and Hockett 2015; U.S. EPA 2012). Because the value is unbounded (i.e., a greater than value), the study most likely overestimates

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the toxicity of aluminum to this species, since the test failed to reach 50% mortality at the highest concentrations tested.

Studies by Vuori (1996) (caddisfly), Mackie (1989) (damselfly) and Rockwood et al. (1990) (dragonfly) suggest some insects may be acutely sensitive to aluminum, but these tests were either conducted at pH<5 (Mackie 1989), or used an atypical endpoint for acute exposures (Rockwood et al. 1990; Vuori 1996). However, when the concentrations are normalized to the conditions in **Appendix A**, LC_{50}s for the damselfly would be greater than 412,645 to greater than 72,075,634 µg/L. (Note: Rockwood et al. and Vuori did not report test hardness so values could not be normalized).

Consistent with data used to calculate the freshwater acute criterion, vertebrates were no more or less sensitive overall to aluminum than invertebrates. Also consistent with vertebrate data from **Appendix H**, acute toxicity data for fish, while variable, provide additional evidence that freshwater fish are acutely sensitive to aluminum. DeLonay et al. (1993) observed reduced 7-day survival of *Oncorhynchus aguabonita* alevin and swim-up larvae exposed to 18,359 µg/L aluminum (pH/total hardness/DOC-normalized). Cutthroat trout (*O. clarkii*) alevin and swim-up larvae also exposed at pH 5 for seven days exhibited reduced survival at 482.0 µg/L (60% reduction) and 340.8 µg/L (~50% reduction) (pH/total hardness/DOC-normalized), respectively (Woodward et al. 1989). Both studies were excluded from acute criteria calculations because of the atypical acute test duration.

In two studies examining the effects of aluminum on rainbow trout survival, pH/total hardness/DOC-normalized *O. mykiss* LC_{50}s after 6 and 7-12 days, respectively, were 2,837 and 460.0 µg/L (Birge et al. 2000; Orr et al. 1986). In two tests with embryo/larva rainbow trout at pH 6.5 and 7.2, Holtze (1983) observed no reduction in survival after an 8-day exposure to 2,544 and 1,023 µg/L aluminum, respectively, when normalized. While these studies demonstrated the sensitivity of rainbow trout survival to aluminum, they were excluded from acute criteria calculations because of atypical acute test durations. In contrast, Hunter et al. (1980) observed 40% mortality at pH/total hardness/DOC-normalized concentration of 18,009 µg/L for rainbow trout, suggesting that rainbow trout could possibly be more tolerant to aluminum than reported by the previous studies. However, this study had only one treatment concentration, did not provide information regarding replicates or the number of fish per replicate, and the fish were fed

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during the study, precluding it from consideration as a reliable toxicity prediction and for criteria derivation.

Unlike the observed results of the acceptable acute studies, other data for the Family Salmonidae appears to be acutely insensitive to aluminum. In a series of eight 4- and 5-day tests with juvenile Atlantic salmon (*Salmo salar)* conducted at pH 4.42-5.26, Roy and Campbell (1995, 1997) observed pH/total hardness/DOC-normalized LC_{50}s ranging from 2,170-47,329 µg/L. Similarly, Wilkinson et al. (1990) observed a 7-day LC_{50} at pH 4.5 of 88 µg/L (or 13,060 µg/L when normalized to **Appendix A** conditions) for juvenile Atlantic salmon. These studies were not included in the acute criteria calculations because of either a non-standard duration, exposure at pH<5, or both.

Among warm water fishes, goldfish embryos (*Carassius auratus*) were highly sensitive to aluminum, with a 7- to 12-day pH/total hardness/DOC-normalized LC_{50} of 271.1 µg/L (Birge et al. 2000). While this value is below the acute criterion at the same normalized conditions (980 µg/L), the study provided little exposure details and exceeded the duration for an acceptable acute exposure toxicity test, therefore, it is likely overestimating the acute toxicity of aluminum to the species. Fathead minnow (*Pimephales promelas*) sensitivity, however, was variable across studies. In two tests that were excluded because test fish were fed, pH/total hardness/DOC-normalized 96-hr and 8-day LC_{50}s were 19,324 and 12,702 µg/L, respectively (Kimball 1978). In a 96-hour test that was excluded because measured total dissolved aluminum concentrations were greater than reported nominal total aluminum concentrations for all but the highest two treatment concentrations, suggesting total aluminum exposures were greater than reported, the pH/total hardness/DOC-normalized 96-hour LC_{50} was greater than 572.8 µg/L (Palmer et al. 1989). In contrast, Buhl (2002) observed a pH/total hardness/DOC-normalized 96-hr EC_{50} for death and immobility of greater than 21,779 µg/L for this species. Birge et al. (1978) and Birge et al. (2000) found largemouth bass (*Micropterus salmoides*) to be sensitive to aluminum, with 8-day and 7- to 12-day pH/total hardness/DOC-normalized LC_{50}s of 124.6 and 156.1 µg/L, respectively. In contrast, Sanborn (1945) observed no mortality in juvenile *M. salmoides* after a 7-day exposure to a pH/total hardness/DOC-normalized concentration of 45,181 µg/L.

Amphibians appear to be less acutely sensitive to aluminum than fish based on the very limited data available, but their sensitivity is highly variable and appears to depend upon life stage, with embryos being more sensitive than tadpoles. In a series of tests with leopard frogs

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(*Rana pipiens*) of different tadpole life stages conducted at low (4.2-4.8) pH and low (2.0 mg/L) total hardness, Freda and McDonald (1990) observed pH/total hardness/DOC-normalized 4 to 5-day LC_{50}s ranging from greater than 57,814 to greater than 490,582 µg/L. In two separate studies conducted at pH 4.5 and low total hardness, the pH/total hardness/DOC-normalized 96-hr LC_{50} for American toad (*Bufo americanus*) tadpoles was 358,450 µg/L (Freda et al. 1990); and the pH/total hardness/DOC-normalized 96-hr LC_{50} for the green tree frog (*Hyla cinerea*) was 200,373 µg/L (Jung and Jagoe 1995). In contrast, when *R. pipiens* embryos were exposed to aluminum for 10-11 days at a higher pH range (7.0-7.8), Birge et al. (2000) observed a normalized LC_{50} of 73.94 µg/L. Birge et al. (2000) also found embryonic spring peepers (*Pseudacris crucifer*) and embryonic Fowler's toads (*Bufo fowleri*) to be highly sensitive to aluminum, with a 7-day normalized LC_{50} of 73.94 and 230.0 µg/L, respectively. These values exceed the typical duration for an acute exposure for the species and therefore overestimate the toxicity of aluminum when comparing them to the acute criterion. However, aluminum sensitivity among amphibian embryos was not always greater than tadpole life stages, as the pH/total hardness/DOC-normalized 96-hr LC_{50} for *R. pipiens* embryos at pH 4.8 was 74,782 µg/L (Freda et al. 1990), similar to the LC_{50}s of *R. pipiens* tadpoles (Freda and McDonald 1990).

5.1.2 Freshwater Chronic Toxicity

Several chronic studies were identified as not meeting quality screening guidelines for inclusion in criterion calculations (**Appendix H** *Other Data on Effects of Aluminum to Freshwater Aquatic Organisms*), but showed similar ranges of toxicity and are presented here to provide additional supporting evidence of the potential toxicity of aluminum to aquatic organisms.

In two unmeasured lifecycle (3-brood) tests, IC_{25}s based on reproduction for *Ceriodaphnia dubia* were 566 and 641 µg/L (pH not reported so values could not be normalized), were within the range of observed acceptable chronic values for this species (Zuiderveen and Birge 1997). In three unmeasured 21-day *Daphnia magna* tests, LC_{50} and reproductive EC_{16} and EC_{50} pH/total hardness/DOC-normalized endpoints were 1,162, 265.6 and 564.3 µg/L, respectively (Biesinger and Christensen 1972). These values are within the range of acceptable chronic data reported for the cladoceran *C. dubia* (**Appendix C**).

Among fish species, the pH/total hardness/DOC-normalized 28-day EC_{50} (death and deformity) for *O. mykiss* of 457.4 µg/L (Birge 1978; Birge et al. 1978) was similar to chronic

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values for acceptable tests with other cold water test species. In addition, the 16-day normalized LC_{50}s for rainbow trout at two different test total hardness levels (20.3 and 103 mg/L as $CaCO_3$) observed by Gundersen et al. (1994) were 485.2 and 1,084 µg/L, respectively. However, the 16-day exposures were about one-fourth the duration of an acceptable ELS test for a salmonid (ASTM 2013). In a 28-day test of *S. fontinalis* conducted at pH 4.4, the pH/total hardness/DOC-normalized MATC for survival was 2,523 µg/L (Ingersoll et al. 1990a). Even though the duration of this test was insufficient and the pH was below 5, it provides additional evidence of the sensitivity of brook trout, a commercially and recreationally important species. Several short-term (7-day) chronic tests conducted by Oregon State University (OSU 2012a) with the fathead minnow at pH 6 and across a range of total hardness and DOC concentrations revealed that both an increase in total hardness and DOC reduced the toxicity of aluminum (non-normalized EC_{20}s ranged from 127.2 to 2,938 µg/L or 1,718 to 7,220 µg/L when normalized to the test conditions in **Appendix C**).

5.1.3 Freshwater Field Studies

Field studies have been conducted to measure effects of aluminum additions to control phosphorus concentrations in lakes, to validate parallel laboratory exposures, and to investigate the effects of acid deposition in aquatic systems. Aluminum sulfate was continuously added for 35 days to the Cuyahoga River 500 meters upstream of Lake Rockwell to control phosphorus concentrations in the reservoir. Artificial colonization substrata were placed at five locations along the treatment reach five weeks before the release, sampled on the day of the release, redeployed after collecting invertebrates immediately before the release, and then sampled weekly throughout the 35-day aluminum addition. After one week of treatment, invertebrate densities declined throughout the study reach, and were completely absent from a site 60 meters downstream of the release point. Once treatment was stopped, invertebrate densities recovered and replaced after approximately three weeks by rapidly colonizing oligochaete taxa (Barbiero et al. 1988).

In Little Rock Lake, WI, sulfuric acid was added to half of the lake between 1984-1990, resulting in a decrease in pH from 6.05 to 4.75 and an increase in aqueous aluminum from 7 to 42 µg/L. The other half of the lake served as a control, where aluminum increased from 7 to 14 µg/L and pH decreased from 6.04 to 5.99 during the same time period (Eaton et al. 1992). In parallel laboratory experiments in 1988, eggs of several fish species were exposed to aluminum

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concentrations ranging from 8.1-86.9 µg/L and pH values ranging from 4.5-5.5 until seven days' post hatch. In both the acidified portion of the lake and in laboratory exposures at comparable aluminum and pH levels, mortality was higher than in controls (Eaton et al. 1992). However, mortality of control fish in both the *in-situ* and laboratory exposures exceeded the minimum 80 percent survival acceptable guideline for tests of this duration.

Additional field studies have evaluated the effects of aluminum and acidification on different trophic level communities. Havens and Decosta (1987) acidified the circumneutral Lake O'Woods (WV) to pH 4.8 and compared phytoplankton and zooplankton assemblages with and without the addition of 300 µg/L aluminum. They observed similar species in all conditions, but the aluminum dosed water exhibited a decrease in chlorophyll *a* concentrations and a drop in zooplankton abundances over the 49-day observation period, while the acidified condition without aluminum addition only exhibited a drop in chlorophyll *a*. The algal biomass decrease was attributed to the initial co-precipitation of phosphorus and/or algal cells with the aluminum hydroxide at circumneutral pH. Bukaveckas (1989) reported similar declines in algal biomass when acidic, aluminum-rich waters are neutralized with lime. In contrast, aluminum addition produced a more pronounced difference in algal community structure and succession when Havens and Heath (1990) gradually acidified (pH 4.5) and dosed East Twin Lake (OH) with 200 µg/L aluminum.

Increased drift of invertebrates (Ephemeroptera, Diptera and Orthocladiinae chironomids) in an acidified (pH~5) stream dosed with 280 µg/L aluminum was observed relative to a non-dosed stream at the same ~5 pH level (Hall et al. 1987). Ormerod et al. (1987), however, found little added effect of 350 µg/L aluminum on stream invertebrates compared with the effects of acidification alone (pH~4.3). In contrast, brown trout and Atlantic salmon showed significantly increased mortalities in the acidified aluminum condition (50 to 87%) relative to the acid-only treatment (7 to 10%). Baldigo and Murdoch (1997) deployed caged brook trout in selected New York Catskill Mountain streams where the pH, aluminum concentration and other stream conditions fluctuated naturally over time. They noted that fish mortality correlated best with high inorganic aluminum concentrations and low water pH (4.4-5.2), with 20 percent mortality observed for brook trout exposed to greater than or equal to 225 µg/L inorganic monomeric aluminum for two days. They also observed, based on regression analysis, that a vast majority (74-99%) of the variability in mortality could be explained by either the mean or median

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inorganic monomeric aluminum concentration, and that the mortality was highly related to inorganic monomeric aluminum, pH, dissolved organic carbon, calcium and chloride concentrations. Bulger et al. (1993) also reported that water pH and monomeric inorganic aluminum concentrations best predicted brown trout populations of 584 Norwegian lakes. Lakes with 133 µg/L aluminum and a pH of 4.8 were devoid of brown trout (39% of the 584 lakes), whereas lakes with 11 µg/L aluminum and a pH of 6.0 had healthy brown trout populations.

5.1.4 Estuarine/Marine Acute Toxicity

SMAVs for five genera representing five species of estuarine/marine organisms were calculated for aluminum (**Table 8**). SMAVs and GMAVs were equal since there is only one species present per genus. The most sensitive genus was the polychaete worm (*Ctenodrilus serratus*), with a SMAV of 97.15 µg/L, followed by two other polychaete worms (*Capitella capitata* and *Neanthes arenaceodentata*) with SMAVs of 404.8 and greater than 404.8 µg/L, respectively. The most tolerant genus was a copepod (*Nitokra spinipes*) with a SMAV of 10,000 µg/L (**Figure 9**). However, the freshwater acute criterion (980 µg/L total aluminum) is much higher than the most sensitive acute estuarine/marine species LC_{50} (97.15 µg/L total aluminum). Thus, at least some invertebrate estuarine/marine species would not be protected if the freshwater acute aluminum criterion was applied in those systems.

Table 8. Ranked Estuarine/Marine Genus Mean Acute Values.

Rank[a]	GMAV (µg/L total Al)	Species	SMAV (µg/L total Al)[b]
5	10,000	Copepod, *Nitokra spinipes*	10,000
4	>1,518	American oyster, *Crassostrea virginica*	>1,518
3	>404.8	Polychaete worm, *Neanthes arenaceodentata*	>404.8
2	404.8	Polychaete worm, *Capitella capitata*	404.8
1	97.15	Polychaete worm, *Ctenodrilus serratus*	97.15

[a] Ranked from the most resistant to the most sensitive based on Genus Mean Acute Value.
[b] From Appendix B: Acceptable Acute Toxicity Data of Aluminum to Estuarine/Marine Aquatic Animals.

In contrast to freshwater, only a few acute studies were identified as not meeting screening guidelines for inclusion in criterion calculations (**Appendix I** *Other Data on Effects of Aluminum to Estuarine/Marine Aquatic Organisms*), but showed similar ranges of toxicity. As

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with other non-conforming studies previously described, the results are presented here to provide additional supporting evidence of the potential toxicity of aluminum to estuarine/marine organisms. In one of these studies, a cohort of sea urchin embryos (*Paracentrotus lividus*) exposed to 539.6 µg/L aluminum for 72-hr exhibited increased developmental defects by 69.7% (Caplat et al. 2010). Although this study was not considered acceptable because the control group exhibited 19.3% defects indicative of some health deficiency, the effect level was comparable to the acute effect levels observed in **Appendix B**. In 24-hr exposures to aluminum added as potassium aluminum sulfate, LC_{50}s for the crab species *Eupagurus bernhardus* and *Carcinus maenas*, the snail *Littorina littorea*, and the mussel *Mytilus edulis* were extremely high, ranging from a low of 250,000 µg/L for *E. bernhardus* to greater than 6,400,000 µg/L for the two mollusk species (Robinson and Perkins 1977). Although these studies were unacceptable because of the atypical acute test duration, they suggest that some saltwater taxa are highly tolerant to acute aluminum exposure.

5.1.5 Estuarine/Marine Chronic Toxicity

There are no acceptable saltwater chronic data available for aluminum (**Appendix D**). However, the EPA identified several chronic studies that did not meet screening guidelines for inclusion in criterion calculations, but provided supporting evidence of potential chronic toxicity of aluminum to aquatic organisms in estuarine/marine environments (**Appendix I** *Other Data on Effects of Aluminum to Estuarine/Marine Aquatic Organisms*). Petrich and Reish (1979) observed a 21-day MATC for reproduction in the polychaete *C. serratus* of 28.28 µg/L. Consistent with acceptable acute test results for this species, this chronic test suggests that polychaetes may be chronically sensitive to aluminum. This study was excluded because of the test duration. In a "semi-chronic" 12-day study of the effects of aluminum on daggerblade grass shrimp (*Palaemonetes pugio*) embryos, the LC_{50} was 1,079 µg/L (Rayburn and Aladdin 2003). This study was not included because it was longer than an acceptable 48-hr acute test, and it was not a full life cycle test.

5.1.6 Bioaccumulation

Three acceptable studies examined the effects of waterborne aluminum bioaccumulation in aquatic organisms (**Appendix G** *Acceptable Bioaccumulation Data of Aluminum by Aquatic Organisms*). Cleveland et al. (1991a) exposed 30-day old brook trout to 200 µg/L of aluminum in test waters at three pH levels (5.3, 6.1, and 7.2) for 56 days. After 56 days, trout were

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transferred to water of the same pH with no aluminum amendments and held for 28 days. Fish were sampled for whole body aluminum on days 3, 7, 14, 28 and 56 of the exposure; and on days 3, 7, 14 and 28 of the depuration period. The estimated time to achieve steady state whole body aluminum concentrations was 1.5 days at pH 5.3, 4.2 days at pH 6.1, and 1.7 days at pH 7.2. Bioconcentration factors (BCF) were inversely related to pH: 142 at pH 5.3, 104 at pH 6.1, and 14.2 at pH 7.2. Mortality was also highest at pH 5.3 and lowest at pH 7.2. In a separate study, Buckler et al. (1995) continuously exposed Atlantic salmon beginning as eyed eggs to four aluminum treatment levels (33, 71, 124, 264 µg/L) at pH 5.5 for 60 days after the median hatch date. Fish were sampled for whole body aluminum after 15, 30, 45, and 60 days post median hatch. After 60 days, average mortality was 15% in the 124 µg/L treatment and 63% in the 264 µg/L treatment. The mortality NOEC and LOEC were 71 and 124 µg/L, respectively. BCFs were directly related to exposure concentration, and were 76, 154, and 190 at treatment levels 33, 71, and 124 µg/L, respectively. A BCF could not be calculated for the 264 µg/L treatment level because there were insufficient surviving fish to analyze. Snails, *Lymnaea stagnalis,* held in neutral pH for 30 days and 242 µg/L total aluminum reached steady with a reported BCF of 4.26 in the digestive gland (Dobranskyte et al. 2004).

As reported in the literature, aquatic organisms can accumulate metals from both aqueous and dietary exposure routes. The relative importance of each, however, is dependent upon the chemical. Aluminum adsorbs rapidly to gill surface from the surrounding water, but cellular uptake from the water is slow, with gradual accumulation by the internal organs over time (Dussault et al. 2001). Bioaccumulation and toxicity via the diet are considered highly unlikely based on studies by Handy (1993) and Poston (1991), and also supported by the lack of any biomagnification within freshwater invertebrates that are likely to be prey of fish in acidic, aluminum-rich rivers (Herrmann and Frick 1995; Otto and Svensson 1983; Wren and Stephenson 1991). The opposite phenomena, trophic dilution up the food chain, has been suggested based on the lowest aluminum accumulation exhibited by fish predators (perch) and highest by the phytoplankton that their zooplankton prey were consuming (King et al. 1992). Thus, the low aluminum BCFs reported in the literature are supported by the slow waterborne uptake and the lack of dietary accumulation.

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5.2 Effects on Aquatic Plants

Aquatic plant data are not used to derive the criteria for aluminum. However, a summary of available data is presented below. For freshwater algae, aluminum effect concentrations ranged from 50 µg/L to 6,477 µg/L, with most effect levels below 1,000 µg/L (**Appendix E** *Acceptable Toxicity Data of Aluminum to Freshwater Aquatic Plants*). Studies for freshwater macrophytes are limited, but available data suggest freshwater macrophytes are more tolerant to aluminum than freshwater algae. The effect concentration for Eurasian watermilfoil is 2,500 µg/L based on root weight (Stanley 1974), which is near the upper range of freshwater algae sensitivities. Several 3-day tests with the green alga *Pseudokirchneriella subcapitata* at pH 6, 7 and 8 across a range of total hardness and DOC concentrations revealed that both an increase in pH, total hardness and DOC reduced the toxicity of aluminum (European Aluminum Association 2009). DeForest et al. (2018a) used these 27 toxicity tests (as summarized in Gensemer et al. 2018) to develop a MLR model to explain the effects of water chemistry on algal toxicity. The MLR model developed was:

$$P.\,subcapitata\ EC_{20} = e^{\left[-61.952+[1.678\times\ln(DOC)]+[4.007\times\ln(hard)]+(17.019\times pH)-(1.020\times pH^2)-[0.204\times pH{:}\ln(DOC)]-[0.556\times pH{:}\ln(hard)]\right]}$$

The MLR model for *P. subcapitata* was within a factor of two for 100% of the predicted versus observed values (DeForest et al. 2018a). Most of the acceptable toxicity data for freshwater aquatic plants (**Appendix E**) did not report all three water quality parameters (i.e., pH, total hardness and DOC) preventing the use of applying the alga based MLR equation to the data. The EPA contacted authors and in limited cases, the authors were able to provide rough estimates of some of the missing information. Normalized lowest observed effect concentrations (LOECs) for the twenty-one day tests as reported by Pilsbury and Kingston (1990) were 3,482 µg/L, while normalized 4-day EC_{50}s for *P. subcapitata* were 620 and 1,067 µg/L (Call et al. 1984). These values are above the chronic criterion at the same test conditions, suggesting that the criteria developed using aquatic animals will also be protective of aquatic plants. This was also observed when normalizing the 3-day *P. subcapitata* test in **Appendix H** (*Other Data on Effects of Aluminum to Freshwater Aquatic Organisms*) with normalized effect concentrations ranging from 161 to 5,113 µg/L. The geometric mean of these values was 1,653 µg/L (Note:

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these tests were excluded from the acceptable table due to the insufficient test duration, less than 4 days).

In contrast to other freshwater plants, duckweed is highly tolerant to aluminum, with an effect concentration based on reduced growth of greater than 45,700 µg/L (Call et al. 1984). For the one acceptable study of a saltwater plant (Seagrass, *Halophila stipulacea*), less than 50% mortality of teeth cells was observed at 26.98 µg/L, and more than 50% mortality of teeth cells observed at 269.8 µg/L (Malea and Haritonidis 1996). In a shorter duration study, the saltwater algal species, *Dunaliella tertiolecta*, also exhibited sensitivity to aluminum, but the effect concentration was higher at 18,160 µg/L (**Appendix I** *Other Data on Effects of Aluminum to Estuarine/Marine Aquatic Organisms*). Although aquatic plant data are not normalized using the alga based MLR equation, the effect levels observed are similar to the available animal data, and the recommended criteria should therefore be protective for algae and aquatic plants.

5.3 Identification of Data Gaps and Uncertainties for Aquatic Organisms

Data gaps and uncertainty were identified for the aluminum criteria. A number of uncertainties are associated with calculation of the freshwater Final Acute Value (FAV) as recommended by the 1985 Guidelines, and include use of limited data for a species or genus, acceptability of widely variable data for a genus, application of adjustment factors, extrapolation of laboratory data to field situations, and data normalization with a MLR model.

5.3.1 Acute Criteria

There are a number of cases in the acute database where only one acute test is used to determine the Species Mean Acute Value (SMAV) and subsequently the Genus Mean Acute Value (GMAV) is based on the one acute test. In this situation, there is a level of uncertainty associated with the GMAV based on the one test result since it does not incorporate the range of values that would be available if multiple studies were available. Such a GMAV is still valid, however, in spite of the absence of these additional data because it represents the best available data and to exclude this data would create an unnecessary data gap. Additionally, many of the acute studies did not report a definitive LC_{50} (i.e., yielded greater than values) because the highest concentration used did not cause more than 50% mortality. This adds more uncertainty since the true LC_{50} is unknown.

The acute criterion is set as equal to half of the FAV to represent a low level of effect for the fifth percentile genus, rather than a 50% effect. This adjustment factor was derived from an

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analysis of 219 acute toxicity tests with a variety of chemicals (see 43 FR 21506-21518 for a complete description) where mortality data were used to determine the highest tested concentration that did not cause mortality greater than that observed in the control (or between 0 and 10%). Application of this adjustment factor is justified because that concentration represents minimal acute toxicity to the species.

5.3.2 Chronic Criteria

The freshwater FCV calculation is also influenced by the limited availability of data and the use of qualitative data to fulfill the one remaining family (Chordata) MDR. The aluminum freshwater chronic database is comprised of 12 species and subsequently 12 genera that provide seven of the eight MDR families as recommended in the 1985 Guidelines. In order to satisfy the eight-family requirement, the dataset included a wood frog (*Rana sylvatica*) chronic study that was relegated to **Appendix H** due to minor methodology issues (pH<5). While this study does not quantitatively affect the criterion value, it was used to fulfill the MDRs per the 1985 Guidelines, thereby allowing direct calculation of the FCV (see **Section 2.7.3**). Additional testing of other species and families in the Phylum Chordata would reduce the uncertainty in the FCV.

5.3.3 Laboratory to Field Exposures

Application of water-only laboratory toxicity tests to develop water quality criteria to protect aquatic species is a basic premise of the 1985 Guidelines, supported by the requirements of a diverse assemblage of eight families and the intended protection goal of 95 percent of all genera. Confirmation has been reported by a number of researchers (Clements and Kiffney 1996; Clements et al. 2002; Mebane 2006; Norberg-King and Mount 1986), thereby indicating that on the whole, extrapolation from the laboratory to the field is a scientifically valid and protective approach for aquatic life criteria development.

The unique chemistry of aluminum (speciation changes and the transient precipitates formed during toxicity testing) and difference between geological aluminum materials suspended in natural water are additional areas of uncertainty (Angel et al. 2016; Cardwell et al. 2018; Gensemer et al. 2018). The use of total aluminum concentrations is justified for laboratory toxicity test data (see **Section 2.6.2**); where the total aluminum concentration is in either a dissolved or precipitated form (Santore et al. 2018). However, natural water samples may also contain other species of aluminum that are not biologically available (i.e., suspended particles, clays and aluminosilicate minerals) (Santore et al. 2018; Wilson 2012). This creates uncertainty

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because the total recoverable aluminum concentrations measured in natural waters may overestimate the potential risks of toxicity to aquatic organisms.

EPA Methods 200.7 and 200.8 are the only currently approved methods for measuring aluminum in natural waters and wastes for NPDES permits (U.S. EPA 1994a,b). Research on new analytical methods is ongoing to address concerns with including aluminum bound to particulate matter (i.e., clay) in the total recoverable aluminum concentrations (OSU 2018c). One approach would not acidify the sample to pH less than 2 but rather to pH 4 (pH 4 extracted method) to better capture the bioavailable fraction of aluminum (CIMM 2016, OSU 2018c). Thus, this draft pH 4 extracted method under development is expected to reduce the uncertainty regarding bioavailable aluminum measurements in the aquatic environment.

5.3.4 Lack of Toxicity Data for Estuarine/Marine Species and Plants

Since limited acceptable acute and chronic data are available for estuarine/marine species, the EPA could not derive estuarine/marine acute and chronic aluminum criteria at this time. In addition, very few acceptable aquatic vascular plant studies are available.

5.3.5 Bioavailability Models

Aluminum toxicity is strongly affected by water chemistry, through its effects on bioavailability. The understanding of the interactions between aluminum species, water characteristics, and aquatic toxicity data has led to the development of several bioavailability models. There are currently two different approaches that take into account aluminum bioavailability in relation to aquatic toxicity that are considered applicable to the development of aquatic life criteria: empirical models that relate toxicity to water chemistry; and Biotic Ligand Models that encompass both abiotic and biotic mechanistic factors determining toxicity.

Initially in considering the array of approaches for criteria development, the EPA considered using an empirical total hardness adjustment equation for criteria development. However, studies that tested aluminum at pH 6 for a variety of organisms (OSU 2012a, 2012b, 2012c, 2012d, 2012e, 2012f, 2012g, 2012h, 2013) indicated additional water chemistry parameters affected bioavailability, and hence aquatic effects of aluminum. In addition, new data are available that supported the development of MLR models that incorporate pH and total hardness. Also, a mechanistic BLM model for aluminum was recently developed (Santore et al. 2018). Finally, an approach described in DeForest et al. (2018a,b) incorporated pH, total hardness and DOC into empirical MLR models to determine if the estimation of aluminum

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bioavailability to animals in freshwater aquatic systems could be applicable in the development of aluminum water quality criteria. The approach resulted in the creation of multiple MLR models that could be used for the development of aluminum water quality criteria methodologies. Both MLR models and the BLM model include the same toxicity test data, with the BLM including additional data on the accumulation of aluminum on the gills of Atlantic salmon (Santore et al 2018). The MLR approach empirically curve-fits log-log pH, total hardness and DOC relationships (with interaction terms) to the empirical data. The BLM uses a mechanistic model based on an underlying theory of how water chemistry input parameters affect aluminum toxicity, although it still has empirically derived factors.

An external peer review of the different aluminum aquatic life criteria approaches was conducted in November 2016 to provide a comparison of the several available approaches to generating aluminum criteria that reflect water quality condition impacts on toxicity. Approaches compared included a 10-parameter BLM, a simplified-BLM approach (e.g., pH, total hardness, dissolved organic carbon, temperature), and MLR models to facilitate evaluation of the most appropriate approaches to consider for aluminum toxicity modeling. The EPA conducted three additional external peer reviews in 2018 regarding the new toxicity data and re-fitted MLR models on: 1) the new invertebrate toxicity tests on *C. dubia* (OSU 2018a); 2) the new fish toxicity tests on *P. promelas* (OSU 2012b); and 3) the new individual and pooled MLRs developed by Deforest et al. (2018b). Based on external peer review comments, ease of use, and transparency, the EPA applied the DeForest et al. (2018b) individual species MLR model to normalize the freshwater acute and chronic data (**Appendix A** and **Appendix C**) and derived the aluminum criteria using the criteria development approaches described in the 1985 Guidelines. The EPA independently examined and verified the quality and fit of the DeForest et al. (2018a,b) MLR models before applying them in this final criteria document.

5.3.6 pH, Total Hardness and DOC MLR Models

There are additional uncertainties, beyond those described above, associated with the normalization of aluminum toxicity data using the MLR models developed by DeForest et al. (2018b). The models were developed with chronic toxicity data from two animal species, one invertebrate (*C. dubia*; a sensitive species) and one fish (fathead minnow; a moderately sensitive species). Incorporating additional species in the model development would improve the representativeness of all species and further validate the MLR model use across species. Though

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the pH, total hardness, and DOC do explain the majority of differences seen in the toxicity data between the two species, there are two MLR models developed (invertebrate *C. dubia* model and vertebrate *P. promelas* model), which better delineate the differences in their uptake of aluminum. Because the arthropod phylum is highly diverse, there is some uncertainty in the application of the *C. dubia* model across other invertebrate taxa. However, among fish (and amphibians), the MLR approach that uses a model optimized solely for those taxa is the best model to use as opposed to a BLM which uses one model to normalize the data for multiple taxa for criteria calculations. Thus, the MLR-based criteria derivation specific to the most sensitive taxa may address additional uncertainty because some of the model differences may be a function of the species physiology in addition to bioavailability, and hence the MLR approach may better capture taxa physiologic differences in sensitivity across different water chemistry conditions. The models are, however, applied across gross taxonomy (vertebrate vs. invertebrate), creating some additional uncertainty. Finally, only chronic data were used in model development, and application to acute toxicity data assumes that the same relationships are present. All of these uncertainties associated with the model are areas where additional research would be helpful.

The models were developed using data that encompass a pH range of 6.0-8.7, DOC range of 0.08-12.3 mg/L and total hardness range of 9.8-428 mg/L (as $CaCO_3$). The authors (DeForest et al. 2018a) noted that the empirical data evaluated support a reduced total hardness effect at higher pH levels (i.e., 8-9), but limited data are available. Additional chronic aluminum toxicity testing at higher pH levels would be useful for further validating the MLR models (i.e., there is a limited amount of data at pH>8). When any of the water quality parameters selected is outside model inputs, the Aluminum Criteria Calculator V.2.0 (*Aluminum Criteria Calculator V.2.0.xlsm*) flags these values and defaults to the maximum bounds for DOC and total hardness. Values generated outside the recommended water quality parameter for pH (6.0-8.2) should be treated with caution because extrapolating beyond the conditions used for model development is highly uncertain. Of particular concern is the quadratic term (pH^2) in the *C. dubia* MLR model which can compound issues with extrapolating. Additional toxicity tests conducted and pH<6.0 and pH> 8.5 would further define behavior of this model.

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5.4 Protection of Endangered Species

Although the dataset for aluminum is not extensive, it does include some data representing species that are listed as threatened or endangered by the U.S. Fish and Wildlife Service and/or National Oceanic and Atmospheric Administration (NOAA) Fisheries. Summaries are provided here describing the available aluminum toxicity data for listed species indicating that the 2018 aluminum criteria are expected to be protective of these listed species, based on available scientific data.

5.4.1 Key Acute Toxicity Data for Listed Fish Species

Tests relating to effects of aluminum on several threatened and endangered freshwater fish species are available (certain populations threatened, and others endangered): rainbow trout, *Oncorhynchus mykiss* with a normalized SMAV of 3,312 µg/L (Call et al. 1984; Gundersen et al. 1994; Holtze 1983); Rio Grande silvery minnow, *Hybognathus amarus* with a normalized SMAV of greater than 21,779 µg/L (Buhl 2002); and Atlantic salmon, *Salmo salar* with a SMAV of 8,642 µg/L (Hamilton and Haines 1995). For this comparison, all SMAVs are normalized to a pH 7, a total hardness of 100 mg/L as $CaCO_3$ and a DOC of 1.0 mg/L. All of the normalized SMAVs are above the recommended acute criterion (CMC) of 980 µg/L at the same pH, total hardness and DOC levels. There are no acceptable acute toxicity data for endangered or threatened estuarine/marine aquatic fish species.

5.4.2 Key Chronic Toxicity Data for Listed Fish Species

While there are no acceptable chronic toxicity data for estuarine/marine endangered and/or threatened fish species, there is one acceptable early life-stage test conducted with the endangered freshwater fish, Atlantic salmon, *Salmo salar*. The test, conducted at a pH of 5.7, yielded a pH/total hardness/DOC-normalized species mean chronic value (SMCV) of 434.4 µg/L (McKee et al. 1989). This value is greater than the recommended chronic criterion of 380 µg/L at the same total hardness, DOC and pH.

5.4.3 Concerns about Federally Listed Endangered Mussels

Some researchers have expressed concerns that mussels may be more sensitive to the effects of aluminum than other organisms. A study by Kadar et al. (2001) indicated that adult *Anodonta cygnea* mussels may be sensitive to aluminum at concentrations above 250 µg/L, with reductions in mean duration of shell opening of 50% at 500 µg/L aluminum in the water column

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(at circumneutral pH) when compared to paired controls. This suggests that chronic elevated aluminum concentrations could lead to feeding for shorter durations with potential implications for survival and growth, and possibly even reproduction. Pynnonen (1990) conducted toxicity tests with two freshwater mussels in the Unionidae family (*Anodonta anatina* and *Unio pictorum*). In both species, pH had a significant effect on accumulation of aluminum in the gills. The *Anodonta* mussel species in the two studies described above are not native to the United States and are included in **Appendix J** (*List of Aluminum Studies Not Used in Document Along with Reasons*). While the *Anodonta* mussel species in these two studies are not native, there are species of the *Anodonta* genus present in the United States. Simon (2005) provides an additional line of evidence that indicates mussels may be more sensitive to the effects of aluminum than other organisms. In a 21-day chronic aluminum toxicity test conducted at circumneutral pH with juvenile unionid freshwater mussel *Villosa iris*, growth was significantly reduced at aluminum levels above 337 µg/L.

New data are available for this update on aluminum toxicity to the fatmucket mussel (*Lampsilis siliquoidea*), another freshwater mussel in the family Unionidae. While the 96-hr LC_{50} juvenile test failed to elicit an acute 50% response at the highest concentration tested (6,302 µg/L total aluminum, or 29,492 µg/L when normalized), the 28-day biomass-normalized SMCV ranked as the fourth most sensitive genus in the dataset. The SMCV is greater than the most sensitive species, Atlantic salmon, and the freshwater criterion value. Thus, the chronic criterion is expected to be protective of this and related species. The fatmucket mussel tested is not a threatened and/or endangered species, but the genus *Lampsilis* contains several listed species with a wide distribution across the United States, and is also member of the family Unionidae.

Freshwater mussels in the family Unionidae are known to be sensitive to a number of chemicals, including metals and organic compounds (Wang et al 2018; U.S. EPA 2013). The EPA's 2013 Aquatic Life Ambient Water Quality Criteria for Ammonia in Freshwater indicates many states in the continental U.S. have freshwater unionid mussel fauna in at least some of their waters (Abell et al. 2000; Williams and Neves 1995; Williams et al. 1993). Roughly one-quarter of the approximately 300 freshwater unionid mussel taxa in the United States are Federally-listed as endangered or threatened species. Additional testing on endangered mussel species, or closely related surrogates, would be useful to further examine the potential risk of aluminum exposures to endangered freshwater mussels.

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5.5 Comparison of 1988 and 2018 Criteria Values

The 1988 aluminum freshwater acute criterion was based on data from eight species of invertebrates and seven species of fish grouped into 14 genera. This 2018 update now includes 13 species of invertebrates, eight species of fish, and one frog species for a total of 22 species grouped into 20 genera. The data in the previous AWQC were not normalized to any water chemistry conditions making it difficult to compare the magnitude of the two criteria.

The 1988 aluminum freshwater chronic criterion was set at 87 µg/L across a pH range 6.5 to 9.0, and across all total hardness and DOC ranges, based on a dataset that included two species of invertebrates and one fish species. This 2018 criteria update includes new data for an additional nine species, and consists of eight invertebrates and four fish species grouped into 12 genera and is a function of pH, total hardness and DOC. Addition of the frog (*Rana sylvatica*) data from **Appendix H** satisfied the MDR for the one missing family (Chordata), thereby allowing for direct calculation of the FCV.

Like the previous AWQC for aluminum, there are still insufficient data to fulfill the estuarine/marine MDRs as per the 1985 Guidelines, therefore the EPA did not derive estuarine/marine criteria at this time. New toxicity data for five genera representing five species of estuarine/marine organisms are presented in this update; no data were available in 1988.

Table 9. Comparison of the 2018 Recommended Aluminum Aquatic Life AWQC and the 1988 Criteria.

Version	Freshwater Acute[a] (1-hour, total aluminum)	Freshwater Chronic[a] (4-day, total aluminum)
2018 AWQC (vary as a function of a site's pH, DOC and total hardness)	1-4,800 µg/L	0.63-3,200 µg/L
1988 AWQC (pH 6.5 – 9.0, across all total hardness and DOC ranges)	750 µg/L	87 µg/L

[a] Values are recommended not to be exceeded more than once every three years on average.
Note: 2018 Criteria values will be different under differing water chemistry conditions as identified in this document, and can be calculated using the Aluminum Criteria Calculator V.2.0 (*Aluminum Criteria Calculator V.2.0.xlsm*) or found in the tables in Appendix K. See Appendix K for specific comparisons of 1988 and 2018 criteria values across water chemistry parameter ranges.

6 UNUSED DATA

For this 2018 criteria update document, the EPA considered and evaluated all available data that could be used to derive the new acute and chronic criteria for aluminum in fresh and

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estuarine/marine waters. A substantial amount of those data were associated with studies that did not meet the basic QA/QC requirements in a manner consistent with the 1985 Guidelines (see Stephan et al. 1985) and reflecting best professional judgments of toxicological effects. A list of all other studies considered, but removed from consideration for use in deriving the criteria, is provided in **Appendix J** (*List of Aluminum Studies Not Used in Document Along with Reasons*) with rationale indicating the reason(s) for exclusion. Note that unused studies from previous AWQC documents were not re-evaluated.

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Appendix A ACCEPTABLE ACUTE TOXICITY DATA OF ALUMINUM TO FRESHWATER AQUATIC ANIMALS

NMED Exhibit 75

Appendix A. Acceptable Acute Toxicity Data of Aluminum to Freshwater Aquatic Animals
(Bold values are used in SMAV calculation).
(Species are organized phylogenetically).

Species	Method[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	LC_{50} / EC_{50} (µg/L)	Normalized Acute Value[b] (µg/L)	Species Mean Acute Value (µg/L)	Reference
Worm (adult, 1.0 cm), *Nais elinguis*	R, M, T	Aluminum sulfate	17.89 (±1.74)	6.51 (±0.01)	3.2	3,874	**9,224**	9,224	Shuhaimi-Othman et al. 2012a, 2013
Snail (adult), *Physa sp.*	S, M, T	Aluminum chloride	47.4 (±4.51)	6.59	1.1[d]	>23,400	**>52,593**	-	Call 1984; Call et al. 1984
Snail (adult), *Physa sp.*	S, M, T	Aluminum chloride	47.4 (±4.51)	7.55	1.1[d]	30,600	**27,057**	-	Call 1984; Call et al. 1984
Snail (adult), *Physa sp.*	S, M, T	Aluminum chloride	47.4 (±4.51)	8.17	1.1[d]	>24,700	>19,341[c]	-	Call 1984; Call et al. 1984
Snail (adult), *Physa sp.*	S, M, T	Aluminum chloride	47.4 (±4.51)	7.46	1.1[d] (aged solution)	55,500	**51,539**	41,858	Call 1984; Call et al. 1984
Snail (adult, 1.5-2.0 cm, 22.5 mg), *Melanoides tuberculata*	R, M, T	Aluminum sulfate	18.72 (±1.72)	6.68 (±0.22)	3.2	68,230	**119,427**	119,427	Shuhaimi-Othman et al. 2012b, 2013
Fatmucket (juvenile, 6 d), *Lampsilis siliquoidea*	R, M, T	Aluminum chloride	107 (±6.3)	8.19 (±0.22)	0.5	>54,300	>57,735[f]	-	Ivey et al. 2014
Fatmucket (juvenile, 7-8 d, 0.38 mm), *Lampsilis siliquoidea*	F, M, T	Aluminum nitrate	106 (104-108)	6.12 (6.10-6.13)	0.48	>6,302	**>29,492**	>29,492	Wang et al. 2016, 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, A	Aluminum chloride	50.0	7.42 (±0.02)	1.1[d]	1,900	**1,771**	-	McCauley et al. 1986
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, A	Aluminum chloride	50.5	7.86 (±0.04)	1.1[d]	1,500	**1,170**	-	McCauley et al. 1986
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, A	Aluminum chloride	50.0	8.13 (±0.03)	1.1[d]	2,560	**1,974**	-	McCauley et al. 1986

NMED Exhibit 75

Species	Method[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	LC_{50} / EC_{50} (µg/L)	Normalized Acute Value[b] (µg/L)	Species Mean Acute Value (µg/L)	Reference
Cladoceran (<24 hr), *Ceriodaphnia dubia*	R, M, T	Aluminum chloride	25 (24-26)	7.5 (7.0-8.0)	0.5[d]	720	**1,321**	-	ENSR 1992d
Cladoceran (<24 hr), *Ceriodaphnia dubia*	R, M, T	Aluminum chloride	49 (46-52)	7.65 (7.3-8.0)	0.5[d]	1,880	**2,516**	-	ENSR 1992d
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, T	Aluminum chloride	95 (94-96)	7.9 (7.7-8.1)	0.5[d]	2,450	**2,559**	-	ENSR 1992d
Cladoceran (<24 hr), *Ceriodaphnia dubia*	R, M, T	Aluminum chloride	193 (192-194)	8.05 (7.8-8.3)	0.5[d]	>99,600	**>88,933**	-	ENSR 1992d
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, NR	Aluminum sulfate	90 (80-100)	7.15 (7.0-7.3)	0.5[d]	3,727	**5,243**	-	Fort and Stover 1995
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, NR	Aluminum sulfate	90 (80-100)	7.15 (7.0-7.3)	0.5[d]	5,673	**7,981**	-	Fort and Stover 1995
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, NR	Aluminum sulfate	89	8.2	0.5[d]	2,880	**3,189**	-	Soucek et al. 2001
Cladoceran (<24 hr), *Ceriodaphnia dubia*	R, U, T	Aluminum chloride	142 (±2)	8.2 (±1)	1.6[d]	153,440	**77,169**		Griffitt et al. 2008
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	10.6	6.01 (5.99-6.03)	0.5[d]	71.12	**2,009**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	10.6	6.05 (6.02-6.07)	2	686.5	**7,721**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	10.6	6.09 (6.03-6.15)	4	1,558.1	**10,568**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	10.6	6.01 (5.95-6.06)	0.5[d] (solution aged 3 hrs)	68.1	**1,924**	-	European Al Association 2009; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	10.6	6.03 (5.95-6.10)	0.5[d] (solution aged 27 hrs)	163.0	**4,394**	-	European Al Association 2009; Gensemer et al. 2018

Species	Method[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	LC_{50} / EC_{50} (µg/L)	Normalized Acute Value[b] (µg/L)	Species Mean Acute Value (µg/L)	Reference
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	10.6	5.97 (5.92-6.01)	0.5[d] (solution aged 51 hrs)	178.5	**5,546**	-	European Al Association 2009; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	10.6	5.92 (5.87-5.96)	0.5[d] (solution aged 99 hrs)	141.0	**4,945**	-	European Al Association 2009; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	10.6	6.99 (6.96-7.01)	0.5[d]	>1,300	**>5,842**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	10.6	7.85 (7.77-7.93)	0.5[d]	>5,000	**>9,735**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	10.6	6.80 (6.55-7.04)	2	>10,000	**>26,061**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	10.6	7.82 (7.49-8.14)	2	>15,000	**>12,984**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	10.6	6.77 (6.51-7.03)	4	>10,000	**>18,075**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	10.6	7.66 (7.39-7.93)	4	>15,000	**>9,538**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	10.6	7.91 (7.82-7.99)	0.5[d] (solution aged 3 hrs)	>2,000	**>3,793**	-	European Al Association 2009; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	10.6	7.89 (7.83-7.95)	0.5[d] (solution aged 27 hrs)	>2,000	**>3,812**	-	European Al Association 2009; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	60	6.04 (6.02-6.05)	0.5[d]	110.8	**867.5**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	60	5.98 (5.90-6.05)	2	1,137.1	**4,376**	-	European Al Association 2009

Species	Method[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	LC_{50} / EC_{50} (µg/L)	Normalized Acute Value[b] (µg/L)	Species Mean Acute Value (µg/L)	Reference
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	60	5.73 (5.39-6.06)	4	8,046.7	**34,704**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	60	6.71 (6.44-6.98)	0.5[d]	>10,000	**>26,800**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	60	7.83 (7.74-7.92)	0.5[d]	>5,000	**>5,975**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	60	6.79 (6.55-7.03)	2	>10,000	**>10,615**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	60	7.67 (7.41-7.92)	2	>15,000	**>8,154**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	60	6.68 (6.35-7.01)	4	>15,000	**>12,073**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	60	7.62 (7.35-7.89)	4	>15,000	**>5,487**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	120	6.06 (5.97-6.14)	2	3,386.8	**6,889**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	120	5.60 (5.22-5.97)	4	10,484.2	**34,985**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	120	6.93 (6.84-7.02)	0.5[d]	>5,000	**>7,361**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	120	7.88 (7.80-7.95)	0.5[d]	>5,000	**>4,896**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	120	6.76 (6.43-7.09)	2	>15,000	**>11,400**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	120	7.71 (7.46-7.95)	2	>15,000	**>6,471**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	120	6.60 (6.21-6.98)	4	>15,000	**>9,047**	-	European Al Association 2009
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U, T	Aluminum nitrate	120	7.60 (7.32-7.87)	4	>15,000	**>4,366**	-	European Al Association 2009

Species	Method[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	LC_{50} / EC_{50} (µg/L)	Normalized Acute Value[b] (µg/L)	Species Mean Acute Value (µg/L)	Reference
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, T	Aluminum nitrate	10.6	6.03 (6.02-6.03)	0.5[d] (stock solution not buffered)	119.71	**3,227**	-	European Al Association 2010
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, T	Aluminum nitrate	10.6	6.03 (6.02-6.03)	0.5[d] (stock solution buffered)	274.78	**7,407**	-	European Al Association 2010
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, T	Aluminum nitrate	10.6	6.03 (6.02-6.03)	0.5[d] (test solution MES buffered)	119.98	**3,234**	-	European Al Association 2010
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, T	Aluminum nitrate	10.6	6.07 (6.06-6.07)	0.5[d] (0.0 µM PO_4 in test solution)	92.495	**2,273**	-	European Al Association 2010
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, T	Aluminum nitrate	10.6	6.09 (6.08-6.09)	0.5[d] (12.0 µM PO_4 in test solution)	313.37	7,355[g]	-	European Al Association 2010
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, T	Aluminum nitrate	10.6	6.10 (6.09-6.11)	0.5[d] (60.0 µM PO_4 in test solution)	332.35	7,625[g]	-	European Al Association 2010
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, T	Aluminum nitrate	10.6	7.08 (7.06-7.09)	0.5[d] (test solution HCl buffered)	>886.4	**>3,528**	-	European Al Association 2010
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, T	Aluminum nitrate	10.6	7.79 (7.70-7.88)	0.5[d] (test solution HEPES buffered)	>4,278.3	**>8,625**	-	European Al Association 2010

Species	Method[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	LC_{50} / EC_{50} (µg/L)	Normalized Acute Value[b] (µg/L)	Species Mean Acute Value (µg/L)	Reference
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, T	Aluminum nitrate	10.6	7.53 (7.45-7.61)	0.5[d] (test solution NaOH adjusted)	132.04	**322.4**	-	European Al Association 2010
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, T	Aluminum nitrate	60.0	6.01 (5.99-6.03)	0.5[d] (stock solution not buffered)	463.26	**3,845**	-	European Al Association 2010
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, T	Aluminum nitrate	60.0	5.99 (5.98-5.99)	0.5[d] (stock solution buffered)	>859.0	**>7,415**	5,863	European Al Association 2010
Cladoceran (0-24 hr), *Ceriodaphnia reticulata*	S, U, T	Aluminum chloride	45.1	7.25 (6.8-7.7)	1.1[d]	2,800	3,070[f]	-	Shephard 1983
Cladoceran (0-24 hr), *Ceriodaphnia reticulata*	F, M, T	Aluminum chloride	45.1	6.0	1.1[d]	304	**1,967**	-	Shephard 1983
Cladoceran (0-24 hr), *Ceriodaphnia reticulata*	F, M, T	Aluminum chloride	4.0	5.5	1.1[d]	362	**53,910**	10,299	Shephard 1983
Cladoceran (0-24 hr), *Daphnia magna*	S, U, NR	Aluminum chloride	48.5 (44-53)	7.8 (7.4-8.2)	1.1[d]	3,900	**3,117**	-	Biesinger and Christensen 1972
Cladoceran (0-24 hr), *Daphnia magna*	S, M, T	Aluminum sulfate	220	7.60 (7.05-8.15)	1.6[d]	38,200	**15,625**	-	Kimball 1978
Cladoceran (0-24 hr), *Daphnia magna*	S, U, T	Aluminum chloride	45.1	7.25 (6.8-7.7)	1.1[d]	2,800	**3,070**	-	Shephard 1983
Cladoceran (<24 hr), *Daphnia magna*	S, U, T	Aluminum nitrate	168	5.99 (5.98-5.99)	0.5[d]	>500	**>2,075**	-	European Al Association 2009
Cladoceran (<24 hr), *Daphnia magna*	S, U, T	Aluminum nitrate	168	6.98 (6.97-6.98)	0.5[d]	>500	>598.9[c]	-	European Al Association 2009
Cladoceran (<24 hr), *Daphnia magna*	S, U, T	Aluminum nitrate	168	7.93 (7.92-7.94)	0.5[d]	>500	>449.2[c]	-	European Al Association 2009

Species	Method[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	LC_{50} / EC_{50} (µg/L)	Normalized Acute Value[b] (µg/L)	Species Mean Acute Value (µg/L)	Reference
Cladoceran (<24 hr), *Daphnia magna*	S, U, T	Aluminum nitrate	168	7.92 (7.90-7.93)	0.5[d]	795.0	**713.2**	-	European Al Association 2009
Cladoceran (<24 hr), *Daphnia magna*	S, U, T	Aluminum nitrate	168	7.95 (7.92-7.97)	2	>1,200	>472.9[c]	-	European Al Association 2009
Cladoceran (<24 hr), *Daphnia magna*	S, U, T	Aluminum nitrate	168	7.93 (7.92-7.94)	3	>1,200	>369.9[c]	2,944	European Al Association 2009
Cladoceran (adult), *Daphnia pulex*	R, U, T	Aluminum chloride	142 (±2)	8.2 (±1)	1.6[d]	3,650	**1,836**	1,836	Griffitt et al. 2008
Ostracod (adult, 1.5 mm, 0.3 mg), *Stenocypris major*	R, M, T	Aluminum sulfate	15.63 (±2.74)	6.51 (±0.01)	3.2	3,102	**8,000**	8,000	Shuhaimi-Othman et al. 2011a, 2013
Amphipod (4 mm), *Crangonyx pseudogracilis*	R, U, T	Aluminum sulfate	50 (45-55)	6.75 (6.7-6.8)	1.6[d]	9,190	**12,901**	12,901	Martin and Holdich 1986
Amphipod (juvenile, 7 d, 1.32 mm), *Hyalella azteca*	F, M, T	Aluminum nitrate	105 (103-108)	6.13 (6.09-6.16)	0.48	>5,997	**>27,766**	>27,766	Wang et al. 2016, 2018
Midge (3rd-4th instar larvae), *Chironomus plumosus*	S, U, T	Aluminum chloride	80	7.0 (±0.5)	1.6[d]	30,000	**25,216**	25,216	Fargasova 2001, 2003
Midge (2nd-3rd instar larvae), *Paratanytarsus dissimilis*	S, U, T	Aluminum sulfate	17.43	7.28 (6.85-7.71)	2.8[d]	>77,700	**>70,647**	>70,647	Lamb and Bailey 1981, 1983
Rainbow trout (alevin), *Oncorhynchus mykiss*	S, U, T	Aluminum sulfate	14.3	5.5	0.4	160	10,037[f]	-	Holtze 1983

Species	Method[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	LC_{50} / EC_{50} (µg/L)	Normalized Acute Value[b] (µg/L)	Species Mean Acute Value (µg/L)	Reference
Rainbow trout (alevin), *Oncorhynchus mykiss*	S, U, T	Aluminum sulfate	14.3	5.5	0.4	310	8,467[f]	-	Holtze 1983
Rainbow trout (fingerling), *Oncorhynchus mykiss*	S, M, T	Aluminum chloride	47.4 (±4.51)	6.59 (±0.15)	1.1[d]	7,400	13,495[f]	-	Call et al. 1984
Rainbow trout (fingerling), *Oncorhynchus mykiss*	S, M, T	Aluminum chloride	47.4 (±4.51)	7.31 (±0.89)	1.1[d]	14,600	11,879[f]	-	Call et al. 1984
Rainbow trout (fingerling), *Oncorhynchus mykiss*	S, M, T	Aluminum chloride	47.4 (±4.51)	8.17 (±0.42)	1.1[d]	>24,700	>7,664[f]	-	Call et al. 1984
Rainbow trout (fingerling), *Oncorhynchus mykiss*	S, M, T	Aluminum chloride	47.4 (±4.51)	7.46 (±0.14)	1.1[d] (18 d aged solution)	8,600	5,915[f]	-	Call et al. 1984
Rainbow trout (juvenile, 1-3 g), *Oncorhynchus mykiss*	F, M, T	Aluminum chloride	26.35 (25.3-27.4)	7.61 (7.58-7.64)	0.5[d]	>9,840	**>7,216**	-	Gundersen et al. 1994
Rainbow trout (juvenile, 1-3 g), *Oncorhynchus mykiss*	F, M, T	Aluminum chloride	45.5 (44.6-46.4)	7.59 (7.55-7.62)	0.5[d]	>8,070	**>5,766**	-	Gundersen et al. 1994
Rainbow trout (juvenile, 1-3 g), *Oncorhynchus mykiss*	F, M, T	Aluminum chloride	88.05 (86.6-89.5)	7.60 (7.58-7.62)	0.5[d]	>8,160	**>5,390**	-	Gundersen et al. 1994
Rainbow trout (juvenile, 1-3 g), *Oncorhynchus mykiss*	F, M, T	Aluminum chloride	127.6 (124.8-130.4)	7.61 (7.58-7.64)	0.5[d]	>8,200	**>5,164**	-	Gundersen et al. 1994
Rainbow trout (juvenile, 1-3 g), *Oncorhynchus mykiss*	F, M, T	Aluminum chloride	23.25 (21.9-24.6)	8.28 (7.97-8.58)	0.5[d]	6,170	**1,685**	-	Gundersen et al. 1994
Rainbow trout (juvenile, 1-3 g), *Oncorhynchus mykiss*	F, M, T	Aluminum chloride	35.4 (33.1-37.7)	8.30 (8.02-8.58)	0.5[d]	6,170	**1,680**	-	Gundersen et al. 1994
Rainbow trout (juvenile, 1-3 g), *Oncorhynchus mykiss*	F, M, T	Aluminum chloride	83.6 (83.0-84.2)	8.31 (8.06-8.56)	0.5[d]	7,670	**2,180**	-	Gundersen et al. 1994

Species	Method[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	LC_{50} / EC_{50} (µg/L)	Normalized Acute Value[b] (µg/L)	Species Mean Acute Value (µg/L)	Reference
Rainbow trout (juvenile, 1-3 g), *Oncorhynchus mykiss*	F, M, T	Aluminum chloride	128.5 (112.5-144.5)	8.31 (8.06-8.56)	0.5[d]	6,930	**2,026**	3,312	Gundersen et al. 1994
Atlantic salmon (sac fry, ≈0.2 g), *Salmo salar*	S, U, T	Aluminum chloride	6.8 (6.6-7.0)	5.5	0.5[d]	584	**20,749**	-	Hamilton and Haines 1995
Atlantic salmon (sac fry, ≈0.2 g), *Salmo salar*	S, U, T	Aluminum chloride	6.8 (6.6-7.0)	6.5	0.5[d]	599	**3,599**	8,642	Hamilton and Haines 1995
Brook trout (14 mo., 210 mm, 130 g), *Salvelinus fontinalis*	F, M, T	Aluminum sulfate	-	6.5	-	3,600	NA[e]	-	Decker and Menendez 1974
Brook trout (14 mo., 210 mm, 130 g), *Salvelinus fontinalis*	F, M, T	Aluminum sulfate	-	6.0	-	4,400	NA[e]	-	Decker and Menendez 1974
Brook trout (14 mo., 210 mm, 130 g), *Salvelinus fontinalis*	F, M, T	Aluminum sulfate	-	5.5	-	4,000	NA[e]	-	Decker and Menendez 1974
Brook trout (0.6 g, 4.4-7.5 cm), *Salvelinus fontinalis*	S, U, T	Aluminum sulfate	40	5.6	1.6[d]	6,530	**30,038**	-	Tandjung 1982
Brook trout (0.6 g, 4.4-7.5 cm), *Salvelinus fontinalis*	S, U, T	Aluminum sulfate	18	5.6	1.6[d]	3,400	**24,514**	-	Tandjung 1982
Brook trout (0.6 g, 4.4-7.5 cm), *Salvelinus fontinalis*	S, U, T	Aluminum sulfate	2	5.6	1.6[d]	370	**9,187**	18,913	Tandjung 1982

Species	Method[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	LC_{50} / EC_{50} (µg/L)	Normalized Acute Value[b] (µg/L)	Species Mean Acute Value (µg/L)	Reference
Green sunfish (juvenile, 3 mo.), *Lepomis cyanellus*	S, M, T	Aluminum chloride	47.4 (±4.51)	7.55 (±0.13)	1.1[d]	>50,000	**>31,087**	>31,087	Call et al. 1984
Guppy, *Poecilia reticulata*	R, M, T	Aluminum sulfate	18.72 (±1.72)	6.68 (±0.2)	3.2	6,760	**9,061**	9,061	Shuhaimi-Othman et al. 2013
Rio Grande silvery minnow (larva, 3-5 dph), *Hybognathus amarus*	R, M, T	Aluminum chloride	140	8.1 (7.9-8.4)	0.5[d]	>59,100	**>21,779**	>21,779	Buhl 2002
Fathead minnow (adult), *Pimephales promelas*	S, U, NR	Aluminum sulfate	-	7.6	-	>18,900	NA[e]	-	Boyd 1979
Fathead minnow (juvenile, 32-33 d), *Pimephales promelas*	S, M, T	Aluminum chloride	47.4 (±4.51)	7.61	1.1[d]	>48,200	**>28,019**	-	Call et al. 1984
Fathead minnow (juvenile, 32-33 d), *Pimephales promelas*	S, M, T	Aluminum chloride	47.4 (±4.51)	8.05	1.1[d]	>49,800	**>17,678**	-	Call et al. 1984
Fathead minnow (juvenile, 11 mm, 3 mg dw), *Pimephales promelas*	F, U, T	Aluminum chloride	21.6 (±1.31)	6.5 (±0.2)	0.9	>400	>1,181[c]	-	Palmer et al. 1989
Fathead minnow (juvenile, 11 mm, 3 mg dw), *Pimephales promelas*	F, U, T	Aluminum chloride	21.6 (±1.31)	7.5 (±0.2)	0.9	>400	>304.5[c]	-	Palmer et al. 1989
Fathead minnow (larva, 7 mm, 0.31 mg, 12 dph), *Pimephales promelas*	F, U, T	Aluminum chloride	21.6 (±1.31)	7.5 (±0.2)	0.9	>400	>304.5[c]	-	Palmer et al. 1989
Fathead minnow (yolk-sac larva, 1 dph), *Pimephales promelas*	F, U, T	Aluminum chloride	21.6 (±1.31)	6.5 (±0.2)	0.9	>400	>1,181[c]	-	Palmer et al. 1989

Species	Method[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	LC_{50} / EC_{50} (µg/L)	Normalized Acute Value[b] (µg/L)	Species Mean Acute Value (µg/L)	Reference
Fathead minnow (yolk-sac larva, 1 dph), *Pimephales promelas*	F, U, T	Aluminum chloride	21.6 (±1.31)	7.5 (±0.2)	0.9	>400	>304.5[c]	-	Palmer et al. 1989
Fathead minnow (larva, 4-6 dph), *Pimephales promelas*	R, M, T	Aluminum chloride	140	8.1 (7.9-8.4)	0.5[d]	>59,100	**>21,779**	>22,095	Buhl 2002
Smallmouth bass (larva, 48 hr post hatch), *Micropterus dolomieui*	S, M, T	Aluminum sulfate	12.15 (12.1-12.2)	5.05 (4.7-5.4)	1.6[d]	130	**2,442**	-	Kane 1984; Kane and Rabeni 1987
Smallmouth bass (larva, 48 hr post hatch), *Micropterus dolomieui*	S, M, T	Aluminum sulfate	12.4 (12.0-12.8)	6.25 (6.0-6.5)	1.6[d]	>978.4	**>3,655**	-	Kane 1984; Kane and Rabeni 1987
Smallmouth bass (larva, 48 hr post hatch), *Micropterus dolomieui*	S, M, T	Aluminum sulfate	12.0	7.5 (7.2-7.8)	1.6[d]	>216.8	>153.4[c]	2,988	Kane 1984; Kane and Rabeni 1987
Green tree frog (tadpole, <1 dph), *Hyla cinerea*	R, M, T	Aluminum chloride	4.55	5.49 (5.48-5.50)	0.5[d]	>405.2	**>18,563**	>18,563	Jung and Jagoe 1995

[a] S=static, F=flow-through, U=unmeasured, M=measured, A=acid exchangeable aluminum, T=total aluminum, D=dissolved aluminum, NR=not reported.

[b] Normalized to pH 7, total hardness of 100 mg/L as $CaCO_3$ and DOC of 1.0 mg/L (see Section 2.7.1). Values in bold are used in SMAV calculations.

[c] Not used to calculate SMAV because either a more definitive value is available or value is considered an outlier.

[d] When definitive DOC values were not reported by the authors: a DOC value of 0.5 mg/L was used when dilution water was reconstituted, 1.1 mg/L when dilution water was Lake Superior, MN water, 2.8 mg/L when dilution water was Liberty Lake, WA water, 1.6 mg/L when dilution water was tap or well water, or half the detection limit when the reported value was less than the detection limit, based on recommendations in the 2007 Freshwater Copper AWQC (U.S. EPA 2007b).

[e] Missing water quality parameters and/or dilution water type needed to estimate water quality parameters, so values cannot be normalized.

[f] Not used to calculate SMAV because flow-through measured test(s) available.

[g] Phosphate in exposure media is providing an ameliorating effect against aluminum.

Appendix B ACCEPTABLE ACUTE TOXICITY DATA OF ALUMINUM TO ESTUARINE/MARINE AQUATIC ANIMALS

NMED Exhibit 75

Appendix B. Acceptable Acute Toxicity Data of Aluminum to Estuarine/Marine Aquatic Animals
(Bold values are used in SMAV calculation).
(Species are organized phylogenetically).

Species	Method[a]	Chemical	Salinity (g/kg)	pH	LC_{50} / EC_{50} (µg/L)	Species Mean Acute Value (µg/L)	Reference
Polychaete worm, *Capitella capitata*	S, U	Aluminum chloride	-	-	**404.8**	404.8	Petrich and Reish 1979
Polychaete worm, *Ctenodrilus serratus*	S, U	Aluminum chloride	-	-	**97.15**	97.15	Petrich and Reish 1979
Polychaete worm, *Neanthes arenaceodentata*	S, U	Aluminum chloride	-	-	**>404.8**	>404.8	Petrich and Reish 1979
Copepod (adult), *Nitokra spinipes*	S, U	Aluminum chloride	7	8	**10,000**	10,000	Bengtsson 1978
American oyster (fertilized eggs, ≤1 hr), *Crassostrea virginica*	S, U	Aluminum chloride	25	7.0-8.5	**>1,518**	>1,518	Calabrese et al. 1973

[a] S=static, F=flow-through, U=unmeasured, M=measured.

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Appendix C ACCEPTABLE CHRONIC TOXICITY DATA OF ALUMINUM TO FRESHWATER AQUATIC ANIMALS

NMED Exhibit 75

Appendix C. Acceptable Chronic Toxicity Data of Aluminum to Freshwater Aquatic Animals
(Bold values are used in SMCV calculation).
(Species are organized phylogenetically).

Species	Test[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	EC_{20} Endpoint	EC_{20} (µg/L)	Normalized Chronic Value[b] (µg/L)	Species Mean Chronic Value (µg/L)	Reference
Oligochaete (<24 hr), *Aeolosoma sp.*	17 d	Aluminum nitrate	48	5.95 (5.8-6.1)	<0.5[c]	Reproduction (population size)	1,235	**20,514**	20,514	OSU 2012e; Cardwell et al. 2018
Rotifer (newly hatched, <2 hr), *Brachionus calyciflorus*	48 hr	Aluminum nitrate	100	6.45 (6.4-6.5)	<0.5[c]	Reproduction (population size)	431.0	**1,845**	-	OSU 2012c; Cardwell et al. 2018
Rotifer (newly hatched, <2 hr), *Brachionus calyciflorus*	48 hr	Aluminum nitrate	63	6.3 (5.98-6.56)	1.39	Reproduction (population size)	1,751	**4,518**	-	OSU 2018e
Rotifer (newly hatched, <2 hr), *Brachionus calyciflorus*	48 hr	Aluminum nitrate	105	6.3 (6.02-6.55)	1.39	Reproduction (population size)	2,066	**3,844**	-	OSU 2018e
Rotifer (newly hatched, <2 hr), *Brachionus calyciflorus*	48 hr	Aluminum nitrate	114	6.2 (5.98-6.47)	2.63	Reproduction (population size)	3,061	**4,323**	-	OSU 2018e
Rotifer (newly hatched, <2 hr), *Brachionus calyciflorus*	48 hr	Aluminum nitrate	105	6.1 (5.89-6.63)	3.77	Reproduction (population size)	4,670	**6,653**	-	OSU 2018e
Rotifer (newly hatched, <2 hr), *Brachionus calyciflorus*	48 hr	Aluminum nitrate	185	6.3 (6.05-6.54)	1.33	Reproduction (population size)	1,604	**2,132**	3,539	OSU 2018e
Great pond snail (newly-hatched, <24 hr), *Lymnaea stagnalis*	30 d	Aluminum nitrate	117	6.0 (5.6-6.4)	<0.5[c]	Biomass	745.7	**5,945**	-	OSU 2012b; Cardwell et al. 2018

Species	Test[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	EC_{20} Endpoint	EC_{20} (µg/L)	Normalized Chronic Value[b] (µg/L)	Species Mean Chronic Value (µg/L)	Reference
Great pond snail (newly-hatched, <24 hr), *Lymnaea stagnalis*	30 d	Aluminum nitrate	121 (121-122)	6.15 (6.08-6.45)	1.37 (1.29-1.45)	Biomass	833.4	**1,812**	-	OSU 2018f
Great pond snail (newly-hatched, <24 hr), *Lymnaea stagnalis*	30 d	Aluminum nitrate	124 (121-127)	6.17 (6.06-6.41)	1.45 (1.38-1.51)	Biomass	1,951	**3,902**	-	OSU 2018f
Great pond snail (newly-hatched, <24 hr), *Lymnaea stagnalis*	30 d	Aluminum nitrate	117 (116-118)	5.98 (5.86-6.16)	3.85 (3.60-4.20)	Biomass	1,392	**2,251**	3,119	OSU 2018f
Fatmucket (6 wk, 1.97 mm), *Lampsilis siliquoidea*	28 d	Aluminum nitrate	105.5 (105-106)	6.04 (5.95-6.12)	0.40 (0.34-0.45)	Biomass	169	**1,026**	1,026	Wang et al. 2016, 2018
Cladoceran (≤16 hr), *Ceriodaphnia dubia*	LC	Aluminum chloride	50	7.15 (±0.05)	1.1[c]	Reproduction (young/adult)	1,780	**2,031**	-	McCauley et al. 1986
Cladoceran (≤16 hr), *Ceriodaphnia dubia*	LC	Aluminum chloride	50.5	7.61 (±0.11)	1.1[c]	Reproduction (young/adult)	<1,100 (MATC)	<925.5[f]	-	McCauley et al. 1986
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum chloride	25 (24-26)	7.65 (7.3-8.0)	0.5[c]	Reproduction (young/female)	1,557	**2,602**	-	ENSR 1992b
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum chloride	47 (46-48)	7.7 (7.3-8.1)	0.5[c]	Reproduction (young/female)	808.7	**1,077**	-	ENSR 1992b
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum chloride	94 (92-96)	8.2 (7.9-8.5)	0.5[c]	Reproduction (young/female)	647.2	**708.8**	-	ENSR 1992b
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum chloride	196 (194-198)	8.45 (8.1-8.8)	0.5[c]	Reproduction (young/female)	683.6	**746.8**	-	ENSR 1992b
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	25	6.34	0.5[c]	Reproduction	36.6	**291.7**	-	European Al Association 2010; Gensemer et al. 2018

Species	Test[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	EC_{20} Endpoint	EC_{20} (µg/L)	Normalized Chronic Value[b] (µg/L)	Species Mean Chronic Value (µg/L)	Reference
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	60	6.4	0.5[c]	Reproduction	160.3	**667.9**	-	European Al Association 2010; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	120	6.38	0.5[c]	Reproduction	221.6	**619.4**	-	European Al Association 2010; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	25	6.34	2	Reproduction	377.4	**1,315**	-	European Al Association 2010; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	60	6.38	2	Reproduction	631.3	**1,187**	-	European Al Association 2010; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	120	6.37	2	Reproduction	1,011.6	**1,254**	-	European Al Association 2010; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	25	6.33	4	Reproduction	622.6	**1,460**	-	European Al Association 2010; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	60	6.3	4	Reproduction	692.9	**981.4**	-	European Al Association 2010; Gensemer et al. 2018

Species	Test[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	EC_{20} Endpoint	EC_{20} (µg/L)	Normalized Chronic Value[b] (µg/L)	Species Mean Chronic Value (µg/L)	Reference
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	120	6.38	4	Reproduction	840.5	**678.9**	-	European Al Association 2010; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	25	6.37	2	Reproduction	353.0	**1,164**	-	Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	25	6.34	2	Reproduction	452.4	**1,576**	-	Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	25	6.35	2	Reproduction	439.7	**1,504**	-	Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	25	7.04	0.5	Reproduction (young/female)	250	**701.1**	-	CECM 2014; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	120	7.14	0.5	Reproduction (young/female)	860	**1,072**	-	CECM 2014; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	25	7.98	0.5	Reproduction (young/female)	700	**1,029**	-	CECM 2014; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	60	8.03	0.5	Reproduction (young/female)	1,010	**1,189**	-	CECM 2014; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	120	8.1	0.5	Reproduction (young/female)	870	**879.6**	-	CECM 2014; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	25	6.34	0.5	Reproduction (young/female)	260	**2,072**	-	CECM 2014; Gensemer et al. 2018
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	120	6.36	0.5	Reproduction (young/female)	390	**1,122**	-	CECM 2014; Gensemer et al. 2018

Species	Test[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	EC_{20} Endpoint	EC_{20} (µg/L)	Normalized Chronic Value[b] (µg/L)	Species Mean Chronic Value (µg/L)	Reference
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	64	6.42	1.87	Reproduction (young/female)	828.6	**1,463**	-	OSU 2018a
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	133	6.325	8.71	Reproduction (young/female)	3,829	**1,973**	-	OSU 2018a
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	138	6.395	12.3	Reproduction (young/female)	6,224	**2,308**	-	OSU 2018a
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	428	6.295	1.64	Reproduction (young/female)	2,011	**1,388**	-	OSU 2018a
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	125	7.205	6.57	Reproduction (young/female)	6,401	**1,614**	-	OSU 2018a
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	127	7.185	12.01	Reproduction (young/female)	6,612	**1,170**	-	OSU 2018a
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	263	8.17	1.3	Reproduction (young/female)	3,749	**1,854**	-	OSU 2018a
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	425	8.21	1.2	Reproduction (young/female)	2,852	**1,372**	-	OSU 2018a
Cladoceran (<24 hr), *Ceriodaphnia dubia*	LC	Aluminum nitrate	125	8.7	1.04	Reproduction (young/female)	1,693	**1,530**	1,181	OSU 2018a
Cladoceran (<24 hr), *Daphnia magna*	LC	Aluminum nitrate	140	6.3	2	Reproduction (young/female)	791.0	**985.3**	985.3	European Al Association 2010; Gensemer et al. 2018
Amphipod (juvenile, 7-9 d), *Hyalella azteca*	28 d	Aluminum nitrate	95	6.35 (6.0-6.7)	0.51	Biomass	199.3	**665.9**	-	OSU 2012h; Cardwell et al. 2018
Amphipod (juvenile, 7 d, 1.31 mm), *Hyalella azteca*	28 d	Aluminum nitrate	106 (105-107)	6.04 (5.92-6.16)	0.33 (0.26-0.39)	Biomass	425	**2,890**	1,387	Wang et al. 2016, 2018

Species	Test[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	DOC (mg/L)	EC_{20} Endpoint	EC_{20} (µg/L)	Normalized Chronic Value[b] (µg/L)	Species Mean Chronic Value (µg/L)	Reference
Midge (1st instar larva, <24 hr), *Chironomus riparius*	30 d	Aluminum sulfate	11.8	5.58 (5.51-5.64)	1.8[e]	Adult midge emergence	29.55	**1,075**	-	Palawski et al. 1989
Midge (1st instar larva, <24 hr), *Chironomus riparius*	30 d	Aluminum sulfate	11.9	5.05 (4.99-5.1)	1.8[e]	Adult midge emergence	84.42	**15,069**	-	Palawski et al. 1989
Midge (1st instar larva, 3d), *Chironomus riparius*	28 d	Aluminum nitrate	91	6.6 (6.3-6.9)	0.51	Reproduction (# of eggs/case)	3,387	**8,181**	5,099	OSU 2012f; Cardwell et al. 2018
Atlantic salmon (embryo), *Salmo salar*	ELS	Aluminum sulfate	12.7	5.7 (5.6-5.8)	1.8[e]	Biomass	61.56	**434.4**	-	McKee et al. 1989
Atlantic salmon (fertilized eggs), *Salmo salar*	ELS	Aluminum sulfate	12.7	5.7 (5.6-5.8)	1.8[e]	Survival	154.2	1,088[d]	434.4	Buckler et al. 1995
Brook trout (eyed eggs), *Salvelinus fontinalis*	ELS	Aluminum sulfate	12.3	6.55 (6.5-6.6)	1.9	Biomass	164.4	**378.7**	-	Cleveland et al. 1989
Brook trout (eyed eggs), *Salvelinus fontinalis*	ELS	Aluminum sulfate	12.8	5.65 (5.6-5.7)	1.8	Biomass	143.5	**1,076**	638.2	Cleveland et al. 1989
Fathead minnow, *Pimephales promelas*	ELS	Aluminum sulfate	220	7.70 (7.27-8.15)	1.6[c]	Biomass	6,194	**2,690**	-	Kimball 1978
Fathead minnow (embryo, <24 hr), *Pimephales promelas*	ELS	Aluminum nitrate	96	6.20 (5.9-6.5)	<0.5[c]	Survival	428.6	**2,154**	2,407	OSU 2012g; Cardwell et al. 2018
Zebrafish (embryo, <36hpf), *Danio rerio*	ELS	Aluminum nitrate	83	6.15 (6.0-6.3)	<0.5[c]	Biomass	234.4	**1,342**	1,342	OSU 2013; Cardwell et al. 2018

[a] LC=Life cycle, ELS=Early life-stage.
[b] Normalized to pH 7, total hardness of 100 mg/L as $CaCO_3$ and DOC of 1.0 mg/L (see Section 2.7.1). Values in bold are used in SMCV calculations.
[c] When definitive DOC values were not reported by the authors: a DOC value of 0.5 mg/L was used when dilution water was reconstituted, 1.1 mg/L when dilution water was Lake Superior water, 1.6 mg/L when dilution water was tap or well water, or half the detection limit when the reported value was less than the detection limit, based on recommendations in the 2007 Freshwater Copper AWQC (U.S. EPA 2007b).
[d] Buckler et al. (1995) appears to be a republication of McKee et al. (1989), but does not report the most sensitive endpoint and therefore only the most sensitive endpoint used for calculation of the SMCV.
[e] DOC was taken from reported values in Cleveland et al. (1989) for a similar pH; all studies are from the same lab and used the same procedures to make the dilution water (well water plus reverse osmosis water mixture).
[f] Value is a MATC, poor dose response prevented an EC_{20} from being calculated; not used in SMCV calculation.

NMED Exhibit 75

Appendix D ACCEPTABLE CHRONIC TOXICITY DATA OF ALUMINUM TO ESTUARINE/MARINE AQUATIC ANIMALS

NMED Exhibit 75

Appendix D. Acceptable Chronic Toxicity Data of Aluminum to Estuarine/Marine Aquatic Animals

Species	Duration	Chemical	Salinity (g/kg)	pH	Chronic Limits (µg/L)	Chronic Value (µg/L)	Effect	Species Mean Chronic Value (µg/L)	Reference
Estuarine/Marine Species									

There are no acceptable estuarine/marine chronic toxicity data for aluminum.

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Appendix E ACCEPTABLE TOXICITY DATA OF ALUMINUM TO FRESHWATER AQUATIC PLANTS

NMED Exhibit 75

Appendix E. Acceptable Toxicity Data of Aluminum to Freshwater Aquatic Plants

Species	Method[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Freshwater Species									
Green alga, *Arthrodesmus octocornus*	S, M	-	-	5.7	21 d	LOEC (number of semicells)	-	50	Pillsbury and Kingston 1990
Green alga, *Arthrodesmus indentatus*	S, M	-	-	5.7	21 d	LOEC (number of semicells)	-	50	Pillsbury and Kingston 1990
Green alga, *Arthrodesmus quiriferus*	S, M	-	-	5.7	21 d	LOEC (number of semicells)	-	50	Pillsbury and Kingston 1990
Green alga, *Dinobryon bavaricum*	S, M	-	-	5.7	21 d	NOEC (number of cells)	-	>200	Pillsbury and Kingston 1990
Green alga, *Elaktothrix sp.*	S, M	-	-	5.7	21 d	Number of cells	100-200	141.4	Pillsbury and Kingston 1990
Green alga, *Oedogonium sp.*	S, M	-	-	5.7	21 d	NOEC (number of cells)	-	>200	Pillsbury and Kingston 1990
Green alga, *Peridinium limbatum*	S, M	-	-	5.7	21 d	NOEC (number of cells)	-	>200	Pillsbury and Kingston 1990
Green alga, *Staurastrum arachne v. curvatum*	S, M	-	-	5.7	21 d	LOEC (number of semicells)	-	50	Pillsbury and Kingston 1990

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Species	Method[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Green alga, *Staurastrum longipes v. contractum*	S, M	-	-	5.7	21 d	LOEC (number of semicells)	-	50	Pillsbury and Kingston 1990
Green alga, *Staurastrum pentacerum*	S, M	-	-	5.7	21 d	LOEC (number of semicells)	-	50.0	Pillsbury and Kingston 1990
Green alga, *Mougeotia sp.*	S, U	Aluminum sulfate	-	4.1	14 d	NOEC (chlorophyll a)	-	3,600	Graham et al. 1996
Green alga, *Monoraphidium dybowskii*	S, U	Aluminum chloride	-	5.0	12 d	EC50 (growth)	-	1,000	Claesson and Tornqvist 1988
Green alga, *Monoraphidium dybowskii*	S, U	Aluminum chloride	-	5.5	12 d	EC50 (growth)	-	1,000	Claesson and Tornqvist 1988
Green alga, *Monoraphidium dybowskii*	S, U	Aluminum chloride	-	6.0	12 d	EC50 (growth)	-	550	Claesson and Tornqvist 1988
Green alga, *Monoraphidium dybowskii*	S, U	Aluminum chloride	14.9	4.8	4 d	Growth	600-1,000	774.6	Hornstrom et al. 1995
Green alga, *Monoraphidium dybowskii*	S, U	Aluminum chloride	14.9	6.8	4 d	LOEC (growth)	-	200	Hornstrom et al. 1995
Green alga, *Monoraphidium griffithii*	S, U	Aluminum chloride	14.9	4.8	4 d	LOEC (growth)	-	100	Hornstrom et al. 1995
Green alga, *Monoraphidium griffithii*	S, U	Aluminum chloride	14.9	6.8	4 d	LOEC (growth)	-	100	Hornstrom et al. 1995

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Species	Method[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Green alga, *Scenedesmus quadricauda*	S, U	Aluminum chloride	-	7.5	4 d	LOEC (growth inhibition)	-	1,500	Bringmann and Kuhn 1959b
Green alga, *Pseudokirchneriella subcapitata*	-	Sodium aluminate	15	7.0	14 d	Reduce cell counts and dry weight	990-1,320	1,143	Peterson et al. 1974
Green alga, *Pseudokirchneriella subcapitata*	S, U	Aluminum chloride	47.4 (±4.51)	7.6	4 d	EC50 (biomass)	-	570	Call et al. 1984
Green alga, *Pseudokirchneriella subcapitata*	S, U	Aluminum chloride	47.4 (±4.51)	8.2	4 d	EC50 (biomass)	-	460	Call et al. 1984
Green alga, *Pseudokirchneriella subcapitata*	S, U	Aluminum sulfate	-	5.5	4 d	LOEC (growth inhibition)	-	160	Kong and Chen 1995
Green alga, *Stichococcus sp.*	S, U	Aluminum chloride	-	5.0	9 d	IC50 (growth rate)	-	560	Tornqvist and Claesson 1987
Green alga, *Stichococcus sp.*	S, U	Aluminum chloride	-	5.0	9 d	EC50 (growth)	-	500	Claesson and Tornqvist 1988
Green alga, *Stichococcus sp.*	S, U	Aluminum chloride	-	5.5	9 d	EC50 (growth)	-	220	Claesson and Tornqvist 1988
Diatom, *Asterionella ralfsii var. americana*	S, M	Aluminum chloride	-	5.0	7-9 d	Growth	404.7-620.5	501.1	Gensemer 1989
Diatom, *Asterionella ralfsii var. americana*	S, M	Aluminum chloride	-	6.0	7-9 d	Growth	404.7-647.5	511.9	Gensemer 1989

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Species	Method[a]	Chemical	Total Hardness (mg/L as $CaCO_3$)	pH	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Diatom, *Asterionella ralfsii var. americana*	S, M	-	-	5.7	21 d	LOEC (number of live cells)	-	50	Pillsbury and Kingston 1990
Diatom, *Cyclotella meneghiniana*	S, U	Aluminum chloride	-	7.9	16 d	Partially inhibit growth	-	809.6	Rao and Subramanian 1982
Diatom, *Cyclotella meneghiniana*	S, U	Aluminum chloride	-	7.9	16 d	Algistatic	-	3,238	Rao and Subramanian 1982
Diatom, *Cyclotella meneghiniana*	S, U	Aluminum chloride	-	7.9	16 d	Algicidal	-	6,477	Rao and Subramanian 1982
Eurasian watermilfoil, *Myriophyllum spicatum*	S, U	-	95.93	-	32 d	IC50 (root dry weight)	-	2,500	Stanley 1974
Duckweed, *Lemna minor*	S, M	Aluminum chloride	47.4 (±4.51)	7.6	4 d	NOEC (reduce frond production)	-	>45,700	Call et al. 1984
Duckweed, *Lemna minor*	S, M	Aluminum chloride	47.4 (±4.51)	8.2	4 d	NOEC (reduce frond production)	-	>45,700	Call et al. 1984

[a] S=static, F=flow-through, U=unmeasured, M=measured.

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Appendix F ACCEPTABLE TOXICITY DATA OF ALUMINUM TO ESTUARINE/MARINE AQUATIC PLANTS

NMED Exhibit 75

Appendix F. Acceptable Toxicity Data of Aluminum to Estuarine/Marine Aquatic Plants

Species	Method[a]	Chemical	Salinity (g/kg)	pH	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Estuarine/Marine Species									
Seagrass, *Halophila stipulacea*	R, U	-	35.0	6.5-7.0	12 d	Observed protoplast necrosis	0.02698-0.2698	0.08532	Malea and Haritonidis 1996
Seagrass, *Halophila stipulacea*	R, U	-	35.0	6.5-7.0	12 d	Greater than 50% mortality of teeth cells	-	269.8	Malea and Haritonidis 1996
Seagrass, *Halophila stipulacea*	R, U	-	35.0	6.5-7.0	12 d	Less than 50% mortality of teeth cells	-	26.98	Malea and Haritonidis 1996

[a] S=static, F=flow-through, U=unmeasured, M=measured.

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Appendix G ACCEPTABLE BIOACCUMULATION DATA OF ALUMINUM BY AQUATIC ORGANISMS

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Appendix G. Acceptable Bioaccumulation Data of Aluminum by Aquatic Organisms

Species	Lifestage	Chemical	Concentration in water (µg/L)	Total Hardness (mg/L as $CaCO_3$)	pH	Tissue	Duration	BCF or BAF	Reference
Freshwater Species									
Snail, *Lymnaea stagnalis*	-	Aluminum nitrate	242	208	7	Digestive gland	30 d	4.26	Dobranskyte et al. 2004
Snail, *Lymnaea stagnalis*	-	Aluminum nitrate	242	208	7	Soft tissue	15 d	2.29	Dobranskyte et al. 2004
Brook trout, *Salvelinus fontinalis*	30 d	Aluminum sulfate	214.0	~12.5	5.3	Whole body	14 d	142	Cleveland et al. 1991a
Brook trout, *Salvelinus fontinalis*	30 d	Aluminum sulfate	223.5	~12.5	6.1	Whole body	14 d	104	Cleveland et al. 1991a
Brook trout, *Salvelinus fontinalis*	30 d	Aluminum sulfate	267.6	~12.5	7.2	Whole body	56 d	14.2	Cleveland et al. 1991a
Atlantic salmon, *Salmo salar*	larva	Aluminum sulfate	33	12.8	5.5	Whole body	60 d (embryo to post-hatch)	76	Buckler et al. 1995
Atlantic salmon, *Salmo salar*	larva	Aluminum sulfate	71	12.8	5.5	Whole body	60 d (embryo to post-hatch)	154	Buckler et al. 1995
Atlantic salmon, *Salmo salar*	larva	Aluminum sulfate	124	12.8	5.5	Whole body	60 d (embryo to post-hatch)	190	Buckler et al. 1995
Species	**Lifestage**	**Chemical**	**Concentration in water (µg/L)**	**Salinity (g/kg)**	**pH**	**Tissue**	**Duration**	**BCF or BAF**	**Reference**
Estuarine/Marine Species									

There are no acceptable estuarine/marine bioaccumulation data for aluminum.

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Appendix H OTHER DATA ON EFFECTS OF ALUMINUM TO FRESHWATER AQUATIC ORGANISMS

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Appendix H. Other Data on Effects of Aluminum to Freshwater Aquatic Organisms

Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Freshwater Species								
Planktonic communities	Aluminum sulfate	1 hr	-	6.1-6.9	Decreased phosphate uptake and photosynthesis	50	Nalewajko and Paul 1985	Community exposure
Algal community	Aluminum sulfate	28 d	-	4.8	Growth	100-500 (NOEC-LOEC)	Genter and Amyot 1994	Community exposure
Microcosm community	Aluminum chloride	21 d	-	-	Production rate	2,000-5,000 (NOEC-LOEC)	Sugiura 2001	Community exposure
Blue-green alga, *Aphanizomenon flos-aquae*	Aluminum sulfate	22 hr	12.6	8.0	IC50 (nitrogen fixation)	>3,942	Peterson et al. 1995	Duration
Green alga, *Dunaliella acidophila*	Aluminum chloride	4-5 d	-	1.0	IC50 (photosynthesis)	>269,800	Gimmler et al. 1991	Lack of exposure details
Green alga, *Dunaliella acidophila*	Aluminum chloride	4-5 d	-	7.0	IC50 (photosynthesis)	134,900	Gimmler et al. 1991	Lack of exposure details
Green alga, *Dunaliella acidophila*	Aluminum chloride	4-5 d	-	1.0	IC50 (growth)	>269,800	Gimmler et al. 1991	Lack of exposure details
Green alga, *Dunaliella parva*	Aluminum chloride	4-5 d	-	7.0	IC50 (photosynthesis)	26,980	Gimmler et al. 1991	Lack of exposure details
Green alga, *Dunaliella parva*	Aluminum chloride	4-5 d	-	5.5	IC50 (growth)	1,619	Gimmler et al. 1991	Lack of exposure details
Green alga, *Chlorella sp.*	Aluminum sulfate	72 hr	1.0 (DOC = 1 mg/L)	5.0	IC50 (growth)	275	Trenfield et al. 2012	Duration
Green alga, *Chlorella sp.*	Aluminum sulfate	72 hr	1.0 (DOC = 2 mg/L)	5.0	IC50 (growth)	613	Trenfield et al. 2012	Duration
Green alga, *Chlorella sp.*	Aluminum sulfate	72 hr	4.1 (DOC = 1 mg/L)	5.0	IC50 (growth)	437	Trenfield et al. 2012	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Green alga, *Chlorella sp.*	Aluminum sulfate	72 hr	4.1 (DOC = 2 mg/L)	5.0	IC50 (growth)	801	Trenfield et al. 2012	Duration
Green alga, *Chlorella pyrenoidosa*	Aluminum sulfate	26 d	-	4.6	Reduced growth	6,000-12,000 (NOEC-LOEC)	Foy and Gerloff 1972	pH too low
Green alga, *Chlorella pyrenoidosa*	Aluminum chloride	5 d	-	5.0	Growth	50-100 (NOEC-LOEC)	Parent and Campbell 1994	pH too low
Green alga, *Chlorella vulgaris*	Aluminum chloride	3-4 mo.	-	<7.0	Inhibited growth	4,000	De Jong 1965	Lack of exposure details
Green alga, *Chlorella vulgaris*	Aluminum chloride	15 d	-	6.8	LC50	107,952	Rai et al. 1998	Lack of exposure details
Green alga, *Chlorella vulgaris*	Aluminum chloride	15 d	-	6.0	LC50	5,937	Rai et al. 1998	Lack of exposure details
Green alga, *Chlorella vulgaris*	Aluminum chloride	3 d	-	4.5	LC50	4,048	Rai et al. 1998	Lack of exposure details
Green alga, *Monoraphidium dybowskii*	Aluminum chloride	9 d	-	5.0	IC56 (growth rate)	1,800	Tornqvist and Claesson 1987	Atypical endpoint
Green alga, *Monoraphidium dybowskii*	Aluminum chloride	9 d	-	5.0	IC42 (growth rate)	560	Tornqvist and Claesson 1987	Atypical endpoint
Green alga, Desmo*desmus subspicatus*	Aluminum chloride	72 hr	-	-	EC50 (growth) - flask	2,206	Eisentraeger et al. 2003	Duration
Green alga, Desmo*desmus subspicatus*	Aluminum chloride	72 hr	-	-	EC50 (growth) - flask	2,894	Eisentraeger et al. 2003	Duration
Green alga, Desmo*desmus subspicatus*	Aluminum chloride	72 hr	-	-	EC50 (growth) - 24 well microplate	2,834	Eisentraeger et al. 2003	Duration

Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Green alga, Desmo*desmus subspicatus*	Aluminum chloride	72 hr	-	-	EC50 (growth) - 24 well microplate	3,340	Eisentraeger et al. 2003	Duration
Green alga, Desmo*desmus subspicatus*	Aluminum chloride	72 hr	-	-	EC50 (growth) - 96 well microplate	2,773	Eisentraeger et al. 2003	Duration
Green alga, Desmo*desmus subspicatus*	Aluminum chloride	72 hr	-	-	EC50 (growth) - 96 well microplate	2,915	Eisentraeger et al. 2003	Duration
Green alga, Desmo*desmus subspicatus*	Aluminum chloride	72 hr	-	-	EC50 (biomass) - flask	2,028	Eisentraeger et al. 2003	Duration
Green alga, Desmo*desmus subspicatus*	Aluminum chloride	72 hr	-	-	EC50 (biomass) - flask	2,423	Eisentraeger et al. 2003	Duration
Green alga, Desmo*desmus subspicatus*	Aluminum chloride	72 hr	-	-	EC50 (unidentified) - flask	2,605	Eisentraeger et al. 2003	Duration
Green alga, Desmo*desmus subspicatus*	Aluminum chloride	72 hr	-	-	EC50 (unidentified) - flask	2,467	Eisentraeger et al. 2003	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 0 mg/L)	6.25	EC50 (biomass)	28.3	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 0 mg/L)	7.23-7.26	EC50 (biomass)	155.5	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 0 mg/L)	8.05-8.12	EC50 (biomass)	851.4	European Al Association 2009; Gensemer et al. 2018	Duration

Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 0 mg/L)	6.29-6.30	EC50 (biomass)	76.4	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 0 mg/L)	7.12-7.13	EC50 (biomass)	232.9	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 0 mg/L)	7.90-8.12	EC50 (biomass)	516.2	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 0 mg/L)	6.22-6.24	EC50 (biomass)	74.2	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 0 mg/L)	7.10-7.13	EC50 (biomass)	226.3	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 0 mg/L)	7.94-8.11	EC50 (biomass)	366.9	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 0 mg/L)	6.25	EC50 (growth rate)	72.1	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 0 mg/L)	7.23-7.26	EC50 (growth rate)	345.6	European Al Association 2009; Gensemer et al. 2018	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 0 mg/L)	8.05-8.12	EC50 (growth rate)	1,351.8	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 0 mg/L)	6.29-6.30	EC50 (growth rate)	206.2	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 0 mg/L)	7.12-7.13	EC50 (growth rate)	584.0	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 0 mg/L)	7.90-8.12	EC50 (growth rate)	1,607.2	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 0 mg/L)	6.22-6.24	EC50 (growth rate)	323.4	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 0 mg/L)	7.10-7.13	EC50 (growth rate)	550.1	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 0 mg/L)	7.94-8.11	EC50 (growth rate)	889.1	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 2 mg/L)	6.19-6.23	EC50 (biomass)	669.9	European Al Association 2009; Gensemer et al. 2018	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 2 mg/L)	6.96-7.05	EC50 (biomass)	1,815.8	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 2 mg/L)	7.74-7.96	EC50 (biomass)	2,157.0	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 2 mg/L)	6.13-6.19	EC50 (biomass)	1,030.1	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 2 mg/L)	6.97-7.04	EC50 (biomass)	2,266.7	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 2 mg/L)	7.82-8.04	EC50 (biomass)	927.1	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 2 mg/L)	6.09-6.18	EC50 (biomass)	1,451.5	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 2 mg/L)	6.94-7.12	EC50 (biomass)	2,591.7	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 2 mg/L)	7.87-8.05	EC50 (biomass)	774.2	European Al Association 2009; Gensemer et al. 2018	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 2 mg/L)	6.19-6.23	EC50 (growth rate)	1,181.1	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 2 mg/L)	6.96-7.05	EC50 (growth rate)	2,896.0	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 2 mg/L)	7.74-7.96	EC50 (growth rate)	4,980.9	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 2 mg/L)	6.13-6.19	EC50 (growth rate)	1,473.5	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 2 mg/L)	6.97-7.04	EC50 (growth rate)	4,332.3	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 2 mg/L)	7.82-8.04	EC50 (growth rate)	2,000.0	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 2 mg/L)	6.09-6.18	EC50 (growth rate)	2,100.1	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 2 mg/L)	6.94-7.12	EC50 (growth rate)	3,645.8	European Al Association 2009; Gensemer et al. 2018	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 2 mg/L)	7.87-8.05	EC50 (growth rate)	1,639.9	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 4 mg/L)	6.09-6.19	EC50 (biomass)	778.2	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 4 mg/L)	6.98-7.10	EC50 (biomass)	2,630.2	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 4 mg/L)	7.82-7.98	EC50 (biomass)	2,229.7	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 4 mg/L)	6.10-6.19	EC50 (biomass)	1,273.7	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 4 mg/L)	7.0-7.05	EC50 (biomass)	2,736.4	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 4 mg/L)	7.78-7.87	EC50 (biomass)	1,660.2	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 4 mg/L)	6.09-6.24	EC50 (biomass)	1,572.8	European Al Association 2009; Gensemer et al. 2018	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 4 mg/L)	7.0-7.09	EC50 (biomass)	3,546.2	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 4 mg/L)	7.77-7.81	EC50 (biomass)	1,521.2	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 4 mg/L)	6.09-6.19	EC50 (growth rate)	1,443.9	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 4 mg/L)	6.98-7.10	EC50 (growth rate)	3,845.9	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	24.3 (DOC = 4 mg/L)	7.82-7.98	EC50 (growth rate)	4,716.1	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 4 mg/L)	6.10-6.19	EC50 (growth rate)	1,890.7	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 4 mg/L)	7.0-7.05	EC50 (growth rate)	4,260.0	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	60 (DOC = 4 mg/L)	7.78-7.87	EC50 (growth rate)	2,905.0	European Al Association 2009; Gensemer et al. 2018	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 4 mg/L)	6.09-6.24	EC50 (growth rate)	2,429.3	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 4 mg/L)	7.0-7.09	EC50 (growth rate)	4,930.0	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	120 (DOC = 4 mg/L)	7.77-7.81	EC50 (growth rate)	2,556.3	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	Solution aged 3 hr (DOC = 0 mg/L)	6.23-6.24	EC50 (growth)	196.2	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	Solution aged 27 hr (DOC = 0 mg/L)	6.12-6.23	EC50 (growth)	182.7	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	Solution aged 3 hr (DOC = 0 mg/L)	7.93-8.06	EC50 (growth)	1,762.4	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	Solution aged 27 hr (DOC = 0 mg/L)	7.93-8.23	EC50 (growth)	1,328.0	European Al Association 2009; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	Medium not buffered (DOC = 0 mg/L)	7.80-8.21	EC50 (growth rate)	1,282.1	European Al Association 2010; Gensemer et al. 2018	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	Medium HEPES buffered (DOC = 0 mg/L)	8.05-8.12	EC50 (growth rate)	1,351.8	European Al Association 2010; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	Medium HEPES buffered (DOC = 0 mg/L)	7.99-8.08	EC50 (growth rate)	1,476.6	European Al Association 2010; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	Medium HEPES buffered (DOC = 0 mg/L)	7.65-7.70	EC50 (growth rate)	1,417.9	European Al Association 2010; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	Medium not buffered (DOC = 0 mg/L)	7.80-8.21	EC50 (biomass)	626.6	European Al Association 2010; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	Medium HEPES buffered (DOC = 0 mg/L)	8.05-8.12	EC50 (biomass)	851.4	European Al Association 2010; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	Medium HEPES buffered (DOC = 0 mg/L)	7.99-8.08	EC50 (biomass)	717.9	European Al Association 2010; Gensemer et al. 2018	Duration
Green alga, *Pseudokirchneriella subcapitata*	Aluminum nitrate	72 hr	Medium HEPES buffered (DOC = 0 mg/L)	7.65-7.70	EC50 (biomass)	563.3	European Al Association 2010; Gensemer et al. 2018	Duration
Red alga, *Cyanidium caldarium*	Aluminum chloride	5-10 d	-	2	Reduced growth rate by 42%	5,396,000	Yoshimura et al. 1999	Lack of exposure details; pH too low
Protozoa, *Euglena gracilis*	Aluminum chloride	10 min	-	6.0-7.0	Some survival	111,800	Ruthven and Cairns 1973	Single-cell organism

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Protozoa (1 wk), *Euglena gracilis*	Aluminum chloride	7 d	-	-	Growth	10,000-15,000 (NOEC-LOEC)	Danilov and Ekelund 2002	Single-cell organism
Protozoa, *Chilomonas paramecium*	Aluminum chloride	10 min	-	5.5-7.4	Some survival	110	Ruthven and Cairns 1973	Single-cell organism
Protozoa, *Microregma heterostoma*	Aluminum chloride	28 hr	-	7.5-7.8	Incipient inhibition	12,000	Bringmann and Kuhn 1959a	Single-cell organism
Protozoa, *Peranema trichoporum*	Aluminum chloride	10 min	-	5.5-6.5	Some survival	62,600	Ruthven and Cairns 1973	Single-cell organism
Protozoa, *Tetrahymena pyriformis*	Aluminum chloride	10 min	-	5.5-6.5	Some survival	100	Ruthven and Cairns 1973	Single-cell organism
Protozoa, *Tetrahymena pyriformis*	Aluminum chloride	96 hr	-	6.5	IC50 (growth)	15,000	Sauvant et al. 2000	Single-cell organism
Protozoa, *Tetrahymena pyriformis*	Aluminum sulfate	96 hr	-	6.5	IC50 (growth)	10,000	Sauvant et al. 2000	Single-cell organism
Protozoa, *Tetrahymena pyriformis*	Aluminum nitrate	96 hr	-	6.5	IC50 (growth)	14,000	Sauvant et al. 2000	Single-cell organism
Rotifer (0-2 hr), *Brachionus calyciflorus*	Aluminum chloride	24 hr	90 (80-100)	7.5	LC50	>3,000	Snell et al. 1991	Lack of exposure details and effects
Nematode (3-4 d, adult), *Caenorhabditis elegans*	Aluminum nitrate	-	-	-	LC50	1,800	Williams and Dusenbery 1990	Test species fed
Nematode, *Caenorhabditis elegans*	Aluminum nitrate	24 hr	-	4.5-6.5	LC50	49,000	Dhawan et al. 2000	Duration; test species fed
Nematode, *Caenorhabditis elegans*	Aluminum nitrate	24 hr	-	4.5-6.5-	EC50 (movement)	3,000	Dhawan et al. 2000	Duration; test species fed
Nematode, *Caenorhabditis elegans*	Aluminum chloride	48 hr	-	-	LC50	18,150	Chu and Chow 2002	Duration
Nematode (adult), *Caenorhabditis elegans*	Aluminum chloride	4 hr	-	-	EC50 (rate of movement)	1,241	Anderson et al. 2004	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Tubificid worm, *Tubifex tubifex*	Aluminum ammonium sulfate	96 hr	245	7.6	EC50 (death and immobility)	50,230	Khangarot 1991	Inappropriate form of toxicant
Planarian (adult), *Dugesia tigrina*	Aluminum chloride	48 hr	47.4	7.48	Mortality	>16,600 (NOEC)	Brooke 1985	Duration
Planarian, *Dugesia tigrina*	-	48 hr	~47.42	7.48	LC50	>23,200	Lange 1985	Duration
Brown hydra, *Hydra oligactis*	Aluminum sulfate	72 hr	-	-	86% mortality	475,000	Kovacevic et al. 2007	Duration
Brown hydra, *Hydra oligactis*	Aluminum sulfate	72 hr	-	-	Tail growth	250,000 (LOEC)	Kovacevic et al. 2007	Duration; atypical endpoint
Green hydra, *Hydra viridissima*	Aluminum sulfate	72 hr	-	-	LC50	475,000-480,000	Kovacevic et al. 2007	Duration
Green hydra, *Hydra viridissima*	Aluminum sulfate	72 hr	-	-	Tail growth	250,000-475,000 (NOEC-LOEC)	Kovacevic et al. 2007	Duration; atypical endpoint
Green hydra, *Hydra viridissima*	Aluminum nitrate	7 d	1.0 (DOC = 1 mg/L)	5.0	IC50 (population growth rate)	56	Trenfield et al. 2012	Duration
Green hydra, *Hydra viridissima*	Aluminum nitrate	7 d	1.0 (DOC = 2 mg/L)	5.0	IC50 (population growth rate)	90	Trenfield et al. 2012	Duration
Green hydra, *Hydra viridissima*	Aluminum nitrate	7 d	4.1 (DOC = 1 mg/L)	5.0	IC50 (population growth rate)	152	Trenfield et al. 2012	Duration
Green hydra, *Hydra viridissima*	Aluminum nitrate	7 d	4.1 (DOC = 2 mg/L)	5.0	IC50 (population growth rate)	166	Trenfield et al. 2012	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Snail, *Amnicola limosa*	Aluminum	96 hr	15.3	3.5	LC50	>1,000	Mackie 1989	pH too low
Snail, *Amnicola limosa*	Aluminum	96 hr	15.3	4.0	LC50	>400	Mackie 1989	pH too low
Snail, *Amnicola limosa*	Aluminum	96 hr	15.3	4.5	LC50	>400	Mackie 1989	pH too low
Snail (adult, 3.5-5.6 g), *Lymnaea stagnalis*	Aluminum nitrate	30 d	-	7.0	Increase in number of granules	300	Elangovan et al. 2000	Unmeasured chronic exposure
Snail (Adult, 3.5-5.6 g), *Lymnaea stagnalis*	Aluminum nitrate	30 d	~74.0	7.0	BCF = 4,500 (whole soft tissue)	234	Elangovan et al. 1997	Steady state not reached
Snail (Adult, 3.5-5.6 g), *Lymnaea stagnalis*	Aluminum nitrate	30 d	~74.0	7.0	BCF = 15,000 (whole soft tissue)	285	Elangovan et al. 1997	Steady state not reached
Snail (25-35 mm), *Lymnaea stagnalis*	Aluminum nitrate	30 d	-	7.3	BCF = 444 (digestive gland)	500	Desouky et al. 2003	Steady state not reached
Zebra mussel (veliger larvae, 135-157 µm), *Dreissena polymorpha*	Aluminum sulfate	24 hr	137.1	7.42-7.48	LC50	130,500	Mackie and Kilgour 1995	Duration
Pea cockle, *Pisidium casertanum*	-	96 hr	15.3	3.5	LC50	>1,000	Mackie 1989	pH too low
Pea cockle, *Pisidium casertanum*	-	96 hr	15.3	4.0	LC50	>400	Mackie 1989	pH too low
Pea cockle, *Pisidium casertanum*	-	96 hr	15.3	4.5	LC50	>400	Mackie 1989	pH too low
Ridged-beak peaclam, *Pisidium compressum*	-	96 hr	15.3	3.5	LC50	>1,000	Mackie 1989	pH too low
Ridged-beak peaclam, *Pisidium compressum*	-	96 hr	15.3	4.0	LC50	>400	Mackie 1989	pH too low
Ridged-beak peaclam, *Pisidium compressum*	-	96 hr	15.3	4.5	LC50	>400	Mackie 1989	pH too low

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (<24 hr), *Ceriodaphnia sp.*	Aluminum chloride	8 d	47.4	7.68	LC50	8,600	Call et al. 1984	Duration
Cladoceran (<24 hr), *Ceriodaphnia sp.*	Aluminum chloride	48 hr	47.4	7.68	LC50	3,690	Call et al. 1984	Species not defined; other data available for the genus
Cladoceran (<24 hr), *Ceriodaphnia sp.*	Aluminum chloride	48 hr	47.4	7.36	LC50	2,300 (aged solution)	Call et al. 1984	Species not defined; other data available for the genus
Cladoceran (<24 hr), *Ceriodaphnia sp.*	Aluminum chloride	LC (3 broods)	47.4	7.68	Reproduction	4,900-12,100 (NOEC-LOEC)	Call et al. 1984	Species not defined; other data available for the genus
Cladoceran, *Ceriodaphnia dubia*	Aluminum chloride	LC (3 broods)	90 (80-100)	-	IC25 (reproduction)	566	Zuiderveen and Birge 1997	Unmeasured chronic exposure
Cladoceran, *Ceriodaphnia dubia*	Aluminum chloride	LC (3 broods)	90 (80-100)	-	IC25 (reproduction)	641	Zuiderveen and Birge 1997	Unmeasured chronic exposure
Cladoceran (<24 hr), *Ceriodaphnia dubia*	Aluminum nitrate	LC (3 broods)	10.6 Solution not filtered (DOC = 0 mg/L)	7.74-7.90	Reproduction - # of juveniles	10.0-100.0 (NOEC-LOEC)	European Al Association 2009	Unmeasured chronic exposure
Cladoceran (<24 hr), *Ceriodaphnia dubia*	Aluminum nitrate	LC (3 broods)	10.6 Solution filtered (DOC = 0 mg/L)	7.79-7.91	Reproduction - # of juveniles	500.0-1,000.0 (NOEC-LOEC)	European Al Association 2009	Unmeasured chronic exposure
Cladoceran (<24 hr), *Ceriodaphnia dubia*	Aluminum nitrate	LC (3 broods)	10.6 Solution not filtered (DOC = 0 mg/L)	6.62-7.03	Reproduction - # of juveniles	100.0-1,000.0 (NOEC-LOEC)	European Al Association 2009	Unmeasured chronic exposure
Cladoceran (<24 hr), *Ceriodaphnia dubia*	Aluminum nitrate	LC (3 broods)	10.6 Solution filtered (DOC = 0 mg/L)	6.66-7.04	Reproduction - # of juveniles	100.0-1,000.0 (NOEC-LOEC)	European Al Association 2009	Unmeasured chronic exposure

Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (mature), *Daphnia catawba*	Aluminum chloride	72 hr	8.07	6.5	Reduced survival	1,020	Havas and Likens 1985b	Duration
Cladoceran (<8 hr), *Daphnia magna*	Aluminum sulfate	16 hr	-	-	Incipient immobilization	10,717	Anderson 1944	Duration
Cladoceran (<8 hr), *Daphnia magna*	Potassium aluminum sulfate	16 hr	-	-	Incipient immobilization	15,677	Anderson 1944	Duration, inappropriate form of toxicant
Cladoceran, *Daphnia magna*	Aluminum chloride	48 hr	-	7.5	Toxic effect	1,000,000	Bringmann and Kuhn 1959a	Endpoint not clearly defined
Cladoceran (≥12 hr), *Daphnia magna*	Aluminum chloride	21 d	45.3	7.74	EC16 (reduced reproduction)	320	Biesinger and Christensen 1972	Unmeasured chronic exposure
Cladoceran (≥12 hr), *Daphnia magna*	Aluminum chloride	21 d	45.3	7.74	EC50 (reduced reproduction)	680	Biesinger and Christensen 1972	Unmeasured chronic exposure
Cladoceran (≥12 hr), *Daphnia magna*	Aluminum chloride	21 d	45.3	7.74	LC50	1,400	Biesinger and Christensen 1972	Unmeasured chronic exposure
Cladoceran, *Daphnia magna*	Sodium aluminate	96 hr	27	7	Mortality	>40,000	Peterson et al. 1974	LC50 or EC50 endpoint not defined
Cladoceran (≥12 hr), *Daphnia magna*	Aluminum sulfate	28 d	220	8.3	Reproduction	4,260 (NOEC)	Kimball 1978	Control survival (70%)
Cladoceran (≥12 hr), *Daphnia magna*	Aluminum sulfate	28 d	220	8.3	Survival	540-1,020 (NOEC-LOEC)	Kimball 1978	Control survival (70%)
Cladoceran (0-24 hr), *Daphnia magna*	-	28 d	-	-	Survival and reproduction	1,890-4,260 (NOEC-LOEC)	Stephan 1978	Author reported that the results are considered questionable for one reason or another [not provided]

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (14 d), *Daphnia magna*	-	7 d	-	-	Survival and reproduction	3,300-8,400 (NOEC-LOEC)	Stephan 1978	Author reported that the results are considered questionable for one reason or another [not provided]
Cladoceran, *Daphnia magna*	-	28 d	-	-	LC50	38,000	Stephan 1978	Author reported that the results are considered questionable for one reason or another [not provided]
Cladoceran, *Daphnia magna*	Aluminum chloride	48 hr	45.4	7.61	EC50	>25,300	Brooke 1985	No dose response observed
Cladoceran, *Daphnia magna*	Aluminum chloride	48 hr	8.26	6.5	Mortality	320	Havas 1985	Dilution water is lake water, atypical endpoint
Cladoceran, *Daphnia magna*	Aluminum chloride	24 hr	8.26	6.5	BCF = 18,000	20	Havas 1985	Duration, lack of exposure details; dilution water is lake water
Cladoceran, *Daphnia magna*	Aluminum chloride	24 hr	8.26	6.5	BCF = 9,600	320	Havas 1985	Duration, lack of exposure details; dilution water is lake water
Cladoceran, *Daphnia magna*	Aluminum chloride	24 hr	8.26	6.5	BCF = 11,000	1,020	Havas 1985	Duration, lack of exposure details; dilution water is lake water

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran, *Daphnia magna*	Aluminum chloride	24 hr	33.35	6.5	BCF = 18,000	20	Havas 1985	Duration, lack of exposure details; dilution water is lake water
Cladoceran, *Daphnia magna*	Aluminum chloride	24 hr	33.35	6.5	BCF = 14,700	1,020	Havas 1985	Duration, lack of exposure details; dilution water is lake water
Cladoceran, *Daphnia magna*	Aluminum chloride	48 hr	-	6.5	Loss of sodium	1,020	Havas and Likens 1985a	Dilution water is lake water, atypical endpoint
Cladoceran, *Daphnia magna*	Aluminum ammonium sulfate	48 hr	240	7.6	LC50	59,600	Khangarot and Ray 1989	Inappropriate form of toxicant
Isopod (7 mm), *Asellus aquaticus*	Aluminum sulfate	72 hr	50	6.75	LC50	4,370	Martin and Holdich 1986	Duration
Amphipod, *Gammarus pseudolimnaeus*	Aluminum chloride	96 hr	47.4	7.53	LC50	22,000	Call et al. 1984	Test species fed
Amphipod, *Hyalella azteca*	-	96 hr	15.3	5.0	LC50	>1,000	Mackie 1989	Not enough information in the paper to determine is acceptable test conditions are met
Amphipod, *Hyalella azteca*	-	96 hr	15.3	5.5	LC50	>400	Mackie 1989	Not enough information in the paper to determine is acceptable test conditions are met

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Amphipod, *Hyalella azteca*	-	96 hr	15.3	6.0	LC50	>400	Mackie 1989	Not enough information in the paper to determine is acceptable test conditions are met
Amphipod (1-11 d), *Hyalella azteca*	-	7 d	18	7.39-8.27	LC50	89	Borgmann et al. 2005	Duration, control mortality (≥80 %)
Amphipod (1-11 d), *Hyalella azteca*	-	7 d	-	8.21-8.46	LC50	>3,150	Borgmann et al. 2005	Duration, control mortality (≥80 %)
Crayfish (80-160 cm), *Pacifastacus leniusculus*	Aluminum nitrate	20 d	-	-	BCF = 3.44 (flexor muscle)	436	Alexopoulos et al. 2003	More accumulation in the controls than exposure
Crayfish (80-160 cm), *Pacifastacus leniusculus*	Aluminum nitrate	20 d	-	-	BCF = 527.5 (gill content)	436	Alexopoulos et al. 2003	Gill content not whole body
Crayfish (larvae), *Procambarus clarkii*	-	30 min	-	-	Oxygen consumption	>100,000 (NOEC)	Becker and Keller 1983	Duration
Caddisfly (larva, 5th instar), *Arctopsyche ladogensis*	Aluminum sulfate	4 d	-	5.0	EC50 (frequency of abnormalities)	938-1,089	Vuori 1996	Atypical endpoint, effect range reported
Damselfly, *Enallagma sp.*	-	96 hr	15.3	3.5	LC50	>1,000	Mackie 1989	pH too low
Damselfly, *Enallagma sp.*	-	96 hr	15.3	4.0	LC50	>400	Mackie 1989	pH too low
Damselfly, *Enallagma sp.*	-	96 hr	15.3	4.5	LC50	>400	Mackie 1989	pH too low
Midge (1st instar larva, 3d), *Chironomus riparius*	Aluminum nitrate	10 d	91	6.5-6.7	Survival	4,281.8->4,281.9 (NOEC-LOEC)	OSU 2012f; Cardwell et al. 2018	Duration

Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Midge (1st instar larva, 3d), *Chironomus riparius*	Aluminum nitrate	10 d	91	6.5-6.7	Growth-dry weight	1,100.2-2,132.7 (NOEC-LOEC)	OSU 2012f; Cardwell et al. 2018	Duration
Midge, *Paratanytarsus dissimilis*	Aluminum sulfate	55 d	17.43	6.63	Survival	800 (LOEC)	Lamb and Bailey 1981, 1983	Not a flow-through chronic exposure
Dragonfly (last instar nymph), *Libellula julia*	Aluminum chloride	96 hr	-	4	Oxygen uptake inhibition	3,000-30,000 (NOEC-LOEC)	Rockwood et al. 1990	Atypical endpoint
Golden trout (alevin), *Oncorhynchus aguabonita aguabonita*	Aluminum sulfate	7 d	4.89	5.0	Survival	97-293 (NOEC-LOEC)	DeLonay 1991; DeLonay et al. 1993	Duration
Golden trout (swim-up larvae), *Oncorhynchus aguabonita aguabonita*	Aluminum sulfate	7 d	4.89	5.0	Survival	97-293 (NOEC-LOEC)	DeLonay 1991; DeLonay et al. 1993	Duration
Cutthroat trout (egg/embryo), *Oncorhynchus clarkii*	-	7 d	42.5	5	Survival	300->300 (NOEC-LOEC)	Woodward et al. 1989	Duration
Cutthroat trout (egg/embryo), *Oncorhynchus clarkii*	-	7 d	42.5	5	Growth	300->300 (NOEC-LOEC)	Woodward et al. 1989	Duration
Cutthroat trout (alevin, 2 d post hatch), *Oncorhynchus clarkii*	-	7 d	42.5	5	Survival	50-100 (NOEC-LOEC)	Woodward et al. 1989	Duration
Cutthroat trout (alevin/larvae), *Oncorhynchus clarkii*	-	7 d	42.5	5	Growth	50->50 (NOEC-LOEC)	Woodward et al. 1989	Duration
Cutthroat trout (swim-up larvae), *Oncorhynchus clarkii*	-	7 d	42.5	5	Survival	<50-50 (NOEC-LOEC)	Woodward et al. 1989	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Rainbow trout (fingerling), *Oncorhynchus mykiss*	Aluminum chloride	-	28.3	8.48	LT50=7.46 d	5,140	Freeman and Everhart 1971	Atypical endpoint, test species fed
Rainbow trout (fingerling), *Oncorhynchus mykiss*	Aluminum chloride	-	28.3	8.99	LT50=2.96 d	5,200	Freeman and Everhart 1971	Atypical endpoint, test species fed
Rainbow trout (fingerling), *Oncorhynchus mykiss*	Aluminum chloride	-	46.8	8.02	LT50=31.96 d	5,230	Freeman and Everhart 1971	Atypical endpoint, test species fed
Rainbow trout (fingerling), *Oncorhynchus mykiss*	Aluminum chloride	-	56.6	6.8	LT50=38.90 d	5,140	Freeman and Everhart 1971	Atypical endpoint, test species fed
Rainbow trout (fingerling), *Oncorhynchus mykiss*	Aluminum chloride	-	56.6	6.52	LT50=43.90 d	513	Freeman and Everhart 1971	Atypical endpoint, test species fed
Rainbow trout (embryo), *Oncorhynchus mykiss*	Aluminum chloride	Fert. to hatch	-	7.0-9.0	No reduced fertility	5,200	Freeman and Everhart 1971	Lack of exposure details
Rainbow trout (embryo/larvae), *Oncorhynchus mykiss*	Aluminum chloride	28 d	104	7.4	EC50 (death and deformity)	560	Birge 1978; Birge et al. 1978	Duration
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Aluminum sulfate	10 d	25	7	0% dead	200,000	Hunter et al. 1980	Duration, test species fed
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Aluminum sulfate	96 hr	25	8	40% dead	50,000	Hunter et al. 1980	Lack of exposure details
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Aluminum sulfate	42 hr	25	8.5	100% dead	50,000	Hunter et al. 1980	Duration; lack of exposure details
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Aluminum sulfate	42 hr	25	9	100% dead	50,000	Hunter et al. 1980	Duration; lack of exposure details
Rainbow trout, *Oncorhynchus mykiss*	-		-	5.0	LC50	160	Holtze 1983	pH too low
Rainbow trout, *Oncorhynchus mykiss*	-		-	4.5	LC50	120	Holtze 1983	pH too low

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Rainbow trout (embryo/larvae), *Oncorhynchus mykiss*	Aluminum sulfate	8 d	14.3	6.5	No effect	1,000	Holtze 1983	Duration, lack of exposure details
Rainbow trout (embryo/larvae), *Oncorhynchus mykiss*	Aluminum sulfate	8 d	14.3	7.2	No effect	1,000	Holtze 1983	Duration, lack of exposure details
Rainbow trout (eyed embryo), *Oncorhynchus mykiss*	Aluminum sulfate	8 d	14.3	6.5	14.2% dead	1,000	Holtze 1983	Duration, lack of exposure details
Rainbow trout (eyed embryo), *Oncorhynchus mykiss*	Aluminum sulfate	8 d	14.3	7.2	14.2% dead	1,000	Holtze 1983	Duration, lack of exposure details
Rainbow trout (juvenile, 5-8 cm), *Oncorhynchus mykiss*	Aluminum sulfate	24 hr	-	6	Opercula rate	200-500 (NOEC-LOEC)	Ogilvie and Stechey 1983	Duration, atypical endpoint
Rainbow trout (juvenile, 5-8 cm), *Oncorhynchus mykiss*	Aluminum sulfate	24 hr	-	6	Cough frequency	100-200 (NOEC-LOEC)	Ogilvie and Stechey 1983	Duration, atypical endpoint
Rainbow trout (3.5 g), *Oncorhynchus mykiss*	Aluminum sulfate	6 d	11.2	5.09-5.31	LC50	175	Orr et al. 1986	Duration
Rainbow trout (alevin, 23-26 dph), *Oncorhynchus mykiss*	Aluminum sulfate	6 d	10.3	5.8	LC50	>1,050	Hickie et al. 1993	Duration
Rainbow trout (alevin, 16-19 dph), *Oncorhynchus mykiss*	Aluminum sulfate	6 d	10.3	4.9	LC50	88	Hickie et al. 1993	Duration, pH too low
Rainbow trout (alevin, 23-26 dph), *Oncorhynchus mykiss*	Aluminum sulfate	6 d	10.3	4.9	LC50	91	Hickie et al. 1993	Duration, pH too low
Rainbow trout (92-220 g), *Oncorhynchus mykiss*	-	1 hr	-	5.4	Gill content (50 µg/g)	954	Handy and Eddy 1989	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Rainbow trout (juvenile, 1-3 g), *Oncorhynchus mykiss*	Aluminum chloride	16 d	20.3	8.3	LC50	1,940	Gundersen et al. 1994	Duration
Rainbow trout (juvenile, 1-3 g), *Oncorhynchus mykiss*	Aluminum chloride	16 d	103.0	8.3	LC50	3,910	Gundersen et al. 1994	Duration
Rainbow trout (embryo), *Oncorhynchus mykiss*	Aluminum chloride	7-12 d	100	7.0-7.8	LC50	560	Birge et al. 2000	Duration
Chinook salmon (juvenile), *Oncorhynchus tshawytscha*	Sodium aluminate	96 hr	28.0	7.00	LC50	>40,000	Peterson et al. 1974	Inappropriate form of toxicant
Atlantic salmon (eggs), *Salmo salar*	Aluminum sulfate	60 d	13.5	5.5	RNA/DNA content	33-264 (NOEC-LOEC)	McKee et al. 1989	Atypical endpoint
Atlantic salmon (>1 yr, 5.9 g), *Salmo salar*	-	7 d	10.4	4.5	LC50	88	Wilkinson et al. 1990	Duration
Atlantic salmon (eggs), *Salmo salar*	Aluminum sulfate	60 d	12.8	5.5	Time to hatch	>264 (NOEC)	Buckler et al. 1995	Atypical endpoint
Atlantic salmon (larva), *Salmo salar*	Aluminum sulfate	60 d	12.8	5.5	Behavior-swimming & feeding activity	<33 (NOEC)	Buckler et al. 1995	Atypical endpoint
Atlantic salmon (juvenile, 1.4 g), *Salmo salar*	Aluminum sulfate	5 d	10.6	4.47	LC50	259	Roy and Campbell 1995	Duration
Atlantic salmon (juvenile, 1.4 g), *Salmo salar*	Aluminum sulfate	5 d	10.6	4.42	LC50	283	Roy and Campbell 1995	Duration
Atlantic salmon (juvenile, 1.4 g), *Salmo salar*	Aluminum sulfate	5 d	10.6	4.83	LC50	121	Roy and Campbell 1995	Duration

Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Atlantic salmon (juvenile, 1.4 g), *Salmo salar*	Aluminum sulfate	5 d	10.6	5.26	LC50	54	Roy and Campbell 1995	Duration
Atlantic salmon (juvenile, 1.4 g), *Salmo salar*	Aluminum sulfate	5 d	10.6	5.24	LC50	51	Roy and Campbell 1995	Duration
Atlantic salmon (juvenile, 6.8 g), *Salmo salar*	Aluminum sulfate	96 hr	10.6	4.86	LC50	75.54	Roy and Campbell 1995	pH too low
Atlantic salmon (juvenile, 1.8 g), *Salmo salar*	Aluminum sulfate	96 hr	10.6	4.99	LC50	79.60	Roy and Campbell 1997	pH too low
Atlantic salmon (juvenile, 1.8 g), *Salmo salar*	Aluminum sulfate	96 hr	10.6	4.96	LC50	124.1	Roy and Campbell 1997	pH too low
Brook trout (alevins, 23.6 mm, 13.4 mg), *Salvelinus fontinalis*	-	15 min	7.2	6.9	Avoidance	389	Gunn and Noakes 1986	Duration, atypical endpoint
Brook trout (juvenile), *Salvelinus fontinalis*	Aluminum hydroxide	24 d	8-10	4.4	Survival	<200-200 (NOEC-LOEC)	Siddens et al. 1986	Duration
Brook trout (juvenile), *Salvelinus fontinalis*	Aluminum hydroxide	24 d	8-10	4.9	Survival	<200-200 (NOEC-LOEC)	Siddens et al. 1986	Duration
Brook trout (1.5 yr), *Salvelinus fontinalis*	-	147 d	Ca = 8 mg/L	5.2	100% survival	54	Mount 1987	Unmeasured chronic exposure
Brook trout (1.5 yr), *Salvelinus fontinalis*	-	147 d	Ca = 8 mg/L	5.2	93% survival	162	Mount 1987	Unmeasured chronic exposure
Brook trout (1.5 yr), *Salvelinus fontinalis*	-	147 d	Ca = 8 mg/L	4.8	100% survival	162	Mount 1987	Unmeasured chronic exposure
Brook trout (1.5 yr), *Salvelinus fontinalis*	-	147 d	Ca = 8 mg/L	4.8	50% survival	486	Mount 1987	Unmeasured chronic exposure
Brook trout (1.5 yr), *Salvelinus fontinalis*	-	147 d	Ca = 0.5 mg/L	5.2	93% survival	54	Mount 1987	Unmeasured chronic exposure

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Brook trout (1.5 yr), *Salvelinus fontinalis*	-	147 d	Ca = 0.5 mg/L	5.2	86% survival	162	Mount 1987	Unmeasured chronic exposure
Brook trout (1.5 yr), *Salvelinus fontinalis*	-	147 d	Ca = 0.5 mg/L	4.8	86% survival	162	Mount 1987	Unmeasured chronic exposure
Brook trout (1.5 yr), *Salvelinus fontinalis*	-	147 d	Ca = 0.5 mg/L	4.8	36% survival	486	Mount 1987	Unmeasured chronic exposure
Brook trout (eggs), *Salvelinus fontinalis*	Aluminum sulfate	60 d	12.5	5.5	Strike frequency	142-292 (NOEC-LOEC)	Cleveland et al. 1989	Atypical endpoint
Brook trout (eggs), *Salvelinus fontinalis*	Aluminum sulfate	60 d	12.5	6.5	Strike frequency	350->350 (NOEC-LOEC)	Cleveland et al. 1989	Atypical endpoint
Brook trout (1 yr), *Salvelinus fontinalis*	Aluminum chloride	28 d	250	4.4	Survival	131-332 (NOEC-LOEC)	Ingersoll et al. 1990a	Duration; pH too low
Goldfish (60-90 mm), *Carassius auratus*	Aluminum potassium sulfate	96 hr	-	6.8	Reduced survival time	5,700	Ellis 1937	Atypical endpoint; no LC50 reported
Goldfish (eggs), *Carassius auratus*	Aluminum chloride	7 d	195	7.4	EC50 (death and deformity)	150	Birge 1978	Duration
Goldfish (embryo), *Carassius auratus*	Aluminum chloride	7-12 d	100	7.0-7.8	LC50	330	Birge et al. 2000	Duration
Common carp (95 g), *Cyprinus carpio*	Aluminum sulfate	4 hr	-	5.2	Ca 2+ flux	30-100 (NOEC-LOEC)	Verbost et al. 1992	Duration, atypical endpoint
Rio Grande silvery minnow (larva, 3-5 dph), *Hybognathus amarus*	Aluminum chloride	96 hr	140	8.1	EC50 (death and immobility)	>59,100	Buhl 2002	Atypical endpoint
Fathead minnow (juvenile), *Pimephales promelas*	Aluminum sulfate	8 d	220	7.3	LC50	22,400	Kimball 1978	Duration, test species fed

Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Fathead minnow (juvenile), *Pimephales promelas*	Aluminum sulfate	96 hr	220	7.34	LC50	35,000	Kimball 1978	Test species fed
Fathead minnow (adult), *Pimephales promelas*	Aluminum chloride	-	-	-	50% reduction in AChE	18,000	Olson and Christensen 1980	Duration unknown, atypical endpoint
Fathead minnow (juvenile, 11 mm), *Pimephales promelas*	Aluminum chloride	96 hr	21.6	5.5	LC50	>50	Palmer et al. 1989	Measured dissolved total Al greater than (unmeasured) nominal total Al.
Fathead minnow (larvae, <24 hr), *Pimephales promelas*	Aluminum chloride	7 d	46	7.5	Growth (weight)	400-740 (NOEC-LOEC)	ENSR 1992a	Duration
Fathead minnow (larvae, <24 hr), *Pimephales promelas*	Aluminum chloride	7 d	194	8.2	Growth (weight)	630-700 (NOEC-LOEC)	ENSR 1992a	Duration
Fathead minnow (≤7 d), *Pimephales promelas*	Aluminum chloride	96 hr	25 (24-26)	8.05 (7.2-8.9)	LC50	1,160	ENSR 1992c	Test species fed
Fathead minnow (≤7 d), *Pimephales promelas*	Aluminum chloride	96 hr	44 (42-46)	8.1 (7.5-8.7)	LC50	8,180	ENSR 1992c	Test species fed
Fathead minnow (≤7 d), *Pimephales promelas*	Aluminum chloride	96 hr	97 (96-98)	8.05 (7.6-8.5)	LC50	20,300	ENSR 1992c	Test species fed
Fathead minnow (≤7 d), *Pimephales promelas*	Aluminum chloride	96 hr	193 (192-194)	8.2 (7.8-8.6)	LC50	44,800	ENSR 1992c	Test species fed
Fathead minnow (larva, 4-6 dph), *Pimephales promelas*	Aluminum chloride	96 hr	140	8.1	EC50 (death and immobility)	>59,100	Buhl 2002	Atypical endpoint
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	12 (DOC = <0.08 mg/L)	6.0	EC20 (mean dry biomass)	127.2	OSU 2012a; Gensemer et al. 2018	Duration

Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	12 (DOC = 0.92 mg/L)	6.1	EC20 (mean dry biomass)	425.7	OSU 2012a; Gensemer et al. 2018	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	12 (DOC = 1.73 mg/L)	6.1	EC20 (mean dry biomass)	632.8	OSU 2012a; Gensemer et al. 2018	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	16 (DOC = 3.35 mg/L)	6.0	EC20 (mean dry biomass)	828.8	OSU 2012a; Gensemer et al. 2018	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	24 (DOC = 0.19 mg/L)	6.1	EC20 (mean dry biomass)	135.8	OSU 2012a; Gensemer et al. 2018	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	60 (DOC = 0.22 mg/L)	6.0	EC20 (mean dry biomass)	314.3	OSU 2012a; Gensemer et al. 2018	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	60 (DOC = 0.86 mg/L)	6.1	EC20 (mean dry biomass)	633.9	OSU 2012a; Gensemer et al. 2018	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	56 (DOC = 1.74 mg/L)	6.0	EC20 (mean dry biomass)	1,325.8	OSU 2012a; Gensemer et al. 2018	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	60 (DOC = 3.51 mg/L)	6.0	EC20 (mean dry biomass)	2,523	OSU 2012a; Gensemer et al. 2018	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	116 (DOC = 0.088 mg/L)	6.1	EC20 (mean dry biomass)	624.1	OSU 2012a; Gensemer et al. 2018	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	116 (DOC = 0.88 mg/L)	6.1	EC20 (mean dry biomass)	773.4	OSU 2012a; Gensemer et al. 2018	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	108 (DOC = 1.56 mg/L)	6.0	EC20 (mean dry biomass)	1,493.7	OSU 2012a; Gensemer et al. 2018	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	112 (DOC = 3.27 mg/L)	6.0	EC20 (mean dry biomass)	2,938	OSU 2012a; Gensemer et al. 2018	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	134 (DOC = 7.0 mg/L)	6.0	EC20 (mean dry biomass)	4,618	OSU 2018b	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	131 (DOC = 11.5 mg/L)	6.0	EC20 (mean dry biomass)	9,511	OSU 2018b	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	422 (DOC = 1.1 mg/L)	6.8	EC20 (mean dry biomass)	2,969	OSU 2018b	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	135 (DOC = 7.2 mg/L)	7.0	EC20 (mean dry biomass)	8,047	OSU 2018b	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	125 (DOC = 11.6 mg/L)	7.0	EC20 (mean dry biomass)	12,542	OSU 2018b	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	288 (DOC = 1.1 mg/L)	8.1	EC20 (mean dry biomass)	5,634	OSU 2018b	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	396 (DOC = 1.6 mg/L)	8.1	EC20 (mean dry biomass)	13,274	OSU 2018b	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	49 (DOC = 0.8 mg/L)	6.1	EC20 (mean dry biomass)	885	OSU 2018d	Duration
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Aluminum nitrate	7 d	94 (DOC = 1.6 mg/L)	6.0	EC20 (mean dry biomass)	1,817	OSU 2018d	Duration
Zebrafish (egg, 1 d), *Danio rerio*	Aluminum chloride	24 hr	40	5	Median day to hatch	16,400 (NOEC)	Dave 1985	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Zebrafish (egg, 1 d), *Danio rerio*	Aluminum chloride	24 hr	40	6	Median day to hatch	16,400 (NOEC)	Dave 1985	Duration
Zebrafish (egg, 1 d), *Danio rerio*	Aluminum chloride	24 hr	40	7	Median day to hatch	16,400 (NOEC)	Dave 1985	Duration
Zebrafish (egg, 1 d), *Danio rerio*	Aluminum chloride	24 hr	40	8	Median day to hatch	16,400 (NOEC)	Dave 1985	Duration
Zebrafish (egg, 1 d), *Danio rerio*	Aluminum chloride	24 hr	40	9	Median survival time	<500-500 (NOEC-LOEC)	Dave 1985	Duration
Zebrafish (larva, 7-8 d), *Danio rerio*	Aluminum chloride	48 hr	40	7	LC50	106,000	Dave 1985	Duration
Zebrafish (larva, 7-8 d), *Danio rerio*	Aluminum chloride	48 hr	40	7.4-7.9	LC50	80,000	Dave 1985	Duration
Zebrafish (3 cm, 5g), *Danio rerio*	Aluminum chloride	4 d	-	-	LC50	56,920	Anandhan and Hemalatha 2009	Lack of exposure details (assumed fed too)
Zebrafish (adult, female), *Danio rerio*	Aluminum chloride	48 hr	142	8.2	LC50	>7,920	Griffitt et al. 2008	Duration
Zebrafish (fry, <24 hr), *Danio rerio*	Aluminum chloride	48 hr	142	8.2	LC50	>10,000	Griffitt et al. 2008	Duration
Zebrafish (adult, female), *Danio rerio*	Aluminum chloride	48 hr	142	6.8	100% mortality	12,500	Griffitt et al. 2011	Duration
Zebrafish (adult, female), *Danio rerio*	Aluminum chloride	48 hr	142	6.8	No mortality	5,000	Griffitt et al. 2011	Duration
Smallmouth bass (eyed egg), *Micropterus dolomieu*	F, M	11 d	15.7	4.8	Survival	100-200 (NOEC-LOEC)	Holtze and Hutchinson 1989	Duration; pH too low
Largemouth bass (juvenile), *Micropterus salmoides*	Aluminum sulfate	7 d	64-80	6.6-7.4	0% dead	50,000	Sanborn 1945	Duration
Largemouth bass (eggs/fry), *Micropterus salmoides*	Aluminum chloride	8 d	93-105	7.2-7.8	LC50	170	Birge et al. 1978	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Largemouth bass (embryo), *Micropterus salmoides*	Aluminum chloride	7-12 d	100	7.0-7.8	LC50	190	Birge et al. 2000	Duration
Striped bass (160 d), *Morone saxatilis*	Aluminum sulfate	7 d	12.5-12.8	7.2	Survival	174-348.8 (NOEC-LOEC)	Buckler et al. Manuscript, 1987	Duration
Striped bass (160 d), *Morone saxatilis*	Aluminum sulfate	7 d	12.5-12.8	6.5	Survival	87.2-174.4 (NOEC-LOEC)	Buckler et al. Manuscript, 1987	Duration
Striped bass (160 d), *Morone saxatilis*	Aluminum sulfate	7 d	12.5-12.8	6	Survival	21.8-43.6 (NOEC-LOEC)	Buckler et al. Manuscript, 1987	Duration
Pike (yolk-sac fry), *Esox lucius*	Aluminum sulfate	10 d	18	4	LC50	~160	Vuorinen et al. 1993	Duration, pH too low
Pike (yolk-sac fry), *Esox lucius*	Aluminum sulfate	10 d	18	4.25	LC50	~325	Vuorinen et al. 1993	Duration, pH too low
Pike (yolk-sac fry), *Esox lucius*	Aluminum sulfate	10 d	18	4.5	LC50	~600	Vuorinen et al. 1993	Duration, pH too low
Pike (yolk-sac fry), *Esox lucius*	Aluminum sulfate	10 d	18	4.75	LC50	~1,000	Vuorinen et al. 1993	Duration, pH too low
White sucker (eyed egg), *Catostomus commersoni*	-	96 hr	15.7	4.8	Survival	100-200 (NOEC-LOEC)	Holtze and Hutchinson 1989	Atypical endpoint; pH too low
Lake whitefish (cleavage egg), *Coregonus clupeaformis*	-	12 d	15.7	4.8	Survival	300 (NOEC)	Holtze and Hutchinson 1989	Duration; pH too low
Bullfrog (embryo), *Rana catesbeiana*	Aluminum chloride	10-12 d	100	7.0-7.8	LC50	80	Birge et al. 2000	Duration
Leopard frog (embryo, 3 hr, Gosner stage 3-4), *Rana pipiens*	Aluminum chloride	4-5 d	2.0	4.6	LC50	811	Freda and McDonald 1990	pH too low

Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Leopard frog (embryo, 3 hr, Gosner stage 3-4), *Rana pipiens*	Aluminum chloride	4-5 d	2.0	4.8	LC50	403	Freda and McDonald 1990	pH too low
Leopard frog (tadpole, Gosner stage 20), *Rana pipiens*	Aluminum chloride	96 hr	2.0	4.4	LC50	>250	Freda and McDonald 1990	pH too low
Leopard frog (tadpole, Gosner stage 20), *Rana pipiens*	Aluminum chloride	96 hr	2.0	4.6	LC50	>250	Freda and McDonald 1990	pH too low
Leopard frog (tadpole, 3 wk), *Rana pipiens*	Aluminum chloride	96 hr	2.0	4.2	LC50	>1,000	Freda and McDonald 1990	pH too low
Leopard frog (tadpole, 3 wk), *Rana pipiens*	Aluminum chloride	96 hr	2.0	4.4	LC50	>1,000	Freda and McDonald 1990	pH too low
Leopard frog (tadpole, 3 wk), *Rana pipiens*	Aluminum chloride	96 hr	2.0	4.6	LC50	>1,000	Freda and McDonald 1990	pH too low
Leopard frog (tadpole, 3 wk), *Rana pipiens*	Aluminum chloride	96 hr	2.0	4.8	LC50	>1,000	Freda and McDonald 1990	pH too low
Leopard frog (embryos), *Rana pipiens*	Aluminum chloride	96 hr	2.0	4.8	LC50	471	Freda et al. 1990	pH too low
Leopard frog (embryo), *Rana pipiens*	Aluminum chloride	10-11 d	100	7.0-7.8	LC50	90	Birge et al. 2000	Duration
Wood frog (eggs), *Rana sylvatica*	-	24 hr	7.78	5.75	Hatch success	20->20 (NOEC-LOEC)	Clark and LaZerte 1985	Duration
Wood frog (eggs), *Rana sylvatica*	-	24 hr	7.78	4.75	Hatch success	100->100 (NOEC-LOEC)	Clark and LaZerte 1985	Duration
Wood frog (eggs), *Rana sylvatica*	-	24 hr	7.78	4.415	Hatch success	10-20 (NOEC-LOEC)	Clark and LaZerte 1985	Duration
Wood frog (eggs), *Rana sylvatica*	-	24 hr	7.78	4.14-5.75	Survival	200 (NOEC)	Clark and LaZerte 1985	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Wood frog (larva, Gosner stage 25), *Rana sylvatica*	Aluminum sulfate	43-102 d	109.9-119.5	4.68-4.70	Survival and growth	2,000 (NOEC)	Peles 2013	pH too low
Spring peeper (embryo), *Pseudacris crucifer*	Aluminum chloride	7 d	100	7.0-7.8	LC50	90	Birge et al. 2000	Duration
Green tree frog (tadpole), *Hyla cinerea*	Aluminum chloride	96 hr	1.5	5.5	Growth	<150-150 (NOEC-LOEC)	Jung and Jagoe 1995	Atypical endpoint
Green tree frog (tadpole), *Hyla cinerea*	Aluminum chloride	96 hr	1.5	4.5	Growth	<150-150 (NOEC-LOEC)	Jung and Jagoe 1995	Atypical endpoint
Green tree frog (tadpole), *Hyla cinerea*	Aluminum chloride	96 hr	1.5	4.5	LC50	277	Jung and Jagoe 1995	pH too low
American toad (eggs), *Bufo americanus*	-	24 hr	7.78	5.75	Hatch success	20->20 (NOEC-LOEC)	Clark and LaZerte 1985	Duration
American toad (eggs), *Bufo americanus*	-	24 hr	7.78	4.75	Hatch success	100->100 (NOEC-LOEC)	Clark and LaZerte 1985	Duration
American toad (eggs), *Bufo americanus*	-	24 hr	7.78	4.14	Hatch success	5-10 (NOEC-LOEC)	Clark and LaZerte 1985	Duration
American toad (eggs), *Bufo americanus*	-	24 hr	7.78	4.14	Hatch success	<10-10 (NOEC-LOEC)	Clark and LaZerte 1985	Duration
American toad (eggs), *Bufo americanus*	-	24 hr	7.78	4.14-5.75	NOEC (survival)	200	Clark and LaZerte 1985	Duration
American toad (tadpoles, Gosner stage 26), *Bufo americanus*	Aluminum chloride	96 hr	2.0	4.5	LC50	672	Freda et al. 1990	pH too low
Common toad (spawn, 0-48 hr), *Bufo bufo*	Aluminum nitrate	7 d	50	6.0	Survival	>320 (NOEC)	Gardner et al. 2002	Duration
Common toad (spawn, 0-48 hr), *Bufo bufo*	Aluminum nitrate	7 d	50	7.5	Survival	>320 (NOEC)	Gardner et al. 2002	Duration

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Species	Chemical	Duration	Total Hardness (mg/L as $CaCO_3$)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Fowler's toad (embryo), *Bufo fowleri*	Aluminum chloride	7 d	100	7.0-7.8	LC50	280	Birge et al. 2000	Duration
Narrow-mouthed toad (eggs), *Gastrophryne carolinensis*	Aluminum chloride	7 d	195	7.4	EC50 (death and deformity)	50	Birge 1978	Duration
Narrow-mouthed toad (eggs), *Gastrophryne carolinensis*	Aluminum chloride	7 d	100	7.0-7.8	LC50	50	Birge et al. 2000	Duration
Marbled salamander (eggs), *Ambystoma opacum*	Aluminum chloride	8 d	93-105	7.2-7.8	EC50 (death and deformity)	2,280	Birge et al. 1978	Duration
Marbled salamander (embryo), *Ambystoma opacum*	Aluminum chloride	9-10 d	100	7.0-7.8	LC50	2,280	Birge et al. 2000	Duration

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Appendix I OTHER DATA ON EFFECTS OF ALUMINUM TO ESTUARINE/MARINE AQUATIC ORGANISMS

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Appendix I. Other Data on Effects of Aluminum to Estuarine/Marine Aquatic Organisms

Species	Chemical	Duration	Salinity (g/kg)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Estuarine/Marine Species								
Phytoplankton, *Dunaliella tertiolecta*	Aluminum nitrate	72 hr	-	8.2	IC25 (inhibit growth)	18,160	Sacan et al. 2007	Duration
Phytoplankton, *Dunaliella tertiolecta*	Aluminum nitrate	72 hr	-	8.2	SC20 (stimulate growth)	4,660	Sacan et al. 2007	Duration
Diatom, *Nitzschia closterium*	Aluminum chloride	72 hr	-	8.2	IC50 (growth rate)	190	Harford et al. 2011	Duration
Polychaete worm, *Ctenodrilus serratus*	Aluminum chloride	21 d	-	7.6-8	Reproduction	20-40 (NOEC-LOEC)	Petrich and Reish 1979	Unmeasured chronic exposure
Sea urchin (embryo), *Paracentrotus lividus*	Aluminum sulfate	72 hr	-	-	69.7% developmental effects	539.6	Caplat et al. 2010	Difficult to determine effect concentration
Bay mussel (28.0 mm), *Mytilus edulis*	Alum (potassium)	24 hr	30	4.4-7.3	LC50	>6,400,000	Robinson and Perkins 1977	Duration
Common winkle (13.3 mm), *Littorina littorea*	Alum (potassium)	24 hr	30	4.4-7.3	LC50	>6,400,000	Robinson and Perkins 1977	Duration
European shore crab (12.6 mm), *Carcinus maenas*	Alum (potassium)	24 hr	30	4.4-7.3	LC50	2,500,000	Robinson and Perkins 1977	Duration
Hermit crab (11.4 mm), *Eupagurus bernhardus*	Alum (potassium)	24 hr	30	4.4-7.3	LC50	250,000	Robinson and Perkins 1977	Duration

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Species	Chemical	Duration	Salinity (g/kg)	pH	Effect	Concentration (µg/L)	Reference	Reason Other Data
Yellow crab (embryo, 4-lobed stage), *Cancer anthonyi*	-	7 d	34	7.8	Survival	<10,000-10,000 (NOEC-LOEC)	MacDonald et al. 1988	Duration, unmeasured chronic exposure
Yellow crab (embryo, 4-lobed stage), *Cancer anthonyi*	-	7 d	34	7.8	Hatching of embryos	<10,000-10,000 (NOEC-LOEC)	MacDonald et al. 1988	Duration, unmeasured chronic exposure
Daggerblade grass shrimp (embryo, 3 d), *Palaemonetes pugio*	-	12 d	20	7.6-8.1	LC50	1,079	Rayburn and Aladdin 2003	Duration

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Appendix J LIST OF ALUMINUM STUDIES NOT USED IN DOCUMENT ALONG WITH REASONS

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Appendix J. List of Aluminum Studies Not Used in Document Along with Reasons

Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Aarab et al.	Histopathology alterations and histochemistry measurements in mussel, *Mytilus edulis* collected offshore from an aluminum smelter industry (Norway)	2008	Bay mussel, *Mytilus edulis*	-	Not applicable; no aluminum toxicity data
Abdelhamid and El-Ayouty	Effect of catfish (*Clarias lazera*) composition of ingestion rearing water contaminated with lead or aluminum compounds	1991	Catfish, *Clarias lazera*	6 wk 50,000 0.33 corrected mortality	Not North American species; dilution water not characterized
Abdel-Latif	The influence of calcium and sodium on aluminum toxicity in Nile tilapia (*Oreochromis niloticus*)	2008	Nile tilapia, *Oreochromis niloticus*	96 hr LC50=175.9	Dilution water not characterized; lack of exposure details
Abraham et al.	Quantified elemental changes in *Aspidisca cicada* and *Vorticella convallaria* after exposure to aluminum, copper, and zinc	1997	Protozoa, *Aspidisca cicada* Protozoa, *Vorticella convallaria*	-	Mixture
Adokoh et al.	Statistical evaluation of environmental contamination, distribution and source assessment of heavy metals (aluminum, arsenic, cadmium, and mercury) in some lagoons and an estuary along the coastal belt of Ghana	2011	-	-	Survey
Ahsan et al.	Comparative proteomic study of arsenic-induced differentially expressed proteins in rice roots reveals glutathione plays a central role during As stress	2008	-	-	Not applicable; no aluminum toxicity data
Al-Aarajy and Al-Saadi	Effect of heavy metals on physiological and biochemical features of *Anabaena cylindrica*	1998	Blue-green alga, *Anabaena cylindrica*	-	Only one exposure concentration; lack of exposure details (duration not reported)
Alessa and Oliveira	Aluminum toxicity studies in *Vaucheria longicaulis v*ar. *macounii* (Xanthophyta, Tribophyceae). I. Effects on cytoplasmic organization	2001a	Alga, *Vaucheria longicaulis* var. m*acouni*	10 hr 2,159 growth ceased	Only one exposure concentration
Alessa and Oliveira	Aluminum toxicity studies in *Vaucheria longicaulis* var. *macounii* (Xanthophyta, Tribophyceae). II. Effects on the F-Actin array	2001b	Alga, *Vaucheria longicaulis* var. m*acouni*	-	Lack of exposure details; dilution water not characterized; only one exposure concentration
Allin and Wilson	Behavioural and metabolic effects of chronic exposure to sublethal aluminum in acidic soft water in juvenile rainbow trout (*Oncorhynchus mykiss*)	1999	Rainbow trout, *Oncorhynchus mykiss*	6 wk 29.2 Reduced appetite	Only one exposure concentration

Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Allin and Wilson	Effects of pre-acclimation to aluminum on the physiology and swimming behaviour of juvenile rainbow trout (*Oncorhynchus mykiss*) during a pulsed exposure	2000	Rainbow trout, *Oncorhynchus mykiss*	-	Pulsed exposures to pollutant
Alquezar et al.	Metal accumulation in the smooth toadfish, *Tetractenos glaber*, in estuaries around Sydney, Australia	2006	Toadfish, *Tetractenos glaber*	-	Not North American species; exposed to mixture
Alstad et al.	The significance of water ionic strength on aluminum in brown trout (*Salmo trutta* L.)	2005	Brown trout, *Salmo trutta*	650 Survival time =16-34 hr	No acclimation to test water; only one exposure concentration
Amato et al.	Concentrations, sources and geochemistry of airborne participate matter at a major European airport	2010	-	-	Not applicable; no aluminum toxicity data
Amenu	A comparative study of water quality conditions between heavily urbanized and less urbanized watersheds of Los Angeles Basin	2011	-	-	Not applicable; no aluminum toxicity data
Anderson	The apparent thresholds of toxicity to *Daphnia magna* for chlorides of various metals when added to Lake Erie water	1948	Cladoceran, *Daphnia magna*	64 hr 6,700 LOEC (mortality)	Lack of exposure details; control data not reported
Andersson	Toxicity and tolerance of aluminum in vascular plants	1988	-	-	Review
Andren and Rydin	Toxicity of inorganic aluminum at spring snowmelt-in-stream bioassays with brown trout (*Salmo trutta* L.)	2012	Brown trout, *Salmo trutta*	-	Mixture; dilution water is river water
Andren et al.	Effects of pH and aluminum on embryonic and early larval stages of Swedish brown frogs Rana arvalis, R. temporaria and R. dalmatina	1988	Brown frog, *Rana arvalis* Brown frog, *Rana temporaria* Brown frog, *Rana dalmatina*	15 d NOEC (mortality) =800, 800, & <800, respectively	Not North American species
Andrews et al.	Selected metals in sediments and streams in the Oklahoma part of the Tri-State Mining District, 2000-2006	2009	-	-	Survey
Annicchiarico et al.	PCBs, PAHs and metal contamination and quality index in marine sediments of the Taranto Gulf	2011	-	-	Survey; sediment

Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Appelberg	Changes in haemolymph ion concentrations of *Astacus astacus* L. and *Pacifastacus leniusclus* (Dana) after exposure to low pH and aluminium	1985	Signal crayfish, *Pacifastacus leniusculus*	14 d 250 Decrease Na^+ haemolymph concentrations	Too few organisms per treatment (4 per treatmen); only 3 exposure concentrations
Arain et al.	Total dissolved and bioavailable elements in water and sediment samples and their accumulation in *Oreochromis mossambicus* of polluted Manchar Lake	2008	Mozambique tilapia, *Oreochromis mossambicus*	-	Survey
Arenhart et al.	Involvement of ASR genes in aluminium tolerance mechanisms in rice	2013	Rice	-	Scientific name not given
Arthur D. Little Inc.	Water quality criteria data book, volume 2; Inorganic chemical pollution of freshwater	1971	-	-	Review; results of previously published papers
AScI Corp.	Aluminum water-effect ratio for the 3M Middleway plant effluent discharge, Middleway, West virginia	1994	Cladoceran, *Daphnia magna* Rainbow trout, *Oncorhynchus mykiss*	-	Mixture
AScI Corp.	Aluminum water-effect ratio for Georgia-Pacific Corporation Woodland, Maine; Pulp and paper operations discharge and St. Croix River	1996	-	-	Review; results of previously published papers
Atland	Behavioural responses of brown trout, *Salmo trutta*, juveniles in concentration gradients of pH and Al - a laboratory study	1998	Atlantic salmon, *Salmo salar*	1 hr 200=avoidance, 70=no avoidance	Only two exposure concentrations
Atland and Barlaup	Avoidance behaviour of Atlantic salmo (*Salmo salar* L.) fry in waters of low pH and elevated aluminum concentration: laboratory experiments	1996	Atlantic salmon, *Salmo salar*	1 hr LC20=85, LC40=160	Only two exposure concentrations
Avis et al.`	Ultrastructural alterations in *Fusarium sambucinum* and *Heterobasidion annosum* treated with aluminum chloride and sodium metabisulfite	2009	Fungus, *Fusarium sambucinum* Fungus, *Heterobasidion annosum*	60 min LOEC (dead conidia) =269,880 for both species	Only two exposure concentrations
Baba and Gunduz	Effect of alteration zones on water quality: a case study from Biga Peninsula, Turkey	2010	-	-	Survey
Bailey et al.	Application of toxicity identification procedures to the echinoderm fertilization assay to identify toxicity in a municipal effluent	1995	Sand dollar, *Dendraster excentricus* Purple urchin, *Stronglocentrotus purpuratus*	-	Mixture; effluent

Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Baker	Aluminum toxicity to fish as related to acid precipitation and Adirondack surface water quality	1981	Brook trout, *Salvelinus fontinalis* White sucker, *Catostomus commersoni*	14 d 46.7% survival=180, 43.4% survival=110	Only two exposure concentrations
Baker	Effects on fish metals associated with acidification	1982	-	-	Review; results of previously published papers
Baker and Schofield	Aluminum toxicity to fish in acidic waters	1982	-	-	Only two exposure concentrations; review of Baker 1982
Baldigo and Murdoch	Effect of stream acidification and inorganic aluminum on mortality of brook trout (Salvelinus fontinalis) in the Catskill Mountains, New York	1997	Brook trout, *Salvelinus fontinalis*	-	Mixture; fluctuating Catskill mountain stream chemical exposure
Ball et al.	Water-chemistry data for selected springs, geysers, and streams in Yellowstone National Park, Wyoming, 2006-2008	2010	-	-	Survey; occurrence
Ballance et al.	Influence of sediment biofilm on the behaviour of aluminum and its bioavailability to the snail *Lymnaea stagnalis* in neutral freshwater	2001	Snail, *Lymnaea stagnalis*	-	Not applicable; no aluminum toxicity data
Barbiero et al.	The effects of a continuous application of aluminum sulfate on lotic benthic invertebrates	1988	-	-	Exposure concentration not known; field dosing of Al sulfate to a reservoir
Barbour and Paul	Adding value to water resource management through biological assessment of rivers	2010	-	-	Not applicable; no aluminum toxicity data
Barcarolli and Martinez	Effects of aluminum in acidic water on hematological and physiological parameters of the neotropical fish *Leporinus macrocephalus* (Anostomidae)	2004	Neotropical fish, *Leporinus macrocephalus*	24 hr 15 Increase hematocrit %; decrease plasma Na, Cl; Increase plasma glucose	Not North American species; only one exposure concentration
Bargagli	Environmental contamination in Antarctic ecosystems	2008	-	-	Survey; occurrence
Barnes	The determination of specific forms of aluminum in natural water	1975	-	-	Not applicable; no aluminum toxicity data
Battram	The effects of aluminum and low pH on chloride fluxes in the brown trout, *Salmo trutta* L.	1988	Brown trout, *Salmo trutta*	-	Acclimation too short; too few organisms per concentration
Beattie and Tyler-Jones	The effects of low pH and aluminum on breeding success in the frog *Rana temporaria*	1992	European common frog, *Rana temporaria*	-	Not North American species; only 3 exposure concentrations

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Beattie et al.	The effects of pH, aluminum concentration and temperature on the embryonic development of the European common frog, *Rana temporaria*	1992	European common frog, *Rana temporaria*	-	Not North American species; cannot determine effect concentration; dose-response not well defined
Becker and Keller	The effects of iron and sulfate compounds on the growth of *Chlorella*	1973	Green alga, *Chlorella vulgaris*	30 d 163,972 Reduced growth	Too few exposure concentrations, lack of exposure details
Belabed et al.	Evaluation de la toxicite de quelques metaux lourds a l'aide du test daphnie	1994	-	-	Text in foreign language
Berg	Aluminum and manganese toxicities in acid coal mine wastes	1978	-	-	Review; results of previously published papers
Berg and Burns	The distribution of aluminum in the tissues of three fish species	1985	Channel catfish, *Ictalurus punctatus* Largemouth bass, *Micropterus salmoides* Gizzard shad, *Dorosoma cepedianum*	-	Exposure concentration not known; field accumulation study
Bergman	Development of biologically relevant methods for determination of bioavailable aluminum in surface waters	1992	Rainbow trout, *Oncorhynchus mykiss* Brook trout, *Salvelinus fontinalis*	-	Mixture; Al and organic acids
Bergman and Mattice	Lake acidification and fisheries project: adult brook trout (*Salvelinus fontinalis*) early life stages	1990	Brook trout, *Salvelinus fontinalis*	-	Review; results of previously published papers
Bergman et al.	Lake acidification and fisheries project: adult brook trout (*Salvelinus fontinalis*)	1988	Brook trout, *Salvelinus fontinalis*	-	Review; results of previously published papers
Berntssen et al.	Responses of skin mucous cells to aluminum exposure at low pH in Atlantic salmon (*Salmo salar*) smolts	1997	Atlantic salmon, *Salmo salar*	55.6, LT50=>80 hr, 91.0, LT50= 29 hr	Dilution water not characterized; not true control group
Bervoets et al.	Use of transplanted zebra mussels (*Dreissena polymorpha*) to assess the bioavailability of microcontaminants in Flemish surface waters	2005	Zebra mussel, *Dreissena polymorpha*	-	Exposure concentration not known; mixture; field accumulation study
Bexfield et al.	Potential chemical effects of changes in the source of water supply for the Albuquerque Bernalillo County Water Utility Authority	2008	-	-	Not applicable; no aluminum toxicity data
Birge et al.	Evaluation of aquatic pollutants using fish and amphibian eggs as bioassy organisms	1979	-	-	Results of previously published papers; review of Birge 1978
Birge et al.	Aquatic toxicity tests on inorganic elements occurring in oil shale	1980	-	-	Results of previously published papers; review of Birge 1978

Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Birge et al.	The reproductive toxicology of aquatic contaminants	1981	-	-	Review; results of previously published papers
Birge et al.	Effects of chemical stresses on behavior of larval and juvenile fishes and amphibians	1993	Fathead minnow, *Pimephales promelas*	50 Reduced feeding	Only two exposure concentrations
Bjerknes et al.	Aluminum in acidic river water causes mortality of farmed Atlantic salmon (*Salmo salar* L.) in Norwegian fjords	2003	Atlantic salmon, *Salmo salar*	-	Exposure concentration not known; field study with run-off to fjord-based farms
Boniardi et al.	Effect of dissolved metals on the organic load removal efficiency of Lemna gibba	1999	Duckweed, *Lemna gibba*	7 d NOEC(growth)= >29,000	Excessive EDTA used (>200 µg/L)
Booth et al.	Effects of aluminum and low pH on net ion fluxes and ion balance in the brook trout (*Salvelinus fontinalis*)	1988	Brook trout, *Salvelinus fontinalis*	-	Mixture; low pH and Al
Bowry	Relative toxicity of different fumigants against the adults of lesser grain borer *Rhizopertha dominica* Fabr. and rice moth *Corcyra cephalonica* Staint	1985	-	-	Not applicable; terrestrial species
Bradford et al.	Effects of low pH and aluminum on two declining species of amphibians in the Sierra Nevada, California	1992	Mountain yellow-legged frog, *Rana muscosa* Yosemite toad, *Bufo canorus*	No effect on hatch time or growth at 75; Effect on hatch time and decrease growth at 75	Only one exposure concentration
Bradford et al.	Effects of low pH and aluminum on amphibians at high elevation in the Sierra Nevada, California	1994	Pacific chorus frog, *Pseudacris regilla* Long-toed salamander, *Ambystoma macrodactylum*	-	Only one exposure concentration at each pH level
Brady and Griffiths	Effects of pH and aluminum on the growth and feeding behaviour of smooth and palmate newt larvae	1995	Newt, *Triturus helveticus* Newt, *Triturus vulgaris*	14 d Reduce growth for both species at 222 and pH=7.0	Only one exposure concentration
Brodeur et al.	Increase of heart rate without elevation of cardiac output in adult Atlantic salmon (*Salmo salar*) exposed to acidic water and aluminum	1999	Atlantic salmon, *Salmo salar*	-	Mixture; dilution water is river water
Brodeur et al.	Effects of subchronic exposure to aluminum in acidic water on bioenergetics of Atlantic salmon (*Salmo salar*)	2001	Atlantic salmon, *Salmo salar*	36 d Decrease growth, but not food consumption at 50	Only one exposure concentration

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Brown	The effects of various cations on the survival of brown trout, *Salmo trutta* at low pHs	1981a	Brown trout, *Salmo trutta*	18 d Increase survival time at 250	Only two exposure concentrations
Brown	Effect of calcium and aluminum concentrations on the survival of brown trout (*Salmo trutta*) at low pH	1983	Brown trout, *Salmo trutta*	16 d 30% survival at 500 (Ca=2 mg/L); 0% survival at 500 (Ca=0.25 mg/L)	Only two exposure concentrations
Brown and Bruland	Dissolved and particulate aluminum in the Columbia River and coastal waters of Oregon and Washington: behavior in near-field and far-field plumes	2009	-	-	Survey; occurrence
Brown et al.	Report on a large fish kill resulting from natural acid water conditions in Australia	1983	-	-	Mixture; Al and low pH
Brown et al.	Effects of low ambient pH and aluminum on plasma kinetics of cortisol, T3, and T4 in rainbow trout (*Oncorhynchus mykiss*)	1990	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species
Brown et al.	Contaminant effects on the tleost fish thyroid	2004	-	-	Review; results of previously published papers
Brumbaugh and Kane	Variability of aluminum concentrations in organs and whole bodies of smallmouth bass (*Micropterus dolomieui*)	1985	Smallmouth bass, *Micropterus dolomieui*	-	Exposure concentration not known; field accumulation study
Budambula and Mwachiro	Metal status of Nairobo river waters and their bioaccumulation in *Labeo cylindricus*	2006	Fish, *Labeo cylindricus*	-	Not North American species; exposure concentration not known; field accumulation study
Buergel and Soltero	The distribution and accumulation of aluminum in rainbow trout following a whole-lake alum treatment	1983	-	-	Exposure concentration not known; field accumulation study
Burrows	Aquatic aluminum: chemistry, toxicology, and environmental prevalence	1977	-	-	Review; results of previously published papers

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Burton and Allan	Influence of pH, aluminum, and organic matter on stream invertebrates	1986	Stonefly, *Nemoura sp.* Isopod, *Asellus intermedius* Snail, *Physella heterostropha* Caddisfly, *Lepidostoma liba* Caddisfly, *Pycnopsyche guttifer*	28 d 35% survival at 500; 20% survival at 500; 55% survival at 500; 50% survival at 500; 70% survival at 500	Only two exposure concentrations
Cai et al.	Developmental characteristics and aluminum resistance of root border cells in rice seedlings	2011	Rice, *Oryza sativa*	-	Dilution water is distilled water
Calevro et al.	Toxic effects of aluminum, chromium and cadmium in intact and regenerating freshwater planarians	1998a	Planarian, *Dugesia etrusca*	15 d NOEC (mortality) =250; LOEC=500	Not North American species
Calevro et al.	Tests of toxicity and teratogenicity in biphasic vertebrates treated with heavy metals (Cr3+, Al3+, Cd2+)	1998b	Newt, *Triturus vulgaris meridionalis* Frog, *Rana esculenta*	170 hr NOEC (embryo development)=404.7; 120 hr NOEC (embryo development)=404.7	Not North American species, unmeasured chronic exposure
Calevro et al.	Bioassays for testing effects of Al, Cr and Cd using development in the amphibian *Pleurodeles waltl* and regeneration in the planarian *Dugesia etrusca*	1999	Planarian, *Dugesia etrusca*	14 d 100% mortality at 13,490 NOEC (regeneration)=1,349	Not North American species
Camargo et al.	Osmo-ionic alterations in a neotropical fish acutely exposed to aluminum	2007	Neotropical fish, *Prochilodus lineatus*	-	Not North American species; lack of exposure details; only one exposure concentration; abstract only
Camargo et al.	How aluminum exposure promotes osmoregulatory disturbances in the neotropical freshwater fish *Prochilus lineatus*	2009	Neotropical fish, *Prochilodus lineatus*	96 hr Increase hemoglobin; increase hematocrit %; decrease plasma ions and osmolarity at 438	Not North American species; only one exposure concentration
Camilleri et al.	Silica reduces the toxicity of aluminum to a Tropical Freshwater Fish (*Mogurnda mogurnda*)	2003	Australian spotted gudgeon, *Mogurnda mogurnda*	96 hr LC50=374; LC50=547	Not North American species

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Campbell et al.	Effect of aluminum and silica acid on the behavior of the freshwater snail *Lymnaea stagnalis*	2000	Snail, *Lymnaea stagnalis*	7 d Reduce behavioral state score (BSS) at 500	Only two exposure concentrations
Capdevielle and Scanes	Effect of dietary acid or aluminum on growth and growth-related hormones in mallard ducklings (*Anas platyrhynchos*)	1995	Mallard duck, *Anas platyrhynchos*	-	Dietary exposure; only two exposure concentrations
Capdevielle et al.	Aluminum and acid effects on calcium and phosphorus metabolism in young growing chickens (*Gallus gallus domesticus*) and mallard ducks (*Anas platyrhynchos*)	1998	Mallard duck, *Anas platyrhynchos*	-	Dietary exposure; only two exposure concentrations
Carballeira et al.	Biomonitoring of sporadic acidification of rivers on the basis of release of preloaded cadmium from the aquatic bryophyte *Fontinalis antipyretica* Hedw	2001	Bryophyte, *Fontinalis antipyretica*	-	Mixture; species prior exposed to Cd
Cardwell et al.	Toxic substances and water quality effects on larval marine organisms, technical report no. 45	1979	-	-	Not applicable; no aluminum toxicity data
Carter and Porter	Trace-element accumulation by *Hygrohypnum ochraceum* in the Upper Rio Grande Basin, Colorado and New Mexico, USA	1997	Bryophyte, *Hygrohypnum ochraceum*	-	Exposure concentration not known (not measured over time); field exposure with transplanted plants
Chakravorty et al.	Primary and secondary stress response of *Channa punctatus* to sublethal aluminium toxicity	2012	Snakehead catfish, *Channa punctatus*	96 hr LC50=220,000	Not North American species
Chamier and Tipping	Effects of aluminum in acid streams on growth and sporulation of aquatic hyphomycetes	1997	Fungi, *Tricladium splendens* Fungi, *Alatospora constricta* Fungi, *Varicosporium elodea*	-	Mixture; low pH and Al
Chang et al.	Response of the mussel *Anadonta grandi* to acid and aluminum. Comparison of blodd ions from laboratory and field results	1988	Mussel, *Anadonta grandi*	-	Mixture; aluminum sulphate added to a lake
Chapman et al.	Concentration factors of chemical elements in edible aquatic organisms	1968	-	-	Review; results of previously published papers
Chapman et al.	Why fish mortality in bioassays with aluminum reduction plant wastes don't always indicate chemical toxicity	1987	-	-	Not applicable; no aluminum toxicity data
Chen	Ecological risk assessment for aquatic species exposed to contaminants in Kelung River, Taiwan	2005	-	-	Not applicable; occurrence; no aluminum toxicity data

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Chen et al.	Environmental factors affecting settlement of quagga mussel (*Dreissena rostriformis bugensis*) veligers in Lake Mead, Nevada-Arizona, USA	2011	Quagga mussel, *Dreissena rostriformis bugensis*	-	Not applicable; no aluminum toxicity data
Chevalier et al.	Acidity and aluminum effects on osmo-iono-regulation in the brook trout	1987	Brook trout, *Salvelinus fontinalis*	7 d Addition of Al kept fish alive compared to control at 500 and pH=5.5	Only one exposure concentration
Christensen	Effects of metal cations and other chemicals upon the in vitro activity of twp enzymes in the blood plasma of the white sucker, *Catostomus commersoni* (lacepede)	1971/ 1972	White sucker, *Catostomus commersoni*	-	In vitro experiment
Christensen and Tucker	Effects of selected water toxicants on the in vitro activity of fish carbonic anhydrase	1976	Channel catfish, *Ictalurus punctatus*	-	Excised cells
Clark and Hall	Effects of elevated hydrogen ion and aluminum concentrations on the survival of amphibian embryos and larvae	1985	Toad, *Bufo americanus* Wood frog, *Rana sylvatica* Spotted salamander, *Ambystoma maculatum*	-	Exposure concentration not known; field experiment: dosed stream pools
Clark and LaZerte	Intraspecific variation in hydrogen ion and aluminum toxicity in *Bufo americanus* and *Ambystoma maculatum*	1987	Toad, *Bufo americanus* Spotted salamander, *Ambystoma maculatum*	-	Pre-exposure to pollutant
Cleveland et al.	Interactive toxicity of aluminum and acidity to early life stages of brook trout	1986	Brook trout, *Salvelinus fontinalis*	30 d Increase egg mortality at 318	Only one exposure concentration
Cleveland et al.	Sensitivity of brook trout to low pH, low calcium and elevated aluminum concentrations during laboratory pulse exposures	1991b	Brook trout, *Salvelinus fontinalis*	-	Only one exposure concentration; mixture; Al and acid pulses
Colman et al.	Determination of dilution factors for discharge of aluminum-containing wastes by public water-supply treatment facilities into lakes and reservoirs in Massachusetts	2011	-	-	Not applicable; no aluminum toxicity data

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Conklin et al.	Comparative toxicity of drilling muds: Role of chromium and petroleum hydrocarbons	1983	Grass shrimp, *Palaemonetes pugio* Sheepshead minnow, *Cyrpinodon variegatus*	-	Mixture; drilling mud
Cook and Haney	The acute effects of aluminum and acidity upon nine stream insects	1984	Five caddisflies, two mayflies, stonefly and beetle	-	Mixture; dilution water is river water
Correa et al.	Changes in oxygen consumption and nitrogen metabolism in the dragonfly *Somatochlora cingulata*	1985	Dragonfly, *Somatochlora cingulata*	96 hr No change in respiratory rate at 30	Lack of exposure details; dilution water not characterized; too few exposure concentration
Correa et al.	Oxygen consumption and ammonia excretion in the detritivore caddisfly *Limnephillus sp.* exposed to low pH and aluminum	1986	Caddisfly, *Limnephillus sp.*	-	Only one exposure concentration; mixture; low pH and Al
Correia et al.	Aluminum as an endocrine disruptor in female Nile tilapia (*Oreochromis niloticus*)	2010	Nile tilapia, *Oreochromis niloticus*	96 hr Increase gonad and decrease liver lipids at 1,600	Only one exposure concentration
Craig et al.	Water quality objectives development document: aluminum	1985	-	-	Review; results of previously published papers
Cravotta et al.	Abandoned mine drainage in the Swatara Creek Basin, southern anthracite coalfield, Pennsylvania, USA: 1. Stream water quality trends coinciding with the return of fish	2010	-	-	Mixture; dilution water is river water
Crawford et al.	A survey of metal and pesticide levels in stormwater retention pond sediments in coastal South Carolina	2010	-	-	Survey; occurrence
Crist et al.	Interaction of metal protons with algae. 3. Marine algae, with emphasis on lead and aluminum	1992	-	-	Bioaccumulation: steady state not reached
Cummins	Effects of aluminum and low pH on growth and development in *Rana temporaria* tadpoles	1986	Brown frog, *Rana temporaria*	18 d Decrease body mass and increase time to metamorph at 800	Not North American species; only two exposure concentrations
Dalziel et al.	The effects of low pH, low calcium concentrations and elevated aluminum concentrations on sodium fluxes in brown trout, *Salmo trutta* L.	1986	Brown trout, *Salmo trutta*	8 hr No effect on Na influx at 215.8	Only one exposure concentration
Delaune et al.	Total Hg, methyl Hg and other toxic heavy metals in a northern Gulf of Mexico Estuary: Louisiana Pontchartrain Basin	2008	-	-	Survey; occurrence

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Desouky	Tissue distribution and subcellular localization of trace metals on the pond snail *Lymnaea stagnalis* with special reference to the role of lysosomal granules in metal sequestration	2006	Snail, *Lymnaea stagnalis*	-	Bioaccumulation: exposure concentration not measured; inadequate exposure methods
Desouky	Metallothionein is up-regulated in molluscan responses to cadmium, but not aluminum, exposure	2012	Snail, *Lymnaea stagnalis* Zebra mussel, *Dreissena polymorpha*	-	Only one exposure concentration; possible prior exposure due to location collected in field
Desouky et al.	Influence of oligomeric silica and humic acids on aluminum accumulation in a freshwater grazing invertebrate	2002	Snail, *Lymnaea stagnalis*	-	Bioaccumulation: steady state not reached
DeWalle et al.	Episodic flow-duration analysis: a method of assessing toxic exposure of brook trout (*Salvelinus fontinalis*) to episodic increases in aluminum	1995	-	-	Not applicable; no aluminum toxicity data
Dickson	Liming toxicity of aluminum to fish	1983	-	-	Not applicable; no aluminum toxicity data
Dietrich and Schlatter	Aluminum toxicity to rainbow trout at low pH	1989a	Rainbow trout, *Oncorhynchus mykiss*	MT50=64 hrs at 200; MT50=45.5 hrs at 400 (pH=5.4); MT50=52 hrs at 400 (pH=5.6)	Only two exposure concentrations
Dietrich and Schlatter	Low levels of aluminum causing death of brown trout (*Salmo trutta fario*, L.) in a Swiss alpine lake	1989b	Brown trout, *Salmo trutta fario*	-	Mixture; exposure concentration varied over time; dilution water is lake water
Dietrich et al.	Aluminum and acid rain: mitigating effects of NaCl on aluminum toxicity to brown trout (*Salmo trutta fario*) in acid water	1989	Brown trout, *Salmo trutta fario*	-	No acclimation to test water; no aluminum toxicity data
Doke et al.	Habitat availability and benthic invertebrate population changes following alum treatment and hypolimnetic oxygenation in Newman Lake, Washington	1995	-	-	Mixture; alum added to lake; no species listed
Doudoroff and Katz	Critical review of literature on the toxicity of industrial wastes and their components to fish. II. The metals, as salts	1953	-	-	Review; results of previously published papers
Driscoll	A procedure for the fractionation of aqueous aluminum in dilute acidic waters	1984	-	-	Not applicable; no aluminum toxicity data
Driscoll	Aluminum in acidic surface waters: chemistry, transport, and effects	1985	-	-	Not applicable; no aluminum toxicity data

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Driscoll et al.	Effect of aluminum speciation on fish in dilute acidified waters	1980	Brook trout, *Salvelinus fontinalis*	14 d 28% survival at 420, pH=5.2; 42% survival at 480, pH=4.4	Lack of exposure details; only two exposure concentrations
Duis and Oberemm	Aluminum and calcium - Key factors determining the survival of vendace embryos and larvae in post-mining lakes?	2001	Vendace, *Coregonus albula*	Decrease hatch % at 2,100, pH=5.0	Not North American species; only one exposure concentration
Durrett et al.	The FRD3-mediated efflux of citrate into the root vasculature is necessary for efficient iron translocation	2007	-	-	Not applicable; no aluminum toxicity data
Dussault et al.	Effects of sublethal, acidic aluminum exposure on blood ions and metabolites, cardiac output, heart ratem and stroke volume of rainbow trout, *Oncorhynchus mykiss*	2001	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species
Dussault et al.	Effects of chronic aluminum exposure on swimming and cardiac performance in rainbow trout, *Oncorhynchus mykiss*	2004	Rainbow trout, *Oncorhynchus mykiss*	6 wk 75% survival at 32	Too few exposure concentrations; too few organisms per concentration
Dwyer et al.	Use of surrogates species in assessing contaminant risk to endangered and threatened species; final report - September 1995	1995	-	-	Not applicable; no aluminum toxicity data
Dwyer et al.	Assessing contaminant sensitivity of endangered and threatened aquatic species: part III. Effluent toxicity tests	2005	-	-	Not applicable; no aluminum toxicity data
Eaton et al.	A field and laboratory investigation of acid effects on largemouth bass, rock bass, black crappie, and yellow perch	1992	Rockbass, *Ambloplites rupestris* Largemouth bass, *Micropterus salmoides* Yellow perch, *Perca flavescens*	Hatch + 7 d NOEC (survival)=44.0; NOEC=44.0; NOEC=25.2	Too few exposure concentrations; control survival issues
Ecological Analysts, Inc.	Study on metals in food fish near the abandoned Vienna fly ash disposal area	1984	-	-	Field exposure, exposure concentrations not measured adequately
Eddy and Talbot	Formation of the perivitelline fluid in Atlantic salmon eggs (*Salmo salar*) in fresh water and in solutions of metal ions	1983	Atlantic salmon, *Salmo salar*	1 hr Inhibit perivitelline fluid formation at 26,980	Dilution water not characterized

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Eddy and Talbot	Sodium balance in eggs and dechlorinated embryos of the Atlantic salmon *Salmo salar* L. exposed to zinc, aluminum and acid waters	1985	Atlantic salmon, *Salmo salar*	-	Too few exposure concentrations; no true control group
Eisler et al.	Fourth annotated bibliography on biological effects of metals in aquatic environments (No. 2247-3132)	1979	-	-	Review
Elangovan et al.	Accumulation of aluminum by the freshwater crustacean Asellus aquaticus in neutral water	1999	Crustacean, *Asellus aquaticus*	-	Bioaccumulation: unmeasured concentration in exposure media
Elsebae	Comparative susceptibility of the Alareesh Marine Culture Center shrimp *Penaeus japonicus* and the brine shrimp *Artemia salina* to different insecticides and heavy metals	1994	Shrimp, *Penaeus japonicus*	96 hr LC50=0.001; LC50=0.0045; LC50=0.1	Not North American species; dilution water not characterized
Elwood et al.	Contribution of gut contents to the concentration and body burden of elements in Tipula spp. from a spring-fed stream	1976	-	-	Field exposure, exposure concentrations not measured adequately
Eriksen et al.	Short-term effects on riverine Ephemeroptera, Plecoptera, and Trichoptera of rotenone and aluminum sulfate treatment to eradicate *Gyrodactylus salaris*	2009	-	-	Mixture; mixed species exposure; dilution water is river water
Ernst et al.	Effects of habitat characteristics and water quality on macroinvertebrate communities along the Neversink River in southeastern New York, 1991-2001	2008	-	-	Not applicable; no aluminum toxicity data
Evans et al.	The effects of aluminum and acid on the gill morphology in rainbow trout, *Salmo gairdneri*	1988	Rainbow trout, *Oncorhynchus mykiss*	14 d LOEC (epithelial hyperplasma) = 269.8 (pH 5.2)	Only three exposure concentrations
Everhart and Freeman	Effect of chemical variations in aquatic environments. Vol. II. Toxic effects of aqueous aluminum to rainbow trout	1973	Rainbow trout, *Oncorhynchus mykiss*	45 d Reduced growth at 514 (pH=8 and pH=6.85)	Too few exposure concentrations; unmeasured chronic exposure
Exley	Avoidance of aluminum by rainbow trout	2000	Rainbow trout, *Oncorhynchus mykiss*	45 min. Avoidance at 33.73	No acclimation to test water
Exley et al.	Silicon, aluminium and the biological availability of phosphorus in algae	1993	Diatom, *Navicula pelliculosa* Green alga, *Chlorella vulgaris*	24 hr 269.8 inhibited growth rate; 24 hr 1,295 inhibited growth rate	Only one exposure concentration
Exley et al.	Polynuclear aluminum and acute toxicity in the fish	1994	-	-	Inappropriate form of toxicant; polynuclear aluminum

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Exley et al.	Kinetic constraints in acute aluminum toxicity in the rainbow trout (*Oncorhynchus mykiss*)	1996	Rainbow trout, *Oncorhynchus mykiss*	-	Only one exposure concentration; no control group
Exley et al.	Hydroxyaluminosilicates and acute aluminum toxicity to fish	1997	Rainbow trout, *Oncorhynchus mykiss*	-	Mixture; Al and Si
Fageria	Influence of aluminum in nutrient solutions on chemical composition in two rice cultivars at different growth stages	1985	Rice, *Oryza sativa*	-	Bioaccumulation study: exposure concentrations not measured
Famoso et al.	Development of a novel aluminum tolerance phenotyping platform used for comparisons of cereal aluminum tolerance and investigations into rice aluminum tolerance mechanisms	2010	Sorghum, *Sorghum bicolor* Wheat, *Triticum aestivum* Rice, *Oryza sativa*	-	Excessive EDTA in growth media (25 mg/L)
Farag et al. 1993	The effects of low pH and elevated aluminum on yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*)	1993	Yellowstone cutthroat trout, *Oncorhynchus clarki bouvieri*	7 d No effect on survival at 50	Too few exposure concentrations; poor control survival
Farringer	The determination of the acute toxicity of rotenone and Bayer 73 to selected aquatic organisms	1972	-	-	Not applicable; no aluminum toxicity data
Fernandez-Davila et al.	Aluminum-induced oxidative stress and neurotoxicity in grass carp (Cyprinidae-*Ctenopharingodon idella*)	2012	Grass carp, *Ctenopharingodon idella*	96 hr Increase lipid peroxidation, dopamine levels, SOD activity and decrease CAT activity in brain tissue at 100	Only one exposure concentration
Finn	The physiology and toxicology of salmonid eggs and larvae in relation to water quality criteria	2007	-	-	Review; results of previously published papers
Fischer and Gode	Toxicological studies in natural aluminum silicates as additives to detergents using freshwater organisms	1977	-	-	Text in foreign language
Fivelstad and Leivestad	Aluminum toxicity to Atlantic salmon (*Salmo salar* L.) and brown trout (*Salmo trutta* L.): Mortality and physiological response	1984	Atlantic salmon, *Salmo salar*	LT50=26 hr at 84.18; LT50=41 hr at 84.72; LT50=62 hr at 45.06	Lack of exposure details; dilution water not characterized
Fjellheim et al.	Effect of aluminium at low pH on the mortality of elvers (*Anguilla anguilla* L.), a laboratory experiment	1985	Eel, *Anguilla anguilla*	-	Only two exposure concentrations; dilution water not characterized

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Fok et al.	Determination of 3,5,3"-triiodo-L-thyronine (T3) levels in tissues of rainbow trout (*Salmo gairdneri*) and the effects of low ambient pH and aluminum.	1990	Rainbow trout, *Oncorhynchus mykiss*	-	Inappropriate form of toxicant ($AlKSO_4$); surgically altered test species
Folsom et al.	Comparative study of aluminum and copper transport and toxicity in an acid-tolerant freshwater green alga	1986	Green alga, *Chlorella saccarophila*	-	Lack of details; cannot determine effect concentration
France and Stokes	Influence of manganese, calcium, and aluminum on hydrogen ion toxicity to the amphipod *Hyalella azteca*	1987	Amphipod, *Hyalella azteca*	-	Mixture; Mn, Ca, pH and Al
Freda	The effects of aluminum and other metals on amphibians	1991	-	-	Review; results of previously published papers
Freeman	Recovery of rainbow trout from aluminum poisoning	1973	Rainbow trout, *Oncorhynchus mykiss*	-	Pre-exposure to pollutant
Frick and Herrmann	Aluminum accumulation in a lotic mayfly at low pH - a laboratory study	1990	Mayfly, *Heptagenia sulphurea*	-	Not North American species; lack of exposure details; cannot determine effect concentration
Fuma et al.	Ecological effects of various toxic agents on the aquatic microcosm in comparison with acute ionizing radiation	2003	Bacteria, *Escherichia coli* Protozoa, *Tetrahymena thermophila* Protozoa, *Euglena gracilis*	-	Mixture; radiation and Al
Gagen	Aluminum toxicity and sodium loss in three salmonid species along a pH gradient in a mountain stream	1986	-	-	Exposure concentration not known; field exposure
Gagen et al.	Mortality of brook trout, mottled sculpins, and slimy sculpins during acidic episodes	1993	Brook trout, *Salvelinus fontinalis* Mottled sculpin, *Cottus bairdi* Slimy sculpin, *Cottus cognatus*	-	Mixture; exposure concentration varied over time; dilution water is river water
Galindo et al.	Genotoxic effects of aluminum on the neotropical fish *Prochilodus lineatus*	2010	Neotropical fish, *Prochilodus lineatus*	96 hr Increase COMET score and number of damaged necleoids at 438	Not North American species, only one exposure concentration
Gallon et al.	Hydrophonic study of aluminum accumulation by aquatic plants: effects of fluoride and pH	2004	Five aquatic plants	-	Bioaccumulation: steady state not reached

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Galloway et al.	Water quality and biological characteristics of the Middle Fork of the Saline River, Arkansas, 2003-06	2008	-	-	Not applicable; no aluminum toxicity data
Garcia-Garcia et al.	Impact of chromium and aluminum pollution on the diversity of zooplankton: a case study in the Chimaliapan wetland (Ramsar Site) (Lerma Basin, Mexico)	2012	-	-	Mixture; dilution water is wetland water
Garcia-Medina et al.	Aluminum-induced oxidative stress in lymphocytes of common carp (*Cyprinus carpio*)	2010	Common carp, *Cyprinus carpio*	96 hr Increase lipid peroxidation and decrease SOD activity at 50	Too few exposure concentrations, dilution water not characterized
Garcia-Medina et al.	Genotoxic and cytotoxic effects induced by aluminum in the lymphocytes of the common carp (*Cyprinus carpio*)	2011	Common carp, *Cyprinus carpio*	96 hr DNA damage: T/N index at 50	Too few exposure concentrations, dilution water not characterized
Garcia-Medina et al.	The relationship of cytotoxic and genotoxic damage with blood aluminum levels and oxidative stress induced by this metal in common carp (*Cyprinus carpio*) erythrocytes	2013	Common carp, *Cyprinus carpio*	96 hr LOEC (reduced USOD and NADPH on erythocytes) = 50	Only three exposure concentrations
Gardner and Al-Hamdani	Interactive effects of aluminum and humic substances on Salvinia	1997	-	-	Not applicable; no aluminum toxicity data
Gardner et al.	Towards the establishment of an environmental quality standard for aluminum in surface waters	2008	-	-	Not applicable; no aluminum toxicity data
Gascon et al.	The interaction of pH, calcium and aluminum concentrations on the survival and development of wood frog (*Rana sylvatica*) eggs and tadpoles	1987	Wood frog, *Rana sylvatica*	100% mortality at 200	Only two exposure concentrations; lack of exposure details; duration not reported
Geiger et al.	Acute toxicities of organic chemicals to fathead minnows (*Pimephales promelas*) Volume V	1990	Fathead minnows, *Pimephales promelas*	-	Not applicable; no aluminum toxicity data
Gensemer	Role of aluminum and growth rate on changes in cell size and silica content of silica-limited populations of *Asterionella ralfsii* var. *americana* (Bacillariophyceae).	1990	Diatom, *Asterionella ralfsii* var. *americana*	21 d Decrease mean cell length, total surface area and biovolume at 75.54	Only two exposure concentrations
Gensemer	The effects of pH and aluminum on the growth of the acidophilic diatom *Asterionella ralfsii* var. *americana*	1991a	Diatom, *Asterionella ralfsii* var. *americana*	-	Review of Gensemer 1989 thesis
Gensemer	The effects of aluminum on phosphorus and silica-limited growth in *Asterionella ralfsii* var. *americana*	1991b	Diatom, *Asterionella ralfsii* var. *americana*	-	Growth stimulation study, not toxicity

Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Gensemer and Playle	The bioavailability and toxicity of aluminum in aquatic environments	1999	-	-	Review; results of previously published papers
Gensemer et al.	Comparative effects of pH and aluminum on silica-limited growth and nutrient uptake in *Asterionella ralfsii* var. *americana* (Bacillariophyceae)	1993	Diatom, *Asterionella ralfsii* var. *americana*	-	Only one exposure concentration; cannot determine effect concentration
Gensemer et al.	Interactions of pH and aluminum on cell length reduction in *Asterionella ralfsii* var. *americana* Korn	1994	Diatom, *Asterionella ralfsii* var. *americana*	25 d No effect on cell length at 539.6	Only one exposure concentration; dilution water not characterized
Genter	Benthic algal populations respond to aluminum, acid, and aluminum-acid mixture in artificial streams	1995	Green alga, *Cosmarium melanosporum* Blue-green alga, *Schizothrix calcicola* Diatom, *Achnanthes minutissima* Diatom, *Naviculoids*	28 d Increased growth at 200	Only one exposure concentration
Gibbons et al.	Effects of multiphase restoration, particularly aluminum sulfate application, on the zooplankton community of a eutrophic lake in eastern Washington	1984	-	-	Exposure concentration not known; population/ community changes of a lake exposed to Al over a series of years
Gill et al.	Assessment of water-quality conditions in Fivemile Creek in the vicinity of the Fivemile Creek Greenway, Jefferson County, Alabama, 2003-2005	2008	-	-	Not applicable; no aluminum toxicity data
Gladden	The effect of aluminum on cortisol levels in goldfish (*Carassius auratus*)	1987	Goldfish, *Carassius auratus*	-	Surgically altered test species
Goossenaerts et al.	A microanalytical study of the gills of aluminum-exposed rainbow trout (*Salmo gairdneri*)	1988	Rainbow trout, *Oncorhynchus mykiss*	72 hr Increase the Al-content of the gills at 190	Duration too short, only one exposure concentration
Gopalakrishnan et al.	Toxicity of heavy metals on embryogenesis and larvae of the marine sedentary polychaete *Hydroides elegans*	2007	Polychaete, *Hydroides elegans*	-	Pre-exposure to pollutant
Goss and Wood	The effects of acid and acid/aluminum exposure on circulating plasma cortisol levels and other blood parameters in the rainbow trout, *Salmo gairdneri*	1988	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered fish
Greger et al.	Aluminum effects on *Scenedesmus obtusiusculus* with different phosphorus status. I. Mineral uptake	1992a	Green alga, *Scenedesmus obtusiusculus*	-	Excessive EDTA in growth media (108 µm Na_2EDTA)

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Greger et al.	Aluminum effects on *Scenedesmus obtusiusculus* with different phosphorus status. II. Growth, photosynthesis and pH	1992b	Green alga, *Scenedesmus obtusiusculus*	-	Excessive EDTA in growth media (108 µm Na_2EDTA)
Gregor et al.	Growth assays with mixed cultures of cyanobacteria and algae assessed by in vivo fluorescence: One step closer to real ecosystems?	2008	Green alga, *Pseudokirchneriella subcapitata* Blue-green alga, *Aphanothece clathrata*	-	Inappropriate form of toxicant (PAX-18)
Guerold et al.	Occurrence of aluminum in chloride cells of *Perla marginata* (Plecoptera) after exposure to low pH and elevated aluminum concentration	1995	Stonefly, *Perla marginata*	-	Not North American species; Bioaccumulation: steady state not reached
Gunn and Keller	Spawning site water chemistry and lake trout (*Salvelinus namaycush*) sac fry survival during spring snow melt	1984	Lake trout, *Salvelinus namaycush*	-	Mixture, Al and low pH
Gunn and Noakes	Latent effects of pulse exposure to aluminum and low pH on size, ionic composition, and feeding efficiency of lake trout (*Salvelinus namaycush*) alevins	1987	Lake trout, *Salvelinus namaycush*	5 d LOEC (growth)=<100	Only two exposure concentrations
Guo et al.	Involvement of antioxidative defense system in rice seedlings exposed to aluminum toxicity and phosphorus deficiency	2012	Rice, *Oryza sativa*	-	Excessive chelator in growth media (5 mg/L Fe-citrate)
Guthrie et al.	Aquatic bacterial populations and heavy metals-II. Influence of chemical content of aquatic environments on bacterial uptake of chemical elements	1977	Bacterial population	-	Exposure concentration not known; field accumulation study
Guzman et al.	Implementing *Lecane quadridentata* acute toxicity tests to assess the toxic effects of selected metals (Al, Fe and Zn)	2010	Rotifer, *Lecane quadridentata*	48 hr LC50=1,572	Not North American species
Hackett	Ecological aspects of the nutrition of *Deschampsia flexuosa* (L.) Trin. III. Investigation of phosphorus requirement and response to aluminium in water culture, and a study of growth in soil	1967	Wavy hair grass, *Deschampsia flexuosa*	-	Not applicable; terrestrial species
Hall et al.	Mortality of striped bass larvae in relation to contaminants and water quality in a Chesapeake Bay tributary	1985	Striped bass, *Morone saxatilis*	-	Exposed to mixture, high control mortality (15-25%); dilution water is river water
Hamilton-Taylor et al.	Depositional fluxes of metals and phytoplankton in Windermere as measured by sediment traps	1984	-	-	Effluent or mixture

Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Handy and Eddy	Surface absorption of aluminium by gill tissue and body mucus of rainbow trout, *Salmo gairdneri*, at the onset of episodic exposure	1989	Rainbow trout, *Oncorhynchus mykiss*	1 hr Gill content=50 µg/g at 954	Only one exposure concentration
Hanks	Effect of metallic aluminum particles on oysters and clams	1965	Soft-shell clam, *Mya arenaria* American oyster, *Crassostrea virginica*	-	Dilution water not characterized, inappropriate form of Al
Harper et al.	In vivo biodistribution and toxicity depends on nanomaterial composition, size, surface functionalisation and route of exposure	2008	Zebrafish, *Danio rerio*	-	Inappropriate form of toxicant (Al-oxide)
Harry and Aldrich	The distress syndrome in *Taphtus glabratus* (Say) as a reaction to toxic concentrations of inorganic ions	1963	Snail, *Taphius glabratus*	24 hr LOEC (distress, inability to move)=5,000	Dilution water is distilled water
Havas	Effects of aluminum on aquatic biota	1986a	-	-	Review
Havas and Hutchinson	Aquatic invertebrates from the Smoking Hills, N.W.T.: effect of pH and metals on mortality	1982	-	-	Mixture
Havas and Hutchinson	Effect of low pH on the chemical composition of aquatic invertebrates from tundra ponds at the Smoking Hills, N.W.T., Canada	1983	-	-	Pre-exposure to pollutant
Havens	Aluminum binding to ion exchange sites in acid-sensitive versus acid tolerant cladocerans	1990	Cladoceran, *Daphnia galeata mendotae* Cladoceran, *Daphnia retrocurva* Cladoceran, *Bosmina longirostris*	24 hr 98% mortality at 200; 94% mortality at 200; 6% mortality at 200	Only one exposure concentration
Havens	Littoral zooplankton response to acid and aluminum stress during short-term laboratory bioassays	1991	-	-	Only one exposure concentration; mixture; low pH and Al
Havens	Acid and aluminum effects on sodium homeostasis and survival of acid-sensitive and acid-tolerant cladocera	1992	Cladoceran, *Daphnia galeata mendotae* Cladoceran, *Bosmina longirostris*	24 hr NOEC (survival)=100; NOEC=200	Only two exposure concentrations
Havens	Acid and aluminum effects on the survival of littoral macro-invertebrates during acute bioassays	1993a	-	-	Only one exposure concentration; control survival issues or mixed species exposure

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Havens	Acid and aluminum effects on osmoregulation and survival of the freshwater copepod *Skistodiaptomus oregonensis*	1993b	Copepod, *Skistodiaptomus oregonensis*	48 hr NOEC (survival)=200 at pH=7.5; LOEC=100 at pH=6.0	Only two exposure concentrations
Havens and Decosta	The role of aluminum contamination in determining phytoplankton and zooplankton responses to acidification	1987	-	-	Mixture; exposure concentration varied over time; Dilution water is lake water
Havens and Heath	Acid and aluminum effects on freshwater zooplankton: and in situ mesocosm study	1989	Zooplankton community	-	Mixture (low pH and Al); only one exposure concentration
Havens and Heath	Phytoplankton succession during acidification with and without increasing aluminum levels	1990	Phytoplankton community	-	Mixture (low pH and Al); only one exposure concentration
Heier et al.	Sublethal effects in Atlantic salmon (*Salmo salar*) exposed to mixtures of copper, aluminum and gamma radiation	2012	Atlantic salmon, *Salmo salar*	48 hr No mortality, but increase plasma glucose and decrease plasma sodium at 267	Only one exposure concentration, too few animals per concentration
Helliwell	Speciation and toxicity of aluminum in a model fresh water	1983	-	-	Lack of details; cannot determine effect concentration
Heming and Blumhagen	Plasma acid-base and electrolyte states of rainbow trout exposed to alum (aluminum sulphate) in acidic and alkaline environments	1988	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered fish
Herkovits et al.	Identification of aluminum toxicity and aluminum-zinc interaction in amphibian *Bufo arenarum* embryos	1997	Toad, *Bufo arenarum*	96 hr LC50=460	Not North American Species
Herrmann and Andersson	Aluminum impact on respiration of lotic mayflies at low pH	1986	-	-	Mixture; dilution water is stream water
Herrmann and Frick	Do stream invertebrates accumulate aluminum at low pH conditions?	1995	-	-	Survey
Hesse	Phosphorus relationships in a mangrove-swamp mud with particular reference to aluminum toxicity	1963	-	-	Sediment
Hill et al.	Zebrafish as a model vertebrate for investigating chemical toxicity	2005	Zebrafish, *Danio rerio*	-	Review
Hockett and Mount	Use of metal chelating agents to differentiate among sources of acute aquatic toxicity	1996	Cladoceran, *Ceriodaphnia dubia*	-	Mixture; EDTA, thiosulfate and Al
Hofler	Action of aluminum salts on Spirogyra and Zygnema	1958	-	-	Text in foreign language

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Horne and Dunson	Exclusion of the Jefferson salamander, *Ambystoma jeffersonianum*, from some potential breeding ponds in Pennsylvania: effects of pH, temperature, and metals on embryonic development	1994	Jefferson salamander, *Ambystoma jeffersonianum*	-	Lack of details; mixture; low pH and AL; duration not reported
Horne and Dunson	Toxicity of metals and low pH to embryos and larvae of the Jefferson salamander, Ambystoma jeffersonianum	1995a	Jefferson salamander, *Ambystoma jeffersonianum*	No effect values presented	No effect values presented
Horne and Dunson	Effects of low pH, metals, and water hardness on larval amphibians	1995b	Wood frog, *Rana sylvatica* Jefferson salamander, *Ambystoma jeffersonianum*	Percent survival depended on hardness, duration and species	Only one exposure concentration
Hornstrom et al.	Effects of pH and different levels of aluminum on lake plankton in the Swedish west coast area	1984	-	-	Survey; mixture; dilution water is lake water
Howells et al.	Effects of acidity, calcium, and aluminum on fish survival and productivity - a review	1983	-	-	Review; results of previously published papers
Howells et al.	EIFAC water quality criteria for European freshwater fish: Report on aluminum	1990	-	-	Review
Huebner and Pynnonen	Viability of glochidia of two species of *Anodonta* exposed to low pH and selected metals	1992	Swan mussel, *Anodonta cygnea*	24 hr glochidia EC50=18,000 at pH 4.5	Not North American species
Hunn et al.	Influence of pH and aluminum on developing brook trout in a low calcium water	1987	Brook trout, *Salvelinus fontinalis*	45 d Reduced growth and some behaviors at 283	Only one exposure concentration
Husaini and Rai	pH dependent aluminum toxicity to *Nostoc linckia*: Studies on phosphate uptake, alkaline and acid phosphatase activity, ATP content, and photosynthesis and carbon fixation	1992	Blue-green alga, *Nostoc linckia*	14 d Reduce photosynthetic O_2 evolution at 53,336	Only three exposure concentrations
Husaini et al.	Impact of aluminum, fluoride and flouroaluminate on ATPase activity og *Nostoc linckia* and *Chlorella vulgaris*	1996	Blue-green alga, *Nostoc linckia* Green alga, *Chlorella vulgaris*	-	Mixture
Hutchinson and Sprague	Toxicity of trace metal mixtures to American flagfish (*Jordanella floridae*) in soft, acidic water and implications for cultural acidification	1986	American flagfish, *Jordanella floridae*	-	Mixture; heavy metals
Hutchinson et al.	Lethal responses of salmonid early life stages to H+ and Al in dilute waters	1987	-	-	Review
Hwang	Lysosomal responses to environmental contaminants in bivalves	2001	American oyster, *Crassostrea virginica*	-	Exposure concentration not known; field accumulation study

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Hyne and Wilson	Toxicity of acid-sulphate soil leachate and aluminum to the embryos and larvae of Australian bass (*Macquaria novemaculeata*) in estuarine water	1997	Australian bass, *Macquaria novemaculeata*	No effect on survival at 1,000 and pH=1,000; Reduce survival by 63% at 500 and pH=4.0	Not North American species; dilution water not characterized
Ingersoll	The effects of pH, aluminum, and calcium on survival and growth of brook trout (*Salvelinus fontinalis*) early life stages	1986	Brook trout, *Salvelinus fontinalis*	-	Survival problems; low fertility success
Ingersoll et al.	Epidermal response to pH, aluminum, and calcium exposure in brook trout (*Salvelinus fontinalis*) fry	1990b	Brook trout, *Salvelinus fontinalis*	-	Only two exposure concentrations; too few test organisms per concentration
Jagoe and Haines	Changes in gill morphology of Atlantic salmon (*Salmo salar*) smolts due to addition of acid and aluminum to stream water	1997	Atlantic salmon, *Salmo salar*	-	Only one exposure concentration, increasing Al concentration over time
Jain et al.	Acute and chronic toxicity of aluminium fluoride to flora and fauna in a microcosm	2012	Duckweed, *Lemna aequinoctialis* Cladoceran, *Daphnia similis* Western mosquitofish, *Gambusis affinis*	-	Inapporiate form of toxicant (Aluminum floride)
Jan and Matsumoto	Early effects of aluminium on nutrient (K, Ca, and Mg) status of different root zones of two rice cultivars	1999	Rice, *Oryza sativa*	-	No control group; only one exposure concentration
Jan and Pettersson	Effects of low aluminium levels on growth and nutrient relations in three rice cultivars with different tolerances to aluminium	1993	Rice, *Oryza sativa*	-	Bioaccumulation study: exposure concentrations not measured
Jancula et al.	Effects of polyaluminium chloride on the freshwater invertebrate Daphnia magna	2011	-	-	Inappropriate form of toxicant; PAX-18 (9% Al)
Jaworska and Tomasik	Metal-metal interactions in biological systems. Part VI. Effects of some metal ions on mortality, pathogenicity and reproductivity of Steinernema carpocapsae and Heterohabditis bacteriophora entomopathogenic nematodes under laboratory conditions	1999	Nematode, *Steinernema carpocapsae*	-	Distilled water without proper salts added
Jaworska et al.	Effect of metal ions under laboratory conditions on the entomopathogenic Steinernema carpocapsae (Rhabditida: sterinernematidae)	1996	Nematode, *Steinernema carpocapsae*	-	Distilled water without proper salts added; infected test organism

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Jaworska et al.	Effect of metal ions on the entomopathogenic nematode *Heterorhabditis bacteriophora* Poinar (Nematode: Heterohabditidae) under laboratory conditions	1997	Nematode, *Heterorhabditis bacteriophora*	-	Distilled water without proper salts added
Jay and Muncy	Toxicity to channel catfish of wastewater from an Iowa coal beneficiation plant	1979	-	-	Effluent
Jensen and Malte	Acid-base and electrolyte regulation, and haemolymph gas transport in crayfish, *Astacus astacus*, exposed to soft, acid water with and without aluminum	1990	Crayfish, *Astacus astacus*	21 d No effect on haemolymph haemocyanin concentration at 675	Not North American species, only one exposure concentration
Jensen and Weber	Internal hypoxia-hypercapnia in tench exposed to aluminum in acid water: Effects on blood gas transport, acid-base status and electrolyte composition in arterial blood	1987	Tench, *Tinca tinca*	-	Surgically altered test species
Ji et al.	Toxicity of oxide nanoparticles to the green algae *Chlorella sp.*	2011	Green alga, *Chlorella sp.*	-	Inappropriate form of toxicant (aluminum oxide)
Jones	The relation between the electrolytic solution pressures on the metals and their toxicity to the stickleback (*Gasterosteus aculeatus* L.)	1939	Threespine stickleback, *Gasterosteus aculeatus*	-	Lack of details; review
Jones	A further study of the relation between toxicity and solution prssure, with *Polycelis nigra* as test animals	1940	Planarian, *Polycelis nigra*	48 hr Survival time affected at 100,000	Not North American species; distilled water without proper salts
Jones et al.	Comparison of observed and calculated concentrations of dissolved Al and Fe in stream water	1974	-	-	Not applicable; no aluminum toxicity data
Jonsson et al.	Metals and linear alkylbenzene sulphonate as inhibitors of the algae *Pseudokirchneriella subcapitata* acid phosphatase activity	2009	Green alga, *Pseudokirchneriella subcapitata*	7 d Decrease relative acitivity at 53,960	Only two exposure concentrations
Juhel et al.	Alumina nanoparticles enhance growth of Lemna minor	2011	Duckweed, *Lemna minor*	-	Inappropriate form of toxicant; nanoparticles
Kadar et al.	Avoidance responses to aluminum in the freshwater bivalve, *Anodonta cygnea*	2001	Swan mussel, *Anodonta cygnea*	15 d Decrease in duration of shell gape at 516.3	Not North American species
Kadar et al.	Effect of sub-lethal concentrations of aluminum on the filtration activity of the freshwater mussel *Anodonta cygnea* L. At Neutral Ph	2002	Swan mussel, *Anodonta cygnea*	15 d Duration of siphon activity at 241.3	Not North American species, only two exposure concentrations

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Kaiser	Correlation and prediction of metal toxicity to aquatic biota	1980	-	-	Review; results of previously published papers
Karlsson-Norrgren et al.	Acid water and aluminum exposure: experimentally induced gill lesions in brown trout, *Salmo trutta* L	1986a	Brown trout, *Salmo trutta*	21 d Alteration in secondary gill lamellae at 200	Too few exposure concentrations, atypical endpoint
Karlsson-Norrgren et al.	Acid water and aluminum exposure: Gill lesions and aluminum accumulation in farmed brown trout, *Salmo trutta* L.	1986b	Brown trout, *Salmo trutta*	-	Bioaccumulation: survey; exposure concentration not measured over time
Keinanen et al.	Ion regulation in whitefish (*Coregonus lavaretus* L.) yolk-sac fry exposed to low pH and aluminum at low and moderate ionic strength	1998	Whitefish, *Coregonus lavaretus*	-	Not North American species; cannot determine effect concentration
Keinanen et al.	Comparison of the responses of the yolk-sac fry of pike (*Esox lucius*) and roach (*Rutilus rutilus*) to low pH and aluminum: sodium influx, development and activity	2000	Pike, *Esox lucius* Roach, *Rutilus rutilus*	10 d NOEC (growth)=600 at pH=5.0; 9 d LOEC (survival)=100 at pH=5.25	Too few exposure concentrations
Keinanen et al.	Fertilization and embryonic development of whitefish (*Coregonus lavaretus lavaretus*) in acidic low-ionic strength water with aluminum	2003	Whitefish, *Coregonus lavaretus lavaretus*	Decrease fertilization % and fertilization rate at 250	Not North American species; only one exposure concentration, duration, exposure methods unknown
Keinanen et al.	The susceptibility of early developmental phases of an acid-tolerant and acid-sensitive fish species to acidity and aluminum	2004	Pike, *Esox lucius*	-	Mixture; dilution water is lake water
Khangarot and Das	Acute toxicity of metals and reference toxicants to a freshwater ostracod, *Cypris subglobosa* Sowerby, 1840 and correlation to EC50 values of other test models	2009	Ostracod, *Cypris subglobosa*	-	Inappropriate form of toxicant (aluminum ammonia sulfate)
Kinross et al.	The influence of pH and aluminum on the growth of filamentous algae in artificial streams	2000	Alga (various species)	~3 d Decrease growth rate at 199.6	Only one exposure concentration
Kitamura	Relation between the toxicity of some toxicants to the aquatic animals (*Tanichthys albonubes* and *Neocaridina denticulata*) and the hardness of the test solution	1990	White cloud mountain minnow, *Tanichthys albonubes*	48 hr LC50=>100,000	Not North American species; text in foreign language
Klaprat et al.	The effect of low pH and aluminum on the olfactory organ of rainbow trout, *Salmo gairdneri*	1988	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species
Klauda and Palmer	Responses of bluback herring eggs and larvae to pulses of aluminum	1987	Blueback herring, *Alosa aestivalis*	-	Pulsed exposures to pollutant

Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Klauda et al.	Sensitivity of early life stages of blueback herring to moderate acidity and aluminum in soft freshwater	1987	Blueback herring, *Alosa aestivalis*	-	Poor control survival (>10%)
Klimek et al.	The toxicity of aluminium salts to *Lecane inermis* rotifers: Are chemical and biological methods used to overcome activated sludge bulking mutually exclusive?	2013	Rotifer, *Lecane inermis*	24 hr EC50=12	Dilution water not characterized
Kline	The effects of organic complexation on aluminum toxicity to rainbow trout (*Oncorhynchus mykiss*)	1992	Rainbow trout, *Oncorhynchus mykiss*	-	Only two exposure concentrations; effect for inorganic Al not total Al
Klusek et al.	Trace element concentrations in the soft tissue of transplanted freshwater mussels near a coal-fired power plant	1993	Eastern lampmussel, *Lampsilis radiata*	-	Field exposure, exposure concentrations not measured
Knapp and Soltero	Trout-zooplankton relationships in Medical Lake, WA following restoration by aluminum sulfate treatment	1983	-	-	Field study, exposure concentration unknown
Kobbia et al.	Studies on the effects of some heavy metals in the biological activities of some phytoplankton species. I. differential tolerance of some Nile phytoplanktonic populations in cultures to the effects of some heavy metals	1986	-	-	Mixed species exposure
Kovacevic et al.	The effect of aluminum on the planarian *Polycelis felina* (Daly.)	2009a	Planarian, *Polycelis felina*	5 d No mortality at 200,000 and pH=6.14	Not North American species
Kovacevic et al.	Aluminum deposition in hydras	2009b	Hydra	-	Bioaccumulation: steady state not reached; static, unmeasured exposure
Krishnasamy and Seshu	Phosphine fumigation influence on rice seed germination and vigor	1990	Rice, *Oryza sativa*	-	Not applicable; no aluminum toxicity data
Kroglund et al.	Exposure to moderate acid water and aluminum reduces Atlantic salmon post-smolt survival	2007	Atlantic salmon, *Salmo salar*	-	Dilution water not characterized; mixture
Kroglund et al.	Water quality limits for Atlantic salmon (*Salmo salar* L.) exposed to short term reductions in pH and increased aluminum simulating episodes	2008	Atlantic salmon, *Salmo salar*	-	Review; results of previously published papers
Kroglund et al.	Recovery of Atlantic salmon smolts following aluminum exposure defined by changes in blood physiology and seawater tolerance	2012	Atlantic salmon, *Salmo salar*	-	Only one exposure concentration; no control group

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Kudlak et al.	Determination of EC50 in toxicity data of selected heavy metals toward *Heterocypris incongruens* and their comparison to "direct-contact" and microbiotests	2011	Ostracod, *Heterocypris incongruens*	-	Sediment contact test; dilution water is distilled water
Kure et al.	Molecular responses to toxicological stressors: Profiling microRNAs in wild Atlantic salmon (*Salmo salar*) exposed to acidic aluminum-rich water	2013	Atlantic salmon, *Salmo salar*	72 hr Decrease sodium and chloride and increase glucose in blood plasma at 123-128	Only one exposure concentration; no true control group
Lacroix et al.	Aluminum dynamics on gills of Atlantic salmon fry in the presence of citrate and effects on integrity of gill structures	1993	Atlantic salmon, *Salmo salar*	-	Mixture; Al and citrate
Laitinen and Valtonen	Cardiovascular, ventilatory and haematological responses of brown trout (*Salmo trutta* L.), to the combined effects of acidity and aluminum in humic water at winter temperatures	1995	Brown trout, *Salmo trutta*	-	Mixture; dilution water is river water
Lange	Toxicity of aluminum to selected freshwater invertebrates in water of pH 7.5	1985	Fingernail clam, *Sphaerium sp.*	4 d LC50=2,360	High control mortality (26.7%)
Lee and Hughes	A plant bioassay protocol for sediment heavy metal toxicity studies using wild rice as an indicator species	1998	Rice, *Oryza sativa*	-	Exposure medium not defined; hard to determine effect concentration
Lee et al.	Zebrafish transgenic line huORFZ is an effective living bioindicator for detecting environmental toxicants	2014	Zebrafish, *Danio rerio*	-	Distilled water without proper salts added
Leino and McCormick	Response of juvenile largemouth bass to different pH and aluminum levels at overwintering temperatures: effects on gill morphology, electrolyte balance, scale calcium, liver glycogen, and depot fat	1993	Largemouth bass, *Micropterus salmoides*	84 d Increase respiratory barrier thickness and interlamellar epithelial thickness in gills at 29.2	Only one exposure concentration; too few animals per concentration
Leino et al.	Effects of acid and aluminum on swim bladder development and yolk absorption in the fathead minnow, *Pimephales promelas*	1988	Fathead minnow, *Pimephales promelas*	38 % hatching success at 25	Only two exposure concentrations, lack of details
Leino et al.	Multiple effects of acid and aluminum on brood stock and progeny of fathead minnows, with emphasis on histopathology	1990	Fathead minnow, *Pimephales promelas*	-	Repeat of used paper (Leino et al. 1989)
Li and Zhang	Toxic effects of low pH and elevated Al concentration on early life stages of several species of freshwater fishes	1992	Grass carp, *Ctenopharingodon idella*	4 d LC50=260	Lack of exposure details; text in foreign language

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Li et al.	Responses of *Ceriodaphnia dubia* to TiO_2 and Al_2O_3 nanoparticles: A dynamic nano-toxicity assessment of energy budget distribution	2011	Cladoceran, *Ceriodaphnia dubia*	-	Inappropriate form of toxicant (nanoparticles)
Li et al.	Surface interactions affect the toxicity of engineered metal oxide nanoparticles toward *Paramecium*	2012	Protozoa, *Paramecium micronucleatum*	-	Inappropriate form of toxicant (nanoparticles)
Lincoln et al.	Quality-assurance data for routine water analyses by the U.S. Geological Survey laboratory in Troy, New York - July 2005 through June 2007	2009	-	-	Not applicable; no aluminum toxicity data
Lindemann et al.	The impact of aluminum on green algae isolated from two hydrochemically different headwater streams, Bavaria, Germany	1990	Green alga, *Chlorella sp.* Green alga, *Scenedesmus sp.*	-	Exposure concentration varied over time
Linnik	Aluminum in natural waters: content, forms of migration, toxicity	2007	-	-	Review; results of previously published papers
Lithner et al.	Bioconcentration factors for metals in humic waters at different pH in the Ronnskar area (N. Sweden)	1995	-	-	Exposure concentration not known; field accumulation study
Lockard and McWalter	Effects of toxic levels of sodium, arsenic, iron and aluminium on the rice plant	1956	Rice	-	Scientific name not provided
Macova et al.	Polyaluminium chloride (PAX-18) - acute toxicity and toxicity for early development stages of common carp (*Cyprinus carpio*)	2009	Common carp, *Cyprinus carpio*	-	Inappropriate form of toxicant, PAX-18 (9% Al)
Macova et al.	Acute toxicity of the preparation PAX-18 for juvenile and embryonic stages of zebrafish (*Danio rerio*)	2010	Zebrafish, *Danio rerio*	-	Inappropriate form of toxicant, PAX-18 (9% Al)
Madigosky et al.	Concentrations of aluminum in gut tissue of crayfish (*Procambarus clarkii*), purged in sodium chloride	1992	Crayfish, *Procambarus clarkii*	-	Exposure concentration not known; field accumulation study
Maessen et al.	The effects of aluminum/calcium and pH on aquatic plants from poorly buffered environments	1992	-	-	Only one exposure concentration; sediment
Malcolm et al.	Relationships between hydrochemistry and the presence of juvenile brown trout (*Salmo trutta*) in headwater streams recovering from acidification	2012	Brown trout, *Salmo trutta*	-	Survey
Malecki-Brown et al.	Alum application to improve water quality in a municipal wastewater treatment wetland: Effects on macrophyte growth and nutrient uptake	2010	Aquatic vegatation	-	Only one exposure concentration; dilution water not characterized; mixture
Malley and Chang	Effects of aluminum and acid on calcium uptake by the crayfish *Orconectes virilis*	1985	Crayfish, *Orconectes virilis*	-	No aluminum toxicity data; calcium uptake with Al treatment

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Malley et al.	Changes in the aluminum content of tissues of crayfish held in the laboratory and in experimental field enclosures	1986	Crayfish, *Orconectes virilis*	-	Mixture; sediment
Malley et al.	Effects on ionic composition of blood tissues of *Anodonta grandis grandis* (Bivalvia) of an addition of aluminum and acid to a lake	1988	Mussel, *Anodonta grandis grandis*	-	Exposure concentrations not known; Al dosed in a lake
Malte	Effects of aluminum in hard, acid water on metabolic rate, blood gas tensions and ionic status in the rainbow trout	1986	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species
Malte and Weber	Respiratory stress in rainbow trout dying from aluminum exposure in soft, acid water, with or without added sodium chloride	1988	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species
Mao et al.	Assessment of sacrificial anode impact by aluminum accumulation in mussel *Mytilus edulis*: a large-scale laboratory test	2011	Bay mussel, *Mytilus edulis*	-	Inappropriate form of toxicant; Al anode
Markarian et al.	Toxicity of nickel, copper, zinc and aluminum mixtures to the white sucker (*Catostomus commersoni*)	1980	White sucker, *Catostomus commersoni*	-	Mixture; industrial effluent streams
Marquis	Aluminum neurotoxicity: An experimental perspective	1982	-	-	Cannot determine effect concentration
Martin et al.	Relationships between physiological stress and trace toxic substances in the bay mussel, *Mytilus edulis*, from San Fransico Bay, California	1984	Bay mussel, *Mytilus edulis*	-	Exposure concentration not known; field accumulation study
Mayer and Ellersieck	Manual of acute toxicity: interpretation and data base for 410 chemicals and 66 species of freshwater animals	1986	-	-	Review; results of previously published papers
McCahon and Pascoe	Short-term experimental acidification of a Welsh stream: Toxicity of different forms of aluminum at low pH to fish and invertebrates	1989	-	-	Mixture; dilution water is stream water
McComick and Jensen	Osmoregulatory failure and death of first-year largemouth bass (*Micropterus salmoides*) exposed to low pH and elevated aluminum at low temperature in soft water	1992	Largemouth bass, *Micropterus salmoides*	84 d 56% survival at 53.9	Only one exposure concentration; duration too short
McCormick et al.	Chronic effects of low pH and elevated aluminum on survival, maturation, spawning and embryo-larval development of the fathead minnow in soft water	1989	Fathead minnow, *Pimephales promelas*	4 d 38% hatch at 49 and pH=5.5; 94% hatch at 66 and pH=7.5	Only two exposure concentrations

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McCormick et al.	Thresholds for short-term acid and aluminum impacts on Atlantic salmon smolts	2012	Atlantic salmon, *Salmo salar*	48 hr No mortality at 169 and pH=6.0; 100% mortality at 184 and pH=5.3	Too few exposure concentrations; duration too short
McCrohan et al.	Bioaccumulation and toxicity of aluminum in the pond snail at neutral pH	2000	Snail, *Lymnaea stagnalis*	-	Dilution water not characterized; lack of exposure details
McDonald and Milligan	Sodium transport in the brook trout, Salvelinus fontinalis: effects of prolonged low pH exposure in the presence and absence of aluminum	1988	Brook trout, *Salvelinus fontinalis*	-	Only one exposure concentration; pre-exposure to pollutant
McDonald et al.	Nature and time course of acclimation to aluminum in juvenile brook trout (*Salvelinus fontinalis*). I. Physiology	1991	Brook trout, *Salvelinus fontinalis*	-	Exposure concentration varied over time; changed dose mid experiment
McKee and Wolf	Water quality criteria. 2nd Edition	1963	-	-	Review; results of previously published papers
McLeish et al.	Skin exposure to micro- and nano-particles can cause haemostasis in zebrafish larvae	2010	Zebrafish, *Danio rerio*	-	Inappropriate form of toxicant (nanoparticles)
Mehta et al.	Relative toxicity of some non-insecticidal chemicals to the free living larvae guinea-worm (*Dracunuculus medinensis*)	1982	Guinea worm (larvae), *Dracunculus medinensis*	24 hr LC50=16,218	Lack of details; dilution water not characterized; exposure methods unknown
Meili and Wills	Seasonal concentration changes of Hg, Cd, Cu and Al in a population of roach	1985	Roach, *Rutilus rutilus*	-	Not North American species; exposure concentration not known; field accumulation study
Meland et al.	Exposure of brown trout (Salmo trutta L.) to tunnel wash water runoff -- Chemical characterisation and biological impact	2010	Brown trout, *Salmo trutta*	-	Mixture; run-off
Mendez	Water-quality data from storm runoff after the 2007 fires, San Diego County, California	2010	-	-	Survey; occurrence
Merrett et al.	The response of macroinvertebrates to low pH and increased aluminum concentrations in Welsh streams: Multiple episodes and chronic exposure	1991	-	-	Mixture; exposure concentration varied over time; dilution water is stream water
Mersch et al.	Transplanted aquatic mosses for monitoring trace metal mobilization in acidified streams of the Vosges Mountains, France	1993	Moss, *Amblystegium riparium*	-	Field exposure, exposure concentrations not measured
Michailova et al.	Functional and structural rearrangements of salivary gland polytene chromosomes of *Chironomus riparius* Mg. (Diptera, Chironomidae) in response to freshly neutralized aluminum	2003	Midge, *Chironomus riparius*	24-25 d Higher frequency of numerous somatic aberrations at 500	Only one exposure concentration

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Minzoni	Effects of aluminum on different forms of phosphorus and freshwater plankton	1984	Zooplankton community	-	Only one exposure concentration
Mitchell	The effects of aluminum and acidity on algal productivity: a study of an effect of acid deposition	1982	Green alga, *Selenastrum capricornutum*	4 hr Productivity drops at 5,000	Lack of details; abstract only
Mo et al.	A study of the uptake by duckweed of aluminum, copper, and lead from aqueous solution	1988	Duckweed	-	No scientific name of test species provided
Mohanty et al.	Effect of a low dose of aluminum on mitotic and meiotic activity, 4C DNA content, and pollen sterility in rice, *Oryza sativa* L	2004	Rice, *Oryza sativa*	-	Only one exposure concentration; distilled water without proper salts added
Monette	Impacts of episodic acid and aluminum exposure on the physiology of Atlantic salmon, *Salmo salar*, smolt development	2007	Atlantic salmon, *Salmo salar*	-	Only one exposure concentration; pulse exposures
Monette and McCormick	Impacts of short-term acid and aluminum exposure on Atlantic salmon (*Salmo salar*) physiology: a direct comparison of parr and smolts	2008	Atlantic salmon, *Salmo salar*	-	Review of Monette 2007
Monette et al.	Effects of short-term acid and aluminum exposure on the parr-smolt transformation in the Atlantic slamon (*Salmo salar*): disruption of seawater tolerance and endocrine status	2008	Atlantic salmon, *Salmo salar*	-	Review of Monette 2007
Monette et al.	Physiological, molecular, and cellular mechanisms of impaired seawater tolerance following exposure of Atlantic salmon, *Salmo salar*, smolts to acid and aluminum	2010	Atlantic salmon, *Salmo salar*	6 d NOEC (mortality)=43; LOEC=71	Only two exposure concentrations;
Morgan et al.	A plant toxicity test with the moss *Physcomitrella patens* (Hedw.) B.S.G.	1990	Moss, *Physcomitrella patens*	-	Lack of details; toxicity information not discernible
Morgan et al.	An aquatic toxicity test using the moss *Physcomitrella patens* (Hedw) B.S.G.	1993	Moss, *Physcomitrella patens*	-	Lack of details; toxicity information not discernible
Mothersill et al.	Multiple stressor effects of radiation and metals in salmon (*Salmo salar*)	2007	Atlantic salmon, *Salmo salar*	-	Only one exposure concentration; too few fish per exposure concentration (3 per treatment)
Mount et al.	Effect of long-term exposure to acid, aluminum, and low calcium in adult brook trout (*Salvelinus fontinalis*). 1. survival, growth, fecundity, and progeny survival	1988a	Brook trout, *Salvelinus fontinalis*	-	Mixture; low pH and Al
Mount et al.	Effect of long-term exposure to acid, aluminum, and low calcium in adult brook trout (*Salvelinus fontinalis*). 2. vitellogenesis and osmoregulation	1988b	Brook trout, *Salvelinus fontinalis*	-	Mixture; low pH and Al

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Mount et al.	Response of brook trout (*Salvelinus fontinalis*) fry to fluctuating acid, aluminum, and low calcium exposures	1990	Brook trout, *Salvelinus fontinalis*	-	Pre-exposure to pollutant; only two exposure concentrations
Mueller et al.	Nature and time course of acclimation to aluminum in juvenile brook trout (*Salvelinus fontinalis*). II. Gill histology	1991	Brook trout, *Salvelinus fontinalis*	-	Only one exposure concentration; exposure concentration varied over time
Mukai	Effects of chemical pretreatment on the germination of statoblasts of the freshwater bryozoan, *Pectinatella gelatinosa*	1977	Bryozoa, *Pectinatella gelatinosa*	-	Not applicable; no aluminum toxicity data
Mulvey et al.	Effects of potassium aluminium sulphate (alum) used in an *Aeromonas salmonicida* bacterin on Atlantic salmon, *Salmo salar*	1995	Atlantic salmon, *Salmo salar*	-	Inject toxicant; inappropriate form of toxicant (potassium aluminum sulphate)
Muniz and Leivestad	Toxic effects of aluminum on the brown trout, *Salmo trutta* L.	1980b	Brown trout, *Salmo trutta*	-	Mixture; dilution water is breakwater
Muniz et al.	Physiological response of brown trout (*Salmo trutta*) spawners and postspawners to acidic alminum-rich stream water	1987	Brown trout, *Salmo trutta*	-	Field exposure, exposure concentrations not measured
Muramoto	Influence of complexans (NTA, EDTA) on the toxicity of aluminum chloride and sulfate to fish at high concentrations	1981	Common carp, *Cyprinus carpio*	48 hr 30% mortality at 8,000 and pH=6.3	Dilution water not characterized
Murungi and Robinson	Synergistic effects of pH and aluminum concentrations on the life expectancy of tilapia (Mozambica) fingerlings	1987	-	-	Scientific name not given
Murungi and Robinson	Uptake and accumulation of aluminum by fish - the modifying effect of added ions	1992	Shiners, *Notropis sp.*	96 hr Whole fish tissue = 0.78 mg/g (dry weight) at 5,000	Lack of details, exposure methods unknown
Musibono and Day	Active uptake of aluminum, copper, and manganese by the freshwater amphipod *Paramelita nigroculus* in acidic waters	2000	Amphipod, *Paramelita nigroculus*	-	Not North American species; mixture
Nagasaka et al.	Novel iron-storage particles may play a role in aluminum tolerance of *Cyanidium caldarium*	2002	Red alga, *Cyanidium caldarium*	-	Only one exposure concentration; mixture (low pH and Al)
Naskar et al.	Aluminum toxicity induced poikilocytosis in an air-breathing telost, *Clarias batrachus* (Linn.)	2006	Catfish, *Clarias batrachus*	5 d Some membrane abnormalities with red blood cells at 165,000	Only two exposure concentrations; non-wild population test animals

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Neave et al.	The transcriptome and proteome are altered in marine polychaetes (Annelida) exposed to elevated metal levels	2012	Polychaete, *Ophelina sp.*	-	Mixture; field study: exposure concentration not known
Negri et al.	Effects of alumina refinery wastewater and signature metal constituents at the upper thermal tolerance of: 2. The early life stages of the coral *Acropora tenuis*	2011	Coral, *Acropora tenuis*	-	Not North American species
Neville	Physiological response of juvenile rainbow trout, Salmo gairdneri, to acid and aluminum - prediction of field responses from laboratory data	1985	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species
Neville and Campbell	Possible mechanisms of aluminum toxicity in a dilute, acidic environment to fingerlings and older life stages of salmonids	1988	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species
Nilsen et al.	Effects of acidic water and aluminum exposure on gill Na+, K+ -ATPase α-subunit isoforms, enzyme activity, physiology and return rates in Atlantic salmon (*Salmo salar* L.)	2010	Atlantic salmon, *Salmo salar*	-	Only one exposure concentration; dilution water not characterized
Nilsen et al.	Atlantic salmon (*Salmo salar* L.) smolts require more than two weeks to recover from acidic water and aluminum exposure	2013	Atlantic salmon, *Salmo salar*	7 d, 86 Gill content=26.6 µg/g dw at pH=5.7	Only one exposure concentration; not whole body or muscle
Norrgren and Degerman	Effects of different water qualities on the early development of Atlantic salmon and brown trout exposed in situ	1993	-	-	Mixture; no control group; dilution water is river water
Norrgren et al.	Accumulation and effects of aluminum in the minnow (*Phoxinus phoxinus* L.) at different pH levels	1991	Minnow, *Phoxinus phoxinus*	48 d No effect on mortality at 174 and pH=7.1; Increase mortality at 168 and pH=5.9	Only one exposure concentration
Nyberg et al.	Labile inorganic manganese - An overlooked reason for fish mortality in acidified streams?	1995	Brown trout, *Salmo trutta*	-	Field exposure, exposure concentrations not measured
Odonnell et al.	A review of the toxicity of aluminum in fresh water	1984	-	-	Review
Olaveson and Nalewajko	Effects of acidity on the growth of two *Euglena* species	2000	Alga, *Euglena mutabilis* Alga, *Euglena gracilis*	-	Mixture (low pH and Al)
Ormerod et al.	Short-term experimental acidification of Welsh stream: Comparing the biological effects of hydrogen ions and aluminum	1987	-	-	Mixture; dilution water is river water

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
OSU (Oregon State University)	Chronic toxicity of aluminum, at pH6, to the freshwater duckweed, *Lemna minor*	2012d	Duckweed, *Lemna minor*	-	Excessive EDTA used
Pagano et al.	Use of sea urchin sperm and embryo bioassay in testing the sublethal toxicity of realistic pollutant levels	1989	-	-	Mixture; effluent
Pagano et al.	Cytogenetic, developmental, and biochemical effects of aluminum, iron, and their mixture in sea urchins and mussels	1996	-	-	Lack of details; exposure duration not reported; cannot determine effect concentration
Pakrashi et al.	Cytotoxicity of aluminium oxide nanoparticles towards fresh water algal isolate at low exposure concentrations	2013a	Alga, *Chlorella ellipsoids*	-	Inappropriate form of toxicant (nanoparticles)
Pakrashi et al.	*Ceriodaphnia dubia* as a potential bio-indicator for assessing acute aluminum oxide nanoparticle toxicity in fresh water environment	2013b	Cladoceran, *Ceriodaphnia dubia*	-	Inappropriate form of toxicant (nanoparticles)
Paladino and Swartz	Interactive and synergistic effects of temperature, acid and aluminum toxicity on fish critical thermal tolerance	1984	-	-	Scientific name not given; lack of exposure details; abstract only
Palmer et al.	Comparative sensitivities of bluegill, channel catfish and fathead minnow to pH and aluminum	1988	Bluegill, *Lepomis macrochirus* Fathead minnow, *Pimephales promelas* Channel catfish, *Ictalurus punctatus*	Exposure concentrations overlapped (all over the place)	Exposure concentrations overlapped
Panda and Khan	Lipid peroxidation and oxidative damage in aquatic duckweed (*Lemna minor* L.) in response to aluminum toxicity	2004	Duckweed, *Lemna minor*	-	Cannot determine effect concentration, dilution media not defined; no statistical analysis
Pandey et al.	Salicylic acid alleviates aluminum toxicity in rice seedlings better than magnesium and calcium by reducing aluminum uptake, suppressing oxidative damage and increasing antioxidative defense	2013	Rice, *Oryza sativa*	12 d Reduced root and shoot length at 13,494	Only one exposure concentration
Papathanasiou et al.	Toxicity of aluminium in natural waters controlled by type rather than quantity of natural organic matter	2011	Snail, *Lymnaea stagnalis*	24 d Decrease mean eggs/day at 500	Only one exposure concentration
Parent et al.	Influences of natural dissolved organic matter on the interaction of aluminum with the microalga Chlorella: a test of free-ion model of trace metal toxicity	1996	Green alga, *Chlorella pyrenoidosa*	-	Mixture; Al and soil fluvic acid

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Parkhurst et al.	Inorganic monomeric aluminum and pH as predictors of acidic water toxicity to brook trout (Salvelinus fontinalis)	1990	Brook trout, *Salvelinus fontinalis*	-	Only three exposure concentrations, difficult to determine effect concentration
Parsons Engineering Science, Inc.	Aluminum water-effect ratio study for the calculation of a site-specific water quality standard in Welsh reservoir	1997	Cladoceran, *Ceriodaphnia dubia* Fathead minnow, *Pimephales promela*	-	Mixture; power plant effluent
Pauwels	Some effects of exposure to acid and aluminum on several lifestages of the Atlantic salmon (*Salmo salar*)	1990	Atlantic salmon, *Salmo salar*	24 d Mortality increased faster at 106 and pH=5.25	Only one exposure concentration
Payton and Greene	A comparison of the effect of aluminum on a single species algal assay and indigenous community algal toxicity bioassay	1980	Green alga, *Scenedesmus bijgua*	-	Lack of details; duration and exposure methods not provided
Peterson et al.	Responses of Atlantic salmon (*Salmo salar*) alevins to dissolved organic carbon and dissolved aluminum at low pH	1989	Atlantic salmon, *Salmo salar*	-	Poor control survival; only two exposure concentrations
Pettersson et al.	Physiological and structural responses of the cyanobacterium *Anabaena cylindrica* to aluminum	1985a	Blue-green alga, *Anabaena cylindrica*	-	Excessive EDTA used (672.52 µg/L)
Pettersson et al.	Accumulation of aluminum by *Anabaena cylindrica* into polyphosphate granules and cell walls: an X-ray energy-dispersive microanalysis study	1985b	Blue-green alga, *Anabaena cylindrica*	-	Bioaccumulation: not renewal or flow-through
Pettersson et al.	Aluminum uptake by A*nabaena cylindrica*	1986	Blue-green alga, *Anabaena cylindrica*	-	Bioaccumulation: not renewal or flow-through; steady state not reached
Pettersson et al.	Aluminum effects on uptake and metabolism of phosphorus by the cyanobacterium *Anabaena cylindrica*	1988	Blue-green alga, *Anabaena cylindrica*	-	Only two exposure concentrations; cannot determine effect concentration; no statistical analysis
Peuranen et al.	Effects of acidity and aluminum on fish gills in laboratory experiments and in the field	1993	Whitefish, *Coregonus lavaretus*	143 d Decrease of respiratory diffusing capacity at 150 and pH=4.75	Not North American species; dilution water not characterized; only one exposure concentration
Phillips and Russo	Metal bioaccumulation in fishes and aquatic invertebrates: A literature review	1978	-	-	Review
Piasecki and Zacharzewski	Influence of coagulants used for lake restoration on *Daphnia magna* Straus (Crustacea, Cladocera)	2010	Cladoceran, *Daphnia magna*	-	Inappropriate form of toxicant, PIX 113 and PAX 18

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Playle	Physiological effects of aluminum on rainbow trout in acidic soft water, with emphasis on the gill micro-environment	1989	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species
Playle and Wood	Water pH and aluminum chemistry in the gill micro-environment of rainbow trout during acid and aluminum exposures	1989	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species
Playle and Wood	Mechanisms of aluminum extraction and accumulation at the gills of rainbow trout, *Oncorhynchus mykiss* (Walbaum), in acidic soft water	1991	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species
Playle et al.	Physiological disturbances in rainbow trout during acid and aluminum exposures	1988	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species
Playle et al.	Physiological disturbances in rainbow trout (*Salmo gairdneri*) during acid and aluminum exposures in soft water of two calcium concentrations	1989	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species
Poleo	Temperature as a major factor concerning fish mortality in acidic Al-rich waters: Experiments with young stage Atlantic salmon (*Salmo salar* L.)	1992	Atlantic salmon, *Salmo salar*	-	Text in foreign language
Poleo	Aluminum polymerization: a mechanism of acute toxicity of aqueous aluminum to fish	1995	-	-	Review
Poleo and Muniz	Effect of aluminum in soft water at low pH and different temperatures on mortality, ventilation frequency and water balance in smoltifying Atlantic salmon, *Salmo salar*	1993	Atlantic salmon, *Salmo salar*	LT50=49 hr at 271 (1˚C); LT50=21 hr at 272 (10˚C)	Only one exposure concentration; no control group
Poleo et al.	The influence of temperature on aqueous aluminum chemistry and survival of Atlantic salmon (*Salmo salar* L.) fingerlings	1991	Atlantic salmon, *Salmo salar*	LT50=170 hr at 403 (1˚C); LT50=46 hr at 402 (10˚C)	Only one exposure concentration; no control group
Poleo et al.	Survival of crucian carp, *Carassius carassius*, exposed to a high low-molecular weight inorganic aluminum challenge	1995	Crucian carp, *Carassius carassius*	-	Not North American species; only two exposure concentrations; no true control group
Poleo et al.	Toxicity of acid aluminum-rich water to seven freshwater fish species: a comparative laboratory study	1997	-	-	Too few organisms per treatment, 1-2 fish per treatment
Poleo et al.	The effect of various metals on *Gyrodactylus salaris* (Plathyrlminthes, Monogenea) infections in Atlantic salmon (*Salmo salar*)	2004	Parasite, *Gyrodactylus salaris* Atlantic salmon, *Salmo salar*	-	Two species tested with one exposure; not sure how much exposure to the parasite

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Pond et al.	Downstream effects of mountaintop coal mining: comparing biological conditions using family- and genus-level macroinvertebrate bioassessment tools	2008	-	-	Field survey, mixture
Poor	Effect of lake management efforts on the trophic state of a subtropical shallow lake in Lakeland, Florida, USA	2010	-	-	Survey
Poston	Effects of dietary aluminum on growth and composition of young Atlantic salmon	1991	Atlantic salmon, *Salmo salar*	-	Fed pollutant
Prange and Dennison	Physiological responses of five seagrass species to trace metals	2000	Seagrass	-	Exposure concentration not known; field accumulation study
Pribyl et al.	Cytoskeletal alterations in interphase cells of the green alga Spirogyra decimina in response to heavy metals exposure: I. the effect of cadmium	2005	Green alga, *Spirogyra decimina*	-	Not applicable; cadmium study
Pynnonen	Aluminum accumulation and distribution in the freshwater clams (Unionidae)	1990	Mussel, *Anodonta anatina* Mussel, *Unio pictorum*	-	Not North American species; exposure concentrations varied too much over time
Quiroz-Vazquez et al.	Bioavailability and toxicity of aluminum in a model planktonic food chain (*Chlamydomonas-Daphnia*) at neutral pH	2010	-	-	Bioaccumulation: not renewal or flow-through; steady state not reached
Radic et al.	Ecotoxicological effects of aluminum and zinc on growth and antioxidants in *Lemna minor* L.	2010	Duckweed, *Lemna minor*	15 d NOEC (relative growth rate)=4,047; LOEC=8,094	
Rahman et al.	Varietal differences in the growth of rice plants in response to aluminum and silicon	1998	Rice	-	Scientific name not given
Rai et al.	Physiological and biochemical responses of *Nostoc linckia* to combined effects of aluminium, fluoride and acidification	1996	Cyanobacteria, *Nostoc linckia*	15 d pH 7.5 LC50=121.4, pH 6.0 LC50=11.13, pH4.5 LC50=3.643	Only three exposure concentrations
Rajesh	Toxic effect of aluminum in *Oreochromis mossambicus* (Peters)	2010	Mozambique tilapia, *Oreochromis mossambicus*	4 d LC50=8,000	Dilution water not characterized
Ramamoorthy	Effect of pH on speciation and toxicity of aluminum to rainbow trout (*Salmo gairdneri*)	1988	Rainbow trout, *Oncorhynchus mykiss*	-	Mixture
Razo-Estrada et al.	Aluminum-induced oxidative stress and apoptosis in liver of the common carp, *Cyprinus carpio*	2013	Common carp, *Cyprinus carpio*	96 hr Increase lipid peroxidation at 50	Only three exposure concentrations

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Reader and Morris	Effects of aluminium and pH on calcium fluxes, and effects of cadmium and manganese on calcium and sodium fluxes in brown trout (*Salmo trutta* L.)	1988	Brown trout, *Salmo trutta*	-	Only one exposure concentration; too few fish per exposure concentration
Reader et al.	Growth, mineral uptake and skeletal calcium deposition in brown trout, *Salmo trutta* L., yolk-sac fry exposed to aluminum and manganese in soft acid water	1988	Brown trout, *Salmo trutta*	-	Mixture, Al, NH_3, NH_4
Reader et al.	The effects of eight trace metals in acid soft water on survival, mineral uptake and skeletal calcium deposition in yolk-sac fry of brown trout, *Salmo trutta* L.	1989	Brown trout, *Salmo trutta*	30 d 0% survival at 178.1 and pH=4.5; No effect on survival at 170.0 at pH=6.5	Only one exposure concentration
Reader et al.	Episodic exposure to acid and aluminum in soft water: survival and recovery of brown trout, *Salmo trutta* L.	1991	Brown trout, *Salmo trutta*	-	No control group
Reid et al.	Acclimation to sublethal aluminum: modification of metal - gill surface interactions of juvenile rainbow trout (*Oncorhynchus mykiss*)	1991	Rainbow trout, *Oncorhynchus mykiss*	-	Only two exposure concentrations; pre-exposure to pollutant
Reznikoff	Micrurgical studies in cell physiology. II. The action of chlorides of lead, mercury, copper, iron, and aluminum on the protoplasm of Amoeba proteus	1926	-	-	Lack of exposure details; dilution water not characterized
Riseng et al.	The effect of pH, aluminum, and chelator manipulations on the growth of acidic and circumneutral species of *Asterionella*	1991	Diatom, *Asterionella ralfsii* Diatom, *Asterionella formosa*	-	Mixture; EDTA and Al
Rizzo et al.	Removal of THM precursors from a high-alkaline surface water by enhanced coagulation and behaviour of THMFP toxicity on *D. magna*	2005	Cladoceran, *Daphnia magna*	-	Not applicable; no aluminum toxicity data
Robertson and Liber	Bioassays with caged *Hyalella azteca* to determine in situ toxicity downstream of two Saskatchewan, Canada, uranium operations	2007	Amphipod, *Hyalella azteca*	-	Mixture; downstream exposure of uranium mining operation
Robertson et al.	Survival of *Cryptosporidium parvum* oocysts under various environmental pressures	1992	Parasite, *Cryptosporidium parvum*	-	Poor control survival; only two exposure concentrations
Robinson and Deano	The synergistic effects of acidity and aluminum on fish (Golden shiners) in Louisiana	1985	Golden shiner, *Notemigonus crystoleucas*	-	Dilution water not characterized; high control mortality (10-20%)

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Robinson and Deano	Acid rain: the effect of pH, aluminum, and leaf decomposition products on fish survival	1986	Golden shiner, *Notemigonus crystoleucas*	-	Only two exposure concentrations
Rosemond et al.	Comparative analysis of regional water quality in Canada using the water quality index	2009	-	-	Survey; no aluminum toxicity data
Rosseland and Skogheim	Comparative study on salmonid fish species in acid aluminum-rich water II. Physiological stress and mortality of one- and two-year-old fish	1984	-	-	Mixture; dilution water is lake water
Rosseland et al.	Mortality and physiological stress of year-classes of landlocked and migratory Atlantic salmon, brown trout and brook trout in acidic aluminium-rich soft water	1986	Atlantic salmon, *Salmo salar* Brown trout, *Salmo trutta* Brook trout, *Salvelinus fontinalis*	83 hr, pH=5.14, 228 100% mortality; 0% mortality; 0% mortality	Dilution water not characterized; only one exposure concentration
Rosseland et al.	Environmental effects of aluminum	1990	-	-	Review of previously published literature
Rosseland et al.	The mixing zone between limed and acidic river waters: Complex aluminum and extreme toxicity for salmonids	1992	-	-	Mixture; exposure concentration varied over time; dilution water is river water
Roy and Bhadra	Hematoxylin staining of seedling roots is a potential phenotypic index for screening of aluminium tolerance in rice (*Oryza sativa* L.)	2013	Rice, *Oryza sativa*	-	Not applicable, no aluminum toxicity information
Royset et al.	Diffusive gradients in thin films sampler predicts stress in brown trout (*Salmo trutta* L.) exposed to aluminum in acid fresh waters	2005	Brown trout, *Salmo trutta*	-	Mixture; dilution water is river water
Rueter et al.	Indirect aluminum toxicity to the green alga *Scenedesmus* through increased cupric ion activity	1987	Green alga, *Scenedesmus quadricauda*	-	Mixture; Al and Cu
Sacan and Balcioglu	Bioaccumulation of aluminium in *Dunaliella tertiolecta* in natural sewater: Aluminium-metal (Cu, Pb, Se) interactions and influence of pH	2001	Phytoplankton, *Dunaliella tertiolecta*	-	Bioaccumulation, steady state not documented
Sadler and Lynam	Some effects on the growth of brown trout from exposure to aluminum at different pH levels	1987	Brown trout, *Salmo trutta*	7 d NOEC (specific growth rate)=18.87 at pH=5.5; LOEC=30.04 at pH=5.5	Too few exposure concentrations; duration

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Sadler and Lynam	The influence of calcium on aluminum-induced changes in the growth rate and mortality of brown trout, *Salmo trutta* L.	1988	Brown trout, *Salmo trutta*	42 d Increase mortality at 54 and hardness from 3-6 mg/L as $CaCO_3$, but not greater than 9 mg/L	Only one exposure concentration
Salbu et al.	Environmentally relevant mixed exposures to radiation and heavy metals induce measurable stress responses in Atlantic salmon	2008	Atlantic salmon, *Salmo salar*	-	Only one exposure concentration; mixture
Sauer	Heavy metals in fish scales: accumulation and effects on cadmium regulation in the mummichog, *Fundulus heteroclitus* L.	1986	Mummichog, *Fundulus heteroclitus*	-	Not applicable; no aluminum toxicity data
Sayer	Survival and subsequent development of brown trout, *Salmo trutta* L., subjected to episodic exposures of acid, aluminum and copper in soft water during embryonic and larval stages	1991	Brown trout, *Salmo trutta*	-	Only one exposure concentration; mixture; low pH and Al
Sayer et al.	Embryonic and larval development of brown trout, Salmo trutta L.: exposure to aluminum, copper, lead or zinc in soft, acid water	1991a	Brown trout, *Salmo trutta*	700 d 13% mortality at 161.8	Only one exposure concentration
Sayer et al.	Embryonic and larval development of brown trout, *Salmo trutta* L.: exposure to trace metal mixtures in soft water	1991b	Brown trout, *Salmo trutta*	-	Only two exposure concentrations; mixture
Sayer et al.	Effects of six trace metals on calcium fluxes in brown trout (*Salmo trutta* L.) in soft water	1991c	Brown trout, *Salmo trutta*	-	Only two exposure concentrations; mixture
Sayer et al.	Mineral content and blood parameters of dying brown trout (*Salmo trutta* L.) exposed to acid and aluminum in soft water	1991d	Brown trout, *Salmo trutta*	4 d Increase haematocrit and decrease plasma sodium levels and whole body sodium and potassium content at 273.6	Only one exposure concentration; too few organisms per concentration
Schindler and Turner	Biological, chemical and physical responses of lakes to experimental acidification	1982	-	-	Mixture, Al and low pH
Schofield and Trojnar	Aluminum toxicity to brook trout (*Salvelinus fontinalis*) in acidified waters	1980	Brook trout, *Salvelinus fontinalis*	-	Mixture; dilution water not characterized
Schumaker et al.	Zooplankton responses to aluminum sulfate treatment of Newman Lake, Washington	1993	-	-	Exposure concentrations not known
Segner et al.	Growth, aluminum uptake and mucous cell morphometrics of early life stages of brown trout, *Salmo trutta*, in low pH water	1988	Brown trout, *Salmo trutta*	5d Decrease weight and length at 230	Only one exposure concentration

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Senger et al.	Aluminum exposure alters behavioral parameters and increases acetylcholinesterase activity in zebrafish (*Danio rerio*) brain	2011	Zebrafish, *Danio rerio*	4 d Increase AChE activity in brain at 10.12 at pH=5.8 but not pH=6.8	Only one exposure concentration
Shabana et al.	Studies on the effects of some heavy metals on the biological activities of some phytoplankton species. II. The effects of some metallic ions on the growth criteria and morphology of *Anabaena oryzae* and *Aulosira fertilissima*	1986a	-	-	Lack of details; cannot determine effect concentration
Shabana et al.	Studies on the effects of some heavy metals on the biological activities os some phytoplankton species. III. Effects Al3+, Cr3+, Pb2+ and Zn 2+ on heterocyst frequency, nitrogen and phosphorus metabolism of *Anabaena oryzae* and *Aulosira fertilissima*	1986b	-	-	Lack of details; cannot determine effect concentration
Sharma et al.	Protective effect of *Spirulina* and tamarind fruit pulp diet supplement in fish (*Gambusia affinis* Baird & Girard) exposed to sublethal concentration of fluoride, aluminum and aluminum fluoride	2012	Western mosquitofish, *Gambusia affinis*	-	Only one exposure concentration; poor control survival
Shuhaimi-Othman et al.	Toxicity of eight metals to Malaysian freshwater midge larvae *Chironomus javanus* (Diptera, Chironomidae)	2011b	Midge, *Chironomus javanus*	4 d LC50=1,430	Not North American species
Shuhaimi-Othman et al.	Toxicity of metals to tadpoles of the commone Sunda toad, *Duttaphrynus melanostictus*	2012c	Sunda toad, *Duttaphrynus melanostictus*	4 d LC50=1,900	Not North American species
Siebers and Ehlers	Heavy metal action on transintegumentary absorption of glycine in two annelid species	1979	-	-	Not applicable; no aluminum toxicity data
Simon	Sediment and interstitial water toxicity to freshwater mussels and the ecotoxicological recovery of remediated acrid mine drainage streams	2005	-	-	Sediment exposure
Sivakumar and Sivasubramanian	FT-IR study of the effect of aluminum on the muscle tissue of *Cirrhinus mrigala*	2011	Carp hawk, *Cirrhinus mrigala*	4 d LC50=8,200	Not North American species; dilution water not characterized
Skogheim and Rosseland	A comparative study on salmonid fish species in acid aluminum-rich water I. Mortality of eggs and alevins	1984	Trout	-	Mixture; dilution water is lake water
Skogheim and Rosseland	Mortality of smolt of Atlantic salmon, *Salmo salar* L., at low levels of aluminum in acidic softwater	1986	Atlantic salmon, *Salmo salar*	-	Mixture; dilution water is lake water

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Skogheim et al.	Addition of NaOH, limestone slurry and finegrained limestone to acidified lake water and the effects on smolts of Atlantic salmon (*Salmo salar* L.)	1987	Atlantic salmon, *Salmo salar*	-	Prior exposure; stressed organisms
Soleng et al.	Toxicity of aqueous aluminum to the ectoparasitic monogenean *Gyrodactylus salaris*	2005	-	-	Only two exposure concentrations; two species tested with one exposure; not sure how much exposure to the parasite
Sonnichsen	Toxicity of a phosphate-reducing agent (aluminum sulphate) on the zooplankton in the lake Lyngby So	1978	-	-	Not applicable; no aluminum toxicity data
Sparling	Conditioned aversion of aluminum sulfate in black ducks	1990	Black ducks, *Anas rubripes*	-	Dietary exposure
Sparling and Lowe	Environmental hazards of aluminum to plants, invertebrates, fish and wildlife	1996a	-	-	Review; results of previously published papers
Sparling and Lowe	Metal concentrations of tadpoles in experimental ponds	1996b	-	-	Exposed through soil
Sparling and Lowe	Metal concentrations in aquatic macrophytes as influenced by soil and acidification	1998	Macrophytes	-	Exposed through soil
Sparling et al.	Responses of amphibian populations to water and soil factors in experimentally-treated aquatic macrocosms	1995	-	-	Exposed through soil
Sparling et al.	Ecotoxicology of aluminum to fish and wildlife	1997	-	-	Review
Staurnes et al.	Reduced carbonic anhydrase and Na-K-ATPase activity in gills of salmonids exposed to aluminium-containing acid water	1984	-	-	Mixture, Al and low pH
Staurnes et al.	Effects of acid water and aluminum on parr-smolt transformation and seawater tolerance in Atlantic salmon, *Salmo salar*	1993	Atlantic salmon, *Salmo salar*	-	Only one exposure concentration; high control mortality (>40%)
Stearns et al.	Occurrence of cyanide-resistant respiration and of increased concentrations of cytochromes in Tetrahymena cells grown with various metals	1978	-	-	Cannot determine effect concentration
Storey et al.	An appraisal of some effects of simulated acid rain and aluminum ions on *Cyclops viridis* (Crustacea, Copepoda) and *Gammarus pulex* (Crustacea, Amphipoda)	1992	Copepod, *Cyclops viridis* Amphipod, *Gammarus pulex*	168 hr LC50=>26,980; LC50=>26,980	Dilution water not characterized
Strigul et al.	Acute toxicity of boron, titanium dioxide, and aluminum nanoparticles to Daphnia magna and Vibrio fischeri	2009	Cladoceran, *Daphnia magna*	-	Inappropriate form of toxicant, nanoparticles

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Sudo and Aiba	Effect of some metals on the specific growth rate of Ciliata isolated from activated sludge	1975	-	-	Pre-exposure to pollutant; isolated from activated sludge
Tabak and Gibbs	Effects of aluminum, calcium and low pH on egg hatching and nymphal survival of *Cloeon triangulifer* McDunnough (Ephemeroptera: Baetidae)	1991	Mayfly, *Cloeon triangulifer*	No effect on hatch success at 100 and pH=5.5	Only two exposure concentrations
Takano and Shimmen	Effects of aluminum on plasma membrane as revealed by analysis of alkaline band formation in internodal cells of *Chara corallina*	1999	Alga, *Chara corallina*	-	Excised cells
Tanaka and Navasero	Aluminum toxicity of the rice plant under water culture conditions	1966	-	-	Species not given
Taneeva	Toxicity of some heavy metals for hydrobionts	1973	Barnacle, *Balanus eburneus*	LC50=240	Text in foreign language
Taskinen et al.	Effect of pH, iron and aluminum on survival of early life history stages of the endangered freshwater pearl mussel, *Margaritifera margaritifera*	2011	Pearl mussel, *Margaritifera margaritifera*	-	Mixture; dilution water is river water
Tease and Coler	The effect of mineral acids and aluminum from coal leachate on substrate periphyton composition and productivity	1984	-	-	Mixture, Al and low pH
Teien et al.	Sodium silicate as alternative to liming-reduced aluminium toxicity for Atlantic salmon (*Salmo salar* L.) in unstable mixing zones	2006b	Atlantic salmon, *Salmo salar*	-	Only one exposure concentration; dilution water not characterized
Terhaar et al.	Toxicity of photographic processing chemicals to fish	1972	-	-	Mixture; no aluminum toxicity data
Thawornwong and Van Diest	Influences of high acidity and aluminum on the growth of lowland rice	1974	Rice	-	Scientific name not provided
Thomas	Effects of certain metallic salts upon fishes	1915	Mummichog, *Fundulus heteroclitus*	36 hr 100% mortality at 2,208; 120 hr 100% mortality at 1,104	Dilution water not characterized; lack of exposure details
Thompson et al.	Concentration factors of chemical elements in edible aquatic organisms	1972	-	-	Review

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Thomsen et al.	Effect of aluminum and calcium ions on survival and physiology of rainbow trout *Salmo gairdneri* (Richardson) eggs and larvae exposed to acid stress	1988	Rainbow trout, *Oncorhynchus mykiss*	25 d LC50=3,800 (soft water); LC50=71,000 (hard water)	Dilution water not characterized; unmeasured chronic exposure
Thorstad et al.	Reduced marine survival of hatchery-reared Atlantic salmon post-smolts exposed to aluminium and moderate acidification in freshwater	2013	Atlantic salmon, *Salmo salar*	-	Only two exposure concentrations; surgically altered test species (outfitted with acoustic transmitters)
Tietge et al.	Morphometric changes in gill secondary lamellae of brook trout (Salvelinus fontinalis) after long-term exposure to acid and aluminum	1988	Brook trout, *Salvelinus fontinalis*	147 d No effect on survival, but decrease growth at 393	Only one exposure concentration
Tipping et al.	Metal accumulation by stream bryophytes, related to chemical speciation	2008	Bryophytes	-	Exposure concentration not known; field accumulation study
Tomasik et al.	The metal-metal interactions in biological systems. Part III. *Daphnia magna*	1995a	Cladoceran, *Daphnia magna*	24 hr 10% mortality at 7,500	High control mortality (10-20%)
Tomasik et al.	The metal-metal interactions in biological systems. Part IV. Freshwater snail *Bulinus globosus*	1995b	Snail, *Bulinus globosus*	96 hr 100% mortality at 10,000; 1% mortality at 3,000	Not North American species
Troilo et al.	Biochemical responses of *Prochilodus lineatus* after 24-h exposure to aluminum	2007	Sabalo, *Prochilodus lineatus*	24 hr Increase in liver GST and increase in gill CAT at 100	Not North American species; lack of details; exposure methods unknown; abstract only
Truscott et al.	Effect of aluminum and lead on activity in the freshwater pond snail *Lymnaea stagnalis*	1995	Snail, *Lymnaea stagnalis*	45 hr Reduce activity at 500	Only two exposure concentrations
Tunca et al.	Tissue distribution and correlation profiles of heavy-metal accumulation in the freshwater crayfish *Astacus leptodactylus*	2013	Crayfish, *Astacus leptodactylus*	-	Field bioaccumulation study: exposure concentration not know; not North American species
Tyler-Jones et al.	The effects of acid water and aluminium on the embryonic development of the common frog, *Rana temporaria*	1989	Common frog, *Rana temporaria*	-	Not North American species; only three exposure concentrations
Umebese and Motajo	Accumulation, tolerance and impact of aluminium, copper and zinc on growth and nitrate reductase activity of *Ceratophyllum demersum* (Hornwort)	2008	Hornwort, *Ceratophyllum demersum*	15 d Decrease dry biomass at 3,000	Only two exposure concentrations

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Upreti et al.	Toxic effects of aluminium and fluoride on planktonic community of the microcosms	2013	Microcosms	-	Only one exposure concentration; dilution water not characterized
van Coillie and Rousseau	Mineral composition of the scales of *Catostomus commersoni* from two different waters: Studies using electron microprobe analysis	1974	White sucker, *Catostomus commersoni*	-	Exposure concentration not known; field accumulation study
van Dam et al.	Impact of acidification on diatoms and chemistry of Dutch moorland pools	1981	-	-	Mixture, Al and low pH
Van Hoecke et al.	Influence of alumina coating on characteristics and effects of SiO2 nanoparticles in algal growth inhibition assays at various pH and organic matter contents	2011	Alga	-	Inappropriate form of toxicant (nanoparticles)
Vazquez et al.	Effects of water acidity and metal concentrations on accumulation and within-plant distribution of metals in the aquatic bryophyte *Fontinalis antipyretica*	2000	Bryophyte, *Fontinalis antipyretica*	-	Exposure concentration not known; field accumulation study
Velzeboer et al.	Release of geosmin by *Anabaena circinalis* following treatment with aluminium sulphate	1995	Cyanobacteria, *Anabaena circinalis*	-	Only two exposure concentrations; dilution water not characterized
Velzeboer et al.	Aquatic ecotoxicity tests of some nanomaterials	2008	-	-	Inappropriate form of toxicant, nanoparticles
Verbost et al.	The toxic mixing zone of neutral and acidic river water: acute aluminum toxicity in brown trout (*Salmo trutta* L.)	1995	Brown trout, *Salmo trutta*	-	Mixture; dilution water is lake water
Vieira et al.	Effects of aluminum on the energetic substrates in neotropical freshwater *Astyanax bimaculatus* (Teleostei: Characidae) females	2013	Two spot astyanax, *Astyanax bimaculatus*	96 hr Decrease T_4 levels and increase T_3 levels at 600	Not North American species; only one exposure concentration
Vinay et al.	Toxicity and dose determination of quillaja saponin, aluminum hydroxide and squalene in olive flounder (*Paralichthys olivaceus*)	2013	Olive flounder, *Paralichthys olivaceus*	-	Injected toxicant
Vincent et al.	Accumulation of Al, Mn, Fe, Cu, Zn, Cd, and Pb by the bryophyte *Scapania undulata* in three upland waters of different pH	2001	Bryophyte, *Scapania undulata*	-	Exposure concentration not known; field accumulation study
Vuorinen et al.	The sensitivity to acidity and aluminum of newly-hatched perch (*Perca fluviatilis*) originating from strains from four lakes with different degrees	1994a	Perch, *Perca fluviatilis*	7 d LC50=>1,000	Not North American species

Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Vuorinen et al.	The sensitivity to acidification of pike (*Esox lucius*), whitefish (*Coregonus lavaretus*) and roach (*Rutilus rutilus*): a comparison of field and laboratory studies	1994b	-	-	Review of Vuorineu et al. 1993
Vuorinen et al.	Reproduction, blood and plasma parameters and gill histology of vendace (*Coregonus albula* L.) in long-term exposure to acidity to aluminum	2003	Vendace, *Coregonus albula*	60 d Decrease growth at 168 and pH=5.25; Decrease growth at 213 and pH=4.75	Not North American species; only one exposure concentration
Wakabayashi et al.	Relative lethal sensitivity of two Daphnia species to chemicals	1988	-	-	Text in foreign language
Walker et al.	Effects of low pH and aluminum on ventilation in the brook trout (*Salvelinus fontinalis*)	1988	Brook trout, *Salvelinus fontinalis*	-	Surgically altered fish; only one exposure concentration
Walker et al.	Effects of long-term preexposure to sublethal concentrations of acid and aluminum on the ventilatory response to aluminum challenge in brook trout (*Salvelinus fontinalis*)	1991	Brook trout, *Salvelinus fontinalis*	-	Pre-exposure to pollutant
Wallen et al.	Toxicity to *Gambusia affinis* of certain pure chemicals in turbid waters	1957	Western mosquitofish, *Gambusia affinis*	96 hr LC50=26,919 ($AlCl_3$); LC50=37,062 ($Al_2(SO_4)_3$	Dilution water not characterized; farm pond with high turbidity and poor fish population
Walton et al.	Tissue accumulation of aluminum is not a predictor of toxicity in the freshwater snail, *Lymnaea stagnalis*	2009	Snail, *Lymnaea stagnalis*	steady state not reached	Lack of details; steady state not reached
Walton et al.	Trophic transfer of aluminium through an aquatic grazer-omnivore food chain	2010a	Snail, *Lymnaea stagnalis* Crayfish, *Pacifasticus leniusculus*	-	Bioaccumulation: steady state not reached
Walton et al.	The suitability of gallium as a substitute for aluminum in tracing experiments	2010b	Snail, *Lymnaea stagnalis*	-	Bioaccumulation: steady state not reached
Wang et al.	Optimising indoor phosphine fumigation of paddy rice bag-stacks under sheeting for control of resistant insects	2006	-	-	Not applicable, no aluminum toxicity information
Wang et al.	Toxicity of nanoparticulate and bulk ZnO, Al2O3 and TiO2 to the nematode *Caenorhabditis elegans*	2009	Nematode, *Caenorhabditis elegans*	-	Inappropriate form of toxicant (nanoparticles)
Wang et al.	Synergistic toxic effect of nano-Al2O3 and As(V) on *Ceriodaphnia dubia*	2011	Cladoceran, *Ceriodaphnia dubia*	-	Inappropriate form of toxicant (nanoparticles)

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Ward et al.	Influences of aqueous aluminum on the immune system of the freshwater crayfish Pacifasticus leniusculus	2006	Crayfish, *Pacifasticus leniusculus*	-	Only one exposure concentration; test organism injected with bacteria
Waring and Brown	Ionoregulatory and respiratory responses of brown trout, *Salmo trutta*, exposed to lethal and sublethal aluminum in acidic soft waters	1995	Brown trout, *Salmo trutta*	5 d NOEC (survival)=12.5; LOEC=25	Too few exposure concentrations
Waring et al.	Plasma prolactin, cortisol, and thyroid response of the brown trout (*Salmo trutta*) exposed to lethal and sublethal aluminum in acidic soft waters	1996	Brown trout, *Salmo trutta*	-	Surgically altered test species
Waterman	Effect of salts of heavy meatls on development of the sea urchin, *Arbacia punctulata*	1937	Sea urchin, *Arbacia punctulata*	-	Dilution water not characterized; cannot determine effect concentration
Wauer and Teien	Risk of acute toxicity for fish during aluminum application to hardwater lakes	2010	-	-	Survey
Weatherley et al.	The response of macroinvertebrates to experimental episodes of low pH with different forms of aluminum, during a natural spate	1988	-	-	Mixture; dilution water is stream water
Weatherley et al.	The survival of early life stages of brown trout (*Salmo trutta* L.) in relation to aluminum speciation in upland Welsh streams	1990	Brown trout, *Salmo trutta*	-	Mixture; dilution water is stream water
Weatherley et al.	Liming acid streams: aluminum toxicity to fish in mixing zones	1991	-	-	Mixture; dilution water is stream water
White et al.	Avoidance of aluminum toxicity on freshwater snails involves intracellular silicon-aluminum biointeraction	2008	Snail, *Lymnaea stagnalis*	-	Mixture, Al and Si
Whitehead and Brown	Endocrine responses of brown trout, Salmo trutta L., to acid, aluminum and lime dosing in a Welsh hill stream	1989	Brown trout, *Salmo trutta*	-	Mixture, field experiment-dosed stream
Wilkinson and Campbell	Aluminum bioconcentration at the gill surface of juvenile Atlantic salmon in acidic media	1993	Atlantic salmon, *Salmo salar*	-	Bioaccumulation: steady state not reached
Wilkinson et al.	Surface complexation of aluminum on isolated fish gill cells	1993	Largemouth bass, *Micropterus salmoides*	-	Exposed cells only
Williams et al.	Assessment of surface-water quantity and quality, Eagle River Watershed, Colorado, 1947-2007	2011	-	-	Not applicable; no aluminum toxicity data
Wilson	Physiological and metabolic costs of acclimation to chronic sub-lethal acid and aluminum exposure in rainbow trout	1996	-	-	Review

Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Wilson and Hyne	Toxicity of acid-sulfate soil leachate and aluminum to embryos of the Sydney Rock Oyster	1997	Sydney rock oyster, *Accostrea commercialis*	48 hr EC50 (development)=222; EC50=227	Not North American species
Wilson and Wood	Swimming performance, whole body ions, and gill A1 accumulation during acclimation to sublethal aluminum in juvenile rainbow trout (*Oncorhynchus mykiss*)	1992	Rainbow trout, *Oncorhynchus mykiss*	22 d No effect on mortality, but decrease weight at 31.4	Only one exposure concentration
Wilson et al.	Metabolic costs and physiological consequences of acclimation to aluminum in juvenile rainbow trout (*Oncorhynchus mykiss*). 1: Acclimation specificity, resting physiology, feeding, and growth	1994a	Rainbow trout, *Oncorhynchus mykiss*	34 d 5.5% mortality at 38.1	Only one exposure concentration
Wilson et al.	Metabolic costs and physiological consequences of acclimation to aluminum in juvenile rainbow trout (*Oncorhynchus mykiss*). 2: Gill morphology, swimming performance, and aerobic scope	1994b	Rainbow trout, *Oncorhynchus mykiss*	34 d Decrease # of mucous cells in gills, oxygen consumption rates, swimming performance at 38	Only one exposure concentration
Wilson et al.	Growth and protein turnover during acclimation to acid and aluminum in juvenile rainbow trout (*Oncorhynchus mykiss*)	1996	Rainbow trout, *Oncorhynchus mykiss*	-	Only one exposure concentration; pre-exposure to pollutant
Winter et al.	Influences of acidic to basic water pH and natural organic matter on aluminum accumulation by gills of rainbow trout (*Oncorhynchus mykiss*)	2005	Rainbow trout, *Oncorhynchus mykiss*	-	Bioaccumulation: not renewal or flow-through exposure; high control mortality
Witters	Acute acid exposure of rainbow trout, S*almo gairdneri* Richardson: effects of aluminum and calcium on ion balance and haematology	1986	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species; only one exposure concentration
Witters et al.	Interference of aluminum and pH on the Na-influx in an aquatic insect *Corixa punctata* (Illig.)	1984	Waterbug, *Corixa punctata*	-	Mixture; low pH and Al
Witters et al.	Ionoregulatory and haematological responses of rainbow trout *Salmo gairdneri* Richardson to chronic acid and aluminum stress	1987a	Rainbow trout, *Oncorhynchus mykiss*	48 hr ~50% mortality at 200	Only one exposure concentration
Witters et al.	Physiological study on the recovery of rainbow trout (*Salmo gairdneri* Richardson) from acid and Al stress	1987b	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species; only one exposure concentration
Witters et al.	Haematological disturbances and osmotic shifts in rainbow trout, *Oncorhynchus mykiss* (Walbaum) under acid and aluminum exposure	1990a	Rainbow trout, *Oncorhynchus mykiss*	2.5 d ~53% mortality at 200	Only one exposure concentration

Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Witters et al.	The effect of humic substances on the toxicity of aluminum to adult rainbow trout, *Oncorhynchus mykiss* (Walbaum)	1990b	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species
Witters et al.	Adrenergic response to physiological disturbances in rainbow trout, Oncorhynchus mykiss, exposed to aluminum at acid pH	1991	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species
Witters et al.	Physicochemical changes of aluminum in mixing zones: Mortality and physiological disturbances in brown trout (*Salmo trutta* L.)	1996	Brown trout, *Salmo trutta*	48 hr 60% mortality at 184.0	Only one exposure concentration
Wold	Some effects of aluminum sulfate and arsenic sulfide on *Daphnia pulex* and *Chironomus tentans*	2001	Cladoceran, *Daphnia pulex* Midge, *Chironomus tentans*	-	Inadequate exposure methods; chronic was a static, unmeasured exposure; pre-exposure to pollutant
Wold et al.	Life-history responses of *Daphnia pulex* with exposure to aluminum sulfate	2005	Cladoceran, *Daphnia pulex*	Increased survivorship in clones that were prior-exposed to alum treated lakes	Only three exposure concentrations; dilution water not characterized
Wood and McDonald	The physiology of acid/aluminum stress in trout	1987	Trout	-	Too few exposure concentrations, cannot determine effect concentration
Wood et al.	Blood gases, acid-base status, ions, and hematology in adult brook trout (*Salvelinus fontinalis*) under acid/aluminum exposure	1988a	Brook trout, *Salvelinus fontinalis*	-	Only one exposure concentration; surgically altered test species
Wood et al.	Physiological evidence of acclimation to acid/aluminum stress in adult brook trout (*Salvelinus fontinalis*). 1. Blood composition and net sodium fluxes	1988b	Brook trout, *Salvelinus fontinalis*	10 wk 28% mortality at 77	Only two exposure concentrations
Wood et al.	Physiological evidence of acclimation to acid/aluminum stress in adult brook trout (*Salvelinus fontinalis*). 2. Blood parameters by cannulation	1988c	Brook trout, *Salvelinus fontinalis*	-	Only one exposure concentration; surgically altered test species
Wood et al.	Whole body ions of brook trout (*Salvelinus fontinalis*) alevins: responses of yolk-sac and swim-up stages to water acidity, calcium, and aluminum, and recovery effects	1990a	Brook trout, *Salvelinus fontinalis*	-	Lack of details; cannot determine effect concentration

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Wood et al.	Effects of water acidity, calcium, and aluminum on whole body ions of brook trout (*Salvelinus fontinalis*) continuously exposed from fertilization to swim-up: a study by instrumental neutron activation analysis	1990b	Brook trout, *Salvelinus fontinalis*	-	Lack of details; cannot determine effect concentration
Woodburn et al.	Accumulation and toxicity of aluminium-contaminated food in the freshwater crayfish, *Pacifastacus leniusculus*	2011	Crayfish, *Pacifastacus leniusculus*	-	Dietary exposure
Wooldridge and Wooldridge	Internal damage in an aquatic beetle exposed to sublethal concentrations of inorganic ions	1969	Aquatic beetle, *Tropistermus lateralis nimbatus*	14 d Change the body fat at 26,981	Only one exposure concentration
Wren et al.	Examination of bioaccumulation and biomagnification of metlas in a Precambrian Shield Lake	1983	-	-	Field exposure, exposure concentrations not measured adequately
Wu et al.	QTLs and epistasis for aluminum tolerance in rice (*Oryza sativa* L.) at different seedling stages	2000	Rice, *Oryza sativa*	-	Only one exposure concentration; difficult to determine effect concentration
Wu et al.	Aluminum nanoparticle exposure in L1 larvae results in more severe lethality toxicity than in L4 larvae or young adults by strengthening the formation of stress response and intestinal lipofuscin accumulation in nematodes	2011	-	-	Inappropriate form of toxicant, nanoparticles
Yang and van den Berg	Metal complexation by humic substances in seawater	2009	-	-	Not applicable; no aluminum toxicity data
Yang et al.	Identification of aluminum-responsive proteins in rice roots by a proteomic approach: Cysteine synthase as a key player in Al response	2007	Rice, *Oryza sativa*	3 d Decreased root length at 53,960	Only two exposure concentrations
Youson and Neville	Deposition of aluminum in the gill epithelium of rainbow trout (*Salmo gairdneri* Richardson) subjected to sublethal concentrations of the metal	1987	Rainbow trout, *Oncorhynchus mykiss*	-	Surgically altered test species
Ytrestoyl et al.	Swimming performance and blood chemistry in Atlantic salmon spawners exposed to acid river water with elevated aluminium concentrations	2001	Atlantic salmon, *Salmo salar*	-	Only one exposure concentrations; dilution water not characterized; no true control group
Zaifnejad et al.	Aluminum and water stress effects on growth and proline of sorghum	1997	Sorghum, *Sorghum bicolor*	-	Inappropriate form of toxicant (aluminum potassium sulfate)
Zaini and Mercado	Calcium-aluminum interaction on the growth of two rice cultivars in culture solution	1984	Rice	-	Scientific name not provided

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Author	Title	Date	Organism(s)	Concentration (µg/L)	Reason Unused
Zarini et al.	Effects produced by aluminum in freshwater communities studied by "enclosure" method	1983	-	-	Mixed species exposure; no species names provided; dilution water not characterized
Zhou and Yokel	The chemical species of aluminum influences its paracellular flux across and uptake into Caco-2 cells, a model of gastrointestinal absorption	2005	-	-	Excised cells, in vitro
Zhu et al.	Comparative toxicity of several metal oxide nanoparticle aqueous suspensions to Zebrafish (*Danio rerio*) early developmental stage	2008	Zebrafish, *Danio rerio*	-	Inappropriate form of toxicant, nanoparticles
Zhu et al.	Acute toxicities of six manufactured nanomaterial suspensions to *Daphnia magna*	2009	Cladoceran, *Daphnia magna*	-	Inappropriate form of toxicant (nanoparticles)

NMED Exhibit 75

Appendix K RECOMMENDED CRITERIA FOR VARIOUS WATER CHEMISTRY CONDITIONS

NMED Exhibit 75

Table K-1. Freshwater CMC at DOC of 0.1 mg/L and Various Water Total Hardness Levels and pHs.

Total Hardness	Acute Criterion (CMC) (µg/L total aluminum) (DOC=0.1 mg/L)																											
	pH 5.0		pH 5.5		pH 6.0		pH 6.5		pH 7.0		pH 7.5		pH 8.0		pH 8.2		pH 8.5		pH 9.0		pH 9.5		pH 10.0		pH 10.5	
10	*1.0*	a	*4.8*	b	18	d	**51**	d	**120**	b	**210**	a	**290**	a	**310**	a	***320***	a	***270***	a	*180*	a	*95*	a	*39*	a
25	*2.4*	a	*10*	h	32	d	**84**	d	**180**	d	**290**	a	**370**	a	**380**	a	***360***	a	***280***	a	*170*	a	*78*	a	*29*	a
50	*4.6*	a	*17*	d	50	d	**120**	d	**240**	d	**380**	a	**440**	a	**430**	a	***400***	a	***280***	a	*160*	a	*67*	a	*23*	a
75	*6.7*	b	*24*	d	64	d	**150**	d	**290**	d	**440**	b	**480**	a	**470**	a	***420***	a	***280***	a	*150*	a	*62*	a	*20*	a
100	*8.8*	b	*30*	d	76	d	**170**	d	**320**	d	**490**	i	**520**	a	**500**	a	***430***	a	***280***	a	*150*	a	*58*	a	*18*	a
150	*13*	c	*40*	d	96	d	**200**	d	**380**	d	**560**	h	**580**	a	**540**	a	***460***	a	***290***	a	*140*	a	*53*	a	*16*	a
200	*17*	c	*49*	d	110	d	**230**	d	**420**	d	**610**	d	**620**	a	**570**	a	***480***	a	***290***	a	*140*	a	*50*	a	*15*	a
250	*20*	d	*58*	d	130	d	**250**	d	**460**	d	**660**	d	**650**	a	**600**	a	***490***	a	***290***	a	*130*	a	*48*	a	*14*	a
300	*24*	d	*66*	d	140	d	**270**	d	**490**	d	**700**	d	**680**	a	**620**	a	***500***	a	***290***	a	*130*	a	*46*	a	*13*	a
350	*28*	d	*73*	d	150	d	**290**	d	**510**	d	**730**	d	**710**	a	**640**	a	***510***	a	***290***	a	*130*	a	*45*	a	*12*	a
400	*31*	d	*80*	d	160	d	**310**	d	**540**	d	760	d	**730**	a	**660**	a	***520***	a	***290***	a	*130*	a	*43*	a	*12*	a
430	*33*	d	*84*	d	170	d	**320**	d	**550**	d	780	d	750	a	**670**	a	***530***	a	***290***	a	*130*	a	*43*	a	*11*	a

Bolded values indicate where the 2018 criteria are lower than the 1988 criteria magnitude within the 1988 pH range applied of 6.5-9.0.
(Italicized and underlined values are outside the pH limits of the empirical data used to generate the MLR models and should be used with caution).

Ranking of four most sensitive genera (Rank 1-Rank 4).

a Daphnia, Ceriodaphnia, Stenocypris, Nais
b Daphnia, Ceriodaphnia, Stenocypris, Micropterus
c Daphnia, Micropterus, Ceriodaphnia, Stenocypris
d Daphnia, Micropterus, Oncorhynchus, Ceriodaphnia
e Daphnia, Micropterus, Oncorhynchus, Salmo
f Micropterus, Daphnia, Oncorhynchus, Salmo
g Micropterus, Oncorhynchus, Daphnia, Salmo
h Daphnia, Micropterus, Ceriodaphnia, Oncorhynchus
i Daphnia, Ceriodaphnia, Micropterus, Stenocypris

Table K-2. Freshwater CCC at DOC of 0.1 mg/L and Various Water Hardness Levels and pHs.

Total Hardness	Chronic Criterion (CCC) (µg/L total aluminum) (DOC=0.1 mg/L)																									
	pH 5.0		pH 5.5		pH 6.0		pH 6.5		pH 7.0		pH 7.5		pH 8.0		pH 8.2		pH 8.5		pH 9.0		pH 9.5		pH 10.0		pH 10.5	
10	*0.63*	a	*3.1*	b	12	d	**33**	e	**77**	b	130	a	180	a	200	a	*200*	a	*170*	a	*110*	a	*59*	a	*24*	a
25	*1.5*	a	*6.7*	c	19	f	**48**	f	120	d	180	a	230	a	240	a	*230*	a	*170*	a	*100*	a	*49*	a	*18*	a
50	*2.9*	a	*11*	e	26	h	**63**	g	140	e	240	b	270	a	270	a	*250*	a	*180*	a	*97*	a	*42*	a	*14*	a
75	*4.3*	b	*14*	f	31	g	**71**	g	160	f	290	b	300	a	290	a	*260*	a	*180*	a	*94*	a	*39*	a	*13*	a
100	*5.8*	b	*17*	f	35	g	**77**	g	180	f	320	c	330	a	310	a	*270*	a	*180*	a	*91*	a	*36*	a	*11*	a
150	*8.6*	c	*21*	h	42	g	87	g	190	g	370	c	360	a	340	a	*290*	a	*180*	a	*88*	a	*33*	a	*10*	a
200	*11*	c	*25*	g	47	g	94	g	200	g	400	e	390	a	360	a	*300*	a	*180*	a	*85*	a	*31*	a	*9.1*	a
250	*13*	d	*28*	g	51	g	100	g	210	g	420	e	410	a	380	a	*310*	a	*180*	a	*83*	a	*30*	a	*8.5*	a
300	*16*	e	*31*	g	55	g	100	g	220	g	430	e	430	a	390	a	*320*	a	*180*	a	*82*	a	*29*	a	*8.0*	a
350	*17*	e	*33*	g	58	g	110	g	220	g	440	e	440	a	400	a	*320*	a	*180*	a	*81*	a	*28*	a	*7.6*	a
400	*19*	e	*36*	g	61	g	110	g	230	g	450	e	460	a	410	a	*330*	a	*180*	a	*80*	a	*27*	a	*7.3*	a
430	*20*	e	*37*	g	63	g	120	g	230	g	450	e	470	a	420	a	*330*	a	*180*	a	*79*	a	*27*	a	*7.1*	a

Bolded values indicate where the 2018 criteria are lower than the 1988 criteria magnitude within the 1988 pH range applied of 6.5-9.0.
(Italicized and underlined values are outside the pH limits of the empirical data used to generate the MLR models and should be used with caution).

Ranking of four most sensitive genera (Rank 1-Rank 4)

a Daphnia, Lampsilis, Ceriodaphnia, Hyalella
b Daphnia, Lampsilis, Ceriodaphnia, Salmo
c Daphnia, Lampsilis, Salmo, Ceriodaphnia
d Daphnia, Salmo, Lampsilis, Ceriodaphnia
e Salmo, Daphnia, Lampsilis, Ceriodaphnia
f Salmo, Daphnia, Lampsilis, Salvelinus
g Salmo, Salvelinus, Daphnia, Lampsilis
h Salmo, Daphnia, Salvelinus, Lampsilis
i Salmo, Salvelinus, Daphnia, Danio
j Salmo, Salvelinus, Danio, Daphnia
k Salmo, Salvelinus, Danio, Pimephales

Table K-3. Freshwater CMC at DOC of 0.5 mg/L and Various Water Total Hardness Levels and pHs.

Total Hardness	Acute Criterion (CMC) (µg/L total aluminum) (DOC=0.5 mg/L)																													
	pH 5.0		pH 5.5		pH 6.0		pH 6.5		pH 7.0		pH 7.5		pH 8.0		pH 8.2		pH 8.5		pH 9.0		pH 9.5		pH 10.0		pH 10.5	
10	*2.6*	a	*13*	a	46	c	**130**	d	**300**	d	**550**	i	770	a	820	a	*830*	a	***710***	a	*470*	a	*250*	a	*100*	a
25	*6.3*	a	*27*	a	86	d	**210**	d	**430**	d	750	d	960	a	980	a	*940*	a	***720***	a	*430*	a	*200*	a	*75*	a
50	*12*	a	*47*	b	130	d	**300**	d	**560**	d	920	d	1,100	b	1,100	a	*1,000*	a	***730***	a	*410*	a	*180*	a	*60*	a
75	*18*	a	*66*	c	170	d	**360**	d	**650**	d	1,000	d	1,300	b	1,200	a	*1,100*	a	***740***	a	*390*	a	*160*	a	*52*	a
100	*23*	a	*82*	d	210	d	**410**	d	**720**	d	1,100	d	1,400	c	1,300	a	*1,100*	a	***740***	a	*380*	a	*150*	a	*48*	a
150	*34*	a	*110*	d	260	d	**480**	d	820	d	1,200	d	1,500	d	1,400	b	*1,200*	a	*750*	a	*370*	a	*140*	a	*42*	a
200	*44*	a	*140*	d	310	d	**550**	d	890	d	1,300	d	1,600	d	1,500	b	*1,200*	a	*750*	a	*360*	a	*130*	a	*38*	a
250	*54*	a	*170*	d	350	d	**600**	d	950	d	1,400	d	1,600	d	1,600	i	*1,300*	a	*760*	a	*350*	a	*130*	a	*35*	a
300	*65*	a	*190*	d	390	d	**650**	e	1,000	e	1,500	d	1,700	d	1,600	c	*1,300*	a	*760*	a	*340*	a	*120*	a	*33*	a
350	*75*	a	*220*	d	420	d	**700**	e	1,100	e	1,500	d	1,800	d	1,700	c	*1,300*	a	*760*	a	*340*	a	*120*	a	*32*	a
400	*85*	a	*240*	d	450	d	**740**	e	1,100	e	1,500	d	1,800	d	1,700	h	*1,400*	a	*760*	a	*330*	a	*110*	a	*30*	a
430	*90*	a	*250*	d	470	d	770	e	1,100	e	1,600	d	1,800	d	1,700	d	*1,400*	a	*760*	a	*330*	a	*110*	a	*30*	a

Bolded values indicate where the 2018 criteria are lower than the 1988 criteria magnitude within the 1988 pH range applied of 6.5-9.0.
(Italicized and underlined values are outside the pH limits of the empirical data used to generate the MLR models and should be used with caution).

Ranking of four most sensitive genera (Rank 1-Rank 4).

a Daphnia, Ceriodaphnia, Stenocypris, Nais
b Daphnia, Ceriodaphnia, Stenocypris, Micropterus
c Daphnia, Micropterus, Ceriodaphnia, Stenocypris
d Daphnia, Micropterus, Oncorhynchus, Ceriodaphnia
e Daphnia, Micropterus, Oncorhynchus, Salmo
f Micropterus, Daphnia, Oncorhynchus, Salmo
g Micropterus, Oncorhynchus, Daphnia, Salmo
h Daphnia, Micropterus, Ceriodaphnia, Oncorhynchus
i Daphnia, Ceriodaphnia, Micropterus, Stenocypris

Table K-4. Freshwater CCC at DOC of 0.5 mg/L and Various Water Hardness Levels and pHs.

Total Hardness	Chronic Criterion (CCC) (µg/L total aluminum) (DOC=0.5 mg/L)																									
	pH 5.0		pH 5.5		pH 6.0		pH 6.5		pH 7.0		pH 7.5		pH 8.0		pH 8.2		pH 8.5		pH 9.0		pH 9.5		pH 10.0		pH 10.5	
10	*1.7*	a	*7.9*	a	31	c	**78**	e	180	e	370	c	480	a	510	a	*520*	a	*440*	a	*300*	a	*150*	a	*63*	a
25	*3.9*	a	*17*	b	52	e	110	h	230	f	470	e	600	a	620	a	*590*	a	*450*	a	*270*	a	*130*	a	*47*	a
50	*7.5*	a	*31*	c	74	f	140	g	270	g	520	f	740	b	710	a	*650*	a	*460*	a	*250*	a	*110*	a	*37*	a
75	*11*	a	*44*	c	89	g	160	g	290	g	560	f	840	c	770	a	*680*	a	*460*	a	*240*	a	*100*	a	*33*	a
100	*14*	a	*54*	d	100	g	170	g	300	g	580	g	910	c	820	a	*710*	a	*460*	a	*240*	a	*95*	a	*30*	a
150	*21*	a	*70*	e	120	g	190	g	320	g	600	g	970	d	910	b	*750*	a	*470*	a	*230*	a	*87*	a	*26*	a
200	*28*	a	*84*	e	130	g	200	g	340	g	610	g	990	e	990	b	*780*	a	*470*	a	*220*	a	*82*	a	*24*	a
250	*34*	a	*96*	f	150	g	220	g	350	g	610	g	1,000	e	1,000	c	*800*	a	*470*	a	*220*	a	*78*	a	*22*	a
300	*40*	a	*110*	f	160	g	230	g	360	g	620	g	1,000	e	1,100	c	*820*	a	*470*	a	*210*	a	*75*	a	*21*	a
350	*47*	a	*120*	f	170	g	240	g	370	g	620	g	1,000	e	1,100	c	*840*	a	*480*	a	*210*	a	*73*	a	*20*	a
400	*53*	a	*130*	f	180	g	250	g	370	g	630	g	1,000	f	1,100	c	*860*	a	*480*	a	*210*	a	*71*	a	*19*	a
430	*57*	a	*140*	f	180	g	250	g	380	g	630	g	1,000	f	1,100	d	*860*	a	*480*	a	*210*	a	*70*	a	*19*	a

Bolded values indicate where the 2018 criteria are lower than the 1988 criteria magnitude within the 1988 pH range applied of 6.5-9.0.
(Italicized and underlined values are outside the pH limits of the empirical data used to generate the MLR models and should be used with caution).

Ranking of four most sensitive genera (Rank 1-Rank 4)

a Daphnia, Lampsilis, Ceriodaphnia, Hyalella
b Daphnia, Lampsilis, Ceriodaphnia, Salmo
c Daphnia, Lampsilis, Salmo, Ceriodaphnia
d Daphnia, Salmo, Lampsilis, Ceriodaphnia
e Salmo, Daphnia, Lampsilis, Ceriodaphnia
f Salmo, Daphnia, Lampsilis, Salvelinus
g Salmo, Salvelinus, Daphnia, Lampsilis
h Salmo, Daphnia, Salvelinus, Lampsilis
i Salmo, Salvelinus, Daphnia, Danio
j Salmo, Salvelinus, Danio, Daphnia
k Salmo, Salvelinus, Danio, Pimephales

Table K-5. Freshwater CMC at DOC of 1.0 mg/L and Various Water Total Hardness Levels and pHs.

Total Hardness	Acute Criterion (CMC) (µg/L total aluminum) (DOC=1.0 mg/L)																											
	pH 5.0		pH 5.5		pH 6.0		pH 6.5		pH 7.0		pH 7.5		pH 8.0		pH 8.2		pH 8.5		pH 9.0		pH 9.5		pH 10.0		pH 10.5	
10	*4.0*	a	*19*	a	70	c	**190**	d	**430**	d	810	d	1,200	a	1,200	a	*1,300*	a	*1,100*	a	*720*	a	*370*	a	*150*	a
25	*9.5*	a	*40*	a	130	d	**310**	d	**620**	d	1,100	d	1,400	c	1,500	a	*1,400*	a	*1,100*	a	*660*	a	*310*	a	*110*	a
50	*18*	a	*72*	b	210	d	**430**	d	790	d	1,300	d	1,700	d	1,700	b	*1,600*	a	*1,100*	a	*610*	a	*270*	a	*90*	a
75	*27*	a	*100*	b	260	d	**520**	d	900	d	1,400	d	1,800	d	1,800	c	*1,700*	a	*1,100*	a	*590*	a	*240*	a	*79*	a
100	*35*	a	*130*	c	320	d	**590**	d	980	d	1,500	d	1,900	d	1,900	d	*1,700*	a	*1,100*	a	*570*	a	*230*	a	*72*	a
150	*51*	a	*170*	d	400	d	**700**	d	1,100	d	1,600	d	2,100	d	2,100	d	*1,800*	a	*1,100*	a	*550*	a	*210*	a	*63*	a
200	*67*	a	*220*	d	470	d	790	d	1,200	e	1,700	d	2,200	d	2,200	d	*1,900*	b	*1,100*	a	*540*	a	*200*	a	*57*	a
250	*82*	a	*260*	d	540	d	870	e	1,300	e	1,800	d	2,200	d	2,200	d	*1,900*	b	*1,100*	a	*530*	a	*190*	a	*53*	a
300	*98*	a	*300*	d	600	d	950	e	1,400	f	1,900	d	2,300	d	2,300	d	*2,000*	b	*1,100*	a	*520*	a	*180*	a	*50*	a
350	*110*	a	*340*	d	650	d	1,000	e	1,500	f	1,900	e	2,300	d	2,300	d	*2,000*	c	*1,200*	a	*510*	a	*180*	a	*48*	a
400	*130*	a	*380*	d	700	d	1,100	f	1,600	f	2,000	e	2,400	d	2,400	d	*2,100*	c	*1,200*	a	*500*	a	*170*	a	*46*	a
430	*140*	a	*400*	d	730	d	1,100	f	1,600	f	2,000	e	2,400	d	2,400	d	*2,100*	c	*1,200*	a	*500*	a	*170*	a	*45*	a

Bolded values indicate where the 2018 criteria are lower than the 1988 criteria magnitude within the 1988 pH range applied of 6.5-9.0.
(Italicized and underlined values are outside the pH limits of the empirical data used to generate the MLR models and should be used with caution).
Ranking of four most sensitive genera (Rank 1-Rank 4).
a Daphnia, Ceriodaphnia, Stenocypris, Nais
b Daphnia, Ceriodaphnia, Stenocypris, Micropterus
c Daphnia, Micropterus, Ceriodaphnia, Stenocypris
d Daphnia, Micropterus, Oncorhynchus, Ceriodaphnia
e Daphnia, Micropterus, Oncorhynchus, Salmo
f Micropterus, Daphnia, Oncorhynchus, Salmo
g Micropterus, Oncorhynchus, Daphnia, Salmo
h Daphnia, Micropterus, Ceriodaphnia, Oncorhynchus
i Daphnia, Ceriodaphnia, Micropterus, Stenocypris

Table K-6. Freshwater CCC at DOC of 1.0 mg/L and Various Water Hardness Levels and pHs.

Total Hardness	Chronic Criterion (CCC) (µg/L total aluminum) (DOC=1.0 mg/L)																							
	pH 5.0		pH 5.5		pH 6.0		pH 6.5		pH 7.0		pH 7.5		pH 8.0		pH 8.2		pH 8.5		pH 9.0		pH 9.5		pH 10.0		pH 10.5	
10	*2.5*	a	*12*	a	47	c	110	e	240	f	500	e	730	b	770	a	*790*	a	*670*	a	*450*	a	*230*	a	*95*	a
25	*5.9*	a	*25*	a	81	e	160	g	300	g	580	f	970	c	930	a	*890*	a	*680*	a	*410*	a	*190*	a	*71*	a
50	*11*	a	*46*	b	110	f	200	g	340	g	620	g	1,100	e	1,100	c	*980*	a	*690*	a	*380*	a	*170*	a	*56*	a
75	*17*	a	*66*	b	140	h	220	g	360	g	640	g	1,100	e	1,200	c	*1,000*	a	*700*	a	*370*	a	*150*	a	*49*	a
100	*22*	a	*85*	c	160	g	240	g	380	g	650	g	1,100	f	1,300	d	*1,100*	a	*700*	a	*360*	a	*140*	a	*45*	a
150	*32*	a	*120*	d	190	g	260	g	400	g	660	g	1,100	f	1,300	e	*1,100*	a	*710*	a	*350*	a	*130*	a	*39*	a
200	*42*	a	*140*	e	210	g	290	g	420	g	670	g	1,100	g	1,300	e	*1,200*	b	*710*	a	*340*	a	*120*	a	*36*	a
250	*51*	a	*160*	e	230	g	300	g	430	g	670	g	1,100	g	1,300	f	*1,300*	b	*720*	a	*330*	a	*120*	a	*33*	a
300	*61*	a	*180*	e	250	g	320	g	440	g	680	g	1,100	g	1,300	f	*1,300*	c	*720*	a	*320*	a	*110*	a	*31*	a
350	*71*	a	*200*	e	260	g	330	g	450	i	680	g	1,100	g	1,300	f	*1,400*	c	*720*	a	*320*	a	*110*	a	*30*	a
400	*80*	a	*220*	e	280	g	340	g	470	j	680	g	1,100	g	1,300	f	*1,400*	c	*720*	a	*310*	a	*110*	a	*29*	a
430	*86*	a	*230*	f	290	g	350	i	470	j	680	g	1,100	g	1,300	f	*1,400*	c	*720*	a	*310*	a	*110*	a	*28*	a

(Italicized and underlined values are outside the pH limits of the empirical data used to generate the MLR models and should be used with caution).

Ranking of four most sensitive genera (Rank 1-Rank 4)

a Daphnia, Lampsilis, Ceriodaphnia, Hyalella
b Daphnia, Lampsilis, Ceriodaphnia, Salmo
c Daphnia, Lampsilis, Salmo, Ceriodaphnia
d Daphnia, Salmo, Lampsilis, Ceriodaphnia
e Salmo, Daphnia, Lampsilis, Ceriodaphnia
f Salmo, Daphnia, Lampsilis, Salvelinus
g Salmo, Salvelinus, Daphnia, Lampsilis
h Salmo, Daphnia, Salvelinus, Lampsilis
i Salmo, Salvelinus, Daphnia, Danio
j Salmo, Salvelinus, Danio, Daphnia
k Salmo, Salvelinus, Danio, Pimephales

Table K-7. Freshwater CMC at DOC of 2.5 mg/L and Various Water Total Hardness Levels and pHs.

Total Hardness	Acute Criterion (CMC) (µg/L total aluminum) (DOC=2.5 mg/L)																									
	pH 5.0		pH 5.5		pH 6.0		pH 6.5		pH 7.0		pH 7.5		pH 8.0		pH 8.2		pH 8.5		pH 9.0		pH 9.5		pH 10.0		pH 10.5	
10	*6.9*	a	*33*	a	120	i	**330**	d	**700**	d	1,300	d	1,900	d	2,100	c	*2,200*	a	*1,900*	a	*1,200*	a	*650*	a	*260*	a
25	*16*	a	*70*	a	230	d	**520**	d	960	d	1,600	d	2,300	d	2,500	d	*2,500*	b	*1,900*	a	*1,100*	a	*530*	a	*200*	a
50	*31*	a	*120*	a	360	d	**720**	d	1,200	d	1,800	d	2,500	d	2,700	d	*2,700*	h	*1,900*	a	*1,100*	a	*460*	a	*160*	a
75	*46*	a	*170*	a	460	d	850	d	1,300	e	2,000	d	2,700	d	2,800	d	*2,800*	d	*1,900*	a	*1,000*	a	*420*	a	*140*	a
100	*60*	a	*220*	b	550	d	970	d	1,500	e	2,100	e	2,700	d	2,900	d	*2,900*	d	*1,900*	a	*990*	a	*400*	a	*120*	a
150	*88*	a	*310*	b	710	d	1,100	d	1,700	f	2,300	e	2,900	d	3,000	d	*3,000*	d	*2,000*	a	*960*	a	*360*	a	*110*	a
200	*120*	a	*390*	c	840	d	1,300	e	1,900	g	2,500	f	2,900	d	3,100	d	*3,000*	d	*2,000*	a	*930*	a	*340*	a	*99*	a
250	*140*	a	*460*	c	960	d	1,500	e	2,100	g	2,600	g	3,000	d	3,100	d	*3,000*	d	*2,000*	a	*910*	a	*330*	a	*92*	a
300	*170*	a	*530*	d	1,100	d	1,600	f	2,200	g	2,700	g	3,000	e	3,100	d	*3,100*	d	*2,000*	a	*890*	a	*320*	a	*87*	a
350	*190*	a	*600*	d	1,200	d	1,700	f	2,300	g	2,800	g	3,100	e	3,200	d	*3,100*	d	*2,000*	a	*880*	a	*310*	a	*83*	a
400	*220*	a	*670*	d	1,200	d	1,800	f	2,400	g	2,900	g	3,100	e	3,200	d	*3,100*	d	*2,000*	a	*870*	a	*300*	a	*79*	a
430	*240*	a	*710*	d	1,300	d	1,900	g	2,400	g	2,900	g	3,100	e	3,200	d	*3,100*	d	*2,000*	a	*860*	a	*290*	a	*77*	a

Bolded values indicate where the 2018 criteria are lower than the 1988 criteria magnitude within the 1988 pH range applied of 6.5-9.0.
(Italicized and underlined values are outside the pH limits of the empirical data used to generate the MLR models and should be used with caution).

Ranking of four most sensitive genera (Rank 1-Rank 4).

a Daphnia, Ceriodaphnia, Stenocypris, Nais
b Daphnia, Ceriodaphnia, Stenocypris, Micropterus
c Daphnia, Micropterus, Ceriodaphnia, Stenocypris
d Daphnia, Micropterus, Oncorhynchus, Ceriodaphnia
e Daphnia, Micropterus, Oncorhynchus, Salmo
f Micropterus, Daphnia, Oncorhynchus, Salmo
g Micropterus, Oncorhynchus, Daphnia, Salmo
h Daphnia, Micropterus, Ceriodaphnia, Oncorhynchus
i Daphnia, Ceriodaphnia, Micropterus, Stenocypris

Table K-8. Freshwater CCC at DOC of 2.5 mg/L and Various Water Hardness Levels and pHs.

Total Hardness	Chronic Criterion (CCC) (µg/L total aluminum) (DOC=2.5 mg/L)																									
	pH 5.0		pH 5.5		pH 6.0		pH 6.5		pH 7.0		pH 7.5		pH 8.0		pH 8.2		pH 8.5		pH 9.0		pH 9.5		pH 10.0		pH 10.5	
10	*4.3*	a	*21*	a	81	c	180	f	340	g	650	g	1,200	e	1,400	c	*1,400*	a	*1,200*	a	*780*	a	*400*	a	*160*	a
25	*10*	a	*44*	a	140	e	250	g	400	g	690	g	1,200	f	1,500	e	*1,600*	b	*1,200*	a	*710*	a	*330*	a	*120*	a
50	*20*	a	*77*	a	200	f	310	g	450	g	710	g	1,200	g	1,500	f	*1,800*	c	*1,200*	a	*660*	a	*290*	a	*98*	a
75	*29*	a	*110*	a	250	f	340	g	480	g	720	g	1,200	g	1,500	g	*1,800*	e	*1,200*	a	*640*	a	*260*	a	*86*	a
100	*38*	a	*140*	b	290	g	370	g	500	g	730	g	1,200	g	1,400	g	*1,700*	e	*1,200*	a	*620*	a	*250*	a	*78*	a
150	*55*	a	*200*	b	340	g	410	g	530	i	740	g	1,100	g	1,400	g	*1,700*	f	*1,200*	a	*600*	a	*230*	a	*68*	a
200	*72*	a	*260*	c	390	g	440	g	560	j	750	j	1,100	g	1,300	g	*1,700*	f	*1,200*	a	*580*	a	*210*	a	*62*	a
250	*89*	a	*310*	c	420	g	470	g	580	j	760	j	1,100	g	1,300	g	*1,600*	f	*1,200*	a	*570*	a	*210*	a	*58*	a
300	*110*	a	*350*	d	460	g	490	i	600	j	770	j	1,100	g	1,300	g	*1,600*	h	*1,200*	a	*560*	a	*200*	a	*54*	a
350	*120*	a	*390*	e	480	g	520	i	610	j	780	j	1,100	g	1,200	g	*1,600*	g	*1,200*	a	*550*	a	*190*	a	*52*	a
400	*140*	a	*430*	e	510	g	540	j	630	j	780	j	1,000	g	1,200	g	*1,500*	g	*1,300*	b	*540*	a	*190*	a	*50*	a
430	*150*	a	*450*	e	520	g	550	j	640	j	790	j	1,000	g	1,200	g	*1,500*	g	*1,300*	b	*540*	a	*180*	a	*48*	a

(Italicized and underlined values are outside the pH limits of the empirical data used to generate the MLR models and should be used with caution).

Ranking of four most sensitive genera (Rank 1-Rank 4)

a Daphnia, Lampsilis, Ceriodaphnia, Hyalella
b Daphnia, Lampsilis, Ceriodaphnia, Salmo
c Daphnia, Lampsilis, Salmo, Ceriodaphnia
d Daphnia, Salmo, Lampsilis, Ceriodaphnia
e Salmo, Daphnia, Lampsilis, Ceriodaphnia
f Salmo, Daphnia, Lampsilis, Salvelinus
g Salmo, Salvelinus, Daphnia, Lampsilis
h Salmo, Daphnia, Salvelinus, Lampsilis
i Salmo, Salvelinus, Daphnia, Danio
j Salmo, Salvelinus, Danio, Daphnia
k Salmo, Salvelinus, Danio, Pimephales

Table K-9. Freshwater CMC at DOC of 5.0 mg/L and Various Water Total Hardness Levels and pHs.

Total Hardness	Acute Criterion (CMC) (µg/L total aluminum) (DOC=5.0 mg/L)																							
	pH 5.0		pH 5.5		pH 6.0		pH 6.5		pH 7.0		pH 7.5		pH 8.0		pH 8.2		pH 8.5		pH 9.0		pH 9.5		pH 10.0		pH 10.5	
10	*10*	a	*50*	a	180	b	**490**	d	970	d	1,700	d	2,600	d	3,000	d	*3,300*	d	*2,800*	a	*1900*	a	*980*	a	*400*	a
25	*25*	a	*110*	a	350	d	760	d	1,300	d	2,000	d	3,000	d	3,300	d	*3,500*	d	*2,900*	a	*1,700*	a	*810*	a	*300*	a
50	*47*	a	*190*	a	550	d	1,000	d	1,600	e	2,400	e	3,100	d	3,400	d	*3,700*	d	*2,900*	a	*1,600*	a	*700*	a	*240*	a
75	*69*	a	*260*	a	710	d	1,200	d	1,900	f	2,600	f	3,200	d	3,500	d	*3,700*	d	*2,900*	b	*1,500*	a	*640*	a	*210*	a
100	*91*	a	*330*	a	850	d	1,400	d	2,100	f	2,800	g	3,300	e	3,500	d	*3,700*	d	*2,900*	b	*1,500*	a	*600*	a	*190*	a
150	*130*	a	*460*	a	1,100	d	1,700	e	2,400	g	3,000	g	3,500	f	3,600	e	*3,700*	d	*2,900*	c	*1,400*	a	*550*	a	*160*	a
200	*170*	a	*590*	b	1,300	d	1,900	e	2,600	g	3,200	g	3,600	f	3,700	e	*3,700*	d	*2,900*	d	*1,400*	a	*520*	a	*150*	a
250	*210*	a	*700*	b	1,500	d	2,100	f	2,800	g	3,400	g	3,700	g	3,700	e	*3,700*	d	*2,900*	d	*1,400*	a	*500*	a	*140*	a
300	*260*	a	*820*	i	1,600	d	2,300	f	3,000	g	3,500	g	3,800	g	3,800	f	*3,700*	d	*2,900*	d	*1,400*	a	*480*	a	*130*	a
350	*290*	a	*930*	c	1,800	d	2,500	g	3,100	g	3,600	g	3,800	g	3,800	f	*3,600*	d	*2,900*	d	*1,300*	a	*460*	a	*130*	a
400	*330*	a	*1,000*	c	1,900	d	2,600	g	3,200	g	3,700	g	3,900	g	3,800	g	*3,600*	d	*2,900*	d	*1,300*	a	*450*	a	*120*	a
430	*360*	a	*1,100*	c	2,000	d	2,700	g	3,300	g	3,700	g	3,900	g	3,900	g	*3,600*	d	*2,900*	d	*1,300*	a	*440*	a	*120*	a

Bolded values indicate where the 2018 criteria are lower than the 1988 criteria magnitude within the 1988 pH range applied of 6.5-9.0.
(Italicized and underlined values are outside the pH limits of the empirical data used to generate the MLR models and should be used with caution).

Ranking of four most sensitive genera (Rank 1-Rank 4).

a Daphnia, Ceriodaphnia, Stenocypris, Nais
b Daphnia, Ceriodaphnia, Stenocypris, Micropterus
c Daphnia, Micropterus, Ceriodaphnia, Stenocypris
d Daphnia, Micropterus, Oncorhynchus, Ceriodaphnia
e Daphnia, Micropterus, Oncorhynchus, Salmo
f Micropterus, Daphnia, Oncorhynchus, Salmo
g Micropterus, Oncorhynchus, Daphnia, Salmo
h Daphnia, Micropterus, Ceriodaphnia, Oncorhynchus
i Daphnia, Ceriodaphnia, Micropterus, Stenocypris

Table K-10. Freshwater CCC at DOC of 5.0 mg/L and Various Water Hardness Levels and pHs.

Total Hardness	Chronic Criterion (CCC) (µg/L total aluminum) (DOC=5.0 mg/L)																							
	pH 5.0		pH 5.5		pH 6.0		pH 6.5		pH 7.0		pH 7.5		pH 8.0		pH 8.2		pH 8.5		pH 9.0		pH 9.5		pH 10.0		pH 10.5	
10	*6.5*	a	*31*	a	120	b	260	f	430	g	740	g	1,300	g	1,700	f	*2,200*	d	*1,800*	a	*1200*	a	*610*	a	*250*	a
25	*15*	a	*66*	a	220	e	350	g	500	g	760	g	1,300	g	1,600	g	*2,000*	e	*1,800*	a	*1,100*	a	*500*	a	*190*	a
50	*30*	a	*120*	a	320	e	430	g	550	g	780	g	1,200	g	1,500	g	*1,900*	h	*1,800*	b	*1,000*	a	*440*	a	*150*	a
75	*43*	a	*160*	a	390	f	480	g	590	i	790	j	1,200	g	1,400	g	*1,800*	g	*1,900*	b	*970*	a	*400*	a	*130*	a
100	*57*	a	*210*	a	450	h	520	g	620	j	810	j	1,100	g	1,300	g	*1,700*	g	*2,000*	c	*940*	a	*380*	a	*120*	a
150	*83*	a	*290*	b	540	g	570	g	660	j	830	j	1,100	i	1,300	g	*1,600*	g	*2,000*	c	*900*	a	*350*	a	*100*	a
200	*110*	a	*380*	b	610	g	620	g	700	j	840	j	1,100	j	1,200	g	*1,500*	g	*1,900*	e	*880*	a	*330*	a	*94*	a
250	*130*	a	*470*	b	670	g	660	i	720	j	850	j	1,100	j	1,200	g	*1,500*	g	*1,800*	e	*860*	a	*310*	a	*87*	a
300	*160*	a	*550*	c	720	g	690	j	750	j	860	j	1,100	j	1,200	i	*1,400*	g	*1,800*	e	*850*	a	*300*	a	*82*	a
350	*180*	a	*620*	c	760	g	730	j	770	j	860	j	1,000	j	1,100	j	*1,400*	g	*1,700*	e	*830*	a	*290*	a	*78*	a
400	*210*	a	*690*	c	800	g	760	j	780	j	870	j	1,000	j	1,100	j	*1,300*	g	*1,700*	e	*820*	a	*280*	a	*75*	a
430	*220*	a	*730*	c	830	g	770	j	790	j	870	j	1,000	j	1,100	j	*1,300*	g	*1,700*	e	*820*	a	*280*	a	*73*	a

(Italicized and underlined values are outside the pH limits of the empirical data used to generate the MLR models and should be used with caution).

Ranking of four most sensitive genera (Rank 1-Rank 4)

a Daphnia, Lampsilis, Ceriodaphnia, Hyalella
b Daphnia, Lampsilis, Ceriodaphnia, Salmo
c Daphnia, Lampsilis, Salmo, Ceriodaphnia
d Daphnia, Salmo, Lampsilis, Ceriodaphnia
e Salmo, Daphnia, Lampsilis, Ceriodaphnia
f Salmo, Daphnia, Lampsilis, Salvelinus
g Salmo, Salvelinus, Daphnia, Lampsilis
h Salmo, Daphnia, Salvelinus, Lampsilis
i Salmo, Salvelinus, Daphnia, Danio
j Salmo, Salvelinus, Danio, Daphnia
k Salmo, Salvelinus, Danio, Pimephales

Table K-11. Freshwater CMC at DOC of 10.0 mg/L and Various Water Total Hardness Levels and pHs.

Total Hardness	Acute Criterion (CMC) (µg/L total aluminum) (DOC=10.0 mg/L)																									
	pH 5.0		pH 5.5		pH 6.0		pH 6.5		pH 7.0		pH 7.5		pH 8.0		pH 8.2		pH 8.5		pH 9.0		pH 9.5		pH 10.0		pH 10.5	
10	*16*	a	*75*	a	280	b	**720**	d	1,300	d	2,200	d	3,300	d	3,800	d	*4,400*	d	*4,300*	b	*2,800*	a	*1,500*	a	*600*	a
25	*37*	a	*160*	a	530	d	1,100	d	1,800	e	2,700	f	3,600	e	4,000	d	*4,500*	d	*4,300*	d	*2,600*	a	*1,200*	a	*450*	a
50	*72*	a	*280*	a	830	d	1,500	d	2,300	f	3,100	g	3,900	f	4,100	e	*4,400*	d	*4,200*	d	*2,400*	a	*1,100*	a	*360*	a
75	*100*	a	*400*	a	1,100	d	1,800	d	2,600	g	3,400	g	4,100	g	4,200	f	*4,300*	d	*4,100*	d	*2,300*	a	*970*	a	*310*	a
100	*140*	a	*500*	a	1,300	d	2,000	e	2,900	g	3,600	g	4,200	g	4,300	g	*4,300*	e	*4,000*	d	*2,300*	a	*910*	a	*280*	a
150	*200*	a	*700*	a	1,700	d	2,500	e	3,300	g	3,900	g	4,300	g	4,400	g	*4,300*	e	*3,900*	d	*2,200*	a	*840*	a	*250*	a
200	*260*	a	*890*	a	2,000	d	2,800	f	3,600	g	4,100	g	4,400	g	4,500	g	*4,300*	f	*3,800*	d	*2,100*	a	*790*	a	*230*	a
250	*330*	a	*1,100*	a	2,300	d	3,100	f	3,800	g	4,200	g	4,500	g	4,500	g	*4,300*	g	*3,700*	d	*2,100*	b	*750*	a	*210*	a
300	*390*	a	*1,200*	b	2,500	d	3,400	g	4,000	g	4,300	g	4,500	g	4,500	g	*4,300*	g	*3,600*	d	*2,000*	b	*720*	a	*200*	a
350	*450*	a	*1,400*	b	2,700	d	3,600	g	4,200	g	4,400	g	4,500	g	4,500	g	*4,300*	g	*3,500*	d	*2,000*	b	*700*	a	*190*	a
400	*510*	a	*1,600*	b	3,000	d	3,900	g	4,300	g	4,500	g	4,600	g	4,500	g	*4,300*	g	*3,500*	d	*2,000*	b	*680*	a	*180*	a
430	*540*	a	*1,700*	b	3,100	d	4,000	g	4,400	g	4,500	g	4,600	g	4,500	g	*4,300*	g	*3,400*	d	*2,000*	i	*670*	a	*180*	a

Bolded values indicate where the 2018 criteria are lower than the 1988 criteria magnitude within the 1988 pH range applied of 6.5-9.0.
(Italicized and underlined values are outside the pH limits of the empirical data used to generate the MLR models and should be used with caution).

Ranking of four most sensitive genera (Rank 1-Rank 4).

a Daphnia, Ceriodaphnia, Stenocypris, Nais
b Daphnia, Ceriodaphnia, Stenocypris, Micropterus
c Daphnia, Micropterus, Ceriodaphnia, Stenocypris
d Daphnia, Micropterus, Oncorhynchus, Ceriodaphnia
e Daphnia, Micropterus, Oncorhynchus, Salmo
f Micropterus, Daphnia, Oncorhynchus, Salmo
g Micropterus, Oncorhynchus, Daphnia, Salmo
h Daphnia, Micropterus, Ceriodaphnia, Oncorhynchus
i Daphnia, Ceriodaphnia, Micropterus, Stenocypris

Table K-12. Freshwater CCC at DOC of 10.0 mg/L and Various Water Hardness Levels and pHs.

Total Hardness	Chronic Criterion (CCC) (µg/L total aluminum) (DOC=10.0 mg/L)																							
	pH 5.0		pH 5.5		pH 6.0		pH 6.5		pH 7.0		pH 7.5		pH 8.0		pH 8.2		pH 8.5		pH 9.0		pH 9.5		pH 10.0		pH 10.5	
10	*9.9*	a	*47*	a	180	b	370	g	540	g	810	g	1,300	g	1,700	g	*2,300*	g	*2,800*	b	*1,800*	a	*930*	a	*380*	a
25	*23*	a	*100*	a	340	d	490	g	610	g	830	i	1,200	g	1,500	g	*2,000*	g	*2,800*	e	*1,600*	a	*760*	a	*280*	a
50	*45*	a	*180*	a	490	e	600	g	690	j	870	j	1,200	j	1,300	g	*1,700*	g	*2,400*	e	*1,500*	a	*660*	a	*220*	a
75	*66*	a	*250*	a	610	f	670	g	740	j	890	j	1,100	j	1,300	j	*1,600*	g	*2,300*	f	*1,500*	a	*600*	a	*200*	a
100	*86*	a	*310*	a	700	f	720	g	780	j	900	j	1,100	j	1,200	j	*1,500*	g	*2,100*	h	*1,400*	a	*570*	a	*180*	a
150	*130*	a	*440*	a	850	g	800	g	830	j	910	j	1,100	j	1,200	j	*1,400*	g	*1,900*	g	*1,400*	a	*520*	a	*160*	a
200	*160*	a	*560*	a	960	g	860	i	870	j	920	j	1,100	j	1,200	j	*1,300*	i	*1,800*	g	*1,300*	b	*490*	a	*140*	a
250	*200*	a	*670*	b	1,100	g	930	j	900	j	930	j	1,100	j	1,100	j	*1,300*	j	*1,700*	g	*1,300*	b	*470*	a	*130*	a
300	*240*	a	*800*	b	1,100	g	980	j	920	j	930	j	1,000	j	1,100	j	*1,200*	j	*1,600*	g	*1,300*	b	*450*	a	*120*	a
350	*280*	a	*920*	b	1,200	g	1,000	j	950	j	950	k	1,000	j	1,100	j	*1,200*	j	*1,500*	g	*1,300*	b	*440*	a	*120*	a
400	*320*	a	*1,000*	b	1,300	g	1,100	j	960	j	970	k	1,000	j	1,100	j	*1,200*	j	*1,500*	g	*1,300*	c	*420*	a	*110*	a
430	*340*	a	*1,100*	b	1,300	g	1,100	j	970	j	970	k	1,000	j	1,100	j	*1,200*	j	*1,400*	g	*1,300*	c	*420*	a	*110*	a

(Italicized and underlined values are outside the pH limits of the empirical data used to generate the MLR models and should be used with caution).

Ranking of four most sensitive genera (Rank 1-Rank 4)

a Daphnia, Lampsilis, Ceriodaphnia, Hyalella
b Daphnia, Lampsilis, Ceriodaphnia, Salmo
c Daphnia, Lampsilis, Salmo, Ceriodaphnia
d Daphnia, Salmo, Lampsilis, Ceriodaphnia
e Salmo, Daphnia, Lampsilis, Ceriodaphnia
f Salmo, Daphnia, Lampsilis, Salvelinus
g Salmo, Salvelinus, Daphnia, Lampsilis
h Salmo, Daphnia, Salvelinus, Lampsilis
i Salmo, Salvelinus, Daphnia, Danio
j Salmo, Salvelinus, Danio, Daphnia
k Salmo, Salvelinus, Danio, Pimephales

Table K-13. Freshwater CMC at DOC of 12.0 mg/L and Various Water Total Hardness Levels and pHs.

Total Hardness	Acute Criterion (CMC) (µg/L total aluminum) (DOC=12.0 mg/L)																									
	pH 5.0		pH 5.5		pH 6.0		pH 6.5		pH 7.0		pH 7.5		pH 8.0		pH 8.2		pH 8.5		pH 9.0		pH 9.5		pH 10.0		pH 10.5	
10	*18*	a	*84*	a	310	b	800	d	1,500	d	2,300	e	3500	d	4,000	d	*4,700*	d	*4,700*	c	*3,200*	a	*1,600*	a	*670*	a
25	*42*	a	*180*	a	590	d	1,200	d	2,000	e	2,900	f	3,800	f	4,100	e	*4,700*	d	*4,600*	d	*2,900*	a	*1,400*	a	*500*	a
50	*80*	a	*320*	a	930	d	1,700	d	2,500	g	3,400	g	4,100	g	4,400	f	*4,500*	d	*4,500*	d	*2,700*	a	*1,200*	a	*400*	a
75	*120*	a	*440*	a	1,200	d	2,000	d	2,900	g	3,600	g	4,300	g	4,500	g	*4,500*	e	*4,300*	d	*2,600*	a	*1,100*	a	*350*	a
100	*150*	a	*560*	a	1,500	d	2,200	e	3,100	g	3,800	g	4,400	g	4,500	g	*4,500*	e	*4,200*	d	*2,500*	a	*1,000*	a	*320*	a
150	*220*	a	*780*	a	1,900	d	2,700	e	3,500	g	4,100	g	4,500	g	4,600	g	*4,500*	f	*4,100*	d	*2,400*	b	*930*	a	*280*	a
200	*290*	a	*990*	a	2,200	d	3,100	f	3,900	g	4,300	g	4,600	g	4,600	g	*4,500*	g	*3,900*	d	*2,400*	b	*880*	a	*250*	a
250	*360*	a	*1,200*	a	2,500	d	3,500	g	4,100	g	4,400	g	4,600	g	4,700	g	*4,500*	g	*3,800*	d	*2,300*	c	*840*	a	*240*	a
300	*430*	a	*1,400*	b	2,800	d	3,700	g	4,300	g	4,500	g	4,700	g	4,700	g	*4,500*	g	*3,700*	d	*2,300*	c	*800*	a	*220*	a
350	*500*	a	*1,600*	b	3,100	d	4,000	g	4,500	g	4,600	g	4,700	g	4,700	g	*4,500*	g	*3,600*	d	*2,200*	h	*780*	a	*210*	a
400	*560*	a	*1,800*	b	3,300	d	4,300	g	4,700	g	4,700	g	4,700	g	4,700	g	*4,400*	g	*3,500*	d	*2,200*	d	*760*	a	*200*	a
430	*600*	a	*1,900*	b	3,500	d	4,400	g	4,800	g	4,800	g	4,700	g	4,700	g	*4,400*	g	*3,500*	d	*2,200*	d	*750*	a	*200*	a

(Italicized and underlined values are outside the pH limits of the empirical data used to generate the MLR models and should be used with caution).

Ranking of four most sensitive genera (Rank 1-Rank 4).

a Daphnia, Ceriodaphnia, Stenocypris, Nais
b Daphnia, Ceriodaphnia, Stenocypris, Micropterus
c Daphnia, Micropterus, Ceriodaphnia, Stenocypris
d Daphnia, Micropterus, Oncorhynchus, Ceriodaphnia
e Daphnia, Micropterus, Oncorhynchus, Salmo
f Micropterus, Daphnia, Oncorhynchus, Salmo
g Micropterus, Oncorhynchus, Daphnia, Salmo
h Daphnia, Micropterus, Ceriodaphnia, Oncorhynchus
i Daphnia, Ceriodaphnia, Micropterus, Stenocypris

Table K-14. Freshwater CCC at DOC of 12.0 mg/L and Various Water Hardness Levels and pHs.

Total Hardness	Chronic Criterion (CCC) (µg/L total aluminum) (DOC=12.0 mg/L)																							
	pH 5.0		pH 5.5		pH 6.0		pH 6.5		pH 7.0		pH 7.5		pH 8.0		pH 8.2		pH 8.5		pH 9.0		pH 9.5		pH 10.0		pH 10.5	
10	*11*	a	*52*	a	200	b	410	g	570	g	820	g	1,300	g	1,600	g	*2,200*	g	*3,200*	c	*2,000*	a	*1,000*	a	*420*	a
25	*26*	a	*110*	a	390	d	540	g	650	g	860	j	1,200	g	1,400	g	*1,900*	g	*2,800*	e	*1,800*	a	*850*	a	*310*	a
50	*50*	a	*200*	a	560	e	650	g	730	j	890	j	1,200	j	1,300	j	*1,700*	g	*2,400*	f	*1,700*	a	*730*	a	*250*	a
75	*73*	a	*280*	a	680	f	730	g	780	j	910	j	1,100	j	1,300	j	*1,500*	g	*2,200*	g	*1,600*	a	*670*	a	*220*	a
100	*96*	a	*350*	a	790	f	780	g	820	j	920	j	1,100	j	1,200	j	*1,400*	g	*2,100*	g	*1,600*	a	*630*	a	*200*	a
150	*140*	a	*490*	a	950	g	870	g	880	j	940	j	1,100	j	1,200	j	*1,300*	j	*1,800*	g	*1,600*	b	*580*	a	*170*	a
200	*180*	a	*620*	a	1,100	g	950	i	920	j	940	j	1,100	j	1,100	j	*1,300*	j	*1,700*	g	*1,600*	b	*550*	a	*160*	a
250	*230*	a	*740*	a	1,200	g	1,000	j	950	j	950	k	1,000	j	1,100	j	*1,200*	j	*1,600*	g	*1,500*	c	*520*	a	*150*	a
300	*270*	a	*880*	b	1,300	g	1,100	j	980	j	980	k	1,000	j	1,100	j	*1,200*	j	*1,500*	g	*1,500*	c	*500*	a	*140*	a
350	*310*	a	*1,000*	b	1,400	g	1,100	j	1,000	j	990	k	1,000	j	1,100	j	*1,200*	j	*1,400*	g	*1,500*	c	*490*	a	*130*	a
400	*350*	a	*1,100*	b	1,400	g	1,200	j	1,000	j	1,000	k	1,000	k	1,000	j	*1,100*	j	*1,400*	g	*1,400*	d	*470*	a	*130*	a
430	*380*	a	*1,200*	b	1,500	g	1,200	j	1,000	j	1,000	k	1,000	k	1,000	j	*1,100*	j	*1,300*	g	*1,400*	e	*470*	a	*120*	a

(Italicized and underlined values are outside the pH limits of the empirical data used to generate the MLR models and should be used with caution).

Ranking of four most sensitive genera (Rank 1-Rank 4)

a Daphnia, Lampsilis, Ceriodaphnia, Hyalella
b Daphnia, Lampsilis, Ceriodaphnia, Salmo
c Daphnia, Lampsilis, Salmo, Ceriodaphnia
d Daphnia, Salmo, Lampsilis, Ceriodaphnia
e Salmo, Daphnia, Lampsilis, Ceriodaphnia
f Salmo, Daphnia, Lampsilis, Salvelinus
g Salmo, Salvelinus, Daphnia, Lampsilis
h Salmo, Daphnia, Salvelinus, Lampsilis
i Salmo, Salvelinus, Daphnia, Danio
j Salmo, Salvelinus, Danio, Daphnia
k Salmo, Salvelinus, Danio, Pimephales

Appendix L EPA's MLR Model Comparison of DeForest et al. (2018b) Pooled and Individual-Species Model Options

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Background

The EPA conducted a comparison of the DeForest et al. (2018b) pooled MLRs (fish and invertebrate data pooled) and individual-species MLRs (fish and invertebrates regressed separately) in order to determine which approach would be most appropriate for use in the Final 2018 Aluminum Aquatic Life AWQC. This appendix describes the EPA's analysis.

DeForest et al. (2018b) updated the individual-species MLR models to incorporate new toxicity data, with the addition of nine *Ceriodaphnia dubia* and nine *Pimephales promelas* toxicity tests under water chemistry conditions that were largely not addressed in the 2017 EPA Draft Aluminum AWQC or the DeForest et al. (2018a) publication. These toxicity tests were conducted by Oregon State University (OSU) and provided to the EPA and DeForest et al. as a courtesy in 2018. These new toxicity tests included fish and invertebrate testing under higher DOC concentration, higher hardness, and slightly higher pH conditions that were not included in the original publication and MLR database (DeForest et al. 2018a). DeForest et al. provided the MLR analyses, using both the new and older datasets in an memorandum to the EPA (DeForest et al. 2018b).

In addition to the analyses described in this appendix, the EPA subjected the DeForest et al. (2018b) memorandum to independent, external expert peer review in 2018. Several of the external peer reviewers noticed trends in the data and criteria derived using the pooled model. (See EPA's website for the Aluminum AWQC [https://www.epa.gov/wqc/aquatic-life-criteria-aluminum] for supporting documentation including the external peer review reports and EPA's responses to the external peer reviewer comments).

The conditions addressed in these new toxicity tests expanded the water quality conditions for model development (**Table L-1**). All conditions and effect concentrations for the 32 *Ceriodaphnia dubia* and 31 *Pimephales promelas* tests are presented in **Table L-2**.

Table L-1. Range of Water Quality Conditions Tested for MLR Model Development.

		Number of test	Range of Water Quality Conditions Tested		
			DOC (mg/L)	pH	Total Hardness (mg/L as $CaCO_3$)
Expanded database	*Ceriodaphnia dubia*	32	0.1-12.3	6.3-8.7	9.8-428
Former database	*Ceriodaphnia dubia*	23	0.1-4	6.3-8.1	9.8-123
Expanded database	*Pimephales promelas*	31	0.08-11.6	6.0-8.12	10.2-422
Former database	*Pimephales promelas*	22	0.08-5.0	6.0-8.0	10.2-127

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Table L-2. Database Used for MLR Model Development.

Species	Endpoint	Duration	DOC (mg/L)	pH	Total Hardness (mg/L)	EC_{20} (µg Al/L)	Lower 95% CI	Upper 95% CI	Reference	
Ceriodaphnia dubia	Reproduction	7 d	0.1	6.92	9.8	124	12	1259	CIMM 2009	
Ceriodaphnia dubia	Reproduction	7 d	0.1	7.84	9.8	379	141	1020	CIMM 2009	
Ceriodaphnia dubia	Reproduction	7 d	0.1	6.34	25	37	22	62	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	0.1	6.4	60	160	123	209	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	0.1	6.38	121	222	105	466	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	2	6.34	25	377	159	895	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	2	6.38	61	631	362	1101	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	2	6.37	121	1012	692	1479	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	4	6.33	25	623	532	729	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	4	6.3	61	693	618	777	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	4	6.38	121	841	773	914	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	0.3	7.15	50	1780			Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	0.3	7.61	51	426	249	727	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	2	6.37	25	353	268	465	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	2	6.34	25	452	401	511	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	2	6.35	25	440	357	523	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	0.5	6.34	26	260	170	310	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	0.5	6.36	122	390	170	450	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	0.5	7	26	250	150	340	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	0.5	7.1	123	860	590	1090	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	0.5	8	25	700	510	830	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	0.5	8	62	1010	740	1180	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	0.5	8.1	123	870	710	1130	Gensemer et al. 2018	
Ceriodaphnia dubia	Reproduction	7 d	1.87	6.42	64	829	437	1572	OSU 2018a	new
Ceriodaphnia dubia	Reproduction	7 d	8.71	6.33	133	3829			OSU 2018a	new
Ceriodaphnia dubia	Reproduction	7 d	12.3	6.40	138	6224	3866	10022	OSU 2018a	new
Ceriodaphnia dubia	Reproduction	7 d	1.64	6.30	428	2011	1539	2628	OSU 2018a	new
Ceriodaphnia dubia	Reproduction	7 d	6.57	7.21	125	6401	4274	9588	OSU 2018a	new
Ceriodaphnia dubia	Reproduction	7 d	12.01	7.19	127	6612			OSU 2018a	new
Ceriodaphnia dubia	Reproduction	7 d	1.3	8.17	263	3749	2904	4838	OSU 2018a	new
Ceriodaphnia dubia	Reproduction	7 d	1.2	8.21	425	2852	1647	4939	OSU 2018a	new

Species	Endpoint	Duration	DOC (mg/L)	pH	Total Hardness (mg/L)	EC_{20} (µg Al/L)	Lower 95% CI	Upper 95% CI	Reference	
Ceriodaphnia dubia	Reproduction	7 d	1.04	8.7	125	1693			OSU 2018a	new
Pimephales promelas	Mean Dry Biomass	7 d	0.3	8	48	10753	1458	79301	Parametrix 2009	
Pimephales promelas	Mean Dry Biomass	7 d	0.08	6	10.6	127	-	-	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	0.19	6.1	25.8	136	98	188	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	0.22	6	60.8	314	200	495	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	0.09	6	123.9	624	410	951	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	0.92	6.1	10.2	426	402	451	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	0.86	6.1	61	634	338	1190	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	0.88	6.1	123.7	773	559	1070	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	1.73	6.1	10.6	633	497	805	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	1.74	6	59.9	1326	1119	1571	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	1.56	6	118.2	1494	1116	1999	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	3.35	6	11.8	829	691	995	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	3.51	6	64.8	2523	1971	3230	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	3.27	6	119.6	2938	2288	3772	Gensemer et al. 2018	
Pimephales promelas	Larval Survival	33 d	0.3	6	93.9	429			Cardwell et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	0.7	6.1	25.9	660	364	1197	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	0.9	6	116	824	393	1729	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	2.9	6.1	122	2210	1640	2978	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	0.8	7.1	26.5	1534	932	2522	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	2.5	7	123	5411	3144	9313	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	0.7	8	28.8	7262	4714	11187	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	5	7.9	127	6795	3161	14607	Gensemer et al. 2018	
Pimephales promelas	Mean Dry Biomass	7 d	7	6.04	134	4618	3281	6499	OSU 2018b	new
Pimephales promelas	Mean Dry Biomass	7 d	11.5	6.04	131	9511	7291	12408	OSU 2018b	new
Pimephales promelas	Mean Dry Biomass	7 d	1.1	6.82	422	2969	2010	4386	OSU 2018b	new
Pimephales promelas	Mean Dry Biomass	7 d	7.2	7.00	135	8047	6273	10322	OSU 2018b	new
Pimephales promelas	Mean Dry Biomass	7 d	11.6	6.96	125	12542	6598	23842	OSU 2018b	new
Pimephales promelas	Mean Dry Biomass	7 d	1.1	8.06	288	5634	1768	17957	OSU 2018b	new
Pimephales promelas	Mean Dry Biomass	7 d	1.6	8.12	396	13274	6674	26401	OSU 2018b	new
Pimephales promelas	Mean Dry Biomass	7 d	0.8	6.1	49	885	574	1365	OSU 2018d	new
Pimephales promelas	Mean Dry Biomass	7 d	1.6	6	94	1817	1444	2287	OSU 2018d	new

DeForest et al. (2018b) developed a pooled MLR model that combined the two datasets, fish and invertebrate, with common slopes for the multiple linear regression test parameters. Deforest et al. (2018b) provided the EPA with a memorandum that presented four new MLR models: 1) a *C. dubia* Individual-species MLR Model; 2) *C. dubia* Pooled MLR Model (*C. dubia* and *P. promelas* data pooled, but using *C. dubia* intercept); 3) *P. promelas* Individual-species MLR Model; and 4) *P. promelas* Pooled MLR Model (*C. dubia* and *P. promelas* data pooled, but using *P. promelas* intercept).

Note: the species-specific intercepts in the pooled model account for the difference in sensitivity of the two test organisms, but slopes for each test parameter are the same. To incorporate these models into AWQC, the EPA evaluated the most appropriate approach to normalize the freshwater aluminum toxicity data by comparing model performance. The DeForest et al. reported models from their 2018 memorandum were:

Invertebrate-focused models

C. dubia Individual-species MLR Model:

$$C.dubia\ EC_{20} = e^{\left[-32.523+[0.597\times\ln(DOC)]+[2.089\times\ln(hard)]+(8.802\times pH)-(0.491\times pH^2)-[0.230\times pH:\ln(hard)]\right]}$$

C. dubia Pooled MLR Model (*C. dubia* and *P. promelas* data pooled, but using *C. dubia* intercept):

$$C.dubia\ EC_{20} = e^{[-8.555+[0.592\times\ln(DOC)]+[2.188\times\ln(hard)]+(1.998\times pH)-[0.268\times pH:\ln(hard)]]}$$

Vertebrate-focused models

P. promelas Individual-species MLR Model:

$$P.promelas\ EC_{20} = e^{[-7.371+[2.209\times\ln(DOC)]+[1.862\times\ln(hard)]+(2.041\times pH)-[0.232\times pH:\ln(hard)]-[0.261\times pH:\ln(DOC)]]}$$

P. promelas Pooled MLR Model (*C. dubia* and *P. promelas* data pooled, but using *P. promelas* intercept):

$$P.promelas\ EC_{20} = e^{[-7.550+[0.592\times\ln(DOC)]+[2.188\times\ln(hard)]+(1.998\times pH)-[0.268\times pH:\ln(hard)]]}$$

The EPA Analysis of the DeForest et al. (2018b) MLR Models

The EPA analyzed model performance to determine if it was more appropriate to normalize the freshwater toxicity data using the two individual models applied to vertebrate and invertebrates separately or to use the common pooled slope model to normalize all the data regardless of taxonomy. As DeForest et al. (2018b) suggested in the memorandum, both the pooled model and the individual models performed similarly when comparing observed versus predicted values, with predicted values within a factor of two being a benchmark to determine performance. **Figure L-1** show that 31/32 (97%) of the predicted values for the *C. dubia* tests for both MLR models were within a factor of two (DeForest et al. 2018b). The individual model for *P. promelas* had a similar level of performance with 30/31 (97%) of the tests within a factor of two, while the pooled model was only slightly less with 29/31 (94%) of the predicted values within a factor of two of the observed values (**Figure L-2**) (DeForest et al. 2018b).

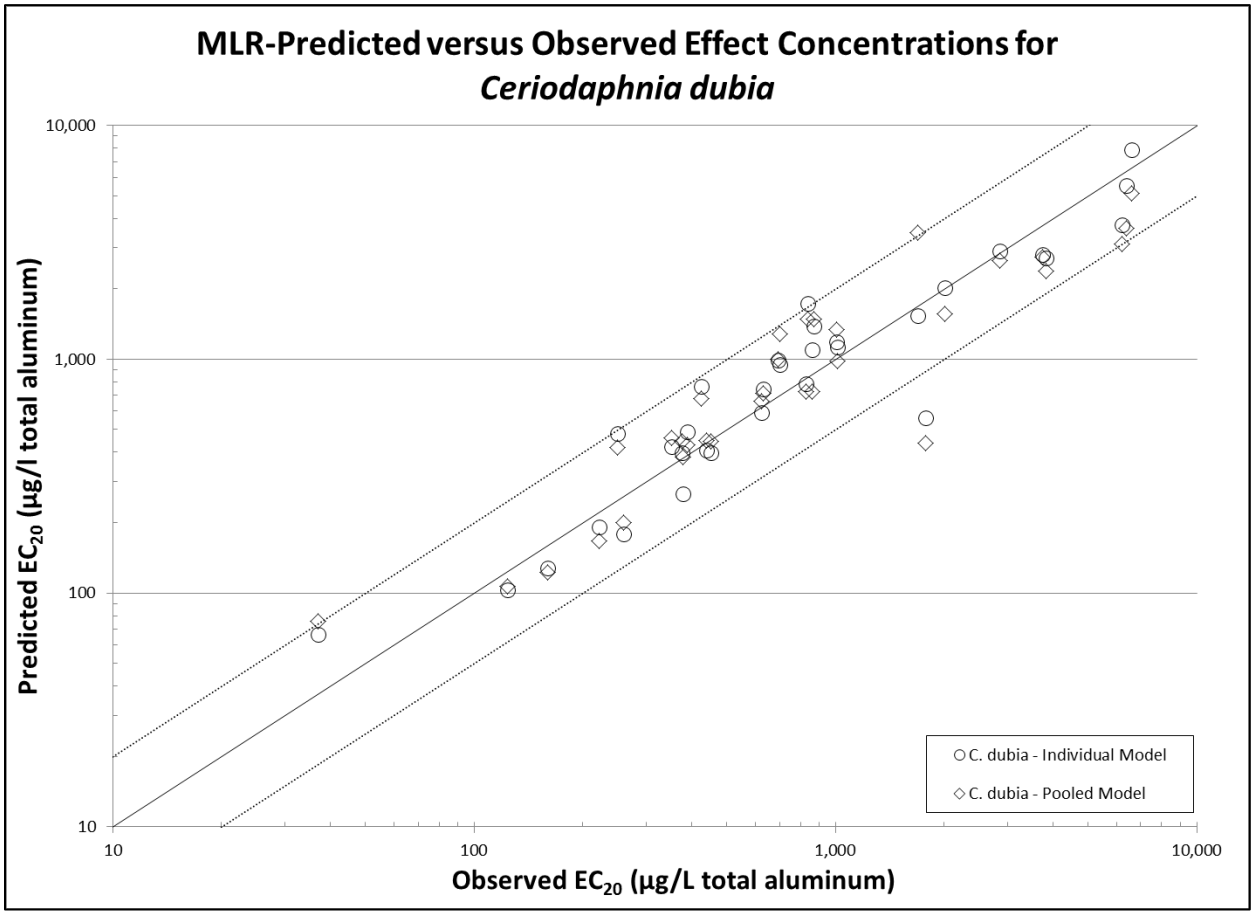


Figure L-1. Predicted versus Observed Values for the *C. dubia* MLR models.
(The solid diagonal line represents a 1:1 relationship while the dotted diagonal lines represent a factor of two).

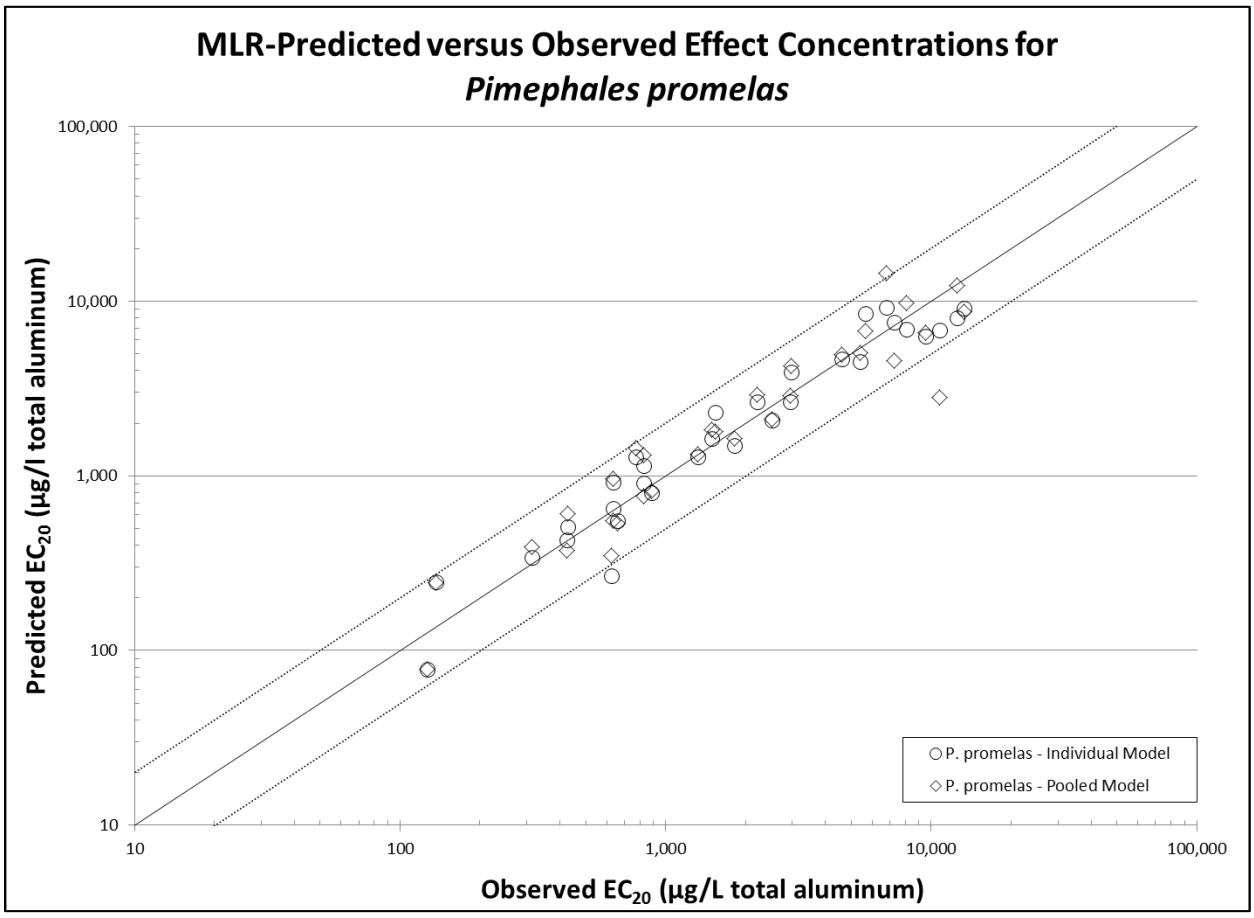


Figure L-2. Predicted versus Observed Values for the *P. promelas* MLR models.
(The solid diagonal line represents a 1:1 relationship while the dotted diagonal lines represent a factor of two).

In order to refine the analysis, the EPA looked at the residuals (observed value minus the predicted value) to determine if one model fit the data better. This analysis is similar to the approach in DeForest et al. (2018a). The residuals were plotted against each individual water quality parameter (pH, total hardness and DOC) to determine if either model generated a biased predicted value. All parameters were natural log transformed for clarity of presentation except pH.

The results of these plots revealed that the *C. dubia* pooled MLR model was over predicting test concentrations (higher predicted EC_{20}s than observed values) as pH increased, and under predicting test concentrations as DOC and total hardness increased (lower predicted EC_{20}s than observed values) (**Figure L-3**, **Figure L-4** and **Figure L-5**). Conversely, the *C. dubia* individual-species MLR model showed no trends in the residuals over any of the test parameters.

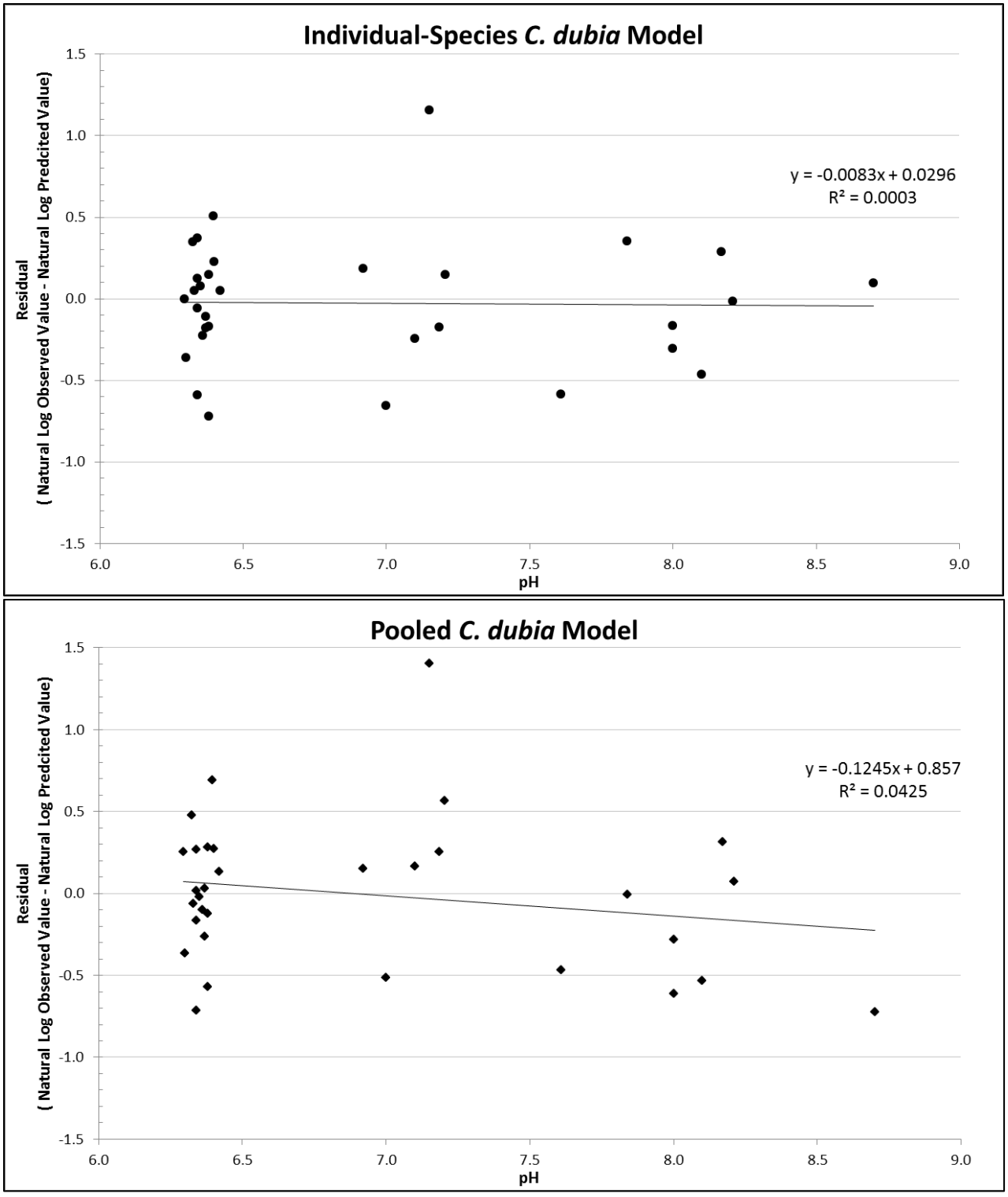


Figure L-3. Residual Plots for the *Ceriodaphnia dubia* models versus pH.

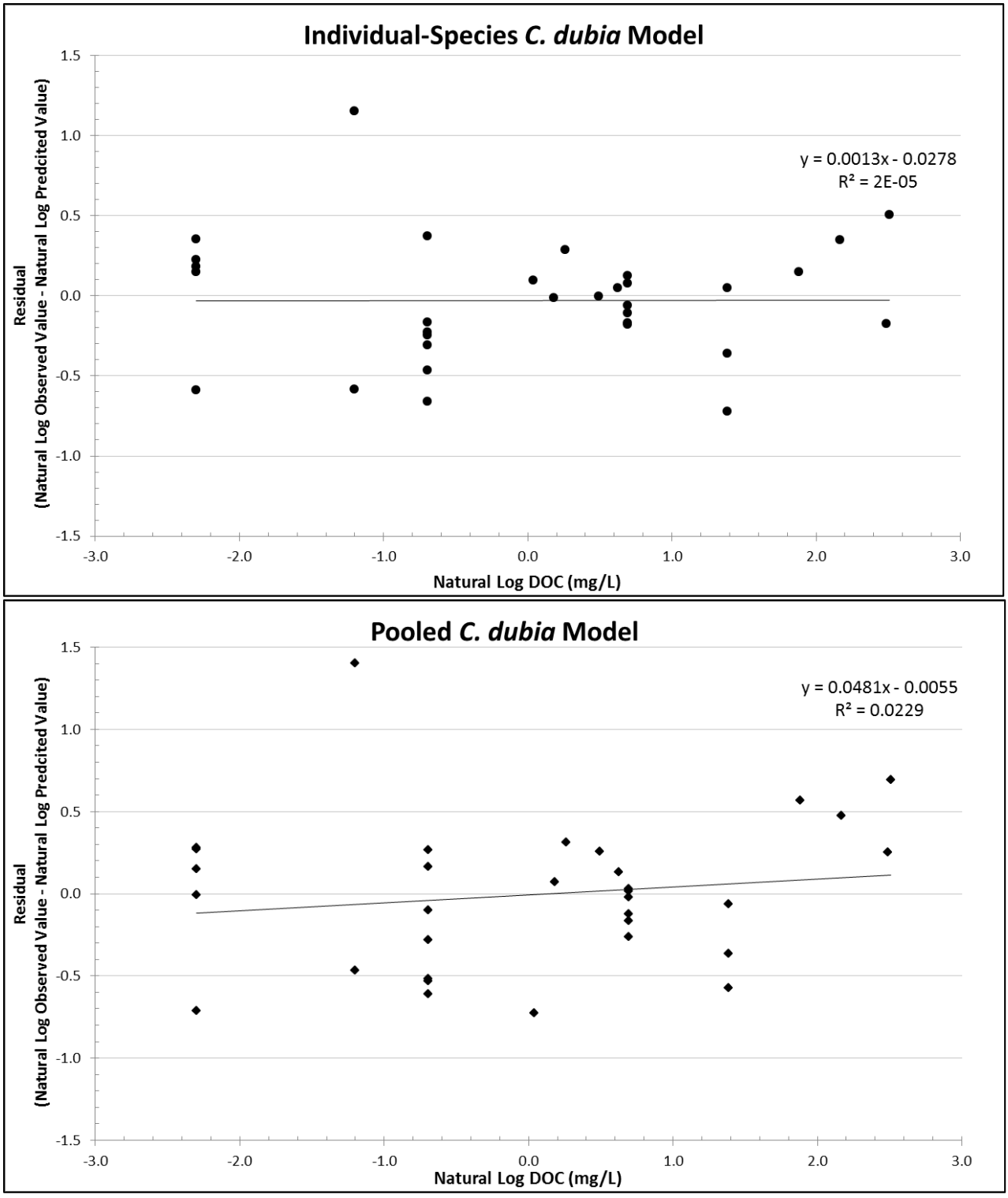


Figure L-4. Residual Plots for the *Ceriodaphnia dubia* models versus DOC

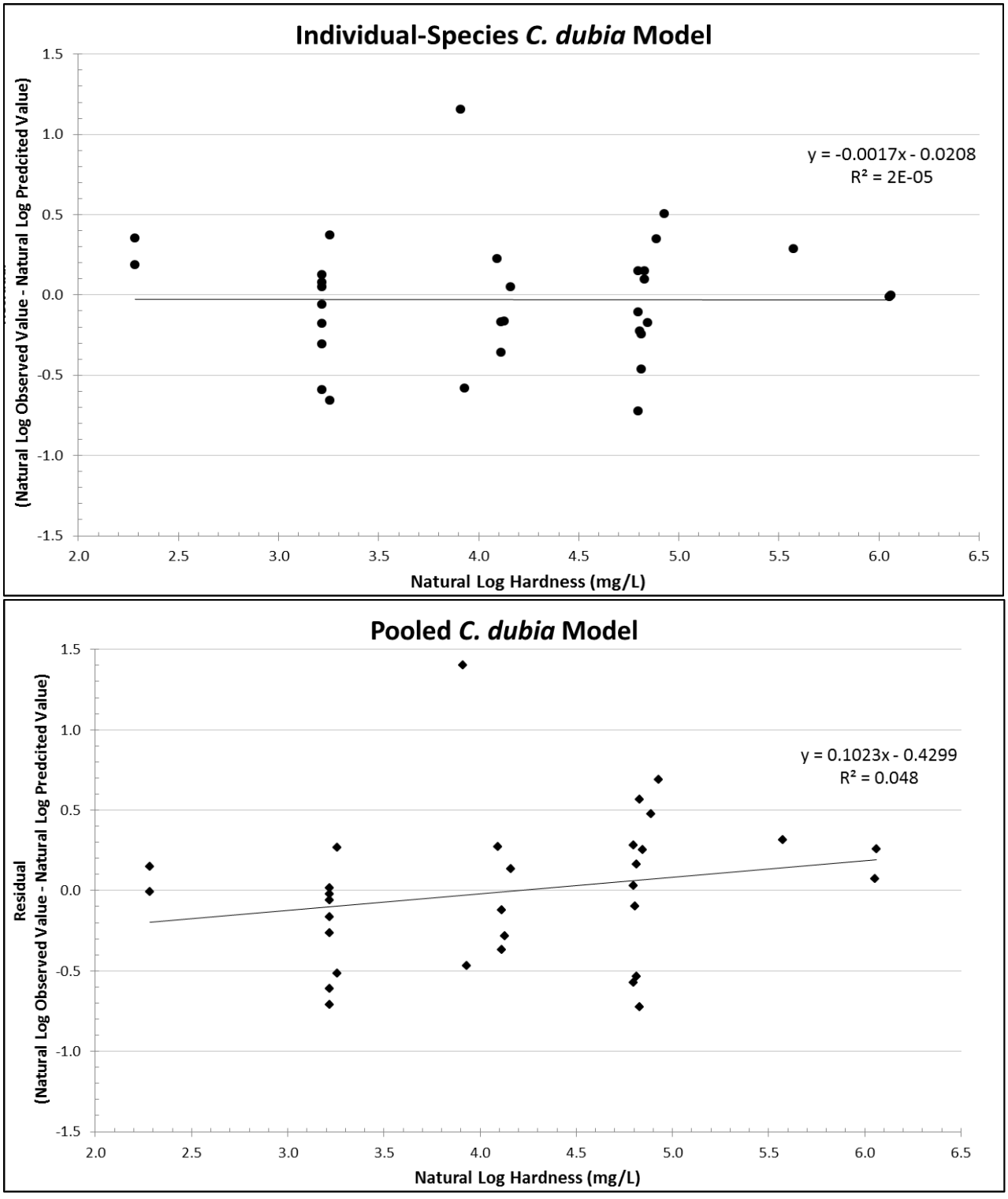


Figure L-5. Residual Plots for the *Ceriodaphnia dubia* models versus Total Hardness.

Similarly, a comparison of the residuals plots for the individual-species *P. promelas* showed no trends in the residuals over any of the test parameters (**Figure L-6**, **Figure L-7** and

Figure L-8). Likewise, there were also trends in the residuals for the pooled *P. promelas* MLR model. The predicted values were over predicting (higher predicted EC_{20}s than observed) as total hardness and DOC increased and under predicting (lower predicted EC_{20}s than observed) as pH increased.

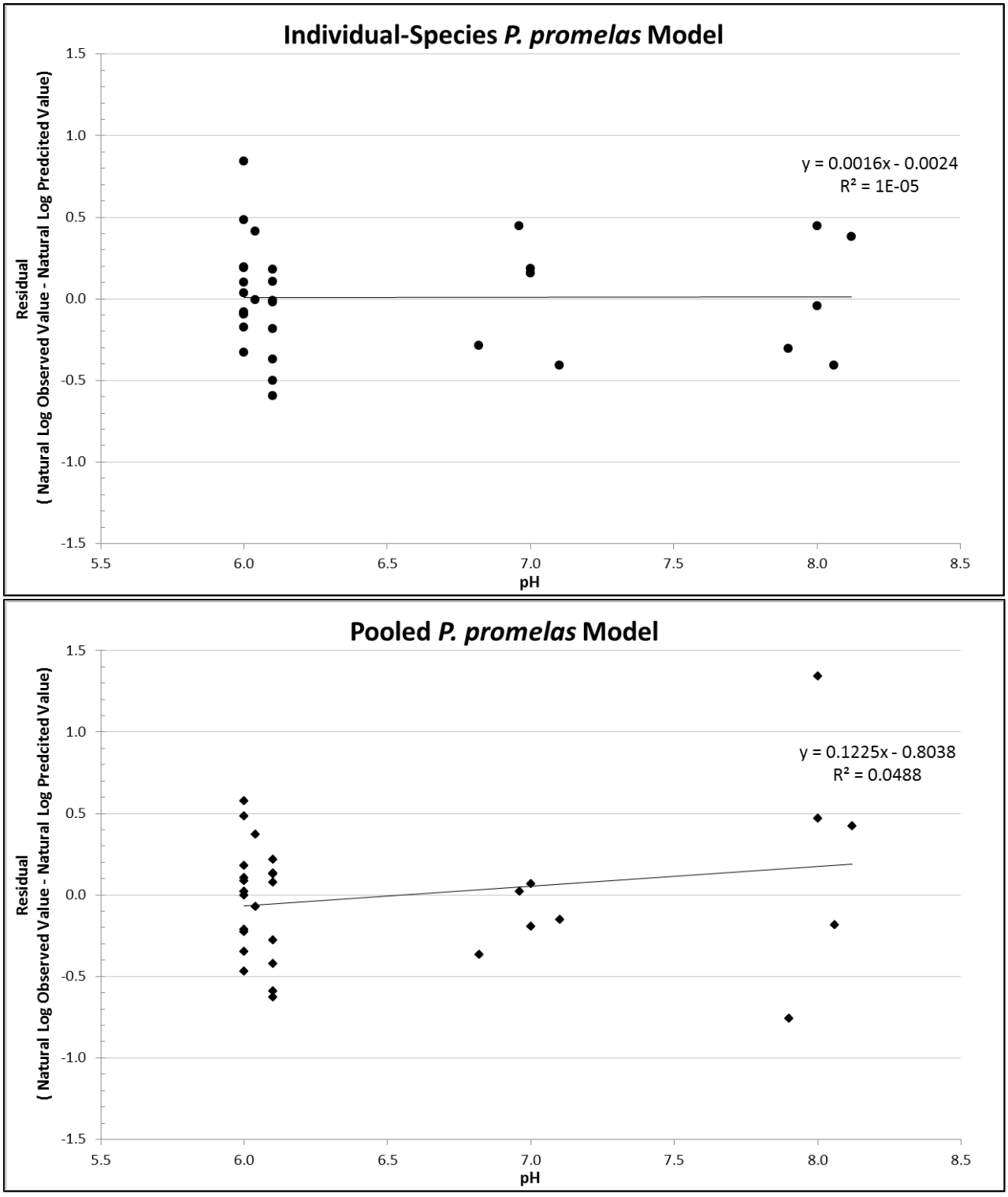


Figure L-6. Residual Plots for the *Pimephales promelas* models versus pH.

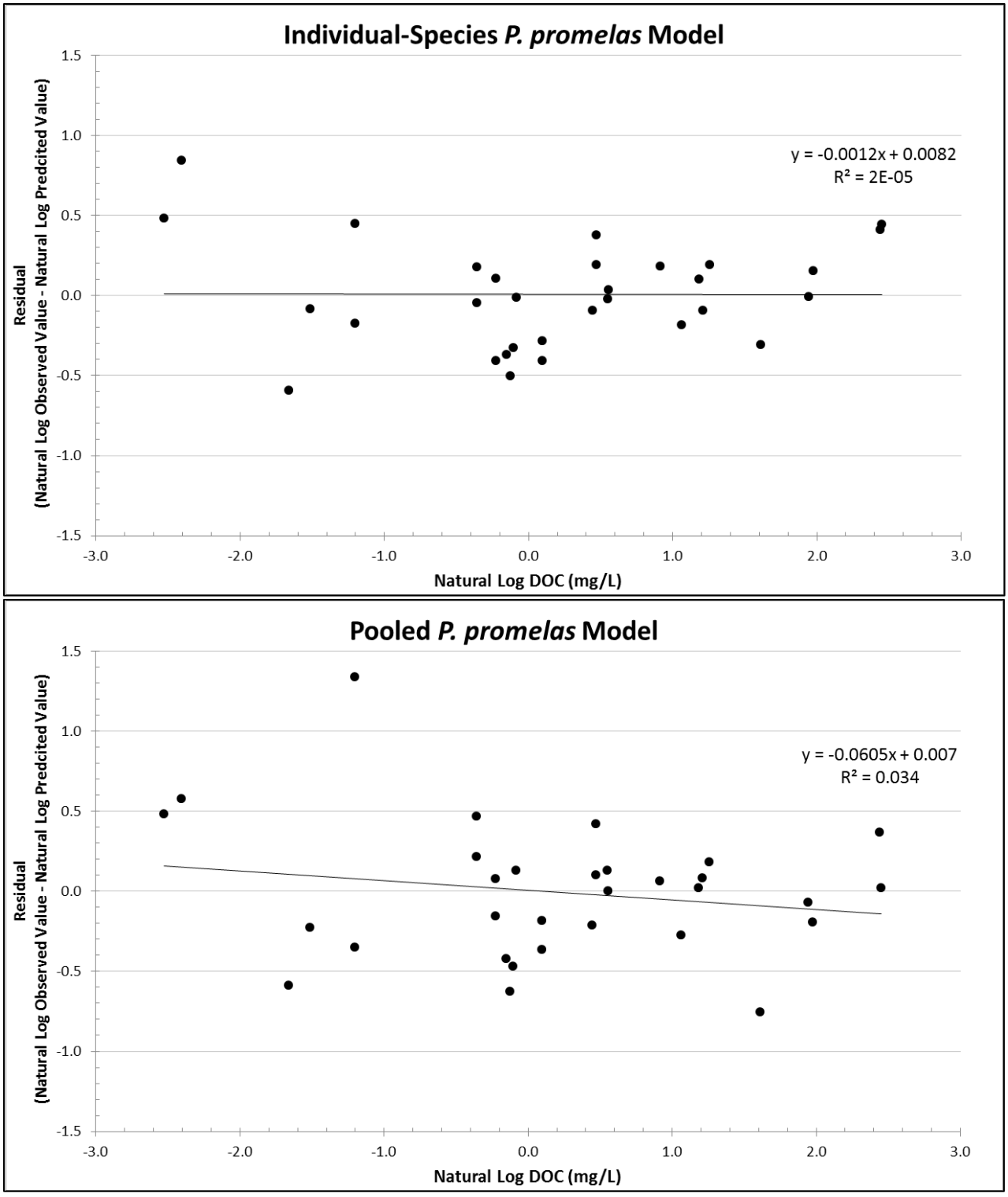


Figure L-7. Residual Plots for the *Pimephales promelas* models versus DOC.

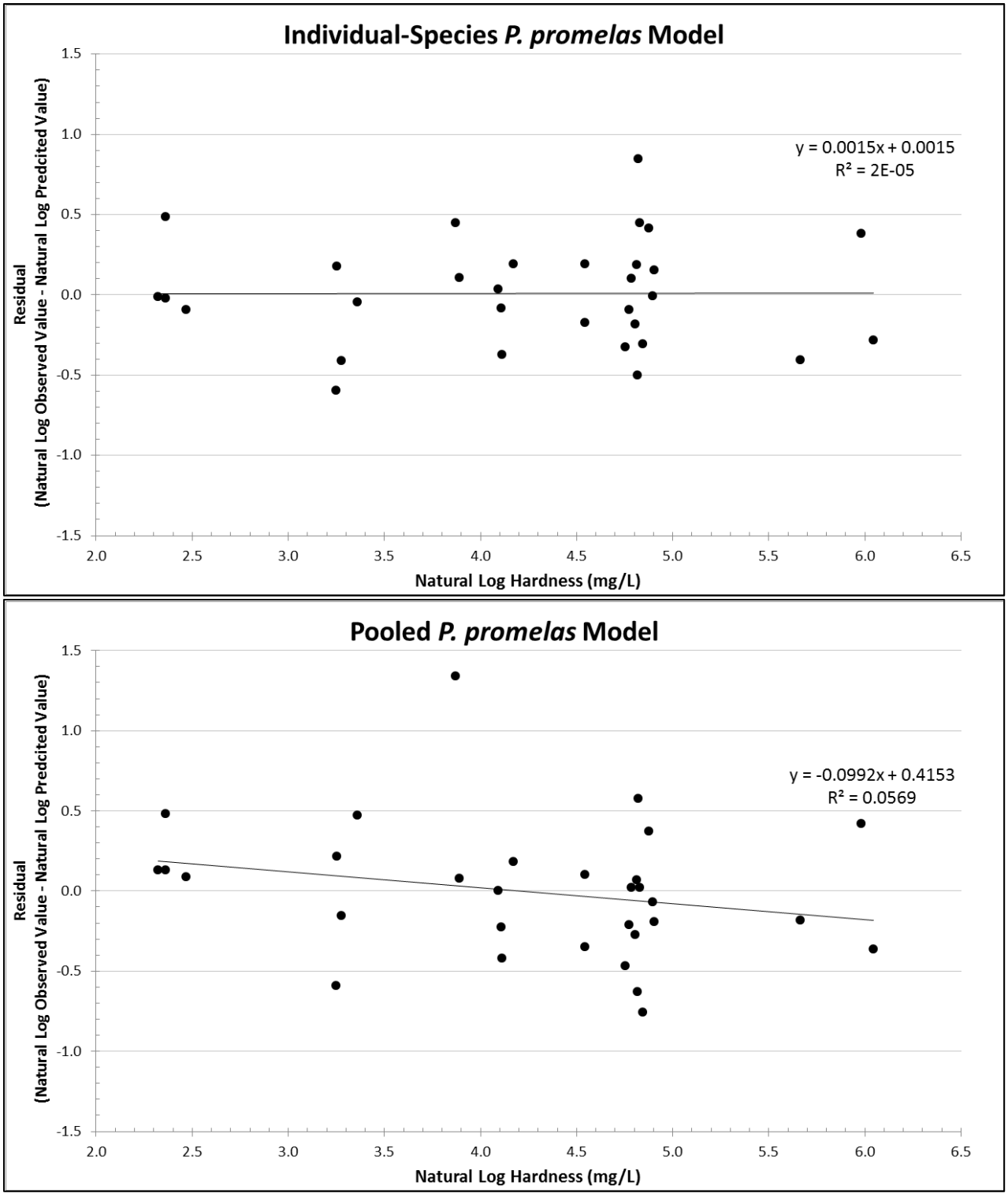


Figure L-8. Residual Plots for the *Pimephales promelas* models versus Total Hardness.

In addition to these residual trends for the pooled model, a poorer fit for the pooled model is indicated by higher standard deviations of the residuals than for the individual-species models.

For the natural logarithm transformed observed and predicted EC_{20}s, the residual standard deviation for the *C. dubia* dataset was 0.45 for the pooled model versus 0.38 for the individual-species model (18% higher). For *P. promelas*, the difference was 0.41 versus 0.32 (27% higher). The statistical significance of this poorer fit was evaluated using an F-test on the merged data across both species. The residual sum-of-squares for the pooled models (SS=11.618, df=57) was reduced 33% by applying the individual-species models (SS=7.814, df=51). For the null hypothesis of no improvement from applying the individual-species models, this translates into a F statistic of 4.14 with 6 and 51 degrees of freedom, rejecting the null hypothesis at $p<0.002$.

Based on these analyses, the EPA decided to use the updated individual-species MLR models presented in DeForest et al. (2018b) to normalize the freshwater aluminum toxicity data in developing the Final 2018 Aluminum Aquatic Life AWQC.

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Department is not proposing a change in PCBs criteria; however, the Department proposes moving the criteria to fit alphabetically within organic pollutants in Table 20.6.4.900(J)(1) NMAC.

In addition to the proposed changes to the aquatic life criteria described above, the Department proposes spelling corrections or completion of missing chemical abstract service numbers for several pollutants.

3. Numeric Criteria Not Proposed for Adoption

a. EPA's Recommended Aluminum Criteria

The Department does not propose adopting the EPA's recommended acute and chronic aquatic life criteria for aluminum as a replacement of the current hardness-based water quality standard. In 2018, EPA published updated aquatic life criteria for aluminum, based on a multiple linear regression ("MLR") model that takes into account the effects of ambient water quality on the bioavailability of aluminum to freshwater aquatic life (**EXHIBIT 42**). The MLR is based on the observed interactions of aluminum, pH, hardness, and dissolved organic carbon ("DOC") in a compilation of toxicity tests consisting of *P. promelas* and *C. dubia.* The EPA found these three parameters have the most significant influence on the toxicity of aluminum. Development of the MLR model included a range of water quality conditions to capture the variability of ambient conditions: pH (6.0-8.7), hardness (9.8 to 428 mg/L), and DOC (0.08 to 12.3 mg/L). The EPA extrapolated the model to expand its applicability but cautions against using the MLR model for conditions outside the range of empirical testing, for pH in particular. The Department has concerns regarding EPA's linear regression extension of the model for pH ranges 5.0 to 6.0 and 8.7 to 10.5. Also of concern, the EPA MLR model guidance acknowledges temperature as a factor in aluminum solubility yet does not include temperature in the MLR model or explain why it did not use temperature.

Although the aluminum MLR model represents the best available science for calculating appropriate aluminum instantaneous water quality criteria ("IWQC") for freshwater aquatic life, the Department proposes retaining the current hardness-based standard. The Department cannot implement the MLR model effectively since the Department does not have a way to determine the MLR model input value of DOC with confidence. The New Mexico Department of Health Scientific Laboratory Division ("SLD") does not currently perform DOC analysis. SLD is building capacity for DOC analysis; however, the Department is uncertain of the implementation date. The Department has considered contract labs for DOC analysis but does not have the resources required for collection at every site. Recognizing that not all states or tribes can collect all required input parameters to the MLR model, the EPA implementation guidance (**EXHIBIT 43**) suggests using either default or ecoregional values for missing site-specific parameters. However, EPA cautions that the approach may be too general for areas of complex geology. The Department considers New Mexico geologically diverse. Default or ecoregional DOC values are unlikely to capture variability across the state or at a specific location under different flow conditions. The EPA provides ecoregional DOC values in its Draft Technical Support Document: Recommended Estimates for Missing Water Quality Parameters for Application in EPA's Biotic Ligand Model (Table 18, **EXHIBIT 44**) based on DOC results from EPA's National Rivers and Streams Assessment. However, the dataset for New Mexico consists of single site visits to relatively few waterbodies. For example, the entire eight-digit Hydrologic Unit Code ("HUC") representing the Pecos Headwaters watershed (13060001) contains four data points from 2008-2014 representing two ecoregions. The dataset does not represent many other areas of the state.

The Department compared criteria calculated from the MLR model and New Mexico's current hardness-based criteria (**EXHIBIT 45**). Overall, the MLR model results are more

conservative (criteria are lower) within the range of DOC values expected for New Mexico's surface waters. At very low hardness, approximately 50 mg/L or less, both the chronic and acute hardness-based criteria are lower than those from the MLR model. The Department completed an analysis of the difference between the current hardness-based criteria and the MRL model criteria for total recoverable aluminum results collected during the 2017-2018 Upper Rio Grande watershed survey. The Department divided each total recoverable aluminum result by the IWQC calculated from the required input parameters, resulting in an exceedance ratio for each sample. The Department used a DOC concentration of 0.7 mg/L, the average of the recommended DOC concentrations for Omernik Level III ecoregions 21 and 22, for the MLR model input value. Exceedance ratios greater than one indicate a sampling result higher than the applicable IWQC. **EXHIBIT 46** graphs the difference between the MLR model exceedance ratio and the hardness-based exceedance ratio. Values greater than zero indicate the MLR model criterion is more stringent than the hardness-based criterion. These results confirm that hardness-based criteria are more stringent than those of the MLR model at lower hardness concentrations. The largest exceedance ratio differences between the hardness-based calculation and MLR model also occur at low hardness. This analysis identified 42 acute and 111 chronic exceedances using the hardness-based calculation, and 59 acute and 110 chronic exceedances using the MLR model. Overall, the hardness-based calculation resulted in more exceedances at lower hardness values and the MLR model resulted in more exceedances at higher hardness values (**EXHIBIT 47**).

The implementation of the 2018 EPA aluminum ambient water quality criteria ("AWQC") is further complicated because the guidance does not address the distinction between the bioavailable species of aluminum and those forms that are geologically based and present in natural waters as suspended sediment. The EPA acknowledges this challenge in its Final Aquatic

Life Ambient Water Quality Criteria for Aluminum 2018 guidance (**EXHIBIT 42**): "…natural water samples may also contain other species of aluminum that are not biologically available (i.e., suspended particles, clays, and aluminosilicate minerals)…This creates uncertainty because the total recoverable aluminum concentrations measured in natural waters may overestimate the potential risks of toxicity to aquatic organisms." Further, the EPA states that new analytical methods are needed, and it expects ongoing research to improve accurate measurement of toxic aluminum. For total recoverable aluminum analyses, the Department currently filters high turbidity samples with a 10-micron filter to remove terrestrial sediment. However, the infiltration of clay and some silt can still occur since these particles may pass through the filter. Adopting the MLR model may require refinement of this process to better discriminate bioavailable aluminum to prevent unnecessary, and potentially costly, impairment listings in high turbidity areas.

The Department concludes that it does not have adequate information to implement the 2018 aluminum aquatic life criteria with confidence. The Department will continue to evaluate the adoption of the revised aluminum criteria and expects to begin sampling and analysis of DOC. The Department estimates an annual cost of 8,500 Work-Time Units ("WTUs") per year for DOC, which is approximately 5% of SWQB's fixed annual budget with SLD. This extra cost reduces the amount the Department can allocate to sampling for other pollutants. Costs may also increase for NPDES permittees to account for additional monitoring.

b. EPA Section 304(a) Arsenic Criteria

The Department does not propose the adoption of the 2002 EPA recommended human health criterion for arsenic. The State documented the reasoning behind the current human health-organism only criterion of 9.0 µg/L in the Statement of Reason from the 2005 Triennial Review (**EXHIBIT 48**). The State adopted a New Mexico-specific criterion using arsenic water column

United States Environmental Protection Agency

Office of Water

EPA- 800-D-21-001

November 2021

Draft Technical Support Document:

Implementing the 2018 Recommended Aquatic Life Water Quality Criteria for Aluminum

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Notice: This question and answer (Q&A) document is intended to support states and authorized tribes wishing to adopt and implement the U.S. Environmental Protection Agency's (EPA's) recommended Clean Water Act (CWA) Section 304(a) *Final Aquatic Life Ambient Water Quality Criteria for Aluminum*. Pursuant to 40 CFR 131.11(b), when establishing numeric criteria designed to protect designated uses, states and authorized tribes should base those criteria on (i) 304(a) guidance, (ii) 304(a) guidance modified to reflect site-specific conditions, or (iii) other scientifically defensible methods. States and authorized tribes may also consider other approaches that are not described in this document.

EPA may update this Q&A document as new information becomes available. Also, although this document cites statutes and regulations that contain requirements applicable to water quality standards, it does not impose legally binding requirements on EPA, states, authorized tribes, other regulatory authorities, or the regulated community. EPA, states, authorized tribes, and other decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from those recommended in this document, as appropriate and consistent with statutory and regulatory requirements. In addition to this document, EPA has posted its Response to Comments on the 2017 Draft Aluminum Ambient Water Quality Criteria document and its responses to external peer review reports of the toxicity assessments used to model bioavailability; these documents can be found at the Agency's website for aluminum criteria: https://www.epa.gov/wqc/aquatic-life-criteria-aluminum.

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Introduction

On December 21, 2018, EPA updated its national Clean Water Act (CWA) Section 304(a) recommendations for freshwater aquatic life criteria for aluminum. The 2018 updated recommended criteria supersede EPA's previous 1988 CWA Section 304(a) aluminum criteria recommendations. The 2018 recommended criteria are water chemistry-dependent; this means that different numeric criteria values may be calculated for different waters that have different water chemistry or even at different times or locations within the same water. To calculate aluminum criteria concentration values, EPA developed the recommended Aluminum Criteria Calculator (Criteria Calculator).[1] The numeric outputs of the Criteria Calculator vary depending on the concurrent values for pH, total hardness, and dissolved organic carbon (DOC) at a given site that are entered as *inputs*. The Criteria Calculator *outputs* for a given set of inputs are the numeric values for the acute and chronic criteria that are protective of freshwater aquatic life uses for that unique set of input conditions.

States and authorized tribes have options for adopting aluminum criteria that may be used singly or in combination:

(1) Adopting by reference to the applicable sections of the CWA Section 304(a) recommended criteria document.

(2) Adopting by reference to the Criteria Calculator [V2.0].

(3) Adopting the criteria value lookup tables; or,

(4) Adopting specific ecoregional, statewide, or localized criteria values for aluminum.

This document is intended to provide additional guidance to states and authorized tribes that are interested in implementing EPA's national CWA Section 304(a) recommended aluminum criteria through a state or tribal water quality standards program.

Section 1 describes some of the flexibilities available to states and authorized tribes if they choose to adopt the recommended criteria (or a modified version of the criteria) into state or tribal water quality standards. This section also recommends additional supporting documentation states or authorized tribes should include in their regulation or implementation documents.

Section 2 responds to technical questions about the Criteria Calculator and includes recommendations on water quality sampling and laboratory analysis.

[1] EPA's CWA Section 304(a) recommended aluminum criteria are based upon multiple linear regression (MLR) models for fish and invertebrate species that use site-specific pH, total hardness, and DOC inputs to quantify the effects of these water chemistry parameters on the toxicity of aluminum to aquatic organisms. The MLR models normalize the available toxicity data to accurately reflect the effects of the site-specific water chemistry on the toxicity of aluminum to tested species. The normalized toxicity test data are then used in the recommended Criteria Calculator to generate protective acute and chronic values for specific ambient water chemistry conditions using EPA's *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and their Uses*. The Criteria Calculator V2.0 is available in Microsoft Excel and in R on EPA's webpage for the Aquatic Life Criteria for Aluminum in Freshwater: https://www.epa.gov/wqc/aquatic-life-criteria-aluminum#2018.

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Section 3 provides information to help develop protective criteria values for sites, considering the spatial and temporal variability of input parameters.

Section 4 provides recommendations for when there are insufficient data for pH, total hardness or DOC.

Section 5 provides information for implementing the recommended criteria through National Pollutant Discharge Elimination System (NPDES) permits.

Section 6 provides information for waterbody assessors who will be implementing the recommended criteria in assessing ambient waters, in determining whether to list waters as not attaining their water quality standards, and in developing Total Maximum Daily Loads (TMDLs) for those listed waters.

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Section 1: Adopting the 2018 Recommended Aquatic Life Water Quality Criteria for Aluminum into State or Tribal Water Quality Standards

1.1. What are EPA's recommended criteria for aluminum?

EPA's recommended freshwater aquatic life criteria for aluminum[2] recognize that the bioavailability[3] (and thus toxicity) of aluminum is dependent on water chemistry. Therefore, the recommended criteria provide the means for states and authorized tribes to develop numeric criteria values at a given site, based on local water chemistry. Specifically, the recommended criteria incorporate a statistical technique, known as multiple linear regression (MLR), to model the relationship between pH, total hardness, and DOC measurements and the toxicity of aluminum based on extensive toxicity testing under different water chemistry conditions.[4] To generate numeric criteria values for a specific set of water-chemistry conditions, users input concurrent data for pH, total hardness, and DOC at a given site into the Criteria Calculator[5] or use lookup tables that provide the same information for those conditions.

Ambient water quality criteria recommendations developed under CWA Section 304(a) are typically expressed in two forms: 1) as *acute criteria* to protect against mortality that occurs due to a short-term exposure to a chemical, and 2) as *chronic criteria* to protect against longer term effects on survival, growth and reproduction that may occur due to a longer-term exposure to a chemical. Both the acute and chronic criteria have three components: concentration (*magnitude*) that is averaged over a given time period (*duration*) that should not be exceeded more than "X" times during a specified time period (*frequency*).

- The *magnitude* component of the recommended aluminum CWA Section 304(a) criteria corresponds to the concentration of aluminum that is protective of the aquatic life designated use under specific conditions of pH, total hardness, and DOC.
- The *duration* term accounts for the limit on exposure timeframe that will protect against adverse effects to aquatic life. Duration is expressed as the time over which a chemical concentration is measured and averaged; that is, as a one-hour average for acute exposures, and a four-day average for chronic exposures for aluminum.

---

[2] Final Aquatic Life Ambient Water Quality Criteria for Aluminum 2018, EPA-822-R-18-001, December 2018, https://www.epa.gov/wqc/2018-final-aquatic-life-criteria-aluminum-freshwater.

[3] Not all forms of aluminum that may be present in ambient waters are biologically available or "bioavailable" to aquatic species. Bioavailable aluminum is the toxicologically relevant fraction(s) of aluminum. Large suspended particles, clays, and aluminosilicate minerals are not generally bioavailable.

[4] Two MLR models, one for invertebrates and one for vertebrates, were used to normalize freshwater aluminum toxicity values. These separate models correspond to effects on invertebrates and vertebrates due to differing effects of pH, total hardness, and DOC on aluminum bioavailability and toxicity, and therefore enable criteria magnitude values to be calculated as a function of the unique chemistry conditions at a given site, at the time at which pH, total hardness, and DOC were measured. Toxicity data show that aluminum toxicity is affected by the concentrations of – and interactions among – these parameters, and EPA's CWA Section 304(a) recommended criteria characterize these relationships.

[5] The Criteria Calculator V2.0 is available in Microsoft Excel and in R Code and Data V.2 on EPA webpage for the Recommended Aquatic Life Criteria for Aluminum in Freshwater: https://www.epa.gov/wqc/aquatic-life-criteria-aluminum#2018.

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- The *frequency* term defines the maximum allowable number of exceedances of the magnitude and duration combination to ensure protection of aquatic life—once in three years on average for aluminum—consistent with recommendations of the 1985 Guidelines.[6]

Input parameters from ambient water samples will yield outputs that represent the recommended magnitude for acute and chronic criteria concentrations of aluminum that would be protective of aquatic life under those specific ambient water quality conditions (i.e., the desired conditions to protect the aquatic life designated use).

If a state or authorized tribe adopts the recommended criteria into its water quality standards, they would also need to adopt the recommendations for the frequency and durations into their standards, as well. In other words, the acute criterion should be expressed as a one-hour average total recoverable[7] aluminum concentration (in µg/L) and the chronic criterion should be expressed as a four-day average total recoverable aluminum concentration (in µg/L). Additionally, the acute and chronic criteria should be expressed as not to be exceeded more than once every three years to ensure protection of aquatic life.

1.2. What flexibility does a state or authorized tribe have when adopting EPA's recommended aluminum criteria into its state or tribal water quality standards, and what are the advantages and potential challenges of each approach?

The regulation at 40 CFR 131.11(a)(1) specifies that states must adopt water quality criteria that are based on sound scientific rationale and protect the designated use. There are several approaches a state or authorized tribe may take to meet this requirement as it relates to EPA's CWA Section 304(a) recommended aluminum criteria.

Under the regulation at 40 CFR 131.11(b)(1), in adopting water quality criteria, states and authorized tribes should adopt water quality criteria based on: EPA's recommended criteria; modifying the Agency's recommended criteria to reflect site-specific conditions, or other scientifically defensible methods.

The Criteria Calculator in EPA's CWA Section 304(a) recommended aluminum criteria to protect aquatic life in freshwater ecosystems generates criteria values that are dependent on the water chemistry at the site. EPA's CWA Section 304(a) criteria for aluminum are recommendations, and not requirements. As discussed below, there are a number of approaches states and authorized tribes may take in adopting these recommended criteria. States and authorized tribes should consider the advantages and potential challenges of each approach, as well as other approaches that may not be described in this document.

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[6] EPA. Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses, PB85-227049, 1985. https://www.epa.gov/sites/production/files/2016-02/documents/guidelines-water-quality-criteria.pdf.

[7] As discussed further in Question 2.4, states and authorized tribes may choose to incorporate an analytical method (a variation in the sample preparation procedure) that measures bioavailable aluminum in ambient samples into its implementation efforts; if it chooses to do so, the state or authorized tribe should consider providing a reference to the modified method procedure in its water quality standards or other legally binding documents.

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When states and authorized tribes choose to adopt both the water chemistry-dependent criteria and an associated derivation methodology; this concept – combining criteria with associated derivation methodology – is referred to as a "performance-based approach." EPA first formalized the concept of a performance-based approach for water quality standards in the preamble of the rule *EPA Review and Approval of State and Tribal Water Quality Standards.*[8] With a performance-based approach, the state or authorized tribe can adopt a process, such as a criteria derivation methodology, rather than a specific outcome, such as a concentration of a pollutant. If a state or authorized tribe adopts a process or methodology that is sufficiently detailed and has suitable safeguards that ensure predictable, repeatable outcomes, EPA can approve that process under CWA Section 303(c), and this initial approval would also serve as the approval of each outcome generated from following that process or method.

If a state or authorized tribe chooses to adopt EPA's recommended aluminum criteria, unchanged, into its water quality standards, EPA recommends choosing one, or a combination,[9] of the following approaches (see Table 1, below):

(5) Adopting by reference to the applicable sections of the CWA Section 304(a) recommended criteria document.

(6) Adopting by reference to the Criteria Calculator [V2.0].

(7) Adopting the criteria value lookup tables[10]; or,

(8) Adopting specific ecoregional, statewide, or localized criteria values for aluminum.

Table 1: Comparison of approaches to adopting the recommended aluminum criteria

Approach to adopting the recommended criteria	**Potential Advantages**	**Potential Challenges**
(1) adopting reference to the CWA Section 304(a) criteria document (which includes the Criteria Calculator and criteria value lookup tables).	This approach may provide the greatest amount of background information and context for the criteria. This approach may also provide the greatest flexibility to states and authorized tribes because it allows multiple ways to calculate criteria values. Statewide adoption of the entire recommended criteria	This approach may be difficult to implement due to individual states' or authorized tribes' legal and administrative requirements (e.g., whether a state's or authorized tribe's regulations allow them to adopt or incorporate by reference). Without additional clarity about aquatic life

[8] *EPA Review and Approval of State and Tribal Water Quality Standards* 65 Fed. Reg. 24641 (Apr. 27, 2000)

[9] For example, approaches (2) and (3) can be adopted together (the Criteria Calculator can be used to derive numeric criteria values (*outputs*) when input parameters (i.e., pH, total hardness, or DOC measures or estimates) are not displayed in the lookup tables). Also, ecoregional criteria default values may be adopted in addition to any of the first three listed approaches. When adopting a combination of approaches, the state or authorized tribe should specify the conditions under which each method would be applied.

[10] If the state or authorized tribe chooses to adopt lookup tables into their water quality standards, they should include information on rounding data when input parameter values for pH, total hardness, or DOC fall between values listed in the lookup tables. Lookup tables are published in Section 4.1, Appendix K of the CWA Section 304(a) criteria document.

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Approach to adopting the recommended criteria	Potential Advantages	Potential Challenges
	document also provides transparency and regulatory certainty to the public and the regulated community and helps to expedite EPA's review of state or tribal water quality standards, as well as a single consultation on the Endangered Species Act.	protection through implementation, this approach may not provide sufficient regulatory certainty.
(2) adopting the Criteria Calculator [V2.0] (or similar method to calculate outputs based on the underlying MLR models).	This is likely the most adaptable and concise approach.	The Criteria Calculator requires users to input data to generate criteria values and therefore would require some data to exist in order to run. Future versions of the Criteria Calculator may require the state or authorized tribe to update their standards to incorporate the revised Criteria Calculator by reference. States and authorized tribes may choose to incorporate regulatory language to accommodate future software updates where the underlying models and toxicity data are the same.
(3) adopting the criteria value lookup tables.	This may be more transparent than adopting only the Criteria Calculator because the lookup tables do not require access to a computer. The lookup tables also display the full range of possible values that could be generated by the Criteria Calculator and therefore might be more transparent and familiar to some users than simply adopting the Criteria Calculator. The tables are included in Appendix K of the recommended criteria document and may be helpful when communicating to the public about the criteria implemented at a given site.	The state or authorized tribe may need to develop a standard procedure to determine which values for pH, total hardness or DOC to use if measured values are *between* the range of input parameter values provided in the lookup table. For example, a state or authorized tribe may decide to always round to the nearest value in the table for each input parameter or may decide to use the value which would yield the most protective criteria. States and authorized tribes may choose to combine this approach with the Criteria Calculator to address this issue of interpolation.
(4) adopting specific ecoregional[11] or	This would allow states and authorized tribes to apply consistent criteria	This approach may be too general for areas with complex geology. That is, use

[11] For more information on how ecoregions are defined, see https://www.epa.gov/eco-research/ecoregions.

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Approach to adopting the recommended criteria	Potential Advantages	Potential Challenges
statewide criteria values.	throughout an ecoregion or state. This approach does not require a state to identify site-specific input parameters because the criteria values are the same for all sites within the ecoregion (or state), calculated based on representative water quality parameters for each ecoregion or state. Alternatively, a state or authorized tribe may choose to adopt such criteria as defaults for use in the absence of ambient data. Default criteria may also help to increase transparency of criteria for the public if they are adequately explained. This approach may be used in combination with the Criteria Calculator or lookup tables.	of specific ecoregional or statewide criteria values does not allow for the use of water chemistry data at individual sites for input parameters.

After adopting the aluminum criteria and obtaining EPA's approval, the state or authorized tribe may derive acute and chronic criteria values (i.e., criteria magnitude values) that correspond to a surface water or an entire geographic area with similar conditions for pH, total hardness, and DOC. EPA recommends that states and authorized tribes adopt criteria that will protect aquatic life over the full range of conditions, including when aluminum is most toxic, throughout the year (i.e., account for the variability of pH, total hardness, and DOC over time). Section 3 on characterizing spatial and temporal variability of input parameters provides more information about how to derive criteria values that will protect aquatic life throughout the temporal and spatial range of water chemistry conditions at a site, including those conditions when aluminum is most bioavailable (hence, most toxic to aquatic life). Bioavailable aluminum is the toxicologically relevant fraction(s) of aluminum, rather than dissolved aluminum generally. For more discussion on the relevant fractions of aluminum and appropriate analytical methods to measure them, see Question 2.4.

To promote transparent and repeatable outcomes, EPA recommends that states and authorized tribes consider making publicly available the input parameters, along with the calculations and the resulting values for aluminum criteria. A map showing the extent of the site to which the criteria values apply would also be helpful to communicate those criteria values to the public and to the regulated community. States and authorized tribes may also choose to include detailed methods, for example, in an appendix to their water quality standards or in a Continuing Planning Process document, as described in 40 CFR 130.5(b)(6). This provision of the CFR implements CWA Section 303(e) and requires that states

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and authorized tribes include, among other things, a process for establishing and assuring implementation for new or revised water quality standards, in continuing planning processes.

In summary, EPA's updated aluminum criteria provide users the flexibility to develop numeric criteria values based on site-specific water chemistry or use default values where water chemistry data are not available. Numeric criteria values can be generated using the Criteria Calculator or by using the lookup tables provided in the appendix. If the criteria were adopted as a statewide methodology, the numeric values at a site could be based on site-specific water chemistry.

1.3. If a state or authorized tribe adopts a methodology, what additional information should be included in their regulation or implementation documents to support such an approach?

When EPA approves a water quality standard in the form of both the water chemistry-dependent criteria and an associated derivation methodology, the state or authorized tribe may use the methodology to derive criteria values that are used for other CWA implementation purposes, without additional EPA review under CWA Section 303(c).[12]

To successfully establish such an approach to deriving aluminum criteria, the state or authorized tribe should demonstrate to EPA that it has a legally binding process or derivation methodology for using the Criteria Calculator (or lookup tables) with enough detail to ensure repeatable, predictable, and protective outcomes. The state or authorized tribe may describe the process in rule, or in a separate implementation document that is incorporated by reference into its water quality standards regulation, and would be legally binding to the extent allowed by state or tribal law. EPA recommends that states and authorized tribes include as part of this process the following, at a minimum, in water quality standards or other legally binding documents:

- A reference to applicable sections of the CWA Section 304(a) recommended criteria document (which includes the Criteria Calculator and criteria value lookup tables) and the Criteria Calculator version to be used;
- A statement of the duration and frequency applicable to the output;
- A statement of, or reference to, data and sampling requirements for Criteria Calculator inputs (i.e., pH, total hardness, and DOC);
- Where appropriate, methods for implementing criteria where sufficient data to run the Criteria Calculator are not available (e.g., default values);
- Where appropriate, information identifying seasons if seasonal criteria are to be used;
- A description of how data inputs will be incorporated into the Criteria Calculator;
- A description of representative sampling methods, how any continuous data will be used, and what standard procedures will be followed if one of the input parameters could not be collected; and

[12] *EPA Review and Approval of State and Tribal Water Quality Standards* 65 Fed. Reg. 24641 (Apr. 27, 2000)

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- A description of how criteria will be generated from a distribution of Criteria Calculator output values for sites with varying conditions of pH, total hardness, and DOC over time.

EPA encourages states and authorized tribes to supplement the legally binding provisions with additional detail in implementation documents or guidance. For example, states and authorized tribes should consider whether to include additional information about sampling or quality assurance plans defining the spatial extent to which Criteria Calculator-derived criteria values would apply, what the state or authorized tribe considers to be "sufficient" ambient water chemistry data to run the Criteria Calculator, and how output values from the Criteria Calculator may be interpreted. Providing additional guidance will increase transparency and facilitate implementation.

1.4. If the recommended aluminum criteria are adopted in the form of the Criteria Calculator, how will the public and entities implementing the criteria know what numeric values represent the site-specific criteria for a given waterbody at a given time?

Where the Criteria Calculator is adopted as the criteria, states and authorized tribes establish criteria magnitude values to be used for CWA implementation purposes on a site-specific basis. In this scenario, the states and authorized tribes would not adopt static or fixed statewide criteria magnitude values into regulation, but instead would calculate those values using the Criteria Calculator as data are collected.

In this scenario, because the criteria magnitude values are calculated from data collected at a particular moment in time, EPA recommends that states and authorized tribes provide publicly available information about each calculated value, along with the spatial extent (i.e., waterbody segment) to which it applies.[13] Making information available to the public, the regulated community, and other stakeholders is important to ensuring regulatory certainty and clarity, particularly when a state or authorized tribe adopts an accompanying derivation methodology (see Question 1.2 for more information on these approaches). A state or authorized tribe may wish to describe how it derived the criteria values, including the data and data source(s) used. Such information may include (but not be limited to) the following:

- The location(s) from which samples were drawn to determine inputs to the Criteria Calculator or lookup tables;
- The timeframe over which samples were drawn, including the number of samples drawn over that timeframe to account for seasonal or other forms of variability;
- Whether the state or authorized tribe relied on site-specific input data, estimated data, or a combination, when developing the site-specific numeric criteria values (or outputs); and
- The date when the criteria values were developed.

[13] When developing criteria for any given site, consideration should be given to what area is defined as the site. See Section 3 for more information on 'site' definition and characterization.

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Additionally, a permitting authority may wish to describe in the permit factsheet or statement of basis how it used the numeric criteria values to determine if there was reasonable potential and if there was reasonable potential how it used the criteria to derive water quality-based effluent limits (WQBELs). Likewise, for TMDL programs, states and authorized tribes may wish to describe how they derived the criteria values and used them to determine TMDL targets. States and authorized tribes may also wish to describe how they generated criteria magnitude values for the aluminum criteria used in assessment and listing methodologies and integrated reports for each assessed waterbody.

1.5. How does the adoption of the new aluminum criteria affect site-specific criteria developed using previous guidance?

Adopting the 2018 recommended criteria does not automatically invalidate existing aluminum criteria. However, EPA's 2018 recommended criteria for protecting aquatic life from the toxic effects of aluminum in freshwater systems represents the most current science. Historically, water effect ratios (WERs) have been used to adjust criteria values where ambient water chemistry was suspected to alter the bioavailability (hence, toxicity) of a metal. However, the MLR-based construct of the 2018 recommended criteria is superior to previously recommended criteria, by better reflecting aluminum toxicity based on water chemistry conditions at a particular site. Therefore, where the new recommended aluminum criteria are adopted, using WERs would be unnecessary. EPA recommends that states and authorized tribes replace any previous aluminum aquatic life criteria (whether statewide or site-specific) with statewide or site-specific criteria developed through the use of the Criteria Calculator, the look up tables, or the ecoregional default values in the 2018 CWA Section 304(a) recommended aluminum criteria.

Criteria already approved by EPA under CWA Section 303(c)—including criteria developed using previous guidance and methods—remain effective for CWA purposes until EPA approves a change to those water quality criteria, or until EPA establishes more stringent water quality criteria. States and authorized tribes are required by 40 CFR 131.20(a) to review their water quality standards every three years. As part of this triennial review, states and authorized tribes must update any criteria for which EPA has published a new or updated CWA 304(a) recommendation or must provide an explanation if they decline to update such criteria.[14]

1.6. Can a state retain an older version of the state's aluminum criteria while also adopting the new CWA Section 304(a) recommended criteria?

EPA recommends that states and authorized tribes have only one set of acute and chronic aluminum criteria applicable to each waterbody. This way, it is clear to the public what the criteria are and what

[14] 40 CFR 131.20(a) requires that "if a State does not adopt new or revised criteria for parameters for which EPA has published new or updated CWA Section 304(a) criteria recommendations, then the State shall provide an explanation when it submits the results of its triennial review to the Regional Administrator consistent with CWA Section 303(c)(1) and the requirements of paragraph (c) of this section."

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criteria will be implemented for all aspects of the CWA programs, including NPDES permitting, CWA Section 303(d) listing, and TMDLs.

A state or authorized tribe, however, may elect to retain its older aluminum criteria statewide while it collects data and adopts new aluminum criteria on a site-specific basis. If a state or authorized tribe chooses this approach, then EPA recommends, in order to provide more clarity to the public, that the state or authorized tribe specify (either in rule or in accompanying implementation procedures) how it will select which set of criteria to be applied to specific waterbodies. Because EPA's national CWA Section 304(a) recommended aluminum criteria represent the most current science regarding aluminum toxicity, EPA recommends that states or authorized tribes apply the new aluminum criteria wherever there are sufficient data to do so. Where states or authorized tribes choose to provide for a transition period to the new criteria, EPA recommends they provide clear information on the length of that period.

1.7. Can states/authorized tribes develop their own regionally informed calculators, or modify the Criteria Calculator to reflect regionally important species or situations, rather than using the CWA Section 304(a) recommended criteria as is?

A state or authorized tribe may develop its own regionally informed calculator or may modify the Criteria Calculator to reflect regional conditions. The water quality standards regulation at 40 CFR 131.11(b)(1)(ii) provides states and authorized tribes with the opportunity to adopt water quality criteria that are "modified to reflect site-specific conditions." As with any criteria, site-specific criteria must protect the designated use, must be based on a sound scientific rationale, and must be approved by EPA. 40 CFR 131.11(a)(1).

One process that can be used to modify criteria to reflect site-specific conditions is the species deletion process (also known as the recalculation procedure).[15] The species deletion process is a process used to modify but retain the taxonomic composition of the toxicity dataset to better match the species assemblage that is known or expected to occur at a particular site, and is not simply removing non-resident species from the Criteria Calculator. This process creates a site-specific toxicity dataset (and corresponding site-specific species sensitivity distribution) that is appropriate for deriving site-specific aquatic life criteria. The species deletion process does this by correcting, adding, or deleting test results based on the resident species of the site. This process is intended to provide flexibility to states and authorized tribes to derive site-specific criteria that best reflect the expected resident species at a site. The species deletion process may result in site-specific criteria that differ from national criteria recommendations when there are demonstrated differences in sensitivity between the expected resident aquatic species and those that were used to derive the national criteria recommendations. In the case of aluminum criteria, a state or authorized tribe could consider generating its own calculator using the same basic datasets and underlying model equations as the national CWA Section 304(a) recommended criteria but adding additional data to account for locally important species and to adjust the species sensitivity distribution. EPA recommends that states and authorized tribes that wish to

[15] USEPA. 2013. Revised Deletion Process for the Site-Specific Recalculation Procedure for Aquatic Life Criteria. EPA-823-R-13-001

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develop aluminum criteria based on the revised deletion process should engage their EPA regional office early in the state's or authorized tribe's criteria development process.

Critical species should be taken into consideration when using the species deletion process. The 2013 revised deletion process document explains that, "A critical species is a resident species that (a) is commercially or recreationally important at the site, or (b) is listed as threatened or endangered under section 4 of the Endangered Species Act, or (c) is a species for which there is firm evidence that its loss would yield an unacceptable impact on the site's commercially or recreationally important species, endangered species, abundances of a variety of other species, or structure or function. The species deletion process should not be undertaken unless toxicity data are available for at least one species in each class of aquatic plants or animals that contains a critical species."[16]

For the species deletion process, all species that occur at the site should be considered when deciding what species, if any, could be deleted from the dataset. Species not present at the site may be representative surrogates for other species for which there were no available toxicity data in the development of the Criteria Calculator database. Therefore, states and authorized tribes should consider how to demonstrate that a species (or any species for which that sensitive species might be a surrogate) is not present at the site before applying the species deletion process. States and authorized tribes that wish to develop site-specific aluminum criteria based on the revised deletion process should engage their EPA regional office early in the process. The Criteria Calculator or associated look-up table adopted into rule also would need to be revised to accurately reflect the revision.

States and authorized tribes using the species deletion process must also ensure that the resulting water quality standards "provide for the attainment and maintenance of the water quality standards of downstream waters" (40 CFR 131.10(b)). This requirement can be met in several ways, including using a combination of water quality standards and general policies. Additional information about this requirement can be found in *Protection of Downstream Waters in Water Quality Standards: Frequently Asked Questions*.[17]

1.8. What methods can be used to derive criteria values that will result in protection of aquatic life at a site, given a range of Criteria Calculator outputs?

EPA recommends that the criteria for each site be derived in a way that will protect aquatic life throughout the range of seasonal and flow conditions at a site, including those conditions of pH, total hardness, and DOC, when aluminum is most bioavailable (hence, toxic effects are greatest). EPA recommends the following three methods for deriving protective criteria values; states and authorized tribes may choose other scientifically defensible and protective methods, as well. Method 1 entails the greatest amount of input parameter data, and Method 3 involves the least (see below). EPA expects

[16] Ibid, 14.

[17] USEPA. 2014. Protection of Downstream Waters in Water Quality Standards: Frequently Asked Questions. EPA 820-F-14-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/sites/default/files/2018-10/documents/protection-downstream-wqs-faqs.pdf

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states and authorized tribes to clearly describe in their water quality standards or other legally binding document how these methods will be used.

Method 1: Identify protective criteria values by selecting one or more individual Criteria Calculator outputs based upon spatially and temporally representative data for inputs. Method 1 can be used where input datasets are more robust and inputs are measured frequently enough to statistically represent changes in the toxicity of aluminum, including water chemistry conditions under which aluminum is most toxic. In this case, the criteria values could be determined by selecting one or more individual outputs that will be protective of aquatic life under the full range of ambient conditions, including conditions of high aluminum toxicity. Method 1 could be used to also establish criteria values to apply on a seasonal basis where the data are sufficient.

Method 2: Generate protective criteria values from the lowest 10^{th} percentile of the distribution of individual Criteria Calculator outputs, based upon spatially and temporally representative data from a site. Although the 10^{th} percentile of outputs should be sufficiently protective in most cases, certain circumstances may warrant use of a different output (e.g., consideration of threatened or endangered species). Sufficient data to characterize the appropriate distribution of outputs are necessary to derive a protective percentile so that the site is protected under conditions where aluminum is most bioavailable.

Method 3: Select the lowest Criteria Calculator outputs calculated from available input data. This could include assessment of individual data points (sometimes referred to as a "point-by-point" approach). Under this method, the lowest values for the acute and chronic criteria would represent the most toxic conditions known at a site. EPA recommends Method 3 be used where few outputs are available (e.g., ten or fewer), due to the higher probability that a sample from a small dataset does not appropriately represent actual variability.

Either Method 2 or 3 is particularly useful when values of acute and chronic criteria need to be protective of particular site conditions, such as for NPDES permitting actions (as discussed in the Section 5 on NPDES permitting). Whichever method is selected, states and authorized tribes should consider developing written implementation methods and make these documents available to the public to maximize transparency, defensibility, and regulatory certainty. To the same end, EPA recommends states or authorized tribes make publicly available the following on the state's or authorized tribe's website, and, if applicable, referenced in the statement of basis for a draft public notice version NPDES permit, draft public notice Integrated Report, or draft public notice TMDL:

- Site-specific water chemistry data, including the inputs used in the Criteria Calculator and resultant criteria values.
- The geographic extent of each site.

As mentioned in Question 1.2, a state or authorized tribe may choose to adopt default criteria for all or some of the waterbodies within the state or tribal jurisdiction. Where a state or authorized tribe chooses to adopt default criteria values, the state or authorized tribe does not need an additional method for reconciling Criteria Calculator outputs, because the default criteria values should already have integrated the concepts above (i.e., ensuring protectiveness under the full range of ambient

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conditions, including those under which aluminum is most bioavailable; hence, when toxicity is greatest).

Section 2: Technical Questions on the Criteria Calculator, Sampling and Laboratory Analysis

2.1. Do the recommended criteria require data for all input parameters be collected concurrently?

EPA recommends that samples tested for all of the three input parameters (total hardness, pH, and DOC) to be used in the Criteria Calculator be collected concurrently, when possible. The criteria models incorporate the influence of input parameters, as well as interactions among those parameters and were based mainly on laboratory studies that had a 3x3x3 factorial design where the three parameters were changed for the laboratory tests.[18] However, if concurrent measurements of all three input parameters are not available, default values for DOC may be used.[19] For more information on the use of default input parameters, see Section 4 for more information on handling missing and insufficient data.

2.2. How can data from continuous monitoring be used with the Criteria Calculator?

EPA understands that continuous monitoring for pH is more common than continuous monitoring for total hardness or DOC, and pH is more likely to exhibit greater variability over a short time period when compared to total hardness and DOC. The variable nature of pH, throughout a day, season, or year of data collection, raises questions about how continuously collected pH data should be paired with discrete measurements of total hardness and DOC. For example, how would one know whether the grab samples collected for measurement of total hardness or DOC were taken at a time when pH was in a range that would yield protective criteria?

High-quality continuous monitoring data for pH can provide information on when grab samples for total hardness and DOC should be collected to ensure the inputs to the Criteria Calculator generate protective acute and chronic criteria values. The solubility of aluminum varies with pH. Aluminum is most soluble at low and high pH values, and most bioavailable at low and high pH values; therefore, EPA recommends the full range of observed pH values be used when evaluating the Criteria Calculator outputs.[20] When sufficient data for total hardness and DOC are available to characterize the expected spatial and

[18] DeForest, D.K., K.V. Brix, L.M. Tear and W.J. Adams. 2018. Multiple linear regression models for predicting chronic aluminum toxicity to freshwater aquatic organisms and developing water quality guidelines. *Environ. Toxicol. Chem*. 37(1): 80-90.

[19] EPA is developing a geospatial tool that will help determine appropriate input parameter estimates. This work is expected to be complete in 2021.

[20] For more information about the Criteria Calculator, please see the Final Aquatic Life Ambient Water Quality Criteria for Aluminum 2018, EPA-822-R-18-001, December 2018, https://www.epa.gov/wqc/2018-final-aquatic-life-criteria-aluminum-freshwater.

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temporal variability, simultaneously collected pH data should be paired with discrete samples to generate a distribution of criteria values (see Question 1.8).

Selecting a conservative value for pH from the range of observed pH values in a continuous dataset as an input (e.g., low or high pH value depending on the range of pH) and using that value with a conservative total hardness or DOC value may also be acceptable; however, the effects are not linear. In some cases, total hardness can influence the criteria value, such that a higher pH input might produce a lower criteria value with a different hardness concentration (Figure A). In general, a neutral pH produces higher values for the criteria, as do higher concentrations of DOC. However, the precise interaction of the three input parameters can be difficult to predict. For this reason, EPA recommends that a user run a series of input parameters then select the one with the lowest criteria value output by the Criteria Calculator (for n < 10) or a low percentile (e.g., 10%) of the criteria values (for n>10). However, a user might decide to input a conservative DOC value in each calculation that included paired pH and total hardness values because the effect of DOC on criteria values is a monotonic reduction of toxicity (Figure B).

Figure A: Model output at constant DOC

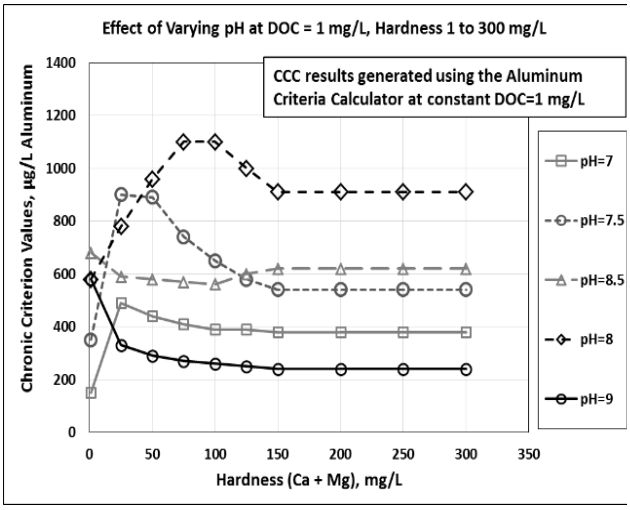
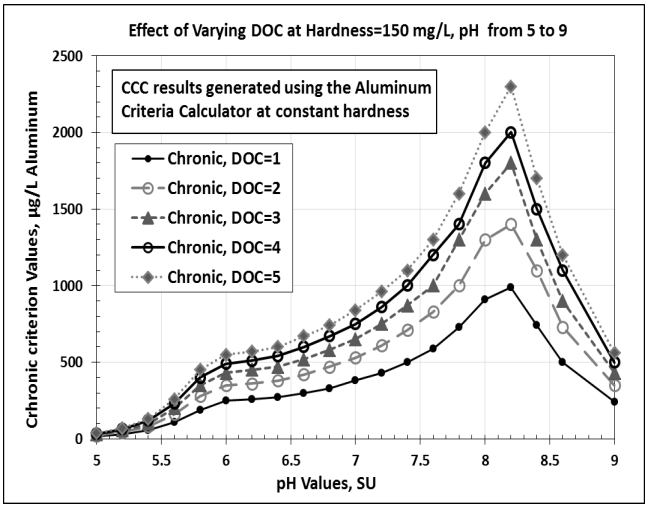


Figure B: Model output at constant hardness



2.3. What are the preferred analytical methods to measure the water quality input parameters required by the Criteria Calculator (pH, total hardness, and DOC)?

For analysis of pH and total hardness, EPA provides "Guidelines Establishing Test Procedures for the Analysis of Pollutants" at 40 CFR Part 136.[21]

[21] Information on these analytical methods is available at https://www.epa.gov/cwa-methods/approved-cwa-chemical-test-methods and https://www.gpo.gov/fdsys/pkg/FR-2017-08-28/pdf/2017-17271.pdf

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Several well established methods are available for measuring DOC,[22] including EPA Method 415.3[23] and USGS Method O-1122-92. In addition, several well established methods for total organic carbon (TOC) are available, including ASTM D6317-15 and *Standard Methods for the Examination of Water and Wastewater* SM 5310. These methods discuss the stringent sample collection and processing measures that are necessary to minimize sample contamination, especially when the DOC concentrations are expected to be low. For example, the sampling container, filtration apparatus, filters and atmospheric exposure might introduce carbon to the sample and in some situations adsorb DOC. Standard Method 5310A identifies filtration protocols and additional quality control (QC) measures (e.g., filter blanks) that may be considered when using a TOC method (i.e., a method that lacks a filtration step) such as SM 5310B, adapted for DOC. Whichever method is selected, all of the specified QC operations are needed to assess the results of the field sample analyses. Example QC operations can be found at 40 CFR Part 136.7.

2.4. What are the preferred analytical test methods to measure aluminum in water?

EPA's CWA Section 304(a) recommended Criteria Calculator for aluminum is based on data for *total recoverable* aluminum. Therefore, it calculates outputs that can be used to generate criteria values for total recoverable aluminum. The approved test methods for measuring total recoverable aluminum in ambient water and wastewater use a variety of analytical instruments (the most commonly used methods are EPA Methods 200.7 and 200.8). However, recent research has indicated that a less aggressive digestion sample preparation procedure may more accurately reflect aluminum toxicity in ambient waters when using the approved analytical methods.

All of the approved total recoverable methods require that the unfiltered samples be preserved in the field by acidifying to pH<2 and digested in the laboratory with strong acid solution, with a pH of -0.05 to +0.7. This process dissolves the monomeric and polymeric forms of aluminum, in addition to colloidal, particulate, and clay minerals (i.e., aluminosilicate minerals known as phyllosilicates). However, under natural conditions not all of these forms would be biologically available to aquatic species. Over the last three decades, the scientific consensus has been that the total recoverable method for aluminum potentially overestimates the biologically available fraction and that a method that better addresses dissolved aluminum and aluminum bound to particulate matter would be useful and more accurately reflect toxicity under natural instream conditions (e.g., He and Ziemkiewics 2016; Ryan *et al*. 2019).[24] EPA's CWA Section 304(a) recommended criteria document also describes this issue.

[22] See National Environmental Methods Index (website): https://www.nemi.gov/methods/analyte_results/?media_name=&source=&instrumentation=&analyte_name=dissolved+organic+carbon&category=.

[23] https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NERL&dirEntryId=214406.

[24] He YT, Ziemkiewicz PF. 2016. Bias in determining aluminum concentrations: Comparison of digestion methods and implications on Al management. *Chemosphere* 159:570–576; Ryan AC, Santore RC, Tobiason S, WoldeGabriel G, and Groffman AR. 2019. Total recoverable aluminum: not totally relevant for water quality standards. *Integrated Environmental Assessment and Management*. 15(6): 974–987.

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As an example of an approach to better measure the biologically available forms of aluminum, research on new analytical methods was published that addresses concerns with total recoverable aluminum concentrations (Rodriguez *et al.* 2019).[25] Under this approach, the analysis does not digest the sample at pH -0.05 to +0.7 , but rather to pH 4 in order to measure only the bioavailable fraction of aluminum in the sample. The authors concluded that their proposed method is able to characterize and differentiate chronic toxicity effects attributable to bioavailable aluminum from nontoxic forms of aluminum (i.e., aluminum contained in the crystal lattice of aluminosilicate minerals) compared with existing methods for total or total recoverable aluminum. The methods for total or total recoverable aluminum may overestimate instream toxic effects by virtue of the digestion-induced dissolution of aluminum from clay minerals that would not dissolve in most ambient waters under ambient pH conditions.

EPA expects that an adjusted analytical method (referred to as a bioavailable analytical method) that uses a less aggressive initial acid digestion that liberates bioavailable forms of aluminum (including amorphous aluminum hydroxide) yet that minimizes dissolution of mineralized forms of aluminum (such as aluminosilicate minerals associated with suspended sediment particles) will better estimate the bioavailable fraction of aluminum under natural instream conditions.

The forms of aluminum introduced into the laboratory toxicity tests, upon which EPA relied for development of the CWA Section 304(a) recommended criteria, were highly soluble salts of aluminum, rather than clays or other aluminum-containing particulates typically found in natural waters. Aluminum from suspended solids and clays would normally be extracted using total recoverable methods that have a strong acid (pH <2) digestion step but would not be biologically available to aquatic species in natural waters. Empirical laboratory testing indicates that measured concentrations of total recoverable (pH -0.05 to +0.7 digestion) and bioavailable aluminum in laboratory waters are essentially equal up to approximately 1 mg/L of aluminum.[26] Studies are underway at Oregon State University with test solutions with greater than 1 mg/L of aluminum to better understand the relationship above 1 mg/L. Initial studies indicate there is little difference between “total recoverable” and “bioavailable” aluminum above 1 mg/L in laboratory waters.

EPA does not intend to develop or require a conversion or translation factor to compare field measurements using a bioavailable method against the promulgated aluminum total recoverable criteria. This is because both bioavailable and total recoverable analytical methods quantify the toxic fraction of aluminum equivalently in laboratory test waters given that standard toxicity test waters do not include suspended solids or clays per test protocols.

NPDES permit limits for metals must be expressed as “total recoverable” metals with the exception of specific circumstances that would not apply for aluminum. 40 CFR 122.45(c). This regulation exists because chemical differences between the effluent discharge and the receiving water body are expected to result in changes in the partitioning between dissolved and adsorbed or particulate forms of metals. However, for ambient water measurements, analytical methods that measure bioavailable aluminum

[25] Rodriguez PH, Arbildua JJ, Villavicencio G, Urrestarazu P, Opazo M, Cardwell AS, Stubblefield W, Nordheim E, Adams W. 2019. Determination of bioavailable aluminum in natural waters in the presence of suspended solids. *Environmental Toxicology and Chemistry*. 38(8):1668-1681.
[26] *ibid*.

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should provide more accurate quantification of the toxic fraction of aluminum. EPA acknowledges that for characterizing ambient waters, states and authorized tribes may utilize, as scientifically appropriate and as allowable by state and federal regulations, analytical methods that measure the bioavailable fraction of aluminum. Such methods employ a less aggressive initial acid digestion, such as to a pH of approximately 4 or lower, that includes the measurement of easily dissolved amorphous aluminum hydroxides, yet minimizes the measurement of mineralized forms of aluminum in aluminosilicate minerals, such as clays, which are associated with suspended sediment particles. Use of such a method for bioavailable aluminum would need to comply with other existing requirements in state or authorized tribal water programs, for example, any applicable quality assurance/quality control requirements. For assessment and listing purposes, ambient field measurements analyzed using a bioavailable analytical method may be compared directly to the criteria because that method represents the toxic fraction of aluminum. States and authorized tribes that adopt aluminum criteria should identify which analytical methods they will use to implement the criteria.

In some circumstances, assessing waters using the analytical method for total recoverable aluminum could result in identification of some waters as not attaining water quality standards for aluminum criteria (i.e., being identified as impaired), where the bioavailable analytical method may not indicate impairment. For example, ambient waters with high amounts of total suspended solids may show elevated concentrations of aluminum based on analysis of the total recoverable fraction, yet these concentrations could actually represent only non-toxic forms of aluminum. EPA's existing regulations applicable to implementation of CWA Section 303 programs, which include assessment and listing of waters, do not require use of analytical test methods promulgated at 40 CFR Part 136, nor do the regulations that apply to the determination of the need for a WQBEL. However, EPA's regulations require that states assemble and evaluate all existing and readily available water quality related data and information for use in developing their CWA Section 303(d) lists (40 CFR 130.7(b)(5)); this would include data for total recoverable aluminum. A state or authorized tribe is not required to use all available data and information to make listing decisions, including total recoverable data, where it can provide a technical, science-based rationale for the exclusion of such data and information. 40 CFR 130.7(b)(6)(iii), For example, a state or authorized tribe may be able to demonstrate that total recoverable aluminum samples are not representative of water quality conditions because non-toxic forms of aluminum are leading to an exceedance above the criteria. In such cases, the state or authorized tribe may decline to rely on total recoverable data, or may assign a greater weight to bioavailable data if it is more representative of water quality for listing purposes.

For developing TMDLs and load allocations, aluminum data from bioavailable analytical methods may also be used as the basis for identifying allocations for TMDLs. This includes both wasteload allocations (WLA) for point sources and load allocations (LA) for nonpoint sources. For implementing a WLA, the associated WQBEL must be assessed for NPDES compliance purposes using aluminum data from total recoverable methods, just as would be the case for other NPDES applications consistent with permitting regulations. NPDES permit limits for aluminum concentrations listed in compliance reports must, by regulation, be measured using analytical methods approved by EPA and published at 40 CFR Part 136. Currently the only approved methods at 40 CFR Part 136 are for "total recoverable aluminum."However, states and authorized tribes may use a bioavailable analytical method to measure aluminum

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concentrations from nonpoint sources (i.e., the LA for surface water runoff) because total suspended solids may include aluminosilicate minerals (e.g., clay minerals) containing aluminum that is not bioavailable under natural conditions.

2.5. What should states and authorized tribes do to ensure data quality for use in the Criteria Calculator?

EPA recommends that states and authorized tribes establish data quality guidelines for data to be input to the Criteria Calculator. Such guidelines would be similar to data quality guidelines used for other water quality criteria. EPA recommends that states develop Quality Assurance Project Plans[27] (QAPPs) for sampling protocols to assure that representative data are collected.

2.6. If data are available only for total organic carbon (TOC), can these be converted to dissolved organic carbon (DOC) for use as input to the Criteria Calculator?

In some cases, states, authorized tribes, or regulated facilities may only have collected data for TOC and not DOC, which is the input parameter for use with the Criteria Calculator. In these situations, a TOC to DOC conversion may be used. Some states have used various methods to convert TOC values to DOC. Data from the U.S. Geological Survey's (USGS) National Water Information System (NWIS) can also provide useful data to supplement state or tribal data when creating translations.[28] It is useful for states and authorized tribes who use a conversion to ensure the details of the conversion are available in the public record for the adoption of the Al criteria or in some other publicly available document.

The following examples demonstrate approaches states have taken to convert TOC data to DOC:

- Kansas uses the TOC to DOC conversion values detailed in EPA-822-R-07-001, *Aquatic Life Ambient Freshwater Quality Criteria – Copper*. See Appendix C-2: Dissolved, Particulate, and Estimated Total Organic Carbon for Streams and Lakes by State.
- Massachusetts uses a TOC to DOC conversion developed by USGS for surface waters in Massachusetts based on a regression of available NWIS data for concurrent measurements of TOC/DOC throughout the state. (See Equation 1)[29] (USGS Untitled Report, *in-prep*).

  Equation 1. TOC to DOC conversion. $$DOC\ (\frac{mg}{L}) = 0.858 * TOC(\frac{mg}{L}) - 0.196$$

- Montana, New Mexico, and Ohio have been collecting both DOC and TOC data at selected sites. These states plan to develop conversion factors based on regression analysis of the TOC and DOC data.

[27] Further information on QAPPs may be found at https://www.epa.gov/quality/guidance-quality-assurance-project-plans-epa-qag-5.
[28] EPA is developing a geospatial tool that will help determine appropriate input parameter estimates. This work is expected to be complete in 2021.
[29] USGS Untitled Report, in-preparation. Publication expected Fall 2021.

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- Oregon generated a translator to convert TOC data to DOC data for use with the Copper Biotic Ligand Model using a regression approach. A single statewide translator was developed using state and USGS NWIS data.

2.7. What information does a single run of the Criteria Calculator provide, and what are the limitations on the output from one set of inputs (single sample)?

The Criteria Calculator can be run for multiple samples of collected data for pH, total hardness, and DOC (inputs),[30] representing a range of conditions at a site. The samples may be taken from a single site throughout the year or from several different sites within a waterbody (or some combination of data collected over geographical space and time). Each sample would provide one set of input parameters and generate one set of outputs (i.e., the acute and chronic criteria). A single run of the Criteria Calculator could, therefore, provide a distribution of (in the case of the Excel version, up to 500) acute and chronic criteria values (outputs) which would be considered protective for each corresponding input sample. From the distribution of outputs, protective values for acute and chronic criteria may be selected. For more on identifying protective criteria values from a distribution of possible values, see Question 1.8.

As the number of samples of pH, total hardness, and DOC increases, the ability to reliably translate Criteria Calculator outputs to a protective criteria value also increases. A single output of the Criteria Calculator represents one moment in time at a single point and may not adequately characterize the variation in water chemistry for a site throughout the year. The uncertainty associated with a criterion based on only one single set of inputs is not a problem unique to the Criteria Calculator, as other water quality parameters vary spatially and temporally. Running the Criteria Calculator with data from multiple sampling events will yield a distribution of multiple output criteria values, from which a sufficiently protective set of criteria may be selected.

2.8. Can the Criteria Calculator still be used when the ambient data are outside the ranges included in the models used to develop the calculator?

Yes, the Criteria Calculator can be used when the ambient data for the input parameters are outside the ranges included in the MLR models. The Criteria Calculator incorporates a data extrapolation to cover a broader range of inputs for pH, and a slightly broader range for hardness. However, the Criteria Calculator does not process input values far outside of the model range. For input values outside the Criteria Calculator range, it will default to the nearest allowable Criteria Calculator input parameter

[30] The number of samples the Criteria Calculator can run at a time depends on the format: the Excel version can handle up to 500 samples. The Criteria Calculator is also available in R; both versions are available on EPA webpage for the Recommended Aquatic Life Criteria for Aluminum in Freshwater: https://www.epa.gov/wqc/aquatic-life-criteria-aluminum#2018. The R version uses the same formulas and data that are found in the Excel version, but the R code can handle a larger number of parameter inputs and can calculate faster. The R code and data are in an easy-to-download Zip file. They can be found under the "2018 Final Aquatic Life Criteria for Aluminum in Freshwater" header.

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value. For example, entering a DOC value of 9.5 mg/L is within the range of the Criteria Calculator input values for DOC, therefore the Criteria Calculator will accept an input of 9.5 mg/L without change. However, an input value of 15 mg/L for DOC will default to an input value of 12 mg/L, the maximum allowable DOC value for the Criteria Calculator. The CWA Section 304(a) recommended aluminum criteria document (see pages xiv-xv)[31] explains the decisions the Agency made regarding the bounds of the input parameter ranges in the Criteria Calculator and its corresponding look-up tables.[32] Table 2, below, summarizes the information from the criteria document and compares the range of values used in the MLR models with the corresponding ranges allowable as inputs to the Criteria Calculator for each input parameter. As discussed in Section 4 of the CWA Section 304(a) recommended aluminum criteria document, the ranges incorporated into the Criteria Calculator will be protective across a broad range of ambient waters found in the United States.

Table 2: Comparison of MLR models and Criteria Calculator input parameters

Input parameter	MLR models range	Criteria Calculator range
pH	6.0 – 8.2	5.0 – 10.5
Total hardness (mg/L)	9.8 – 428	0.01 – 430
Dissolved organic carbon (mg/L)	0.08 – 12.3	0.08 – 12.0

2.9. How is the multiple linear regression (MLR) technique different from the Biotic Ligand Model (BLM)?

EPA considered multiple options when developing the national CWA Section 304(a) recommended criteria for aluminum, including the Biotic Ligand Model (BLM).[33] Both the BLM and the multiple linear regression (MLR) models are used to estimate the bioavailability – and resultant toxicity – of metals to aquatic species based on water chemistry at a site, including pH, total hardness, and DOC as inputs. The BLM, however, includes an additional seven inputs.

- The BLM, which is a mechanistic model, uses a series of submodels to estimate the capacity of metals to accumulate or bind to active sites on the gills of aquatic organisms. The submodels are

[31] Final Aquatic Life Ambient Water Quality Criteria for Aluminum 2018, EPA-822-R-18-001, December 2018, https://www.epa.gov/wqc/2018-final-aquatic-life-criteria-aluminum-freshwater.

[32] Two models, one for invertebrates and one for vertebrates, were used to normalize freshwater aluminum toxicity values. These separate models correspond to effects on invertebrates and vertebrates due to differing effects of pH, total hardness, and DOC on aluminum bioavailability and toxicity, and therefore enable the criteria magnitudes to be calculated as a function of the unique chemistry conditions at a given site.

[33] The BLM was formerly referred to as the "gill model." It is a metal bioavailability model that uses metal speciation across water chemistries and associated binding of a metal to fish gills with associated toxicity, receiving waterbody characteristics and monitoring data to develop site-specific water quality criteria. A BLM model was used to develop the 2007 CWA 304(a) aquatic life criteria recommendation for copper.

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based on an underlying theory of how overall water chemistry, as defined by the ten input parameters, affects the toxicity of metals.

- The MLR approach used to develop the Criteria Calculator empirically curve-fits log-log pH, total hardness, and DOC relationships (with interaction terms) to the empirical data.

EPA evaluated the use of empirical, non-mechanistic MLR models for aluminum as a bioavailability-based approach for deriving water quality criteria as well as a BLM for aluminum. The Criteria Calculator associated with EPA's 2018 CWA Section 304(a) recommended criteria for aluminum uses the MLR approach. Given that the MLR and the BLM approaches performed comparably, EPA decided to use an empirical MLR approach in this aluminum criteria update rather than a BLM due to:

- the relative simplicity and transparency of the MLR model,
- the relative similarity to the available BLM outputs, and
- the decreased number of water chemistry input data parameters needed to derive criteria at different sites.

Under 40 CFR 131.11, states and authorized tribes may use EPA's CWA Section 304(a) recommended criteria with modifications or may use other scientifically defensible methods to develop their own criteria. Regardless of the method used, a state or authorized tribe must submit the criteria to EPA for review and approval. EPA's current recommendation, based on the latest scientific knowledge, employs an MLR model. It is possible to use other modeling approaches, such as the BLM, to predict aluminum toxicity and account for the water chemistry parameters that influence toxicity the most.

If presented with proposed aluminum criteria based on a BLM or different approach, EPA would evaluate its scientific basis and protectiveness of the designated use. For additional information and references, see Section 5.3 of the recommended criteria document available at: https://www.epa.gov/wqc/2018-final-aquatic-life-criteria-aluminum-freshwater.

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Section 3: Characterizing Spatial and Temporal Variability of Input Parameters to Develop Protective Criteria Values

3.1. How should the *site* be defined for measuring input parameters to calculate protective numeric criteria values?

A *site* may be a state, region, watershed, segment of a waterbody, category of water (e.g., cold-water lakes), etc., but the criteria are to be derived to provide adequate protection for the entire site regardless of how the site is defined. A site could also be a facility mixing zone, an assessment unit, a watershed, or any spatial area that a state or authorized tribe has data to represent.

When defining a site, states and authorized tribes should consider the following:

- How the site definition will facilitate developing criteria values that are protective of the range of conditions expected to occur within the defined site.
- How the site definition will capture significant influences on water chemistry.
- How the size or spatial variability of the site can impact the number of water samples required to adequately characterize the spatial and temporal variability of a site.
- How to communicate a clear definition of the site's area or condition for which the criteria values apply.
- How, if at all, the site definition differs depending on the intended CWA program (e.g., is the receiving water site of a NPDES permit discharge location different from the assessment unit site?).

Regardless of how the "site" is defined, pursuant to 40 CFR 131.10(b), states and authorized tribes must consider downstream water quality standards when establishing protective criteria in upstream waters. For additional information on site-specific water quality criteria, see 40 CFR 131.10(b) and chapter 3 of EPA's *Water Quality Standards Handbook*.[34]

3.2. How does the definition of a site impact sampling design and number of sampling locations needed to characterize the spatial variability of a site?

The number of sampling locations needed to characterize spatial variability at a site will vary with physical and chemical characteristics of the site. Samples should be collected from enough locations so that the resulting dataset captures the expected spatial variability in pH, total hardness, and DOC of the site, based on the observed range of physical and chemical conditions.

When designing a sampling plan to develop inputs for the Criteria Calculator, unique characteristics of a waterbody segment should be considered such as size, flow, and presence of springs, tributaries, and outfalls. States and authorized tribes may also want to consider differences in hydrology, geology, eco-

[34] USEPA. 1994. Water Quality Criteria. Chapter 3 in *Water Quality Standards Handbook*. EPA 823-B-94-005a. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/wqs-tech/water-quality-standards-handbook.

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region, watershed land use (e.g., urban, forested, cultivated, wetlands), trophic state (i.e., level of biological activity in the waterbody), and riparian condition within and among sites to inform decisions on the number of sampling locations needed. For example, land use within the watershed, the trophic state, and presence of discharges from a wastewater treatment plant can all influence the variability in concentrations of any of the input parameters.

Generally, relatively large or heterogeneous waterbodies will require more sampling locations to characterize the spatial variability, as compared to the number of sampling locations required to characterize small or homogenous systems. When a wide range of characteristics or water quality conditions is observed in a large waterbody, states and authorized tribes may consider dividing the waterbody into smaller segments or sites for purposes of establishing input values for the Criteria Calculator.

States or authorized tribes considering use of existing or new data for the development of default numeric values over larger geographic scales should evaluate existing data, monitoring strategies and other data sources to evaluate spatial and temporal representativeness of the data so that the variability in pH, total hardness, and DOC is understood. Sampling data from waterbodies with high levels of bioavailable aluminum should be included in the dataset to be representative of the observed site conditions.

See the Section 5 on NPDES permitting for additional considerations for monitoring to characterize waters impacted by point sources.

3.3. How can a sampling plan be developed to capture the range of conditions that affect aluminum bioavailability (hence, toxicity) at a site?

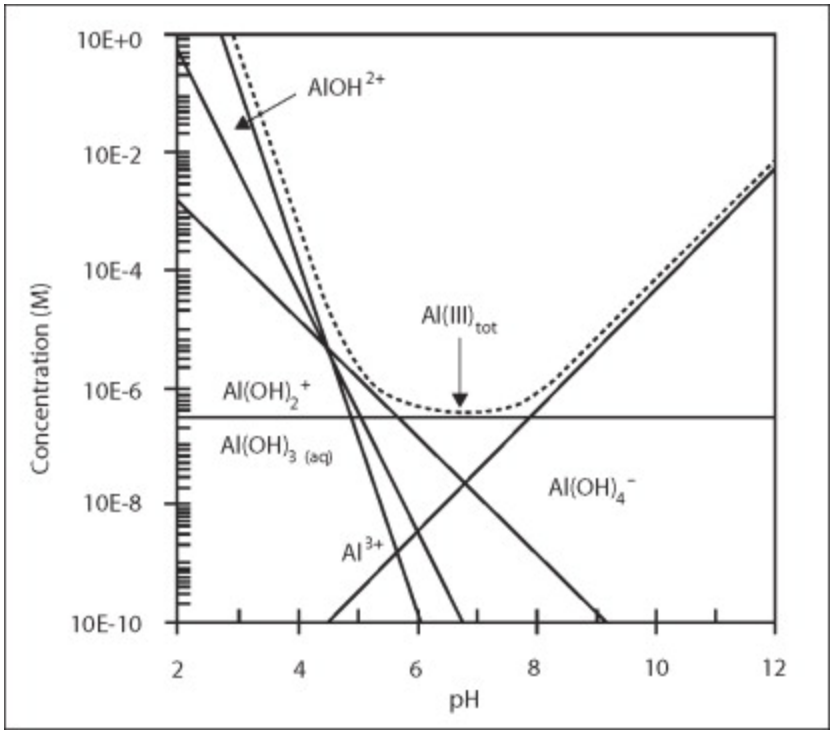
Understanding how aluminum bioavailability changes with increasing or decreasing values of pH, total hardness, and DOC will help when designing sampling plans intended to capture the range of ambient chemistry conditions. A sampling plan should be designed to capture the conditions under which aluminum would be most bioavailable; these conditions have the highest acute toxicity, and also the highest chronic toxicity, with respect to aluminum. However, because the input parameters interact in complex ways, it is not possible to generalize about a universal set of input parameter conditions that would represent conditions of the highest toxicity, with respect to aluminum. Nonetheless, there are some general observations regarding pH, total hardness, and DOC:

- Values of pH in the circumneutral range are associated with lower solubility of aluminum (see Figure C) and conditions of lower bioavailability and toxicity with respect to aluminum (see Figures A and B). Values of pH may vary over several units due to photosynthetic activity in the waterbody (lowest pH at dawn and highest pH in early afternoon coincident with peak photosynthetic activity). Significant diurnal variation in pH values due to photosynthesis and respiration patterns can affect the calculated aluminum criteria values by 1,000 µg/L or more. Therefore, it would be useful to sample during times when pH is expected to be highest or lowest at a particular site, in order to capture conditions under which aluminum would be

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most bioavailable and toxic. Sampling early in the morning, before photosynthetic activity begins, and mid-afternoon, when photosynthetic activity peaks, may capture the extremes of pH at a site. Alternatively, data loggers could also be used to capture a range of pH values, including times (such as night) when sampling and monitoring is impractical (see Question 2.2 for more information on the use of continuous monitoring data). Effluent discharges to the waterbody that vary over the course of the day or week may also affect pH.

Figure C: Solubility of aluminum hydroxide over a range of pH. Minimum solubility (~0.000001 M) achieved under near-neutral conditions of pH.



Source: Membrane filtration: Managing aluminum in membrane filtration. Filtration + Separation. Volume 51(4):26-28. July-August 2014. https://doi.org/10.1016/S0015-1882(14)70145-4 (p 27)

- Total hardness in flowing waters may be related to stream flow or other factors that alter the concentrations of calcium and magnesium (the components of total hardness). These ions are derived mainly from weathering of rocks and minerals in natural settings and exist in the dissolved phase in most fresh waters.
- DOC can bind aluminum, rendering it less bioavailable (hence, less toxic). In general, DOC and bioavailability of aluminum are inversely correlated. That is, low concentrations of DOC are associated with higher bioavailability of aluminum; hence, yield more stringent (lower) aluminum criteria values. High concentrations of DOC bind aluminum and reduce bioavailability; hence, yield less stringent (i.e., higher) aluminum criteria values. Sampling at times when DOC is low could help capture conditions under which aluminum is more bioavailable (i.e., conditions are more toxic). Seasonal patterns in DOC concentrations at a site may vary depending on soil type, vegetation, upstream inputs, and climate.

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A sampling plan should also consider other factors, such as precipitation events and snow-melt cycles, particularly for waters that receive stormwater flows. Increased flows may affect the pH and other chemical parameters of the waterbody for up to several hours following a storm event. Wet season and dry season flows may lead to extremes in the conditions that affect aluminum bioavailability. Considering the variety of factors that may affect toxicity over time at a site can help identify strategic times to sample. Strategically timed sampling is more likely to result in development of criteria values for a site that will be protective during more sensitive times (i.e., times when aluminum is most bioavailable). Conditions like time of day, date, and weather should be noted when sampling occurs.

The Criteria Calculator generates both acute and chronic criteria values from the same set of data inputs. The diurnal variability of input parameters may affect acute criteria values more than chronic criteria values, because chronic values are averaged over a four-day period. Capturing the variability of input parameter values on longer time scales (e.g., the average pH over a one- to four-day period) may be informative for chronic criteria values, because understanding that variability will help inform the design of routine sampling plans that include the collection of discrete measurements.

3.4. If monitoring shows seasonal differences in data, can seasonal data be separated out to generate seasonal criteria values?

If enough data are available and those data indicate significant seasonal differences in toxicity with respect to aluminum, it is possible to separate and create criteria values for application on a seasonal basis. For example, if spring snowmelt or heavy seasonal rainfall in the area significantly change the water chemistry parameters that affect aluminum bioavailability (hence, toxicity) during that season, then a state or authorized tribe may consider spring values that differ from values that apply during other seasons. The criteria values should protect the designated uses in all of the seasons. If states or authorized tribes choose to adopt seasonal criteria into their water quality standards, they should clearly define those seasons in their water quality standards.

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Section 4: Handling Missing or Insufficient Data When Using the Criteria Calculator

4.1. Where can I find additional data to use as inputs to the Criteria Calculator?

The sufficiency of data for pH, total hardness and DOC will depend on the range of variation in the values of those parameters throughout the year. In general, more data are important for waterbodies with characteristics that exhibit a greater range of variability, to achieve an acceptable level of confidence as defined by the user. If a state or authorized tribe has limited data, EPA recommends that the state or authorized tribe consider data from the Water Quality Portal. The Water Quality Portal is a service provided jointly by the EPA, USGS, and the National Water Quality Monitoring Council that uses the EPA's Water Quality Exchange format to share over 380 million water qualtiy data records. It serves data collected by over 900 federal, state, tribal and other partners including the USGS's National Water Information System (NWIS) data (See: https://www.waterqualitydata.us/).[35] Note: Whatever dataset a state or authorized tribe uses, some level of quality assurance is vital, particularly with methods for handling total hardness or DOC, for which the analyst must comply with methodologies and holding times to ensure the resulting data meet state or tribal data quality requirements specified in the respective Quality Assurance Project Plans, or QAPPs.

4.2. Must states and authorized tribes have default input parameters or default criteria values for aluminum?

States and authorized tribes are not required to identify default input parameters or default criteria values for aluminum; however, states and authorized tribes are required to protect the designated uses of waterbodies within their jurisdictions.[36] The protectiveness of a state or authorized tribe's approach to adopting EPA's CWA Section 304(a) recommended criteria will be determined by both the *implementation methods* associated with the criteria and the *input parameter data* (for pH, total hardness, and DOC) used to calculate the criteria values for a given waterbody. See Question 1.2 for more information on approaches to adopting aluminum criteria, including default criteria.

For states and authorized tribes that choose to adopt the criteria in the form of the Criteria Calculator or lookup tables, the adoption of default input values or default criteria values can help to ensure that aquatic life uses will be protected in all waters within their jurisdiction, regardless of data availability for pH, total hardness, or DOC. When considering the establishment of default input parameters, it is especially important to keep in mind the complex (e.g., non-monotonic) relationship between pH and aluminum toxicity as well as the high natural variability of pH. Both issues make it uniquely challenging to establish protective pH default values. See Question 3.3 for more information. Having numeric default criteria values available may also help ensure that anyone implementing the criteria (e.g., a

[35] EPA is developing a geospatial tool that will help determine appropriate input parameter estimates. This work is expected to be complete in 2021.

[36] As provided at 40 CFR 131.11(a), state and tribal water quality criteria must be protective of the designated use based on a sound scientific rationale.

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permit writer, or someone assessing the water) will have a clear numeric basis for implementation, providing transparency for the public and the regulated community.

4.3. Would default criteria be overly stringent?

Because default criteria are generally applied to a broad geographical area (e.g., ecoregions), it is possible that defaults will result in criteria values that are more or less stringent than the criteria values would be if calculated based on the water chemistry parameters at a given location. The accuracy of an established default value will depend on the method used to group together similar waterbodies that share common physical and chemical characteristics. After grouping similar waterbodies, the state or authorized tribe can derive default values for those waters in each group.

States and authorized tribes have flexibility in the method used to derive default values and may choose whatever grouping method they believe will result in the most accurate defaults, provided that they have sufficient data to support such a method. If states or authorized tribes believe that the default criteria values are more stringent than necessary to protect aquatic life in a specific waterbody, site specific ambient data may be collected and used in the Criteria Calculator to establish site-specific criteria values.

4.4. Must states and authorized tribes use EPA ecoregions to develop default criteria values or can they use the state's own approach?

As described in Question 4.3, states and authorized tribes have discretion on how to establish default criteria values, including how to identify the geographic units to which defaults will be applied, which datasets are used to generate the defaults, and how to generate the default values from those data. A key consideration is grouping waterbodies with similar water chemistry. One option is to group waterbodies based on ecoregions, geographic divisions for which EPA has already processed data and provided DOC estimates. However, states and authorized tribes may elect to use additional data or data divided into different regions. For example, Oregon has "geo-regional" divisions. States and authorized tribes may also choose to define default values by stream order if sufficient data exist to support such a division.

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Section 5: Implementing the Recommended Aluminum Criteria in National Pollutant Discharge Elimination System (NPDES) Permitting

5.1. When using the Criteria Calculator for permitting (i.e., for reasonable potential analysis (RPA) or for developing WQBELs), how will an NPDES permit writer know what inputs to use?

NPDES permit writers should follow their state's criteria implementation guidance.[37] As stated in EPA's *NPDES Permit Writers' Manual,* [38] the goal of the permit writer is to derive effluent limitations that are enforceable, adequately account for effluent variability, consider available receiving water dilution, protect against acute and chronic impacts, account for compliance monitoring sampling frequency, and assure attainment of water quality standards and any applicable waste load allocation.

As described throughout this document, states and authorized tribes that adopt the recommended aluminum criteria should provide sufficient information and explanation in the criteria itself or in implementing documents so permit writers, the regulated community, and the public understand how the criteria operate to protect designated uses. In some cases, the state or authorized tribe may have adopted numeric criteria values for aluminum (e.g., Criteria Calculator outputs) as its water quality standards or adopted default input parameter values to be used in absence of ambient data. In other cases, the state may have adopted provisions specifying how ambient data, if available, must be used in the Criteria Calculator, and how criteria values must be generated. In the absence of state implementation guidance or other provisions, permit writers may also consider existing practices for similar model-based criteria. Permit writers may also wish to consult the water quality standards experts for the state or authorized tribe and the permitting authority may seek guidance from EPA.

5.2. When using the Criteria Calculator to derive criteria values to use for developing NPDES permits, should the inputs be based on upstream ambient waters, the effluent, or a measured or modeled mix of ambient waters and effluent?

The general principles regarding discharges affecting water chemistry in the context of NPDES permitting for aluminum are similar to permitting for discharges of other metals for which criteria are hardness-based. State water quality standards and permitting policies and procedures should include information on how to select locations for obtaining representative input water chemistry values in a manner that ensures calculated criteria are protective of applicable aquatic life designated uses. If

[37] Additional information on the calculation of design conditions can be found in EPA's *Technical Guidance on Supplementary Stream Design Conditions for Steady State Stream Modeling*. U. S. Environmental Protection Agency, Office of Water, Washington, D.C. EPA-440-48-80-91. December 1988. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=00001JA6.txt

[38] USEPA. 2010. NPDES Permit Writers' Manual. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. EPA-833-K-10-001. September 2010. https://www.epa.gov/sites/default/files/2015-09/documents/pwm_2010.pdf

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obtaining chemistry values is not practicable or possible, model inputs could be calculated as described below.

When a discharge from a point source to a receiving water or tributary is expected to influence the chemistry of the receiving water at the permitted discharge location or a downstream location, ambient sampling locations should include locations representing conditions in the waterbody after complete mixing. The number of sampling locations and the frequency of sampling should be adequate to characterize the spatial and temporal variability of the site (see Question 3.2 and Question 3.3 for more information).

If the boundaries of the mixing zone cannot be determined, or if downstream sampling reflecting conditions after mixing is not practicable, input parameter values representing those conditions may be estimated from concentration and flow values for the point source or tributary and the waterbody. In doing so, a range of observed or expected upstream and effluent/tributary conditions should be evaluated. Care should be taken to consider the buffering capacity (alkalinity) of the waters being mixed when estimating the mixed pH.

In general, effluent water chemistry alone should not be used to determine model input parameters. However, this might be appropriate in an effluent-dominated stream. For more information on effluent-dominated streams, see Question 5.4.

5.3. If the state or authorized tribe has adopted the Criteria Calculator or lookup tables, how may a permit writer account for both the most appropriate conditions with respect to receiving water chemistry in deriving appropriate criteria values and "critical conditions" used in reasonable potential determinations and calculating a WQBEL?

In general, as discussed in EPA's *Technical Support Document for Water Quality-Based Toxics Control* and *NPDES Permit Writers' Manual*, NPDES permit writers seek to represent "critical conditions" in their calculations so that the resulting WQBELs will be set at a level necessary to meet water quality standards under those critical conditions and therefore under other foreseeable conditions.

Deriving applicable water quality criteria values (taking into account the most sensitive water chemistry conditions) is one calculation. Developing WQBELs based on those criteria values and using "critical conditions" is a subsequent calculation. The two steps are described below:

Step 1: If the state has adopted aluminum criteria values as static numeric values for a site, the permit writer would use those values. If not, the permit writer should use the Criteria Calculator as follows:

> The permit writer should run the Criteria Calculator using data that represent the spatial and temporal variability at the site, including the most sensitive conditions. The criteria should protect aquatic life throughout the year, over the range of expected conditions, including conditions under which aluminum would be most bioavailable (hence, most toxic) to aquatic life (see Question 1.2 for more information). The criteria values derived from the distribution of

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criteria values should protect for the full range of conditions. (See Section 3 on characterizing spatial and temporal variability for more information).

Step 2: Determine the Need for and Derive WQBELs

After applicable criteria values are derived to protect for the range of conditions, the permit writer must determine whether a facility's discharge is causing, has the reasonable potential to cause, or contributes to an excursion of that criteria (also known as "reasonable potential analysis", or RPA). If a WQBEL is needed, then NPDES permit limits should be derived based on the criteria and assuming "critical conditions" to ensure the WQBEL is as stringent as necessary to meet the criteria.[39]

NPDES permit writers often complete RPAs and derive WQBELs based on a set of steady-state conditions, called "critical conditions" in order to ensure that the WQBELs will protect receiving water quality. Commonly, the 7Q10 or 4B3 stream flow is used to determine wasteload allocations based on chronic aquatic life criteria, and the 1Q10 or 1B3 stream flow is used to determine wasteload allocations based on acute aquatic life criteria. The NPDES authority may also use other critical flows as specified in the relevant water quality standards or permitting policies and procedures. Critical low flows represent relatively little available dilution in the receiving water. Permit limits are then based on the wasteload allocation, acute or chronic, whichever is more restrictive. EPA has provided guidance regarding critical low flows for permitting.[40]

The critical low flow used in RPA and WQBEL calculations may not correspond to the flows typically associated with water chemistry conditions under which aluminum would be most bioavailable (hence, most toxic). In order to ensure water quality is protective of the designated use, criteria values that will be protective of the range of conditions, including conditions under which aluminum would be most bioavailable, should be applied in conjunction with the critical conditions used in RPA and WQBEL calculations. This would ensure a protective limit.

EPA recommends that as RP and WQBELs are reevaluated at permit reissuance, permit writers consider potential changes to water chemistry since the last issuance. Conditions that render aluminum more or less bioavailable in receiving waters could change as the result of a newly permitted discharge or modification of an existing discharge, land-use changes, or changes to hydrologic conditions; all of which may affect pH, total hardness, and DOC.

5.4. Would the recommended aluminum criteria be appropriate for deriving criteria values in effluent-dominated streams?

Yes, the Criteria Calculator and lookup tables can be used to derive criteria values in effluent-dominated streams. As in any case, the nature of the discharge in relation to stream conditions should be

[39] For more information on critical conditions, see Chapter 6 of the NPDES Permit Writers' Manual.
[40] For more on critical conditions, see EPA's *Technical Support Document for Water Quality-based Toxics Control* (March 15, 1991). https://www3.epa.gov/npdes/pubs/owm0264.pdf.

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considered when determining a sampling approach. EPA is aware that in some cases, sampling for inputs to model-based criteria is conducted upstream of the discharge (or the "natural" receiving water, absent any effect of the effluent). However, in other cases sampling for inputs reflects the water chemistry that will exist in the receiving water *after* the receiving water and effluent completely mix (downstream of the discharge). The upstream approach would be more conservative/protective if the discharge itself has characteristics that mitigate aluminum toxicity, such as high concentrations of DOC.

5.5. Can the recommended aluminum criteria be implemented in an NPDES permit for a facility that has not yet started discharging?

Permitting (both determining the need for and deriving a WQBEL) is always a predictive exercise based on critical effluent projections and critical stream conditions that are anticipated during the permit term. The predictive models for both the criteria calculation and for effluent and receiving water mixing are always improved with more refined input values; however, the analyses can be performed using expected ranges of input values even before a discharge occurs.

5.6. To the extent input parameters to the Criteria Calculator vary throughout the year (e.g., seasonally), and thus criteria values may vary, should permit limits also vary?

Seasonal WQBELs can be developed based on calculated seasonal criteria values. As discussed in the response to Question 3.4, the Criteria Calculator may be used to generate seasonal water quality criteria values. The NPDES authority could use the different criteria as the basis for determining reasonable potential and deriving the WQBELs.

Additionally, even in cases where there are not seasonal criteria, NPDES authorities have discretion to provide seasonal or tiered flow limitations in NPDES permits based on seasonal critical conditions, where appropriate, unless the state's water quality standards prohibit this. Where not prohibited, seasonal WQBELs could be based on year-round criteria values but different flow scenarios and background concentrations. To develop seasonal WQBELs, the permit writer would have to model the critical stream flow, background concentrations, and effluent and stream flows during any season in which the criteria were applicable.

EPA recommends that as reasonable potential and WQBELs are reevaluated at permit reissuance, permit writers consider potential changes to water chemistry since the last issuance. Conditions that render aluminum more or less bioavailable in receiving waters could change as the result of a newly permitted discharge or modification of an existing discharge, land-use changes, or changes to hydrologic conditions; all of which may affect pH, total hardness, and DOC. In some cases, additional data and/or monitoring would be required to determine when the various seasonal or tiered flow limits apply.

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5.7. Does EPA have any recommendations on criteria development at the watershed scale, or the potential for shared data collection and implementation at multiple NPDES facilities located in the same general vicinity?

EPA has not developed specific guidance on watershed scale permitting for toxic metals, though specific TMDLs may provide some examples of how to gather and share data to support use of the Criteria Calculator. A key question for the state to consider is whether the water quality data used as inputs to the Criteria Calculator would be representative of the entire area to which the criteria would apply. For more information regarding site characterization, see Section 3 on characterizing spatial and temporal variability. If a TMDL exists for a particular waterbody or watershed, more information may be available that could be used in considering the appropriate watershed scale. More information on watershed-scale permitting is available at https://www.epa.gov/npdes/watershed-based-permitting.

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Section 6: Implementing the Recommended Aluminum Criteria in Assessments, Listings, and Total Maximum Daily Loads (TMDLs)

6.1. How will assessment and listing staff know what numeric values represent "the criteria" when assessing waters with respect to the recommended aluminum criteria?

As described throughout this document, states and authorized tribes that adopt some or all of the recommended aluminum criteria should provide sufficient information and explanation in the criteria itself or in implementing documents so permit writers, the regulated community, and the public understand how the criteria operate to protect designated uses. As discussed in Question 1.2 above, states have options for how to adopt EPA's aluminum criteria recommendation. Specifically, states may develop criteria values at different scales (e.g., statewide, ecoregional, site-specific) using EPA's recommended tools (e.g., the Criteria Calculator, look up tables) and submit those values as criteria to EPA for approval under CWA Section 303(c). States may also adopt both the water chemistry-dependent criteria and an associated derivation methodology whereby the same tools are described along with criteria derivation and implementation methods. EPA recommends that criteria derivation and implementation be included in the state's or authorized tribe's water quality standards. As such, states and authorized tribes should be able to determine the applicable water quality criteria for aluminum for completing water quality assessments by consulting EPA-approved aluminum criteria and associated criteria derivation and implementation methods.

6.2. How should states and authorized tribes prepare to transition to assess waters based on their new Criteria Calculator-based aluminum criteria, particularly for waters for which input parameter data are unavailable?

State and authorized tribes should monitor for input parameters and aluminum if they plan to transition to uses of the 2018 recommended criteria. The Criteria Calculator relies on ambient data, so collecting as much data as feasible before running the Criteria Calculator will facilitate assessment of these criteria. During the time of transition to the new criteria, states may maintain aluminum listings on the CWA Section 303(d) list that were based on the state's or authorized tribe's previously applicable aluminum criteria until water quality can be evaluated using the new criteria for aluminum.

6.3. If the state or authorized tribe only has data on aluminum in the dissolved form (when the criteria are expressed as total recoverable), how does that affect assessment and listing?

As described in EPA's CWA Section 304(a) recommended aluminum criteria document, measurements of dissolved aluminum do not sufficiently characterize the full spectrum of forms of aluminum that contribute to toxicity. EPA recommends that if a state or authorized tribe adopts the recommended criteria, it collects data in a form that appropriately characterizes the bioavailability of aluminum.

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EPA's regulations require that states and authorized tribes assemble and evaluate all existing and readily available water quality-related data and information in developing their CWA Section 303(d) lists (40 CFR 130.7(b)(5)), which would include data and information on the dissolved form of aluminum. However, a state or authorized tribe is not required to use all available data and information to make listing decisions where it can provide a technical, science-based rationale for the exclusion of such data and information. 40 CFR 130.7(b)(6)(iii). For example, a state or authorized tribe may demonstrate that the use of dissolved aluminum measurements in impairment decisions may underestimate the bioavailable aluminum in the waterway and not be representative of the water's impairment status, especially when the levels of aluminum measured as dissolved are below the Criteria Calculator values. However, dissolved aluminum measurements that show concentrations above the criterion would likely indicate that the criterion is exceeded. If a state or authorized tribe decides not to use dissolved aluminum data and information for making listing decisions, particularly measurements that show concentrations above the criterion, it must provide a technical, science-based rationale.

6.4. How does EPA recommend applying the Criteria Calculator for a water that is impaired with respect to one or more of the input parameters?

In some situations, the values for the input parameters would themselves cause impairment of the water (e.g., pH that is outside the range of an approved water quality standard for a state's pH criteria which specify a pH range between 6.5 and 9). If a state or authorized tribe finds that values for input parameters indicate nonattainment of state standards, then the waterbody should be placed on the list of impaired waters for these and any other parameters that are not meeting water quality standards (per 40 CFR 130.7(b)(1)).

The water may or may not be impaired with respect to aluminum, even if one or more of the input parameters causes impairments of other water quality criteria. The Criteria Calculator can be used with a wide range of inputs, regardless of whether those inputs themselves would be considered causes of impairment. For more information about using the Criteria Calculator for values inside and outside the ranges covered by the Criteria Calculator, see Question 2.8.

The Criteria Calculator-derived aluminum criteria are not a substitute for other integrating measures of water quality, such as biological assessments and ambient toxicity tests. When available, the result of these integrative tests should be considered data and information that states and authorized tribes are required to assemble and evaluate for assessment determinations (40 CFR 130.7(b)(5)).

6.5. When both the water chemistry-dependent criteria and an associated derivation methodology are adopted into WQS which aluminum value should be used to develop TMDLs?

States and authorized tribes should develop TMDLs to address the applicable aluminum criteria adopted by the states and authorized tribes and approved by EPA. States and authorized tribes have the option of choosing one, or a combination, of the approaches described in Question 1.2 above.

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States and authorized tribes that adopt a methodology as part of their criteria should include implementation methods in their water quality standards or other legally binding documents, as described in Question 1.3. Such implementation methods should clearly describe which aluminum criteria value is applicable for TMDL development purposes, particularly for states that adopt a combination of the approaches listed above (e.g., ecoregional default values and criteria values derived from the Criteria Calculator).

6.6. When should states and authorized tribes develop TMDLs based on EPA's recommended aluminum criteria?

CWA Section 303(d) requires states and authorized tribes to develop a TMDL when they identify a waterbody as not meeting applicable water quality standards and place the impairment on their biennial CWA Section 303(d) list. As part of the biennial list, states and authorized tribes are required to prioritize impairments on their CWA Section 303(d) lists for TMDL development, taking into account the severity of the pollution and the uses to be made of such waters, and include a schedule of TMDLs that will be developed over the next two years. See 40 CFR 130.7(b)(4). The opportunity to prioritize impairments for TMDL development provides states and authorized tribes flexibility on scheduling TMDL development for waters not meeting the aluminum water quality standard. Such flexibility may be important to states and authorized tribes that identify impaired waters for inclusion on the 303(d) list using small datasets (such as in method 3 in Question 1.8) because the criteria value may not represent conditions under which aluminum is most bioavailable. In these circumstances, states and authorized tribes can consider scheduling these TMDLs for development once the criteria value for the site is derived in a way that will protect aquatic life throughout the range of seasonal and flow conditions at a site, including those conditions of pH, total hardness, and DOC, when aluminum is most bioavailable.

6.7. Can states and authorized tribes write a TMDL to achieve a presumptive aluminum criteria value that is based on a planned change to one of the input variables?

States and authorized tribes should develop TMDLs for the aluminum criteria value that exists at the time of developing the TMDL rather than a presumptive aluminum criteria value based on a planned increase or decrease to one or more of the input parameters (i.e., pH, total hardness, and DOC). As discussed in Question 1.8, the methods for deriving the recommended criteria value are based on input variable values observed in the field. The methods do not provide for a consideration of presumptive, or potential, input variable values that may be realized in the future after practices are put in place to change the input variables. However, as discussed in the previous question, states and authorized tribes have flexibility on prioritizing and scheduling TMDLs for development. As such, instead of developing a TMDL based on the current aluminum criteria value, a state or authorized tribe may first choose to calculate a new criteria value after measures are taken to change the input variables and those changes are realized in the field.

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335. The Commission adopts the identical NMED and UC proposals to revise the chronic and acute criteria for mercury to be consistent with EPA's recommended criteria pursuant to 40 CFR §131.11.

336. The Commission adopts the identical NMED and UC proposals to add a methylmercury criterion of 0.3 mg/kg for protection of human health, as recommended by EPA in 2001.

337. The Commission adopts NMED's proposed revised nitrate criteria based on the research of Dr. Sam Fernald of New Mexico State University, who demonstrated that the revised criteria protect livestock watering.

338. Regarding the "Aquatic Life" criteria the Commission adopts the identical NMED and UC proposals to delete the beryllium criteria because EPA has withdrawn its recommended values. EPA no longer recommends beryllium aquatic life criteria.

339. Regarding the "Human Health" criteria the Commission adopts NMED's proposal to amend the criteria based upon the current EPA recommendations in National Recommended Water Quality Criteria: 2002, EPA-822-R-02-047. The recalculated criteria integrate an updated national default fish consumption rate (17.5 g/day) and, in some cases, relative source contribution values obtained from primary drinking water standards and new cancer potency information from EPA's Integrated Risk Information System.

340. Of these criteria, only the arsenic criterion is New Mexico-specific (e.g., the updated national default fish consumption rate applied to site-specific data collected during a 1997 joint agency study of arsenic in the middle Rio Grande in the vicinity of Albuquerque. The site specific data included: (1) geometric mean of dissolved arsenic concentrations from all river and drain stations of 2.88 mg/L; (2) geometric mean of total arsenic concentrations in eight composited fish-tissue samples from fish collected in the river and drains of 13.13 µg/kg; and (3) risk assumptions, including (a) risk level = 10^{-5}; (b) body weight = 70 kg; (c) cancer potency factor = 1.5; (d) bioaccumulation factor = 4.57 L/kg (geomean tissue 13.13/ geomean H20 2.88); and (e) inorganic As = 65 percent). The recalculation resulted in an arsenic criterion of 9.0 µg/L for consumption of organisms only, and 2.3 µg/L for consumption of water plus organisms. The Commission

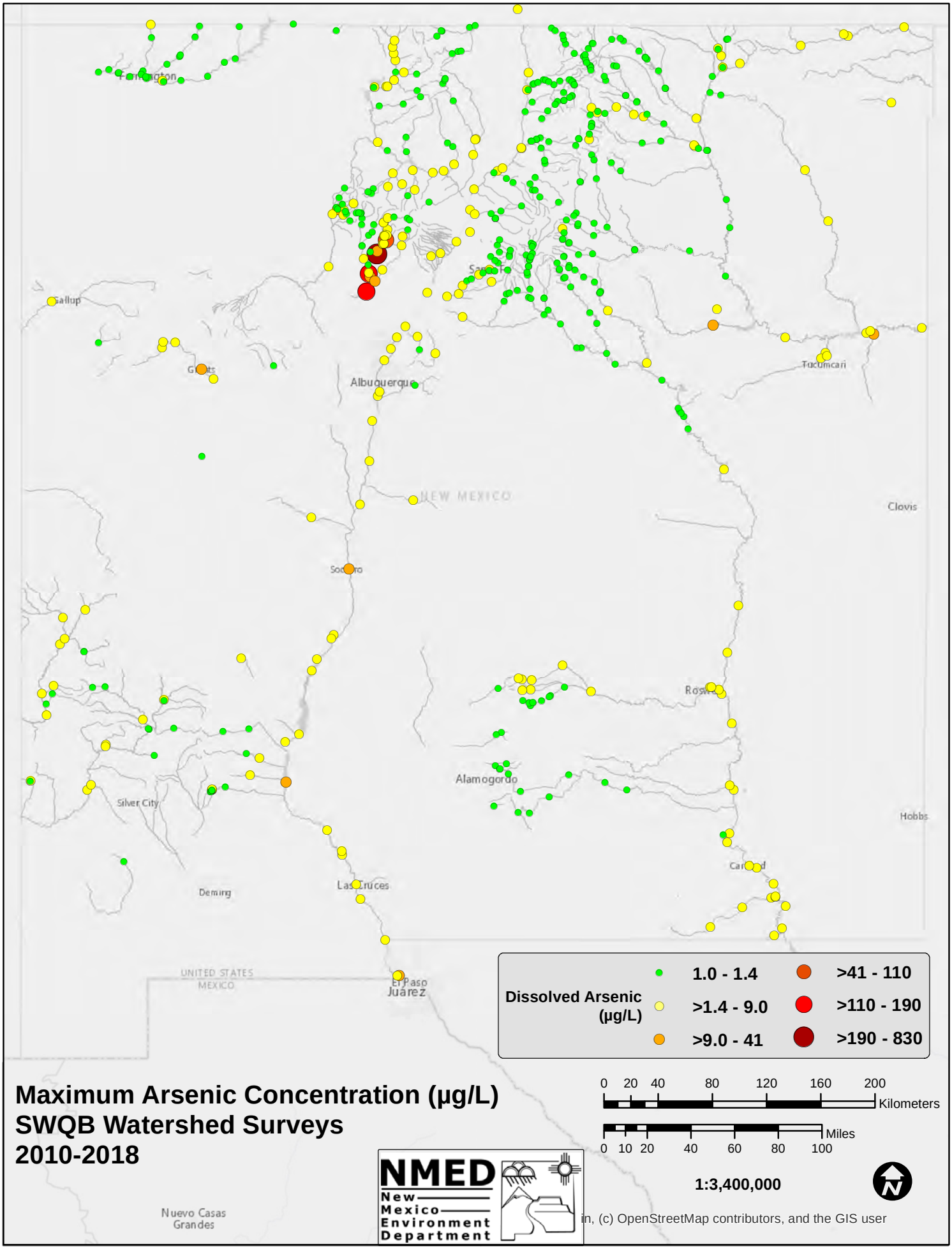
expresses its concern to the department that the assumptions of the level of fish consumption from the Rio Grande may be overstated.

341. The Commission rejects AB's proposal to include numeric criteria for perchlorate-domestic water supply- at 1 ug/L for lack of credible scientific data in the record, and because EPA has not recommended a criterion for ambient waters.

342. The Commission rejects AB's proposal to change the criteria for uranium, dissolved- Domestic Water Supply to 7 ug/L for lack of credible scientific data in the record, and because EPA has not recommended a criterion for ambient waters. The Commission is concerned about uranium, and mindful that it recently lowered the ground water standard, but the record in this triennial review simply does not support such a change at this time.

343. The Commission rejects AB's proposed wildlife habitat dissolved aluminum numeric criterion, proposed aquatic life cyanide numeric criteria, and proposed wildlife habitat and aquatic life selenium numeric criteria for lack of credible scientific data in the record.

[tables begin on next page]



Maximum Arsenic Concentration (µg/L)
SWQB Watershed Surveys
2010-2018

United States
Environmental Protection
Agency

Office of Water
4304T

EPA-822-R-07-001
February 2007



AQUATIC LIFE AMBIENT FRESHWATER QUALITY CRITERIA - COPPER

2007 Revision

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AQUATIC LIFE AMBIENT FRESHWATER QUALITY CRITERIA - COPPER

2007 Revision

(CAS Registry Number 7440-50-8)

February 2007

U.S. Environmental Protection Agency
Office of Water
Office of Science and Technology
Washington, DC

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NOTICES

This document has been reviewed in accordance with U.S. EPA policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This document can be downloaded from EPA's website at:
http://www.epa.gov/waterscience/criteria/aqlife.html

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FOREWORD

Section 304(a)(l) of the Clean Water Act of 1977 (P.L. 95-217) requires the Administrator of the Environmental Protection Agency to publish water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water, including ground water. This document is a revision of criteria based upon consideration of comments received from independent peer reviewers and the public. Criteria contained in this document supplement any previously published EPA aquatic life criteria for the same pollutant(s).

The term "water quality criteria" is used in two sections of the Clean Water Act, section 304(a)(l) and section 303(c)(2). The term has a different program impact in each section. In section 304, the term represents a non-regulatory, scientific assessment of health or ecological effects. Criteria presented in this document are such scientific assessments. If water quality criteria associated with specific waterbody uses are adopted by a state or tribe as water quality standards under section 303, they become enforceable maximum acceptable pollutant concentrations in ambient waters within that state or tribe. Water quality criteria adopted in state or tribal water quality standards could have the same numerical values as criteria developed under section 304. However, in many situations states or tribes might want to adjust water quality criteria developed under section 304 to reflect local environmental conditions. Alternatively, states or tribes may use different data and assumptions than EPA in deriving numeric criteria that are scientifically defensible and protective of designated uses. It is not until their adoption as part of state or tribal water quality standards that criteria become regulatory. Guidelines to assist the states and tribes in modifying the criteria presented in this document are contained in the Water Quality Standards Handbook (U.S. EPA 1994). The handbook and additional guidance on the development of water quality standards and other water-related programs of this agency have been developed by the Office of Water.

This document is guidance only. It does not establish or affect legal rights or obligations. It does not establish a binding norm and cannot be finally determinative of the issues addressed. Agency decisions in any particular situation will be made by applying the Clean Water Act and EPA regulations on the basis of specific facts presented and scientific information then available.

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ACRONYMS

ACR	Acute-Chronic Ratio
BL	Biotic Ligand
BLM	Biotic Ligand Model
CCC	Criterion Continuous Concentration
CF	Conversion Factors
CMC	Criterion Maximum Concentration
CWA	Clean Water Act
DIC	Dissolved Inorganic Carbon
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
EC	Effect Concentration
EPA	Environmental Protection Agency
FACR	Final Acute-Chronic Ratio
FAV	Final Acute Value
FCV	Final Chronic Value
FIAM	Free Ion Activity Model
GMAV	Genus Mean Acute Value
GSIM	Gill Surface Interaction Model
LC50	Lethal Concentration at 50 Percent Effect Level
LOAEC	Lowest Observed Adverse Effect Concentration
NASQAN	National Stream Quality Accounting Network
NOAEC	No Observed Adverse Effect Concentration
pH	Negative logarithm of the concentration (mol/L) of the $H_3O^+[H^+]$ ion; scale range from 0 to 14
SMAV	Species Mean Acute Values
STORET	EPA STOrage and RETrieval Data System
WER	Water-Effect Ratio
WET	Whole Effluent Toxicity
WQC	Water Quality Criteria

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1.0 INTRODUCTION

Copper is an abundant trace element found in the earth's crust and is a naturally occurring element that is generally present in surface waters (Nriagu, 1979). Copper is a micronutrient for both plants and animals at low concentrations and is recognized as essential to virtually all plants and animals (Kapustka et al., 2004). However, it may become toxic to some forms of aquatic life at elevated concentrations. Thus, copper concentrations in natural environments, and its biological availability, are important. Naturally occurring concentrations of copper have been reported from 0.03 to 0.23 µg/L in surface seawaters and from 0.20 to 30 µg/L in freshwater systems (Bowen, 1985). Copper concentrations in locations receiving anthropogenic inputs can vary anywhere from levels that approach natural background to 100 µg/L or more (e.g., Lopez and Lee, 1977; Nriagu, 1979; Hem, 1989) and have in some cases been reported in the 200,000 µg/L range in mining areas (Davis and Ashenberg, 1989; Robins et al., 1997). Mining, leather and leather products, fabricated metal products, and electric equipment are a few of the industries with copper-bearing discharges that contribute to anthropogenic inputs of copper to surface waters (Patterson et al., 1998).

Over the past 20 years, the U.S. Environmental Protection Agency (EPA) has published a number of guidance documents containing aquatic life criteria recommendations for copper (e.g., U.S. EPA 1980, 1985, 1986, 1996). The present document contains EPA's latest criteria recommendations for protection of aquatic life in ambient freshwater from acute and chronic toxic effects from copper. These criteria are based on the latest available scientific information, supplementing EPA's previously published recommendations for copper. This criteria revision incorporated new data on the toxicity of copper and used the biotic ligand model (BLM), a metal bioavailability model, to update the freshwater criteria. With these scientific and technical revisions, the criteria will provide improved guidance on the concentrations of copper that will be protective of aquatic life. The BLM is not used in the saltwater criteria derivation because further development is required before it will be suitable for use to evaluate saltwater data.

This document provides updated guidance to states and authorized tribes to establish water quality standards under the Clean Water Act (CWA) to protect aquatic life from elevated copper exposure. Under the CWA, states and authorized tribes are to establish water quality criteria to protect designated uses. Although this document constitutes EPA's scientific recommendations regarding ambient concentrations of copper, it does not substitute for the CWA or EPA's regulations, nor is it a regulation itself. Thus, it cannot impose legally binding requirements on EPA, states, tribes, or the regulated community, and might not apply to a particular situation based on the circumstances. State and tribal decision makers retain the discretion in adopting approaches, on a case-by-case basis, that differ from this guidance when appropriate. EPA may change this guidance in the future.

Although the BLM has been used in place of the formerly applied hardness-based approach, the updated freshwater criteria derivations in this document are still based on the principles set forth in the *Guidelines for Deriving Numerical Water Quality Criteria for the Protection of Aquatic Life and Their Uses* (Stephan et al. 1985, hereafter referred to as the Guidelines). Section 2 of this document provides an overview of copper bioavailability and the BLM. Additional information on the generalized BLM framework, theoretical background, model calibration, and application for the BLM can be found in the published literature. Section 3 of this document discusses general

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procedures and requirements for applying the BLM to criteria. Section 4 provides the derivation of criteria Final Acute Value (FAV) and Final Chronic Value (FCV) for freshwater organisms. Section 5 discusses plant data and Section 6 discusses other data not included in the criteria derivation. Sections 7 and 8 provide the final criteria statements and information on implementation. Various supplementary information is provided in several appendices.

2.0 APPROACHES FOR EVALUATING COPPER BIOAVAILABILITY

2.1 *General Aspects of Copper Bioavailability*

The toxicity of a chemical to an aquatic organism requires the transfer of the chemical from the external environment to biochemical receptors on or in the organism at which the toxic effects are elicited. Often, this transfer is not simply proportional to the total chemical concentration in the environment, but varies according to attributes of the organism, chemical, and exposure environment so that the chemical is more or less "bioavailable". Definitions of bioavailability vary markedly (e.g., National Research Council, 2003) and are often specific to certain situations, but a useful generic definition is the relative facility with which a chemical is transferred from the environment to a specified location in an organism of interest.

Of particular importance to bioavailability is that many chemicals exist in a variety of forms (chemical species). Such chemical speciation affects bioavailability because relative uptake rates can differ among chemical species and the relative concentrations of chemical species can differ among exposure conditions. At equilibrium in oxygenated waters, "free" copper exists as cupric ion - Cu(II) weakly associated with water molecules ($Cu{\cdot}nH_2O^{+2}$), but this species is usually a small percentage of the total copper. Most dissolved copper is part of stronger complexes with various ligands (complexing chemicals that interact with metals), including dissolved organic compounds, hydroxides, carbonates, and other inorganic ligands. Substantial amounts of copper can also be adsorbed to or incorporated into suspended particles. More information on copper speciation in freshwater can be found in Kramer et al. (1997), Bryan et al. (2002), and Smith et al. (2002).

Copper toxicity has been reported to vary markedly due to various physicochemical characteristics of the exposure water (e.g., either laboratory or field), including temperature, dissolved organic compounds, suspended particles, pH, and various inorganic cations and anions, including those composing hardness and alkalinity (see reviews by Sprague, 1968; Hunt, 1987; Campbell, 1995; Allen and Hansen, 1996; Paquin et al., 2002). Many of these physicochemical factors affect copper speciation, and their effects on copper toxicity therefore could be due to effects on copper bioavailability. That bioavailability is an important factor is evident from uptake of copper by aquatic organisms being reduced by various organic compounds and inorganic ligands known to complex copper (Muramoto, 1980; Buckley et al., 1984; Playle et al., 1993 a,b; MacRae et al., 1999).

A "ligand" is a complexing chemical (ion, molecule, or molecular group) that interacts with a metal like copper to form a larger complex. A "biotic ligand" is a complexing chemical that is a component of an organism (e.g. chemical site on a fish gill). For certain ligands, some studies have demonstrated that the concentration of free copper associated with a specified level of accumulation or toxicity changes little as the ligand concentration is varied, despite major changes in the

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proportion of copper bound to the ligand (see review by Campbell, 1995). This suggests that, even at low concentrations, free copper is more important to bioavailability than the ligand-bound copper. This is expected if accumulation and toxicity are dependent on the binding of copper to a biochemical receptor "X" on the surface of the organism, forming a chemical species X-Cu (receptor-bound metal) that is a first limiting step in accumulation and toxicity. By standard chemical equilibrium expressions, the amount of such species and the consequent biological effects would be a function of the activity of just free copper (Morel, 1983 a), a relationship commonly referred to as the free ion activity model (FIAM). Ligand-bound copper (Cu-L) would contribute to copper bioavailability if (a) a species X-Cu-L is formed that is important to copper accumulation/toxicity, (b) the microenvironment near the organism surface is such that Cu-L dissociates and increases the free copper activity interacting with "X", or (c) copper uptake is via mechanisms that do not entail binding to such a receptor and can accommodate different copper species. Some studies have indicated dissolved complexes of copper do contribute to bioavailability (reviews by Sprague, 1968; Hunt, 1987; Campbell, 1995; Allen and Hansen, 1996; Paquin et al., 2002).

The effects of physicochemical factors on copper toxicity are diverse and the specific chemistry of the exposure water will determine whether or not there are appreciable effects on copper speciation and a resulting strong relationship of toxicity to free copper. Usually copper toxicity is reduced by increased water hardness (reviews by Sprague, 1968; Hunt, 1987; Campbell, 1995; Allen and Hansen, 1996; Paquin et al., 2002), which is composed of cations (primarily calcium and magnesium) that do not directly interact with copper in solution so as to reduce bioavailability. In some cases, the apparent effect of hardness on toxicity might be partly due to complexation of copper by higher concentrations of hydroxide and/or carbonate (increased pH and alkalinity) commonly associated with higher hardness. However, significant effects on toxicity often are still present when hardness is increased in association with anions which do not interact strongly with copper (Inglis and Davis, 1972; Chakoumakos et al., 1979; Miller and Mackay, 1980; Erickson et al., 1987). Hardness cations could have some limited effect on copper speciation by competing with copper for the same dissolved ligands, but increased hardness would then increase free copper and thus increase, not decrease, toxicity. Sodium has also been reported to affect copper toxicity (Erickson et al., 1996 b) and pH effects can be partly due to effects of hydrogen ion other than on copper speciation (Peterson et al., 1984).

The effects of hardness cations could be explained by the competing with copper for the biochemical receptor "X", thus reducing copper uptake (Zitko, 1976; Zitko et al., 1976; Pagenkopf, 1983). Reduced metal bioavailability due to increased hardness cations has been experimentally demonstrated (Playle et al., 1992; Meyer et al., 1999, 2002), although this does not specifically establish cation competition as the mechanism. Pagenkopf (1983) provided a mathematical description of a Gill Surface Interaction Model (GSIM) that addressed the effects on metal toxicity of both metal speciation and cations via the interactions of gill surface biochemical receptors with the free toxic metal, other metal species, hardness cations, and hydrogen ion.

The empirical evidence demonstrates that copper toxicity is affected by exposure conditions and that much of these effects is plausibly attributed to effects of ligands and cations on copper bioavailability. However, it should not be presumed that all of the observed effects of the physicochemical factors on copper toxicity reflect effects on bioavailability, or that bioavailability

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effects are just due to ligand complexation and cation competition. For example, acute copper toxicity in aquatic organisms has been related to disruption of osmoregulation, specifically sodium/potassium exchange (Lauren and MacDonald, 1986; Wood, 1992; Wood et al., 1997; Paquin et al., 2002), which can be affected by calcium other than by competition with copper for the same biochemical receptor. Similarly, reported effects of sodium and potassium on copper toxicity (Erickson et al., 1996 b) might simply reflect favorable or unfavorable ion exchange gradients, rather than any effect on copper bioavailability. Nevertheless, the effects of ligand complexation and cation competition on copper bioavailability provide a reasonable conceptual framework for improved descriptions of how copper toxicity differs across exposure conditions.

2.2 *Existing Approaches*

EPA aquatic life criteria for metals address the reported effects of hardness on metal toxicity using empirical regressions of toxic concentrations versus hardness for available toxicity data across a wide range of hardness (Stephan et al., 1985). Such regressions provided the relative amount by which the criteria change with hardness, but have certain limitations. The regressions were not just of hardness, but of any other factor that was correlated with hardness in the toxicity data set used for the regressions, particularly pH and alkalinity. Although these regressions therefore address more bioavailability issues than hardness alone, they best apply to waters in which the correlations among hardness, pH, and alkalinity are similar to the data used in the regressions. The separate effects of these factors are not addressed for exposure conditions in which these correlations are different. In addition, some physicochemical factors affecting metal toxicity, such as organic carbon, are not addressed at all.

Existing EPA metals criteria also address bioavailability by using dissolved metal as a better approximation for metal bioavailability than total metal (U.S. EPA, 1993). Although this approach accounts for the low bioavailability of metal on suspended particles, it does not address the major effects of various dissolved species on bioavailability. This approach could conceivably be further developed to include just part of the dissolved copper, but this not only requires resolving what species to include, how to weight them, and how to assess their concentrations, but also would not address the effects of cations and other factors that affect toxicity in addition to metal speciation. Such a "bioavailable fraction" approach is not justified, because no fraction of metals species provides a constant measure of toxicity.

To address more completely the modifying effects of water quality than the hardness regressions achieve, EPA issued guidance in the early 1980s on the water-effect ratio (WER) method (Carlson et al., 1984; U.S. EPA, 1983, 1992, 1994). The WER is "a biological method to compare bioavailability and toxicity in receiving waters versus laboratory test waters" (U.S. EPA, 1992). A WER is calculated by dividing the acute LC50 of the metal, determined in water collected from the receiving water of interest, by the LC50 of the metal determined in a standard laboratory water, after adjusting both test waters to the same hardness. The standard laboratory water LC50 is used as the denominator to reflect that this LC50 is measured in test water that has water quality characteristics representative of the test waters used to develop the Water Quality Criteria (WQC) toxicity database, at least as a good approximation. The national hardness-based acute criterion concentration is then multiplied by this ratio (i.e., the WER) to establish a site-specific criterion that reflects the effect of site water characteristics on toxicity. However, a WER accounts only for

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interactions of water quality parameters and their effects on metal toxicity to the species tested and in the water sample collected at a specific location and at a specific time. There is also significant cost to generate a single WER.

Because of the limitations of these past approaches for addressing bioavailability in metals criteria, there is a need for an approach that (1) explicitly and quantitatively accounts for the effect of individual water quality parameters that modify metal toxicity and (2) can be applied more cost-effectively and easily, and hence more frequently across spatial and temporal scales. An assessment framework that incorporates the bioavailability mechanisms discussed in Section 2.1 was therefore used to address more comprehensively the effects of physicochemical exposure conditions on copper toxicity with lower costs than required by the WER approach.

2.3 *The Biotic Ligand Model and Its Application to Criteria Development*

The interactions of toxic metal species and other exposure water constituents with biological surface receptors described by Zitko (1976), Morel (1983), and Pagenkopf (1983) provided the basic conceptual and mathematical structure for the bioavailability model to be used here (Figure 1). Subsequent experimental work has supported various model tenets by demonstrating the effects of complexing ligands and competing cations on accumulation of toxic metals at fish gills and the relationship of toxic effects to accumulation, and has also provided estimates of various model parameters (Playle et al., 1992, 1993a,b; Janes and Playle, 1995; MacRae et al., 1999, Meyer et al., 1999, 2002; McGeer et al., 2002). Various efforts in metal speciation modeling also have provided the ability to do better speciation calculations, especially regarding complexation of metals by organic matter (e.g., Tipping, 1994). This experimental work has supported further metal toxicity model development (Meyer, 1999; Brown and Markich, 2000; McGeer et al., 2002; Di Toro et al., 2001; Santore et al., 2001; Paquin et al., 2002). This bioavailability modeling approach is now commonly termed "Biotic Ligand Models" to broaden the scope beyond gill surfaces and to acknowledge that the biochemical receptor "X" discussed in Section 2.1 is a metal-binding ligand that is treated similarly to ligands in the exposure water, except that it is on the organism and is the keystone for metal accumulation and toxicity.

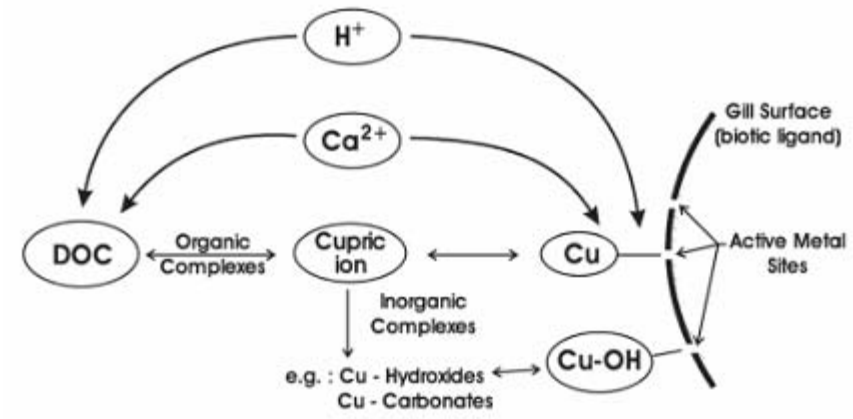


Figure1. Conceptual Diagram of Copper Speciation and Copper-Gill Model (after Pagenkopf, 1983)

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Briefly, available evidence indicates that both free copper and copper monohydroxide bind to a biotic ligand "Lb" on the organism's surface (Lb-Cu and Lb-CuOH) and that death occurs when a certain amount of the total biotic ligand sites are occupied by copper. This ligand must be at the organism surface because the model describes its interactions with the external exposure water. However, this does not mean that this ligand is the site of toxic action; rather it is only necessary to assume that copper accumulation at the site(s) of toxic action is proportional to binding at the biotic ligand (i.e., the biotic ligand controls bioavailability). Other cations also will bind to the biotic ligand, affecting copper bioavailability because higher concentrations of copper are needed for copper to reach toxic levels. The binding to the biotic ligand is considered to be at equilibrium, with apparent (activity-corrected) equilibrium constants K_{LbCu}, K_{LbCuOH}, and K_{LbCj}, respectively, for free copper, copper hydroxide, and the "jth" competing cation. Chemical speciation in the exposure water is also considered to be at equilibrium, and chemical speciation calculations are conducted to compute the free copper, copper hydroxide, and competing cation activities to which the biotic ligand is exposed. Because binding to the actual biotic ligand cannot be measured, it is expected that accumulation relationships for some measurable variable (e.g., the total metal in gill tissue) provide a reasonable surrogate for the actual biotic ligand. Because criteria deal with concentrations eliciting a certain level of effects on groups of organisms (e.g., LC50s), model calculations are for an organism with characteristics appropriate for such group-wide statistics.

How the BLM is applied to criteria can be best discussed by starting with the following general expression for the BLM:

$$EC = EC_0 \cdot f_C \cdot f_L \qquad \text{Equation 1}$$

where EC is the total dissolved copper concentration eliciting an effect, EC_0 is a baseline EC in the absence of any complexing ligands and competing cations, f_C should be a factor (<1) for how much competing cations increase EC, and f_L should be a factor (<1) for how much complexing ligands increase EC. For the BLM used here:

$$EC_0 = \frac{f_{LbT}}{(1 - f_{LbT}) \cdot K_{LbCu}} \qquad \text{Equation 2}$$

$$f_C = 1 + \sum_j^m \left(K_{CjLb} \cdot [C_j]\right) \qquad \text{Equation 3}$$

$$f_L = \frac{1}{\alpha_{Cu^{+n}} + \frac{K_{LbCuOH}}{K_{LbCu}} \cdot \alpha_{CuOH}} \qquad \text{Equation 4}$$

where f_{LbT} is the fraction of the biotic ligand sites that must be occupied by copper to elicit the toxicity of interest (e.g., a lethal accumulation divided by the accumulation capacity), m is the

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number of competing cations included in the model, [Cj] is the concentration of the jth competing cation, α_{Cu+2} is the ratio of free copper concentration to total dissolved copper concentration, α_{CuOH} is the ratio for the copper hydroxide complex, and the ratio K_{LbCuOH}/K_{LbCu} specifies the bioavailability of CuOH relative to free copper. Thus, in the absence of complexing ligands and competing cations, the toxic concentration is only a function of the binding strength of free copper and the copper occupied fraction of biotic ligand sites needed to elicit toxicity. The increase in the effect concentration due to competing cations is simply a sum of the products of their concentrations and binding constants. The increase in the effect concentration due to complexing ligands is the inverse of the sum of the products of the relative bioavailabilities and concentration fractions of the species that bind to the biotic ligand (free copper and copper hydroxide).

If toxicity to all the biological species in the criteria (at least the most sensitive ones) were determined based on measured accumulation properties and the relationship of toxicity to accumulation, the above model equations would be directly applied in criteria calculations. However, this is not the case. Although gill accumulation properties and lethal accumulations have been measured for certain species and conditions, and this has been useful in validating BLM assumptions and formulations, the data that must be applied to the criteria consists of water effect concentration (ECs) for biological species for which this accumulation information is generally not available. The BLM therefore is needed, not to make absolute calculations regarding toxic concentrations, but to extrapolate toxic concentrations from one exposure condition to another:

$$EC_A = EC_B \cdot \frac{f_{C,A} \cdot f_{I,A}}{f_{C,B} \cdot f_{I,B}} \qquad \text{Equation 5}$$

where the A and B subscripts refer to different exposure conditions. The general procedure that was followed for criteria development here was to use the above equation to normalize all available toxicity data to a reference exposure condition, calculate criteria values at the reference condition, and again use the above equation to compute criteria at other conditions.

This means that the BLM assumptions and parameters that just pertain to EC_0 are not important to its application to criteria, which actually simplifies model validation and parameterization needs. In particular, there is no need to estimate f_{LbT}, or the lethal accumulations and accumulation capacities that define this fraction. Furthermore, the absolute values of K_{LbCu} and K_{LbCuOH} do not need to be known, only their relative value (and if copper binding to the biotic ligand was dependent only on free copper, the value of K_{LbCu} would not be needed at all). Absolute values are only needed for the binding constants for the competing cations, as well as the various constants needed in speciation calculations to estimate α_{Cu+2} and α_{CuOH}. For BLM application to criteria, the important concern is whether f_C and f_L are suitably formulated and parameterized, and not with issues that relate to lethal accumulations and accumulation capacities.

2.4 *BLM Uncertainties and Performance*

The BLM employed here uses equilibrium reactions of copper and other cations with a single, simple type of surface ligand as the focus for all the effects of physicochemical exposure conditions on toxicity, and thus is a simple, approximate representation for the complex set of chemical

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reactions and transfers involved with environmental copper concentrations eliciting toxicity. As already noted, cation effects might involve mechanisms other than competition for a surface ligand. The microenvironment at the gill might change copper speciation. Multiple mechanisms that do not react the same to external conditions might be involved in copper bioavailability and toxicity. Accumulation parameters based on bulk gill measurements will likely not be the same as those for the biotic ligand. Nonequilibrium processes might be important, especially regarding the relationship of copper-binding on a surface ligand to toxic action.

However, any model is a simplification of reality and the existence of uncertainties does not preclude a model from being useful and justified. Despite its simplicity, the BLM used here provides a reasonable mechanistic framework for the well-established effects of copper speciation, explicitly addressing the relative bioavailability of different copper species. It also includes a plausible mechanism that allows the effects of cations to be addressed and uses a comprehensive model for calculating the required concentrations of various chemical species. Even if the mechanistic descriptions are incomplete, this model allows the major empirical effects of complexing ligands and competing cations to be described in a more comprehensive and reasonable fashion than other approaches.

Because this model is used in criteria to predict relative effects of physicochemical exposure factors, its utility for criteria can be judged based on how well it predicts the relative effects of these factors in copper toxicity studies. Examples of BLM performance for various exposure factors and studies are provided in the technical support document for this criteria. Figure 2 shows one example from a study on the effects of various exposure conditions on the acute lethality of copper to fathead minnows. This set of exposures consisted of synthetic exposure solutions of various total ion concentrations with fixed ratios of the major cations and anions, at a fixed pH (8.0) and low dissolved organic matter (< 0.5 mg/L). Observed dissolved LC50s (solid circles with uncertainty bars) varied by 24-fold for only a 9-fold change in total ions. These large effects reflect the combined influences of increased alkalinity (copper carbonate complex formation), hardness, and sodium. Considering the wide range of the observed LC50s and that the model was not fitted to these data, BLM-predicted LC50s (open symbols) were rather accurate, ranging from 55 to 87% (average 75%) of the observed value. More importantly for criteria, the predicted relative change across the range of total ion concentration was 20-fold, very close to that observed.

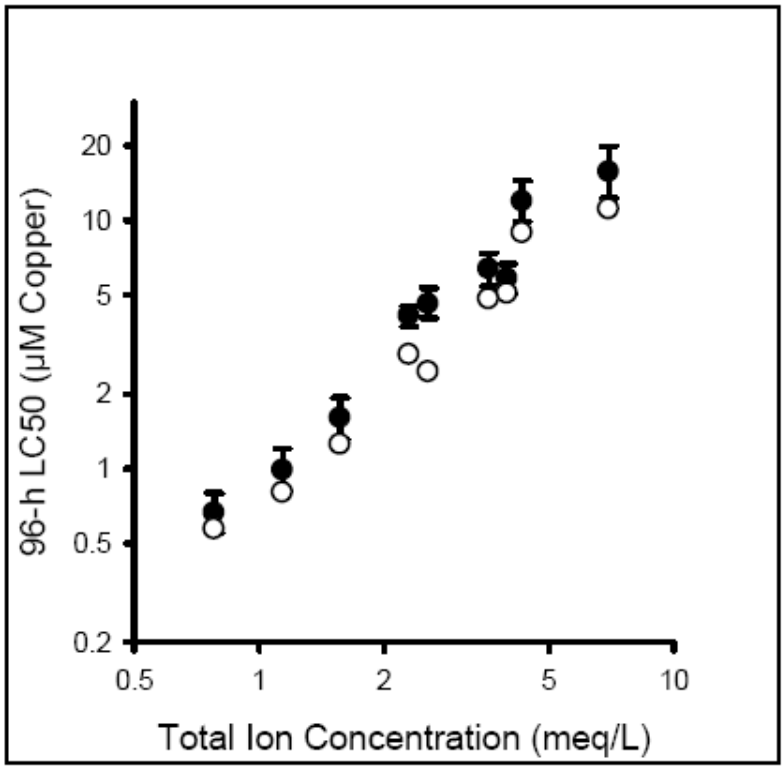


Figure 2. Effects of increasing total ion concentration on the acute lethality of copper to fathead minnows at constant pH=8 and low DOC < 0.5 mg/L. Solid symbols represent observed values, open symbols represent predicted values.

Model performance can also be judged across a variety of factors as in Figure 3, which shows predicted versus observed LC50s for a large number of exposures in the cited study, which varied hardness, alkalinity, sodium, and pH together and separately over a wide range. Observed LC50s varied by about 60-fold, but predicted values deviated from observed values by only 0.12 log units (a factor of 1.3) on average, and at worst only slightly more than a factor of 2. Again, more information on model performance is provided in the Technical Support Document and the figures here just provide some examples demonstrating the utility of this model for use in criteria.

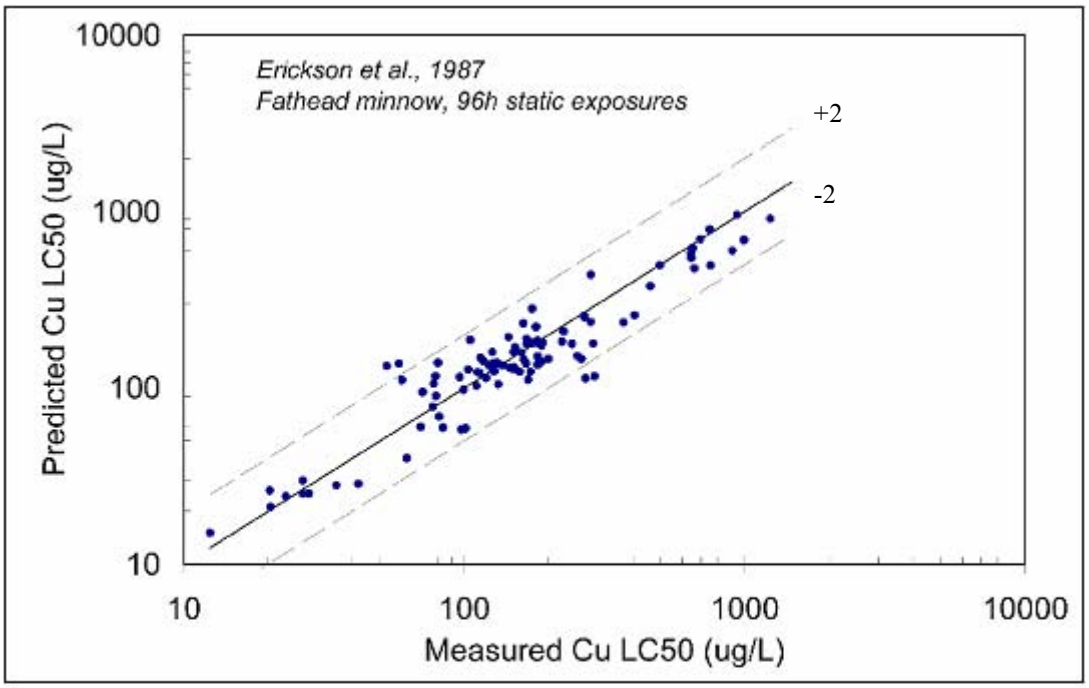


Figure 3. Comparison of Predicted and Measured Acute Copper Toxicity to *P. promelas*.

The use of the BLM to predict the bioavailability and toxicity of copper to aquatic organisms under site-specific conditions is a significant change from the previous Criterion Maximum Concentration (CMC) derivation methodology. Previous aquatic life criteria documents for copper (e.g., U.S. EPA, 1980, 1985, 1996) expressed the CMC as a function of water hardness. Now, EPA chooses to utilize the BLM to update its freshwater acute criterion because the BLM accounts for all important inorganic and organic ligand interactions of copper while also considering competitive interactions that influence binding of copper at the site of toxicity, or the "biotic ligand." The BLM's ability to incorporate metal speciation reactions and organism interactions allows prediction of metal effect levels to a variety of organisms over a wide range of water quality conditions. Accordingly, the BLM is an attractive tool for deriving water quality criteria. Application of the BLM has the potential to substantially reduce the need for site-specific modifications, such as Water Effect Ratio, to account for site-specific chemistry influences on metal toxicity.

The updated BLM-based WQC will in some cases be more stringent and in other cases less stringent than the hardness based WQC. As there is not a single WQC value to use for comparison purposes, it will only be possible to provide illustrative examples of each situation. It is the judgement of the EPA that the BLM-based WQC for Cu will provide an improved framework for evaluating a level of protection (LOP) that is consistent with the LOP that was intended by the 1985 Guidelines (i.e., a 1-in-3 year exceedance frequency that will be protective of 95% of the genera).

While the BLM is currently considered appropriate for use to derive an updated freshwater CMC for the acute WQC, further development is required before it will be suitable for use to

evaluate a saltwater CMC or a Criterion Continuous Concentration (CCC) or chronic value (freshwater or saltwater WQC).

3.0 INCORPORATION OF THE BLM INTO CRITERIA DERIVATIONS PROCEDURES

3.1 *General Final Acute Value (FAV) Procedures*

Application of the acute copper BLM to the derivation of the copper FAV is analogous to procedures already described in the Guidelines for metals criteria using empirical hardness regressions. For these hardness-dependent metals criteria, LC50s at various hardness are normalized to a reference hardness using the regression slopes. The normalized LC50s for each biological species are averaged to derive Species Mean Acute Values (SMAVs) at the reference hardness. The SMAVs within each genus are then averaged to derive Genus Mean Acute Values (GMAVs) at the reference hardness. The Guidelines' procedures for estimating the fifth percentile of the GMAVs are then used to derive the FAV at the reference hardness. FAVs for other hardness can then be derived using the hardness regression slope, and these FAVs are used to calculate the Criterion Maximum Concentration (CMC) by dividing the FAV by 2.0 and the Final Chronic Values (FCV) by dividing the FAV by the Final Acute-Chronic Ratio (FACR). Following the Guidelines, the Criterion Continuous Concentration (CCC) is set to the FCV unless other data justifies a lower value.

Extending this procedure to apply the BLM simply involves normalizing the LC50s to a reference exposure condition that includes all the physicochemical exposure factors important to the BLM, not just hardness. For this normalization, the BLM provides the factors f_C and f_L discussed in Section 2.3, these factors serving the same purpose as the hardness regression slope described above. Each LC50 to be used in criteria derivation would be normalized to the reference exposure conditions by the equation:

$$LC50_R = LC50_A \cdot \frac{f_{C,R} \cdot f_{L,R}}{f_{C,A} \cdot f_{L,A}} \qquad \text{Equation 6}$$

where the subscript A refers to the exposure conditions for the observed LC50 and the subscript R refers to the reference exposure conditions to which the LC50 is being normalized. These normalized LC50s are then used to derive the SMAVs, GMAVs, and FAV at the reference exposure condition as described above for the hardness-corrected criteria. The BLM is then used to derive FAVs at other exposures by the equation:

$$FAV_B = FAV_R \cdot \frac{f_{C,B} \cdot f_{L,B}}{f_{C,R} \cdot f_{L,R}} \qquad \text{Equation 7}$$

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where the subscript B refers to the exposure conditions for which an FAV is desired. These BLM-derived FAVs are then used to derive CMCs and CCCs following standard Guidelines procedures.

For the criteria in this document, the reference exposure conditions to which LC50s are normalized and at which the reference FAV is calculated are as follows (see also footnote f in Table 1). The water chemistry used in the normalization was based on the EPA formulation for moderately-hard reconstituted water, but any other water chemistry could have been used. In this formulation the parameters included: temperature = 20°C, pH = 7.5, DOC = 0.5 mg/L, Ca = 14.0 mg/L, Mg = 12.1 mg/L, Na = 26.3 mg/L, K = 2.1 mg/L, SO_4 =81.4 mg/L, Cl = 1.90 mg/L, Alkalinity = 65.0 mg/L and S = 0.0003 mg/L.

3.2 *BLM Input Parameters*

For applying an LC50 to criteria derivations and for determining an FAV at exposure conditions of interest, the necessary water quality input parameters for BLM calculations are temperature, pH, dissolved organic carbon, major geochemical cations (calcium, magnesium, sodium, and potassium), dissolved inorganic carbon (DIC, the sum of dissolved carbon dioxide, carbonic acid, bicarbonate, and carbonate), and other major geochemical anions (chloride, sulfate). DIC measurements are typically not made in the environment, and an alternative input parameter is alkalinity, which can be used with pH and temperature to estimate DIC. There is some evidence that other metals such as iron and aluminum can have an effect on copper toxicity to aquatic organisms, which might be due to interactions of these metals with the biotic ligand, effects of these metals on organic carbon complexation of copper, or adsorption of copper to iron and aluminum colloids which are present in filtrates used to measure dissolved copper. These metals are not currently included in routine BLM inputs, but users are encouraged to measure dissolved iron and aluminum as part of monitoring efforts to support possible future criteria applications.

A number of fixed parameters are also used in the BLM but are not required user inputs in criteria derivations. These include the variety of equilibrium constants used in copper speciation calculations, and also the binding constants for copper and various cations to the biotic ligand. The values for these constants were obtained from work by Playle and coworkers (Playle et al., 1992, 1993a,b) and also by inference from the relationship of toxicity to various water quality characteristics. More information about these parameters can be obtained from the technical support document.

3.3 *Data Screening Procedures*

To use a toxicity test in the derivation of BLM-based criteria, information must be available for the various water quality parameters described in Section 3.2. This is in contrast to past metals criteria, for which the only necessary water quality parameter was hardness. Many of these parameters are not routinely measured in toxicity tests and, if measured, are not necessarily reported in the primary literature for the test, especially for older toxicity tests. However, this information might be available from supplemental sources or be estimated based on other information. Therefore, in addition to reviewing the primary sources for relevant information,

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additional efforts were made to obtain or estimate the necessary water quality parameters for as many of the available LC50s as possible.

A detailed description of these efforts is provided in Appendix C, Estimation of Water Chemistry Parameters for Acute Copper Toxicity Tests, and are summarized as follows. Reports of acute copper toxicity tests identified in literature searches were reviewed to identify LC50s for possible inclusion in the criteria derivation. In addition to test acceptability standards specified in the Guidelines, the current effort also required that the LC50s be based on measured copper concentrations. LC50s based on nominal concentrations have been used in previous criteria, but there are enough measured LC50s for copper that this was considered to be no longer warranted, especially considering the more advanced bioavailability assessments represented by the BLM. For the identified LC50s, the primary reports were reviewed to record all reported information on dilution and test water chemistry. Any additional references specified by the authors were also obtained and reviewed. If test waters were synthetically prepared based on specified formulas, these were used to estimate parameters as appropriate. When critical water chemistry parameters were not available, authors were contacted regarding unpublished information or to measure missing water chemistry parameters in dilution source waters. If primary or corresponding authors could not be contacted, an attempt was made to contact secondary authors or personnel from the laboratories where the studies were conducted. Where actual water chemistry data were unavailable, data from other studies with the same water source were used as surrogate values if appropriate. Absent this, the U.S. Geological Survey's National Stream Quality Accounting Network (NASQAN) and the EPA STOrage and RETrieval (STORET) were used to obtain data for ambient surface waters which were the source of water for a test. In some instances other available sources were contacted to obtained water chemistry data (e.g., city drinking water treatment personnel). The acquired data were scrutinized for representativeness and usefulness for estimating surrogate values to complete the water quality information for the dilution and/or test water that was used in the original studies. When the above sources could not be used, geochemical ion inputs were based on reported hardness measurements and regressions relationships constructed for the relationship of various ions to hardness from NASQAN data.

As with any modeling effort, the reliability of model output depends on the reliability of model inputs. Although the input data have been closely scrutinized, the reliability of the BLM-normalized LC50s are subject to the uncertainties of the estimation procedures described above. Therefore, a ranking system was devised to rank the quality of the chemical characterization of the test water. Studies with a rank of 1 contain all of the necessary parameters for BLM input based on measurements from either the test chambers or the water source. In general, studies in which the BLM input parameters were reported for test chamber samples take precedence over studies in which the parameters were reported only for the source water. A characterization ranking of 2 denotes those studies where not all parameters were measured, but reliable estimates of the requisite concentrations could be made. Similarly, a rank of 3 denotes studies in which all parameters except DOC were measured, but reliable estimates of DOC could be made. For the majority of the tests, a chemical characterization of 4+ was assigned because hardness, alkalinity, and pH were measured, and the ionic composition could be reliably estimated or calculated. A 4- was assigned to those studies conducted using standard reconstituted water in which hardness, alkalinity, or pH was either measured or referenced, and the recipe for the water is known (ASTM, 2000; U.S. EPA, 1993). The chemical characterization rank of 5 was ascribed to studies in which

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one of the key parameters (DOC, Ca, pH, alkalinity) was not measured, and when it could not be reliably estimated. If two or more key parameters (DOC, Ca, pH, alkalinity) were not measured and could not be reliably estimated, a study was given a chemical characterization rank of 6. Studies receiving a quality rating of greater than 4+ (i.e., higher than 4) were not used in the criteria development procedures because the estimates for some of the key input parameters were not thought to be reliable, all other studies were used.

3.4 *Conversion Factors*

The LC50s used in deriving previous EPA metals criteria were based on total metal concentration (measured or nominal) and the criteria were consequently for total metals concentration. EPA afterwards made the decision that metals criteria should be based on dissolved metal because it was thought to better represent the bioavailable fraction of the metal (U.S. EPA, 1993). It was thus necessary to convert the criteria to a dissolved concentration basis. However, at that time, most toxicity tests reported only total concentration, so that a procedure was necessary to estimate the likely fractions of metals that were dissolved in typical toxicity tests. Studies were therefore conducted to determine these fractions under a variety of test conditions that mimicked the conditions in the tests used to derive the metals criteria (University of Wisconsin-Superior, 1995). These tests demonstrated high fractions of dissolved copper and resulted in a conversion factor (CF) of 0.96 for converting both the CMC and CCC for copper from a total to dissolved basis (Stephan, 1995). The BLM-derived criteria developed here also uses dissolved copper as the basis for criteria, assuming a negligible bioavailability for particulate copper. The conversion factor of 0.96 was also used to convert total to dissolved copper for any toxicity test for which dissolved copper measurements were not available.

3.5 *Final Chronic Value (FCV) Procedures*

Because the minimum eight family data requirements for chronic toxicity data were not met in order to calculate the FCV by the fifth percentile method used for the FAV and because insufficient information was available to develop a chronic BLM, EPA derived the CCC utilizing the Acute to Chronic Ratio (ACR) approach from the Guidelines (Stephan et al., 1985). To calculate the FCV at a specific water chemistry, the FAV at that chemistry is divided by the FACR. This entails the assumption that the acute BLM reasonably approximates the bioavailability relationships for chronic toxicity. Limited data available regarding effects of water chemistry on sublethal effects and chronic lethality do show substantial effects of organic matter, alkalinity, pH, and sodium (Winner, 1985; Erickson et al., 1996 a,b) similar to those in the acute BLM used here. For hardness, apparent effects are limited and uncertain, but the use of the acute BLM does not introduce major uncertainties in this regard because the effects of hardness by itself in the acute BLM are also limited.

4.0 DATA SUMMARY AND CRITERIA CALCULATION

4.1 *Summary of Acute Toxicity to Freshwater Animals and Criteria Calculation*

The screening procedure outlined in Sec. 3.3 (high quality data = 1, low quality data > 4, e.g. 4+) identified approximately 600 acute freshwater toxicity tests with aquatic organisms and copper

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potentially acceptable for deriving criteria. Of these tests, approximately 100 were eliminated from the criteria derivation process because they did not report measured copper concentrations. Nearly 150 additional tests were eliminated from the calculation of the FAV because they received a quality rating of greater than 4 in the quality rating scheme described in section 3.3 described above.

Data from approximately 350 tests were used to derive normalized LC50 values, including 15 species of invertebrates, 22 species of fish, and 1 amphibian species (Table 1), representing 27 different genera. Species Mean Acute Values (SMAVs) at the reference chemistry were calculated from the normalized LC50s and Genus Mean Acute Values (GMAVs) at the normalization chemistry were calculated from the SMAVs.

SMAVs ranged from 2.37 µg/L for the most sensitive species, *Daphnia pulicaria*, to 107,860 µg/L for the least sensitive species, *Notemigonus crysoleucas*. Cladocerans were among the most sensitive species, with *D. pulicaria, D. magna*, *Ceriodaphnia dubia*, and *Scapholeberis sp.* being four out of the six most sensitive species. Invertebrates in general were more sensitive than fish, representing the 10 lowest SMAVs.

The 27 GMAVs calculated from the above-mentioned SMAVs ranged from 4.05 µg/L for *Daphnia* to 107,860 µg/L for *Notemigonus* (Table 3a). Nine of the 10 most sensitive genera were invertebrates. The salmonid genus *Oncorhynchus* was the most sensitive fish genus, with a GMAV of 31.39 µg/L and an overall GMAV ranking of 10.

The ranked GMAVs are presented in Figure 4. Pursuant to procedures used to calculate the FAV, a FAV of 4.67 µg/L was derived from the four GMAVs with cumulative probabilities closest to the 5th percentile toxicity value for all the tested genera (Table 3b). The presumption is that this

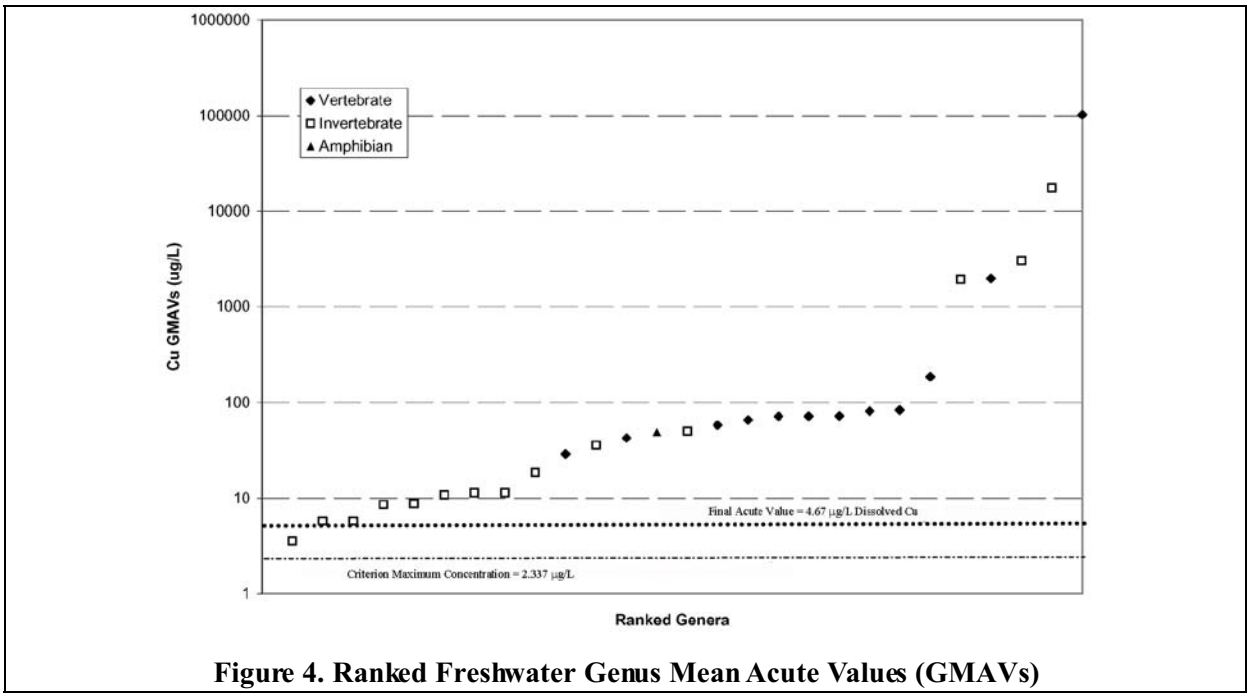


Figure 4. Ranked Freshwater Genus Mean Acute Values (GMAVs)

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acute toxicity value represents the LC50 for an organism that is sensitive at the 5th percentile of the GMAV distribution. The CMC is the FAV divided by two. Therefore, the freshwater dissolved copper CMC for the reference chemistry presented is 2.337 µg/L.

Site-water chemistry parameters are needed to evaluate a criterion. This is analogous to the situation that previously existed for the hardness-based WQC, where a hardness concentration was necessary in order to derive a criterion. Examples of CMC calculations at various water chemistry conditions are presented in Figure 5 and Appendix G.

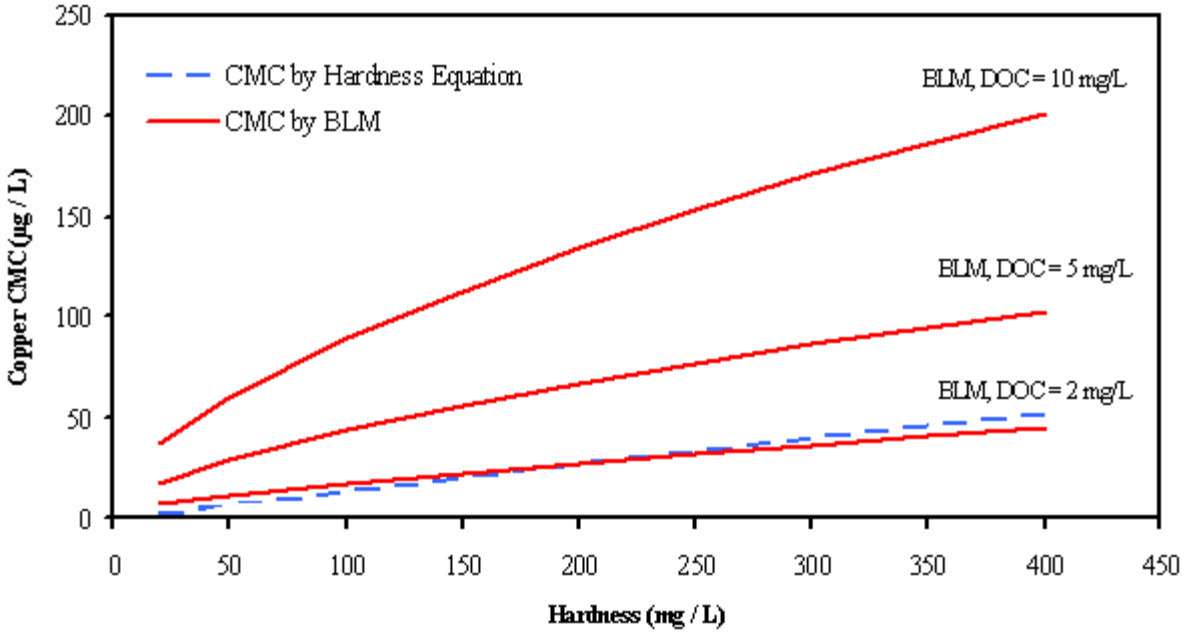


Figure 5. Comparison of CMC calculated by BLM or Hardness Equation Alkalinity (11 - 245 mg CaCO3/L) and pH (7.3 - 8.7) Covary with Hardness

4.1.1 *Comparison With Earlier Hardness-Adjusted Criteria*

EPA's earlier freshwater copper criteria recommendations were hardness-dependent values. One would expect a BLM-based criterion calculation procedure to yield the more appropriate criterion—appropriate in the sense that it accounts for the important water chemistry factors that affect toxicity, including DOC complexation, where the hardness correction does not. Application of the BLM in field situations where DOC is expected to be present at higher concentrations than those observed in laboratory studies would likely improve the performance of the BLM compared with the hardness adjustment. The reason is that the BLM would reasonably account for the typically observed increase in effect levels under such conditions, while the hardness-based approach would not (Figure 5).

As a comparison between the hardness typical of the previous copper criterion and this revised criterion using the BLM, both procedures were used to calculate criterion values for waters with a range in hardness as specified by the standard EPA recipes (U.S. EPA, 1993). The EPA formulations specify the concentration of various salts and reagents to be used in the synthesis of

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laboratory test waters with specific hardness values (e.g., very soft, soft, moderately hard, hard, or very hard). As the water hardness increases in these recipes, pH and alkalinity also increase. This has implications for the BLM because the bioavailability of copper would be expected to decrease with increasing pH and alkalinity due to the increasing degree of complexation of copper with hydroxides and carbonates and decreasing proton competition with the metal at both DOM and biotic ligand binding sites. The BLM criterion for these waters agrees very well with that calculated by the hardness equation used in previous copper criterion documents (Figure 5). However, alkalinity and pH change as hardness changes in the EPA recipes. The BLM prediction is taking all of these changes in water quality into account.

It is possible to use the BLM to look only at the change in predicted WQC with changes in hardness (e.g., alkalinity and pH remaining constant). The hardness equation is based on waters where changes in hardness are accompanied by changes in pH and alkalinity. However, there are many possible natural waters where changes in hardness are not accompanied by changes in pH and alkalinity (such as water draining a region rich in gypsum). In these cases, the hardness equation based criterion will still assume a response that is characteristic of waters where hardness, alkalinity, and pH co-vary, and will likely be underprotective relative to the level of protection intended by the Guidelines, in high hardness waters. Conversely, in waters where the covariation between hardness, pH, and alkalinity is greater than is typical for data in Table 1, the hardness equation based criteria may be overprotective. Appendix G shows representative water quality criteria values using both the BLM and the hardness equation approaches for waters with a range in pH, hardness, and DOC concentrations. The hardness approach does not consider pH and DOC while the BLM approach takes those water quality parameters into consideration.

4.2 Formulation of the CCC

4.2.1 *Evaluation of Chronic Toxicity Data*

In aquatic toxicity tests, chronic values are usually defined as the geometric mean of the highest concentration of a toxic substance at which no adverse effect is observed (highest no observed adverse effect concentration, or NOAEC) and the lowest concentration of the toxic substance that causes an adverse effect (lowest observed adverse effect concentration, or LOAEC). The significance of the observed effects is determined by statistical tests comparing responses of organisms exposed to low-level and control concentrations of the toxic substance against responses of organisms exposed to elevated concentrations. Analysis of variance is the most common test employed for such comparisons. This approach, however, has the disadvantage of resulting in marked differences between the magnitudes of the effects corresponding to the individual chronic values, because of variation in the power of the statistical tests used, the concentrations tested, and the size and variability of the samples used (Stephan and Rogers, 1985).

An alternative approach to calculating chronic values focuses on the use of point estimates such as from regression analysis to define the dose-response relationship. With a regression equation or probit analysis, which defines the level of adverse effects as a function of increasing concentrations of the toxic substance, it is possible to determine the concentration that causes a specific small effect, such as a 5 to 30 percent reduction in response. To make chronic values reflect a uniform level of effect, regression and probit analyses were used, where possible, both to demonstrate that a significant concentration-effect relationship was present and to estimate chronic

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values with a consistent level of effect. The most precise estimates of effect concentrations can generally be made for 50 percent reduction (EC50); however, such a major reduction is not necessarily consistent with criteria providing adequate protection. In contrast, a concentration that causes a low level of reduction, such as an EC5 or EC10, might not be statistically significantly different from the control treatment. As a compromise, the EC20 is used here to represent a low level of effect that is generally significantly different from the control treatment across the useful chronic datasets that are available for copper. The EC20 was also viewed as providing a level of protection similar to the geometric mean of the NOEC and LOEC. Since the EC20 is not directly dependent on the tested dilution series, similar EC20s should be expected irrespective of the tested concentrations, provided that the range of tested concentrations is appropriate.

Regression or probit analysis was utilized to evaluate a chronic dataset only in cases where the necessary data were available and the dataset met the following conditions: (1) it contained a control treatment (or low exposure data point) to anchor the curve at the low end, (2) it contained at least three concentrations, and (3) two of the data points had effect variable values below the control and above zero (i.e., "partial effects"). Control concentrations of copper were estimated in cases where no measurements were reported. These analyses were performed using the Toxicity Relationship Analysis Program software (version 1.0; U.S. EPA, Mid-Continental Ecology Division, Duluth, MN, USA). Additional detail regarding the aforementioned statistical procedures is available in the cited program.

When the data from an acceptable chronic test met the conditions for the logistic regression or probit analysis, the EC20 was the preferred chronic value. When data did not meet the conditions the chronic value was usually set to the geometric mean of the NOAEC and the LOAEC. However, when no treatment concentration was an NOAEC, the chronic value is reported as less than the lowest tested concentration.

For life-cycle, partial life-cycle, and early life stage tests, the toxicological variable used in chronic value analyses was survival, reproduction, growth, emergence, or intrinsic growth rate. If copper apparently reduced both survival and growth (weight or length), the product of variables (biomass) was analyzed, rather than analyzing the variables separately. The most sensitive of the toxicological variables was generally selected as the chronic value for the particular study.

A species-by-species discussion of each acceptable chronic test on copper evaluated for this document is presented in Appendix F. Figures that present the data and regression/probability distribution line for each of the acceptable chronic test which contained sufficient acceptable data are also provided in Appendix F.

4.2.2 *Calculation of Freshwater CCC*

Acceptable freshwater chronic toxicity data from early life stage tests, partial life-cycle tests, and full life-cycle tests were available for 29 tests including data for 6 invertebrate species and 10 fish species (Table 2a). The 17 chronic values for invertebrate species range from 2.83 (*D. pulex)* to 34.6 µg/L (*C. dubia*); and the 12 chronic values for the fish species range from <5 (brook trout) to 60.4 µg/L (northern pike). Of the 29 chronic tests, comparable acute values are available for 18 of the tests (Table 2c). The relationship between acute toxicity values and ACRs is presented in Figure 6. The supporting acute and chronic test values for the ACRs and the species mean ACRs are

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presented in Table 2c. For the 11 tests in Table 2a with chronic values both from a regression EC20 and the geometric mean of the NOAEC and LOAEC, the EC20 averaged 81% of the geometric mean, demonstrating the similar level of protection for the two approaches.

Overall, individual ACRs varied from <1 (0.55) for *C. dubia* (Oris et al., 1991) to 191.6 for the snail, *Campeloma decisum* (Arthur and Leonard, 1970). Species mean acute-chronic ratios ranged from 1.48 in saltwater for the sheepshead minnow (Hughes et al., 1989) to 171.2 in freshwater for the snail, *C. decisum*. Pursuant to the Guidelines (Stephan et al., 1985), consideration was given to calculating the FACR based on all ACRs within a factor of 10, but because there appeared to be a relationship between acute sensitivity and ACRs (Figure 6), the FACR was derived from data for species whose SMAVs were close to the FAV. The FACR of 3.22 was calculated as the geometric mean of the ACRs for sensitive freshwater species, *C. dubia, D. magna, D. pulex, O. tshawytscha*, and *O. mykiss* along with the one saltwater ACR for *C. variegatus* (Table 2b). Based on the normalization water chemistry conditions used for illustrative purposes in the document, the freshwater site specific FAV value is 4.67 µg/L, which divided by the FACR of 3.22 results in a freshwater FCV of 1.45 µg/L dissolved Cu.

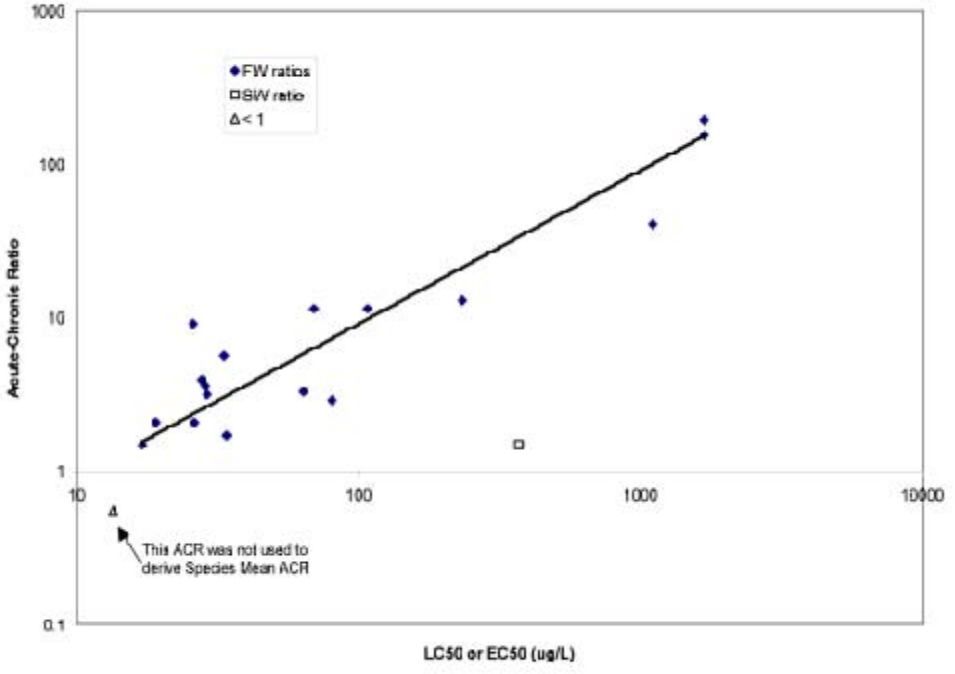


Figure 6. Relationship Between Freshwater Acute Copper Sensitivity (LC50 or EC50) and Acute-Chronic Ratios

5.0 PLANT DATA

Copper has been widely used as an algicide and herbicide for nuisance aquatic plants (McKnight et al., 1983). Although copper is known as an inhibitor of photosynthesis and plant growth, toxicity data on individual species suitable for deriving aquatic life criteria (Table 4) are not numerous.

The relationship of copper toxicity to the complexing capacity of the water or the culture medium is now widely recognized (Gächter et al., 1973; Petersen, 1982), and several studies have used algae to "assay" the copper complexing capacity of both fresh and salt waters (Allen et al., 1983; Lumsden and Florence, 1983; Rueter, 1983). It has also been shown that algae are capable of excreting complexing substances in response to copper stress (McKnight and Morel, 1979; Swallow et al., 1978; van den Berg et al., 1979). Foster (1982) and Stokes and Hutchinson (1976) have identified resistant strains and/or species of algae from copper (or other metal) impacted environments. A portion of this resistance probably results from induction of the chelate-excretion mechanism. Chelate excretion by algae may also serve as a protective mechanism for other aquatic organisms in eutrophic waters; that is, where algae are capable of maintaining free copper activities below harmful concentrations.

Copper concentrations from 1 to 8,000 µg/L have been shown to inhibit growth of various freshwater plant species. Very few of these tests, though, were accompanied by analysis of actual copper exposure concentrations. Notable exceptions are freshwater tests with green alga including *Chlamydomonas reinhardtii* (Schafer et al., 1993; Winner and Owen, 1991b), which is the only flow-through, measured test with an aquatic plant, *Chlorella vulgaris* and *Selenastrum capricornutum* (Blaylock et al., 1985). There is also a measured test with duckweed, *Lemna minor* (Taraldsen and Norberg-King, 1990).

A direct comparison between the freshwater plant data and the BLM derived criteria is difficult to make without a better understanding of the composition of the algal media used for different studies (e.g., DOC, hardness, and pH) because these factors influence the applicable criteria comparison. BLM derived criteria for certain water conditions, such as low to mid-range pH, hardness up to 100 mg/L as $CaCO_3$, and low DOC are in the range of, if not lower than, the lowest reported toxic endpoints for freshwater algal species and would therefore appear protective of plant species. In other water quality conditions BLM-derived criteria may be significantly higher (see Figure 5).

Two publications provide data for the red algae *Champia parvula* that indicate that reproduction of this species is especially sensitive to copper. The methods manual (U.S. EPA 1988) for whole effluent toxicity (WET) testing contains the results of six experiments showing nominal reproduction LOECs from 48-hr exposures to 1.0 to 2.5 µg/L copper (mean 2.0 µg/L); these tests used a mixture of 50 percent sterile seawater and 50 percent GP2 medium copper. The second study by Morrison et al. (1989) evaluated interlaboratory variation of the 48-hr WET test procedure; this six-test study gave growth EC50 values from 0.8 to 1.9 µg/L (mean 1.0 µg/L). Thus, there are actually 12 tests that provide evidence of significant reproductive impairment in *C. parvula* at nominal copper concentrations between 0.8 and 2.5 µg/L. For these studies though, the dilution water source was not identified.

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One difficulty in assessing these data is the uncertainty of the copper concentration in the test solutions, primarily with respect to any background copper that might be found in the dilution water, especially with solutions compounded from sea salts or reagents. Thus, with a CCC of 1.9 µg/L dissolved copper, the significance of a 1 or 2 µg/L background copper level to a 1 to 3 µg/L nominal effect level can be considerable.

The reproduction of other macroalgae appears to be generally sensitive to copper, but not to the extent of *Champia*. Many of these other macroalgae appear to have greater ecological significance than *Champia*, several forming significant intertidal and subtidal habitats for other saltwater organisms, as well as being a major food source for grazers. Reproductive and growth effects on the other species of macroalgae sometimes appear to occur at copper concentrations between 5 and 10 µg/L (Appendix B, Other Data). Thus, most major macrophyte groups seem to be adequately protected by the CMC and CCC, but appear similar in sensitivity to some of the more sensitive groups of saltwater animals.

6.0 OTHER DATA

Many of the data identified for this effort are listed in Appendix B, Other Data, for various reasons, including exposure durations other than 96 hours with the same species reported in Table 1, and some exposures lasting up to 30 days. Acute values for test durations less than 96 hours are available for several species not shown in Table 1. Still, these species have approximately the same sensitivities to copper as species in the same families listed in Table 1. Reported LC50s at 200 hours for chinook salmon and rainbow trout (Chapman, 1978) differ only slightly from 96-hour LC50s reported for these same species in the same water.

A number of other acute tests in Appendix B were conducted in dilution waters that were not considered appropriate for criteria development. Brungs et al. (1976) and Geckler et al. (1976) conducted tests with many species in stream water that contained a large amount of effluent from a sewage treatment plant. Wallen et al. (1957) tested mosquitofish in a turbid pond water. Until chemical measurements that correlate well with the toxicity of copper in a wide variety of waters are identified and widely used, results of tests in unusual dilution waters, such as those in Appendix B, will not be very useful for deriving water quality criteria.

Appendix B also includes tests based on physiological effects, such as changes in appetite, blood parameters, stamina, etc. These were included in Appendix B because they could not be directly interpreted for derivation of criteria. For the reasons stated in this section above, data in Appendix B was not used for criteria derivation.

A direct comparison of a particular test result to a BLM-derived criterion is not always straightforward, particularly if complete chemical characterization of the test water is not available. Such is the case for a number of studies included in Appendix B. While there are some test results with effect concentrations below the example criteria concentrations presented in this document, these same effect concentrations could be above criteria derived for other normalization chemistries, raising the question as to what is the appropriate comparison to make. For example, Appendix B includes an EC50 for *D. Pulex* of 3.6 µg/L (Koivisto et al., 1992) at an approximate hardness of 25 mg/L (33 mg/L as $CaCO_3$). Yet, example criteria at a hardness of 25 mg/L (as $CaCO_3$) (including those in Figure 6) range from 0.23 µg/L (DOC = 0.1 mg/L) to 4.09 µg/L (DOC = 2.3 mg/L) based

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on the DOC concentration selected for the synthetic water recipe. The chemical composition for the Koivisto et al. (1992) study would dictate what the appropriate BLM criteria comparison should be.

Based on the expectation that many of the test results presented in Appendix B were conducted in laboratory dilution water with low levels of DOC, the appropriate comparison would be to the criteria derived from low DOC waters. Comparing many of the values in Appendix B to the example criteria presented in this document, it appears that a large proportion of Appendix B values are above these concentration levels. This is a broad generalization though and as stated previously, all important water chemistry variables that affect toxicity of copper to aquatic organisms should be considered before making these types of comparisons.

Studies not considered suitable for criteria development were placed in Appendix G, Unused Data.

7.0 NATIONAL CRITERIA STATEMENT

The available toxicity data, when evaluated using the procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that freshwater aquatic life should be protected if the 24-hour average and four-day average concentrations do not respectively exceed the acute and chronic criteria concentrations calculated by the Biotic Ligand Model.

A return interval of 3 years between exceedances of the criterion continues to be EPA's general recommendation. However, the resilience of ecosystems and their ability to recover differ greatly. Therefore, scientific derivation of alternative frequencies for exceeding criteria may be appropriate.

8.0 IMPLEMENTATION

The use of water quality criteria in designing waste treatment facilities and appropriate effluent limits involves the use of an appropriate wasteload allocation model. Although dynamic models are preferred for application of these criteria, limited data or other factors may make their use impractical, in which case one should rely on a steady-state model. EPA recommends the interim use of 1B3 or 1Q10 for criterion maximum concentration stream design flow and 4B3 or 7Q10 for the criterion continuous concentration design flow in steady-state models. These matters are discussed in more detail in the Technical Support Document for Water Quality-Based Toxics Control (U.S. EPA, 1991).

With regard to BLM-derived freshwater criteria, to develop a site-specific criterion for a stream reach, one is faced with determining what single criterion is appropriate even though a BLM criterion calculated for the event corresponding to the input water chemistry conditions will be time-variable. This is not a new problem unique to the BLM—hardness-dependent metals criteria are also time-variable values. Although the variability of hardness over time can be characterized, EPA has not provided guidance on how to calculate site-specific criteria considering this variability. Multiple input parameters for the BLM could complicate the calculation of site-specific criteria because of their combined effects on variability. Another problem arise from potential scarcity of data from small stream reaches with small dischargers. The EPA is currently exploring two

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approaches to fill data gaps in such situations. One potential approach is the selection of values based on geography, the second approach is based on correlations between measured parameters and missing parameter measurements. A companion document in the form of Supplementary Training Materials, addressing issues related to data requirements, implementation, permitting, and monitoring will be released via EPA's website following the publication of this criteria document.□□

Table 1. Acute Toxicity of Copper to Freshwater Animals

Species[a]	Organism Age, Size, or Lifestage	Method[b]	Chemical[c]	Reported LC50 or EC50 (total µg/L)[d]	Reported LC50 or EC50 (Diss. µg/L)[e]	BLM Data Label	BLM Normalized LC50 or EC50 (µg/L)[f]	Species Mean Acute Value (µg/L)[g]	Reference
Worm,	adult (mixed age)	S,M,T	N	130	---	LUVA01S	37.81	48.41	Schubauer-Berigan et al. 1993
Lumbriculus variega	adult (mixed age)	S,M,T	N	270	---	LUVA02S	55.39		Schubauer-Berigan et al. 1993
	adult (mixed age)	S,M,T	N	500	---	LUVA03S	54.18		Schubauer-Berigan et al. 1993
Snail,	1.1-2.7 cm	F,M,T	S	2000	---	CADE01F	4319	3573	Arthur and Leonard 1970
Campeloma	1.1-2.7 cm	F,M,T	S	1400	---	CADE02F	2956		Arthur and Leonard 1970
Snail, *Juga plicifera*	adult	F,M,T	C	15	---	JUPL01F	12.31	12.31	Nebeker et al. 1986b
Snail, *Lithoglyphus virens*	adult	F,M,T	C	8	---	LIVI01F	6.67	6.67	Nebeker et al. 1986b
Snail,	0.4-0.7 cm	F,M,T	S	41	---	PHIN01F	21.81	20.41	Arthur and Leonard 1970
Physa integra	0.4-0.7 cm	F,M,T	S	37	---	PHIN02F	19.09		Arthur and Leonard 1970
Freshwater mussel,	juvenile	S,M,T	S	27	---	ACPE01S	10.36	11.33	Keller unpublished
Actinonaias	juvenile	S,M,T	S	<29	---	ACPE02S	12.39		Keller unpublished
Freshwater mussel,	1-2 d juv	S,M,T	S	86	---	UTIM01S	177.9	52.51	Keller and Zam 1991
Utterbackia imbecilli	1-2 d juv	S,M,T	S	199	---	UTIM02S	172.3		Keller and Zam 1991
	juvenile	S,M,T	N	76	---	UTIM03S	40.96		Keller unpublished
	juvenile	S,M,T	N	85	---	UTIM04S	43.22		Keller unpublished
	juvenile	S,M,T	N	41	---	UTIM05S	24.12		Keller unpublished
	juvenile	S,M,T	S	79	---	UTIM06S	39.04		Keller unpublished
	juvenile	S,M,T	S	72	---	UTIM07S	39.96		Keller unpublished
	juvenile	S,M,T	S	38	---	UTIM08S	28.31		Keller unpublished
Cladoceran,	<4 h	S,M,T	C	19	---	CEDU01S	10.28	5.93	Carlson et al. 1986
Ceriodaphnia dubia	<4 h	S,M,T	C	17	---	CEDU02S	9.19		Carlson et al. 1986
	<12 h	S,M,D	---	-	25	CEDU03S	7.98		Belanger et al. 1989
	<12 h	S,M,D	---	-	17	CEDU04S	5.25		Belanger et al. 1989
	<12 h	S,M,D	---	-	30	CEDU05S	9.80		Belanger et al. 1989
	<12 h	S,M,D	---	-	24	CEDU06S	7.63		Belanger et al. 1989
	<12 h	S,M,D	---	-	28	CEDU07S	9.06		Belanger et al. 1989
	<12 h	S,M,D	---	-	32	CEDU08S	10.56		Belanger et al. 1989
	<12 h	S,M,D	---	-	23	CEDU09S	7.28		Belanger et al. 1989
	<12 h	S,M,D	---	-	20	CEDU10S	6.25		Belanger et al. 1989
	<12 h	S,M,D	---	-	19	CEDU11S	5.91		Belanger et al. 1989
	<12 h	S,M,D	---	-	26	CEDU12S	3.10		Belanger et al. 1989
	<12 h	S,M,D	---	-	21	CEDU13S	2.46		Belanger et al. 1989
	<12 h	S,M,D	---	-	27	CEDU14S	3.24		Belanger et al. 1989
	<12 h	S,M,D	---	-	37	CEDU15S	4.66		Belanger et al. 1989
	<12 h	S,M,D	---	-	34	CEDU16S	4.22		Belanger et al. 1989
	<12 h	S,M,D	---	-	67	CEDU17S	5.50		Belanger et al. 1989
	<12 h	S,M,D	---	-	38	CEDU18S	2.72		Belanger et al. 1989
	<12 h	S,M,D	---	-	78	CEDU19S	6.74		Belanger et al. 1989
	<12 h	S,M,D	---	-	81	CEDU20S	7.10		Belanger et al. 1989
	<12 h	S,M,D	---	-	28	CEDU21S	4.10		Belanger and Cherry 1990

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Table 1. Acute Toxicity of Copper to Freshwater Animals

Species[a]	Organism Age, Size, or Lifestage	Method[b]	Chemical[c]	Reported LC50 or EC50 (total µg/L)[d]	Reported LC50 or EC50 (Diss. µg/L)[e]	BLM Data Label	BLM Normalized LC50 or EC50 (µg/L)[f]	Species Mean Acute Value (µg/L)[g]	Reference
	<12 h	S,M,D	---	-	84	CEDU22S	10.74		Belanger and Cherry 1990
	<12 h	S,M,T	S	13.4	---	CEDU23S	6.19		Oris et al. 1991
	<24 h	R,M,T,D	S	6.98	5.54	CEDU24R	5.03		Diamond et al. 1997b
Cladoceran,	1 d	S,M,T	C	9.1	---	DAMA01S	3.42	6.00	Nebeker et al. 1986a
Daphnia magna	1 d	S,M,T	C	11.7	---	DAMA02S	4.43		Nebeker et al. 1986a
	<2 h	S,M,T	C	6.6	---	DAMA03S	2.50		Nebeker et al. 1986a
	<2 h	S,M,T	C	9.9	---	DAMA04S	3.78		Nebeker et al. 1986a
	1 d	S,M,T	C	11.7	---	DAMA05S	13.46		Nebeker et al. 1986a
	<4 h	S,M,T	C	6.7	---	DAMA06S	8.21		Nebeker et al. 1986a
	1 d	S,M,T	C	9.1	---	DAMA07S	4.40		Nebeker et al. 1986a
	<2 h	S,M,T	C	5.2	---	DAMA08S	2.16		Nebeker et al. 1986a
	<24 h	S,M,T	S	41.2	---	DAMA09S	21.55		Baird et al. 1991
	<24 h	S,M,T	S	10.5	---	DAMA10S	5.63		Baird et al. 1991
	<24 h	S,M,T	S	20.6	---	DAMA11S	11.31		Baird et al. 1991
	<24 h	S,M,T	S	17.3	---	DAMA12S	9.48		Baird et al. 1991
	<24 h	S,M,T	S	70.7	---	DAMA13S	33.58		Baird et al. 1991
	<24 h	S,M,T	S	31.3	---	DAMA14S	16.90		Baird et al. 1991
	<24 h	S,M,I	S	7.1	---	DAMA15S	2.67		Meador 1991
	<24 h	S,M,I	S	16.4	---	DAMA16S	4.26		Meador 1991
	<24 h	S,M,I	S	39.9	---	DAMA17S	5.18		Meador 1991
	<24 h	S,M,I	S	18.7	---	DAMA18S	3.39		Meador 1991
	<24 h	S,M,I	S	18.9	---	DAMA19S	1.99		Meador 1991
	<24 h	S,M,I	S	39.7	---	DAMA20S	3.04		Meador 1991
	<24 h	S,M,I	S	46	---	DAMA21S	8.93		Meador 1991
	<24 h	S,M,I	S	71.9	---	DAMA22S	9.97		Meador 1991
	<24 h	S,M,I	S	57.2	---	DAMA23S	5.76		Meador 1991
	<24 h	S,M,I	S	67.8	---	DAMA24S	4.16		Meador 1991
	<24 h	S,M,T	C	26	---	DAMA25S	10.34		Chapman et al. Manuscript
	<24 h	S,M,T	C	30	---	DAMA26S	9.04		Chapman et al. Manuscript
	<24 h	S,M,T	C	38	---	DAMA27S	9.84		Chapman et al. Manuscript
	<24 h	S,M,T	C	69	---	DAMA28S	12.31		Chapman et al. Manuscript
	<24 h	S,M,T,D	S	4.8	---	DAMA29S	1.22		Long's MS Thesis
	<24 h	S,M,T,D	S	7.4	---	DAMA30S	16.29		Long's MS Thesis
	<24 h	S,M,T,D	S	6.5	---	DAMA31S	2.11		Long's MS Thesis
Cladoceran,	---	S,M,T	S	11.4	---	DAPC01S	1.63	2.73	Lind et al. Manuscript (1978)
Daphnia pulicaria	---	S,M,T	S	9.06	---	DAPC02S	1.04		Lind et al. Manuscript (1978)
	---	S,M,T	S	7.24	---	DAPC03S	0.88		Lind et al. Manuscript (1978)
	---	S,M,T	S	10.8	---	DAPC04S	1.13		Lind et al. Manuscript (1978)
	---	S,M,T	S	55.4	---	DAPC05S	8.81		Lind et al. Manuscript (1978)
	---	S,M,T	S	55.3	---	DAPC06S	6.03		Lind et al. Manuscript (1978)
	---	S,M,T	S	53.3	---	DAPC07S	4.12		Lind et al. Manuscript (1978)
	---	S,M,T	S	97.2	---	DAPC08S	3.94		Lind et al. Manuscript (1978)

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Species[a]	Organism Age, Size, or Lifestage	Method[b]	Chemical[c]	Reported LC50 or EC50 (total µg/L)[d]	Reported LC50 or EC50 (Diss. µg/L)[e]	BLM Data Label	BLM Normalized LC50 or EC50 (µg/L)[f]	Species Mean Acute Value (µg/L)[g]	Reference
	---	S,M,T	S	199	---	DAPC09S	3.01		Lind et al. Manuscript (1978)
	---	S,M,T	S	213	---	DAPC10S	7.63		Lind et al. Manuscript (1978)
	---	S,M,T	S	165	---	DAPC11S	5.78		Lind et al. Manuscript (1978)
	---	S,M,T	S	35.5	---	DAPC12S	1.83		Lind et al. Manuscript (1978)
	---	S,M,T	S	78.8	---	DAPC13S	2.36		Lind et al. Manuscript (1978)
	---	S,M,T	S	113	---	DAPC14S	1.06		Lind et al. Manuscript (1978)
	---	S,M,T	S	76.4	---	DAPC15S	2.36		Lind et al. Manuscript (1978)
	---	S,M,T	S	84.7	---	DAPC16S	6.62		Lind et al. Manuscript (1978)
	---	S,M,T	S	184	---	DAPC17S	7.14		Lind et al. Manuscript (1978)
	---	S,M,T	S	9.3	---	DAPC18S	1.11		Lind et al. Manuscript (1978)
	---	S,M,T	S	17.8	---	DAPC19S	2.11		Lind et al. Manuscript (1978)
	---	S,M,T	S	23.7	---	DAPC20S	2.67		Lind et al. Manuscript (1978)
	---	S,M,T	S	27.3	---	DAPC21S	2.77		Lind et al. Manuscript (1978)
	---	S,M,T	S	25.2	---	DAPC22S	2.81		Lind et al. Manuscript (1978)
	---	S,M,T	S	25.1	---	DAPC23S	2.60		Lind et al. Manuscript (1978)
	---	S,M,T	S	25.1	---	DAPC24S	2.31		Lind et al. Manuscript (1978)
Cladoceran, *Scapholeberis sp.*	adult	S,M,T	C	18	---	SCSP01S	9.73	9.73	Carlson et al. 1986
Amphipod,	1-3 d	F,M,T	S	22	---	GAPS01F	10.39	9.60	Arthur and Leonard 1970
Gammarus	1-3 d	F,M,T	S	19	---	GAPS02F	8.86		Arthur and Leonard 1970
Amphipod,	7-14 d	S,M,T	N	17	---	HYAZ01S	12.19	12.07	Schubauer-Berigan et al. 1993
Hyalella azteca	7-14 d	S,M,T	N	24	---	HYAZ02S	9.96		Schubauer-Berigan et al. 1993
	7-14 d	S,M,T	N	87	---	HYAZ03S	15.77		Schubauer-Berigan et al. 1993
	<7 d	S,M,T	S	24.3	---	HYAZ04S	8.26		Welsh 1996
	<7 d	S,M,T	S	23.8	---	HYAZ05S	8.09		Welsh 1996
	<7 d	S,M,T	S	8.2	---	HYAZ06S	15.49		Welsh 1996
	<7 d	S,M,T	S	10	---	HYAZ07S	18.80		Welsh 1996
Stonefly, *Acroneuria lycorias*	---	S,M,T	S	8300	---	ACLY01S	20636	20636	Warnick and Bell 1969
Midge, *Chironomus*	4th instar	S,M,T	S	739	---	CHDE01S	1987	1987	Kosalwat and Knight 1987
Shovelnose sturgeon, *Scaphirhynchus*	fry, 6.01 cm, 0.719 g	S,M,T	S	160	---	SCPL01S	69.63	69.63	Dwyer et al. 1999
Apache trout, *Oncorhynchus*	larval, 0.38 g	S,M,T	S	70	---	ONAP01S	32.54	32.54	Dwyer et al. 1995
Lahontan cutthroat	larval, 0.34 g	S,M,T	S	80	---	ONCL01S	34.26	32.97	Dwyer et al. 1995
Oncorhynchus clarki henshawi	larval, 0.57 g	S,M,T	S	60	---	ONCL02S	24.73		Dwyer et al. 1995

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Cutthroat trout,	7.4 cm, 4.2 g	F,M,T,D	C	398.91	367	ONCL03F	67.30		Chakoumakos et al. 1979
Oncorhynchus clarki	6.9 cm, 3.2 g	F,M,T,D	C	197.87	186	ONCL04F	44.91		Chakoumakos et al. 1979
	8.8 cm, 9.7 g	F,M,T,D	C	41.35	36.8	ONCL05F	21.87		Chakoumakos et al. 1979
	8.1 cm, 4.4 g	F,M,T,D	C	282.93	232	ONCL06F	51.94		Chakoumakos et al. 1979
	6.8 cm, 2.7 g	F,M,T,D	C	186.21	162	ONCL07F	111.3		Chakoumakos et al. 1979
	7.0 cm, 3.2 g	F,M,T,D	C	85.58	73.6	ONCL08F	39.53		Chakoumakos et al. 1979
	8.5 cm, 5.2 g	F,M,T,D	C	116.67	91	ONCL09F	19.63		Chakoumakos et al. 1979
	7.7 cm, 4.4 g	F,M,T,D	C	56.20	44.4	ONCL10F	18.81		Chakoumakos et al. 1979
	8.9 cm, 5.7 g	F,M,T,D	C	21.22	15.7	ONCL11F	10.60		Chakoumakos et al. 1979
Pink salmon,	alevin (newly hatched	F,M,T	S	143	---	ONGO01F	41.65	40.13	Servizi and Martens 1978
Oncorhynchus gorbu	alevin	F,M,T	S	87	---	ONGO02F	19.70		Servizi and Martens 1978
	fry	F,M,T	S	199	---	ONGO03F	78.76		Servizi and Martens 1978
Coho salmon,	6 g	R,M,T,I	---	164	---	ONKI01R	106.09	22.93	Buckley 1983
Oncorhynchus kisutc	parr	F,M,T	C	33	---	ONKI02F	20.94		Chapman 1975
	adult, 2.7 kg	F,M,T	C	46	---	ONKI03F	32.66		Chapman and Stevens 1978
	fry	F,M,T,D,I	---	61	49	ONKI04F	12.67		Mudge et al. 1993
	smolt	F,M,T,D,I	---	63	51	ONKI05F	13.19		Mudge et al. 1993
	fry	F,M,T,D,I	---	86	58	ONKI06F	11.95		Mudge et al. 1993
	parr	F,M,T,D,I	---	103	78	ONKI07F	22.98		Mudge et al. 1993
Rainbow trout,	larval, 0.67 g	S,M,T	S	110	---	ONMY01S	41.64	22.19	Dwyer et al. 1995
Oncorhynchus mykis	larval, 0.48 g	S,M,T	S	50	---	ONMY02S	25.26		Dwyer et al. 1995
	larval, 0.50 g	S,M,T	S	60	---	ONMY03S	29.46		Dwyer et al. 1995
	swim-up, 0.25 g	R,M,T,D	C	46.7	40	ONMY04R	10.90		Cacela et al. 1996
	swim-up, 0.25 g	R,M,T,D	C	24.2	19	ONMY05R	9.04		Cacela et al. 1996
	swim-up, 0.20-0.24 g	R,M,T,D	C	0	3.4	ONMY06R	5.02		Welsh et al. 2000
	swim-up, 0.20-0.24 g	R,M,T,D	C	0	8.1	ONMY07R	11.97		Welsh et al. 2000
	swim-up, 0.20-0.24 g	R,M,T,D	C	0	17.2	ONMY08R	13.80		Welsh et al. 2000
	swim-up, 0.20-0.24 g	R,M,T,D	C	0	32	ONMY09R	23.84		Welsh et al. 2000
	alevin	F,M,T	C	28	---	ONMY10F	20.30		Chapman 1975, 1978
	swim-up, 0.17 g	F,M,T	C	17	---	ONMY11F	12.54		Chapman 1975, 1978
	parr, 8.6 cm, 6.96 g	F,M,T	C	18	---	ONMY12F	9.87		Chapman 1975, 1978
	smolt, 18.8 cm, 68.19	F,M,T	C	29	---	ONMY13F	22.48		Chapman 1975, 1978
	1 g	F,M,T,D	C	-	169	ONMY14F	23.41		Chakoumakos et al. 1979
	4.9 cm	F,M,T,D	C	-	85.3	ONMY15F	10.20		Chakoumakos et al. 1979
	6.0 cm, 2.1 g	F,M,T,D	C	-	83.3	ONMY16F	9.93		Chakoumakos et al. 1979
	6.1 cm, 2.5 g	F,M,T,D	C	-	103	ONMY17F	12.71		Chakoumakos et al. 1979
	2.6 g	F,M,T,D	C	-	274	ONMY18F	44.54		Chakoumakos et al. 1979
	4.3 g	F,M,T,D	C	-	128	ONMY19F	16.51		Chakoumakos et al. 1979
	9.2 cm, 9.4 g	F,M,T,D	C	-	221	ONMY20F	33.33		Chakoumakos et al. 1979
	9.9 cm, 11.5 g	F,M,T,D	C	-	165	ONMY21F	22.70		Chakoumakos et al. 1979
	11.8 cm, 18.7 g	F,M,T,D	C	-	197	ONMY22F	28.60		Chakoumakos et al. 1979
	13.5 cm, 24.9 g	F,M,T,D	C	-	514	ONMY23F	99.97		Chakoumakos et al. 1979

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	13.4 cm, 25.6 g	F,M,T,D	C	-	243	ONMY24F	37.88		Chakoumakos et al. 1979
	6.7 cm, 2.65 g	F,M,T	C	2.8	---	ONMY25F	7.00		Cusimano et al. 1986
	parr	F,M,T,D,I	---	90	68	ONMY26F	19.73		Mudge et al. 1993
	swim-up, 0.29 g	F,M,T,D	C	19.6	18	ONMY27F	8.10		Cacela et al. 1996
	swim-up, 0.25 g	F,M,T,D	C	12.9	12	ONMY28F	32.15		Cacela et al. 1996
	swim-up, 0.23 g	F,M,T,D	C	5.9	5.7	ONMY29F	24.80		Cacela et al. 1996
	swim-up, 0.23 g	F,M,T,D	C	37.8	35	ONMY30F	16.16		Cacela et al. 1996
	swim-up, 0.26 g	F,M,T,D	C	25.1	18	ONMY31F	37.66		Cacela et al. 1996
	swim-up, 0.23 g	F,M,T,D	C	17.2	17	ONMY32F	24.19		Cacela et al. 1996
	0.64 g, 4.1 cm	F,M,T,D	C	101	---	ONMY33F	39.73		Hansen et al. 2000
	0.35 g, 3.4 cm	F,M,T,D	C	308	---	ONMY34F	85.83		Hansen et al. 2000
	0.68 g, 4.2 cm	F,M,T,D	C	93	---	ONMY35F	95.9		Hansen et al. 2000
	0.43 g, 3.7 cm	F,M,T,D	C	35.9	---	ONMY36F	50.83		Hansen et al. 2000
	0.29 g, 3.4 cm	F,M,T,D	C	54.4	---	ONMY37F	47.69		Hansen et al. 2000
Sockeye salmon,	alevin (newly hatched	F,M,T	S	190	---	ONNE01F	71.73	54.82	Servizi and Martens 1978
Oncorhynchus nerka	alevin	F,M,T	S	200	---	ONNE02F	79.52		Servizi and Martens 1978
	alevin	F,M,T	S	100	---	ONNE03F	23.74		Servizi and Martens 1978
	alevin	F,M,T	S	110	---	ONNE04F	27.22		Servizi and Martens 1978
	alevin	F,M,T	S	130	---	ONNE05F	35.36		Servizi and Martens 1978
	fry	F,M,T	S	150	---	ONNE06F	45.37		Servizi and Martens 1978
	smolt, 5.5 g	F,M,T	S	210	---	ONNE07F	87.77		Servizi and Martens 1978
	smolt, 5.5 g	F,M,T	S	170	---	ONNE08F	57.53		Servizi and Martens 1978
	smolt, 5.5 g	F,M,T	S	190	---	ONNE09F	71.73		Servizi and Martens 1978
	smolt, 4,8 g	F,M,T	S	240	---	ONNE10F	114.4		Servizi and Martens 1978
Chinook salmon,	alevin, 0.05 g	F,M,T	C	26	---	ONTS01F	14.48	25.02	Chapman 1975, 1978
Oncorhynchus tshaw	swim-up, 0.23 g	F,M,T	C	19	---	ONTS02F	10.44		Chapman 1975, 1978
	parr, 9.6 cm, 11.58 g	F,M,T	C	38	---	ONTS03F	28.30		Chapman 1975, 1978
	smolt, 14.4 cm, 32.46	F,M,T	C	26	---	ONTS04F	20.09		Chapman 1975, 1978
	3 mo, 1.35 g	F,M,T,I	C	10.2	---	ONTS05F	19.41		Chapman and McCrady 1977
	3 mo, 1.35 g	F,M,T,I	C	24.1	---	ONTS06F	30.91		Chapman and McCrady 1977
	3 mo, 1.35 g	F,M,T,I	C	82.5	---	ONTS07F	32.74		Chapman and McCrady 1977
	3 mo, 1.35 g	F,M,T,I	C	128.4	---	ONTS08F	20.66		Chapman and McCrady 1977
	swim-up, 0.36-0.45 g	F,M,T,D	C	0	7.4	ONTS09F	36.49		Welsh et al. 2000
	swim-up, 0.36-0.45 g	F,M,T,D	C	0	12.5	ONTS10F	30.85		Welsh et al. 2000
	swim-up, 0.36-0.45 g	F,M,T,D	C	0	14.3	ONTS11F	31.49		Welsh et al. 2000
	swim-up, 0.36-0.45 g	F,M,T,D	C	0	18.3	ONTS12F	48.56		Welsh et al. 2000

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Bull trout,	0.130 g, 2.6 cm	F,M,T,D	C	228	---	SACO01F	69.70	68.31	Hansen et al. 2000
Salvelinus confluent	0.555 g, 4.0 cm	F,M,T,D	C	207	---	SACO02F	63.62		Hansen et al. 2000
	0.774 g, 4.5 cm	F,M,T,D	C	66.6	---	SACO03F	74.18		Hansen et al. 2000
	1.520 g, 5.6 cm	F,M,T,D	C	50	---	SACO04F	63.60		Hansen et al. 2000
	1.160 g, 5.2 cm	F,M,T,D	C	89	---	SACO05F	71.11		Hansen et al. 2000
Chiselmouth, *Acrocheilus*	4.6 cm, 1.25 g	F,M,T	C	143	---	ACAL01F	216.3	216.3	Andros and Garton 1980
Bonytail chub, *Gila elegans*	larval, 0.29 g	S,M,T	S	200	---	GIEL01S	63.22	63.22	Dwyer et al. 1995
Golden shiner, *Notemigonus crysoleucas*	---	F,M,T	C	84600	---	NOCR01F	107860	107860	Hartwell et al. 1989
Fathead minnow,	adult, 40 mm	S,M,T	S	310	---	PIPR01S	266.3	69.63	Birge et al. 1983
Pimephales promela	adult, 40 mm	S,M,T	S	120	---	PIPR02S	105.61		Birge et al. 1983
	adult, 40 mm	S,M,T	S	390	---	PIPR03S	207.3		Birge et al. 1983; Benson & Birge
	---	S,M,T	C	55	---	PIPR04S	38.08		Carlson et al. 1986
	---	S,M,T	C	85	---	PIPR05S	70.71		Carlson et al. 1986
	<24 h	S,M,T	N	15	---	PIPR06S	11.23		Schubauer-Berigan et al. 1993
	<24 h	S,M,T	N	44	---	PIPR07S	18.03		Schubauer-Berigan et al. 1993
	<24 h	S,M,T	N	>200	---	PIPR08S	24.38		Schubauer-Berigan et al. 1993
	<24 h, 0.68 mg	S,M,T	S	4.82	---	PIPR09S	8.87		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	8.2	---	PIPR10S	16.72		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	31.57	---	PIPR11S	25.15		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	21.06	---	PIPR12S	17.67		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	35.97	---	PIPR13S	21.24		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	59.83	---	PIPR14S	16.64		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	4.83	---	PIPR15S	5.92		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	70.28	---	PIPR16S	13.34		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	83.59	---	PIPR17S	8.22		Welsh et al. 1993
	<24 h, 0.68 mg	S,M,T	S	182	---	PIPR18S	13.91		Welsh et al. 1993
	larval, 0.32 g	S,M,T	S	290	---	PIPR19S	73.92		Dwyer et al. 1995
	larval, 0.56 g	S,M,T	S	630	---	PIPR20S	157.9		Dwyer et al. 1995
	larval, 0.45 g	S,M,T	S	400	---	PIPR21S	103.2		Dwyer et al. 1995
	larval, 0.39 g	S,M,T	S	390	---	PIPR22S	161.7		Dwyer et al. 1995
	3.2-5.5 cm, 0.42-3.23	S,M,T	S	450	---	PIPR23S	152.9		Richards and Beitinger 1995
	2.8-5.1 cm, 0.30-2.38	S,M,T	S	297	---	PIPR24S	77.75		Richards and Beitinger 1995
	1.9-4.6 cm, 0.13-1.55	S,M,T	S	311	---	PIPR25S	67.56		Richards and Beitinger 1995
	3.0-4.8 cm, 0.23-1.36	S,M,T	S	513	---	PIPR26S	76.36		Richards and Beitinger 1995
	<24 h	S,M,T,D	S	62.23	53.96	PIPR27S	25.70		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	190.5	165.18	PIPR28S	87.89		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	68.58	59.46	PIPR29S	28.59		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	168.91	146.46	PIPR30S	89.18		Erickson et al. 1996a,b

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Table 1. Acute Toxicity of Copper to Freshwater Animals

Species[a]	Organism Age, Size, or Lifestage	Method[b]	Chemical[c]	Reported LC50 or EC50 (total µg/L)[d]	Reported LC50 or EC50 (Diss. µg/L)[e]	BLM Data Label	BLM Normalized LC50 or EC50 (µg/L)[f]	Species Mean Acute Value (µg/L)[g]	Reference
	<24 h	S,M,T,D	S	94.62	82.04	PIPR31S	49.27		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	143.51	124.43	PIPR32S	104.90		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	120.65	103.76	PIPR33S	86.54		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	196.85	167.32	PIPR34S	122.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	133.35	120.02	PIPR35S	75.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	184.15	169.42	PIPR36S	122.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	304.8	268.22	PIPR37S	78.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	292.1	242.44	PIPR38S	201.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	133.35	113.35	PIPR39S	100.75		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	92.71	77.88	PIPR40S	72.95		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	152.4	128.02	PIPR41S	112.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	177.8	151.13	PIPR42S	136.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.2	166.62	PIPR43S	136.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	190.5	163.83	PIPR44S	147.7		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	196.85	157.48	PIPR45S	125.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	234.95	199.71	PIPR46S	157.4		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	146.05	128.52	PIPR47S	127.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	171.45	150.88	PIPR48S	153.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	152.4	131.06	PIPR49S	114.57		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	184.15	160.21	PIPR50S	131.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.2	182.88	PIPR51S	130.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.2	180.85	PIPR52S	105.76		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.2	176.78	PIPR53S	128.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	222.25	188.91	PIPR54S	122.1		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	146.05	125.60	PIPR55S	111.87		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	139.7	117.35	PIPR56S	85.45		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	139.7	114.55	PIPR57S	83.10		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	152.4	126.49	PIPR58S	85.82		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.2	172.72	PIPR59S	110.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	196.85	167.32	PIPR60S	106.46		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	266.7	226.70	PIPR61S	133.4		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	99.06	84.20	PIPR62S	138.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	111.13	97.79	PIPR63S	165.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	78.74	70.08	PIPR64S	114.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	92.71	81.58	PIPR65S	121.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	85.09	77.43	PIPR66S	106.69		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	123.19	110.87	PIPR67S	124.7		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	165.1	151.89	PIPR68S	114.24		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	190.5	175.26	PIPR69S	89.93		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	165.1	145.29	PIPR70S	140.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	127	111.76	PIPR71S	100.16		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	92.08	79.18	PIPR72S	58.74		Erickson et al. 1996a,b

Table 1. Acute Toxicity of Copper to Freshwater Animals

Species[a]	Organism Age, Size, or Lifestage	Method[b]	Chemical[c]	Reported LC50 or EC50 (total µg/L)[d]	Reported LC50 or EC50 (Diss. µg/L)[e]	BLM Data Label	BLM Normalized LC50 or EC50 (µg/L)[f]	Species Mean Acute Value (µg/L)[g]	Reference
	<24 h	S,M,T,D	S	66.68	60.01	PIPR73S	37.67		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	393.70	370.08	PIPR74S	163.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	317.50	292.10	PIPR75S	252.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	107.95	101.47	PIPR76S	169.6		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	67.95	62.51	PIPR77S	146.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	45.72	42.06	PIPR78S	126.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	177.80	172.47	PIPR79S	197.6		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	13.97	12.43	PIPR80S	28.13		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	304.80	271.27	PIPR81S	149.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	71.12	71.12	PIPR82S	105.76		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	83.82	79.63	PIPR83S	108.41		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	104.78	99.54	PIPR84S	114.7		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	139.70	132.72	PIPR85S	137.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	152.40	137.16	PIPR86S	114.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	260.35	182.25	PIPR87S	114.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	488.95	268.92	PIPR88S	122.1		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.20	188.98	PIPR89S	147.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	704.85	662.56	PIPR90S	185.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	952.50	904.88	PIPR91S	197.1		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	1244.60	995.68	PIPR92S	188.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	1485.90	891.54	PIPR93S	135.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	781.05	757.62	PIPR94S	181.4		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	476.25	404.81	PIPR95S	172.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	273.05	262.13	PIPR96S	191.4		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	22.23	20.45	PIPR97S	59.14		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	24.13	23.16	PIPR98S	64.08		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	36.83	34.99	PIPR99S	97.49		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	27.94	27.94	PIPR100S	78.99		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	26.67	26.67	PIPR101S	72.86		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	20.32	20.32	PIPR102S	50.73		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	26.67	26.67	PIPR103S	68.24		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	190.50	182.88	PIPR104S	146.6		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	109.86	96.67	PIPR105S	93.76		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.20	182.88	PIPR106S	128.86		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	209.55	190.69	PIPR107S	113.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	146.05	127.06	PIPR108S	101.01		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	165.10	148.59	PIPR109S	120.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	254.00	223.52	PIPR110S	137.6		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	311.15	283.15	PIPR111S	142.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	165.10	150.24	PIPR112S	106.74		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	920.75	644.53	PIPR113S	131.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	1073.15	697.55	PIPR114S	116.5		Erickson et al. 1996a,b

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Table 1. Acute Toxicity of Copper to Freshwater Animals

Species[a]	Organism Age, Size, or Lifestage	Method[b]	Chemical[c]	Reported LC50 or EC50 (total µg/L)[d]	Reported LC50 or EC50 (Diss. µg/L)[e]	BLM Data Label	BLM Normalized LC50 or EC50 (µg/L)[f]	Species Mean Acute Value (µg/L)[g]	Reference
	<24 h	S,M,T,D	S	1003.30	752.48	PIPR115S	109.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	933.45	653.42	PIPR116S	123.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	742.95	646.37	PIPR117S	129.6		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	1879.60	939.80	PIPR118S	124.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	266.70	253.37	PIPR119S	176.1		Erickson et al. 1996a,b
	---	F,M,T	S	114.00	---	PIPR120F	17.99		Lind et al. Manuscript (1978)
	---	F,M,T	S	121.00	---	PIPR121F	19.70		Lind et al. Manuscript (1978)
	---	F,M,T	S	88.50	---	PIPR122F	13.27		Lind et al. Manuscript (1978)
	---	F,M,T	S	436.00	---	PIPR123F	78.50		Lind et al. Manuscript (1978)
	---	F,M,T	S	516.00	---	PIPR124F	50.09		Lind et al. Manuscript (1978)
	---	F,M,T	S	1586.00	---	PIPR125F	66.49		Lind et al. Manuscript (1978)
	---	F,M,T	S	1129.00	---	PIPR126F	73.03		Lind et al. Manuscript (1978)
	---	F,M,T	S	550.00	---	PIPR127F	42.76		Lind et al. Manuscript (1978)
	---	F,M,T	S	1001.00	---	PIPR128F	34.39		Lind et al. Manuscript (1978)
	30 d, 0.15 g	F,M,T,D	N	96.00	88.32	PIPR129F	39.58		Spehar and Fiandt 1986
	<24 h	F,M,T,D	S	31.75	27.94	PIPR130F	8.69		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	117.48	105.73	PIPR131F	37.88		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	48.26	40.06	PIPR132F	10.80		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	73.03	64.26	PIPR133F	22.19		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	59.06	49.02	PIPR134F	20.32		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	78.74	67.72	PIPR135F	18.51		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	22.23	18.67	PIPR136F	13.61		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	6.99	6.15	PIPR137F	10.94		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	22.23	20.45	PIPR138F	17.70		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	107.32	93.36	PIPR139F	67.09		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	292.10	245.36	PIPR140F	17.75		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	81.28	72.34	PIPR141F	41.16		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	298.45	229.81	PIPR142F	16.18		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	241.30	195.45	PIPR143F	24.40		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	133.35	109.35	PIPR144F	21.07		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	93.98	78.00	PIPR145F	50.83		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	67.95	45.52	PIPR146F	23.18		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	4.76	4.38	PIPR147F	40.09		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	13.97	12.43	PIPR148F	45.37		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	29.85	26.86	PIPR149F	59.43		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	59.69	51.33	PIPR150F	58.84		Erickson et al. 1996a,b
Northern squawfish,	larval, 0.32 g	S,M,T	S	380	---	PTLU01S	88.44	132.2	Dwyer et al. 1995
Ptychocheilus orego	larval, 0.34 g	S,M,T	S	480	---	PTLU02S	197.6		Dwyer et al. 1995

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Table 1. Acute Toxicity of Copper to Freshwater Animals

Species[a]	Organism Age, Size, or Lifestage	Method[b]	Chemical[c]	Reported LC50 or EC50 (total µg/L)[d]	Reported LC50 or EC50 (Diss. µg/L)[e]	BLM Data Label	BLM Normalized LC50 or EC50 (µg/L)[f]	Species Mean Acute Value (µg/L)[g]	Reference
Northern squawfish,	5.0 cm, 1.33 g	F,M,T	C	23	---	PTOR01F	17.02	14.61	Andros and Garton 1980
Ptychocheilus orego	7.2 cm, 3.69 g	F,M,T	C	18	---	PTOR02F	12.54		Andros and Garton 1980
Razorback sucker,	larval, 0.31 g	S,M,T	S	220	---	XYTE01S	63.78	78.66	Dwyer et al. 1995
Xyrauchen texanus	larval, 0.32 g	S,M,T	S	340	---	XYTE02S	97.0		Dwyer et al. 1995
Gila topminnow, *Poeciliposis*	2.72 cm, 0.219 g	S,M,T	S	160	---	POAC01S	56.15	56.15	Dwyer et al. 1999
Bluegill,	3.58 cm, 0.63 g	R,M,D	C	-	2200	LEMA01R	2202	2231	Blaylock et al. 1985
Lepomis macrochiru	12 cm, 35 g	F,M,T	S	1100	---	LEMA02F	2305		Benoit 1975
	2.8-6.8 cm	F,M,T	C	1000	---	LEMA03F	4200		Cairns et al. 1981
	3.58 cm, 0.63 g	F,M,D	C	-	1300	LEMA04F	1163		Blaylock et al. 1985
Fantail darter,	3.7 cm	S,M,T	S	330	---	ETFL01S	117.7	124.3	Lydy and Wissing 1988
Etheostoma flabellar	3.7 cm	S,M,T	S	341	---	ETFL02S	121.1		Lydy and Wissing 1988
	3.7 cm	S,M,T	S	373	---	ETFL03S	122.8		Lydy and Wissing 1988
	3.7 cm	S,M,T	S	392	---	ETFL04S	136.6		Lydy and Wissing 1988
Greenthroat darter, *Etheostoma*	2.26 cm, 0.133 g	S,M,T	S	260	---	ETLE01S	82.80	82.80	Dwyer et al. 1999
Johnny darter,	3.9 cm	S,M,T	S	493	---	ETNI01S	167.3	178.3	Lydy and Wissing 1988
Etheostoma nigrum	3.9 cm	S,M,T	S	483	---	ETNI02S	164.2		Lydy and Wissing 1988
	3.9 cm	S,M,T	S	602	---	ETNI03S	200.1		Lydy and Wissing 1988
	3.9 cm	S,M,T	S	548	---	ETNI04S	183.9		Lydy and Wissing 1988
Fountain darter, *Etheostoma rubrum*	2.02 cm, 0.062 g	S,M,T	S	60	---	ETRU01S	22.74	22.74	Dwyer et al. 1999
Boreal toad, *Bufo boreas*	tadpole, 0.012 g	S,M,T	S	120	---	BUBO01S	47.49	47.49	Dwyer et al. 1999

[a] Species appear in order taxonomically, with invertebrates listed first, fish, and an amphibian listed last. Species within each genus are ordered alphabetically. Within each species, tests are ordered by test method (static, renewal, flow-through) and date.

[b] S = static, R = renewal, F = flow-through, U = unmeasured, M = measured, T = exposure concentrations were measured as total copper, D = exposure concentrations were measured as dissolved copper.

[c] S = copper sulfate, N = copper nitrate, C = copper chloride.

[d] Values in this column are total copper LC50 or EC50 values as reported by the author.

[e] Values in this column are dissolved copper LC50 or EC50 values either reported by the author or if the author did not report a dissolved value then a conversion factor (CF) was applied to the total copper LC50 to estimate dissolved copper values.

[f] Normalization Chemistry

Temp	pH	Diss Cu	DOC	%HA	Ca	Mg	Na	K	SO_4	Cl	Alkalinity	S
Deg C		ug/L	mg/L		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
20.00	7.5	1.00	0.5	10.0	14.0	12.1	26.3	2.1	81.4	1.9	65.0	0.0003

g Underlined LC50s or EC50s not used to derive SMAV because considered extreme value.

* Table updated as of March 2, 2007

Table 2a. Chronic Toxicity of Copper to Freshwater Animals

Species	Test[a]	Chemical	Endpoint	Hardness (mg/L as CaCO3)	Chronic Limits (µg/L)	Chronic Values		Species Mean Chronic Value (Total µg/L)	Genus Mean Chronic Value (Total µg/L)	ACR	Reference
						Chronic Value[b] (µg/L)	EC20[b] (µg/L)				
Rotifer, *Brachionus calyciflorus*	LC,T	Copper sulfate	Intrinsic growth rate	85	2.5-5.0	3.54	-	3.54	3.54		Janssen et al. 1994
Snail, *Campeloma decisum (Test 1)*	LC,T	Copper sulfate	Survival	35-55	8-14.8	10.88	8.73	9.77	9.77	191.6	Arthur and Leonard 1970
Snail, *Campeloma decisum (Test 2)*	LC,T	Copper sulfate	Survival	35-55	8-14.8	10.88	10.94			153.0	Arthur and Leonard 1970
Cladoceran, *Ceriodaphnia dubia (New River)*	LC,D	-	Reproduction	179	6.3-9.9	7.90[c] (8.23)	-	19.3	19.3	3.599	Belanger et al. 1989
Cladoceran, *Ceriodaphnia dubia (Cinch River)*	LC,D	-	Reproduction	94.1	<19.3-19.3	<19.3	19.36[c] (20.17)			3.271	Belanger et al. 1989
Cladoceran, *Ceriodaphnia dubia*	LC,T	Copper sulfate	Survival and reproduction	57	-	24.50	-			0.547	Oris et al. 1991
Cladoceran, *Ceriodaphnia dubia*	LC,T	Copper sulfate	Survival and reproduction	57	-	34.60	-				Oris et al. 1991
Cladoceran, *Ceriodaphnia dubia*	LC,T,D	Copper chloride	Reproduction		12-32	19.59	9.17			2.069	Carlson et al. 1986
Cladoceran, *Daphnia magna*	LC,T	Copper chloride	Reproduction	85	10-30	17.32	-	14.1	8.96		Blaylock et al. 1985
Cladoceran, *Daphnia magna*	LC,T	Copper chloride	Carapace length	225	12.6-36.8	21.50	-				van Leeuwen et al. 1988
Cladoceran, *Daphnia magna*	LC,T	Copper chloride	Reproduction	51	11.4-16.3	13.63	12.58			2.067	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC,T	Copper chloride	Reproduction	104	20-43	29.33	19.89			1.697	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC,T	Copper chloride	Reproduction	211	7.2-12.6	9.53	6.06			11.39	Chapman et al. Manuscript
Cladoceran, *Daphnia pulex*	LC,T	Copper sulfate	Survival	57.5 (No HA)	4.0-6.0	4.90	2.83	5.68		9.104	Winner 1985
Cladoceran, *Daphnia pulex*	LC,T	Copper sulfate	Survival	115 (No HA)	5.0-10.0	7.07				3.904	Winner 1985
Cladoceran, *Daphnia pulex*	LC,T	Copper sulfate	Survival	230 (0.15 HA)	10-15	12.25	9.16			3.143	Winner 1985

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Table 2a. Chronic Toxicity of Copper to Freshwater Animals

Species	Test[a]	Chemical	Endpoint	Hardness (mg/L as CaCO3)	Chronic Limits (µg/L)	Chronic Values		Species Mean Chronic Value (Total µg/L)	Genus Mean Chronic Value (Total µg/L)	ACR	Reference
						Chronic Value[b] (µg/L)	EC20[b] (µg/L)				
Caddisfly, *Clistoronia magnifica*	LC,T	Copper chloride	Emergence (adult 1st gen)	26	8.3-13	10.39	7.67	7.67	7.67		Nebeker et al. 1984b
Rainbow trout, *Oncorhynchus mykiss*	ELS,T continuous	Copper chloride	Biomass	120			27.77	23.8	11.9	2.881	Seim et al. 1984
Rainbow trout, *Oncorhynchus mykiss*	ELS,T	Copper sulfate	Biomass	160-180	12-22	16.25	20.32				Besser et al. 2001
Chinook salmon, *Oncorhynchus tshawytscha*	ELS,T	Copper chloride	Biomass	20-45	<7.4	<7.4	5.92	5.92		5.594	Chapman 1975, 1982
Brown trout, *Salmo trutta*	ELS,T	Copper sulfate	Biomass	45.4	20.8-43.8	29.91	-	29.9	29.9		McKim et al. 1978
Brook trout, *Salvelinus fontinalis*	PLC,T	Copper sulfate	Biomass	35.0	<5 -5	<5	-	12.5	19.7		Sauter et al. 1976
Brook trout, *Salvelinus fontinalis*	ELS,T	Copper sulfate	Biomass	45.4	22.3-43.5	31.15	-				McKim et al. 1978
Lake trout, *Salvelinus namaycush*	ELS, T	Copper sulfate	Biomass	45.4	22.0-43.5	30.94	-	30.9			McKim et al. 1978
Northern pike, *Esox lucius*	ELS, T	Copper sulfate	Biomass	45.4	34.9-104.4	60.36	-	60.4	60.4		McKim et al. 1978
Bluntnose minnow *Pimephales notatus*	LC,T	Copper sulfate	Egg production	172-230	<18-18	18.00	-	18.0	13.0	12.88	Horning and Neiheisel 1979
Fathead minnow, *Pimephales promelas*	ELS,T,D	-	Biomass	45			9.38	9.38		11.40	Lind et al. manuscript
White sucker, *Catostomus commersoni*	ELS, T	Copper sulfate	Biomass	45.4	12.9-33.8	20.88	-	20.9	20.9		McKim et al. 1978
Bluegill (larval), *Lepomis macrochirus*	ELS,T,D	Copper sulfate	Survival	44-50	21-40	28.98	27.15	27.2	27.2	40.52	Benoit 1975

[a] LC = life-cycle; PLC = partial life-cyle; ELS = early life state; T = total copper; D = dissolved copper.

[b] Results are based on copper, not the chemical.

[c] Chronic values based on dissolved copper concentration.

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Table 2b. Chronic Toxicity of Copper to Saltwater Animals

Species	Test	Chemical	Salinity (g/kg)	Limits (µg/L)	Chronic Value (µg/L)	Chronic Value Dissolved (µg/L)	ACR	Reference
Sheepshead minnow, *Cyprinodon variegatus*	ELS	Copper chloride	30	172-362	249	206.7	1.48	Hughes et al. 1989

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Table 2c. Acute-Chronic Ratios

Species	Hardness (mg/L as $CaCO_3$)	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio	Reference	Overall Ratio for Species	
Snail,	35-55	1673[a]	8.73	191.61	Arthur and Leonard 1970		
Campeloma decisum	35-55	1673[a]	10.94	152.95	Arthur and Leonard 1970	171.19	
Cladoceran,	[redacted]	28.42[b]	7.90	3.60	[redacted]		
Ceriodaphnia dubia	[redacted]	63.33[b]	19.36	3.27	[redacted]		
	57	13.4	24.5	0.55	Oris et al. 1991		
	--	[redacted]	9.17	1.96	[redacted]	2.85[g]	✓
Cladoceran,	51	26	12.58	2.07	Chapman et al. Manuscript		
Daphnia magna	104	33.76[d]	19.89	1.70	Chapman et al. Manuscript		
	211	69	6.06	11.39	Chapman et al. Manuscript	3.42	✓
Cladoceran,	57.5	25.737	2.83	9.10	[redacted]		
Daphnia pulex	115	27.6	7.07	3.90	[redacted]		
	230	28.79	9.16	3.14	[redacted]	4.82	✓
Rainbow trout, *Oncorhynchus mykiss*	120	80	27.77	2.88	Seim et al. 1984	2.88	✓
Chinook salmon, *Oncorhynchus tshawytscha*	20-45	33.1	5.92	5.59	Chapman 1975, 1982	5.59	✓
Bluntnose minnow, *Pimephales notatus*	172-230	231.9[e]	18	12.88	Horning and Neiheisel 1979	12.88	
Fathead minnow, *Pimephales promelas*	45	106.875[f]	9.38	11.40	Lind et al. 1978	11.40	
Bluegill, *Lepomis macrochirus*	21-40	1100	27.15	40.52	Benoit 1975	40.49	
Sheepshead minnow, *Cyprinodon variegatus*	-	368	249	1.48	Hughes et al. 1989	1.48	✓

[a]Geometric mean of two values from Arthur and Leonard (1970) in Table 1.

[b]Geometric mean of five values from Belanger et al. (1989) in Table 1. ACR is based on dissolved metal measurements.

[c]Geometric mean of two values from Carlson et al. (1986) in Table 1.

[d]Geometric mean of two values from Chapman manuscript in Table 1.

[e]Geometric mean of two values of three values from Horning and Neiheisel (1979) in Appendix C.

[f]Geometric mean of three values from Lind et al. (1978) in Table 1.

[g]ACR from Oris et al. (1991) not used in calculating overall ratio for species because it is <1.

FACR
Freshwater final acute-chronic ratio = 3.22
Saltwater final acute-chronic ratio = 3.22

* Table updated as of March 2, 2007

Table 3a. Ranked Freshwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios

Rank	GMAV	Species	SMAV (µg/L)	ACR
27	107,860	Golden shiner, *Notemigonus crysoleucas*	107,860	
26	20,636	Stonefly, *Acroneuria lycorias*	20,636	
25	3,573	Snail, *Campeloma decisum*	3,573	171.19
24	2,231	Bluegill sunfish, *Lepomis macrochirus*	2,231	40.49
23	1,987	Midge, *Chironomus decorus*	1,987	
22	216.3	Chiselmouth, *Acrocheilus alutaceus*	216.3	
21	80.38	Fantail darter, *Etheostoma flabellare*	124.3	
		Greenthroat darter, *Etheostoma lepidum*	82.80	
		Johnny darter, *Etheostoma nigrum*	178.3	
		Fountain darter, *Etheostoma rubrum*	22.74	
20	78.66	Razorback sucker, *Xyrauchen texanus*	78.66	
19	69.63	Fathead minnow, *Pimephales promelas*	69.63	11.40
18	69.63	Shovelnose sturgeon, *Scaphirhynchus platorynchus*	69.63	
17	68.31	Bull trout, *Salvelinus confluentus*	68.31	
16	63.22	Bonytail chub, *Gila elegans*	63.22	
15	56.15	Gila topminnow, *Poeciliposis occidentalis*	56.15	
14	52.51	Freshwater mussel, *Utterbackia imbecillis*	52.51	
13	48.41	Worm, *Lumbriculus variegatus*	48.41	
12	47.49	Boreal toad, *Bufo boreas*	47.49	
11	43.94	Colorado squawfish, *Ptychocheilus lucius*	132.2	
		Northern squawfish, *Ptychocheilus oregonensis*	14.61	
10	31.39	Apache trout, *Oncorhynchus apache*	32.54	
		Cutthroat trout, *Oncorhynchus clarki*	32.97	
		Pink salmon, *Oncorhynchus gorbuscha*	40.13	
		Coho salmon, *Oncorhynchus kisutch*	22.93	
		Rainbow trout, *Oncorhynchus mykiss*	22.19	2.88
		Sockeye salmon, *Oncorhynchus nerka*	54.82	
		Chinook salmon, *Oncorhynchus tshawytscha*	25.02	5.59
9	20.41	Snail, *Physa integra*	20.41	
8	12.31	Snail, *Juga plicifera*	12.31	
7	12.07	Amphipod, *Hyalella azteca*	12.07	
6	11.33	Freshwater mussel, *Actinonaias pectorosa*	11.33	
5	9.73	Cladoceran, *Scapholeberis sp.*	9.73	
4	9.60	Amphipod, *Gammarus pseudolimnaeus*	9.60	
3	6.67	Snail, *Lithoglyphus virens*	6.67	
2	5.93	Cladoceran, *Ceriodaphnia dubia*	5.93	2.85
1	4.05	Cladoceran, *Daphnia magna*	6.00	3.42
		Cladoceran, *Daphnia pulicaria*	2.73	

* Table updated as of March 2, 2007

Table 3b. Freshwater Final Acute Value (FAV) and Criteria Calculations

Calculated Freshwater FAV based on 4 lowest values: Total Number of GMAVs in Data Set = 27					
Rank	**GMAV**	**lnGMAV**	**$(lnGMAV)^2$**	**P = R/(n+1)**	**SQRT(P)**
4	9.600	2.261	5.114	0.143	0.378
3	6.670	1.897	3.599	0.107	0.327
2	5.930	1.780	3.170	0.071	0.267
1	4.050	1.398	1.954	0.036	0.189
Sum:		**7.33671**	**13.83657**	**0.35714**	**1.16153**
S =	4.374				
L =	0.5641				
A =	1.542				
Calculated FAV =	**4.674452**				
Calculated CMC =	**2.337**				

Dissolved Copper Criterion Maximum Concentration (CMC) = 2.337 µg/L (for example normalization chemistry see Table 1, footnote f)
Criteria Lethal Accumulation (LA50) based on example normalization chemistry = 0.03395 nmol/g wet wt
Criterion Continuous Concentration (CCC) = 4.67445/3.22 = 1.4516932 µg/L (for example normalization chemistry see Table 1, footnote f)

S = Scale parameter or slope
L = Location parameter or intercept
P = Cumulative probability
A = lnFAV

* Table updated as of March 2, 2007

Table 4. Toxicity of Copper to Freshwater Plants

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result[b] (Total µg/L)	Reference
Blue-green alga, *Anabaena flos-aqua*	S,U	Copper sulfate	65.2	96 hr	EC75 (cell density)	200	Young and Lisk 1972
Bllue-green alga, *Anabaena variabilis*	S,U	Copper sulfate	65.2	-	EC85 (wet weight)	100	Young and Lisk 1972
Blue-green alga, *Anabaena* strain 7120	-	-	-	-	Lag in growth	64	Laube et al. 1980
Blue-green alga, *Chroococcus paris*	S,U	Copper nitrate	54.7	10 days	Growth reduction	100	Les and Walker 1984
Blue-green alga, *Microcystis aeruginosa*	S,U	Copper sulfate	54.9	8 days	Incipient inhibition	30	Bringmann 1975; Bringmann and Kuhn 1976, 1978a,b
Alga, *Ankistrodesmus braunii*	-	-	-	-	Growth reduction	640	Laube et al. 1980
Green alga, *Chlamydomonas* sp.	S,U	Copper sulfate	68	10 days	Growth inhibition	8,000	Cairns et al. 1978
Green alga, *Chlamydomonas reinhardtii*	S,M,T	-	90 - 133	72 hr	NOEC (deflagellation)	12.2-49.1	Winner and Owen 1991a
Green alga, *Chlamydomonas reinhardtii*	S,M,T	-	90 - 133	72 hr	NOEC (cell density)	12.2-43.0	Winner and Owen 1991a
Green alga, *Chlamydomonas reinhardtii*	F,M,T	-	24	10 days	EC50 (cell density)	31.5	Schafer et al. 1993
Green alga, *Chlorella pyrenoidosa*	S,U	-	-	96 hr	ca. 12 hr lag in growth	1	Steeman-Nielsen and Wium-Andersen 1970
Green alga, *Chlorella pyrenoidosa*	S,U	-	54.7	-	Growth inhibition	100	Steeman-Nielsen and Kamp-Nielsen 1970
Green alga, *Chlorella pyrenoidosa*	S,U	Copper sulfate	365	14 days	EC50 (dry weight)	78-100	Bednarz and Warkowska-Dratnal 1985
Green alga, *Chlorella pyrenoidosa*	S,U	Copper sulfate	36.5	14 days	EC50 (dry weight)	78-100	Bednarz and Warkowska-Dratnal 1985
Green alga, *Chlorella pyrenoidosa*	S,U	Copper sulfate	3.65	14 days	EC50 (dry weight)	78-100	Bednarz and Warkowska-Dratnal 1983/1984
Green alga, *Chlorella saccharophila*	S,U	Copper chloride	-	96 hr	96-h EC50	550	Rachlin et al. 1982
Green alga, *Chlorella vulgaris*	S,U	Copper sulfate	2,000	96 hr	Growth inhibition	200	Young and Lisk 1972
Green alga, *Chlorella vulgaris*	S,U	Copper chloride		33 days	EC20 (growth)	42	Rosko and Rachlin 1977
Green alga, *Chlorella vulgaris*	F,U	Copper sulfate	-	96 hr	EC50 or EC50 (cell numbers)	62	Ferard et al. 1983
Green alga, *Chlorella vulgaris*	S,M,D	Copper sulfate	-	96 hr	IC50	270	Ferard et al. 1983
Green alga, *Chlorella vulgaris*	S,M,T	Copper chloride	-	96 hr	EC50 (cell density)	200	Blaylock et al. 1985
Green alga, *Chlorella vulgaris*	S,U	Copper sulfate	17.1	7 days	15% reduction in cell density	100	Bilgrami and Kumar 1997

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Table 4. Toxicity of Copper to Freshwater Plants

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result[b] (Total µg/L)	Reference
Green alga, *Scenedesmus quadricauda*	S,U	Copper sulfate	68	10 days	Growth reduction	8,000	Cairns et al. 1978
Green alga, *Scenedesmus quadricauda*	S,U	Copper sulfate	181	7 days	LOEC (growth)	1,100	Bringmann and Kuhn 1977a, 1978a,b, 1979, 1980a
Green alga, *Selenastrum capricornutum*	S,U	Copper chloride	14.9	14 days	EC50 (cell volume)	85	Christensen et al. 1979
Green alga, *Selenastrum capricornutum*	S,U	Copper chloride	14.9	7 days	LOEC (growth)	50	Bartlett et al. 1974
Green alga, *Selenastrum capricornutum*	S,M,T	Copper chloride	24.2	96 hr	EC50 (cell count)	400	Blaylock et al. 1985
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	9.3	96 hr	EC50 (cell count)	48.4	Blaise et al. 1986
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	9.3	96 hr	EC50 (cell count)	44.3	Blaise et al. 1986
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	9.3	96 hr	EC50 (cell count)	46.4	Blaise et al. 1986
Green alga, *Selenastrum capricornutum*	S,U	Copper chloride	15	2-3 wk	EC50 (biomass)	53.7	Turbak et al. 1986
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	14.9	5 days	Growth reduction	58	Nyholm 1990
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	9.3	96 hr	EC50 (cell count)	69.9	St. Laurent et al. 1992
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	9.3	96 hr	EC50 (cell count)	65.7	St. Laurent et al. 1992
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	24.2	96 hr	EC50 (cell count)	54.4	Radetski et al. 1995
Green alga, *Selenastrum capricornutum*	R,U	Copper sulfate	24.2	96 hr	EC50 (cell count)	48.2	Radetski et al. 1995
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	16	96 hr	EC50 (cell density)	38	Chen et al. 1997
Algae, mixed culture	S,U	Copper sulfate	-	-	Significant reduction in blue-green algae and nitrogen fixation	5	Elder and Horne 1978
Diatom, *Cyclotella meneghiniana*	S,U	Copper sulfate	68	10 days	Growth inhibition	8,000	Cairns et al. 1978
Diatom, *Navicula incerta*	S,U	Copper chloride	-	96 hr	EC50	10,429	Rachlin et al. 1983
Diatom, *Nitzschia linearis*	-	-	-	5 day	EC50	795-815	Academy of Natural Sciences 1960; Patrick et al. 1968
Diatom, *Nitzschia palea*	-	-	-	-	Complete growth inhibition	5	Steeman-Nielsen and Wium-Andersen 1970
Duckweed, *Lemna minor*	F	-	-	7 day	EC50	119	Walbridge 1977
Duckweed, *Lemna minor*	S,U	Copper sulfate	-	28 days	Significant plant damage	130	Brown and Rattigan 1979

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Table 4. Toxicity of Copper to Freshwater Plants

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result[b] (Total µg/L)	Reference
Duckweed, *Lemna minor*	S,U	-	0	96 hr	EC50 (frond number)	1,100	Wang 1986
Duckweed, *Lemna minor*	S,U	Copper sulfate	78	96 hr	EC50 (chlorophyll a reduction)	250	Eloranta et al. 1988
Duckweed, *Lemna minor*	R,M,T	Copper nitrate	39	96 hr	Reduced chlorophyll production	24	Taraldsen and Norberg-King 1990
Eurasian watermilfoil, *Myriophyllum spicatum*	S,U	-	89	32 days	EC50 (root weight)	250	Stanley 1974

[a] S=Static; R=Renewal; F=Flow-through; M=Measured; U=Unmeasured; T=Total metal conc. measured; D=dissolved metal conc. measured.

[b] Results are expressed as copper, not as the chemical.

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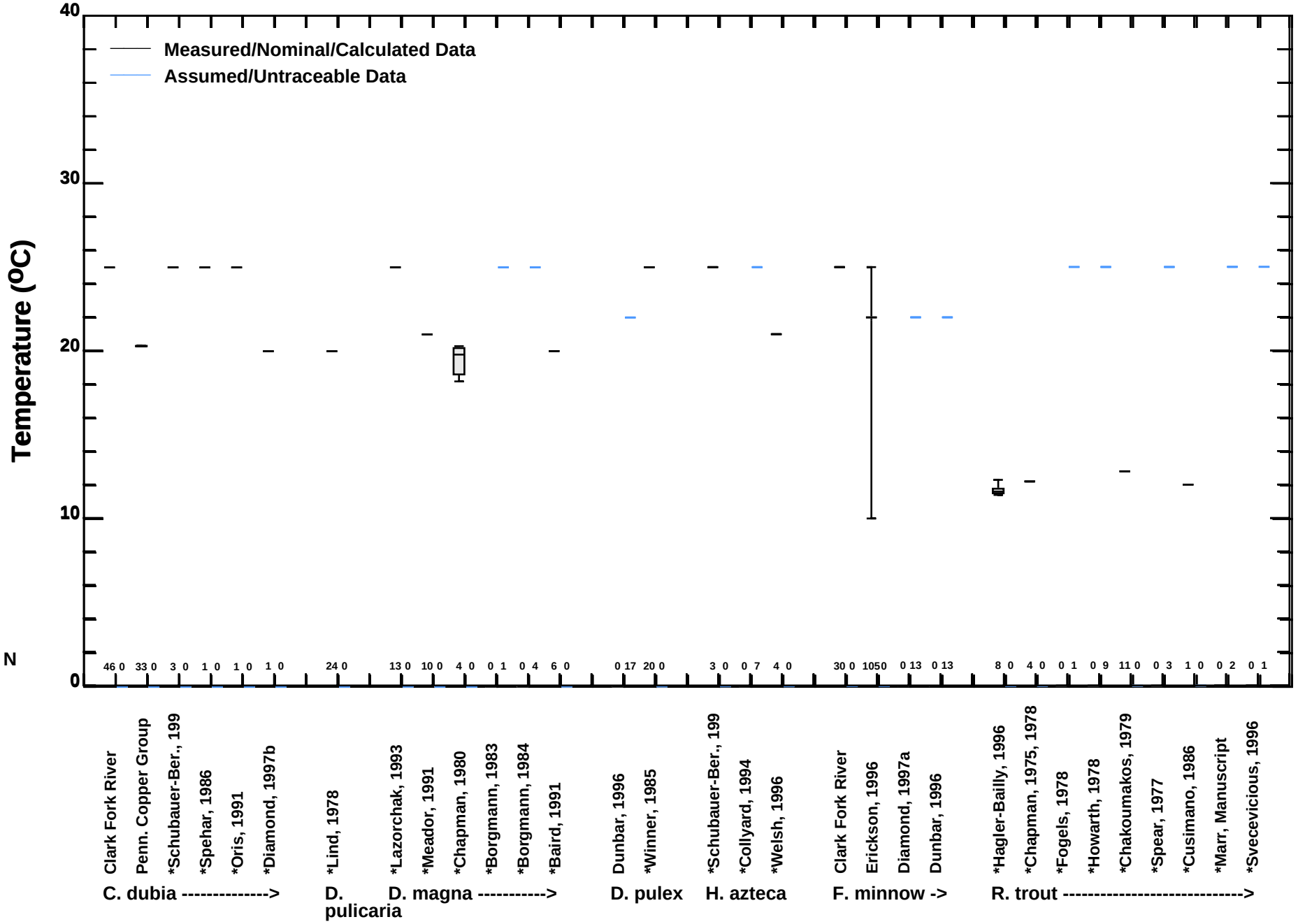
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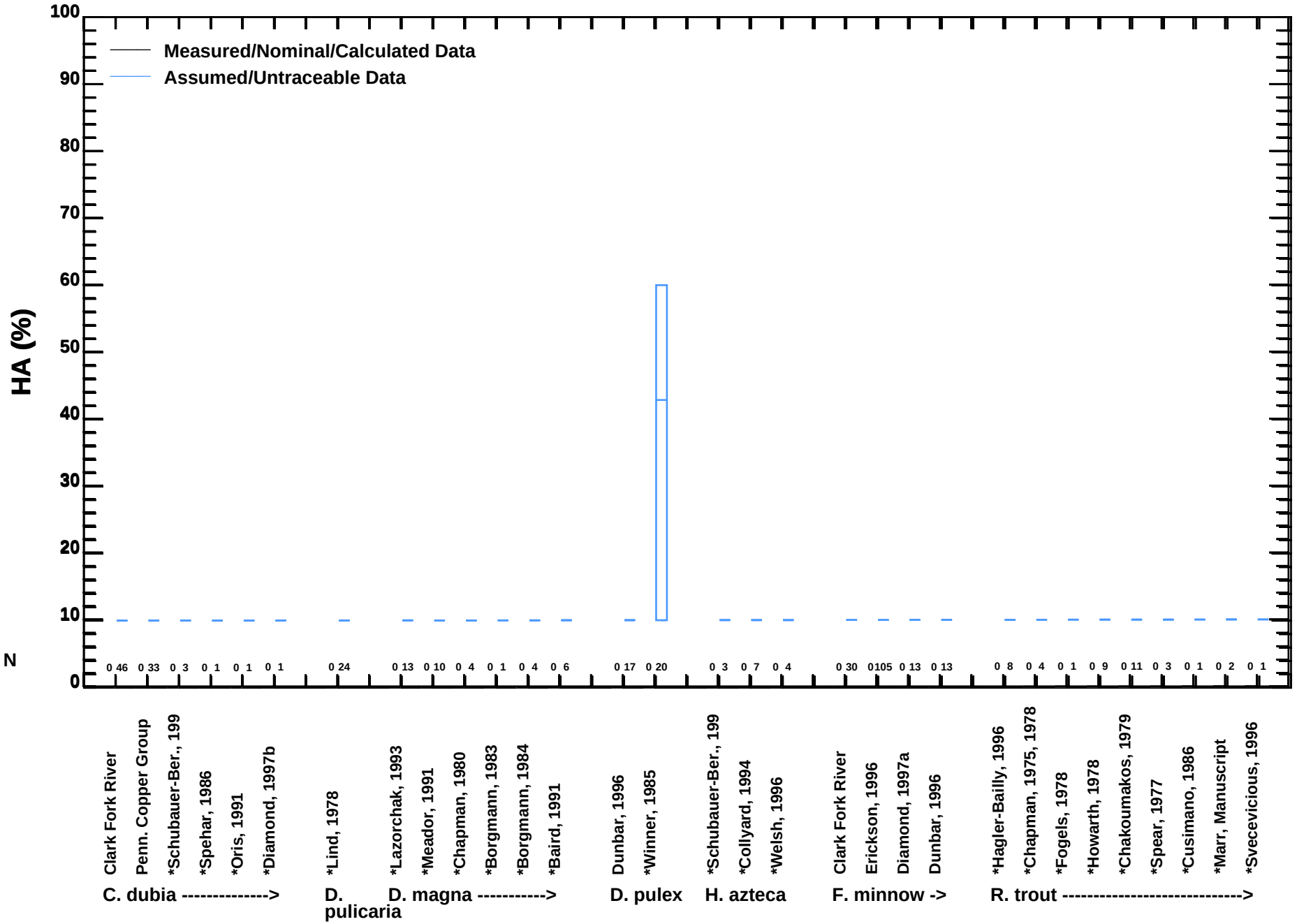
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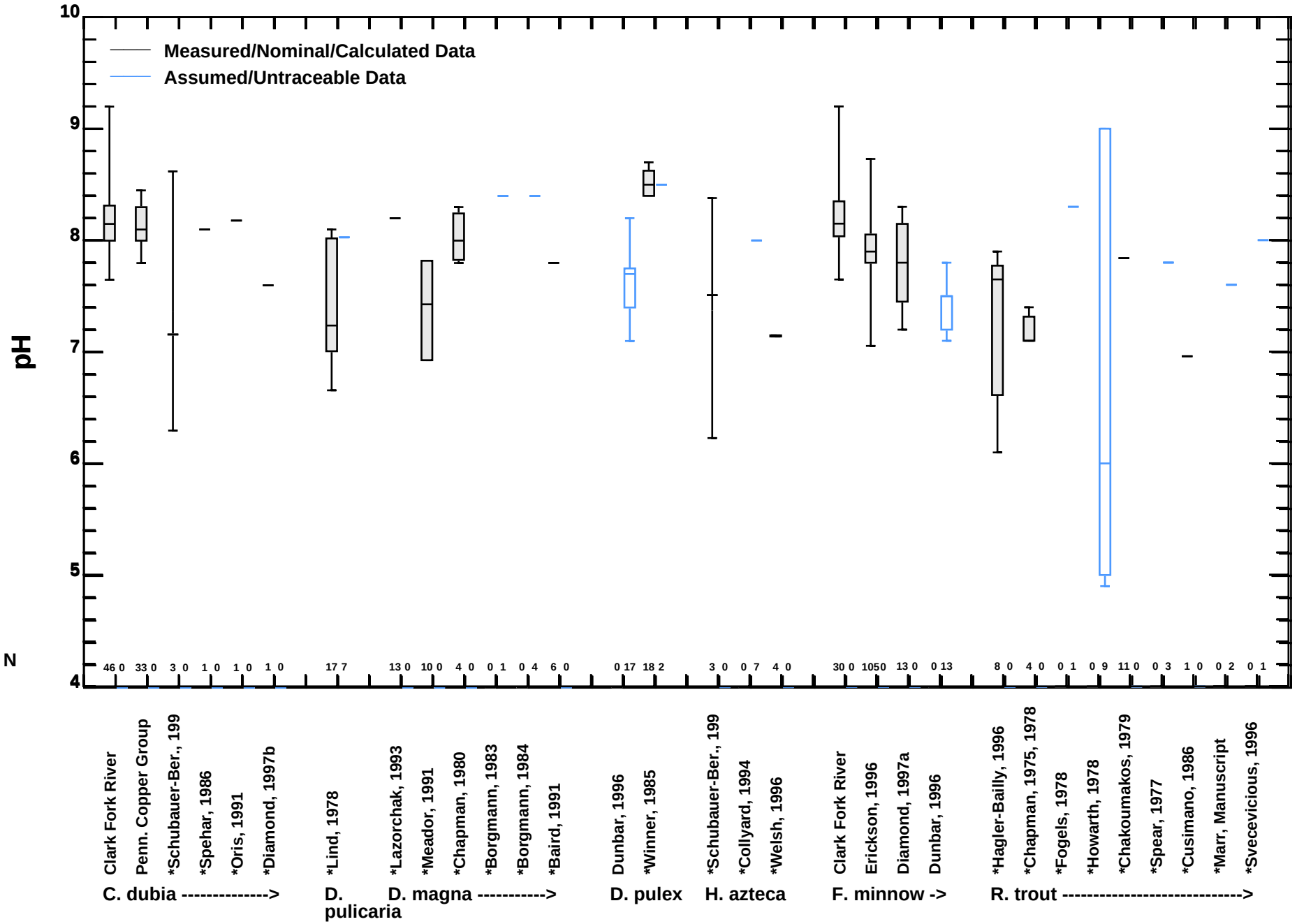
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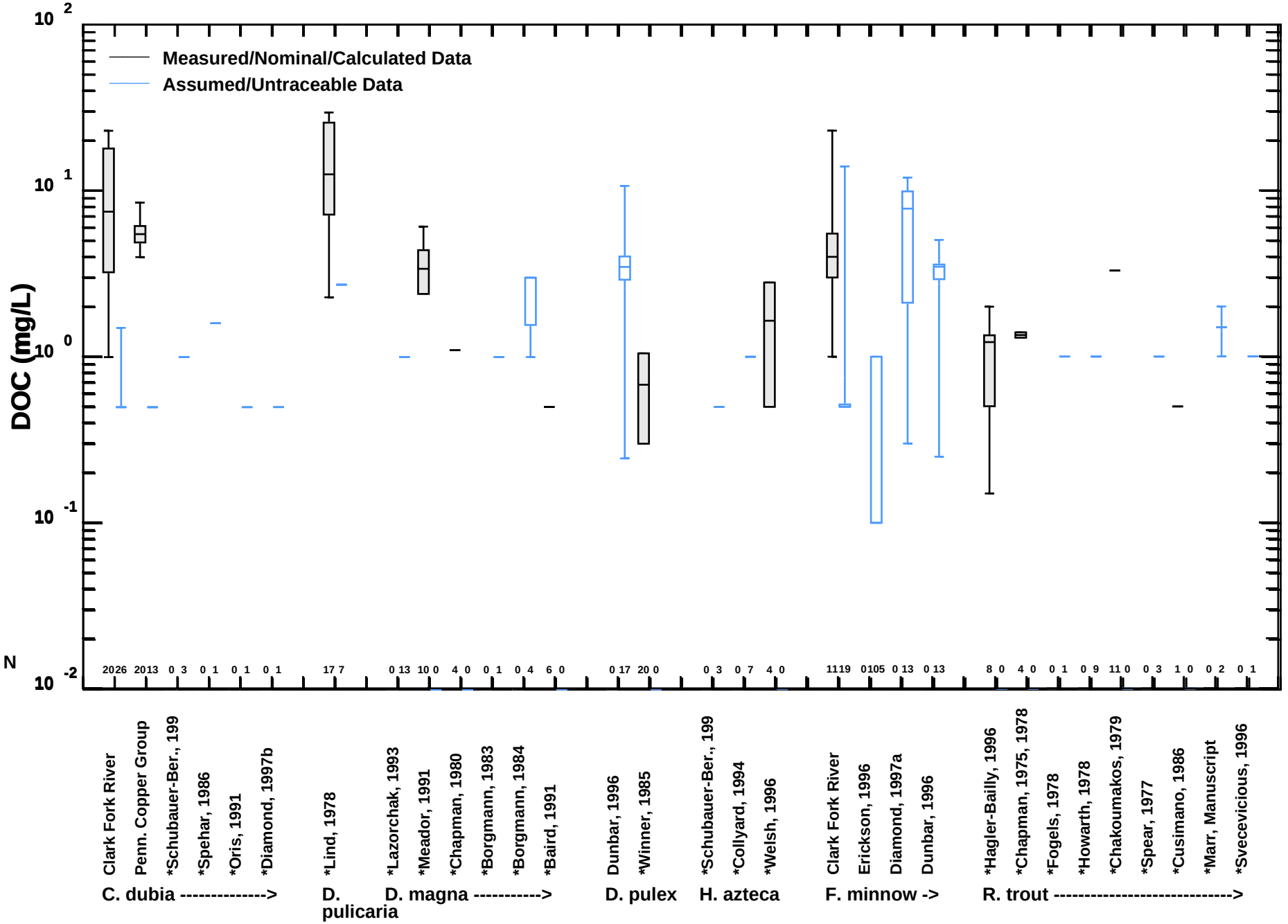
Appendices

Appendix A. Ranges in Calibration and Application Data Sets


Measured/Nominal/Calculated Data
Assumed/Untraceable Data
Temperature (°C)
40
30
20
10
0
N
46 0
33 0
3 0
1 0
1 0
1 0
24 0
13 0
10 0
4 0
0 1
0 4
6 0
0 17
20 0
3 0
0 7
4 0
30 0
105 0
0 13
0 13
8 0
4 0
0 1
0 9
11 0
0 3
1 0
0 2
0 1
Clark Fork River
Penn. Copper Group
*Schubauer-Ber., 199
*Spehar, 1986
*Oris, 1991
*Diamond, 1997b
*Lind, 1978
*Lazorchak, 1993
*Meador, 1991
*Chapman, 1980
*Borgmann, 1983
*Borgmann, 1984
*Baird, 1991
Dunbar, 1996
*Winner, 1985
*Schubauer-Ber., 199
*Collyard, 1994
*Welsh, 1996
Clark Fork River
Erickson, 1996
Diamond, 1997a
Dunbar, 1996
*Hagler-Bailly, 1996
*Chapman, 1975, 1978
*Fogels, 1978
*Howarth, 1978
*Chakoumakos, 1979
*Spear, 1977
*Cusimano, 1986
*Marr, Manuscript
*Svecevicious, 1996
C. dubia ---------->
D. pulicaria
D. magna ---------->
D. pulex
H. azteca
F. minnow ->
R. trout ---------->
Median, Range and Quartiles of Temperature in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)

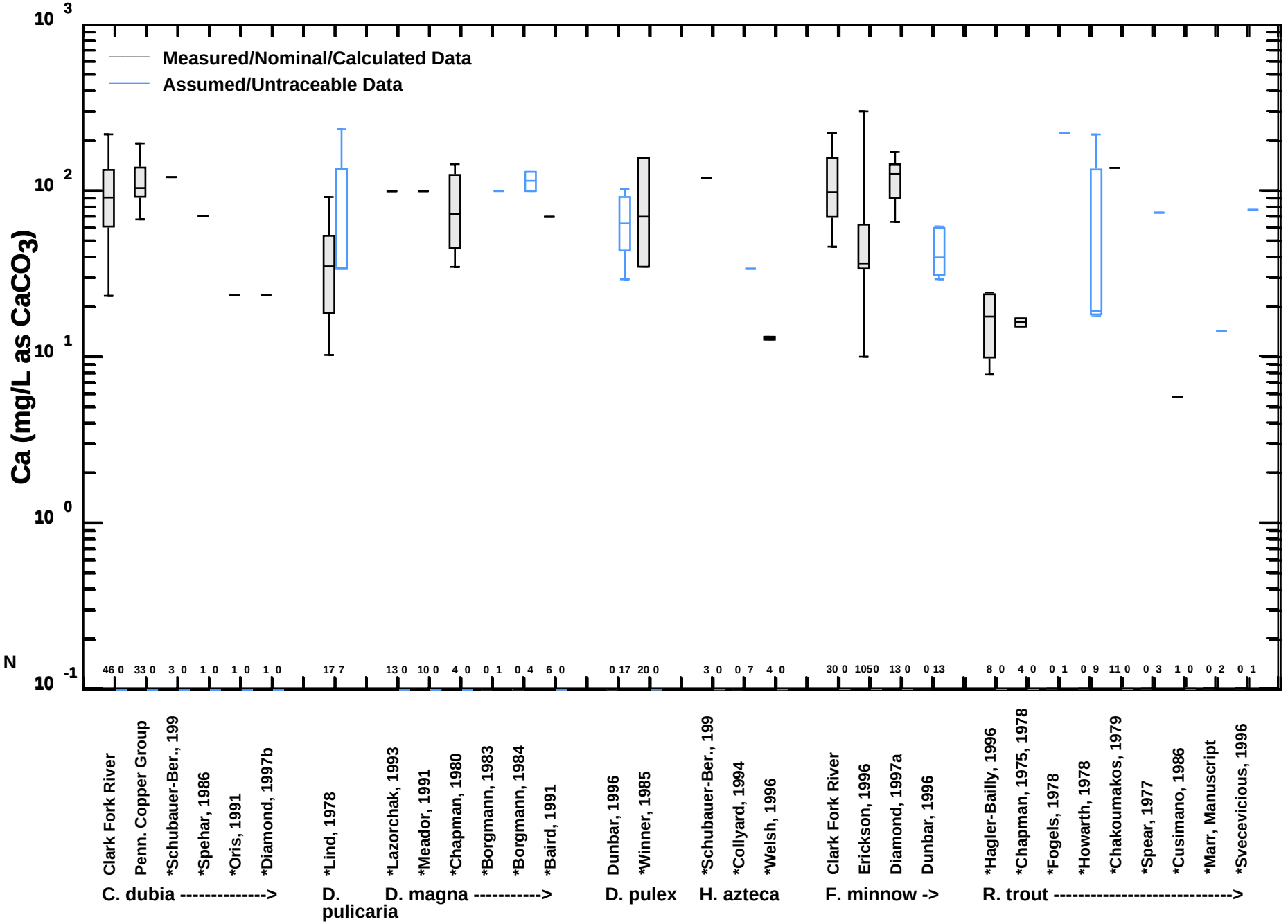

Measured/Nominal/Calculated Data
Assumed/Untraceable Data
HA (%)
100
90
80
70
60
50
40
30
20
10
0
N
0 46
0 33
0 3
0 1
0 1
0 1
0 24
0 13
0 10
0 4
0 1
0 4
0 6
0 17
0 20
0 3
0 7
0 4
0 30
0105
0 13
0 13
0 8
0 4
0 1
0 9
0 11
0 3
0 1
0 2
0 1
Clark Fork River
Penn. Copper Group
*Schubauer-Ber., 199
*Spehar, 1986
*Oris, 1991
*Diamond, 1997b
*Lind, 1978
*Lazorchak, 1993
*Meador, 1991
*Chapman, 1980
*Borgmann, 1983
*Borgmann, 1984
*Baird, 1991
Dunbar, 1996
*Winner, 1985
*Schubauer-Ber., 199
*Collyard, 1994
*Welsh, 1996
Clark Fork River
Erickson, 1996
Diamond, 1997a
Dunbar, 1996
*Hagler-Bailly, 1996
*Chapman, 1975, 1978
*Fogels, 1978
*Howarth, 1978
*Chakoumakos, 1979
*Spear, 1977
*Cusimano, 1986
*Marr, Manuscript
*Svecevicious, 1996
C. dubia ---------->
D. pulicaria
D. magna ---------->
D. pulex
H. azteca
F. minnow ->
R. trout ---------->
Median, Range and Quartiles of HA in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)

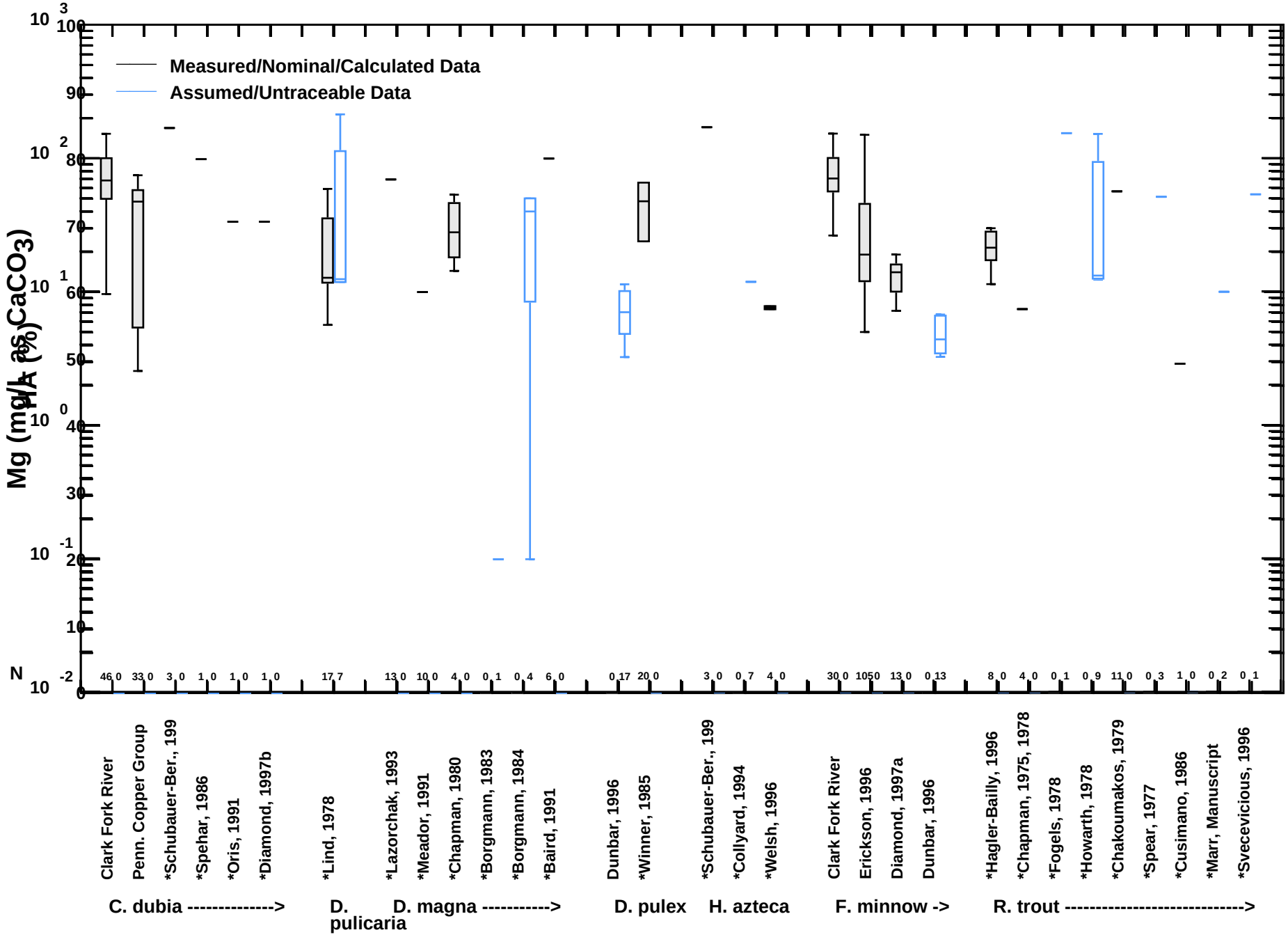

Measured/Nominal/Calculated Data
Assumed/Untraceable Data
pH
N
10
9
8
7
6
5
4
46 0
33 0
3 0
1 0
1 0
1 0
17 7
13 0
10 0
4 0
0 1
0 4
6 0
0 17
18 2
3 0
0 7
4 0
30 0
105 0
13 0
0 13
8 0
4 0
0 1
0 9
11 0
0 3
1 0
0 2
0 1
Clark Fork River
Penn. Copper Group
*Schubauer-Ber., 199
*Spehar, 1986
*Oris, 1991
*Diamond, 1997b
*Lind, 1978
*Lazorchak, 1993
*Meador, 1991
*Chapman, 1980
*Borgmann, 1983
*Borgmann, 1984
*Baird, 1991
Dunbar, 1996
*Winner, 1985
*Schubauer-Ber., 199
*Collyard, 1994
*Welsh, 1996
Clark Fork River
Erickson, 1996
Diamond, 1997a
Dunbar, 1996
*Hagler-Bailly, 1996
*Chapman, 1975, 1978
*Fogels, 1978
*Howarth, 1978
*Chakoumakos, 1979
*Spear, 1977
*Cusimano, 1986
*Marr, Manuscript
*Svecevicious, 1996
C. dubia ---------->
D. pulicaria
D. magna ---------->
D. pulex
H. azteca
F. minnow ->
R. trout ---------->
Median, Range and Quartiles of pH in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



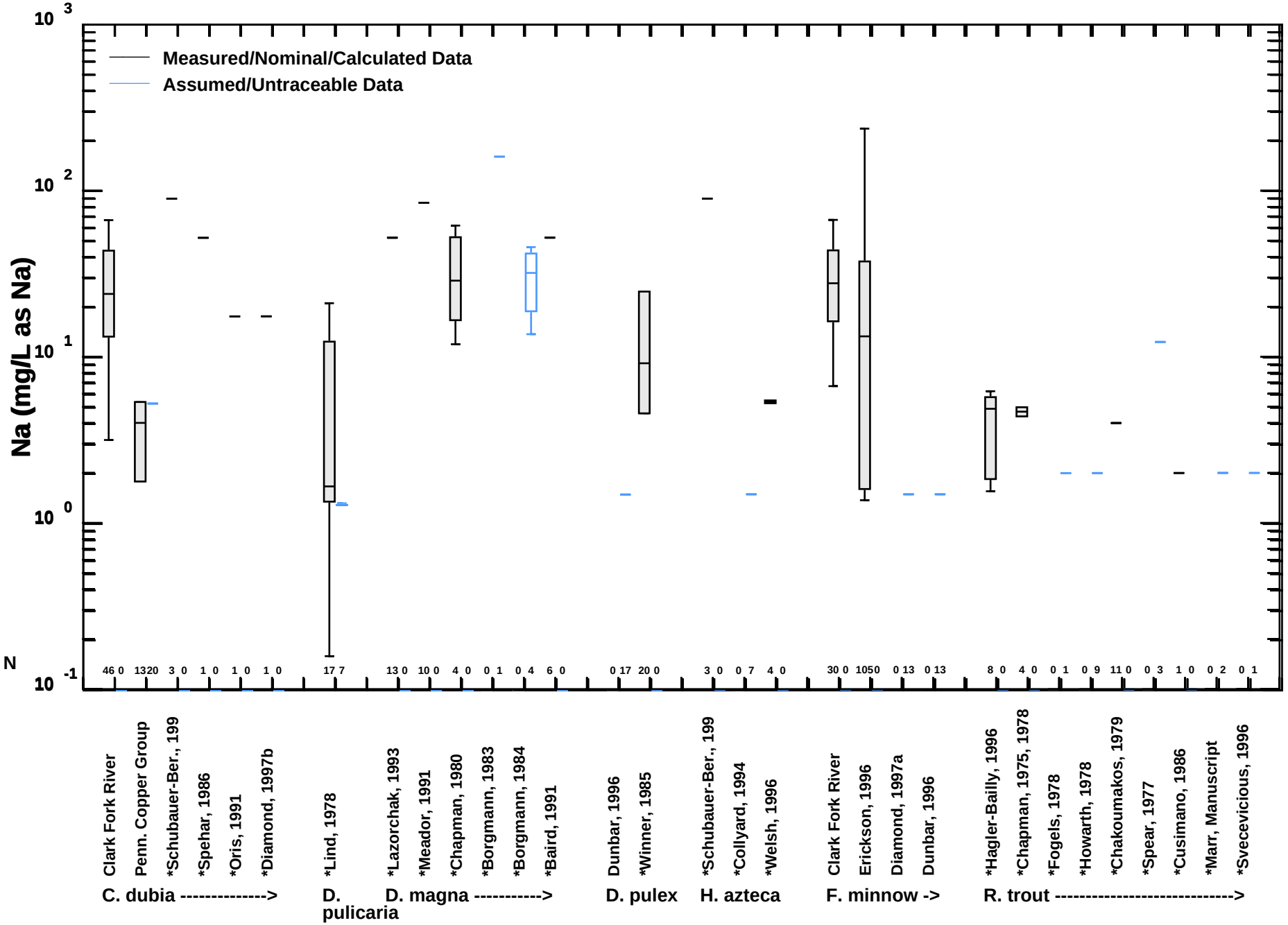
Median, Range and Quartiles of DOC in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)

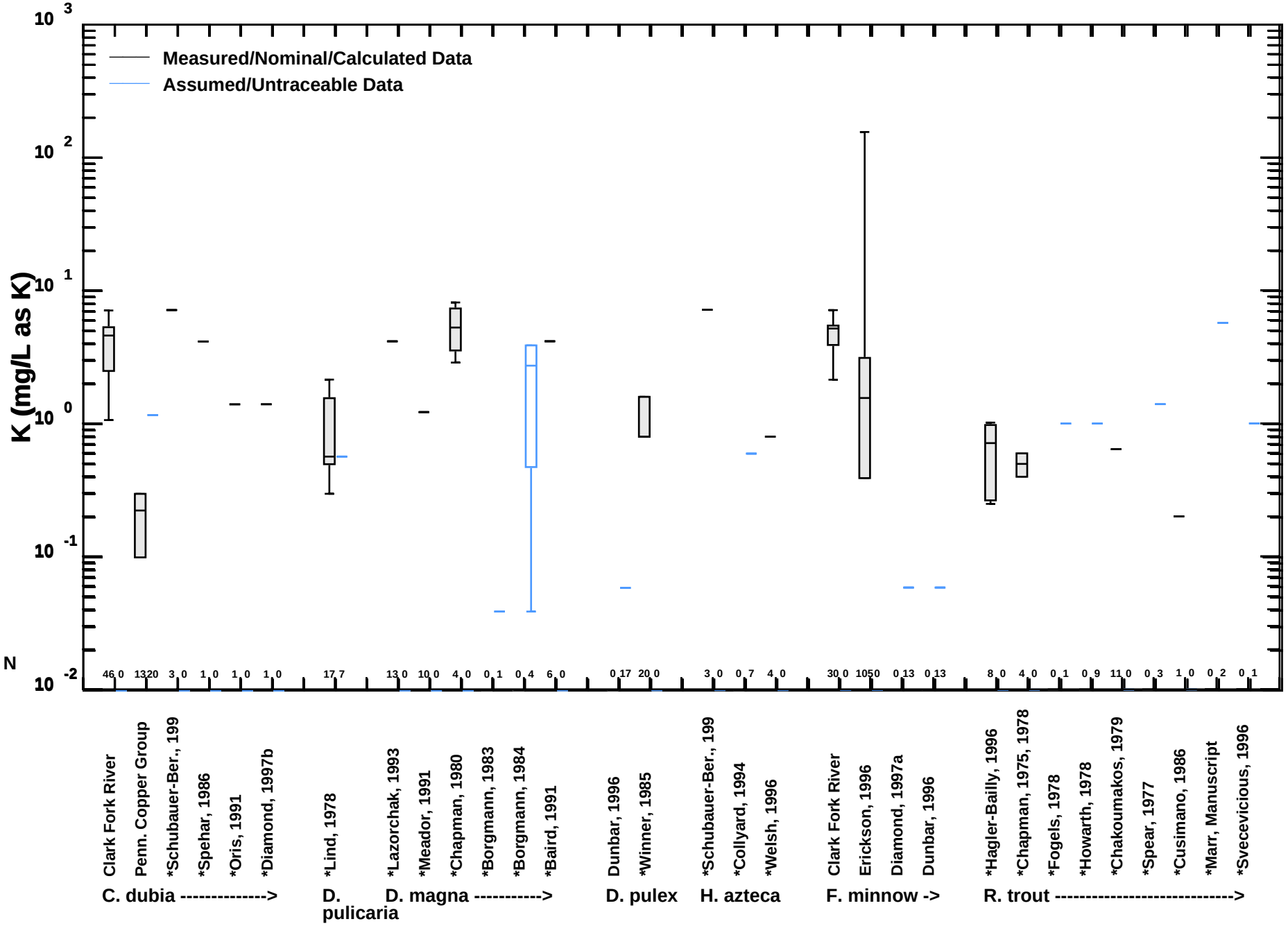
NMED Exhibit 80


Measured/Nominal/Calculated Data
Assumed/Untraceable Data
Ca (mg/L as CaCO3)
10 3
10 2
10 1
10 0
10 -1
N
46 0
33 0
3 0
1 0
1 0
1 0
17 7
13 0
10 0
4 0
0 1
0 4
6 0
0 17
20 0
3 0
0 7
4 0
30 0
105 0
13 0
0 13
8 0
4 0
0 1
0 9
11 0
0 3
1 0
0 2
0 1
Clark Fork River
Penn. Copper Group
*Schubauer-Ber., 199
*Spehar, 1986
*Oris, 1991
*Diamond, 1997b
*Lind, 1978
*Lazorchak, 1993
*Meador, 1991
*Chapman, 1980
*Borgmann, 1983
*Borgmann, 1984
*Baird, 1991
Dunbar, 1996
*Winner, 1985
*Schubauer-Ber., 199
*Collyard, 1994
*Welsh, 1996
Clark Fork River
Erickson, 1996
Diamond, 1997a
Dunbar, 1996
*Hagler-Bailly, 1996
*Chapman, 1975, 1978
*Fogels, 1978
*Howarth, 1978
*Chakoumakos, 1979
*Spear, 1977
*Cusimano, 1986
*Marr, Manuscript
*Svecevicious, 1996
C. dubia ---------->
D. pulicaria
D. magna ---------->
D. pulex
H. azteca
F. minnow ->
R. trout ---------->
Median, Range and Quartiles of Ca in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)

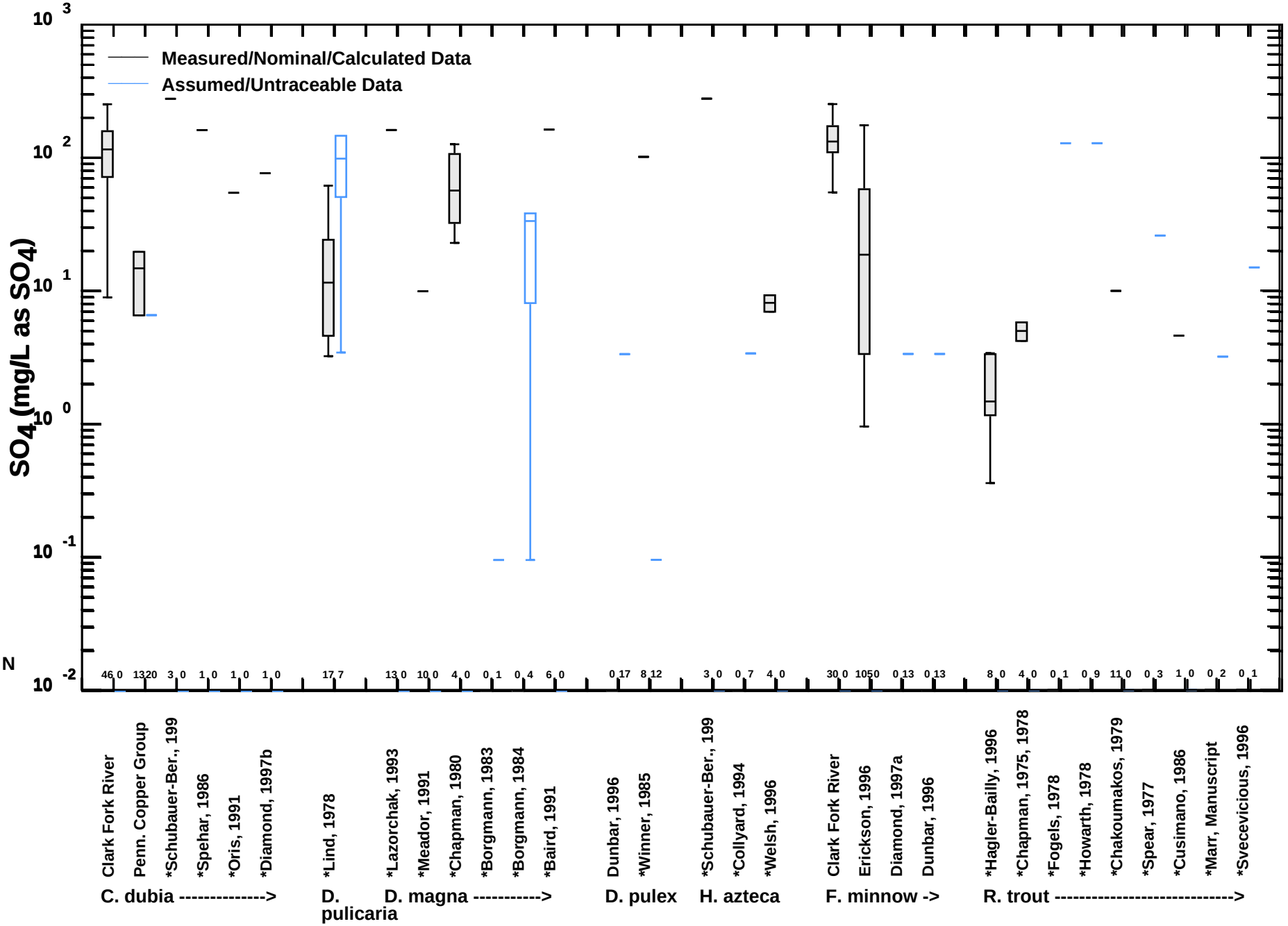


Median, Range and Quartiles of HA in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)

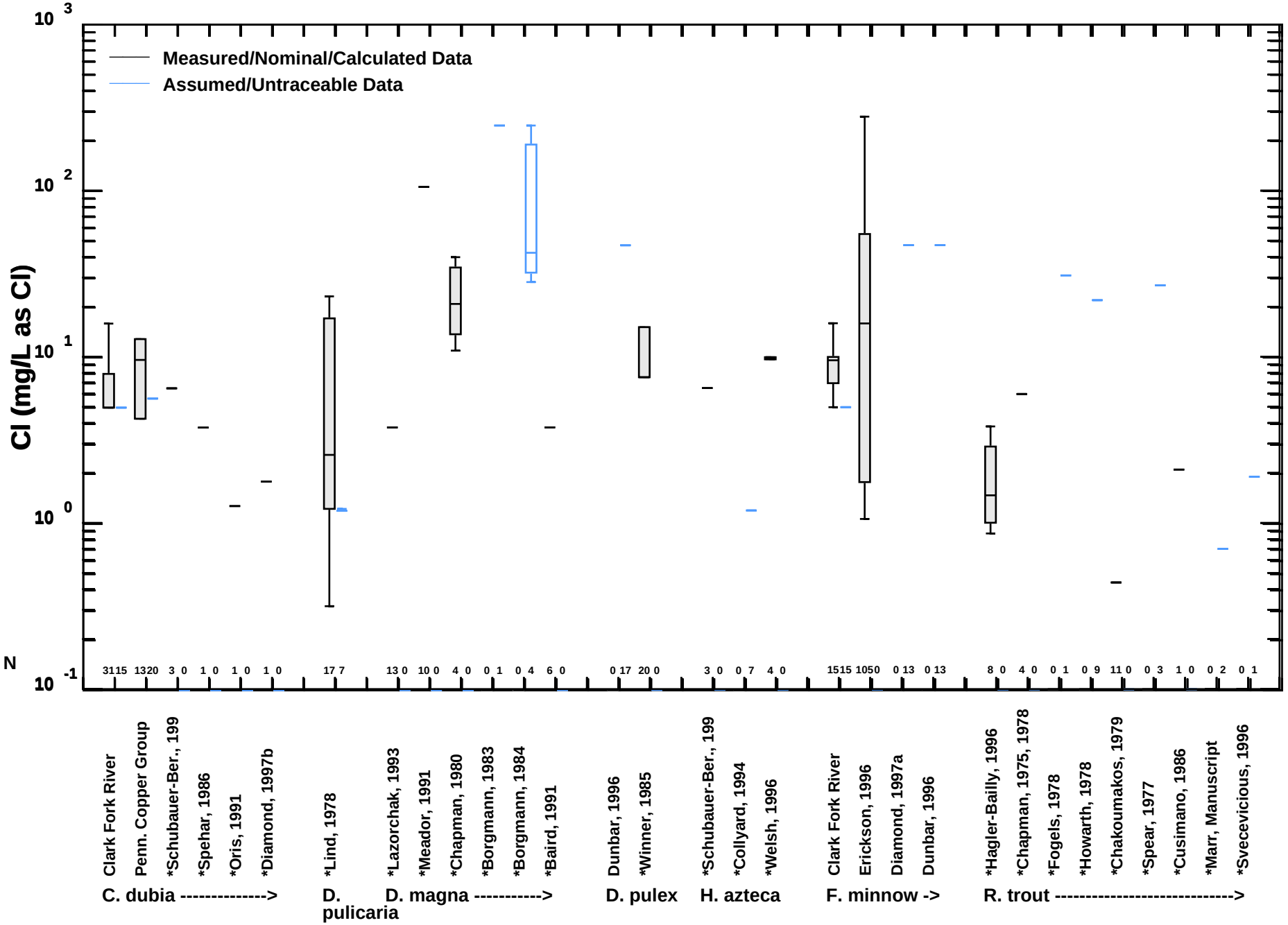

Measured/Nominal/Calculated Data
Assumed/Untraceable Data
Na (mg/L as Na)
10 3
10 2
10 1
10 0
10 -1
N
46 0
13 20
3 0
1 0
1 0
1 0
17 7
13 0
10 0
4 0
0 1
0 4
6 0
0 17
20 0
3 0
0 7
4 0
30 0
105 0
0 13
0 13
8 0
4 0
0 1
0 9
11 0
0 3
1 0
0 2
0 1
Clark Fork River
Penn. Copper Group
*Schubauer-Ber., 199
*Spehar, 1986
*Oris, 1991
*Diamond, 1997b
*Lind, 1978
*Lazorchak, 1993
*Meador, 1991
*Chapman, 1980
*Borgmann, 1983
*Borgmann, 1984
*Baird, 1991
Dunbar, 1996
*Winner, 1985
*Schubauer-Ber., 199
*Collyard, 1994
*Welsh, 1996
Clark Fork River
Erickson, 1996
Diamond, 1997a
Dunbar, 1996
*Hagler-Bailly, 1996
*Chapman, 1975, 1978
*Fogels, 1978
*Howarth, 1978
*Chakoumakos, 1979
*Spear, 1977
*Cusimano, 1986
*Marr, Manuscript
*Svecevicious, 1996
C. dubia ---------->
D. pulicaria
D. magna ---------->
D. pulex
H. azteca
F. minnow ->
R. trout ---------->
Median, Range and Quartiles of Na in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



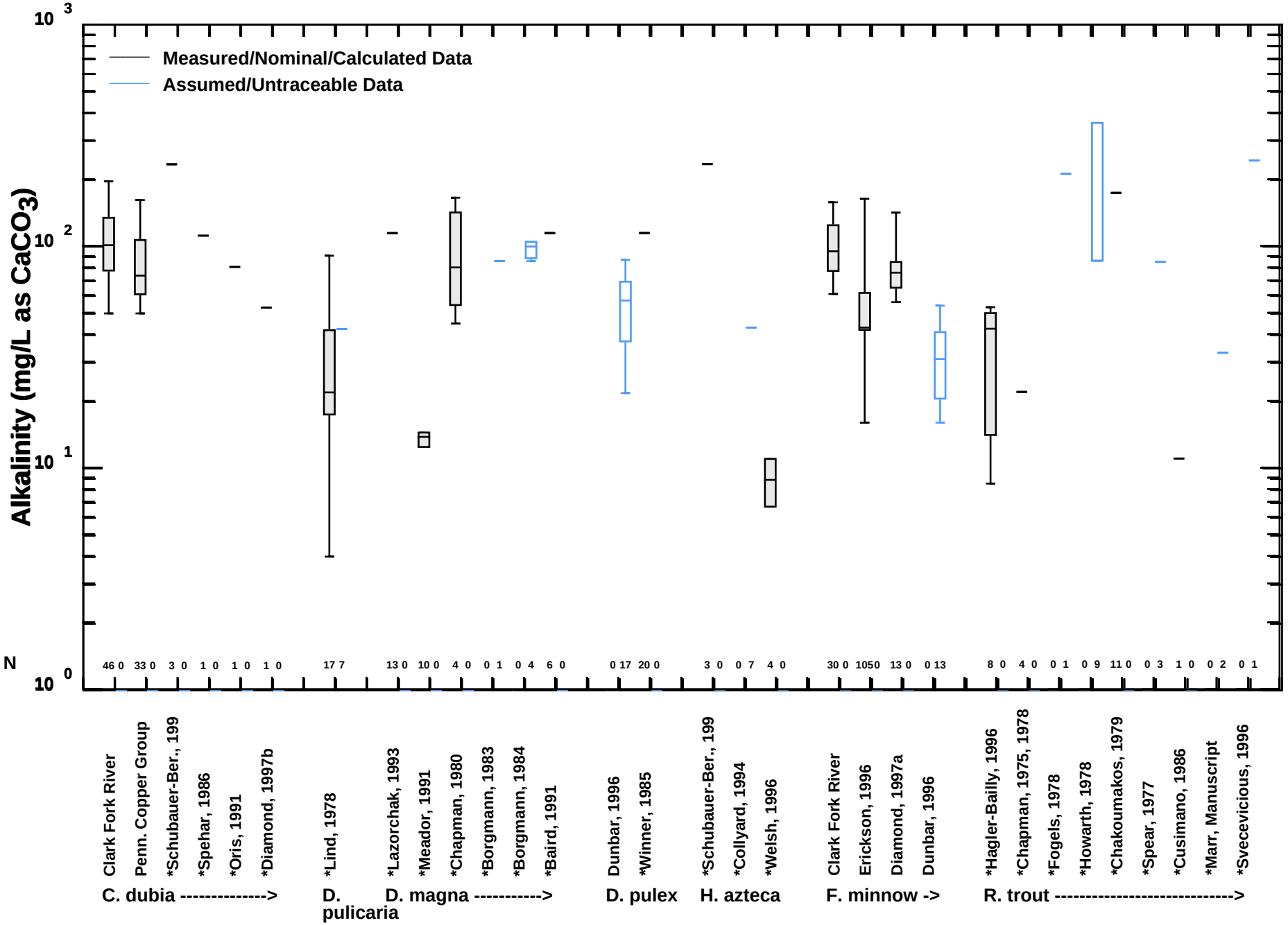
Median, Range and Quartiles of K in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



Median, Range and Quartiles of SO4 in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



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Measured/Nominal/Calculated Data
Assumed/Untraceable Data
Alkalinity (mg/L as CaCO3)
10 3
10 2
10 1
10 0
N
46 0
33 0
3 0
1 0
1 0
1 0
17 7
13 0
10 0
4 0
0 1
0 4
6 0
0 17
20 0
3 0
0 7
4 0
30 0
1050
13 0
0 13
8 0
4 0
0 1
0 9
11 0
0 3
1 0
0 2
0 1
Clark Fork River
Penn. Copper Group
*Schubauer-Ber., 199
*Spehar, 1986
*Oris, 1991
*Diamond, 1997b
*Lind, 1978
*Lazorchak, 1993
*Meador, 1991
*Chapman, 1980
*Borgmann, 1983
*Borgmann, 1984
*Baird, 1991
Dunbar, 1996
*Winner, 1985
*Schubauer-Ber., 199
*Collyard, 1994
*Welsh, 1996
Clark Fork River
Erickson, 1996
Diamond, 1997a
Dunbar, 1996
*Hagler-Bailly, 1996
*Chapman, 1975, 1978
*Fogels, 1978
*Howarth, 1978
*Chakoumakos, 1979
*Spear, 1977
*Cusimano, 1986
*Marr, Manuscript
*Svecevicious, 1996
C. dubia ---------->
D. pulicaria
D. magna ---------->
D. pulex
H. azteca
F. minnow ->
R. trout ---------->
Median, Range and Quartiles of Alkalinity in BLM Calibration and Application Datasets
(All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)

Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Bacteria, *Escherichia coli*	S,U	Copper sulfate	-	48 hr	Threshold of inhibited glucose use; measured by pH change in media	80	-	Bringmann and Kuhn 1959a
Bacteria, *Pseudomonas putida*	S,U	Copper sulfate	81.1	16 hr	EC3 (cell numbers)	30	-	Bringmann and Kuhn 1976, 1977a, 1979, 1980a
Protozoan, *Entosiphon sulcatum*	S,U	Copper sulfate	81.9	72 hr	EC5 (cell numbers)	110	-	Bringmann 1978; Bringmann and Kuhn 1979, 1980a,
Protozoan, *Microrega heterostoma*	S,U	Copper sulfate	214	28 hr	Threshold of decreased feeding rate	50	-	Bringmann and Kuhn 1959b
Protozoan, *Chilomonas paramecium*	S,U	Copper sulfate	-	48 hr	Growth threshold	3,200	-	Bringmann and Kuhn 1980b, 1981
Protozoan, *Uronema parduezi*	S,U	Copper sulfate	-	20 hr	Growth threshold	140	-	Bringmann and Kuhn 1980b, 1981
Protozoa, mixed species	-	-	-	7 days	Reduced rate of colonization	167	-	Cairns et al. 1980
Protozoa, mixed species	S,M,T	Copper sulfate	-	15 days	Reduced rate of colonization	100	-	Buikema et al. 1983
Green alga, *Cladophora glomerata*	Dosed stream	Copper sulfate	226-310	10 mo	Decreased abundance from 21% down to 0%	120	-	Weber and McFarland 1981
Green alga, *Chlamydomonas reinhardtii*	-	Copper sulfate	76	72 hr	Deflagellation	6.7	-	Garvey et al. 1991
Green alga, *Chlamydomonas reinhardtii*	-	Copper sulfate	76	72 hr	Deflagellation	6.7	-	Garvey et al. 1991
Green alga, *Chlamydomonas reinhardtii*	-	Copper sulfate	76	72 hr	Deflagellation	16.3	-	Garvey et al. 1991
Green alga, *Chlamydomonas reinhardti*	-	Copper sulfate	76	72 hr	Deflagellation	25.4	-	Garvey et al. 1991
Green alga, *Chlorella* sp.	S,U	Copper nitrate	-	28 hr	Inhibited photosynthesis	6.3	-	Gachter et al. 1973
Green alga, *Chlorella pyrenoidosa*	S,U	-	29.4	72 hr	IC50 (cell division rate)	16	-	Stauber and Florence 1989
Green alga, *Chlorella pyrenoidosa*	S,U	-	14.9	72 hr	IC50 (cell division rate)	24	-	Stauber and Florence 1989
Green alga, *Chlorella pyrenoidosa*	S,U	Copper sulfate	82	4 hr	Disturbed photosystem II	25	-	Vavilin et al. 1995
Green alga, *Eudorina californica*	S,U	Copper sulfate	19.1	-	Decrease in cell density	5,000	-	Young and Lisk 1972
Green alga (flagellate cells), *Haematococcus* sp.	S,U	Copper sulfate	2	24 hr	Inhibited growth during 96 hr recovery period	50	-	Pearlmutter and Buchheim 1983
Green alga, *Scenedesmus quadricauda*	S,U	Copper sulfate	214	96 hr	Threshold of effect on cell numbers	150	-	Bringmann and Kuhn 1959b
Green alga, *Scenedesmus quadricauda*	S,U	Copper sulfate	60	72 hr	EC3 (cell numbers)	1,100	-	Bringmann and Kuhn 1980a
Green alga, *Scenedesmus quadricauda*	S,U	Copper sulfate	34.8	24 hr	EC50 (photosynthesis)	100	-	Starodub et al. 1987

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Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Green alga, *Scenedesmus quadricauda*	S,U	Copper sulfate	34.8	24 hr	NOEC (growth)	50	-	Starodub et al. 1987
Green alga, *Scenedesmus quadricauda*	S,U	Copper sulfate	34.8	24 hr	NOEC (growth)	50	-	Starodub et al. 1987
Green alga, *Scenedesmus quadricauda*	S,U	Copper sulfate	34.8	24 hr	NOEC (growth)	>200	-	Starodub et al. 1987
Green alga, *Selenastrum capricornutum*	S,U	Copper chloride	14.9	7 days	Growth reduction	50	-	Bartlett et al.1974
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	29.3	72 hr	EC50 (cell count)	19	-	Vasseur et al. 1988
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	24.2	72 hr	EC50 (cell count)	41	-	Vasseur et al. 1988
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	24.2	72 hr	EC50 (cell count)	28	-	Vasseur et al. 1988
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	14.9	72 hr	EC50 (cell count)	60	-	Vasseur et al. 1988
Green alga, *Selenastrum capricornutum*	S,U	Copper sulfate	24.2	72 hr	EC50 (cell count)	28.5	-	Benhra et al. 1997
Green alga, *Selenastrum capricornutum*	F,U	Copper sulfate	15	24 hr	EC50 (cell density)	21	-	Chen et al. 1997
Diatom, *Cocconeis placentula*	Dosed stream	Copper sulfate	226-310	10 mo	Decreased abundance from 21% down to <1%	120	-	Weber and McFarland 1981
Phytoplankton, mixed species	S,U	-	-	124 hr	Averaged 39% reduction in primary production	10	-	Cote 1983
Macrophyte, *Elodea canadensis*	S,U	Copper sulfate	-	24 hr	EC50 (photosynthesis)	150	-	Brown and Rattigan 1979
Microcosm	F,M,T,D	Copper sulfate	200	32 wk	LOEC (primary production)	9.3	-	Hedtke 1984
Microcosm	F,M,T,D	Copper sulfate	200	32 wk	NOEC (primary production)	4	-	Hedtke 1984
Microcosm	F,M,T	Copper sulfate	76.7	96 hr	Significant drop in no. of taxa and no. of individuals	15	-	Clements et al. 1988
Microcosm	F,M,T	Copper sulfate	58.5	10 days	Significant drop in no. of individuals	2.5	-	Clements et al. 1989
Microcosm	F,M,T	Copper sulfate	151	10 days	58% drop in no. of individuals	13.5	-	Clements et al. 1989
Microcosm	F,M,T	Copper sulfate	68	10 days	Significant drop in species richness and no. of individuals	11.3	-	Clements et al. 1990
Microcosm	F,M,T	Copper sulfate	80	10 days	Significant drop in species richness and no. of individuals	10.7	-	Clements et al. 1990
Microcosm	S,M,T	Copper sulfate	102	5 wk	14-28% drop in phytoplankton species richness	20	-	Winner and Owen 1991b
Microcosm	F,M,T	-	160	28 days	LOEC (species richness)	19.9	-	Pratt and Rosenberger 1993

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Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Dosed stream	F,M,D	Copper sulfate	56	1 yr	Shifts in periphyton species abundance	5.208	-	Leland and Carter 1984
Dosed stream	F,M,D	Copper sulfate	56	1 yr	Reduced algal production	5.208	-	Leland and Carter 1985
Sponge, *Ephydatia fluviatilis*	S,U	Copper sulfate	200	10 days	Reduced growth by 33%	6	-	Francis and Harrison 1988
Sponge, *Ephydatia fluviatilis*	S,U	Copper sulfate	200	10 days	Reduced growth by 100%	19	-	Francis and Harrison 1988
Rotifer, *Philodina acuticornis*	S,U	Copper sulfate	45	48 hr	LC50 (5^0 C)	1,300	-	Cairns et al. 1978
Rotifer, *Philodina acuticornis*	S,U	Copper sulfate	45	48 hr	LC50 (10^0 C)	1,200	-	Cairns et al. 1978
Rotifer, *Philodina acuticornis*	S,U	Copper sulfate	45	48 hr	LC50 (15^0 C)	1,130	-	Cairns et al. 1978
Rotifer, *Philodina acuticornis*	S,U	Copper sulfate	45	48 hr	LC50 (20^0 C)	1,000	-	Cairns et al. 1978
Rotifer, *Philodina acuticornis*	S,U	Copper sulfate	45	48 hr	LC50 (25^0 C)	950	-	Cairns et al. 1978
Rotifer, *Brachionus calyciflorus*	S, U	Copper sulfate	39.8	24 hr	EC50 (mobility)	200	-	Couillard et al. 1989
Rotifer (2 hr), *Brachionus calyciflorus*	S,U	Copper sulfate	-	2 hr	LOEC (swimming activity)	12.5	-	Charoy et al. 1995
Rotifer, *Brachionus calyciflorus*	S,U	Copper sulfate	90	24 hr	EC50 (mobility)	76	-	Ferrando et al. 1992
Rotifer (2 hr), *Brachionus calyciflorus*	S,U	Copper sulfate	90	5 hr	EC50 (filtration rate)	34	-	Ferrando et al. 1993a
Rotifer (2 hr), *Brachionus calyciflorus*	S,U	Copper sulfate	90	6 days	LOEC (reproduction decreased 26%)	5	-	Janssen et al. 1993
Rotifer (2 hr), *Brachionus calyciflorus*	S,U	Copper sulfate	90	5 hr	LOEC (reduced swimming speed)	12	-	Janssen et al. 1993
Rotifer (2 hr), *Brachionus calyciflorus*	S,U	Copper sulfate	85	3 days	LOEC (reproduction decreased 27%)	5	-	Janssen et al. 1994
Rotifer (2 hr), *Brachionus calyciflorus*	S,U	Copper sulfate	85	3 days	LOEC (reproduction decreased 29%)	5	-	Janssen et al. 1994
Rotifer (2 hr), *Brachionus calyciflorus*	S,U	Copper sulfate	85	8 days	LOEC (reproduction decreased 47%)	5	-	Janssen et al. 1994
Rotifer (2 hr), *Brachionus calyciflorus*	S,U	Copper chloride	170	35 min	LOEC (food ingestion rate)	100	-	Juchelka and Snell 1994
Rotifer (2 hr), *Brachionus calyciflorus*	S,U	Copper sulfate	63.2	24 hr	EC50 (mobility)	9.4	-	Porta and Ronco 1993
Rotifer (2 hr), *Brachionus calyciflorus*	S,U	-	90	2 days	LOEC (reproduction decreased 100%)	30	-	Snell and Moffat 1992
Rotifer (<2 hr), *Brachionus calyciflorus*	S, U	-	85	24 hr	EC50 (mobility)	26	-	Snell et al. 1991b

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Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Rotifer (<2 hr), *Brachionus calyciflorus*	S, U	-	85	24 hr	EC50 (mobility; 10^0 C)	18	-	Snell 1991; Snell et al. 1991b
Rotifer (<2 hr), *Brachionus calyciflorus*	S, U	-	85	24 hr	EC50 (mobility; 15^0 C)	31	-	Snell 1991; Snell et al. 1991b
Rotifer (<2 hr), *Brachionus calyciflorus*	S, U	-	85	24 hr	EC50 (mobility; 20^0 C)	31	-	Snell 1991; Snell et al. 1991b
Rotifer (<2 hr), *Brachionus calyciflorus*	S, U	-	85	24 hr	EC50 (mobility; 25^0 C)	26	-	Snell 1991; Snell et al. 1991b
Rotifer (<2 hr), *Brachionus calyciflorus*	S, U	-	85	24 hr	EC50 (mobility; 30^0 C)	25	-	Snell 1991; Snell et al. 1991b
Rotifer (<3 hr), *Brachionus rubens*	S, U	Copper sulfate	90	24 hr	LC50	19	-	Snell and Persoone 1989b
Rotifer, *Keratella cochlearis*	S,U	Copper chloride	-	24 hr	LC50	101	-	Borgman and Ralph 1984
Worm, *Aeolosoma headleyi*	S,U	Copper sulfate	45	48 hr	LC50 (5^0 C)	2,600	-	Cairns et al. 1978
Worm, *Aeolosoma headleyi*	S,U	Copper sulfate	45	48 hr	LC50 (10^0 C)	2,300	-	Cairns et al. 1978
Worm, *Aeolosoma headleyi*	S,U	Copper sulfate	45	48 hr	LC50 (15^0 C)	2,000	-	Cairns et al. 1978
Worm, *Aeolosoma headleyi*	S,U	Copper sulfate	45	48 hr	LC50 (20^0 C)	1,650	-	Cairns et al. 1978
Worm, *Aeolosoma headleyi*	S,U	Copper sulfate	45	48 hr	LC50 (50 C)	1,000	-	Cairns et al. 1978
Worm (adult), *Lumbriculus variegatus*	S,U	Copper sulfate	30		LC50	150		Bailey and Liu, 1980
Worm (7 mg), *Lumbriculus variegatis*	F,M,T	Copper sulfate	45	10 days	LC50	35	-	West et al. 1993
Tubificid worm, *Limnodrilus hoffmeisteri*	S,U	Copper sulfate	100		LC50	102		Wurtz and Bridges 1961
Tubificid worm, *Tubifex tubifex*	R, U	Copper sulfate	245		LC50	158		Khangarot 1991
Snail (11-27 mm), *Campeloma decisum*	F,M,T	Copper sulfate	45	6 wk	LOEC (mortality)	14.8	-	Arthur and Leonard 1970
Snail, *Gyraulus circumstriatus*	S,U	Copper sulfate	100		LC50	108		Wurtz and Bridges 1961
Snail, *Goniobasis livescens*	S,U	Copper sulfate	154	48 hr	LC50	860	-	Cairns et al. 1976
Snail, *Goniobasis livescens*	S,M,D	Copper sulfate	154	96 hr	LC50	-	390	Paulson et al. 1983
Snail, *Nitrocris* sp.	S,U	Copper sulfate	45	48 hr	LC50 (5^0 C)	3,000	-	Cairns et al. 1978
Snail, *Nitrocris* sp.	S,U	Copper sulfate	45	48 hr	LC50 (10^0 C)	2,400	-	Cairns et al. 1978

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Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Snail, *Nitrocris* sp.	S,U	Copper sulfate	45	48 hr	LC50 (15^0 C)	1,000	-	Cairns et al. 1978
Snail, *Nitrocris* sp.	S,U	Copper sulfate	45	48 hr	LC50 (20^0 C)	300	-	Cairns et al. 1978
Snail, *Nitrocris* sp.	S,U	Copper sulfate	45	48 hr	LC50 (25^0 C)	210	-	Cairns et al. 1978
Snail, *Lymnaea emarginata*	S,U	Copper sulfate	154	48 hr	LC50	300	-	Cairns et al. 1976
Snail (adult), *Juga plicifera*	F,M,T	Copper chloride	23	30 days	LC50	6	-	Nebeker et al. 1986b
Snail (adult), *Lithoglyphus virens*	F,M,T	Copper chloride	23	30 days	LC50	4	-	Nebeker et al. 1986b
Snail, *Physa heterostropha*	S,U	Copper sulfate	100		LC50	69		Wurtz and Bridges 1961
Freshwater mussel (released glochidia), *Actinonaias pectorosa*	R,M	Copper sulfate	140	24 hr		132		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Actinonaias pectorosa*	R,M	Copper sulfate	150	24 hr		93		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Actinonaias pectorosa*	R,M	Copper sulfate	170	24 hr		67		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Actinonaias pectorosa*	R,M	Copper sulfate	140	24 hr		42		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Actinonaias pectorosa*	R,M	Copper sulfate	170	48 hr		51		Jacobson et al. 1997
Freshwater mussel (1-2 d), *Anodonta grandis*	S,M,T	Copper sulfate	70	24 hr	LC50	44	-	Jacobson et al. 1993
Freshwater mussel (1-2 d), *Anodonta imbecilis*	S,M,T	Copper sulfate	39	48 hr	LC50	171	-	Keller and Zam 1991
Freshwater mussel (1-2 d), *Anodonta imbecilis*	S,M,T	Copper sulfate	90	48 hr	LC50	388	-	Keller and Zam 1991
Freshwater mussel (released glochidia), *Lampsilis fasciola*	R,M,T	Copper sulfate	170	24 hr		48		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Lampsilis fasciola*	R,M,T	Copper sulfate	160	24 hr		26		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Lampsilis fasciola*	R,M,T	Copper sulfate	75	24 hr		46		Jacobson et al. 1997

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Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Freshwater mussel (released glochidia), *Lampsilis fasciola*	R,M,T	Copper sulfate	170	48 hr		40		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Medionidus conradicus*	R,M,T	Copper sulfate	185	24 hr		69		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Medionidus conradicus*	R,M,T	Copper sulfate	185	24 hr		40		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Medionidus conradicus*	R,M,T	Copper sulfate	185	24 hr		37		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Medionidus conradicus*	R,M,T	Copper sulfate	170	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Medionidus conradicus*	R,M,T	Copper sulfate	160	24 hr		41		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Medionidus conradicus*	R,M,T	Copper sulfate	150	24 hr		81		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Medionidus conradicus*	R,M,T	Copper sulfate	170	48 hr		16		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Pygranodon grandis*	R,M,T	Copper sulfate	170	24 hr		>160		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Pygranodon grandis*	R,M,T	Copper sulfate	170	24 hr		347		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Pygranodon grandis*	R,M,T	Copper sulfate	50	24 hr		46		Jacobson et al. 1997
Freshwater mussel (1-2 d), *Villosa iris*	S,M,T	Copper sulfate	190	24 hr	LC50	83	-	Jacobson et al. 1993
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	190	24 hr		80		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	190	24 hr		73		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	185	24 hr		65		Jacobson et al. 1997

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Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	185	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	170	24 hr		75		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	160	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	160	24 hr		36		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	155	24 hr		39		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	155	24 hr		37		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	150	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	150	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	55	24 hr		55		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	55	24 hr		38		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	50	24 hr		71		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	160	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	170	48 hr		66		Jacobson et al. 1997
Freshwater mussel (released glochidia), *Villosa iris*	R,M,T	Copper sulfate	150	48 hr		46		Jacobson et al. 1997
Zebra mussel (1.6-2.0 cm), *Dreissena polymorpha*	R,M,T	Copper chloride	268	9 wk	EC50 +F106(filtration rate)	43	-	Kraak et al. 1992

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Zebra mussel (1.6-2.0 cm), *Dreissena polymorpha*	R,M,T	Copper chloride	268	10 wk	NOEC (filtration rate)	13	-	Kraak et al. 1993
Asiatic clam (1.0-2.1 cm), *Coprbicula fluminea*	S,M,T	Copper sulfate	64	96 hr (24hr LC50 also reported)	LC50	40	-	Rodgers et al. 1980
Asiatic clam (1.0-2.1 cm), *Coprbicula fluminea*	F,M,T	Copper sulfate	64	96 hr (24 hr LC50 also reported)	LC50	490	-	Rodgers et al. 1980
Asiatic clam (juvenile), *Corbicula fluminea*	F,M,D	Copper sulfate	78	30 days	43.3% mortality	14.48	-	Belanger et al. 1990
Asiatic clam (juvenile), *Corbicula fluminea*	F,M,D	Copper sulfate	78	30 days	Stopped shell growth	8.75	-	Belanger et al. 1990
Asiatic clam (adult), *Corbicula fluminea*	F,M,D	Copper sulfate	78	30 days	13.3% mortality	14.48	-	Belanger et al. 1990
Asiatic clam (adult), *Corbicula fluminea*	F,M,D	Copper sulfate	71	30 days	25% mortality	16.88	-	Belanger et al. 1990
Asiatic clam (adult), *Corbicula fluminea*	F,M,D	Copper sulfate	78	30 days	Inhibited shell growth	8.75	-	Belanger et al. 1990
Asiatic clam (adult), *Corbicula fluminea*	F,M,D	Copper sulfate	-	15-16 days	LC50	-	-	Belanger et al. 1991
Asiatic clam (adult), *Corbicula fluminea*	F,M,D	Copper sulfate	-	19 days	LC100	-	-	Belanger et al. 1991
Asiatic clam (veliger larva), *Corbicula manilensis*	S,M,T	Copper chloride	-	24 hr	34% mortality	10	-	Harrison et al. 1981, 1984
Asiatic clam (juvenile), *Corbicula manilensis*	S,M,T	Copper chloride	17	24 hr	LC50	100	-	Harrison et al. 1984
Asiatic clam (veliger), *Corbicula manilensis*	S,M,T	Copper chloride	17	24 hr	LC50	28	-	Harrison et al. 1984
Asiatic clam (trochophore), *Corbicula manilensis*	S,M,T	Copper chloride	17	8 hr	LC100	7.7	-	Harrison et al. 1984
Asiatic clam (adult), *Corbicula manilensis*	F,M,T	Copper chloride	17	7 days	LC50	3,638	-	Harrison et al. 1981, 1984
Asiatic clam (adult), *Corbicula manilensis*	F,M,T	Copper chloride	17	42 days	LC50	12	-	Harrison et al. 1981, 1984
Asiatic clam (4.3 g adult), *Corbicula manilensis*	F,M,T	Copper chloride	17	30 days	LC50	11	-	Harrison et al. 1984
Cladoceran, *Bosmina longirostrus*	S, U	Copper sulfate	33.8		EC50	1.6		Koivisto et al. 1992
Cladoceran (<24 hr), *Daphnia ambigua*	S,U	Copper sulfate	145	72 hr	LC50	86.5	-	Winner and Farrell 1976
Cladoceran (<24 hr), *Daphnia ambigua*	S,U	Copper sulfate	145	Life span (ca. 5 wk)	Chronic limits (inst. rate of population growth)	50	-	Winner and Farrell 1976
Cladoceran, *Ceriodaphnia dubia*	S,U	Copper sulfate	188		EC50	36.6		Bright 1995

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Cladoceran, *Ceriodaphnia dubia*	S,U	Copper sulfate	204		EC50	19.1		Bright 1995
Cladoceran, *Ceriodaphnia dubia*	S,U	Copper sulfate	428		EC50	36.4		Bright 1995
Cladoceran, *Ceriodaphnia dubia*	S,U	Copper sulfate	410		EC50	11.7		Bright 1995
Cladoceran, *Ceriodaphnia dubia*	S,U	Copper sulfate	494		EC50	12.3		Bright 1995
Cladoceran, *Ceriodaphnia dubia*	S,U	Copper sulfate	440		EC50	12		Bright 1995
Cladoceran, *Ceriodaphnia dubia*	S,U	Copper chloride	90	1 hr	NOEC (ingestion)	30	-	Juchelka and Snell 1994
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S,M,D	Copper sulfate	6-10	48 hr	LC50	-	2.72	Suedel et al. 1996
Cladoceran (<12 hr), *Ceriodaphnia dubia*	S,M,D	-	113.6	48 hr	LC50	-	52	Belanger and Cherry 1990
Cladoceran (<12 hr), *Ceriodaphnia dubia*	S,M,D	-	113.6	48 hr	LC50	-	76	Belanger and Cherry 1990
Cladoceran (<12 hr), *Ceriodaphnia dubia*	S,M,D	-	113.6	48 hr	LC50	-	91	Belanger and Cherry 1990
Cladoceran (<48 h), *Ceriodaphnia dubia*	S,M,T	Copper nitrate	280 - 300	48 hr	LC50	9.5	-	Schubauer-Berigan et al. 1993
Cladoceran (<48 h), *Ceriodaphnia dubia*	S,M,T	Copper nitrate	280 - 300	48 hr	LC50	28	-	Schubauer-Berigan et al. 1993
Cladoceran (<48 h), *Ceriodaphnia dubia*	S,M,T	Copper nitrate	280 - 300	48 hr	LC50	200	-	Schubauer-Berigan et al. 1993
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S,M,T,D	Copper nitrate	100	48 hr	LC50	66	60.72	Spehar and Fiandt 1986
Cladoceran, *Ceriodaphnia dubia*	R,U	Copper nitrate	111	10 days	LC50	53	-	Cowgill and Milazzo 1991a
Cladoceran, *Ceriodaphnia dubia*	R,U	Copper nitrate	111	10 days	NOEC (reproduction)	96	-	Cowgill and Milazzo 1991a
Cladoceran, *Ceriodaphnia dubia*	R,U	Copper sulfate	90	-	LOEC (reproduction)	44	-	Zuiderveen and Birge 1997
Cladoceran, *Ceriodaphnia dubia*	R,U	Copper sulfate	90	-	LOEC (reproduction)	40	-	Zuiderveen and Birge 1997
Cladoceran, *Ceriodaphnia dubia*	R,M,T	-	20	-	IC50 (reproduction)	5	-	Jop et al. 1995
Cladoceran (<24 hrs), *Ceriodaphnia reticulata*	S, U	Copper chloride	240		EC50	23		Elnabarawy et al. 1986
Cladoceran, *Ceriodubia reticulata*	S,U	-	43-45		EC50	17		Mount and Norberg 1984
Cladoceran, *Daphnia magna*	-	Copper sulfate	-	72 hr	EC50 (mobility; 10^0 C)	61	-	Braginskij and Shcherben 1978

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cies	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Cladoceran, *Daphnia magna*	-	Copper sulfate	-	72 hr	EC50 (mobility; 15^0 C)	70	-	Braginskij and Shcherben 1978
Cladoceran, *Daphnia magna*	-	Copper sulfate	-	72 hr	EC50 (mobility; 20^0 C)	21	-	Braginskij and Shcherben 1978
Cladoceran, *Daphnia magna*	-	Copper sulfate	-	72 hr	EC50 (mobility; 30^0 C)	9.3	-	Braginskij and Shcherben 1978
Cladoceran, *Daphnia magna*	S,U	Copper sulfate	-	16 hr	EC 50 (mobility)	38	-	Anderson 1944
Cladoceran (<8 hr), *Daphnia magna*	S,U	Copper chloride	-	64 hr	Immobilization threshold	12.7	-	Anderson 1948
Cladoceran (1 mm), *Daphnia magna*	S,U	Copper nitrate	100	24 hr	EC 50 (mobility)	50	-	Bellavere and Gorbi 1981
Cladoceran (1 mm), *Daphnia magna*	S,U	Copper nitrate	200	24 hr	EC 50 (mobility)	70	-	Bellavere and Gorbi 1981
Cladoceran, *Daphnia magna*	S,U	-	100	48 hr	EC50 (mobility)	254	-	Borgmann and Ralph 1983
Cladoceran, *Daphnia magna*	S,U	-	100	49 hr	EC50 (mobility)	1,239	-	Borgmann and Ralph 1983
Cladoceran, *Daphnia magna*	S,U	Copper sulfate	45	48 hr	EC50 (mobility; 5^0 C)	90	-	Cairns et al. 1978
Cladoceran, *Daphnia magna*	S,U	Copper sulfate	45	48 hr	EC50 (mobility; 10^0 C)	70	-	Cairns et al. 1978
Cladoceran, *Daphnia magna*	S,U	Copper sulfate	45	48 hr	EC50 (mobility; 15^0 C)	40	-	Cairns et al. 1978
Cladoceran, *Daphnia magna*	S,U	Copper sulfate	45	48 hr	EC50 (mobility; 25^0 C)	7	-	Cairns et al. 1978
Cladoceran (4 days), *Daphnia magna*	S,U	Copper sulfate	-	24 hr	EC50 (filtration rate)	59	-	Ferrando and Andreu 1993
Cladoceran (24-48 hr), *Daphnia magna*	S,U	Copper sulfate	90	24 hr	EC50 (mobility)	380	-	Ferrando et al. 1992
Cladoceran, *Daphnia magna*	S,U	Copper sulfate	50		EC50	7		Oikari et al. 1992
Cladoceran, *Daphnia magna*	S,U	Copper sulfate	-	48 hr	EC50 (mobility)	45	-	Oikari et al. 1992
Cladoceran (<24 hr), *Daphnia magna*	S,U	Copper sulfate	145	Life span (ca. 18 wk)	Chronic limits (inst. rate of population growth)	70	-	Winner and Farrell 1976
Cladoceran (<24 hrs), *Daphnia magna*	S,M,D	Copper sulfate	72-80	48 hr	LC50	-	11.3	Suedel et al. 1996
Cladoceran (<24 hrs), *Daphnia magna*	S,M,I	-	180	-	LC50	55.3	-	Borgmann and Charlton 1984
Cladoceran (<24 hr), *Daphnia magna*	S,M,I	Copper sulfate	100	48 hr	EC50 (mobility)	46.0	-	Meador 1991
Cladoceran (<24 hr), *Daphnia magna*	S,M,I	Copper sulfate	100	48 hr	EC50 (mobility)	57.2	-	Meador 1991

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Cladoceran (<24 hr), *Daphnia magna*	S,M,I	Copper sulfate	100	48 hr	EC50 (mobility)	67.8	-	Meador 1991
Cladoceran (<24 hr), *Daphnia magna*	S,M,T	Copper sulfate	100	72 hr	EC50 (mobility)	52.8	-	Winner 1984b
Cladoceran (<24 hr), *Daphnia magna*	S,M,T	Copper sulfate	100	72 hr	EC50 (mobility)	56.3	-	Winner 1984b
Cladoceran (<24 hr), *Daphnia magna*	S,M,T	Copper chloride	85	96 hr	EC50 (mobility)	130	-	Blaylock et al. 1985
Cladoceran (24 hr), *Daphnia magna*	R,U	Copper sulfate	-	48 hr	EC50 (mobility)	18	-	Kazlauskiene et al. 1994
Cladoceran (<24 hr), *Daphnia parvula*	S,U	Copper sulfate	145	72 hr	EC50 (mobility)	72	-	Winner and Farrell 1976
Cladoceran (<24 hr), *Daphnia parvula*	S,U	Copper sulfate	145	72 hr	EC50 (mobility)	57	-	Winner and Farrell 1976
Cladoceran (<24 hr), *Daphnia parvula*	S,U	Copper sulfate	145	Life span (ca. 10 wk)	Chronic limits (inst. rate of population growth)	50	-	Winner and Farrell 1976
Cladoceran, *Daphnia pulex*	S,U	Copper sulfate	45		EC50	10		Cairns et al. 1978
Cladoceran, *Daphnia pulex*	S,U	-	45		EC50	53		Mount and Norberg 1984
Cladoceran (<24 hrs), *Daphnia pulex*	S, U	Copper chloride	240		EC50	31		Elnabarawy et al. 1986
Cladoceran (<24 hrs), *Daphnia pulex*	S, U	Copper sulfate	33.8		EC50	3.6		Koivisto et al. 1992
Cladoceran (<24 hrs), *Daphnia pulex*	S,U	Copper chloride	80-90		EC50	18		Roux et al. 1993
Cladoceran (<24 hrs), *Daphnia pulex*	S,U	Copper chloride	80-90		EC50	24		Roux et al. 1993
Cladoceran (<24 hrs), *Daphnia pulex*	S,U	Copper chloride	80-90		EC50	22		Roux et al. 1993
Cladoceran (<24 hr), *Daphnia pulex*	S,U	Copper sulfate	145	72 hr	EC50 (mobility)	86	-	Winner and Farrell 1976
Cladoceran (<24 hr), *Daphnia pulex*	S,U	Copper sulfate	145	72 hr	EC50 (mobility)	54	-	Winner and Farrell 1976
Cladoceran (<24 hr), *Daphnia pulex*	S,U	Copper sulfate	145	Life span (ca. 7 wk)	Chronic limits (inst. rate of population growth)	50	-	Winner and Farrell 1976
Cladoceran, *Daphnia pulex*	S,U	Copper sulfate	45	48 hr	EC50 (mobility)	70	-	Cairns et al. 1978
Cladoceran, *Daphnia pulex*	S,U	Copper sulfate	45	48 hr	EC50 (mobility)	60	-	Cairns et al. 1978
Cladoceran, *Daphnia pulex*	S,U	Copper sulfate	45	48 hr	EC50 (mobility)	20	-	Cairns et al. 1978
Cladoceran, *Daphnia pulex*	S,U	Copper sulfate	45	48 hr	EC50 (mobility)	56	-	Cairns et al. 1978

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Cladoceran (<24 hr), *Daphnia pulex*	S,U	Copper sulfate	200	24 hr	EC50 (mobility)	37.5	-	Lilius et al. 1995
Cladoceran, *Daphnia pulex*	S,M,T	Copper sulfate	106	48 hr	EC50 (mobility)	29	-	Ingersoll and Winner 1982
Cladoceran, *Daphnia pulex*	S,M,T	Copper sulfate	106	48 hr	EC50 (mobility)	20	-	Ingersoll and Winner 1982
Cladoceran, *Daphnia pulex*	S,M,T	Copper sulfate	106	48 hr	EC50 (mobility)	25	-	Ingersoll and Winner 1982
Cladoceran, *Daphnia pulex*	R,U	Copper sulfate	85	21 days	Reduced fecundity	3	-	Roux et al. 1993
Cladoceran, *Daphnia pulex*	R,M,T	Copper sulfate	106	70 days	Significantly shortened life span; reduced brood size	20	-	Ingersoll and Winner 1982
Cladoceran, *Daphnia pulicaria*	S,M,T	-	31	48 hr	EC50 (mobility; TOC=14 mg/L)	55.4	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	29	49 hr	EC50 (mobility; TOC=13 mg/L)	55.3	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	28	50 hr	EC50 (mobility; TOC=13 mg/L)	53.3	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	28	50 hr	EC50 (mobility; TOC=28 mg/L)	97.2	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	100	51 hr	EC50 (mobility; TOC=34 mg/L)	199	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	86	52 hr	EC50 (mobility; TOC=34 mg/L)	627	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	84	53 hr	EC50 (mobility; TOC=32 mg/L)	165	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	16	54 hr	EC50 (mobility; TOC=12 mg/L)	35.5	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	151	55 hr	EC50 (mobility; TOC=13 mg/L)	78.8	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	96	56 hr	EC50 (mobility; TOC=28 mg/L)	113	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	26	57 hr	EC50 (mobility; TOC=25 mg/L)	76.4	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	84	58 hr	EC50 (mobility; TOC=13 mg/L)	84.7	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	92	59 hr	EC50 (mobility; TOC=21 mg/L)	184	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	-	106	60 hr	EC50 (mobility; TOC=34 mg/L)	240	-	Lind et al. manuscript
Cladoceran, *Daphnia pulicaria*	S,M,T	Copper sulfate	106	48 hr	LC50	240	-	Lind et al. manuscript
Cladoceran, *Simocephalus serrulatus*	S,M,T	Copper nitrate	8	24 hr	EC50 (mobility; TOC=11 mg/L)	12	-	Giesy et al. 1983

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Cladoceran, *Simocephalus serrulatus*	S,M,T	Copper nitrate	16	25 hr	EC50 (mobility; TOC=12.4 mg/L)	7.2	-	Giesy et al. 1983
Cladoceran, *Simocephalus serrulatus*	S,M,T	Copper nitrate	16	26 hr	EC50 (mobility; TOC=15.6 mg/L)	24.5	-	Giesy et al. 1983
Cladoceran (<24 hr), *Simocephalus vetulus*	S,U	-	45			57		Mount and Norberg 1984
Cladoceran (life cycle), *Bosmina longirostris*	R,U	Copper sulfate	-	13 days	LOEC (intrinsic rate of population increase)	18	-	Koivisto and Ketola 1995
Copepods (mixed sp), Primarily *Acanthocyclops vernalis* and *Diacyclops thomasi*	R,M,I	Copper chloride	-	1 wk	EC20 (growth)	42	-	Borgmann and Ralph 1984
Copepod (adults and copepodids V), *Tropocyclops prasinus mexicanus*	S, U	Copper sulfate	10			29		Lalande and Pinel-Alloul 1986
Copepod (adults and copepodids V), *Tropocyclops prasinus mexicanus*	S, U	Copper sulfate	10	96 hr	LC50	247	-	Lalande and Pinel-Alloul 1986
Amphipod (0.4 cm), *Crangonyx pseudogracilis*	R,U	Copper sulfate	45-55			1290		Martin and Holdich 1986
Amphipod (4 mm), *Crangonyx psuedogracilis*	R,U	Copper sulfate	50	48 hr	LC50	2,440	-	Martin and Holdich 1986
Amphipod, *Gammarus fasciatus*	S,U	Copper sulfate	206	48 hr	LC50	210	-	Judy 1979
Amphipod, *Gammarus lacustris*	S,U	Copper sulfate	-	96 hr	LC50	1,500	-	Nebeker and Gaufin 1964
Amphipod (2-3 wk), *Hyallela azteca*	S,M,T	Copper sulfate	6-10	-	LC50	65.6	-	Suedel et al. 1996
Amphipod (0-1 wk), *Hyallela azteca*	R,M,T	Copper nitrate	130	10 wk	Significant mortality	25.4	-	Borgmann et al. 1993
Amphipod (7-14 days), *Hyallela azteca*	F,M,T	Copper sulfate	46	10 days	LC50	31	-	West et al. 1993
Crayfish (intermoult adult, 19.6 g), *Cambarus robustus*	S,M,D	-	10-12	96 hr	LC50	-	830	Taylor et al. 1995
Crayfish (1.9-3.2 cm), *Orconectes limosus*	S,M,T	Copper chloride	-	96 hr	LC50	600	-	Boutet and Chaisemartin 1973
Crayfish (3.0-3.5 cm), *Orconectes rusticus*	F,U	Copper sulfate	100-125			3,000		Hubschman 1967
Crayfish (embryo), *Orconectes rusticus*	F,U	Copper sulfate	113	2 wk	52% mortality of newly hatched young	250	-	Hubschman 1967

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Crayfish (3.14 mg dry wt.), *Orconectes rusticus*	F,U	Copper sulfate	113	2 wk	23% reduction in growth	15	-	Hubschman 1967
Crayfish (30-40 mm), *Orconectes* sp.		-	113	48 hr	LC50	2,370	-	Dobbs et al. 1994
Crayfish, *Procambarus clarkii*	F,M,T	Copper chloride	17	1358 hr	LC50	657	-	Rice and Harrison 1983
Mayfly (6th-8th instar), *Stenonema* sp.	S,M,T	-	110	48 hr	LC50	453	-	Dobbs et al. 1994
Mayfly, *Cloeon dipterium*	-	Copper sulfate	-	72 hr	LC50 (10^0 C)	193	-	Braginskij and Shcherban 1978
Mayfly, *Cloeon dipterium*	-	-	-	72 hr	LC50 (15^0 C)	95.2	-	Braginskij and Shcherban 1978
Mayfly, *Cloeon dipterium*	-	-	-	72 hr	LC50 (25^0 C)	53	-	Braginskij and Shcherban 1978
Mayfly, *Cloeon dipterium*	-	-	-	72 hr	LC50 (30^0 C)	4.8	-	Braginskij and Shcherban 1978
Mayfly, *Ephemerella grandis*	F,M,T	Copper sulfate	50	14 days	LC50	180-200	-	Nehring 1976
Mayfly, *Ephemerella subvaria*	S,M	Copper sulfate	44	48 hr	LC50	320	-	Warnick and Bell 1969
Mayfly (6th-8th instar), *Isonychia bicolor*	S,M,T	-	110	48 hr	LC50	223	-	Dobbs et al. 1994
Stonefly, *Pteronarcys californica*	F,M,T	Copper sulfate	50	14 days	LC50	12,000	-	Nehring 1976
Caddisfly, *Hydropsyche betteni*	S,M,T	Copper sulfate	44	14 days	LC50	32,000	-	Warnick and Bell 1969
Midge (2nd instar), *Chironomus riparius*	S,M,T	-	110	48 hr	LC50	1,170	-	Dobbs et al. 1994
Midge (1st instar), *Chironomus tentans*	S,U	Copper sulfate	42.7			16.7		Gauss et al. 1985
Midge (1st instar), *Chironomus tentans*	S,U	Copper sulfate	109.6			36.5		Gauss et al. 1985
Midge (1st instar), *Chironomus tentans*	S,U	Copper sulfate	172.3			98.2		Gauss et al. 1985
Midge (4th instar), *Chironomus tentans*	S,U	Copper sulfate	42.7			211		Gauss et al. 1985
Midge (4th instar), *Chironomus tentans*	S,U	Copper sulfate	109.6			977		Gauss et al. 1985
Midge (4th instar), *Chironomus tentans*	S,U	Copper sulfate	172.3			1184		Gauss et al. 1985
Midge, *Chironomus tentans*	S,U	Copper sulfate	25			327		Khangarot and Ray 1989
Midge (2nd instar), *Chironomus tentans*	S,M,T	Copper sulfate	8	96 hr	LC50	630	-	Suedel et al. 1996

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Midge (4th instar), *Chironomus tentans*	F,M,T	Copper chloride	36	20 days	LC50	77.5	-	Nebeker et al. 1984b
Midge (embryo), *Tanytarsus dissimilis*	S,M,T	Copper chloride	46.8	10 days	LC50	16.3	-	Anderson et al. 1980
Midge, Unidentified	F,M,T,D	Copper sulfate	200	32 wk	Emergence	30	-	Hedtke 1984
Bryozoan (2-3 day ancestrula), *Lophopodella carteri*	S,U	-	190-220			510		Pardue and Wood 1980
Bryozoan (2-3 day ancestrula), *Pectinatella magnifica*	S,U	-	190-220			140		Pardue and Wood 1980
Bryozoan (2-3 day ancestrula), *Plumatella emarginata*	S,U	-	190-220			140		Pardue and Wood 1980
American eel (5.5 cm glass eel stage), *Anguilla rostrata*	S,U	Copper sulfate	40-48	96 hr	LC50	2,540		Hinton and Eversole 1978
American eel (9.7 cm black eel stage), *Anguilla rostrata*	S,U	Copper sulfate	40-48	96 hr	LC50	3,200		Hinton and Eversole 1979
American eel, *Anguilla rostrata*	S,M,T	Copper nitrate	53	96 hr	LC50	6,400	-	Rehwoldt et al. 1971
American eel, *Anguilla rostrata*	S,M,T	Copper nitrate	55	96 hr	LC50	6,000	-	Rehwoldt et al. 1972
Arctic grayling (larva), *Thymallus arcticus*	S,U	Copper sulfate	41.3	96 hr	LC50	67.5		Buhl and Hamilton 1990
Arctic grayling (larva), *Thymallus arcticus*	S,U	Copper sulfate	41.3	96 hr	LC50	23.9		Buhl and Hamilton 1990
Arctic grayling (larva), *Thymallus arcticus*	S,U	Copper sulfate	41.3	96 hr	LC50	131		Buhl and Hamilton 1990
Arctic grayling (swim-up), *Thymallus arcticus*	S,U	Copper sulfate	41.3	96 hr	LC50	9.6		Buhl and Hamilton 1990
Arctic grayling (0.20 g juvenile), *Thymallus arcticus*	S,U	Copper sulfate	41.3	96 hr	LC50	2.7		Buhl and Hamilton 1990
Arctic grayling (0.34 g juvenile), *Thymallus arcticus*	S,U	Copper sulfate	41.3	96 hr	LC50	2.58		Buhl and Hamilton 1990
Arctic grayling (0.81 g juvenile), *Thymallus arcticus*	S,U	Copper sulfate	41.3	96 hr	LC50	49.3		Buhl and Hamilton 1990
Arctic grayling (0.85 g juvenile), *Thymallus arcticus*	S,U	Copper sulfate	41.3	96 hr	LC50	30		Buhl and Hamilton 1990
Coho salmon (larva), *Oncorhynchus kisutch*	S,U	Copper sulfate	41.3	96 hr	LC50	21		Buhl and Hamilton 1990
Coho salmon (larva), *Oncorhynchus kisutch*	S,U	Copper sulfate	41.3	96 hr	LC50	19.3		Buhl and Hamilton 1990
Coho salmon (0.41 g juvenile), *Oncorhynchus kisutch*	S,U	Copper sulfate	41.3	96 hr	LC50	15.1		Buhl and Hamilton 1990

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Coho salmon (0.47 g juvenile), *Oncorhynchus kisutch*	S,U	Copper sulfate	41.3	96 hr	LC50	23.9		Buhl and Hamilton 1990
Coho salmon (0.87 g juvenile), *Oncorhynchus kisutch*	S,U	Copper sulfate	41.3	96 hr	LC50	31.9		Buhl and Hamilton 1990
Coho salmon (10 cm), *Oncorhynchus kisutch*	S,U	Copper sulfate	-	72 hr	LC50	280	-	Holland et al. 1960
Coho salmon (9.7 cm), *Oncorhynchus kisutch*	S,U	Copper sulfate	-	72 hr	LC50	190	-	Holland et al. 1960
Coho salmon (9.7 cm), *Oncorhynchus kisutch*	S,U	Copper sulfate	-	72 hr	LC50	480	-	Holland et al. 1960
Coho salmon (juvenile), *Oncorhynchus kisutch*	R,M,T,I	-	33	96 hr	LC50 (TOC=7.3 mg/L)	164	-	Buckley 1983
Coho salmon (juvenile), *Oncorhynchus kisutch*	R,M,T,I	-	33	96 hr	LC50	286		Buckley 1983
Coho salmon (6.3 cm), *Oncorhynchus kisutch*	F,U	Copper sulfate	-	30 days	LC50	360	-	Holland et al. 1960
Coho salmon (6.3 cm), *Oncorhynchus kisutch*	F,U	Copper sulfate	-	72 hr	LC50	370	-	Holland et al. 1960
Coho salmon (smolts), *Oncorhynchus kisutch*	F,M,T	Copper chloride	91	144 hr	Decrease in survival upon transfer to 30 ppt seawater	20	-	Lorz and McPherson 1976
Coho salmon (smolts >10 cm), *Oncorhynchus kisutch*	F,M,T	Copper chloride	91	165 days	Decrease in downstream migration after release	5	-	Lorz and McPherson 1976
Coho salmon (7.8 cm), *Oncorhynchus kisutch*	F,M,T	Copper acetate	276	14 wk	15% reduction in growth	70	-	Buckley et al. 1982
Coho salmon (7.8 cm), *Oncorhynchus kisutch*	-	-	276	7 days	LC50	220	-	Buckley et al. 1982
Coho salmon (3-8 g), *Oncorhynchus kisutch*	F,M,T	Copper acetate	280	7 days	LC50	275	-	McCarter and Roch 1983
Coho salmon (3-8 g), *Oncorhynchus kisutch*	F,M,T	Copper acetate	280	7 days	LC50 (acclimated to copper for 2 wk)	383	-	McCarter and Roch 1983
Coho salmon (parr), *Oncorhynchus kisutch*	F,M,T,D,I	-	24.4	61 days	NOEC (growth and survival)	22	-	Mudge et al. 1993
Coho salmon, *Oncorhynchus kisutch*	F,M,T,D,I	-	31.1	60 days	NOEC (growth and survival)	18	-	Mudge et al. 1993
Coho salmon (parr), *Oncorhynchus kisutch*	F,M,T,D,I	-	31	61 days	NOEC (growth and survival)	33	-	Mudge et al. 1993
Rainbow trout (15-40g) *Oncorhynchus mykiss*	F,M,	Copper chloride	--	120 hr	LA50 (50% mortality)	~1.4 ug Cu/g gill	-	MacRae et al. 1999
Sockeye salmon (yeasrling), *Oncorhynchus nerka*	S,U	Copper sulfate	12	1-24 hr	Drastic increase in plasma corticosteroids	64	-	Donaldson and Dye 1975
Sockeye salmon (fry, 0.132 g, 2.95 cm), *Oncorhynchus nerka*	R,M,T	Copper chloride	36-46	96 hr	LC50	220	-	Davis and Shand 1978

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Sockeye salmon (fry, 0.132 g, 2.95 cm), *Oncorhynchus nerka*	R,M,T	Copper chloride	36-46	96 hr	LC50	210	-	Davis and Shand 1978
Sockeye salmon (fry, 0.132 g, 2.95 cm), *Oncorhynchus nerka*	R,M,T	Copper chloride	36-46	96 hr	LC50	240	-	Davis and Shand 1978
Sockeye salmon (fry, 0.132 g, 2.95 cm), *Oncorhynchus nerka*	R,M,T	Copper chloride	36-46	96 hr	LC50	103	-	Davis and Shand 1978
Sockeye salmon (fry, 0.132 g, 2.95 cm), *Oncorhynchus nerka*	R,M,T	Copper chloride	36-46	96 hr	LC50	240	-	Davis and Shand 1978
Chinook salmon (18-21 weeks), *Oncorhynchus tshawytscha*	S,U	Copper sulfate	211	96 hr	LC50	58		Hamilton and Buhl 1990
Chinook salmon (18-21 weeks), *Oncorhynchus tshawytscha*	S,U	Copper sulfate	211	96 hr	LC50	54		Hamilton and Buhl 1990
Chinook salmon (18-21 weeks), *Oncorhynchus tshawytscha*	S,U	Copper sulfate	343	96 hr	LC50	60		Hamilton and Buhl 1990
Chinook salmon (5.2 cm), *Oncorhynchus tshawytscha*	S,U	Copper nitrate	-	5 days	LC50	178	-	Holland et al. 1960
Chinook salmon (eyed embryos) *Oncorhynchus tshawytscha*	F,M,D	Copper sulfate	44	26 days	93% mortality	41.67	-	Hazel and Meith 1970
Chinook salmon (alevin), *Oncorhynchus tshawytscha*	F,M,T	Copper chloride	23	200 hr	LC50	20	-	Chapman 1978
Chinook salmon (alevin), *Oncorhynchus tshawytscha*	F,M,T	Copper chloride	23	200 hr	LC10	15	-	Chapman 1978
Chinook salmon (swimup), *Oncorhynchus tshawytscha*	F,M,T	Copper chloride	23	200 hr	LC50	19	-	Chapman 1978
Chinook salmon (swimup), *Oncorhynchus tshawytscha*	F,M,T	Copper chloride	23	200 hr	LC10	14	-	Chapman 1978
Chinook salmon (parr), *Oncorhynchus tshawytscha*	F,M,T	Copper chloride	23	200 hr	LC50	30	-	Chapman 1978
Chinook salmon (parr), *Oncorhynchus tshawytscha*	F,M,T	Copper chloride	23	200 hr	LC10	17	-	Chapman 1978
Chinook salmon (smolt), *Oncorhynchus tshawytscha*	F,M,T	Copper chloride	23	200 hr	LC50	26	-	Chapman 1978
Chinook salmon (smolt), *Oncorhynchus tshawytscha*	F,M,T	Copper chloride	23	200 hr	LC10	18	-	Chapman 1978
Chinook salmon (3.9-6.8 cm), *Oncorhynchus tshawytscha*	F,M,T	Copper sulfate	20-22	96 hr	LC50	32	-	Finlayson and Verrue 1982
Cutthroat trout (3-5 mo), *Oncorhynchus clarki*	F,M	Copper chloride	50	20 min	avoidance of copper	7.708	-	Woodward et al. 1997

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Rainbow trout, *Oncorhynchus mykiss*	-	-	320	48 hr	LC50	500	-	Brown 1968
Rainbow trout (9-16 cm), *Oncorhynchus mykiss*	In situ	-	21-26	48 hr	LC50	70	-	Calamari and Marchetti 1975
Rainbow trout (0.4 g), *Oncorhynchus mykiss*	S,U	Copper sulfate	-	96 hr	LC50	185	-	Bills et al. 1981
Rainbow trout (larva), *Oncorhynchus mykiss*	S, U	Copper sulfate	41.3	96 hr	LC50	36		Buhl and Hamilton 1990
Rainbow trout (0.60 g juvenile), *Oncorhynchus mykiss*	S, U	Copper sulfate	41.3	96 hr	LC50	13.8		Buhl and Hamilton 1990
Rainbow trout (13-15 cm), *Oncorhynchus mykiss*	S,U	Copper sulfate	250	72 hr	LC50	580	-	Brown et al. 1974
Rainbow trout (13-15 cm), *Oncorhynchus mykiss*	S,U	Copper sulfate	250	72 hr	LC50	960	-	Brown et al. 1974
Rainbow trout (3.2 cm), *Oncorhynchus mykiss*	S,U	Copper sulfate	-	24 hr	LC50	140	-	Shaw and Brown 1974
Rainbow trout (3.2 cm), *Oncorhynchus mykiss*	S,U	Copper sulfate	-	24 hr	LC50	130	-	Shaw and Brown 1974
Rainbow trout (4.0-10.6 cm), *Oncorhynchus mykiss*	S,U	Copper sulfate	45	24 hr	LC50 (5^0 C)	950	-	Cairns et al. 1978
Rainbow trout (4.0-10.6 cm), *Oncorhynchus mykiss*	S,U	Copper sulfate	45	24 hr	LC50 (15^0 C)	430	-	Cairns et al. 1978
Rainbow trout (4.0-10.6 cm), *Oncorhynchus mykiss*	S,U	Copper sulfate	45	24 hr	LC50 (30^0 C)	150	-	Cairns et al. 1978
Rainbow trout (0.52-1.55 g), *Oncorhynchus mykiss*	S,U	Copper sulfate	-	96 hr	LC50 (Silver Cup diet)	23.9	-	Marking et al. 1984
Rainbow trout (0.41-2.03 g), *Oncorhynchus mykiss*	S,U	Copper sulfate	-	96 hr	LC50 (purified H440)	11.3	-	Marking et al. 1984
Rainbow trout (0.0.40-1.68 g), *Oncorhynchus mykiss*	S,U	Copper sulfate	-	96 hr	LC50 (SD-9 diet)	15.9	-	Marking et al. 1984
Rainbow trout (0.0.34-1.52 g), *Oncorhynchus mykiss*	S,U	Copper sulfate	-	96 hr	LC50 (liver diet)	14.3	-	Marking et al. 1984
Rainbow trout (0.0.38-1.30 g), *Oncorhynchus mykiss*	S,U	Copper sulfate	-	96 hr	LC50 (brine shrimp diet)	11.3	-	Marking et al. 1984
Rainbow trout (embryo), *Oncorhynchus mykiss*	S,U	Copper chloride	30	56 hr	LC50	100	-	Rombough 1985
Rainbow trout (6.6 cm), *Oncorhynchus mykiss*	R,U	Copper sulfate	320	72 hr	LC50	1,100	-	Lloyd 1961
Rainbow trout (6.6 cm), *Oncorhynchus mykiss*	R,U	Copper sulfate	17.5	7 days	LC50	44	-	Lloyd 1961
Rainbow trout, *Oncorhynchus mykiss*	R,U	Copper sulfate	320	48 hr	LC50	270	-	Herbert and Vandyke 1964
Rainbow trout (yearling), *Oncorhynchus mykiss*	R,U	Copper sulfate	240	48 hr	LC50	750	-	Brown and Dalton 1970

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Rainbow trout (13-15 cm), *Oncorhynchus mykiss*	R,U	Copper sulfate	250	8 days	LC50	500	-	Brown et al. 1974
Rainbow trout (embryo), *Oncorhynchus mykiss*	R,U	Copper sulfate	104	28 days	LC50	90	-	Birge 1978; Birge et al. 1978
Rainbow trout (embryo), *Oncorhynchus mykiss*	R,U	Copper sulfate	101	28 days	EC50 (death or deformity)	110	-	Birge et al. 1980; Birge and Black 1979
Rainbow trout (embryo), *Oncorhynchus mykiss*	R,U	Copper sulfate	101	28 days	EC10 (death or deformity)	16.5	-	Birge et al. 1980
Rainbow trout (eyed embryos), *Oncorhynchus mykiss*	R,U	Copper sulfate	-	96 hr	LC50	1,150	-	Kazlauskiene et al. 1994
Rainbow trout (larva), *Oncorhynchus mykiss*	R,U	Copper sulfate	-	96 hr	LC50	430	-	Kazlauskiene et al. 1994
Rainbow trout (16-18 cm), *Oncorhynchus mykiss*	R,U	Copper sulfate	-	96 hr	LC50	930	-	Kazlauskiene et al. 1994
Rainbow trout (embryo), *Oncorhynchus mykiss*	R,M,T	Copper sulfate	62.9	7-9 mo	Lesions in olfactory rosettes	22	-	Saucier et al. 1991b
Rainbow trout (embryo), *Oncorhynchus mykiss*	R,M,T	Copper sulfate	62.9	7-9 mo	31% mortality	22	-	Saucier et al. 1991b
Rainbow trout (eyed embryos), *Oncorhynchus mykiss*	R,M,T	Copper sulfate	40-48	96 hr	LC50	400	-	Giles and Klaverkamp 1982
Rainbow trout (yearling), *Oncorhynchus mykiss*	R,M,T	Copper sulfate	36.5	21 days	Elevated plasma cortisol returned to normal	45	-	Munoz et al. 1991
Rainbow trout (embryo), *Oncorhynchus mykiss*	R,M,T	Copper sulfate	44	96 hr	15-20% post-hatch mortality	80	-	Giles and Klaverkamp 1982
Rainbow trout (embryo), *Oncorhynchus mykiss*	R,M,T	Copper sulfate	62.9	7-9 mo	Inhibited olfactory discrimination	22	-	Saucier et al. 1991a
Rainbow trout (5.1-7.6 cm), *Oncorhynchus mykiss*	F,U	Copper nitrate	-	96 hr	LC50	253	-	Hale 1977
Rainbow trout (11 cm), *Oncorhynchus mykiss*	F,U	-	100	96 hr	LC50	250	-	Goettl et al. 1972
Rainbow trout (5 wk post swimup) *Oncorhynchus mykiss*	F,U	Copper sulfate	89.5	1 hr	Avoidance	10	-	Folmar 1976
Rainbow trout (18.5-26.5 cm), *Oncorhynchus mykiss*	F,U	Copper sulfate	90	2 hr	55% depressed olfactory response	50	-	Hara et al. 1976
Rainbow trout (3.2 cm), *Oncorhynchus mykiss*	F,M,I	Copper sulfate	-	8 days	LC50	500	-	Shaw and Brown 1974
Rainbow trout (12-16 cm), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	300	14 days	LC50	870	-	Calamari and Marchetti 1973
Rainbow trout (adult), *Oncorhynchus mykiss*	F,M,T	Copper chloride	42	-	LC50	57	-	Chapman 1975, Chapman and Stevens 1978
Rainbow trout (53.5 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	365	96 hr	LC50	465	-	Lett et al. 1976

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Rainbow trout (53.5 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	365	15 days	Transient decrease in food consumption	100	-	Lett et al. 1976
Rainbow trout (alevin), *Oncorhynchus mykiss*	F,M,T	Copper chloride	24	200 hr	LC50	20	-	Chapman 1978
Rainbow trout (alevin), *Oncorhynchus mykiss*	F,M,T	Copper chloride	24	200 hr	LC10	19	-	Chapman 1978
Rainbow trout (swimup), *Oncorhynchus mykiss*	F,M,T	Copper chloride	24	200 hr	LC50	17	-	Chapman 1978
Rainbow trout (swimup), *Oncorhynchus mykiss*	F,M,T	Copper chloride	24	200 hr	LC10	9	-	Chapman 1978
Rainbow trout (parr), *Oncorhynchus mykiss*	F,M,T	Copper chloride	25	200 hr	LC50	15	-	Chapman 1978
Rainbow trout (parr), *Oncorhynchus mykiss*	F,M,T	Copper chloride	25	200 hr	LC10	8	-	Chapman 1978
Rainbow trout (smolt), *Oncorhynchus mykiss*	F,M,T	Copper chloride	25	200 hr	LC50	21	-	Chapman 1978
Rainbow trout (smolt), *Oncorhynchus mykiss*	F,M,T	Copper chloride	25	200 hr	LC10	7	-	Chapman 1978
Rainbow trout, *Oncorhynchus mykiss*	F,M,T	Copper sulfate	112.4	80 min	Avoidance threshold	74	-	Black and Birge 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	49	15-18 days	LC50	48	-	Miller and MacKay 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	51	15-18 days	LC50	46	-	Miller and MacKay 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	57	15-18 days	LC50	63	-	Miller and MacKay 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	12	15-18 days	LC50	19	-	Miller and MacKay 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	99	15-18 days	LC50	54	-	Miller and MacKay 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	98	15-18 days	LC50	78	-	Miller and MacKay 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	12	15-18 days	LC50	18	-	Miller and MacKay 1980
Rainbow trout (>8 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	97	15-18 days	LC50	96	-	Miller and MacKay 1980
Rainbow trout (200-250 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	320	4 mo	Altered liver and blood enzymes and mitochondrial function	30	-	Arillo et al. 1984
Rainbow trout (7 cm), *Oncorhynchus mykiss*	F,M,T	Copper chloride	28.4	20 min	Avoidance	6.4	-	Giattina et al. 1982
Rainbow trout (2.70 g), *Oncorhynchus mykiss*	F,M,T	Copper chloride	9.2	96 hr	LC50	4.2	-	Cusimano et al. 1986
Rainbow trout (2.88 g), *Oncorhynchus mykiss*	F,M,T	Copper chloride	9.2	96 hr	LC50	66	-	Cusimano et al. 1986

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Rainbow trout (2.88 g), *Oncorhynchus mykiss*	F,M,T	Copper chloride	9.2	168 hr	LC50	36.7	-	Cusimano et al. 1986
Rainbow trout (2.70 g), *Oncorhynchus mykiss*	F,M,T	Copper chloride	9.2	168 hr	LC50	3.1	-	Cusimano et al. 1986
Rainbow trout (2.65 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	9.2	168 hr	LC50	2.3	-	Cusimano et al. 1986
Rainbow trout (5 day embryo), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	87.7	48 hr	LC50	8,000	-	Shazili and Pascoe 1986
Rainbow trout (10 day embryo), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	87.7	48 hr	LC50	2,000	-	Shazili and Pascoe 1986
Rainbow trout (15 day embryo), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	87.7	48 hr	LC50	400	-	Shazili and Pascoe 1986
Rainbow trout (22 day embryo), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	87.7	48 hr	LC50	600	-	Shazili and Pascoe 1986
Rainbow trout (29 day embryo), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	87.7	48 hr	LC50	400	-	Shazili and Pascoe 1986
Rainbow trout (36 day embryo), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	87.7	48 hr	LC50	100	-	Shazili and Pascoe 1986
Rainbow trout (2 day larva), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	87.7	48 hr	LC50	100	-	Shazili and Pascoe 1986
Rainbow trout (7 day larva), *Oncorhynchus mykiss*	F,M,T	Copper nitrate	87.7	48 hr	LC50	100	-	Shazili and Pascoe 1986
Rainbow trout (yearling), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	63	15 days	Olfactory receptor degeneration	20	-	Julliard et al. 1993
Rainbow trout (swimup), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	60.9	13-40 wk	Inhibited olfactory discrimination	20	-	Saucier and Astic 1995
Rainbow trout (swimup), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	60.9	40 wk	43% mortality	40	-	Saucier and Astic 1995
Rainbow trout (9.0-11.5 cm, 10.6 g), *Oncorhynchus mykiss*	F,M,T	Copper sulfate	284	96 hr	LC50	650	-	Svecevicius and Vosyliene 1996
Rainbow trout (3.5 cm), *Oncorhynchus mykiss*	F,M,T	Copper chloride	24.2	96 hr	LC50	12.7	-	Marr et al. Manuscript
Rainbow trout (3.5 cm), *Oncorhynchus mykiss*	F,M,T	Copper chloride	24.2	96 hr	LC50	16.6	-	Marr et al. Manuscript
Rainbow trout (3.5 cm), *Oncorhynchus mykiss*	F,M,T	Copper chloride	24.2	96 hr	LC50	21.4	-	Marr et al. Manuscript
Rainbow trout (3.5 cm), *Oncorhynchus mykiss*	F,M,T	Copper chloride	24.2	96 hr	LC50	34.2	-	Marr et al. Manuscript
Rainbow trout (10.0 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	362	144 hr	LC50 (extruded diet)	276	-	Dixon and Hilton 1981
Rainbow trout (10.9 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	362	144 hr	LC50 (steam pelleted diet)	350	-	Dixon and Hilton 1981

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Rainbow trout (12.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	362	144 hr	LC50 (Low carbohydrate diet)	408	-	Dixon and Hilton 1981
Rainbow trout (11.6 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	362	144 hr	LC50 (high carbohydrate diet)	246	-	Dixon and Hilton 1981
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level	329	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level	333	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level	311	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level	274	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level	371	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level (acclimated to 30 ug/L)	266	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level (acclimated to 58 ug/L)	349	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level (acclimated to 94 ug/L)	515	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level (acclimated to 13 ug/L)	564	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), *Oncorhynchus mykiss*	F,M,D	Copper sulfate	374	21 days	Incipient lethal level (acclimated to 19 ug/L)	708	-	Dixon and Sprague 1981a
Rainbow trout (2.9 g), *Oncorhynchus mykiss*	F,M,D	Copper chloride	30.5	ca. 2 hr	Inhibited avoidance of serine	6.667	-	Rehnberg and Schreck 1986
Rainbow trout (3.2 g), *Oncorhynchus mykiss*	F,M,T,D	Copper sulfate	30	96 hr	LC50	-	19.9	Howarth and Sprague 1978
Rainbow trout (1.4 g), *Oncorhynchus mykiss*	F,M,T,D	Copper sulfate	101	96 hr	LC50	-	176	Howarth and Sprague 1978
Rainbow trout (2.2 g), *Oncorhynchus mykiss*	F,M,T,D	Copper sulfate	370	96 hr	LC50	-	232	Howarth and Sprague 1978
Rainbow trout (smolt), *Oncorhynchus mykiss*	F,M,T,D	Copper sulfate	363	>10 days	LC50	97.92	-	Fogels and Sprague 1977
Rainbow trout (parr), *Oncorhynchus mykiss*	F,M,T,D,I	-	31.0	62 days	NOEC (growth and survival)	90	-	Mudge et al. 1993
Atlantic salmon (2-3 yr parr), *Salmo salar*	S,M,T	-	8-10	96 hr	LC50	125	-	Wilson 1972
Atlantic salmon (6.4-11.7 cm), *Salmo salar*	F,M,T	Copper sulfate	20	7 days	LC50	48	-	Sprague 1964
Atlantic salmon (7.2-10.9 cm), *Salmo salar*	F,M,T	-	14	7 days	LC50	32	-	Sprague and Ramsay 1965
Brown trout (3-6 day larva), *Salmo trutta*	S,M,T	Copper chloride	4	30 days	>90% mortality	80	-	Reader et al. 1989

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Brown trout (larva), *Salmo trutta*	S,M,T	Copper chloride	4	30 days	>90% mortality	20	-	Sayer et al. 1989
Brown trout (larva), *Salmo trutta*	S,M,T	Copper chloride	22	30 days	<10% mortality	80	-	Sayer et al. 1989
Brown trout (larva), *Salmo trutta*	F,M,T	Copper chloride	25	60 days	Inhibited growth	4.6	-	Marr et al. 1996
Brook trout, *Salvelinus fontinalis*	-	-	-	24 hr	Significant change in cough rate	9	-	Drummond et al. 1973
Brook trout (1 g), *Salvelinus fontinalis*	S,M,T	Copper chloride	4	80 hr	75% mortality	25.4	-	Sayer et al. 1991 b, c
Brook trout (8 mo), *Salvelinus fontinalis*	R,M,T	-	20	10 days	IC50 (growth)	187	-	Jop et al. 1995
Brook trout (15-20 cm), *Salvelinus fontinalis*	F,M,T	Copper sulfate	47	21 days	Altered Blood Hct, RBC, Hb, Cl, PGOT, Osmolarity, protein	38.2	-	McKim et al. 1970
Brook trout (13-20 cm), *Salvelinus fontinalis*	F,M,T	Copper sulfate	47	337 days	Altered blood PGOT	17.4	-	McKim et al. 1970
Goldfish (3.8-6.3 cm), *Carassius auratus*	S,U	Copper sulfate	20	96 hr	LC50	36		Pickering and Henderson 1966
Goldfish (10.5 g), *Carassius auratus*	S,M,T	Copper sulfate	34.2	-	LC50	150	-	Hossain et al. 1995
Goldfish (embryo), *Carrassius auratus*	R,U	Copper sulfate	195	7 days	EC50 (death or deformity)	5,200	-	Birge 1978; Birge and Black 1979
Goldfish, *Carassius auratus*	R,U	Copper sulfate	45	24 hr	LC50 (5^0 C)	2,700	-	Cairns et al. 1978
Goldfish, *Carassius auratus*	R,U	Copper sulfate	45	24 hr	LC50 (15^0 C)	2,900	-	Cairns et al. 1978
Goldfish, *Carassius auratus*	R,U	Copper sulfate	45	24 hr	LC50 (30^0 C)	1,510	-	Cairns et al. 1978
Common carp (1.8-2.1 cm), *Cyprinus carpio*	S,U	Copper sulfate	144-188	96 hr	LC50	117.5		Deshmukh and Marathe 1980
Common carp (5.0-6.0 cm), *Cyprinus carpio*	S,U	Copper sulfate	144-188	96 hr	LC50	530		Deshmukh and Marathe 1980
Common carp (embryo), *Cyprinus carpio*	S,U	Copper sulfate	360	-	EC50 (hatch and deformity)	4,775	-	Kapur and Yadav 1982
Common carp (embryo), *Cyprinus carpio*	S,U	Copper acetate	274	96 hr	LC50	140	-	Kaur and Dhawan 1994
Common carp (larva), *Cyprinus carpio*	S,U	Copper acetate	274	96 hr	LC50	4	-	Kaur and Dhawan 1994
Common carp (fry), *Cyprinus carpio*	S,U	Copper acetate	274	96 hr	LC50	63	-	Kaur and Dhawan 1994
Common carp, *Cyprinus carpio*	S,M,T	Copper nitrate	53	-	LC50	110	-	Rehwoldt et al. 1971
Common carp, *Cyprinus carpio*	S,M,T	Copper nitrate	55	-	LC50	800	-	Rehwoldt et al. 1972

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Common carp (4.7-6.2 cm), *Cyprinus carpio*	R,U	Copper sulfate	19	96 hr	LC50	63		Khangarot et al. 1983
Common carp (embryo and larva), *Cyprinus carpio*	R,U	Copper sulfate	50	108 hr	77% deformed	10	-	Wani 1986
Common carp (3.5 cm), *Cyprinus carpio*	R,U	Copper sulfate	-	96 hr	LC50	300	-	Alam and Maughan 1992
Common carp (6.5 cm), *Cyprinus carpio*	R,U	Copper sulfate	-	96 hr	LC50	1,000	-	Alam and Maughan 1992
Common carp (embryo), *Cyprinus carpio*	R,M,T	Copper sulfate	50	72 hr	Prevented hatching	700	-	Hildebrand and Cushman 1978
Common carp (1 mo), *Cyprinus carpio*	R,M,T	Copper nitrate	84.8	1 wk	Raised critical D.O. and altered ammonia excretion	14.0	-	De Boeck et al. 1995a
Common carp (22.9 cm), *Cyprinus carpio*	F,M,T	Copper chloride	17	48 hr	LC50	170	-	Harrison and Rice 1981
Common carp (embryo and larva), *Cyprinus carpio*	F,M,T	Copper chloride	100	168 hr	55% mortality	19	-	Stouthart et al. 1996
Common carp (embryo and larva), *Cyprinus carpio*	F,M,T	Copper chloride	100	168 hr	18% mortality;	50.8	-	Stouthart et al. 1996
Bonytail (larva), *Gila elegans*	S, U	Copper sulfate	199	96 hr	LC50	364		Buhl and Hamilton 1996
Bonytail (100-110 days), *Gila elegans*	S, U	Copper sulfate	199	96 hr	LC50	231		Buhl and Hamilton 1996
Golden shiner (11-13 cm), *Notemigonus crysoleucas*	S,U	Copper sulfate	221	94 hr	Decreased serum osmolality	2,500	-	Lewis and Lewis 1971
Golden shiner, *Notemigonus crysoleucas*	S,U	Copper sulfate	45	24 hr	LC50 (5^0 C)	330	-	Cairns et al. 1978
Golden shiner, *Notemigonus crysoleucas*	S,U	Copper sulfate	45	24 hr	LC50 (15^0 C)	230	-	Cairns et al. 1978
Golden shiner, *Notemigonus crysoleucas*	S,U	Copper sulfate	45	24 hr	LC50 (30^0 C)	270	-	Cairns et al. 1978
Golden shiner, *Notemigonus crysoleucas*	F,M,T	Copper chloride	72.2	15 min	EC50 (avoidance)	26	-	Hartwell et al. 1989
Striped shiner, *Notropis chrysocephalus*	F,M,T,D	Copper sulfate	318	96 hr	LC50	3,400	-	Geckler et al. 1976
Striped shiner (4.7 cm) *Notropis chrysocephalus*	F,M,T,D	Copper sulfate	316	96 hr	LC50	4,000	-	Geckler et al. 1976
Striped shiner (5.0 cm) *Notropis chrysocephalus*	F,M,T,D	Copper sulfate	274	96 hr	LC50	5,000	-	Geckler et al. 1976
Striped shiner, *Notropis chrysocephalus*	F,M,T,D	Copper sulfate	314	96 hr	LC50	8,400	-	Geckler et al. 1976

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Striped shiner, *Notropis chrysocephalus*	F,M,T,D	Copper sulfate	303	96 hr	LC50	16,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	208	48 hr	LC50	290	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	132	48 hr	LC50	150	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	182	48 hr	LC50	200	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	233	48 hr	LC50	180	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	282	48 hr	LC50	260	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	337	48 hr	LC50	260	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	322	48 hr	LC50	6,300	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	322	48 hr	LC50	11,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	322	48 hr	LC50	25,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	203	48 hr	LC50	160	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	203	48 hr	LC50	1,100	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,U	Copper sulfate	203	48 hr	LC50	2,900	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	320	48 hr	LC50	6,300	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	324	48 hr	LC50	9,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	324	48 hr	LC50	4,700	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	320	48 hr	LC50	11,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	318	48 hr	LC50	5,700	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	318	48 hr	LC50	10,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	314	48 hr	LC50	8,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	318	48 hr	LC50	11,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	324	48 hr	LC50	9,700	-	Geckler et al. 1976

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	339	48 hr	LC50	7,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	310	48 hr	LC50	12,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	310	48 hr	LC50	21,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	302	48 hr	LC50	19,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	296	48 hr	LC50	8,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	332	48 hr	LC50	11,000	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	340	48 hr	LC50	6,300	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	296	48 hr	LC50	1,500	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	306	48 hr	LC50	750	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	308	48 hr	LC50	2,500	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	304	48 hr	LC50	1,600	-	Geckler et al. 1976
Bluntnose minnow, *Pimephales notatus*	S,M,D	Copper sulfate	315	48 hr	LC50	4,000	-	Geckler et al. 1976
Bluntnose minnow (3.9 cm), *Pimephales notatus*	F,M,T,D	Copper sulfate	314	96 hr	LC50	6,800	-	Geckler et al. 1976
Bluntnose minnow (5.3 cm), *Pimephales notatus*	F,M,T,D	Copper sulfate	303	96 hr	LC50	13,000	-	Geckler et al. 1976
Fathead minnow (adult), *Pimephales promelas*	S,U	Copper sulfate	103-104	96 hr	LC50	210		Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S,U	Copper sulfate	103-104	96 hr	LC50	310		Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S,U	Copper sulfate	103-104	96 hr	LC50	120		Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S,U	Copper sulfate	103-104	96 hr	LC50	210		Birge et al. 1983; Benson and Birge 1985
Fathead minnow (adult), *Pimephales promelas*	S,U	Copper sulfate	254-271	96 hr	LC50	390		Birge et al. 1983; Benson and Birge 1985
Fathead minnow, *Pimephales promelas*	S,U	Copper sulfate	200	96 hr	LC50	430		Mount 1968
Fathead minnow, *Pimephales promelas*	S,U	Copper sulfate	31	96 hr	LC50	84		Mount and Stephan 1969
Fathead minnow (3.8-6.3 cm), *Pimephales promelas*	S,U	Copper sulfate	20	96 hr	LC50	25		Pickering and Henderson 1966

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Fathead minnow (3.8-6.3 cm), *Pimephales promelas*	S,U	Copper sulfate	20	96 hr	LC50	23		Pickering and Henderson 1966
Fathead minnow (3.8-6.3 cm), *Pimephales promelas*	S,U	Copper sulfate	20	96 hr	LC50	23		Pickering and Henderson 1966
Fathead minnow (3.8-6.3 cm), *Pimephales promelas*	S,U	Copper sulfate	20	96 hr	LC50	22		Pickering and Henderson 1966
Fathead minnow (3.8-6.3 cm), *Pimephales promelas*	S,U	Copper sulfate	360	96 hr	LC50	1760		Pickering and Henderson 1966
Fathead minnow (3.8-6.3 cm), *Pimephales promelas*	S,U	Copper sulfate	360	96 hr	LC50	1140		Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	S,U	Copper sulfate	20	96 hr	LC50	50		Tarzwell and Henderson 1960
Fathead minnow, *Pimephales promelas*	S,U	Copper sulfate	400	96 hr	LC50	1,400		Tarzwell and Henderson 1960
Fathead minnow (3.2-4.2 cm), *Pimephales promelas*	S,M	Copper acetate	44	96 hr	LC50	117	-	Curtis et al. 1979; Curtis and Ward 1981
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	294	96 hr	LC50	16,000	-	Brungs et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	120	96 hr	LC50	2,200	-	Brungs et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	298	96 hr	LC50	16,000	-	Brungs et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	280	96 hr	LC50	3,300	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	244	96 hr	LC50	1,600	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	212	96 hr	LC50	2,000	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	260	96 hr	LC50	3,500	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	224	96 hr	LC50	9,700	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	228	96 hr	LC50	5,000	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	150	96 hr	LC50	2,800	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	310	96 hr	LC50	11,000	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	280	96 hr	LC50	12,000	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	280	96 hr	LC50	11,000	-	Brungs et al. 1976; Geckler et al. 1976

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	260	96 hr	LC50	22,200	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	308	96 hr	LC50	4,670	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	206	96 hr	LC50	920	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	262	96 hr	LC50	1,190	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	322	96 hr	LC50	2,830	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	210	96 hr	LC50	1,450	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	260	96 hr	LC50	1,580	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	252	96 hr	LC50	1,000	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	312	96 hr	LC50	5,330	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	276	96 hr	LC50	4,160	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	252	96 hr	LC50	10,550	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	298	96 hr	LC50	22,200	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	282	96 hr	LC50	21,800	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), *Pimephales promelas*	S,M,D	Copper sulfate	284	96 hr	LC50	23,600	-	Geckler et al. 1976
Fathead minnow (<24 h), *Pimephales promelas*	S,M,T	Copper nitrate	290	96 hr	LC50	>200	-	Schubauer-Berigan et al. 1993
Fathead minnow (<24 h), *Pimephales promelas*	S,M,T	Copper sulfate	16.8	96 hr	LC50	36.0	-	Welsh et al. 1993
Fathead minnow (<24 h), *Pimephales promelas*	S,M,T	Copper sulfate	19.0	96 hr	LC50	70.3	-	Welsh et al. 1993
Fathead minnow (<24 h), *Pimephales promelas*	S,M,T	Copper sulfate	19.0	96 hr	LC50	85.6	-	Welsh et al. 1993
Fathead minnow (<24 h), *Pimephales promelas*	S,M,T	Copper sulfate	19.0	96 hr	LC50	182.0	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), *Pimephales promelas*	S,M,T	Copper sulfate	17	96 hr	LC50	1.99	-	Welsh et al. 1993

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Fathead minnow (<24 h; 0.68 mg), *Pimephales promelas*	S,M,T	Copper sulfate	20.5	96 hr	LC50	4.86	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), *Pimephales promelas*	S,M,T	Copper sulfate	16.5	96 hr	LC50	11.1	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), *Pimephales promelas*	S,M,T	Copper sulfate	17.5	96 hr	LC50	9.87	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), *Pimephales promelas*	S,M,T	Copper sulfate	17	96 hr	LC50	15.7	-	Welsh et al. 1993
Fathead minnow (60-90 days), *Pimephales promelas*	S,M,T	-	110	48 hr	LC50	284	-	Dobbs et al. 1994
Fathead minnow (3 wk), *Pimephales promelas*	S,M,T	Copper sulfate	101	48 hr	Short-term intolerance of hypoxia (2 mg D.O./L)	186	-	Bennett et al. 1995
Fathead minnow (2-4 day), *Pimephales promelas*	S,M,T	Copper sulfate	6-10	-	LC50	12.5	-	Suedel et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	9.9	96 hr	LC50	10.7	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	7.1	96 hr	LC50	6.3	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	8.3	96 hr	LC50	12.2	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	8.9	96 hr	LC50	9.5	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	16.8	96 hr	LC50	26.8	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	12.2	96 hr	LC50	21.2	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	9.4	96 hr	LC50	19.8	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	11.4	96 hr	LC50	31.9	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	10.9	96 hr	LC50	26.1	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	12.4	96 hr	LC50	26.0	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T	Copper sulfate	17.4	96 hr	LC50	169.5	-	Welsh et al. 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T,D	Copper sulfate	46	96 hr	LC50	17.15	14.87	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T,D	Copper sulfate	46	96 hr	LC50	21.59	18.72	Erickson et al. 1996a,b

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T,D	Copper sulfate	47	96 hr	LC50	123.19	106.8	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T,D	Copper sulfate	45	96 hr	LC50	42.56	36.89	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), *Pimephales promelas*	S,M,T,D	Copper sulfate	46	96 hr	LC50	83.19	72.13	Erickson et al. 1996a,b
Fathead minnow, *Pimephales promelas*	S,M,T,D	Copper sulfate	100	96 hr	LC50 (fish from metal-contaminated pond)	360	-	Birge et al. 1983
Fathead minnow, *Pimephales promelas*	S,M,T,D	Copper sulfate	250	96 hr	LC50 (fish from metal-contaminated pond)	410	-	Birge et al. 1983
Fathead minnow (<24 hr), *Pimephales promelas*	R,U	-	45	7 days	LC50	70	-	Norberg and Mount 1985
Fathead minnow (<24 hr), *Pimephales promelas*	R,U	-	45	7 days	LOEC (growth)	26	-	Norberg and Mount 1985
Fathead minnow (<24 hr), *Pimephales promelas*	R,U	Copper sulfate	345	4 days	RNA threshhold effect	130	-	Parrott and Sprague 1993
Fathead minnow (embryo), *Pimephales promelas*	R,U	Copper sulfate	106	5 days	LC50	480	-	Fort et al. 1996
Fathead minnow (embryo), *Pimephales promelas*	R,U	Copper sulfate	106	5 days	LC50	440	-	Fort et al. 1996
Fathead minnow (embryo), *Pimephales promelas*	R,U	Copper sulfate	106	5 days	EC50 (malformation)	270	-	Fort et al. 1996
Fathead minnow (embryo), *Pimephales promelas*	R,U	Copper sulfate	106	5 days	EC50 (malformation)	260	-	Fort et al. 1996
Fathead minnow (embryo), *Pimephales promelas*	R,U	Copper sulfate	106	7 days	LC50	310	-	Fort et al. 1996
Fathead minnow (embryo), *Pimephales promelas*	R,U	Copper sulfate	106	7 days	LC50	330	-	Fort et al. 1996
Fathead minnow (embryo), *Pimephales promelas*	R,U	Copper sulfate	106	7 days	EC50 (malformation)	190	-	Fort et al. 1996
Fathead minnow (embryo), *Pimephales promelas*	R,U	Copper sulfate	106	7 days	EC50 (malformation)	170	-	Fort et al. 1996
Fathead minnow (embryo), *Pimephales promelas*	R,U	Copper sulfate	106	7 days	LOEC (length)	160	-	Fort et al. 1996
Fathead minnow (embryo), *Pimephales promelas*	R,U	Copper sulfate	106	7 days	LOEC (length)	180	-	Fort et al. 1996
Fathead minnow (larva), *Pimephales promelas*	R,M,T	Copper sulfate	180	7 days	LOEC (growth)	25	-	Pickering and Lazorchak 1995
Fathead minnow (larva), *Pimephales promelas*	R,M,T	Copper sulfate	218	7 days	LOEC (growth)	38	-	Pickering and Lazorchak 1995
Fathead minnow (larva), *Pimephales promelas*	R,M,T	Copper sulfate	218	7 days	LOEC (growth)	38	-	Pickering and Lazorchak 1995
Fathead minnow (3-7 days), *Pimephales promelas*	R,M,T	Copper sulfate	74	48 hr	LC50	225	-	Diamond et al. 1997b

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Fathead minnow (larva), *Pimephales promelas*	R,M,T,D	Copper sulfate	80	48 hr	LC50	35.9	-	Diamond et al. 1997a
Fathead minnow (larva), *Pimephales promelas*	R,M,T,D	Copper sulfate	80	48 hr	LC50	28.9	-	Diamond et al. 1997a
Fathead minnow (larva), *Pimephales promelas*	R,M,T,D	Copper sulfate	80	48 hr	LC50	20.7	-	Diamond et al. 1997a
Fathead minnow (larva), *Pimephales promelas*	R,M,T,D	Copper sulfate	80	48 hr	LC50	80.8	-	Diamond et al. 1997a
Fathead minnow (3-7 days), *Pimephales promelas*	R,M,T,D	Copper sulfate	80	48 hr	LC50	297.1	-	Diamond et al. 1997b
Fathead minnow (3-7 days), *Pimephales promelas*	R,M,T,D	Copper sulfate	72	48 hr	LC50	145.8	-	Diamond et al. 1997b
Fathead minnow (32-38 mm), *Pimephales promelas*	F,M,T	Copper sulfate	244	9 mo	LOEC (93% lower fecundity)	120	-	Brungs et al. 1976
Fathead minnow (larva), *Pimephales promelas*	F,M,T	Copper sulfate	202	-	LC50	250	-	Scudder et al. 1988
Fathead minnow (embryo), *Pimephales promelas*	F,M,T	Copper sulfate	202	34 days	Reduced growth; increased abnormality	61	-	Scudder et al. 1988
Fathead minnow (embryo), *Pimephales promelas*	F,M,T	Copper sulfate	202	34 days	LC50	123	-	Scudder et al. 1988
Fathead minnow (24-96 hr), *Pimephales promelas*	F,M,T	Copper sulfate	10.7	21 days	Incipient lethal level	6.2	-	Welsh 1996
Fathead minnow (24-96 hr), *Pimephales promelas*	F,M,T	Copper sulfate	10.7	21 days	Growth (length) reduced by 8%	5.3	-	Welsh 1996
Fathead minnow (24-96 hr), *Pimephales promelas*	F,M,T	Copper sulfate	9.3	21 days	Incipient lethal level	17.2	-	Welsh 1996
Fathead minnow (24-96 hr), *Pimephales promelas*	F,M,T	Copper sulfate	9.3	21 days	Growth (length) reduced by 17%	16.2	-	Welsh 1996
Fathead minnow (<24 hrs), *Pimephales promelas*	F,M,T	Copper sulfate	46	96 hr	LC50	305	-	Erickson et al. 1996 a,b
Fathead minnow (<24 hrs), *Pimephales promelas*	F,M,T	Copper sulfate	46	96 hr	LC50	298.6	-	Erickson et al. 1996 a, b
Fathead minnow, *Pimephales promelas*	F,M,T	-	30	96 hr	LC50 (TOC=12 mg/L)	436	-	Lind et al. manuscript
Fathead minnow, *Pimephales promelas*	F,M,T	-	37	96 hr	LC50 (TOC=13 mg/L)	516	-	Lind et al. manuscript
Fathead minnow, *Pimephales promelas*	F,M,T	-	87	96 hr	LC50 (TOC=36 mg/L)	1,586	-	Lind et al. manuscript
Fathead minnow, *Pimephales promelas*	F,M,T	-	73	96 hr	LC50 (TOC=28 mg/L)	1,129	-	Lind et al. manuscript
Fathead minnow, *Pimephales promelas*	F,M,T	-	84	96 hr	LC50 (TOC=15 mg/L)	550	-	Lind et al. manuscript
Fathead minnow, *Pimephales promelas*	F,M,T	-	66	96 hr	LC50 (TOC=34 mg/L)	1,001	-	Lind et al. manuscript

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Fathead minnow, *Pimephales promelas*	F,M,T	-	117	96 hr	LC50 (TOC=30 mg/L)	2,050	-	Lind et al. manuscript
Fathead minnow, *Pimephales promelas*	F,M,T	-	121	96 hr	LC50 (TOC=30 mg/L)	2,336	-	Lind et al. manuscript
Fathead minnow, *Pimephales promelas*	F,M,T	Copper sulfate	117	96 hr	LC50	2,050	-	Lind et al. manuscript
Fathead minnow, *Pimephales promelas*	F,M,T	Copper sulfate	121	96 hr	LC50	2,336	-	Lind et al. manuscript
Fathead minnow (4.4 cm), *Pimephales promelas*	F,M,T,D	Copper sulfate	314	96 hr	LC50	11,000	-	Geckler et al. 1976
Fathead minnow (4.2 cm), *Pimephales promelas*	F,M,T,D	Copper sulfate	303	96 hr	LC50	15,000	-	Geckler et al. 1976
Fathead minnow (<24 hrs), *Pimephales promelas*	F,M,T,D	Copper sulfate	45	96 hr	LC50	158.8	138.1	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), *Pimephales promelas*	F,M,T,D	Copper sulfate	45	96 hr	LC50	80.01	72.01	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), *Pimephales promelas*	F,M,T,D	Copper sulfate	46	96 hr	LC50	20.96	18.23	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), *Pimephales promelas*	F,M,T,D	Copper sulfate	44	96 hr	LC50	50.8	39.12	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), *Pimephales promelas*	F,M,T,D	Copper sulfate	45	96 hr	LC50	65.41	45.78	Erickson et al. 1996a,b
Colorado squawfish (larva), *Ptychocheilus lucius*	S,U	Copper sulfate	199	96 hr	LC50	363		Buhl and Hamilton 1996
Colorado squawfish (155-186 days), *Ptychocheilus lucius*	S,U	Copper sulfate	199	96 hr	LC50	663		Buhl and Hamilton 1996
Colorado squawfish (32-40 days posthatch), *Ptychocheilus lucius*	S,U	Copper sulfate	144	96 hr	LC50	293		Hamilton and Buhl 1997
Colorado squawfish (32-40 days posthatch), *Ptychocheilus lucius*	S,U	Copper sulfate	144	96 hr	LC50	320		Hamilton and Buhl 1997
Creek chub, *Semotilus atromaculatus*	F,M,T	Copper sulfate	316	96 hr	LC50	11,500	-	Geckler et al. 1976
Creek chub, *Semotilus atromaculatus*	F,M,T	Copper sulfate	274	96 hr	LC50	1,100	-	Geckler et al. 1976
Razorback sucker (larva), *Xyrauchen texanus*	S,U	Copper sulfate	199	96 hr	LC50	404		Buhl and Hamilton 1996
Razorback sucker (102-116 days), *Xyrauchen texanus*	S,U	Copper sulfate	199	96 hr	LC50	331		Buhl and Hamilton 1996
Razorback sucker (13-23 days posthatch), *Xyrauchen texanus*	S,U	Copper sulfate	144	96 hr	LC50	231		Hamilton and Buhl 1997

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Razorback sucker (13-23 days posthatch), *Xyrauchen texanus*	S,U	Copper sulfate	144	96 hr	LC50	314		Hamilton and Buhl 1997
Brown bullhead, *Ictallurus nebulosus*	F,M,T	Copper sulfate	303	96 hr	LC50	12,000	-	Geckler et al. 1976
Brown bullhead (5.2 cm), *Ictalurus nebulosus*	F,M,T	Copper sulfate	314	96 hr	LC50	5,200	-	Geckler et al. 1976
Channel catfish (13-14 cm), *Ictalurus punctatus*	S,U	Copper sulfate	221	94 hr	Decreased serum osmolality	2,500	-	Lewis and Lewis 1971
Channel catfish, *Ictalurus punctatus*	S,U	Copper sulfate	45	24 hr	LC50 (5^0 C)	3,700	-	Cairns et al. 1978
Channel catfish, *Ictalurus punctatus*	S,U	Copper sulfate	45	24 hr	LC50 (15^0 C)	2,600	-	Cairns et al. 1978
Channel catfish, *Ictalurus punctatus*	S,U	Copper sulfate	45	24 hr	LC50 (30^0 C)	3,100	-	Cairns et al. 1978
Channel catfish, *Ictalurus punctatus*	S,U	Copper sulfate	100	10 days	EC50 (death and deformity)	6,620	-	Birge and Black 1979
Channel catfish (fingerlings), *Ictalurus punctatus*	S,U	Copper sulfate	16	96 hr	LC50	54		Straus and Tucker 1993
Channel catfish (fingerlings), *Ictalurus punctatus*	S,U	Copper sulfate	16	96 hr	LC50	55		Straus and Tucker 1993
Channel catfish (fingerlings), *Ictalurus punctatus*	S,U	Copper sulfate	83	96 hr	LC50	762		Straus and Tucker 1993
Channel catfish (fingerlings), *Ictalurus punctatus*	S,U	Copper sulfate	83	96 hr	LC50	700		Straus and Tucker 1993
Channel catfish (fingerlings), *Ictalurus punctatus*	S,U	Copper sulfate	161	96 hr	LC50	768		Straus and Tucker 1993
Channel catfish (fingerlings), *Ictalurus punctatus*	S,U	Copper sulfate	161	96 hr	LC50	1139		Straus and Tucker 1993
Channel catfish (fingerlings), *Ictalurus punctatus*	S,U	Copper sulfate	287	96 hr	LC50	1041		Straus and Tucker 1993
Channel catfish (fingerlings), *Ictalurus punctatus*	S,U	Copper sulfate	287	96 hr	LC50	925		Straus and Tucker 1993
Channel catfish (400-600 g), *Ictalurus punctatus*	F,M,T	Copper sulfate	-	10 wk	Significant mortality	354	-	Perkins et al. 1997
Channel catfish (4.1 gm), *Ictalurus punctatus*	F,M,T,D	Copper sulfate	319	14 days	LC50	1,229	-	Richey and Roseboom 1978
Channel catfish (5.7 gm), *Ictalurus punctatus*	F,M,T,D	Copper sulfate	315	14 days	LC50	1,073	-	Richey and Roseboom 1978
Banded killifish, *Fundulus diaphanus*	S,M,T	Copper nitrate	53	-		860	-	Rehwoldt et al. 1971
Banded killifish, *Fundulus diaphanus*	S,M,T	Copper nitrate	55	-		840	-	Rehwoldt et al. 1972

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Flagfish (0.1-0.3 g), *Jordanella floridae*	F,M,T,D	Copper sulfate	363	10 days	LC50	-	680	Fogels and Sprague 1977
Flagfish (0.1-0.3 g), *Jordanella floridae*	F,M,T,D	Copper sulfate	363	96 hr	LC50	-	1,270	Fogels and Sprague 1977
Mosquitofish (3.8-5.1 cm female), *Gambusia affinis*	S,U	Copper nitrate	27-41	96 hr	LC50	93		Joshi and Rege 1980
Mosquitofish (3.8-5.1 cm female), *Gambusia affinis*	S,U	Copper sulfate	27-41	96 hr	LC50	200		Joshi and Rege 1980
Mosquitofish (2.5 cm male), *Gambusia affinis*	S,U	-	50	96 hr	LC50	3,500		Kallanagoudar and Patil 1997
Mosquitofish (2.5 cm male), *Gambusia affinis*	S,U	-	150	96 hr	LC50	5,000		Kallanagoudar and Patil 1997
Mosquitofish (2.5 cm male), *Gambusia affinis*	S,U	-	300	96 hr	LC50	6,000		Kallanagoudar and Patil 1997
Mosquitofish (3.5 cm female), *Gambusia affinis*	S,U	-	50	96 hr	LC50	2,500		Kallanagoudar and Patil 1997
Mosquitofish (3.5 cm female), *Gambusia affinis*	S,U	-	150	96 hr	LC50	2,900		Kallanagoudar and Patil 1997
Mosquitofish (3.5 cm female), *Gambusia affinis*	S,U	-	300	96 hr	LC50	5,000		Kallanagoudar and Patil 1997
Mosquitofish (0.8 cm fry), *Gambusia affinis*	S,U	-	50	96 hr	LC50	900		Kallanagoudar and Patil 1997
Mosquitofish (0.8 cm fry), *Gambusia affinis*	S,U	-	150	96 hr	LC50	1,400		Kallanagoudar and Patil 1997
Mosquitofish (0.8 cm fry), *Gambusia affinis*	S,U	-	300	96 hr	LC50	2,000		Kallanagoudar and Patil 1997
Mosquito fish, *Gambusia affinis*	S,U	Copper sulfate	-	96 hr	LC50 (high turbidity)	75,000	-	Wallen et al. 1957
Mosquito fish, *Gambusia affinis*	R,M	Copper sulfate	45	48 hr	LC50	180	-	Chagnon and Guttman 1989
Guppy (1.5 cm), *Poecilia reticulata*	S,U	Copper sulfate	230	96 hr	LC50	1,230		Khangarot 1981
Guppy (1.62 cm), *Poecilia reticulata*	S,U	Copper sulfate	240	96 hr	LC50	764		Khangarot et al. 1981b
Guppy (1.9-2.5 cm), *Poecilia reticulata*	S,U	Copper sulfate	20	96 hr	LC50	36		Pickering and Henderson 1966
Guppy (1.5 cm), *Poecilia reticulata*	R,U	Copper sulfate	260	96 hr	LC50	2,500		Khangarot et al. 1981a
Guppy (0.8-1.0 cm), *Poecilia reticulata*	R,U	Copper sulfate	144-188	96 hr	LC50	160		Deshmukh and Marathe 1980
Guppy (1.2-2.3 cm; female), *Poecilia reticulata*	R,U	Copper sulfate	144-188	96 hr	LC50	275		Deshmukh and Marathe 1980

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Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Guppy (2.3-2.8 cm; male), *Poecilia reticulata*	R,U	Copper sulfate	144-188	96 hr	LC50	210		Deshmukh and Marathe 1980
Guppy (340 mg; female), *Poecilia reticulata*	R,U	Copper sulfate	144-188	96 hr	LC50	480		Deshmukh and Marathe 1980
Guppy (1.5 cm), *Poecilia reticulata*	R,U	Copper sulfate	260	48 hr	LC50	2,500	-	Khangarot et al. 1981a
Guppy (1.5 cm), *Poecilia reticulata*	R, U	Copper sulfate	181	96 hr	LC50	986	-	Khangarot and Ray 1987b
Guppy (1 mo), *Poecilia reticulata*	F,U	Copper sulfate	76	24 hr	LC50	1,370	-	Minicucci 1971
Guppy (1 mo), *Poecilia reticulata*	F,U	Copper sulfate	76	24 hr	LC50	930	-	Minicucci 1971
Guppy (1 mo), *Poecilia reticulata*	F,U	Copper sulfate	76	24 hr	LC50	1,130	-	Minicucci 1971
White perch, *Morone americana*	S,M,T	Copper nitrate	53	-	LC50	6,200	-	Rehwoldt et al. 1971
White perch, *Morone americana*	S,M,T	Copper nitrate	55	-	LC50	6,400	-	Rehwoldt et al. 1972
Striped bass (larva), *Morone saxitilis*	S,U	Copper chloride	34.6	96 hr	LC50	50		Hughes 1973
Striped bass (larva), *Morone saxitilis*	S,U	Copper sulfate	34.6	96 hr	LC50	100		Hughes 1973
Striped bass (3.5-5.1 cm), *Morone saxitilis*	S,U	Copper chloride	34.6	96 hr	LC50	50		Hughes 1973
Striped bass (3.1-5.1 cm), *Morone saxitilis*	S,U	Copper sulfate	34.6	96 hr	LC50	150		Hughes 1973
Striped bass (35-80 day), *Morone saxitilis*	S,U	Copper sulfate	285	96 hr	LC50	270		Palawski et al. 1985
Striped bass (6 cm), *Morone saxitilis*	S,U	Copper sulfate	35	96 hr	LC50	620		Wellborn 1969
Striped bass, *Morone saxitilis*	S,M,T	Copper nitrate	53	96 hr	LC50	4,300	-	Rehwoldt et al. 1971
Striped bass, *Morone saxitilis*	S,M,T	Copper nitrate	55	96 hr	LC50	2,700	-	Rehwoldt et al. 1972
Rock bass, *Ambloplites rupestris*	F,M,T	-	24	96 hr	LC50 (high TOC)	1,432	-	Lind et al. manuscript
Pumpkinseed (1.2 g), *Lepomis gibbosus*	S,M,T	Copper nitrate	53	-	LC50	2,400	-	Rehwoldt et al. 1971
Pumpkinseed (1.2 g), *Lepomis gibbosus*	S,M,T	Copper nitrate	55	-	LC50	2,700	-	Rehwoldt et al. 1972
Pumpkinseed, *Lepomis gibbosus*	S,M,T	Copper nitrate	53	96 hr	LC50	2,400	-	Rehwoldt et al. 1971
Pumpkinseed, *Lepomis gibbosus*	S,M,T	Copper nitrate	55	96 hr	LC50	2,700	-	Rehwoldt et al. 1972

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Bluegill, *Lepomis macrochirus*	S,U	Copper chloride	43	96 hr	LC50	770		Academy of Natural Sciences 1960
Bluegill, *Lepomis macrochirus*	S,U	Copper sulfate	43	96 hr	LC50	1,250		Academy of Natural Sciences 1960 Cairns and Scheier 1968; Patrick et
Bluegill, *Lepomis macrochirus*	S,U	Copper sulfate	45	24 hr	LC50 (5^0 C)	2,590	-	Cairns et al. 1978
Bluegill, *Lepomis macrochirus*	S,U	Copper sulfate	45	24 hr	LC50 (15^0 C)	2,500	-	Cairns et al. 1978
Bluegill, *Lepomis macrochirus*	S,U	Copper sulfate	45	24 hr	LC50 (30^0 C)	3,820	-	Cairns et al. 1978
Bluegill (3-4 cm), *Lepomis macrochirus*	S,U	-	119	8 days	33% reduction in locomotor activity	40	-	Ellgaard and Guillot 1988
Bluegill (4.2 cm), *Lepomis macrochirus*	S,U	Copper sulfate	52	96 hr	LC50	254		Inglis and Davis 1972
Bluegill (4.2 cm), *Lepomis macrochirus*	S,U	Copper sulfate	209	96 hr	LC50	437		Inglis and Davis 1972
Bluegill (4.2 cm), *Lepomis macrochirus*	S,U	Copper sulfate	365	96 hr	LC50	648		Inglis and Davis 1972
Bluegill (5-15 g), *Lepomis macrochirus*	S,U	Copper sulfate	35	2-6 days	8% increase in oxygen consumption rates	300	-	O'Hara 1971
Bluegill (3.8-6.3 cm), *Lepomis macrochirus*	S,U	Copper sulfate	20	96 hr	LC50	660		Pickering and Henderson 1966
Bluegill (3.8-6.3 cm), *Lepomis macrochirus*	S,U	Copper sulfate	360	96 hr	LC50	10,200		Pickering and Henderson 1966
Bluegill, *Lepomis macrochirus*	S,U	Copper sulfate	20	96 hr	LC50	200		Tarzwell and Henderson 1960
Bluegill, *Lepomis macrochirus*	S,U	Copper sulfate	400	96 hr	LC50	10,000		Tarzwell and Henderson 1960
Bluegill (5-11 cm), *Lepomis macrochirus*	S,U	Copper sulfate	46	48 hr	LC50	3,000	-	Turnbull et al. 1954
Bluegill (5-11 cm), *Lepomis macrochirus*	S,U	Copper sulfate	101.2	48 hr	LC50	7,000	-	Turnbull et al. 1954
Bluegill (0.51g), *Lepomis macrochirus*	S,M,T	-	110	48 hr	LC50	4,300	-	Dobbs et al. 1994

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Appendix B. Other Data on Effects of Copper on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Total Concentration (µg/L)[b]	Dissolved Concentration (µg/L)	Reference
Bluegill (5-9 cm), *Lepomis macrochirus*	S,M,T	Copper chloride	45-47	-	LC50	710	-	Trama 1954
Bluegill (5-9 cm), *Lepomis macrochirus*	S,M,T	Copper sulfate	45-47	-	LC50	770	-	Trama 1954
Bluegill (5-15 g), *Lepomis macrochirus*	F,M	Copper sulfate	35	-	LC50	2400	-	O'Hara 1971
Bluegill (3.5-6.0 cm), *Lepomis macrochirus*	F,M,T	Copper sulfate	112.4	80 min	Avoidance threshold	8,480	-	Black and Birge 1980
Bluegill (3.2-6.7 cm), *Lepomis macrochirus*	F,M,T	Copper chloride	21.2-59.2	96 hr	LC50	1,100	-	Thompson et al. 1980
Bluegill (3.2-6.7 cm), *Lepomis macrochirus*	F,M,T	Copper chloride	21.2-59.2	96 hr	LC50	900	-	Thompson et al. 1980
Bluegill (35.6-62.3 g), *Lepomis macrochirus*	F,M,T	Copper sulfate	273.3	24-96 hr	Various behavioral changes	34	-	Henry and Atchison 1986
Bluegill, *Lepomis macrochirus*	F,M,T	Copper chloride	157	24-96 hr	27% reduction in food consumption	31	-	Sandheinrich and Atchison 1989
Bluegill, *Lepomis macrochirus*	F,M,T,D	Copper sulfate	316	96 hr	LC50 (high BOD)	16,000	-	Geckler et al. 1976
Bluegill, *Lepomis macrochirus*	F,M,T,D	Copper sulfate	318	96 hr	LC50 (high BOD)	17,000	-	Geckler et al. 1976
Bluegill (0.14-0.93 g), *Lepomis macrochirus*	F,M,T,D	Copper sulfate	246	14 days	LC50	-	2,500	Richey and Roseboom 1978
Bluegill (1.15-2.42 g), *Lepomis macrochirus*	F,M,T,D	Copper sulfate	237	14 days	LC50	-	3,700	Richey and Roseboom 1978
Bluegill (48.3 g), *Lepomis macrochirus*	F,M,T,D	Copper sulfate	40	96 hr	Biochemical changes	2,000	-	Heath 1984
Largemouth bass (embryo), *Micropterus salmoides*	R,U	Copper sulfate	100	8 days	EC50 (death and deformity)	6,560	-	Birge et al. 1978; Birge and Black 1979
Largemouth bass, *Micropterus salmoides*	F,U	-	-	24 hr	Affected opercular rhythm	48	-	Morgan 1979
Rainbow darter, *Etheostoma caeruleum*	F,M,T,D	Copper sulfate	318	96 hr	LC50 (high BOD)	4,500	-	Geckler et al. 1976
Rainbow darter, *Etheostoma caeruleum*	F,M,T,D	Copper sulfate	316	96 hr	LC50 (high BOD)	8,000	-	Geckler et al. 1976
Rainbow darter, Etheostoma caeruleum	F,M,T,D	Copper sulfate	274	96 hr	LC50 (high BOD)	2,800	-	Geckler et al. 1976
Rainbow darter (4.6 cm), *Etheostoma caeruleum*	F,M,T,D	Copper sulfate	314	96 hr	LC50 (high BOD)	4,800	-	Geckler et al. 1976
Rainbow darter (4.6 cm), *Etheostoma caeruleum*	F,M,T,D	Copper sulfate	303	96 hr	LC50 (high BOD)	5,300	-	Geckler et al. 1976
Fantail, *Etheostoma flabellare*	S,M,T	Copper sulfate	170	96 hr	Lowered critical thermal maximum	43	-	Lydy and Wissing 1988

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Appendix C. Estimation of Water Chemistry Parameters for Acute Copper Toxicity Tests

FINAL REPORT

ESTIMATION OF WATER CHEMISTRY PARAMETERS FOR ACUTE COPPER TOXICITY TESTS

For:

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FOREWORD

This report was developed by the Great Lakes Environmental Center. Some minor revisions were made by the U.S. Environmental Protection Agency (EPA). These revisions were primarily editorial. Additional editorial and formatting revisions were made by the CDM Group, Inc.

The purpose of this report is to provide input water chemistry information for a Biotic Ligand Model (BLM) analysis of the acute copper toxicity data in Table 1a of the U.S. Environmental Protection Agency's (EPA) draft 2003 Update of Ambient Water Quality Criteria for Copper. EPA will use these BLM data to derive adjusted aquatic life criteria for copper. Many of the reported Table 1a acute copper toxicity data lack sufficient information on the chemistry of the dilution water to generate BLM-derived critical accumulation values. This compendium contains data from the primary authors of these articles. It also contains recommendations for the use of these data, additional supporting documentation and/or computations, and recommendations for estimating missing parameters.

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Estimation of Water Chemistry Parameters for Acute Copper Toxicity Tests

To prepare for the possibility of incorporating the Biotic Ligand Model (BLM) (Di Toro et al. 2001) into an updated copper aquatic life criteria document, the U.S. Environmental Protection Agency (EPA) sought to generate a data table summarizing the acute toxicity of copper to freshwater organisms that included the following parameters: alkalinity, dissolved organic carbon (DOC), pH, and the major anions (Cl and SO_4) and cations (Ca, Mg, Na, K) of the test water. Published literature was reviewed and appropriate information tabulated, but measurements for many of the aforementioned parameters were not reported. To resolve the overwhelming number of missing test water chemistry values in the database, certain authors were contacted for additional information and to obtain additional measurements in waters where critical information was either not measured or not reported. EPA also attempted to determine appropriate methods for estimating test water chemistry in the absence of reported values. The information received from the authors and recommended procedures for estimating missing parameters are the subject of this report.

1.0 Data Acquisition

The authors of several studies were contacted for additional information on the chemistry of the water or methods used in their studies. If the primary or corresponding authors could not be contacted, an attempt was made to contact secondary authors or personnel from the laboratories where the studies had been conducted. In a few instances, this initial effort failed to produce the desired information, and censored databases (U.S. Geological Survey's [USGS] National Stream Quality Accounting Network [NASQAN] and EPA's STOrage and RETrieval [STORET] data warehouse) were consulted to obtain the missing data. As a last resort, other available sources of water compositional data (e.g., city drinking water treatment officials) were contacted.

The acquired data were scrutinized for representativeness and usefulness in estimating surrogate values to complete the water quality information in the original studies. Summary tables and figures generated from these data are included in the following pages, which serve as the basis for the addition of values in the spreadsheets. Information used for the tabular and graphical summaries of these data is included in separate appendices.

2.0 Technical Issues and Corresponding Recommendations

2.1 *Estimating Ion Concentrations*

Develop a methodology for estimating Ca, Mg, Na, K, Cl, and SO_4 concentrations in laboratory-reconstituted waters.

Recommendation: The best approach for estimating ion concentrations in standard laboratory-reconstituted water involves scaling default ion concentrations based on measured hardness. The default ion concentrations can be computed from the concentrations of the salts added. The use of calculated ion concentrations as input for the BLM applies only to reconstituted water prepared following the standard recipes reported in guidance documents for conducting acute bioassays with aquatic organisms (ASTM 2000; U.S. EPA 1993) (see Table 1). If similar salts are added in different amounts, then the ion concentrations must be calculated using the recipe reported

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in the article. Otherwise, specific ion ratios, and more importantly ion concentrations, cannot be calculated.

Table 1. Standard Reconstituted Water Composition and Target Water Quality Characteristics

	Reagent Added (mg/L)				Final Water Quality		
Water Type	$NaHCO_3$	$CaSO_4 \cdot 2H_2O$	$MgSO_4$	KCl	pH[a]	Hardness[a]	Alkalinity[b]
Very Soft	12.0	7.5	7.5	0.5	6.4-6.8	10-13	10-13
Soft	48.0	30.0	30.0	2.0	7.2-7.6	40-48	30-35
Mod. Hard	96.0	60.0	60.0	4.0	7.4-7.8	80-100	60-70
Hard	192.0	120.0	120.0	8.0	7.6-8.0	160-180	110-120
Very Hard	384.0	240.0	240.0	16.0	8.0-8.4	280-320	225-245

[a] Approximate equilibrium pH after 24-hour aeration
[b] Expressed as mg/L $CaCO_3$

When standard laboratory-reconstituted water is cited as the dilution water, and no additional measurements are reported, the recommended approach for estimating ion concentrations is to use the ion concentrations calculated from the amount of salts added for the type of reconstituted water reported in the article. For example, if the range of hardness of the reconstituted water is reported as 80-100 mg/L $CaCO_3$, then the specific ion concentrations calculated from the standard recipe for moderately hard reconstituted water should be used for BLM input (see Table 2 and example calculation in Appendix D-2). The use of ion concentrations calculated from the standard recipes assumes that salts were stored in a manner to prevent hydration and that technician errors in weighing of salts, measurements of dilution water, and measurement of solution volumes were minimal.

Alternatively, if the authors state that moderately hard water was prepared following one of the standard recipes, and they measured the hardness of the water, then the calculated ion concentrations should be adjusted to account for any difference from the mean of the expected range. For example, if the mean measured hardness in a test water prepared using the recipe for moderately hard reconstituted water was 78 mg/L $CaCO_3$, the Ca:Mg ratio would be 0.700 for all reconstituted water types, and the respective Ca and Mg concentrations could be calculated using the following equations:

$$Ca = (0.4008 \times \text{measured hardness}) \div [1 + (1 \div \text{Ca:Mg ratio})] \quad \textbf{Equation 1}$$

$$Mg = (0.2431 \times \text{measured hardness}) \div (1 + \text{Ca:Mg ratio}) \quad \textbf{Equation 2}$$

The remaining ion concentrations are each multiplied by 0.92 (quotient of 78 and 85 mg/L $CaCO_3$, the latter of which is the expected hardness for moderately hard reconstituted water), as in Table 1.

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Table 3 provides ion concentrations predicted for a standard reconstituted water mix using the hardness adjustment in accordance with the example above.

Note that this same rationale for scaling the default major anions and cations in reconstituted water also applies to a variety of natural surface and well waters. Analysis of St. Louis River, MN, water and Western Fish Toxicology Station (WFTS) well water indicated that a strong linear relationship also exists between water hardness and the major anion (Cl, SO_4) and cation (Ca, Mg, Na) concentrations in these water types (see Sections 2.6, 2.7, and 2.19). The strong relationships are consistent with findings

Table 2. Calculated Ion Concentrations Based on the Standard Salts Added

Water Type (Nominal Hardness Range)	Specific Ions[a] (mg/L)						Ca:Mg[b]	Expected Hardness (mg/L $CaCO_3$)[c]
	Ca	Mg	Na	K	Cl	SO_4		
Very Soft (10-13 mg/L $CaCO_3$)	1.75	1.51	3.28	0.262	0.238	10.2	0.700	11
Soft (40-48 mg/L $CaCO_3$)	6.99	6.06	13.1	1.05	0.951	40.7	0.700	42
Moderately Hard (80-100 mg/L $CaCO_3$)	14.0	12.1	26.3	2.10	1.90	81.4	0.700	85
Hard (160-180 mg/L $CaCO_3$)	27.9	24.2	52.5	4.20	3.80	163	0.700	170
Very Hard (280-320 mg/L $CaCO_3$)	55.9	48.5	105	8.39	7.61	325	0.700	339

[a] Ion concentrations were calculated from standard salt recipes (refer to Table 1 and example calculation for very soft water in Appendix D-1).

[b] Ratio equals quotient of (Ca÷40.08) and (Mg÷24.31), where 40.08 and 24.31 are the molecular weights of Ca and Mg, respectively, in units of mg/mmol.

[c] Hardness calculated according to the concentrations of Ca and Mg given here and the equation given in Appendix D-1.

Table 3. Adjusted Ion Concentrations for a Standard Reconstituted Water Mix Based on Reported Hardness

Moderately Hard Reconstituted Water	Hardness (mg/L $CaCO_3$)	Specific Ions (mg/L)					
		Ca	Mg	Na	K	Cl	SO_4
Nominal	85[a]	14.0	12.1	26.3	2.10	1.90	81.4
Adjusted	78	12.9	11.2	***24.2***	***2.10***	***1.75***	***74.9***

[a] Expected hardness based on the amount of salts added (from Table 1). Calcium and magnesium are calculated using Equations 1 and 2. Other adjusted values (italic and bold) are a result of the product of the ratio of measured hardness (78 mg/L) to expected hardness (85 mg/L) and nominal ion concentrations, e.g., the adjusted sodium ion concentration for a standard laboratory reconstituted water mix based on a reported total hardness of 78 mg/L $CaCO_3$ is: 78÷85=0.92; 0.92*26.3=24.2.

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presented in an earlier comprehensive report by Erickson (1985). Note, however, that because there is generally poor correlation between K and water hardness in the various ambient surface and ground water types (see Section 2.6), the value calculated for K should not be scaled according to hardness.

2.2 *pH Adjustment with HCl*

Schubauer-Berigan et al. (1993) adjusted pH using HCl but reported only nominal hardness and alkalinity. The tests were conducted at the EPA Office of Research and Development, Mid-Continent Ecology Division, Duluth, MN, using a standard very hard reconstituted water mix. The authors need to be contacted to obtain any additional water chemistry data they might have.

Recommendation: Alkalinity and hardness were not measured in the tests reported in Schubauer-Berigan et al. (1993), and no additional water chemistry data are available from the study (Phil Monson, U.S. EPA-Duluth, personal communication). The HCl required to adjust the pH was assumed to be added in amounts too small to significantly affect any of the other water quality parameters (Gerald Ankley, U.S. EPA-Duluth, personal communication). Based on these remarks, we believe ion concentrations for this particular study should be estimated using methods outlined in Section 2.1.

2.3 *Estimation of DOC*

How should DOC be estimated if only total organic carbon (TOC) was measured in the study? Can DOC be estimated if no measurements of organic carbon were reported in the study?

Recommendation: As a general rule, TOC values can be used directly in place of DOC for dechlorinated and de-ionized city tap water, well water, and oligotrophic lake water (e.g., Lake Superior water). TOC values are not recommended in place of DOC for water from estuaries, wetlands, or higher order streams unless data are included that indicate otherwise. Rather, the proportion of organic carbon expected to be dissolved in surface waters should be estimated and used to scale the measured TOC value. When possible, the DOC:TOC ratio for a surface water should be obtained using the USGS NASQAN dataset. The NASQAN dataset can be reached through the USGS Web site (water.usgs.gov/nasqan/data/finaldata.html). If a representative ratio for a particular body of water cannot be determined, the ratio for the particular water type (lake or stream) should be obtained from the final draft of the Ambient Water Quality Criteria Derivation Methodology Human Health Technical Support Document (U.S. EPA 1998a, Table 2.4.11). A summary of these data, by State, is provided in Appendix D-2. In this appendix, TOC is operationally defined as the sum of DOC and particulate organic carbon (POC). The national mean fraction of organic carbon is 86 percent for streams and 88 percent for lakes. The DOC:TOC ratio can be applied to lakes or streams within a State to obtain an estimate of DOC from values reported for TOC.

Example:

Reference	Water Body	TOC (mg/L)	DOC:TOC	Estimated DOC (mg/L)
Lind et al. manuscript	St. Louis R, MN	32	0.87	28

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For tests with reconstituted, city tap, or well water, default DOC values can be applied if the author does not report a measured value. The recommended default TOC (DOC) value for laboratory prepared reconstituted water is 0.5 mg carbon/L (note: some newer laboratory water systems can achieve a TOC of less than 0.5 mg/L). For regular city tap and well water, a value of 1.6 mg carbon/L can be assumed. The recommended default value for laboratory-prepared reconstituted water is based on the arithmetic mean of recent measurements of DOC in reconstituted water prepared at two Federal (U.S. EPA Cincinnati, OH, and USGS Yankton, SD) and two consulting (Commonwealth Biomonitoring and GLEC) laboratories (range 0.1 to 1 mg/L). The recommended default value for dechlorinated city tap and well water is based on the arithmetic mean of measurements of DOC in source water from Lake Ontario (Environment Canada, Burlington, ON) and the New River, VA (City of Blacksburg, VA), and well water from Oak Ridge National Laboratory (Oak Ridge, TN) and EPA's WFTS (Corvallis, OR). The DOC values in these waters ranged from 1.1 to 2.5 mg/L.

For tests conducted in surface waters, we do not recommend the use of a default DOC value because of the large variability of DOC observed. Rather, a reliable database such as USGS NASQAN (as described above) should be searched for DOC measurements. If a database such as NASQAN is consulted, only those DOC measurements closest to the time of the study should be considered as surrogate values. In general, these DOC concentrations should not differ by more than a factor of 1.25. If DOC measurements for the surface water cannot be obtained from a reliable source, then the toxicity test should not be included in Table 1 for BLM normalization.

2.4 *DOC in Lake Superior Water*

Lake Superior water has been used in a number of acute and chronic toxicity studies included in the Aquatic Life Criteria for Copper (U.S. EPA 1998b). Dissolved organic matter (DOM) in Lake Superior is assumed to be anywhere from 1 to 3 mg/L (Russ Erickson, U.S. EPA-Duluth, personal communication; McGeer et al. 2000). This value is expected to be at least 90 percent of TOC (or 2 mg/L) (see Spehar and Fiandt 1986). A default value based on recent measurements is needed for DOC in Lake Superior water.

Recommendation: Recent measurements of TOC in Lake Superior dilution water are in Appendix D-3 (Greg Lien, U.S. EPA-Duluth, personal communication). The geometric mean concentration of TOC in Lake Superior dilution water from multiple measurements is 1.27 mg/L. Given the recommendation in Section 2.3, the recommended DOC for Lake Superior dilution water is 1.1 mg/L (1.27 mg/L × 0.88).

2.5 *Applying Water Chemistry Data to Lake Superior Water*

The ionic composition included in the Table 1 spreadsheet for Lake Superior water is based on concentrations converted from values reported in Erickson et al. (1996b): Ca at 0.68 meq/L = 13.6 mg/L; Mg at 0.24 meq/L = 2.9 mg/L; Na at 0.065 meq/L = 1.5 mg/L; K at 0.015 meq/L = 0.59 mg/L; SO_4 at 0.070 meq/L = 3.4 mg/L; Cl at 0.035 meq/L = 1.2 mg/L; and alkalinity at 0.85 meq/L = 43 mg/L. The concentrations for most of these parameters were also reported in Biesinger and Christensen (1972) and approximate those listed above. Should the Erickson et al. (1996b) data be applied to all Lake Superior studies, or is there a stronger rationale for applying the Biesinger and Christensen (1972) data to the older studies?

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Recommendation: We recommend applying the mean of the Erickson et al. (1996b) citation and Biesinger and Christensen (1972) water chemistry data to all Lake Superior studies prior to 1987, when the results were initially reported. After 1987, we recommend use of the Erickson et al. (1996b) water chemistry data alone (Table 4). For each test, Ca and Mg concentrations should be estimated using Equations 1 and 2, the Ca:Mg ratios given below, and the measured hardness of the test water (Section 2.1). Ions other than K should be scaled according to the measured test hardness, also discussed in Section 2.1.

Table 4. Recommended Spreadsheet Addition for Lake Superior Dilution Water

			Specific Ions (mg/L)						
Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Pre-1987[a]	46	42	13.6	3.0	2.75	1.3	0.57	1.2	3.4
Post-1987[b]	46	43	13.6	2.9	2.84	1.5	0.59	1.2	3.4

[a] Mean of the Erickson et al. (1996b) and Biesinger and Christensen (1972) water chemistry data
[b] Erickson et al. (1996b) water chemistry data alone

2.6 *Predicting Ionic Composition of WFTS Well Water*

The following studies seem were conducted at EPA's WFTS using well water: Andros and Garton (1980), Chapman (1975, 1978), Chapman and Stevens (1978), Lorz and McPherson (1976), Nebeker et al. (1984a, 1986a, b), and Seim et al. (1984). Among these studies, however, there is a wide range of hardness values (20-100 mg/L), and the ionic composition of the water was not always reported.

The large variation in WFTS well water hardness, and consequently, ionic composition, is due to seasonal variability (Samuelson 1976). The TOC content of this water has been reported to be 1.1 mg/L (McCrady and Chapman 1979), of which 100 percent is expected to be dissolved. A general strategy is needed to predict the ionic composition of WFTS well water based on measured water hardness.

Recommendation: The well feeding the WFTS is susceptible to influx from ground water during rain events in late fall and winter (November through March or April). During this period the water
hardness can reach measured levels as high as 100 mg/L $CaCO_3$. Over the remaining months (particularly from July to November), hardness stabilizes at around 25 to 40 mg/L $CaCO_3$, as do other water quality parameters (Al Nebeker, U.S. EPA Corvallis, personal communication; Samuelson 1976). It is important to note that the high hardness reported for WFTS well water is sporadic, even in the winter.

The recommended strategy for filling the existing gaps in data reported from studies using this well water is to estimate the ion concentrations on the basis of their relationship to the total hardness measured during a particular test. The acceptability of tests conducted using WFTS water depends on the range of hardness values reported, i.e., if the hardness varies widely over the course of a particular test, then perhaps the test should not be used. Regression analyses were performed using measured hardness and ion data for the WFTS well water reported in Samuelson (1976), April 1972

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to April 1974, and supplemented with additional data from Gary Chapman, personal communication (only those data from May 1974 to April 1978; see Appendix D-4). These relationships and the corresponding regression equations are presented in Figures 1 through 6 (found at the end of this report). Major ion concentrations for WFTS well water were predicted using the regression equations over a wide range of water hardness (10 to 80 mg/L $CaCO_3$) to determine the accuracy of the procedure (Table 5). The error between predicted and measured ion concentrations is generally within 10 percent for all ions except K, where a default value of 0.7 mg/L was chosen for all hardness levels (actual range is 0.1 to 1.1 mg/L, with the majority of data falling between 0.5 and 0.9 mg/L). The correlation coefficient (R^2) for the relationship between K and water hardness in WFTS well water was only 0.124. Note: BLM predictions of copper gill accumulation and toxicity are relatively insensitive to the concentration of K, so errors in its estimation should not appreciably affect model predictions. The following regression equations were used to generate the example data provided in Table 5:

$$[Ca] = 0.3085 + (\text{measured hardness} * 0.2738)$$
$$[Mg] = 0.5429 + (\text{measured hardness} * 0.0573)$$
$$[Na] = 3.3029 + (\text{measured hardness} * 0.0713)$$
$$[Cl] = 2.7842 + (\text{measured hardness} * 0.1278)$$
$$[SO_4] = -3.043 + (\text{measured hardness} * 0.2816)$$

Lorz and McPherson (1976) and the Seim et al. (1984) tests were not run in WFTS well water, but in water from different wells along the Willamette River. Water chemistry appears to be less variable for these wells (Harold Lorz and Wayne Seim, personal communication). The following additional water chemistry information for the two well water types used in these studies was provided by the respective authors in January 2001.

Many of the studies conducted by Chapman used reverse osmosis treatment to maintain a blended water supply that was of essentially constant ion content throughout the tests. All the test data from Chapman appear to be acceptable; the only test complicated by fluctuating hardness was the 22-month chronic zinc test with sockeye salmon, and that test produced only a NOEC.

Table 5. Predicted Ion Concentrations in WFTS Well Water Based on Measured Hardness

Total Hardness (Mean Measured value) mg/L $CaCO_3$	Predicted Ion Concentrations (mg/L)					
	Ca	Mg	Na	Cl	SO_4	Default[a] K
15.00	4.42	1.40	4.10	4.70	1.18	0.70
20.00	5.78	1.69	4.46	5.34	2.59	0.70
25.00	7.15	1.98	4.82	5.98	4.00	0.70
30.00	8.52	2.26	5.17	6.62	5.41	0.70
35.00	9.89	2.55	5.53	7.26	6.81	0.70
40.00	11.26	2.83	5.88	7.90	8.22	0.70
45.00	12.63	3.12	6.24	8.54	9.63	0.70
50.00	14.00	3.41	6.60	9.17	11.04	0.70
55.00	15.37	3.69	6.95	9.81	12.45	0.70
60.00	16.74	3.98	7.31	10.45	13.85	0.70
65.00	18.11	4.27	7.67	11.09	15.26	0.70

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70.00	19.47	4.55	8.02	11.73	16.67	0.70
75.00	20.84	4.84	8.38	12.37	18.08	0.70
80.00	22.21	5.13	8.74	13.01	19.49	0.70

[a] Value not corrected. Assume default value of 0.70 mg/L.

Recommended Spreadsheet Addition for Oregon Well Water.

	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)			Specific Ions[a] (mg/L)						
Applied to:			pH	DOC	Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Lorz and McPherson 1976	95	66	6.8-7.9	1.6[B]	19	12	1.0	7.6	1.0	7.0	12
Seim et al. 1984	120	126	7.7	1.6[B]	34	8.6	2.4	15	0.7	5.0	2.3

[a] Specific ion values were obtained through personal communication with the primary authors; hardness, alkalinity, and pH values are as reported in the article. The Ca:Mg ratios were calculated on the basis of data provided by authors, then Ca and Mg values used were back-calculated on the basis of these ratios and the measured test hardness (see Equations 1 and 2).
[b] Suggested default value for untreated well water (see Section 2.3).

2.7 *Data for Measurement of Blacksburg/New River Water*

A substantial amount of acute copper toxicity data to various freshwater organisms is reported using dechlorinated City of Blacksburg, VA, tap water. These include studies by Belanger et al. (1989), Cairns et al. (1981), Hartwell et al. (1989), and Thompson et al. (1980). Hardness, alkalinity, and pH values are reported for City of Blacksburg water in all of these studies, but the ionic compositional data are not. This information is required to obtain BLM-normalized LC50s for these data.

Recommendation: According to Don Cherry (personal communication), tests conducted at Virginia Polytechnic Institute and State University used City of Blacksburg, VA, tap water, which is drawn from the nearby New River. Don Cherry collected a sample of New River water for analysis under Work Assignment 1-20. The results of the analysis are provided in Appendix D-5. The sample was of untreated natural water prior to any treatment by the City of Blacksburg. Values for treated New River water (city) were provided by Jerry Higgins, Water Superintendent, City of Blacksburg. Table 6 summarizes the measured values for New River and City of Blacksburg dechlorinated tap water.

Historically, hardness and alkalinity vary substantially in dechlorinated City of Blacksburg tap water and in raw New River water (Table 6). Some of this difference may be attributed to seasonal effects. For example, strong seasonal influence was observed in both well water (influenced by surface water, i.e., WFTS well water; see Section 2.6) and a natural surface water (St. Louis River, MN; refer ahead to Section 2.19). Previously, we plotted ion concentrations against hardness for each of these two water types (Figures 1 through 6 and Appendix D-6). The relationships were good in almost all cases (positive, R^2 = 0.5 to 0.9), and the resultant regression equations were used to scale ion concentrations according to reported water hardness. Incomplete datasets, however, preclude the use

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of the same approach for City of Blacksburg tap and raw New River water. Instead, we recommend using the ion and hardness values from the City of Blacksburg water sample and USGS NASQAN ion data, respectively (Table 6), to generate surrogate ion values for the respective waters that were not reported in the previous studies (indicated by the shaded area in Table 6). The operation is simply to multiply ion concentrations for the "acquired data" by the ratio of hardness values in City of Blacksburg and NASQAN water and the corresponding test waters as was done in Section 2.1. We used the NASQAN ion data as the basis for scaling the raw New River water ion estimates because NASQAN represents data collected over several representative years, including the years in the timeframe in which the studies of interest were initiated and completed. The exception was with DOC. We felt that the DOC value obtained from the sample of New River water collected in August 2000 would be more representative than the few values generated from NASQAN (all pre-1980).

2.8 *Cu Concentrations and Alkalinity*

The methods sections of both Belanger and Cherry (1990) and Belanger et al. (1989) state that total and dissolved Cu were measured, but it is not clear whether the reported LC50s are based on total or dissolved copper concentration. Also, in Belanger and Cherry (1990), pH was adjusted with sodium hydroxide (NaOH) or nitric acid (HNO_3), but only nominal pHs were reported. Alkalinity and hardness after pH adjustment were not reported. Can alkalinity be adjusted for these tests?

Recommendation: The concentration Cu in algae is reported on a total metal basis in Belanger et al. (1989) and Belanger and Cherry (1990). The Cu in water is reported on an acid-soluble basis. The acid-soluble concentration of Cu in water was used to derive the LC50. For all intents and purposes, acid-soluble Cu can be considered as dissolved Cu because the acidification of the filtrate after filtration is probably sufficient to obtain most of the Cu associated with colloidal material. Normally a digestion procedure is required to convert all Cu to the dissolved form. If the sample had not been filtered, it would not have been acceptable because it could have been elevated by dissolution of particulate copper.

The pH levels achieved in the batch culture pH tests in Belanger and Cherry (1990) were reported as 6.15, 8.02, and 8.95. Given the proximity of these values to the desired target pH values of 6, 8, and 9, respectively, it would appear that the researchers were able to closely approximate the nominal pH levels, including those selected for the acute heavy metal tests (also pH 6, 8, and 9, respectively). Assuming that the target pH values of 6, 8, and 9 were achieved in the acute tests, adjustment with NaOH and HNO_3 would have affected alkalinity, but probably not hardness or the major anion and cation concentrations, except possibly Na. The contribution to Na by the addition of NaOH was probably small, so no further adjustment would be necessary.

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Table 6. Comparison of Values for Untreated (Natural) and Treated (Dechlorinated City of Blacksburg, VA) New River Water

Source	Water Type	pH	Total Hardness (mg/L $CaCO_3$)	Total Alkalinity (mg/L $CaCO_3$)	Specific Ions (mg/L)							Ca:Mg ratio	DOC (mg/L)
					Ca	Mg	Na	K	Cl	SO_4	NO_3		
Acquired Data													
City of Blacksburg, VA[a]	City	8.5	44	39	-	-	9.3	-	33	45	-	-	1.5
Cherry 2000 (08/00)[b]	New R.	8.0	-	52	15	0.6	6.6	2.0	6.1	9.8	0.7		2
NASQAN[c]	New R.	-	61	-	15	5.8	3.4	1.6	4.0	13	0.8	1.6	5.4
Values To Be Applied to Table 1 Toxicity Tests[d]													
Belanger et al. 1989	City	7.7	45	40	11	4.2	9.5	1.6	34	46	-	1.6	1.5
Hartwell et al. 1989	City	7.5	72	43	18	6.8	15	1.6	54	74	-	1.6	1.5
Cairns et al. 1981	City	7.0	26	27	6.4	2.4	5.5	1.6	19	26	-	1.6	1.5
Thompson et al. 1980	City	7.2	40	28	9.9	3.8	8.5	1.6	30	41	-	1.6	1.5
Belanger et al. 1989	New R.	8.2	94	70	23	8.8	5.2	1.6	6.2	20	-	1.6	2
Belanger and Cherry 1990	New R.	6, 8, 9	98	74	24	9.1	5.4	1.6	6.4	21	-	1.6	2

[a] Data provided by Gerard (Jerry) Higgins of Blacksburg-Christianburg VPI Water Authority, Blacksburg, VA. Values presented are from a grab sample collected January 31, 2000. Organic carbon (originally measured and reported as TOC) is assumed to be 100 percent dissolved.

[b] Sample provided by Don Cherry, Virginia Polytechnic Institute and State University, Blacksburg, VA, and analyzed by Environmental Health Laboratories, South Bend, IN. Values presented are from a grab sample collected August 2000. The value for Mg of 0.6 mg/L appears to be a reporting error, and was not used for subsequent calculations of total hardness or scaling of ion values.

[c] Data obtained from USGS NASQAN database. Values presented are means of 213 samples, except for DOC, which is a mean of seven samples, collected and analyzed from January 1973 to August 1995.

[d] Shaded area indicates mean values estimated from previously (NASQAN) or recently measured (Cherry 2000 or City of Blacksburg; nonadjusted) ion values. All values have been rounded to two significant figures. Shaded values were derived according to text above using the approach outlined in Section 2.1.

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Using a nomograph found in Faust and Aly (1981), alkalinity at pH 6 should be approximately 33 percent of the alkalinity at pH 8, and alkalinity at pH 9 should be 5 percent higher than the alkalinity at pH 8 (Table 7). Therefore, the values for alkalinity in Table 7 should be used for the acute toxicity tests presented in Belanger and Cherry (1990) in this case. For other analyses, different adjustment factors may be appropriate, based on other interpretations from the Faust and Aly nomograph or other methods as well. Appropriate consideration should also be given to the test system equilibration with the atmosphere.

Table 7. Estimated Alkalinity in Natural Surface Water Based on pH

Source Water	Nominal pH	Alkalinity (mg/L $CaCO_3$)
New River	6	24.5
	8.1	74.2[a]
	9	77.9
Clinch River	6	47.6
	8.3	144[a]
	9	152
Amy Bayou	6	40.2
	8.3	122[a]
	9	128

[a] Indicates values reported in text.

2.9 *Calculation of DOC and Humic Acid*

What was the technical approach used to calculate DOC and percent humic acid (HA) for the Winner (1985) toxicity tests?

Recommendation: At a nominal HA concentration of 0.0 mg/L in soft and medium hardness test waters, the DOC is assumed to be that of the ultrapure laboratory water, which is estimated to be 0.3 mg/L (approximately one-half of the recommended default value for DOC in laboratory water; see Section 2.3). At nominal HA concentrations of 0.15, 0.75, and 1.50 mg/L, the DOC is calculated by dividing by a value of 2, based on the assumption in the BLM User's Guide (Di Toro et al. 2000) that the percent carbon in HA is 0.50 (see example below and Table 8). Because the water used to obtain these HA concentrations was ultrapure laboratory water, 0.3 mg carbon/L was added; final rounded values of 0.38, 0.68, and 1.1 are recommended.

Table 8. Estimates of Dissolved Organic Carbon and Percent Humic Acid for the Winner (1985) Toxicity Tests

Humic Acid Added (mg/L)[a]	Calculated DOC (mg/L)	Calculated Percent Humic Acid
0	0.3	10
0.15	0.38	28
0.75	0.68	60
1.5	1.1	74

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[a] As indicated in Table 3 of Winner (1985).

2.10 *Alkalinity of Lake Superior Water*

For the Lind et al. (manuscript) tests conducted in Lake Superior water (adjusted with $CaSO_4$ or $MgSO_4$), is there any way to estimate alkalinity values?

Recommendation: For tests conducted in Lake Superior water, assume an alkalinity of 42 mg/L $CaCO_3$ (see Section 2.5).

2.11 *Availability of LC50s*

The LC50s reported by Collyard et al. (1994) are shown graphically in publication. The LC50s provided in Table 1 are interpolated from the figure. Are the actual measured LC50s available from the authors?

Recommendation: The actual LC50s generated and presented graphically in Collyard et al. (1994) have been archived at U.S. EPA-Duluth, as reported by Gerald Ankley (personal communication, 3 November 2000). These values are not readily available in any other form. The data are acceptable as is on the basis of recommendations in the Guidelines (Stephan et al. 1985). Precedence for the use of values gleaned from graphical data is provided in the 2001 Update of Ambient Water Quality Criteria for Cadmium (U.S. EPA 2001).

2.12 *Cl and Na Concentrations*

Cl and Na ion concentrations of the tap water used for testing in Rice and Harrison (1983) were derived from the addition of 20 mg/L sodium chloride (NaCl). What are the specific concentrations of the individual ions from the addition of the salt? What concentrations do you suggest using for K and SO_4 in this water?

Recommendation: The Cl content of the tap dilution water used in Rice and Harrison (1983) was reported as having been derived from the addition of 20 mg/L of NaCl. Assuming that the initial Na and Cl concentrations in tap water were essentially zero, the concentrations of these ions can be calculated in the following way:

The molecular weight of NaCl is 58.44 g/mol. The atomic weight of Na is 22.98 mg/L and the atomic weight of Cl is 35.453 mg/L.

The concentration of Na is:

20 mg NaCl/L * 1 mmol NaCl/58.44 mg NaCl = 0.342 mmol NaCl/L.
0.342 mmol NaCl * 1 mmol Na/1 mmol NaCl * 22.98 mg Na/1 mmol Na = 7.86 mg Na/L.

The concentration of Cl is:

20 mg NaCl/L × 1 mmol NaCl/58.44 mg NaCl = 0.342 mmol NaCl/L.

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0.342 mmol NaCl × 1 mmol Na/1 mmol NaCl × 35.453 mg Cl/1 mmol Cl
= 12.12 mg Cl/L.

Given the potentially large dichotomy between the default ion concentrations and measured hardness of the water used in this study, we recommend adjusting the default SO_4 concentration according to measured hardness as in Section 2.1. We do not, however, recommend adjusting the current default value of 1.0 mg/L for K.

2.13 *Calculating DOC in Dilution Water*

The dilution water used in the acute copper toxicity tests with cutthroat trout in Chakoumakos et al. (1979) was a different mix of spring water and de-ionized water for each test. Ca and Mg concentrations were measured and reported for each of the test waters used, but measurements of the other ions were reported only for the undiluted spring water. Based on a percentage dilution, ions other than Ca and Mg were estimated in the following way: hardness was measured in the spring water and in each of the test waters; the proportion of spring water was calculated for each test using these measured hardness values; this proportion was then multiplied by the concentration of, for example, Na in the spring water to get an estimated Na value for each test. TOC in the spring water was 3.3 mg/L. Should the same approach as that used to estimate the other ions be used to calculate DOC, which was only measured in undiluted spring water?

Recommendation: The concentrations of the major cations and anions in the dilution water used by Chakoumakos et al. (1979) were calculated based on the percent dilution of natural spring water with de-ionized water. The same correction can be used to estimate DOC, with the following assumptions. First, the TOC in spring water was 100 percent dissolved. Second, the DOC of de-ionized water was 0.5 mg/L. If these assumptions are acceptable, the DOCs for H/H, M/H, L/H, H/M, M/M, L/M, H/L, M/L, and L/L would be 3.3, 1.5, 0.75, 3.3, 1.7, 0.94, 2.8, 1.5, and 0.87 mg/L, respectively.

2.14 *Ionic Composition of Chehalis River Water*

The ionic composition of Chehalis River, WA, water is needed to fill in existing data gaps used for BLM analysis of acute toxicity reported in Mudge et al. (1993). The publication states, "Water quality data collected during this bioassay program is similar to historical data for Chehalis River (WPPSS 1982) and other Pacific NW streams (Samuelson 1976)." Are data from Samuelson (1976) acceptable for use in approximating these ion concentrations? Furthermore, are there any dissolved or ionic LC50s available other than those reported in the publication?

Recommendation: The following additional water chemistry information for the Chehalis River dilution water used in the studies reported by Mudge et al. (1993) was provided by the author on 20 November 2000. These measurements were made on Chehalis River water at the time of testing. A corresponding value for DOC was obtained from the NASQAN dataset.

Recommended spreadsheet addition for Chehalis River dilution water

		Specific Ions (mg/L)						
Applied to:	DOC (mg/L)	Ca	Mg	Ca:Mg	Na	K	Cl	SO_4

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Mudge et al. 1993	3.2[a]	7.1	2.4	1.8	5.1	0.65	4.5 (May) 4.2 (Jun) 3.1 (Sep)	4.0 (May) 3.5 (May-Jul) 2.3 (Sep)

[a] Value from the USGS NASQAN dataset, 1980-1982, when the tests were conducted.

2.15 *Chemistry of Water in Howarth and Sprague (1978)*

What is the ionic composition and organic carbon content of test waters used in Howarth and Sprague (1978)? The waters used for testing were various mixes of University of Guelph (Guelph, ON, Canada) well water and de-ionized well water. The de-ionized well water was reported as "having retained its original chloride content (22 mg/l)," but the values for the other major anion and cation concentrations were not reported. Furthermore, the equation provided for calculating alkalinity from pH and hardness (supposedly accounting for 96.7 percent of the variability) appears unreliable. For example, using the equation and a total water hardness of 364 mg/L $CaCO_3$ at pH 9, one obtains an estimated alkalinity value of 341 mg/L $CaCO_3$. In contrast, the measured alkalinity reported in the text for this level of hardness and pH was 263 mg/L $CaCO_3$.

Recommendation: The equation provided in the text of Howarth and Sprague (1978) for calculating alkalinity appears unreliable. The calculated alkalinity does not approximate measured alkalinity within a reasonable degree of accuracy. Values of hardness, pH, and alkalinity in Dixon and Sprague (1981a), which used the same water source in their toxicity tests, give greater evidence of this; i.e., using the measured value of hardness of 374 mg/L $CaCO_3$ and a pH of 7.75, the alkalinity calculated with the equation is 98 mg/L $CaCO_3$. This compares rather poorly with the measured alkalinity of 223 mg/L $CaCO_3$. Instead, alkalinity can be estimated using the nomograph from Faust and Aly (1981) as in Section 2.8.

It is possible to apply the procedure used with the Chakoumakos et al. (1979) data here, i.e., using the ratio of hardness in full-strength well water and de-ionized well water to calculate the dilution of the other major ion concentrations. However, no values are given for Na or K in University of Guelph well water. This study is also complicated by the reverse-osmosis unit used to create the de-ionized well water. In particular, the statement concerning the retention of the original Cl concentration in the de-ionized well water implies an ionic exchange that would also require a cation (to maintain charge balance). The cation involved is unknown. As discussed in a phone conversation with John Sprague on 17 November 2000, and later that day with Scott Howarth (Environment Canada), NaCl may have leached through the RO unit. Assuming that Na and Cl leached through the unit in equivalent proportions, a value of 14 mg/L for Na can be back-calculated from the reported Cl concentration of 22 mg/L.

Default DOC concentrations of 1.6 and 0.5 mg/L were assumed for the well water and de-ionized water used in the tests, respectively (see Section 2.3). The DOC concentrations were adjusted for each particular test water hardness level based on the proportion of well water and de-ionized water used to achieve the desired test hardness level. In the example provided in Table 9, the dilution factor of 0.27, based on the ratio of the average hardness of well water (366 mg/L $CaCO_3$) versus the average hardness of well plus de-ionized well water (100 mg/L $CaCO_3$), was applied to the starting DOC concentrations to achieve an estimate of the DOC concentrations at 100 mg/L $CaCO_3$). Table

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9 shows the results of similar adjustments made for the major anions and cations based on the data reported in Howarth and Sprague (1978).

2.16 *Default Values for Analyte Concentrations*

What value should be used when a specific analyte is not detected at its designated detection limit?

Recommendation: The use of half the detection limit (DL) is most appropriate when the concentration of an analyte is not detected. One-half the DL will closely approximate a replacement value for censored data in a log-normally distributed population that includes several measured values (Berthouex and Brown 1994; Dolan and El-Shaarawi 1991). This way some of the "nondetect" samples will actually be counted as detected.

Table 9. Example Calculations to Estimate Water Chemistry of Tests Conducted at 100 mg/L $CaCO_3$ by Howarth and Sprague (1978) Using a Mixture of University of Guelph Well Water and De-ionized Water

Parameter (units in mg/L)	De-ionized water	Well Water	Example Calculations for Mixture
Hardness	0	366	100 (i.e., 0.27 dilution factor)
Ca	0	77 (from Dixon & Sprague 1981)	21
Mg	0	43 (from Dixon & Sprague 1981)	12
Na	14 (assuming NaCl used for the softening process)	14 (estimated from [Cl])	14
K	0	2.4 (based on personal communication from Dr. Patricia Wright, Univ. of Guelph, Guelph, ON)	0.66
Cl	22 (stated as not having changed from the water softening process)	22	22
SO_4	0	129	35
DOC	0.5 (default value for de-ionized waters)	1.6 (default value for well waters)	0.8
Alkalinity (calculated using ratios as in Section 2.8):			
at pH 6	0[a]	81.5	22
at pH 7	0[a]	205	55
at pH 8	0[a]	250	N/A
at pH 9	0[a]	263	70

[a] Alkalinity in de-ionized well water is assumed to be 0.0 mg/L.

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2.17 *Organic Carbon Content of Samples*

Can any information be obtained on the organic carbon content of the spring water / City of Cincinnati, OH, tap water mixes used in Brungs et al. (1973), Geckler et al. (1976), Horning and Neiheisel (1979), Mount (1968), Mount and Stephan (1969), and Pickering et al. (1977)?

Recommendation: The water used for all tests was a mixture of spring-fed pond water (originating at the Newtown Fish Farm) and carbon-filtered, demineralized Cincinnati tap water. The water was mixed to achieve the desired test hardness level and discharged to a large (several thousand gallon) concrete reservoir that fed the test system. The detention time varied anywhere from 30 to 90 days, depending on the study, which was sufficient to allow the growth of phytoplankton and zooplankton in moderate abundance. No additional information regarding the TOC (DOC) concentration or treatment of this water is available at this time. The recommended organic carbon content of spring/city water mix is currently a conservative 1.6 mg/L, but could be as high as 2.5 mg/L, the highest DOC concentration recorded for a natural surface or well water used for studies included in this report (see Section 2.3). Considering the long retention time, and the fact that the natural water was spring-fed pond water, the more conservative DOC value of 2.5 mg/L is recommended for this water.

2.18 *Additional Water Chemistry Data Needed*

Additional water chemistry data are needed for Bennett et al. (1995) and Richards and Beitinger (1995). In the case of Richards and Beitinger 1995, only the ranges of measured pH, alkalinity, and hardness across all tests were given.

Recommendation: Detailed pH, alkalinity, and hardness values were provided by both Bennett et al. (1995) and Richards and Beitinger (1995) (Appendixes D-7 and D-9, respectively). The studies performed by Bennett et al. were conducted using dechlorinated City of Denton, TX, tap water (from Lake Roy Roberts). The author was not able to provide any additional data regarding the ionic composition of this water; however, based on supplementary data, mean values of pH, alkalinity, and temperature were 8.07 and 89.7 mg/L $CaCO_3$ and 21.4 C, respectively. Richards and Beitinger's studies were conducted using standard reconstituted (hard) water. To estimate the ionic composition of this water, refer to recommendations provided in Section 2.1.

2.19 *Estimating Data for Waters*

Values for DOC, TSS, Ca, Mg, Na, K, SO_4, and Cl are needed for the following natural waters:

Water Body	Reference
American River, California – sand filtered	Finlayson and Verrue 1982
Clinch River – 11µm filtered	Belanger et al. 1989
	Belanger and Cherry 1990
Amy Bayou	Belanger and Cherry 1990
Blaine Creek, Kentucky – 1.6 µm filtered	Dobbs et al. 1994
S. Kawishiwi	Lind et al. manuscript
St. Louis River	Lind et al. manuscript
Lake One	Lind et al. manuscript

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Colby Lake	Lind et al. manuscript
Cloquet Lake	Lind et al. manuscript
Greenwood Lake	Lind et al. manuscript
Embarrass River	Lind et al. manuscript
Green Duwamish River	Buckley 1983
Chehalis River	Mudge et al. 1993
Pinto Creek, AZ	Lewis 1978
Naugatuck River	Carlson et al. 1986

Recommendation: On the following pages are data (current and/or historical, presented as arithmetic means) from selected natural waters that were retrieved from NASQAN, STORET, or a secondary source (as indicated). As mentioned earlier (see Sections 2.6 and 2.7), given the reasonably good correlation between most of the major anion and cations (except K) and water hardness in natural surface and well waters, we recommend using the ion and hardness values retrieved from these various sources to estimate the ion concentrations in the test water used in the previous studies. The operation, again, is simply to multiply the ion concentrations listed below by the ratio of hardness values presented below and the earlier test waters.

Note that additional data were not available for Blaine Creek, KY, or Pinto Creek, AZ, and although additional data were obtained from the City of Sacramento, CA, regarding the American River, the default DOC value (8.2 mg/L) for California streams may be artificially high on the basis of reported values of DOC in the Sacramento River (1.2 mg C/L), of which the American River is a tributary. Therefore, the data from Finlayson and Verrue (1982) have been relegated to "other data." Likewise, Amy Bayou is a highly contaminated and dynamic system (Don Cherry, personal communication), and BLM normalization is not recommended for these data. A large annual variability in water quality also excludes the use of surrogate STORET data for the Embarrass River, MN, for BLM analysis (Lind et al. manuscript).

American River, CA (Appendix C-9). Source: Ron Myers, City of Sacramento, CA, Water Quality Laboratory

	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)			Specific Ions (mg/L)						
Applied to:			pH	DOC	Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Finlayson and Verrue 1982	21	22	7.5	-[a]	5.6	1.8	2.0	3.0	-	2.6	3.8

[a] DOC and K data for the American River were not available.

Clinch River, VA (Appendix D-5): Source: Don Cherry, VA Poly. Inst. & State Univ., Blacksburg,VA

	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)			Specific Ions (mg/L)						
Applied to:			pH	DOC	Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Belanger et al. 1989, and Belanger and Cherry 1990	150	150	8.3	2.3	42	11	2.3	12	2.4	9.2	19

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S. Kawishiwi River, MN (Appendix C-10). Source: STORET

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L) Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Lind et al. manuscript	24	18	6.6	-[a]	5.6	2.4	1.5	1.3	0.5	1.0	4.9

[a] DOC data for this river were not available. TOC measurements reported by Lind et al. (manuscript) should be adjusted based on a mean DOC:TOC ratio (0.8721) in Minnesota streams (see Section 2.3 and Appendix D-2).

Lake One, MN (Appendix C-10). Source: STORET

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L) Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Lind et al. manuscript	10	15	6.7	-[a]	2.8	0.7	1.8	0.1	0.3	0.2	4.2

[a] DOC data for this lake were not available. TOC measurements reported by Lind et al. (manuscript) should be adjusted based on a mean DOC:TOC ratio (0.9677) in Minnesota lakes (see Section 2.3 and Appendix D-2).

Colby Lake, MN (Appendix C-10). Source: STORET

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L) Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Lind et al. manuscript	56	33	7.1	-[a]	13.3	5.4	1.6	4.0	1.4	7.3	23

[a] DOC data for this lake were not available. TOC measurements reported by Lind et al. (manuscript) should be adjusted based on a mean DOC:TOC ratio (0.9677) in Minnesota lakes (see Section 2.3 and Appendix D-2).

Cloquet Lake, MN (Appendix C-10). Source: STORET

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L) Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Lind et al. manuscript	27	21	7.2	-[a]	6.9	2.3	1.4	1.9[b]	1.4[c]	1.2	5.6

[a] DOC data for this lake were not available. TOC measurements reported by Lind et al. (manuscript) should be adjusted based on a mean DOC:TOC ratio (0.9677) in Minnesota lakes (see Section 2.3 and Appendix D-2).
[b] Na data for this lake were not available. The Na value given here is based on data for Colby Lake, MN, and was scaled on the basis of hardness (see Section 2.1): Na = 4.0 mg Na/L * (27 mg/L $CaCO_3$ / 56 mg/L $CaCO_3$).
[c] K data for this lake were not available. The K value given here is from data for Colby Lake, MN. This value was not scaled on the basis of hardness (see discussion of K-hardness relationship in Sections 2.1 and 2.7).

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Greenwood Lake (Appendix C-10), MN. Source: STORET

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L) Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Lind et al. manuscript	17	11	6.4	-[a]	4	1.8	2.4	0.2[b]	0.3[c]	1.7	7.6

[a] DOC data for this lake were not available. TOC measurements reported by Lind et al. (manuscript) should be adjusted based on a mean DOC:TOC ratio (0.9677) in Minnesota lakes (see Section 2.3 and Appendix D-2).
[b] Na data for this lake were not available. The Na value given here is based on data for Lake One, MN, and was scaled based on hardness: Na = 0.1 mg Na/L * (17 mg/L $CaCO_3$ / 10 mg/L $CaCO_3$).
[c] K data for this lake were not available. The K value given here is from data for Lake One, MN. This value was not scaled on the basis of hardness (see discussion of K-hardness relationship in Sections 2.1 and 2.7).

St. Louis River, MN (Appendix C-6). Source: NASQAN

Note: for the St. Louis River dataset (1973 to 1993), a question arose as to which data would be most representative for estimating the ion concentrations in St. Louis River water for BLM analysis. In order to determine this, the relationship between hardness and Na ion for all 20 years was plotted. Linear regression was used to fit the data. Most data showed very high coefficient correlation (0.8-0.94). For each of these 20 regression lines, the slope and intercept coefficients were plotted on separate graphs as functions of time (Figures 7 and 8). The following conclusions were derived:

- A significant event occurred in 1976 and perhaps 1977 that affected the water balance of the St. Louis River. A wastewater treatment plant was built, which substantially improved the water quality (Jesse Anderson, Minn. Pollution Control Bd., personal communication).

- For the 1979-1993 period, hardness and ion concentrations did not change significantly as absolute values. Therefore, general equations (which could be used to extrapolate water chemistry data till year 2000 and before 1979) can be obtained connecting hardness, alkalinity, pH, and the major ion concentrations.

- The exponential growth in the values between 1973 and 1979 shows that averaging values on seasonal and annual basis is not appropriate. The constant values for the slopes and intercepts for 1979-1993 allow mean monthly and annual interpretation of the data.

- The regression equations derived for 1977 alone are recommended to predict ion concentrations based on the water hardness levels measured in the Lind et al. (manuscript). The equations derived for each ion are provided in Appendix D-6 with the corresponding figures.

Green-Duwamish River, WA. Source: James Buckley

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L) Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Buckley 1983	33	29	7.2	3.2[a]	8.9	2.8	2.0	7.5	1.2	7.0	6.3

[a] Value given as TOC. DOC data for this river were not available. TOC measurements reported by Buckley et al. (1983) should be adjusted on the basis of a mean DOC:TOC ratio (0.7803) in Washington streams (see Section 2.3 and Appendix C-2).

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Naugatuck River, WA. Source: STORET

Applied to:	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	pH	DOC	Specific Ions (mg/L) Ca	Mg	Ca:Mg	Na	K	Cl	SO_4
Carlson et al. 1986	39	20	6.4	3.7[a]	9.9	3.3	1.9	9.9	2.3	-	22

[a] Value given as TOC. DOC data for this river were not available. TOC measurements reported by Carlson et al. (1986) should be adjusted on the basis of a mean DOC:TOC ratio (0.8711) in Connecticut streams (see Section 2.3 and Appendix C-2).

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Figure 1. Relationship between Ca and hardness in WFTS well water

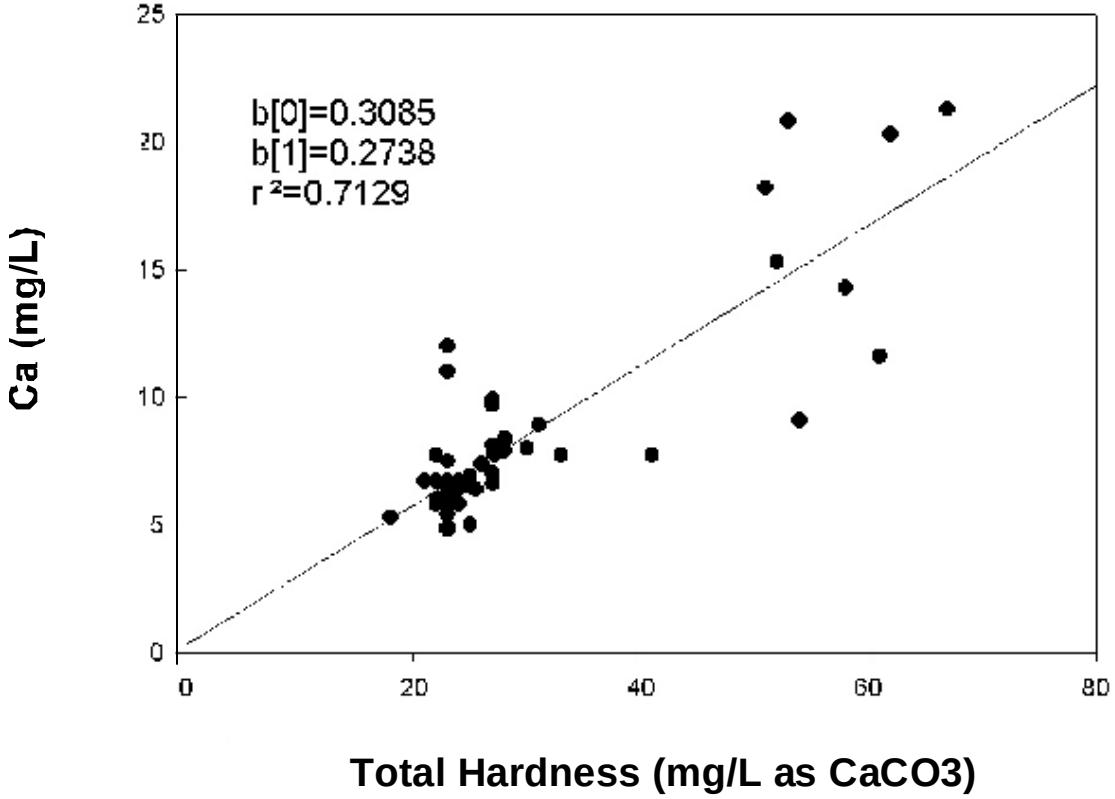


Figure 2. Relationship between Mg and hardness in WFTS well water.

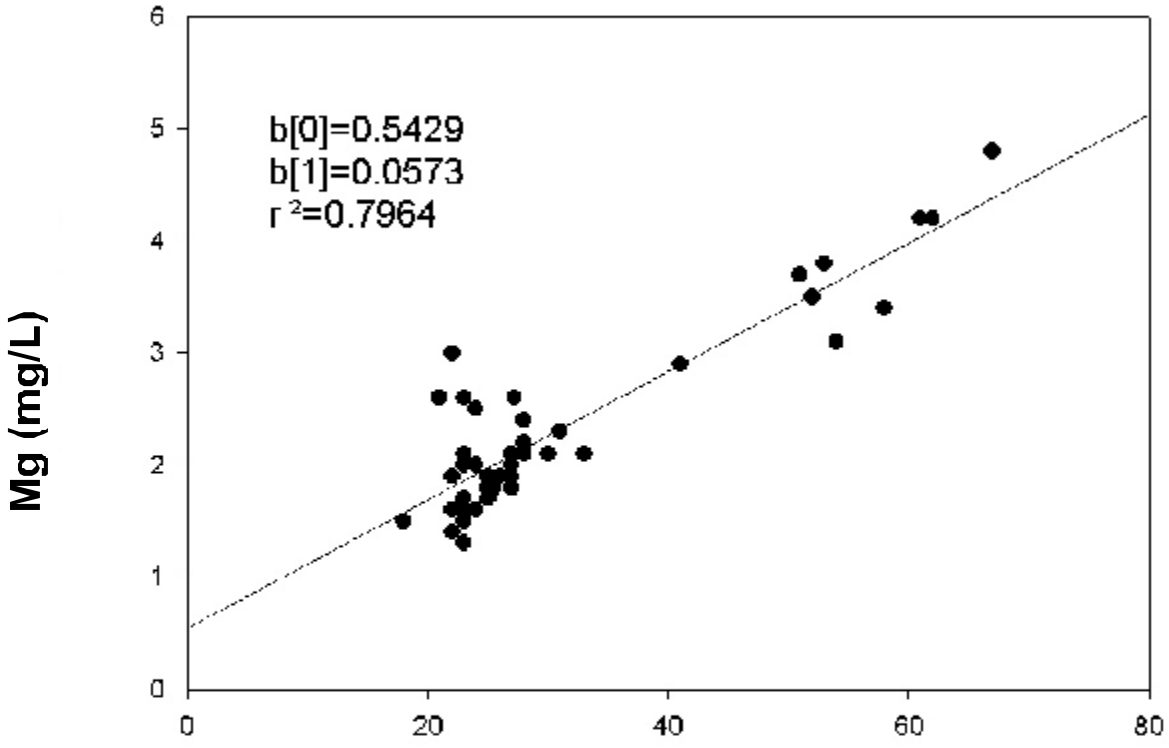
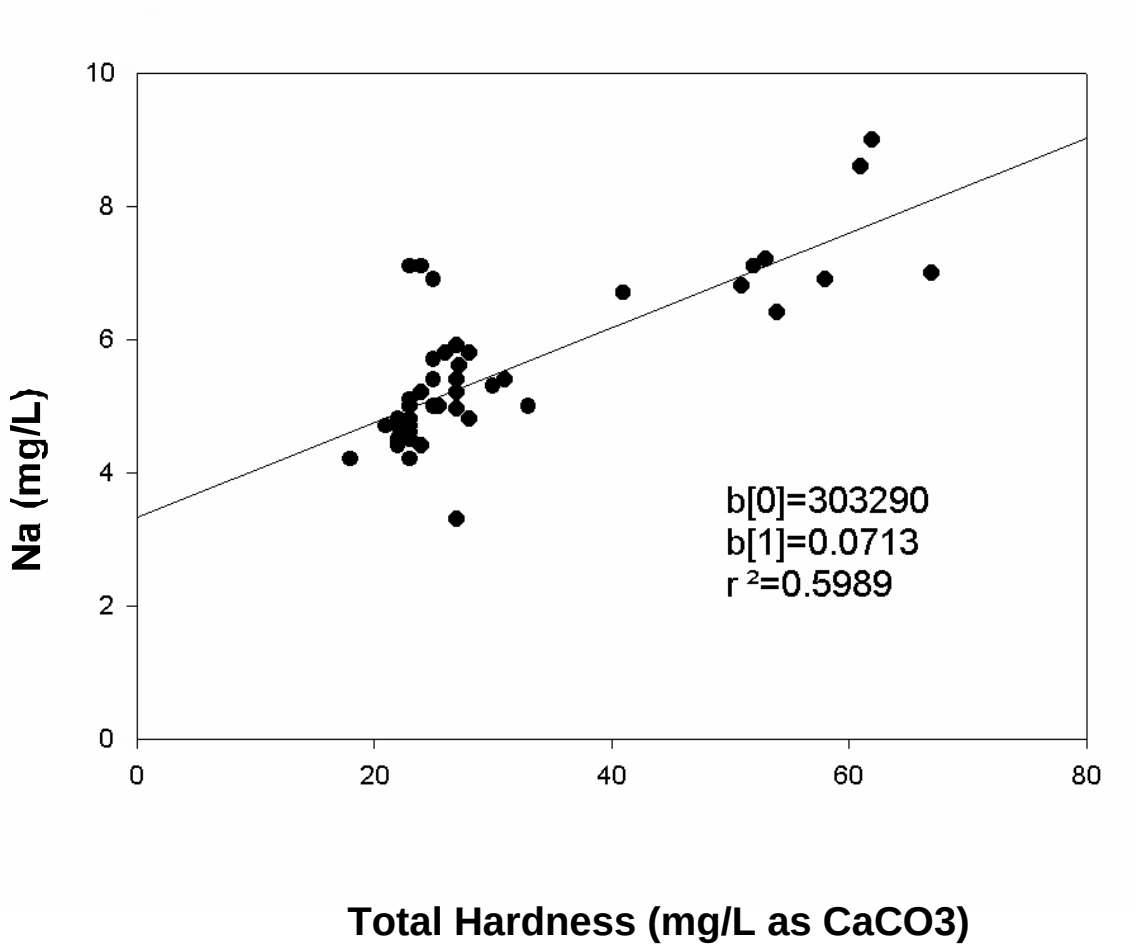


Figure 3. Relationship between Na and hardness in WFTS well water.



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Figure 4. Relationship between K and hardness in WFTS well water

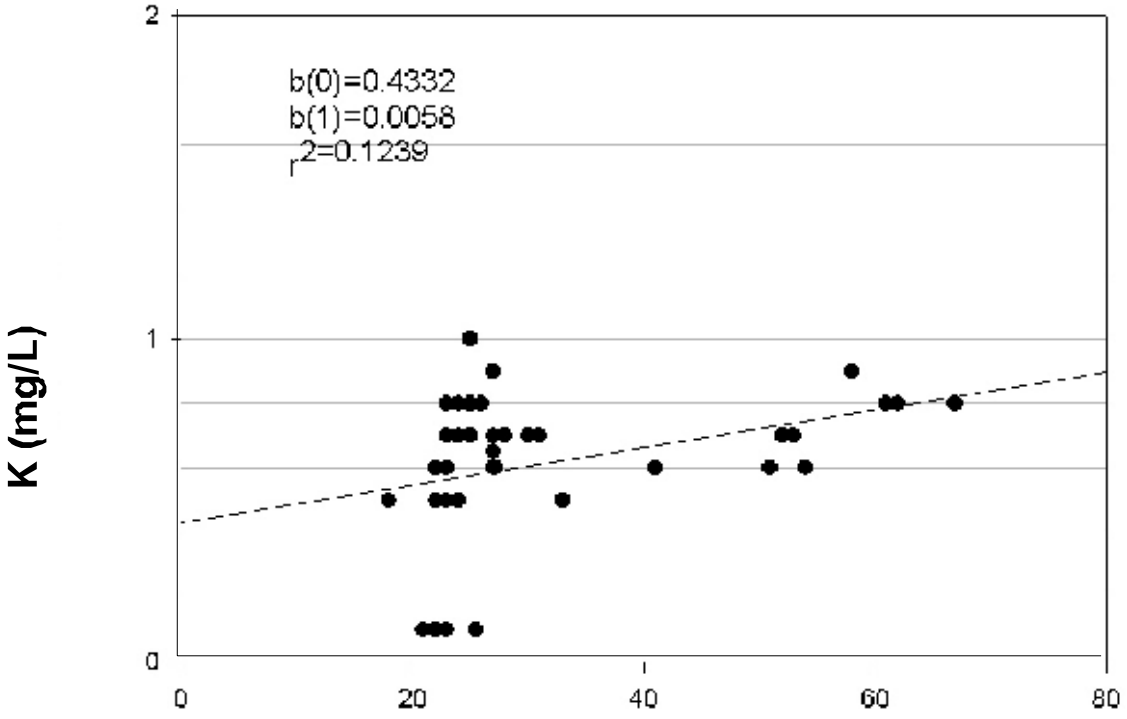


Figure 5. Relationship between Cl and hardness in WFTS well water.

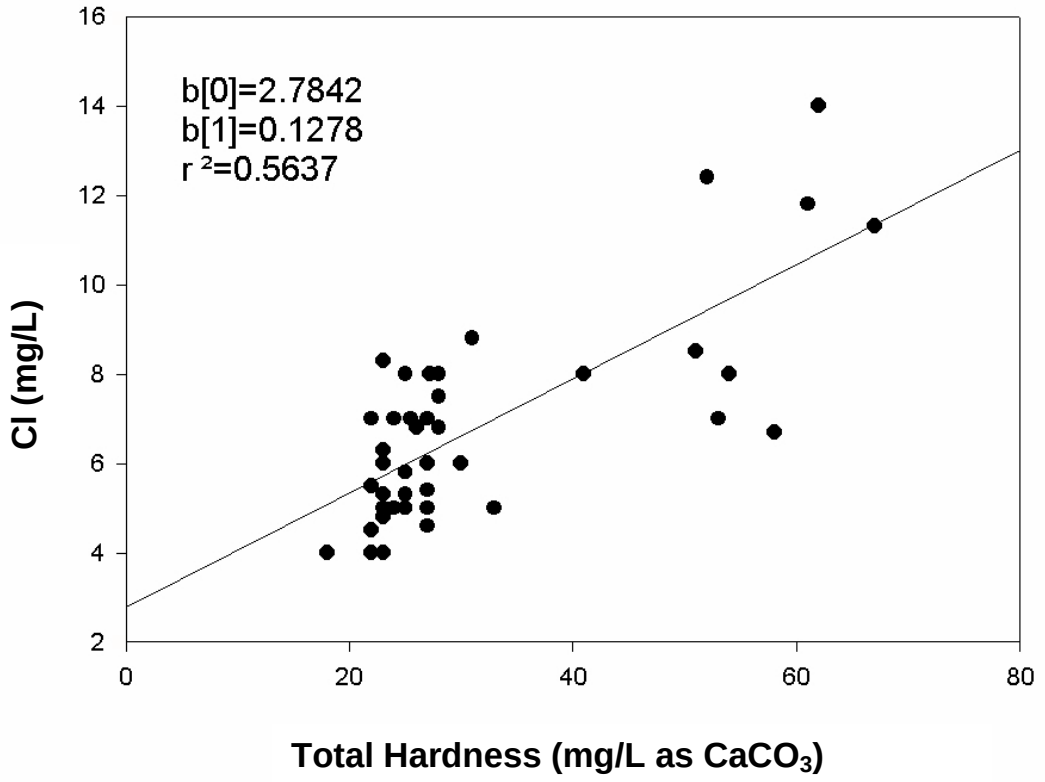


Figure 6. Relationship between SO_4 and hardness in WFTS well water.

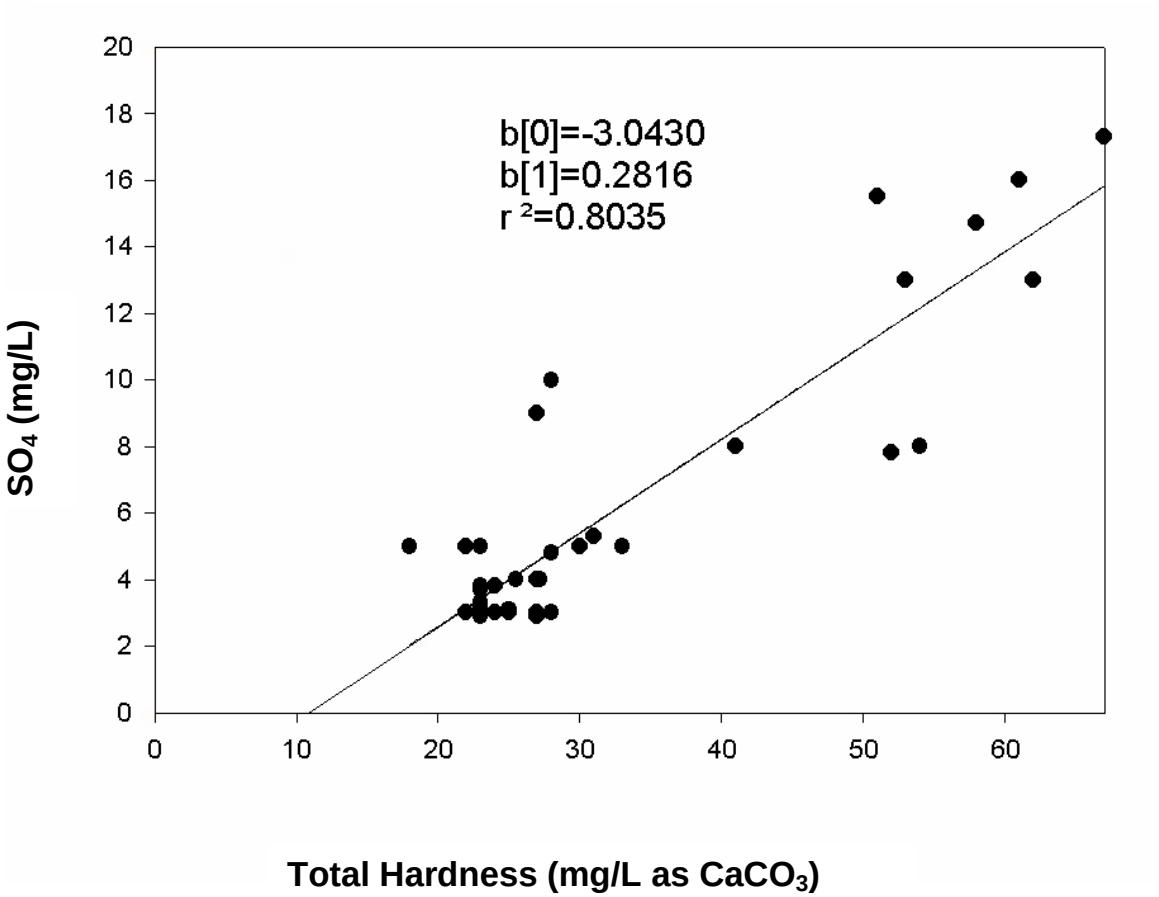


Figure 7. Slopes of the regression equations derived for Na concentration in St. Louis River, MN, water versus water hardness from 1973 to 1993.

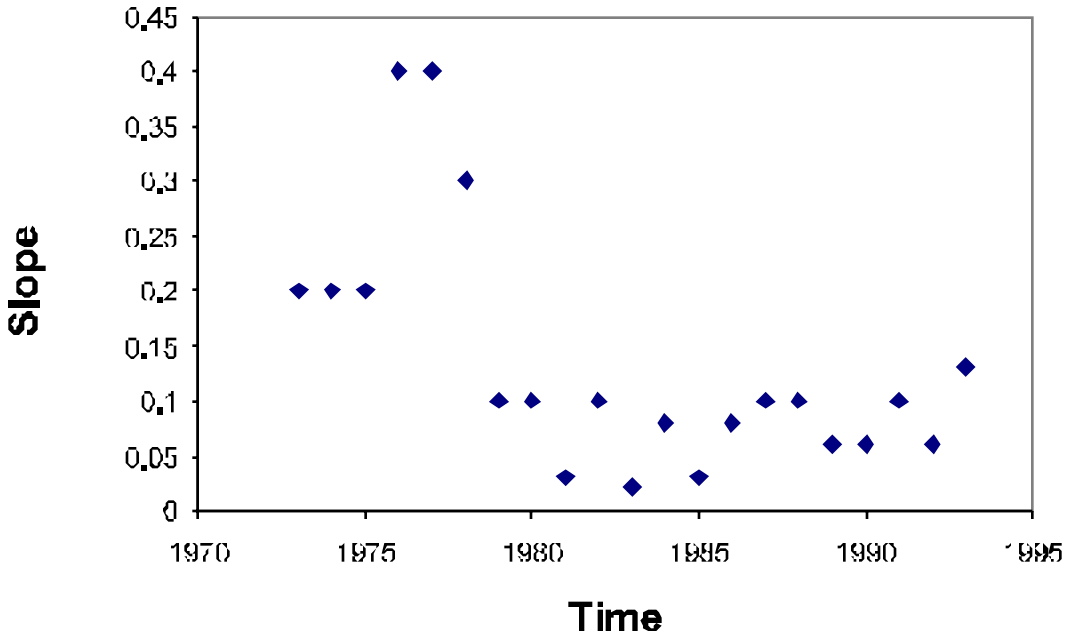
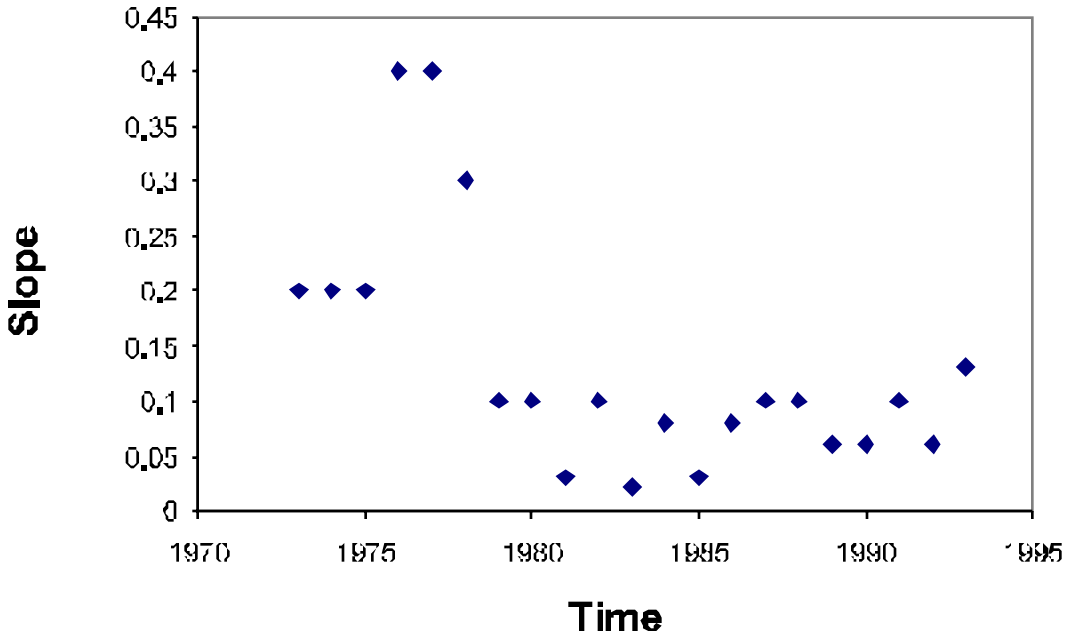


Figure 8. Intercepts of the regression equations derived for Na concentration in St. Louis River, MN water versus water hardness from 1973 to 1993.



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Appendix C-1. Calculations for Ionic Composition of Standard Laboratory-Reconstituted Water

Molecular Weights	Atomic Weights
$NaHCO_3$ = 84.03	Na = 22.98
$CaSO_4.2H_2O$ = 172.12	Ca = 40.08
$MgSO_4$= 120.37	Mg = 24.31
KCl = 74.55	K = 39.10
SO_4 = 96.06	Cl = 35.45

Example Calculation

[Na] in very soft water:
12 mg $NaHCO_3$/L x 1 mmol $NaHCO_3$/84.03 mg $NaHCO_3$ = 0.143 mmol $NaHCO_3$/L.
0.143 mmol $NaHCO_3$/L x (1 mmol Na/1 mmol $NaHCO_3$) x 22.98 mg Na/1 mmol Na = 3.3 mg Na/L.

[Ca] in very soft water:
7.5 mg $CaSO_4$.2H2O/L x 1 mmol $CaSO_4.2H_2O$/172.12 mg $CaSO_4.2H_2O$ = 0.044 mmol $CaSO_4.2H_2O$/L.
0.044 mmol $CaSO_4.2H_2O$/L x (1 mmol Ca/1 mmol $CaSO_4.2H_2O$) x 40.08 mg Ca/1 mmol Ca = 1.8 mg Ca/L.

[Mg] in very soft water:
7.5 mg $MgSO_4$/L x 1 mmol $MgSO_4$/120.37 mg $MgSO_4$ = 0.062 mmol $MgSO_4$/L.
0.062 mmol $MgSO_4$/L x (1 mmol Mg/1 mmol $MgSO_4$) x 24.31 mg Mg/1 mmol Mg = 1.5 mg Mg/L.

[K] in very soft water:
0.5 mg KCl/L x 1 mmol KCl/74.55 mg KCl = 0.0067 mmol KCl/L.
0.0067 mmol KCl/L x (1 mmol K/1 mmolKCl) x 39.102 mg K/1 mmol K = 0.26 mg K/L.

[Cl] in very soft water:
0.5 mg KCl/L x 1 mmol KCl/74.55 mg KCl = 0.0067 mmol KCl/L.
0.0067 mmol KCl/L x (1 mmol Cl/1 mmolKCl) x 35.453 mg Cl/1 mmol K = 0.24 mg Cl/L.

[SO_4] in very soft water:
7.5 mg $CaSO_4.2H_2O$/L x 1 mmol $CaSO_4.2H_2O$/172.12 mg $CaSO_4.2H_2O$ = 0.044 mmol $CaSO_4.2H_2O$/L.
0.044 mmol $CaSO_4.2H_2O$/L x (1 mmol SO_4/1 mmol $CaSO_4.2H_2O$) x 96.064 mg Ca/1 mmol Ca = 4.2 mg Ca/L.

[SO_4] in very soft water:
7.5 mg $MgSO_4$/L x 1 mmol $MgSO_4$/120.37 mg $MgSO_4$ = 0.062 mmol $MgSO_4$/L.
0.062 mmol $MgSO_4$/L x (1 mmol SO_4/1 mmol $MgSO_4$) x 96.064 mg Mg/1 mmol Mg = 6.0 mg Mg/L.

Total SO_4 = 10.2 mg/L

Conversion Factors to calculate water hardness (as $CaCO_3$) from [Ca] and [Mg]:

[Ca] x 2.497
[Mg] x 4.116

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Appendix C-2. Dissolved, Particulate, and Estimated Total Organic Carbon for Streams and Lakes by State (as presented in EPA Document #822-B-98-005)

	Streams				Lakes			
State	POC	DOC	Est. TOC	Est. DOC:TOC	POC	DOC	Est. TOC	Est. DOC:TOC
AK	0.54	4.6	5.14	89.49	0.53	6.4	6.93	92.35
AL	0.72	3.4	4.12	82.52	---	---	---	---
AR	0.8	7.2	8	90.00	0.4	2.7	3.1	87.10
AZ	0.71	5.2	5.91	87.99	0.52	4.2	4.72	88.98
CA	1.13	8.2	9.33	87.89	0.32	2.3	2.62	87.79
CO	1.29	8.6	9.89	86.96	---	---	---	---
CT	0.71	4.8	5.51	87.11	---	---	---	---
DC	---	---	---	---	---	---	---	---
DE*	0.7	7.1	7.8	91.03	---	---	---	---
FL^	0.68	16.1	16.78	95.95	2.9	12.1	15	80.67
GA	0.67	4.3	4.97	86.52	---	---	---	---
HI	0.59	4	4.59	87.15	---	---	---	---
IA	1.79	11.6	13.39	86.63	---	---	---	---
ID	0.6	3.2	3.8	84.21	---	---	---	---
IL	1.77	6.8	8.57	79.35	0.12	4.7	4.82	97.51
IN	0.71	9.2	9.91	92.84	---	---	---	---
KS	1.75	5.2	6.95	74.82	1.53	4.5	6.03	74.63
KY	0.75	3.1	3.85	80.52	---	---	---	---
LA	1.52	6.9	8.42	81.95	0.65	5.6	6.25	89.60
MA	0.47	5.9	6.37	92.62	---	---	---	---
MD	1.66	3.7	5.36	69.03	---	---	---	---
ME	0.46	15.3	15.76	97.08	---	---	---	---
MI	0.58	6.3	6.88	91.57	0.32	2.7	3.02	89.40
MN	1.79	12.2	13.99	87.21	0.16	4.8	4.96	96.77
MO	0.56	4.2	4.76	88.24	---	---	---	---
MT	0.9	9.4	10.3	91.26	0.91	8.2	9.11	90.01
NC	1.14	11.5	12.64	90.98	---	---	---	---
ND	1.14	14.5	15.64	92.71	0.8	14.9	15.7	94.90
NE	1.84	6.8	8.64	78.70	---	---	---	---
NH	0.28	4.2	4.48	93.75	---	---	---	---
NJ	0.69	5.5	6.19	88.85	1.04	5	6.04	82.78
NM	1.43	6.3	7.73	81.50	0.51	5.2	5.71	91.07
NV	0.82	4.2	5.02	83.67	---	---	---	---
NY	1.4	4	5.4	74.07	0.46	2.4	2.86	83.92
OH	0.57	5	5.57	89.77	0.49	2.6	3.09	84.14
OK^	1.27	7.7	8.97	85.84	1.72	15	16.72	89.71
OR*^	1.14	2.1	3.24	64.81	0.64	4.4	5.04	87.30
PA	2.19	5.4	7.59	71.15	0.63	3.2	3.83	83.55
RI*	0.42	8.3	8.72	95.18	---	---	---	---
SC	0.7	5.7	6.4	89.06	---	---	---	---
SD	1.25	7.6	8.85	85.88	---	---	---	---
TN	0.67	2.3	2.97	77.44	---	---	---	---
TX	1.33	6.5	7.83	83.01	1.55	10.3	11.85	86.92
UT^	1.38	8.9	10.28	86.58	0.5	2.4	2.9	82.76
VA	0.81	4.7	5.51	85.30	---	---	---	---
VT	0.31	4.5	4.81	93.56	---	---	---	---
WA	1.52	5.4	6.92	78.03	0.61	2.8	3.41	82.11
WI	1.03	9.2	10.23	89.93	0.16	4.1	4.26	96.24
WV	0.63	2.8	3.43	81.63	---	---	---	---
WY	1.07	8.2	9.27	88.46	---	---	---	---

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State	POC	DOC	Streams Est. TOC	Est. DOC:TOC	POC	DOC	Lakes Est. TOC	Est. DOC:TOC
			Mean	85.71			Mean	87.84
			Max	97.08			Max	97.51
			Min	64.81			Min	74.63

* States where sample size was low for streams.

^ States where sample size was low for lakes.

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Appendix C-3. Mean TOC and DOC in Lake Superior Dilution Water (data from Greg Lien, U.S. EPA-Duluth, MN)

	Replicate	Ambient (8/29/2000)	pH 7.0 (8/30/2000)	pH 6.2 (8/31/2000)
Filter Blank*		-0.04	0.22	0.38
Pre-gill experiment TOC	a	1.13	1.34	1.26
	b	1.37	1.30	1.36
	Mean	1.25	1.32	1.31
Post-gill experiment TOC	a	1.20	1.24	1.18
	b	1.27	1.46	1.10
	Mean	1.24	1.35	1.14
Pre-gill experiment DOC	a	1.96	1.51	1.34
	b	1.52	1.28	0.99
	Mean	1.74	1.40	1.17
Post-gill experiment DOC	a	1.49	1.36	1.44
	b	1.64	1.58	1.24
	Mean	1.57	1.47	1.34

* Filter blank is ultra-pure Duluth-EPA laboratory water.

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Appendix C-4. Measured Hardness and Major Ion and Cation Concentrations in WFTS Well Water from April 1972 to April 1978. Concentrations Given as Mg/L (data from Samuelson 1976 and Chapman, personal communication)

Month	Total Hardness	Ca	Mg	Na	K	SO_4	Cl
Mar-72							
Apr-72		7.9	2	5	1.1	<10.0	8
May-72	22	5.8	1.4	4.4	0.5	<5.0	7
Jun-72	24	5.8	1.6	4.4	0.5	3	7
Jul-72	23	6.7	1.6	4.6	0.5	<1.0	8.3
Aug-72	23	6.5	1.7	4.7	0.5	<10.0	6.3
Sep-72	22	6	1.6	4.5	0.6	<10.0	4
Oct-72	22	6.7	1.9	4.7	0.6	5	5.5
Nov-72	23	6.2	1.6	4.2	0.6	3.7	5.3
Dec-72	23	6.2	1.5	4.2	0.5	3	4
Jan-73	52	15.3	3.5	7.1	0.7	7.8	12.4
Feb-73	33	7.7	2.1	5	0.5	5	5
Mar-73	30	8	2.1	5.3	0.7	5	6
Apr-73	31	8.9	2.3	5.4	0.7	5.3	8.8
May-73	28	8.3	2.4	5.8	0.7	3	8
Jun-73	28	8.4	2.2	5.8	0.7	4.8	7.5
Jul-73	26	7.4	1.9	5.8	0.8	<5.0	6.8
Aug-73	25	6.5	1.7	5.7	0.7	3.1	5.8
Sep-73	25	6.7	1.7	5.4	0.7	3.1	5.3
Oct-73	27	7	1.8	5.4	0.7	2.9	5.4
Nov-73	28	7.9	2.1	4.8	0.7	10	6.8
Dec-73	62	20.3	4.2	9	0.8	13	14
Jan-74	67	21.3	4.8	7	0.8	17.3	11.3
Feb-74	58	14.3	3.4	6.9	0.9	14.7	6.7
Mar-74	53	20.8	3.8	7.2	0.7	13	7
Apr-74	51	18.2	3.7	6.8	0.6	15.5	8.5
May-74	23	7.5	2.1	4.6	0.6	5	4.8
Jun-74	22	6	1.9	4.8	0.5	3	4.5
Jul-74	23	5.4	1.7	5	0.6	3.3	6.3
Aug-74	23	4.8	1.6	5	0.7	3	6
Sep-74	23	5.8	1.5	5.1	0.7	2.9	4.8
Oct-74	23	11	2	7.1	0.8	3.1	5
Nov-74	23	12	2.6	4.5	0.5	3.8	5.3
Dec-74	24	6.4	2.5	5.2	0.7	3.8	5
Jan-75	41	7.7	2.9	6.7	0.6	8	8
Feb-75	61	11.6	4.2	8.6	0.8	16	11.8
Mar-75	54	9.1	3.1	6.4	0.6	8	8
Apr-75		4.4	1.6	4.4	0.5	3	5
May-75		7.2	2	5	0.5	6	7
Jun-75		4.4	1.6	4.6	0.6	5	6
Jul-75		5.2	1.6	7	0.7	5	7
Aug-75		5.2	1.4	7	0.6	5	5
Sep-75		4.5	1.5	4.5	0.7	5	4
Oct-75		7.1	1.9	4.3	0.5	20	5
Nov-75	18	5.3	1.5	4.2	0.5	5	4
Dec-75							
Jan-76							
Feb-76		9.8	5	5.4	0.4	9	9
Mar-76				4.1	0.1	3	6
Apr-76				5.3	0.1	6	9

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Month	Total Hardness	Ca	Mg	Na	K	SO_4	ClD
May-76		7.9	1.8	4.5	0.5	3	6
Jun-76	27	8.1	1.9	3.3	0.6	4	7
Jul-76	26						
Aug-76	23	4.9	1.3	4.8	0.1	3	6
Sep-76	23	6.7	2.6	4.7	0.1		
Oct-76	21	6.7	2.6	4.7	0.1		
Nov-76	22	7.7	3	4.7	0.1	3	
Dec-76	25.5	6.4	1.8	5	0.1	4	7
Jan-77	27.2	7.7	2.6	5.6	0.6	4	8
Feb-77		10.7	4.9	5.9	0.6	3	11
Mar-77						3	8
Apr-77		10.7	2.2	5.5	0.8	3	7
May-77	25	5	1.8	5	0.8	3	5
Jun-77	27	6.6	2	5.2	0.7	3	5
Jul-77	24	6.7	2	7.1	0.8	3	7
Aug-77	25	6.9	1.9	6.9	1		8
Sep-77	27	9.9	2.1	5.9	0.9	3	6
Oct-77						3	
Nov-77		6.6	2.1	5.6	0.9	10	4.6
Dec-77	27	9.7		4.95	0.65	9	4.6
Jan-78		10.9	3.75		0.85	6	12
Feb-78		10.6	3.8	8.6	0.7	5	11
Mar-78		10.2	2.6	4.7	0.6	6	9
Apr-78		8.3	2.4		0.7	5	9.55

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Date	pH	Hardness	Alkalinity	Ca	Mg	Na	K	Cl	SO_4	NO_3	DOCD
19790329	7.6	80	63	19	8	8.4	2.3	7.8	13		
19790430	7.6	37	29	8.7	3.7	2.2	1.3	2.8	8.9		20
19790611	7.2	47	34	11	4.8	3.1	0.8	2.8	9.4		
19790723	7.6	73	55	17	7.3	3.9	0.9	3.7	8.9		30
19790827	7.2										
19791015	8.1	74	54	16	8.2	5	1.1	3.9	13	0.01	12
19791126	7.8	61	52	14	6.3	3.8	0.9	3.6	11	0.37	
19800121	7.6	60	53	14	6	3.8	0.9	3.2	9.9	0.15	
19800219	7.4	63	51	15	6.2	3.9	0.8	2.9	9.2	0.19	17
19800331	8.4	68	64	16	6.9	4.2	1.1	3.5	9.2	0.3	
19800602	8.3	84	72	19	8.8	6.4	1.2	5	15	0.01	21
19800630	8.3	93	68	21	9.9	7.9	1.4	6.7	24	0.02	
19800804	8.1	130	110	28	14	10	1.9	11	24	0.01	13
19800902	7.8	110	82	24	11	7.2	1.7	7.6	18	0.01	
19800929	7.6	73	54	16	8.1	5.7	1.4	5.8	14	0.12	
19801103	7	82	58	18	8.9	5.6	1.3	6.9	18	0.19	23
19801208		67	50	15	7.2	4.6	1	4.1	11	0.19	
19810105	7.6	70	55	16	7.2	4.2	1.1	4.1	13	0.23	
19810209	7.5	68	58	16	6.9	4.9	1	3.5	8.1	0.27	14
19810309	7.7	61	57	14	6.2	5.2	1.8	5.1	8.6	0.36	
19810504	7.3	42	40	9.6	4.3	3.7	1.2	3.6	9.6	0.18	21
19810706	7.4	51	39	12	5	3.5	1.2	3.2	7.5	0.14	10
19810908	7.9	73	64	16	8	4.2	0.8	4.2	8.3	0.11	
19811020	7.6	51	37	12	5.2	4.3	1.2	4.2	8.9	0.31	
19820113		62	52	14	6.5	4	0.9	3.7	9.3	0.24	
19820309	7.4	66	58	15	7	5.3	1	3.8	11	0.36	
19820420	7.2	32	25	7.5	3.3	2.1	1.3	2.3	6	0.19	
19820621	7.9	61	55	14	6.4	4.3	1.1	4	10	0.1	
19820809	7.4	66	54	15	6.9	3.9	0.6	3.5	9	0.25	
19821004	8	73	63	15	8.7	4.9	1	4.7	13	0.11	
19821207	7.3	55	43	12	6.1	4.2	0.8	3.3	16	0.24	
19830131	6.9	62	50	14	6.5	4.1	0.8	3.5	15	0.36	
19830328	7.5	68	56	15	7.3	4.5	1.2	4.1	15	0.35	
19830523	8.2	68	53	15	7.5	4	1.3	0.8	23	0.12	
19830718	7.6	67	53	15	7.2	3.7	1.3	3.7	22	0.15	
19831031	7.7	64	48	14	7	3.9	1.2	3.5	24	0.12	
19840109	7.4	57	50	13	6	3.6	0.9	3.4	13	0.23	
19840306	7.1	66	57	15	7	4.4	0.9	5.2	8.7	0.31	
19840424	7.2	51	39	11	5.6	3.1	1.4	3.2	14	0.12	
19840619	9.5	52	39	12	5.3	2.9	0.8	3.6	10	0.13	
19840822	6.4	70	58	15	7.9	4.7	1	3.8	17	0.1	
19841009	7.6	73		16	7.9	4.6	1	3.7	15	0.1	
19841120	7.1	64		14	7.1	3.9	0.9	3.7	14	0.24	
19850211	7	69		15	7.7	4.6	1.1	4	11	0.27	
19850325	7.3	61		13	7	5.6	2.5	6.6	16	0.31	
19850506	7.4	55		12	6	3.6	1.7	4.2	14	0.15	
19850730	7.6	62		14	6.6	3.2	0.9	4	9.8	0.1	
19851021	7.5	58		12	6.8	3.7	1.1	0.2	12	0.13	

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Appendix C-6. Water Composition of St. Louis River, MN, from USGS NASQAN and Select Relationships to Water Hardness

Date	pH	Hardness	Alkalinity	Ca	Mg	Na	K	Cl	SO_4	NO_3	DOC
19730222	6.8	68	53	17	6.3	11	1.6	14	14	0.19	
19730503	7.1	58	46	14	5.5	6.6	1.1	9.5	13	0.17	
19730816	6.9	70	51	17	6.6	7.6	1.2	9	20	0.01	
19731128	7	65	48	16	6.1	7.5	1.3	8.8	14		
19740221	7	64	48	16	5.8	8.9	1.3	12	14		
19740516	6.9	45	32	11	4.3	3.5	1.2	3.8	11		
19740919		88	60	21	8.6	12	1.8	17	23		
19741030	7.3	83	62	23	6.3	13	1.3	16	23		
19741209	7.4	86	62	22	7.6	12	1.6	15	18		
19750121	7.3	74	66	18	7	10	1.1	12	13		
19750303	7.3	74	68	17	7.6	10	1.7	11	12		
19750407	7.2	95	80	22	9.7	11	2	14	16		
19750527	7.5	63	50	15	6.1	8.5	1.5	9.2	12		
19750708	9.2	58	43	14	5.7	3.2	1	3.4	10		
19750818	7.2	73	56	18	6.9	12	1.3	16	16		
19750929	7.4	90	72	23	8	12	1.5	13	20		
19751110	7.1	90	63	22	8.4	12	1.7	15	24		
19751216	7.6	87	61	22	7.8	14	1.6	16	28		
19760209	7.5	72	59	18	6.6	13	1.6	13	18		
19760322	7.7	78	65	19	7.4	12	1.4	11	17		
19760503	7.6	59	43	14	5.8	7.9	1.3	8.6	15		
19760614	7.5	94	75	22	9.4	16	1.9	20	20		
19760726	7.4	93	80	22	9.3	21	1.9	25	24		
19760908	7.5	82	78	18	9.1	17	2.5	9.3	26		
19761019	7.5	83	72	20	8.1	21	1.6	24	21		
19761129	7.4	95	74	22	9.7	25	1.8	32	24		
19770110	7.3	85	88	20	8.4	17	1.5	15	19		
19770214	8.2	82	73	20	7.8	18	1.7	26	17		
19770404	7.3	87	67	21	8.5	20	2.4	28	24		
19770516	7.3	120	98	29	11	30	2.8	26	36		
19770628	7.8	100	75	24	9.9	13	2	16	23		
19770808	7.4	110	90	26	10	27	2.2	32	28		
19770919	7.4	73	44	17	7.3	6.6	1.7	8.9	17		
19771031	7.6	64	47	15	6.5	7.9	1.3	9.7	22		37
19771212	7.5	65	50	15	6.8	6.3	1.2	7.1	16		
19780123	7.3	71	52	17	6.9	12	1.5	9.4	18		
19780306	7.2	67	48	16	6.5	8.8	1.2	17	16		32
19780417	7.5	43	28	10	4.3	4.2	1.8	5.7	15		
19780530	7.9	64	54	15	6.4	5.7	1.5	7.1	14		33
19780710	7.4	53	44	13	5.1	4.3	1.3	5.3	8.9		
19780821	8.4	60	42	15	5.5	5.3	1.5	6.5	12		36
19781002	7.7	71	57	17	6.9	8.2	1.1	9.6	15		24
19781115	7.4	68	52	16	6.8	11	1.1	10	12		
19781218	7.4	68	55	16	6.9	11	1	9.2	14		
19790205	7.4	63	57	15	6.3	334.4	1	3.1	8		12

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Date	pH	Hardness	Alkalinity	Ca	Mg	Na	K	Cl	SO_4	NO_3	DOCD
19790329	7.6	80	63	19	8	8.4	2.3	7.8	13		
19790430	7.6	37	29	8.7	3.7	2.2	1.3	2.8	8.9		20
19790611	7.2	47	34	11	4.8	3.1	0.8	2.8	9.4		
19790723	7.6	73	55	17	7.3	3.9	0.9	3.7	8.9		30
19790827	7.2										
19791015	8.1	74	54	16	8.2	5	1.1	3.9	13	0.01	12
19791126	7.8	61	52	14	6.3	3.8	0.9	3.6	11	0.37	
19800121	7.6	60	53	14	6	3.8	0.9	3.2	9.9	0.15	
19800219	7.4	63	51	15	6.2	3.9	0.8	2.9	9.2	0.19	17
19800331	8.4	68	64	16	6.9	4.2	1.1	3.5	9.2	0.3	
19800602	8.3	84	72	19	8.8	6.4	1.2	5	15	0.01	21
19800630	8.3	93	68	21	9.9	7.9	1.4	6.7	24	0.02	
19800804	8.1	130	110	28	14	10	1.9	11	24	0.01	13
19800902	7.8	110	82	24	11	7.2	1.7	7.6	18	0.01	
19800929	7.6	73	54	16	8.1	5.7	1.4	5.8	14	0.12	
19801103	7	82	58	18	8.9	5.6	1.3	6.9	18	0.19	23
19801208		67	50	15	7.2	4.6	1	4.1	11	0.19	
19810105	7.6	70	55	16	7.2	4.2	1.1	4.1	13	0.23	
19810209	7.5	68	58	16	6.9	4.9	1	3.5	8.1	0.27	14
19810309	7.7	61	57	14	6.2	5.2	1.8	5.1	8.6	0.36	
19810504	7.3	42	40	9.6	4.3	3.7	1.2	3.6	9.6	0.18	21
19810706	7.4	51	39	12	5	3.5	1.2	3.2	7.5	0.14	10
19810908	7.9	73	64	16	8	4.2	0.8	4.2	8.3	0.11	
19811020	7.6	51	37	12	5.2	4.3	1.2	4.2	8.9	0.31	
19820113		62	52	14	6.5	4	0.9	3.7	9.3	0.24	
19820309	7.4	66	58	15	7	5.3	1	3.8	11	0.36	
19820420	7.2	32	25	7.5	3.3	2.1	1.3	2.3	6	0.19	
19820621	7.9	61	55	14	6.4	4.3	1.1	4	10	0.1	
19820809	7.4	66	54	15	6.9	3.9	0.6	3.5	9	0.25	
19821004	8	73	63	15	8.7	4.9	1	4.7	13	0.11	
19821207	7.3	55	43	12	6.1	4.2	0.8	3.3	16	0.24	
19830131	6.9	62	50	14	6.5	4.1	0.8	3.5	15	0.36	
19830328	7.5	68	56	15	7.3	4.5	1.2	4.1	15	0.35	
19830523	8.2	68	53	15	7.5	4	1.3	0.8	23	0.12	
19830718	7.6	67	53	15	7.2	3.7	1.3	3.7	22	0.15	
19831031	7.7	64	48	14	7	3.9	1.2	3.5	24	0.12	
19840109	7.4	57	50	13	6	3.6	0.9	3.4	13	0.23	
19840306	7.1	66	57	15	7	4.4	0.9	5.2	8.7	0.31	
19840424	7.2	51	39	11	5.6	3.1	1.4	3.2	14	0.12	
19840619	9.5	52	39	12	5.3	2.9	0.8	3.6	10	0.13	
19840822	6.4	70	58	15	7.9	4.7	1	3.8	17	0.1	
19841009	7.6	73		16	7.9	4.6	1	3.7	15	0.1	
19841120	7.1	64		14	7.1	3.9	0.9	3.7	14	0.24	
19850211	7	69		15	7.7	4.6	1.1	4	11	0.27	
19850325	7.3	61		13	7	5.6	2.5	6.6	16	0.31	
19850506	7.4	55		12	6	3.6	1.7	4.2	14	0.15	
19850730	7.6	62		14	6.6	3.2	0.9	4	9.8	0.1	
19851021	7.5	58		12	6.8	3.7	1.1	0.2	12	0.13	

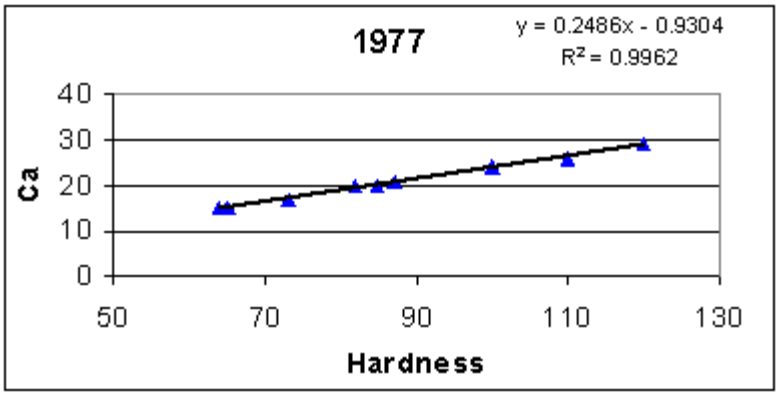
NMED Exhibit 80

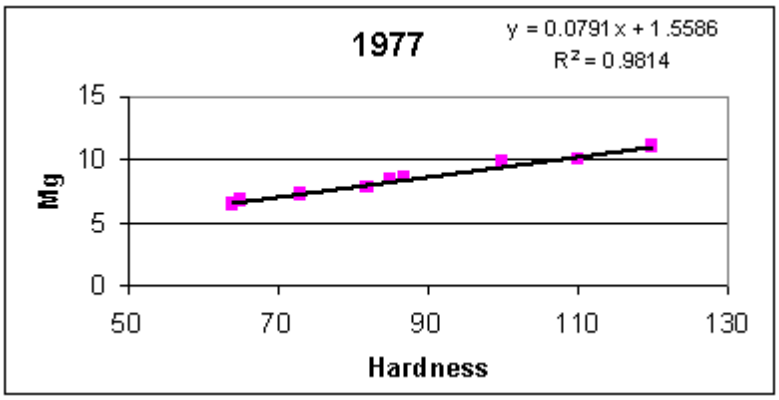
Date	pH	Hardness	Alkalinity	Ca	Mg	Na	K	Cl	SO_4	NO_3	DOCD
19851203	7.4	73		16	8	4	1	4.2	18	0.16	
19860303	7.4	66		15	7	4	1	3.4	10	0.24	
19860407	7.3									0.19	
19860602	7.5	58		13	6.3	3.5	1	2.8	15	0.1	
19860818	7.9	74		15	8.9	4.6	1.2	3.7	24	0.1	
19861112	7.5	55		12	6	3.4	1.4	3.8	19	0.27	
19861210	7.3	70	57	13	9	5	1	4.8	21	0.16	
19870218	7	66		15	6.8	3.7	0.9	3.1	12	0.24	
19870518	8	83		18	9.3	5.8	1.2	5	10	0.1	
19870622	7.8	75		16	8.5	6.2	1.1	5.2	19	0.1	
19870721	7.6	51		12	5.2	2.8	1.3	3.1	15	0.1	
19871028	8	82		17	9.6	6.8	1.4	1.3	19	0.1	
19871208	7.9	69		15	7.7	5.3	1.4	4.8	17	0.1	
19880119	7.4	73		16	8	5.1	1	3.6	15	0.15	
19880223	7.4	85		19	9.2	6.5	8.5	5.1	16	0.2	
19880412	7.4	42		9.2	4.7	3	2.8	5	20	0.25	
19880907	7.1	70		15	8	5.3	1.5	6.1	18	0.15	
19881031	7.6	100		21	12	9	1.9	7.8	27	0.1	
19881130	7.6	78		17	8.6	5.5	1.3	5.5	19	0.19	
19890221	7.1	77		17	8.4	6.3	1.3	4.4	17	0.25	
19890410	7.2	48		11	5	4.9	1.8	8.1	8	0.37	
19890626	7.4	63		14	6.8	4.6	1.1	5	12	0.15	
19890814	8.1	95		20	11	9.1	1.5	8.9	18	0.1	
19891101	8.1	110		20	15	7.8	1.9	6.3	31	0.1	
19891218	7.5	88		17	11	6.1	1.4	5	22	0.16	
19900123	7.3	100		18	14	7.2	1.7	5.2	28	0.23	
19900416	7.5	62		13	7.2	5.1	1.9	5.4	14	0.2	
19900716	7.7	70		15	8	5.7	1.3	5.4	11	0.2	
19900820	8.1	95		20	11	7.8	1.5	7.9	20	0.1	
19901009	7.3	81		18	8.7	5.4	1.5	5.7	13	0.1	
19910102	7.4	83		19	8.7	5.3	1.4	5	12	0.2	
19910212	7.1	80		18	8.5	6.8	1.3	3.9	11	0.2	
19910502	6.7	56		13	5.8	4	1	3.7	7.9	0.1	
19910610	7.3	64		15	6.5	4	0.7	4.1	6.9	0.12	
19910731	7.8	55		13	5.4	2.5	1	2.6	3.8	0.05	
19910801	7.3										
19911003	7.8	67		15	7.1	4.4	1	4.4	9.6	0.068	
19911204	7.4	61		13	6.9	4.8	1	3.5	7	0.18	
19920113	7.9	67		15	7.2	4.3	1.1	3.2	9.3	0.21	
19920413	7.7	30		7.8	2.5	2.5	0.3	2.4	4.8	0.16	
19920722	7.6	71		16	7.5	4.8	0.9	2.1	9.6	0.11	
19921026	8.2	86		18	10	5.3	1.2	5.4	14		
19921216	7.6	89		19	10	6	1.2	5.6	13	0.25	
19930201	7.2	83		18	9.1	7.3	1.2	7.3	12	0.28	
19930426	7.7	66		15	6.8	4.1	1.2	4.9	9.5	0.092	
19930722	7.5	64		15	6.5	4	0.2	3.9	7.7	0.079	
19931201	7.7	80		17	9	4.8	1	4	11	0.16	

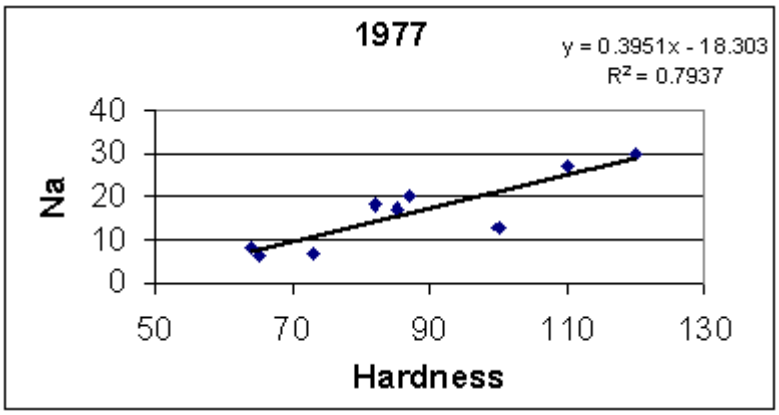
NMED Exhibit 80

Date	pH	Hardness	Alkalinity	Ca	Mg	Na	K	Cl	SO_4	NO_3	DOCD
19940216	7.3										
19940511	7.7	51		11	5.6	3.7	1.1	3.4	9.4	0.076	
MIN	6.4	30	25	7.5	2.5	2.1	0.2	0.2	3.8	0.01	10
MAX	9.5	130	110	29	15	30	8.5	32	36	0.37	37
MEAN	7.52	71.11	56.94	16.16	7.46	7.09	1.37	7.39	15.04	0.17	22.19

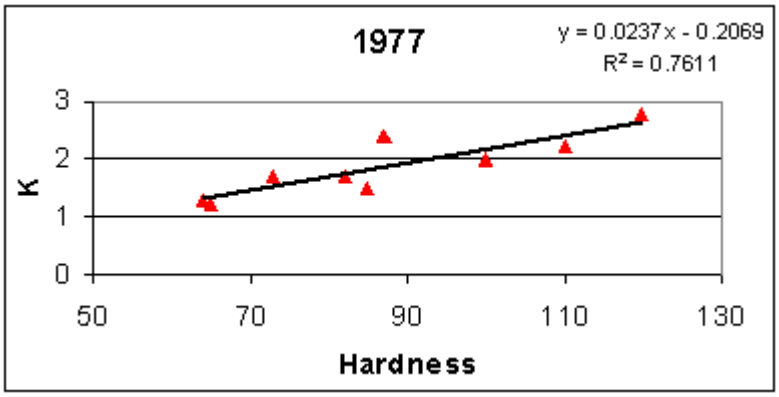
NMED Exhibit 80

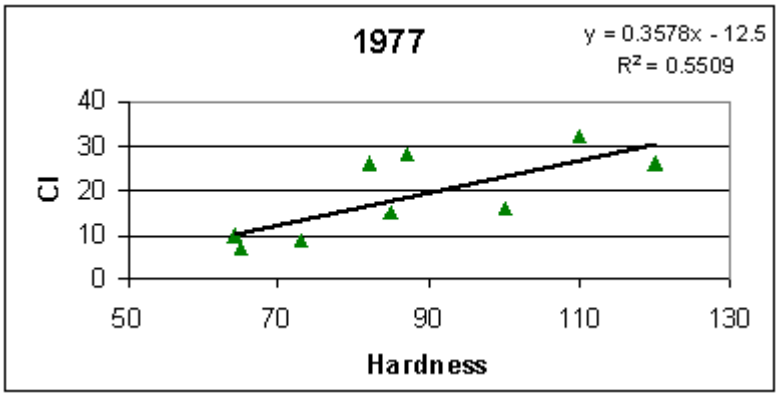


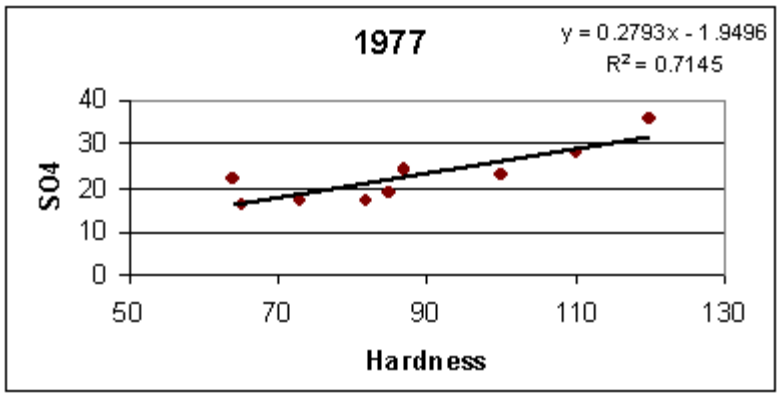




NMED Exhibit 80


1977
y = 0.0237x - 0.2069
R² = 0.7611
K
3
2
1
0
50
70
90
110
130
Hardness


1977
y = 0.3578x - 12.5
R² = 0.5509
Cl
40
30
20
10
0
50
70
90
110
130
Hardness


1977
y = 0.2793x - 1.9496
R² = 0.7145
SO4
40
30
20
10
0
50
70
90
110
130
Hardness

Appendix C-7. Supplementary Data for Bennett et al. (1995)

Tank	Dose (µg Cu/L)	Conductivity (µmho/cm)	pH	Oxygen (mg/L)	Temp (°C)	Alkalinity (as mg $CaCO_3$/L)	Hardness (as mg $CaCO_3$/L)
0 hours **7/9/92**							
a	897	325	8.62	7.5	21	100	96
b	897	300	8.6	7.6	21	100	96
c	897	320	8.6	7.6	21	80	96
d	607	320	8.62	7.7	21	80	96
e	607	370	8.62	7.6	21	80	96
f	607	328	8.64	7.6	21	80	96
g	93	310	8.64	7.6	21	80	96
h	93	370	8.69	7.5	21	80	96
I	93	310	8.6	7.6	21	80	96
j	505	310	8.62	7.7	21	100	96
k	505	310	8.65	7.7	21	80	96
l	505	320	8.69	7.7	21	80	96
m	319	320	8.69	7.7	21	80	96
n	319	330	8.68	7.7	21	80	96
o	319	320	8.67	7.7	21	80	96
p	0	310	8.62	7.5	21	80	96
q	0	320	8.63	7.6	21	80	96
r	0	320	8.6	7.7	21	80	96
24 hours **7/10/92**							
a	897	300	7.78	8.5	21.5	60	104
b	897	305	7.64	8.4	22	80	100
c	897	305	7.68	8.5	22	90	100
d	607	300	7.7	8.4	21.5	90	100
e	607	305	7.65	8.4	21.5	80	100
f	607	305	7.75	8.4	21.5	80	100
g	93	300	7.77	9.1	22	80	100
h	93	295	7.76	9.2	21.5	80	108
I	93	295	7.76	9	21.5	85	100
j	505	300	7.73	8.8	22	90	84
k	505	300	7.71	8.8	21.5	80	100
l	505	300	7.73	8.7	21.5	80	100
m	319	300	7.74	9.1	21.5	80	100
n	319	300	7.52	8.5	22	80	100
o	319	310	7.79	8.7	22.5	80	100
p	0	305	7.79	9.1	22	80	100
q	0	305	7.7	9.1	22	80	104
r	0	300	7.71	9.1	22	80	104
48 hours **7/11/92**							
a	897	*	*	*	*	*	*
b	897	*	*	*	*	*	*
c	897	320	8.1	7.2	21.5	100	96
d	607	315	7.91	6.9	21.5	100	96
e	607	310	7.84	6.8	21.5	100	100
f	607	315	8	7	21.5	100	104
g	93	300	8.19	7.7	21.5	100	100

NMED Exhibit 80

Tank	Dose (µg Cu/L)	Conductivity (µmho/cm)	pH	Oxygen (mg/L)	Temp (°C)	Alkalinity (as mg $CaCO_3$/L)	Hardness (as mg $CaCO_3$/L)D
h	93	300	8.13	7.7	21	100	100
I	93	300	8.16	7.6	21	100	104
j	505	310	8.1	7.5	21	80	100
k	505	310	8.12	7.4	21	100	100
l	505	310	8.13	7.4	21	80	100
m	319	310	8.12	7.4	21	100	100
n	319	310	7.8	6.4#	21.5	100	100
o	319	310	8.18	7.3	22	100	96
p	0	300	8.16	8	21.5	80	100
q	0	300	8.1	7.9	21.5	80	104
r	0	300	8.21	8	21.5	100	100
***72 hours* 7/12/92**							
a	897	*	*	*	*	*	*
b	897	*	*	*	*	*	*
c	897	*	*	*	*	*	*
d	607	310	8.02	8.9	21.5	100	100
e	607	315	8.04	8.8	21.5	100	100
f	607	315	8.02	8.7	21.5	80	100
g	93	310	7.92	9.1	21.5	100	104
h	93	305	7.91	9.1	21	100	100
I	93	310	7.91	9	21	80	106
j	505	315	7.97	8.9	21.5	100	104
k	505	310	7.96	8.9	21	100	100
l	505	310	7.96	9	21	80	104
m	319	310	7.91	9	21	100	100
n	319	310	7.97	9	21	80	100
o	319	320	7.99	8.8	22	100	104
p	0	300	7.86	9.3	21.5	100	104
q	0	300	7.81	9.1	21.5	80	100
r	0	305	7.93	9.3	21.5	80	100
***96 hours* 7/13/92**							
a	897	*	*	*	*	*	*
b	897	*	*	*	*	*	*
c	897	*	*	*	*	*	*
d	607	320	8.03	7.3	21.5	100	104
e	607	320	8.07	7.3	21.5	100	100
f	607	325	8.02	7.2	21.5	100	104
g	93	325	7.95	7.1	21.5	120	104
h	93	315	8.03	7.5	21	100	100
I	93	310	8.02	7.4	21	100	100
j	505	320	8.06	7.4	21.5	80	100
k	505	320	8.05	7.4	21	120	100
l	505	320	8.03	7.3	21	100	104
m	319	315	8.05	7.5	21	100	104
n	319	320	8.06	7.4	21	100	100
o	319	330	8.08	7.3	22	100	104

NMED Exhibit 80

Tank	Dose (µg Cu/L)	Conductivity (µmho/cm)	pH	Oxygen (mg/L)	Temp (°C)	Alkalinity (as mg $CaCO_3$/L)	Hardness (as mg $CaCO_3$/L)D
p	0	330	7.78	8.1	21.5	80	96
q	0	325	7.75	7.9	21.5	80	104
r	0	330	7.86	8.1	21.5	80	100

* All fish dead, no water quality measured.

Air stone had fallen out of tank.

NMED Exhibit 80

Appendix C-8. Supplementary Data for Richards and Beitinger (1995)

Acclimation Temperature	5°C		12°C		22°C		32°C	
Replicate	1	2	1	2	1	2	1	2
Sample size	30	36	30	36	36	30	33	29
pH	8.2-8.3	7.8-8.2	8.4-8.5	8.2-8.4	8.3-8.4	8.1-8.5	8.4-8.5	8.4-8.5
Hardness (mg/l $CaCO_3$)	164-180	152-166	152-168	148-170	164-174	162-172	164-168	162-172
Alkalinity (mg/l $CaCO_3$)	125-140	130-140	130-140	130-140	140-145	140-145	135-140	135-145
Weights of minnows (g)	0.62-3.23	0.42-2.64	0.56-2.38	0.30-1.93	0.66-1.15	0.13-1.55	0.26-1.36	0.23-1.32
Lengths of minnows (cm)	3.3-5.5	3.2-5.2	3.2-4.9	2.8-5.1	1.9-4.3	2.4-4.6	3.0-4.8	3.3-4.8

NMED Exhibit 80

Appendix C-9. Data for the American River, CA, for July 1978 Through December 1980 (data from the City of Sacramento, CA, Water Quality Laboratory; personal communication). Units Are mg/L.

Date	pH	Hardness	Alkalinity	Ca	Mg	Ca:Mg	Na	Cl	SO_4
Jul-78	7.6	20	22	5.2	1.7	3.06	3.2	2.6	4
Aug-78	7.6	20	22	4.9	1.9	2.58	3.4	2.8	5
Sep-78	7.5	20	22	5.2	1.7	3.06	3.5	2.6	4
Oct-78	7.3	20	22	5	1.8	2.78	3.6	3	4
Nov-78	7.2	20		4.9	1.9	2.58	3.9		5
Dec-78									
Jan-79	7.4	23	24	5.1	2.1	2.43	3.2	2.9	4
Feb-79	7.5	24	25	6.5	1.9	3.42	3	3	5
Mar-79	7.6	26	27	7.4	1.8	4.11	3.3	2.7	6
Apr-79	7.7	27	27	7.5	2	3.75	3.6	2.7	7
May-79	7.6	25	26	5.7	2.6	2.19	3.4	2.4	6
Jun-79	7.7	22	24	5.7	1.9	3.00	3.1	2.5	4
Jul-79	7.6	21	22	5.3	1.9	2.79	3	2.7	4
Aug-79	7.5	21	22	5.6	1.7	3.29	3.2	2.4	5
Sep-79	7.3	20	21	5.7	1.4	4.07	3.5	2.5	3
Oct-79	7.2	19	20	5.5	1.3	4.23	3.1	2.8	3
Nov-79									
Dec-79									
Jan-80	7.5	23	23	6.1	1.9	3.21	2.4	2.6	4
Feb-80	7.4	23	23	6.1	1.9	3.21	2.7	2.3	2
Mar-80	7.5	24	26	5.8	2.3	2.52	2	2.3	2
Apr-80	7.7	25	25	6.4	2.2	2.91	1.9	2.5	3
May-80	7.5	22	21	6.1	1.6	3.81	2.4	2.4	3
Jun-80	7.3	19	21	5.1	1.5	3.40	2.3	2.4	2
Jul-80	7.4	18	20	4.6	1.6	2.88	2.6	2.1	3
Aug-80	7.5	18	21	5.2	1.2	4.33	3	2.7	2
Sep-80	7.3	18	20	4.9	1.4	3.50	2.9	2.4	4
Oct-80	7.3	18	20	5	1.3	3.85	3	2.7	2
Mean	7.5	21.4	22.8	5.6	1.8	3.2	3.0	2.6	3.8
max	7.7	27.0	27.0	7.5	2.6	4.3	3.9	3.0	7.0
min	7.2	18.0	20.0	4.6	1.2	2.2	1.9	2.1	2.0

NMED Exhibit 80

Appendix C-10. STORET Data for Minnesota Lakes and Rivers

Date	pH	Hardness	Alkalinity	Ca	Mg	Ca:Mg	Na	K	Cl	SO_4	NO_3	TOC	DOC	Sulfide
Embarrass River, MN														
3/22/76	7	133	103	27	16	1.69	2.5	2	11	34				
4/29/76	6.7	25.3	23	5.2	3	1.73	2.8	0.7	2.9	8.4	0.04	16		0.6
5/28/76	6.5		53						3.5	12				
6/28/76	6.9	44	36	9.9	4.6	2.15	3.9	0.3	5	13	0.04	37		
7/28/76	6.6		76	5.2					4.8	7.5				
8/26/76	6.9	100	110	24	9.9	2.42	9	1	8.4	5.6		21		0.6
Means	6.8	75.58	66.83	14.26	8.38	2.00	4.55	1.00	5.93	13.42	0.04	24.67		0.60
max.	7	133	110	27	16	2.42	9	2	11	34	0.04	37		0.6
min.	6.5	25.3	23	5.2	3	1.69	2.5	0.3	2.9	5.6	0.04	16		0.6
S. Kawishiwi River, MN														
10/16/75	6.4	21	14	4.9	2.1	2.33	1.3	0.4	0.5	4.4	0.01	12		0.2
11/6/75	6.9	24	19	5.5	2.5	2.20	1.2	0.4	0.6	4.1				
12/11/75		39	23	10	3.4	2.94	1.4	0.4	1.5					0.2
1/9/76	6.6	29	24	6.2	3.2	1.94	1.6	0.8	2.3	7				
2/4/76	6.3	24	20	5.2	2.7	1.93	1.7	0.6	0.9	6.3	0.16	16		0
3/9/76	6.9	23	23	5.7	2.2	2.59	1.5	0.5	0.9	4.9				1
4/23/76	6.6	14	8	3.4	1.3	2.62	0.9	0.4	0.7	4.8				0.2
5/25/76	6.8	16	11	4	1.5	2.67	0.9	0.4	0.7	4.8				
6/25/76	6.6		16						1.1	3.3				1.8
7/23/76	6.7		19						1.2	4.4				0.5
Means	6.6	23.75	17.70	5.61	2.36	2.40	1.31	0.49	1.04	4.89	0.09	14.00		0.56
max.	6.9	39	24	10	3.4	2.94	1.7	0.8	2.3	7	0.16	16		1.8
min.	6.3	14	8	3.4	1.3	1.93	0.9	0.4	0.5	3.3	0.01	12		0
Colby Lake, MN														
LCY2														
6/17/96	8.5	56	33	13	5.7	2.28	4.3	1.5	6.3	22	0.25	17		
6/17/96	6.8										0.25	17		
6/17/96	6.9	71	33	17	7	2.43	4.3	1.4	9.4	22		18		
LCY1														
6/17/96	6.8	54	33	12	5.8	2.07	3.9	1.4	6.6	26	0.3	16		
6/17/96	6.8											16		
6/17/96	6.5	41	34	11	3.2	3.44	3.6	1.3	6.8	22	0.33	17		
6/17/96	7.4	83	39	21	7.3	2.88			7.8	52	0.18			
Means	7.1	55.50	33.25	13.25	5.43	2.55	4.03	1.40	7.28	23.00	0.28	16.83		
max.	8.5	71	34	17	7	3.44	4.3	1.5	9.4	26	0.33	18		
min.	6.5	41	33	11	3.2	2.07	3.6	1.3	6.3	22	0.25	16		
Cloquet Lake, MN														
7/13/76	6.4	17	11	4	1.8	2.22			1.7	7.6	0	38		
Lake One, MN														
10/16/75	7.2	27	21	6.9	2.3	3.00			1.2	5.6	0.02	22		
Greenwood Lake, MN														
7/6/76	6.7	10	15	2.8	0.7	4.00	0.1	0.3	0.2	4.2	0	11		

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Appendix D. Saltwater Conversion Factors for Dissolved Values

Appendix D
Saltwater Conversion Factors for Dissolved Values

February 14, 2007

U.S. Environmental Protection Agency
Office of Water
Office of Science and Technology
Washington, D.C.

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Saltwater Conversion Factors for Converting Nominal or Total Copper Concentrations to Dissolved Copper Concentrations

The U.S. EPA changed its policy in 1993 of basing water quality criteria for metals from a total metal criteria to a dissolved metal criteria. The policy states "the use of dissolved metal to set and measure compliance with water quality standards is the recommended approach, because dissolved metal more closely approximates the bioavailable fraction of metal in the water column than does total recoverable metal" (Prothro 1993). All of the criteria for metals to this date were based upon total metal and very few data were available with dissolved concentrations of the metals. A problem was created by the new policy of how to derive dissolved metal concentrations for studies in which this form of the metal was not measured. The U.S. EPA attempted to develop correction factors for each metal for which criteria exist for both fresh- and saltwater (Lussier et al. 1995; Stephan 1995). In the case of saltwater, a correction for copper was not derived.

Several saltwater studies are available that report nominal, total, and dissolved concentrations of copper in laboratory water (Table 1) from site-specific water effect ratio (WER) studies. These studies show relatively consistent ratios for the nominal-to-dissolved concentrations and for the total-to-dissolved concentrations. Calculation of a mean ratio (conversion factor) to convert nominal and total copper concentrations to dissolved copper permits the use of the results for critical studies without dissolved copper measurements.

Three studies, each with multiple tests per study, were useful for deriving the conversion factors. One study was conducted for the lower Hudson River in the New York/New Jersey Harbor (SAIC 1993). The tests were conducted with harbor site water and with EPA Environmental Research Laboratory - Narragansett water from Narragansett Bay, Massachusetts. Only the tests with laboratory water were used for this exercise. Three series of 48-hour static tests were conducted with various animals. Salinity ranged from 28 to 32 ppt during all the tests. Series 1 tests were not used to calculate ratios for dissolved-to-total or dissolved-to-nominal copper concentrations, because in many instances, concentrations of measured copper did not increase as nominal concentrations increased. Of the series 2 tests, only the coot clam (*Mulinia lateralis*) tests were successful and used to calculate ratios. Three replicate tests without ultraviolet (UV) light present and one test with UV light present were reported with total and dissolved copper measurements made at 0 hr and 48 hr (end) of the tests. Dissolved-to-total and dissolved-to-nominal ratios were calculated for the four tests each with two time intervals. The mean ratio for the dissolved-to-total measurements is 0.943 and the mean ratio for the dissolved-to-nominal is 0.917. A third series of static tests was conducted by SAIC and the mussel (*Mytilus sp.*) test was the only successful test. Again the tests were conducted as three replicate tests without UV light and a fourth with UV light. The mean test ratio for dissolved-to-total copper was 0.863 and the dissolved-to-nominal mean test ratio was 0.906.

The summer flounder (*Paralichthys dentatus*) was exposed to copper in laboratory water for 96 hours in a static test (CH2MHill 1999a). The water was collected from Narragansett Bay and diluted with laboratory reverse osmosis water to dilute the solution to 22 ppt salinity. Three tests were run with copper concentrations measured at the start of the tests as total recoverable and dissolved copper. Five exposure concentrations were used to conduct the tests. Only the two lowest concentrations were used to derive ratios for dissolved-to-total and dissolved-to-nominal copper mean ratios. These concentrations were at the approximate 500 µg/L or lower concentrations, and are in the range of most copper concentrations routinely tested in the laboratory. The mean dissolved-to-total and dissolved-to-nominal ratios were 0.947 and 0.836, respectively.

Three 48-hour static tests were conducted with the blue mussel (*Mytilus edulis*) in water from the

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same source and treated in the same manner as the summer flounder tests (CH2MHill 1999b). Salinity was diluted to 20 ppt. Exposures were made at eight concentrations of copper and total and dissolved copper concentrations were measured only at the start of the tests. Mean ratios for the dissolved-to-total and dissolved-to-nominal copper were calculated by combining the ratios calculated for each of the test concentrations. The mean dissolved-to-total and dissolved-to-nominal ratios were 0.979 and 0.879, respectively.

A study was conducted by the City of San Jose, CA to develop a WER for San Francisco Bay in which copper was used as a toxicant and the concentrations used in the laboratory exposures were measured as total and dissolved copper (Environ. Serv. Dept., City of San Jose 1998). Mussels and the purple sea urchin (*Strongylocentrotus purpuratus*) were used as the test organisms. Tests were conducted in filtered natural sea water from San Francisco Bay that was diluted to a salinity of 28 ppt. The mussel test was of 48-hour duration and the purple sea urchin test was of 96-hour duration. Five concentrations of copper were used in the toxicity tests with the concentrations measured at the start of each test. (During each test, a single concentration of copper was measured at the termination of the test and this value was not used in the calculations.) Twenty-two tests were conducted during a 13-month period with the mussel and two tests were conducted with the purple sea urchin. The mean dissolved-to-total and dissolved-to-nominal ratios for the mussel tests were 0.836 and 0.785, respectively. The mean dissolved-to-total and dissolved-to-nominal ratios for the purple sea urchin were 0.883 and 0.702, respectively.

For some of the tests, control concentrations had measured concentrations of total and dissolved copper. These values were not used to calculate ratios for dissolved-to-total and dissolved-to-nominal copper concentrations. All mean ratios were calculated as the arithmetic mean and not as a geometric mean of the available ratios. When the data are normally distributed, the arithmetic mean is the appropriate measure of central tendency (Parkhurst 1998) and is a better estimator than the geometric mean. All concentrations of copper used to calculate ratios should be time-weighted averages (Stephan 1995). In all instances of data used to calculate ratios, the concentrations were identical to time-weighted values because either only one value was available or if two were available they were of equal weight.

Based on the information presented above the overall ratio for correcting total copper concentrations to dissolved copper concentrations is 0.909 based upon the results of six sets of studies. This is comparable to its equivalent factor in freshwater, which is 0.960 ± 0.037 (Stephan 1995). When it is necessary to convert nominal copper concentrations to dissolved copper concentrations the conversion factor is 0.838 based upon the same studies. The means of both conversion factors have standard deviations of less than ten percent of the means (Table 1).

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Table D-1. Summary of Saltwater Copper Ratios

Species	Mean Dissolved-to-Total Ratio	Mean Dissolved-to-Nominal Ratio	Reference
Coot clam, *Mulinia lateralis*	0.943	0.917	SAIC 1993
Summer flounder, *Paralichthys dentatus*	0.947	0.836	CH2MHill 1999a
Blue mussel, *Mytilus sp*	0.863	0.906	SAIC 1993
Blue mussel, *Mytilus edulis*	0.979	0.879	CH2MHill 1999b
Blue mussel, *Mytilus sp*	0.836	0.785	Environ. Serv. Dept., City of San Jose 1998
Purple sea urchin, *Strongylocentrotus purpuratus*	0.883	0.702	Environ. Serv. Dept., City of San Jose 1998
Arithmetic Mean	0.909	0.838	
Standard Deviation	±0.056	±0.082	

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Appendix E. BLM Input Data and Notes

Appendix E. BLM Table

BLM Data Label	Model Output: Critical Accumulation	Hard-ness (mg/L)	Model Input: Temp (ºC)	pH	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	Notes
LUVA01S	1.1869	290	25	6.57	124.8	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5
LUVA02S	2.1707	290	25	7.29	259.2	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5
LUVA03S	2.0991	290	25	8.25	480	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5
CADE01F	27.6903	44.9	15	7.7	1920	1.1	10	13.1965	2.911001	1.27	0.56	3.32	1.2	42.7	0.0003	1,2,3,6,7,8
CADE02F	26.6895	44.9	15	7.7	1344	1.1	10	13.1965	2.911001	1.27	0.56	3.32	1.2	42.7	0.0003	1,2,3,6,7,8
JUPL01F	0.1537	21	15	7.20	14.4	1.1	10	6.0583	1.7462	4.5302	0.7	2.8706	5.468	26	0.0003	1,3,6,7,9,10
LIVI01F	0.0570	21	15	7.2	7.68	1.1	10	6.0583	1.7462	4.5302	0.7	2.8706	5.468	26	0.0003	1,3,6,7,9,10
PHIN01F	0.4378	44.9	15	7.7	39.36	1.1	10	13.1965	2.911001	1.27	0.56	3.32	1.2	42.7	0.0003	1,2,3,6,7,8
PHIN02F	0.3410	44.9	15	7.7	35.52	1.1	10	13.1965	2.911001	1.27	0.56	3.32	1.2	42.7	0.0003	1,2,3,6,7,8
ACPE01S	0.1147	96	25	8.35	25.92	0.5	10	15.8434	13.728	29.734	2.3762	92.159	2.1544	102	0.0003	1,2,3,4,6,7,20
ACPE02S	0.1556	68	25	8.35	27.84	0.5	10	11.2224	9.724	21.061	1.6831	65.279	1.526	108	0.0003	1,2,3,4,6,7,20
UTIM01S	8.2925	39	23	7.4	82.56	0.5	10	6.43638	5.577	12.079	0.9653	37.439	0.8752	32.5	0.0003	1,2,3,4,6,11
UTIM02S	8.0633	90	23	7.6	191.04	0.5	10	13.9716	12.11764	26.253	2.098	81.372	1.9022	65	0.0003	1,2,3,4,12
UTIM03S	1.3555	92	25	8.1	72.96	0.5	10	29.0614	4.73839	30.798	1.6408	46.006	32.716	77	0.0003	1,2,3,4,6,7,53
UTIM04S	1.4793	86	25	8.2	81.6	0.5	10	27.1661	4.429364	28.79	1.5338	43.005	30.583	78	0.0003	1,2,3,4,6,7,53
UTIM05S	0.5289	90	25	8	39.36	0.5	10	28.4296	4.635381	30.129	1.6052	45.006	32.005	78	0.0003	1,2,3,4,6,7,53
UTIM06S	1.2514	90	24	8.2	75.84	0.5	10	14.8532	12.87	13.938	1.1138	43.199	1.0099	99	0.0003	1,2,3,4,5,6,7
UTIM07S	1.3009	90	25	7.9	69.12	0.5	10	28.4296	4.635381	30.129	1.6052	45.006	32.005	99	0.0003	1,2,3,4,6,7,53
UTIM08S	0.7111	86	25	7.9	36.48	0.5	10	14.193	12.298	13.318	1.0643	41.279	0.965	59	0.0003	1,2,3,4,5,6,7
CEDU01S	0.1132	52	24.5	7.5	18.24	1.1	10	15.2833	3.371316	1.5	0.57	3.8	1.4	55	0.0003	1,2,3,6,7,8
CEDU02S	0.0941	52	24.5	7.5	16.32	1.1	10	15.2833	3.371316	1.5	0.57	3.8	1.4	55	0.0003	1,2,3,6,7,8
CEDU03S	0.0751	45	25	7.72	25	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU04S	0.0400	45	25	7.72	17	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU05S	0.1046	45	25	7.72	30	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU06S	0.0700	45	25	7.72	24	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU07S	0.0920	45	25	7.72	28	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU08S	0.1184	45	25	7.72	32	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU09S	0.0651	45	25	7.72	23	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU10S	0.0517	45	25	7.72	20	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU11S	0.0476	45	25	7.72	19	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU12S	0.0194	94.1	25	8.15	26	2	10	23.2094	8.79835	5.2449	1.6	20.054	6.1705	69.6	0.0003	1,2,6,7,17
CEDU13S	0.0144	94.1	25	8.15	21	2	10	23.2094	8.79835	5.2449	1.6	20.054	6.1705	69.6	0.0003	1,2,6,7,17
CEDU14S	0.0206	94.1	25	8.15	27	2	10	23.2094	8.79835	5.2449	1.6	20.054	6.1705	69.6	0.0003	1,2,6,7,17

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Appendix E. BLM Table

BLM Data Label	Model Output	Hard-ness (mg/L)	Model Input														Notes
	Critical Accumulation		Temp (ºC)	pH	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	
CEDU15S	0.0338	94.1	25	8.15	37	2	10	23.2094	8.79835	5.2449	1.6	20.054	6.1705	69.6	0.0003	1,2,6,7,17
CEDU16S	0.0294	94.1	25	8.15	34	2	10	23.2094	8.79835	5.2449	1.6	20.054	6.1705	69.6	0.0003	1,2,6,7,17
CEDU17S	0.0428	179	25	8.31	67	2.3	10	50.1069	13.12323	14.32	2.4	22.673	10.979	140.1	0.0003	1,2,6,7,18
CEDU18S	0.0164	179	25	8.31	38	2.3	10	50.1069	13.12323	14.32	2.4	22.673	10.979	140.1	0.0003	1,2,6,7,18
CEDU19S	0.0579	179	25	8.31	78	2.3	10	50.1069	13.12323	14.32	2.4	22.673	10.979	140.1	0.0003	1,2,6,7,18
CEDU20S	0.0627	179	25	8.31	81	2.3	10	50.1069	13.12323	14.32	2.4	22.673	10.979	140.1	0.0003	1,2,6,7,18
CEDU21S	0.0283	97.6	25	8	28	2	10	24.0727	9.1256	5.44	1.6	20.8	6.4	74.2	0.0003	1,2,6,7,17
CEDU22S	0.1218	182	25	8	84	2.3	10	50.9467	13.34317	14.56	2.4	23.053	11.163	144.3	0.0003	1,2,6,7,18
CEDU23S	0.0510	57.1	25	8.18	12.864	0.5	10	9.42352	8.1653	17.685	1.4133	54.815	1.2814	81	0.0003	1,2,3,4,6,7,20
CEDU24R	0.0377	80	20	7.6	5.5396825	0.5	10	13.2028	11.44	24.778	1.9801	76.799	1.7953	53	0.0003	1,2,6,7,20,21
DAMA01S	0.0221	39	20	7.8	8.736	1.1	10	10.9867	2.7776	5.8136	0.7	7.9394	7.7684	51	0.0003	1,2,3,6,7,9,10
DAMA02S	0.0315	39	20	7.8	11.232	1.1	10	10.9867	2.7776	5.8136	0.7	7.9394	7.7684	51	0.0003	1,2,3,6,7,9,10
DAMA03S	0.0147	38	20	7.79	6.336	1.1	10	10.7129	2.7203	5.7423	0.7	7.6578	7.6406	50	0.0003	1,2,3,6,7,9,10
DAMA04S	0.0253	38	20	7.79	9.504	1.1	10	10.7129	2.7203	5.7423	0.7	7.6578	7.6406	50	0.0003	1,2,3,6,7,9,10
DAMA05S	0.1799	39	20	6.9	11.232	1.1	10	10.9867	2.7776	5.8136	0.7	7.9394	7.7684	30	0.0003	1,2,3,6,7,9,10
DAMA06S	0.0786	39	20	6.9	6.432	1.1	10	10.9867	2.7776	5.8136	0.7	7.9394	7.7684	30	0.0003	1,2,3,6,7,9,10
DAMA07S	0.0312	26	20	7.6	8.736	1.1	10	7.4273	2.0327	4.8867	0.7	4.2786	6.107	24	0.0003	1,2,3,6,7,9,10
DAMA08S	0.0123	27	20	7.7	4.992	1.1	10	7.7011	2.09	4.958	0.7	4.5602	6.2348	24	0.0003	1,2,3,6,7,9,10
DAMA09S	0.4278	170	20	7.8	39.552	0.5	10	27.9433	24.23527	52.507	4.1961	162.74	3.8045	115	0.0003	3,4,22,23
DAMA10S	0.0443	170	20	7.8	10.08	0.5	10	27.9433	24.23527	52.507	4.1961	162.74	3.8045	115	0.0003	3,4,22,23
DAMA11S	0.1330	170	20	7.8	19.776	0.5	10	27.9433	24.23527	52.507	4.1961	162.74	3.8045	115	0.0003	3,4,22,23
DAMA12S	0.0990	170	20	7.8	16.608	0.5	10	27.9433	24.23527	52.507	4.1961	162.74	3.8045	115	0.0003	3,4,22,23
DAMA13S	0.9670	170	20	7.8	67.872	0.5	10	27.9433	24.23527	52.507	4.1961	162.74	3.8045	115	0.0003	3,4,22,23
DAMA14S	0.2716	170	20	7.8	30.048	0.5	10	27.9433	24.23527	52.507	4.1961	162.74	3.8045	115	0.0003	3,4,22,23
DAMA15S	0.0160	109.9	21	6.93	6.816	2.4	10	40.0	2.43	85.1	1.23	10	106	12.5	0.0003	1,2,3,6,7,24
DAMA16S	0.0298	109.9	21	6.93	15.744	3.4	10	40.0	2.43	85.1	1.23	10	106	12.5	0.0003	1,2,3,6,7,24
DAMA17S	0.0393	109.9	21	7.43	38.304	3.4	10	40.0	2.43	85.1	1.23	10	106	13.875	0.0003	1,2,3,6,7,19,24
DAMA18S	0.0219	109.9	21	7.43	17.952	2.4	10	40.0	2.43	85.1	1.23	10	106	13.875	0.0003	1,2,3,6,7,19,24
DAMA19S	0.0111	109.9	21	7.82	18.144	2.4	10	40.0	2.43	85.1	1.23	10	106	14.5	0.0003	1,2,3,6,7,19,24
DAMA20S	0.0189	109.9	21	7.82	38.112	3.4	10	40.0	2.43	85.1	1.23	10	106	14.5	0.0003	1,2,3,6,7,19,24
DAMA21S	0.0898	109.9	21	6.93	44.16	4.4	10	40.0	2.43	85.1	1.23	10	106	12.5	0.0003	1,2,3,6,7,24
DAMA22S	0.1076	109.9	21	6.93	69.024	6.1	10	40.0	2.43	85.1	1.23	10	106	12.5	0.0003	1,2,3,6,7,24
DAMA23S	0.0458	109.9	21	7.43	54.912	4.4	10	40.0	2.43	85.1	1.23	10	106	13.875	0.0003	1,2,3,6,7,19,24
DAMA24S	0.0288	109.9	21	7.82	65.088	4.4	10	40.0	2.43	85.1	1.23	10	106	14.5	0.0003	1,2,3,6,7,19,24

Appendix E. BLM Table

BLM Data Label	Model Output	Hard-ness (mg/L)	Model Input														Notes
	Critical Accumulation		Temp (ºC)	pH	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	
DAMA25S	0.1143	52	18.2	7.8	24.96	1.1	10	14	3.5	12	2.9	23	11	45	0.0003	1,2,3,6,7,9,25
DAMA26S	0.0917	105	20.3	7.9	28.8	1.1	10	29	6.8	29	5.3	57	21	79	0.0003	1,2,3,6,7,9,25
DAMA27S	0.1053	106	19.7	8.1	36.48	1.1	10	29	6.8	29	5.3	57	21	82	0.0003	1,2,3,6,7,9,25
DAMA28S	0.1538	207	19.9	8.3	66.24	1.1	10	58	13	62	8.2	127	40	166	0.0003	1,2,3,6,7,9,25
DAMA29S	0.0062	7.1	24	8.55	4.608	0.5	10	1.15182	1.027387	3.5102	2.8052	6.8159	2.5434	56	0.0003	1,2,3,4,6,7,56
DAMA30S	0.2536	20.6	24	6.97	7.104	0.5	10	3.39973	2.9458	2.5478	2.1356	19.776	1.9363	60	0.0003	1,2,3,4,6,7,56
DAMA31S	0.0119	23	24	8.52	6.24	0.5	10	3.79581	3.289	2.8446	2.3845	22.08	2.1619	64	0.0003	1,2,3,4,6,7,56
DAPC01S	0.0087	48	18	8.03	10.944	2.288	10	14.1077	3.111984	1.36	0.57	3.55	1.25	42	0.0003	1,2,3,6,7,15,26
DAPC02S	0.0052	48	18	8.03	8.6976	2.816	10	14.1077	3.111984	1.36	0.57	3.55	1.25	42	0.0003	1,2,3,6,7,15,26
DAPC03S	0.0043	48	18	8.01	6.9504	2.728	10	14.1077	3.111984	1.36	0.57	3.55	1.25	44	0.0003	1,2,3,6,7,15,26
DAPC04S	0.0057	44	18	8.04	10.368	3.08	10	12.932	2.852652	1.24	0.57	3.25	1.15	42	0.0003	1,2,3,6,7,15,26
DAPC05S	0.0879	31	18	6.66	53.184	12.2094	10	7.37407	3.063455	1.6792	0.5	6.3292	1.2917	27	0.0003	1,2,3,6,7,27,28
DAPC06S	0.0490	29	18	6.97	53.088	11.3373	10	6.89832	2.865813	1.5708	0.5	5.9208	1.2083	27	0.0003	1,2,3,6,7,27,28
DAPC07S	0.0285	28	18	7.2	51.168	11.3373	10	6.66045	2.766992	1.5167	0.5	5.7167	1.1667	22	0.0003	1,2,3,6,7,27,28
DAPC08S	0.0268	88	18	7.01	93.312	24.4188	10	20.9464	8.5194	16.466	1.8787	22.629	18.986	20	0.0003	1,2,3,6,7,27,29
DAPC09S	0.0187	100	18	7.55	191.04	29.6514	10	23.9296	9.4686	21.207	2.1631	25.98	23.28	20	0.0003	1,2,3,6,7,27,29
DAPC10S	0.0701	82	18	6.99	204.48	27.9072	10	19.4548	8.0448	14.095	1.7365	20.953	16.84	18	0.0003	1,2,3,6,7,27,29
DAPC11S	0.0460	84	18	7.01	158.4	27.9072	10	19.952	8.203	14.885	1.7839	21.512	17.555	17	0.0003	1,2,3,6,7,27,29
DAPC12S	0.0100	16	18	7.39	34.08	11.6124	10	4.13844	1.379481	0.16	0.3	6.72	0.32	11	0.0003	1,2,3,6,7,27,28
DAPC13S	0.0137	151	18	7.76	75.648	12.5801	10	36.7872	14.39533	10.786	1.4	62.018	19.684	44	0.0003	1,2,3,6,7,27,28
DAPC14S	0.0053	96	18	8.1	108.48	27.0956	10	22.0888	9.939946	6.8571	1.4	19.911	4.2667	91	0.0003	1,2,3,6,7,27,28
DAPC15S	0.0137	26	18	7.24	73.344	24.1925	10	7.37925	1.844812	0.26	0.3	11.624	2.6	4	0.0003	1,2,3,6,7,27,28
DAPC16S	0.0564	84	18	7.08	81.312	12.5801	10	20.4644	8.008	6	1.4	34.5	10.95	13	0.0003	1,2,3,6,7,27,28
DAPC17S	0.0633	92	18	7.22	176.64	20.3217	10	22.4134	8.770667	6.5714	1.4	37.786	11.993	19	0.0003	1,2,3,6,7,27,28
DAPC18S	0.0056	47	18	8.03	8.928	2.728	10	13.8137	3.047151	1.33	0.57	3.47	1.23	42.5	0.0003	1,2,3,6,7,15,26
DAPC19S	0.0119	97	18	8.03	17.088	2.728	10	34	2.9	1.3	0.57	51.3	1.2	42.5	0.0003	1,2,3,6,7,15,30
DAPC20S	0.0160	147	18	8.03	22.752	2.728	10	54	2.9	1.3	0.57	99.3	1.2	42.5	0.0003	1,2,3,6,7,15,30
DAPC21S	0.0168	247	18	8.03	26.208	2.728	10	94	2.9	1.3	0.57	147.3	1.2	42.5	0.0003	1,2,3,6,7,15,30
DAPC22S	0.0171	97	18	8.03	24.192	2.728	10	13.6	15.2	1.3	0.57	51.3	1.2	42.5	0.0003	1,2,3,6,7,15,30
DAPC23S	0.0155	147	18	8.03	24.096	2.728	10	13.6	27.5	1.3	0.57	99.3	1.2	42.5	0.0003	1,2,3,6,7,15,30
DAPC24S	0.0133	247	18	8.03	24.096	2.728	10	13.6	51.9	1.3	0.57	147.3	1.2	42.5	0.0003	1,2,3,6,7,15,30
SCSP01S	0.1034	52	24.5	7.5	17.28	1.1	10	15.2833	3.371316	1.47	0.57	3.84	1.36	55	0.0003	1,2,3,6,7,8
GAPS01F	0.1153	44.9	15	7.7	21.12	1.1	10	13.1965	2.911001	1.27	0.57	3.32	1.17	42.7	0.0003	1,2,3,6,7,8
GAPS02F	0.0888	44.9	15	7.7	18.24	1.1	10	13.1965	2.911001	1.27	0.57	3.32	1.17	42.7	0.0003	1,2,3,6,7,8

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Appendix E. BLM Table

BLM Data Label	Model Output	Hard-ness (mg/L)	Model Input														Notes
	Critical Accumulation		Temp (ºC)	pH	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	
HYAZ01S	0.1511	290	25	6.23	16.32	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5,13
HYAZ02S	0.1074	290	25	7.51	23.04	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5,13
HYAZ03S	0.2392	290	25	8.38	83.52	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5,13
HYAZ04S	0.0794	20.5	21	7.15	23.328	2.8	10	5.1	1.9	5.3	0.8	9.3	10.0	6.7	0.0003	3,31
HYAZ05S	0.0768	20.5	21	7.15	22.848	2.8	10	5.1	1.9	5.3	0.8	9.3	10.0	6.7	0.0003	3,31
HYAZ06S	0.2314	20.6	21	7.14	7.872	0.5	10	5.3	1.8	5.5	0.8	7.0	9.7	11.0	0.0003	3,31
HYAZ07S	0.3312	20.6	21	7.14	9.6	0.5	10	5.3	1.8	5.5	0.8	7.0	9.7	11.0	0.0003	3,31
ACLY01S	29.5658	42	18.5	7.0	7968	1.1	10	12.3442	2.722986	1.3	0.57	3.4	1.2	47	0.0003	1,2,3,6,7,8
CHDE01S	25.2731	44	20	7.40	709.44	0.5	10	6.99	6.06	13.1	1.05	40.7	0.951	32.5	0.0003	1,2,3,4,32,33
SCPL01S	2.9865	167	22	7.6	153.6	0.5	10	27.5609	23.881	51.724	4.1335	160.32	3.7478	115	0.0003	1,2,3,4,6,7,20
ONAP01S	0.9139	169	12	8	67.2	0.5	10	27.891	24.167	52.344	4.183	162.24	3.7927	117	0.0003	1,2,3,4,6,7,20
ONCL01S	1.0007	169	12	8.1	76.8	0.5	10	27.891	24.167	52.344	4.183	162.24	3.7927	117	0.0003	1,2,3,4,6,7,20
ONCL02S	0.5538	169	12	8.25	57.6	0.5	10	27.891	24.167	52.344	4.183	162.24	3.7927	117	0.0003	1,2,3,4,6,7,20
ONCL03F	2.8512	205	13.7	7.73	367	3.3	10	49.8	19.6	4	0.64	10	0.44	178	0.0003	1,2,6,7,34
ONCL04F	1.5731	69.9	13.7	8.54	186	1.5	10	18.4	5.8	1.405	0.2248	3.5126	0.1546	174	0.0003	1,2,6,7,35
ONCL05F	0.4400	18	13.7	8.07	36.8	0.75	10	4.8	1.5	0.3618	0.0579	0.9045	0.0398	183	0.0003	1,2,6,7,35
ONCL06F	1.9714	204	13.7	7.61	232	3.3	10	64.7	10.3	4.1005	0.6561	10.251	0.4511	77.9	0.0003	1,2,6,7,35
ONCL07F	5.2514	83	13.7	7.4	162	1.7	10	20.4	7.8	1.6683	0.2669	4.1709	0.1835	70	0.0003	1,2,6,7,35
ONCL08F	1.2778	31.4	13.7	8.32	73.6	0.94	10	7.9	2.7	0.6312	0.101	1.5779	0.0694	78.3	0.0003	1,2,6,7,35
ONCL09F	0.3591	160	13.7	7.53	91	2.8	10	57.5	4.0	3.2161	0.5146	8.0402	0.3538	26.0	0.0003	1,2,6,7,35
ONCL10F	0.3318	74.3	13.7	7.57	44.4	1.5	10	24.7	3.1	1.4935	0.239	3.7337	0.1643	22.7	0.0003	1,2,6,7,35
ONCL11F	0.1192	26.4	13.7	7.64	15.7	0.87	10	6.0	2.8	0.5307	0.0849	1.3266	0.0584	20.1	0.0003	1,2,6,7,35
ONGO01F	1.3932	83.1	7.15	7.63	137.28	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONGO02F	0.3615	83.1	7.15	7.63	83.52	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONGO03F	3.5018	83.1	7.15	7.63	191.04	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONKI01R	4.9807	33	13.5	7.29	157.44	2.496	10	8.77741	2.698479	7.3188	1.15	6.1426	6.8124	29	0.0003	1,2,3,6,7,27,36
ONKI02F	0.4054	25	12	7.30	31.68	1.3	10	6.8	1.8	5.0	0.6	4.2	6	24	0.0003	3,37
ONKI03F	0.9203	20	9.4	7.29	44.16	1.3	10	5.7845	1.6889	4.4589	0.7	2.589	5.3402	22	0.0003	1,2,3,6,7,10,38
ONKI04F	0.1617	31.1	13.3	7.30	49	3.2	10	8.01999	2.695987	5.12	0.653	4	4.5	29.6	0.0003	1,2,6,7,39
ONKI05F	0.1736	31.1	13.3	7.30	51	3.2	10	8.01999	2.695987	5.12	0.653	4	4.5	29.6	0.0003	1,2,6,7,39
ONKI06F	0.1461	31.6	15.7	7.50	58	3.2	10	8.14893	2.739331	5.12	0.653	3.5	4.2	30.4	0.0003	1,2,6,7,39
ONKI07F	0.4829	31	15.3	7.20	78	3.2	10	7.99421	2.687318	5.12	0.653	2.3	3.1	29.7	0.0003	1,2,6,7,39
ONMY01S	1.3925	169	12	8.2	105.6	0.5	10	27.891	24.167	52.344	4.183	162.24	3.7927	117	0.0003	1,2,3,4,6,7,20
ONMY02S	0.5765	169	12	7.95	48	0.5	10	27.891	24.167	52.344	4.183	162.24	3.7927	117	0.0003	1,2,3,4,6,7,20

Appendix E. BLM Table

BLM Data Label	Model Output	Hard-ness (mg/L)	Model Input														Notes
	Critical Accumulation		Temp (ºC)	pH	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	
ONMY03S	0.7648	169	12	7.95	57.6	0.5	10	27.891	24.167	52.344	4.183	162.24	3.7927	117	0.0003	1,2,3,4,6,7,20
ONMY04R	0.1249	44.1	11.5	7.7	40	2	10	9.07	4.1	4.75	1.02	3.3	1.56	49.7	0.0003	40
ONMY05R	0.0917	44.6	11.5	7.8	19	0.99	10	7.37	6.1	6.24	0.8	1.31	3.82	53.1	0.0003	40
ONMY06R	0.0376	38.7	12	7.62	3.4	0.33	10	2.37	8.65	13.7	0.15	0.36	20.3	40	0.0003	51
ONMY07R	0.1465	39.3	12	7.61	8.1	0.36	10	14.1	1.8	13.2	0.1	0.36	19.9	41.7	0.0003	51
ONMY08R	0.1881	89.5	12	8.21	17.2	0.345	10	15	11.85	10.05	1	0.36	6.73	97.5	0.0003	51
ONMY09R	0.5172	89.67	12	8.15	32	0.345	10	28.9	3.15	32.5	0.5	0.36	45.2	97.25	0.0003	51
ONMY10F	0.3824	23	12.2	7.1	26.88	1.4	10	6.1	1.8	4.4	0.4	5.8	6	22	0.0003	3,37
ONMY11F	0.1589	23	12.2	7.1	16.32	1.4	10	6.1	1.8	4.4	0.4	5.8	6	22	0.0003	3,37
ONMY12F	0.1059	23	12.2	7.4	17.28	1.3	10	6.8	1.8	5.0	0.6	4.2	6	22	0.0003	3,37
ONMY13F	0.4633	23	12.2	7.1	27.84	1.3	10	6.8	1.8	5.0	0.6	4.2	6	22	0.0003	3,37
ONMY14F	0.4998	194	12.8	7.84	169	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY15F	0.1118	194	12.8	7.84	85.3	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY16F	0.1069	194	12.8	7.84	83.3	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY17F	0.1627	194	12.8	7.84	103	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY18F	1.5525	194	12.8	7.84	274	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY19F	0.2605	194	12.8	7.84	128	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY20F	0.9538	194	12.8	7.84	221	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY21F	0.4717	194	12.8	7.84	165	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY22F	0.7244	194	12.8	7.84	197	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY23F	4.6605	194	12.8	7.84	514	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY24F	1.1894	194	12.8	7.84	243	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY25F	0.0613	9.2	15.5	6.96	2.688	0.5	10	2.3	0.7	2	0.2	4.6	2.1	11	0.0003	3,41
ONMY26F	0.3626	31	15.3	7.2	68	3.2	10	7.99421	2.687318	5.12	0.653	2.3	3.1	29.7	0.0003	1,2,6,7,39
ONMY27F	0.0770	36.1	11.4	7.6	18	1.31	10	4.03	7.13	1.56	0.26	1.49	0.88	36.6	0.0003	40
ONMY28F	0.8944	36.2	11.5	6.1	12	1.36	10	3.93	7.27	1.57	0.28	1.47	0.87	8.5	0.0003	40
ONMY29F	0.5568	20.4	11.7	7.5	5.7	0.15	10	3.13	2.77	2.62	0.25	0.36	1.48	23	0.0003	40
ONMY30F	0.2504	45.2	11.7	7.7	35	1.23	10	9.7	4.43	5.33	0.97	3.41	1.47	50	0.0003	40
ONMY31F	1.1775	45.4	11.8	6.3	18	1.22	10	9.7	4.43	5.02	0.98	3.37	1.37	10.9	0.0003	40
ONMY32F	0.5318	41.9	12.3	7.9	17	0.33	10	6.6	5.97	5.89	0.63	1.11	3.37	48.3	0.0003	40
ONMY33F	1.2884	214	7.64	7.94	96.96	0.27	10	49.4	24.1	10.3	1.75	18.9	5.28	198	0.0003	1,2,3,6,7,54,55
ONMY34F	3.8957	220	7.74	7.92	295.68	0.36	10	51.2	25.5	8.36	2.1	24	4.64	197	0.0003	1,2,3,6,7,54,55
ONMY35F	4.4437	105	7.77	7.82	89.28	0.1	10	23.1	11.8	3.54	3.22	17.1	2.91	94.1	0.0003	1,2,3,6,7,54,55
ONMY36F	1.9096	98.2	8.49	7.89	34.464	0.045	10	22.3	11.2	3.58	0.9	11.5	2.85	87.9	0.0003	1,2,3,6,7,54,55

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Appendix E. BLM Table

BLM Data Label	Model Output	Hard-ness (mg/L)	Model Input														Notes
	Critical Accumulation		Temp (ºC)	pH	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	
ONMY37F	1.7297	104	16.3	7.83	52.224	0.28	10	22.4	11.4	3.76	2.72	12.4	3.01	97.6	0.0003	1,2,3,6,7,54,55
ONNE01F	3.1060	83.1	7.15	7.63	182.4	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE02F	3.5466	83.1	7.15	7.63	192	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE03F	0.5132	83.1	7.15	7.63	96	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE04F	0.6617	83.1	7.15	7.63	105.6	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE05F	1.0574	83.1	7.15	7.63	124.8	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE06F	1.6007	83.1	7.15	7.63	144	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE07F	4.0021	83.1	7.15	7.63	201.6	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE08F	2.2920	83.1	7.15	7.63	163.2	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE09F	3.1060	83.1	7.15	7.63	182.4	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE10F	5.4103	83.1	7.15	7.63	230.4	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONTS01F	0.2050	23	12.2	7.4	24.96	1.3	10	6.8	1.8	5.0	0.6	4.2	6	22	0.0003	3,37
ONTS02F	0.1161	23	12.2	7.4	18.24	1.3	10	6.8	1.8	5.0	0.6	4.2	6	22	0.0003	3,37
ONTS03F	0.7109	23	12.2	7.1	36.48	1.4	10	6.1	1.8	4.4	0.4	5.8	6	22	0.0003	3,37
ONTS04F	0.3750	23	12.2	7.1	24.96	1.3	10	6.8	1.8	5.0	0.6	4.2	6	22	0.0003	3,37
ONTS05F	0.3517	13	12	7.15	9.792	0.5	10	2.14546	1.859	4.0264	0.3218	12.48	0.2917	12	0.0003	1,2,3,4,6,7,20
ONTS06F	0.8340	46	12	7.55	23.136	0.5	10	7.59162	6.578	14.247	1.1386	44.159	1.0323	35	0.0003	1,2,3,4,6,7,20
ONTS07F	0.9241	182	12	8.12	79.2	0.5	10	30.0364	26.026	56.37	4.5048	174.72	4.0844	125	0.0003	1,2,3,4,6,7,20
ONTS08F	0.3954	359	12	8.49	123.264	0.5	10	59.2477	51.337	111.19	8.8858	344.64	8.0566	243	0.0003	1,2,3,4,6,7,20
ONTS09F	1.1161	36.6	12	7.71	7.4	0.055	10	6.36	4.73	4.84	0.22	0.94	2.79	40.8	0.0003	51
ONTS10F	0.8313	34.6	12	7.79	12.5	0.19	10	7.82	3.17	9.98	0.11	0.73	8.34	40.6	0.0003	51
ONTS11F	0.8622	38.3	12	7.71	14.3	0.24	10	6.33	5.1	5.27	0.6	0.99	2.96	43.6	0.0003	51
ONTS12F	1.7785	35.7	12	7.74	18.3	0.17	10	8.15	3.38	10	0.37	0.76	9.1	43.3	0.0003	51
SACO01F	2.9901	214	7.64	7.94	218.88	0.27	10	49.4	24.1	10.3	1.75	18.9	5.28	198	0.0003	1,2,3,6,7,54,55
SACO02F	2.6420	220	7.74	7.92	198.72	0.36	10	51.2	25.5	8.36	2.1	24	4.64	197	0.0003	1,2,3,6,7,54,55
SACO03F	3.2456	105	7.77	7.82	63.936	0.1	10	23.1	11.8	3.54	3.22	17.1	2.91	94.1	0.0003	1,2,3,6,7,54,55
SACO04F	2.6405	98.2	8.49	7.89	48	0.045	10	22.3	11.2	3.58	0.9	11.5	2.85	87.9	0.0003	1,2,3,6,7,54,55
SACO05F	3.0680	104	16.3	7.83	85.44	0.28	10	22.4	11.4	3.76	2.72	12.4	3.01	97.6	0.0003	1,2,3,6,7,54,55
ACAL01F	9.7513	54	10.5	7.3	137.28	1.1	10	15.0937	3.6371	6.8831	0.7	12.163	9.6854	43	0.0003	1,2,3,6,7,9,10
GIEL01S	2.6186	173	22	8.05	192	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,6,7,20
NOCR01F	29.9790	72.2	25	7.50	81216	1.5	10	17.8079	6.7507	15.26	1.6	73.841	54.15	42.5	0.0003	2,3,6,7,16,42
PIPR01S	11.3981	103	22	7.4	297.6	0.5	10	28.4667	7.773195	27.778	2.6358	29.602	53.021	65	0.0003	1,2,3,4,6,48
PIPR02S	4.9570	103	22	7.4	115.2	0.5	10	28.4667	7.773195	27.778	2.6358	29.602	53.021	65	0.0003	1,2,3,4,6,48
PIPR03S	9.4256	263	22	7.4	374.4	0.5	10	72.6868	19.84806	36.487	3.4623	77.901	130.77	65	0.0003	1,2,3,4,6,48

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Appendix E. BLM Table

BLM Data Label	Model Output	Hard-ness (mg/L)	Model Input														Notes
	Critical Accumulation		Temp (ºC)	pH	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	
PIPR04S	1.2005	52	24.5	7.4	52.8	1.1	10	15.2833	3.371316	1.47	0.57	3.84	1.36	55	0.0003	1,2,3,6,7,8
PIPR05S	3.0479	52	24.5	7.4	81.6	1.1	10	15.2833	3.371316	1.47	0.57	3.84	1.36	55	0.0003	1,2,3,6,7,8
PIPR06S	0.1314	290	25	6.27	14.4	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5
PIPR07S	0.3064	290	25	7.14	42.24	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5
PIPR08S	0.5392	290	25	8.6	192	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5
PIPR09S	0.0890	19	22	7.06	4.6272	0.6	10	4.9	1.64	3.7	0.78	9.6	5.8	11.17	0.0003	3,49
PIPR10S	0.2665	19.5	22	7.25	7.872	0.4	10	5.2	1.64	5.36	0.79	2.45	8.6	12.7	0.0003	3,49
PIPR11S	0.5716	16.5	22	6.36	30.3072	3.3	10	4.1	1.54	2.82	0.76	9.4	4.7	8.46	0.0003	3,49
PIPR12S	0.2950	17	22	6.42	20.2176	3.1	10	4.2	1.56	2.74	0.74	7.4	4.6	3.4	0.0003	3,49
PIPR13S	0.4162	19	22	6.38	34.5312	4.3	10	5	1.62	7.04	0.72	10.2	12.2	7.83	0.0003	3,49
PIPR14S	0.2640	17	22	7.15	57.4368	3.4	10	4.2	1.54	2.9	1	7.4	4.7	8.74	0.0003	3,49
PIPR15S	0.0477	17	22	7.16	4.6368	0.8	10	4.5	1.46	2.68	0.78	10.9	3.8	9.3	0.0003	3,49
PIPR16S	0.1770	17.5	22	7.13	67.4688	5.1	10	4.6	1.48	2.62	0.77	10.5	3.5	8.95	0.0003	3,49
PIPR17S	0.0787	18.5	22	7.06	80.2464	10.5	10	5	1.54	2.64	0.8	10.7	3.5	8.29	0.0003	3,49
PIPR18S	0.1907	18.5	22	6.90	174.72	15.6	10	4.9	1.5	3.54	0.99	7	5.2	9.52	0.0003	3,49
PIPR19S	3.2305	173	22	8.25	278.4	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
PIPR20S	7.4512	173	22	8.1	604.8	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
PIPR21S	4.8297	173	22	8.15	384	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
PIPR22S	7.6122	173	22	7.3	374.4	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
PIPR23S	7.2327	166	5	8.05	432	0.5	10	27.3959	23.738	51.415	4.1088	159.36	3.7253	132.5	0.0003	1,2,3,4,6,7,20
PIPR24S	3.4469	159	12	8.35	285.12	0.5	10	26.2406	22.737	49.247	3.9355	152.64	3.5682	135	0.0003	1,2,3,4,6,7,20
PIPR25S	2.8678	168	22	8.3	298.56	0.5	10	27.7259	24.024	52.034	4.1583	161.28	3.7702	142.5	0.0003	1,2,3,4,6,7,20
PIPR26S	3.3686	167	32	8.45	492.48	0.5	10	27.5609	23.881	51.724	4.1335	160.32	3.7478	140	0.0003	1,2,3,4,6,7,20
PIPR27S	0.5950	45.54059	22	7.93	53.958366	1.1	10	13.4911	2.888065	1.6093	0.391	3.362	1.4181	42.037464	0.0003	43,44
PIPR28S	4.0104	45.54059	22	7.93	165.17867	1.1	10	13.4911	2.888065	91.27	0.391	3.362	143.23	42.037464	0.0003	43,44
PIPR29S	0.7241	44.53969	22	7.98	59.464322	1.1	10	13.1946	2.824591	1.6093	0.391	3.362	1.4181	42.037464	0.0003	43,44
PIPR30S	4.0805	44.53969	22	7.98	146.45842	1.1	10	13.1946	2.824591	45.98	0.391	3.362	72.324	44.039248	0.0003	43,44
PIPR31S	1.8188	44.53969	22	7.99	82.038741	1.1	10	13.1946	2.824591	1.6093	0.391	3.362	1.4181	42.53791	0.0003	43,44
PIPR32S	4.9213	45.54059	22	7.96	124.4346	1.1	10	13.4911	2.888065	1.6093	0.391	3.362	36.871	43.038356	0.0003	43,44
PIPR33S	3.9367	45.04014	22	7.79	103.759	1.1	10	13.3428	2.856328	1.6093	0.391	3.362	1.4181	46.041032	0.0003	43,44
PIPR34S	5.7875	45.04014	22	7.81	167.3225	1.1	10	13.3428	2.856328	47.589	0.391	99.42	1.4181	46.041032	0.0003	43,44
PIPR35S	3.2914	138.1231	22	7.785	120.015	1.1	10	12.892	25.75825	1.6093	0.391	3.362	72.324	43.038356	0.0003	43,44
PIPR36S	5.7959	151.1347	22	7.78	169.418	1.1	10	14.1065	28.18476	1.6093	0.391	99.42	1.4181	43.038356	0.0003	43,44
PIPR37S	3.4870	138.1231	22	8.02	268.224	1.1	10	12.892	25.75825	1.6093	0.391	3.362	1.4181	149.13291	0.0003	43,44

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Appendix E. BLM Table

BLM Data Label	Model Output	Hard-ness (mg/L)	Model Input														Notes
	Critical Accumulation		Temp (ºC)	pH	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	
PIPR38S	9.2068	139.124	22	7.775	242.443	1.1	10	51.1778	2.779812	1.6093	0.391	99.42	1.4181	43.038356	0.0003	43,44
PIPR39S	4.7038	47.04192	22	7.78	113.3475	1.1	10	13.4268	4.010325	1.6093	0.391	3.362	1.4181	43.038356	0.0003	43,44
PIPR40S	3.1754	37.033	22	7.785	77.8764	0.88	10	11.022	3.281175	2.9887	0.391	3.362	1.4181	43.038356	0.0003	43,45
PIPR41S	5.3335	60.05352	22	7.795	128.016	1.1	10	15.2304	5.954725	1.6093	0.391	17.771	1.4181	43.038356	0.0003	43,44
PIPR42S	6.4718	76.06779	22	7.8	151.13	1.1	10	18.8376	7.413025	1.6093	0.391	32.179	1.7727	42.037464	0.0003	43,44
PIPR43S	6.4642	103.0919	22	7.805	166.624	1.1	10	25.05	10.2081	2.0691	0.391	60.036	1.7727	43.038356	0.0003	43,44
PIPR44S	7.0015	103.0919	22	7.78	163.83	1.1	10	32.064	4.010325	1.8392	0.391	58.115	1.7727	40.03568	0.0003	43,44
PIPR45S	5.9820	107.0954	22	7.79	157.48	1.1	10	18.2364	15.43368	1.6093	0.391	61.957	1.7727	43.038356	0.0003	43,44
PIPR46S	7.4331	134.1195	22	7.8	199.7075	1.1	10	32.2644	13.00318	1.6093	0.391	88.854	1.7727	43.038356	0.0003	43,44
PIPR47S	6.0725	45.04014	22	7.815	128.524	1.1	10	14.028	2.18745	1.3794	0.391	3.362	1.0636	41.036572	0.0003	43,44
PIPR48S	7.2713	46.04103	22	7.82	150.876	1.1	10	14.028	2.18745	6.2072	1.5639	5.7635	7.0906	42.037464	0.0003	43,44
PIPR49S	5.4175	45.04014	22	7.82	131.064	1.1	10	14.028	2.18745	15.173	1.5639	10.566	15.245	41.036572	0.0003	43,44
PIPR50S	6.2395	45.04014	22	7.81	160.2105	1.1	10	14.2284	2.18745	35.174	1.5639	21.613	36.162	41.036572	0.0003	43,44
PIPR51S	6.2194	44.03925	22	7.82	182.88	1.1	10	15.03	2.18745	62.992	1.5639	40.825	70.906	40.03568	0.0003	43,44
PIPR52S	4.9667	45.04014	22	7.81	180.848	1.1	10	14.4288	2.18745	101.39	1.9549	59.076	107.78	41.036572	0.0003	43,44
PIPR53S	6.1183	46.04103	22	7.81	176.784	1.1	10	14.2284	2.18745	57.015	19.158	40.825	71.97	42.037464	0.0003	43,44
PIPR54S	5.7931	189.1686	22	7.82	188.9125	1.1	10	55.11	15.79825	1.6093	0.782	152.25	1.0636	42.037464	0.0003	43,44
PIPR55S	5.2814	46.04103	22	7.865	125.603	1.1	10	14.6292	3.15965	1.3794	0.391	3.362	1.0636	42.037464	0.0003	43,44
PIPR56S	3.8765	75.0669	22	7.87	117.348	1.1	10	24.4488	5.954725	1.3794	0.391	30.739	1.0636	41.036572	0.0003	43,44
PIPR57S	3.7460	46.04103	22	7.865	114.554	1.1	10	14.4288	3.15965	19.771	0.391	12.488	18.436	41.036572	0.0003	43,44
PIPR58S	3.8963	74.06601	22	7.85	126.492	1.1	10	24.4488	6.07625	18.392	0.391	38.903	18.436	42.037464	0.0003	43,44
PIPR59S	5.1820	133.1186	22	7.85	172.72	1.1	10	41.082	11.6664	18.392	0.391	98.94	18.436	42.037464	0.0003	43,44
PIPR60S	5.0050	76.06779	22	7.85	167.3225	1.1	10	24.048	6.07625	47.589	0.782	58.115	52.116	43.038356	0.0003	43,44
PIPR61S	6.3379	134.1195	22	7.84	226.695	1.1	10	40.8816	11.6664	49.198	0.782	118.63	51.052	43.038356	0.0003	43,44
PIPR62S	6.5522	52.04638	22	7.96	84.201	0.3	10	12.024	4.13185	1.6093	0.391	10.566	1.7727	42.037464	0.0003	43,46
PIPR63S	7.7846	51.04549	22	7.96	97.79	0.3	10	11.2224	3.8888	2.7588	0.782	10.566	3.5453	41.036572	0.0003	43,46
PIPR64S	5.4254	50.0446	22	7.945	70.0786	0.3	10	11.022	3.767275	5.9773	1.5639	12.007	8.1542	41.036572	0.0003	43,46
PIPR65S	5.7632	51.04549	22	7.965	81.5848	0.3	10	11.2224	3.8888	11.955	2.3459	15.369	15.245	42.037464	0.0003	43,46
PIPR66S	5.0152	51.04549	22	7.96	77.4319	0.3	10	11.2224	3.767275	23.22	3.1279	21.613	30.135	41.036572	0.0003	43,46
PIPR67S	5.9195	53.04728	22	7.97	110.871	0.3	10	11.2224	3.767275	46.899	4.6918	33.62	59.207	41.537018	0.0003	43,46
PIPR68S	5.4017	53.04728	22	7.96	151.892	0.3	10	11.6232	3.8888	117.94	7.0377	68.201	141.81	42.037464	0.0003	43,46
PIPR69S	4.1225	52.04638	22	7.94	175.26	0.3	10	11.4228	3.767275	236.79	10.948	128.24	279.72	43.038356	0.0003	43,46
PIPR70S	6.6575	47.04192	25	7.82	145.288	1.1	10	13.9359	2.983276	1.6093	0.391	3.362	1.4181	42.53791	0.0003	43,44
PIPR71S	4.6725	47.04192	20	7.82	111.76	1.1	10	13.9359	2.983276	1.6093	0.391	3.362	1.4181	43.038356	0.0003	43,44

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Appendix E. BLM Table

BLM Data Label	Model Output	Hard-ness (mg/L)	Model Input														Notes
	Critical Accumulation		Temp (ºC)	pH	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	
PIPR72S	2.3613	47.04192	15	7.82	79.1845	1.1	10	13.9359	2.983276	1.6093	0.391	3.362	1.4181	42.53791	0.0003	43,44
PIPR73S	1.1782	47.04192	10	7.82	60.0075	1.1	10	13.9359	2.983276	1.6093	0.391	3.362	1.4181	42.53791	0.0003	43,44
PIPR74S	7.6860	140.1249	22	8.03	370.078	0.3	10	29.058	12.03098	25.059	4.3008	60.036	25.881	98.087416	0.0003	43,46
PIPR75S	10.9585	88.0785	22	7.965	292.1	0.3	10	19.038	7.04845	14.943	2.7369	37.943	17.017	63.056196	0.0003	43,46
PIPR76S	7.9470	59.05263	22	7.89	101.473	0.3	10	12.024	4.61795	9.1959	0.782	23.054	9.9268	39.034788	0.0003	43,46
PIPR77S	6.9448	41.03657	22	7.825	62.5094	0.3	10	8.2164	3.038125	7.5866	2.7369	13.928	6.3815	29.025868	0.0003	43,46
PIPR78S	5.9976	27.02408	22	7.745	42.0624	0.3	10	5.6112	1.822875	4.598	2.3459	8.6452	4.2544	23.020516	0.0003	43,46
PIPR79S	9.0570	43.03836	22	7.885	172.466	1.1	10	10.4208	2.67355	1.6093	0.782	2.8817	1.4181	42.037464	0.0003	43,44
PIPR80S	0.7034	25.0223	22	7.565	12.4333	0.3	10	6.68596	2.02764	3.4485	1.1729	4.3226	4.9634	16.014272	0.0003	43,46
PIPR81S	7.0672	107.0954	22	8.105	271.272	0.3	10	28.6924	8.631893	14.254	1.9549	19.212	16.308	80.07136	0.0003	43,46
PIPR82S	4.9660	87.0776	22	7.055	71.12	0.3	10	23.3293	7.018455	13.564	1.9549	19.212	15.954	58.051736	0.0003	43,46
PIPR83S	5.1028	85.07582	22	7.33	79.629	0.3	10	22.793	6.857111	13.794	1.9549	19.212	15.954	58.051736	0.0003	43,46
PIPR84S	5.4229	88.0785	22	7.605	99.53625	0.3	10	23.5975	7.099127	13.564	1.9549	19.212	15.954	59.052628	0.0003	43,46
PIPR85S	6.5439	87.0776	22	7.745	132.715	0.3	10	23.3293	7.018455	14.484	1.9549	18.731	15.954	59.052628	0.0003	43,46
PIPR86S	5.4310	87.0776	22	8.07	137.16	0.3	10	23.3293	7.018455	12.644	1.9549	18.731	15.954	59.052628	0.0003	43,46
PIPR87S	5.4306	87.0776	22	8.375	182.245	0.3	10	23.3293	7.018455	13.334	1.9549	18.731	15.954	59.052628	0.0003	43,46
PIPR88S	5.7955	87.0776	22	8.73	268.9225	0.3	10	23.3293	7.018455	14.254	1.9549	18.731	14.89	59.052628	0.0003	43,46
PIPR89S	6.9862	87.0776	22	8.115	188.976	0.3	10	23.3293	7.018455	12.874	1.9549	18.731	15.954	59.052628	0.0003	43,46
PIPR90S	8.5781	251.2239	22	7.2	662.559	0.3	10	67.127	20.35751	57.475	4.6918	72.524	62.397	150.1338	0.0003	43,46
PIPR91S	9.0461	252.2248	22	7.575	904.875	0.3	10	67.3945	20.43861	57.475	4.6918	70.603	62.043	164.14629	0.0003	43,46
PIPR92S	8.7054	252.2248	22	7.915	995.68	0.3	10	67.3945	20.43861	57.475	4.6918	73.484	62.043	150.1338	0.0003	43,46
PIPR93S	6.4404	251.2239	22	8.275	891.54	0.3	10	67.127	20.35751	57.475	4.6918	73.484	62.043	143.12756	0.0003	43,46
PIPR94S	8.4348	200.1784	22	8.05	757.6185	0.3	10	53.5426	16.18781	37.243	3.5188	49.47	46.798	128.11418	0.0003	43,46
PIPR95S	8.0730	140.1249	22	7.95	404.8125	0.3	10	37.4414	11.35479	22.99	2.3459	28.817	25.172	99.088308	0.0003	43,46
PIPR96S	8.8271	90.08028	22	8.045	262.128	0.3	10	24.1338	7.260471	14.254	1.9549	18.731	15.599	65.05798	0.0003	43,46
PIPR97S	2.3840	19.01695	22	7.525	20.447	0.3	10	5.08133	1.541007	3.4485	0.782	0.9606	4.9634	19.016948	0.0003	43,46
PIPR98S	2.6680	34.03033	22	7.53	23.1648	0.3	10	9.0929	2.757591	3.4485	0.782	9.6058	4.6089	20.01784	0.0003	43,46
PIPR99S	4.5268	51.04549	22	7.54	34.9885	0.3	10	13.6394	4.136386	3.4485	0.782	16.81	4.6089	21.018732	0.0003	43,46
PIPR100S	3.5167	29.02587	22	7.585	27.94	0.3	10	7.75571	2.352063	3.4485	0.782	5.2832	4.6089	22.019624	0.0003	43,46
PIPR101S	3.1703	30.02676	22	7.605	26.67	0.3	10	8.02315	2.433168	1.3794	0.782	4.3226	2.4817	23.020516	0.0003	43,46
PIPR102S	1.9033	27.02408	22	7.55	20.32	0.3	10	7.22084	2.189852	10.345	1.1729	5.2832	13.118	20.01784	0.0003	43,46
PIPR103S	2.9068	27.02408	22	7.525	26.67	0.3	10	7.22084	2.189852	20.691	1.5639	10.566	26.59	20.01784	0.0003	43,46
PIPR104S	6.9464	90.08028	22	7.995	182.88	0.3	10	24.1338	7.260471	14.254	1.9549	19.212	15.954	63.056196	0.0003	43,46
PIPR105S	4.3303	60.05352	22	8.11	96.6724	0.3	10	16.0463	4.866337	11.955	1.5639	3.8423	17.372	58.051736	0.0003	43,46

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Appendix E. BLM Table

BLM Data Label	Model Output	Hard-ness (mg/L)	Model Input														Notes
	Critical Accumulation		Temp (ºC)	pH	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	
PIPR106S	6.1231	120.107	22	8.09	182.88	0.3	10	32.0926	9.732674	11.955	1.5639	33.62	17.372	59.052628	0.0003	43,46
PIPR107S	5.3380	180.1606	22	8.09	190.6905	0.3	10	48.1389	14.59901	11.955	1.5639	62.438	17.017	58.051736	0.0003	43,46
PIPR108S	4.7175	91.08117	22	8.125	127.0635	0.3	10	24.3369	7.380611	11.955	1.5639	19.212	15.954	59.052628	0.0003	43,46
PIPR109S	5.7327	90.08028	22	8.155	148.59	0.3	10	24.0695	7.299505	2.299	6.2557	15.85	6.027	60.05352	0.0003	43,46
PIPR110S	6.5363	93.08296	22	8.135	223.52	0.3	10	24.8718	7.542822	35.864	3.9098	27.377	49.989	62.055304	0.0003	43,46
PIPR111S	6.7795	92.08206	22	8.145	283.1465	0.3	10	24.6043	7.461717	71.728	7.4287	41.305	102.81	61.054412	0.0003	43,46
PIPR112S	5.0174	91.08117	22	8.19	150.241	0.3	10	24.402	7.341142	14.484	15.248	18.731	17.372	62.055304	0.0003	43,46
PIPR113S	6.2630	144.1284	22	8.38	644.525	0.3	10	38.5111	11.67921	34.485	3.1279	12.488	42.189	138.1231	0.0003	43,46
PIPR114S	5.5141	292.2605	22	8.27	697.5475	0.3	10	78.092	23.68284	34.485	3.1279	87.893	57.079	137.1222	0.0003	43,46
PIPR115S	5.1749	440.3925	22	8.225	752.475	0.3	10	117.673	35.68647	34.485	3.1279	175.31	41.125	133.11864	0.0003	43,46
PIPR116S	5.8459	217.1936	22	8.31	653.415	0.3	10	58.0341	17.59992	34.485	3.1279	46.588	43.253	133.11864	0.0003	43,46
PIPR117S	6.1591	218.1945	22	8.305	646.3665	0.3	10	58.3016	17.68102	6.8969	1.5639	38.903	9.5723	140.12488	0.0003	43,46
PIPR118S	5.9250	212.1891	22	8.345	939.8	0.3	10	56.6969	17.19439	103.45	7.8197	65.319	124.79	143.12756	0.0003	43,46
PIPR119S	8.2172	92.08206	22	8.125	253.365	0.3	10	24.6701	7.421814	14.254	1.9549	19.212	16.663	63.056196	0.0003	43,46
PIPR120F	0.3052	48	25	8.03	109.44	2.64	10	14.1077	3.111984	1.35	0.57	3.54	1.25	44	0.0003	1,2,3,6,7,15,26
PIPR121F	0.3617	45	25	8.04	116.16	2.64	10	13.2259	2.917485	1.27	0.57	3.33	1.17	44	0.0003	1,2,3,6,7,15,26
PIPR122F	0.1755	46	25	7.98	84.96	2.64	10	13.5198	2.982318	1.3	0.57	3.4	1.2	41	0.0003	1,2,3,6,7,15,26
PIPR123F	3.4889	30	25	6.82	418.56	10.4652	10	7.1362	2.964634	1.625	0.5	6.125	1.25	21	0.0003	1,2,3,6,7,27,28
PIPR124F	1.8656	37	25	7.28	495.36	11.3373	10	8.80131	3.656382	2.0042	0.5	7.5542	1.5417	21	0.0003	1,2,3,6,7,27,28
PIPR125F	2.8066	87	25	7.11	1522.56	31.3956	10	20.6978	8.4403	16.071	1.855	22.35	18.629	20	0.0003	1,2,3,6,7,27,29
PIPR126F	3.1774	73	25	6.94	1083.84	24.4188	10	17.2174	7.3329	10.539	1.5232	18.439	13.619	18	0.0003	1,2,3,6,7,27,29
PIPR127F	1.4538	84	25	7.07	528	14.5155	10	20.4644	8.008	6	1.4	34.5	10.95	12	0.0003	1,2,3,6,7,27,28
PIPR128F	1.0075	66	25	6.97	960.96	32.9018	10	16.0792	6.292	4.7143	1.4	27.107	8.6036	12	0.0003	1,2,3,6,7,27,28
PIPR129F	1.2809	43.9	25	7.4	88.32	2	10	12.9026	2.846168	1.24	0.57	3.24	1.14	42.4	0.0003	1,2,6,7,8,14,15
PIPR130F	0.0860	47.04192	22	8.1	27.94	1.1	10	13.9359	2.983276	1.6093	0.391	3.362	1.4181	42.53791	0.0003	43,44
PIPR131F	1.1899	243.2168	22	8.01	105.7275	1.1	10	92.7261	2.884195	47.129	0.391	3.362	143.23	43.038356	0.0003	43,44
PIPR132F	0.1230	255.7279	22	8.01	40.0558	1.1	10	14.1661	53.5752	1.6093	0.391	3.362	143.23	43.538802	0.0003	43,44
PIPR133F	0.4522	47.04192	22	8.1	64.262	1.1	10	13.9359	2.983276	47.589	0.391	3.362	72.324	43.538802	0.0003	43,44
PIPR134F	0.3833	45.04014	22	8.02	49.01565	1.1	10	13.3428	2.856328	1.6093	0.391	3.362	1.4181	43.038356	0.0003	43,44
PIPR135F	0.3216	45.04014	22	8.65	67.7164	1.1	10	13.3428	2.856328	1.6093	0.391	3.362	1.4181	47.041924	0.0003	43,44
PIPR136F	0.1834	45.54059	22	7.3	18.669	1.1	10	13.4911	2.888065	1.6093	0.391	3.362	1.4181	44.039248	0.0003	43,44
PIPR137F	0.1256	49.04371	22	6.63	6.1468	1.1	10	14.5289	3.110224	1.6093	0.391	3.362	1.4181	49.043708	0.0003	43,44
PIPR138F	0.2961	45.04014	22	7.16	20.447	1.1	10	13.3428	2.856328	1.6093	0.391	3.362	15.599	26.023192	0.0003	43,44
PIPR139F	2.8408	43.03836	22	7.93	93.36405	1.1	10	12.7498	2.72938	1.6093	0.391	3.362	1.4181	41.036572	0.0003	43,44

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Appendix E. BLM Table

BLM Data Label	Model Output	Hard-ness (mg/L)	Model Input														Notes
	Critical Accumulation		Temp (ºC)	pH	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	
PIPR140F	0.0373	45.54059	22	7.91	245.364	6.1	83.7705	13.4911	2.888065	1.6093	0.391	3.362	1.4181	44.039248	0.0003	43,47
PIPR141F	1.3667	45.04014	22	7.94	72.3392	1.1	10	13.3428	2.856328	1.6093	0.391	3.362	1.4181	43.038356	0.0003	43,44
PIPR142F	0.0310	45.04014	22	7.95	229.8065	6.1	83.7705	13.3428	2.856328	1.6093	0.391	3.362	1.4181	43.038356	0.0003	43,47
PIPR143F	0.1023	45.54059	22	7.94	195.453	3.6	72.5	13.4911	2.888065	1.6093	0.391	3.362	1.4181	44.039248	0.0003	43,47
PIPR144F	0.1038	45.04014	22	7.91	109.347	2.35	57.8723	13.3428	2.856328	1.6093	0.391	3.362	1.4181	42.037464	0.0003	43,47
PIPR145F	1.9076	44.03925	22	7.87	78.0034	1.1	10	13.0463	2.792854	1.6093	0.391	3.362	1.4181	42.037464	0.0003	43,44
PIPR146F	0.4905	44.03925	22	7.84	45.52315	1.1	10	13.0463	2.792854	1.6093	0.391	3.362	19.145	17.015164	0.0003	43,44
PIPR147F	1.3078	22.52007	22	6.01	4.3815	0.3	10	6.01736	1.824876	3.4485	0.391	3.362	4.2544	15.01338	0.0003	43,46
PIPR148F	1.5995	24.02141	22	7.02	12.4333	0.3	10	6.41852	1.946535	3.6784	0.391	3.362	4.9634	17.015164	0.0003	43,46
PIPR149F	2.4015	23.02052	22	8	26.8605	0.3	10	6.15108	1.865429	4.1382	0.782	3.362	4.9634	17.51561	0.0003	43,46
PIPR150F	2.3670	21.51918	22	9.01	51.3334	0.3	10	5.74992	1.743771	4.598	1.5639	3.362	4.9634	19.016948	0.0003	43,46
PTLU01S	4.0390	173	22	8.3	364.8	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
PTLU02S	9.0637	173	22	7.25	460.8	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
PTOR01F	0.2752	25	7.8	7.3	22.08	1.1	10	7.1535	1.9754	4.8154	0.7	3.997	5.9792	25	0.0003	1,2,3,6,7,9,10
PTOR02F	0.1587	54	11.5	7.3	17.28	1.1	10	15.0937	3.6371	6.8831	0.7	12.163	9.6854	43	0.0003	1,2,3,6,7,9,10
XYTE01S	2.6511	173	22	8.15	211.2	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
XYTE02S	4.5011	173	22	8.05	326.4	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
POAC01S	2.2126	167	22	8	153.6	0.5	10	27.5609	23.881	51.724	4.1335	160.32	3.7478	115	0.0003	1,2,3,4,6,7,20
LEMA01R	25.6628	85	20.2	7.3	2200	1.1	10	23.9	6.5	0.64	0.46	4.32	1.5	82	0.0003	50
LEMA02F	25.8381	45	20	7.5	1056	1.1	10	13.2259	2.917485	1.3	0.57	3.4	1.2	43	0.0003	1,2,3,6,7,8
LEMA03F	27.6113	25.9	19	7.03	960	1.5	10	6.38814	2.42165	5.4743	1.6	26.489	19.425	27.1	0.0003	1,2,3,6,7,16
LEMA04F	22.5658	85	21.85	7.45	1300	1.1	10	23.9	6.5	0.64	0.46	4.32	1.5	82	0.0003	50
ETFL01S	5.5744	170	20	7.8	316.8	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETFL02S	5.7421	170	20	7.8	327.36	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETFL03S	5.8278	170	20	7.9	358.08	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETFL04S	6.4920	170	20	7.8	376.32	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETLE01S	3.7314	167	22	8	249.6	0.5	10	27.5609	23.881	51.724	4.1335	160.32	3.7478	115	0.0003	1,2,3,4,6,7,20
ETNI01S	7.8536	170	20	7.8	473.28	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETNI02S	7.7256	170	20	7.8	463.68	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETNI03S	9.1617	170	20	7.8	577.92	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETNI04S	8.5329	170	20	7.8	526.08	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETRU01S	0.4735	167	22	8.2	57.6	0.5	10	27.5609	23.881	51.724	4.1335	160.32	3.7478	115	0.0003	1,2,3,4,6,7,20
BUBO01S	1.7185	167	22	7.9	115.2	0.5	10	27.5609	23.881	51.724	4.1335	160.32	3.7478	115	0.0003	1,2,3,4,6,7,20

Appendix F. Regression Plots

Appendix F. Analyses of Chronic Data

The following pages contain figures and other information related to the regression and probability distribution analyses that were performed to calculate chronic EC20s. The initial parameter estimates are shown in the tables below. In the figures that follow, circles denote measured responses and solid lines denote estimated regression lines.

Probability Distribution Analysis

Species	Study	Test	Endpoint	Final Estimates				
				Control Value	EC50	Standard Deviation	EC20	EC10
Snail, *Campeloma decisum (Test 1)*	Arthur and Leonard 1970	LC	Survival	0.925	14.50	0.192	8.73	7.01
Snail, *Campeloma decisum (Test 2)*	Arthur and Leonard 1970	LC	Survival	0.875	11.80	0.339	10.94	9.16
Cladoceran, *Daphnia pulex*	Winner 1985	LC	Survival	1.00	4.57	0.260	2.83	2.24
Cladoceran, *Daphnia pulex*	Winner 1985	LC	Survival	0.900	11.3	0.111	9.16	8.28
Caddisfly, *Clistoronia magnifica*	Nebeker et al. 1984b	LC	Emergence (adult 1st gen)	0.750	20.0	0.300	7.67	5.63
Bluegill (larval), *Lepomis macrochirus*	Benoit 1975	ELS	Survival	0.880	39.8	0.250	27.15	21.60

Logistic Regression Analysis

Species	Study	Test	Endpoint	Final Estimates				
				Control Value	EC50	Slope	EC20	EC10
Cladoceran, *Ceriodaphnia dubia*	Carlson et al. 1986	LC	Reproduction	13.10	14.6	1.36	9.17	7.28
Cladoceran, *Daphnia magna*	Chapman et al. Manuscript	LC	Reproduction	171.5	16.6	1.40	12.58	10.63
Cladoceran, *Daphnia magna*	Chapman et al. Manuscript	LC	Reproduction	192.1	28.4	1.59	19.89	16.34
Cladoceran, *Daphnia magna*	Chapman et al. Manuscript	LC	Reproduction	88.0	15.8	1.00	6.06	3.64
Rainbow trout, *Oncorhynchus mykiss*	Seim et al. 1984	ELS	Biomass	137.6	40.7	1.69	27.77	22.16
Rainbow trout, *Oncorhynchus mykiss*	Besser et al. 2001	ELS	Biomass	1224	29.2	1.99	20.32	16.74
Chinook salmon, *Oncorhynchus tshawytscha*	Chapman 1975, 1982	ELS	Biomass	0.901	9.55	1.27	5.92	4.47
Fathead minnow, *Pimephales promelas*	Lind et al. manuscript	ELS	Biomass	108.4	11.4	4.00	9.38	8.67

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Evaluation of the Chronic Data Available for Freshwater Species

Following is a species-by-species discussion of each chronic test on copper evaluated for this document. Also presented are the results of regression analysis and probability distribution analysis of each dataset that was from an acceptable chronic test and contained sufficient acceptable data. For each such dataset, this appendix contains a figure that presents the data and regression/probability distribution line.

Brachionus calyciflorus. The chronic toxicity of copper was ascertained in 4-day renewal tests conducted at regular intervals throughout the life of the freshwater rotifer, *B. calyciflorus* (Janssen et al. 1994). The goal of this study was to develop and examine the use of this rotifer as a viable test organism. The effect of copper on the age-specific survivorship and fertility of *B. calyciflorus* was determined, but no individual replicate data were provided and only three copper concentrations were tested, which precludes these data from further regression analysis. Chronic limits based on the intrinsic rate of natural increase were 2.5 µg/L total copper (NOAEC) and 5.0 µg/L total copper (LOAEC). The chronic value determined via traditional hypothesis testing is 3.54 µg/L total copper (Table 2a).

Campeloma decisum. Adult *C. campeloma* were exposed to five concentrations of total copper and a control (Lake Superior water) under flow-through conditions in two 6-week studies conducted by Arthur and Leonard (1970). Adult survival in the two separate chronic copper toxicity test trials was markedly reduced in the two highest copper concentrations, 14.8 and 28.0 µg/L, respectively. The authors reported that growth, as determined from cast exoskeleton, was not measurable for this test species, although the authors did observe that the adult snails would not consume food at the two highest copper concentrations. Control survival was 80 percent or greater. Chronic values of 10.88 µg/L total copper were obtained for survival based on the geometric mean of the NOAEC and LOAEC of 8.0 and 14.8 µg/L, respectively, in both tests. The corresponding EC20s were 8.73 and 10.94 µg/L (Table 2a).

Ceriodaphnia dubia. The chronic toxicity of copper to *C. dubia* was determined in ambient river water collected upstream of known point-source discharges of domestic and industrial wastes as part of a water effect ratio study (Carlson et al. 1986). In this study, survival and young production of *C. dubia* were assessed using a 7-day life-cycle test. Organisms were not affected at total copper concentrations ranging from 3 to 12 µg/L (5 to 10 µg/L dissolved copper). There was a 62.7 percent reduction in survival and 97 percent reduction in the mean number of young produced per female at 32 µg/L total copper (27 µg/L dissolved copper). No daphnids survived to produce young at 91 µg/L total copper. Control survival during the study was 80 percent, which included one male. The chronic value EC20 selected for *C. dubia* in this study, 9.17 µg/L derived from a nonlinear regression evaluation, was based on mean number of young produced (reproduction).

The effects of water hardness on the chronic toxicity of copper to *C. dubia* were assessed by Belanger et al. (1989) using 7-day life-cycle tests. *C. dubia* 2 to 8 hours old were exposed to copper in ambient surface water from the New and Clinch Rivers, Virginia. Mean water hardness levels were 179 and 94 mg/L as $CaCO_3$, respectively. Test water was renewed on days 3 and 5. The corresponding chronic values for reproduction based on the NOAEC and LOAEC approach were 7.9 and <19.3 µg/L dissolved copper, respectively. The EC20 value for number of young (neonates) produced in Clinch River water (water hardness of 94 mg/L as $CaCO_3$) was 19.36 µg/L dissolved copper. The EC20 for young produced in New River water was not calculated. The chronic values were converted to total copper using the freshwater conversion factor for copper 0.96 (e.g., 7.897/0.96). The resulting total chronic values for the New and Clinch rivers are 8.23 and 20.17 µg/L, respectively.

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Copper was one of 12 toxicants examined by Oris et al. (1991) in their comparisons between a 4-day survival and reproduction toxicity test utilizing *C. dubia* and a standard 7-day life-cycle test for the species. The reported 7-day chronic values for survival and reproduction (mean total young per living female) in two tests based on the traditional hypothesis testing techniques were 24.5 and 34.6 µg/L total copper. Comparable point estimates for these 7-day tests could not be calculated using regression analysis.

Daphnia magna. Blaylock et al. (1985) reported the average numbers of young produced for six broods of *D. magna* in a 14-day chronic exposure to copper. A significant reduction was observed in the mean number of young per female at a concentration of 30 µg/L total copper, the highest copper concentration tested. At this concentration, young were not produced at brood intervals 5 and 6. Reproduction was not affected at 10 µg/L total copper. The chronic value determined for this study (17.32 µg/L total copper) was based on the geometric mean of the NOAEC, 10 µg/L, and LOAEC, 30 µg/L.

Van Leeuwen et al. (1988) conducted a standard 21-day life-cycle test with *D. magna*. The water hardness was 225 mg/L as $CaCO_3$. Carapace length was significantly reduced at 36.8 µg/L total copper, although survival was 100 percent at this concentration. Carapace length was not affected at 12.6 µg/L total copper. No daphnids survived at 110 µg/L concentration. The highest concentration not significantly different from the control for survival was 36.8 µg/L. The lowest concentration significantly different from the control based on survival was 110 µg/L, resulting in a chronic value of 63.6 µg/L for survival. The chronic value based on carapace length was 21.50 µg/L. The 21-day EC10 as reported by the author was 5.9 µg/L total copper.

Chronic (21-day) renewal toxicity tests were conducted using *D. magna* to determine the relationship between water hardness (nominal values of 50, 100, and 200 mg/L as $CaCO_3$, respectively) and the toxicity of total copper (Chapman et al. unpublished manuscript). All test daphnids were <1 day old at the start of the tests. The dilution water was well water from the Western Fish Toxicology Station (WFTS), Corvallis, Oregon. Test endpoints were reproduction (total and live young produced per female) and adult survival. The survival of control animals was 100 percent at nominal water hardness levels of 50 and 200 mg/L as $CaCO_3$, and 80 percent at a hardness of 100 mg/L as $CaCO_3$. The chronic values for total young produced per female (fecundity) based on the geometric mean of the NOAEC and LOAEC were 13.63, 29.33, and 9.53 µg/L at the nominal hardness levels of 50, 100, and 200 mg/L as $CaCO_3$, respectively. The corresponding EC20 values for reproduction calculated using nonlinear regression analysis were 12.58, 19.89, and 6.06 µg/L total copper. The chronic toxicity of copper to *D. magna* was somewhat ameliorated from an increase in water hardness from 50 to 100 mg/L as $CaCO_3$, but slightly increased from 100 to 200 mg/L as $CaCO_3$.

Daphnia pulex. Winner (1985) evaluated the effects of water hardness and humic acid on the chronic toxicity (42-day) of copper to *D. pulex*. Contrary to the expectation that sublethal endpoints are more sensitive indicators of chronic toxicity, reproduction was not a sensitive indicator of copper stress in this species. Water hardness also had little effect on the chronic toxicity of copper (similar to *D. magna* trends), but humic acid significantly reduced chronic toxicity of copper when added to the varying water types. The survival chronic values based on the NOAEC and LOAEC values for the three low to no humic acid studies were 4.90, 7.07, and 12.25 µg/L total copper at hardnesses of 57.5, 115, and 230 (0.15 mg/L HA) µg/L as $CaCO_3$, respectively. The EC20 values calculated for the low and high hardness studies using nonlinear regression techniques were 2.83 and 9.16 µg/L at hardness values of 57.5 and 230 (0.15 mg/L HA) µg/L as $CaCO_3$, respectively.

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Clistoronia magnifica. The effects of copper on the lifecycle of the caddisfly, *C. magnifica*, were examined in Nebeker et al. (1984b). The test included continuous exposure of first-generation aquatic larvae and pupae through to a third generation of larvae. A significant reduction in adult emergence occurred at 13.0 µg/L total copper from first-generation larvae. No observed adverse effect to adult emergence occurred at 8.3 µg/L total copper. Percent larval survival was close to the control value of 80 percent. The chronic value based on hypothesis testing was 10.39 µg/L total copper. The corresponding EC20 value for adult emergence was 7.67 µg/L total copper.

Oncorhynchus mykiss. The growth and survival of developing *O. mykiss* embryos continuously and intermittently exposed to copper for up to 85 days post-fertilization was examined by Seim et al. (1984). Results only from the continuous exposure study are considered here for deriving a chronic value. A flow-through apparatus was used to deliver six concentrations and a control (untreated well water; average of 3 µg/L copper) to a single incubation chamber. Continuous copper exposure of steelhead embryos in the incubation chambers was begun 6 days post-fertilization. At 7 weeks post-fertilization, when all control fish had hatched and reached swim-up stage, subsamples of approximately 100 alevins were transferred to aquaria and the same exposure pattern continued. Dissolved oxygen remained near saturation throughout the study. Water hardness averaged 120 mg/L as $CaCO_3$. Survival of steelhead embryos and alevins exposed continuously to total copper concentrations in the range of 3 (controls) to 30 µg/L was greater than 90 percent or greater. Survival was reduced at 57 µg/L and completely inhibited at 121 µg/L. A similar effect on survival was observed for embryos and alevins exposed to a mean of 51 (peak 263) and 109 (peak 465) µg/L of copper in the intermittent exposure, respectively. The adverse effect of continuous copper exposure on growth (measured on a dry weight basis) was observed at concentrations as low as 30 µg/L. (There was a 30 percent reduction in growth during the intermittent exposure at 16 µg/L.) The chronic limits for survival of embryos and alevin steelhead trout exposed continuously to copper were 16 and 31 µg/L, respectively (geometric mean = 22.27 µg/L). The EC20 for biomass for the continuous exposure was 27.77 µg/L.

Besser et al. (2001) conducted an ELS toxicity test with copper and the rainbow trout, *O. mykiss*, starting with eyed embryos and continuing for 30 days after the fish reached the swim-up stage. The total test period was 58 days. The test was conducted in ASTM moderately hard reconstituted water with a hardness of approximately 160 to 180 mg/L as $CaCO_3$. Twenty-five eyed embryos were held in each of four replicate egg cups at each concentration. Survival was monitored daily. At the end of the test, surviving fish in each replicate chamber were weighed (dry weight). Dry weights were used to determine growth and biomass of surviving fish. The no observed effect concentrations (NOECs) for survival and biomass were both 12 µg/L and the lowest observed effect concentrations (LOECs) for survival and biomass was also the same for both endpoints, 22 µg/L. The chronic values for biomass and survival based on the geometric mean of the NOEC and LOEC were 16.25 µg/L. The corresponding EC20 for biomass was 20.32 µg/L.

Oncorhynchus tshawytscha. The draft manuscript prepared by Chapman (1975/1982) provides the results from a 4-month egg through fry partial chronic test conducted to determine the effects of copper on survival and growth of *O. tshawytscha*. Continuous exposure occurred from several hours post-fertilization through hatch, swim-up, and feeding fry stages. The test was terminated after 14 weeks post-hatch. The dilution water was WFTS well water. Because of the influence of the nearby Willamette River on the hardness of this well water, reverse osmosis water was mixed periodically with ambient well water to attain a consistent hardness. The typical hardness of this well water was approximately 23 mg/L as $CaCO_3$. Control survival exceeded 90 percent for the test. The measured total copper concentrations during the test were 1.2 (control), 7.4, 9.4, 11.7, 15.5, and 20.2 µg/L, respectively. Copper adversely affected survival at 11.7 µg/L copper and higher, and growth was reduced at all copper concentrations tested compared with the growth of control fish. The chronic limits for copper in this study were

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estimated to be less than 7.4 µg/L. The EC20 value estimated for biomass is 5.92 µg/L total copper based on a logistic nonlinear regression model.

Salmo trutta. McKim et al. (1978) examined the survival and growth (expressed as standing crop) of embryo-larval and early juvenile brown trout to copper. The most sensitive exposure was with embryos exposed for 72 days. The NOAEC and LOAEC, as obtained from the figure, were 20.8 and 43.8 µg/L total copper, respectively. Data were not available to calculate point estimates at the 20 percent effect level using regression analysis. The chronic value selected for this species was 29.91 µg/L total copper (geometric mean of 20.8 and 43.8 µg/L total copper).

Salvelinus fontinalis. Sauter et al. (1976) examined the effects of copper on selected freshwater fish species at different hardness levels (softwater at 37.5 mg/L as $CaCO_3$; hardwater at 187 mg/L as $CaCO_3$) during a series of partial life-cycle (PLC) tests. The species tested were brook trout (*Salvelinus fontinalis*), channel catfish (*Ictalurus punctatus*), and walleye (*Stizostedion vitreum*). Because of the poor embryo and larval survival of control animals (in all cases less than 70 percent), results from tests with channel catfish and walleye were not included in Table 2a. One of the replicate control chambers from the PLC tests conducted with brook trout in hard water also exhibited poor hatchability (48 percent) and survival (58 percent) between 31 and 60 days of exposure. Therefore, the data for brook trout in hard water were not included in the subsequent EC20 (regression) analysis either.

The softwater test with brook trout was conducted using untreated well water with an average water hardness of 35 mg/L as $CaCO_3$. This PLC exposure consisted of six copper concentrations and a control. Hatchability was determined by examining randomly selected groups of 100 eggs from each replicate exposure tank. Growth and survival of fry were determined by impartially reducing the total sample size to 50 fry per tank and assessing their progress over 30 day intervals up to 60 days post-hatch. The chronic limits based on the growth (wet weight and total length) of larval brook trout after 60 days of exposure to copper in soft water were <5 and 5 µg/L. The resultant chronic value for soft water based on hypothesis testing was <5 µg/L. The corresponding EC20 values based on total length, wet weight, and biomass (the product of wet weight and survival) for brook trout in the soft-water exposures after 60 days were not amenable to nonlinear regression analysis.

McKim et al. (1978) examined survival and growth (expressed as standing crop) of embryo-larval and early juvenile brook trout exposed to copper. The embryo exposure was for 16 days, and the larval-early-juveniles exposure lasted 60 days. The NOAEC and LOAEC were 22.3 and 43.5 µg/L total copper, respectively. Data were not available to calculate point estimates at the 20 percent effect level using regression analysis. The chronic value for this species was 31.15 µg/L total copper (geometric mean of 22.3 and 43.5 µg/L total copper).

Salvelinus namaycush. McKim et al. (1978) examined the survival and growth (expressed as standing crop) of embryo-larval and early juvenile lake trout exposed to copper. The embryo exposure was for 27 days, and the larval-early-juveniles exposure lasted 66 days. The NOAEC and LOAEC were 22.0 and 43.5 µg/L total copper, respectively. Data were not available to calculate point estimates at the 20 percent effect level using regression analysis. The chronic value for this species was 30.94 µg/L total copper (geometric mean of 22.0 and 43.5 µg/L total copper).

Esox lucius. McKim et al. (1978) examined the survival and growth (expressed as standing crop) of embryo-larval and early juvenile northern pike exposed to copper. The embryo exposure was for 6 days, and the larval-early-juveniles exposure lasted 34 days. The NOAEC and LOAEC were 34.9 and 104.4 µg/L total copper, respectively. The authors attributed the higher tolerance of *E. lucius* to copper to the very short embryonic exposure period compared with salmonids and white sucker, *Catostomus*

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commersoni. Data were not available to calculate point estimates at the 20 percent effect level using regression analysis. The chronic value for this species was 60.36 µg/L total copper (geometric mean of 34.9 and 104.4 µg/L total copper).

Pimephales notatus. An experimental design similar to that described by Mount and Stephan (1967) and Mount (1968) was used to examine the chronic effect of copper on the bluntnose minnow, *P. notatus* (Horning and Neiheisel 1979). Measured total copper concentrations were 4.3 (control), 18.0, 29.9, 44.1, 71.8, and 119.4 µg/L, respectively. The experimental dilution water was a mixture of spring water and demineralized City of Cincinnati tap water. Dissolved oxygen was kept at 5.9 mg/L or greater throughout the test. Total water hardness ranged from 172 to 230 mg/L as $CaCO_3$. The test was initiated with 22 6-week-old fry. The fish were later separated according to sex and thinned to a sex ratio of 5 males and 10 females per duplicated test chamber. Growth (total length) was significantly reduced in parental and first (F_1) generation *P. notatus* after 60 days of exposure to the highest concentration of copper tested (119.4 µg/L). Survival of parental *P. notatus* exposed to this same high test concentration was also lower (87 percent) at the end of the test compared with the other concentrations (range of 93 to 100 percent). Copper at concentrations of 18 µg/L and greater significantly reduced the number of eggs produced per female. The number of females available to reproduce was generally the same up to about 29.9 µg/L of copper. The chronic limits were based on an NOAEC and LOAEC of <18 and 18 µg/L for number of eggs produced per female. An EC20 was not estimated by nonlinear regression; nevertheless, in this case an EC20 is likely to be substantially below 18 µg/L.

Pimephales promelas. The results from a 30-day ELS toxicity test to determine the chronic toxicity of copper to *P. promelas* using dilution water from Lake Superior (hardness ranging from 40 to 50 mg/L as $CaCO_3$) was included in Table 2a from a manuscript prepared by Lind et al. in 1978. In this experiment, five test concentrations and a control were supplied by a continuous-flow diluter. The exposure began with embryos 1 day post-fertilization. Pooled results from fish dosed in replicate exposure chambers were given for mean percentage embryo survival to hatch, mean percentage fish survival after hatch, and mean fish wet weight after 30 days. The percentage of embryo survival to hatch was not affected by total copper concentrations as high as 52.1 µg/L total copper. Survival after hatch, however, was compromised at 26.2 µg/L, and mean wet weight of juvenile fathead minnows was significantly reduced at 13.1 µg/L of copper. The estimated EC20 value for biomass was 9.376 µg/L total copper.

Catastomus commersoni. McKim et al. (1978) examined the survival and growth (expressed as standing crop) of embryo-larval and early juvenile white sucker exposed to copper. The embryo exposure was for 13 days, and the larval-early-juvenile exposure lasted 27 days. The NOAEC and LOAEC were 12.9 and 33.8 µg/L total copper, respectively. The resulting chronic value based on hypothesis testing for this species was 20.88 µg/L total copper (geometric mean of 12.9 and 33.8 µg/L total copper).

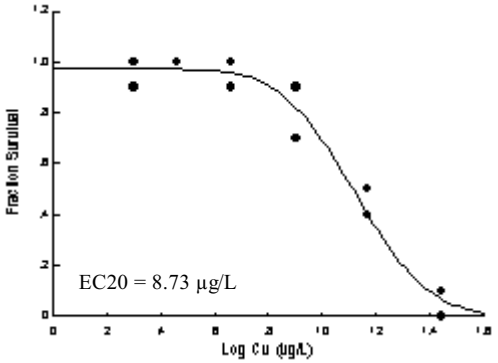
Lepomis macrochirus. Results from a 22-month copper life-cycle toxicity test with bluegill (*L. macrochirus*) were reported by Benoit (1975). The study included a 90-day embryo-larval survival and growth component. The tests were conducted at the U.S. EPA National Water Quality Laboratory in Duluth, Minnesota, using Lake Superior water as the dilution water (average water hardness = 45 mg/L as $CaCO_3$). The test was initiated in December 1969 with 2-year-old juvenile *L. macrochirus*. In May 1971, the fish were sexed and randomly reduced to three males and seven females per tank. Spawning commenced on 10 June 1971. The 90-day embryo-larval exposure was initiated when 12 lots of 50 newly hatched larvae from one of the two control groups were randomly selected and transferred to duplicate grow-out chambers at 1 of 6 total copper concentrations: 3 (control), 12, 21, 40, 77, and 162 µg/L, respectively. In the 22-month juvenile through adult exposure, survival, growth, and reproduction were unaffected at 77 µg/L of copper and below. No spawning occurred at 162 µg/L. Embryo hatchability and

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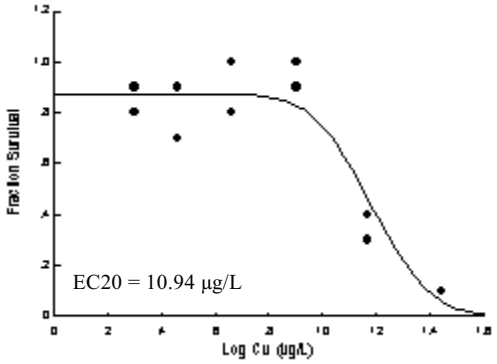
survival of 4-day-old larvae at 77 µg/L did not differ significantly from those of controls. However, after 90 days of exposure, survival of larval *L. macrochirus* at 40 and 77 µg/L was significantly lower than for controls, and no larvae survived at 162 µg/L. Growth remained unaffected at 77 µg/L. Based on the 90-day survival of bluegill larvae, the chronic limits were estimated to be 21 and 40 µg/L (geometric mean = 28.98 µg/L). The corresponding EC20 for embryo-larval survival was 27.15 µg/L.

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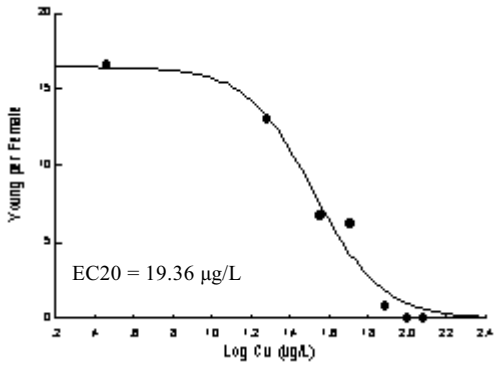
***Campeloma decisum* (Test 1), Life-cycle, Arthur and Leonard 1970**



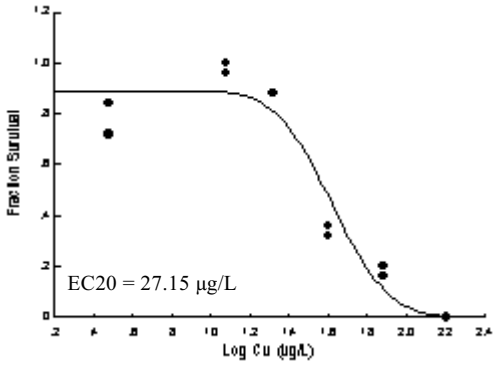
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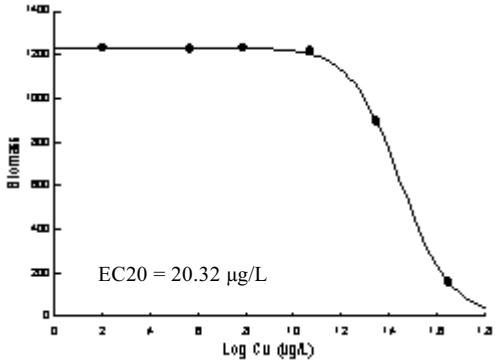
***Ceriodaphnia dubia* (Clinch River), Life-cycle, Belanger et al. 1989**



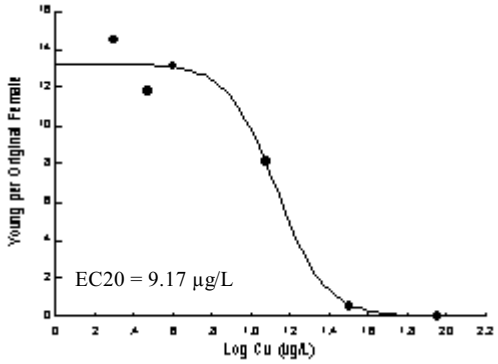
***Lepomis macrochirus*, Early Life-stage, Benoit 1975**



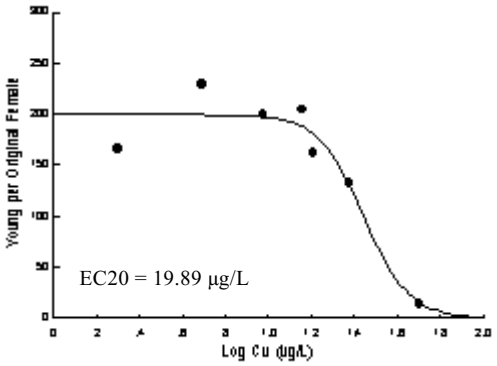
***Oncorhynchus mykiss*, Early Life-Stage, Besser et al. 2001**



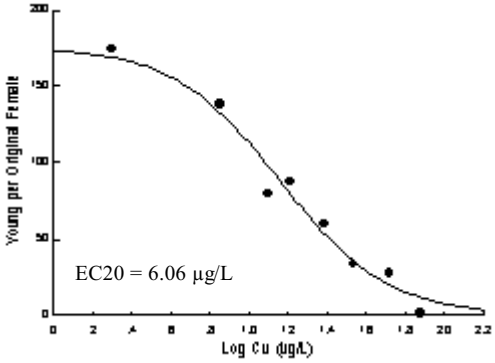
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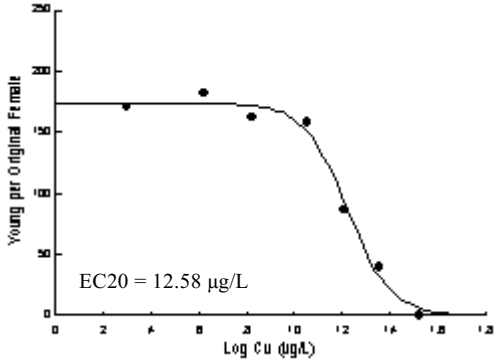
***Daphnia magna* (Hardness 104), Life-cycle, Chapman et al. Manuscript**



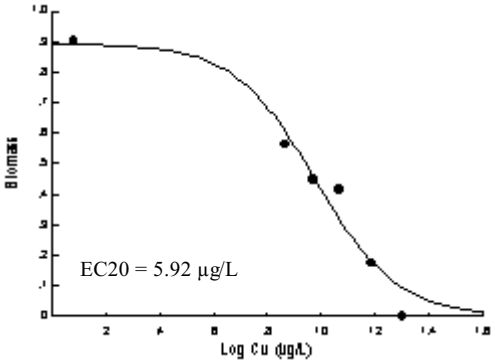
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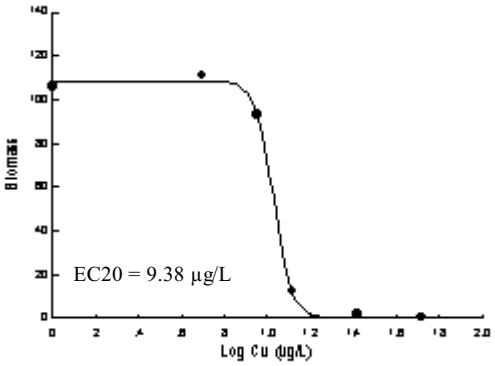
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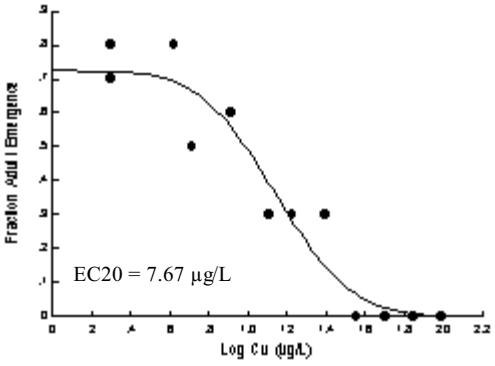
***Oncorhynchus tshawytscha*, Early Life-Stage, Chapman 1975 & 1982**



***Pimephales promelas*, Early Life-stage, Lind et al. 1978**

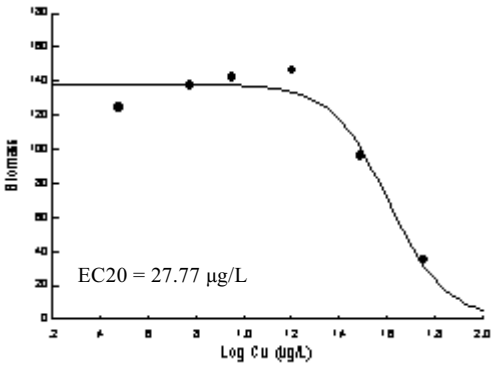


***Clistoronia magnifica*, Life-cycle, Nebeker et al. 1984a**

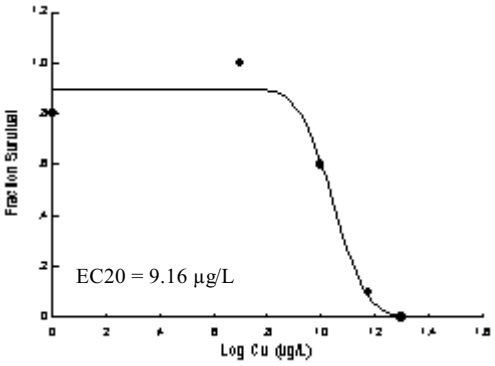


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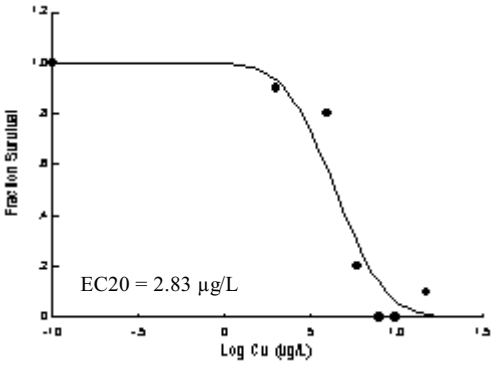
***Oncorhynchus mykiss,* Early Life-stage, Seim et al. 1984**



***Daphnia pulex* (Hardness 230 HA 0.15), Life-cycle, Winner 1985**



***Daphnia pulex (Hardness 57)*, Life-cycle, Winner 1985**



Appendix G. Example Water Quality Criteria Values Using the BLM and the Hardness Equation

Appendix G: Representative water quality criteria values using the BLM and the Hardness equation approaches for waters with a range in pH, Hardness, and DOC concentrations. The BLM calculation assumed that alkalinity was correlated with pH, and that other major ions were correlated with hardness based on observed correlations in EPA synthetic water recipes.

pH	Hardness	DOC	Hardness Equation Based Water Quality Criterion for Cu[1]	BLM Based Instantaneous Water Quality Criterion for Cu
	mg/L $CaCO_3$	mg / L	µg / L	µg / L
6.5	40	2	5.9	1.6
		4	5.9	3.3
		8	5.9	6.8
		16	5.9	14.3
	80	2	11.3	1.9
		4	11.3	3.8
		8	11.3	7.7
		16	11.3	16.0
	159	2	21.7	2.3
		4	21.7	4.5
		8	21.7	9.2
		16	21.7	18.9
	317	2	41.5	2.8
		4	41.5	5.6
		8	41.5	11.4
		16	41.5	23.1
7.0	40	2	5.9	3.9
		4	5.9	8.0
		8	5.9	16.4
		16	5.9	34.3
	80	2	11.3	4.4
		4	11.3	8.8
		8	11.3	18.0
		16	11.3	37.0
	159	2	21.7	5.1
		4	21.7	10.3
		8	21.7	20.7
		16	21.7	42.4
	317	2	41.5	6.2
		4	41.5	12.4
		8	41.5	24.9
		16	41.5	50.6

pH	Hardness	DOC	Hardness Equation Based Water Quality Criterion for Cu[1]	BLM Based Instantaneous Water Quality Criterion for Cu
	mg/L $CaCO_3$	mg / L	µg / L	µg / L
7.5	40	2	5.9	7.9
		4	5.9	15.8
		8	5.9	32.4
		16	5.9	67.3
	80	2	11.3	8.7
		4	11.3	17.4
		8	11.3	35.3
		16	11.3	72.5
	159	2	21.7	10.1
		4	21.7	20.1
		8	21.7	40.5
		16	21.7	82.4
	317	2	41.5	12.0
		4	41.5	23.9
		8	41.5	47.8
		16	41.5	96.8
8.0	40	2	5.9	13.8
		4	5.9	27.6
		8	5.9	55.8
		16	5.9	115.0
	80	2	11.3	15.5
		4	11.3	30.6
		8	11.3	61.4
		16	11.3	125.1
	159	2	21.7	18.0
		4	21.7	35.3
		8	21.7	70.3
		16	21.7	142.0
	317	2	41.5	21.5
		4	41.5	41.6
		8	41.5	82.3
		16	41.5	165.1

pH	Hardness	DOC	Hardness Equation Based Water Quality Criterion for Cu[1]	BLM Based Instantaneous Water Quality Criterion for Cu
	mg/L $CaCO_3$	mg / L	μg / L	μg / L
8.5	40	2	5.9	22.5
		4	5.9	43.3
		8	5.9	85.6
		16	5.9	172.9
	80	2	11.3	26.0
		4	11.3	49.1
		8	11.3	96.0
		16	11.3	191.6
	159	2	21.7	31.4
		4	21.7	58.0
		8	21.7	111.7
		16	21.7	220.6
	317	2	41.5	39.1
		4	41.5	70.3
		8	41.5	132.8
		16	41.5	259.6

Notes:

[1] : Hardness Equation: $\boldsymbol{CMC} = \boldsymbol{e}^{(0.9422\,[\ln(H)] - 1.7)}$

where:
H = water hardness (mg/L $CaCO_3$)

* Appendix updated as of March 2, 2007

Appendix H. Unused Data

APPENDIX H. UNUSED DATA

Based on the requirements set forth in the guidelines (Stephan et al. 1985), the following studies are not acceptable for the following reasons and are classified as unused data.

Studies Were Conducted with Species That Are Not Resident in North America

Abalde et al. (1995)
Abel (1980)
Ahsanullah and Ying (1995)
Ahsanullah et al. (1981)
Aoyama and Okamura (1984)
Austen and McEvoy (1997)
Bougis (1965)
Cid et al. (1995, 1996a,b)
Collvin (1984)
Cosson and Martin (1981)
Daly et al. (1990a,b, 1992)
Denton and Burdon-Jones (1986)
Drbal et al. (1985)
Giudici and Migliore (1988)
Giudici et al. (1987, 1988)
Gopal and Devi (1991)
Gustavson and Wangberg (1995)
Hameed and Raj (1989)
Heslinga (1976)
Hori et al. (1996)
Huebner and Pynnonen (1992)
Ismail et al. (1990)
Jana and Bandyopadhyaya (1987)
Jindal and Verma (1989)
Jones (1997)
Kadioglu and Ozbay (1995)
Karbe (1972)
Knauer et al. (1997)
Kulkarni (1983)
Kumar et al. (1985)
Lan and Chen (1991)
Lee and Xu (1984)
Luderitz and Nicklisch (1989)
Majori and Petronio (1973)
Masuda and Boyd (1993)
Mathew and Fernandez (1992)
Maund et al. (1992)
Migliore and Giudici (1988)
Mishra and Srivastava (1980)
Negilski et al. (1981)
Nell and Chvojka (1992)
Neuhoff (1983)
Nias et al. (1993)
Nonnotte et al. (1993)
Pant et al. (1980)
Paulij et al. (1990)
Peterson et al. (1996)
Pistocchi et al. (1997)
Pynnonen (1995)
Raj and Hameed (1991)
Rajkumar and Das (1991)
Reeve et al. (1977)
Ruiz et al. (1994, 1996)
Saward et al. (1975)
Schafer et al. (1993)
Smith et al. (1993)
Solbe and Cooper (1976)
Steeman-Nielsen and Bruun-Laursen (1976)
Stephenson (1983)
Takamura et al. (1989)
Taylor et al. (1991, 1994)
Timmermans (1992)
Timmermans et al. (1992)
Vardia et al. (1988)
Verriopoulos and Moraitou-Apostolopoulou (1982)
Visviki and Rachlin (1991)
Weeks and Rainbow (1991)
White and Rainbow (1982)
Wong and Chang (1991)
Wong et al. (1993)

Copper Was a Component of a Drilling Mud, Effluent, Mixture, Sediment, or Sludge

Buckler et al. (1987)
Buckley (1994)
Clements et al. (1988)
de March (1988)
Hollis et al. (1996)
Horne and Dunson (1995)
Hutchinson and Sprague (1987)
Kraak et al. (1993 and 1994a,b)
Lowe (1988)
McNaught (1989)
Munkittrick and Dixon (1987)
Pellegrini et al. (1993)
Roch and McCarter (1984a,b)
Roch et al. (1986)
Sayer et al. (1991b)
Weis and Weis (1993)
Widdows and Johnson (1988)
Wong et al. (1982)

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These Reviews Only Contain Data That Have Been Published Elsewhere

Ankley et al. (1993)
Borgmann and Ralph (1984)
Chapman et al. (1968)
Chen et al. (1997)
Christensen et al. (1983)
Dierickx and Brendael-Rozen (1996)
DiToro et al. (1991)
Eisler (1981)
Eisler et al. (1979)
Enserink et al. (1991)
Felts and Heath (1984)
Gledhill et al. (1997)
Handy (1996)
Hickey et al. (1991)
Janssen et al. (1994)
LeBlanc (1984)
Lilius et al. (1994)
Meyer et al. (1987)
Ozoh (1992c)
Peterson et al. (1996)
Phillips and Russo (1978)
Phipps et al. (1995)
Spear and Pierce (1979b)
Starodub et al. (1987b)
Taylor et al. (1996)
Thompson et al. (1972)
Toussaint et al. (1995)

No Interpretable Concentration, Time, Response Data, or Examined Only a Single Concentration

Asztalos et al. (1990)
Beaumont et al. (1995a,b)
Beckman and Zaugg (1988)
Bjerselius et al. (1993)
Carballo et al. (1995)
Daoust et al. (1984)
De Boeck et al. (1995b, 1997)
Dick and Dixon (1985)
Felts and Heath (1984)
Ferreira (1978)
Ferreira et al. (1979)
Hansen et al. (1993, 1996)
Heath (1987, 1991)
Hughes and Nemcsok (1988)
Julliard et al. (1996)
Koltes (1985)
Kosalwat and Knight (1987)
Kuwabara (1986)
Lauren and McDonald (1985)
Leland (1983)
Lett et al. (1976)
Miller and McKay (1982)
Mis and Bigaj (1997)
Nalewajko et al. (1997)
Nemcsok et al. (1991)
Ozoh (1990)
Ozoh and Jacobson (1979)
Parrott and Sprague (1993)
Pyatt and Dodd (1986)
Riches et al. (1996)
Sayer (1991)
Sayer et al. (1991a,b)
Schleuter et al. (1995, 1997)
Starcevic and Zielinski (1997)
Steele (1989)
Taylor and Wilson (1994)
Viale and Calamari (1984)
Visviki and Rachlin (1994b)
Waiwood (1980)
Webster and Gadd (1996)
Wilson and Taylor (1993a,b)
Winberg et al. (1992)
Wundram et al. (1996)
Wurts and Perschbacher (1994)

No Useable Data on Copper Toxicity or Bioconcentration

Cowgill et al. (1986)
de March (1979)
Lehman and Mills (1994)
Lustigman (1986)
Lustigman et al. (1985)
MacFarlane et al. (1986)
van Hoof et al. (1994)
Weeks and Rainbow (1992)
Wong et al. (1977)
Wren and McCarroll (1990)
Zamuda et al. (1985)

Results Not Interpretable as Total or Dissolved Copper

Brand et al. (1986)
MacFie et al. (1994)
Riedel (1983)
Sanders and Jenkins (1984)
Sanders and Martin (1994)
Sanders et al. (1995)
Stearns and Sharp (1994)
Stoecker et al. (1986)
Sunda et al. (1987)
Winberg et al. (1992)

Some of these studies would be valuable if copper criteria were developed on the basis of cupric ion activity.

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Organisms Were Selected, Adapted or Acclimated for Increased Resistance to Copper

Fisher (1981)
Fisher and Fabris (1982)
Hall (1980)
Hall et al. (1989)
Harrison and Lam (1983)
Harrison et al. (1983)
Lumoa et al. (1983)
Lumsden and Florence (1983)
Munkittrick and Dixon (1989)
Myint and Tyler (1982)
Neuhoff (1983)
Parker (1984)
Phelps et al. (1983)
Ray et al. (1981)
Sander (1982)
Scarfe et al. (1982)
Schmidt (1978a,b)
Sheffrin et al. (1984)
Steele (1983b)
Takamura et al. (1989)
Viarengo et al. (1981a,b)
Wood (1983)

Either the Materials, Methods, Measurements or Results Were Insufficiently Described

Abbe (1982)
Alam and Maughan (1995)
Balasubrahmanyam et al. (1987)
Baudouin and Scoppa (1974)
Belanager et al. (1991)
Benedeczky et al. (1991)
Benedetti et al. (1989)
Benhra et al. (1997)
Bouquegneau and Martoja (1982)
Burton and Stemmer (1990)
Burton et al. (1992)
Cabejszek and Stasiak (1960)
Cain and Luoma (1990)
Chapman (1975, 1982)
Cochrane et al. (1991)
Devi et al. (1991)
Dirilgen and Inel (1994)
Dodge and Theis (1979)
Doucet and Maly (1990)
Dunbar et al. (1993)
Durkina and Evtushenko (1991)
Enesco et al. (1989)
Erickson et al. (1997)
Evans (1980)
Ferrando and Andreu (1993)
Finlayson and Ashuckian (1979)
Furmanska (1979)
Gibbs et al. (1981)
Gordon et al. (1980)
Gould et al. (1986)
Govindarajan et al. (1993)
Hayes et al. (1996)
Howard and Brown (1983)
Janssen et al. (1993)
Janssen and Persoone (1993)
Kean et al. (1985)
Kentouri et al. (1993)
Kessler (1986)
Khangarot et al. (1987)
Kobayashi (1996)
Kulkarni (1983)
Labat et al. (1977)
Lakatos et al. (1993)
LeBlanc (1985)
Leland et al. (1988)
Mackey (1983)
Magni (1994)
Martin et al. (1984)
Martincic et al. (1984)
McIntosh and Kevern (1974)
McKnight (1980)
Moore and Winner (1989)
Muramoto (1980, 1982)
Nyholm and Damgaard (1990)
Peterson et al. (1996)
Pophan and D'Auria (1981)
Reed-Judkins et al. (1997)
Rehwoldt et al. (1973)
Riches et al. (1996)
Sakaguchi et al. (1977)
Sanders et al. (1995)
Sayer (1991)
Schultheis et al. (1997)
See et al. (1974)
Shcherban (1977)
Smith et al. (1981)
Sorvari and Sillanpaa (1996)
Stearns and Sharp (1994)
Strong and Luoma (1981)
Sullivan and Ritacco (1988)
Taylor (1978)
Taylor et al. (1994)
Thompson (1997)
Trucco et al. (1991)
Verma et al. (1980)
Visviki and Rachlin (1994a)
Watling (1983)
Winner et al. (1990)
Young and Harvey (1988, 1989)
Zhokhov (1986)

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Questionable Effect Levels Due to Graphical Presentation of Results

Alliot and Frenet-Piron (1990)
Andrew (1976)
Arsenault et al. (1993)
Balasubrahmanyam et al. (1987)
Bjerselius et al. (1993)
Bodar et al. (1989)
Chen (1994)
Cowgill and Milazzo (1991b)
Cvetkovic et al. (1991)
Dodoo et al. (1992)
Francisco et al. (1996)
Gupta et al. (1985)
Hansen et al. (1996)
Hoare and Davenport (1994)
Lauren and McDonald (1985)
Llanten and Greppin (1993)
Metaxas and Lewis (1991)
Michnowicz and Weeks (1984)
Miersch et al. (1997)
Nasu et al. (1988)
Pearlmutter and Lembi (1986)
Pekkala and Koopman (1987)
Peterson et al. (1984)
Romanenko and Yevtushenko (1985)
Sanders et al. (1994)
Smith and Heath (1979)
Stokes and Hutchinson (1976)
Winner and Gauss (1986)
Wong (1989)
Young and Lisk (1972)

Studies of Copper Complexation With No Useable Toxicology Data for Surface Waters

Borgmann (1981)
Filbin and Hough (1979)
Frey et al. (1978)
Gillespie and Vaccaro (1978)
Guy and Kean (1980)
Jennett et al. (1982)
Maloney and Palmer (1956)
Nakajima et al. (1979)
Stauber and Florence (1987)
Sunda and Lewis (1978)
Swallow et al. (1978)
van den Berg et al. (1979)
Wagemann and Barica (1979)

Questionable Treatment of Test Organisms or Inappropriate Test Conditions or Methodology

Arambasic et al. (1995)
Benhra et al. (1997)
Billard and Roubaud (1985)
Bitton et al. (1995)
Brand et al. (1986)
Bringmann and Kuhn (1982)
Brkovic-Popovic and Popovic (1977a,b)
Dirilgen and Inel (1994)
Folsom et al. (1986)
Foster et al. (1994)
Gavis et al. (1981)
Guanzon et al. (1994)
Hawkins and Griffith (1982)
Ho and Zubkoff (1982)
Hockett and Mount (1996)
Huebert et al. (1993)
Huilsom (1983)
Jezierska and Slominska (1997)
Kapu and Schaeffer (1991)
Kessler (1986)
Khangarot and Ray (1987a)
Khangarot et al. (1987)
Lee and Xu (1984)
Marek et al. (1991)
McLeese (1974)
Mis et al. (1995)
Moore and Winner (1989)
Nasu et al. (1988)
Ozoh and Jones (1990b)
Reed and Moffat (1983)
Rueter et al. (1981)
Sayer et al. (1989)
Schenck (1984)
Shaner and Knight (1985)
Sullivan et al. (1983)
Tomasik et al. (1995)
Watling (1981, 1982, 1983)
Wikfors and Ukeles (1982)
Wilson (1972)
Wong and Chang (1991)
Wong (1992)

High control mortalities occurred in all except one test reported by Sauter et al. (1976). Control mortality exceeded 10% in one test by Mount and Norberg (1984). Pilgaard et al. (1994) studied interactions of copper and hypoxia, but failed to run a hypoxic control. Beaumont et al. (1995a,b) studied interactions of temperature, acid pH and copper, but never separated pH and copper effects. The 96-hour values reported by Buikema et al. (1974a,b) were subject to error because of possible reproductive interactions (Buikema et al. 1977).

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Bioconcentration Studies Not Conducted Long Enough, Not Steady-State, Not Flow-through, or Water Concentrations Not Adequately Characterized or Measured

Anderson and Spear (1980a)
Felton et al. (1994)
Griffin et al. (1997)
Harrison et al. (1988)
Krantzberg (1989)
Martincic et al. (1992)
McConnell and Harrel (1995)
Miller et al. (1992)
Ozoh (1994)
Wright and Zamuda (1987)
Xiaorong et al. (1997)
Yan et al. (1989)
Young and Harvey (1988, 1989)
Zia and Alikhan (1989)

Anderson (1994), Anderson et al. (1994), Viarengo et al. (1993), and Zaroogian et al. (1992) reported on *in vitro* exposure effects. Benedeczky et al. (1991) studied only effects of injected copper. Ferrando et al. (1993b) studied population effects of copper and cladoceran predator on the rotifer prey, but the data are difficult to interpret. A similar problem complicated use of the cladoceran competition study of LeBlanc (1985).

NMED Exhibit 80

Training materials on Copper BLM: Implementation

US Environmental Protection Agency
Office of Science and Technology
Standards and Health Protection Division
1200 Pennsylvania Avenue, N.W. (MC 4305T)
Washington, D.C. 20460

NMED Exhibit 81

1. Implementation

1.1 What options are available to states and tribes for adopting and implementing the updated national recommended criteria statement?

States and tribes have flexibility in implementing the updated copper criteria. States and tribes can implement the BLM-based criteria as a performance-based approach and may choose either incremental or statewide implementation depending on their needs and resources. For many states and tribes, EPA regards incremental implementation as the most feasible and efficient means of implementing the updated criteria.

For states and tribes choosing to implement the BLM-based criteria using an incremental approach, EPA recommends moving as quickly as possible to adopt the BLM methodology into State or tribal water quality standards (while retaining the hardness criteria) to utilize the latest available science to develop site-specific copper criteria on a targeted basis. This approach should result in more appropriate criteria more quickly for waters where the hardness-based copper criteria may be potentially over-protective, such as waters with high DOC, or potentially under-protective, such as waters with low pH. Under this approach, the hardness-based criterion remains in State (or tribal) water quality standards and applies to all waters except for those where site-specific criteria are derived using the BLM.

States choosing to use the BLM on a targeted basis may consider adding a paragraph to their water quality standards noting that site-specific criteria for copper may be developed on a case-by-case basis using the approach described in EPA's *Aquatic Life Ambient Freshwater Quality Criteria – Copper 2007 Revision* (EPA-822-R-07-001). Or, states may choose to include a footnote indicating that if a site-specific criterion is generated using the BLM, the BLM-derived value becomes the site-specific copper criterion (see 40 CFR §131.36(b)(2) for an example). EPA recommends that states and tribes maintain an updated listing of the water bodies for which the BLM has been used as the basis for a site-specific freshwater copper criterion.

This incremental or targeted approach would provide states and tribes with the flexibility to use the BLM on a limited basis where it will have the most impact. Once developed for particular water segments, BLM-based criteria would provide the basis for permitting and assessment decisions.

In situations where states or tribes choose not to use the BLM, the state (or tribe) may continue to use the WER method as a means of developing site-specific criteria. Done this way, there would be two ways to develop site-specific criteria: 1) using the hardness-based criteria with a WER, and 2) using the BLM on a targeted basis. The permitting authority may consider requiring individual dischargers to collect the monitoring data in order to use the BLM, which EPA expects in most cases would be less expensive to obtain than site-specific toxicology data to develop a WER.

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An alternative implementation approach would be where states or tribes choose to adopt the national criteria recommendation (the BLM) as the statewide standard. States and tribes can develop numeric results up front when adopting the revised criteria or later when developing permits or conducting assessments. Under this approach, the BLM-based criteria would replace the hardness-based criteria for copper. This approach allows states and tribes to use the latest available science to apply a copper criterion to each site that would best reflect predicted effects on aquatic life based on the behavior of copper in the receiving stream. States and tribes can incorporate BLM input parameters into their statewide monitoring programs to ensure that data are available to use the BLM. The additional monitoring data may later prove to be useful if and when the BLM is developed and calibrated for other metals, such as zinc and silver.

This statewide implementation option could likely result in increased costs to state monitoring programs, because some of the BLM input parameters (particularly DOC) are not routinely monitored. In addition, selecting this option may obligate the state or tribe to use the BLM, even for waters where the hardness-based criteria may be adequate.

1.2 Have any states or tribes used the BLM to calculate site-specific copper criteria?

Yes. Colorado has used the BLM as an alternative means to develop site-specific WER for several effluent dominated stream segments. The Colorado Water Quality Division developed informal guidance regarding use of the BLM. This informal guidance suggests the following:

- Water quality samples should be taken above and below wastewater treatment facilities. The downstream sample should be taken where the effluent has fully mixed with the receiving water. More than one sampling site is recommended for stream segments longer than five miles.
- Water quality samples should be taken below each National Pollutant Discharge Elimination System (NPDES) permit discharge for stream segments with more than one NPDES permit.
- Water quality data should adequately describe seasonal attributes of a stream.
- At least one year of water quality data is recommended, with a minimum of 24 sampling events.

The suggestions outlined in Colorado's informal guidance should not be construed as EPA's recommendations for how to use the BLM; rather, the guidelines are presented here as an illustrative example of how one State has used the BLM.

Additionally, Massachusetts Department of Environmental Protection (MA DEP) evaluated the applicability of the BLM to develop site-specific copper criteria in the Taunton River watershed. Water quality samples were collected at 13 sites (10 in stream locations and three publicly-owned treatment works (POTWs) discharge points) in the watershed; samples were taken in the spring (to capture average to high flow conditions)

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and the summer (to capture low flow conditions). Samples were taken both upstream and downstream of three POTWs discharging to the Taunton River and its tributaries.

1.3 How does the BLM compare to the WER method in terms of cost?

In general, EPA expects the water chemistry data required by the BLM to be less expensive than WER toxicity testing on a per site basis. States routinely monitor for some of the BLM input parameters; therefore, the need for a state or tribe to initiate monitoring for all 10 input parameters to use the BLM represents a worst-case scenario. States and tribes may choose to work with direct dischargers to collect monitoring data for the BLM. Parameter estimation techniques may also eventually reduce the implementation costs.

It is difficult to do a direct cost comparison of the BLM and WER method because the cost of data collection and analysis will vary depending on the location and site-specific conditions of the site. Currently, dischargers typically pay for WER testing, while the costs of using the BLM may be borne by the discharger or the state (or tribe), depending on how states (and tribes) choose to implement the updated criteria.

Costs associated with implementing the BLM include those for field work (including sample collection containers and technician-hours in the field) and laboratory services (including analytical services and other lab charges, such as sample handling and disposal and reporting forms). EPA estimates that the total cost for one set of 10 input parameters is approximately $325. Depending on the number of data sets collected, BLM-related costs may range from $325 (the cost of an “instantaneous criterion”) to $1300 (the cost of one sampling event per season, for a total of four) or more per site. There could be additional costs that vary depending on the location and complexity of the site, including study design to define the site, statistical evaluation of the sampling scheme, and transportation.

Costs associated with the Streamlined WER method to develop a site-specific criterion include the costs of two (or more) sampling events (with a representative sample of upstream water and effluent taken for each sampling event), side-by-side toxicity tests for laboratory and site water with one test species; and other measurements (including hardness, pH, alkalinity, total suspended solids (TSS), and DOC for both the site water and the laboratory water). EPA estimates the cost of the Streamlined WER method (two samples and one test species) to be approximately $10,000.

Costs associated with the 1994 Interim WER method (the “non-streamlined” method) are likely to be higher, given that the Interim WER method recommends three sampling events for one species, and one sampling event with a second species (for a total of four WER tests). EPA estimates the cost of using the1994 Interim WER method at a relatively simple site to be on the order of $20,000. Some more complex applications of the WER method have costs over $100,000.

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1.4 Will existing site-specific freshwater copper criteria derived using the WER method need to be revised using the BLM?

A state or tribe may choose to retain the WER-adjusted hardness criterion or use the BLM on a targeted basis to develop site-specific criteria. EPA developed different BLM implementation options for states and tribes to consider (see Question 1.1).

1.5 If the BLM results in a different criterion than a state currently has, will a use attainability analysis (UAA) be needed to change a use?

A UAA would not be required if application of the BLM for copper resulted in different criteria, assuming that the state or tribe would not be revising the underlying designated use. In that circumstance, a UAA would not be necessary regardless of whether application of the BLM results in a more or less stringent copper criterion. On the other hand, if the designated use would be revised to a different aquatic life use subcategory, and a less stringent criterion for copper (or any other parameter) would also be adopted, a UAA would need to be prepared pursuant to 40 CFR 131.10(j)(2).

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Madam Hearing Officer.

EXAMINATION

BY COMMISSIONER DOMINGUEZ:

Q. Good afternoon, Mr. Fulton. Thank you for your testimony today.

My line of questioning shall be a little bit broader in scope than my colleague to your right. If my questions get outside the scope of your testimony, I'm sure that Ms. Olson will object.

With that leg out, if I heard you correctly, you provided testimony at the prior Triennial Review, or you were at or attended the Triennial Review. Is that correct?

A. That's correct, Commissioner Dominguez.

Q. So you probably recall there was a point in time where there was a fair amount of discussion about the best available science and what constitutes best available science.

The Copper Criteria that's being proposed in this Petition, in your

professional opinion, is this the best available science?

A. Yes. In my best professional opinion the Proposal in front of the Commission today, Site-Specific Water Quality Criteria for copper, was developed and reflects the best available science.

Q. Okay. Thank you.

Dr. White talked about, you know, there was 18-plus years of very robust data sets that were used to arrive at what you have arrived at. Is the 2007 EPA guidance best suited for Site-Specific Criteria development partially due to just the sheer volume of data that's necessary to actually get to an end point?

A. That's a really good question; I think one can make that argument or come to that conclusion.

You know, there's a number of sites that probably have non-detect copper, and so copper is just no concern. You know, why would that particular site want to spend all the resources that is required in the Copper BLM?

As you saw today it takes effort to collect the data necessary to evaluate the BLM and to analyze the data necessary to evaluate the BLM.

Conversely, other states have fully adopted the BLM, but that's a complex process because it's, for some of the reasons I mentioned in my testimony, a complex piece of software. Adopting software creates challenges, and fully adopting the complex software requires pretty robust implementation guidance, and statewide implementation guidance.

In that regard there is probably something to be said for adopting it on a segment-specific basis.

Q. Thank you for laying a foundation to my next question:

If a state was going to look at adopting something statewide, is it more realistic to utilize the software versus developing equations like you have for these specific sites?

A. Well as you saw today there is a lot of work that went into developing

those equations. However, there is obvious benefit to it because of the reasons I've mentioned; it is fewer parameters. It's very transparent to look at an equation. I can see, you know, the appeal for statewide adoption of similar equations.

However I think that other states have shown that the software can effectively be adopted statewide. I think the question of adopting the software statewide, you know, depends on whether it could be streamlined by making assumptions for missing parameters.

For example, what does a site do if they don't have DOC, or a given Cad ion or N ion; would they use some reference value? I think it's entirely possible to do both. I think that just adopting the software version statewide requires a different set of analyses and uncertainties than we faced for the Plateau given the, you know, robustness and availability of data that we had for the Plateau.

Q. Okay. Thank you for that answer.

Part of where this line of questioning is coming from is, of course, EPA came out with this around 2007. That was probably about the time I started on this Commission, and I've sat through more Triennial Reviews than I care to remember, and there is a common thread through all of them that the amount of resources that it takes to adopt the 2007 guidance from EPA, this State has never really had the resources to do that. It's been a common theme up until the point where you guys have Petitioned for the site-specific.

My hat is off to the Petitioners for the amount of work that went into this site-specific, because I think we have to move towards the best science available.

I think that's what the public expects this Commission to do for protection of waters is to utilize the best science available, so I applaud the effort in moving that direction, realizing this is a fairly small step in the big

scheme of things statewide, but I think it's a proper step, so thank you.

That's all the questions I have.

HEARING OFFICER ORTH: Thank you.

Vice Chair Zemlick.

EXAMINATION

BY VICE CHAIRWOMAN ZEMLICK:

Q. Thank you for your testimony.

They have asked a lot of my questions, but the one remaining is along the lines of what my colleagues asked:

Do you have a sense for what sort of threshold there may be in terms of the amount of data required to develop these site-specific thresholds for other locations in the state?

A. Yeah, good question. Thank you, Commissioner, for the question:

At a minimum, you know, any time we talk about Site-Specific Water Quality Criteria generally speaking, the objective is to capture the variation that may be expected within a given water body,

EPA 440-9-76-023

QUALITY CRITERIA FOR WATER



U.S. ENVIRONMENTAL PROTECTION AGENCY
Washington, D.C. 20460

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

26 JUL 1976

OFFICE OF WATER AND
HAZARDOUS MATERIALS

To the Reader:

Thousands of fine scientists throughout the country have contributed directly or indirectly to this publication on "Quality Criteria for Water." This volume represents a stock-taking effort on the part of this Agency to identify as precisely as possible at this time, on a national scale, the various water constituents that combine to form the concept of "Quality Criteria for Water". This process of definition will continue far into the future because research related to water quality is a never-ending evolutionary process, and the water environment is so complex that man's efforts to define it will never attain finite precision.

Water quality criteria do not have direct regulatory use, but they form the basis for judgment in several Environmental Protection Agency and State programs that are associated with water quality considerations. The criteria presented in this publication should not be used as absolute values for water quality. As it is stated in the chapter on "The Philosophy of Quality Criteria" there is variability in the natural quality of water and certain organisms become adapted to that quality, which may be considered extreme in other areas. These criteria represent scientific judgments based upon literature and research about the concentration-effect relationship to a particular water quality constituent upon a particular aquatic species within the limits of experimental investigation. They should be used with considered judgment and with an understanding of their development. The judgment associated with their use should include the natural quality of water under consideration, the kinds of organisms that it contains, the association of those species to the particular species described in this volume upon which criteria values have been placed, and the local hydrologic conditions.

It must be emphasized that national criteria can never be developed to meet the individual needs of each of the Nation's waterways--the natural variability within the aquatic ecosystem can never

be identified with a single numerical value. Water quality criteria will change in the future as our knowledge and perception of the intricacies of water improve. There is no question but that criteria for some constituents will change within a period of only two years based upon research now in progress. That is a mark of continuing progressive research effort, as well as a mark of a better understanding by man of the environment that he inhabits.

This, then, is the challenge for the future: to expand upon our present baseline of knowledge of the cause-effect relationships of water constituents to aquatic life and of the antagonistic and synergistic reactions among many quality constituents in water; and to mold such future knowledge into realistic, environmentally protective criteria to insure that the water resource can fulfill society's needs.

Eckardt C. Beck
Deputy Assistant Administrator
for Water Planning and Standards

FOREWORD

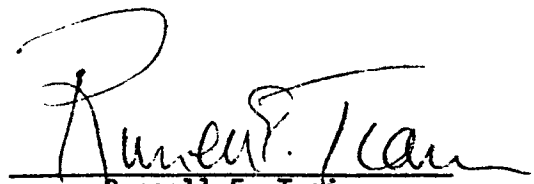
The Federal Water Pollution Control Act Amendments of 1972 require the Administrator of the Environmental Protection Agency to publish criteria for water quality accurately reflecting the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare which may be expected from the presence of pollutants in any body of water, including ground water. Proposed Water Quality Criteria were developed and a notice of their availability was published on October 26, 1973 (38 FR 29646). This present volume represents a revision of the proposed water quality criteria based upon a consideration of comments received from other Federal agencies, State agencies, special interest groups, and individual scientists.

This volume, Quality Criteria for Water, addresses the effects of those basic water constituents and pollutants that are considered most significant in the aquatic environment in the context of our present knowledge and experience. The format for criteria presentation has been altered substantially from the proposed volume. It is believed that the alphabetical arrangement of the water quality constituents and the form in which the information is arranged will be of considerable help to the reader in using this volume. For each basic water constituent or pollutant there is a recommended criterion, an introduction, a rationale supporting the recommended criterion and a list of the references cited in the development of the recommendation.

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The thrust of this volume is to recommend criteria levels for a water quality that will provide for the protection and propagation of fish and other aquatic life and for recreation in and on the water in accord with the 1983 goals of P.L. 92-500. Criteria also are presented for the domestic water supply use. Generally, these water uses are the highest achievable beneficial uses and water quality that supports these uses will also be suitable for agricultural and industrial uses. In those few exceptions, criteria are presented to provide a safe water quality for agricultural use, or water quality conditions associated with agricultural and industrial uses are discussed in the rationale supporting a criterion recommendation.

Guidelines to implement the consideration of criteria presented in this volume in the development of water quality standards, and in other water-related programs of this Agency, are being developed and will be available for use by the States, other agencies, and interested parties in the near future.



Russell E. Train
Administrator

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PREFACE

The genesis of water quality criteria in the United States began in the early 1900's. Marsh[1/], in 1907, published on the effects of industrial wastes on fish. Shelford[2/], in 1917, published effect data on fish for a large number of gas-waste constituents. In this early publication he reiterated that the toxicity of waste differs for different species of fish and generally is greater for the smaller and younger fish. Powers[3/], working with Shelford, experimented with the goldfish as a test animal for aquatic toxicity studies.

A monumental early effort to describe and record the effects of various concentrations of a great number of substances on aquatic life was that of Ellis in 1937. Ellis[4/] reviewed the existing literature for 114 substances in a 72-page document and listed lethal concentrations found by the various authors. He provided a rationale for the use of standard test animals in aquatic bioassay procedures and he used the common goldfish, Crassius auratus and the entomostracan, Daphnia magna, as test species in which experiments were made in constant temperature cabinets.

Early efforts to summarize knowledge concerning water quality criteria

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1/ M.C. MARSH, The effect of some industrial wastes on fishes. Water supply and irrigation paper No. 192, U.S. Geol. Sur., pp. 337-348 (1907).

2/ V.E. SHELFORD, An experimental study of the effects of gas wastes upon fishes, with especial reference to stream pollution. Bull. Illinois State Lab. for Nat. History, 11:381-412 (1917).

3/ E.B. POWERS, The goldfish (Carassius carassius) as a test animal in the study of toxicity. Illinois Biol. Mono., 4:127-193 (1917).

4/ M.M. ELLIS, Detection and measurement of stream pollution. Bull. U.S. Bureau of Fisheries, 48:365-437 (1937).

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took the form of a listing of the concentration, the test organism, the results of the test within a time period, and the reference for a cause-effect relationship for a particular water contaminant. In early bioassay efforts insufficient attention was given to the quality of the dilution water used for the experiment and to the effects of such dilution water on the relative toxicity of the tested contaminant. As a result, conclusions from citations of such references were, at best, difficult to formulate and most often were left to the discretion of the reader.

In 1952, the State of California[5/] published a 512-page book on "Water Quality Criteria" that contained 1,369 references. This classic reference summarized water quality criteria promulgated by State and interstate agencies, as well as the legal application of such criteria. Eight major beneficial uses of water were described. Three-hundred pages of the document were devoted to cause-effect relationships for major water pollutants. The concentration-effect levels for the pollutant in question were discussed for each of the designed water uses.

The State of California's 1952 Water Quality Criteria edition was expanded and tremendously enhanced into a second edition edited by Messrs. Jack E. McKee and Harold W. Wolf and published in 1963 by the Resources Agency of California, State Water Quality Control Board[6/]. This edition, which included 3,827 cited references, was a monumental effort in bringing together under one cover the world's literature on water quality criteria as of the date of publication. Criteria were identified and referenced for a host of water quality

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5/ Water Quality Criteria. State Water Pollution Control Board, Sacramento, California.

6/ J.E. McKEE and H.W. WOLF, Water Quality Criteria, State Water Quality Control Board, Sacramento, California, Pub. 3-A (1963)

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characteristics according to their effects on domestic water supplies, industrial water supplies, irrigation waters, fish and other aquatic life, shellfish culture, and swimming and other recreational uses. Specific values were arranged in ascending order, with appropriate references, as they had been reported damaging to fish or as not harmful to fish in the indicated time and under the conditions of exposure. The results of such a tabulation presented a range of values and, as would be expected by those investigating such conditions, there was often an overlap in values between those concentrations that had been reported by others as harmful. Such an anomaly is due to differences in investigative techniques among investigators, the characteristics of the water used as a dilutent for the toxicant, the physiological state of the test organisms, and variations in the temperature under which the tests were conducted. Nevertheless, the tabulation of criteria values for each of the water quality constituents has been helpful through time to predict a range within which a water quality constituent would have a deleterious effect upon the receiving waterway.

In 1966 the Secretary of the Interior appointed a number of nationally recognized scientists to a National Technical Advisory Committee to develop water quality criteria for five specified uses of water: domestic water supply, recreation, fish and wildlife, agricultural, and industrial. In 1968 the report was published[7/]. This report constituted the most comprehensive documentation to date on water quality requirements for particular and defined water uses. The book was intended to be used as a basic reference by personnel in State water pollution control agencies engaged in water quality studies and water quality standards setting activities. In some respects, this volume represented

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7/ Water Quality Criteria, A Report of the National Technical Advisory Committee to the Secretary of the Interior. U.S. Government Printing Office, Washington, D.C. (1968).

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a marriage between the best available experimental or investigative criteria recorded in the literature and the judgments of recognized water quality experts with long experience in associated management practices. Its publication heralded a change in the concepts of water quality criteria from one that listed a series of concentration-effect levels to another that recommended concentrations that would ensure the protection of the quality of the aquatic environment and the continuation of the designated water use. When a specific aquatic life recommendation for a particular water pollutant could not be made because of either a lack of information or conflicting information, a recommendation was made to substitute a designated application factor based upon data obtained from a 96-hour bioassay using a sensitive aquatic organism and the receiving water as a diluent for the toxicity test.

The U.S. Environmental Protection Agency contracted with the National Academy of Sciences and the National Academy of Engineering to embellish the concept of the 1966 National Technical Advisory Committee's Water Quality Criteria and to develop a water quality criteria document that would include current knowledge. The result was a 1974 publication that presented water quality criteria as of 1972[8/].

The Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) mandated that the Environmental Protection Agency publish water quality criteria accurately reflecting the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare which may be expected from the presence of pollutants in any body of water.

8/ Water Quality Criteria, 1972. National Academy of Sciences, National Academy of Engineering. U.S. Government Printing Office, Washington, D.C. (1974).

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Section 304(a) of P.L. 92-500 states, "(1) The Administrator, after consultation with appropriate Federal and State agencies and other interested persons, shall develop and publish, within one year after October 18, 1972 (and from time to time thereafter revise) criteria for water quality accurately reflecting the latest scientific knowledge (A) on the kind and extent of all identifiable effects on health and welfare including, but not limited to, plankton, fish, shellfish, wildlife, plant life, shorelines, beaches, esthetics, and recreation which may be expected from the presence of pollutants in any body of water, including ground water; (B) on the concentration and dispersal of pollutants, or their byproducts, through biological physical, and chemical processes; and (C) on the effects of pollutants on biological community diversity, productivity, and stability, including information on the factors affecting rates of eutrophication and rates of organic and inorganic sedimentation for varying types of receiving waters.

"(2) The Administrator, after consultation with appropriate Federal and State agencies and other interested persons, shall develop and publish, within one year after October 18, 1972 (and from time to time thereafter revise) information (A) on the factors necessary to restore and maintain the chemical, physical, and biological integrity of all navigable waters, ground waters, waters of the contiguous zone, and the oceans; (B) on the factors necessary for the protection and propagation of shellfish, fish, and wildlife for classes and categories of receiving waters and to allow recreational activities in an on the water; and (C) on the measurement and classification of water quality; and (D) for the purpose of Section 303 of this title, on and the identification of pollutants suitable for maximum daily load measurement correlated with the achievement of water quality objectives.

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"(3) Such criteria and information and revisions thereof shall be issued to the States and shall be published in the Federal Register and otherwise made available to the public."

Section 101(a)(2) of P.L. 92-500 states, "It is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife, and provides for recreation in and on the water, will be achieved by July 1, 1983."

The objectives of this volume are to respond to these sections of the Act and thus establish water quality criteria. The QCW will be expanded periodically in the future to include additional constituents as data become available. While the NAS/NAE 1972 Water Quality Criteria considered aluminum, antimony, bromine, cobalt, fluoride, lithium, molybdenum, thallium, uranium and vanadium, these presently are not included in this volume; however, they should be given consideration in the development of State Water Quality Standards and quality criteria may be developed for them in future volumes of the QCW. In particular geographical areas or for specific water uses such as the irrigation of certain crops, some of these constituents may have harmful effects. Until such time that criteria for the 10 aforementioned constituents are developed, information relating to their effects on the aquatic ecosystem may be found in the NAS/NAE 1972 Water Quality Criteria.

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PREPARATION OF THIS VOLUME

A volume of this scope results from the efforts of many dedicated people and includes technical specialists located throughout the Agency's operational programs and in its research laboratories. The responsibility for coordinating compilation efforts and in preparing manuscript was assigned to the Criteria Branch of the Criteria and Standards Division within the Office of Water Planning and Standards, EPA.

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THE PHILOSOPHY OF QUALITY CRITERIA

Water quality criteria specify concentrations of water constituents which, if not exceeded, are expected to support an aquatic ecosystem suitable for the higher uses of water. Such criteria are derived from scientific facts obtained from experimental or *in situ* observations that depict organism responses to a defined stimulus or material under identifiable or regulated environmental conditions for a specified time period.

Water quality criteria are not intended to offer the same degree of safety for survival and propagation at all times to all organisms within a given ecosystem. They are intended not only to protect essential and significant life in water, as well as the direct users of water, but also to protect life that is dependent on life in water for its existence, or that may consume intentionally or unintentionally any edible portion of such life.

The criteria levels for domestic water supply incorporate available data for human health protection. Such values are different from the criteria levels necessary for protection of aquatic life. The Agency's interim primary drinking water regulations (40 *Federal Register* 59566 December 24, 1975), as required by the Safe Drinking Water Act (42 U.S.C. 300f, *et seq.*), incorporate applicable domestic water supply criteria. Where pollutants are identified in both the quality criteria for domestic water supply and the Drinking Water Standards, the concentration levels are identical. Water treatment may not significantly affect the removal of certain pollutants.

What is essential and significant life in water? Do Daphnia or stonefly nymphs qualify as such life? Why does 1/100th of a concentration that is lethal to 50 percent of the test organisms (LC50) constitute a criterion in some instances, whereas 1/20 or 1/10th of some effect levels constitute a criterion in other instances? These are questions that often are asked of those who undertake the task of criteria formulation.

The universe of organisms composing life in water is great in both kinds and numbers. As in the human population, physiological variability exists among individuals of the same species in response to a given stimulus. A much greater response variation exists among species of aquatic organisms. Thus, aquatic organisms do not exhibit the same degree of harm, individually or by species, from a given concentration of a toxicant or potential toxicant within the environment. In establishing a level or concentration of a quality constituent as a criterion it is necessary to ensure a reasonable degree of safety for those more sensitive species that are important to the functioning of the aquatic ecosystem even though data on the response of such species to the quality constituent under consideration may not be available. The aquatic food web is an intricate relationship of predator and prey organisms. A water constituent that may in some way destroy or eliminate an important segment of that food web would, in all likelihood, destroy or seriously impair other organisms associated with it.

Although experimentation relating to the effects of particular substances under controlled conditions began in the early 1900's, the effects of any substance on more than a few of the vast number of aquatic organisms have not

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been investigated. Certain test animals have been selected by investigators for intensive investigation because of their importance to man, because of their availability to the researcher and because of their physiological responses to the laboratory environment. As general indicators of organism responses such test organisms are representative of the expected results for other associated organisms. In this context Daphnia or stoneflies or other associated organisms indicate the general levels of toxicity to be expected among untested species. In addition, test organisms are themselves vital links within the food web that results in the fish population in a particular waterway.

The ideal data base for criteria development would consist of information on a large percentage of aquatic species and would show the community response to a range of concentrations for a tested constituent during a long time period. This information is not available but investigators are beginning to derive such information for a few water constituents. Where only 96-hour bioassay data are available, judgmental prudence dictates that a substantial safety factor be employed to protect all life stages of the test organism in waters of varying quality, as well as to protect associated organisms within the aquatic environment that have not been tested and that may be more sensitive to the test constituent. Application factors have been used to provide the degree of protection required. Safe levels for certain chlorinated hydrocarbons and certain heavy metals were estimated by applying an 0.01 application factor to the 96 hour LC50 value for sensitive aquatic organisms. Flow-through bioassays have been conducted for some test indicator organisms over a substantial period of their life history. In a few other cases, information is available for the organism's natural life or for more than one generation of the species. Such data may indicate a minimal effect level, as well as a no-effect level.

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The word "criterion" should not be used interchangeably with, or as a synonym for, the word "standard." The word "criterion" represents a constituent concentration or level associated with a degree of environmental effect upon which scientific judgment may be based. As it is currently associated with the water environment it has come to mean a designated concentration of a constituent that when not exceeded, will protect an organism, an organism community, or a prescribed water use or quality with an adequate degree of safety. A criterion, in some cases, may be a narrative statement instead of a constituent concentration. On the other hand a standard connotes a legal entity for a particular reach of waterway or for an effluent. A water quality standard may use a water quality criterion as a basis for regulation or enforcement, but the standard may differ from a criterion because of prevailing local natural conditions, such as naturally occurring organic acids, or because of the importance of a particular waterway, economic considerations, or the degree of safety to a particular ecosystem that may be desired.

Toxicity to aquatic life generally is expressed in terms of acute (short-term) or chronic (long-term) effects. Acute toxicity refers to effects occurring in a short time period; often death is the end point. Acute toxicity can be expressed as the lethal concentration for a stated percentage of organisms tested, or the reciprocal, which is the tolerance limit of a percentage of surviving organisms. Acute toxicity for aquatic organisms generally has been expressed for 24- to 96-hour exposures.

Chronic toxicity refers to effects through an extended time period. Chronic toxicity may be expressed in terms of an observation period equal to the lifetime of an organism or to the time span of more than one generation. Some chronic effects may be reversible, but most are not.

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Chronic effects often occur in the species population rather than in the individual. If eggs fail to develop or the sperm does not remain viable, the species would be eliminated from an ecosystem because of reproductive failure. Physiological stress may make a species less competitive with others and may result in a gradual population decline or absence from an area. The elimination of a microcrustacean that serves as a vital food during the larval period of a fish's life could result ultimately in the elimination of the fish from an area. The phenomenon of bioaccumulation of certain materials may result in chronic toxicity to the ultimate consumer in a food chain. Thus, fish may mobilize lethal toxicants from their fatty tissues during periods of physiological stress. Egg shells of predatory birds may be weakened to a point of destruction in the nest. Bird chick embryos may have increased mortality rates. There may be a hazard to the health of man if aquatic organisms with toxic residues are consumed.

The fact that living systems, i.e. individuals, populations, species and ecosystems can take up, accumulate, and bioconcentrate man-made and natural toxicants is well documented. In aquatic systems biota are exposed directly to pollutant toxicants through submersion in a relatively efficient solvent (water) and are exposed indirectly through food webs and other biological, chemical, and physical interactions. Initial toxicant levels, if not immediately toxic and damaging, may accumulate in the biota or sediment over time and increase to levels that are lethal or sublethally damaging to aquatic organisms or to consumers of these organisms. Water quality criteria reflect a knowledge of the capacity for environmental accumulation, persistence, and effects of specific toxicants in specific aquatic systems.

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Ions of toxic materials frequently cause adverse effects because they pass through the semipermeable membranes of an organism. Molecular diffusion through membranes may occur for some compounds such as pesticides, polychlorinated biphenyls and other toxicants. Some materials may not pass through membranes in their natural or waste-discharged state, but in water they may be converted to states that have increased ability to affect organisms. For example, certain microorganisms can methylate mercury thus producing a material that more readily enters physiological systems. Some materials may have multiple effects; for example an iron salt may not be toxic, an iron floc or gel may be an irritant or clog fish gills to effect asphyxiation, iron at low concentrations can be a trace nutrient but at high concentrations it can be a toxicant. Materials also can affect organisms if their metabolic byproducts cannot be excreted. Unless otherwise stated, criteria are based on the total concentration of the substance because an ecosystem can produce chemical, physical and biological changes that may be detrimental to organisms living in or using the water.

In prescribing water quality criteria certain fundamental principles dominate the reasoning process. In establishing a level or concentration as a criterion for a given constituent it was assumed that other factors within the aquatic environment are acceptable to maintain the integrity of the water. Interrelationships and interactions among organisms and their environment, as well as the interrelationships of sediments and the constituents they contain to the water above, are recognized as fact.

Antagonistic and synergistic reactions among many quality constituents in water also are recognized as fact. The precise definition of such reactions and their relative effects on particular segments of aquatic life have not been identified with scientific precision. Historically, much of the data to support criteria development was of an ambient concentration-organism response nature. Recently, data are becoming

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available on long-term chronic effects on particular species. Studies now determine carcinogenic, teratogenic, and other insidious effects of toxic materials.

Some unpolluted waters in the nation may exceed designated criteria for particular constituents. There is variability in the natural quality of water and certain organisms become adapted to that quality which may be considered extreme in other areas. Likewise, it is recognized that a single criterion cannot identify minimal quality for the protection of the integrity of water for every aquatic ecosystem in the nation. To provide an adequate degree of safety to protect againstlong-term effects may result in a criterion that cannot be detected with present analytical tools. In some cases, a mass balance calculation can provide a means of assurance that the integrity of of the waterway is not being degraded.

Water quality criteria do not have direct regulatory impact, but they form the basis for judgment in several Environmental Protection Agency programs that are derived from water quality considerations. For example, water quality standards developed by the States under Section 303 of the Act and approved by EPA are to be based on the water quality criteria, appropriately modified to take account of local conditions. The local conditions to be considered include actual and projected uses of the water, natural background levels of particular constituents, the presence or absence of sensitive important species, characteristics of the local biological community, temperature and weather, flow characteristics, and synergistic or antagonistic effects of combinations of pollutants.

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Similarly, by providing a judgment on desirable levels of ambient water quality, water quality criteria are the starting point in deriving toxic pollutant effluent standards pursuant to Section 307(a) of the Act. Other EPA programs that make use of water quality criteria include drinking water standards, the ocean dumping program, designation of hazardous substances, dredge spoil criteria development, removal of in-place toxic materials, thermal pollution, and pesticide registration.

To provide the water resource protection for which they are designed, quality criteria should apply virtually to all of the nation's navigable waters with modifications for local conditions as needed. To violate quality criteria for any substantial length of time or in any substantial portion of a waterway may result in an adverse effect on aquatic life and perhaps a hazard to man or other consumers of aquatic life.

Quality criteria have been designed to provide long-term protection. Thus, they may provide a basis for effluent standards, but it is not intended that criteria values become effluent standards. It is recognized that certain substances may be applied to the aquatic environment with the concurrence of a governmental agency for the precise purpose of controlling or managing a portion of the aquatic ecosystem; aquatic herbicides and aquatic piscicides are examples of such substances. For such occurrences, criteria obviously do not apply. It is recognized further that pesticides applied according to official label instructions to agricultural and forest lands may be washed to a receiving waterway by a torrential rainstorm. Under such conditions it is believed that such diffuse source inflows should receive consideration

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similar to that of a discrete effluent discharge and that in such instances the criteria should be applied to the principal portion of the waterway rather than to that peripheral portion receiving the diffuse inflow.

The format for presenting water quality criteria includes a concise statement of the dominant criterion or criteria for a particular constituent followed by a narrative introduction, a rationale that includes justification for the designated criterion or criteria, and a listing of the references cited within the rationale. An effort has been made to restrict supporting data to those which have either been published or are in press awaiting publication. A particular constituent may have more than one criterion to ensure more than one water use or condition, i.e., hard or soft water where applicable, suitability as a drinking water supply source, protection of human health when edible portions of selected biota are consumed, provision for recreational bathing or water skiing, and permitting an appropriate factor of safety to ensure protection for essential warm or cold water associated biota.

Criteria are presented for those substances that may occur in water where data indicate the potential for harm to aquatic life, or to water users, or to the consumers of the water or of the aquatic life. Presented criteria do not represent an all-inclusive list of constituent contaminants. Omissions from criteria should not be construed to mean that an omitted quality constituent is either unimportant or non-hazardous.

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AESTHETIC QUALITIES

CRITERIA:

All waters free from substances attributable to wastewater or other discharges that:

(1) settle to form objectionable deposits;

(2) float as debris, scum, oil, or other matter to form nuisances;

(3) produce objectionable color, odor, taste, or turbidity;

(4) injure or are toxic or produce adverse physiological responses in humans, animals or plants; and,

(5) produce undesirable or nuisance aquatic life.

RATIONALE

Aesthetic qualities of water address the general principles laid down in common law. They embody the beauty and quality of water and their concepts may vary within the minds of individuals encountering the waterway. A rationale for these qualities cannot be developed with quantifying definitions; however, decisions concerning such quality factors can portray the best in the public interest.

Aesthetic qualities provide the general rules to protect water against environmental insults; they provide minimal freedom requirements from pollution; they are essential properties to protect the nation's waterways.

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ALKALINITY

CRITERION:

20 mg/l or more as $CaCO_3$ for freshwater aquatic life except where natural concentrations are less.

INTRODUCTION:

Alkalinity is the sum total of components in the water that tend to elevate the pH of the water above a value of about 4.5 It is measured by titration with standardized acid to a pH value of about 4.5 and it is expressed commonly as milligrams per liter of calcium carbonate. Alkalinity, therefore, is a measure of the buffering capacity of the water, and since pH has a direct effect on organisms as well as an indirect effect on the toxicity of certain other pollutants in the water, the buffering capacity is important to water quality. Examples of commonly occurring materials in natural waters that increase the alkalinity are carbonates, bicarbonates, phosphates and hydroxides.

RATIONALE:

The alkalinity of water used for municipal water supplies is important because it affects the amounts of chemicals that need to be added to accomplish coagulation, softening and control of corrosion in distribution systems. The alkalinity of water assists in the neutralization of excess acid produced during the addition of such materials as aluminum sulfate during chemical coagulation. Waters having sufficient alkalinity do not have to be supplemented with artificially added materials to increase the alkalinity. Alkalinity resulting from naturally occurring materials such as carbonate and bicarbonate is not considered a health hazard in drinking water supplies, per se, and naturally occurring

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maximum levels up to approximately 400 mg/l as calcium carbonate are not considered a problem to human health (NAS, 1974).

Alkalinity is important for fish and other aquatic life in freshwater systems because it buffers pH changes that occur naturally as a result of photosynthetic activity of the chlorophyll-bearing vegetation. Components of alkalinity such as carbonate and bicarbonate will complex some toxic heavy metals and reduce their toxicity markedly. For these reasons, the National Technical Advisory Committee (NTAC, 1968) recommended a minimum alkalinity of 20 mg/l and the subsequent NAS Report (1974) recommended that natural alkalinity not be reduced by more than 25 percent but did not place an absolute minimal value for it. The use of the 25 percent reduction avoids the problem of establishing standards on waters where natural alkalinity is at or below 20 mg/l. For such waters, alkalinity should not be further reduced.

The NAS Report recommends that adequate amounts of alkalinity be maintained to buffer the pH within tolerable limits for marine waters. It has been noted as a correlation that productive waterfowl habitats are above 25 mg/l with higher alkalinities resulting in better waterfowl habitats (NTAC, 1968).

Excessive alkalinity can cause problems for swimmers by altering the pH of the lacrimal fluid around the eye, causing irritation.

For industrial water supplies high alkalinity can be damaging to industries involved in food production, especially those in which acidity accounts for flavor and stability, such as the carbonated beverages. In other instances, alkalinity is desirable because water with a high alkalinity is much less corrosive.

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A brief summary of maximum alkalinities accepted as a source of raw water by industry is included in Table 1. The concentrations listed in the table are for water prior to treatment and thus are only desirable ranges and not critical ranges for industrial use.

The effect of alkalinity in water used for irrigation may be important in some instances because it may indirectly increase the relative proportion of sodium in soil water. As an example, when bicarbonate concentrations are high, calcium and magnesium ions that are in solution precipitate as carbonates in the soil water as the water becomes more concentrated through evaporation and transpiration. As the calcium and magnesium ions decrease in concentration, the percentage of sodium increases and results in soil and plant damage. Alkalinity may also lead to chlorosis in plants because it causes the iron to precipitate as a hydroxide (NAS, 1974). Hydroxyl ions react with available iron in the soil water and make the iron unavailable to plants. Such deficiencies induce chlorosis and further plant damage. Usually alkalinity must exceed 600 mg/l before such affects are noticed, however.

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TABLE I *

MAXIMUM ALKALINITY IN WATERS USED AS A SOURCE OF SUPPLY PRIOR TO TREATMENT

Industry	Alkalinity mg/l as $CaCO_3$
Steam Generation Boiler Makeup.....	350
Steam Generation Cooling.....	500
Textile Mill Products.....	50-200
Paper and Allied Products.....	75-150
Chemical and Allied Products.....	500
Petroleum Refining.....	500
Primary Metals Industries.....	200
Food Canning Industries.....	300
Bottled and Canned Soft Drinks.....	85

* NAS, 1974

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AMMONIA

CRITERION:

0.02 mg/l (as Un-ionized Ammonia) for freshwater aquatic life.

Concentrations of Total Ammonia ($NH_3 + NH_4^+$) Which Contain an Un-ionized Ammonia Concentration of 0.020 mg/ℓ NH_3*

Temperature (°C)	pH Value								
	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
5	160.	51.	16.	5.1	1.6	0.53	0.18	0.071	0.036
10	110.	34.	11.	3.4	1.1	0.36	0.13	0.054	0.031
15	73.	23.	7.3	2.3	0.75	0.25	0.093	0.043	0.027
20	50.	16.	5.1	1.6	0.52	0.18	0.070	0.036	0.025
25	35.	11.	3.5	1.1	0.37	0.13	0.055	0.031	0.024
30	25.	7.9	2.5	0.81	0.27	0.099	0.045	0.028	0.022

*[Abstracted from Thurston et al. (1974)]

INTRODUCTION:

Ammonia is a pungent, colorless, gaseous, alkaline compound of nitrogen and hydrogen that is highly soluble in water. It is a biologically active compound present in most waters as a normal biological degradation product of nitrogenous organic matter. It may also reach ground and surface waters through discharge of industrial wastes containing ammonia as a byproduct or wastes from industrial processes using "ammonia water".

When ammonia dissolves in water, some of the ammonia reacts with the water to form ammonium ions. A chemical equilibrium is established which

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contains un-ionized ammonia (NH_3), ionized ammonia (NH_4^+), and hydroxide ions (OH^-). The equilibrium for these chemical species can be expressed in simplified form by the following equation:

$$NH_3 + H_2O \rightleftharpoons NH_3 \cdot H_2O \rightleftharpoons NH_4^+ + OH^-$$

In the above equation NH_3 represents ammonia gas combining with water. The term $NH_3 \cdot H_2O$ represents the un-ionized ammonia molecule which is loosely attached to water molecules. Dissolved un-ionized ammonia will be represented for convenience as NH_3. The ionized form of ammonia will be represented as NH_4^+. The term total ammonia will refer to the sum of these ($NH_3 + NH_4^+$).

The toxicity of aqueous solutions of ammonia is attributed to the NH_3 species. Because of the equilibrium relationship among NH_3, NH_4^+, and OH^-, the toxicity of ammonia is very much dependent upon pH as well as the concentration of total ammonia. Other factors also affect the concentration of NH_3 in water solutions, the most important of which are temperature and ionic strength. The concentration of NH_3 increases with increasing temperature, and decreases with increasing ionic strength. In aqueous ammonia solutions of dilute saline concentrations, the NH_3 concentration decreases with increasing salinity.

A table of percent NH_3 for aqueous ammonia solutions of zero salinity at different values of pH and temperature is given below. This percentage can be used to determine the amount of total ammonia which is in the most toxic (NH_3) form.

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Percent Un-ionized Ammonia in Aqueous Ammonia Solutions*

Temperature (°C)	pH Value								
	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
5	0.013	0.040	0.12	0.39	1.2	3.8	11.	28.	56.
10	0.019	0.059	0.19	0.59	1.8	5.6	16.	37.	65.
15	0.027	0.087	0.27	0.86	2.7	8.0	21.	46.	73.
20	0.040	0.13	0.40	1.2	3.8	11.	28.	56.	80.
25	0.057	0.18	0.57	1.8	5.4	15.	36.	64.	85.
30	0.080	0.25	0.80	2.5	7.5	20.	45.	72.	89.

*[Thurston, et al. (1974)]

RATIONALE:

It has been known since early in this century that ammonia is toxic to fishes and that the toxicity varies with the pH of the water. Chipman (1934) demonstrated that undissociated ammonia (NH_3) was the chemical species toxic to goldfish, amphipods, and cladocerans. He concluded from his studies that the toxicity of ammonium salts was pH-dependent and was directly related to the concentration of undissociated ammonia. Chipman's work was confirmed by Wuhrmann, et al. (1947) who concluded that the NH_3 fraction was toxic to fish and that the NH_4^+ fraction had little or no toxicity. Further studies by Wuhrmann and Woker (1948) and Downing and Merkens (1955) agreed with these earlier findings. Tabata (1962), however, has attributed some degree of toxicity to fishes and invertebrates to the NH_4^+ species (less than 1/50th that of NH_3).

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In most natural waters, the pH range is such that the NH_4^+ fraction of ammonia predominates; however, in highly alkaline waters, the NH_3 fraction can reach toxic levels. Many laboratory experiments of relatively short duration have demonstrated that the lethal concentrations for a variety of fish species are in the range of 0.2 to 2.0 mg/l NH_3 with trout being the most sensitive and carp the most resistant. Although coarse fish such as carp survive longer in toxic solutions than do salmonids, the difference in sensitivity between fish species to prolonged exposure is probably less than the tenfold range given as the lethal range. The lowest lethal concentration reported for salmonids is 0.2 mg/l NH_3 for rainbow trout fry (Liebmann, 1960). The toxic concentration for Atlantic salmon smolts (Herbert and Shurben, 1965) and for rainbow trout (Ball, 1967) was found to be only slightly higher. Although the concentration of NH_3 below 0.2 mg/l may not kill a significant proportion of a fish population, such concentration may still exert an adverse physiological or histopathological effect (Flis, 1968; Lloyd and Orr, 1969; Smith and Piper, 1974). Fromm (1970) found that at total ammonia ($NH_3 + NH_4^+$) concentrations of 3 mg/l ammonia nitrogen, the trout became hyperexcitable; at 5 mg/l, ammonia excretion by rainbow trout was inhibited; and at 8 mg/l (approximately 1 mg/l NH_3), 50 percent died within 24 hours. Burrows (1964) found progressive gill hyperplasia in fingerling chinook salmon during a six-week exposure to a total ammonia concentration (expressed as NH_4) of 0.3 mg/l (0.002 mg/l NH_3), which was the lowest concentration applied. Reichenbach-Klinke (1967) also noted gill hyperplasia, as well as pathological effects on

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the liver and blood of various species at a concentration of 0.27 mg/l NH_3. Flis (1968) noted that exposure of carp to sublethal NH_3 concentrations resulted in extensive necrotic changes and tissue disintegration in various organs.

Herbert and Shurben (1965) reported that the resistance of yearling rainbow trout to ammonia increased with salinity (i.e. dilution with about 30 percent sea water) but above that level resistance appeared to decrease. Katz and Pierro (1967) subjected fingerling coho salmon to an ammonia waste at salinity levels of 20, 25, and 29 parts per thousand (i.e. dilution with about 57-83 percent sea water) and also found that toxicity increased with increased salinity. In saline waters the NH_4^+/NH_3 ratio must be adjusted by consideration of the activity of the charged species and total ionic strength of the solution. In dilute saline waters this ratio will change to favor NH_4^+, and thereby reduce the concentration of the toxic NH_3 species. At higher salinity levels the reported toxic effects of ammonia to fish must therefore be attributed to some mechanism other than changes in the NH_4^+/NH_3 ratio. Data on the effect of ammonia on marine species are limited and the information on anadromous species generally has been reported in conjunction with studies on freshwater species.

Although the NH_3 fraction of total ammonia increases with temperature, the toxic effect of NH_3 *vs.* temperature is not clear. Burrows (1964) has reported that the recovery rate from hyperplasia in gill tissues of chinook salmon exposed first to ammonia at sublethal levels and then to fresh water was less at 6°C than at 14°C. In this experiment, comparison was made between two different age classes of salmon.

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Levels of un-ionized ammonia in the range of 0.20 to 2 mg/l have been shown to be toxic to some species of freshwater aquatic life. To provide safety for those life forms not examined, 1/10th of the lower value of this toxic effect range results in a criterion of 0.020 mg/l of un-ionized ammonia. This criterion is slightly lower than that recommended for European inland fisheries (EIFAC, 1970) for temperatures above 5° C and pH values below 8.5. Measurement of values of total ammonia for calculation of values in the range of 0.020 mg/l NH_3 is well within current analytical capability.

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ARSENIC

CRITERIA:

50 ug/l for domestic water supplies (health);

100 ug/l for irrigation of crops.

INTRODUCTION:

Arsenic is a shiny, gray, brittle element possessing both metallic and non-metallic properties. Compounds of arsenic are ubiquitous in nature, insoluble in water and occur mostly as arsenides and arsenopyrites. Samplings from 130 water stations in the United States have shown arsenic concentrations of 5 to 336 ug/l with a mean level of 64 ug/l (Kopp, 1969). Arsenic normally is present in sea water at concentrations of 2 to 3 ug/l.

Arsenic exists in the trivalent and pentavalent states and its compounds may be either organic or inorganic. Trivalent inorganic arsenicals are more toxic than the pentavalent forms both to mammals and aquatic species. Though most forms of arsenic are toxic to humans, arsenicals have been used in the medical treatment of spirochaetal infections, blood dyscrasias and dermatitis (Merck Index, 1968). Arsenic and arsenicals have many diversified industrial uses such as hardening of copper and lead alloys, pigmentation in paints and fireworks, and the manufacture of glass, cloth and electrical semiconductors. Arsenicals are used in the formulation of herbicides for forest management and agriculture.

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RATIONALE:

Arsenic concentrations in most community drinking water supplies in the United States range from a trace to approximately 0.1 mg/l (McCabe, et al., 1970).

Inorganic arsenic is absorbed readily from the gastrointestinal tract, the lungs, and to a lesser extent from the skin, and becomes distributed throughout the body tissues and fluids (Sollman, 1957). It is excreted via urine, feces, sweat, and the epithelium of the skin (Ducoff, et al., 1948; Musil and Dejmal, 1957).

After cessation of continuous exposure, arsenic excretion may continue for as long as 70 days (DuBois and Geiling, 1959).

Since the early nineteenth century arsenicals have been suspected of being carcinogenic (Paris, 1820; Sommers and McManus, 1953; Boutwell, 1963; Hueper and Payne, 1963).

According to Frost (1967), the most toxic arsenicals are well tolerated at concentrations of 10 to 20 ppm arsenic in the diet. The least toxic arsenicals can be fed without injury at levels which contribute up to at least 1000 ppm arsenic in the diet. He concluded that arsenicals appear remarkably free of carcinogenic properties.

In man, subacute and chronic arsenic poisoning may be insidious and pernicious. The symptoms of mild chronic poisoning are fatigue

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and loss of energy. In more severe intoxication the following symptoms may be observed: gastrointestinal catarrh, kidney degeneration, tendency to edema, polyneuritis, liver cirrhosis, bone marrow injury, exfoliate dermatitis and altered skin pigmentation (DiPalma, 1965; Goodman and Gilman, 1965). No true tolerance of arsenic has ever been demonstrated (Dubois and Geiling, 1959). During chronic exposure, trivalent arsenic accumulates mainly in bone, muscle, and skin and to a lesser degree in the liver and kidneys (Smith, 1967).

Reports from epidemiological studies in Taiwan indicate that 0.3 mg/l arsenic in drinking water resulted in increased incidences of hyperkeratosis and skin cancer with increased consumption of water (Chen and Wu, 1962; Tseng, et al., 1968; Yeh, et al., 1968). A similar situation has been reported in Argentina (Trelles, et al., 1970). Dermatological manifestations of arsenicism were noted in children in Antofagasta, Chile who used a water supply containing an arsenic concentration of 0.8 mg/l. A new water supply was provided and preliminary data showed that the quantity of arsenic in hair decreased (Borgono and Grieber, 1972).

Arsenicism affecting two members of a family whose well water concentration varied from 0.5 to 2.75 mg/l arsenic over a period of several months was reported in Nevada (Craun and McCabe, 1971). A study in California indicated that a greater proportion of the population had elevated concentrations of arsenic in hair when their drinking water had more than 0.12 mg/l arsenic than when concentrations were lower, but illness was not noted (Goldsmith, et al., 1972). In none of the cited incidents of apparent correlation of arsenic in drinking water with increased incidence of hyperkeratosis and skin cancer has there been any confirmed evidence that arsenic was the etiologic agent in the production of carcinomas.

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It is estimated that the total intake of arsenic from food averages 900 ug/day (Schroeder and Balassa, 1966). At the concentration of 50 ug/l recommended for drinking water supply and an average intake of 2 liters of water per day, the intake from water could reach 100 ug/day or approximately 10 percent of the total ingested arsenic.

Although arsenic is concentrated in aquatic organisms, it is evidently not progressively concentrated along a food chain. In addition, arsenic consumed as an organically-bound species in flesh appears to have low toxicity (Ferguson and Gavis, 1972). Surber and Meehan (1931) found that fish-food organisms generally can withstand concentrations of approximately 1.73 mg/l of arsenious trioxide (1.3 mg/l arsenic) in a sodium arsenite solution. Concentrations of 4 mg/l sodium arsenite (2.3 mg/l as arsenic) in confined outdoor pools have been found to reduce survival and growth of fish and to reduce bottom fauna and plankton populations (Gilderhus, 1966).

Trivalent arsenic is highly toxic to invertebrates. Conversely, pentavalent arsenic is of relatively low toxicity. In Lake Erie water Daphnia were observed to exhibit initial symptoms of immobility at 18 to 31 mg/l of sodium arsenate or 4.3 to 7.5 mg/l as arsenic (Anderson, 1944, 1946). The lethal threshold of sodium arsenate for minnows has been reported to be 234 mg/l as arsenic at 16° C to 20° C (Wilber, 1969).

Ambient arsenic concentrations in sea water are reported to be accumulated by oysters and other molluscan shellfish (Sautet, et al., 1964;

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Lowman, et al., 1971). Wilber (1969) reported concentrations of 100 mg/kg in shellfish.

Beginning in 1926 and for many years thereafter, sodium arsenite was used for the control of vascular aquatic plants in the public lakes of Wisconsin (Mackenthun, 1950). Dosages up to 10 mg/l of the white arsenic equivalent were used depending on the physical character of the area to be treated. Harm to fish life within the lakes or to fishing was not noted.

Lueschow (1964) found that Wisconsin lakes naturally may contain 10 ug/l of arsenic. Pewaukee Lake, Wisconsin, a lake of 2300 acres, received 215,174 pounds of arsenic for aquatic vegetation control in a 14-year period beginning in 1950. From 1959 to 1964, arsenic concentrations in the lake's outlet reached a maximum of 463 ug/l arsenic and consistently were above 100 ug/l. The mean arsenic concentration in lake bottom muds was 208 ug/g on a dry weight basis. A single sample of Cladophora sp. collected from Pewaukee Lake in 1962 contained 1258 ug/g arsenic (dry weight). Fresh shoots of mature Myriophyllum sp. stems contained 228 and 561 ug/g arsenic (dry weight).

Benthic invertebrates, Chaoborus punctipennis and Tendipedidae, were present in Pewaukee Lake in populations that reached 288 per square foot. Lueschow concluded that the trivalent inorganic arsenic was 10 to 15 times more toxic to Tendipedes plumosus than the pentavalent form. His studies indicate that the trivalent inorganic arsenic is converted to pentavalent arsenic within 30 days and that long-term survival of

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typical benthic organisms would be normal at concentrations as high as 1,920 ug/g arsenic (dry weight) in lake muds.

The data cited above indicate that freshwater fish-food organisms are adversely affected by concentrations of arsenic as low as 1.3 mg/l, and the mobility of the freshwater crustacean Daphnia is impaired by a concentration of arsenic as low as 4.3 mg/l. However, these data are not considered to be sufficient to recommend any numerical criterion for freshwater aquatic life. Such data as do exist indicate that the 50 ug/l criterion established for domestic water supplies should be protective of aquatic life.

Rasmussen and Henry (1965) found that arsenic at 0.5 mg/l in nutrient solutions produced toxicity symptoms in seedlings of the pineapple and orange. Below this concentration, no symptoms of toxicity were found. Clements and Heggeness (1939) reported that 0.5 mg/l arsenic as arsenite in nutrient solutions produced an 80 percent yield reduction in tomatoes. Following a review of available literature the National Academy of Sciences (NAS, 1974) suggests that a concentration of 100 ug/l could be used for 100 years on sandy soils, and a concentration of 2 mg/l used for a period of 20 years or 0.5 mg/l used for 100 years on clayey soils with an adequate margin of safety. Because of these factors, a criterion of 100 ug/l for the irrigation of crops is recommended. The herbicidal properties of arsenic in water to aquatic vegetation also are recognized. Although data are not sufficiently precise to recommend a criterion, such data as do exist indicate that 100 ug/l would be protective of aquatic vegetation.

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BARIUM

CRITERION:

1 mg/l for domestic water supply (health).

INTRODUCTION:

Barium is a yellowish-white metal of the alkaline earth group. It occurs in nature chiefly as barite, $BaSO_4$, and witherite, $BaCO_3$, both of which are highly insoluble salts. The metal is stable in dry air, but readily oxidized by humid air or water.

Many of the salts of barium are soluble in both water and acid, and soluble barium salts are reported to be poisonous (Lange, 1961; NAS, 1974). However, barium ions generally are thought to be rapidly precipitated or removed from solution by adsorption and sedimentation (McKee and Wolf, 1963; NAS, 1974).

While barium is a malleable, ductile metal, its major commercial value is in its compounds. Barium compounds are used in a variety of industrial applications including the metallurgic, paint, glass and electronics industries, as well as for medicinal purposes.

RATIONALE:

Concentrations of barium in domestic drinking water supplies generally range from less than 0.6 ug/l to approximately 10 ug/l with upper limits in a few midwestern and western states ranging from 100 to 3,000 ug/l (PHS, 1962/1963; Katz, 1970; Little, 1971). Barium enters the body primarily through air and water, since

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appreciable amounts are not contained in foods (NAS, 1974).

The fatal dose of barium for man is reported to be 550 to 600 mg. Ingestion of soluble barium compounds may also result in effects on the gastrointestinal tract causing vomiting and diarrhea and on the central nervous system causing violent tonic and clonic spasms followed in some cases by paralysis (Browning, 1961; and Patty, 1962, cited in Preliminary Air Pollution Survey of Barium and Its Compounds, 1969). Barium salts are considered to be muscle stimulants, especially for the heart muscle (Sollmann, 1957). By constricting blood vessels, barium may cause an increase in blood pressure. On the other hand, it is not likely that barium accumulates in the bone, muscle, kidney, or other tissues because it is readily excreted (Browning, 1961; McKee and Wolf, 1963).

Stokinger and Woodward (1958) developed a safe concentration for barium in drinking water based on the limiting values for industrial atmospheres, an estimate of the amount absorbed into the blood stream, and daily consumption of two liters of water. From these factors they arrived at a limiting concentration of 2 mg/l for a healthy adult human population, to which a safety factor was applied to allow for any possible accumulation in the body. Since barium is not removed by conventional water treatment processes and because of the toxic effect on the heart and blood vessels, a limit of 1 mg/l is recommended for barium in domestic water supplies.

Experimental data indicate that the soluble barium concentration in fresh and marine water generally would have to exceed 50 mg/l before toxicity to aquatic life would be expected. In most natural waters, there is sufficient sulfate or carbonate to precipitate the barium present in the water as a virtually insoluble, non-toxic compound. Recognizing that the physical and chemical properties of barium generally will preclude the existence of the toxic soluble form under usual marine and freshwater conditions, a restrictive criteria for aquatic life appears unwarranted.

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BERYLLIUM

CRITERIA:

11 ug/l for the protection of aquatic life in soft fresh water;*

1,100 ug/l for the protection of aquatic life in hard fresh water;*

100 ug/l for continuous irrigation on all soils; except

500 ug/l for irrigation on neutral to alkaline fine-textured soils.

INTRODUCTION:

Beryllium is not likely to occur at significantly toxic levels in ambient natural waters (McKee and Wolf, 1963). Although the chloride and nitrate salts of beryllium are very water soluble, and the sulfate is moderately so, the carbonate and hydroxide are almost insoluble in cold water (Lange, 1961). Kopp and Kroner (1967) reported that for 1,577 surface water samples collected at 130 sampling points in the United States, 85 samples (5.4 percent) contained from 0.01 to 1.22 ug/l with a mean of 0.19 ug/l beryllium. The concentration of beryllium in sea water is 6×10^{-4} ug/l (Goldberg, et al., 1971).

RATIONALE:

The major human toxic hazard potential of beryllium is via the inhalation of beryllium-containing fumes and dusts that might emanate from processing and fabrication operations. Beryllium could enter waters in effluents from certain metallurgical plants (NAS, 1974).

*See criteria for Hardness (p. 147). The beryllium concentration that will be protective of a given aquatic ecosystem can be obtained by conducting flow-through bioassays using ambient water and native species of fish and invertebrates.

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Contact dermatitis, characterized by itching and reddened, elevated, or fluid-accumulated lesions, which appear particularly on the exposed surfaces of the body, may occur either on an allergic basis or from primary irritation following contact with soluble beryllium salts (Van Ordstrand, et al., 1945; McCord, 1951). A latent period is occasionally noted, indicating the development of delayed hypersensitivity (NIOSH, 1972).

Ocular effects may occur as inflammation of the conjunctiva in "splash burn" or in association with contact dermatitis (Van Ordstrand, et al., 1945). Splashes may also cause corneal burns closely resembling those produced by acids and alkalies, and fluid accumulation and reddening around the eye socket are frequently noted (NIOSH, 1972).

Beryllium is demonstrably toxic by most routes of administration (NIOSH, 1972), but its oral toxicity is notably different from that by other routes. The sulfate, for example, while highly toxic by all other routes at a single dose level, is practically non-toxic by mouth at a level several thousand-fold greater by multiple dose (Reeves, 1965; Stokinger and Stroud, 1951).

Tarzwell and Henderson (1960) obtained 96-hour LC_{50} values ranging from 0.15 mg/l beryllium (when tested as the nitrate and chloride) to 0.2 mg/l beryllium (when tested as the sulfate) for fathead minnows in soft water (20 mg/l $CaCO_3$, total alkalinity of 18 mg/l, and pH of 7.4), and from 11 mg/l beryllium (as sulfate) to 20 mg/l beryllium (as nitrate) for fathead minnows in hard water (400 mg/l $CaCO_3$, total alkalinity of

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360 mg/l, and pH of 8.2). For bluegill they obtained 96-hour LC_{50} values of 1.3 mg/l beryllium in soft water and 12 mg/l beryllium in hard water (both as the sulfate.)

Slonim (1973) obtained 96-hour LC_{50} static bioassay values of 0.19 mg/l beryllium for the common guppy, Poecilia reticulata, in soft water with a hardness of 20 to 25 mg/l as $CaCO_3$, total alkalinity of 16 to 18 mg/l, and pH of 6.3 to 6.5, and 20.3 mg/l beryllium in hard water with a hardness of 400 to 500 mg/l, alkalinity of 185 to 230 mg/l, and pH of 7.8 to 8.2.

Slonim and Slonim (1973) studied the influence of water hardness on the toxicity of beryllium sulfate to the common guppy, Poecilia reticulata, by simultaneously conducting static bioassays at 400, 275, 150, and 22 mg/l hardness as $CaCO_3$. The 96-hour LC_{50} values were 20.0, 13.7, 6.1, and 0.16 mg/l, respectively. In a water hardness of 22 mg/l, 80 percent of the test fish survived 0.1 mg/l beryllium for 96 hours, whereas 100 percent survived control conditions. In a water hardness of 150 mg/l, 70 percent survived 5 mg/l beryllium for 96 hours and 100 percent survived 2.5 mg/l beryllium.

Slonim and Ray (1975) studied the influence of water hardness on the toxicity of beryllium sulfate to two species of salamander larvae by conducting static bioassays at hardness levels of 400 mg/l and 20 to 25 mg/l as $CaCO_3$. In hard water all of the test organisms survived exposure to 10 mg/l beryllium throughout the exposure period, whereas there was a significant decline in survival with time in soft water.

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The 96-hour LC_{50} values were 26.3 mg/l beryllium in hard water, and 4.7 mg/l beryllium in soft water.

Based on the fathead minnow and bluegill data of Tarzwell and Henderson (1960), the observations of Slonim and Ray (1975) on salamander larva survival, and the observations of Slonim and Slonim (1973) on guppy survival, the criterion for the protection of aquatic biota is established at 1.1 mg/l beryllium in hard fresh water. This value assumes an application factor of 0.1 of the 96-hour LC_{50} value for fathead minnows. For soft fresh water, in view of the reported approximate 100-fold increase in acute fish toxicity over that found in hard water, the criterion for the protection of aquatic biota is set at 0.011 mg/l beryllium.

Beryllium has been reported to be concentrated 1000 times in marine organisms (Goldberg, et al., 1971). The average concentration factors for marine benthic algae, phytoplankton, and zooplankton also have been reported as 110, 1000, and 15 mg/l, respectively (Lowman, et al., 1971). Riley and Roth (1971) reported levels of 1.1 to 18 mg/l beryllium for various species of marine algae. The 96-hour TLm value for beryllium resulting from tests performed on the killifish, Fundulus heteroclitus, was 41 mg/l (Jackim, et al., 1970). These data do not represent an adequate base upon which to establish a marine criterion.

Beryllium has been shown to inhibit photosynthesis in terrestrial plants (Bollard and Butler, 1966), and to be toxic to some varieties

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of citrus seedlings at 2.5 mg/l beryllium (Haas, 1932). Romney, et al. (1962) found that beryllium at 0.5 mg/l in nutrient solutions reduced the growth of bush beans, and Romney and Childress (1965) found that concentrations of 2 mg/l or greater in nutrient solutions reduced the growth of tomatoes, peas, soybeans, lettuce, and alfalfa plants. Additions of soluble beryllium salts at levels equivalent to 4 percent of the cation-adsorption capacity of two acid soils reduced the yields of ladino clover; beryllium carbonate and beryllium oxide at the same levels did not reduce yields, suggesting that beryllium in calcareous soils might be less active than in acid soils. Williams and LeRiche (1968) found that beryllium at 2 mg/l in nutrient solutions was toxic to mustard, whereas 5 mg/l was required for growth reduction in kale. In view of its toxicity in nutrient solutions in acid soils, the criteria for beryllium in irrigation waters are 0.10 mg/l for use on all soils, except 0.50 mg/l for use on neutral to alkaline fine-textured soils.

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BORON

CRITERION:

750 ug/l for long-term irrigation on sensitive crops.

INTRODUCTION:

Boron is not found in its elemental form in nature; it is usually found as a sodium or calcium borate salt. Boron salts are used in fire retardants, the production of glass, leather tanning and finishing industries, cosmetics, photographic materials, metallurgy, and for high energy rocket fuels. Elemental boron also can be used in nuclear reactors for neutron absorption. Borates are used as "burnable" poisons.

RATIONALE:

Boron is an essential element for growth of plants but there is no evidence that it is required by animals. The maximum concentration found in 1,546 samples of river and lake waters from various parts of the United States was 5.0 mg/l; the mean value was 0.1 mg/l (Kopp and Kroner, 1967). Ground waters could contain substantially higher concentrations at certain places. The concentration in sea water is reported as 4.5 mg/l in the form of borate (NAS, 1974). Naturally occurring concentrations of boron should have no effects on aquatic life.

The minimum lethal dose for minnows exposed to boric acid at 20° C for 6 hours was reported to be 18,000 to 19,000 mg/l in distilled water and 19,000 to 19,500 mg/l in hard water (Le Clerc and Devlaminck, 1955; Le Clerc, 1960).

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In the dairy cow, 16 to 20 g/day of boric acid for 40 days produced no ill effects (McKee and Wolf, 1963).

Sensitive crops have shown toxic effects at 1000 ug/l or less of boron (Richards, 1954). Bradford (1966), in a review of boron deficiencies and toxicities, stated that when the boron concentration in irrigation waters was greater than 0.75 mg/l, some sensitive plants such as citrus began to show injury. Biggar and Fireman (1960) showed that with neutral and alkaline soils of high absorption capacities, water containing 2 mg/l boron might be used for some time without injury to sensitive plants. The criterion of 750 ug/l is thought to protect sensitive crops during long-term irrigation.

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CADMIUM

CRITERIA:

10 ug/l for domestic water supply (health).

Aquatic Life:

Fresh Water

Soft Water*	Hard Water*	
0.4 ug/l	1.2 ug/l	for cladocerans and salmonid fishes;
4.0 ug/l	12.0 ug/l	for other, less sensitive, aquatic life.

Marine

5.0 ug/l

INTRODUCTION:

Cadmium is a soft, white, easily fusible metal similar to zinc and lead in many properties and readily soluble in mineral acids. Biologically, cadmium is a nonessential, nonbeneficial element recognized to be of high toxic potential. It is deposited and accumulated in various body tissues and is found in varying concentrations throughout all areas where man lives. Within the past two decades industrial production and use of the metal has increased. Concomitantly, there have been incidences of acute cases of clinically identifiable cadmiosis. Cadmium may function in or may be an etiological factor for various human pathological processes including testicular tumors, renal dysfunction, hypertension, arteriosclerosis, growth inhibition, chronic diseases of old age, and cancer.

*See Criteria for Hardness (p. 147). The cadmium concentration that will be protective of a given aquatic ecosystem can be obtained by conducting flow-through bioassays using ambient water and native species of fish and invertebrates.

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Cadmium occurs in nature chiefly as a sulfide salt, frequently in association with zinc and lead ores. Accumulations of cadmium in soils in the vicinity of mines and smelters may result in high local concentrations in nearby waters. The salts of the metal also may occur in wastes from electroplating plants, pigment works, textile and chemical industries. Seepage of cadmium from electroplating plants has resulted in groundwater cadmium concentrations of 0.01 to 3.2 mg/l (Lieber and Welsch, 1954). Kopp and Kroner (1967) on one occasion reported 120 ug/l dissolved cadmium in the Cuyahoga River at Cleveland, Ohio. However, dissolved cadmium was found in less than 3 percent of 1,577 water samples examined for the United States, with a mean of slightly under 10 ug/l. Most fresh waters contain less than 1 ug/l cadmium and most analyses of sea water indicate an average concentration of about 0.15 ug/l (Fleischer, et al., 1974).

RATIONALE:

Cadmium has been shown to be toxic to man when ingested or inhaled. Exposure by the former route causes symptoms resembling food poisoning. A group of school children became ill after eating popsicles containing 13 to 15 mg/l cadmium (Frant and Kleeman, 1941), and this level, equivalent to 1.3 to 3.0 mg of cadmium ingested, commonly is considered the emetic threshold concentration.

In a specially designed study, five groups of rats were exposed to drinking water containing cadmium concentrations of 0.1 mg/l to 10 mg/l. Although no visible toxic effects were noted, the content of cadmium in the kidney and liver increased in direct proportion

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to the dose at all levels of exposure. At the end of one year, tissue concentrations were approximately double those found after six months (Ginn and Volker, 1944). Later work confirmed that virtually no absorbed cadmium was eliminated (Decker, et al., 1958).

Drinking water containing excessive cadmium led to the occurrence of itai-itai disease among the Japanese (Kobayashi, 1970). Within 15 years 200 cases of this disease were recorded in the Jintsu River Valley, half of which resulted in death. The disease is characterized by rheumatic symptoms with intense pain in the bones caused by a loss of bone minerals with the bones becoming as flexible as soft tissues. Yamagata and Shigematsu (1970) estimated that a daily intake of 600 ug cadmium would not produce itai-itai disease in an endemic area.

Studies in animals (Ferm, et al., 1969; Chernoff, 1973) as well as observations in human fetuses (Chaube, et al., 1973; and Friberg, et al., 1974) indicate that the placenta is not a complete barrier against the transfer of cadmium. About 6 percent of the cadmium that enters the stomach via food or drink is absorbed into the body tissues and about 30 percent of the cadmium inhaled into the lungs by breathing and smoking is absorbed (EPA, In Press). Presently there are no known physiological needs for cadmium and no mechanism by which the body maintains cadmium at a constant safe level. Once absorbed, it is stored largely in the kidneys and liver and is excreted at an extremely slow rate.

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Chronic kidney disease (renal tubular dysfunction) will begin to occur in an individual when the cadmium accumulated in the kidneys reaches a critical concentration. While the critical concentration varies from one individual to another, the threshold of observed effect is about 200 ppm of cadmium in the renal cortex (Friberg, et al., 1974). Individuals have been found with several times this level without evidence of kidney disease. At a 10 ug/l criterion, as recommended in drinking water, the maximum daily intake of cadmium would not exceed 20 ug from water, assuming a 2-liter daily consumption. The daily intake from other sources is up to 60 ug in the population of the United States (Schroeder, et al., 1961).

Pickering and Gast (1972) conducted two separate flow-through tests on the chronic toxicity of cadmium to the fathead minnow, Pimephales promelas, using water of 202 mg/l hardness, 157 mg/l alkalinity, and 7.7 pH. Five cadmium concentrations from 4 to 350 ug/l were delivered to the exposure chambers in each test over the life history of the fish. A concentration of 57 ug/l cadmium decreased survival of developing embryos. At levels from 4.5 to 37 ug/l no adverse effect on survival, growth, or reproduction was found. Eaton (1974b) exposed bluegill sunfish, Lepomis macrochirus, to five cadmium concentrations ranging from 31 to 2,140 ug/l for 11 months in a flow-through system using water of the same hardness as above. Nine of the 18 adult bluegill sunfish exposed to 80 ug/l died by the end of the test, while all of those exposed to 31 ug/l and the control survived. Although at 80 ug/l cadmium the hatchability of eggs was not measurably affected, the survival and growth of the resulting larvae were severely reduced after 60 days. Larvae exposed to 31 ug/l cadmium survived and grew about as well as the control fish. Sixty days

after hatching in hard water, growth and survival of channel catfish fry, Ictalurus punctatus, was reduced significantly at a cadmium concentration of 17 ug/l but not at 12 ug/l (Eaton, 1974a). Thus, in hard water, a criterion of 12 ug/l cadmium represents a demonstrated no-effect level for catfish and therefore was chosen to protect non-salmonid freshwater fish species. No data are available upon which to base an acceptable concentration for the chronic exposure of sensitive vertebrates or invertebrates in hard water, therefore a criterion is proposed which is reduced from the less sensitive aquatic life value by the same factor (0.1) as the criterion for soft water, i.e. 1.2 ug/l for salmonids and invertebrates.

Spehar (1974) reported on chronic toxicity tests with cadmium using a topminnow native to Florida in water with a hardness of 41 to 45 mg/l as $CaCO_3$, alkalinity of 38 to 43 mg/l, and a pH of 7.4. There was a significant reduction in the number of eggs produced per female at 8.1 ug/l cadmium, but fish in 4.1 ug/l were unaffected. A criterion of 4.0 ug/l cadmium is selected as offering protection to warm water fish species in soft water.

Three consecutive generations of brook trout, Salvelinus fontinalis, were exposed to cadmium concentrations rangipg from 6.4 ug/l to 0.5 ug/l in a test water of similar hardness (Benoit, et al., In Press). Second generation fish exposed to 6.4 and 3.4 ug/l cadmium were smaller at three months than fish exposed to lower concentrations. Both first and second generation fish suffered extensive mortalities during spawning in 3.4 ug/l cadmium. Egg hatchability, survival, growth, and reproduction of fish exposed to 1.7 ug/l were equal to those of control fish.

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When embryos and larvae-juveniles of brook trout, Salvelinus fontinalis; brown trout, Salmo trutta; lake trout, Salvelinus namaycush; northern pike, Esox lucius; white suckers, Catastomus commersoni; smallmouth bass, Micropterus dolomieui; and coho salmon, Oncorhynchus kisutch, were exposed to cadmium concentrations ranging from 0.4 to 100 ug/l in soft water, all suffered a reduction in standing crop at 12 ug/l. Standing crop survival times and weights were virtually equal among the four species when exposed to 4 ug/l; 1.2 ug/l was the highest cadmium concentration not causing a reduction among the other three salmonid species after 30 to 120 days of exposure (Eaton, 1974a).

Tests in water with 23 mg/l hardness, 18 mg/l alkalinity, and a pH of 7.3 in a flow-through system indicated a 96-hour LC50 of 2.0 ug/l for the initial feeding stage of chinook salmon, Oncorhynchus tshawytscha, and 0.92 ug/l for 5-month-old steelhead trout, Salmo gairdneri. A criterion of 0.4 ug/l for cadmium is believed to offer protection to the cladocerans and salmonids in soft water (Eaton, 1974a).

Anderson, et al., (1975) , determined the 10-day LC50 for the midge Tanytarsus dissimilis to be 3.4 ug/l in a flow-through system, soft water (48 mg/l) bioassay involving at least one molt. A concentration of 3.1 ug/l retarded growth but 1.9 ug/l elicited no obvious effect. Biesinger and Christensen (1972) measured the toxicity of cadmium to Daphnia magna during an entire life cycle in test water with a hardness of 45 mg/l, alkalinity of 42 mg/l, and a pH of 7.7. It was found that

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50 percent of the daphnids exposed to cadmium concentrations of 5 ug/l were killed in three weeks. The production of young was reduced by 50 percent compared to the controls in a cadmium concentration of 0.7 ug/l. Several invertebrate species have been found much less sensitive to cadmium in acute tests than in the midge and cladoceran exposures cited above. (Rehwoldt, et al., 1973; Thorp and Lake, 1974; Warnick and Bell, 1969). These data support a criterion for some invertebrates in soft water that is identical to that for salmonids.

Steward and Pesche, as reported by Eisler (1974), stated that for grass shrimp, Palaemonetes pugio, which were subjected to cadmium chloride in flowing sea water, 69 percent died in 43 days in 500 ug/l cadmium and 10 percent died in a 250 ug/l cadmium solution. Hermit crabs, Pagurus longicarpus, all died in a 250 ug/l cadmium solution, and 30 percent died in 43 days in a 120 ug/l solution. In 63 days, 40 percent died in a 60 ug/l cadmium solution. All of the controls survived.

Eisler (1971) found that the 96-hour LC50 for three species of marine decapod crustaceans ranged between 320 and 420 ug/l at 20° C and 20 mg/l alkalinity. The 96-hour LC25 was 180 ug/l for the hermit crab, Pagurus longicarpus, and the grass shrimp, Palaemonetes vulgaris, and 80 ug/l for the sand shrimp, Crangon septemspinosa.

Zaroogian, as reported by Eisler (1974), states that adult oysters, Crassostrea virginica, exposed to 10 ug/l cadmium between April 1973 and August 1973 accumulated 18,000 ug/kg of cadmium in wet whole

meat, which exceeds the human emetic threshold of 13,000 to 15,000 ug/kg. Oysters retained virtually all of the accumulated cadmium for at least several months and some histopathology was evident. Under natural conditions, significantly greater numbers of larvae from cadmium-stressed oysters failed to develop when compared to controls after 48 or 72 hours. A criterion of one-half of the level at which oysters accumulate cadmium in excess of the human emetic threshold (i.e. 5 ug/l) is believed to provide protection for consumers of oysters.

Data by Page, et al. (In Press), show that the yield of beans, beets, and turnips was reduced about 25 percent by 0.10 mg/l cadmium in nutrient solutions; whereas cabbage and barley yields decreased 20 to 50 percent at 1.0 mg/l.

Yamagata and Shigematsu (1970) have demonstrated that foods cultured on cadmium-polluted soils irrigated with cadmium-polluted water can accumulate sufficient cadmium to be hazardous to humans who consume these foods. Chaney (1973) suggests that it is not the cadmium concentration per se in the soil that determines cadmium accumulation by plants and that as long as the ratio of zinc to cadmium is 100 or greater, foods will not accumulate hazardous concentrations of cadmium. The subject is complex and additional research is needed to resolve potential hazards associated with the cadmium-zinc-soil-plant system.

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Fish and certain invertebrates have been found to be sensitive to low levels of cadmium in water. Salmonids and cladocerans appear to be the most sensitive among organisms tested. Increased hardness and/or alkalinity have been demonstrated to decrease the toxicity of cadmium in acute freshwater mortality tests, but may have less of an effect at low cadmium levels. Edible marine organisms can concentrate cadmium levels and become hazardous to be ultimate consumer. Lowman, et al. (1971) reported a concentration factor of 1,000 for cadmium in fish muscle. The criteria necessary to protect fish and other aquatic life are more stringent than those necessary to protect a public water supply or other uses. Data support a division of criteria for "hard" and "soft" water environments.

The data used to develop a criteria for cadmium were obtained over a range of hardness, alkalinity and pH values. Their usefullness in developing criteria will be limited to the range of physical parameters for which experimental data are available. Interpolation of the present data will be required to derive criteria for aquatic ecosystems which do not approximate the experimental conditions.

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CHLORINE

CRITERIA:

Total residual chlorine:

2.0 ug/l for salmonid fish;
10.0 ug/l for other freshwater and marine organisms.

INTRODUCTION:

Elemental chlorine is a greenish-yellow gas that is highly soluble in water. It reacts readily with many inorganic substances and all animal and plant tissues. The denaturing effect of chlorine on animal and plant tissues forms the basis for its use as an effective water or wastewater disinfectant. When chlorine dissolves in water, it hydrolyzes according to the reaction: $Cl_2 + H_2O \longrightarrow HOCl + H^+ + CL^-$. Unless the concentration of the chlorine solution is above 1000 mg/l, all chlorine will be in the form of HOCl or its dissociated ions H^+ and OCl^-. The HOCl is a weak acid and is dissociated according to the equation, $HOCl \rightleftharpoons H^+ + OCl^-$.

The ratio between HOCl and OCl^- is a function of the pH, with 96 percent HOCl remaining at pH 6, 75 percent at pH 7, 22 percent at pH 8, and 3 percent at pH 9. The relationship of HOCl to pH is significant as the undissociated form appears to be the bactericidal agent in the use of chlorine for disinfection (Moore, 1951).

Chlorine is not a natural constituent of water. Free available chlorine (HOCl and OCl^-) and combined available chlorine (mono- and

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di-chloramines) appear transiently in surface or ground waters as a result of disinfection of domestic sewage or from industrial processes that use chlorine for bleaching operations or to control organisms that grow in cooling water systems.

RATIONALE:

Chlorine, in the free available form reacts readily with nitrogenous organic materials to form chloramines. These compounds are toxic to fish. Chloramines have been shown to be slightly less toxic to fish than free chlorine, but their toxicity is considered to be close enough to free chlorine that differentiation is not warranted (Merkens, 1958). Since the addition of chlorine or hypochlorites to water containing nitrogenous materials rapidly forms chloramines, toxicity in most waters is related to the chloramine concentration. The toxicity to aquatic life of chlorine will depend upon the concentration of total residual chlorine, which is the amount of free chlorine plus chloramines. The persistence of chloramines is dependent on the availability of material with a lower oxidation-reduction potential.

In field studies in Maryland and Virginia, Tsai (1973) observed that downstream from plants discharging chlorinated sewage effluents, the total numbers of fish species were drastically reduced with the stream bottom clear of aquatic organisms characteristically present in unchlorinated wastewater discharges. No fish were found in water with a chlorine residual above 0.37 mg/l and the species diversity

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index reached zero at 0.25 mg/l. A 50 percent reduction in the species diversity index occurred at 0.10 mg/l. Of the 45 species of fish observed in the study areas, the brook trout and brown trout were the most sensitive and were not found at residual chlorine levels above about 0.02 mg/l. In studies of caged fish placed in waters downstream from chlorinated wastewater discharges, the Michigan Department of Natural Resources (1971) reported that 50 percent of the rainbow trout died within 96 hours at residual chlorine concentrations of 0.014 to 0.029 mg/l. Some fish died as far as 0.8 miles (1.3 km) downstream from the outfall.

Studies described by Brungs (1973) indicate that salmonids are the most sensitive fish to chlorine. A residual chlorine concentration of 0.006 mg/l was lethal to trout fry in two days (Coventry, et al., 1935). The 7-day LC_{50} for rainbow trout was 0.08 mg/l with an estimated median period of survival of one year at 0.004 mg/l (Merkens, 1958). Rainbow trout were shown to avoid a concentration of 0.001 mg/l (Sprague and Drury, 1969). Dandy (1972) demonstrated that brook trout had a mean survival time of 9 hours at 0.35 mg/l, 18 hours at 0.08 mg/l and 48 hours at 0.04 mg/l, with mortality of 67 percent after 4 days at 0.01 mg/l. Pike (1971) observed a 50 percent brown trout mortality at 0.02 mg/l within 10.5 hours and 0.01 mg/l with 43.5 hours.

The range of acutely lethal residual chlorine concentrations is narrow for various species of warm water fish. Arthur (1972) determined

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96-hour LC_{50} values for the walleye, black bullhead, white sucker, yellow perch, largemouth bass, and the fathead minnow. The observed concentration range was 0.09 to 0.30 mg/l.

Using fathead minnows in a continuous bioassay technique at Michigan treatment plants, Zillich (1972) found that an average concentration of 0.16 to 0.21 mg/l killed all of the test fish and that concentrations as low as 0.07 mg/l caused some mortalities. Pyle (1960) demonstrated a 50 percent mortality of smallmouth bass exposed to 0.5 mg/l within 15 hours. The mean 96-hour LC_{50} value for golden shiners was 0.19 mg/l (Esvelt, et al., 1971). Arthur and Eaton (1971), working with fathead minnows and the freshwater crustacean, Gammarus pseudolimnaeus, in dilute wastewater, found that the 96-hour LC_{50} of total residual chlorine for Gammarus was 0.22 mg/l and that all fathead minnows were dead after 72 hours at 0.15 mg/l. At concentrations of .09 mg/l, all fish survived until the seventh day when the first death occurred. In exposure to 0.05 mg/l residual chlorine, these investigators found reduced survival of Gammarus and at 0.0034 mg/l there was reduced reproduction. Growth and survival of fathead minnows after 21 weeks were not affected by continuous exposure to 0.043 mg/l residual chlorine. The highest level showing no significant effect was 0.016 mg/l. Working with secondary wastewater effluent, Arthur (1972) found that reproduction by Gammarus was reduced by residual concentrations above 0.012 mg/l residual chlorine.

In marine water, 0.05 mg/l was the critical chlorine level for young Pacific salmon exposed for 23 days (Holland, et al., 1960). The

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lethal threshold for chinook salmon and coho salmon for a 72-hour exposure was noted by these investigators to be less than 0.01 mg/l chlorine. Studies on the effect of residual chlorine to marine phytoplankton indicate that continuous exposure to 0.10 mg/l reduced primary production by 70 percent while 0.2 mg/l for 1.5 hours reduced primary production by 25 percent (Carpenter, et al., 1972). Laboratory studies on ten species of marine phytoplankton indicate that a 50 percent reduction in growth rate occurred at chlorine concentrations of 0.075 to 0.250 mg/l during a 24-hour exposure period (Gentile, et al., 1973). Oysters are sensitive to chlorine concentrations of 0.01 to 0.05 mg/l and react by reducing pumping activity. At chlorine concentrations of 1.0 mg/l, effective pumping could not be maintained (Galtsoff, 1946).

Chlorine residuals of 10 ug/l have been shown to kill adult salmonid fish in a period of several days in fresh water and the fry of these species have been killed in chlorine residuals of 6 ug/l. The criterion of 2 ug/l chlorine should afford protection to this group of fish when exposed on a continuing basis. Considering the data presented above, a criterion of 10 ug/l should afford protection to other freshwater fish and marine aquatic life (Brungs, In Press). Brungs (1973) reported that aquatic organisms may tolerate short-term exposure to higher levels of residual chlorine than the concentrations which have adverse chronic effects. Basch and Truchan (In Press) have shown that repeated daily exposure at these levels will have toxic effects on aquatic life.

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CHROMIUM

CRITERIA:

50 ug/l for domestic water supply (health);

100 ug/l for freshwater aquatic life

INTRODUCTION:

Chromium is the seventeenth most abundant nongaseous element in the earth's crust (Schroeder, 1970); its concentration range in the continental crust is 80 to 200 mg/kg, with an average of 125 mg/kg (NAS, 1974a). Although chromium has oxidation states ranging from Cr^{-2} to Cr^{+6}, the trivalent form most commonly is found in nature. Chromium is found rarely in natural waters, ranking twenty-seventh or lower among the elements in seawater and generally is well below 1 ug/l. Kopp (1969) reported that for 1,577 surface water samples collected at 130 sampling points in the United States, 386 samples contained from 1 to 112 ug/l; the mean was 9.7 ug/l chromium. Durum, et al.,(1971) in a similar survey of 700 samples, found that none contained over 50 ug/l of hexavalent chromium and 11 contained over 5 ug/l. Chromium is found in air, soil, some foods, and most biological systems; it is recognized as an essential trace element for humans (NAS, 1974a).

RATIONALE:

The earliest consequences of mild chromium deficiency in experimental animals is a reduced sensitivity of peripheral tissues to insulin; more severe deficiency in rats and mice results in fasting hyperglycemia,

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glycosuria, and mild growth retardation that is probably due, at least in part, to reduced insulin activation. Glucose intolerance is a common human problem, and one of its many possible causes is chromium deficiency (NAS, 1974a).

The biological activity of chromium, i.e., its effect as an essential metal, is restricted to its trivalent state, Cr^{3+}. The Cr^{3+} ion forms complexes that are stable at or below pH 4, but which readily hydrolyze at "high" pH values; resulting in the formation of polynucleate bridge complexes. At the normal pH of blood, Cr^{3+} exists in large, insoluble macro-molecules which precipitate and become biologically inert; Cr^{3+} must therefore be supplied as a complex of suitable stability in order to be utilized.

Because of the present inadequacy of knowledge about the forms and biological availability of chromium in foods, it is not possible to quantify human dietary requirements. It is known that adult urinary loss is 5 to 10 ug/day, and since this constitutes the major portion of the daily loss, at least this much must be replaced to maintain balance. Based on rat studies indicating that absorption of various Cr^{3+} compounds can range from below 1 percent to 25 percent of a given dose, and assuming that the human case is similar, a dietary intake of 20 to 500 ug/day would balance urinary losses. It is estimated that daily chromium intakes in the U.S. are marginal and vary from 5 to 100 ug (WHO, 1973); it seems unlikely that any Cr^{3+} ingested via public drinking water would be appreciably assimilated.

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No harmful effects were observed when food or water containing moderate amounts of Cr^{3+} was administered to laboratory animals, e.g., cats that were fed chromic phosphate or oxydicarbonate at 50 to 1000 mg/day for 80 days, or rats drinking water containing 25 mg/l for a year or 5 mg/l throughout their lives (NAS, 1974a).

Hexavalent chromium, on the other hand, is irritating and corrosive to the mucous membranes; it is absorbed via ingestion, through the skin, and by inhalation, and is toxic when introduced into laboratory animals systemically (NAS, 1974a). Knowledge of the harmful human health effects of hexavalent chromium has been obtained almost entirely from occupational health effects. Lung cancer, ulceration and perforation of the nasal septum, and a variety of other respiratory complications and skin effects have been observed.

Symptoms of excessive dietary intake of chromium in man are unknown, and chromium deficiency is of greater nutritional concern than over-exposure. Chromium is the only element whose tissue concentration appears to decline with increasing age in the U.S. population; lung concentrations do not decline with age, suggesting that lung chromium is not in equilibrium with that in the rest of the body (NAS, 1974a).

Berg and Burbank (1972) compared concentrations of eight carcinogenic trace metals in water supplies (after Kopp and Kroner, 1967) with State cancer mortalities for major U.S. water basins, and no significant correlations were found for chromium. It should be emphasized that these data are not conclusive.

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The U.S. Public Health Service Drinking Water Standard (USPHS, 1962) states that the presence of hexavalent chromium in excess of 0.05 mg/l shall constitute grounds for rejection of the supply, and no harmful human health effects have been reported at this level. The NAS/NAE Committee on Water Quality Criteria recommended (NAS, 1974) that public water supply sources for drinking water contain no more than 0.05 mg/l total chromium, largely on the basis that lifetime tolerable levels of chromate ion are not known for man. There are insufficient data on the effect of the defined treatment process on chromate chromium removal. Chromium as Cr^{3+} is not likely to be present in waters of pH 5 and above because the hydrated oxide is very sparingly soluble.

A family of four individuals is known to have drunk water for a period of 3 years at a chromium level of 0.45 mg/l without known effects on their health as determined by a single medical examination (Davids and Lieber, 1951). A study was designed by MacKenzie, et al. (1958) to determine the toxicity of hexavalent and trivalent chromium ions to rats at various drinking water levels. After one year at levels of 0.45 to 25 mg/l, this study showed no evidence of toxic response in body weight, food consumption, blood changes, or mortality. However, significant accumulation of chromium occurred in the tissues at concentrations greater than 5 mg/l. Recent studies (Naumova, 1965) demonstrated that 0.1 mg of $K_2Cr_2O_7$/kg enhances the secretory and motor activity of the dog intestine.

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From these and other studies (Gross and Heller, 1946; Brard, 1935; Conn, et al., 1932; Schroeder, et al., 1963; Schroeder, et al., 1963a), it appears that a concentration of 50 ug/l of chromium in domestic water supply incorporates a reasonable safety factor to avoid any hazard to human health.

In addition, the possibility of dermal effects from bathing in water containing 50 ug/l chromium would likewise appear remote, although chromium is recognized as a potent skin sensitizer. Domestic water supplies should, therefore, contain no more than 50 ug/l total chromium.

Fish appear to be relatively tolerant of chromium, but some aquatic invertebrates are quite sensitive. Toxicity varies with species, chromium oxidation state, and pH. Pickering and Henderson (1966) conducted static bioassays with four warm water fish species; fathead minnows, Pimephales promelas; bluegill, Lepomis macrochirus; goldfish, Carassius auratus; and guppies, Poecilia reticulata. They obtained soft water (hardness - 20 mg/l; alkalinity - 18 mg/l; pH - 7.5) 96-hour LC_{50} values for hexavalent chromium ranging from 17.6 mg/l for fathead minnows to 118 mg/l for bluegill; hard water (hardness - 360 mg/l; alkalinity - 300 mg/l; pH - 8.2) 96-hour LC_{50} values for hexavalent chromium ranging from 27.3 mg/l for fathead minnows to 133 mg/l for bluegill. Their 96-hour LC_{50} trivalent chromium values (chromium potassium sulfate) ranged from 3.33 mg/l for guppies to 7.46 mg/l for bluegill in soft water. The LC_{50} for fathead minnows exposed to potassium chromate in soft water was 45.6 mg/l.

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Pickering (NAS, 1974) found 96-hour LC_{50} and safe hexavalent chromium concentrations of 33 mg/l and 1.0 mg/l, respectively, for fathead minnows in hard water. Pickering's Cr^{3+} data for fathead minnows in hard water showed a 96-hour LC_{50} of 27 mg/l and a safe concentration of 1.0 mg/l. Benoit (In Press) obtained soft water (45 mg/l hardness) 96-hour LC_{50} and safe hexavalent chromium values of 59 mg/l and 0.2 mg/l, respectively, for brook trout, Salvelinus fontinalis, and 69 and 0.2 mg/l, respectively, for rainbow trout, Salmo gairdneri.

Olson (1958) found the growth and survival of chinook salmon, Oncorhynchus kisutch, alevins and juveniles to be significantly reduced at hexavalent chromium concentrations of 0.2 mg/l. He saw no detrimental effects on salmon alevins at trivalent chromium concentrations of 0.2 mg/l. Beisinger and Christensen (1972) reported a 16 percent reproductive impairment in Daphnia magna in soft water (45 mg/l as $CaCO_3$) at a concentration of 0.33 mg/l of trivalent chromium.

The data available indicate hexavalent chromium to be somewhat more toxic than trivalent chromium in the case of chinook salmon, and since significant effects were seen on fish at 0.2 mg/l of hexavalent chromium a recommended criterion of 0.10 mg/l should provide adequate protection for both freshwater invertebrates and fish.

Lowman, et al. (1971) reported marine chromium concentration factors of 1,600 in benthic algae, 2,300 in phytoplankton, 1,900 in zooplankton, 440 in molluscan soft parts, and 70 in fish muscle.

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Raymont and Shields (1964) reported chromium threshold toxicity levels of 5 mg/l for small prawns, Leander squilla, 20 mg/l (as Na_2CrO_4) for the shore crab, Carcinas maenus, and 1 mg/l for the polychaete, Nereis virens. Doudoroff and Katz (1953) found that mummichogs, Fundulus heteroclitus, tolerated 200 mg/l $K_2Cr_2O_4$ in seawater for over a week.

Holland, et al. (1960) reported that 31.8 mg/l chromium (as K_2CrO_4) in sea water was 100 percent fatal to coho salmon, Oncorhynchus kisutch, and Gooding (1954) reported that 17.8 mg/l hexavalent chromium in sea-water was toxic to the same species.

Clendenning and North (1960) showed that 5.0 mg/l hexavalent chromium reduced photosynthesis by 50 percent in the giant kelp, Macrocystis pyrifera, during 4 days of exposure.

Based on the foregoing discussion of the marine toxicity of chromium, its accumulation at all trophic levels, and the sensitivity of lower aquatic forms to chromium, the freshwater criterion should protect marine populations.

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FECAL COLIFORM BACTERIA

CRITERION:

Bathing Waters

Based on a minimum of not less than five samples taken over a 30-day period, the fecal coliform bacterial level should not exceed a log mean of 200 per 100 ml, nor should more than 10 percent of the total samples taken during any 30 day period exceed 400 per 100 ml.

Shellfish Harvesting Waters

Not to exceed a median fecal coliform bacterial concentration of 14 MPN per 100 ml with not more than 10 percent of samples exceeding 43 MPN per 100 ml for the taking of shellfish.

INTRODUCTION:

It was recognized even before the microbial etiology of disease was known, that water can serve as a medium for the transfer of disease. The cause-effect relationship of disease transmission and specific fecally-associated microbes was initially defined by Von Fritsch in 1880, when he identified *Klebsiella spp.* in human feces. Further confirmation of the

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relationship between fecally-associated microbes and potential disease was developed by Escherich when he described Bacillus coli (Escherichia coli) as an indicator of pollution (Wolf, 1972; Guarraia, 1972). Since these early observations, the role of biological indicator organisms in defining water quality has become essential and addresses three categories generally: to identify environmental changes; to quantify pollution levels; or to be used in laboratories to study under controlled conditions phenomena which could be extrapolated to the environment (Butler, et al., 1972).

Microbiological indicators have been used to determine or indicate the safety of water for drinking, swimming and shellfish harvesting. As our knowledge concerning microbiology has increased, so has our understanding of the complex interrelationship of the various organisms with disease. Viruses causing a number of diseases and non-fecally associated bacteria causing infections of the ear, eye, nose and throat all have been isolated from water (Bonde, 1974; Scarpino, 1974). The relationship between numbers of specific disease causing organisms in water and the potential for transmission of disease remains elusive since the number of organisms required to cause disease varies depending upon the organism, the host, and the manner in which the bacteria and host interact. For example, in some instances a single cell of Salmonella, or a single plaque-forming unit (PFU) may be all that is necessary to cause a

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disease; however, in other instances the numbers of bacteria necessary to cause an illness may be up to 10^6 to 10^7 or even more viable organisms. The use to which water is put (i.e., swimming or drinking) the type of water, (marine or fresh), and the geographical location are all factors to be weighed in determining safe microbiological criteria.

Ideally, a microbiological indicator organism should fulfill all of the following criteria: (1) It should be applicable to all types of water, (2) it should be present whenever pathogens are present with a survival time equal to that of the hardiest enteric pathogen, and (3) the indicator should not reproduce in contaminated waters thus resulting in inflated values (Scarpino, 1974). Unfortunately, no such indicator organisms are known. Use has been made of coliform or fecal coliform bacteria as indicators of pollution.

Bacteria of the coliform group are considered the primary indicators of fecal contamination and are one of the most frequently applied indicators of water quality. The coliform group is made up of a number of bacteria including the genera Klebsiella, Escherichia, Serratia, Erwinia and Enterobacteria. Total coliform bacteria are all gram negative asporogenous rods and have been associated with feces of warmblooded animals.

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and with soil. The fecal coliform bacteria, which comprise a portion of the total coliform group, are able to grow at 44.5° C and ferment lactose producing acid and gas. Use of fecal coliform bacteria has proven to be of more sanitary significance than the use of total coliform bacteria because they are restricted to the intestinal tract of warm-blooded animals and are now used to define water quality for swimming. Arguments have been advanced for the use of Escherichia coli as the indicator of choice for fresh fecal pollution (Bonde, 1966). However, the methods for its identification require time, complex biochemical reactions, and experienced microbiologists, and the information gained by the additional work and expense involved in its identification may not provide sufficient additional information above the elevated temperature test (for fecal coliform bacteria) to warrant its use.

Enterococci were recognized as early as 1890 as being indicators of recent fecal pollution from warm-blooded animals (Geldreich and Kenner, 1969). The enterococci possess many characteristics which make them an ideal indicator system since they do not multiply in the aquatic environment and are serologically characteristic. However, there are numerous biotypes, and no good standardized method is available for biochemical testing. Such methodology is essential since identification is based primarily upon biochemical characterization.

Additional microbial systems have also been proposed as potential indicators of fecal pollution. Clostridium perfringens, an anaerobic spore former, has been associated frequently with sewage pollution. However, in a suspension of fecal material the ratio of Cl. perfringens to E. coli may differ from that in the effluent from a sewage treatment plant, in seawater or in sludge. Also the spores of Cl. perfringens are resistant and will vegetate upon culturing, hence it would be difficult to associate their presence with recent pollution.

Presence of microorganisms other than fecal coliform bacteria may also be indicative of water quality; however, the strict correlation between a pollutant problem other than fecal pollution and the numbers of the indicator organism is not always clear. The pseudomonads that are comprised of numerous free living saprophytes found in both fresh and marine waters have only one of its members as a known pathogen, Pseudomonas aeruginosa, which may be an indicator of pollution from the presence of warm-blooded animals (Ringem and Drake, 1952; Taylor, 1968; Reitler and Seligaman, 1957). While the number of P. aeruginosa in sewage usually is quite low and occurs too sporadically to be of value as an indicator organism for fecal pollution (Bonde, 1974), this organism may be an indicator of human pollution other than fecal.

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Bacterial pathogens, which occur in bathing waters and may cause disease even when not ingested are Klebsiella pneumoniae and Pseudomonas aeruginosa.

RATIONALE:

Bathing Waters

Pollution of aquatic systems by the excreta of warmblooded animals creates public health problems for man and animals and potential disease problems for aquatic life. It is known that enteric microbial pathogens may inhabit the gut of most warmblooded animals and are shed in feces. The presence of bacterial, viral, protozoan, and possibly fungal species which are either pathogens for or possess the potential to infect man and other organisms is indicated by the presence of the fecal coliform group of bacteria. Thus, the number of fecal coliforms present is indicative of the degree of health risk associated with using the water for drinking, swimming, or shellfish harvesting.

Arguments against the use of fecal coliform bacteria to define swimming quality in waters have noted the paucity of epidemiological evidence linking fecal coliform levels in bathing waters and the incidence of disease (Moore, 1959; 1971).

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A problem of potential medical significance is the transfer of characteristics which will alter the resistance of pathogenic bacteria, i.e. the R-factor (RTF - resistance transfer factor), to certain antibiotics, heavy metals and ultraviolet light. The significance of this, while not fully known, suggests that human pathogens in water may become resistant to common antibiotic therapy once the bacteria infect man or animals. One example of this problem has been already reported. Recently an outbreak of typhoid fever was found to be caused by Salmonella typhi containing the chloramphenical and amphicillin resistant factor (Datta and Olearte, 1974; Olearte and Galindo, 1973).

Disease transmission via the aquatic route including drinking water, recreational water, and seafood from polluted water, has been and continues to be a problem. Presently, the indicator systems considered to be the most practical are the coliform and the fecal coliform groups. Additional microbiological problems, which can be anticipated by the presence of specific bacteria or viruses, are recognized. Correlation between human pollution sources and the numbers and significance of the microbial system in question remain elusive. Nevertheless, as the relationships become clear additional criteria for water quality will evolve. Berg (1974) has shown that Polio Virus I at a concentration of 2 plaque forming units (PFU), a standard means for measuring virus concentrations in tissue culture, will cause disease in 67 percent of the uninnoculated population.

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However, the lack of epidemiological correlation between fecal coliform levels in coastal swimming waters and the incidence of disease may not have validity in fresh waters and it does not take into account non-reported diseases which may develop as an unrecognized result of swimming in polluted waters. Epidemiological evidence is but one consideration in setting microbiological criteria. The presence of fecal coliform bacteria indicates degradation of water quality and a relative risk of disease transmission.

In studies conducted in Lake Michigan at Chicago, Illinois (Smith, et al., 1951), in an inland river (Smith and Woolsey, 1952) and in tidal waters at Long Island, New York (Smith and Woolsey, 1961), a statistically significant increase in the incidence of illness was observed among swimmers who used the Lake Michigan beaches on selected days and the Ohio River beach of poorest water quality. The mean total coliform bacteria content of fresh waters was 2,300 per 100 ml and 2,700 per 100 ml, respectively. No relationship between the total coliform levels and swimming-related diseases was found at the ocean beach. These studies demonstrated that an appreciably higher overall illness incidence may be expected among swimmers when compared to non-swimmers, but the data are inconclusive. The data provide a positive correlation between total coliform numbers and the increased risk of disease associated with swimming in these waters. The diseases found were infections of the eye, ear,

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nose, and throat, as well as intestinal ailments (Stevenson, 1953).

Outbreaks of typhoid fever (Salmonella typhi) have been associated with swimmers in "heavily" polluted beaches in western Australia (Kovacs, 1959; Snow, 1959). In this case, a sewer outfall pipe was located one mile from the bathing beach where the typhoid outbreaks occurred and the sewer was overloaded because of rapid population growth. Use of a log mean of 200 fecal coliform bacteria per 100 ml, with the provision that 10 percent of the total samples during a thirty-day period not exceed 400 fecal coliforms per 100 ml, allows for variations in environmental conditions such as shifts in wind direction, current flow, and tidal fluctuations. At levels above the 200 fecal coliforms per 100 ml the risk of exposure to pathogenic microbes increases. Correlation between the fecal coliform level and microbial pathogen levels is the important relationship, since the fecal coliforms themselves serve as an indicator of the quality of water in relation to fecally associated microbial pathogens. Direct demonstration of the microbial pathogens is not always feasible.

Detection of Salmonella has shown that in fecally polluted marine waters the level may vary between 1 and 1,000 per liter (McCoy, 1964). Occurrences of viruses in ocean waters at levels of 60 plaque-forming units (PFU) per liter have been found

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(Shuval, et al., 1971). It is estimated that these values may represent only 10 to 50 percent of the total viral pathogens present because of the limited recovery efficiency of the methods used. Also, other viruses associated with feces may be present but may not grow in the tissue culture systems used.

Another important consideration in determining the safe microbiological criterion is the minimum dosage necessary to infect a bather. As few as 3 to 5 organisms of S. typhosa have been reported to cause infection, whereas, 1×10^5 to 1×10^7 cells for other Salmonella serotypes may be required to produce disease. Similarly, massive concentrations of cells of enteropathogenic E. coli have been reported necessary to produce infections in adult volunteers. Alteration of gastric function either by raising the pH in the stomach or by facilitating gastric emptying can reduce this dosage several orders of magnitude. Recent data from experiments with adult volunteers indicate that the infectious dose for Shigella flexneri 2a is less than 200 cells (Geldreich, 1974). Although enteric viruses are found in relatively small numbers in polluted waters, their occurrence could be hazardous since the minimum infective dose for humans has not been firmly established. For children, the minimum infective dose may be 1 or 2 PFU (Plotkin and Katz, 1967), while for adults the minimum infective dose may be the same or higher.

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However, less is known concerning the minimal infective dose for pathogenic bacteria that cause ear, eye, nose, and throat ailments (Geldreich, 1974).

Use of fecal coliform bacteria as a single parameter for monitoring recreational water quality must ultimately relate to the probable occurrence of waterborne pathogens. Currently, the only relationship which has been developed between the fecal coliform indicator and waterborne pathogens is that of Salmonella to fecal coliform density. Data which have been developed indicate a sharp increase in the frequency of Salmonella detection when fecal coliform densities are above 200 organisms per 100 ml of freshwater. When there are over 200 fecal coliforms per 100 ml, Salmonella isolation should approach 100 percent frequency. Data from estuarine waters were grouped to include the level of 1 to 70 fecal coliforms that is of interest to investigators of shellfish waters. For this range, below 70 fecal coliforms per 100 ml, only 6.7 percent of the 184 Salmonella examinations were positive. At the 200 fecal coliform level, the 28.4 percent occurrence of Salmonella in estuarine waters was essentially identical with data compiled from freshwater environments. In polluted estuarine waters containing fecal coliforms ranging from 201 to above 2,000, a recovery of

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Salmonella was seen 60 percent of the time. The recovery rate of Salmonella in estuarine waters is lower than that in fresh waters. In fresh water, Salmonella were recovered 85 to 98 percent of the time, in the range of from 201 to 2,000 fecal coliforms. The lower value for isolation of Salmonella from estuarine waters may be related to limitations of Salmonella methodology (Geldreich, 1972). It must be noted that any projection of the qualitative recoveries of Salmonella into a comparison with fecal coliform quantification has recognized limitations. Such projections do nevertheless suggest that the 200 fecal coliform per 100 ml limit for recreational waters is a useful water quality value.

Evaluation of the microbiological suitability for marine and fresh waters should be based upon the fecal coliform levels. As determined by either the multiple-tube fermentation for marine water or the membrane filter method for fresh water, and based upon a minimum of not less than five samples taken over not more than a 30-day period, the fecal coliform bacterial level should not exceed a log mean of 200 per 100 ml, nor should more than 10 percent of total samples during any 30-day period exceed 400 per 100 ml.

Shellfish

Shellfish, being filter feeders, require a high quality of water in order to be microbiologically safe for human consumption

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as either raw or partially cooked. Fecal coliform bacteria, other bacterial pathogens, and viruses found in water and sediments are concentrated by shellfish, depending upon temperature, density of pathogens, currents, depth, water chemistry, and shellfish feeding activity (Van Donsel and Geldreich, 1971; Metcalf and Stiles, 1968). Once concentration of pathogens occurs, flushing of microorganisms will not necessarily occur at the same rate (Janssen, 1974; Kelly and Arcisy, 1954). Because of the established relationship between coliform levels and enteric pathogens, shellfish waters historically have been classified on the basis of total coliform levels.

An attempt by the National Shellfish Program has been made to correlate fecal coliform bacteria to enteric pathogens. Ideally, any specific fecal coliform bacterial limit for shellfish should be based on a correlation with pathogenic occurrences in the aquatic environment and with epidemiological evidence of increased health risk among shellfish consumers. However, these data are not available and calculations have been based on health risks incurred through increased pathogen occurrence in waters of differing levels of fecal contamination. Recent data in shellfish growing waters have shown that Salmonella occurred in 4.7 percent of water samples having fecal coliform densities of 1 to 29 per 100 ml (Slanetz et al., 1974). Oysters growing in these waters accumulated from 33 to 2200 fecal coliform bacteria

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per 100 grams of shellfish meat, with Salmonella occurrence at 6.1 percent.

Shellfish contamination is intensified further by the normal accumulation of waterborne organisms in bottom sediments through the action of sedimentation. Investigation of both the overlying water and bottom sediments from lakes and streams has indicated a 100- to 1000-fold increase in fecal coliform densities at the water-sediment interface (Van Donsel and Geldreich, 1971). Enteric viruses (Coxsackie B3) in the bottom sediment of shellfish growing waters along the New Hampshire estuary have been found when the fecal coliform densities were as low as 10 organisms per 100 ml in the overlying waters (Slanetz et al., 1965)

Indicators of fecal pollution more specific than the total coliforms in shellfish waters have been sought. Candidate organisms or groups of organisms include E. coli and the fecal coliform group. The fecal coliforms have a higher positive correlation with fecal contamination from all warm blooded animals than does E. coli (Geldreich, 1974). Usually E. coli is the most numerous bacterium of the fecal coliform group; however, under some conditions other fecal coliforms may predominate (Sears et al., 1950). Analysis of data comparing the correlation of fecal coliforms and E. coli to fecal coliform sources confirms the fact that the fecal coliforms

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reflect sanitary quality of water. In comparing results of the fecal coliform test to those of the E. coli procedure in shellfish waters, E. coli was reported to range from 75 to 90 percent of the fecal coliform population with the fecal coliform bacteria giving a 96.6 percent correlation (Presnell, 1974). Therefore, the use of the fecal coliform test avoids the undesirable risk of excluding some fecal contamination.

The microbiological criterion for shellfish water quality has been accepted by international agreement to be 70 total coliforms per 100 ml, using a median MPN, with no more than 10 percent of the values exceeding 230 total coliforms. No evidence of epidemiological outbreak from consumption of raw shellfish which were grown in waters meeting this bacteriological criterion has been demonstrated. This standard has proven to be a practical limit when supported by sanitary surveys of the growing waters, acceptable quality in shellfish meats and good epidemiological evidence. However, evidence from field investigations suggests that not all total coliform occurrences can be associated with fecal pollution (Gallagher, et al., 1969). Thus, attention has been directed toward the adoption of the fecal coliform test to measure more precisely the occurrence and magnitude of fecal pollution in shellfish growing waters.

A series of studies was initiated by the National Shellfish Sanitation Program and data relating the occurrence of total

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coliforms to numbers of fecal coliforms were compiled. Information was received from 15 States and 2 Canadian provinces and was arbitrarily divided into 4 geographical areas: northwest, southern states, mid-Atlantic, and northeast. A total of 3,695 coliform values and 3,574 fecal coliform values were included in the tabulations. The prime objective was to determine the correlation between the two indicator groups and secondarily, to determine whether or not coliform data could be used as a basis for evaluation of a potential fecal coliform standard.

The data show that a 70 coliform MPN per 100 ml at the 50th percentile was equivalent to a fecal coliform MPN of 14 per 100 ml. The data, therefore, indicate that a median value for a fecal coliform standard is 14 and the 90th percentile should not exceed 43 for a 5 tube, 3 dilution method (Hunt and Springer, 1973).

Evaluation of the microbiological suitability of waters for recreational taking of shellfish should be based upon the fecal coliform bacterial levels. When possible, samples should be collected under those conditions of tide and reasonable rainfall when pollution is most likely to be maximum in the area to be classified. The median fecal coliform value should not exceed an MPN of 14 per 100 ml and not more than 10 percent of the samples should exceed an MPN of 43.

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COLOR

CRITERIA:

Waters shall be virtually free from substances producing objectionable color for aesthetic purposes;

the source of supply should not exceed 75 color units on the platinum-cobalt scale for domestic water supplies; and

increased color (in combination with turbidity) should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life.

INTRODUCTION:

Color in water principally results from degradation processes in the natural environment. Although colloidal forms of iron and manganese occasionally are the cause of color in water, the most common causes are complex organic compounds originating from the decomposition of naturally-occurring organic matter (AWWA, 1971). Sources of organic material include humic materials from the soil such as tannins, humic acid and humates; decaying plankton; and other decaying aquatic plants. Industrial discharges may contribute similar compounds, for example those from the pulp and paper and tanning industries. Other industrial discharges may contain brightly colored substances such as those from certain processes in textile and chemical industries.

Surface waters may appear colored because of suspended matter which comprises turbidity. Such color is referred to as apparent color and is differentiated from true color caused by colloidal humic materials (Sawyer, 1960). Natural color is reported in color "units" which generally are determined by use of the platinum-cobalt method (Standard Methods, 1971).

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There is no general agreement as to the chemical composition of natural color, and in fact, the composition may vary chemically from place to place (AWWA, 1971). Black and Christman (1963a) characterized color-causing colloids examined as aromatic, polyhydroxy, methoxy carboxylic acids. Shapiro (1964) characterized color-causing constituents as being dialyzable and composed of aliphatic, polyhydroxy, carboxylic acids with molecular weights varying from less than 200 to approximately 400. The colloidal fraction of color exists in the 3.5 to 10 mμ diameter range (Black and Christman, 1963b). These same authors summarized other characteristics of color observed in laboratory studies of natural waters: color is caused by light scattering and fluorescence rather than absorption of light energy and pH affects both particle size of the color-causing colloids and the intensity of color itself.

RATIONALE:

Color in water is an important constituent in terms of aesthetic considerations. To be aesthetically pleasing, water should be virtually free from substances introduced by man's activities which produce objectionable color. "Objectionable color" is defined to be a significant increase over natural background levels. Non-natural colors such as dyes should not be perceptible by the human eye as such colors are especially objectionable to those who receive pleasure by viewing water in its natural state. Because of the extreme variations in the natural background amount of color, it is meaningless to attempt numerical limits. The aesthetic attributes of water depend on one's appreciation of the water setting.

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The effects of color on public water supplies also are principally aesthetic. The 1962 Drinking Water Standards (PHS, 1962) recommended that color in finished waters should not exceed 15 units on the platinum-cobalt scale. Water consistently can be treated using standard coagulation, sedimentation and filtration processes to reduce color to substantially less than 15 color units when the source water does not exceed 75 color units (AWWA, 1971; NAS, 1974).

The effects of color in water on aquatic life principally are to reduce light penetration and thereby generally reduce photosynthesis by phytoplankton and to restrict the zone for aquatic vascular plant growth.

The light supply necessary to support plant life is dependent on both intensity and effective wave lengths (Welch, 1952). In general, the rate of photosynthesis increases with the intensity of the incident light. Photosynthetic rates are most affected in the red region and least affected in the blue-violet region of incident light (Welch, 1952). It has been found that in colored waters the red spectrum is not a region of high absorption so that the effective penetration, and therefore the intensity for photosynthesis, is not as restricted as are other wave lengths. It should be emphasized that transmission of all parts of the spectrum is affected by color, but the greatest effect is on the shortwave or blue end of the spectrum (Birge and Juday, 1930). In highly colored waters (45 to 132 color units) Birge and Juday (1930) measured the light transmission as a percentage of the incident level and found very little blue, 50 percent or less yellow, and 100 to 120 percent red.

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The light intensity required for some aquatic vascular plants to photosynthetically balance the oxygen used in respiration may be 5 percent of full sunlight during maximum summer illumination periods (NTAC, 1968). As much as 10 percent of the incident light may be required for plankton to likewise photosynthetically produce sufficient oxygen to balance their respiration requirements (NTAC, 1968). The depth at which such a compensation point is reached, called the compensation depth, delineates the zone of effective photosynthetic oxygen production. To maintain satisfactory biological conditions, this depth cannot be substantially reduced.

Industrial requirements as related to water color have been summarized (NAS, 1974). Table 2 lists the maximum value used as a source of water for various industries and industrial uses. Through treatment, such waters can be made to meet almost any industrial requirement.

Table 2.

Maximum color of surface waters that have been used as sources for industrial water supplies.

Industry or Industrial Use	Color, units
Boiler make-up	1,200
Cooling water	1,200
Pulp and paper	360
Chemical and allied products	500
Petroleum	25

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COPPER

CRITERIA:

1.0 mg/l for domestic water supplies (welfare).

For freshwater and marine aquatic life, 0.1 times a 96-hour LC50 as determined through nonaerated bioassay using a sensitive aquatic resident species.

INTRODUCTION:

Copper occurs as a natural or native metal and in various mineral forms such as cuprite and malachite. The most important copper ores are sulfides, oxides, and carbonates. Copper has been mined and used in a variety of products by man since prehistoric times. Uses for copper include electrical products, coins, and metal plating. Copper frequently is alloyed with other metals to form various brasses and bronzes. Oxides and sulfates of copper are used for pesticides, algicides, and fungicides. Copper frequently is incorporated into paints and wood preservatives to inhibit growth of algae and invertebrate organisms, such as the woodborer, Teredo, on vessels.

Copper is an essential trace element for the propagation of plants and performs vital functions in several enzymes and a major role in the synthesis of chlorophyll. A shortage of copper in soil may lead to chlorosis which is characterized by yellowing of plant leaves. In copper deficient soils it may be added as a trace nutrient supplement to other fertilizers.

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Copper is required in animal metabolism. It is important in invertebrate blood chemistry and for the synthesis of hemoglobin. In some invertebrate organisms a protein, hemocyanin, contains copper and serves as the oxygen-carrying mechanism in the blood. An overdose of ingested copper in mammals acts as an emetic.

In examining over 1500 surface water samples from the United States, Kopp and Kroner (1967) found soluble copper in 74 percent of the samples with an average concentration of 15 µg/l and a maximum concentration of 280 µg/l of copper. The average concentration of copper in seawater approximately 3.0 µg/l (Mero, 1964).

RATIONALE:

Concentrations of copper found in natural waters are not known to have an adverse effect on humans. Prolonged oral administration of excessive quantities of copper may result in liver damage, but water supplies seldom have sufficient copper to effect such damages. Young children require approximately 0.1 mg/day of copper for normal growth and the daily requirement for adults was estimated to be about 2 mg/day (Sollman, 1957). Copper in excess of 1 mg/l may impart some taste to water. Because of a possible undesirable taste in drinking water at higher concentrations, a limit of 1 mg/l is recommended.

Testing precipitated copper in lake bottom muds resulting from copper sulfate application to control nuisance algae, Mackenthun and Cooley (1952) concluded that the toxic limit to a midge, Tendipides plumosus,

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and a fingernail clam, Pisidium idahoense was about 9,000 mg/kg of copper in mud on a dry weight basis.

The toxicity of copper to aquatic life is dependent on the alkalinity of the water as the copper ion is complexed by anions present, which in turn affect toxicity. At lower alkalinity copper is generally more toxic to aquatic life. Other factors affecting toxicity include pH and organic compounds. Relatively high concentrations of copper may be tolerated by adult fish for short periods of time; the critical effect of copper appears to be its higher toxicity to young or juvenile fish.

Doudoroff and Katz (1953), in reviewing literature on the acute toxicity of copper, concluded that in most natural fresh waters in the United States copper concentrations below 25 µg/l as copper evidently are not rapidly fatal for most common fish species. In acute tests Jones (1964) reported that copper sulfate in soft water (12 mg/l $CaCO_3$) was toxic to rainbow trout at 60 µg/l copper. In very hard water (320 mg/l $CaCO_3$) the toxic concentration was 600 µg/l copper. A summary of acute toxicity data is given in Table 3. In checking this table the reader should consider the species tested, pH, alkalinity, and hardness if alkalinity is not given (in most natural waters alkalinity parallels hardness). In general the salmonids are very sensitive and the centrarchids are less sensitive to copper.

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TABLE 3

The acute toxicity (24-, 48-, 96-hr TL50 values) of copper to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alkalinity	Hardness	Reference
Rainbow trout (Salmo gairdneri)	4 month old (7g)	Copper	96	FT*	11.6-12.4	0.02 Cu	6.8-7.0	17-26	20-25	(6)
Rainbow trout	Juveniles	Copper	24	S**	15 -15.6	1.25 Cu	7.3-7.4	200	290	(5)
		sulfate	96	S	15	0.89 Cu				
Rainbow trout	—	Copper	48	S	15	0.4-0.5 Cu	7.6	200	320	(2)
Brook trout (Salvelinus fontinalis)	14 month old	Copper	96	FT	12±1	0.10 Cu	7.5	41.6	45	(9)
Atlantic salmon (Salmo salar)	Juveniles	Copper	96	S	18-21	.125 Cu	6.5-6.7	4	8-10	(22)
Atlantic salmon	Juveniles	Copper	24	FT	15	.028 Cu	7.1-7.5	—	20	(16)
Chinook salmon (Oncorhynchus tshawytscha)	At hatch	Copper	96	FT	11.1-12.0	0.031 Cu	6.8-7.0	17-26	20-25	(6)
	1 month old	Copper	96	FT	10.8-12.5	0.018 Cu				

*FT - flow-through bioassay
**S - static bioassay

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The acute toxicity (24-, 48-, 96-hr TL50 values) of copper to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alkalinity	Hardness	Reference
Chinook salmon	-	Cupric nitrate	<96	s	9.5	0.178 Cu^{++}	7.75-7.85	-	80	(8)
Silver salmon (Oncorhynchus kisutch)	-	Copper sulfate	96	s	10 10	0.45 Cu^{++}	7.75-7.85	-	40	(8)
Bluegills (Lepomis macrochirus)	1-2 g	$CuSO_4 \cdot 5H_2O$	24 48 96	s	25	0.86 $CuSO_4 \cdot 5H_2O$ 0.74 $CuSO_4 \cdot 5H_2O$ 0.66 $CuSO_4 \cdot 5H_2O$	7.5	18	20	(13)
Bluegills	Juveniles (35 g)	$CuSO_4$	96	FT	20±1	1.1 Cu	7-8	43	45	(1)
Bluegills	5-9 cm	Copper chloride	96	s	20	0.71 Cu^{++}	≤5.3	3-6	45-47	(18)
		Copper sulfate	96	s	20	0.77 Cu^{++}				
Bluegills	-	Copper sulfate	96	s	--	0.2 Copper sulfate	7.4	18	20	(17)
Bluegills	1-2 g	$CuSO_4 \cdot 5H_2O$	24 48 96	s	25	10.7 $CuSO_4 \cdot 5H_2O$ 10.2 $CuSO_4 \cdot 5H_2O$ 10.2 $CuSO_4 \cdot 5H_2O$	7.5	300	360	(13)
Bluegills	-	Copper sulfate	96	s	-	10.2 Copper sulfate	8.2	360	400	(17)

The acute toxicity (24-, 48-, 96-hr TL50 values) of copper to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alkalinity	Hardness	Reference
Bluegills	-	Copper sulfate (synthetic water)	48	s	20	7.0 Cu	8.3	72	101.2	(19)
Fathead minnow (Pimephales promelas)	1-2 g	$CuSO_4 \cdot 5H_2O$	24 48 96	s	25	0.038 $CuSO_4 \cdot 5H_2O$ 0.028 $CuSO_4 \cdot 5H_2O$ 0.023 $CuSO_4 \cdot 5H_2O$	7.5	18	20	(13)
Fathead minnow	-	$CuSO_4$	96	FT s	25±1 25±1	0.075 Cu 0.084 Cu	6.9-7.2	30	31	(11)
Fathead minnow	-	Copper sulfate	96	s	-	0.05 Copper sulfate	7.4	18	20	(17)
Fathead minnow	1 g	Copper cyanide	24 48 96	s	19.5-20.5	1.8 Cu 1.6 Cu 1.2 Cu	6.5	10	14	(7)
Fathead minnow	1-2 g	$CuSO_4 \cdot 5H_2O$	24 48 96	s	25	2.15 $CuSO_4 \cdot 5H_2O$ 1.50 $CuSO_4 \cdot 5H_2O$ 1.45 $CuSO_4 \cdot 5H_2O$	7.5	300	360	(13)
Fathead minnow	20-69 mm	Copper	96	s	4-30	0.56-0.99 Cu	8-8.5	90-230	120-336	(4).

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The acute toxicity (24-, 48-, 96-hr TL50 values) of copper to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alkalinity	Hardness	Reference
Fathead minnow	10-15 mm	$CuSO_4$	96	s FT	16-25	0.430 Cu 0.470 Cu	7.9	161	200	(10)
Fathead minnow	56 mm 1.6 g	Copper	96	FT	24±1	0.44 Cu	-	-	200	(12)
Fathead minnow	-	Copper sulfate	96	s	-	1.4 Copper sulfate	8.2	360	400	(17)
Banded killifish (Fundulus diaphanus)	≤20 cm	$Cu(NO_3)_2$	24 48 96	s	17	1.50 Cu^{++} 0.92 Cu^{++} 0.86 Cu^{++}	7.8	-	5.3	(14)
Banded killifish	≤20 cm	$Cu(NO_3)_2$	24 48 96	s	28	1.30 Cu^{++} 0.98 Cu^{++} 0.84 Cu^{++}	8.0	-	55	(15)
Striped bass (Morone saxatilis)	≤20 cm	$Cu(NO_3)_2$	24 48 96	s	17	8.3 Cu^{++} 6.2 Cu^{++} 4.3 Cu^{++}	7.8	-	53	(14)
Striped bass	≤20 cm	$Cu(NO_3)_2$	24 48 96	s	28	8.4 Cu^{++} 6.6 Cu^{++} 4.0 Cu^{++}	8.0	-	55	(15)
Striped bass	Fingerlings (2.7 g)	Copper sulfate	24 48 96	s	21	1.5 Copper sulfate 1.15 Copper sulfate 0.62 Copper sulfate	8.2	64	35	(21)

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The acute toxicity (24-, 48-, 96-hr TL50 values) of copper to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alkalinity	Hardness	Reference
Pumpkin-seed (*Lepomis gibbosus*)	≤20 cm	$Cu(NO_3)_2$	24 48 96	s	17	3.8 Cu^{++} 2.9 Cu^{++} 2.4 Cu^{++}	7.8	-	53	(14)
Pumpkin-seed	≤20 cm	$Cu(NO_3)_2$	24 48 96	s	28	3.5 Cu^{++} 2.9 Cu^{++} 2.7 Cu^{++}	8.0	-	55	(15)
White perch (*Morone*) *americana*	≤20 cm	$Cu(NO_3)_2$	24 48 96	s	17	11.8 Cu^{++} 8.0 Cu^{++} 6.2 Cu^{++}	7.8	-	53	(14)
White perch	≤20 cm	$Cu(NO_3)_2$	24 48 96	s	28	11.5 Cu^{++} 7.9 Cu^{++} 6.4 Cu^{++}	8.0	-	55	(15)
Carp (*Cyprinus carpio*)	≤20 cm	$Cu(NO_3)_2$	24 48 96	s	17	2.10 Cu^{++} 1.00 Cu^{++} 0.81 Cu^{++}	7.8	-	53	(14)
Carp	≤20 cm	$Cu(NO_3)_2$	24 48 96	s	28	1.90 Cu^{++} 1.20 Cu^{++} 0.80 Cu^{++}	8.0	-	55	(15)

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The acute toxicity (24-, 48-, 96-hr TL50 values) of copper to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alkalinity	Hardness	Reference
Brown bullhead (Ictalurus nebulosus)	Juveniles	Copper sulfate	96	FT	23	0.18 Cu	7.2-8.2	156	200	(3)
Bluntnose minnow (Pimephales notatus)	84 mm 6.7 g	Copper	96	FT	24±1	0.29 Cu	7.9	154	200	(12)
Stoneroller (Campostoma anomalum)	60 mm	Copper	96	FT	24±1	0.30 Cu	7.9	154	200	(12)
Creek chub (Semotilus atromaculatus)	64 mm 4.0 g	Copper	96	FT	24±1	0.31 Cu	7.9	154	200	(12)
Blacknose dace (Rhinichthys atratulus)	47 mm 1.1 g	Copper	96	FT	24±1	0.33 Cu	7.9	154	200	(12)
Rainbow darter (Etheostoma caeruleum)	41 mm	Copper	96	FT	24±1	0.33 Cu	7.9	154	200	(12)

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The acute toxicity (24-, 48-, 96-hr TL50 values) of copper to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alkalinity	Hardness	Reference
Goldfish (Carassius auratus)	1-2 g	$CuSO_4 \cdot 5H_2O$	24 48 96		25	0.094 $CuSO_4 \cdot 5H_2O$ 0.043 $CuSO_4 \cdot 5H_2O$ 0.036 $CuSO_4 \cdot 5H_2O$	7.5	18	20	(13)
Guppy (Lebistes reticulatus)	0.1-0.2 g	$CuSO_4 \cdot 5H_2O$	24 48 96	s	25	0.130 $CuSO_4 \cdot 5H_2O$ 0.073 $CuSO_4 \cdot 5H_2O$ 0.036 $CuSO_4 \cdot 5H_2O$	7.5	18	20	(13)
Mosquito fish (Gambusia affinis	-	Copper sulfate	24 48 96	s	24-27	122 Copper sulfate 84 Copper sulfate 75 Copper sulfate	6.1-8.1	<100	-	(20)

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Sprague and Ramsay (1965) determined the level beyond which the organism can no longer survive for an indefinite period of time for juvenile Atlantic salmon, Salmo salar, at 17° C. For copper in a water with a total hardness of 14 mg/l as $CaCO_3$ this level was 32 µg/l. At 28 µg/l copper there were no salmon deaths in 168 hours.

Sprague (1964) found that Atlantic salmon, Salmo salar, tended to avoid a concentration of copper as low as 4.0 µg/l.

Mount and Stephan (1969) reported that in chronic tests with fathead minnows in water with a hardness of 200 mg/l as $CaCO_3$, 33 µg/l copper did not affect survival or the physical appearance of the fish but did prevent spawning. No effects were noted at 14.5 µg/l copper. In soft water with a hardness of 30 mg/l as $CaCO_3$, the no-effect level for the fathead minnow, Pimephales promelas, was about 10.6 ug/l copper. These investigators reported application factors of between 0.13 and 0.22 and between 0.03 and 0.08, respectively, for soft and hard water. The maximum concentration of copper having no detectable effect on the brown bullhead, Ictalurus nebulosus, in 600 days in water with a hardness of 202 mg/l as $CaCO_3$ was determined to be between 16 and 27 µg/l (Brungs et al., 1973). Benoit (1975) exposed bluegills (Lepomis macrochirus) to copper in soft water for 22 months and found the "no-effect" level to be 21 ug/l copper.

McKim and Benoit (1971) conducted chronic tests with brook trout, Salvelinus fontinalis, exposed to copper in water with a mean alkalinity of 41.6 mg/l as $CaCO_3$. A copper concentration of 17.5 µg/l did not adversely affect survival, growth, or spawning of adult brook trout or the hatchability of the eggs; however this concentration affected the survival and growth of juveniles. The "no-effect" level established

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for the young brook trout was 9.5 µg/l copper. In a second generation exposure of brook trout to copper, McKim and Benoit (1974) found that exposure to "sublethal concentrations of copper from yearling through spawning to 3 month juveniles" was sufficient to establish a "no-effect" concentration (i.e., the "no-effect" level noted above caused no adverse effects on the second generation). These authors reported an application factor of between 0.17 and 0.10 of the 96-hour LC50 value for the brown trout only.

Biesinger and Christensen (1972) found a 16 percent reproductive impairment at 22 µg/l copper for Daphnia magna in chronic (3-week) tests in water with a total hardness of 45.3 mg/l as $CaCO_3$. The 3-week LC50 was 44 µg/l copper. The total copper concentration having no effect on Campeloma decisum, Physa integra, and Gammarus pseudolimnaeus in chronic studies was between 8.0 and 14.8 µg/l in water with a total hardness of 45.3 mg/l as $CaCO_3$ (Arthur and Leonard, 1970).

The concentration of copper that has been associated experimentally with no harmful effect for several aquatic species is about 5 to 15 µg/l. This is very close to the average ambient freshwater concentration now found where copper occurs in measurable quantity. In waters with high alkalinity and/or with much organic material many species will be able to tolerate higher ambient copper concentrations. In such cases, the criterion should not exceed 0.1 of the 96-hour LC50 (the approximate mean application factor from tests reported above) as determined through bioassays using sensitive resident species.

Copper is present in sea water at a concentration of approximately 3 µg/l but copper added to the marine environment is readily precipitated in the alkaline and saline environment. Toxicity of copper to fishes in

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marine waters has not been studied, but for Nereis virens, a polychaete invertebrate, the toxic threshold for copper was 100 µg/l (Raymont and Shields, 1964). Copper is toxic to oysters at concentrations above 100 µg/l (Galtsoff, 1932). Clendenning and North (1960) found inhibition of photosynthesis in the giant kelp, Macrocystis pyrifera, at copper concentrations of 60 µg/l. This commercially important marine plant is used for several industrial processes and for important food additives. In areas where this plant is especially significant it may be prudent to establish a restrictive copper criterion.

Adult softshell clams, Mya arenaria, were the most sensitive marine macroorganisms tested in static copper toxicity bioassays. LC0, LC50 and LC100 values after 168 hours at 30 o/oo salinity and 22°C were 25, 35 and 50 ug/l, respectively. At 17°C, these values were 75, 86 and 100 ug/l, respectively, for the same time period (unpublished manuscript). Copper is selectively concentrated over zinc by adult softshell clams, Mya arenaria, Concentrations of greater then 20 ug/l are fatal after exposure of several weeks (Pringle, et al., 1968). The 9-day LC50 for newly hatched Fundulus heteroclitus larvae was 160 ug/l (Gentile, 1975).

These data are insufficient to derive a satisfactory criteria number, but it is apparent that copper does exhibit toxicity to the few species tested. Therefore, it is recommended that .1 of the 96-hour LC50 for a sensitive aquatic species present be adopted.

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The only known industrial use of water affected by copper is the production of textiles which requires a minimum concentration (as low as 10 µg/l) for some select processes. If needed, the low concentrations found in natural water may be reduced readily by various forms of treatment including coagulation and precipitation or ion exchange resins. Thus, no water quality criterion for copper in industrial water supplies is proposed.

The minimum reported concentration of copper that begins to exhibit toxicity to some agricultural plants is 100 µg/l, which is considerably more than the average found in the Nation's waters. The adverse effect of copper on plants can be overcome readily by proper management through irrigation or by the addition of materials such as lime, phosphate. fertilizers, or iron salts to the soil (Reuther and Labanauskas, 1966). No criterion is proposed for copper in water used for agricultural purposes.

Copper sulfate has been used widely in the control of algae in water supply reservoirs and in recreational lakes. At Madison, Wisconsin, its use for such purposes began in 1918 (Mackenthun and Cooley, 1952). Copper sulfate was used first as a fish poison in 1914, and in 1953 it was used experimentally by the Massachusetts Division of Fisheries and Game in accelerating fish movements in ponds which were being fyke-trapped for the removal of overabundant par and weed species. It has since been used as a standard accessory tool in netting operations (Tompkins and Bridges, 1958).

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CYANIDE

CRITERIA:

5.0 ug/l for freshwater and marine aquatic life and wildlife.

INTRODUCTION:

Cyanide is one of the simplest and most readily formed organic moieties. Cyanide and compounds of cyanide are almost universally present where life and industry are found. Besides being very important in a number of manufacturing processes, they are found in many plants and animals as metabolic intermediates which generally are not stored for long periods of time.

In addition to the simple hydrocyanic acid (HCN), the alkali metal salts such as potassium cyanide (KCN) and sodium cyanide (NaCN), are commonly occurring forms and sources of cyanide. The latter compounds are readily dissolved in water; the extent of HCN formation is pH-dependent. A significant fraction of the cyanide exists as HCN molecules up to a pH of approximately 8, and the fraction increases rapidly as the pH of the solution decreases. When these simple salts dissociate in aqueous solution, the cyanide ion combines with the hydrogen ion to form hydrocyanic acid, which is toxic to aquatic life. Chemically, the cyanide ion behaves similarly to the halide ions--chloride, fluoride, bromide and iodide.

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The cyanide ion combines with numerous heavy metal ions to form metallocyanide complexes. The stability of these anions is highly variable. Those formed with zinc and cadmium are not stable; dissociation and production of hydrocyanic acid in near neutral or acidic environments is rapid. In turn, some of the metallocyanide anions are extremely stable. Cobaltocyanide is difficult to destroy with highly destructive acid distillation in a laboratory. The iron cyanides are also very stable but exhibit the phenomenon of photodecomposition, and in the presence of sunlight the material dissociates to release the cyanide ion, thus affecting toxicity; at night the reaction may reverse to produce a less toxic form or state.

A wide variety of organic compounds may contain cyanide functional groups. These compounds belong to a class of organic chemicals called nitriles, few of which dissociate to liberate cyanide ions or molecular HCN. In addition, there are also complex organic acids, alcohols, esters, and amides that contain the cyanide radicals. These organic compounds are used for numerous products or may be a waste by-product. Their toxicity, persistence, and chemistry in the aquatic environment are not well known except for a few specific compounds.

Cyanide toxicity is essentially an inhibition of oxygen metabolism, i.e., rendering the tissues incapable of exchanging oxygen. The cyanogen compounds are true noncumulative protoplasmic poisons (can be detoxified readily) since they arrest the activity of all forms of animal life. Cyanide shows a very specific type of toxic action. It

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inhibits the cytochrome oxidase system which facilitates electron transfer from reduced metabolites to molecular oxygen. The ferric iron-porphyrin molecule responsible for the catalytic action of cytochrome oxidase is the reactive site where cyanide combines with ferric(+++) iron atoms to form a reversible complex. Other enzymes containing a metal porphyrin molecule, e.g., peroxidases and xanthine oxidase, are also strongly inhibited by cyanide. Only undissociated HCN inhibits the consumption of oxygen in the tissues, causing cellular asphyxia (histotoxic anoxia) by attaching itself to the iron of the prosthetic group of the enzyme cytochrome oxidase.

Hydrocyanic acid can be absorbed readily and carried in the plasma but does not combine with hemoglobin because its iron atom is divalent (ferrous). Instead, cyanide combines with methemoglobin, a mildly oxidized form of hemoglobin in which the iron atom is trivalent (ferric). Methemoglobin, which cannot carry oxygen, normally represents only a small fraction of the total hemoglobin. Since it forms an irreversible and innocuous complex with cyanide, it is an active cyanide detoxifying agent. Amyl nitrite and other agents can be used to increase the level of methemoglobin to counteract cyanide toxicity. A few of the ways in which cyanide can be metabolized within a pattern of normal physiology are by the production of thiocyanate, reaction with hydroxocobalamin to form the harmless cyanocobalamin, combination with amino acids, oxidation to carbon dioxide and formate, etc. The conversion of only free cyanide and not organically bound cyano groups

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to thiocyanate (SCN^-) by action of the enzyme rhodanese is considered to be the primary method of detoxification of cyanide. Rhodanese is absent from blood and skeletal muscle, but is abundant in the liver. Thiocyanate is eliminated irregularly and slowly in the urine.

The action of cyanide on the respiration of the cell and the primary methods of detoxification of cyanide have been noted above. However, it should be pointed out that cyanide does not completely abolish cellular respiration. It is possible that a small amount of residual respiratory activity is made possible by cytochrome b activity, since this substance does not require the cyanide-susceptible cytochrome oxidase. An alternative explanation of residual respiratory activity of the cyanide-poisoned system is found in the action of the flavin aerobic dehydrogenases, which can transfer hydrogen to molecular oxygen without the cytochrome system.

The persistence of cyanide in water is highly variable. This variability is dependent upon the chemical form of cyanide in the water, the concentration of cyanide, and the nature of other constituents. Cyanide may be destroyed by strong oxidizing agents such as permanganates and chlorine. Chlorine is commonly used to oxidize strong cyanide solutions to produce carbon dioxide and ammonia; if the reaction is not carried through to completion, cyanogen chloride may remain as a residual and this material is also toxic. If the pH of the receiving waterway is acid and the stream is well aerated,

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gaseous hydrogen cyanide may evolve from the waterway to the atmosphere. At low concentrations or toxicity and with acclimated microflora, cyanide may be decomposed by microorganisms in both anaerobic and aerobic environments or waste treatment systems.

Hydrocyanic acid probably is the most toxic form of cyanide in water. The ratio of hydrocyanic acid to total cyanide is quite variable. Under natural conditions this variation is due to fluctuations in pH. Photochemical action can also affect this ratio. Fluctuation in pH is caused by acid wastewater discharges, and photosynthetic and respiration cycles of aquatic plant life affect the formation, stability and toxicity of HCN. Since such chemical and physical conditions will dictate the form of cyanide, the cyanide criteria must be based on the concentration of total cyanide present in the water.

RATIONALE:

Cyanide ingested by humans at quantities of 10 mg or less per day is not toxic and is biotransformed to the less toxic thiocyanate. Lethal toxic effects from the ingestion of water containing cyanide occur only when cyanide concentrations are high and overwhelm the detoxifying mechanisms of the human body. Continuous long-term consumption of up to nearly 5 mg per day has shown no injurious effects (Bodansky and Levy, 1923).

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A review of the available pertinent data on the acute toxicity of simple cyanides to fish reveals the following minimum lethal (threshold) concentrations of free cyanide from data obtained from experiments ranging from 12 minutes to 10 days: brook trout, Salvelinus fontinalis (Karsten, 1934); rainbow trout, Salmo gairdneri (Herbert and Merkens, 1952); brown trout, Salmo trutta (Burdick, et al., 1958); smallmouth bass, Micropterus dolomieu (Burdick, et al., 1958); bluegills, Lepomis macrochirus (Doudoroff, et al., 1966); and fathead minnows, Pimephales promelas (Doudoroff, 1956), are reported to be 50, 70 (60 determined concentration), 70, 104, 150, and 180 ug/l as cyanide, respectively.

Research at the University of Minnesota has revealed that the minimum lethal (threshold) concentrations, as determined from continuous flow bioassays in which routine analyses for cyanide were performed, are generally lower than the above reported values. The threshold concentrations, expressed as mg/l cyanide, for the brook trout, Salvelinus fontinalis; bluegill, Lepomis macrochirus; and fathead minnow, Pimephales promelas, were determined to be 0.057 at 10°C, 0.104 at 25°C, and 0.120 at 25°C, respectively (Broderius, 1974).

In review it can be concluded that free cyanide concentrations in the range from 50 to 100 ug/l as cyanide have proven eventually

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fatal to many sensitive fishes, and levels much above 200 ug/l probably are rapidly fatal to most fish species.

Downing (1954), Cairns and Scheier (1958), and Burdick, et al. (1958) have shown that the toxicity of free cyanides increases with any reduction in dissolved oxygen below the 100 percent saturation level. Cairns and Scheier (1958) observed that even periodic lowering of dissolved oxygen decreased the tolerance of bluegills to cyanide.

The tolerance of fish to cyanide solutions that are rapidly lethal has been reported to decrease with a rise in temperature. This increased toxicity may be explained in part by the increased metabolism of fish at higher temperatures.

Contradictory information from the literature indicates the uncertainty between the relationship of toxicity of simple cyanides to fish and the pH of the test solution. However, since undissociated hydrogen cyanide has been demonstrated to be the toxic cyanide species in simple cyanide solutions, changes in the pH of natural waters below a value of about 8.3 should have no measurable effect on the acute toxicity of simple cyanides to fish. There is no apparent relationship among toxicity to fish, the alkalinity and the hardness of the dilution water.

Cyanide is acutely toxic to most fishes at concentrations ranging from 50 to 200 ug/l (Herbert and Merkens, 1952; Burdick, et al., 1958; Cairns and Scheier, 1958; Doudoroff, 1956; Turnbull, et al., 1954; Lipschuetz and Cooper, 1955; Washburn, 1948).

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Some information on chronic or sublethal effects of cyanide is also available. Leduc (1966) found increased intestinal secretions in the fish, Cichlasoma bimaculatum, at concentrations as low as 20 ug/l and reduced swimming capability at concentrations of 40 ug/l. Costa (1965) reported that three common species of fish detected and avoided cyanide concentrations of 26 ug/l in approximately an hour or less. Exposure to cyanide concentrations as low as 10 ug/l reduced the swimming ability or endurance of brook trout, Salvelinus fontinalis (Neil, 1957). Growth, or food conversion efficiency of coho salmon, Oncorhynchus kisutch, was reduced at hydrogen cyanide concentrations of 20 ug/l. Small freshwater fish of the family Cichlidae exposed to a cyanide concentration of 15 ug/l lost weight more rapidly than the control fish in water free from cyanide (Leduc, 1966).

The effects of cyanide on marine life have not been investigated adequately to determine separate water quality criteria, but based on the physiological mechanisms of cyanide, toxicity to marine life probably is similar to that of freshwater life. Since marine waters generally are alkaline, the toxicity of cyanide should be less than in fresh waters where pH fluctuations occur more readily and frequently. Thus, an additional factor exists to provide a margin of safety and compensation for a lack of specific data on which to base the criterion for marine aquatic life.

Cyanide has not been reported to have any direct effect on recreational uses of water other than its effects on aquatic life. No information is available on adverse effects of cyanide in agricultural

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practices nor in industrial uses of water containing cyanide.

Since cyanide concentrations as low as 10 ug/l have been reported to cause adverse effects on fish, an ambient concentration of 5 ug/l is believed to provide protection with a reasonable margin of safety.

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GASES, TOTAL DISSOLVED

CRITERION:

To protect freshwater and marine aquatic life, the total dissolved gas concentrations in water should not exceed 110 percent of the saturation value for gases at the existing atmospheric and hydrostatic pressures.

RATIONALE:

Fish in water containing excessive dissolved gas pressure or tension are killed when dissolved gases in their circulatory system come out of solution to form bubbles (emboli) which block the flow of blood through the capillary vessels. In aquatic organisms this is commonly referred to as "gas bubble disease". External bubbles (emphysema) also appear in the fins, on the opercula, in the skin and in other body tissues. Aquatic invertebrates are also affected by gas bubble disease, but usually at supersaturation levels higher than those lethal to fish.

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The standard method of analyzing for gases in solutions has been the Van Slyke method (Van Slyke, et al., 1934); now gas chromatography also is used for determination of individual and total gases. For determination of total gas pressure, Weiss has developed the saturometer, a device based upon a thin-wall silicone rubber tube that is permeable to gases but impermeable to water; gases pass from the water through the tube, thus raising the internal gas pressure which is measured by a manometer or pressure gauge connected to the tube (NAS, 1974). This method alone does not separate the total gas pressure into the separate components, but Winkler oxygen determinations can be run simultaneously, and gas concentrations can be calculated.

Total dissolved gas concentrations must be determined because analysis of individual gases may not determine with certainty that gas supersaturation exists. For example, water could be highly supersaturated with oxygen, but if nitrogen were at less than saturation, the saturation as measured by total gas pressure might not exceed one hundred percent. Also, if the water was highly supersaturated with dissolved oxygen, the oxygen alone might be sufficient to

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create gas pressures or tensions greater than the criterion limits, but one would not know the total gas pressure or tension, or by how much the criterion was exceeded. The rare and inert gases such as argon, neon, and helium are not usually involved in causing gas bubble disease as their contribution to total gas presures is very low. Dissolved nitrogen (N_2), which comprises roughly 80 percent of the earth's atmosphere, is nearly inert biologically and is the most significant cause of gas bubble disease in aquatic animals. Dissolved oxygen, which is extremely bioactive, is consumed by the metabolic processes of the organism and is less important in causing serious gas bubble disease though it may be involved in initiating emboli formation in the blood (Nebeker, et al., 1976a.).

Percent saturation of water containing a given amount of gas varies with the absolute temperature and with the pressure. Because of the pressure changes, percent saturation with a given amount of gas changes with depth of the water. Gas supersaturation decreases by 10 percent per meter of increase in water depth due to hydrostatic pressure; a gas that is at 130 percent saturation at the

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surface would be at 100 percent saturation at 3 meters' depth. Compensation for altitude may be needed because a reduction in atmospheric pressure changes the water/gas equilibria resulting in changes in solubility of dissolved gases.

There are several ways that total dissolved gas supersaturation can occur:

(1) Excessive biological activity--dissolved oxygen concentrations often reach supersaturation due to excessive algal photosynthesis. Renfro (1963) reported gas bubble disease in fishes resulting, in part, from algal blooms. Algal blooms often accompany an increase in water temperature and this higher temperature further contributes to supersaturation.

(2) Lindroff (1957) reported that water spillage at hydropower dams caused supersaturation. When excess water is spilled over the face of a dam it entrains air as it plunges to the stilling or plunge pool at the base of the dam. The momentum of the fall carries the water and

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entrained gases to great depths in the pool and, under increased hydrostatic pressure, the entrained gases are driven into solution causing supersaturation of dissolved gases.

(3) Gas bubble disease may be induced by discharges from power generating and other thermal sources (Marcello, et al., 1975). Cool, gas-saturated water is heated as it passes through the condenser or heat exchanger. As the temperature of the water rises, percent saturation increases due to the reduced solubility of gases at higher temperatures. Thus the discharged water becomes supersaturated with gases and fish or other organisms living in the heated water may exhibit gas bubble disease (DeMont and Miller, 1972; Malouf, et al., 1972; and Keup, 1975).

In recent years, gas bubble disease has been identified as a major problem affecting valuable stocks of salmon and trout in the Columbia River system (Rulifson and Abel, 1971). The disease is caused by high concentrations of dissolved atmospheric gas which "enter" the river's water during heavy spilling at hydroelectric dams. A report by

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Ebel, et al. (1975) presents results from field and laboratory studies on the lethal, sublethal, and physiological effects of gas on fish, depth distribution of fish in the river (fish can compensate for some high concentrations of gas by moving deeper into the water column), detection and avoidance of gas concentrations by fish, intermittent exposure of fish to gas concentrations, and bioassays of many species of fish exposed to different concentrations of gas. Several conclusions resulting from these studies are:

(1) When either juvenile or adult salmonids are confined to shallow water (1 m), substantial mortality occurs at and above 115 percent total dissolved gas saturation.

(2) When either juvenile or adult salmonids are free to sound and obtain hydrostatic compensation either in the laboratory or in the field, substantial mortality still occurs when saturation levels (of total dissolved gases) exceed 120 percent saturation.

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(3) On the basis of survival estimates made in the Snake River from 1966 to 1975, it is concluded that juvenile fish losses ranging from 40 to 95 percent do occur and a major portion of this mortality can be attributed to fish exposure to supersaturation by atmospheric gases during years of high flow.

(4) Juvenile salmonids subjected to sublethal periods of exposure to supersaturation can recover when returned to normally saturated water, but adults do not recover and generally die from direct and indirect effects of the exposure.

(5) Some species of salmon and trout can detect and avoid supersaturated water; others may not.

(6) Higher survival was observed during periods of intermittent exposure than during continuous exposure.

(7) In general, in acute bioassays, salmon and trout were less tolerant than the non-salmonids.

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Dawley and Ebel (1975) found that exposure of juvenile spring chinook salmon, Oncorhynchus tshawytscha, and steelhead trout, Salmo gairdneri, to 120 percent saturation for 1.5 days resulted in over 50 percent mortality; 100 percent mortality occurred in less than 3 days. They also determined that the threshold level where significant mortalities begin occurring is at 115 percent nitrogen saturation (111 percent total gas saturation in this test).

Rucker (1974), using juvenile coho salmon, Oncorhynchus kisutch, determined the effect of individual ratios of oxygen and nitrogen and established that a decrease in lethal effect occurred when the nitrogen content fell below 109 percent saturation even though total gas saturation remained at 119 percent saturation, indicating the importance of determining the concentration of the individual components (O_2 and N_2) of the atmospheric supersaturation. Nebeker, et al. (1976a), using juvenile sockeye salmon, Oncorhynchus nerka, also showed that there was a significant increase in fish mortality when the nitrogen concentration was increased while holding the total percent saturation constant. They also showed that there

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was no significant difference in fish mortality at different CO_2 concentrations.

Research completed by Bouck, et al. (1975) showed that gas supersaturated water at and above 115 percent total gas saturation is acutely lethal to most species of salmonids, with 120 percent saturation and above rapidly lethal to all salmonids tested. Levels as low as 110 percent will produce emphysema in most species. Steelhead trout were most sensitive to gas-supersaturated water followed by sockeye salmon, Oncorhynchus nerka. Chinook salmon, Oncorhynchus tshawytscha, were intermediate in sensitivity. Coho salmon, Oncorhynchus kisutch, were significantly the more tolerant of the salmonids though still much more susceptible than non-salmonids like bass or carp.

Daphnia magna exhibited a sensitivity to supersaturation similar to that of the salmonids (Nebeker, et al., 1975), with 115 percent saturation lethal within a few days; stoneflies exhibited an intermediate sensitivity similar to bass with mortality at 130 percent saturation; and crayfish

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were very tolerant, with levels near 140 percent total gas saturation resulting in mortality.

No differences are proposed in the criteria for freshwater and marine aquatic life as the data available indicate that there probably is little difference in overall tolerances between marine and freshwater species.

The development of gas bubble disease in menhaden, Brevoortia sp., and their tolerance to gas saturation in laboratory bioassays and in the field (Pilgrim Nuclear Power Station Discharge Canal) are discussed by Clay, et al. (1975) and Marcello, et al. (1975). At 100 percent and 105 percent nitrogen saturation, no gas bubbles developed externally or in any of the internal organs of menhaden. At 105 percent nitrogen saturation, however, certain behavioral changes became apparent. Fish sloughed off mucus, swam erratically, were more excitable, and became darker in color. Menhaden behavioral changes observed at 110 percent nitrogen saturation were similar to those noted at 105 percent. In addition, at 110 percent gas emboli were found in the intestines, the pyloric caeca, and occasionally the

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operculum. The behavioral changes described were also observed at 115 percent, and clearly defined subcutaneous emphysema was observed in the fins and occasionally in the eye. At 120 percent and 130 percent nitrogen saturation, menhaden developed (within a few hours) classic symptoms of gas bubble disease. Externally, emboli were evident in all fins, the operculum, and within the oral cavity. Exophthalmia also occurred and emboli developed in internal organs. The bulbous arteriosis and swim bladder were severely distended, and emboli were found along the length of the gill arterioles resulting in hemostasis. At water temperatures of 30°C, menhaden did not survive, regardless of gas saturation level. At water temperatures of 15°, 22°, and 25°C, 100 percent of the menhaden died within 24 hours at 120 percent and 130 percent gas saturation. Fifty percent died after 96 hours at 115 percent (22°C). Menhaden survival after 96 hours at 110 percent nitrogen saturation ranged from 92 percent at 22° and 25° to 83 percent at 15°C. Observations on the relationship between the mortality rate of menhaden and gas saturation levels at Pilgrim Station during the April 1975 incident suggest that the fish may tolerate somewhat higher gas saturation levels in nature.

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It has been shown by Bouck, et al. (1975) and Dawley, et al. (1975) that survival of salmon and steelhead smolts in seawater is not affected by prior exposure to gas supersaturation while in fresh water. No significant mortality of juvenile coho and sockeye salmon occurred when they were exposed to sublethal concentrations of supersaturated water and then transferred to seawater (Nebeker, et al. 1976b).

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HARDNESS

INTRODUCTION:

Water hardness is caused by the polyvalent metallic ions dissolved in water. In fresh waters these are principally calcium and magnesium although other metals such as iron, strontium, and manganese contribute to the extent that appreciable concentrations are present. Hardness commonly is reported as an equivalent concentration of calcium carbonate ($CaCO_3$).

The concept of hardness comes from water supply practice. It is measured by soap requirements for adequate lather formation and as an indicator of the rate of scale formation in hot water heaters and low pressure boilers. A commonly used classification is given in the following table (Sawyer, 1960).

Classification of Water by Hardness Content

Conc., mg/l $CaCO_3$	Description
0 - 75	soft
75 - 150	moderately hard
150 - 300	hard
300 and up	very hard

Natural sources of hardness principally are limestones which are dissolved by percolating rainwater made acid by dissolved carbon dioxide. Industrial and

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industrially related sources include the inorganic chemical industry and discharges from operating and abandoned mines.

Hardness in fresh water frequently is distinguished in carbonate and non-carbonate fractions. The carbonate fraction is chemically equivalent to the bicarbonates present in water. Since bicarbonates generally are measured as alkalinity, the carbonate hardness usually is considered equal to the alkalinity.

RATIONALE:

The determination of hardness in raw waters subsequently treated and used for domestic water supplies is useful as a parameter to characterize the total dissolved solids present and for calculating chemical dosages where lime-soda softening is practiced. Because hardness concentrations in water have not been proven health related, the final level achieved principally is a function of economics. Since hardness in water can be removed with treatment by such processes as lime-soda softening and zeolite or ion exchange systems, a criterion for raw waters used for public water supply is not practical.

The effects of hardness on freshwater fish and other aquatic life appear to be related to the ions causing the hardness rather than hardness. Both the NTAC (NTAC, 1968) and NAS (NAS, 1974) panels have recommended against the use of the term hardness but suggest the inclusion of the concentrations of the specific ions. This procedure should avoid confusion in future studies but is not helpful in evaluating previous studies. For most existing data, it is difficult to determine whether toxicity of various metal ions is reduced because of the formation of metallic hydroxides and carbonates caused by the associated increases in alkalinity, or because of an antagonistic effect of one of the principal cations contributing to hardness, e.g., calcium, or a combination of both

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effects. Stiff (1971) presented a theory (without proof) that if cupric ions were the toxic form of copper while copper carbonate complexes were relatively non-toxic, then the observed difference in toxicity of copper between hard and soft waters can be explained by the difference in alkalinity rather than hardness. Doudoroff and Katz (1953), in their review of the literature on toxicity, presented data showing that increasing calcium in particular reduced the toxicity of other heavy metals. Under usual conditions in fresh water and assuming that other bivalent metals behave similarly to copper, it is reasonable to assume that both effects occur simultaneously and explain the observed reduction of toxicity of metals in waters containing carbonate hardness. The amount of reduced toxicity related to hardness, as measured by a 40-hour LC_{50} for rainbow trout, has been estimated to be about four times for copper and zinc when the hardness was increased from 10 to 100 mg/l as $CaCO_3$ (NAS, 1974).

Limits on hardness for industrial uses are quite variable. Table 4 lists maximum values that have been accepted by various industries as a source of raw water (NAS, 1974). Subsequent treatment generally can reduce hardness to tolerable limits although costs of such treatment are an important factor in determining its desirability for a particular water source.

Hardness is not a determination of concern for irrigation use of water. The concentrations of the cations, calcium and magnesium, which comprise hardness, are important in determining the exchangeable sodium in a given water. This particular calculation will be discussed under total dissolved solids rather than hardness.

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Table 4

Maximum Hardness Levels Accepted
by Industry as a Raw Water Source*

Industry	Maximum Concentration mg/l as $CaCO_3$
Electric Utilities	5,000
Textile	120
Pulp and Paper	475
Chemical	1,000
Petroleum	900
Primary Metals	1,000

* Requirements for final use within a process may be essentially zero which requires treatment for concentration reductions.

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IRON

CRITERIA:

0.3 mg/l for domestic water supplies (welfare).

1.0 mg/l for freshwater aquatic life.

INTRODUCTION:

Iron is the fourth most abundant, by weight, of the elements that make up the earth's crust. Common in many rocks it is an important component of many soils, especially the clay soils where usually it is a major constituent. Iron in water may be present in varying quantities dependent upon the geology of the area and other chemical components of the waterway.

Iron is an essential trace element required by both plants and animals. In some waters it may be a limiting factor for the growth of algae and other plants; especially this is true in some marl lakes where it is precipitated by the highly alkaline conditions. It is a vital oxygen transport mechanism in the blood of all vertebrate and some invertebrate animals.

The ferrous, or bivalent (Fe^{++}), and the ferric, or trivalent (Fe^{+++}) irons, are the primary forms of concern in the aquatic environment, although other forms may be in organic and inorganic wastewater streams. The ferrous (Fe^{++}) form can persist in waters void of dissolved oxygen and originates usually from groundwaters or mines when these are pumped or drained. For practical purposes the ferric (Fe^{+++}) form is insoluble. Iron can exist in natural organometallic or humic compounds and colloidal forms. Black or brown swamp waters may contain iron concentrations of several mg/l in the presence or absence of dissolved oxygen, but this iron form has litte effect on aquatic

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life because it is complexed or relatively inactive chemically or physiologically.

In stratified lakes with anaerobic hypolimnia, soluble ferrous iron occurs in the deep, anaerobic waters. During the autumnal or vernal overturns and with aeration of these lakes, it is oxidized rapidly to the ferric ion that precipitates to the bottom sediments as a hydroxide, $Fe(OH)_3$, or with other anions. If hydrogen sulfide (H_2S) is present in anaerobic bottom waters or muds, ferrous sulfide (FeS) may be formed. Ferrous sulfide is a black compound and results in the production of black mineral muds.

Prime iron pollution sources are industrial wastes, mine drainage waters, and iron-bearing groundwaters. In the presence of dissolved oxygen, iron in water from mine drainage is precipitated as a hydroxide, $Fe(OH)_3$. These yellowish or ochre precipitates produce "yellow boy" deposits found in many streams draining coal mining regions of Appalachia. Occasionally ferric oxide (Fe_2O_3) is precipitated forming red waters. Both of these precipitates form as gels or flocs that may be detrimental, when suspended in water, to fishes and other aquatic life. They can settle to form flocculant materials that cover stream bottoms thereby destroying bottom-dwelling invertebrates, plants or incubating fish eggs. With time these flocs can consolidate to form cement-like materials, thus consolidating bottom gravels into pavement-like areas that are unsuitable as spawning sites for nest building fishes; particularly this is detrimental to trout and salmon populations whose eggs are protected in the interstices of gravel and incubated with oxygen-bearing waters passing through the gravel.

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RATIONALE:

Iron is an objectionable constituent in water supplies for either domestic or industrial use. Iron appreciably affects the taste of beverages (Riddick, et al., 1958) and can stain laundered clothes and plumbing fixtures. A study by the Public Health Service (Cohen, et al., 1960) indicates that the taste of iron may be detected readily at 1.8 mg/l in spring water and at 3.4 mg/l in distilled water.

The daily nutritional requirement for iron is 1 to 2 mg, but intake of larger quantities is required as a result of poor absorption. Diets contain 7 to 35 mg per day and average 16 mg (Sollman, 1957). The iron criterion in water is to prevent objectionable tastes or laundry staining (0.3 mg/l) constitutes only a small fraction of the iron normally consumed and is of aesthetic rather than toxicological significance.

Warnick and Bell (1969) obtained 96-hour LC_{50} values of 0.32 mg/l iron for mayflies, stoneflies, and caddisflies; all are important fish food organisms. Brandt (1948) found iron toxic to carp, Cyprinus carpio, at concentrations of 0.9 mg/l when the pH of the water was 5.5. Pike, Esox lucius, and trout (species not known) died at iron concentrations of 1 to 2 mg/l (Doudoroff and Katz, 1953). In an iron polluted Colorado stream, neither trout nor other fish were found until the waters were diluted or the iron had precipitated to effect a concentration of less than 1.0 mg/l even though other water quality constituents measured were suitable for the presence of trout (FWPCA, 1967).

Ferric hydroxide flocs have been observed to coat the gills of white perch Roccus americanus, minnows and silversides, Menidia sp. (Olsen, et al.,

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1941). The smothering effects of settled iron precipitates may be particularly detrimental to fish eggs and bottom-dwelling fish food organisms. Iron deposits in the Brule River, Michigan and Wisconsin were found to have a residual long-term adverse effect on fish food organisms even after the pumping of iron-bearing waters from deep shaft iron mines had ceased (West, et al., 1963). Settling iron flocs have also been reported to trap and carry diatoms downward in waters (Olsen, et al., 1941).

Ellis (1937) found that in 69 of 75 study sites with good fish fauna, the iron concentration was less than 10.0 mg/l. The European Inland Fisheries Advisory Commission (1964) recommended that iron concentrations not exceed 1.0 mg/l in waters to be managed for aquatic life.

Based on field observations principally, a criterion of 1 mg/l iron for freshwater aquatic life is believed to be adequately protective. As noted, data obtained under laboratory conditions suggest a greater toxicity for iron than that obtained in natural ecosystems. Ambient natural waters will vary with respect to alkalinity, pH, hardness, temperature and the presence of ligands which change the valence state and solubility, and therefore the toxicity of the metal.

The effects of iron on marine life have not been investigated adequately to determine a water quality criterion. Dissolved iron readily precipitates in alkaline sea waters. Fears have been expressed that these settled iron flocs may have adverse effects on important benthic commercial mussels and other shellfish resources.

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Iron has not been reported to have a direct effect on the recreational uses of water other than its effects on aquatic life. Suspended iron precipitates may interfere with swimming and be aesthetically objectionable. Deposits of yellow ochre or reddish iron oxides can be aesthetically objectionable.

Iron at exceedingly high concentrations has been reported to be toxic to livestock and interfere with the metabolism of phosphorus (NAS, 1974). Dietary supplements of phosphorus can be used to overcome this metabolic deficiency (McKee and Wolf, 1963). In aerated soils, iron in irrigation waters is not toxic. Precipitated iron may complex phosphorus and molybdenum making them less available as plant nutrients. In alkaline soils, iron may be so insoluble as to be deficient as a trace element and result in chlorosis, an objectionable plant nutrient deficiency disease. Rhoades (1971) reported a reduction in the quality of tobacco because of precipitated iron oxides on the leaves when the crop was spray irrigated with water containing 5 mg/l of soluble iron.

For some industries, iron concentrations in process waters lower than that prescribed above for public water supplies are required or desirable. Examples include high pressure boiler feed waters; scouring, bleaching, and dyeing of textiles; certain types of paper production; some chemicals; some food processing; and leather finishing industries.

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LEAD

CRITERIA:

50 ug/l for domestic water supply (health);

0.01 times the 96-hour LC_{50} value, using the receiving or comparable water as the diluent and soluble lead measurements (non-filtrable lead using an 0.45 micron filter), for sensitive freshwater resident species.

INTRODUCTION:

In addition to their natural occurrence, lead and its compounds may enter and contaminate the global environment at any stage during mining, smelting, processing, and use. The annual increase in lead consumption in the U.S. during the 10-year period from 1962-1971 averaged 2.9 percent, largely due to increased demands for electrochemical batteries and gasoline additives (Ryan, 1971). In 1971 the total U.S. lead consumption was 1,431,514 short tons, of which 42 percent came from recycled lead (Ryan, 1971). Of the 1971 U.S. lead consumption, approximately 25 percent was as metallic lead or lead alloy (Ryan, 1971; NAS, 1972). Non-industrial sources that may contribute to the possibility of ingestion of lead by man include the indoor use of lead-bearing paints and plaster, improperly glazed earthenware, lead fumes on ashes produced in burning lead battery casings, and exhaust from internal combustion engines.

Most lead salts are of low solubility. Lead exists in nature mainly as lead sulfide (galena); other common natural forms are lead carbonate (cerussite), lead sulfate (anglesite), and lead chlorophosphate (pyromorphite). Stable complexes result also from the interaction of

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lead with the sulfhydryl, carboxyl, and amine coordination sites characteristically found in living matter. The toxicity of lead in water, like that of other heavy metals, is affected by pH, hardness, organic materials and the presence of other metals. The aqueous solubility of lead ranges from 500 ug/l in soft water to 3 ug/l in hard water.

Lead enters the aquatic environment through precipitation, lead dust fallout, erosion and leaching of soil, municipal and industrial waste discharges, and the runoff of fallout deposits from streets and other surfaces. Extrapolations from recent studies (EPA, 1972; University of Illinois, 1972) indicate that nationally as much as 5,000 tons of lead per year may be added to the aquatic environment as a result of urban runoff.

Mediterranean and Pacific surface waters contain up to 0.20 and 0.35 mg/l of lead, respectively (NAS, 1972), which is about 10 times the estimated pre-industrial lead content of marine waters. The lead content of rivers and lakes also has increased in recent years (NAS, 1972). It may be inferred from available data that the mean natural lead content of the world's lakes and rivers ranges from 1 to 10 ug/l (Livingstone, 1963); the lead content of rural U.S. soils is 10 to 15 ug/g (Chow and Patterson, 1962), and the usual range of lead-in-soil concentrations is 2 to 200 ppm, exclusive of areas near lead ore deposits (Motto, et al., 1970), although many urban soil concentrations are much higher.

In the analyses of over 1,500 stream samples, Kopp and Kroner report that lead was observed at measurable levels with a

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frequency of under 20 percent. The mean concentration of the positive occurrences was 23 ug/l. The highest incidence of occurrence of lead was observed in the Western Great Lakes Basin where the frequency was slightly above 40 percent. The highest recorded concentration was 140 ug/l in the Ohio River at Evansville, Indiana.

RATIONALE:

As far as is known, lead has no beneficial or desirable nutritional effects. Lead is a toxic metal that tends to accumulate in the tissues of man and other animals. Although seldom seen in the adult population, irreversible damage to the brain is a frequent result of lead intoxication in children. Such lead intoxication most commonly results from ingestion of lead-containing paint still found in older homes. The major toxic effects of lead include anemia, neurological dysfunction, and renal impairment. The most common symptoms of lead poisoning are anemia, severe intestinal cramps, paralysis of nerves (particularly of the arms and legs), loss of appetite, and fatigue; the symptoms usually develop slowly. High levels of exposure produce severe neurologic damage, often manifested by encephalopathy and convulsions; such cases frequently are fatal. Lead is strongly suspected of producing subtle effects (i.e., effects due to low level or long term exposures insufficient to produce overt symptoms) such as impaired neurologic and motor development and renal damage in children (EPA, 1973). Subclinical lead effects are distinct from those of residual damage following lead intoxication.

Biochemical effects of lead include inhibition of erythrocyte delta-aminolevulinic acid dehydrase (ALAD) activity, increased urinary

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excretion of delta-aminolevulinic acid (ALA-U), and increased blood lead concentration. The increase in ALA-U is of particular interest because it rarely is produced by any substance other than lead; it is related directly to inhibition of ALAD, the enzyme that converts ALA-U to porphobilinogen. Recent work indicates that lead interferes with heme biosynthesis, and thus elevates ALA-U excretion, at levels well below 40 ug/100 ml whole blood (Secchi, et al., 1974; Haeger-Aronsen, et al., 1974). As a result of this work, the Center for Disease Control has recommended that the upper limit of normal for lead in the blood of children be revised downward from 40 ug to 30 ug/100 ml whole blood. An ad hoc committee, appointed by the U.S. Public Health Service to establish a daily permissible intake of lead without excessive body lead burden in children, concluded that the level of such intake is 300 ug from all sources (King, 1971). The gastrointestinal absorption and retention of lead is greater in children than in adults, 53 percent and 18 percent, respectively, as shown in recent studies (Alexander, et al., 1973). The average daily intake of lead from diet and air among young children probably amounts to up to 2/3 of the daily permissible intake, leaving a very narrow margin of safety (King, 1971; Lin-Fu, 1973). Compared to adults, food and air intake by children is proportionally greater than their weight, e.g., a 1-year-old child, with only about 1/7 of the body weight of an adult, has 1/4 to 1/3 of the daily adult air intake and 40 to 60 percent of the dietary intake of an adult (NAS, 1972), so that his lead intake is proportionally greater on a body weight basis. Alexander, et al. (1973) have suggested a daily limit of lead intake for 0-5 year-olds of 10 ug/kg.

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Considerable evidence has been developed demonstrating that laboratory animals on high lead dosages show teratogenic effects; however, no such effects have been observed in cattle or sheep (NAS, 1972). Epidemiologic studies have demonstrated no relationship between lead exposure and cancer incidence in man, but it is known that lead at concentrations of one percent or more in the diet causes renal cancer in rats (NAS, 1972).

The lead content in public water supplies in the U.S. in 1962 ranged from traces to 62 ug/l (Dufor and Becker, 1964). Continuous monitoring of the U.S. water supplies since 1962 has demonstrated that their lead content has, in general, not exceeded the U.S. Public Health Service standard of 50 ug/l (USPHS, 1962). McCabe (1970) reported on 2,595 distribution samples and showed that 73 percent contained less than the USPHS limit. McCabe, et al. (1970) found that the range of lead concentrations in finished U.S. community water was from non-detectable to 0.64 mg/l. Of the 969 water supplies surveyed, 1.4 percent exceeded 0.05 mg/l of lead. Five of the water supplies in this sample contained sufficient lead to equal or exceed Kehoe's (1966) estimated maximum safe level of lead intake (600 ug/day) without considering the possible additional contributions to the total intake by other sources and routes of exposure. In drinking water lead should be kept to a minimum; a criterion of 50 ug/l is attainable and protective. Experience indicates that fewer than four percent of the water samples analyzed exceed the 50 ug/l limit and that the majority of these are due to corrosion problems and are not due to naturally occurring lead content in raw waters.

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For the fathead minnow, Pimephales promelas, Pickering and Henderson (1966) have determined the 96-hour TLm values for lead (chloride) to be 5.6 to 7.3 mg/l in soft water (20 to 45 mg/l as $CaCO_3$) Brown (1968) reported a 96-hour LC_{50} of 1 mg/l for rainbow trout, Salmo gairdneri, in soft water (50 mg/l as $CaCO_3$). The 96-hour LC_{50} value for lead in hard water was 482 mg/l for fathead minnows (Pickering and Henderson, 1966). Other short-term fish toxicity data are in Table 5.

Preliminary information on 2- to 3-month exposures of rainbow and brook trout indicated detrimental effects at 0.10 mg/l of lead in soft water (20-45 mg/l as $CaCO_3$) (NAS, 1974). Growth of guppy species was affected by 1.24 mg/l of lead (Crandall and Goodnight, 1962); Jones (1939) and Hawksley (1967) found chronic or sublethal effects on three-spine stickelback species from lead concentrations of 0.1 and 0.3 mg/l, and the conditioned behavior of goldfish, Carassius auratus, in a light-dark shuttlebox was adversely affected by 0.07 mg/l of lead in soft water (50 ppm $CaCO_3$ added to deionized tap water) (Weir and Hine, 1970).

A concentration of 30 ug/l lead in a 3-week exposure produced 16 percent reproductive impairment in Daphnia magna in water with a hardness of 45 mg/l $CaCO_3$ (Biesinger and Christensen, 1972). The 96-hour LC_{50} for rainbow trout species in hard water (alkalinity 243 mg/l) for total lead was 471 mg/l and the highest mean continuous flow concentration that did not have an adverse effect on survival, growth, and reproduction was 0.12 and 0.36 mg/l (Davies and Everhart, 1973).

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For dissolved lead, the 96-hour LC_{50} was 1.38 mg/l and the no-effect level was 18 to 32 ug/l. Total and free lead were considered to be the same in soft water. The 18-day LC_{50} in soft water (alkalinity 26.4 mg/l) was 140 ug/l and the highest mean continuous flow concentration that did not have an adverse effect on survival, growth and reproduction was 6.0 to 11.9 ug/l. The no-effect concentrations were determined on the occurrence of abnormal black tails caused by chronic lead exposure. Acute toxicity values for several species of fish in water of various qualities are presented in Table 5. When referring to this table, the reader should consider the species tested, pH, alkalinity, and hardness if alkalinity is not given (in most natural waters alkalinity parallels hardness). In general, the salmonids are most sensitive to lead in soft water, but the influence of pH, and other factors on the solubility and form of the lead preclude the recommendation of a freshwater criteria based on acute toxicities alone.

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Table 5

The acute toxicity (24-, 48-, 96-hr. TL50 values) of lead to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alk.	Hd.	Reference
Rainbow trout (Salmo gairdneri)	~31.5 g/fish	$Pb(NO_3)_2$	24	F.T.*	14.7	3.75 Pb	7.15-7.5	41-42	43-45	1
Rainbow trcut	~24 g/fish ~132 mm/fish	$Pb(NO_3)_2$	96	S*	7	1.38 free Pb	6.89-8.78	7-21 228 in control	300	3
Rainbow trout	~24 g/fish ~132 mm/fish	$Pb(NO_3)_2$	96	S	7	471 Pb	6.89-8.78	7-21 228 in control	300	3
Rainbow trout	~5.9 g/fish ~85.9 mm/fish	$Pb(NO_3)_2$	96	S	13.8-14.2	542 Pb	6.23-7.17	6-25 228 in control	385	3
Brook trout (Salvelinus fontinalis)	~ 102 g/fish	$Pb(NO_3)_2$	96	F.T.	12	4.5 Pb	6.9-7.1	43	45	1
Brook trout	~ 40 g/fish	$Pb(NO_3)_2$	96	F.T.	14	5.8 Pb	7.0-7.4	40-42	43-45	1
Coho Salmon (Oncorhyncus kisutch)	4-wk. post-hatch	$PbCl_2$	96	S	10	0.8 Pb	-	-	17-26	2
Coho Salmon	5-wk. post-hatch	$PbCl_2$	96	S	10	0.8 Pb	-	-	17-26	2
Coho Salmon	6-wk. post-hatch	$PbCl_2$	96	S	10	0.52 Pb	-	-	17-26	2
Coho Salmon	7-wk. post-hatch	$PbCl_2$	96	S	10	0.52 Pb	-	-	17-26	2

* F.T. = Flow Through
* S = Static

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The acute toxicity (24-, 48-, 96-hr. TL50 values) of lead to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alk.	Hd.	Reference
Sticklebacks (Gasterosteus aculeatus)	-	-	96	S	-	0.1 Pb	7.0-8.5	-	-	4
Mosquito fish (Gambusia affinis)	Adult Females	$Pb(NO_3)_2$	24	S	22-24	240 $Pb(NO_3)_2$ (150 Pb)	7.7-8.3	<100	-	9
Mosquito fish	Adult Females	$Pb(NO_3)_2$	48	S	22-24	240 $Pb(NO_3)_2$ (150 Pb)	7.7-8.3	<100	-	9
Mosquito fish	Adult Females	$Pb(NO_3)_2$	96	S	22-24	240 $Pb(NO_3)_2$ (150 Pb)	7.7-8.3	<100	-	9
Mosquito fish	Adult Females	Lead oxide	24	S	18-20	>56,000 PbO	7.1-7.2	<100	-	9
Mosquito fish	Adult Females	Lead oxide	48	S	18-20	>56,000 PbO	7.1-7.2	<100	-	9
Mosquito fish	Adult Females	Lead oxide	96	S	18-20	>56,000 PbO	7.1-7.2	<100	-	9
Gold fish (Carassius auratus)	1-2 g/fish 1.5-2.5 in./fish	$PbCl_2$	24	S	25	45.4 Pb	7.5	18	20	6
Gold fish	1-2 g/fish 1.5-2.5 in./fish	$PbCl_2$	48	S	25	31.5 Pb	7.5	18	20	6
Gold fish	1-2 g/fish 1.5-2.5 in./fish	$PbCl_2$	96	S	25	31.5 Pt	7.5	18	20	6

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The acute toxicity (24-, 48-, 96-hr. TL50 values) of lead to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alk.	Hd.	Reference
Guppies (Poecilia reticulatus)	0.1-0.2 g/fish 0.75-1 in./fish	$PbCl_2$	24	S	25	24.5 Pb	7.5	18	20	6
Guppies	0.1-0.2 g/fish 0.75-1 in./fish	$PbCl_2$	48	S	25	24.5 Pb	7.5	18	20	6
Guppies	0.1-0.2 g/fish 0.75-1 in./fish	$PbCl_2$	96	S	25	20.6 Pb	7.5	18	20	6
Bluegills (Lepomis macrochirus)	1-2 g/fish 1.5-2.5 in./fish	$PbCl_2$	24	S	25	25.9 Pb	7.5	18	20	6
Bluegills	1-2 g/fish 1.5-2.5 in./fish	$PbCl_2$	48	S	25	24.5 Pb	7.5	18	20	6
Bluegills	1-2 g/fish 1.5-2.5 in./fish	$PbCl_2$	96	S	25	23.8 Pb	7.5	18	20	6
Bluegills	~5 g/fish ~7 cm/fish	$(C_2H_5)_4Pb$	24	S	20	2.0 Pb	6.9-7.5	33-81	84-163	8
Bluegills	~5 g/fish ~7 cm/fish	$(C_2H_5)_4Pb$	48	S	20	1.4 Pb	6.9-7.5	33-81	84-163	8
Bluegills	1-2 g/fish 1.5-2.5 in./fish	$PbCl_2$	24	S	25	482 Pb	8.2	300	360	6
Bluegills	1-2 g/fish 1.5-2.5 in./fish	$PbCl_2$	48	S	25	468 Pb	8.2	300	360	6
Bluegills	1-2 g/fish 1.5-2.5 in./fish	$PbCl_2$	96	S	25	442 Pb	8.2	300	360	6

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The acute toxicity (24-, 48-, 96-hr. TL50 values) of lead to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alk.	Hd.	Reference
Fatheads (Pimephales promelas)	1-2 g/fish 1.5-2.5 in./fish	$PbCl_2$	24	S	25	8.18-11.5 Pb	7.5	18	20	6
Fatheads	1-2 g/fish 1.5-2.5 in./fish	$PbCl_2$	48	S	25	5.99-11.5 Pb	7.5	18	20	6
Fatheads	1-2 g/fish 1.5-2.5 in./fish	$PbCl_2$	96	S	25	5.58-7.33 Pb	7.5	18	20	6
Fatheads	-	$PbCl_2$	48	F.T.	-	1.1 Pb	7.4	18	20	5
Fatheads	-	$PbCl_2$	96	F.T.	-	0.97 Pb	7.4	18	20	5
Fatheads	-	$PbCl_2$	96	S	-	5.6 Pb	7.4	18	20	5
Fatheads	-	$PbCl_2$	96	-	-	2.4 Pb	7.4	18	20	7
Fatheads	1-2 g/fish 1.5-2.5 in./fish	$Pb(C_2H_3O_2)_2 \cdot 3H_2O$	24	S	25	14.6 Pb	7.5	18	20	6
Fatheads	1-2 g/fish 1.5-2.5 in./fish	$Pb(C_2H_3O_2)_2 \cdot 3H_2O$	48	S	25	10.4 Pb	7.5	18	20	6
Fatheads	1-2 g/fish 1.5-2.5 in/fish	$Pb(C_2H_3O_2)_2 \cdot 3H_2O$	96	S	25	7.48 Pb	7.5	18	20	6
Fatheads	1-2 g/fish 1.5-2.5 in./fish	$PbCl_2$	24	S	25	482 Pb	8.2	300	360	6
Fatheads	1-2 g/fish 1.5-2.5 in./fish	$PbCl_2$	48	S	25	482 Pb	8.2	300	360	6
Fatheads	1-2 g/fish 1.5-2.5 in./fish	$PbCl_2$	96	S	25	482 Pb	8.2	300	360	6
Fatheads	-	$PbCl_2$	96	S	-	>75 Pb	8.2	360	400	7

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There are few data from which to draw conclusions about the relationship of safe levels for a given species in hard and soft water. The differences in lethal levels between very soft and very hard water is 100 to 500 times because of insolubility and precipitation. The single source of information for chronic and acute effects in hard and soft water is for rainbow trout (Davies and Everhart, 1973) and shows these significant factors:

Hardwater data were reported in terms of both total and free lead. The static acute hard water bioassay (mean hardness, 353.5 mg/l; methyl orange alkalinity, 243.1 mg/l; and pH, 8.02) demonstrated 96-hour TL_{50} (50 percent tolerance limit) concentration of 471 mg/l total lead and 1.38 mg/l free lead.

In the chronic hard water tests, lead-attributed mortalities occurred at levels of 3240 ug/l total lead and 64 ug/l free lead, while the maximum acceptable toxicant concentrations, based on the occurrence of black tails, were found to be 120 ug/l to 360 ug/l total lead and 18 ug/l to 32 ug/l free lead.

Soft water data were reported in terms of free lead. The flow-through acute soft water bioassay (mean hardness, 27.2 mg/l; methyl orange alkalinity, 26.4 mg/l; and pH 6.88) demonstrated an 18-day TL_{50} (50 percent tolerance limit) of 140 ug/l free lead.

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In the chronic soft water tests, lead-attributed mortalities occurred in fry and fingerling fish at a concentration of 95.2 ug/l, while three-year-old brood fish produced viable eggs and fry when exposed to any but the highest (27.9 ug/l) concentration. The maximum acceptable toxicant concentration, based on the occurrence of black tails, was determined to be between 11.9 and 6.0 ug/l.

A criterion involving an application factor of 0.01 multiplied by the acute 96-hour LC_{50} value expressed as dissolved lead is used to estimate the safe concentration for various fish species. Based upon the existing data, as well as upon the sensitivity of various species of fish to other metals, it is highly probable that salmon, trout, minnows and catfish will be especially sensitive to lead as compared to bass, sunfish and perch. Therefore, tests for acute toxicity should be performed on the more sensitive species when establishing standards for lead. This approach requires the experimental determination of LC_{50} values before a criterion can be determined, but the extreme effect of various water characteristics on lead solubility and toxicity warrants this additional effort.

Berry (1924) found that a concentration of lead nitrate of 25 mg/l was required to cause toxic effects to oats and tomato plants. At a concentration of 50 mg/l, plant death occurred. Hopper (1937) found that 30 mg/l of lead in nutrient solutions was toxic to bean plants.

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Wilkins (1957) found that lead at 10 mg/l as lead nitrate reduced root growth. Since dissolved lead contents in soils were usually from 0.05 to 5.0 mg/kg (Brewer, 1966), little toxicity can be expected. It was shown that the principal entry of lead into plants was from aerial deposits rather than from absorption from soils (Page, et al., 1971), indicating that lead that falls into the soil is not available to plants.

There is no question that some marine organisms can concentrate the lead present in sea water. Wilder (1952) reported lobster dying in 6 to 20 days when held in lead-lined tanks. Calabrese, et al. (1973) found a 48-hour LC_{50} of 1730 ug/l and a 48-hour LC_{50} of 2450 ug/l for oyster, Crassostrea virginica, eggs. The remarkable ability of the eastern oyster, Crassostrea virginica, to concentrate lead was demonstrated (Pringle, et al., 1968) by exposing them to flowing sea water containing lead concentrations of 25 ug/l, 50 ug/l, 100 ug/l, and 200 ug/l; after 49 days, the total accumulation of lead amounted to 17, 35, 75, and 200 ppm (wet weight), respectively, and those oysters exposed to the two highest lead levels, upon gross examination, showed considerable atrophy and diffusion of the gonadal tissue, edema, and less distinction of hepatopancreas and mantle edge.

North and Clendenning (1958) reported that lead nitrate at 4.1 mg/l of lead showed no deleterious effect on the photosynthesis rate in kelp, Macrocystis pyrifera, exposed for four days. However, there are insufficient data upon which to base a marine criterion at this time.

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MANGANESE

CRITERIA:

50 ug/l for domestic water supplies (welfare);

100 ug/l for protection of consumers of marine mollusks.

INTRODUCTION:

Manganese does not occur naturally as a metal but is found in various salts and minerals, frequently in association with iron compounds. The principal manganese-containing substances are manganese dioxide (MnO_2), pyrolusite, manganese carbonate (rhodocrosite) and manganese silicate (rhodonite). The oxides are the only important minerals mined. Manganese is not mined in the United States except when manganese is contained in iron ores that are deliberately used to form ferro-manganese alloys.

The primary uses of manganese are in metal alloys, dry cell batteries, micro-nutrient fertilizer additives, organic compounds used in paint driers and as chemical reagents. Permanganates are very strong oxidizing agents of organic materials.

Manganese is a vital micro-nutrient for both plants and animals. When manganese is not present in sufficient quantities, plants exhibit chlorosis (a yellowing of the leaves) or failure of the leaves to develop properly. Inadequate quantities of manganese in domestic animal food results in reduced reproductive capabilities and deformed or poorly maturing young. Livestock feeds usually have sufficient manganese, but beef cattle on a high corn diet may require a supplement.

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RATIONALE:

Although inhaled manganese dusts have been reported to be toxic to humans, manganese normally is ingested as a trace nutrient in food. The average human intake is approximately 10 mg/day (Sollman, 1957). Very large doses of ingested manganese can cause some disease and liver damage but these are not known to occur in the United States. Only a few manganese toxicity problems have been found throughout the world and these have occurred under unique circumstances, i.e., a well in Japan near a deposit of buried batteries (McKee and Wolf, 1963).

It is possible to partially sequester manganese with special treatment but manganese is not removed in the conventional treatment of domestic waters (Riddick, et al., 1958; Illig, 1960). Consumer complaints arise when manganese exceeds a concentration of 150 ug/l in water supplies (Griffin, 1960). These complaints are concerned primarily with the brownish staining of laundry and objectionable tastes in beverages. It is possible that the presence of low concentrations of iron may intensify the adverse effects of manganese. Manganese at concentrations of about 10 to 20 ug/l is acceptable to most consumers. A criterion for domestic water supplies of 50 ug/l should minimize the objectionable qualities.

McKee and Wolf (1963) summarized data on toxicity of manganese to freshwater aquatic life. Ions of manganese are found rarely at concentrations above 1 mg/l. The tolerance values reported range from 1.5 mg/l to over 1000 mg/l. Thus, manganese is not considered to be a problem in fresh waters. Permanganates have been reported to kill fish in 8 to 18 hours at concentrations of 2.2 to 4.1 mg/l, but permanganates are not persistent because they rapidly oxidize organic materials and are

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thereby reduced and rendered nontoxic.

Few data are available on the toxicity of manganese to marine organisms. The ambient concentration of manganese is about 2 ug/l (Fairbridge, 1966). The material is rapidly assimilated and bioconcentrated into nodules that are deposited on the sea floor. The major problem with manganese may be concentration in the edible portions of mollusks, as bioaccumulation factors as high as 12,000 have been reported (NAS, 1974). In order to protect against a possible health hazard to humans by manganese accumulation in shellfish, a criterion of 100 ug/l is recommended for marine water.

Manganese is not known to be a problem in water consumed by livestock. At concentrations of slightly less than 1 mg/l to a few milligrams per liter, manganese may be toxic to plants from irrigation water applied to soils with pH values lower than 6.0. The problem may be rectified by liming soils to increase the pH. Problems may develop with long-term (20 year) continuous irrigation on other soils with water containing about 10 mg/l of manganese (NAS, 1974). But as stated above, manganese rarely is found in surface waters at concentrations greater than 1 mg/l. Thus, no specific criterion for manganese in agricultural waters is proposed. In select areas, and where acidophilic crops are cultivated and irrigated, a criterion of 200 ug/l is suggested for consideration.

Most industrial users of water can operate successfully where the criterion proposed for public water supplies is observed. Examples of industrial

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tolerance of manganese in water are summarized for industries such as dyeing, milk processing, paper, textiles, photography and plastics (McKee and Wolf, 1963). A more restrictive criterion may be needed to protect or ensure product quality.

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MERCURY

CRITERIA:

2.0 ug/l for domestic water supply (health);

0.05 ug/l for freshwater aquatic life and wildlife;

0.10 ug/l for marine aquatic life.

INTRODUCTION:

Mercury is a silver-white, liquid metal solidifying at -38.9° C to form a tin-white, ductile, malleable mass. It boils at 356.9° C, has a specific gravity of 13.6 and a vapor pressure of 1.2×10^{-3} mm of mercury. Mercury has three oxidation states: (1) zero (elemental mercury); (2) +1 (mercurous compounds); and (3) +2 (mercuric compounds). Mercury is widely distributed in the environment and biologically is a non-essential or non-beneficial element. Historically it was recognized to possess a high toxic potential and was used as a germicidal or fungicidal agent for medical and agricultural purposes.

Human poisoning by mercury or its compounds clinically has been recognized. Although its toxic properties are well known, dramatic instances of toxicosis in man and animals have occurred recently, e.g., the Minamata Bay poisonings (Irukayama, et al., 1962; Irukayama, 1967). In addition to the incidents in Japan, poisonings have also occurred in Iraq, Pakistan and Guatemala as a result of ingestion of flour and seed treated with methyl and ethylmercury compounds (Bakir, et al., 1973). Mercury intoxication may be acute or chronic and toxic effects vary with the form of mercury and its mode of entry into the organism. The mercurous salts are less soluble than the mercuric and consequently are less toxic. For man, the fatal oral dose of mercuric salts ranges from 20 mg to 3.0 g (Stokinger, 1963). Symptoms of acute, inorganic mercury poisoning include pharyngitis, gastroenteritis, vomiting followed by ulcerative hemorrhagic colitis, nephritis,

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hepatitis, and circulatory collapse. Chronic mercury poisoning results from exposure to small amounts of mercury over extended time periods. Chronic poisoning from inorganic mercurials most often has been associated with industrial exposure, whereas poisoning from the organic derivatives has been the result of accidents or environmental contamination. Alkyl compounds are the derivatives of mercury most toxic to man, producing illness, irreversible neurological damage, or death from the ingestion of amounts in milligrams (Berglund and Berlin, 1969).

The mercury content of unpolluted U.S. rivers from 31 States where natural mercury deposits are unknown is less than 0.1 ug/l (Wershaw, 1970). Jenne (1972) found also that the majority of U.S. waters contained less than 0.1 ug/l of mercury. The lower limit of detection in these studies was 0.1 ug/l. Total mercury values of 0.045 ug/l recently were determined in Connecticut River water by Fitzgerald and Lyons (1973) using more sensitive methods. Marine waters have been shown to contain concentrations of mercury from a low of .03 to a high of 0.2 ug/l, but most marine waters fall within the range of .05 to .19 ug/l mercury (Robertson, et al., 1972). Mining, agriculture and waste discharges contribute to the natural levels found.

RATIONALE:

Several forms of mercury, ranging from elemental to dissolved inorganic and organic species, are expected to occur in the environment. The recent discovery that certain microorganisms have the ability to convert inorganic and organic forms of mercury to the highly toxic methyl or dimethyl mercury has made any form of mercury potentially hazardous to the environment

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(Jensen and Jernelov, 1969). In studies on the biochemical kinetics of mercury methylation, Bisogni and Lawrence (1973) demonstrated that in water, under naturally occurring conditions of pH and temperature, inorganic mercury can be converted readily to methylmercury.

Wood (1974) has argued further that whenever mercury in any form is added to the aquatic environment, a combination of microbially catalyzed reactions and chemical equilibrium systems is capable of leading to steady state concentrations of dimethyl mercury, methylmercuric ion, metallic mercury, mercuric ion, and mercurous ion. Thus, it is evident that the total mercury level should be the basis for a mercury criterion instead of any particular form in which it may be found within a sample.

Hannerz (1968), using 0.1 mg/l of several mercury compounds in ponds, concluded that algae and other aquatic plants accumulate mercury primarily by surface adsorption. This study demonstrated that all of the mercury compounds used were taken up by fish both directly from the water and from food. The accumulation rate was shown to be fast, while the elimination rate was slow, leading to concentration factors of 3,000-fold and higher. According to McKim (1974), concentration factors by fish in excess of 10,000 times the amount of mercury in the surrounding water have been demonstrated.

In a test period of 20 to 48 weeks, several species of fish accumulated more than 0.5 ug/gm mercury in their tissues from a water habitat containing 0.018 to 0.030 ug/l methylmercury (McKim, et al., In Press) representing concentration factors of from 27,800 to 16,600.

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Quantities of ingested mercury safe for man can be estimated from data presented in "Methyl Mercury in Fish" (1971). From epidemiological evidence, the lowest whole-blood concentration of methylmercury associated with toxic symptoms is 0.2 ug/g. This blood concentration can be compared to 60 ug/g mercury in hair. These values, in turn, correspond to prolonged continuous exposure at approximately 0.3 mg/70 kg body weight/day. By using a safety factor of 10, the maximum dietary intake from all sources, including air, water, and food, should not exceed 30 ug/person/day mercury. Although the safety factor is computed for adults, limiting ingestion by children to 30 ug/day of mercury is believed to afford some lesser degree of safety. If the exposure to mercury were from fish alone, the limit would allow for a maximum daily consumption of 60 grams (420 g/week) of fish containing 0.5 mg/kg mercury. A drinking water criterion of 2.0 ug/l would permit a daily intake of 4 ug mercury assuming an average consumption of 2 liters of water per day. If the mercury is not all in the alkyl form, a greater margin of safety will exist.

The levels of mercury in tissues of livestock consumed by humans should not exceed 0.5 mg/kg mercury. The tissue concentration of 0.5 mg/kg correlates approximately with a blood level of 0.1 ug/l. A mercury level of less than 1.0 ug/l in livestock water is considered compatible with these concentrations, thus a mercury concentration of 0.05 ug/l will provide an adequate safety factor.

Several chronic toxicity tests have been conducted to measure the adverse effects of organomercurials on survival, growth, and reproduction of several fish species. In a 3-year chronic toxicity study involving

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three generations of brook trout, Salvelinus fontinalis, exposed to methylmercuric chloride, gross toxic symptoms were observed after six-months' exposure of yearling trout to 2.9 ug/l of mercury (McKim, et al., In Press). Spawning occurred at all lower mercury concentrations tested, but the offspring of parental fish exposed to 0.93 ug/l of mercury exhibited reduction in growth 90 days after hatching. After 24-months' exposure of second generation fish to 0.93 ug/l, behavioral symptoms were noted, there was no spawning, and mortality was 94 percent. No adverse effects were observed in the brook trout exposed to methylmercuric chloride concentrations of 0.29 ug/l mercury and below. A full life cycle chronic toxicity test was conducted with fathead minnows, Pimephales promelas, exposed to methylmercuric chloride (Mount, 1974). All died after three months' exposure to concentrations of 0.80 and 0.41 ug/l mercury. Ninety-two percent of the fish exposed to 0.23 ug/l mercury also died within the three-month period. Spawning was completely inhibited at 0.12 ug/l mercury with males not developing sexually. No toxic effects were noted on survival or growth of the offspring produced in 0.07 ug/l of mercury.

Two chronic toxicity tests were conducted with one invertebrate, Daphnia magna. Mercury as mercuric chloride and methylmercuric chloride caused significant reproductive impairment at concentrations of 2.7 ug/l and 0.04 ug/l mercury, respectively (Biesinger, 1974).

Matida, et al. (1971) found that the LC_{50} for phenylmercuric acetate, methylmercuric chloride, and mercuric chloride with rainbow trout fingerlings, Salmo gairdneri, were 8.5, 30, and 310 ug/l, respectively. Wobeser (1973) examined the toxicity of methylmercuric chloride to two life stages

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of rainbow trout. The 96-hour LC_{50} for newly hatched sac fry was 24 ug/l of mercury, while rainbow trout fingerlings had a 96-hour LC_{50} value of 42 ug/l.

Eisler (1974) found that concentrations of 1.0 ug/l mercury represent a distinct threat to selected species of marine organisms and, based on a comparison with freshwater species, the accumulation of mercury is similar in fresh and marine water.

Because of methylation and bioconcentration of methylmercury, mercury limits must take into consideration the food chain transport path from aquatic organisms to man. Regardless of the mercury form present, the major portion of the mercury will ultimately reside in the bottom sediments where, through microbial action, mono- and dimethylmercury can be formed.

These forms of mercury are bioconcentrated many-fold in fish and other aquatic organisms because of the very rapid uptake and the relative inability of the fish to excrete methylmercury from their tissues. As a result, methylmercury in fish tissues may exceed the 0.5 mg/kg FDA guideline. This occurs in water concentrations that have no observed toxic effects on the fish. Methylation rates are highly dependent upon water quality conditions, but sufficient evidence exists to suggest that the process can occur in the pH range of 5 to 9 under aerobic or anaerobic conditions; hence, it is assumed that methylation can and will occur in natural waters.

Demethylation processes can deplete methylmercury concentrations in water. Methylmercury appears to persist for sufficient time periods, however to allow uptake by aquatic organisms. Hence, demethylation processes can have an effect on uptake rates of methylmercury, but do not terminate the transport path. It appears that the methylation process takes place at the water/sediment interface, particularly in the sediment area in which the benthic organisms are most active. The movement of benthos within the sediments contributes

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to the methylation process by physically expanding the area of water/ sediment interface. Through ingestion of the detritus in the sediments, benthos acquire a body burden of mercury that will in turn be transported to fish upon ingestion.

The FDA established guideline for mercury in edible fish is 0.5 mg/kg. Thus, the maximum level of mercury in receiving waters should be based on the premise that this level should not be exceeded. A mercury concentration factor for certain freshwater species has been shown to be in excess of 10,000.

Upon dividing the 0.5 mg/l FDA temporary tolerance by the 10,000-fold accumulation factor, a level of 0.05 ug/l for total mercury in fresh water results, which can be assumed to protect the human consumer of freshwater fish. It was pointed out above that 0.04 ug/l mercury as methylmercuric chloride caused significant reproductive impairment to Daphnia magna. Recognizing, however, that natural total mercury concentrations in fresh water are in the same range, and that a total mercury level of 0.05 ug/l would be divided among several chemical forms which differ markedly in their toxicity, it is believed that a criterion of 0.05 ug/l total mercury will offer a reasonable level of protection to freshwater aquatic life as well as to the human consumer.

Recognizing that seawater contains about 0.1 ug/l mercury and that this level is 1/10 of that found by Eisler (1974) to represent a threat to selected species of marine organisms, it is recommended that the criterion for the protection of marine aquatic life be 0.1 ug/l.

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MIXING ZONES

INTRODUCTION:

A mixing zone is an area contiguous to a discharge where receiving water quality may neither meet all quality criteria nor requirements otherwise applicable to the receiving water. It is obvious that any time an effluent is added to a receiving waterway, where the effluent is poorer in quality, there will be a zone of mixing. The mixing zone should be considered as a place where wastes and water mix and not as a place where effluents are treated.

RATIONALE:

Because damage to the aquatic resource can occur when quality standards are violated, the permissible size of a mixing zone is dependent upon the acceptable amount of damage. The permissible size depends in part on the size of the particular receiving water; the larger the water body, the larger the mixing zone may be without violating quality standards in more than a given percentage of the total area or volume of the receiving water. Likewise, the greater number of mixing zones within a reach of river or within a water body, the smaller each must be in order to maintain an appropriate mixing zone to water body ratio. Future industrial and population growths must be considered in designating such areas for wastes admixture.

As a guideline, the quality for life within a mixing zone should be such that the 96-hour LC_{50} for biota significant to the indigenous aquatic community is not exceeded; the mixing zone should be free from effluent substances that will settle to form objectionable deposits, free from effluent-associated materials that float to form unsightly masses, and free from effluent-associated substances that produce objectionable color, odor, or turbidity.

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A prime purpose in designating the location, size, and area constraints of a mixing zone is to protect the aquatic life within the receiving waterway. Shallow water areas, generally, are the nursery areas for aquatic ecosystems. Designating offshore mixing areas or providing a larger available volume or area for mixing offshore as a viable alternative to a smaller shoreside area has a lesser potential for adverse biotic effects than a comparable discharge area in shallow water. Offshore, diffusion will tend to occur in all directions and not be constrained by a land barrier. Mixing zones may be less harmful biologically when located deep within the receiving water and, wherever possible, beneath the light-penetration area where photosynthesis occurs and algae and associated protozoa and other organisms provide the extensive base for the aquatic food web.

An axiom of environmental quality is that different areas vary in ecological importance, one from the other. Generally the highest importance, and therefore the greatest protection, must be placed on shallow-water shoreline areas of rivers, lakes and coastal zones and on the nation's wetlands. These are commonly the areas that protect the young and supply the food not only for the animals that live in open waters but also for those animals that depend upon water in some measure for their existence. Likewise, one local aquatic area may have a higher social or ecological value than another, and the higher that value the greater the protection from degradation that is warranted within a waste mixing area.

Mixing zones should be located in such a manner that they do not form a barrier to the migratory routes of aquatic species. On a given reach of a stream or river , it would be good practice to limit the total mixing zone area to one-third of the receiving water width. In the same fashion, the combined

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areas of all mixing zones within a lake should not exceed ten percent of the lake surface area. In some cases, this maximum should be reduced depending on lake volume and other local conditions. Within an estuary, the maximal dimension of the mixing area should not exceed 10 percent of the cross-sectional area of the waterway. It is not the objective of this rationale to outline limits for effluents, but to provide the reader with some of the general biological and physical considerations necessary for the establishment of mixing zones.

In essence, the positioning of mixing zones should be accomplished in a manner that will provide the greatest protection to aquatic life and for the various uses of water. Generally, shoreline and surface areas for waste admixture should be discouraged in preference to deep water, offshore designations. The relative social and ecological values of the aquatic life that may inhabit a particular waterway area should be given due consideration in zone definition. (Fetterolf, 1973; NAS, 1974) The designation of particular mixing zones is a task that should follow the biological, physical and chemical appraisal of the receiving waterway.

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NICKEL

CRITERION:

0.01 of the 96-hour LC50 for freshwater and marine aquatic life.

INTRODUCTION:

Nickel is a silver-white, metallic element seldom occurring in nature in the elemental form. Nickel salts are soluble and can occur as a leachate from nickel-bearing ores. Kopp and Kroner (1967) detected nickel in the Lake Erie Basin at a frequency of 53 percent and a mean concentration of 56 ug/l. At several selected stations, dissolved nickel ranged from 3 to 86 ug/l and suspended nickel from 5 to 900 ug/l. Nickel is present in sea water at 5 to 7 ug/l (NAS, 1974).

RATIONALE:

Nickel is considered to be relatively non-toxic to man (Schroeder, et al., 1961) and a limit for nickel is not included in the EPA National Interim Primary Drinking Water Regulations ((40 FR 59566, December 24, 1975)The toxicity of nickel to aquatic life, as reported by McKee and Wolf (1963), indicates tolerances that vary widely and that are influenced by species, pH, synergistic effects and other factors. The survival curves for sticklebacks in soft tap water indicate a lethal limit of 800 ug/l nickel (Jones, 1939). Pickering and Henderson (1964) reported that 96-hour LC_{50} values of nickel in soft water for four species of fish varied from 4.6 to 9.8 mg/l, and in hard

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water for two fish species, the 96-hour LC_{50} varied from 39.2 to 42.4 mg/l. The 96-hour LC_{50} values for two species of aquatic insects were reported by Warnick and Bell (1969) to be 4.0 and 33.5 mg/l nickel. Biesinger and Christensen (1972) found that the three-week LC50 value for Daphnia magna in soft water was 130 ug/l nickel; 95 ug/l caused a 50 percent impairment in reproductivity, and 30 ug/l caused a 16 percent impairment.

In continuous bioassay tests designed to determine chronic effects, Pickering (1974) demonstrated that nickel concentrations of 380 ug/l and lower in hard water did not adversely affect survival, growth, or reproduction of the fathead minnow. Nickel concentrations of 730 ug/l caused a significant reduction both in the number of eggs per spawning and in the hatchability of the eggs.

Calabrese, et al.,(1973) reported a 48-hour LC50 of 1,180 ug/l for American oyster embryo, Crassostrea virginica, for larvae of the hard shell clam, Mercenaria mercenaria (Calabrese & Nelson, 1974). Jones (1939) reported a 96-hour LC50 of 800 ug/l for the euryhaline stickleback, Gasterosteus aculeatus. Gentile (1975) found that the 96-hour LC50 for the marine copepod, Acartia tonsa was 625 ug/l.

Nickel salts have been shown to be injurious to plants. In sand and nickel solution experiments, Vanselow (1966) demonstrated that at 0.5 to 1.0 mg/l, nickel is toxic to a number of plants. The toxicity exhibited to plants by nickel varied widely with the species. McKee and Wolf (1963) indicated that nickel was extremely toxic to citrus. Chang and Sherman (1953) found

that tomato seedlings were injured by 0.5 mg/l nickel. Hop plants were shown to be injured by nickel at 1.0 mg/l (Legg and Ormerod, 1958). Plants exhibiting less susceptibility to nickel were: oats, with toxic effects at 2.5 mg/l (Crooke, 1954); corn at 2 mg/l; and tobacco with no toxic effects at 3.0 mg/l (Soane and Saunders, 1959).

Data indicate that, (1) nickel in water is toxic to plant life at concentrations as low as 500 ug/l, (2) nickel adversely affects reproduction of a freshwater crustacean at concentrations as low as 95 ug/l, (3) marine clam larvae can be killed by concentrations of nickel as low as 310 ug/l, and (4) reproduction of the fathead minnow is detrimentally affected by nickel at concentrations as low as 730 ug/l. Concentrations of nickel at or below 100 ug/l should not be harmful to irrigated plants or marine and freshwater aquatic organisms.

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NITRATES; NITRITES

CRITERION:

10 mg/l nitrate nitrogen (N) for domestic water supply (health).

INTRODUCTION:

Two gases (molecular nitrogen and nitrous oxide) and five forms of nongaseous, combined nitrogen (amino and amide groups, ammonium, nitrite, and nitrate) are important in the nitrogen cycle. The amino and amide groups are found in soil organic matter and as constituents of plant and animal protein. The ammonium ion is either released from proteinaceous organic matter and urea, or is synthesized in industrial processes involving atmospheric nitrogen fixation. The nitrite ion is formed from the nitrate or the ammonium ions by certain microorganisms found in soil, water, sewage, and the digestive tract. The nitrate ion is formed by the complete oxidation of ammonium ions by soil or water microorganisms; nitrite is an intermediate product of this nitrification process. In oxygenated natural water systems nitrite is rapidly oxidized to nitrate. Growing plants assimilate nitrate or ammonium ions and convert them to protein. A process known as denitrification takes place when nitrate-containing soils become anaerobic and the conversion to nitrite, molecular nitrogen, or nitrous oxide occurs. Ammonium ions may also be produced in some circumstances.

Among the major point sources of nitrogen entry into water bodies are municipal and industrial wastewaters, septic tanks, and feedlot discharges. Diffuse sourcescof nitrogen include farm-site fertilizer and animal wastes, lawn fertilizer, leachate from waste disposal in dumps or sanitary landfills, atmospheric fallout, nitric oxide and nitrite

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discharges from automobile exhausts and other combustion processes, and losses from natural sources such as mineralization of soil organic matter (NAS, 1972). Water reuse systems in some fish hatcheries employ a nitrification process for ammonia reduction; this may result in exposure of the hatchery fish to elevated levels of nitrite (Russo, et al., 1974).

RATIONALE:

In quantities normally found in food or feed, nitrates become toxic only under conditions in which they are, or may be, reduced to nitrites. Otherwise, at "reasonable" concentrations, nitrates are rapidly excreted in the urine. High intake of nitrates constitutes a hazard primarily to warm blooded animals under conditions that are favorable to their reduction to nitrite. Under certain circumstances, nitrate can be reduced to nitrite in the gastrointestinal tract which then reaches the bloodstream and reacts directly with hemoglobin to produce methemoglobin, with consequent impairment of oxygen transport.

The reaction of nitrite with hemoglobin can be hazardous in infants under three months of age. Serious and occasionally fatal poisonings in infants have occurred following ingestion of untreated well waters shown to contain nitrate at concentrations greater than 10 mg/l nitrate nitrogen (N) (NAS, 1974). High nitrate concentrations frequently are found in shallow farm and rural community wells, often as the result of inadequate protection from barnyard drainage or from septic tanks (USPHS, 1961; Stewart, et al., 1967). Increased concentrations of nitrates also have been found in streams from farm tile drainage in areas of intense fertilization and farm crop production (Harmeson, et al., 1971). Approximately 2000 cases of infant methemoglobinemia

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have been reported in Europe and North America since 1945; 7 to 8 percent of the affected infants died (Walton, 1951; Sattelmacher, 1962). Many infants have drunk water in which the nitrate nitrogen content was greater than 10 mg/l without developing methemoglobinemia. Many public water supplies in the United States contain levels that routinely are in excess of this amount, but only one U.S. case of infant methemoglobinemia associated with a public water supply has ever been reported (Vigil, et al., 1965). The differences in susceptibility to methemoglobinemia are not yet understood but appear to be related to a combination of factors including nitrate concentration, enteric bacteria, and the lower acidity characteristic of the digestive systems of baby mammals. Methemoglobinemia symptoms and other toxic effects were observed when high nitrate well waters containing pathogenic bacteria were fed to laboratory mammals (Wolff, et al., 1972). Conventional water treatment has no significant effect on nitrate removal from water (NAS, 1974).

Because of the potential risk of methemoglobinemia to bottle-fed infants, and in view of the absence of substantiated physiological effects at nitrate concentrations below 10 mg/l nitrate nitrogen, this level is the criterion for domestic water supplies. Waters with nitrite nitrogen concentrations over 1 mg/l should not be used for infant feeding. Waters with a significant nitrite concentration usually would be heavily polluted and probably bacteriologically unacceptable.

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Westin (1974) determined that the respective 96-hour and 7-day LC_{50} values for chinook salmon, Oncorhynchus tshawytscha, were 1310 and 1080 mg/l nitrate nitrogen in fresh water and 990 and 900 mg/l nitrate nitrogen in 15 o/oo saline water. For fingerling rainbow trout, Salmo gairdneri, the respective 96-hour and 7-day LC_{50} values were 1360 and 1060 mg/l nitrate nitrogen in fresh water, and 1050 and 900 mg/l nitrate nitrogen in 15 o/oo saline water. Trama (1954) reported that the 96-hour LC_{50} for bluegills, Lepomis macrochirus, at 20° C was 2000 mg/l nitrate nitrogen (sodium nitrate) and 420 mg/l

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nitrate nitrogen (potassium nitrate). Knepp and Arkin (1973) observed that largemouth bass, Micropterus salmoides, and channel catfish, Ictalurus punctatus, could be maintained at concentrations up to 400 mg/l nitrate (90 mg/l nitrate nitrogen) without significant effect upon their growth and feeding activities.

The 96-hour and 7-day LC_{50} values for chinook salmon, Oncorhynchus tshawytscha, were found to be 0.9 and 0.7 mg/l nitrite nitrogen in fresh water (Westin, 1974). Smith and Williams (1974) tested the effects of nitrite nitrogen and observed that yearling rainbow trout, Salmo gairdneri, suffered a 55 percent mortality after 24 hours at 0.55 mg/l, fingerling rainbow trout suffered a 50 percent mortality after 24 hours of exposure at 1.6 mg/l, and chinook salmon, Oncorhynchus tshawytscha, suffered a 40 percent mortality within 24 hours at 0.5 mg/l. There were no mortalities among rainbow trout exposed to 0.15 mg/l nitrite nitrogen for 48 hours. These data indicate that salmonids are more sensitive to nitrite toxicity than are other fish species, e.g., minnows, Phoxinus laevis, that suffered a 50 percent mortality within 1.5 hours of exposure to 2030 mg/l nitrite nitrogen, but required 14 days of exposure for mortality to occur at 10 mg/l (Klingler, 1957), and carp, Cyprinus carpio, when raised in a water reuse system, tolerated up to 1.8 mg/l nitrite nitrogen (Saeki, 1965).

Gillette, et al. (1952) observed that the critical range for creek chub, Semotilus atromaculatus, was 80 to 400 mg/l nitrite nitrogen. Wallen, et al. (1957) reported a 24-hour LC_{50} of 1.6 mg/l nitrite nitrogen, and 48- and 96-hour LC_{50} values of 1.5 mg/l nitrite

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nitrogen for mosquitofish, Gambusia affinis. McCoy (1972) tested the nitrite susceptibility of 13 fish species and found that logperch, Percina caprodes, were the most sensitive species tested (mortality at 5 mg/l nitrite nitrogen in less than 3 hours of exposure), whereas carp, Cyprinus carpio, and black bullheads, Ictalurus melas, survived 40 mg/l nitrite nitrogen for a 48-hour exposure period; the common white sucker, Catostomus commersoni, and the quillback, Carpiodes cyprinus, survived 100 mg/l for 48 and 36 hours, respectively.

Russo, et al. (1974) performed flow-through nitrite bioassays in hard water (hardness = 199 mg/l $CaCO_3$, alkalinity = 176 mg/l $CaCO_3$, pH = 7.9) on rainbow trout, Salmo gairdneri, of four different sizes, and obtained 96-hour LC_{50} values ranging from 0.19 to 0.39 mg/l nitrite nitrogen. Duplicate bioassays on 12-gram rainbow trout were continued long enough for their toxicity curves to level off, and asymptotic LC_{50} concentrations of 0.14 and 0.15 mg/l were reached in 8 days; on day 19, additional mortalities occurred. For 2-gram rainbow trout, the minimum tested level of nitrite nitrogen at which no mortalities were observed after 10 days was 0.14 mg/l; for the 235-gram trout, the minimum level with no mortality after 10 days was 0.06 mg/l.

It is concluded that: (1) levels of nitrate nitrogen at or below 90 mg/l would have no adverse effects on warm water fish (Knepp and Arkin, 1973); (2) nitrite nitrogen at or below 5 mg/l should be protective of most warm water fish (McCoy, 1972); and (3) nitrite nitrogen at or below 0.06 mg/l should be protective of salmonid fishes (Russo, et al., 1974; Russo and Thurston, 1975). These levels

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either are not known to occur or would be unlikely to occur in natural surface waters.

Recognizing that concentrations of nitrate or nitrite that would exhibit toxic effects on warm or cold water fish could rarely occur in nature, restrictive criteria are not recommended.

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OIL AND GREASE

CRITERIA:

For domestic water supply: Virtually free from oil and grease, particularly from the tastes and odors that emanate from petroleum products.

For aquatic life:

(1) 0.01 of the lowest continuous flow 96-hour LC50 to several important freshwater and marine species, each having a demonstrated high susceptibility to oils and petrochemicals.

(2) Levels of oils or petrochemicals in the sediment which cause deleterious effects to the biota should not be allowed.

(3) Surface waters shall be virtually free from floating nonpetroleum oils of vegetable or animal origin, as well as petroleum derived oils.

INTRODUCTION:

It has been estimated that between 5 and 10 million metric tons of oil enter the marine environment annually (Blumer, 1970). A major difficulty encountered in the setting of criteria for oils and grease is that these are not definitive chemical categories, but include thousands of organic compounds with varying physical, chemical, and toxicological properties. They may be volatile or non-volatile, soluble or insoluble, persistent or easily degraded.

RATIONALE:

Field and laboratory evidence have demonstrated both acute lethal toxicity and long-term sublethal toxicity of oils to aquatic organisms. Events such as the Tampico Maru wreck of 1957 in Baja, California, (Diaz-Piferrer, 1962), and the No. 2 fuel oil spill in West Falmouth,

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Massachusetts,in 1969 (Hampson and Sanders, 1969), both of which caused immediate death to a wide variety of organisms, are illustrative of the lethal toxicity that may be attributed to oil pollution. Similarly, a gasoline spill in South Dakota in November 1969 (Bugbee and Walter, 1973), was reported to have caused immediate death to the majority of freshwater invertebrates and 2500 fish, 30 percent of which were native species of trout. Because of the wide range of compounds included in the category of oil, it is impossible to establish meaningful 96-hour LC_{50} values for oil and grease without specifying the product involved. However, as the data in Table 6 show, the most susceptible category of organisms, the marine larvae, appear to be intolerant of petroleum pollutants, particularly the water soluble compounds, at concentrations as low as 0.1 mg/l.

The long-term sublethal effects of oil pollution refer to interferences with cellular and physiological processes such as feeding and reproduction which do not lead to immediate death of the organism. Disruption of such behavior apparently can result from petroleum product concentrations as low as 10 to 100 ug/l (see Table 7).

Table 7 summarizes some of the sublethal toxicities for various petroleum pollutants and various aquatic species. In addition to sublethal effects reported at the 10 to 100 ug/l level, it has been shown that petroleum products can harm aquatic life at concentrations as low as 1 ug/l (Jacobson and Boylan, 1973).

Bioaccumulation of petroleum products presents two especially important public health problems: (1) the tainting of edible, aquatic

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Table 6

Summary of lethal toxicities of various petroleum products to aquatic organisms (a thorough discussion of duration and test conditions is found in Moore, Dwyer & Katz, 1973)

TYPE ORGANISM	Soluble Hydrocarbons	Dispersants	#2 Fuel Oil/ Kerosene	Fresh Crude	Gasoline	Diesel Fuel	Refinery Effluents	Waste Oil	Lubricants	Residuals	Weathered Crude
Marine Flora	(29) (29) 10 ppm-650 ppm	(29) (31) 1.2 ppm-313 mg/l [ppm]	(31) <100 µl/l [ppm]	(31) Toxic to many salt marsh plants				(14) 10 ppm			(29) Coating more
Finfish	(29) (29) 5 ppm-50 ppm	(29) (29) 1 ppm->10,000 mg/l (ppm)	(40) 550 µg/ml (ppm)	(35) 88 mg/l (ppm) (31) 18 mg/l. [x10³ ppm]	(29) 91 ppm	(29) 284-420 ppm		(14) 2700 ppm		(29) 2000-510,000 mg/l [ppm]	Significant than lethal toxicity
Larvae and eggs	(29) (29) 0.1 ppm-1 ppm	(29) (29) 1 ppm-42 ppm	(31) 0.1 µl/l [ppm] (40) 4 µg/ml [ppm]	(31) 0.1 µl/l [ppm] (27) (29) 100 ppm				(14) 1->25ppm		(29) No effect reported	
Pelagic Crustacea	(29) (29) 1 ppm-10 ppm	(29) (29) 5 ppm-100 ppm	(29) (29) 5 ppm-50ppm	(29) 0.1 ml/l [x10³ ppm]- (29) 40 ppt [x10³ ppm]				(14) 15->50ppm			
Benthic Crustacea	(29) (29) 1 ppm-10 ppm	(29) (29) 2 ppm-100 ppm	(29) (29) 5 ppm-50 ppm	(15) 0.56 mg/l [ppm]						(29) >10,000 ppm	
Gastropods	(29)* (29)* 10 ppm-100 ppm	(29) (29) 5 ppm-2000 ppm	(29) (29) 50ppm-500ppm	(29) Toxicity reported for several species, but no concentration given.						(29) No effect reported	
Bivalves	(29) (29) 5 ppm-500 ppm	(29) (29) 0.5 ppm-100 ppm	(31) 30-40 ml/l [x10³ ppm]	(31) 1 ml/l [x10³ ppm]- (20) 10⁵ ppm						(29) Incorporation	
Other Benthic Invertebrates	(29) (29) 1 ppm-10 ppm	(29) (29) 5 ppm-100,000ppm	(29) (29) 5 ppm-50 ppm	(29) 100-5100 ppm						(31) 1,952-2,417 mg/l [ppm]	
Freshwater Finfish	(41) (34) 10 ppm-4,924 ppm	(31) 10 ppm	(31) 1,000-150,000 mg/l [ppm]	(12) 0.[illegible] mg/l [ppm] (30) 500 mg/l [ppm]	(26) [ppm] (31) 180 mg/l [ppm]	(31) 160-4000 mg/l [ppm]	(13) ~39 ppm		(31) 3000-180,000 mg/l [ppm]		
Freshwater Flora		(31) 200 ppm									
Mammals & Birds	Most lethal (or sub-lethal) effects are caused by physical coating, entanglement, ingestion of fine oil droplets, or incorporation of hydrocarbons through food chains.										

Note: 1) Numbers in brackets represent reported values (volume to volume or weight to volume basis) converted to ppm.
2) Numbers in parentheses refer to references.
3) Asterisks indicate values estimated by Moore, Dwyer, & Katz, 1973 (However estimates are supported by examples given therein)
4) In some cases, the above values have been taken from summary type presentations (for example: Moore, Dwyer & Katz, 1973); the corresponding reference numbers therefore do not necessarily refer to the original publication.
5) The manner in which the above values are reported is only an attempt to exemplify the ranges in threshold lethal toxicities, based on some of the existing published data, and should therefore not be regarded as absolute limits of toxicity for a given category of toxicant or test organism. It must be understood that there exists numerous additional published data that fall within the ranges suggested above, and possibly data that may suggest further widening these ranges. It is not the author's intention to herein summarize all of the toxicity values reported thus far for petroleum and petroleum products.

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TABLE 7

SUMMARY OF SOME SUBLETHAL EFFECTS OF PETROLEUM PRODUCTS ON MARINE LIFE

TYPE ORGANISM	SPECIES	REFERENCE	TYPE PETROLEUM PRODUCT	CONCENTRATION	SUBLETHAL RESPONSE
Marine Flora					
	phytoplankton (Chlorella vulgaris)	Kauss, et al, 1972*2	crude Naphthelene	1ppm 3ppm	suppress growth Reduction of bicarbonate uptake
	phytoplankton (diatoms and dinoflagellates)	Mironov, 1970*1,2	"oil"	10^{-1} 10^{-4} ppm	Inhibition or delay in cellular division
	phytoplankton (Asterionella japonica)	Aubert, et al., 1969*1	Kerosene	3ppm; 3Fppm	Depression of growth rate
	phytoplankton (Phaeodactylum tricornutum)	Lacaze, 1967*1	Kuwait crude	"1 ppm"	Depression of growth rate
	phytoplankton (Monochrysis lutheri)	Strand, et al., 1971*1	Kuwait crude; dispersant emulsions	20-100 ppm	inhibition of growth; reduction of bicarbonate uptake at 50 ppm
	phytoplankton (Phaeodactylum tricornutum, Skeletonema costotum, Chlorella sp., Chlamydomonas sp.)	Nuzzi, 1973*1	Extracts of outboard motor oils, No. 6 fuel oil, No. 2 fuel oil.		
	phytoplankton	Gordon and Prouse, 1973*-	Venezuelan crude, No. 2 and 6 Fuel oils.	10-200 mg/l (ppm)	stimulation of photosynthesis at 10-30 mg/l decrease in photosynthesis at 100-200 Mg/l No. 2 fuel oil.
	Kelp (Macrocystis angustifolia	Wilber, 1968*2	Toluene	10 ppm	75% reduction in photosynthesis within 96 hr
	Lichen (Lichen pygmaea)	Brown, 1972*1	Kuwait crude, BP_{1002}	0.1-100 ppm	1 ppm emulsified decrease total C^{14} Fixation
Larvae and eggs	Pink Salmon fry (Oncorhynchus gorbuscha)	Rice, 1973	Prudhoe Bay crude	1.6 ppm	Avoidance effects, could have effect on migration behavior
	Black sea turbot (Rhombus maeoticus)	Mironov, 1967	"oil"	0.01 ppm	Irregularity and delay in hatching-resulting larvae deformed and inactive
	Plaice larvae (Pleuronectes platessa)	Wilson, 1970*2	BP 1002	0-10 ppm	Disruption of photomotor and feeding behavior
	Cod fish larvae (Gadus morrhua)	Kuhnhold, 1970*1	Iranian Crude	Aqueous extracts from 10^{2} ppm, 10^{-} ppm	Adverse effect on behavior leading to death
	Lobster larvae (Homarus americanus)	Wells, 1972*1	Venezuelan crude	6 ppm	delay molt to 4th stage
	Sea Urchin larvae (Strongylocentrotus [illegible])	Allen, 1971*2	extracts of Bunker C	0.1-1 ppm	interference with fertilized egg development
	Barnacle larvae (Balanus)	Mironov, 1970	"Oil"	.0-100 ml/l(ppm)	abnormal development
	Crab larvae (Pachygrapsus crassipes)	Mironov, 1970	"Oil"	10-100 ml/l(ppm)	initial increase in respiration

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SUMMARY OF SOME SUBLETHAL EFFECTS OF PETROLEUM PRODUCTS ON MARINE LIFE

TYPE ORGANISM	SPECIES	REFERENCE	TYPE PETROLEUM PRODUCT	CONCENTRATION	SUBLETHAL RESPONSE
FISH	Chinook salmon (Oncorhynchus tshawytscha) Striped Bass (Morone saxatilis)	Anderson & Bailey, 1973*1	Benzene	5, 10 ppm	Initial increase in respiration.
	Menidia menidia	Gardner, et al,1973	Crude (whole fraction) (water-soluble (water-insoluble	140 ppm (v/v) 12 ppm estimated 588 ppm (v/v)	Histological damage to chemoreceptors.
CRUSTACEANS	Lobster, (Homarus americanus)	Blumer, et al,1973	Crude, kerosene	10 ppm	Effects of chemoreception, feeding times, stress behavior, regression, growth
	Pollicipes polymerus	Straughan, 1971	Crude-Santa Barbara	Field study after blowout.	Apparent decrease in adult brooding; no recruitment in oiled areas.
	Lobster (H. americanus)	Atema and Stein, 1972	La Rosa Crude	Extracts	Delay in feeding.
	Pachygrapsus crassipes	Kittredge, 1971*1	Crude	Dilutions of diethyl ether extracts (1:100)	Inhibition of feeding.
	Uca pugnax	Krebs, 1973*1	No. 2 Fuel oil	Field observations after W.Falmouth spill	Adverse effects on sexual behavior.
MOLLUSCS	Mussel (Mytilus edulis)	Gilfillan,1973*2	Crude	1 ppm	Reduction in carbon budget (increase in respiration; decrease in feeding.)
	Snail (Nassarius absoletus)	Blumer, et al,1973	Kerosene	Saturated extract diluted 10^{10}	40% reductin in chemotactic perception of food.
	Snail (Nassarius obsoletus)	Jacobson & Boylan 1973	Kerosene	0.001 - 0.004 ppm	Reductin in chemotactic perception of food
	Clam (Mya arenaria)	Barry and Yevich, 1974	No. 2 fuel oil	collected from field	Gonadal tumors
	Oyster (Crassostrea virginica)	Mackin and Hopkins, 1961	Bleedwater		Reduced growth and glycogen content
	Snail (Littorina littorea)	Perkins, 1970*1	BP 1002	30 ppm	significant inhibition to growth
	Oyster (Crassostrea virginica)	Menzel, 1968; in Nelson-Smith, 1973	"oil"	0.01 ppm	market tainting
	Mussel (Mytilus edulis)	Blumer, et al, 1971*1	No. 2 fuel oil	collected from field after spill	Inhibition in development of gonads
OTHER BENTHIC INVERTEBRATES	Polychaeta (Capitella capitata)	Bellan, et al, 1973*1	Detergent	0.01-10 ppm	Decrease in survival, fecundity

Note: *1=taken from National Academy of Sciences, 1975
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species, and (2) the possibility of edible marine organisms incorporating the high boiling, carcinogenic polycyclic aromatics in their tissues. Nelson-Smith (1971) reported that 0.01 mg/l of crude oil caused tainting in oysters. Moore, et al. (1973) reported that concentrations as low as 1 to 10 ug/l could lead to tainting within very short periods of time. It has been shown that chemicals responsible for cancer in animals and man (such as 3,4-benzopyrene) occur in crude oil (Blumer, 1970). It has also been shown that marine organisms are capable of incorporating potentially carcinogenic compounds into their body fat where the compounds remain unchanged (Blumer, 1970).

Oil pollutants may also be incorporated into sediments. There is evidence that once this occurs in the sediments below the aerobic surface layer, petroleum oil can remain unchanged and toxic for long periods, since its rate of bacterial degradation is slow. For example, Blumer (1970) reported that No. 2 fuel oil incorporated into the sediments after the West Falmouth spill persisted for over a year, and even began spreading in the form of oil-laden sediments to more distant areas that had remained unpolluted immediately after the spill. The persistence of unweathered oil within the sediment could have a long-term effect on the structure of the benthic community or cause the demise of specific sensitive important species. Moore, et al. (1973) reported concentrations of 5 mg/l for the carcinogen, 3,4-benzopyrene in marine sediments.

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Mironov (1967) reported that 0.01 mg/l oil produced deformed and inactive flatfish larvae. Mironov (1970) also reported inhibition or delay of cellular division in algae by oil concentrations of 10^{-4} to 10^{-1} mg/l. Jacobsen and Boylan (1973) reported a reduction in the chemotactic perception of food by the snail, Nassarius obsoletus, at kerosene concentrations of 0.001 to 0.004 mg/l. Bellen, et al. (1972) reported decreased survival and fecundity in worms at concentrations of 0.01 to 10 mg/l of detergent.

Because of the great variability in the toxic properties of oil, it is difficult to establish a numerical criterion which would be applicable to all types of oil. Thus, an application factor of 0.01 of the 96-hour LC50 as determined by using continuous flow with a sensitive resident species should be employed for individual petrochemical components.

There is a paucity of toxicological data on the ingestion of the components of refinery wastewaters by humans or by test animals. It is apparent that any tolerable health concentrations for petroleum derived substances far exceed the limits of taste and odor. Since petroleum derivatives become organoleptically objectionable at concentrations far below the human chronic toxicity, it appears that hazards to humans will not arise from drinking oil-polluted waters (Johns Hopkins University, 1956; Mckee and Wolf, 1963). Oils of animal or vegetable origin generally are non-toxic to humans and aquatic life.

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In view of the problem of petroleum oil incorporation in sediments, its persistence and chronic toxic potential, and the present lack of sufficient toxicity data to support specific criteria, concentrations of oils in sediments should not approach levels that cause deleterious effects to important species or the bottom community as a whole.

Petroleum and nonpetroleum oils share some similar physical and chemical properties. Because they share common properties, they may cause similar harmful effects in the aquatic environment by forming a sheen, film or discoloration on the surface of the water. Like petroleum oils, nonpetroleum oils may occur at four levels of the aquatic environment: (a) floating on the surface, (b) emulsified in the water column, (c) solubilized, and (d) settled on the bottom as a sludge. Analogous to the grease balls from vegetable oil and animal fats are the tar balls of petroleum origin which have been found in the marine environment or washed ashore on beaches.

Oils of any kind can cause: (a) drowning of waterfowl because of loss of buoyancy, exposure because of loss of insulating capacity of feathers, and starvation and vulnerability to predators due to lack of mobility, (b) lethal effects on fish by coating epithelial surfaces of gills, thus preventing respiration, (c) potential fish kills due to biochemical oxygen demand, (d) asphyxiation of benthic life forms when floating masses become engaged with surface debris and settle on the bottom, and (e) adverse aesthetic effects of fouled shorelines and beaches. These and other effects have been documented in the U. S. Department of Health, Education and Welfare report on "Oil Spills Affecting the Minnesota and Mississippi Rivers" and the 1975 "Proceedings of the Joint Conference on Prevention and Control of Oil Spills."

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Oils of animal or vegetable origin generally are chemically non-toxic to humans or aquatic life; however, floating sheens of such oils result in deleterious environmental effects described in this criterion.
Thus, it is recommended that surface waters shall be virtually free from floating non-petroleum oils of vegetable or animal origin. This same recommendation applies to floating oils of petroleum origin since they too may produce the above effects.

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DISSOLVED OXYGEN

CRITERIA:

Aesthetics: Water should contain sufficient dissolved oxygen to maintain aerobic conditions in the water column and, except as affected by natural phenomena, at the sediment-water interface.

Freshwater aquatic life: A minimum concentration of dissolved oxygen to maintain good fish populations is 5.0 mg/liter. The criterion for salmonid spawning beds is a minimum of 5.0 mg/liter in the interstitial water of the gravel.

INTRODUCTION:

Dissolved oxygen historically has been a major constituent of interest in water quality investigations. It generally has been considered as significant in the protection of aesthetic qualities of water as well as for the maintenance of fish and other aquatic life. Traditionally, the design of waste treatment requirements was based on the removal of oxygen demanding materials so as to maintain the dissolved oxygen concentration in receiving waters at prescribed levels. Sophisticated techniques have been developed to predict the dissolved oxygen concentration under various hydrologic, hydrographic, and waste loading conditions (Velz, 1970). Dissolved oxygen concentrations are an important gage of existing water quality and the ability of a water body to support a well balanced aquatic fauna.

RATIONALE:

The aesthetic qualities of water require sufficient dissolved oxygen present to avoid the onset of septic conditions with its attendant malodorous emissions. Insufficient dissolved oxygen in the water column causes the anaerobic decomposition of any organic materials present. Such decomposition tends to cause the formation of noxious gases such as hydrogen sulfide and the development of carbon dioxide and methane in the sediments which bubble to the surface or which tend to float settled sludge as mats which are composed of various organic materials.

Dissolved oxygen in bodies of water used for municipal water supplies is desirable as an indicator of satisfactory water quality in terms of low residuals of biologically available organic materials. In addition, dissolved oxygen in the water column prevents the chemical reduction and subsequent leaching of iron and manganese principally from the sediments (Environmental Protection Agency, 1973). These metals cause additional expense in the treatment of water or affect consumers' welfare by causing taste and staining plumbing fixtures and other surfaces which contact the water in the presence of oxygen (NAS, 1974).

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Dissolved oxygen also is required for the biochemical oxidation of ammonia ultimately to nitrate in natural waters. This reduction of ammonia reduces the chlorine demand of waters and increases the disinfection efficiency of chlorination (NAS, 1974).

The disadvantage of substantial quantities of dissolved oxygen in water used as a source of municipal water supply is the increased rates of corrosion of metal surfaces in both the water treatment facilities and in the distribution system (NAS, 1974).
Such corrosion, in addition to the direct damage, can increase the concentration of iron (and other metals) which may cause taste in the water, as well as staining.

A discussion of oxygen criteria for freshwater fish must take into account these facts: (1) fish vary in their oxygen requirements according to species, age, activity, temperature, and nutritional state; (2) they are found from time to time, and can survive for a while, at oxygen concentrations considerably below that considered suitable for a thriving population; and (3) although there is much literature on the oxygen consumption of fish and the effects of varying oxygen concentrations on behavior and survival, few investigators have employed methods or sought endpoints that can be related with confidence to maintaining a good fish population.

To allow for the differences among requirements affected by species and other variables, the dissolved oxygen criteria are based on the concentration that will support a well-rounded population of fish (Ellis, 1937) as it would occur under natural conditions. A population of fish is composed of a number of different but more or less interdependent species, of different feeding and reproductive habits, but which will include game and pan fish (bass, pike, trout, perch, sunfish, crappie, depending upon the location), some so-called rough or coarse fish (carp, buffalo, bullhead, sucker, chub), and large numbers of smaller 'forage' fish (e.g., minnows). Theoretically it should be possible to base oxygen criteria on the needs of the most sensitive component of such a population, but there is not enough information for this at present; that is why the criteria must be based on oxygen concentrations known to permit the maintenance and well-being of the population as a whole.

The requirement that the data be applicable to naturally occurring populations imposes limits on the types of research that can be used as a basis for the criterion. Aside from a few papers on feeding, growth, and survival in relation to oxygen concentration, very little of the laboratory-based literature has a direct bearing; field data are in general more useful. Field studies have the disadvantage that the numbers of variables encountered in the natural environment (temperature, pH, dissolved solids, food supply, and the like, as well as dissolved oxygen) make it necessary to be conservative in relating fish abundance and distribution to oxygen concentration alone, but enough observations have been made under a variety of conditions that the importance of oxygen concentration seems clear.

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Field studies, in which fish catches have been related to dissolved oxygen concentrations measured at the same time, indicate that a dissolved oxygen concentration of 3 mg/liter is too low to maintain a good fish population (Thompson, 1925; Ellis, 1937; Brinley, 1944), and this finding is supported by laboratory observations that in the vicinity of 3 mg/liter and below feeding is diminished or stopped (Lindroth, 1949; Mount, 1960; Herrmann, et al., 1962), and growth is reduced (Hamdorf, 1961; Itazawa, 1971), even when the lowered oxygen concentration occurs for only part of the day (Stewart, et al., 1967).

A dissolved oxygen concentration of 4 mg/liter seems to be about the lowest that will support a varied fish population (Ellis, 1937), even in the winter (Thompson, 1925), and for a well-rounded population including game fish it should be above that. Both Ellis (1937) and Brinley (1944) set the minimum for a well rounded population at 5 mg/liter. It should be pointed out, however, that Thompson found the greatest variety of species at 9 mg/liter, Ellis found good populations more frequently at 6 than at 5 mg/liter, and Brinley reported the best concentrations for game fish populations to be above 5 mg/liter. The belief that 5 mg/liter is adequate is supported by the fact that the introduced rainbow trout thrives in Lake Titicaca (Everett, 1973) where, because of the altitude, the oxygen concentration in fully saturated water is not over 5 mg/liter.

Fish embryonic and larval stages are especially vulnerable to reduced oxygen concentrations because their ability to extract oxygen from the water is not fully developed and they cannot move away from adverse conditions. Although many species can develop at oxygen concentrations as low as 2.5 to 3 mg/liter, the effects of a reduced oxygen concentration even as high as 5 or 6 mg/liter can cause a partial mortality or at the least retard development (Brungs, 1971; Siefert et al., 1973, 1974, 1975; Carlson et al., 1974; Carlson and Siefert, 1974; Garside, 1966; Gulidov, 1969; Hamdorf, 1961). Unless it is extreme, however, the retardation need not be permanent or detrimental to the species (Brannon, 1965; Eddy, 1972). For most fish, maintaining a minimum of 5 mg/liter in the water mass in the vicinity of the embryos and larvae should suffice.

Special treatment is required for species, such as the salmonids, that bury their fertilized eggs in gravel. The flow through gravel is often slow, especially if siltation has occurred, and if it is slow enough the developing fish and other organisms can easily deplete the oxygen supply enough to cause damage, especially if the concentration in the water is relatively low before it enters the gravel (Cooper, 1965; Coble, 1961; Brannon, 1965). With a permeable gravel and abundant flow, 5 mg/liter in the overlying water should be enough. This concentration could well be inadequate, however, with a less porous gravel and a slower flow. Since the permeability and flow have so important a bearing on the initial oxygen concentration required to maintain the intragravel concentration, and since these characteristics vary with location, it is proposed that the criterion for salmonid spawning beds be stated as not less than 5 mg/liter in the gravel. This would require that the concentration in the water entering the gravel be 5 mg/liter or more, increasing as the intragravel flow rate decreased.

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Decreased dissolved oxygen levels, if sufficiently severe, can adversely affect aquatic insects and other animals upon which fish feed. Sprague (1963) has evaluated such effects on several crustaceans while others have evaluated caddisfly larvae and stonefly nymphs (Doudoroff and Shumway, 1970). However, many other invertebrates are less sensitive to lowered dissolved oxygen concentrations and may be equally suitable fish food. Doudoroff and Shumway (1970) concluded that as long as dissolved oxygen concentrations remain entirely satisfactory for fish, no material impairment of the food resources for fish ascribable to dissolved oxygen insufficiency will occur.

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ALDRIN-DIELDRIN

CRITERIA:

.003 ug/l for freshwater and marine aquatic life.

The persistence, bioaccumulation potential and carcinogenicity of aldrin-dieldrin cautions human exposure to a minimum.

RATIONALE:

Since dieldrin is a highly persistent chemical which bioaccumulates in aquatic organisms used for human food and is also considered a potential human carcinogen, levels of dieldrin in waterways should be kept as low as feasible. Action by the Environmental Protection Agency in suspending the production and use of dieldrin should result in a gradual decrease in concentrations in the environment. Such additions should not be permitted without substantial documentation that alternatives are either infeasible or potentially more hazardous. The persistence, bioaccumulative properties and carcinogenic potential of dieldrin should be taken into account when determining the uses of water with measurable amounts of dieldrin.

Aldrin is metabolically converted to dieldrin by aquatic organisms. Residues in goldfish, Carassius auratus, exposed to aldrin for 32 days were found to consist of 93.9 percent or more dieldrin except for visceral fat where residues were 100 percent dieldrin after 31.5 to 92.4 days' exposure (Gakstatter, 1968). Epoxidation of aldrin to dieldrin was found to occur also at lower trophic levels. The relative rates of this conversion were low for algae and high for the protozoa (Kahn, et al., 1972). Because of this metabolic conversion and because of evidence that dieldrin is as toxic or slightly more toxic than aldrin to aquatic organisms

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(Jensen and Gaufin, 1966; Henderson, et al., 1959), an acceptable water concentration is based on the presence of either aldrin or dieldrin or the sum of both.

In two studies comprising five long-term oral studies feeding dieldrin to CF-1 mice at various concentrations, liver enlargements and tumors were detectable. Appearance of tumors was dose responsive since tumors occurred 9 months following treatment with 10 ppm; 19 months with 5 ppm; and 23 months with 2.5 ppm. Further, the group all experienced a decrease in survival rates. At intake rates of 1.25 ppm and 1 ppm dieldrin, no liver enlargements were detected clinically and survival was not affected (Walker, et al., 1972).

The best evidence that aldrin-dieldrin poses a cancer hazard to man is provided by mouse laboratory data. Although the liver was the principal organ affected in the mouse and was a major site of action in rats, there was an increase of tumors in the lungs and other organs (Keller, et al., 1974).

Ninety-six-hour LC50 values of 16, 7.9, and 8.5 ug/l dieldrin have been reported for the fathead minnow, Pimephales promelas; bluegill, Lepomis macrochirus; and green sunfish, Lepomis cyanellus, respectively (Tarzwell and Henderson, 1956).

The LC50 for the stonefly naiad, Acroneuria pacifica, exposed to dieldrin in a continuous flow bioassay system for 20 days was 0.2 ug/l (Jensen and Gaufin, 1966). The 48-hour EC50 (immobilization value at 15°C) for daphnids, Simocephalus serrulatus and Daphnia pulex, to dieldrin was 0.24 mg/l and 0.25 mg/l, respectively (Sanders and Cope, 1966).

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The sailfin molly, Poecilia latipinna, appears to be the most sensitive freshwater fish species tested for chronic effects; growth rates and reproductive performance were adversely affected during a 34-week exposure to dieldrin at 0.75 ug/l (Lane and Livingston, 1970). Guppy, Poecilia reticulata, populations were affected by levels of dieldrin at 1.8 ug/l water concentration during a 14-month exposure. Exposed populations developed greater total numbers of individuals than did controls. This phenomenon may have been caused by slight change in the feeding behavior of the adults induced by dieldrin, consisting of inhibition of the normal predation by the adults upon the fry (Cairns, et al., 1967).

Residue accumulation of dieldrin and aldrin is well documented. Levels of dieldrin in fish tissue from Lake Michigan have been as much as 100,000 times (wet weight basis) the dieldrin levels occurring in the water (Reinert, 1970). Lake water concentrations in Lake Michigan were in the 1 to 3 nanogram/liter range, and whole-fish concentrations ranged from a low of 0.03 ppm for lake whitefish to 0.20 ppm for lake herring, 0.23 ppm for bloater, and 0.28 ppm for kiyi. Laboratory exposures of fish, invertebrates, and algae have indicated that residue accumulation

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of aldrin and dieldrin is significant. The Reticulate sculpin, Cottus perplexus, exposed to 8.6, 1.7, 0.86, 0.17, 0.086, and 0.017 ug/l dieldrin in water for 32 days were found to have tissue concentrations (wet weight basis) often exceeding 50,000 times the water exposure level (Chadwick and Brockson, 1969). The sailfin molly, Poecilia latipinna, exposed for 34 weeks at 12, 6, 3, 1.5, and 0.75 ug/l dieldrin in water concentrated dieldrin in all tissues (wet weight basis) at least 10,000 times (Lane and Livingston, 1970). At the termination of a 64-week exposure of the ostracod, Chlamydotheca arcuata, to water concentrations of aldrin at 0.01 and 0.10 ug/l and dieldrin at 0.01 and 0.10 ug/l, dieldrin recovery from the tissue (dry weight basis) was 12,000 to 260,000 times the initial theoretical water concentrations (Kawatski and Schmulbach, 1971). In a model ecosystem study, residue accumulation factors (wet weight basis) for dieldrin were determined to be 114,935 times water concentration for the snail, 7,480 times water concentration for algae, 6,145 times water concentration for fish, 2,145 times water concentration for Daphnia, 1,280 times water concentration for Elodea, 247 times water concentration for the crab, and 1,015 times water concentration for the clam (Sanborn and Yu, 1973). In continuous flow exposure to less than 0.1 ug/l aldrin in water for a three-day period, residue accumulation factors (dry weight basis) were determined for cladocera, Daphnia magna, to be

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141,000 times water concentration; ephemeroptera, Hexagenia billineata, 31,400 times water concentration; and diptera, Chironomus sp., 22,800 times water concentration (Johnson, et al., 1971); for the alga, Scenedesmus obliquus, 1,282 times water concentration after 1.5 days; 13,954 times water concentration for Daphnia magna after 3 to 4 days, and an estimated 49,307 times water concentration for the guppy, Poecilia reticulata, after 18 days' exposure (Reinert, 1972).

In relating accumulation factors to the acceptable level of aldrin and dieldrin allowable in water, it is necessary to know the significance of tissue residue levels. Data on the toxicity of ingested levels of aldrin and dieldrin in aquatic organisms are few. In rainbow trout, Salmo gairdneri, fed dietary dieldrin dosages of 0.36, 1.08, 3.6, and 10.8 ug dieldrin per gram of food (ppm), brain concentrations of three amino acids associated with ammonia detoxifying mechanisms - glutamate, aspartate, and alanine - were significantly altered. In the two highest dosages the brain ammonia concentration increased (Mehrle and Bloomfield, 1974). The implication is that brain ammonia detoxifying mechanisms play an important role in maintaining ammonia values within physiological limits, and that fish carrying body burdens of dieldrin would be less tolerant to increased concentrations of ammonia in water.

Some data available on terrestrial vertebrates indicate that aldrin-dieldrin dietary levels as low as 1 ppm may produce observable effects. In long-term feeding studies 1 ppm dieldrin affected reproduction in the

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Hungarian partridge (Neill, et al., 1969). Slight eggshell thinning was noted in mallard ducks fed 3 ppm dieldrin (Lehner and Egbert, 1969). Deer were affected by long-term feeding at 2 ppm dieldrin (Murphy and Korschgen, 1970). A guideline of 0.3 ppm has been set by the Food and Drug Administration as an upper limit on food for human consumption.

Considering the 100,000-fold bioaccumulation of dieldrin in fish tissue from Lake Michigan cited above (Reinert, 1970) and the FDA tissue residue administrative guideline of 0.3 ppm as a maximum level for human consumption, the resulting maximum water level is 0.003 ug/l. This level is lower than the lowest measured 96-hour LC_{50} (7.9 ug/l for bluegill) by a factor of 0.0004, and lower than the 20 day LC_{50} for the stonefly, Acroneuria pacifica, by a factor of 0.02. It is therefore believed to provide an adequate level of protection for freshwater aquatic life.

In bioassays performed on the mullet, Mugilidae sp., death occurred for 15 percent of the test organisms at 0.5 ug/l dieldrin. When exposed to dieldrin at 1.35 ug/l for four days, fish were found to have degenerative changes in the gills and visceral tissue (Parrish, et al., 1973). A sensitive marine crab, Leptodius floridanus, exhibited delay in development at concentrations of 1 and 0.5 ug/l dieldrin (Epifanio, 1971). At 1 ug/l dieldrin there was a 70 percent mortality of pink shrimp, Penaeus duorarum, within 24 hours and the 96-hour LC_{50} was 0.7 ug/l for the same organism (Parrish, et al., 1973).

A residue accumulation factor of 800 times water concentration (wet weight basis) was found for the estuarine mollusc, Rangia cuneata, for a

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36-hour exposure with a maximum accumulation factor of 2,000 times water concentration in a 72-hour exposure to dieldrin. The clam showed "no evidence for a cessation of the uptake mechanism over a period of time up to 72 hours" (Petrocelli, et al., 1973). At a water concentration of 0.5 ug/l it was determined that the rate of dieldrin uptake from water by crab larvae, Leptodius floridanus, was 0.191 ppm per day from water (Epifanio, 1973). Bioconcentration factors in estuarine organisms exposed for 96-hours to dieldrin ranged from 2,400 to 21,500 for oysters; 280 to 420 for pink shrimp; 470 to 750 for grass shrimp; and 3,500 to 7,300 for sheepshead minnows (Parrish, et al., 1973). Concentration factors in spot exposed to dieldrin for 35 days were as great as 113,000 in liver, 11,000 in muscle and 6,000 in whole fish. Spot lost all detectable dieldrin after 13 days in dieldrin-free sea water (Parrish, et al., 1973). Marine phytoplankton exposed for two hours have been shown to accumulate dieldrin (Rice and Sikka, 1973). In a study designed to investigate the accumulation and metabolism of dieldrin by species representing different taxonomic divisions of marine phytoplankton, concentration factors observed were: Skeletonema costatum (Bacillariophyta), 15,882; Cyclotella nana (Bacillariophyta), 4,810; Tetraselmis chuii (Euglenophyta), 8,588; Isochrysis galbana (Chrysophyta), 8,238; Olisthodiscus luteus (Xanthophyta), 4,900; and Amphidinium carteri (Pyrrophyta), 982.

No data on bioaccumulation from the environment are available for marine fish. In the absence of such data, there is no reason to assume that the accumulation factor for marine fish would be less than that observed for Lake Michigan fish. Therefore, the freshwater criterion of 0.003 ug/l is also recommended for marine aquatic life.

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CHLORDANE

CRITERIA:

0.01 ug/l for freshwater aquatic life.
0.004 ug/l for marine aquatic life.

The persistence, bioaccumulation potential and carcinogenicity of chlordane cautions human exposure to a minimum.

RATIONALE:

Since chlordane is a highly persistent chemical which bioaccumulates in aquatic organisms used for human food and also is considered a potential human carcinogen (Train, 1974), levels of chlordane in waterways should be kept as low as feasible. The December 24, 1975 action by the Environmental Protection Agency in suspending the production and use of chlordane should result in a gradual decrease in concentrations in the environment. Such additions should not be permitted without substantial documentation that alternatives are either infeasible or potentially more hazardous. The persistence, bioaccumulative properties and carcinogenic potential of chlordane should be taken into account when determining the uses of water with measurable amounts of chlordane.

Literature references indicate the existence of an extremely wide range for the acute toxicity of chlordane to various species of freshwater fishes. As recorded, these values for 24- to 96-hour exposures range from 5 to 3,000 ug/l (Cardwell, et al., 1975; Katz, 1961; Lawrence, 1950; National Technical Advisory Committee, 1968; Clemens and Sneed, 1959; Macek, et al., 1969). Physical conditions varied among the tests reported and, in addition, most were conducted under

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static conditions and actual water concentrations were not measured. Although individual acute toxicity values may be questionable, some tests using several species under uniform conditions indicate that variability of experimental techniques alone cannot account for the wide range of values published. A recent study by Cardwell, et al., (1975) utilizing flow-through systems and measured concentrations of chlordane yielded 96-hour LC50 values of 37, 47, and 59 ug/l for fathead minnows, brook trout, and bluegills, respectively. These values fall within the range of the majority of acute toxicity values reported in the literature. The most sensitive fish reported was the pike, which suffered distress after 24 hours at 5 ug/l and 100 percent mortality within this period at 50 ug/l (Ludemann and Neumann, 1962).

Published acute toxicity values for U.S. freshwater invertebrates are similar to those for fishes and range from 4 to 10,000 ug/l (Cardwell, et al., 1975; Naqvi and Ferguson, 1969; National Technical Advisory Committee, 1968; Sanders 1969, 1972). Daphnia magna and Hyallela azteca tested under flow-through conditions yielded 96-hour LC50 values of 28 and 97 ug/l (Cardwell, et al., 1975), falling within the range of the majority of values reported for acute toxicity to invertebrates. The most sensitive species reported was the glass shrimp, Palaemonetes kadiakensis, with 96-hour LC50 values of 10 and 4 ug/l, respectively, in static versus flow-through bioassays (Sanders, 1972). Ludemann and Neumann (1962) found that Chironomus larvae had a 24-hour static test LC50 value of 10 ug/l.

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Cardwell, et al. (1975), conducted long-term flow-through studies which included reproduction and survival of progeny with several aquatic species. Statistically significant detrimental effects could not be measured at concentrations of 0.5 ug/l (bluegills), 0.7 ug/l (Chironomus No. 51, a midge), 5 ug/l (Hyallela azteca), and 12 ug/l (Daphnia magna). Survival of brook trout larvae to 12 days was reduced by 35 percent at 0.3 ug/l (the lowest concentration tested) but overall effects were decreasing at this level.

Available acute toxicity values indicate that individual species of both fishes and invertebrates vary greatly in sensitivity to chlordane but both groups are within the same general range. Most of these acute toxicity values are also nearer to the lower limits of this sensitivity range. Data for the application factors derived using acute and sub-chronic toxicity concentrations are limited to the study by Cardwell, et al. (1975). These factors were 0.009 and less than 0.008 for the fishes and 0.381 and 0.055 for the invertebrates.

Nominal pesticide concentrations in the water were reported for these tests. The true concentrations of chlordane may have been somewhat lower as Cardwell, et al. (1975), found that concentrations could not be maintained above half of nominal even when the test water was continually replaced. Therefore, the water quality criterion should be set lower than the calculated value using the experimentally determined application factor (0.009 X 5.0 ug/l = 0.045 ug/l). For this reason the calculated value for chlordane is xxxxxxxxxx lowered to a recommended concentration in freshwater that should not exceed 0.01 ug/l. If the proposed freshwater water quality criterion of 0.01 is not exceeded it is estimated that levels reached in freshwater

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fishes should seldom be greater than 1.0 mg/kg. Based on present knowledge, it is not anticipated that a concentration of this magnitude would be detrimental to piscivorous birds.

Michael, et al. (1956), found that the time required to kill one-half of the brine shrimp, Artemia salina, nauplii exposed to 10 ug/l was 2-3 hours. Butler, et al. (1960), determined that 24 hours' exposure of the oyster, Crassostrea virginica, to 10 ug/l chlordane produced growth inhibition.

Korn and Earnest(1974) found the 96-hour LC50 of chlordane to be 11.8 ug/l for the striped bass, Morone saxatilis. Butler (1963) reported the following 48-hour LC50 values: brown shrimp, Penaeus aztecus -- 4.4 ug/l; juvenile blue crabs, Callinectes sapidus -- 480 ug/l; and juvenile white mullet, Mugil curema -- 5.5 ug/l. Parrish, et al. (In Press), reported the following 96-hour LC50 values: pink shrimp, Penaeus duorarum -- 0.4 ug/l; grass shrimp, Palaemonetes pugio -- 4.8 ug/l; sheepshead minnow, Cyprinodon variegatus -- 24.5 ug/l; and the pinfish, Lagodon rhomboides -- 6.4 ug/l. The EC50 for shell deposition by the eastern oyster, Crassostrea virginica, was found to be 6.2 ug/l. The most sensitive marine species tested was the pink shrimp, Penaeus duorarum, for which a 96-hour LC50 of 0.4 ug/l was reported.

It appears that reported concentrations of "total chlordane" in fishes have been calculated from measurements of one or two of its major components under the assumption that the ratio of components was similar in both the parent compound and the tissue residues. More

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sophisticated analytical techniques currently available indicate that this assumption is in error and, in addition, the components in tissue residues may have been incorrectly quantified. Fishes can concentrate chlordane directly from water by a factor of 1000 to 3000 times and invertebrates may concentrate to twice this magnitude (Cardwell, et al., 1975). Data on the bioaccumulation of chlordane by estuarine organisms have been reported by Parrish, et al. (In Press). In the 96-hour test, chlordane concentration factors were 3,200 to 8,300 in oysters, Crassostrea virginica ; 4,000 to 6,000 in pink shrimp, Penaeus duorarum ; 1,900 to 2,300 in grass shrimp, Palaemonetes pugio ; 12,600 to 18,700 in pinfish, Lagodon rhomboides . Schimmel, et al.,(In Press), exposed estuarine fishes to trans-chlordane for 96 hours and reported concentration factors ranging from 3,700 to 6,800 in edible portions. Reported concentrations of 10 to 100 ug/kg were common in fish samples obtained throughout the U.S. and a few residues above 1000 ug/kg were observed (Henderson, et al., 1969 and 1971). Corresponding water concentrations are not available, but measurements above nanogram/liter levels have seldom been found in natural waters except near the discharges of manufacturing and formulating operations (Barthel, et al., 1969; Casper, 1967; Godsil and Johnson, 1968). Therefore, allowing for errors in residue measurements and lack of direct correlation, the possibility exists that fishes can concentrate chlordane up to 100,000 times the ambient water concentration. High rates of accumulation could occur in higher trophic level organisms through multiple steps in the food chain although evidence directly related to chlordane is not available to support this hypothesis.

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Based on the persistence, bioaccumulation potential and carcinogenicity of chlordane, an application factor of .01 is applied to the most sensitive marine aquatic species, the pink shrimp. This results in a marine criterion of .004 ug/l.

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Chlorophenoxy Herbicides
2, 4-D; 2, 4, 5-TP

CRITERIA:

2, 4-D	100 ug/l	for domestic water supply (health)
2,4,5-TP	10 ug/l	for domestic water supply (health)

RATIONALE:

Two widely used herbicides are 2, 4-D (2, 4-dichlorophenoxyacetic acid) and 2, 4, 5-TP (silvex) [2-(2, 4, 5-trichlorophenoxy) propionic acid]. Each of these compounds is formulated in a variety of salts and esters that may have a marked difference in herbicidal properties, but all are hydrolyzed rapidly to the corresponding acid in the body.

The subacute oral toxicity of chlorophenoxy herbicides has been investigated in a number of species of experimental animals (Palmer and Radeleff, 1964; Lehman, 1965). The dog was found to be sensitive and often displayed mild injury in response to doses of 10 mg/kg/day for 90 days, and serious effects from a dose of 20 mg/kg/day for 90 days. Lehman (1965) reported that the no-effect level of 2, 4-D is 0.5 mg/kg/day in the rat, and 8.0 mg/kg/day in the dog.

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Data are available on the toxicity of 2, 4-D to man. A daily dosage of 500 mg (about 7 mg/kg) produced no apparent ill effects in a volunteer over a 21-day period (Kraus, 1946). When 2, 4-D was investigated as a possible treatment for disseminated coccidioidomycosis, the patient had no side effects from 18 intravenous doses during 33 days; each of the last 12 doses in the series was 800 mg (about 15 mg/kg) or more, the last being 2000 mg (about 37 mg/kg) (Seabury, 1963). A nineteeth and final dose of 3600 mg (67 mg/kg) produced mild symptoms.

Table 8 illustrates the derivation of the criteria for the two chlorophenoxy herbicides most widely used. The long-term no-effects levels (mg/kg/day) are listed for the rat and the dog. These values are adjusted by a factor of 1/500 for 2, 4-D and 2, 4, 5-TP. The safe levels are then readjusted to reflect total allowable intake per person. Since little 2, 4-D or 2, 4, 5-TP is expected to occur in foods, 20 percent of the safe exposure level can reasonably be allocated to water without jeopardizing the health of the consumer.

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TABLE 8. DERIVATION OF APPROVAL LIMITS (AL) FOR CHLOROPHENOXY HERBICIDES

Compound	Lowest Long-Term Levels with Minimal or No Effects		Calculated Maximum Safe Levels From all Sources of Exposure			Water	
	Species	mg/kg/day[a]	Safety Factor (X)	mg/kg/day	mg/man/day[b]	% of Safe Level	AL mg/l[c]
2,4-D	Rat	0.5**	1/500	0.1	7.0	20	0.1
	Dog	8.0 **	1/500	0.016	1.12[d]		
2,4,5-TP	Rat	2.6 *	1/500	0.005	0.35	20	0.01
	Dog	0.9 *	1/500	0.002	0.14[d]		

[a] Assume weight of rat = 0.3 kg and of dog = 10 kg; assume average daily food consumption of rat = 0.05 kg and of dog = 0.2 kg.

[b] Assume average weight of human adult = 70 kg.

[c] Assume average daily intake of water for man = 2 liters.

[d] Chosen as basis on which to derive AL.

* Kraus, as cited by Mitchess, J.W., R.E. Hogson, and C.R. Gaetjens, 1946.

** Lehman, A.J., 1965.

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CRITERION:

0.001 ug/l for freshwater and marine aquatic life.

The persistence, bioaccumulation potential and carcinogenicity of DDT cautions human exposure to a minimum.

RATIONALE:

In general, DDT (1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane) refers to DDT and its metabolites. Acute toxicity to mammals generally is low; however, aquatic organisms exhibit sensitivity to this pesticide at levels in micrograms per liter. Such levels range from a 96-hour LC_{50} of 0.24 ug/l for the crayfish, Orconectes nais (Sanders, 1972), to a 96-hour LC_{50} of 2 ug/l for the largemouth bass, Micropterus salmoides (Macek and McAllister, 1970), to a 96-hour LC_{50} of 27 ug/l for the goldfish, Carassius auratus (Henderson, et al., 1959).

Since DDT is a highly persistent chemical which bioaccumulates in aquatic organisms used for human food and also is considered a potential human carcinogen (Train, 1975), levels of DDT in waterways should be kept as low as feasible. Action by the Environmental Protection Agency in suspending the production and use of DDT should result in a gradual decrease in concentrations in the environment. Such additions should not be permitted without substantial documentation that alternatives are either infeasible or potentially more hazardous. The persistence, bioaccumulative properties and carcinogenic potential of

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DDT should be taken into account when determining the uses of water containing measurable amounts of DDT.

Two- to 4-day LC50's for freshwater aquatic invertebrates and fish exposed to DDT in water generally have ranged in the low microgram per liter levels with the invertebrates being somewhat more sensitive (Sanders, 1969; Sanders, 1972; Sanders and Cope, 1966 and 1968 Henderson, et al, 1959; Macek and McAllister, 1970). The most sensitive freshwater organism for which there are data is the crayfish, Orconectes nais, which had a 96-hour LC50 of 0.24 ug/l (Sanders, 1972). Of marine organisms the most sensitive are the shrimp, Penaeus duorarum and P. setiferus, for which no survival was observed at 0.12 ug/l after 28 days' exposure and 30 percent mortality observed at 0.05 ug/l after 56 days (Nimmo, et al., 1970)

DDT will accumulate in the food chain. Field data where pesticide levels in both the water and aquatic organisms have been measured depict the quantity attributable to this bioaccumulation. A residue accumulation of up to two million times was calculated for fish from the field data of Reinert (1970). The measured DDT water concentration in his study of Lake Michigan was in the nanogram per liter range. This accumulation is 20 times greater than that observed in the National Water Quality Laboratory, Duluth, Minnesota, where residue accumulation of 100,000 times was observed. If one uses a two million times residue accumulation factor and a DDT water concentration of 0.002 ug/l an expected DDT body burden of 4 mg/kg (ppm) in fish would result.

Other studies show that measurable quantities of DDT can be found in natural waters of North America. DDT averaged 0.02 ug/l in the San Diego River, California, in the spring-fall dry weather flow of 1973 (Young and Beeson, 1974). DDT in ocean water along the west coast has ranged from 0.0023 to 0.0056 ug/l (Cox, 1971). Rivers flowing

into estuaries (Brazos and Colorado in Texas) each have a two-year average of 0.03 ug/l (Manigold and Schulze, 1969).

In laboratory studies, Hansen and Wilson (1970) found that the bio-accumulation factor from water to pinfish, Lagodon rhomboides, was 10,000 times and to Atlantic croaker, Micropogon undulatus, 38,000 times, or an average of about 25,000 times for these fishes. The discrepancy between laboratory and field data may be due to the many additional trophic levels involved in field exposures.

In controlled studies, Heath, et al. (1969) determined that DDE, in concentrations of 10 and 40 ppm DDE in dry feed, impaired reproductive success of penned mallards, Anas platyrhynchos. Eggshells of birds exposed to these concentrations were 13 percent thinner, with 25 percent of the eggs showing cracking after one month. DDT induced thinning of shells at a concentration of 25 ppm with an 18 percent cracking of the shells. Since DDT metabolizes to DDE, eggshell thinning may be partly due to DDE. The association of DDE residues with eggshell thinning was shown for the brown pelican, Pelecanus occidentalis (Blus, et al., 1972). The level of DDE in the eggs which did not produce a significant effect, i.e., thinning, was estimated to be 0.5 mg/kg. However, from the data presented, 2.0 mg/kg represents a conservative estimate of the no-effect level in the eggs.

Feeding studies have shown that black ducks fed DDT in food produced eggs containing residues of about ten-fold the DDT in the diet. Furthermore, a continuous diet of 3.0 mg/kg (wet weight) in natural food

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adversely affected reproduction (Longcore, et al., 1971). Extrapolating the egg concentration data in ducks to pelicans, an estimate can be made that the diet of pelicans should contain no more than 0.1 the estimated (2.0 mg/kg) no-effect level of DDT in eggs, or about 0.2 mg/kg.

Based on the considerations of bioaccumulation potential in fish, likelihood of conversion to DDE, and dosage levels known to adversely affect birds, it is recommended that DDT concentrations in water should not exceed 0.001 ug/l.

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CRITERION:

0.1 ug/l for freshwater and marine aquatic life

RATIONALE:

Static LC_{50} bioassays yielded toxicity values for the organophosphorus pesticide, demeton, for carp, goldfish, fathead minnow, channel catfish, guppy, rainbow trout, and bluegill, ranging from 70 ug/l to 15,000 ug/l (Henderson and Pickering, 1958; Ludemann and Neumann, 1962; Macek and McAllister, 1970; McCann and Jasper, 1972; Pickering, et al., 1962). Results of these tests demonstrate an apparent sharp division in species sensitivity, with bluegill, Lepomis macrochirus; rainbow trout, Salmo gairdneri; and guppy, Poecilia reticulata, being susceptible to lower concentrations while the remaining species were comparatively resistant. In the 96-hour exposures toxicity did not increase significantly with time, indicating that concentrations close to nominal may not have been maintained for more than a few hours. Bluegills with a 24-hour LC_{50} of 70 ug/l were the most sensitive fish (McCann and Jasper, 1972).

When fish were exposed to acutely toxic levels of demeton for 12 hours by Weiss (1959 and 1961) the maximum inhibition of brain acetylcholinesterase (AChE) was not reached. The lowest levels of AChE occurred after 24 to 48 hours. It was demonstrated that maximum inhibition could last as long as two weeks after exposure, and subsequent recovery to

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levels approaching normal took many more weeks. Weiss (1958) reported a significant increase in mortality of fathead minnows exposed for a second time to the organophosphate, Sarin, before the fish had recovered normal brain AChE levels. The resistance of fully recovered fish was equal to that of previously unexposed controls. Weiss and Gakstatter (1964a) reported no significant inhibition of brain AChE in bluegills, goldfish, and shiners, Notemigonus crysoleucas, following 15-day exposures to demeton at continuously replenished, nominal concentrations of 1 ug/l.

Acute toxicity values reported for invertebrates range from 10 to 100,000 ug/l (Ludemann and Neumann, 1962; Sanders, 1972). In general, molluscs and tubifex worms were very resistant while the smaller crustaceans and insect larvae were susceptible. Ludemann and Neumann (1962) reported that Chironomus plumosus larvae were the most sensitive species they tested. A 24-hour exposure at 10 ug/l produced undefined effects while 100 percent were killed at 1000 ug/l. Calculated LC_{50} data for invertebrates apparently are limited to a single, nominal concentration static exposure of Gammarus fasciatus (Sanders, 1972). These 24- and 96-hour LC_{50} values are reported as 500 and 27 ug/l, indicating a time-related effect not observed in the bioassays with fishes. As only a few of the sensitive species have been tested and great variance in response can result with different test methods, caution must be exercised in estimating the sub-acute concentration for aquatic fauna in general. It appears that no study has been made of possible residual effects, other than AChE inhibition, which might result from short exposures to sub-acute concentrations of organophosphates.

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There are few data on the toxicity of demeton to marine organisms. Butler (1964) reported a 48-hour EC_{50} of 63 ug/l for the pink shrimp, Penaeus duorarum, and a 24-hour LC_{50} of 550 ug/l for the spot, Leiostomus xanthurus.

Chronic demeton toxicity data for freshwater organisms are not currently available. Since there are no data available at this time to indicate long-term no-effect levels for aquatic organisms, a criterion must be derived based partly on the fact that all organophosphates inhibit the production of the AChE enzyme. Demeton is unique, however, in that the persistence of its AChE inhibiting ability is greater than that of ten other common organophosphates, even though its acute toxicity is apparently less. The effective "half-life" of AChE inhibition for demeton is greater than one year (Weiss and Gakstatter, 1964b). Because such inhibition may be additive with repeated exposures and may be compounded by any of the organophosphates, it is recommended that a criterion for demeton be based primarily on its enzyme-inhibiting potential. A criterion of 0.1 ug/l demeton for freshwater and marine aquatic life is recommended since it will not be expected to significantly inhibit AChE over a prolonged period of time. In addition, the criteria recommendation is in close agreement with the criteria for the other organophosphates.

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ENDOSULFAN

CRITERIA:

0.003 ug/l for freshwater aquatic life;

0.001 ug/l for marine aquatic life.

RATIONALE:

The acute toxicity of endosulfan (also known as thiodan) to different fish species varies widely. Macek, et al. (1969) exposed rainbow trout, Salmo gairdneri, to endosulfan at three temperatures and computed 24-hour and 96-hour LC50s. At 1.6° C, 7.2° C, and 12.7° C the 24-hour LC50's were 13, 6.1, and 3.2 ug/l, respectively. The corresponding 96-hour LC_{50} values were 2.6, 1.7, and 1.5 ug/l. Schoettger (1970), however, reports the 96-hour LC_{50} for rainbow trout to be 0.8 ug/l at 1.5° C and 0.3 ug/l at 10° C. He also determined the 96-hour LC_{50} for the western white sucker, Castostomus commersoni, to be 3.5 ug/l at 10° C and 3.0 ug/l at 19° C.

A massive fish kill in the Rhine River was attributed to a maximum concentrations of 0.7 ug/l endosulfan (Greve and Wit, 1971). The 96-hour LC_{50} at 20° C in a static bioassay using the guppy, Poecilia reticulata, was 4.2 ug/l based on the computed concentration. The measured concentration was only 0.2 ug/l (Herzel and Ludemann, 1971).

The 24-, 48-, and 96-hour LC_{50s} for the amphipod, Gammarus lacustris, were found to be 9.2, 6.4, and 5.8 ug/l (Sanders, 1969). Sanders and Cope (1968) determined the 24-, 48-, and 96-hour LC50's for naiads of the stonefly, Pteronarcys

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californica, to be 24, 5.6, and 2.3 ug/l, respectively. The 96-hour LC_{50} for Gammarus fasciatus was found to be 6.0 ug/l (Sanders, 1972).

No data are available on the levels to which endosulfan could be expected to accumulate in tissues of aquatic organisms at various water concentrations. Residues in fish are not anticipated to pose a hazard to fish-eating predators because of endosulfan's low oral toxicity to birds (Heath, et al., 1972) and mammals (Lindquist and Dahm, 1957). The U.S. Food and Drug Administration has not set allowable limits for endosulfan in edible fish tissues.

A 0.01 application factor applied to the lowest measured 96-hour LC_{50} for the rainbow trout (which appears to be the most sensitive native freshwater organism) results in a freshwater criterion of 0.003 ug/l.

Portman and Wilson (1971) determined the acute toxicity of endosulfan to a marine fish and several invertebrates by means of static bioassays. The 48-hour LC_{50} for the ~~pogge~~ a fish, Agonus cataphractes, was 30 ug/l; the 48-hour LC_{50} for a mussel, the European cockle, Cardium edule, was greater than 10,000 ug/l; the 48-hour LC_{50} for the shrimp, Crangon crangon, was 10 ug/l.

Butler (1963) reported a 48-hour EC_{50} death or loss of equilibrium of 0.2 ug/l for the brown shrimp, Penaeus aztecus, a 48-hour EC_{50} for juvenile blue crabs, Callinectes sapidus, of 35 ug/l; and a 48-hour EC_{50} of 0.6 ug/l for juvenile white mullet, Mugil curema. A concentration of 65 ug/l resulted in a 50 percent decrease in shell growth of the American oyster, Crassostrea virginica, at 28° C and a salinity

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of 22 o/oo. Korn and Earnest (1974) report a 96-hour LC_{50} of 0.1 ug/l for the striped bass, Morone saxatilis.

Use of an application factor of 0.01 times the 96-hour LC_{50} of the most sensitive marine organism tested, the striped bass, results in a marine criterion of 0.001 ug/l.

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ENDRIN

CRITERIA:

0.2 ug/l for domestic water supply (health);

0.004 ug/l for freshwater and marine aquatic life.

RATIONALE:

The highest level of endrin found to have minimal or no long-term effects in the most sensitive animal tested, the dog, is 1.0 mg/kg in the diet or 0.02 mg/kg of body weight/day (Treon, et al., 1955). Where adequate human data are not available for corroboration of the animal results, the total "safe" intake level is assumed to be 1/500 of the "no effect" or "minimal effect" level reported for the most sensitive animal tested.

Applying the available data and based upon the assumptions that 20 percent of the total intake of endrin is from drinking water, that the average person weighs 70 kg and consumes 2 liters of water per day, the formula for calculating a criterion is .02 mg/kg x 0.2 x 70 kg x 1/500 x 1/2 = .00028 mg/l thus deriving the criterion level for domestic water supply of 0.2 ug/l.

Toxicity data for the flagfish, Jordanella floridae, indicate that the "safe" concentration as determined in a long-term exposure involving reproduction is about 0.30 of the 96-hour LC_{50} (Hermanutz, 1974). Ninety-six-hour LC50's for some of the sensitive freshwater fish tested are as follows: bluegills, 0.6 ug/l (Henderson, et al., 1959); rainbow trout, 0.6 ug/l and coho salmon, 0.5 ug/l (Katz, 1961); juvenile striped bass (freshwater and estuarine life-phase), 0.094 ug/l (Korn and Earnest, 1974);

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cutthroat trout, 0.113 ug/l (Post and Schroeder, 1971). Therefore, the estimated "safe" water concentrations for these sensitive fish, based on the flagfish application factor is approximately 0.03 to 0.18 ug/l.

Stonefly naiads appear to be the most sensitive invertebrates tested. Jensen and Gaufin (1966) found the 30-day LC_{50} for the naiad, Acroneuria pacifica, to be 0.035 ug/l. Based on these data, the safe water concentration should be less than 0.035 ug/l to fully protect stoneflies throughout their entire life cycle, as well as organisms more sensitive than those that have been tested.

Fathead minnows, Pimephales promelas, exposed to 0.015 ug/l in the ambient water had total body residues 10,000 times greater than the water concentrations (Mount and Putnicki, 1966). Residue accumulation up to 10,000-fold was observed in flagfish exposed for 60 days to several concentrations between 0.05 and 0.3 ug/l (Hermanutz, 1974). Concentration factors for estuarine organisms exposed to endrin for 96-hours were a maximum of 1,600 in oysters, 1,100 in pink shrimp, 860 in grass shrimp, 4,500 in sheepshead minnows and 2,500 in the sailfin molly (Schimmel, et al., 1975). Johnson (1967) calculated the concentration in adult medeka tissue to be 17,000 to 26,000 times the water concentration. It is quite possible that some fish would accumulate endrin to 30,000 times water concentration. This degree of accumulation is based only on observations of uptake directly from the water and does not allow for accumulation via the food chain or significantly higher accumulation rates possible in other, untested fish species.

Endrin has been found to be eliminated quickly after termination of exposure. Channel catfish tissue residues were reduced

from 0.41 to 0.02 ug/g (about 95 percent reduction) within 13 days after the addition of endrin to the water was stopped (Argyle, et al., 1973). Marine spot tissue residues of 78.0 ppb were reduced below detection levels within 13 days (Lowe, 1966). Recent unpublished data showing that flagfish eliminated about 95 percent in five days support this observation. This apparent ability to excrete endrin readily may reduce the threat of extremely high residue accumulations.

Levels of 0.1 ug/l have been shown to be 100 percent lethal to the marine spot, Leiostomus xanthuras, within five days, while approximately half the population survived at a level of 0.075 ug/l after 19 days (Lowe, 1966).

Davis and Hidu (1969) reported the 48-hour TLm of American oyster eggs to be 0.79 mg/l and the 14-day TLm for larvae to be greater than 10 mg/l.

Eisler (1969) determined the following 96-hour LC_{50} values: Sand shrimp, Crangon septemspinosa - 1.7 ug/l; grass shrimp, Palaemonetes pugio - 1.8 ug/l; and hermit crab, Pagurus longicarpus - 12 ug/l. The following 96-hour LC_{50} values were reported by Eisler (1970): Atlantic silverside, Menidia menidia - 0.05 ug/l; blue head, Thalassoma bifasciatum - 0.1 ug/l; striped killifish, Fundulus majalis - 0.3 ug/l; striped mullet, Mugil cephalus - 0.3 ug/l; American eel, Anguilla rostrata - 0.6 ug/l; mummichog, Fundulus heteroclitus - 0.6 ug/l; and Northern puffer, Sphoeroides maculatus - 3.1 ug/l. **The 96-hour LC50 for striped bass was 0.094 µg/l**

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(Korn and Earnest, 1974), shiner perch, Cymatogastes aggregata, 0.12 ug/l and dwarf perch, Micrometrus minimus, 0.13 ug/l (Earnest and Benville, 1972). Ninety-six hour LC50's based on measured concentrations were 0.63 ug/l for sailfin mollies, Poecilia latipinna, 0.38 ug/l for sheepshead minnow, Cyprinodon variegatus, 0.63 ug/l for grass shrimp, Palaemonetes pugio, and 0.037 ug/l for pink shrimp, Penaeus duorarum (Schimmel, et al., 1975). Data on the effects of endrin in an exposure throughout the entire life cycle of the sheepshead minnow indicate that a "safe" concentration to protect for reproductive effects would be about 0.3 of the 96-hour LC50 (Hansen, In Press). An application factor of 0.01 of the 96-hour LC50 may be over protective. Therefore, for endrin this factor should be 0.1. Based on this, the criterion for salt water should be 0.1 of the 96-hour LC50 for pink shrimp: 0.004 ug/l. This criterion should also be protective of freshwater aquatic life.

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GUTHION

CRITERION:

.01 ug/l for freshwater and marine aquatic life.

RATIONALE:

Ninety-six-hour LC_{50} values for fish exposed to the organophosphorus pesticide, guthion, range from 4 to 4,270 ug/l (Katz, 1961; Pickering, et al., 1962; Lahav and Sarig, 1969; Macek, et al., 1969; Macek and McAllister, 1970). The only long-term fish exposure data available are those obtained recently by Adelman and Smith (unpublished data). Decreased spawning (eggs produced per female) was observed in fathead minnows, Pimephales promelas, exposed during a complete life cycle. An estimated "safe" long-term exposure concentration for fathead minnows lies between 0.3 and 0.5 ug/l. Survival of larvae was reduced at approximately 0.7 ug/l.

An investigation of the persistence of guthion in fish revealed that 50 percent of the chemical was lost in less than 1 week (Meyer, 1965). Analysis of plankton and pondwater in the same study indicated a 50 percent loss of guthion in about 48 hours. Flint, et al. (1970) determined the half-life of guthion at 30° C in pondwater and in a phosphate buffer protected from light in the laboratory. The half-life in pondwater was 1.2 days whereas that in the laboratory solution was 10 days. The more rapid degradation in pondwater was attributed to the effect of sunlight and microorganisms.

Organophosphate pesticides are toxic because they inhibit the enzyme acetylcholinesterase (AChE) which is essential to nerve impulse conduction

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and transmission (Holland, et al., 1967). Weiss (1958, 1959, 1961) demonstrated that a 40 to 70 percent inhibition of fish brain AChE usually is lethal. Centrarchids generally are considered one of the more sensitive groups of fish to guthion (Pickering, et al., 1962; Weiss and Gakstatter, 1964; Meyer, 1965). Weiss and Gakstatter (1964) found that over a 15-day period bluegills, Lepomis macrochirus, exhibited AChE inhibition at 1.0 ug/l guthion but not at 0.1 ug/l. Exposure at 0.05 ug/l for 30 days also failed to produce inhibition below the range of normal variation, but the authors stated that it appeared there was a downward trend in brain enzyme activity and that if exposure was continued a definite reduction might develop. Weiss (1961) found that about 30 days were required for fathead minnow and bluegill brain AChE levels to recover after 8 to 24 hours exposure to 10 ug/l guthion.

Benke and Murphy (1974) showed that repetitive injection of fish with guthion caused cumulative inhibition of brain AChE and mortality. After substantial inhibition by guthion exposure, it takes several weeks for brain AChE of fishes to return to normal even though exposure is discontinued (Weiss, 1959 and 1961; Carter, 1971). Inhibition of brain AChE of fishes by 46 percent or more has been associated with harmful effects in exposures to other organophosphate pesticides for a life cycle (Eaton, 1970) and for shorter periods (Carter, 1971; Coppage and Duke, 1971; Coppage, 1972; Coppage and Matthews, 1974; Post and Leasure, 1974; Coppage, et al., In Press). In static tests, similar inhibition of AChE and mortality were caused in the sheepshead minnow, Cyprinodon variegatus, in 2, 24, 48, and 72 hours at concentrations of 50, 7, 3.5, and 3 ug/l, respectively (Coppage, 1972). These data indicate that reduction of brain AChE activity of marine fishes by 70 to 80 percent or more in short-term exposures to guthion may be associated with some deaths.

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There is no evidence to indicate that guthion would cause adverse effects through the food chain. Tissue residue accumulation for whole fish calculated from the data of Meyer (1965) indicate no more than a 20-fold accumulation. LD_{50} toxicity values for birds are relatively high and range from 70 to 2,000 mg/kg (Tucker and Crabtree, 1970).

Ninety-six-hour LC_{50} values for aquatic invertebrates range from 0.10 to 22.0 ug/l (Nebeker and Gaufin, 1964; Gaufin, et al., 1965; Jensen and Gaufin, 1966; Sanders and Cope, 1968; Sanders, 1969 and 1972). Sanders (1972) exposed the grass shrimp, Paleomonetes kadiakensis, to guthion in a continuous flow bioassay for up to 20 days and found that the 5-and 20-day LC_{50} values were 1.2 and 0.16 ug/l, respectively. He found that the amphipod, Gammarus fasciatus, was the most sensitive aquatic organism tested, with a 96-hour LC50 of 0.10 ug/l. Jensen and Gaufin (1966), also using a continuous flow system, exposed two species of stonefly naiads in 4- and 30-day studies. They observed 96-hour and 30-day LC_{50} values for Acroneuria pacifica of 2.0 and 0.24 ug/l, respectively, whereas for Pteronarcys californica the values were 4.6 and 1.3 ug/l, respectively.

Results of other toxicity studies on marine organisms have been reported. The 24-hour LC_{50} for the white mullet, Mugil curema, was found to be 5.5 ug/l guthion (Butler, 1963). The 96-hour LC_{50} for the striped mullet, Mugil cephalus, was determined by Lahav and Sarig (1969) to be 8 ug/l guthion. Portman (1972) reported the 48-hour LC_{50} for the

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fish, Pleuronectes limanda, to be 10 to 30 ug/l. The 48-hour LC_{50} for the European shrimp, Crangon crangon, was found to be 0.33 ug/l guthion (Portman, 1972). Butler (1963) found that the 24-hour EC_{50} for blue crab, Callinectes sapidus, was 550 ug/l and the 48-hour EC_{50} for pink shrimp, Penaeus duorarum, as 4.4 ug/l guthion. The 48-hour TLm was estimated to be 620 ug/l for fertilized oyster eggs, Crassostrea virginica, and 860 ug/l for fertilized clam eggs, Mercenaria mercenaria (Davis and Hidu, 1969).

A criterion level of 0.01 ug/l for guthion is based upon use of an 0.1 application factor applied to the 96-hour LC50 of 0.1 ug/l for Gammarus and a similar value of 0.3 ug/l for the European shrimp.

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NMED Exhibit 83

HEPTACHLOR

CRITERION:

.001 ug/l for freshwater and marine aquatic life.

The persistence, bioaccumulation potential and carcinogenicity of heptachlor cautions human exposure to a minimum.

RATIONALE:

The acute toxicity of heptachlor to mammals is generally low; however, aquatic organisms exhibit sensitivity to this pesticide at microgram per liter levels. Such levels range from a 96-hour LC_{50} of 3 ug/l for the juvenile striped bass, Morone saxatilis (Korn and Earnest, 1974) to a 96-hour LC_{50} of 111.9 ug/l for the threespine stickleback, Gasterosteus aculeatus (Katz, 1961). Sanders and Cope (1968) reported even lower 96-hour LC_{50} values for three species of stoneflies; Pteronarcys californica, 1.1 ug/l; Pteronarcella badia, 0.9 ug/l and Claassenia sabulosa, 2.8 ug/l.

Anderson (1960) found that Daphnia magna were immobilized after 50 hours exposure to 57.77 ug/l. A 48-hour LC_{50} of 42 ug/l heptachlor for Daphnia pulex was reported by Cope (1966). Sanders and Cope (1968) determined the 96-hour LC_{50} values for the stoneflies, Pteronarcys californica, Pteronarcella badia and Claassenia sabulosa to be 1.1, 0.9 and 2.8 ug/l, respectively.

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Sanders (1972) found the grass shrimp, Palaemonetes kadiakensis, with a 96-hour LC_{50} of 1.8 ug/l, to be the most sensitive among three crustaceans tested in static bioassays. Stoneflies, therefore, appear to be the most sensitive group of freshwater organisms among those tested.

Cope (1966) found the 48-hour LC_{50} for heptachlor to the bluegill, Lepomis macrochirus, and rainbow trout, Salmo gairdneri, to be 26 ug/l and 9 ug/l, respectively. The 96-hour LC_{50} of heptachlor for the bluegill was determined by Weiss (1964) to be 19 ug/l. Katz (1961) found that the 96-hour LC50's of heptachlor for the coho salmon, Oncorhynchus kisutch; chinook salmon, Oncorhynchus tschawytscha; rainbow trout, Salmo gairdneri; and threespine stickleback, Gasterosteus aculeatus, were 59, 17.3, 19.4, and 111.9 ug/l, respectively. The 96-hour LC_{50} of heptachlor to the fathead minnow, Pimephales promelas; bluegill, Lepomis macrochirus; goldfish, Carassius auratus; and guppy, Poecilia reticulata, were determined to be 94, 230 and 170 ug/l, respectively (Henderson, et al., 1959).

Data are available on marine animals exposed to heptachlor in 96-hour flow-through bioassays. The 96-hour LC50 of the marine bluehead, Thalassoma bifasciatum, was determined to be 0.8 ug/l (Eisler, 1970). Korn and Earnest (1974) determined the 96-hour LC50 using juvenile striped bass, Morone saxatilis, to be 3.0 ug/l. Schimmel et al., (In Press) reported the following 96-hour LC50's in flow-through bioassays: pink shrimp, Penaeus duorarum, 0.11 ug/l; grass shrimp, Palaemonetes vulgaris, 1.06 ug/l; sheepshead minnow, Cyprinodon variegatus, 3.68 ug/l; pinfish, Lagodon rhomboides, 3.77 ug/l; spot, Leiostomus xanthurus, 0.85 ug/l. Shell deposition of the American oyster, Crassostrea virginica, was inhibited by 50 percent (EC50) at 1.5 ug/l heptachlor.

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Heptachlor will accumulate in the food chain. Wilson (1965) demonstrated that oysters can concentrate heptachlor almost 18,000 times (wet weight basis). Andrews et al. (1966) reported concentration factors as high as 1,840 in field tests with bluegill, Lepomis macrochirus. Since the effective (as opposed to the applied) concentration was apparently lower than the initial levels because of sorption and biological uptake, true concentration factors must have been higher than reported. For example, 24 hours after treatment with 24 ug/l the pond water contained only 2 ug/l. Using this concentration and the 46.0 ppm residue found in the fish, a concentration factor of 23,000 can be calculated. The involvement of several trophic levels might also increase the degree of accumulation. Schimmel, et al., (In Press) reported that heptachlor concentration factors ranged from 2,800 to 21,300 in estuarine fishes exposed for 96 hours; oyster bioconcentration factors ranged from 4,500 to 8,500, and factors of 206 to 700 occurred in similar tests with crustaceans.

Birds are sensitive to low dosages of heptachlor in their diet. Heath, et al. (1972) found the 5-day LC_{50} for the young of four species to range from 24 to 54 ppm. All woodcock died from a dietary dosage of 0.72 ppm and some died from 0.22 ppm (Stickel and Stickel, 1965). Residues of this magnitude (0.2 ppm) would result in fish or other aquatic life if they were exposed to 0.01 ug/l of heptachlor and accumulated it at 20,000 times water

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concentrations. Such residues would pose a hazard to birds as sensitive as woodcock that fed on these fish. Residues of this magnitude fall just under the 0.3 ppm guideline established by the U.S. Food and Drug Administration as the limit allowed in edible fish tissue (U.S. Food and Drug Administration, 1974).

Since heptachlor is a highly persistent chemical which bioaccumulates in aquatic organims used for human food and also is considered a potential human carcinogen (Train, 1974) levels of heptachlor in waterways should be kept as low as feasible. The July 1975 action by the Environmental Protection Agency in suspending the production and use of heptachlor should result in a gradual decrease in concentrations in the environment. Any addition of heptachlor to water should be considered potentially hazardous to humans. Such additions should not be permitted without substantial documentation that alternatives are either infeasible or potentially more hazardous. The persistence, bioaccumulative properties and carcinogenic potential of heptachlor should be taken into account when determining the uses of water containing measurable amounts of heptachlor.

Using an 0.01 application factor to the 96-hour LC50 of 0.1 ug/l for the pink shrimp, a marine criterion of 0.001 ug/l is obtained. Toxicity and demonstrated bioaccumulation potential of heptachlor in freshwater biota reflects the applicability of the marine criterion to freshwater.

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LINDANE

CRITERIA:

4.0 ug/l for domestic water supply (health);

0.01 ug/l for freshwater aquatic life;

0.004 ug/l for marine aquatic life

RATIONALE:

The highest level of lindane found to have minimal or no long-term effects in the most sensitive mammal tested, the dog, is 15.0 mg/kg in the diet or 0.3 mg/kg of body weight/day (Lehman, 1965). Where adequate human data are not available for corroboration of the animal results, the total "safe" drinking intake level is assumed to be 1/500 of the "no effect" or "minimal effect" level reported for the most sensitive animal tested.

Applying the available data and based upon the assumption that 20 percent of the total intake of lindane is from drinking water, that the average person weighs 70 kg and consumes 2 liters of water per day, the formula for calculating a criterion is 0.3 mg/kg x 0.2 x 70 kg x 1/500 x 1/2 = .004 mg, thus deriving the criterion level for domestic water supply of 4 ug/l.

The brown trout, Salmo trutta, apparently is the fish most sensitive to lindane among those species on which aquatic bioassays have been performed, with a 96-hour LC_{50} of 2 ug/l (Macek and McAllister, 1970). Several authors (Boyd and Ferguson, 1964; Naqvi, et al., 1969; Minchew and Ferguson, 1970) have documented increased resistance to lindane toxicity among fish and

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invertebrates experiencing previous exposure to the chemical. The most sensitive invertebrates tested appear to be only slightly more sensitive than fish. Two investigators (Snow, 1958; Cope, 1965) reported TLm values of 1 ug/l for stoneflies. Sanders and Cope (1968) reported a TLm for stoneflies of 4.5 ug/l lindane. Macek, et al. (1974) determined the acute and chronic toxicities of lindane to Daphnia magna; the midge, Chironomus tentans; and the scud, Gammarus fasciatus. The midge was the most sensitive of these species, with 2.2 ug/l being the highest concentration producing no observable adverse effect. A concentration of 11 ug/l was determined to be "safe" for Daphnia, the least sensitive, over three consecutive generations of exposure.

A criterion of 0.01 ug/l for fresh waters is derived by applying an application factor of 0.01 to the TLM for the stonefly, 1.0 ug/l. The brown trout, a sensitive human food organism, was shown to have a 96-hour LC_{50} of 2.0 ug/l. Hence the criterion level would provide for a margin of safety for both recreationally important organisms as well as trophic levels in the aquatic environment which are significant in the food chain.

Only limited information is available on accumulation of lindane in fish tissues. However, Macek, et al. (1974) observed whole-body (eviscerated) levels (wet weight) of 500 times the corresponding water concentrations in fathead minnows, Pimephales promelas, that had been exposed for several months. Butler (1967) observed accumulations of up to 250 times exposure concentrations in marine mollusks (wet weight basis).

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The recommended guideline of the U.S. Food and Drug Administration for lindane in edible fish tissue is 0.3 mg/kg (FDA, 1974). Thus, if the observed 500-fold accumulation were to occur, a lindane criterion of 0.01 ug/l in water would result in a tissue concentration in freshwater fish of .005 mg/kg, which is well below the FDA guideline.

Eisler (1969) reported 96-hour LC_{50} values of 5.0 ug/l for both the hermit crab, Pagurus longicarpus, and the sand shrimp, Crangon septemspinosa, and 10 ug/l for the grass shrimp, Palaemonetes pugio. Butler (1963) found the following 48-hour LC_{50} values: brown shrimp, Penaeus aztecus - 0.4 ug/l; juvenile white mullet, Mugil curema - 30 ug/l; and the longnose killifish, Fundulus similis - 240 ug/l. A 96-hour LC_{50} of 7.3 ug/l for the striped bass, Morone saxatilis was reported by Korn and Earnest (1974). Schimmel (unpublished data) found the pink shrimp, Penaeus duorarum, 96-hour LC50 to be 0.17 ug/l, grass shrimp Palaemonetes pugio, 4.4 ug/l and pinfish, Lagodon rhomboides, 30.6 ug/l in flow-through bioassays.

Until additional data on the effect of lindane to marine organisms are available, it is recommended that a marine criterion be based on 0.01 of the 0.4 ug/l 96-hour LC_{50} value for the brown shrimp. The marine criterion is, therefore, 0.004 ug/l.

Unpublished data suggest that the pink shrimp is a more sensitive species than the brown shrimp; however for purposes of achieving a criterion the published data were used. A level of 0.004 ug/l should provide a margin of safety for both sensitive species.

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NMED Exhibit 83

MALATHION

CRITERION:

0.1 ug/l for freshwater and marine aquatic life.

RATIONALE:

The freshwater fish most sensitive to malathion, an organophosphorus pesticide, appear to be the salmonids and centrarchids. Post and Schroeder (1971) report a 96-hour LC_{50} between 120 and 265 ug/l for 4 species of salmonids. Macek and McAllister (1970) found a 96-hour LC_{50} range between 101 and 285 ug/l for 3 species of centrarchids and 3 species of salmonids. Other 96-hour LC50's are: rainbow trout, Salmo gairdneri, 68 ug/l (Cope, 1965); largemouth bass, Micropterus salmoides, 50 ug/l (Pickering, et al., 1962) and chinook salmon, Oncorhynchus tshawytscha, 23 ug/l (Katz, 1961). All of the above tests were in static systems. Eaton (1970) determined a 96-hour LC_{50} for bluegill, Lepomis macrochirus, in a flow-through system at 110 ug/l. Macek and McAllister (1970) reported a similar 96-hour LC_{50} for the bluegill in a static exposure. Static 96-hour LC50s of 120 and 160 ug/l were reported by Post and Schroeder (1971) for brook trout, Salvelinus fontinalis. Bender (1969) indicated that the acute toxicity to fathead minnows, Pimephales promelas, is slightly greater (about 2.0 times) in a static system than in a flow-through system. The flow-through acute toxicity to fathead minnows reported by Mount and Stephan (1967) approximated the static acute toxicity reported by Henderson and Pickering (1958) and Bender (1969).

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Many aquatic invertebrates appear to be more sensitive than fish to malathion. The 96-hour LC_{50} for Gammarus lacustris was 1.0 ug/l (Sanders, 1969); for Pteronarcella badia, 1.1 ug/l (Sanders and Cope, 1968); and for Gammarus fasciatus, 0.76 ug/l (Sanders, 1972). The 48-hour LC_{50} for Simocephalus serrulatus was 3.5 ug/l and for Daphnia pulex, 1.8 ug/l (Sanders and Cope, 1966). Daphnia were immobilized in 50 hours in 0.9 ug/l (Anderson, 1960). The 24-hour LC50s for two species of midge larvae were 2.1 ug/l (Mulla and Khasawinah, 1969) and 2.0 ug/l (Karnak and Collins, 1974).

Safe life cycle exposure concentrations for the more sensitive invertebrates are not known. The most sensitive aquatic organisms probably have not yet been tested; safe concentrations for the most sensitive invertebrates exposed through a complete life cycle have not been determined; and effects of low concentrations on invertebrate behavior are unknown.

The stability of malathion in water is dependent on the chemical and biological conditions of the water (Paris, et al., 1975). Weiss and Gakstatter (1964) have shown that the half-life of malathion was reduced from about 5 months at pH 6 to one to two weeks at pH 8. Eichelberger and Lichtenberg (1971) found that only 10 percent remained in the Little Miami River (pH

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7.3-8.0) after 2 weeks. Bender (1969) states that one of the malathion breakdown products may be more toxic than the parent compound.

It has been shown that a measured concentration of 575 ug/l malathion in flowing seawater kills 40 to 60 percent of the marine fish, Lagodon rhomboides, in 3.5 hours and causes about 75 percent brain acetylcholinesterase (AChE) inhibition (Coppage, et al., 1975). Similar inhibition of AChE and mortality were caused in pinfish in 24, 48, and 72 hours at measured concentrations of 142, 92 and 58 ug/l, respectively. A concentration of 31 ug/l caused 34 percent AChE inhibition in pinfish but no deaths in 72 hours. Coppage and Matthews (1974) demonstrated that death may be associated with reductions of brain AChE activity of four marine fishes by 70 to 80 percent or more in short-term exposures to malathion. Coppage and Duke (1971) found that moribund mullet, Mugil cephalus, in an estuary sprayed with malathion (3 oz./acre) during a large-scale mosquito control operation had about 98 percent inhibition of brain AChE This is in agreement with 70 to 80 percent or more inhibition of brain AChE levels at and below which some deaths are likely to occur in short-term exposure. Spot, Leiostomus xanthurus, and Atlantic croaker, Micropogon undulatus, also had substantial inhibition of brain AChE during the spray operation (70 percent or more inhibition).

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Toxicity studies have been made on a number of marine animals. Eisler (1970) studied the 96-hour LC_{50} for several marine fishes at 20° C in static, aerated seawater. The 96-hour LC_{50} values (in ug/l) were: Menidia menidia, 125; Mugil cephalus, 550; Fundulus majalis, 250; Fundulus heteroclitus, 240; Sphaeroides maculatus, 3,250; Anguilla rostrata, 82, and Thalassoma bifasciatum, 27. Katz (1961) reported the static 24 hour LC_{50} for Gasterosteus aculeatus in 25 o/oo saltwater as 76.9 ug/l active ingredient. The 96-hour LC_{50} for striped bass, Morone saxatilis, in intermittent flowing seawater has been reported as 14 ug/l (U.S. BSFW 1970).

Reporting on studies of the toxicity of malathion on marine invertebrates, Eisler (1969) found the 96-hour LC_{50} (static, 24 o/oo salinity aerated) to be 33 ug/l for sand shrimp, Crangon septemspinosa; 82 ug/l for grass shrimp, Palaemonetes vulgaris; and 83 ug/l for hermit crab, Pagurus longicarpus. Growth of oyster, Crassostrea virginica, was reduced 32 percent by 96-hour exposure to 1 mg/l (Butler, 1963). The 48-hour LC_{50} for fertilized eggs of oysters was estimated by Davis and Hidu (1969) to be 9.07 mg/l and the 14-day LC_{50} for larvae, 2.66 mg/l.

Malathion enters the aquatic environment primarily as a result of its application as an insecticide. Because it degrades quite rapidly in most waters depending on pH, its occurrence is sporadic rather than continuous. Because the toxicity

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is exerted through inhibition of the enzyme acetylcholinesterase (AChE) and because such inhibition may be additive with repeated exposures and may be caused by any of the organo-phosphorus insecticides, inhibition of AChE by more than 35 percent may be expected to result in damage to aquatic organisms.

An application factor of 0.1 is applied to the 96-hour LC50 data for Gammarus lacustris, G. fasciatis and Daphnia , which are all approximately 1.0 ug/l, yielding a criterion of 0.1 ug/l.

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NMED Exhibit 83

METHOXYCHLOR

CRITERIA:

100 ug/l for domestic water supply (health);

0.03 ug/l for freshwater and marine aquatic life.

RATIONALE:

The highest level of methoxychlor found to have minimal or no long-term effects in man is 2.0 mg/kg of body weight/day (Lehman, 1965). Where adequate human data are available for corroboration of the animal results, the total "safe" drinking water intake level is assumed to be 1/100 of the "no effect" or "minimal effect" level reported for the most sensitive animal tested, in this case, man.

Applying the available data and based upon the assumptions that 20 percent of the total intake of methoxychlor is from drinking water, that the average person weighs 70 kg and consumes 2 liters of water per day, the formula for calculating a criterion is 2.0 mg/kg x 0.2 x 70 kg x 1/100 x 1/2 = 0.14 mg/l. A criterion level for domestic water supply of 100 ug/l is recommended.

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Few data are available on acute and chronic effects of methoxychlor on freshwater fish. Merna and Eisele (1973) observed reduced hatchability of fathead minnow, Pimephales promelas, embryos at 0.125 ug/l and lack of spawning at 2.0 ug/l. Yellow perch, Perca flavescens, exposed to 0.6 ug/l for eight months exhibited reduced growth. The 96-hour LC_{50} concentration was 7.5 and 22 ug/l for the fathead minnow and yellow perch, respectively. Korn and Earnest (1974) obtained a 96-hour LC_{50} of 3.3 ug/l with juvenile striped bass, Morone saxatilis, exposed to methoxychlor in a flowing-water bioassay.

Sanders (1972) determined a 96-hour LC_{50} value of 0.5 ug/l for the crayfish, Orconectes nais. Merna and Eisele (1973) obtained a 96-hour LC_{50} value of 0.61 ug/l for the scud, Gammarus pseudolimnaeus and 96-hour LC50s ranging from 1.59 to 7.05 ug/l for the crayfish, Orconectes nais, and three aquatic insect larvae. In 28-day exposures, reduction in emergence of mayflies, Stenonema sp., and in pupation of caddisflies, Cheumatopsyche sp., were observed at 0.5 and 0.25 ug/l concentrations, respectively. They also found methoxychlor to be degraded in a few weeks or less in natural waters.

Eisele (1974) conducted a study in which a section of a natural stream was dosed at 0.2 ug/l methoxychlor for one year. The near extinction of one species of scud, Hyallella azteca, and

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reductions in populations of other sensitive species, as well as biomass were observed. Residue accumulation of up to 1,000 times the level in the stream was observed in first-year crayfish, Orconectes nais. Metcalf, et al. (1971) traced the rapid conversion of methoxychlor to water soluble compounds and elimination from the tissues of snails, mosquito larvae, and mosquitofish. Thus, methoxychlor appears to be considerably less bioaccumlative in aquatic organisms than some of the other chlorinated pesticides.

Methoxychlor has a very low accumulation rate in birds and mammals (Stickel, 1973), and relatively low avian (Heath, et al., 1972), and mammalian (Hodge, et al., 1950) toxicities. No administrative guidelines for acceptable levels in edible fish tissues have been established by the U.S. Food and Drug Administration.

The above data indicate that 0.1 ug/l methoxychlor would be just below chronic effect level for the fathead minnow and one-fifth the acute toxicity level in a crayfish species. Therefore, a criterion level of 0.03 ug/l is recommended. This criterion should protect fish as sensitive as striped bass and is ten times lower than the level causing effects on some invertebrate populations in a one-year dosing of a natural stream.

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Bahner and Nimmo (1974) found the 96-hour LC_{50} of methoxychlor for the pink shrimp, Penaeus duorarum, to be 3.5 ug/l and the 30-day LC_{50} to be 1.3 ug/l. Using an application factor of 0.01 with the pink shrimp acute toxicity of 3.5 ug/l, the recommended criterion for the marine environment is 0.03 ug/l.

Butler (1971) found accumulation factors of 470 and 1,500 for the molluscs, Mercenaria mercenaria, and Mya arenaria, respectively, when exposed to 1 ug/l methoxychlor for 5 days. Using the 1,500 accumulation factor as a basis, a water concentration of 0.2 ug/l would be required to meet the U.S. Food and Drug Administration's guideline for methoxychlor in meat products. Thus, the recommended marine criterion of 0.03 ug/l is an order of magnitude lower than this concentration.

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MIREX

CRITERION:

0.001 ug/l for freshwater and marine aquatic life.

RATIONALE:

Mirex is used to control the imported fire ant Solenopsis saevissima richteri in the southeastern United States. Its use is essentially limited to the control of this insect and it is always presented in bait. In the most common formulation, technical grade mirex is dissolved in soybean oil and sprayed on corncob grits. The bait produced in this manner consists of 0.3 percent mirex, 14.7 percent soybean oil, and 85 percent corncob grits. The mirex bait often is applied at a rate of 1.4 kilograms per hectare, equivalent to 4.2 grams of toxicant per hectare.

Relatively few studies have been made of the effects of mirex on freshwater invertebrates. Of these, only Ludke, et al. (1971) report chemical analyses of mirex in the water. Their study reported effects on two crayfish species exposed to mirex by three techniques. First, field-collected crayfish were exposed to several sublethal concentrations of technical grade mirex solutions for various periods of time; second, crayfish were exposed to mirex leached from bait (0.3 percent active ingredient); and third, the crayfish were fed mirex bait.

Procambarus blandingi juveniles were exposed to 1 or 5 ug/l for 6 to 144 hours, transferred to clean water and observed for 10 days. After 5 days in clean water, 95 percent of the animals exposed to 1 ug/l for 144 hours were dead. Exposure to 5 ug/l for 6, 24, and 58 hours resulted in 26, 50, and 98 percent mortality 10 days after transfer to clean water.

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Crayfish, Procambarus hayi, were exposed to 0.1 and 0.5 ug/l for 48 hours. Four days after transfer to clean water, 65 percent of the animals exposed to 0.1 ug/l were dead. At the 0.5 ug/l concentration, 71 percent of the animals were dead after 4 days in clean water. Tissue residue accumulations (wet weight basis) ranged from 940- to 27,210-fold above water concentrations. In leached bait experiments, 10 bait particles were placed in 2 liters of water but isolated from 20 juvenile crayfish. Thirty percent of the crayfish were dead in 4 days and 95 percent were dead in 7 days. Water analysis indicated mirex concentrations of 0.86 ug/l. In feeding experiments, 108 crayfish each were fed one bait particle. Mortality was noticed on the first day after feeding and by the sixth day, 77 percent were dead. In another experiment, all crayfish were dead 4 days after having been fed two bait particles each. From this report it is obvious that mirex is extremely toxic to these species of crayfish. Mortality and accumulation increases with time of exposure to the insecticide. Concentrations as low as 0.1 ug/l or the ingestion of one particle resulted in death.

Research to determine effects of mirex on fish has been concentrated on species which have economic and sport fishery importance. Hyde, et al. (1974) applied mirex bait (0.3 percent mirex) at the standard rate (1.4 kg bait per hectare) to four ponds containing channel catfish, Ictalurus punctatus. Three applications were made over an 8-month period with the first application 8 days after fingerling (average weight 18.4 g) catfish were placed in the ponds. Fish were collected at each subsequent application (approximately 4-month intervals). Two and one-half months after the final application, the ponds were drained, all fish were measured, weighed, and the percent survival was calculated.

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Mirex residues in the fish at termination of the experiment ranged from 0.015 ug/g (ppm) in the fillet to 0.255 ug/g in the fat.

In another study, Van Valin, et al. (1968) exposed bluegills, Lepomis macrochirus, and the goldfish, Carassius auratus, to mirex by feeding a mirex-treated diet (1, 3, and 5 mg mirex per kg body weight) or by treating holding ponds with mirex bait (1.3, 100, and 1000 ug/l computed water concentration). They reported no mortality or tissue pathology for the bluegills; however, after 56 days of exposure, gill breakdown in goldfish was found in the 100 and 1000 ug/l contact exposure ponds, and kidney breakdown was occurring in the 1000 ug/l ponds. Mortality in the feeding experiments was not related to the level of exposure, although growth of the bluegills fed 5 ug/l mirex was reduced.

In laboratory and field test systems reported concentrations of mirex usually are between 0.5 and 1.0 ug/l (Van Valin, et al., 1968; Ludke, et al., 1971). Although mirex seldom is found above 1 ug/l in the aquatic environment, several field studies have shown that the insecticide is accumulated through the food chain. Borthwick, et al. (1973) reported the accumulation of mirex in South Carolina estuaries. Their data revealed that mirex was transported from treated land and marsh to the estuary animals and that accumulation, especially in predators, occurred. In the test area, water samples consistently were less than 0.01 ug/l. Residues in fish varied from non-detectable to 0.8 ug/g with 15 percent of the samples containing residues. The amount of mirex and the percent of samples containing mirex increased at higher trophic levels. Fifty-four percent of the raccoons sampled contained mirex residues up to 4.4 ug/g

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and 78 percent of the birds contained residues up to 17 ug/g. Naqvi and de la Cruz (1973) reported average residues for molluscs (0.15 ug/g) fish (0.26 ug/g), insects (0.29 ug/g), crustaceans (0.44 ug/g), and annelids (0.63 ug/g). They also reported that mirex was found in areas not treated with mirex which suggests movement of the pesticide in the environment. Wolfe and Norment (1973) sampled an area for one year following an aerial application of mirex bait (2.1 g mirex/hectare). Crayfish residues ranged from 0.04 to 0.16 ug/g. Fish residues were about 2 to 20 times greater than the controls and averaged from 0.01 to 0.76 ug/g. Kaiser (1974) reported the presence of Mirex in fish from the Bay of Quinte, Lake Ontario, Canada. Concentrations range from 0.02 ug/g in the gonads of the northern long nose gar, Lepistosteus osseus, to 0.05 ug/g in the areal fin of northern pike, Esox lucius. Mirex has never been registered for use in Canada.

Mirex does not appear to be greatly toxic to birds, with LC50's for the young of four species ranging from 547 to greater than 1667 ug/g (Heath, et al., 1972). Long-term dietary dosages caused no adverse effect at 3 ug/g with mallards and 13 ug/g with pheasants (Heath and Spann, 1973). However, it has been reported (Stickel, et al., 1973) that the persistence of mirex in bird tissue exceeds that of all organochlorine compounds tested except for DDE. Delayed mortality occurred among birds subjected to doses above expected environmental concentration.

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A summary examination of the data available at this time shows a mosaic of effects. Crayfish and channel catfish survival is affected by mirex in the water or by ingestion of the bait particles. Bioaccumulation is well established for a wide variety of organisms but the effect of this bioaccumulation on the aquatic ecosystem is unknown. There is evidence that mirex is very persistent in bird tissue. Considering the extreme toxicity and potential for bioaccumulation, every effort should be made to keep mirex bait particles out of water containing aquatic organisms and

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water concentrations should not exceed 0.001 ug/l mirex. This value is based upon an application factor of 0.01 applied to the lowest levels at which effects on crayfish have been observed.

Data upon which to base a marine criterion involve several estuarine and marine crustaceans. A concentration of 0.1 ug/l technical grade mirex in flowing sea water was lethal to juvenile pink shrimp, Penaeus durorarum, in a three-week exposure (Lowe, et al., 1971). In static tests with larval stages (megalopal) of the mud crab, Rhithropanopeus harrisii, reduced survival was observed in 0.1 ug/l mirex (Bookhout, et al., 1972). ~~1972)~~. In three of four 28-day seasonal flow-through experiments, Tagatz, et al., (1975) found reduced survival of Callinectes sapidus, Penaeus durorarum, and grass shrimp, Palaemonetes pugio, at levels of 0.12 ug/l in summer, 0.06 ug/l in fall, and 0.09 ug/l in winter.

Since two reports, Lowe, et al., (1971) and Bookhout, et al., (1972), reported that effects of mirex on estuarine and marine crustaceans were observed only after considerable time had elapsed, it seems reasonable that length of exposure is an important consideration for this chemical. This may not be the case in fresh water since the crayfish were affected within 48 hours. Therefore, a 3 to 4 week exposure might be considered "acute" and by applying an application factor of 0.01 to a reasonable average of toxic effect levels as summarized above, a recommended marine criterion of 0.001 ug/l results.

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PARATHION

CRITERION:

0.04 ug/l for freshwater and marine aquatic life.

RATIONALE:

Acute static LC_{50} values of the organophosphorus pesticide, parathion, for freshwater fish have ranged generally from about 50 ug/l for more sensitive species such as bluegills, Lepomis macrochirus, to about 2.5 mg/l for the more resistant species such as minnows (U.S. Environmental Protection Agency, 1975). In flowing water exposures, Spacie (1975) obtained 96-hour LC_{50} values of 0.5 mg/l, 1.6 mg/l, and 1.76 mg/l for bluegills, Lepomis macrochirus, fathead minnows, Pimephales promelas, and brook trout, Salvelinus fontinalis, respectively. Korn and Earnest (1974) found a 96-hour LC_{50} of 18 ug/l for juvenile freshwater and estuarine striped bass Morone saxatilis, in a flowing water system.

Few chronic exposure data are available for aquatic organisms. Brown bullheads, Ictalurus nebulosus, exposed to 30 ug/l parathion for 30 days exhibited tremors; at 60 ug/l they convulsed and were found to have developed a deformed vertebral column (Mount and Boyle, 1969). In a 23-month exposure of bluegills, Spacie (1975) observed deformities (scoliosis and a characteristic protrusion in the throat region) at 0.34 ug/l, but not at 0.16 ug/l. Tremors, convulsions, hypersensitivity, and hemorrhages also were evident at higher concentrations.

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Reproductive impairment and deformities were observed in fathead minnows exposed to 4.0 ug/l for 8 1/2 months. Development of brook trout, S. fontinalis embryos exposed to 32 ug/l was abnormal and mortalities associated with premature hatching were observed. Embryos at 10 ug/l appeared normal. No adverse effect on juveniles and adults was evident during 9 months exposure to 7 ug/l.

Inhibition of cholinesterase enzymes is the well established mode of physiological action of parathion and other organic phosphorous pesticides (Weiss, 1958). The degree of inhibition of brain acetylcholinesterase (AChE) activity has been the most frequently used measure of effect of these pesticides. Various studies (Weiss, 1958, 1959, 1961; Murphy et al., 1968; Gibson et al., 1969) have shown the degree of inhibition to be dependent upon toxicant concentration, length of exposure, and species sensitivity. The results of these studies have also indicated that death results from AChE inhibition ranging from 25 to 90 percent of normal. Weiss (1959) also showed that susceptibility depended upon the extent of recovery of AChE activity following prior exposure and that the recovery period for fish exposed to parathion was relatively long. In bluegills, AChE activity was only 50 percent recovered 30 days after exposure to 1 mg/l for 6 to 7 hours (Weiss, 1961).

Some of the other physiological effects observed to result from exposure of fish to parathion have been inhibition of spermatogenesis in guppies Poecilia reticulata, at 10 ug/l (Billard and deKinkelin, 1970), alternation of oxygen consumption rate in bluegills, Lepomis macrochirus at 100 ug/l (Dowden, 1966), and liver enlargement associated with increased pesticide-hydrolizing capability in mosquitofish, Gambusia affinis, (Ludke, 1970).

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Parathion has been found acutely toxic to aquatic invertebrates at under one microgram per liter, e.g., a 50-hour LC_{50} of 0.8 ug/l for Daphnia magna, 48-hour LC_{50} of 0.6 ug/l for Daphnia pulex, and 48-hour LC_{50} of 0.37 for Simocephalus serrulatus (a daphnid) (Sanders and Cope, 1966); a 5-day LC_{50} of 0.93 ug/l for the larval stonefly, Acroneuria pacifica (Jensen and Gaufin, 1964); and a 96-hour LC_{50} of 0.43 ug/l for the larval caddisfly, Hydropsyche californica (Gaufin et al., 1965). Mulla and Khasawinah (1969) obtained a 24-hour LC_{50} of 0.5 ug/l for 4th instar larvae of the midge Tanypus grodhausi. Spacie (1975) obtained 96-hour LC50's in flow-through bioassays of 0.62 ug/l for Daphnia magna, 0.40 ug/l for the scud, Gammarus fasciatus, and 31.0 ug/l for 4th instar of Chironomous tentans, a midge. Other invertebrates have been found acutely sensitive to parathion in concentrations of from 1 to 30 ug/l in water (U. S. Environmental Protection Agency, 1975).

Few longer exposures have been conducted. Jensen and Gaufin (1964) obtained 30-day LC50's for Pteronarcys californica and Acroneuria pacifica of 2.2 and 0.44 ug/l, respectively. Spacie (1975) found the three-week LC_{50} for Daphnia magna to be 0.14 ug/l. Statistically significant reproductive impairment occurred at concentrations above 0.08 ug/l. A 43-day LC_{50} of 0.07 ug/l was reported for Gammarus fasciatus and a concentration of 0.04 ug/l produced significantly greater mortality than among controls.

Limited information is available on persistence of parathion in water. Eichelberger and Lichtenberg (1971) determined the half-life in river water (pH 7.3 - 8.0) to be one week. Using AChE inhibitory capacity as the indicator, Weiss and Gakstatter (1964) found the half-life of parathion

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or its active breakdown products to be 40, 35, and 20 days in "natural" waters having a pH of 5.1, 7.0, and 8.4, respectively. The possibility of breakdown resulting in compounds more toxic than parathion was suggested by Burke and Ferguson (1969) who determined that the toxicity of this pesticide to mosquitofish, Gambusia affinis, was greater in static than in flowing water test systems. Sanders (1972), in 96-hour bioassays with the scud, Gammarus fasciatus, and glass shrimp, Palaemonetes kadiakensis, also observed greater toxicity under static than in flow-through conditions.

Tissue accumulations of parathion by exposed aquatic organisms are not great and do not appear to be very persistent. Mount and Boyle (1969) observed concentrations in the blood of bullhead, Ictalurus melas, up to about 50 times water concentrations. Spacie (1975) found muscle concentrations in chronically exposed brook trout, S. fontinalis to be several hundred times water concentrations; bluegills, Lepomis macrochirus, had about 25 times water concentrations in their bodies. Leland (1968) demonstrated a biological half-life of parathion in rainbow trout, Salmo gairdneri, exposed and then placed in fresh water to be only 30 to 40 hours. It is not expected that parathion residues in aquatic organisms exposed to the recommended criterion concentrations will be a hazard to consumer organisms.

Weiss and Gakstatter (1964) have shown that 15-day continuous exposure to parathion (1.0 ug/l) can produce progressively greater (i.e., cumulative) brain AChE inhibition in a fish species. After substantial inhibition by parathion exposure, it takes several weeks for brain AChE of exposed fishes to return to normal even though exposure is discontinued (Weiss 1959, 1961). Inhibition of brain AChE of fishes by 46 percent or

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more has been associated with harmful effects in exposures to organophosphate pesticides for one life cycle (Eaton, 1970) and for short periods (Carter, 1971; Coppage and Duke, 1971; Coppage, 1972; Coppage and Matthews, 1974; Post and Leasure, 1974; Coppage et al., 1975). It has been shown that a concentration of 10 ug parathion/l of flowing sea water kills 40 to 60 percent of the marine fishes Lagodon rhomboides (pinfish) and Leostomus xanthurus (spot) in 24 hours and causes about 87 to 92 percent brain AChE inhibition (Coppage and Matthews, 1974). Similar inhibition of AChE and mortality were caused in sheepshead minnows, Cyprinodon variegatus, in 2, 24, 48, and 72 hours at concentrations of 5000, 2000, 100, and 10 ug/l, respectively in static tests (Coppage, 1972). These data indicate that reductions of brain AChE activity of marine fishes by 70 to 80 percent or more in short-term exposures to parathion may be associated with some deaths.

Other estimates of parathion toxicity to marine organisms follow. The 48-hour EC_{50} for parathion to Penaeus duorarum was found to be 0.2 ug/l (Lowe et al., 1970). Lahav and Sarig (1969) reported the 96-hour LC_{50} for mullet, Mugil cephalus, to be 125 ug/l. The shell growth of the oyster, Crassostrea virginica, was found by Lowe et al. (1970) to be decreased by 22 percent after 96 hours in 1.0 mg/l.

An application factor of 0.1 is applied to the 96-hour LC50 data for invertebrates which range upward from 0.4 ug/l. A criteria of 0.04ug/l is recommended for marine and freshwater aquatic life.

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TOXAPHENE

CRITERIA:

5 ug/l for domestic water supply (health);

0.005 ug/l for freshwater and marine aquatic life.

RATIONALE:

The highest level of toxaphene found to have minimal or no long-term effects in the most sensitive mammal tested, the dog, is 10.0 mg/kg in the diet or 1.7 mg/kg of body weight/day (Lehman, 1965). Where adequate human data are not available for corroboration of the animal results, the total "safe" intake level is assumed to be 1/500 of the "no effect" or "minimal effect" level reported for the most sensitive animal tested.

Applying the available data and based upon the assumption that 20 percent of the total intake of toxaphene is from drinking water, that the average person weighs 70 kg and consumes 2 liters of water per day, the formula for calculating a criterion is 1.7 mg/kg X 0.2 X 70 kg X 1/500 X 1/2 =0.024 mg/l. However, at 0.024 mg/l there is an organoleptic effect which has been shown to occur at the level of 0.005 mg/l (Cohen, et al., 1961). Thus the criterion is set at 5 ug/l.

Macek and McAllister (1970) reported 96-hour LC50 values for 12 fish species ranging from 2 ug/l for largemouth bass, Micropterus

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salmoides, to 18 ug/l for bluegill, Lepomis macrochirus. Mahdi (1966) reported 96-hour LC50 values as low as 1.8 ug/l for black bullhead, Ictalurus melas, and as high as 50 ug/l for goldfish, Carrassius auratus, and Henderson, et al. (1959) reported 96-hour TLm values from 3.5 ug/l for bluegill to 20 ug/l for guppies, Poecilia reticulata. The 96-hour LC_{50} values for three stonefly species, Pteronarcys californica, Pteronarcella badia, and Claassenia sabulosa, were reported by Sanders and Cope (1968) to range from 1.3 to 3.0 ug/l.

In a chronic continuous flow bioassay with brook trout, Salvelinus fontinalis, Mayer, et al. (1975) found that toxaphene in water at a level of 0.039 ug/l adversely affected the growth and development of brook trout fry. The mortality of fish at this level was significantly greater than the controls, indicating a no-effect level of less than 0.039 ug/l. The 96-hour LC_{50} of toxaphene for 16-month-old trout was 10.8 ug/l. Mehrle and Mayer (1975) conducted a series of long-term studies on the fathead minnow, Pimephales promelas, exposing the organisms for 150 days to concentrations of toxaphene as low as 0.055 ug/l in a flow-through system. Their results confirmed the Mayer, et al.,(1975) work, showing that growth of all fish exposed to concentrations of 0.055 ug/l was significantly reduced. A no-effect level for this freshwater fish would be less than 0.055 ug/l.

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Hughes (1968) reported that lakes treated with toxaphene concentrations ranging from 40 to 150 ug/l remained toxic to fish for periods of a few months to five years. Terriere, et al. (1966) reported that a lake treated with toxaphene as a piscicide remained toxic to fish for at least five years. Bioconcentration factors of toxaphene were 500 for aquatic plants, 1,000 to 2,000 for aquatic animals other than fish, and 10,000 to 20,000 for rainbow trout in the lake. Mayer, et al. (1975) observed accumulations of 5,000 to 21,000 times water concentrations in brook trout exposed only through the water. Accumulation factors of 3,400 to 17,000 from aqueous solution have been reported for bacteria, algae and fungi (Paris, et al., 1975).

Heath, et al. (1972) reported the 5-day dietary LC_{50} to be 96 to 142 ppm for young birds of four species. No reproductive impairment occurred in mallards resulting from a long-term dietary dosage of 7 ppm and starlings tolerated 45 ppm for long periods (Patuxent Wildlife Research Center, Laurel, Maryland, unpublished data). At water levels known to affect fish (0.04 ug/l, Mayer, et al., 1975) and with accumulation factors similar to those cited above (20,000 times), resulting residue levels (0.04 x 20,000= 0.8 ppm) would not be expected to approach dosage levels known to be a hazard to birds.

No guideline for toxaphene has been set by the U.S. Food and Drug Administration as a residue limit for edible tissues of fish for human consumption.

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Lowe (1964) reported a 24-hour LC_{50} of 3.2 ug/l, a 48-hour LC_{50} of 1.0 ug/l, and a 144-hour LC_{50} of 0.5 ug/l for the spot, Leiostomus xanthurus. Butler (1963) reported a 90.8 percent decrease in productivity of natural phytoplankton communities during a 4-hour exposure to a concentration of 1,000 ug/l of toxaphene. Lowe also reported a 48-hour EC_{50} of 4.9 ug/l for the brown shrimp, Penaeus aztecus; and a 48-hour EC_{50} of 330 ug/l for juvenile blue crabs, Callinectes sapidus. A concentration of 57 ug/l resulted in a 50 percent decrease in oyster, Crassostrea virginica, shell growth after 96 hours of exposure at a water temperature of 31° C and 24 o/oo salinity, whereas 63 ug/l produced the same effect at 19° C and 19 o/oo salinity. The 48-hour LC_{50} for the juvenile white mullet, Mugil curema, was 5.5 ug/l.

Korn and Earnest (1974) report a 96-hour LC_{50} for the striped bass, Morone saxatilis of 4.4 ug/l. The 96-hour LC_{50} for the pinfish, Lagodon rhomboides, an organism of wide geographic distribution and ecological importance (Caldwell, 1957), has been reported as 0.5 ug/l (Schimmel, et al., in preparation). While the use of an application factor of 0.01 has been recommended by the NAS-NAE (NAS, 1974) its use is especially appropriate in the case of toxaphene because long-term studies with fathead minnows, Pimephales promelas (Mehrle and Mayer, 1975), and brook trout, Salvelinus fontinalis (Mayer, et al., 1975), have failed to establish a no-effect level. Application of the 0.01 factor to the 96-hour LC_{50} for the pinfish yields a marine criterion of 0.005 ug/l.

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A no-effect level was not achieved in the studies using freshwater organisms. Mortality and adverse physiological and physical effects were detected at the lowest concentration used, 0.039 ug/l. Hence, for toxaphene, the use of the same criterion for both marine and freshwater is recommended.

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pH

CRITERIA:

Range	
5 - 9	Domestic water supplies (welfare);
6.5 - 9.0	Freshwater aquatic life;
6.5 - 8.5*	Marine aquatic life.

INTRODUCTION:

"pH" is a measure of the hydrogen ion activity in a water sample. It is mathematically related to hydrogen ion activity according to the expression: $pH = - \log 10 (H^+)$, where (H^+) is the hydrogen ion activity.

The pH of natural waters is a measure of acid-base equilibrium achieved by the various dissolved compounds, salts and gases. The principal system regulating pH in natural waters is the carbonate system which is composed of carbon dioxide (CO_2), carbonic acid (H_2CO_3), bicarbonate ion (HCO_3^-), and carbonate ions ($CO_3^=$). The interactions and kinetics of this system have been described by Stumm and Morgan (1970).

pH is an important factor in the chemical and biological systems of natural waters. The degree of dissociation of weak acids or bases is affected by changes in pH. This effect is important because the toxicity of many compounds is affected by the degree of dissociation. One such

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*. . . but not more than 0.2 units outside of normally occurring range.

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example is hydrogen cyanide (HCN). Cyanide toxicity to fish increases as the pH is lowered because the chemical equilibrium is shifted toward an increased concentration of HCN. Similar results have been shown for hydrogen sulfide (H_2S) (Jones, 1964).

The solubility of metal compounds contained in bottom sediments or as suspended material also is affected by pH. For example, laboratory equilibrium studies under anaerobic conditions indicated that pH was an important parameter involved in releasing manganese from bottom sediments (Delfino and Lee, 1971).

The pH of a water does not indicate ability to neutralize additions of acids or bases without appreciable change. This characteristic, termed "buffering capacity," is controlled by the amounts of alkalinity and acidity present.

RATIONALE:

Knowledge of pH in the raw water used for public water supplies is important because without adjustment to a suitable level, such waters may be corrosive and adversely affect treatment processes including coagulation and chlorination.

Coagulation for removal of colloidal color by use of aluminum or iron salts generally has an optimum pH range of 5.0 to 6.5 (Sawyer, 1960). Such optima are predicated upon the availability of sufficient alkalinity to complete the chemical reactions.

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The effect of pH on chlorine in water principally is on the equilibrium between hypochlorous acid (HOCl) and the hypochlorite ion (OCl^-) according to the reaction:

$$HOCl = H^+ + OCl^-$$

Butterfield (1948) has shown that chlorine disinfection is more effective at values less than pH 7. Another study (Reid and Carlson, 1974) has indicated, however, that in natural waters no significant difference in the kill rate for Escherichia coli was observed between pH 6 and pH 8.

Corrosion of plant equipment and piping in the distribution system can lead to expensive replacement as well as the introduction of metal ions such as copper, lead, zinc and cadmium. Langelier (1936) developed a method to calculate and control water corrosive activity that employs calcium carbonate saturation theory and predicts whether the water would tend to dissolve or deposit calcium carbonate. By maintaining the pH at the proper level, the distribution system can be provided with a protective calcium carbonate lining which prevents metal pipe corrosion. Generally, this level is above pH 7 and frequently approaches pH 8.3, the point of maximum bicarbonate/carbonate buffering.

Since pH is relatively easily adjusted prior to and during water treatment, a rather wide range is acceptable for waters serving as a source of public water supply. A range of pH from 5.0 to 9.0 would provide a water treatable by typical (coagulation, sedimentation, filtration and chlorination) treatment plant processes. As the range is extended, the cost of neutralizing chemicals increases.

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A review of the effects of pH on freshwater fish has been published by the European Inland Fisheries Advisory Commission (EIFAC, 1969). The Commission concluded: "There is no definite pH range within which a fishery is unharmed and outside which it is damaged, but rather, there is a gradual deterioration as the pH values are further removed from the normal range. The pH range which is not directly lethal to fish is 5 - 9; however, the toxicity of several common pollutants is markedly affected by pH changes within this range, and increasing acidity or alkalinity may make these poisons more toxic. Also, an acid discharge may liberate sufficient CO_2 from bicarbonate in the water either to be directly toxic, or to cause the pH range 5 - 6 to become lethal."

Mount (1973) performed bioassays on the fathead minnow, Pimephales promelas, for a 13-month, one generation time period to determine chronic pH effects. Tests were run at pH levels of 4.5, 5.2,

pH Range	Effect on Fish*
5.0 - 6.0	Unlikely to be harmful to any species unless either the concentration of free CO_2 is greater than 20 ppm, or the water contains iron salts which are precipitated as ferric hydroxide, the toxicity of which is not known.
6.0 - 6.5	Unlikely to be harmful to fish unless free carbon dioxide is present in excess of 100 ppm.
6.5 - 9.0	Harmless to fish, although the toxicity of other poisons may be affected by changes within this range.

* EIFAC, 1969.

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5.9, 6.6, and a control of 7.5. At the two lowest pH values (4.5 and 5.2) behavior was abnormal and the fish were deformed. At pH values less than 6.6, egg production and egg hatchability were reduced when compared with the control. It was concluded that a pH of 6.6 was marginal for vital life functions.

Bell (1971) performed bioassays with nymphs of caddisflies (two species), and stoneflies (four species), dragonflies (two species), and mayflies (one species). All are important fish food organisms. The 30-day TL_{50} values ranged from 2.45 to 5.38 with the caddisflies being the most tolerant and the mayflies the least tolerant. The pH values at which 50 percent of the organisms emerged ranged from 4.0 to 6.6 with increasing percentage emergence occurring with the increasing pH values.

Based on present evidence, a pH range of 6.5 to 9.0 appears to provide adequate protection for the life of freshwater fish and bottom dwelling invertebrate fish food organisms. Outside of this range, fish suffer adverse physiological effects increasing in severity as the degree of deviation increases until lethal levels are reached.

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Conversely, rapid increases in pH can cause increased NH_3 concentrations which are also toxic. Ammonia has been shown to be ten times as toxic at pH 8.0 as at pH 7.0 (EIFAC, 1969).

The chemistry of marine waters differs from that of fresh water because of the large concentration of salts present. In addition to alkalinity based on the carbonate system, there is also alkalinity from other weak acid salts such as borate. Because of the buffering system present in sea water, the naturally occurring variability of pH is less than in fresh water. Some marine communities are more sensitive to pH change than others (NAS, 1974). Normal pH values in sea water are 8.0 to 8.2 at the surface decreasing to 7.7 to 7.8 with increasing depth (Capurro, 1970). The NAS Committee's review (NAS, 1974) indicated that plankton and benthic invertebrates are probably more sensitive than fish to changes in pH and that mature forms and larvae of oysters are adversely affected at the extremes of the pH range of 6.5 to 9.0. However, in the shallow, biologically active waters in tropical or subtropical areas, large diurnal pH changes occur naturally because of photosynthesis. pH values may range from 9.5 in the daytime to 7.3 in the early morning before dawn. Apparently these communities are adapted to such variations or intolerant species are able to avoid extremes by moving out of the area.

For open ocean waters where the depth is substantially greater than the euphotic zone, the pH should not be changed more than 0.2 units

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outside of the naturally occurring variation or in any case outside the range of 6.5 to 8.5. For shallow, highly productive coastal and estuarine areas where naturally occurring pH variations approach the lethal limits for some species, changes in pH should be avoided but in any case not exceed the limits established for fresh water, i.e., pH of 6.5 to 9.0. As with the freshwater criteria, rapid pH fluctuations that are due to waste discharges should be avoided. Additional support for these limits is provided by Zirino and Yamamoto (1972). These investigators developed a model which illustrates the effects of variable pH on copper, zinc, cadmium, and lead; small changes in pH cause large shifts in these metallic complexes. Such changes may affect toxicity of these metals.

For the industrial classifications considered, the NAS report (NAS, 1974) tabulated the range of pH values used by industry for various process and cooling purposes. In general, process waters used varied from pH 3.0 to 11.7, while cooling waters used varied from 5.0 to 8.9. Desirable pH values are undoubtedly closer to neutral to avoid corrosion and other deleterious chemical reactions. Waters with pH values outside these ranges are considered unusable for industrial purposes.

The pH of water applied for irrigation purposes is not normally a critical parameter. Compared with the large buffering capacity of the soil matrix, the pH of applied water is rapidly changed to approximately that of the soil. The greatest danger in acid soils is that metallic ions such as iron, manganese or aluminum may be dissolved

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in concentrations which are subsequently directly toxic to plants. Under alkaline conditions, the danger to plants is the toxicity of sodium carbonates and bicarbonates either directly or indirectly (NAS, 1974).

To avoid undesirable effects in irrigation waters, the pH should not exceed a range of 4.5 to 9.0.

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PHENOL

CRITERION:

1 ug/l for domestic water supply (welfare), and
to protect against fish flesh tainting.

INTRODUCTION:

Phenolic compounds include a wide variety of organic chemicals. The phenols may be classified into monohydric, dihydric, and polyhydric phenols depending upon the number of hydroxyl groups attached to the aromatic ring. Phenol itself, which has but one hydroxyl group, is the most typical of the group and is often used as a model compound. The properties of phenol, with certain modifications depending on the nature of the substituents on the benzene ring, are shared by other phenolic compounds. Phenolic compounds arise from the distillation of coal and wood; from oil refineries; chemical plants; livestock dips; human and other organic wastes; hydrolysis, chemical oxidation and microbial degradation of pesticides; and from naturally occurring sources and substances. Some compounds are refractory to biological degradation and can be transported long distances in water.

RATIONALE:

Phenolic compounds can affect freshwater fishes adversely by direct toxicity to fish and fish-food organisms; by lowering the amount of available oxygen because of the high oxygen demand of the compounds and by tainting of fish flesh (EIFAC, 1973). Shelford (1917) observed

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that a concentration of 1 cc per liter (purity of compound and concentration are unknown) was rapidly fatal to fish but solutions of one half to three quarters of this amount (i.e., .5 to .75 cc) would require up to one hour to kill fish. Subsequent studies have confirmed the toxicity of phenol to both adult and immature organisms (EIFAC, 1973). Decreased egg development in the oyster, Crassostrea virginica, has been found to occur at levels of 2 mg/l phenol (Davis and Hidu, 1969).

Various environmental conditions will increase the toxicity of phenol. Lower dissolved oxygen concentrations, increased salinity and increased temperature all enhance the toxicity of phenol (EIFAC, 1973). It has been shown that phenol and o-cresol have 24-hour LC50's of 5 and 2 mg/l respectively for trout embryos (Albersmeyer and von Erichsen, 1959). Rainbow trout were killed in 7.3 mg/l phenol in 2 hours and in 6.5 mg/l phenol in 12 hours; at these concentrations there was rapid damage to gills and severe pathology of other tissues (Mitrovic, et al., 1968). Pathologic changes in gills and in fish tissues were found at concentrations in the range of 20 to 70 ug/l phenol (Reichenback-Klinke, 1965).

McKee and Wolf (1963), following a review of world literature, concluded that phenol in a concentration of 1 ug/l would not interfere with domestic water supplies, 200 ug/l would not interfere with fish and aquatic life, 50 mg/l would not interfere with irrigation, and 1,000 mg/l would not interfere with stock watering.

A major aesthetic problem associated with phenolic compounds is their organoleptic properties in water and fish flesh. Threshold odor levels range from 55 ug/l for p-cresol (Rosen, et al., 1962) to

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2 ug/l for 2-chlorophenol (Burttschell, et al., 1959). The chlorinated phenols present problems in drinking water supplies because phenol is not removed efficiently by conventional water treatment and can be chlorinated during the final water treatment process to form persistent odor-producing compounds. Thus, odor problems are created in the distribution system. Boetius (1954), Fetterolf (1962), Schulze (1961), and Shumway (1966) estimated threshold fish flesh tainting concentrations for o-chlorophenol, p-chlorophenol, and 2, 4-dichlorophenol to range from 0.1 ug/l to 15 ug/l. The O-chlorophenol produced tainting at the lower concentration.

A criterion of 1 ug/l phenol, which is about half of the chlorophenol odor effect level for a water supply and near the threshold fish flesh tainting concentration, should protect the freshwater environment for such users.

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PHOSPHORUS

CRITERION:

0.10 ug/l yellow (elemental) phosphorus for marine or estuarine waters.

INTRODUCTION

Phosphorus in the elemental form is particularly toxic and is subject to bioaccumulation in much the same way as mercury. Phosphorus as phosphate is one of the major nutrients required for plant nutrition and is essential for life. In excess of a critical concentration, phosphates stimulate plant growths. During the past 30 years, a formidable case has developed for the belief that increasing standing crops of aquatic plants, which often interfere with water uses and are nuisances to man, frequently are caused by increasing supplies of phosphorus. Such phenomena are associated with a condition of accelerated eutrophication or aging of waters. Generally, it is recognized that phosphorus is not the sole cause of eutrophication but there is substantiating evidence that frequently it is the key element of all of the elements required by freshwater plants, and generally, it is present in the least amount relative to need. Therefore, an increase in phosphorus allows use of other already present nutrients for plant growth. Further, of all of the elements required for plant growth in the water environment, phosphorus is the most easily controlled by man.

Large deposits of phosphate rock are found near the western shore of Central Florida, as well as in a number of other States. Deposits in Florida are found in the form of pebbles which vary in size from fine sand to about the size of a human foot. These pebbles are embedded in a matrix of clay and

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and sand. The phosphate rock beds lie within a few feet of the surface and mining is accomplished by use of hydraulic water jets and a washing operation that separates the phosphate from waste materials. The process is similar to that of strip-mining. Florida, Idaho, Montana, North Carolina, South Carolina, Tennessee, Utah, Virginia, and Wyoming share phosphate mining activities.

Phosphates enter waterways from several different sources. The human body excretes about one pound per year of phosphorus expressed as "P." The use of phosphate detergents and other domestic phosphates increases the per capita contribution to about 3-1/2 pounds per year of phosphorus as P. Some industries, such as potato processing, have wastewaters high in phosphates. Crop, forest, idle, and urban land contribute varying amounts of phosphorus diffused sources in drainage to watercourses. This drainage may be surface runoff of rainfall, effluent from tile lines, or return flow from irrigation. Cattle feedlots, concentrations of domestic duck or wild duck populations, tree leaves, and fallout from the atmosphere all are contributing sources.

Evidence indicates that: (1) high phosphorus concentrations are associated with accelerated eutrophication of waters, when other growth-promoting factors are present; (2) aquatic plant problems develop in reservoirs and other standing waters at phosphorus values lower than those critical in flowing streams; (3) reservoirs and lakes collect phosphates from influent streams and store a portion of them within consolidated sediments, thus serving as a phosphate sink; and, (4) phosphorus concentrations critical to noxious plant growth vary and nuisance growths may result from a particular concentration of phosphate in one geographical area but not in another. The amount or percentage of inflowing nutrients that may be retained by a lake or reservoir is variable and will depend upon: (1) the nutrient loading to the lake or reservoir; (2) the volume of the euphotic zone; (3) the extent of biological activities;

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(4) the detention time within the lake basin or the time available for biological activities; and, (5) the level of discharge from the lake or of the penstock from the reservoir.

Once nutrients are combined within the aquatic ecosystem, their removal is tedious and expensive. Phosphates are used by algae and higher aquatic plants and may be stored in excess of use within the plant cell. With decomposition of the plant cell, some phosphorus may be released immediately through bacterial action for recycling within the biotic community, while the remainder may be deposited with sediments. Much of the material that becomes combined with the consolidated sediments within the lake bottom is bound permanently and will not be recycled into the system.

RATIONALE

Elemental Phosphorus

Isom (1960) reported an LC50 of 0.105 mg/l at 48 hours and 0.025 mg/l at 160 hours for bluegill sunfish, Lepomis macrochirus, exposed to yellow phosphorus in distilled water at 26° C and pH 7. The 125- and 195-hour LC50's of yellow phosphorus to Atlantic cod, Gadus morhua, and Atlantic salmon, Salmo salar smolts in continuous-exposure experiments was 1.89 and 0.79 ug/l, respectively.(Fletcher and Hoyle, 1972). No evidence of an incipient lethal level was observed since the lowest concentration of P_4 tested was 0.79 ug/l. Salmon that were exposed to elemental phosphorus concentrations of 40 ug/l or less developed a distinct external red color and showed signs of extensive hemolysis. The predominant features of P_4 poisoning in salmon were external redness, hemolysis, and reduced hematocrits.

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Following the opening of an elemental phosphorus production plant in Long Harbour, Placentia Bay, Newfoundland, divers observed dead fish upon the bottom throughout the Harbour (Peer, 1972). Mortalities were confined to a water depth of less than 18 meters. There was visual evidence of selective mortality among benthos. Live mussels were found within 300 meters of the effluent pipe, while all scallops within this area were dead.

Fish will concentrate elemental phosphorus from water containing as little as 1 ug/l (Idler, 1969). In one set of experiments, a cod swimming in water containing 1 ug/l elemental phosphorus for 18 hours concentrated phosphorus to 50 ug/kg in muscle, 150 ug/kg in fatty tissue, and 25,000 ug/kg in the liver (Idler, 1969 ; Jangaard, 1970). The experimental findings showed that phosphorus is quite stable in the fish tissues.

The criterion of 0.10 ug/l elemental phosphorus for marine or estuarine waters is 1/10 of demonstrated lethal levels to important marine organisms and of levels that have been found to result in significant bioaccumulation.

Phosphate Phosphorus

Although a total phosphorus criterion to control nuisance aquatic growths is not presented, it is believed that the following rationale to support such a criterion, which currently is evolving, should be considered.

Total phosphate phosphorus concentrations in excess of 100 ug/l P may interfere with coagulation in water treatment plants. When such concentrations exceed 25 ug/l at the time of the spring turnover on a volume-weighted basis in lakes or reservoirs, they may occasionally stimulate excessive or nuisance

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growths of algae and other aquatic plants. Algal growths impart undesirable tastes and odors to water, interfere with water treatment, become aesthetically unpleasant and alter the chemistry of the water supply. They contribute to the phenomenon of cultural eutrophication.

To prevent the development of biological nuisances and to control accelerated or cultural eutrophication, total phosphates as phosphorus (P) should not exceed 50 ug/l in any stream at the point where it enters any lake or reservoir, nor 25 ug/l within the lake or reservoir. A desired goal for the prevention of plant nuisances in streams or other flowing waters not discharging directly to lakes or impoundments is 100 ug/l total P (Mackenthun, 1973). Most relatively uncontaminated lake districts are known to have surface waters that contain from 10 to 30 ug/l total phosphorus as P (Hutchinson, 1957).

The majority of the Nation's eutrophication problems are associated with lakes or reservoirs and currently there are more data to support the establishment of a limiting phosphorus level in those waters than in streams or rivers that do not directly impact such water. There are natural conditions, also, that would dictate the consideration of either

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a more or less stringent phosphorus level. Eutrophication problems may occur in waters where the phosphorus concentration is less than that indicated above and, obviously, there would be a need in such waters to have nutrient limits that are more stringent. Likewise, there are those waters within the Nation where phosphorus is not now a limiting nutrient and where the need for phosphorus limits is substantially diminished. Such conditions are described in the last paragraph of this rationale.

There are two basic needs in establishing a phosphorus criterion for flowing waters: one is to control the development of plant nuisances within the flowing water and, in turn, to control and prevent animal pests that may become associated with such plants; the other is to protect the downstream receiving waterway, regardless of its proximity in linear distance. It is evident that a portion of that phosphorus that enters a stream or other flowing waterway eventually will reach a receiving lake or estuary either as a component of the fluid mass, as bed load sediments that are carried downstream, or as floating organic materials that may drift just above the stream's bed or float on its water's surface. Superimposed on the loading from the inflowing waterway, a lake or estuary may receive additional phosphorus as fallout from the air shed or as a direct introduction from shoreline areas.

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Another method to control the inflow of nutrients, particularly phosphates, into a lake is that of prescribing an annual loading to the receiving water. Vollenweider (1973) suggests total phosphorus (P) loadings in grams per square meter of surface area per year that will be a critical level for eutrophic conditions within the receiving waterway for a particular water volume where the mean depth of the lake in meters is divided by the hydraulic detention time in years. Vollenweider's data suggest a range of loading values that should result in oligotrophic lake water quality.

Mean Depth/Hydraulic Detention Time (meters/year)	Oligotrophic or Permissible Loading (grams/meter^2/year)	Eutrophic or Critical Loading (grams/meter^2/year)
0.5	0.07	0.14
1.0	0.10	0.20
2.5	0.16	0.32
5.0	0.22	0.45
7.5	0.27	0.55
10.0	0.32	0.63
25.0	0.50	1.00
50.0	0.71	1.41
75.0	0.87	1.73
100.0	1.00	2.00

There may be waterways wherein higher concentrations or loadings of total phosphorus do not produce eutrophy, as well as those waterways wherein lower concentrations or loadings of total phosphorus may be associated with popula-

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tions of nuisance organisms. Waters now containing less than the specified amounts of phosphorus should not be degraded by the introduction of additional phosphates.

It should be recognized that a number of specific exceptions can occur to reduce the threat of phosphorus as a contributor to lake eutrophy. Often, naturally occurring phenomena limit the development of plant nuisances; often there are technological or cost-effective limitations to the control of introduced pollutants. Exceptions to the threat of phosphorus in eutrophication occur in waters highly laden with natural silts or colors which reduce the penetration of sunlight needed for plant photosynthesis; in those waters whose morphometric features of steep banks, great depth, and substantial flows contribute to a history of no plant problems; in those waters that are managed primarily for waterfowl or other wildlife; in those waters where an identified nutrient other than phosphorus is limiting to plant growth and the level and nature of such limiting nutrient would not be expected to increase to an extent that would influence eutrophication; and in those waters where phosphorus control cannot be sufficiently effective under present technology to make phosphorus the limiting nutrient. No national criterion is presented for phosphate phosphorus for the control of eutrophication.

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PHTHALATE ESTERS

CRITERION:

3 ug/l for freshwater aquatic life.

INTRODUCTION:

Phthalate esters are organic compounds extensively used as plasticizers, particularly in polyvinyl chloride plastics. The function of a plasticizer is to change the characteristics of the plastic resin by making them more flexible or to improve their workability. Some plastic formulations may contain up to 60 parts per hundred of a phthalate ester. Several phthalate esters are synthesized and vary in the side chain length and structure attached to the parent benzene ring. Certain esters, the di-2-ethylhexyl and di-n-butyl phthalates, are used as an orchard acaricide and insect repellent, respectively.

Occurrence of the phthalate residues has been demonstrated in fresh (Mayer, et al., 1971), marine (Morris, 1970), industrial and heavily populated waters (Stalling, 1972). No well documented information exists on the fate of the phthalate compounds in aquatic environments (Mayer, et al., 1972).

RATIONALE:

Acute toxicity of the phthalate esters tested has been shown to be quite low (Sanders et al., 1973). Mayer and Sanders (1973) determined the 96-hour LC_{50} of di-n-butyl phthalate to be 1.3 mg/l for the fathead minnow, Pimephales promelas; 0.73 mg/l for the bluegill, Lepomis macrochirus; 2.91 mg/l for channel catfish, Ictalurus punctatus; 6.47 mg/l for rainbow trout, Salmo gairdneri; 2.10 mg/l for the scud, Gammarus pseudolimnaeus; and >10 mg/l for the crayfish, Orconectes nais. Daphnia magna, when exposed to the di-2-ethylhexyl phthalate at

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levels of from 3 ug/l to 30 ug/l for 21 days, exhibited a decrease in the numbe of young produced of 60 to 83 percent, respectively.

Ability of aquatic organisms to accumulate various phthalate residues depend upon the ester, concentration and time of exposure. Concentration factors up to 6,600 have been reported for di-n-butyl phthalate in midge larva, Chironomus plumosus, after seven days exposure to 0.18 ug/l. Amphipods, Gammarus pseudolimnaeus, were found to concentrate the di-2-ethylhexyl phthalate 13,400 times in water containing 0.1 ug/l after 14 days exposure (Sanders et al., 1973). Daphnia magna were exposed to 0.1 ug/l of radioactively labeled phthalate for 7 days and then transferred to fresh flowing water to determine the time required for elimination of phthalate residues (Mayer and Sanders, 1973). After 3 days, 50 percent of the total radioactivity remained; 25 percent of the activity was still present after 7 days in fresh water.

Phthalate esters can be detrimental to aquatic organisms at low water concentrations. Ability to concentrate high levels from water and reproductive impairment in certain species are suggestive of potential environmental damage. While the fate of these compounds remains obscure, their presence in water affects successful growth and reproduction essential for maintenance of animal populations. A freshwater criterion of 3 ug/l is recommended even though some reproductive impairment was seen in daphnids, since all other species tested were so much more resistant. Until additional effect data become available this criterion should be a goal for marine waters.

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POLYCHLORINATED BIPHENYLS

CRITERION:

.001 ug/l for freshwater and marine aquatic life and for consumers thereof.

Every reasonable effort should be made to minimize human exposure.

INTRODUCTION:

Polychlorinated biphenyls (PCB's) are a class of compounds produced by the chlorination of biphenyls and are registered in the United States under the trade name, Aroclor (R) . The degree of chlorination determines their chemical properties, and generally their composition can be identified by the numerical nomenclature, e.g., Aroclor 1242, Aroclor 1254, etc. The first two digits represent the molecular type and the last two digits the average percentage by weight of chlorine (NTIS, 1972).

Identification of PCB's in the presence of organochlorine pesticides such as DDT and DDE has been difficult in the past because of their similar chromatographic characteristics (Risebrough, et al., 1968).

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In PCB analysis today, the interference of organochlorine hydrocarbons is overcome by sequential column chromatography on Florisil and silica gel (Armour and Burke, 1970; FDA, 1971). Gas-liquid chromatography with highly sensitive and selective detectors has been employed successfully in the detection of PCB's at low levels (Nebeker and Puglisi, 1974).

PCB compounds are slightly soluble in water (25-200 ug/l at 25°C), soluble in lipids, oils, organic solvents, and resistant to both heat and biological degradation (NTIS, 1972; Nisbet, et al., 1972). Typically, the specific gravity, boiling point, and melting point of PCB's increase with their chlorine content. PCB's are relatively non-flammable, have useful heat exchange and dielectric properties, and now are used principally in the electrical industry in capacitors and transformers.

RATIONALE:

The acute and chronic effects of PCB's have been determined on a number of aquatic organisms.

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Ninety-six-hour LC50 values for newly hatched fathead minnows, Pimephales promelas, were 15 ug/l for Aroclor 1242 and 7.7 ug/l for Aroclor 1254. In 60-day continuous flow bioassays 50 percent of the fathead minnows were killed in 8.8 ug/l Aroclor 1242 and in 4.6 ug/l Aroclor 1254 (Nebeker, et al., 1974). Nine-month continuous flow bioassay tests were conducted in the same series of experiments reported by Nebeker, et al. (1974). The spawning of fathead minnows was significantly affected at concentrations of 1.8 ug/l Aroclor 1254; concentrations of Aroclor 1242 above 10 ug/l were lethal to newly hatched fry. Defoe, et al. (In Press) conducted similar flow-through acute and chronic studies with fathead minnows using Aroclor 1248 and 1260. The calculated 30-day TL50 for newly hatched fathead minnows was 4.7 ug/l for Aroclor 1248 and 3.3 ug/l for Aroclor 1260. Fathead minnows were able to reproduce successfully at PCB concentrations which were acutely lethal to the larvae.

Stalling and Mayer (1972) determined 96-hour LC50 values ranging from 1,170 to 50,000 ug/l for cutthroat trout, Salmo clarki, using Aroclors 1221-1268. With rainbow trout, Salmo gairdneri, and Aroclors 1242-1260 the acute toxicity was

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greater than 1500 mg/l. Fifteen-day intermittent-flow bioassays carried out with bluegills, Lepomis macrochirus, and Arcclors 1242, 1248 and 1254 resulted in LC50 values of 54, 76 and 204 ug/l, respectively.

Johnson (1973), Mayer (1975) and Veith (1975) conducted bioassays which showed that the toxicity of Aroclor 1016, introduced recently to replace PCB's of the Aroclor 1200 series in many applications, was similar to that of Aroclor 1242.

Nebeker and Puglisi (1974) conducted bioassays with Daphnia magna exposed to concentrations of Aroclors 1221-1268. In continuous flow tests Aroclor 1254 was the most toxic with a 3-week LC50 of 1.3 ug/l; 100 percent mortality occurred at 3.5 ug/l and 100 percent reproductive impairment occurred at 3.8 ug/l. Stalling and Mayer (1972) and Mayer et al. (1975) conducted flow-through and static bioassay tests on freshwater invertebrates which likewise indicated that these organisms are generally more susceptible to acute toxic effects of PCB's than fish.

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Studies of the Milwaukee River (Wisconsin) revealed PCB concentrations in ambient water of 2.0 to 2.8 ug/l and residues in fish as high as 405 ug/g (Veith and Lee, 1971). Open water Lake Michigan PCB concentrations have been reported to be less than 0.01 ug/l; mean residues in coho salmon, Oncorhynchus kisutch, were about 15 ug/g (Veith, 1973). Veith (1973) found that goldfish, Carassius auratus, in the lower Milwaukee River accumulated Aroclor 1248 approximately 0.7×10^5 to 2×10^5 times depending upon the ambient water concentration. From both laboratory and river system studies, many aquatic organisms appear to bioaccumulate PCB mixtures containing 3, 4, 5, and 6 chlorine atoms per molecule approximately 3×10^3 to 2×10^5 times the concentration in the water. Tissue residues in fathead minnows, Pimephales promelas, ranged from 0.7 ug/g of Aroclor 1248 in control fish to 1036 ug/g of Aroclor 1254 in fish held for 8 months in water containing 4.0 ug/l of Aroclor 1254 (Nebeker, et al., 1974). The latter case indicates a bioaccumulation factor of 2.3×10^5, which is essentially independent of the PCB concentration in the water.

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Bluegill sunfish, Lepomis macrochirus, exposed to Aroclors 1248 and 1254 exhibited a bioaccumulation factor of 7.1×10^4 (Stalling and Mayer, 1972). The bioaccumulation factor for gizzard shad, Dorosoma cepedianum, in the Saginaw River (Michigan) varied between 0.6×10^5 and 1.5×10^5 for Aroclor 1254 (Michigan Water Resource Commission, 1973).

On the basis of the FDA action level of 5 ug/g in fish tissue, and both laboratory and field derived bioaccumulation levels for fathead minnows, Pimephales promelas, and goldfish, Carassius auratus, in the range of 0.7×10^3 to 2.3×10^5 , an ambient water concentration of no more than 0.022 ug/l would be permissible. However, lake trout from the Great Lakes larger than 12 inches in length generally contain more than 5 ug/g of PCB's and chub from the Great Lakes generally contain PCB's in amounts approaching or slightly exceeding 5 ug/g. Since monitoring data on the Great Lakes' waters consistently indicate concentrations equal to or less than .01 ug/l, a criterion of less than 0.01 ug/l for all fishes appears necessary.

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A residue level of 2 ug/g in fish consumed by commercial ranch mink has been shown to preclude survival of mink offspring (Ringer, et al., 1972). Reproduction was nearly eliminated in ranch mink fed a beef diet containing 0.64 ug/g of Aroclor 1254 (Platonow and Kalstad, 1973). This suggests that a tissue level limit of not more than 0.5 ug/g would be required to protect ranch mink, and by implication, other carnivorous mammals. These data, plus the fact that lake trout from the Great Lakes (in water with PCB levels equal to or less than 0.01 ug/l) already exceed the 5 ug/g FDA limit, justify a fresh water criterion of not greater than 0.001 ug/l.

Median PCB concentrations in whole fish of eight species from Long Island Sound obtained in 1970 were reported to be on the order of 1 ug/g, as were comparable concentrations found in fish off the coast of Southern California (Hays and Risebrough, 1972; Risebrough, 1969). Generally, residues in ocean fish have been below 1 ug/g (Risebrough, 1970).

Surveys of Escambia Bay (Florida) during the period September 1969 to December 1971 produced data on the

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pathways and effects of PCB's in the estuarine and marine environments. The sediment reservoir of Aroclor 1254 is thought to be a continuing source of PCB's to aquatic biota. The initial survey of Escambia Bay biota revealed fish, shrimp, and crabs with levels as high as 12 ug/g. Higher levels of PCB's were detected in higher trophic levels than shrimp, which could implicate a chain transfer from sediment to large animals (Duke, 1974).

From the Escambia Bay data, which include flow-through bioassays with residue analyses where possible, the following conclusions were reached: (1) all of the Aroclors tested are acutely toxic to certain estuarine organisms; (2) bioassays lasting longer than 96 hours demonstrated that Aroclor 1254 is toxic to commercial shrimp at less than 1 ug/l; (3) fish, particularly sheepshead minnows, Cyprinodon variegatus, are extremely sensitive to Aroclor 1254 with 0.1 ug/l lethal to fry; and, (4) acute toxicity of Aroclor 1016 to estuarine organisms is similar to that of other Aroclors but it appears less toxic to marine fish in long-term exposures than does Aroclor 1254 (Duke, 1974; Schimmel, et al., 1974).

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Oysters, Crassostrea virginica, were sensitive to Aroclor 1260 with growth diminished by 44 percent in concentrations of 10 ug/l and by 52 percent in 100 ug/l. Approximately 10 percent of the pink shrimp, Penaeus duorarum, died in 100 ug/l, but no apparent effects on pinfish, Lagodon rhomboides, were noted at that concentration. Aroclor 1254 had no apparent effect on juvenile pinfish at 100 ug/l in 48-hour flow-through tests, but killed 100 percent of the pink shrimp. At 100 ug/l of Aroclor 1254 for 96 hours, shell growth of oysters was inhibited and was decreased 41 percent at levels of 10 ug/l. The toxicity of Aroclor 1248 and 1242 to shrimp and pinfish was similar to that of Aroclor 1254. Aroclor 1242 was toxic to oysters at 100 ug/l. Killifish, Fundulus heteroclitus, exposed to 25 ug/l of Aroclor 1221 suffered 85 percent mortality. In 96-hour bioassays, Aroclor 1016 was toxic to an estimated 50 percent of the oysters, Crassostrea virginica; brown shrimp, Penaeus aztecus; and grass shrimp, Palecmonetes pugio, at 10 ug/l; it was lethally toxic to 18 percent of the pinfish at 100 ug/l (Duke, 1974).

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Young oysters, Crassostrea virginica, exposed to Aroclor 1254 in flowing sea water for 24 weeks experienced reduction in growth rates at 4.0 ug/l, but apparently were not affected by 1.0 ug/l. Oysters accumulated as much as 100,000 times the test-water concentration of 1.0 ug/l. General tissue alterations in the vesicular connective tissue around the diverticula of the hepatopancreas were noted in the oysters exposed to 5.0 ug/l. No significant mortality was observed in oysters exposed continuously to 0.01 ug/l of Aroclor 1254 for 56 weeks (Duke, 1974).

Blue crabs, Callinectes sapidus, apparently were not affected by 20 days' exposure to 5.0 ug/l of Aroclor 1254. Pink shrimp exposed under similar conditions experienced a 72 percent mortality. In subsequent flow-through bioassays, 51 percent of the juvenile shrimp were killed by Aroclor 1254 in 15 days and 50 percent of the adult shrimp were killed at 3.0 ug/l in 35 days. From pathological examinations of the exposed pink shrimp, it appears that Aroclor 1254 facilitates or enhances the susceptibility to latent viral infections. Aroclor 1254 was lethal to grass shrimp, Paleomonetes pugio, at 4.0 ug/l in 16 days, to

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amphipods at 10 ug/l in 30 days, and to juvenile spot, Leiostomus xanthurus, at 5.0 ug/l after 20 to 45 days. Sheepshead minnows, Cyprinodon variegatus, were the most sensitive estuarine organisms to Aroclor 1254 with 0.8 ug/l lethal to the fry within 2 weeks. Aroclor 1016, in two different 42-day flow-through bioassays, caused significant mortalities of pinfish at 32 ug/l and 21 ug/l. Pathological examination of those exposed to 32 ug/l revealed several liver and pancreatic alterations. Sheepshead minnows in 28-day Aroclor 1016 flow-through bioassays were not affected by concentrations of 10 ug/l or less, but died at 32 and 100 ug/l (Duke, 1974). The bioaccumulation factors determined by the flow-through bioassays are:

Aroclor	Organism	Time	Accumulation Factors (as a multiplier of test water concentrations)
1254	Oyster (Crassostrea virginica)	30 days	1.01×10^5
1254	Blue crab (Callinectes sapidus)	20 days	4×10^3
1254	Grass shrimp (Paleomonetes pugio)	7 days	3.2×10^3 to 11×10^3
1254	Spot (Leiostomus xanthurus)	14-28 days	37×10^3

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1254	Pinfish (Lagodon rhomboides)	35 days	21.8×10^3
1016	Pinfish (Lagodon rhomboides)	42 days	11×10^3 to 24×10^3
1016	Sheepshead minnow (Cyprinodon variegatus)		2.5×10^3 to 8.1×10^3

Based upon an accumulation factor of 100,000 in the oyster, it is necessary to limit the marine water concentration of PCB's to a maximum of 0.01 ug/l to protect the human consumer. However, data on the toxicity of Aroclor 1254 to sheepshead minnow fry mentioned earlier (Schimmel, et al., 1974), which indicate lethality at 0.1 ug/l, justify lowering the latter concentration by a factor of 0.01 to obtain a marine criterion of 0.001 ug/l. This level is further supported by the evidence cited earlier suggesting that a food tissue level of 0.5 ug/g, or 0.1 times the FDA level for human consumption, is necessary to protect carnivorous mammals.

Evidence is accumulating that PCB's do not contribute to shell thinning of bird eggs (NAS, 1974). Dietary PCB's produced no shell thinning in eggs of mallard ducks (Heath, et al., 1972). PCB's may increase susceptibility to

infectious agents such as viral diseases (Friend and Trainer, 1970), and increase the activity of liver enzymes that degrade steroids, including sex hormones (Risebrough, et al., 1968; Street, et al., 1968). Laboratory studies have indicated that PCB's with their derivatives or metabolites, cause embryonic death of birds (Voss and Koeman, 1970). Feeding PCB's to White Leghorn pullets at a level of 20 ppm caused a significant decrease in hatchability of the eggs and viability of the surviving progeny (Lillie, et al., 1974; Lillie, et al., 1975); in many cases, the cause of embryo mortality was attributed to gross abnormalities which ranged from edema to malformed appendages (Cecil, et al., 1974).

Exposure to PCB's is known to cause skin lesions (Schwartz and Peck, 1943) and to increase liver enzyme activity that may have a secondary effect on reproductive processes (Risebrough, 1969; Street, et al., 1968; Wasserman, et al., 1970). It is not clear whether the effects are due to the PCB's or their contaminants, the chlorinated dibenzofurans, which are highly toxic (Bauer, et al., 1961; Schultz, 1968; Varrett, 1970). While chlorinated

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dibenzofurans are a by-product of PCB production, it is not known whether they are also produced by the degradation of PCB's (NAS, 1974).

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SELENIUM

CRITERIA:

10 ug/l for domestic water supply (health);

For marine and freshwater aquatic life; 0.01 of the 96-hour LC_{50} as determined through bioassay using a sensitive resident species.

INTRODUCTION:

Biologically, selenium is an essential, beneficial element recognized as a metabolic requirement in trace amounts for animals but toxic to them when ingested in amounts ranging from about 0.1 to 10 mg/kg of food. The national levels of selenium in water are proportional to the selenium in the soil. In low selenium areas, the content of water may be well below 1 ug/l (Lindberg, 1968). In water from seleniferous areas, levels of selenium of 50 to 300 ug/l have been reported (WHO, 1972). Selenium appears in the soil as basic ferric selenite, calcium selenate, and as elemental selenium. Elemental selenium must be oxidized to selenite or selenate before it has appreciable solubility in water.

RATIONALE:

Selenium is considered toxic to man. Symptoms appear similar to those of arsenic poisoning (Keboe, et al., 1944; Fairhill, 1941). Any consideration of the toxicity of selenium to man must take into consideration the dietary requirement for the element in amounts estimated to be 0.04 to .10 mg/kg of food. Considering this requirement in conjunction with evidence that ingestion of selenium in amounts as low

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as .07 mg per day has been shown to give rise to signs of selenium toxicity, selenium concentrations above 10 ug/l should not be permitted in drinking water (Smith, et al., 1936; Smith and West, 1937). The USPHS drinking water standards recommend that drinking water supplies contain no more than 0.01 mg/l of selenium (USPHS, 1962).

As sodium selenite, 2.0 mg/l of selenium has been demonstrated to be lethal to goldfish, Carassius auratus, in 18 to 46 days (Ohio River Valley Water Sanitation Commission, 1950). Bringmann and Kuhn (1959) demonstrated the threshold effect of selenium as sodium selenite on a freshwater crustacean, an alga and a bacterium. In two days the median threshold effect occurred at 2.5 mg/l with Daphnia; in 4 days the median threshold effect was 2.5 mg/l with Scenedesmus, at 90 mg/l with Escherichia coli:, and 183 mg/l for the protozoan, Microregma.

Selenium in water apparently is toxic at concentrations of 2.5 mg/l or less to those few species tested. Animals can beneficially metabolize ingested selenium in amounts of 0.01 to 0.10 mg/kg of food.

Based on the data available, freshwater fish should not be exposed to water containing more than 0.01 of the 96-hour LC50 as determined through bioassay using a sensitive resident species.

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SILVER

CRITERIA:

50 ug/l for domestic water supply (health).

For marine and fresh water aquatic life 0.01 of the 96-hour LC_{50} as determined through bioassay using a sensitive resident species.

INTRODUCTION:

Biologically, silver is a non-essential, non-beneficial element recognized as causing localized skin discoloration in humans, and as being systemically toxic to aquatic life. Ingestion of silver or silver salts by humans results in deposition of silver in skin, eyes and mucous membranes that causes a blue-gray discoloration without apparent systemic reaction (Hill, 1957). Because of its strong bactericidal action, silver has been considered for use as a water disinfectant. Dosages of 0.001 to 500 ug/l of silver have been reported sufficient to sterilize water (McKee and Wolf, 1963). At these concentrations, the ingestion of silver has no obvious detrimental effect on humans.

RATIONALE:

The 1962 USPHS Drinking Water Standards contained a limit for silver of 0.05 mg/l. This limit was established because of the evidence that silver, once absorbed, is held indefinitely in tissues, particularly the skin, without evident loss through usual channels of elimination or reduction by transmigration to other body sites, and because of the probable high absorbability of silver bound to sulfur components of food cooked in silver-containing water (Aub and Fairhall, 1942). A study of the toxic

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effects of silver added to drinking water of rats showed pathologic changes in kidneys, liver and spleen at concentrations of 400, 700, and 1,000 ug/l (Just and Szniolis, 1936).

Using silver nitrate, Coleman and Clearly (1974) demonstrated that juvenile largemouth bass, Micropterus salmoides, and bluegill, Lepomis macrochirus exposed to silver in concentrations of 0.3 to 70 ug/l accumulated the metal, especially in the internal organs and gills. The quantity of accumulated silver increased as exposure concentrations increased with a subsequent equilibrium developing between the water and tissue concentrations. After two months' exposure to 7 ug/l silver, the concentration of silver in gills exceeded that in the gills of the control fish by 200-fold. The 70 ug/l concentration of silver was lethally toxic to bass.

Data compiled by Doudoroff and Katz (1953) show that sticklebacks were killed by a 20 ug/l concentration of silver nitrate in two days. Anderson (1948) reported that the toxic threshold of silver nitrate for sticklebacks, Gasterosteus aculeatus, was 3.0 ug/l as silver. He also found that Daphnia magna were immobilized by 3.2 ug/l as silver. Jones (1939) found the lethal concentration of silver nitrate for sticklebacks was 3.0 ug/l as silver. In differing concentrations the average survival times of the fish were; one week at 4.0 ug/l, four days at 10.0 ug/l, and only one day at 100.0 ug/l.

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In a 10-month bioassay on rainbow trout, Salmo gairdneri, exposed to silver nitrate, Geottl, et al. (1974) determined that no significant number of test fish died when exposed to silver concentrations of .09 and 0.17 ug/l as silver. The results did not reflect possible effects of silver on spawning behavior or reproduction.

Using silver thiosulfate, silver nitrate, silver carbonate and silver chloride, Terhaar, et al. (1972) reported that all of a test group of 20 fathead minnows, Pimephales promelas, survived exposure for 96 hours to 5,000 ug/l silver as silver thiosulfate; at 250,000 ug/l 15 of 20 fish died. Silver nitrate in concentrations of 1,000 and 100.0 ug/l as silver killed 16 out of 20 and 12 out of 20 fish, respectively. Silver carbonate killed all 20 test fish at concentrations of 1,000 ug/l.

In marine waters a concentration of 400 ug/l as silver killed 90 percent of test barnacles, Balanus balanoides (Clarke, 1947). Silver nitrate effects on the development of sea urchin, Arbacia, have been reported at approximately 0.5 ug/l (Wilber, 1969). Calabrese, et al. (1973) reported an LC_{50} (48-hour) of 5.8 ug/l as silver for oyster larvae, Crassostrea virginica, and an LC_{50} (48-hour) of 21.0 ug/l as silver for larvae of the hard-shell clam, Mercenaria mercenaria. Jackim, et al. (1970) reported a sublethal enzyme effect at a concentration of 20.0 ug/l as silver for Fundulus heteroclitus.

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It is apparent that there is a wide variation in the toxicity of silver compounds to aquatic life and that the degree of dissociation characteristic of these compounds affects toxicity. Since little information is available on the movement and chemical stability of these compounds in the aquatic environment, a silver criterion must be based on the total silver concentration.

The silver criterion should be established at 0.01 of the 96-hour LC_{50} as determined through bioassay using a sensitive resident species. This application factor has been recommended (NAS, 1974) for persistent or cumulative toxicants.

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SOLIDS (DISSOLVED) AND SALINITY

CRITERION:

250 mg/l for chlorides and sulfates
in domestic water supplies (welfare).

INTRODUCTION:

Dissolved solids and total dissolved solids are terms generally associated with freshwater systems and consist of inorganic salts, small amounts of organic matter and dissolved materials (Sawyer, 1960). The equivalent terminology in Standard Methods is filtrable residue (Standard Methods, 1971). Salinity is an oceanographic term, and although not precisely equivalent to the total dissolved salt content it is related to it (Capurro, 1970). For most purposes, the terms total dissolved salt content and salinity are equivalent. The principal inorganic anions dissolved in water include the carbonates, chlorides, sulfates and nitrates (principally in ground waters); the principal cations are sodium, potassium, calcium, and magnesium.

RATIONALE:

Excess dissolved solids are objectionable in drinking water because of possible physiological effects, unpalatable mineral tastes and higher costs because of corrosion or the necessity for additional treatment.

The physiological effects directly related to dissolved solids include laxative effects principally from sodium sulfate and magnesium sulfate and the adverse effect of sodium on certain patients afflicted with cardiac disease and women with toxemia associated with pregnancy. One study was made

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using data collected from wells in North Dakota. Results from a questionnaire showed that with wells in which sulfates ranged from 1,000 to 1,500 mg/l, 62 percent of the respondents indicated laxative effects associated with consumption of the water. However, nearly one-quarter of the respondents to the questionnaire reported difficulties when concentrations ranged from 200 to 500 mg/l (Moore, 1952). To protect transients to an area, a sulfate level of 250 mg/l should afford reasonable protection from laxative effects.

As indicated, sodium frequently is the principal component of dissolved solids. Persons on restricted sodium diets may have an intake restricted from 500 to 1,000 mg/day (Nat. Res. Coun., 1954). That portion ingested in water must be compensated by reduced levels in food ingested so that the total does not exceed the allowable intake. Using certain assumptions of water intake (e.g., 2 liters of water consumed per day) and sodium content of food, it has been calculated that for very restricted sodium diets, 20 mg/l in water would be the maximum, while for moderately restricted diets, 270 mg/l would be maximum. Specific sodium levels for entire water supplies have not been recommended but various restricted sodium intakes are recommended because: (1) the general population is not adversely affected by sodium, but various restricted sodium intakes are recommended by physicians for a significant portion of the population, and; (2) 270 mg/l of sodium is representative of mineralized waters that may be aesthetically unacceptable, but many domestic water supplies exceed this level. Treatment for removal of sodium in water supplies is costly (NAS, 1974).

A study based on consumer surveys in 29 California water systems was made to measure the taste threshold of dissolved salts in water (Bruvold et al., 1969) Systems were selected to eliminate possible interferences from other taste-causing substances than dissolved salts. The study revealed that consumers rated waters with 319 to 397 mg/l dissolved solids as "excellent" while those with 1283 to

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1333 mg/l dissolved solids were "unacceptable" depending on the rating system used. A "good" rating was registered for dissolved solids less than 658 to 755 mg/l. These results should be interpreted with consideration of consumer acclimation to such waters. The PHS Drinking Water Standards (1962) recommended a maximum dissolved solids concentration of 500 mg/l unless more suitable supplies were unavailable.

Specific constituents included in the dissolved solids in water may cause mineral taste at lower concentrations than other constituents. Chloride ions have frequently been cited as having a low taste threshold in water. Data from Ricter and MacLean (1939) on a taste panel of 53 adults indicated that. 61 mg/l NaCl was the median level for detecting a difference from distilled water. At a median concentration of 395 mg/l chloride a salty taste was distinguishable, although the range was from 120 to 1215 mg/l. Lockhart, et al. (1955) evaluated the effect of chlorides on water used for brewing coffee. Threshold concentrations for chloride ranged from 210 mg/l to 310 mg/l depending on the associated cation. These data indicate that a level of 250 mg/l chlorides is a reasonable maximum level to protect consumers of drinking water.

The causation of corrosion and encrustation of metallic surfaces by water containing dissolved solids is well known. In water distribution systems corrosion is controlled by insulating dissimilar metal connections by non-metallic materials, use of pH control and corrosion inhibitors, or some form of galvanic or impressed electrical current systems (Lehmann, 1964). Damage in household systems occurs to water piping, wastewater piping, water heaters, faucets, toilet flushing mechanisms, garbage grinders and both clothes and dishwashing machines.

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By use of water with 1,750 mg/l dissolved solids as compared with 250 mg/l, service life reductions ranged from 70 percent for toilet flushing mechanisms to 30 percent for washing equipment. Such increased corrosion was calculated in 1968 to cost the consumer an additional $0.50 per 1,000 gallons used (Patterson and Banker, 1968).

All species of fish and other aquatic life must tolerate a range of dissolved solids concentrations in order to survive under natural conditions. Based on studies in Saskatchewan it has been indicated that several common freshwater species survived 10,000 mg/l dissolved solids, that whitefish and pike-perch survived 15,000 mg/l, but only the stickleback survived 20,000 mg/l dissolved solids. It was concluded that lakes with dissolved solids in excess of 15,000 mg/l were unsuitable for most freshwater fishes (Rawson and Moore, 1944). The NTAC Report (1968) also recommended maintaining osmotic pressure levels of less than that caused by a 15,000 mg/l solution of sodium chloride.

Marine fishes also exhibit variance in ability to tolerate salinity changes. However, fishkills in Laguna Madre off the Texas coast have occurred with salinities in the range of 75 to 100 o/oo. Such concentrated sea water is caused by evaporation and lack of exchange with the Gulf of Mexico (Rounsefell and Everhart, 1953).

Estuarine species of fish are tolerant of salinity changes ranging from fresh to brackish to sea water. Anadromous species likewise are tolerant although evidence indicates that the young cannot tolerate the change until the normal time of migration (Rounsefell and Everhart, 1953). Other aquatic species are more dependent on salinity for protection from predators or require

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certain minimal salinities for successful hatching of eggs. The oyster drill cannot tolerate salinities less than 12.5 o/oo. Therefore, estuarine segments containing salinities below about 12.5 o/oo produce most of the seed oysters for planting (Rounsefell and Everhart, 1953). Based on similar examples, the NTAC Report (1968) recommended that to protect fish and other marine animals no changes in hydrography or stream flow should be allowed that permanently change isohaline patterns in the estuary by more than 10 percent from natural variation.

Many of the recommended game bird levels for dissolved solids concentrations in drinking water have been extrapolated from data collected on domestic species such as chickens. However, young ducklings were reported poisoned in Suisan Marsh by salt when maximum summer salinities varied from 0.55 to 1.74 o/oo with means as high as 1.26 o/oo (Griffith, 1963).

Indirect effects of excess dissolved solids are primarily the elimination of desirable food plants and other habitat forming plants. Rapid salinity changes cause plasmolysis of tender leaves and stems because of changes in osmotic pressure. The NTAC Report (1968) recommended the following limits in salinity variation from natural to protect wildlife habitats:

Natural Salinity (o/oo)	Variation Permitted (o/oo)
0 to 3.5	1
3.5 to 13.5	2
13.5 to 35	4

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Agricultural uses of water are also limited by excessive dissolved solids concentrations. Studies have indicated that chickens, swine, cattle and sheep can survive on saline waters up to 15,000 mg/l of salts of sodium and calcium combined with bicarbonates, chlorides and sulfates but only 10,000 mg/l of corresponding salts of potassium and magnesium. The approximate limit for highly alkaline waters containing sodium and calcium carbonates is 5,000 mg/l (NTAC, 1968).

Irrigation use of water is not only dependent upon the osmotic effect of dissolved solids, but also on the ratio of the various cations present. In arid and semiarid areas general classification of salinity hazards has been prepared (NTAC, 1968) (see Table 9).

Table 9 **Dissolved Solids Hazard for Irrigation Water (mg/l)**

Water from which no detrimental effects will usually be noticed	500
Water which can have detrimental effects on sensitive crops	500-1,000
Water that may have adverse effects on many crops and requires careful management practices	1,000-2,000
Water that can be used for tolerant plants on permeable soils with careful management practices	2,000-5,000

The amount of sodium and the percentage of sodium in relation to other cations are often important. In addition to contributing to osmotic pressure, sodium is toxic to certain plants, especially fruits, and frequently causes problems in soil structure, infiltration and permeability rates (Agriculture Handbook #60,

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1954). A high percentage of exchangeable sodium in soils containing clays that swell when wet can cause a soil condition adverse to water movement and plant growth. The exchangeable-sodium percentage (ESP)* is an index of the sodium status of soils. An ESP of 10 to 15 percent is considered excessive if a high percentage of swelling clay minerals is present (Agricultural Handbook #60, 1954).

For sensitive fruits, the tolerance for sodium for irrigation water is for a sodium adsorption ratio (SAR)** of about 4, whereas for general crops and forages a range of 8 to 18 is generally considered usable (NTAC, 1968). It is emphasized that application of these factors must be interpreted in relation to specific soil conditions existing in a given locale and therefore frequently requires field investigation.

Industrial requirements regarding the dissolved solids content of raw waters is quite variable. Table 10 indicates maximum values accepted by various industries for process requirements (NAS, 1974). Since water of almost any dissolved solids concentration can be de-ionized to meet the most stringent requirements, the economics of such treatment are the limiting factor for industry.

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*$ESP = \frac{100[a + b(SAR)]}{1 \quad [a + b(SAR)]}$

where: a = intercept representing experimental error (ranges from -0.06 to 0.01)
b = slope of regression line (ranges from 0.014 to 0.016)

**SAR = sodium adsorption ratio = $\frac{Na}{[0.5(Ca + Mg)]^{0.5}}$

SAR is expressed as milliequivalents

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Table 10

Total Dissolved Solids Concentrations of Surface Waters that have been Used as Sources for Industrial Water Supplies

Industry/Use	Maximum Concentration (mg/l)
Textile	150
Pulp and Paper	1,080
Chemical	2,500
Petroleum	3,500
Primary Metals	1,500
Copper Mining	2,100
Boiler Make-up	35,000

Source: NAS, 1974

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SOLIDS (SUSPENDED, SETTLEABLE) AND TURBIDITY

CRITERIA:

Freshwater fish and other aquatic life:

> Settleable and suspended solids should not reduce the depth of the compensation point for photosythetic activity by more then 10 percent from the seasonably established norm for aquatic life.

INTRODUCTION

The term "suspended and settleable solids" is descriptive of the organic and inorganic particulate matter in water. The equivalent terminology used for solids in Standard Methods (APHA, 1971) is total suspended matter for suspended solids, settleable matter for settleable solids, volatile suspended matter for volatile solids and fixed suspended matter for fixed suspended solids. The term "solids" is used in this discussion because of its more common use in the water pollution control literature.

RATIONALE:

Suspended solids and turbidity are important parameters in both municipal and industrial water supply practices. Finished drinking waters have a maximum limit of 1 turbidity unit where the water enters the distribution system. This limit is based on health considerations as it relates to effective chlorine disinfection. Suspended matter provides areas where micro-organisms do not come into contact with the chlorine disinfectant (NAS, 1974). The ability of common water treatment processes (i.e., coagulation, sedimentation, filtration and chlorination) to remove suspended matter to achieve acceptable

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final turbidities is a function of the composition of the material as well as its concentration. Because of the variability of such removal efficiency, it is not possible to delineate a general raw water criterion for these uses.

Turbid water interferes with recreational use and aesthetic enjoyment of water. Turbid waters can be dangerous for swimming, especially if diving facilities are provided because of the possibility of unseen submerged hazards and the difficulty in locating swimmers in danger of drowning (NAS, 1974). The less turbid the water the more desirable it becomes for swimming and other water contact sports. Other recreational pursuits such as boating and fishing will be adequately protected by suspended solids criteria developed for protection of fish and other aquatic life.

Fish and other aquatic life requirements concerning suspended solids can be divided into those whose effect occurs in the water column and those whose effect occurs following sedimentation to the bottom of the water body. Noted effects are similar for both fresh and marine waters.

The effects of suspended solids on fish have been reviewed by the European Inland Fisheries Advisory Commission (EIFAC, 1965). This review identified four effects on the fish and fish food populations, namely:

> "(1) by acting directly on the fish swimming in water in which solids are suspended, and either killing them or reducing their growth rate, resistance to disease, etc.;
> (2) by preventing the successful development of fish eggs and larvae;
> (3) by modifying natural movements and migrations of fish;
> (4) by reducing the abundance of food available to the fish; . . ."

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Settleable materials which blanket the bottom of water bodies damage the invertebrate populations, block gravel spawning beds, and if organic, remove dissolved oxygen from overlying waters (EIFAC, 1965; Edberg and Hofsten, 1973). In a study downstream from the discharge of a rock quarry where inert suspended solids were increased to 80 mg/l, the density of macroinvertebrates decreased by 60 percent while in areas of sediment accumulation benthic invertebrate populations also decreased by 60 percent regardless of the suspended solid concentrations (Gammon, 1970). Similar effects have been reported downstream from an area which was intensively logged. Major increases in stream suspended solids (25 ppm turbidity upstream vs. 390 ppm downstream) caused smothering of bottom invertebrates reducing organism density to only 7.3 per square foot versus 25.5 per square foot upstream (Tebo, 1955).

When settleable solids block gravel spawning beds which contain eggs, high mortalities result although there is evidence that some species of salmonids will not spawn in such areas (EIFAC, 1965).

It has been postulated that silt attached to the eggs prevents sufficient exchange of oxygen and carbon dioxide between the egg and the overlying water. The important variables are particle size, stream velocity and degree of turbulence (EIFAC, 1965).

Deposition of organic materials to the bottom sediments can cause imbalances in stream biota by increasing bottom animal density, principally worm populations, and diversity is reduced as pollution sensitive forms disappear (Mackenthun, 1973). Algae likewise fluorish in such nutrient rich areas although forms may become less desirable (Tarzwell and Gaufin, 1953).

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Plankton and inorganic suspended materials reduce light penetration into the water body reducing the depth of the photic zone. This reduces primary production and decreases fish food. The NAS committee recommended that the depth of light penetration not be reduced by more than 10 percent (NAS, 1974). Additionally, the near surface waters are heated because of the greater heat absorbency of the particulate material which tends to stabilize the water column and prevents vertical mixing (NAS, 1974). Such mixing reductions decrease the dispersion of dissolved oxygen and nutrients to lower portions of the water body.

One partially offsetting benefit of suspended inorganic material in water is the sorption of organic materials such as pesticides. Following this sorption process subsequent sedimentation may remove these materials from the water column into the sediments (NAS, 1974).

Identifiable effects of suspended solids on irrigation use of water include the formation of crusts on top of the soil which inhibits water infiltration, plant emergence and impedes soil aeration; the formation of films on plant leaves which blocks sunlight and impedes photosynthesis and which may reduce the marketability of some leafy crops like lettuce; and finally the adverse effect on irrigation reservoir capacity, delivery canals and other distribution equipment (NAS, 1974).

The criteria for freshwater fish and other aquatic life is essentially that proposed by the N.A.S. and the Great Lakes Water Quality Board.

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SULFIDE - HYDROGEN SULFIDE

CRITERION:

2 ug/l undissociated H_2S for fish and other aquatic life, fresh and marine water

INTRODUCTION:

Hydrogen sulfide is a soluble, highly poisonous, gaseous compound having the characteristic odor of rotten eggs. It is detectable in air by humans at a dilution of 0.002 ppm. It will dissolve in water at 4000 mg/l at 20°C and one atmosphere of pressure. Hydrogen sulfide biologically is an active compound that is found primarily as an anaerobic degradation product of both organic sulfur compounds and inorganic sulfates. Sulfides are constituents of many industrial wastes such as those from tanneries, paper mills, chemical plants and gas works. The anaerobic decomposition of sewage, sludge beds, algae and other naturally deposited organic material is a major source of hydrogen sulfide.

When soluble sulfides are added to water they react with hydrogen ions to form HS^- or H_2S, the proportion of each

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depending on the pH. The toxicity of sulfides derives primarily from H_2S rather than from the hydrosulfide (HS^-) or sulfide ($S^=$) ions. When hydrogen sulfide dissolves in water it dissociates according to the reactions:

$$H_2S \rightleftharpoons HS^- + H^+ \text{ and } HS^- \rightleftharpoons S^= + H^+$$

At pH 9 about 99 percent of the sulfide is in the form of HS^-, at pH 7 the sulfide is equally divided between HS^- and H_2S and at pH 5 about 99 percent of the sulfide is present as H_2S (NAS 1974). The fact that H_2S is oxidized in well-aerated water by natural biological systems to sulfates or is biologically oxidized to elemental sulfur has caused investigators to minimize the toxic effects of H_2S on fish and other aquatic life.

RATIONALE:

The degree of hazard exhibited by sulfide to aquatic animal life is dependent on the temperature, pH and dissolved oxygen. At lower pH values a greater proportion is in the form of the toxic undissociated H_2S. In winter when the pH is neutral or below or when dissolved oxygen levels are low but not lethal to fish, the hazard from sulfides is exacerbated. Fish exhibit a strong avoidance reaction to sulfide. Based on data from experiments with the stickleback, Jones (1964) hypothesized that if fish

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encounter a lethal concentration of sulfide there is a reasonable chance they will be repelled by it before they are harmed. This of course assumes that an escape route is open.

Many past data on the toxicity of hydrogen sulfide to fish and other aquatic life have been based on extremely short exposure periods. Consequently these early data have indicated that concentrations between 0.3 and 0.4 mg/l permit fish to survive (Van Horn 1958, Boon and Follis 1967, Theede et al., 1969). Recent long-term data, both in field situations and under controlled laboratory conditions, demonstrate hydrogen sulfide toxicity at lower concentrations.

Colby and Smith (1967) found that concentrations as high as 0.7 mg/l existed within 20 mm of the bottom of sludge beds, and the levels of 0.1 to 0.02 mg/l were common within the first 20 mm of water above this layer. Walleye, Stizostedion vitreum, eggs held in trays in this zone did not hatch. Adelman and Smith (1970) reported that the hatchability of northern pike, Esox lucius, eggs was substantially reduced at 25 ug/l H_2S; at 47 ug/l mortality was almost complete. Northern pike fry had

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96-hour LC_{50} values that varied from 17 to 32 ug/l at normal oxygen levels of 6.0 mg/l. The highest concentration of hydrogen sulfide that had no observable effect on eggs and fry was 14 and 4 ug/l, respectively. Smith and Oseid (1972), working on eggs, fry and juveniles of walleyes and white suckers, Catostomus commersoni , and Smith (1971), working on walleyes and fathead minnows, Pimephales promelas , found that safe levels varied from 2.9 ug/l to 12 ug/l with eggs being the least sensitive and juveniles being the most sensitive in short-term tests. In 96-hour bioassays, fathead minnows and goldfish, Carassius auratus, varied greatly in tolerance to hydrogen sulfide with changes in temperature. They were more tolerant at low temperatures (6 to 10°C). Holland, et al. (1960) reported that 1.0 mg/l sulfide caused 100 percent mortality in 72 hours with Pacific salmon.

On the basis of chronic tests evaluating growth and survival, the safe H_2S level for bluegill, Lepomis macrochirus, juveniles and adults was 2 ug/l. Egg deposition in bluegills was reduced after 46 days in 1.4 ug/l H_2S (Smith and Oseid, 1974). White sucker eggs were hatched at 15 ug/l, but juveniles showed growth reductions at 1 ug/l. Safe levels for fathead minnows were between 2 and 3 ug/l. Studies showed that safe levels for Gammarus pseudolimnaeus and Hexagenia limbata were 2 and 15 ug/l, respectively (Oseid and Smith, 1974a, 1974b). Some species typical of normally stressed habitats, Asellus spp., were much more resistant (Oseid and Smith, 1974c).

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Sulfide criteria for domestic or livestock use have not been established because the unpleasant odor and taste would preclude such use at hazardous concentrations.

It is recognized that the hazard from hydrogen sulfide to aquatic life is often localized and transient. Available data indicate that water containing concentrations of 2.0 ug/l undissociated H_2S would not be hazardous to most fish and other aquatic wildlife, but concentrations in excess of 2.0 ug/l would constitute a long-term hazard.

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TAINTING SUBSTANCES

CRITERION:

> Materials should not be present in concentrations that individually or in combination produce undesirable flavors which are detectable by organoleptic tests performed on the edible portions of aquatic organisms.

RATIONALE:

Fish or shellfish with abnormal flavors, colors, tastes or odors are either not marketable or will result in consumer complaints and possible rejection of the food source even though subsequent lots of organisms may be acceptable. Poor product quality can and has seriously affected or eliminated the commercial fishing industry in some areas. Recreational fishing also can be affected adversely by off-flavored fish. For the majority of sport fishermen, the consumption of their catch is part of their recreation and off-flavored catches can result in diversion of the sportsmen to other water bodies. This can have serious economic impact on the established recreation industries such as tackle and bait sales and boat and cottage rental.

Water Quality Criteria, 1972 (NAS, 1974) lists a number of wastewaters and chemical compounds that have been found to lower the palatability of fish flesh. Implicated wastewaters included those from 2,4-D manufacturing plants, kraft and neutral sulfite pulping processes, municipal wastewater treatment plants, oily wastes, refinery wastes, phenolic wastes, and wastes from slaughterhouses. The list of implicated chemical compounds is long; it includes cresol and phenol compounds, kerosene, naphthol, styrene, toluene, and exhaust outboard motor fuel. As little as 0.1 ug/l o-chlorophenol was reported to cause tainting of fish flesh.

Shumway and Palensky (1973) determined estimated threshold concentrations for

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twenty-two organic compounds. The values ranged from 0.4 ug/l (2,4-dichlorophenol) to 95,000 ug/l (formaldehyde). An additional twelve compounds were tested, seven of which were not found to impair flavor at or near lethal levels.

Thomas (1973) reviewed the literature on tainting substances and listed serious problems that have occurred; he detailed studies and methodology used in the evaluation of the palatability of fishes in the Ohio River as affected by various waste discharges. The susceptibility of fishes to the accumulation of tainting substances is variable and dependent upon the species, length of exposure, and the pollutant. As little as 5 ug/l of gasoline can impart off-flavors to fish (Boyle, 1967).

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TEMPERATURE

CRITERIA

Freshwater Aquatic Life

For any time of year, there are two upper limiting temperatures for a location (based on the important sensitive species found there at that time):

1. One limit consists of a maximum temperature for short exposures that is time dependent and is given by the species-specific equation:

$$\text{Temperature}_{(C^o)} = (1/b)(\log_{10}[\text{time}_{(\text{min})}] - a) - 2^oC$$

where: $\log_{10}$ = logarithm to base 10. (common logarithm)

a = intercept on the "y" or logarithmic axis of the line fitted to experimental data and which is available from Appendix II-C, NAS, 1974 for some species.

b = slope of the line fitted to experimental data and available from Appendix II-C, NAS, 1974 for some species.

and

2. The second value is a limit on the weekly average temperature that:

   a. in the cooler months (mid-October to mid-April in the north and December to February in the south) will protect against mortality of important species if the elevated plume temperature is suddenly dropped to the ambient temperature, with the limit being the acclimation temperature minus 2^oC when the lower lethal threshold temperature equals the ambient water temperature (in some regions this limitation may also be applicable in summer).

or

   b. In the warmer months (April through October in the north and March through November in the south) is determined by adding to the physiological optimum temperature (usually for growth) a factor calculated as one-third of the difference between the ultimate upper incipient lethal temperature and the optimum temperature for the most sensitive important species (and appropriate life state) that normally is found at that location and time.

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or

c. During reproductive seasons (generally April through June and September through October in the north and March through May and October through November in the south) the limit is that temperature that meets site-specific requirements for successful migration, spawning, egg incubation, fry rearing, and other reproductive functions of important species. These local requirements should supersede all other requirements when they are applicable.

or

d. There is a site-specific limit that is found necessary to preserve normal species diversity or prevent appearance of nuisance organisms.

Marine Aquatic Life

In order to assure protection of the characteristic indigenous marine community of a water body segment from adverse thermal effects:

a) the maximum acceptable increase in the weekly average temperature due to artificial sources is 1° C (1.8° F) during all seasons of the year, providing the summer maxima are not exceeded; and

b) daily temperature cycles characteristic of the water body segment should not be altered in either amplitude or frequency.

Summer thermal maxima, which define the upper thermal limits for the communities of the discharge area, should be established on a site-specific basis. Existing studies suggest the following regional limits:

	Short-term Maximum	Maximum True Daily Mean*
Sub-tropical Regions (south of Cape Canaveral and Tampa Bay, Florida, and Hawaii	32.2° C (90° F)	29.4°C (85°F)
Cape Hatteras, N.C., to Cape Canaveral, Fla.	32.2° C (90° F)	29.4° C (85° F)
Long Island (south shore) to Cape Hatteras, N.C.	30.6° C (87° F)	27.8° C (82° F)

(* True Daily Mean = average of 24 hourly temperature readings.)

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Baseline thermal conditions should be measured at a site where there is no unnatural thermal addition from any source, which is in reasonable proximity to the thermal discharge (within 5 miles) and which has similar hydrography to that of the receiving waters at the discharge.

INTRODUCTION

The uses of water by man in and out of its natural situs in the environment are affected by its temperature. Offstream domestic uses and instream recreation are both partially temperature dependent. Likewise, the life associated with the aquatic environment in any location has its species composition and activity regulated by water temperature. Since essentially all of these organisms are so called "cold blooded" or poikilotherms, the temperature of the water regulates their metabolism and ability to survive and reproduce effectively. Industrial uses for process water and for cooling is likewise regulated by the water's temperature. Temperature, therefore, is an important physical parameter which to some extent regulates many of the beneficial uses of water. To quote from the FWPCA (1967), "Temperature, a catalyst, a depressant, an activator, a restrictor, a stimulator, a controller, a killer, is one of the most important and most influential water quality characteristics to life in water."

RATIONALE

The suitability of water for total body immersion is greatly affected by temperature. In temperate climates, dangers from exposure to low temperatures is more prevalent than exposure to elevated water temperatures. Depending on the amount of activity by the swimmer, comfortable temperatures range from 20°C to 30°C. Short durations of lower and higher temperatures can be tolerated by most individuals. For example, for a 30-minute period, temperatures of 10°C or 35°C can be tolerated without harm by most individuals (NAS, 1974).

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Temperature also affects the self-purification phenomenon in water bodies and therefore the aesthetic and sanitary qualities that exist. Increased temperatures accelerate the biodegradation of organic material both in the overlying water and in bottom deposits which makes increased demands on the dissolved oxygen resources of a given system. The typical situation is exacerbated by the fact that oxygen becomes less soluble as water temperature increases. Thus, greater demands are exerted on an increasingly scarce resource which may lead to total oxygen depletion and obnoxious septic conditions. These effects have been described by Phelps (1944), Camp (1963), and Velz (1970).

Indicator enteric bacteria, and presumably enteric pathogens, are likewise affected by temperature. It has been shown that both total and fecal coliform bacteria die away more rapidly in the environment with increasing temperatures (Ballentine and Kittrell, 1968).

Temperature effects have been shown for water treatment processes. Lower temperatures reduce the effectiveness of coagulation with alum and subsequent rapid sand filtration. In one study, difficulty was especially pronounced below 5°C (Hannah, et al., 1967). Decreased temperature also decreases the effectiveness of chlorination. Based on studies relating chlorine dosage to temperature, and with a 30-minute contact time, dosages required for equivalent disinfective effect increased by as much as a factor of 3 when temperatures were decreased from 20° C to 10° C (Reid and Carlson, 1974). Increased temperature may increase the odor of water because of the increased volatility of odor-causing compounds (Burnson, 1938). Odor problems associated with plankton may also be aggravated.

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The effects of temperature on aquatic organisms have been the subject of several comprehensive literature reviews (Brett, 1956; Fry, 1967; FWPCA, 1967; Kinne, 1970) and annual literature reviews published by the Water Pollution Control Federation (Coutant, 1968, 1969, 1970, 1971; Coutant and Goodyear, 1972; Coutant and Pfuderer, 1973, 1974). Only highlights from the thermal effects on aquatic life are presented here.

Temperature changes in water bodies can alter the existing aquatic community. The dominance of various phytoplankton groups in specific temperature ranges has been shown. For example, from 20°C to 25°C, diatoms predominated; green algae predominated from 30°C to 35°C; and blue-greens predominated above 35°C (Cairns, 1956). Likewise, changes from a cold water fishery to a warm water fishery can occur because temperature may be directly lethal to adults or fry; cause a reduction of activity; or limit reproduction (Brett, 1960).

Upper and lower limits for temperature have been established for many aquatic organisms. Considerably more data exist for upper as opposed to lower limits. Tabulations of lethal temperatures for fish and other organisms are available (Jones, 1964: FWPCA, 1967; NAS, 1974). Factors such as diet, activity, age, general health, osmotic stress, and even weather contribute to the lethality of temperature. The aquatic species, thermal acclimation state and exposure time are considered the critical factors (Parker and Krenkel, 1969).

The effects of sublethal temperatures on metabolism, respiration, behavior, distribution and migration, feeding rate, growth and reproduction have been summarized by De Sylva (1969). Another study has illustrated that inside the tolerance zone there is encompassed a more restrictive temperature range in

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which normal activity and growth occur; and yet an even more restrictive zone inside that in which normal reproduction will occur (Brett, 1960).

De Sylva (1969) has summarized available data on the combined effects of increased temperature and toxic materials on fish. The available data indicate that toxicity generally increases with increased temperature and that organisms subjected to stress from toxic materials are less tolerant of temperature extremes.

The tolerance of organisms to extremes of temperature is a function of their genetic ability to adapt to thermal changes within their charactertistic temperature range, the acclimation temperature prior to exposure, and the time of exposure to the elevated temperature (Coutant, 1972). The upper incipient lethal temperature or the highest temperature that 50% of a sample of organisms can survive is determined on the organism at the highest sustainable acclimation temperature. The lowest temperature that 50% of the warm acclimated organisms can survive in is the ultimate lower incipient lethal temperature. True acclimation to changing temperatures requires several days (Brett, 1941). The lower end of the temperature accommodation range for aquatic life is $0^{o}C$ in fresh water and somewhat less for saline waters. However, organisms acclimated to relatively warm water, when subjected to reduced temperatures which under other conditions of acclimation would not be detrimental, may suffer a significant mortality due to thermal shock (Coutant, 1972).

Through the natural changes in climatic conditions, the temperatures of water bodies fluctuate daily, as well as seasonally. These changes do not eliminate indigenous aquatic populations, but affect the existing community structure and the geographical distribution of species. Such temperature changes are necessary to induce the reproductive cycles of aquatic organisms and to regulate other life factors (Mount, 1969).

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Artifically induced changes such as the return of cooling water or the release of cool hypolimnetic waters from impoundments may alter indigenous aquatic ecosystems (Coutant, 1972). Entrained organisms may be damaged by temperature increases across cooling water condensers if the increase is sufficiently great or the exposure period sufficiently long. Impingement upon condenser screens, chlorination for slime control or other physical insults damage aquatic life (Raney, 1969; Patrick, 1969 (b)). However, Patrick (1969(a)) has shown that algae passing through condensers are not injured if the temperature of the outflowing water does not exceed 34°C to 34.5°C

In open waters elevated temperatures may affect periphyton, benthic invertebrates, and fish in addition to causing shifts in algal predominance. Trembley (1960) studied the Delaware River downstream from a power plant and concluded that the periphyton population was considerably altered by the discharge.

The number and distribution of bottom organisms decrease as water temperatures increase. The upper tolerance limit for a balanced benthic population structure is approximately 32°C. A large number of these invertebrate species are able to tolerate higher temperatures than those required for reproduction (FWPCA, 1967).

In order to define criteria for fresh waters, Coutant (1972) cited the following as currently defineable requirements:

"1. Maximum sustained temperatures that are consistent with maintaining desirable levels of productivity,

2. Maximum levels of metabolic acclimation to warm temperatures that will permit return to ambient winter temperatures should artificial sources of heat cease,

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3. Time dependent temperature limitations for survival of brief exposures to temperature extremes, both upper and lower,

4. Restricted temperature ranges for various states of reproduction including (for fish) gametogenesis, spawning migration, release of gametes, development of the embryo, commencement of independent feeding (and other activities) by juveniles, and temperatures required for metamorphosis, emergence or other activities of lower forms,
5. Thermal limits for diverse species compositions of aquatic communities, particularly where reduction in diversity creates nuisance growths of certain organisms, or where important food sources (food chains) are altered,
6. Thermal requirements of downstream aquatic life (in rivers) where upstream diminution of a cold water resource will adversely affect downstream temperature requirements."

The major portion of such information that is available, however, is for freshwater fish species rather than lower forms or marine aquatic life.

The temperature-time duration for short term exposures such that 50 percent of a given population will survive an extreme temperature frequently is expressed mathematically by fitting experimental data with a straight line on a semi-logarithmic plot with time on the logarithmic scale and temperature on the linear scale. (See Fig. 1). In equation form this 50 percent mortality relationship is:

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$$\log_{10}(\text{time}_{(\text{minutes})}) = a + b\ (\text{Temperature}_{(^\circ C)})$$

where: $\log_{10}$ = logarithm to base 10 (common logarithm)

a = intercept on the "y" or logarithmic axis of the line fitted to experimental data and which is available from Appendix II-C, NAS, 1974 for some species.

b = slope of the line fitted to experimental data and which is available from Appendix II-C, NAS, 1974 for some species.

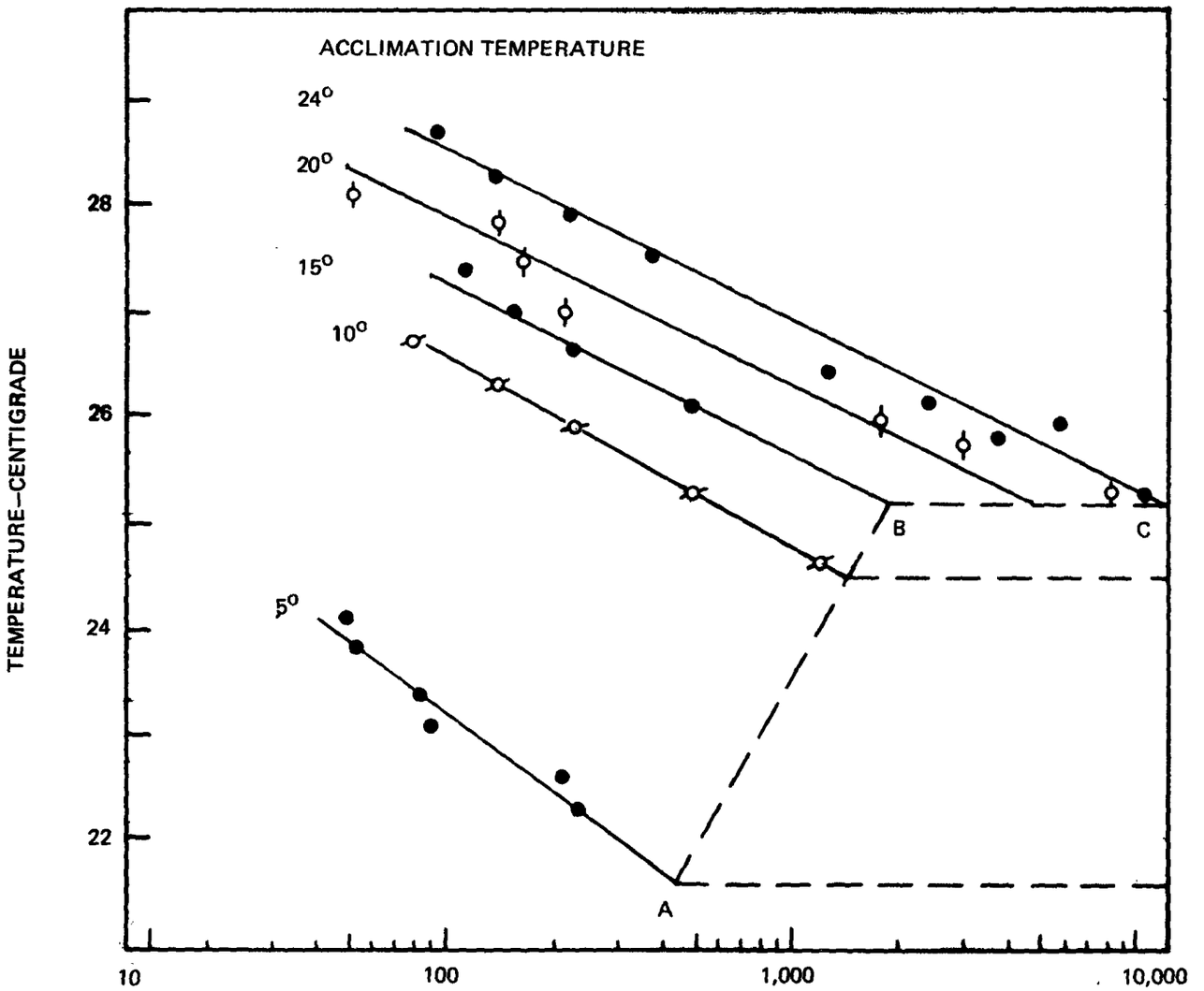
To provide a safety factor so that none or only a few organisms will perish, it has been found experimentally that a criterion of 2° C below maximum temperature is usually sufficient (Black, 1953). To provide safety for all the organisms, the temperature causing a median mortality for 50 percent of the population would be calculated and reduced by 2° C in the case of an elevated temperature. Available scientific information includes upper and lower incipient lethal temperatures, coefficients "a" and "b" for the thermal resistance equation, and information on size, life stage, and geographic source of the particular test species (Appendix II-C, NAS, 1974)

Maximum temperatures for an extensive exposure (e.g., more than 1 week) must be divided into those for warmer periods and winter. Other than for reproduction, the most temperature-sensitive life function appears to be growth (Coutant, 1972). Coutant (1972) has suggested that a satisfactory estimate of a limiting maximum weekly mean temperature* is an average of the optimum temperature for growth and the temperature for zero net growth.

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* maximum weekly mean temperature - true mean temperature for a calendar week which is a higher value than for any other week. Can be determined from continuous measurements, hourly determinations, or some other non-biased statistical method of analyzing temperature data.

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Figure 1. MEDIAN RESISTANCE TIMES TO HIGH TEMPERATURES AMONG YOUNG CHINOOK (Oncorhynchus tshawytscha) ACCLIMATED TO TEMPERATURES INDICATED. LINE A-B DENOTES RISING LETHAL THRESHOLD (incipient lethal temperatures) WITH INCREASING ACCLIMATION TEMPERATURE. THIS RISE EVENTUALLY CEASES AT THE ULTIMATE LETHAL THRESHOLD (ultimate upper incipient lethal temperature), LINE B-C. (TAKEN FROM NAS, 1974)

Because of the difficulty in determining the temperature of zero net growth, essentially the same temperature can be derived by adding to the optimum temperature (for growth or other physiological functions) a factor calculated as 1/3 of the difference between the ultimate upper incipient lethal temperature and the optimum temperature (NAS, 1974). In equation form:

$$\begin{array}{l}\text{Maximum weekly} \\ \text{average} \\ \text{temperature}\end{array} = \begin{array}{l}\text{optimum} \\ \text{temperature}\end{array} + 1/3 \begin{array}{l}(\text{ultimate upper} \\ (\text{incipient lethal} \\ (\text{temperature}\end{array} - \begin{array}{l}\text{optimum} \\ \text{temperature}\end{array}\begin{array}{l}) \\ ) \\ )\end{array}$$

Since temperature tolerance varies with various states of development of a particular species, the criterion for a particular location would be calculated for the most important life form likely to be present during a particular month. One caveat in using the maximum weekly mean temperature is that the limit for short-term exposure must not be exceeded. Example calculations for predicting the summer maximum temperatures for short-term survival and for extensive exposure for various fish species are presented in Table 11. These calculations use the above equations and data from ERL-Duluth, 1976.

The winter maximum temperature must not exceed the ambient water temperature by more than the amount of change a specimen acclimated to the plume temperature can tolerate. Such a change could occur by a cessation of the source of heat or by the specimen being driven from an area by addition of biocides or other factors. However, there are inadequate data to estimate a safety factor for the "no stress" level from cold shocks (NAS, 1974). Figure 2 was developed from available data in the literature (ERL-Duluth, 1976) and can be used for estimating allowable winter temperature increases.

Coutant (1972) has reviewed the effects of temperature on aquatic life reproduction and development. Reproductive events are noted as perhaps the most thermally restricted of all life phases assuming other factors are at or

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TABLE 11

Example Calculated Values for
Maximum Weekly Average Temperatures for Growth and Short-Term
Maxima for Survival for Juveniles and
Adults During the Summer
(Centigrade and Fahrenheit)

Species	Growth[a]	Maxima[b]
Atlantic Salmon	20 (68)	23 (73)
Bigmouth Buffalo	-	-
Black Crappie	27 (81)	-
Bluegill	32 (90)	35 (95)
Brook Trout	19 (66)	24 (75)
Carp	-	-
Channel Catfish	32 (90)	35 (95)
Coho Salmon	18 (64)	24 (75)
Emerald Shiner	30 (86)	-
Freshwater Drum	-	-
Lake Herring (Cisco)	17 (63)[c]	25 (77)
Largemouth Bass	32 (90)	34 (93)
Northern Pike	28 (82)	30 (86)
Rainbow Trout	19 (66)	24 (75)
Sauger	25 (77)	-
Smallmouth Bass	29 (84)	-
Smallmouth Buffalo	-	-
Sockeye Salmon	18 (64)	22 (72)
Striped Bass	-	-
Threadfin Shad	-	-
White Bass	-	-
White Crappie	28 (82)	-
White Sucker	28 (82)[c]	-
Yellow Perch	29 (84)	-

a - Calculated according to the equation (using optimum temperature for growth)

maximum weekly average temperature for growth = optimum temperature + 1/3 (ultimate incipient lethal temp. - optimum temperature

b - Based on temperature $(^{o}C) = 1/b\ (\log_{10}\ time_{(min.)} - a) - 2^{o}C$, acclimation at the maximum weekly average temperature for summer growth, and data in Appendix II-C of Water Quality Criteria, 1972 (NAS, 1973).

c - Based on data for larvae (ERL-Duluth, 1976).

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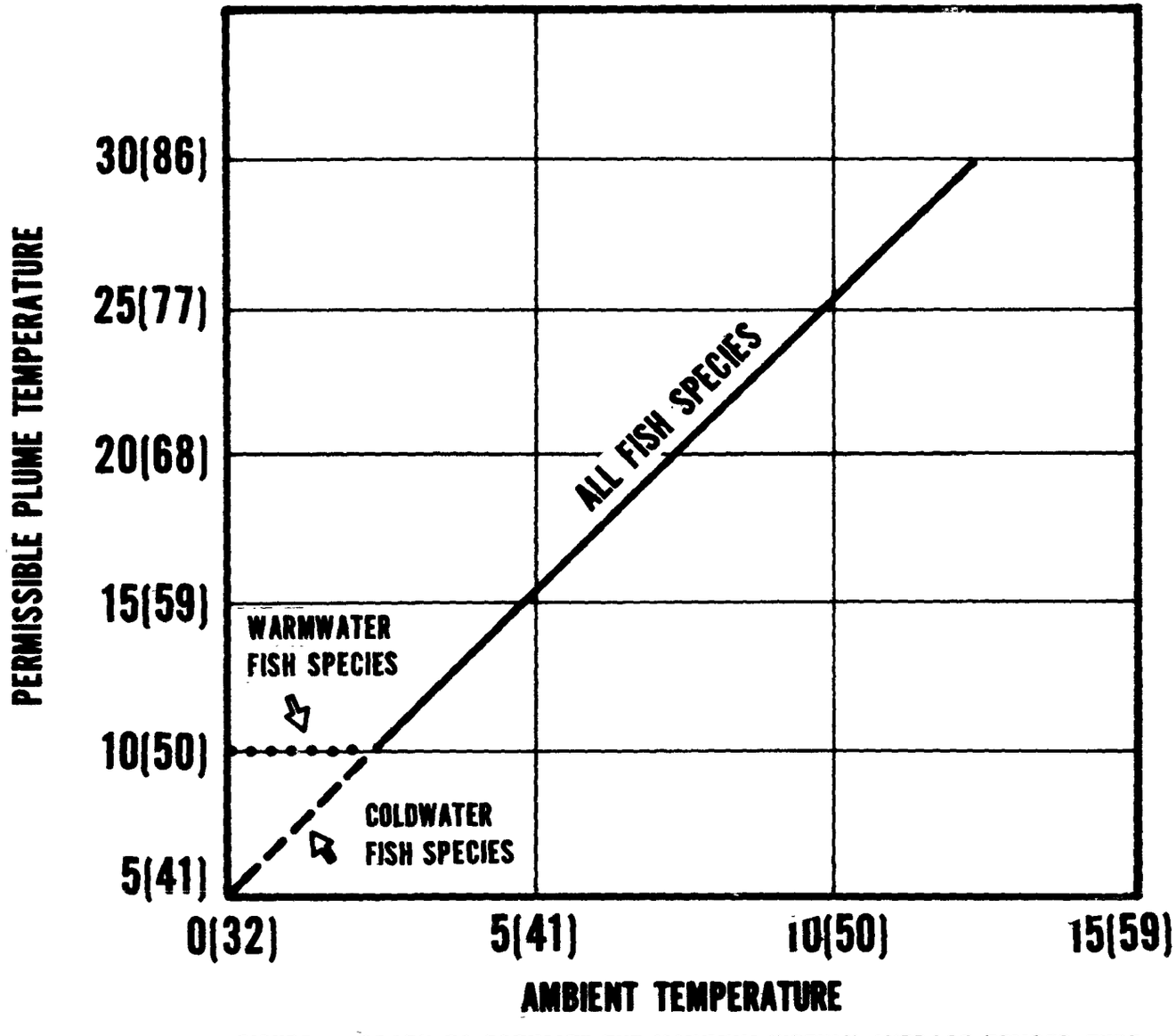


FIGURE 2. GRAPH TO ESTIMATE THE MAXIMUM WEEKLY AVERAGE TEMPERATURE OF PLUMES FOR VARIOUS AMBIENT TEMPERATURES, °C (°F)

near optimum levels. Unnatural short-term temperature fluctuations appear to cause reduced reproduction of fish and invertebrates. There are inadequate data available quantitating the most temperature-sensitive life stages among various aquatic species. Uniform elevation of temperature a few degrees, but still within the spawning range may lead to advanced spawning for spring spawning species and delays for fall spawners. Such changes may not be detrimental unless asynchrony occurs between newly hatched juveniles and their normal food source. Such asynchrony may be most pronounced among anadromous species or other migrants who pass from the warmed area to a normally chilled, unproductive area. Reported temperature data on maximum temperatures for spawning and embryo survival have been summarized in Table 12 (from ERL-Duluth 1976).

Although the limiting effects of thermal addition to estuarine and marine waters are not as conspicuous in the fall, winter and spring as during the summer season of maximum heat stress, nonetheless crucial thermal limitations do exist. Hence, it is important that the thermal additions to the receiving waters be minimized during all seasons of the year. Size of harvestable stocks of commercial fish and shellfish, particularly near geographic limits of the fishery, appear to be markedly influenced by slight changes in the long-term temperature regime (Dow, 1973).

Jefferies and Johnson (1974) studied the relationship between temperature and annual variation in 7-year catch data for winter flounder, Pseudopleuronectes americanus, in Narragansett Bay, Rhode Island. A 78 percent decrease in annual catch correlated closely with a 0.5°C increase in the average temperature over the 30-month period between spawning and recruitment into

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TABLE 12

Summary of Reported Values for
Maximum Weekly Average Temperature for Spawning and Short-Term
Maxima for Embryo Survival During the Spawning Season
(Centigrade and Fahrenheit)

Species	Spawning[a]		Embryo Survival[b]	
Atlantic Salmon	5	(41)	7	(45)
Bigmouth Buffalo	17	(63)	27	(81)c
Black Crappie	-		-	
Bluegill	25	(77)	34	(93)
Brook Trout	9	(48)	13	(55)
Carp	21	(70)	33	(91)
Channel Catfish	27	(81)	29	(84)
Coho Salmon	10	(50)	13	(55)
Emerald Shiner	24	(75)	28	(82)c
Freshwater Drum	21	(70)	26	(79)
Lake Herring (Cisco)	3	(37)	8	(46)
Largemouth Bass	21	(70)	27	(81)
Northern Pike	11	(52)	19	(66)
Rainbow Trout	9	(48)	13	(55)
Sauger	10	(50)	21	(70)
Smallmouth Bass	17	(63)	-	
Smallmouth Buffalo	17	(63)	21	(70)
Sockeye Salmon	10	(50)	13	(55)
Striped Bass	18	(64)	24	(75)
Threadfin Shad	18	(64)	34	(93)
White Bass	17	(63)	26	(79)
White Crappie	18	(64)	23	(73)
White Sucker	10	(50)	20	(68)
Yellow Perch	12	(54)	20	(68)

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a - the optimum or mean of the range of spawning temperatures reported for the species (ERL-Duluth, 1976).

b - the upper temperature for successful incubation and hatching reported for the species (ERL-Duluth, 1976).

c - upper temperature for spawning

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the fishery. Sissenwine's 1974 model predicts a 68 percent reduction of recruitment in yellowtail flounder, Limanda ferruginea, with a 1° C long-term elevation in southern New England waters.

Community balance can be influenced strongly by such temperature dependent factors as rates of reproduction, recruitment and growth of each component population. A few degrees elevation in average monthly temperature can appreciably alter a community through changes in inter-species relationships. A 50 percent reduction in the soft-shell clam fishery in Maine by the green crab, Carcinus maenus, illustrates how an increase in winter temperatures can establish new predator-prey relationships. Over a period of four years, there was a natural amelioration of temperature and the monthly mean for the coldest month of each year did not fall below 2° C. This apparently precluded appreciable ice formation and winter cold kill of the green crab and permitted a major expansion of its population, with increased predation of the soft-shell clam resulting (Glude, 1954; Welch, 1968).

Temperature is a primary factor controlling reproduction and can influence many events of the reproductive cycle from gametogenesis to spawning. Among marine invertebrates, initiation of reproduction (gametogenesis) is often triggered during late winter by attainment of a minimum environmental threshold temperature. In some species, availability of adequate food is also a requisite (Pearse, 1970; Sastry, 1975; deVlaming, 1971). Elevated temperature can limit gametogenesis by preventing accumulation of nutrients in the gonads. This problem could be acute during the winter if food availability and feeding activity is reduced. Most marine organisms spawn during the spring and summer; gametogenesis is usually initiated during the previous fall. It should also be noted that there are some species which

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spawn only during the fall (herring), while others spawn during the winter and very early spring. At the higher latitudes, winter breeders include such estuarine community dominants as acorn barnacles, Balanus balanus, and B. balanoides, the edible blue mussel Mytilus edulis, sea urchin, Strongylocentrotus drobachiensis, sculpin, and the winter flounder, Pseudopleuronectes americanus. The two boreal barnacles require temperatures below 10°C before egg production will be initiated (Crisp, 1957). It is clear that adaptations for reproduction exist which are dependent on temperature conditions close to the natural cycle.

Juvenile and adult fish usually thermoregulate behaviorally by moving to water having temperatures closest to their thermal preference. This provides a thermal environment which approximates the optimal temperature for many physiological functions, including growth (Neill and Magnuson, 1974). As a consequence, fishes usually are attracted to heated water during the fall, winter, and spring. Avoidance will occur as water temperature exceeds the preferendum by 1 to 3° C (Coutant, 1975). This response precludes problems of heat stress for juvenile and adult fishes during the summer, but several potential problems exist during the other seasons. The possibility of cold shock and death of plume-entrained fish due to winter plant shutdown is well recognized. Also, increased incidence of disease and a deterioration of physiological condition has been observed among plume-entrained fishes, perhaps due to insufficient food (Massengill, 1973). A weight loss of approximately 10% for each 1°C rise in water temperature has been observed in fish when food is absent (Phillips et al., 1960) There may also be indirect adverse effects on the indigenous community due to increased predation pressure if thermal addition leads to a concentration of fish which are dependent on this community for their food.

Fish migration is often linked to natural environmental temperature cycles. In early spring, fish employ temperature as their environmental cue to migrate northward (e.g., menhaden, bluefish) or to move inshore (winter

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flounder). Likewise, water temperature strongly influences timing of spawning runs of anadromous fish into rivers (Leggett and Whitney, 1972). In the autumn, a number of juvenile marine fishes and shrimp are dependent on a drop in temperature to trigger their migration from estuarine nursery grounds for oceanic dispersal or southward migration (Lund and Maltezos, 1970; Talbot, 1966).

Thermal discharges should not alter diurnal and tidal temperature variations normally experienced by marine communities. Laboratory studies show thermal tolerance to be enhanced when animals are maintained under a diurnally fluctuating temperature regime rather than at a constant temperature (Costlow and Bookhout, 1971; Furch, 1972; Hoss, et al., 1975). A daily cyclic regime can be protective additionally as it reduces duration of exposure to extreme temperatures (Pearce, 1969; Gonzalez, 1972).

Summer thermal maxima should be established to protect the various marine communities within each biogeographic region. During the summer, naturally elevated temperatures may be of sufficient magnitude to cause death or emigration (Chin, 1961; Glynn, 1968; Vaughn, 1918) This more commonly occurs in tropical and warm temperate zone waters, but has been reported for enclosed bays and shallow waters in other regions as well (Nichols, 1918). Summer heat stress also can contribute to increased incidence of disease or parasitism (Sinderman, 1965); reduce or block sexual maturation (Thorhaug, et al., 1971; deVlaming, 1972); inhibit or block embryonic cleavage of larval development (Calabrese, 1969); reduce feeding and growth of juveniles and adults (Olla and Studholme, 1971);

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result in increased predation (Gonzalez, 1972); and reduce productivity of macroalgae and seagrasses (South and Hill, 1970; Zieman, 1970). The general ceilings set forth here are derived from studies delineating limiting temperatures for the more thermally sensitive species or communities of a biogeographic region.

Thermal effects data are presently insufficient to set general temperature limits for all coastal biogeographic regions. The data enumerated in the Appendix, plus any additional data subsequently generated, should be utilized to develop thermal limits which specifically consider communities relevant to given water bodies.

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Appendix

A Summary of the Thermal Effects Literature for the United States Estuarine and Coastal Biota

Recommended marine thermal criteria are based on scientific evaluation of available data. Representative thermal effects data are summarized here for an array of ecologically diverse marine organisms, grouped by biotic region. Since the summer temperature regime can provide "worst case" thermal conditions, studies dealing with warm-acclimated organisms are cited primarily. Findings of sublethal effects studies are listed also. Twenty-four-hour TLm (median tolerance limit) data have been adjusted by subtracting 2.2°C to estimate the upper thermal protection limit for the life history stage in question (Mihursky, 1969). Recognized biological variables such as recent environmental history, nutritional state, size, sex, and age have been considered for all thermal effects investigations. Likewise, contrasting methods of study were considered. Normally, thermal effects data derived in one biotic region should not be applied to another. Latitudinally separated populations of widely distributed species may exhibit significant genetic variability and usually have experienced different, recent environmental histories. Boundaries for regional ceilings are demarcated by biogeographic provinces. Species composition of the marine system, and most important, responses to elevated

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temperature, are generally similar within a region. Boundaries of a biotic province are characterized by significant thermal discontinuities. Boundary areas are maintained during summer or winter due to combined forces of current, wind, and coastal geomorphology. On the east coast, Cape Canaveral, Fla.; Cape Hatteras, North Carolina; and Cape Cod, Massachusetts, represent these boundaries. On the west coast, Point Conception in southern California marks the limit of warm and cold temperate zones.

Boreal Zone, Atlantic Coast: This region extends from Cape Cod, Mass., to the Gulf of Maine. Insufficient data are available for setting regional temperature limits. Upper limits should be determined on a case-by-case basis using best available data for the site and its environs.

In the boreal region, maintenance of a general temperature regime resembling natural conditions is particularly important during winter months. Some boreal species require periods of uninterrupted low water temperatures to fulfill environmental requirements for successful maturation of sexual products, spawning, and subsequent egg and larval survival. Winter flounder, Pseudopleuronectes americanus, have an upper limit for spawning of 5.5°C (Bigelow and Schroeder, 1953). Spawning occurs during the winter.

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Ten degrees centigrade is the upper thermal limit for Atlantic salmon, Salmo salar, smolt migration to the sea, which normally occurs in June. Twelve degrees centigrade inhibits maturation of sex products (DeCola, 1970). Development of winter flounder, Pseudopleuronectes americanus, eggs to hatching is reduced 50 percent at 13°C (Rogers, in press). Blood worm, Glycera americana, spawning is induced when temperatures reach 13°C (Creaser, 1973). Fifteen degrees centigrade is the upper limit for spawning Atlantic herring, Clupea harengus, (Hela and Laevastu, 1962) and of an amphipod, Psammonx nobilis, (Scott, 1975). In Atlantic herring, there is above normal incidence of a protozoan disease at 15°C (Sinderman, 1965) and at 16°C, there is a prevalence of erythrocyte degeneration (Sherburne, 1973). Field mortality of yellowtail flounder larvae, Limanda ferruginea, was observed at 17.8°C (Colton, 1959). The protection limit for yearling Atlantic herring, Clupea harengus, (48-hr. TLm - 2.2°C) is 19.0°C (Brawn, 1960). At 21°C, embryonic development ceases in the amphipod, Gammarus duebeni, (Steele and Steele, 1969). Above 21.2°C, spores are killed and growth is reduced in the macroalga, Chondrus crispus, which is commercially harvested as Irish moss (Prince and Kingsbury, 1973).

Cold Temperate Zone, Atlantic Coast: Temperature ceilings are particularly critical in the southern portion of this region (south shore of Long Island to Cape Hatteras, N.C.) where enclosed sounds and large coastal-plain bays and rivers are

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prevalent. Maximum temperatures should not exceed 30.6°C. Were temperatures of 30°C to persist for over 4 to 6 hours, appreciable stress or direct mortality would occur among juvenile winter flounder, Pseudopleuronectes americanus; striped mullet larvae, Mugil cephalus; Atlantic silverside eggs and adults, Menidia menidia; adult northern puffer, Sphaeroides maculatus; adult blue mussel, Mytilus edulis; and adult soft shell clam, Mya arenaria. Specific critical temperatures for these species are detailed in Table 13 The adult protection limit (TLm - 2.2°C) is 28.8°C for sand shrimp, Crangon septemspinosa, and 30.8°C for opossum shrimp, Neomysis americanus. Both are important food organisms for fish (Mihursky and Kennedy, 1967). Respiration rate is depressed above 30°C in the mole crab, (Edwards and Irving, 1943). At 31.5°C, there is 67 percent mortality in coot clams when exposed for 6 hours (Kennedy, et al., 1974).

A true daily mean limit of 27.8°C approximates the upper limit for larval growth of the coot clam (27.5°C; Calabrese, 1969). Between 28°C and 30°C juvenile amphipods, Corophium insidiosum, leave their tubes and thereby lose natual protection from predation (Gonzalez, 197[illegible]). Such elevated temperatures may also have subtle sublethal effects, such as reducing feeding and growth. In the quahaug, Mercenaria mercenaria, growth is optimum at 20°C (Ansell, 1968). Growth is inhibited above 24°C in a rock weed, Ascophyllum nodosum, (South and Hill, 1970). Prolonged

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TABLE SELECTED THERMAL REQUIREMENTS & LIMITING TEMPERATURE DATA
COLD TEMPERATE ZONE, ATLANTIC COAST:
South of Long Island, N.Y. to Cape Hatteras, N.C.

Temperature °C	°F	Effect	Species	Seasonal Occurrence	Reference
30	86.0	Avoidance response breakdown (CTM)	Morone saxatilis (striped bass)	April-November	Gift & Westman, 1971
29.8	85.6	Behavior-reduced feeding and behavior altered	Pomatomus saltatrix (bluefish)	May-October	Olla, et al 1969
29.4	84.9	Survival-eggs (50% optimal survival)	Menidia menidia (Atlantic silverside)	May-June	Everich & Neves, 1973 (unpublished)
29.1	84.3	Survival-larvae (TLm)	Mugil cephalus (striped mullet)	January-April (coastal waters)	Cortenay & Roberts, 1973
29.0	84.2	Survival-adult protection limit (TLm - 2.2°C)	Sphaeroides maculatus (Northern puffer)	January-December	Hoff & Westman, 1966
29.0	84.2	Avoidance response	Brevoortia tyrannus (Atlantic menhaden)	April-October	Meldrim & Gift, 1971
29.2	82.7	Survival-adult protection limit (TLm - 2.2°C)	Menidia menidia (Atlantic silverside)	April-November	Hoff & Westman, 1966
28.0	82.4	Survival-adult limit	Mya arenaria (soft shell clam)	January-December	Pfitzenmeyer (pers comm)
27.5	81.5	Development-upper limit larval development	Mulinia lateralis (coot clam)	March-October	Calabrese, 1969
26.9	80.4	Survival-juvenile protection limit (TLm - 2.2°C)	Pseudopleuronectes americanus (winter flounder)	April-December	Hoff & Westman, 1966
26.5	79.7	Avoidance response	Cynoscian regalis (sea trout)	May-October	Gift & Westman, 1971
26.0	78.8	Survival-adult	Mytilus edulis (blue mussel)	January-December	Gonzalez, 1972
25.5	77.9	Avoidance response	Leiostomus xanthrus (spot)	January-December	Gift & Westman, 1971
24.8	76.7	Occurrence-maximum temperature for occurrence in Chesapeake Bay	Urophycis regius (spotted hake)	January-December	Barans, 1972
24.6	76.2	Survival-larvae (TLm)	Menidia menidia (Atlantic silverside)	May-June	Everich & Neves, 1973 (unpublished)

Compiled by ERL-Narragansett, 1976

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locomotion is markedly reduced at 22°C in the Jonah crab, Cancer borealis; at 28°C in Cancer irroratus (Jeffries, 1967). An oyster pathogen, Democystidium marinum, readily proliferates above 25°C (Andrews, 1965).

High temperature usually will elicit avoidance response in fishes. Avoidance is triggered at 29°C in Atlantic menhaden, Brevoortia tyrannus, and at 26.5°C in sea trout, Cynoscion regalis, (Meldrin and Gift, 1971). Breakdown of the avoidance response in striped bass, Morone saxatilis, occurs at 30°C (Gift and Westman, 1971). Maximum reported temperature for capture of spotted hake, Urophycis regius, is 24.8°C in the Chesapeake Bay (Barans, 1972).

North of Long Island, a 1.0°C rise above summer ambient provides reasonable protection. For example, maximum short-term temperatures in Narragansett Bay, Rhode Island, usually would not exceed 23.4°C in August, judging from 15-year mean temperature data for Fox Island. Larval Atlantic silverside, juvenile winter flounder, and blue mussel should be protected by that thermal limitation. The thermal protection limit (TLm - 2.2°C) for juvenile winter flounder is 26.9°C (Gift and Westman, 1971).

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Repeated exposures to 25°C would stress the blue mussel, Mytilus edulis, by causing cessation of feeding (Gonzalez, 1972). Diurnal summer maxima exceeding 22°C can alter normal metabolic rates in embryonic tautog, Tautoga onitis, (Laurence, 1973) and cause feeding problems for adult winter flounder (Olla, 1969) and the sand-collar snail, Polinices duplicata, (Hanks, 1953).

Optimum for summer development of the rock crab, Cancer irroratus, and Jonah crab, C. borealis, larvae is 20°C; at 25°C, mortality precludes completion of larval development (Sastry and Vargo, in press). Between 15 and 20°C, activity of the amphipod, Gammarus oceanicus, is much reduced (Halcrow and Boyd, 1967). Initiation of spawning is often cued by temperature. Blue mussel spawning occurs when spring temperatures reach 12°C (Engle and Loosanoff, 1944). A minimum of 10°C is required for their embryonic development (Brenko and Calabrese, 1969) and spawning occurs at 15°C. Peak spawning runs of American shad, Alosa sapidissima, into rivers occurs at 19.5°C (15 year average, Connecticut River); downstream migration of juveniles occurs as temperature falls below 15.5°C (Leggett and Whitney, 1972). Menhaden migrate at 10°C (Bigelow and Schroeder, 1953); striped bass, Morone saxatilis, migrate into or leave rivers at 6 to 7.5°C (Merriman, 1941). In the fall and winter, fishes congregate in discharge plumes which exceed these temperatures. These fishes exhibit increased incidence of disease and a general loss of physiological condition (Mihursky, et al; 1970).

Warm Temperate Zone, Atlantic and Gulf Coasts: This region tends from Cape Hatteras, N.C., to Cape Canaveral, Florida, and

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on the Gulf Coast from Tampa, Florida, to Mexico. The recommended regional ceiling is a short-term maximum of 32.2°C . Prolonged exposures to temperatures near this level would adversely affect portions of the biota. At 33°C, bay anchovy, Anchoa mitchilli, embryonic development is reduced to 50 percent of optimum (Rebel, 1973). The upper limit for growth of juvenile white shrimp, Penaeus setiferus, is 32.5°C (Zein-Eldin and Griffith, 1969). A decline in field abundance of brown shrimp, Penaeus aztecus, at temperatures above 30°C was reported by Chin (1961).

Protection limits (50 percent of optimal survival) of two sardines, Harengula jaguana and Harengula pensacolae, for development of the yolk sac larval stage are 31.4°C and 32.2°C, respectively (Rebel, 1973; Sakensa, et al., 1972). Larval pinfish, Lagodon rhomboides, and spot, Leiostomus xanthurus, exhibit a breakdown in avoidance response mechanisms at 31.0°C and 31.1°C, respectively (Hoss, D.E., et al., 1974). The protection limit (TLm - 2.2°C) for young-of-the-year Atlantic menhaden is 30.8°C (Lewis and Hettler, 1968). Upper limit for adult growth of the quahaug, Mercenaria mercenaria, is 31°C (Ansell, 1968).

Daily mean temperatures continually exceeding 29°C would result in mortality of striped mullet eggs, Mugil cephalus.

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Their 96-hour TLm is 26.4°C (Courtenay and Roberts, 1973). Egg and yolk sac larval survival of sea bream, Archosargus rhomboidalis, is reduced to 50 percent of optimal at 29.1°C. For yellowfin menhaden, Brevoortia smithi, exposure to 29.8°C reduced survival of egg and yolk sac larvae to 50 percent of optimal (Rebel, 1973). Sublethal but potentially damaging ecological effects could occur at levels well below 29°C. For example, the upper limit for optimal growth of post-larval brown shrimp, Penaeus aztecus, is 27.5°C (Zein-Eldin and Alrich, 1965). Developing embryos and fry of striped bass cannot tolerate 26.7°C in fresh water (Shannon, 1969). This report may also apply to fry in waters at the head of estuaries. This species spawns in early spring. Elevation of winter temperatures above 20°C in St. Johns River, Florida, could interfere with upstream migration of American shad, Alosa sapidissima, (Leggett and Whitney, 1972).

Sub-Tropical Regions: Ceilings for sub-tropical regions such as south Florida (Cape Canaveral and Tampa southward), and Hawaii are an instantaneous maximum 32.2°C and a true daily mean not exceeding 29.4°C. Ceilings for true tropical sites should be developed from studies of indigenous populations of relevant communities. Physiological variation in thermal adaptations and tolerances have been reported for coral between sub-tropical (Hawaii, 19-22° Lat.) and true tropical sites (Eniwetok Atol, Marshall Islands, 11° Lat.) (Jokiel, et al., in press).

Much of the following thermal effects data represent southern Florida or Hawaiian biota. A review by Zieman and Wood (1975) suggests that the thermal optimum is 26-28°C for tropical marine systems, with chronic exposure to temperatures between 28°C and 30°C causing heat stress. Death of the biota is readily discernible between 30°C and 32°C. Mayer (1914) recognized that nearshore

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tropical marine biota normally live at temperatures only a few degrees below their upper lethal limit. A study of elevated temperature effects on the benthic community in Biscayne Bay, Florida, resulted in the following data (Roessler, 1974):

Phylum	Temperature for High Species Diversity (°C)	Temperature for 50 Percent Species Exclusion (°C)
Molluscs	26.7	31.4
Echinoderms	27.2	31.8
Coelenterates	25.9	29.5
Porifera	24.0	31.2

Other thermal data for tropical biota include a 25.4-27.8°C optimum for fouling community larval settlement (Roessler, 1974); 25°C optimum for larval development of Polyonyx gibbesi, a commensal crab (Gore, 1968); 27°C for growth and gonad development in sea urchins, Lytechinus variegatus, and for growth in a snail, Cantharus tinctus, (Albertson, 1973); 27 to 28°C optimum for larval development of pink shrimp, Penaeus duorarum, (Thorhaug, et al., 1971a); and 30°C optium for turtle grass, Thalassia testudinum, productivity (Zieman, 1970). Kuthalingham (1959) studied thermal tolerance of newly hatched larvae of ten tropical marine fishes in the laboratory. When held at a series of constant temperatures for 12 hours immediately following

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hatch, optimal survival for all species fell between 28°C to 30°C, but their tolerance limit ranged from 30°C to 32°C.

Thermal stress of the fouling community is seen in a 50 percent reduced settlement rate of larvae at 28°C (Roessler, 1974). Fifty percent reduction in gonadal volume of the sea urchin, Lytechinus variegatus, occurs at 29.9°C (Thorhaug, et al., 1971b). Irreversible plasmyolysis of the macroalga, Valonia ventricosa, at 29.9°C and of Valonia macrophysa at temperatures above 29.7°C has been reported. Survival of developing embryos to the yolk sac larval stage was reduced to 50 percent of optimal at 29.1°C among sea bream, Archosargus rhomboidalis. At 29.8°C, yellowfin menhaden, Brevoortia smithi, and at 31.4°C scaled sardines, Harengula jaguana, suffer similar mortalities during early development (Rebel, 1973). Temperatures in excess of 31°C to 33°C can interfere with embryonic development in six species of mangrove-associated nematodes, even though adults can tolerate an additional 2°C to 7°C (Hopper, et al., 1973). Upper limit for larval (naupliar) metamorphosis in pink shrimp, Penaeus duorarum, is 31.5°C (Thorhaug, et al., 1971b). Upper lethal temperatures include 31.5°C for five species of Valonia (Thorhaug, 1970); death in 3 to 8 hours for five Hawaiian corals at 31-32°C (Edmondson, 1928; Jokiel and Coles, 1974); 32°C Tlm (95-hour) for the sea squirt, Ascidia nigra, and sea urchin, Lytechinus variegatis, (Chesher, 1971). Average daily temperatures near 31°C

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for three to ten days result in decreased growth in seagrass, Thallassia testudinum and red macroalgae, Laurencia poitei. Between 32°C and 33°C, health and abundance of these species declines markedly (Thorhaug, 1971, 1973). Replacement of seagrass is slow, especially if rhizomes are damaged due to excessive consumption of stored starch during heat stress (Zieman, 1970). Recovery of Thallassia beds may take decades (Zieman and Wood, 1975).

Pacific Coast: Fewer thermal effects studies have been conducted on West Coast species. However, the concept of seasonal restrictions for temperature elevations above ambient are well supported in several East Coast provinces and is deemed applicable to the West Coast as a general biological principle. Data are not sufficient to develop general regional ceilings. These must be determined on a case-by-case basis until general principles emerge.

The Pacific Coast consists of two distinct biogeographical regions; the cold temperate province ranges north from Point Conception, California and the warm temperate region from Point Conception southward. Published data should provide a general indication of possible adverse effects of excessive thermal discharge on indigenous species.

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Pacific Cold Temperate Zone: Some winter and spring spawning temperature ranges include 3°C to 6°C for Pacific herring, Clupea pallasi, (McCauley and Hancock, 1971); 7°C to 8°C for English sole, Parophrys vetulus, (Alderdice and Forrester, 1968); 13°C for May and June spawning of razor clams, Siliqua patula, (McCauley and Hancock, 1971); and 12°C to 14°C for native little neck clams, Protothaca staminea, (Schink and Woelke, 1973). Optimal growth occurs at 10°C in the small filamentous red algae, Antithamnion spp., (West, 1968), and 12°C to 16°C is optimal for growth and reproduction of various red and brown algae, including kelp, Macrocystis pyrifera, (Druehl and Hisiao, 1969). Twelve to 16°C favors sea grasses, Zostera marina and Phyllospadix scouleri (McRoy, 1970). Spawning migration of striped bass, Morone saxatilis, occurs at 15°C to 18°C (Albrecht, 1964); in American shad, Alosa sapidissima, spawning runs occur at 16.0-19.5°C (Leggett & Whitney,1972). At Vancouver Island, B.C., distribution of a kelp, Laminaria groenlandica , is temperature influenced . The long stipe form is not found above 13°C; the short stipe form does not occur above 17°C . In the laboratory, elevation of temperature to 13°C produces abnormal sporophytes (Druehl, 1967). Dungeness crab, Cancer magister, larval development is optimal at 10 and 13.9°C, survival is reduced at 17.8°C, with no survival to megalops at 21.7°C (Reed, 1969). The Upper thermal limit for razor clam embryonic and larval development is 17°C (McCauley and Hancock, 1971). Upper growth limit

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for small filamentous red algae, Antithamnion spp, is 18°C (West, 1968). King salmon migration into the San Joaquin River may be delayed by estuarine temperatures in excess of 17.8°C (Dunham, 1968).

The sea grass, Phyllospadix scouleri, begins to die off (McRoy, 1970), and the pea pod borer, Botula fulcata, ceases to develop at 20°C (Fox and Corcoran, 1957). Twenty degrees centigrade also is the upper limit for embryonic and larval development of the summer-spawning horse clam, Tresus nuttalli, and native little neck clam, Protothaca staminea, (Schink and Woelke, 1973). Upper incipient lethal temperature for the mysid shrimp, Neomysis intermedia, is 21.7°C (Hair, 1971). This value is corroborated by reports of a drop in field populations of this important fish food organism above 22.2°C in the San Joaquin estuary (Heubach, 1969). Twenty-two degrees centigrade is the upper tolerance limit for embryological development of the wooly sculpin, Clinocottus analis, (Hubbs, 1966). A four-hour exposure to 23°C results in significant mortality of the adult razor clam, Siliqua patula, (Woelke, 1971) and the sockeye salmon, Oncorhynchus nerka, (Brett and Alderdice, 1958). Striped bass, Morone saxatilis, are believed to be stressed at temperatures above 23.9°C (Dunham, 1968). Sexual maturation in a gobiid fish, Gillicthys mirabilis, is blocked at high temperatures. Gonadal regression begins at 22°C in females; at 24°C in males.

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Gonadal recrudescence will not occur at 24°C or above, regardless of photoperiod (DeVlaming, 1972). The 36-hour TLm for red abalone adults is 23°C when acclimated to 15°C; for the embryos, 26°C, when exposed for 30 hours (Ebert, 1974). Sea urchin, Strongylocentrotus purpuratus, upper tolerance limit is 23.5°C for adults (Gonor, 1968); 25°C is lethal to embryos and renders adults limp and unresponsive after 4 hours (Farmanfarmaian and Giese, 1963).

Pacific Warm Temperate Zone: The thermal threshold for spawning in Pacific sardine, Sardinops caerulea, is 13°C (Marr, 1962). Reports of temperature optima for spawning include 15°C in a ctenophore, Pleurobranchia bachei, (Hirota, 1973); 16°C in the spring spawning wooly sculpin, Clinocottus analis, (Graham, 1970); 17.5°C for northern anchovy, Engraulis mordax; 19°C for opaleye fish, Girella nigricans, (Norris, 1963). Larval survival is best at 16 to 18°C in white abalone, Haliotis sorenseni, (Leighton, 1972).

Limiting effects of temperature include scarcity of the kelp isopod in the beds above 17.8°C (Jones, 1971). Upper limit for growth in Pleurobranchia bachei is 17°C; 20°C is the upper tolerance limit for the adult ctenophore (Hirota, 1973). Twenty degrees centigrade also causes limited survival in recently settled juvenile white abalone (Leighton, 1972). Limiting

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effects for wooly sculpin include the upper limit of optimal growth at 21°C; at 22°C, a 50 percent reduction in the successful development of eggs; at 24°C, the upper limit for embryonic development is reached (Hubbs, 1966). Sea Urchins, Strongylocentrotus sp. are weakened or killed at 24°C to 25°C (Leighton, 1971). At 25°C, partial osmoregulatory failure occurs in staghorn sculpin, Leptocottus armatus, at 37.6 o/oo (Morris, 1960). A maximum temperature of occurrence of 25°C is reported for top smelt, Atherinops affinis, by Doudoroff (1945) and northern anchovy, Engraulis mordax, (Baxter, 1967). For topsmelt, the upper limit at which larvae hatch is 26.8°C (Hubbs, 1965).

Natural summer temperatures are stressful to beds of giant kelp, Macrocystis pyrifera, in southern California. This precludes any summer thermal discharge in the vicinity of these beds. Deterioration of surface blades is evident from late June onward, due in part to reduced photosynthesis (Clendenning, 1971). Several weeks' exposure to 18.9°C is harmful to the beds (Jones, 1971), while temperatures over 20°C result in pronounced loss of kelp (North, 1964). Brandt (1923) reported that there was some 60 percent reduction of kelp harvest when the average temperature was 20.65°C and that a bacterial disease, black rot, thrives on kelp at 18-20°C. One-day exposure to 22°C is quite harmful to cultured gametophytes of giant kelp (North, 1972).

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ZINC

CRITERIA:

5,000 ug/l for domestic water supplies (welfare);

For freshwater aquatic life, 0.01 of the 96-hour LC_{50} as determined through bioassay using a sensitive resident species.

INTRODUCTION:

Zinc usually is found in nature as the sulfide; it is often associated with sulfides of other metals, especially lead, copper cadmium, and iron. Most other zinc minerals probably have been formed as oxidation products of the sulfide; they represent only minor source of zinc. Nearly 3,000,000 short tons of recoverable zinc per year are mined in the world; about 500,000 tons of this come from the United States.

Zinc (as metal) is used in galvanizing, i.e., coating (hot dipping) of various iron and steel surfaces with a thin layer of zinc to retard corrosion of the coated metal. In contact with iron, zinc is oxidized preferentially, thus protecting the iron. The second most important use of zinc, reaching major proportions in the last quarter century, is in the preparation of alloys for dye casting. Zinc is used also in brass and bronze alloys, slush castings (in the rolled or extruded state), in the production of zinc oxide and other chemical products, and in photoengraving and printing plates.

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Kopp and Kroner (1967) report that in 1,207 positive tests for zinc on samples from U.S. waterways, the maximum observed value was 1,183 ug/l (Cuyahoga River at Cleveland, Ohio) and the mean was 64 ug/l. Dissolved zinc was measured in over 76 percent of all water samples tested. The highest mean zinc value, 205 ug/l, was found in the Lake Erie Basin, whereas the lowest mean zinc value, 16 ug/l, was observed in the California Basin. In seawater, zinc is found at a maximum concentration of about 10 ug/l.

RATIONALE:

Zinc is an essential and beneficial element in human metabolism (Vallee, 1957). The daily requirement of preschool-aged children is 0.3 mg Zn/kg body weight. The daily adult human intake averages 0 to 15 mg/ zinc; deficiency in children leads to growth retardation. Community water supplies have contained 11 to 27 mg/l without harmful effects (Anderson, et al., 1934; Bartow and Weigle, 1932). However, in tests performed by a taste panel, 5 percent of the observers were able to distinguish between water containing 4 mg/l zinc as $ZnSO_4$, which had a bitter or astringent taste, and water containing no zinc salts (Cohen, et al., 1960). Because zinc in water produces undesirable aesthetic effects, the concentration of zinc in domestic water supplies should be below 5 mg/l (5,000 ug/l).

The toxicity of zinc compounds to aquatic animals is modified by several environmental factors, particularly hardness, dissolved oxygen, and temperature. Skidmore (1964), in undertaking a review of the literature on the toxicity of zinc to fish, reported that salts of the

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alkaline-earth metals are antagonistic to the action of zinc salts, and salts of certain heavy metals are synergistic in soft water. Both an increase in temperature and a reduction in dissolved oxygen increase the toxicity of zinc. Toxic concentrations of zinc compounds cause adverse changes in the morphology and physiology of fish. Acutely toxic concentrations induce cellular breakdown of the gills, and possibly the clogging of the gills with mucous. Chronically toxic concentrations of zinc compounds, in contrast, cause general enfeeblement and widespread histological changes to many organs, but not to gills. Growth and maturation are retarded.

Using dilution water with calcium of 1.7 mg/l and magnesium of 1.0 mg/l, Affleck (1952) found a 54 percent mortality of rainbow trout fry in 28 days in a zinc concentration of 10 ug/l. Pickering and Henderson (1966) determined the 96-hour LC_{50} of zinc for fathead minnows, Pimephales promelas, and bluegills, Lepomis macrochirus, using static test conditions. For fathead minnows in soft water (20 mg/l $CaCO_3$) the LC_{50} was 870 ug/l, and in hard water (360 mg/l $CaCO_3$) it was 33,000 ug/l. Bluegills were more resistant in both waters. Similarly, the lethal threshold concentration was 3 or 4 times as high for coarse fish as for trout, Salvelinus fontinalis, (Ball, 1967).

The 24-hour LC_{50} of zinc for rainbow trout, Salmo gairdneri, was reduced only 20 percent when the fish were forced to swim at 85 percent of their maximum sustained swimming speed (Herbert and Shurben, 1964). The maximum effect of a reduction in dissolved oxygen from 6 to 7 mg/l to 2 mg/l on the acute toxicity of zinc was a 50-percent increase (Lloyd, 1961; Cairns and Scheier, 1958; Pickering, 1968).

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The Atlantic salmon, Salmo salar, was tested in a 168-hour continuous-flow bioassay at 17° C in water with a total hardness of 14 mg/l $CaCO_3$. The incipient lethal level, the level beyond which the organism can no longer survive, was 420 ug/l of zinc (Sprague and Ramsay, 1965).

Brungs (1969) found that in water with a total hardness of 200 mg/l $CaCO_3$, 180 ug/l zinc caused an 83 percent reduction in eggs produced by the fathead minnow, Pimephales promelas, in chronic tests. The tests lasted 10 months and the control test water contained 30 ug/l zinc. The 96-hour continuous-flow TLm was determined to be 9,200 ug/l zinc.

A number of short term fish toxicity data are detailed in Table 14. When referring to this table, the reader should consider the species tested, pH, alkalinity, and hardness (if alkalinity is not given (in most natural waters alkalinity parallels hardness). In general, the salmonids are most sensitive to elemental zinc in soft water; the rainbow trout Salmo gairdneri is the most sensitive in hard waters. The influence of the pH on solubility of zinc complexes, and the resulting toxicity of zinc, is clearly shown in the data presented on the fathead minnow, Pimephales promelas. The influence of pH and other factors on the solubility and form of the zinc preclude the recommendation of a freshwater or marine criteria based on acute toxicities alone.

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Wurtz (1962) performed bioassays on young pond snails, Physa heterostropha, in waters with a total hardness of 100 mg/l and 20 mg/l $CaCO_3$. In water with a temperature of 51° F, the soft water tests resulted in a 96-hour LC_{50} of 303 ug/l zinc, whereas the 96-hour LC_{50} in hard water was 434 ug/l zinc. The LC_{50} of a zinc sulfate solution in dilution water with a total hardness of 44 mg/l $CaCO_3$ for a 10-day test to a mayfly, Ephemerella subvaria, was 16,000 ug/l (Warnick and Bell, 1969). In such tests with several heavy metals, the immature insects seem to be less sensitive than many fishes that have been tested.

The 48-hour LC_{50} for Daphnia magna in soft water with a hardness of 45 mg/l $CaCO_3$ and an alkalinity of 42 mg/l has been found to be 100 ug/l; in 70 ug/l zinc, there was a 16 percent reproductive impairment in a 3-week chronic test (Biesinger and Christensen, 1972).

Toxicities of zinc in nutrient solutions have been demonstrated for a number of plants. Hewitt (1948) found that zinc at 16 to 20 mg/l produced iron deficiencies in sugar beets. Hunter and Vergnano (1953) found toxicity to oats at 25 mg/l. Millikan (1947) found that 2.5 mg/l produced iron deficiency in oats. Early (1943) found that the Peking variety of soybeans was killed at 0.4 mg/l, whereas the Manchu variety was killed at 1.6 mg/l zinc.

Although few data are available on the effects of zinc in the marine environment, it is accumulated by some species, and marine animals contain zinc in the range of 6 to 1,500 mg/kg (NTAC, 1968). As a goal, the marine environment should be protected to the same level as the fresh water environment.

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TABLE [redacted]

The acute toxicity (24-, 48-, 96-hr TL50 values) of zinc to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alkalinity	Hardness	Reference
Brook trout (Salvelinus fontinalis)	3.0 g 3.9 g 19.0 g	$ZnSO_4 \cdot 7H_2O$	96	FT*	14.8-15.5	1.38 Zn 2.09 Zn 2.50 Zn	7.3-7.7	42	45	(7)
Brook trout	3.0 g 3.9 g 19.0 g	$ZnSO_4 \cdot 7H_2O$	96	FT	14.8-15.5	5.50 Zn 6.05 Zn 4.92 Zn	7.3-7.7	-	100±10	(7)
Rainbow trout (Salmo gairdneri)	3.9 g 4.9 g 28.4 g	$ZnSO_4 \cdot 7H_2O$	96	FT	14.8-15.5	0.285 Zn 0.506 Zn 0.820 Zn	7.3-7.7	42	45	(7)
Rainbow trout	Juveniles	$ZnSO_4$	96	FT	12.7	0.43 Zn	6.8	25	26	(15)
Rainbow trout	7 g	Zinc	96	FT	11.6-12.4	0.10 Zn	6.8-7.0	17-26	20-25	(4)
Rainbow trout	Fingerlings	Zinc sulfate	48	FT	17.7	0.91 Zn	6.9	41.5	44	(6)
Rainbow trout	1.5 g	Zinc	96	S*	10	0.09 Zn	7	20	20	(5)
Rainbow trout	Juveniles	$ZnSO_4$	96	FT	16.2	7.21 Zn	7.8	238	333	(15)
Rainbow trout	3.9 g 4.9 g 28.4 g	$ZnSO_4 \cdot 7H_2O$	96	FT	14.8-15.5	2.40 Zn 2.66 Zn 1.95 Zn	7.3-7.7	-	100±10	(7)
Rainbow trout	-	Zinc	48	S	15	3.2 Zn	7.6	200	300	(1)

*flow-through bioassay
**static bioassay

98h

The acute toxicity (24-, 48-, 96-hr TL50 values) of zinc to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alkalinity	Hardness	Reference
Cutthroat trout (Salmo clarki)	-	Zinc	24 48 96 24	FT FT FT S	--	0.62 Zn 0.27 Zn 0.09 Zn 0.42 Zn	7	23.9	-	(11)
Chincok salmon (Oncorhynchus tshawytcha)	At hatch	Zinc	96	FT	11.1-12.0	>0.70 Zn	6.8-7.0	17-26	20-25	(4)
	1 month old	Zinc	96	FT	10.8-12.5	0.103 Zn				
Atlantic salmon (Salmo salar)	Juveniles	Zinc	24	FT	15	0.65 Zn	7.1-7.5	-	20	(17)
Fathead minnow (Pimephales promelas)	1-2 g	$ZnSO_4 \cdot 7H_2O$	24 48 96	S	15	0.92 $ZnSO_4 \cdot 7H_2O$ 0.87 $ZnSO_4 \cdot 7H_2O$ 0.87 $ZnSO_4 \cdot 7H_2O$	7.5	18	20	(9)
Fathead minnow	1-2 g	$Zn(C_2H_3O_2)_2$	24 48 96	S	15	1.03 $Zn(C_2H_3O_2)_2$ 0.88 $Zn(C_2H_3O_2)_2$ 0.88 $Zn(C_2H_3O_2)_2$	7.5	18	20	(9)
Fathead minnow	1-2 g	$ZnSO_4 \cdot 7H_2O$	96	FT	25±1	12.5-13.8 Zn^{++} 6.2-13.7 Zn^{++} 4.7-6.1 Zn^{++}	6 7 8	-	50.2 50 50	(8)
Fathead minnow	1-2 g	$ZnSO_4 \cdot 7H_2O$	96	FT	25±1	18.5-25.0 Zn^{++} 12.3-12.5 Zn^{++} 8.1-10.9 Zn^{++}	6 7 8	-	100	(8)

The acute toxicity (24-, 48-, 96-hr TL50 values) of zinc to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alkalinity	Hardness	Reference
Fathead minnow	1-2 g	$ZnSO_4 \cdot 7H_2O$	96	FT	25±1	25.0-39.5 Zn^{++} 13.6-19.3 Zn^{++} 8.2-21.0 Zn^{++}	6 7 8	-	200	(8)
Fathead minnow	1-2 g	$ZnSO_4 \cdot 7H_2O$	24 48 96	S	15	34.5 $ZnSO_4 \cdot 7H_2O$ 33.4 $ZnSO_4 \cdot 7H_2O$ 33.4 $ZnSO_4 \cdot 7H_2O$	7.5	300	360	(9)
Fathead minnow	Eggs	$ZnSO_4 \cdot 7H_2O$	24 48 96	FT	20	3.95 Zn 2.55 Zn 1.84 Zn	7.5-7.6	44-58	174-198	(10)
Fathead minnow	Fry	$ZnSO_4 \cdot 7H_2O$	24 48 96	FT	20	0.95 Zn 0.95 Zn 0.87 Zn	7.5-7.6	44-58	174-198	(10)
Fathead minnow	45 (mm)	Zinc	24 48 96	S	23.2	8.9 Zn 7.8 Zn 7.6 Zn	6.2	-	166	(12)
Fathead minnow	2-3 g	$ZnSO_4 \cdot 7H_2O$	96	S FT	23	12.5 Zn 9.2 Zn	7.4-7.9	-	203	(2)
Bluegills (Lepomis macrochirus)	1-2 g	$ZnSO_4 \cdot 7H_2O$	24 48 96	S	15	6.48 $ZnSO_4 \cdot 7H_2O$ 5.46 $ZnSO_4 \cdot 7H_2O$ 5.38 $ZnSO_4 \cdot 7H_2O$	7.5	18	20	(9)

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The acute toxicity (24-, 48-, 96-hr TL50 values) of zinc to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alkalinity	Hardness	Reference
Bluegills	1-2 g	$ZnCl_2$	24 48 96	S	15	7.24 $ZnCl_2$ 5.76 $ZnCl_2$ 5.37 $ZnCl_2$	7.5	18	20	(9)
Bluegills	37 g	$ZnSO_4$	96	FT	7-9	10.6 Zn^{++}	7.8	35.6	46	(3)
Bluegills	1-2 g	$ZnSO_4 \cdot 7H_2O$	24 48 96	S	15	40.9 $ZnSO_4 \cdot 7H_2O$ 40.9 $ZnSO_4 \cdot 7H_2O$ 40.9 $ZnSO_4 \cdot 7H_2O$	7.5	300	360	(9)
Flagfish (Jordanella floridae)	20 (mm)	$ZnSO_4 \cdot 7H_2O$	96	FT	25±2	1.5 Zn	7.5	42	45	(16)
Banded killifish (Fundulus diaphanus)	≤20 (cm)	$Zn(NO_3)_2$	24 48 96	S	17	22.6 Zn^{++} 20.7 Zn^{++} 19.1 Zn^{++}	7.8	-	53	(13)
Banded killifish	≤20 (cm)	$Zn(NO_3)_2$	24 48 96	S	28	23.0 Zn^{++} 20.4 Zn^{++} 19.2 Zn^{++}	8.0	-	55	(14)
Striped bass (Roccus saxatilis)	≤20 (cm)	$Zn(NO_3)_2$	24 48 96	S	17	11.2 Zn^{++} 10.0 Zn^{++} 6.7 Zn^{++}	7.8	-	53	(13)

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The acute toxicity (24-, 48-, 96-hr TL50 values) of zinc to several species of fish in water of various water qualities.
(continued)

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alkalinity	Hardness	Reference
Striped bass	≤20 (cm)	$Zn(NO_3)_2$	24 48 96	S	28	11.3 Zn^{++} 10.0 Zn^{++} 6.8 Zn^{++}	8.0	-	55	(14)
Pumpkinseed (Lepomis gibbosus)	≤20 (cm)	$Zn(NO_3)_2$	24 48 96	S	17	25.2 Zn^{++} 21.8 Zn^{++} 20.0 Zn^{++}	7.8	-	53	(13)
Pumpkinseed	≤20 (cm)	$Zn(NO_3)_2$	24 48 96	S	28	25.1 Zn^{++} 21.9 Zn^{++} 20.1 Zn^{++}	8.0	-	55	(14)
White perch (Roccus americanus)	≤20 (cm)	$Zn(NO_3)_2$	24 48 96	S	17	13.6 Zn^{++} 10.2 Zn^{++} 14.3 Zn^{++}	7.8	-	53	(13)
White perch	≤20 (cm)	$Zn(NO_3)_2$	24 48 96	S	28	13.5 Zn^{++} 10.1 Zn^{++} 14.4 Zn^{++}	8.0	-	55	(14)
Carp (Cyprinus carpio)	≤20 (cm)	$Zn(NO_3)_2$	24 48 96	S	17	14.3 Zn^{++} 9.3 Zn^{++} 7.8 Zn^{++}	7.8	-	53	(13)
Carp	≤20 (cm)	$Zn(NO_3)_2$	24 48 96	S	28	14.4 Zn^{++} 9.2 Zn^{++} 7.8 Zn^{++}	8.0	-	55	(14)

The acute toxicity (24-, 48-, 96-hr TL50 values) of zinc to several species of fish in water of various water qualities.

Species	Size	Compound	Exposure time (hr)	Exposure type	Temperature (°C)	Concentration (mg/l)	pH	Alkalinity	Hardness	Reference
Carp	2.5-3.0 (cm)	Zinc sulfate	48	S	28-30	10-12 $ZnSO_4$	7.0-7.2	46	-	(18)
Goldfish (Carassius auratus)	1-2 g	$ZnSO_4 \cdot 7H_2O$	24 48 96	S	15	9.07 $ZnSO_4 \cdot 7H_2O$ 6.44 $ZnSO_4 \cdot 7H_2O$ 6.44 $ZnSO_4 \cdot 7H_2O$	7.5	18	20	(9)
Guppy (Lebistes reticulatus)	0.1-0.2 g	$ZnSO_4 \cdot 7H_2O$	24 48 96	S	15	2.90 $ZnSO_4 \cdot 7H_2O$ 1.96 $ZnSO_4 \cdot 7H_2O$ 1.27 $ZnSO_4 \cdot 7H_2O$	7.5	18	20	(9)
Southern platyfish (Xiphophorus maculatus)	20.8 (cm)	Zinc sulfate	24 48 96	S	23.2	23.0 Zn 18.0 Zn 12.0 Zn	6.2		166	(12)

*FT = Flow-through.

*S = Static.

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GLOSSARY

Acutely toxic: Causing death or severe damage to an organism by poisoning during a brief exposure period, normally ninety-six hours or less, although there is no clear line of demarcation between acute and chronic toxicity.

Chronically toxic: Causing death or damage to an organism by poisoning during prolonged exposure, which, depending on the organism tested and the test conditions and purposes, may range from several days, to weeks, months, or years.

Dose equivalent: The product of the absorbed dose from ionizing radiation and such factors to account for differences in biological effectiveness due to the type of radiation and its distribution in the body as specified by the International Commission on Radiological Units and Measurements (ICRU).

EC50: The concentration at which a specified effect is observed under the test conditions in a specified time in fifty percent of the organisms tested. Examples of specified effects are hemorrhaging, decreased feeding, dilation of pupils, and altered swimming patterns.

Gross alpha particle activity: The total radioactivity due to alpha particle emission as inferred from measurements on a dry sample exclusive of the contribution, if any, due to radon and uranium.

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Gross beta particle activity: The total radioactivity due to beta particle emission as inferred from measurements on a dry sample exclusive of the contribution, if any, due to potassium-40 and other naturally occurring radionuclides.

LC25: The concentration of a toxicant that is lethal (fatal) to twenty-five percent of the organisms tested under the test conditions in a specified time.

LC50: The concentration of a toxicant which is lethal (fatal) to fifty percent of the organisms tested under the test conditions in a specified time.

LD50: The dose of a toxicant that is lethal (fatal) to fifty percent of the organisms tested under the test conditions in a specified time. A dose is the quantity actually administered to the organism and is not identical with a concentration, which is the amount of toxicant in a unit of test medium rather than the amount ingested by or administered to the organism.

Liter (l): The volume occupied by one kilogram of water at a pressure of 760 mm of mercury and a temperature of 4 C. A liter is 0.9463 quart.

Man-made beta particle and photon emitters: All radionuclides emitting beta particles and/or photons listed in Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air or Water for Occupational Exposure, NBS Handbook 69, except the daughter products of thorium-232, uranium-235, and uranium-238.

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Microgram per liter (ug/l): The concentration at which one millionth of a gram (10^{-6}g) is contained in a volume of one liter. There are 453.59 grams in a pound.

Microgram per kilogram (ug/kg): The concentration at which one millionth of a gram (one microgram) is contained in a mass of one kilogram. A kilogram is 2.2046 pounds.

Milligram per kilogram (mg/kg): The concentration at which one thousandth of a gram (one milligram) is contained in a mass of one kilogram. A gram contains 1000 milligrams.

Milligram per liter (mg/l): The concentration at which one milligram (10^{-3}g) is contained in a volume of one liter.

Milliliter (ml): A volume equal to one thousandth of a liter.

Most Probable Number (MPN): The statistically determined number which represents the number of individuals most likely present in a given sample or aliquot, based on test data.

Nanogram per liter (ng/l): The concentration at which one billionth of a gram (10^{-9}g) is contained in a volume of one liter.

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Part per million (ppm): A concentration at which one unit is contained in a total of a million units. Any units may be used (e.g., weight, volume) but in any given application identical units should be used (e.g., grams per million grams or liters per million liters).

Parts per thousand (o /oo): A concentration at which one unit is contained in a total of a thousand units. The rules for using this term are the same as those for parts per million. Normally, this term is used to specify the salinity of estuarine or sea waters.

Picocurie (pCi): That quantity of radioactive material producing 2.22 nuclear transformations per minute.

Rem: The unit of dose equivalent from ionizing radiation to the total body or any internal organ or organ system. A millirem (mrem) is 1/1000 of a rem (0.001 rem).

TL50: - Median Tolerance Limit: The concentration of a test material at which just fifty percent of the test animals are able to survive under test conditions for a specified period of exposure.

TLm : Synonymous with TL_{50}.

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United States
Environmental Protection
Agency

Office of Water
Office of Science and Technology
4304

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October 2000

Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000)



NMED Exhibit 84

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Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000)

Final

Office of Science and Technology
Office of Water
U.S. Environmental Protection Agency
Washington, DC 20460

NMED Exhibit 84

NOTICE

The policies and procedures set forth in this document are intended solely to describe EPA methods for developing or revising ambient water quality criteria to protect human health, pursuant to Section 304(a) of the Clean Water Act, and to serve as guidance to States and authorized Tribes for developing their own water quality criteria. This guidance does not substitute for the Clean Water Act or EPA's regulations; nor is it a regulation itself. Thus, it does not impose legally-binding requirements on EPA, States, Tribes or the regulated community, and may not apply to a particular situation based upon the circumstances.

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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FOREWORD

This document presents EPA's recommended Methodology for developing ambient water quality criteria as required under Section 304(a) of the Clean Water Act (CWA). The Methodology is guidance for scientific human health assessments used by EPA to develop, publish, and from time to time revise, recommended criteria for water quality accurately reflecting the latest scientific knowledge. The recommended criteria serve States and Tribes' needs in their development of water quality standards under Section 303(c) of the CWA.

The term "water quality criteria" is used in two sections of the Clean Water Act, Section 304(a)(1) and Section 303(c)(2). The term has a different program impact in each section. In Section 304, the term represents a scientific assessment of ecological and human health effects that EPA recommends to States and authorized Tribes for establishing water quality standards that ultimately provide a basis for controlling discharges or releases of pollutants. Ambient water quality criteria associated with specific stream uses when adopted as State or Tribal water quality standards under Section 303 define the maximum levels of a pollutant necessary to protect designated uses in ambient waters. The water quality criteria adopted in the State or Tribal water quality standards could have the same numerical limits as the criteria developed under Section 304. However, in many situations States and authorized Tribes may want to adjust water quality criteria developed under Section 304 to reflect local environmental conditions and human exposure patterns before incorporation into water quality standards. When adopting their water quality criteria, States and authorized Tribes have four options: (1) adopt EPA's 304(a) recommendations; (2) adopt 304(a) criteria modified to reflect site-specific conditions; (3) develop criteria based on other scientifically defensible methods; or (4) establish narrative criteria where numeric criteria cannot be determined.

EPA will use this Methodology to develop new ambient water quality criteria and to revise existing recommended water quality criteria. It also provides States and authorized Tribes the necessary guidance to adjust water quality criteria developed under Section 304 to reflect local conditions or to develop their own water quality criteria using scientifically defensible methods consistent with this Methodology. EPA encourages States and authorized Tribes to use this Methodology to develop or revise water quality criteria to appropriately reflect local conditions. EPA believes that ambient water quality criteria inherently require several risk management decisions that are, in many cases, better made at the State, Tribal, or regional level. Additional guidance to assist States and authorized Tribes in the modification of criteria based on the Methodology will accompany this document in the form of three companion Technical Support Documents on Risk Assessment, Exposure Assessment, and Bioaccumulation Assessment.

_____

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Potential areas for conflict of interest were investigated via direct inquiry with the peer reviews and review of their current affiliations. No conflicts of interest were identified.

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LIST OF ACRONYMS

ADI	Acceptable Daily Intake
ARAR	Applicable or Relevant and Appropriate Requirements
ASTM	American Society of Testing and Materials
AWQC	Ambient Water Quality Criteria
BAF	Bioaccumulation Factor
BAF_{ℓ}^{fd}	Baseline Bioaccumulation Factor
BCF	Bioconcentration Factor
BCF_{ℓ}^{fd}	Baseline Bioconcentration Factor
$BCF_{\mathbf{T}}^{\mathbf{t}}$	Bioconcentration Factor Based on Total Concentrations in Tissue and Water
BMD	Benchmark Dose
BMDL	Lower-Bound Confidence Limit on the BMD
BMF	Biomagnification Factor
BMR	Benchmark Response
BSAF	Biota-Sediment Accumulation Factors
BW	Body Weight
C_{ℓ}	Lipid-normalized Concentration
C_{soc}	Organic Carbon-normalized Concentration
C_t	Concentration of the Chemical in the Specified Wet Tissue
C_w	Concentration of the Chemical in Water
CDC	U.S. Centers for Disease Control and Prevention
CSFII	Continuing Survey of Food Intake by Individuals
CWA	Clean Water Act
DDT	1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane
DDE	1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene
DDD	1,1-dichloro-2,2-bis(p-chlorophenyl)ethane
DI	Drinking Water Intake
DNA	Deoxyribonucleic Acid
DNOC	2,4-dinitro-o-cresol
DOC	Dissolved Organic Carbon
ED_{10}	Dose Associated with a 10 Percent Extra Risk
EPA	Environmental Protection Agency
f_{fd}	Fraction Freely Dissolved
f_{ℓ}	Fraction Lipid
FCM	Food Chain Multiplier
FEL	Frank Effect Level
FI	Fish Intake
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GLI	Great Lakes Water Quality Initiative
HCBD	Hexachlorobutadiene
IARC	International Agency for Research on Cancer
II	Incidental Ingestion
ILSI	International Life Sciences Institute

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IRIS	Integration Risk Information System
kg	kilogram
K_{ow}	Octanol-Water Partition Coefficient
L	Liter
LAS	Linear Alkylbenzesulfonate
LED_{10}	The Lower 95 Percent Confidence Limit on a Dose Associated with a 10 Percent Extra Risk
LMS	Linear Multistage Model
LOAEL	Lowest Observed Adverse Effect Level
M_l	Mass of Lipid in Specified Tissue
M_t	Mass of Specified Tissue (Wet Weight)
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MF	Modifying Factor
mg	Milligrams
ml	Milliliters
MOA	Mode of Action
MOE	Margin of Exposure
NCHS	National Center for Health Statistics
NCI	National Cancer Institute
NFCS	Nationwide Food Consumption Survey
NHANES	National Health and Nutrition Examination Survey
NOAEL	No Observed Adverse Effect Level
NOEL	No Observed Effect Level
NPDES	National Pollutant Discharge Elimination System
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyls
POD	Point of Departure
POC	Particulate Organic Carbon
RDA	Recommended Daily Allowance
RfC	Reference Concentration
RfD	Reference Dose
RfD_{DT}	Reference Dose for Developmental Effects
RPF	Relative Potency Factor
RSC	Relative Source Contribution
RSD	Risk-Specific Dose
SAB	Science Advisory Board
SDWA	Safe Drinking Water Act
SF	Safety Factor
STORET	Storage Retrieval
TEAM	Total Exposure Assessment Methodology
TEF	Toxicity Equivalency Factor
TMDL	Total Maximum Daily Load
TSD	Technical Support Document
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency

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UF	Uncertainty Factor
WQBEL	Water Quality-Based Effluent Limits

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1. INTRODUCTION

1.1 WATER QUALITY CRITERIA AND STANDARDS

Pursuant to Section 304(a)(1) of the Clean Water Act (CWA), the U.S. Environmental Protection Agency (EPA) is required to publish, and from time to time thereafter revise, criteria for water quality accurately reflecting the latest scientific knowledge on the kind and extent of all identifiable effects on human health which may be expected from the presence of pollutants in any body of water.

Historically, the ambient water quality criteria (AWQC or 304(a) criteria) provided two essential types of information: (1) discussions of available scientific data on the effects of the pollutants on public health and welfare, aquatic life, and recreation; and (2) quantitative concentrations or qualitative assessments of the levels of pollutants in water which, if not exceeded, will generally ensure adequate water quality for a specified water use. Water quality criteria developed under Section 304(a) are based solely on data and scientific judgments on the relationship between pollutant concentrations and environmental and human health effects. The 304(a) criteria do not reflect consideration of economic impacts or the technological feasibility of meeting the criteria in ambient water. These 304(a) criteria may be used as guidance by States and authorized Tribes to establish water quality standards, which ultimately provide a basis for controlling discharges or releases of pollutants into ambient waters.

In 1980, AWQC were derived for 64 pollutants using guidelines developed by the Agency for calculating the impact of waterborne pollutants on aquatic organisms and on human health. Those guidelines consisted of systematic procedures for assessing valid and appropriate data concerning a pollutant's acute and chronic adverse effects on aquatic organisms, nonhuman mammals, and humans.

1.2 PURPOSE OF THIS DOCUMENT

The *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000)* (hereafter the "2000 Human Health Methodology") addresses the development of AWQC to protect human health. The Agency intends to use the 2000 Human Health Methodology both to develop new AWQC for additional pollutants and to revise existing AWQC. Within the next several years, EPA intends to focus on deriving AWQC for chemicals of high priority (including, but not limited to, mercury, arsenic, PCBs, and dioxin). Furthermore, EPA anticipates that 304(a) criteria development in the future will be for bioaccumulative chemicals and pollutants considered highest priority by the Agency. The 2000 Human Health Methodology is also intended to provide States and authorized Tribes flexibility in establishing water quality standards by providing scientifically valid options for developing their own water quality criteria that consider local conditions. States and authorized Tribes are strongly encouraged to use this Methodology to derive their own AWQC. However, the 2000 Human Health Methodology also defines the default factors EPA intends to use in evaluating and determining consistency of State water quality standards with the requirements of the CWA. The Agency intends to use these default factors to calculate national water quality criteria under

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Section 304(a) of the Act. EPA will also use this Methodology as guidance when promulgating water quality standards for a State or Tribe under Section 303(c) of the CWA.

This Methodology does not substitute for the CWA or EPA's regulations; nor is it a regulation itself. Thus, the 2000 Human Health Methodology cannot impose legally-binding requirements on EPA, States, Tribes or the regulated community, and may not apply to a particular situation based upon the circumstances. EPA and State/Tribal decision-makers retain the discretion to use different, scientifically defensible, methodologies to develop human health criteria on a case-by-case basis that differ from this Methodology where appropriate. EPA may change the Methodology in the future through intermittent refinements as advances in science or changes in Agency policy occur.

The 2000 Human Health Methodology incorporates scientific advancements made over the past two decades. The use of this Methodology is an important component of the Agency's efforts to improve the quality of the Nation's waters. EPA believes the Methodology will enhance the overall scientific basis of water quality criteria. Further, the Methodology should help States and Tribes address their unique water quality issues and risk management decisions, and afford them greater flexibility in developing their water quality programs.

There are three companion Technical Support Document (TSD) volumes for the 2000 Human Health Methodology: a Risk Assessment TSD; an Exposure Assessment TSD; and a Bioaccumulation TSD. These documents are intended to further support States and Tribes in developing AWQC to reflect local conditions. The Risk Assessment TSD (USEPA, 2000) is being published concurrently with this Methodology. Publication of the Exposure Assessment and Bioaccumulation TSDs are anticipated in 2001.

1.3 HISTORY OF THE AMBIENT WATER QUALITY CRITERIA (AWQC) METHODOLOGY

In 1980, EPA published AWQC for 64 pollutants/pollutant classes identified in Section 307(a) of the CWA and provided a methodology for deriving the criteria (USEPA, 1980). These 1980 AWQC National Guidelines (or the "1980 Methodology") for developing AWQC for the protection of human health addressed three types of endpoints: noncancer, cancer, and organoleptic (taste and odor) effects. Criteria for protection against noncancer and cancer effects were estimated by using risk assessment-based procedures, including extrapolation from animal toxicity or human epidemiological studies. Basic human exposure assumptions were applied to the criterion equation.

The risk assessment-based procedures used to derive the AWQC to protect human health were specific to whether the endpoint was cancer or noncancer. When using cancer as the critical risk assessment endpoint (which had been assumed not to have a threshold), the AWQC were presented as a range of concentrations associated with specified incremental lifetime risk

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levels[1]. When using noncancer effects as the critical endpoint, the AWQC reflected an assessment of a "no-effect" level, since noncancer effects were assumed to have a threshold. The key features of each procedure are described briefly in the following paragraphs.

Cancer effects. If human or animal studies on a contaminant indicated that it induced a statistically significant carcinogenic response, the 1980 AWQC National Guidelines treated the contaminant as a carcinogen and derived a low-dose cancer potency factor from available animal data using the linearized multistage model (LMS). The LMS, which uses a linear, nonthreshold assumption for low-dose risk, was used by the Agency as a science policy choice in protecting public health, and represented a plausible upper limit for low-dose risk. The cancer potency factor, which expresses incremental, lifetime risk as a function of the rate of intake of the contaminant, was then combined with exposure assumptions to express that risk in terms of an ambient water concentration. In the 1980 AWQC National Guidelines, the Agency presented a range of contaminant concentrations corresponding to incremental cancer risks of 10^{-7} to 10^{-5} (that is, a risk of one additional case of cancer in a population of ten million to one additional cancer case in a population of one hundred thousand, respectively).

Noncancer effects. If the pollutant was not considered to have the potential for causing cancer in humans (later defined as a known, probable, or possible human carcinogen by the 1986 *Guidelines for Carcinogen Risk Assessment,* USEPA, 1986d), the 1980 AWQC National Guidelines treated the contaminant as a noncarcinogen; a criterion was derived using a threshold concentration for noncancer adverse effects. The criteria derived from noncancer data were based on the Acceptable Daily Intake (ADI) (now termed the reference dose [RfD]). ADI values were generally derived using a no-observed-adverse-effect level (NOAEL) from animal studies, although human data were used whenever available. The ADI was calculated by dividing the NOAEL by an uncertainty factor to account for uncertainties inherent in extrapolating limited toxicological data to humans. In accordance with the National Research Council recommendations of 1977 (NRC, 1977), safety factors (SFs) (later redefined as uncertainty factors) of 10, 100, or 1,000 were used, depending on the quality of the data.

Organoleptic effects. Organoleptic characteristics were also used in developing criteria for some contaminants to control undesirable taste and/or odor imparted by them to ambient water. In some cases, a water quality criterion based on organoleptic effects would be more stringent than a criterion based on toxicologic endpoints. The 1980 AWQC National Guidelines emphasized that criteria derived for organoleptic endpoints are not based on toxicological information, have no direct relationship to adverse human health effects and, therefore, do not necessarily represent approximations of acceptable risk levels for humans.

[1]Throughout this document, the term "risk level" regarding a cancer assessment using linear approach refers to an upper-bound estimate of excess lifetime cancer risk.

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1.4 RELATIONSHIP OF WATER QUALITY STANDARDS TO AWQC

Under Section 303(c) of the CWA, States have the primary responsibility for establishing water quality standards, defined under the Act as designated beneficial uses of a water segment and the water quality criteria necessary to support those uses. Additionally, Native American Tribes authorized to administer the water quality standards program under 40 CFR 131.8 establish water quality standards for waters within their jurisdictions. This statutory framework allows States and authorized Tribes to work with local communities to adopt appropriate designated uses and to adopt criteria to protect those designated uses. Section 303(c) provides for EPA review of water quality standards and for promulgation of a superseding Federal rule in cases where State or Tribal standards are not consistent with the applicable requirements of the CWA and the implementing Federal regulations, or where the Agency determines Federal standards are necessary to meet the requirements of the Act. Section 303(c)(2)(B) specifically requires States and authorized Tribes to adopt water quality criteria for toxics for which EPA has published criteria under Section 304(a) and for which the discharge or presence could reasonably be expected to interfere with the designated use adopted by the State or Tribe. In adopting such criteria, States and authorized Tribes must establish numerical values based on one of the following: (1) 304(a) criteria; (2) 304(a) criteria modified to reflect site-specific conditions; or, (3) other scientifically defensible methods. In addition, States and authorized Tribes can establish narrative criteria where numeric criteria cannot be determined.

It must be recognized that the Act uses the term "criteria" in two different ways. In Section 303(c), the term is part of the definition of a water quality standard. Specifically, a water quality standard is composed of designated uses and the criteria necessary to protect those uses. Thus, States and authorized Tribes are required to adopt regulations which contain legally enforceable criteria. However, in Section 304(a) the term criteria is used to describe the scientific information that EPA develops to be used as guidance by States, authorized Tribes and EPA when establishing water quality standards pursuant to 303(c). Thus, two distinct purposes are served by the 304(a) criteria. The first is as guidance to the States and authorized Tribes in the development and adoption of water quality criteria which will protect designated uses, and the second is as the basis for promulgation of a superseding Federal rule when such action is necessary.

1.5 NEED FOR THE AWQC METHODOLOGY REVISIONS

Since 1980, EPA risk assessment practices have evolved significantly in all of the major Methodology areas: that is, cancer and noncancer risk assessments, exposure assessments, and bioaccumulation. When the 1980 Methodology was developed, EPA had not yet developed formal cancer or noncancer risk assessment guidelines. Since then, EPA has published several risk assessment guidelines. In cancer risk assessment, there have been advances in the use of mode of action (MOA) information to support both the identification of potential human carcinogens and the selection of procedures to characterize risk at low, environmentally relevant exposure levels. EPA published *Proposed Guidelines for Carcinogen Risk Assessment* (USEPA, 1996a, hereafter the "1996 proposed cancer guidelines"). These guidelines presented revised procedures to quantify cancer risk at low doses, replacing the current default use of the LMS model. Following review by the Agency's Science Advisory Board (SAB), EPA published the

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revised *Guidelines for Carcinogen Risk Assessment–Review Draft* in July 1999 (USEPA, 1999a, hereafter the "1999 draft revised cancer guidelines"). In noncancer risk assessment, the Agency is moving toward the use of the benchmark dose (BMD) and other dose-response approaches in place of the traditional NOAEL approach to estimate an RfD or Reference Concentration (RfC). *Guidelines for Mutagenicity Risk Assessment* were published in 1986 (USEPA, 1986b). In 1991, the Agency published *Guidelines for Developmental Toxicity Risk Assessment* (USEPA, 1991), and it issued *Guidelines for Reproductive Toxicity Risk Assessment* in 1996 (USEPA, 1996b). In 1998, EPA published final *Guidelines for Neurotoxicity Risk Assessment* (USEPA, 1998), and in 1999 it issued the draft *Guidance for Conducting Health Risk Assessment of Chemical Mixtures* (USEPA, 1999b).

In 1986, the Agency made available to the public the Integrated Risk Information System (IRIS). IRIS is a database that contains risk information on the cancer and noncancer effects of chemicals. The IRIS assessments are peer reviewed and represent EPA consensus positions across the Agency's program and regional offices.

New studies have addressed water consumption and fish tissue consumption. These studies provide a more current and comprehensive description of national, regional, and special-population consumption patterns that EPA has reflected in the 2000 Human Health Methodology. In addition, more formalized procedures are now available to account for human exposure from multiple sources when setting health goals such as AWQC that address only one exposure source. In 1986, the Agency published the *Total Exposure Assessment Methodology (TEAM) Study: Summary and Analysis, Volume I, Final Report* (USEPA, 1986c), which presents a process for conducting comprehensive evaluation of human exposures. In 1992, EPA published the revised *Guidelines for Exposure Assessment* (USEPA, 1992), which describe general concepts of exposure assessment, including definitions and associated units, and provide guidance on planning and conducting an exposure assessment. The *Exposure Factors Handbook* was updated in 1997 (USEPA, 1997a). Also in 1997, EPA developed *Guiding Principles for Monte Carlo Analysis* (USEPA, 1997b) and published its *Policy for Use of Probabilistic Analysis in Risk Assessment* (see http://www.epa.gov/ncea/mcpolicy.htm). The Monte Carlo guidance can be applied to exposure assessments and risk assessments. The Agency has recently developed the Relative Source Contribution (RSC) Policy for assessing total human exposure to a contaminant and apportioning the RfD among the media of concern, published for the first time in this Methodology.

The Agency has moved toward the use of a bioaccumulation factor (BAF) to reflect the uptake of a contaminant from all sources (e.g., ingestion, sediment) by fish and shellfish, rather than just from the water column as reflected by the use of a bioconcentration factor (BCF) in the 1980 Methodology. The Agency has also developed detailed procedures and guidelines for estimating BAF values.

Another reason for the 2000 Human Health Methodology is the need to bridge the gap between the differences in the risk assessment and risk management approaches used by EPA's Office of Water for the derivation of AWQC under the authority of the CWA and Maximum Contaminant Level Goals (MCLGs) under the Safe Drinking Water Act (SDWA). Three notable differences are the treatment of chemicals designated as Group C, possible human carcinogens

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under the 1996 proposed cancer guidelines, the consideration of non-water sources of exposure when setting an AWQC or MCLG for a noncarcinogen, and cancer risk ranges. Those three differences are described in the three subsections below, respectively.

1.5.1 Group C Chemicals

Chemicals were typically classified as Group C–i.e., possible human carcinogens–under the existing (1986) EPA cancer classification scheme for any of the following reasons:

1) Carcinogenicity has been documented in only one test species and/or only one cancer bioassay and the results do not meet the requirements of "sufficient evidence."

2) Tumor response is of marginal statistical significance due to inadequate design or reporting.

3) Benign, but not malignant, tumors occur with an agent showing no response in a variety of short-term tests for mutagenicity.

4) There are responses of marginal statistical significance in a tissue known to have a high or variable background rate.

The 1986 *Guidelines for Carcinogen Risk Assessment* (hereafter the "1986 cancer guidelines") specifically recognized the need for flexibility with respect to quantifying the risk of Group C, possible human carcinogens. The 1986 cancer guidelines noted that agents judged to be in Group C, possible human carcinogens, may generally be regarded as suitable for quantitative risk assessment, but that case-by-case judgments may be made in this regard.

The EPA Office of Water has historically treated Group C chemicals differently under the CWA and the SDWA. It is important to note that the 1980 AWQC National Guidelines for setting AWQC under the CWA predated EPA's carcinogen classification system, which was proposed in 1984 (USEPA, 1984) and finalized in 1986 (USEPA, 1986a). The 1980 AWQC National Guidelines did not explicitly differentiate among agents with respect to the weight of evidence for characterizing them as likely to be carcinogenic to humans. For all pollutants judged as having adequate data for quantifying carcinogenic risk–including those now classified as Group C–AWQC were derived based on data on cancer incidence. In the1980 AWQC National Guidelines, EPA emphasized that the AWQC for carcinogens should state that the recommended concentration for maximum protection of human health is zero. At the same time, the criteria published for specific carcinogens presented water concentrations for these pollutants corresponding to individual lifetime excess cancer risk levels in the range of 10^{-7} to 10^{-5}.

In the development of national primary drinking water regulations under the SDWA, EPA is required to promulgate a health-based MCLG for each contaminant. The Agency policy has been to set the MCLG at zero for chemicals with strong evidence of carcinogenicity associated with exposure from water. For chemicals with limited evidence of carcinogenicity, including many Group C agents, the MCLG was usually obtained using an RfD based on the

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pollutant's noncancer effects with the application of an additional uncertainty factor of 1 to 10 to account for carcinogenic potential of the chemical. If valid noncancer data for a Group C agent were not available to establish an RfD but adequate data are available to quantify the cancer risk, then the MCLG was based upon a nominal lifetime excess cancer risk in the range of 10^{-6} to10^{-5} (ranging from one case in a population of one million to one case in a population of one hundred thousand). Even in those cases where the RfD approach has been used for the derivation of the MCLG for a Group C agent, the drinking water concentrations associated with excess cancer risks in the range of 10^{-6} to 10^{-5} were also provided for comparison.

It should also be noted that EPA's pesticides program has applied both of the previously described methods for addressing Group C chemicals in actions taken under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and finds both methods applicable on a case-by-case basis. Unlike the drinking water program, however, the pesticides program does not add an extra uncertainty factor to account for potential carcinogenicity when using the RfD approach.

In the 1999 draft revised cancer guidelines, there are no more alphanumeric categories. Instead, there will be longer narratives for hazard characterization that will use consistent descriptive terms when assessing cancer risk.

1.5.2 Consideration of Non-water Sources of Exposure

The 1980 AWQC National Guidelines recommended that contributions from non-water sources, namely air and non-fish dietary intake, be subtracted from the Acceptable Daily Intake (ADI), thus reducing the amount of the ADI "available" for water-related sources of intake. In practice, however, when calculating human health criteria, these other exposures were generally not considered because reliable data on these exposure pathways were not available. Consequently, the AWQC were usually derived such that drinking water and fish ingestion accounted for the entire ADI (now called RfD).

In the drinking water program, a similar "subtraction" method was used in the derivation of MCLGs proposed and promulgated in drinking water regulations through the mid-1980s. More recently, the drinking water program has used a "percentage" method in the derivation of MCLGs for noncarcinogens. In this approach, the percentage of total exposure typically accounted for by drinking water, referred to as the relative source contribution (RSC), is applied to the RfD to determine the maximum amount of the RfD "apportioned" to drinking water reflected by the MCLG value. In using this percentage procedure, the drinking water program also applies a ceiling level of 80 percent of the RfD and a floor level of 20 percent of the RfD. That is, the MCLG cannot account for more than 80 percent of the RfD, nor less than 20 percent of the RfD.

The drinking water program usually takes a conservative approach to public health by applying an RSC factor of 20 percent to the RfD when adequate exposure data do not exist, assuming that the major portion (80 percent) of the total exposure comes from other sources, such as diet.

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In the 2000 Human Health Methodology, guidance for the routine consideration of non-water sources of exposure [both ingestion exposures (e.g., food) and exposures other than the oral route (e.g., inhalation)] is presented. The approach is called the Exposure Decision Tree. Relative source contribution estimates will be made by EPA using this approach, which allows for use of either the subtraction or percentage methods, depending on chemical-specific circumstances, within the 20 to 80 percent range described above.

1.5.3 Cancer Risk Ranges

In addition to the different risk assessment approaches discussed above for deriving AWQC and MCLGs for Group C agents, there have been different risk management approaches by the drinking water and surface water programs on lifetime excess risk values when setting health-based criteria for carcinogens. The surface water program has derived AWQC for carcinogens that generally corresponded to lifetime excess cancer risk levels of 10^{-7} to 10^{-5}. The drinking water program has set MCLGs for Group C agents based on a slightly less stringent risk range of 10^{-6} to 10^{-5}, while MCLGs for chemicals with strong evidence of carcinogenicity (that is, classified as Group A, known, or B probable, human carcinogen) are set at zero. The drinking water program is now following the principles of the 1999 draft revised cancer guidelines to determine the type of low-dose extrapolation based on mode of action.

It is also important to note that under the drinking water program, for those substances having an MCLG of zero, enforceable Maximum Contaminant Levels (MCLs) have generally been promulgated to correspond with cancer risk levels ranging from 10^{-6} to 10^{-4}. Unlike AWQC and MCLGs which are strictly health-based criteria, MCLs are developed with consideration given to the costs and technological feasibility of reducing contaminant levels in water to meet those standards.

With the 2000 Human Health Methodology, EPA will publish its national 304(a) water quality criteria at a 10^{-6} risk level, which EPA considers appropriate for the general population. EPA is increasing the degree of consistency between the drinking water and ambient water programs, given the somewhat different requirements of the CWA and SDWA.

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1.6 OVERVIEW OF THE AWQC METHODOLOGY REVISIONS

The following equations for deriving AWQC include toxicological and exposure assessment parameters which are derived from scientific analysis, science policy, and risk management decisions. For example, values for parameters such as a field-measured BAF or a point of departure from an animal study [in the form of a lowest-observed-adverse-effect level (LOAEL)/no-observed -adverse-effect level (NOAEL)/lower 95 percent confidence limit on a dose associated with a 10 percent extra risk (LED_{10})] are empirically measured using scientific methods. By contrast, the decision to use animal effects as surrogates for human effects involves judgment on the part of the EPA (and similarly, by other agencies) as to the best practice to follow when human data are lacking. Such a decision is, therefore, a matter of science policy. The choice of default fish consumption rates for protection of a certain percentage (i.e., the 90th percentile) of the general population is clearly a risk management decision. In many cases, the Agency has selected parameter values using its best judgment regarding the overall protection afforded by the resulting AWQC when all parameters are combined. For a longer discussion of the differences between science, science policy, and risk management, please refer to Section 2 of this document. Section 2 also provides further details with regard to risk characterization for this Methodology, with emphasis placed on explaining the uncertainties in the overall risk assessment.

The generalized equations for deriving AWQC based on noncancer effects are:

Noncancer Effects[2]

$$AWQC = RfD \cdot RSC \cdot \left(\frac{BW}{DI + \sum_{i=2}^{4} (FI_i \cdot BAF_i)} \right) \qquad \text{(Equation 1-1)}$$

Cancer Effects: Nonlinear Low-Dose Extrapolation

$$AWQC = \frac{POD}{UF} \cdot RSC \cdot \left(\frac{BW}{DI + \sum_{i=2}^{4} (FI_i \cdot BAF_i)} \right) \qquad \text{(Equation 1-2)}$$

[2] Although appearing in this equation as a factor to be multiplied, the RSC can also be an amount subtracted. Refer to the explanation key below the equations.

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Cancer Effects: Linear Low-Dose Extrapolation

$$AWQC = RSD \cdot \left(\frac{BW}{DI + \sum_{i=2}^{4} (FI_i \cdot BAF_i)} \right) \qquad \text{(Equation 1-3)}$$

where:

AWQC	=	Ambient Water Quality Criterion (mg/L)
RfD	=	Reference dose for noncancer effects (mg/kg-day)
POD	=	Point of departure for carcinogens based on a nonlinear low-dose extrapolation (mg/kg-day), usually a LOAEL, NOAEL, or LED_{10}
UF	=	Uncertainty Factor for carcinogens based on a nonlinear low-dose extrapolation (unitless)
RSD	=	Risk-specific dose for carcinogens based on a linear low-dose extrapolation (mg/kg-day) (dose associated with a target risk, such as 10^{-6})
RSC	=	Relative source contribution factor to account for non-water sources of exposure. (Not used for linear carcinogens.) May be either a percentage (multiplied) or amount subtracted, depending on whether multiple criteria are relevant to the chemical.
BW	=	Human body weight (default = 70 kg for adults)
DI	=	Drinking water intake (default = 2 L/day for adults)
FI_i	=	Fish intake at trophic level (TL) I (I = 2, 3, and 4) (defaults for total intake = 0.0175 kg/day for general adult population and sport anglers, and 0.1424 kg/day for subsistence fishers). Trophic level breakouts for the general adult population and sport anglers are: TL2 = 0.0038 kg/day; TL3 = 0.0080 kg/day; and TL4 = 0.0057 kg/day.
BAF_i	=	Bioaccumulation factor at trophic level I (I=2, 3 and 4), lipid normalized (L/kg)

For highly bioaccumulative chemicals where ingestion from water might be considered negligible, EPA is currently evaluating the feasibility of developing and implementing AWQCs that are expressed in terms of concentrations in tissues of aquatic organisms. Such tissue residue criteria might be used as an alternative to AWQCs which are expressed as concentrations in water, particularly in situations where AWQCs are at or below the practical limits for quantifying a chemical in water. Even though tissue residue criteria would not require the use of a BAF in their derivation, implementing such criteria would still require a mechanism for relating chemical loads and concentrations in water and sediment to concentrations in tissues of appropriate fish and shellfish (e.g., a BAF or bioaccumulation model). At this time, no revisions are planned to the Methodology to provide specific guidance on developing fish tissue-based water quality criteria. However, guidance may be provided in the future either as a separate document or integrated in a specific 304(a) water quality criteria document for a chemical that warrants such an approach.

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AWQC for the protection of human health are designed to minimize the risk of adverse effects occurring to humans from chronic (lifetime) exposure to substances through the ingestion of drinking water and consumption of fish obtained from surface waters. The Agency is not recommending the development of additional water quality criteria similar to the "drinking water health advisories" that focus on acute or short-term effects; these are not seen as routinely having a meaningful role in the water quality criteria and standards program. However, as discussed below, there may be some instances where the consideration of acute or short-term toxicity and exposure in the derivation of AWQC is warranted.

Although the AWQC are based on chronic health effects data (both cancer and noncancer effects), the criteria are intended to also be protective against adverse effects that may reasonably be expected to occur as a result of elevated acute or short-term exposures. That is, through the use of conservative assumptions with respect to both toxicity and exposure parameters, the resulting AWQC should provide adequate protection not only for the general population over a lifetime of exposure, but also for special subpopulations who, because of high water- or fish-intake rates, or because of biological sensitivities, have an increased risk of receiving a dose that would elicit adverse effects. The Agency recognizes that there may be some cases where the AWQC based on chronic toxicity may not provide adequate protection for a subpopulation at special risk from shorter-term exposures. The Agency encourages States, Tribes, and others employing the 2000 Human Health Methodology to give consideration to such circumstances in deriving criteria to ensure that adequate protection is afforded to all identifiable subpopulations. (See Section 4.3, Factors Used in the AWQC Computation, for additional discussion of these subpopulations.)

The EPA is in the process of revising its cancer guidelines, including its descriptions of human carcinogenic potential. Once final guidelines are published, they will be the basis for assessment under this methodology. In the meanwhile, the 1986 guidelines are used and extended with principles discussed in EPA's 1999 *Guidelines for Carcinogen Risk Assessment - Review Draft* (hereafter "1999 draft revised cancer guidelines"). These principles arise from new science about cancer discovered in the last 15 years and from EPA policy of recent years supporting full characterization of hazard and risk both for the general population and potentially sensitive groups such as children. These principles are incorporated in recent and ongoing assessments such as the reassessment of dioxin, consistent with the 1986 guidelines. Until final guidelines are published, information is presented to describe risk under both the old guidelines and draft revisions. Dose-response assessment under the 1986 guidelines employs a linearized multistage model to extrapolate tumor dose-response observed in animal or human studies down to zero dose, zero extra risk. The dose-response assessment under EPA's 1999 draft revised cancer guidelines is a two-step process. In the first step, the response data are modeled in the range of empirical observation. Modeling in the observed range is done with biologically based or appropriate curve-fitting modeling. In the second step, extrapolation below the range of observation is accomplished by biologically based modeling if there are sufficient data or by a default procedure (linear, nonlinear, or both). A point of departure (POD) for extrapolation is estimated from modeling observed data. The lower 95 percent confidence limit on a dose associated with 10 percent extra risk (LED_{10}) is the standard POD for low-dose extrapolation. The linear default procedure is a straight line extrapolation to the origin (i.e., zero dose, zero extra risk) from the POD, which is the LED_{10} identified in the observable response

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range. The result of this procedure is generally comparable (within 2-fold) to that of using a linearized multistage model under existing, 1986 guidelines. The linear low-dose extrapolation applies to agents that are best characterized by the assumption of linearity (e.g., direct DNA reactive mutagens) for their MOA. A linear approach would also be applied when inadequate or no information is available to explain the carcinogenic MOA; this is a science policy choice in the interest of public health. If it is determined that the MOA understanding fully supports a nonlinear extrapolation, the AWQC is derived using the nonlinear default which is based on a margin of exposure (MOE) analysis using the LED_{10} as the POD and applying uncertainty factors (UFs) to arrive at an acceptable MOE. There may be situations where it is appropriate to apply both the linear and nonlinear default procedures (e.g., for an agent that is both DNA reactive and active as a promoter at higher doses).

For substances that are carcinogenic, particularly those for which the MOA suggests nonlinearity at low doses, the Agency recommends that an integrated approach be taken in looking at cancer and noncancer effects. If one effect does not predominate, AWQC values should be determined for both carcinogenic and noncarcinogenic endpoints. The lower of the resulting values should be used for the AWQC.

When deriving AWQC for noncarcinogens and carcinogens based on a nonlinear low-dose extrapolation, a factor is included to account for other non-water exposure sources [both ingestion exposures (e.g., food) and exposures other than the oral route (e.g., inhalation)] so that the entire RfD, or POD/UF, is not apportioned to drinking water and fish consumption alone. Guidance is provided in the 2000 Human Health Methodology for determining the factor (i.e., the RSC) to be used for a particular chemical. The Agency is recommending the use of an Exposure Decision Tree procedure to support the determination of the appropriate RSC value for a given water contaminant. In the absence of data, the Agency intends to use 20 percent of the RfD (or POD/UF) as the default RSC in calculating 304(a) criteria or promulgating State or Tribal water quality standards under Section 303(c).

With AWQC derived for carcinogens based on a linear low-dose extrapolation, the Agency will publish recommended criteria values at a 10^{-6} risk level. States and authorized Tribes can always choose a more stringent risk level, such as 10^{-7}. EPA also believes that criteria based on a 10^{-5} risk level are acceptable for the general population as long as States and authorized Tribes ensure that the risk to more highly exposed subgroups (sportfishers or subsistence fishers) does not exceed the 10^{-4} level. Clarification on this risk management decision is provided in Section 2 of this document.

The default fish consumption value for the general adult population in the 2000 Human Health Methodology is 17.5 grams/day, which represents an estimate of the 90th percentile consumption rate for the U.S. adult population based on the U.S. Department of Agriculture's (USDA's) Continuing Survey of Food Intake by Individuals (CSFII) 1994-96 data (USDA, 1998). EPA will use this default intake rate with future national 304(a) criteria derivations or revisions. This default value is chosen to be protective of the majority of the general population. However, States and authorized Tribes are urged to use a fish intake level derived from local data on fish consumption in place of this default value when deriving AWQC, ensuring that the fish intake level chosen is protective of highly exposed individuals in the population. EPA has

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provided default values for States and authorized Tribes that do not have adequate information on local or regional consumption patterns, based on numerous studies that EPA has reviewed on sport anglers and subsistence fishers. EPA's defaults for these population groups are estimates of their average consumption. EPA recommends a default of 17.5 grams/day for sport anglers as an approximation of their average consumption and 142.4 grams/day for subsistence fishers, which falls within the range of averages for this group. Consumption rates for women of childbearing age and children younger than 14 are also provided to maximize protection in those cases where these subpopulations may be at greatest risk.

In the 2000 Human Health Methodology, criteria are derived using a BAF rather than a BCF. To derive the BAF, States and authorized Tribes may use EPA's Methodology or any method consistent with this Methodology. EPA's highest preference in developing BAFs are BAFs based on field-measured data from local/regional fish.

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USEPA (U.S. Environmental Protection Agency). 1999b. *Guidance for Conducting Health Risk Assessment of Chemical Mixtures*. Final Draft. Risk Assessment Forum Technical Panel. Washington, DC. EPA/NCEA-C-0148. September. Website: http://www.epa.gov/ncea/raf/rafpub.htm

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2. CLARIFICATIONS ON THE METHODOLOGY, RISK CHARACTERIZATION, AND OTHER ISSUES FOR DEVELOPING CRITERIA

2.1 IDENTIFYING THE POPULATION SUBGROUP THAT THE AWQC SHOULD PROTECT

Water quality criteria are derived to establish ambient concentrations of pollutants which, if not exceeded, will protect the general population from adverse health impacts from those pollutants due to consumption of aquatic organisms and water, including incidental water consumption related to recreational activities. For each pollutant, chronic criteria are derived to reflect long-term consumption of food and water. An important decision to make when setting AWQC is the choice of the particular population to protect. For instance, criteria could be set to protect those individuals who have average or "typical" exposures, or the criteria could be set so that they offer greater protection to those individuals who are more highly exposed. EPA has selected default parameter values that are representative of several defined populations: adults in the general population; sport (recreational) fishers; subsistence fishers; women of childbearing age (defined as ages 15-44); and children (up to the age of 14). In deciding on default parameter values, EPA is aware that multiple parameters are used in combination when calculating AWQC (e.g., intake rates and body weight). EPA describes the estimated population percentiles that are represented by each of the default exposure parameter values in Section 4.

EPA's national 304(a) criteria are usually derived to protect the majority of the general population from chronic adverse health effects. EPA has used a combination of median values, mean values, and percentile estimates for the parameter value defaults to calculate its national 304(a) criteria. EPA believes that its assumptions afford an overall level of protection targeted at the high end of the general population (i.e., the target population or the criteria-basis population). EPA also believes that this is reasonably conservative and appropriate to meet the goals of the CWA and the 304(a) criteria program. EPA considers that its target protection goal is satisfied if the population as a whole will be adequately protected by the human health criteria when the criteria are met in ambient water. However, associating the derived criteria with a specific population percentile is far more difficult, and such a quantitative descriptor typically requires detailed distributional exposure and dose information. EPA's *Guidelines For Exposure Assessment* (USEPA, 1992) describes the extreme difficulty in making accurate estimates of exposures and indicates that uncertainties at the more extreme ends of the distribution increase greatly. On quantifying population exposures/risks, the guidelines specifically state:

> *In practice, it is difficult even to establish an accurate mean health effect risk for a population. This is due to many complications, including uncertainties in using animal data for human dose-response relationships, nonlinearities in the dose-response curve, projecting incidence data from one group to another dissimilar group, etc. Although it has been common practice to estimate the number of cases of disease, especially cancer, for populations exposed to chemicals, it should be understood that these estimates are not meant to be accurate estimates of real (or actuarial) cases of disease. The estimate's value lies in framing*

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hypothetical risk in an understandable way rather than in any literal interpretation of the term "cases."

Although it is not possible to subject the estimates to such a rigorous analysis (say, for example, to determine what criterion value provides protection of exactly the 90th percentile of the population), EPA believes that the combination of parameter value assumptions achieves its target goal, without being inordinately conservative. The standard assumptions made for the national 304(a) criteria are as follows. The assumed body weight value used is an arithmetic mean, as are the RSC intake estimates of other exposures (e.g., non-fish dietary), when data are available. The BAF component data (e.g., for lipid values, for particulate and dissolved organic carbon) are based on median (i.e., 50th percentile) values. The drinking water intake values are approximately 90th percentile estimates and fish intake values are 90th percentile estimates. EPA believes the use of these values will result in 304(a) criteria that are protective of a majority of the population; this is EPA's goal.

However, EPA also strongly believes that States and authorized Tribes should have the flexibility to develop criteria, on a site-specific basis, that provide additional protection appropriate for highly exposed populations. EPA is aware that exposure patterns in general, and fish consumption in particular, vary substantially. EPA understands that highly exposed populations may be widely distributed geographically throughout a given State or Tribal area. EPA recommends that priority be given to identifying and adequately protecting the most highly exposed population. Thus, if the State or Tribe determines that a highly exposed population is at greater risk and would not be adequately protected by criteria based on the general population, and by the national 304(a) criteria in particular, EPA recommends that the State or Tribe adopt more stringent criteria using alternative exposure assumptions.

EPA has provided recommended default intake rates for various population groups for State and Tribal consideration. EPA does not intend for these alternative default values to be prescriptive. EPA strongly emphasizes its preference that States and Tribes use local or regional data over EPA's defaults, if they so choose, as being more representative of their population groups of concern.

In the course of updating the 2000 Human Health Methodology, EPA received some questions regarding the population groups for which the criteria would be developed. EPA does not intend to derive multiple 304(a) criteria for all subpopulation groups for every chemical. As stated above, criteria that address chronic adverse health effects are most applicable to the CWA Section 304(a) criteria program and the chemicals evaluated for this program. If EPA determined that pregnant women/fetuses or young children were the target population (or criteria basis population) of a chemical's RfD or POD/UF, then the 304(a) criteria would be developed using exposure parameters for that subgroup. This would only be relevant for acute or subchronic toxicity situations. This does not conflict with the fact that chronic health effects potentially reflect a person's exposure during both childhood and adult years.

For RfD-based and POD/UF-based chemicals, EPA's policy is that, in general, the RfD (or POD/UF) should not be exceeded and the exposure assumptions used should reflect the population of concern. It is recommended that when a State or authorized Tribe sets a

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waterbody-specific AWQC, they consider the populations most exposed via water and fish. EPA's policy on cancer risk management goals is discussed in Section 2.4.

Health Risks to Children

In recognition that children have a special vulnerability to many toxic substances, EPA's Administrator directed the Agency in 1995 to explicitly and consistently take into account environmental health risks to infants and children in all risk assessments, risk characterizations, and public health standards set for the United States. In April 1997, President Clinton signed Executive Order 13045 on the protection of children from environmental health risks, which assigned a high priority to addressing risks to children. In May 1997, EPA established the Office of Children's Health Protection to ensure the implementation of the President's Executive Order. EPA has increased efforts to ensure its guidance and regulations take into account risks to children. Circumstances where risks to children should be considered in the context of the 2000 Human Health Methodology are discussed in the Section 3.2, Noncancer Effects (in terms of developmental and reproductive toxicity) and in Section 4, Exposure (for appropriate exposure intake parameters).

Details on risk characterization and the guiding principles stated above are included in EPA's March 21, 1995 policy statement and the discussion of risk characterization (USEPA, 1995) and the 1999 *Guidelines for Carcinogen Risk Assessment. Review Draft* (USEPA, 1999a) and the *Reproductive and Toxicity Risk Assessment Guidelines* of 1996 (USEPA, 1996b).

2.2 SCIENCE, SCIENCE POLICY, AND RISK MANAGEMENT

An important part of risk characterization, as described later in Section 2.7, is to make risk assessments transparent. This means that conclusions drawn from the science are identified separately from policy judgments and risk management decisions, and that the use of default values or methods, as well as the use of assumptions in risk assessments, are clearly articulated. In this Methodology, EPA has attempted to separate scientific analysis from science policy and risk management decisions for clarity. This should allow States and Tribes (who are also prospective users of this Methodology) to understand the elements of the Methodology accurately and clearly, and to easily separate out the scientific decisions from the science policy and risk management decisions. This is important so that when questions are asked regarding the scientific merit, validity, or apparent stringency or leniency of AWQC, the implementer of the criteria can clearly explain what judgments were made to develop the criterion in question and to what degree these judgments were based on science, science policy, or risk management. To some extent this process will also be displayed in future AWQC documents.

When EPA speaks of science or scientific analysis, it is referring to the extraction of data from toxicological or exposure studies and surveys with a minimum of judgment being used to make inferences from the available evidence. For example, if EPA is describing a POD from an animal study (e.g., a LOAEL), this is usually determined as a lowest dose that produces an observable adverse effect. This would constitute a scientific determination. Judgments applying science policy, however, may enter this determination. For example, several scientists may differ in their opinion of what is adverse, and this in turn can influence the selection of a LOAEL

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in a given study. The use of an animal study to predict effects in a human in the absence of human data is an inherent science policy decision. The selection of specific UFs when developing an RfD is another example of science policy. In any risk assessment, a number of decision points occur where risk to humans can only be inferred from the available evidence. Both scientific judgments and policy choices may be involved in selecting from among several possible inferences when conducting a risk assessment.

Risk management is the process of selecting the most appropriate guidance or regulatory actions by integrating the results of risk assessment with engineering data and with social, economic, and political concerns to reach a decision. In this Methodology, the choice of a default fish consumption rate which is protective of 90 percent of the general population is a risk management decision. The choice of an acceptable cancer risk by a State or Tribe is a risk management decision.

Many of the components in the 2000 Human Health Methodology are an amalgam of science, science policy, and/or risk management. For example, most of the default values chosen by EPA are based on examination of scientific data and application of either science policy or risk management. This includes the default assumption of 2 liters a day of drinking water; the assumption of 70 kilograms for an adult body weight; the use of default percent lipid and particulate organic carbon/dissolved organic carbon (POC/DOC) for developing national BAFs; the default fish consumption rates for the general population and sport and subsistence anglers; and the choice of a default cancer risk level. Some decisions are more grounded in science and science policy (such as the choice of default BAFs) and others are more obviously risk management decisions (such as the determination of default fish consumption rates and cancer risk levels). Throughout the 2000 Human Health Methodology, EPA has identified the kind of decision necessary to develop defaults and what the basis for the decision was. More details on the concepts of science analysis, science policy, risk management, and how they are introduced into risk assessments are included in *Risk Assessment in the Federal Government: Managing the Process* (NRC, 1983).

2.3 SETTING CRITERIA TO PROTECT AGAINST MULTIPLE EXPOSURES FROM MULTIPLE CHEMICALS (CUMULATIVE RISK)

EPA is very much aware of the complex issues and implications of cumulative risk and has endeavored to begin developing an overall approach at the Agency-wide level. Assuming that multiple exposures to multiple chemicals are additive is scientifically sound if they exhibit the same toxic endpoints and modes of action. There are numerous publications relevant to cumulative risk that can assist States and Tribes in understanding the complex issues associated with cumulative risk. These include the following:

- Durkin, P.R., R.C. Hertzberg, W. Stiteler, and M. Mumtaz. 1995. The identification and testing of interaction patterns. *Toxicol. Letters* 79:251-264.

- Hertzberg, R.C., G. Rice, and L.K. Teuschler. 1999. Methods for health risk assessment of combustion mixtures. In: *Hazardous Waste Incineration: Evaluating the Human*

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Health and Environmental Risks. S. Roberts, C. Teaf and J. Bean, (eds). CRC Press LLC, Boca Raton, FL. Pp. 105-148.

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- USEPA. 1989b. *Interim Procedures for Estimating Risks Associated with Exposures to Mixtures of Chlorinated Dibenzo-p-Dioxins and -Dibenzofurans (CDDs and CDFs) and 1989 Update*. Risk Assessment Forum. Washington, DC. EPA/625/3-89/016. March.

The Agency's program offices are also engaged in on-going discussions of the great complexities, methodological challenges, data adequacy needs and other information gaps, as well as the science policy and risk management decisions that will need to be made, as they pursue developing a sound strategy and, eventually, specific guidance for addressing cumulative

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risks. As a matter of internal policy, EPA is committed to refining the Methodology as advances in relevant aspects of the science improve, as part of the water quality criteria program.

2.4 CANCER RISK RANGE

For deriving 304(a) criteria or promulgating water quality criteria for States and Tribes under Section 303(c) based on the 2000 Human Health Methodology, EPA intends to use the 10^{-6} risk level, which the Agency believes reflects an appropriate risk for the general population. EPA's program office guidance and regulatory actions have evolved in recent years to target a 10^{-6} risk level as an appropriate risk for the general population. EPA has recently reviewed the policies and regulatory language of other Agency mandates (e.g., the Clean Air Act Amendments of 1990, the Food Quality Protection Act) and believes the target of a 10^{-6} risk level is consistent with Agency-wide practice.

EPA believes that both 10^{-6} and 10^{-5} may be acceptable for the general population and that highly exposed populations should not exceed a 10^{-4} risk level. States or Tribes that have adopted standards based on criteria at the 10^{-5} risk level can continue to do so, if the highly exposed groups would at least be protected at the 10^{-4} risk level. However, EPA is not automatically assuming that 10^{-5} will protect "the highest consumers" at the 10^{-4} risk level. Nor is EPA advocating that States and Tribes automatically set criteria based on assumptions for highly exposed population groups at the 10^{-4} risk level. The Agency is simply endeavoring to add that a specific determination should be made to ensure that highly exposed groups do not exceed a 10^{-4} risk level. EPA understands that fish consumption rates vary considerably, especially among subsistence populations, and it is such great variation among these population groups that may make either 10^{-6} or 10^{-5} protective of those groups at a 10^{-4} risk level. Therefore, depending on the consumption patterns in a given State or Tribal jurisdiction, a 10^{-6} or 10^{-5} risk level could be appropriate. In cases where fish consumption among highly exposed population groups is of a magnitude that a 10^{-4} risk level would be exceeded, a more protective risk level should be chosen. Such determinations should be made by the State or Tribal authorities and are subject to EPA's review and approval or disapproval under Section 303(c) of the CWA.

Adoption of a 10^{-6} or 10^{-5} risk level, both of which States and authorized Tribes have chosen in adopting water quality standards to date, represents a generally acceptable risk management decision, and EPA intends to continue providing this flexibility to States and Tribes. EPA believes that such State or Tribal decisions are consistent with Section 303(c) if the State or authorized Tribe has identified the most highly exposed subpopulation, has demonstrated that the chosen risk level is adequately protective of the most highly exposed subpopulation, and has completed all necessary public participation. States and authorized Tribes also have flexibility in how they demonstrate this protectiveness and obtain such information. A State or authorized Tribe may use existing information as well as collect new information in making this determination. In addition, if a State or authorized Tribe does not believe that the 10^{-6} risk level adequately protects the exposed subpopulations, water quality criteria based on a more stringent risk level may be adopted. This discretion includes combining the 10^{-6} risk level with fish consumption rates for highly exposed population groups.

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It is important to understand that criteria for carcinogens are based on chosen risk levels that inherently reflect, in part, the exposure parameters used to derive those values. Therefore, changing the exposure parameters also changes the risk. Specifically, the incremental cancer risk levels are *relative*, meaning that any given criterion associated with a particular cancer risk level is also associated with specific exposure parameter assumptions (e.g., intake rates, body weights). When these exposure parameter values change, so does the relative risk. For a criterion derived on the basis of a cancer risk level of 10^{-6}, individuals consuming up to 10 times the assumed fish intake rate would not exceed a 10^{-5} risk level. Similarly, individuals consuming up to 100 times the assumed rate would not exceed a 10^{-4} risk level. Thus, for a criterion based on EPA's default fish intake rate (17.5 gm/day) and a risk level of 10^{-6}, those consuming a pound per day (i.e., 454 grams/day) would potentially experience between a 10^{-5} and a 10^{-4} risk level (closer to a 10^{-5} risk level). (Note: Fish consumers of up to 1,750 gm/day would not exceed the 10^{-4} risk level.) If a criterion were based on high-end intake rates and the relative risk of 10^{-6}, then an average fish consumer would be protected at a cancer risk level of approximately 10^{-8}. The point is that the risks for different population groups are not the same.

2.5 MICROBIOLOGICAL AMBIENT WATER QUALITY CRITERIA

Guidance for deriving microbiological AWQC is not a part of this Methodology. In 1986, EPA published *Ambient Water Quality Criteria for Bacteria - 1986* (USEPA, 1986a), which updated and revised bacteriological criteria previously published in 1976 in *Quality Criteria for Water* (USEPA, 1976). The inclusion of guidance for deriving microbiological AWQC was considered in the 1992 national workshop that initiated the effort to revise the 1980 Methodology and was recommended by the SAB in 1993. Since that time, however, efforts separate from these Methodology revisions have addressed microbiological AWQC concerns. The purpose of this section is to briefly describe EPA's current recommendations and activities.

EPA's *Ambient Water Quality Criteria for Bacteria - 1986* recommends the use of *Escherichia coli* and enterococci rather than fecal coliforms (USEPA, 1986a). EPA's criteria recommendations are:

- Fresh water: *E. coli* not to exceed 126/100 ml or enterococci not to exceed 33/100 ml; and

- Marine water: enterococci not to exceed 35/100 ml.

These criteria should be calculated as the geometric mean based on five equally spaced samples taken over a 30-day period.

In addition, EPA recommends that States adopt a single sample maximum, based on the expected frequency of use. No sample taken should exceed this value. EPA specifies appropriate single sample maximum values in the 1986 criteria document.

<u>Current Activities and Plans for Future Work</u>

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EPA has identified development of microbial water quality criteria as part of its strategy to control waterborne microbial disease, by controlling pathogens in waterbodies and by protecting designated uses, such as recreation and public water supplies. The program fosters an integrated approach to protect both ground-water and surface water sources. EPA plans to conduct additional monitoring for *Cryptosporidium parvum* and *E. coli*, and determine action plans in accordance with the results of this monitoring.

EPA recommends no change at this time in the stringency of its bacterial criteria for recreational waters; existing criteria and methodologies from 1986 will still apply. The recommended methods for *E. coli* and enterococci have been improved. As outlined in the *Action Plan for Beaches and Recreational Waters* (Beach Action Plan, see below), the Agency plans to conduct national studies on improving indicators together with epidemiology studies for new criteria development (USEPA, 1999b). The Agency is also planning to establish improved temporal and spatial monitoring protocols.

In the Beach Action Plan, EPA identifies a multi-year strategy for monitoring recreational water quality and communicating public health risks associated with potentially pathogen-contaminated recreational rivers, lakes, and ocean beaches. It articulates the Agency's rationale and goals in addressing specific problems and integrates all associated program, policy, and research needs and directions. The Beach Action Plan also provides information on timing, products and lead organization for each activity. These include activities and products in the areas of program development, risk communication, water quality indicator research, modeling and monitoring research, and exposure and health effects research.

Recently, EPA approved new 24-hour *E. coli* and enterococcus tests for recreational waters that may be used as an alternative to the 48-hour test (USEPA, 1997). EPA anticipates proposing these methods for inclusion in the 40 CRF 136 in the Fall of 2000. EPA has also published a video with accompanying manual on the original and newer methods for enterococci and *E. coli* (USEPA, 2000).

As part of the Beach Action Plan, EPA made the following recommendations for further Agency study:

- Future criteria development should consider the risk of diseases other than gastroenteritis. EPA intends to consider and evaluate such water-related exposure routes as inhalation and dermal absorption when addressing microbial health effects. The nature and significance of other than the classical waterborne pathogens are to some degree tied to the particular type of waste sources.

- A new set of indicator organisms may need to be developed for tropical water if it is proven that the current fecal indicators can maintain viable cell populations in the soil and water for significant periods of time in uniform tropical conditions. Some potential alternative indicators to be fully explored are coliphage, other bacteriophage, and *Clostridium perfringens*.

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- Because animal sources of pathogens of concern for human infection such as *Giardia lamblia*, *Cryptosporidium parvum*, and *Escherichia coli* 0157:H7 may be waterborne or washed into water and thus become a potential source for infection, they should not be ignored in risk assessment. A likely approach would be phylogenetic differentiation; that is, indicators that are specific to, or can discriminate among, animal sources.

- EPA intends to develop additional data on secondary infection routes and infection rates from prospective epidemiology studies and outbreaks from various types of exposure (e.g., shellfish consumption, drinking water, recreational exposure).

- EPA needs to improve sampling strategies for recreational water monitoring including consideration of rainfall and pollution events to trigger sampling.

2.6 RISK CHARACTERIZATION CONSIDERATIONS

On March 21, 1995, EPA's Administrator issued the *EPA Risk Characterization Policy and Guidance* (USEPA, 1995). This policy and guidance is intended to ensure that characterization information from each stage of a risk assessment is used in forming conclusions about risk and that this information is communicated from risk assessors to risk managers, and from EPA to the public. The policy also provides the basis for greater clarity, transparency, reasonableness, and consistency in risk assessments across EPA programs. The fundamental principles which form the basis for a risk characterization are as follows:

- Risk assessments should be transparent, in that the conclusions drawn from the science are identified separately from policy judgments, and the use of default values or methods and the use of assumptions in the risk assessment are clearly articulated.

- Risk characterizations should include a summary of the key issues and conclusions of each of the other components of the risk assessments, as well as describe the likelihood of harm. The summary should include a description of the overall strengths and limitations (including uncertainties) of the assessment and conclusions.

- Risk characterizations should be consistent in general format, but recognize the unique characteristics of each specific situation.

- Risk characterizations should include, at least in a qualitative sense, a discussion of how a specific risk and its context compares with similar risks. This may be accomplished by comparisons with other pollutants or situations on which the Agency has decided to act, or other situations with which the public may be familiar. The discussion should highlight the limitations of such comparisons.

- Risk characterization is a key component of risk communication, which is an interactive process involving exchange of information and expert opinion among individuals, groups, and institutions.

Additional guiding principles include:

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- The risk characterization integrates the information from the hazard identification, dose-response, and exposure assessments, using a combination of qualitative information, quantitative information, and information regarding uncertainties.

- The risk characterization includes a discussion of uncertainty and variability in the risk assessment.

- Well-balanced risk characterizations present conclusions and information regarding the strengths and limitations of the assessment for other risk assessors, EPA decision-makers, and the public.

In developing the methodology presented here, EPA has closely followed the risk characterization guiding principles listed above. As States and Tribes adopt criteria using the 2000 Human Health Methodology, they are strongly encouraged to follow EPA's risk characterization guidance. There are a number of areas within the Methodology and criteria development process where risk characterization principles apply:

- Integration of cancer and noncancer assessments with exposure assessments, including bioaccumulation potential determinations, in essence, weighing the strengths and weaknesses of the risk assessment as a whole when developing a criterion.

- Selecting a fish consumption rate, either locally derived or the national default value, within the context of a target population (e.g., sensitive subpopulations) as compared to the general population.

- Presenting cancer and/or noncancer risk assessment options.

- Describing the uncertainty and variability in the hazard identification, the dose-response, and the exposure assessment.

2.7 DISCUSSION OF UNCERTAINTY

2.7.1 Observed Range of Toxicity Versus Range of Environmental Exposure

When characterizing a risk assessment, an important distinction to make is between the observed range of adverse effects (from an epidemiology or animal study) and the environmentally observed range of exposure (or anticipated human exposure) to the contaminant. In many cases, EPA intends to apply default factors to account for uncertainties or incomplete knowledge in developing RfDs or cancer risk assessments using nonlinear low-dose extrapolation to provide a margin of protection. In reality, the actual effect level and the environmental exposure levels may be separated by several orders of magnitude. The difference between the dose causing some observed response and the anticipated human exposure should be described by risk assessors and managers, especially when comparing criteria to environmental levels of a contaminant.

2.7.2 Continuum of Preferred Data/Use of Defaults

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In both toxicological and exposure assessments, EPA has defined a continuum of preferred data for toxicological assessments ranging from a highest preference for chronic human data (e.g., studies that examine a long-term exposure of humans to a chemical, usually from occupational and/or residential exposure) and actual field data for many of the exposure parameter values (e.g., locally derived fish consumption rates, waterbody-specific bioaccumulation rates), to default values which are at the lower end of the preference continuum. EPA has supplied default values for all of the risk assessment parameters in the 2000 Human Health Methodology; however, it is important to note that when default values are used, the uncertainty in the final risk assessment may be higher, and the final resulting criterion may not be as applicable to local conditions, than is a risk assessment derived from human/field data. Using defaults assumes generalized conditions and may not capture the actual variability in the population (e.g., sensitive subpopulations/high-end consumers). If defaults are chosen as the basis for criteria, these inherent uncertainties should be communicated to the risk manager and the public. While this continuum is an expression of preference on the part of EPA, it does not imply in any way that any of the choices are unacceptable or scientifically indefensible.

2.7.3 Significant Figures

The number of significant figures in a numeric value is the number of certain digits plus one estimated digit. Digits should not be confused with decimal places. For example, 15.1, 0.0151, and 0.0150 all have 3 significant figures. Decimal places may have been used to maintain the correct number of significant figures, but in themselves they do not indicate significant figures (Brinker, 1984). Since the number of significant figures must include only one estimated digit, the sources of input parameters (e.g., fish consumption and water consumption rates) should be checked to determine the number of significant figures associated with data they provide. However, the original measured values may not be available to determine the number of significant figures in the input parameters. In these situations, EPA recommends utilizing the data as presented.

When developing criteria, EPA recommends rounding the number of significant figures at the end of the criterion calculation to the same number of significant figures in the least precise parameter. This is a generally accepted practice which can be found described in greater detail in APHA (1992) and Brinker (1984). The general rule is that for multiplication or division, the resulting value should not possess any more significant figures than is associated with the factor in the calculation with the least precision. When numbers are added or subtracted, the number that has the fewest decimal places, not necessarily the fewest significant figures, puts the limit on the number of places that justifiably may be carried in the sum or difference. Rounding off a number is the process of dropping one or more digits so that the value contains only those digits that are significant or necessary in subsequent computations (Brinker, 1984). The following rounding procedures are recommended: (1) if the digit 6, 7, 8, or 9 is dropped, increase the preceding digit by one unit; (2) if the digit 0, 1, 2, 3, or 4 is dropped, do not alter the preceding digit; and (3) if the digit 5 is dropped, round off the preceding digit to the nearest even number (e.g., 2.25 becomes 2.2 and 2.35 becomes 2.4) (APHA, 1992; Brinker, 1984).

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EPA recommends that calculations of water quality criteria be performed without rounding of intermediate step values. The resulting criterion may be rounded to a manageable number of decimal places. However, in no case should the number of digits presented exceed the number of significant figures implied in the data and calculations performed on them. The term "intermediate step values" refers to values of the parameters in Equations 1-1 through 1-3. The final step is considered the resulting AWQC. Although AWQC are, in turn, used for purposes of establishing water quality-based effluent limits (WQBELs) in National Pollutant Discharge Elimination System (NPDES) permits, calculating total maximum daily loads (TMDLs), and applicable or relevant and appropriate requirements (ARARs) for Superfund, they are considered the final step of this Methodology and, for the purpose of this discussion, where the rounding should occur.

The determination of appropriate significant figures inevitably involves some judgment given that some of the equation parameters are adopted default exposure values. Specifically, the default drinking water intake rate of 2 L/day is a value adopted to represent a majority of the population over the course of a lifetime. Although supported by drinking water consumption survey data, this value was adopted as a policy decision and, as such, does not have to be considered in determining the parameter with the least precision. That is, the resulting AWQC need not always be reduced to one significant digit. Similarly, the 70-kg adult body weight has been adopted Agency-wide and represents a default policy decision.

The following example with a simplified AWQC equation illustrates the rule described above. The example is for hexachlorobutadiene (HCBD), which EPA used to demonstrate the 1998 draft Methodology revisions (USEPA, 1998b). The parameters that were calculated (i.e., not policy adopted values) include values with significant figures of two (the POD and RSC), three (the UF), and four (the FI and BAF). Based on the 2000 Human Health Methodology, the final criterion should be rounded to two significant figures. The bold numbers in parentheses indicate the number of significant figures and those with asterisks also indicate Agency adopted policy values.

$$AWQC = \frac{POD}{UF} \cdot RSC \cdot \left(\frac{BW}{DI + (FI \cdot BAF)} \right) \qquad \text{(Equation 2-1)}$$

Example [Refer to draft HCBD document for details on the POD/UF, RSC and BAF data (EPA 822-R-98-004). Also note that the fish intake rate in this example is the revised value.]:

$$AWQC = \left(\frac{0.054\mathbf{(2)}}{300\mathbf{(3)}} - 1.2 \times 10^{-4}\mathbf{(2)} \right) \times \left(\frac{70\mathbf{(2^*)}}{2\mathbf{(1^*)} + (0.01750\mathbf{(4)} \times 3{,}180\mathbf{(4)})} \right)$$

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AWQC = 7.3×10^{-5} mg/L (0.073 µg/L, rounded from 7.285×10^{-2} µg/L)
* represents Agency adopted policy value

A number of the values used in the equation may result in intermediate step values that have more than four figures past the decimal place and may be carried throughout the calculation. However, carrying more than four figures past the decimal place (equivalent to the most precise parameter) is unnecessary as it has no effect on the resulting criterion value.

2.8 OTHER CONSIDERATIONS

2.8.1 Minimum Data Considerations

For many of the preceding technical areas, considerations have been presented for data quality in developing toxicological and exposure assessments. For greater detail and discussion of minimum data recommendations, the reader is referred to the specific sections in the Methodology on cancer and noncancer risk assessments (and especially to the referenced EPA risk assessment guidelines documents), exposure assessment, and bioaccumulation assessment, in addition to the TSD volumes for each.

2.8.2 Site-Specific Criterion Calculation

The 2000 Human Health Methodology allows for site-specific modifications by States and Tribes to reflect local environmental conditions and human exposure patterns. "Local" may refer to any appropriate geographic area where common aquatic environmental or exposure patterns exist. Thus "local" may signify Statewide, regional, a river reach, or an entire river.

Such site-specific criteria may be developed as long as the site-specific data, either toxicological or exposure-related, is justifiable. For example, when using a site-specific fish consumption rate, a State should use a value that represents at least the central tendency of the population surveyed (either sport or subsistence, or both). If a site-specific fish consumption rate for sport anglers or subsistence anglers is lower than an EPA default value, it may be used in calculating AWQC. However, to justify such a level (either higher or lower than EPA defaults), the State should assemble appropriate survey data to arrive at a defensible site-specific fish consumption rate.

Such data must also be submitted to EPA for its review when approving or disapproving State or Tribal water quality standards under Section 303(c). The same conditions apply to site-specific calculations of BAF, percent fish lipid, or the RSC. In the case of deviations from toxicological values (i.e., IRIS values: verified noncancer and cancer assessments), EPA strongly recommends that the data upon which the deviation is based be presented to and approved by the Agency before a criterion is developed.

Additional guidance on site-specific modifications to the 2000 Human Health Methodology is provided in each of the three TSD volumes.

2.8.3 Organoleptic Criteria

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Organoleptic criteria define concentrations of chemicals or materials which impart undesirable taste and/or odor to water. Organoleptic effects, while significant from an aesthetic standpoint, are not a significant health concern. In developing and utilizing such criteria, two factors must be appreciated: (1) the limitations of most organoleptic data; and (2) the human health significance of organoleptic properties. In the past, EPA has developed organoleptic criteria if organoleptic data were available for a specific contaminant. The 1980 AWQC National Guidelines made a clear distinction that organoleptic criteria and toxicity-based criteria are derived from completely different endpoints, and that organoleptic criteria have no demonstrated relationship to potential adverse human health effects because there is no toxicological basis. EPA acknowledges that if organoleptic effects (i.e., objectionable taste and odor) cause people to reject the water and its designated uses, then the public is effectively deprived of the natural resource. It is also possible that intense organoleptic characteristics could result in depressed fluid intake which, in turn, might lead to an indirect human health effect via decreased fluid consumption. Although EPA has developed organoleptic criteria in the past and may potentially do so in the future, this will not be a significant part of the water quality criteria program. EPA encourages the development of organoleptic criteria when States and Tribes believe they are needed. However, EPA cautions States and Tribes that the quality of organoleptic data is often significantly less than that of toxicologic data used in establishing health-based criteria. Therefore, a comprehensive evaluation of available organoleptic data should be made, and the selection of the most appropriate database for the criterion should be based on sound scientific judgment.

In 1980, EPA provided recommended criteria summary language when both types of data are available. The following format was used and is repeated here:

> *For comparison purposes, two approaches were used to derive criterion levels for ____. Based on available toxicity data, for the protection of public health the derived level is ____. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water the estimated level is ____. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have no demonstrated relationship to potential adverse human health effects.*

Similarly, the 1980 Methodology recommended that in those instances where a level to limit toxicity cannot be derived, the following statement should be provided:

> *Sufficient data are not available for ____ to derive a level which would protect against the potential toxicity of this compound.*

2.8.4 Criteria for Chemical Classes

The 2000 Human Health Methodology also allows for the development of a criterion for classes of chemicals, as long as a justification is provided through the analysis of mechanistic data, toxicokinetic data, structure-activity relationship data, and limited acute and chronic toxicity data. When potency differences between members of a class is great (such as in the case

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of chlorinated dioxins and furans), toxicity equivalency factors (TEFs) may be more appropriately developed than one class criterion.

A chemical class is defined as any group of chemical compounds which are similar in chemical structure and biological activity, and which frequently occur together in the environment usually because they are generated by the same commercial process. In criterion development, isomers should be regarded as part of a chemical class rather than as a single compound. A class criterion, therefore, is an estimate of risk/safety which applies to more than one member of a class. It involves the use of available data on one or more chemicals of a class to derive criteria for other compounds of the same class in the event that there are insufficient data available to derive compound-specific criteria. The health-based criterion may apply to the water concentration of each member of the class, or may apply to the sum of the water concentrations of the compounds within the class. Because relatively minor structural changes within the class of compounds can have pronounced effects on their biological activities, reliance on class criteria should be minimized depending on the data available.

The following guidance should also be followed when considering the development of a class criterion.

- A detailed review of the chemical and physical properties of the chemicals within the group should be made. A close relationship within the class with respect to chemical activity would suggest a similar potential to reach common biological sites within tissues. Likewise, similar lipid solubilities would suggest the possibility of comparable absorption and distribution.

- Qualitative and quantitative toxicological data for chemicals within the group should be examined. Adequate toxicological data on a number of compounds within a group provides a more reasonable basis for extrapolation to other chemicals of the same class than minimal data on one chemical or a few chemicals within the group.

- Similarities in the nature of the toxicological response to chemicals in the class provides additional support for the prediction that the response to other members of the class may be similar. In contrast, where the biological response has been shown to differ markedly on a qualitative and quantitative basis for chemicals within a class, the extrapolation of a criterion to other members is not appropriate.

- Additional support for the validity of extrapolation of a criterion to other members of a class could be provided by evidence of similar metabolic and toxicokinetic data for some members of the class.

Additional guidance is described in the *Technical Support Document on Health Risk Assessment of Chemical Mixtures* (USEPA, 1990).

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2.9.5 Criteria for Essential Elements

Developing criteria for essential elements, particularly metals, must be a balancing act between toxicity and the requirement for good health. The AWQC must consider essentiality and cannot be established at levels that would result in deficiency of the element in the human population. The difference between the recommended daily allowance (RDA) and the daily doses causing a specified risk level for carcinogens or the RfDs for noncarcinogens defines the spread of daily doses within which the criterion may be derived. Because errors are inherent in defining both essential and adverse-effect levels, the criterion is derived from a dose level near the center of such dose ranges.

The process for developing criteria for essential elements should be similar to that used for any other chemical with minor modifications. The RfD represents concern for one end of the exposure spectrum (toxicity), whereas the RDA represents the other end (minimum essentiality). While the RDA and RfD values might occasionally appear to be similar in magnitude to one another, it does not imply incompatibility of the two methodological approaches, nor does it imply inaccuracy or error in either calculation.

2.9 REFERENCES

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3. RISK ASSESSMENT

This section describes the methods used to estimate ambient water quality criteria (AWQC) for the protection of human health for carcinogenic chemicals (Section 3.1) and for noncarcinogenic chemicals (Section 3.2).

3.1 CANCER EFFECTS

3.1.1 Background on EPA Cancer Risk Assessment Guidelines

The current EPA *Guidelines for Carcinogen Risk Assessment* were published in 1986 (USEPA, 1986a, hereafter the "1986 cancer guidelines"). The 1986 cancer guidelines categorize chemicals into alpha-numerical Groups: A, known human carcinogen (sufficient evidence from epidemiological studies or other human studies); B, probable human carcinogen (sufficient evidence in animals and limited or inadequate evidence in humans); C, possible human carcinogen (limited evidence of carcinogenicity in animals in the absence of human data); D, not classifiable (inadequate or no animal evidence of carcinogenicity); and E, evidence of noncarcinogenicity for humans (no evidence of carcinogenicity in at least two adequate animal tests in different species or in both adequate epidemiological and animal studies). Within Group B there are two subgroups, Groups B1 and B2. Group B1 is reserved for agents for which there is limited evidence of carcinogenicity from epidemiological studies. Group B2 is generally for agents for which there is sufficient evidence from animal studies and for which there is inadequate evidence or no data from epidemiological studies (USEPA, 1986). The system was similar to that used by the International Agency for Research on Cancer (IARC).

The 1986 cancer guidelines include guidance on what constitutes sufficient, limited, or inadequate evidence. In epidemiological studies, sufficient evidence indicates a causal relationship between the agent and human cancer; limited evidence indicates that a causal relationship is credible, but that alternative explanations, such as chance, bias, or confounding, could not adequately be excluded; inadequate evidence indicates either lack of pertinent data, or a causal interpretation is not credible. In general, although a single study may be indicative of a cause-effect relationship, confidence in inferring a causal association is increased when several independent studies are concordant in showing the association. In animal studies, sufficient evidence includes an increased incidence of malignant tumors or combined malignant and benign tumors:

- In multiple species or strains;
- In multiple experiments (e.g., with different routes of administration or using different dose levels);
- To an unusual degree in a single experiment with regard to high incidence, unusual site or type of tumor, or early age at onset;
- Additional data on dose-response, short-term tests, or structural activity relationships.

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In the 1986 cancer guidelines, hazard identification and the weight-of-evidence process focus on tumor findings. The weight-of-evidence approach for making judgments about cancer hazard analyzes human and animal tumor data separately, then combines them to make the overall conclusion about potential human carcinogenicity. The next step of the hazard analysis is an evaluation of supporting evidence (e.g., mutagenicity, cell transformation) to determine whether the overall weight-of-evidence conclusion should be modified.

For cancer risk quantification, the 1986 cancer guidelines recommend the use of linearized multistage model (LMS) as the only default approach. The 1986 cancer guidelines also mention that a low-dose extrapolation model other than the LMS might be considered more appropriate based on biological grounds. However, no guidance is given in choosing other approaches. The 1986 cancer guidelines recommended the use of body weight raised to the 2/3 power ($BW^{2/3}$) as a dose scaling factor between species.

3.1.2 EPA's Proposed Guidelines for Carcinogen Risk Assessment and the Subsequent July, 1999 Draft Revised Cancer Guidelines

In 1996, EPA published *Proposed Guidelines for Carcinogen Risk Assessment* (USEPA, 1996a, hereafter the "1996 proposed cancer guidelines"). After the publication of the 1996 proposed cancer guidelines and a February, 1997 and January, 1999 Science Advisory Board (SAB) review, a revision was made in July, 1999 *Guidelines for Carcinogen Risk Assessment - Review Draft* (hereafter the "1999 draft revised cancer guidelines"; USEPA, 1999a), and an SAB meeting was convened to review this revised document. When final guidelines are published, they will replace the 1986 cancer guidelines. These revisions are designed to ensure that the Agency's cancer risk assessment methods reflect the most current scientific information and advances in risk assessment methodology.

In the meanwhile, the 1986 guidelines are used and extended with principles discussed in the 1999 draft revised cancer guidelines. These principles arise from scientific discoveries concerning cancer made in the last 15 years and from EPA policy of recent years supporting full characterization of hazard and risk both for the general population and potentially sensitive groups such as children. These principles are incorporated in recent and ongoing assessments such as the reassessment of dioxin, consistent with the 1986 guidelines. Until final guidelines are published, information is presented to describe risk under both the 1986 guidelines and 1999 draft revisions.

The 1999 draft revised cancer guidelines call for the full use of all relevant information to convey the circumstances or conditions under which a particular hazard is expressed (e.g., route, duration, pattern, or magnitude of exposure). They emphasize understanding the mode of action (MOA) whereby the agent induces tumors. The MOA underlies the hazard assessment and provides the rationale for dose-response assessments.

The key principles in the 1999 draft revised cancer guidelines include:

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a) Hazard assessment is based on the analysis of all biological information rather than just tumor findings.

b) An agent's MOA in causing tumors is emphasized to reduce the uncertainty in describing the likelihood of harm and in determining the dose-response approach(es).

c) The 1999 draft revised cancer guidelines emphasize the conditions under which the hazard may be expressed (e.g., route, pattern, duration and magnitude of exposure). Further, the guidelines call for a *hazard characterization* to integrate the data analysis of all relevant studies into a weight-of-evidence conclusion of hazard and to develop a working conclusion regarding the agent's mode of action in leading to tumor development.

d) A weight-of-evidence narrative with accompanying descriptors (listed in Section 3.1.3.1 below) would replace the current alphanumeric classification system. The narrative summarizes the key evidence for carcinogenicity, describes the agent's MOA, characterizes the conditions of hazard expression, including route of exposure, describes any disproportionate effects on subgroups of the human population (e.g., children), and recommends appropriate dose-response approach(es). Significant strengths, weaknesses, and uncertainties of contributing evidence are also highlighted.

e) Biologically based extrapolation models are the preferred approach for quantifying risk. These models integrate data and conclusions about events in the carcinogenic process throughout the dose-response range from high to low doses. It is anticipated, however, that the necessary data for the parameters used in such models will not be available for most chemicals. The 1999 draft revised cancer guidelines allow for alternative quantitative methods, including several default approaches.

f) Dose-response assessment is a two-step process. In the first step, response data are modeled in the observable range of data and a determination is made of the point of departure (POD) from the observed range to extrapolate to low doses. The second step is extrapolation from the POD to estimate dose-response at lower doses. In addition to modeling tumor data, the 1999 draft revised cancer guidelines call for the use and modeling of other kinds of responses if they are considered to be more informed measures of carcinogenic risk. Nominally, these responses reflect key events in the carcinogenic process integral to the MOA of the agent.

g) Three default approaches are provided–linear, nonlinear, or both when adequate data are unavailable to generate a biologically based model. As the first step for all approaches, curve fitting in the observed range is used to determine a POD. A standard POD is the effective dose corresponding to the lower 95 percent limit on

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a dose associated with 10 percent extra risk (LED_{10}).[3] *Linear*: The linear default is a straight line extrapolation from the response at LED_{10} to the origin (zero dose, zero extra risk). *Nonlinear*: The nonlinear default begins with the identified POD and provides a margin of exposure (MOE) analysis rather than estimating the probability of effects at low doses. The MOE analysis is used to determine the appropriate margin between the POD and the exposure level of interest, in this Methodology, the AWQC. The key objective of the MOE analysis is to describe for the risk manager how rapidly responses may decline with dose. Other factors are also considered in the MOE analysis (i.e., nature of the response, slope of the dose-response curve, human sensitivity compared with experimental animals, nature and extent of human variability in sensitivity and human exposure). *Linear and nonlinear*: Section 3.1.3.4E describes the situations when both linear and nonlinear defaults are used.

h) The approach used to calculate an oral human equivalent dose when assessments are based on animal bioassays has been refined and includes a change in the default assumption for interspecies dose scaling. The 1999 draft revised cancer guidelines use body weight raised to the 3/4 power.

EPA health risk assessment practices for both cancer and noncancer endpoints are beginning to come together with recent proposals to emphasize MOA understanding in risk assessment and to model response data in the observable range to derive PODs for data sets and benchmark doses (BMDs) for individual studies. The modeling of observed response data to identify PODs in a standard way will help to harmonize cancer and noncancer dose-response approaches and permit comparisons of cancer and noncancer risk estimates.

3.1.3 Methodology for Deriving AWQC[4] by the 1999 Draft Revised Cancer Guidelines

Following the publication of the *Draft Water Quality Criteria Methodology: Human Health* (USEPA, 1998a) and the accompanying TSD (USEPA, 1998b), EPA received comments from the public. EPA also held an external peer review of the draft Methodology. Both the peer reviewers and the public recommended that EPA incorporate the new approaches into the AWQC Methodology.

Until new guidelines are published, the 1986 cancer guidelines will be used along with principles of the 1999 draft revised cancer guidelines. The 1986 guidelines are the basis for IRIS risk numbers which were used to derive the current AWQC. Each new assessment applying the principles of the 1999 draft revised cancer guidelines will be subject to peer review before being used as the basis of AWQC.

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[3] Use of the LED_{10} as the point of departure is recommended with this Methodology, as it is with the 1999 draft revised cancer guidelines.

[4] Additional information regarding the revised method for assessing carcinogens may be found in the *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000). Technical Support Document, Volume 1: Risk Assessment* (USEPA, 2000).

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The remainder of Section 3 illustrates the methodology for deriving numerical AWQC for carcinogens applying the 1999 draft revised cancer guidelines (USEPA, 1999a). This discussion of the revised methodology for carcinogens focuses primarily on the quantitative aspects of deriving numerical AWQC values. It is important to note that the cancer risk assessment process outlined in the 1999 draft revised cancer guidelines is not limited to the quantitative aspects. A numerical AWQC value derived for a carcinogen is to be based on appropriate hazard characterization and accompanied by risk characterization information.

This section contains a discussion of the weight-of-evidence narrative, that describes all information relevant to a cancer risk evaluation, followed by a discussion of the quantitative aspects of deriving numerical AWQC values for carcinogens. It is assumed that data from an appropriately conducted animal bioassay or human epidemiological study provide the underlying basis for deriving the AWQC value. The discussion focuses on the following: (1) the weight-of-evidence narrative; (2) general considerations and framework for analysis of the MOA; (3) dose estimation; (4) characterizing dose-response relationships in the range of observation and at low, environmentally relevant doses; (5) calculating the AWQC value; (6) risk characterization; and (7) use of Toxicity Equivalent Factors (TEF) and Relative Potency Estimates. The first three topics encompass the quantitative aspects of deriving AWQC for carcinogens.

3.1.3.1 Weight-of-Evidence Narrative[5]

The 1999 draft revised cancer guidelines include a weight-of-evidence narrative that is based on an overall judgment of biological and chemical/physical considerations. Hazard assessment information accompanying an AWQC value for a carcinogen in the form of a weight-of-evidence narrative is described in the footnote. Of particular importance is that the weight-of-evidence narrative explicitly provides adequate support based on human studies, animal bioassays, and other key evidence for the conclusion whether the substance is or is likely to be carcinogenic to humans from exposures through drinking water and/or fish ingestion. The Agency emphasizes the importance of providing an explicit discussion of the MOA for the substance in the weight-of-evidence narrative if data are available, including a discussion that relates the MOA to the quantitative procedures used in the derivation of the AWQC.

3.1.3.2 Mode of Action - General Considerations and Framework for Analysis

[5] The weight-of-evidence narrative is intended for the risk manager, and thus explains in nontechnical language the key data and conclusions, as well as the conditions for hazard expression. Conclusions about potential human carcinogenicity are presented by route of exposure. Contained within this narrative are simple likelihood descriptors that essentially distinguish whether there is enough evidence to make a projection about human hazard (i.e., Carcinogenic to humans; Likely to be carcinogenic to humans; Suggestive evidence of carcinogenicity but not sufficient to assess human carcinogenic potential; Data are inadequate for an assessment of human carcinogenic potential; and Not likely to be carcinogenic to humans). Because one encounters a variety of data sets on agents, these descriptors are not meant to stand alone; rather, the context of the weight-of-evidence narrative is intended to provide a transparent explanation of the biological evidence and how the conclusions were derived. Moreover, these descriptors should not be viewed as classification categories (like the alphameric system), which often obscure key scientific differences among chemicals. The new weight-of-evidence narrative also presents conclusions about how the agent induces tumors and the relevance of the mode of action to humans, and recommends a dose-response approach based on the MOA understanding (USEPA, 1996a, 1999a).

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An MOA is composed of key events and processes starting with the interaction of an agent with a cell, through operational and anatomical changes, resulting in cancer formation. "Mode" of action is contrasted with "mechanism" of action, which implies a more detailed, molecular description of events than is meant by MOA.

Mode of action analysis is based on physical, chemical, and biological information that helps to explain key events[6] in an agent's influence on development of tumors. Inputs to MOA analysis include tumor data in humans, animals, and among structural analogues as well as the other key data.

There are many examples of possible modes of carcinogenic action, such as mutagenicity, mitogenesis, inhibition of cell death, cytotoxicity with reparative cell proliferation, and immune suppression. All pertinent studies are reviewed in analyzing an MOA, and an overall weighing of evidence is performed, laying out the strengths, weaknesses, and uncertainties of the case as well as potential alternative positions and rationales. Identifying data gaps and research needs is also part of the assessment.

Mode of action conclusions are used to address the question of human relevance of animal tumor responses, to address differences in anticipated response among humans such as between children and adults or men and women, and as the basis of decisions about the anticipated shape of the dose-response relationship.

In reaching conclusions, the question of "general acceptance" of an MOA will be tested as part of the independent peer review that EPA obtains for its assessment and conclusions.

Framework for Evaluating a Postulated Carcinogenic Mode(s) of Action

The framework is intended to be an analytic tool for judging whether available data support a mode of carcinogenic action postulated for an agent and includes nine elements:

1. Summary description of postulated MOA
2. Identification of key events
3. Strength, consistency, specificity of association
4. Dose-response relationship
5. Temporal relationship
6. Biological plausibility and coherence
7. Other modes of action
8. Conclusion
9. Human relevance, including subpopulations

3.1.3.3 Dose Estimation

[6]A "key event" is an empirically observable, precursor step that is itself a necessary element of the mode of action, or is a marker for such an element.

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A. Determining the Human Equivalent Dose by the Oral Route

An important objective in the dose-response assessment is to use a measure of internal or delivered dose at the target site where possible. This is particularly important in those cases where the carcinogenic response information is being extrapolated to humans from animal studies. Generally, by the oral exposure route, the measure of a dose provided in the underlying human studies or animal bioassays is the applied dose, typically given in terms of unit mass per unit body weight per unit time, (e.g., mg/kg-day). When animal bioassay data are used, it is necessary to make adjustments to the applied dose values to account for differences in toxicokinetics between animals and humans that affect the relationship between applied dose and delivered dose at the target organ.

In the estimation of a human equivalent dose, the 1999 draft revised cancer guidelines recommend that when adequate data are available, the doses used in animal studies can be adjusted to equivalent human doses using toxicokinetic information on the particular agent. However, in most cases, there are insufficient data available to compare dose between species. In these cases, the estimate of a human equivalent dose is based on science policy default assumptions. To derive an equivalent human oral dose from animal data, the default procedure in the 1999 draft revised cancer guidelines is to scale daily applied oral doses experienced for a lifetime in proportion to body weight raised to the 3/4 power ($BW^{3/4}$). The adjustment factor is used because metabolic rates, as well as most rates of physiological processes that determine the disposition of dose, scale this way. Thus, the rationale for this factor rests on the empirical observation that rates of physiological processes consistently tend to maintain proportionality with body weight raised to 3/4 power (USEPA, 1992a, 1999a).

The use of $BW^{3/4}$ is a departure from the scaling factor of $BW^{2/3}$ that was based on surface area adjustment and was included in the 1980 AWQC National Guidelines as well as the 1986 cancer guidelines.

B. Dose-Response Analysis

If data on the agent are sufficient to support the parameters of a biologically based model and the purpose of the assessment is such as to justify investing resources supporting its use, this is the preferred approach for both the observed tumor and related response data and for extrapolation below the range of observed data in either animal or human studies.

3.1.3.4 Characterizing Dose-Response Relationships in the Range of Observation and at Low Environmentally Relevant Doses

The first quantitative component in the derivation of AWQC for carcinogens is the dose-response assessment in the range of observation. For most agents, in the absence of adequate data to generate a biologically based model, dose-response relationships in the observed range can be addressed through curve-fitting procedures for response data. It should be noted that the 1999 draft revised cancer guidelines call for modeling of not only tumor data in the observable range, but also other responses thought to be important events preceding tumor development (e.g., DNA adducts, cellular proliferation, receptor binding, hormonal changes). The modeling of

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these data is intended to better inform the dose-response assessment by providing insights into the relationships of exposure (or dose) below the observable range for tumor response. These non-tumor response data can only play a role in the dose-response assessment if the agent's carcinogenic mode of action is reasonably understood, as well as the role of that precursor event.

The 1999 draft revised cancer guidelines recommend calculating the lower 95 percent confidence limit on a dose associated with an estimated 10 percent increased tumor or relevant non-tumor response (LED_{10}) for quantitative modeling of dose-response relationships in the observed range. The estimate of the LED_{10} is used as the POD for low-dose extrapolations discussed below. This standard point of departure (LED_{10}) is adopted as a matter of science policy to remain as consistent and comparable from case to case as possible. It is also a convenient comparison point for noncancer endpoints. The rationale supporting use of the LED_{10} is that a 10 percent response is at or just below the limit of sensitivity for discerning a statistically significant tumor response in most long-term rodent studies and is within the observed range for other toxicity studies. Use of lower limit takes experimental variability and sample size into account. The ED_{10} (central estimate) is also presented as a reference for comparison uses, especially for use in relative hazard/potency ranking among agents for priority setting.

For some data sets, a choice of the POD other than the LED_{10} may be appropriate. The objective is to determine the lowest reliable part of the dose-response curve for the beginning of the second step of the dose-response assessment—determine the extrapolation range. Therefore, if the observed response is below the LED_{10}, then a lower point may be a better choice (e.g., LED_5). Human studies more often support a lower POD than animal studies because of greater sample size.

The POD may be a NOAEL when a margin of exposure analysis is the nonlinear dose-response approach. The kinds of data available and the circumstances of the assessment both contribute to deciding to use a NOAEL or LOAEL which is not as rigorous or as ideal as curve fitting, but can be appropriate. If several data sets for key events and tumor response are available for an agent, and they are a mixture of continuous and incidence data, the most practicable way to assess them together is often through a NOAEL/LOAEL approach.

When an LED value estimated from animal data is used as the POD, it is adjusted to the human equivalent dose using an interspecies dose adjustment or a toxicokinetic analysis as described in Section 3.1.3.3.

Analysis of human studies in the observed range is designed on a case-by-case basis depending on the type of study and how dose and response are measured in the study.

A. Extrapolation to Low, Environmentally Relevant Doses

In most cases, the derivation of an AWQC will require an evaluation of carcinogenic risk at environmental exposure levels substantially lower than those used in the underlying study. Various approaches are used to extrapolate risk outside the range of observed experimental data. In the 1999 draft revised cancer guidelines, the choice of extrapolation method is largely

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dependent on the mode of action. It should be noted that the term "mode of action" (MOA) is deliberately chosen in the 1999 draft revised cancer guidelines in lieu of the term "mechanism" to indicate using knowledge that is sufficient to draw a reasonable working conclusion without having to know the processes in detail as the term mechanism might imply. The 1999 draft revised cancer guidelines favor the choice of a biologically based model, if the parameters of such models can be calculated from data sources independent of tumor data. It is anticipated that the necessary data for such parameters will not be available for most chemicals. Thus, the 1999 draft revised cancer guidelines allow for several default extrapolation approaches (low-dose linear, nonlinear, or both).

B. Biologically Based Modeling Approaches

If a biologically based approach has been used to characterize the dose-response relationships in the observed range, and the confidence in the model is high, it may be used to extrapolate the dose-response relationship to environmentally relevant doses. For the purposes of deriving AWQC, the environmentally relevant dose would be the risk-specific dose (RSD) associated with incremental lifetime cancer risks in the 10^{-6} to 10^{-4} range for carcinogens for which a linear extrapolation approach is applied.[7] The use of the RSD and the POD/UF to compute the AWQC is presented in Section 3.1.3.5, below. Although biologically-based approaches are appropriate both for characterizing observed dose-response relationships and extrapolating to environmentally relevant doses, it is not expected that adequate data will be available to support the use of such approaches for most substances. In the absence of such data, the default linear approach, the nonlinear (MOE) approach, or both linear and nonlinear approaches will be used.

[7] For discussion of the cancer risk range, see Section 2.4.

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C. Default Linear Extrapolation Approach

The default linear approach replaces the LMS approach that has served as the default for EPA cancer risk assessments. Any of the following conclusions leads to selection of a linear dose-response assessment approach:

- There is an absence of sufficient tumor MOA information.
- The chemical has direct DNA mutagenic reactivity or other indications of DNA effects that are consistent with linearity.
- Human exposure or body burden is high and near doses associated with key events in the carcinogenic process (e.g., 2,3,7,8-tetrachlorodibenzo-p-dioxin).
- Mode of action analysis does not support direct DNA effects, but the dose-response relationship is expected to be linear (e.g., certain receptor-mediated effects).

The procedures for implementing the default linear approach begin with the estimation of a POD as described above. The point of departure, LED_{10}, reflects the interspecies conversion to the human equivalent dose and the other adjustments for less-than-lifetime experimental duration. In most cases, the extrapolation for estimating response rates at low, environmentally relevant exposures is accomplished by drawing a straight line between the POD and the origin (i.e., zero dose, zero extra risk). This is mathematically represented as:

$$y = mx + b \qquad \text{(Equation 3-1)}$$
$$b = 0$$

where:

y	=	Response or incidence
m	=	Slope of the line (cancer potency factor) = $\Delta y/\Delta x$
x	=	Dose
b	=	Slope intercept

The slope of the line, "m" (the estimated cancer potency factor at low doses), is computed as:

$$m = \frac{0.10}{LED_{10}} \qquad \text{(Equation 3-2)}$$

The RSD is then calculated for a specific incremental targeted lifetime cancer risk (in the range of 10^{-6} to 10^{-4}) as:

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$$RSD = \frac{\text{Target Incremental Cancer Risk}}{m} \qquad \text{(Equation 3-3)}$$

where:

RSD	=	Risk-specific dose (mg/kg-day)
Target Incremental Cancer Risk[8]	=	Value in the range of 10^{-6} to10^{-4}
m	=	Cancer potency factor $(mg/kg\text{-}day)^{-1}$

The use of the RSD to compute the AWQC is described in Section 3.1.3.5 below.

D. Default Nonlinear Approach

As discussed in the 1999 draft revised cancer guidelines, any of the following conclusions leads to a selection of a nonlinear (MOE) approach to dose-response assessment:

- A tumor MOA supporting nonlinearity applies (e.g., some cytotoxic and hormonal agents such as disruptors of hormonal homeostasis), and the chemical does not demonstrate mutagenic effects consistent with linearity.

- An MOA supporting nonlinearity has been demonstrated, and the chemical has some indication of mutagenic activity, but it is judged not to play a significant role in tumor causation.

Thus, a default assumption of nonlinearity is appropriate when there is no evidence for linearity and sufficient evidence to support an assumption of nonlinearity. The MOA may lead to a dose-response relationship that is nonlinear, with response falling much more quickly than linearly with dose, or being most influenced by individual differences in sensitivity. Alternatively, the MOA may theoretically have a threshold (e.g., the carcinogenicity may be a secondary effect of toxicity or of an induced physiological change that is itself a threshold phenomenon).

The nonlinear approach may be used, for instance, in the case of a bladder tumor inducer, where the chemical is not mutagenic and causes only stone formation in male rat bladders at high doses. This dynamic leads to tumor formation only at the high doses. Stone and subsequent tumor formation are not expected to occur at doses lower than those that induce the physiological changes that lead to stone formation. (More detail on this chemical is provided in the cancer section of the Risk Assessment TSD; USEPA, 2000). EPA does not generally try to distinguish between modes of action that might imply a “true threshold” from others with a

[8]In 1980, the target lifetime cancer risk range was set at 10-7 to 10-5. However, both the expert panel for the AWQC workshop (USEPA, 1993) and the peer review workshop experts (USEPA,1999c) recommended that EPA change the risk range to 10-6 to 10-4, to be consistent with SDWA program decisions. See Section 2.4 for more details.

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nonlinear dose-response relationship, because there is usually not sufficient information to distinguish between those possibilities empirically.

The nonlinear MOE approach in the 1986 proposed cancer guidelines compares an observed response rate such as the LED_{10}, NOAEL, or LOAEL with actual or nominal environmental exposures of interest by computing the ratio between the two. In the context of deriving AWQC, the environmentally relevant exposures are nominal targets rather than actual exposures.

If the evidence for an agent indicates nonlinearity (e.g., when carcinogenicity is secondary to another toxicity for which there is a threshold), the MOE analysis for the toxicity is similar to what is done for a noncancer endpoint, and an RfD or RfC for that toxicity may also be estimated and considered in the cancer assessment. However, a threshold of carcinogenic response is not necessarily assumed. It should be noted that for cancer assessment, the MOE analysis begins from a POD that is adjusted for toxicokinetic differences between species to give a human equivalent dose.

To support the use of the MOE approach, risk assessment information provides evaluation of the current understanding of the phenomena that may be occurring as dose (exposure) decreases substantially below the observed data. This gives information about the risk reduction that is expected to accompany a lowering of exposure. The various factors that influence the selection of the UF in an MOE approach are also discussed below.

There are two main steps in the MOE approach. The first step is the selection of a POD. The POD may be the LED_{10} for tumor incidence or a precursor, or in some cases, it may also be appropriate to use a NOAEL or LOAEL value. When animal data are used, the POD is a human equivalent dose or concentration arrived at by interspecies dose adjustment (as discussed in Section 3.1.3.3) or toxicokinetic analysis.

The second step in using MOE analysis to establish AWQC is the selection of an appropriate margin or UF to apply to the POD. This is supported by analyses in the MOE discussion in the risk assessment. The following issues should be considered when establishing the overall UF for the derivation of AWQC using the MOE approach (others may be found appropriate in specific cases):

- The nature of the response used for the dose-response assessment, for instance, whether it is a precursor effect or a tumor response. The latter may support a greater MOE.

- The slope of the observed dose-response relationship at the POD and its uncertainties and implications for risk reduction associated with exposure reduction. (A steeper slope implies a greater reduction in risk as exposure decreases. This may support a smaller MOE).

- Human sensitivity compared with that of experimental animals.

- Nature and extent of human variability and sensitivity.

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- Human exposure. The MOE evaluation also takes into account the magnitude, frequency, and duration of exposure. If the population exposed in a particular scenario is wholly or largely composed of a subpopulation of special concern (e.g., children) for whom evidence indicates a special sensitivity to the agent's MOA, an adequate MOE would be larger than for general population exposure.

E. Both Linear and Nonlinear Approaches

Any of the following conclusions leads to selection of both a linear and nonlinear approach to dose-response assessment. Relative support for each dose-response method and advice on the use of that information needs to be documented for the AWQC. In some cases, evidence for one MOA is stronger than for the other, allowing emphasis to be placed on that dose-response approach. In other cases, both modes of action are equally possible, and both dose-response approaches should be emphasized.

- Modes of action for a single tumor type support both linear and nonlinear dose response in different parts of the dose-response curve (e.g., 4,4' methylene chloride).

- A tumor mode of action supports different approaches at high and low doses; e.g., at high dose, nonlinearity, but, at low dose, linearity (e.g., formaldehyde).

- The agent is not DNA-reactive and all plausible modes of action are consistent with nonlinearity, but not fully established.

- Modes of action for different tumor types support differing approaches, e.g., nonlinear for one tumor type and linear for another due to lack of MOA information (e.g., trichloroethylene).

3.1.3.5 <u>AWQC Calculation</u>

A. Linear Approach

The following equation is used for the calculation of the AWQC for carcinogens where an RSD is obtained from the linear approach:

$$AWQC = RSD \cdot \left(\frac{BW}{DI + \sum_{i=2}^{4} (FI_i \cdot BAF_i)} \right) \qquad \text{(Equation 3-4)}$$

AWQC	=	Ambient water quality criterion (mg/L)
RSD	=	Risk-specific dose (mg/kg-day)
BW	=	Human body weight (kg)
DI	=	Drinking water intake (L/day)

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FI_i	=	Fish intake at trophic level I (I = 2, 3, and 4) (kg/day)
BAF_i	=	Bioaccumulation factor for trophic level I (I = 2, 3, and 4), lipid normalized (L/kg)

B. Nonlinear Approach

In those cases where the nonlinear, MOE approach is used, a similar equation is used to calculate the AWQC [9]

$$AWQC = \frac{POD}{UF} \cdot RSC \cdot \left(\frac{BW}{DI + \sum_{i=2}^{4} (FI_i \cdot BAF_i)} \right) \qquad \text{(Equation 3-5)}$$

where variables are defined as for Equation 3-4 and:

POD	=	Point of departure (mg/kg-day)
UF	=	Uncertainty factor (unitless)
RSC	=	Relative source contribution (percentage or subtraction)

Differences between the AWQC values obtained using the linear and nonlinear approaches should be noted. First, the AWQC value obtained using the default linear approach corresponds to a specific estimated incremental lifetime cancer risk level in the range of 10^{-4} to 10^{-6}. In contrast, the AWQC obtained using the nonlinear approach does not describe a specific cancer risk. The AWQC calculations shown above are appropriate for waterbodies that are used as sources of drinking water.

The actual AWQC chosen for the protection of human health is based on a review of all relevant information, including cancer and noncancer data. The AWQC may, or may not, utilize the value obtained from the cancer analysis in the final AWQC value. The endpoint selected for the AWQC will be based on consideration of the weight of evidence and a complete analysis of all toxicity endpoints.

3.1.3.6 Risk Characterization

Risk assessment is an integrative process that is documented in a risk characterization summary. Risk characterization is the final step of the risk assessment process in which all preceding analyses (i.e., hazard, dose-response, and exposure assessments) are tied together to convey the overall conclusions about potential human risk. This component of the risk assessment process characterizes the data in nontechnical terms, explaining the extent and weight of evidence, major points of interpretation and rationale, and strengths and weaknesses of

[9] Although appearing in this equation as a factor to be multiplied, the RSC can also be an amount subtracted.

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the evidence, and discussing alternative approaches, conclusions, uncertainties, and variability that deserve serious consideration.

Risk characterization information accompanies the numerical AWQC value and addresses the major strengths and weaknesses of the assessment arising from the availability of data and the current limits of understanding the process of cancer causation. Key issues relating to the confidence in the hazard assessment and the dose-response analysis (including the low-dose extrapolation procedure used) are discussed. Whenever more than one interpretation of the weight of evidence for carcinogenicity or the dose-response characterization can be supported, and when choosing among them is difficult, the alternative views are provided along with the rationale for the interpretation chosen in the derivation of the AWQC value. Where possible, quantitative uncertainty analyses of the data are provided; at a minimum, a qualitative discussion of the important uncertainties is presented.

3.1.3.7 Use of Toxicity Equivalence Factors and Relative Potency Estimates

The 1999 draft revised cancer guidelines state:

> *A toxicity equivalence factor (TEF) procedure is one used to derive quantitative dose-response estimates for agents that are members of a category or class of agents. TEFs are based on shared characteristics that can be used to order the class members by carcinogenic potency when cancer bioassay data are inadequate for this purpose. The ordering is by reference to the characteristics and potency of a well-studied member or members of the class. Other class members are indexed to the reference agent(s) by one or more shared characteristics to generate their TEFs.*

In addition, the 1999 draft revised cancer guidelines state that TEFs are generated and used for the limited purpose of assessment of agents or mixtures of agents in environmental media when better data are not available. When better data become available for an agent, the TEF should be replaced or revised. To date, adequate data to support use of TEFs have been found only for dibenzofurans (dioxins) and coplanar polychlorinated biphenyls (PCBs) (USEPA, 1989, 1999b).

The uncertainties associated with TEFs must be described when this approach is used. This is a default approach to be used when tumor data are not available for individual components in a mixture. Relative potency factors (RPFs) can be similarly derived and used for agents with carcinogenicity or other supporting data. The RPF is conceptually similar to TEFs, but does not have the same level of data to support it and thus has a less rigorous definition compared with the TEF. TEFs and RPFs are used only when there is no better alternative. When they are used, assumptions and uncertainties associated with them are discussed. As of today, there are only three classes of compounds for which relative potency approaches have been examined by EPA: dibenzofurans (dioxins), polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs). There are limitations to the use of TEF and RFP approaches, and caution should be exercised when using them. More guidance can be found in the draft document for conducting health risk assessment of chemical mixtures, published by the EPA Risk Assessment Forum (USEPA,1999b).

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3.1.4 References for Cancer Section

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3.2 NONCANCER EFFECTS

3.2.1 1980 AWQC National Guidelines for Noncancer Effects

In the 1980 AWQC National Guidelines, the Agency evaluated noncancer human health effects from exposure to chemical contaminants using Acceptable Daily Intake (ADI) levels. ADIs were calculated by dividing NOAELs by safety factors (SFs) to obtain estimates of doses of chemicals that would not be expected to cause adverse effects over a lifetime of exposure. In accordance with the National Research Council report of 1977 (NRC, 1977), EPA used SFs of 10, 100, or 1,000, depending on the quality and quantity of the overall database. In general, a factor of 10 was suggested when good-quality data identifying a NOAEL from human studies were available. A factor of 100 was suggested if no human data were available, but the database contained valid chronic animal data. For chemicals with no human data and scant animal data, a factor of 1,000 was recommended. Intermediate SFs could also be used for databases that fell between these categories.

AWQC were calculated using the ADI levels together with standard exposure assumptions about the rates of human ingestion of water and fish, and also accounting for intake from other sources (see Equation 1-1 in the Introduction). Surface water concentrations at or below the calculated criteria concentrations would be expected to result in human exposure levels at or below the ADI. Inherent in these calculations is the assumption that, generally, adverse effects from noncarcinogens exhibit a threshold.

3.2.2 Noncancer Risk Assessment Developments Since 1980

Since 1980, the risk assessment of noncarcinogenic chemicals has changed. To remove the value judgments implied by the words “acceptable” and “safety,” the ADI and SF terms have been replaced with the terms RfD and UF/modifying factor (MF), respectively.

For the risk assessment of general systemic toxicity, the Agency currently uses the guidelines contained in the IRIS background document entitled *Reference Dose (RfD): Description and Use in Health Risk Assessments* (hereafter the “IRIS background document”. That document defines an RfD as “an estimate (with uncertainty spanning approximately an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious effects over a lifetime” (USEPA,

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1993a). The most common approach for deriving the RfD does not involve dose-response modeling. Instead, an RfD for a given chemical is usually derived by first identifying the NOAEL for the most sensitive known toxicity endpoint, that is, the toxic effect that occurs at the lowest dose. This effect is called the critical effect. Factors such as the study protocol, the species of experimental animal, the nature of the toxicity endpoint assessed and its relevance to human effects, the route of exposure, and exposure duration are critically evaluated in order to select the most appropriate NOAEL from among all available studies in the chemical's database. If no appropriate NOAEL can be identified from any study, then the LOAEL for the critical effect endpoint is used and an uncertainly factor for LOAEL-to-NOAEL extrapolation is applied. Using this approach, the RfD is equal to the NOAEL (or LOAEL) divided by the product of UFs and, occasionally, an MF:

$$\text{RfD (mg/kg/day)} = \frac{\text{NOAEL (or LOAEL)}}{\text{UF} \cdot \text{MF}} \qquad \text{(Equation 3-6)}$$

The definitions and guidance for use of the UFs and the MFs are provided in the IRIS background document and are repeated in Table 3-1.

The IRIS background document on the RfD (USEPA, 1993a) provides guidance for critically assessing noncarcinogenic effects of chemicals and for deriving the RfD. Another reference on this topic is Dourson (1994). Furthermore, the Agency has also published separate guidelines for assessing specific toxic endpoints, such as developmental toxicity (USEPA, 1991a), reproductive toxicity (USEPA, 1996a), and neurotoxicity risk assessment (USEPA, 1995). These endpoint-specific guidelines will be used for their respective areas in the hazard assessment step and will complement the overall toxicological assessment. It should be noted, however, that an RfD, derived using the most sensitive known endpoint, is considered protective against all noncarcinogenic effects.

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TABLE 3-1. UNCERTAINTY FACTORS AND THE MODIFYING FACTOR

Uncertainty Factor	Definition
UF_H	Use a 1, 3, or 10-fold factor when extrapolating from valid data in studies using long-term exposure to average healthy humans. This factor is intended to account for the variation in sensitivity (intraspecies variation) among the members of the human population.
UF_A	Use an additional factor of 1, 3, or 10 when extrapolating from valid results of long-term studies on experimental animals when results of studies of human exposure are not available or are inadequate. This factor is intended to account for the uncertainty involved in extrapolating from animal data to humans (interspecies variation).
UF_S	Use an additional factor of 1, 3, or 10 when extrapolating from less-than-chronic results on experimental animals when there are no useful long-term human data. This factor is intended to account for the uncertainty involved in extrapolating from less-than-chronic NOAELs to chronic NOAELs.
UF_L	Use an additional factor of 1, 3, or 10 when deriving an RfD from a LOAEL, instead of a NOAEL. This factor is intended to account for the uncertainty involved in extrapolating from LOAELs to NOAELs.
UF_D	Use an additional 3- or 10-fold factor when deriving an RfD from an "incomplete" database. This factor is meant to account for the inability of any single type of study to consider all toxic endpoints. The intermediate factor of 3 (approximately ½ $\log_{10}$ unit, i.e., the square root of 10) is often used when there is a single data gap exclusive of chronic data. It is often designated as UF_D.

Modifying Factor

Use professional judgment to determine the MF, which is an additional uncertainty factor that is greater than zero and less than or equal to 10. The magnitude of the MF depends upon the professional assessment of scientific uncertainties of the study and database not explicitly treated above (e.g., the number of species tested). The default value for the MF is 1.

Note: With each UF or MF assignment, it is recognized that professional scientific judgment must be used. The total product of the uncertainty factors and modifying factor should not exceed 3,000.

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Similar to the procedure used in the 1980 AWQC National Guidelines, the revised method of deriving AWQC for noncarcinogens uses the RfD together with various assumptions concerning intake of the contaminant from both water and non-water sources of exposure. The objective of an AWQC for noncarcinogens is to ensure that human exposure to a substance related to its presence in surface water, combined with exposure from other sources, does not exceed the RfD. The algorithm for deriving AWQC for noncarcinogens using the RfD is presented as Equation 1-1 in the Introduction.

3.2.3 Issues and Recommendations Concerning the Derivation of AWQC for Noncarcinogens

During a review of the 1980 AWQC National Guidelines (USEPA, 1993b), the Agency identified several issues that must be resolved in order to develop a final revised methodology for deriving AWQC based on noncancer effects. These issues, as discussed below, mainly concern the derivation of the RfD as the basis for such an AWQC. Foremost among these issues is whether the Agency should revise the present method or adopt entirely new procedures that use quantitative dose-response modeling for the derivation of the RfD. Other issues include the following:

- Presenting the RfD as a single point value or as a range to reflect the inherent imprecision of the RfD;
- Selecting specific guidance documents for derivation of noncancer health effect levels;
- Considering severity of effect in the development of the RfD;
- Using less-than-90-day studies as the basis for RfDs;
- Integrating reproductive/developmental, immunotoxicity, and neurotoxicity data into the RfD calculation;
- Applying toxicokinetic data in risk assessments; and
- Considering the possibility that some noncarcinogenic effects do not exhibit a threshold.

3.2.3.1 Using the Current NOAEL/UF-Based RfD Approach or Adopting More Quantitative Approaches for Noncancer Risk Assessment

The current NOAEL/UF-based RfD methodology, or its predecessor ADI/SF methodology, have been used since 1980. This approach assumes that there is a threshold exposure below which adverse noncancer health effects are not expected to occur. Exposures above this threshold are believed to pose some risk to exposed individuals; however, the current approach does not address the nature and magnitude of the risk above the threshold level (i.e., the shape of the dose-response curve above the threshold). The NOAEL/UF-based RfD approach is intended primarily to ensure that the RfD value derived from the available data falls below the population effects threshold. However, the NOAEL/UF-based RfD procedure has

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limitations. In particular, this method requires that one of the actual experimental doses used by the researchers in the critical study be selected as the NOAEL or LOAEL value. The determination that a dose is a NOAEL or LOAEL will depend on the biological endpoints used and the statistical significance of the data. Statistical significance will depend on the number and spacing of dose groups and the numbers of animals used in each dose group. Studies using a small number of animals can limit the ability to distinguish statistically significant differences among measurable responses seen in dose groups and control groups. Furthermore, the determination of the NOAEL or LOAEL also depends on the dose spacing of the study. Doses are often widely spaced, typically differing by factors of three to ten. A study can identify a NOAEL and a LOAEL from among the doses studied, but the "true" effects threshold cannot be determined from those results. The study size and dose spacing limitations also limit the ability to characterize the nature of the expected response to exposures between the observed NOAEL and LOAEL values.

The limitations of the NOAEL/UF approach have prompted development of alternative approaches that incorporate more quantitative dose-response information. The traditional NOAEL approach for noncancer risk assessment has often been a source of controversy and has been criticized in several ways. For example, experiments involving fewer animals tend to produce higher NOAELs and, as a consequence, may produce higher RfDs. Larger sample sizes, on the other hand, should provide greater experimental sensitivity and lower NOAELs. The focus of the NOAEL approach is only on the dose that is the NOAEL, and the NOAEL must be one of the experimental doses. It also ignores the shape of the dose-response curve. Thus, the slope of the dose-response plays little role in determining acceptable exposures for human beings. Therefore, in addition to the NOAEL/UF-based RfD approach described above, EPA will accept other approaches that incorporate more quantitative dose-response information in appropriate situations for the evaluation of noncancer effects and the derivation of RfDs. However, the Agency wishes to emphasize that it still believes the NOAEL/UF RfD methodology is valid and can continue to be used to develop RfDs.

Two alternative approaches that may have relevance in assisting in the derivation of the RfD for a chemical are the BMD and the categorical regression approaches. These alternative approaches may overcome some of the inherent limitations in the NOAEL/UF approach. For example, the BMD analyses for developmental effects show that NOAELs from studies correlate well with a 5 percent response level (Allen et al., 1994). The BMD and the categorical regression approaches usually have greater data requirements than the RfD approach. Thus, it is unlikely that any one approach will apply to every circumstance; in some cases, different approaches may be needed to accommodate the varying databases for the range of chemicals for which water quality criteria must be developed. Acceptable approaches will satisfy the following criteria: (1) meet the appropriate risk assessment goal; (2) adequately describe the toxicity database and its quality; (3) characterize the endpoints properly; (4) provide a measure of the quality of the "fit" of the model when a model is used for dose-response analysis; and (5) describe the key assumptions and uncertainties.

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A. The Benchmark Dose

The BMD is defined as the dose estimated to produce a predetermined level of change in response (the Benchmark Response level, or BMR) relative to control. The BMDL is defined as the statistical lower confidence limit on the BMD. In the derivation of an RfD, the BMDL is used as the dose to which uncertainty factors are applied instead of the NOAEL. The BMD approach first models a dose-response curve for the critical effect(s) using available experimental data. Several mathematical algorithms can be used to model the dose-response curve, such as polynomial or Weibull functions. To define a BMD from the modeled curve for quantal data, the assessor first selects the BMR. The choice of the BMR is critical. For quantal endpoints, a particular level of response is chosen (e.g., 1 percent, 5 percent, or 10 percent). For continuous endpoints, the BMR is the degree of change from controls and is based on what is considered a biologically significant change. The BMD is derived from the BMR dose by applying the desired confidence limit calculation. The RfD is obtained by dividing the BMD by one or more uncertainty factors, similar to the NOAEL approach. Because the BMD is used like the NOAEL to obtain the RfD, the BMR should be selected at or near the low end of the range of increased risks that can be detected in a study of typical size. Generally, this falls in the range between the ED_{01} and the ED_{10}.

The Agency will accept use of a BMD approach to derive RfDs for those agents for which there is an adequate database. There are a number of technical decisions associated with the application of the BMD technique. These include the following:

- The definition of an adverse response;
- Selection of response data to model;
- The form of the data used (continuous versus quantal);
- The choice of the measures of increased risk (extra risk versus additional risk);
- The choice of mathematical model (including use of nonstandard models for unusual data sets);
- The selection of the BMR;
- Methods for calculating the confidence interval;
- Selection of the appropriate BMD as the basis for the RfD (when multiple endpoints are modeled from a single study, when multiple models are applied to a single response, and when multiple BMDs are calculated from different studies); and
- The use of uncertainty factors with the BMD approach.

These topics are discussed in detail in Crump et al. (1995) and in the Risk Assessment TSD Volume (USEPA, 2000). The use of the BMD approach has been discussed in general terms by several authors (Gaylor, 1983; Crump, 1984; Dourson et al., 1985; Kimmel and Gaylor, 1988; Brown and Erdreich, 1989; Kimmel, 1990). The International Life Sciences Institute

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(ILSI) also held a major workshop on the BMD in September 1993; the workshop proceedings are summarized in ILSI (1993) and in Barnes et al. (1995). For further information on these technical issues, the reader is referred to the publications referenced above.

The BMD approach addresses several of the quantitative or statistical criticisms of the NOAEL approach. These are discussed at greater length in Crump et al. (1995) and are summarized here. First, the BMD approach uses all the dose-response information in the selected study rather than just a single data point, such as the NOAEL or LOAEL. By using response data from all of the dose groups to model a dose-response curve, the BMD approach allows for consideration of the steepness of the slope of the curve when estimating the ED_{10}. The use of the full data set also makes the BMD approach less sensitive to small changes in data than the NOAEL approach, which relies on the statistical comparison of individual dose groups. The BMD approach also allows consistency in the consideration of the level of effect (e.g., a 10 percent response rate) across endpoints.

The BMD approach accounts more appropriately for the size of each dose group than the NOAEL approach. Laboratory tests with fewer animals per dose group tend to yield higher NOAELs, and thus higher RfDs, because statistically significant differences in response rates are harder to detect. Therefore, in the NOAEL approach, dose groups with fewer animals lead to a higher (less conservative) RfD. In contrast, with the BMD approach, smaller dose groups will tend to have the effect of extending the confidence interval around the ED_{10}; therefore, the lower confidence limit on the ED_{10} (the BMD) will be lower. With the BMD approach, greater uncertainty (smaller test groups) leads to a lower (more conservative) RfD.

There are some issues to be resolved before the BMD approach is used routinely. These were identified in a 1996 Peer Consultation Workshop (USEPA, 1996b). Methods for routine use of the BMD are currently under development by EPA. Several RfCs and RfDs based on the BMD approach are included in EPA's IRIS database. These include reference values for methylmercury based on delayed postnatal development in humans; carbon disulfide based on neurotoxicity; 1,1,1,2-tetrafluoroethane based on testicular effects in rats; and antimony trioxide based on chronic pulmonary interstitial inflammation in female rats.

Various mathematical approaches have been proposed for modeling developmental toxicity data (e.g., Crump, 1984; Kimmel and Gaylor, 1988; Rai and Van Ryzin, 1985; Faustman et al., 1989), which could be used to calculate a BMD. Similar methods can be used to model other types of toxicity data, such as neurotoxicity data (Gaylor and Slikker, 1990, 1992; Glowa and MacPhail, 1995). The choice of the mathematical model may not be critical, as long as estimation is within the observed dose range. Since the model fits a mathematical equation to the observed data, the assumptions in a particular model regarding the existence or absence of a threshold for the effect may not be pertinent (USEPA, 1997). Thus, any model that suitably fits the empirical data is likely to provide a reasonable estimate of a BMD. However, research has shown that flexible models that are nonsymmetric (e.g., the Weibull) are superior to symmetric models (e.g., the probit) in estimating the BMD because the data points at the higher doses have less influence on the shape of the curve than at low doses. In addition, models should incorporate fundamental biological factors where such factors are known (e.g., intralitter correlation for developmental toxicity data) in order to account for as much variability in the

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data as possible. The Agency is currently using the BMD approach in risk assessments where the data support its use. Draft guidelines for application of the BMD approach also are being developed by the Agency.

Use of BMD methods involves fitting mathematical models to dose-response data obtained primarily from toxicology studies. When considering available models to use for a BMD analysis, it is important to select the model that fits the data the best and is the most biologically appropriate. EPA has developed software following several years of research and development, expert peer review, public comment, subsequent revision, and quality assurance testing. The software (BMDS, Version 1.2) can be downloaded from http://www.epa.gov/ncea/bmds.htm. BMDS facilitates these operations by providing simple data-management tools, a comprehensive help manual, an online help system, and an easy-to-use interface to run multiple models on the same dose-response data.

As part of this software package, EPA has included sixteen (16) different models that are appropriate for the analysis of dichotomous (quantal) data (Gamma, Logistic, Log-Logistic, Multistage, Probit, Log-Probit, Quantal-Linear, Quantal-Quadratic, Weibull), continuous data (Linear, Polynomial, Power, Hill), and nested developmental toxicology data (NLogistic, NCTR, Rai & Van Ryzin). Results from all models include a reiteration of the model formula and model run options chosen by the user, goodness-of-fit information, the BMD, and the estimate of the lower-bound confidence limit on the benchmark dose (BMDL). Model results are presented in textual and graphical output files which can be printed or saved and incorporated into other documents.

B. Categorical Regression

Categorical regression is an emerging technique that may have relevance for the derivation of RfDs or for estimating risk above the RfD (Dourson et al., 1997; Guth et al., 1997). The categorical regression approach, like the BMD approach, can be used to estimate a dose that corresponds to a given probability of adverse effects. This dose would then be divided by UFs to establish an RfD. However, unlike the BMD approach, the Categorical regression approach can incorporate information on different health endpoints in a single dose-response analysis. For those health effects for which studies exist, responses to the substance in question are grouped into severity categories; for example (1) no effect, (2) no adverse effect, (3) mild-to-moderate adverse effect, and (4) frank effect. These categories correspond to the dose categories currently used in setting the RfD, namely, the no-observed-effect level (NOEL), NOAEL, LOAEL, and frank-effect level (FEL), respectively. Logistic transformation or other applicable mathematical operations are used to model the probability of experiencing effects in a certain category as a function of dose (Harrell, 1986; Hertzberg, 1989). The "acceptability" of the fit of the model to the data can be judged using several statistical measures, including the χ^2 statistic, correlation coefficients, and the statistical significance of its model parameter estimates.

The resulting mathematical equation can be used to find a dose (or the lower confidence bound on the dose) at which the probability of experiencing adverse effects does not exceed a selected level, e.g., 10 percent. This dose (like the NOAEL or BMD) would then be divided by

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relevant UFs to calculate an RfD. For more detail on how to employ the categorical regression approach, see the discussion in the Risk Assessment TSD (USEPA, 2000).

As with the BMD approach, the categorical regression approach has the advantage of using more of the available dose-response data to account for response variability as well as accounting for uncertainty due to sample size through the use of confidence intervals. Additional advantages of categorical regression include the combining of data sets prior to modeling, thus allowing the calculation of the slope of a dose-response curve for multiple adverse effects rather than only one effect at a time. Another advantage is the ability to estimate risks for different levels of severity from exposures above the RfD.

On the other hand, as with BMD, opinions differ over the amount and adequacy of data necessary to implement the method. The categorical regression approach also requires judgments regarding combining data sets, judging goodness-of-fit, and assigning severity to a particular effect. Furthermore, this approach is still in the developmental stage. It is not recommended for routine use, but may be used when data are available and justify the extensive analyses required.

C. Summary

Whether a NOAEL/UF-based methodology, a BMD, a categorical regression model, or other approach is used to develop the RfD, the dose-response-evaluation step of a risk assessment process should include additional discussion about the nature of the toxicity data and its applicability to human exposure and toxicity. The discussion should present the range of doses that are effective in producing toxicity for a given agent; the route, timing, and duration of exposure; species specificity of effects; and any toxicokinetic or other considerations relevant to extrapolation from the toxicity data to human-health-based AWQC. This information should always accompany the characterization of the adequacy of the data.

3.2.3.2 Presenting the RfD as a Single Point or as a Range for Deriving AWQC

Although the RfD has traditionally been presented and used as a single point, its definition contains the phrase ". . . an estimate (with uncertainty spanning perhaps an order of magnitude) . . ." (USEPA, 1993a). Underlying this concept is the reasoning that the selection of the critical effect and the total uncertainty factor used in the derivation of the RfD is based on the "best" scientific judgment, and that competent scientists examining the same database could derive RfDs which varied within an order of magnitude.

In one instance, IRIS presented the RfD as a point value within an accompanying range. EPA derived a single number as the RfD for arsenic (0.3 μg/kg-day), but added that "strong scientific arguments can be made for various values within a factor of 2 or 3 of the currently recommended RfD value, i.e., 0.1 to 0.8 μg/kg/day" (USEPA, 1993c). EPA noted that regulatory managers should be aware of the flexibility afforded them through this action.

There are situations in which the risk manager can select an alternative value to use in place of the RfD in the AWQC calculations. The domain from which this alternative value can

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be selected is restricted to a defined range around the point estimate. As explained further below, the Agency is recommending that sometimes the use of a value other than the calculated RfD point estimate is appropriate in characterizing risk. The selection of an alternative value within an appropriate range must be determined for each individual situation, since several factors affect the selection of the alternative value. Observing similar effects in several animal species, including humans, can increase confidence in the selection of the critical effect and thereby narrow the range of uncertainty. There are other factors that can affect the precision. These include the slope of the dose-response curve, seriousness of the observed effect, dose spacing, and possibly the route for the experimental doses. Dose spacing and the number of animals in the study groups used in the experiment can also affect the confidence in the RfD.

To derive the AWQC, the calculated point estimate of the RfD is the default. Based on consideration of the available data, the use of another number within the range defined by the product of the UF(s) (and MF, if used) could be justified in some specific situations. This means that there are risk considerations which indicate that some value in the range other than the point estimate may be more appropriate, based on human health or environmental fate considerations. For example, the bioavailability of the contaminant in fish tissues is one factor to consider. If bioavailability from fish tissues is much lower than that from water and the RfD was derived from a study in which the contaminant exposure was from drinking water, the alternative to the calculated RfD could be selected from the high end of the range and justified using the quantitative difference in bioavailability.

Most inorganic contaminants, particularly divalent cations, have bioavailability values of 20 percent or less from a food matrix, but are much more available (about 80 percent or higher) from drinking water. Accordingly, the external dose necessary to produce a toxic internal dose would likely be higher for a study where the exposure occurred through the diet rather than the drinking water. As a result, the RfD from a dietary study would likely be higher than that for the drinking water study if equivalent external doses had been used. Conversely, in cases where the NOAEL that was the basis for the RfD came from a dietary study, the alternative value could be slightly lower than the calculated RfD.

Because the uncertainty around the dose-response relationship increases as extrapolation below the observed data increases, the use of an alternative point within the range may be more appropriate in characterizing the risk than the use of the calculated RfD, especially in situations when the uncertainty is high. Therefore, as a matter of policy, the 2000 Human Health Methodology permits the selection of a single point within a range about the calculated RfD to be used as the basis of the AWQC if an adequate justification of the alternative point is provided. More complete discussion of this option, including limitations on the span of the range, is provided in the Risk Assessment TSD (USEPA, 2000).

3.2.3.3 Guidelines to be Adopted for Derivation of Noncancer Health Effects Values

The Agency currently is using the IRIS background document as the general basis for the risk assessment of noncarcinogenic effects of chemicals (USEPA, 1993a). EPA recommends continued use of this document for this purpose. However, it should be noted that the process for evaluating chemicals for inclusion in IRIS is undergoing revision (USEPA, 1996c). The

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revised assessments for many chemicals are now available on IRIS and can be consulted as examples of the RfD development process and required supporting documentation.

3.2.3.4 Treatment of Uncertainty Factors/Severity of Effects During the RfD Derivation and Verification Process

During the RfD derivation and toxicology review process, EPA considers the uncertainty in extrapolating between animal species and within individuals of a species, as well as specific uncertainties associated with the completeness of the database. The Agency's RfD Work Group has always considered the severity of the observed effects induced by the chemical under review when choosing the value of the UF with a LOAEL. For example, during the derivation and verification of the RfD for zinc (USEPA, 1992), an uncertainty factor less than the standard factor of 10 (UF of 3) was assigned to the relatively mild decrease in erythrocyte superoxide dismutase activity in human subjects. EPA recommends that the severity of the critical effect be assessed when deriving an RfD and that risk managers be made aware of the severity of the effect and the weight placed on this attribute of the effect when the RfD was derived.

3.2.3.5 Use of Less-Than-90-Day Studies to Derive RfDs

Generally, less-than-90-day experimental studies are not used to derive an RfD. This is based on the rationale that studies lasting for less than 90 days may be too short to detect various toxic effects. However, EPA, has in certain circumstances, derived an RfD based on a less-than-90-day study. For example, the RfD for nonradioactive effects of uranium is based on a 30-day rabbit study (USEPA, 1989). The short-term exposure period was used, because it was adequate for determining doses that cause chronic toxicity. In other cases, it may be appropriate to use a less-than-90-day study because the critical effect is expressed in less than 90 days. For example, the RfD for nitrate was derived and verified using studies that were less than 3-months in duration (USEPA, 1991b). For nitrate, the critical effect of methemoglobinemia in infants occurs in less than 90 days. When it can be demonstrated from other data in the toxicological database that the critical adverse effect is expressed within the study period and that a longer exposure duration would not exacerbate the observed effect or cause the appearance of some other adverse effect, the Agency may choose to use less-than-90-day studies as the basis of the RfD. Such values would have to be used with care because of the uncertainty in determining if other effects might be expressed if exposure was of greater duration than 90 days.

3.2.3.6 Use of Reproductive/Developmental, Immunotoxicity, and Neurotoxicity Data as the Basis for Deriving RfDs

All relevant toxicity data have some bearing on the RfD derivation and verification and are considered by EPA. The "critical" effect is the adverse effect most relevant to humans or, in the absence of an effect known to be relevant to humans, the adverse effect that occurs at the lowest dose in animal studies. If the critical effect is neurotoxicity, EPA will use that endpoint as the basis for the derivation and verification of an RfD, as it did for the RfD for acrylamide. Moreover, the Agency is continually revising its procedures for noncancer risk assessment. For example, EPA has released guidelines for deriving developmental RfDs (RfD_{DT}, USEPA, 1991a), for using reproductive toxicity (USEPA, 1996a), and neurotoxicity (USEPA, 1995) data

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in risk assessments. The Agency is currently working on guidelines for using immunotoxicity data to derive RfDs. In addition, the Agency is proceeding with the process of generating acceptable emergency health levels for hazardous substances in acute exposure situations based on established guidelines (NRC, 1993).

3.2.3.7 Applicability of Toxicokinetic Data in Risk Assessment

All pertinent toxicity data should be used in the risk assessment process, including toxicokinetic and mechanistic data. The Agency has used toxicokinetic data in deriving the RfD for cadmium and other compounds and currently is using toxicokinetic data to better characterize human inhalation exposures from animal inhalation experiments during derivation/verification of RfCs. In analogy to the RfD, the RfC is considered to be an estimate of a concentration in the air that is not anticipated to cause adverse noncancer effects over a lifetime of inhalation exposure (USEPA, 1994; Jarabek, 1995a). For RfCs, different dosimetry adjustments are made to account for the differences between laboratory animals and humans in gas uptake and disposition or in particle clearance and retention. This procedure results in calculation of a "human equivalent concentration." Based on the use of these procedures, an interspecies UF of 3 (i.e., approximately $10^{0.5}$), instead of the standard factor of 10, is used in the RfC derivation (Jarabek, 1995b).

Toxicokinetics and toxicodynamics of a chemical each contribute to a chemical's observed toxicity, and specifically, to observed differences among species in sensitivity. Toxicokinetics describes the disposition (i.e., deposition, absorption, distribution, metabolism, and elimination of chemicals in the body) and can be approximated using toxicokinetic models. Toxicodynamics describes the toxic interaction of the agent with the target cell. In the absence of specific data on their relative contributions to the toxic effects observed in species, each is considered to account for approximately one-half of the difference in observed effects for humans compared with laboratory animals. The implication of this assumption is that an interspecies uncertainty factor of 3 rather than 10 could be used for deriving an RfD when valid toxicokinetic data and models can be applied to obtain an oral "human equivalent applied dose" (Jarabek, 1995b). If specific data exist on the relative contribution of either element to observed effects, that proportion will be used. The role exposure duration may play, and whether or not the chemical or its damage may accumulate over time in a particular scenario, also requires careful consideration (Jarabek, 1995c).

3.2.3.8 Consideration of Linearity (or Lack of a Threshold) for Noncarcinogenic Chemicals

It is quite possible that there are chemicals with noncarcinogenic endpoints that have no threshold for effects. For example, in the case of lead, it has not been possible to identify a threshold for effects on neurological development. Other examples could include genotoxic teratogens and germline mutagens. Genotoxic teratogens act by causing mutational events during organogenesis, histogenesis, or other stages of development. Germline mutagens interact with germ cells to produce mutations which may be transmitted to the zygote and expressed during one or more stages of development. However, there are few chemicals which currently have sufficient mechanistic information about these possible modes of action. It should be recognized that although an MOA consistent with linearity is possible (especially for agents

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known to be mutagenic), this has yet to be reasonably demonstrated for most toxic endpoints other than cancer.

EPA has recognized the potential for nonthreshold noncarcinogenic endpoints and discussed this issue in the *Guidelines for Developmental Toxicity Risk Assessment* (USEPA, 1991a) and in the 1986 *Guidelines for Mutagenicity Risk Assessment* (USEPA, 1986). An awareness of the potential for such teratogenic/mutagenic effects should be established in order to deal with such data. However, without adequate data to support a genetic or mutational basis for developmental or reproductive effects, the default becomes a UF or MOA approach, which are procedures utilized for noncarcinogens assumed to have a threshold. Therefore, genotoxic teratogens and germline mutagens should be considered an exception while the traditional uncertainty factor approach is the general rule for calculating criteria or values for chemicals demonstrating developmental/reproductive effects. For the exceptional cases, since there is no well-established mechanism for calculating criteria protective of human health from the effects of these agents, criteria will be established on a case-by-case basis. Other types of nonthreshold noncarcinogens must also be handled on a case-by-case basis.

3.2.3.9 Minimum Data Guidance

For details on minimum data guidance for RfD development, see the Risk Assessment TSD (USEPA, 2000).

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3.2.4 References for Noncancer Effects

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4. EXPOSURE

The derivation of AWQC for the protection of human health requires information about both the toxicological endpoints of concern for water pollutants and the pathways of human exposure to those pollutants. The two primary pathways of human exposure to pollutants present in a particular ambient waterbody that have been considered in deriving AWQC are direct ingestion of drinking water obtained from that waterbody and the consumption of fish/shellfish obtained from that waterbody. The water pathway also includes other exposures from household uses (e.g., showering). The derivation of an AWQC involves the calculation of the maximum water concentration for a pollutant (i.e., the water quality criteria level) that ensures drinking water and/or fish ingestion exposures will not result in human intake of that pollutant in amounts that exceed a specified level based upon the toxicological endpoint of concern.

The equation for noncancer effects is presented again here, in simplified form, to emphasize the exposure-related parameters (in bold). [Note: the RSC parameter also applies to nonlinear low-dose extrapolation for cancer effects and the other exposure parameters apply to all three of the equations (see Section 1.6).]

$$AWQC = RfD \bullet \boldsymbol{RSC} \bullet \frac{(\boldsymbol{BW})}{\left[\boldsymbol{DI} + (\boldsymbol{FI} \bullet BAF)\right]} \qquad \text{(Equation 4-1)}$$

where:

AWQC	=	Ambient Water Quality Criterion (mg/L)
RfD	=	Reference dose for noncancer effects (mg/kg-day)
RSC	=	Relative source contribution factor to account for non-water sources of exposure
BW	=	Human body weight (kg)
DI	=	Drinking water intake (L/day)
FI	=	Fish intake (kg/day)
BAF	=	Bioaccumulation factor (L/kg)

The following subsections discuss exposure issues relevant to the 2000 Human Health Methodology: exposure policy issues; consideration of non-water sources of exposure (the Relative Source Contribution approach); and the factors used in AWQC computation. In relevant sections, science policy and risk management decisions made by EPA are discussed.

4.1 EXPOSURE POLICY ISSUES

This section discusses broad policy issues related to exposure concerning the major objectives that the Agency believes should be met in setting AWQC.

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An Exposure Assessment TSD provides greater detail on numerous topics discussed in this guidance: suggested sources of contaminant concentration and exposure intake information; suggestions of survey methods for obtaining and analyzing exposure data necessary for deriving AWQC; summaries of studies on fish consumption among sport fishers and subsistence fishers; more detailed presentation of parameter values (e.g., fish consumption rates, body weights); and additional guidance on the application of the RSC approach.

4.1.1 Sources of Exposure Associated With Ambient Water

4.1.1.1 Appropriateness of Including the Drinking Water Pathway in AWQC

EPA intends to continue including the drinking water exposure pathway in the derivation of its national default human health criteria (AWQC), as has been done since the 1980 AWQC National Guidelines were first published.

EPA recommends inclusion of the drinking water exposure pathway where drinking water is a designated use for the following reasons: (1) Drinking water is a designated use for surface waters under the CWA and, therefore, criteria are needed to assure that this designated use can be protected and maintained. (2) Although rare, there are some public water supplies that provide drinking water from surface water sources without treatment. (3) Even among the majority of water supplies that do treat surface waters, existing treatments may not necessarily be effective for reducing levels of particular contaminants. (4) In consideration of the Agency's goals of pollution prevention, ambient waters should not be contaminated to a level where the burden of achieving health objectives is shifted away from those responsible for pollutant discharges and placed on downstream users to bear the costs of upgraded or supplemental water treatment.

This policy decision has been supported by the States, most of the public stakeholders, and by external peer reviewers. As with the other exposure parameters, States and authorized Tribes have the flexibility to use alternative intake rates if they believe that drinking water consumption is substantively different than EPA's recommended default assumptions of 2 L/day for adults and 1 L/day for children. EPA recommends that States and authorized Tribes use an intake rate that would be protective of a majority of consumers and will consider whether an alternative assumption is adequately protective of a State's or Tribe's population based on the information or rationale provided at the time EPA reviews State and Tribal water quality standards submissions.

4.1.1.2 Setting Separate AWQC for Drinking Water and Fish Consumption

In conjunction with the issue of the appropriateness of including the drinking water pathway explicitly in the derivation of AWQC for the protection of human health, EPA intends to continue its practice of setting a single AWQC for both drinking water and fish/shellfish consumption, and a separate AWQC based on ingestion of fish/shellfish alone. This latter criterion applies in those cases where the designated uses of a waterbody include supporting fishable uses under Section 101(a) of the CWA and, thus, fish or shellfish for human consumption, but not as a drinking water supply source (e.g., non-potable estuarine waters).

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EPA does not believe that national water quality criteria for protection of drinking water uses only are particularly useful for two reasons. First, State and Tribal standards for human health are set to protect Section 101(a) uses (e.g., "fishable, swimmable uses") under the CWA. Second, most waters have multiple designated uses. Additionally, the water quality standards program protects aquatic life. The 2000 Human Health Methodology revisions do not change EPA's policy to apply aquatic life criteria to protect aquatic species where they are more sensitive (i.e., when human health criteria would not be protective enough) or where human health via fish or water ingestion is not an issue.

4.1.1.3 Incidental Ingestion from Ambient Surface Waters

The 2000 Human Health Methodology does not routinely include criteria to address incidental ingestion of water from recreational uses. EPA has considered whether there are cases where water quality criteria for the protection of human health based only on fish ingestion (or only criteria for the protection of aquatic life) may not adequately protect recreational users from health effects resulting from incidental water ingestion.

EPA reviewed information that provided estimates of incidental water ingestion rates averaged over time. EPA generally believes that the averaged amount is negligible and will not have any impact on the chemical criteria values representative of both drinking water and fish ingestion. A lack of impact on the criteria values would likely also be true for chemical criteria based on fish consumption only, unless the chemical exhibits no bioaccumulation potential. However, EPA also believes that incidental/accidental water ingestion could be important for the development of microbial contaminant water quality criteria, and for either chemical or microbial criteria for States where recreational uses such as swimming and boating are substantially higher than the national average. EPA also notes that some States have indicated they already have established incidental ingestion rates for use in developing criteria. Therefore, although EPA will not use this intake parameter when deriving its national 304(a) chemical criteria, limited guidance is provided in the Exposure Assessment TSD volume in order to assist States and authorized Tribes that face situations where this intake parameter could be of significance.

4.2 CONSIDERATION OF NON-WATER SOURCES OF EXPOSURE WHEN SETTING AWQC

4.2.1 Policy Background

The 2000 Human Health Methodology uses different approaches for addressing non-water exposure pathways in setting AWQC for the protection of human health depending upon the toxicological endpoint of concern. With those substances for which the appropriate toxic endpoint is carcinogenicity based on a linear low-dose extrapolation, only the two water sources (i.e., drinking water and fish ingestion) are considered in the derivation of the AWQC. Non-water sources are not considered explicitly. In the case of carcinogens based on linear low-dose extrapolation, the AWQC is being determined with respect to the *incremental* lifetime risk posed by a substance's presence in water, and is not being set with regard to an individual's total risk from all sources of exposure. Thus, the AWQC represents the water concentration that would be

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expected to increase an individual's lifetime risk of carcinogenicity from exposure to the particular pollutant by no more than one chance in one million, regardless of the additional lifetime cancer risk due to exposure, if any, to that particular substance from other sources.

Furthermore, health-based criteria values for one medium based on linear low-dose extrapolation typically vary from values for other media in terms of the concentration value, and often the associated risk level. Therefore, the RSC concept could not even theoretically apply unless all risk assessments for a particular carcinogen based on linear low-dose extrapolation resulted in the same concentration value and same risk level; that is, an apportionment would need to be based on a single risk value and level.

In the case of substances for which the AWQC is set on the basis of a carcinogen based on a nonlinear low-dose extrapolation or for a noncancer endpoint where a threshold is assumed to exist, non-water exposures are considered when deriving the AWQC using the RSC approach. The rationale for this approach is that for pollutants exhibiting threshold effects, the objective of the AWQC is to ensure that an individual's total exposure does not exceed that threshold level.

There has been some discussion of whether it is, in fact, necessary in most cases to explicitly account for other sources of exposure when computing the AWQC for pollutants exhibiting threshold effects. It has been argued that because of the conservative assumptions generally incorporated in the calculation of RfDs (or POD/UF values) used as the basis for the AWQC derivation, total exposures slightly exceeding the RfD are unlikely to produce adverse effects.

EPA emphasizes that the purpose of the RSC is to ensure that the level of a chemical allowed by a criterion or multiple criteria, when combined with other identified sources of exposure common to the population of concern, will not result in exposures that exceed the RfD or the POD/UF. The policy of considering multiple sources of exposure when deriving health-based criteria has become common in EPA's program office risk characterizations and criteria and standard-setting actions. Numerous EPA workgroups have evaluated the appropriateness of factoring in such exposures, and the Agency concludes that it is important for adequately protecting human health. Consequently, EPA risk management policy has evolved significantly over the last six years. Various EPA program initiatives and policy documents regarding aggregate exposure and cumulative risk have been developed, including the consideration of inhalation and dermal exposures. Additionally, accounting for other exposures has been included in recent mandates (e.g., the Food Quality Protection Act) and, thus, is becoming a requirement for the Agency. The Exposure Decision Tree approach has been shared with other EPA offices, and efforts to coordinate policies on aggregate exposure, where appropriate, have begun. EPA intends to continue developing policy guidance on the RSC issue and guidance to address the concern that human health may not be adequately protected if criteria allow for higher levels of exposure that, combined, may exceed the RfD or POD/UF. EPA also intends to refine the 2000 Human Health Methodology in the future to incorporate additional guidance on inhalation and dermal exposures. As stated previously, EPA is required to derive national water quality criteria under Section 304(a) of the CWA and does not intend to derive site-specific criteria. However, States and authorized Tribes have the flexibility to make alternative exposure and RSC estimates based on local data, and EPA strongly encourages this.

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Uncertainty factors used in the derivation of the RfD (or POD/UF) to account for intra- and interspecies variability and the incompleteness of the toxicity data set(s)/animal studies are specifically relevant to the chemical's internal toxicological action, irrespective of the sources of exposure that humans may be experiencing. The Agency's policy is to consider and account for other sources of exposure in order to set protective health criteria. EPA believes that multiple route exposures may be particularly important when uncertainty factors associated with the RfD are small. Although EPA is well aware that RfDs are not all equivalent in their derivation, EPA does not believe that uncertainty in the toxicological data should result in less stringent criteria by ignoring exposure sources. However, the RSC policy approach does allow less stringent assumptions when multiple sources of exposure are not anticipated.

The AWQC are designed to be protective criteria, generally applicable to the waters of the United States. While EPA cannot quantitatively predict the actual human health risk associated with combined exposures above the RfD or POD/UF, a combination of health criteria for multiple media exceeding the RfD or POD/UF may not be sufficiently protective. Therefore, EPA's policy is to routinely account for all sources and routes of non-occupational exposure when setting AWQC for noncarcinogens and for carcinogens based on nonlinear low-dose extrapolations. EPA believes that maintaining total exposure below the RfD (or POD/UF) is a reasonable health goal and that there are circumstances where health-based criteria for a chemical should not exceed the RfD (or POD/UF), either alone (if only one criterion is relevant, along with other intake sources considered as background exposures) or in combination. EPA believes its RSC policy ensures this goal.

Also, given the inability to reasonably predict future changes in exposure patterns, the uncertainties in the exposure estimates due to typical data inadequacy, possible unknown sources of exposure, and the potential for some populations to experience greater exposures than indicated by the available data, EPA believes that utilizing the entire RfD (or POD/UF) does not ensure adequate protection.

4.2.2 The Exposure Decision Tree Approach

As indicated in Section 1, EPA has, in the past, used a "subtraction" method to account for multiple sources of exposure to pollutants. In the subtraction method, other sources of exposure (i.e., those other than the drinking water and fish exposures) are subtracted from the RfD (or POD/UF). However, EPA also previously used a "percentage" method for the same purpose. In this approach, the percentage of total exposure typically accounted for by the exposure source for which the criterion is being determined, referred to as the relative source contribution (RSC), is applied to the RfD to determine the maximum amount of the RfD "apportioned" to that source. With both procedures, a "ceiling" level of 80 percent of the RfD and a "floor level" of 20 percent of the RfD are applied.

The subtraction method is considered acceptable when only one criterion is relevant for a particular chemical. The percentage method is recommended in the context of the above goals when multiple media criteria are at issue. The percentage method does not simply depend on the amount of a contaminant in the prospective criterion source only. It is intended to reflect health considerations, the relative portions of other sources, and the likelihood for ever-changing levels

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in each of those multiple sources (due to ever-changing sources of emissions and discharges). Rather than simply defaulting in every instance, the Agency attempts to compare multiple source exposures with one another to estimate their relative contribution to the total–given that understanding the degree to which their concentrations vary, or making any distributional analysis, is often not possible. The criteria levels, when multiple criteria are at issue, are based on the actual levels, with an assumption that there may be enough relative variability such that an apportionment (relating that percentage to the RfD) is a reasonable way of accounting for the uncertainty regarding that variability.

The specific RSC approach recommended by EPA, which we will use for the derivation of AWQC for noncarcinogens and carcinogens assessed using nonlinear low-dose extrapolation, is called the Exposure Decision Tree and is described below. To account for exposures from other media when setting an AWQC (i.e., non-drinking water/non-fish ingestion exposures, and inhalation or dermal exposures), the Exposure Decision Tree for determining proposed RfD or POD/UF apportionments represents a method of comprehensively assessing a chemical for water quality criteria development. This method considers the adequacy of available exposure data, levels of exposure, relevant sources/media of exposure, and regulatory agendas (i.e., whether there are multiple health-based criteria or regulatory standards for the same chemical). The Decision Tree addresses most of the disadvantages associated with the exclusive use of either the percentage or subtraction approaches, because they are not arbitrarily chosen prior to determining the following: specific population(s) of concern, whether these populations are relevant to multiple-source exposures for the chemical in question (i.e., whether the population is actually or potentially experiencing exposure from multiple sources), and whether levels of exposure, regulatory agendas, or other circumstances make apportionment of the RfD or POD/UF desirable. Both subtraction and percentage methods are potentially utilized under different circumstances with the Exposure Decision Tree approach, and the Decision Tree is recommended with the idea that there is enough flexibility to use other procedures if information on the contaminant in question suggests it is not appropriate to follow the Decision Tree. EPA recognizes that there may be other valid approaches in addition to the Exposure Decision Tree.

The Exposure Decision Tree approach allows flexibility in the RfD (or POD/UF) apportionment among sources of exposure. When adequate data are available, they are used to make protective exposure estimates for the population(s) of concern. When other sources or routes of exposure are anticipated but data are not adequate, there is an even greater need to make sure that public health protection is achieved. For these circumstances, a series of qualitative alternatives is used (with the less adequate data or default assumptions) that allow for the inadequacies of the data while protecting human health. Specifically, the Decision Tree makes use of chemical information when actual monitoring data are inadequate. It considers information on the chemical/physical properties, uses of the chemical, and environmental fate and transformation, as well as the likelihood of occurrence in various media. Review of such information, when available, and determination of a reasonable exposure characterization for the chemical will result in a water quality criterion that more accurately reflects exposures than automatically using a default value. Although the 20 percent default will still generally be used when information is not adequate, the need for using it should be reduced. There may also be some situations where EPA would consider the use of an 80 percent default (see Section 4.2.3).

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The Decision Tree also allows for use of either the subtraction or percentage method to account for other exposures, depending on whether one or more health-based criterion is relevant for the chemical in question. The subtraction method is considered acceptable when only one criterion is relevant for a particular chemical. In these cases, other sources of exposure can be considered "background" and can be subtracted from the RfD (or POD/UF).

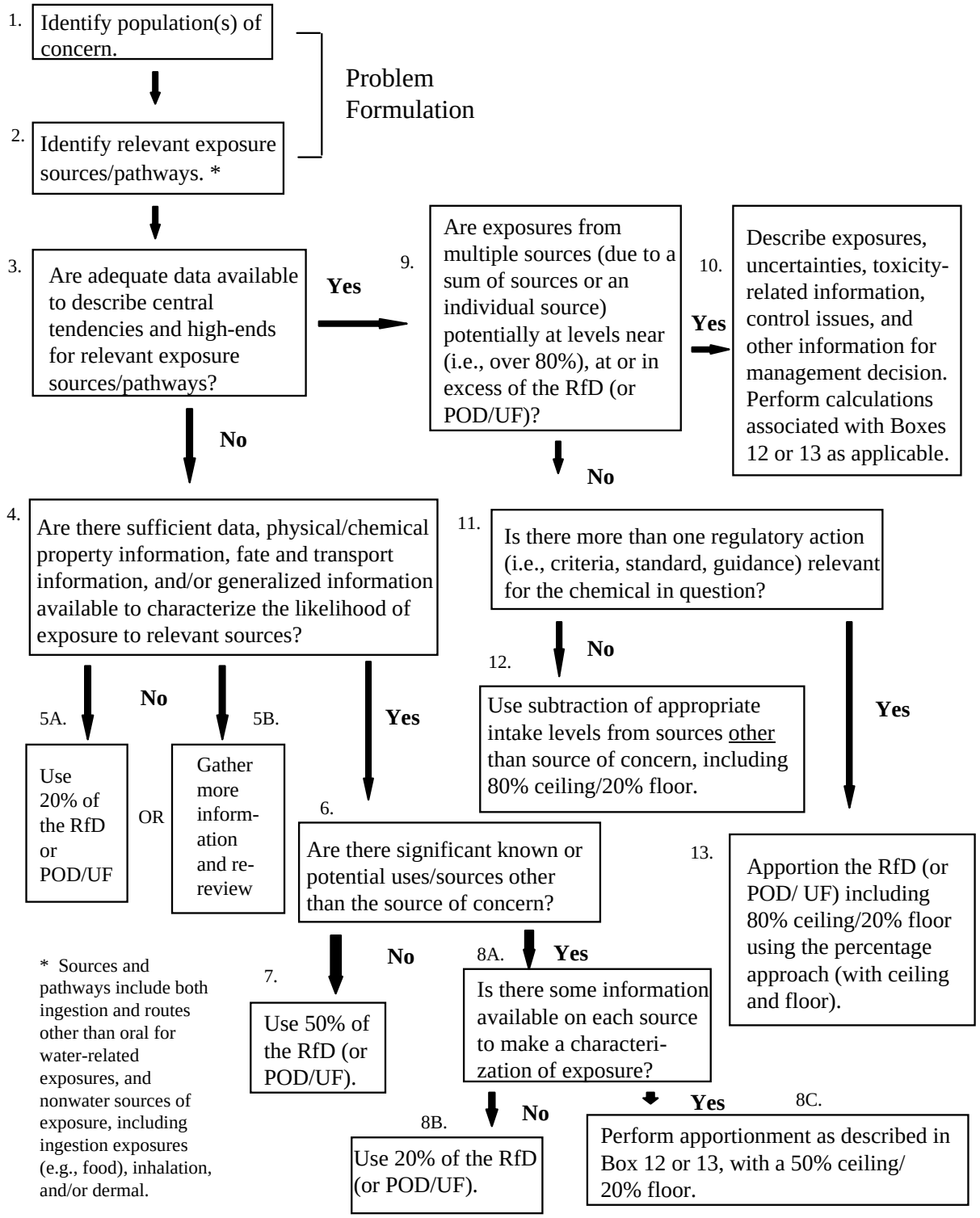
EPA cautions States and Tribes when using the subtraction method in these circumstances. The subtraction method results in a criterion allowing the maximum possible chemical concentration in water after subtracting other sources. As such, it removes any cushion between pre-criteria levels (i.e., actual "current" levels) and the RfD, thereby setting criteria at the highest levels short of exceeding the RfD. It is somewhat counter to the goals of the CWA for maintaining and restoring the nation's waters. It is also directly counter to Agency policies, explicitly stated in numerous programs, regarding pollution prevention. EPA has advocated that it is good health policy to set criteria such that exposures are kept low when current levels are already low. The subtraction method generally results in criteria levels of a contaminant in a particular medium at significantly higher levels than the percentage method and, in this respect, is contradictory to such goals. In fact, many chemicals have pre-criteria levels in environmental media substantially lower (compared to the RfD) than the resulting criteria allow.

When more than one criterion is relevant to a particular chemical, apportioning the RfD (or POD/UF) via the percentage method is considered appropriate to ensure that the combination of criteria and, thus, the potential for resulting exposures do not exceed the RfD (or POD/UF). The Exposure Decision Tree (with numbered boxes) is shown in Figure 4-1. The explanation in the text on the following pages must be read in tandem with the Decision Tree figure; the text in each box of the figure only nominally identifies the process and conditions for determining the outcome for that step of the Decision Tree. The underlying objective is to maintain total exposure below the RfD (or POD/UF) while generally avoiding an extremely low limit in a single medium that represents just a nominal fraction of the total exposure. To meet this objective, all proposed numeric limits lie between 80 percent and 20 percent of the RfD (or POD/UF). Again, EPA will use the Exposure Decision Tree approach when deriving its AWQC but also recognizes that departures from the approach may be appropriate in certain cases. EPA understands that there may be situations where the Decision Tree procedure is not practicable or

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Figure 4-1

Exposure Decision Tree for Defining Proposed RfD (or POD/UF) Apportionment



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may be simply irrelevant after considering the properties, uses, and sources of the chemical in question. EPA endorses such flexibility by States and authorized Tribes when developing alternative water quality criteria in order to choose other procedures that are more appropriate for setting health-based criteria and, perhaps, apportioning the RfD or POD/UF, as long as reasons are given as to why it is not appropriate to follow the Exposure Decision Tree approach and as long as the steps taken to evaluate the potential sources and levels of exposure are clearly described. Often, however, the common situation of multiple exposure sources for a chemical is likely to merit a Decision Tree evaluation for the purpose of developing human health water quality criteria for a given chemical.

It is clear that this will be an interactive process; input by exposure assessors will be provided to, and received from, risk managers throughout the process, given that there may be significant implications regarding control issues (i.e., cost/feasibility), environmental justice issues, etc. In cases where the Decision Tree is not chosen, communication and concurrence about the decision rationale and the alternative water quality criteria are of great importance.

Descriptions of the boxes within the Decision Tree are separated by the following process headings to facilitate an understanding of the major considerations involved. The decision to perform, or not to perform, an apportionment could actually be made at several points during the Decision Tree process. Working through the process is most helpful for identifying possible exposure sources and the potential for exposure, determining the relevancy of the Decision Tree to developing an AWQC for a particular chemical and, possibly, determining the appropriateness of using an alternative approach to account for overall exposure. "Relevancy" here means determining whether more than one criterion, standard, or other guidance is being planned or is in existence for the chemical in question. Additional guidance for States and Tribes that wish to use the Exposure Decision Tree is provided in the Exposure Assessment TSD.

4.2.2.1 Problem Formulation

Initial Decision Tree discussion centers around the first two boxes: identification of population(s) of concern (Box 1) and identification of relevant exposure sources and pathways (Box 2). The term "problem formulation" refers to evaluating the population(s) and sources of exposure in a manner that allows determination of the potential for the population of concern to experience exposures from multiple sources for the chemical in question. Also, the data for the chemical in question must be representative of each source/medium of exposure and be relevant to the identified population(s). Evaluation includes determining whether the levels, multiple criteria or regulatory standards, or other circumstances make apportionment of the RfD or POD/UF reasonable. The initial problem formulation also determines the exposure parameters chosen, the intake assumptions chosen for each route, and any environmental justice or other social issues that aid in determining the population of concern. The term "data," as used here and discussed throughout this section, refers to ambient sampling data (whether from Federal, regional, State, or area-specific studies) and not internal human exposure measurements.

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4.2.2.2 Data Adequacy

In Box 3, it is necessary that adequate data exist for the relevant sources/pathways of exposure if one is to avoid using default procedures. The adequacy of data is a professional judgment for each individual chemical of concern, but EPA recommends that the minimum acceptable data for Box 3 are exposure distributions that can be used to determine, with an acceptable 95 percent confidence interval, the central tendency and high-end exposure levels for each source. In fact, distributional data may exist for some or most of the sources of exposure.

There are numerous factors to consider in order to determine whether a dataset is adequate. These include: (1) sample size (i.e., the number of data points); (2) whether the data set is a random sample representative of the target population (if not, estimates drawn from it may be biased no matter how large the sample); (3) the magnitude of the error that can be tolerated in the estimate (estimator precision); (4) the sample size needed to achieve a given precision for a given parameter (e.g., a larger sample is needed to precisely estimate an upper percentile than a mean or median value); (5) an acceptable analytical method detection limit; and (6) the functional form and variability of the underlying distribution, which determines the estimator precision (e.g., whether the distribution is normal or lognormal and whether the standard deviation is 1 or 10). Lack of information may prevent assessment of each of these factors; monitoring study reports often fail to include background information or sufficient summary statistics (and rarely the raw data) to completely characterize data adequacy. Thus, a case-by-case determination of data adequacy may be necessary.

That being stated, there are some guidelines, as presented below, that lead to a rough rule-of-thumb on what constitutes an "adequate" sample size for exposure assessment. Again, first and foremost, the representativeness of the data for the population evaluated and the analytical quality of the data must be acceptable. If so, the primary objective then becomes estimating an upper percentile (e.g., say the 90th) and a central tendency value of some exposure distribution based on a random sample from the distribution. Assuming that the distribution of exposures is unknown, a nonparametric estimate of the 90th percentile is required. The required estimate, based on a random sample of *n* observations from a target population, is obtained by ranking the data from smallest to largest and selecting the observation whose rank is 1 greater than the largest integer in the product of 0.9 times *n*. For example, in a data set of 25 points, the nonparametric estimate of the 90th percentile is the 23rd largest observation.

In addition to this point estimate, it is useful to have an upper confidence bound on the 90th percentile. To find the rank of the order statistic that gives an upper 95 percent confidence limit on the 90th percentile, the smallest value of *r* that satisfies the following formula is determined:

$$0.95 \approx \sum_{i=0}^{r-1} \binom{n}{i} 0.9^{i}\ 0.1^{n-i} \qquad \text{(Equation 4-2)}$$

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where:

r	=	the rank order of the observation
n	=	the number of observations
I	=	integer from 0 to r - 1

For relatively small data sets, the above formula will lead to selecting the largest observation as the upper confidence limit on the 90th percentile. However, the problem with using the maximum is that, in many environmental datasets, the largest observation is an outlier and would provide an unrealistic upper bound on the 90th percentile. It would, therefore, be preferable if the sample size *n* were large enough so that the formula yielded the second largest observation as the confidence limit (see for example Gibbons, 1971).

This motivates establishing the following criterion for setting an "adequate" sample size: pick the smallest *n* such that the nonparametric upper 95 percent confidence limit on the 90th percentile is the second largest value. Application of the above formula with *r* set to *n*-1 yields *n* = 45 for this minimum sample size.

For the upper 95 percent confidence limit to be a useful indicator of a high-end exposure, it must not be overly conservative (too large relative to the 90th percentile). It is, therefore, of interest to estimate the expected magnitude of the ratio of the upper 95 percent confidence limit to the 90th percentile. This quantity generally cannot be computed, since it is a function of the unknown distribution. However, to get a rough idea of its value, consider the particular case of a normal distribution. If the coefficient of variation (i.e., the standard deviation divided by the mean) is between 0.5 and 2.0, the expected value of the ratio in samples of 45 will be approximately 1.17 to 1.31; i.e., the upper 95 percent confidence limit will be only about 17 to 31 percent greater than the 90th percentile on the average.

It should be noted that the nonparametric estimate of the 95 percent upper confidence limit based on the second largest value can be obtained even if the data set has only two detects (it is assumed that the two detects are greater than the detection limit associated with all non-detects). This is an argument for using nonparametric rather than parametric estimation, since use of parametric methods would require more detected values. On the other hand, if non-detects were not a problem and the underlying distribution were known, a parametric estimate of the 90th percentile would generally be more precise.

As stated above, adequacy also depends on whether the samples are relevant to and representative of the population at risk. Data may, therefore, be adequate for some decisions and inadequate for others; this determination requires some professional judgment.

If the answer to Box 3 is no, based on the above determination of adequacy, then the decision tree moves to Box 4. As suggested by the separate boxes, the available data that will be reviewed as part of Box 4 do not meet the requirements necessary for Box 3. In Box 4, any limited data that are available (in addition to information about the chemical/physical properties, uses, and environmental fate and transformation, as well as any other information that would characterize the likelihood of exposure from various media for the chemical) are evaluated to

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make a qualitative determination of the relation of one exposure source to another. Although this information should always be reviewed at the outset, it is recommended that this information also be used to estimate the health-based water quality criteria. The estimate should be rather conservative (as indicated in the Decision Tree), given that it is either not based on actual monitoring data or is based on data that has been considered to be inadequate for a more accurate quantitative estimate. Therefore, greater uncertainties exist and accounting for variability is not really possible. Whether the available data are adequate and sufficiently representative will likely vary from chemical to chemical and may depend on the population of concern. If there are some data and/or other information to make a characterization of exposure, a determination can be made as to whether there are significant known or potential uses for the chemical/sources of exposure other than the source of concern (i.e., in this case, the drinking water and fish intakes relevant to developing an AWQC) that would allow one to anticipate/quantify those exposures (Box 6). If there are not, then it is recommended that 50 percent of the RfD or POD/UF can be safely apportioned to the source of concern (Box 7). While this leaves half of the RfD or POD/UF unapportioned, it is recommended as the maximum apportionment due to the lack of data needed to more accurately quantify actual or potential exposures. If the answer to the question in Box 6 is yes (there is multiple source information available for the exposures of concern), and some information is available on each source of exposure (Box 8A), apply the procedure in either Box 12 or Box 13 (depending on whether one or more criterion is relevant to the chemical), using a 50 percent ceiling (Box 8C)–again due to the lack of adequate data. If the answer to the question in Box 8A is no (there is no available information to characterize exposure), then the 20 percent default of the RfD or POD/UF is used (Box 8B).

If the answer to the question in Box 4 is no; that is, there are not sufficient data/information to characterize exposure, EPA intends to generally use the "default" assumption of 20 percent of the RfD or POD/UF (Box 5A) when deriving or revising the AWQC. It may be better to gather more data or information and re-review when this information becomes available (Box 5B). EPA has done this on occasion when resources permit the acquisition of additional data to enable better estimates of exposure instead of the default. If this is not possible, then the assumption of 20 percent of the RfD or POD/UF (Box 5A) should be used. Box 5A is likely to be used infrequently with the Exposure Decision Tree approach, given that the information described in Box 4 should be available in most cases. However, EPA intends to use 20 percent of the RfD (or POD/UF), which has also been used in past water program regulations, as the default value.

4.2.2.3 Regulatory Actions

If there are adequate data available to describe the central tendencies and high ends from each exposure source/pathway, then the levels of exposure relative to the RfD or POD/UF are compared (Box 9). If the levels of exposure for the chemical in question are not near (currently defined as greater than 80 percent), at, or in excess of the RfD or POD/UF, then a subsequent determination is made (Box 11) as to whether there is more than one health-based criterion or regulatory action relevant for the given chemical (i.e., more than one medium-specific criterion,

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standard or other guidance being planned, performed or in existence for the chemical). The subtraction method is considered acceptable when only one criterion (standard, etc.) is relevant for a particular chemical. In these cases, other sources of exposure can be considered "background" and can be subtracted from the RfD (or POD/UF). When more than one criterion is relevant to a particular chemical, apportioning the RfD (or POD/UF) via the percentage method is considered appropriate to ensure that the combination of health criteria, and thus the potential for resulting exposures, do not exceed the RfD (or POD/UF).

As indicated in Section 2, for EPA's national 304(a) criteria, the RSC intake estimates of non-water exposures (e.g., non-fish dietary exposures) will be based on arithmetic mean values when data are available. The assumed body weight used in calculating the national criteria will also be based on average values. The drinking water and fish intake values are 90th percentile estimates. EPA believes that these assumptions will be protective of a majority of the population and recommends them for State and Tribal use. However, States and authorized Tribes have the flexibility to choose alternative intake rate and exposure estimate assumptions to protect specific population groups that they have chosen.

4.2.2.4 Apportionment Decisions

If the answer to the question in Box 11 is no (there is not more than one relevant medium-specific criterion/regulatory action), then the recommended method for setting a health-based water quality criterion is to utilize a subtraction calculation (Box 12). Specifically, appropriate intake values for each exposure source other than the source of concern are subtracted out. EPA will rely on average values commonly used in the Agency for food ingestion and inhalation rates, combined with mean contaminant concentration values, for calculating RSC estimates to subtract. Alternatively, contaminant concentrations could be selected based on the variability associated with those concentrations for each source. This implies that a case-by-case determination of the variability and the resulting intake chosen would be made, as each chemical evaluated can be expected to have different variations in concentration associated with each source of intake. However, EPA anticipates that the available data for most contaminants will not allow this for determination (based on past experience). Guidance addressing this possibility is addressed in the Exposure Assessment TSD. EPA does not recommend that high-end intakes be subtracted for every exposure source, since the combination may not be representative of any actually exposed population or individual. The subtraction method would also include an 80 percent ceiling and a 20 percent floor.

If the answer to the question in Box 11 is yes (there is more than one medium-specific criterion/regulation relevant), then the recommended method for setting health-based water quality criteria is to apportion the RfD or POD/UF among those sources for which health-based criteria are being set (Box 13). This is done via a percentage approach (with a ceiling and floor). This simply refers to the percentage of overall exposure contributed by an individual exposure source. For example, if for a particular chemical, drinking water were to represent half of total exposure and diet were to represent the other half, then the drinking water contribution (or RSC) would be 50 percent. The health-based criteria would, in turn, be set at 50 percent of the RfD or POD/UF. This method also utilizes an appropriate combination of intake values for each

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exposure source based on values commonly used in the Agency for food ingestion and inhalation rates, combined with mean contaminant concentration values.

Finally, if the levels of exposure for the chemical in question are near (currently defined as greater than 80 percent), at, or in excess of the RfD or POD/UF (i.e., the answer in Box 9 is yes), then the estimates of exposures and related uncertainties, recommended apportionment (either box 12 or 13), toxicity-related information, control issues, and other information are to be presented to managers for a decision (Box 10). The high levels referred to in Box 9 may be due to one source contributing that high level (while other sources contribute relatively little) or due to more than one source contributing levels that, in combination, approach or exceed the RfD or POD/UF. Management input may be necessary due to the control issues (i.e., cost and feasibility concerns), especially when multiple criteria are at issue. In practice, risk managers are routinely a part of decisions regarding regulatory actions and will be involved with any recommended outcome of the Exposure Decision Tree or, for that matter, any alternative to the Exposure Decision Tree. However, because exposures approach or exceed the RfD or POD/UF and because the feasibility of controlling different sources of exposure are complicated issues, risk managers will especially need to be directly involved in final decisions in these circumstances.

It is emphasized here that the procedures in these circumstances are not different than the procedures when exposures are not at or above the RfD (or POD/UF). Therefore, in these cases, estimates should be performed as with Boxes 11, 12, and 13. The recommendation should be made based on health-based considerations only, just as when the chemical in question was not a Box 10 situation. If the chemical is relevant to one health criterion or regulatory action only, the other sources of exposure could be subtracted from the RfD or POD/UF to determine if there is any leftover amount for setting the criterion. If the chemical is a multiple media criteria issue, then an apportionment should be made, even though it is possible that all sources would need to be reduced. Regardless of the outcome of Box 9, all apportionments made (via the methods of Boxes 12 or 13) should include a presentation of the uncertainty in the estimate and in the RfD or POD/UF for a more complete characterization.

The process for a Box 10 situation (versus a situation that is not) differs in that the presentations for Boxes 12 and 13 are based on apportionments (following the review of available information and a determination of appropriate exposure parameters) that must address additional control issues and may result in more selective reductions. With Box 10, one or several criteria possibilities ("scenarios") could be presented for comparison along with implications of the effects of various control options. It is appropriate to present information in this manner to risk managers given the complexity of these additional control issues.

4.2.3 Additional Points of Clarification on the Exposure Decision Tree Approach for Setting AWQC

As with Box 9, if a determination is made in Box 8A (i.e., information is available to characterize exposure) that exposures are near, at, or above the RfD (or POD/UF) based on the available information, the apportionments made need to be presented to risk managers for decision. If information is lacking on some of the multiple exposure sources, then EPA would use a default of 20 percent of the RfD or POD/UF (Box 8B).

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Results of both Boxes 12 and 13 rely on the 80 percent ceiling and 20 percent floor. The 80 percent ceiling was implemented to ensure that the health-based goal will be low enough to provide adequate protection for individuals whose total exposure to a contaminant is, due to any of the exposure sources, higher than currently indicated by the available data. This also increases the margin of safety to account for possible unknown sources of exposure. The 20 percent floor has been traditionally rationalized to prevent a situation where small fractional exposures are being controlled. That is, below that point, it is more appropriate to reduce other sources of exposure, rather than promulgating standards for *de minimus* reductions in overall exposure.

If it can be demonstrated that other sources and routes of exposure are not anticipated for the pollutant in question (based on information about its known/anticipated uses and chemical/physical properties), then EPA would use the 80 percent ceiling. EPA qualifies this policy with the understanding that as its policy on cumulative risk assessment continues to develop, the 80 percent RSC may prove to be underprotective.

In the cases of pollutants for which substantial data sets describing exposures across all anticipated pathways of exposure exist, and probabilistic analyses have been conducted based on those data, consideration will be given to the results of those assessments as part of the Exposure Decision Tree approach for setting AWQC.

For many chemicals, the rate of absorption from ingestion can differ substantially from absorption by inhalation. There is also available information for some chemicals that demonstrates appreciable differences in gastrointestinal absorption depending on whether the chemical is ingested from water, soil, or food. For some contaminants, the absorption of the contaminant from food can differ appreciably for plant compared with animal food products. Regardless of the apportionment approach used, EPA recommends using existing data on differences in bioavailability between water, air, soils, and different foods when estimating total exposure for use in apportioning the RfD or POD/UF. The Agency has developed such exposure estimates for cadmium (USEPA, 1994). In the absence of data, EPA will assume equal rates of absorption from different routes and sources of exposure.

4.2.4 Quantification of Exposure

When selecting contaminant concentration values in environmental media and exposure intake values for the RSC analysis, it is important to realize that each value selected (including those recommended as default assumptions in the AWQC equation) may be associated with a distribution of values for that parameter. Determining how various subgroups fall within the distributions of overall exposure and how the combination of exposure variables defines what population is being protected is a complicated and, perhaps, unmanageable task, depending on the amount of information available on each exposure factor included. Many times, the default assumptions used in EPA risk assessments are derived from the evaluation of numerous studies and are considered to generally represent a particular population group or a national average. Therefore, describing with certainty the exact percentile of a particular population that is protected with a resulting criteria is often not possible.

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By and large, the AWQC are derived to protect the majority of the general population from chronic adverse health effects. However, as stated above in Section 4.1.1.1, States and authorized Tribes are encouraged to consider protecting population groups that they determine are at greater risk and, thus, would be better protected using alternative exposure assumptions. The ultimate choice of the contaminant concentrations used in the RSC estimate and the exposure intake rates requires the use of professional judgment. This is discussed in greater detail in the Exposure Assessment TSD.

4.2.5 Inclusion of Inhalation and Dermal Exposures

EPA intends to develop policy guidelines to apply to this Methodology for explicitly incorporating inhalation and dermal exposures. When estimating overall exposure to pollutants for AWQC development, EPA believes that the sources of inhalation and dermal exposures considered should include, on a case-by-case basis, both non-oral exposures from water and other inhalation and dermal sources (e.g., ambient or indoor air, soil). When the policy guidelines are completed, this Methodology will be refined to include that guidance.

A number of drinking water contaminants are volatile and thus diffuse from water into the air where they may be inhaled. In addition, drinking water is used for bathing and, thus, there is at least the possibility that some contaminants in water may be dermally absorbed. Volatilization may increase exposure via inhalation and decrease exposure via ingestion and dermal absorption. The net effect of volatilization and dermal absorption upon total exposure to volatile drinking water contaminants is unclear in some cases and varies from chemical to chemical. Dermal exposures are also important to consider for certain population groups, such as children and other groups with high soil contact.

With regard to additional non-water related exposures, it is clear that the type and magnitude of toxicity produced via inhalation, ingestion, and dermal contact may differ; that is, the route of exposure can affect absorption of a chemical and can otherwise modify its toxicity. For example, an inhaled chemical such as hydrogen fluoride may produce localized effects on the lung that are not observed (or only observed at much higher doses) when the chemical is administered orally. Also, the active form of a chemical (and principal toxicity) can be the parent compound and/or one or more metabolites. With this Methodology, EPA recommends that differences in absorption and toxicity by different routes of exposure be determined and accounted for in dose estimates and applied to the exposure assessment. EPA acknowledges that the issue of whether the doses received from inhalation and ingestion exposures are cumulative (i.e., toward the same threshold of toxicity) is complicated. Such a determination involves evaluating the chemical's physical characteristics, speciation, and reactivity. A chemical may also exhibit different metabolism by inhalation versus oral exposure and may not typically be metabolized by all tissues. In addition, a metabolite may be much more or much less toxic than the parent compound. Certainly with a systemic effect, if the chemical absorbed via different routes enters the bloodstream, then there is some likelihood that it will contact the same target organ. Attention also needs to be given to the fact that both the RfD and RfC are derived based on the administered level. Toxicologists generally believe that the effective concentration of the active form of a chemical(s) at the site(s) of action determines the toxicity. If specific differences between routes of exposure are not known, it may be reasonable to assume that the

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internal concentration at the site from any route contributes as much to the same effect as any other route. A default of assuming equal absorption has often been used. However, for many of the chemicals that the Agency has reviewed, there is a substantial amount of information already known to determine differences in rates of absorption. For example, absorption is, in part, a function of blood solubility (i.e., Henry's Constant) and better estimations than the default can be made.

The RSC analyses that accompany the 2000 Human Health Methodology accommodate inclusion of inhalation exposures. Even if different target organs are involved between different routes of exposure, a conservative policy may be appropriate to keep all exposures below a certain level. A possible alternative is to set allowable levels (via an equation) such that the total of ingestion exposures over the ingestion RfD added to the total of inhalation exposures over the inhalation RfC is not greater than 1 (Note: the RfD is typically presented in mg/kg-day and the RfC is in mg/m^3). Again, EPA intends to develop guidance for this Methodology to explicitly incorporate inhalation and dermal exposures, and will refine the Methodology when that guidance is completed.

4.3 EXPOSURE FACTORS USED IN THE AWQC COMPUTATION

This section presents values for the specific exposure factors that EPA will use in the derivation of AWQC. These include human body weight, drinking water consumption rates, and fish ingestion rates.

When choosing exposure factor values to include in the derivation of a criterion for a given pollutant, EPA recommends considering values that are relevant to population(s) that is (are) most susceptible to that pollutant. In addition, highly exposed populations should be considered when setting criteria. In general, exposure factor values specific to adults and relevant to lifetime exposures are the most appropriate values to consider when determining criteria to protect against effects from long-term exposure which, by and large, the human health criteria are derived to protect. However, infants and children may have higher rates of water and food consumption per unit body weight compared with adults and also may be more susceptible to some pollutants than adults (USEPA, 1997a). There may be instances where acute or subchronic developmental toxicity makes children the population group of concern. In addition, exposure of pregnant women to certain toxic chemicals may cause developmental effects in the fetus (USEPA, 1997b). Exposures resulting in developmental effects may be of concern for some contaminants and should be considered along with information applicable to long-term health effects when setting AWQC. (See Section 3.2 for further discussion of this issue.) Short-term exposure may include multiple intermittent or continuous exposures occurring over a week or so. Exposure factor values relevant for considering chronic toxicity, as well as exposure factor values relevant for short-term exposure developmental concerns, that could result in adverse health effects are discussed in the sections below. In appropriate situations, EPA may consider developing criteria for developmental health effects based on exposure factor values specific to children or to women of childbearing age. EPA encourages States and Tribes to do the same when health risks are associated with short-term exposures.

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EPA believes that the recommended exposure factor default intakes for adults in chronic exposure situations are adequately protective of the population over a lifetime. In providing additional exposure intake values for highly exposed subpopulations (e.g., sport anglers, subsistence fishers), EPA is providing flexibility for States and authorized Tribes to establish criteria specifically targeted to provide additional protection using adjusted values for exposure parameters for body weight, drinking water intake, and fish consumption. The exposure factor values provided for women of childbearing age and children would only be used in the circumstances indicated above.

Each of the following sections recommends exposure parameter values for use in developing AWQC. These are based on both science policy decisions that consider the best available data, as well as risk management judgments regarding the overall protection afforded by the choice in the derivation of AWQC. These will be used by EPA to derive new, or revise existing, 304(a) national criteria.

4.3.1 Human Body Weight Values for Dose Calculations

The source of data for default human body weights used in deriving the AWQC is the third *National Health and Nutrition Examination Survey* (NHANES III). NHANES III represents a very large interview and examination endeavor of the National Center for Health Statistics (NCHS) and included participation from the Centers for Disease Control (CDC). The NHANES III was conducted on a nationwide probability sample of over 30,000 persons from the civilian, non-institutionalized population of the United States. The survey began in October 1988 and was completed in October 1994 (WESTAT, 2000; McDowell, 2000). Body weight data were taken from the NHANES III Examination Data File. Sampling weights were applied to all persons examined in the Mobile Examination Centers (MECs) or at home, as was recommended by the NHANES data analysts (WESTAT, 2000).

The NHANES III survey has numerous strengths and very few weaknesses. Its primary strengths are the national representativeness, large sample size, and precise estimates due to this large sample size. Another strength is its high response rate; the examination rate was 73 percent overall, 89 percent for children under 1 year old, and approximately 85 percent for children 1 to 5 years old (McDowell, 2000). Interview response rates were even higher, but the body weight data come from the NHANES examinations; that is, all body weights were carefully measured by survey staff, rather than the use of self-reported body weights. The only significant potential weakness of the NHANES data is the fact that the data are now between 6 and 12 years old. Given that there were upward trends in body weight from NHANES II to NHANES III, and that NCHS has indicated the prevalence of overweight people increased in all age groups, the data could underestimate current body weights if that trend has continued (WESTAT, 2000).

The NHANES III collected standard body measurements of sample subjects, including height and weight, that were made at various times of the day and in different seasons of the year. This technique was used because one's weight may vary between winter and summer and may fluctuate with recency of food and water intake and other daily activities (McDowell, 2000).

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As with the other exposure assumptions, States and authorized Tribes are encouraged to use alternative body weight assumptions for population groups other than the general population and to use local or regional data over default values as more representative of their target population group(s).

4.3.1.1 Rate Protective of Human Health from Chronic Exposure

EPA recommends maintaining the default body weight of 70 kg for calculating AWQC as a representative average value for both male and female adults. As previously indicated, exposure factor values specific to adults are recommended to protect against effects from long-term exposure. The value of 70 kg is based on the following information. In the analysis of the NHANES III database, median and mean values for female adults 18-74 years old are 65.8 and 69.5 kg, respectively (WESTAT, 2000). For males in the same age range, the median and mean values are 79.9 and 82.1 kg, respectively. The mean body weight value for men and women ages 18 to 74 years old from this survey is 75.6 kg (WESTAT, 2000). This mean value is higher than the mean value for adults ages 20-64 years old of 70.5 kg from a study by the National Cancer Institute (NCI) which primarily measured drinking water intake (Ershow and Cantor, 1989). The NCI study is described in the subsection on Drinking Water Intake Rates that follows (Section 4.3.2). The value from the NHANES III database is also higher than the value given in the revised EPA *Exposure Factors Handbook* (USEPA, 1997b), which recommends 71.8 kg for adults, based on the older NHANES II data. The Handbook also acknowledges the commonly used 70 kg value and encourages risk assessors to use values which most accurately reflect the exposed population. However, the point is also made that the 70 kg value is used in the derivation of cancer slope factors and unit risks that appear in IRIS. Consistency is advocated between the dose-response relationship and exposure factors assumed. Therefore, if a value higher than 70 kg is used, the assessor needs to adjust the dose-response relationship as described in the Appendix to Chapter 1, Volume 1 of the Handbook (USEPA, 1997b).

4.3.1.2 Rates Protective of Developmental Human Health Effects

As noted above, pregnant women may represent a more appropriate population for which to assess risks from exposure to chemicals in ambient waters in some cases, because of the potential for developmental effects in fetuses. In these cases, body weights representative of women of childbearing age may be appropriate to adequately protect offspring from such health effects. To determine a mean body weight value appropriate to this population, separate body weight values for women in individual age groups within the range of 15 to 44 years old were analyzed from the NHANES III data (WESTAT, 2000). The resulting median and mean body weight values are 63.2 and 67.3 kg, respectively. Ershow and Cantor (1989) present body weight values specifically for pregnant women included in the survey; median and mean weights are 64.4 and 65.8 kilograms, respectively. Ershow and Cantor (1989), however, do not indicate the ages of these pregnant women. Based on this information for women of childbearing age and pregnant women, EPA recommends use of a body weight value of 67 kg in cases where pregnant women are the specific population of concern and the chemical of concern exhibits reproductive and/or developmental effects (i.e., the critical effect upon which the RfD or POD/UF is based). Using the 67 kg assumption would result in lower (more protective) criteria than criteria based on 70 kg.

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As discussed earlier, because infants and children generally have a higher rate of water and food consumption per unit body weight compared with adults, a higher intake rate per unit body weight may be needed when comparing estimated exposure doses with critical doses when RfDs are based on health effects in children. To calculate intake rates relevant to such effects, the body weight of children should be used. As with the default body weight for pregnant women, EPA is not recommending the development of additional AWQC (i.e., similar to drinking water health advisories) that focus on acute or short-term effects, since these are not seen routinely as having a meaningful role in the water quality criteria program. However, there may be circumstances where the consideration of exposures for these groups is warranted. Although the AWQC generally are based on chronic health effects data, they are intended to also be protective with respect to adverse effects that may reasonably be expected to occur as a result of elevated shorter-term exposures. EPA acknowledges this as a potential course of action and is, therefore, recommending these default values which EPA would consider in an appropriate circumstance and for States and authorized Tribes to utilize in such situations.

EPA is recommending an assumption of 30 kg as a default child's body weight to calculate AWQC to provide additional protection for children when the chemical of concern indicates health effects in children are of predominant concern (i.e., test results show children are more susceptible due to less developed immune systems, neurological systems, and/or lower body weights). The value is based on the mean body weight value of 29.9 kg for children ages 1 to14 years old, which combines body weight values for individual age groups within this larger group. The mean value is based on body weight information from NHANES III for individual-year age groups between one and 14 years old (WESTAT, 2000). A mean body weight of 28 kg is obtained using body weight values from Ershow and Cantor (1989) for five age groups within this range of 0-14 years and applying a weighting method for different ages by population percentages from the U.S. Bureau of the Census. The 30 kg assumption is also consistent with the age range for children used with the estimated fish intake rates. Unfortunately, fish intake rates for finer age group divisions are not possible due to the limited sampling base from the fish intake survey; there is limited confidence in calculated values (e.g., the mean) for such fine age groups. Given this limitation, the broad age category of body weight for children is suitable for use with the default fish intake assumption.

Given the hierarchy of preferences regarding the use of fish intake information (see Section 4.3.3), States may have more comprehensive data and prefer to target a more narrow, younger age group. If States choose to specifically evaluate toddlers, EPA recommends using 13 kg as a default body weight assumption for children ages 1 to 3 years old. The median and mean values of body weight for children 1 to 3 years old are 13.2 and 13.1 kg, respectively, based on an analysis of the NHANES III database (WESTAT, 2000). The NHANES III median and mean values for females between 1 and 3 years old are 13.0 and 12.9 kg, respectively, and are 13.4 and 13.4 kg for males, respectively. Median and mean body weight values from the earlier Ershow and Cantor (1989) study for children ages 1 to 3 years old were 13.6 and 14.1 kg, respectively. Finally, if infants are specifically evaluated, EPA recommends a default body weight of 7 kg based on the NHANES III analysis. Median and mean body weights for both male and female infants (combined) 2 months old were 6.3 and 6.3 kg, respectively, and for infants 3 months old were 7.0 and 6.9 kg, respectively. With the broader age category of males and females 2 to 6 months old, median and mean body weights were 7.4 and 7.4 kg, respectively. The NHANES

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analysis did not include infants under 2 months of age. Although EPA is not recommending body weight values for newborns, the NCHS National Vital Statistics Report indicates that, for 1997, the median birth weight ranged from 3 to 3.5 kg, according to WESTAT (2000).

Body weight values for individual ages within the larger range of 0-14 years are listed in the Exposure Assessment TSD for those States and authorized Tribes who wish to use body weight values for these individual groups. States and Tribes may wish to consider certain general developmental ages (e.g., infants, pre-adolescents, etc.), or certain specific developmental landmarks (e.g., neurological development in the first four years), depending on the chemical of concern. EPA encourages States and authorized Tribes to choose a body weight intake from the tables presented in the TSD, if they believe a particular age subgroup is more appropriate.

4.3.2 Drinking Water Intake Rates

The basis for the drinking water intake rates (also for the fish intake rates presented in Section 4.3.3) is the 1994-96 Continuing Survey of Food Intake by Individuals *(*CSFII) conducted by the U.S. Department of Agriculture (USDA, 1998). The CSFII survey collects dietary intake information from nationally representative samples of non-institutionalized persons residing in United States households. Households in these national surveys are sampled from the 50 states and the District of Columbia. Each survey collects daily consumption records for approximately 10,000 food codes across nine food groups. These food groups are (1) milk and milk products; (2) meat, poultry, and fish; (3) eggs; (4) dry beans, peas, legumes, nuts, and seeds; (5) grain products; (6) fruit; (7) vegetables; (8) fats, oils, and salad dressings; and (9) sweets, sugars, and beverages. The survey also asks each respondent how many fluid ounces of plain drinking water he or she drank during each of the survey days. In addition, the CSFII collects household information, including the source of plain drinking water, water used to prepare beverages, and water used to prepare foods. Data provide "up-to-date information on food intakes by Americans for use in policy formation, regulation, program planning and evaluation, education, and research." The survey is "the cornerstone of the National Nutritional Monitoring and Related Research Program, a set of related federal activities intended to provide regular information on the nutritional status of the United States population" (USDA, 1998).

The 1994-96 CSFII was conducted according to a stratified, multi-area probability sample organized using estimates of the 1990 United States population. Stratification accounted for geographic location, degree of urbanization, and socioeconomics. Each year of the survey consisted of one sample with oversampling for low-income households.

Survey participants provided two non-consecutive, 24-hour days of dietary data. Both days' dietary recall information was collected by an in-home interviewer. Interviewers provided participants with an instructional booklet and standard measuring cups and spoons to assist them in adequately describing the type and amount of food ingested. If the respondent referred to a cup or bowl in their own home, a 2-cup measuring cup was provided to aid in the calculation of the amount consumed. The sample person could fill their own bowl or cup with water to represent the amount eaten or drunk, and the interviewer could then measure the amount consumed by pouring it into the 2-cup measure. The Day 2 interview occurred three to 10 days

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after the Day 1 interview, but not on the same day of the week. The interviews allowed participants "three passes" through the daily intake record to maximize recall (USDA, 1998). Proxy interviews were conducted for children aged six and younger and sampled individuals unable to report due to mental or physical limitations. The average questionnaire administration time for Day 1 intake was 30 minutes, while Day 2 averaged 27 minutes.

Two days of dietary recall data were provided by 15,303 individuals across the three survey years. This constitutes an overall two-day response rate of 75.9 percent. Survey weights were corrected by the USDA for nonresponse.

All three 1994-96 CSFII surveys are multistage, stratified-cluster samples. Sample weights, which project the data from a sampled individual to the population, are based on the probability of an individual being sampled at each stage of the sampling design. The sample weights associated with each individual reporting two days of consumption data were adjusted to correct for nonresponse bias.

The 1994-96 CSFII surveys have advantages and limitations for estimating per capita water (or fish) consumption. The primary advantage of the CSFII surveys is that they were designed and conducted by the USDA to support unbiased estimation of food consumption across the population in the United States and the District of Columbia. Second, the survey is designed to record daily intakes of foods and nutrients and support estimation of food consumption.

One limitation of the 1994-96 CSFII surveys is that individual food consumption data were collected for only two days–a brief period which does not necessarily depict "usual intake." Usual dietary intake is defined as "the long-run average of daily intakes by an individual." Upper percentile estimates may differ for short-term and longer-term data because short-term food consumption data tend to be inherently more variable. It is important to note, however, that variability due to duration of the survey does not result in bias of estimates of overall mean consumption levels. Also, the multistage survey design does not support interval estimates for many of the subpopulations of interest because of sparse representation in the sample. Subpopulations with sparse representation include Native Americans on reservations and certain ethnic groups. While these individuals are participants in the survey, they are not present in sufficient numbers to support consumption estimates.

Despite these limitations, the CSFII is considered one of the best sources of current information on consumption of water and fish-containing foods. The objective of estimating per capita water and fish consumption by the United States population is compatible with the statistical design and scope of the CSFII survey.

4.3.2.1 Rate Protective of Human Health from Chronic Exposure

EPA recommends maintaining the default drinking water intake rate of 2 L/day to protect most consumers from contaminants in drinking water. EPA believes that the 2 L/day assumption is representative of a majority of the population over the course of a lifetime. EPA also notes that there is comparatively little variability in water intake within the population compared with

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fish intake (i.e., drinking water intake varies, by and large, by about a three-fold range, whereas fish intake can vary by 100-fold). EPA believes that the 2 L/day assumption continues to represent an appropriate risk management decision. The results of the 1994-96 CSFII analysis indicate that the arithmetic mean, 75th, and 90th percentile values for adults 20 years and older are 1.1, 1.5, and 2.2 L/day, respectively (USEPA, 2000a). The 2 L/day value represents the 86th percentile for adults. These values can also be compared to data from an older National Cancer Institute (NCI) study, which estimated intakes of tapwater in the United States based on the USDA's 1977-78 Nationwide Food Consumption Survey (NFCS). The arithmetic mean, 75th, and 90th percentile values for adults 20 - 64 years old were 1.4, 1.7, and 2.3 L/day, respectively (Ershow and Cantor, 1989). The 2 L/day value represents the 88th percentile for adults from the NCI study.

The 2 L/day assumption was used with the original 1980 AWQC National Guidelines and has also been used in EPA's drinking water program. EPA believes that the newer studies continue to support the use of 2 L/day as a reasonable and protective consumption rate that represents the intake of most water consumers in the general population. However, individuals who work or exercise in hot climates could have water consumption rates significantly above 2 L/day, and EPA believes that States and Tribes should consider regional or occupational variations in water consumption.

4.3.2.2 Rates Protective of Developmental Human Health Effects

Based on the 1994-96 CSFII study data, EPA also recommends 2 L/day for women of childbearing age. The analysis for women of childbearing age (ages 15-44) indicate mean, 75th, and 90th percentile values of 0.9, 1.3, and 2.0 L/day, respectively. These rates compare well with those based on an analysis of tapwater intake by pregnant and lactating women by Ershow et al. (1991), based on the older USDA data, for women ages 15-49. Arithmetic mean, 75th and 90th percentile values were 1.2, 1.5, and 2.2 L/day, respectively, for pregnant women. For lactating women, the arithmetic mean, 75th and 90th percentile values were 1.3, 1.7, and 1.9 L/day, respectively.

As noted above, because infants and children have a higher daily water intake per unit body weight compared with adults, a water consumption rate measured for children is recommended for use when RfDs are based on health effects in children. Use of this water consumption rate should result in adequate protection for infants and children when setting criteria based on health effects for this target population. EPA recommends a drinking water intake of 1 L/day to, again, represent a majority of the population of children that consume drinking water. The results of the 1994-96 CSFII analysis indicate that for children from 1 to 10 years of age, the arithmetic mean, 75th, and 90th percentile values are 0.4, 0.6, and 0.9 L/day, respectively (USEPA, 2000a). The 1 L/day value represents the 93rd percentile for this group. The arithmetic mean, 75th, and 90th percentile values for smaller children, ages 1 to 3 years, are 0.3, 0.5, and 0.7 L/day, respectively. The 1 L/day value represents the 97th percentile of the group ages 1 to 3 years old. For the category of infants under 1 year of age, the arithmetic mean, 75th, and 90th percentile values are 0.3, 0.7, and 0.9 L/day, respectively. These data can similarly be compared to those of the older National Cancer Institute (NCI) study. The arithmetic mean, 75th, and 90th percentile values for children 1 to 10 years old were 0.74, 0.96, and 1.3 L/day,

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respectively. The mean, 75th, and 90th percentile values for children 1 to 3 years old in the NCI study were 0.6, 0.8, and 1.2 L/day, respectively. Finally, the mean, 75th, and 90th percentile values for infants less than 6 months old were 0.3, 0.3, and 0.6 L/day, respectively (Ershow and Cantor, 1989).

4.3.2.3 Rates Based on Combining Drinking Water Intake and Body Weight

As an alternative to considering body weight and drinking water intake rates separately, EPA is providing rates based on intake per unit body weight data (in units of ml/kg) in the Exposure Assessment TSD, with additional discussion on their use. These rates are based on self-reported body weights from the CSFII survey respondents for the 1994-96 data. While EPA intends to derive or revise national default criteria on the separate intake values and body weights, in part due to the strong input received from its State stakeholders, the ml/kg-BW/day values are provided in the TSD for States or authorized Tribes that prefer their use. It should be noted that in their 1993 review, EPA's Science Advisory Board (SAB) felt that using drinking water intake rate assumptions on a per unit body weight basis would be more accurate, but did not believe this change would appreciably affect the criteria values (USEPA, 1993).

4.3.3 Fish Intake Rates

The basis for the fish intake rates is the 1994-96 CSFII conducted by the USDA, and described above in Section 4.3.2.

4.3.3.1 Rates Protective of Human Health from Chronic Exposure

EPA recommends a default fish intake rate of 17.5 grams/day to adequately protect the general population of fish consumers, based on the 1994 to 1996 data from the USDA's CSFII Survey. EPA will use this value when deriving or revising its national 304(a) criteria. This value represents the 90th percentile of the 1994-96 CSFII data. This value also represents the uncooked weight estimated from the CSFII data, and represents intake of freshwater and estuarine finfish and shellfish only. For deriving AWQC, EPA has also considered the States' and Tribes' needs to provide adequate protection from adverse health effects to highly exposed populations such as recreational and subsistence fishers, in addition to the general population. Based on available studies that characterize consumers of fish, recreational fishers and subsistence fishers are two distinct groups whose intake rates may be greater than the general population. It is, therefore, EPA's decision to discuss intakes for these two groups, in addition to the general population.

EPA recommends default fish intake rates for recreational and subsistence fishers of 17.5 grams/day and 142.4 grams/day, respectively. These rates are also based on uncooked weights for fresh/estuarine finfish and shellfish only. However, because the level of fish intake in highly exposed populations varies by geographical location, EPA suggests a four preference hierarchy for States and authorized Tribes to follow when deriving consumption rates that encourages use of the best local, State, or regional data available. A thorough discussion of the development of this policy method and relevant data sources is contained in the Exposure Assessment TSD. The hierarchy is also presented here because EPA strongly emphasizes that States and authorized

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Tribes should consider developing criteria to protect highly exposed population groups and use local or regional data over the default values as more representative of their target population group(s). The four preference hierarchy is: (1) use of local data; (2) use of data reflecting similar geography/population groups; (3) use of data from national surveys; and (4) use of EPA's default intake rates.

The recommended four preference hierarchy is intended for use in evaluating fish intake from fresh and estuarine species only. Therefore, to protect humans who additionally consume marine species of fish, the marine portion should be considered an *other source of exposure* when calculating an RSC for dietary intake. Refer to the Exposure Assessment TSD for further discussion. States and Tribes need to ensure that when evaluating overall exposure to a contaminant, marine fish intake is not double-counted with the other dietary intake estimate used. Coastal States and authorized Tribes that believe accounting for total fish consumption (i.e., fresh/estuarine and marine species) is more appropriate for protecting the population of concern may do so, provided that the marine intake component is not double-counted with the RSC estimate. Tables of fish consumption intakes based on the CSFII in the TSD provide rates for fresh/estuarine species, marine species, and total (combined) values to facilitate this option for States and Tribes. Throughout this section, the terms "fish intake" or "fish consumption" are used. These terms refer to the consumption of finfish and shellfish, and the CSFII survey includes both. States and Tribes should ensure that when selecting local or regionally-specific studies, both finfish and shellfish are included when the population exposed are consumers of both types.

EPA's first preference is that States and authorized Tribes use the results from fish intake surveys of local watersheds within the State or Tribal jurisdiction to establish fish intake rates that are representative of the defined populations being addressed for the particular waterbody. Again, EPA recommends that data indicative of fresh/estuarine species only be used which is, by and large, most appropriate for developing AWQC. EPA also recommends the use of uncooked weight intake values, which is discussed in greater detail with the fourth preference. States and authorized Tribes may use either high-end values (such as the 90^{th} or 95^{th} percentile values) or average values for an identified population that they plan to protect (e.g., subsistence fishers, sport fishers, or the general population). EPA generally recommends that arithmetic mean values should be the lowest value considered by States or Tribes when choosing intake rates for use in criteria derivation. When considering geometric mean (median) values from fish consumption studies, States and authorized Tribes need to ensure that the distribution is based on survey respondents who reported consuming fish because surveys based on both consumers and nonconsumers can often result in median values of zero. If a State or Tribe chooses values (whether the central tendency or high-end values) from studies that particularly target high-end consumers, these values should be compared to high-end fish intake rates for the general population to make sure that the high-end consumers within the general population would be protected by the chosen intake rates. EPA believes this is a reasonable procedure and is also consistent with the recent Great Lakes Water Quality Initiative (known as the "GLI") (USEPA, 1995). States and authorized Tribes may wish to conduct their own surveys of fish intake, and EPA guidance is available on methods to conduct such studies in *Guidance for Conducting Fish and Wildlife Consumption Surveys* (USEPA, 1998). Results from broader geographic regions in which the State or Tribe is located can also be used, but may not be as applicable as results from

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local watersheds. Since such studies would ultimately form the basis of a State or Tribe's AWQC, EPA would review any surveys of fish intake for consistency with the principles of EPA's guidance as part of the Agency's review of water quality standards under Section 303(c).

If surveys conducted in the geographic area of the State or Tribe are not available, EPA's second preference is that States and authorized Tribes consider results from existing fish intake surveys that reflect similar geography and population groups (e.g., from a neighboring State or Tribe or a similar watershed type), and follow the method described above regarding target values to derive a fish intake rate. Again, EPA recommends the use of uncooked weight intake values and the use of fresh/estuarine species data only. Results of existing local and regional surveys are discussed in greater detail in the TSD.

If applicable consumption rates are not available from local, State, or regional surveys, EPA's third preference is that States and authorized Tribes select intake rate assumptions for different population groups from national food consumption surveys. EPA has analyzed one such national survey, the 1994-96 CSFII. As described in Section 4.3.2, this survey, conducted annually by the USDA, collects food consumption information from a probability sample of the population of all 50 states. Respondents to the survey provide two days of dietary recall data. A detailed description of the combined 1994-96 CSFII survey, the statistical methodology, and the results and uncertainties of the EPA analyses are provided in a separate EPA report (USEPA, 2000b). The Exposure Assessment TSD for this Methodology presents selected results from this report including point and interval estimates of combined finfish and shellfish consumption for the mean, 50^{th} (median), 90^{th}, 95^{th}, and 99^{th} percentiles. The estimated fish consumption rates are by fish habitat (i.e., freshwater/estuarine, marine and all habitats) for the following population groups: (1) all individuals; (2) individuals age 18 and over; (3) women ages 15-44; and (4) children age 14 and under. Three kinds of estimated fish consumption rates are provided: (1) per capita rates (i.e., rates based on consumers and nonconsumers of fish from the survey period– refer to the TSD for further discussion); (2) consumers-only rates (i.e., rates based on respondents who reported consuming finfish or shellfish during the two-day reporting period); and (3) per capita consumption by body weight (i.e., per capita rates reported as milligrams of fish per kilogram of body weight per day).

EPA's fourth preference is that States and authorized Tribes use as fish intake assumptions the following default rates, based on the 1994-96 CSFII data, that EPA believes are representative of fish intake for different population groups: 17.5 grams/day for the general adult population and sport fishers, and 142.4 grams/day for subsistence fishers. These are risk management decisions that EPA has made after evaluating numerous fish intake surveys. These values represent the uncooked weight intake of freshwater/estuarine finfish and shellfish. As with the other preferences, EPA requests that States and authorized Tribes routinely consider whether there is a substantial population of sport fishers or subsistence fishers when developing site-specific estimates, rather than automatically basing them on the typical individual. Because the combined 1994-96 CSFII survey is national in scope, EPA will use the results from this survey to estimate fish intake for deriving national criteria. EPA has recognized the data gaps and uncertainties associated with the analysis of the 1994-96 CSFII survey in the process of making its default recommendations. The estimated mean of freshwater and estuarine fish ingestion for adults is 7.50 grams/day, and the median is 0 grams/day. The estimated 90^{th}

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percentile is 17.53 grams/day; the estimated 95th percentile is 49.59 grams/day; and the estimated 99th percentile is 142.41 grams/day. The median value of 0 grams/day may reflect the portion of individuals in the population who never eat fish as well as the limited reporting period (2 days) over which intake was measured. By applying as a default 17.5 grams/day for the general adult population, EPA intends to select an intake rate that is protective of a majority of the population (again, the 90th percentile of consumers and nonconsumers according to the 1994-96 CSFII survey data). Trophic level breakouts are: TL2 = 3.8 grams/day; TL3 = 8.0 grams/day; and TL4 = 5.7 grams/day. EPA further considers 17.5 grams/day to be indicative of the average consumption among sport fishers based on averages in the studies reviewed, which are presented in the Exposure Assessment TSD. Similarly, EPA believes that the assumption of 142.4 grams/day is within the range of average consumption estimates for subsistence fishers based on the studies reviewed. Experts at the 1992 National Workshop that initiated the effort to revise this Methodology acknowledged that the national survey high-end values are representative of average rates for highly exposed groups such as subsistence fishermen, specific ethnic groups, or other highly exposed people. EPA is aware that some local and regional studies indicate greater consumption among Native American, Pacific Asian American, and other subsistence consumers, and recommends the use of those studies in appropriate cases, as indicated by the first and second preferences. Again, States and authorized Tribes have the flexibility to choose intake rates higher than an average value for these population groups. If a State or authorized Tribe has not identified a separate well-defined population of high-end consumers and believes that the national data from the 1994-96 CSFII are representative, they may choose these recommended rates.

As indicated above, the default intake values are based on the uncooked weights of the fish analyzed. There has been some question regarding whether to use cooked or uncooked weights of fish intake for deriving the AWQC. Studies show that, typically, with a filet or steak of fish, the weight loss in cooking is about 20 percent; that is, the uncooked weight is approximately 20 percent higher (Jacobs et al., 1998). This obviously means that using uncooked weights results in a slightly higher intake rate and slightly more stringent AWQC. In researching consumption surveys for this proposal, EPA has found that some surveys have reported rates for cooked fish, others have reported uncooked rates, and many more are unclear as to whether cooked or uncooked rates are used. The basis of the CSFII survey was prepared or *as consumed* intakes; that is, the survey respondents estimated the weight of fish that they consumed. This was also true with the GLI (which was specifically based on studies describing consumption rates of cooked fish) and, by and large, cooked fish is what people consume. However, EPA's *Guidance For Assessing Chemical Contaminant Data For Use In Fish Advisories* recommends analysis and advisories based on uncooked fish (USEPA, 1997a). EPA considered the potential confusion over the fact that the uncooked weights are used in the fish advisory program. Further, the measures of a contaminant in fish tissue samples that are applicable to compliance monitoring and the permitting program are related to the uncooked weights. The choice of intakes is also complicated by factors such as the effect of the cooking process, the different parts of a fish where a chemical may accumulate, and the method of preparation.

After considering all of the above (in addition to public input received), EPA will derive its national default criteria based on the uncooked weight fish intakes. The Exposure

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Assessment TSD provides additional guidance on site-specific modifications. Specifically, an alternate approach is described for calculating AWQC with the *as consumed* weight–which is more directly associated with human exposure and risk–and then adjusting the value by the approximate 20 percent loss to an uncooked equivalent (thereby representing the same relative risk as the *as consumed* value). This approach results in a different AWQC value (than using the uncooked weights) and represents a more direct translation of the *as consumed* risk to the uncooked equivalent. However, EPA understands that it is more scientifically rigorous and may be too intensive of a process for States and Tribes to rely on. The option is presented in the TSD to offer States and authorized Tribes greater flexibility with their water quality standards program.

The default fish intake values also reflect specific designations of species classified in accordance with information regarding the life history of the species or based on landings information form the National Marine Fisheries Service. Most significantly, salmon has been reclassified from a freshwater/estuarine species to a marine species. As marine harvested salmon represents approximately 99 percent of salmon consumption in the 1994-96 CSFII Survey, removal reduces the overall fresh/estuarine fish consumption rate by 13 percent. Although they represent a very small percentage of freshwater/estuarine intake, land-locked and farm-raised salmon consumed by 1994-96 CSFII respondents are still included. The rationale for the default intake species designations is explained in the Exposure Assessment TSD. Once again, EPA emphasizes the flexibility for States and authorized Tribes to use alternative assumptions based on local or regional data to better represent their population groups of concern.

4.3.3.2 Rates Protective of Developmental Human Health Effects

Exposures resulting in health effects in children or developmental effects in fetuses may be of primary concern. As discussed at the beginning of this section on exposure factors used, in a situation where acute or sub-chronic toxicity and exposure are the basis of an RfD (or POD/UF), EPA will consider basing its national default criteria on children or women of childbearing age, depending on the target population at greatest risk. EPA recommends that States and authorized Tribes use exposure factors for children or women of childbearing age in these situations. As stated previously, EPA is not recommending the development of additional AWQC but is acknowledging that basing a criterion on these population groups is a potential course of action and is, therefore, recommending the following default intake rates for such situations.

EPA's preferences for States and authorized Tribes in selecting values for intake rates relevant for children is the same as that discussed above for establishing values for average daily consumption rates for chronic effects; i.e., in decreasing order of preference, results from fish intake surveys of local watersheds, results from existing fish intake surveys that reflect similar geography and population groups, the distribution of intake rates from nationally based surveys (e.g., the CSFII), or lastly, the EPA default rates. When an RfD is based on health effects in children, EPA recommends a default intake rate of 156.3 grams/day for assessing those contaminants that exhibit adverse effects. This represents the 90th percentile consumption rate for actual consumers of freshwater/estuarine finfish and shellfish for children ages 14 and under using the combined 1994 to 1996 results from the CSFII survey. The value was calculated based

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on data for only those children who ate fish during the 2-day survey period, and the intake was averaged over the number of days during which fish was actually consumed. EPA believes that by selecting the data for consumers only, the 90th percentile is a reasonable intake rate to approximate consumption of fresh/estuarine finfish and shellfish within a short period of time for use in assessments where adverse effects in children are of primary concern. As discussed previously, EPA will use a default body weight of 30 kg to address potential acute or subchronic effects from fish consumption by children. EPA is also providing these default intake values for States and authorized Tribes that choose to provide additional protection when developing criteria that they believe should be based on health effects in children. This is consistent with the rationale in the recent GLI (USEPA, 1995) and is an approach that EPA believes is reasonable. Distributional information on intake values relevant for assessing exposure when health effects to children are of concern is presented in the Exposure Assessment TSD.

There are also cases in which pregnant women may be the population of most concern, due to the possibility of developmental effects that may result from exposures of the mother to toxicants. In these cases, fish intake rates specific to females of childbearing age are most appropriate when assessing exposures to developmental toxicants. When an RfD is based on developmental toxicity, EPA proposes a default intake rate of 165.5 grams/day for assessing exposures for women of childbearing age from contaminants that cause developmental effects. This is equivalent to the 90th percentile consumption rate for actual consumers of freshwater/ estuarine finfish and shellfish for women ages 15 to 44 using the combined 1994 to1996 results from the CSFII survey. As with the rate for children, this value represents only those women who ate fish during the 2-day survey period. As discussed previously, EPA will use a default body weight of 67 kg for women of childbearing age.

4.3.3.3 Rates Based on Combining Fish Intake and Body Weight

As with the drinking water intake values, EPA is providing values for fish intake based on a per unit body weight basis (in units of mg/kg) in the Exposure Assessment TSD. These rates use the self-reported body weights of the 1994-96 CSFII survey. Again, while EPA intends to derive or revise national default criteria on the separate intake values and body weights, the mg/kg-BW/day values are provided in the TSD for States or authorized Tribes that prefer their use.

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5. BIOACCUMULATION

5.1 INTRODUCTION

Aquatic organisms can accumulate certain chemicals in their bodies when exposed to these chemicals through water, their diet, and other sources. This process is called bioaccumulation. The magnitude of bioaccumulation by aquatic organisms varies widely depending on the chemical but can be extremely high for some highly persistent and hydrophobic chemicals. For such highly bioaccumulative chemicals, concentrations in aquatic organisms may pose unacceptable human health risks from fish and shellfish consumption even when concentrations in water are too low to cause unacceptable health risks from drinking water consumption alone. These chemicals may also biomagnify in aquatic food webs, a process whereby chemical concentrations increase in aquatic organisms of each successive trophic level due to increasing dietary exposures (e.g., increasing concentrations from algae, to zooplankton, to forage fish, to predatory fish).

In order to prevent harmful exposures to waterborne chemicals through the consumption of contaminated fish and shellfish, national 304(a) water quality criteria for the protection of human health must address the process of chemical bioaccumulation in aquatic organisms. For deriving national 304(a) criteria to protect human health, EPA accounts for potential bioaccumulation of chemicals in fish and shellfish through the use of national bioaccumulation factors (BAFs). A national BAF is a ratio (in L/kg) that relates the concentration of a chemical in water to its expected concentration in commonly consumed aquatic organisms in a specified trophic level. An illustration of how national BAFs are used in the derivation of 304(a) criteria for carcinogens using linear low-dose extrapolation is shown in the following equation:

$$AWQC = RSD \bullet \left(\frac{BW}{DI + \sum_{i=2}^{4} (FI_i \bullet BAF_i)} \right) \qquad \text{(Equation 5-1)}$$

where:

RSD	=	Risk specific dose (mg/kg-day)
BW	=	Human body weight (kg)
DI	=	Drinking water intake (L/day)
FI_i	=	Fish intake at trophic level I, where I=2, 3, and 4;
BAF_i	=	National bioaccumulation factor at trophic level I, where I=2, 3, and 4

The purpose of this chapter is to present EPA's recommended methodology for deriving national bioaccumulation factors for setting national 304(a) water quality criteria to protect human health. A detailed scientific basis of the recommended national BAF methodology is provided in the Bioaccumulation TSD. While the methodology detailed in this chapter is

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intended to be used by EPA for deriving national BAFs, EPA encourages States and authorized Tribes to derive BAFs that are specific to certain regions or waterbodies, where appropriate. Guidance to States and authorized Tribes for deriving site-specific BAFs is provided in the Biaccumulation TSD.

5.1.1 Important Bioaccumulation and Bioconcentration Concepts

Several attributes of the bioaccumulation process are important to understand when deriving national BAFs for use in setting national 304(a) criteria. First, the term "bioaccumulation" refers to the uptake and retention of a chemical by an aquatic organism from all surrounding media (e.g., water, food, sediment). The term "bioconcentration" refers to the uptake and retention of a chemical by an aquatic organism from water only. For some chemicals (particularly those that are highly persistent and hydrophobic), the magnitude of bioaccumulation by aquatic organisms can be substantially greater than the magnitude of bioconcentration. Thus, an assessment of bioconcentration alone would underestimate the extent of accumulation in aquatic biota for these chemicals. Accordingly, EPA's guidelines presented in this chapter emphasize the measurement of chemical bioaccumulation by aquatic organisms, whereas EPA's 1980 Methodology emphasized the measurement of bioconcentration.

Another noteworthy aspect of bioaccumulation process is the issue of steady-state conditions. Specifically, both bioaccumulation and bioconcentration can be viewed simply as the result of competing rates of chemical uptake and depuration (chemical loss) by an aquatic organism. The rates of chemical uptake and depuration can be affected by various factors including the properties of the chemical, the physiology of the organism in question, water quality and other environmental conditions, ecological characteristics of the waterbody (e.g., food web structure), and the concentration and loadings history of the chemical. When the rates of chemical uptake and depuration are equal, tissue concentrations remain constant over time and the distribution of the chemical between the organism and its source(s) is said to be at steady-state. For constant chemical exposures and other conditions, the steady-state concentration in the organism represents the highest accumulation potential of the chemical in that organism under those conditions. The time required for a chemical to achieve steady state has been shown to vary according to the properties of the chemical and other factors. For example, some highly hydrophobic chemicals can require long periods of time to reach steady state between environmental compartments (e.g., many months), while highly hydrophilic chemicals usually reach steady-state relatively quickly (e.g., hours to days).

Since national 304(a) criteria for the protection of human health are typically designed to protect humans from harmful lifetime or long-term exposures to waterborne contaminants, the assessment of bioaccumulation that equals or approximates steady-state accumulation is one of the principles underlying the derivation of national BAFs. For some chemicals that require relatively long periods of time to reach steady-state in tissues of aquatic organisms, changes in water column concentrations may occur on a much more rapid time scale compared to the corresponding changes in tissue concentrations. Thus, if the system departs substantially from steady-state conditions and water concentrations are not averaged over a sufficient time period, the ratio of the tissue concentration to a water concentration may have little resemblance to the steady-state ratio and have little predictive value of long-term bioaccumulation potential.

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Therefore, BAF measurements should be based on water column concentrations which are averaged over a sufficient period of time (e.g., a duration comparable to the time required for the chemical to reach steady-state). In addition, BAF measurements should be based on adequate spatial averaging of both tissue and water column concentrations for use in deriving 304(a) criteria for the protection of human health.

For this reason, a BAF is defined in this Methodology as representing the ratio (in L/kg-tissue) of a concentration of a chemical in tissue to its concentration in the surrounding water in situations where the organism and its food are exposed and the ratio does not change substantially over time (i.e., the ratio which reflects bioaccumulation at or near steady-state). A bioconcentration factor (BCF) is the ratio (in L/kg-tissue) of the concentration of a substance in tissue of an aquatic organism to its concentration in the ambient water, in situations where the organism is exposed through the water only and the ratio does not change substantially over time.

5.1.2 Goal of the National BAF

The goal of EPA's national BAF is to represent the long-term, average bioaccumulation potential of a chemical in edible tissues of aquatic organisms that are commonly consumed by humans throughout the United States. National BAFs are not intended to reflect fluctuations in bioaccumulation over short time periods (e.g., a few days) because 304(a) human health criteria are generally designed to protect humans from long-term exposures to waterborne chemicals. National BAFs are also intended to account for some major chemical, biological, and ecological attributes that can affect bioaccumulation in bodies of water across the United States. For example, separate procedures are provided for deriving national BAFs depending on the type of chemical (i.e., nonionic organic, ionic organic, inorganic and organometallic). In addition, EPA's national BAFs are derived separately for each trophic level to account for potential biomagnification of some chemicals in aquatic food webs and broad physiological differences between trophic levels that may influence bioaccumulation. Because lipid content of aquatic organisms and the amount of organic carbon in the water column have been shown to affect bioaccumulation of nonionic organic chemicals, EPA's national BAFs are adjusted to reflect the lipid content of commonly consumed fish and shellfish and the freely dissolved fraction of the chemical in ambient water for these chemicals.

5.1.3 Changes to the 1980 Methodology

Numerous scientific advances have occurred in the area of bioaccumulation since the publication of the 1980 Methodology for deriving AWQC for the protection of human health (USEPA, 1980). These advances have significantly increased our ability to assess and predict the bioaccumulation of chemicals in aquatic biota. As a result, EPA has revised the bioaccumulation portion of the 1980 Methodology to reflect the current state of the science and to improve accuracy in assessing bioaccumulation for setting 304(a) criteria for the protection of human health. The changes contained in the bioaccumulation portion of the 2000 Human Health Methodology are mostly designed to:

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- Improve the ability to incorporate chemical exposure from sediments and aquatic food webs in assessing bioaccumulation potential,

- Expand the ability to account for site-specific factors which affect bioaccumulation, and

- Incorporate new data and assessment tools into the bioaccumulation assessment process.

A summary of the key changes that have been incorporated into the bioaccumulation portion of the 2000 Human Health Methodology and appropriate comparisons to the1980 Methodology are provided below.

5.1.3.1 Overall Approach

The 1980 Methodology for deriving 304(a) criteria for the protection of human health emphasized the assessment of bioconcentration (uptake from water only) through the use of the BCF. Based on the 1980 Methodology, measured BCFs were usually determined from laboratory data unless field data demonstrated consistently higher or lower accumulation compared with laboratory data. In these cases, "field BCFs" (currently termed field-measured BAFs) were recommended for use. For lipophilic chemicals where lab or field-measured data were unavailable, EPA recommended predicting BCFs from the octanol-water partition coefficient and the following equation from Veith et al. (1979): "log BCF = (0.85 log K_{ow}) - 0.70".

The 2000 Human Health Methodology revisions contained in this chapter emphasize the measurement of bioaccumulation (uptake from water, sediment, and diet) through the use of the BAF. Consistent with the 1980 Methodology, measured data are preferred over predictive approaches for determining the BAF (i.e., field-measured BAFs are generally preferred over predicted BAFs). However, the 2000 Human Health Methodology contains additional methods for deriving a national BAF that were not available in 1980. The preference for using the BAF methods also differs depending on the type and properties of the chemical. For example, the BAF derivation procedure differs for each of three broadly defined chemical categories: (1) nonionic organic, (2) ionic organic, and (3) inorganic and organometallic chemicals. Furthermore, within the category of nonionic organic chemicals, different procedures are used to derive the BAF depending on a chemicals' hydrophobicity and extent of chemical metabolism that would be expected to occur in aquatic biota.

5.1.3.2 Lipid Normalization

In the 1980 Methodology, BCFs for lipophilic chemicals were normalized by the lipid fraction in the tissue of fish and shellfish used to determine the BCF. Lipid normalization enabled BCFs to be averaged across tissues and organisms. Once the average lipid-normalized BCF was determined, it was adjusted by the consumption-weighted lipid content of commonly consumed aquatic organisms in the United States to obtain an overall consumption-weighted BCF. A similar procedure has been retained in the 2000 Human Health Methodology, whereby BAFs for nonionic organic chemicals are lipid normalized and adjusted by the consumption-weighted lipid content of commonly consumed organisms to obtain a BAF for criteria

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calculations. However, the 2000 Human Health Methodology uses more up-to-date lipid data and consumption data for deriving the consumption-weighted BAFs.

5.1.3.3 Bioavailability

Bioconcentration factors derived according to the 1980 Methodology were based on the total concentration of the chemical in water, for both lipophilic and nonlipophilic chemicals. In the 2000 Human Health Methodology, BAFs for nonionic organic chemicals are derived using the most bioavailable fraction (i.e., the freely dissolved fraction) to account for the influence of particulate and dissolved organic carbon on a chemical's bioavailability. Such BAFs are then adjusted to reflect the expected bioavailability at the sites of interest (i.e., by adjusting for organic carbon concentrations at the sites of interest). Procedures for accounting for the effect of organic carbon on bioaccumulation were published previously by EPA under the Great Lakes Water Quality Initiative (GLWQI or GLI) rulemaking (USEPA, 1995a,b). Bioavailability is also considered in developing BAFs for the other chemical classes defined in the 2000 Human Health Methodology (e.g., ionic organics, inorganics/organometallics) but is done so on a chemical-by-chemical basis.

5.1.3.4 Trophic Level Considerations

In the 1980 Methodology, BCFs were determined and used for criteria derivation without explicit regard to the trophic level of the aquatic organism (e.g., benthic filter feeder, forage fish, predatory fish). Over the past two decades, much information has been assembled which demonstrates that an organism's trophic position in the aquatic food web can have an important effect on the magnitude of bioaccumulation of certain chemicals. In order to account for the variation in bioaccumulation that is due to trophic position of the organism, the 2000 Human Health Methodology recommends that BAFs be determined and applied on a trophic level-specific basis.

5.1.3.5 Site-Specific Adjustments

The 1980 Methodology contained little guidance for making adjustments to the national BCFs to reflect site- or region-specific conditions. The 2000 Human Health Methodology has greatly expanded the guidance to States and authorized Tribes for making adjustments to national BAFs to reflect local conditions. This guidance is contained in the Bioaccumulation TSD. In the Bioaccumulation TSD, guidance and data are provided for adjusting national BAFs to reflect the lipid content in locally consumed aquatic biota and the organic carbon content in the waterbodies of concern. This guidance also allows the use of appropriate bioaccumulation models for deriving site-specific BAFs. EPA also plans to publish detailed guidance on designing and conducting field bioaccumulation studies for measuring BAFs and biota-sediment accumulation factors (BSAFs). In general, EPA encourages States and authorized Tribes to make site-specific modifications to EPA's national BAFs provided such adjustments are scientifically defensible and adequately protect the designated use of the waterbody.

While the aforementioned revisions are new to EPA's Methodology for deriving national 304(a) criteria for the protection of human health, many of these refinements have been

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incorporated in prior Agency guidance and regulations. For example, the use of food chain multipliers to account for the biomagnification of nonionic organic chemicals in aquatic food webs when measured data are unavailable was introduced by EPA in three documents*: Technical Support Document for Water Quality-Based Toxics Control* (USEPA, 1991), a draft document entitled *Assessment and Control of Bioconcentratable Contaminants in Surface Waters* (USEPA, 1993), and in the *Great Lakes Water Quality Initiative* (GLI) (USEPA, 1995b). Similarly, procedures for predicting BAFs using BSAFsand incorporating the effect of organic carbon on bioavailability were used to derive water quality criteria under the GLI.

5.1.4 Organization of This Section

The methodology for deriving national BAFs for use in deriving National 304(a) Human Health AWQC is provided in the following sections. Important terms used throughout this chapter are defined in Section 5.2. Section 5.3 provides an overview of the BAF derivation guidelines. Detailed procedures for deriving national BAFs are provided in Section 5.4 for nonionic organic chemicals, in Section 5.5 for ionic organic chemicals, and in Section 5.6 for inorganics and organometallic chemicals. Literature cited is provided in Section 5.7.

5.2 DEFINITIONS

The following terms and definitions are used throughout this chapter.

Bioaccumulation. The net accumulation of a substance by an organism as a result of uptake from all environmental sources.

Bioconcentration. The net accumulation of a substance by an aquatic organism as a result of uptake directly from the ambient water, through gill membranes or other external body surfaces.

Bioaccumulation Factor (BAF). The ratio (in L/kg-tissue) of the concentration of a substance in tissue to its concentration in the ambient water, in situations where both the organism and its food are exposed and the ratio does not change substantially over time. The BAF is calculated as:

$$BAF = \frac{C_t}{C_w} \qquad \text{(Equation 5-2)}$$

where:

C_t = Concentration of the chemical in the specified wet tissue
C_w = Concentration of chemical in water

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Bioconcentration Factor (BCF). The ratio (in L/kg-tissue) of the concentration of a substance in tissue of an aquatic organism to its concentration in the ambient water, in situations where the organism is exposed through the water only and the ratio does not change substantially over time. The BCF is calculated as:

$$BCF = \frac{C_t}{C_w} \qquad \text{(Equation 5-3)}$$

where:

C_t = Concentration of the chemical in the specified wet tissue
C_w = Concentration of chemical in water

Baseline BAF (BAF_ℓ^{fd}). For nonionic organic chemicals (and certain ionic organic chemicals where similar lipid and organic carbon partitioning behavior applies), a BAF (in L/kg-lipid) that is based on the concentration of freely dissolved chemical in the ambient water and the lipid normalized concentration in tissue.

Baseline BCF (BCF_ℓ^{fd}). For nonionic organic chemicals (and certain ionic organic chemicals where similar lipid and organic carbon partitioning behavior applies), a BCF (in L/kg-lipid) that is based on the concentration of freely dissolved chemical in the ambient water and the lipid normalized concentration in tissue.

Biomagnification. The increase in tissue concentration of a chemical in organisms at successive trophic levels through a series of predator-prey associations, primarily through the mechanism of dietary accumulation.

Biomagnification Factor (BMF). The ratio (unitless) of the tissue concentration of a chemical in a predator at a particular trophic level to the tissue concentration in its prey at the next lower trophic level for a given waterbody and chemical exposure. For nonionic organic chemicals (and certain ionic organic chemicals where similar lipid and organic carbon partitioning behavior applies), a BMF can be calculated using lipid-normalized concentrations in the tissue of organisms at two successive trophic levels as:

$$BMF_{(TL,\ n)} = \frac{C_{\ell\ (TL,\ n)}}{C_{\ell\ (TL,\ n-1)}} \qquad \text{(Equation 5-4)}$$

where:

$C_{\ell\ (TL,\ n)}$ = Lipid-normalized concentration in appropriate tissue of predator organism at a given trophic level (TL "n")

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$C_{\ell\ (TL,\ n-1)}$ = Lipid-normalized concentration in appropriate tissue of prey organism at the next lower trophic level from the predator (TL "n-1")

For inorganic, organometallic, and certain ionic organic chemicals where lipid and organic carbon partitioning does not apply, a BMF can be calculated using chemical concentrations in the tissue of organisms at two successive trophic levels as:

$$BMF_{(TL,\ n)} = \frac{C_{t\ (TL,\ n)}}{C_{t\ (TL,\ n-1)}} \qquad \text{(Equation 5-5)}$$

where:

$C_{t\ (TL,\ n)}$ = Concentration in appropriate tissue of predator organism at trophic level "n" (may be either wet weight or dry weight concentration so long as both the predator and prey concentrations are expressed in the same manner)

$C_{t\ (TL,\ n-1)}$ = Concentration in appropriate tissue of prey organism at the next lower trophic level from the predator (may be either wet weight or dry weight concentration so long as both the predator and prey concentrations are expressed in the same manner)

Biota-Sediment Accumulation Factor (BSAF). For nonionic organic chemicals (and certain ionic organic chemicals where similar lipid and organic carbon partitioning behavior applies), the ratio of the lipid-normalized concentration of a substance in tissue of an aquatic organism to its organic carbon-normalized concentration in surface sediment (expressed as kg of sediment organic carbon per kg of lipid), in situations where the ratio does not change substantially over time, both the organism and its food are exposed, and the surface sediment is representative of average surface sediment in the vicinity of the organism. The BSAF is defined as:

$$BSAF = \frac{C_{\ell}}{C_{soc}} \qquad \text{(Equation 5-6)}$$

where:

C_{ℓ} = The lipid-normalized concentration of the chemical in tissues of the biota (µg/g lipid)

C_{soc} = The organic carbon-normalized concentration of the chemical in the surface sediment (µg/g sediment organic carbon)

Depuration. The loss of a substance from an organism as a result of any active or passive process.

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Food Chain Multiplier (FCM). For nonionic organic chemicals (and certain ionic organic chemicals where similar lipid and organic carbon partitioning behavior applies), the ratio of a baseline BAF_{ℓ}^{fd} for an organism of a particular trophic level to the baseline BCF_{ℓ}^{fd} (usually determined for organisms in trophic level one). For inorganic, organometallic, and certain ionic organic chemicals where lipid and organic carbon partitioning does not apply, a FCM is based on total (wet or dry weight) concentrations of the chemical in tissue.

Freely Dissolved Concentration. For nonionic organic chemicals, the concentration of the chemical that is dissolved in ambient water, excluding the portion sorbed onto particulate or dissolved organic carbon. The freely dissolved concentration is considered to represent the most bioavailable form of an organic chemical in water and, thus, is the form that best predicts bioaccumulation. The freely dissolved concentration can be determined as:

$$C_w^{fd} = (C_w^t) \cdot (f_{fd}) \qquad \text{(Equation 5-7)}$$

where:

C_w^{fd}	=	Freely dissolved concentration of the organic chemical in ambient water
C_w^t	=	Total concentration of the organic chemical in ambient water
f_{fd}	=	Fraction of the total chemical in ambient water that is freely dissolved

Hydrophilic. A term that refers to the extent to which a chemical is attracted to partitioning into the water phase. Hydrophilic organic chemicals have a greater tendency to partition into polar phases (e.g., water) compared to chemicals of hydrophobic chemicals.

Hydrophobic. A term that refers to the extent to which a chemical avoids partitioning into the water phase. Highly hydrophobic organic chemicals have a greater tendency to partition into nonpolar phases (e.g., lipid, organic carbon) compared with chemicals of lower hydrophobicity.

Lipid-normalized Concentration (C_{ℓ}). The total concentration of a contaminant in a tissue or whole organism divided by the lipid fraction in that tissue or whole organism. The lipid-normalized concentration can be calculated as:

$$C_{\ell} = \frac{C_t}{f_{\ell}} \qquad \text{(Equation 5-8)}$$

where:

C_t	=	Concentration of the chemical in the wet tissue (either whole organism or specified tissue)

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f_ℓ = Fraction lipid content in the organism or specified tissue

Octanol-water Partition Coefficient (K_{ow}). The ratio of the concentration of a substance in the n-octanol phase to its concentration in the aqueous phase in an equilibrated two-phase octanol-water system. For log K_{ow}, the log of the octanol-water partition coefficient is a base 10 logarithm.

Organic Carbon-normalized Concentration (C_{soc}). For sediments, the total concentration of a contaminant in sediment divided by the fraction of organic carbon in sediment. The organic carbon-normalized concentration can be calculated as:

$$C_{soc} = \frac{C_s}{f_{oc}} \qquad \text{(Equation 5-9)}$$

where:

C_s = Concentration of chemical in sediment
f_{oc} = Fraction organic carbon in sediment

Uptake. Acquisition by an organism of a substance from the environment as a result of any active or passive process.

5.3 FRAMEWORK FOR DETERMINING NATIONAL BIOACCUMULATION FACTORS

5.3.1 Four Different Methods

Bioaccumulation factors used to derive national BAFs can be measured or predicted using some or all of the following four methods, depending on the type of chemical and its properties. These methods are:

(1) a measured BAF obtained from a field study (i.e., a field-measured BAF);

(2) a BAF predicted from a field-measured BSAF;

(3) a BAF predicted from a laboratory-measured BCF (with or without adjustment by an FCM); and

(4) a BAF predicted from a chemical's octanol-water partition coefficient (K_{ow}), with or without adjustment using an FCM.

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A brief summary of each of the four methods is provided below. Additional details on the use of these four methods is provided in Section 5.4 (for nonionic organics), Section 5.5 (for ionic organics) and Section 5.6 (for inorganics and organometallics).

1. **Field-Measured BAF.** Use of a field-measured BAF, which is the most direct measure of bioaccumulation, is the only method that can be used to derive a national BAF for all types of chemicals (i.e., nonionic organic, ionic organic, and inorganic and organometallic chemicals). A field-measured BAF is determined from a field study using measured chemical concentrations in the aquatic organism and its surrounding water. Because field studies are conducted in natural aquatic ecosystems, a field-measured BAF reflects an organism's exposure to a chemical through all relevant exposure pathways (i.e., water, sediment, and diet). A field-measured BAF also reflects any metabolism of a chemical that might occur in the aquatic organism or its food web. Therefore, field-measured BAFs are appropriate for all chemicals, regardless of the extent of chemical metabolism in biota.

2. **Field-measured BSAF.** For nonionic organic chemicals (and certain ionic organic chemicals where similar lipid and organic carbon partitioning behavior applies), a BAF can also be predicted from BSAFs. A BSAF is similar to a field-measured BAF in that the concentration of a chemical in biota is measured in the field and reflects an organism's exposure to all relevant exposure routes. A BSAF also reflects any chemical metabolism that might occur in the aquatic organism or its food web. However, unlike a field-measured BAF which references the biota concentration to the water concentration, a BSAF references the biota concentration to the sediment concentration. Use of the BSAF procedure is restricted to organic chemicals which are classified as being moderately to highly hydrophobic.

3. **Lab-measured BCF.** A laboratory-measured BCF can also be used to estimate a BAF for organic and inorganic chemicals. However, unlike a field-measured BAF or a BAF predicted from a field-measured BSAF, a laboratory-measured BCF only reflects the accumulation of chemical through the water exposure route. Laboratory-measured BCFs may therefore under estimate BAFs for chemicals where accumulation from sediment or dietary sources is important. In these cases, laboratory-measured BCFs can be multiplied by a FCM to reflect accumulation from non-aqueous (i.e., food chain) pathways of exposure. Since a laboratory-measured BCF is determined using the measured concentration of a chemical in an aquatic organism and its surrounding water, a laboratory-measured BCF reflects any metabolism of the chemical that occurs in the organism, but not in the food web.

4. **K_{ow}.** A chemical's octanol-water partition coefficient, or K_{ow}, can also be used to predict a BAF for nonionic organic chemicals. This procedure is appropriate only for nonionic organic chemicals (and certain ionic organic chemicals where similar lipid and organic carbon partitioning behavior applies). The K_{ow} has been extensively correlated with the BCF for nonionic organic chemicals that are poorly metabolized by aquatic organisms. Therefore, where substantial metabolism is known to occur in biota, the K_{ow} is not used

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to predict the BAF. For nonionic organic chemicals where chemical exposure through the food web is important, use of the K_{ow} alone will under predict the BAF. In such cases, the K_{ow} is adjusted with a FCM similar to the BCF procedure above.

5.3.2 Overview of BAF Derivation Framework

Although up to four methods can be used to derive a BAF as described in the previous section, it is evident that these methods do not apply equally to all types of chemicals. In addition, experience demonstrates that the required data will usually not be available to derive a BAF value using all of the applicable methods. As a result, EPA has developed the following guidelines to direct users in selecting the most appropriate method(s) for deriving a national BAF.

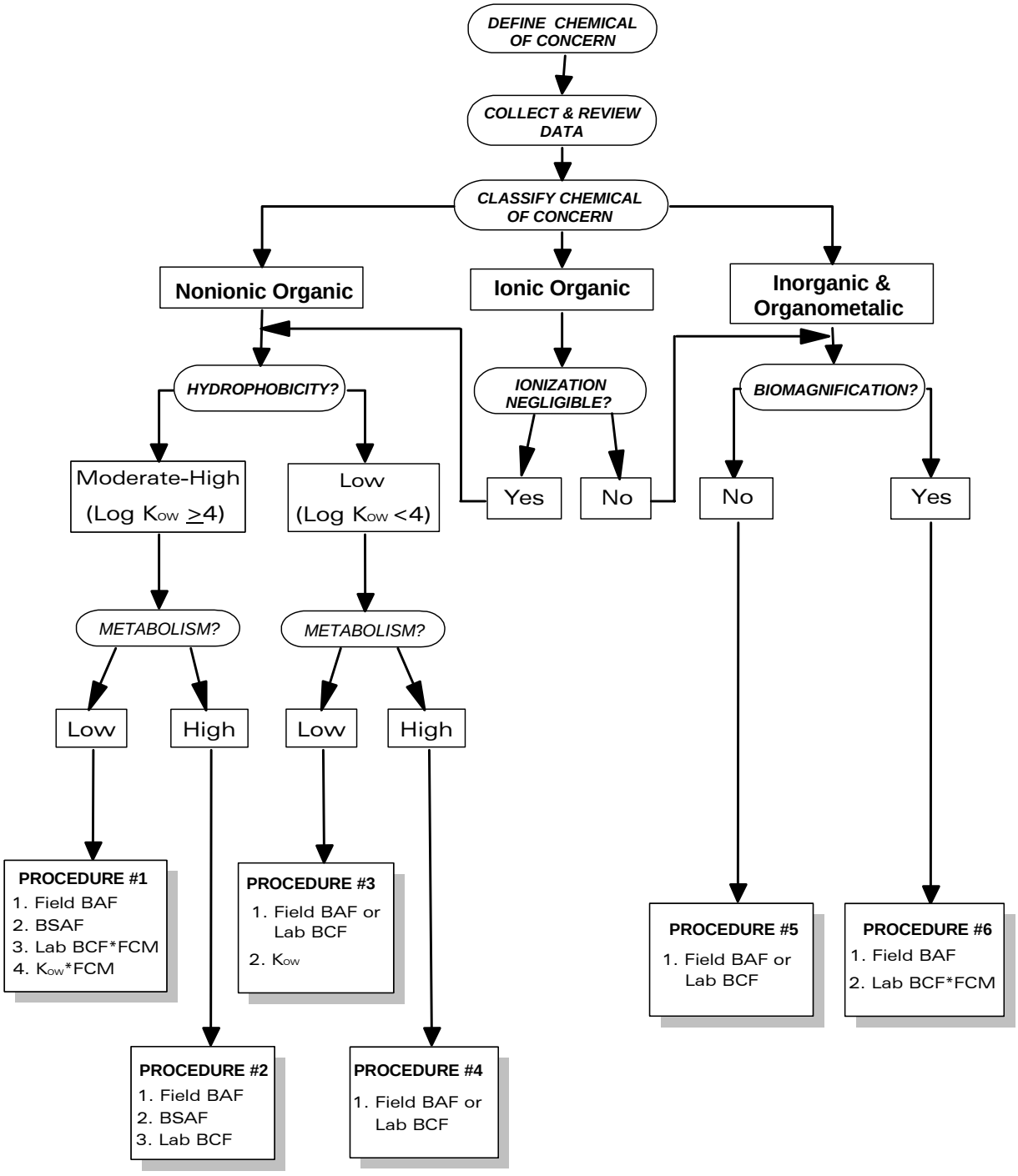
Figure 5-1 shows the overall framework of EPA's national BAF methodology. This framework illustrates the major steps and decisions that will ultimately lead to calculating a national BAF using one of six hierarchical procedures shown at the bottom of Figure 5-1. Each procedure contains a hierarchy of the BAF derivation methods discussed above, the composition of which depends on the chemical type and certain chemical properties (e.g., its degree of hydrophobicity and expected degree of metabolism and biomagnification). The number assigned to each BAF method within a procedure indicates its general order of preference for deriving a national BAF value. The goal of the framework and accompanying guidelines is to enable full use of available data and methods for deriving a national BAF value while appropriately restricting the use of certain methods to reflect their inherent limitations.

The first step in the framework is to define the chemical of concern. As described in Section 5.3.3, the chemical used to derive the national BAF should be consistent with the chemical used to derive the critical health assessment value. The second step is to collect and review all relevant data on bioconcentration and bioaccumulation of the chemical of concern (see Section 5.3.4). Once pertinent data are reviewed, the third step is to classify the chemical of concern into one of three broadly defined chemical categories: (1) nonionic organic chemicals, (2) ionic organic chemicals, and (3) and inorganic and organometallic chemicals. Guidance for classifying chemicals into these three categories is provided in Section 5.3.5.

After a chemical has been classified into one of the three categories, other information is used to select one of six hierarchical procedures to derive the national BAF. The specific procedures for deriving a BAF for each chemical group are discussed in Section 5.4 for nonionic organics, Section 5.5 for ionic organics, and Section 5.6 for inorganics and organometallics.

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Figure 5-1. Framework for Deriving a National BAF



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Detailed guidance concerning the first three steps of the derivation process (i.e, defining the chemical of concern, collecting and reviewing data, and classifying the chemical of concern) is provided in the following three sections.

5.3.3 Defining the Chemical of Concern

Defining the chemical of concern is the first step in deriving a national BAF. This step involves precisely defining the form(s) of the chemical upon which the national BAF value will be derived. Although this step is usually straightforward for single chemicals, complications can arise when the chemical of concern occurs as a mixture. The following guidelines should be followed for defining the chemical of concern.

1. Information for defining the chemical of concern should be obtained from the health and exposure assessment portions of the criteria derivation effort. The chemical(s) used to derive the national BAF should be consistent with the chemical(s) used to derive the reference dose (RfD), point of departure/uncertainty factor (POD/UF), or cancer potency factor.

2. In most cases, the RfD, POD/UF, or cancer potency factor will be based on a single chemical. In some cases, the RfD, POD/UF, or cancer potency factor will be based on a mixture of compounds, typically within the same chemical class (e.g., toxaphene, chlordane). In these situations, the national BAF should be derived in a manner that is consistent with the mixture used to express the health assessment.

    a. If sufficient data are available to reliably assess the bioaccumulation of each relevant compound contained in the mixture, then the national BAF(s) should be derived using the BAFs for the individual compounds of the mixture and appropriately weighted to reflect the mixture composition used to establish the RfD, POD/UF, or cancer potency factor. An example of this approach is shown in the derivation of BAFs for PCBs in the GLI Rulemaking (USEPA, 1997).

    b. If sufficient data are not available to reliably assess the bioaccumulation of individual compounds of the mixture, then the national BAF(s) should be derived using BAFs for the same or appropriately similar chemical mixture as that used to establish the RfD, POD/UF, or cancer potency value.

5.3.4 Collecting and Reviewing Data

The second step in deriving a national BAF is to collect and review all relevant bioaccumulation data for the chemical of concern. The following guidance should be followed for collecting and reviewing bioaccumulation data for deriving national BAFs.

1. All data on the occurrence and accumulation of the chemical of concern in aquatic animals and plants should be collected and reviewed for adequacy.

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2. A comprehensive literature search strategy should be used for gathering bioaccumulation-related data. An example of a comprehensive literature search strategy is provided in the Bioaccumulation TSD.

3. All data that are used should contain sufficient supporting information to indicate that acceptable measurement procedures were used and that the results are probably reliable. In some cases it may be appropriate to obtain additional written information from the investigator.

4. Questionable data, whether published or unpublished, should not be used. Guidance for assessing the acceptability of bioaccumulation and bioconcentration studies is found in Sections 5.4, 5.5, and 5.6.

5.3.5 Classifying the Chemical of Concern

The next step in deriving a national BAF consists of classifying the chemical of concern into one of three categories: nonionic organic, ionic organic, and inorganic and organometallic (Figure 5-1). This step helps to determine which of the four methods described in Section 5.3.1 are appropriate for deriving BAFs. The following guidance applies for classifying the chemical of concern.

1. **Nonionic Organic Chemicals.** For the purposes of the 2000 Human Health Methodology, nonionic organic chemicals are those organic compounds that do not ionize substantially in natural bodies of water. These chemicals are also referred to as neutral or nonpolar organics in the scientific literature. Due to their neutrality, nonionic organic chemicals tend to associate with other neutral (or near neutral) compartments in aquatic ecosystems (e.g., lipid, organic carbon). Examples of nonionic organic chemicals which have been widely studied in terms of their bioaccumulation include polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins and furans, many chlorinated pesticides, and polynuclear aromatic hydrocarbons (PAHs). Procedures for deriving a national BAF for nonionic organic chemicals are provided in Section 5.4.

2. **Ionic Organic Chemicals.** For the purposes of the 2000 Human Health Methodology, ionic organic chemicals are considered to include those chemicals that contain functional groups with exchangeable protons such as hydroxyl, carboxylic, and sulfonic groups and functional groups that readily accept protons such as amino and aromatic heterocyclic nitrogen (pyridine) groups. Ionic organic chemicals undergo ionization in water, the extent of which depends on pH and the pKa of the chemical. Because the ionized species of these chemicals behave differently from the neutral species, separate guidance is provided for deriving BAFs for ionic organic chemicals. Procedures for deriving national BAFs for ionic organic chemicals are provided in Section 5.5.

3. **Inorganic and Organometallic Chemicals.** The inorganic and organometallic category is considered to include inorganic minerals, other inorganic compounds and elements, metals (e.g., copper, cadmium, chromium, zinc), metalloids (selenium, arsenic) and

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organometallic compounds (e.g., methylmercury, tributyltin, tetraalkyllead). Procedures for deriving BAFs for inorganic and organometallic chemicals are provided in Section 5.6.

5.4 NATIONAL BIOACCUMULATION FACTORS FOR NONIONIC ORGANIC CHEMICALS

5.4.1 Overview

This section contains the methodology for deriving national BAFs for nonionic organic chemicals as defined in Section 5.3.5. The four general steps of this methodology are:

1. Selecting the BAF derivation procedure,
2. Calculating individual baseline BAF_{ℓ}^{fd}s,
3. Selecting the final baseline BAF_{ℓ}^{fd}s, and
4. Calculating the national BAFs from the final baseline BAF_{ℓ}^{fd}s.

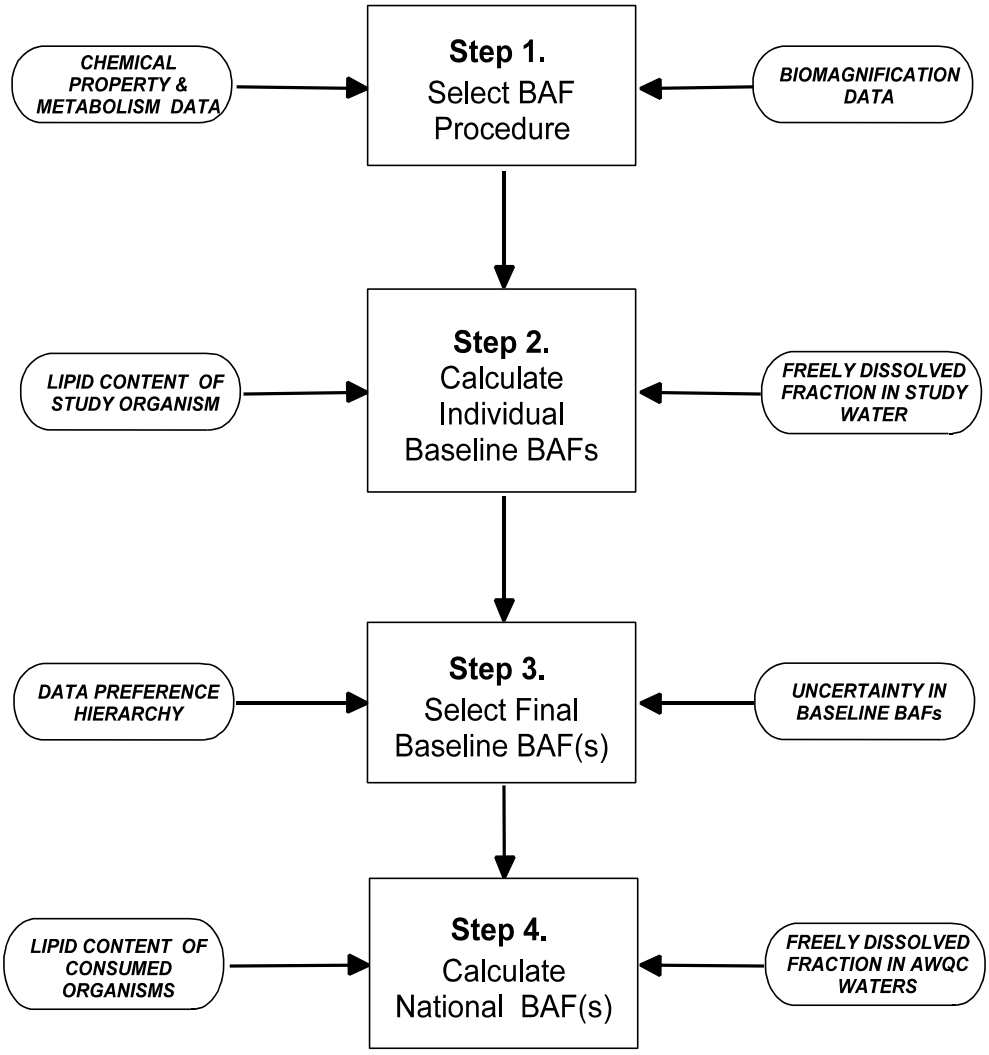
A schematic of this four-step process is shown in Figure 5-2.

Step 1 of the methodology (selecting the BAF derivation procedure) determines which of the four BAF procedures summarized in Figure 5-1 will be appropriate for deriving the national BAF. Step 2 involves calculating individual, species-specific BAF_{ℓ}^{fd}s using all of the methods available within the selected BAF derivation procedure. Calculating the individual baseline BAF_{ℓ}^{fd}s involves using data from the field site or laboratory where the original data were collected to account for site-specific factors which affect the bioavailability of the chemical to aquatic organisms (e.g., lipid content of study organisms and freely dissolved concentration in study water). Step 3 of the methodology consists of selecting the final baseline BAF_{ℓ}^{fd}s from the individual baseline BAF_{ℓ}^{fd}s by taking into account the uncertainty in the individual BAFs and the data preference hierarchy selected in Step 1. The final step is to calculate a BAF (or BAFs) that will be used in the derivation of 304(a) criteria (i.e., referred to as the national BAF). This step involves adjusting the final baseline BAF_{ℓ}^{fd}(s) to reflect certain factors that affect bioavailablity of the chemical to aquatic organisms in waters to which the national 304(a) criteria will apply (e.g., the freely dissolved fraction expected in U.S. waters and the lipid content of consumed aquatic organisms). Baseline BAF_{ℓ}^{fd}s are not used directly in the derivation of the 304(a) criteria because they do not reflect the conditions that affect bioavailability in U.S. waters.

Section 5.4.2 below provides detailed guidance for selecting the appropriate BAF derivation procedure (Step 1 of the process). Guidance on calculating individual baseline BAF_{ℓ}^{fd}s, selecting the final baseline BAF, and calculating the national BAF (Steps 2 through 4 of the process) is provided in separate sections under each of the four BAF derivation procedures.

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Figure 5-2. BAF Derivation for Nonionic Organic Chemicals



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5.4.2 Selecting the BAF Derivation Procedure

This section describes the decisions that should be made to select one of the four available hierarchical procedures for deriving a national BAF for nonionic organic chemicals (Procedures #1 through #4 of Figure 5-1). As shown in Figure 5-1, two decision points exist in selecting the BAF derivation procedure. The first decision point requires knowledge of the chemical's hydrophobicity (i.e., the K_{ow} of the chemical). Guidance for selecting the K_{ow} for a chemical is provided in the Bioaccumulation TSD. The K_{ow} provides an initial basis for assessing whether biomagnification may be a concern for nonionic organic chemicals. The second decision point is based on the rate of metabolism for the chemical in the target organism. Guidance for assessing whether a high or low rate of metabolism is likely for a chemical of concern is provided below in Section 5.4.2.3. With the appropriate information for these two decision points, the BAF derivation procedure should be selected using the following guidelines.

5.4.2.1 <u>Chemicals with Moderate to High Hydrophobicity</u>

1. For the purposes of the 2000 Human Health Methodology, nonionic organic chemicals with log K_{ow} values equal to or greater than 4.0 should be classified as moderately to highly hydrophobic. For moderately to highly hydrophobic nonionic organic chemicals, available data indicate that exposure through the diet and other non-aqueous routes can become important in determining chemical residues in aquatic organisms (e.g., Russell et al., 1999; Fisk et al., 1998; Oliver and Niimi, 1983; Oliver and Niimi, 1988; Niimi, 1985; Swackhammer and Hites, 1988). Dietary and other non-aqueous exposure can become extremely important for those nonionic organic chemicals that are poorly metabolized by aquatic biota (e.g., certain PCB congeners, chlorinated pesticides, and polychlorinated dibenzo-p-dioxins and furans).

2. **Procedure #1** should be used to derive national BAFs for moderately to highly hydrophobic nonionic organic chemicals in cases where:

   (a) the rate of chemical metabolism by target aquatic organisms is expected to be sufficiently low such that biomagnification is of concern, or

   (b) the rate of chemical metabolism by target aquatic organisms is not sufficiently known.

   Procedure #1 accounts for non-aqueous exposure and the potential for biomagnification in aquatic food webs through the use of field-measured values for bioaccumulation (i.e., field measured BAF or BSAF) and FCMs when appropriate field data are unavailable. Guidance on deriving national BAFs using Procedure #1 is found below in Section 5.4.3.

3. **Procedure #2** should be used to derive the national BAFs for moderately to highly hydrophobic nonionic organic chemicals in cases where:

   (a) the rate of chemical metabolism by target aquatic organisms is expected to be sufficiently high such that biomagnification is not of concern.

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Procedure #2 relaxes the requirement of using FCMs and eliminates the use of K_{ow}-based estimates of the BAF, two procedures that are most appropriate for poorly metabolized nonionic organic chemicals. Guidance on deriving national BAFs using Procedure #2 is found below in Section 5.4.4.

5.4.2.2 Chemicals with Low Hydrophobicity

1. For the purposes of these guidelines, nonionic organic chemicals with log K_{ow} values less than 4.0 should be classified as exhibiting low hydrophobicity. For nonionic organic chemicals that exhibit low hydrophobicity (i.e., log $K_{ow} < 4.0$), available information indicates that non-aqueous exposure to these chemicals is not likely to be important in determining chemical residues in aquatic organisms (e.g., Fisk et al., 1998; Gobas et al., 1993; Connolly and Pedersen, 1988; Thomann, 1989). For this group of chemicals, laboratory-measured BCFs and K_{ow}-predicted BCFs do not require adjustment with FCMs for determining the national BAF (Procedures #3 and #4), unless other appropriate data indicate differently.

   Other appropriate data include studies clearly indicating that non-aqueous exposure is important such that use of a BCF would substantially underestimate residues in aquatic organisms. In these cases, Procedure #1 should be used to derive the BAF for nonionic organic chemicals with log $K_{ow} < 4.0$. Furthermore, the data supporting the K_{ow} determination should be carefully reviewed for accuracy and appropriate interpretation, since the apparent discrepancy may be due to errors in determining K_{ow}.

2. **Procedure #3** should be used to derive national BAFs for nonionic organic chemicals of low hydrophobicity in cases where:

   (a) the rate of chemical metabolism by target aquatic organisms is expected to be negligible, such that tissue residues of the chemical of concern are not substantially reduced compared to an assumption of no metabolism, or

   (b) the rate of chemical metabolism by target aquatic organisms is not sufficiently known.

   Procedure #3 includes the use of K_{ow}-based estimates of the BCF to be used when lab or field data are absent. Guidance on deriving national BAFs using Procedure #3 is found below in Section 5.4.5.

3. **Procedure #4** should be used to derive national BAFs for nonionic organic chemicals of low hydrophobicity in cases where:

   (a) the rate of chemical metabolism by target aquatic organisms is expected to be sufficiently high, such that tissue residues of the chemical of concern are substantially reduced compared with an assumption of no metabolism.

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Procedure #4 eliminates the option of using K_{ow}-based estimates of the BAF because the K_{ow} may over-predict accumulation when a chemical is metabolized substantially by an aquatic organism. Guidance on deriving national BAFs using Procedure #4 is found below in Section 5.4.6.

5.4.2.3 Assessing Metabolism

Currently, assessing the degree to which a chemical is metabolized by aquatic organisms is confounded by a variety of factors. First, conclusive data on chemical metabolism in aquatic biota are largely lacking. Such data include whole organism studies where the metabolic rates and breakdown products are quantified in fish and other aquatic organisms relevant to human consumption. However, the majority of information on metabolism is derived from *in vitro* liver microsomal preparations in which primary and secondary metabolites may be identified and their rates of formation may or may not be quantified. Extrapolating results from *in vitro* studies to the whole organism involves considerable uncertainty. Second, there are no generally accepted procedures for reliably predicting chemical metabolism by aquatic organisms in the absence of measured data. Third, the rate at which a chemical is metabolized by aquatic organisms can be species and temperature dependent. For example, PAHs are known to be metabolized readily by vertebrate aquatic species (primarily fish), although at rates much less than those observed for mammals. However, the degree of metabolism in invertebrate species is generally much less than the degree in vertebrate species (James, 1989). One hypothesis for this difference is that the invertebrate species lack the detoxifying enzymes and pathways that are present in many vertebrate species.

Given the current limitations on assessing the degree of chemical metabolism by aquatic organisms, the assessment of metabolism should be made on a case-by-case basis using a weight-of-evidence approach. When assessing a chemical's likelihood to undergo substantial metabolism in a target aquatic organism, the following data should be carefully evaluated:

(1) *in vivo* chemical metabolism data,
(2) bioconcentration and bioaccumulation data,
(3) data on chemical occurrence in target aquatic biota, and
(4) *in vitro* chemical metabolism data.

1. ***In vivo* Data.** *In vivo* data on metabolism in aquatic organisms are from studies of chemical metabolism using whole organisms. These studies are usually conducted using large fish from which blood, bile, urine, and individual tissues can be collected for the identification and quantification of metabolites formed over time. *In vivo* studies are considered the most useful for evaluating a chemical's degree of metabolism in an organism because both oxidative (Phase I) and conjugative (Phase II) metabolism can be assessed in these studies. Mass-balance studies, in which parent compound elimination is quantified separately from biotransformation and elimination of metabolites, allow calculation of conversion rate of parent to metabolite as well as metabolite elimination. This information might be used to estimate loss due to metabolism separately from that due to elimination of the parent compound for adjustment of K_{ow}-predicted BAFs. However, due to the analytical and experimental challenges these studies pose, data of

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this type are limited. Less rigorous *in vivo* metabolism studies might include the use of metabolic blockers to demonstrate the influence of metabolism on parent compound kinetics. However, caution should be used in interpretation of absolute rates from these data due to the lack of specificity of mammalian derived blockers in aquatic species (Miranda et al., 1998).

2. **Bioconcentration or Bioaccumulation Data.** Data on chemical bioconcentration or bioaccumulation in aquatic organisms can be used indirectly for assessing metabolism. This assessment involves comparing acceptable lab-measured BCFs or field-measured BAFs (after converting to baseline values using procedures below) with the chemical's predicted value based on K_{ow}. The theoretical basis of bioconcentration and bioaccumulation for nonionic organic chemicals indicates that a chemical's baseline BCF should be similar to its K_{ow}-predicted value if metabolism is not occurring or is minimal (see the Bioaccumulation TSD). This theory also indicates that baseline BAFs should be similar to or higher than the K_{ow} for poorly metabolized organic chemicals, with highly hydrophobic chemicals often exhibiting higher baseline BAFs than K_{ow} values. Thus, if a chemical's baseline BCF or BAF is substantially lower than its K_{ow}, this may be an indication that the chemical is being metabolized by the aquatic organism of concern. Note, however, that this difference may also indicate problems in the experimental design or analytical chemistry, and that it may be difficult to discern the difference.

3. **Chemical Occurrence Data.** Although by no means definitive, data on the occurrence of chemicals in aquatic biota (i.e., residue studies) may offer another useful line of evidence for evaluating a chemical's likelihood to undergo substantial metabolism. Such studies are most useful if they have been conducted repeatedly over time and over wide geographical areas. Such studies might indicate a chemical is poorly metabolized if data show that the chemical is being biomagnified in the aquatic food web (i.e., higher lipid-normalized residues in successive trophic levels). Conversely, such studies might indicate a chemical is being metabolized substantially if residue data show a decline in residues with increasing trophic level. Again, other reasons for increases or decreases in concentrations with increasing trophic level might exist and should be carefully evaluated (e.g., incorrect food web assumptions, differences in exposure concentrations).

4. ***In vitro* Data.** *In vitro* metabolism data include data from studies where specific sub-cellular fractions (e.g., microsomal, cytosolic), cells, or tissues from an organism are tested outside the body (i.e., in test-tubes, cell- or tissue-culture). Compared with *in vivo* studies of chemical metabolism in aquatic organisms, *in vitro* studies are much more plentiful in the literature, with the majority of studies characterizing oxidative (Phase I) reactions de-coupled from conjugative (Phase II) metabolism. Cell, tissue, or organ level *in vitro* studies are less common but provide a more complete assessment of metabolism. While such studies are particularly useful for identifying the pathways, rates of formation, and metabolites formed, as well as the enzymes involved and differences in the temperature dependence of metabolism across aquatic species, they suffer from uncertainty when results are extrapolated to the whole organism. This uncertainty results from the fact that dosimetry (i.e., delivery of the toxicant to, and removal of metabolite

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from, the target tissue) cannot currently be adequately reproduced in the laboratory or easily modeled.

When assessing chemical metabolism using the above information, the following guidelines apply.

a. A finding of substantial metabolism should be supported by two or more lines of evidence identified using the data described above.

b. At least one of the lines of evidence should be supported by either *in vivo* metabolism data or acceptable bioconcentration or bioaccumulation data.

c. A finding of substantial metabolism in one organism should not be extrapolated to another organism or another group of organisms unless data indicate similar metabolic pathways exist (or are very likely to exist) in both organisms. *In vitro* data may be particularly useful in cross-species extrapolations.

d. Finally, in situations where sufficient data are not available to properly assess the likelihood of significant metabolism in aquatic biota of concern, the chemical should be assumed to undergo little or no metabolism. This assumptions reflects a policy decision by EPA to err on the side of public health protection when sufficient information on metabolism is lacking.

5.4.3 Deriving National BAFs Using Procedure #1

This section contains guidance for calculating national BAFs for nonionic organic chemicals using Procedure #1 shown in Figure 5-1. The types of nonionic organic chemicals for which Procedure #1 is most appropriate are those that are classified as moderately to highly hydrophobic and subject to low (or unknown) rates of metabolism by aquatic biota (see Section 5.4.2 above). Non-aqueous contaminant exposure and subsequent biomagnification in aquatic food webs are of concern for chemicals that are classified in this category. Some examples of nonionic organic chemicals for which Procedure #1 is considered appropriate include:

- tetra-, penta- & hexachlorobenzenes;
- PCBs;
- octachlorostyrene;
- hexachlorobutadiene;
- endrin, dieldrin, aldrin;
- mirex, photomirex;
- DDT, DDE, DDD; and
- heptachlor, chlordane, nonachlor.

Under Procedure #1, the following four methods may be used in deriving a national BAF:

- using a BAF from an acceptable field study (i.e., a field-measured BAF);
- predicting a BAF from an acceptable field-measured BSAF;

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- predicting a BAF from an acceptable laboratory-measured BCF and FCM; and
- predicting a BAF from an acceptable K_{ow} and FCM.

As shown in Figure 5-2, once the derivation procedure has been selected, the next steps in deriving a national BAF for a given trophic level include: calculating individual baseline BAF_{ℓ}^{fd}s (step 2), selecting the final baseline BAF_{ℓ}^{fd} (step 3), and calculating the national BAF from the final baseline BAF_{ℓ}^{fd} (step 4). Each of these three steps is discussed separately below.

5.4.3.1 Calculating Individual Baseline BAF_{ℓ}^{fd}s

Calculating an individual baseline BAF_{ℓ}^{fd} involves normalizing the field-measured BAF_T^t (or laboratory-measured BCF_T^t) which are based on total concentrations in tissue and water by the lipid content of the study organisms and the freely dissolved concentration in the study water. Both the lipid content in the organism and the freely dissolved concentration (as influenced by organic carbon in water) have been shown to be important factors that influence the bioaccumulation of nonionic organic chemicals (e.g., Mackay, 1982; Connolly and Pederson, 1988; Thomann, 1989, Suffet et al., 1994). Therefore, baseline BAF_{ℓ}^{fd}s (which are expressed on a freely dissolved and lipid-normalized basis) are considered more amenable to extrapolating between different species and bodies of water compared to BAFs expressed using the total concentration in the tissue and water. Because bioaccumulation can be strongly influenced by the trophic position of aquatic organisms (either due to biomagnification or physiological differences), extrapolation of baseline BAF_{ℓ}^{fd}s should not be performed between species of different trophic levels.

1. For each species for which acceptable data are available, calculate all possible baseline BAF_{ℓ}^{fd}s using each of the four methods shown above for Procedure #1.

2. Individual baseline BAF_{ℓ}^{fd}s should be calculated from field-measured BAF_T^ts, field-measured BSAFs, laboratory BCF_T^ts, and the K_{ow} according to the following procedures.

A. Baseline BAF_{ℓ}^{fd}s from Field-Measured BAFs

A baseline BAF_{ℓ}^{fd} should be calculated from each field-measured BAF_T^t using information on the lipid fraction in the tissue of concern for the study organism and the fraction of the total chemical that is freely dissolved in the study water.

1. **Baseline BAF_{ℓ}^{fd} Equation.** For each acceptable field-measured BAF_T^t, calculate a baseline BAF_{ℓ}^{fd} using the following equation:

$$\text{Baseline } BAF_{\ell}^{fd} = \left[\frac{\text{Measured } BAF_T^t}{f_{fd}} - 1 \right] \left(\frac{1}{f_{\ell}} \right) \qquad \text{(Equation 5-10)}$$

where:

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Baseline BAF_{ℓ}^{fd}	=	BAF expressed on a freely dissolved and lipid-normalized basis
Measured BAF_T^t	=	BAF based on total concentration in tissue and water
f_{ℓ}	=	Fraction of the tissue that is lipid
f_{fd}	=	Fraction of the total chemical that is freely dissolved in the ambient water

The technical basis of Equation 5-10 is provided in the Bioaccumulation TSD. Guidance for determining each component of Equation 5-10 is provided below.

2. **Determining the Measured BAF_T^t.** The field-measured BAF_T^t shown in Equation 5-10 should be calculated based on the total concentration of the chemical in the appropriate tissue of the aquatic organism and the total concentration of the chemical in ambient water at the site of sampling. The equation to derive a measured BAF_T^t is:

$$\text{Measured } BAF_T^t = \frac{C_t}{C_w} \qquad \text{(Equation 5-11)}$$

where:

C_t	=	Total concentration of the chemical in the specified wet tissue
C_w	=	Total concentration of chemical in water

The data used to calculate a field-measured BAF_T^t should be reviewed thoroughly to assess the quality of the data and the overall uncertainty in the BAF value. The following general criteria apply in determining the acceptability of field-measured BAFs that are being considered for deriving national BAFs using Procedure #1.

a. Aquatic organisms used to calculate a field-measured BAF_T^t should be representative of aquatic organisms that are commonly consumed in the United States. An aquatic organism that is not commonly consumed in the United States can be used to calculate an acceptable field-measured BAF_T^t provided that the organism is considered to be a reasonable surrogate for a commonly consumed organism. Information on the ecology, physiology, and biology of the organism should be reviewed when assessing whether an organism is a reasonable surrogate of a commonly consumed organism.

b. The trophic level of the study organism should be determined by taking into account its life stage, diet, size, and the food web structure at the study location. Information from the study site (or similar sites) is preferred when evaluating trophic status. If such information is lacking, general information for assessing trophic status of aquatic organisms can be found in USEPA (2000a,b,c).

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c. The percent lipid of the tissue used to determine the field-measured BAF_T^t should be either measured or reliably estimated to permit lipid-normalization of the chemical's tissue concentration.

d. The study from which the field-measured BAF_T^t is derived should contain sufficient supporting information from which to determine that tissue and water samples were collected and analyzed using appropriate, sensitive, accurate, and precise analytical methods.

e. The site of the field study should not be so unique that the BAF cannot be reasonably extrapolated to other locations where the BAF and resulting criteria will apply.

f. The water concentration(s) used to derive the BAF should reflect the average exposure of the aquatic organism that corresponds to the concentration measured in its tissue of concern. For nonionic organic chemicals, greater temporal and spatial averaging of chemical concentrations is required as the K_{ow} increases. In addition, as variability in water concentrations increase, greater temporal and spatial averaging is also generally required. Greater spatial averaging is also generally required for more mobile organisms.

g. The concentrations of particulate organic carbon and dissolved organic carbon in the study water should be measured or reliably estimated.

EPA is currently developing guidance for designing and conducting field studies for determining field-measured BAF_T^ts, including recommendations for minimum data requirements. A more detailed discussion of factors that should be considered when determining field-measured BAF_T^ts is provided in the Bioaccumulation TSD.

3. **Determining the Fraction Freely Dissolved (f_{fd}).** As illustrated by Equation 5-10, the fraction of the nonionic organic chemical that is freely dissolved in the study water is required for calculating a baseline BAF_ℓ^{fd} from a field-measured BAF_T^t. The freely dissolved fraction is the portion of the nonionic organic chemical that is not bound to particulate organic carbon or dissolved organic carbon. Together, the concentration of a nonionic organic chemical that is freely dissolved, bound to dissolved organic carbon, and bound to particulate organic carbon constitute its total concentration in water. As discussed further in the Bioaccumulation TSD, the freely dissolved fraction of a chemical is considered to be the best expression of the bioavailable form of nonionic organic chemicals to aquatic organisms (e.g., Suffet et al., 1994; USEPA, 1995b). Because the fraction of a nonionic organic chemical that is freely dissolved may vary among different bodies of water as a result of differences in dissolved and particulate organic carbon in the water, the bioavailability of the total chemical concentration in water is expected to vary from one body of water to another. Therefore, BAFs which are based on the freely dissolved concentration in water (rather than the total concentration in water) are considered to be more reliable for extrapolating and aggregating BAFs among different bodies of water. Currently, availability of BAFs based on measured freely dissolved

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concentrations is very limited, partly because of difficulties in analytically measuring the freely dissolved concentration. Thus, if a BAF based on the total water concentration is reported in a given study, the fraction of the chemical that is freely dissolved should be predicted using information on the organic carbon content in the study water.

a. **Equation for Determining the Freely Dissolved Fraction.** If reliable measured data are unavailable to directly determine the freely dissolved fraction of the chemical in water, the freely dissolved fraction should be estimated using the following equation.

$$f_{fd} = \frac{1}{[1 + (POC \cdot K_{ow}) + (DOC \cdot 0.08 \cdot K_{ow})]} \qquad \text{(Equation 5-12)}$$

where:

POC	=	concentration of particulate organic carbon (kg/L)
DOC	=	concentration of dissolved organic carbon (kg/L)
K_{ow}	=	n-octanol water partition coefficient for the chemical

In Equation 5-12, K_{ow} is being used to estimate the partition coefficient to POC (i.e., K_{POC} in L/kg) and $0.08 \cdot K_{ow}$ is being used to estimate the partition coefficient to DOC (i.e., the K_{DOC} in L/kg). A discussion of the technical basis, assumptions, and uncertainty associated with the derivation and application of Equation 5-12 is provided in the Bioaccumulation TSD.

b. **POC and DOC Values.** When converting from the total concentration of a chemical to a freely dissolved concentration using Equation 5-12 above, the POC and DOC concentrations should be obtained from the original study from which the field-measured BAF is determined. If POC and DOC concentrations are not reported in the BAF study, reliable estimates of POC and DOC might be obtained from other studies of the same site used in the BAF study or closely related site(s) within the same water body. When using POC/DOC data from other studies of the same water body, care should be taken to ensure that environmental and hydrological conditions that might affect POC or DOC concentrations (i.e., runoff events, proximity to ground water or surface water inputs, sampling season) are reasonably similar to those in the BAF study. Additional information related to selecting POC and DOC values is provided in the Bioaccumulation TSD.

In some cases, BAFs are reported using the concentration of the chemical in filtered or centrifuged water. When converting these BAFs to a freely dissolved basis, the concentration of POC should be set equal to zero when using Equation 5-12. Particulates are removed from water samples by filtering or centrifuging the sample.

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c. **Selecting K_{ow} Values.** A variety of techniques are available to measure or predict K_{ow} values. The reliability of these techniques depends to a large extent on the K_{ow} of the chemical. Because K_{ow} is an important input parameter for calculating the freely dissolved concentration of nonionic organic chemicals and for deriving BAFs using the other three methods of Procedure #1, care should be taken in selecting the most reliable K_{ow} value. The value of K_{ow} for use in estimating the freely dissolved fraction and other procedures used to derive national BAFs should be selected based on the guidance presented in the Bioaccumulation TSD.

4. **Determining the Fraction Lipid (f_ℓ).** Calculating a baseline BAF_ℓ^{fd} for a nonionic organic chemical using Equation 5-10 also requires that the total chemical concentration measured in the tissue used to determine the field-measured BAF_T^t be normalized by the lipid fraction (f_ℓ) in that same tissue. Lipid normalization of tissue concentrations reflects the assumption that BAFs (and BCFs) for nonionic organic chemicals are directly proportional to the percent lipid in the tissue upon which they are based. This assumption means that an organism with a two percent lipid content would be expected to accumulate twice the amount of a chemical at steady state compared with an organism with one percent lipid content, all else being equal. The assumption that aquatic organisms accumulate nonionic organic chemicals in proportion to their lipid content has been extensively evaluated in the literature (Mackay, 1982; Connell, 1988; Barron, 1990) and is generally accepted. Because the lipid content in aquatic organisms can vary both within and across species, BAFs that are expressed using the lipid-normalized concentration (rather than the total concentration in tissue) are considered to be the most reliable for aggregating multiple BAF values for a given species. Additional discussion of technical basis, assumptions, and uncertainties involved in lipid normalization is provided in the Bioaccumulation TSD.

a. The lipid fraction f_ℓ, is routinely reported in bioaccumulation studies involving nonionic organic chemicals. If the lipid fraction is not reported in the BAF study, it can be calculated using the following equation if the appropriate data are reported:

$$f_\ell = \frac{M_\ell}{M_t} \qquad \text{(Equation 5-13)}$$

where:

M_ℓ = Mass of lipid in specified tissue
M_t = Mass of specified tissue (wet weight)

b. Because lipid content can vary within an aquatic organism (and among tissues within that organism) due to several factors including the age and sex of the organism, changes in dietary composition, season of sampling and reproductive status, the lipid fraction used to calculate a baseline BAF_ℓ^{fd} should be measured in

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the same tissue and organisms used to determine the field-measured BAF_T^t, unless comparability is demonstrated across organisms.

c. Experience has shown that different solvent systems used to extract lipids for analytical measurement can result in different quantities of lipids being extracted and measured in aquatic organisms (e.g., Randall et al.,1991, 1998). As a result, lipid measurements determined using different solvent systems might lead to apparent differences in lipid-normalized concentrations and lipid-normalized BAFs. The extent to which different solvent systems might affect lipid extractions (and lipid-normalized concentrations) is thought to vary depending on the solvent, chemical of concern, and lipid composition of the tissue being extracted. Guidance on measurement of lipid content, including the choice of solvent system and how different solvent systems may affect lipid content, is provided in the Bioaccumulation TSD.

B. Baseline BAF_ℓ^{fd} Derived from BSAFs

The second method of determining a baseline BAF_ℓ^{fd} for the chemical of concern in Procedure #1 involves the use of BSAFs. Although BSAFs may be used for measuring and predicting bioaccumulation directly from concentrations of chemicals in surface sediment, they may also be used to estimate BAFs (USEPA, 1995b; Cook and Burkhard, 1998). Since BSAFs are based on field data and incorporate effects of chemical bioavailability, food web structure, metabolism, biomagnification, growth, and other factors, BAFs estimated from BSAFs will incorporate the net effect of all these factors. The BSAF approach is particularly beneficial for developing water quality criteria for chemicals which are detectable in fish tissues and sediments, but are difficult to detect or measure precisely in the water column.

As shown by Equation 5-14 below, predicting baseline BAF_ℓ^{fd}s using BSAFs requires that certain types of data be used for the chemicals of interest (for which BAFs are to be determined) and reference chemicals (for which BAFs are measured) from a common sediment-water-organism data set. Differences between BSAFs for different organic chemicals are good measures of the relative bioaccumulation potentials of the chemicals. When calculated from a common organism-sediment sample set, chemical-specific differences in BSAFs reflect the net effect of biomagnification, metabolism, food chain, bioenergetics, and bioavailability factors on the degree of each chemical's equilibrium/disequilibrium between sediment and biota. At equilibrium, BSAFs are expected to be approximately 1.0. However, deviations from 1.0 (reflecting disequilibrium) are common due to: conditions where water is not at equilibrium with surface sediment; differences in organic carbon content of water and sediment; kinetic limitations for chemical transfer between sediments and water associated with specific biota; biomagnification; or biological processes such as growth or biotransformation. BSAFs are most useful (i.e., most predictable from one site to another) when measured under steady-state (or near steady-state) conditions. The use of non-steady-state BSAFs, such as found with new chemical loadings or rapid increases in loadings, increases uncertainty in this method for the relative degree of disequilibrium between the reference chemicals and the chemicals of interest. In general, the fact that concentrations of hydrophobic chemicals in sediment are less sensitive than concentrations in water to fluctuations in chemical loading and distribution makes the BSAF

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method robust for estimating BAFs. Results from validation of the BAF procedure in Lake Ontario, the Fox River and Green Bay, Wisconsin, and the Hudson River, New York, demonstrate good agreement between observed and BSAF-predicted BAFs in the vast majority of comparisons made. Detailed results of the validation studies for the BSAF procedure are provided in the Bioaccumulation TSD.

Baseline BAF_{ℓ}^{fd}s should be calculated using acceptable BSAFs for chemicals of interest and appropriate sediment-to-water fugacity (disequilibrium) ratios $(\prod_{socw})_r/(K_{ow})_r$ for reference chemicals under the following guidelines.

1. **Baseline BAF_{ℓ}^{fd} Equation.** For each species with an acceptable field measured $(BSAF)_I$, a baseline BAF_{ℓ}^{fd} for the chemical of interest may be calculated using the following equation with an appropriate value of $(\prod_{socw})_r/(K_{ow})_r$:

$$(Baseline\ BAF_{\ell}^{fd})_i = (BSAF)_i \frac{(D_{i/r})\ (\prod_{socw})_r\ (K_{ow})_i}{(K_{ow})_r} \qquad \text{(Equation 5-14)}$$

where:

$(\text{Baseline } BAF_{\ell}^{fd})_I$	=	BAF expressed on a freely dissolved and lipid-normalized basis for chemical of interest "I"
$(BSAF)_I$	=	Biota-sediment accumulation factor for chemical of interest "I"
$(\prod_{socw})_r$	=	sediment organic carbon to water freely dissolved concentration ratio of reference chemical "r"
$(K_{ow})_I$	=	octanol-water partition coefficient for chemical of interest "I"
$(K_{ow})_r$	=	octanol-water partition coefficient for the reference chemical "r"
$D_{i/r}$	=	ratio between $\prod_{socw}/K_{ow}$ for chemicals "I" and "r" (normally chosen so that $D_{i/r} = 1$)

The technical basis, assumptions, and uncertainties associated with Equation 5-14 are provided in the Bioaccumulation TSD. Guidance for determining each component of Equation 5-14 is provided below.

2. **Determining Field-Measured BSAFs.** BSAFs should be determined by relating lipid-normalized concentrations of chemicals in an organism (C_{ℓ}) to organic carbon-normalized concentrations of the chemicals in surface sediment samples (C_{soc}) using the following equation:

$$BSAF = \frac{C_{\ell}}{C_{soc}} \qquad \text{(Equation 5-15)}$$

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a. **Lipid-Normalized Concentration.** The lipid-normalized concentration of a chemical in an organism should be determined by:

$$C_{\ell} = \frac{C_t}{f_{\ell}} \qquad \text{(Equation 5-16)}$$

where:

C_t = Concentration of the chemical in the wet tissue (either whole organism or specified tissue) (µg/g)
f_{ℓ} = Fraction lipid content in the tissue

b. **Organic Carbon-Normalized Concentration.** The organic carbon-normalized concentration of a chemical in sediment should be determined by:

$$C_{soc} = \frac{C_s}{f_{oc}} \qquad \text{(Equation 5-17)}$$

where:

C_s = Concentration of chemical in sediment (µg/g sediment)
f_{oc} = Fraction organic carbon in sediment

The organic carbon-normalized concentrations of the chemicals in surface sediment samples should be associated with the average exposure environment of the organism.

3. **Sediment-to-Water Partition Coefficient** $(\prod_{socw})_r$. Sediment-to-water partition coefficients for reference chemicals should be determined by:

$$(\prod_{socw})_r = \frac{(C_{soc})_r}{(C_w^{fd})_r} \qquad \text{(Equation 5-18)}$$

where:

$(C_{soc})_r$ = Concentration of a reference chemical in sediment normalized to sediment organic carbon
$(C_w^{fd})_r$ = Concentration of the reference chemical freely dissolved in water

4. **Selecting Reference Chemicals.** Reference chemicals with $(\prod_{socw}) / (K_{ow})$ similar to that of the chemical of interest are preferred for this method. Theoretically, knowledge of the

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difference between sediment-to-water fugacity ratios for two chemicals, "I" and "r" ($D_{i/r}$), could be used when reliable reference chemicals that meet the fugacity equivalence condition are not available. Similarity of $(\prod_{socw}) / (K_{ow})$ for two chemicals can be indicated on the basis of similar physical-chemical behavior in water (persistence, volatilization), similar mass loading histories, and similar concentration profiles in sediment cores.

Validation studies have demonstrated that choosing reference chemicals with well quantified concentrations in water is important because the uncertainty associated with measurement of barely detected chemicals is large (see the Bioaccumulation TSD). Similarity between K_{ow} values of the reference and target chemicals is generally desirable, although recent validation studies indicate that the accuracy of the method is not substantially decreased through use of reference chemicals with large differences in K_{ow}, as long as the chemicals are structurally similar and have similar persistence behavior in water and sediments.

5. The following data, procedural, and quality assurance requirements should be met for predicting baseline BAF_{ℓ}^{fd}s using field-measured BSAFs:

   a. Data on the reference chemicals and chemicals of interest should come from a common organism-water-sediment data set at a particular site.

   b. The chemicals of interest and reference chemicals should have similar physicochemical properties and persistence in water and sediment.

   c. The loadings history of the reference chemicals and chemicals of interest should be similar such that their expected sediment-water disequilibrium ratios $(\prod_{socw}/K_{ow})$ would not be expected to be substantially different (i.e., $D_{i/r} \sim 1$).

   d. The use of multiple reference chemicals is generally preferred for determining the value of $(\prod_{socw})_r$ so long as the concentrations are well quantified and the aforementioned conditions for selecting reference chemicals are met. In some cases, use of a single reference chemical may be necessary because of limited data.

   e. Samples of surface sediments (0-1 cm is ideal) should be from locations in which sediment is regularly deposited and is representative of average surface sediment in the vicinity of the organism.

   f. The K_{ow} value for the target and reference chemicals should be selected as described in the Bioaccumulation TSD.

   g. All other data quality and procedural guidelines described earlier for determining field-measured BAFs in Section 5.4.3.1(A) should be met.

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Further details on the requirements for predicting BAFs from BSAF measurements, including the data, assumptions, and limitations of this approach are provided in the Bioaccumulation TSD.

C. Baseline BAF_{ℓ}^{fd} from a Laboratory-Measured BCF_T^t and FCM

The third method in Procedure #1 consists of using a laboratory-measured BCF_T^t (i.e., a BCF based on total concentrations in tissue and water) and FCMs to predict a baseline BAF_{ℓ}^{fd} for the chemical of concern. The BCF_T^t is used in conjunction with an FCM because non-aqueous routes of exposure and subsequent biomagnification is of concern for the types of chemicals applicable to Procedure #1. A laboratory-measured BCF inherently accounts for the effects of chemical metabolism that occurs in the organism used to calculate the BCF, but does not account for metabolism which may occur in other organisms of the aquatic food web.

1. **Baseline BAF_{ℓ}^{fd} Equation.** For each acceptable laboratory-measured BCF_T^t, calculate a baseline BAF_{ℓ}^{fd} using the following equation:

$$\text{Baseline } BAF_{\ell}^{fd} = (FCM) \cdot \left[\frac{\text{Measured } BCF_T^t}{f_{fd}} - 1 \right] \cdot \left(\frac{1}{f_{\ell}} \right) \qquad \text{(Equation 5-19)}$$

where:

Baseline BAF_{ℓ}^{fd}	=	BAF expressed on a freely dissolved and lipid-normalized basis
Measured BCF_T^t	=	BCF based on total concentration in tissue and water
f_{ℓ}	=	Fraction of the tissue that is lipid
f_{fd}	=	Fraction of the total chemical in the test water that is freely dissolved
FCM	=	The food chain multiplier either obtained from Table 5-1 by linear interpolation for the appropriate trophic level, or from appropriate field data

The technical basis for Equation 5-19 is provided in the Bioaccumulation TSD. Guidance for determining each component of Equation 5-19 is provided below.

2. **Determining the Measured BCF_T^t.** The laboratory-measured BCF_T^t shown in Equation 5-19 should be calculated using information on the total concentration of the chemical in the tissue of the organism and the total concentration of the chemical in the laboratory test water. The equation to derive a measured BCF_T^t is:

$$\text{Measured } BCF_T^t = \frac{C_t}{C_w} \qquad \text{(Equation 5-20)}$$

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where:

C_t = Total concentration of the chemical in the specified wet tissue
C_w = Total concentration of chemical in the laboratory test water

The data used to calculate a laboratory-measured BCF_T^t should be reviewed thoroughly to assess the quality of the data and the overall uncertainty in the BCF value. The following general criteria apply in determining the acceptability of laboratory-measured BCF_T^t.

a. The test organism should not be diseased, unhealthy, or adversely affected by the concentration of the chemical because these attributes may alter accumulation of chemicals compared with healthy organisms.

b. The total concentration of the chemical in the water should be measured and should be relatively constant during the exposure period.

c. The organisms should be exposed to the chemical using a flow-through or renewal procedure.

d. The percent lipid of the tissue used to normalize the BCF_T^t should be either measured or reliably estimated to permit lipid normalization of chemical concentrations.

e. The concentrations of particulate organic carbon and dissolved organic carbon in the study water should be measured or reliably estimated.

f. Aquatic organisms used to calculate a laboratory-measured BCF_T^t should be representative of those aquatic organisms that are commonly consumed in the United States. An aquatic organism which is not commonly consumed in the United States can be used to calculate an acceptable laboratory-measured BCF_T^t provided that the organism is considered to be a reasonable surrogate for a commonly consumed organism. Information on the ecology, physiology, and biology of the organism should be reviewed when assessing whether an organism is a reasonable surrogate of a commonly consumed organism.

g. BCFs may be based on measurement of radioactivity from radiolabeled parent compounds only when the BCF is intended to include metabolites, when there is confidence that there is no interference due to metabolites of the parent compounds, or when studies are conducted to determine the extent of metabolism, thus allowing for a proper correction.

h. The calculation of the BCF_T^t should appropriately address growth dilution, which can be particularly important in affecting BCF_T^t determinations for poorly depurated chemicals.

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I. Other aspects of the methodology used should be similar to those described by the American Society of Testing and Materials (ASTM, 1999) and USEPA *Ecological Effects Test Guidelines* (USEPA, 1996).

j. In addition, the magnitude of the K_{ow} and the availability of corroborating BCF data should be considered. For example, if the steady-state method is used for the BCF_T^t determination, exposure periods longer than 28 days will generally be required for highly hydrophobic chemicals to reach steady state between the water and the organism.

k. If a baseline BCF_ℓ^{fd} derived from a laboratory-measured BCF_T^t consistently increases or decreases as the chemical concentration increases in the test solutions for the test organisms, the BCF_T^t should be selected from the test concentration(s) that would most closely correspond to the 304(a) criterion. Note: a BCF_T^t should not be calculated from a control treatment.

3. **Selecting Food Chain Multipliers.** An FCM reflects a chemical's tendency to biomagnify in the aquatic food web. Values of FCMs greater than 1.0 are indicative of biomagnification and typically apply to organic chemicals with log K_{ow} values between 4.0 and 9.0. For a given chemical, FCMs tend to be greater at higher trophic levels, although FCMs for trophic level three can be higher than those for trophic level four.

Food chain multipliers used to derive baseline BAF_ℓ^{fd}s using Procedure #1 can be selected from model-derived or field-derived estimates.

a. **Model-Derived FCMs.** For nonionic organic chemicals appropriate for Procedure #1, EPA has calculated FCMs for various K_{ow} values and trophic levels using the bioaccumulation model of Gobas (1993). The FCMs shown in Table 5-1 were calculated using the Gobas model as the ratio of the baseline BAF_ℓ^{fd}s for trophic levels 2, 3, and 4 to the baseline BCF_ℓ^{fd}.

EPA recommends using the biomagnification model by Gobas (1993) to derive FCMs for nonionic organic chemicals for several reasons. First, the Gobas model includes both benthic and pelagic food chains, thereby incorporating exposure of organisms to chemicals from both the sediment and the water column. Second, the input data needed to run the model can be readily defined. Third, the predicted BAFs using the model are in agreement with field-measured BAFs for chemicals, even those with very high log K_{ow}s. Finally, the model predicts chemical residues in benthic organisms using equilibrium partitioning theory, which is consistent with EPA's equilibrium partitioning sediment guidelines (USEPA, 2000d).

The Gobas model requires input of specific data on the structure of the food chain and the water quality characteristics of the water body of interest. For calculating national BAFs, a mixed pelagic/benthic food web structure consisting of four trophic levels is assumed. Trophic level 1 is phytoplankton, trophic level 2 is

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zooplankton, trophic level 3 is forage fish (e.g., sculpin and smelt), and trophic level 4 are predatory fish (e.g., salmonids). Additional assumptions are made regarding the composition of the aquatic species' diets (e.g., salmonids consume 10 percent sculpin, 50 percent alewives, and 40 percent smelt), the physical parameters of the aquatic species (e.g., lipid values), and the water quality characteristics (e.g., water temperature, sediment organic carbon).

A mixed pelagic/benthic food web structure has been assumed for the purpose of calculating FCMs because it is considered to be most representative of the types of food webs that occur in aquatic ecosystems. FCMs derived using the mixed pelagic/benthic structure are also about mid-range in magnitude between a 100% pelagic and 100% benthic driven food web (see the Bioaccumulation TSD). The validity of FCMs derived using the mixed pelagic/benthic food web structure has

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Table 5-1
Food-Chain Multipliers for Trophic Levels 2, 3 and 4
(Mixed Pelagic and Benthic Food Web Structure and $\prod_{socw} / K_{OW} = 23$)

Log K_{OW}	Trophic Level 2	Trophic Level 3	Trophic Level 4	Log K_{OW}	Trophic Level 2	Trophic Level 3	Trophic Level 4
4.0	1.00	1.23	1.07	6.6	1.00	12.9	23.8
4.1	1.00	1.29	1.09	6.7	1.00	13.2	24.4
4.2	1.00	1.36	1.13	6.8	1.00	13.3	24.7
4.3	1.00	1.45	1.17	6.9	1.00	13.3	24.7
4.4	1.00	1.56	1.23	7.0	1.00	13.2	24.3
4.5	1.00	1.70	1.32	7.1	1.00	13.1	23.6
4.6	1.00	1.87	1.44	7.2	1.00	12.8	22.5
4.7	1.00	2.08	1.60	7.3	1.00	12.5	21.2
4.8	1.00	2.33	1.82	7.4	1.00	12.0	19.5
4.9	1.00	2.64	2.12	7.5	1.00	11.5	17.6
5.0	1.00	3.00	2.51	7.6	1.00	10.8	15.5
5.1	1.00	3.43	3.02	7.7	1.00	10.1	13.3
5.2	1.00	3.93	3.68	7.8	1.00	9.31	11.2
5.3	1.00	4.50	4.49	7.9	1.00	8.46	9.11
5.4	1.00	5.14	5.48	8.0	1.00	7.60	7.23
5.5	1.00	5.85	6.65	8.1	1.00	6.73	5.58
5.6	1.00	6.60	8.01	8.2	1.00	5.88	4.19
5.7	1.00	7.40	9.54	8.3	1.00	5.07	3.07
5.8	1.00	8.21	11.2	8.4	1.00	4.33	2.20
5.9	1.00	9.01	13.0	8.5	1.00	3.65	1.54
6.0	1.00	9.79	14.9	8.6	1.00	3.05	1.06
6.1	1.00	10.5	16.7	8.7	1.00	2.52	0.721
6.2	1.00	11.2	18.5	8.8	1.00	2.08	0.483
6.3	1.00	11.7	20.1	8.9	1.00	1.70	0.320
6.4	1.00	12.2	21.6	9.0	1.00	1.38	0.210
6.5	1.00	12.6	22.8				

been evaluated in several different ecosystems including Lake Ontario, the tidally influenced Bayou D'Inde in Louisiana, the Fox River and Green Bay, Wisconsin, and the Hudson River in New York. Additional details of the validation of EPA's national default FCMs and the assumptions, uncertainties, and input parameters for the model are provided in the Bioaccumulation TSD.

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Although EPA uses the FCMs in Table 5-1 to derive its national 304(a) criteria, EPA recognizes that food webs of other waterbodies might differ from the assumptions used to calculate national BAFs. In these situations, States and authorized Tribes may wish to use alternate food web structures for calculating FCMs for use in setting State or Tribal water quality criteria. Additional guidance on the use of alternate food web structures for calculating State, Tribal, or site-specific criteria is provided in the Bioaccumulation TSD.

b. **Field-Derived FCMs.** In addition to model-derived estimates of FCMs, field data may also be used to derive FCMs. Currently, the use of field-derived FCMs is the only method recommended for estimating FCMs for inorganic and organometalic chemicals because appropriate model-derived estimates are not yet available (see Section 5.6). In contrast to the model-based FCMs described previously, field-derived FCMs account for any metabolism of the chemical of concern by the aquatic organisms used to calculate the FCM.

Field-derived FCMs should be calculated using lipid-normalized concentrations of the nonionic organic chemical in appropriate predator and prey species using the following equations.

$$FCM_{TL2} = BMF_{TL2} \quad \text{(Equation 5-21)}$$

$$FCM_{TL3} = (BMF_{TL3})\,(BMF_{TL2}) \quad \text{(Equation 5-22)}$$

$$FCM_{TL4} = (BMF_{TL4})\,(BMF_{TL3})\,(BMF_{TL2}) \quad \text{(Equation 5-23)}$$

where:

FCM = Food chain multiplier for designated trophic level (TL2, TL3, or TL4)
BMF = Biomagnification factor for designated trophic level (TL2, TL3, or TL4)

The basic difference between FCMs and BMFs is that FCMs relate back to trophic level one (or trophic level two as assumed by the Gobas (1993) model), whereas BMFs always relate back to the next lowest trophic level. For nonionic organic chemicals, BMFs can be calculated from tissue residue concentrations determined in biota at a site according to the following equations.

$$BMF_{TL2} = (C_{\ell, TL2}) / (C_{\ell, TL1}) \quad \text{(Equation 5-24)}$$

$$BMF_{TL3} = (C_{\ell, TL3}) / (C_{\ell, TL2}) \quad \text{(Equation 5-25)}$$

$$BMF_{TL4} = (C_{\ell, TL4}) / (C_{\ell, TL3}) \quad \text{(Equation 5-26)}$$

where:

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C_ℓ = Lipid-normalized concentration of chemical in tissue of appropriate biota that occupy the specified trophic level (TL2, TL3, or TL4)

In addition to the acceptability guidelines pertaining to field-measured BAFs, the following procedural and quality assurance requirements apply to field-measured FCMs.

(1) Information should be available to identify the appropriate trophic levels for the aquatic organisms and appropriate predator-prey relationships for the site from which FCMs are being determined. General information on determining trophic levels of aquatic organisms can be found in USEPA 2000a,b,c.

(2) The aquatic organisms sampled from each trophic level should reflect the most important exposure pathways leading to human exposure via consumption of aquatic organisms. For higher trophic levels (e.g., 3 and 4), aquatic species should also reflect those that are commonly consumed by humans.

(3) The studies from which the FCMs are derived should contain sufficient supporting information from which to determine that tissue samples were collected and analyzed using appropriate, sensitive, accurate, and precise methods.

(4) The percent lipid should be either measured or reliably estimated for the tissue used to determine the FCM.

(5) The tissue concentrations should reflect average exposure over the approximate time required to achieve steady-state in the target species.

D. Baseline BAF_ℓ^{fd} from a K_{ow} and FCM

The fourth method in Procedure #1 consists of using a K_{ow} and an appropriate FCM for estimating the baseline BAF_ℓ^{fd}. In this method, the K_{ow} is assumed to be equal to the baseline BCF_ℓ^{fd}. Numerous investigations have demonstrated a linear relationship between the logarithm of the BCF and the logarithm of the octanol-water partition coefficient (K_{ow}) for organic chemicals for fish and other aquatic organisms. Isnard and Lambert (1988) list various regression equations that illustrate this linear relationship. When the regression equations are constructed using lipid-normalized BCFs, the slopes and intercepts are not significantly different from one and zero, respectively (e.g., de Wolf, et al., 1992). The underlying assumption for the linear relationship between the BCF and K_{ow} is that the bioconcentration process can be viewed as the partitioning of a chemical between the lipid of the aquatic organisms and water and that the K_{ow} is a useful surrogate for this partitioning process (Mackay, 1982). To account for biomagnification, Procedure #1 requires the K_{ow} value be used in conjunction with an appropriate FCM.

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1. **Baseline BAF_{ℓ}^{fd} Equation.** For each acceptable K_{ow} value and FCM for the chemical of concern, calculate a baseline BAF_{ℓ}^{fd} using the following equation.

$$\text{Baseline } BAF_{\ell}^{fd} = (FCM) \cdot (K_{ow}) \qquad \text{(Equation 5-27)}$$

where:

Baseline BAF_{ℓ}^{fd}	=	BAF expressed on a freely dissolved and lipid-normalized basis for a given trophic level
FCM	=	The food chain multiplier for the appropriate trophic level obtained from Table 5-1 by linear interpolation or from appropriate field data (used with Procedure #1 only)
K_{ow}	=	Octanol-water partition coefficient

The BCF-K_{ow} relationship has been developed primarily for nonionic organic chemicals that are not readily metabolized by aquatic organisms and thus is most appropriate for poorly-metabolized nonionic organic chemicals (i.e., Procedures #1 and #3 as depicted in Figure 5-1). For poorly-metabolized nonionic organic chemicals with large log K_{ow}s (i.e., > 6), reported log BCFs are often not equal to log K_{ow}. EPA believes that this nonlinearity is primarily due to not accounting for several factors which affect the BCF determination. These factors include not basing BCFs on the freely dissolved concentration in water, not accounting for growth dilution, not assessing BCFs at steady-state, inaccuracies in measurements of uptake and elimination rate constants, and complications from the use of solvent carriers in the exposure. Application of Equation 5-27 for predicting BAFs has been conducted in several different ecosystems including Lake Ontario, the tidally influenced Bayou D'Inde in Louisiana, the Fox River and Green Bay, Wisconsin, and the Hudson River in New York. Additional detail on the validation, technical basis, assumptions, and uncertainty associated with Equation 5-27 and is provided in the Bioaccumulation TSD.

2. **FCMs and K_{ow}s**. Food chain multipliers and K_{ow} values should be selected as described previously in Procedure #1.

5.4.3.2 Selecting Final Baseline BAF_{ℓ}^{fd}s

After calculating individual baseline BAF_{ℓ}^{fd}s using as many of the methods in Procedure #1 as possible, the next step is to determine a final baseline BAF_{ℓ}^{fd} for each trophic level from the individual baseline BAF_{ℓ}^{fd}s (see Figures 5-1 and 5-2). The final baseline BAF_{ℓ}^{fd} will be used in the last step to determine the national BAF for each trophic level. The final baseline BAF_{ℓ}^{fd} for each trophic level should be determined from the individual baseline BAF_{ℓ}^{fd}s by considering the data preference hierarchy defined by Procedure #1 and uncertainty in the data. The data preference hierarchy for Procedure #1 is (in order of preference):

1. a baseline BAF_{ℓ}^{fd} from an acceptable field-measured BAF (method 1)

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2. a baseline BAF_{ℓ}^{fd} predicted from an acceptable field-measured BSAF (method 2),
3. a baseline BAF_{ℓ}^{fd} predicted from an acceptable BCF and FCM (method 3), or
4. a baseline BAF_{ℓ}^{fd} predicted from an acceptable K_{ow} and FCM (method 4).

This data preference hierarchy reflects EPA's preference for BAFs based on field-measurements of bioaccumulation (methods 1 and 2) over those based on laboratory-measurements and/or predictions of bioaccumulation (methods 3 and 4). However, this data preference hierarchy should not be considered inflexible. Rather, it should be used as a guide for selecting the final baseline BAF_{ℓ}^{fd}s when the uncertainty is similar among two or more baseline BAF_{ℓ}^{fd}s derived using different methods. The following steps and guidelines should be followed for selecting the final baseline BAF_{ℓ}^{fd}s using Procedure #1.

1. **Calculate Species-Mean Baseline BAF_{ℓ}^{fd}s.** For each BAF method where more than one acceptable baseline BAF_{ℓ}^{fd} is available for a given species, calculate a species-mean baseline BAF_{ℓ}^{fd} as the geometric mean of all available individual baseline BAF_{ℓ}^{fd}s. When calculating a species-mean baseline BAF_{ℓ}^{fd}, individual baseline BAF_{ℓ}^{fd}s should be reviewed carefully to assess the uncertainty in the BAF values. For highly hydrophobic chemicals applicable to Procedure #1, particular attention should be paid to whether sufficient spatial and temporal averaging of water and tissue concentrations was likely achieved in the BAF, BSAF, or BCF study. Highly uncertain baseline BAF_{ℓ}^{fd}s should not be used. Large differences in individual baseline BAF_{ℓ}^{fd}s for a given species (e.g., greater than a factor of 10) should be investigated further. In such cases, some or all of the baseline BAF_{ℓ}^{fd}s for a given species might not be used. Additional discussion on evaluating acceptability of BAF values is provided in the Bioaccumulation TSD.

2. **Calculate Trophic-Level-Mean Baseline BAF_{ℓ}^{fd}s.** For each BAF method where more than one acceptable species-mean baseline BAF_{ℓ}^{fd} is available within a given trophic level, calculate a trophic-level-mean baseline BAF_{ℓ}^{fd} as the geometric mean of acceptable species-mean baseline BAF_{ℓ}^{fd}s in that trophic level. Trophic-level-mean baseline BAF_{ℓ}^{fd}s should be calculated for trophic levels two, three, and four because available data on U.S. consumers of fish and shellfish indicate significant consumption of organisms in these trophic levels.

3. **Select a Final Baseline BAF_{ℓ}^{fd} for Each Trophic Level.** For each trophic level, select the final baseline BAF_{ℓ}^{fd} using best professional judgment by considering: (1) the data preference hierarchy shown previously, (2) the relative uncertainty in the trophic-level-mean baseline BAF_{ℓ}^{fd}s derived using different methods, and (3) the weight of evidence among the four methods.

    a. In general, when more than one trophic-level-mean baseline BAF_{ℓ}^{fd} is available for a given trophic level, the final trophic-level-mean baseline BAF_{ℓ}^{fd} should be selected from the most preferred BAF method defined by the data preference hierarchy for Procedure #1.

    b. If uncertainty in a trophic-level-mean baseline BAF based on a higher tier (more preferred) method is judged to be substantially greater than a trophic-level-mean

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baseline BAF from a lower tier method, and the weight of evidence among the various methods suggests that a BAF value from lower tier method is likely to be more accurate, then the final baseline BAF_{ℓ}^{fd} should be selected using a trophic level-mean baseline BAF_{ℓ}^{fd} from a lower tier method.

c. When considering the weight of evidence among the various BAF methods, greater confidence in the final baseline BAF_{ℓ}^{fd} is generally assigned when BAFs from a greater number of methods are in agreement for a given trophic level. However, lack of agreement among methods does not necessarily indicate less confidence if such disagreements can be adequately explained. For example, if the chemical of concern is metabolized by aquatic organisms represented by a BAF value, one would expect disagreement between a field-measured BAF (the highest priority data) and a predicted BAF using a K_{ow} and model-derived FCM. Thus, field-measured BAFs should generally be given the greatest weight among methods because they reflect direct measures of bioaccumulation and incorporate any metabolism which might occur in the organism and its food web.

d. The above steps should be performed for each trophic level until a final baseline BAF_{ℓ}^{fd} is selected for trophic levels two, three, and four.

5.4.3.3 Calculating National BAFs

The last step in deriving a national BAF for each trophic level is to convert the final baseline BAF_{ℓ}^{fd} determined in the previous step to a BAF that reflects conditions to which the national 304(a) criteria will apply (Figure 5-2). Since a baseline BAF_{ℓ}^{fd} is by definition normalized by lipid content and expressed on a freely dissolved basis, it needs to be adjusted to reflect the lipid fraction of aquatic organisms commonly consumed in the U.S. and the freely dissolved fraction expected in U.S. bodies of water. Converting a final baseline BAF_{ℓ}^{fd} to a national BAF requires information on: (1) the percent lipid of the aquatic organisms commonly consumed by humans, and (2) the freely dissolved fraction of the chemical of concern that would be expected in the ambient waters of interest. For each trophic level, a national BAF should be determined from a final baseline BAF_{ℓ}^{fd} according to the following guidelines.

1. **National BAF Equation.** For each trophic level, calculate a national BAF using the following equation.

$$\text{National BAF}_{(TL\ n)} = [(\text{Final Baseline BAF}_{\ell}^{fd})_{TL\ n} \cdot (f_{\ell})_{TL\ n} + 1] \cdot (f_{fd}) \qquad \text{(Equation 5-28)}$$

where:

Final Baseline BAF_{ℓ}^{fd} = Final trophic-level-mean baseline BAF expressed on a freely dissolved and lipid-normalized basis for trophic level "n"

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$f_{\ell(TL\ n)}$	=	Lipid fraction of aquatic species consumed at trophic level "n"
f_{fd}	=	Fraction of the total chemical in water that is freely dissolved

The technical basis of Equation 5-28 is provided in the Bioaccumulation TSD. Guidance for determining each component of Equation 5-28 is provided below.

2. **Determining the Final Baseline BAF_{ℓ}^{fd}.** The final trophic-level-mean baseline BAF_{ℓ}^{fd}s used in this equation are those which have been determined using the guidance presented in Section 5.4.3.2 for selecting the final baseline BAF_{ℓ}^{fd}s.

3. **Lipid Content of Commonly Consumed Aquatic Species.** As illustrated by Equation 5-28, the percent lipid of the aquatic species consumed by humans is needed to accurately characterize the potential exposure to a chemical from ingestion of aquatic organisms.

   a. **National Default Lipid Values.** For the purposes of calculating a national 304(a) criterion, the following national default values for lipid fraction should be used: 1.9% (for trophic level two organisms), 2.6% (for trophic level three organisms), and 3.0% (for trophic level four organisms).

      These national default values for lipid content reflect national per capita average patterns of fish consumption in the United States. Specifically, they were calculated using the consumption-weighted mean lipid content of commonly consumed fish and shellfish as identified by the USDA Continuing Survey of Food Intake by Individuals (CSFII) for 1994 through 1996. This same national survey data was used to derive national default values of fish consumption. To maintain consistency with the fish consumption assumptions, only freshwater and estuarine organisms were included in the derivation of the national default lipid values. Additional details on the technical basis, assumptions, and uncertainty in the national default values of lipid fraction are provided in the Bioaccumulation TSD.

      Although national default lipid values are used by EPA to set national 304(a) criteria, EPA encourages States and authorized Tribes to use local or regional data on lipid content of consumed aquatic species when adopting criteria into their water quality standards because local or regional consumption patterns (and lipid content) can differ from national consumption patterns. Additional guidance on developing site-specific values of lipid content, including a database of lipid content for many commonly consumed aquatic organisms, is found in the Bioaccumulation TSD.

4. **Freely Dissolved Fraction.** The third piece of information required for deriving a national BAF is the freely dissolved fraction of the chemical of concern that is expected

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in waters of the United States. As noted previously, expressing BAFs on the freely dissolved concentration in water allows a common basis for averaging BAFs from several studies. However, for use in criteria development, these BAFs should be converted back to values based on the total concentration in the water to be consistent with monitored water column and effluent concentrations, which are typically based on total concentrations of chemicals in the water. This should be done by multiplying the freely dissolved baseline BAF_{ℓ}^{fd} by the fraction of the freely dissolved chemical expected in water bodies of the United States where criteria are to be applied, as shown in Equation 5-29.

$$f_{fd} = \frac{1}{[1 + (POC \cdot K_{ow}) + (DOC \cdot 0.08 \cdot K_{ow})]} \qquad \text{(Equation 5-29)}$$

where:

POC	=	national default value for the particulate organic carbon concentration (kg/L)
DOC	=	national default value for the dissolved organic carbon concentration (kg/L)
K_{ow}	=	n-octanol water partition coefficient for the chemical

Equation 5-29 is identical to Equation 5-12, which was used to determine the freely dissolved fraction for deriving baseline BAF_{ℓ}^{fd}s from field-measured BAFs. However, the POC and DOC concentrations used in Equation 5-29 reflect those values that are expected in U.S. bodies of water, not the POC and DOC values in the study water used to derive the BAF. Guidance for determining each component of Equation 5-29 follows.

a. **National Default Values of POC and DOC.** For estimating the freely dissolved fraction of the chemical of concern that is expected in U.S. water bodies, national default values of 0.5 mg/L (5×10^{-7} kg/L) for POC and 2.9 mg/L (2.9×10^{-6} kg/L) for DOC should be used. These values are 50th percentile values (medians) based on an analysis of over 110,000 DOC values and 85,000 POC values contained in EPA's STORET database from 1980 through 1999. These default values reflect a combination of values for streams, lakes and estuaries across the United States. Additional details on the technical basis, assumptions, and uncertainty in the derivation and application of the national default values of POC and DOC are provided in the Bioaccumulation TSD.

   Although national default values of POC and DOC concentrations are used by EPA to set national 304(a) criteria as described by this document, EPA encourages States and authorized Tribes to use local or regional data on POC and DOC when adopting criteria into their water quality standards. EPA encourages States and Tribes to consider local or regional data on POC and DOC because local or regional conditions may result in differences in POC or DOC

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concentrations compared with the values used as national defaults. Additional guidance on developing local or regional values of POC and DOC, including a database of POC and DOC values segregated by waterbody type, is found in the Bioaccumulation TSD.

b. **K_{ow} Value.** The value selected for the K_{ow} of the chemical of concern should be the same value used in earlier calculations (e.g., for calculating baseline BAF_{ℓ}^{fd}s and FCMs). Guidance for selecting the K_{ow} value is found in the Bioaccumulation TSD.

5.4.4 Deriving National BAFs Using Procedure #2

This section provides guidance for calculating national BAFs for nonionic organic chemicals using Procedure #2 shown in Figure 5-1. The types of nonionic organic chemicals for which Procedure #2 is most appropriate are those that are classified as moderately to highly hydrophobic and subject to high rates of metabolism by aquatic biota (see Section 5.4.2 above). Non-aqueous contaminant exposure and subsequent biomagnification in aquatic food webs are not generally of concern for chemicals that are classified in this category. As a result, FCMs are not used in this procedure. In addition, K_{ow} -based predictions of bioconcentration are not used in this procedure since the K_{ow} /BCF relationship is primarily based on poorly metabolized chemicals. Some nonionic organic chemicals for which Procedure #2 is probably appropriate include certain PAHs which are believed to be metabolized substantially by fish (e.g., benzo[a]pyrene, phenanthrene, fluoranthene, pyrene, benzo[a]anthracene and chrysene/triphenylene; USEPA, 1980; Burkhard and Lukasewycz, 2000).

According to Procedure #2, the following three methods can be used in deriving a national BAF:

- using a BAF from an acceptable field study (i.e., a field-measured BAF) (method 1),
- predicting a BAF from an acceptable BSAF (method 2), and
- predicting a BAF from an acceptable BCF (method 3).

Each of these three methods relies on measured data for assessing bioaccumulation and therefore, includes the effects of chemical metabolism by the study organism in the BAF estimate. The field-measured BAF and BSAF methods also incorporate any metabolism which occurs in the aquatic food web.

As shown in Figure 5-2, the next steps in deriving a national BAF after selecting the derivation procedure are: (1) calculating individual baseline BAF_{ℓ}^{fd}s, (2) selecting the final baseline BAF_{ℓ}^{fd}s, and (3) calculating the national BAFs. Each of these three steps is discussed separately below.

5.4.4.1 Calculating Individual Baseline BAF_{ℓ}^{fd}s

As described previously in Procedure #1, calculating individual baseline BAF_{ℓ}^{fd}s involves normalizing the measured BAF_{T}^{t} or BCF_{T}^{t} (which are based on the total chemical in water and

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tissue) by the lipid content of the study organisms and the freely dissolved fraction of the chemical in the study water. Converting measured BAF_T^t (or BCF_T^t) values to baseline BAF_ℓ^{fd} (or BCF_ℓ^{fd}) values is designed to account for variation in measured BAF_T^ts that is caused by differences in lipid content of study organisms and differences in the freely dissolved fraction of chemical in study waters. Therefore, baseline BAF_ℓ^{fd}s are considered more amenable for extrapolating and averaging BAFs across different species and different study waters compared with total BAF_T^ts.

1. For each species where acceptable data are available, calculate all possible baseline BAF_ℓ^{fd}s using each of the three methods shown above for Procedure #2.

2. Individual baseline BAF_ℓ^{fd}s should be calculated from field-measured BAF_T^ts, field-measured BSAFs, and laboratory BCF_T^ts according to the following procedures.

A. Baseline BAF_ℓ^{fd} from Field-Measured BAFs

1. Except where noted below, a baseline BAF_ℓ^{fd} should be calculated from a field-measured BAF_T^t using the guidance and equations outlined in Section 5.4.3.1(A) for determining baseline BAF_ℓ^{fd}s from field-measured BAFs in Procedure #1.

2. Because nonionic organic chemicals applicable to Procedure #2 have relatively high rates of metabolism in aquatic organisms, they will tend to reach steady state more quickly than nonionic organic chemicals with similar K_{ow} values but which undergo little or no metabolism. Therefore, less temporal averaging of chemical concentrations would generally be required for determining field-measured BAF_T^ts with highly metabolizable chemicals compared with chemicals that are poorly metabolized by aquatic biota.

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B. Baseline BAF_{ℓ}^{fd} Derived from Field-measured BSAFs

1. A baseline BAF_{ℓ}^{fd} should be calculated from a field-measured BSAF using the guidance and equations outlined in Section 5.4.3.1(B) for determining baseline BAF_{ℓ}^{fd}s from field-measured BSAFs in Procedure #1.

C. Baseline BAF_{ℓ}^{fd} from a Laboratory-Measured BCF

1. Except where noted below, a baseline BAF_{ℓ}^{fd} should be calculated from a laboratory-measured BCF_{T}^{t} using the guidance and equations outlined in Section 5.4.3.1(c) for determining baseline BAF_{ℓ}^{fd}s from a laboratory-measured BCF and FCM in Procedure #1.

2. Because biomagnification is not an overriding concern for nonionic organic chemicals applicable to Procedure #2, food chain multipliers are not used in the derivation of a baseline BAF_{ℓ}^{fd} from a laboratory-measured BCF_{T}^{t} .

5.4.4.2 Selecting Final Baseline BAF_{ℓ}^{fd}s

After calculating individual, baseline BAF_{ℓ}^{fd}s using as many of the methods in Procedure #2 as possible, the next step is to determine a final baseline BAF_{ℓ}^{fd} for each trophic level from the individual baseline BAF_{ℓ}^{fd}s. The final baseline BAF_{ℓ}^{fd} will be used in the last step to determine the national BAF for each trophic level. A final baseline BAF_{ℓ}^{fd} for each trophic level should be determined from the individual baseline BAF_{ℓ}^{fd}s by considering the data preference hierarchy defined by Procedure #2 and uncertainty in the data. The data preference hierarchy for Procedure #2 is (in order of preference):

1. a baseline BAF_{ℓ}^{fd} from an acceptable field-measured BAF (method 1),
2. a baseline BAF_{ℓ}^{fd} from an acceptable field-measured BSAF (method 2), or
3. a baseline BAF_{ℓ}^{fd} from an acceptable laboratory-measured BCF (method 3).

This data preference hierarchy reflects EPA's preference for BAFs based on field-measurements of bioaccumulation (methods 1 and 2) over those based on laboratory-measurements (method 3). However, as explained in Procedure #1, this data preference hierarchy should not be considered inflexible. Rather, it should be used as a guide for selecting the final baseline BAF_{ℓ}^{fd}s when the underlying uncertainty is similar among two or more baseline BAF_{ℓ}^{fd}s derived using different methods. Although biomagnification is not generally a concern for chemicals subject to Procedure #2, trophic level differences in bioaccumulation might be substantial to the extent that the rate of chemical metabolism by organisms in different trophic levels differs. For example, certain PAHs have been shown to be metabolized to a much greater extent by some fish compared with some invertebrate species (James, 1989). Therefore, final baseline BAF_{ℓ}^{fd}s for chemicals applicable to Procedure #2 should be determined on a trophic-level-specific basis according to the following guidelines.

1. The final baseline BAF_{ℓ}^{fd}s in Procedure #2 should be selected according to the same steps described in Procedure #1 but with the substitution of the data preference hierarchy described above for Procedure #2. Specifically, the species-mean baseline BAF_{ℓ}^{fd}s,

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trophic-level-mean baseline BAF_{ℓ}^{fd}s, and the final baseline BAF_{ℓ}^{fd}s should be determined according to the guidelines presented in Procedure #1 (Section 5.4.3.2, Steps 1, 2, and 3).

5.4.4.3 Calculating the National BAFs

As described in Procedure #1, the last step in deriving national BAFs for nonionic organic chemicals is to convert the final baseline BAF_{ℓ}^{fd}s determined in the previous step to BAFs which reflect conditions to which the national 304(a) criteria will apply (Figure 5-2).

1. For trophic levels two, three, and four, national BAFs should be calculated from the final baseline BAF_{ℓ}^{fd}s using the same equation and procedures described previously in Procedure #1 (see Section 5.4.3.3 entitled "Calculating the National BAFs").

5.4.5 Deriving National BAFs Using Procedure #3

This section provides guidance for calculating national BAFs for nonionic organic chemicals using Procedure #3 shown in Figure 5-1. The types of nonionic organic chemicals for which Procedure #3 is most appropriate are those that are classified as low in hydrophobicity (i.e., log K_{ow} values less than 4.0) and subject to low (or unknown) rates of metabolism by aquatic biota (see Section 5.4.2 above). Non-aqueous contaminant exposure and subsequent biomagnification in aquatic food webs are not generally of concern for chemicals that are classified in this category (Fisk et al., 1998; Gobas et al., 1993; Connolly and Pedersen, 1988; Thomann, 1989). As a result, FCMs are not used in this procedure.

According to Procedure #3, the following three methods can be used in deriving a national BAF:

- using a BAF from an acceptable field study (i.e., a field-measured BAF),
- predicting a BAF from an acceptable laboratory-measured BCF, and
- predicting a BAF from an acceptable K_{ow}.

After selecting the derivation procedure, the next steps in deriving a national BAF at a given trophic level for nonionic organic chemicals are: (1) calculating individual baseline BAF_{ℓ}^{fd}s, (2) selecting the final baseline BAF_{ℓ}^{fd}, and (3) calculating the national BAF (Figure 5-2). Each of these three steps is discussed separately below.

5.4.5.1 Calculating Individual Baseline BAF_{ℓ}^{fd}s

Calculating individual baseline BAF_{ℓ}^{fd}s involves normalizing each measured BAF_{T}^{t} or BCF_{T}^{t} (which are based on the total chemical in water and tissue) by the lipid content of the study organism and the freely dissolved fraction of the chemical in the study water. For additional discussion of the technical basis for calculating baseline BAF_{ℓ}^{fd}s, see Section 5.4.3.1 in Procedure #1.

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1. For each species where acceptable data are available, calculate all possible baseline BAF_{ℓ}^{fd}s using each of the three methods shown above for Procedure #3.

2. An individual baseline BAF_{ℓ}^{fd} should be calculated from field-measured BAF_{T}^{t}s, laboratory-measured BCF_{T}^{t}s, and K_{ow} values according to the following procedures.

A. Baseline BAF_{ℓ}^{fd} from Field-Measured BAFs

1. Except where noted below, a baseline BAF_{ℓ}^{fd} should be calculated from a field-measured BAF_{T}^{t} using the guidance and equations outlined in Section 5.4.3.1(A) in Procedure #1.

2. **Freely Dissolved Fraction**. Due to their low hydrophobicity (i.e., log $K_{ow} < 4.0$), nonionic organic chemicals applicable to Procedure #3 are expected to remain almost entirely in the freely dissolved form in natural waters with dissolved and particulate organic carbon concentrations typical of most field BAF studies. Therefore, the freely dissolved fraction should be assumed to be equal to 1.0, unless the concentrations of DOC and POC are very high in the field BAF study. For studies with very high DOC or POC concentrations, (e.g., about 100 mg/L or higher for DOC or 10 mg/L or higher for POC), the freely dissolved fraction may be substantially lower than 1.0 and therefore should be calculated using Equation 5-12.

3. **Temporal Averaging of Concentrations.** Also due to their low hydrophobicity, nonionic organic chemicals appropriate to Procedure #3 will also tend to reach steady state quickly compared with those chemicals to which Procedure #1 applies. Therefore, the extent of temporal averaging of tissue and water concentrations is typically much less than that required for highly hydrophobic chemicals to which Procedure #1 is applied. In addition, field studies used to calculate BAFs for these chemicals should have sampled water and tissue at similar points in time because tissue concentrations respond more rapidly to changes in water concentrations. EPA will be providing additional guidance on appropriate BAF study designs for nonionic organic chemicals (including those appropriate to Procedure #3) in its forthcoming guidance document on conducting field BAF and BSAF studies.

B. Baseline BAF_{ℓ}^{fd} from a Laboratory-Measured BCF

1. Except where noted below, a baseline BAF_{ℓ}^{fd} should be calculated from a laboratory-measured BCF_{T}^{t} using the guidance and equations outlined in Section 5.4.3.1(c) of Procedure #1.

2. **Food Chain Multipliers.** Because biomagnification is not an overriding concern for the minimally hydrophobic chemicals applicable to Procedure #3, FCMs are not used in the derivation of a baseline BAF_{ℓ}^{fd} from a laboratory-measured BCF_{T}^{t}.

3. **Freely Dissolved Fraction**. Due to their low hydrophobicity (i.e., log $K_{ow} < 4.0$), nonionic organic chemicals to which Procedure #3 is applied are expected to remain

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almost entirely in the freely dissolved form in waters containing dissolved and particulate organic carbon concentrations typical of laboratory BCF studies. Therefore, the freely dissolved fraction should usually be assumed equal to 1.0. The freely dissolved fraction will be substantially less than 1.0 only in situations where unusually high concentrations of DOC and POC are present in the laboratory BCF study (e.g., above about 100 mg/L for DOC or about 10 mg/L for POC). In this situation, the freely dissolved fraction should be calculated according to Equation 5-12.

C. Baseline BAF_{ℓ}^{fd} from a K_{ow}

1. Except where noted below, a baseline BAF_{ℓ}^{fd} should be calculated from an acceptable K_{ow} using the guidance and equations outlined in Section 5.4.3.1(D) in Procedure #1.

2. Because biomagnification is not an overriding concern for nonionic organic chemicals with low hydrophobicity (i.e., log K_{ow} < 4.0), food chain multipliers are not used in Procedure #3 for deriving the baseline BAF_{ℓ}^{fd} from a K_{ow}.

5.4.5.2 Selecting Final Baseline BAF_{ℓ}^{fd}s

After calculating individual baseline BAF_{ℓ}^{fd}s using as many of the methods in Procedure #3 as possible, the next step is to determine a final baseline BAF_{ℓ}^{fd} for each trophic level from the individual baseline BAF_{ℓ}^{fd}s (Figure 5-2). The final baseline BAF_{ℓ}^{fd} will be used in the last step to determine the national BAF for each trophic level. The final baseline BAF_{ℓ}^{fd} for each trophic level should be determined from the individual baseline BAF_{ℓ}^{fd}s by considering the data preference hierarchy defined by Procedure #3 and uncertainty in the data. The data preference hierarchy for Procedure #3 is (in order of preference):

1. a baseline BAF_{ℓ}^{fd} from an acceptable field-measured BAF or laboratory-measured BCF, or
2. a baseline BAF_{ℓ}^{fd} predicted from an acceptable K_{ow} value.

This data preference hierarchy reflects EPA's preference for BAFs that are based on measured data (field-measured BAFs and laboratory-measured BCFs) over BAFs based on predictive methods (K_{ow}). This data preference hierarchy should be used as a guide for selecting the final baseline BAF_{ℓ}^{fd}s when the uncertainty is similar among two or more baseline BAF_{ℓ}^{fd}s derived using different methods. Since bioaccumulation via dietary uptake and subsequent biomagnification generally are not of concern for chemicals subject to Procedure #3, field-measured BAFs and laboratory-measured BCFs are considered equally in determining the national BAF.

Final baseline BAF_{ℓ}^{fd}s should be selected for each trophic level using the following steps and guidelines.

1. **Calculate Species-Mean Baseline BAF_{ℓ}^{fd}s.** For each BAF method (i.e., field-measured BAF, BAF from a lab-measured BCF, or BAF from a K_{ow}) where more than one

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acceptable baseline BAF_{ℓ}^{fd} is available for a given species, calculate a species-mean baseline BAF_{ℓ}^{fd} according to the guidance described previously in Procedure #1.

2. **Calculate Trophic-Level-Mean Baseline BAF_{ℓ}^{fd}s.** For each BAF method where more than one acceptable species-mean baseline BAF_{ℓ}^{fd} is available within a given trophic level, calculate the trophic-level-mean baseline BAF_{ℓ}^{fd} as the geometric mean of acceptable species-mean baseline BAF_{ℓ}^{fd}s in that trophic level.

3. **Select a Final Baseline BAF_{ℓ}^{fd} for Each Trophic Level.** For each trophic level, select the final baseline BAF_{ℓ}^{fd} using best professional judgment by considering: (1) the data preference hierarchy, (2) the relative uncertainties among trophic-level-mean baseline BAF_{ℓ}^{fd}s derived using different methods, and (3) the weight of evidence among the three methods.

   a. In general, when more than one trophic-level-mean baseline BAF_{ℓ}^{fd} is available within a given trophic level, the final baseline BAF_{ℓ}^{fd} should be selected from the most preferred BAF method defined by the data preference hierarchy for Procedure #3. Within the first data preference tier, field-measured BAFs and laboratory-measured BCFs are considered equally desirable for deriving a final trophic-level-mean baseline BAF_{ℓ}^{fd} using Procedure #3. If a trophic-level-mean baseline BAF_{ℓ}^{fd} is available from both a field-measured BAF and a laboratory-measured BCF, the final baseline BAF_{ℓ}^{fd} should be selected using the trophic-level-mean baseline BAF_{ℓ}^{fd} or BCF_{ℓ}^{fd} with the least overall uncertainty.

   b. If uncertainty in a trophic-level-mean baseline BAF_{ℓ}^{fd} based on a higher tier (more preferred) method is judged to be substantially greater than a trophic-level-mean baseline BAF_{ℓ}^{fd} from a lower tier method, then the final baseline BAF_{ℓ}^{fd} should be selected using a trophic-level-mean baseline BAF_{ℓ}^{fd} from a lower tier method.

   c. The above steps should be performed for each trophic level until a final baseline BAF_{ℓ}^{fd} is selected for trophic level two, three, and four.

5.4.5.3 Calculating the National BAFs

As described in Procedure #1, the last step in deriving a national BAF for a given trophic level for nonionic organic chemicals is to convert the final baseline BAF_{ℓ}^{fd} determined in the previous step to a BAF that reflect conditions to which the national 304(a) criterion will apply (Figure 5-2). Each national BAF should be determined from a final baseline BAF_{ℓ}^{fd} according to the following guidelines.

1. **National BAF Equation.** Except where noted below, national BAFs for trophic levels two, three, and four should be calculated from the final, trophic-level-mean baseline BAF_{ℓ}^{fd}s using Equation 5-28 and associated guidance described in Procedure #1 (see Section 5.4.3.3).

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2. **Freely Dissolved Fraction**. Due to their low hydrophobicity (i.e., log K_{ow} < 4.0), a freely dissolved fraction of 1.0 should be assumed for calculating national BAFs for nonionic organic chemicals using Procedure #3. A freely dissolved fraction of 1.0 should be assumed because at a log K_{ow} of less than 4.0, nonionic organic chemicals are expected to remain over 99 percent in the freely dissolved form at POC and DOC concentrations corresponding to national default values for U.S. bodies of water (i.e., 0.5 mg/L and 2.9 mg/L, respectively).

5.4.6 Deriving National BAFs Using Procedure #4

This section provides guidance for calculating national BAFs for nonionic organic chemicals using Procedure #4 shown in Figure 5-1. The types of nonionic organic chemicals for which Procedure #4 is most appropriate are those that are classified as having low hydrophobicity and subject to high rates of metabolism by aquatic biota (see Section 5.4.2 above). Non-aqueous contaminant exposure and subsequent biomagnification in aquatic food webs are not generally of concern for chemicals that are classified in this category. As a result, FCMs are not used in this procedure. In addition, K_{ow} -based predictions of bioconcentration are not used in this procedure since the K_{ow} /BCF relationship is primarily based on poorly metabolized chemicals. One example of a nonionic organic chemical for which Procedure #4 appears appropriate is butyl benzyl phthalate in fish. Using radiolabeling techniques with confirmation by chromatographic analysis, Carr et al. (1997) present evidence that indicates butyl benzyl phthalate is extensively metabolized in sunfish. Carr et al. (1997) also report measured BCFs (and subsequently lipid-normalized BCFs) which are substantially below predicted BCFs based on log $K_{ow.}$ In a study of chlorinated anilines (which would be essentially un-ionized at ambient pH), de Wolf et al. (1992) reported measured BCFs substantially lower than those predicted based on K_{ow}. The authors suggested that biotransformation (metabolism) involving the amine (NH_2) was responsible for the lower measured BCFs.

According to Procedure #4, the following two methods can be used in deriving a national BAF:

- using a BAF from an acceptable field study (i.e., a field-measured BAF), and
- predicting a BAF from an acceptable BCF.

After selecting the derivation procedure, the next steps in deriving a national BAF for a given trophic level for nonionic organic chemicals are: (1) calculating individual baseline BAF_{ℓ}^{fd}s, (2) selecting the final baseline BAF_{ℓ}^{fd}, and (3) calculating the national BAF (Figure 5-2). Each of these three steps is discussed separately below.

5.4.6.1 Calculating Individual Baseline BAF_{ℓ}^{fd}s

Calculating individual baseline BAF_{ℓ}^{fd}s involves normalizing the measured BAF_T^t or BCF_T^t (which are based on the total chemical in water and tissue) by the lipid content of the study organism and the freely dissolved fraction of the chemical in the study water. For additional discussion of the technical basis for calculating baseline BAF_{ℓ}^{fd}s, see Section 5.4.3.1 in Procedure #1.

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1. For each species where acceptable data are available, calculate all possible baseline BAF_{ℓ}^{fd}s using each of the two methods shown above for Procedure #4.

2. Individual baseline BAF_{ℓ}^{fd}s should be calculated from field-measured BAF_{T}^{t}s and laboratory-measured BCF_{T}^{t}s according to the following procedures.

A. Baseline BAF_{ℓ}^{fd} from Field-Measured BAFs

1. A baseline BAF_{ℓ}^{fd} should be calculated from a field-measured BAF_{T}^{t} using the guidance and equations outlined in Section 5.4.3.1(A) in Procedure #1.

2. **Freely Dissolved Fraction**. Due to their low hydrophobicity (i.e., log K_{ow} < 4.0), nonionic organic chemicals applicable to Procedure #4 are expected to remain almost entirely in the freely dissolved form in natural waters with dissolved and particulate organic carbon concentrations typical of most field BAF studies. Therefore, the freely dissolved fraction should be assumed equal to 1.0 unless the concentrations of DOC and POC are very high in the field BAF study. For studies with very high DOC or POC concentrations, (e.g., about 100 mg/L or higher for DOC or 10 mg/L or higher for POC), the freely dissolved fraction may be substantially lower than 1.0 and therefore should be calculated using Equation 5-12.

3. **Temporal Averaging of Concentrations.** Also due to their low hydrophobicity, nonionic organic chemicals appropriate to Procedure #4 will also tend to reach steady-state quickly compared with those chemicals to which Procedure #1 applies. Therefore, the extent of temporal averaging of tissue and water concentrations is typically much less than that required for highly hydrophobic chemicals to which Procedure #1 is applied. In addition, field studies used to calculate BAFs for these chemicals should have sampled water and tissue at similar points in time because tissue concentrations should respond rapidly to changes in water concentrations. EPA will be providing additional guidance on appropriate BAF study designs for nonionic organic chemicals (including those appropriate to Procedure #4) in its forthcoming guidance document on conducting field BAF and BSAF studies.

B. Baseline BAF_{ℓ}^{fd} from a Laboratory-Measured BCF

1. Except where noted below, a baseline BAF_{ℓ}^{fd} should be calculated from a laboratory-measured BCF_{T}^{t} using the guidance and equations outlined in Section 5.4.3.1(c) of Procedure #1.

2. **Food Chain Multipliers.** Because biomagnification is not an important concern for the minimally hydrophobic chemicals applicable to Procedure #4, FCMs are not used in the derivation of a baseline BAF_{ℓ}^{fd} from a laboratory-measured BCF_{T}^{t}.

3. **Freely Dissolved Fraction**. Due to their low hydrophobicity (i.e., log K_{ow} < 4.0), nonionic organic chemicals to which Procedure #4 is applied are expected to remain

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almost entirely in the freely dissolved form in waters containing dissolved and particulate organic carbon concentrations typical of laboratory BCF studies. Therefore, the freely dissolved fraction should usually be assumed to be equal to 1.0. The freely dissolved fraction will be substantially less than 1.0 only in situations where unusually high concentrations of DOC and POC are present in the lab BCF study (e.g., above about 100 mg/L for DOC or about 10 mg/L for POC). In this situation, the freely dissolved fraction should be calculated according to Equation 5-12.

5.4.6.2 Selecting Final Baseline BAF_{ℓ}^{fd}s

After calculating individual baseline BAF_{ℓ}^{fd}s using as many of the methods in Procedure #4 as possible, the next step is to determine a final baseline BAF_{ℓ}^{fd} for a given trophic level from the individual baseline BAF_{ℓ}^{fd}s (Figure 5-2). The final baseline BAF_{ℓ}^{fd} will be used in the last step to determine the national BAF for each trophic level. A final baseline BAF_{ℓ}^{fd} should be determined for each trophic level from the individual baseline BAF_{ℓ}^{fd}s by considering the data preference hierarchy defined by Procedure #4 and uncertainty in the data. The data preference hierarchy for Procedure #4 is:

1. a baseline BAF_{ℓ}^{fd} from an acceptable field-measured BAF or predicted from an acceptable laboratory-measured BCF.

Since bioaccumulation via dietary uptake and subsequent biomagnification generally are not of concern for chemicals subject to Procedure #4, field-measured BAFs and laboratory-measured BCFs are considered equally in determining the national BAF.

Final baseline BAF_{ℓ}^{fd}s should be selected for each trophic level using the following steps and guidelines.

1. **Calculate Species-Mean Baseline BAF_{ℓ}^{fd}s.** For each BAF method (i.e., field-measured BAF or a BAF from a lab-measured BCF) where more than one acceptable baseline BAF_{ℓ}^{fd} is available for a given species, calculate a species-mean baseline BAF_{ℓ}^{fd} according to the guidance described previously in Procedure #1.

2. **Calculate Trophic-Level-Mean Baseline BAF_{ℓ}^{fd}s.** For each BAF method where more than one acceptable species-mean baseline BAF_{ℓ}^{fd} is available within a given trophic level, calculate the trophic-level-mean baseline BAF_{ℓ}^{fd} as the geometric mean of acceptable species-mean baseline BAF_{ℓ}^{fd}s for that trophic level.

3. **Select a Final Baseline BAF_{ℓ}^{fd} for Each Trophic Level.** For each trophic level, select the final baseline BAF_{ℓ}^{fd} using best professional judgment by considering: (1) the data preference hierarchy, and (2) the relative uncertainties among trophic-level-mean BAFs derived using different methods.

    a. As discussed above, field-measured BAFs and laboratory-measured BCFs are considered equally desirable for deriving a final trophic-level-mean baseline

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BAF_{ℓ}^{fd} using Procedure #4. If a trophic-level-mean baseline BAF_{ℓ}^{fd} is available from both a field-measured BAF and a laboratory-measured BCF, the final baseline BAF_{ℓ}^{fd} should be selected using the trophic-level-mean baseline BAF_{ℓ}^{fd} or BCF_{ℓ}^{fd} with the least overall uncertainty.

b. The above steps should be performed for each trophic level until a final baseline BAF_{ℓ}^{fd} is selected for trophic levels two, three, and four.

5.4.6.3 Calculating National BAFs

As described in Procedure #1, the last step in deriving a national BAF for a given trophic level for nonionic organic chemicals is to convert the final baseline BAF_{ℓ}^{fd} determined in the previous step to a BAF that reflects conditions to which the national 304(a) criterion will apply (Figure 5-2). Each national BAF should be determined from a final baseline BAF_{ℓ}^{fd} according to the following guidelines.

1. **National BAF Equation.** Except where noted below, national BAFs for trophic-levels two, three, and four should be calculated from the final, trophic-level-mean baseline BAF_{ℓ}^{fd}s using the same equation and procedures described previously in Procedure #1 (see Section 5.4.3.3 in Procedure #1).

2. **Freely Dissolved Fraction**. Due to their low hydrophobicity (i.e., log $K_{ow} < 4.0$), a freely dissolved fraction of 1.0 should be assumed for calculating national BAFs for nonionic organic chemicals using Procedure #4. A freely dissolved fraction of 1.0 should be assumed because at a log K_{ow} value of less than 4.0, nonionic organic chemicals are expected to remain over 99 percent in the freely dissolved form at POC and DOC concentrations corresponding to national default values for U.S. bodies of water (i.e., 0.5 mg/L and 2.9 mg/L, respectively).

5.5 NATIONAL BIOACCUMULATION FACTORS FOR IONIC ORGANIC CHEMICALS

This section contains guidelines for deriving national BAFs for ionic organic chemicals (i.e., organic chemicals which undergo significant ionization in water). As defined in Section 5.3.5, ionic organic chemicals contain functional groups which can either readily donate protons (e.g., organic acids with hydroxyl, carboxylic, and sulfonic groups) or readily accept protons (e.g., organic bases with amino and aromatic heterocyclic nitrogen groups). Some examples of ionic organic compounds include:

- chlorinated phenols (e.g., 2,4,6-trichlorophenol, pentachlorophenol),
- chlorinated phenoxyalkanoic acids (e.g., 2,4-dichlorophenoxyacetic acid [2,4-D]),
- nitrophenols (e.g., 2-nitrophenol, 2,4,6-trinitrophenol),
- cresols (e.g., 2,4-dinitro-*o*-cresol [DNOC]),
- pyridines (e.g., 2,4-dimethypyidine),
- aliphatic and aromatic amines (e.g., trimethylamine, aniline), and

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- linear alkylbenzenesulfonate (LAS) surfactants.

Ionic organic chemicals are considered separately for deriving national BAFs because the anionic or cationic species of these chemicals behave much differently in the aquatic environment compared with their neutral (un-ionized) counterparts. The neutral species of ionic organic chemicals are thought to behave in a similar manner as nonionic organic compounds (e.g., partitioning to lipids and organic carbon as a function of hydrophobicity). However, the ionized (cationic, anionic) species exhibit a considerably more complex behavior involving multiple environmental partitioning mechanisms (e.g., ion exchange, electrostatic, and hydrophobic interactions) and a dependency on pH and other factors including ionic strength and ionic composition (Jafvert et al., 1990; Jafvert 1990; Schwarzenbach, et al., 1993). As a consequence, methods to predict the environmental partitioning of organic cations and anions are less developed and validated compared with methods for nonionic organic chemicals (Spacie, 1994; Suffet et al., 1994).

Given the current limitations in the state of the science for predicting the partitioning and bioaccumulation of the ionized species of ionic organic chemicals, procedures for deriving national BAFs for these chemicals differ depending on the extent to which the fraction of the total chemical is likely to be represented by the ionized (cationic, anionic) species in U.S. surface waters. When a significant fraction of the total chemical concentration is expected to be present as the ionized species in water, procedures for deriving the national BAF rely on empirical (measured) methods (i.e., Procedures #5 and 6 in Section 5.6). When an insignificant fraction of the total chemical is expected to be present as the ionized species (i.e., the chemical exists essentially in the neutral form), procedures for deriving the national BAF will follow those established for nonionic organic chemicals (e.g., Procedures #1 through #4 in Section 5.4). The following guidelines apply for assessing the occurrence of cationic and anionic forms at typical environmental pH ranges.

1. For the ionic organic chemical of concern, the dissociation constant, pK_a, should be compared to the range of pH values expected in fresh and estuarine waters of the U.S. At pH equal to the pK_a, 50% of the organic acid or base is expected to be present in the ionized species. The pH values for U.S. fresh and estuarine waters typically range between 6 and 9, although somewhat higher and lower values can occur in some bodies of water (e.g., acidic bogs and lakes, highly alkaline and eutrophic systems, etc.).

2. For organic acids, the chemical will exist almost entirely in its un-ionized form when pH is about 2 or more units below the pK_a. For organic bases, the chemical will exist almost entirely in its un-ionized form when pH is about 2 or more units above the pK_a. In these cases, the aqueous behavior of the chemical would be expected to be similar to nonionic organic chemicals. Therefore, national BAF should usually be derived using Procedures #1 through #4 in Section 5.4.

3. When pH is greater than the pK_a minus 2 for organic acids (or less than the pKa plus 2 for organic bases), the fraction of the total chemical that is expected to exist in its ionized form can become significant (i.e., $\geq$1% in the ionized). In these cases, the national BAF should usually be derived using Procedures #5 and #6 in Section 5.6.

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4. In general, most organic acids (e.g., pentachlorophenol and silvex), exist primarily in the ionized form in ambient waters because their pK_a's (4.75 and 3.07, respectively) are much smaller than the pH of the ambient waters. Conversely, most organic bases, (e.g., aniline) exist mostly in the un-ionized form in ambient waters because their pK_a's (4.63 for aniline) are much smaller than the pH of the ambient waters.

5. The above guidelines are intended to be a general guide for deriving national BAFs for ionic organic chemicals, not an inflexible rule. Modifications to these guidelines should be considered on a case-by-case basis, particularly when such modifications are strongly supported by measured bioaccumulation or bioconcentration data. For example, initial models have been developed for predicting the solid and organic-phase partitioning of certain organic acids (e.g., Jafvert 1990, Jafvert et al., 1990). As these or other models become more fully developed and appropriately validated in the future, they should be considered in the development of national BAFs. In addition, since pH is a controlling factor for dissociation and subsequent partitioning of ionic organic chemicals, consideration should be given to expressing BAFs or BCFs as a function of pH (or other factors) where sufficient data exist to reliably establish such relationships.

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5.6 NATIONAL BIOACCUMULATION FACTORS FOR INORGANIC AND ORGANOMETALLIC CHEMICALS

This section contains guidelines for deriving national BAFs for inorganic and organometallic chemicals as defined in Section 5.3.5. The derivation of BAFs for inorganic and organometallic chemicals differs in several ways from procedures for nonionic organic chemicals. First, lipid normalization of chemical concentrations in tissues does not generally apply for inorganic and organometallic chemicals. Thus, BAFs and BCFs cannot be extrapolated from one tissue to another based on lipid-normalized concentrations as is done for nonionic organic chemicals. Second, the bioavailability of inorganics and organometallics in water tends to be chemical-specific and thus, the techniques for expressing concentrations of nonionic organic chemicals based on the freely dissolved form do not generally apply. Third, at the present time there are no generic bioaccumulation models that can be used to predict BAFs for inorganic and organometallic chemicals as a whole, unlike the existence of K_{ow}-based models for nonionic organic chemicals. While some chemical-specific bioaccumulation models have been developed for inorganic and organometallic chemicals (e.g., Mercury Cycling Model by Hudson et. al, 1994), those models currently tend to require site-specific data for input to the model and are restricted to site-specific applications. As the models become more fully developed and validated in the future, they should be considered on a case-by-case basis in conjunction with the following procedures for deriving national BAFs.

5.6.1 Selecting the BAF Derivation Procedure

As shown in Figure 5-1, national BAFs can be derived using two procedures for inorganic and organometallic chemicals (Procedures #5 and #6). The choice of the BAF derivation procedure depends on whether or not the chemical undergoes biomagnification in aquatic food webs.

1. For many inorganic and organometallic chemicals, biomagnification does not occur and the BCF will be equal to the BAF. For these types of chemicals, Procedure #5 should be used to derive the national BAF. Procedure #5 considers BAFs and BCFs to be of equal value in determining the national BAF and does not require the use of FCMs with BCF measurements. Guidance for deriving BAFs using Procedure #5 is provided in Section 5.6.3.

2. For some inorganic and organometallic chemicals (e.g., methylmercury), biomagnification does occur and Procedure #6 should be used to determine the national BAF. Procedure #6 gives general preference to the use of field-measured BAFs over laboratory-measured BCFs and requires FCMs to be used with BCF measurements for predicting BAFs. Guidance for deriving BAFs using Procedure #6 is provided in Section 5.6.4.

3. Determining whether or not biomagnification occurs for inorganic and organometallic chemicals requires chemical-specific data on measured concentrations of the chemical in aquatic organisms and their prey. Concentrations in aquatic organisms that increase substantially at successive trophic levels of a food web suggest that biomagnification is

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occurring. Concentrations in aquatic organisms that remain about the same or decrease at successive trophic levels of a food web suggest that biomagnification is not occurring. When comparing tissue concentrations for assessing biomagnification, care should be taken to ensure that the aquatic organisms chosen actually represent functional predator-prey relationships and that all major prey species are considered in the comparisons.

5.6.2 Bioavailability

The chemical-specific nature of inorganic and organometallic bioavailability is likely due in part to chemical-specific differences in several factors which affect bioavailability and bioaccumulation. These factors include differences in the mechanisms for chemical uptake by aquatic organisms (e.g., passive diffusion, facilitated transport, active transport), differences in sorption affinities to biotic and abiotic ligands, and differences in chemical speciation in water. Some inorganic and organometallic chemicals exist in multiple forms and valence states in aquatic ecosystems that can differ in their bioavailability to aquatic organisms and undergo conversions between forms. For example, selenium can exist in various forms in aquatic ecosystems, including inorganic selenite($^{+4}$) and selenate($^{+6}$) oxyanions, elemental selenium (^{0}) under reducing conditions (primarily in sediments), and organoselenium compounds of selenide ($^{-2}$). Dominant forms of mercury in natural, oxic waters include inorganic ($^{+2}$) mercury compounds and methylmercury; the latter is generally considered to be substantially more bioavailable than inorganic mercury compounds to higher trophic level organisms. Although a generic analogue to the "freely dissolved" conversion for nonionic organic chemicals does not presently exist for inorganic and organometallic chemicals as a whole, the occurrence and bioavailability of different forms of these chemicals should be carefully considered when deriving national BAFs.

1. If data indicate that: (1) a particular form (or multiple forms) of the chemical of concern largely governs its bioavailability to target aquatic organisms, and (2) BAFs are more reliable when derived using the bioavailable form(s) compared with using other form(s) of the chemical of concern, then BAFs and BCFs should be based on the appropriate bioavailable form(s).

2. Because different forms of many inorganic and organometallic chemicals may interconvert once released to the aquatic environment, regulatory and mass balance considerations typically require an accounting of the total concentration in water. In these cases, sufficient data should be available to enable conversion between total concentrations and the other (presumably more bioavailable) forms in water.

5.6.3 Deriving BAFs Using Procedure #5

This section contains guidance for calculating national BAFs for inorganic and organometallic chemicals using Procedure #5 as shown in Figure 5-1. The types of inorganic and organometallic chemicals for which Procedure #5 is appropriate are those that are not likely to biomagnify in aquatic food webs (see Section 5.1 above). In Procedure #5, two methods are available to derive the national BAF for a given trophic level:

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- using a BAF from an acceptable field study (i.e., field-measured BAF), or
- predicting a BAF from an acceptable laboratory-measured BCF.

Individual BAFs should be determined from field-measured BAFs or laboratory-measured BCFs according to the following guidelines.

5.6.3.1 Determining Field-Measured BAFs

1. Except where noted below, field-measured BAFs should be determined using the guidance provided in Section 5.4.3.1(A) of Procedure #1.

2. As described previously, conversion of field-measured BAFs to baseline BAF_{ℓ}^{fd}s based on lipid-normalized and freely-dissolved concentrations does not apply for inorganic and organometallic chemicals. Therefore, the guidance and equations provided in Procedure #1 which pertain to converting field-measured BAFs to baseline BAF_{ℓ}^{fd}s and subsequently to national BAFs do not generally apply to inorganic chemicals. As discussed in Section 5.6.2 above, an analogous procedure in concept might be required for converting total BAFs to BAFs based on the most bioavailable form(s) for some inorganic and organometallic chemicals of concern. Such procedures should be applied on a chemical-specific basis.

3. BAFs should be expressed on a wet-weight basis; BAFs reported on a dry-weight basis can be used only if they are converted to a wet-weight basis using a conversion factor that is measured or reliably estimated for the tissue used in the determination of the BAF.

4. BAFs should be based on concentrations in the edible tissue(s) of the biota unless it is demonstrated that whole-body BAFs are similar to edible tissue BAFs. For some finfish and shellfish species, whole body is considered to be the edible tissue.

5. The concentrations of an inorganic or organometallic chemical in a bioaccumulation study should be greater than normal background levels and greater than levels required for normal nutrition of the test species if the chemical is a micronutrient, but below levels that adversely affect the species. Bioaccumulation of an inorganic or organometallic chemical that is essential to the nutrition of aquatic organisms might be overestimated if concentrations are at or below normal background levels due to selective accumulation by the organisms to meet their nutritional requirements.

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5.6.3.2 Determining Laboratory-Measured BCFs

1. Except where noted below, BAFs should be predicted from laboratory-measured BCFs using the guidance provided in Section 5.4.3.1(c) of Procedure #1.

2. As described previously, conversion of laboratory-measured BCFs to baseline BCF_{ℓ}^{fd}s based on lipid-normalized and freely dissolved concentrations does not apply for inorganic and organometallic chemicals. Therefore, the guidance and equations provided in Procedure #1 which pertain to converting laboratory-measured BCFs to baseline BCF_{ℓ}^{fd}s and subsequently to national BCFs do not generally apply to inorganic and organometallic chemicals. As discussed in Section 5.6.2 above, an analogous procedure in concept might be required for converting total BCFs to BCFs based on the most bioavailable form(s) of some inorganic and organometallic chemicals of concern. Such procedures should be applied on a chemical-specific basis. In addition, the use of FCMs with BCFs does not apply to chemicals applicable to Procedure #5.

3. BCFs should be expressed on a wet-weight basis; BCFs reported on a dry-weight basis can be used only if they are converted to a wet-weight basis using a conversion factor that is measured or reliably estimated for the tissue used in the determination of the BCF.

4. BCFs should be based on concentrations in the edible tissue(s) of the biota unless it is demonstrated that whole-body BCFs are similar to edible tissue BCFs. For some finfish and shellfish species, whole body is considered to be the edible tissue.

5. The concentrations of an inorganic or organometallic chemical in a bioconcentration test should be greater than normal background levels and greater than levels required for normal nutrition of the test species if the chemical is a micronutrient, but below levels that adversely affect the species. Bioaccumulation of an inorganic or organometallic chemical that is essential to the nutrition of aquatic organisms might be overestimated if concentrations are at or below normal background levels due to selective accumulation by the organisms to meet their nutritional requirements.

5.6.3.3 Determining the National BAFs

After calculating individual BAFs using as many of the methods in Procedure #5 as possible, the next step is to determine national BAFs for each trophic level from the individual BAFs. The national BAFs will be used to determine the national 304(a) criteria. The national BAFs should be determined from the individual BAFs by considering the data preference hierarchy defined for Procedure #5 and uncertainty in the data. The data preference hierarchy for Procedure #5 is:

1. a BAF from an acceptable field-measured BAF or predicted from an acceptable laboratory-measured BCF.

Since bioaccumulation via dietary uptake and subsequent biomagnification are not of concern for chemicals subject to Procedure #5, field-measured BAFs and laboratory-measured

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BCFs are considered equally in determining the national BAFs. The national BAFs should be selected for each trophic level using the following steps and guidelines.

1. **Calculate Species-Mean BAFs.** For each BAF method where more than one acceptable field-measured BAF (or a BAF predicted from a BCF) is available for a given species, calculate the species-mean BAF as the geometric mean of all acceptable individual measured or BCF-predicted BAFs. When calculating species-mean BAFs, individual measured or BCF-predicted BAFs should be reviewed carefully to assess uncertainties in the BAF values. Highly uncertain BAFs should not be used. Large differences in individual BAFs for a given species (e.g., greater than a factor of 10) should be investigated further and in such cases, some or all of the BAFs for a given species might not be used. Additional discussion on evaluating the acceptability of BAF and BCF values is provided in the Bioaccumulation TSD.

2. **Calculate Trophic-Level-Mean BAFs.** For each BAF method where more than one acceptable species-mean BAF is available within a given trophic level, calculate the trophic-level-mean BAF as the geometric mean of acceptable species-mean BAFs in that trophic level. Trophic-level-mean BAFs should be calculated for trophic levels two, three and four because available data on U.S. consumers of fish and shellfish indicate significant consumption of organisms in these trophic levels.

3. **Select a Final National BAF for Each Trophic Level.** For each trophic level, select the final national BAF using best professional judgment by considering: (1) the data preference hierarchy in Procedure #5, and (2) the relative uncertainties among trophic level-mean BAFs derived using different methods.

    a. As discussed above, field-measured BAFs and laboratory-measured BCFs are considered equally desirable for deriving a final national BAF using Procedure #5. If a trophic-level-mean BAF is available from both a field-measured BAF and a laboratory-measured BCF, the final national BAF should be selected using the trophic-level-mean BAF with the least overall uncertainty.

    b. The above steps should be performed for each trophic level until a national BAF is selected for trophic levels two, three, and four.

5.6.4 Deriving BAFs Using Procedure #6

This section contains guidance for calculating national BAFs for inorganic and organometallic chemicals using Procedure #6 as shown in Figure 5-1. The types of inorganic and organometallic chemicals for which Procedure #6 is appropriate are those that are considered likely to biomagnify in aquatic food webs (see Section 5.6.1 above). Methylmercury is an example of an organometallic chemical to which Procedure #6 applies. In Procedure #6, two methods are available to derive the national BAF:

- using a BAF from an acceptable field study (i.e., field-measured BAF), or

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- predicting a BAF from an acceptable laboratory-measured BCF and a FCM.

Individual BAFs should be determined from field-measured BAFs or laboratory-measured BCFs and FCMs according to the following guidelines.

5.6.4.1 Determining Field-Measured BAFs

1. Field-measured BAFs should be determined using the guidance provided in Section 5.6.3.1 of Procedure #5.

5.6.4.2 Determining Laboratory-Measured BCFs

1. Except where noted below, BAFs should be predicted from laboratory-measured BCFs using the guidance provided in Section 5.6.3.2 of Procedure #5.

2. Because biomagnification is of concern for chemicals applicable to Procedure #6, BAFs should be predicted from laboratory-measured BCF using FCMs. Currently, there are no generic models from which to predict FCMs for inorganic or organometallic chemicals. Therefore, FCMs should be determined using field data as described in the section entitled: "Field-Derived FCMs" in Section 5.4.3.1(c) of Procedure #1. Unlike nonionic organic chemicals, field-derived FCMs for inorganic and organometallic chemicals are not based on lipid-normalized concentrations in tissues. For calculating FCMs for inorganic and organometallic chemicals, concentrations in tissues should be based on the consistent use of either wet-weight or dry-weight concentrations in edible tissues. FCMs should be derived for trophic levels two, three, and four.

5.6.4.3 Determining the National BAF

After calculating individual BAFs using as many of the methods in Procedure #6 as possible, the next step is to determine national BAFs for each trophic level from the individual BAFs. The national BAFs will be used to determine the national 304(a) criteria. The national BAFs should be determined from the individual BAFs by considering the data preference hierarchy defined for Procedure #6 and uncertainty in the data. The data preference hierarchy for Procedure #6 is (in order of preference):

1. a BAF from an acceptable field-measured BAF, or
2. a predicted BAF from an acceptable laboratory-measured BCF and FCM.

This data preference hierarchy reflects EPA's preference for field-measured BAFs over BAFs predicted from a laboratory-measured BCF and FCM, because field-measured BAFs are direct measures of bioaccumulation and biomagnification in aquatic food webs. BAFs predicted from laboratory-measured BCFs and FCMs indirectly account for biomagnification through the use of the FCM. For each trophic level, the national BAFs should be determined using the following steps and guidelines.

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1. **Calculate Species-Mean BAFs.** For each BAF method where more than one acceptable field-measured BAF or BAF predicted using a BCF and FCM is available, calculate a species-mean BAF according to the guidance described previously in Procedure #5.

2. **Calculate Trophic Level-Mean BAFs.** For each BAF method where more than one acceptable species-mean BAF is available within a given trophic level, calculate the trophic level-mean BAF according to guidance described previously in Procedure #5.

3. **Select a Final National BAF for Each Trophic Level.** For each trophic level, select the final national BAF using best professional judgment by considering: (1) the data preference hierarchy in Procedure #6, and (2) the relative uncertainties among trophic level-mean BAFs derived using different methods.

    a. When a trophic-level mean BAF is available using both methods for a given trophic level (i.e., a field-measured BAF and a BAF predicted from a BCF and FCM), the national BAF should usually be selected using the field-measured BAF which is the preferred BAF method in the data preference hierarchy in Procedure #6.

    b. If uncertainty in the trophic-level mean BAF derived using field-measured BAFs is considered to be substantially greater than a trophic-level mean BAF derived using a BCF and FCM, the national BAF for that trophic level should be selected from the second tier (BCF · FCM) method.

    c. The above steps should be performed for each trophic level until a national BAF is selected for trophic levels two, three, and four.

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Guidelines for Deriving Numerical National Water Quality Criteria for the Protection Of Aquatic Organisms and Their Uses

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Notices

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Special Note

This December 2010 electronic version of the 1985 Guidelines serves to meet the requirements of Section 508 of the Rehabilitation Act. While converting the 1985 Guidelines to a 508-compliant version, EPA updated the taxonomic nomenclature in the tables of Appendix 1 to reflect changes that occurred since the table were originally produced in 1985. The numbers included for Phylum, Class and Family represent those currently in use from the Integrated Taxonomic Information System, or ITIS, and reflect what is referred to in ITIS as Taxonomic Serial Numbers. ITIS replaced the National Oceanographic Data Center (NODC) taxonomic coding system which was used to create the original taxonomic tables included in the 1985 Guidelines document (NODC, Third Addition - see Introduction). For more information on the NODC taxonomic codes, see http://www.nodc.noaa.gov/General/CDR-detdesc/taxonomic-v8.html.

The code numbers included in the reference column of the tables have not been updated from the 1985 version. These code numbers are associated with the old NODC taxonomic referencing system and are simply replicated here for historical purposes. Footnotes may or may not still apply.

EPA is working on a more comprehensive update to the 1985 Guidelines, including new taxonomic tables which better reflect the large number of aquatic animal species known to be propagating in U.S. waters.

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Executive Summary

Derivation of numerical national water quality criteria for the protection of aquatic organism and their uses is a complex process (Figure 1) that uses information from many areas of aquatic toxicology. After a decision is made that a national criterion is needed for a particular material, all available information concerning toxicity to, and bioaccumulation by, aquatic organisms is collected, reviewed for acceptability, and sorted. If enough acceptable data on acute toxicity to aquatic animals are available, they are used to estimate the highest one-hour average concentration that should not result in unacceptable effects on aquatic organisms and their uses. If justified, this concentration is made a function of a water quality characteristic such as pH, salinity, or hardness. Similarly, data on the chronic toxicity of the material to aquatic animals are used to estimate the highest four-daily average concentration that should not cause unacceptable toxicity during a long-term exposure. If appropriate, this concentration is also related to a water quality characteristic.

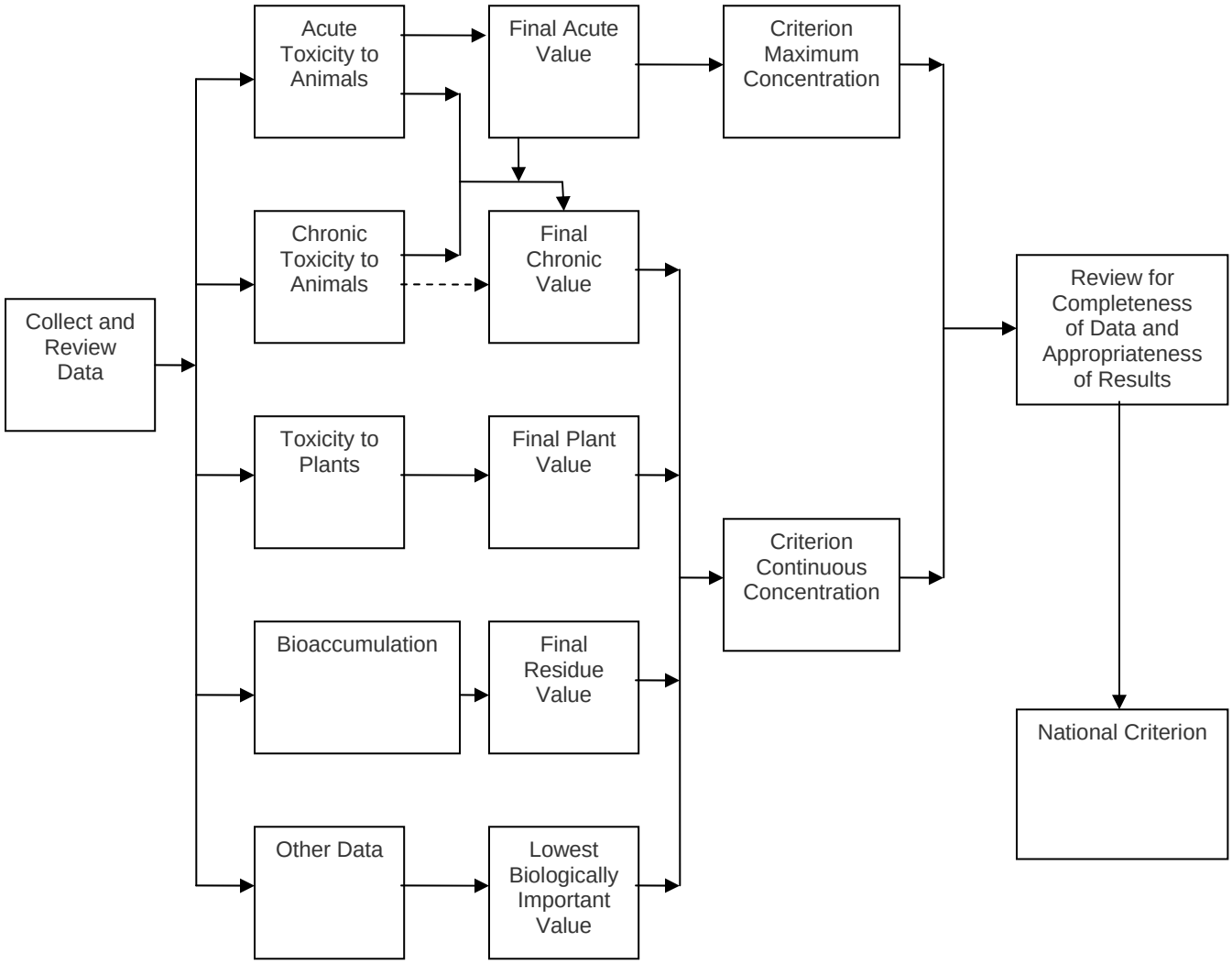
Data on toxicity to aquatic plants are examined to determine whether plants are likely to be unacceptably affected by concentrations that should not cause unacceptable effects on animals. Data on bioaccumulation by aquatic organisms are used to determine if residues might subject edible species to restrictions by the U.S. Food and Drug Administration or if such residues might harm some wildlife consumers of aquatic life. All other available data are examined for adverse effects that might be biologically important.

If a thorough review of the pertinent information indicates that enough acceptable data are available, numerical national water quality criteria are derived for fresh water or salt water or both to protect aquatic organisms and their uses from unacceptable effects due to exposures to high concentrations for short periods of time, lower concentrations for longer periods of time, and combinations of the two.

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Figure 1

Derivation of Numerical National Water Quality Crtieria for the Protection of Aquatic Organisms and Their Uses



Introduction

Of the several possible forms of criteria, the numerical form is the most common, but the narrative (e.g., pollutants must not be present in harmful concentrations) and operational (e.g., concentrations of pollutants must not exceed one-tenth of the 96-hr LC50) forms can be used if numerical criteria are not possible or desirable. If it were feasible, a freshwater (or saltwater) numerical aquatic life national criterion* for a material should be determined by conducting field tests on a wide variety of unpolluted bodies of fresh (or salt) water. It would be necessary to add various amounts of the material to each body of water in order to determine the highest concentration that would not cause any unacceptable long-term or short-term effect on the aquatic organisms or their uses. The lowest of these highest concentrations would become the freshwater (or saltwater) national aquatic life water quality criterion for that material, unless one or more of the lowest concentrations were judged to be outliers. Because it is not feasible to determine national criteria by conducting such field tests, these Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses (hereafter referred to as the National Guidelines) describe an objective, internally consistent, appropriate, and feasible way of deriving national criteria, which are intended to provide the same level of protection as the infeasible field testing approach described above.

Because aquatic ecosystems can tolerate some stress and occasional adverse effects, protection of all species at all times and places is not deemed necessary. If acceptable data are available for a large number of appropriate taxa from an appropriate variety of taxonomic and functional groups, a reasonable level of protection will probably be provided if all except a small fraction of the taxa are protected, unless a commercially or recreationally important species is very sensitive. The small fraction is set at 0.05 because other fractions resulted in criteria that seemed too high or too low in comparison with the sets of data from which they were calculated. Use of 0.05 to calculate a Final Acute Value does not imply that this percentage of adversely affected taxa should be used to decide in a field situation whether a criterion is too high or too low or just right.

Determining the validity of a criterion derived for a particular body of water, possibly by modification of a national criterion to reflect local conditions [1, 2, 3], should be based on an operation definition of "protection of aquatic organisms and their uses" that takes into account the practicalities of field monitoring programs and the concerns of the public. Monitoring programs should contain sampling points at enough times and places that all unacceptable changes, whether caused directly or indirectly, will be detected. The programs should adequately monitor the kinds of species of concern to the public, i.e., fish in fresh water and fish and macroinvertebrates in salt water. If the kinds of species of concern cannot be adequately monitored at a reasonable cost, appropriate surrogate species should be monitored. The kinds of species most likely to be good surrogates are those that either (a) are a major food of the desired kinds of species or (b) utilize the same food as the desired species or (c) both. Even if a major adverse effect on appropriate surrogate species does not directly result in an unacceptable effect on the kinds of species of concern to the public, it indicates a high probability that such an effect will occur.

* The term "national criteria" is used herein because it is more descriptive than the synonymous term "section 304(a) criteria", which is used in the Water Quality Standards Regulation [1].

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To be acceptable to the public and useful in field situations, protection of aquatic organisms and their uses should be defined as prevention of unacceptable long-term short-term effects on (1) commercially, recreationally, and other important species and (2) (a) fish and benthic invertebrate assemblages in rivers and streams, and (b) fish, benthic invertebrate, and zooplankton assemblages in lakes, reservoirs, estuaries, and oceans. Monitoring programs intended to be able to detect unacceptable effects should be tailored to the body of water of concern so that necessary samples are obtained at enough times and places to provide adequate data on the populations of the important species, as well as data directly related to the reasons for their being considered important. For example, for substances that are residue limited, species that are consumed should be monitored for contaminants to ensure that wildlife predators are protected, FDA action levels are not exceeded, and flavor is not impaired. Monitoring programs should also provide data on the number of taxa and number of individuals in the above-named assemblages that can be sampled at reasonable cost. The amount of decrease in the number of taxa or number of individuals in an assemblage that should be considered unacceptable should take into account appropriate features of the body of water and its aquatic community. Because most monitoring programs can only detect decreases of more than 20 percent, any statistically significant decrease should usually be considered unacceptable. The insensitivity of most monitoring programs greatly limits their usefulness for studying the validity of criteria because unacceptable changes can occur and not be detected. Therefore, although limited field studies can sometimes demonstrate that criteria are underprotective, only high quality field studies can reliably demonstrate that criteria are not underprotective.

If the purpose of water quality criteria were to protect only commercially and recreationally important species, criteria specifically derived to protect such species and their uses from the direct adverse effects of a material would probably, in most situations, also protect those species from indirect adverse effects due to effects of the material on other species in the ecosystem. For example, in most situations either the food chain would be more resistant than the important species and their uses or the important species and their food chains would be adaptable enough to overcome effects of the material on portions of the food chains.

These National Guidelines have been developed on the theory that effects which occur on a species in appropriate laboratory tests will generally occur on the same species in comparable field situations. All North American bodies of water and resident aquatic species and their uses are meant to be taken into account, except for a few that may be too atypical, such as the Great Salt Lake, brine shrimp, and the siscowet subspecies of lake trout, which occurs in Lake Superior and contains up to 67% fat in the fillets [4]. Derivation of criteria specifically for the Great Salt Lake or Lake Superior might have to take brine shrimp and siscowet, respectively, into account.

Numerical aquatic life criteria derived using these National Guidelines are expressed as two numbers, rather than the traditional one number, so that the criteria more accurately reflect toxicological and practical realities. If properly derived and used, the combination of a maximum concentration and a continuous concentration should provide an appropriate degree of protection of aquatic organisms and their uses from acute and chronic toxicity to animals, toxicity to plants, and bioaccumulation by aquatic organisms, without being as restrictive as a one-number criterion would have to be in order to provide the same degree of protection.

Criteria produced by these Guidelines are intended to be useful for developing water quality standards, mixing zone standards, effluent limitations, etc. The development of such standards

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and limitations, however, might have to take into account such additional factors as social, legal, economic, and hydrological considerations, the environmental and analytical chemistry of the material, the extrapolation from laboratory data to field situations, and relationships between species for which data are available and species in the body of water of concern. As an intermediate step in the development of standards, it might be desirable to derive site-specific criteria by modification of national criteria to reflect such local conditions as water quality, temperature, or ecologically important species [1, 2, 3]. In addition, with appropriate modifications these National Guidelines can be used to derive criteria for any specific geographical area, body of water (such as the Great Salt Lake), or group of similar bodies of water, if adequate information is available concerning the effects of the material of concern on appropriate species and their uses.

Criteria should attempt to provide a reasonable and adequate amount of protection with only a small possibility of considerable overprotection or underprotection. It is not enough that a national criterion be the best estimate that can be obtained using available data; it is equally important that a criterion be derived only if adequate appropriate data are available to provide reasonable confidence that it is a good estimate. Therefore, these National Guidelines specify certain data that should be available if a numerical criterion is to be derived. If all the required data are not available, usually a criterion should not be derived. On the other hand, the availability of all required data does not ensure that a criterion can be derived.

A common belief is that national criteria are based on "worst case" assumptions and that local considerations will raise, but not lower, criteria. For example, it will usually be assumed that if the concentration of a material in a body of water is lower than the national criterion, no unacceptable effects will occur and no site-specific criterion needs to be derived. If, however, the concentration of a material in a body of water is higher than the national criterion, it will usually be assumed that a site-specific criterion should be derived. In order to prevent the assumption of the "worst case" nature of national criteria from resulting in the underprotection of too many bodies of water, national criteria must be intended to protect all or almost all bodies of water. Thus, if bodies of water and the aquatic communities in them do differ substantially in their sensitivities to a material, national criteria should be at least somewhat overprotective for a majority of the bodies of water. To do otherwise would either (a) require derivation of site-specific criteria even if the site-specific concentration were substantially below the national criterion or (b) cause the "worst case" assumption to result in the underprotection of numerous bodies of water. On the other hand, national criteria are probably underprotective of some bodies of water.

The two factors that will probably cause the most difference between national and site-specific criteria are the species that will be exposed and the characteristics of the water. In order to ensure that national criteria are appropriately protective, the required data for national criteria include some species that are sensitive to many materials and national criteria are specifically based on tests conducted in water relatively low in particulate matter and organic matter. Thus, the two factors that will usually be considered in the derivation of site-specific criteria from national criteria are used to help ensure that national criteria are appropriately protective.

On the other hand, some local conditions might require that site-specific criteria be lower than national criteria. Some untested locally important species might be very sensitive to the material of concern, and local water quality might not reduce the toxicity of the material. In addition,

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aquatic organisms in field situations might be stressed by diseases, parasites, predators, other pollutants, contaminated or insufficient food, and fluctuating and extreme conditions of flow, water quality, and temperature. Further, some materials might degrade to more toxic materials, or some important community functions or species interactions might be adversely affected by concentrations lower than those that affect individual species.

Criteria must be used in a manner that is consistent with the way in which they were derived if the intended level of protection is to be provided in the real world. Although derivation of water quality criteria for aquatic life is constrained by the ways toxicity and bioconcentration tests are usually conducted, there are still many different ways that criteria can be derived, expressed, and used. The means used to derive and state criteria should relate, in the best possible way, the kinds of data that are available concerning toxicity and bioconcentration and the ways criteria can be used to protect aquatic organisms and their uses.

The major problem is to determine the best way that the statement of a criterion can bridge the gap between the nearly constant concentrations used in most toxicity and bioconcentration tests and the fluctuating concentrations that usually exist in the real world. A statement of a criterion as a number that is not to be exceeded any time or place is not acceptable because few, if any, people who use criteria would take it literally and few, if any, toxicologists would defend a literal interpretation. Rather than try to reinterpret a criterion that is neither useful nor valid, it is better to develop a more appropriate way of stating criteria.

Although some materials might not exhibit thresholds, many materials probably do. For any threshold material, continuous exposure to any combination of concentrations below the threshold will not cause an unacceptable effect (as defined on pages 1 and 2) on aquatic organisms and their uses, except that the concentration of a required trace nutrient might be too low. However, it is important to note that this is a threshold of unacceptable effect, not a threshold of adverse effect. Some adverse effect, possibly even a small reduction in the survival, growth, or reproduction of a commercially or recreationally important species, will probably occur at, and possibly even below, the threshold. The Criterion Continuous Concentration (CCC) is intended to be a good estimate of this threshold of unacceptable effect. If maintained continuously, any concentration above the CCC is expected to cause an unacceptable effect. On the other hand, the concentration of a pollutant in a body of water can be above the CCC without causing an unacceptable effect if (a) the magnitudes and durations of the excursions above the CCC are appropriately limited and (b) there are compensating periods of time during which the concentration is below the CCC. The higher the concentration is above the CCC, the shorter the period of time it can be tolerated. But it is unimportant whether there is any upper limit on concentrations that can be tolerated instantaneously or even for one minute because concentrations outside mixing zones rarely change substantially in such short periods of time.

An elegant, general approach to the problem of defining conditions (a) and (b) would be to integrate the concentration over time, taking into account uptake and depuration rates, transport within the organism to a critical site, etc. Because such an approach is not currently feasible, an approximate approach is to require that the average concentration not exceed the CCC. The average concentration should probably be calculated as the arithmetic average rather than the geometric mean [5]. If a suitable averaging period is selected, the magnitudes and durations of concentrations above the CCC will be appropriately limited, and suitable compensating periods below the CCC will be required.

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In the elegant approach mentioned above, the uptake and depuration rates would determine the effective averaging period, but these rates are likely to vary from species to species for any particular material. Thus the elegant approach might not provide a definitive answer to the problem of selecting an appropriate averaging period. An alternative is to consider that the purpose of the averaging period is to allow the concentration to be above the CCC only if the allowed fluctuating concentrations do not cause more adverse effect than would be caused by a continuous exposure to the CCC. For example, if the CCC caused a 10% reduction in growth of rainbow trout, or a 13% reduction in survival of oysters, or a 7% reduction in reproduction of smallmouth bass, it is the purpose of the averaging period to allow concentrations above the CCC only if the total exposure will not cause any more adverse effect than continuous exposure to the CCC would cause.

Even though only a few tests have compared the effects of a constant concentration with the effects of the same average concentration resulting from a fluctuating concentration, nearly all the available comparisons have shown that substantial fluctuations result in increased adverse effects [5, 6]. Thus if the averaging period is not to allow increased adverse effects, it must not allow substantial fluctuations. Life-cycle tests with species such as mysids and daphnids and early life-stage tests with warmwater fishes usually last for 20 to 30 days. An averaging period that is equal to the length of the test will obviously allow the worst possible fluctuations and would very likely allow increased adverse effects.

An averaging period of four days seems appropriate for use with the CCC for two reasons. First, it is substantially shorter than the 20 to 30 days that is obviously unacceptable. Second, for some species it appears that the results of chronic tests are due to the existence of a sensitive life stage at some time during the test [7], rather than being caused by either long-term stress or long-term accumulation of the test material in the organism. The existence of a sensitive life stage is probably the cause of acute-chronic ratios that are not much greater than 1, and is also possible when the ratio is substantially greater than 1. In addition, some experimentally determined acute-chronic ratios are somewhat less than 1, possibly because prior exposure during the chronic test increased the resistance of the sensitive life stage [8]. A four-day averaging period will probably prevent increased adverse effects on sensitive life stages by limiting the durations and magnitudes of exceedences* of the CCC.

The considerations applied to interpretation of the CCC also apply to the CMC. For the CMC the averaging period should again be substantially less than the lengths of the tests it is based on, i.e., substantially less than

48 to 96 hours. One hour is probably an appropriate averaging period because high concentrations of some materials can cause death in one to three hours. Even when organisms do not die within the first hour or so, it is not known how many might have died due to delayed effects of this short of an exposure. Thus it is not appropriate to allow concentrations above the CMC to exist for as long as one hour.

The durations of the averaging periods in national criteria have been made short enough to restrict allowable fluctuations in the concentration of the pollutant in the receiving water and to restrict the length of time that the concentration in the receiving water can be continuously above

* Although "exceedence" has not been found in any dictionary, it is used here because it is not appropriate to use "violation" in conjunction with criteria, no other word seems appropriate, and all appropriate phrases are awkward.

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a criterion concentrations. The statement of a criterion could specify that the four-day average should never exceed the CCC and that the one-hour average should never exceed the CMC. However, one of the most important uses of criteria is for designing waste treatment facilities. Such facilities are designed based on probabilities and it is not possible to design for a zero probability. Thus, one of the important design parameters is the probability that the four-day average or the one-hour-average will be exceeded, or, in other words, the frequency with which exceedences will be allowed.

The frequency of allowed exceedences should be based on the ability of aquatic ecosystems to recover from the exceedences, which will depend in part on the magnitudes and durations of the exceedences. It is important to realize that high concentrations caused by spills and similar major events are not what is meant by an "exceedence", because spills and other accidents are not part of the design of the normal operation of waste treatment facilities. Rather, exceedences are extreme values in the distribution of ambient concentrations and this distribution is the result of the usual variations in the flows of both the effluent and the receiving water and the usual variations in the concentrations of the material of concern in both the effluent and in the upstream receiving water. Because exceedences are the result of usual variation, most of the exceedences will be small and exceedences as large as a factor of two will be rare. In addition, because these exceedences are due to random variation, they will not be evenly spaced. In fact, because many receiving waters have both one-year and multi-year cycles and many treatment facilities have daily, weekly, and yearly cycles, exceedences will often be grouped, rather than being evenly spaced or randomly distributed. If the flow of the receiving water is usually much greater than the flow of the effluent, normal variation and the flow cycles will result in the ambient concentration usually being below the CCC, occasionally being near the CCC, and rarely being above the CCC. In addition, exceedences that do occur will be grouped. On the other hand, if the flow of the effluent is much greater than the flow of the receiving water, the concentration might be close to the CCC much of the time and rarely above the CCC, with exceedences being randomly distributed.

The abilities of ecosystems to recover differ greatly, and depend on the pollutant, the magnitude and duration of the exceedence, and the physical and biological features of the ecosystem. Documented studies of recoveries are few, but some systems recover from small stresses in six weeks whereas other systems take more than ten years to recover from severe stress [3]. Although most exceedences are expected to be very small, larger exceedences will occur occasionally. Most aquatic ecosystems can probably recover from most exceedences in about three years. Therefore, it does not seem reasonable to purposely design for stress above that caused by the CCC to occur more than once every three years on the average, just as it does not seem reasonable to require that these kinds of stresses only occur once every five or ten years on the average.

If the body of water is not subject to anthropogenic stress other than the exceedences of concern and if exceedences as large as a factor of two are rare, it seems reasonable that most bodies of water could tolerate exceedences once every three years on the average. In situations in which exceedences are grouped, several exceedences might occur in one or two years, but then there will be, for example, 10 to 20 years during which no exceedences will occur and the concentration will be substantially below the CCC most of the time. In situations in which the concentration is often close to the CCC and exceedences are randomly distributed, some adverse effect will occur regularly, and small additional, unacceptable effects will occur about every

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third year. The relative long-term ecological consequences of evenly spaced and grouped exceedences are unknown, but because most exceedences will probably be small, the long-term consequences should be about equal over long periods of time.

The above considerations lead to a statement of a criterion in the frequency-intensity-duration format that is often used to describe rain and snow fall and stream flow, e.g., how often, on the average, does more than ten inches of rain fall in a week? The numerical values chosen for frequency (or average recurrence interval), intensity (i.e., concentration), and duration (of averaging period) are those appropriate for national criteria. Whenever adequately justified, a national criterion may be replaced by a site-specific criterion [1], which may include not only site-specific criterion concentrations [2], but also site-specific durations of averaging periods and site-specific frequencies of allowed exceedences [3].

The concentrations, durations, and frequencies specified in criteria are based on biological, ecological, and toxicological data, and are designed to protect aquatic organisms and their uses from unacceptable effects. Use of criteria for designing waste treatment facilities requires selections of an appropriate wasteload allocation model. Dynamic models are preferred for the application of water quality criteria, but a steady-state model might have to be used instead of a dynamic model in some situations. Regardless of the model that is used, the durations of the averaging periods and the frequencies of allowed exceedences must be applied correctly if the intended level of protection is to be provided. For example, in the criterion statement frequency refers to the average frequency, over a long period of time, of rare events (i.e., exceedences). However, in some disciplines, frequency is often thought of in terms of the average frequency, over a long period of time, of the years is which rare events occur, without any consideration of how many rare events occur within each of those eventful years. The distinction between the frequency of events and the frequency of years in important for all those situations in which the rare events, e.g., exceedences, tend to occur in groups within the eventful years. The two ways of calculating frequency produce the same results in situations in which each rare event occurs in a different year because then the frequency of events is the same as the frequency of eventful years.

Because fresh water and salt water have basically different chemical compositions and because freshwater and saltwater (i.e., estuarine and true marine) species rarely inhabit the same water simultaneously, these National Guidelines provide for the derivation of separate criteria for these two kinds of water. For some materials sufficient data might not be available to allow derivation of criteria for one or both kinds of water. Even though absolute toxicities might be different in fresh and salt waters, such relative data as acute-chronic ratios and bioconcentration factors often appear to be similar in the two waters. When data are available to indicate that these ratios and factors are probably similar, they are used interchangeably.

The material for which a criterion is desired is usually defined in terms of a particular chemical compound or ion, or a group of closely related compounds or ions, but it might possibly be defined in terms of an effluent. These National Guidelines might also be useful for deriving criteria for temperature, dissolved oxygen, suspended solids, pH, etc., if the kinds of data on which the Guidelines are based are available.

Because they are meant to be applied only after a decision has been made that a national water quality criterion for aquatic organisms is needed for a material, these National Guidelines do not

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address the rationale for making that decision. If the potential for adverse effects on aquatic organisms and their uses is part of the basis for deciding whether an aquatic life criterion is needed for a material, these Guidelines will probably be helpful in the collection and interpretation of relevant data. Such properties as volatility might affect the fate of a material in the aquatic environment and might be important when determining whether a criterion is needed for a material; for example, aquatic life criteria might not be needed for materials that are highly volatile or highly degradable in water. Although such properties can affect how much of the material will get from the point of discharge through any allowed mixing zone to some portion of the ambient water and can also affect the size of the zone of influence in the ambient water, such properties do not affect how much of the material aquatic organisms can tolerate in the zone of influence.

This version of the National Guidelines provides clarifications, additional details, and technical and editorial changes from the previous version [9]. These modifications are the result of comments on the previous version and subsequent drafts [10], experience gained during the U.S. EPA's use of previous versions and drafts, and advances in aquatic toxicology and related fields. Future versions will incorporate new concepts and data as their usefulness is demonstrated. The major technical changes incorporated into this version of the National Guidelines are:

1. The requirement for acute data for freshwater animals has been changed to include more tests with invertebrate species. The taxonomic, functional, and probably the toxicological, diversities among invertebrate species are greater than those among vertebrate species and this should be reflected in the required data.

2. When available, 96-hr EC50s based on the percentage of fish immobilized plus the percentage of fish killed are used instead of 96-hr LC50s for fish; comparable EC50s are used instead of LC50s for other species. Such appropriately defined EC50s better reflect the total severe acute adverse impact of the test material on the test species than do LC50s or narrowly defined EC50s. Acute EC50s that are based on effects that are not severe, such as reduction in shell deposition and reduction in growth, are not used in calculating the Final Acute Value.

3. The Final Acute Value is now defined in terms of Genus Mean Acute Values rather than Species Mean Acute Values. A Genus Mean Acute Value is the geometric mean of all the Species Mean Acute Values available for species in the genus. On the average, species within a genus are toxicologically much more similar than species in different genera, and so the use of Genus Mean Acute Values will prevent data sets from being biased by an overabundance of species in one or a few genera.

4. The Final Acute Value is now calculated using a method [11] that is not subject to the bias and anomalous behavior that the previous method was. The new method is also less influenced by one very low value because it always gives equal weight to the four values that provide the most information about the cumulative probability of 0.05. Although the four values receive the most weight, the other values do have a substantial effect on the Final Acute Value (see examples in Appendix 2).

5. The requirements for using the results of tests with aquatic plants have been made more stringent.

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6. Instead of being equal to the Final Acute Value, the Criterion Maximum Concentration is now equal to one-half the Final Acute Value. The Criterion Maximum Concentration is intended to protect 95 percent of a group of diverse genera, unless a commercially or recreationally important species is very sensitive. However, a concentration that would severely harm 50 percent of the fifth percentile or 50 percent of a sensitive important species cannot be considered to be protective of that percentile or that species. Dividing the Final Acute Value by 2 is intended to result in a concentration that will not severely adversely affect too many of the organisms.

7. The lower of the two numbers in the criterion is now called the Criterion Continuous Concentration, rather than the Criterion Average Concentration, to more accurately reflect the nature of the toxicological data on which it is based.

8. The statement of a criterion has been changed (a) to include durations of averaging periods and frequencies of allowed exceedences that are based on what aquatic organisms and their uses can tolerate, and (b) to identify a specific situation in which site-specific criteria [1, 2, 3] are probably desirable.

In addition, Appendix 1 was added to aid in determining whether a species should be considered resident in North America and its taxonomic classification. Appendix 2 explains the calculation of the Final Acute Value.

The amount of guidance in these National Guidelines has been increased, but much of the guidance is necessarily qualitative rather than quantitative; much judgment will usually be required to derive a water quality criterion for aquatic organisms and their uses. In addition, although this version of the National Guidelines attempts to cover all major questions that have arisen during use of previous versions and drafts, it undoubtedly does not cover all situations that might occur in the future. All necessary decisions should be based on a thorough knowledge of aquatic toxicology and an understanding of these Guidelines and should be consistent with the spirit of these Guidelines, i.e., to make best use of the available data to derive the most appropriate criteria. These National Guidelines should be modified whenever sound scientific evidence indicates that a national criterion produced using these Guidelines would probably be substantially overprotective or underprotective of the aquatic organisms and their uses on a national basis. Derivation of numerical national water quality criteria for aquatic organisms and their uses is a complex process and requires knowledge in many areas of aquatic toxicology; any deviation from these Guidelines should be carefully considered to ensure that it is consistent with other parts of these Guidelines.

I. Definition of Material of Concern

A. Each separate chemical that does not ionize substantially in most natural bodies of water should usually be considered a separate material, except possibly for structurally similar organic compounds that only exist in large quantities as commercial mixtures of various compounds and apparently have similar biological, chemical, physical, and toxicological properties.

B. For chemicals that do ionize substantially in most natural bodies of water (e.g., some phenols and organic acids, some salts of phenols and organic acids, and most

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inorganic salts and coordination complexes of metals), all forms that would be in chemical equilibrium should usually be considered one material. Each different oxidation state of a metal and each different nonionizable covalently bonded organometallic compound should usually be considered a separate material.

C. The definition of the material should include an operational analytical component. Identification of a material simply, for example, as "sodium" obviously implies "total sodium", but leaves room for doubt. If "total" is meant, it should be explicitly stated. Even "total" has different operational definitions, some of which do not necessarily measure "all that is there" in all samples. Thus, it is also necessary to reference or describe the analytical method that is intended. The operational analytical component should take into account the analytical and environmental chemistry of the material, the desirability of using the same analytical method on samples from laboratory tests, ambient water, and aqueous effluents, and various practical considerations, such as labor and equipment requirements and whether the method would require measurement in the field or would allow measurement after samples are transported to a laboratory.

   The primary requirements of the operational analytical component are that it be appropriate for use on samples of receiving water, that it be compatible with the available toxicity and bioaccumulation data without making extrapolations that are too hypothetical, and that it rarely result in underprotection or overprotection of aquatic organisms and their uses. Because an ideal analytical measurement will rarely be available, a compromise measurement will usually have to be used. This compromise measurement must fit with the general approach that if an ambient concentration is lower than the national criterion, unacceptable effects will probably not occur, i.e., the compromise measurement must not err on the side of underprotection when measurements are made on a surface water. Because the chemical and physical properties of an effluent are usually quite different from those of the receiving water, an analytical method that is acceptable for analyzing an effluent might not be appropriate for analyzing a receiving water, and vice versa. If the ambient concentration *calculated* from a measured concentration in an effluent is higher than the national criterion, an additional option is to *measure* the concentration after dilution of the effluent with receiving water to determine if the measured concentration is lowered by such phenomena as complexation or sorption. A further option, of course, is to derive a site-specific criterion [1, 2, 3]. Thus, the criterion should be based on an appropriate analytical measurement, but the criterion is not rendered useless if an ideal measurement either is not available or is not feasible.

   NOTE: The analytical chemistry of the material might have to be taken into account when defining the material or when judging the acceptability of some toxicity tests, but a criterion should not be based on the sensitivity of an analytical method. When aquatic organisms are more sensitive than routine analytical methods, the proper solution is to develop better analytical methods, not to underprotect aquatic life.

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II. Collection of Data

A. Collect all available data on the material concerning (a) toxicity to, and bioaccumulation by, aquatic animals and plants, (b) FDA action levels [12], and (c) chronic feeding studies and long-term field studies with wildlife species that regularly consume aquatic organisms.

B. All data that are used should be available in typed, dated, and signed hard copy (publication, manuscript, letter, memorandum, etc.) with enough supporting information to indicate that acceptable test procedures were used and that the results are probably reliable. In some cases it may be appropriate to obtain additional written information from the investigator, if possible. Information that is confidential or privileged or otherwise not available for distribution should not be used.

C. Questionable data, whether published or unpublished, should not be used. For example, data should usually be rejected if they are from tests that did not contain a control treatment, tests in which too many organisms in the control treatment died or showed signs of stress or disease, and tests in which distilled or deionized water was used as the dilution water without addition of appropriate salts.

D. Data on technical grade materials may be used if appropriate, but data on formulated mixtures and emulsifiable concentrates of the material of concern should not be used.

E. For some highly volatile, hydrolyzable, or degradable materials it is probably appropriate to use only results of flow-through tests in which the concentrations of test material in the test solutions were measured often enough using acceptable analytical methods.

F. Data should be rejected if they were obtained using:

    1. Brine shrimp, because they usually only occur naturally in water with salinity greater than 35 g/kg.

    2. Species that do not have reproducing wild populations in North America (see Appendix 1).

    3. Organisms that were previously exposed to substantial concentrations of the test material or other contaminants.

G. Questionable data, data on formulated mixtures and emulsifiable concentrates, and data obtained with non-resident species in North America or previously exposed organisms may be used to provide auxiliary information but should not be used in the derivation of criteria.

III. Required data

A. Certain data should be available to help ensure that each of the four major kinds of possible adverse effects receives adequate consideration. Results of acute and chronic toxicity tests with representative species of aquatic animals are necessary so that data available for tested species can be considered a useful indication of the sensitivities of

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appropriate untested species. Fewer data concerning toxicity to aquatic plants are required because procedures for conducting tests with plants and interpreting the results of such tests are not as well developed. Data concerning bioaccumulation by aquatic organisms are only required if relevant data are available concerning the significance of residues in aquatic organisms.

B. To derive a criterion for freshwater aquatic organisms and their uses, the following should be available:

1. Results of acceptable acute tests (see Section IV) with at least one species of freshwater animal in at least eight different families such that all of the following are included:

    a. the family Salmonidae in the class Osteichthyes

    b. a second family in the class Osteichthyes, preferably a commercially or recreationally important warmwater species (e.g., bluegill, channel catfish, etc.)

    c. a third family in the phylum Chordata (may be in the class Osteichthyes or may be an amphibian, etc.)

    d. a planktonic crustacean (e.g., cladoceran, copepod, etc.)

    e. a benthic crustacean (e.g., ostracod, isopod, amphipod, crayfish, etc.)

    f. an insect (e.g., mayfly, dragonfly, damselfly, stonefly, caddisfly, mosquito, midge, etc.)

    g. a family in a phylum other than Arthropoda or Chordata (e.g., Rotifera, Annelida, Mollusca, etc.)

    h. a family in any order of insect or any phylum not already represented.

2. Acute-chronic ratios (see Section VI) with species of aquatic animals in at least three different families provided that one of the three species:

    - at least one is a fish
    - at least one is an invertebrate
    - at least one is an acutely sensitive freshwater species (the other two may be saltwater species).

3. Results of at least one acceptable test with a freshwater alga or vascular plant (see Section VIII). If plants are among the aquatic organisms that are most sensitive to the material, results of a test with a plant in another phylum (division) should also be available.

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4. At least one acceptable bioconcentration factor determined with an appropriate freshwater species, if a maximum permissible tissue concentration is available (see Section IX).

C. To derive a criterion for saltwater aquatic organisms and their uses, the following should be available:

1. Results of acceptable acute tests (see Section IV) with at least one species of saltwater animal in at least eight different families such that all of the following are included:

    a. two families in the phylum Chordata

    b. a family in a phylum other than Arthropoda or Chordata

    c. either the Mysidae or Penaeidae family

    d. three other families not in the phylum Chordata (may include Mysidae or Penaeidae, whichever was not used above)

    e. any other family.

2. Acute-chronic ratios (see Section VI) with species of aquatic animals in at least three different families provided that of the three species:

    - at least one is a fish
    - at least one is an invertebrate
    - at least one is an acutely sensitive saltwater species (the other two may be freshwater species).

3. Results of at least one acceptable test with a saltwater alga or vascular plant (see Section VIII). If plants are among the aquatic organisms most sensitive to the material, results of a test with a plant in another phylum (division) should also be available.

4. At least one acceptable bioconcentration factor determined with an appropriate saltwater species, if a maximum permissible tissue concentration is available (see Section IX).

D. If all the required data are available, a numerical criterion can usually be derived, except in special cases. For example, derivation of a criterion might not be possible if the available acute-chronic ratios vary by more than a factor of ten with no apparent pattern. Also, if a criterion is to be related to a water quality characteristic (see Sections V and VII), more data will be necessary.

Similarly, if all required data are not available, a numerical criterion should not be derived except in special cases. For example, even if not enough acute and chronic data are available, it might be possible to derive a criterion if the available data

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clearly indicate that the Final Residue Value should be much lower than either the Final Chronic Value or Final Plant Value.

E. Confidence in a criterion usually increases as the amount of available pertinent data increases. Thus, additional data are usually desirable.

IV. Final Acute Value

A. Appropriate measures of the acute (short-term) toxicity of the material to a variety of species of aquatic animals are used to calculate the Final Acute Value. The Final Acute Value is an estimate of the concentration of the material corresponding to a cumulative probability of 0.05 in the acute toxicity values for the genera with which acceptable acute tests have been conducted on the material. However, in some cases, if the Species Mean Acute Value of a commercially or recreationally important species is lower than the calculated Final Acute Value, then that Species Mean Acute Value replaces the calculated Final Acute Value in order to provide protection for that important species.

B. Acute toxicity tests should have been conducted using acceptable procedures [13].

C. Except for test with saltwater annelids and mysids, results of acute tests during which the test organisms were fed should not be used, unless data indicate that the food did not affect the toxicity of the test material.

D. Results of acute tests conducted in unusual dilution water, e.g., dilution water in which total organic carbon or particulate matter exceeded 5 mg/L, should not be used, unless a relationship is developed between acute toxicity and organic carbon or particulate matter or unless data show that organic carbon, particulate matter, etc., do not affect toxicity.

E. Acute values should be based on endpoints which reflect the total severe acute adverse impact of the test material on the organisms used in the test. Therefore, only the following kinds of data on acute toxicity to aquatic animals should be used:

1. Tests with daphnids and other cladocerans should be started with organisms less than 24 hours old and tests with midges should be started with second- or third-instar larvae. The result should be the 48-hr EC50 based on percentage of organisms immobilized plus percentage of organisms killed. If such an EC50 is not available from a test, the 48-hr LC50 should be used in place of the desired 48-hr EC50. An EC50 or LC50 of longer than 48 hr can be used as long as the animals were not fed and the control animals were acceptable at the end of the test.

2. The result of a test with embryos and larvae of barnacles, bivalve molluscs (clams, mussels, oysters, and scallops), sea urchins, lobsters, crabs, shrimp, and abalones, should be the 96-hr EC50 based on the percentage of organisms with incompletely developed shells plus the percentage of organisms killed. If such an EC50 is not available from a test, the lower of the 96-hr EC50 based on the percentage of organisms with incompletely developed shells and the 96-hr LC50

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should be used in place of the desired 96-hr EC50. If the duration of the test was between 48 and 96 hr, the EC50 or LC50 at the end of the test should be used.

3. The acute values from tests with all other freshwater and saltwater animal species and older life stages of barnacles, bivalve molluscs, sea urchins, lobsters, crabs, shrimps, and abalones should be the 96-hr EC50 based on the percentage of organisms exhibiting loss of equilibrium plus the percentage of organisms immobilized plus the percentage of organisms killed. If such an EC50 is not available from a test, the 96-hr LC50 should be used in place of the desired 96-hr EC50.

4. Tests with single-celled organisms are not considered acute tests, even if the duration was 96 hours or less.

5. If the tests were conducted properly, acute values reported as "greater than" values and those which are above the solubility of the test material should be used, because rejection of such acute values would unnecessarily lower the Final Acute Value by eliminating acute values for resistant species.

F. If the acute toxicity of the material to aquatic animals apparently has been shown to be related to a water quality characteristic such as hardness or particulate matter for freshwater animals or salinity or particulate matter for saltwater animals, a Final Acute Equation should be derived based on that water quality characteristic. Go to Section V.

G. If the available data indicate that one or more life stages are at least a factor of two more resistant than one or more other life stages of the same species, the data for the more resistant life stages should not be used in the calculation of the Species Mean Acute Value because a species can only be considered protected from acute toxicity if all life stages are protected.

H. The agreement of the data within and between species should be considered. Acute values that appear to be questionable in comparison with other acute and chronic data for the same species and for other species in the same genus probably should not be used in calculation of a Species Mean Acute Value. For example, if the acute values available for a species or genus differ by more than a factor of 10, some or all of the values probably should not be used in calculations.

I. For each species for which at least one acute value is available, the Species Mean Acute Value (SMAV) should be calculated as the geometric mean of the results of all flow-through tests in which the concentrations of test material were measured. For a species for which no such result is available, the SMAV should be calculated as the geometric mean of all available acute values, i.e., results of flow-through tests in which the concentrations were not measured and results of static and renewal tests based on initial concentrations (nominal concentrations are acceptable for most test materials if measured concentrations are not available) of test material.

NOTE: Data reported by original investigators should not be rounded off. Results of all intermediate calculations should be rounded [14] to four significant digits.

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NOTE: The geometric mean of N numbers is the Nth root of the product of the N numbers. Alternatively, the geometric mean can be calculated by adding the logarithms of the N numbers, dividing the sum by N, and taking the antilog of the quotient. The geometric mean of two numbers is the square root of the product of the two numbers, and the geometric mean of one number is that number. Either natural (base e) or common (base 10) logarithms can be used to calculate geometric means as long as they are used consistently within each set of data, i.e., the antilog used must match the logarithm used.

NOTE: Geometric means, rather than arithmetic means, are used here because the distributions of sensitivities of individual organisms in toxicity tests on most materials and the distributions of sensitivities of species within a genus are more likely to be lognormal than normal. Similarly, geometric means are used for acute-chronic ratios and bioconcentration factors because quotients are likely to be closer to lognormal than normal distributions. In addition, division of the geometric mean of a set of numerators by the geometric mean of the set of corresponding denominators will result in the geometric mean of the set of corresponding quotients.

J. For each genus for which one or more SMAVs are available, the Genus Mean Acute Value (GMAV) should be calculated as the geometric mean of the SMAVs available for the genus.

K. Order the GMAVs from high to low.

L. Assign ranks, R, to the GMAVs from "1" for the lowest to "N" for the highest. If two or more GMAVs are identical, arbitrarily assign them successive ranks.

M. Calculate the cumulative probability, P, for each GMAV as R/(N+1).

N. Select the four GMAVs which have cumulative probabilities closest to 0.05 (if there are less than 59 GMAVs, these will always be the four lowest GMAVs).

O. Using the selected GMAVs and Ps, calculate

$$S^2 = \frac{\sum((\ln GMAV)^2) - ((\sum \ln GMAV))^2 / 4}{\sum (F) - ((\sum(\sqrt{P}))^2 / 4)}$$

$$L = (\sum (\ln GMAV) - S(\sum(\sqrt{P}))) / 4$$

$$A = S(\sqrt{0.05}) + L$$

$$FAV = e^A$$

(See [11] for development of the calculation procedure and Appendix 2 for an example calculations and computer program.)

NOTE: Natural logarithms (logarithms to base e, denoted as ln) are used herein merely because they are easier to use on some hand calculators and computers than common (base 10) logarithms. Consistent use of either will produce the same result.

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P. If for a commercially or recreationally important species the geometric mean of the acute values from ~~the~~ flow-through tests in which the concentrations of test material were measured is lower than the calculated Final Acute Value, then that geometric mean should be used as the Final Acute Value instead of the calculated Final Acute Value.

Q. Go to Section VI.

V. Final Acute Equation

A. When enough data are available to show that acute toxicity to two or more species is similarly related to a water quality characteristic, the relationship should be taken into account as described in Sections B-G below or using analysis of covariance [15, 16]. The two methods are equivalent and produce identical results. The manual method described below provides an understanding of this application of covariance analysis, but computerized versions of covariance analysis are much more convenient for analyzing large data sets. If two or more factors affect toxicity, multiple regression analysis should be used.

B. For each species for which comparable acute toxicity values are available at two or more different values of the water quality characteristic, perform a least squares regression of the acute toxicity values on the corresponding values of the water quality characteristic to obtain the slope and its 95% confidence limits for each species.

NOTE: Because the best documented relationship is that between hardness and acute toxicity of metals in fresh water and a log-log relationship fits these data, geometric means and natural logarithms of both toxicity and water quality are used in the rest of this section. For relationships based on other water quality characteristics, such as pH, temperature, or salinity, no transformation or a different transformation might fit the data better, and appropriate changes will be necessary throughout this section.

C. Decide whether the data for each species is useful, taking into account the range and number of the tested values of the water quality characteristic and the degree of agreement within and between species. For example, a slope based on six data points might be of limited value if it is based only on data for a very narrow range of values of the water quality characteristic. A slope based on only two data points, however, might be useful if it is consistent with other information and if the two points cover a broad enough range of the water quality characteristic. In addition, acute values that appear to be questionable in comparison with other acute and chronic data available for the same species and for other species in the same genus probably should not be used. For example, if after adjustment for the water quality characteristic, the acute values available for a species or genus differ by more than a factor of 10, rejection of some or all of the values is probably appropriate. If useful slopes are not available for at least one fish and one invertebrate or if the available slopes are too dissimilar or if too few data are available to adequately define the relationship between acute toxicity and the water quality characteristic, return to Section IV.G., using the results of tests

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conducted under conditions and in waters similar to those commonly used for toxicity tests with the species.

D. Individually for each species calculate the geometric mean of the available acute values and then divide each of the acute values for a species by the mean for the species. This normalizes the acute values so that the geometric mean of the normalized values for each species individually and for any combination of species is 1.0.

E. Similarly normalize the values of the water quality characteristic for each species individually.

F. Individually for each species perform a least squares regression of the normalized acute toxicity values on the corresponding normalized values of the water quality characteristic. The resulting slopes and 95% confidence limits will be identical to those obtained in Section B above. Now, however, if the data are actually plotted, the line of best fit for each individual species will go through the point 1,1 in the center of the graph.

G. Treat all the normalized data as if they were all for the same species and perform a least squares regression of all the normalized acute values on the corresponding normalized values of the water quality characteristic to obtain the pooled acute slope, V, and its 95% confidence limits. If all the normalized data are actually plotted, the line of best fit will go through the point 1,1 in the center of the graph.

H. For each species calculate the geometric mean, W, of the acute toxicity values and the geometric mean, X, of the values of the water quality characteristic. (These were calculated in steps D and E above.)

I. For each species calculate the logarithm, Y, of the SMAV at a selected value, Z, of the water quality characteristic using the equation:

$$Y = \ln W - V(\ln X - \ln Z).$$

J. For each species calculate the SMAV at Z using the equation: $SMAV = e^{Y}$.

NOTE: Alternatively, the SMAVs at Z can be obtained by skipping step H above, using the equations in steps I and J to adjust each acute value individually to Z, and then calculating the geometric mean of the adjusted values for each species individually. This alternative procedure allows an examination of the range of the adjusted acute values for each species.

K. Obtain the Final Acute Value at Z by using the procedure described in Section IV.J-O.

L. If the SMAV at Z of a commercially or recreationally important species is lower than the calculated Final Acute Value at Z, then that SMAV should be used as the Final Acute Value at Z instead of the calculated Final Acute Value.

M. The Final Acute Equation is written as: Final Acute Value = $e^{(V[\ln(\text{water quality characteristic})] + \ln A - V[\ln Z])}$, where V = pooled acute slope and A = Final Acute Value at Z. Because

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V, A, and Z are known, the Final Acute Value can be calculated for any selected value of the water quality characteristic.

VI. Final Chronic Value

A. Depending on the data that are available concerning chronic toxicity to aquatic animals, the Final Chronic Value might be calculated in the same manner as the Final Acute Value or by dividing the Final Acute Value by the Final Acute-Chronic Ratio. In some cases it may not be possible to calculate a Final Chronic Value.

NOTE: As the name implies, the acute-chronic ration (ARC) is a way of relating acute and chronic toxicities. The acute-chronic ratio is basically the inverse of the application factor, but this new name is better because it is more descriptive and should help prevent confusion between "application factors" and "safety factors". Acute-chronic ratios and application factors are ways of relating the acute and chronic toxicities of a material to aquatic organisms. Safety factors are used to provide an extra margin of safety beyond the known or estimated sensitivities of aquatic organisms. Another advantage of the acute-chronic ratio is that it will usually be greater than one; this should avoid the confusion as to whether a large application factor is one that is close to unity or one that has a denominator that is much greater than the numerator.

B. Chronic values should be based on results of flow-through (except renewal is acceptable for daphnids) chronic tests in which the concentrations of test material in the test solutions were properly measured at appropriate times during the test.

C. Results of chronic tests in which survival, growth, or reproduction in the control treatment was unacceptably low should not be used. The limits of acceptability will depend on the species.

D. Results of chronic tests conducted in unusual dilution water, e.g., dilution water in which total organic carbon or particulate matter exceeded 5 mg/L, should not be used, unless a relationship is developed between chronic toxicity and organic carbon or particulate matter or unless data show that organic carbon, particulate matter, etc., do not affect toxicity.

E. Chronic values should be based on endpoints and lengths of exposure appropriate to the species. Therefore, only results of the following kinds of chronic toxicity tests should be used:

1. Life-cycle toxicity tests consisting of exposures of each of two or more groups of individuals of a species to a different concentration of the test material throughout a life cycle. To ensure that all life stages and life processes are exposed, tests with fish should begin with embryos or newly hatched young less than 48 hours old, continue through maturation and reproduction, and should end not less than 24 days (90 days for salmonids) after the hatching of the next generation. Tests with daphnids should begin with young less than 24 hours old and last for not less than 21 days. Tests with mysids should begin with young less than 24 hours old and continue until 7 days past the median time of first brood release in the

controls. For fish, data should be obtained and analyzed on survival and growth of adults and young, maturation of males and females, eggs spawned per female, embryo viability (salmonids only), and hatchability. For daphnids, data should be obtained and analyzed on survival and young per female. For mysids, data should be obtained and analyzed on survival, growth, and young per female.

2. Partial life-cycle toxicity tests consisting of exposures of each of two or more groups of individuals of a species of fish to a different concentration of the test material through most portions of a life cycle. Partial life-cycle tests are allowed with fish species that require more than a year to reach sexual maturity, so that all major life stages can be exposed to the test material in less than 15 months. Exposure to the test material should begin with immature juveniles at least 2 months prior to active gonad development, continue through maturation and reproduction, and end not less than 24 days (90 days for salmonids) after the hatching of the next generation. Data should be obtained and analyzed on survival and growth of adults and young, maturation of males and females, eggs spawned per female, embryo viability (salmonids only), and hatchability.

3. Early life-stage toxicity tests consisting of 28- to 32-day (60 days post hatch for salmonids) exposures of the early life stages of a species of fish from shortly after fertilization through embryonic, larval, and early juvenile development. Data should be obtained and analyzed on survival and growth.

   NOTE: Results of an early life-stage test are used as predictions of results of life-cycle and partial life-cycle tests with the same species. Therefore, when results of a life-cycle or partial life-cycle test are available, results of an early life-stage test with the same species should not be used. Also, results of early life-stage tests in which the incidence of mortalities or abnormalities increased substantially near the end of the test should not be used because results of such tests are possibly not good predictions of the results of comparable life-cycle or partial life-cycle tests.

F. A chronic value may be obtained by calculating the geometric mean of the lower and upper chronic limits from a chronic test or by analyzing chronic data using regression analysis. A lower chronic limit is the highest tested concentration (a) in an acceptable chronic test, (b) which did not cause an unacceptable amount of adverse effect on any of the specified biological measurements, and (c) below which no tested concentration caused an unacceptable effect. An upper chronic limit is the lowest tested concentration (a) in an acceptable chronic test, (b) which did cause an unacceptable amount of adverse effect on one or more of the specified biological measurements, and (c) above which all tested concentrations also caused such an effect.

   NOTE: Because various authors have used a variety of terms and definitions to interpret and report results of chronic tests, reported results should be reviewed carefully. The amount of effect that is considered unacceptable is often based on a statistical hypothesis test, but might also be defined in terms of a specified percent reduction from the controls. A small percent reduction (e.g., 3%) might be

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considered acceptable even if it is statistically significantly different from the control, whereas a large percent reduction (e.g., 30%) might be considered unacceptable even if it is not statistically significant.

G. If the chronic toxicity of the material to aquatic animals apparently has been shown to be related to a water quality characteristic such as hardness or particulate matter for freshwater animals or salinity or particulate matter for saltwater animals, a Final Chronic Equation should be derived based on that water quality characteristic. Go to Section VII.

H. If chronic values are available for species in eight families as described in Sections III.B.1 or III.C.1, a Species Mean Chronic Value (SMCV) should be calculated for each species for which at least one chronic value is available by calculating the geometric mean of all chronic values available for the species, and appropriate Genus Mean Chronic Values should be calculated. The Final Chronic Value should then be obtained using the procedure described in Section IV.J-O. Then go to Section VI.M.

I. For each chronic value for which at least one corresponding appropriate acute value is available, calculate an acute-chronic ratio, using for the numerator the geometric mean of the results of all acceptable flow-through (except static is acceptable for daphnids) acute tests in the same dilution water and in which the concentrations were measured. For fish, the acute test(s) should have been conducted with juveniles. The acute test(s) should have been part of the same study as the chronic test. If acute tests were not conducted as part of the same study, acute tests conducted in the same laboratory and dilution water, but in a different study, may be used. If no such acute tests are available, results of acute tests conducted in the same dilution water in a different laboratory may be used. If no such acute tests are available, an acute-chronic ratio should not be calculated.

J. For each species, calculate the species mean acute-chronic ratio as the geometric mean of all acute-chronic ratios available for that species.

K. For some materials the acute-chronic ratio seems to be the same for all species, but for other materials the ratio seems to increase or decrease as the Species Mean Acute Value (SMAV) increases. Thus the Final Acute-Chronic Ratio can be obtained in four ways, depending on the data available:

    1. If the species mean acute-chronic ratio~~s~~ seems to increase or decrease as the SMAV increases, the Final Acute-Chronic Ratio should be calculated as the geometric mean of the acute-chronic ratios for species whose SMAVs are close to the Final Acute Value.

    2. If no major trend is apparent and the acute-chronic ratios for a number of species are within a factor of ten, the Final Acute-Chronic Ratio should be calculated as the geometric mean of all the species mean acute-chronic ratios available for both freshwater and saltwater species.

    3. For acute tests conducted on metals and possibly other substances with embryos and larvae of barnacles, bivalve molluscs, sea urchins, lobsters,

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crabs, shrimp, and abalones (see Section IV.E.2), it is probably appropriate to assume that the acute-chronic ratio is 2. Chronic tests are very difficult to conduct with most such species, but it is likely that the sensitivities of embryos and larvae would determine the results of life-cycle tests. Thus, if the lowest available SMAVs were determined with embryos and larvae of such species, the Final Acute-Chronic Ratio should probably be assumed to be 2, so that the Final Chronic Value is equal to the Criterion Maximum Concentration (see Section XI.B).

4. If the most appropriate species mean acute-chronic ratios are less than 2.0, and especially if they are less than 1.0, acclimation has probably occurred during the chronic test. Because continuous exposure and acclimation cannot be assured to provide adequate protection in field situations, the Final Acute-Chronic Ratio should be assumed to be 2, so that the Final Chronic Value is equal to the Criterion Maximum Concentration (see Section XI.B).

If the available species mean acute-chronic ratios do not fit one of these cases, a Final Acute-Chronic Ratio probably cannot be obtained, and a Final Chronic Value probably cannot be calculated.

L. Calculate the Final Chronic Value by dividing the Final Acute Value by the Final Acute-Chronic Ratio. If there was a Final Acute Equation rather than a Final Acute Value, see also Section VII.A.

M. If the Species Mean Chronic Value of a commercially or recreationally important species is lower than the calculated Final Chronic Value, then that Species Mean Chronic Value should be used as the Final Chronic Value instead of the calculated Final Chronic Value.

N. Go to Section VIII.

VII. Final Chronic Equation

A. A Final Chronic Equation can be derived in two ways. The procedure described here in Section A will result in the chronic slope being the same as the acute slope. The procedure described in Sections B-N will usually result in the chronic slope being different from the actual slope.

1. If acute-chronic ratios are available for enough species at enough values of the water quality characteristic to indicate that the acute-chronic ratio is probably the same for all species and is probably independent of the water quality characteristic, calculate the Final Acute-Chronic Ratio as the geometric mean of the available species mean acute-chronic ratios.

2. Calculate the Final Chronic Value at the selected value Z of the water quality characteristic by dividing the Final Acute Value at Z (see Section V.M.) by the Final Acute-Chronic Ratio.

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3. Use V = pooled acute slope (see section V.M.) as L = pooled chronic slope.

4. Go to Section VII.M.

B. When enough data are available to show that chronic toxicity to at least one species is related to a water quality characteristic, the relationship should be taken into account as described in Sections B-G below or using analysis of covariance [15, 16]. The two methods are equivalent and produce identical results. The manual method described below provides an understanding of this application of covariance analysis, but computerized versions of covariance analysis are much more convenient for analyzing large data sets. If two more factors affect toxicity, multiple regression analysis should be used.

C. For each species for which comparable chronic toxicity values are available at two or more different values of the water quality characteristic, perform a least squares regression of the chronic toxicity values on the corresponding values of the water quality characteristic to obtain the slope and its 95% confidence limits for each species.

NOTE: Because the best documented relationship is that between hardness and acute toxicity of metals in fresh water and a log-log relationship fits these data, geometric means and natural logarithms of both toxicity and water quality are used in the rest of this section. For relationships based on other water quality characteristics, such as pH, temperature, or salinity, no transformation or a different transformation might fit the data better, and appropriate changes will be necessary throughout this section. It is probably preferable, but not necessary, to use the same transformation that was used with the acute values in Section V.

D. Decide whether the data for each species is useful, taking into account the range and number of the tested values of the water quality characteristic and the degree of agreement within and between species. For example, a slope based on six data points might be of limited value if it is based only on data for a very narrow range of values of the water quality characteristic. A slope based on only two data points, however, might be useful if it is consistent with other information and if the two points cover a broad enough range of the water quality characteristic. In addition, chronic values that appear to be questionable in comparison with other acute and chronic data available for the same species and for other species in the same genus probably should not be used. For example, if after adjustment for the water quality characteristic, the chronic values available for a species or genus differ by more than a factor of 10, rejection of some or all of the values is probably appropriate. If a useful chronic slope is not available for at least one species or if the available slopes are too dissimilar or if too few data are available to adequately define the relationship between chronic toxicity and the water quality characteristic, it might be appropriate to assume that the chronic slope is the same as the acute slope, which is equivalent to assuming that the acute-chronic ratio is independent of the water quality characteristic. Alternatively, return to Section VI.H, using the results of tests

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conducted under conditions and in waters similar to those commonly used for toxicity tests with the species.

E. Individually for each species calculate the geometric mean of the available chronic values and then divide each chronic value for a species by the mean for the species. This normalizes the chronic values so that the geometric mean of the normalized values for each species individually and for any combination of species is 1.0.

F. Similarly normalize the values of the water quality characteristic for each species individually.

G. Individually for each species perform a least squares regression of the normalized chronic toxicity values on the corresponding normalized values of the water quality characteristic. The resulting slopes and the 95% confidence limits will be identical to those obtained in Section B above. Now, however, if the data are actually plotted, the line of best fit for each individual species will go through the point 1,1 in the center of the graph.

H. Treat all the normalized data as if they were all for the same species and perform a least squares regression of all the normalized chronic values on the corresponding normalized values of the water quality characteristic to obtain the pooled chronic slope, L, and its 95% confidence limits. If all the normalized data are actually plotted, the line of best fit will go through the point 1,1 in the center of the graph.

I. For each species calculate the geometric mean, M, of the toxicity values and the geometric mean, P, of the values of the water quality characteristic. (These were calculated in steps E and F above.)

J. For each species calculated the logarithm, Q, of the Species Mean Chronic Value at a selected value, Z, of the water quality characteristic using the equation: $Q = \ln M - L(\ln P - \ln Z)$.

NOTE: Although it is not necessary, it will usually be best to use the same value of the water quality characteristic here as was used in Section V.I.

K. For each species calculate a Species Mean Chronic Value at Z using the equation: $SMCV = e^{Q}$.

NOTE: Alternatively, the Species Mean Chronic Values at Z can be obtained by skipping step J above, using the equations in steps J and K to adjust each acute value individually to Z and then calculating the geometric means of the adjusted values for each species individually. This alternative procedure allows an examination of the range of the adjusted chronic values for each species.

L. Obtain the Final Chronic Value at Z by using the procedure described in Section IV.J-O.

M. If the Species Mean Chronic Value at Z of a commercially or recreationally important species is lower than the calculated Final Chronic Value at Z, then that Species Mean

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N. The Final Chronic Equation is written as: Final Chronic Value = $e^{(L[\ln(\text{water quality characteristic})] + \ln S - L[\ln Z])}$, where L = pooled chronic slope and S = Final Chronic Value at Z. Because L, S and Z are known, the Final Chronic Value can be calculated for any selected value of the water quality characteristic.

VIII. Final Plant Value

A. Appropriate measures of the toxicity of the material to aquatic plants are used to compare the relative sensitivities of aquatic plants and animals. Although procedures for conducting and interpreting the results of toxicity tests with plants are not well developed, results of tests with plants usually indicate that criteria which adequately protect aquatic animals and their uses will probably also protect aquatic plants and their uses.

B. A plant value is the result of a 96-hr test conducted with an alga or a chronic test conducted with an aquatic vascular plant.

NOTE: A test of the toxicity of a metal to a plant usually should not be used if the medium contained an excessive amount of a complexing agent, such as EDTA, that might affect the toxicity of the metal. Concentrations of EDTA above about 200 µg/L should probably be considered excessive.

C. The Final Plant Value should be obtained by selecting the lowest result from a test with an important aquatic plant species in which the concentrations of test material were measured and the endpoint was biologically important.

IX. Final Residue Value

A. The Final Residue Value is intended to (a) prevent concentrations in commercially or recreationally important aquatic species from affecting marketability because of exceedance of applicable FDA action levels and (b) protect wildlife, including fishes and birds, that consume aquatic organisms from demonstrated unacceptable effects. The Final Residue Value is the lowest of the residue values that are obtained by dividing maximum permissible tissue concentrations by appropriate bioconcentration or bioaccumulation factors. A maximum permissible tissue concentration is either (a) an FDA action level [12] for fish oil or for the edible portion of fish or shellfish, or (b) a maximum acceptable dietary intake based on observations on survival, growth, or reproduction in a chronic wildlife feeding study or a long-term wildlife field study. If no maximum permissible tissue concentration is available, go to Section X because no Final Residue Value can be derived.

B. Bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) are quotients of the concentration of a material in one or more tissues of an aquatic organism divided by the average concentration in the solution in which the organism had been living. A BCF is intended to account only for net uptake directly from water, and thus almost

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has to be measured in a laboratory test. Some uptake during the bioconcentration test might not be directly from water if the food sorbs some of the test material before it is eaten by the test organisms. A BAF is intended to account for the net uptake from both food and water in a real-world situation. A BAF almost has to be measured in a field situation in which predators accumulate the material directly from water and by consuming prey that itself could have accumulated the material from both food and water. The BCF and BAF are probably similar for a material with a low BCF, but the BAF is probably higher than the BCF for materials with high BCFs. Although BCFs are not too difficult to determine, very few BAFs have been measured acceptably because it is necessary to make enough measurements of the concentration of the material in water to show that it was reasonably constant for a long enough period of time over the range of territory inhabited by the organisms. Because so few acceptable BAFs are available, only BCFs will be discussed further. However, if an acceptable BAF is available for a material, it should be used instead of any available BCFs.

C. If a maximum permissible tissue concentration is available for a substance (e.g., parent material, parent material plus metabolites, etc.), the tissue concentration used in the calculation of the BCF should be for the same substance. Otherwise, the tissue concentration used in the calculation of the BCF should be that of the material and its metabolites which are structurally similar and are not much more soluble in water than the parent material.

D.

1. A BCF should be used only if the test was flow-through, the BCF was calculated based on measured concentrations of the test material in tissue and in the test solution, and the exposure continued at least until either apparent steady-state or 28 days was reached. Steady-state is reached when the BCF does not change significantly over a period of time, such as two days or 16 percent of the length of the exposure, whichever is longer. The BCF used from a test should be the highest of (a) the apparent steady-state BCF, if apparent steady-state was reached, (b) the highest BCF obtained, if apparent steady-state was not reached, and (c) the projected steady-state BCF, if calculated.

2. Whenever a BCF is determined for a lipophilic material, the percent lipids should also be determined in the tissue(s) for which the BCF was calculated.

3. A BCF obtained from an exposure that adversely affected the test organisms may be used only if it is similar to a BCF obtained with unaffected organisms of the same species at lower concentrations that did not cause adverse effects.

4. Because maximum permissible tissue concentrations are almost never based on dry weights, a BCF calculated using dry tissue weights must be converted to a wet tissue weight basis. If no conversion factor is reported with the BCF, multiply the dry weight BCF by 0.1 for plankton and by 0.2 for individual species of fishes and invertebrates [17].

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5. If more than one acceptable BCF is available for a species, the geometric mean of the available values should be used, except that if the BCFs are from different lengths of exposure and the BCF increases with length of exposure, the BCF for the longest exposure should be used.

E. If enough pertinent data exist, several residue values can be calculated by dividing maximum permissible tissue concentrations by appropriate BCFs:

1. For each available maximum acceptable dietary intake derived from a chronic feeding study or a long-term field study with wildlife, including birds and aquatic organisms, the appropriate BCF is based on the whole body of aquatic species which constitute or represent a major portion of the diet of the tested wildlife species.

2. For an FDA action level for fish or shellfish, the appropriate BCF is the highest geometric mean species BCF for the edible portion (muscle for decapods, muscle with or without skin for fishes, adductor muscle for scallops, and total soft tissue for other bivalve molluscs) of a consumed species. The highest species BCF is used because FDA action levels are applied on a species-by-species basis.

F. For lipophilic materials, it might be possible to calculate additional residue values. Because the steady-state BCF for a lipophilic material seems to be proportional to percent lipids from one tissue to another and from one species to another [18, 19, 20], extrapolations can be made from tested tissues or species to untested tissues or species on the basis of percent lipids.

1. For each BCF for which the percent lipids is known for the same tissue for which the BCF was measured, normalize the BCF to a one percent lipid basis by dividing the BCF by the percent lipids. This adjustment to a one percent lipid basis is intended to make all the measured BCFs for a material comparable regardless of the species or tissue with which the BCF was measured.

2. Calculate the geometric mean normalized BCF. Data for both saltwater and freshwater species should be used to determine the mean normalized BCF, unless the data show that the normalized BCFs are probably not similar.

3. Calculate all possible residue values by dividing the available maximum permissible tissue concentrations by the mean normalized BCF and by the percent lipids values appropriate to the maximum permissible tissue concentrations, i.e.,

$$\text{Residue Value} = \frac{(\text{maximum permissible tissue concentration})}{(\text{mean normalized BCF})\,(\text{appropriate percent lipids})}$$

a. For an FDA action level for fish oil, the appropriate percent lipids value is 100.

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b. For an FDA action level for fish, the appropriate percent lipids value is 11 for freshwater criteria and 10 for saltwater criteria because FDA action levels are applied on a species-by-species basis to commonly consumed species. The highest lipid contents in the edible portions of important consumed species are about 11 percent for both the freshwater chinook salmon and lake trout and about 10 percent for the saltwater Atlantic herring [21].

c. For a maximum acceptable dietary intake derived from a chronic feeding study or a long-term field study with wildlife, the appropriate percent lipids is that of an aquatic species or group of aquatic species which constitute a major portion of the diet of the wildlife species.

G. The Final Residue Value is obtained by selecting the lowest of the available residue values.

NOTE: In some cases the Final Residue Value will not be low enough. For example, a residue value calculated from an FDA action level will probably result in an average concentration in the edible portion of a fatty species that is at the action level. Some individual organisms, and possibly some species, will have residue concentrations higher than the mean value but no mechanism has been devised to provide appropriate additional protection. Also, some chronic feeding studies and long-term field studies with wildlife identify concentrations that cause adverse effects but do not identify concentrations which do not cause adverse effects; again no mechanism has been devised to provide appropriate additional protection. These are some of the species and uses that are not protected at all times in all places.

X. Other Data

Pertinent information that could not be used in earlier sections might be available concerning adverse effects on aquatic organisms and their uses. The most important of these are data on cumulative and delayed toxicity, flavor impairment, reduction in survival, growth, or reproduction, or any other adverse effect that has been shown to be biologically important. Especially important are data for species for which no other data are available. Data from behavioral, biochemical, physiological, microcosm, and field studies might also be available. Data might be available from tests conducted in unusual dilution water (see IV.D and VI.D), from chronic tests in which the concentrations were not measured (see VI.B), from tests with previously exposed organisms (see II.F), and from tests on formulated mixtures or emulsifiable concentrates (see II.D). Such data might affect a criterion if the data were obtained with an important species, the test concentrations were measured, and the endpoint was biologically important.

XI. Criterion

A. A criterion consists of two concentrations: the Criterion Maximum Concentration and the Criterion Continuous Concentration.

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B. The Criterion Maximum Concentration (CMC) is equal to one-half the Final Acute Value.

C. The Criterion Continuous Concentration (CCC) is equal to the lowest of the Final Chronic Value, the Final Plant Value, and the Final Residue Value, unless other data (see Section X) show that a lower value should be used. If toxicity is related to a water quality characteristic, the CCC is obtained from the Final Chronic Equation, the Final Plant Value, and the Final Residue Value by selecting the one, or the combination, that results in the lowest concentrations in the usual range of the water quality characteristic, unless other data (see Section X) show that a lower value should be used.

D. Round [14] both the CMC and the CCC to two significant digits.

E. The criterion is stated as:

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, (1) aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration of (2) does not exceed (3) µg/L more than once every three years on the average and if the one-hour average concentration does not exceed (4) µg/L more than once every three years on the average.

where (1) = insert "freshwater" or "saltwater"

(2) = insert name of material

(3) = insert the Criterion Continuous Concentration

(4) = insert the Criterion Maximum Concentration.

XII. Final Review

A. The derivation of the criterion should be carefully reviewed by rechecking each step of the Guidelines. Items that should be especially checked are:

1. If unpublished data are used, are they well documented?
2. Are all required data available?
3. Is the range of acute values for any species greater than a factor of 10?
4. Is the range of Species Mean Acute Values for any genus greater than a factor of 10?
5. Is there more than a factor of ten difference between the four lowest Genus Mean Acute Values?
6. Are any of the four lowest Genus Mean Acute Values questionable?

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7. Is the Final Acute Value reasonable in comparison with the Species Mean Acute Values and Genus Mean Acute Values?

8. For any commercially or recreationally important species, is the geometric mean of the acute values from flow-through tests in which the concentrations of test material were measured lower than the Final Acute Value?

9. Are any of the chronic values questionable?

10. Are chronic values available for acutely sensitive species?

11. Is the range of acute-chronic ratios greater than a factor of 10?

12. Is the Final Chronic Value reasonable in comparison with the available acute and chronic data?

13. Is the measured or predicted chronic value for any commercially or recreationally important species below the Final Chronic Value?

14. Are any of the other data important?

15. Do any data look like they might be outliers?

16. Are there any deviations from the Guidelines? Are they acceptable?

B. On the basis of all available pertinent laboratory and field information, determine if the criterion is consistent with sound scientific evidence. If it is not, another criterion, either higher or lower, should be derived using appropriate modifications of these Guidelines.

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References

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[11] Erickson, R.J. and C.E. Stephan. 1985. Calculation of the Final Acute Value for Water Quality Criteria for Aquatic Organisms. National Technical Information Service, Springfield, Virginia. PB88-214994.

[12] U.S. Food and Drug Administration. 1981. Compliance Policy Guide. Compliance Guidelines Branch, Washington, DC.

[13] For good examples of acceptable procedures, see:

ASTM Standard E 729, Practice for Conducting Acute Toxicity Tests with Fishes, Macroinvertebrates, and Amphibians.

ASTM Standard E 724, Practice for Conducting Static Acute Toxicity Tests with Larvae of Four Species of Bivalve Molluscs.

[14] Huth, E.J., et al. 1978. Council of Biology Editors Style Manual, 4th Ed. Council of Biology Editors, Inc., Bethesda, Maryland. p. 117.

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Appendix 1. Resident North American Species of Aquatic Animals Used in Toxicity and Bioconcentation Tests

Introduction

These lists identify species of aquatic animals which have reproducing wild populations in North America and have been used in toxicity or bioconcentration tests. "North America" includes only the 48 contiguous states, Canada, and Alaska; Hawaii and Puerto Rico are not included. Saltwater (i.e., estuarine and true marine) species are considered resident in North America if they inhabit or regularly enter shore waters on or above the continental shelf to a depth of 200 meters. Species do not have to be native to be resident. Unlisted species should be considered resident North American species if they can be similarly confirmed or if the test organisms were obtained from a wild population in North America.

The sequence for fishes is taken from A List of Common and Scientific Names of Fishes from the United States and Canada. For other species, the sequence of phyla, classes, and families is taken from the NODC Taxonomic Code, Third Edition, National Oceanographic Data Center, NOAA, Washington, DC 20235, July, 1981, and the numbers given are from that source to facilitate verification. Within a family, genera are in alphabetical order, as are species in a genus.

The references given are those used to confirm that the species is a resident North American species. (The NODC Taxonomic Code contains foreign as well as North American species.) If no such reference could be found, the species was judged to be nonresident. No reference is given for organisms not identified to species; these are considered resident only if obtained from wild North American populations. A few nonresident species are listed in brackets and noted as "nonresident" because they were mistakenly identified as resident in the past or to save other investigators from doing literature searches on the same species.

Special Note

This December 2010 electronic version of the 1985 Guidelines serves to meet the requirements of Section 508 of the Rehabilitation Act. While converting the 1985 Guidelines to a 508-compliant version, EPA updated the taxonomic nomenclature to reflect changes that occurred since the tables were originally produced in 1985. The numbers included for Phylum, Class and Family represent those currently in use from the Integrated Taxonomic Information System, or ITIS, and reflect what is referred to in ITIS as Taxonomic Serial Numbers. ITIS replaced the National Oceanographic Data Center (NODC) taxonomic coding system which was used to create the original taxonomic tables included in the 1985 Guidelines document (NODC, Third Addition - see Introduction). For more information on the NODC taxonomic codes, see http://www.nodc.noaa.gov/General/CDR-detdesc/taxonomic-v8.html.

The code numbers included in the reference column of the tables have not been updated from the 1985 version. These code numbers are associated with the old NODC taxonomic referencing system and are simply replicated here for historical purposes. Footnotes may or may not still apply.

EPA is working on a more comprehensive update to the 1985 Guidelines, including new taxonomic tables which better reflect the large number of aquatic animal species known to be propagating in U.S. waters.

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Freshwater Species Table

Synonyms appear after the official Scientific Name and are marked with an asterisk (*).
Non-resident species are noted in the Reference column and are marked with a dagger (†)

Class	Family	Species		Reference
		Common Name	Scientific Name	
Phylum: Porifera (46861)				
Demospongiae 47528	Spongillidae 47691	Sponge	*Ephydatia fluviatilis*	P93
Phylum: Cnidaria (48738)				
Hydrozoa 48739	Hydridae 50844	Hydra	*Hydra oligactis*	E318, P112
		Hydra	*Hydra littoralis*	E321, P112
Phylum: Platyhelminthes (53963)				
Turbellaria 53964	Planariidae 54502	Planarian	*Dugesia dorotocephala*	D22
		Planarian	*Dugesia lugubris* *Dugesia polychroa*‡	D24
		Planarian	*Planaria gonocephala*	[1]
		Planarian	*Polycelis felina*§	nonresident
	Dendrocoelidae 54469	Planarian	*Procotyla fluviatilis* *Dendrocoelum lacteum**	E334, P132, D63
Phylum: Gastrotricha (57597)				
Chaetonotida 57822	Chaetonotidae 57823	Gastrotrich	*Lepidodermella squamata* *Lepidodermella squamatum**	E413
Phylum: Rotifera (58239)				
Eurotatoria (Formerly Bdelloidea) 654070	Philodinidae 58266	Rotifer	*Philodina acuticornis*	Y
		Rotifer	*Philodina roseola*	E487
Eurotatoria (Formerly Monogononta) 654070	Brachionidae 58344	Rotifer	*Keratella cochlearis*	E442, P188
		Rotifer	*Keratella sp.*	[2]
Phylum: Annelida (64357)				
Polychaeta (Formerly Archiannelida) 64358	Aeolosomatidae 68423	Worm	*Aeolosoma headleyi*	E528, P284
Clitellata (Formerly Oligochaeta) 568832	Lumbriculidae 68440	Worm	*Lumbriculus variegatus*	E533, P290
	Tubificidae 68585	Tubificid worm	*Branchiura sowerbyi*	E534, P289, GG
		Tubificid worm	*Limnodrilus hoffmeisteri*	E536, GG
		Tubificid worm	*Quistadrilus multisetosus* *Peloscolex multisetosus**	E535, GG
		Tubificid worm	*Rhyacodrilus montanus*	GG
		Tubificid worm	*Spirosperma ferox* *Peloscolex ferox**	GG
		Tubificid worm	*Spirosperma nikolskyi* *Peloscolex variegatus**	E534, GG
		Tubificid worm	*Stylodrilus heringianus*	GG

‡ Synonym
§ Non-resident species

Class	Family	Species		Reference
		Common Name	Scientific Name	
		Tubificid worm	*Tubifex tubifex*	E536, P289, GG
		Tubificid worm	*Varichaeta pacifica*	GG
	Naididae 68854	Worm	*Nais sp.*	2
		Worm	*Paranais sp.*	2
		Worm	*Pristina sp.*	2
Clitellata (Formerly Hirudinea) 568832	Erpobdellidea 69438	Leech	*Erpobdella octoculata*	Formerly nonresident (BB16)
Phylum: Mollusca (69458)				
Gastropoda 69459	Viviparidae 70304	Snail	*Campeloma decisum*	P731, M216
	Bithyniidae (Amnicolidae) (Bulimidae) (Hydrobiidae) 70745	Snail	*Amnicola sp.*	2
	Pleuroceridae 71541	Snail	*Goniobasis livescens*	P732
		Snail	*Elimia virginica* *Goniobasis virginica*[*]	E1137
		Snail	*Leptoxis carinata* *Nitocris carinata*[*] *Mudalia carinata*[*]	X, E1137
		Snail	*Nitocris sp.*	2
	Lymnaeidae 76483	Snail	*Lymnaea acuminata*[†]	nonresident
		Snail	*Lymnaea catascopium* *Lymnaea emerginata*[*] *Stagnicola emerginata*[*]	M328
		Snail	*Lymnaea elodes* *Lymnaea palustris*[*]	E1127, M351
		Snail	*Lymnaea luteola*[†]	nonresident M266
		Snail	*Lymnaea stagnalis*	E1127, P728, M296
		Snail	*Lymnaea sp.*	2
	Planorbidae 76591	Snail	*Biomphalaria glabrata*	Formerly nonresident (M390)
		Snail	*Gyraulus circumstriatus*	P729, M397
		Snail	*Helisoma campanulatum*	M445
		Snail	*Helisoma trivolvis*	P729, M452
	Physidae 76676	Snail	*Aplexa hypnorum*	E1126, P727, M373
		Snail	*Physa fontinalis*[†]	nonresident M373
		Snail	*Physa gyrina*	E1126, P727, M373
		Snail	*Physa heterostropha*	M378
		Snail	*Physa integra*	P727
		Snail	*Physa sp.*	2
Bivalvia (Pelecypoda) 79118	Margaritiferidae 79914	Mussel	*Margaritifera margaritifera*	E1138, P748, J11
	Unionidae (Formerly Amblemidae) 79913	Mussel	*Amblema plicata*	AA122
	Unionidae	Mussel	*Anodonta imbecillis*	J72, AA122

Class	Family	Species		Reference
		Common Name	Scientific Name	
	79913	Mussel	*Carunculina parva* *Toxolasma texasensis*[*]	J19, AA122
		Mussel	*Cyrtonaias tampicoenis*	P759, AA122
		Mussel	*Elliptio complanata*	J13
	Corbiculidae 81381	Asiatic clam	*Corbicula fluminea*	E1159
		Asiatic clam	*Corbicula manilensis*	P749
	Pisidiidae Sphaeriidae[*] 81388	Fingernail clam	*Eupera cubensis* *Eupera singleyi*[*]	E1158, P763, G9
		Fingernail clam	*Musculium transversum* *Sphaerium transversum*[*]	M160, G11
		Fingernail clam	*Sphaerium corneum*	G12
Phylum: Arthropoda (82696)				
Branchiopoda (Formerly Crustacea) 83687	Lynceidae 83769	Conchostracan	*Lynceus brachyurus*	E580, P344
	Sididae 83834	Cladoceran	*Diaphanosoma sp.*	2
	Daphniidae 83872	Cladoceran	*Ceriodaphnia acanthina*	E618
		Cladoceran	*Ceriodaphnia reticulata*	E618, P368
		Cladoceran	*Daphnia ambigua*	E607, P369
		Cladoceran	*Daphnia carinata*	[3]
		Cladoceran	*Daphnia cucullata*[†]	nonresident
		Cladoceran	*Daphnia galeata mendotae*	E610, P370
		Cladoceran	*Daphnia hyalina*	[4]
		Cladoceran	*Daphnia longispina*	[5]
		Cladoceran	*Daphnia magna*	E605, P367
		Cladoceran	*Daphnia parvula*	E611
		Cladoceran	*Daphnia pulex*	E613, P367
		Cladoceran	*Daphnia pulicaria*	A
		Cladoceran	*Daphnia similis*	E606, P367
		Cladoceran	*Simocephalus serrulatus*	E617, P370
		Cladoceran	*Simocephalus vetulus*	E617, P370
	Moinidae (Formerly Daphnidae) 84162	Cladoceran	*Moina macrocopa*	E622, P372
		Cladoceran	*Moina rectirostris*	E623
	Bosminidae 83935	Cladoceran	*Bosmina longirostris*	E624, P373
	Polyphemidae 83959	Cladoceran	*Polyphemus pediculus*	E599, P385
Ostracoda (Formerly Crustacea) 84195	Cyprididae Cypridae[*] 84462	Ostracod	*Cypretta kawatai*[†]	nonresident U
		Ostracod	*Cypridopsis vidua*	E770, P430
Maxillopoda (Formerly Crustacea) 621145	Diaptomidae 85779	Copepod	*Eudiaptomus padanus*[†]	nonresident
	Temoridae 85855	Copepod	*Epischura lacustris*	E751, P407
	Cyclopidae 88634	Copepod	*Cyclops abyssorum*[†]	nonresident
		Copepod	*Cyclops bicuspidatus*	E807, P405
		Copepod	*Cyclops vernalis*	E804, P405
		Copepod	*Cyclops viridis* *Acanthocyclops viridis*[*]	E803, P397

Class	Family	Species		Reference
		Common Name	Scientific Name	
		Copepod	*Acanthocyclops sp.*	2
		Copepod	*Diacyclops sp.*	2
		Copepod	*Eucyclops agilis*	P403
		Copepod	*Mesocyclops leuckarti*	E812, P403
Malacostraca (Formerly Crustacea) 89787	Asellidae 92657	Isopod	*Asellus aquaticus*[†]	nonresident (I2)
		Isopod	*Caecidotea bicrenata* (Formerly *Asellus bicrenata)*	HH (I1,2)
		Isopod	*Asellus brevicaudus*	E875, P447, I
		Isopod	*Asellus communis*	E875, P448, I
		Isopod	*Asellus intermedius*	E875, P448, I
		Isopod	*Asellus meridionalis*[†] *Asellus meridianus*[*†]	nonresident
		Isopod	*Asellus racovitzai*	P449, I
		Isopod	*Lirceus alabamae*	P875, I
	Crangonyctidae (Formerly Gammaridae) 95080	Amphipod	*Crangonyx pseudogracilis*	P459, T68, FF23
	Gammaridae 93745	Amphipod	*Gammarus fasciatus*	E877, P458, T53
		Amphipod	*Gammarus lacustris*	E877, P458, FF23
		Amphipod	*Gammarus pseudolimnaeus*	E877, P458, T48
		Amphipod	*Gammarus pulex*[†]	nonresident
		Amphipod	*Gammarus tigrinus*	L51, FF17
		Amphipod	*Gammarus sp.*	2
	Hyalellidae (Talitridae) 94022	Amphipod	*Hyalella azteca* *Hyalella knickerbockeri*[*]	E876, P457, T154
	Palaemonidae 96213	Prawn	*Macrobrachium lamarrei*[†]	nonresident
		Prawn	*Macrobrachium rosenbergii*	[6]
		Prawn	*Palaemonetes kadiakensis*	E881, P484
	Cambaridae (Formerly Astacidae) 97336	Crayfish	*Cambarus latimanus*	E897
		Crayfish	*Faxonella clypeata*	E890
		Crayfish	*Orconectes immunis*	E894, P482
		Crayfish	*Orconectes limosus*	E893, P482
		Crayfish	*Orconectes propinquus*	E894, P482
		Crayfish	*Orconectes nais*	E894
		Crayfish	*Orconectes rusticus*	E893, P482
		Crayfish	*Orconectes virilis*	E894, P483
		Crayfish	*Pacifastacus trowbridgii*	E883
		Crayfish	*Procambarus acutus*	P482
		Crayfish	*Procambarus clarki* *Procambarus clarkii*[*]	E885, P482
		Crayfish	*Procambarus simulans*	E888, P482
		Crayfish	*Procambarus sp.*	2
Insecta 99208	Heptageniidae 100504	Mayfly	*Maccaffertium ithaca* *Stenonema ithaca*[*]	S173, O205
		Mayfly	*Maccaffertium modestum* *Stenonema rubrum*[*]	S178, O205
	Baetidea	Mayfly	*Callibaetis skokianus*	S116, N9

Class	Family	Species		Reference
		Common Name	Scientific Name	
	100755	Mayfly	*Callibaetis sp.*	2
		Mayfly	*Cloeon dipterum*	O173
	Leptophlebiidae 101095	Mayfly	*Paraleptophlebia praepedita*	S89, O233
	Ephemerellidae 101232	Mayfly	*Drunella doddsii* *Ephemerella doddsi*[*]	O245
		Mayfly	*Drunella grandis* *Ephemerella grandis*[*]	O245
		Mayfly	*Ephemerella subvaria*	N9, O248, S71
		Mayfly	*Ephemerella sp.*	2
	Caenidea 101467	Mayfly	*Caenis diminuta*	S51, O268
	Ephemeridae 101525	Mayfly	*Ephemera simulans*	S36, N9, O283
		Mayfly	*Hexagenia bilineata*	N9, S39, O290
		Mayfly	*Hexagenia rigida*	O290, S41, N9
		Mayfly	*Hexagenia sp.*	2
	Libellulidae 101797	Dragonfly	*Pantala hymenaea* *Pantala hymenea*[*]	N15, V603
	Coenagrionidae Agrionidae[*] Coenagriidae[*] 102077	Damselfly	*Enallagma aspersum*	DD
		Damselfly	*Ischnura elegans*[†]	nonresident
		Damselfly	*Ischnura verticalis*	N15, E918
		Damselfly	*Ischnura sp.*	2
	Pteronarcyidae (Formerly Pteronarcidae) Pleronarcyidae[*] 102470	Stonefly	*Pteronarcella badia*	L172
		Stonefly	*Pteronarcys californica*	L173
		Stonefly	*Pteronarcys dorsata*	E947
		Stonefly	*Pteronarcys sp.*	2
	Nemouridae 102517	Stonefly	*Nemoura cinerea*[†]	nonresident
	Perlidae 102914	Stonefly	*Acroneuria lycorias*	N4, E953
		Stonefly	*Acroneuria pacifica*	E953, L180
		Stonefly	*Claassenia sabulosa*	E953
		Stonefly	*Agnetina capitata* *Neophasganophora capitata*[*] *Phasganophora capitata*[*]	E953, CC407
	Perlodidae 102994	Stonefly	*Skwala americana* *Arcynopteryx parallela*[*]	E954
	Nepidae 103747	Water Scorpion	*Ranatra elongate*[†] (Species cannot be confirmed in ITIS)	nonresident
	Dytiscidae 111963	Beetle	-	2
	Elmidae Elminthidae[*] 114093	Beetle	*Stenelmis sexlineata*	W21
	Hydropsychidae 115398	Caddisfly	*Arctopsyche grandis*	L251, II98
		Caddisfly	*Hydropsyche betteni*	N24
		Caddisfly	*Hydropsyche californica*	L253
		Caddisfly	*Hydropsyche sp.*	2
	Limnephilidae 115933	Caddisfly	*Clistoronia magnifica*	II206
		Caddisfly	*Philarctus quaeris*	II272

Class	Family	Species		Reference
		Common Name	Scientific Name	
	Brachycentridae 116905	Caddisfly	*Brachycentrus sp.*	2
	Tipulidae 118840	Crane fly	*Tipula sp.*	2
	Ceratopogonidae 127076	Biting midge	-	2
	Culicidae 125930	Mosquito	*Aedes aegypti*	EE3
		Mosquito	*Culex pipiens*	EE3
	Chironomidae 127917	Midge	*Chironomus plumosus* *Tendipas plumosus*[*]	L423
		Midge	*Chironomus tentans*	Q
		Midge	*Chironomus thummi*[†]	nonresident
		Midge	*Chironomus sp.*	2
		Midge	*Paratanytarsus parthenogeneticus*	[7]
		Midge	*Paratanytarsus dissimilis* *Tanytarsus dissimilis*[*]	R11
	Athericidae (Formerly Rhagionidae) Leptidae[*] 130928	Snipe fly	*Atherix sp.*	2
Phylum: Ectoprocta (155470)				
Phylactolaemata 156688	Pectinatellidae (Formerly Pectinatelcidae) 156729	Bryozoan	*Pectinatella magnifica*	E502, P269
	Lophopodidae 156714	Bryozoan	*Lophopodella carteri*	E502, P2671
	Plumatellidae 156690	Bryozoan	*Plumatella emarginata*	E505, P272
Phylum: Chordata (158852)				
Agnatha 159693	Petromyzontidae 159697	Sea lamprey	*Petromyzon marinus*	F11
Actinopterygii (Formerly Osteichthyes) 161061	Anguillidae 161125	American eel	*Anguilla rostrata*	F15
	Salmonidae 161931	Pink salmon	*Oncorhynchus gorbuscha*	F18
		Coho salmon	*Oncorhynchus kisutch*	F18
		Sockeye salmon	*Oncorhynchus nerka*	F19
		Chinook Salmon	*Oncorhynchus tshawytscha*	F19
		Mountain whitefish	*Prosopium williamsoni*	F19
		Golden Trout	*Oncorhynchus aguabonita* (Formerly *Salmo aguabonita)*	F19
		Cutthroat trout	*Oncorhynchus clarki* (Formerly *Salmo clarki)*	F19
		Rainbow trout Steelhead trout[*]	*Oncorhynchus mykiss* (Formerly *Salmo gairdneri)*	F19
		Atlantic salmon	*Salmo salar*	F19
		Brown trout	*Salmo trutta*	F19
		Brook trout	*Salvelinus fontinalis*	F19
		Lake trout	*Salvelinus namaycush*	F19

Class	Family	Species		Reference
		Common Name	Scientific Name	
	Esocidae 162137	Northern pike	*Esox lucius*	F20
	Cyprinidae 163342	Chiselmouth	*Acrocheilus alutaceus*	F21
		Longfin dace	*Agosia chrysogaster*	F21
		Central stoneroller	*Campostoma anomalum*	F21
		Goldfish	*Carassius auratus*	F21
		Common carp	*Cyprinus carpio*	F21
		Zebra danio Zebrafish*	*Danio rerio*† *Brachydanio rerio*†*	nonresident F96
		Silverjaw minnow	*Notropis buccatus* *Ericymba buccata**	F21
		Golden shiner	*Notemigonus crysoleucas*	F23
		Pugnose shiner	*Notropis anogenus*	F23
		Emerald shiner	*Notropis atherinoides*	F23
		Striped shiner	*Luxilus chrysocephalus* *Notropis chrysocephalus**	F23
		Common shiner	*Luxilus cornutus* *Notropis cornutus**	F23
		Pugnose minnow	*Opsopoeodus emiliae* *Notropis emiliae**	F24
		Spottail shiner	*Notropis hudsonius*	F24
		Red shiner	*Cyprinella lutrensis* *Notropis lutrensis**	F24
		Spotfin shiner	*Cyprinella spiloptera* *Notropis spilopterus**	F25
		Sand shiner	*Notropis stramineus*	F25
		Steelcolor shiner	*Cyprinella whipplei* *Notropis whipplei**	F25
		Northern redbelly dace	*Phoxinus eos*	F25
		Bluntnose minnow	*Pimephales notatus*	F25
		Fathead minnow	*Pimephales promelas*	F25
		Northern squawfish	*Ptychocheilus oregonensis*	F25
		Blacknose dace	*Rhinichthys atratulus*	F25
		Speckled dace	*Rhinichthys osculus*	F25
		Bitterling	*Rhodeus sericeus*	F26
		Rudd	*Scardinius erythrophthalmus*	F26
		Creek chub	*Semotilus atromaculatus*	F26
		Pearl dace	*Margariscus margarita* *Semotilus margarita**	F26
		Tench	*Tinca tinca*	F26
	Catostomidae 163892	White sucker	*Catostomus commersoni*	F26
		Mountain sucker	*Catostomus platyrhynchus*	F26
	Ictaluridae 163995	Black bullhead	*Ameiurus melas* *Ictalurus melas**	F27
		Yellow bullhead	*Ameiurus natalis* *Ictalurus natalis**	F27
		Brown bullhead	*Ameiurus nebulosus* *Ictalurus nebulosus**	F27
		Channel catfish	*Ictalurus punctatus*	F27

Class	Family	Species		Reference
		Common Name	Scientific Name	
	Clariidae 164118	Walking catfish	*Clarias batrachus*	F28
	Adrianichthyidae (Formerly Oryziidae) 165623	Medaka	*Oryzias latipe*[†]	nonresident F96
	Cyprinodontidae 165629	Banded killifish	*Fundulus diaphanus*	F33
		Flagfish	*Jordanella floridae*	F33
	Poeciliidae 165876	Mosquitofish	*Gambusia affinis*	F33
		Amazon molly	*Poecilia formosa*	F34
		Sailfin molly	*Poecilia latipinna*	F34
		Molly	*Poecilia sp.*	
		Guppy	*Poecilia reticulata* *(Lebistes reticulatus,* Obs.*)*	F34
		Southern platyfish	*Xiphophorus maculatus*	F34
	Gasterosteidae 166363	Brook stickleback	*Culaea inconstans*	F35
		Threespine stickleback	*Gasterosteus aculeatus*	F35
		Ninespine stickleback	*Pungitius pungitius*	F35
	Percichthyidae 170315	White perch	*Morone americana* *(Roccus americanus,* Obs.*)*	F36
		Striped bass	*Morone saxatilis* *(Roccus saxatilis,* Obs.*)*	F36
	Centrarchidae 168093	Rock bass	*Ambloplites rupestris*	F38
		Green sunfish	*Lepomis cyanellus*	F38
		Pumpkinseed	*Lepomis gibbosus*	F38
		Orangespotted sunfish	*Lepomis humilis*	F38
		Bluegill	*Lepomis macrochirus*	F38
		Longear sunfish	*Lepomis megalotis*	F38
		Redear sunfish	*Lepomis microlophus*	F38
		Smallmouth bass	*Micropterus dolomieui*	F39
		Largemouth bass	*Micropterus salmoides*	F39
		White crappie	*Pomoxis annularis*	F39
		Black crappie	*Pomoxis nigromaculatus*	F39
	Percidae 168356	Rainbow darter	*Etheostoma caeruleum*	F39
		Johnny darter	*Etheostoma nigrum*	F40
		Orangethroat darter	*Etheostoma spectabile*	F40
		Yellow perch	*Perca flavescens*	F41
		Walleye	*Sander vitreus* *Stizostedion vitreum vitreum*[*]	F41
	Sciaenidae 169237	Freshwater drum	*Aplodinotus grunniens*	F45
	Cichlidae 169770	Oscar	*Astronotus ocellatus*	F47
		Blue tilapia	*Tilapia aurea*	F47
		Mozambique tilapia	*Oreochromis mossambicus* *Tilapia mossambica*[*]	F47
	Cottidae 167196	Mottled sculpin	*Cottus bairdi*	F60
Amphibia 173420	Ranidae 173433	Bullfrog	*Rana catesbeiana*	B206
		Green frog	*Rana clamitans*	B206

Class	Family	Species		Reference
		Common Name	Scientific Name	
		Pig frog	*Lithobates grylio* *Rana grylio*[*]	B206
		River frog	*Rana heckscheri*	B206
		Leopard frog	*Rana pipiens*	B205
		Wood frog	*Rana sylvatica*	B206
		Frog	*Rana temporia*[†]	nonresident
		Leopard frog	*Lithobates sphenocephalus sphenocephalus* (Formerly *Rana spenocephala)*	JJ
	Microhylidae 173465	Eastern narrow-mouthed toad	*Gastrophryne carolinensis*	B192
	Bufonidae 173471	American toad	*Anaxyrus americanus americanus* *Bufo americanus*[*]	B196
		Toad	*Bufo bufo*[†]	nonresident
		Green toad	*Anaxyrus debilis debilis* *Bufo debilis*[*]	B197
		Fowler's toad	*Anaxyrus fowleri* *Bufo fowleri*[*]	B196
		Red-spotted toad	*Anaxyrus punctatus* *Bufo punctatus*[*]	B198
		Woodhouse's toad	*Anaxyrus woodhousii woodhousii* *Bufo woodhousii*[*]	B196
	Hylidae 173497	Northern cricket frog	*Acris crepitans*	B203
		Southern gray treefrog	*Hyla chrysoscelis*	B201
		Spring creeper	*Pseudacris crucifer* *Hyla crucifer*[*]	B202
		Barking treefrog	*Hyla gratiosa*	B201
		Squirrel treefrog	*Hyla squirella*	B201
		Gray treefrog	*Hyla versicolor*	B200
		Northern chorus frog	*Pseudacris triseriata*	B202
	Pipidae 173547	African clawed frog	*Xenopus laevis*	Z16
	Ambystomatidae 173588	Spotted salamander	*Ambystoma maculatum*	B176
		Mexican axolotl	*Ambystoma mexicanum*[†]	nonresident
		Marbled salamander	*Ambystoma opacum*	B176
	Salamandridae 173613	Newt	*Notophthalmus viridescens* *Triturus viridescens*[*]	B179

Footnotes for Freshwater Species

[1] Apparently this is an outdated name (D19, 20). Organisms identified as such should only be used if they were obtained from North America.

[2] Apparently this is an outdated name (D19, 20). Organisms identified as such should only be used if they were obtained from North America.

[3] If from North America, it is resident and should be called *D. similis* (C). If not from North America, it should be considered nonresident.

[4] If from North America, it is resident and may be any one of a number of species such as *D. laevie*, *D. dubia*, or *D. galeate mendoca* (C). If not from North America, it should be considered nonresident.

[5] If from North America, it is resident and may be any one of a number of species such as *D. ambigua*, *D. longiremis*, or *D. rosea* (C). If not from North America, it should be considered nonresident.

[6] This species might be established in portions of the southern United States.

[7] The taxonomy of this species and this and similar genera has not been clarified, but this species should be considered resident.

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Saltwater Species Table

Synonyms appear after the official Scientific Name and are marked with an asterisk (*).
Non-resident species are noted in the Reference column and are marked with a dagger (†)

Class	Family	Species		Reference
		Common Name	Scientific Name	
Phylum: Cnidaria (Coelenterata) (48738)				
Hydroza 48739	Campanulariidae 49470	Hydroid	*Campanularia flexiosa* *Campanularia flexuosa***	B122, E81
		Hydroid	*Laomedea loveni*††	nonresident
		Hydromedusa	*Phialidium sp.*	[1] (E81)
	Campanulinidae 49756	Hydroid	*Eirene viridula*†	nonresident
Phylum: Ctenophora (53856)				
Tentaculata 53858	Pleurobrachiidae 53860	Ctenophore	*Pleurobrachia pileus*	B218, E162
	Mnemiidae 53915	Ctenophore	*Mnemiopsis mccradyi*	C39, I94
Phylum: Nemertea (Rhynchocoela) (57411)				
Heteronemertea 57438	Lineidae 57443	Nemertine worm	*Cerebratulus fuscus*	B252
Phylum: Rotifera (Rotatoria) (58239)				
Monogononta 58342	Brachionidae 58344	Rotifer	*Brachionus plicatilis*	B272
Phylum: Annelida (64357)				
Polychaeta 64358	Phyllodocidae 65228	Polychaete worm	*Phyllodoce maculata* *Anaitides maculata** *Nereiphylla maculata**	E334
	Nereididae (Nereidae) 65870	Polychaete worm	*Neanthes arenaceodentata* *Nereis arenaceodentata**	E377
		Polychaete worm	*Neanthes vaali*†	nonresident
		Polychaete worm	*Nereis diversicolor* *Neanthes diversicolor**	E337, F527
		Sand worm	*Nereis virens* *Neanthes virens**	B317, E337, C58
		Polychaete worm	*Nereis sp.*	
	Dorvilleidae 66478	Polychaete worm	*Ophryotrocha diadema*	P23
		Polychaete worm	*Ophryotrocha labronica*† *Ophryotrocha labrunica**†	nonresident
	Spionidae 66781	Polychaete worm	*Polydora websteri*	E338
	Cirratulidae 67116	Polychaete worm	*Cirriformia spirabranchia*	G253
	Ctenodrilidae 67217	Polychaete worm	*Ctenodrilus serratus*	G275
	Capitellidae 67413	Polychaete worm	*Capitella capitata*	B358, E337
	Arenicolidae 67500	Polychaete worm	*Arenicola marina*	B369, E337

** Synonym
†† Non-resident species

Class	Family	Species		Reference
		Common Name	Scientific Name	
	Sabellidae 68076	Polycheate worm	*Eudistylia vancouveri*	DD
Oligochaeta 68422	Tubificidae 68585	Oligochaete worm	*Limnodriloides verrucosus*	Z
		Oligochaete worm	*Monopylephorus cuticulatus*	Z
		Oligochaete worm	*Peloscolex gabriellae* *Tubificoides gabriellae*[*]	Z
Phylum: Mollusca (69458)				
Gastropoda 69459	Haliotididae 566897	Black abalone	*Haliotis cracherodii*	C88, D17
		Red abalone	*Haliotis rufescens*	D18
	Calyptraeidae 72611	Common Atlantic slippershell	*Crepidula fornicata*	C90, D141
	Muricidae 73236	Oyster drill	*Urosalpinx cinerea* *Urosalpinx cinereus*[*]	B646, D179, E264
	Melongenidae (Neptuneidae) 74069	Channeled whelk	*Busycotypus canaliculatus* *(Formerly Busycon canaliculatum)*	B655, D223, E264
	Nassariidae (Nassidae) 74102	Mud snail	*Nassarius obsoletus* *Nassa obsoleta*[*] *Icyanassa obsoleta*[*]	B649, D226, E264
Bivalvia (Pelecypoda) 79118	Mytilidae 79451	Northern horse mussel	*Modiolus modiolus*	D434
		Blue mussel	*Mytilus edulis*	B566, C101, D428, E299
		Mediterranean mussel	*Mytilus galloprovincialis*[†]	nonresident
	Pectinidae 79611	Bay scallop	*Argopecten irradians*	D447
	Ostreidae 79866	Pacific oyster	*Crassostrea gigas*	C102, D456, E300
		Eastern oyster	*Crassostrea virginica*	D456, E300
		Oyster	*Crassostrea sp.*	1
		Oyster	*Ostrea edulis*	E300
	Cardiidae 80865	Cockle	*Cerastoderma edule*[†] *Cardium edule*[*†]	nonresident
	Mactridae 80942	Clam	*Mulinia lateralis*	D491
		Common rangia	*Rangia cuneata*	D491, E301
		Surf clam	*Spisula solidissima*	B599, D489, E301
	Tellinidae 81032	Clam	*Macoma inquinata*	D507
		Bivalve	*Tellina tenuis*[†]	nonresident
	Veneridae 81439	Quahog clam	*Mercenaria mercenaria*	D523, E301
		Common Pacific littleneck	*Protothaca staminea*	D526
		Japanese littleneck clam	*Tapes philippinarum*	D527
	Myidae 81688	Soft-shell clam	*Mya arenaria*	B602, D536, E302
Phylum: Arthropoda (82696)				
Merostomata 82698	Limulidae 82701	Horseshoe crab	*Limulus polyphemus*	B533, E403, H30
Branchiopoda (Formerly Crustacea) 83687	Artemiidae 83689	Brine shrimp	*Artemia salina*[†]	[2] nonresident
Maxillopoda (Formerly Crustacea) 621145	Calanidae 85259	Copepod	*Calanus helgolandicus*	Q25
		Copepod	*Undinula vulgaris*	Q29
	Eucalanidae 85299	Copepod	*Eucalanus elongatus*	AA
		Copepod	*Subeucalanus pileatus* *Eucalanus pileatus*[*]	AA
	Pseudocalanidae 85351	Copepod	*Pseudocalanus minutus*	E447, I155, Q43

Class	Family	Species		Reference
		Common Name	Scientific Name	
	Euchaetidae 85524	Copepod	*Euchaeta marina*	Q63
	Metridinidae (Formerly Metridiidae) 593501	Copepod	*Metridia pacifica*	X179, Y
	Pseudodiaptomidae 85847	Copepod	*Pseudodiaptomus coronatus*	E447, I154, Q101
	Temoridae 85855	Copepod	*Eurytemora affinis*	E450, I155, Q111
	Pontellidae 86038	Copepod	*Labidocera scotti*	R157
	Acartiidae 86083	Copepod	*Acartia clausi*	E447
		Copepod	*Acartia tonsa*	E447, I154
	Harpacticidae 86329	Copepod	*Tigriopus californicus*	J78
		Copepod	*Tigriopus japanicus*†	nonresident
	Tisbidae 86444	Copepod	*Tisbe holothuriae*	BB
	Ameiridae (Formerly Canthocamptidae) 86999	Copepod	*Nitokra spinipes* *Nitocra spinipe**	Q240
	Archaeobalanidae (Formerly Balanidae) 89681	Barnacle	*Semibalanus balanoides* *Balanus balanoides**	B424, E457
	Balanidae 89599	Barnacle	*Balanus crenatus*	B426, E457
		Barnacle	*Balanus eburneus*	B424, E457
		Barnacle	*Balanus improvisus*	B426, E457
Malacostraca (Formerly Crustacea) 89787	Mysidae 89856	Mysid	*Heteromysis formosa*	E513, K720
		Mysid	*Americamysis bahia* *Mysidopsis bahia**	U173
		Mysid	*Americamysis bigelowi* *Mysidopsis bigelowi**	E513, K720
		Mysid	*Neomysis sp.*	1
	Idoteidae 92564	Isopod	*Idotea balthica* *Idothea baltica**	B446, E483
		Isopod	*Idotea emarginata*†	nonresident
		Isopod	*Idotea neglecta*†	nonresident
	Janiridae 92810	Isopod	*Jaera albifrons*†	nonresident
		Isopod	*Jaera albifrons sensu*†	nonresident
		Isopod	*Jaera nordmanni*†	nonresident
	Ampeliscidae 93320	Amphipod	*Ampelisca abdita*	E488, L136
	Eusiridae (Pontogeneiidae) 93681	Amphipod	*Pontogeneia sp.*	1
	Gammaridae 93745	Amphipod	*Gammarus duebeni*	L56
		Amphipod	*Gammarus oceanicus*	E489, L50
		Amphipod	*Gammarus tigrinus*	L51
		Amphipod	*Gammarus zaddachi*†	nonresident
		Amphipod	*Marinogammarus obtusatus*	L58
	Uristadae (Formerly Lysianassidae) 621432	Amphipod	*Anonyx sp.*	1
	Euphausiidae (Thysanopodidae) 95500	Euphausiid	*Euphausia pacifica*	M15
	Penaeidae	Brown shrimp	*Penaeus aztecus*	E518, N17

Class	Family	Species		Reference
		Common Name	Scientific Name	
	95602	Pink shrimp	*Penaeus duorarum*	E518, N17
		White shrimp	*Penaeus setiferus*	E518, N17
		Blue Shrimp	*Penaeus stylirostris*†	nonresident
	Palaemonidae 96213	Shrimp	*Leander paucidens*†	nonresident
		Prawn	*Leander squilla*† *Palaemon elegans**†	nonresident
		Prawn	*Macrobrachium rosenbergii*	[3]
		Korean shrimp	*Palaemon macrodactylus*	T380
		Grass shrimp	*Palaemonetes pugio*	E521, N59
		Grass shrimp	*Palaemonetes vulgaris*	B500, E521, N56
	Hippolytidae 96746	Sargassum shrimp	*Latreutes fucorum*	N78
	Pandalidae 96965	Coon stripe shrimp	*Pandalus danae*	T306, W163
		Shrimp	*Pandalus goniurus*	W163
		Pink shrimp	*Pandalus montagui*	B494, E522, W163
	Crangonidae 97106	Sand shrimp	*Crangon crangon*†	nonresident
		Bay shrimp	*Crangon franciscorum* *Crago franciscorum**	V176, W164
		Shrimp	*Crangon nigricauda*	V176, W164
		Sand shrimp	*Crangon septemspinosa*	B500, E522
	Nephropidae (Homaridae) 97307	American lobster	*Homarus americanus*	B502, E532
		European lobster	*Homarus gammarus*†	nonresident
	Paguridae 97774	Hermit crab	*Pagurus longicarpus*	B514, E537, N125
	Cancridae 98670	Rock crab	*Cancer irroratus*	B518, E543, N175
		Dungeness crab	*Cancer magister*	T166, V185, W177
	Portunidae 98689	Blue crab	*Callinectes sapidus*	B521, C80, E543, N168
		Green crab	*Carcinus maenas*	C80, E543
	Xanthidae (Pilumnidae) 98748	Mud crab	*Eurypanopeus depressus*	B522, E543, N195
		Crab	*Leptodius floridanus*	S80
		Mud crab	*Rhithropanopeus harrisii*	E543, N187
	Varunidae (formerly Grapsidae) 621521	Shore crab	*Hemigrapsus nudus*	CC
		Shore crab	*Hemigrapsus oregonensis*	CC
	Sesarmidae (formerly Grapsidae) 621520	Drift line crab	*Armases cinereum* *(Sesarma cinereum)*	B526, E544, N222
		Crab	*Sesarma haematocheir*†	nonresident
	Ocypodidae 99080	Fiddler crab	*Uca pugilator*	B526, E544, N232
Phylum: Echinodermata (156857)				
Asteroidea 156862	Asteriidae 157212	Starfish	*Asterias forbesi*	B728, E578, O392
Ophiuroidea 157325	Ophiothricidae 157792	Brittle star	*Ophiothrix spiculata*	O672, T526
Echinoidea 157821	Arbaciidae 157904	Sea urchin	*Arbacia lixula*†	nonresident
		Sea urchin	*Arbacia punctulata*	B762, E572
	Toxopneustidae 157919	Sea urchin	*Lytechinus pictus*	T253
		Sea urchin	*Pseudocentrotus depressus*†	nonresident
	Echinidae 157940	[chinoderm	*Paracentrotus lividus*†	nonresident
	Echinometridae 157955	Coral reef echinoid	*Echinometra mathaei*†	nonresident [Hawaii only]

Class	Family	Species		Reference
		Common Name	Scientific Name	
	Strongylocentrotidae 157965	Sea urchin	*Strongylocentrotus purpuratus*	O574, T202
	Dendrasteridae 158008	Sand dollar	*Dendraster excentricus*	O537, V363
Phylum: Chaetognatha (158650)				
Sagittoidea 158655	Sagittidae 158726	Arrow worm	*Ferosagitta hispida* *Sagitta hispida*[*]	E218
Phylum: Chordata (158852)				
Chondrichthyes 159785	Rajidae 160845	Thornback ray	*Raja clavata*[†]	nonresident
Actinopterygii (Formerly Osteichthyes) 161061	Anguillidae 161125	American eel	*Anguilla rostrata*	A15
	Clupeidae 161700	Atlantic menhaden	*Brevoortia tyrannus*	A17
		Gulf menhaden	*Brevoortia patronus*	A17
		Atlantic herring	*Clupea harengus* *Clupea harengus harengus*[*]	A17
		Pacific herring	*Clupea pallasii* *Clupea harengus pallasii*[*]	A17
		Herring	*Clupea harengus*	A17
	Engraulidae 553173	Northern anchovy	*Engraulis mordax*	A18
		Nehu	*Encrasicholina purpurea*[†] *tolephorus purpureus*[*†]	nonresident [Hawaii only]
	Salmonidae 161931	Pink salmon	*Oncorhynchus gorbuscha*	A18
		Chum salmon	*Oncorhynchus keta*	A18
		Coho salmon	*Oncorhynchus kisutch*	A18
		Sockeye salmon	*Oncorhynchus nerka*	A19
		Chinook salmon	*Oncorhynchus tshawytscha*	A19
		Rainbow trout (Steelhead trout)	*Oncorhynchus mykiss* (Formerly *Salmo gairdneri)*	A19
		Atlantic salmon	*Salmo salar*	A19
	Gadidae 164701	Atlantic cod	*Gadus morhua*	A30
		Haddock	*Melanogrammus aeglefinus*	A30
	Cyprinodontidae 165629	Sheepshead minnow	*Cyprinodon variegatus*	A33
		Mummichog	*Fundulus heteroclitus*	A33
		Striped killifish	*Fundulus majalis*	A33
		Longnose killifish	*Fundulus similis*	A33
	Poeciliidae 165876	Mosquitofish	*Gambusia affinis*	A33
		Sailfin molly	*Poecilia latipinna*	A34
	Atherinidae 165984	Inland silverside	*Menidia beryllina*	A34
		Atlantic silverside	*Menidia menidia*	A34
		Tidewater silverside	*Menidia peninsulae*	A34
	Gasterosteidae 166363	Threespine stickleback	*Gasterosteus aculeatus*	A35
		Fourspine stickleback	*Apeltes quadracus*	A35
	Syngnathidae 166443	Northern pipefish	*Syngnathus fuscus*	A36
	Percichthyidae 170315	Striped bass	*Morone saxatilis* (*Roccus saxatilis,* Obs.*)*	A36
	Kuhliidae 168083	Mountain bass	*Kuhlia sandvicensis*[†]	nonresident [Hawaii only]
	Carangidae 168584	Florida Pompano	*Trachinotus carolinus*	A43

Class	Family	Species		Reference
		Common Name	Scientific Name	
	Sparidae 169180	Pinfish	*Lagodon rhomboides*	A45
	Sciaenidae 169237	Spot	*Leiostomus xanthurus*	A46
		Atlantic croaker	*Micropogonias undulatus*	A46
		Red drum	*Sciaenops ocellatus*	A46
	Embiotocidae 169735	Shiner perch	*Cymatogaster aggregata*	A47
		Dwarf perch	*Micrometrus minimus*	A48
	Pomacentridae 170044	Blacksmith	*Chromis punctipinnis*	A48
	Labridae 170477	Cunner	*Tautogolabrus adspersus*	A49
		Bluehead	*Thalassoma bifasciatum*	A49
	Mugilidae 170333	Mullet	*Aldrichetta forsteri*†	nonresident
		Striped mullet	*Mugil cephalus*	A49
		White mullet	*Mugil curema*	A49
	Ammodytidae 171670	Pacific sand lance	*Ammodytes hexapterus*	A53
	Gobiidae 171746	Longjaw mudsucker	*Gillichthys mirabilis*	A54
		Naked goby	*Gobiosoma bosci*	A54
	Cottidae 167196	Tidepool sculpin	*Oligocottus maculosus*	A61
	Bothidae 172714	Speckled sanddab	*Citharichthys stigmaeus*	A64
		Summer Flounder	*Paralichthys dentatus*	A64
	Pleuronectidae 172859	Dab	*Limanda limanda*†	nonresident
		Plaice	*Pleuronectes platessa*†	nonresident
		English sole	*Parophrys vetulus*	A65
		Winter flounder	*Pseudopleuronectes americanus*	A65
	Balistidae 173128	Planehead filefish	*Monacanthus hispidus*	A66
	Tetraodontidae 173283	Northern puffer	*Sphoeroides maculatus*	A66

Footnotes for Saltwater Species

[1] Organisms not identified to species are considered resident only if obtained from wild populations in North America.

[2] This species should not be used because it might be too atypical.

[3] This species might be established in portions of the southern United States.

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Appendix 2. Example Calculation of Final Acute Value, Computer Program, and Printouts

A. Example Calculation

N = total number of MAVs in data set = 8

Rank	MAV	ln(MAV)	$\ln(MAV)^2$	P = R / (N+1)	$\sqrt{P}$
4	6.4	1.8563	3.4458	0.44444	0.66667
3	6.2	1.8245	3.3290	0.33333	0.57735
2	4.8	1.5686	2.4606	0.22222	0.47140
1	0.4	-0.9163	0.8396	0.11111	0.33333
Sum		4.3331	10.0750	1.11110	2.04875

$$S^2 = \frac{10.0750 - (4.3331)^2 / 4}{1.11110 - (2.04875)^2 / 4} = 87.134$$

$S = 9.3346$

$L = [\ 4.3331 - (9.3346)(2.04875)] / 4 = -3.6978$

$A = (9.3346)\ (\sqrt{0.05}\ ) - 3.6978 = -1.6105$

$FAV = e^{-1.6105} = 0.1998$

B. Example Computer Program in BASIC Language for Calculating the FAV

```
10    REM This program calculates the FAV when there are less than
20    REM 59 MAVs in the data set
30    X = 0
40    X2 = 0
50    Y = 0
60    Y2 = 0
70    PRINT "How many MAVs are in the data set?"
80    INPUT N
90    PRINT "What are the four lowest MAVs?"
100   FOR R = 1 TO 4
110         INPUT V
```

```
120         X = X + LOG(V)
130         X2 = X2 + (LOG(V)) * (LOG(V))
140         P = R / (N + 1)
150         Y2 = Y2 + P
160         Y = Y + SQR((X2 – X * X / 4))
170   NEXT R
180   S = SQR((X2 – X * X / 4) / (Y2 – Y * Y / 4))
190   L = (X – S * Y) / 4
200   A = S * SQR(0.05) + L
210   F = EXP(A)
220   PRINT "FAV = " F
230   END
```

C. Example Printouts from Program

```
How many MAVs are in the data set?
? 8
What are the four lowest MAVs?
? 6.4
? 6.2
? 4.8
? .4
FAV = 0.1998


How many MAVs are in the data set?
? 16
What are the four lowest MAVs?
? 6.4
? 6.2
? 4.8
? .4
FAV = 0.4365
```

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Environmental Protection
Agency

Office of Water
Regulations and Standards
Criteria and Standards Division
Washington, DC 20460

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Water

EPA

Ambient Water Quality Criteria for Zinc - 1987

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AMBIENT AQUATIC LIFE WATER QUALITY CRITERIA FOR

ZINC

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
ENVIRONMENTAL RESEARCH LABORATORIES
DULUTH, MINNESOTA
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FOREWORD

Section 304(a)(1) of the Clean Water Act of 1977 (P.L. 95-217) requires the Administrator of the Environmental Protection Agency to publish water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water, including ground water. This document is a revision of proposed criteria based upon consideration of comments received from other Federal agencies, State agencies, special interest groups, and individual scientists. Criteria contained in this document replace any previously published EPA aquatic life criteria for the same pollutant(s).

The term "water quality criteria" is used in two sections of the Clean Water Act, section 304(a)(1) and section 303(c)(2). The term has a different program impact in each section. In section 304, the term represents a non-regulatory, scientific assessment of ecological effects. Criteria presented in this document are such scientific assessments. If water quality criteria associated with specific stream uses are adopted by a State as water quality standards under section 303, they become enforceable maximum acceptable pollutant concentrations in ambient waters within that State. Water quality criteria adopted in State water quality standards could have the same numerical values as criteria developed under section 304. However, in many situations States might want to adjust water quality criteria developed under section 304 to reflect local environmental conditions and human exposure patterns before incorporation into water quality standards. It is not until their adoption as part of State water quality standards that criteria become regulatory.

Guidelines to assist States in the modification of criteria presented in this document, in the development of water quality standards, and in other water-related programs of this Agency, have been developed by EPA.

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Director
Office of Water Regulations and Standards

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Introduction*

Zinc is the fourth most widely used metal in the world (Cammarota 1980), and its major uses are for galvanizing steel, for producing alloys, and as an ingredient in rubber and paints. Because zinc(II) substitutes to some extent for magnesium in the silicate minerals of igneous rocks, weathering of bedrock gives rise to zinc in surface water. Zinc always has the oxidation state of +2 in aqueous solution. Zinc(II) is amphoteric, dissolving in acids to form hydrated Zn(II) cations and in strong bases to form zincate anions, usually $Zn(OH)_4^{-2}$. Complexes of zinc with the common ligands of surface waters are soluble in neutral and acidic solutions, so that zinc is readily transported in most natural waters and is one of the most mobile of the heavy metals. Concentrations of zinc in uncontaminated fresh water are typically in the range of 0.5 to 10 µg/L (Trefry and Presley 1979), whereas concentrations in clean sea water range from 0.002 to 0.1 µg/L and increase with depth (Salomons and Forstner 1984; Wallace et al. 1983).

Zinc occurs in many forms in natural waters and aquatic sediments. At pH = 6.0 in fresh water, the dominant forms of dissolved zinc are the free ion (98%) and zinc sulfate (2%), whereas at pH = 9.0, the dominant forms are the mono-hydroxide ion (78%), zinc carbonate (16%), and the free ion (6%) (Turner et al. 1981). In sea water at pH = 8.1, the dominant species of soluble zinc are zinc hydroxide (62%), the free ion (17%), the mono-chloride ion (6.4%), and zinc carbonate (5.8%)

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* An understanding of the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" (Stephan et al. 1985), hereafter referred to as the Guidelines, and the response to public comment (U.S. EPA 1985a) is necessary in order to understand the following text, tables, and calculations.

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(Zirino and Yamamoto 1972). At pH = 7.0, the percentage of dissolved zinc present in sea water as the free ion increases to 50%. In the presence of dissolved organic materials, particularly humic substances, the major fraction of dissolved zinc is in the form of zinc-organic complexes (Lu and Chen 1977).

Zinc can be present in sediments in several forms, including precipitated $Zn(OH)_2$, precipitates with ferric and manganic oxyhydroxides, insoluble organic complexes, insoluble sulfides, and residual forms (Patrick et al. 1977). As sediments change from a reduced to an oxidized state, more zinc is mobilized and released in a soluble form (Lu and Chen 1977). The bioavailability of different forms of zinc in sediment varies substantially and is poorly understood (Luoma and Bryan 1979). Baccini (1985), Krantzberg and Stokes (1985), and Salomons (1985) reported that benthic organisms influenced the partitioning of zinc between sediment and the water column.

Most of the zinc introduced into the aquatic environment is partitioned into sediment by sorption onto hydrous iron and manganese oxides, clay minerals, and organic materials (Lu and Chen 1977; Luoma and Bryan 1981; Parker et al. 1982; Warren 1981). Precipitation of the sulfide is an important control on the mobility of zinc in reducing environments, and precipitation of the hydroxide, carbonate, and basic sulfate salts can occur when zinc is present in high concentrations. Formation of complexes with organic and inorganic ligands can increase the solubility of zinc and might increase or decrease the tendency for zinc to be sorbed (Salomons and Forstner 1984).

The tendency of zinc to be sorbed is affected not only by the form of the zinc and the nature and concentration of the sorbent but also by pH

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and salinity. In a study of heavy metal sorption by two oxides and two soils, zinc was completely removed from solution when pH exceeded 7, but little or no zinc was sorbed when pH was below 6. Addition of inorganic complexing ligands enhanced sorption (Huang et al. 1977). Helz et al. (1975) and Solomons (1980) found less sorption of zinc to particulate matter and sediment as salinity increased. This phenomenon was exhibited by many other metals as well and apparently is due to displacement of the sorbed zinc ions by alkali and alkaline earth cations, which are abundant in brackish and saline waters. An increase in pH can increase sorption of zinc even if salinity increases (Millward and Moore 1982; Solomons 1980). Watanabe et al. (1985) reported that sorption of zinc was also dependent on the organic carbon content of river sediments.

Zinc is an essential micronutrient for all living organisms (Leland and Kuwabara 1985). Because zinc is essential, aquatic organisms have evolved efficient mechanisms for accumulation of zinc from water and food. The concentration of zinc in tissues of aquatic organisms is far in excess of that required for various metabolic functions (Wolfe 1970). Much of the excess zinc is bound to macromolecules or is present as insoluble metal inclusions in tissues (Simkiss et al. 1982). Inducible low molecular weight metal-binding proteins, metallothioneins, are thought to function, in part, in the intracellular sequestration and regulation of the essential metals zinc and copper (Kojima and Kogi 1978; Roesijadi 1981).

Above some theoretical maximum beneficial concentration of zinc in water, there exists a range of zinc concentrations that is readily tolerated through each organism's capacity to regulate the uptake, internal distribution, and excretion of zinc (Weiner and Giesy 1979). This range undoubtedly varies among individuals, species, and larger phylogenetic groups. In

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addition, this tolerated range probably varies with the range of zinc concentrations to which various populations have been historically exposed and acclimated. Thus, biological variability in tolerance of zinc is probably the result of phylogenetic differences and historic exposure patterns, both short-term and geologic in scale.

Paramount to the question of the toxicity of zinc are the physical and chemical forms of zinc, the toxicity of each form, and the degree of interconversion among the various forms. Presumably, all forms of zinc that can be sorbed or bound by biological tissues are potentially toxic. Most likely, zinc will not be sorbed or bound unless it is dissolved, but some dissolution of zinc can reasonably be expected to occur in the alimentary canal following ingestion of particulates containing undissolved zinc. Thus, the toxicity of undissolved zinc to a particular species probably depends on feeding habits. Therefore, plants and most fish are probably relatively unaffected by suspended zinc, but many invertebrates and some fishes might be adversely affected by ingestion of sufficient quantities of particulates containing zinc.

The toxicity of zinc, as well as other heavy metals, is apparently influenced by a number of chemical factors including calcium, magnesium, hardness, pH, and ionic strength. These factors appear to affect the toxicity of zinc either by influencing the availability of zinc or by inhibiting the sorption or binding of available zinc by biological tissues. In fresh water zinc appears to be less toxic at high hardness for a variety of reasons, such as:

1) The ions contributing to hardness, primarily calcium and magnesium, are divalent and compete with zinc, which is also divalent, for sites of uptake and binding in biological tissues.

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2) Harder waters have higher ionic strengths due to the greater quantity of charged ions (primarily mono- and divalent cations and anions) in solution, and these ions electrostatically inhibit the ability of other ions, such as zinc, to approach the sorption or binding sites of the organisms. Thus zinc ions have lower activity in harder waters.

3) Generally, harder waters have higher alkalinities and higher pHs, resulting in the formation of insoluble, and possible soluble, zinc carbonate and hydroxide compounds that are not sorbed by many species.

Thus, hardness appears to be the single best water quality characteristic to reflect the variation in zinc toxicity induced by differences in general water chemistry.

Because of the variety of forms of zinc (Callahan et al. 1979; Hem 1972; Salomons and Forstner 1984) and lack of definitive information about their relative toxicities, no available analytical measurement is known to be ideal for expressing aquatic life criteria for zinc. Previous aquatic life criteria for zinc (U.S. EPA 1980) were expressed in terms of total recoverable zinc (U.S. EPA 1983a), but this measurement is probably too rigorous in some situations. Acid-soluble zinc (operationally defined as the zinc that passes through a 0.45 μm membrane filter after the sample is acidified to pH = 1.5 to 2.0 with nitric acid) is probably the best measurement at the present for the following reasons:

1. This measurement is compatible with nearly all available data concerning toxicity of zinc to, and bioaccumulation of zinc by, aquatic organisms. No test results were rejected just because it was likely that they would have been substantially different if they had been reported in terms of acid-soluble zinc. For example, results reported in terms of dissolved

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zinc would not have been used if the concentration of precipitated zinc had been substantial.

2. On samples of ambient water, measurement of acid-soluble zinc will probably measure all forms of zinc that are toxic to aquatic life or can be readily converted to toxic forms under natural conditions. In addition, this measurement probably will not measure several forms, such as zinc that is occluded in minerals, clays, and sand or is strongly sorbed to particulate matter, that are not toxic and are not likely to become toxic under natural conditions. Although this measurement (and many others) will measure soluble complexed forms of zinc, such as the EDTA complex of zinc, that probably have low toxicities to aquatic life, concentrations of these forms probably are negligible in most ambient water.
3. Although water quality criteria apply to ambient water, the measurement used to express criteria is likely to be used to measure zinc in aqueous effluents. Measurement of acid-soluble zinc probably will be applicable to effluents because it will measure precipitates, such as carbonate and hydroxide precipitates of zinc, that might exist in an effluent and dissolve when the effluent is diluted with receiving water. If desired, dilution of effluent with receiving water before measurement of acid-soluble zinc might be used to determine whether the receiving water can decrease the concentration of acid-soluble zinc because of sorption.
4. The acid-soluble measurement is probably useful for most metals, thus minimizing the number of samples and procedures that are necessary.
5. The acid-soluble measurement does not require filtration at the time of collection, as does the dissolved measurement.

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6. The only treatment required at the time of collection is preservation by acidification to pH = 1.5 to 2.0, similar to that required for the total recoverable measurement.
7. Durations of 10 minutes to 24 hours between acidification and filtration of most samples of ambient water probably will not affect the result substantially.
8. The carbonate system has a much higher buffer capacity from pH = 1.5 to 2.0 than it does from pH = 4 to 9 (Weber and Stumm 1963).
9. Differences in pH within the range of 1.5 to 2.0 probably will not affect the result substantially.
10. The acid-soluble measurement does not require a digestion step, as does the total recoverable measurement.
11. After acidification and filtration of the sample to isolate the acid-soluble zinc, the analysis can be performed using either atomic absorption spectrophotometric or ICP-atomic emission spectrometric analysis (U.S. EPA 1983a), as with the total recoverable measurement.

Thus, expressing aquatic life criteria for zinc in terms of the acid-soluble measurement has both toxicological and practical advantages. On the other hand, because no measurement is known to be ideal for expressing aquatic life criteria for zinc or for measuring zinc in ambient water or aqueous effluents, measurement of both acid-soluble zinc and total recoverable zinc in ambient water or effluent or both might be useful. For example, there might be cause for concern if total recoverable zinc is much above an applicable limit, even though acid-soluble zinc is below the limit.

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Unless otherwise noted, all concentrations reported herein from toxicity and bioconcentration tests are expected to be essentially equivalent to acid-soluble zinc concentrations. All concentrations are expressed as zinc, not as the chemical tested. The criteria presented herein supersede previous aquatic life water quality criteria for zinc (U.S. EPA 1976,1980) because these new criteria were derived using improved procedures and additional information. Whenever adequately justified, a national criterion may be replaced by a site-specific criterion (U.S. EPA 1983b), which may include not only site-specific criterion concentrations (U.S. EPA 1983c), but also site-specific durations of averaging periods and site-specific frequencies of allowed excursions (U.S. EPA 1985b). The latest comprehensive literature search for information for this document was conducted in July, 1986; some more recent information might have been included.

Acute Toxicity to Aquatic Animals

Available data, which are usable according to the Guidelines, on the acute toxicity of zinc to aquatic animals are presented in Table 1. Acute values for freshwater invertebrates ranged from 32 to 40,930 µg/L (Table 1), and those for fishes ranged from 66 to 40,900 µg/L, except for two values that appeared high for the guppy. The two ranges are very similar and very wide, probably due at least in part to hardness-related factors.

Although many factors might affect the results of tests of the toxicity of zinc to aquatic organisms (Sprague 1985), water quality criteria can quantitatively take into account only factors for which enough data are available to show that the factor similarly affects the

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results of tests with a variety of species. Hardness is often thought of as having a major effect on the toxicity of zinc in fresh water, although the observed effect is probably due to one or more of a number of usually interrelated ions, such as hydroxide, carbonate, calcium, and magnesium. Hardness (expressed as mg $CaCO_3$/L) is used here as a surrogate for the ions that affect the results of toxicity tests on zinc. An analysis of covariance (Dixon and Brown 1979; Neter and Wasserman 1974) was performed using the natural logarithm of the acute value as the dependent variable, species as the treatment or grouping variable, and the natural logarithm of hardness as the covariate or independent variable. This analysis of covariance model was fit to the data in Table 1 for the eight species for which acute values are available over a range of hardness such that the highest hardness is at least three times the lowest and the highest is also at least 100 mg/L higher than the lowest. The eight slopes are between 0.56 and 1.65 (see end of Table 1) and most are close to the slope of 1.0 that is expected on the basis that zinc, calcium, magnesium, and carbonate all have a charge of two. An F-test showed that, under the assumption of equality of slopes, the probability of obtaining eight slopes as dissimilar as these is $P = 0.77$. This was interpreted as indicating that it is reasonable to assume that the slopes for these eight species are the same.

Where possible, the pooled slope of 0.8473 was used to adjust the freshwater acute values in Table 1 to hardness = 50 mg/L. Species Mean Acute Values were calculated as geometric means of the adjusted acute values. Five of the seven most resistant species (Table 3) were tested in a series of experiments reported by Rehwoldt et al. (1971,1972,1973) using Hudson River water, and high acute values were obtained in two

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other tests whose results were placed in Table 6 because the organisms were not identified to genus. It is not known whether the river water reduced the toxicity of zinc or if the species were inherently resistant. Rehwoldt et al. (1971,1972) also reported LC50s of 6,700 and 6,800 µg/L for the striped bass, Morone saxatilis. These were considerably higher than the LC50s reported by Hughes (1970,1973) and Palawski et al. (1985) for the same species, although the values reported by Hughes were not used due to inadequate acclimation of the test organisms.

Genus Mean Acute Values (GMAVs) at hardness = 50 mg/L (Table 3) were then calculated as geometric means of the available freshwater Species Mean Acute Values. The GMAV for Morone was based only on the SMAV for the striped bass because of the probability that the LC50s reported by Rehwoldt et al. (1971,1972) were two high for both species in this genus. Of the 35 genera for which acute values are available, the most sensitive genus, Ceriodaphnia, is about 950 times more sensitive than the most resistant genus, Argia. Acute values are available for more than one species in each of seven genera and the range of Species Mean Acute Values within each genus is less than a factor of 3.7. The freshwater Final Acute Value for zinc at hardness = 50 mg/L was calculated to be 130.1 µg/L using the procedure described in the Guidelines and the Genus Mean Acute Values in Table 3. This value is above the Species Mean Acute Value for a cladoceran and for the striped bass, but the results for the striped bass were not obtained in a flow-through test in which the concentrations of test material were measured. Thus, the freshwater Criterion Maximum Concentration (in µg/L) = $e^{(0.8473[\ln(\text{hardness})]+0.8604)}$

Acute tests considered useful in the derivation of a saltwater criterion for zinc have been conducted with 26 species of invertebrates

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and 7 species of fish (Table 1). The range of Species Mean Acute Values for saltwater invertebrates extends from 195 µg/L for embryos of the quahog clam, Mercenaria mercenaria, (Calabrese and Nelson 1974) to 320,400 µg/L for adults of the clam Macoma balthica (Bryant et al. 1985). The range of Species Mean Acute Values for fish is narrower, extending from 191.4 µg/L for larvae of the cabezon, Scorpaenichthys marmoratus, (Dinnel et al. 1983) to 38,000 µg/L for juvenile spot, Leiostomus xanthurus (Hansen 1983). As a general rule, early life stages of saltwater invertebrates and fish are more sensitive to zinc than juveniles and adults.

Both temperature and salinity affect the results of acute tests on zinc. The effect of temperature has been studied with four bivalve molluscs and one amphipod, whereas the effect of salinity has been studied with a worm, clam, amphipod, two isopods, and a fish (Table 1). In general, the LC50 increases as salinity increases (presumably because complexation by chloride increases) and as temperature decreases. However, the LC50 for a species also seems to decrease as salinity and temperature deviate from the optimum for the species.

Of the 28 genera for which saltwater Genus Mean Acute Values are available (Table 3), the most sensitive genus, Scorpaenichthys is about 1,700 times more sensitive than the most resistant, Macoma. Clams are both sensitive and resistant to zinc. Acute values are available for more than one species in each of five genera and the range of Species Mean Acute Values within each genus is less than a factor of 5.2. The saltwater Final Acute Value for zinc was calculated to be 190.2 µg/L, which is slightly lower than the acute value for the most sensitive species.

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Chronic Toxicity to Aquatic Animals

Although most of the chronic toxicity tests conducted on zinc with freshwater species were in soft water ranging in hardness from 25 to 52 mg/L, Chapman et al. (Manuscript) studied the chronic toxicity of zinc to *Daphnia magna* at hardnesses of 52, 104, and 211 mg/L (Table 2). They found that the chronic toxicity of zinc decreased when hardness increased from 52 to 104 mg/L. When hardness was further increased to 211 mg/L, the toxicity of zinc did not change. No other data are available concerning the relationship between hardness and the chronic toxicity of zinc.

The chronic values for the two species of freshwater invertebrates ranged from 46.73 to >5,243 µg/L, whereas those for six species of fish ranged from 36.41 to 854.7 µg/L.

A life-cycle toxicity test has been conducted with the saltwater mysid, *Mysidopsis bahia* (Lussier et al. 1985). Survival, days to first brood, and young/female reproductive day were all affected at 231 µg/L, but no effects were detected at 120 µg/L.

Acute-chronic ratios are available for six freshwater and one saltwater species. The freshwater Species Mean Acute-Chronic Ratios range from 0.7027 to 41.20, whereas the saltwater ratio is 2.997 (Table 3). Because the Final Acute-Chronic Ratio is meant to apply to sensitive species, which often have lower acute-chronic ratios than resistant species, it was calculated as the geometric mean of the ratios for the freshwater *Daphnia magna*, chinook salmon, and rainbow trout and the saltwater mysid. The resulting value of 2.208 is lower than all the other Species Mean Acute-Chronic Ratios (Table 3). Division of the freshwater and saltwater Final Acute Values by 2.208 results in freshwater and saltwater Final Chronic Values of 58.92 µg/L (at hardness = 50 mg/L) and 86.14 µg/L,

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respectively. In spite of the data on the effect of hardness on the chronic toxicity of zinc to Daphnia magna, the freshwater chronic slope is assumed to be the same as the acute slope, resulting in a freshwater Final Chronic Value = $e^{(0.8473[\ln(\text{hardness})]+0.7614)}$.

Toxicity to Aquatic Plants

Toxicity tests on zinc have been conducted with 20 species of freshwater plants, which were affected by zinc concentrations ranging from 30 to >200,000 µg/L (Table 4). Although tests have been conducted with several vascular plants, both the highest and lowest values were obtained with algae.

Few data are available concerning the effect of hardness on toxicity to plants. One study with the diatom, Navicula seminulum, (Academy of Natural Sciences 1960) tested zinc toxicity at two hardnesses. At hardness = 58.46 mg/L, zinc was more toxic, on the average, than in tests at hardness = 174 mg/L. However, there was overlap in EC50s between the hardnesses tested. The toxicity of zinc to algae might be related to the concentration of phosphate or nitrate (Kuwabara 1985; Rao and Subramanian 1982).

The toxicity of zinc to saltwater plants has been tested with 18 species of phytoplankton and 8 species of macroalgae (Tables 4 and 6). The diatom, Schroederella schroederi, was the most sensitive phytoplankter, with a 48-hour EC50 of 19.01 µg/L. Other species affected at concentrations less than the Final Chronic Value are Cricosphaera carterae, Isochrysis gabana, Thalassiosira rotula, Glenodinium halli, and Gymnodinium splendens. Macroalgae were affected at concentrations $\geq$100 µg/L. Therefore, although data on most saltwater plants indicate that they will be protected by a

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saltwater criterion derived from data on animals, some phytoplankters might be affected under certain environmental conditions.

Bioaccumulation

Six freshwater species were exposed to zinc and had tissue concentrations measured after sufficient time to achieve steady-state (Table 5). Bioconcentration factors (BCF) ranged from 51 for the Atlantic salmon (Farmer et al. 1979) to 1,130 for a mayfly (Nehring 1976). A mean BCF of 100 was obtained in three tests with a clam (Graney et al. 1983), and the BCF of 106 for a stonefly was much lower than that for the mayfly. Both the flagfish and the guppy had BCFs between 400 and 500. Atchinson et al. (1977), McIntosh and Bishop (1976), and Murphy et al. (1978a,b) measured the concentrations of zinc in several species of fish obtained from a pond contaminated with zinc. Direct accumulation from water did not appear to be a major route of uptake of zinc by two species of fish in a lake (Klaverkamp et al. 1983). Cushing and Rose (1970), Cushing and Watson (1971), and Cushing et al. (1975) studied the uptake of zinc by periphyton and fish in microcosms. Van der Werff (1984) found that humic and fulvic acids reduced the uptake of zinc by an alga.

Bioaccumulation data for zinc are available for six species of saltwater algae and seven species of saltwater animals (Table 5). Steady-state BCFs derived from laboratory exposures of saltwater algae for periods of 0.5 to 140 days ranged from 75.5 for the brown macroalga, Laminaria digitata (Haritonidis et al. 1983) to 10,768 for another brown macroalga, Fucus serratus (Young 1975). BCFs based on data derived from field collections of macroalgae ranged from 1,027 to 2,029 for a third brown macroalga, Fucus vesiculosus (Foster 1976; Foster and Bale 1975).

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BCFs derived from laboratory exposures of saltwater animals for periods of 14 to 126 days range from 3.692 in the whole body of the shrimp, Pandalus montagui (Ray et al. 1980) to 23,820 in the total soft tissue of the eastern oyster, Crassostrea virginica (Shuster and Pringle 1968).

For the mummichog, Fundulus heteroclitus, the BCF for both whole body and scales decreased with increasing concentration in water between 210 and 7,880 µg/L (Sauer and Watabe 1984). At all concentrations, the scales had a higher BCF than the whole body. Sequestration of zinc in scales, which is accompanied by a decrease in scale calcification (Sauer and Watabe 1984), might be a mechanism of zinc storage or detoxification in fish. O'Grady (1981) showed that sea trout, Salmo trutta, mobilized zinc stored in its scales during the upstream spawning migration.

For both algae and animals, there is a definite trend toward an inverse relationship between concentration in water and BCF. This is best exemplified by the data in Table 5 for the brown macroalga, Laminaria digitata (Bryan 1969) and the mummichog, Fundulus heteroclitus (Sauer and Watabe 1984). Seip (1979) developed a mathematical model for the accumulation of zinc and other metals by the brown macroalga, Ascophyllum nodosum. The concentration of zinc in the alga was found to be an approximately linear function of the mean concentration of zinc in water up to about 100 µg/L. Because the slope of the curve was less than 1, BCFs tended to decrease with increasing concentration in water.

No U.S. FDA action level or other maximum acceptable concentration in tissue is available for zinc, and, therefore, no Final Residue Value can be calculated.

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Other Data

A wide variety of other data is presented in Table 6. In a test on zinc phosphate, growth of a freshwater green alga was inhibited during a 14-day exposure to 64 µg/L (Garton 1972). Growth of Scenedesmus quadricauda was inhibited during exposure to 1,200 µg/L in river water (Bringmann and Kuhn 1959a,b). The primary productivity of plankton was reduced when exposed to 15 µg/L for 14 days (Marshall et al. 1983).

Several studies have been conducted on the effect of temperature on the acute toxicity of zinc (Braginskiy and Shcherban 1978; Cairns et al. 1975a, 1978; Pickering and Henderson 1966; See et al. 1974; Smith and Heath 1979). Except for the rainbow trout and golden shiners, the species were more sensitive to zinc at higher temperatures. Snails were more sensitive to thermal shock after exposure to zinc (Cairns et al. 1976).

Concentrations of dissolved oxygen down to 3.5 mg/L did not affect the toxicity of zinc to the bluegill, but lower concentrations did (Pickering 1968). Anderson (1973) and Anderson and Weber (1975) found that the acute sensitivity of the guppy to zinc depended on the weight of the fish. Sabodash (1974) studied the effects of zinc and calcium on survival and growth of larval grass carp.

Most insects were more resistant to zinc than the other freshwater species tested. Mayflies, damselflies, stoneflies, and caddisflies had LC50s ranging from 1,330 to 58,100 µg/L (Table 6). One midge (Chironomous sp.) had a 96-hr LC50 of 18,200 µg/L (Rehwoldt et al. 1973), whereas another (Tanytarsus dissimilis) had a 10-day LC50 of 36.8 µg/L (Anderson et al. 1980). The T. dissimilis value is very low compared to other values obtained with insects.

Although most LC50s for rainbow trout ranged from 2,000 to 5,000 µg/L, Garton (1972) obtained an LC50 of 90 µg/L in a test on zinc phosphate.

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A 7-day EC50 of 10 µg/L was obtained with embryos and larva of the narrow-mouthed toad (Birge 1978; Birge et al. 1979).

Cairns et al. (1975b) and Khangarot (1982) examined the effect of feeding on the results of acute tests on zinc, whereas McLeay and Munro (1979) and Sparks et al. (1972b) studied the effects of photoperiod and shelters, respectively. Brafield and Mattiessen (1976), Hughes (1975), Hughes and Tort (1985), and Thompson et al. (1983) studied the effect of zinc on respiration of fishes. Allen et al. (1980) and Muramota (1978) found that various chelating agents reduced the acute toxicity of zinc. Several studies examined the use of fishes as biomonitoring organisms for zinc (Cairns and Waller 1971; Cairns et al. 1973a; Sparks et al. 1972; Waller and Cairns 1972).

Many studies have examined zinc as a dietary requirement for freshwater plants (e.g., Vaughn et al. 1982) and fish (e.g., Barash et al. 1982; Bell et al. 1984; Dabrowski et al. 1981; Gatlina and Wilson 1983,1984; Jeng and Sun 1981; Ketola 1979; Knox et al. 1982,1984; Ogino and Yang 1978,1979; Richardson et al. 1985; Rodgers 1982; Satoh et al. 1983a,b,c; Takeda and Shimma 1977).

Armitage (1980), Armitage and Blackburn (1985), Austin and Munteanu (1984), Carlson et al. (1986), Eichenberger (1981), Eichenberger et al. (1981), Foster (1982a), Harding et al. (1981), Hughes (1985), Lang and Lang-Dobler (1979), Maas (1978), Meyer (1978), Rice (1977), Roline and Boehmke (1981), Ruthven and Cairns (1973), Say and Whitton (1983), Say et al. (1977), Sheehan and Knight (1985), Shehata and Whitton (1981), Solbe (1973), Swain and White (1985), Swift (1985), Wehr and Whitton (1983b,c), Wentsel and McIntosh (1977), Williams and Mount (1965), Yan

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et al. (1985), Yasuno et al. (1985), and Zanella (1982) investigated relationships between the abundance and diversity of freshwater species and the concentration of zinc in water and sediment.

The detoxification of zinc was studied by Kito et al. (1982), Klaverkamp et al. (1985), Ley et al. (1983), Marofante (1962), Pierson (1985a,b), Roch and McCarter (1984a,b), and Takeda and Shimizu (1982).

Low concentrations of zinc stimulate the rate of growth of saltwater microalgae. Concentrations equal to or less than 100 µg/L stimulated growth of Nitzchia longissima during exposures lasting one to five days (Subramanian et al. 1980). Similarly, growth of Skeletonema costatum was both stimulated by zinc concentrations equal to or lower than 200 µg/L during one to five days of exposure (Subramanian et al. 1980) and reduced by 20% during exposure for 10 to 14 days to 100 µg/L zinc (Braek et al. 1976). Wikfors and Ukeles (1982) reported a 6.7% increase in the growth of Phaeodactylum tricornutum during exposure for 12 days to 4,800 µg/L. Therefore the difference between beneficial and detrimental concentrations of zinc to phytoplankton might be small and dependent on the species and exposure.

Stromgren (1979) studied the effect of zinc on growth of five species of saltwater macroalgae. Growth was reduced at 1,400, but not 100, µg/l for Ascophyllum nodosum, Fucus serratus, Fucus spiralis, and Pelvetia canaliculata, and at 7,000, but not 3,500, µg/L for Fucus vesiculosus. Bryan (1969) reported reduced growth of Laminaria digitata during exposure for 24 days to concentrations as low as 100 µg/L. A concentration of 250 µg/L reduced growth of sporophytes of Laminaria hyperboria, whereas 5,000 µg/L induced abnormal maturation of gametophytes of the same species (Hopkins and Kain 1971). Zinc concentrations as low as 8.8 µg/L altered lipid metabolism in Fucus serratus (Smith and Harwood 1984).

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Two ciliate protozoans exhibited markedly different sensitivities to zinc. Growth of Cristigera sp. was reduced by exposure for four to five hours to concentrations as low as 50.63 µg/L (Gray 1974; Gray and Ventilla 1973), but a concentration of 10,000 µg/L only reduced the growth of Euplotes vannus by 10% (Persoone and Uyttersprot 1975).

Bryan and Hummerstone (1973) compared the sensitivity of the polychaete, Nereis diversicolor, from sediments heavily contaminated with zinc and other metals to that of the same species from clean sediments at three salinities (Tables 1 and 6). At all three salinities, worms from the contaminated sediments were less than a factor of two more resistant to zinc than those from clean sediments. Worms from the contaminated sediments also had somewhat lower BCFs than worms from clean sediments when exposed to zinc in the laboratory for 34 days. These results suggest that acclimation or genetic adaptation of the worms to contaminated sediments provided only a minor ability to regulate zinc more efficiently than worms from uncontaminated sediments.

The polychaetes, Ophryotiocha diadema and Ctenodrilus serratus, were exposed to zinc in partial life-cycle tests that began with adults and examined effects on survival and reproduction (Reish and Carr 1978). Population size was reduced 500 µg/L in both static tests but effects of zinc were not detected at 100 µg/L.

A variety of responses were observed in mud snails, Nassarius obsoletus, during exposure for 72 hr to progressively higher concentrations of zinc (MacInnes and Thurberg 1973). At 2,000 µg/L, there was a depression of oxygen consumption. Locomotor behavior was inhibited at 10,000 µg/L, and death ensued at 50,000 µg/L. Similarly, shell deposition by adults of the blue mussel, Mytilus edulis, was inhibited by 50% following exposure

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for two to six days to ≥60 µg/L (Manley et al. 1984; Stromgren 1982). The EC50 based on reduced byssal thread production was 1,800 µg/L, whereas the 7-day LC50 was 5,000 µg/L (Martin et al. 1975). The 72-hr EC50 for development of mussel embryos to the veliger stage was between 96 and 314 µg/L (Dinnel et al. 1983).

Different life stages and developmental processes of gametes, embryos, and larvae of Pacific oysters have different sensitivities to zinc. The ability of oyster sperm to fertilize eggs was depressed by 50% after exposure for 60 min to 443.6 µg/L (Dinnel et al. 1983). The 48-hr LC50 for embryos was 241.5 µg/L (Brereton et al. 1973). Larvae developed abnormally and grew more slowly than controls at zinc concentrations between 125 and 500 µg/L (Brereton et al. 1973), whereas EC50s for growth of 6-day-old and 16-day old larvae exposed for four days were 80 and 95 µg/L, respectively (Watling 1982). The 96-hr LC50 for 6-day and 16-day larvae was in excess of 100 µg/L, whereas that for 19-day larvae was between 30 and 35 µg/L (Watling 1982). Significant delay of, and reduction in, successful settlement was observed after 5 days in 125 µg/L (Boyden et al. 1975) and after 20 days in 10 to 20 µg/L (Watling 1983). Juvenile oyster spat had a 23-day LC50 of 75 µg/L (Watling 1983).

Exposure to 176 µg/L for 72 hr caused a 50% reduction in the rate of calcium uptake by larvae of the clam, Mulinia lateralis, whereas a concentration of 200 µg/L caused 53% mortality among the clam larvae in the same time period (Ho and Suboff 1982). The 8 to 10-day LC50 was 195.4 µg/L for larvae of the quahog clam, Mercenaria mercenaria and growth of survivors was estimated to be reduced by 38.4% (Calabrese et al. 1977).

At concentrations as low as 250 µg/L, zinc caused significant delays in molting and development rate of larvae of the grass shrimp, Palaemonetes

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pugio, particularly under stressful temperature-salinity regimes (McKenney 1979; McKenney and Neff 1979,1981). Concentrations of 25 to 50 µg/L were without effect on the development rate of larvae of the mud crab, Rhithropanopeus harrisii (Benijts-Claus and Benijts 1975). However, in the presence of lead at 25 to 50 µg/L, these concentrations of zinc produced a significant delay in the rate of larval development of mud crabs. Rate of limb regeneration by adults of the fiddler crab, Uca pugilator, was inhibited at zinc concentrations of 1,000 (Weis 1980). This inhibitory effect was amplified at low salinities.

Motility of the sperm of the sea urchins, Arbacia punctulata and Strongylocentrotus purpuratus, was stimulated by brief exposure to zinc concentrations at or below 1,634 and 654.8 µg/L, respectively (Timourian and Watchmaker 1977; Young and Nelson 1974). At concentrations of 3,269 and 6,538 µg/L, respectively, sperm motility was inhibited. Reduction of the ability of echinoderm sperm to fertilize eggs appeared to be more sensitive than sperm motility to the toxic effects of zinc (Dinnel et al. 1983). EC50s after one hour of exposure of sperm ranged from 28 to 382.8 µg/L. In tests with the sand dollar, Dendraster excentricus, and two sea urchins, Strongylocentrotus droebachiensis and S. purpuratus, development to the pluteus stage was less sensitive than fertilization. Waterman (1937) found that 810 µg/L inhibited gastrulation and that 2,314 µg/L was lethal to embryos of Arbacia punctulata.

Somasundarum et al. (1984a,b,c,d;1985) identified several developmental anomalies and histopathological lesions in developing embryos and larvae of Atlantic herring, Clupea harengus, that were exposed to 50 to 12,000 µg/L. Zinc concentrations below 6,000 µg/L did not affect embryo volume. Below 2,000 µg/L, zinc accelerated embryonic development, but

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6,000 µg/L inhibited development. At zinc concentrations as low as 50 µg/L, there was a significant increase in the incidence of jaw and branchial abnormalities. Concentrations above 500 µg/L increased the incidence of vertebral abnormalities. Significant decreases in the size of the otic capsules and eyes were observed at zinc concentrations higher than 2,000 and 6,000 µg/L, respectively. Ultrastructural changes in brain cells and somatic musculature were observed in herring larvae that were allowed to develop for 14 days in sea water containing 50 to 12,000 µg/L.

In contrast to the toxic effects noted above, Weis et al. (1981) found that exposure to 10,000 µg/L ameliorated teratogenic effects on Fundulus heteroclitus exposed to methyl mercury. Also, zinc concentrations of 1,000 µg/L or greater enhanced regeneration of the tail fin and ameliorated effects of methyl mercury on fin regeneration in adult mummichogs (Weis and Weis 1980).

Exposure of adult mummichogs to 2,200 µg/L resulted in increased activity of the hepatic enzyme aminolevulinic acid dehydrase (Jackim 1973), whereas exposure to 60,000 µg/L caused 30% mortality and histopathological lesions in the oral epithelium of survivors (Eisler and Gardner 1973). Calcification of the scales of juvenile mummichogs was inhibited at 760 to 7,100 µg/L (Sauer and Watabe 1984).

Crustaceans and fish are able to accumulate zinc from both water and food. For adult green crabs, Carcinus maenas, the BCF for zinc from water was 130 and the bioaccumulation factor (BAF) for zinc from water and food was 210 (Renfro et al. 1975), but the BAF was not significantly higher. However the BAF was statistically higher than the BCF with adult mosquito fish, Gambusia affinis, and juvenile spot, Leiostomus xanthurus (Willis and Sunda 1984). At 120 days, the BAF and BCF for uptake of zinc from

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water alone and water plus food by mosquito fish were 45 and 8, respectively. The BAF and BCF for spot after a 28-day exposure were 28 and 3, respectively. These results suggest that these fish obtain five to nine times more zinc from food than from water. It must be recognized, however, that the relative magnitude of the contribution from both sources to the concentration of zinc in saltwater animals will depend on the relative concentrations of zinc in the water and food. Eisler (1967) and Eisler and Gardner (1973) have shown that BCFs for adult mummichogs, Fundulus heteroclitus, are inversely related to the concentration of zinc in the water.

Unused Data

Some data on the effects of zinc on aquatic organisms were not used because the studies were conducted with species that are not resident in North America (e.g., Abbasi and Soni 1986; Ahsanullah and Arnott 1978; Baudoin and Scoppa 1974; Bengtsson 1974a,b,c,d,e; Carter and Nicholas 1978; Chapman and Dunlop 1981; Dunlop and Chapman 1981; Greenwood and Fielder 1983; Harrison 1969; Howell 1985; Jones and Wacker 1979; Jones et al. 1984; Karbe et al. 1975; Khangarot 1981,1984; Khangarot et al. 1982, 1985; Kumar and Pant 1984; Lomte and Jackhar 1982; Lyon et al. 1983; Martin et al. 1977; Mathur et al. 1981; McFeters et al. 1983; Mecham and Holliman 1975; Millington and Walker 1983; Milner 1982; Murti and Shukla 1984; Natarajan 1982; Nazarenko 1970; Pentreath 1973; Sartory and Lloyd 1976; Sastry and Subhadra 1984; Saxena and Parashari 1983; Seiffer and Schoof 1967; Shaffi 1979; Shehata and Whitton 1981; Shukla et al. 1983; Solbe and Flook 1975; Speranza et al. 1977; Srivastava et al. 1985; Stary and Krantzer 1982; Subhadra and Sastry 1985; Thorp and Lake 1974; Verma et al. 1984; Wagh et al. 1985; White and Rainbow 1982; Willis 1983)

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or because the test specices was not obtained in North America and was not identified well enough to determine whether it is resident in North America (e.g., Greichus et al. 1978; Jennett et al. 1981; Pommery et al. 1985; Tishinova 1977). Results (e.g., Bagshaw et al. 1986; Brown and Ahsanullah 1971) of tests conducted with brine shrimp, Artemia sp., were not used because these species are from a unique saltwater environment.

Babich and Stotzky (1985), Biddinger and Gloss (1984), Cairns (1957), Campbell and Stokes (1985), Connolly (1985), Doudoroff and Katz (1953), Duxbury (1985), Eisler (1981), Hartman (1980), Kaiser (1980), LeBlanc (1984), Lim (1972), Lloyd (1965), Macek and Sleight (1977), Mancini (1983), McKim (1977), Pagenkopf (1976), Patrick et al. (1968), Phillips and Russo (1978), Polikarpov (1966), Rai et al. (1981b), Riordan (1976), Skidmore (1964), Skidmore and Firth (1983), Slooff et al. (1986), Sprague et al. (1964), Strufe (1964), Taylor et al. (1982), Thomson and MacPhee (1985), Vernon (1954), Vymazal (1985), Weatherley et al. (1980), and Whitton (1970) only contain data that have been published elsewhere.

Results were not used if either the test procedures, test material, or dilution water was not adequately described (e.g., Back 1983; Bates et al. 1981; Baudin 1983a,b; Berg and Brazzell 1975; Biegert and Valkovic 1980; Birge and Just 1973,1975; Bradley and Sprague 1983; Brauwers 1982; Brkovic-Popovic and Popovic 1977a,b; Brown 1968; Carpenter 1927; Coburn and Friedman 1976; Danil'chenko 1977; Darnall et al. 1986; Dilling and Healy 1927; Fleming and Richards 1982; Hutchinson and Sprague 1985; Ishizaka et al. 1966; Joraensostrorasks and McLaughlin 1974; Knittel 1980; Labat et al. 1977; Miller et al. 1985; Muramoto 1980; Pavicic 1980; Petry 1983; Rao and Saxena 1981; Sabodash 1974; See et al. 1974,1975;

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Sicko-Goad and Lazinsky 1981; Tokunago and Kishikawa 1982; Vinot and Larpent 1984).

Data were not used if zinc was a component of an effluent (e.g., Bailey and Liu 1980; Cherry et al. 1979; Finlayson and Ashuchian 1979; Frazier 1976; Grushko et al. 1980; Guthrie et al. 1977; Jay and Muncy 1979; Lewis 1986; Lu et al. 1975; Nagy-Toth and Barna 1983; Nehring and Goettl 1974; Neufeld and Wallach 1984; Newman et al. 1985; O'Conner 1976; Oladimeji and Wade 1984; Ozlmek 1985; Phillips and Gregory 1980; Rana and Kumar 1975; Roesijadi et al. 1984; Saunders and Sprague 1967; Sprecht et al. 1984; Wang 1982; Whitton et al. 1981; Wong and Tam 1984a,b; Wood 1975), mixture (e.g., Baker and Boldigo 1984; Besser 1985; Biesinger et al. 1974; Birge et al. 1978; Borgmann 1980; Brown et al. 1969; Cairns and Scheier 1968; Cearley 1971; Chang et al. 1981; Christensen et al. 1985; Cowgill et al. 1986; Danil'chenko and Stroganov 1975; Davies 1985; Davies and Woodling 1980; Doudoroff 1956; Doudoroff et al. 1966; Eaton 1973; Eisler 1977b; Finlayson and Verrue 1980; Giesy et al. 1980; Hedtke and Puglisi 1980; Henry and Atchison 1979a,b; Hutchinson and Czyrska 1972; Hutchinson and Sprague 1983; Lubinski and Sparks 1981; Markarian et al. 1980; Marking and Bills 1985; McLeese and Ray 1984; Muller and Payer 1980; Muska 1977; Patrick and Loutit 1976,1978; Pope 1981; Roch and McCarter 1984c,1986; Roch et al. 1985,1986; Rodgers and Beamish 1983; Sprague 1965; Stromegren 1980; Vymazal 1984; Wong et al. 1982a,b,1984b), or a sediment (e.g., Arruda et al. 1983; Broberg 1984; Bryan et al. 1983; Dean 1974; Krantzberg 1983; Laskowski-Hoke and Prater 1984; Lewis and McIntosh 1984, 1986; Luoma and Jenne 1977; Malueg 1984; McMurtry 1984; Munawar et al. 1985; Oakden et al. 1984; Ray et al. 1981; Seelye et al. 1982; Wentsel et al. 1977; Wong and Kwan 1981; Wong and Tam 1984; Wong et al. 1984a).

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Data were not used if the organisms were exposed to zinc by injection or gavage or in food (e.g., Barash et al. 1982; Baudin 1985; Bell et al. 1984; Cancalon 1982; Cowgill et al. 1985; Dallinger and Wieser 1984; Dixon and Compher 1977; Gatlin and Wilson 1983,1984; Hibiya and Oguri 1961; Jeng and Sun 1981; Knox et al. 1984; Lyon et al. 1984; Mansouri-Aliabadi and Sharp 1985; Marafonte 1976; Ogino and Yang 1978,1979; Patrick and Loutit 1978; Richardson et al. 1985; Saiki and Mori 1955; Satoh et al. 1983a,b; Smith-Sonneborn et al. 1983; Suzuki and Ebihara 1984; Suzuki and Kawamura 1984; Suzuki et al. 1983,1984; Takeda and Shimma 1977; Vaughan et al. 1982; Windom et al. 1982; Young 1975).

Adragna and Privitera (1978,1979), Akberali and Earnshaw (1982), Anderson et al. (1978), Babich et al. (1985,1986a,b), Brown (1976), Burton and Peterson (1979), Cenini and Turner (1983), Crespo (1984), Crist et al. (1981), Doyle et al. (1981), Everaarts et al. (1979), Fleming et al. (1982), George (1983), Hiller and Perlmutter (1971), Hiltibran (1971), Kodama et al. (1982a), Nemosok et al. (1984), Rachlin and Perlmutter (1969), Sirover and Loeb (1976), and Watson and Beamish (1981) only exposed enzymes, excised or homogenized tissue, or cell cultures.

Results of some laboratory tests were not used because the tests were conducted in distilled or deionized water without addition of appropriate salts (e.g., Afflect 1952; Carter and Cameron 1973; Eddy and Fraser 1982; Matthiessen and Brafield 1973; McDonald et al. 1980; Porter and Hakanson 1976; Stary and Kratzer 1982; Stary et al. 1983; Taylor 1978; Vijayamadhavan and Iwai 1975; Wang 1959) or were conducted in chlorinated or "tap" water (e.g., Goodman 1951; Grande 1966; Haider and Wunder 1983; Hughes and Adeney 1977; Jones 1935,1938,1939; Matthiessen and Brafield 1977; Rahel

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1981; Shcherban 1977; Skidmore 1970; Skidmore and Tovell 1972). Dilution water was at too low a pH in tests by Michnowicz and Weaks (1984), whereas temperature fluctuated too much in the test reported by Mills (1976b).

Allan et al. (1980), Bates et al. (1983), Buikema et al. (1974a,b, 1977), Cairns and Dickson (1970), Fayed and Abd-El-Shafy (1985), Kuwabara (1985), Mills (1976a,b), Petersen (1982), Rainbow et al. (1980), Ruthven and Cairns (1973), Say and Whitton (1977), Sullivan et al. (1973), and Zitko et al. (1973) used dilution water that contained too high a concentration of chelating agent or other organic matter. Mukhopadhyay and Konar (1984) used a phosphate buffer, which might have detoxified zinc, although their LC50s for two invertebrate species were quite low after adjustment for hardness.

Benson and Birge (1985), Berglind and Dave (1984), and Birge et al. (1983) cultured or acclimated organisms in one water and conducted tests in another. Hughes (1970,1973) did not acclimate organisms for a long enough time. Tests conducted with too few test organisms (e.g., Applegate et al. 1957; Gardner 1975; McLeese 1976; Sprague 1964a; Tishinova 1977) were not used. High control mortalities occurred in tests reported by Cairns and Scheier (1964) and Havas and Hutchinson (1982). The water quality varied too much during tests conducted by Cairns et al. (1981), Nehring and Goettl (1974), and Thompson et al. (1980). Toxicity tests conducted without controls were not used (e.g., Graham et al. 1986). The 96-hr values reported by Buikema et al. (1974a,b) were subject to error because of possible reproductive interactions (Buikema et al. 1977). The test organisms were possibly stressed by disease or parasites during tests reported by Boyce and Yamada (1977), Guth et al. (1977), and Sakanari et al. (1984). Hublou et al. (1954) conducted tests on zinc leached from galvanized trays. Anudu (1983), Bradley et al. (1985a,b),

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Cairns (1972), Cairns et al. (1973a,b), DeFilippis and Pallaghy (1976), Duncan and Klaverkamp (1980), Foster (1982b), LeBlanc (1982), and Wang (1986b) conducted studies of acclimation to zinc or used organisms that had been exposed or were resistant to zinc.

Biochemical and histological studies were not used (e.g., Anderson and Sparks 1978; Canalon 1982; Cenini and Turner 1979; Eddy and Talbot 1985; Kearns and Atchison 1979; Kodama et al. 1982a,b; Nemcsok et al. 1984; Rachlin et al. 1985; Sailer et al. 1980; Schmitt et al. 1984; Taban et al. 1982; Thomas et al. 1985; Vijayamadhauan and Iwai 1975; Watson and Beamish 1980; Watson and McKoewn 1976; Yamamoto et al. 1977).

Results of chronic tests were not used if the concentration of test material was not measured (e.g., Winner and Gauss 1986) or if the test solutions were only renewed once a week (e.g., Crandall and Goodnight 1962,1963). Data on toxicity or accumulation or both from microcosm or model ecosystem studies were not used if the concentration of zinc in water decreased with time (e.g., Bachman 1963; Davis and Negilski 1972).

Results of laboratory bioconcentration tests were not used if the test was not flow-through or renewal (e.g., Dean 1974; Evtushenko et al. 1984; Fayed et al. 1983; Hughes and Flos 1978; Joyner 1961; Joyner and Eisler 1961; Lyngby et al. 1982; Skipnes et al. 1975; Sklar 1980; Slater 1961; Young 1977) or if the concentration of zinc in the test solution was not adequately measured (e.g., Mellinger 1972; Munda 1979,1984; Phillips 1976,1977). Hardy and Raber (1985) did not measure the concentration of zinc in tissues.

Van Hoof and Van San (1981) found high concentrations of zinc in their control fish. Harvey (1974) studied depuration, but not uptake, of zinc by a freshwater clam, and Ferguson and Bubela (1974) studied uptake by homogenized algal suspensions. The concentration of zinc fluctuated too much in the tests reported by Kormondy (1965) and O'Grady and Obdullah (1985).

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Reports of the concentrations of zinc in wild aquatic organisms (e.g., Abdullah et al. 1976; Abo-Rady 1979,1983; Adams et al. 1980,1981; Amemiya and Nakayama 1984; Anderson 1977; Anderson et al. 1978; Arnac and Lassus 1985; Badsha and Goldspink 1982; Bailey and Stokes 1985; Barber and Trefry 1981; Bohn and Fallis 1978; Bosserman 1985; Bradley and Morris 1986; Brezina and Arnold 1977; Brooks et al. 1976; Brown 1977; Brown and Chlow 1977; Burrows and Whitton 1983; Burton and Peterson 1979; Bussey et al. 1976; Caines et al. 1985; Chapman 1985; Chassard and Balvay 1978; Coughtrey and Martin 1977; Cover and Wilhm 1982; Cowx 1982; Dallinger and Kautzky 1985; EIFAC 1977; Elder and Mattraw 1984; Elliott et al. 1981; Elwood et al. 1976; Estabrook et al. 1985; Felat and Melzer 1978; Fletcher and King 1978; Fletcher et al. 1975; Franzin and McFarlane 1980; Frazier 1975; Friant and Koerner 1981; Friant and Sherman 1980; Gale et al. 1973a,b; Giesy and Weiner 1977; Greichus et al. 1978; Guillizzoni 1980; Hakanson 1984; Harding and Whitton 1978; Heit and Klusek 1985; Holm 1980; Howard and Brown 1983; Huggett et al. 1973; Jeng and Lo 1974; Johannessan et al. 1983; Jones et al. 1985; Kleinert et al. 1974; Kole et al. 1978; Korda et al. 1977; Lee et al. 1984; Lewis 1980; Lobel and Wright 1983; Lord et al. 1977; Lowe et al. 1985; Lucas and Edgington 1970; Lundholm and Andersson 1985; Maas 1978; McFarlane and Franzin 1978; McHardy and George 1985; Moreau et al. 1983; Morrison et al. 1985; Nabrzyski 1975; Nabrzyski and Gajewski 1978; Namminga and Wilhm 1977; Ney and Martin 1985; Ney et al. 1982; Norris and Lake 1984; O'Grady 1981; Paul and Pillai 1983; Pennington et al. 1982; Percy and Borland 1985; Peverly 1985; Rabe et al. 1977; Ranta et al. 1978; Ray and White 1979; Rehwoldt et al. 1976; Romberg and Refro 1973; Salanki et al. 1982; Saltes and Bailey 1984; Seagle and Ehlmann 1974; Shearer 1984; Shimma et al. 1984;

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Shuman et al. 1977; Simpson 1979; Stary et al. 1982; Stokes et al. 1985; Strufe 1964; Teherani et al. 1979; Tessier et al. 1984; Tisa and Strange 1981; Tsui and McCart 1981; Uthe and Bligh 1971; Van Coillie and Rousseau 1974; Van Loon and Beamish 1977; Villarreal-Trevino et al. 1986; Vinikour et al. 1980; Wachs 1982; Walker et al. 1975; Wehr and Whitton 1983a,b; Wehr et al. 1983; Whitton et al. 1981,1982; Wiener and Giesy 1979; Winger and Andreasen 1985; Wissmar et al. 1982; Young and Blevins 1981, Zadory 1984) were not used to calculate bioaccumulation factors because either the number of measurements of the concentration in water was too small or the range of the measured concentrations in water was too large.

Summary

Acute toxicity values are available for 43 species of freshwater animals and data for eight species indicate that acute toxicity decreases as hardness increases. When adjusted to a hardness of 50 mg/L, sensitivities range from 50.70 µg/L for Ceriodaphnia reticulata to 88,960 µg/L for a damselfly. Additional data indicate that toxicity increases as temperature increases. Chronic toxicity data are available for nine freshwater species. Chronic values for two invertebrates ranged from 46.73 µg/L for Daphnia magna to >5,243 µg/L for the caddisfly, Clistoronia magnifica. Chronic values for seven fish species ranged from 36.41 µg/L for the flagfish, Jordanella floridae, to 854.7 µg/L for the brook trout, Salvelinus fontinalis. Acute-chronic ratios ranged from 0.2614 to 41.20, but the ratios for the sensitive species were all less than 7.3.

The sensitivity range of freshwater plants to zinc is greater than that for animals. Growth of the alga, Selenastrum capricornutum, was inhibited by 30 µg/L. On the other hand, with several other species of

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green algae, 4-day EC50s exceeded 200,000 µg/L. Zinc was found to bioaccumulate in freshwater animal tissues from 51 to 1,130 times the concentration present in the water.

Acceptable acute toxicity values for zinc are available for 33 species of saltwater animals including 26 invertebrates and 7 fish. LC50s range from 191.5 µg/L for cabezon, Scorpaenichthys marmoratus to 320,400 µg/L for adults of another clam, Macoma balthica. Early life stages of saltwater invertebrates and fishes are generally more sensitive to zinc than juveniles and adults. Temperature has variable and inconsistent effects on the sensitivity of saltwater invetebrates to zinc. The sensitivity of saltwater animals to zinc decreases with increasing salinity, but the magnitude of the effect is species-specific.

A life-cycle test with the mysid, Mysidopsia bahia, found unacceptable effects at 120 µg/L, but not at 231 µg/L, and the acute-chronic ratio was 2.997. Seven species of saltwater plants were affected at concentrations ranging from 19 to 10,100 µg/L. Bioaccumulation data for zinc are available for seven species of saltwater algae and five species of saltwater animals. Steady-state zinc bioconcentration factors for the twelve species range from 3.692 to 23,820.

National Criteria

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration (in µg/L) of zinc does not exceed the numerical value given by

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$e^{(0.8473[\ln(\text{hardness})]+0.7614)}$ more than once every three years on the average and if the one-hour average concentration (in µg/L) does not exceed the numerical value given by $e^{(0.8473[\ln(\text{hardness})]+0.8604)}$ more than once every three years on the average. For example, at hardnesses of 50, 100, and 200 mg/L as $CaCO_3$ the four-day average concentrations of zinc are 59, 110, and 190 µg/L, respectively, and the one-hour average concentrations are 65, 120, and 210 µg/L. If the striped bass is as sensitive as some data indicate, it will not be protected by this criterion.

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, saltwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration of zinc does not exceed 86 µg/L more than once every three years on the average and if the one-hour average concentration does not exceed 95 µg/L more than once every three years on the average.

"Acid-soluble" is probably the best measurement at present for expressing criteria for metals and the criteria for zinc were developed on this basis. However, at this time, no EPA approved method for such a measurement is available to implement criteria for metals through the regulatory programs of the Agency and the States. The Agency is considering development and approval of a method for a measurement such as "acid-soluble." Until one is approved, however, EPA recommends applying criteria for metals using the total recoverable method. This has two impacts: (1) certain species of some metals cannot be measured because the total recoverable method cannot distinguish between individual oxidation

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states, and (2) in some cases these criteria might be overly protective when based on the total recoverable method.

Three years is the Agency's best scientific judgment of the average amount of time aquatic ecosystems should be provided between excursions (U.S. EPA 1985b). The resiliencies of ecosystems and their abilities to recover differ greatly, however, and site-specific allowed excursion frequencies may be established if adequate justification is provided.

Use of criteria for developing water quality-based permit limits and for designing waste treatment facilities requires selection of an appropriate wasteload allocation model. Dynamic models are preferred for the application of these criteria (U.S. EPA 1985b). Limited data or other considerations might make their use impractical, in which case one must rely on a steady-state model (U.S. EPA 1986).

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Table 1. Acute Toxicity of Zinc to Aquatic Animals

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Adjusted LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)****	Reference
			FRESHWATER SPECIES				
Worm, *Lumbriculus variegatus*	S, U	Zinc chloride	30	6,300	9,712	9,712	Bailey and Liu 1980
Tubificid worm, *Limnodrilus hoffmeisteri*	S, U	Zinc sulfate	100	>2,274	>1,264	>1,264	Wurtz and Bridges 1961
Worm, *Nais* sp.	S, M	-	50	18,400†	18,400	18,400	Rehwoldt et al. 1973
Snail (embryo), *Amnicola* sp.	S, M	-	50	20,200†	20,200	-	Rehwoldt et al. 1973
Snail (adult), *Amnicola* sp.	S, M	-	50	14,000†	14,000	16,820	Rehwoldt et al. 1973
Snail (adult), *Helisoma campanulatum*	S, U	Zinc sulfate	20 (12.8°C)	870	1,891	-	Wurtz 1962
Snail (adult), *Helisoma campanulatum*	S, U	Zinc sulfate	20 (22.8°C)	1,270	2,760	-	Wurtz 1962
Snail (adult), *Helisoma campanulatum*	S, U	Zinc sulfate	100 (12.8°C)	3,030	1,684	-	Wurtz 1962
Snail (adult), *Helisoma campanulatum*	S, U	Zinc sulfate	100 (22.8°C)	1,270	705.9	1,578	Wurtz 1962
Snail (adult), *Physa gyrina*	F, M	Zinc chloride	36	1,274	1,683	1,683	Nebeker et al. 1986
Snail, *Physa heterostropha*	S, U	Zinc chloride	45 (20°C)	1,800	1,968	-	Cairns and Scheier 1958b; Academy of Natural Sciences 1960

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Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Adjusted LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)****	Reference
Snail, Physa heterostropha	S, U	Zinc chloride	45 (30°C)	1,000	1,093	-	Cairns and Scheier 1958b; Academy of Natural Sciences 1960
Snail, Physa heterostropha	S, U	Zinc chloride	170 (20°C)	6,200	2,198	-	Cairns and Scheier 1958b; Academy of Natural Sciences 1960
Snail, Physa heterostropha	S, U	Zinc chloride	170 (30°C)	7,100	2,517	-	Cairns and Scheier 1958b; Academy of Natural Sciences 1960
Snail (adult), Physa heterostropha	S, U	Zinc sulfate	20	1,110	2,413	-	Wurtz and Bridges 1961; Wurtz 1962
Snail (adult), Physa heterostropha	S, U	Zinc sulfate	100	3,160	1,756	-	Wurtz and Bridges 1961; Wurtz 1962
Snail (young), Physa heterostropha	S, U	Zinc sulfate	20 (10.6°C)	303	658.6	-	Wurtz 1962
Snail (young), Physa heterostropha	S, U	Zinc sulfate	20 (12.8°C)	434	943.3	-	Wurtz 1962
Snail (young), Physa heterostropha	S, U	Zinc sulfate	20 (32.2°C)	350	760.8	-	Wurtz 1962
Snail (young), Physa heterostropha	S, U	Zinc sulfate	100 (10.6°C)	434	241.2	-	Wurtz 1962
Snail (young), Physa heterostropha	S, U	Zinc sulfate	100 (12.8°C)	1,390	772.6	-	Wurtz 1962
Snail (young), Physa heterostropha	S, U	Zinc sulfate	100 (32.2°C)	1,110	617.0	1,088	Wurtz 1962
Asiatic clam (10-21 mm), Corbicula fluminea	S, M	Zinc sulfate	64	6,040†	4,900	4,900	Cherry et al. 1980; Rodgers et al. 1980

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Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Adjusted LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)****	Reference
Cladoceran (<24 hr), Ceriodaphnia dubia	R, M	Zinc chloride	52	180	174.1	174.1	Carlson et al. 1986
Cladoceran, Ceriodaphnia reticulata	S, U	-	45	76	83.10	-	Mount and Norberg 1984
Cladoceran, Ceriodaphnia reticulata	S, U	Zinc chloride	45	41	44.82	-	Carlson and Roush 1985
Cladoceran, Ceriodaphnia reticulata	S, M	Zinc chloride	45	32	34.99	50.70	Carlson and Roush 1985
Cladoceran, Daphnia magna	S, U	Zinc chloride	-	<71.95	-	-	Anderson 1948
Cladoceran, Daphnia magna	S, U	Zinc chloride	45.3	100	108.7	-	Biesinger and Christensen 1972
Cladoceran, Daphnia magna	S, M	Zinc sulfate	45	280	306.1	-	Cairns et al. 1978
Cladoceran, Daphnia magna	S, U	-	45	68	74.35	-	Mount and Norberg 1984
Cladoceran, Daphnia magna	S, M	Zinc chloride	54	334	312.9	-	Chapman et al. Manuscript
Cladoceran, Daphnia magna	S, M	Zinc chloride	105	525	280.0	-	Chapman et al. Manuscript
Cladoceran, Daphnia magna	S, M	Zinc chloride	196	655	205.8	-	Chapman et al. Manuscript
Cladoceran, Daphnia magna	F, M	Zinc chloride	130	798.9	355.5	355.5	Attar and Maly 1982
Cladoceran, Daphnia pulex	S, M	Zinc sulfate	45	500	546.7	-	Cairns et al. 1978
Cladoceran, Daphnia pulex	S, U	-	45	107	117.0	252.9	Mount and Norberg 1984

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Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Adjusted LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)****	Reference
Isopod (3-7 mm), Asellus bicrenata	F, M	Zinc sulfate	220	20,110††	5,731	5,731	Bosnak and Morgan 1981
Isopod, Asellus communis	S, U	Zinc sulfate	20	12,734	27,680	-	Wurtz and Bridges 1961
Isopod, Asellus communis	S, U	Zinc sulfate	100	8,755	4,866	11,610	Wurtz and Bridges 1961
Isopod (3-7 mm), Lirceus alabamae	F, M	Zinc sulfate	152	8,375††	3,265	3,265	Bosnak and Morgan 1981
Amphipod, Crangonyx pseudogracilis	R, U	Zinc sulfate	50	19,800	19,800	19,800	Martin and Holdich 1986
Amphipod, Gammarus sp.	S, M	-	50	8,100†	8,100	8,100	Rehwoldt et al. 1973
Damselfly, Argia sp.	S, U	Zinc sulfate	20	40,930	88,960	88,960	Wurtz and Bridges 1961
Bryozoan, Pectinatella magnifica	S, U	-	190-220	4,310	1,307	1,307	Pardue and Wood 1980
Bryozoan, Lophopodella carteri	S, U	-	190-220	5,630	1,707	1,707	Pardue and Wood 1980
Bryozoan, Plumatella emarginata	S, U	-	190-220	5,300	1,607	1,607	Pardue and Wood 1980

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Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Adjusted LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)****	Reference
American eel, Anguilla rostrata	S, M	-	55	14,500†	13,380	-	Rehwoldt et al. 1972
American eel, Anguilla rostrata	S, M	Zinc nitrate	53	14,600†	13,900	13,630	Rehwoldt et al. 1973
Coho salmon (yearling), Oncorhynchus kisutch	R, M	Zinc chloride	94	4,600	2,694	-	Lorz and McPherson 1976,1977
Coho salmon, Oncorhynchus kisutch	F, M	Zinc chloride	25	905	1,628	1,628	Chapman and Stevens 1978
Sockeye salmon (parr), Oncorhynchus nerka	F, M	Zinc chloride	22	749	1,502	1,502	Chapman 1975,1978a
Chinook salmon (alevin), Oncorhynchus tshawytscha	F, M	Zinc chloride	23	>661†††	-	-	Chapman 1975,1978b
Chinook salmon (juvenile), Oncorhynchus tshawytscha	F, M	Zinc sulfate	21	84	175.2	-	Finlayson and Verrue 1982
Chinook salmon (swim-up alevin), Oncorhynchus tshawytscha	F, M	Zinc chloride	23	97	187.3	-	Chapman 1975,1978b
Chinook salmon (parr), Oncorhynchus tshawytscha	F, M	Zinc chloride	23	463	894.0	-	Chapman 1975,1978b
Chinook salmon (smolt), Oncorhynchus tshawytscha	F, M	Zinc chloride	23	701	1,354	446.4	Chapman 1975,1978b
Cutthroat trout (fingerling), Salmo clarki	R, M	Zinc sulfate	-	90†	-	-	Rabe and Sappington 1970
Rainbow trout (juvenile), Salmo gairdneri	F, M	Zinc sulfate	330	7,210	1,457	-	Sinley et al. 1974
Rainbow trout (juvenile), Salmo gairdneri	F, M	Zinc sulfate	25	430	773.6	-	Sinley et al. 1974
Rainbow trout (30.5 g), Salmo gairdneri	F, M	Zinc sulfate	30	430	662.9	-	Goetti et al. 1974
Rainbow trout (22.6 g), Salmo gairdneri	F, M	Zinc sulfate	30	810	1,249	-	Goetti et al. 1974

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Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Adjusted LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)****	Reference
Rainbow trout (29.7 g), Salmo gairdneri	F, M	Zinc sulfate	30	410	632.1	-	Goetti et al. 1974, 1976
Rainbow trout (18.3 g),	F, M	Zinc sulfate	312	4,520	958.0	-	Goetti et al. 1974,
Rainbow trout (2.0 g), Salmo gairdneri	F, M	Zinc sulfate	312	1,190	252.2	-	Goetti et al. 1974, 1976
Rainbow trout (34.6 g), Salmo gairdneri	F, M	Zinc sulfate	23	560	1,081	-	Goettle et al. 1974 1976
Rainbow trout (4.9 g), Salmo gairdneri	F, M	Zinc sulfate	22	240	481.2	-	Goetti et al. 1974, 1976
Rainbow trout (52.1 g), Salmo gairdneri	F, M	Zinc sulfate	30	830	1,280	-	Goetti et al. 1974, 1976
Rainbow trout (15.4 g), Salmo gairdneri	F, M	Zinc sulfate	314	7,210	1,520	-	Goetti et al. 1974, 1976
Rainbow trout (72 g), Salmo gairdneri	F, M	Zinc sulfate	102	1,000	546.6	-	Goetti et al. 1974, 1976
Rainbow trout (juvenile), Salmo gairdneri	R, U	Zinc sulfate	5	280	1,970	-	McLeay 1976
Rainbow trout (alevin), Salmo gairdneri	F, M	Zinc chloride	23	815	1,574	-	Chapman 1975,1978b
Rainbow trout (swim-up alevin), Salmo gairdneri	F, M	Zinc chloride	23	93	179.6	-	Chapman 1975,1978b
Rainbow trout (parr), Salmo gairdneri	F, M	Zinc chloride	23	136	262.6	-	Chapman 1975,1978b
Rainbow trout (smolt), Salmo gairdneri	F, M	Zinc chloride	23	>651†††	-	-	Chapman 1975,1978b
Rainbow trout (adult male), Salmo gairdneri	F, M	Zinc chloride	83	1,755	1,142	-	Chapman and Stevens 1978

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Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Adjusted LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)****	Reference
Rainbow trout (juvenile), Salmo gairdneri	F, M	Zinc sulfate	46.8	370	391.3	-	Holcombe and Andrew 1978
Rainbow trout (juvenile), Salmo gairdneri	F, M	Zinc sulfate	47.0	517	544.8	-	Holcombe and Andrew 1978
Rainbow trout (juvenile), Salmo gairdneri	F, M	Zinc sulfate	44.4	756	836.0	-	Holcombe and Andrew 1978
Rainbow trout (juvenile), Salmo gairdneri	F, M	Zinc sulfate	178	2,510	855.9	-	Holcombe and Andrew 1978
Rainbow trout (juvenile), Salmo gairdneri	F, M	Zinc sulfate	179	2,960	1,005	-	Holcombe and Andrew 1978
Rainbow trout (juvenile), Salmo gairdneri	F, M	Zinc sulfate	170	1,910	677.2	-	Holcombe and Andrew 1978
Rainbow trout (fingerling), Salmo gairdneri	S, M	Zinc sulfate	14	560	1,647	-	Spry and Wood 1984
Rainbow trout (fry), Salmo gairdneri	F, M	Zinc chloride	9.2 (pH=7.0)	66	277.0	689.3	Cusimano et al. 1986
Atlantic salmon (parr), Salmo salar	F, M	Zinc sulfate	14	740	2,176	2,176	Carson and Carson 1972
Brook trout (juvenile), Salvelinus fontinalis	F, M	Zinc sulfate	46.8	1,550	1,639	-	Holcombe and Andrew 1978
Brook trout (juvenile), Salvelinus fontinalis	F, M	Zinc sulfate	47.0	2,120	2,234	-	Holcombe and Andrew 1978
Brook trout (juvenile), Salvelinus fontinalis	F, M	Zinc sulfate	44.4	2,420	2,676	-	Holcombe and Andrew 1978
Brook trout (juvenile), Salvelinus fontinalis	F, M	Zinc sulfate	178	6,140	2,094	-	Holcombe and Andrew 1978
Brook trout (juvenile), Salvelinus fontinalis	F, M	Zinc sulfate	179	6,980	2,369	-	Holcombe and Andrew 1978

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Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Adjusted LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)****	Reference
Brook trout (juvenile), Salvelinus fontinalis	F, M	Zinc sulfate	170	4,980	1,766	2,100	Holcombe and Andrew 1978
Longfin dace (juvenile), Agosia chrysogaster	R, M	Zinc sulfate	217	790†	227.8	227.8	Lewis 1978
Goldfish, Carassius auratus	S, U	Zinc sulfate	50	7,500	7,500	-	Cairns et al. 1969
Goldfish (1-2 g), Carassius auratus	S, U	Zinc sulfate	20	6,440	14,000	10,250	Pickering and Henderson 1966
Common carp (<20 cm), Cyprinus carpio	S, M	Zinc nitrate	53	7,800†	7,424	-	Rehwoldt et al. 1971
Common carp, Cyprinus carpio	S, M	-	55	7,800†	7,194	-	Rehwoldt et al. 1972
Common carp (2.1 g), Cyprinus carpio	R, U	Zinc sulfate	19	3,120	7,083	7,233	Khangarot et al. 1983
Golden shiner, Notemigonus crysoleucas	S, U	Zinc sulfate	50	6,000	6,000	6,000	Cairns et al. 1969
Fathead minnow (embryo), Pimephales promelas	F, M	Zinc sulfate	174-198	1,820	599.0	-	Pickering and Vigor 1965
Fathead minnow (embryo), Pimephales promelas	F, M	Zinc sulfate	174-198	1,850	608.9	-	Pickering and Vigor 1965
Fathead minnow (fry), Pimephales promelas	F, M	Zinc sulfate	174-198	870	286.3	-	Pickering and Vigor 1965
Fathead minnow (1-2 g), Pimephales promelas	S, U	Zinc sulfate	20 (15°C)	2,550	5,543	-	Pickering and Henderson 1966

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Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Adjusted LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)****	Reference
Fathead minnow (1-2 g) Pimephales promelas	S, U	-	20 (15°C)	2,330	5,064	-	Pickering and Henderson 1966
Fathead minnow (1-2 g), Pimephales promelas	S, U	Zinc sulfate	20 (25°C)	770 (780)	1,674	-	Pickering and Henderson 1966
Fathead minnow (1-2 g), Pimephales promelas	S, U	Zinc sulfate	20 (25°C)	960	2,087	-	Pickering and Henderson 1966
Fathead minnow (1-2 g), Pimephales promelas	S, U	Zinc sulfate	360 (25°C)	33,400	6,271	-	Pickering and Henderson 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	63	12,500	10,280	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	54	13,800	12,930	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	97	18,500	10,550	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	103	25,000	13,550	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	212	29,000	8,528	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	208	35,500	10,610	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	54	13,700	12,840	-	Mount 1966

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Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Adjusted LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)****	Reference
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	63	6,200	5,097	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	100	12,500	6,948	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	99	12,500	7,007	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	186	19,000	6,242	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	195	13,600	4,293	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	54	4,700	4,403	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	49	5,100	5,188	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	98	8,100	4,580	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	102	9,900	5,411	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	193	8,200	2,611	-	Mount 1966
Fathead minnow (1-2 g), Pimephales promelas	F, M	Zinc sulfate	216	15,500	4,486	-	Mount 1966
Fathead minnow (44.6 mm), Pimephales promelas	S, U	Zinc sulfate	166	7,630	2,760	-	Rachlin and Perlmutter 1968

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Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Adjusted LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)****	Reference
Fathead minnow (2-3 g), Pimephales promelas	F, M	Zinc sulfate	203	8,400	2,563	-	Brungs 1969
Fathead minnow (2-3 g), Pimephales promelas	F, M	Zinc sulfate	203	10,000	3,051	-	Brungs 1969
Fathead minnow (2-3 g), Pimephales promelas	S, U	Zinc sulfate	203	12,000	3,661	-	Brungs 1969
Fathead minnow (2-3 g), Pimephales promelas	S, U	Zinc sulfate	203	13,000	3,966	-	Brungs 1969
Fathead minnow (4 wk), Pimephales promelas	F, M	Zinc sulfate	46	600	643.9	-	Benoit and Holcombe 1978
Fathead minnow (1-2 g), Pimephales promelas	S, M	Zinc sulfate	45	3,100	3,389	-	Judy and Davies 1979
Fathead minnow (juvenile), Pimephales promelas	F, M	Zinc sulfate	220	2,610	743.8	-	Broderius and Smith 1979
Fathead minnow (larva), Pimephales promelas	S, M	Zinc chloride	45	396	433.0	-	Carlson and Roush 1985
Fathead minnow (<24 hr), Pimephales promelas	S, M	Zinc chloride	52	551	533.0	3,830	Carlson et al. 1986
Northern squawfish (juvenile), Ptychocheilus oregonensis	F, M	Zinc chloride	20-30	3,498	6,404	-	Andros and Garton 1980
Northern squawfish (juvenile), Ptychocheilus oregonensis	F, M	Zinc chloride	20-30	3,693	6,761	6,580	Andros and Garton 1980
White sucker (17.7 g), Catostomus commersoni	F, M	Zinc chloride	18	2,200	5,228	5,228	Duncan and Klaverkamp 1983

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Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Adjusted LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)****	Reference
Banded killifish (<20 cm), Fundulus diaphanus	S, M	Zinc nitrate	53	19,100†	18,180	-	Rehwoldt et al. 1971
Banded killifish, Fundulus diaphanus	S, M	-	55	19,200†	17,710	17,940	Rehwoldt et al. 1972
Flagfish (juvenile), Jordanella floridae	F, M	Zinc sulfate	44	1,500	1,672	1,672	Spehar 1976a,b
Guppy (6 mo), Poecilia reticulata	S, U	Zinc sulfate	20	1,270	2,760	-	Pickering and Henderson 1966
Guppy, Poecilia reticulata	S, U	Zinc sulfate	120	30,000	14,290	-	Cairns et al. 1969
Guppy (fry), Poecilia reticulata	S, M	Zinc sulfate	30	1,740	2,682	-	Pierson 1981
Guppy (adult male), Poecilia reticulata	S, M	Zinc sulfate	30	5,050	7,785	-	Pierson 1981
Guppy (adult female), Poecilia reticulata	S, M	Zinc sulfate	30	6,400	9,866	-	Pierson 1981
Guppy (adult male), Poecilia reticulata	S, U	Zinc sulfate	118	300,000††††	-	-	Sehgal and Saxena 1988
Guppy (adult female), Poecilia reticulata	S, U	Zinc sulfate	118	278,000††††	-	6,053	Sehgal and Saxena 1988
Southern platyfish (20.8 mm), Xiphophorus maculatus	S, U	Zinc sulfate	166	12,000	4,341	4,341	Rachlin and Perlmutter 1968
White perch (<20 cm), Morone americana	S, M	Zinc nitrate	53	14,300†	13,610	-	Rehwoldt et al. 1971
White perch, Morone americana	S, M	-	55	14,400†	13,280	13,450†††††	Rehwoldt et al. 1972
Striped bass (fingerling), Morone saxatilis	S, M	Zinc nitrate	53	6,700†,††††	-	-	Rehwoldt et al. 1971

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Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Adjusted LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)****	Reference
Striped bass, Morone saxatilis	S, M	-	55	6,800†,††††	-	-	Rehwoldt et al. 1972
Striped bass (63 d), Morone saxatilis	S, U	Zinc chloride	40	120	145.0	-	Palawski et al. 1985
Striped bass (63 d), Morone saxatilis	S, U	Zinc chloride	285	430	98.40	119.4	Palawski et al. 1985
Pumpkinseed (<20 cm), Lepomis gibbosus	S, M	Zinc nitrate	53	20,000†	19,040	-	Rehwoldt et al. 1971
Pumpkinseed, Lepomis gibbosus	S, M	-	55	20,100†	18,540	18,790	Rehwoldt et al. 1972
Bluegill (3.5-3.9 g), Lepomis macrochirus	S, U	Zinc chloride	45 (18°C)	4,200	4,592	-	Cairns and Scheier 1957, 1968; Academy of Natural Sciences 1960
Bluegill (3.5-3.9 g), Lepomis macrochirus	S, U	Zinc chloride	45 (30°C)	3,500	3,827	-	Cairns and Scheier 1957; Academy of Natural Sciences 1960
Bluegill (3.5-3.9 g), Lepomis macrochirus	S, U	Zinc chloride	170 (18°C)	12,900	4,574	-	Cairns and Scheier 1957; Academy of Natural Sciences 1960
Bluegill (3.5-3.9 g), Lepomis macrochirus	S, U	Zinc chloride	170 (30°C)	12,500	4,432	-	Cairns and Scheier 1957; Academy of Natural Sciences 1960
Bluegill (2.5-3.9 g), Lepomis macrochirus	S, U	Zinc chloride	45	8,020	8,769	-	Cairns and Scheier 1958a; Academy of Natural Sciences 1960
Bluegill (0.96 g), Lepomis macrochirus	F, M	Zinc chloride	45	3,573	3,907	-	Cairns and Scheier 1959
Bluegill (2.80 g), Lepomis macrochirus	F, M	Zinc chloride	45	3,453	3,775	-	Cairns and Scheier 1959

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Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Adjusted LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)****	Reference
Bluegill (54.26 g), Lepomis macrochirus	F, M	Zinc chloride	45	3,314	3,623	-	Cairns and Scheier 1959
Bluegill (1-2 g), Lepomis macrochirus	S, U	Zinc sulfate	20 (15°C)	6,440	14,000	-	Pickering and Henderson 1966
Bluegill (1-2 g), Lepomis macrochirus	S, U	Zinc sulfate	20 (25°C)	5,460	11,870	-	Pickering and Henderson 1966
Bluegill (1-2 g), Lepomis macrochirus	S, U	Zinc sulfate	20 (25°C)	4,850	10,540	-	Pickering and Henderson 1966
Bluegill (1-2 g), Lepomis macrochirus	S, U	Zinc sulfate	20 (25°C)	5,820	12,650	-	Pickering and Henderson 1966
Bluegill (1-2 g), Lepomis macrochirus	S, U	Zinc chloride	20 (25°C)	5,370	11,670	-	Pickering and Henderson 1966
Bluegill (1-2 g), Lepomis macrochirus	S, U	Zinc sulfate	360 (25°C)	40,900	7,679	-	Pickering and Henderson 1966
Bluegill, Lepomis macrochirus	F, M	Zinc sulfate	46	9,900	10,620	-	Cairns et al. 1971
Bluegill, Lepomis macrochirus	F, M	Zinc sulfate	46	12,100	12,990	5,937	Cairns et al. 1971
Mozambique tilapia (18 g), Tilapia mossambica	S, U	Zinc chloride	115	1,600††	790.0	790.0	Qureshi and Saksena 1980

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Table 1. (Continued)

Species	Method*	Chemical	Salinity (g/kg)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
			SALTWATER SPECIES			
Polychaete worm (juvenile), Neanthes arenaceodentata	S, U	Zinc sulfate	-	900	-	Reish et al. 1976
Polychaete worm (adult), Neanthes areanceodentata	S, U	Zinc sulfate	-	1,800	1,273	Reish et al. 1976
Polychaete worm (adult), Nereis diversicolor	R, U	Zinc sulfate	0.35	1,500	-	Bryan and Hummerstone 1973
Polychaete worm (adult), Nereis diversicolor	R, U	Zinc sulfate	3.5	11,000	-	Bryan and Hummerstone 1973
Polychaete worm (adult), Nereis diversicolor	R, U	Zinc sulfate	17.5	55,000	9,682	Bryan and Hummerstone 1973
Polychaete worm (adult), Nereis virens	S, U	Zinc chloride	20	8,100	8,100	Eisler and Hennekey 1977
Polychaete worm (adult), Ophryotrocha diadema	S, U	Zinc sulfate	-	1,400	1,400	Reish and Carr 1978
Polychaete worm (adult), Ctenodrilus serratus	S, U	Zinc sulfate	-	7,100	7,100	Reish and Carr 1978
Polychaete worm (larva), Capitella capitata	S, U	Zinc sulfate	-	1,700	-	Reish et al. 1976
Polychaete worm (adult), Capitella capitata	S, U	Zinc sulfate	-	3,500	2,439	Reish et al. 1976
Mud snail (adult), Nassarius obsoletus	S, U	Zinc chloride	20	50,000	50,000	Eisler and Hennekey 1977
Blue mussel, Mytilus edulis planulatus	R, M	Zinc chloride	34 (21°C)	2,500	-	Ahsanullah 1976
Blue mussel, Mytilus edulis planulatus	F, M	Zinc chloride	- (18°C)	3,600	-	Ahsanullah 1976
Blue mussel, Mytilus edulis planulatus	F, M	Zinc chloride	- (18°C)	4,300	3,934	Ahsanullah 1976

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Table 1. (Continued)

Species	Method*	Chemical	Salinity (g/kg)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Pacific oyster (embryo), Crassostrea gigas	S, M	Zinc chloride	-	263.5*****	-	Nelson 1972
Pacific oyster (embryo), Crassostrea gigas	S, M	Zinc chloride	30	206.5	233.3	Dinnel et al. 1983
Eastern oyster (embryo), Crassostrea virginica	S, U	Zinc chloride	25	310	-	Calabrese et al. 1973
Eastern oyster (embryo), Crassostrea virginica	S, U	Zinc chloride	26	205.7	-	MacInnes and Calabrese 1978
Eastern oyster (embryo), Crassostrea virginica	S, U	Zinc chloride	26 (25°C)	324.5	-	MacInnes and Calabrese 1978
Eastern oyster (embryo), Crassostrea virginica	S, U	Zinc chloride	26 (30°C)	229.6	262.5	MacInnes and Calabrese 1978
Clam (adult), Macoma balthica	S, U	Zinc sulfate	15 (5°C)	140,000	-	Bryant et al. 1985
Clam (adult), Macoma balthica	S, U	Zinc sulfate	25 (5°C)	700,000	-	Bryant et al. 1985
Clam (adult), Macoma balthica	S, U	Zinc sulfate	35 (5°C)	750,000	-	Bryant et al. 1985
Clam (adult), Macoma balthica	S, U	Zinc sulfate	15 (10°C)	210,000	-	Bryant et al. 1985
Clam (adult), Macoma balthica	S, U	Zinc sulfate	25 (10°C)	900,000	-	Bryant et al. 1985
Clam (adult), Macoma balthica	S, U	Zinc sulfate	35 (10°C)	950,000	-	Bryant et al. 1985
Clam (adult), Macoma balthica	S, U	Zinc sulfate	15 (15°C)	60,000	-	Bryant et al. 1985

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Table 1. (Continued)

Species	Method*	Chemical	Salinity (g/kg)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Clam (adult), *Macoma balthica*	S, U	Zinc sulfate	25 (15°C)	180,000	-	Bryant et al. 1985
Clam (adult), *Macoma balthica*	S, U	Zinc sulfate	35 (15°C)	250,000	320,400	Bryant et al. 1985
Quahog clam (embryo), *Mercenaria mercenaria*	S, U	Zinc chloride	25	195	195	Calabrese and Nelson 1974
Soft-shell clam (adult), *Mya arenaria*	S, U	Zinc chloride	20	7,700	-	Eisler and Hennekey 1977
Soft-shell clam (adult), *Mya arenaria*	S, U	Zinc chloride	30	5,200	6,328	Eisler 1977a
Squid (larva), *Loligo opalescens*	S, M	Zinc chloride	30	>1,920	>1,920	Dinnel et al. 1983
Copepod (adult), *Eurytemora affinis*	S, U	Zinc chloride	30	4,074	4,074	Lussier and Cardin 1985
Copepod (adult), *Acartia clausi*	S, U	Zinc chloride	30	1,507	1,507	Lussier and Cardin 1985
Copepod (adult), *Acartia tonsa*	S, U	Zinc chloride	30	294.2	294.2	Lussier and Cardin 1985
Copepod (adult), *Nitocra spinipes*	S, U	Zinc chloride	7	1,450	1,450	Bengtsson 1978
Mysid (juvenile), *Mysidopsis bahia*	S, M	Zinc chloride	30	520.8	-	Lussier and Gentile 1985
Mysid (juvenile), *Mysidopsis bahia*	S, M	Zinc chloride	30	547.2	-	Lussier and Gentile 1985
Mysid (juvenile), *Mysidopsis bahia*	F, M	Zinc chloride	30	499	499	Lussier et al. 1985

Table 1. (Continued)

Species	Method*	Chemical	Salinity (g/kg)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Mysid (juvenile), Mysidopsis bigelowi	S, M	Zinc chloride	30	591.3	591.3	Lussier and Gentile 1985
Amphipod (adult), Corophium volutator	S, U	Zinc sulfate	5 (5°C)	1,000	-	Bryant et al. 1985
Amphipod (adult), Corophium volutator	S, U	Zinc sulfate	10 (5°C)	4,600	-	Bryant et al. 1985
Amphipod (adult), Corophium volutator	S, U	Zinc sulfate	15 (5°C)	6,500	-	Bryant et al. 1985
Amphipod (adult), Corophium volutator	S, U	Zinc sulfate	25 (5°C)	12,000	-	Bryant et al. 1985
Amphipod (adult), Corophium volutator	S, U	Zinc sulfate	35 (5°C)	16,000	-	Bryant et al. 1985
Amphipod (adult), Corophium volutator	S, U	Zinc sulfate	5 (10°C)	>128,000††††	-	Bryant et al. 1985
Amphipod (adult), Corophium volutator	S, U	Zinc sulfate	10 (10°C)	1,600	-	Bryant et al. 1985
Amphipod (adult), Corophium volutator	S, U	Zinc sulfate	15 (10°C)	8,500	-	Bryant et al. 1985
Amphipod (adult), Corophium volutator	S, U	Zinc sulfate	25 (10°C)	11,000	-	Bryant et al. 1985
Amphipod (adult), Corophium volutator	S, U	Zinc sulfate	35 (10°C)	15,000	-	Bryant et al. 1985
Amphipod (adult), Corophium volutator	S, U	Zinc sulfate	5 (15°C)	1,100	-	Bryant et al. 1985
Amphipod (adult), Corophium volutator	S, U	Zinc sulfate	10 (15°C)	3,200	-	Bryant et al. 1985

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Table 1. (Continued)

Species	Method*	Chemical	Salinity (g/kg)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Amphipod (adult), Corophium volutator	S, U	Zinc sulfate	15 (15°C)	3,400	-	Bryant et al. 1985
Amphipod (adult), Corophium volutator	S, U	Zinc sulfate	25 (15°C)	4,400	-	Bryant et al. 1985
Amphipod (adult), Corophium volutator	S, U	Zinc sulfate	35 (15°C)	3,600	4,683	Bryant et al. 1985
Lobster (adult), Homarus americanus	F, U	Zinc sulfate	-	48,000†*	-	Haya et al. 1983
Lobster (larva), Homarus americanus	S, U	Zinc chloride	30	575	-	Johnson 1985
Lobster (larva), Homarus americanus	S, U	Zinc chloride	30	574.5	-	Johnson 1985
Lobster (larva), Homarus americanus	S, U	Zinc chloride	30	362.5	-	Johnson 1985
Lobster (larva), Homarus americanus	S, U	Zinc chloride	30	175	380.5	Johnson 1985
Hermit crab (adult), Pagurus longicarpus	S, U	Zinc chloride	20	400	400	Eisler and Hennekey 1977
Dungeness crab (larva), Cancer magister	S, M	Zinc chloride	30	586.1	586.1	Dinnel et al. 1983
Green crab (larva), Carcinus maenas	S, U	Zinc sulfate	-	1,000	1,000	Connor 1972
Starfish (adult), Asterias forbesii	S, U	Zinc chloride	20	39,000	39,000	Eisler and Hennekey 1977
Mummichog (adult), Fundulus heteroclitus	S, U	Zinc chloride	6.1	17,500	-	Dorfman 1977
Mummichog (adult), Fundulus heteroclitus	S, U	Zinc chloride	24	31,500	-	Dorfman 1977

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Table 1. (Continued)

Species	Method*	Chemical	Salinity (g/kg)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Mummichog (adult), Fundulus heteroclitus	S, U	Zinc sulfate	6.0	32,000	-	Dorfman 1977
Mummichog (adult), Fundulus heteroclitus	S, U	Zinc sulfate	22.9	27,500	-	Dorfman 1977
Mummichog (adult), Fundulus heteroclitus	S, U	Zinc chloride	20	60,000	-	Eisler and Hennekey 1977
Mummichog (larva), Fundulus heteroclitus	S, U	Zinc chloride	30	83,040	36,630	Cardin 1985
Atlantic silverside (2-wk larva), Menidia menidia	S, U	Zinc chloride	31.2	4,960	-	Cardin 1985
Atlantic silverside (newly hatched larva), Menidia menidia	S, U	Zinc chloride	30	4,170	-	Cardin 1985
Atlantic silverside (newly hatched larva), Menidia menidia	S, U	Zinc chloride	30.2	3,703	-	Cardin 1985
Atlantic silverside (newly hatched larva), Menidia menidia	S, U	Zinc chloride	30	3,060	-	Cardin 1985
Atlantic silverside (newly hatched larva), Menidia menidia	S, U	Zinc chloride	30	2,728	3,640	Cardin 1985
Tidewater silverside (juvenile), Menidia peninsulae	S, U	Zinc sulfate	20	5,600	5,600	Hansen 1983
Striped bass (63 day), Morone saxatilis	S, U	Zinc chloride	1	430	430	Palawski et al. 1985
Spot (juvenile), Leiostomus xanthurus	S, U	Zinc sulfate	25	38,000	38,000	Hansen 1983

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Table 1. (Continued)

Species	Method*	Chemical	Salinity (g/kg)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Cabezon (larva), Scorpaenichthys marmoratus	S, M	Zinc chloride	27	191.4	191.4	Dinnel et al. 1983
Winter flounder (larva), Pseudopleuronectes americanus	S, U	Zinc chloride	30	18,207	-	Cardin 1985
Winter flounder (larva), Pseudopleuronectes americanus	S, U	Zinc chloride	30	4,922	9,467	Cardin 1985

* S = static; R = renewal; F = flow-through; M = measured; U = measured.

** Results are expressed as zinc, not as the chemical.

*** Freshwater LC50s and EC50s were adjusted to hardness = 50 mg/L using the pooled slope of 0.8195 (see text). When the hardness is given as a range, the geometric mean of the limits of the range was used as the hardness.

**** Freshwater Species Mean Acute Values were calculated at hardness = 50 mg/L.

***** Calculated by probit analysis of the authors' data.

† In river water or stream water.

†† Average of values calculated using two different methods.

††† Value not used in calculation of slope or Species Mean Acute Value because this was a "greater than" value and a number of other values are available for this species.

†††† Value not used in calculation of slope or Species Mean Acute Value because value appeared to be high in comparison with other values available for this species.

††††† Not used in calculation of Genus Mean Acute Value (see text).

†* Value not used in calculation of Species Mean Acute Value because data are available for a more sensitive life stage.

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Table 1. (Continued)

Results of Covariance Analysis of Freshwater Acute Toxicity versus Hardness

Species	n	Slope	Standard Deviation	95% Confidence Limits	Degrees of Freedom
Physa heterostropha	12	0.9296	0.2590	0.3521, 1.5071	10
Daphnia magna	7	1.2549	0.4026	0.2206, 2.2892	5
Rainbow trout	25	0.8755	0.1152	0.6370, 1.1140	23
Brook trout	6	0.8179	0.1243	0.4731, 1.1627	4
Fathead minnow	36	0.8310	0.2217	0.3802, 1.2818	34
Guppy	5	1.6441	0.4432	0.2323, 3.0559	3
Striped bass	2	0.6500	-*	-* , -*	0
Bluegill	16	0.5603	0.1461	0.2467, 0.8739	14
All of above	109	0.8473**	0.0866	0.6754, 1.0192	100

* Standard deviation and confidence limits cannot be calculated because degrees of freedom = 0.

** P = 0.77 for equality of slopes.

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Table 2. Chronic Toxicity of Zinc to Aquatic Animals

Species	Test*	Chemical	Hardness (mg/L as $CaCO_3$)	Limits (µg/L)**	Chronic Value (µg/L)	Reference
			FRESHWATER SPECIES			
Cladoceran, *Daphnia magna*	LC	Zinc chloride	45	<140.3†	<140.3	Biesinger et al. 1986
Cladoceran, *Daphnia magna*	LC	Zinc chloride	52	97-190	135.8	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Zinc chloride	104	43-52	47.29	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Zinc chloride	211	42-52	46.73	Chapman et al. Manuscript
Caddisfly, *Clistoronia magnifica*	LC	Zinc chloride	31	>5,243††	>5,243	Nebeker et al. 1984
Sockeye salmon, *Oncorhynchus nerka*	ELS	Zinc chloride	32-37	>242††	>242	Chapman 1978a
Chinook salmon, *Oncorhynchus tshawytscha*	ELS	Zinc chloride	25	270-510	371.1	Chapman 1975
Rainbow trout, *Salmo gairdneri*	ELS	Zinc sulfate	26	140-547	276.7	Sinley et al. 1974
Rainbow trout, *Salmo gairdneri*	ELS	Zinc chloride	25	444-819	603.0	Cairns et al. 1982
Brook trout, *Salvelinus fontinalis*	LC	Zinc sulfate	45.9	534-1,368	854.7	Holcombe et al. 1979
Fathead minnow, *Pimephales promelas*	LC	Zinc sulfate	46	78-145	106.3	Benoit and Holcombe 1978
Flagfish, *Jordanella floridae*	LC	Zinc sulfate	44	26-51	36.41	Spehar 1976a,b
Guppy, *Poecilia reticulata*	LC	Zinc sulfate	30	<173†	<173	Pierson 1981

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Table 2. (Continued)

Species	Test*	Chemical	Hardness (mg/L as $CaCO_3$)	Limits (µg/L)**	Chronic Value (µg/L)	Reference
			SALTWATER SPECIES			
Mysid, *Mysidopsis bahia*	LC	Zinc chloride	30†††	120-231	166.5	Lussier et al. 1985

* LC = life-cycle or partial life-cycle; ELS = early life-stage.

** Results are based on measured concentrations of zinc.

† Unacceptable effects occurred at all concentrations tested.

†† The highest concentration tested did not cause unacceptable effects.

††† Salinity (g/kg), not hardness.

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Table 2. (Continued)

Species	Hardness (mg/L as $CaCO_3$)	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio
		Acute-Chronic Ratio		
Cladoceran, *Daphnia magna*	52-54	334	135.8	2.459
Cladoceran, *Daphnia magna*	104-105	525	47.29	11.10
Cladoceran, *Daphnia magna*	196-211	655	46.73	14.02
Sockeye salmon, *Onchohynchus nerka*	32-37	1,470	>242	<6.074
Chinook salmon *Oncorhynchus tshawytscha*	23-25	97-701*	371.1	0.2614-1.889
Rainbow trout, *Salmo gairdneri*	25-26	430	276.7	1.554
Brook trout, *Salvelinus fontinalis*	45.9	1,996**	854.7	2.335
Fathead minnow, *Pimephales promelas*	46	600	106.3	5.644
Flagfish, *Jordanella floridae*	44	1,500	36.41	41.20
Mysid, *Mysidopsis bahia*	30***	499	166.5	2.997

* Range of values given in Chapman (1975,1978a) for juveniles.

** Geometric mean of three values in Table 1 from Holcombe and Andrew (1978).

*** Salinity (g/kg).

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Table 3. Ranked Genus Mean Acute Values with Species Mean Acute-Chronic Ratios

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)***	Species Mean Acute-Chronic Ratio****
		FRESHWATER SPECIES		
35	88,960	Damselfly, *Argia* sp.	88,960	-
34	19,800	Amphipod, *Crangonyx pseudogracilis*	19,800	-
33	18,400	Worm, *Nais* sp.	18,400	-
32	17,940	Banded killifish, *Fundulus diaphanus*	17,940	-
31	16,820	Snail, *Amnicola* sp.	16,820	-
30	13,630	American eel, *Anguilla rostrata*	13,630	-
29	10,560	Pumpkinseed, *Lepomis gibbosus*	18,790	-
		Bluegill, *Lepomis macrochirus*	5,937	-
28	10,250	Goldfish, *Carassius auratus*	10,250	-
27	9,712	Worm, *Lumbriculus variegatus*	9,712	-
26	8,157	Isopod, *Asellus bicrenata*	5,731	-
		Isopod, *Asellus communis*	11,610	-

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Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)***	Species Mean Acute-Chronic Ratio****
25	8,100	Amphipod, *Gammarus* sp.	8,100	-
24	7,233	Common carp, *Cyprinus carpio*	7,233	-
23	6,580	Northern squawfish, *Ptychocheilus oregonensis*	6,580	-
22	6,053	Guppy, *Poecilia reticulata*	6,053	-
21	6,000	Golden shiner, *Notemigonus crysoleucas*	6,000	-
20	5,228	White sucker, *Catostomus commersoni*	5,228	-
19	4,900	Asiatic clam, *Corbicula fluminea*	4,900	-
18	4,341	Southern platyfish, *Xiphophorus maculatus*	4,341	-
17	3,830	Fathead minnow, *Pimephales promelas*	3,830	5.644
16	3,265	Isopod, *Lirceus alabamae*	3,265	-
15	2,100	Brook trout, *Salvelinus fontinalis*	2,100	2.335
14	1,707	Bryozoan, *Lophopodella carteri*	1,707	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)***	Species Mean Acute-Chronic Ratio****
13	1,672	Flagfish, *Jordanella floridae*	1,672	41.20
12	1,607	Bryozoan, *Plumatella rostrata*	1,607	-
11	1,578	Snail, *Helisoma campanulatum*	1,578	-
10	1,353	Snail, *Physa gyrina*	1,683	-
		Snail, *Physa heterostropha*	1,088	-
9	1,307	Bryozoan, *Pectinatella magnifica*	1,307	-
8	>1,264	Tubificid worm, *Limnodrilus hoffmeisteri*	>1,264	-
7	1,225	Rainbow trout, *Salmo gairdneri*	689.3	1.554
		Atlantic salmon, *Salmo salar*	2,176	-
6	1,030	Coho salmon, *Oncorhynchus kisutch*	1,628	-
		Sockeye salmon, *Oncorhynchus nerka*	1,502	<6.074
		Chinook salmon, *Oncorhynchus tshawytscha*	446.4	0.7027†
5	790.0	Mozambique tilapia, *Tilapia mossambica*	790.0	-

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Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)***	Species Mean Acute-Chronic Ratio****
4	299.8	Cladoceran, Daphnia magna	355.5	7.260††
		Cladoceran, Daphnia pulex	252.9	-
3	227.8	Longfin dace, Agosia chrysogaster	227.8	-
2	119.4	Striped bass, Morone saxatilis	119.4	-
1	93.95	Cladoceran, Ceriodaphnia dubia	174.1	-
		Cladoceran, Ceriodaphnia reticulata	50.70	-

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Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)***	Species Mean Acute-Chronic Ratio****
		SALTWATER SPECIES		
28	320,400	Clam, *Macoma balthica*	320,400	-
27	50,000	Mud snail, *Nassarius obsoletus*	50,000	-
26	39,000	Starfish, *Asterias forbesii*	39,000	-
25	38,000	Spot, *Leiostomus xanthurus*	38,000	-
24	36,630	Mummichog, *Fundulus heteroclitus*	36,630	-
23	9,467	Winter flounder, *Pseudopleuronectes americanus*	9,467	-
22	7,100	Polychaete worm, *Ctenodrilus* worm	7,100	-
21	6,328	Soft-shell clam, *Mya arenaria*	6,328	-
20	4,683	Amphipod, *Corophium volutator*	4,683	-
19	4,515	Atlantic silverside, *Menidia menidia*	3,640	-
		Tidewater silverside, *Menidia peninsulae*	5,600	-

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Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)***	Species Mean Acute-Chronic Ratio****
18	8,856	Polychaete worm, Nereis diversicolor	9,682	-
		Polychaete worm, Nereis virens	8,100	-
17	4,074	Copepod, Eurytemora affinis	4,074	-
16	3,934	Blue mussel, Mytilus edulis	3,934	-
15	2,439	Polychaete worm, Capitella capitata	2,439	-
14	>1,920	Squid, Loligo opalescens	>1,920	-
13	1,450	Copepod, Nitocra spinipes	1,450	-
12	1,400	Polychaete worm, Ophryotrocha diadema	1,400	-
11	1,273	Polychaete worm Neanthes arenaceodentata	1,273	-
10	1,000	Green crab, Carcinus maenus	1,000	-
9	665.9	Copepod, Acartia clausi	1,507	-
		Copepod, Acartia tonsa	294.2	-
8	586.1	Dungeness crab, Cancer magister	586.1	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)***	Species Mean Acute-Chronic Ratio****
7	543.2	Mysid, *Mysidopsis bahia*	499	2.997
		Mysid, *Mysidoopsis bigelowi*	591.3	-
6	430	Striped bass, *Morone saxatilis*	430	-
5	400	Hermit crab, *Pagurus longicarpus*	400	-
4	380.5	Lobster, *Homarus americanus*	380.5	-
3	247.5	Pacific oyster, *Crassostrea gigas*	233.3	-
		Eastern oyster, *Crassostrea virginica*	262.5	-
2	195	Quahog clam, *Mercenaria mercenaria*	195	-
1	191.4	Cabezon, *Scorpaenichthys marmoratus*	191.4	-

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value. Inclusion of "greater than" values does not necessarily imply a true ranking, but does allow use of all genera for which useful data are available so that the Final Acute Value is not unnecesarily lowered.

** Freshwater Genus Mean Acute Values are at hardness = 50 mg/L.

*** From Table 1; freshwater values are at hardness = 50 mg/L.

**** From Table 2.

† Geometric mean of range given in Table 2.

†† Geometric mean of three values in Table 2.

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Table 3. (Continued)

Fresh water

Final Acute Value = 130.1 µg/L (at hardness = 50 mg/L)

Criterion Maximum Concentration = (130.1 µg/L) / 2 = 65.05 µg/L (at hardness = 50 mg/L)

Pooled Slope = 0.8473 (see Table 1)

ln(Criterion Maximum Intercept) = ln(65.05) - [slope x ln(50)]

= 4.175 - (0.8473 x 3.9120) = 0.8604

Criterion Maximum Concentration = $e^{(0.8473[\ln(\text{hardness})]+0.8604)}$

Final Acute-Chronic Ratio = 2.208 (see text)

Final Chronic Value = (130.1 µg/L) / 2.208 = 58.92 µg/L (at hardness = 50 mg/L)

Assumed Chronic Slope = 0.8473 (see text)

ln(Final Chronic Intercept) = ln(58.92) - [slope x ln(50)]

= 4.076 - (0.8473 x 3.9120) = 0.7614

Final Chronic Value = $e^{(0.8473[\ln(\text{hardness})]+0.7614)}$

Salt water

Final Acute Value = 190.2 µg/L

Criterion Maximum Concentration = (190.2 µg/L) / 2 = 95.10 µg/L

Final Acute-Chronic Ratio = 2.208 (see text)

Final Chronic Value = (190.2 µg/L) / 2.208 = 86.14 µg/L

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Table 4. Toxicity of Zinc to Aquatic Plants

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration (days)	Effect	Concentration (µg/L)[a]	Reference
			FRESHWATER SPECIES			
Blue-green alga, *Chroococcus paris*	Zinc sulfate	-	10	Reduced growth	>400	Les and Walker 1984
Green alga, *Chlamydomonas variabilis*	-	-	6	30% reduction in division rate	503	Bates et al. 1983
Green alga, *Chlamydomonas sp.*	Zinc sulfate	68	10	Reduced growth	15,000	Cairns et al. 1978
Green alga, *Chlorella pyrenoidosa*	Zinc sulfate	-	4	LC50	>200,000	Wong et al. 1979
Green alga, *Chlorella saccharophila*	Zinc chloride	-	4	EC50	7,100	Rachlin et al. 1982
Green alga, *Chlorella salina*	Zinc sulfate	-	4	LC50	>200,000	Wong et al. 1979
Green alga, *Chlorella vulgaris*	Zinc sulfate	-	4	EC50 (growth)	2,400	Rachlin and Farran 1974
Green alga, *Chlorella vulgaris*	Zinc chloride	-	15	EC50 (growth)	11,990-23,980	Rai et al. 1981a
Green alga, *Chlorella vulgaris*	Zinc chloride	-	33	EC50 (cell division)	5,100	Rosko and Rachlin 1977
Green alga, *Scenedesmus quadricauda*	Zinc sulfate	68	5	Reduced growth	20,000	Cairns et al. 1978
Green alga, *Scenedesmus quadricauda*	Zinc sulfate	-	4	LC50	>200,000	Wong et al. 1979
Green alga, *Selenastrum capricornutum*	Zinc chloride	-	7	Incipient growth inhibition	30	Bartlett et al. 1974
Green alga, *Selenastrum capricornutum*	Zinc chloride	-	14	EC95 (growth)	40.4	Greene et al. 1975

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Table 4. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration (days)	Effect	Concentration (µg/L)*	Reference
Green alga, *Selenastrum capricornutum*	Zinc chloride	-	14	EC95 (growth)	68	Greene et al. 1975
Green alga, *Selenastrum capricornutum*	-	-	14-21	EC50 (biomass)	50.9	Turbak et al. 1986
Diatom, *Cyclotella meneghiniana*	Zinc sulfate	68	5	Reduced growth	20,000	Cairns et al. 1978
Diatom, *Navicula incerta*	Zinc chloride	-	4	EC50	10,000	Rachlin et al. 1983
Diatom, *Navicula seminulum*	-	58 (22°C)	5	EC50 (growth)	4,290	Academy of Natural Sciences 1960
Diatom, *Navicula seminulum*	-	58 (28°C)	5	EC50 (growth)	1,590	Academy of Natural Sciences 1960
Diatom, *Navicula seminulum*	-	58 (30°C)	5	EC50 (growth)	1,320	Academy of Natural Sciences 1960
Diatom, *Navicula seminulum*	-	174 (22°C)	5	EC50 (growth)	4,050	Academy of Natural Sciences 1960
Diatom, *Navicula seminulum*	-	174 (28°C)	5	EC50 (growth)	2,310	Academy of Natural Sciences 1960
Diatom, *Navicula seminulum*	-	174 (30°C)	5	EC50 (growth)	3,220	Academy of Natural Sciences 1960
Diatom, *Nitzschia linearis*	Zinc chloride	294.6	5	LC50	4,300	Patrick et al. 1968
Duckweed, *Lemma gibba*	Zinc sulfate	-	70	Did not reduce biomass	654	Van der Werff and Pruyt 1982
Duckweed, *Lemna minor*	Zinc sulfate	-	28	EC50 (tissue damage and death)	67,700	Brown and Rattigan. 1979
Duckweed, *Lemna minor*	-	-	4	EC50 (growth)	10,000	Wang 1986a

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Table 4. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration (days)	Effect	Concentration (µg/L)*	Reference
Duckweed, *Spirodela polyrhiza*	Zinc sulfate	-	70	Did not reduce biomass	654	Van der Werff and Pruyt 1982
Macrophyte, *Callitriche plataycarpa*	Zinc sulfate	-	73	Did not reduce biomass	654	Van der Werff and Pruyt 1982
Eurasian watermilfoil, *Myriophyllum spicatum*	-	-	32	EC50 (root weight)	21,600	Stanley 1974
Macrophyte, *Elodea canadensis*	Zinc sulfate	-	28	EC50 (tissue damage and death)	22,500	Brown and Rattigan 1979
Macrophyte, *Elodea nuttallii*	Zinc sulfate	-	73	Did not reduce biomass	654	Van der Werff and Pruyt 1982
		SALTWATER SPECIES				
Diatom, *Navicula incerta*	Zinc chloride	-	4	EC50 (growth)	10,100	Rachlin et al. 1983
Diatom, *Nitzschia closterium*	Zinc sulfate	-	4	EC50 (growth)	271	Rosko and Rachlin 1975
Diatom, *Nitzschia closterium*	Zinc sulfate	-	4	EC50** (growth)	360	Rosko and Rachlin 1975
Diatom, *Schroederella schroederi*	Zinc sulfate	32***	4	EC50 (growth)	19.01†	Kayser 1977
Dinoflagellate, *Gymnodinium splendens*	Zinc sulfate	32***	4	EC50 (growth)	3,716†	Kayser 1977
Dinoflagellate, *Procentrum micans*	Zinc sulfate	32***	4	EC50 (growth)	319.1†	Kayser 1977

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Table 4. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration (days)	Effect	Concentration (µg/L)*	Reference
Coccolithophorid, Cricosphaera carterae	Zinc sulfate	-	4	EC50 (growth)	76.69**	Stillwell 1977
Giant kelp (young fronds), Macrocystis pyrifera	-	-	4	EC50 (photosynthetic rate)	10,000	Clendenning and North 1959

* Concentration of zinc, not the chemical.

** With chelating agent.

*** Salinity (g/kg), not hardness.

† Calculated from author's data.

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Table 5. Bioaccumulation of Zinc by Aquatic Organisms

Species	Chemical	Concentration in water (µg/L)*	Hardness (mg/L as $CaCO_3$)	Duration (days)	Tissue	BCF or BAF**	Reference
			FRESHWATER SPECIES				
Asiatic clam, (1-3 yr), Corbicula fluminea	Zinc sulfate	218	58.3	28	Soft tissue	126.2***	Graney et al. 1983
Asiatic clam, (1-3 yr), Corbicula fluminea	Zinc sulfate	433	58.3	28	Soft tissue	71.6***	Graney et al. 1983
Asiatic clam, (1-3 yr), Corbicula fluminea	Zinc sulfate	835	58.3	28	Soft tissue	102.2***	Graney et al. 1983
Mayfly, Ephemerella grandis	Zinc sulfate	-	30-70	14	Whole body	1,130	Nehring 1976
Stonefly, Pteronarcys californica	Zinc sulfate	-	30-70	14	Whole body	106	Nehring 1976
Atlantic salmon, Salmo salar	Zinc sulfate	-	12-24	80	Whole body	51	Farmer et al. 1979
Flagfish, Jordanella floridae	Zinc sulfate	139	45	100	Whole body	417.3***	Spehar et al. 1978
Guppy, Poecilia reticulata	Zinc sulfate	173	30	134	Whole body	477.8 534.9	Pierson 1981
Guppy, Poecilia reticulata	Zinc sulfate	328	30	134	Whole body	492.8 965.5	Pierson 1981
Guppy, Poecilia reticulata	Zinc sulfate	607	30	134	Whole body	466.3 512.4	Pierson 1981

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Table 5. (Continued)

Species	Chemical	Concentration in water (µg/L)*	Salinity (g/kg)	Duration (days)	Tissue	BCF or BAF**	Reference
			SALTWATER SPECIES				
Green alga, *Dunaliella tertiolecta*	Zinc chloride	7.2-98,000	-	0.5****	Whole cells	10,000	Fisher et al. 1984
Diatom, *Thalassiosira pseudonana*	Zinc chloride	7.2-98,000	-	0.5****	Whole cells	12,000	Fisher et al. 1984
Brown macroalga, *Ascophyllum nodosum*	-	11.3	-	*****	Whole plant	1,318***,†	Foster 1976
Brown macroalga, *Fucus serratus*	Zinc chloride	9.5	-	140	Whole plant	10,768†	Young 1975
Brown macroalga, *Fucus vesiculosus*	-	5.21-11.9	-	*****	Whole plant	2,029 (5)	Morris and Bale 1975
Brown macroalga, *Fucus vesiculosus*	-	11.3	-	*****	Whole plant	1,027***,†	Foster 1976
Brown macroalga, *Laminaria digitata*	Zinc sulfate	2.4-500	-	30-31††	Growth region above stipe	75.5-295.0***†	Bryan 1969
Peerlwinkle (adult), *Littorina obtusata*	Zinc chloride	11	-	50	Soft tissue	670†	Young 1975
Eastern oyster (adult), *Crassostrea virginica*	Zinc chloride	100	-	126	Soft tissue	23,820†	Schuster and Pringle 1968
Eastern oyster (adult), *Crassostrea virginica*	Zinc chloride	200	-	126	Soft tissue	17,640†	Schuster and Pringle 1968
Soft-shell clam (adult), *Mya arenaria*	Zinc chloride	200	-	50	Soft tissue	85†	Pringle et al. 1968
Soft-shell clam (adult), *Mya arenaria*	Zinc chloride	200	-	49	Soft tissue	135†	Schuster and Pringle 1968

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Table 5. (Continued)

Species	Chemical	Concentration in water (µg/L)*	Salinity (g/kg)	Duration (days)	Tissue	BCF or BAF**	Reference
Barnacle (adult), Balanus balanoides	-	18.6	-	30	Soft tissue	951.6†	White and Walker 1981
Shrimp (adult), Pandalus montagui	Zinc chloride	65	-	14	Whole body	3.692***,†,†††	Ray et al. 1980
Mummichog (juvenile), Fundulus heteroclitus	Zinc chloride	210	-	56	Scales	40.95†,†††	Sauer and Watabe 1984
Mummichog (juvenile), Fundulus heteroclitus	Zinc chloride	210	-	56	Whole body	18.10†,†††	Sauer and Watabe 1984
Mummichog (juvenile), Fundulus heteroclitus	Zinc chloride	810	-	56	Scales	43.21†,†††	Sauer and Watabe 1984
Mummichog (juvenile), Fundulus heteroclitus	Zinc chloride	810	-	56	Whole body	15.80†,†††	Sauer and Watabe 1984
Mummichog (juvenile), Fundulus heteroclitus	Zinc chloride	7,880	-	56	Scales	28.60†,†††	Sauer and Watabe 1984
Mummichog (juvenile), Fundulus heteroclitus	Zinc chloride	7,880	-	56	Whole body	4.467†,†††	Sauer and Watabe 1984

* Measured concentration of zinc.

** Bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) are based on measured concentrations of zinc in water and in tissue. Number of exposure concentrations from which the geometric mean factor was calculated is given in parentheses when it is greater than 1.

*** Factor was converted from dry weight to wet weight basis.

**** Steady-state reached.

***** Field study.

† Calculated from authors' data or graph.

†† Steady-state not reached.

††† Concentration of zinc was the same in exposed and control animals.

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Table 6. Other Data on Effects of Zinc on Aquatic Organisms

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)[a]	Reference
			FRESHWATER SPECIES			
Green alga, *Chlorella vulgaris*	Zinc sulfate	-	1 hr	33% reduction in survival	100,000	Agrawal 1984
Green alga, *Selenastrum capricornutum*	Zinc phosphate	-	14 days	Inhibited growth	64	Garton 1972
Green alga, *Selenastrum capricornutum*	Zinc sulfate	-	4 hr	EC50 (oxygen production)	1,000	Hendricks 1978
Green alga, *Chlorella vulgaris*	Zinc sulfate	-	3 wk	BCF=210	-	Coleman et al. 1971
Green alga, *Pediastrum tetras*	Zinc sulfate	-	3 wk	BCF=133	-	Coleman et al. 1971
Green alga, *Scenedesmus quadricauda*	Zinc sulfate	-	96 hr	Incipient inhibition (river water)	1,066-1,400 (1,200)	Bringmann and Kuhn 1959a,b
Periphyton, Mixed species	-	-	3 wk**	BAF=1,100-6,304	-	Johnson et al. 1978
Waterweed, *Elodea (Anacharis) canadensis*	Zinc sulfate	-	1 day	EC50 (oxygen) production)	8,100	Brown and Rattigan 1979
Moss, *Fontinalis antipyretica*	Zinc chloride	-	1-6 days	Reduced photosynthesis	100	Weise et al. 1985
Bacterium, *Escherichia coli*	Zinc sulfate	-	30 min	EC50 (inhibition of TDH activity)	653.7	Cenci et al. 1985
Bacterium, *Escherichia coli*	Zinc sulfate	-	-	Incipient inhibition	1,400-2,300	Bringmann and Kuhn 1959a
Mixed heterotrophic bacteria	Zinc chloride	-	0.5 hr	No significant mortality	1,000	Albright et al. 1972
Mixed heterotrophic bacteria	Zinc chloride	-	3 days	Reduced growth	50	Albright and Wilson 1974

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Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)*	Reference
Bacterium, *Nitrobacter* sp. and *Nitrosomonas* sp.	-	-	4 hr	EC50	100,000	Williamson and Nelson 1983
Protozoan, *Microregma heterostoma*	Zinc sulfate	-	28 hr	Incipient inhibition	330	Bringmann and Kuhn 1959b
Protozoan, *Paramecium caudatum*	Zinc sulfate	-	1.5 hr	Reduced vitality	3,500	Mills 1976a
Euglena, *Euglena viridis*	Zinc sulfate	-	3 wk	BCF=144	-	Coleman et al. 1971
Plankton, Mixed species	-	-	2 wk	Reduced primary productivity	15	Marshall et al. 1983
Zooplankton, Mixed species	Zinc chloride	-	3 wk	Reduced crustacean density and diversity	100	Marshall et al. 1981
Rotifer, *Philodina acuticornis*	Zinc sulfate	45	48 hr	LC50(5°C) (10°C) (15°C) (20°C) (25°C)	1,550 1,300 780 600 500	Cairns et al. 1978
Worm, *Aeolosoma headleyi*	Zinc sulfate	45	48 hr	LC50(5°C) (10°C) (15°C) (20°C) (25°C)	18,100 17,600 15,600 15,000 13,500	Cairns et al. 1978
Tubificid worm, *Tubifex tubifex*	Zinc sulfate	34.2	48 hr	LC50	2,980	Brkovic-Popovic and Popovic 1977a
Tubificid worm, *Tubifex tubifex*	Zinc chloride	224	48 hr	LC50	130,000	Qureshi et al. 1980
Tubificid worm, *Tubifex tubifex* and *Limnodrilus hoffmeisteri*	Zinc sulfate	-	24 hr	LC50	46,000	Whitley 1968

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Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)*	Reference
Snail, *Gonlobasis livescens*	Zinc sulfate	137-171	48 hr	LC50	13,500	Cairns et al. 1976
Snail, *Nitocris* sp.	Zinc sulfate	45	48 hr	LC50(5°C) (10°C) (15°C) (20°C) (25°C)	4,800 4,600 2,800 1,900 1,650	Cairns et al. 1978
Snail, *Lymnaea emarginata*	Zinc sulfate	137-171	48 hr	LC50	4,150	Cairns et al. 1976
Snail (adult), *Physa gyrina*	Zinc chloride	36	30 days	No effect LC50	570 771	Nebeker et al. 1986
Snail, *Physa integra*	Zinc sulfate	137-171	48 hr	LC50	4,400	Cairns et al. 1976
Cladoceran, *Ceriodaphnia dubia*	Zinc chloride	36	7 days	Chronic value (river water)	167	Carlson et al. 1986
Cladoceran, *Ceriodaphnia dubia*	Zinc chloride	36 36 68 82 90	48 hr 48 hr 48 hr 48 hr 48 hr	EC50 (immobilization; river water)	164 149 222 366 255	Carlson et al. 1986
Cladoceran (<6 hr), *Ceriodaphnia reticulata*	Zinc chloride	353 376 392 362 392	48 hr	EC50 (high solids)	224 114 96 264 195	Carlson and Roush 1985

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Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)*	Reference
Cladoceran (adult), Daphnia galeata mendotae	-	-	2 wk	BCF=9,400 BCF=5,833 BCF=6,333	15 30 60	Marshall et al. 1983
Cladoceran (young), Daphnia galeata mendotae	-	-	2 wk	BCF=9,933 BCF=6,933	15 30	Marshall et al. 1983
Cladoceran, Daphnia magna	Zinc sulfate	-	16 hr	EC50 (immobilization)	<19,440	Anderson 1944
Cladoceran, Daphnia magna	Zinc sulfate	-	48 hr	EC50 (river water)	1,800	Bringmann and Kuhn 1959a,b
Cladoceran, Daphnia magna	Zinc chloride	45.3	48 hr	EC50 (immobilization) (fed)	280	Biesinger and Christensen 1972
Cladoceran, Daphnia magna	Zinc chloride	45.3	21 days	EC50 (immobilization)	158	Biesinger and Christensen 1972
Cladoceran, Daphnia magna	Zinc chloride	45.3	21 days	16% reproductive impairment	70	Biesinger and Christensen 1972
Cladoceran, Daphnia magna	Zinc chloride	288	24 hr	EC50 (swimming)	14,000	Bringmann and Kuhn 1977
Cladoceran (3-5 days), Daphnia magna	Zinc sulfate	-	72 hr	LC50 (10°C) (15°C) (25°C) (30°C)	5,050 1,096 565 14.0	Braginskiy and Shcherban 1978
Cladoceran (adult), Daphnia magna	Zinc sulfate	-	72 hr	LC50 (10°C) (15°C) (25°C) (30°C)	1,316 1,100 1,010 5.0	Braginskiy and Shcherban 1978
Cladoceran, Daphnia magna	Zinc sulfate	45	48 hr	LC50 (5°C) (10°C) (15°C) (20°C)	2,300 1,700 1,100 560	Cairns et al. 1978

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Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)[a]	Reference
Cladoceran, *Daphnia magna*	Zinc sulfate	130-160	50-70 days	Reduced longevity	100	Winner 1981
Cladoceran, *Daphnia pulex*	Zinc sulfate	45	48 hr	LC50 (5°C) (10°C) (15°C) (25°C)	1,600 1,200 940 280	Cairns et al. 1978
Cladoceran *Bosmina longirostris*	-	-	2 wk	BCF=11,930 BCF= 6,300 BCF= 5,183	15 30 60	Marshall et al. 1983
Cladoceran, *Eubosmina coregoni*	-	-	2 wk	BCF=10,870 BCF= 6,833 BCF= 3,867	15 30 60	Marshall et al. 1983
Copepod (adult), *Tropocykops prasinus*	Zinc chloride	10 10 120	48 hr	EC50 (motility)	52 264 2,934	Lalande and Pinel-Alloul 1986
Crayfish (adult), *Orconectes virilis*	Zinc sulfate	26	14 days	LC50	84,000	Mirenda 1986
Mayfly, *Cloeon dipterum*	Zinc sulfate	-	72 hr	LC50 (10°C) (15°C) (25°C) (30°C)	35,710 6,920 2,846 1,330	Braginskiy and Shcherban 1978
Mayfly (nalad), *Ephemerella grandis*	Zinc sulfate	30-70	14 days	LC50	>9,200	Nehring 1976
Mayfly, *Ephemerella subvaria*	Zinc sulfate	54	10 days	LC50	16,000	Warnick and Bell 1969
Damselfly, Unidentified	-	50	96 hr	LC50	26,200	Rehwoldt et al. 1973
Stonefly (nalad), *Pteronarcys californica*	Zinc sulfate	30-70	14 days	LC50	>13,900	Nehring 1976
Stonefly, *Acroneuria lycorias*	Zinc sulfate	50	14 days	LC50	32,000	Warnick and Bell 1969
Caddisfly, *Hydropsyche bettini*	Zinc sulfate	52	11 days	LC50	32,000	Warnick and Bell 1969

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Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)*	Reference
Caddisfly, Unidentified	-	50	96 hr	LC50	58,100	Rehwoldt et al. 1973
Mosquito (pupa), Aedes aegypti	Zinc sulfate	4	72 hr	20% mortality 30% mortality	500 5,000	Abbasi et al. 1985
Midge, Chironomous sp.	-	50	96 hr	LC50	18,200	Rehwoldt et al. 1973
Midge (embryo to 3rd instar), Tanytarsus dissimilis	Zinc chloride	46.8	10 days	LC50	36.8	Anderson et al. 1980
Coho salmon (fry), Oncorhynchus kisutch	Zinc sulfate	3-10	24 hr	Decrease white blood cells	500	McLeay 1975
Coho salmon (2.9 g), Oncorhynchus kisutch	Zinc chloride	30.5	1.75 hr	No effect on olfaction	654	Rehnberg and Schreck 1986
Sockeye salmon (alevin) (acclimated to zinc), Oncorhynchus nerka	Zinc chloride	-	96 hr	LC50	1,663	Chapman 1978a
Sockeye salmon (alevin) (acclimated to zinc), Oncorhynchus nerka	Zinc chloride	-	115 hr	LC50	>630	Chapman 1978a
Sockeye salmon (alevin), Oncorhynchus nerka	Zinc chloride	-	115 hr	LC50	447	Chapman 1978a
Sockeye salmon, Oncorhynchus nerka	Zinc chloride	20-84	3 mo	None (adult to smolt)	112	Chapman 1978a
Rainbow trout, Salmo gairdneri	Zinc sulfate	320	285 min 180 min 162 min	LT50	10,000 11,000 11,500	Lloyd 1960
Rainbow trout (7.62 cm), Salmo gairdneri	Zinc sulfate	15-20	7 days	LC50 (fed)	560	Lloyd 1961a,b
Rainbow trout (7.62 cm), Salmo gairdneri	Zinc sulfate	320	3 days	LC50 (fed)	3,500	Lloyd 1961a,b
Rainbow trout (fingerling), Salmo gairdneri	Zinc sulfate	320	48 hr	LC50	3,860	Herbert and Shurben 1964

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Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)*	Reference
Rainbow trout, *Salmo gairdneri*	Zinc sulfate	44	48 hr	LC50 (high sodium chloride)	910	Herbert and Shurben 1964
Rainbow trout, *Salmo gairdneri*	Zinc sulfate	320	48 hr	LC50 (low D.O.)	2,400	Herbert and Shurben 1964
Rainbow trout (3-4 mo), *Salmo gairdneri*	Zinc sulfate	320	48 hr	LC50	2,460	Herbert and VanDyke 1964
Rainbow trout (yearling), *Salmo gairdneri*	Zinc sulfate	320	48 hr	LC50	5,000	Herbert and Wakeford 1964
Rainbow trout (46.7-125.5 g), *Salmo gairdneri*	Zinc sulfate	290	5 days	LC50	4,600	Ball 1967
Rainbow trout (13.7 g), *Salmo gairdneri*	Zinc sulfate	290	100 days	Damaged gills	800	Brown et al. 1968
Rainbow trout, *Salmo gairdneri*	Zinc sulfate	13-15	10 min	Avoidance	5.6	Sprague 1968
Rainbow trout (1 yr), *Salmo gairdneri*	Zinc sulfate	240	48 hr	LC50	4,000	Brown and Dalton 1970
Rainbow trout (100.9 g), *Salmo gairdneri*	Zinc sulfate	51	-	Tissue hypoxia	40,000	Burton et al. 1972b
Rainbow trout (fry), *Salmo gairdneri*	Zinc phosphate	20	96 hr	LC50	90	Garton 1972
Rainbow trout (embryo), *Salmo gairdneri*	Zinc sulfate	25	5 days	LC50	135	Sinley et al. 1974
Rainbow trout (fingerling to adult), *Salmo gairdneri*	Zinc sulfate	333	22 mo	LC10	1,055	Sinley et al. 1974
Rainbow trout (15-17.5 cm), *Salmo gairdneri*	Zinc sulfate	504	48 hr	LC50	4,760	Solbe 1974
Rainbow trout, *Salmo gairdneri*	Zinc sulfate	51-68	48 hr	Decreased blood pO_2 and pH	1,430	Sellers et al. 1975
Rainbow trout (200 mm), *Salmo gairdneri*	Zinc sulfate	98	10 days	LC50	800	Goetti et al. 1976

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Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)*	Reference
Rainbow trout, Salmo gairdneri	Zinc sulfate	-	5.1-10.5 hr	Increased lactic acid	15,340	Hodson 1976
Rainbow trout (yearling), Salmo gairdneri	Zinc sulfate	374	85 days	Inhibited growth	1,120	Watson and McKeown 1976
Rainbow trout (2 mo), Salmo gairdneri	Zinc acetate	-	96 hr	LC50	550	Hale 1977
Rainbow trout, Salmo gairdneri	Zinc sulfate	36	24 hr	LC50(5°C) (15°C) (30°C)	2,800 1,560 2,100	Cairns et al. 1978
Rainbow trout (embryo, larva), Salmo gairdneri	Zinc chloride	104 (92-110)	28 days	EC50 (death and deformity)	1,060 (1,120)	Birge 1978; Birge et al. 1978,1980,1981
Rainbow trout, Salmo gairdneri	Zinc chloride	112	40 min	94% avoidance	47	Black and Birge 1980a,b
Rainbow trout (80-120 g), Salmo gairdneri	Zinc sulfate	-	30 days	Increased gill enzymes	290	Watson and Beamish 1980
Rainbow trout (50 g), Salmo gairdneri	Zinc sulfate	18.7	72 hr	LC50	2,000	Lovegrove and Eddy 1982
Rainbow trout, Salmo gairdneri	Zinc chloride	-	96 hr	Circulatory vasoconstriction	1,250	Tuurala and Solvio 1982
Rainbow trout (juvenile), Salmo gairdneri	Zinc sulfate	6.0-6.5	9 days	Hyperglycemia	352	Wagner and McKeown 1982
Rainbow trout (juvenile), Salmo gairdneri	-	-	42 days	Damaged hepatocytes	431.5	Leland 1983
Rainbow trout (fingerling), Salmo gairdneri	Zinc sulfate	14 (pH=6.0)	96 hr	LC50	670	Spry and Wood 1984

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Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)*	Reference
Rainbow trout (gamete), Salmo gairdneri	Zinc sulfate	-	40 min	Reduction in spermatozoa survival; no effect on fertilization	20,000	Billard and Roubaud 1985
Rainbow trout (2.7-3.3 g), Salmo gairdneri	-	385 (pH=6.99)	9.4 hr	LT50	19,100	Bradley and Sprague 1985
		30.5 (pH=6.98)	10.4 hr		5,780	
		390 (pH=5.49)	11.5 hr		18,900	
		32.5 (pH=5.49)	16.0 hr		5,570	
		389 (pH=7.00)	6.3 hr		26,900	
		385 (pH=6.99)	9.4 hr		19,100	
		388 (pH=7.02)	12.9 hr		13,800	
Rainbow trout (embryo), Salmo gairdneri	Zinc nitrate	30	10 hr	LT50	14,000	Rombough 1985
			9 hr		13,000	
			20 hr		12,000	
			18 hr		11,000	
			18 hr		10,000	
			18 hr		9,000	
			20 hr		8,000	
			36 hr		6,000	
			>168 hr		2,000	
Rainbow trout (embryo with capsule removed), Salmo gairdneri	Zinc nitrate	30	14 hr	LT50	14,000	Rombough 1985
			18 hr		13,000	
			36 hr		12,000	
			30 hr		11,000	
			37 hr		10,000	
			58 hr		9,000	
			70 hr		8,000	
			>168 hr		6,000	
			>168 hr		2,000	

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Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)*	Reference
Rainbow trout (5 days post fertilization), Salmo gairdneri	Zinc sulfate	87.7	48 hr	LC50	24,000	Shazili and Pascoe 1986
Rainbow trout (10 days post fertilization), Salmo gairdneri	Zinc sulfate	87.7	48 hr	LC50	<1,000	Shazili and Pascoe 1986
Rainbow trout (15 days post fertilization), Salmo gairdneri	Zinc sulfate	87.7	48 hr	LC50	9,100	Shazili and Pascoe 1986
Rainbow trout (22 days post fertilization), Salmo gairdneri	Zinc sulfate	87.7	48 hr	LC50	7,000	Shazili and Pascoe 1986
Rainbow trout (29 days post fertilization), Salmo gairdneri	Zinc sulfate	87.7	48 hr	LC50	4,300	Shazili and Pascoe 1986
Rainbow trout (36 days post fertilization), Salmo gairdneri	Zinc sulfate	87.7	48 hr	LC50	9,200	Shazili and Pascoe 1986
Rainbow trout (2 days post hatch), Salmo gairdneri	Zinc sulfate	87.7	48 hr	LC50	3,200	Shazili and Pascoe 1986
Rainbow trout (7 days post hatch), Salmo gairdneri	Zinc sulfate	87.7	48 hr	LC50	3,400	Shazili and Pascoe 1986
Atlantic salmon (parr), Salmo salar	Zinc sulfate	18	4 hr	EC50 (avoidance)	49.88	Sprague 1964b
Atlantic salmon (7.38 g), Salmo salar	-	14	23-25 hr	LT50	954.4	Zitko and Carson 1976
Atlantic salmon, Salmo salar	-	14	-	Incipient lethal level	150-1,000	Zitko and Carson 1977

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Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)[a]	Reference
Atlantic salmon (juvenile), Salmo salar	Zinc sulfate	12.1-24.4	21 days	LC50	1,450 1,600 510 1,460 340 350	Farmer et al. 1979
Atlantic salmon (yearling), Salmo salar	Zinc sulfate	14	>168 hr 58 hr 15.6 hr 9.4 hr 2.6 hr	LT50	300 410 650 1,060 4,190	Sprague and Ramsay 1965
Goldfish (3-5 g), Carassius auratus	Zinc sulfate	-	1-4 hr	LT50	100,000	Ellis 1937
Goldfish (immature), Carassius auratus	Zinc sulfate	29	7 days	Histological damage	2,000	Bromage and Fuchs 1976
Goldfish (embryo, larva), Carassius auratus	Zinc chloride	195	7 days	EC50 (death and deformity)	2,540	Birge 1978
Goldfish, Carassius auratus	Zinc sulfate	36	24 hr	LC50(5°C) (15°C) (30°C)	103,000 40,000 24,000	Cairns et al. 1978
Common carp (embryo), Cyprinus carpio	Zinc sulfate	360	-	EC50 (hatch)	14,420	Kapur and Yadav 1982
Common carp (350-400 g), Cyprinus carpio	Zinc chloride	-	2 hr	GOT, GPT and LDH unaffected	4,797	Nemcsok and Boross 1982
Common carp (2.1 g), Cyprinus carpio	Zinc sulfate	19	48 hr	LC50	7,280	Khangarot et al. 1984
Golden shiner, Notemigonus crysoleucas	Zinc sulfate	36	24 hr	LC50(5°C) (15°C) (30°C)	11,400 7,760 8,330	Cairns et al. 1978

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Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)*	Reference
Fathead minnow (1-2 g), *Pimephales promelas*	Zinc acetate	20	96 hr	LC50	880	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	Zinc sulfate	203	10 mo	EC83 (fecundity)	180	Brungs 1969
Fathead minnow, (adult), *Pimephales promelas*	Zinc chloride	103 254-271	96 hr	LC50 (Fish from pond contaminated with heavy metals)	6,140 5,960	Birge et al. 1983
Fathead minnow, (larva), *Pimephales promelas*	Zinc chloride	392	96 hr	LC50 (high solids)	<2,660 <2,930	Carlson and Roush 1985
Fathead minnow (larva), *Pimephales promelas*	-	48	7 days	Reduced growth	125	Norberg and Mount 1985
Fathead minnow (<24 hr), *Pimephales promelas*	Zinc chloride	36 55 68 82 90	96 hr	LC50 (river water)	393 440 556 655 807	Carlson et al. 1986
Channel catfish, (fingerling), *Ictalurus punctatus*	Zinc sulfate	206-236	40 hr	Decreased blood osmolarity	12,000	Lewis and Lewis 1971
Channel catfish, (embryo, larva), *Ictalurus punctatus*	Zinc chloride	90	5 days	Increased albanism	-	Westerman and Birge 1978
Channel catfish, (fingerling), *Ictalurus punctatus*	Zinc sulfate	313	14 days	LC50 (high alkalinity)	8,200	Reed et al. 1980
Guppy (5 mo), *Poecilia reticulata*	Zinc sulfate	-	4 mo	Reduced reproduction	880	Uvlovo and Beatty 1979
Guppy, *Poecilia reticulata*	Zinc sulfate	260	96 hr	LC50 (high solids)	54,950	Khangarot 1981

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Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)[a]	Reference
Guppy (184 mg), *Poecilia reticulata*	Zinc sulfate	260	48 hr	LC50	75,000	Khangarot et al. 1981
Guppy (fry), *Poecilia reticulata*	Zinc sulfate	30	167.5 hr	LC50	1,450	Pierson 1981
Striped bass (embryo), *Morone saxatilis*	-	137	20-25 hr	LC50	1,850	O'Rear 1971
Striped bass (fry), *Morone saxatilis*	-	137	48 hr	LC50	1,180	O'Rear 1971
Bluegill (2.5-3.9 g), *Lepomis macrochirus*	Zinc chloride	44.3	96 hr	LC50 (periodic low D.O.)	4,900	Cairns and Scheier 1958a; Academy of Natural Sciences 1960
Bluegill, *Lepomis macrochirus*	Zinc sulfate	370	20 days	LC50(DO=1.91) (DO=2.12) (DO=3.46) (DO=3.29) (DO=5.50) (DO=5.53)	7,200 7,500 10,700 10,500 12,000 10,700	Pickering 1968
Bluegill (fry), *Lepomis macrochirus*	Zinc sulfate	51	3 days	Lethal	235	Cairns and Sparks 1971; Sparks et al. 1972b.
Bluegill (18.7 g), *Lepomis macrochirus*	Zinc sulfate	68	12 hr 4.7 hr	LT50(20°C) (30°C)	32,000 32,000	Burton et al. 1972a
Bluegill (39.97 g), *Lepomis macrochirus*	Zinc sulfate	-	1-24 hr	Increased cough response	3,000	Sparks et al. 1972a
Bluegill, *Lepomis macrochirus*	Zinc sulfate	36	24 hr	LC50(5°C) (15°C) (30°C)	23,000 19,100 8,850	Cairns et al. 1978
Bluegill (juvenile), *Lepomis macrochirus*	Zinc chloride	112	40 min	13% avoidance	43,700	Black and Birge 1980
Bluegill (fry), *Lepomis macrochirus*	Zinc sulfate	313	14 days	LC50 (high alkalinity)	11,000	Reed et al. 1980

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Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)*	Reference
Largemouth bass (embryo, larva), Micropterus salmoides	Zinc chloride	93-105	8 days	EC50 (death and deformity)	5,160	Birge et al. 1978
Largemouth bass (juvenile), Micropterus salmoides	Zinc sulfate	112	40 min	57% avoidance	7,030	Black and Birge 1980
Largemouth bass (embryo, larva), Micropterus salmoides	Zinc chloride	-	9 days	EC50 (death and deformity)	5,180	Black and Birge 1980
Largemouth bass (fingerling), Micropterus salmoides	Zinc sulfate	313	14 days	LC50 (high alkalinity)	8,000	Reed et al. 1980
Narrow-mouthed toad (embryo, larva), Gastrophryne carolinensis	Zinc chloride	195	7 days	EC50 (death and deformity)	10	Birge 1978; Birge et al. 1979
Marbled salamander (embryo, larva), Ambystoma opacum	Zinc chloride	93-105	8 days	EC50 (death and deformity)	2,380	Birge et al. 1978

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Table 6. (Continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)*	Reference
			SALTWATER SPECIES			
Green alga, *Carteria* sp.	^{65}Zinc	35	7 days	BCF = 2,184***	-	Styron et al. 1976
Green alga, *Chlamydomonas* sp.	^{65}Zinc	34	7 days	BCF = 16,12***	-	Styron et al. 1976
Green alga, *Dunaliella euchlora*	Zinc chloride	-	12 days	EC50 (growth)	>33,600	Wikfors and Ukeles 1982
Green alga, *Dunaliella euchlora*	Zinc sulfate	-	12 days	EC50 (growth)	37,220†	Wikfors and Ukeles 1982
Green alga, *Dunaliella salina*	^{65}Zinc	44	7 days	BCF = 43,88***	-	Styron et al. 1976
Green alga, *Dunaliella tertiolecta*	Zinc sulfate	-	15 min	No effect on potassium retention	6,538	Overnell 1975
Green alga, *Dunaliella trertiolecta*	Zinc sulfate	-	15 min	EC50 (oxygen production)	65,380	Overnell 1976
Green alga, *Dunaliella tertiolecta*	Zinc chloride	-	72 hr	EC50 (growth)	13,000	Fisher et al. 1984
Green alga, *Nanochloris atomus*	^{65}Zinc	42	7 days	BCF = 16,12***	-	Styron et al. 1976
Golden-brown alga, *Isochrysis galbana*	-	12 16 20 28	48 hr (16°C)	Reduced chlorophyll *a* about 65%	2,000 430 810 1,200	Wilson and Freeberg 1980
Golden-brown alga, *Isochrysis galbana*	-	7 12 16 20 28 37	48 hr (20°C)	Reduced chlorophyll *a* about 65%	4,400 1,300 74 520 100 2,300	Wilson and Freeberg 1980
Golden-brown alga, *Isochrysis galbana*	-	12 16 20 28	48 hr (28°C)	Reduced chlorophyll *a* about 65%	1,000 3,000 800 3,000	Wilson and Freeberg 1980

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Table 6. (Continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)*	Reference
Golden-brown alga, Isochrysis galbana	Zinc chloride	-	12 days	EC50 (growth)	>33,600	Wikfors and Ukeles 1982
Golden-brown alga, Isochrysis galbana	Zinc sulfate	-	12 days	EC50 (growth)	33,100†	Wikfors and Ukeles 1982
Golden-brown alga, Monochrysis lutheri	Zinc sulfate	-	15 min	EC50 (reducted oxygen production)	1,308-1,961	Overnell 1976
Golden-brown alga, Monochrysis lutheri	Zinc chloride	-	12 days	EC50 (growth)	>33,600	Wikfors and Ukeles 1982
Golden-brown alga, Monochrysis lutheri	Zinc sulfate	-	12 days	EC50 (growth)	31,010†	Wikfors and Ukeles 1982
Diatom, Achnanthes brevipes	^{65}Zinc	40	7 days	BCF = 0.04***	-	Styron et al. 1976
Diatom, Nitzschia longissima	Zinc sulfate	30	1-5 days	Stimulated growth	≤100	Subramanian et al. 1980
Diatom, Phaeodactylum tricornutum	Zinc chloride	-	11-15 days	23% reduction in growth	25,000	Jensen et al. 1974
Diatom, Phaeodactylum tricornutum	Zinc chloride	-	13 days	BCF = 1,800***,†	250	Jensen et al. 1974
Diatom, Phaeodactylum tricornutum	Zinc chloride	-	14 days	BCF = 873***,†	10,000	Jensen et al. 1974
Diatom, Phaeodactylum tricornutum	Zinc sulfate	-	15 min	No effect on oxygen evolution	>65,380	Overnell 1976
Diatom, Phaeodactylum tricornutum	^{65}Zinc	37	7 days	BCF = 16.12***	-	Styron et al. 1976
Diatom, Phaeodactylum tricornutum	Zinc sulfate	25	10-14 days	19% reduction in growth	3,000	Braek et al. 1980
Diatom, Phaeodactylum tricornutum	Zinc chloride	-	12 days	EC50 (growth)	>33,600	Wikfors and Ukeles 1982

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Table 6. (Continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[a]	Reference
Diatom, *Phaeodactylum tricornutum*	Zinc sulfate	-	12 days	74.2% reduction in growth	48,000	Wikfors and Ukeles 1982
Diatom, *Skeletonema costatum*	Zinc chloride	-	13 days	BCF = 4,000***,†	-	Jensen et al. 1974
Diatom, *Skeletonema costatum*	Zinc chloride	-	12 days	BCF = 160***,†	-	Jensen et al. 1974
Diatom, *Skeletonema costatum*	Zinc chloride	-	11-15 days	23% reduction in growth	50	Jensen et al. 1974
Diatom, *Skeletonema costatum*	Zinc sulfate	-	10-14 days	EC50 (growth)	192.9†	Braek et al. 1976
Diatom, *Skeletonema costatum*	Zinc sulfate	-	10-14 days	EC50 (growth)	175.6†	Braek et al. 1976
Diatom, *Skeletonema costatum*	Zinc sulfate	-	15 min	No effect on oxygen evolution	>65,380	Overnell 1976
Diatom, *Skeletonema costatum*	Zinc sulfate	25	10-14 days	20% reduction in growth	100	Braek et al. 1980
Diatom, *Skeletonema costatum*	Zinc sulfate	30	1-3 days	Stimulated growth	≤200	Subramanian et al. 1980
Diatom, *Skeletonema costatum*	Zinc chloride	-	3 days	Altered cytoplasmic morphology	265	Smith 1983
Diatom, *Skeletonema costatum*	Zinc chloride	-	3 days	BCF = 765	-	Smith 1983
Diatom, *Thalassiosira pseudonana*	Zinc chloride	-	11-15 days	41% reduction in growth	500	Jensen et al. 1974
Diatom, *Thalassiosira pseudonana*	Zinc chloride	-	13 days	BCF = 148***,†	-	Jensen et al. 1974
Diatom, *Thalassiosira pseudonana*	Zinc chloride	-	15 days	BCF = 350***,†	-	Jensen et al. 1974

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Table 6. (Continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)*	Reference
Diatom, *Thalassiosira pseudonana*	Zinc sulfate	-	10-14 days	EC50 (growth)	470.8†	Braek et al. 1976
Diatom, *Thalassiosira pseudonana*	-	14	2 days (12°C) (16°C) (20°C) (24°C) (28°C)	Reduced chlorophyll *a* about 65%	 <100 170 <100 <100 200	Wilson and Freeberg 1980
Diatom, *Thalassiosira pseudonana*	Zinc chloride	-	72 hr	EC50 (growth)	823.1	Fisher et al. 1984
Diatom, *Thalassiosira rotula*	Zinc sulfate	32	5 days	EC50 (growth)	25.80†	Kayser 1977
Phytoplankton (diatom)	-	-	**	BAF = 113	-	Martin and Knauer 1972
Dinoflagellate, *Amphidinium carteri*	Zinc sulfate	-	10-14 days	EC50 (growth)	559.2†	Braek et al. 1976
Dinoflagellate, *Amphidinium carteri*	Zinc sulfate	-	10-14 days	No significant effect on growth; inhibited growth in presence of 50 µg copper/L	200	Braek et al. 1976
Dinoflagellate, *Glenodinium halli*	-	28	2 days	Reduced chlorophyll *a* about 65%	20	Wilson and Freeberg 1980
Dinoflagellate, *Gymnodinium splendens*	-	14	2 days (16°C) (30°C)	Reduced chlorophyll *a* about 65%	 700 1,400	Wilson and Freeberg 1980
Dinoflagellate, *Gymnodinium splendens*	-	28	2 days (16°C) (20°C) (24°C) (28°C) (30°C)	Reduced chlorophyll *a* about 65%	 392 240 110 120 300	Wilson and Freeberg 1980

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Table 6. (Continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)*	Reference
Dinoflagellate, *Scrippsiella faeroense*	Zinc sulfate	32	50 days	33% reduction in cell numbers	10,000	Kayser 1977
Brown macroalga, *Ascophyllum nodosum*	-	-	**	BAF = 1,603***,††	-	Melhuus et al. 1978
Brown macroalga, *Ascophyllum nodosum*	Zinc chloride	33	10 days	Decreased growth; no effect at 100 µg/L	250	Stromgren 1979
Brown macroalga, *Fucus serratus*	Zinc chloride	33	10 days	Decreased growth; no effect at 100 µg/L	1,400	Stromgren 1979
Brown macroalga, *Fucus serratus*	Zinc chloride	-	1 hr	Altered lipid metabolism	≥8.8	Smith and Harwood 1984
Brown macroalga, *Fucus spiralis*	Zinc chloride	33	10 days	Decreased growth; no effect at 100 µg/L	1,400	Stromgren 1979
Brown macroalga, *Fucus vesiculosis*	-	-	**	BAF = 1,612***,††	-	Melhuus et al. 1978
Brown macroalga, *Fucus vesiculosis*	Zinc chloride	33	10 days	Decreased growth; no effect at 2,900 µg/L	7,000	Stromgren 1979
Brown macroalga, *Laminaria digitata*	Zinc sulfate	-	24 days	Reduced growth	≥100	Bryan 1969
Brown macroalga, *Laminaria hyperborea*	Zinc sulfate	-	8-10 days	Reduced growth of sporophytes	250	Hopkins and Kain 1971
Brown macroalga, *Laminaria hyperborea*	Zinc sulfate	-	7 days	Abnormal maturation of gametophytes	5,000	Hopkins and Kain 1971
Brown macroalga, *Pelvetia canaliculata*	Zinc chloride	33	10 days	Decreased growth; no effect at 100 µg/L	1,400	Stromgren 1979
Green macroalga, *Ulva lactuca*	Zinc chloride	-	6 days	BCF = 255***,†	65.38	Haritonidis et al. 1983
Green macroalga, *Ulva lactuca*	Zinc chloride	-	6 days	BCF = 5,150***,†	6,538	Haritonidis et al. 1983

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Table 6. (Continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)*	Reference
Red macroalga, *Gracilaria verrucosa*	Zinc chloride	-	6 days	BCF = 107.5***,†	65.38	Haritonidis et al. 1983
Red macroalga, *Gracilaria verrucosa*	Zinc chloride	-	6 days	BCF = 16.25***,†	653.8	Haritonidis et al. 1983
Red macroalga, *Gracilaria verrucosa*	Zinc chloride	-	6 days	BCF = 3.225***,†	6,538	Haritonidis et al. 1983
Ciliate protozoan, *Cristigera* sp.	Zinc sulfate	34	4-5 hr	Reduced growth	50.63	Gray and Ventilla 1973; Gray 1974
Ciliate protozoan, *Euplotes vannus*	Zinc chloride	35	48 hr	10% reduction in growth	10,000	Persoone and Uytterspot 1975
Ciliate protozoan, *Euplotes vannus*	Zinc chloride	35	48 hr	100% reduction in in growth	100,000	Persoone and Uytterspot 1975
Polychaete worm (juvenile), *Neanthes arenaceodentata*	Zinc sulfate	-	28 days	LC50	900	Reish et al. 1976
Polychaete worm (adult), *Neanthes arenaceodentata*	Zinc sulfate	-	28 days	LC50	1,400	Reish et al. 1976
Polychaete worm (adult),††† *Nereis diversicolor*	Zinc sulfate	0.35 3.5 17.5	96 hr	LC50	2,300 14,600 94,000	Bryan and Hummerstone 1973
Polychaete worm (adult),††† *Nereis diversicolor*	Zinc sulfate	17.5	34 days	BCF = 26.57† 9.214 19.71 15.47 3.314 2.867 1.274 1.204	10,000 10,000 25,000 25,000 100,000 100,000 250,000 250,000	Bryan and Hummerstone 1973
Polychaete worm (adult), *Ophryotrocha diadema*	Zinc chloride	31	48 hr	LC50	330-1,000	Parker 1984

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Table 6. (Continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)*	Reference
Polychaete worm, *Ophryotrocha diadema*	Zinc sulfate	-	21 days	Chronic value;**** (acute-chronic ratio = 6.261)	223.6	Reish and Carr 1978
Polychaete worm, *Ctenodrilus serratus*	Zinc sulfate	-	21 days	Chronic value;**** (acute-chronic ratio = 31.75)	223.6	Reish and Carr 1978
Polychaete worm (larva), *Capitella capitata*	Zinc sulfate	-	>16 days	Abnormal development	50-100	Reish et al. 1974
Polychaete worm (adult), *Capitella capitata*	Zinc sulfate	-	28 days	LC50	1,250	Reish et al. 1976
Mud snail (adult), *Nassarius obsoletus*	Zinc chloride	25	72 hr	Depressed oxygen consumption	≥2,000	MacInnes and Thurberg 1973
Mud snail (adult), *Nassarius obsoletus*	Zinc chloride	25	72 hr	Inhibited locomotor behavior	10,000	MacInnes and Thurberg 1973
Mud snail (adult), *Nassarius obsoletus*	Zinc chloride	25	72 hr	Mortality	50,000	MacInnes and Thurberg 1973
Blue mussel (adult), *Mytilus edulis*	Zinc sulfate	-	7 days	LC50	>5,000	Martin et al. 1975
Blue mussel (adult), *Mytilus edulis*	Zinc sulfate	-	7 days	EC50 (byssal thread production)	1,800	Martin et al. 1975
Blue mussel (adult), *Mytilus edulis*	Zinc chloride	22	Approx. 10 days 6 days 4 days	LT50 (10°C) (16°C) (22°C)	 3,000 3,000 3,000	Cotter et al., 1982
Blue mussel (adult), *Mytilus edulis*	Zinc chloride	35	14 days	Reduced resistance to thermal shock	800-1,000	Cotter et al. 1982

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Table 6. (Continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[a]	Reference
Blue mussel (adult), Mytilus edulis	Zinc chloride	33.1	2-6 days	EC50 (shell growth)	60	Stromgren 1982
Blue mussel (embryo), Mytilus edulis	Zinc chloride	30	72 hr	EC50 (development) to veliger)	>96<314	Dinnel et al. 1983
Blue mussel (adult), Mytilus edulis	-	-	3 days	Reduced shell deposition	≥200	Manley et al. 1984
Pacific oyster (larva), Crassostrea gigas	Zinc sulfate	29	6 days	Abnormal development and decreased growth	≥125	Brereton et al. 1973
Pacific oyster (embryo), Crassostrea gigas	Zinc sulfate	29	2 days	LC50	241.5[†]	Brereton et al. 1973
Pacific oyster (larva), Crassostrea gigas	Zinc sulfate	29	5 days	Delayed and reduced larval settlement	125	Boyden et al. 1975
Pacific oyster (6-day larva), Crassostrea gigas	Zinc chloride	34	4 days	EC50 (growth)	80	Watling 1982
Pacific oyster (6-day larva), Crassostrea gigas	Zinc chloride	34	4 days	LC50	>100	Watling 1982
Pacific oyster (16-day larva), Crassostrea gigas	Zinc chloride	34	4 days	EC50 (growth)	95	Watling 1982
Pacific oyster (16-day larva), Crassostrea gigas	Zinc chloride	34	4 days	LC50	>100	Watling 1982
Pacficic oyster (sperm), Crassostrea gigas	Zinc chloride	27	60 min	EC50 (fertilization) success)	443.6	Dinnel et al. 1983
Pacific oyster (19-day larva), Crassostrea gigas	-	34	20 days	Reduced larval settlement	10-20	Watling 1983

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Table 6. (Continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[a]	Reference
Pacific oyster (19-day larva), Crassostrea gigas	-	34	6 days	EC50 (larval settling)	30-35	Watling 1983
Pacific oyster (juvenile), Crassostrea gigas	-	34	23 days	LC50	75	Watling 1983
Clam (larva), Mulinia lateralis	Zinc chloride	34	72 hr	53% mortality	200	Ho and Zubkoff 1982
Clam (larva), Mulinia lateralis	Zinc chloride	34	72 hr	EC50 (uptake of calcium)	176	Ho and Zubkoff 1982
Quahog clam (larva), Mercenaria mercenaria	Zinc chloride	24	8-10 days	LC50	195.4	Calabrese et al. 1977
Copepod (adult), Paracalanus parvus	Zinc chloride	35	24 hr	LC50	1,380	Arnott and Ahsanullah 1979
Copepod (adult), Pseudodiaptomus coronatus	Zinc chloride	30	72 hr	LC50	3,150	Lussier and Cardin 1985
Copepod (adult), Acartia clausi	Zinc chloride	30	72 hr	LC50	707.1	Lussier and Cardin 1985
Copepod (adult), Acartia simplex	Zinc chloride	35	24 hr	LC50	1,860	Arnott and Ahsanullah 1979
Copepod (adult), Scutellidium sp.	Zinc chloride	35	24 hr	LC50	1,090	Arnott and Ahsanullah 1979
Zooplankton (copepod and euphausid)	-	-	**	BAF = 1,670	-	Martin and Knauer 1972
Barnacle (adult), Balanus balanoides	Zinc nitrate	-	2 days	LC90	32,000	Clarke 1947
Barnacle (adult), Balanus balanoides	Zinc nitrate	-	5 days	LC90	8,000	Clarke 1947

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Table 6. (Continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)*	Reference
Isopod (adult), Idotea baltica	Zinc sulfate	13.6 20.4 27.2	48 hr 80 hr 70 hr	LT50	10,000	Jones 1975
Isopod (adult), Idotea baltica	Zinc sulfate	34.0	120 hr	40% mortality	10,000	Jones 1975
Isopod (adult), Idotea baltica	Zinc sulfate	27.2-34.0	120 hr	No effect on osmo-regulatory ability	10,000	Jones 1975
Isopod (adult), Idotea baltica	Zinc sulfate	13.6 20.4 27.2 34.0	<24 hr 30 hr 70 hr 54 hr	LT50	20,000	Jones 1975
Iospod (adult), Idotea baltica	Zinc sulfate	34.0	120 hr	Affected osmo-regulatory ability	20,000	Jones 1975
Isopod (adult), Jaera albifrons	Zinc sulfate	13.6 20.4 27.2 34.0	120 hr	80% mortality 30% mortality 6% mortality 16% mortality	10,000	Jones 1975
Iospod (adult), Jaera albifrons	Zinc sulfate	13.6 20.4 27.2 34.0	120 hr	84% mortality 44% mortality 40% mortality 22% mortality	20,000	Jones 1975
Isopod (adult), Jaera albifrons	Zinc sulfate	3.4	120 hr	Affected osmo-regulatory ability	20,000	Jones 1975
Isopod (adult), Jaera albifrons	Zinc sulfate	17-34	120 hr	No effect on osmo-regulatory ability	20,000	Jones 1975
Grass shrimp (larva), Palaemonetes pugio	Zinc chloride	3-31	35 days	Mortality related to salinity and temperature; altered development rates	≥250	McKenney 1979; McKenney and Neff 1979, 1981

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Table 6. (Continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[a]	Reference
Pink shrimp (adult), Pandalus montagui	Zinc sulfate	-	48 hr	LC50	4,050[†]	Portman 1968
American lobster (adult), Homarus americanus	Zinc sulfate	-	96 hr	No significant effects on adenylate energy charge; significant decreases in activity of Na/K-ATPase and residual ATPase in gills	62,000	Haya et al. 1983
American lobster (adult), Homarus americanus	Zinc sulfate	-	96 hr	BCF = 20.56 (gill)[†]	25,000-62,000	Haya et al. 1983
Green crab (adult), Carcinus maenas	Zinc sulfate	-	48 hr	LC50	14,500	Connor 1972
Green crab (adult), Carcinus maenas	Zinc sulfate	-	48 hr	LC50	Approx. 8,100[†]	Portman 1968
Green crab (adult), Carcinus maenas	^{65}Zinc chloride	38	3 mo	BCF = 130	-	Renfro et al. 1975
Green crab (adult), Carcinus maenas	^{65}Zinc chloride	38	3 mo	BAF = 210	-	Renfro et al. 1975
Mud crab (larva), Rhithropanopeus harrisii	Zinc chloride	20	13-18 days	No significan delay in development rate	25-50	Benijts-Claus and Benijts 1975
Mud crab (larva), Rhithropanopeus harrisii	Zinc chloride	20	13-18 days	Significant delay in development in combination with 25-50 µg lead/L	25-50	Benijts-Claus and Benijts 1975
Fiddler crab (adult), Uca pugilator	Zinc chloride	15 and 30	21 days	Inhibited limb regeneration; effect greater at lower salinities	≥1,000	Weis 1980
Starfish (adult), Asterias forbesii	Zinc sulfate	-	24 hr	Loss of equilibrium	2,212	Galtsoff and Loosanoff 1937

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Table 6. (Continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[a]	Reference
Sand dollar (sperm), Dendraster excentricus	Zinc chloride	27	60 min	EC50 (fertilization success)	28	Dinnel et al. 1983
Sand dollar (embryo), Dendraster excentricus	Zinc chloride	30	72 hr	EC50 (development to pluteus stage)	580-820	Dinnel et al. 1983
Sea urchin (embryo), Arbacia punctulata	Zinc chloride	-	21-42 hr	Inhibited gastrulation	1,199	Waterman 1937
Sea urchin (embryo), Arbacia punctulata	Zinc chloride	-	21-42 hr	Mortality and inhibition of gastrulation	3,998	Waterman 1937
Sea urchin (embryo), Arbacia punctulata	Zinc sulfate	-	21-42 hr	Inhibited gastrulation	810	Waterman 1937
Sea urchin (embryo), Arbacia punctulata	Zinc sulfate	-	21-42 hr	Mortality and inhibition of gastrulation	2,314	Waterman 1937
Sea urchin (embryo), Arbacia punctulata	Zinc acetate	-	21-42 hr	Inhibited gastrulation	3,564	Waterman 1937
Sea urchin (gamete), Arbacia punctulata	Zinc chloride	-	4-12 min	Stimulated sperm motility	1,634	Young and Nelson 1974
Sea urchin (gamete), Arbacia punctulata	Zinc chloride	-	4-12 min	Reduced sperm motility	3,269	Young and Nelson 1974
Green sea urchin (sperm), Strongylocentrotus droebachiensis	Zinc chloride	27	60 min	EC50 (fertilization success)	147.6 382.8	Dinnel et al. 1983
Green sea urchin (embryo), Strongylocentrotus droebachiensis	Zinc chloride	30	5 days	EC50 (development to pluteus stage	>26.6<50.6	Dinnel et al. 1983
Red sea urchin (sperm), Strongylocentrotus franciscanus	Zinc chloride	27	60 min	EC50 (fertilization success)	313.3	Dinnel et al. 1983

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Table 6. (Continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)*	Reference
Purple sea urchin (gamete), Strongylocentrotus purpuratus	-	-	100-400 min	Enhanced sperm motility	653.8	Timourian and Watchmaker 1977
Purple sea urchin (gamete), Strongylocentrotus purpuratus	-	-	0-100 min	No effect on sperm motility	6,538	Timourian and Watchmaker 1977
Purple sea urchin (gamete), Strongylocentrotus purpuratus	-	-	100-400 min	Inhibited sperm motility	6,538	Timourian and Watchmaker 1977
Purple sea urchin (sperm), Strongylocentrotus purpuratus	Zinc chloride	27	60 min	EC50 (fertilization success)	206.1 261.8	Dinnel et al. 1983
Purple sea urchin (embryo), Strongylocentrotus purpuratus	Zinc chloride	30	5 days	EC50 (development to pluteus stage)	23.1	Dinnel et al. 1983
Atlantic herring (embryo), Clupea harengus	Zinc sulfate	21	17 days	Reduced embryo volume	≥2,000	Somasundaram et al. 1984a
Atlantic herring (embryo), Clupea harengus	Zinc sulfate	21	17 days	Faster yolk utilization	≥100	Sonasundaram et al. 1984a
Atlantic herring (embryo), Clupea harengus	Zinc sulfate	21	17 days	Slower development rate	6,000	Somasundarum et al. 1984a
Atlantic herring (embryo and larva), Clupea harengus	Zinc sulfate	21	27 days	Jaw and branchial abnormalities	≥50	Somasundaram et al. 1984a
Atlantic herring (larva), Clupea harengus	Zinc sulfate	21	27 days	Vertebral abnormalities	≥500	Somasundaram et al. 1984a
Atlantic herring (larva), Clupea harengus	Zinc sulfate	21	27 days	Decrease in size of otic capsul	≥2,000	Somasundaram et al. 1984a
Atlantic herring (larva), Clupea harengus	Zinc sulfate	21	27 days	Decrease in eye/body length ratio	≥6,000	Somasundaram et al. 1984a

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Table 6. (Continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[a]	Reference
Atlantic herring (larva), Clupea harengus	Zinc sulfate	21	14 days	Ultrastructural changes in brain cells and somatic muscle tissues	≥500	Somasundaram et al. 1984c,d
Coho salmon (sperm), Oncorhynchus kistuch	Zinc chloride	27	60 min	EC50 (fertilization success)	1,208	Dinnel et al. 1983
Rainbow trout (yearling), Salmo gairdneri	Zinc sulfate	5.8 11.5 16.3 24.1	48 hr	LC50	27,000† 64,000† 64,000† 34,000†	Herbert and Wakeford 1964
Atlantic salmon (smolt), Salmo salar	Zinc sulfate	5.8 11.5 16.3 24.1	48 hr	LC50	16,000† 35,000† 32,000† 27,000†	Herbert and Wakeford 1964
Mummichog (adult), Fundulus heteroclitus	Zinc chloride	24	192 hr	100% survival	43,000	Eisler 1967
Mummichog (adult), Fundulus heteroclitus	Zinc chloride	24	48 hr	100% mortality	157,000	Eisler 1967
Mummichog (adult), Fundulus heteroclitus	Zinc chloride	24	48 hr	BCF = 7,643***,† (fish that died during exposure)	157,000	Eisler 1967
Mummichog (adult), Fundulus heteroclitus	Zinc chloride	20	96 hr	BCF = 35.61***,†	36,000	Eisler and Gardner 1973
Mummichog (adult), Fundulus heteroclitus	Zinc chloride	20	96 hr	BCF = 18.83***,†	60,000	Eisler and Gardner 1973
Mummichog (adult), Fundulus heteroclitus	Zinc chloride	20	96 hr	30% mortality; histopathological lesions in oral epithelium	60,000	Eisler and Gardner 1973

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Table 6. (Continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)*	Reference
Mummichog (adult), Fundulus heteroclitus	Zinc chloride	-	14 days	Increased activity of liver enzyme	2,200	Jackim 1973
Mummichog (adult), Fundulus heteroclitus	Zinc chloride	10-30	14 days	Enhanced regeneration of tail fin and ameliorated effects of methyl mercury	>1,000	Weis and Weis 1980
Mummichog (embryo), Fundulus heteroclitus	Zinc chloride	30	96 hr	Ameliorated teratogenic effects of methyl mercury	10,000	Weis et al. 1981
Mummichog (juvenile), Fundulus heteroclitus	Zinc chloride	25	70 days	Inhibited scale calcification	760-7,100	Sauer and Watabe 1984
Mummichog (juvenile), Fundulus heteroclitus	Zinc chloride	30	56 days	BCF = 33.91-240.0 (scales)	210-7,880	Sauer and Watabe 1984
Mosquitofish (adult), Gambusia affinis	††††	30	120 days	BCF = 8† (uptake from water alone)	650	Willis and Sunda 1984
Mosquitofish (adult), Gambusia affinis	††††	30	120 days	BAF = 45† (uptake from food and water)	650	Willis and Sunda 1984
Spot (juvenile), Leiostomus xanthurus	††††	30	28 days	BCF = 3† (uptake from water alone)	650	Willis and Sunda 1984
Spot (juvenile), Leiostomus xanthurus	††††	30	28 days	BAF = 28† (uptake from food and water)	650	Willis and Sunda 1984

* Concentration of zinc, not the chemical.

** Field study.

*** Converted from dry weight to wet weight basis.

**** Static test; concentrations not measured.

† Derived from authors' data or graph.

†† Geometric mean of data from four stations, but concentrations in water varied widely.

††† Animals obtained from sediment heavily contaminated with zinc.

†††† Nitrilotriacetic acid (NTA) was used to buffer the concentration of zinc ions.

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WATER QUALITY STANDARDS

FOR

INTERSTATE AND INTRASTATE STREAMS

IN NEW MEXICO

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New Mexico Water Quality Control Commission
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CONSTITUENT AGENCIES:

Environment Department
State Engineer and Interstate Stream Commission
Game and Fish Department
Oil Conservation Division
Department of Agriculture
State Park and Recreation Division
Soil and Water Conservation Division
Bureau of Mines and Mineral Resources
Member-at-Large

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WATER QUALITY STANDARDS
FOR
INTERSTATE AND INTRASTATE STREAMS
IN NEW MEXICO

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WATER QUALITY CONTROL COMMISSION
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WATER QUALITY STANDARDS FOR INTERSTATE AND INTRASTATE STREAMS IN NEW MEXICO

(Supersedes WQCC 88-1 filed March 24, 1988)

PART 1

1-100. PURPOSE AND AUTHORITY.

A. The purpose of these standards is to designate the uses for which the surface waters of the State of New Mexico shall be protected and to prescribe the water quality standards necessary to sustain the designated uses.

B. These standards are consistent with Section 101(a)(2) of the federal Clean Water Act, as amended, (33 U.S.C. 1251 et seq.) which declares that "it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983...." Agricultural, municipal, domestic and industrial water supply are other essential uses of New Mexico's water; however, water contaminants resulting from these activities will not be permitted to lower the quality of streams below that which is required for recreation and maintenance of a fishery, where practicable.

C. These standards are adopted by the Water Quality Control Commission under the authority of Paragraph C, Section 74-6-4 of the New Mexico Water Quality Act (NMSA 1978).

D. Part 3 of the Water Quality Control Commission Regulations includes standards to protect ground water and regulations controlling discharges onto or below the surface of the ground.

E. These water quality standards do not grant to the Commission or any other entity the power to take away or modify property rights in water.

F. Adopted August 22, 1973; revised September 29, 1975, January 13, 1976, February 8, 1977, March 14, 1978, May 23, 1979, July 8, 1980, April 22, 1981, May 11, 1982, June 8, 1982, November 20, 1984, January 8, 1985, August 18, 1987, March 8, 1988, May 22, 1991, and October 8, 1991.

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1-101. ANTIDEGRADATION POLICY AND IMPLEMENTATION PLAN.

A. Antidegradation Policy: Degradation of waters the quality of which is better than the stream standards established by the New Mexico Water Quality Control Commission is not reasonable degradation and is subject to abatement under the authority granted the Commission by the New Mexico Water Quality Act, as amended, unless it is justifiable as a result of necessary economic and social development. Existing instream water uses and water quality necessary to sustain existing uses shall be maintained and protected in all surface waters of the State. No degradation shall be allowed in high quality waters of designated national and state monuments, parks and wildlife refuges including waters designated by the U.S. Congress under the Wild and Scenic Rivers Act, if such degradation would impair any of the qualities which caused designation of these waters, parks and wildlife refuges. To protect the existing quality of water, the Commission under that Act will require the highest and best degree of effluent treatment practicable. In those cases where potential water quality impairment associated with a thermal discharge is involved, this antidegradation policy shall be consistent with Section 316 of the federal Clean Water Act. In implementing this section, the Commission through the appropriate regional offices of the United States Environmental Protection Agency will keep the Administrator advised and provided with such information concerning the waters of New Mexico as he will need to discharge his responsibilities under the federal Clean Water Act.

B. Implementation Plan: The New Mexico Environment Department, acting under authority delegated by the Commission, implements the water quality standards, including the antidegradation policy, by establishing and maintaining controls on the discharge of pollutants to surface waters. This stepwise process involves several interrelated programs and is summarized in the following paragraphs. The Department:

1. obtains information pertinent to the impact of the effluent on the receiving water and advises the prospective discharger of requirements for obtaining a permit to discharge;

2. reviews the adequacy of the existing data base and, if needed, obtains additional data by conducting an intensive survey of the receiving water;

3. assesses the probable impact of the effluent on the receiving water relative to its attainable or designated uses and numeric and narrative standards;

4. requires the highest and best degree of wastewater treatment practicable and commensurate with protecting and maintaining the designated uses and existing water quality of receiving waters, or attainable uses and existing water quality of unclassified lakes and perennial streams and perennial reaches of interrupted streams;

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5. develops water quality based effluent limitations and comments on technology based effluent limitations, as appropriate, for inclusion in any federal permit issued to a discharger pursuant to Section 402 of the Clean Water Act;

6. requires that these effluent limitations be included in any such permit as a condition for state certification pursuant to Section 401 of the federal Clean Water Act;

7. coordinates its water pollution control activities with other constituent agencies of the Commission, and with local, state and federal agencies, as appropriate;

8. develops and pursues inspection and enforcement programs to ensure that dischargers comply with state regulations, and complements EPA's enforcement of federal permits;

9. ensures that the provisions for public participation required by the New Mexico Water Quality Act and the federal Clean Water Act are followed;

10. provides continuing technical training for wastewater treatment facility operators through the utility operators training and certification programs;

11. provides funds to assist the construction of publicly owned wastewater treatment facilities through the wastewater construction program authorized by Section 601 of the federal Clean Water Act, and through funds appropriated by the New Mexico Legislature;

12. conducts water quality surveillance of the waters of the State to assess the effectiveness of water pollution controls and to determine whether water quality standards are being attained;

13. encourages, in conjunction with other state agencies, voluntary implementation of the best management practices set forth in the "State of New Mexico Water Quality Management Plan;" and

14. evaluates effectiveness of best management practices selected to prevent or abate non-point sources of water pollutants.

1-102. GENERAL STANDARDS.

General standards are established to sustain and protect uses which are existing or attainable by flows resulting from point source discharges or the earth's natural hydrologic cycle. These general standards apply at all times, except as otherwise specified in Sections 1-102.F, 1-102.K, 1-105.B, 1-105.E, 3-101 or Part 2, to all surface waters of the State. Watercourses shall be free of any water contaminant in such quantity and of such duration as may with reasonable probability injure human health, animal or plant life or property, or to unreasonably interfere with the public welfare or the use of property. The occurrence

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of a water contaminant or a deficiency of dissolved oxygen attributable to natural causes or the reasonable operation and maintenance of irrigation and flood control facilities is not subject to these general standards. The foregoing provision does not include major reconstruction of storage dams or diversion dams except for emergency actions necessary to protect health and safety of the public, or discharges from municipal separate storm sewers.

A. Stream Bottom Deposits: The stream shall be free of water contaminants from other than natural causes that will settle and adversely inhibit the growth of normal flora and fauna or significantly alter the physical or chemical properties of the bottom. Siltation resulting from the reasonable operation and maintenance of irrigation and flood control facilities is not subject to these standards.

B. Floating Solids, Oil and Grease: Receiving water shall be free of objectionable oils, scum, grease and other floating materials resulting from other than natural causes.

C. Color: Color-producing materials resulting from other than natural causes shall not create an aesthetically undesirable condition nor should color impair the use of the water by desirable aquatic life presently common in New Mexico waters.

D. Odor and Taste of Fish: Water contaminants from other than natural causes shall be limited to concentrations that will not impart unpalatable flavor to fish, or result in offensive odor arising from the stream or otherwise interfere with the reasonable use of the water.

E. Plant Nutrients: Plant nutrients from other than natural causes shall not be present in concentrations which will produce undesirable aquatic life or result in a dominance of nuisance species in receiving waters.

F. Hazardous Substances: Toxic substances such as, but not limited to, pesticides, herbicides, heavy metals, and organics, shall not be present in receiving waters in concentrations which will change the ecological conditions of receiving waters to an extent detrimental to man or other organisms of direct or indirect commercial, recreational, or aesthetic value. Toxicities of substances in receiving waters will be determined by appropriate bioassay techniques, or other acceptable means, for the particular form of aquatic life which is to be preserved with the concentrations of toxic substances not to exceed 5% of the LC-50 (see 3-100.T) provided that: toxic substances which, through uptake in the aquatic food chain and/or storage in plant and animal tissues, can be magnified to levels which are toxic to man or other organisms, shall not be present in concentrations which result in this biological magnification or exceed 1% of the LC-50. Chlorine residual shall not be considered a hazardous substance when discharged to non-perennial streams, provided that such discharge does not reach a perennial stream or perennial reaches of an interrupted stream except in response to direct precipitation or runoff.

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G. Radioactivity: The radioactivity of surface waters shall be maintained at the lowest practical level and shall in no case exceed the standards set forth in Part 4 of New Mexico Environmental Improvement Board Radiation Protection Regulations, filed March 10, 1989.

H. Pathogens: The stream shall be virtually free of pathogens. In particular, waters used for irrigation of table crops such as lettuce shall be virtually free of Salmonella and Shigella species.

I. Temperature: Maximum temperatures for each stream reach have been specified in Part 2 of these standards. However, the introduction of heat by other than natural causes shall not increase the temperature, as measured from above the point of introduction, by more than 2.7 C (5 F) in a stream, or more than 1.7 C (3 F) in a lake or reservoir. In no case will the introduction of heat be permitted when the maximum temperature specified for the reach (generally 20 C (68 F) for coldwater fisheries and 32.2 C (90 F) for warmwater fisheries) would thereby be exceeded. These temperature standards shall not apply to impoundments constructed offstream for the purpose of heat disposal. High water temperatures caused by unusually high ambient air temperatures or the reasonable operation of irrigation and aquacultural facilities are not violations of these standards.

J. Turbidity: Turbidity attributable to other than natural causes shall not reduce light transmission to the point that desirable aquatic life presently common in New Mexico waters is inhibited or that will cause substantial visible contrast with the natural appearance of the water. Turbidity attributable to natural causes or the reasonable operation of irrigation and flood control facilities is not subject to these standards.

K. Salinity: Where existing information is sufficient numerical standards for total dissolved solids (or conductivity), chlorides and sulfates, have been adopted in Part 2 of these standards.

1. For the tributaries of the Colorado River System, the State of New Mexico will cooperate with the Colorado River Basin States and the federal government to support and implement the salinity policy and program outlined in the report "1990 Review, Water Quality Standards for Salinity, Colorado River System."

2. Numeric criteria for salinity are established at three points in the Colorado River Basin as follows: below Hoover Dam, 723 mg/l; below Parker Dam, 747 mg/l; and at Imperial Dam, 879 mg/l.

3. As a part of the program, objectives for New Mexico shall include the elimination of discharges of water containing solids in solution as a result of the use of water to control or convey fly ash from coal-fired electric generators, wherever practicable.

4. In determining compliance with the numeric criteria hereby adopted, salinity (TDS) is determined by the "calculation method" (sum of

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constituents) as described in the latest edition of "Techniques of Water-Resources Investigations of the United States Geological Survey, Methods for Collection and Analysis of Water Samples for Dissolved Minerals and Gases."

L. Dissolved Gases: Surface waters shall be free of nitrogen and other dissolved gases at levels above 110% saturation when this supersaturation is attributable to municipal, industrial or other discharges.

1-103. SAMPLING AND ANALYSIS.

A. All methods of sample collection, preservation and analysis used in determining water quality and maintenance of these standards shall be in accordance with currently approved procedures given in the latest edition of:

1. "Standard Methods for the Examination of Water and Wastewater," American Public Health Association; or

2. "Methods for Chemical Analysis of Water and Wastes" and other publications of the Analytical Quality Control Laboratory, EPA; or

3. "Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act," 40 CFR Part 136; or

4. "National Handbook of Recommended Methods for Water-Data Acquisition," U.S. Geological Survey."

B. Bacteriological Surveys:

1. The monthly logarithmic mean shall be used in assessing attainment of standards when a minimum of five samples is collected in a 30-day period.

C. Sampling Procedures:

1. Streams: Stream monitoring stations below waste discharges shall be located a sufficient distance downstream to ensure adequate vertical and lateral mixing.

2. Lakes: Sampling stations in lakes shall be located at least 250 feet from a waste discharge.

3. Lakes: Except for the restriction specified in Section 103.C.2, lake sampling stations shall be located at any site where the attainment of a water quality standard is to be assessed. Water quality measurements taken at intervals in the entire water column at a sampling station shall be averaged for the epilimnion, or in the absence of an epilimnion, for the upper 1/3 of the water column of the lake to determine attainment of standards, except that attainment of standards for toxic

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substances shall be assessed during periods of complete vertical mixing, e.g., during spring or fall turnover, or by taking depth-integrated composite samples of the water column.

D. Acute toxicity of effluent to aquatic life shall be determined using the procedures specified in U.S. Environmental Protection Agency "Methods for Measuring the Acute Toxicity of Effluents to Freshwater and Marine Organisms" (3rd Ed., 1985, EPA 600/4-85/013), or latest edition thereof, which is incorporated herein by reference. Acute toxicities of substances shall be determined using at least two species tested in whole effluent and a series of effluent dilutions. Acute toxicity due to discharges shall not occur within the wastewater mixing zone in any stream with an existing or designated fishery use.

E. Chronic toxicity of effluent or ambient surface water to aquatic life shall be determined using the procedures specified in U.S. Environmental Protection Agency "Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms" (2nd Ed., 1989, EPA 600/4-89/001), or latest edition thereof, which is incorporated herein by reference. Chronic toxicities of substances shall be determined using at least two species tested in ambient surface water or whole effluent and a series of effluent dilutions. Chronic toxicity due to discharges shall not occur at the critical low flow in any stream with an exiting or designated fishery use more that once every three years.

1-104. REVIEW OF STANDARDS, NEED FOR ADDITIONAL STUDIES.

A. Section 303(c)(1) of the federal Clean Water Act requires that public hearings be held at least once every three years for the purpose of reviewing and proposing necessary revisions of these water quality standards.

B. It is recognized that, in some cases, numeric standards have been adopted which reflect stream use designations rather than existing stream conditions. Narrative standards are required for many constituents because accurate data on background levels are lacking. More intensive water quality monitoring may identify stream reaches where existing quality is considerably better than the established standards. When justified by sufficient data and need, the stream standards will be modified to reflect true stream conditions.

C. It is also recognized that contributions of water contaminants by diffuse non-point sources of water pollution may make attainment of certain standards difficult. Revision of these standards may be required as new information is obtained on non-point sources and other problems unique to semi-arid regions.

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1-105. APPLICABILITY OF WATER QUALITY STANDARDS.

A. The numeric standards for salinity set out in Part 2 shall apply at the downstream point of the reach in question.

B. Critical Low Flow: The numeric standards set under Section 1-102.F, Part 2 and Section 3-101 may not be attainable when streamflow is less than the critical low flow of the stream in question. The critical low flow of a stream at a particular site shall be the minimum average four consecutive day flow which occurs with a frequency of once in three years (4Q3). Critical low-flow numeric values may be determined on an annual, a seasonal or a monthly basis, as appropriate, after due consideration of site-specific conditions.

C. Guaranteed Minimum Flow: On a case-by-case basis and upon consultation with the Interstate Stream Commission, the Water Quality Control Commission may allow the use of a contractually guaranteed minimum streamflow in lieu of a critical low flow determined under Section 1-105.B. Should drought, litigation or any other reason interrupt or interfere with minimum flows under a guaranteed minimum flow contract for a period of at least thirty consecutive days, such permission may, at the sole discretion of the WQCC, then be revoked. Any minimum flow specified under such revoked permission shall be superseded by a critical low flow determined under Section 1-105.B. A public notice of the request for a guaranteed minimum flow shall be published by the Environment Department at least 30 days prior to scheduled action by the Commission. These water quality standards do not grant to the Commission or any other entity the power to create, take away or modify property rights in water.

D. Mixing Zones: A limited mixing zone, contiguous to a point source wastewater discharge, may be allowed in any stream receiving such a discharge. Mixing zones serve as regions of initial dilution which allow the application of a dilution factor in calculations of effluent limitations. Effluent limitations shall be developed which will protect the most sensitive designated or attainable aquatic use of the receiving water.

E. Limitations: Wastewater mixing zones, in which the numeric standards set under Section 1-102.F., Part 2 or Section 3-101 may be exceeded, shall be subject to the following limitations:

1. Mixing zones are not allowed for discharges to publicly owned lakes or reservoirs; these effluents shall meet all applicable standards set under Section 1-102.F, Part 2 and Section 3-101 at the point of discharge.

2. The shape and volume of a particular mixing zone will depend on site-specific conditions such as, but not limited to, wastewater flow, receiving water critical low flow, outfall design, channel characteristics and climatic conditions, and shall be determined on a case-by-case basis.

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3. All applicable water quality standards set under Section 1-102.F, Part 2 and Section 3-101 shall be attained at the boundaries of mixing zones. A continuous zone of passage through or around the mixing zone shall be maintained in which the water quality meets all applicable standards and allows the migration of aquatic life presently common in New Mexico waters with no effect on their populations.

4. Mixing zones shall be free of substances in concentrations which are acutely toxic to aquatic organisms passing through the zone of mixing. Compliance with this provision shall be determined by performance of the biomonitoring procedures set out in Section 1-103.D, or by demonstration of compliance with acute standards set out in Section 3-101.J and applicable un-ionized ammonia and total chlorine residual standards set out in Sections 3-101.A, 3-101.C, 3-101.E, 3-101.F and 3-101.H.

1-106. COMPLIANCE WITH WATER QUALITY STANDARDS.

A. Compliance with acute water quality standards shall be determined from the analytical results of a single grab sample. Acute standards shall not be exceeded.

B. Compliance with chronic water quality standards shall be determined from the arithmetic mean of the analytical results of a minimum of four samples collected on each of four consecutive days. Chronic standards shall not be exceeded more than once every three years.

C. Compliance with water quality standards for un-ionized ammonia shall be determined by performing the biomonitoring procedures set out in Section 1-103.E, or by attainment of applicable ammonia standards set out in Sections 3-101.A, 3-101.C, 3-101.E, 3-101.F and 3-101.H.

D. Compliance Schedules: It shall be the policy of the Commission to allow on a case-by-case basis the inclusion of a schedule of compliance in a National Pollutant Discharge Elimination System (NPDES) permit issued to an existing facility. Such schedule of compliance will be for the purpose of providing a permittee with adequate time to make treatment facility modifications necessary to comply with water quality based permit limitations determined to be necessary to implement new or revised water quality standards. Compliance schedules may be included in NPDES permits at the time of permit renewal or modification and shall be written to require compliance at the earliest practicable time. Compliance schedules shall also specify milestone dates so as to measure progress towards final project completion (e.g., design completion, construction start, construction completion, date of compliance).

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PART 2

STREAM USE DESIGNATIONS AND STANDARDS

2-100. RIO GRANDE BASIN.

2-101. The main stem of the Rio Grande from the International Boundary and Water Commission sampling station above American Dam upstream to one mile below Percha Dam.[1]

A. Designated Uses: irrigation, limited warmwater fishery, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall not exceed 34 C (93.2 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 1,000/100 ml; no single sample shall exceed 2,000/100 ml (see 1-103.B).

3. At mean monthly flows above 350 cfs, the monthly average concentration for: TDS shall be less than 2,000 mg/l, sulfate shall be less than 500 mg/l, and chlorides shall be less than 400 mg/l.

2-102. The main stem of the Rio Grande from one mile below Percha Dam upstream to the headwaters of Caballo Reservoir including Caballo Reservoir.[1]

A. Designated Uses: irrigation, livestock and wildlife watering, primary contact recreation, and warmwater fishery.

B. Standards:

1. At any sampling site: dissolved oxygen shall be greater than 5.0 mg/l except for brief periods (6 hours or less) of not less than 4.0 mg/l, pH shall be within the range of 6.0 to 9.0, temperature shall be less than 32.2 C (90 F), and turbidity shall be less than 50 NTU.

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[1]Sustained flow in the Rio Grande below Caballo Reservoir is dependent on release from Caballo Reservoir during the irrigation season; at other times of the year, there may be little or no flow.

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2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

3. The open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders.

2-103. The main stem of the Rio Grande from the headwaters of Caballo Lake upstream to Elephant Butte Dam[1] and perennial reaches of tributaries to the Rio Grande in Sierra and Socorro counties.

A. Designated Uses: fish culture, irrigation, livestock and wildlife watering, marginal coldwater fishery, secondary contact recreation, and warmwater fishery.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 25 C (77 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 1,000/100 ml; no single sample shall exceed 2,000/100 ml (see 1-103.B).

2-104. Elephant Butte Reservoir.

A. Designated Uses: irrigation storage, livestock and wildlife watering, primary contact recreation, and warmwater fishery.

B. Standards:

1. At any sampling site: dissolved oxygen shall be greater than 5.0 mg/l except for brief periods (6 hours or less) of not less than 4.0 mg/l, pH shall be within the range of 6.6 to 9.0, temperature shall be less than 32.2 C (90 F), and turbidity shall be less than 50 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

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[1]Flow in this reach of the Rio Grande main stem is dependent upon release from Elephant Butte Dam.

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3. The open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders.

2-105. The main stem of the Rio Grande from the headwaters of Elephant Butte Reservoir upstream to Alameda Bridge (Corrales Bridge), including any flow below the perennial reaches of the Rio Puerco and Jemez River which enters the main stem of the Rio Grande.

A. Designated Uses: irrigation, limited warmwater fishery, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 4.0 mg/l, pH shall be within the range of 6.0 to 9.0, and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 1,000/100 ml; no single sample shall exceed 2,000/100 ml (see 1-103.B).

3. At mean monthly flows above 100 cfs, the monthly average concentration for: TDS shall be less than 1,500 mg/l, sulfate shall be less than 500 mg/l, and chloride shall be less than 250 mg/l.

2-105.1 The main stem of the Rio Grande from Alameda Bridge (Corrales Bridge) upstream to the Angostura Diversion Works.

A. Designated Uses: irrigation, limited warmwater fishery, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.0 to 9.0, and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

3. At mean monthly flows above 100 cfs, the monthly average concentration for: TDS shall be less than 1,500 mg/l, sulfate shall be less than 500 mg/l, and chloride shall be less than 250 mg/l.

2-105.5 The Jemez River from its confluence with the Rio Guadalupe upstream to State Highway 4 near the town of Jemez Springs and perennial reaches of Vallecito Creek.

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A. Designated Uses: coldwater fishery, primary contact recreation, irrigation, and livestock and wildlife watering.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, temperature shall be less than 25 C (77 F), total chlorine residual shall be less than 0.002 mg/l, pH shall be within the range of 6.6 to 8.8, and turbidity shall be less than 25 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

3. The open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders.

2-106. The Jemez River and all its tributaries above State Highway 4 near the town of Jemez Springs and the Guadalupe River and all its tributaries.

A. Designated Uses: domestic water supply, fish culture, high quality coldwater fishery, irrigation, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.02 mg/l; conductivity shall be less than 400 umhos; dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; total inorganic nitrogen (as N) shall be less than 1.0 mg/l; pH shall be within the range of 6.6 to 8.8; temperature shall be less than 20 C (68 F); total chlorine residual shall be less than 0.002 mg/l; total organic carbon shall be less than 7 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l; and turbidity shall be less than 25 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

2-107. Perennial reaches of Bluewater Creek, Rio Moquino, Seboyeta Creek, Rio Paguate, the Rio Puerco within the Santa Fe National Forest, and all other perennial reaches of tributaries to the Rio Puerco including the Rio San Jose in Cibola County from the USGS gaging station at Correo upstream to Horace Springs.

A. Designated Uses: coldwater fishery, domestic water supply, fish culture, irrigation, livestock and wildlife watering, and primary contact recreation.

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B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, total inorganic nitrogen (as N) shall be less than 2.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 20 C (68 F), total chlorine residual shall be less than 0.002 mg/l, total phosphorus (as P) shall be less than 0.1 mg/l, and turbidity shall be less than 25 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

3. The open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders.

2-108. The main stem of the Rio Grande from Angostura Diversion Works upstream to Cochiti Dam.

A. Designated Uses: irrigation, livestock and wildlife watering, secondary contact recreation, coldwater fishery, and warmwater fishery.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 9.0, temperature shall be less than 25 C (77 F), and total chlorine residual shall be less than 0.002 mg/l.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-108.5 Perennial reaches of Las Huertas Creek.

A. Designated Uses: coldwater fishery, irrigation, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 25 C (77 F), and total chlorine residual shall be less than 0.002 mg/l.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

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2-109. Cochiti Reservoir.

A. Designated Uses: livestock and wildlife watering, warmwater fishery, coldwater fishery, and primary contact recreation.

B. Standards:

1. At any sampling site: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 25 C (77 F), turbidity shall be less than 25 NTU, and total chlorine residual shall be less than 0.002 mg/l.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

3. The open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders.

2-110. The Santa Fe River and its tributaries from Cochiti Reservoir upstream to the outfall of the Santa Fe wastewater treatment facility.

A. Designated Uses: irrigation, livestock and wildlife watering, marginal coldwater fishery, secondary contact recreation, and warmwater fishery.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 4.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 30 C (86 F), and turbidity shall be less than 50 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 1,000/100 ml; no single sample shall exceed 2,000/100 ml (see 1-103.B).

2-111. The main stem of the Rio Grande from the headwaters of Cochiti Reservoir upstream to Taos Junction Bridge, Embudo Creek from its mouth on the Rio Grande upstream to the junction of the Rio Pueblo and the Rio Santa Barbara, the Santa Cruz River below Santa Cruz Dam, the Rio Tesuque below the Santa Fe National Forest and the Pojoaque River below Nambe Dam.

A. Designated Uses: irrigation, livestock and wildlife watering, marginal coldwater fishery, secondary contact recreation, and warmwater fishery.

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B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.6, temperature shall be less than 22 C (71.6 F), and turbidity shall be less than 50 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 1,000/100 ml; no single sample shall exceed 2,000/100 ml (see 1-103.B).

3. At mean monthly flows above 100 cfs, the monthly average concentration for: TDS shall be less than 500 mg/l, sulfate shall be less than 150 mg/l, and chloride shall be less than 25 mg/l.

2-112. The perennial reaches of Rio Vallecitos and its tributaries, and Rio del Oso, and El Rito Creek above the town of El Rito.

A. Designated Uses: domestic water supply, irrigation, high quality coldwater fishery, livestock and wildlife watering, and secondary contact recreation.

B. Standards

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.02 mg/l; conductivity shall be less than 300 umhos; dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; total inorganic nitrogen (as N) shall be less than 1.0 mg/l; pH shall be within the range of 6.6 to 8.8; temperature shall be less than 20 C (68 F); total chlorine residual shall be less than 0.002 mg/l; total organic carbon shall be less than 7 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l; and turbidity shall be less than 10 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

2-113. The Rio Chama from its mouth on the Rio Grande upstream to Abiquiu Reservoir, the Rio Tusas, the Rio Ojo Caliente, Abiquiu Creek, and El Rito Creek below the town of El Rito.

A. Designated Uses: irrigation, livestock and wildlife watering, marginal coldwater fishery, warmwater fishery, and secondary contact recreation.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 31 C (87.8 F).

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2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 1,000/100 ml; no single sample shall exceed 2,000/100 ml (see 1-103.B).

2-114. Abiquiu Reservoir.

A. Designated Uses: irrigation storage, livestock and wildlife watering, primary contact recreation, coldwater fishery, and warmwater fishery.

B. Standards:

1. At any sampling site: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 25 C (77 F), and total chlorine residual shall be less than 0.002 mg/l.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

3. The open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders.

2-115. The Rio Chama from the headwaters of Abiquiu Reservoir upstream to El Vado Reservoir and the Rio Gallina and Rio Puerco de Chama north of State Highway 96.

A. Designated Uses: irrigation, livestock and wildlife watering, coldwater fishery, warmwater fishery, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 26 C (78.8 F), and total chlorine residual shall be less than 0.002 mg/l.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-116. All perennial reaches of tributaries to the Rio Chama above Abiquiu Reservoir except the Rio Gallina and Rio Puerco de Chama north of State Highway 96 and the main stem of the Rio Chama from the headwaters of El Vado Reservoir upstream to the New Mexico-Colorado line.

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A. Designated Uses: domestic water supply, fish culture, high quality coldwater fishery, irrigation, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.02 mg/l; conductivity shall be less than 500 umhos (1,000 umhos for Coyote Creek); dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; total inorganic nitrogen (as N) shall be less than 1.0 mg/l; pH shall be within the range of 6.6 to 8.8; temperature shall be less than 20 C (68 F); total chlorine residual shall be less than 0.002 mg/l; total organic carbon shall be less than 7 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l; and turbidity shall be less than 25 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

2-117. El Vado and Heron Reservoirs.

A. Designated Uses: irrigation storage, wildlife and livestock watering, primary contact recreation, and coldwater fishery.

B. Standards:

1. At any sampling site: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 20 C (68 F), and total chlorine residual shall be less than 0.002 mg/l, and turbidity shall be less than 25 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

3. The open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders.

2-118. Perennial tributaries to the Rio Grande in Bandelier National Monument and their headwaters in Sandoval County, all perennial reaches of tributaries to the Rio Grande in Santa Fe County unless included in other segments.

A. Designated Uses: domestic water supply, high quality coldwater fishery, irrigation, livestock and wildlife watering, municipal and industrial water supply, and secondary contact recreation.

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B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.02 mg/l, conductivity shall be less than 300 umhos; dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; total inorganic nitrogen (as N) shall be less than 1.0 mg/l; pH shall be within the range of 6.6 to 8.8; temperature shall be less than 20 C (68 F); total chlorine residual shall be less than 0.002 mg/l; total organic carbon shall be less than 7 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l; and turbidity shall be less than 10 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

2-119. The main stem of the Rio Grande from Taos Junction Bridge upstream to the New Mexico-Colorado line, the Red River from its mouth on the Rio Grande upstream to the mouth of Placer Creek, and the Rio Pueblo de Taos from its mouth on the Rio Grande upstream to Los Cordovas.

A. Designated Uses: coldwater fishery, fish culture, irrigation, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 20 C (68 F), and total chlorine residual shall be less than 0.002 mg/l, and turbidity shall be less than 50 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

2-120. The Red River upstream of the mouth of Placer Creek, all tributaries to the Red River, and all other perennial reaches of tributaries to the Rio Grande in Taos and Rio Arriba counties unless included in other segments.

A. Designated Uses: domestic water supply, fish culture, high quality coldwater fishery, irrigation, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.02 mg/l; conductivity shall be less than 400 umhos (500 umhos for the Rio Fernando de Taos); dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; total inorganic nitrogen (as N)

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shall be less than 1.0 mg/l; pH shall be within the range of 6.6 to 8.8; temperature shall be less than 20 C (68 F); total chlorine residual shall be less than 0.002 mg/l; total organic carbon shall be less than 7 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l; and turbidity shall be less than 25 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

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2-200. PECOS RIVER BASIN.

2-201. The main stem of the Pecos River from the New Mexico-Texas line upstream to the USGS gaging station near Malaga.

A. Designated Uses: irrigation, livestock and wildlife watering, secondary contact recreation, and warmwater fishery.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to. 8.8, and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

3. At all flows above 50 cfs: TDS shall be less than 20,000 mg/l, sulfate shall be less than 3,000 mg/l, and chloride shall be less than 10,000 mg/l.

2-202. The main stem of the Pecos River from the USGS gaging station near Malaga upstream to Lower Tansil Dam,[1] including the Black River, the Delaware River and Blue Spring.

A. Designated Uses: industrial water supply, irrigation, livestock and wildlife watering, secondary contact recreation, and warmwater fishery.

B. Standards:

1. In any single sample, dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 9.0, and temperature shall be less than 34 C (93.2 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

3. At all flows above 50 cfs: TDS shall be less than 8,500 mg/l, sulfate shall be less than 2,500 mg/l, and chloride shall be less than 3,500 mg/l.

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[1]Diversion for irrigation frequently limits summer flow in this reach to that contributed by springs along the watercourse.

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2-203. The main stem of the Pecos River from Lower Tansil Dam upstream to Avalon Dam, including Tansil Lake.

A. Designated Uses: industrial water supply, livestock and wildlife watering, primary contact recreation, and warmwater fishery.

B. Standards:

1. At any sampling site: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 34 C (93.2 F), and turbidity shall be less than 25 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

3. The open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders.

2-204. The main stem of the Pecos River from Avalon Dam upstream to Brantley Dam, including Avalon Reservoir.

A. Designated Uses: irrigation storage, livestock and wildlife watering, secondary contact recreation, and warmwater fishery.

B. Standards:

1. At any sampling site: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 1,000/100 ml; no single sample shall exceed 2,000/100 ml (see 1-103.B).

2-205. Brantley Reservoir.

A. Designated Uses: irrigation storage, livestock and wildlife watering, primary contact recreation, and warmwater fishery.

B. Standards:

1. At any sampling site: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

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3. The open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders.

2-206. The main stem of the Pecos River from the headwaters of Brantley Reservoir upstream to Acme, including flow from below the perennial reaches of the Rio Penasco, the Rio Hondo, and the Rio Felix which enters the main stem of the Pecos River.

A. Designated Uses: irrigation, livestock and wildlife watering, secondary contact recreation, and warmwater fishery.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 1,000/100 ml; no single sample shall exceed 2,000/100 ml (see 1-103.B).

3. At all flows above 50 cfs: TDS shall be less than 14,000 mg/l, sulfate shall be less than 3,000 mg/l, and chloride shall be less than 6,000 mg/l.

2-207. The main stem of the Pecos River from Acme upstream to Sumner Dam.

A. Designated Uses: fish culture, irrigation, limited warmwater fishery, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 1,000/100 ml; no single sample shall exceed 2,000/100 ml (see 1-103.B).

3. At all flows above 50 cfs: TDS shall be less than 8,000 mg/l, sulfate shall be less than 2,500 mg/l, and chloride shall be less than 4,000 mg/l.

2-208. Perennial reaches of the Rio Penasco and its tributaries above Dunken, and perennial reaches of Bonito Creek below Angus, the Rio Ruidoso below Seeping Springs Lakes, and Agua Chiquita.

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A. Designated Uses: fish culture, irrigation, livestock and wildlife watering, coldwater fishery, and secondary contact recreation.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 30 C (86 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-209. Eagle Creek above Alto Reservoir, Bonito Creek upstream of Angus, and the Rio Ruidoso and its tributaries above Seeping Springs Lakes.

A. Designated Uses: domestic water supply, fish culture, high quality coldwater fishery, irrigation, livestock and wildlife watering, municipal and industrial water supply, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.02 mg/l; conductivity shall be less than 600 umhos in Eagle Creek, 1,100 umhos in Bonito Creek, and 1,500 umhos in the Rio Ruidoso; dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; total inorganic nitrogen (as N) shall be less than 1.0 mg/l; pH shall be within the range of 6.6 to 8.8; temperature shall be less than 20 C (68 F); total chlorine residual shall be less than 0.002 mg/l; total organic carbon shall be less than 7 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l; and turbidity shall be less than 10 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

2-210. Sumner Reservoir.

A. Designated Uses: irrigation storage, livestock and wildlife watering, primary contact recreation, and warmwater fishery.

B. Standards:

1. At any sampling site: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 32.2 C (90 F), and turbidity shall be less than 25 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

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3. The open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders.

2-211. The main stem of the Pecos River from the headwaters of Sumner Reservoir upstream to Anton Chico.

A. Designated Uses: fish culture, irrigation, limited warmwater fishery, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

3. At all flows above 50 cfs: TDS shall be less than 3,000 mg/l, sulfate shall be less than 2,000 mg/l, and chloride shall be less than 400 mg/l.

2-211.3 MacAllister Lake.

A. Designated Uses: coldwater fishery, secondary contact recreation, and livestock and wildlife watering.

B. Standards:

1. At any sampling site: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 25 C (77 F), and total chlorine residual shall be less than 0.002 mg/l.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 1,000/100 ml; no single sample shall exceed 2,000/100 ml (see 1-103.B).

2-211.5 Storrie Lake.

A. Designated Uses: coldwater fishery, warmwater fishery, primary contact recreation, livestock and wildlife watering, and irrigation storage.

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B. Standards:

1. At any sampling site: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 20 C (68 F), total chlorine residual shall be less than 0.002 mg/l, and turbidity shall be less than 25 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

3. The open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders.

2-212. The Gallinas River and all its tributaries above the diversion for the Las Vegas municipal reservoir and perennial reaches of Tecolote Creek and its perennial tributaries.

A. Designated Uses: domestic water supply, high quality coldwater fishery, irrigation, livestock and wildlife watering, municipal and industrial water supply, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.02 mg/l; conductivity shall be less than 300 umhos except conductivity shall be less than 450 umhos in Wright Canyon Creek; dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; total inorganic nitrogen (as N) shall be less than 1.0 mg/l; pH shall be within the range of 6.6 to 8.8; temperature shall be less than 20 C (68 F); total chlorine residual shall be less than 0.002 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l; and turbidity shall be less than 10 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

2-213. The main stem of the Pecos River from Anton Chico upstream to one river mile below the bridge on State Highway 223, and perennial reaches of the Gallinas River from its mouth upstream to the diversion for the Las Vegas municipal reservoir.

A. Designated Uses: irrigation, livestock and wildlife watering, marginal coldwater fishery, and secondary contact recreation.

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B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 30 C (86 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 1,000/100 ml; no single sample shall exceed 2,000/100 ml (see 1-103.B).

3. At all flows above 10 cfs: TDS shall be less than 250 mg/l, sulfate shall be less than 25 mg/l, and chloride shall be less than 5 mg/l.

2-214. Cow Creek and all its tributaries and the main stem of the Pecos River from one river mile below the bridge on State Highway 223 upstream to its headwaters, including all tributaries thereto.

A. Designated Uses: domestic water supply, fish culture, high quality coldwater fishery, irrigation, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.02 mg/l; conductivity shall be less than 300 umhos; dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; total inorganic nitrogen (as N) shall be less than 1.0 mg/l; pH shall be within the range of 6.6 to 8.8; temperature shall be less than 20 C (68 F); total chlorine residual shall be less than 0.002 mg/l; total organic carbon shall be less than 7 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l; and turbidity shall be less than 10 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

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2-300. CANADIAN RIVER BASIN.

2-301. The main stem of the Canadian River from the New Mexico-Texas line upstream to Ute Dam, and any flow which enters the main stem from Revuelto Creek.

A. Designated Uses: irrigation, limited warmwater fishery, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 32.2 C (90 F), and TDS shall be less than 6,500 mg/l at flows above 25 cfs.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-302. Ute Reservoir.

A. Designated Uses: livestock and wildlife watering, municipal and industrial water supply, primary contact recreation, and warmwater fishery.

B. Standards:

1. At any sampling site: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, turbidity shall be less than 25 NTU and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

3. The open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders.

2-303. The main stem of the Canadian River from the headwaters of Ute Reservoir upstream to Conchas Dam and Ute Creek and its perennial tributaries.

A. Designated Uses: irrigation, limited warmwater fishery, livestock and wildlife watering, and secondary contact recreation.

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B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-304. Conchas Reservoir.

A. Designated Uses: irrigation storage, livestock and wildlife watering, primary contact recreation and warmwater fishery.

B. Standards:

1. At any sampling site: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 32.2 C (90 F), and turbidity shall be less than 25 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

3. The open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders.

2-305. The main stem of the Canadian River from the headwaters of Conchas Reservoir upstream to the New Mexico-Colorado line, and Conchas River and any flow from below the perennial reaches of the Mora River, Cimarron River, Vermejo River, Chicorica Creek which enters the main stem of the Canadian River, and perennial reaches of Raton and Una de Gato creeks.

A. Designated Uses: irrigation, limited warmwater fishery, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 32.2 C (90 F), and TDS shall be less than 3,500 mg/l at flows above 10 cfs.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

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2-305.3 Perennial reaches of the Mora River from the USGS gaging station near Shoemaker upstream to Mora, all perennial reaches of tributaries to the Mora River downstream from State Highway 518 in San Miguel and Mora counties, perennial reaches of Ocate Creek and its tributaries downstream of Ocate, and perennial reaches of Rayado Creek downstream of Miami Lake diversion in Colfax County.

A. Designated Uses: marginal coldwater fishery, warmwater fishery, secondary contact recreation, irrigation, and livestock and wildlife watering.

B. Standards:

1. At any sampling site: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, temperature shall be less than 25 C (77 F), total chlorine residual shall be less than 0.002 mg/l, and pH shall be within the range of 6.6 to 8.8.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-305.5 Charette Lakes.

A. Designated Uses: coldwater fishery, warmwater fishery, secondary contact recreation, livestock and wildlife watering.

B. Standards:

1. At any sampling site: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 20 C (68 F), and total chlorine residual shall be less than 0.002 mg/l.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 1,000/100 ml; no single sample shall exceed 2,000/100 ml.

2-306. The Mora River and its tributaries above Mora, all tributaries to the Mora River upstream from State Highway 518, Coyote Creek, the Cimarron River above State Highway 21 in Cimarron, all tributaries to the Cimarron River, Rayado Creek above Miami Lake diversion, Ocate Creek and its tributaries upstream of Ocate, and all other tributaries to the Canadian River northwest and north of U.S. Highway 64 in Colfax County unless included in other segments.

A. Designated Uses: domestic water supply, irrigation, high quality coldwater fishery, livestock and wildlife watering, municipal and industrial water supply, and secondary contact recreation.

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B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.02 mg/l; conductivity shall be less than 500 umhos/cm (at 25 C); dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; total inorganic nitrogen (as N) shall be less than 1.0 mg/l; pH shall be within the range of 6.6 to 8.8; temperature shall be less than 20 C (68 F); total chlorine residual shall be less than 0.002 mg/l; total organic carbon shall be less than 7 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l; and turbidity shall be less than 25 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

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2-400. SAN JUAN RIVER BASIN.

2-401. The main stem of the San Juan River from the point where the San Juan leaves New Mexico and enters Colorado upstream to U.S. Highway 64 at Blanco, and any flow which enters the San Juan River from the Mancos and Chaco Rivers.

A. Designated Uses: municipal and industrial water supply, irrigation, livestock and wildlife watering, secondary contact recreation, marginal coldwater fishery, and warmwater fishery.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-402. La Plata River from its confluence with the San Juan River upstream to the New Mexico-Colorado line.

A. Designated Uses: irrigation, limited warmwater fishery, marginal coldwater fishery, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-403. The Animas River from its confluence with the San Juan upstream to U.S. Highway 550 at Aztec.

A. Designated Uses: municipal and industrial water supply, irrigation, livestock and wildlife watering, marginal coldwater fishery, secondary contact recreation, and warmwater fishery.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 27 C (80.6 F).

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2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-404. The Animas River from U.S. Highway 550 upstream to the New Mexico-Colorado line.

A. Designated Uses: coldwater fishery, irrigation, livestock and wildlife watering, municipal and industrial water supply, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 20 C (68 F), total phosphorus (as P) shall be less than 0.1 mg/l, and total chlorine residual shall be less than 0.002 mg/l.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-405. The main stem of the San Juan River from U.S. Highway 64 at Blanco upstream to the Navajo Dam.

A. Designated Uses: high quality coldwater fishery, irrigation, livestock and wildlife watering, municipal and industrial water supply, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.02 mg/l; conductivity shall be less than 400 umhos/cm (at 25 C); dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; total inorganic nitrogen shall be less than 1.0 mg/l (as N); pH shall be within the range of 6.6 to 8.8; temperature shall be less than 20 C (68 F); total chlorine residual shall be less than 0.002 mg/l; total organic carbon shall be less than 7 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l; and turbidity shall be less than 10 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

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2-406. Navajo Reservoir in New Mexico.

A. Designated Uses: coldwater fishery, warmwater fishery, irrigation storage, livestock and wildlife watering, municipal and industrial water storage, and primary contact recreation.

B. Standards:

1. At any sampling site: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 20 C (68 F), total phosphorus (as P) shall be less than 0.1 mg/l, total chlorine residual shall be less than 0.002 mg/l, and turbidity shall be less than 25 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

3. The open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders.

2-407. The Navajo and Los Pinos Rivers in New Mexico.

A. Designated Uses: coldwater fishery, irrigation, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 20 C (68 F), total phosphorus (as P) shall be less than 0.1 mg/l; and total chlorine residual shall be less than 0.002 mg/l.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

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2-500. GILA RIVER BASIN.

2-501. The main stem of the Gila River from the New Mexico-Arizona line upstream to State Highway 464 in Red Rock.

A. Designated Uses: irrigation, limited warmwater fishery, livestock and wildlife watering, and primary contact recreation.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-502. The main stem of the Gila River from State Highway 464 in Red Rock upstream to Gila Hot Springs and perennial reaches of tributaries to the Gila River below the town of Cliff.

A. Designated Uses: industrial water supply, irrigation, livestock and wildlife watering, marginal coldwater fishery, primary contact recreation, and warmwater fishery.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 28 C (82.4 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-503. The main stem of the Gila River from Gila Hot Springs upstream to the headwaters and all perennial tributaries to the Gila River at or above the town of Cliff.

A. Designated Uses: domestic water supply, high quality coldwater fishery, irrigation, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.02 mg/l; conductivity shall be less than 300 umhos for the main stem of the Gila River above Gila Hot Springs and 400 umhos for other reaches; dissolved oxygen shall be greater than 6.0 mg/l or 85% of

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saturation, whichever is greater; total inorganic nitrogen (as N) shall be less than 1.0 mg/l; pH shall be within the range of 6.6 to 8.8; temperature shall be less than 20 C (68 F) except in the East Fork of the Gila River and Sapillo Creek below Lake Roberts where the temperature shall be less than 32.2 C (90 F); total chlorine residual shall be less than 0.002 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l; total organic carbon shall be less than 7 mg/l; and turbidity shall be less than 10 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

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2-600. SAN FRANCISCO RIVER BASIN.

2-601. The main stem of the San Francisco River from the New Mexico-Arizona line upstream to the State Highway 12 at Reserve and perennial reaches of Mule Creek.

A. Designated Uses: irrigation, limited warmwater and marginal coldwater fishery, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 5.0 mg/l, pH shall be within the range of 6.6 to 9.0, and temperature shall be less than 32.2 C (90 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-602. The main stem of the San Francisco River from State Highway 12 at Reserve upstream to the New Mexico-Arizona line.

A. Designated Uses: coldwater fishery, irrigation, livestock and wildlife watering, and primary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, and total chlorine residual shall be less than 0.002 mg/l, and temperature shall be less than 25 C (77 F).

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

2-603. All perennial reaches of tributaries to the San Francisco River at or above the Town of Glenwood.

A. Designated Uses: domestic water supply, fish culture, high quality coldwater fishery, irrigation, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.02 mg/l; conductivity shall be less than 400 umhos; dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; total inorganic nitrogen (as N) shall be less than 1.0 mg/l; pH

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shall be within the range of 6.6 to 8.8; temperature shall be less than 20 C (68 F) except in Tularosa Creek, where the temperature shall be less than 25 C (77 F); total chlorine residual shall be less than 0.002 mg/l; total organic carbon shall be less than 7 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l; and turbidity shall be less than 10 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

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2-700. DRY CIMARRON RIVER.

2-701. Perennial portions of the Dry Cimarron River in Union and Colfax counties and perennial reaches of Oak Creek, Long Canyon, and Corrumpa and Carrizozo creeks.

A. Designated Uses: coldwater fishery, irrigation, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 25 C (77 F), TDS shall be less than 1,200 mg/l, sulfate shall be less than 600 mg/l, chloride shall be less than 40 mg/l, and total chlorine residual shall be less than 0.002 mg/l.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

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2-800. CLOSED BASINS.

2-801. Rio Tularosa lying east of the old U.S. Highway 70 bridge crossing east of Tularosa, and all perennial tributaries to the Tularosa Basin except Three Rivers.

A. Designated Uses: coldwater fishery, fish culture, irrigation, livestock and wildlife watering, municipal and industrial water supply, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, and temperature shall be less than 20 C (68 F) and total chlorine residual shall be less than 0.002 mg/l.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

2-802. Perennial reaches of Three Rivers.

A. Designated Uses: irrigation, domestic water supply, high quality coldwater fishery, secondary contact recreation, and livestock and wildlife watering.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.02 mg/l; conductivity shall be less than 500 umhos; dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; total inorganic nitrogen (as N) shall be less than 1.0 mg/l; pH shall be within the range of 6.6 to 8.8; temperature shall be less than 20 C (68 F); total chlorine residual shall be less than 0.002 mg/l; total organic carbon shall be less than 7 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l; and turbidity shall be less than 10 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

2-803. The Mimbres River downstream of the USGS gaging station at Mimbres and all perennial reaches of tributaries thereto.

A. Designated Uses: coldwater fishery, irrigation, livestock and wildlife watering, and secondary contact recreation.

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B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 20 C (68 F), and total chlorine residual shall be less than 0.003 mg/l.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

2-804. The Mimbres River upstream of the USGS gaging station at Mimbres and all perennial tributaries thereto.

A. Designated Uses: irrigation, domestic water supply, high quality coldwater fishery, livestock and wildlife watering, and secondary contact recreation.

B. Standards:

1. In any single sample: un-ionized ammonia (as N) shall not exceed 0.02 mg/l, conductivity shall be less than 300 umhos; dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; total inorganic nitrogen (as N) shall be less than 1.0 mg/l; pH shall be within the range of 6.6 to 8.8; temperature shall be less than 20 C (68 F); total chlorine residual shall be less than 0.002 mg/l; total organic carbon shall be less than 7 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l; and turbidity shall be less than 10 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see 1-103.B).

2-805. Perennial reaches of the Sacramento River (Sacramento-Salt Flat Closed Basin) and all perennial tributaries thereto.

A. Designated Uses: domestic and municipal water supply, livestock and wildlife watering, marginal coldwater fishery, and secondary contact recreation.

B. Standards:

1. In any single sample: dissolved oxygen shall be greater than 6.0 mg/l, pH shall be within the range of 6.6 to 8.8, temperature shall be less than 25 C (77 F), and turbidity shall be less than 10 NTU.

2. The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see 1-103.B).

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PART 3

3-100. DEFINITIONS.

A. "Acute toxicity" means toxicity involving a stimulus severe enough to induce a response in 96 hours of exposure or less. Acute toxicity is not always measured in terms of lethality, but may include other toxic effects that occur within a short time period.

B. "Attainable use" means a use of a surface Water of the State which has water quality and all other characteristics necessary to support and maintain the use, as specified in Section 3-101 of these standards, or which would support and maintain the use after the implementation of water quality standards as specified in Section 1-101.B of these standards.

C. "Best management practices" means schedules of activities, prohibitions of certain practices, implementation of maintenance procedures, or other measures or practices selected by the State or a designated management agency to achieve control of non-point sources of water pollutants.

D. "cfs" means cubic feet per second.

E. "Chronic toxicity" means toxicity involving a stimulus that lingers or continues for a relatively long period relative to the life span of an organism. Chronic effects include, but are not limited to, lethality, growth impairment, behavioral modifications, disease and reduced reproduction.

F. "Coldwater fishery" means a stream reach, lake or impoundment where the water temperature and other characteristics are suitable for the support or propagation or both of coldwater fishes such as brown, cutthroat, brook, or rainbow trout.

G. "Designated use" means those uses specified in Part 2 of "Water Quality Standards for Interstate and Intrastate Streams in New Mexico" for each water body or segment whether or not they are being attained.

H. "Dissolved" means a constituent of a water sample which will pass through a 0.45 micrometer pore-size membrane filter under a pressure differential not exceeding one atmosphere. The "dissolved" fraction is also termed "filterable residue."

I. "Domestic water supply" means a surface water that may be used for drinking or culinary purposes after disinfection.

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J. "Ephemeral stream" means a stream or reach of a stream that flows briefly only in direct response to precipitation or snowmelt in the immediate locality; its channel bed is always above the water table of the region adjoining the stream.

K. "Existing use" means those uses actually attained in a water body whether or not they are included in the water quality standards.

L. "Fecal coliform bacteria" means the portion of the coliform group which is present in the gut or the feces of warmblooded animals. It generally includes organisms which are capable of producing gas from lactose broth in a suitable culture medium within 24 hours at 44.5 $\pm$ 0.2 C.

M. "Fish culture" means production of coldwater or warmwater fishes in a hatchery or rearing station.

N. "Flow," relative to the four definitions of streams herein, means natural flow ensuing from the earth's hydrologic cycle, i.e., atmospheric precipitation resulting in surface and, or, ground-water runoff. Natural in-stream flow may be interrupted or eliminated by dams and diversions.

O. "High quality coldwater fishery" means a perennial stream reach in a minimally disturbed condition which has considerable aesthetic value and is a superior coldwater fishery habitat. A stream reach to be so categorized must have water quality, stream bed characteristics, and other attributes of habitat sufficient to protect and maintain a propagating coldwater fishery (i.e., a population of reproducing salmonids).

P. "Intermittent stream" means a stream or reach of a stream that flows only at certain times of the year, such as when it receives flow from springs, melting snow, or localized precipitation. Syn: temporary stream, seasonal stream.

Q. "Interrupted stream" means a stream that contains perennial reaches with intervening intermittent or ephemeral reaches. Ant: continuous stream.

R. "Interstate waters" means all surface waters which cross or form a part of the border between States.

S. "Intrastate waters" means all surface waters of the State which are not interstate waters.

T. "LC-50" means the concentration of a substance that is lethal to 50% of the test organisms within a defined time period. The length of the time period, which may vary from 24 hours to one week or more, depends on the test method selected to yield the information desired.

U. "Limited warmwater fishery" means a stream reach where intermittent flow may severely limit the ability of the reach to sustain a

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natural fish population on a continuous annual basis; or a stream where historical data indicate that water temperature may routinely exceed 32.2 C (90 F).

V. "Limiting nutrient" means the nutrient or combination of nutrients available in minimal quantities with respect to the growth requirements of algae and higher aquatic plants and upon which the growth of these organisms is therefore dependent.

W. "Marginal coldwater fishery" means a stream reach, lake or impoundment known to support a coldwater fish population during at least some portion of the year, even though historical data indicates that the maximum temperature in the stream may exceed 20 C (68 F).

X. "Micrograms per liter (ug/l)" means micrograms of solute per liter of solution; equivalent to parts per billion when the specific gravity of the solution = 1.000.

Y. "Milligrams per liter (mg/l)" means milligrams of solute per liter of solution; equivalent to parts per million when the specific gravity of the solution = 1.000.

Z. "Natural causes" means those causal agents which would affect water quality in the absence of man's actions. Natural causes do not include point source discharges, nonpoint source pollution or any other culturally induced impairment of the chemical, physical, biological or radiological integrity of water.

AA. "Nonpoint Source Pollution" means the alteration of surface waters by land management or land-use activities which are not regulated as point sources and which degrade the quality or adversely affects the biological community inhabiting the waters.

BB. "NTU" means nephelometric turbidity units based on a standard method using formazin polymer or its equivalent as the standard reference suspension. Nephelometric turbidity measurements expressed in units of NTU are numerically identical to the same measurements expressed in units of FTU (formazin turbidity units).

CC. "Perennial stream" means a stream or reach of a stream that flows continuously throughout the year in all years; its upper surface, generally, is lower than the water table of the region adjoining the stream. Syn: permanent stream, live stream.

DD. "Picocurie (pCi)" means a measure of radioactivity equal to the quantity of a radioactive substance in which the rate of disintegrations is 2.22 per minute.

EE. "Point source" means any discernible, confined, and discrete conveyance from which pollutants are or may be discharged into a water body, but does not include return flows from irrigated agriculture.

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FF. "Primary Contact" means any recreational or other water use in which there is prolonged and intimate contact with the water, such as swimming and water skiing, involving considerable risk of ingesting water in quantities sufficient to pose a significant health hazard.

GG. "Secondary contact" means any recreational or other water use in which contact with the water may occur and in which the probability of ingesting appreciable quantities of water is minimal, such as fishing, wading, commercial and recreational boating and any limited seasonal contact.

HH. "Segment" means a water quality standards segment, the surface waters of which have common hydrologic characteristics or flow regulation regimes, possess common natural physical, chemical, and biological characteristics, and exhibit common reactions to external stresses, such as the discharge of pollutants.

II. "TDS" means total dissolved solids, also termed "total filterable residue."

JJ. "Technology-based controls" means the application of technology-based effluent limitations as required under Section 301(b) of the Clean Water Act.

KK. "Total" means a constituent of a water sample which is analytically determined without filtration.

LL. "Total inorganic nitrogen" means the sum of nitrate nitrogen, nitrite nitrogen, and total ammonia nitrogen.

MM. "Toxic pollutant" means those pollutants, or combination of pollutants, including disease-causing agents, which after discharge and upon exposure, ingestion, inhalation or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will cause death, disease, behavioral malfunctions (including malfunctions in reproduction) or physical deformations in such organisms or their offspring.

NN. Tubidity" is an expression of the optical property in water that causes incident light to be scattered or absorbed rather than transmitted in straight lines.

OO. "Warmwater fishery" means a stream reach, lake or impoundment where the water temperature and other characteristics are suitable for the support and propagation of warmwater fishes such as large-mouth black bass, small-mouth black bass, crappie, white bass, bluegill, flathead catfish, or channel catfish.

PP. "Water," for purposes of these standards, means all surface waters including waters situated wholly or partly within or bordering upon the State, whether public or private, except private waters that do not combine with other surface or subsurface water.

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QQ. "Water contaminant" means any substance which alters the physical, chemical or biological qualities of water.

RR. "Watercourse" means any river, creek, arroyo, canyon, draw, or wash, or any other channel having definite banks and beds with visible evidence of the occasional flow of water. Syn: stream.

SS. "Waters of the State" means all interstate and intrastate waters including natural ponds and lakes, playa lakes, reservoirs, perennial streams and their tributaries, intermittent streams, sloughs, prairie potholes and wetlands.

TT. "Water pollutant" means a water contaminant in such quantity and of such duration as may with reasonable probability injure human health, animal or plant life or property, or to unreasonably interfere with the public welfare or the use of property.

UU. "Water quality-based controls" means effluent limitations, as provided under Section 301(b)(1)(C) of the Clean Water Act, which are developed and imposed on point-source dischargers in order to protect and maintain applicable water quality standards. These controls are more stringent than the technology-based effluent limitations required under other paragraphs of Section 301(b).

VV. "Wetlands" means those areas which are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions in New Mexico.

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3-101. STANDARDS[1] APPLICABLE TO ATTAINABLE OR DESIGNATED USES UNLESS OTHERWISE SPECIFIED IN PART 2.

A. Coldwater Fishery: Un-ionized ammonia (as N) shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, temperature shall be less than 20 C (68 F), total chlorine residual shall not exceed 0.004 mg/l, and pH shall be within the range of 6.6 to 8.8. The acute and chronic standards set out in Section 3-101.J are applicable to this use.

B. Domestic Water Supply: Waters designated for use as domestic water supplies shall not contain substances in concentrations that create a lifetime cancer risk of more than one cancer per 100,000 exposed persons. The following numeric standards shall not be exceeded:

Dissolved arsenic	0.05 mg/l
Dissolved barium	1. mg/l
Dissolved cadmium	0.010 mg/l
Dissolved chromium	0.05 mg/l
Dissolved lead	0.05 mg/l
Total mercury	0.002 mg/l
Dissolved nitrate (as N)	10. mg/l
Dissolved selenium	0.05 mg/l
Dissolved silver	0.05 mg/l
Dissolved cyanide	0.2 mg/l
Dissolved uranium	5.0 mg/l
Radium-226 + radium-228	30.0 pCi/l

C. High Quality Coldwater Fishery: Dissolved oxygen shall be greater than 6.0 mg/l or 85% of saturation, whichever is greater; temperature shall be less than 20 C (68 F); pH shall be within the range of 6.6 to 8.8; un-ionized ammonia (as N) shall not exceed 0.02 mg/l; total chlorine residual shall not exceed 0.004 mg/l; total phosphorus (as P) shall be less than 0.1 mg/l;[2] total inorganic nitrogen (as N) shall be less than 1.0 mg/l;[2] total organic carbon shall be less than 7 mg/l; turbidity shall be less than 10 NTU (25 NTU in certain reaches where natural background prevents attainment of lower turbidity); and conductivity (at 25 C) shall be less than a limit varying between 300 umhos/cm and 1,500 umhos/cm depending on the natural background in particular stream reaches (the intent of this standard is to prevent excessive increases in dissolved solids which would result in changes in stream community structure). The acute and chronic standards set out in Section 3-101.J are applicable to this use.

D. Irrigation (or Irrigation Storage): The monthly logarithmic mean of fecal coliform bacteria shall not exceed 1,000/100 ml; no single sample shall exceed 2,000/100 ml. The following numeric standards shall not be exceeded:

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Dissolved aluminum	5.0	mg/l
Dissolved arsenic	0.10	mg/l
Dissolved boron	0.75	mg/l
Dissolved cadmium	0.01	mg/l
Dissolved chromium	0.10	mg/l
Dissolved cobalt	0.05	mg/l
Dissolved copper	0.20	mg/l
Dissolved lead	5.0	mg/l
Dissolved selenium	0.13	mg/l
Dissolved selenium in presence of >500 mg/l SO_4	0.25	mg/l
Dissolved vanadium	0.1	mg/l
Dissolved zinc	2.0	mg/l

E. Limited Warmwater Fishery: Standards are the same as for "Warmwater Fishery" except on a case by case basis, the dissolved oxygen may reach a minimum of 4.0 mg/l or maximum temperatures may exceed 32.2 C. The acute and chronic standards set out in Section 3-101.J are applicable to this use.

F. Marginal Coldwater Fishery: Standards are the same as for "Coldwater Fishery" except on a case by case basis, the dissolved oxygen may reach a minimum of 5.0 mg/l or maximum temperatures may exceed 25 C and the pH may range from 6.6 to 9.0. The acute and chronic standards set out in Section 3-101.J are applicable to this use.

G. Primary Contact Recreation: The monthly logarithmic mean of fecal coliform bacteria shall not exceed 200/100 ml, no single sample shall exceed 400/100 ml; the open water shall be free of algae in concentrations which cause nuisance conditions or gastrointestinal or skin disorders; pH shall be within the range of 6.6 to 8.8; and turbidity shall be less than 25 NTU.

H. Warmwater Fishery: Un-ionized ammonia (as N) shall not exceed 0.06 mg/l, dissolved oxygen shall be greater than 5 mg/l, temperature shall be less than 32.2 C (90 F), and pH shall be within the range of 6.0 to 9.0 and total chlorine residual shall not exceed 0.008 mg/l. The acute and chronic standards set out in Section 3-101.J are applicable to this use.

I. Fish culture and municipal and industrial water supply and storage are also designated in particular stream reaches where these uses are actually being realized. However, no numeric standards apply uniquely to these uses. Water quality adequate for these uses is ensured by the general standards and numeric standards for bacterial quality, pH, and temperature which are established for all stream reaches listed in Part 2 of the standards.

J. The following schedule of numeric standards and equations for the substances listed shall apply to the subcategories of fisheries identified in Section 3-101:

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Chronic Criteria[3]

Dissolved aluminum		87.0	(10^{-3}) mg/l
Dissolved beryllium		5.3	(10^{-3}) mg/l
Total mercury		0.012	(10^{-3}) mg/l
Dissolved selenium		5.0	(10^{-3}) mg/l
Dissolved silver		0.12	(10^{-3}) mg/l
Total cyanide		5.2	(10^{-3}) mg/l
Total chlordane		0.0043	(10^{-3}) mg/l
Dissolved cadmium[5]	e(0.7852[ln(hardness)]-3.49)		(10^{-3}) mg/l
Dissolved chromium[6]	e(0.819[ln(hardness)+1.561)		(10^{-3}) mg/l
Dissolved copper	e(0.8545[ln(hardness)]-1.465)		(10^{-3}) mg/l
Dissolved lead	e(1.273[ln(hardness)]-4.705)		(10^{-3}) mg/l
Dissolved nickel	e(0.846[ln(hardness)]+1.1645)		(10^{-3}) mg/l
Dissolved zinc	e(0.8473[ln(hardness)]+0.7614)		(10^{-3}) mg/l

Acute Criteria[4]

Dissolved aluminum		750	(10^{-3}) mg/l
Dissolved beryllium		130	(10^{-3}) mg/l
Total mercury		2.4	(10^{-3}) mg/l
Dissolved selenium		20.0	(10^{-3}) mg/l
Dissolved silver	e(1.72[ln(hardness)]-6.52)		(10^{-3}) mg/l
Total cyanide		22.0	(10^{-3}) mg/l
Total chlordane		2.4	(10^{-3}) mg/l
Dissolved cadmium	e(1.128[ln(hardness)]-3.828)		(10^{-3}) mg/l
Dissolved chromium[6]	e(0.819[ln(hardness)+3.688)		(10^{-3}) mg/l
Dissolved copper	e(0.9422[ln(hardness)]-1.464)		(10^{-3}) mg/l
Dissolved lead	e(1.273[ln(hardness)]-1.46)		(10^{-3}) mg/l
Dissolved nickel	e(0.76[ln(hardness)]+4,02		(10^{-3}) mg/l
Dissolved zinc	e(0.8473[ln(hardness)]+0.8604)		(10^{-3}) mg/l

K. Livestock and Wildlife Watering: The following numeric standards shall not be exceeded:

Dissolved aluminum	5.0	mg/l
Dissolved arsenic	0.02	mg/l
Dissolved boron	5.0	mg/l
Dissolved cadmium	0.05	mg/l
Dissolved chromium[6]	1.0	mg/l
Dissolved cobalt	1.0	mg/l
Dissolved copper	0.5	mg/l
Dissolved lead	0.1	mg/l
Total mercury	0.01	mg/l
Dissolved selenium	0.05	mg/l
Dissolved vanadium	0.1	mg/l
Dissolved zinc	25.0	mg/l
Radium-226 + radium-228	30.0	pCi/l

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[1]For waters with more than a single attainable or designated use the applicable criteria are those which will protect and sustain the most sensitive use.

[2]As the need arises, the State shall determine for specified stream segments or relevant portions thereof whether the limiting nutrient for the growth of aquatic plants is nitrogen or phosphorus. Upon such a determination the waters in question shall be exempt from the standard for the nutrient found to be not limiting. Until such a determination is made, standards for both nutrients shall apply. If co-limitation is found, the waters in question shall be exempt from the total inorganic nitrogen standard. The State shall make available a list of those waters for which the limiting nutrient has been determined.

[3]The chronic criteria shall be applied to the arithmetic mean of four samples collected on each of four consecutive days. Chronic criteria shall not be exceeded more than once every three years.

[4]The acute criteria shall be applied to any single grab sample. Acute criteria shall not be exceeded.

[5]For numeric standards dependent on hardness, hardness (as mg $CaCO_3$/l) shall be determined as needed from available verifiable data sources including, but not limited to, the U.S. Environmental Protection Agency's STORET water quality database.

[6]The criteria for chromium shall be applied to an analysis which measures both the trivalent and hexavalent ions.

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capping the range at 220 is consistent with the highest hardness concentration used in toxicity tests. The new equations apply at hardness concentrations from 0 to 220 mg/L, and the criteria values for a hardness of 220 ug/L applies at higher hardness concentrations. The criteria values for a hardness of 25 ug/L apply at hardnesses less than 25 mg/L because no compelling basis exists for limiting the application of the proposed criteria to hardness of 25 mg/L and above, and because the criteria were based in part on toxicity studies conducted in waters softer than 25 mg/L.

520. The Commission adopts CMI and LANS/DOE's proposal to update the hardness-based acute and chronic aquatic life criteria for dissolved cadmium based on EPA's criteria derivation and recalculation procedures.

521. The current acute and chronic standards for dissolved cadmium in New Mexico are based on EPA's 2001 criteria update. The proposed changes are based on a more recent review technical review and update of the 2001 revised cadmium standards that resulted in new cadmium acute and chronic equations adopted by the State of Colorado in 2005 and approved by EPA.

522. The proposed change follows EPA's guidance for developing numeric criteria for the protection of aquatic life (USEPA, 1985). Updating the criteria as proposed retains the level of protection intended by EPA guidance for deriving numeric criteria for aquatic life designated uses.

523. The Commission adopts CMI and LANS/DOE's proposal to update the hardness-based acute and chronic aquatic life criteria for dissolved zinc based on EPA's criteria derivation and recalculation procedures.

524. The acute and chronic standards for zinc are based on EPA's 1996 criteria update. The proposed changes for zinc equations are based on a more recent review of the updated zinc standards adopted by the State of Colorado, a subsequent review of the EPA recalculation procedure, additional literature searches in 2008 as part of a site-specific zinc standards evaluation for Colorado streams, and additional data from

recently available studies conducted by the International Lead-Zinc Research Organization (ILZRO).

525. The proposed change follows EPA's guidance for developing numeric criteria for the protection of aquatic life (USEPA, 1985). Updating the criteria as proposed retains the level of protection intended by EPA guidance for deriving numeric criteria for aquatic life designated uses.

526. The Commission adopts CMI's proposal to add acute and chronic criteria for dissolved manganese because the criteria rely on updated scientific information and are consistent with EPA's 1985 Guidelines.

527. Neither EPA nor New Mexico currently has manganese ambient water quality standards for the protection of aquatic life. Manganese can be a metal of concern in the west, where manganese deposits are present in the Rocky Mountain and Great Basin Regions. Additional sources of manganese come from iron manufacture industry, volcanic activity, and use of fertilizers. These sources, combined with the natural deposits, can contribute to elevated concentrations of manganese in watersheds with no apparent adverse effect on aquatic biota.

528. The proposed criteria follow the manganese criteria adopted in Colorado, which were developed based on available literature and toxicity testing conducted jointly by industry and the Colorado Division of Wildlife. These hardness-based equations were developed based on the EPA standards derivation procedure, were adopted by the Colorado Water Quality Control Commission in 2000, and have been approved by EPA for use in Colorado.

J. Use-Specific Numeric criteria.

(1) Notes applicable to the Table of Numeric Criteria in paragraph (2):

(a) Where the letter "a" is indicated in a cell, the criterion is hardness-based and can be referenced in Subsection I of 20.6.4.900 NMAC.

(b) Where the letter "b" is indicated in a cell, the criterion can be referenced in Subsection C of 20.6.4.900 NMAC.

(c) Criteria are in µg/L unless otherwise indicated.

(d) Abbreviations are as follows: CAS – Chemical Abstracts Service (see definition for "CAS Number" in 20.6.4.7 NMAC); DWS – domestic water supply; Irr – irrigation; LW – livestock watering; WH – wildlife habitat; HH-OO – human health-organism only; C – cancer-causing; P – persistent.

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Acrolein	107-02-8	18				3.0	3.0		
Carbaryl	63-25-2					2.1	2.1		
Chlorpyrifos	2921-88-2					0.083	0.041		
Demeton	8065-48-3						0.1		
Guthion	86-50-0						0.01		
Malathion	121-75-5						0.1		
Methoxychlor	72-43-5						0.03		
Mirex	2385-85-5						0.001		
Parathion	56-38-2					0.065	0.013		
Tributyltin (TBT)	Various					0.46	0.072		

EPA Determination: *The EPA's approval of aquatic life criteria for acrolein, cadmium, carbaryl, chloride, chlorpyrifos, demeton, iron, guthion, malathion, methoxychlor, mirex, parathion, and tributyltin are subject to consultation pursuant to Section 7(a)(2) of the ESA. The EPA is taking no action on these revised aquatic life criteria, pending the conclusion of ESA consultation. The criteria for acrolein, cadmium, carbaryl, chloride, chlorpyrifos, demeton, iron, guthion, malathion, methoxychlor, mirex, parathion, and tributyltin are not effective for CWA purposes until approved by the EPA. See Section V for additional information regarding the completion of the ESA consultation.*

K. The criteria for total ammonia consider sensitive freshwater mussel species in the family Unionidae, freshwater non-pulmonate snails, and *Oncorhynchus* spp. (a genus of fish in the family Salmonidae), hence further protecting the aquatic community. The total ammonia criteria magnitude is measured as Total Ammonia Nitrogen (TAN) mg/L. TAN is the sum of and TAN mg/L magnitude is derived as a function of pH and temperature (EPA 2013).

L. The acute aquatic life criteria for TAN (mg/L) was derived by the EPA (2013) as the one-hour average concentration of TAN mg/L that shall not be exceeded more than once every three years on average. The EPA acute criterion magnitude was derived using the following equation:

$$\text{Acute TAN Criterion Magnitude for 1-hour average} = \text{MIN}\left(\left(\frac{0.275}{1+10^{7.204-pH}}+\frac{39}{1+10^{pH-7.204}}\right),\left(0.7249\text{x}\left(\frac{0.0114}{1+10^{7.204-pH}}+\frac{1.6181}{1+10^{pH-7.204}}\right)\text{x}\left(23.12\times 10^{0.036(20-T)}\right)\right)\right)$$

T (temperature °C) and pH are defined as the paired values associated with the TAN sample

(1) Temperature and pH-dependent values of the acute TAN criterion magnitude – when *Oncorhynchus* spp. absent.

	Temperature (°C)																				
pH	0-10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	51	48	44	41	37	34	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	49	46	42	39	36	33	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	46	44	40	37	34	31	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9
6.8	44	41	38	35	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	41	38	35	32	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	38	35	33	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9	7.3
7.1	34	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7

7.2	31	29	27	25	23	21	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6
7.3	27	26	24	22	20	18	17	16	14	13	12	11	10	9.5	8.7	8	7.4	6.8	6.3	5.8	5.3
7.4	24	22	21	19	18	16	15	14	13	12	11	9.8	9	8.3	7.7	7	6.5	6	5.5	5.1	4.7
7.5	21	19	18	17	15	14	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4
7.6	18	17	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	2.9
7.8	13	12	11	10	9.3	8.5	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4	3.7	3.4	3.2	2.9	2.7	2.5
7.9	11	9.9	9.1	8.4	7.7	7.1	6.6	3	5.6	5.1	4.7	4.3	4	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	8.8	8.2	7.6	7	6.4	5.9	5.4	5	4.6	4.2	3.9	3.6	3.3	3	2.8	2.6	2.4	2.2	2	1.9	1.7
8.1	7.2	6.8	6.3	5.8	5.3	4.9	4.5	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4
8.2	6	5.6	5.2	4.8	4.4	4	3.7	3.4	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	4.9	4.6	4.3	3.9	3.6	3.3	3.1	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1	0.96
8.4	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79
8.5	3.3	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.98	0.9	0.83	0.77	0.71	0.65
8.6	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.5	1.3	1.2	1.1	1	0.96	0.88	0.81	0.75	0.69	0.63	0.58	0.54
8.7	2.3	2.2	2	1.8	1.7	1.6	1.4	1.3	1.2	1.1	1	0.94	0.87	0.8	0.74	0.68	0.62	0.57	0.53	0.49	0.45
8.8	1.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37
8.9	1.6	1.5	1.4	1.3	1.2	1.1	1	0.93	0.85	0.79	0.72	0.67	0.61	0.56	0.52	0.48	0.44	0.4	0.37	0.34	0.32
9.0	1.4	1.3	1.2	1.1	1	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37	0.34	0.32	0.29	0.27

(2) Temperature and pH-dependent values for the acute TAN criterion magnitude-when *Oncorhynchus* spp. are present.

	Temperature (°C)																
pH	0-14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	33	33	32	29	27	25	23	21	19	18	16	15	14	12	12	11	9.9
6.6	31	31	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	30	30	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9
6.8	28	28	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	26	26	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	24	24	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	8	7.3
7.1	22	22	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	20	20	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6
7.3	18	18	17	16	14	13	12	11	10	9.5	8.7	8	7.4	6.8	6.3	5.8	5.3
7.4	15	15	15	14	13	12	11	9.8	9	8.3	7.7	7	6.5	6	5.5	5.1	4.7
7.5	13	13	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4
7.6	11	11	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	9.6	9.6	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	3
7.8	8.1	8.1	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4	3.7	3.4	3.2	2.9	2.7	2.5
7.9	6.8	6.8	6.6	6	5.6	5.1	4.7	4.3	4	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	5.6	5.6	5.4	5	4.6	4.2	3.9	3.6	3.3	3	2.8	2.6	2.4	2.2	2	1.9	1.7
8.1	4.6	4.6	4.5	4.1	3.8	3.5	3.2	3	2.7	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4
8.2	3.8	3.8	3.7	3.5	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	3.1	3.1	3.1	2.8	2.6	2.4	2.2	2	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1	1

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8.4	2.6	2.6	2.5	2.3	2.1	2	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1	0.9	0.9	0.8
8.5	2.1	2.1	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1	0.9	0.8	0.8	0.7	0.7
8.6	1.8	1.8	1.7	1.6	1.5	1.3	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.6	0.6	0.5
8.7	1.5	1.5	1.4	1.3	1.2	1.1	1	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5
8.8	1.2	1.2	1.2	1.1	1	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4
8.9	1	1	1	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.3
9.0	0.88	0.9	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3

M. The chronic aquatic life criteria for TAN (mg/L) was derived by the EPA (2013) as a thirty-day rolling average concentration of TAN mg/L that shall not be exceeded more than once every three years on average. In addition, the highest four-day average within the 30-day averaging period should not be more than 2.5 times the CCC (e.g., 2.5 x 1.9 mg TAN/L at pH 7 and 20°C, or 4.8 mg TAN/L) more than once in three years on average. The EPA chronic criterion magnitude was derived using the following equation:

Chronic TAN Criterion Magnitude for 30-day average=

$$0.8876 \times \left(\frac{0.0278}{1+10^{7.688-pH}} + \frac{1.1994}{1+10^{pH-7.688}}\right) \times \left(2.126 \times 10^{0.028\times(20-MAX(T,7))}\right)$$

'T' (temperature °C) and pH are defined as the paired values associated with the 'TAN sample.

Temperature and pH-Dependent Values of the Chronic TAN Criterion Magnitude.

	Temperature (°C)																							
pH	0-7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	4.9	4.6	4.3	4.1	3.8	3.6	3.3	3.1	2.9	2.8	2.6	2.4	2.3	2.1	2	1.9	1.8	1.6	1.5	1.5	1.4	1.3	1.2	1.1
6.6	4.8	4.5	4.3	4	3.8	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1
6.7	4.8	4.5	4.2	3.9	3.7	3.5	3.2	3	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1
6.8	4.6	4.4	4.1	3.8	3.6	3.4	3.2	3	2.8	2.6	2.4	2.3	2.1	2	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1
6.9	4.5	4.2	4	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1
7.0	4.4	4.1	3.8	3.6	3.4	3.2	3	2.8	2.6	2.4	2.3	2.2	2	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1
7.1	4.2	3.9	3.7	3.5	3.2	3	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1
7.2	4	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1	1	0.9
7.3	3.8	3.5	3.3	3.1	2.9	2.7	2.6	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1	1	0.9	0.9
7.4	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1	1	0.9	0.9	0.8
7.5	3.2	3	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7
7.6	2.9	2.8	2.6	2.4	2.3	2.1	2	1.9	1.8	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7
7.7	2.6	2.4	2.3	2.2	2	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6
7.8	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5
7.9	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5	0.5	0.5
8.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.4	0.4	0.4
8.1	1.5	1.5	1.4	1.3	1.2	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4
8.2	1.3	1.2	1.2	1.1	1	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3
8.3	1.1	1.1	1	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
8.4	1	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
8.5	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
8.6	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
8.7	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1

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8.8	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
8.9	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
9.0	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

[20.6.4.900 NMAC - Rp 20 NMAC 6.1.3100, 10/12/2010; A, 10/11/2002; A, 5/23/2005; A, 7/17/2005; A, 12/1/2010; A, 3/2/2017; A, 4/23/2022]

EPA Determination:

As part of its 2020 triennial review, the NMED proposed, and the Commission adopted the EPA's updated § 304(a) recommended acute and chronic aquatic life criteria for Total Ammonia Nitrogen (TAN). The associated revisions to 20.6.4.900(K), (L) and (M) NMAC, including the equations, temperature and pH-dependent values in the associated tables are all consistent with the values in EPA's current nationally recommended freshwater ammonia criteria. However, the EPA acknowledges that the value of 3.0 for pH 7.9 and 17°C in (L)(1), should be 6.0 when the equation for the Acute TAN Criterion Magnitude for 1-hour average is applied. This is a typographical error that is also present in EPA's Ammonia 2013 aquatic life criteria document and the EPA cautions NMED to beware of the difference in the criteria and correct in their next revision. Since the acute criterion equation is correct, this typographical error is nonsubstantive. These revisions are consistent with the EPA's recommended § 304(a) criteria and with language in 40 CFR §131.20(a). However, the EPA approval of aquatic life criteria is subject to consultation pursuant to Section 7(a)(2) of the ESA. The EPA is taking no action on the revised ammonia aquatic life criteria and narrative in 20.6.4.900(K), (L) and (M) NMAC and these provisions are not effective for CWA purposes until approved by the EPA. See Section V for additional information regarding the completion of the ESA consultation.

IV. Provisions the EPA Is Disapproving

[RESERVED]

V. Additional Considerations

Endangered Species Act Consultation

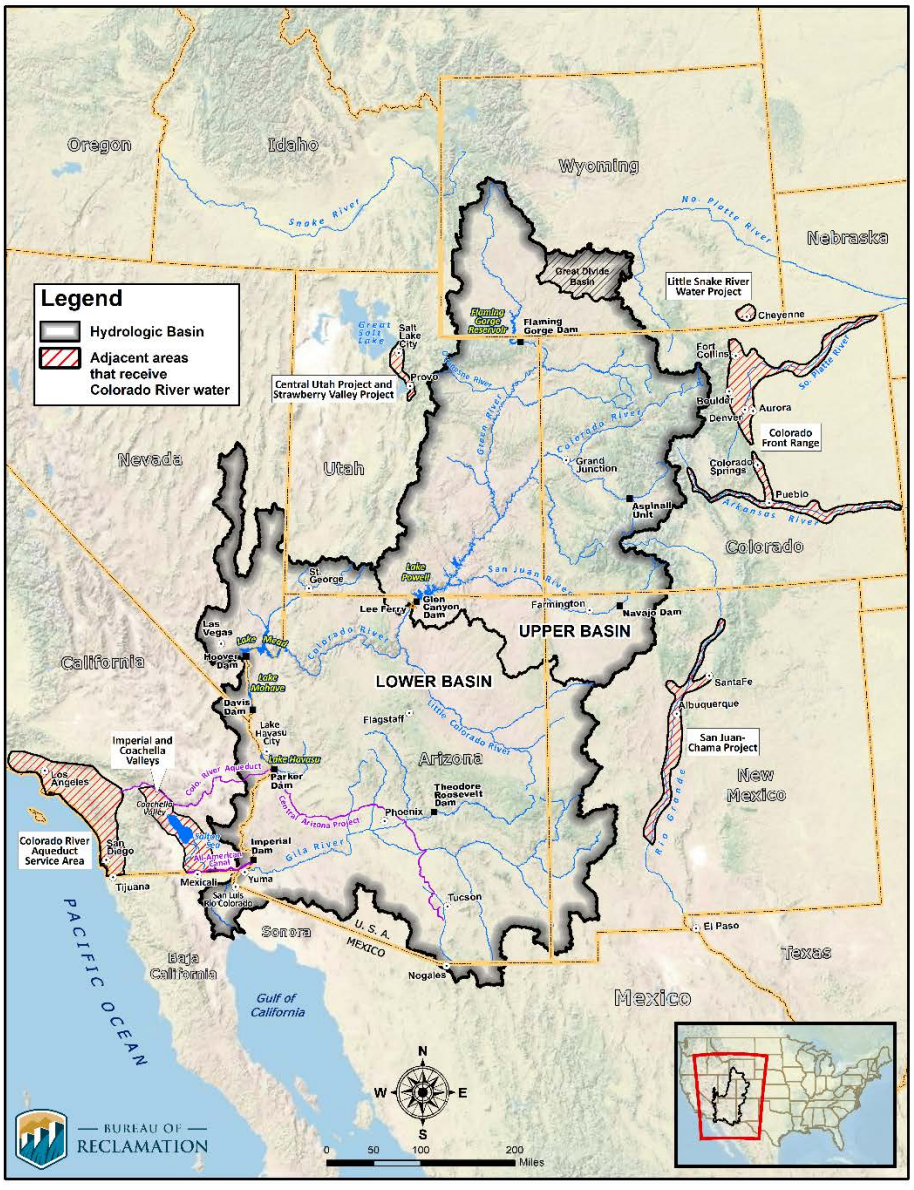
The EPA's approval of revised WQS and associated aquatic life criteria are subject to the consultation requirement of Section 7(a)(2) of the Endangered Species Act[14] (ESA). Under Section 7(a)(2) of the ESA, the EPA has the obligation to ensure that its approval of modifications to the *New Mexico Standards for Interstate and Intrastate Waters* (20.6.4 NMAC) will not jeopardize the continued existence of threatened and endangered species and critical habitat in New Mexico.

[14] Endangered Species Act, 16 U.S.C. §1536

NMED Exhibit 89

2023 Review

Water Quality Standards for Salinity
Colorado River System



October 2023

Colorado River Basin Salinity Control Forum

NMED Exhibit 90

2023 Review

WATER QUALITY STANDARDS FOR SALINITY
COLORADO RIVER SYSTEM

October 2023

Prepared by

Colorado River Basin Salinity Control Forum

COLORADO RIVER BASIN SALINITY CONTROL FORUM

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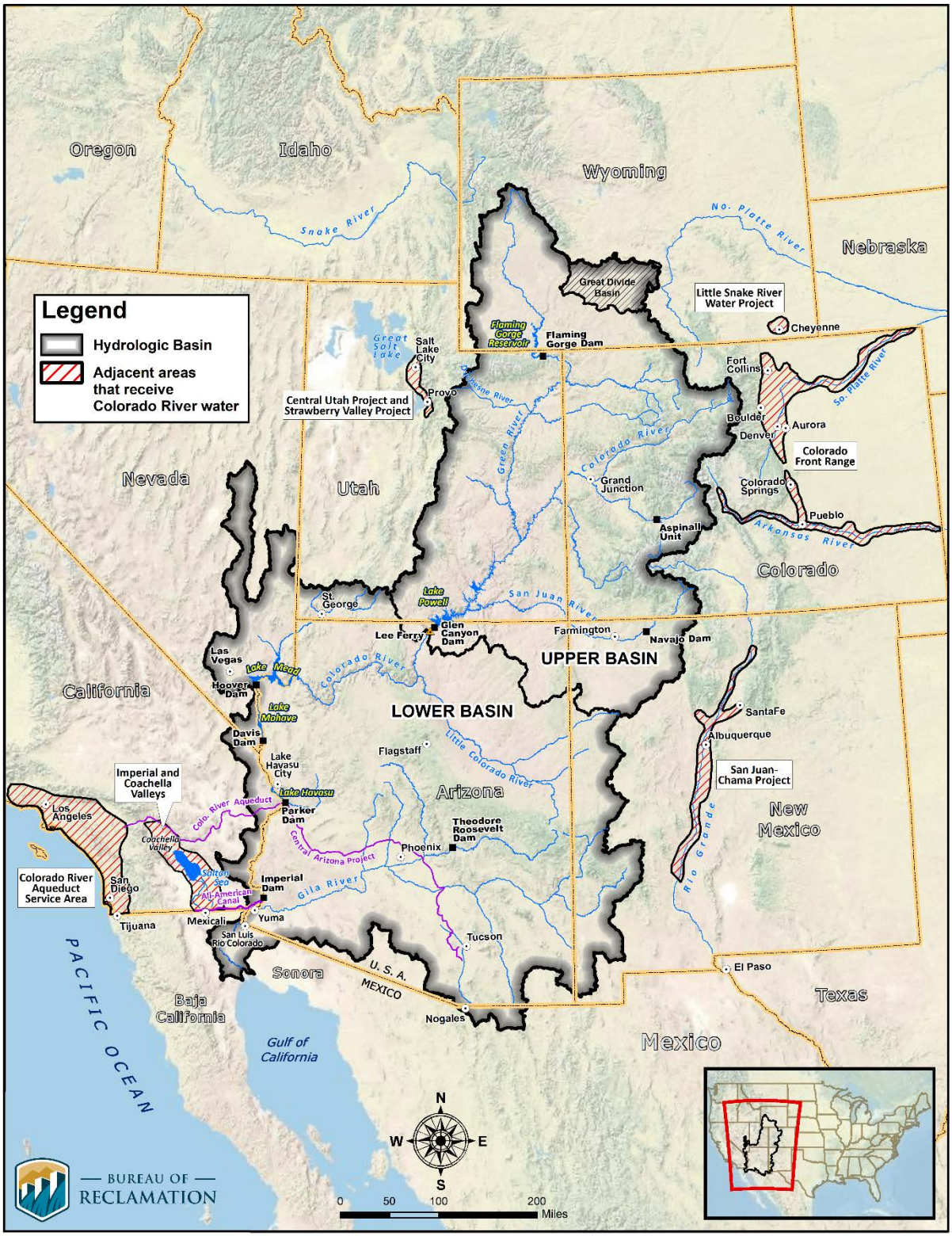
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FORUM

Don A. Barnett, Executive Director
Colorado River Basin Salinity Control Forum

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The Colorado River Basin

TRANSMITTAL LETTERS

The Federal Water Pollution Control Act requires that at least once every three years the Basin States review water quality standards relating to the salinity of the Colorado River. The states collectively initiated this review under the direction of the Forum.

With the adoption of this final review, copies are being sent to the Colorado River Basin State Governors listed below for inclusion within their individual state water quality standards.

Honorable Katie M. Hobbs
Governor of Arizona
State Capitol
Phoenix, AZ 85007

Honorable Michelle Lujan Grisham
Governor of New Mexico
State Capitol
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Honorable Gavin Newsom
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Honorable Jared Polis
Governor of Colorado
State Capitol
Denver, CO 80203

Honorable Mark Gordon
Governor of Wyoming
State Capitol
Cheyenne, WY 82002

Honorable Joe Lombardo
Governor of Nevada
State Capitol
Carson City, NV 89701

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LIST OF ABBREVIATIONS AND DEFINITIONS

208 Plan	Section 208 of the Clean Water Act amendments of 1972 and 1977 requiring integrated area-wide plans and programs for dealing with water pollution problems
Act	The Colorado River Basin Salinity Control Act (P.L. 93-320) (1974), as amended by P.L. 98-569 (1984), P.L. 104-20 (1995), P.L. 104-127 (1996), P.L. 106-459 (2000), P.L. 107-171 (2002) and P.L. 110-246 (2008)
Basin	Colorado River Basin
Basin Funds	Lower Colorado River Basin Development Fund and Upper Colorado River Basin Fund
Basin States	Arizona, California, Colorado, Nevada, New Mexico, Utah, Wyoming
BSP	Basin States Program
Basinwide Program	Basinwide Salinity Control Program
BLM	United States Bureau of Land Management
Clean Water Act	P.L. 92-500
Congress	United States Congress
CRSS	Colorado River Simulation System
EQIP	Environmental Quality Incentives Program
EPA	United States Environmental Protection Agency
Forum	Colorado River Basin Salinity Control Forum
maf	million acre-feet
mgd	million gallons per day
mg/L	milligrams per liter
M tons	million tons (of salt)
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
Program	Colorado River Basin Salinity Control Program
Reclamation	United States Bureau of Reclamation
Review	Triennial Review, *Water Quality Standards for Salinity, Colorado River System*
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WWTP	Wastewater Treatment Plant

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SUMMARY

This document is a review of the water quality standards for salinity in the Colorado River. Section 303 of the Clean Water Act amendments to the Federal Water Pollution Control Act require that water quality standards are reviewed every three years. Accordingly, the seven-state Colorado River Basin Salinity Control Forum has reviewed the existing state-adopted and EPA-approved water quality standards for salinity consisting of numeric criteria and a Plan of Implementation. Upon adoption by the Forum, this Review will be submitted to the governors of each of the Basin States for inclusion in their state water quality standards.

The Forum recommends no change in the numeric salinity criteria at the three stations located on the lower main stem of the Colorado River. The numeric criteria at these stations will remain:

Station	Salinity in mg/L[1]
Below Hoover Dam	723
Below Parker Dam	747
At Imperial Dam	879

The Plan of Implementation is intended to maintain the salinity concentrations at or below the numeric criteria while the Basin States continue to use the waters of the Colorado River. The Colorado River Basin Salinity Control Act requires the implementation of salinity control programs to reduce the salinity of the Colorado River. Reducing the salinity of the Colorado River water reduces economic impacts to its users. While the Plan of Implementation included in this Review provides high confidence that the numeric criteria will not be exceeded during the review period, the Forum will continue to evaluate opportunities for additional salinity control that will increase economic and environmental benefits realized in the Colorado River Basin.

The Forum's Plan of Implementation includes:

1. Construction of salinity control measures by Reclamation, USDA (Natural Resources Conservation Service), and BLM to the extent that those measures remain viable and appropriately cost effective.

2. State implementation of the Forum's adopted policies for effluent limitations under the National Pollutant Discharge Elimination System (Appendix B of this Review).

3. Implementation of non-point source management plans developed by the states and approved by EPA.

Item 1 of the plan listed above is to be implemented by federal agencies in conjunction with state, local and private participants. The Forum works jointly with federal agencies on developing measures to be implemented. Items 2 and 3 are primarily implemented by the Colorado River Basin states.

[1] Flow-weighted average annual salinity concentration which is defined as the total annual salt load divided by the total annual streamflow.

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To date the program has implemented more than 1.33 million tons of annual salinity control. The current Plan of Implementation, approved by the Forum, anticipates that an additional 51,700 tons of annual salinity control be implemented over the next three years. Reclamation's numerical modeling indicates that with this implementation there is a 6 percent probability of exceeding the numeric criteria over the next three years. If current program funding levels were to continue through 2040 a total of 1.49 million tons of annual control would be achieved. With an increase of salinity control implementation to 9,000 tons annually under Reclamation's Basinwide Program, a total of 1.55 million tons of salinity control would be implemented by 2040 with a 9 percent probability of exceeding the numeric criteria between now and 2040. The Salinity Control Program continues to be a successful federal and state partnership that has environmental and economic benefits for users of Colorado River water.

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PURPOSE OF THE REVIEW

The *2023 Review: Water Quality Standards for Salinity, Colorado River System* (Review) is prepared and submitted in response to Section 303(c) of Public Law (P.L.) 92-500 (Clean Water Act) by the seven state Colorado River Basin Salinity Control Forum (Forum) on behalf of the governors of their respective states. This review of the water quality standards includes the numeric criteria and the Plan of Implementation developed and adopted by the Forum. This is the 17th review conducted by the Forum. Section 303(c)(1) of the Clean Water Act requires that:

> The governor of a state or the state water pollution control agency of such state shall from time to time (but at least once each three-year period beginning with the date of enactment of the Federal Water Pollution Control Act Amendments of 1972) hold public hearings for the purpose of reviewing applicable water quality standards and, as appropriate, modifying and adopting standards. Results of such review shall be made available to the Administrator [of the Environmental Protection Agency].

The scope of this Review is limited to the portion of the Colorado River Basin (Basin) above Imperial Dam and how this area of the Basin is in compliance with the water quality standards approved by the United States Environmental Protection Agency (EPA) in 1975 (Standards). This Review focuses on the 2024 to 2026 period (review period) and evaluates the appropriateness of the Standards in the Basin. Background information and activities regarding historical actions relative to the development and adoption of salinity standards are contained in the Forum report, *Water Quality Standards for Salinity, Including Numeric Criteria and Plan of Implementation for Salinity Control, Colorado River System*, Colorado River Basin Salinity Control Forum, June 1975.

Below Imperial Dam, salinity is controlled as a federal responsibility to meet the terms contained within Minute No. 242 titled "Permanent and Definitive Solution to the International Problem of the Salinity of the Colorado River" to the Mexican Water Treaty of 1944. Minute No. 242 requires that measures be taken to assure that Colorado River water delivered to Mexico upstream from Morelos Dam will have an average annual salinity concentration of no more than 115 ± 30 parts per million total dissolved solids (TDS) higher than the average annual flow-weighted salinity concentration of the Colorado River water arriving at Imperial Dam.

Nothing in this Review shall be construed to alter, amend, repeal, interpret, modify or be in conflict with the provisions of the Boulder Canyon Project Act (45 Stat. 1057), the Boulder Canyon Project Adjustment Act (54 Stat. 774), the Colorado River Basin Project Act (82 Stat. 885), the Colorado River Compact, the Colorado River Storage Project Act (70 Stat. 105), the Upper Colorado River Basin Compact, or the Treaty with the United Mexican States (Treaty Series 994).

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HISTORY AND BACKGROUND

The Colorado River Basin Salinity Control Program (Program) is a unique cooperative watershed-scale effort between several federal agencies and seven states designated to meet national, international, and state water quality objectives. The Forum participates with federal, state, and local agencies and private participants to ensure the successful execution of the triennial Plan of Implementation through on-the-ground activities and encouraging legislative support for federal funding.

The Basin is 242,000 square miles[2] (approximately 155 million acres) of the western United States and a small portion of northern Mexico. Currently, about 40 million[3] people in the seven western states of Arizona, California, Nevada (Lower Basin States) and Colorado, New Mexico, Utah, and Wyoming (Upper Basin States), collectively referred to as the Basin States, rely on the Colorado River and its tributaries to provide some, if not all, of their municipal water needs. Additionally, water from the Colorado River system is utilized to irrigate nearly 5.5 million acres of land[4] in the Basin, producing some 15 percent of the nation's crops and about 13 percent of its livestock, which combined generate many billions of dollars a year in economic benefits.

The Colorado River also serves as the lifeblood for thirty[5] federally recognized Native American Indian tribes, seven National Wildlife Refuges, four National Recreation Areas and eleven National Park units. Hydropower facilities along the Colorado River supply more than 4,200 megawatts of electrical capacity to help meet the power needs of the West and reduce the use of fossil fuels. Finally, the Colorado River is vital to Mexico, supporting a thriving agricultural industry in the San Luis and Mexicali Valleys and providing municipal water supplies for communities in the Mexican States of Sonora and Baja California.

The Colorado River system is operated in accordance with the Law of the River[6], which apportions a total of 16.5 million acre-feet (maf) between the Basin States and Mexico. Currently, the 10-year (2011 through 2020) basin-wide average historical natural flow[7] of 13.5 maf is less than the consumptive uses and losses in the Basin, which have averaged 14.6 maf.[8]

---

[2] Colorado River System, Consumptive Uses and Losses Report, 1996-2000, Bureau of Reclamation.

[3] About 40 million people were estimated to be within the hydrologic boundaries of the Basin in the United States, as well as in the adjacent areas of the Basin States that receive Colorado River water, in 2015. See Colorado River Basin Water Supply and Demand Study - Technical Report C, U.S. Bureau of Reclamation, 2012.

[4] It is estimated that there were 5.5 million irrigated acres in the hydrologic boundaries of the Basin in the United States, as well as in the adjacent areas of the Basin States that receive Colorado River water, in 2015 based on interpolated acreage data from Scenario A Current Projections. See Colorado River Basin Water Supply and Demand Study - Technical Report C, U.S. Bureau of Reclamation, 2012.

[5] Reclamation, Draft Supplemental Environmental Impact Statement, Near-term Colorado River Operations, April 2023.

[6] The treaties, compacts, decrees, statutes, regulations, contracts and other legal documents and agreements applicable to the allocation, appropriation, development, exportation, and management of the waters of the Colorado River Basin are often collectively referred to as the "Law of the River."

[7] Natural flow represents the flow that would have occurred at the location had depletions and reservoir regulation not been present upstream of that location. This value was provided by the U.S. Bureau of Reclamation.

[8] Basinwide consumptive use and losses estimated over the period 2011-2020, including the 1944 Treaty delivery to Mexico, reservoir evaporation, and other losses due to operational inefficiencies as estimated by Reclamation.

Salinity-caused impacts have long been a major concern in the United States and Mexico. The salinity in the river generally increases as it flows downstream. The Colorado River has carried an average salt load of approximately 9 million tons annually past Hoover Dam, the uppermost location at which numeric criteria have been established.

The salts in the Colorado River system are naturally occurring and pervasive. Many of the saline sediments of the Basin were deposited in prehistoric marine environments. Salts contained within the sedimentary rocks are easily eroded, dissolved, and transported into the river system.

In a 1971 study[9], EPA analyzed salt loading in the Basin and divided it into two categories, naturally occurring and human-caused. EPA concluded that about half (47 percent) of the salinity concentration measured at Hoover Dam is from natural sources, including salt contributions from saline springs, groundwater discharge into the river system (excluding irrigation return flows), erosion and dissolution of sediments, and the concentrating effects of evaporation and transpiration[10]. Other natural sources include salt contributions from non-point (excluding irrigated agriculture) or unidentified sources, or from the vast, sparsely populated regions of the Basin, many of which are administered by the United States Bureau of Land Management (BLM) or other governmental agencies. Of the land within the Basin, about 75 percent is owned and administered by the federal government or held in trust for Indian tribes. The greatest portion of the naturally occurring salt load originates on these federally owned and administered lands.

EPA estimated that out of Basin exports (3 percent), agricultural irrigation (37 percent), reservoir evaporation and phreatophyte use (12 percent), and municipal and industrial uses (1 percent) account for 53 percent of the salinity concentration in water arriving at Hoover Dam. Much of the salt load contribution from irrigated agriculture is from federally developed irrigation projects. Other human activities, including livestock grazing, wildlife management, logging, mining, oil exploration, road building, recreation and urbanization can influence the rate of natural salt movement from rock formations and soils to the river system.

In 1972, the federal government enacted the Clean Water Act mandating efforts to develop and maintain water quality standards in the United States. At the same time, Mexico and the United States engaged in discussions to address the issue of increasing salinity in the Colorado River water being delivered to Mexico. The Basin States established the Forum in 1973. The Forum is composed of representatives from each of the Basin States appointed by the governors of the respective states. The Forum was created for interstate cooperation and to provide the states with the information necessary to comply with Section 303(a) and (b) of the Clean Water Act.

EPA promulgated a regulation[11] in December 1974 which set forth a basin-wide salinity control policy for the Basin. This regulation established a standards procedure and required the Basin States to adopt and submit for approval to EPA water quality standards for salinity, including numeric criteria and a Plan of Implementation, consistent with the policy stated in the regulation. As described in the Numeric Criteria section below, in compliance with the regulation, the Forum

[9] The Mineral Quality Problem in the Colorado River, Summary Report, Environmental Protection Agency, Regions VIII and IX, 65pp., 1971.
[10] Note the EPA study also identified that about 66% of the total salt load arriving at Hoover Dam was from natural sources. A recent USGS study confirms this amount estimating that 68% of the salt load is from natural sources (see Tillman, F.D. et al, A Review of Current Capabilities and Science Gaps in Water Supply Data, Modeling, and Trends for Water Availability Assessments in the Upper Colorado River Basin. *Water*, 2022, 14, 3813.
[11] EPA Regulation – 40 CFR, Part 120

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selected three numeric criteria stations on the main stem of the lower Colorado River as being appropriate points to measure the salinity concentrations of the river. These stations are located at the following points: (1) below Hoover Dam, (2) below Parker Dam, and (3) at Imperial Dam. The Forum also adopted a water quality standard for the Colorado River Basin including both a Plan of Implementation and numeric criteria.

The Colorado River Basin Salinity Control Act (P.L. 93-320) (1974) (Act) established the Colorado River Basin Salinity Control Program under Title II to address the concerns raised by EPA. The Act also created the Colorado River Basin Salinity Control Advisory Council to advise the federal agencies regarding administration of the Program. P.L. 93-320 has been amended several times since its original enactment. P.L. 98-569 (1984) authorized the United States Department of Agriculture's (USDA) on-farm program. P.L. 104-20 (1995) created the United States Bureau of Reclamation's (Reclamation) Basinwide Salinity Control Program (Basinwide Program). The Federal Agriculture Improvement and Reform Act (P.L. 104-127) (1996) (1996 Farm Bill) authorized up-front cost sharing by the Basin States and modified the USDA authorities, including the use of the Environmental Quality Incentives Program (EQIP). P.L. 106-459 (2000) increased the appropriation ceiling. The Food, Conservation, and Energy Act of 2008 (P.L. 110-246) (2008 Farm Bill) created the Basin States Program (BSP). The Agricultural Improvement Act of 2018 (P.L. 115-334) continued the authorization of EQIP.

UNDERSTANDING THE SALINITY OF THE COLORADO RIVER

In general, the salinity concentration of the water in the Colorado River increases from the headwaters to the terminus in the Gulf of California, known in Mexico as the Sea of Cortez. Much of the salt is picked up in the Upper Basin, and some tributary streams average higher concentrations of salt than the main stem.

As with most large rivers, the natural flow of the Colorado River increases from its headwaters to its terminus. Today, however, the flow of the Colorado River decreases below Hoover Dam due to diversions. Imperial Dam is the last major diversion point for uses in the United States. In normal years, 1.5 maf is scheduled to pass Imperial Dam for deliveries to Mexico.

Reclamation has developed a map of the Basin showing the average flows and the corresponding salinity concentrations for the years 2017-2021. This map is provided for general illustrative purposes as Figure 1. The average flow of the Colorado River and its important tributaries are indicated by the width of the line, and the salinity concentrations are illustrated by colors coded to ranges in TDS.

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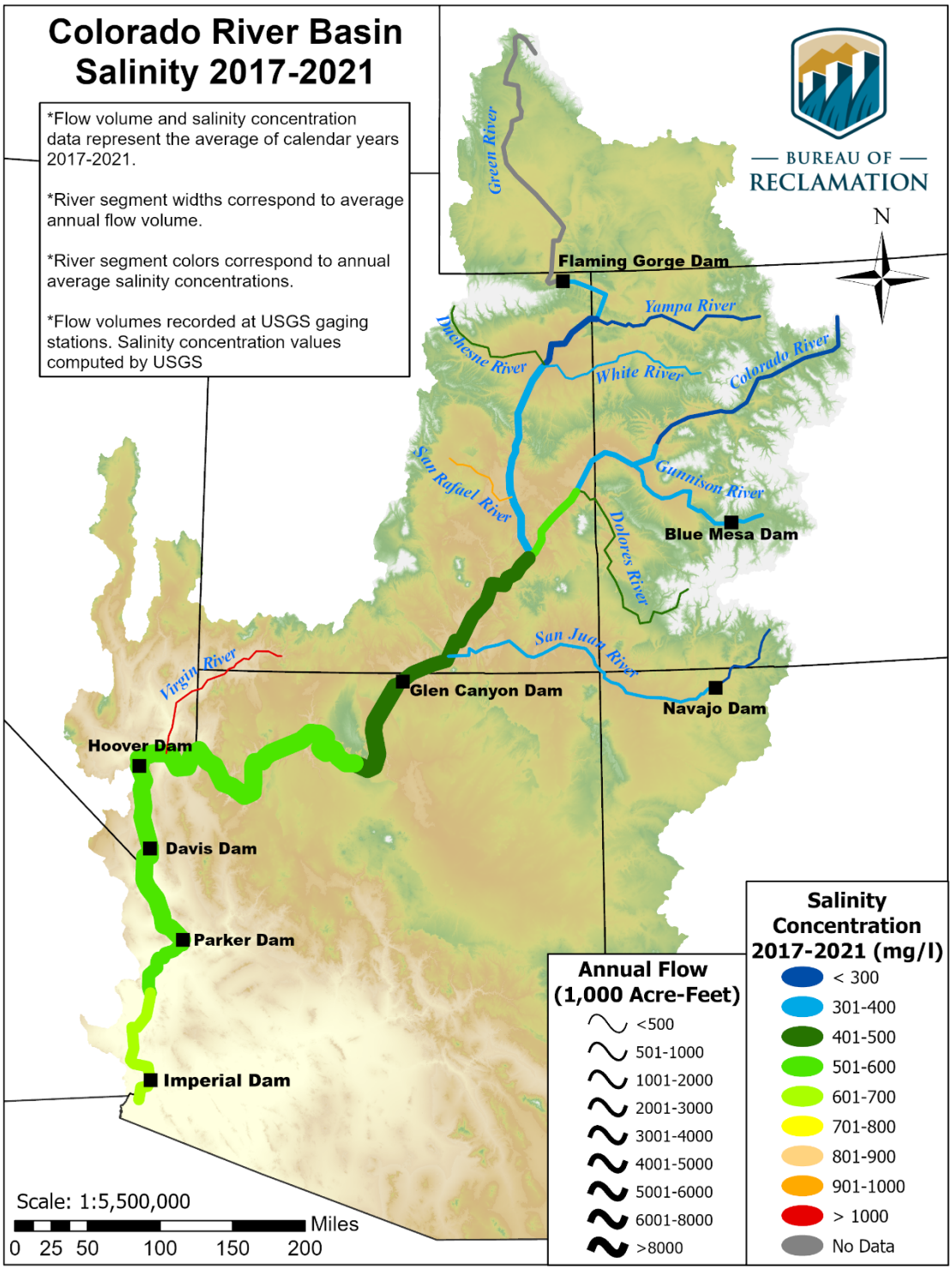


Figure 1 - 2017-2021 Average generalized flow and salinity concentrations across the Colorado River Basin.

In general, over the last thirty years the salinity concentrations have decreased at all three of the numeric criteria stations (see Figure 2). The values for the observed flow-weighted average salinity at the Numeric Criteria Stations are provided in Appendix A. In this Review, the terms "salinity," "TDS" and "concentration," each in mg/L, are used interchangeably.

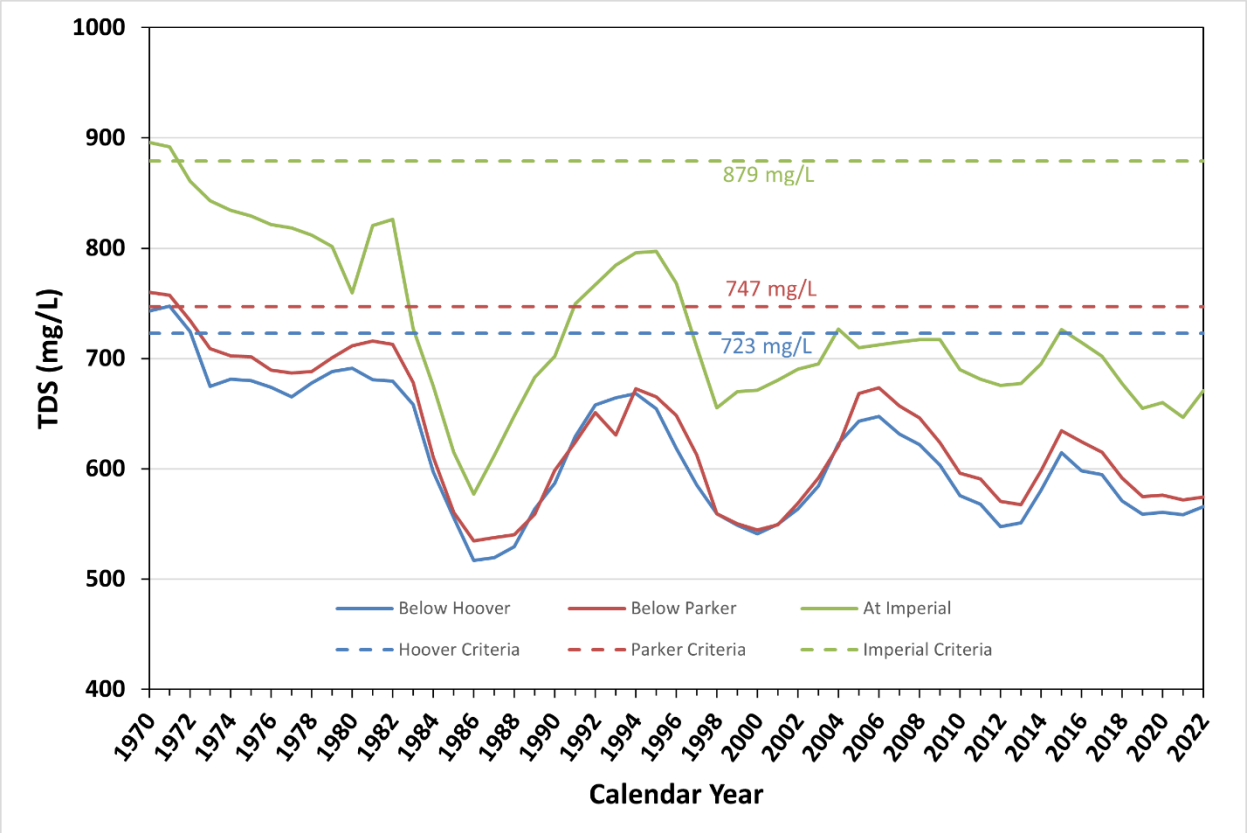


Figure 2 - Flow weighted average annual salt concentrations at Numeric Criteria Stations.

PROVISION FOR REVIEWING AND REVISING THE STANDARD

The Colorado River water quality standards for salinity and the approach taken by the Basin States in complying with the standards are unique. The salinity concentrations that are projected in the future have not been shown to have adverse effects on human health or wildlife. Thus, the Program is different from most other water quality standard compliance programs. The standards adopted by the Forum and the Basin States and approved by EPA consist of the numeric criteria and the Plan of Implementation. The numeric criteria portion of the water quality standards is established to protect against increases in economic damages to infrastructure and crop production. The Plan of Implementation is designed to maintain the flow-weighted average annual salinity at or below the numeric criteria for the benefit of future generations in states reliant on the Colorado River.

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The Program is a basin-wide coordinated effort among federal, state, and local agencies, and participants to control salt loading. The Forum, in its statement of "Principles and Assumptions for Development of Colorado River Salinity Standards and Implementation Plan," approved by the Forum on September 20, 1974, stated under Principle 7:

> The Plan of Implementation shall be reviewed and modified as appropriate from time to time, but at least once every three years. At the same time, the (numeric) standards, as required by Section 303 (c) (1) of P.L. 92-500, shall be reviewed for the purpose of modifying and adopting standards consistent with the plan so that the Basin States may continue to develop their compact-apportioned waters while providing the best practicable water quality in the Colorado River Basin.[12]

NUMERIC CRITERIA

EPA promulgated a regulation that set forth a salinity control policy for the Basin. This policy required that the flow-weighted average annual salinity in the lower main stem of the Colorado River be maintained at or below the 1972 levels. The points in the lower main stem of the Colorado River where the flow-weighted average annual salinity is measured are at the following three stations: 1) below Hoover Dam, 2) below Parker Dam, and 3) at Imperial Dam. The basis for selecting these stations is their proximity to key diversion facilities on the lower Colorado River. Nevada diverts main stem water from Lake Mead for use in the Las Vegas area. The Metropolitan Water District of Southern California and the Central Arizona Project divert water from Lake Havasu, impounded behind Parker Dam, for millions of water users in southern California and central Arizona, respectively. The large agricultural areas in the Imperial and Coachella Valleys in California and the Yuma area in Arizona are served by diversions at Imperial Dam.

The numeric criteria for each of those stations as established in 1972 are as follows:

Below Hoover Dam	723 mg/L
Below Parker Dam	747 mg/L
At Imperial Dam	879 mg/L

While the federal regulations provide for temporary increases above the numeric criteria levels if sufficient control measures are included in the Plan of Implementation, no temporary increases are anticipated during this review period.

The Forum believes the Review is the appropriate setting to recommend any changes to the numeric criteria. The Forum finds the current numeric criteria are adequate for the next three years and recommends no changes at this time. Because of the potential economic benefit to the Basin, the Forum believes there is justification to maintain salinity levels below the numeric criteria and remove additional salt from the Colorado River, thus saving several hundred million dollars in annual damages.

[12] Water Quality Standards for Salinity, Including Numeric Criteria and Plan of Implementation for Salinity Control, Colorado River System, Colorado River Basin Salinity Control Forum, 1975 Review, p. 133.

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PLAN OF IMPLEMENTATION

General

The Plan of Implementation is designed to keep the flow-weighted average annual salinity concentrations at or below the 1972 numeric criteria levels for the benefit of future generations in states reliant on the Colorado River. Measures in place are currently controlling 1.33 million tons of salt annually. The Plan of Implementation would implement practices to control an additional 51,700 tons of salt per year by 2026. With the Plan of Implementation as proposed in this Review in place, the probability of exceeding the numeric criteria during the review period is small based on Reclamation computer model simulations. The analysis indicates the probability of exceeding the numeric criteria with the Plan of Implementation in place in any of the next three years at the Hoover Dam, Parker Dam and Imperial Dam stations is 6 percent. This low probability of exceedance was an important factor in the Forum's decision to adopt the Plan of Implementation accompanying this Review.

The Plan of Implementation is composed of many actions contemplated by the federal and state agencies and includes projects that remove the required salt tonnage to meet the Plan goal. This will principally be accomplished by reducing the salt contributions to the Colorado River from existing sources and minimizing future increases in salt load caused by human activities. For this Review, the Plan of Implementation can be briefly summarized as follows:

1. Implementation of salinity control measures by Reclamation, Natural Resources Conservation Service (NRCS), the BSP and BLM to the extent that those measures remain viable and appropriately cost effective.

2. Pumping operations at the Paradox Valley Unit (PVU) were suspended in March 2019 following earthquake activity. Brine injection was resumed on an interim basis in June 2022 at the rate of about 65,000 tons per year. Concerns about seismic activity have called into question the remaining useful life of the existing brine injection well. Reclamation did not select a brine disposal alternative in its Environmental Impact Statement published in 2020. Because the brine injection well is presently functioning, through the review period (2024-2026), for modeling purposes, 65,000 tons of annual salinity control will be shown for PVU. However, because a new brine disposal alternative has not yet been identified, in order to represent the uncertainty of future PVU operations, for modeling purposes herein, the injection rate is reduced by 20%, or 13,000 tons per year for each year from 2027 through 2031 after which zero tons of salinity control is used thereafter through 2040. This is not a statement of the Forum's position on the need for continued salinity control at the PVU but simply a recognition of the uncertainty with continued operations of the injection well between now and 2040.

3. Application of the Forum-adopted policies by each of the states. (The texts of the policies are included in Appendix B, and a list of National Pollutant Discharge Elimination System (NPDES) permits issued pursuant to these policies is found in Appendices C and D of this Review.)

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4. Implementation of non-point source management plans developed by the states in collaboration with stakeholders (including, but not limited to, landowners as well as state, federal and local agencies), and approved by EPA (see the State Water Quality Management Plans section of this Review).

The Forum participates with federal, state, and local agencies and private participants to ensure the Plan of Implementation is executed. The Forum also urges Congress to appropriate the funds needed for implementation and recommends legislative changes when necessary.

Constructed Measures

Congress enacted Public Law 93-320 in June of 1974 with the Forum's support. Title II of the Public Law created a water quality program for addressing salinity in the Colorado River in the United States above Imperial Dam. Primary responsibility for Title II was given to the Secretary of the Interior, with Reclamation being instructed to investigate and build the Paradox Valley, Grand Valley, Las Vegas Wash and Crystal Geyser salinity control units. The Secretary of Agriculture was also instructed to support the effort within existing authorities.

Public Law 93-320 has been amended several times. The amendments directed the Secretary of the Interior and the Secretary of Agriculture to give preference to the salinity control units with the least cost per unit of salinity reduction. The amendments established a BLM program, a voluntary on-farm salinity control program to be implemented by USDA (including the voluntary replacement of incidental fish and wildlife values foregone as a result of the on-farm measures) and the Basin States Program. Through implementation of these programs, many cost-effective salt-load reducing activities have been accomplished.

USDOI-Reclamation

The Act was amended by P.L. 104-20 to authorize the Basinwide Program. The Basinwide Program uses a competitive process that has greatly increased the federal cost effectiveness of salinity control. Reclamation may implement a variety of effective salinity control measures, but most projects concentrate on improving the efficiency of off-farm irrigation delivery systems. Reclamation solicits applications through a Notice of Funding Opportunity (NOFO) process for projects that will reduce the salinity of the Colorado River. Reclamation evaluates and ranks each application and awards grants to the highest-ranking applications. Cost effectiveness is the prime criteria in the evaluation[13]. The timing of the NOFO is based on the need for more salinity control projects, and it relates to the amount of federal appropriation Reclamation receives to implement its portion of the Program. P.L. 104-20 and P.L. 106-459 increased the authorization ceiling for Reclamation's salinity control program.

USDA-NRCS

The NRCS program generally concentrates on improving on-farm systems. NRCS salinity activities fall mainly under the authorities of EQIP. EQIP for Colorado River salinity control was authorized and initially funded under the 1996 Farm Bill and reauthorized by the Agricultural

[13] Criteria included with documentation for each funding announcement (https:/usbr.gov/us/progact/salinity/index.html)

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Improvement Act of 2018 (P.L. 115-334) (2018). NRCS accepts applications under EQIP and evaluates, ranks, and selects those applications that best meet the goals of the salinity control program. Based on the applications, NRCS provides technical and financial assistance to the producers. Under the Agricultural Improvement Act of 2018, NRCS may also now enter into EQIP contracts with "water management entities" including states, irrigation districts, and similar entities to implement water conservation and efficiency practices. NRCS also offers financial assistance for voluntary replacement of fish and wildlife values forgone.

USDOI - BLM

The goal of the BLM program is to reduce the mobilization of salts to the Colorado River from BLM administered public lands. Salt reduction is achieved by controlling both point and non-point sources of salt contributions, recognizing that the majority of salt derived from public lands is of non-point source origin. Salt loading from non-point sources is mainly reduced by minimizing soil erosion.

Basin States Program

Public Law 110-246 amended the Act and created the Basin States Program (BSP) through which money from the Lower Colorado River Basin Development Fund and the Upper Colorado River Basin Fund (Basin Funds) is used for cost sharing in Reclamation and NRCS salinity control programs. These are administered by Reclamation in consultation with the Colorado River Basin Salinity Control Advisory Council. Cost share on federal appropriations expended by both Reclamation and NRCS for salinity control in the Basin is required by the Act. The money for the Basin Funds comes from levies assessed on users of power generated within the Basin. The required cost share on the original salinity control units of Paradox, Grand Valley and Las Vegas Wash is 25 percent of the project cost. Salinity control units and programs implemented subsequent to the original units require a 30 percent cost share from the Basin Funds.

For cost-share dollars generated by the federal expenditures under the Basinwide Program, Reclamation expends the required cost-share funding, together with appropriated funds in the Basinwide Program, through a public grant process. BSP funding generated by federal appropriations expended in EQIP is managed by Reclamation to administer the BSP and to enter into the following agreements: (1) with irrigation entities to implement salinity projects through the NOFO, (2) other federal agencies for studies and research, (3) the states of Colorado, Utah and Wyoming to fund approved salinity control activities, and (4) other entities for approved salinity control activities and salinity control projects. Each of the state agencies has the same goal of providing salinity control in the most cost-effective manner. The cost-share aspects of the BSP have proven very useful as a means of achieving additional cost-effective salinity control. The BSP complements the NRCS and Reclamation programs in a comprehensive manner and facilitates local water user participation.

<u>Accomplishments and Future Control</u>

The Plan of Implementation recognizes that the Forum, participating federal agencies and the Basin States each have specific responsibilities for addressing salinity on the Colorado River. The

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Forum, in conjunction with the Colorado River Basin Salinity Control Advisory Council, will continue to provide overall coordination and a continuing review of salinity conditions and program effectiveness, and will advise the participating federal agencies regarding the implementation of salinity control efforts.

To date, it is estimated that the Program has reduced the annual salt loading in the Colorado River by approximately 1,332,400 tons, resulting in approximately 103 - 120 mg/L reduction in salinity concentrations in the Lower Basin. Figures 3 – 5 show the comparison of measured salinity levels as compared to what salinity levels would have been without implementation of the Program at the three numeric criteria stations. Table 1 gives a brief summary of the measures that have been implemented to date, the areas where those measures have occurred, and the tons of salt controlled per year associated with each area. Figure 6 shows the salinity areas where these measures have been implemented.

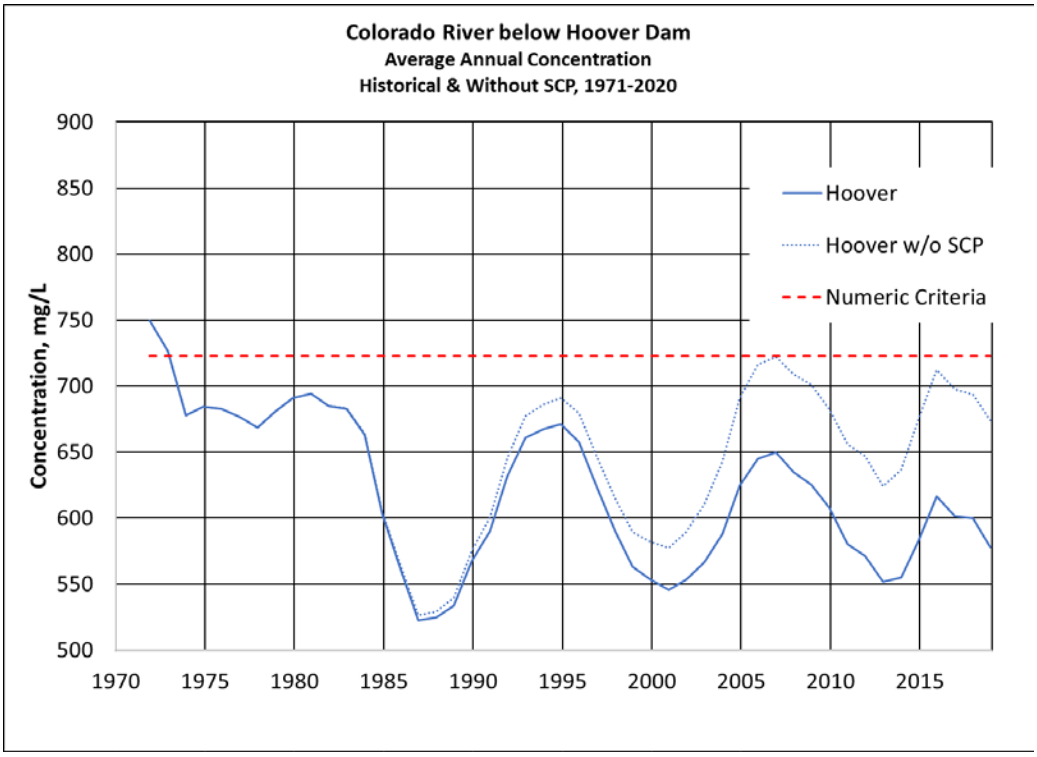


Figure 3 - Salinity Control Program impact on average annual concentration of the Colorado River below Hoover Dam 1971-2020. Historic flow-weighted salinity concentrations with and without the Salinity Control Program.

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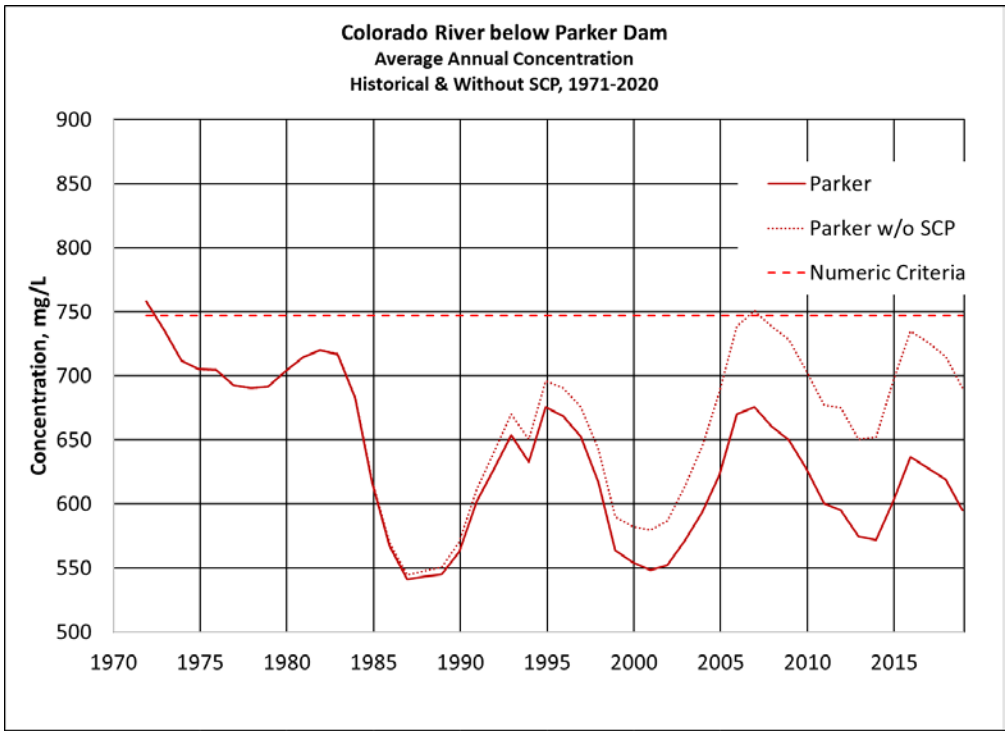


Figure 4 - Salinity Control Program impact on average annual concentration of the Colorado River below Parker Dam 1971-2020. Historic flow-weighted salinity concentrations with and without the Salinity Control Program.

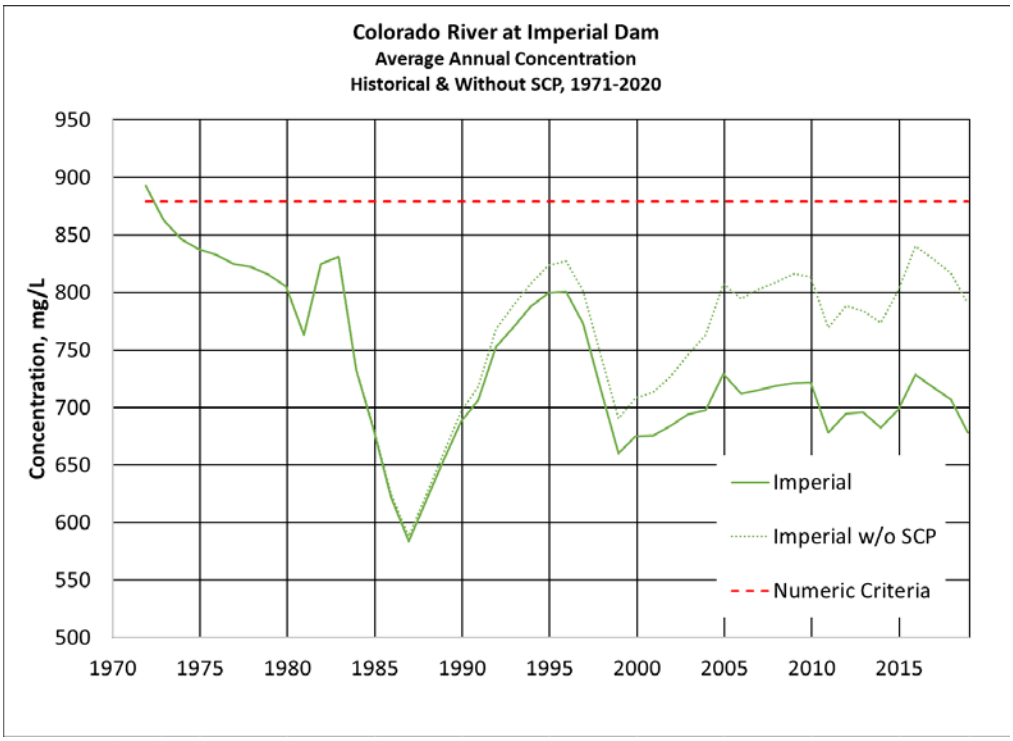


Figure 5 - Salinity Control Program impact on average annual concentration of the Colorado River at Imperial Dam 1971-2020. Historic flow-weighted salinity concentrations with and without the Salinity Control Program.

Table 1 - Control Measures in Place in 2023

	Tons/Year		Tons/Year
Agricultural Measures	**1,191,900**	**Other Measures**	**140,500**
Big Sandy	71,500	**Paradox Valley Unit**	65,000
West Blacks Fork	1,100	**Meeker Dome**	48,000
Grand Valley	285,000	**Las Vegas Wash**	3,800
Green River	3,300	**Ashley Valley WWTP**	9,100
Henrys Fork	2,000	**BLM Point Source***	14,600
Lower Gunnison	278,900		
Mancos	8,700		
Manila	23,500		
McElmo (Dolores)	57,900		
Muddy Creek	5,000		
Paria	1,800		
Price-San Rafael	170,300		
San Juan	53,200		
Silt	2,600		
Uinta	217,700		
USDA Tier 2	9,400		
TOTAL			**1,332,400**

** See discussion relative the modeling of future PVU operations found on page 10

*BLM Nonpoint Source controls not included herein

The Plan of Implementation assumes that measures currently in place continue to operate through the review period (2024 - 2026) and beyond. Improved water delivery and irrigation systems will need to be continually maintained and efficiently operated to provide reliable salinity control. Much of the financial burden of O&M and replacement of irrigation systems falls to salinity program participants who are the agricultural producers in the Basin. The Forum acknowledges the need for producers to maintain their improved irrigation practices through continued efforts and financial investment. The same is true for the non-agricultural measures as well. The best example may be the Paradox Valley Unit (PVU). The expected life and continued effectiveness of the PVU project is a matter of study by Reclamation and the Forum. As described on page 10, because a brine disposal replacement alternative has not yet been identified, for modeling herein it is presumed that the project will not provide any control beginning in 2027.

It should be noted that Table 1 includes 14,600 tons of salinity control implemented by BLM through the plugging of abandoned, flowing oil and gas wells. Most of BLM's salinity control activities center around efforts to reduce saline soil erosion such as improving grazing and watershed management efforts, or mitigation after oil and gas development, fire, or OHV damage. Therefore, activities are more of an offset to ongoing causes of salinity rather than an improvement from 1972 conditions when the Program was initiated. As such, though critically important to the Program and the overall water quality of the Colorado River System, these activities are not included in Tables 2 and 3 which show potential gains or improvements over 1972 conditions.

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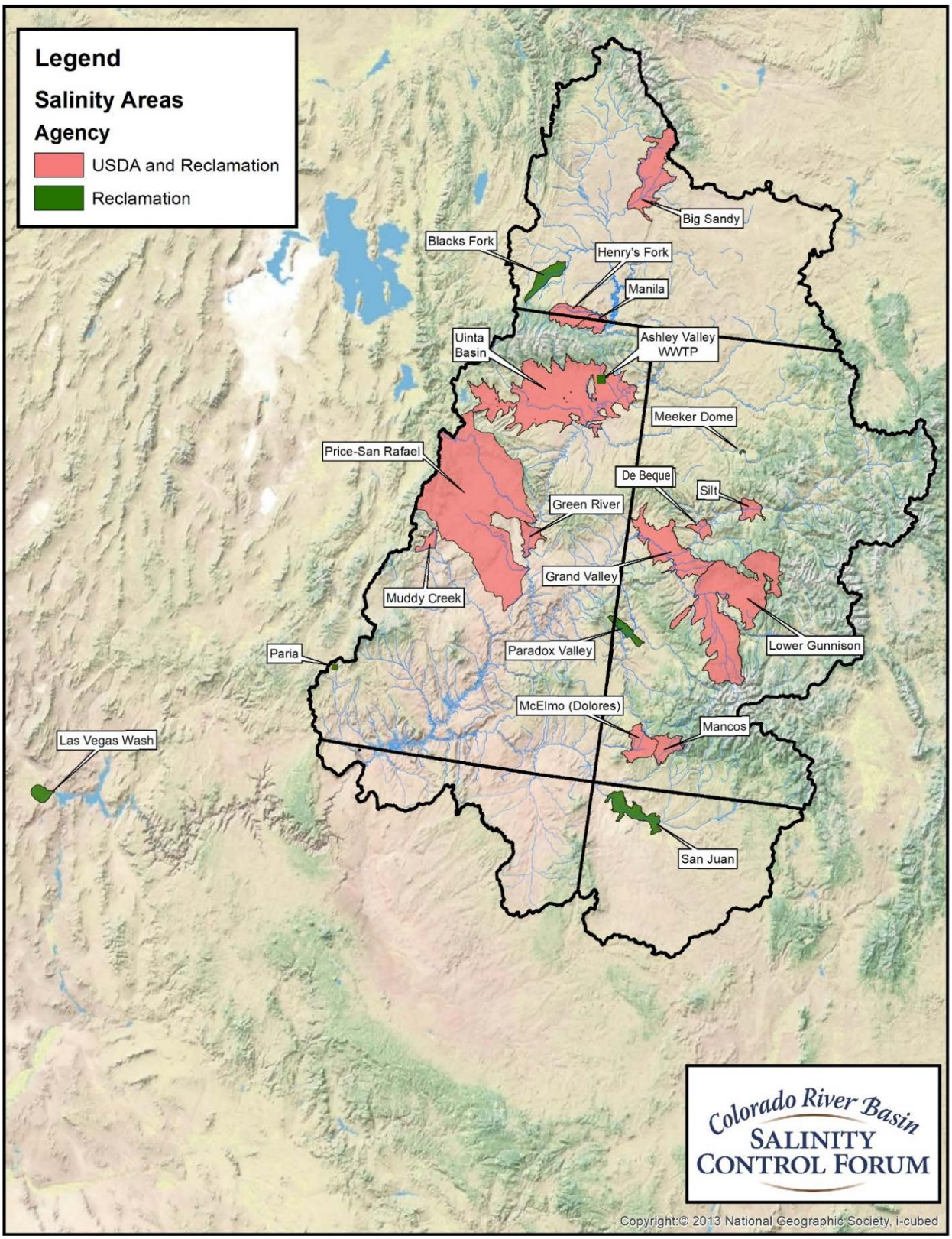


Figure 6 - Colorado River Basin Salinity Control Areas

The Plan of Implementation anticipates the continuation of the Program through the period of the Review. As presented in Table 2, it is anticipated that an additional 51,700 tons annually will be controlled by the Program as set forth in the 2023 Plan of Implementation, resulting in a total of 1,384,100 tons of annual reduction by 2026.

Table 2 - Additional Controls - Plan of Implementation 2026**

Funding Source		Tons/Year as of 2026
RECLAMATION (Basinwide Program)*		22,200
BASIN STATES PROGRAM (BSP)		7,900
USDA NRCS (EQIP)		21,600
TOTAL**		**51,700**

*Includes cost-share dollars from Basin States Program
** BLM Nonpoint Source controls not included herein

This Plan of Implementation mainly focuses on the improvement of agricultural practices in the Upper Colorado River Basin. These improvements include both on-farm and off-farm activities. The majority of the salt reduction will occur in established salinity project areas, but some will occur outside those areas. Table 3 provides existing and some potential salinity control project areas and an estimate of the potential salt reductions for both on- and off-farm projects that could occur in those areas.

Table 3 - Remaining Potential Salinity Control (2024-2040)*

Project Area	Total Tons/year	Percent remaining
Big Sandy	35,660	33%
West Blacks Fork	26,900	96%
Grand Valley	211,460	43%
Green River	10,400	76%
Henrys Fork	16,120	89%
Lower Gunnison	473,100	63%
Mancos	15,000	63%
Manila	11,100	32%
McElmo (Dolores)	39,940	41%
Muddy Creek	8,060	62%
Paria	30	2%
Price-San Rafael	38,490	18%
San Juan	9,330	15%
Silt	9,460	78%
Uinta	68,800	24%
USDA Tier 2	6,610	41%
Nonpoint Sources*		
TOTAL**	**980,460**	

*BLM Nonpoint Source controls not included
**Saline Groundwater Sources not included

The potential additional controllable salt remaining in all the identified areas is estimated to be 980,460 tons annually, and thus the potential available tons exceed the 51,700 tons of additional annual salinity control identified by the Plan of Implementation. Additional salinity control areas may be identified in the future.

Forum Policies and NPDES Permits

Important components of the Plan of Implementation are the Forum policies and NPDES permits which guide Basin States activities associated with the control of salt discharge to the Colorado River. In 1977, the Forum adopted the Policy for Implementation of Colorado River Salinity Standards through the NPDES Permit Program. This policy provides guidance for the regulation of municipal and industrial point source discharges of saline water. In 1980, the Forum adopted a policy to encourage the use of brackish and/or saline waters for industrial purposes where it is environmentally sound and economically feasible. A third policy dealing with intercepted groundwater was adopted by the Forum in 1982. In 1988, the Forum adopted a fourth policy which addresses the salinity of water discharges from fish hatcheries. The Forum subsequently updated its NPDES policy in 2002 to clarify the Forum policies for consistent implementation among the Basin States. In 2015, a Forum subcommittee found that the States are consistently implementing the policies. These policies are found in Appendix B of this report.

Each of the states has adopted the Forum policies presented in Appendix B. Salinity discharge requirements for these permits are evaluated and practicable controls are required during the permit process. A listing of NPDES permits and level of compliance of discharge facilities within the Basin are presented in Appendix C. Some NPDES permits are issued by the various EPA Regions in the Basin for federal facilities and Native American tribes without NPDES primacy. The State of New Mexico does not yet have NPDES primacy; therefore, EPA Region 6 issues NPDES permits in New Mexico, which are certified by the New Mexico Environment Department. Forum policies also apply to EPA-issued NPDES permits and hence, become a part of the Plan of Implementation. The NPDES permits issued by EPA can be found in Appendix D of this report. During the period of this Review, the status of implementation of NPDES permits and water quality management plans in each of the states follows:

State Water Quality Management Plans

ARIZONA

Scope

The Colorado River enters Arizona and the Lower Basin near Page and travels through the Grand Canyon before turning southward at Lake Mead (Hoover Dam) and flowing to the Gulf of California. There are four major drainages in Arizona's portion of the Basin which are regulated under the NPDES program: 1) the Little Colorado River; 2) the Virgin River; 3) the Bill Williams River, formed by the Big Sandy and the Santa Maria Rivers at Alamo Lake, which empties into the Colorado River above Parker Dam; and 4) the Gila River, which joins the Colorado River below Imperial Dam. Because the Gila River is below Imperial Dam, facilities that discharge to the Gila River or its tributaries do not require conformance with the Forum policies.

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NPDES Permitting

The Water Quality Division of the Arizona Department of Environmental Quality (ADEQ) administers the Arizona Pollutant Discharge Elimination System (AZPDES) program on non-Indian country lands. All permits for domestic wastewater and industrial discharges, with direct river discharges, are written in conformance with associated Forum policies. ADEQ continues to evaluate and revise other discharge permits as information becomes available.

Currently there are 25 active individual discharge permit holders in Arizona's non-tribal portion of the Colorado River system. Of these, 20 permits are for municipal or domestic wastewater discharges. The other 5 permits are for industrial discharges related to fish hatcheries, mines, water treatment or water delivery. Additionally, there are 3 inactive permits that were terminated or expired since the 2020 triennial review. A specific listing of the individual permits and the status of compliance with Forum policies is contained in Appendix C.

There are currently 22 stream segments and lakes in the Basin that are listed in the state's 2022 Section 303(d) list as impaired in the following watersheds: Bill Williams (3), Colorado River Grand Canyon (9), Colorado River Lower Gila (4), Little Colorado River (6). No waters are currently listed for salinity, which only applies to the Colorado River. The primary causes of impairment are selenium (8), mercury (8), suspended sediment (3), *E. Coli* (3), ammonia (2), copper (1), beryllium (1), and dissolved oxygen (1). Complete assessment information can be found on ADEQ's website.

Watershed Planning

ADEQ's TMDL Program and the Water Quality Improvement Grant Program utilize comprehensive watershed-based plans, which contain EPA's required nine elements, to help focus funding to those areas and projects that have the greatest chance for improving water quality. These plans contain implementation strategies for many of the impaired waters, as well as Best Management Practices to address existing and potential issues in the watershed.

Work plans are developed to secure grant funding under the Clean Water Act, Section 319(h) for watershed level planning and implementation. The work plans identify and coordinate efforts by state, federal and local agencies, along with watershed groups and private citizens, to reduce or prevent nonpoint source pollution through the use of Best Management Practices and "on-the-ground" projects.

CALIFORNIA

Note that California administers NPDES permits similar to other states, but it does not currently have any active NPDES permits which discharge in the Colorado River Basin.

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COLORADO

Scope

Colorado's portion of the Colorado River Basin is comprised of six major drainages: 1) the main stem of the Colorado River from the continental divide to the Utah border, 2) the Roaring Fork River Basin, 3) the Yampa/White River Basin which flows to the Green River in Utah, 4) the Gunnison River Basin, 5) the Dolores River which flows to the main stem in Utah, and 6) the San Juan Basin which flows into New Mexico and then to the main stem in Utah.

NPDES Permitting

The Colorado Department of Public Health and Environment, Water Quality Control Division (CDPHE, WQCD), administers the NPDES permitting program in the Colorado River Basin, with the exception that EPA issues permits for point source discharges on the Southern Ute and Ute Mountain Ute Reservations, as well as for federally owned lands such as National Parks. This would include permits for discharges to groundwater that would contribute salinity to the Colorado River system through a hydrologic connection to surface waters. Permits for industrial and municipal discharges are written in conformance with the associated Forum policies. Colorado continues to issue stormwater permits to construction of oil and gas development sites and related infrastructure (e.g. roads) of one or more acres of disturbance, even though the Energy Policy Act had exempted this activity from the requirement to obtain a permit at the federal level.

Currently there are more than 300 active discharge permits and permit certifications in the Colorado portion of the Colorado River Basin where the salinity requirements have been addressed. A specific listing of these permits is contained in Appendix C.

Water Quality Assessments and TMDLs

The waters in Colorado's portion of the Colorado River Basin, particularly at higher elevation, are generally of good quality. Based on the 2022 303(d) List of Impaired Waters, there are 195 water quality impaired stream segments in the Colorado River Basin in Colorado (Gunnison River Basin: 70 impaired segments; Upper and Lower Colorado River Basin: 91 impaired segments; San Juan River Basin: 34 impaired segments). Of these, a significant majority in the lower ends of these basins are impaired for selenium. Water quality impairments in the mountainous portions of these basins are due to high concentrations of metals, primarily caused by the remnants of historic mining activities. No waters are currently listed for salinity related impacts.

The lower portions of each of these basins are underlain by bedrock deposits of the cretaceous period, most notably Mancos Shale and Dakota Sandstone. The Mancos Shale is a marine deposit and, as such, contains significant amounts of readily soluble constituent materials, including selenium. Groundwater which leaches to the relatively impermeable shale deposits tends to dissolve selenium and, as it flows atop the bedrock strata toward surface drainages, carries elevated levels of dissolved selenium with it. Various anthropogenic activities like sand and gravel extraction and agricultural and urban landscape irrigation accelerate the mobilization and transport of selenium from shale and shale-derived soil to surface water.

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Given the selenium impairments, CDPHE, WQCD prioritized developing selenium Total Maximum Daily Loads (TMDLs) for several impaired tributaries within the Colorado River basin. One of the primary reasons for prioritizing these TMDLs is the impact the selenium loading is having on threatened and endangered fish habitat. Additional water quality monitoring and TMDL development for tributaries from Glenwood Springs to the Utah state line is underway with completion targeted for 2024. Activities are also ongoing to address the nonpoint source contributions that will be identified in these TMDLs. Many BMPs that are implemented to address the selenium nonpoint source contributions are anticipated to reduce salinity as well.

Watershed Planning - Colorado River Basin Selenium/Salinity Nonpoint Source Activities

CDPHE, WQCD supported watershed- and regional-scale water quality planning and BMP implementation for selenium and salinity reduction in the Basin. While the focus has been on selenium, control techniques for selenium are generally thought to reduce salinity loading because seepage and deep percolation of water into the local Mancos Shale and associated soils is a primary source of both salt and selenium loading. Numerous projects for selenium and salinity control are ongoing in the Basin with a primary emphasis in the Lower Gunnison which was the largest contributing tributary. The Gunnison River Basin Selenium Management Program, which was developed in response to the 2009 USFWS Gunnison Basin Programmatic Biological Opinion, provides details of past, current, and planned selenium control projects. Selenium reductions associated with this program are attributed to previous and on-going off-farm and on-farm salinity control efforts implemented through the Colorado River Basin Salinity Control Program, Environmental Quality Incentives Program, National Irrigation Water Quality Program, Natural Resources Conservation Service Regional Conservation Partnership Program, Colorado Department of Natural Resources Species Conservation Trust Program, and Colorado Nonpoint Source Program Clean Water Act Section 319. The Colorado Nonpoint Source Program provided funding assistance for additional irrigation lateral piping in the Basin and continues to work with local communities and producers to support implementation of BMPs. USGS studies have shown that irrigation efficiency efforts are contributing to a downward trend in selenium loading (https://pubs.er.usgs.gov/ publication/sir20185001) and this downward trend was reflected in the removal of the Lower Gunnison segment (COGULG02) from the 2022 303(d) List of Impaired Waters by the Colorado Water Quality Control Commission.

NEVADA

Scope

The Basin within Nevada consists of three major tributaries: 1) the Virgin River, 2) the Muddy River, and 3) the Las Vegas Wash. All of these tributaries flow into Lake Mead and provide nearly all of the inflow to the river from Nevada.

NPDES Permitting

The Nevada Division of Environmental Protection is the EPA delegated authority for the issuance of NPDES Permits. As of December 31, 2022, there were 52 active discharge permits in the Nevada portion of the Colorado River System. The largest dischargers, the City of Las Vegas with a permitted discharge maximum flow of up to 101 mgd (91 mgd from the Water Pollution Control Facility and 10 mgd from the Durango Hills Facility), the Clark County Water Reclamation

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District with a permitted discharge maximum flow of up to 150 mgd, the City of Henderson with a permitted discharge maximum flow of up to 48 mgd (40 mgd from the Kurt R. Segler Water Reclamation Facility and 8 mgd from the Southwest Water Reclamation Facility), and the City of North Las Vegas with a permitted discharge maximum flow up to 25 mgd. The quality of the water affected by these permits is closely monitored and all necessary programs to protect water quality standards are being implemented. Nevada continues to apply the policies adopted by the Forum.

Water Quality Management Planning

Area-wide water quality management planning duties and powers have been vested to certain counties and entities. The Clark County Board of Commissioners was designated the Area-Wide Water Quality Management Planning organization within Clark County. The initial 208 Plan was adopted by the Clark County Board of Commissioners in 1978 and was approved by the EPA. Since that time, several 208 Plan revisions have been made as needed to address changing needs.

NEW MEXICO

Scope

New Mexico's portion of the Basin above Imperial Dam is comprised of two major drainages: 1) the Rio Puerco, which is a tributary of the Little Colorado River, and 2) the San Juan River, which is a major tributary of the Colorado River.

NPDES Permitting

The NPDES program is administered by the EPA Region 6 in the State of New Mexico, including Tribal Nations and except for facilities on the Navajo Nation which are issued by EPA Region 9. The New Mexico Environment Department (NMED) Surface Water Quality Bureau (SWQB) assists the EPA Region 6 in implementing the Clean Water Act Section 402 NPDES permit program by reviewing federal permits and preparing Section 401 certifications to certify that the permit also complies with New Mexico law. Permits for industrial and municipal discharges are written in conformance with the associated Forum policies. The State of New Mexico adopts the standards of the Forum by reference in the Water Quality Standards for Interstate and Intrastate Surface Waters at 20.6.4.54 NMAC. Currently, there are 35 discharge permits (active and inactive) in the New Mexico portion of the Basin, of which EPA Region 6 administers 22 permits and EPA Region 9 administers 13 Navajo Reservation permits. Of these, 18 permits (14 state, 4 Navajo Nation) are for industrial discharges and 16 permits (6 state, 1 Jicarilla Apache, 9 Navajo Nation) are associated with municipal wastewater discharges.

Water Quality Assessment and TMDLs

The New Mexico Water Quality Control Commission currently adopts the water quality framework developed and proposed by the NMED which includes the State of New Mexico Water Quality Management Plan and the New Mexico Nonpoint Source Management Plan. Both plans cover the entire state, except for tribal and pueblo lands which are under the jurisdiction of the respective Tribes and Pueblos. Much of the Basin in New Mexico falls within the Navajo Nation boundary.

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The following TMDLs have been adopted by the New Mexico Water Quality Control Commission and approved by EPA within the New Mexico portion of the Basin at this time:

Gallegos Canyon (San Juan to Navajo boundary) selenium
San Juan River (Animas River to Canon Largo) sedimentation, *E.coli*
Animas River (San Juan River to Estes Arroyo) temperature, *E.coli*
Animas River (San Juan River to Estes Arroyo) total nitrogen, total phosphorus
Animas River (Estes Arroyo to Southern Ute) *E.coli*, total phosphorus
La Plata River (McDermott Arroyo to CO border) *E.coli*
La Plata River (McDermott Arroyo to CO border) dissolved oxygen
La Plata River (San Juan River to McDermott Arroyo) sedimentation, *E.coli*
San Juan River (Navajo and at Hogback to Animas River) *E.coli*

The most recent San Juan Basin Surface Water Quality Survey was conducted in 2017 and 2018 by the NMED SWQB. These data were assessed to determine the current impairments and de-listing, and for the future TMDL development. These surveys are normally scheduled throughout the various watersheds and basins in the state on a 7- to 8-year cycle. The NMED SWQB in coordination with the EPA and Navajo Nation currently conducts additional water quality sampling as a result of the 2015 Gold King Mine Spill.

Watershed Planning

Work plans have been developed and grant funding secured under Clean Water Act Section 319(h) for watershed-associated development, riparian area restoration, certification of Section 404 permits, spill response and treatment of abandoned mines. The work plans identify and coordinate efforts by state, federal and local agencies, along with other groups and private citizens, to reduce or prevent non-point source pollution and implement Best Management Practices to reduce nonpoint source pollutants. The NMED and the San Juan Watershed Group, an unincorporated citizen and interagency group funded by the Section 319(h) program, are working to improve water quality in the San Juan River by implementing Best Management Practices for non-point source contributors of nutrients and *E. coli*. State Revolving Loan Funds and other funds are authorized and available for use in funding salinity control projects. State actions in support of salinity control include: 1) inclusion of salinity control measures in the Section 208 plans, 2) dissemination of information on salinity sources and control, 3) consultation with industries on potential salinity reduction measures, 4) implementation of Forum policy through NPDES permits, and 5) maintaining a continuous water quality planning program whereby new or additional salinity control measures can be addressed. Funding associated with the 2015 Gold King Mine Spill is also used to conduct San Juan River Watershed conferences where on-going watershed restoration and sampling efforts are presented.

UTAH

Scope

Utah's portion of the Colorado River Basin is comprised of ten major sections: 1) the main stem of the Colorado River from the Colorado border to the Arizona Border in Lake Powell, 2) the

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Green River Basin from the Wyoming state line in Flaming Gorge Reservoir to the confluence with the Colorado River, 3) the Duchesne River Basin, 4) the lower Yampa and White River Basins which flow to the Green River in Utah, 5) the Price and San Rafael River Basins, 6) the Dirty Devil and Escalante Rivers, 7) the lower portion of the San Juan River Basin which flows into the main stem of the Colorado River in Utah, 8) the Paria River, 9) the Kanab Creek Basin to the Arizona State Line, and 10) the Virgin River Basin to the Arizona state line.

NPDES Permitting

The Utah Division of Water Quality (DWQ) within the Utah Department of Environmental Quality administers the NPDES permitting program in Utah. Permits for industrial and municipal discharges within the Colorado River Basin are written in conformance with the associated Forum policies and are available for viewing online at the UPDES Permitting Program webpage.

As of December 31, 2022, there are 71 discharge permits as issued by DWQ in the Utah portion of the Colorado River Basin. Of these, 32 are for municipal discharges and 39 are for industrial discharges, of which 7 industrial permits have been recently terminated. A specific listing of the individual permits and their compliance status is presented in Appendix C. Multiple discharge permits for coal mining operations in Utah were developed to offset salinity contributions from industrial sources in accordance with the Forum policy initially adopted as part of the 2002 Triennial Review. The salinity-offset project plans have been finalized previously, with projects implemented to offset salinity contributions in excess of the one-ton-per-day requirement from those facilities.

Water Quality Assessments and TMDLs

The waters in Utah's portion of the Colorado River Basin are generally of good quality; however, there are 29 assessment units currently listed as impaired for impacts from TDS according to the 303(d) list presented in the 2022 Integrated Report. These segments are generally in the lower reaches of the respective basins and are the result of a combination of natural salt loadings and agricultural drainage. TMDLs have been developed for a number of assessment units to address past impairments from TDS and can be viewed on DWQ's Approved TMDL webpage.

Watershed Planning

Utah's Watershed Management Program is focused on protecting and restoring the water quality of its streams, lakes, and groundwater resources by employing the following key elements: Stewardship, Monitoring and Assessment, Coordination, and Watershed Planning. Although projects exist in other regions, currently the Upper Colorado Basin region in Utah has no watershed planning projects in progress to specifically address Total Dissolved Solids. The Basin Plans for the Utah State Water Plan include water quality as part of the process, and these plans are updated periodically.

WYOMING

Scope

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Wyoming's portion of the Basin is comprised of two major mainstream drainages: 1) the Little Snake River, which is a tributary of the Yampa River in Colorado, and 2) the Green River, which empties into Flaming Gorge Reservoir on the Wyoming-Utah border.

NPDES Permits

Currently there are 28 active discharge permits in the Wyoming portion of the Colorado River system. All permits for industrial and municipal discharges are written in conformance with Forum policies. Of the 28 permits, 11 are for industrial discharges related to fish hatcheries, coal mines, power plants or oil and gas production facilities and 17 of the permits are associated with municipal wastewater discharges. These facilities serve a total population of approximately 50,000 people. A specific listing of the individual permits and compliance status is contained in Appendix C.

Water Quality Assessments and TMDLs

The waters in the Upper Colorado River Basin within Wyoming are generally of good quality. There are currently 14 streams and river segments identified as impaired within the Basin in Wyoming's 2020 Integrated 305(b) and 303(d) Report. Of these, two segments are impaired for salinity-related impacts; Bitter Creek in the Green River Basin and Muddy Creek in the Little Snake River Basin both are listed as impaired for chloride.

Other water quality impairments in the Green River Basin include sedimentation/siltation, *E. coli*/fecal coliform, and pH. Other water quality impairments in the Little Snake River Basin include physical substrate habitat alterations, nutrients, temperature, selenium, and heavy metals. A web map of the assessed waterbodies, which includes summary information and links to fact sheets, assessment reports, TMDLs, and more is available on WDEQ's Water Quality Assessment webpage under the "Reports" tab.

There are eight completed TMDLs within the Basin that are not directly associated with salinity concerns. Water quality monitoring and data analysis by WDEQ are ongoing in Bitter Creek to support future development of TMDLs or alternative approaches. A TMDL for Muddy Creek is not scheduled for development at this time.

Watershed Planning

Watershed planning and restoration activities continue for several of the impaired waterbodies within the Green River and Little Snake River Basins. In the past five years, two nine-element watershed-based plans were published by local conservation districts and approved for use in the competitive proposal process for Section 319(h) water quality implementation projects.

Local Conservation Districts serve a key leadership role in planning and implementation in Wyoming, and detailed information on their efforts in the Green and Little Snake River Basins can be found in the 2018 Wyoming Watersheds Progress Report, prepared by the Wyoming Association of Conservation Districts. A new report is under development and anticipated to be published within the next year.

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In 2010, the Wyoming Water Development Commission (WWDC) revised the Green River Basin Plan, which includes the Little Snake River Drainage. The plan updated information about the current uses and projected future uses of water in the Basin and includes other useful information such as irrigated lands delineation, hydrologic modeling of major streams, estimated availability of surface and groundwater for future use, and recommendations and strategies for facing current and future water use challenges.

In 2018, the WWDC published an updated Environmental and Recreational Water Use Analysis to accompany the 2010 basin plan. The study identified a consistent viewpoint and accounting process for environmental and recreational water demands to help guide river basin planning efforts moving forward. More information on planning and implementation in the Green and Little Snake River Basins is presented below.

Green River Basin:
In 2018, the Sublette County Conservation District completed a nine-element watershed-based plan to address the sediment impairment in a segment of the Little Sandy River within the Green River basin. The plan identifies ways that excessive erosion and sedimentation in the impaired segment could be addressed through best management practices and river restoration.

Sweetwater County Conservation District completed a stream restoration project on Bitter Creek in 2018 that stabilized a headcut by replacing a failing drop structure with an improved structure that promotes channel stability.

In 2021, the Sweetwater County Conservation District completed a nine-element watershed-based plan to address the fecal coliform impairments in Bitter and Killpecker Creeks and discuss the chloride issues in Bitter Creek (within the Green River basin). The plan provides planning and methodology to improve water quality within the Bitter Creek watershed, which includes Killpecker Creek. As shown above, the WDEQ continues to assess the chloride impairment, therefore a detailed plan to address this component will come at a later date.

Other entities have also been actively pursuing stream and river restoration projects in the Green River Basin. The Wyoming Game and Fish Department (WGFD) and Trout Unlimited continue to restore segments of the New Fork River and the Green River. These projects are supported by Section 319(h) funding, as well as numerous other local, state, and federal funding sources.

Little Snake River Basin:
Coordinated resource management in the Little Snake River Basin led to successful restoration of three impaired waterbodies in the Muddy Creek watershed through improved grazing management, stream stabilization projects, and wetlands development. These efforts were applauded on EPA's Nonpoint Source Success Story website. Little Snake River Conservation District continues to lead restoration activities on other impaired waterbodies in the basin, including erosion and sediment reduction projects in the Little Snake River.

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CONCLUSION AND ADOPTION OF THE STANDARDS

The water quality standards for salinity control in the Colorado River consist of two components: the numeric criteria and the Plan of Implementation. No changes have been made to the numeric criteria since their adoption by the seven Basin States in 1975 and subsequent approval by EPA. Following their 2023 triennial review process, the Forum again concludes that the numeric criteria are appropriate and recommends no changes. The Forum also finds that the updated Plan of Implementation is adequate for maintaining salinity concentrations below the numeric criteria through 2026, thus providing significant benefits to the Colorado River Basin. If the Plan of Implementation is executed successfully, the probability of exceeding the numeric criteria is estimated to be 6 percent in any given year of the review period, thereby providing a measurable improvement to the quality of the Colorado River.

The Program cannot be successful without the cooperation of many agencies and governments at the local, state, and federal levels. First, the Program relies on landowners to implement cost-effective salinity control measures. Second, the Program is dependent on a multitude of agreements among the seven Basin States which have always been accomplished by consensus. Lastly, the Program depends on the three federal agencies that implement salinity control, as well as other federal agencies such as the United States Fish & Wildlife Service, United States Geological Survey and EPA. Based on their involvement in the preparation of this Review, it is expected that cooperating federal agencies will support the Plan of Implementation and its programs.

In June of 2023, the Forum adopted the proposed 2023 Review for public comment. During the summer of 2023, the Forum and the seven Basin States solicited comments on the Review from the public and cooperating agencies. Each state used its own comment solicitation method, and the Forum posted the proposed 2023 Review on its website. No public comments were received. At the Forum meeting held on October 24, 2023, the Forum approved this 2023 Review.

With the approval of this Review by the Forum, each of the seven Basin States will include these standards as a part of their own water quality standards through their respective procedures. The states will obtain approval of their water quality standards from EPA based on their respective regions. The State of New Mexico will submit its triennial review to EPA Region 6 in Dallas, Texas; Colorado, Utah and Wyoming will submit to EPA Region 8 in Denver, Colorado; and Arizona, California and Nevada will submit to EPA Region 9 in San Francisco, California. It is anticipated that EPA will fully support this salinity control effort by approval of each state's submittals.

FUTURE PROGRAM

As described in earlier sections of this report, the water quality standard for salinity in the Colorado River Basin is expected to be met during the review period (over the next three years, 2024-2026). Given average hydrology in the Basin, the probability of exceeding the numeric criteria, while putting into practice the outlined Plan of Implementation, is well within the established water quality standard. Nonetheless, as water development continues to occur throughout the Basin, salinity concentrations and the associated economic damages are projected to increase. Therefore,

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this section analyzes the comparative changes in Colorado River salinity under different implementation scenarios from the present through 2040. The efforts of the Program are to minimize downstream economic damages while the states continue to use water from the Colorado River. This effort is increasingly challenging as economic damage levels and costs increase over time, thus placing greater burdens on Program implementation.

Reclamation used its Colorado River Simulation System (CRSS) model to project salinity levels for the period 2023 through 2040 with the varying levels of Program implementation. The CRSS model simulates 33 separate hydrologic traces for each year (1988-2020) and then calculates the average annual salinity. A detailed description of the CRSS model and the model runs made for this Review are found in Appendix E.

The Forum requested that Reclamation analyze the effects on the salinity of the Colorado River for four levels of program implementation (tons of salt removed). The Forum chose the levels of implementation based on different assumptions regarding federal funding, state cost share and the tons of salt available for future control. These scenarios require different levels of anticipated funding to support implementation. For each modeled scenario, 65,000 tons of salinity control was modeled for PVU through 2026 following a ramp down of 20% (13,000 tons) per year from 2027 through 2031 after which there was modeled no salinity control at PVU through 2040.

Scenario 1 shows no additional salinity control measures implemented after 2023. Also included in this scenario is the modeled ramping down and loss of salinity control at PVU described above. Hence, Table 1 shows 1,332,400 tons of present salinity control but Scenario 1 shows no additional salinity control at 1.27 million tons due to the loss of salinity control at PVU.

Scenario 2 shows controls associated with current and projected limited program funding levels through 2040. Reclamation's Basinwide program maintains a funding level of $10 million in 2023 and then funding levels of $8.4 million through 2040. NRCS funding follows the agency's 3-year funding plan for 2024-2026 and is reduced to $12 million through 2029 and then $10 million through 2040.

Scenario 3 shows the same funding levels for NRCS as Scenario 2 and a funding level of $10.7 million for Reclamation through 2026 and then a fixed rate of implementation of 9,000 tons per year thereafter.

Scenario 4 shows controls associated with controlling the maximum potential identified salt load by 2040 (Table 3) and is shown as an upper bound, not a practical plan of implementation.

Table 4 shows the four scenarios modeled by Reclamation with the tons of annual salinity control in place by the year 2040.

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Table 4 - Plan of Implementation Levels Modeled by CRSS

Description	Total Control
Scenario 1 - No Additional Controls beyond 2023 (does not implement the Plan of Implementation identified herein)	1.27M tons
Scenario 2 - Controls associated with limited program funding levels through 2040	1.49M tons
Scenario 3 - Controls associated with fixed implementation through 2040	1.55M tons
Scenario 4 - Controls associated with controlling maximum potential identified salt load by 2040	2.21M tons

Note: "No additional controls" contemplates some continuing O&M expenditures to maintain existing facilities.

Note: Uses the 2023 Review scenarios with 0 tons Paradox controls for 2031-2040

The modeling shows that the difference between no additional salinity controls (Scenario 1) and the proposed plan of implementation of 1.55 million tons (Scenario 3) is 27 mg/L at Imperial Dam by the year 2040. These values are summarized in Figures 7, 8 and 9 and Table 5 below for the three numeric criteria points.

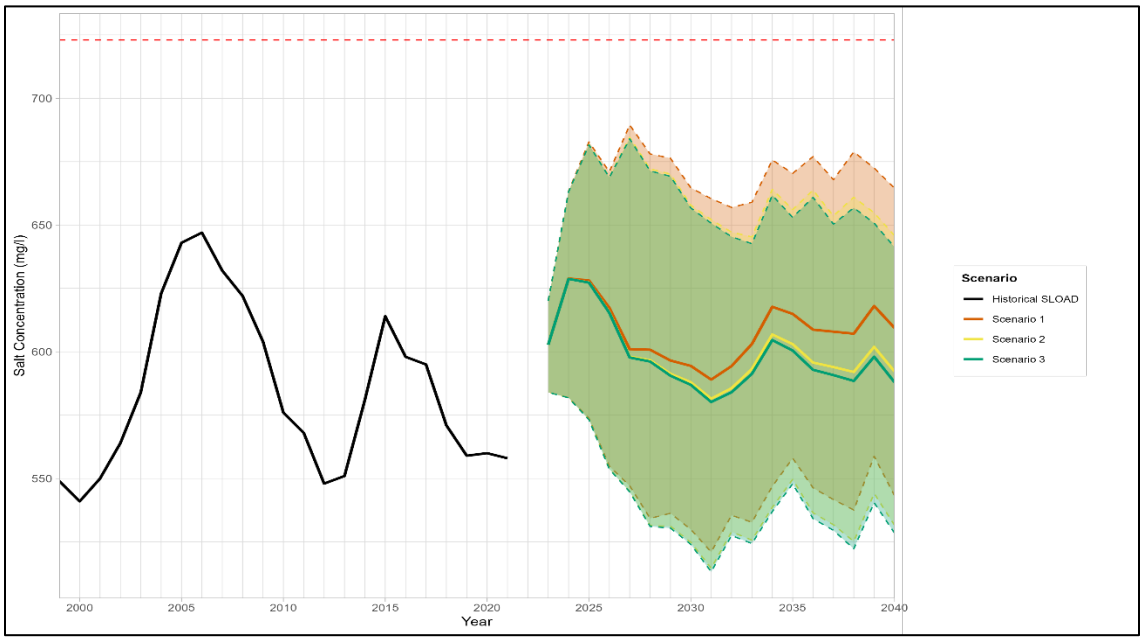


Figure 7 - Projected average annual salinity concentration below Hoover Dam. The colored solid lines are the mean values, and the shaded cloud area represents the 10th to 90th percentiles of each scenario's annual values. The black line represents the historical observed concentration from the SLOAD program. The red dotted line represents the numeric criteria.

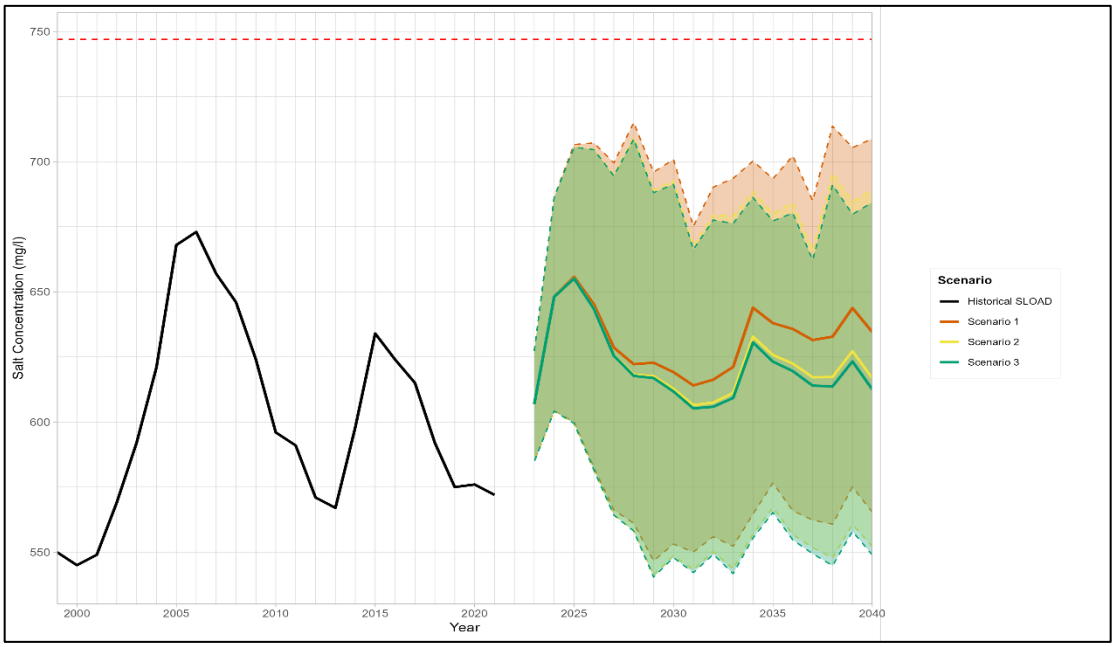


Figure 8 - Projected average annual salinity concentration below Parker Dam. The colored solid lines are the mean values, and the shaded cloud area represents the 10th to 90th percentiles of each scenario's annual values. The black line represents the historical observed concentration from the SLOAD program. The red dotted line represents the numeric criteria.

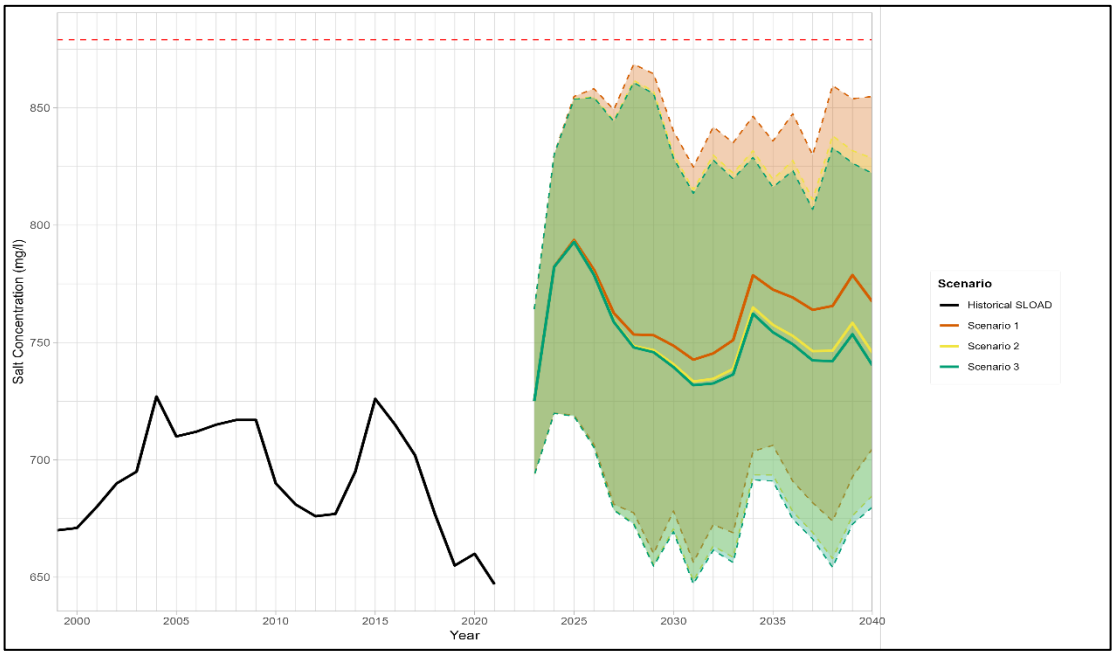


Figure 9 - Projected average annual salinity concentration at Imperial Dam. The colored solid lines are the mean values, and the shaded cloud area represents the 10th to 90th percentiles of each scenario's annual values. The black line represents the historical observed concentration from the SLOAD program. The red dotted line represents the numeric criteria.

To further understand the impacts of reducing the salinity concentrations in the Lower Basin, the Forum used Reclamation's Salinity Economic Impact Model (SEIM), which is described in Appendix F, to estimate damages under the four implementation alternatives. Damage estimates for each alternative are listed in Table 5 under the heading "Total Quantified Damages." Estimated damage reductions resulting from lower salinity concentrations projected under each alternative were derived by subtracting the "Total Quantified Damages" from the base case of 1.27M tons removed, or $447 million of annual damages. These estimates are listed in Table 5 as "Annual Damage Reductions." The SEIM model only estimates damages to the Lower Basin that can be reasonably *quantified* at the present time (see Appendix F). In addition to the currently *unquantified* damages in the Lower Basin, there are also benefits from the Program in the Upper Basin that have yet to be quantified. The SEIM was updated for the 2023 Review. Reclamation's consultant completed a review and update of the SEIM including updates to input data and cost functions where possible. Major changes included updates to residential impact functions, agricultural crop salinity thresholds, unified methods for calculating agricultural leaching and water utility costs. In 2022, the SEIM Committee, a subgroup of state and federal work group members, updated crop prices, price indices, water blending data and population projections to the latest available information.

Table 5 – Annual Damages and Damage Reductions

Alternative	Salinity Reduction at Imperial Dam in 2040 (mg/L)	Total Quantified Damages ($M)	Annual Damage Reductions as Compared to No Additional Future Controls Beyond 2020 ($M)
1.27M tons removed	--	447	--
1.49M tons removed	21	397.4	49.6
1.55M tons removed	27	385.1	61.9
2.21M tons removed	90	239.9	207.1

All damage and reduced-damage estimates correspond to year 2040.

Note: Uses the 2023 Review scenarios with 0 tons Paradox controls for 2031-2040

From these calculations, it can be seen that as more salinity control is implemented and the concentrations at the numeric criteria points are reduced, the *quantified* economic damages projected to be experienced annually by users in the Lower Basin are also reduced. For example, as indicated in Table 5, with the additional 280,000 tons of control (the difference between the 1.27 million ton and 1.55 million ton alternatives) annually, the *quantified* economic damages to agricultural and municipal and industrial water users are reduced by approximately $61.9 million annually. If the Plan of Implementation is implemented, then the probability of exceeding the numeric criteria values at the three stations is about 9 percent.

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While it is essential to continue to maintain salinity concentrations at or below the numeric criteria, the Forum will continue to focus on opportunities to further reduce future economic damages. The Forum believes a more robust salinity control program is needed to achieve the reductions indicated in Table 5. Two of the challenges facing the Forum in pursuing such a program are finding cost effective salinity control projects and acquiring the necessary funding to implement those projects. Persistent drought has reduced Colorado River flows thereby reducing power production which reduces the cost-share dollars available for Program funding. The Forum is committed to continue working with the federal agencies to identify cost effective projects. The Forum is also committed to working with the federal agencies and Congress to seek additional appropriations and to generate the cost share revenues needed to support additional federal expenditures. The Forum determines that all of the alternatives evaluated above are economically justifiable. However, given the current financial constraints, the Forum, for this review period, will pursue a Program designed to remove at least 1.55 million tons annually by the year 2040. This may require legislation to alter the states' cost share or other actions to meet the identified Program levels.

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APPENDIX A

Observed Flow-Weighted Salinity Values
at the Numeric Criteria Stations

Observed Flow-Weighted Average Salinity at the Numeric Criteria Stations (Total Dissolved Solids in mg/L)[1]

Calendar Year	Below Hoover Dam	Below Parker Dam	At Imperial Dam
(Numeric Criteria)	(723 mg/L)	(747 mg/L)	(879 mg/L)
1970	743	760	896
1971	748	758	892
1972	724	734	861
1973	675	709	843
1974	681	702	834
1975	680	702	829
1976	674	690	822
1977	665	687	819
1978	678	688	812
1979	688	701	802
1980	691	711	760
1981	681	716	821
1982	680	713	826
1983	658	678	727
1984	597	611	675
1985	556	561	615
1986	517	535	577
1987	519	537	612
1988	529	540	648
1989	564	559	683
1990	587	598	702
1991	629	624	749
1992	658	651	767
1993	664	631	785
1994	668	673	796
1995	655	665	797
1996	618	648	768
1997	585	612	710
1998	559	559	655
1999	549	550	670
2000	541	545	671
2001	550	549	680
2002	564	569	690
2003	584	592	695
2004	623	621	727
2005	643	668	710
2006	647	673	712
2007	632	657	715
2008	622	646	717
2009	604	624	717
2010	576	596	690
2011	568	591	681
2012	548	571	676
2013	551	567	677
2014	581	598	695
2015	614	634	726
2016	598	624	715
2017	595	615	702
2018	571	592	677
2019	559	575	655
2020	560	576	660
2021[2]	558	572	647
2022[2]	566	575	671

1 Determined by the USGS from data collected by Reclamation and USGS

2 2021-2022 values are provisional

Salinity concentrations are based on TDS as the sum of constituents whenever possible. The sum of constituents is defined to include calcium, magnesium, sodium, chloride, sulfate, a measure of the carbonate equivalent of alkalinity and, if measured, silica and potassium.

APPENDIX B

Forum Policies

POLICY FOR IMPLEMENTATION OF COLORADO RIVER SALINITY STANDARDS THROUGH THE NPDES PERMIT PROGRAM

Adopted by
The Colorado River Basin Salinity Control Forum

February 28, 1977
Revised October 30, 2002

In November 1976, the United States Environmental Protection Agency Regional Administrators notified each of the seven Colorado River Basin states of the approval of the water quality standards for salinity for the Colorado River System as contained in the document entitled "Proposed Water Quality Standards for Salinity Including Numeric Criteria and Plan of Implementation for Salinity Control, Colorado River System, June 1975, and the supplement dated August 25, 1975. The salinity standards including numeric criteria and a plan of implementation provide for a flow weighted average annual numeric criteria for three stations in the lower main stem of the Colorado River: below Hoover Dam, below Parker Dam, and at Imperial Dam.

In 1977, the states of the Colorado River Basin adopted the "Policy for Implementation of Colorado River Salinity Standards through the NPDES Permit Program." The plan of implementation is comprised of a number of federal and non-federal projects and measures to maintain the flow- weighted average annual salinity in the Lower Colorado River at or below numeric criteria at the three stations as the Upper and Lower Basin states continue to develop their compact-apportioned waters. One of the components of the Plan consists of the placing of effluent limitations, through the National Pollutant Discharge Elimination System (NPDES) permit program, on industrial and municipal discharges.

NPDES Policy for Municipal and Industrial Discharges of Salinity in the Colorado River

The purpose of this policy is to provide more detailed guidance in the application of salinity standards developed pursuant to Section 303 and through the NPDES permitting authority in the regulation of municipal and industrial sources. (See Section 402 of the Federal Water Pollution Control Act.) The objective of the policy, as provided in Sections I.A. and I.B., is to achieve "no salt return" whenever practicable for industrial discharges and an incremental increase in salinity over the supply water for municipal discharges. This policy is applicable to discharges that would have an impact, either direct or indirect on the lower main stem of the Colorado River System. The lower main stem is defined as that portion of the River from Hoover Dam to Imperial Dam.

In October, 2002, the Forum substantially amended the NPDES policies relating to industrial discharges but made no changes to the procedures for municipal discharges. In the printing of the 2002 Review, however, the section relating to municipal discharges and an additional appendix entitled “Guidance on New Construction Determination” were inadvertently omitted. Both errors have been corrected in this printing and the Forum reaffirms the validity of all of the policies as they appear in this document.

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NPDES Policies Separately Adopted by the Forum

The Forum developed a separate and specific policy for the use of brackish and/or saline waters for industrial purposes on September 11, 1980. The Forum addressed the issue of intercepted ground water and adopted a specific policy dealing with that type of discharge on October 20, 1982. On October 28, 1988, the Forum adopted a specific policy addressing the water use and discharge associated with fish hatcheries. Each of these separately adopted policies is attached hereto.

NPDES Policies for Specified Industrial Discharges – 2002 Amendments

On October 30, 2002, the Forum amended this policy for implementation of Colorado River salinity standards through the NPDES permit program in order to address the following three additional types of industrial discharges: (1) water that has been used for once-through noncontact cooling water purposes; (2) new industrial sources that have operations and associated discharges at multiple locations; and (3) "fresh water industrial discharges" where the discharged water does not cause or contribute to exceedances of the salinity standards for the Colorado River System. This policy was also amended to encourage new industrial sources to conduct or finance one or more salinity-offset projects in cases where the permittee has demonstrated that it is not practicable to prevent the discharge of all salt from proposed new construction.

Discharges Of Once-Through Noncontact Cooling Water

Section I.C. of this policy has been added to address discharges of water that has been used for once-through noncontact cooling water purposes. The policy for such discharges shall be to permit these uses based upon a finding that the returned water does not contribute to the loading or the concentration of salts in the waters of the receiving stream beyond a *de minimis* amount. A *de minimis* amount is considered, for purposes of this policy, as an average annual increase of not more than 25 milligrams per liter (mg/L) in total dissolved solids measured at the discharge point or outfall prior to any mixing with the receiving stream in comparison to the total dissolved solids concentration measured at the intake monitoring point of the cooling process or facility. This policy is not intended to supersede any other water quality standard that applies to the receiving stream, including but not limited to narrative standards promulgated to prohibit impairment of designated uses of the stream. It is the intent of the Forum to permit the return of once-through noncontact cooling water only to the same stream from which the water was diverted. Noncontact cooling water is distinguished from blowdown water, and this policy specifically excludes blowdown or any commingling of once-through noncontact cooling water with another waste stream prior to discharge to the receiving stream. Sections I.A. and I.B. of this policy govern discharges of blowdown or commingled water.

New Industrial Sources with Operations and Discharges at Multiple Locations under Common or Affiliated Ownership or Management

Recently there has been a proliferation of new industrial sources that have operations and associated discharges at multiple locations. An example is the recent growth in the

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development of energy fuel and mineral resources that has occurred in the Upper Colorado River Basin. This type of industrial development may involve the drilling of relatively closely spaced wells into one or more geological formations for the purpose of extracting oil, gas or minerals in solution. Large-scale ground water remediation efforts involving multiple pump and treat systems operating for longer than one year may share similar characteristics. With such energy and mineral development and ground water remediation efforts there is the possibility of a single major industrial operation being comprised of numerous individual point source discharges under common or affiliated ownership or management that produce significant quantities of water as a waste product or byproduct over a long period. Given the large areal scope of these types of major industrial sources and the often elevated concentrations of salinity in their produced water, the total amount of salt loading that they could generate may be very large in comparison to the Forum's past and present salt removal projects. Relatively small quantities of this produced water could generate one ton per day in discharges to surface waters. Since salinity is a conservative water quality constituent, such discharges of produced water, if uncontrolled, could have an adverse effect on achieving the adopted numeric salinity standards for the Colorado River System.

These kinds of major industrial sources strain the conventional interpretation of the industrial source waiver for new construction set forth in Section I.A.1.a. of this policy, which authorizes a discharge of salinity from a single point source of up to one ton per day in certain circumstances. The Forum adopted this provision in 1977, well before most of the new major industrial sources that have operations and discharges at multiple locations began to appear in the Colorado River Basin. A new category of industrial sources is, therefore, warranted. NPDES permit requirements for New Industrial Sources with Operations and Discharges at Multiple Locations under Common or Affiliated Ownership or Management are set forth in Section I.D. of this policy. These new requirements are intended to apply to new industrial sources with operations that commence discharging after October 30, 2002.

For purposes of interpreting this policy, "common or affiliated ownership or management" involves the authority to manage, direct, superintend, restrict, regulate, govern, administer, or oversee, or to otherwise exercise a restraining or directing influence over activities at one or more locations that result in a discharge of salinity into the Colorado River System. Common or affiliated ownership or management may be through the ownership of voting securities or may be indicated where individual sources are related through one or more joint ventures, contractual relationships, landlord/tenant or lessor/lessee arrangements. Other factors that indicate two or more discharging facilities are under common or affiliated ownership or management include: sharing corporate executive officers, pollution control equipment and responsibilities, common workforces, administrative functions, and/or payroll activities among operational facilities at different locations.

Fresh Water Industrial Discharges

Sections I.A. and I.B. of this policy have been amended to allow the permitting authority to authorize "fresh water industrial discharges" where the discharged water does not cause

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or contribute to exceedances of the adopted numeric salinity standards for the Colorado River System. Different end-of-pipe concentrations of salinity as shown in Table 1 of the policy, are appropriate for discharges to tributaries depending upon their location within the Basin. The concept of "benchmark concentrations" has been developed in order to address this need for different end-of-pipe concentrations. These benchmark concentrations are not to be interpreted as water quality standards. Rather, they are intended to serve solely for the establishment of effluent limits for implementing the waiver for "fresh water discharges." The allowance for freshwater discharges is intended to preserve flows from discharges in the Basin, which do not cause significant degradation of existing ambient quality with respect to salinity. Operations or individual discharges that qualify for the freshwater waiver shall not be subject to any further limitation on salt loading under this policy.

Salinity-Offset Projects

This policy has been amended to allow the permitting authority to authorize industrial sources of salinity to conduct or finance one or more salinity-offset projects when the permittee has determined that it is not practicable: (i) to prevent the discharge of all salt from proposed new construction; (ii) to reduce the salt loading to the Colorado River to less than one ton per day or 366 tons per year; or (iii) the proposed discharge is of insufficient quality in terms of TDS concentrations that it could be considered "fresh water" as defined below. Presently, the permitting authority can consider the costs and availability of implementing off-site salinity control measures to mitigate the adverse impacts of the permitted salt load. It is not intended that the applicant be required to develop or design an off-site salinity control project or establish a salt bank, but rather to assess the costs of conducting or buying into such projects where they are available. In the future the Forum or another entity may create a trading/banking institution to facilitate the implementation of a salinity-offset program, basin-wide. This would allow industrial sources to conduct or finance the most cost effective project available at the time an offset project is needed regardless of the project's location in the Basin.

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NPDES PERMIT PROGRAM POLICY
FOR IMPLEMENTATION OF COLORADO RIVER SALINITY STANDARDS

I. Industrial Sources

The Salinity Standards state that "The objective for discharges shall be a no-salt return policy whenever practicable." This is the policy that shall be followed in issuing NPDES discharge permits for all new industrial sources, and upon the reissuance of permits for all existing industrial sources, except as provided herein. The following addresses those cases where "no discharge of salt@ may be deemed not to be practicable.

A. New Construction

1. "New construction@ is defined as any facility from which a discharge may occur, the construction of which is commenced after October 18, 1975. (Date of submittal of water quality standards as required by 40 CFR 120, December 11, 1974.) Attachment 1 provides guidance on new construction determination. "A new industrial source with operations and discharging facilities at multiple locations under common or affiliated ownership or management@ shall be defined for purposes of NPDES permitting, as an industrial source that commenced construction on a pilot, development or production scale on or after October 30, 2002.

   a. The permitting authority may permit the discharge of salt upon a satisfactory demonstration by the permittee that:

      i. It is not practicable to prevent the discharge of all salt from the new construction or,

      ii. In cases where the salt loading to the Colorado River from the new construction is less than one ton per day or 366 tons per year, or

      iii. The proposed discharge from the new construction is of sufficient quality in terms of TDS concentrations that it can be considered "fresh water" that would have no adverse effect on achieving the adopted numeric standards for the Colorado River System. The permitting authority may consider a discharge to be fresh water if the maximum TDS concentration is: (i) 500 mg/L for discharges into the Colorado River and its tributaries upstream of Lees Ferry, Arizona; or, (ii) 90% of the applicable in-stream salinity standard at the appropriate benchmark monitoring station for discharges into the Colorado River downstream of Lees Ferry as shown in Table 1, below

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Table 1

	Benchmark Monitoring Station	Applicable Criteria	Freshwater Discharge (mg/L)
1	Colorado River at Lees Ferry, Arizona	N/A	500
2	Colorado River below Hoover Dam	723	650
3	Colorado River below Parker Dam	747	675
4	Colorado River at Imperial Dam	879	790

b. Unless exempted under Sections I.A.1.a.ii. or iii., above, the demonstration by the applicant must include information on the following factors relating to the potential discharge:

i. Description of the proposed new construction.

ii. Description of the quantity and salinity of the water supply.

iii. Description of water rights, including diversions and consumptive use quantities.

iv. Alternative plans that could reduce or eliminate salt discharge. Alternative plans shall include:

(A) Description of alternative water supplies, including provisions for water reuse, if any;

(B) Description of quantity and quality of proposed discharge;

(C) Description of how salts removed from discharges shall be disposed of to prevent such salts from entering surface waters or groundwater aquifers;

(D) Costs of alternative plans in dollars per ton of salt removed; and

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(E) Unless the permitting authority has previously determined through prior permitting or permit renewal actions that it is not practicable to prevent the discharge of all salt from the new construction in accordance with Section I.A.1.a.i., the applicant must include information on project options that would offset all or part of the salt loading to the Colorado River associated with the proposed discharge or that would contribute to state or interstate salinity control projects or salt banking programs.

v. A statement as to the one plan among the alternatives for reduction of salt discharge that is recommended by the applicant and also information as to which of the other evaluated alternatives are economically infeasible.

vi. Such other information pertinent to demonstration of non- practicability as the permitting authority may deem necessary.

c. In determining what permit conditions shall be required under I.A.1.a.i., above, the permit issuing authority shall consider, but not be limited to the following:

i. The practicability of achieving no-discharge of salt from the new construction.

ii. Where "no discharge" is determined not to be practicable:

(A) The impact of the total proposed salt discharge of each alternative on the lower main stem in terms of both tons per year and concentration.

(B) Costs per ton of salt removed from the discharge for each plan alternative.

(C) Capability of minimizing salinity discharge.

(D) If applicable under I.A.1.b.(iv)(E), costs and practicability of offsetting all or part of the salt load by the implementation of salt removal or salinity control projects elsewhere in the Colorado River Basin. The permittee shall evaluate the practicability of offsetting all or part of the salt load by comparing such factors as the cost per ton of salt removal for projects undertaken by the Colorado River Basin Salinity Control Forum and the costs in damages associated with increases in salinity concentration against the permittee's cost in conducting or buying into such projects where they are available.

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iii. With regard to subparagraphs, (b) and (c) above, the permit issuing authority shall consider the compatibility of state water laws with either the complete elimination of a salt discharge or any plan for minimizing a salt discharge.

B. Existing Facilities or any discharging facility, the construction of which was commenced before October 18, 1975

1. The permitting authority may permit the discharge of salt upon a satisfactory demonstration by the permittee that it is not practicable to prevent the discharge of all salt from an existing facility.

2. The demonstration by the applicant must include, in addition to that required under Section I.A.1.b the following factors relating to the potential discharge:

a. Existing tonnage of salt discharged and volume of effluent.

b. Cost of modifying existing industrial plant to provide for no salt discharge.

c. Cost of salt minimization.

3. In determining what permit conditions shall be required, the permit issuing authority shall consider the items presented under I.A.1.c.(ii), and in addition; the annual costs of plant modification in terms of dollars per ton of salt removed for:

a. No salt return.

b. Minimizing salt return.

4. The no-salt discharge requirement may be waived in those cases where:

a. The discharge of salt is less than one ton per day or 366 tons per year; or

b. The permitting authority determines that a discharge qualifies for a "fresh water waiver" irrespective of the total daily or annual salt load. The maximum TDS concentration considered to be fresh water is 500 mg/L for discharges into the Colorado River and its tributaries upstream of Lees Ferry, Arizona. For discharges into the Colorado River downstream of Lees Ferry the maximum TDS concentration considered to be afresh water shall be 90% of the applicable in-stream standard at the appropriate benchmark monitoring station shown in Table 1, above.

C. Discharge of Once-Through Noncontact Cooling Water

1. Definitions:

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a. The terms "noncontact cooling water" and "blowdown@ are defined as per 40CFR 401.11 (m) and (n).

b. "Noncontact cooling water" means water used for cooling that does not come into direct contact with any raw material, intermediate product, waste product or finished product.

c. "Blowdown" means the minimum discharge of recirculating water for the purpose of discharging materials contained in the water, the further buildup of which would cause concentration in amounts exceeding limits established by best engineering practice.

d. "Salinity" shall mean total dissolved solids as the sum of constituents.

2. Permits shall be authorized for discharges of water that has been used for once-through noncontact cooling purposes based upon a finding that the returned water does not contribute to the loading of salts or the concentration of salts in the waters of the receiving stream in excess of a *de minimis* amount.

3. This policy shall not supplant nor supersede any other water quality standard of the receiving stream adopted pursuant to the Federal Clean Water Act, including but not limited to impairment of designated uses of the stream as established by the governing water quality authority having jurisdiction over the waters of the receiving stream.

4. Noncontact cooling water shall be distinguished from blowdown, and Section 1.C. of this policy specifically excludes blowdown or any commingling of once-through noncontact cooling water with another waste stream prior to discharge to the receiving stream. Sections I.A. and I.B of this policy shall in all cases govern discharge of blowdown or commingled water.

5. Once-through noncontact cooling water shall be permitted to return only to the same stream from which the water was diverted.

6. Because the increase in temperature of the cooling water will result in some evaporation, a *de minimis* increase in the concentration of dissolved salts in the receiving water may occur. An annual average increase in total dissolved solids of not more than 25 milligrams per liter (mg/L) measured at the intake monitoring point, as defined below, of the cooling process or facility, subtracted from the effluent total dissolved solids immediately upstream of the discharge point to the receiving stream, shall be considered *de minimis*.

7. At the time of NPDES discharge permit issuance or reissuance, the permitting authority may permit a discharge in excess of the 25 mg/L increase based upon a satisfactory demonstration by the permittee pursuant to Section 1.A.1.a.

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8. Once-through demonstration data requirements:

   a. Description of the facility and the cooling process component of the facility.

   b. Description of the quantity, salinity concentration and salt load of intake water sources.

   c. Description of the discharge, covering location, receiving waters, quantity of salt load and salinity concentration of both the receiving waters and the discharge.

   d. Alternative plans for minimizing salt discharge from the facility which shall include:

      i. Description of alternative means to attain no discharge of salt.

      ii. Cost of alternative plans in dollars per ton of salt removed from discharge.

      iii. Such other information pertinent to demonstration of non- practicability as the permitting authority may deem necessary.

9. If, in the opinion of the permitting authority, the database for the salinity characteristics of the water source and the discharge is inadequate, the permit will require that the permittee monitor the water supply and the discharge for salinity. Such monitoring program shall be completed in two years and the permittee shall then present the once-through demonstration data as specified above.

10. All new and reissued NPDES permits for once-through noncontact cooling water discharges shall require at a minimum semiannual monitoring of the salinity of the intake water supply and the effluent, as provided below.

    a. The intake monitoring point shall be the point immediately before the point of use of the water.

    b. The effluent monitoring point shall be prior to the discharge point at the receiving stream or prior to commingling with another waste stream or discharge source.

    c. Discrete or composite samples may be required at the discretion of the permitting authority, depending on the relative uniformity of the salinity of the water supply.

    d. Analysis for salinity may be either total dissolved solids or electrical conductivity where a satisfactory correlation with total dissolved solids has

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been established. The correlation shall be based on a minimum of five different samples.

D. Discharges of Salinity from a New Industrial Source with Operations and Discharging Facilities at Multiple Locations

1. The objective for discharges to surface waters from a new industrial source with operations and discharging facilities at multiple locations shall be to assure that such operations will have no adverse effect on achieving the adopted numeric salinity standards for the Colorado River System.

2. NPDES permit requirements for a new industrial source with operations and discharging facilities at multiple locations shall be defined, for purposes of establishing effluent limitations for salinity, as a single industrial source if these facilities meet the criteria:

   a. The discharging facilities are interrelated or integrated in any way including being engaged in a primary activity or the production of a principle product; and

   b. The discharging facilities are located on contiguous or adjacent properties or are within a single production area e.g. geologic basin, geohydrologic basin, coal or gas field or 8 digit hydrologic unit watershed area; and

   c. The discharging facilities are owned or operated by the same person or by persons under common or affiliated ownership or management.

3. The permitting authority may permit the discharge of salt from a new industrial source with operations and discharging facilities at multiple locations if one or more of the following requirements are met:

   a. The permittee has demonstrated that it is not practicable to prevent the discharge of all salt from the industrial source. This demonstration by the applicant must include detailed information on the factors set forth in Section I.A.1.b of the Policy for implementation of Colorado River Salinity Standards through the NPDES permit program; with particular emphasis on an assessment of salinity off-set options that would contribute to state or interstate salinity control projects or salt banking programs and offset all or part of the salt loading to the Colorado River associated with the proposed discharge.

   b. In determining what permit conditions shall be required under I.A.1.a.i., above, the permit issuing authority shall consider the requirement for an offset project to be feasible if the cost per ton of salt removal in the offset project options (i.e. the permittee's cost in conducting or buying into such projects where they are available) is less than or equal to the cost per ton of

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salt removal for projects undertaken by the Colorado River Basin Salinity Control Forum or less than the cost per ton in damages caused by salinity that would otherwise be cumulatively discharged from the outfalls at the various locations with operations controlled by the industrial source; or

c. The pemittee has demonstrated that one or more of the proposed discharges is of sufficient quality in terms of TDS concentrations to qualify for a "fresh water waiver" from the policy of "no salt return, whenever practical.@ An individual discharge that can qualify for a fresh water waiver shall be considered to have no adverse effect on achieving the adopted numeric salinity standards for the Colorado River System.

4. For the purpose of determining whether a freshwater waiver can be granted, the quality of water discharged from the new industrial source with operations and discharging facilities at multiple locations, determined as the flow weighted average of salinity measurements at all outfall points, must meet the applicable benchmark concentration in accordance with Section I.A.1.a.iii., as set forth above.

5. Very small-scale pilot activities, involving 5 or fewer outfalls, that are sited in areas not previously developed or placed into production by a new industrial source operations and discharges at multiple locations under common or affiliated ownership or management, may be permitted in cases where the discharge of salt from each outfall is less than one ton per day or 366 tons per year. However, no later than the date of the first permit renewal after the pilot activities have become part of a larger industrial development or production scale effort, all discharging facilities shall be addressed for permitting purposes as a single industrial source with operations and discharges at multiple locations under common or affiliated ownership or management.

6. The public notice for NPDES permits authorizing discharges from operations at multiple locations with associated outfalls shall be provided promptly and in the most efficient manner to all member states in the Colorado River Basin Salinity Control Forum in relation to this policy.

II. Municipal Discharges

The basic policy is that a reasonable increase in salinity shall be established for municipal discharges to any portion of the Colorado River stream system that has an impact on the lower main stem. The incremental increase in salinity shall be 400 mg/L or less, which is considered to be a reasonable incremental increase above the flow weighted average salinity of the intake water supply.

F. The permitting authority may permit a discharge in excess of the 400 mg/L incremental increase at the time of issuance or reissuance of a NPDES discharge permit, upon satisfactory demonstration by the permittee that it is not practicable to attain the 400 mg/L limit.

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G. Demonstration by the applicant must include information on the following factors relating to the potential discharge:

1. Description of the municipal entity and facilities.

2. Description of the quantity and salinity of intake water sources.

3. Description of significant salt sources of the municipal wastewater collection system, and identification of entities responsible for each source, if available.

4. Description of water rights, including diversions and consumptive use quantities.

5. Description of the wastewater discharge, covering location, receiving waters, quantity, salt load, and salinity.

6. Alternative plans for minimizing salt contribution from the municipal discharge. Alternative plans should include:

   a. Description of system salt sources and alternative means of control.

   b. Cost of alternative plans in dollars per ton, of salt removed from discharge.

7. Such other information pertinent to demonstration of non-practicability as the permitting authority may deem necessary.

H. In determining what permit conditions shall be required, the permit issuing authority shall consider the following criteria including, but not limited to:

1. The practicability of achieving the 400 mg/L incremental increase.

2. Where the 400 mg/L incremental increase is not determined to be practicable:

   a. The impact of the proposed salt input of each alternative on the lower main stem in terms of tons per year and concentration.

   b. Costs per ton of salt removed from discharge of each alternative plan.

   c. Capability of minimizing the salt discharge.

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D. If, in the opinion of the permitting authority, the data base for the municipal waste discharger is inadequate, the permit will contain the requirement that the municipal waste discharger monitor the water supply and the wastewater discharge for salinity. Such monitoring program shall be completed within 2 years and the discharger shall then present the information as specified above.

E. Requirements for establishing incremental increases may be waived in those cases where the incremental salt load reaching the main stem of the Colorado River is less than one ton per day or 366 tons per year. Evaluation will be made on a case-by-case basis.

F. All new and reissued NPDES permits for all municipalities shall require monitoring of the salinity of the intake water supply and the wastewater treatment plant effluent in accordance with the following guidelines:

Treatment Plant Design Capacity	Monitoring Frequency	Type of Sample
<1.0 MGD*	Quarterly	Discrete
1.0 - 5.0 MGD	Monthly	Composite
>5.0 - 50.0 MGD	Weekly	Composite
50.0 MGD	Daily	Composite

1. Analysis for salinity may be either as total dissolved solids (TDS) or be electrical conductivity where a satisfactory correlation with TDS has been established. The correlation should be based on a minimum of five different samples.

2. Monitoring of the intake water supply may be at a reduced frequency where the salinity of the water supply is relatively uniform.

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Attachment 1

Guidance on New Construction Determination

For purposes of determining a new construction, a source should be considered new if by October 18, 1975, there has not been:

I. Significant site preparation work such as major clearing or excavation; and/or

II. Placement, assembly or installation of unique facilities or equipment at the premises where such facilities or equipment will be used; and/or

III. Any contractual obligation to purchase unique facilities or equipment. Facilities and equipment shall include only the major items listed below, provided that the value of such items represents a substantial commitment to construct the facility:

A. structures; or
B. structural materials; or
C. machinery; or
D. process equipment; or
E. construction equipment.

IV. Contractual obligation with a firm to design, engineer, and erect a completed facility (i.e., a turnkey plant).

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POLICY FOR USE OF
BRACKISH AND/OR SALINE WATERS
FOR INDUSTRIAL PURPOSES

Adopted by
The Colorado River Basin Salinity Control Forum

September 11, 1980

The states of the Colorado River Basin, the Federal Executive Department, and the Congress have all adopted as a policy that the salinity in the lower main stem of the Colorado River shall be maintained at or below the flow-weighted average values found during 1972, while the Basin states continue to develop their compact-apportioned waters. In order to achieve this policy, all steps which are practical and within the framework of the administration of states' water rights must be taken to reduce the salt load of the river. One such step was the adoption in 1975 by the Forum of a policy regarding effluent limitations for industrial discharges with the objective of "no-salt return" wherever practicable. Another step was the Forum's adoption in 1977 of the "Policy for Implementation of Colorado River Salinity Standards through the NPDES Permit Program." These policies are part of the basinwide plan of implementation for salinity control which has been adopted by the seven Basin states.

The Forum finds that the objective of maintaining 1972 salinity levels would be served by the exercise of all feasible measures including, wherever practicable, the use of brackish and/or saline waters for industrial purposes.

The summary and page 32 of the Forum's 1978 Revision of the Water Quality Standards for Salinity state: AThe plan also contemplates the use of saline water for industrial purposes whenever practicable,...@ In order to implement this concept and thereby further extend the Forum's basic salinity policies, the Colorado River Basin states support the Water and Power Resources Service (WPRS) appraisal study of saline water collection, pretreatment and potential industrial use.

The Colorado River Basin contains large energy resources which are in the early stages of development. The WPRS study should investigate the technical and financial feasibility of serving a significant portion of the water requirements of the energy industry and any other industries by the use of Basin brackish and/or saline waters. The Forum recommends that:

I. The Colorado River Basin states, working with federal agencies, identify, locate and quantify such brackish and/or saline water sources.

II. Information on the availability of these waters be made available to all potential users.

III. Each state encourage and promote the use of such brackish and/or saline waters, except where it would not be environmentally sound or economically feasible, or would significantly increase consumptive use of Colorado River System water in the state above that which would otherwise occur.

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IV. The WPRS, with the assistance of the states, encourages and promotes the use of brackish return flows from federal irrigation projects in lieu of fresh water sources, except where it would not be environmentally sound or economically feasible, or would significantly increase consumptive use of Colorado River System water.

V. The WPRS considers a federal contribution to the costs of industrial use of brackish and/or saline water, where cost-effective, as a joint private-government salinity control measure. Such activities shall not delay the implementation of the salinity control projects identified in Title II of P.L. 93-320.

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POLICY FOR IMPLEMENTATION OF COLORADO RIVER SALINITY STANDARDS THROUGH THE NPDES PERMIT PROGRAM FOR INTERCEPTED GROUND WATER

Adopted by
The Colorado River Basin Salinity Control Forum

October 20, 1982

The States of the Colorado River Basin in 1977 agreed to the APolicy for Implementation of Colorado River Salinity Standards through the NPDES Permit Program@ with the objective for industrial discharge being Ano-salt return@ whenever practicable. That policy required the submittal of information by the applicant on alternatives, water rights, quantity, quality, and costs to eliminate or minimize the salt discharge. The information is for use by the NPDES permit-issuing agency in evaluating the practicability of achieving Ano-salt@ discharge.

There are mines and wells in the Basin which discharge intercepted ground waters. The factors involved in those situations differ somewhat from those encountered in other industrial discharges. Continued development will undoubtedly result in additional instances in which permit conditions must deal with intercepted ground water.

The discharge of [1]intercepted ground water needs to be evaluated in a manner consistent with the overall objective of Ano-salt return@ whenever practical. The following provides more detailed guidance for those situations where ground waters are intercepted with resultant changes in ground-water flow regime.

I. The Ano-salt@ discharge requirement may be waived at the option of the permitting authority in those cases where the discharged salt load reaching the main stem of the Colorado River is less than one ton per day or 366 tons per year. Evaluation will be made on a case-by-case basis.

II. Consideration should be given to the possibility that the ground water, if not intercepted, normally would reach the Colorado River System in a reasonable time frame. An industry desiring such consideration must provide detailed information including a description of the topography, geology, and hydrology. Such information must include direction and rate of ground-water flow; chemical quality and quantity of ground water; and the location, quality, and quantity of surface streams and springs that might be affected. If the information adequately demonstrates that the ground water to be intercepted normally would reach the river system in a reasonable time frame and would contain approximately the same or greater salt load than if intercepted, and if no significant localized problems

[1]The term Aintercepted ground water@ means all ground water encountered during mining or other industrial operations.

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would be created, then the permitting agency may waive the Ano-salt@ discharge requirement.

III. In those situations where the discharge does not meet the criteria in I or II above, the applicant will be required to submit the following information for consideration:

A. Description of the topography, geology, and hydrology. Such information must include the location of the development, direction and rate of ground-water flow, chemical quality and quantity of ground water, and relevant data on surface streams and springs that are or might be affected. This information should be provided for the conditions with and without the project.

B. Alternative plans that could substantially reduce or eliminate salt discharge. Alternative plans must include:

1. Description of water rights, including beneficial uses, diversions, and consumptive use quantities.

2. Description of alternative water supplies, including provisions for water reuse, if any.

3. Description of quantity and quality of proposed discharge.

4. Description of how salts removed from discharges shall be disposed of to prevent their entering surface waters or ground-water aquifers.

5. Technical feasibility of the alternatives.

6. Total construction, operation, and maintenance costs; and costs in dollars per ton of salt removed from the discharge.

7. Closure plans to ensure termination of any proposed discharge at the end of the economic life of the project.

8. A statement as to the one alternative plan for reduction of salt discharge that the applicant recommends be adopted, including an evaluation of the technical, economic, and legal Practicability of achieving no discharge of salt.

9. Such information as the permitting authority may deem necessary.

IV. In determining whether a Ano-salt@ discharge is Practicable, the Permit-issuing authority shall consider, but not be limited to, the water rights and the technical, economic, and legal practicability of achieving no discharge of salt.

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V. Where Ano-salt@ discharge is determined not to be Practicable the permitting authority shall, in determining permit conditions, consider:

A. The impact of the total proposed salt discharge of each alternative on the lower main stem in terms of both tons per year and concentration.

B. Costs per ton of salt removed from the discharge for each plan alternative.

C. The compatibility of state water laws with each alternative.

D. Capability of minimizing salinity discharge.

E. The localized impact of the discharge.

F. Minimization of salt discharges and the preservation of fresh water by using intercepted ground water for industrial processes, dust control, etc. whenever it is economically feasible and environmentally sound.

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POLICY FOR IMPLEMENTATION OF COLORADO RIVER SALINITY STANDARDS THROUGH THE NPDES PERMIT PROGRAM FOR FISH HATCHERIES

Adopted by
The Colorado River Basin Salinity Control Forum

October 28, 1988

The states of the Colorado River Basin in 1977 adopted the APolicy for Implementation of Colorado River Salinity Standards through the NPDES Permit Program.@ The objective was for Ano-salt return@ whenever practicable for industrial discharges and an incremental increase in salinity over the supply water for municipal discharges. The Forum addressed the issue of intercepted ground water under the 1977 policy, and adopted a specific policy dealing with that type of discharge.

A specific water use and associated discharge which has not been here-to-fore considered is discharges from fish hatcheries. This policy is limited exclusively to discharges from fish hatcheries within the Colorado River Basin. The discharges from fish hatcheries need to be addressed in a manner consistent with the 1977 and 1980 Forum policies.

The basic policy for discharges from fish hatcheries shall permit an incremental increase in salinity of 100 mg/L or less above the flow weighted average salinity of the intake supply water. The 100 mg/L incremental increase may be waived if the discharged salt load reaching the Colorado River system is less than one ton per day, or 366 tons per year. Evaluation is to be made on a case-by-case basis.

I. The permitting authority may permit a discharge in excess of the 100 mg/L incremental increase at the time of issuance or reissuance of a NPDES discharge permit. Upon satisfactory demonstration by the permittee that it is not practicable to attain the 100 mg/L limit.

II. Demonstration by the applicant must include information on the following factors relating to the potential discharge:

   A. Description of the fish hatchery and facilities.

   B. Description of the quantity and salinity of intake water sources.

   C. Description of salt sources in the hatchery.

   D. Description of water rights, including diversions and consumptive use quantities.

   E. Description of the discharge, covering location, receiving waters, quantity salt load, and salinity.

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F. Alternative plans for minimizing salt discharge from the hatchery. Alternative plans should include:

1. Description of alternative means of salt control.

2. Cost of alternative plans in dollars per ton, of salt removed from discharge.

G. Such other information pertinent to demonstration of non-practicability as the permitting authority may deem necessary.

III. In determining what permit conditions shall be required, the permit-issuing authority shall consider the following criteria including, but not limited to:

A. The practicability of achieving the 100 mg/L incremental increase.

B. Where the 100 mg/L incremental increase is not determined to be practicable:

1. The impact of the proposed salt input of each alternative on the lower main stem in terms of tons per year and concentration.

2. Costs per ton of salt removed from discharge of each alternative plan.

3. Capability of minimizing the salt discharge.

IV. If, in the opinion of the permitting authority, the database for the hatchery is inadequate, the permit will contain the requirement that the discharger monitor the water supply and the discharge for salinity. Such monitoring program shall be completed within two years and the discharger shall then present the information as specified above.

V. All new and reissued NPDES permits for all hatcheries shall require monitoring of the salinity of the intake water supply and the effluent at the time of peak fish population.

A. Analysis for salinity may be either as total dissolved solids (TDS) or be electrical conductivity where a satisfactory correlation with TDS has been established. The correlation should be based on a minimum of five different samples.

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APPENDIX C

States NPDES Permits List

LEGEND

NPDES PERMITS
EXPLANATION CODES

COLORADO RIVER BASIN SALINITY CONTROL FORUM
January 1, 2020, through December 31, 2022

NPDES permits are reviewed under two different criteria under Forum policy; these being municipal and industrial. In order for a permittee to be in compliance under the municipal criteria, the increase in concentration between inflow and outflow cannot be greater than 400 mg/L. Forum industrial criteria requires that no industrial user discharges more than 1.00 ton/day. Under Forum policy there can be granted exceptions to these limitations by the states. The following gives an explanation of the current status of the NPDES permits. Because at any given time many of the permits identified in this list are being reviewed, reissued, and/or terminated, and new discharge permits are being filed, this list must be considered as being subject to frequent change.

MUNICIPAL

(M) Municipal user in compliance with Forum policy.

(M-A) Municipal user in compliance with the 400 mg/L incremental increase provision.

(M-B) Municipal user in compliance with the 1 ton per day or 366 tons per year provision for intermittent discharges.

(M-1)* Permit has expired or been revoked. No discharge.

(M-2) Permittee did not discharge during the reporting period.

(M-3) Measurement of TDS is not currently required, but the state and/or EPA plans to require measurements of both inflow and outflow when the permit is reissued.

Measurements of inflow are not consistent with Forum policy;

(M-4A) Therefore, it is not known whether or not this municipal user is in compliance.

(M-4B) However, since outflow concentration is less than 500 mg/L it is presumed that this permit is not in violation of the ≤400 mg/L increase.

(M-5) Permittee is in violation of Forum policy in that there is an increase in concentration of >400 mg/L over the source waters. No provision has been made allowing this violation of Forum policy.

(M-5A) The state and/or EPA is currently working to bring permittee into compliance.

(M-5B) Though discharge is >400 mg/L over source waters, in keeping with Forum policy the permittee has demonstrated the salt reduction is not practicable and the requirement has been waived.

(M-6) This permit requires no discharge or discharge only under rare and extreme hydrologic conditions. Thus, flow and concentration measurements are not required.

(M-7) Insufficient data to know the current status of this permit.

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* Permits that have been expired or revoked and listed with the M-1 and I-1 explanation codes shall be removed from the NPDES list during the subsequent triennial review.

INDUSTRIAL

(I) Industrial user in compliance with Forum policy.

(I-A) Industrial user in compliance with the Forum's salinity offset policy.

(I-B) Industrial user in compliance with the 1 ton per day or 366 tons per year provision for intermittent discharges.

(I-1)* Permit has expired or been revoked. No discharge.

(I-2) Permittee did not discharge during the reporting period.

(I-3) Measurement of TDS is not currently required, but the state and/or EPA plans to require measurements of both volume and concentration of outflow when the permit is reissued.

(I-4) Either concentration or volume of outflow are not currently being reported, thus the permittee is in violation of Forum policy. It is not known if the discharge is in excess of the <1.00 ton/day requirement.

(I-5) Permittee is in violation of Forum policy in that discharge of salts is >1.00 ton/day. No provision has been made allowing this violation of Forum policy.

(I-5A) The state and/or EPA is currently working to bring permittee into compliance.

(I-5B) Though discharge is >1.00 ton/day, in keeping with Forum policy the permittee has demonstrated the salt reduction is not practicable and the requirement has been waived.

(I-5C) The use of ground water under this permit is for geothermal energy and only heat is extracted. The intercepted salt and water are naturally tributary to the Colorado River System and hence, this discharge does not increase salt in the river. The permit is covered by the Forum's policy on intercepted ground waters.

(I-5D) This permit is in compliance with the Forum's policy for fish hatcheries. The use of the water is a one-time pass through, and the incremental increase in salinity is ≤ 100 mg/l.

(I-5E) This permit is for the interception and passage of ground waters and thus is excepted under the Forum's policy on intercepted ground waters.

(I-6) This permit requires no discharge or discharge only under rare and extreme hydrologic conditions. Thus, flow and concentration measurements are not required.

(I-7) Insufficient data to know the current status of this permit.

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LEGEND (continued)

NPDES PERMITS
REACH DEMARCATIONS

COLORADO RIVER BASIN SALINITY CONTROL FORUM

In order to provide a better understanding of the location of the various NPDES permits and the geographical sequence in the Colorado River System, each of the following NPDES permits is identified with a Colorado River reach number. The reach numbers have their origin in the old CRSS river model. Though this model is no longer used, the reach numbers assist in understanding the general location of the permits. The reaches are defined as:

100	Upper Main Stem	from headwaters of Colorado River to Colorado River near Cameo
190	Taylor Park	from headwaters of Gunnison River to above Blue Mesa Reservoir
200	Blue Mesa	from above Blue Mesa Reservoir to below Blue Mesa Dam
210	Morrow Point	from below Blue Mesa Dam to Crystal Reservoir
220	Lower Gunnison	from Crystal Reservoir to confluence with Colorado River
300	Grand Valley	from Colorado River near Cameo to confluence with Green River
310	Dolores River	from headwaters of Dolores River to confluence with Colorado River
401	Fontenelle	from headwaters of Green River to Green River near Green River, WY
411	Flaming Gorge	from Green River near Green River, WY to confluence with White and Duchesne Rivers
500	Yampa River	from headwaters of Yampa River to confluence with Green River
510	White River	from headwaters of White River to confluence with Green River
600	Green River	Green River from confluence with White and Duchesne Rivers to confluence with Colorado River
610	Duchesne River	from headwaters of Duchesne River to confluence with Green River
700	Lake Powell	Colorado River from confluence of with Green River to Lees Ferry
710	San Rafael River	from headwaters of San Rafael River to confluence with Green River
801	Upper San Juan River	from headwaters of San Juan River to San Juan near Bluff
802	Lower San Juan River	from San Juan near Bluff to confluence with Lake Powell
900	Glen Canyon to Lake Mead	Colorado River from Lees Ferry to backwaters of Lake Mead
905	Virgin River	from headwaters of Virgin River to backwaters of Lake Mead
910	Lake Mead	from backwaters of Lake Mead to Colorado River below Hoover Dam
920	Lake Mohave	Colorado River from below Hoover Dam down to I-40 bridge
930	Lake Havasu	Colorado River from I-40 bridge to below Parker Dam
940	Parker Dam to Imperial Dam	Colorado River from below Parker Dam to above Imperial Dam
945	Imperial Dam	Colorado River from above Imperial Dam to Gila and Yuma users

NMED Exhibit 90

NPDES PERMITS

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NPDES PERMIT#	REACH	NAME of Discharging Facility	TDS Conc. AVG.	Flow Rate AVG.	Salt Load Tons/Day	Explanation Code
Arizona						
AZ0025224	900	APACHE-SITGREAVES NATIONAL FOREST BLACK MESA			0.0000	M-1
AZ0026697	900	BISON RANCH	16.3	0.0196	0.0013	M-4B
AZ0024015	900	CANYON-VALLE AIRPORT WWTP			0.0000	M-2
AZ0025755	900	CITY OF WILLIAMS - WASTEWATER TREATMENT PLANT	221	0.39	0.3594	M-A
AZ0023639	900	FLAGSTAFF, CITY OF RIO DE FLAG POTW	372	0.85	1.3186	M-A
AZ0020427	900	FLAGSTAFF, CITY OF WILDCAT HILL POTW	446	2.56	4.7611	M-A
AZ0026263	900	HIGH COUNTRY PINES	549	0.005	0.0114	M-B
AZ0025542	900	HOLBROOK, CITY OF PAINTED MESA POTW			0.0000	M-2
AZ0026034	900	SNOWFLAKE, CITY OF POTW			0.0000	M-1
AZ0026719	900	TUSAYAN WASTEWATER RECLAMATION FACILITY	464	0.14	0.2709	M-B
AZ0026182	900	USBR/GLEN CANYON WWTP	1032	0.001	0.0043	M-B
AZ0026280	900	USBR/GLEN CANYON PPDS	464	0.17	0.3289	I
AZ0023612	900	USNPS/GRAND CANYON/ DESERT VIEW			0.0000	M-1
AZ0023621	900	USNPS/GRAND CANYON/INDIAN GARDENS	182	0.3	0.2277	I
AZ0110426	900	USNPS/GRAND CANYON/NORTH RIM	543	0.027	0.0611	M-B
AZ0024015	900	VALLE AIRPARK WASTEWATER RECLAMATION FACILITY			0.0000	M-2
AZ0022152	900	USNPS/GRAND CANYON/SOUTH RIM WWTP	513	0.15	0.3209	M-B
AZ0026310	900	WINSLOW, CITY OF POTW			0.0000	M-2
AZ0023655	905	VIRGIN RIVER DOMESTIC WASTEWATER IMP DISTRICT	825	0.028	0.0963	M-A
AZ0025160	910	USBR/HOOVER DAM	860	0.03	0.1076	M-B
AZ0000132	910	USFWS/WILLOW BEACH NATIONAL FISH HATCHERY	579	7.5	18.1082	I-5D
AZ0026808	920	BULLHEAD, CITY OF SECTION 10 WWTP			0.0000	M-2
AZ0110248	920	USBR/DAVIS DAM			0.0000	I-1
AZ0023990	930	CAWCD-HAVASU PUMPING PLANT	573	0.77	1.8398	I-5
AZ0026018	930	KINGMAN, CITY OF DOWNTOWN POTW	572	0.23	0.5486	M-B
AZ0022756	930	PETRO STOP CENTER/KINGMAN	610	0.0260	0.0661	M-B
AZ0022268	930	FREEPORT-McMoRan BAGDAD Inc.			0.0000	I-3
AZ0023752	940	QUARTZSITE, CITY OF POTW	1348	0.17	0.9556	M-B
Colorado						
CO0000003	220	Ouray Silver Mine	224.4	0.567	0.530	I-B
CO0000010	510	Rangely WWTF	633.7	0.148	0.391	M-A
CO0000012	300	Palisade WWTF Brentwood Dr	377.9	0.181	0.285	M-A
CO0000051	100	Iles Dome Unit Production	1369.3	0.637	3.639	I-5
CO0000132	220	Sanborn Creek and Elk Creek Coal Mines	0.0		0.000	I-2
CO0000213	310	New Horizon Mine	224.2	0.655	0.612	I-B
CO0020699	100	Granby Sanitation District WWTF		0.379	0.000	M-7
CO0020826	100	Blue River WWTF	558.6	1.164	2.712	M-A
CO0020834	500	Steamboat Springs WWTF	362.7	2.693	4.073	M-4B
CO0020907	220	Olathe WWTF	2123.1	0.134	1.190	M-5B
CO0021369	100	Vail WWTF	432.2	1.237	2.230	M-A
CO0021385	100	Red Cliff WWTF	328.3	0.032	0.044	M-A
CO0021539	100	Farmers Korner WWTF	380.3	1.915	3.037	M-A
CO0021598	100	Copper Mtn Cons Metro Dist WWTF	351.9	0.210	0.308	M-A
CO0022756	190	Pitch Reclamation Project	836.3	0.404	1.407	I-5B
CO0022969	500	Morrison Creek Metro Water and San Dist WWTF	77373.1	0.053	17.083	M-5
CO0023086	100	Snowmass Water and San Dist	233.7	0.737	0.718	M-A
CO0023485	300	Grand Mesa Metro Dist 2 WWTF	237.3	0.008	0.008	M-A
CO0023876	100	Arapahoe Basin Ski Area	969.8	0.008	0.030	M-5/M-B
CO0024007	310	Naturita WWTF	572.2	0.026	0.061	M-A
CO0024431	100	Avon WWTF			0.000	M-2
CO0026051	100	Winter Park Water and San Dist WWTF		0.157	0.000	M-7
CO0000221	500	Seneca Mine Complex	2565.1	0.093	1.000	I-B
CO0026387	100	Aspen Consolidated San Dist WWTF	610.4	1.304	3.319	M-A
CO0027146	300	Roadside North and South Mines	1235.0	0.167	0.859	I-B
CO0027154	500	Mines 1 and 2 And Eckman Park Mine	4271.8	0.257	4.578	I-5B
CO0027171	190	Mt Crested Butte Water and San Dist WWTF	242.1	0.287	0.290	M-A
CO0029955	100	Summit County Snake River WWTF	307.0	0.571	0.731	M-A
CO0030449	220	West Montrose San Dist WWTF	487.0	0.317	0.645	M-A

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CO0030635	500	Yampa WWTF	350.5	0.031	0.046	M-A
CO0031062	500	Steamboat Mountain School WWTF	390.0	0.003	0.005	M-A
CO0031984	220	Cedaredge WWTF		0.144	0.000	M-7
CO0032115	500	Trapper Mine		0.128	0.000	I-4
CO0033791	300	Clifton Regional WWTF	557.7	0.950	2.209	M-A
CO0034142	500	Williams Fork Mine	1825.0	0.018	0.133	I-B
CO0035394	190	Mt Emmons Project	821.5	0.407	1.393	I-5
CO0035556	500	Steamboat Lake WSD WWTF	462.7	0.034	0.065	M-A
CO0036251	310	Jd 7 And Jd 9 Mines			0.000	I-2
CO0036684	500	Fish Creek Tipple	3567.6	0.018	0.274	I-B
CO0037206	220	Ruby Trust Mine	297.0	0.531	0.657	I-B
CO0037311	100	Edwards WWTF	647.3	1.009	2.723	M-A
CO0037681	100	Table Mountain WWTF	315.6	0.384	0.506	M-A
CO0037729	220	Crawford WWTF	312.5	0.024	0.031	M-A
CO0038024	510	Deserado Mine	3158.3	0.153	2.016	I-5
CO0038342	300	McClane Canyon Mine		0.072	0.000	I-4
CO0038598	100	Sunlight WWTF	590.3	0.006	0.015	I-B
CO0038776	220	West Elk Mine		0.015	0.000	I-4
CO0039624	220	Montrose WWTP	851.7	2.111	7.498	M-5
CO0039641	220	Delta WWTF	1171.2	0.933	4.558	M-5
CO0040037	500	Craig WWTF	805.6	0.793	2.665	M-5
CO0040053	300	Persigo WWTF	772.3	8.860	28.535	M-5
CO0040142	100	Upper Fraser Valley Treatment Plant		0.668	0.000	M-7
CO0040487	300	Valleywide Sewerage System	744.3	0.043	2.066	M-A
CO0040673	190	Lake City WWTF	340.2	0.087	0.124	M-A
CO0040959	500	Hayden Town of	549.6	0.179	0.411	M-A
CO0041106	500	Oak Creek WWTF	484.8	0.112	0.227	M-A
CO0041530	190	Gunnison WWTF	396.4	1.040	1.719	M-A
CO0042161	500	Foidel Creek Mine	4021.0	0.210	3.529	I-5
CO0042447	100	Rifle Station	1806.9	0.028	0.212	I-B
CO0042480	100	Eagle Mine Remediation	2968.3	0.378	4.674	I-5B
CO0042617	220	Horizon Health Care and Retirement Community WWTF	343.3	0.006	0.009	M-A
CO0043397	220	Ouray WWTF	594.8	0.159	0.394	M-A
CO0044750	100	Roaring Fork Water and San Dist WWTF	753.0	0.063	0.199	M-A
CO0044776	220	Bowie No 2 Mine			0.000	I-2
CO0044903	220	Hotchkiss WWTF	963.5		0.000	M-2
CO0045161	500	Colowyo Mine	3126.2	0.101	1.311	I-5
CO0045217	220	Irwin Mountain Lodge			0.000	M-2
CO0045411	100	Crooked Creek Ranch	1327.4	0.004	0.021	M-5/M-B
CO0045420	100	Iowa Hill Water Reclamation Facility			0.000	M-2
CO0045501	100	Tabernash Meadows Water and San Dist WWTF		0.045	0.000	M-7
CO0045802	100	Oak Meadows WWTF	789.1	0.019	0.062	M-A
CO0046124	100	Spring Valley San Dist WWTF	766.9	0.039	0.126	M-4A
CO0046175	100	Gilsonite Refinery Sand and Gravel Facility			0.000	I-2
CO0046370	100	Redstone Water and San District WWTF	361.8	0.019	0.029	M-A
CO0046566	100	Devils Thumb Ranch	464.8	0.010	0.020	M-A
CO0000230	100	Henderson Mill			0.000	I-2
CO0047139	510	Meeker San Dist WWTF	798.9	0.111	0.371	M-5/M-B
CO0047431	220	Paonia WWTF	754.2	0.129	0.404	M-5/M-B
CO0047449	500	Milner Community WWTF	691.1	0.015	0.042	M-A
CO0047562	300	Whirlwind Project			0.000	I-2
CO0048119	190	Golden Wonder Mine	1214.5	0.003	0.014	I-B
CO0048135	300	De Beque WWTF	898.8	0.028	0.104	M-A
CO0048143	300	Mesa WSD WWTF	702.7	0.007	0.019	M-A
CO0048151	100	Rifle Regional WW Reclamation Facility	1108.0	0.748	3.458	M-5
CO0048233	100	Minrec North Thompson Ponds			0.000	I-2
CO0048241	100	Eagle WWTF	732.2	0.491	1.500	M-A
CO0048275	500	Peabody Sage Creek Mine	4329.8	0.089	1.602	I-5B
CO0048437	100	Kremmling WWTF	282.6	0.138	0.163	M-A
CO0048577	100	Iron Mountain Hot Springs		0.456	0.000	I-4
CO0048623	500	Sidney Peak Ranch Barn Spring	2050.0	0.011	0.093	I-B

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CO0048815	100	South Canyon Landfill			0.000	I-2
CO0048823	100	Avalanche Ranch	1520.6	0.122	0.775	I-B
CO0048830	100	Gypsum WWTF	414.7	0.539	0.932	M-A
CO0048847	300	PWI #535	840.5	0.002	0.007	I-B
CO0048852	100	Glenwood Springs Reg WWTF		0.935	0.000	M-7
CO0048854	100	Fruita WRF	624.2	0.906	2.357	M-A
CO0048873	220	Somerset Central WTF			0.000	M-2
CO0048900	190	Bear Ranch WWTF1 and WWTF2	417.7	0.001	0.001	M-A
CO0048901	100	Eagle Valley Clean Energy	2803.6	0.214	11.691	I-5
CO0000248	100	Climax Mine	1033.5	15.558	67.052	I-5B
CO0048945	310	Nucla WWTF	1116.6	0.100	0.464	M-5/M-B
CO0048952	100	Lib 4	242.1	0.166	0.167	I-B
CO0048958	100	Glenwood Hot Spgs Lodge and Pool		2.804	0.000	I-4
CO0048972	100	Coal Ridge 1 Underground Mine			0.000	I-2
CO0048983	220	Ouray Hot Springs Pool	13513.7	0.129	7.251	I-5
CO0048999	500	Old Town Hot Springs	940.0	0.281	1.103	I-5
CO0049022	100	CR 5001 WWTF	156.0	0.003	0.002	M-A
CO0049023	190	Upper Gold Links Mine			0.000	I-2
CO0049024	190	Sacramento Access Tunnel			0.000	I-2
CO0049026	100	Mid Valley Metro Dist WWTF	418.3	0.361	0.630	M-A
CO0049036	100	Frost Creek Clubhouse WWTF			0.000	M-2
CO0049041	190	Boullion King Mine			0.000	I-2
CO0049045	220	Bowie No 1 Mine			0.000	I-2
CO0049047	100	C Lazy U Ranch WWTF			0.000	I-2
COG130001	100	Crystal River State Fish Hatchery	350.2	5.267	7.691	I-5
COG130004	190	Pitkin State Fish Hatchery	110.1	3.243	1.488	I-5
COG130006	190	Roaring Judy State Fish Hatchery	183.4	4.362	3.336	I-5
COG130007	500	Finger Rock State Fish Hatchery	158.0	1.667	1.098	I-5
COG130011	100	Rifle Falls State Fish Hatchery		5.644	0.000	I-4
COG315481	510	A27 CDP Liquids Line Release Remediation Project	730.9	40.750	124.200	I-5
COG315592	100	Vail Health - Dillon Medical Building	1028.3	13.261	56.862	I-5
COG315607	100	Aspen City Offices	186.5	763.000	593.389	I-5
COG317084	100	Snowmass Building 12 Aura		0.116	0.000	I-4
CO0000540	310	Nucla Station	387.0	0.070	0.112	I-B
COG318043	100	Ritz Carlton Residences and Club at Vail	515.1			I-4
COG318057	100	Keystone Lodge and Argentine Condos	155.5	0.031	0.020	I-B
COG318058	100	Red Hawk Lodge	162.4	0.511	0.346	I-B
COG318062	100	Solaris	1022.4	0.506	2.156	I-5
COG318064	100	Lion The	1037.6		0.000	I-4
COG318065	100	Manor Vail Resort	681.2	0.768	2.181	I-5
COG318074	100	Bank of the West GJ	6660.5	0.000	0.001	I-B
COG318077	100	Springs Lodge	165.0	0.089	0.061	I-B
COG318079	100	Arrabelle Hotel	742.4		0.000	I-4
COG318096	220	Town of Hotchkiss Drain Seep Line	1364.9	0.024	0.139	I-B
COG318104	100	Dillon Medical Office Building	889.2	0.000	0.000	I-B
COG500001	500	Bunn Ranch Pit			0.000	I-2
COG500003	300	Latham Burkett Pit	3235.0	0.170	2.296	I-5
COG500010	190	Gunnison Pit	399.6	0.194	0.324	I-B
COG500062	500	Williams Fork Pit			0.000	I-2
COG500088	100	Eagle West Pit	1319.3	0.510	2.808	I-5
COG500114	100	Silt Pit			0.000	I-2
COG500119	100	Chambers Pit	1566.7	0.199	1.299	I-5
COG500127	220	Whitewater Pit No 500	1160.8	1.188	5.751	I-5
COG500161	100	South Fruita Pit			0.000	I-2
COG500210	220	Mule Farm Gravel Pit			0.000	I-2
COG500216	100	River Road Pit	4221.1	0.425	7.474	I-5
COG500225	510	Blair Mesa Pit			0.000	I-2
COG500229	100	West Rifle Pit			0.000	I-2
COG500243	500	Hogue River Pit	410.1	0.474	0.811	I-B
COG500252	100	Loesch Pit			0.000	I-2
COG500263	100	Orchard Grove Industrial Park 23 1/4 Road Pit	3997.2	0.249	4.157	I-5

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COG500267	100	Sievers Ranch Pit	376.1	0.179	0.280	I-B
COG500299	100	Railhead Gravel Pit		0.371	0.000	I-4
COG500308	300	Feuerborn Gravel Pit			0.000	I-2
COG500312	500	Mesa Gravel Pit			0.000	I-2
COG500342	100	Gypsum Ranch Pit			0.000	I-2
COG500348	100	23 Road Pit			0.000	I-2
COG500350	500	Tellier Pit	617.3	0.025	0.064	I-B
COG500356	100	Yule Marble Quarry			0.000	I-2
COG500364	100	Soaring Eagle Gravel Pit			0.000	I-2
COG500380	100	Monument View Gravel Pit			0.000	I-2
COG500396	500	Camilletti Milner Pit 2	337.9	0.748	1.054	I-5
COG500408	100	Mamm Creek Gravel Pit			0.000	I-2
COG500419	500	Deakins Pit	2087.4	0.483	4.207	I-5
COG500420	190	Sea Horse 2 Pit	257.1	1.583	1.698	I-5
COG500429	300	De Beque Gravel Pit			0.000	I-2
COG500433	100	Maryland Creek Ranch Pit			0.000	I-2
COG500435	300	D Road Gravel Pit	3714.8	1.188	18.403	I-5
COG500437	100	15 Road Pit	3211.1	0.786	10.525	I-5
COG500439	220	Bennett Gravel Pit	1600.0	0.545	3.636	I-5
COG500444	220	Delta Paving Pit			0.000	I-2
COG500464	220	Anderson Pit	1132.5	3.066	14.478	I-5
COG500467	100	Glens Pit	1360.9	0.135	0.768	I-B
COG500482	100	North Bank Pit	1018.9	0.731	3.106	I-5
COG500484	510	White River City Pit	1310.0	0.315	1.721	I-5
COG500491	100	20 Road Gravel Pit			0.000	I-2
COG500498	220	Tri County Pit	1875.0	0.428	3.347	I-5
COG501505	300	Una Pit	1050.0	0.930	4.072	I-5
COG501510	100	Scott Pit			0.000	I-2
COG501513	300	32 Rd Gravel Pit			0.000	I-2
COG501517	510	Flintstone Piceance Pit			0.000	I-2
COG501522	500	Lyster Pit	1879.3	0.090	0.705	I-B
COG501524	500	Wand Pit			0.000	I-2
COG501525	500	Gehrman Pit	418.0	0.352	0.614	I-B
COG501528	500	Frentress Gravel Pit			0.000	I-2
COG501532	220	Gunnison River Gravel Pit 5		0.624	0.000	I-4
COG501534	500	Steamboat Sand and Gravel Fisker Trail	214.1		0.000	I-4
COG501542	300	De Beque Pit No 2	2630.0	0.192	2.106	I-5
COG501545	220	Warren Gravel Pit			0.000	I-2
COG501559	220	Uncompahgre Pit			0.000	I-2
COG501567	300	Otter Creek Pit	6432.5	0.183	4.901	I-5
COG501615	220	North R 34 Pit			0.000	I-2
COG501617	300	5 Mile Pit			0.000	I-2
COG502149	500	Bear River Sand and Gravel			0.000	I-2
COG588006	100	Riverbend Subdivision	1310.0	0.012	0.064	M-A
COG588008	100	West Glenwood Springs San Dist	355.9	0.286	0.424	M-A
COG588012	190	Almont WWTF	397.8	0.014	0.023	M-A
COG588029	100	El Rocko MHP	498.6	0.005	0.010	M-A
COG588032	220	Delta Correctional Center	451.6	0.011	0.021	M-A
COG588035	100	H Lazy F MHP WWTF	686.3	0.014	0.040	M-A
COG588041	100	Ouray Ranch	201.2	0.008	0.006	M-A
COG588045	190	Crested Butte South Metro Dist WWTF	340.4	0.080	0.113	M-A
COG588046	100	Silt WWTF	776.7	0.226	0.733	M-A
COG588047	220	Ridgway WWTF	573.4	0.077	0.185	M-A
COG588049	100	Lazy Glen	332.0	0.026	0.036	M-A
COG588050	100	Carbondale WWTF	337.4	0.509	0.716	M-A
COG588051	801	Dillon Medical Office Building	318.9	0.047	0.062	M-A
COG588052	190	L and N WWTF	625.0	0.004	0.011	M-A
COG588061	100	Talbott Enterprises	1353.1	0.071	0.403	M-A
COG588062	100	New Castle WWTF 6 St	758.5	0.263	0.831	M-5/M-B
COG588063	100	Basalt San Dist WWTF	285.3	0.430	0.512	M-A
COG588066	100	Riversbend Apartments	669.4	0.001	0.003	M-A

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COG588067	100	Grizzly Creek Rest Area WWTF	1937.6	0.001	0.005	M-5/M-B
COG588070	100	Two Rivers Village Metro Dist WWTF	461.3	0.039	0.075	M-A
COG588072	100	C Lazy U Ranch WWTF	342.0	0.006	0.009	M-A
COG588074	100	Blue Creek Ranch WWTF	764.4	0.013	0.042	M-5/M-B
COG588075	100	Bair Ranch Rest Area	2187.6	0.001	0.010	M-5/M-B
COG588076	100	Hanging Lake Rest Area WWTF	979.5	0.001	0.004	M-5/M-B
COG588079	100	East River Regional San Dist WWTF	407.3	0.041	0.070	M-A
COG588083	100	Rock Gardens PUD	457.6	0.003	0.007	M-A
COG588084	100	Hot Sulphur Springs WWTF	382.1	0.055	0.087	M-A
COG588085	100	Aspen Village WWTF	367.3	0.031	0.047	M-A
COG588086	300	SW Mesa Co Rural Pub Imp Dist WWTF	969.5	0.015	0.060	M-5/M-B
COG588103	100	Woody Creek MHP	279.5	0.018	0.021	M-A
COG588109	190	Ute Trail Ranch	446.1	0.002	0.003	M-A
COG588112	190	Camp Gunnison Church Camp	387.1	0.003	0.005	M-A
COG588116	100	Roundup River Ranch WWTF	874.1	0.001	0.004	M-A
COG588123	190	SCS Generational Properties			0.000	M-2
COG588132	190	Vickers Horse River Ranch	469.3	0.001	0.002	M-A
COG588138	190	Taylor River Canyon LLC	561.5	0.001	0.002	M-5/M-B
COG588141	500	Phippsburg WWTF Routt County	597.5	0.011	0.027	M-4A
COG588147	100	River Dance RV Park	776.8	0.001	0.003	M-A
COG589040	500	Maybell WWTF			0.000	M-2
COG589086	300	Battlement Mesa Metro District WWTF	741.1	0.335	1.036	M-A
COG589091	220	Elk Meadows	561.3	0.003	0.007	M-A
CO0020443	190	Crested Butte WWTF		0.172	0.000	M-7
COG589110	100	Wastewater Treatment Svc WWTF	909.6	0.045	0.170	M-A
COG589139	100	Canyon Creek Estates	779.5	0.012	0.039	M-A
COG589146	500	Timbers WSD WWTF	208.0	0.009	0.008	M-A
COG589147	500	Steamboat Mountain School WWTF	338.0	0.005	0.007	M-A
COG589148	100	C Lazy U Ranch WWTF	363.1	0.006	0.010	M-A
COG589158	100	River Dance RV Park			0.000	M-2
COG589159	500	Oak Creek WWTF	566.0	0.111	0.262	M-4A
COG589170	190	Crested Butte South Metro Dist WWTF			0.000	M-2
COG589190	190	East River Regional San Dist WWTF		0.269	0.000	M-7
COG590008	100	West Glenwood Springs San Dist	368.3	0.269	0.412	M-A
COG590012	190	Almont WWTF	402.7	0.011	0.018	M-A
COG590029	100	El Rocko MHP	511.3	0.002	0.005	M-A
COG590035	100	H Lazy F MHP WWTF	667.0	0.013	0.036	M-A
COG590050	100	Carbondale WWTF	325.5	0.472	0.640	M-A
COG590052	190	L and N WWTF	600.7	0.008	0.019	M-A
COG590062	100	New Castle WWTF 6 St	745.0	0.310	0.964	M-5/M-B
COG590066	100	Riversbend Apartments	890.8	0.001	0.004	M-A
COG590067	100	Grizzly Creek Rest Area WWTF	2680.0	0.001	0.007	M-5/M-B
COG590070	100	Two Rivers Village Metro Dist WWTF	648.0	0.041	0.111	M-A
COG590074	100	Blue Creek Ranch WWTF	749.2	0.009	0.027	M-5/M-B
COG590075	100	Bair Ranch Rest Area	1705.6	0.001	0.006	M-5/M-B
COG590076	100	Hanging Lake Rest Area WWTF	1029.3	0.001	0.004	M-5/M-B
COG590084	100	Hot Sulphur Springs WWTF	363.5	0.048	0.072	M-A
COG590109	190	Ute Trail Ranch	449.2	0.002	0.004	M-A
COG590132	190	Vickers Horse River Ranch	710.0	0.002	0.005	M-A
COG590138	190	Taylor River Canyon LLC			0.000	M-2
COG603008	100	Founders Garage Eagle	511.8		0.000	I-4
COG603009	220	Montrose WWTP			0.000	I-2
COG603022	100	Fidelity Mtge			0.000	I-2
COG603031	100	Parking Garage Pitkin Co	549.5		0.000	I-4
COG603041	500	Howelsen Place			0.000	I-2
COG603045	500	Lake Catamount WWTF	242.5		0.000	I-4
COG603050	100	Little Nell Well City Well 4	319.0		0.000	I-4
COG603117	100	Frisco Sanitation District WWTP	262.3		0.000	I-4
COG603127	100	Ritz Carlton Residences and Club at Vail			0.000	I-2
COG603128	500	Trailhead Lodge Steamboat			0.000	I-2
COG603151	100	Arrabelle Hotel	634.0		0.000	I-4

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COG603155	100	Solaris	1018.8		0.000	I-4
COG603170	100	Fraser Crossing Founders Pointe			0.000	I-2
COG603205	100	Passport Parking Garage Vail	563.7		0.000	I-4
COG603219	100	Springs Lodge	145.0		0.000	I-4
COG603220	100	Keystone Lodge and Argentine Condos	114.6		0.000	I-4
COG603222	100	Manor Vail Resort	742.3		0.000	I-4
COG603223	100	Red Hawk Lodge	138.6		0.000	I-4
COG603260	300	Bank of the West GJ	7467.2		0.000	I-4
COG603285	220	Town of Hotchkiss Drain Seep Line	1225.1		0.000	I-4
COG603295	100	Lion The	997.3		0.000	I-4
COG603333	100	Residences at the Little Nell	320.0		0.000	I-4
COG603370	100	Fraser Town of Well 8			0.000	I-2
COG603373	510	Meeker Water Supply Improvements			0.000	I-2
COG603380	300	Corner Square Building 3	2177.7		0.000	I-4
COG603393	100	Vail Health East Wing Ph II	241.5		0.000	I-4
COG603394	100	Goose Pasture Tarn Dam			0.000	I-1
COG605009	100	Covered Bridge Building	311.0	0.095	0.123	I-B
COG605015	100	Main St Station Breckenridge		0.127	0.000	I-4
COG608005	500	Lake Catamount WWTF	239.3	0.002	0.002	I-B
COG641006	100	Dillon Straight Creek WTP	200.7	0.180	0.150	I-B
COG641015	220	Cedaredge WTP	95.8	0.005	0.002	I-B
COG641019	100	Hot Sulphur Springs WTP	191.7	0.025	0.020	I-B
COG641027	100	Nettle Creek WTF			0.000	I-2
COG641031	100	Brush Creek WTP			0.000	I-2
COG641037	300	Palisade WTF and Tank			0.000	I-2
COG641044	100	Big Mac Water Treatment Plant		0.012	0.000	I-4
COG641052	100	Red Mountain WTF			0.000	I-2
COG641058	100	Upper Eagle Regional WTR Auth			0.000	I-2
COG641066	100	Castle Creek WTP	351.2	0.031	0.045	I-B
COG641067	100	Wayne Bristol WTF	72.4	0.014	0.004	I-B
COG641068	300	Battlement Mesa Metro District WTP	389.5	0.867	1.407	I-5
COG641072	100	Gateway Mesa WTP	672.2	0.003	0.009	I-B
COG641081	220	Orchard City WTP	66.9	0.549	0.153	I-B
COG641087	100	Little Mac WTF		0.004	0.000	I-4
COG641091	220	Hotchkiss WTF			0.000	I-2
COG641092	100	New Castle WTF	266.4	0.070	0.077	I-B
COG641094	100	Roaring Fork WTP			0.000	I-2
COG641095	100	Basalt Springs WTF	92.5	0.004	0.001	I-B
COG641104	220	Spaulding Peak Treatment Plant	95.2	0.034	0.014	I-B
COG641105	100	Edwards Drinking Water Facility	202.7	0.007	0.006	I-B
COG641111	310	Mustang WTF			0.000	I-2
COG641112	100	Silt WTF	565.9	0.248	0.586	I-B
COG641114	100	Mosher Plant	166.1	0.245	0.169	I-B
CO0020451	100	Frisco Sanitation District WWTP	415.8	0.577	1.000	M-4B
COG641134	220	Paonia WTP aka Lower Plant			0.000	I-2
COG641135	100	Red Sky Ranch WTP	605.0	0.013	0.034	I-B
COG641154	100	Hamilton Creek Metropolitan District		0.058	0.000	I-4
COG641170	190	Dos Rios WTF			0.000	I-2
COG641181	100	Peak 9 Water Plant	56.3	0.058	0.014	I-B
COG641195	100	Granby South Service Area WTP			0.000	I-2
COG641200	100	Eagle Lower Basin Water Treatment Plant			0.000	I-2
COG641201	100	No Name Cave System		0.240	0.000	I-4
COG840002	100	Greenback Shaeffer Ranch Facility			0.000	I-2
COG840015	100	Parachute Treatment Facility			0.000	I-2
COG850008	500	Hayden Gulch Loadout			0.000	I-2
COG850028	220	Terror Creek Loadout			0.000	I-2
COG850043	220	Bowie No 1 Mine			0.000	I-2
COG850051	500	Peabody Twentymile 6 Main N Shaft			0.000	I-2
COG850054	500	Foidel Creek Mine			0.000	I-2
COG850062	310	New Horizon North Mine			0.000	I-2

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Nevada						
NV0000060	910	Titanium Metals Corporation	636.7	1.370	3.637	I-7
NV0020133	910	City of Las Vegas Water Pollution Control Facility	998.9	45.300	188.693	M-A
NV0020192	910	NDOW - Lake Mead Fish Hatchery				I - 5D
NV0021261	910	Flamingo Water Resource Center (formerly Clark County Water	1065.4	107.700	478.481	M-A
NV0021563	920	Laughlin Water Reclamation Facility (formerly Clark County Wat	1067.2	1.478	6.577	M-A
NV0021750	910	Wastegate Las Vegas Resort and Casino (formerly Las Vegas Hilt	687	0.003	0.010	I
NV0021911	910	Las Vegas Valley MS4				I-7
NV0022098	910	Kurt R. Segler Water Reclamation Facility - City of Henderson	1096.8	14.364	65.696	M-A
NV0022195	910	Valley Hospital Medical Center		0.005		I-5E
NV0022691	910	Lake Las Vegas Resort (Dam)				I-2
NV0022772	910	Sterling/Squire/Crescendo HOA (formerly Saxton)	5148.5	0.324	6.956	I-5E
NV0022781	910	Shanghai Partners - Tomiyasu Residence	500.0	0.100	0.209	I
NV0022870	910	7-Eleven Store # 19653				I-2
NV0022888	910	Las Vegas Sands-Venetian Casino Resort	1454.0	0.118	0.715	I
NV0022942	910	Lloyd D. George Federal Courthouse	6475.0	0.019	0.513	I
NV0022985	910	Planet Hollywood Resort Casino (formerly Aladdin Resort)				I-2
NV0022993	910	Golden Nugget Hotel and Casino	404.0	0.000	0.000	I-5E
NV0023043	910	Maryland Villas Apartment Complex	1600.0	0.001	0.007	I
NV0023060	910	Nevada Environmental Response Trust (formerly Tronox LLC)	4050.0	1.694	28.609	I-5E
NV0023159	910	Clark County Regional Justice Center	1255.3	0.006	0.031	I
NV0023191	910	Caesar's Palace Hotel and Casino	1991.1	0.044	0.365	I
NV0023221	910	7-Eleven Store # 27607				I-2
NV0023256	910	The Stirling Club	2233.3	0.026	0.242	I
NV0023477	910	Sky Las Vegas Master Association	1735.0	0.001	0.007	I
NV0023485	910	Las Vegas Academy				I-2
NV0023515	910	The Cosmopolitan of Las Vegas (formerly The Cosmopolitan Res	1675.0	0.023	0.161	I
NV0023558	910	The Martin (formerly Panorama Towers)	1763.8	0.001	0.007	I
NV0023566	910	Fountainbleau Casino and Resort	2475.0	0.162	1.672	I-5E
NV0023604	910	Howard Hughes (formerly Howard Hughes Office Complex)	1743.3	0.000	0.000	I-5E
NV0023621	910	Resorts World Las Vega (formerly Echelon Resort)	1750.0	0.145	1.058	I-5E
NV0023647	910	City of North Las Vegas Water Reclamation Facility	933.0	18.467	71.848	M-A
NV0023663	910	Former Conoco Station No. 28003	1596.7	0.002	0.013	I
NV0023701	910	CityCenter (formerly City Center Land)	2281.3	0.152	1.446	I-5E
NV0023736	910	Bowman Reservoir & Muddy River Outfalls				I-2
NV0023744	910	Four Points Sheraton (formerly Baymont Inn and Suites)		0.010	0.000	I-5E
NV0023761	910	McCarran International Airport	1337.5	0.026	0.145	I
NV0023809	910	Terrible Herbst #225	0.0	0.0000	0.000	I
NV0023841	910	Hudson Cleaners	1887.5	0.0147	0.116	I
NV0023931	910	Mendenhall Center - UNLV	2793.0	0.0040	0.047	I
NV0024104	910	LVVWD/SNWA Operations and Maintenance		1.1325	0.000	M-7
NV0024112	910	Endeavour, LLC - AGTS (formerly American Pacific Corp AGTS)	2325.0	0.9788	9.490	I-7
NV0024121	910	City of North Las Vegas Utilities Water System O&M	561.9	0.4227	0.990	M
NV0024139	910	City of Henderson Water Systems and Facilities		0.1584	0.000	M-7
NV0024201	910	STATEWIDE VAULT MAINTENANCE DEWATERING	0.0	0.0000	0.000	I-7
NV0024202	910	Sunset Regional Park Splash Pad	506.0	0.0904	0.191	I
NV0024220	910	VILLAGE SHOP #4/SINCLAIR STATION	1203	0.0012	0.006	I
NV0024227	910	Former PJs Cleaners	2986.7	0.0181	0.225	I
NV0024232	910	Las Vegas Convention and Visitors Authority Remediation Syste	2489.5	0.1676	1.740	I-5E
NV0024235	910	TBC - The Boring Company				I-2
NV0024239	910	Allegiant Stadium	1616.5	0.0166	0.112	I
NV0024240	910	Whitney Channel Replacement	4665.0	0.1837	3.574	I-5E
NV0024242	910	Clark County Public Works				I-2
New Mexico*						
NM0028762	801	Aztec, City of / WTP	407.5	0.1625	0.1614	I
NM0020168	801	Aztec, City of / WWTP	253	0.584	0.61	M
NM0020770	801	Bloomfield, City of / WWTP	315	0.85	1.11	M
NM0031135	801	Farmington Electric Utility System (FEUS)-Bluff View	NA	NA	2000	I

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NM0020583	801	Farmington WWTP	420.54	5.15	9.03	M-5A
NM0030953	801	Navajo Dam DWC & NSW, Inc	0	0	0	I-2
NM0031194	801	US BOR Cutter Lateral Water Treatment Plant	0	0	0.00	I-2
NM0024163		Reserve, Village of WWTP				
NM0029505	801	Westmoreland San Juan Mining LLC - La Plata	0	0	0	I-3
NM0028746	801	Wesmoreland San Juan Mine LLC - San Juan	0	0	4000	I
NM0020672	900	Gallup WWTP	NA	2.25	9.97	M-4A
NM0023396	900	Ramah Water & Sanitation Dist.	580	0.03	0.045	M-5
NM0031229	801	USBOR San Juan Lateral WTP	388	0.132	0.2136	I
***Permits in New Mexico are issued by the U.S. EPA and certified by the State of New Mexico Environmental Department.**						
Utah						
UT0025828	300	Courthouse Wash Water	-	0.03	0.182	I
UT0025712	300	Energy Queen Mine	-	-	-	I-2
UT0026166	300	Red Cliffs Lodge	-	-	-	M-2
UT0020419	300	Moab, City of	405	1.07	1.81	M-A
UT0023922	300	Rim Mine	-	-	-	I-2
UT0025810	300	Velvet Mine	-	-	-	I-2
UTG640027	411	Ashely Valley WTP	-	-	-	M-6
UTG640003	411	Ashley Springs WTP	-	-	-	M-6
UT0025348	411	Ashley Valley Water & Sewer, Mechanical	481	2.58	5.19	M-4B
UTG640014	411	Dutch John WTP	-	-	-	M-6
UT0000035	411	Ashley Valley Operating	1196	0.73	3.63	I-A
UT0024015	411	Intermountain Concrete	119.3	0.01	0.005	I-B
UTG640023	411	Manilla WTP	-	-	-	M-6
UT0020338	411	USBOR-Flaming Gorge Dam	785	0.0014	0.005	M
UTG130001	411	USFWS-Jones Hole Fish Hatchery	164	7.06	4.83	I-5D
UTG040007	600	Coal Energy Group-Wildcat Loadout	-	-	-	I-2
UTG040011	600	Canyon Fuel Co.- Banning Loadout	-	-	-	I-2
UT0025593	600	Canyon Fuel Co.- Dugout Mine	736	0.325	0.995	I-A
UT0023540	600	Canyon Fuel Co.- Skyline Mine	561	5.185	12.13	I-A
UT0023680	600	Canyon Fuel Co.-Soldier Creek Coal	-	-	-	I-2
UTG040030	600	Coal Energy Group-Kinney No. 2 Mine	-	0	0	I-1
UTG640012	600	E. Carbon City-Sunnyside CWTP	-	-	-	M-6
UTG640017	600	Green River WTP	-	-	-	M-6
UT0025771	600	Green River, City of	4720	0.52	10.1	M-B
UT0023094	600	Hiawatha Coal Company	750	0.184	0.575	I-B
UT0026018	600	Lila Canyon Mine	1606	36.74	8.93	I-A
UTG040024	600	Lila Canyon Mine	-	0	0	I-1
UTG040010	600	Price River Terminal/Wellington Coal Prep Plant	-	-	-	I-2
UTG640035	600	Price City WTP	-	-	-	M-6
UT0021814	600	Price River Water Imp. Dist.	1068	1.43	6.37	M-A
UTG640034	600	Price River WID	-	-	-	M-6
UTG040005	600	Savage Industries Coal Terminal (CV-Spur)	-	-	-	I-2
UTG040025	600	Star Point Coal Refuse Pile (Sunnyside Cogen)	-	-	-	I-2
UT0024759	600	Sunnyside Cogeneration Plant	-	-	-	I-2
UTG040029	600	Andalex Tower Mine	-	-	-	I-2
UT0025640	600	West Ridge Mine	-	-	-	I-2
UT0020095	610	Duchesne City Corp.	-	0	0	M-2
UT0025801	610	Duchesne Valley WTP	375.1	0.25	0.289	I
UTG640008	610	Myton Community Water System	-	-	-	M-6
UT0023001	610	Neola Town Water & Sewer Assoc.	-	0	0	M-2
UTG640002	610	Tridell-Lapoint Water WTP	-	-	-	M-6
UTG130012	610	UDWR-Whiterocks Fish Hatchery	249	5.05	5.25	I-5D
UT0022918	700	Canyon Fuel Co.- SUFCo Mine	875	3.97	14.5	I-A
UT0025798	700	Capital Reef National Park	-	-	-	I-2
UTG040026	700	Bronco Utah Operations-Hidden Valley Mine	-	-	-	I-2
UT0022616	700	Bronco Utah Operations-Emery Deep Mine	1445	0.693	4.175	I-5B
UTG130003	700	UDWR-Egan/Bicknell Fish Hatchery	131	8.75	4.77	I-5D
UTG130007	700	UDWR-Loa Fish Hatchery	-	-	-	I-5D

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UTG640004	700	USNPS-Glen Canyon Hite WTP	-	-	-	M-6
UT0023663	710	Castle Valley SSD-Castle Dale	-	0	0	M-2
UT0020052	710	Castle Valley SSD-Ferron	-	0	0	M-2
UT0021296	710	Castle Valley SSD-Huntington	3811	0.278	4.42	M-B
UTG640030	710	Emery WTP	-	-	-	M-6
UTG640039	710	Ferron WTP	-	-	-	M-6
UT0024368	710	Princess Mine aka Crandall Canyon Mine	539	0.36	0.8	I
UTG640040	710	Huntington WTP	-	-	-	M-6
UTG640031	710	Orangeville WTP	-	-	-	M-6
UTG040006	710	Bear Canyon Mine	847	0.247	0.873	I
UT0023604	710	PacifiCorp-Deer Creek Mine	-	-	-	I-2
UTG040009	710	Hunter Plant Coal Prep & Blend Facility	-	-	-	I-2
UT0023728	710	Fossil Rock-Trail Mountain Mine	-	-	-	I-2
UT0022896	710	PacifiCorp-Wilberg Mine	1072	0.077	0.344	I
UTG640019	802	Blanding Culinary Water Treatment	-	-	-	M-6
UT0024503	802	Monticello	-	0	0	M-2
UTG640015	802	Monticello City (Culinary WTP)	-	-	-	M-6
UT0025992	900	Alton Coal Development	728	0.026	0.079	I
UT0025224	905	Springdale	971	0.27	1.08	M-B
UT0026123	905	Gunlock DW Plant	-	-	-	I-2
UT0026131	905	Sand Hollow DW Plant	929	0.003	0.012	I-B
UTG640021	905	St. George WTP	-	-	-	M-6
UT0024686	905	St. George, City of	1181	11.8	58.2	M-5B
Wyoming						
WY0000027	401	Green River-Rock Springs JPB Water Plant			0	M-2
WY0000094	401	Boulder Rearing Station	68	1.62	0.46	I-5D
WY0020133	401	Big Piney Wastewater Lagoon	659	0.0817	0.22	M-B
WY0020656	401	Pinedale Wastewater Lagoons	186	0.645	0.5	M-4B
WY0021806	401	Superior Waste Water Lagoon			0	M-2
WY0021997	401	Marbleton Wastewater Lagoon	676	0.445	1.25	M-A
WY0022080	401	LaBarge Wastewater Lagoon			0.1	M-B
WY0022128	401	B & R Mobile Home Village			0.02	M-B
WY0022357	401	Rock Springs WWTP	1037	2.92	12.63	M-5B
WY0023124	401	Daniels Mobile Home Park				M-1
WY0023825	401	Stansbury Mine			0	I-2
WY0028886	401	Leucite Hills Mine				I-1
WY0030261	401	Black Butte Mine				I-1
WY0030350	401	Jim Bridger Mine			0	I-2
WY0054224	401	Jensen Disposal Facility - New Fork Discharge	160	0.03	0.02	I-B
WY0054232	401	Jensen Disposal Facility - Sand Draw Discharge				I-1
WY0094528	401	BLM Rock Springs Wild Horse Facility			0	I-2
WY0020443	411	Green River Wastewater Lagoon	400	0.895	1.49	M-A
WY0056499	411	Pioneer Cryogenic Gas Plant			0.03	I-B
WY0022896	411	Mountain View Wastewater Lagoon			0.46	M-B
WY0000051	411	Kemmerer Mine			0.39	I-B
WY0000116	411	Kemmerer Water Treatment Plant	277	0.19	0.22	M-4B
WY0020117	411	Lyman Wastewater Lagoon			0.18	M-B
WY0020311	411	Naughton Plant			4.27	I-5B
WY0020320	411	Kemmerer Wastewater Treatment	608	0.285	0.72	M-B
WY0022071	411	Fort Bridger Sewer District			0.39	M-B
WY0022373	411	Granger Wastewater Lagoon				M-1
WY0032697	411	Carter Creek Gas Plant			0	I-2
WY0036153	411	Ft. Bridger Travel Stop			0	M-2
WY0094811	411	Haystack Coal				I-1
WY0096849	411	Love's Travel Stops and Country Stores #888			0	I-2
WY0021938	500	Dixon Wastewater Lagoon	354	0.044	0.06	M-A
WY0022888	500	Baggs Wastewater Lagoons			0.28	M-B
WY0042145	500	Cow Creek Unit				I-1
WY0054038	500	Cow Creek CBNG Project				I-1

NPDES PERMITS						
Colorado River Basin Salinity Control Forum						
January 1, 2020, through December 31, 2022						
NPDES PERMIT#	**REACH**	**NAME of Discharging Facility**	**TDS Conc. AVG.**	**Flow Rate AVG.**	**Salt Load Tons/Day**	**Explanation Code**
WY0056847	500	Morgan Run Unit II				I-1
WY00996679	500	Cow Creek Project			0	I-2
WY0096776	500	Atalantic Rim CBM Project			0	I-2

APPENDIX D

EPA NPDES Permits List

LEGEND

NPDES PERMITS
EXPLANATION CODES

COLORADO RIVER BASIN SALINITY CONTROL FORUM
January 1, 2020, through December 31, 2022

NPDES permits are reviewed under two different criteria under Forum policy; these being municipal and industrial. In order for a permittee to be in compliance under the municipal criteria, the increase in concentration between inflow and outflow cannot be greater than 400 mg/L. Forum industrial criteria requires that no industrial user discharges more than 1.00 ton/day. Under Forum policy there can be granted exceptions to these limitations by the states. The following gives an explanation of the current status of the NPDES permits. Because at any given time many of the permits identified in this list are being reviewed, reissued, and/or terminated, and new discharge permits are being filed, this list must be considered as being subject to frequent change.

MUNICIPAL

(M) Municipal user in compliance with Forum policy.

(M-A) Municipal user in compliance with the 400 mg/L incremental increase provision.

(M-B) Municipal user in compliance with the 1 ton per day or 366 tons per year provision for intermittent discharges.

(M-1)* Permit has expired or been revoked. No discharge.

(M-2) Permittee did not discharge during the reporting period.

(M-3) Measurement of TDS is not currently required, but the state and/or EPA plans to require measurements of both inflow and outflow when the permit is reissued.

Measurements of inflow are not consistent with Forum policy;

(M-4A) Therefore, it is not known whether or not this municipal user is in compliance.

(M-4B) However, since outflow concentration is less than 500 mg/L it is presumed that this permit is not in violation of the ≤400 mg/L increase.

(M-5) Permittee is in violation of Forum policy in that there is an increase in concentration of >400 mg/L over the source waters. No provision has been made allowing this violation of Forum policy.

(M-5A) The state and/or EPA is currently working to bring permittee into compliance.

(M-5B) Though discharge is >400 mg/L over source waters, in keeping with Forum policy the permittee has demonstrated the salt reduction is not practicable and the requirement has been waived.

(M-6) This permit requires no discharge or discharge only under rare and extreme hydrologic conditions. Thus, flow and concentration measurements are not required.

(M-7) Insufficient data to know the current status of this permit.

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* Permits that have been expired or revoked and listed with the M-1 and I-1 explanation codes shall be removed from the NPDES list during the subsequent triennial review.

INDUSTRIAL

(I) Industrial user in compliance with Forum policy.

(I-A) Industrial user in compliance with the Forum's salinity offset policy.

(I-B) Industrial user in compliance with the 1 ton per day or 366 tons per year provision for intermittent discharges.

(I-1)* Permit has expired or been revoked. No discharge.

(I-2) Permittee did not discharge during the reporting period.

(I-3) Measurement of TDS is not currently required, but the state and/or EPA plans to require measurements of both volume and concentration of outflow when the permit is reissued.

(I-4) Either concentration or volume of outflow are not currently being reported, thus the permittee is in violation of Forum policy. It is not known if the discharge is in excess of the <1.00 ton/day requirement.

(I-5) Permittee is in violation of Forum policy in that discharge of salts is >1.00 ton/day. No provision has been made allowing this violation of Forum policy.

(I-5A) The state and/or EPA is currently working to bring permittee into compliance.

(I-5B) Though discharge is >1.00 ton/day, in keeping with Forum policy the permittee has demonstrated the salt reduction is not practicable and the requirement has been waived.

(I-5C) The use of ground water under this permit is for geothermal energy and only heat is extracted. The intercepted salt and water are naturally tributary to the Colorado River System and hence, this discharge does not increase salt in the river. The permit is covered by the Forum's policy on intercepted ground waters.

(I-5D) This permit is in compliance with the Forum's policy for fish hatcheries. The use of the water is a one-time pass through, and the incremental increase in salinity is ≤ 100 mg/l.

(I-5E) This permit is for the interception and passage of ground waters and thus is excepted under the Forum's policy on intercepted ground waters.

(I-6) This permit requires no discharge or discharge only under rare and extreme hydrologic conditions. Thus, flow and concentration measurements are not required.

(I-7) Insufficient data to know the current status of this permit.

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LEGEND (continued)

NPDES PERMITS
REACH DEMARCATIONS

COLORADO RIVER BASIN SALINITY CONTROL FORUM

In order to provide a better understanding of the location of the various NPDES permits and the geographical sequence in the Colorado River System, each of the following NPDES permits is identified with a Colorado River reach number. The reach numbers have their origin in the old CRSS river model. Though this model is no longer used, the reach numbers assist in understanding the general location of the permits. The reaches are defined as:

100	Upper Main Stem	from headwaters of Colorado River to Colorado River near Cameo
190	Taylor Park	from headwaters of Gunnison River to above Blue Mesa Reservoir
200	Blue Mesa	from above Blue Mesa Reservoir to below Blue Mesa Dam
210	Morrow Point	from below Blue Mesa Dam to Crystal Reservoir
220	Lower Gunnison	from Crystal Reservoir to confluence with Colorado River
300	Grand Valley	from Colorado River near Cameo to confluence with Green River
310	Dolores River	from headwaters of Dolores River to confluence with Colorado River
401	Fontenelle	from headwaters of Green River to Green River near Green River, WY
411	Flaming Gorge	from Green River near Green River, WY to confluence with White and Duchesne Rivers
500	Yampa River	from headwaters of Yampa River to confluence with Green River
510	White River	from headwaters of White River to confluence with Green River
600	Green River	Green River from confluence with White and Duchesne Rivers to confluence with Colorado River
610	Duchesne River	from headwaters of Duchesne River to confluence with Green River
700	Lake Powell	Colorado River from confluence of with Green River to Lees Ferry
710	San Rafael River	from headwaters of San Rafael River to confluence with Green River
801	Upper San Juan River	from headwaters of San Juan River to San Juan near Bluff
802	Lower San Juan River	from San Juan near Bluff to confluence with Lake Powell
900	Glen Canyon to Lake Mead	Colorado River from Lees Ferry to backwaters of Lake Mead
905	Virgin River	from headwaters of Virgin River to backwaters of Lake Mead
910	Lake Mead	from backwaters of Lake Mead to Colorado River below Hoover Dam
920	Lake Mohave	Colorado River from below Hoover Dam down to I-40 bridge
930	Lake Havasu	Colorado River from I-40 bridge to below Parker Dam
940	Parker Dam to Imperial Dam	Colorado River from below Parker Dam to above Imperial Dam
945	Imperial Dam	Colorado River from above Imperial Dam to Gila and Yuma users

EPA ADMINISTERED NPDES PERMITS
Colorado River Basin Salinity Control Forum
January 1, 2020, through December 31, 2022

NPDES PERMIT#	REACH	NAME of Discharging Facility	TDS Conc. AVG.(Mg/L)	Flow Rate AVG.(MGD)	Salt Load Tons/Day	Explanation Code
* Permit issued to a federal agency (except in NM) or an Indian tribe and the responsibility of EPA						
** Issued by a tribal entity with delegation of the NPDES program						
Region 6 Permits						
NM0030520*	801	Village of Dulce (Tribe)	273	0.32	0.364291	M
All other permits in New Mexico are issued by the U.S. EPA and certified by the State of New Mexico Environmental Department as reported in Appendix C.						
Region 8 Permits						
CO0034975*	190	USNPS - Colorado National Monument				M-6
CO0000086*	220	HOTCHKISS NTL. FISH HATCHERY	19	4.31	0.341	I-5D
CO0022853*	801	SOUTHERN UTE INDIAN TRIBE(E)	323	0.321	0.432	M
CO0034398*	801	USDINPS-MESA VERDE NAT PARK (E)	326	0.034	0.046	M
CO0034622*	801	USDINPS-MESA VERDE NAT PARK (E)		0.044		M-3
CO0034665*	801	FOUR CORNER MATERIALS	154	1.251	0.803	I
CO0034959*	801	IGNACIO PEAK WASTEWATER LAGOON				M-6
CO0034967*	801	SOUTHERN UTE WATER TRTMNT PLNT				M-2
COG589201*	801	TOWAOC WASTEWATER LAGOON				M-6
COG589202*	801	WHITE MESA WASTEWATER LAGOONS				M-6
COG589203*	801	TOWAOC WASTEWATER LAGOON 2				M-6
UT0000167*	510	American Gilsonite Co.	2,714	0.385	4.357	I-7
UT0025259*	510	American Gilsonite Co.			19.080	I-2
Region 9 Permits						
AZ0024619*	900	HOPI INDIAN NATION/ UPPER VILLAGE OF MOENKOPI WWTP				M
AZ0021415*	940	COLORADO RIVER JOINT VENTURE	<400	1.2		M
NN0000019	801	APS Four Corners Power Plant		4.2		I-7
NN0028193	801	NTEC Navajo Mine				I-7
NN0020869	801	BIA Crystal Boarding School		0.015		M-6
NN0020800	801	BIA Nenahnezad Community School		0.024		M-6
NN0020991	801	BIA Pueblo Pintado		0.016		M-6
NN0020621	801	NTUA Shiprock		1		M-6
NN0020265**	802	NTUA/CHINLE	<400	0.783		M
NN0020281**	802	NTUA/KAYENTA	<400	0.9		M
NN0020133	803	NACOGDOCHES OIL & GAS	<400	0.01		I-1
NN0020290**	900	NTUA/TUBA CITY	<400	1.1		M-6
NN0021555**	900	NTUA/WINDOW ROCK-FT.DEFIANCE	<400	1.32		M-6
NN0021610**	900	CAMERON TRADING POST		0.054		M-6
NN0022179**	900	PEABODY WESTERN COAL COMPANY/BLACK MESA COMPLEX				I
NN0022195**	900	NTUA/GANADO	<400	0.4		M
NN0024228**	900	NTUA/PINON WWTP				M
NN0030337**	900	BIA/LOW MOUNTAIN BOARDING SCHOOL	<400	0.014		M
NN0020958	900	BIA Wingate School		0.1		M-6
NN0029386	900	Chevron Mining, Inc. / McKinley Mine				I-7
NN0030335	900	NTUA Navajo Townsite		0.32		M-6
NN0030325	900	Ramah Navajo School Board - Pine Hill		0.035		M-6
NN0025178	900	RJG Inc. - Gouldings Lodge		0.072		M-6
NN0030339**		BIA/LUKACHUKAI COMMUNITY SCHOOL				M-6
NN0030343		NTUA Northern Edge Casino		0.03		M
NN0030344		NTUA Twin Arrows Casino		0.13		M
NN0030345		Navajo Engineering & Construction Authority (NECA)				M
NN0030346		Mariano Lake Waterline Project				M
NNG990001		General Permit for Low Threat Discharges in Navajo Nation		Varies		Varies

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APPENDIX E

Colorado River Simulation System
Model Description

COLORADO RIVER SIMULATION SYSTEM
MODEL DESCRIPTION

The Colorado River Simulation System (CRSS) is the official long-term basin-wide planning model used by Reclamation's Upper Colorado and Lower Colorado Regions to simulate future Colorado River system conditions. The model framework used for this process is commercial software called RiverWare™, a generalized river basin modeling software package developed by the University of Colorado through a cooperative arrangement with Reclamation, the Tennessee Valley Authority, and the U.S. Army Corps of Engineers.

CRSS was originally developed by Reclamation in the early 1970s and was implemented in RiverWare™ in 1996. The model projects future river and reservoir conditions on a monthly timestep over a period of decades into the future. CRSS has been used for most major modeling studies on the Colorado River, including several National Environmental Policy Act Environmental Impact Statements (EIS), the Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead EIS. CRSS was also the primary modeling tool for system projections in Reclamation's Colorado River Basin Water Supply and Demand Study under WaterSMART.

There are numerous inputs to, and assumptions made by, CRSS with respect to future conditions on the Colorado River. The input data for CRSS includes hydrologic inflows, various physical process parameters such as the evaporation rates for each reservoir, initial reservoir conditions, and the future diversion and depletion schedules for entities in the Basin States and for Mexico. These future schedules are based on demand and depletion projections prepared and submitted by the Basin States. The rules of operation of the Colorado River mainstream reservoirs, including Lakes Powell and Mead, are also provided as input to the model. These sets of operating rules describe how water is released and delivered under various hydrologic and system conditions.

As the period of analysis increases, the uncertainty in these inputs and assumptions also increases. Therefore, a large amount of uncertainty in the corresponding outputs is expected. Consequently, CRSS is not used to predict future conditions, but rather to simulate what might occur. CRSS is especially useful in making a relative comparison between hydrologic and salinity concentration impacts from different alternatives by holding constant most inputs, as well as other key modeling assumptions, so as to isolate the differences due to each alternative. Additionally, sensitivity analyses that answer the question, "What is the sensitivity of the output to a particular set of inputs or assumptions?" are commonly performed.

Future conditions of the Colorado River system are most sensitive to assumptions with respect to future inflows. Because it is impossible to predict the actual future inflows into the system, a range of possible future inflows are analyzed and used to quantify the probability of occurrences of particular events (e.g., higher or lower lake elevations). This technique involves running multiple hydrologic sequences for each scenario or operational alternative. These sequences can be derived from a number of techniques. Depending on the project and planning period, Reclamation has used techniques based on the historical observed natural flow record (1906-2020), the paleo record derived from tree-rings (762-2005), and 112 downscaled Global Climate Model (GCM) projections based on 16 unique GCMs. For this Review, the index sequential method (ISM) was

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applied to the 1988-2020 "Stress Test" period to generate 33 different future inflow scenarios. The drier "Stress Test" hydrology has become standard in recent CRSS water supply studies. Previous Reviews have used the wetter 1906-present "full record" and "Pluvial Removed" hydrologies.

The CRSS RiverWare™ model includes a salinity module to analyze salinity concentrations throughout the Colorado River Basin. The salinity model simulates the effects of water development projects and the salinity control program (SCP) on future salinity concentration levels in the Colorado River. The salinity control criteria are purposely designed to be long-term and non-degradational goals, rather than exceedance standards such as those used for industry or drinking water. Efforts of the SCP are designed to meet the criteria by implementing, as needed, the most cost-effective salinity control projects. This ensures that the salinity control numeric criteria will continue to be met in the future, even with the salinity impacts produced by increasing Upper Basin depletions.

The model assumes salinity is a conservative water quality parameter, and reservoirs are modeled as fully mixed systems. Salinity module inputs include salinity accompanying hydrologic inflows, initial reservoir salinity concentrations, estimates of salt loading due to agricultural return flows and salt removed by salinity control projects. Model results simulate annual average salinity concentrations at the numeric criteria stations downstream of Hoover Dam and Parker Dam and at Imperial Dam and can be used to analyze the probability of exceeding the numeric criteria in future years.

The salinity module within CRSS is intended for long-term (15 to 20 years) simulation and it is highly sensitive to initial conditions during the first 10 to 12 years.

Modeling Assumptions for the 2023 Triennial Review

The following lists major modeling assumptions in a bulleted format for the 2023 Triennial Review. These assumptions reflect the January 2022 version of CRSS. Documents referenced in these assumptions include the *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lake Powell and Lake Mead Final Environmental Impact Statement* (FEIS, 2007A), *Record of Decision* (ROD) *for Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead* (Interim Guidelines, 2007B), Colorado River Basin Water Supply and Demand Study (Basin Study, 2012), Colorado River Lower Basin Drought Contingency Plan (LB DCP, 2019), Minute No. 323 to the 1944 U.S. Mexico Water Treaty (Minute 323, 2017), and the Prairie and Rajagopalan (2007) article entitled "A basin wide stochastic salinity model." Refer to these documents for additional detail regarding specific assumptions. All runs were performed using the CRSS long-term planning model.

Key Assumptions Common to All Scenarios Updated Since the 2020 Triennial Review

- Simulations run from January 2023 through December 2040 at a monthly time step
- Initial conditions for all reservoirs are 2022 end-of-calendar year (EOCY) observed values
    - Initial reservoir salt concentrations are December 2022 downstream flow weighted annual average concentrations from SLOAD. A high December 2022 Lees Ferry concentration, used to initialize Lake Powell concentration, explains the early spike in simulation results.
    - Intentionally Created Surplus (ICS) initial balances were updated for January 2023
- Continued Upper Basin Drought Response Operations and other elements of the Upper

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Basin DCP are not modeled.

- Future water demands for the Upper Division States are based on depletion projections from the 2016 Upper Colorado River Commission (UCRC) Demand Schedule for the Upper Colorado River Division States ("2016 Schedule", 2016).
    - Incorporation of the 2016 schedule required a redesign of layout of Upper Basin water users in CRSS. The new layout more clearly distinguishes between current agriculture uses and future projected growth. Over successive changes to CRSS and its demand schedules agricultural growth uses had been mixed up with present level uses. Growth in agricultural use is modeled at fixed salinity pickup concentrations so high projections of growth, not supported by current trends in agricultural use, resulted in a large increase in salinity loading at the beginning of model simulations. The new schedule and layouts result in approximately 500,000 tons less salt entering the Upper Basin and brings concentration projections in line with historical averages.
    - Reclamation incorporated the 2016 Schedule for the first time in the January 2021 CRSS official model run. The Upper Division States and UCRC assisted with the representation of this new schedule in CRSS. During this process, the need for additional refinements to the representation of Upper Colorado River Basin water use in CRSS was identified. Reclamation is currently working with the Upper Division States and UCRC on such refinements.
- Water Quality Improvement Projects (WQIP) have been updated to reflect historical and projected control levels.

Other Assumptions Common to All Scenarios

- Future hydrologic inflows are generated at 29 separate inflow points or nodes in the Colorado River watershed using the Indexed Sequential Method (Interim Guidelines EIS, Chapter 4.2.5). This technique is applied to the 33-year (1988 through 2020) historical record of calculated natural flows to produce 33 hydrologic inflow sequences or traces for each scenario.
- Future salinity concentrations are generated at 20 nodes in the Colorado River watershed using Reclamation's nonparametric natural salt model. The natural salt model includes annual total flow-salt mass (Upper Basin) and intervening flow-salt mass (Lower Basin) regressions built with 1991-2020 natural flow and salt mass data. The natural salt model provides salt mass based on flows. Salt concentrations are computed from flow and salt mass. Prairie and Rajagopalan (2007) describes the methods used in the basin-wide salinity modeling framework.
- Annual salt loading values from agriculture are assumed constant throughout the simulation horizon. Variations in salt mass resulting from variation in flow conditions (high and low) are not considered; therefore, when computing natural salt, we expect negative natural salt values.
- Salt concentrations on reaches are limited to their historical minimum and maximums with the remainder being stored for later release when concentrations are again within these bounds.
- Future water demands for the Lower Division States (during Normal Conditions) are according to the schedules provided for the 2007 FEIS for the 2007 Interim Guidelines modeling with updates to Nevada's demands in May 2019.
- For 2023-2026, Lake Powell and Lake Mead are operated according to the 2007 Interim Guidelines, LB DCP, and Minute 323. For modeling purposes, these operations are assumed to continue through 2040.
    - Lower Basin and Mexico shortages and surpluses are specified in the 2007 Interim

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Guidelines and Minute 323, respectively.
    - LB DCP contributions and Mexico Binational Water Scarcity Contingency Plan savings are specified in the LB DCP and Minute 323, respectively
- Lake Mohave, Lake Havasu, Taylor Park and Fontenelle reservoirs are operated in accordance with their existing rule curves (2007 FEIS, Appendix A). The Aspinall Unit, Flaming Gorge, and Navajo are operated according to their existing RODs (Basin Study).
- Yuma Desalting Plant is assumed to not operate.

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References

U.S. Bureau of Reclamation. (2007A). Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lake Powell and Lake Mead Final Environmental Impact Statement. Retrieved from https://www.usbr.gov/lc/region/programs/strategies/Cowaterops.html

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Upper Colorado River Commission. (2016). 2016 UCRC Demand Schedule for the Upper Colorado River Division States. Retrieved from https://ucrcommission.com/wp-content/uploads/2018/02/2016-UCRC-Demand-Schedule.pdf

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APPENDIX F

Salinity Economic Impact Model Description

SALINITY ECONOMIC IMPACT MODEL DESCRIPTION

SEIM Background

The Salinity Economic Impact Model (SEIM) estimates the annual quantified damages (economic impacts) incurred in metropolitan and agricultural areas in the Lower Colorado River Basin (LCRB) that depend, either wholly or in part, on Colorado River water.

The SEIM is the current version of a salinity model that was originally developed in the late 1980s by the Milliken Chapman Research Group, Inc. (Lohman, 1988) to quantify the economic impacts of salinity from projects improving water efficiency in the Lower Colorado River Basin. Strategies to improve agricultural water efficiency included concrete-lining canals and retrofitting flood irrigation systems with drip or sprinkler irrigation systems. Prior to the use of salinity models such as the SEIM, the impacts of the salinity reduction on the economies of Lower Colorado River water users were unknown.

The model development in the 1980s was funded by the Bureau of Reclamation to quantify the efforts of the Colorado River Basin Salinity Control Advisory Council (Advisory Council). The Advisory Council's function is to:

> *"…advise the Secretaries of the Departments of the Interior and Agriculture…on all matters relating to efficient and timely planning and execution of salinity control measures…specified in the Colorado River Basin Salinity Control Act."*

The original salinity model estimated the economic impact due to salinity by considering five economic sectors that may be impacted by high-salinity Colorado River water. Over time, the original salinity model was updated and modified as new data became available. Brummer and Yahnke (1999) provided improved agricultural economic impact procedures for all areas except the Metropolitan Water District (MWD) service area. The MWD service area improvements are documented in MWD and Bureau of Reclamation (1999) and included updated procedures and data across all economic sectors.

A second salinity model was developed in the early 2000s based on this revised salinity model to improve the representation of the Central Arizona portion of the original model and support salinity economic impact analysis for the Central Arizona Salinity Study (Bureau of Reclamation, 2003). From 2003 until 2016, these two salinity models were run in tandem whenever an economic impact analysis was needed. In 2016, these two models were combined into a single Excel workbook model or the SEIM.

Beginning in 2015, the SEIM was reviewed by representatives from Arizona, California, and Nevada to provide recommendations on redefining model regions and updating data for use in the 2017 Triennial Review. Another objective of the SEIM review was to improve usability, efficiency, and transparency of the SEIM.

In 2020, Daniel B. Stephens & Associates, Inc. (DBS&A) completed a review of SEIM and updated the model, input data and cost functions where possible (2019a, 2019b, 2020). Major

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changes included updates to residential impact functions, agricultural crop salinity thresholds, unified methods for calculating agricultural leaching and water utility costs. DBS&A recommend regular updates to input data. In 2022, the SEIM Committee, a subgroup of state and federal work group members, updated crop prices, price indices, water blending data and population projections. Additional updates for non-MWD regions included crop acreages, treatment plant capacities, and industrial water use. MWD also updated recycled water use data.

SEIM Methodology

The SEIM estimates the economic impact attributed to areas receiving Colorado River water with salinity levels greater than a baseline value of 500 mg/L[1] total dissolved solids (TDS) or areas increasing local TDS concentrations due to blending with Colorado River Water higher than 500 mg/L on residential water-using appliances, the treatment and infrastructure replacement costs in the commercial, industrial, and water utilities sectors, and income losses to agriculture. It also estimates the additional costs related to meeting California water quality standards for groundwater and recycled water use in the MWD service area. The model does not calculate an absolute value of the economic impacts due to salinity. Rather, the model estimates salinity impacts from the baseline condition (500 mg/L) and then calculates the change in economic impacts when salinity concentrations rise above or decline below the baseline condition. A few subareas, such as the North West subarea within MWD, typically do not receive Colorado River supplies. As a result, these subareas are not affected by changing Colorado River salinity levels and do not contribute damages to the overall total in the model.

Where possible, published cost data have been used in the SEIM. Crop prices and crop yields were obtained from the United States Department of Agriculture's National Agricultural Statistics Service (USDA-NASS). Five-year (2017 – 2021) averages of state-level crop prices and yields were used unless the county-level crop prices were available. In sectors where new cost data are not available, historical cost data have been indexed to 2021 prices. The Consumer Price Index (CPI) is used for residential and commercial prices (Federal Reserve Bank of St. Louis, 2022a). The Gross Domestic Product Implicit Price Deflator (GDPDef) is used for agricultural prices and revenues (Federal Reserve Bank of St. Louis, 2022b). The Producer Price Index (PPI) was used to estimate salinity costs in the industrial, agricultural (leaching costs only), utilities, groundwater, and recycling economic sectors (Bureau of Labor Statistics, 2022).

Reclamation uses the Colorado River Simulation System (CRSS) to project future salinity levels in the river. These projections incorporate the effect of current and future salinity control projects implemented mainly in the Upper Colorado River Basin through the Colorado River Basin Salinity Control Forum (Forum). In addition to these projected salinity concentrations, SEIM model inputs include projected population, housing, and employment statistics along with projected residential, commercial, and industrial water demands obtained from Forum members. The model currently projects annual economic impacts due to elevated salinity for any year between 2020 and 2040.

The SEIM accepts projected salinity concentrations from the CRSS at three diversion points along the mainstem of the Lower Colorado River. Quantified damages due to salinity concentration are

[1] U.S. EPA's secondary drinking water quality standard

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estimated for seven economic sectors across five regions. Table 1 summarizes the diversion points, economic sectors and regions that are included in the SEIM.

Table 2 lists the regions and their subareas as represented in the model. It should be noted that some subarea names are county names and the subarea may not include the entire county, only the portion that received Lower Colorado River mainstem waters. The SEIM estimates the annual quantitative damages by diversion point and economic sector for each region and subarea listed above. Table 3 presents the impacted items that are included in each economic sector's categories.

Table 1
Names of Locations, Damage Sectors, and Regions Included in SEIM

Diversion Points	Economic Sectors	Regions
Hoover Dam	Agriculture	Central Arizona
Parker Dam	Residential	Mainstem Arizona
Imperial Dam	Commercial	Mainstem Nevada
	Utility	Mainstem California, Non-MWD
	Industrial	MWD Service Area
	Groundwater[2]	
	Recycling**Error! Bookmark not defined.** & POTW	

Table 2
Subareas within Each Region in SEIM

Region	Subarea
Central Arizona	Phoenix AMA[3], Pinal AMA, Tucson AMA
Mainstem Arizona	Mohave County, La Paz County, Yuma County
Mainstem Nevada	Clark County
Mainstem California Non-MWD	Imperial County, San Bernardino County, Riverside County
MWD	Northwest, Los Angeles, West Basin, Central Basin, San Gabriel, Chino Basin, Orange County, Western Riverside, San Diego, Eastern Riverside

Table 3
Economic Sector Impact Category Items Included in the SEIM

Economic Sector	Impact Category Items
Residential	Water Pipes, Water Heater, Faucet, Garbage Disposal, Clothes Washer, Dishwasher, Water Softener, Detergent
Commercial	Sanitary, Cooling, Irrigation, Kitchen, Laundry, Misc.
Industrial	Process Water, Cooling Tower, Boiler, Sanitation, Irrigation
Water Utilities	Treatment Plant, Distribution System

[2] Only applies to MWD Service Area

[3] These are active management areas (AMA) in Central Arizona in which groundwater use is strictly regulated by the Arizona Department of Water Resources. Nearly 80% of Arizona's population resides in these 3 AMAs.

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Groundwater	Direct Recharge, Indirect Recharge, Incidental Recharge
Recycled Water	Irrigation, Direct Groundwater Recharge, Indirect Groundwater Recharge
Agriculture	**MWD Subareas Crops:** Strawberry, Nursery, Cut Flowers, Misc. Vegetable, Citrus, Avocado, Vineyard, Pasture/grain, Deciduous, Field Crops **All Other Subareas Crops:** Head Lettuce, Leaf Lettuce, Romaine Lettuce, Broccoli, Cauliflower, Alfalfa Hay, Onions, Avocados, Cantaloupe, Carrots, Oranges, Tangerines, Lemon/Limes, Grapefruit, Table Grapes, Potatoes, Corn, Wheat, Cotton, Barley, Olives, Honeydews, Tomatoes, Leaching Management Costs

The SEIM estimates damages (economic impact) on residential, industrial, commercial, water utility, and agriculture sectors, as well as on groundwater and recycled water. A general description

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of how each sector is calculated in the SEIM model is provided below.

Figure 1 presents a map of the regions included in the SEIM with shading indicating the portion of each subarea that receives Colorado River mainstem waters, along with the economic sectors impacted within each respective subarea.

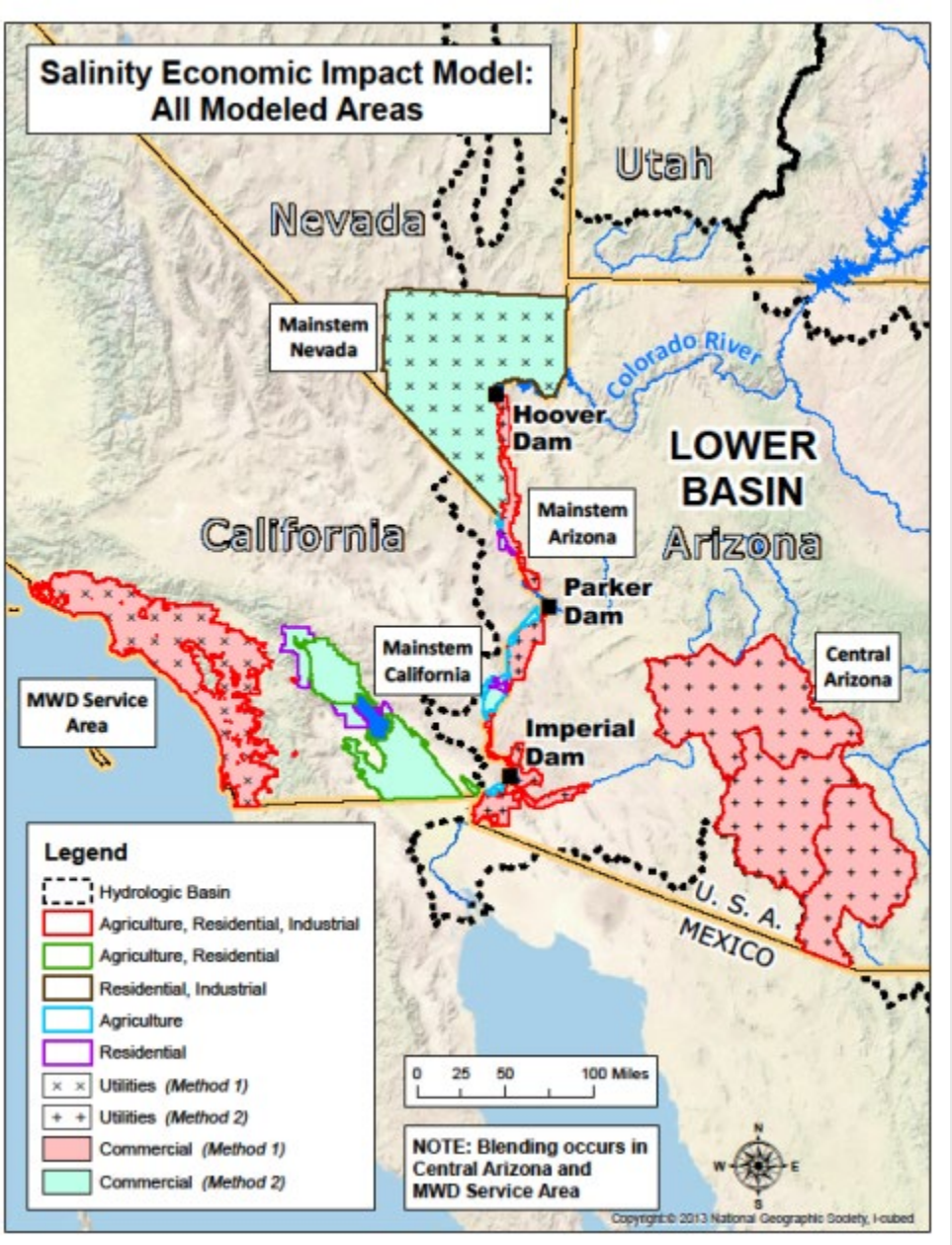


Figure 1 – Economic Sectors for the Regions Included in the SEIM

Residential Damage Calculation

The SEIM model estimates increased annual cost for each subarea based on the reduced useful life of water-using appliances and fixtures from increased average annual salinity, the household adoption rate of appliances and fixtures, the cost of an appliance or fixture, and the number of households. Some additional costs are based on the share of households adopting practices that

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avoid salinity costs. Input data and useful life functions based on given salinity values are documented in the DBS&A technical memorandums (2019a, 2019b, 2020).

Commercial Damage Calculation

Commercial damages are calculated for six different water use categories: sanitary, cooling, irrigation, kitchens, laundries, and others. The former version of the model calculated costs differently for Mainstem Nevada and Mainstem CA compared to the rest of the areas. The 2020 SEIM was updated so that all subareas use the same method (DBS&A, 2020). The economic costs are calculated based on the water use categories and the estimated costs of using water with an increased TDS concentration.

Industrial Damage Calculation

Salinity damages are estimated in the SEIM for eight major types of industrial water use. Damage functions developed for these categories are applied to the amount of industrial water use by category for each subarea in the model. Industries with processes requiring better quality water have larger costs associated with increasing salinity.

Water Utilities Damage Calculation

The SEIM estimates the damages to water utilities as the total capital cost for water treatment. The former version of the model calculated costs differently for MWD, Mainstem Nevada and Mainstem CA compared to the rest of the areas. The 2020 SEIM was updated so that all subareas use the same method (DBS&A, 2020). The method uses total water treatment plant capacity and estimates unit cost for affected water treatment capital. This new method does not include distribution costs which were deemed to be minimal assuming that treated water corrosivity is stabilized prior to entering the distribution system.

Agriculture Damage Calculation

Agriculture damages are estimated in the SEIM through changes in gross revenue due to reduced crop yields of salt-sensitive crops. Crop yield functions for the most common types of agriculture were developed or used from available research. The number of acres and current crop price per acre were updated with best available data in the current SEIM model. The gross crop revenue is estimated based on the crop yield per acre at a given salinity level and the price per acre for that crop. The revenue computed in the SEIM from the projected salinity concentrations is compared to the revenue computed from baseline conditions to determine the change in revenue from increases in salinity for each subarea in the model. Subareas with more acres of crops sensitive to salinity changes have the largest amount of damages from reduced crop yields.

Groundwater, Recycling and Wastewater

The SEIM calculates the costs of removing salts to maintain water quality requirements for groundwater and recycled water that are used extensively in the MWD service area. MWD estimates the amount of water and wastewater that drains into the groundwater system and the amount that is used for recycled water purposes. Salinity cost functions (costs to desalt these sources of water) are used to estimate the costs at given salinity levels.

SEIM Results

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The latest SEIM, Version 2.1, dated 2/17/23, was used during the 2023 Triennial Review to estimate quantified damages in the Lower Colorado River Basin. Table 4 presents the diversion point projected salinity concentrations from CRSS and the SEIM average annual quantified damages for the years 2023 and 2040. Table 5 presents the annual reduction in salinity concentration and quantified damages as of 2040, relative to Scenario 1, at each diversion point and as a LCRB total. Scenarios represented in Tables 4 and 5 are as follows:

- 2023 Conditions: Salinity controls as of 2023.
- Scenario 1 - No additional controls beyond 2023 (does not implement the Plan of Implementation identified herein)
- Scenario 2 - Controls associated with limited program funding levels through 2040
- Scenario 3 - Controls associated with fixed implementation through 2040
- Scenario 4 - Controls associated with controlling maximum potential identified salt load by 2040

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Table 4
Average Annual Colorado River Salinity Concentrations and Annual Quantified Damages, 2023 and 2040

2023							
	Average Annual Concentration (mg/L)			Average Annual Quantified Damages ($ millions)			
Scenario	Hoover	Parker	Imperial	Hoover	Parker	Imperial	Total
Scenario 1	603	607	725	$28.1	$134.7	$185.3	$348.1
Scenario 2	603	607	725	$28.1	$134.7	$185.3	$348.1
Scenario 3	603	607	725	$28.1	$134.7	$185.3	$348.1
Scenario 4	602	607	725	$27.8	$134.7	$185.3	$347.8

2040[4]							
	Average Annual Concentration (mg/L)			Average Annual Quantified Damages ($ millions)			
Scenario	Hoover	Parker	Imperial	Hoover	Parker	Imperial	Total
Scenario 1	609	635	767	$36.3	$185.6	$225.2	$447.0
Scenario 2	592	617	746	$30.8	$160.9	$205.8	$397.4
Scenario 3	588	613	740	$29.5	$155.4	$200.2	$385.1
Scenario 4	538	561	677	$13.0	$84.0	$142.8	$239.9

[4] Scenarios assume 0 tons Paradox controls for 2027-2040

Table 4 shows that average annual salinity concentrations and average annual quantified damages due to salinity at the three key locations (Hoover, Parker, and Imperial) will increase between 2023 and 2040 if no additional controls are built.

Table 5
<u>Reduction</u> in Average Annual Colorado River Salinity Concentration and Annual Quantified Damages in 2040, Relative to Scenario 1 ("No Additional Controls Beyond 2023")

2040[4]							
	Annual Concentration Reduction relative to Scenario 1 (mg/L)			Annual Quantified Damage Reduction relative to Scenario 1 ($ millions)			
Alternative	Hoover	Parker	Imperial	Hoover	Parker	Imperial	Total
Scenario 1	0	0	0	$0.0	$0.0	$0.0	$0.0
Scenario 2	17	18	21	$5.5	$24.7	$19.4	$49.6
Scenario 3	21	22	27	$6.7	$30.2	$25.0	$61.9
Scenario 4	71	74	90	$23.3	$101.5	$82.4	$207.1

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Table 5 shows that all scenarios with funding and salinity controls greater than 2023 levels (i.e., Scenarios 2, 3, and 4) would reduce average annual salinity concentrations and annual quantified damages relative to Scenario 1, which would hold funding and salinity control at 2023 levels. For example, Scenario 3 (Controls associated with fixed implementation through 2040) would reduce 2040 average annual salinity concentrations by 22 mg/L at Parker, relative to Scenario 1, and would reduce 2040 total annual quantified damages by $62 million, relative to Scenario 1.

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STATE OF NEW MEXICO
WATER QUALITY CONTROL COMMISSION

IN THE MATTER OF:

PETITION FOR REGULATORY CHANGE TO
ADOPT AMENDMENTS TO 20.6.4 NMAC –
Standards For Interstate and Intrastate Surface Waters **WQCC 25-75 (R)**

DIRECT TECHNICAL TESTIMONY OF NATHANIEL REYNOLDS

I. INTRODUCTION

My name is Nathaniel Reynolds, and I am presenting this written testimony (**NMED Exhibit 91)** on behalf of the Department concerning proposed changes to numerical Water Quality Standards (WQS or Standards) codified at Title 20, Chapter 6, Part 4, of the New Mexico Administrative Code (20.6.4 NMAC).

My testimony will provide the technical basis and reasoning for proposed amendments to water quality criteria in 20.6.4.900(D) NMAC including:

- Updating the primary contact criterion for total microcystins, and
- Updating the primary contact criterion for cylindrospermospin.

II. QUALIFICATIONS

I am currently employed by the New Mexico Environment Department (NMED) Surface Water Quality Bureau (SWQB) Monitoring and Standards Section (MASS) as a Senior Water Quality Standards Scientist and have held this position since November 2024. I am responsible for evaluating proposed water quality standards and preparing technical water quality standards demonstrations for New Mexico's surface waters in accordance with the New Mexico Water Quality Act (WQA) and the federal Clean Water Act (CWA). I also serve as the Harmful Algal Blooms (HABs) Outreach Coordinator, and an integral member of the initial HABs program

development team. In this role I convened the New Mexico Harmful Algal Blooms Work Group to address HABs in the state with lake managers, governmental agencies and researchers and began a HABs response monitoring strategy and HABs public safety efforts. In July 2026, my efforts in collaboration with the rest of the MASS HABs team culminated in the release of the Department's formalized HAB Advisory Program which included a HAB Advisory Guidance document establishing thresholds for advisories, actions to be taken by resource managers and the recreating public, and a HAB Advisory Map to quickly, clearly, and concisely communicate HAB events and risk to the public.

I hold a Bachelor of Science degree in Chemistry from Loyola University New Orleans. Prior to working for NMED SWQB, I worked in land management with various agencies. From October 2022 to November 2023, I served at the Resource Conservation District of the Santa Monica Mountains collecting biological and fish community data and conducting riparian habitat and lagoon monitoring, water quality testing, and vegetation surveys. Before that, I conducted wildlife monitoring surveys to comply with the National Environmental Policy Act (NEPA) and the Endangered Species Act (ESA) in the Seqouia National Forest with the Great Basin Institute. From May 2021 to November 2021 I was a biological technician at the Carson National Forest where I performed headwater stream restoration and monitoring; assisted in Burned Area Emergency Response (BAER) assessments; assisted with the permit process on varying projects related to acequia construction, watershed restoration, permit compliance, and long-term monitoring; cultivated relationships in collaborative efforts with organizations such as the Albuquerque Wildlife Federation and Trout Unlimited; and participated in cattle exclosure construction, canopy cover surveys, silviculture project monitoring, *E. coli* sampling, safety hazard analysis,

archeological surveys, hosting volunteer events, and data management. An accurate and up-to-date copy of my resume is included as **NMED Exhibit 92**.

III. Proposed Primary Contact Criteria Amendments

In May 2019, the U.S. Environmental Protection Agency (EPA) published its nationally recommended Human Health Recreational Ambient Water Quality Criteria for Microcystins and Cylindrospermopsin (**NMED Exhibit 93**). The EPA based the new criteria on the latest scientific knowledge about the potential human exposure risk effects and the toxins' adverse effects to the liver and kidney as well as the reproductive, respiratory, and digestive systems. These effects range from acute short-term to chronic long-term health effects. The WQCC adopted numeric criteria for the State's designated recreational primary contact use for cyanotoxins affiliated with HABs during the 2020 Triennial Review. In the Department's original petition for the 2020 Triennial Review, the Department proposed:

> "a maximum of 8 micrograms per liter (µg/L) for total microcystins, and a maximum of 15 µg/L for cylindrospermopsin."

However, the San Juan Water Commission (SJWC) suggested that "NMED should justify the proposed duration as "maximum" for the cyanotoxins or change it to a monthly statistic similar to *E. coli* bacteria." The Department responded in its amended petition by proposing revised criteria based on EPA's recommended recurrence frequency, which was adopted by the WQCC as follows:

> ". . .a single sample of total microcystins of 8 µg/L with no more than three exceedances within a 12-month period and a single sample of cylindrospermopsin of 15 µg/L with no more than three exceedances within a 12-month period. . ."

NMED used EPA's Draft Technical Support Document (TSD) for Microcystin and Cylindrospermopsin (**NMED Exhibit 94**) during the 2020 Triennial Review. EPA has now finalized the TSD, which states "EPA recommends that each state or authorized tribe documents the recurrence frequency in the state or tribal water quality standards *or supporting documents*" (emphasis added) **(NMED Exhibit 95).** EPA also affirms that, "[s]tates and authorized tribes may adopt one or both of the national CWA Section 304(a) recommended criteria into their state or tribal water quality standards (WQS) or may use the recommended criteria magnitude values as the basis for swimming advisories and related public notification purposes." In response to the criteria adopted during the 2020 Triennial Review, as well as increasing temperatures, longer growing seasons, and the Bureau's responsive monitoring to recent algae blooms, in 2025 SWQB launched a preliminary Harmful Algal Blooms (HABs) Advisory Program, in collaboration with the New Mexico Department of Health (NMDOH), resource management agencies, and other stakeholders, which is designed to determine and communicate risks associated with HABs to the public quickly and clearly. The Bureau learned a lot from that inaugural year, so in July 2026, SWQB established a *HABs Advisory Program Guidance* document **(NMED Exhibit 96)** that uses documented advisory thresholds, including total microcystin and cylindrospermopsin concentrations, to assign a recreational or swimming advisory status to lakes and other waterbodies, inform the HAB Advisory Map, and notify the public about current health risks[1].

The Department recommends removing the frequency and duration in 20.6.4.900(D) NMAC while preserving the magnitude (i.e., EPA's swimming advisory recommendations) to read:

D. Primary contact: The following criteria apply to this use:

[1] The HABs Advisory Map is available at: https://www.env.nm.gov/surface-water-quality/habs/.

(1) [~~The monthly geometric mean of~~] E. coli bacteria (monthly geometric mean) [~~of~~] 126 cfu/100 mL or MPN/100 ml[~~,~~].

(2) [~~a single sample of~~]E. coli bacteria (single sample) [~~of~~] 410 cfu/100 mL or MPN/100 mL[~~,~~].

(3) [~~a single sample of~~]total microcystins (single sample) [~~of~~] 8 µg/L[~~ with no more than three exceedances within a 12-month period and~~].

(4) [~~a single sample of~~]cylindrospermopsin (single sample) [~~of~~] 15 µg/L[~~ with no more than three exceedances within a 12-month period, and~~].

(5) pH [~~within the range of~~] 6.6 to 9.0[~~ apply to this use. The results for E. coli may be reported as either colony forming units (CFU) or the most probable number (MPN) depending on the analytical method used.~~]

After the Department reformatted this subsection in the proposed rules attached to the Amended Petition, staff realized the Department neglected to retain the references to "single sample" for total microcystins and cylindrospermopsin that were in the proposed rules filed with the original Petition. Therefore, NMED proposes including the language in green above for clarity.

Currently, the Department is using EPA's recommended criteria magnitude values for advisories and related public notification purposes. The SWQB also assesses water quality data against the criteria according to the *Comprehensive Assessment and Listing Methodology* (CALM)[2] and its associated appendices to determine if a waterbody is attaining its uses, including primary contact recreation (20.6.4.12 NMAC). The methodologies contained within the CALM cover the decision-making process for both listing and delisting causes of impairment and the CWA § 303(d)/§ 305(b) Integrated Report (IR) **(NMED Exhibit 30)** details designated use impairment by assessment unit (i.e., waterbody or stream reach). Available microcystin and cylindrospermopsin data are integral to the Department's advisory and impairment determination processes, but each process requires different frequency and duration collection strategies and

[2] https://www.env.nm.gov/surface-water-quality/calm/

considerations. In addition, EPA recognizes in its Final Technical Support Document **(NMED Exhibit 95)** that there are multiple environmental factors that can cause variability in bloom formation and toxin production, and it is appropriate for states to consider a pattern of multiple excursions within a recreational season as well as a pattern of excursions in multiple years (i.e., more than one year) when determining whether the primary contact recreation use is attained.

Therefore, the Department proposes to strike the frequency and duration components for microcystin and cylindrospermopsin from 20.6.4.900(D) NMAC because SWQB has documented the recurrence frequency and duration in supporting documents like the *HABs Advisory Program Guidance* and CALM, similar to other pollutants. SWQB staff with monitoring, assessment, and water quality standards expertise regularly review and update these supporting documents and SWQB issues a public review and comment period for the CALM every two years prior to data assessment. We are still learning about HABs in New Mexico and improving our local dataset to better understand the temporal nature of cyanotoxins and recurrence intervals that may impair the recreational contact use. Documenting sampling and assessment details in supporting documents such as these that are routinely updated by subject matter experts when new information and data become available, which is especially important with emerging contaminants like microcystin and cylindrospermopsin, provides the Department flexibility to ensure SWQB's HAB Advisory Program and CWA § 303(d)/§ 305(b) IR assessment methods are aligned with the current state of knowledge and research, available New Mexico-specific data, evolving methodologies, and best practices.

IV. CONCLUSION

The Department recommends that the Commission adopt the proposed amendments to the Standards filed with the Department's First Amended Petition (**NMED Exhibit 27**), with the

additions of "…(single sample)" as discussed above, and based on the testimony of SWQB's witnesses.

This concludes my direct technical testimony.

PROFESSIONAL EXPERIENCE

New Mexico Environment Department:
Water Quality Standards Scientist: December 2023- Present
Prepared technically and scientifically defensible demonstrations, evaluating proposed amendments for testimony before the Water Quality Control Commission on regulatory changes to water quality standards, in accordance with various State and Federal acts and regulations, reviewed and developed technical reports, briefings, and work plans, managed specific tasks, performed water data collection and analysis, reviewed and developed water quality standards amendments, including Use Attainability Analyses, temporary standards, site-specific criteria, and other scientific studies to support changes to designated uses or water quality criteria, supported and provided technical assistance to outside entities on "third-party proposals" to amend water quality standards. Initiated Harmful Algal Bloom Advisory Program which included creating a working group, monitoring for cyanobacteria and associated cyanotoxins, drafting of NMED's first Harmful Algal Bloom Advisory Guidance.

California Conservation Corps and AmeriCorps Watershed Stewards Program:
Corpsmember: October 2022- November 2023
Served at the Resource Conservation District of the Santa Monica Mountains. With the biology department, collected field data including snorkel surveys for Steelhead Trout, electrofishing and PIT tagging, riparian habitat monitoring, Benthic Macroinvertebrate sample collection, water quality testing, Western Pond Turtle trapping and monitoring, amphibian surveys, lagoon monitoring, seining for Tidewater Gobies, Oak tree monitoring, vegetation surveys, and tree planting. Working with organizational partners, performed data management and report writing, program management, grant budgeting, equipment management, leading volunteers, and public outreach.

Great Basin Institute:
Wildlife Crew Member: May 2022-September 2022
Planned and performed Spotted Owl and Goshawk surveys in the Sequoia Complex Fire scar. Navigation and safety in high intensity burn scar. Understanding and implementing survey protocols as pertaining to the project. Used audio calling to find and establish primary activity centers of birds. Follow up surveys to determine reproductive status of the birds, attempting to establish whether both a male and female are present and find any nests or offspring.

PROFESSIONAL EXPERIENCE

Carson National Forest:
Natural Resources Biological Technician (Seasonal): May 2021-November 2021
Engaged in headwater stream restoration and monitoring utilizing a variety of low impact structures. Assisted in Burned Area Emergency Response assessment for burn severity, soil stability, and potential flooding. Acted as a biological resource advisor on the 2021 Rainbow Family Gathering incident. Gained expertise in permitting by assisting in all stages of the permit process on varying projects from the original consultation for acequia construction to NEPA surveys to implementation of watershed restoration structures, compliance on bridge construction, and long-term monitoring. Cultivated relationships in collaborative efforts with organizations such as the Albuquerque Wildlife Federation and Trout Unlimited. Participated in cattle exclosure construction, canopy cover surveys, silviculture project monitoring, E. coli sampling, safety hazard analysis, wading, archeological surveys, hosted volunteer events, on and off-road driving, UTV operation, and data management.

Valles Caldera National Preserve:
Entomology and Plant Ecology Intern: May 2017 - August 2017 (Comparable to GS-5 40hrs/wk)
Performed electro-shock fish surveys, rangeland monitoring, field identification of plants and vegetation monitoring, invasive plant surveys, invasive plant removal including chemical applications, thistle classification, plant identification, Douglas Fir bark beetle kill surveys, seeding, pheromone traps, pitfall traps, bug sorting and pinning.

Loyola University New Orleans:
Research Assistant: June 2014 - May 2018
Designed and executed synthesis experiments in an organic chemistry lab. Created and maintained detailed lab notebook records documenting all actions, times, and discussion of results. Techniques include 60 MHz and 400 MHz NMR spectroscopy, mass spectrometry, thin layer and column chromatography, Suzuki-Miyaura coupling reactions, recrystallization, precipitation reactions.

Citations:
March 2017: “Synthesis, resolution and crystal structures of two enantiomeric rhodamine derivatives.” Clifton J. Stephenson, Joel T. Mague, Nathaniel Kamm, Nathalie Aleman, Dayla Rich, Quynh-Nhu Dang and Ha Van Nguyen. Act. Cryst. E Volume 73, Part 3, pages 327-333.

EDUCATION

Loyola University New Orleans **Bachelor of Science in Chemistry- ACS Certified** May 2018

United States Environmental Protection Agency

Office of Water
Mail Code 4304T

EPA 822-R-19-001
May 2019

Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin

NMED Exhibit 93

Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin

Prepared by:

U.S. Environmental Protection Agency
Office of Water (4304T)
Health and Ecological Criteria Division
Washington, DC

EPA Document Number: 822-R-19-001
Date: May 2019

NMED Exhibit 93

NOTICES

This document has been drafted and approved for publication by the Health and Ecological Criteria Division, Office of Science and Technology, United States Environmental Protection Agency, and is approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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FOREWORD

Section 304(a) of the Clean Water Act (CWA) requires the Administrator of the U.S. Environmental Protection Agency (EPA) to publish water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water, including ground water.

The EPA is publishing these recommended values under CWA 304(a) for states to consider as the basis for swimming advisories for notification purposes in recreational waters to protect the public. The EPA envisions that if states decide to use the values as swimming advisory values they might do so in a manner similar to their current recreational water advisory programs. Alternatively, states may consider using these same values when adopting new or revised water quality standards (WQS). If adopted by states as WQS and approved by the EPA under CWA 303(c), the WQS could be used for all CWA purposes. States may also wish to consider using these values as both swimming advisory values and WQS.

This document has undergone an EPA intra-agency peer-review process. The Health and Ecological Criteria Division, Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency has completed the final review and the document is approved for publication. The values were derived using the existing peer-reviewed and published science on the adverse human health effects of the toxins including previous EPA analysis, such as the EPA's *Health Effects Support Document for the Cyanobacterial Toxin Microcystins* and *Health Effects Support Document for the Cyanobacterial Toxin Cylindrospermopsin* (HESDs), and the EPA's *Drinking Water Health Advisory for the Cyanobacterial Microcystin Toxins* and *Drinking Water Health Advisory for the Cyanobacterial Toxin Cylindrospermopsin* (Drinking Water Health Advisories) (U.S. EPA 2015a, 2015b, 2015c, 2015d). The EPA used established criteria methodologies (U.S. EPA 2000) and recreation-specific exposure parameters from the EPA's *Exposure Factors Handbook* (EFH) (U.S. EPA 2011) to derive these values. Detailed information that can be found in the EPA's HESDs and Drinking Water Health Advisories is summarized in this document.

The term "water quality criteria" is used in two sections of the CWA section 304(a)(1) and section 303(c)(2). The term has a different legal meaning in each section. In section 304, the term represents a non-regulatory, scientific assessment of effects on human health or aquatic life. The criteria recommendations presented in this document are such a scientific assessment. If the state or authorized tribe adopts water quality criteria associated with specific designated uses as WQS under section 303, and approved by the EPA, they become applicable CWA WQS in ambient waters within that state or tribe. Water quality criteria adopted in state or tribal WQS could have the same numerical values as criteria developed by the EPA under section 304. Alternatively, states and authorized tribes may derive numeric criteria based on other scientifically defensible methods, but the criteria must be protective of designated uses. States and tribes can adopt criteria into their standards. When approved by the EPA, the criteria become Clean Water Act-applicable WQS. Guidelines to assist in modifying the criteria recommendations presented in this document are contained in the Water Quality Standards Handbook (U.S. EPA 2012).

This document provides recommendations only. It does not establish or affect legal rights or obligations. It does not establish a binding norm and cannot be finally determinative of the issues addressed. Agency decisions in any particular situation will be made by applying the CWA and EPA regulations on the basis of specific facts presented and scientific information then available.

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ACKNOWLEDGMENTS

The development of this document was made possible through an effort led by John Ravenscroft, EPA Project Manager, Health and Ecological Criteria Division, Office of Science and Technology, Office of Water. The following Office of Science and Technology staff provided valuable contributions to the development and review of this document: Tracy Bone, Dr. Lesley D'Anglada, Dr. Joyce Donohue, Lars Wilcut, Oakridge Institute for Science and Education (ORISE) fellow Meghann Niesen, and summer intern Ana-Maria Murphy-Teixidor.

The EPA gratefully acknowledges the valuable contributions of the EPA internal technical reviewers who reviewed this document. Staff from the following EPA program and regional offices completed a formal review of these *Human Health Recreational Ambient Water Quality Criteria (AWQC) or Swimming Advisories for Microcystins and Cylindrospermopsin*.

U.S. EPA Office of Children's Health Protection

U.S. EPA Office of General Counsel

U.S. EPA Office of Policy

U.S. EPA Office of Research and Development

U.S. EPA Office of Water

Office of Ground Water and Drinking Water

Office of Science and Technology

Office of Wastewater Management

Office of Wetlands, Oceans, and Watersheds

U.S. EPA Regional Offices

- Region 1
- Region 4
- Region 5
- Region 7
- Region 8

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ACRONYMS AND ABBREVIATIONS

ACC	ambient cyanotoxin concentration
AWQC	ambient water quality criteria
AWWARF	American Water Works Association Research Foundation
BAX	BCL2 Associated X, Apoptosis Regulator
Bcl-2	BCL2 Apoptosis Regulator
BGAS	blue-green algae supplements
BID	BH3 interacting domain death agonist
BW	body weight
C.	*Cylindrospermopsis*
CalEPA	California Environmental Protection Agency
CAS	Chemical Abstracts Service
CAWS	Chicago Area Waterway System
CCD	cyanobacterial cell density
CDC	U.S. Centers for Disease Control and Prevention
CDEEP	Connecticut Energy and Environmental Protection
CDPH	Connecticut Department of Public Health
CFU	colony forming unit
CI	confidence interval
cm	centimeter
CTA	cell toxin amount
CWA	Clean Water Act
CyAN	Cyanobacteria Assessment Network
CYP450	Cytochrome P450
DFB	DeFlorio-Barker et al. (2017)
DIN	dissolved inorganic nitrogen
DIP	dissolved inorganic phosphorus
DON	dissolved organic nitrogen
dw	dry weight
E.	*Escherichia*
EFH	*Exposure Factors Handbook*
ELISA	Enzyme Linked Immunosorbent Assay
EPA	U.S. Environmental Protection Agency
FAQs	frequently asked questions
Fe	iron
fg	femtogram
g	grams
GI	gastrointestinal
GI2	more severe gastrointestinal symptom index
GM	geometric mean
GSD	geometric standard deviation

HAB	harmful algal bloom
HABISS	Harmful Algal Bloom-related Illness Surveillance System
HESD	Health Effects Support Document
HPLC	high performance liquid chromatography
IDEQ	Idaho Department of Environmental Quality
IQR	interquartile range
IR	ingestion rate
kg	kilograms
km	kilometer
K_{oc}	soil organic carbon-water partition coefficient
K_{ow}	octanol-water partition coefficient
L	liter
LA	leucine, alanine
LC/MS/MS	liquid chromatography with tandem mass spectrometry
LF	leucine, phenylalanine
LC_{50}	lethal concentration causing the death of 50 percent of a group of test animals
LD_{50}	lethal dose causing the death of 50 percent of a group of test animals
LOAEL	lowest-observed-adverse-effect-level
LOD	level of detection
LPS	lipopolysaccharide
LR	leucine, arginine
LW	leucine, tryptophan
LY	leucine, tyrosine
M.	*Microcystis*
m^3	cubic meter
mcy	three-letter nomenclature for genes that produce microcystins
mg	milligram
mL	milliliter
MW	molecular weight
MS	mass spectroscopy
n	sample size
N	nitrogen
N/A	not available
NASA	National Aeronautics and Space Administration
ng	nanogram
NHMRC	National Health and Medical Research Council
NLA	National Lakes Assessment
NOAA	National Oceanic and Atmospheric Administration
NOAEL	no-observed-adverse-effect-level
NORS	National Outbreak Reporting System
NYSDOH	New York State Department of Health

OATP	organic anion transporting polypeptide
OHHABS	One Health Harmful Algal Bloom System
OPP	EPA Office of Pesticide Programs
OR	odds ratio
ORSANCO	Ohio River Valley Water Sanitation Commission
P	phosphorus
PCR	polymerase chain reaction
pg	picogram
pH	potential of hydrogen
ppb	parts per billion
PWS	public drinking water system
qPCR	quantitative polymerase chain reaction
rDNA	ribosomal deoxyribonucleic acid
RfD	reference dose
ROS	reactive oxygen species
RR	relative risk or when microcystin-RR it means arginine, arginine
RSC	relative source contribution
SDWA	Safe Drinking Water Act
SWIMODEL	Swimmers Exposure Assessment Model
t	event duration
TBD	to be determined
TDI	tolerable daily intake
TN:TP	total nitrogen ratio to total phosphorus
TOXLINE	Toxicology Literature Online
U.S.	United States of America
UF	uncertainty factor
URL	Uniform Resource Locator
µg	microgram
μm^3	cubic micrometer
USGS	U.S. Geological Survey
WHO	World Health Organization
WHOI	Woods Hole Oceanographic Institute
WoS	Web of Science
WQS	water quality standards
WSDE	Washington State Department of Ecology
YR	tyrosine, arginine

1.0 EXECUTIVE SUMMARY

Cyanobacteria, also commonly referred to as blue-green algae, are photosynthetic bacteria that are ubiquitous in nature and are found in surface waters. Environmental conditions that promote excessive growth of cyanobacteria in surface waters can lead to situations in which cyanobacterial cell density is high, known as blooms. Nitrogen and phosphorus levels, the ratio of nitrogen to phosphorus, water temperature, organic matter availability, light attenuation, pH, and water column stratification are environmental factors that play an important role in the development of cyanobacterial blooms and their production of cyanotoxins. Some cyanobacteria, but not all, have the ability to produce toxins. The toxin-producing cyanobacteria contain genes that confer the ability to produce toxins and are referred to as toxigenic cells. The abundance of toxigenic cyanobacteria can vary within the overall cyanobacteria population, between waterbody to waterbody, and over time within a single waterbody.

Microcystins can be produced by a variety of toxigenic cyanobacteria genera, including *Microcystis*, *Anabaena*, *Dolichospermum, Nostoc*, *Oscillatoria*, *Fischerella*, *Planktothrix*, and *Gloeotrichia*. Some of these species can be distributed through the water column, concentrate in the upper layers, or form surface scums depending on environmental conditions. More than 100 microcystin congeners exist, which vary based on amino acid composition. The majority of toxicological data on the effects of microcystins are available for microcystin featuring leucine and arginine (microcystin-LR), which is also a frequently monitored congener. Microcystins are water soluble and tend to remain contained within the toxigenic cyanobacterial cell until the cell breaks and they are released into the water. Microcystins typically have a half-life of four to 14 days in surface waters or may persist longer, depending on factors such as photodegradation, bacteria, and the presence of organic matter. Microcystins can persist even after a toxigenic cyanobacterial bloom is no longer visible.

Cylindrospermopsin can be produced by a variety of toxigenic cyanobacteria species, including *Cylindrospermopsis raciborskii*, *Aphanizomenon*, *Anabaena*, *Lyngbya wollei*, and *Raphidiopsis*. Some of these species tend not to form visible surface scums, and the highest concentrations of total cyanobacterial cells typically occur below the water surface. Two congeners of cylindrospermopsin, as well as two structural analogs, have been identified. Cylindrospermopsin can be retained within the cell or released into the water. The biodegradation of cylindrospermopsin in natural water bodies is a complex process that can be influenced by many environmental factors, including toxin concentration, water temperature, sunlight, and the presence of cell pigments and bacteria. Half-lives of 11 to 15 days and up to eight weeks have been reported for cylindrospermopsin in surface waters.

This document for microcystins and cylindrospermopsin focuses on the human health risks associated with incidental ingestion while recreating in freshwaters containing these harmful cyanotoxins. The recommended cyanotoxin values apply to freshwaters with the recreational designated use. The toxins that are produced by cyanobacteria growing in freshwaters can enter estuarine and marine waters as waters containing the toxins flow downstream. The EPA recognizes that there may be circumstances where harmful cyanobacterial blooms (also known as harmful algal blooms or HABs) can impact downstream marine and estuarine waters. This document provides information on occurrence and incidental ingestion in estuarine and marine waters for states to consider but does not provide recommendations for those waters. Exposure to cyanobacteria and their toxins can also occur through non-recreational pathways such as consumption of cyanotoxin-contaminated drinking water and food (including fish), and during bathing or showering. This document does not address or provide recommendations for non-recreational exposures.

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The EPA is publishing these recommended values for microcystins[1] and cylindrospermopsin under the Clean Water Act (CWA) section 304(a) for states to consider as the basis for swimming advisories for notification purposes to protect public health in recreational waters. The EPA envisions that if states decide to use the values as swimming advisory values, they would do so in a manner similar to their current recreational water advisory programs. Alternatively, states may consider using these same values when adopting new or revised water quality standards (WQS). If adopted as WQS and approved by the EPA under the CWA section 303(c), the WQS could be used for all CWA purposes. States may also wish to consider using these values as both swimming advisory values and WQS.

The recommended values in this document leverage the information that the EPA collected and evaluated in its *Health Effects Support Document for the Cyanobacterial Toxin Microcystins* and *Health Effects Support Document for the Cyanobacterial Toxin Cylindrospermopsin* (HESDs), and the EPA's *Drinking Water Health Advisory for the Cyanobacterial Microcystin Toxins* and *Drinking Water Health Advisory for the Cyanobacterial Toxin Cylindrospermopsin* (Drinking Water Health Advisories) (U.S. EPA 2015a, 2015b, 2015c, 2015d).

The EPA evaluated the health effects of microcystins and derived a reference dose (RfD) in its 2015 *Health Effects Support Document for the Cyanobacterial Toxin Microcystins* (U.S. EPA 2015d). Exposure to elevated levels of microcystins can potentially lead to liver damage. The critical study for the derivation of the microcystins RfD was conducted by Heinze (1999) based on rat exposure to microcystin-LR in drinking water. The critical effect from this study was slight to moderate liver lesions with necrosis and increased liver weight and enzymes associated with tissue damage. The EPA established the RfD based on microcystin-LR and used it as a surrogate for other microcystin congeners. Monitoring and toxicity studies suggest that the microcystin-LR is the most frequently occurring congener and is more toxic than other congeners of microcystin evaluated (Loftin et al. 2016b; U.S. EPA 2015d; Ito et al. 2002; Rinehart et al. 1994; Vesterkvist and Meriluoto 2003; WHO 1999). The EPA used the RfD to derive its previously published Drinking Water Health Advisories for microcystins (U.S. EPA 2015a) and the recommended values in this document. The dose and critical effects that the EPA used from Heinze (1999) to establish the RfD are supported by a Guzman and Solter (1999) study, also conducted in rats.

The EPA evaluated the health effects of cylindrospermopsin and derived an RfD in its 2015 *Health Effects Support Document for the Cyanobacterial Toxin Cylindrospermopsin* (U.S. EPA 2015c). The kidneys and liver appear to be the primary target organs for cylindrospermopsin toxicity. The critical study that the EPA used to derive the cylindrospermopsin RfD was conducted by Humpage and Falconer (2002, 2003) based on drinking water exposure to mice. Adverse effects on the kidneys were manifested by decreases in urinary protein concentration and increased relative kidney weight. Upon considering all effects observed by Humpage and Falconer (2002, 2003), increased relative kidney weight was considered the most appropriate basis for quantitation (U.S. EPA 2015c). The EPA used the RfD to derive its previously published Drinking Water Health Advisories for cylindrospermopsin (U.S. EPA 2015b).

Based on available noncancer health effects information, the EPA is recommending values protective of primary contact recreation as follows:

[1] Microcystins comprise a class of over 100 congeners and unless specified otherwise, "microcystins" refers to total microcystins.

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- For microcystins, the recommended recreational value is 8 micrograms (μg)/liter (L).
- For cylindrospermopsin, the recommended recreational value is 15 μg/L.

These values are based on the exposure experienced by recreating children due to their higher exposures compared with other age groups. Given that toxigenic cyanobacterial blooms typically are seasonal events, recreational exposures are likely to be episodic, and may be short term in nature. The EPA recommends that if used as a swimming advisory to protect swimmers at a beach, these values not be exceeded on any single day. If used as a water quality criterion for assessment and listing purposes, the EPA recommends a maximum of three excursions across a recreational season and observation of that pattern across multiple years to reflect seasonal dynamics and occurrence patterns of HABs.

At this time, available data are insufficient to develop quantitative recreational values for total cyanobacterial cell density related to inflammatory health endpoints. The reported epidemiological relationships between cell density exposure and specific health outcomes (e.g., dermal symptoms, eye/ear irritation, fever, gastrointestinal (GI) illness, and respiratory symptoms) are not consistent. The uncertainties related to the epidemiological study differences, such as study size, species and strains of cyanobacteria present, and the total cyanobacterial cell densities associated with significant health effects, do not provide sufficient information to determine a consistent association between total cyanobacterial densities associated with adverse inflammatory health effects. The EPA recognizes that some states have included total cyanobacterial cell density values as an important part of their HAB management strategy. Available information on health endpoints, cell density, and guidelines developed by other authorities on total cyanobacteria cells is described in the Effects Characterization section of the document (section 7.5) and in Appendix D.

Because the EPA's recommendations in this document are cyanotoxin concentrations, it can be helpful for risk-management purposes to understand how this relates to toxigenic cyanobacteria in the waterbody, as the abundance of toxigenic cells in a water body affects the amount of cyanotoxin produced. The number of toxigenic cyanobacteria relative to the number of total cyanobacteria can vary in time and space. Quantifying the abundance of toxigenic cyanobacteria is a better predictor of potential toxin production compared to quantifying total cyanobacteria. The EPA presents a toxigenic cell number based on the number of toxigenic cells that could produce microcystins equivalent to the recommended magnitude. The Effects Characterization section also describes gene-based detection methods (i.e., quantitative polymerase chain reaction (qPCR)) that can target and quantify the toxigenic subpopulation of cyanobacteria that are present in a waterbody.

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2.0 INTRODUCTION AND BACKGROUND

Section 304(a) of the CWA requires the Administrator of the EPA to publish water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water.

Currently there are no U.S. federal water quality criteria or regulations for cyanobacteria or cyanotoxins in drinking water under the Safe Drinking Water Act (SDWA) or in ambient waters under the CWA. No cyanotoxins are included on EPA's priority pollutant list.[2] In 2015, the EPA published non-regulatory Drinking Water Health Advisories (U.S. EPA 2015a, 2015b) to provide information for public health officials or other interested groups on two cyanotoxins (microcystins and cylindrospermopsin) that can affect drinking water quality but are not regulated under SDWA.

The EPA is publishing these recommended values for microcystins and cylindrospermopsin under the CWA section 304(a) for states to consider as the basis for swimming advisories for notification purposes to protect public health in recreational waters. The EPA envisions that if states decide to use the values as swimming advisory values, they would do so in a manner similar to their current recreational water advisory programs. Alternatively, states may consider using these same values when adopting new or revised WQS. If adopted as WQS and approved by the EPA under the CWA section 303(c), the WQS could be used for all CWA purposes. States may also wish to consider using these values as both swimming advisory values and WQS.

The EPA-recommended values in this document leverage the information that the EPA collected and evaluated in its *Health Effects Support Document for the Cyanobacterial Toxin Microcystins* and *Health Effects Support Document for the Cyanobacterial Toxin Cylindrospermopsin* (HESDs), and its *Drinking Water Health Advisory for the Cyanobacterial Microcystin Toxins* and *Drinking Water Health Advisory for the Cyanobacterial Toxin Cylindrospermopsin* (Drinking Water Health Advisories) (U.S. EPA 2015a, 2015b, 2015c, 2015d).

This document for microcystins and cylindrospermopsin focuses on the human health risks associated with incidental ingestion while recreating in freshwaters containing these harmful cyanotoxins. The recommended cyanotoxin values apply to freshwaters with the recreational designated use. The toxins that are produced by cyanobacteria growing in freshwaters can enter estuarine and marine waters as waters containing the toxins flow downstream. The EPA recognizes that there may be circumstances where harmful cyanobacterial blooms (also known as HABs) can impact downstream marine and estuarine waters. This document provides information on occurrence and incidental ingestion in estuarine and marine waters for states to consider but does not provide recommendations for those waters. Exposure to cyanobacteria and their toxins can also occur through non-recreational pathways such as consumption of cyanotoxin-contaminated drinking water and food (including fish), and during bathing or showering. This document does not address or provide recommendations for non-recreational exposures.

International and State Guidelines

The World Health Organization (WHO 2003a) published a series of guideline values for recreational exposure to cyanobacteria associated with incremental severity and probability of health effects at increasing densities of total cyanobacteria and corresponding concentrations of chlorophyll *a* (if

[2] https://www.epa.gov/sites/production/files/2015-09/documents/priority-pollutant-list-epa.pdf

cyanobacteria dominate) (Table 2-1). The WHO also considered the potential for liver damage by microcystins in deriving the recommended total cyanobacterial cell densities. Potential concentrations of microcystins that could be associated with each guidance level are discussed in the WHO document. However, it should be noted that actual microcystin concentrations at each WHO action level could vary depending on the composition of toxigenic strains in the cyanobacterial community present and the dominant species of microcystin producer present in a bloom. For example, at a total cyanobacterial cell density of 100,000 cells/milliliter (mL), an estimated microcystin concentration of 20 µg/L could occur assuming all cells present are toxin-producing *Microcystis* species and the average cellular toxin content was 0.2 picogram (pg) microcystin per cell (WHO 2003a). Microcystin concentrations could range from 50 to 100 µg/L, or higher, if another toxin-producing species, such as *Planktothrix*, is present at the same cell density.

Table 2-1. WHO (2003a) Recreational Guidance/Action Levels for Cyanobacteria, Chlorophyll *a*, and Estimated Corresponding Microcystin Level

Relative Probability of Acute Health Effects	Cyanobacteria (cells/mL)	Chlorophyll *a* (µg/L)	Estimated Corresponding Microcystin Levels (µg/L)
Low	≤ 20,000	≤ 10	< 10[a]
Moderate	> 20,000–100,000	> 10–50	2–4 to 20[a,b]
High	> 100,000	> 50	> 20

[a] WHO estimated that 2 to 4 µg microcystins/L may be expected, with 10 µg/L possible, at a cell density of 20,000 cells/mL if microcystin-producing cyanobacteria are dominant.

[b] At 100,000 cyanobacterial cells/mL, a concentration of 20 µg microcystins/L is likely if the bloom consists of *Microcystis* and has an average toxin content of 0.2 pg/cell.

For these guidelines, the WHO recommended values that included the potential health effects from exposure to total cyanobacteria because it was "unclear whether all important cyanotoxins had been identified and that the health outcomes observed after recreational exposure could be related to cyanobacterial substances other than the well-known cyanotoxins" (WHO 2003a). The different guideline levels were an effort to distinguish between irritative or inflammatory-response symptoms associated with total cyanobacterial cells and the more severe hazard of exposure to elevated concentrations of cyanotoxins, particularly microcystins. The cell-associated inflammatory responses are represented by the low probability of adverse health effects category of ≤ 20,000 cells/mL, corresponding to ≤ 10 µg/L chlorophyll *a* if cyanobacteria dominate. According to the WHO, as the density of cyanobacteria increase above that level, the probability of inflammatory responses increases, and the potential for more severe adverse health effects associated with exposure to the cyanotoxins also increases. The WHO high-risk category includes both > 100,000 cells/mL, corresponding to 50 µg/L of chlorophyll *a*, if cyanobacteria dominate, and > 20 µg/L microcystin levels. Health effects at this level are expected to be primarily due to the toxic effects of microcystins. Very high densities of cells occurring in scums—for example, > 10 million cells/mL or > 5,000 chlorophyll *a*—can be associated with very high concentrations of toxin, for example 2,000 µg/L of microcystins in the top 4 cm of a water body (WHO 2003a). Scums that accumulate along the shoreline due to wind can be associated with a thousand-fold higher density of cells (WHO 2003a).

The WHO guideline value development was informed by results from a review conducted by Chorus and Bartram (1999). A primary study identified in this review was a prospective epidemiology study by Pilotto et al. (1997), which evaluated health effects after recreational exposure to total cyanobacteria and reported associations between total cyanobacterial cell densities and health. Pilotto et al. (1997) found a

significant association among recreators exposed to greater than 5,000 cells/mL. The WHO chose a guideline level of 20,000 cells/mL to represent the upper bound of the "low probability of adverse health effects" category (WHO 2003a). While the association among recreators exposed to greater than 5,000 cells/mL for more than one hour and one or more symptoms reported in Pilotto et al. (1997) was statistically significant, the WHO states that they represented less than 30 percent of the individuals exposed (Chorus and Bartram 1999). Therefore, the level of health effect and the small number of people affected at 5,000 cells/mL were not considered by the WHO to be a basis to justify action (WHO 2003a).

The WHO pointed out that the potential concentration of microcystins could vary depending on the composition of toxigenic strains within the overall cyanobacterial community present and the dominant species of microcystin producer present in a bloom. The WHO states that, at the same cyanobacterial cell density, cyanotoxin levels could approximately double if *Planktothrix agardhii* were the dominant member of the community.

Many countries have adopted the multiple parameters that the WHO discusses for recreational waters including cell density, biovolume, and cyanotoxin concentration (see Table 2-2). Some international authorities have multiple action levels. For brevity, Table 2-2 presents the guideline reflecting the lowest concentration of microcystins or density of cyanobacterial cells or narrative guidelines that recommended or triggered a health protective action for countries that have adopted action levels. For a more complete list of guideline or action levels and recommended actions for international jurisdictions, see Appendix A. The EPA did not identify any recreational guideline levels for cylindrospermopsin established by other international regulatory authorities.

Table 2-2. International Recreational Water Guideline or Action Levels for Cyanobacteria and Microcystins

Jurisdiction	Lowest Recreational Water Guideline/Action Level[a]	Reference
Australia[b]	microcystins (total): $\geq$ 10 µg/L or *Microcystis aeruginosa* (total): $\geq$ 500 to < 5,000 cells/mL or cyanobacteria (total): $\geq$ 0.4 to < 4 mm^3/L (where a known toxin producer is dominant in the total biovolume) or total biovolume of all cyanobacterial material $\geq$ 10 mm^3/L (where known toxins are not present)	Australian Government National Health and Medical Research Council (2008)
Canada	microcystins (total): ≥ 20 µg/L (expressed as microcystin-LR) or cyanobacteria (total): ≥ 100,000 cells/mL	Health Canada (2012)
Cuba	cyanobacteria: > 1 of the species known as potentially toxic or phytoplankton cells: > 20,000 – to < 100,000 cells/mL, > 50 percent of cells cyanobacteria	German Federal Environment Agency (2012)[c]
Czech Republic	cells: > 20,000 cells/mL	German Federal Environment Agency (2012)[c]
Denmark	chlorophyll *a*: > 50 µg/L, dominated by cyanobacteria or visible surface scum	German Federal Environment Agency (2012)[c]
European Union	appropriate monitoring must be implemented if there is a risk of proliferation of algae. Member state authorities responsible must take management measures and provide information immediately if a proliferation of cyanobacteria (or blue algae) occurs.	European Parliament and the Council of the European Union (2006)
Finland	algae (includes cyanobacteria): detected	German Federal Environment Agency (2012)[c]

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Jurisdiction	Lowest Recreational Water Guideline/Action Level[a]	Reference
France[b]	microcystins: > 25 µg/L or cyanobacteria: > 20,000 to < 100,000 cells/mL (± 20 percent)	German Federal Environment Agency (2012)[c]
Germany	Secchi Disk reading > 1 m and (microcystins): ≥ 10 µg/L or chlorophyll *a* (with dominance by cyanobacteria): ≥ 40 µg/L or biovolume: ≥ 1 mm^3/L)	German Federal Environment Agency (2012)[c]
Hungary	microcystins: ≥ 4 to < 10 µg/L or cell count: ≥ 20,000 to < 50,000 cells/mL or chlorophyll *a* (with dominance by cyanobacteria): ≥ 10 to < 25 µg/L	German Federal Environment Agency (2012)[c]
Italy[b]	microcystin-LR: > 20 µg/L equivalents or cyanobacterial cell count for cyanotoxin-producing species other than those that produce microcystins (e.g., cylindrospermopsin) > 100,000 cells/mL (± 20 percent) or transparency ≤ 1 m and total phosphorus > 20 µg/L and total cyanobacterial cell count > 2,000 to ≤ 20,000 cells/mL (± 20 percent) or transparency ≥ 1 m and total phosphorus > 20 µg/L and total cyanobacterial cell count ≤ 2,000 cells/mL	Funari et al. (2017)
Netherlands	chlorophyll *a*: ≥ 12.5 to ≤ 75 µg/L or biovolume (cyanobacterial cell count): ≥ 2.5 to ≤ 15 mm^3/L	German Federal Environment Agency (2012)[c]
New Zealand[b]	microcystins (total): ≥ 12 µg/L or cyanobacteria (benthic): 20−50 percent coverage of potentially toxigenic cyanobacteria attached to substrate or cyanobacteria (total): > 0.5 to < 1.8 mm^3/L (biovolume equivalent of potentially toxic cyanobacteria) or cyanobacteria (total): > 0.5 to < 10 mm^3/L (biovolume equivalent of the combined total of all cyanobacteria)	Wood et al. (2008)
Poland	visible blooms	German Federal Environment Agency (2012)[c]
Scotland[b]	chlorophyll *a*: ≥ 10 µg/L with dominance of cyanobacteria or cyanobacteria: ≥ 20,000 cells/mL	Scottish Government Health and Social Care Directorates Blue-Green Algae Working Group (2012)
Spain	cyanobacteria proliferation potential (low)	German Federal Environment Agency (2012)[c]
Turkey	microcystin-LR: > 25 µg/L equivalents or cells: ≥ 20,000 to 100,000 cells/mL	German Federal Environment Agency (2012)[c]
World Health Organization (WHO)	cyanobacteria: 20,000 cells/mL or chlorophyll *a*: 10 µg/L (approximately 2-4 µg microcystins/L, assuming cyanobacteria dominance)	Chorus and Bartram (1999); WHO (2003a)

[a] More details are provided in Appendix A.

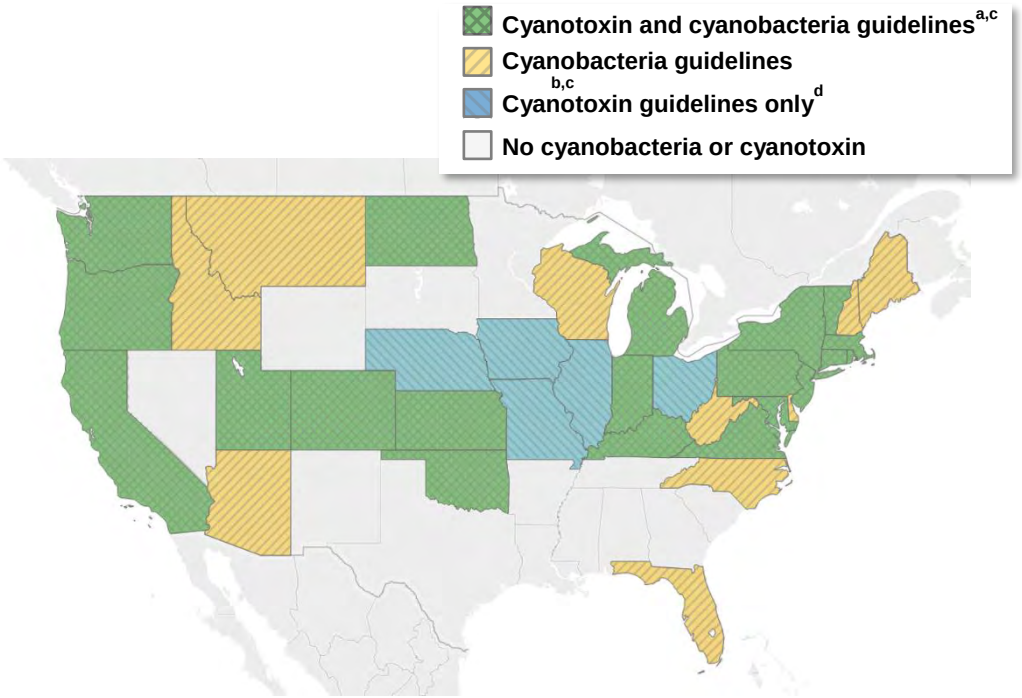
[b] The lowest guideline values for each quantitative parameter (i.e., cyanotoxin concentration, cyanobacterial cell density, biovolume) are not associated with the same action level. For example, for Australia, the lowest cyanobacterial cell density and biovolume criteria trigger the green level surveillance mode, and the lowest cyanotoxin concentration triggered the red level action mode.

[c] Following the VIIIth International Conference on Toxic Cyanobacteria, the German Federal Environmental Agency compiled and published in 2012 regulatory approaches to the assessment and management of cyanotoxin risks based on contributions by member countries.

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As of March 2018, approximately 35 U.S. states have implemented cyanobacterial HAB guidelines for recreational waterways. As graphically shown in Figure 2-1, five states have quantitative or qualitative cyanotoxin guidelines only, and 20 states have quantitative guidelines for cyanotoxins, as well as either quantitative or qualitative guidelines for total cyanobacterial cell density. Qualitative guidelines for cell density use visual inspection rather than quantitative detection methods. In addition, 10 states had quantitative guidelines for cyanobacterial cell density only or had qualitative guidelines for cyanobacteria only. Seven states have guideline levels that address toxin-producing cyanobacteria as a proportion of the total cyanobacterial population or include a toxin-specific cyanobacteria cell density (California, Idaho, Maryland, New York, New Hampshire, Oregon, and Virginia). The Karuk Tribe, located in California, developed cell-based values for posting cyanotoxin public health warnings for the tribe's recreational waters (Kann 2014). Its values were based on the site-specific relationships between the cell densities of *Microcystis* and the level of microcystins observed in Karuk waters. For example, in the Klamath River, at 20,000 cells *Microcystis*/mL, the probability of exceeding 4 µg/L microcystins was 55 percent, while at 5,000 cells/mL there were no exceedances. Because the probability of exceeding the microcystins benchmark rapidly increased at cell densities above 5,000 *Microcystis*/mL, the Karuk Tribe uses that value to inform decision-making for health warnings (Kann 2014).

Figure 2-1. State Guidelines for Cyanotoxins and Cyanobacteria in Recreational Water by Type and Scope of Guidelines



[a] Includes states with quantitative cyanotoxin guidelines as well as either quantitative or qualitative cyanobacteria guidelines.

[b] Includes states that either have quantitative cyanobacteria guidelines only or qualitative guidelines only.

[c] The EPA found that Texas and North Carolina published guidelines in the past, but the guidelines were no longer on their websites.

[d] Missouri has presence/absence testing for cyanotoxins and quantitative thresholds.

For brevity, Table 2-3 lists the lowest recreational water guideline or narrative guidelines or action levels for microcystins, cylindrospermopsin, or total cyanobacteria that trigger or recommend a health protective action for U.S. states. For a more complete list of state guideline or action levels see

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Appendix B. Parameters and values used as the basis for guidelines varied across states, as did the methodologies for developing the values.

Table 2-3. State Guideline or Action Levels for Microcystins, Cylindrospermopsin, and Cyanobacterial Cells in Recreational Water

State	Lowest Recreational Water Guideline or Action Level[a]	Reference
Arizona	Blue-green algae (mean value based on a minimum of two sample events within one peak season): 20,000 cells/mL and Chlorophyll *a* result (mean value based on a minimum of two sample events within one peak season) in target range	Arizona Department of Environmental Quality (2008)
California	Microcystins: 0.8 µg/L	Butler et al. (2012); Cyanobacteria Harmful Algal Bloom Network (2016a, 2016b)
	Cylindrospermopsin: 1 µg/L	
	Toxin-producing cyanobacteria: 4,000 cells/mL	
	Site-specific indicators of cyanobacteria (e.g., blooms, scums, mats)	
Colorado	Microcystin-LR: ≥ 10 µg/L and < 20 µg/L	Colorado Department of Public Health and Environment (2016)
	Cylindrospermopsin: ≥ 7 µg/L	
	Potentially toxic algae are visible	
Connecticut[b]	Combination of visual inspection, cell counts: Visual rank category 2: Blue-green algae cells > 20,000 cells/mL and < 100,000 cells/mL	Connecticut Department of Public Health (CDPH) and Connecticut Energy and Environmental Protection (CDEEP) (CDPH and CDEEP 2017; CDEEP 2017)
Delaware	Thick green, white, or red scum on surface of pond	Delaware Department of Natural Resources and Environmental Control: Division of Water (2016)
Florida	Cyanobacteria bloom	Florida Department of Environmental Protection (2019)
Idaho	*Microcystis* or *Planktothrix*: > 40,000 cells/mL	IDEQ (2015)
	Sum of all potentially toxigenic taxa: ≥ 100,000 cells/mL	
Illinois	Microcystin-LR: > 10 µg/L	Illinois Environmental Protection Agency (2018); Illinois Environmental Protection Agency (2013)
Indiana	Blue-green algae: 100,000 cells/mL	Indiana Department of Environmental Management (2018)
	Microcystin-LR: 4 µg/L	
	Cylindrospermopsin: 8 µg/L	
Iowa	Microcystin: ≥ 20 µg/L	Iowa Environmental Council (2018)
Kansas	Cyanobacteria: ≥ 80,000 and < 250,000 cells/mL	Kansas Department of Health and Environment (2015a); Kansas Department of Health and Environment (2015b)
	Microcystin: ≥ 4 and < 20 µg/L	
Kentucky	Blue-green algae: > 100,000 cells/mL	Kentucky Department for Environmental Protection (2014)

State	Lowest Recreational Water Guideline or Action Level[a]	Reference
	Microcystins: > 20 µg/L	Commonwealth of Kentucky Department for Environmental Protection Division of Water (2015)
Maine	Secchi disk reading < 2 meters caused by algae	Maine Department of Environmental Protection (2013)
Maryland	*Microcystis aeruginosa* or other potential microcystin-producing blue-green algae > 40,000 cells/mL, and samples contain microcystins: > 10 ppb	Wazniak personal communication (2016); Maryland Department of Natural Resources (2014)
Massachusetts	Blue-green algae: > 50,000 cells/mL	Massachusetts Bureau of Environmental Health (2015); Massachusetts Department of Public Health (2008)
	Microcystins: ≥ 14 µg/L	
Michigan	Microcystin: ≥ 20 µg/L	Michigan Department of Environmental Quality (2018); Kohlhepp G (2015)
	Chlorophyll *a*: > 30 µg/L and visible surface accumulations/scum are present, or cells are visible throughout the water column	
Missouri	Microcystins: presence (test strip range 0 to 10 ng/mL)	Missouri Department of Natural Resources (2017)
	Cylindrospermopsin: presence (test strip range 0 to 10 ng/mL)	
Montana	Reservoirs that seem stagnated and harbor large quantities of algae	State of Montana Newsroom (2015)
Nebraska	Microcystin: ≥ 20 µg/L	Nebraska Department of Environmental Quality and Nebraska Department of Health and Human Services: Division of Public Health (2018)
New Hampshire	Cyanobacteria: > 50 percent of total cell counts from toxigenic cyanobacteria	New Hampshire Department of Environmental Services (2014)
New Jersey	Microcystins (as total including -LR and other detectable congeners): 3 µg/L	New Jersey Department of Environmental Protection (2017)
	Cylindrospermopsin: 8 µg/L	
	Cyanobacterial cell count: ≥ 20,000 cells/mL	
New York	Bloom: credible report or digital imagery of a bloom determined as likely to be potentially toxic cyanobacteria by DEC or DOH staff	New York State Department of Environmental Conservation (2017)
	Blue-green chlorophyll *a*: > 25 µg/L	
	Microcystin-LR: > 4 µg/L	
North Carolina	Visible discoloration or surface scum	North Carolina Health and Human Services: Division of Public Health (2014)
North Dakota	Blue-green algae bloom is present over a significant portion of the lake AND microcystin-LR: ≥ 10 µg/L	North Dakota Department of Health: Division of Water Quality (2016)
Ohio	Microcystins: 6 µg/L	Ohio EPA (2016)
	Cylindrospermopsin: 5 µg/L	
Oklahoma	Cyanobacteria: 100,000 cell/mL	Oklahoma Legislature (2012)

State	Lowest Recreational Water Guideline or Action Level[a]	Reference
	Microcystin: > 20 µg/L	
Oregon	Cylindrospermopsin: ≥ 8 µg/L	Oregon Health Authority (2018)
	Microcystin: ≥ 4 µg/L	
	Microcystis: > 40,000 cells/mL	
	Planktothrix: > 40,000 cells/mL	
	Toxigenic species: > 100,000 cells/mL	
	Visible scum with documentation and testing	
Pennsylvania	Microcystin: > 6 µg/L	Pennsylvania Department of Environmental Protection (2014)
	Cylindrospermopsin: > 5 µg/L	
	HAB verified by visual observation	
Rhode Island	Cyanobacteria: > 70,000 cells/mL	Rhode Island Department of Environmental Management and Rhode Island Department of Health (2013)
	Microcystin-LR: ≥ 14 µg/L	
	Visible cyanobacteria scum or mat	
Utah	Cyanobacteria: 20,000–10,000,000 cells/mL	Utah Department of Environmental Quality and Department of Health (2017)
	Microcystin: 4–2,000 µg/L	
Vermont	Cylindrospermopsin: ≥ 10 µg/L	Vermont Department of Health (2015)
	Microcystin-LR (equivalents): ≥ 6 µg/L	
	Visible known blue-green algae bloom/scum or an unknown, potentially blue-green algae (i.e., not pollen), bloom/scum	
Virginia	Blue-green algal "scum" or "mats" on water surface	Virginia Department of Health (2012)
	Microcystin: > 6 µg/L	
	Microcystis: 5,000 to < 20,000 cells/mL	
Washington	Bloom is forming or a bloom scum is visible (toxic algae may be present); cyanotoxin levels do not exceed thresholds	Hardy and Washington State Department of Health (2008); Hardy and Washington State Department of Health (2011)
	Microcystins: 6 µg/L	
	Cylindrospermopsin: 4.5 µg/L	
West Virginia	Blue-green algal blooms observed and monitored	West Virginia Department of Health and Human Resources (2015)
Wisconsin	Cyanobacteria: > 100,000 cells/mL	Wisconsin Department of Natural Resources (2012); Wisconsin Department of Health Services (2016)
	Visible scum layer	Werner and Masnado (2014) ; Wisconsin Department of Health Services (2016)

[a] More details are provided in Appendix B.
[b] Connecticut states "based on US EPA's draft recreational criterion, CT DPH suggests a cyanotoxin threshold of 4 µg/L microcystin."
[c] The EPA found that Texas published guidelines in the past, but the guidelines were no longer on its website.

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3.0 NATURE OF THE STRESSORS

This section describes cyanobacteria and cyanobacterial blooms that have the potential to produce microcystins and cylindrospermopsin. It also describes the chemical and physical properties, sources and occurrence information in different media, environmental fate, and toxicokinetics for the cyanotoxins. The information in this section is based on information the EPA presented in its HESDs and Drinking Water Health Advisories (U.S. EPA 2015a, 2015b, 2015c, 2015d). The EPA conducted supplemental literature searches in September 2015 to capture new references related to the following topics:

- Levels of human exposure to cylindrospermopsin or microcystins through recreational water activities.
- Health effects for humans or animals exposed to cylindrospermopsin or microcystins.
- State and international safety levels or criteria for microcystins or cylindrospermopsin.
- Recreational exposure ingestion rates for children's age groups.
- Incidents of pet or livestock adverse health effects, including mortality, due to exposure to cyanotoxins.

For detailed information on these supplemental literature searches and the five research questions that correspond to the bullets above, see Appendix C.

Cyanobacteria are a group of microorganisms that naturally occur in freshwater and marine environments and can be found at higher densities in eutrophic or nutrient-enriched water bodies. Many cyanobacteria are capable of producing toxins, referred to as cyanotoxins, which can adversely affect human health. Under the right conditions of water temperature, light, pH, nutrient availability, and other factors, cyanobacteria can reproduce rapidly, forming what are commonly referred to as cyanobacterial HABs. Other microorganisms can form HABs, but for the purpose of this document the usage of "HABs" refers to cyanobacterial HABs unless otherwise specified.

3.1 Cyanobacteria and Cyanobacterial Blooms

Cyanobacteria are photosynthetic prokaryotes (Seckbach and Oren 2007) and are ubiquitous in the environment. Cyanobacteria smaller than 2.0 µm are known as picocyanobacteria (Jakubowska and Szeląg-Wasielewska 2015). The chloroplast, found in photosynthetic eukaryotes like algae and plants, evolved from an endosymbiotic relationship with cyanobacteria (Kutschera and Niklas 2005). Ecologists historically grouped cyanobacteria, often referred to as "blue-green algae," with eukaryotic algae because they contain chlorophyll *a* and can perform oxygenic photosynthesis. However, cyanobacteria are prokaryotes (i.e., no discrete membrane-bound nucleus or membrane-bound subcellular organelles) and are genetically related to other bacteria in the eubacteria domain. Taxonomically, they are classified in the phylum Cyanobacteria or Cyanophyceae (Carmichael 2008; O'Neil et al. 2012).

Cyanobacteria, including picocyanobacteria, can produce bioactive compounds including toxins, which can be harmful. These biomolecules include hepatotoxic, neurotoxic, and cytotoxic compounds and compounds that can result in allergic reactions (Burkholder and Glibert 2006; Carmichael 1994; Jaiswal et al. 2008; Jakubowska and Szeląg-Wasielewska 2015; Śliwińska-Wilczewska et al. 2018; Volk and

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Mundt 2007). Studies have shown that exposure to cyanobacterial cells can cause health effects that are independent of the cyanotoxins; this information is detailed in Appendix D.

Under certain conditions, cyanobacteria possessing the toxin synthesis genes, also referred to as toxigenic cyanobacteria, begin producing cyanotoxins. Numerous biotic and abiotic factors can influence not only the dominance of cyanobacteria within the overall phytoplankton community, but also the proportion of toxigenic cyanobacteria relative to non-toxin-producing cyanobacteria (Davis et al. 2009; Hyenstrand et al. 1998; McCarthy et al. 2009; Neilan et al. 2013; Gobler et al. 2016). Multiple species of cyanobacteria are capable of producing the same toxin, such as the microcystins, which can pose a risk to human and animal health (Crawford et al. 2017). Although scientists have observed a generalized relationship between cyanobacteria density or chlorophyll *a* and cyanotoxin concentration, these relationships are affected by the dominance of the toxin-producing cyanobacteria within the overall cyanobacterial community (Zhang et al. 2014; Loftin et al. 2016b).

Members of the genera *Microcystis*, *Dolichospermum* (*Anabaena*), *Nostoc*, *Fischerella*, *Planktothrix* (formerly *Oscillatoria*), and *Gloeotrichia* can produce microcystins (Carey et al. 2012b; Codd et al. 2005; Duy et al. 2000; Stewart et al. 2006c). *Microcystis aeruginosa* occurs mostly at the surface with higher light intensities and in shallow lakes. Kosten et al. (2012) surveyed 143 shallow lakes along a latitudinal gradient (between 5–55°S and 38–68°N) from subarctic Europe to southern South America. *Microcystis* have been documented to occur in blooms on all continents except Antarctica and often dominate phytoplankton assemblages in the summer (O'Neil et al. 2012). *Microcystis* have been documented throughout the United States (Carmichael 2001; Jacoby et al. 2000). Species of cyanobacteria, like *Microcystis*, that occur at or near the surface due to buoyancy and wind, can accumulate on shores and bays where they can form scums (Australian Government National Health and Medical Research Council 2008; WHO 2003b).

Cylindrospermopsin can be produced by a number of cyanobacterial species including *Raphidiopsis raciborskii* (formerly Cylindrospermopsis raciborskii),[3] *Aphanizomenon flos-aquae*, *Aphanizomenon gracile*, *Aphanizomenon ovalisporum*, *Umezakia natans*, *Anabaena bergii*, *Anabaena lapponica*, *Anabaena planctonica*, *Lyngbya wollei*, *Raphidiopsis curvata*, and *Raphidiopsis mediterranea* (B-Béres et al. 2015; Kokocinski et al. 2013; McGregor et al. 2011; Moreira et al. 2013). These species do not tend to form visible surface scums and the highest concentrations of cyanobacterial cells occurs below the water surface (Falconer 2005).

Cylindrospermopsin-producing cyanobacteria occur in tropical or subtropical regions, as well as warmer temperate regions. For example, *Cylindrospermopsis raciborskii* occurs in freshwater ponds, rivers, reservoirs, and eutrophic lakes and has been found in Australia, Asia, Europe, Africa, and South, Central, and North America (Fuentes et al. 2010). According to a survey conducted in Florida in 1999 from June to November, the most frequently observed toxigenic cyanobacteria were *Microcystis* (43.1 percent), *Cylindrospermopsis* (39.5 percent), and *Anabaena* (28.7 percent) (Burns 2008).

Research indicates that cyanotoxins can confer competitive advantage for survival and replication and are associated with physiological functions of cyanobacterial cell signaling, nutrient uptake, iron scavenging, maintenance of homeostasis, and protection against oxidative stress (Holland and Kinnear 2013). Cylindrospermopsin production provides a competitive advantage to cyanobacteria when phosphorus becomes scarce. Bar-Yosef et al. (2010) observed that when phosphorus is scarce, the

[3] Cyanobacteria taxonomy is continuously being revised. The genus *Cylindrospermopsis* has been renamed to *Raphidiopsis*. This document mostly maintains the genus name of *Cylindrospermopsis.*

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cyanobacterium *Aphanizomenon ovalisporum* releases cylindrospermopsin, which causes other microorganisms to release alkaline phosphatase, a compound that will increase available free phosphorus. Subsequently, *Aphanizomenon* can gain access to phosphorus made available by other microorganisms while simultaneously conserving the energy and resources required to express and excrete alkaline phosphatase (Bar-Yosef et al. 2010). The precise ecological function of microcystins has not been determined conclusively (Zurawell et al. 2005). Studies comparing wild-types and mutants of a microcystin-producing species, examining the genes involved in microcystin biosynthesis, and evaluating *Microcystis* colony size have suggested that microcystins play important physiological roles in cyanobacteria, including colony formation (Kaplan et al. 2012; Zurawell et al. 2005). Gobler et al. (2007) observed decreased zooplankton grazing when toxigenic *Microcystis* were actively producing microcystin. Although cyanotoxins can negatively affect humans and other animals, research suggests that the primary functions of cyanotoxins are in cyanobacterial physiology and microbial ecology.

Cyanobacteria can regulate their buoyancy; thus, they can actively seek water depths with optimal growth conditions and will enlarge their gas vesicles to adapt to turbulent conditions. When weather conditions shift from turbulent to strongly stratified, excessively buoyant cells may accumulate at the surface because the regulation of buoyancy takes a few days (Australian Government National Health and Medical Research Council 2008, WHO 2003b). When the rate of cyanobacterial cell growth exceeds the loss rate for a population, positively buoyant, floating cyanobacterial cells can also accumulate at the surface (Falconer 1998). This accumulation can form a visibly colored scum on the water surface, which can contain more than 10,000 cells/mL (Falconer 1998). Scums can pose an elevated health risk to recreational users. The floating scum can be concentrated by prevailing winds in certain surface water areas, especially at the shore as is the case for *Microcystis*. Scums have frequently been reported to accumulate cells and cyanotoxin concentration by a factor of 1,000 or more, with million-fold accumulations resulting in pea soup consistency (Australian Government National Health and Medical Research Council 2008; WHO 2003b).

The microbial community can be complex and variable. It can consist of multiple different species and strains of cyanobacteria and other microbes. Microbial interactions can occur within blooms, such as competition and adaptation between toxic and nontoxic cyanobacterial strains, as well as impacts from viruses and zooplankton grazers like *Daphnia* (large generalist grazers), copepods, and cladocerans (Ger et al. 2014). Each of these microbial-related factors can cause fluctuations in bloom development and composition.

3.1.1 Environmental Factors Influencing Occurrence of Cyanobacteria and Cyanotoxins

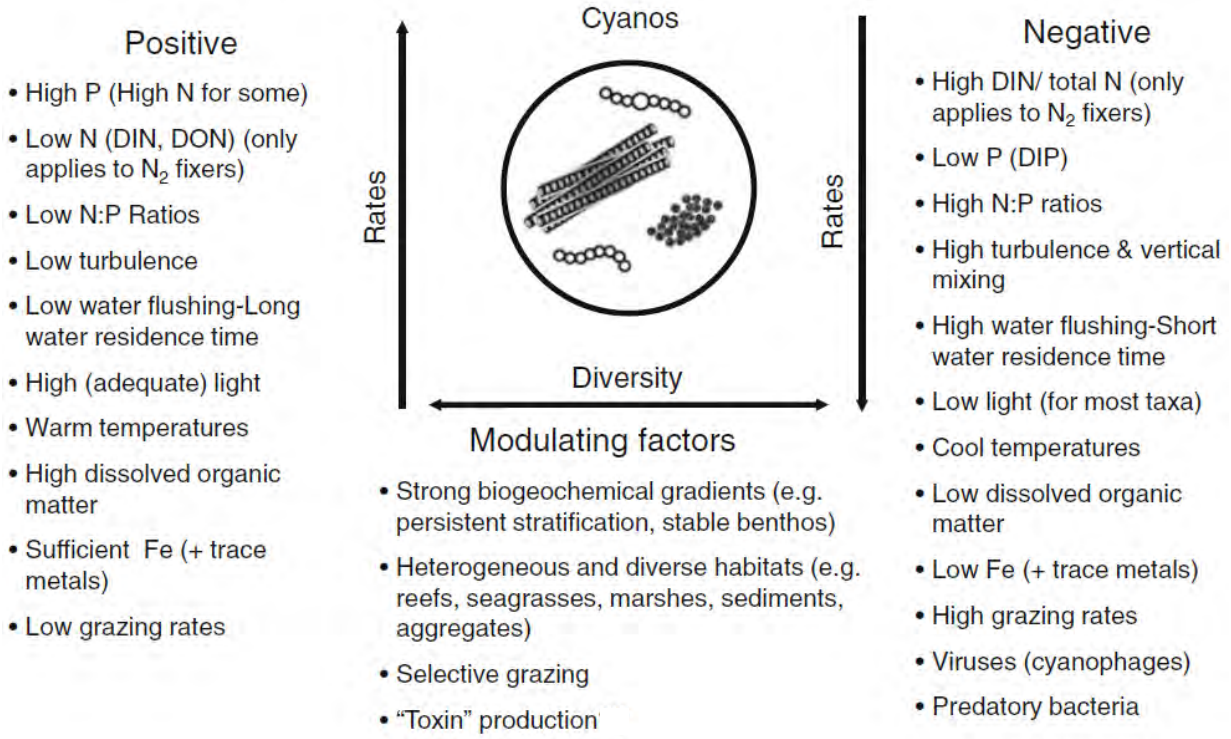
A variety of physical, chemical, and environmental factors can influence both cyanobacteria proliferation and toxin production, including nutrient (e.g., nitrogen and phosphorus) concentrations, water temperature, light levels, and pH. Other factors include water turbulence, mixing, and flushing, oxidative stressors, and interactions with other biota (e.g., viruses, bacteria, and animal grazers), as well as their combined effects (Paerl and Otten 2013a, 2013b). See Figure 3-1.

Total cyanobacterial density in a bloom and cyanotoxin concentration are not always closely related. Cyanotoxin concentrations depend on the dominance and diversity of species and strains within the bloom along with environmental and ecosystem influences on bloom dynamics (Chorus et al. 2000; Hitzfeld et al. 2000; WHO 1999). Cyanotoxin production can vary among strains and clones of a single species (Carmichael 1994; Utkilen and Gjølme 1992) and within and between blooms (Codd and Bell 1985). Growth phase also can influence cyanotoxin production (Jaiswal et al. 2008). Biomass and toxin production do not necessarily coincide (section 7.5.2.3). Francy et al. (2016) modeled the relationship of

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environmental variables compared to cyanotoxin levels. They demonstrated that some environmental factors such as measures of the algal community (e.g., phycocyanin, cyanobacterial biovolume, and cyanobacterial gene concentrations) and pH are strongly correlated with microcystin concentrations.

Figure 3-1. Environmental Factors Influencing Total Cyanobacterial Blooms, Reproduced from Paerl and Otten (2013b)



Cyanotoxins can be found inside the cell (i.e., intracellular) or external to the cell in the water (i.e., extracellular). The proportion of intracellular versus extracellular cyanotoxin can vary. Extracellular microcystins (either dissolved in water or bound to other materials) typically are less than 30 percent of the total microcystin concentration in source water (Graham et al. 2010). Most of the microcystins are intracellular and released into the water when the toxigenic cyanobacterial cells rupture or die. Cylindrospermopsin can be retained within the cyanobacterial cell or released. The ratio of intracellular to extracellular cyanotoxin can change depending on the growth phase with as much as 50 percent of cylindrospermopsin produced by *Cylindrospermopsis raciborskii* released extracellularly (Griffiths and Saker 2003).

A complex interplay of environmental factors dictates the spatial and temporal changes in the concentration of cyanobacterial cells and their toxins with respect to the dominant species. Factors such as the amount and timing of nutrient supply (i.e., nutrient concentration and nutrient loading), the relative proportions of nutrients (i.e., nitrogen to phosphorus ratio), dissolved organic matter availability, temperature, and light attenuation, as well as other physico-chemical processes, can play a role in shaping cyanobacterial bloom composition and cyanotoxin production (Paerl and Huisman 2008; Paerl and Otten 2013b).

Some cyanobacteria possess toxin genes that enable them to produce toxins, while other cyanobacteria do not contain toxin genes and therefore cannot produce toxins. For example, cyanobacteria that can produce microcystins contain a collection of genes, called "*mcy*" genes, that when expressed produce

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microcystins. Multiple species of cyanobacteria can contain this set of genes. Together these species comprise microcystin-producing toxigenic cyanobacteria. Ten genes are in the microcystin gene cluster, *mcyA* through *mcyJ* (Tillett et al. 2000). Different researchers have studied the occurrence and prevalence of these genes within cyanobacteria populations.

Environmental factors can provide competitive advantages to *Microcystis* relative to other phytoplankton (Jacoby et al. 2000; Marmen et al. 2016). Evidence suggests that these environmental factors also affect the relative abundance of microcystin-producing strains and non-microcystin-producing strains (Marmen et al. 2016). *Microcystis* thrive in warmer temperatures, with optimal growth and photosynthesis occurring above 25°C (O'Neil et al. 2012). A Japanese study between May and November 2006 found that the toxin-producing species, *Microcystis aeruginosa*, dominated in months with relatively higher water temperatures, while the non-toxin-producing species, *M. wesenbergii*, dominated in months with lower water temperatures (Imai et al. 2009). The genetic composition of the bloom can also influence the degree of toxicity associated with an algal bloom. Lee et al. (2015) found that *Microcystis* typically comprised less than one percent of the total cyanobacterial abundance in Vancouver Lake, Washington, but the majority of the *Microcystis* cells contained the toxin-producing gene. Despite comprising a small percentage of the total cyanobacterial community in this lake, *Microcystis* were the sole microcystin-producing cyanobacteria and were responsible for microcystin concentrations that exceeded the WHO guidelines several times throughout the sampling period. In addition, increases in phosphate concentrations were associated with increases in both toxigenic and non-toxigenic *Microcystis* and with toxin production. The authors note that quantifying *Microcystis mcyE* gene (one of the genes responsible for toxin production) copy number, rather than relying solely on visual cell counts, might be a better estimate of overall cyanotoxin concentration (Lee et al. 2015).

Zhang et al. (2015) observed that low flow conditions favored total cyanobacteria and higher flow conditions favored green algae. Loftin et al. (2016a) suggest that low stream flow, shallow depth, and high water-column light penetration in Piedmont streams favored periphyton occurrence (mixture of algae, cyanobacteria, heterotrophic bacteria, and detritus).

Phytoplankton competition and food web interactions occur as blooms develop, persist, and decline, thereby impacting cyanotoxin concentrations in surface waters. In addition, potential warming of surface waters and changes in precipitation could result in changes in ecosystem dynamics that lead to more frequent formation of cyanobacteria blooms and their associated toxins (Paerl et al. 2011; Paerl and Huisman 2008; Paerl and Otten 2013b).

3.1.1.1 Nutrients

Nutrients, particularly nutrient over-enrichment, are key environmental drivers that influence the proportion of cyanobacteria in the phytoplankton community, the cyanobacterial biovolume, cyanotoxin production, and the impact that cyanobacteria may have on ecosystem function and water quality (Yang et al. 2016a; Beaulieu et al. 2013; Paerl et al. 2011). Cyanobacteria have been shown to dominate the phytoplankton communities in eutrophic lakes (Downing et al. 2001; Monchamp et al. 2014). Phosphorus loading has been linked to the proliferation of cyanobacteria and the shift toward cyanobacterial dominance of the phytoplankton community (O'Neil et al. 2012). However, it is important to consider both phosphorus and nitrogen when considering the occurrence of toxigenic cyanobacterial blooms. Cyanobacterial toxin concentrations are also associated with nutrient levels (Wang et al. 2002); however, different cyanobacteria species use organic and inorganic nutrient forms differently. Dolman et al. (2012) found that total cyanobacterial biomass was higher in lakes with above-

average nitrogen and phosphorus concentrations and that concentrations of all cyanotoxin groups were higher in lakes with higher total nitrogen and total phosphorus concentrations.

Paerl (2008) demonstrated that nitrogen and phosphorus additions, both independently and together, can stimulate primary productivity and *Cylindrospermopsis raciborskii* biomass. Elevated nitrogen and phosphorus loading can enhance the growth and cyanotoxin levels of *Microcystis* blooms and microcystin synthetase gene expression (Gobler et al. 2007; O'Neil et al. 2012; Marmen et al. 2016). Gobler et al. (2007) found that *Microcystis* dominance and toxin production was stimulated by elevated nitrogen and suppressed by nitrogen limiting conditions. Toxin production may cause the inhibition of grazing by mesozooplankton and further accumulation of cyanobacterial cells. Willis et al. (2015) found the highest growth rates for environmental isolates of *Cylindrospermopsis raciborskii* were observed with the addition of nitrogen.

The relative abundance of nitrogen and phosphorus can be an important consideration in regards to toxigenic cyanobacterial blooms. Loadings of nitrogen, or phosphorus, or both, to water bodies from agricultural, industrial, and urban sources influences the development of total cyanobacterial blooms and are associated with cyanotoxin production (Paerl et al. 2011). Smith (1983) was the first to describe a strong relationship between the relative amounts of nitrogen and phosphorus in surface waters and toxigenic cyanobacterial blooms. Smith proposed that cyanobacteria should be superior competitors under conditions of nitrogen limitation because of their unique capacity for nitrogen fixation, although many cyanobacteria like *Microcystis* that produce toxins do not fix nitrogen. Many toxigenic cyanobacterial blooms are comprised of non-nitrogen-fixing genera and in the presence of elevated phosphorus, nitrogen can be a limiting factor for biomass proliferation and microcystin production (Gobler et al. 2007). Schindler et al. (2008) demonstrated that lower nitrogen inputs relative to phosphorus loadings can lead to dominance of nitrogen-fixing cyanobacteria in mesocosm- and ecosystem-scale experiments in prairie and boreal lakes. Otten et al. (2012) reported higher average microcystin concentrations and a higher prevalence of toxigenic *Microcystin* biomass at sites that had narrower TN:TP ratios (< 20) in Lake Taihu, China. Fortin et al. (2015) demonstrated that the dominance of *Microcystis* depended on the ratio of nitrogen to phosphorus, with a (mass) ratio 11:1 resulting in the highest abundance of *Microcystis*, whereas the concentrations of each nutrient were significant factors affecting the amount of biomass that could be generated.

Cyanotoxin concentration can be related to cyanobacterial cell abundance, which is facilitated by nutrient availability (Welker 2008), so nutrient concentration can be correlated to cyanotoxin concentration. Yuan et al. (2014; 2015) developed nutrient thresholds related to microcystin concentrations, cyanobacterial biovolume, and chlorophyll *a*. Nutrient availability, environmental conditions, and ecosystem interactions can affect the production and amount of toxins that cells produce and release (Bar-Yosef et al. 2010; Dolman et al. 2012; Graham et al. 2004; Paerl et al. 2001). For example, both nitrogen and phosphorus have been shown to promote the production of microcystins during bloom events (Davis et al. 2009; Gobler et al. 2016; Ha et al. 2009). Horst et al. (2014) found a significant positive relationship between cellular microcystin amounts and nitrate concentration with nitrogen limitation related to lower cell quotas of microcystin. Ha et al. (2009) found that microcystin concentrations were highly associated with *mcyA* gene copies and that high concentrations of nitrates and ammonium increased microcystin production by promoting the growth of toxigenic *Microcystis*. Elevated phosphorus has been shown to favor toxigenic strains over non-toxin strains coupled with higher intracellular toxin concentrations (Boopathi and Ki 2014; Burford et al. 2016).

Soluble phosphates and nitrates may also result in the increased production of microcystins (ILS 2000; O'Neil et al. 2012; Paerl and Scott 2010; Wang et al. 2010). Davis et al. (2009) found that growth rates

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of toxigenic *Microcystis* were higher than nontoxic strains as temperature increased in the presence of elevated soluble phosphorus and that toxigenic cells contained more copies of the gene *mcyD* under these conditions. The authors conclude that lakes experiencing this combination of factors could experience more toxic blooms (Davis et al. 2009). In the Sacramento-San Joaquin delta in California nitrogen and phosphorus are available in non-limiting amounts and facilitate persistence of total cyanobacterial blooms (Berg and Sutula 2015). A study by Lehman et al. (2015) characterizes nitrogen sources of a *Microcystis* bloom in the San Francisco Estuary using stable isotopes. They reported that ammonium from the Sacramento River was the likely sole source of the nitrogen for most of the bloom, overriding nitrate contributions from the San Joaquin River.

Jacoby et al. (2000) characterized multiple physical and chemical environmental factors associated with blooms in the summer of 1994 and 1995 at Steilacoom Lake, Washington. The dominance of *Microcystis aeruginosa* in the lake was associated with low nitrogen-to-phosphorus ratios and low nitrate-nitrogen with sufficient ammonium-nitrogen. Microcystin concentrations were positively correlated with increasing soluble reactive phosphorus concentrations with the highest microcystin concentrations associated with a low ratio of soluble nitrogen to soluble reactive phosphorus (less than five). The authors reported that microcystin production per gram cyanobacterial biomass was not consistent, thus no relationship was found between *Microcystis aeruginosa* abundance and microcystin concentration. A significant positive relationship between total phosphorus concentrations and total cyanobacteria densities was observed in both years of the study (Jacoby et al. 2000).

During bloom events, nutrients on a local scale are incorporated into the production of biomass and decrease in the water column within the bloom, even in eutrophic water bodies. Kuniyoshi et al. (2013) showed that phosphate deficiency resulting from exponential biomass production can result in approximately seven-fold increase in microcystin synthesis. Bar-Yosef et al. (2010) reported that cylindrospermopsin-producing *Aphanizomenon* excrete cylindrospermopsin when phosphorus-limiting conditions occur within the bloom, to induce other cells to produce and excrete alkaline phosphatase, thus increasing availability of extracellular inorganic phosphate. Cylindrospermopsin is energetically cheaper for the cell to produce relative to alkaline phosphatase (Raven 2010) and coupled with a high-affinity phosphorus uptake protein also found in these cells, allows *Aphanizomenon* to increase rapidly, outcompeting other cyanobacteria and dominate a bloom (Bar-Yousef et al. 2010). Preußel et al. (2014) observed that cylindrospermopsin is actively released from *Aphanizomenon ovalisporum* cells subjected to phosphorus limitation, a condition that occurs during the exponential biomass production in a bloom event.

Eutrophic systems already subject to bloom events are prone to further expansion of these blooms due to additional nitrogen inputs, especially if these nutrients are available from internal sources. As the trophic state increases, aquatic systems absorb higher concentrations of nitrogen (Paerl and Huisman 2008; Paerl and Otten 2013b). Recent surveys of cyanobacterial and algal productivity in response to nutrient pollution across geographically diverse eutrophic lakes, reservoirs, estuarine and coastal waters, and in different experimental enclosures of varying sizes demonstrate that greater stimulation is routinely observed in response to both nitrogen and phosphorus additions. Further, this evidence suggests that nutrient co-limitation is widespread (Elser et al. 2007; Lewis et al. 2011; Paerl et al. 2011). These results suggest that reductions in nutrient concentration would reduce eutrophication and cyanobacterial bloom expansion. For example, analysis of observational data collected at high spatial scales support the idea that controlling total phosphorus and total nitrogen could reduce the frequency of high microcystin contamination events by reducing the biomass of total cyanobacteria in the system (Orihel et al. 2012; Scott et al. 2013; Yuan et al. 2014). In addition, reduction of phosphorus in the absence of concurrent

reductions in nitrogen loading may not effectively control the growth, toxicity, or both of cyanobacteria such as *Microcystis* (Gobler et al. 2016). Study authors concluded that reduction of specific nutrient species, such as soluble forms of nitrogen and phosphorus, could reduce the dominance of toxigenic cyanobacteria in the lake microbial community, which could, in turn, decrease the incidences of elevated toxin levels (Davis et al., 2010; Gobler et al. 2016).

3.1.1.2 Temperature

Cyanobacterial blooms commonly occur from spring to early fall in various regions of the United States (Wynne and Stumpf 2015). Conditions such as elevated water temperatures and increased vertical stratification in lakes and reservoirs can support proliferation of total cyanobacteria (Paerl and Huisman 2008). The increasing body of laboratory and field data (Carey et al. 2012a; De Senerpont Domis et al. 2007; Huisman et al. 2005; Jeppesen et al. 2009; Kosten et al. 2012; Reynolds 2006; Wagner and Adrian 2009; Weyhenmeyer 2001) suggest that an increase in temperature may influence cyanobacterial dominance in phytoplankton communities. Some cyanobacteria have higher optimal growth temperatures compared with other phytoplankton and can proliferate at higher water temperatures by outcompeting these other phytoplankton groups (Elliott 2010; Paerl et al. 2011). Warmer water temperatures favor surface bloom-forming cyanobacterial genera because they are heat-adapted, and their maximal growth rates occur at relatively high temperatures, with optimum growth temperatures ranging from 30 to 35°C and optimum microcystin production ranging from 20 to 25°C (Giannuzzi 2018; Reynolds 2006; Robarts and Zohary 1987; WHO 2003b). As the growth rates of the eukaryotic taxa decline in response to warming water temperature, cyanobacterial growth rates reach their optima. Davis et al. (2009) found in four U.S. lakes that concurrent increases in temperature and phosphorus concentrations yielded the highest growth rates of toxic *Microcystis* cells, which led them to conclude that eutrophication and warm temperatures may promote the growth of toxic, rather than nontoxic, populations of *Microcystis* leading to blooms with higher microcystin content.

Cyanobacteria are typically known to proliferate in warm water environments such as tropical and temperate lakes and rivers, but they can also proliferate in cooler water environments under mesophilic and psychrophilic conditions (Seckback and Oren 2007). Cyanobacteria are also found in Antarctic habitats where they play a significant role in microbial ecosystem dynamics by providing fixed carbon via photosynthesis (Singh and Elster 2007). Cyanobacteria can grow in these extreme environments because they can adapt to survive freeze/thaw cycles and they can metabolize at near 0°C (Singh and Elster 2007).

The increase in water column stability associated with higher temperatures, less flow, and shallower water can also favor total cyanobacteria growth (Carey et al. 2012a; Wagner and Adrian 2009). In a study of 143 shallow lakes sampled along a latitudinal transect ranging from subarctic Europe to southern South America, Kosten et al. (2012) reported the percentage of cyanobacteria relative to total phytoplankton biovolume increased steeply with temperature in the lakes. The series of conditions most likely to result in cyanobacterial dominance begin with elevated winter–spring rainfall and runoff, followed by protracted periods of summer drought where temperatures, vertical stratification, and water residence times all increase simultaneously (Paerl and Otten 2013b).

Indirectly, warming can increase nutrient concentrations by enhancing mineralization (Gudasz et al. 2010; Kosten et al. 2009; Kosten et al. 2010) by temperature- or anoxia-mediated sediment phosphorus release (Jensen and Andersen 1992; Søndergaard et al. 2003). Thus, increases in temperature can indirectly increase cyanobacterial biomass through its effect on nutrient concentrations. Others have suggested that warmer conditions may raise total phytoplankton biomass through an alteration of top-

down regulation by selective grazing that favors larger size phytoplankton species and cyanobacterial blooms (Jeppesen et al. 2009; Jeppesen et al. 2010; Teixeira-de Mello et al. 2009). The relationship between temperature and cyanobacterial dominance can be explained not only through a temperature-related effect on the competitive advantage of cyanobacteria, but also by factors such as the percent area covered and the volume of the lake taken up by submerged macrophytes (Carey et al. 2012a; Kosten et al. 2012).

Cylindrospermopsis raciborskii was first identified in the tropics but has also been increasingly found in temperate regions since it was first found in North America in 1955 (Hong et al. 2006). *Cylindrospermopsis raciborskii* blooms are most likely to occur between the temperatures of 25 to 32°C but can sustain biomass at temperatures as low as 11°C (Antunes et al. 2015). In Florida, *C. raciborskii* was found to be the dominant cyanobacteria species in one lake all year round (Burns 2008). In 2006, *C. raciborskii* was detected in lakes in southern Louisiana (Fuentes et al. 2010). Conditions promoting its growth were shallow, warm surface water (over 30°C) and low light intensities. The highest densities of *C. raciborskii* were observed from June through August with densities ranging from 37,000 cells/mL to more than 160,000 cells/mL. In a study of two lakes directly connected to Lake Michigan, Hong et al. (2006) found low levels of *C. raciborskii* only in the late summer, and these were associated with elevated bottom water temperatures and phosphorus concentrations.

3.1.1.3 Sunlight

Sunlight availability and turbidity can have a strong influence on the cyanobacteria species that predominate, as well as the depth at which they occur (Carey et al. 2012a; Falconer 2005). The authors (Carey et al. and Falconer) found a greater proportion of the total phytoplankton biovolume attributable to cyanobacteria in lakes with high rates of light absorption. They could not establish cause and effect from their field data, but other controlled experiments and field data have demonstrated that light availability can affect the competitive balance among a large group of shade-tolerant species of cyanobacteria, primarily *Oscillatoriales* and other phytoplankton species (Scheffer et al. 1997; Smith 1986).

3.1.1.4 pH Levels

Total cyanobacterial blooms intensify and persist at pH levels between six and nine (Caraco and Miller 1998; WHO 2003a). Kosten et al. (2012) noted that pH affected cyanobacteria abundance in lakes along a latitudinal transect from Europe to southern South America. The percentage of cyanobacteria in the 143 shallow lakes sampled highly correlated with pH, increasing as the pH increased. Shapiro (1984) hypothesized that cyanobacteria have a competitive advantage over other phytoplankton species because they are efficient users of carbon dioxide in water. When dissolved carbon dioxide is high (low pH), conditions favor growth and replication of the green algal colonies over the blue-green cyanobacteria (Caraco and Miller 1998; Shapiro 1984). At alkaline pH levels, inorganic carbon is present as carbonate anion rather than as carbon dioxide, carbonic acid, or bicarbonate anion. This situation favors the growth of cyanobacteria because they can carry out photosynthesis when the levels of dissolved carbon dioxide are very low (high pH). The blue-green algae have a much higher photosynthetic demand for the dissolved carbon dioxide allowing them to out compete the green algae for the limited supply (Caraco and Miller 1998; Shapiro 1984). Thus, a higher water column pH can correlate with a higher proportion of cyanobacteria in an algal bloom.

The Caraco and Miller (1998) study suggests that pH and dissolved carbon dioxide, although chemically linked, are also independent factors in bloom dynamics because, even when dissolved carbon dioxide in

water is mechanically enriched, an alkaline pH still favors growth of the cyanobacteria over the green algae if nutrient inputs are constant.

3.2 Cyanotoxins

Much of the information and the studies summarized in this section for microcystins and cylindrospermopsin are described in detail in the EPA's HESDs and Drinking Water Health Advisories for microcystins and cylindrospermopsin (U.S. EPA 2015a, 2015b, 2015c, 2015d). The EPA's HESDs established the scientific basis for the EPA Drinking Water Health Advisories and also informed the EPA in developing these ambient water quality criteria (AWQC) or swimming advisories. This section summarizes the information that is provided in more detail in the EPA's HESDs. Additional information can be found in the EPA's HESDs for microcystins and cylindrospermopsin (U.S. EPA 2015c, 2015d).

3.2.1 Chemical and Physical Properties

Structurally, microcystins are monocyclic heptapeptides that contain seven amino acids joined end to end and then head to tail to form cyclic compounds that are comparatively large; molecular weights range from approximately 800 to 1,100 g/mole for the different congeners (e.g., microcystin-LR is 995.17 g/mole). The cyclic peptides include more than 100 congeners of microcystins (Niedermeyer 2014). Figure 3-2 provides the structure of microcystin where X and Y represent variable amino acids. Although substitutions mostly occur in positions X and Y, other modifications have been reported for all the amino acids (Puddick et al. 2015).

The microcystin congeners are named based on their two variable amino acids (Carmichael et al. 1988). For example, microcystin-LR, the most common congener (Carmichael 1992). The letters used to identify the variable amino acids are the standard single letter abbreviations for the amino acids found in proteins. The variable amino acids are usually the L-amino acids as found in proteins. In Figure 3-2, which shows the structure of microcystin-LR, leucine is in the X position and arginine is in the Y position. Table 3-1 lists the most common microcystin congeners, including the amino acids in the X and Y positions.

There are other variants of microcystins besides those that arise because of the two interchangeable amino acids on the microcystin ring. For example, demethylated congeners have been observed in Europe; Wejnerowski et al. (2018) identified demethylated forms of microcystin-RR and microcystin-LR in a toxigenic cyanobacterial bloom in Poland. Observations of demethylated microcystins suggest that more than 200 microcystin congeners are possible.

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Figure 3-2. Structure of Microcystin (Kondo et al. 1992)

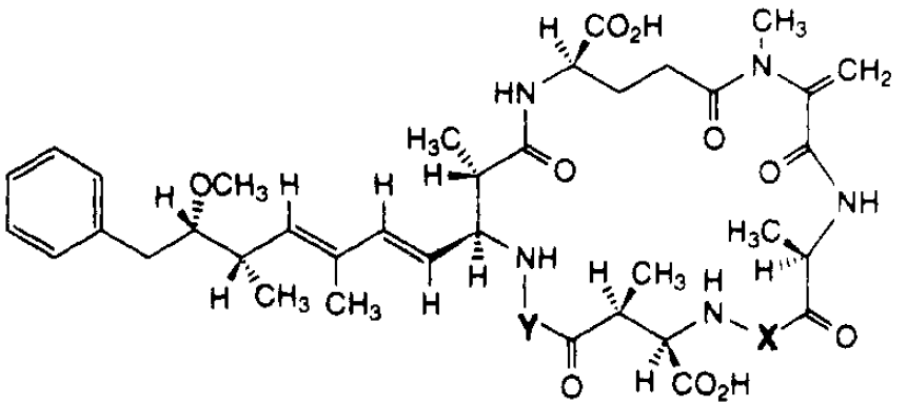


Table 3-1. Abbreviations for Selected Microcystins (Yuan et al. 1999)

Microcystin Congeners	Amino Acid in X	Amino Acid in Y
Microcystin-LR	Leucine	Arginine
Microcystin-RR	Arginine	Arginine
Microcystin-YR	Tyrosine	Arginine
Microcystin-LA	Leucine	Alanine
Microcystin-LY	Leucine	Tyrosine
Microcystin-LF	Leucine	Phenylalanine
Microcystin-LW	Leucine	Tryptophan

The preponderance of toxicological data on the effects of microcystins result from tests using the microcystin-LR congener. Toxicity data suggest that microcystin-LR is as potent as or more potent than other studied microcystins and that the most toxic microcystins are those with the more hydrophobic L-amino acids (e.g., -LA, -LR, and -YR); the least toxic are those with hydrophilic amino acids, such as microcystin-RR (U.S. EPA 2015d; Ito et al. 2002; Rinehart et al. 1994; Vesterkvist and Meriluoto 2003; WHO 1999). Data on the -RR, -YR, and -LA congeners, however, are limited, and toxicity values cannot be derived for them. Therefore, values developed from data specific to microcystin-LR can represent other present microcystin congeners.

Table 3-2 provides chemical and physical properties of microcystin-LR. Microcystins are water soluble. In aquatic environments, the cyclic peptides tend to remain contained within the cyanobacterial cell and are released in substantial amounts only when the cell walls are broken down (cell lysis).

Cylindrospermopsin is a tricyclic alkaloid with the molecular formula of $C_{15}H_{21}N_5O_7S$ (Ohtani et al. 1992) and a molecular weight of 415.43 g/mole. It is a dipolar ion with localized positive and negative charges (Ohtani et al. 1992). The chemical structure of cylindrospermopsin is presented in Figure 3-3(a). Two naturally occurring congeners of cylindrospermopsin have been identified, 7-epi-cylindrospermopsin (the epimer of cylindrospermopsin) and 7-deoxycylindrospermopsin; see Figure 3-3(b) and (c) (de la Cruz et al. 2013; Norris et al. 1999). Recently, Wimmer et al. (2014) identified two new analogs, 7-deoxy-desulfo-cylindrospermopsin and 7-deoxy-desulfo-12-acetylcylindrospermopsin,

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from the Thai strain of *Cylindrospermopsis raciborskii*. However, it is not clear if these are cylindrospermopsin congeners, precursors, or degradation products.

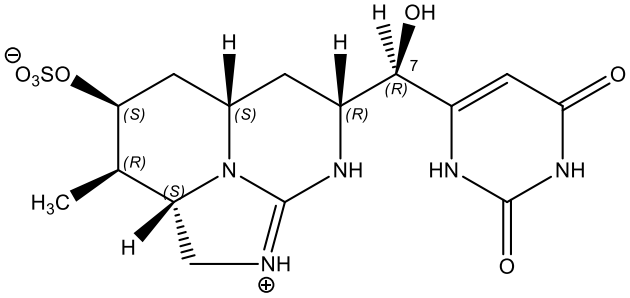
Table 3-2. Chemical and Physical Properites of Microcystin-LR

Property	Microcystin-LR
Chemical Abstracts Registry (CAS) Number	101043-37-2
Chemical Formula	$C_{49}H_{74}N_{10}O_{12}$
Molecular Weight	995.17 g/mole
Color/Physical State	Solid
Boiling Point	Not available (N/A)
Melting Point	N/A
Density	1.29 g/cm^3
Vapor Pressure at 25°C	N/A
Henry's Law Constant	N/A
Log Octanol-Water Partition Coefficient (K_{ow})	2.16; -1.41 to 1.67 as pH decreases
Soil Organic Carbon-Water Partition Coefficient (K_{oc})	N/A
Solubility in Water	Highly*
Other Solvents	Ethanol and methanol

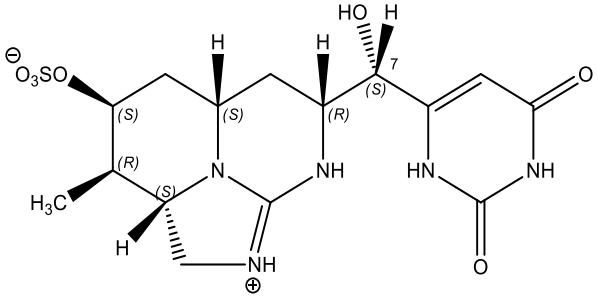
Sources: Chemical Book (2012); TOXLINE (2012); Ward and Codd (1999) and McCord et al. (2018) for log K_{ow}.
* Microcystin congeners vary in their relative solubility in water.

Figure 3-3. Structure of Cylindrospermopsin and Structurally Related Cylindrospermopsins (de la Cruz et al. 2013)

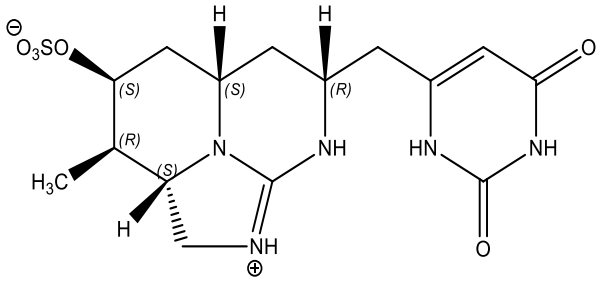
(a) Cylindrospermopsin



(b) 7-epi-cylindrospermopsin (the epimer of cylindrospermopsin)



(c) 7-deoxycylindrospermopsin



The physical and chemical properties of cylindrospermopsin are presented in Table 3-3. Cylindrospermopsin is highly soluble in water (Chiswell et al. 1999; Moore et al. 1998). It is isolated for commercial use mostly from *Cylindrospermopsis raciborskii*. Some relevant physico-chemical properties of cylindrospermopsin could not be identified, and no physico-chemical properties were found for the structurally related cylindrospermopsins.

Table 3-3. Chemical and Physical Properties of Cylindrospermopsin

Property	Cylindrospermopsin
CAS Registry Number	143545-90-8
Chemical Formula	$C_{15}H_{21}N_5O_7S$
Molecular Weight	415.43 g/mole
Color/Physical State	White powder
Boiling Point	N/A
Melting Point	N/A
Density	2.03 g/cm^3
Vapor Pressure at 25°C	N/A
Henry's Law Constant	N/A
K_{ow}	N/A
K_{oc}	N/A
Solubility in Water	Highly
Other Solvents	Dimethyl sulfoxide and methanol

Sources: Chemical Book (2012); TOXLINE (2012).

3.2.2 Sources and Occurrence in Surface Waters

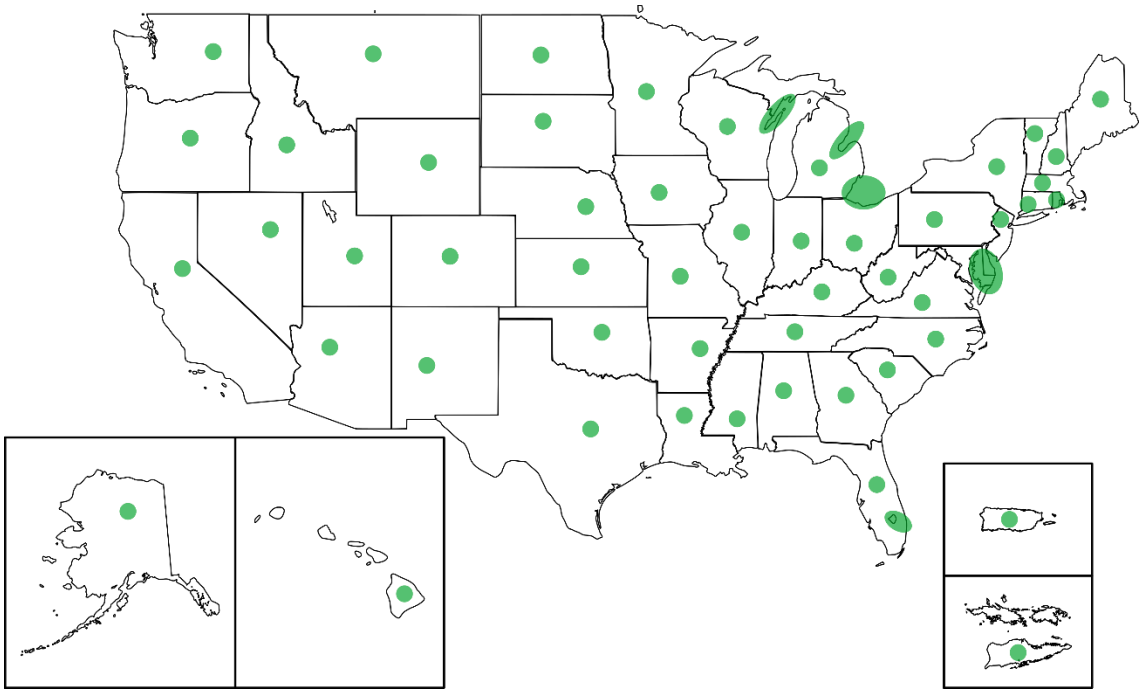
Because they are a natural part of algal communities, cyanobacteria are commonly observed in freshwater systems. The occurrence of HABs has been documented in surface waters of all 50 states as well as U.S. territories between 2006 and 2015 as shown in Figure 3-4 (Richlen 2016; WHOI 2016). Figure 3-4 also identifies areas where more widespread HAB problems have occurred (e.g., parts of the Great Lakes).

Figure 3-5 shows the number of 2017 freshwater HAB recreational notices states publicly reported, organized by the EPA region between June 2 and August 1, 2017. To develop this regional summary map, the EPA researched and compiled publicly available reports posted on states' websites between these dates. During that time, states reported at least 281 notices for freshwater HABs with reported microcystin concentrations ranging from not detected (i.e., below the limit of detection) to 382 µg/L. These notices included cautions, warnings, public health advisories, and public health warnings due to

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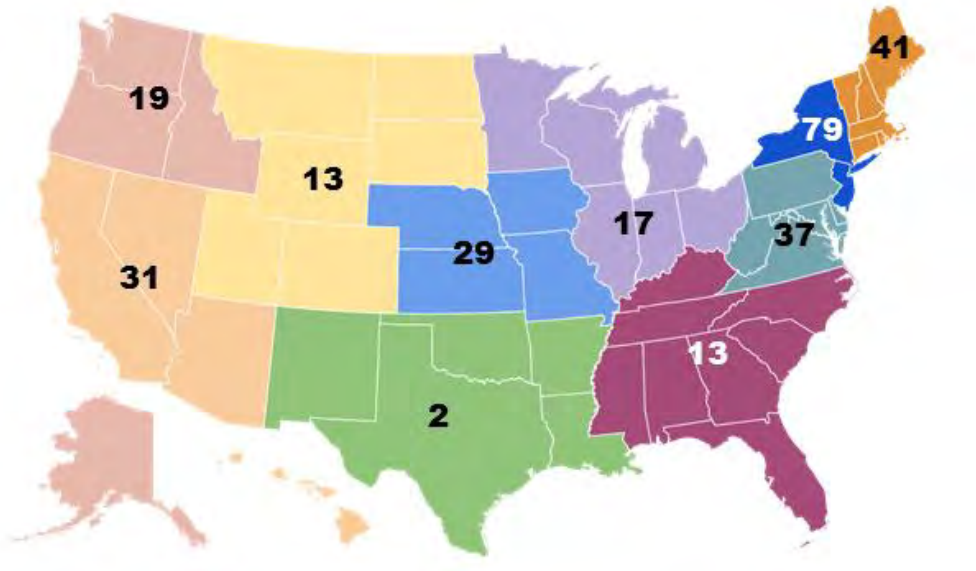
the presence of total cyanobacteria, cyanotoxins, or both. These notices can last for multiple days. The review was not exhaustive and might not reflect all the monitoring, beach, or general health advisories (e.g., some advisories at local or county-level may not be posted on the state website). Thus, the number of actual HAB notices during this time might be higher. In addition, many states have only recently begun to monitor HABs, so monitoring may be limited.

Figure 3-4. Generalized Distribution of Cyanobacterial HABs in the United States and Territories



[a] Graphic adapted from a Woods Hole Oceanographic Institute (WHOI) map of HABs that occurred between 2006 and 2015. It reflects input from HAB experts with broad experience in HAB events and reports to the U.S. National Office for Harmful Algal Blooms (Richlen 2016; WHOI 2016). Each state that has experienced one or more cyanobacterial HAB is indicated with a single green dot. Larger green ovals mark areas where more widespread cyanobacterial HAB problems occurred.

Figure 3-5. State-reported HAB Notices by EPA Region, June 2 to August 1, 2017



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3.2.2.1 Microcystins

Microcystins are the most common cyanotoxins found worldwide and have been reported in surface waters in most of the states in the United States (Funari and Testai 2008; Loftin et al. 2016b; U.S. EPA 2009). Dry-weight concentrations of microcystins in surface freshwater toxigenic cyanobacterial blooms or surface freshwater samples reported worldwide between 1985 and 1996 ranged from 1 to 7,300 µg/g. Water concentrations of extracellular plus intracellular microcystins ranged from 0.04 to 25,000 µg/L. The remainder of this section provides examples of microcystin concentrations reported in ambient waters in the United States.

The EPA (U.S. EPA 2009) reported on the 2007 National Lakes Assessment (NLA), a national probability-based survey of the nation's lakes, ponds, and reservoirs. The NLA provided estimates of the condition of natural and man-made freshwater lakes, ponds, and reservoirs greater than 4 hectares (10 acres) and at least one meter deep. The 2007 NLA study surveyed 1,028 inland lakes and included measured microcystin concentrations, total cyanobacterial cell counts, and chlorophyll *a* concentrations. Microcystins were quantified using enzyme-linked immunosorbent assays (ELISA) with a detection limit of 0.1 µg/L (Loftin et al. 2016b). At each lake site, crews collected samples at a single station located at the deepest point in the lake and at ten stations around the lake perimeter. Due to the design of the survey, samples were taken at random and not necessarily where a bloom was occurring.

The 2007 NLA found that total cyanobacteria were detected in 98 percent of samples and were the dominant member of the phytoplankton community in 76 percent of samples (Loftin et al. 2016b; U.S. EPA 2009). Subsequent analysis indicated that potential microcystin-producing species occurred in 95 percent of samples (Loftin et al. 2016b). Microcystins were the most commonly detected class of cyanotoxins found in 32 percent of lakes in the contiguous United States (Loftin et al. 2016b; U.S. EPA 2009) and 39 percent of streams in the southeastern United States (Loftin et al. 2016a). Microcystins present in lakes ranged from the limit of detection (0.1 µg/L) to 225 µg/L with a mean concentration of 3.0 µg/L (detections only). Approximately 1.1 percent of lake samples exceeded 10 µg/L microcystins, and approximately 27 percent and 44 percent of lakes exceeded the WHO low-risk threshold for cyanobacterial abundance and chlorophyll *a*, respectively (Loftin et al. 2016b).

Lakes in states with microcystins levels > 10 µg/L reported in the 2007 NLA are shown in Table 3-4. The 2007 NLA data show two states (North Dakota and Nebraska) had nine percent of samples above 10 µg/L. Other states including Iowa, Texas, South Dakota, and Utah also had samples that exceeded 10 µg/L, but the frequency of detection was lower. Several of the 2007 NLA samples in North Dakota, Nebraska, and Ohio exceeded 20 µg/L (192, 225, and 78 µg/L, respectively).

In 2012, the EPA expanded on the 2007 NLA to include smaller water bodies in this statistically designed survey. Results represent the population of natural lakes, ponds, and reservoirs across the lower 48 states (not including the Great Lakes or the Great Salt Lake). To be included, in the survey lakes had to be larger than 2.47 acres (1 hectare), at least 3.3 feet (1 meter) deep, with a minimum quarter acre (0.1 hectare) of open water (U.S. EPA 2016). Data were collected from 1,038 lakes selected from a stratified random sample based on ecoregion, state, and surface area in the larger inference population (the set of 111,818 lakes). The NLA used thresholds established by the WHO to determine risk of exposure to cyanotoxins. Microcystins were detected in 39 percent of lakes monitored, but less than one percent exceeded the WHO estimates for microcystins at moderate or high risk of exposure. Less than one percent of lakes are in the most and moderately disturbed condition (i.e., have a high or moderate risk of exposure), and 99 percent are either least disturbed or show no detection of microcystins. Between 2007 and 2012, the percentage of lakes categorized as most disturbed for

microcystins did not change (U.S. EPA 2016), even though there was a significant increase in the detection of microcystins (+9.5 percent).

Table 3-4. States Surveyed as Part of the 2007 NLA with Water Body Microcystin Concentrations above 10 µg/L (U.S. EPA 2009)

State	Number of Sites Sampled	Percentage of Samples with Detection of Microcystins > 10 µg/L	Maximum Detection of Microcystins
North Dakota	38	9.1 percent	192 µg/L
Nebraska	42	9.1 percent	225 µg/L
South Dakota	40	4.9 percent	33 µg/L
Ohio	21	4.5 percent	78 µg/L*
Iowa	20	4.5 percent	38 µg/L*
Utah	26	3.6 percent	15 µg/L*
Texas	51	1.8 percent	28 µg/L*

*Single sample.

The NLA used total cyanobacterial cell counts as an indicator of water quality impacts of microcystins; 15 percent of lakes were classified in the most disturbed condition, 23 percent were classified as moderately disturbed, and 61 percent were classified as least disturbed. Between 2007 and 2012, there was a statistically significant increase (+8.3 percent) in the number of lakes in the most disturbed category for cyanobacterial cell counts. Lakes that were considered most disturbed exceeded the WHO recreational levels of concern (20 µg of microcystins/L).

A survey conducted during the spring and summer of both 1999 and 2000 in more than 50 lakes in New Hampshire found measurable microcystin concentrations in all samples (Haney and Ikawa 2000). Microcystins were analyzed by ELISA and were found in all the lakes sampled with a mean concentration of 0.1 µg/L.

A survey conducted in Florida in 1999 found potential microcystin-producing genera in water samples, including, *Microcystis* (43.1 percent), *Anabaena* (28.7 percent), *Planktothrix* (13.8 percent), *Aphanizomenon* (7.2 percent), and *Coelosphaerium* (3.6 percent) (Burns 2008). Although *Planktothrix* and *Aphanizomenon* were found less frequently than were the other genera, at times they accounted for a significant portion of the cyanobacterial community present. Microcystins were the most commonly found toxins in Florida waters, occurring in all samples analyzed containing cyanotoxins (Burns 2008).

In 2002, the Monitoring and Event Response to Harmful Algal Blooms in the Lower Great Lakes project evaluated the occurrence and distribution of cyanotoxins in the lower Great Lakes region (Boyer 2007). Analysis for total microcystins was performed using protein phosphatase inhibition assay. Microcystins were detected in at least 65 percent of the samples, mostly in Lake Erie, Lake Ontario, and Lake Champlain.

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A 2004 study of the Great Lakes found high levels of cyanotoxins during the month of August (Makarewicz et al. 2006). Microcystin-LR was analyzed by protein phosphatase inhibition assay (limit of detection of 0.003 µg/L) and was detected at levels of 0.008 µg/L in the nearshore and 0.076 µg/L in the bays and rivers. This study reported higher levels of microcystin-LR (1.6 to 10.7 µg/L) in smaller lakes in the Lake Ontario watershed.

In 2005, Washington State Department of Ecology developed the Ecology Freshwater Algae Program to focus on the monitoring and management of cyanobacteria in Washington lakes, ponds, and streams (WSDE 2012). Microcystin levels ranged from the detection limit (0.05 µg/L) to 4,620 µg/L in 2008, to 18,700 µg/L in 2009, to 853 µg/L in 2010, and to 26,400 µg/L in 2011 (Hamel 2009, 2011, 2012).

In 2006, the U.S. Geological Survey (USGS) conducted a study of 23 lakes in the midwestern United States in which total cyanobacterial blooms were sampled to determine the co-occurrence of cyanotoxins in cyanobacterial blooms (Graham et al. 2010). This study reported that microcystins were detected in 91 percent of the lakes sampled with 17 percent of microcystin-positive samples exceeding 20 µg/L. The researchers also found that cylindrospermopsin co-occurred with microcystins in nine percent of samples (Graham et al. 2010). Mixtures of all the microcystin congeners measured (-LA, -LF, -LR, -LW, -LY, -RR, and -YR) were common. Microcystin-LR and -RR were the dominant congeners detected with mean concentrations of 104 and 910 µg/L, respectively.

The Ohio EPA (2012) has been monitoring inland lakes since 2007 for cyanotoxins. Of the Ohio lakes sampled during the 2007 NLA, 36 percent had detectable levels of microcystins. In 2010, the Ohio EPA sampled Grand Lake St. Marys for cylindrospermopsin, microcystins, and other cyanotoxins. Microcystin levels ranged from below the detection limit (< 0.15 µg/L) to more than 2,000 µg/L. Follow-up samples taken in 2011 for microcystins indicated concentrations exceeded 50 µg/L in August. During the same month, sampling in Lake Erie found microcystin levels exceeding 100 µg/L.

The USGS monitored Lake Houston in Texas from 2006 to 2008 and found microcystins in 16 percent of samples and at concentrations less than or equal to 0.2 µg/L (Beussink and Graham 2011). The USGS also did a study in the Upper Klamath Lake in Oregon in 2007 and detected total microcystin concentrations between 1 µg/L and 17 µg/L (VanderKooi et al. 2010). In 2011, the USGS conducted a study on the upstream reservoirs of the Kansas River to characterize the transport of cyanobacteria and associated compounds (Graham et al. 2012). Concentrations of total microcystins were low in the majority of the tributaries with the exception of Milford Lake, which had higher total microcystin concentrations, some exceeding the Kansas recreational guideline level of 20 µg/L. Upstream from Milford Lake, a cyanobacterial bloom was observed with a total microcystin concentration of 150,000 µg/L. When sampled a week later, total microcystin concentrations were less than 1 µg/L. The study authors indicated that this might be due to dispersion of microcystins through the water column or to other areas, or by degradation of microcystins via abiotic and biological processes. Samples taken during the same time from outflow waters contained total microcystin concentrations of 6.2 µg/L.

In 2008, the National Oceanic and Atmospheric Administration (NOAA) began monitoring for total cyanobacterial blooms in Lake Erie using high temporal resolution satellite imagery. Using the Great Lakes Coastal Forecast System, forecasts of bloom transport are created to estimate the trajectory of the bloom, which are distributed as bulletins to local managers, health departments, researchers, and other stakeholders. To evaluate bloom toxicity, the Great Lakes Environmental Research Laboratory collected samples at six to eight stations each week for 24 weeks, measuring cyanotoxin concentrations as well as chlorophyll biomass and an additional 18 parameters (e.g., nutrients) to improve future forecasts of these blooms. Microcystins were separated into particulate (cell-bound) and dissolved (extracellular) phases

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(Graham and Jones 2007; Zastepa et al. 2014). In 2014, particulate microcystin concentrations ranged from below detection to 36.7 µg/L. Samples taken in 2015 and 2016 showed particulate microcystin concentration ranges from below detection to 9.19 µg/L and from below detection to 21.26 µg/L, respectively. Particulate microcystin concentrations peaked in August 2014 at all sites. Dissolved microcystin concentrations were also collected at each site in 2014 from September until the end of the sampling period in November, as well as during the field sampling seasons in 2015 and 2016. During the final months of sampling in 2014 (October to November), dissolved microcystin concentrations were detected with peak concentrations of 0.8 µg/L (mean: 0.28 +/- 0.2 µg/L) whereas particulate microcystin concentrations were below detection limits on many dates, indicating that a majority of the microcystins (mean: 72 percent +/- 37 percent) were in the dissolved form, as the bloom declined in intensity. Measured dissolved microcystin concentrations in the following two years ranged from levels below detection to peaks of 0.69 µg/L in September 2015 and 1.76 µg/L in July 2016 (NOAA 2014).

A 2014 survey of southeastern U.S. streams detected microcystins in 39 percent of the samples (29 of 75 sites) (Loftin et al. 2016a). The stream sample concentrations ranged from the minimum reporting limit of 0.1 µg/L to 3.2 µg/L. In some cases, the source of the cyanobacteria in flowing water bodies was traced to an upstream water body such as a lake or reservoir.

From August to October 2015, a bloom identified as *Microcystis aeruginosa* occurred on the Ohio River (ORSANCO 2017). Patches of the bloom covered 636 miles of the river and peaked in late September. The Ohio River Valley Water Sanitation Commission (ORSANCO) collected over 150 river samples, which were analyzed for microcystins. Of the samples collected by ORSANCO, 15 (10 percent) were greater than 6 µg/L. The highest microcystin concentration was 1900 µg/L from a sample collected at river mile 468.8 (Cincinnati, Ohio). No toxins were detected in finished drinking water (tested by utilities and state agencies). Ohio, West Virginia, Kentucky, and Indiana issued recreation notices for the Ohio River as the bloom extended into their areas. Illinois issued a precautionary statement concerning recreation in the river due to concern that the bloom would reach their border. These recreation advisories were lifted after the bloom ended (ORSANCO 2017).

From July 14 to September 14, 2016, an extensive cyanobacterial bloom covering 100 square miles occurred in Utah Lake, Jordan River, and nearby canals. Microcystin-LR concentrations ranged from below the detection limit to 0.23 µg/L, and the highest total microcystin concentration reported was 176 µg/L (Utah Department of Environmental Quality 2016). Both maximum values were from samples collected at the surface near an accumulation of cyanobacteria. Cyanobacteria composition observed during the 2016 bloom varied in both time and space, but was primarily dominated by *Aphanizomenon* or *Dolichospermum*. Other taxa including *Geitlerinema*, *Pseudanabaena*, and *Phormidium* were also observed in significant densities in a few samples (Utah Department of Environmental Quality 2016).

Lake Okeechobee, located north of the Everglades, is the largest freshwater lake in Florida. It is subject to agricultural runoff from adjacent cattle farms and sugar cane fields, which contribute to the formation of massive cyanobacterial blooms (Parker 2016). Water may be pumped out of the lake to the coast through the St. Lucie River and the Caloosahatchee River to prevent the lake level from rising too high after periods of heavy rain (Parker 2016). In July 2016, a 239-square mile cyanobacterial bloom in Lake Okeechobee was discharged and flowed through canals, rivers, and estuaries to the ocean. As a result of the microcystin levels in the river and at the coast, and the visible cyanobacterial scum in the lake and river, a state of emergency was declared in the counties of Martin, St. Lucie, Palm Beach, and Lee. From May 4 to August 4, 2016, the Florida Department of Environmental Protection took approximately 200 water samples from the St. Lucie River and estuary, Caloosahatchee River and estuary, Lake Okeechobee, Indian River Lagoon, and other nearshore marine locations (Florida Department of

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Environmental Protection 2016). The microcystin concentrations in freshwater were reported in Lake Okeechobee (from not detected to 382.3 µg/L). Elevated levels were also reported in the St. Lucie River and the St. Lucie Canal (from not detected to 80.3 µg/L). Among the cyanobacteria species identified were *Microcystis aeruginosa*, *Scrippsiella trochoidea*, *Planktolyngbya limnetica*, *Dolichospermum circinalis*, and *Plectonema wollei* (Florida Department of Environmental Protection 2016).

3.2.2.2 Cylindrospermopsin

In general, fewer surface water occurrence data were available for cylindrospermopsin compared with microcystins. During blooms, testing for microcystins is much more common than is testing for cylindrospermopsin.

In a 1999 study, *Cylindrospermopsis* was detected in 40 percent of 167 water samples taken from 87 water bodies in Florida (Burns 2008). The actual cylindrospermopsin concentrations were not reported, but all samples containing the organism *Cylindrospermopsis* were positive for the toxin cylindrospermopsin.

In 2005, the U.S. Army Corps of Engineers detected cylindrospermopsin at a maximum concentration of 1.6 µg/L in lake water samples from Oklahoma (Lynch and Clyde 2009).

The USGS detected cylindrospermopsin in nine percent of blooms sampled during a 2006 USGS survey of 23 lakes in the midwestern United States (Graham et al. 2010). The low concentrations of cylindrospermopsin detected (0.12 to 0.14 µg/L) in the study occurred in bloom communities dominated by the genera *Aphanizomenon* or *Anabaena* and *Microcystis*.

The USGS analyzed the stored samples collected during the 2007 EPA NLA (U.S. EPA 2009) and detected cylindrospermopsin in four percent of samples, with a mean concentration 0.56 µg/L and a range from the limit of detection, 0.01 µg/L, to a maximum of 4.4 µg/L (Loftin et al. 2016b). Potential cylindrospermopsin-producing species (*Anabaena*, *Aphanizomenon*, *Cylindrospermopsis*, *Lyngbya*, and *Raphidiopsis*) occurred in 67 percent of samples (Loftin et al. 2016b). Cylindrospermopsins occurred most frequently in the midwestern and south-central United States and parts of Florida.

In Grand Lake in St. Marys, Ohio, cylindrospermopsin concentrations as high as 9 µg/L were reported in 2010 (Ohio EPA 2012).

3.2.3 Estuarine and Marine Waters

In Japan, the Isahaya Reservoir discharges water into Isahaya Bay. The reservoir experiences algal blooms seasonally, with species including nontoxic cyanobacteria as well a microcystin-producing *Microcystis aeruginosa* (Umehara et al. 2012). Water from the reservoir is discharged to the bay after rainfall events, even during periods of *Microcystis aeruginosa* blooms. Between November 2008 and November 2009, Umehara et al. (2012) estimated that 64.5 kilograms (kg) of microcystins were discharged to the bay, of which only 0.7 kg deposited on the floor. The authors speculated that because the majority of microcystins remain in the water, it is likely that they are washed out to other coastal areas with strong tides (Umehara et al. 2012).

In 2007, Miller et al. (2010) confirmed the presence of *Microcystis* and microcystins in Lake Pinto's downstream tributaries within 1 kilometer (km) of Monterey Bay in California after a large cyanobacterial bloom in the lake, and detected microcystins in nearshore marine waters following the

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rainy season. The same researchers observed sea otters dying from consuming microcystin-contaminated clams, mussels, and oysters near ocean outflows of freshwater systems (Miller et al. 2010). A follow-up study was designed by Gibble and Kudela (2014) to identify the potential pathways leading to microcystin contamination in coastal ecosystems in and around Monterey Bay. They surveyed 21 sites at the land-sea interface in 2010–2011 followed by a survey of four watersheds in 2011–2013. In the first year of a three-year study, microcystins were detected in 15 of 21 freshwater, estuarine, and marine locations. In the two subsequent years, monitoring focused on four major watersheds that feed into Monterey Bay. The authors observed high microcystin concentrations in both autumn and spring seasons and concluded that microcystins are likely present throughout the year and transfer to the coastal environment, with the potential to be a persistent issue in the Monterey Bay area. The authors also correlated anthropogenic nutrient loadings with microcystins. Concentrations ranged from undetectable up to 20 ng/g resin, which translates to approximately 20 parts per billion (ppb) microcystins in the water column.

Otten et al. (2015) used microbial source tracking techniques to trace the source of a toxic *Microcystis* bloom in the Klamath River in Oregon to a single upstream reservoir. The use of assays targeting gene sequences for phycocyanin and microcystin synthase allowed the quantification of total and toxigenic *Microcystis*. Their results showed that large quantities of cyanobacterial cells could withstand passage through hydroelectric installations and transport over 300 km. Microcystin concentrations ranged from 165 µg/L in a reservoir upstream to 3.6 µg/L within the lower estuary less than 1 km from the Pacific Ocean (Otten et al. 2015).

The large cyanobacterial bloom in Lake Okeechobee, Florida, in 2016 (described above) flowed downstream and impacted estuarine and marine waters, resulting in beach closures along the Atlantic (Chaney 2016; Florida Department of Environmental Protection 2016). From May 4 to August 4, 2016, the Florida Department of Environmental Protection sampled freshwater, estuarine waters, and nearshore marine waters. The highest concentration reported (414.3 µg/L) was collected in Martin County at Bathtub Reef, a beach along the Atlantic Ocean. Sampling efforts in estuarine water, for example at a marina in the St. Lucie River, reported a concentration of 78 µg/L. The majority of marine waters sampled had low levels of microcystins (not detected or approximately 1 µg/L).

3.2.4 Other Sources of Microcystins and Cylindrospermopsin

Cyanotoxins have the potential to occur in drinking water, ground water, fish, shellfish, dietary supplements, air, soil, and sediments. These potential sources of cyanotoxins are discussed briefly in section 7.6. Exposure to these toxins in finished drinking water is also characterized in the Drinking Water Health Advisories (U.S. EPA 2015a, 2015b).

3.3 Environmental Fate

Different physical and chemical processes are involved in the persistence, breakdown, and movement of microcystins and cylindrospermopsin in aquatic systems as described below.

3.3.1 Mobility

Microcystins may adsorb onto naturally suspended solids and dried crusts of cyanobacteria. They can precipitate out of the water column and reside in sediments for months (Falconer 1998; Han et al. 2012). A study conducted by the USGS and the University of Central Florida determined that microcystin-LR and cylindrospermopsin did not sorb in sandy aquifers and were transported along with ground water

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(O'Reilly et al. 2011). The authors suggested that the removal of microcystin-LR was due to biodegradation.

Cyanotoxins that are produced by cyanobacteria growing in freshwaters can enter estuarine and marine waters as waters containing the toxins flow downstream. Studies have demonstrated that toxigenic cyanobacteria can travel long distances in freshwater and can reach estuarine and marine waters from coastal lakes, reservoirs, and rivers (Preece et al. 2017).

In sediments, cylindrospermopsin exhibits some adsorption to organic carbon, with little adsorption observed on sandy and silt sediments (Klitzke et al. 2011). The low adsorption of cylindrospermopsin reduces its residence time in sediments, thus reducing the opportunity for microbial degradation.

3.3.2 Persistence

3.3.2.1 Microcystins

Microcystins are relatively stable and resistant to chemical hydrolysis or oxidation at or near neutral pH. Elevated or low pH or temperatures above 30°C may cause slow hydrolysis. Microcystins have been observed to persist for 21 days to two to three months in solution and up to six months in dry scum (Funari and Testai 2008; Rapala et al. 2006). Environmental conditions such as temperature, pH, presence of light, salinity, and presence of certain aquatic bacteria can influence the rate of microcystin degradation (Schmidt et al. 2014). Microcystins can persist even after a cyanobacterial bloom is no longer visible (Lahti et al. 1997b; Zastepa et al. 2014). In a study by Zastepa et al. (2014), dissolved microcystin-LA was present at a concentration of 20 µg/L or greater for 9.5 weeks even though the *Microcystis* bloom was not visible after five weeks.

In the presence of full sunlight, microcystins undergo photochemical breakdown, but this varies by microcystin congener (Chorus et al. 2000; WHO 1999). Zastepa et al. (2014) suggest that microcystin-LA degrades at a slower rate than microcystin-LR, -RR, and -YR congeners. The presence of water-soluble cyanobacterial cell pigments, in particular phycobiliproteins, enhances this breakdown. Breakdown can occur in as few as two weeks to longer than six weeks, depending on the concentration of pigment and the intensity of the light (Tsuji et al. 1994, 1995).

Several other factors, including pH, wavelength of light (Schmidt et al. 2014), and whether microcystins are dissolved or present in particulate matter (Lahti et al. 1997b) can affect the rate of transformation or photodegradation. According to Tsuji et al. (1994, 1995), microcystin-LR was photodegraded with a half-life of about five days in the presence of 5 mg/L of extractable cyanobacterial pigment. Humic substances can act as photosensitizers and can increase the rate of microcystins breakdown in sunlight. Others have found that high concentrations of humic acids can slow the rate of microcystins transformation by sunlight (Schmidt et al. 2014). In deeper or turbid water, the breakdown rate is slower. Welker and Steinberg (2000) estimated the maximum rate of microcystin-LR degradation in the presence of humic substance photosensitizers. Extrapolating results from their small experimental tubes to a water column of 1 meter, Schmidt et al. (2014) estimated the half-life of microcystin-LR to be 90 to 120 days per meter of water depth in surface waters. The researchers demonstrated that the wavelength of light can also affect degradation rates; complete microcystins degradation was observed within one hour when exposed to 254-nm light and within five days using 365-nm light. According to Lahti et al. (1997b), microcystin-LR follows first-order decay kinetics, with a decimal reduction time of 30 days for dissolved microcystins compared with 15 days for microcystins found in particulate matter. Zastepa et

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al. (2014) also found that dissolved microcystin-LA persists longer than microcystin-LA in particulates, with in situ half-lives of 15.8 days and 6.5 days, respectively.

Microcystins are susceptible to biodegradation by aquatic bacteria found naturally in surface waters (Jones et al. 1994). Bacteria isolates of *Arthrobacter, Brevibacterium, Rhodococcus, Paucibacter*, and various strains of the genus *Sphingomonas* (*Pseudomonas*) have been reported to be capable of degrading microcystin-LR (de la Cruz et al. 2011; Han et al. 2012). These degradative bacteria have also been found in sewage effluent (Lam et al. 1995), lake water (Cousins et al. 1996; Jones et al. 1994; Lahti et al. 1997b), and lake sediment (Lahti et al. 1997a; Rapala et al. 1994; U.S. EPA 2015a). Lam et al. (1995) reported that the biotransformation of microcystin-LR followed a first-order decay with a half-life of 0.2 to 3.6 days. In a study conducted by Jones et al. (1994) with microcystin-LR in different natural surface waters, microcystin-LR persisted for three days to three weeks; however, more than 95 percent loss occurred within three to four days. A study by Christoffersen et al. (2002) measured half-lives in the laboratory and in the field of approximately one day, driven largely by bacterial aerobic metabolism. These researchers found that approximately 90 percent of the initial amount of microcystins disappeared from the water phase within five days, irrespective of the starting concentration. Other researchers (Edwards et al. 2008) have reported half-lives of four to 14 days, with longer half-lives associated with a flowing stream and shorter half-lives associated with lakes. Microcystin-LR degradation by *Sphingopyxis* species was observed with an optimal degradation rate at pH values between 6.5 and 8.5 (Schmidt et al. 2014). Several studies have demonstrated bacterial degradation of microcystin-LR, but other congeners, such as microcystin-LF or -LA, were not significantly degraded (Zastepa et al. 2014). During periods of high toxigenic cyanobacterial densities, the composition of other bacteria in the community may shift in response. In a study of the San Juan reservoir in Spain, Lezcano et al. (2017) found that several classes, orders, and families of known biodegrading bacteria, such as the *Spirobacillales* order, increased by more than a factor of 1.5 during the peak of a cyanobacterial bloom. The increase in relative abundance suggests that these biodegraders may play a role in microcystins degradation in the environment. Although microcystin-degrading bacteria might be present, initial degradation rates could be slow because the bacteria need time to begin using the toxins as carbon or energy sources (Hyenstrand et al. 2003). Microcystins can accumulate in the water column if these biodegrading bacteria are not present at the time of a toxic bloom (Schmidt et al. 2014). Cousins et al. (1996) demonstrated that microcystin experimentally added into reservoir water has a half-life of three to four days, whereas microcystin spiked into the same matrix but sterilized (so biodegrading bacteria are dead) had no significant change in the 12 days of the experiment. The authors concluded that biodegradation was the primary mechanism of microcystin reductions in the raw reservoir water.

Where rivers discharge to the ocean, freshwater cyanobacteria, cyanotoxins, or both can enter the marine environment (Andersen et al. 1993; Miller et al. 2010). Miller et al. (2010) confirmed the transfer of freshwater microcystins to the marine environment; the researchers found that after introducing *Microcystis* cyanobacteria to a saline environment, cyanobacteria can survive for 48 hours before lysing and releasing microcystins. Microcystin concentrations in these experiments decreased in the range of 44 to 71 percent after one hour in the saline environment, but continued to be detected in the seawater for at least 21 days, based on a detection limit of 0.02 µg/L (Miller et al. 2010).

3.3.2.2 Cylindrospermopsin

Cylindrospermopsin is relatively stable in the dark and at temperatures from 4°C to 50°C for up to five weeks (ILS 2000). Cylindrospermopsin is also resistant to changes in pH and remains stable for up to eight weeks at pH 4, 7, and 10. In the absence of cyanobacterial cell pigments, cylindrospermopsin tends

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to be relatively stable in sunlight, with a half-life of 11 to 15 days in surface waters (Funari and Testai 2008).

Like microcystins, degradation of cylindrospermopsin increases in the presence of cell pigments such as chlorophyll *a* and phycocyanin, a blue photosynthetic pigment found in cyanobacteria. When exposed to both sunlight and cell pigments, cylindrospermopsin breaks down rapidly—more than 90 percent within two to three days (Chiswell et al. 1999).

Bacteria have been shown to decompose cylindrospermopsin in laboratory studies; the biodegradation is influenced by the cyanotoxin concentration, temperature, and pH. Mohamed and Alamri (2012) reported that *Bacillus* bacteria degraded cylindrospermopsin and that degradation occurred in six days at the highest toxin concentration (300 µg/L) and in seven or eight days at lower concentrations (10 and 100 µg/L, respectively). The biodegradation rate was also reported to depend on temperature and pH, with the highest rates occurring in warm waters (25 and 30°C) and neutral to slightly alkaline conditions (pH 7 and 8). Klitzke and Fastner (2012) confirmed the observations of Mohamed and Alamri (2012), noting that a decrease in temperature from 20 to 10°C slowed down degradation by a factor of 10. They also found that degradation slowed significantly under anaerobic conditions, with half-lives of 2.4 days under aerobic conditions and 23.6 days under anaerobic conditions.

3.4 Toxicokinetics

Limited data are available regarding the toxicokinetics of microcystins in environmental exposure conditions (U.S. EPA 2015d). Available intestinal data indicate that the organic anion transporting polypeptide (OATP) family transporters facilitate the absorption of microcystins from the intestinal tract into liver, brain, and other tissues, as well as their export out of organs and tissues (Cheng et al. 2005; Fischer et al. 2005; Svoboda et al. 2011). However, bile acids and other physiologically relevant substrates compete with microcystins for transporter uptake by the liver (Thompson and Pace 1992); reduction or elimination of liver toxicity has been observed during in vivo or in vitro exposures when microcystin uptake by OATP transporters is limited or inhibited (Hermansky et al. 1990a, 1990b; Runnegar et al. 1995; Runnegar and Falconer 1982; Runnegar et al. 1981). Both in vivo and in vitro studies have shown biliary excretion of microcystins (Falconer et al. 1986; Pace et al. 1991; Robinson et al. 1991), possibly via conjugation with cysteine and glutathione (Kondo et al. 1996). Additional details of microcystin toxicokinetics can be found in the EPA's Drinking Water Health Advisory and HESD for microcystins (U.S. EPA 2015a, 2015d).

Limited toxicokinetic data for cylindrospermopsin are available and are derived from mice intraperitoneal studies and in vivo studies that do not necessarily reflect environmental exposure conditions (U.S. EPA 2015c; Pichardo et al. 2017). Cylindrospermopsin is absorbed from the GI tract (Humpage and Falconer 2003; Shaw et al. 2001; Shaw et al. 2000) and is distributed primarily to the liver but also to the kidneys and spleen (Norris et al. 2001). The metabolism and toxicity of cylindrospermopsin is mediated by hepatic cytochrome P450 (CYP450) enzymes, and the periacinar region of the liver appears to be the main target of toxicity where cylindrospermopsin and its metabolites bind to proteins (Norris et al. 2001; Runnegar et al. 1995; Shaw et al. 2001; Shaw et al. 2000). Elimination of cylindrospermopsin was continuous over a monitoring period of 24 hours, with a large mean total recovery primarily from urine, and to a smaller extent, feces, after 24 hours (Norris et al. 2001). Additional details of cylindrospermopsin toxicokinetics can be found in the EPA's Drinking Water Health Advisory and HESD for cylindrospermopsin (U.S. EPA 2015b, 2015c).

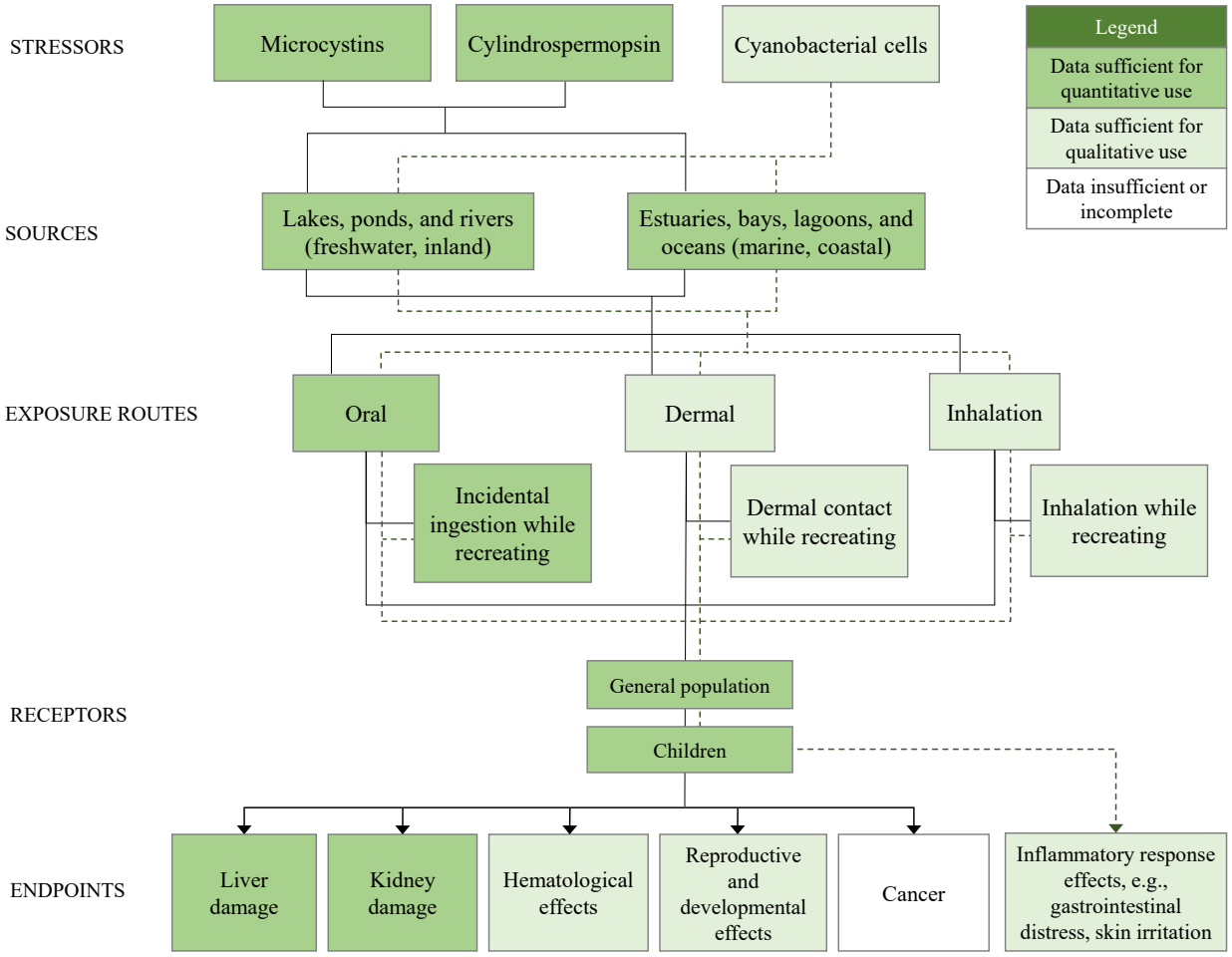
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4.0 PROBLEM FORMULATION

4.1 Conceptual Model

This conceptual model provides useful information that characterizes and communicates the potential health risks related to exposure to microcystins and cylindrospermopsin in recreational waters. The model depicts the sources of the cyanotoxins in these waters, the recreational routes of exposure for sensitive biological receptors of concern, and the potential assessment endpoints (e.g., effects such as kidney and liver toxicity) (Figure 4-1).

Figure 4-1. Conceptual Model of Exposure Pathways to the Cyanotoxins, Microcystins and Cylindrospermopsin, and Cyanobacteria in Surface Waters While Recreating



4.1.1 Conceptual Model Diagram for Recreational Exposure

The conceptual model is intended to explore potential links of exposure to a contaminant or stressor with the adverse effects and toxicological endpoints important for management goals, including the development of recreational AWQC. Boxes that are shaded darker green indicate pathways that the EPA considered quantitatively in estimating the advisory level, whereas boxes shaded lighter green indicate data were sufficient for qualitative use and the white boxes did not have sufficient data for the EPA to

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evaluate quantitatively or qualitatively. The solid lines are for the cyanotoxins and the dotted lines are for the cyanobacterial cells.

4.1.2 Factors Considered in the Conceptual Model for Microcystins and Cylindrospermopsin

Stressors

The stressors are microcystins and cylindrospermopsin concentrations in water. These toxins can be produced by cyanobacteria occurring in freshwater. The EPA concluded that although statistically significant associations with adverse health effects occur across a wide range of cyanobacterial cell densities, criteria cannot be derived based on cyanobacterial cell density at this time. Effects related to cyanobacterial cells are discussed in section 7.5.1 and Appendix D.

Sources

Cyanobacteria occur naturally in surface waters, such as lakes, ponds, rivers, estuaries, bays, lagoons, and oceans in or surrounding the United States. Some genera of the cyanobacteria, including *Microcystis*, *Cylindrospermopsis*, *Anabaena*, *Planktothrix*, and *Nostoc*, can produce the cyanotoxins microcystins and cylindrospermopsin. This assessment focuses on cyanotoxins produced by these cyanobacteria in freshwater. These toxins have the potential to affect downstream waters, including coastal areas where surface water containing the toxins discharges into estuarine and marine waters.

Routes of Exposure

Exposure to cyanotoxins from recreational water sources can occur via oral exposure (incidental ingestion while recreating); dermal exposure (contact of exposed parts of the body with water containing cyanotoxins during recreational activities such as swimming, wading, or water skiing); and inhalation exposure to contaminated aerosols (while recreating). The route of exposure considered quantitatively in this assessment is the oral exposure to microcystins and cylindrospermopsin via incidental ingestion while swimming. Inhalation can occur from exposures from personal watercraft and boat spray. Dermal exposure can occur through recreational water contact; however, significant dermal absorption of microcystins and cylindrospermopsin is not expected due to the large size and charged nature of these molecules and the lack of dermal receptor sites capable of uptake (Butler et al. 2012; U.S. EPA 2004; U.S. EPA 2007). Sufficient data to quantify toxicity via the inhalation and dermal exposure routes were not available. The dermal and inhalation routes of exposure are discussed further in the Effects Characterization section (7.4).

Receptors

Anyone who recreates in a water body where cyanotoxins are present could be exposed to cyanotoxins through ingestion, dermal contact, and inhalation of aerosols while recreating in contaminated surface waters. Recreating children can be at greater risk from exposure to microcystins or cylindrospermopsin because they have smaller body mass compared to adults, they spend more time in contact with the water compared to adults, and they incidentally ingest more water than adults while recreating. Therefore, the EPA has determined that childhood is the most vulnerable lifestage due to potential increased exposure while recreating when compared with adults. The EPA evaluates and discusses differences between lifestages in the Effects Characterization section (7.3).

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While there are examples in the literature and reports of animal poisonings and death due to exposure of cyanotoxins, values protective of animals such as dogs and livestock are not generated in this document. However, section 7.8 discusses some animal-specific issues, including a summary of guidelines that several states have developed for animals.

Endpoints

Available microcystin toxicity data indicate that the primary target organ for microcystins is the liver as described in the EPA's HESD for microcystins (U.S. EPA 2015d).

Available cylindrospermopsin toxicity data are described in the EPA's HESD for cylindrospermopsin (U.S. EPA 2015c). For cylindrospermopsin, the EPA selected kidney effects as the endpoint on which to quantify the measure of effect. However, in both the critical study and the supporting studies there is evidence that cylindrospermopsin can also alter the shape of red blood cells.

Clinical, epidemiological, and outbreak study results (see Appendix D) suggest a link between an increase in adverse inflammatory symptoms among recreators and elevated cyanobacterial cell densities. However, there is considerable uncertainty and variability associated with the epidemiological results, which did not identify consistent effects at similar cyanobacterial densities. Specifically, significant associations occur across a wide range of cell densities; associations vary with different self-reported health endpoints or combined symptom categories. Potential inflammatory health effects related to exposure to total cyanobacterial cells are described in the Effects Characterization section (7.5.1) and in Appendix D, both of which include a discussion of the uncertainties related to associations with cyanobacterial cells.

4.2 Analysis Plan

The EPA's 2000 *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health* (2000 Human Health Methodology) outlines the Agency's process for deriving AWQC and guides the development of these recreational criteria and swimming advisory recommendations (U.S. EPA 2000).

The 2000 Human Health Methodology includes identifying the population subgroup that should be protected and evaluating cancer and non-cancer endpoints, measures of effect, measures of exposure, and relative source contribution (RSC). In this analysis plan, the EPA describes: (1) the RfD previously derived for microcystins and cylindrospermopsin (measure of effect); (2) the calculation for the recreational criteria; (3) incidental ingestion exposure in terms of volume ingested, duration of exposure, and body weight (measure of exposure) described in the EPA's *Exposure Factors Handbook* (EFH) and data reported in the peer-reviewed scientific literature; and (4) discusses the RSC. These criteria focus on human exposure as a result of primary contact recreation activities, such as swimming, during which immersion and incidental ingestion of ambient water are likely.

The EPA's HESD for microcystins and HESD for cylindrospermopsin (U.S. EPA 2015c, 2015d) provide the health effects basis for the development of the Drinking Water Health Advisories for microcystins and cylindrospermopsin (U.S. EPA 2015a, 2015b), including the basis for estimating the point of departure. To develop its HESDs for microcystins and cylindrospermopsin, the EPA assembled available information on toxicokinetics, acute, short-term, subchronic, and chronic toxicity along with developmental and reproductive toxicity, neurotoxicity, immunotoxicity, genotoxicity, and cancer in

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humans and animals. For detailed descriptions of the literature search strategies, see the EPA's HESDs for microcystins and cylindrospermopsin (U.S. EPA 2015c, 2015d).

The EPA's HESDs were subject to rigorous internal and external peer review before being finalized in 2015. The information evaluated for these documents also supports the development of the recreational criteria and swimming advisories for microcystins and cylindrospermopsin, which evaluate exposure via recreational water ingestion. The EPA conducted supplemental literature searches to capture new references, including effects related to recreational exposure to cells. For detailed information on the search terms, see Appendix C.

4.2.1 Approach for Recreational AWQC and Swimming Advisory Derivation

The recreational AWQC and swimming advisory recommendations for microcystins and cylindrospermopsin are calculated as described in the 2000 Human Health Methodology and presented in the equation below:

$$\text{Recreational AWQC } (\mu g/L) = \text{RfD} \times \frac{\text{BW}}{\text{IR}}$$

Where:

RfD	=	reference dose (μg/kg body weight/day)
BW	=	mean body weight (kg)
IR	=	ingestion rate (L/day) (discussed in section 4.2.3.1)

4.2.1.1 Magnitude, Duration, and Frequency

Recreational criteria, like other 304(a) criteria, consist of a magnitude, duration, and frequency. Magnitude is the numeric expression of the maximum amount of the contaminant that may be present in a water body that supports the designated use. Duration is the period over which the magnitude is calculated. Frequency of excursion describes the number of times the contaminant may be present above the magnitude over the specified period (duration). A criterion is derived such that the combination of magnitude, duration, and frequency protect the designated use (e.g., primary contact recreation).

4.2.2 Measures of Effect

The EPA's HESDs for microcystins and cylindrospermopsin (U.S. EPA 2015c, 2015d), provide the health effects basis for development of an oral toxicity value or the RfD, including the selection of the critical study and critical endpoints and application of uncertainty factors (UFs). In derivation of the recreational criteria and swimming advisory recommendations, the EPA uses these toxicity values as the measure of effect for oral exposure through incidental ingestion while recreating. The RfDs described in the EPA's HESDs are based on short-term and subchronic studies and therefore are an estimate (with uncertainties spanning perhaps an order of magnitude) of the daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a short-term exposure period.

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4.2.3 Measures of Exposure

The EPA selected incidental ingestion during primary contact activities (such as swimming) in derivation of the recreational criteria and swimming advisories because data suggest that incidental ingestion can be considered the highest potential exposure pathway for cyanotoxins while recreating. Dorevitch et al. (2011) studied the volume of water ingested during a range of recreational activities in the Chicago Area Waterway System (CAWS) and at a public outdoor swimming pool. Study participants took part in one of the following activities on the CAWS: canoeing, fishing, kayaking, motor boating, or rowing. In the swimming pool, participants took part in canoeing, fishing, kayaking, swimming, or wading/splashing. The results indicate that the odds of ingesting a teaspoon or more of water are significantly higher among swimmers than among those who just immersed their head in a swimming pool or those who participated in the other, more limited contact activities on surface waters. Therefore, the EPA determined that using a swimmer scenario for exposure as the basis for the criteria is protective of these other aquatic activities.

Inhalation exposure occurs during swimming; however, data are not sufficient to quantify health effects resulting from inhalation exposure to cyanotoxins at this time. See section 7.4.1 for a characterization of potential effects from inhalation exposure.

Dermal exposure happens during swimming; however, significant dermal absorption of the toxins microcystins and cylindrospermopsin is not expected due to the large size and charged nature of these molecules (Butler et al. 2012; U.S. EPA 2004; U.S. EPA 2007). Because available data are not sufficient, the EPA is not quantifying effects resulting from dermal exposure to cyanotoxins. See section 7.4.2 for a characterization of dermal exposure to these cyanotoxins.

Dermal exposure to cyanobacterial cells can also result in adverse health effects, such skin rashes, eye irritation, and ear irritation. Because adequate effects data are not available, the EPA is not quantifying effects resulting from exposure to cells at this time; effects are described qualitatively. Available epidemiological study results do not provide consistent associations between cell densities and the inflammatory health endpoints. See section 7.5.1 for a characterization of potential effects from recreational exposure to cyanobacterial cells.

All recreational exposure studies that included both children and adults found that age tended to influence incidental ingestion exposure while recreating. More specifically, children tend to ingest more water and spend more time in the water compared with adults (Dufour et al. 2017; Dufour et al. 2006; Schets et al. 2011; U.S. EPA 2011). Data supporting the selected exposure factors are described in the sections that follow.

The measure of exposure is the 90th percentile of the daily incidental ingestion rate (volume of surface water incidentally ingested per day) and body weight (kg). Both body weight and incidental ingestion while recreating are parameters that vary with age. The EPA's 2000 Human Health Methodology (2000) outlines EPA's process for deriving AWQC and guides the development of these recreational criteria and swimming advisory recommendations.

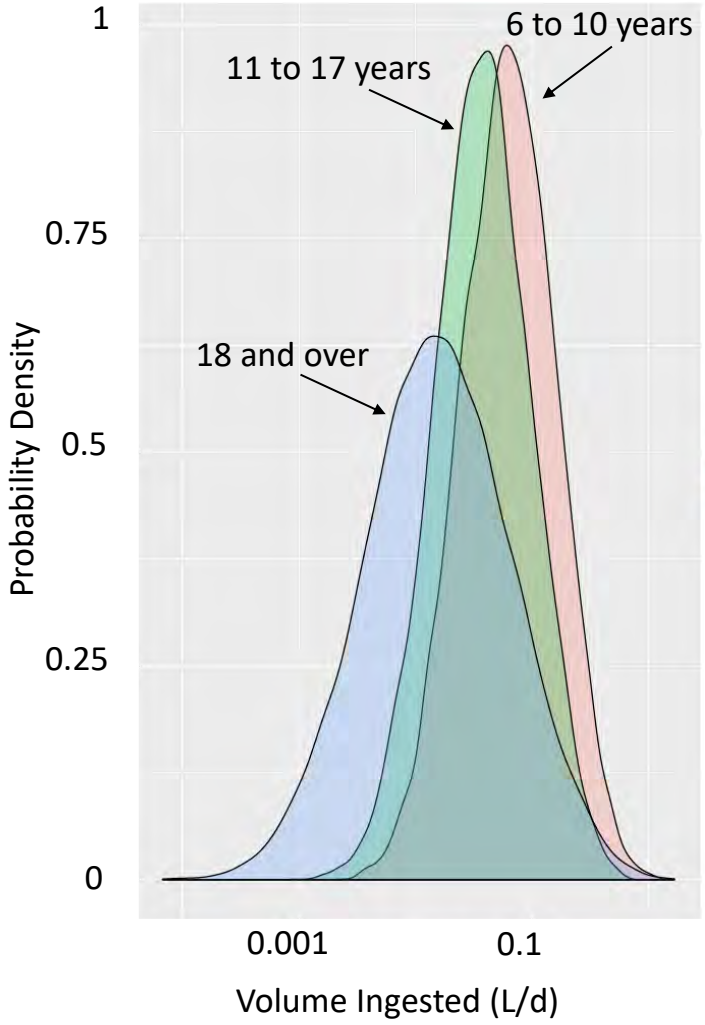
4.2.3.1 Incidental Ingestion

To calculate the recreational incidental ingestion rate in units of volume per day, the EPA combined a distribution of incidental ingestion volumes (volume per event normalized to volume per hour) and a distribution of exposure durations (hours per day). The EPA uses the 90th percentile of the combined

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distribution of ingestion rate and exposure duration to represent incidental ingestion per day, consistent with the EPA's Human Health Methodology (U.S. EPA 2000). Probability density plots of the combined distributions are shown in Figure 4-2. The ingestion data demonstrate that the mean ingestion rate for children six to 10 years is higher than for older children and adults. These data are discussed in the following sections.

Figure 4-2. Combined Distributions for Age Groups

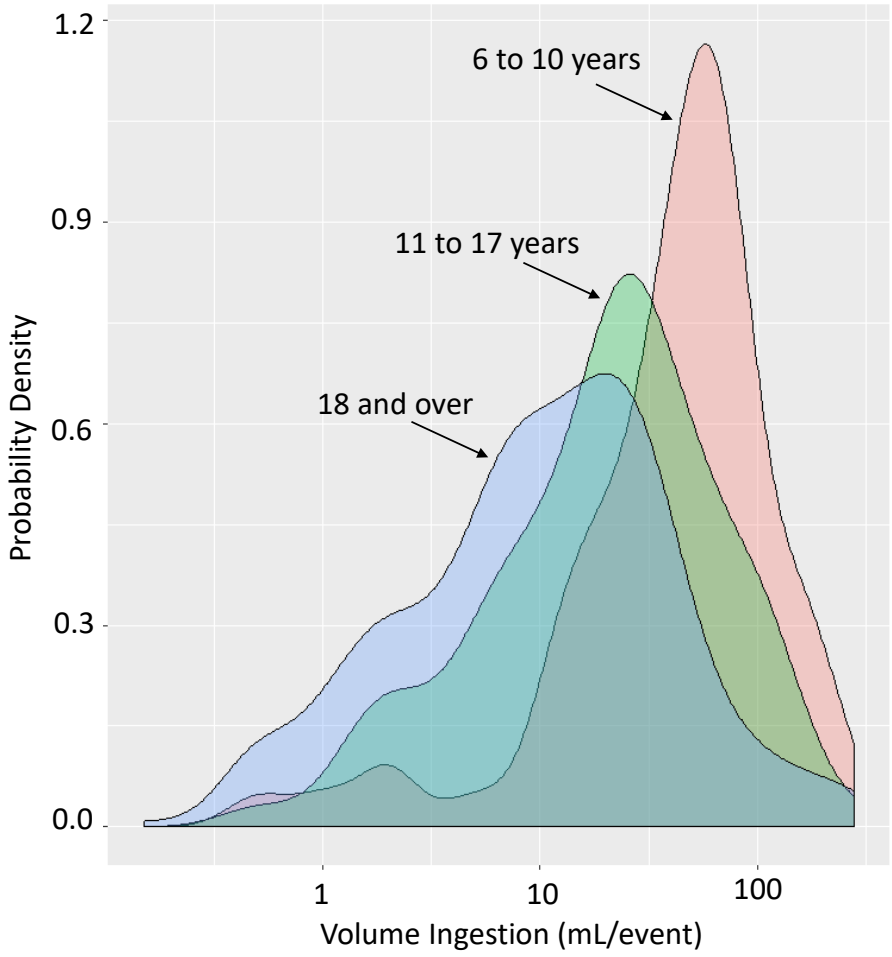


Ingestion Volume Studies

The EPA evaluated seven studies on ingestion and selected the dataset collected and analyzed by Dufour et al. (2017) for development of these AWQC or swimming advisory recommendations. This study used the same methodology as an earlier study (Dufour et al. 2006) but included 10 times more participants. Both studies used cyanuric acid as an indicator of amount of pool water ingested while swimming in an outdoor pool. Pool water samples were collected before the start of swimming activities, and participants' urine was collected for 24 hours after the swimming event ended; pool water and urine samples were analyzed for cyanuric acid. The dataset collected by Dufour et al. (2017) included age information for each particpant ages six to 81 years, whereas the 2006 study classified individuals as over or under 18 years old. Both studies did not include children younger than six years old. The 2017

study recorded time spent in the water for each participant. The 2017 study results highlighted that younger children tested ingested more than older children or adults. The EPA selected the Dufour et al. (2017) dataset to calculate incidental ingestion volume because of the larger number of particpants, the inclusion of additional age groups, and recording of the duration exposure of each participant. The raw data collected and analyzed by Dufour et al. (2017) was provided by the study authors (U.S. EPA 2018a). The EPA adjusted (i.e., normalized) the volume ingested by each participant to one hour based on the length of time that participant reported being in the water. The summary statistics the EPA calculated using this dataset are shown in Appendix E (Table E-1). Figure 4-3 shows the raw data density plots for the Appendix E Dufour data separately grouped as age groups six to 10, 11 to 17, and 18 years and over. The density plots show the volume of incidental ingestion (mL) per recreational event on a log scale. To develop the distribution, each participant's volume ingested was adjusted to one hour based on the length of time that participant reported being in the water. Incidental ingestion was recorded for 66 individuals in the six- to 10-year category.

Figure 4-3. Incidential Ingestion for Age Groups Based on Appendix E Dufour Data



Appendix F describes seven studies that reported incidental ingestion while recreating, but only three others reported ingestion estimates for children (Dufour et al. 2006; Schets et al. 2011; Suppes et al. 2014). These other studies reported children's ingestion volumes similar to Dufour et al. (2017). Although these other studies corroborate the Dufour et al. (2017) findings, they were not selected for deriving the ingestion rate. Dufour et al. (2006) had fewer age groups (i.e., six to 17 and 18+ years), smaller sample size, and did not record time spent in water for each participant, making it a less robust

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study than Dufour et al. (2017). Schets et al. (2011) collected data in the Netherlands, which may not be representative of the United States due to different behavioral trends in the resident population, including effects of temperature on recreating patterns. In addition, Schets et al. (2011) ingestion volumes are based on self-reported estimates; parents estimated volumes for children five and younger. Self- and parent-reported estimates are more uncertain than the methods used by Dufour et al. (2017). Suppes et al. (2014) used video and urine analysis to estimate ingestion volume. In Suppes et al. (2014) quantitative data were available for 35 participants, which is much lower than the sample size for Dufour et al. (2017). In addition, Suppes et al. (2014) only reported two age groups, children (five to 17 years) and adults (18+ years), which does not allow for the finer discernment of exposure patterns that is possible with the Appendix E and U.S. EPA (2018a) data.

Appendix F also describes the methodology used by the EPA's Office of Pesticide Programs (OPP) to calculate exposures to pool chemicals during swimming to support registration decisions. The Swimmers Exposure Assessment Model (SWIMODEL) (U.S. EPA 2003) uses incidental ingestion values for children that are twice the values used for noncompetitive adult swimmers. The model assumes an incidental ingestion rate of 0.050 L/hour for children ages seven to 10 years and 11 to 14 years while swimming noncompetitively. Incidental ingestion rates among adults while swimming competitively and noncompetitively are 0.0125 L/hour and 0.025 L/hour, respectively.

Duration of Recreational Exposure

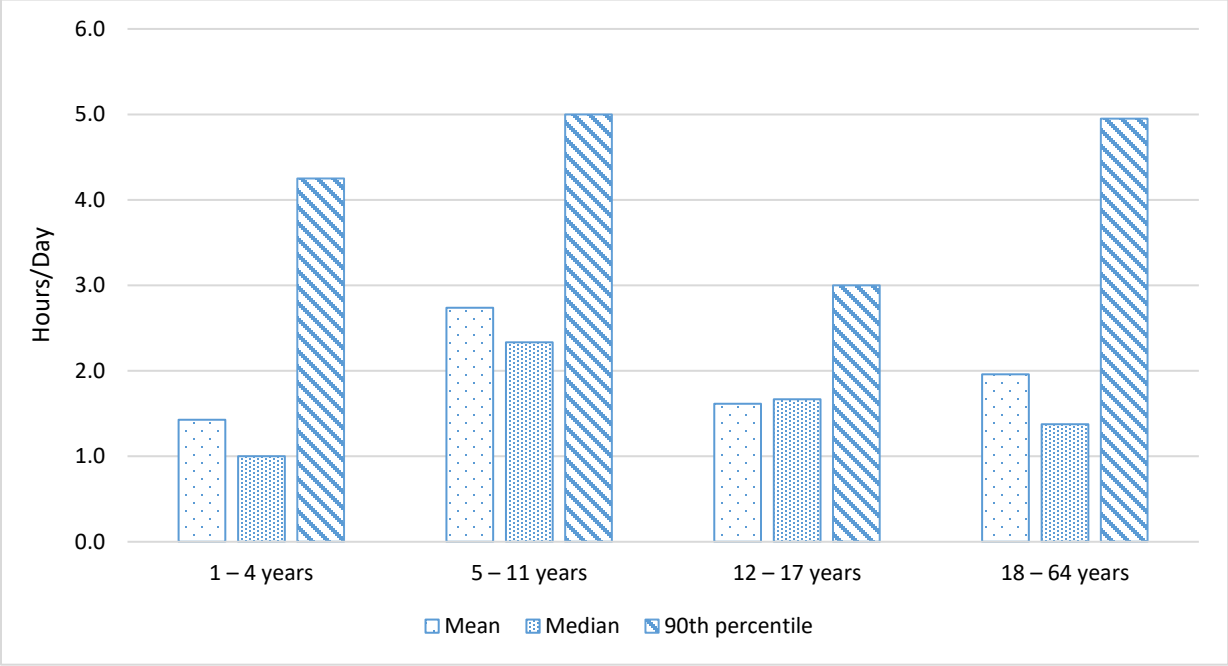
Duration of recreational exposure quantifies the length of time people might be exposed to cyanotoxins during their primary contact recreational use. Duration is needed to convert recreational ingestion rates in units of volume per hour to an amount incidentally ingested per day, which is the exposure parameter needed to derive the recommended cyanotoxin values.

The EPA selected recreational exposure data from the EFH (U.S. EPA 2011) for the development of these criteria/swimming advisories. The EPA's EFH (2011) lists time spent per 24 hours in an outdoor spa or pool for different age groups. The data are based on analysis of the National Human Activity Pattern Survey (U.S. EPA 1996). Figure 4-4 compares point estimates for the recreational duration data for different age groups and shows that recreators ages five to 11 years (n = 15) tend to spend more time in the water than other child age groups and adults. A duration was not provided for children younger than age one year.

The EPA investigated available exposure parameters for children younger than six years old, but they have large uncertainties given the lack of measured incidental ingestion data for this age group (see section 7.3.2). See section 7.2 (Recreational Exposure Duration) for further discussion of the available data for recreational exposure duration. The EPA used the distribution of exposure durations for children ages five to 11 years (n = 15; units are hour/day) as described below to calculate incidental ingestion per day.

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Figure 4-4. Direct Contact Recreational Exposure Duration by Age Group, Based on Table 16-20 in U.S. EPA (2011)[a]



[a] This figure shows a comparison of point estimates. The EPA used the whole distribution for ages five to 11 years in deriving the AWQC and swimming advisory magnitudes.

Determination of Incidental Ingestion per Day

The incidental ingestion volume per day the EPA used to calculate the AWQC or swimming advisories is the product of the distribution of children's incidental ingestion rate for children ages six to 10 years (Appendix E; U.S. EPA 2018a) and the distribution of exposure durations for children ages five to 11 years (U.S. EPA 2011). The lifestage grouping for the duration data include children one year older and one year younger than the lifestage group for the incidental ingestion data.

The individual ingestion rate data points (adjusted to L/hour) were used to calculate a mean and standard deviation of the log-normal transformed dataset. This distribution was combined with the distribution of hours of recreation per day (ages five to 11 years) from the 2011 EFH (Table 16-20 *Time Spent (minutes/day) in Selected Outdoor Locations, Doers Only, At Home in the Outdoor Pool or Spa*). The mathematical relationship between the two variables and the daily incidental ingestion rate is shown in this equation:

$$\text{Ingestion Volume (L/hour)} \times \text{Recreation Duration (hour/day)} = \text{Daily Incidental Ingestion Rate (L/day)}$$

The EPA used probabilistic (Monte Carlo) simulation to develop the combined distribution of these variables as follows:

- Estimated statistical distributions for hourly ingestion rate and recreation duration for different age groups.
- Sampled randomly one value from each of these distributions.

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- Multiplied the two sampled values.
- Repeated a large number of times (i.e., 100,000 times) to populate the distribution for daily ingestion rate (L/day) or the combined distribution.
- Reported results as summary statistics of the combined distribution.

The distribution shape that best fit the datasets was log-normal for both ingestion volume and exposure duration. Table 4-1 presents summary statistics for different age groups based on the combined distribution analysis. As per the EPA's 2000 Human Health Methodology (U.S. EPA 2000), the 90th percentile of exposure, represented by this combined distribution (0.21 L/day) was used as a point estimate for deriving the AWQC or swimming advisories. Details and the R code for this analysis are shown in Appendix E. Appendix E also includes the mean, median, and standard deviation for the distributions for ages six to 10, 11 to 17, and 18 years and older.

Table 4-1. Results of the Combined Distribution Analysis

Age Group	Summary Statistics for Ingestion Rate (L/day)		
	Median	Mean	90th Percentile
6 to 10 years	0.063	0.094	0.21
11 to 17 years	0.038	0.058	0.13
18+ years	0.015	0.04	0.10

4.2.3.2 Body Weight

Table 8-1 in the EPA's EFH (U.S. EPA 2011) reported body weight statistics based on the National Health and Nutrition Examination Survey, including for a range of age groups. The EPA selected children aged six to 10 years because it reflected the age group with higher ingestion volumes (Appendix E; U.S. EPA 2018a; U.S. EPA 2011) and exposure duration (U.S. EPA 2011).[4] As per the EPA's 2000 Human Health Methodology (U.S. EPA 2000), mean body weight (31.8 kg) was used for deriving the AWQC or swimming advisories. Section 7.3.2 provides a discussion of younger children's exposure factors.

4.2.4 Relative Source Contribution (RSC)

The RSC component of the AWQC calculation allows a percentage of the exposure to a contaminant to include other potential exposure sources. The RSC describes the portion of the RfD available for AWQC-related sources (U.S. EPA 2000); the remainder of the RfD is allocated to other sources of the contaminant. The EPA focused on recreational exposures to microcystins and cylindrospermopsin in ambient freshwaters. To derive recommendations protective of the recreational designated use, the EPA assumes all cyanotoxin exposure is from incidental ingestion of water while recreating; therefore, no RSC term is applied.

[4] The age group six to 10 years includes 10-year-old children. The EPA's *Exposure Factors Handbook* labels this age group as six to < 11 years.

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5.0 EFFECTS ASSESSMENT

The health effects studies summarized below for microcystins and cylindrospermopsin are described in detail in the EPA's HESDs and Drinking Water Health Advisories for these two cyanotoxins (U.S. EPA 2015a, 2015b, 2015c, 2015d).

5.1 Hazard Identification

5.1.1 Noncancer Health Effects

5.1.1.1 Animal Toxicity Studies

Microcystins

The preponderance of animal toxicity data on the noncancer effects of microcystins is restricted to the microcystin-LR congener. Available data on the RR, YR, and LA congeners do not provide dose-response information sufficient for quantification. The EPA is using data on effects of microcystin-LR to represent other microcystin congeners (U.S. EPA 2015d). Observed effects in animals exposed orally or via intraperitoneal infusion to microcystin-LR include liver, reproductive, developmental, kidney, and GI effects (Chernoff et al. 2002; Falconer et al. 1998; Fawell et al. 1999; Fitzgeorge et al. 1994; Guzman and Solter 1999, 2002; Heinze 1999; Ito et al. 1997a, 1997b; Yoshida et al. 1997). Most oral and injection studies in laboratory animals have demonstrated that the liver is a primary target organ for microcystin toxicity. Liver effects, as well as kidney effects, have been reported in acute, short-term, and subchronic oral studies in laboratory animals exposed to microcystin-LR, in addition to reproductive effects following short-term and subchronic oral exposures. Studies evaluating the chronic toxicity of microcystins have not shown clinical signs of toxicity and are limited by study design and by the lack of quantitative data. For individual study details see the EPA's HESD for microcystins (U.S. EPA 2015d).

Available animal data on the acute oral toxicity of microcystin-LR provide evidence of hepatotoxicity. Liver effects described in the above studies are summarized in Table 5-1. A single oral dose of 500 μg microcystin-LR/kg resulted in diffuse hemorrhage in the liver of mice and rats; more pronounced liver damage occurred at higher doses (Ito et al. 1997a; Fawell et al. 1999; Yoshida et al. 1997). Studies that utilized parenteral administration of microcystin-LR show a steep dose-response with rapid onset of liver damage.

The findings in acute and subchronic studies support the liver as a target organ for microcystin-LR toxicity. The EPA identified a 28-day short-term study by Heinze (1999) as the critical study for derivation of an RfD. Male hybrid rats (10/group) were administered microcystin-LR in drinking water at doses of 0, 50, or 150 μg/kg body weight (Heinze 1999). Liver effects included increased liver weight, and slight to moderate liver necrosis lesions with or without hemorrhages at the low dose and with dose-related increases in necrotic severity. The necrosis was accompanied by changes in serum enzymes indicative of liver damage. All rats in each dose group had liver necrosis. Data were not collected prior to the end of the study so it is not known when during the 28-day study period these effects were manifested.

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Table 5-1. Liver Effects in Animals Exposed to Microcystins in Selected Acute and Short-term Studies as Discusssed in the EPA's *Health Effects Support Document for the Cyanobacterial Toxin Microcystins* (U.S. EPA 2015d)

Species	Exposure Route	Dosing Regimen	Micro-cystin Congener	Description of Liver Effects	Study
Female BALB/c mice (n = 7)	Gavage	Single dose of 0, 8,000, 10,000, or 12,500 µg/kg Examination at 24 hours after treatment	LR	Centrilobular hemorrhage, hepatocyte degeneration	Yoshida et al. (1997)
Male ICR mice aged (n = 29 age 32 weeks) and young (n = 12 age 5 weeks)	Gavage	Single dose of 500 µg/kg Animals sacrificed at 2, 5, and 19 hours after treatment	LR	Bleeding and disappearance of hepatocytes in the whole liver or in centrilobular region, friable tissue, necrosis, or eosinophilic changes in the centrilobular region	Ito et al. (1997a)
CR1:CD-1(ICR)BR(VAF plus) mice and CR1:CD(SD)BR(VAF plus) rats (5 males and 5 females per group)	Gavage	Single dose of 500, 1,500, or 5,000 µg/kg (no control) Animals sacrificed at day 14 post treatment	LR	Darkly discolored and distended livers; moderate or marked centrilobular hemorrhage of liver; diffuse hemorrhage in the liver	Fawell et al. (1999)
Male ICR mice (n = 5 per group)	Gavage	Repeated doses of 0, 4.6, 23, 46, 93, or 186 µg/kg/day for 7 days Animals sacrificed at day 7	RR	Dose-dependent increase in apoptosis	Huang et al. (2011)
Male hybrid rats (F1 generation of female WELS/Fohm × male BDIX) (10 per group)	Drinking water	Repeated doses of 0, 50, or 150 µg/kg/day for 28 days	LR	Hepatocyte degeneration, hemorrhage, and necrosis; increase in periodic acid-Schiff-positive substances (indicating cell damage), Kupffer cell activation	Heinze (1999)
Male Sprague-Dawley rats (3 per group)	Intraperitoneal infusion	Repeated doses of 0, 16, 32, or 48 µg/kg/day for 28 days	LR	Fibrous tissue, cell death, necrosis, lipid vacuoles, Kupffer cell activation (+2 and +3 severity rating)	Guzman and Solter (1999)

The liver effects in the Heinze (1999) study were supported by additional data from a study by Guzman and Solter (1999). Rats exposed via intraperitoneal infusion displayed histological evidence of liver

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damage (i.e., inflammation, fibrous tissue, necrosis, and apoptosis). The study authors identified a no-observed-adverse-effect-level (NOAEL) of 16 µg/kg/day and a lowest-observed-adverse-effect-level (LOAEL) of 32 µg/kg/day. Microcystin-LR was delivered directly to the livers of the animals in the study by implanted osmotic pumps and this may account for the liver effects observed at lower doses compared to Heinze (1999). Guzman and Solter (1999) only included three rats per group exposed to doses of 0, 16, 32, or 48 µg/kg/day of microcystin for 28 days, which is a limitation of the study design. Although adverse liver effects were observed, the limited numbers of animals per dose group (n = 3) and the exposure route, which bypassed intestinal barriers to absorption, resulted in greater uncertainty than Heinze (1999). Thus, Guzman and Solter (1999) was not used to derive the RfD.

Some studies observed other kinds of effects following short-term or subchronic oral or intraperitoneal exposures. These studies, including limitations, are discussed in the EPA's HESD for microcystins (U.S. EPA 2015d). Potential effects included reproductive toxicity in males (Chen et al. 2011), maternal mortality (Fawell et al. 1999; Chernoff et al. 2002), and fetal body weight changes (i.e., at 2,000 µg/kg, administered orally during gestational days six to 15, at which significant maternal mortality was observed) (Fawell et al. 1999). Chernoff et al. (2002) did not report adverse effects on fetal or pup weights in two separate intraperitoneal studies.

Cylindrospermopsin

The available acute, short-term, and subchronic studies for cylindrospermopsin (Bazin et al. 2012; Humpage and Falconer 2002; 2003; Reisner et al. 2004; Terao et al. 1994; Shaw et al. 2001) support the liver and kidneys as the primary targets for cylindrospermopsin toxicity (summarized in Table 5-2), with effects on red blood cells also evident. These effects were observed in mice given single or repeated doses of purified cylindrospermopsin via oral administration or intraperitoneal injection (Bazin et al. 2012; Humpage and Falconer 2002, 2003; Reisner et al. 2004; Terao et al. 1994). The EPA did not find health effects information for other cylindrospermopsin congeners or analogs.

No oral reproductive or developmental studies are available for cylindrospermopsin. Developmental toxicity studies following intraperitoneal administration of cylindrospermopsin provide some evidence for maternal toxicity and decreased postnatal pup survival and body weight (Chernoff et al. 2011; Rogers et al. 2007). For individual study details, see the EPA's HESD for cylindrospermopsin (U.S. EPA 2015c).

The RfD for cylindrospermopsin was derived from the 11-week critical study by Humpage and Falconer (2002, 2003). This study was an 11-week study in mice, and the critical effect identified was kidney toxicity. The short-term studies available for cylindrospermopsin (Shaw et al. 2001; Reisner et al. 2004), were also evaluated and are considered supportive of the critical study; however, the EPA concluded that they were not suitable for quantification based on limitations including the use of extract, lack of adequate numbers of animals, monitored endpoints, the limited number of doses tested and endpoints monitored.

Humpage and Falconer (2002, 2003) identified a NOAEL of 30 µg/kg/day and a LOAEL of 60 µg/kg/day for increases in relative kidney weight in mice treated with purified cylindrospermopsin by gavage for 11 weeks. There were indications of reduced renal function effects, decreased urinary protein, and red blood cell effects (including increased bilirubin, spleen weight and polychromasia, indicative of hemolysis) at doses above the LOAEL. Although effects on kidney weight and urine protein levels were observed in male mice, the biological relevance of the latter effect and whether it would also occur in female mice needs further investigation. Mice are known to excrete a group of

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highly polymorphic, low-molecular-weight urinary proteins that play important roles in social recognition and mate assessment. The relevance of the urinary protein findings in mice to humans is unknown. Humpage and Falconer (2002, 2003) found signs indicative of hemolysis (e.g., increased bilirubin, spleen weight and polychromasia), however these changes were not statistically significant.

Results from Reisner et al. (2004) corroborate Humpage and Falconer (2002, 2003) with comparable effects observed in mice during a three-week study. The kidney and red blood cell effects observed by Reisner et al. (2004) occurred at a LOAEL of 66 μg/kg/day in drinking water. The study authors demonstrated significant increases in hematocrit, acanthocytes (abnormal red blood cells), and liver and testes weights in exposed animals and a duration-related nonsignificant increase in kidney weight. The red blood cell effects were seen as early as the end of the first week of dosing and were present in each of the three weekly blood samples collected. Sukenik et al. (2006) observed similar effects on red blood cells (increases in hematocrit from week 16 to 32 accompanied by increased numbers of acanthocytes up to week 42) in male and female mice exposed to gradually increasing concentrations of cylindrospermopsin (i.e., from 100 to 550 μg/L) in drinking water for 42 weeks. Mice were given cylindrospermopsin in the form of spent medium on which cultures of *Aphanizomenon ovalisporum* had been grown; other medium components were not characterized. The authors proposed a LOAEL of 20 μg/kg/day (equivalent to 200 μg/L) for male and female mice based on changes in hematocrit at 16 weeks (Sukenik et al. 2006). This study was not selected as a critical study because this study used a single dose; however, the kidney and red blood cell effects at that dose after three weeks were comparable to the effects seen in the Humpage and Falconer (2002, 2003) study at a slightly lower 60 mg/kg/day dose after 11 weeks.

The short-term study by Shaw et al. (2001) was also considered in the development of the RfD for cylindrospermopsin. Shaw et al. (2001) reported liver effects (fatty infiltration) in mice given 50 μg/kg purified cylindrospermopsin by gavage for 14 days; this dose is lower than the NOAEL identified in the key study by Humpage and Falconer (2002, 2003). However, the EPA concluded that the Shaw et al. (2001) study was not suitable for quantification based on the limited number of doses tested.

A 90-day oral toxicity study by Chernoff et al. (2018) demonstrated signs of hepatic and renal injury in mice at all dose levels (0, 75, 150, and 300 μg/kg/day). Liver toxicity effects were noted by elevated absolute and relative liver weights, increases in serum alanine aminotransferase activity, reduced serum blood urea nitrogen and cholesterol levels, and increased incidence of hepatocellular hypertrophy and cord disruption. Renal toxicity effects were demonstrated in elevated absolute and relative kidney weights and renal cellular hypertrophy, tubule dilation, and cortical tubule lesions. Males showed more susceptibility to toxic effects; liver and kidney/body weight ratios, reduced cholesterol levels, cellular signs of inflammation, and degree and extent of renal histopathological damage were all observed to be more prominent in males. A NOAEL was not determined for any dose level based on significant liver and kidney effects exhibited in the 75 μg/kg group. The LOAEL of 75 μg/kg observed by Chernoff et al. (2018) is higher than the Humpage and Falconer (2002, 2003) NOAEL of 30 μg/kg.

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Table 5-2. Kidney and Liver Effects in Animals Exposed to Cylindrospermopsin (Purified) in Acute and Key Short-term Studies in the *Health Effects Support Document for the Cyanobacterial Toxin Cylindrospermopsin* (U.S. EPA 2015c)

Species	Exposure Route	Dosing Regimen	Description of Kidney and Liver Effects	Study
Male Swiss albino mice (10 mice per group, except the highest dose group, which included 6 mice)	Gavage	Repeated doses of 0, 30, 60, 120, or 240 µg/kg/day for 11 weeks	Kidney: dose-related increases in relative kidney weight, proximal renal tubular damage, decreased urinary protein Liver: necrosis, inflammatory foci, and bile duct changes	Humpage and Falconer (2002, 2003)
CD-1 (Swiss-Webster) mice (18 to 20 per group)	Gavage	Repeated doses of 0, 75, 150, or 300 µg/kg/day for 90 days	Kidney: elevated absolute and relative kidney weights, renal cellular hypertrophy, tubule dilation, cortical tubule lesions Liver: elevated absolute and relative liver weights, increases in serum alanine aminotransferase activity, reduced serum blood urea nitrogen and cholesterol levels, increased incidence of hepatocellular hypertrophy and cord disruption	Chernoff et al. (2018)
Male Swiss mice (3 per group)	Gavage	Single dose of 1,000, 2,000, or 4,000 µg/kg Examination at 24 hours after treatment	Liver: dark red liver, apoptosis in the liver and the kidneys	Bazin et al. (2012)
Male ICR mice (n = 24, single group)	Intraperitoneal injection	Single dose of 200 µg/kg Three animals sacrificed at 8 time points, 16–100 hours after treatment	Kidney: proliferation of the endoplasmic reticulum and fat droplet accumulation in cells along the brush borders of the tubules plus limited single cell necrosis Liver: necrosis in the centrilobular region	Terao et al. (1994)
Male ICR mice (4 per group)	Drinking water	Repeated doses of 0 or 0.6 mg/L (estimated at 66 µg/kg/day) for 3 weeks	Kidney: duration-related nonsignificant increase in kidney weight Liver: increases in relative weight	Reisner et al. (2004)
Quackenbush mice (4 per group)	Intraperitoneal injection	Single dose of 200 µg/kg	Liver: fatty infiltration and cell necrosis	Shaw et al. (2001)

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Species	Exposure Route	Dosing Regimen	Description of Kidney and Liver Effects	Study
Quackenbush mice (4 per group)	Gavage or intraperitoneal injection	0 to 300 μg/kg/day (oral) or 0 to 25 μg/kg/day (intraperitoneal injection) for 14 days	Liver: fatty infiltration (oral), foamy hepatocellular cytoplasm (intraperitoneal injection)	Shaw et al. (2001)

The Humpage and Falconer (2002, 2003) study was determined to be the most appropriate for the quantitative assessment because the LOAEL at 11 weeks would be protective for the effects seen at three weeks in the shorter duration study. For these reasons, this RfD was deemed suitable for development of the short-term drinking water health advisory and for use in recreational exposure scenarios. The EPA's HESD and Health Advisory documents for cylindrospermopsin describe the selection of the critical study and effect in detail and provide the rationale for applicability of the longer-term duration study (U.S. EPA 2015c).

5.1.1.2 Human Studies

Microcystins

The EPA identified the available epidemiological, outbreak, and case study reports on adverse health effects from oral exposures to microcystins. Limited human studies examining microcystin effects on humans exposed via drinking water are available, and no dose response data from oral exposure to microcystins in ambient water were identified. The scant human data on the oral toxicity of microcystin-LR are limited by the potential co-exposure to other pathogens, cyanotoxins, and microorganisms; by the lack of quantitative information; and by the failure to control for confounding factors. Available human studies evidence is supportive of the liver as a target organ for toxicity (Carmichael 2001; Falconer et al. 1983; Giannuzzi et al. 2011; Hilborn et al. 2013; Jochimsen et al. 1998; Li et al. 2011b). The EPA identified four epidemiological studies, three case reports, and two outbreak summaries that evaluated human health effects associated with recreational exposures to cyanobacteria and microcystins. This human health effects information is summarized in the paragraphs that follow.

Backer et al. (2008) characterized microcystin concentrations in blood and reported symptoms in people recreating in a lake with a *Microcystis aeruginosa* bloom to those of people recreating in a nearby bloom-free lake. Low levels of total microcystins (detection limit = 0.08 ng/m^3) were detected in air samples collected above a lake bloom. Phytoplankton counts ranged from 175,000 to 688,000 cells per mL with > 95 percent of those cells being cyanobacteria. Cell densities of potentially toxigenic cyanobacteria ranged from approximately 54,000 to 144,000 cells/mL. Although a visible bloom was present and contained cyanobacterial species capable of producing microcystin, microcystin concentrations in water during the study were low and ranged from 2 to 5 μg/L. Recreational users of the lake at the time of the bloom had no detectable microcystins in their blood and did not report an increase in GI, dermal, respiratory, or neurological symptoms after spending time on the lake. Adenoviruses (level of detection (LOD) = 1,250 gene copy equivalents) and enteroviruses (LOD = 200 plaque forming units/10 L) were not detected in any water sample. This study was limited in the number of participants (n = 104) and included a limited number of exposure days in the analysis (three days). The study demonstrated that people recreating on or in a water body can be exposed to aerosolized microcystins. However, given the limited number of participants and exposure days, and the low levels of microcystins present in the water and as aerosols, there were no reported increases in self-reported symptoms following recreational exposures. Other symptoms consistent with microcystin intoxication (e.g., liver toxicity) were not included in the study.

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Backer et al. (2010) applied the same experimental approach at three lakes in California. Two of the lakes experienced blooms producing much higher microcystin concentrations compared with the lakes studied in the Backer et al. (2008) study, and the third lake did not contain a toxin-producing bloom. Eighty-one people, aged 12 and older, participated in the study and engaged in waterskiing, using personal watercraft, swimming, or wading. Total microcystins present in the lake containing toxic blooms ranged from < 10 µg/L to > 500 µg/L. Measured microcystin concentrations from personal air samples ranged from the limit of detection (0.1 ng/m^3) to 2.89 ng/m^3; the mean air concentration was 0.4 ng/m^3. Similarly, nasal swabs ranged from below the limit of detection to 5 ng, and all blood samples were below the limit of detection. Recreators had a significantly higher amount of microcystins present in nasal swabs after exposure. No statistically significant differences were noted in the frequency of reported GI, dermal, or respiratory symptoms between participants immediately after they engaged in direct- or indirect-contact recreational activities in the lake with a cyanobacterial bloom and those in a lake without a cyanobacterial bloom. Other symptoms consistent with microcystin intoxication (e.g., liver toxicity) were not included in the study. Adenoviruses or enteroviruses were not detected at the study locations. The authors concluded that it is possible for microcystins to become aerosolized, which in turn represents a potential route of exposure to recreators. They recommended additional research studying larger populations and sensitive subgroups.

Lévesque et al. (2014) conducted a prospective study of residents living in proximity to three lakes in Canada affected by cyanobacteria and microcystins to investigate the relationship between recreational exposure, specifying full contact and limited contact with lake water, and the incidence of GI, dermal, respiratory, and other symptoms (e.g., ear pain, muscle pain). Full contact included swimming, waterskiing, windsurfing, use of watercraft involving launching, accidental falls, and similar activities, and limited contact included fishing, use of watercraft not involving launching, and other activities. The authors reported a dose-effect relationship (p-trend = 0.001) between total cyanobacterial cell counts and severe GI illness with a significant increase in reported symptoms starting at 20,000 cells/mL and above. The study reported a relative risk value of 3.28 (95 percent confidence interval (CI): 1.69–6.37) for the more severe GI symptom index (i.e., GI2, defined as diarrhea or vomiting or (nausea and fever) or (abdominal cramps and fever)) for exposures by full or limited contact to concentrations higher than 100,000 cells/mL (Lévesque et al. 2014). Adjusted relative risks of GI illness were significantly high for limited contact, but no relationship was found between GI symptoms and full contact. The authors explained that study participants avoided full contact with lake waters when high densities of cyanobacteria were visible, but continued to have limited contact. No significant fecal contamination measured by *Escherichia coli* (*E. coli*) was observed with geometric means in the lakes ranging from 8 to 145 colony forming units (CFU)/100 mL.[5] No associations were observed between any symptoms and recreational exposures to microcystins. Overall, the microcystin concentrations were low during the study, and the reported lower bound of the upper tertile was 0.2456 µg/L. The maximum microcystin concentrations for which recreational-related GI symptoms were reported was 7.65 g/L; however, microcystins occurred at much higher concentrations (e.g., maximum reported microcystin concentrations of 108 µg/L and 773 µg/L at two of the study locations), but there was no significant trend of increasing illness symptoms with elevated toxin concentrations. The study did not characterize the primary endpoint of concern for exposure to microcystins (i.e., liver toxicity) and did not conduct the necessary medical testing to determine liver function impairment.

Lévesque et al. (2016) provided additional analysis of the prospective study reported previously. Because GI illness was significantly associated with increasing cyanobacterial cell densities and GI

[5] Current Canadian recreational water guidelines for *E. coli*: geometric mean ≤ 200 *E. coli*/100 mL and single-sample maximum ≤ 400 *E. coli*/100 mL (Health Canada 2012).

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symptoms can be related to cellular constituents, also termed *endotoxins* in the literature, the authors characterized the relationship between endotoxin exposure and illness in the study participants. Endotoxins include cell wall-associated lipopolysaccharides present in cyanobacteria and Gram negative bacteria. Frozen filters collected during the study were analyzed for endotoxins. The authors found a weak correlation between endotoxin levels and cyanobacteria cell density and reported a significant trend of increasing GI illness with increasing endotoxin concentrations. They also suggest that endotoxin concentrations could be a surrogate for another stressor. They cite other researchers that have suggested the endotoxins could be contributed by other members of the microbial community or the reported symptoms could be related to another stressor (Berg et al. 2008; Blahova et al. 2013; Rapala et al. 2002; Stewart 2006d).

In a recent case report by Vidal et al. (2017), a 20-month-old child and three adults reported GI symptoms several hours after engaging in bathing and other recreational activities at beaches in Montevideo, Uruguay, during January 2015. At that time, a cyanobacterial bloom of mainly *Microcystis* occurred in the River de la Plata. While the GI symptoms in the adults (i.e., diarrhea) rapidly resolved, the child's symptoms (i.e., diarrhea and vomiting) persisted. The child developed fatigue and jaundice, and five days after the exposure, she was admitted to hospital. Tests showed significant increases in bilirubin and serum liver enzymes, and a diagnosis of acute liver failure was given. The child was recommended for, and received, a liver transplant. The city government's beach monitoring program from April 2014 to March 2015 reported mean and maximum microcystin concentrations of 2.9 µg/L of 56 µg/L, respectively. These levels were reported in water samples from the beaches the family used with cyanobacteria presence but without cyanobacterial foam. Mean and maximum microcystin concentrations of 2,900 µg/L and 8,200 µg/L, respectively, were reported in water samples with cyanobacterial foam. The monitoring program also reported geometric means of fecal coliform values below the limit of 1,000 CFU/100 mL. After the child received a liver transplant, histological analysis of the explanted liver revealed liver damage characterized by hemorrhagic necrosis, intracytoplasmic cholestasis, large and multinucleated hepatocytes, proliferation, and nodular regeneration. The pathological findings and detection of microcystin-LR in the liver (2.4 ng microcystin-LR/g and 75.4 ng (D-Leu1) microcystin-LR/g liver) led to a diagnosis of acute liver failure related to exposure to microcystin-LR and cyanobacteria.

In another case report, acute intoxication with microcystin-producing cyanobacterial blooms in recreational water was reported in Argentina in 2007 (Giannuzzi et al. 2011). A male Jet Skier was exposed to a *Microcystis* bloom containing 33,680 and 35,740 cells/mL. A level of 48.6 µg/L of microcystin-LR concentrations was detected in water samples associated with the bloom. The subject was immersed for two hours as a result of an accident that required him to swim to the shoreline towing the Jet Ski. Four hours later the subject reported experiencing nausea and abdominal pain. Three days later the subject sought medical assistance because of respiratory distress requiring his hospitalization. One week after the exposure, the patient developed a hepatotoxicosis with a significant increase of serum alanine aminotransferase, aspartate aminotransferase, and γ-glutamyltransferase. With treatment, the patient recovered within 20 days.

An outbreak among army recruits undergoing canoe exercises who had consumed reservoir water containing a bloom of *Microcystis aeruginosa* reported symptoms of headache, sore throat, vomiting and nausea, stomach pain, dry cough, diarrhea, blistering around the mouth, and pneumonia (Turner et al. 1990). Microcystins, including microcystin-LR, were present in bloom samples. However, high levels of *E. coli* were also found in reservoir water after two weeks. The authors suggested that exposure

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to microcystins may have had a role in some of the clinical symptoms; however, this case report information is insufficient to establish cause and effect.

Dziuban et al. (2006) and Hilborn et al. (2014) reported 10 outbreaks associated with recreational exposure to cyanobacteria in which microcystins were detected. Hilborn et al. (2014) reported that eight of these investigations evaluated the presence of cyanotoxins; eight detected microcystins; and two detected cylindrospermopsin. In four of the outbreaks, microcystin concentrations ranged from 0.2 µg/L to > 2,000 µg/L. Four outbreaks had microcystin concentrations > 20 µg/L. Cylindrospermopsin and anatoxin-a also were detected in three of the outbreaks. In one outbreak, 20.8 µg/L microcystins was measured, and other cyanotoxins were either not detected or measured. The nine persons reporting illness for this outbreak had symptoms that included abdominal cramps (3 people), diarrhea (3), nausea (3) vomiting (2), fever (2), headache (2), rash (8), eye irritation (1), ear ache (1), neurologic symptoms (2), tingling (2), confusion (1), and respiratory symptoms (1) (Hilborn et al. 2014). Dziuban et al. (2006) reported on two 2004 cyanobacteria-associated outbreaks in which 22 cases of illness were associated with elevated levels of microcystins in Nebraska lakes. The predominant illnesses in both outbreaks included dermatitis and gastroenteritis, and individuals who sought medical care showed a combination of rashes, diarrhea, cramps, nausea, vomiting, and fevers. Walker et al. (2008) also reported about a Nebraska outbreak. Levels of total microcystins at the east swimming beach of Pawnee Lake exceeded 15 ppb on July 12, 2004, and a health alert was issued. However, heavy public use of Pawnee Lake occurred that weekend and more than 50 calls were received from the public, complaining about symptoms such as skin rashes, lesions, blisters, vomiting, headaches, and diarrhea after swimming or water skiing in Pawnee Lake (Walker et al. 2008). The outbreak reports data are not sufficient to establish cause and effects for microcystins because of weaknesses in the nature of the data reported and the many potential confounding variables. The researchers concluded that the disease outbreak data suggest that the time to onset of effects might be rapid, that children might be at higher risk for illness, and that these types of outbreaks occur during the warmer months. Hilborn et al. (2014) noted that HAB-associated illness from recreational exposure might be underreported due to multiple possible exposure routes and the non-specific nature of potential health effects.

Graham et al. (2009) counted 36 states with anecdotal reports of acute cyanotoxin poisonings of animals, humans, or both as reported in journal articles and newspaper articles (Chorus and Bartram 1999; Hilborn et al. 2014; Huisman et al. 2005; Yoo et al. 1995).

Information on the human health effects of microcystins based on epidemiological studies related to drinking water exposures to microcystins are discussed in detail in the EPA's HESD for microcystins (U.S. EPA 2015d). These studies are summarized in the paragraphs that follow.

An epidemiology study done in Australia compared the hepatic enzyme levels from patients served by a public water supply contaminated with a *Microcystis aeruginosa* bloom with enzyme levels from patients living in areas served by water supplies uncontaminated by cyanobacteria (Falconer et al. 1983). Although the authors observed significant variability in enzyme levels between the two groups, the findings were attributed by the authors to the imprecise method of study participant selection and confounding factors such as alcoholism and chronic kidney disease among some of the participants.

A cross-sectional study conducted in China assessed the relationship between the consumption of drinking water and aquatic food (carp and duck) contaminated with microcystins and liver damage in children (Li et al. 2011b). The authors found that mean serum levels of microcystins ranged from below detection to 1.3 µg microcystin-LR equivalents/L. According to the authors, hepatitis B infection was a greater risk for liver damage among these children than the microcystins exposure.

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An outbreak of acute liver failure occurred in a dialysis clinic in 1996 in Caruaru, Brazil, where dialysis water was contaminated with microcystins, and possibly cylindrospermopsin. Of the 130 patients who received their routine hemodialysis treatment (intravenously) at that time, 116 reported symptoms of headache, eye pain, blurred vision, nausea, and vomiting. Subsequently, 100 of the affected patients developed acute liver failure and, of these, 76 died (Carmichael et al. 2001; Jochimsen et al. 1998). Analyses of blood, sera, and liver samples from the patients revealed microcystins.

In another contamination event at a dialysis center in Rio de Janeiro, Brazil, in 2001, 44 dialysis patients were potentially exposed to microcystin concentrations of 0.32 µg/L, detected in the activated carbon filter used in an intermediate step for treating drinking water to prepare dialysate (Soares et al. 2005). Concentrations of 0.4 µg/L microcystin-LR were detected in the drinking water. Serum samples were collected from 13 dialysis patients 31 to 38 days after the detections in water samples, and patients were monitored for eight weeks. Concentrations of microcystin-LR in the serum ranged from 0.46 to 0.96 ng/mL. Although the biochemical outcomes varied among the patients, markers of hepatic cellular injury and of chlolestasis (elevations of AST, ALT bilirubin, ALP, and GGT) in serum during weeks one to eight after treatment frequently exceeded normal values (Hilborn et al. 2013). Because microcystin-LR was not detected in the dialysate during weekly monitoring after the first detection, the authors suggested that the patients were not continuously exposed to the toxin and that the toxin detected in the serum after eight weeks may have been present in the form of bound toxin in the liver (Soares et al. 2005). Results were consistent with a mild to moderate mixed liver injury (Hilborn et al. 2013). Although the patients in the study had pre-existing diseases, the direct intravenous exposure to dialysate prepared from surface drinking water supplies put them at risk for cyanotoxin exposure and resultant adverse effects (Hilborn et al. 2013).

Cylindrospermopsin

No epidemiological studies were identified for recreational exposure to cylindrospermopsin.

Hilborn et al. (2014) reported two outbreaks associated with recreational exposure to HABs in which cylindrospermopsin was detected between 2009 and 2010. However, cyanobacteria, microcystins, and other cyanotoxins were also present. As mentioned earlier, the results reported from the outbreaks should not be interpreted as cause and effect.

Human data on oral toxicity of cylindrospermopsin are limited, but results indicate that kidney and liver exhibit adverse effects due to cylindrospermopsin exposures. Information on the human health effects of cylindrospermopsin based on epidemiological studies related to drinking water are discussed in detail in the EPA's HESD for cylindrospermopsin (U.S. EPA 2015c). This information is summarized in the paragraphs that follow.

Reports of a hepatoenteritis-like outbreak (mostly in children) in Palm Island, Australia, in 1979 were attributed to consumption of drinking water with a bloom of *Cylindrospermopsis raciborskii*, a cyanobacteria that can produce cylindrospermopsin. No data are available on exposure levels or potential co-exposures to other cyanobacterial toxins and microorganisms. The majority of the cases, mostly children, required hospitalization. The clinical picture included fever, headache, vomiting, bloody diarrhea, hepatomegaly, and kidney damage with loss of water, electrolytes, and protein (Byth 1980; Griffiths and Saker 2003).

Dermal exposure to cylindrospermopsin was evaluated using skin-patch testing in humans (Pilotto et al. 2004; Stewart et al. 2006a). Exposed individuals showed mild irritation, but no statistically significant

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dose-response relationship or reaction rates were found between skin reactions and increasing cell concentrations for either whole or lysed cells (Pilotto et al. 2004). No detectable skin reactions were observed in individuals exposed to lyophilized *Cylindrospermopsis raciborskii* (Stewart et al. 2006a).

5.1.1.3 Mode of Action for Noncancer Health Effects

Microcystins

Mechanistic studies have shown the importance of membrane transporters for systemic uptake and tissue distribution of microcystins by all exposure routes (Feurstein et al. 2010; Fischer et al. 2005). The importance of the membrane transporters to systemic uptake and tissue access is demonstrated by studies where there was either no liver damage or reduced damage when the hepatic organic anion transporting polypeptide (OATP) receptors were inhibited (Hermansky et al. 1990a, 1990b; Thompson and Pace 1992). OATPs are a transporter family that controls uptake of microcystins by the liver (Fischer et al. 2005).

The uptake of microcystins causes protein phosphatase inhibition and a loss of coordination between cytoskeletal protein phosphorylation by kinases and dephosphorylation by phosphatases. This event initiates altered cell function followed by cellular apoptosis and necrosis (Barford et al. 1998). Both cellular kinases and phosphatases keep the balance between phosphorylation and dephosphorylation of key cellular proteins controlling organization of the cytoskeleton, metabolic processes, gene regulation, cell cycle control, transport and secretory processes, and cell adhesion. Each of the microcystin congeners evaluated (LR, LA, and LL) interacts with catalytic subunits of protein phosphatases PP1 and PP2A, inhibiting their functions (Craig et al. 1996).

As a consequence of the microcystin-induced changes in cytoskeleton proteins, an increase in cellular reactive oxygen species (ROS) leads to cellular apoptosis. In both in vitro and in vivo studies, cellular pro-apoptotic Bax and Bid proteins increased whereas anti-apoptotic Bcl-2 decreased (Fu et al. 2005; Huang et al. 2011; Li et al. 2011a; Takumi et al. 2010; Weng et al. 2007; Xing et al. 2008). Mitochondrial membrane potential and permeability transition pore changes (Ding and Nam Ong 2003; Zhou et al. 2012) lead to membrane loss of cytochrome c, a biomarker for apoptotic events. Wei et al. (2008) identified a time-dependent increase in ROS production and lipid peroxidation in mice after exposure to microcystin-LR. Following intraperitoneal injection of 55 μg/kg of body weight microcystin-LR, the levels of hepatic ROS increased within 0.5 hours of treatment and continued to accumulate for up to 12 hours in a time-dependent manner.

Cylindrospermopsin

Despite the number of studies that have been published, the mechanisms for liver and kidney toxicity by cylindrospermopsin are not completely characterized.

In vitro and in vivo studies showed that cylindrospermopsin can inhibit hepatic protein synthesis (Froscio et al. 2003; Froscio et al. 2008; Terao et al. 1994), which could impact mouse urinary protein production leading to decreased urinary excretion of these proteins. Available evidence indicates that protein synthesis inhibition is not decreased by broad-spectrum CYP450 inhibitors, but they do reduce cytotoxicity (Bazin et al. 2010; Froscio et al. 2003). Hepatotoxicity appears to be CYP450-dependent, which indicates a possible involvement of oxidized or fragmented metabolites and mechanisms other than protein synthesis inhibition (Froscio et al. 2003; Humpage et al. 2005; Norris et al. 2002; Norris et al. 2001).

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In the Reisner et al. (2004) and Sukenik et al. (2006) reports, microscopic examination of blood samples showed the presence of red blood cells with spiked surfaces rather than their normal biconcave-disc shape. The authors attributed the acanthocyte formation to an increase in the cholesterol to phospholipid ratio of the red blood cell membrane. Phospholipids constitute the matrix material of cell membranes. The authors hypothesized that this change was the consequence of decreased activity of plasma lecithin cholesterol acyl transferase, an enzyme associated with high-density lipoproteins and the esterification of plasma cholesterol. Effects on the cholesterol content of the red blood cell membrane can occur with inhibition of the enzyme increasing membrane fluidity and mean corpuscular volume. Removal of the abnormal blood cells by the spleen increases both spleen weight and serum bilirubin as well as stimulates hematopoiesis. Additional research is needed to examine the lecithin cholesterol acyl transferase enzyme inhibition hypothesis to confirm whether it accounts for the effects on the red blood cell as a result of cylindrospermopsin exposure.

Kidney necrosis and a decreased renal failure index at the high cylindrospermopsin doses in Humpage and Falconer (2002, 2003) are also indicative of an effect on the kidney. Numerous signs of renal damage including proteinuria, glycosuria, and hematuria were also observed in humans after a hepatoenteritis-like outbreak in Palm Island, Australia, in 1979 (Byth 1980). The outbreak was attributed to consumption of drinking water from source waters with a bloom of *Cylindrospermopsis raciborskii*. These effects have been shown to be related to impaired kidney function (Byth 1980); however, no mode of action information for kidney effects was observed in the available animal or human studies of cylindrospermopsin. Because all the studies were conducted in mice, a species that excretes low-molecular-weight proteins in urine, a study is needed of cylindrospermopsin in a laboratory species that does not excrete protein in the urine to determine whether there are comparable effects on kidney weight, protein excretion, and renal cellular damage.

5.1.2 Cancer

5.1.2.1 Weight of Evidence Classification

While there is evidence of an association between liver and colorectal cancers in humans and microcystins exposure and some evidence that microcystin-LR is a tumor promoter in mechanistic studies, there is "*inadequate information to assess carcinogenic potential"* of microcystins in humans (U.S. EPA 2005b). The human studies are limited by lack of exposure information and the uncertainty regarding whether these studies adequately controlled for confounding factors such as hepatitis B infection. No chronic cancer bioassays for microcystins in animals are available. The EPA (U.S. EPA 2005a) states that the descriptor of "*inadequate information to assess carcinogenic potential*" is appropriate when available data are judged inadequate for applying one of the other descriptors or for situations where there is little or no pertinent information or conflicting information. The guidelines also state that (p. 2-52) "Descriptors can be selected for an agent that has not been tested in a cancer bioassay if sufficient other information, e.g., toxicokinetic and mode of action information, is available to make a strong, convincing, and logical case through scientific inference." In the case of microcystins, the data suggest that microcystin-LR may be a tumor promoter but not an initiator. Without strong epidemiological data and a chronic bioassay of purified microcystin-LR, the data do not support classifying microcystin-LR as a carcinogen.

No chronic cancer bioassays of cylindrospermopsin were located in the literature. Limited data from an in vivo study showed no indication that the cyanobacterial extract containing cylindrospermopsin in the presence of a tumor promotor indicated preneoplastic changes consistent with its having tumorigenic

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activity in mice (Falconer and Humpage 2001). Following the EPA guidelines (U.S. EPA 2005a), there is inadequate information to assess carcinogenic potential of cylindrospermopsin.

5.2 Dose-response Assessment

The RfD value for microcystins used to derive this recreational AWQC or swimming advisory is described in the EPA's HESD for microcystins (U.S. EPA 2015d). The EPA identified a 28-day study in male hybrid rats by Heinze (1999) as the critical study (described in section 5.1.1). A LOAEL of 50 µg/kg/day was identified based on increased liver weight, slight to moderate liver necrosis (necrotic severity was dose-related) with hemorrhages, and increased enzyme levels, which was used to derive an RfD of 0.05 µg/kg/day. The EPA selected the study by Heinze (1999) based on the appropriateness of the study duration, the use of multiple doses, dose-related toxicological responses, and histopathological evaluations of toxicity. After 28 days of exposure, rat organ weights (liver, kidneys, adrenals, thymus, and spleen) were measured, and hematology, serum biochemistry, and histopathology of liver and kidneys were evaluated. The critical effect in the Heinze (1999) study was supported by additional acute and subchronic data as described in the EPA's HESD for microcystins and summarized in section 5.1.1.1. The EPA's selection of uncertainty factors and derivation of the RfD are documented in its HESD for microcystins (U.S. EPA 2015d).

The RfD value for cylindrospermopsin used to derive the AWQC and swimming advisory is described in the EPA's HESD for cylindrospermopsin (U.S. EPA 2015c). The EPA identified an 11-week study in mice by Humpage and Falconer (2002, 2003) as the critical study for development of the RfD. The NOAEL was 30 µg/kg/day dose for increases in relative kidney weight seen at the LOAEL of 60 µg/kg/day. Increased relative kidney weights was the critical effect on which to base the point of departure. The EPA's selection of UFs and derivation of the RfD are documented in its HESD for cylindrospermopsin (U.S. EPA 2015c).

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6.0 RECOMMENDED RECREATIONAL CRITERIA AND SWIMMING ADVISORY DERIVATION

This section summarizes the inputs and shows the calculation for the recommended recreational criteria and swimming advisories for microcystins and cylindrospermopsin.

6.1 Microcystins Magnitude

The magnitude of the recommended recreational criteria and swimming advisory for microcystin toxins is calculated as follows:

$$\text{Recreational value } (\mu g/L) = RfD \times \frac{BW}{IR}$$

Where:

RfD (µg/kg/day)	=	0.05 µg/kg/day (U.S. EPA 2015d)
BW (kg)	=	31.8 kg (mean body weight of children six to 10 years; U.S. EPA 2011)
IR (L/day)	=	0.21 L/day (90th percentile daily recreational water incidental ingestion rate for children age six to 10 years; Appendix E; U.S. EPA 2018a; U.S. EPA 2011; see section 4.2.3.1)

$$\text{Microcystins recommended recreational value} = 0.05\ \mu g/kg/day \times \frac{31.8\ kg}{0.21\ L/day} = 8\ \mu g/L$$

6.2 Cylindrospermopsin Magnitude

The magnitude of the recommended recreational criteria and swimming advisory values for cylindrospermopsin is calculated as follows:

$$\text{Recreational value } (\mu g/L) = RfD \times \frac{BW}{IR}$$

Where:

RfD (µg/kg/day)	=	0.1 µg/kg/day (U.S. EPA 2015c)
BW (kg)	=	31.8 kg (mean body weight of children six to 10 years; U.S. EPA 2011)
IR (L/day)	=	0.21 L/day (90th percentile daily recreational water incidental ingestion rate for children age six to 10 years; Appendix E; U.S. EPA 2018a; U.S. EPA 2011; see section 4.2.3.1)

$$\text{Cylindrospermopsin recommended recreational value} = 0.1\ \mu g/kg/day \times \frac{31.8\ kg}{0.21\ L/day} = 15\ \mu g/L$$

6.3 Frequency and Duration for Recreational Criteria

The frequency and duration components of a criterion describe how often and for how long a water body's conditions can exceed the magnitude and be protective of the designated use (U.S. EPA 2005c). HABs can occur naturally, but can be an uncommon event due to a convergence of climatic and other environmental factors that result in a single short-term bloom lasting days or a couple of weeks. In some cases, multiple HABs can occur in a single year. Alternatively, longer-term HABs can occur regularly in some waters lasting for a few weeks, months, or possibly all year. HABs can occur while conditions conducive to cyanobacterial proliferation exist and limit the use of the water body for primary recreation. Water bodies where a toxic HAB has occurred in the past may experience repeat occurrences of elevated toxins when bloom-promoting conditions reoccur. In some circumstances, anthropogenic inputs are identified and controlled, and the conditions that cause the bloom can be mitigated.

The EPA recognizes that a single sample above the cyanotoxin criteria magnitude does not necessarily indicate that the designated recreational use is not attained. However, when cyanotoxin concentrations exceed the criteria magnitude either in multiple short-term blooms within a year or from a single bloom that persists for an extended period within a year, and when these patterns occur in more than one year, the designated recreational use may not be attained. The frequency and duration components discussed in this section support the identification of a trend or pattern of cyanotoxin excursions that state decision makers can use to inform the evaluation of a water body. The EPA recommends that decisions on whether the designated recreational use is attained should be flexible enough to address both types of exposure patterns when patterns reoccur in more than one year (short-term blooms that occur frequently in a recreational season, or blooms that persist for an extended period during a recreational season). States may want to evaluate the pattern of bloom occurrence and toxin concentrations within and across years to determine if there is a trend toward degradation of the water quality.

The EPA's recommended criteria duration rely on the underlying toxicity data used to derive the criteria. For both toxins, animal toxicological studies consistently demonstrate adverse health effects at various dosages and relevant timeframes. See Tables 5-1 and 5-2. For microcystins, the key study (Heinze 1999) shows adverse liver effects from repeated microcystin exposures (50 and 150 μg/kg body weight) during a study duration of 28 days. Another supporting study showed similar effects (Guzman and Solter 1999). For cylindrospermopsin, the key study (Humpage and Falconer 2002, 2003) had a duration of 11 weeks. The shorter-term studies available for cylindrospermopsin (Shaw et al., 2001; Reisner et al., 2004) were not suitable for quantification due to study limitations; however, effects observed in these studies are the same or similar to the Humpage and Falconer study (2002, 2003) and occur at similar doses. The LOAEL derived from Humpage and Falconer (2002, 2003) was determined to be protective for the adverse effects observed in the shorter duration studies. For both key studies, adverse health effects were noted at the end of the study period and it is not known if those effects occurred earlier.

The criteria are based on the same science used to develop the EPA's Drinking Water Health Advisories for microcystins and cylindrospermopsin, which are 10-day advisories (U.S. EPA 2015a, 2015b). The 10-day drinking water health advisory values represent concentrations of cyanotoxins in finished drinking water below which adverse noncarcinogenic effects are not expected to result from ingestion of drinking water over a 10-day period. Following the detection and confirmation of microcystins or cylindrospermopsin in finished drinking water above the health advisory values, the EPA recommends that drinking water utilities initiate actions to reduce exposure to consumers including determining when to notify drinking water consumers who may be more susceptible to adverse outcomes (U.S. EPA 2015c). If the advisory level continues to be exceeded after 10 days, additional public health measures can be taken, including a do-not-drink and do-not-boil water advisory. Recreational water managers

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have fewer options to reduce exposure to toxins in recreational waters than do drinking water treatment operators, as recreational water does not go through a treatment process.

The EPA recommends states use 10-day assessment periods over the course of a recreation season to evaluate ambient water body condition and recreational use attainment. The 10-day period links the water body assessment to the adverse health effects from ingestion of the toxins over short-term exposures, consistent with the EPA's Drinking Water Health Advisory (described in greater detail in section 5.1). Also, Cordell (2012) discussed decade-long trends in outdoor recreation activities showing a significant proportion (43 percent) of Americans visited a beach in 2005–2009, up almost 21 percent over the previous decade. Over the same timeframe, participation in swimming in lakes and streams (42 percent of the population) increased by 14 percent (Cordell 2012). Beach visitation surveys have shown that nearly half (47 percent) of the local population are regular beach users with five or more visits in a recreation season (Caldwell et al. 2013). The recommended assessment period is reasonable considering beach visitation rates for recreators living in proximity to a beach or vacationing at a beach for a week or two with daily beach visits expected. Exposure to recreational waters containing microcystins or cylindrospermopsin at or below the recommended magnitude concentrations over the short-term 10-day duration would not be expected to result in the adverse health effects discussed in section 5.

The EPA recommends that if toxin concentrations are higher than the criterion magnitude in a sample collected during a 10-day assessment period, that period should be considered an excursion from the recreational criteria. Elevated toxin concentrations can occur over hours, days, or a couple of weeks and are counted as excursions in a recreational season. A short-term HAB that does not reoccur can result in a small number of excursions of the criteria but is not expected to result in impairment of the recreational use. Such algal blooms may result from conditions that occur naturally (e.g., as a result of unusually hot conditions), but not frequently. Following an excursion (an exceedance during the 10-day assessment period), the EPA recommends increasing the monitoring frequency to better understand the temporal and spatial nature of cyanotoxin occurrence in the affected waterbody.

In some waterbodies, longer-term HABs can persist for many weeks to months with conditions conducive to cyanobacterial proliferation. This can result in many excursions of the recommended toxin values during a recreation season. The EPA recommends that when more than three excursions (an exceedance during the 10-day assessment period) occur within a recreational season and that pattern reoccurs in more than one year, it is an indication the water quality is or is becoming degraded such that the water body no longer supports the recreational use. Recreational freshwaters at lower latitudes can have longer recreational seasons compared with those waters found at higher latitudes. For those waters in more temperate areas with a recreational season of approximately 100 days (i.e., from Memorial Day to Labor Day), three excursions could translate into a maximum of 30 percent of the recreational season not supporting the designated recreational use. Surface waters in areas with longer recreational seasons can also experience conditions that can support HAB proliferation and cyanotoxin occurrence for a longer period of the year. A maximum of three excursions across a recreational season reflects seasonal dynamics and occurrence patterns of HABs within years and the potential for adverse health effects over a short-term duration of exposure (i.e., approximately 30 days).

The EPA recognizes that multiple environmental factors can cause variability in bloom formation and toxin production, and that some years may produce HABs that occur for long periods, or HABs of shorter duration that occur repeatedly throughout a single recreational season, but such events may not occur every year. Therefore, the EPA concludes that it is appropriate to consider a pattern of multiple excursions within a recreational season as well as in multiple years (i.e., more than one year) when

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determining whether the use is attained. It is important to note that the years with multiple excursions do not have to be consecutive to indicate a water quality problem. The upper-bound frequency (e.g., one year out of three years) is a risk-management decision that states need to determine when developing their water quality standards (WQS). States should include in their WQS the maximum number of years a pattern of cyanotoxin excursions can occur for the recreational use to remain supported.

The EPA does not recommend using a 10-day average concentration or a rolling average to determine an excursion, consistent with available toxicity information. States have flexibility in applying the 10-day assessment period. Some may choose to use pre-defined 10-day assessment periods for water bodies with a documented history of HAB occurrence or detection of elevated levels of cyanotoxins. Another approach is to begin the 10-day assessment period upon observation of a visible bloom. However, only considering the presence of visible blooms can miss episodes of elevated toxins (Raymond 2016). States are encouraged to consider the application of the frequency and duration components to capture elevated toxin concentrations, which may or may not coincide with the general proliferation of total cyanobacteria at high densities. More information on implementation of these values as criteria is provided in technical support materials.

6.4 Frequency and Duration for Swimming Advisory

Local and state governments can use swimming advisories to provide information to recreators on their potential exposure to cyanobacteria and their toxins. Some local and state governments currently post notifications for swimmers, in the form of advisories or warnings, when a cyanobacterial bloom is reported in recreational waters or when cyanotoxin levels exceed advisory thresholds. Table B-2 in Appendix B summarizes currently available information on state cyanotoxin-related guidelines and associated actions, including the issuance of swimming advisories.

The EPA recommends that the magnitude of the swimming advisory value not be exceeded on any single day, to provide timely information for people visiting beaches. The EPA also recommends that any exceedance of the recommended magnitude result in a swimming advisory being issued until the toxin concentration falls below the recommended magnitude. By increasing the monitoring frequency at a site where a swimming advisory is issued, water resources managers may get a clearer understanding of the temporal and spatial nature of water quality that can be useful in making decisions that protect the recreational use. Increased monitoring can also help water managers decide when to remove an advisory. The EPA has published materials for recreational water body managers that describe communicating risk to the public about cyanotoxins in recreational water bodies, monitoring, and responding to HABs (U.S. EPA 2017).

6.5 Recommended Recreational Criteria and Swimming Advisory for Microcystins and Cylindrospermopsin

The magnitude, duration, and frequency are summarized in Table 6-1.

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Table 6-1. Recreational Criteria or Swimming Advisory Recommendations for Microcystins and Cylindrospermopsin[a]

Application of Recommended Values	Microcystins			Cylindrospermopsin		
	Magnitude (µg/L)	Duration	Frequency	Magnitude (µg/L)	Duration	Frequency
Recreational Water Quality Criteria	8	1 in 10-day assessment period across a recreational season	More than 3 excursions in a recreational season, not to be exceeded in more than one year[b]	15	1 in 10-day assessment period across a recreational season	More than 3 excursions in a recreational season, not to be exceeded in more than one year[b]
Swimming Advisory		One day	Not to be exceeded		One day	Not to be exceeded

[a] These recommendations can apply independently within an advisory program or in WQS. States can choose to apply either or both toxin recommendations when evaluating excursions within and across recreational seasons.

[b] An excursion is defined as a 10-day assessment period with any toxin concentration higher than the criteria magnitude. When more than three excursions occur within a recreational season and that pattern reoccurs in more than one year, it is an indication the water quality has been or is becoming degraded and is not supporting its recreational use. **As a risk-management decision, states should include in their WQS an upper-bound frequency stating the number of years that pattern can reoccur and still support its recreational use.**

The recommended magnitude represents the concentration of microcystins or cylindrospermopsin that is not expected to result in adverse human health effects from short-term recreational exposure to the toxins via incidental ingestion while swimming, based on exposure to young children. The adverse health effects include liver toxicity (for microcystins) and kidney toxicity (for cylindrospermopsin) and could result from exposures to waters containing elevated levels of these toxins.

The **water quality criteria** developed by the EPA describe the magnitude, duration, and the frequency of occurrence of pollutants. HABs may be caused or exacerbated by human activities and elevated nutrient concentrations, but cyanotoxins differ from other pollutants as they are not typically discharged into a water body. The EPA developed recommended criteria for these cyanotoxins that provide a magnitude (8 µg/L microcystins or 15 µg/L cylindrospermopsin) and duration (not to be exceeded in more than three 10-day assessment periods over the course of a recreational season). The EPA expects states to make an explicit risk management decision regarding the frequency (i.e., the number of years this pattern of exceedances can occur in the waterbody) and still support its recreational use.

As a basis for issuing a **swimming advisory**, the EPA recommends a concentration of 8 µg/L microcystins or 15 µg/L cylindrospermopsin not be exceeded on a single day. This is consistent with the goal of a swimming advisory to provide prompt information to people who wish to use the water body for recreation.

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7.0 EFFECTS CHARACTERIZATION

7.1 Enhanced Susceptibility

Based on the available studies in animals, individuals with liver or kidney disease may be more susceptible to health effects than the general population as the detoxification mechanisms in the liver and impaired excretory mechanisms in the kidney may be compromised. Data from an episode in a dialysis clinic in Caruaru, Brazil, where microcystins (and possibly cylindrospermopsin) were not removed by treatment of dialysis water, identify dialysis patients as a population of potential concern in cases where the drinking water source was contaminated with cyanotoxins.

The data on red blood cell acanthocytes observed in animal studies of cylindrospermopsin suggest that individuals that suffer from anemia (e.g., hemolytic or iron-deficiency) might be a potentially sensitive population. Several rare genetic defects such as abetalipoproteinemia (i.e., a rare autosomal recessive disorder that interferes with the normal absorption of fat and fat-soluble vitamins from food) and hypobetalipoproteinemia are associated with abnormal red blood cell acanthocytes, which appears to result from a defect in expression of hepatic apoprotein B-100, a component of serum low-density lipoprotein complexes (Kane and Havel 1989). Individuals with either condition might be sensitive to exposure to cylindrospermopsin.

Available animal data are not sufficient to determine if there is a definitive difference in the response of males versus females following oral exposure to microcystins. Fawell et al. (1999) observed a slight difference between male and female mice in body weight and serum proteins, but no sex-related differences in liver pathology. Available animal data are not sufficient to determine if there is a definitive difference in the response of males versus females following oral exposure to cylindrospermopsin.

7.2 Recreational Exposure Duration

Recreational exposure data available in the literature are expressed in two primary ways: 1) the volume of water incidentally ingested during recreation (e.g., L/hr), and 2) the duration of the recreational activity (e.g., minutes of recreation per day). A daily incidental ingestion rate distribution was developed by combining these two distributions (for more information see Appendix E). The 90th percentile of the daily incidental ingestion rate distribution for children (see section 7.3) was selected for the derivation of the criteria and swimming advisories, consistent with the 2000 Human Health Methodology.

The EPA identified the following sources of data on the duration of the recreational activity: the EPA's EFH (2011); Schets et al. (2011); and DeFlorio-Barker et al. (2017) (DFB study). See Table 7-1a and Table 7-1b for summary overviews of these studies. One major difference between the studies is in the unit of exposure, reported in minutes per day in one study and minutes per swimming event in the two other studies.

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Table 7-1a. Durations of Recreational Exposures in Minutes per Day

Reference	Recreational Environment	Age Group (Years Old)	Sample Size	Mean	Units
U.S. EPA *Exposure Factors Handbook* (2011)	In Outdoor Pool or Spa	1 to 4	9	85.6	minutes per day
		5 to 11	15	164.2	
		12 to 17	5	97.0	
		18 to 64	44	117.6	
		> 64	10	78.9	

Table 7-1b. Durations of Recreational Exposures in Minutes per Swimming Event[a]

Reference	Recreational Environment	Age Group (Years Old)	Sample Size	Mean	Units
Schets et al. (2011)	Freshwater	< 15 Years	1,689	79.0	minutes per event
		16+	4,123	54.0	
	Swimming Pool	< 15	1,689	81.0	minutes per event
		16+	4,123	67.5	
DeFlorio-Barker et al. (2017)	Freshwater	< 1	171	56	minutes per event
		1 to 3	1,061	66.7	
		4 to 7	1,738[b]	88.5	
		8 to 12	2,136[c]	92.9	
		13 to 18	1,855	64	
		19 to 34	5,478	45.4	
		35+	8,058	47	
	Marine	< 1	350	60.5	
		1 to 3	2,687	79.1	
		4 to 7	4,260	107.8	
		8 to 12	5,398	121.4	
		13 to 18	4,021	102	
		19 to 34	10,786	68.2	
		35+	19,745	66.9	

[a] Additional information is needed to translate minutes per event to minutes per day.

[b] Number of children ages 4–7 reported to have contact with water: 1,562.

[c] Number of children ages 8–12 reported to have contact with water: 1,901.

The EPA considered these three studies and selected the EFH for use in deriving the criteria and swimming advisories primarily because the EFH dataset represents exposures in minutes per day. Other datasets measured the duration of recreational exposure on an event basis, which require assumptions about how many recreational events occur per day to create the relevant distribution. The EPA conducted analyses comparing these datasets, as described below to evaluate the differences in the distributions given differences in sample size, and evaluated differences given different assumptions of number of events per day.

The EFH (U.S. EPA 2011) lists time spent per 24 hours in an outdoor spa or pool for different age groups (including children five to 11 years old). The EPA acknowledges that the reported sample size

for this study is small (n = 15) for the five-to-11-year-old group. Schets et al. (2011) demonstrate that time spent in swimming pools is similar to time spent in freshwater and therefore EPA concluded that these data are representative of recreational exposure in freshwater. The EFH also presents data for minutes spent "outdoors at a pool/river/lake." The EPA did not select these data as it is uncertain if this is time spent in the water, or total time "at" the location.

Schets et al. (2011) investigated swimming durations in freshwater, marine water, and pools. They surveyed 8,000 adults, 1,924 of whom also provided estimates for their eldest child (< 15 years of age) and found that children spend, on average, 25 minutes longer swimming in freshwater compared to adults. Schets et al. (2011) reported similar mean duration times between swimming pools and freshwater locations for children less than 15 years old (average of 81 and 79 minutes per event, respectively; upper 95 percent CI: 200 and 270 minutes per event, respectively).

The DFB study (DeFlorio-Barker et al., 2017) compiled self-reported swimming durations from epidemiological study surveys from 12 beaches in which participants were asked to estimate, in minutes, the total time they spent in the water. Parents or guardians were responsible for answering survey questions assessing exposures such as getting water in the mouth or swallowing water, on behalf of their minor children. The study results represent 2,136 children ages eight to 12 years and 1,738 children ages four to seven recreating in freshwater. Marine recreators spent more time in the water compared with freshwater recreators. The authors suggest that behaviors may have been influenced by the warmer water at most of the marine sites (California and Gulf Coast) compared with the freshwater sites in the Great Lakes.

Although not represented in Table 7-1 a or b, the EPA's OPP uses a different approach to estimate chemical exposures for children during pool swimming, for use in its SWIMODEL (U.S. EPA 2003). This model simulates short-term exposure using a high-end estimate of exposure-time per event to represent a maximum, one-time exposure. It also simulates intermediate/long-term exposure using a shorter event duration to represent an average of maximum and minimum exposures over time. Among competitive children swimmers, the short-term exposure duration used by the SWIMODEL is one hour per day for children ages six to 10 and two hours per day for children ages 11 to 15 years based on a survey of swim coaches (U.S. EPA 2003). The competitive swimming scenario (e.g., children swimming laps) is appropriate for conducting risk assessments of exposure to swimming pool chemicals. However, it is less relevant to children's recreational activities in lakes or rivers and therefore was not used in this assessment.

7.2.1 Comparison of Duration of Exposure Distributions

Because the DFB study has a much larger sample size compared to the study results reported in EPA's EFH, the EPA conducted a statistical analysis to compare the distributions of duration of exposure. Because the DFB study age groupings and the EFH age groupings do not exactly align, the EPA compared the four-to-seven and the eight-to-12 age groups from the DFB study with the five-to-11 age group presented in the EFH. Both studies include self-reported data, which are prone to recall bias. Adult recollection of their children's time spent in the water is also uncertain. However, there is no reason to believe there would be differential recall bias between the studies.

Table 7-2 shows the parameters used to create distributions for EFH and DFB studies. The EPA used assumptions of one swimming event per day and two events per day to translate the DFB duration from minutes per event to minutes per day for two different age groups. The EPA assumed the underlying distributions of exposure durations were log-normal. The observed mean and standard deviations in

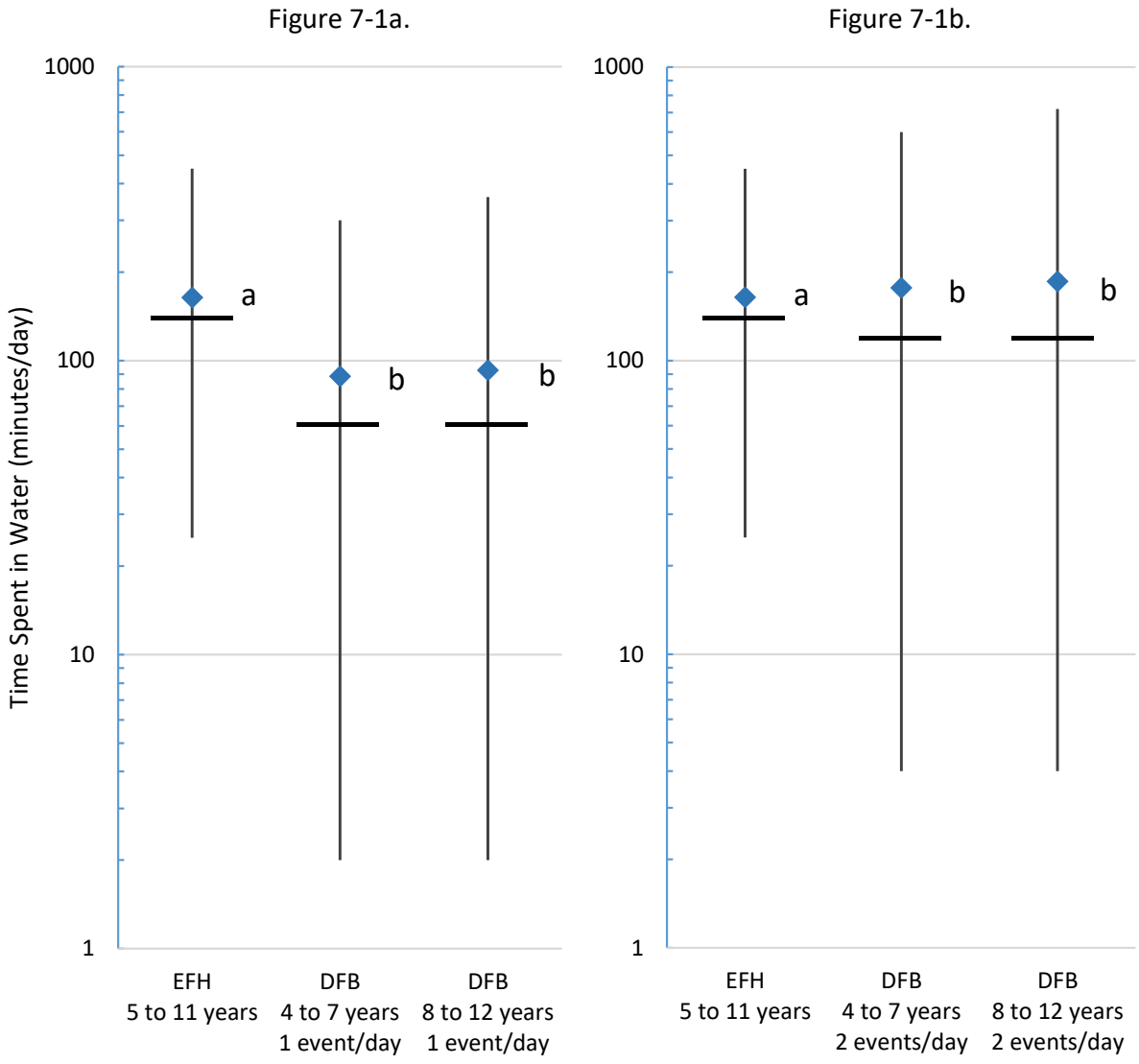
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Table 7-2 defined the parameters of the underlying log-normal distributions. The standard deviations take into consideration the numbers of samples, and therefore address differences in numbers of participants in the EFH and DFB studies. A large number (1 million) of samples were drawn from each log-normal distribution defined using these parameters. The distributions were truncated to reflect the observed maximum and minimum values in the EFH and DFB studies for the age groups of interest. Figures 7-1 a and b show the five resulting distributions: the EFH distribution and the DFB distributions assuming one (Figure 7-1a) and two (Figure 7-1b) events per day.

Table 7-2. Parameters Used to Fit Recreation Duration Distributions in Freshwater

Parameter Source	Age Group (sample size)	Mean (min/day)	Standard deviation	Minimum (min/day)	Maximum (min/day)
EPA 2011 EFH (minutes/day)	5 to 11 years (n = 15)	164.2	103.97	25	450
DFB 2017 (minutes/day, assuming one event/day)	4 to 7 years (n = 1,562)	88.5 (1 event)	62.8	2	300
DFB 2017 (minutes/day, assuming two events/day)		177 (2 events)	125.6	4	600
DFB 2017 minutes/day, assuming one event/day)	8 to 12 years (n = 1,901)	92.9 (1 event)	64.7	2	360
DFB 2017 minutes/day, assuming two event/day)		185.8 (2 events)	129.4	4	720

Figure 7-1 a and b. Comparison of Children's Duration of Time Spent Recreating



Comparison of children's time spent in water between EPA's 2011 *Exposure Factors Handbook* (five to 11 years old) (EFH; U.S. EPA 2011) and the DeFlorio-Barker study (DFB) (four to seven and eight to 12 years old) (DeFlorio-Barker et al. 2017) assuming one swimming event per day (Figure 7-1a) or two swimming events per day (Figure 7-1b) for the DFB data. The range of each distribution is represented by the vertical solid line, the short horizontal line indicates the median, and blue diamonds represent the mean. Letters beside the means denote significant differences of the means.

The EPA conducted two statistical tests to compare these distributions; one based on the means of the distributions and the other based on the full distributions. The full duration distribution, not the mean, in combination with the distribution of volume ingested per hour, was used to calculate the daily incidental ingestion rate. The EPA also explored how these comparisons change when one assumes that children engage in one or two swimming events per day (e.g., those who swam, took a break, and then re-entered the water at a later point in the day). The changes in the parameters are shown in Table 7-2.

For the comparison of the means, the EPA used a two-tailed t-test with unequal variances. The mean of the EFH is statistically different from both the DFB age group means (p-value < 0.001) for both one and two events per day. The means of the two DFB age groups are not statistically different from each other

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(p-value = 0.08) assuming both one event and two events per day. Statistical differences between the means are denoted by letters (a and b) in Figure 7-1. Assuming two events per day for the DFB studies, the means for both DFB study age groups are significantly higher ($p < 0.001$) than the EFH mean. The larger sample size available in the DFB study results in a narrower confidence interval around the mean time spent in water, compared to the 95 percent CI for the mean used in the EFH.

For the comparison of the distributions, the EPA used the Kruskal-Wallis test. Results show that the EFH distribution is not statistically significantly different from either DFB age group distributions (p-value = 0.499, assuming one event per day; p-value = 0.498, assuming two events per day).

The EPA concluded that because the EFH and DFB distributions are not significantly different, the EFH dataset is the most appropriate for deriving criteria and swimming advisory values as it does not require additional assumptions about the number of swimming events that occur per day. The 90th percentile incidental ingestion rates are shown in Table 7-3 below for the EFH distribution and for the DFB distributions. The resulting 90th percentiles of daily incidental ingestion rate are also shown. The 90th percentile of daily ingestion rate based on the EFH distribution most closely corresponds to the 90th percentile of daily ingestion rate using the DFB dataset when two swimming events per day are assumed.

Table 7-3. Calculated Daily Incidental Ingestion Rates Based on EFH and DFB Datasets

Volume per Hour Data Source	Event Duration Data Source	Age Group (years)	Events per Day (if assumed)	90th Percentile Daily Ingestion Rate (L/day)
Recreational AWQC Appendix E full dataset (L/hr)	EPA *Exposure Factors Handbook* (2011)[a] (hr/day)	5 to 11	not needed	0.21
	DeFlorio-Barker et al. (2017) (DFB) (hr/event)	4 to 7	1	0.11
			2	0.23
		8 to 12	1	0.12
			2	0.24

[a] This distribution was used in the derivation of the criteria and recreational swimming advisories.

7.3 Evaluation of Health Protective Values for Different Lifestages

The EPA compiled and evaluated available information for various life stages before selecting children ages six to 10 years as the basis for the recreational criteria values or swimming advisory. This section discusses potential health protective values for children and adults (section 7.3.1) and focuses on exposures of younger children (less than six years) (section 7.3.2).

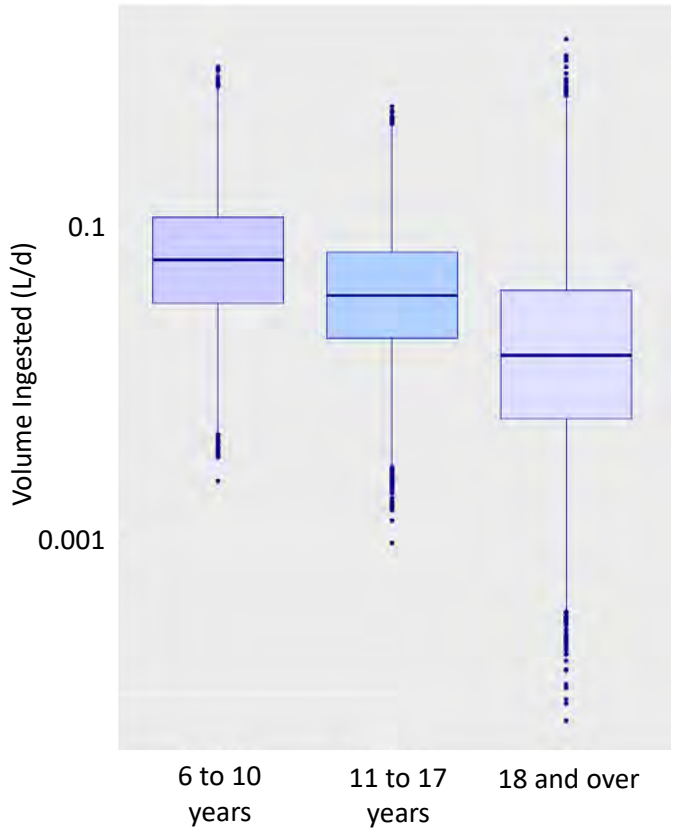
7.3.1 Consideration of Multiple Lifestages

The EPA used the Appendix E and the Dufour et al. (2017) dataset provided in U.S. EPA (2018a) to generate the box and whisker plots shown in Figure 7-2 for three life stages (children six to 10 years, children 11 to 17 years, and adults 18 years or older). The Appendix E Dufour data for volume ingested per swimming event was normalized to one hour. Each participant's volume ingested was adjusted to one hour based on the length of time that participant reported being in the water. The EPA converted volume of water ingested from L/event to L/hour, then used the swimming duration per day from the EPA's 2011 EFH (hours/day). The distributions were assumed to be log-normal and the plot is

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visualized in log space. The EPA used the Appendix E Dufour data on ingestion rate (shown in Figure 7-2) and the body weight estimates from the EPA's (2011) EFH (kg) to calculate the ingestion normalized by body weight (L/kg/day) shown in Figure 7-3.

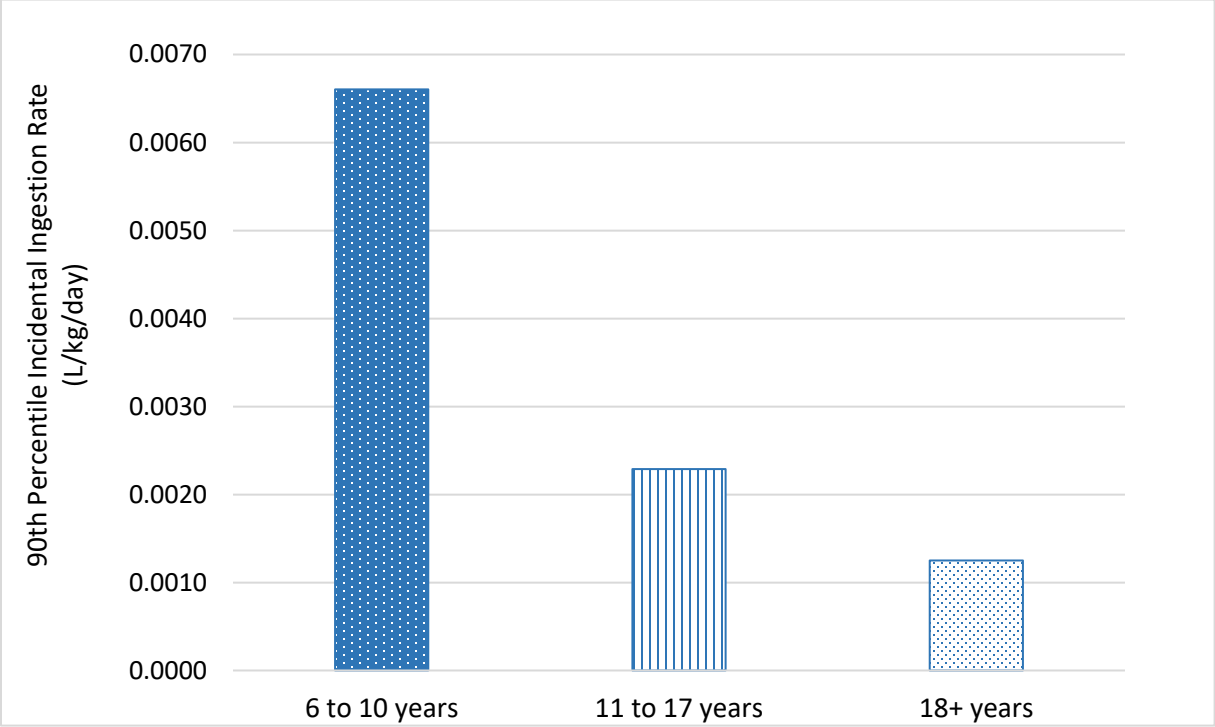
Figure 7-2. Incidental Ingestion During Recreational Activity Based on Age (Appendix E)



In this box plot, the horizontal line the middle of the box is the median (Q2). The length of the box is the interquartile range (IQR) or the 25th percentile to the 50th percentile. The upper whisker vertical line extends to the greatest value less than or equal to Q3+1.5*IQR; the lower whisker extends to the smaller value less than or equal to Q1-1.5*IQR. The dots represent extreme values that are either greater than the upper whisker or lower than the lower whisker.

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Figure 7-3. Comparison of Children and Adults Incidental Ingestion Rate During Recreational Activity Adjusted for Body Weight



Body weight varies by age. Table 8-1 in the EPA's EFH (U.S. EPA 2011) reported recommended statistics based on the 1999–2006 National Health and Nutrition Examination Survey. Table 7-4 shows the mean body weight for the age groups compared in this section (U.S. EPA 2011).

Table 7-4. Mean Body Weight by Age Group Based on U.S. EPA (2011)

Age Group	Body Weight (kg)
Children 6 to 10 years	31.8
Children 11 to 17 years	56.8
Adults 18 to 64	80

The EPA estimated recreational health protective values for these three different age groups for microcystins and cylindrospermopsin to demonstrate the variability due to body weight, recreational

water incidental ingestion, and exposure duration by lifestage. Inputs for these calculations are in Table 7-5.

Table 7-5. Inputs for Calculation of Protective Values for Microcystins and Cylindrospermopsin

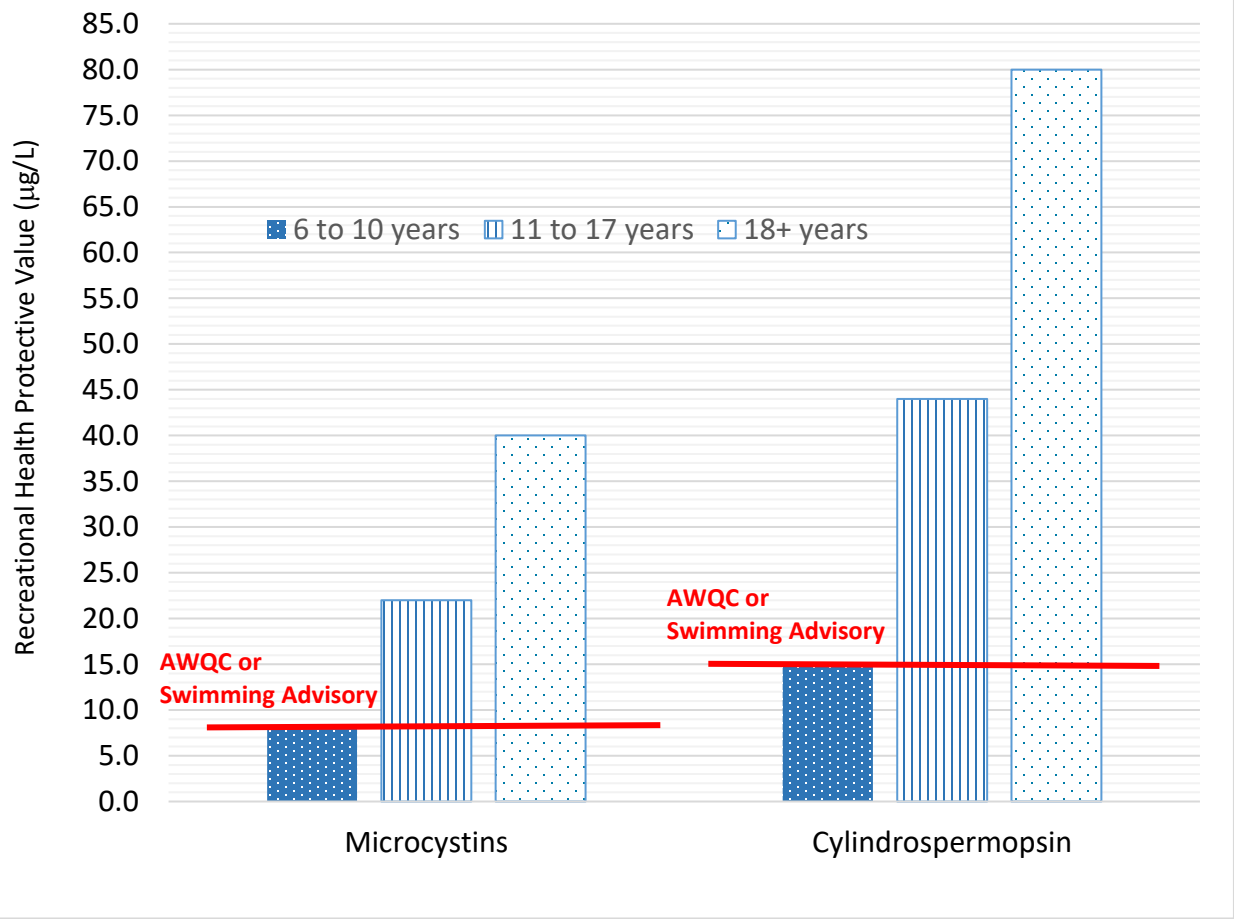
Age Group	Ingestion Rate [a] (L/day)	Body Weight [b] (kg)
Children 6 to 10 years	0.21	31.8
Children 11 to 17 years	0.13	56.8
Adults 18+ years	0.10	80.0

[a] Value is 90th percentile of the combined distribution (i.e., ingestion and duration data combined); see Appendix E.

[b] For children age 6 to 10 years, the mean body weight for the 6-to-10-year age group (31.8 kg) was used. For 11 to 17 years, the mean body weight for the 11- to 15-year-old age group (56.8 kg) was used because it was the closest age group available from the EPA's *Exposure Factors Handbook* (U.S. EPA 2011). For adults 18+ the mean body weight for the 21+ year age group (80 kg) was used (U.S. EPA 2011).

As illustrated in Figure 7-4, the AWQC and swimming advisories the EPA calculated to be protective of children ages six to 10 years are also protective of older children and adults.

Figure 7-4. Comparison of Calculated Recreational Health Protective Values for Microcystins and Cylindrospermopsin for Children, Older Children, and Adults



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7.3.2 Exposure Factors for Children Younger Than Six Years Old

In the calculation of the cyanotoxin values reported in section 6, the EPA utilized exposure parameters reported in the EFH (U.S. EPA 2011) and peer-reviewed study data (study design presented in Dufour et al. 2017; data analyzed in Appendix E; U.S. EPA 2018a). The available incidental ingestion volume and exposure duration values from the Appendix E and the EPA's EFH (U.S. EPA 2011), respectively, were limited to specific age ranges. For incidental ingestion, the data reported were limited to children six years old and older because the Dufour et al. (2017) study design did not include children younger than six years. The EPA's EFH (U.S. EPA 2011) provided a mean recreational exposure duration for children ages one to four years (1.4 hour/day). This duration is shorter than the mean duration for children ages five to less than 11 years (2.7 hour/day). Values for exposure duration were not available for children younger than one year.

The EPA found one other study that characterized incidental ingestion for children. Schets et al. (2011) reported incidental ingestion volumes and durations of recreational events for children ages zero to < 15 years. However, the study did not further divide this cohort into younger children and older children. The incidental ingestion data for children < 15 years represent parental estimates of volumes of freshwater incidentally ingested by their children, which is a different methodological approach compared to the more quantitative approach used by Dufour et al. (2017). The exposure durations were also parental estimates.

The EPA calculated the 90th percentile incidental ingestion rate per day for children younger than six years old in order to compare the daily ingestion rate (L/day) between children six to 10 years and those younger than six years. The daily ingestion rate (0.21 L/day) used to derive the recreational criteria was calculated by combining the distributions for incidental ingestion and exposure duration via a probabilistic (Monte Carlo) analysis (described in section 4.2.3.1). The daily ingestion rate for children younger than six years old (0.11 L/day) was a mixed-age estimate calculated by dividing the 90th percentile for incidental ingestion for children age six to 10 years (0.077 L/hour; see Appendix E) by the mean exposure duration for children one to four years (1.4 hour/day; U.S. EPA 2011). The daily ingestion rate for children younger than six years old is lower than for children six to 10 years old. This calculation was also performed using data from Schets et al. (2011) and resulted in a daily ingestion rate of 0.1 L/day.[6] The EPA evaluated the effect of using parameter values for children younger than six years by including an age-specific body weight and the mixed-age estimate for the daily ingestion rate (L/day) parameters. Table 7-6 shows a comparison of the microcystins magnitude for the two different age groups, children ages six to 10 years and children ages one to less than six years.

The estimates for children younger than six years have large uncertainties given the lack of measured incidental ingestion data specifically for this age group. Information on exposure durations for children less than one-year-old is also lacking. Because exposure durations are greatest for five- to 11-year-olds, the EPA concluded that calculating the ingestion rate using a higher duration was protective of children younger than six years old. Research designed to fill this data gap could be helpful for characterizing the risks to children younger than six years old. Specifically, data to better characterize the volume of water ingested during recreational events would enhance EPA's confidence that the criteria values are protective of children younger than six years old.

[6] This number was calculated as follows: 0.07 L/hour (90th percentile ingestion volume for age zero to less than 15 years from Schets et al. (2011)) divided by 1.4 hr/d (mean for children one to four years from U.S. EPA 2011).

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Table 7-6. Microcystins Magnitude Comparison Between Children Six to 10 and Children One to Less Than Six Years Old

Age Group	RfD (µg/kg/day)	Body Weight (kg)	Ingestion Rate (L/day)	Magnitude (µg/L)	Magnitude (µg/L) Rounded
6 to 10 years	0.05	31.8	0.21	7.57	8
1 to < 6 years	0.05	15.6 [a]	0.11	7.09	7

[a] This value is the weighted mean of the age groups one to less than two years, two to less than three years, three to less than six years (U.S. EPA 2011).

7.4 Other Recreational Exposure Pathways

The EPA selected primary contact activities and incidental ingestion of water as the primary exposure pathway for derivation of the recreational criteria and swimming advisories. Inhalation and dermal toxicity data were not available; however, there are limited available data to estimate inhalation and dermal exposure. The EPA conducted analyses to compare inhalation and dermal exposure to incidental ingestion of the cyanotoxins while recreating. Section 7.4.1 compares recreational ingestion and inhalation exposures to microcystins. Similarly, section 7.4.2 compares recreational ingestion and dermal exposure. Section 7.7 briefly discusses tribal considerations. Further research is needed to better understand the toxicity from inhalation and dermal exposure to cyanotoxins. The EPA describes the screening analyses in this section because sufficient data to quantify toxicity via these routes were not available.

7.4.1 Inhalation of Cyanotoxins

Volatilization of microcystins and cylindrospermopsin from water to air is not expected due to their size and charges. Both cyanotoxins are rather large molecules compared to volatile chemicals. Microcystin-associated acid groups are charged at the pH of normal surface waters. Cylindrospermopsin features both negative and positive changes and, like other zwitterions, do not volatilize significantly into the air from water (Butler et al. 2012).

According to Wood and Dietrich (2011), waterborne cyanotoxins can be aerosolized through a bubble-bursting process, in which the cyanobacteria and cyanotoxins are ejected and carried into the air where they can bind to particulate matter. Microcystins that are free or bound to particulate matter in air can be deposited into the deepest bronchiolar or alveolar cavities; air borne cyanobacterial cells from aerosolized water droplets would likely be deposited in the upper respiratory tract (Wood and Dietrich 2011).

The EPA identified field studies that measured recreators' exposure levels to aerosols containing microcystins from lakes with blooms containing microcystin-producing *Microcystis aeruginosa*. The studies found low inhalation exposures. In one study, Backer et al. (2008) used personal air samplers in a three-day study of recreational activities in a lake with a cyanobacterial bloom, either carried by the study participant or placed on the participant's boat. The microcystin concentrations in air ranged from below the limit of detection (0.0037 ng/m^3) to 0.456 ng/m^3. Backer et al. (2010) also detected microcystins in ambient air for one day, at one lake, and only from the shoreline sampler. The average air concentration was 0.052 ng/m^3. Backer et al. (2010) also collected 44 personal air samples, which ranged from the limit of detection (0.1 ng/m^3) to 0.4 ng/m^3. The study identified no associations between health effects and microcystin concentrations from inhalation exposure from activities that included swimming, water skiing, Jet Skiing, or boating. The authors noted that the daily mean microcystin

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concentrations in personal air samples did not correlate with the concentrations of *Microcystis aeruginosa* cells, dissolved microcystins, or total microcystins in the sampled lake water.

In another study by Backer et al. (2010), the lakes had a wider range of concentrations of microcystins (< 10 to > 500 µg/L). The study authors measured microcystins exposure via personal air samplers, nasal swabs, and blood samples for individuals whose activities included swimming, boating, tubing/wakeboarding, riding watercraft, wading, and fishing at the lakes. They found low microcystin levels in personal air samplers below the limit of detection (0.1 ng/m^3) to 2.89 ng/m^3 and also in nasal swabs below the limit of detection (0.1 ng) to 5 ng. The average aerosolized microcystin concentration was approximately 0.3 ng/m^3. Based on the nasal swab data, the investigators estimated on average that the adults inhaled 0.8 ng of microcystins. Microcystin concentration in the water-soluble plasma fraction of the study subjects was also below the limit of detection (1 µg/L). The investigators cautioned that microcystin might be bound to a protein component in the blood or sequestered in liver tissue.

Wood and Dietrich (2011) studied Lake Rotorua (New Zealand) when it was experiencing a dense bloom of microcystin-producing *Microcystis*. The authors measured a maximum microcystin concentration in the water of 2,140 µg/L and air concentrations from 0.0003 to 0.0018 ng/m^3.

Cheng et al. (2007) used high volume and personal air samplers to measure microcystins in the air at a lake with a cyanobacterial bloom. The authors measured low microcystin concentrations in the water (approximately 1 µg/L) and air concentrations ranging from below the detection limit (0.02 ng/m^3) to 0.08 ng/m^3.

The EPA performed a screening analysis to characterize potential relative exposures. The EPA analyzed the relative potential dose of the cyanotoxins via inhalation exposure compared to oral ingestion to evaluate if recreational criteria values or swimming advisories based on ingestion could be protective of the other exposure routes. Although the recreational use is primary contact recreation, such as swimming, data are available for secondary contact activities such as Jet Skiing or boating and white-capped wave, bubble-bursting action, which can result in cyanotoxins becoming aerosols (microscopic liquid or solid particles suspended in air).

Using the information from Cheng et al. (2007) and inhalation exposure parameters provided in the EPA's EFH (2011), the EPA compared the estimated microcystin ingested dose to the inhaled dose. The first step in this comparative screening analysis was to calculate the incidental ingestion dose using the following equation:

$$\text{Ingestion dose (ng/day)} = \text{Ingestion rate} \times \text{Concentration}_{\text{water}}$$

Where:

Ingestion rate = 90th percentile incidental ingestion rate based on combined distributions of incidental ingestion (Appendix E) and recreational duration (U.S. EPA 2011) (L/day)

$\text{Concentration}_{\text{water}}$ = assumed concentration in water (1,000 ng/L from Cheng et al. (2007)) (ng/L)

The parameters used in the calculation of the estimated ingestion dose for each age group are presented in Table 7-7.

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Table 7-7. Ingestion Parameters and Estimated Ingestion Dose for Screening-level Comparative Inhalation Exposure Analysis

Age Group	Ingestion Rate (L/day) [a]	Concentration in Water (ng/L) [b]	Ingestion Dose (ng/day)
Children	0.21	1000	210
Adults	0.10	1000	100

[a] Daily recreational incidental ingestion rate calculated in combined distribution analysis for children and adults as described in section 4.2.3.1.

[b] Cheng et al. (2007) measured 0.08 ng/m^3 in air near surface waters with a concentration of 1 µg/L microcystins. This concentration in water was assumed as part of this analysis because Cheng et al. (2007) provided aerosolized levels given a specific concentration in water.

The second step in the comparative screening analysis was to estimate the inhaled dose using the following equation:

$$\text{Inhalation dose (ng/day)} = \text{Inhalation rate} \times \text{Inhalation duration} \times \text{Concentration}_{air}$$

Where:

Inhalation rate = inhalation rate from the EPA's EFH (U.S. EPA 2011; Table 6-2) (m^3/min)

Inhalation duration = inhalation exposure duration from the EPA's EFH (U.S. EPA 2011; Table 16-20) (minutes/day)

$\text{Concentration}_{air}$ = concentration in air (0.08 ng/m^3) assumed from Cheng et al. (2007) (ng/m^3)

The inhalation exposure parameters the EPA used in this equation and the resulting estimated inhaled dose are listed in Table 7-8. The EPA selected inhalation rates for children and adults from the EPA's EFH (U.S. EPA 2011). For this conservative comparative analysis, the EPA selected the highest 95th percentile short-term, moderate intensity activity level inhalation rate—the volume of air inhaled per minute (m^3/minute)—listed for children and adults in EPA's EFH Table 6-2 "Recommended Short-

Table 7-8. Inhalation Exposure Parameters and Estimated Inhaled Dose

Age Group	Inhalation Rate (m^3/min)[a]	Duration of Inhalation Exposure per Day (minutes/day)[b]	Daily Inhalation Rate Adjusted for Duration of Exposure (m^3/day)	Concentration in Air (ng/m^3)[c]	Estimated Inhalation Dose (ng/day)
Children	0.037	560	21	0.08	1.7
Adults	0.04	511	20	0.08	1.6

[a] The EPA's *Exposure Factors Handbook* (EFH; U.S. EPA 2011) did not report recommended short-term, moderate intensity activity level inhalation rate values for children or adults in aggregate; used highest inhalation rate listed for children and adult age groups for this conservative screen. For children, it was the age group 16 to < 21 years, and for adults, it was 51 to < 61 years.

[b] Values are the longest 90th percentile duration reported for child and adult age groups in the EPA's EFH (U.S. EPA 2011) from Table 16-20 "Time Spent (minutes/day) in Selected Outdoor Locations, Doers Only, Outdoors at a Pool/River/Lake." The child and adult age groups with the longest durations spent near or in the water were children 1 to 4 years old and adults 18 to 64 years old.

[c] Cheng et al. (2007) measured 0.08 ng/m^3 in air near surface waters with a concentration of 1 mg/L microcystins.

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Term Exposure Values for Inhalation (males and females combined)." The child and adult age groups with the highest of these inhalation rates were 16 to < 21 years and 51 to < 61 years, respectively.

To estimate the amount inhaled in a day, the EPA multiplied the inhalation rates for children and adults by an estimated daily inhalation exposure duration for each of these age groups. The EPA estimated daily inhalation exposure duration using a different dataset from the set it used for the incidental ingestion analysis (described in section 4.2.3.1). This was because people do not need to enter the water to be exposed via inhalation, they only need to be *near* or *at* the water. In contrast, recreators who incidentally ingest water while swimming must be *in* the water.

The EPA's EFH (U.S. EPA 2011) provides in Table 16-20 the time spent (in minutes/day) outdoors at a pool/river/lake. The EPA estimated inhalation exposure duration using the number of minutes per day spent outdoors at a pool/river/lake (U.S. EPA 2011). The EPA selected the longest 90th percentile duration values reported for child and adult age groups. The child and adult age groups with the longest times spent outdoors at a pool/river/lake were children one to four years old and adults 18 to 64 years old.

A comparison of the EPA's EFH data provided for time spent outdoors at a pool/river/lake and time spent in the water indicates that all age groups spent more time at a pool/river/lake than they spend in a pool/spa (U.S. EPA 2011). Consistent with the trend that children have longer durations of recreation in water than adults, children's time spent near recreational waters was greater than adults. The children's age group exposure patterns differed between the datasets. The data suggest younger children (one to four years) spend more time at recreational waters compared to school-aged children (five years and older), but children five to 11 years old spend more time in the water compared to other children (U.S. EPA 2011).

It is reasonable that younger children spend more time engaged in activities *at* a pool/river/lake compared to time spent recreating in recreational waters. The EPA selected this dataset to characterize inhalation exposure because younger children can spend more time playing on a beach, where they can be exposed to aerosolized cyanotoxins, than in the water where incidental ingestion can be the primary route of exposure.

The final step for this comparative screening analysis was to compare the ingestion and inhalation doses. The results are presented in Table 7-9. Using conservative assumptions for inhalation rates and inhalation exposure duration and comparing with daily incidental ingestion rates, the ingested dose is estimated to be higher than the estimated inhaled dose for children and adults. This analysis is for screening only and is highly uncertain. Further research is needed to better understand the toxicity from inhalation exposure to cyanotoxins.

Table 7-9. Results of Screening Analysis Comparing Ingestion and Inhalation Doses

Age Group	Ingestion Dose (ng/day)	Inhalation Dose (ng/day)
Children	210	1.7
Adults	100	1.6

[a] Calculations used unrounded parameters; results slightly differ with rounded values.

This analysis supports the conclusion that the inhaled dose can be much less than the incidental ingestion dose while recreating. The studies conducted by Backer et al. (2008, 2010) found low microcystin levels in aerosols above lakes with low or high microcystin concentrations and did not detect microcystin levels in the blood of study participants. In an animal study, no clinical signs or

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effects on body or organ weights were observed after exposure to microcystin-LR aerosol (Benson et al. 2005). The EPA did not conduct a similar analysis for cylindrospermopsin because published measured air concentration data for this cyanotoxin were not available.

The California Environmental Protection Agency (CalEPA) came to a similar conclusion for water skiers (Butler et al. 2012). They cited Cheng et al. (2007) and noted that their results showed that a liter of water contains 700,000 to 800,000 times the amount of cyanotoxins as in a cubic meter of air. CalEPA calculated that this concentration is equivalent to 1.3 to 1.4 µL aerosolized microcystins/m^3. Compared to the ingestion assumptions used for swimmers in the calculation of their recreational guideline (i.e., 50 mL/hour), CalEPA calculated that a water skier would have to inhale at least 35,000 m^3/hour while skiing to achieve a dose equal to the swimmer, which is 17,000 times the inhalation rate of a marathon runner. CalEPA concluded that a water skier would not inhale enough aerosol to receive a dose similar to what a swimmer gets from ingestion.

Another comparison considers spray exposures from personal watercraft and boat spray. Sinclair et al. (2016) modeled a water-spray exposure scenario and observed much lower exposures than those resulting from swimming or limited contact recreational activities reported in the previous study. Thus, the EPA expects that the comparison above based on exposure from secondary contact recreation is protective of primary contact recreation. Sinclair et al. (2016) also measured urinary concentrations of cyanuric acid after 26 participants' exposure to spray in a simulated 10-minute car wash situation. Subjects wore a protective coverall with hood, vinyl gloves, waterproof footwear, and safety glasses to ensure that only their face and mouths were exposed. The estimated median and 90th percentile ingestion volumes were 0.18 and 1.89 mL, respectively. Converted to a duration of one hour, the amounts would be 1.08 mL and 11.3 mL, which are much lower than the incidental ingestion intakes per hour.

7.4.2 Dermal Absorption

The EPA did not find any peer-reviewed measured data for microcystins or cylindrospermopsin dermal absorption. The EPA's *Dermal Exposure Assessment: A Summary of EPA Approaches* (U.S. EPA 2007) states that to get through the skin, a chemical must dissolve into the stratum corneum, which is a stabilized lipid barrier; therefore, lipid solubility is required initially (U.S. EPA 2007).

The EPA performed a comparative screening analysis to estimate the potential dermal absorbed dose of microcystins and compare it to the incidentally ingested dose. The first step in this comparative screening analysis was to calculate the incidental ingestion dose using the following equation:

$$\text{Ingestion dose} = \text{Ingestion rate} \times \text{Concentration}_{\text{water}}$$

Where:

Ingestion rate = 90th percentile incidental ingestion rate based on combined distributions of incidental ingestion (Appendix E) and recreational duration (EFH; U.S. EPA 2011) (L/day)

$\text{Concentration}_{\text{water}}$ = concentration in water assumed as the health protective value the EPA derived in this document for microcystins (mg/L)

The parameters used in the calculation of the estimated ingestion dose are presented in Table 7-10.

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Table 7-10. Ingestion Parameters and Estimated Ingestion Dose for Screening-level Comparative Dermal Absorption Exposure Analysis

Ingestion Rate (L/day)[a]	Chemical Concentration in Water (mg/L)[b]	Ingestion Dose (mg/day)
0.21	0.008	0.002

[a] Daily recreational incidental ingestion rate calculated in combined distribution analysis for children and adults as described in section 4.2.3.1.

[b] Concentration in water assumed to be the health protective value for microcystins the EPA derived in this document, converted to mg/L.

To estimate the potential dermal absorbed dose, the EPA used exposure equations in its *Risk Assessment Guidance for Superfund* (U.S. EPA 2004). The first step was to use chemical-specific octanol-water partition coefficient and molecular weight values to estimate dermal permeability, a parameter needed for the equation to estimate dermally absorbed dose. Octanol-water partition coefficients are available for four microcystins, including microcystin-LR. Ward and Codd (1999) estimated the log octanol-water partition coefficients of microcystin-LR, -LY, -LW and -LF using high performance liquid chromatography (HPLC) as 2.16, 2.92, 3.46, and 3.56, respectively. The EPA could not estimate cylindrospermopsin dermal absorption due to the lack of these lipophilicity parameters.

The equation to estimate skin permeability coefficient from U.S. EPA (2004) is:

$$\text{Log } K_p = -2.80 + 0.66 \times \log K_{ow} - 0.0056 \times MW$$

Where:

K_p = dermal permeability coefficient of compound in water (cm/hour)

K_{ow} = octanol-water partition coefficient from Ward and Codd (1999) (dimensionless)

MW = molecular weight (g/mole)

The chemical-specific dermal exposure parameters used to estimate skin permeability are listed in Table 7-11.

Table 7-11. Parameters Used to Estimate Skin Permeability of Microcystins

Microcystin Congener	Log K_{ow}[a]	Molecular Weight (g/mole)	Skin Permeability Coefficient (Log K_p)	Skin Permeability Coefficient (K_p) (cm/hour)
Microcystin-LR	2.16	995.17	-6.95	1.1×10^{-7}
Microcystin-LY	2.92	1002.16	-6.48	3.3×10^{-7}
Microcystin-LW	3.46	1025.2	-6.26	5.5×10^{-7}
Microcystin-LF	3.56	986.16	-5.97	1.1×10^{-6}

[a] Ward and Codd (1999)

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The equation to estimate dermal absorbed dose for highly ionized organic chemicals from U.S. EPA (2004) is:

$$\text{Dermal absorbed dose} = K_p \times \text{Concentration}_{water} \times t$$

Where:

Dermal absorbed dose	=	dermal absorbed dose per event (mg/cm^2-event)
K_p	=	dermal permeability coefficient of compound in water (cm/hour)
$\text{Concentration}_{water}$	=	chemical concentration in water (mg/cm^3)
t	=	event duration (hour/event)

The exposure parameters and estimated microcystins absorbed dose based on these calculations are presented in Table 7-12.

Table 7-12. Dermal Absorption Exposure Parameters and Estimated Dermal Absorbed Dose

Microcystin Congener	Chemical Conc. in Water (mg/cm^3)[a]	Event Duration[b] (hour/event) (mean for 5- to 11-year-olds)	Dermal Absorbed Dose per Event (mg/cm^2-event)	Total Body Surface Area (cm^2)[c]	Dermal Absorbed Dose per Event (mg/event)
Microcystin-LR	8×10^{-6}	2.7	2.4×10^{-12}	14,800	3.6×10^{-8}
Microcystin-LY			7.1×10^{-12}		1.0×10^{-7}
Microcystin-LW			1.2×10^{-11}		1.8×10^{-7}
Microcystin-LF			2.3×10^{-11}		3.4×10^{-7}

[a] Concentration in water assumed to be the health protective value for microcystins the EPA derived in this document, converted to mg/cm^3.

[b] Event duration is defined as time spent per day in outdoor pool or spa at home as reported in the EPA's EFH (U.S. EPA 2011).

[c] Value is 95th percentile Children 6 to 10 years from U.S. EPA (2011), converted to cm^2.

The final step for this comparative screening analysis was to compare the ingestion and dermal absorbed doses. The results are presented in Table 7-13. The estimated ingested dose is higher than the estimated dermal absorbed dose for children. This assessment is highly uncertain. Further research is needed to better understand the toxicity from dermal exposure to cyanotoxins.

CalEPA also concluded dermal absorption of microcystins and cylindrospermopsin while swimming is not expected to be significant due to the large size and charged nature of these molecules (Butler et al. 2012). CalEPA eliminated the dermal absorption pathway from its risk assessment of microcystins and cylindrospermopsin citing evidence that similarly large molecules such as antibiotics have not been able to be formulated in a way to penetrate the skin (Butler et al. 2012). A U.S. Army-contracted in vitro study by Kemppainen et al. (1990) measured microcystin dermal penetration in 48 hours through excised human abdominal skin and found 0.9 (± 0.3) percent of the total dose in water penetrated through the skin; however, this study has not been peer reviewed.

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Table 7-13. Results of Screening Analysis Comparing Ingestion and Dermal Absorbed Doses

Microcystin Congener	Ingestion Dose (mg/day)	Dermal Absorbed Dose[a] (mg/event)
Microcystin-LR	0.002	3.6×10^{-8}
Microcystin-LY	0.002	1.0×10^{-7}
Microcystin-LW	0.002	1.8×10^{-7}
Microcystin-LF	0.002	3.4×10^{-7}

[a] Calculations used unrounded parameters; results slightly differ with rounded values.

7.5 Cyanobacterial Cells

Cyanobacteria are associated with two distinct types of stressors, as described in the conceptual model, section 4.1. The first type of stressor are the toxins (microcystins and cylindrospermopsin) produced by the cyanobacteria. Section 3 of this document discusses the nature of these stressors and section 5 discusses related health effects endpoints. These stressors are the basis of the recreational criteria and swimming advisories. The second type of stressor is cyanobacterial cells. At this time, available data are insufficient to develop quantitative recreational values for total cyanobacterial cell density related to inflammatory health endpoints. However, various state and international agencies use total cyanobacterial cell densities in decision-making to determine water quality and to post recreational warnings to the public.

Exposure to cyanobacteria cells in ambient waters is associated with numerous inflammatory health endpoints, including: rashes, respiratory and GI distress, and ear and eye irritation. These effects can be the result of direct contact with bioactive compounds in the cyanobacteria (also referred to as "endotoxins"), or by contact with cyanobacteria-associated microbial commensals via dermal, oral, or inhalation exposure routes (Eiler and Bertilsson 2004; Gademann and Portmann 2008). Section 7.5.1 and Appendix D provide more information about the health effects associated with exposure to cyanobacteria cells based on the scientific literature and related uncertainties. Section 7.5.2 presents information about the use of total cyanobacteria, or other biomass metrics, as an indicator of potential hazard associated with cells or cyanotoxins. Gene-based enumeration methods, satellite remote sensing and uncertainties related to use of cells as indicators are also described. Section 7.5.3 discusses guidelines that use total cyanobacterial cell density as an indicator for toxin presence, quantification of toxigenic cells, and an approach providing cell density estimates related to the recommended 304(a) cyanotoxin criteria.

7.5.1 Health Effects Associated with Cyanobacterial Cells and Uncertainties

Various health studies, described in more detail in Appendix D, relate recreational exposure to increasing densities of cyanobacterial cells with increased incidence of specific health endpoints that can be described as acute inflammatory or allergenic reactions. The EPA identified epidemiological studies, clinical studies, and recreational water outbreak reports in searches of the publicly available and peer-reviewed scientific literature that characterize the human health effects associated with recreating in surface waters where cyanobacteria were present (see Appendix D).

The epidemiological studies provide evidence for statistically significant associations between cyanobacterial cell densities and possible inflammatory or allergenic health endpoints:

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- Pilotto et al. (1997) reported a significant association with the occurrence of one or more symptoms, such as skin rashes, eye irritation, ear irritation, gastrointestinal distress, fever and respiratory symptoms, and exposure to greater than 5,000 cells/mL for more than one hour. In discussing the significance of the trend of increasing symptom occurrence and with the 5,000 cells/mL cut point, Pilotto et al. (1997) specifically suggested that the 20,000 cell/mL threshold might be too high to be adequately protective of recreators.

- Stewart et al. (2006d) found a significant increase in the inflammatory health effects associated with recreators exposed to > 100,000 total cyanobacteria/mL or a total cyanobacterial surface area > 12 mm^2/mL.

- Lévesque et al. (2014) observed a significant increase in GI symptoms associated with recreational contact. The increase in GI symptoms was significant in the > 20,000-cells/mL and > 100,000-cells/mL categories, and the positive trend for increasing illness with increased total cyanobacterial cell densities also was significant at p-value = 0.001.

- Lin et al. (2015) reported significant associations between respiratory symptoms and exposure to the 25th to 75th percentile range of cyanobacterial cells excluding picocyanobacteria (range 37–237 cells/mL) and between reported respiratory, rash, and earache symptoms and exposure to the highest quartile (range 237–1,461 cells/mL). The 1,461-cells/mL value was the highest cell density observed in that study (Lin et al. 2015).

- Lévesque et al. (2016) reported a significant trend of increasing of GI illness in recreators associated with exposure to the concentration of endotoxins. The authors noted a positive correlation between endotoxin concentrations and total cyanobacterial counts. Relative risks for GI illness were higher for families that also received drinking water from the lakes studied or from wells under the influence of surface water contamination. There was no relationship between GI illness and exposure to *E. coli*. Relative risks also increased for recreators engaged in full (e.g., swimming, water skiing, diving, etc.) or limited (e.g., fishing, use of watercraft) contact recreation and adjustment for the level of exposure did not alter the health relationship.

The variability in the reported epidemiological associations in these studies in both the range of cyanobacterial cell densities reported and specific symptomologies characterized limited identification of a discrete cyanobacterial cell density value associated with a consistent level of effect. Some researchers have suggested that the lack of a described dose-response characterizing cell-related inflammatory health effects could suggest a "threshold" rather than a specific dose-response relationship (Cochrane et al. 2015; Stewart et al. 2006b). Allergy is an example of a threshold mechanism, meaning that there is a level of exposure (i.e., a threshold value) below which the development of sensitization and the elicitation of an allergic reaction will not occur. Defining accurate numerical values for threshold exposure levels is difficult due to lack of validated methods and uncertainties about the mechanism of sensitization (Cochrane et al. 2015).

Scientists investigating the health effects posed by cyanobacteria have pointed out factors that contribute to the epidemiological variability observed and uncertainties in determining what level of cyanobacterial cells result in a specific level of inflammatory responses. For example:

- There are differing cyanobacterial community composition and proportions of the more allergenic, non-cyanotoxin-producing strains relative to the cyanotoxin-producing strains at each

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site. Researchers have reported non-toxin-producing strains can be more allergenic compared to toxin-producing strains (Torokne et al. 2001).

- There is variability in sensitivity in the study populations.
- There are differences among the specific sites studied.
- The limited size of some studies could have affected the ability to detect significantly increased rates of illness in individual symptom categories (Pilotto et al. 1997; Stewart et al. 2006b). Small sample size diminishes the statistical power of the study and the ability to detect an association if one exists (Rothman et al. 2008).
- The incomplete characterization or consideration of frank or opportunistic pathogens that could co-occur with cyanobacteria in ambient waters also complicates conclusions related to the etiologic agent of the reported symptoms (Lévesque et al. 2014; Lin et al. 2015; Pilotto et al. 1997; Stewart et al. 2006b).

The number of cells in freshwater reported to be statistically-associated with a significant increase in inflammatory endpoints ranged from 5,000 to 100,000 cells per mL. The EPA concluded that, although significant associations with adverse health effects occur across a wide range of cyanobacterial cell densities, the EPA cannot derive the CWA section 304(a) criteria based on total cyanobacterial cell density at this time. There is considerable uncertainty and variability associated with the epidemiological results that did not identify consistent effects at similar cell densities and available data do not support a consistent quantitative dose-response relationship.

Additional research is needed to better describe the health effects associated with exposure to cyanobacteria with more precision using consistent health symptomologies in context with the community of cyanobacteria present (e.g., population of toxigenic versus non-toxin-producing cyanobacteria, shifts in community profile during the study, etc.) and other factors that influence the proliferation of cyanobacteria. Based on currently available science, inflammatory illnesses are significantly increased at values above 100,000 cyanobacterial cells per mL. Guideline values currently in use (see sections 2.1 and 7.5.3) that are within the 5,000 to 100,000 cell density range can find supporting scientific evidence in the peer-reviewed literature described above and in Appendix D.

7.5.2 Cyanobacteria Biomass Measurements as Indicators of Hazard

Under certain conditions, cyanobacteria possessing the toxin synthesis genes, also referred to as toxigenic cyanobacteria, begin producing cyanotoxins. Toxigenic cyanobacteria are a functional subgroup of the total cyanobacterial population that may be present in a water body and the proportion of toxigenic cells present can vary geographically and over time. Numerous biotic and abiotic factors can influence not only the dominance of cyanobacteria within the overall phytoplankton community, but also the proportion of toxigenic cyanobacteria relative to non-toxin-producing cyanobacteria (Davis et al. 2009; Hyenstrand et al. 1998; McCarthy et al. 2009; Neilan et al. 2013; Gobler et al. 2016). Multiple species of cyanobacteria are capable of producing the same toxin, such as the microcystins, which can pose a risk to human and animal health (Crawford et al. 2017). Although scientists have observed a generalized relationship between total cyanobacteria density or chlorophyll *a* and cyanotoxin concentration, these relationships are affected by the dominance of the toxin-producing cyanobacteria within the overall cyanobacterial community (Zhang et al. 2014; Loftin et al. 2016b).

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Total cyanobacterial cell biomass, described by cell densities or other metrics, such as chlorophyll *a*, can function as a measure of the ecological health of a water body and as an indicator of potential public health hazards, such as inflammatory reactions from exposure to cells and adverse health effects associated with the presence of cyanotoxins. The extent, frequency, persistence, and severity of cyanobacteria proliferation can indicate the eutrophic status of a water body (Yuan and Pollard 2015). Surface water enrichment with nitrogen, notably reduced forms of nitrogen, and phosphorus have been linked to cyanobacteria becoming the dominant phytoplankton (Beaulieu et al. 2013; Glibert et al. 2016; Paerl 2008; Watson et al. 1997). Proliferating cyanobacterial biomass can result in an increased potential for toxins being produced (Pearl et al. 2001; Otten et al. 2012).

Although there can be large variation in the number of toxigenic cyanobacteria present relative to non-toxigenic cyanobacteria in any given body of water, measures of the total cyanobacterial biomass, such as cell counts, chlorophyll, or even visual assessments, can be used effectively in decision-making as early warnings of potential HAB-associated hazards (Loftin et al. 2016b). Pacheco et al. (2016) stated that these measurements can be good indicators of the potential risk of cyanotoxin exposure and useful when access to more sophisticated approaches, resources, or expertise may be limiting. Measurements of total cyanobacteria may also be particularly useful in waters with a history of HAB occurrence and the presence of elevated cyanotoxins.

7.5.2.1 Remote Sensing Techniques for Estimating Cyanotoxins

New and innovative methods, such as remote sensing techniques using satellite imagery, coupled with quantitative analysis to identify cyanobacterial blooms are of increasing interest to states. To date, these techniques cannot yet detect cyanotoxins, but they can quantify cyanobacterial densities in water bodies, an indicator of potential for cyanotoxin presence. Satellite measures of chlorophyll *a*, phycocyanin, or both are used to estimate cyanobacterial cell density based on validated algorithms that quantify relationships between these parameters and in situ measurements of cell density. For example, Stumpf (2014) and Wynne et al. (2010) readily detected by satellite areas of high *Microcystis* densities in larger freshwater bodies, such as Lake Erie.

U.S. EPA has collaborated since 2015 with the National Aeronautics and Space Administration (NASA), NOAA, and the USGS on the Cyanobacteria Assessment Network (CyAN) project. This project is developing the capability to detect and quantify total cyanobacterial blooms and related water quality of U.S. lakes and estuaries using satellite data records (U.S. EPA 2018b). This includes improving interpretation of satellite data and refining algorithms across satellite platforms. CyAN defined an approach for identifying lakes that can be spatially resolved (i.e., visually separated) with satellite imagery given differences in pixel resolutions, a method to quantify frequency of bloom occurrence in recreational freshwater sites, and a method for evaluating changes in the spatial extent of cyanobacterial blooms over time to support state-level assessments (Clark et al. 2017; Urquhart et al. 2017). CyAN has developed a mobile application that makes its processed satellite data more widely available. In 2017, the application was made available to state agencies for beta testing (U.S. EPA 2018b). A CyAN project that compares satellite-based estimations of total cyanobacterial cell density data from monitoring programs in eight states in the eastern United States found that satellite information provided robust estimates for freshwater lakes greater than 100 hectares when the cell densities less than 109,000 cells/mL and above 1 million cells/mL (Lunetta et al. 2015). The estimates were less on target for intermediate densities (i.e., between 110,000 and 1 million cells). The authors attributed this lower performance to the gap in taxonomic information needed to facilitate conversions between cell count and cell volumes (Lunetta et al. 2015).

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Challenges remain for using remote sensing for cyanotoxin detection and mapping and Stumpf et al. (2016) identify these and a strategy for resolving them. The challenges they note include the lack of a steady relationship between the indicator pigments (i.e., chlorophyll *a* or phycocyanin) and cyanotoxins. These relationships may be valid for several weeks but start to vary over longer time periods due to changes in the amount of cyanotoxin produced as a function of cyanobacterial biomass. Strategic collection of pigment and toxin measurements will improve the application of remote sensing and associated models. The Ocean Land Colour Imager on the Sentinel-3 satellite, launched in 2016, will help address this need and improve data availability for most medium to large lakes around the world.

Given the inherent spatial uncertainty in the distribution of blooms and the potential issues with use of the appropriate satellite product, more attention should be given to the use of field measurements of reflectance to parameterize derivative-based pigment models (Tomlinson et al. 2016). This approach will help standardize processing of the satellite data to consistent reflectance-based products. Standardization is a factor in pigment and cyanotoxin measurement that will also require closer scrutiny. Propagation of known measurement error and uncertainty into the models will establish confidence levels for a variety of applications besides toxin maps. Improving strategies for collecting pigment measurement with toxin measurement will allow a better understanding and use of remote sensing to inform monitoring of toxins in lakes.

7.5.2.2 Molecular Methods for Estimating Cyanotoxins

Scientists have applied newer methods of quantifying microbes in environmental matrices, which increases understanding of bloom dynamics and functional subgroups of cyanobacteria, such as the toxigenic cells (Davis et al. 2009). The use of gene-based enumeration methods allows the quantification of cyanobacteria that contain specific gene sequences for toxin synthesis—without which a cell cannot produce the toxin. When toxigenic cyanobacteria are characterized with these tools, they have been shown to be better predictors of subsequent increases in toxin concentrations than with other traditional enumeration methods.

More recently, the use of gene-based quantification methods has helped to shed light on the community dynamics within a bloom, understand some of the factors that trigger toxic blooms, and provide faster and less expensive measurements of potential bloom toxicity compared to ELISA- and LC/MS/MS-based methodologies. Researchers have shown that microcystins and cylindrospermopsin are produced by non-ribosome-associated peptide synthetases (Dittmann et al. 1997; Moreira et al. 2013). The microcystin synthetase complex is encoded by 10 *mcy* genes (*mcyA* to *mcyJ*) (Neilan et al. 2013). Studies have characterized the abundance of various *mcy* genes in ambient waters (Pacheco et al. 2016; Qiu et al. 2013). The cylindrospermopsin synthetase gene cluster, *cyr*, is not as well characterized, but has been studied in multiple cylindrospermopsin-producing cyanobacteria (Neilan et al. 2013). Other researchers have used qPCR methods to characterize the relative abundance of total cyanobacteria, *Cylindrospermopsis raciborskii* and cylindrospermopsin synthase in lake water (Moreira et al. 2011). Selected examples of monitoring studies using gene-based approaches are described below.

- Davis et al. (2009) characterized toxic and nontoxic strains of *Microcystis* by quantifying the *mcyD* (toxigenic strains) and the 16S rDNA genes (all *Microcystis*) in four lakes in the northeastern United States over a two-year period. At all sites, toxigenic *Microcystis* were a better predictor of microcystin concentrations compared to total cyanobacteria, total *Microcystis*, chlorophyll *a*, or other environmental factors. Gene copies of *mcyD* were significantly correlated with microcystin concentrations in every lake studied (Davis et al. 2009).

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- HABs in lakes and reservoirs are prevalent in Alberta, Canada, and are affected predominantly by elevated microcystins (Alberta Health 2014). Multiple Canadian governmental departments and public health laboratories in Alberta conducted a monitoring and advisory program for cyanobacteria at beaches. Among the findings were: microcystin-producing cyanobacteria species were dominant in most lakes with blooms peaking in late August to September, microcystin concentrations exceeding Canadian guidelines were not consistently associated with elevated total cyanobacterial cell densities in most cases, and the *mcyE* gene measured by qPCR was a good predictor for cyanobacterial blooms in some lakes (Alberta Health 2014).

- In response to the 2014 Lake Erie HAB event that contaminated the drinking water of Toledo, Ohio, the EPA revised the monitoring requirements for Ohio public water systems. Included in those requirements are testing for the *mycE* gene. If > 5 *myc*E genes/µL are detected in raw water samples, public water systems must monitor for microcystins (Ohio EPA 2017). Ohio is currently testing qPCR methods for total cyanobacteria (16s rDNA) and toxigenic cyanobacteria such as microcystin (*mcy*E gene) and saxitoxin (*sxt*A gene) producers. Ohio's HAB response strategy for recreational waters (Ohio EPA 2017) includes qPCR assessment for cyanotoxin-production genes as an option for cyanobacterial screening. If the qPCR testing indicates an abundance of toxigenic cyanobacteria, additional analysis for the toxin is recommended (Ohio EPA 2017).

- In Lake Champlain, in the northeastern United States, Fortin et al. (2015) applied qPCR-based methods and high-throughput sequencing to evaluate the effect of physico-chemical parameters and nutrients on the dynamics of cyanobacterial community. The researchers observed that total cyanobacteria were correlated with microcystin concentrations (Fortin et al. 2015). They also showed a significant correlation between the microcystin concentrations, the abundance of the *mcyD* gene, and the abundance of *Microcystis* 16S rDNA gene copies. Previous work had shown that *Microcystis* were the predominant microcystin producer present in the same water body (Ngwa et al. 2014).

- Pacheco et al. (2016) reviewed studies examining relationships between the prevalence of microcystin synthetase genes and microcystin concentration, and between chlorophyll *a* or cell density and microcystin concentration. While many studies included in the review did show a correlation for both comparisons, some did not. A lack of correlation between the synthetase genes and microcystin concentration was reported in studies that: (1) extracted the particulate-associated microcystins only; (2) included waters with very low concentrations of total microcystins (e.g., < 0.5 µg/L); or (3) in one study, monitored lakes at a single fixed point in the pelagic zone at the deepest site in each lake using depth-integrated water samples representing the entire photic zone (Beversdorf et al. 2015a; Pacheco et al. 2016). For studies not reporting a correlation between chlorophyll *a* or cell density and toxin concentration, only particulate-associated microcystin was analyzed or a very low concentration (e.g., < 0.05 µg/L) of total microcystins was observed (Pacheco et al. 2016). Zhang et al. (2014), one of the studies included in the Pacheco et al. (2016) review, characterized cylindrospermopsin- and microcystin-producing genotypes in the Macau reservoir, China, and found high cylindrospermopsin concentrations correlated to the prevalence of the *pks* gene ($r^2 = 0.95$, p-value < 0.01) and that *Cylindrospermopsis* dominated the cyanobacterial population in the reservoir studied.

- Crawford et al. (2017) applied an integrated monitoring approach including microscopic cyanobacteria identification, multiplex qPCR for toxin genes, and toxin analysis to assess

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potential risks and inform bloom management decisions in a HAB event on the Murray River, Australia, in 2016. The qPCR results showed that cylindrospermopsin and saxitoxin genes were present, but were below the level of quantification. No microcystin genes were detected. The qPCR results were corroborated with the lack of detection of any cylindrospermopsin, microcystin, or saxitoxin (Crawford et al. 2017).

7.5.2.3 Uncertainties in Using Cyanobacterial Cells as Indicators

While cell density and pigment measurements can be useful for early detection of cyanobacterial proliferation and informative for bloom monitoring, these approaches may not be sufficiently accurate to predict risk from cyanotoxins (Pacheco et al. 2016). Uncertainties related to the use of total cyanobacteria in decision-making related to toxin concentrations should be considered.

1. Toxigenic cell densities can be a better indicator of the potential of a bloom to produce cyanotoxins compared to measures of total cyanobacterial biomass.

The amount of toxin produced by a toxigenic cyanobacterial cell and the relative abundance of toxigenic strains relative to non-toxigenic ones can vary considerably and be affected by environmental factors (Gobler et al. 2016). Gene-based quantification of toxigenic cyanobacteria can be beneficial for decision-making for HAB management approaches (Lee et al. 2015; Crawford et al. 2017). Davis et al. (2009) observed that quantifying toxigenic *Microcystis* was a better predictor of in situ microcystin levels than other surrogates, such as total cyanobacteria and chlorophyll *a*. The use of qPCR to characterize temporal and spatial variations in the abundance of toxigenic strains can identify the capability of a bloom to produce toxins, and hence the potential for recreator exposure to toxins, including perhaps prior to the hazardous condition occurring (Pacheco et al. 2016).

The importance of the toxigenic cyanobacterial cells has been recognized by the WHO and previously discussed in section 2.1. Based on toxigenic *Microcystis*, approximately 20 µg microcystins per L could be expected, but other species, such as *Planktothrix*, can contain higher microcystin concentrations in a cell compared to *Microcystis* (Fastner et al. 1999). Thus, the WHO commented that microcystin concentrations could be much higher (e.g., 50–100 µg/L) if species with high microcystin content dominate a bloom (WHO 2003a).

2. Total cyanobacteria can be informative as an indicator for the presence of toxins if toxigenic species are abundant or the dominant members of the cyanobacterial community.

Evidence from prior monitoring may demonstrate toxigenic strains tend to dominate blooms in a water body or that a prior bloom had increased densities of toxigenic species occurring in conjunction with elevated toxins. Studies showing good correlation between increased cell densities or other parameters linked to cell proliferation and elevated toxin concentrations can also show the bloom is dominated by toxin-producing species (Rinta-Kanto et al. 2009; Zhang et al. 2014; Pacheco et al. 2016). In one study on Lake Erie over multiple seasons, Rinta-Kanto et al. (2009) observed a positive correlation between the abundance of cyanobacterial and *Microcystis* gene copies and the number of microcystin synthetase genes. *Microcystis* were a strong contributor to the concentration of microcystins in Lake Erie and the relative abundance of *Microcystis* cells was correlated with microcystin concentrations (Rinta-Kanto et al. 2009). Lack of correlation can occur when toxigenic cell density is low or undetectable (Crawford et al. 2017) or low concentrations of toxin are recorded (Rinta-Kanto et al. 2009) and in such cases measures of total cyanobacteria are not good indicators of toxins.

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3. The proliferation of toxigenic cells and the timing of the presence of elevated toxin concentrations may or may not coincide with the visible proliferation of a HAB.

Decisions to issue recreational water warnings/advisories, or initiate monitoring for cyanotoxins based on total cyanobacteria once a bloom is observed (i.e., green, discolored water, or scum formation/accumulation associated with high densities of cells) may overlook situations where extracellular toxins are present. Cells may accumulate in locations different from where the bloom originated (e.g., by wind or wave action, or both, or be transported downstream). A cell density of 40,000 cells/mL is lower than what might be typically associated with a visible bloom (WHO 2003a). Decision points contingent on visually confirmed blooms may miss or delay the identification of the hazardous condition associated with exposure to elevated cyanotoxins, especially in water bodies with a previous history of HAB events or toxin detections and the downstream waters potentially affected by the HAB.

Davis et al. (2009, 2010) observed bloom dominance shift between toxigenic strains and non-toxigenic strains over the course of a summer. Spatial and temporal dynamics in cyanobacterial population succession is noted in other seasonal studies (Sabart et al. 2010; Otten et al. 2012, Beversdorf et al. 2015b; Fortin et al. 2015; Chen et al. 2017). Ha et al. (2009) observed similar seasonal variations in both the gene copies of microcystin synthetase genes and for total cyanobacteria gene copies, although the cyanobacterial community was consistently dominated by microcystin-producing cells throughout the study.

7.5.3 Use of Cyanobacteria Cell Densities in Guidelines

7.5.3.1 Cyanobacteria Cell Guidelines

A number of states and international agencies include both total cyanobacteria and toxigenic cyanobacteria density guidelines to account for both inflammatory- and toxin-associated health endpoints. Cyanobacterial cell densities used by states and local health departments to provide guidance to recreators on water quality are presented elsewhere in this document (see Table 2-3 for a list of states with cyanobacterial cell density guidelines; see Appendix B for state guidelines and associated actions).

As discussed in section 2.1, the 35 states that currently have HAB-related guidelines include different approaches and guideline levels (see Table 2-3). Seven states have guideline levels that address toxin-producing cyanobacteria as a proportion of the total cyanobacterial population or include a toxin-specific cyanobacteria cell density (California, Idaho, Maryland, New York, New Hampshire, Oregon, and Virginia). The Karuk Tribe, located in California, developed cell-based values for posting cyanotoxin public health warnings for the tribe's recreational waters (Kann 2014).

As described in section 2.1 of this document, the WHO (2003a) guideline value development was informed by results from a review conducted by Chorus and Bartram (1999) and a prospective epidemiology study by Pilotto et al. (1997), which evaluated health effects after recreational exposure to cyanobacteria and reported associations between cyanobacterial cell densities and health. The WHO recommended three tiers of guideline values describing an increasing scale of potential adverse health effects and "between the chiefly irritative symptoms caused by unknown cyanobacterial substances and the potentially more severe hazard of exposure to high concentrations of cyanotoxins, particularly microcystins."

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- The lowest tier of guideline values (< 20,000 cyanobacterial cells per ml; < 10 µg/L chlorophyll *a*) was mainly associated with a significant increase in irritative or allergenic effects (the inflammatory health endpoints). The WHO, using conservative assumptions, also estimated that microcystin concentrations of 2 to 4 µg/L, and possibly up to 10 µg/L, may be expected at a cell density of 20,000 cells/mL where microcystin producers dominate.

- The second tier (20,000 to 100,000 cyanobacterial cells per ml; 10 to 50 µg/L chlorophyll *a*), describing a moderate probability of adverse health effects from cyanotoxins was informed by (1) modifying the value for the WHO drinking water guideline for microcystin-LR for a recreational exposure scenario and (2) translating microcystin concentrations to cell densities based on the average microcystin content of *Microcystis* cells. The WHO, using conservative assumptions, also estimated that 100,000 cyanobacterial cells/mL could correspond to 20 µg microcystins/L if a bloom consists of *Microcystis* and has an average microcystin content of 0.2 pg/cell.

- At the third tier (> 100,000 cells per mL; > 50 µg/L chlorophyll *a*) "there is the potential for some frequently occurring species (i.e., *Microcystis*) to form scums," which can "increase risks for bathers and others involved in body-contact water sports." The high probability of adverse health effects category is associated with the elevated potential for exposure to cyanotoxins and the potential for severe health outcomes. "The presence of cyanobacterial scum in swimming areas represents the highest risk of adverse health effects due to abundant evidence for potentially severe health outcomes associated with these scums."

- Very high densities of cells occurring in scums (e.g., > 10 million cells/mL or > 5,000 µg/L chlorophyll *a*) can be associated with very high concentrations of toxin.

The Australian National Health and Medical Research Council (NHMRC) published a two-tiered guideline for managing cyanobacteria in recreational water (NHMRC 2008). Tier one includes numeric targets for microcystins based on children's recreational exposures and a toxigenic cell density for *Microcystis aeruginosa*. The NHMRC recommends a secondary guideline for the protection from health hazards associated with high densities of non-toxigenic cyanobacteria consistent with the WHO cyanobacterial cell density recommendations for the moderate probability of health effects. NHMRC used the epidemiological results published by Stewart et al. (2006b) to inform the derivation of the Australian total cyanobacteria guideline number. Stewart et al. (2006b) found a significant increase in the inflammatory health effects associated with recreators exposed to >100,000 total cyanobacteria/mL or a total cyanobacterial surface area > 12 mm^2/mL. Because different cyanobacteria species can have different sizes, the surface area estimate of biomass can take those size differences into account (e.g., 1,000 very big cells versus 1,000 very small cells). NHMRC converted the cell surface reported by Stewart et al. (2006b) to an equivalent biovolume and rounded that value to 10 mm^3/L. This biovolume guideline value applies when toxigenic cyanobacteria are absent in a bloom (NHMRC 2008)

NHMRC calculated a child-based total microcystin concentration of 9.4 µg/L, rounded to 10 µg/L (NHMRC 2008). The authors then converted the toxin concentration to an equivalent toxigenic cell density (50,000 *Microcystis aeruginosa*/mL) using the microcystin cell quota value (0.2 pg/cell). To account for the potential hazard posed by other microcystin-producing cyanobacteria, the cell density was converted into a biovolume equivalent (4 mm^3/L). Other species have different cell sizes, so the biovolume measurement allows comparisons with the other known toxin-producing cyanobacteria that may be present. The biovolume equivalent applies to the total of all cyanobacteria where a known toxin producer is dominant (NHMRC 2008).

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7.5.3.2 Amount of Toxin per Cell

Toxigenic cyanobacteria produce cyanotoxins that can accumulate inside the cells or be released to the water column. The amounts of toxin produced by a toxigenic cyanobacterium is also referred to as "cell quota." There is variability in the estimate of cyanotoxin concentrations associated with cell density, in part because a bloom can contain both the toxigenic and non-toxin-producing strains of the same species and cyanobacterial community differences between locations could affect the level of cyanotoxin that is present. Thus, it is important to understand the abundance of toxigenic cyanobacteria in a water body. As discussed above, characterizing the abundance of toxin genes can be a better predictor of toxin produced than can calculations based on a toxin cell quota. The WHO's microcystin estimates at the different risk levels were based on converting the recommended total cyanobacterial cell density using a *Microcystis* cell quota value for microcystins (0.2 pg/cell) derived from a laboratory study conducted by Mole et al. (1997) reporting an average microcystin cell quota in laboratory cultures of 0.2 pg/cell (range: 0.07–0.3 pg/cell) (Fitzgerald et al. 1999), but other species and strains of microcystin producers could result in much higher water-column microcystin concentrations given the same cell density (WHO 2003a).

The EPA searched the published peer-reviewed scientific literature for information on the amount of microcystin and cylindrospermopsin produced by or contained in a cell to inform the development of toxigenic cell densities equivalent to the recommended criteria concentrations. Appendix G presents the details related to the search strategy, reference prioritization and search results. The search resulted in the collation of multiple studies reporting cell quotas for microcystin and cylindrospermopsin in multiple genera of cyanobacteria. Laboratory-based culture studies with numerous clones of *Microcystis aeruginosa*, *Cylindrospermopsis raciborskii, Planktothrix agardhii*, and *Planktothrix rubescens* were also found. Many of these references also included either biomass-toxin conversions or graphic data that would support conversion factors from cyanobacterial cell density (expressed in a variety of units including: cells/L, biovolume (μm^3/L), and chlorophyll *a*/L) to toxin concentrations for these species. Aggregated data are presented in Table 7-12. Table G-3 in Appendix G provides additional detail on the studies identified containing cell quota information.

To facilitate a comparison of this information with the value used by the WHO, the EPA organized the reported cell quota information by toxin and by genus (Table 7-14). Within each row, the study type, quantification method, reported means and ranges, and references to the original study are included. Not every study reported a mean, median, maximum, or minimum, so each row represents a collation of the values reported. Ranges of reported cell quotas were large. For example, for all microcystin-producing genera, reported cell quotas ranged from 0 to 4.3 pg/cell and the reported range of the means were 0.015 to 0.58 pg/cell. For *Microcystis*, the mean of the means, for seven studies published between 2008 and 2013, was 0.15 pg/cell. This value is similar to the 0.2 pg/cell value used by the WHO and provides additional evidence that this conversion factor is supported by multiple scientific studies. For the genus *Planktothrix*, the studies identified by the EPA do not suggest that this genus produces much higher amount of microcystin compared to *Microcystis*. However, the EPA's literature search focused on more recently published data and the *Planktothrix* values in the summary table come from only two recent studies that may have not characterized toxin production under optimal conditions. Based on the data presented in Table 7-14, the EPA concluded that the microcystin cell quota used by the WHO is supported. The caveat expressed by the WHO (i.e., cell quota values can be variable within and between species of microcystin-producing cyanobacteria) is also substantiated by the EPA's literature search results. The EPA included the 0.2 pg/cell value in the calculation of a toxigenic cell density for

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microcystin-producing cyanobacteria equivalent to the recommended toxin magnitude (see section 7.5.3.3).

The EPA also collated similar information for cylindrospermopsin cell quotas. As with other aspects of cylindrospermopsin, less information was available, but multiple field and laboratory studies reporting the mass of toxin per cell were identified. The range of cylindrospermopsin cell quotas (0.0028–14.6 pg/cell in *Cylindrospermopsis*) was larger than for microcystins, as was the range of reported means (0.0028–0.17 pg/cell). The highest value (14.6 pg/cell) was reported from a field study (see Table G-1). The highest value reported in a laboratory study was 0.17 pg/cell. The mean value for all studies was 0.047 pg/cell (n = 10) and for field studies (n = 2) was 0.023 pg/cell. Given the few number of field studies, large uncertainties exist with how representative the mean is of the central tendency of the range. Less information was identified for *Aphanizomenon*, another well-known cylindrospermopsin producer. To have a similar confidence level in the cylindrospermopsin cell quota data compared to microcystins, additional data and an improved sense of the central tendency within the reported ranges is needed. At present, the EPA is not sufficiently confident in the cylindrospermopsin cell quota database to estimate a toxigenic cell density specific for cylindrospermopsin.

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Table 7-14. Aggregated Cell Quota Summary Data for Selected Microcystin and Cylindrospermopsin-producing Genera

Toxin Genus	Quantification Method[a]; Study Type[b]	Range of Means[c]	Mean[c,d]	Median of Means[c]	Minimum; Maximum[c,e]	References
Microcystins						
All microcystin-producing genera	Mass per cell; Field and lab	0.015 pg/cell – 0.58 pg/cell	0.11 pg/cell	0.091 pg/cell	0 pg/cell – 4.3 pg/cell	Orr and Jones (1998); Jähnichen et al. (2001); Wiedner et al. (2003); Akcaalan et al. (2006); Jähnichen et al. (2007); Briand et al. (2008); Fahnenstiel et al. (2008); Vasconcelos et al. (2011); Sitoki et al. (2012); Tao et al. (2012); Wood et al. (2012); Cires et al. (2013); Sabart et al. (2013); Wang et al. (2013); Pineda-Mendoza et al. (2014); Chia et al. (2016); Wei et al. (2016)
Microcystis	Mass per cell; Field and lab	0.015 pg/cell – 0.58 pg/cell	0.11 pg/cell	0.072 pg/cell	0 pg/cell – 4.3 pg/cell	Orr and Jones (1998); Jähnichen et al. (2001); Wiedner et al. (2003); Jähnichen et al. (2007); Fahnenstiel et al. (2008); Vasconcelos et al. (2011); Sitoki et al. (2012); Tao et al. (2012); Wood et al. (2012); Cires et al. (2013); Sabart et al. (2013); Wang et al. (2013); Pineda-Mendoza et al. (2014); Chia et al. (2016); Wei et al. (2016)
	Mass per cell; Field	0.015 pg/cell – 0.58 pg/cell	0.15 pg/cell	0.075 pg/cell	0 pg/cell; 4.19 pg/cell	Fahnenstiel et al. (2008); Vasconcelos et al. (2011); Sitoki et al. (2012); Tao et al. (2012); Cires et al. (2013); Sabart et al. (2013); Wang et al. (2013)
Planktothrix	Mass per cell; Field and lab	0.076 pg/cell – 0.24 pg/cell	0.12 pg/cell	0.10 pg/cell	0.076 pg/cell; 0.24 pg/cell[e]	Akcaalan et al. (2006); Briand et al. (2008);
	Mass per cell; Field	0.091 pg/cell – 0.24 pg/cell	0.16 pg/cell	0.16 pg/cell	0.091 pg/cell; 0.24 pg/cell[e]	Akcaalan et al. (2006); Briand et al. (2008)
Fisherella	Mass per biomass; Lab	N/A	N/A	N/A	43 µg/g	Cires et al. (2014)

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Toxin Genus	Quantification Method[a]; Study Type[b]	Range of Means[c]	Mean[c,d]	Median of Means[c]	Minimum; Maximum[c,e]	References
Cylindrospermopsin						
Aphanizomenon	Mass per biomass; Field and lab	N/A	N/A	N/A	7,390 µg/g; 9,330 µg/g	Yilmaz et al. (2008)
Cylindrospermopsis	Mass per cell; Field and lab	0.0028 pg/cell – 0.17 pg/cell	0.047 pg/cell	0.027 pg/cell	0.0028 pg/cell[e]; 14.6 pg/cell	Hawkins et al. (2001); Orr et al. (2010); Carneiro et al. (2013); Mohamed and Al-Shehri (2013); Davis et al. (2014); Pierangelini et al. (2015); Willis et al. (2015); Willis et al. (2016); Yang et al. (2016a)
	Mass per cell; Field	0.023 pg/cell	0.023 pg/cell	N/A	0.006 pg/cell; 14.6 pg/cell	Orr et al. (2010); Mohamed and Al-Shehri (2013)
	Mass per cell; Lab	0.0028 pg/cell – 0.17 pg/cell	0.052 pg/cell	0.031 pg/cell	0.0028 pg/cell[e]; 0.17 pg/cell[e]	Hawkins et al. (2001); Carneiro et al. (2013); Davis et al. (2014); Pierangelini et al. (2015); Willis et al. (2015); Willis et al. (2016); Yang et al. (2016a)
	Mass per biovolume; Lab	N/A	N/A	N/A	416 fg/µm^3; 447 fg/µm^3	Pierangelini et al. (2015)

fg = femtogram; pg = picogram; µg = microgram; N/A = not available.

[a] Various methods were used to quantify toxin quotas and quota values were presented in different forms, including toxin mass per cyanobacterial cell and toxin mass per cyanobacterial biomass.

[b] Studies were conducted in two different settings: the field (i.e., environmental) or a laboratory.

[c] Study authors reported data using multiple measurement units. When possible, the EPA converted data to the standard units of pg per cell. The EPA did not identify appropriate conversion factors that would allow genus-specific conversion of quotas described in mass per biomass to mass per cell.

[d] Shows single reported mean if only one study was available or average of reported means.

[e] If reported toxin quota means from one study were the lowest or highest toxin quotas reported within a genus, then these values were listed as the minimum or maximum values, respectively, to better reflect the range of toxin quota values.

[f] *Cylindrospermopsis* is now known as *Raphidiopsis.*

Challenges with collating this information include the variable conditions under which the studies characterized toxin quotas and the various ways the toxin quota data were reported. Conditions under which the toxin quotas were studied include laboratory and field conditions, different environmental and collection-based strains included in the study, and the different environmental conditions existing at the various locations where the field studies were conducted. For the latter, information on some of the external factors affecting toxin production is summarized above to help demonstrate the complex interactions that affect not just if the toxin is produced, but also how much toxin can be produced. The various ways that toxin cell quotas were reported include: toxin mass per cell, toxin mass per unit biomass, and toxin mass per unit biovolume. When possible, the EPA converted the cell quota information into pg per cell to enable a straightforward comparison to the WHO value.

7.5.3.3 Toxigenic Cyanobacteria Value Associated with Recommended Microcystins Criteria/Swimming Advisory

As discussed in section 7.5.3.2 the abundance of toxigenic cells in a water body affects the amount of cyanotoxin produced. The number of toxigenic cyanobacteria relative to the number of total cyanobacteria can vary in time and space. Quantifying the abundance of toxigenic cyanobacteria is a better predictor of potential toxin production compared to total cyanobacteria. Below, the EPA presents a similar approach to that used by the WHO to calculate a cyanobacterial cell density corresponding to recommended criteria/ swimming advisory value for microcystins. Because more data are available for microcystins compared to cylindrospermopsin, this calculation is based on microcystins only.

$$\text{Cyanobacterial cell density (CCD)} = \frac{\text{Ambient cyanotoxin concentration (ACC)}}{\text{Cell toxin amount (CTA)}}$$

Where:

CCD	=	calculated toxigenic cell density associated with a specific toxin concentration
ACC	=	specific toxin concentration target in ambient water (e.g., AWQC value)
CTA	=	amount of toxin produced in a cyanobacterial cell

For the microcystins-producing cyanobacteria (e.g., *Microcystis*):

ACC	=	8 µg/L; recommended recreational criteria value for microcystins
CTA	=	0.2 pg/cell; reported mean concentration of microcystin in a cell of microcystin-producing cyanobacteria

Adding in the conversion factors to convert units, the equation is:

$$\text{CCD} = \frac{\text{ACC (µg/L)} \times 10^6 \text{ pg/µg}}{\text{CTA (0.2 pg/cell)}} \times \frac{\text{L}}{1000 \text{ mL}}$$

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Adding in the values,

$$\text{CCD} = \frac{8\ \mu\text{g/L} \times 10^6\ \text{pg/}\mu\text{g}}{0.2\ \text{pg/cell}} \times \frac{1\ \text{L}}{1000\ \text{mL}} = 40{,}000\ \text{cells/mL}$$

Thus, a toxigenic microcystin-producing cell density of 40,000 cells/mL has the potential to result in a microcystin concentration of 8 µg/L.

7.6 Other Sources of Microcystins and Cylindrospermopsin

Although the EPA is not including other sources of cyanotoxins in this recreational exposure scenario, the Agency has included summary information on potential sources of cyanotoxins, such as drinking water, ground water, fish, shellfish, dietary supplements, air, soil, and sediments. Exposure to cyanotoxins in finished drinking water is characterized in the Drinking Water Health Advisories (U.S. EPA 2015a, 2015b). States may wish to consider these other sources of cyanotoxins in their public health approach.

7.6.1 Drinking Water

The occurrence of cyanotoxins in drinking water depends on their levels in the raw source water and the effectiveness of treatment methods for removing cyanobacteria and cyanotoxins during the production of drinking water. The EPA has provided *Recommendations for Public Water Systems to Manage Cyanotoxins in Drinking Water* to assist public drinking water systems (PWSs) that choose to develop system-specific plans for evaluating their source waters for vulnerability to contamination by microcystins and cylindrospermopsin (U.S. EPA 2015e). Cyanotoxin management plan templates, water treatment optimization, and a communications tool box are also available on the EPA's Cyanotoxins in Drinking Water website (U.S. EPA 2015e).

The American Water Works Association Research Foundation (AWWARF) conducted a study on the occurrence of cyanobacterial toxins in source and treated drinking waters from 24 public water systems in the United States and Canada in 1996–1998 (AWWARF 2001). Of 677 samples tested, microcystins were found in 80 percent (539) of the waters sampled, including source and treated waters. Only two samples of finished drinking water were above 1 µg/L. A survey conducted in 2000 in Florida (Burns 2008) reported that microcystins were the most commonly found toxin in pre- and post-treated drinking water. Finished water concentrations ranged from below detection levels to 12.5 µg/L.

During the summer of 2003, a survey was conducted to test for microcystins in 33 U.S. drinking water treatment plants in the northeastern and midwestern United States (Haddix et al. 2007). Microcystins were detected at low levels ranging from undetectable (< 0.15 µg/L) to 0.36 µg/L in all 77 finished water samples.

In August 2014, the city of Toledo, Ohio, issued a do-not-drink or -boil advisory to nearly 500,000 customers in response to the presence of total microcystins in the city's finished drinking water at levels up to 2.50 µg/L. The presence of the toxins was due to a cyanobacterial bloom near Toledo's drinking water intake located on Lake Erie. The advisory was lifted two days later, after treatment adjustments led to the reduction of the cyanotoxin concentrations to concentrations below the WHO guideline value of 1 µg/L in all samples from the treatment plant and distribution system.

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During the late spring and early summer of 2018, both microcystins and cylindrospermopsin were found in the finished drinking water of Salem, Oregon (Novak Consulting Group 2018). Salem's finished drinking water source is the North Santiam River, which is fed by Detroit Lake, a reservoir located southeast of the city. In late May 2018, the State of Oregon issued a recreational advisory for cyanotoxins for Detroit Lake. Less than a week later, the City of Salem issued a do not drink advisory due to the presence of levels of microcystins and cylindrospermopsin in drinking water exceeding health advisories. The drinking water advisory was lifted in the beginning of July based on many consecutive days of finished water results being below health advisory levels.

The EPA has published Drinking Water Health Advisories to address microcystins and cylindrospermopsin in drinking water (U.S. EPA 2015a, 2015b).

7.6.2 Ground Water

Only very limited data are available on microcystins in ground water and no monitoring data were identified for cylindrospermopsin. A study reported microcystins in ground water from a well located near the shore of Lake Chaohu, in China (also known as Chao Lake), which contained high microcystin concentrations (Yang et al. 2016b). Therefore, under certain conditions, ground water hydraulically connected to surface water has the potential to be contaminated by cyanotoxins.

7.6.3 Fish and Shellfish

Fish and shellfish living in waters affected by a cyanobacterial bloom may accumulate cyanotoxins in their muscle tissue and internal organs (Gibble et al. 2016; Kinnear 2010). Some authors have found that microcystins accumulate less in the edible parts of aquatic organisms, such as muscle (Deblois et al. 2011; Gutiérrez-Praena et al. 2013; Song et al. 2009; Vareli et al. 2012; Wilson et al. 2008; Xie et al. 2005; Zimba et al. 2006). Cylindrospermopsin has also been found in fish and shellfish exposed for longer periods of time to a cyanobacterial bloom (Funari and Testai 2008; Ibelings and Chorus 2007; Kinnear 2010; Saker and Eaglesham 1999). For additional information on occurrence of microcystins and cylindrospermopsin in fish and shellfish, please see the Health Advisory document published (U.S. EPA 2015a, 2015b).

7.6.4 Dietary Supplements

Extracts from *Arthrospira* (Spirulina) and *Aphanizomenon flos-aquae* have been used as dietary blue-green algae supplements (BGAS) (Funari and Testai 2008). These supplements are reported to have beneficial health effects including supporting weight loss, and increasing alertness, energy and mood elevation for people suffering from depression (Jensen et al. 2001). A study suggested that BGAS could be contaminated with microcystins ranging from 1 μg/g up to 35 μg/g (Dietrich and Hoeger 2005). In two separate studies, Heussner et al. (2012) and Roy-Lachapelle et al. (2017) both analyzed 18 different commercially available BGAS for the presence of cyanotoxins. Heussner et al. (2012) reported that all products containing *Dolichospermum flos-aquae* (formerly *Aphanizomenon flos-aquae*) tested positive for microcystins at levels ≤ 1 μg microcystin-LR equivalents/g dry weight. Cylindrospermopsin was not found in any of the supplements. Roy-Lachapelle et al. (2017) reported that of the 14 products containing *Spirulina*, three contained total microcystins at levels ≤ 1 μg/g. All four products containing *Dolichospermum flos-aquae* tested positive for total microcystins ranging from 0.8 μg/g to 8.2 μg/g using the Adda oxidation method and from 0.52 μg/g to 5.8 μg/g using the sums of microcystins standards. Cylindrospermopsin was not found in any of the supplements.

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7.6.5 Ambient Air

Four studies provide air concentration data for cyanotoxins indicating that recreational surface waters with toxigenic cyanobacterial blooms can result in aerosolized cyanotoxins (Backer et al. 2008, 2010; Wood and Dietrich 2011; Cheng et al. 2007). These studies are summarized in section 7.4.1.

7.6.6 Soils and Sediments

Microcystins can adsorb onto naturally suspended solids and dried crusts of cyanobacteria. Cyanotoxins can precipitate out of the water column and reside in sediments for months (Falconer 1998; Han et al. 2012; Wu et al. 2012). In sediments, cylindrospermopsin adsorbs to organic carbon, with little adsorption observed in sandy and silt sediments (Klitzke et al. 2011). The low adsorption of cylindrospermopsin in sediments/silts with low levels of organic carbon reduces the opportunity for microbial degradation.

Maghsoudi et al. (2015) tested adsorption of cyanotoxins onto three fractionated sediment particles, clay-silt (< 75 μm), fine sand (75–315 um) and coarse sand (315–2000 μm) and found that adsorption capacity of coarse sand fraction for all the tested cyanotoxins was less than four percent of the clay-silt fraction. They found that highest adsorption for cylindrospermopsin, microcystin-LW, and microcystin-LF were 73, 57, and 55 percent, respectively, and occurred within two hours. Desorption experiments demonstrated that less than nine percent of cyanotoxins desorbed from sediment within 96 hours.

Song et al. (2015) found that a statistically significant part of the variability of the microcystin concentration in the sediments could be explained by a combination of variables in the water column, such as total microcystins in the water, cyanobacterial biomass in water, pH, and temperature.

7.7 Tribal Considerations

The EPA considered alternative exposure scenarios tribal communities might have, given their cultural practices. Native American food foraging customs or cultural or religious ceremonies can put them into primary or secondary contact with cyanotoxins. Primary contact ceremonial use may include the use of a surface water body for religious or traditional purposes by members of a tribe, involving immersion and intentional or incidental ingestion of water (Eastman 2007).

It is uncertain whether these activities would lead to cyanotoxin exposures higher than the primary recreational contact assumptions for incidental ingestion and exposure duration used in this assessment.

7.8 Livestock and Pet Concerns

The earliest observations of adverse effects of cyanobacterial exposure to animals include the rapid death of stock animals in Australia in 1878 (Francis 1878). Since then, numerous cases of mammal and bird deaths have been documented (Backer et al. 2015; Hilborn and Beasley 2015). These cases were reported throughout the 20th century on all continents except Antarctica (Stewart et al. 2008). The impacts of cyanotoxins on domestic and companion animals are likely under-recognized because many cases are misdiagnosed, few cases are biochemically confirmed, and even fewer are reported in the scientific literature or to animal health systems (Zaias et al. 2010).

Livestock and pets potentially can be exposed to higher concentrations of cyanotoxins, or have increased exposure to cyanotoxins than humans because they are known to consume cyanobacterial scum and mats

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and drink cyanobacteria-contaminated water (Backer et al. 2013). Dogs are also at risk, as they may lick cyanobacterial cells from their fur after swimming in a water body with an ongoing bloom (CDC 2017a). Mats and scums can represent thousand-fold to million-fold concentrations of cyanobacterial cell populations, and published microcystin concentrations have ranged up to 24 mg microcystins/L from scum material (Chorus and Bartram 1999). Common signs of HAB cyanotoxin poisonings in pets include repeated vomiting, diarrhea, loss of appetite, abdominal swelling, stumbling, seizures, convulsions, disorientation, inactivity, or skin rashes and hives, and in extreme cases collapse and sudden death (CDC 2017a; New York Sea Grant 2014; Trevino-Garrison et al. 2015). Although reports of livestock deaths are uncommon, in extreme cases, death can occur minutes after drinking from a contaminated water source. Acute symptoms of cyanotoxin poisoning can include loss of appetite, weakness, staggering, or inflammation of the muzzle, ear, or udder. Higher levels of cyanotoxins can lead to severe liver damage, the development of jaundice, and severe photosensitization. Often livestock or pets that recover from these ailments can then suffer from chronic failure to thrive (Australia Department of Economic Development Jobs Transport and Resources 2013; Robinson and Alex 1987).

The Centers for Disease Control and Prevention (CDC) provides multiple resources, such as frequently asked questions (FAQs), Veterinarian Cards, and Animal Safety Alerts, to help educate the public of the dangers associated with cyanotoxin exposure to pets (CDC 2017a, 2017b, 2017c). The CDC suggests that pet owners prevent their animals from playing in or drinking scummy water. If a dog has been swimming in scummy water, the CDC recommends rinsing them off immediately to prevent the dog from licking cyanobacteria off their fur (CDC 2017b).

The CDC recommends that pet owners contact a veterinarian if their animal shows the following symptoms of cyanotoxin poisoning: loss of appetite, loss of energy, vomiting, stumbling and falling, foaming at the mouth, diarrhea, convulsions, excessive drooling, tremors and seizures or any other unexplained sickness after being contacted with water (CDC 2017c). While there have been no HAB-associated human deaths in the United States, there have been many pet deaths (especially dogs) due to cyanotoxin exposure via swimming and ingesting contaminated waters. Overall, CDC encourages the public to follow the phrase “when in doubt, its best to keep out” (CDC 2017a).

The One Health Concept acknowledges a connection between human, animal, and environmental health, suggesting that HAB-associated animal illnesses and deaths could serve as predictors of potential HAB-associated risks in humans (CDC 2017d). Following this concept, the CDC created a voluntary reporting system called the One Health Harmful Algal Bloom System (OHHABS) (CDC 2017d). While there are other reporting systems that capture aggregate information on human illnesses or outbreaks, such as the National Outbreak Reporting System (NORS), OHHABS expands reporting to include HAB-associated environmental data, animal case data, and human case data (CDC 2017d). By collecting this information, the goal of OHHABS is to better understand HABs and HAB-associated illnesses. Members of the public can report HABs and cases of HAB-related human or animal illness by contacting local or state public health agencies (CDC 2017d).

The New York State Department of Health (NYSDOH) applied the One Health approach to implement a pilot surveillance system of HAB-related illnesses in 2015. During this pilot period, three dogs were reported to have GI symptoms after exposure to HABs in recreational water; one of these cases was also associated with a human case (Figgatt et al. 2017).

7.8.1 States and Animal HAB Guidelines

A few states have guideline levels specific to the protection of animals from cyanotoxin poisoning (Appendix H). California calculated cattle and dog action levels for the cyanotoxins microcystin and cylindrospermopsin (Butler et al. 2012). California first calculated an RfD (mg/kg body weight/day) for domestic animals for each of the cyanotoxins, based on laboratory studies. For both dogs and cattle, California estimated drinking water ingestion rates (L/kg body weight/day) based on two publications by the National Research Council, *Nutrient Requirements for Beef Cattle and Nutrient Requirements for Dogs and Cats*, and applied an UF of three to account for preferential consumption of cyanobacteria. To determine action levels (acute action level of 100 µg/L for microcystins and 200 µg/L for cylindrospermopsin), California divided the domestic animal RfD for each cyanotoxin by the final water and cyanobacterial biomass intake exposure levels calculated for cattle and dogs, and performed a unit conversion, providing a cyanotoxin concentration that would result in exposure at the RfD level or below. The state performed these calculations for an acute (lethal) and a subchronic scenario.

Oregon followed a similar approach to California's to calculate dog-specific guideline values for the cyanotoxins cylindrospermopsin, microcystin, anatoxin-a, and saxitoxin (Oregon Health Authority 2018). Oregon estimated tolerable daily intake (TDI) values for humans (µg/kg body weight/day) for each of the cyanotoxins, and applied these values to dogs (Farrer et al. 2015). Using California's dog-specific exposure estimate (L/kg body weight/day), Oregon divided the human TDI by the dog-specific ingestion rate to determine its guideline values (0.2 µg/L for microcystin and 0.4 µg/L for cylindrospermopsin).

Grayson County in Texas estimated the quantity of water that would result in a potentially lethal dose of microcystin and cylindrospermopsin for small and large dogs. Using advisory levels of 20 ppb for microcystin and cylindrospermopsin, the county calculated the volume of water that would result in a lethal or near-lethal dose of cyanotoxin by extrapolating the results of mouse studies to 10- and 80-pound dogs. This estimate does not include additional dose amounts that could be ingested by a dog while self-grooming cyanobacteria scum off its fur (Lillis et al. 2012).

At Presque Isle State Park in Pennsylvania, a HABs task force (a partnership of six agencies and organizations) monitors for microcystin and cylindrospermopsin at multiple locations on Lake Erie within the park. Some of the locations monitored include designated dog beaches. Warning signs are posted specifically for dog owners when microcystin levels are detected above 0.2 µg/L (Schnars personal communication 2017; Best personal communication 2017).

Other states mention animal poisoning in their guideline documents but do not give guideline values specific to livestock or companion animals. For example, Utah and Washington report that animal illness or death can be reason to issue or accelerate a HAB advisory warning (Hardy and Washington State Department of Health 2008; Utah Department of Environmental Quality and Department of Health 2017). Ohio includes pets in their public health advisory at threshold levels of 6 µg/L for microcystin and 5 µg/L for cylindrospermopsin; however, Ohio issues the disclaimer that thresholds used are protective of human exposure and may or may not be protective of animals such as dogs or livestock (Ohio EPA 2016). Several other states including Connecticut, Idaho, Kansas, Massachusetts, Nebraska, Vermont, and Virginia provide information via pamphlets and state websites warning about harm to pets or other animals or post about harm to animals in their beach warnings and advisory signage (CDPH 2017; CDEEP 2017; IDEQ 2015; Kansas Department of Health and Environment 2016; Massachusetts Bureau of Environmental Health 2015; Nebraska Department of Environmental Quality and Nebraska Department of Health and Human Services: Division of Public Health 2018; Vermont Department of Health 2015; Virginia Department of Health 2012).

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APPENDIX A. INTERNATIONAL RECREATIONAL WATER GUIDELINES FOR CYANOTOXINS AND CYANOBACTERIA

Jurisdiction	Recreational Water Guideline Level	Recommended Action
Australia[a]	Cyanobacteria (total): $\geq$ 10 mm^3/L (where known toxins are not present)	Red level action mode; level 2 guideline: • Immediately notify health authorities for advice on health risk. • Make toxicity assessment or toxin measurement of water if this has not already been done. • Health authorities warn of risk to public health (i.e., the authorities make a health risk assessment considering toxin monitoring data, sample type and variability).
	Cyanobacteria (total): $\geq$ 4 mm^3/L (where a known toxin producer is dominant in the total biovolume)	Red level action mode; level 1 guideline: • Immediately notify health authorities for advice on health risk. • Make toxicity assessment or toxin measurement of water if this has not already been done. • Health authorities warn of risk to public health (i.e., the authorities make a health risk assessment considering toxin monitoring data, sample type and variability).
	Cyanobacteria (total): $\geq$ 0.4 to < 10 mm^3/L (where known toxin producers are not present)	Amber level alert mode: • Increase sampling frequency to twice weekly where toxigenic species are dominant within the alert level definition (i.e., total biovolume). • Monitor weekly or fortnightly where other types are dominant. • Make regular visual inspections of water surface for scums. • Decide on requirement for toxicity assessment or toxin monitoring.
	Cyanobacteria (total): $\geq$ 0.4 to <4 mm^3/L (where a known toxin producer is dominant in the total biovolume)	Amber level alert mode: • Increase sampling frequency to twice weekly where toxigenic species are dominant within the alert level definition (i.e., total biovolume). • Monitor weekly or fortnightly where other types are dominant. • Make regular visual inspections of water surface for scums. • Decide on requirement for toxicity assessment or toxin monitoring.
	Cyanobacteria (total): $\geq$ 0.04 to <0.4 mm^3/L	Green level surveillance mode: • Weekly sampling and cell counts at representative locations in the water body where known toxigenic species are present; or • Fortnightly for other types including regular visual inspection of water surface for scums.
	Cyanobacterial scums consistently present	Red level action mode; level 2 guideline: • Immediately notify health authorities for advice on health risk. • Make toxicity assessment or toxin measurement of water if this has not already been done. • Health authorities warn of risk to public health (i.e., the authorities make a health risk assessment considering toxin monitoring data, sample type and variability).

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Jurisdiction	Recreational Water Guideline Level	Recommended Action
	Microcystins (total): ≥ 10 µg/L	Red level action mode; level 1 guideline: • Immediately notify health authorities for advice on health risk. • Make toxicity assessment or toxin measurement of water if this has not already been done. • Health authorities warn of risk to public health (i.e., the authorities make a health risk assessment considering toxin monitoring data, sample type and variability).
	Microcystis aeruginosa (total): ≥ 50,000 cells/ml	Red level action mode; level 1 guideline: • Immediately notify health authorities for advice on health risk. • Make toxicity assessment or toxin measurement of water if this has not already been done. • Health authorities warn of risk to public health (i.e., the authorities make a health risk assessment considering toxin monitoring data, sample type and variability).
	Microcystis aeruginosa (total): ≥ 5,000 to < 50,000 cells/ml	Amber level alert mode: • Increase sampling frequency to twice weekly where toxigenic species are dominant within the alert level definition (i.e., total biovolume). • Monitor weekly or fortnightly where other types are dominant. • Make regular visual inspections of water surface for scums. • Decide on requirement for toxicity assessment or toxin monitoring
	Microcystis aeruginosa (total): ≥ 500 to < 5,000 cells/ml	Green level surveillance mode: • Weekly sampling and cell counts at representative locations in the water body where known toxigenic species are present; or • Fortnightly for other types including regular visual inspection of water surface for scums.
Canada[d]	Cyanobacteria (total): ≥ 100,000 cells/ml	Issue swimming advisory.
	Detection of a cyanobacterial bloom	Issue beach closure.
	Microcystins (total): ≥ 20 µg/L (expressed as microcystin-LR)	Issue swimming advisory.
Cuba[c]	Any report of toxic effect in humans or animals	Action (in red): as for "Alert," but with increased actions for public communication.
	Benthic mats: < 40 percent coverage of surfaces with any cyanobacteria; > 20 percent with toxicogenic cyanobacteria; > 50 percent with potentially toxicogenic cyanobacteria	Alert: increased sampling (weekly and more sites); daily inspection; notification to public health unit and local managers; report to local government; warning of the public.

Jurisdiction	Recreational Water Guideline Level	Recommended Action
	(particularly where they are visibly detaching and accumulating in scum)	
	Cyanobacteria: < 500 cells/ml	Monthly visual inspection.
	Cyanobacteria: ≥ 1 of the species known as potentially toxic	Alert: increased sampling (weekly and more sites); daily inspection; notification to public health unit and local managers; report to local government; warning of the public.
	Phytoplankton cells: ≥ 20,000 to < 100,000 cells/ml, > 50 percent of cells cyanobacteria	Alert: increased sampling (weekly and more sites); daily inspection; notification to public health unit and local managers; report to local government; warning of the public.
	Phytoplankton: > 0 to < 1,500 cells/ml	Monthly visual inspection and sampling at least four months per year.
	Scum consistently present; confirmed bloom persistence	Action (in red): as for "Alert," but with increased actions for public communication.
Czech Republic[c]	Cells: > 100,000 cells/ml	Second warning level: closure for public recreation.
	Cells: > 20,000 cells/ml	First warning level (not otherwise specified).
Denmark[c]	Chlorophyll *a*: > 50 µg/L, dominated by cyanobacteria	Relevant authorities are informed and decide when and how the public should be informed; warnings include signs, media, and contact to local user groups such as kindergartens, scouts, water sports clubs.
	Visible surface scum	Relevant authorities are informed and decide when and how the public should be informed; warnings include signs, media, and contact to local user groups such as kindergartens, scouts, water sports clubs.
European Union[f]	Cyanobacterial proliferation (occurrence)	When cyanobacterial proliferation occurs and a health risk has been identified or presumed, adequate management measures shall be taken immediately to prevent exposure, including information to the public.
	Cyanobacterial proliferation (potential for)	Appropriate monitoring shall be carried out to enable timely identification of health risks.
Finland[c]	Algae (includes cyanobacteria): detected	Level 1: Possibly microscopic examination and even toxin analysis if there is a specific cause such as very popular beach or reports of adverse health effects or animal deaths.

Jurisdiction	Recreational Water Guideline Level	Recommended Action
	Algae (includes cyanobacteria): high amount	Level 2: Preferably microscopical examination; toxin analysis; warning of the public is compulsory.
	Algae (includes cyanobacteria): very high amount	Level 3: Preferably microscopical examination; toxin analysis; warning of the public is compulsory.
France[c]	Bloom, scum, change in water color	Microscopy examination. If cyanobacteria are absent: no further action. If present: counting and genus identification.
	Cyanobacteria: < 20,000 cells/ml (± 20 percent)	Active daily monitoring. Counting at least on a weekly basis. Normal recreational activity at the site.
	Cyanobacteria: > 100,000 cells/ml (± 20 percent)	Bathing and recreational activities are restricted. Public is informed.
	Cyanobacteria: ≥ 20,000 to < 100,000 cells/ml (± 20 percent)	Active daily monitoring. Counting on a weekly basis. Recreational activities are still allowed; the public is informed by posters on site.
	Microcystins: 25 µg/L (± 5 percent)	If microcystins < 25 µg/L bathing and recreational activities are restricted. If microcystins > 25 µg/L bathing is banned and recreational activities are restricted. In either case, public is informed.
	Visible scum or foam in recreational or bathing area	All water activities in this area are prohibited. Restrictions do not necessarily apply to the whole recreational site. Other areas without scum may still be open.
Germany[c]	Secchi Disk reading > 1 m AND biovolume: < 1 mm^3/L	Monitor further cyanobacterial development.
	Secchi Disk reading > 1 m AND biovolume: ≥ 1 mm^3/L	Publish warnings, discourage bathing, consider temporary closure.
	Secchi Disk reading > 1 m AND chlorophyll *a* (with dominance by cyanobacteria): < 40 µg/L	Monitor further cyanobacterial development.
	Secchi Disk reading > 1 m AND chlorophyll *a* (with dominance by cyanobacteria): ≥ 40 µg/L	Publish warnings, discourage bathing, consider temporary closure.

Jurisdiction	Recreational Water Guideline Level	Recommended Action
	Secchi Disk reading > 1 m AND microcystins: < 10 µg/L	Monitor further cyanobacterial development.
	Secchi Disk reading > 1 m AND microcystins: ≥ 10 µg/L	Publish warnings, discourage bathing, consider temporary closure.
	Visible heavy scums and/or microcystins: > 100 µg/L	Publish warnings, discourage bathing, temporary closure is recommended.
Hungary[c]	Cell count: ≥ 50,000 to < 100,000 cells/ml	No recommended actions listed, water body classification: Acceptable.
	Cell count: < 20,000 cells/ml	No recommended actions listed, water body classification: Excellent.
	Cell count: ≥ 20,000 to < 50,000 cells/ml	No recommended actions listed, water body classification: Good.
	Cell count: ≥ 100,000 cells/ml	No recommended actions listed, water body classification: Unacceptable.
	Chlorophyll *a* (with dominance by cyanobacteria): < 10 µg/L	No recommended actions listed, water body classification: Excellent.
	Chlorophyll *a* (with dominance by cyanobacteria): ≥ 10 to < 25 µg/L	No recommended actions listed, water body classification: Good.
	Chlorophyll *a* (with dominance by cyanobacteria): ≥ 25 to < 50 µg/L	No recommended actions listed, water body classification: Acceptable.
	Chlorophyll *a* (with dominance by cyanobacteria): ≥ 50 µg/L	No recommended actions listed, water body classification: Unacceptable.
	Microcystins: ≥ 4 to < 10 µg/L	No recommended actions listed, water body classification: Good.
	Microcystins: ≥ 10 to < 20 µg/L	No recommended actions listed, water body classification: Acceptable.
	Microcystins: < 4 µg/L	No recommended actions listed, water body classification: Excellent.
	Microcystins: ≥ 20 µg/L	No recommended actions listed, water body classification: Unacceptable.

Jurisdiction	Recreational Water Guideline Level	Recommended Action
Italy[i]	Cyanobacterial cell count for cyanotoxin-producing species other than microcystins (e.g., cylindrospermopsin, anatoxin-a) > 100,000 cells/ml (± 20 percent)	Emergency phase: weekly sampling and intensified visual inspection; quantification of all identified cyanotoxins; health surveillance; temporary bans on bathing and removal of scums from water and shoreline in addition to alert phase management measure.
	Cylindrospermopsin and anatoxin-a > 20 µg/L	Emergency phase: weekly sampling and intensified visual inspection; quantification of all identified cyanotoxins; health surveillance; temporary bans on bathing and removal of scums from water and shoreline in addition to alert phase management measures.
	Microcystin-LR: > 20 µg/L equivalents	Emergency phase: weekly sampling and intensified visual inspection; quantification of all identified cyanotoxins; health surveillance; temporary bans on bathing and removal of scums from water and shoreline in addition to alert phase management measures.
	Total cyanobacterial cell count > 20,000 cells/ml (± 20 percent) AND microcystin-LR < 20 µg/L equivalents	Alert phase: weekly sampling and visual inspection every 2 days; assessment of bloom extent and stretches of coastline affected; identify presence of cyanotoxins other than microcystins (when relevant); management measures put in place to inform citizens and prevent hazardous exposures using informative and warning panels/signs at waterfront and/or at beach access points, newsletters, brochures, publications on regional and national websites, local information systems, social network, and a Ministry toll-free number.
	Transparency ≥ 1 m AND total phosphorus < 20 µg/L	Routine phase 1: monthly sampling.
	Transparency ≥ 1 m AND total phosphorus > 20 µg/L AND total cyanobacterial cell count ≤ 2,000 cells/ml	Routine phase 2: monthly sampling and weekly visual inspection.
	Transparency ≤ 1 m AND total phosphorus > 20 µg/L AND total cyanobacterial cell count > 2,000 to < 20,000 cells/ml (± 20 percent)	Routine phase 3: fortnightly sampling and weekly visual inspection.
	Visible surface scum	Emergency phase: weekly sampling and intensified visual inspection; quantification of all identified cyanotoxins; health surveillance; temporary bans on bathing and removal of scums from water and shoreline in addition to alert phase management measures.
Netherlands[c]	Biovolume (cyanobacterial cell count): > 0 to < 2.5 mm^3/L	Surveillance level: continue fortnightly monitoring

Jurisdiction	Recreational Water Guideline Level	Recommended Action
	Biovolume (cyanobacterial cell count): > 15 mm^3/L (if 80 percent dominance of microcystin producers and microcystins < 20 µg/L, revert to Alert Level 1).	Alert level 2: weekly monitoring and advice against bathing (by public authority): "You are advised not to bathe in this water;" prohibition by local authority is possible.
	Biovolume (cyanobacterial cell count): ≥ 2.5 to ≤ 15 mm^3/L	Alert level 1: weekly monitoring and issue warning (by site operator) for duration of that week: "Toxic blue-green algae. Risk of skin irritation or intestinal problems." In case of daily site inspection, reevaluate the warning on a daily basis.
	Chlorophyll *a*: > 0 to < 12.5 µg/L	Surveillance level: continue fortnightly monitoring.
	Chlorophyll *a*: > 75 µg/L	Alert level 2: weekly monitoring and advice against bathing (by public authority): "You are advised not to bathe in this water;" prohibition by local authority is possible.
	Chlorophyll *a*: ≥ 12.5 to ≤ 75 µg/L	Alert level 1: weekly monitoring and issue warning (by site operator) for duration of that week: "Toxic blue-green algae. Risk of skin irritation or intestinal problems." In case of daily site inspection, reevaluate the warning on a daily basis.
	Surface scum: category 1	Surveillance level: continue fortnightly monitoring.
	Surface scum: category 2	Alert level 1: weekly monitoring and issue warning (by site operator) for duration of that week: "Toxic blue-green algae. Risk of skin irritation or intestinal problems." In case of daily site inspection, reevaluate the warning on a daily basis.
	Surface scum: category 3	Alert level 2: weekly monitoring and advice against bathing (by public authority): "You are advised not to bathe in this water"; prohibition by local authority is possible.
New Zealand[h]	Cyanobacteria (benthic): 20−50 percent coverage of potentially toxigenic cyanobacteria attached to substrate	Alert (amber mode): • Notify the public health unit. • Increase sampling to weekly. • Recommend erecting an information sign. • Consider increasing the number of survey sites. • If toxigenic cyanobacteria dominate the samples, testing for cyanotoxins is advised. If cyanotoxins are detected in mats or water samples, consult the testing laboratory to determine if levels are hazardous.
	Cyanobacteria (benthic): greater than 50 percent coverage of potentially toxigenic cyanobacteria attached to substrate	Action (red mode) situation 1: • Immediately notify the public health unit. • If potentially toxic taxa are present (see Table 2) then consider testing samples for cyanotoxins. • Notify the public of the potential risk to health.

Jurisdiction	Recreational Water Guideline Level	Recommended Action
	Cyanobacteria (benthic): Up to 20 percent coverage of potentially toxigenic cyanobacteria attached to substrate	Surveillance (green mode): • Undertake fortnightly surveys between spring and autumn at representative locations in the water body where known mat proliferations occur and where there is recreational use.
	Cyanobacteria (benthic): up to 50 percent where potentially toxigenic cyanobacteria are visibly detaching from the substrate, accumulating as scums along the river's edge or becoming exposed on the river's edge as the river level drops.	Action (red mode) situation 2: • Immediately notify the public health unit. • If potentially toxic taxa are present (see Table 2) then consider testing samples for cyanotoxins. • Notify the public of the potential risk to health.
	Cyanobacteria (total): < 0.5 mm^3/L (biovolume equivalent of the combined total of all cyanobacteria)	Surveillance (green mode): • Undertake weekly or fortnightly visual inspection and sampling of water bodies where cyanobacteria are known to proliferate between spring and autumn.
	Cyanobacteria (total): $\leq$ 500 cells/ml	Surveillance (green mode): • Undertake weekly or fortnightly visual inspection and sampling of water bodies where cyanobacteria are known to proliferate between spring and autumn.
	Cyanobacteria (total): $\geq$ 1.8 mm^3/L (biovolume equivalent of potentially toxic cyanobacteria)	Action (red mode) situation 1: • Continue monitoring as for alert (amber mode). • If potentially toxic taxa are present (see Table 1), then consider testing samples for cyanotoxins • Notify the public of a potential risk to health.
	Cyanobacteria (total): $\geq$ 0.5 to < 1.8 mm^3/L (biovolume equivalent of potentially toxic cyanobacteria)	Alert (amber mode): • Increase sampling frequency to at least weekly. • Notify the public health unit. • Multiple sites should be inspected and sampled.
	Cyanobacteria (total): $\geq$ 0.5 to < 10 mm^3/L (total biovolume of all cyanobacterial material where the cyanobacterial population has been tested and shown not to contain known toxins)	Alert (amber mode): • Increase sampling frequency to at least weekly. • Notify the public health unit. • Multiple sites should be inspected and sampled.
	Cyanobacteria (total): $\geq$ 10 mm^3/L (total biovolume of all cyanobacterial material	Action (red mode) situation 2:

Jurisdiction	Recreational Water Guideline Level	Recommended Action
	where the cyanobacterial population has been tested and shown not to contain known toxins)	• Continue monitoring as for alert (amber mode). • If potentially toxic taxa are present (see Table 1), then consider testing samples for cyanotoxins. • Notify the public of a potential risk to health.
	Cyanobacterial scums consistently present for more than several days in a row	Action (red mode) situation 3: • Continue monitoring as for alert (amber mode). • If potentially toxic taxa are present (see Table 1), then consider testing samples for cyanotoxins. • Notify the public of a potential risk to health.
	Microcystins (total): ≥ 12 µg/L	Action (red mode) situation 1: • Continue monitoring as for alert (amber mode). • If potentially toxic taxa are present (see Table 1), then consider testing samples for cyanotoxins. • Notify the public of a potential risk to health.
Poland[c]	Visible blooms	Sampling of bathing sites not less than 4 times per season (the interval between sampling does not exceed one month), including responses to cyanobacteria if blooms are observed.
Scotland[e]	Chlorophyll *a*: ≥ 10 µg/L with dominance of cyanobacteria	1. Watch for scum or conditions conducive to scums. 2. Discourage bathing and further investigate hazard. 3. Post on-site risk advisory signs. 4. Inform relevant authorities.
	Cyanobacteria: ≥ 20,000 cells /ml	1. Watch for scum or conditions conducive to scums. 2. Discourage bathing and further investigate hazard. 3. Post on-site risk advisory signs. 4. Inform relevant authorities.
	Cyanobacterial scum formation in bathing areas	1. Immediate action to control contact with scums; possible prohibition of swimming and other water contact activities. 2. Public health follow-up investigation. 3. Inform public and relevant authorities.
Singapore[c]	Chlorophyll *a*: ≤ 50 µg/L (of 95 percent of a 3-year rolling period)	Status of the sites reviewed annually. If the assessment is that the water body is unsuitable for primary water contact activities, the public is notified.
Spain[c]	Cyanobacteria proliferation potential (High, Medium, Low)	Criteria for assessment of health risk and response are set locally; some health authorities use WHO scheme, others include further risk parameters (such as number of users, type of use); temporary closure has occasionally occurred based on the abundance of cyanobacteria.

Jurisdiction	Recreational Water Guideline Level	Recommended Action
Turkey[c]	Cells: < 20,000 cells/ml	Level 1: recreational activities are allowed to continue and users are informed by posters on site. Monitoring (sampling, counting and species identification) should be done fortnightly.
	Cells: 20,000–100,000 cells/ml	Level 2: At > 20 000 cells/mL, microcystins are analyzed. If microcystin-LR equivalents >25 µg/L, immediate action to inform relevant authorities and public. Discourage users from swimming and other water contact activities by advisory signs on site.
	Chlorophyll *a* (if dominated by cyanobacteria): < 10 µg/L	Level 1: recreational activities are allowed to continue and users are informed by posters on site. Monitoring (sampling, counting and species identification) should be done fortnightly.
	Microcystin-LR: < 10 µg/L equivalents	Level 1: recreational activities are allowed to continue and users are informed by posters on site. Monitoring (sampling, counting and species identification) should be done fortnightly.
	Microcystin-LR: > 25 µg/L equivalents	Level 2: At > 20,000 cells/mL, microcystins are analyzed. If microcystin-LR equivalents >25 µg/L, immediate action to inform relevant authorities and public. Discourage users from swimming and other water contact activities by advisory signs on site.
	Visible scum in bathing area	Level 3: all activities in the water may be prohibited.
World Health Organization (WHO)[b,g]	Chlorophyll *a*: 10 µg/L with dominance of cyanobacteria	Low risk: post on-site advisory signs, inform relevant authorities.
	Chlorophyll *a*: 50 µg/L with dominance of cyanobacteria	Moderate risk: watch for scums or conditions conducive to scums, discourages swimming and further investigate hazard, post on-site risk advisory signs, inform relevant authorities.
	Cyanobacteria: 100,000 cells/ml	Moderate risk: watch for scums or conditions conducive to scums, discourages swimming and further investigate hazard, post on-site risk advisory signs, inform relevant authorities.
	Cyanobacteria: 20,000 cells/ml	Low risk: post on-site advisory signs, inform relevant authorities.
	Cyanobacterial scum formation in areas where whole-body contact and/or risk of ingestions/aspiration occur	High risk: immediate action to control contact with scums, possible prohibition of swimming and other water contact activities, public health follow-up investigation, inform public and relevant authorities.

[a] Australian Government National Health and Medical Research Council (2008). Guidelines for Managing Risk in Recreational Water.
[b] Chorus, I. and Bartram, J. (eds.) (1999). Toxic cyanobacteria in water: A guide to public health significance, monitoring and management. E. and F.N. Spon, Chapman, and Hall, London, United Kingdom.
[c] Federal Environment Agency (Germany) (2012). Current approaches to Cyanotoxin risk assessment, risk management and regulations in different countries.
[d] Health Canada (2012). Guidelines for Canadian Recreational Water Quality, Third Edition. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario. (Catalogue No H129-15/2012E).
[e] Scottish Government Health and Social Care Directorates Blue-Green Algae Working Group (2012). Cyanobacteria (Blue-Green Algae) in Inland and Inshore Waters:

Assessment and Minimization of Risks to Public Health.

[f] European Parliament and the Council of the European Union (2006). Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC.

[g] WHO (World Health Organization) (2003). Guidelines for Safe Recreational Water Environments: Volume 1: Coastal and Fresh Waters. World Health Organization.

[h] Wood, S; Hamilton, D; Safi, K; Williamson, W. (2008). New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters: Interim Guidelines. New Zealand Ministry for the Environment and Ministry of Health.

[i] Funari, W; Manganelli, M; Buratti, FM; Testai, E. (2017). Cyanobacteria blooms in water: Italian guidelines to assess and manage the risk associated to bathing and recreational activities. *Science of the Total Environment, 598*, 867-880.

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APPENDIX B. STATE RECREATIONAL WATER GUIDELINES FOR CYANOTOXINS AND CYANOBACTERIA

EPA compiled the information presented in this appendix based on searches of state websites for publicly available information regarding guidelines or action levels for cyanotoxins and cyanobacteria. Online searches for state guidance were conducted in 2015, 2016, and 2018. Direct personal communication of state guidelines and state public comments on the draft AWQC revealed some updated information.

Table B-1. Summary Counts of State Recreational Water Guidelines for Cyanotoxins and Cyanobacteria by Type and Scope of Guidelines

Recreational Water Guideline Type and Scope	Number of States and List of States	Additional Information
Quantitative guidelines for cyanobacteria only	5 states: Arizona, Idaho, Maine, New Hampshire, Wisconsin	Measurements for these criteria include cyanobacterial cell densities, proportion of toxigenic cyanobacteria, chlorophyll concentration, and Secchi disk depth measurements.
Quantitative guidelines for cyanotoxins only	4 states: Illinois, Iowa, Nebraska, Ohio	State guidelines address four cyanotoxins in order from most to least common: microcystins (24 states) anatoxin-a (11 states) cylindrospermopsin (9 states) saxitoxin (5 states)
Quantitative guidelines for cyanotoxins and either quantitative or qualitative guidelines for cyanobacteria	20 states: California, Colorado, Connecticut, Indiana, Kansas, Kentucky, Maryland, Massachusetts, Michigan, New Jersey, New York, North Dakota, Oklahoma, Oregon, Pennsylvania, Rhode Island, Utah, Vermont, Virginia, Washington	
Qualitative guidelines only	6 states: Delaware, Florida, Missouri, Montana, North Carolina, West Virginia	Examples include: presence of surface scum visible discoloration presence of potentially toxic algae presence/absence test for microcystins
Guidelines under development	4 states: Arkansas, Georgia, Minnesota, Wyoming	

Note: The EPA found that Texas and North Carolina published guidelines in the past, but the guidelines are no longer found on their websites. Missouri is in the process of developing quantitative thresholds.

Table B-2. State Recreational Water Quality Guideline for Cyanotoxins and Cyanobacteria Sorted by Type

State	Recreational Water Guideline Level	Recommended Action	Reference
States with Guidelines Based on Cyanobacteria Only			
Arizona	Blue-green algae (mean value based on a minimum of two sample events within one peak season): 20,000 cells/ml and Chlorophyll *a* result (mean value based on a minimum of two sample events within one peak season) in target range	Violation of the Narrative Nutrient Standard.	Arizona Department of Environmental Quality (2008). Narrative Nutrient Standard Implementation Procedures for Lakes and Reservoirs. http://www.azdeq.gov/environ/water/standards/download/draft_nutrient.pdf. Last Accessed: 11/27/2018.
Idaho	*Microcystis* or *Planktothrix*: >40,000 cells/ml	Public health advisory posting by Public Health District in conjunction with water body operator.	IDEQ (Idaho Department of Environmental Quality) (2015). Blue-Green Algae Bloom Response Plan: Final. http://www.healthandwelfare.idaho.gov/Portals/0/Health/EnvironmentalHealth/Idaho%20Blue-Green%20Algae%20Response%20PlanFinal.pdf. Last Accessed: 11/27/2018.
	Sum of all potentially toxigenic taxa: ≥ 100,000 cells/ml	Public health advisory posting by Public Health District in conjunction with water body operator.	
	Visible surface scum that is associated with toxigenic species	Public health advisory posting by Public Health District in conjunction with water body management agency.	

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State	Recreational Water Guideline Level	Recommended Action	Reference
Maine	Secchi disk reading < 2 meters caused by algae	Body of water considered impaired, but still safe to swim.	Maine Department of Environmental Protection (2013). Reports of Algal Blooms. http://www.maine.gov/dep/water/lakes/repbloom.html. Last Accessed: 11/27/2018.
New Hampshire	Cyanobacteria: > 50 percent of total cell counts from toxigenic cyanobacteria OR the cyanobacteria cell count is greater than 70,000 cells per ml of water	Post beach advisory.	New Hampshire Department of Environmental Services (2014). Beach Advisories. http://des.nh.gov/organization/divisions/water/wmb/beaches/advisories.htm. Last Accessed: 11/27/2018.
Wisconsin	Cyanobacteria: > 100,000 cells/ml	Post health advisory and possible beach closure.	Wisconsin Department of Natural Resources (2012). Draft Blue-Green Algae Section of 303 (d) Report – 7/3/2012: Harmful Algal Blooms. http://dnr.wi.gov/lakes/bluegreenalgae/documents/HarmfulAlgalBloomsvs2.pdf. Last Accessed: 11/27/2018. Wisconsin Department of Health Services (2016). Harmful Algal Blooms Toolkit: A Planning Guide for Public Health and Emergency Response Professionals. https://www.dhs.wisconsin.gov/publications/p0/p00853.pdf. Last Accessed: 11/27/2018.
	Visible scum layer	Post health advisory and possible beach closure.	Werner M, and Masnado R (2014). Guidance for Local Health Departments: Cyanobacteria and Human Health. http://city.milwaukee.gov/ImageLibrary/Groups/healthAuthors/DCP/PDFs/CyanobacteriaLHD.pdf. Last Accessed: 11/27/2018. Wisconsin Department of Health Services (2016). Harmful Algal Blooms Toolkit: A Planning Guide for Public Health and

State	Recreational Water Guideline Level	Recommended Action	Reference
			Emergency Response Professionals. https://www.dhs.wisconsin.gov/publications/p0/p00853.pdf. Last Accessed: 11/27/2018.
States with Guidelines Based on Cyanotoxin(s) Only			
Illinois	Microcystin-LR: > 10 µg/L	Appropriate lake management personnel and Illinois EPA staff will be notified; follow-up monitoring by the Illinois EPA may occur as professional judgment dictates and staff, laboratory, and financial resources allow.	Illinois Environmental Protection Agency (2013). 2013 Statewide Harmful Algal Bloom Program. https://www2.illinois.gov/epa/topics/water-quality/monitoring/algal-bloom/Pages/2013-program.aspx. Last Accessed: 11/27/2018. Illinois Environmental Protection Agency (2018). Blue-Green Algae and Harmful Algal Blooms. https://www2.illinois.gov/epa/topics/water-quality/monitoring/algal-bloom/Pages/default.aspx. Last Accessed: 12/5/2018.
Iowa	Microcystin: ≥ 20 µg/L	Warnings are posted at state park beaches.	Iowa Environmental Council (2018). Toxic Blue-Green Algae: A Threat to Iowa Beachgoers. http://www.iaenvironment.org/our-work/clean-water-and-land-stewardship/swimming-advisories. Last Accessed: 11/27/2018.
Nebraska	Microcystin: ≥ 20 µg/L	Health alert; signs posted advising public to use caution; affected swimming beaches will be closed; boating and other recreational activities will be allowed, but public advised to use caution and avoid prolonged exposure to the water.	Nebraska Department of Environmental Quality and Nebraska Department of Health and Human Services: Division of Public Health (2018). Fact Sheet: Precautions and facts regarding toxic algae at Nebraska Lakes.

State	Recreational Water Guideline Level	Recommended Action	Reference
			http://deq.ne.gov/NDEQProg.nsf/OnWeb/ENV042607. Last Accessed: 5/10/2019.
Ohio	Anatoxin-a: 300 µg/L	Issue no contact advisory.	Ohio EPA (2016). State of Ohio Harmful Algal Bloom Response Strategy For Recreational Waters. http://epa.ohio.gov/portals/35/hab/HABResponseStrategy.pdf. Last Accessed: 11/27/2018.
	Anatoxin-a: 80 µg/L	Issue recreational public health advisory.	
	Cylindrospermopsin: 20 µg/L	Issue no contact advisory.	
	Cylindrospermopsin: 5 µg/L	Issue recreational public health advisory.	
	Microcystins: 20 µg/L	Issue no contact advisory.	
	Microcystins: 6 µg/L	Issue recreational public health advisory.	
	Saxitoxin: 0.8 µg/L	Issue recreational public health advisory.	
	Saxitoxin: 3 µg/L	Issue no contact advisory.	
States with Guidelines Based on Cyanobacteria and Cyanotoxin(s)			
California	Anatoxin-a: detection using an analytical method that detects <1 µg/L	Caution trigger level: increase monitoring and post caution sign warning people to stay away from scum and warning people to keep pets and livestock away from water and scum.	Butler N, Carlisle J, Kaley KB, and Linville R (2012). Toxicological Summary and Suggested Action Levels to Reduce Potential Adverse Health Effects of Six Cyanotoxins. http://www.waterboards.ca.gov/water_issues/programs/peer_review/docs/calif_cyanotoxins/cyanotoxins053112.pdf. Last Accessed: 11/27/2018. Cyanobacteria Harmful Algal Bloom Network (2016a). Appendix to the CCHAB Preliminary Changes to the Statewide Voluntary Guidance of CyanoHABs in Recreational Waters.
	Anatoxin-a: 20 µg/L	Warning tier 1: post warning sign stating that swimming is not recommended and that pets and livestock should be kept away from the water.	
	Anatoxin-a: 90 µg/L	Danger tier 2: post sign stating that there is a present danger and that people, pets and livestock should stay out of the water and away from water spray.	
	Cylindrospermopsin: 1 µg/L	Caution trigger level: increase monitoring and post caution sign warning people to stay away from scum and warning people to keep pets and livestock away from water and scum.	

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State	Recreational Water Guideline Level	Recommended Action	Reference
	Cylindrospermopsin: 4 µg/L	Warning tier 1: post warning sign stating that swimming is not recommended and that pets and livestock should be kept away from the water.	http://www.mywaterquality.ca.gov/monitoring_council/cyanohab_network/docs/appendix_a.pdf. Last Accessed: 11/27/2018. Cyanobacteria Harmful Algal Bloom Network (2016b). Table 1: CyanoHAB trigger levels for human health. http://www.mywaterquality.ca.gov/monitoring_council/cyanohab_network/docs/triggers.pdf. Last Accessed: 11/27/2018.
	Cylindrospermopsin: 17 µg/L	Danger tier 2: post sign stating that there is a present danger and that people, pets and livestock should stay out of the water and away from water spray.	
	Microcystins: 0.8 µg/L	Caution trigger level: increase monitoring and post caution sign warning people to stay away from scum and warning people to keep pets and livestock away from water and scum.	
	Microcystins: 6 µg/L	Warning tier 1: post warning sign stating that swimming is not recommended and that pets and livestock should be kept away from the water.	
	Microcystins: 20 µg/L	Danger tier 2: post sign stating that there is a present danger and that people, pets and livestock should stay out of the water and away from water spray.	
	Site-specific indicators of cyanobacteria (e.g., blooms, scums, mats)	Caution trigger level: increase monitoring and post caution sign warning people to stay away from scum and warning people to keep pets and livestock away from water and scum.	
	Toxin-producing cyanobacteria: 4,000 cells/ml	Caution trigger level: increase monitoring and post caution sign warning people to stay away from scum and warning people to keep pets and livestock away from water and scum.	
Colorado	Anatoxin-a: ≥ 7 µg/L	Issue toxic algae caution: a. post sign with “caution” language. b. perform routine testing for toxin levels. bi. if test results are below caution thresholds, test at	Colorado Department of Public Health and Environment. Algae bloom risk-management toolkit for recreational waters.

State	Recreational Water Guideline Level	Recommended Action	Reference
		least once per week until algae visually subsides. bii. if test results are above caution thresholds, test at least twice per week until toxin levels are below caution thresholds for two consecutive tests. c. notify drinking water providers and county health department if toxin levels exceed the caution thresholds. d. toxic algae caution ends when there is no visual evidence of algae and toxin levels are non-detectable for two consecutive weeks. di. notify drinking water providers and county health department that bloom has ended. dii. remove "caution" sign.	https://www.colorado.gov/pacific/cdphe/harmful-algae-blooms . Last Accessed: 11/27/2018
	Cylindrospermopsin: ≥ 7 µg/L	Issue toxic algae caution: a. post sign with "caution" language. b. perform routine testing for toxin levels. bi. if test results are below caution thresholds, test at least once per week until algae visually subsides. bii. if test results are above caution thresholds, test at least twice per week until toxin levels are below caution thresholds for two consecutive tests. c. notify drinking water providers and county health department if toxin levels exceed the caution thresholds. d. toxic algae caution ends when there is no visual evidence of algae and toxin levels are non-detectable for two consecutive weeks. di. notify drinking water providers and county health department that bloom has ended. dii. remove "caution" sign.	
	Microcystin-LR: ≥ 10 µg/L and < 20 µg/L	Issue toxic algae caution: a. post sign with "caution" language. b. perform routine testing for toxin levels. bi. if test results are below caution thresholds, test at least once per week until algae visually subsides.	

State	Recreational Water Guideline Level	Recommended Action	Reference
		bii. if test results are above caution thresholds, test at least twice per week until toxin levels are below caution thresholds for two consecutive tests. c. notify drinking water providers and county health department if toxin levels exceed the caution thresholds. d. toxic algae caution ends when there is no visual evidence of algae and toxin levels are non-detectable for two consecutive weeks. di. notify drinking water providers and county health department that bloom has ended. dii. remove "caution" sign.	
	Microcystin-LR: ≥ 20 µg/L	Issue toxic algae warning: a. immediately post sign with "warning" language. b. take necessary steps to prevent contact with water in affected area for humans and pets. c. notify drinking water providers and county health department if toxin levels exceed warning thresholds. d. test at least twice per week until toxin levels are below warning thresholds for two consecutive tests. e. posting can be reduced to "caution" language when microcystin test results drop below the warning threshold and no new human illness or pet deaths have been reported for two consecutive weeks.	
	Saxitoxin: ≥ 4 µg/L	Issue toxic algae caution: a. post sign with "caution" language. b. perform routine testing for toxin levels. bi. if test results are below caution thresholds, test at least once per week until algae visually subsides. bii. if test results are above caution thresholds, test at least twice per week until toxin levels are below caution thresholds for two consecutive tests. c. notify drinking water providers and county health department if toxin levels exceed the caution thresholds.	

State	Recreational Water Guideline Level	Recommended Action	Reference
		d. toxic algae caution ends when there is no visual evidence of algae and toxin levels are non-detectable for two consecutive weeks. di. notify drinking water providers and county health department that bloom has ended. dii. remove "caution" sign.	
	Potentially toxic algae are visible	Issue toxic algae caution: a. post sign with "caution" language. b. perform routine testing for toxin levels. bi. if test results are below caution thresholds, test at least once per week until algae visually subsides. bii. if test results are above caution thresholds, test at least twice per week until toxin levels are below caution thresholds for two consecutive tests. c. notify drinking water providers and county health department if toxin levels exceed the caution thresholds. d. toxic algae caution ends when there is no visual evidence of algae and toxin levels are non-detectable for two consecutive weeks. di. notify drinking water providers and county health department that bloom has ended. dii. remove "caution" sign.	
Connecticut	Visual rank category 2: cyanobacteria present in low numbers; there are visible small accumulations but water is generally clear; OR blue-green algae cells > 20,000 cells/ml and < 100,000 cells/ml	Notify Connecticut Department of Public Health (CT DPH), Connecticut Department of Energy and Environmental Protection (CT DEEP); increase regular visual surveillance until conditions change; consider cautionary postings at public access points.	Connecticut Department of Public Health and Connecticut Department of Energy and Environmental Protection (CDPH and CDEEP) (2017). Guidance to Local Health Departments for Blue-Green Algae Blooms in Recreational Freshwaters. http://www.ct.gov/deep/lib/deep/water/water_quality_management/monitoringpubs/bluegreenalgaeblooms_guidanceforlhds_2017version.pdf. Last Accessed: 11/27/2018.
	Visual rank category 3: cyanobacteria present in high numbers; scums may or may not be present; water is discolored throughout; large areas affected; color assists to rule out sediment and other algae; OR blue-green algae cells > 100,000 cells/ml	Update/inform CTDPH and CTDEEP and expand risk communication efforts; collect samples for analysis and/or increase frequency of visual assessment; POSTED BEACH CLOSURE: if public has beach access, alert water users that a blue-green	

State	Recreational Water Guideline Level	Recommended Action	Reference
		algae bloom is present; POSTED ADVISORY: at other impacted access points.	Connecticut Department of Energy and Environmental Protection (CDEEP). (2017). Comment Letter Regarding Human Health Recreational Ambient Water Quality Criteria and/or Swimming Advisories for Microcystins and Cylindrospermopsin. March 20, 2017. Docket No. EPA-HQ-OW-2016-0715. https://www.regulations.gov/docket?D=EPA-HQ-OW-2016-0715. Last accessed: 11/27/2018.
	Anatoxin-a: 80 µg/L	Issue recreation advisory.	
Indiana	Blue-green algae: 100,000 cells/ml	Issue recreation advisory.	Indiana Department of Environmental Management (2018). Blue-Green Algae: Indiana Reservoir and Lake Update. http://www.in.gov/idem/algae/. Last Accessed: 11/27/2018.
	Cylindrospermopsin: 8 µg/L	Issue recreation advisory.	
	Microcystin-LR: 20 µg/L	Close beaches.	
	Microcystin-LR: 4 µg/L	Issue recreation advisory.	
	Cyanobacteria: ≥ 10,000,000 cells/ml	Recommended that all in-lake recreation cease and that picnic, camping and other public land activities adjacent to affected waters be closed.	
Kansas	Cyanobacteria: ≥ 250,000 cells/ml	Issue public health warning.	Kansas Department of Health and Environment (2015). Guidelines for Addressing Harmful Algal Blooms in Kansas Recreational Waters. http://www.kdheks.gov/algae-illness/download/HAB_policy.pdf. Last Accessed: 11/27/2018. Kansas Department of Health and Environment (2015). Harmful Algal Blooms (HABs): KDHE Agency Response Plan. http://www.kdheks.gov/algae-illness/download/HAB_response_plan.pdf. Last Accessed: 11/27/2018.
	Cyanobacteria: ≥ 80,000 and < 250,000 cells/ml	Issue public health watch.	
	Microcystin: ≥ 2,000 µg/L	Recommended that all in-lake recreation cease and that picnic, camping and other public land activities adjacent to affected waters be closed.	
	Microcystin: ≥ 20 µg/L	Issue public health warning.	
	Microcystin: ≥ 4 and < 20 µg/L	Issue public health watch.	
	Blue-green algae: > 100,000 cells/ml	Issue an HAB advisory.	

State	Recreational Water Guideline Level	Recommended Action	Reference
Kentucky	Microcystins: > 20 µg/L	Issue recreational use advisory.	Kentucky Department for Environmental Protection (2014). Harmful Algal Blooms: Background. http://water.ky.gov/waterquality/Documents/HAB_FACTs/HAB%20Background%20Fact%20Sheet.pdf. Last Accessed: 11/27/2018.
	Microcystis aeruginosa or other potential microcystin-producing blue-green algae > 40,000 cells/ml, and samples contain microcystins: > 10 ppb	Put up signs advising public of health risk, notify local press (through joint DHMH, DNR, MDE press release) and coordinate with local health department, place advisory information on DNR web site (Eyes on the Bay), Maryland Healthy Beaches web site if a swimming beach is affected, or other local web site. MDE will initiate emergency closure to shellfish harvesting if warranted, and coordinate with DNR Natural Resource Police.	Commonwealth of Kentucky: Department for Environmental Protection Division of Water (2015). Harmful Algal Blooms. http://water.ky.gov/waterquality/pages/HABS.aspx. Last Accessed: 11/27/2018.
Maryland	Presence of potentially toxic algae	Issue algae bloom beach alert.	Wazniak C personal communication. (2016). Regarding Maryland Department of Natural Resources Harmful Algal Bloom (HAB) Monitoring and Management SOP. Sent via email correspondence from Catherine Wazniak, Program Manager at the MD DNR, on February 22, 2016, to John Ravenscroft, U.S. EPA. Maryland Department of Natural Resources (2014). Harmful Algal Bloom Management in the Chesapeake and Coastal Bays. http://dnr.maryland.gov/waters/bay/Documents/HAB_Management.pdf. Last Accessed: 11/27/2018.
	Blue-green algae: > 50,000 cells/ml	Toxin testing of lysed cells should be done to ensure that guideline of 14 ppb is not exceeded.	

State	Recreational Water Guideline Level	Recommended Action	Reference
Massachusetts	Blue-green algae: > 70,000 cells/ml	Post an advisory against contact with the water.	Massachusetts Bureau of Environmental Health (2015). MDPH Guidelines for Cyanobacteria in Freshwater Recreational Water Bodies in Massachusetts. Boston, Massachusetts. http://www.mass.gov/eohhs/docs/dph/environmental/exposure/protocol-cyanobacteria.pdf. Last Accessed: 11/27/2018. Massachusetts Department of Public Health (2008). MDPH guidelines for cyanobacteria in freshwater recreational water bodies in Massachusetts. http://www.mass.gov/eohhs/docs/dph/environmental/exposure/protocol-cyanobacteria.pdf. Last Accessed: 11/27/2018.
	Microcystins: ≥ 14 µg/L	Post an advisory against contact with the water.	
	Visible cyanobacteria scum or mat is evident	MDPH recommends an immediate posting by the local health department, state agency, or relevant authority to advise against contact with the water body.	
	Microcystin: ≥20 micrograms per liter (µg/L)	Not reported.	
Michigan	Other algal toxins are at or above appropriate guidelines that have been reviewed by MDEQ-WRD	Not reported. Post advisory.	Michigan Department of Environmental Quality (2018). Algae (Harmful Algal Blooms) website http://www.michigan.gov/deq/0,4561,7-135-3313_3681_3686_3728-383630--,00.html. Last Accessed: 11/27/2018. Kohlhepp (2015) Harmful Algal Bloom Monitoring and Assessment in Michigan Waters. Michigan Department of Environmental Quality Water Resources Division. MI/DEQ/WRD-15/013. http://www.michigan.gov/documents/deq/wrd-swas-algae-HABsummary_551207_7.pdf. Last Accessed: 03/6/2018.
	Chlorophyll *a*: >30 µg/L and visible surface accumulations/scum are present, or cells are visible throughout the water column		
	Microcystins (as total including –LR and other detectable congeners): 3 µg/L		
New Jersey	Cylindrospermopsin: 8 µg/L	Post advisory.	

State	Recreational Water Guideline Level	Recommended Action	Reference
	Anatoxin-a: 27 µg/L	Post advisory.	New Jersey Department of Environmental Protection (2017). Cyanobacterial Harmful Algal Bloom (HAB) Freshwater Recreational Response Strategy. http://www.state.nj.us/dep/wms/bfbm/NJHABResponseStrategy.pdf. Last Accessed: 11/27/2018
	Cyanobacterial cell count: ≥ 20,000 cells/ml	Post advisory.	
	Visual indication of a bloom – receipt of a bloom report or digital photograph	Suspicious Bloom: DEC HABs Program staff determine if a bloom is Suspicious and whether collection of a sample is feasible or warranted.	
New York	Blue-green chlorophyll levels: ≥ 25 µg/L; OR Microscopic confirmation that majority of sample is cyanobacteria and present in bloom-like densities; OR only in absence of the previous criteria being met: microcystin ≥ 4 µg/L but less than 20 µg/L and accompanied by ancillary evidence of the presence or recent history of a bloom	Confirmed Bloom: Signs have been developed by NY State Department of Health for use at regulated swimming beaches when Local Health Department personnel or beach operators close beaches. Online summer notification provides weekly update on the number of HABs locations in New York is included in MakingWaves, the DEC email subscription.	New York State Department of Environmental Conservation (2017). Harmful Algal Blooms (HABs) Program Guide. http://www.dec.ny.gov/docs/water_pdf/habsprogramguide.pdf. Last Accessed: 11/27/2018.
	Microcystin ≥ 20 µg/L (shoreline samples only); OR microcystin ≥ 10 µg/L (open water samples only); OR known risk of exposure to anatoxin or another cyanotoxin, based on consult between DEC HABS Program and NYSDOH staff	Confirmed with High Toxins Bloom: Signs have been developed by NY State Department of Health for use at regulated swimming beaches when Local Health Department personnel or beach operators close beaches. Online summer notification provides weekly update on the number of HABs locations in New York is included in MakingWaves, the DEC email subscription.	
	Blue-green algae bloom is present AND microcystin-LR: < 10 µg/L	Issue advisory.	
North Dakota	Blue-green algae bloom is present over a significant portion of the lake AND microcystin-LR: ≥ 10 µg/L	Issue warning.	North Dakota Department of Health: Division of Water Quality (2016). Blue-green algae advisories and warnings.
	Cyanobacteria: 100,000 cell/ml	Issue advisory.	

State	Recreational Water Guideline Level	Recommended Action	Reference
			http://www.ndhealth.gov/wq/sw/habs/defaulthabs.htm. Last Accessed: 11/27/2018.
Oklahoma	Microcystin: > 20 µg/L	Issue advisory.	Oklahoma Legislature (2012). SB 259 Bill Summary. http://webserver1.lsb.state.ok.us/CF/2011-12%20SUPPORT%20DOCUMENTS/BILLSUM/House/SB259%20ccr%20a%20billsum.doc. Last Accessed: 11/27/2018.
	Anatoxin-a: ≥ 20 µg/L	Issue public health advisory.	
Oregon	Cylindrospermopsin: ≥ 20 µg/L	Issue public health advisory.	Oregon Health Authority (2018). Oregon Harmful Algae Bloom Surveillance (HABS) Program Public Health Advisory Guidelines: Harmful Algae Blooms in Freshwater Bodies. https://www.oregon.gov/oha/ph/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Documents/HABPublicHealthAdvisoryGuidelines.pdf. Last Accessed: 11/27/2018.
	Microcystin: ≥ 10 µg/L	Issue public health advisory.	
	Microcystis: > 40,000 cells/ml	Issue public health advisory.	
	Planktothrix: > 40,000 cells/ml	Issue public health advisory.	
	Saxitoxin: ≥ 10 µg/L	Issue public health advisory.	
	Toxigenic species: > 100,000 cells/ml	Issue public health advisory.	
	Visible scum with documentation and testing	Issue public health advisory.	
	Microcystin: > 6 µg/L	Recreational Public Health Advisory.	
Pennsylvania	Microcystin: > 20 µg/L	Recreational No Contact Advisory.	Pennsylvania Department of Environmental Protection (2014). Lake Erie Harmful Algal Bloom Monitoring and Response Strategy for Recreational Waters. https://seagrant.psu.edu/sites/default/files/PA%20Lake%20Erie%20Harmful%20Algal%20Bloom%20Response%20Strategy%20For%20Recreational%20Waters%20-%202nd%20Draft.pdf. Last Accessed: 11/27/2018.
	Cylindrospermopsin: > 5 µg/L	Recreational Public Health Advisory.	
	Cylindrospermopsin: > 20 µg/L	Recreational No Contact Advisory.	
	Anatoxin-a: > 80 µg/L	Recreational Public Health Advisory.	
	Anatoxin-a: > 300 µg/L	Recreational No Contact Advisory.	
	Saxitoxin: > 0.8 µg/L	Recreational Public Health Advisory.	
	Saxitoxin: > 3 µg/L	Recreational No Contact Advisory.	

State	Recreational Water Guideline Level	Recommended Action	Reference
	HAB verified by visual observation	Recreational no contact advisory.	
	Cyanobacteria: > 70,000 cells/ml	Issue health advisory.	
Rhode Island	Microcystin-LR: ≥ 14 µg/L	Issue health advisory.	Rhode Island Department of Environmental Management, and Rhode Island Department of Health (2013). Cyanobacteria Related Public Health Advisories in Rhode Island. http://www.health.ri.gov/publications/datareports/2013CyanobacteriaBloomsInRhodeIsland.pdf. Last Accessed: 11/27/2018.
	Visible cyanobacteria scum or mat	Issue health advisory.	
	Anatoxin-a: detection 90 µg/L	Tier 2: Warning: Issue WARNING advisory, Post WARNING signs, sampling recommended weekly.	
Utah	Anatoxin-a: > 90 µg/L	Tier 3: Danger: Issue DANGER advisory, Post DANGER signs, consider CLOSURE, sampling recommended at least weekly.	Utah Department of Environmental Quality and Department of Health (2017). Utah HAB Guidance Summary. http://health.utah.gov/enviroepi/appletree/HAB/HAB_Guidance_Summary_2017.pdf . Last Accessed: 11/27/2018.
	Cyanobacteria: 20,000 – 10,000,000 cells/ml	Tier 2: Warning: Issue WARNING advisory, Post WARNING signs, sampling recommended weekly.	
	Cyanobacteria: >10,000,000 cells/ml	Tier 3: Danger: Issue DANGER advisory, Post DANGER signs, consider CLOSURE, sampling recommended at least weekly.	
	Microcystin: 4 – 2,000 µg/L	Tier 2: Warning: Issue WARNING advisory, Post WARNING signs, sampling recommended weekly.	
	Microcystin: > 2,000 µg/L	Tier 3: Danger: Issue DANGER advisory, Post DANGER signs, consider CLOSURE, sampling recommended at least weekly.	
	Cylindrospermopsin: > 8 µg/L	Tier 2 or 3: Consult with Utah Department of Environmental Quality and Utah Department of Health as needed on this issue.	
	Reports of animal illnesses or death	Tier 2: Warning: Issue WARNING advisory, Post WARNING signs, sampling recommended weekly.	

State	Recreational Water Guideline Level	Recommended Action	Reference
	Reports of human illness	Tier 3: Danger: Issue DANGER advisory, Post DANGER signs, consider CLOSURE, sampling recommended at least weekly.	
	Anatoxin-a: ≥ 10 µg/L	Close recreational beaches.	
Vermont	Cylindrospermopsin: ≥ 10 µg/L	Close recreational beaches.	Vermont Department of Health (2015). Cyanobacteria (Blue-green Algae) Guidance for Vermont Communities. http://www.healthvermont.gov/sites/default/files/documents/2016/12/ENV_RW_CyanobacteriaGuidance.pdf. Last Accessed: 11/27/2018.
	Microcystin-LR (equivalents): ≥ 6 µg/L	Close recreational beaches.	
	Visible known blue-green algae bloom/scum or an unknown, potentially blue-green algae (i.e., not pollen), bloom/scum	Close recreational beaches.	
	Blue-green algal "scum" or "mats" on water surface	Immediate public notification to avoid all recreational water contact where bloom is present; continue weekly sampling.	
Virginia	Microcystin: > 6 µg/L	Immediate public notification to avoid all recreational water contact where bloom is present; continue weekly sampling.	Virginia Department of Health (Division of Environmental Epidemiology) (2012). Virginia Recreational Water Guidance for Microcystin and *Microcystis* Blooms: Provisional Guidance. http://www.vdh.virginia.gov/content/uploads/sites/12/2016/02/VDHMicrocystisGuidance.pdf. Last Accessed: 11/27/2018.
	Microcystis: > 100,000 cells /ml	Immediate public notification to avoid all recreational water contact where bloom is present; continue weekly sampling.	
	Microcystis: 20,000 to 100,000 cells/ml	Notify public through press release and/or signage; advise people and pet owners that harmful algae are present; initiate weekly water sampling.	
	Microcystis: 5,000 to < 20,000 cells/ml	Local agency notification; initiate bi-weekly water sampling.	
	Anatoxin-a: 1 µg/L	Tier 2: local health posts WARNING sign; local health takes additional site-specific steps; minimum weekly sampling. In addition, if history of high toxicity, or reports of illness, pet death than tier 3: local health posts DANGER sign; lake closed.	

State	Recreational Water Guideline Level	Recommended Action	Reference
Washington	Bloom is forming or a bloom scum is visible (toxic algae may be present); toxin levels do not exceed thresholds	Tier 1: local health posts CAUTION sign; samples taken and sent for toxicity tests; weekly sampling until bloom dissipates.	Hardy J, and Washington State Department of Health (2008). Washington State Recreational Guidance for Microcystins (Provisional) and Anatoxin-a (Interim/Provisional). http://www.doh.wa.gov/Portals/1/Documents/4400/334-177-recguide.pdf. Last Accessed: 11/27/2018.
	Cylindrospermopsin: 4.5 µg/L	Tier 2: local health posts WARNING sign; local health takes additional site-specific steps; minimum weekly sampling. In addition, if history of high toxicity, or reports of illness, pet death than tier 3: local health posts DANGER sign; lake closed.	Hardy J, and Washington State Department of Health (2011). Washington State Provisional Recreational Guidance for Cylindrospermopsin and Saxitoxin. http://www.doh.wa.gov/portals/1/documents/4400/332-118-cylindrosax%20report.pdf. Last Accessed: 11/27/2018.
	Microcystins: 6 µg/L	Tier 2: local health posts WARNING sign; local health takes additional site-specific steps; minimum weekly sampling. In addition, if history of high toxicity, or reports of illness, pet death than tier 3: local health posts DANGER sign; lake closed.	
	Saxitoxin: 75 µg/L	Tier 2: local health posts WARNING sign; local health takes additional site-specific steps; minimum weekly sampling. In addition, if history of high toxicity, or reports of illness, pet death than tier 3: local health posts DANGER sign; lake closed.	Hardy J, and Washington State Department of Health (2008). Washington State Recreational Guidance for Microcystins (Provisional) and Anatoxin-a (Interim/Provisional). http://www.doh.wa.gov/Portals/1/Documents/4400/334-177-recguide.pdf. Last Accessed: 11/27/2018.
	Saxitoxin: 75 µg/L	Tier 2: local health posts WARNING sign; local health takes additional site-specific steps; minimum weekly sampling. In addition, if history of high	Hardy J, and Washington State Department of Health (2011). Washington State Provisional Recreational Guidance for Cylindrospermopsin and Saxitoxin.

State	Recreational Water Guideline Level	Recommended Action	Reference
		toxicity, or reports of illness, pet death than tier 3: local health posts DANGER sign; lake closed.	http://www.doh.wa.gov/portals/1/documents/4400/332-118-cylindrosax%20report.pdf. Last Accessed: 11/27/2018.
States with Qualitative Guidelines Only			
Delaware	Thick green, white, or red scum on surface of pond	Post water advisory signs.	Delaware Department of Natural Resources and Environmental Control: Division of Water. Blue-Green Algae in Delaware. (2016). http://www.dnrec.delaware.gov/wr/INFORMATION/OTHERINFO/Pages/Blue-GreenAlgae.aspx. Last Accessed: 11/27/2018.
Florida	Cyanobacteria bloom	Issue health advisory; post warning signs.	Florida Department of Environmental Protection (2019). Freshwater Algal Blooms: Frequently Asked Questions. https://floridadep.gov/sites/default/files/freshwater-algal-bloom-faqs_2019.pdf Last Accessed: 5/10/2019.
Missouri	Microcystins: presence (test strip range 0 to 10 ng/ml) Cylindrospermopsin: presence (test strip range 0 to 10 ng/ml) Anatoxin-a: presence (test strip range 0 to 2.5 ng/ml)	Missouri has a multi-agency proactive approach to address events which can result in the decision to temporary close swim beaches and post notices regarding the bloom around the lake to protect the citizens of Missouri from the health risk posed by exposure to a HAB. Information is also released to through the news media and social media to quickly share the possible health risk with the largest audience possible.	Missouri Department of Natural Resources (2017) Qualitative screening of algal toxins in drinking water and recreational waters using strip test by Abraxas, Inc. https://dnr.mo.gov/env/docs/mdnresp360.pdf. Last Accessed: 11/27/2018. Missouri Department of Natural Resources (2018) Harmful Algal Blooms and Blue-Green Algae. Website https://dnr.mo.gov/env/cyanobacteria.htm. and http://ephtn.dhss.mo.gov/EPHTN_Data_Portal/pdf/success-stories/MO-Blue-Green-

State	Recreational Water Guideline Level	Recommended Action	Reference
			Algae-Task-Force-Establishment.pdf Last Accessed: 11/27/2018.
Montana	Reservoirs that seem stagnated and harbor large quantities of algae	The Montana Department of Environmental Quality advises people to avoid swimming in ponds, lakes, or reservoirs.	State of Montana Newsroom (2015). DEQ Issues Advisory on Blue-Green Algae Blooms: Ponds, Lakes, and Reservoirs Most Often Affected. http://news.mt.gov/Home/ArtMID/24469/ArticleID/1564/DEQ-Issues-Advisory-on-Blue-Green-Algae-Blooms. Last Accessed: 11/27/2018.
North Carolina	Visible discoloration or surface scum	Microcystin testing.	North Carolina Health and Human Services: Division of Public Health (2014). Occupational and Environmental Epidemiology: Cyanobacteria (Blue-green Algae). http://epi.publichealth.nc.gov/oee/a_z/algae.html. Last Accessed: 11/27/2018.
West Virginia	Blue-green algal blooms observed and monitored	Issue public health advisory.	West Virginia Department of Health and Human Resources (2015). DHHR Continuing to Monitor Blue-Green Algal Blooms on the Ohio River: Residents Advised to Adhere to Public Health Advisory. http://www.dhhr.wv.gov/News/2015/Pages/DHHR-Continuing-to-Monitor-Blue-Green-Algal-Blooms-on-the-Ohio-River%3B-Residents-Advised-to-Adhere-to-Public-Health-Advisory.aspx. Last Accessed: 11/27/2018.
States with Guidelines Under Development			
Arkansas	TBD	TBD	Arkansas Beautiful Buffalo River Action Committee (2018). https://bbrac.arkansas.gov/pdfs/201701205

State	Recreational Water Guideline Level	Recommended Action	Reference
			-arkansas-harmful-algal-bloom-(habs)-workgroup.pdf. Last Accessed: 11/27/2018.
Georgia	TBD	TBD	Georgia Department of Public Health (2018). https://www.gachd.org/programs-services/environmental-health-2/beach_water_testing/. Last Accessed: 03/6/2018.
Minnesota	TBD	TBD	Minnesota Department of Health (2015). Toxicological Summary for: Microcystin-LR. http://www.health.state.mn.us/divs/eh/risk/guidance/gw/microcystin.pdf. Last Accessed: 11/27/2018.
Wyoming	TBD	TBD	Wyoming Department of Environmental Quality (2018). Harmful Algal Bloom Website. http://deq.wyoming.gov/wqd/nutrient-pollution/resources/harmful-algal-blooms/. Last Accessed: 11/27/2018.

Note: Alabama, Alaska, Hawaii, Louisiana, Mississippi, Nevada, New Mexico, South Carolina, South Dakota, Tennessee, and Texas did not have guidelines available online. Missouri is in the process of developing quantitative thresholds.

APPENDIX C. LITERATURE SEARCH DOCUMENTATION

The recreational ambient water quality criteria (AWQC) or swimming advisories document for microcystins and cylindrospermopsin relied significantly on information identified, reviewed, and synthesized in the EPA's *Health Effects Support Document for the Cyanobacterial Toxin Microcystins*, *Heath Effects Support Document for the Cyanobacterial Toxin Cylindrospermopsin*, *Drinking Water Health Advisory for the Cyanobacterial Microcystin Toxins*, and *Drinking Water Health Advisory for the Cyanobacterial Toxin Cylindrospermopsin* (U.S. EPA 2015c, 2015d, 2015a, 2015b). The EPA conducted supplemental literature searches to answer additional questions related to recreational exposures, exposure factors, and to identify new health data.

For the Health Effects Support Documents (HESDs), the EPA conducted a comprehensive literature search from January 2013 to May 2014 using Toxicology Literature Online (TOXLINE), PubMed, and Google Scholar. The EPA assembled available information on occurrence; environmental fate; mechanisms of toxicity; acute, short-term, subchronic, and chronic toxicity and cancer in humans and animals; and toxicokinetics and exposure. For a detailed description of the literature review search and strategy, see the HESDs for microcystins and cylindrospermopsin (U.S. EPA 2015c, 2015d).

The EPA conducted supplemental literature searches in September 2015 to capture references published since the completion of the HESDs' literature searches and to account for the recreational exposure scenario. The specific questions investigated include:

1. What levels of anatoxin-a, cylindrospermopsin, or microcystins are humans—of all ages, including children—exposed to through recreational use (activities) in freshwaters or marine waters from incidental ingestion, inhalation, and dermal exposure routes?
2 What health effects information for humans or animals exposed to cylindrospermopsin or microcystins (through ingestion, inhalation, and dermal exposure routes) has been published since the health effects literature searches were conducted for the EPA's 2015 HESDs for cylindrospermopsin and microcystins?
3. What recreational water use safety levels or criteria have been set for microcystins or cylindrospermopsin by states or international governments, and how did they derive them?
4. What new information, if any, is available regarding how aquatic recreational exposure ingestion rates in children differ among age groups between zero and 18 years?
5. What incidents of companion animal (e.g., dogs, horses) or livestock poisonings, including mortality or adverse health effects, due to exposure to cyanotoxins in freshwaters, marine waters, or beaches have occurred in the past 15 years? Specifically, when and where did these incidents occur, to which cyanotoxin were the animals exposed, how were they exposed, and what were the weights and breeds of the affected animal(s)?

The EPA implemented a unique literature search strategy to address each research question. Trial searches were conducted, and results were evaluated to refine the search strategies (e.g., to reduce retrieval of citations unrelated to the research questions). The search strings were refined to improve the relevancy of the results. The literature search strategies implemented for each research question are subsequently detailed.

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Research Question 1: What levels of anatoxin-a, cylindrospermopsin, or microcystins are humans—of all ages, including children—exposed to through recreational use (activities) in freshwaters or marine waters, from incidental ingestion, inhalation, and dermal exposure routes?

The EPA searched the bibliographic databases, PubMed and Web of Science (WoS), to identify candidate journal article literature relevant to human exposure to anatoxin-a, cylindrospermopsin, or microcystins through recreational activities. PubMed and WoS contain peer-reviewed journal abstracts and articles on various biological, medical, public health, and chemical topics. The WoS search string differs slightly from the PubMed search string due to how the search engines treat search terms with more than one word. Both search strings are presented below.

Results

The searches returned 321 journal articles after removing duplicates between PubMed and WoS results. Based on a screening review of each article's title and abstract, the EPA retrieved nine articles that appeared to be studies that measured, reviewed, or estimated human recreational exposure to cyanotoxins.

PubMed Search:

("*A. lemmermannii Raphidiopsis mediterranea*" OR *Anabaena flos-aquae* OR *flos-aquae* OR anatoxin-a OR *Aphanizomenon* OR cylindrospermopsin OR "*C. raciborskii*" OR *Cuspidothrix* OR *Cylindrospermopsis* OR *Cylindrospermum* OR "*Cylindrospermopsis raciborskii*" OR *Dolichospermum* OR "*M. aeruginosa*" OR *Microcystis* OR microcystin OR microcystins OR *Oscillatoria* OR *Planktothrix* OR *Phormidium* OR *Tychonema* OR *Woronichinia*)

AND

("boogie board" OR "boogie boarding" OR "jet ski" OR "jet skier" OR "jet skiers" OR "jet skiing" OR "water ski" OR "water skier" OR "water skiers" OR "water skiing" OR aerosol OR boat OR boating OR boats OR bodyboard OR bodyboarding OR canoe OR canoeing OR canoes OR capsize OR capsized OR dermal OR inhalation OR inhale OR kayak OR kayaker OR kayaking OR kayaks OR kneeboard OR kneeboarding OR paddle OR paddling OR raft OR rafting OR rafts OR recreation OR recreational OR rowing OR skin OR surf OR surfer OR surfing OR swim OR swimmer OR swimmers OR swimming OR tubing OR wading OR wakeboarding OR wakeboard)

AND

("marine water" OR "surface water" OR beach OR beaches OR estuaries OR estuarine OR estuary OR "fresh water" OR freshwater OR lake OR lakes OR ocean OR oceans OR pond OR ponds OR reservoir OR reservoirs OR river OR rivers OR sea OR stream OR streams OR water)

Filters: English
Date search was conducted: 10/9/2015
Publication dates searched: 1/1/1995 – 10/9/2015

Web of Science Search:

("*lemmermannii Raphidiopsis mediterranea*" OR *Anabaena flos-aquae* OR *flos-aquae* OR anatoxin OR *Aphanizomenon* OR cylindrospermopsin OR "*C. raciborskii*" OR *Cuspidothrix* OR *Cylindrospermopsis* OR *Cylindrospermum* OR "*Cylindrospermopsis raciborskii*" OR *Dolichospermum* OR "*M. aeruginosa*"

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OR *Microcystis* OR microcystin OR microcystins OR *Oscillatoria* OR *Planktothrix* OR *Phormidium* OR *Tychonema* OR *Woronichinia*)

AND

("boogie board" OR "boogie boarding" OR "jet ski" OR "jet skier" OR "jet skiers" OR "jet skiing" OR "water ski" OR "water skier" OR "water skiers" OR "water skiing" OR aerosol OR boat OR boating OR boats OR bodyboard OR bodyboarding OR canoe OR canoeing OR canoes OR capsize OR capsized OR dermal OR inhalation OR inhale OR kayak OR kayaker OR kayaking OR kayaks OR kneeboard OR kneeboarding OR paddle OR paddling OR raft OR rafting OR rafts OR recreation OR recreational OR rowing OR skin OR surf OR surfer OR surfing OR swim OR swimmer OR swimmers OR swimming OR tubing OR wading OR wakeboarding OR wakeboard)

AND

("marine water" OR "surface water" OR beach OR Beaches OR estuaries OR estuarine OR estuary OR "fresh water" OR freshwater OR lake OR lakes OR ocean OR oceans OR pond OR ponds OR reservoir OR reservoirs OR river OR rivers OR sea OR stream OR streams OR water)

Filters: English
Date search was conducted: 10/9/2015
Publication dates searched: 1/1/1995–10/9/2015

C.1 Research Question 2: What health effects information for humans or animals exposed to microcystins, cylindrospermopsin, or anatoxin-a (through ingestion, inhalation, and dermal exposure routes) has been published since the health effects literature searches were conducted for the EPA's 2015 HESDs for Cylindrospermopsin and Microcystins?

The EPA searched PubMed and WoS to identify candidate journal article literature relevant to health effects associated with exposure to anatoxin-a, cylindrospermopsin, or microcystins. The WoS search string differs slightly from the PubMed search string due to how the search engines treat search terms with more than one word. Both search strings are presented below.

Results

The searches returned 1,000 journal articles after removing duplicates between PubMed and WoS results. Based on a screening review of each article's title and abstract, the EPA retrieved 40 articles that appeared to be prospective human epidemiological studies (n = 1), ecological human epidemiologic studies (n = 2), reviews of human health effects (n = 4), in vivo animal studies (n = 30), or reviews of in vivo animal studies (n = 3).

PubMed Search:

("*A. lemmermannii Raphidiopsis mediterranea*" OR *Anabaena flos-aquae* OR *flos-aquae* OR anatoxin-a OR *Aphanizomenon* OR cylindrospermopsin OR "*C. raciborskii*" OR *Cuspidothrix* OR *Cylindrospermopsis* OR *Cylindrospermum* OR "*Cylindrospermopsis raciborskii*" OR *Dolichospermum* OR "*M. aeruginosa*" OR *Microcystis* OR microcystin OR microcystins OR *Oscillatoria* OR *Planktothrix* OR *Phormidium* OR *Tychonema* OR *Woronichinia*)

AND

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("non cancer" OR "blurred vision" OR "cell damage" OR "cellular damage" OR "health effect" OR "health endpoint" OR "health outcome" OR "health risk" OR "loss of protein" OR "loss of water" OR "micronucleated binucleate cell" OR abdominal pain OR ache OR acute OR alanine aminotransferase OR allergic OR allergies OR allergy OR aspartate aminotransferase OR blister OR blistered OR blisters OR cancer OR carcinogen OR carcinogenic OR carcinogens OR chronic OR clinical OR cough OR dermal OR detoxification OR detoxify OR develop OR development OR developmental OR dialysis OR diarrhea OR disease OR DNA OR dyspnea OR electrolyte OR emergency room OR enzyme OR enzymes OR epidemiologic OR epidemiological OR epidemiology OR epilepsy OR epileptic OR epithelium OR eye OR failure OR fever OR gastrointestinal OR genetox OR genotoxic OR glutamyltransferase OR head OR hematologic OR hematological OR hepatic OR histopathologic OR histopathological OR histpathology OR hospital OR hospitalizations OR hospitals OR hospitalization OR ill OR illness OR illnesses OR intoxicate OR intoxicated OR irritate OR irritated OR kidney OR larynx OR lesion OR lesions OR liver OR lung OR lymph OR lymph nodes OR lymphatic OR metabolic OR metabolism OR mucosa OR mutate OR mutated OR mutation OR mutations OR nausea OR necrosis OR neonatal OR neonate OR neonates OR neoplasm OR neurologic OR neurological OR noncancer OR oral OR organ OR pain OR placenta OR pneumonia OR polymorphism OR polymorphisms OR prenatal OR red blood cell OR renal OR reproduction OR respiratory OR seizure OR sick OR sickness OR skin OR stomach OR subacute OR subchronic OR symptom OR symptoms OR teratogen OR teratogenic OR teratogens OR throat OR toxic OR toxicity OR trachea OR tumor OR tumors OR urinary OR urine OR vomit OR vomiting OR conjugate OR conjugated OR diagnose OR diagnosis OR diagnosed OR diagnoses)

Filters: English
Date search was conducted: 10/9/2015
Publication dates searched: 1/1/2014–10/9/2015

Web of Science Search:

("*lemmermannii Raphidiopsis mediterranea*" OR *Anabaena flos-aquae* OR *flos-aquae* OR anatoxin OR *Aphanizomenon* OR cylindrospermopsin OR "*C. raciborskii*" OR *Cuspidothrix* OR *Cylindrospermopsis* OR *Cylindrospermum* OR "*Cylindrospermopsis raciborskii*" OR *Dolichospermum* OR "*M. aeruginosa*" OR *Microcystis* OR microcystin OR microcystins OR *Oscillatoria* OR *Planktothrix* OR *Phormidium* OR *Tychonema* OR *Woronichinia*)

AND

("non cancer" OR "blurred vision" OR "cell damage" OR "cellular damage" OR "health effect" OR "health endpoint" OR "health outcome" OR "health risk" OR "micronucleated binucleate cell" OR abdominal pain OR ache OR acute OR alanine aminotransferase OR allergic OR allergies OR allergy OR aspartate aminotransferase OR blister OR blistered OR blisters OR cancer OR carcinogen OR carcinogenic OR carcinogens OR chronic OR clinical OR cough OR dermal OR detoxification OR detoxify OR develop OR development OR developmental OR dialysis OR diarrhea OR disease OR DNA OR dyspnea OR electrolyte OR emergency room OR enzyme OR enzymes OR epidemiologic OR epidemiological OR epidemiology OR epilepsy OR epileptic OR epithelium OR eye OR failure OR fever OR gastrointestinal OR genetox OR genotoxic OR glutamyltransferase OR head OR hematologic OR hematological OR hepatic OR histopathologic OR histopathological OR histpathology OR hospital OR hospitalizations OR hospitals OR hospitalization OR ill OR illness OR illnesses OR intoxicate OR intoxicated OR irritate OR irritated OR kidney OR larynx OR lesion OR lesions OR liver OR lung OR lymph OR lymph nodes OR lymphatic OR metabolic OR metabolism OR mucosa OR mutate OR mutated OR mutation OR mutations OR nausea OR necrosis OR neonatal OR neonate OR neonates OR

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neoplasm OR neurologic OR neurological OR noncancer OR oral OR organ OR pain OR placenta OR pneumonia OR polymorphism OR polymorphisms OR prenatal OR red blood cell OR renal OR reproduction OR respiratory OR seizure OR sick OR sickness OR skin OR stomach OR subacute OR subchronic OR symptom OR symptoms OR teratogen OR teratogenic OR teratogens OR throat OR toxic OR toxicity OR trachea OR tumor OR tumors OR urinary OR urine OR vomit OR vomiting OR conjugate OR conjugated OR diagnose OR diagnosis OR diagnosed OR diagnoses)

Filters: English
Date search was conducted: 10/9/2015
Publication dates searched: 1/1/2014–10/9/2015

WoS research areas searched: Environmental Sciences Ecology OR Marine Freshwater Biology OR Toxicology OR Pharmacology Pharmacy OR Public Environmental Occupational Health OR Microbiology OR Immunology OR Biotechnology Applied Microbiology OR Biochemistry Molecular Biology OR Research Experimental Medicine OR Water Resources OR Infectious Disease OR Science Technology Other Topics OR Life Sciences Biomedicine Other Topics OR Gastroenterology Hepatology OR Pediatrics.

C.2 Research Question 3: What recreational water use safety levels or criteria have been set for microcystins or cylindrospermopsin by states or international governments and how did they derive them?

To identify state-level recreational guidelines for cyanobacteria and cyanotoxins, the EPA searched the websites of state-level departments of public health, environmental health, and natural resources for all 50 U.S. states. If relevant recreational guidelines were not found by searching state-level websites, the EPA conducted Google searches of the internet using state names, key terms for cyanobacteria and cyanotoxins (e.g., harmful algal bloom, blue-green algae, microcystin, cylindrospermopsin), and key terms for guidelines (e.g., advisory, guidance, guideline, standard, regulation). For international governments, the EPA used the 2012 report, *Current Approaches to Cyanotoxin Risk Assessment, Risk Management and Regulations in Different Countries*, by Dr. Ingrid Chorus, Federal Environment Agency, Germany, to identify international government recreational safety levels for cyanobacteria and cyanotoxins. In addition, the EPA implemented the same search strategy as used for U.S. states to identify updated international recreational guidelines or guideline levels not featured in the 2012 report by Dr. Ingrid Chorus.

C.3 Research Question 4: What new information, if any, is available regarding how aquatic recreational exposure ingestion rates in children differ among age groups between zero and 18 years?

Search of Bibliographic Databases

The EPA searched PubMed, WoS, and Google Scholar to identify literature that has cited, or is similar (based on terms identified in the titles and abstracts) to, the studies that provide water ingestion data for swimmers or during water recreational activities in the EPA's (2011) *Exposure Factors Handbook* (EFH) (i.e., Dorevitch et al. 2011; Dufour et al. (2006); Schets et al. 2011). The PubMed and WoS searches were conducted on 10/9/2015, the publication dates searched were 1/1/2011 to 10/9/2015, and an English filter was applied. The Google Scholar search was conducted on 10/9/2015 and could not be limited by year or language.

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Results

Together all three searches returned 341 journal articles. Duplicates were removed between PubMed and WoS, but this total might include duplicates between Google Scholar results and WoS/PubMed results. Based on a screening review of each article's title and abstract, the EPA retrieved five articles, four of which were published between 2013 and 2015 and appeared to measure or estimate incidental water ingestion. The EPA also retrieved one 2012 study that assessed duration of non-swimming recreational water exposure by using novel time lapse photography technology.

Google Search of Internet

In addition, the EPA conducted a Google search of the internet focused on specified URL domains (listed in Table C-1) to identify candidate gray literature (e.g., state, federal, or international government reports or guidance). The Google search string is presented below. The Google search of the internet could not be limited by year or language.

Table C-1. Internet URL Domains Searched for Research Question 4

Organization	URL Domain
U.S. Government	.gov .us
All U.S. States	Google Custom Search Engine
Centers for Disease Control and Prevention, including Agency for Toxic Substances and Disease Registry	cdc.gov
Australia, including Australian Department of Health	gov.au
Canada, including Health Canada	gc.ca
European Union, including • European Chemicals Agency • European Commissions on Environment, Public Health, Food, and Health and Consumers	europa.eu
Public Health England	hpa.org.uk
United Kingdom	gov.uk
Germany	.de
Education websites	.edu
HERA (Human and Environmental Risk Assessment) Project	heraproject.com
World Health Organization	who.int

Results

The Google search returned 390 results after removing duplicates. Based on a preliminary screen of each result, the EPA retrieved two documents which appeared to either derive or cited an incidental ingestion rate while recreating which had not previously been identified during the literature search process.

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Google Search of Internet (conducted separately for each URL domain listed in Table C-1)

(pool OR swim OR swimmer OR swimmers OR swimming OR recreation OR recreational)

AND

(adolescents OR boys OR child OR children OR girls OR kids OR teenagers)

AND

("activity-related ingestion" OR "incidental ingestion" OR "activity-related ingestion" OR "ingestion of water" OR "water ingestion")

AND

rate

AND

inurl:.

Filters: None
Date search was conducted: 10/9/2015
Dates searched: Not specified
Web browser: Internet Explorer

C.4 Research Question 5: What incidents of companion animal (e.g., dogs, horses) or livestock poisonings, including mortality or adverse health effects, due to exposure to cyanotoxins in freshwaters, marine water, or beaches have occurred in the past 15 years? Specifically, when and where did these incidents occur, to which cyanotoxin were the animals exposed, how were they exposed, and what were the weights and breeds of the affected animal(s)?

The EPA searched PubMed, WoS, and Agricola to identify candidate journal article literature relevant to companion animal or livestock poisoning due to exposures to cyanobacterial cells, anatoxin-a, cylindrospermopsin, or microcystins. The EPA first searched PubMed and WoS with a focus on dogs. The EPA conducted two additional searches in PubMed, WoS, and Agricola focused on livestock, and on cats and birds. The search strings for each search iteration are presented below.

Results

The number of journal articles returned by the three searches is provided in Table C-2. Based on a screening review of the article's title and abstract, the EPA retrieved five of the 35 journal articles retrieved during the search focused on dogs. These five articles appeared to provide information about an incident of cyanotoxin exposure to an animal where the authors confirm that the animal was exposed to a cyanotoxin by either measuring the concentration of cyanotoxin found in the animal or by sampling the body of water to which the animal had contact.

Table C-2. Number of Journal Articles Returned by Three Search Strategies for Research Question 5

Search Strategy Focus	Number of Results Returned from PubMed, WoS, and Agricola Searches
Dogs	35[a]
Livestock	100
Cats and birds	169[b]

[a] Search conducted in PubMed and WoS only.

[b] Duplicates between PubMed/WoS results and Agricola results were not removed. Therefore, the cats and birds search might include duplicates between Agricola results and PubMed/WoS results.

C.4.1 Search Strategy Focused on Dogs

PubMed Search

("*A. lemmermannii Raphidiopsis mediterranea*" OR *flos-aquae* OR anatoxin-a OR *Aphanizomenon* OR cylindrospermopsin OR "*C. raciborskii*" OR *Cuspidothrix* OR *Cylindrospermopsis* OR *Cylindrospermum* OR "*Cylindrospermopsis raciborskii*" OR *Dolichospermum* OR "*M. aeruginosa*" OR *Microcystis* OR microcystin OR microcystins OR *Oscillatoria* OR *Planktothrix* OR *Phormidium* OR *Tychonema* OR *Woronichinia* OR Cyanobacteria OR cyanotoxin OR Cyanotoxins OR "harmful algae" OR "harmful algal bloom" OR blue green algae)

AND

("health effect" OR "health endpoint" OR "health outcome" OR dead OR death OR deaths OR died OR disease OR diseased OR diseases OR exposed OR exposure OR ill OR illness OR illnesses OR infect OR infected OR infection OR infections OR morbidity OR mortality OR poison OR poisoned OR poisoning OR poisonings OR sick OR sickness OR toxic OR toxicity OR diagnose OR diagnosis OR diagnosed OR diagnoses)

AND

(canine OR canines OR dog OR dogs OR "*Canis lupus familiaris*" OR "*Canis familiaris*")

Filters: English
Date search was conducted: 10/5/2015
Publication dates searched: 1/1/2012–10/5/2015

Web of Science Search

("*lemmermannii Raphidiopsis mediterranea*" OR *flos-aquae* OR anatoxin OR *Aphanizomenon* OR cylindrospermopsin OR "*C. raciborskii*" OR *Cuspidothrix* OR *Cylindrospermopsis* OR *Cylindrospermum* OR "*Cylindrospermopsis raciborskii*" OR *Dolichospermum* OR "*M. aeruginosa*" OR *Microcystis* OR microcystin OR microcystins OR *Oscillatoria* OR *Planktothrix* OR *Phormidium* OR *Tychonema* OR *Woronichinia* OR Cyanobacteria OR cyanotoxin OR Cyanotoxins OR "harmful algae" OR "harmful algal bloom" OR blue green algae)

AND

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("health effect" OR "health endpoint" OR "health outcome" OR dead OR death OR deaths OR died OR disease OR diseased OR diseases OR exposed OR exposure OR ill OR illness OR illnesses OR infect OR infected OR infection OR infections OR morbidity OR mortality OR poison OR poisoned OR poisoning OR poisonings OR sick OR sickness OR toxic OR toxicity OR diagnose OR diagnosis OR diagnosed OR diagnoses)

AND

(canine OR canines OR dog OR dogs OR "*Canis lupus familiaris*" OR "*Canis familiaris*")

Filters: English
Date search was conducted: 10/5/2015
Publication dates searched: 1/1/2012–10/5/2015

C.4.2 Search Strategy Focused on Livestock

PubMed and Agricola Searches

("*A. lemmermannii Raphidiopsis mediterranea*" OR *flos-aquae* OR anatoxin-a OR *Aphanizomenon* OR cylindrospermopsin OR "*C. raciborskii*" OR *Cuspidothrix* OR *Cylindrospermopsis* OR *Cylindrospermum* OR "*Cylindrospermopsis raciborski*i" OR *Dolichospermum* OR "*M. aeruginosa*" OR *Microcystis* OR microcystin OR microcystins OR *Oscillatori*a OR *Planktothrix* OR *Phormidium* OR *Tychonema* OR *Woronichinia* OR *Cyanobacteria* OR *cyanotoxin* OR *Cyanotoxins* OR "harmful algae" OR "harmful algal bloom" OR blue green algae)

AND

("health effect" OR "health endpoint" OR "health outcome" OR dead OR death OR deaths OR died OR disease OR diseased OR diseases OR exposed OR exposure OR ill OR illness OR illnesses OR infect OR infected OR infection OR infections OR morbidity OR mortality OR poison OR poisoned OR poisoning OR poisonings OR sick OR sickness OR toxic OR toxicity OR diagnose OR diagnosis OR diagnosed OR diagnoses)

AND

(alpaca OR alpacas OR bronco OR broncos OR buffalo OR bull OR bulls OR cattle OR colt OR colts OR cow OR cows OR bovine OR bison OR oxen OR donkey OR donkeys OR duck OR ducks OR equine OR ewe OR ewes OR fillies OR filly OR foal OR foals OR gelding OR geldings OR heifer OR heifers OR horse OR horses OR lamb OR lambs OR livestock OR llama OR llamas OR mare OR mares OR mule OR mules OR mustang OR mustangs OR ponies OR pony OR ram OR rams OR sheep OR stallion OR stallions OR steer OR pig OR pigs OR piglet OR piglets)

Filters: English
Date search was conducted: 11/25/2015
Publication dates searched: 1/1/2012–11/25/2015

Web of Science Search:

("*lemmermannii Raphidiopsis mediterranea*" OR *flos-aquae* OR anatoxin OR *Aphanizomenon* OR cylindrospermopsin OR "*C. raciborskii*" OR *Cuspidothrix* OR *Cylindrospermopsis* OR *Cylindrospermum* OR "*Cylindrospermopsis raciborskii*" OR *Dolichospermum* OR "*M. aeruginosa*" OR

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Microcystis OR microcystin OR microcystins OR *Oscillatoria* OR *Planktothrix* OR *Phormidium* OR *Tychonema* OR *Woronichinia* OR Cyanobacteria OR cyanotoxin OR Cyanotoxins OR "harmful algae" OR "harmful algal bloom" OR blue green algae)

AND

("health effect" OR "health endpoint" OR "health outcome" OR dead OR death OR deaths OR died OR disease OR diseased OR diseases OR exposed OR exposure OR ill OR illness OR illnesses OR infect OR infected OR infection OR infections OR morbidity OR mortality OR poison OR poisoned OR poisoning OR poisonings OR sick OR sickness OR toxic OR toxicity OR diagnose OR diagnosis OR diagnosed OR diagnoses)

AND

(alpaca OR alpacas OR bronco OR broncos OR buffalo OR bull OR bulls OR cattle OR colt OR colts OR cow OR cows OR bovine OR bison OR oxen OR donkey OR donkeys OR duck OR ducks OR equine OR ewe OR ewes OR fillies OR filly OR foal OR foals OR gelding OR geldings OR heifer OR heifers OR horse OR horses OR lamb OR lambs OR livestock OR llama OR llamas OR mare OR mares OR mule OR mules OR mustang OR mustangs OR ponies OR pony OR ram OR rams OR sheep OR stallion OR stallions OR steer OR pig OR pigs OR piglet OR piglets)

Filters: English
Date search was conducted: 11/25/2015
Publication dates searched: 1/1/2012–11/25/2015

C.4.3 Search Strategy Focused on Cats and Birds

PubMed and Agricola Searches

("*A. lemmermannii Raphidiopsis mediterranea*" OR *flos-aquae* OR anatoxin-a OR *Aphanizomenon* OR cylindrospermopsin OR "*C. raciborskii*" OR *Cuspidothrix* OR *Cylindrospermopsis* OR *Cylindrospermum* OR "*Cylindrospermopsis raciborskii*" OR *Dolichospermum* OR "*M. aeruginosa*" OR *Microcystis* OR microcystin OR microcystins OR *Oscillatoria* OR *Planktothrix* OR *Phormidium* OR *Tychonema* OR *Woronichinia* OR *Cyanobacteria* OR cyanotoxin OR Cyanotoxins OR "harmful algae" OR "harmful algal bloom" OR blue green algae)

AND

("health effect" OR "health endpoint" OR "health outcome" OR dead OR death OR deaths OR died OR disease OR diseased OR diseases OR exposed OR exposure OR ill OR illness OR illnesses OR infect OR infected OR infection OR infections OR morbidity OR mortality OR poison OR poisoned OR poisoning OR poisonings OR sick OR sickness OR toxic OR toxicity OR diagnose OR diagnosis OR diagnosed OR diagnoses)

AND

(feline OR felines OR cat OR cats OR kitten OR kittens OR "*F. Catus*" OR "*Felis Catus*" OR bird OR birds OR avian OR waterfowl)

Filters: English
Date search was conducted: 2/1/2016
Publication dates searched: 1/1/2012–2/1/2016

Web of Science Search

("*lemmermannii Raphidiopsis mediterranea*" OR *flos-aquae* OR anatoxin OR *Aphanizomenon* OR cylindrospermopsin OR "*C. raciborskii*" OR *Cuspidothrix* OR *Cylindrospermopsis* OR *Cylindrospermum* OR "*Cylindrospermopsis raciborskii*" OR *Dolichospermum* OR "*M. aeruginosa*" OR *Microcystis* OR microcystin OR microcystins OR *Oscillatoria* OR *Planktothrix* OR *Phormidium* OR *Tychonema* OR *Woronichinia* OR Cyanobacteria OR cyanotoxin OR Cyanotoxins OR "harmful algae" OR "harmful algal bloom" OR blue green algae)

AND

("health effect" OR "health endpoint" OR "health outcome" OR dead OR death OR deaths OR died OR disease OR diseased OR diseases OR exposed OR exposure OR ill OR illness OR illnesses OR infect OR infected OR infection OR infections OR morbidity OR mortality OR poison OR poisoned OR poisoning OR poisonings OR sick OR sickness OR toxic OR toxicity OR diagnose OR diagnosis OR diagnosed OR diagnoses)

AND

(feline OR felines OR cat OR cats OR kitten OR kittens OR "*F. Catus*" OR "*Felis Catus*" OR bird OR birds OR avian OR waterfowl)

Filters: English
Date search was conducted: 2/1/2016
Publication dates searched: 1/1/2012–2/1/2016

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APPENDIX D. REVIEW OF THE STATE OF THE SCIENCE ON CYANOBACTERIAL CELLS HEALTH EFFECTS

D.1 Introduction

This appendix provides information gathered and reviewed to determine the state of the science on health effects from cyanobacterial cells. The EPA conducted literature searches to identify studies relevant to the health effects from cyanobacterial cells. Detailed information on the design and implementation of these searchers is provided in Appendix C. Results from these literature searches were reviewed for relevance to cyanobacterial cell exposures and health effects.

D.1.1 Animal Studies

Cyanobacterial cells cause allergenicity and irritation in animals, independent of whether the cyanobacterial cells produce toxin. Three animal studies (Shirai et al. 1986; Stewart et al. 2006c; Torokne et al. 2001) demonstrated hypersensitivity reactions and dermal and eye irritation in several species that did not correlate with microcystin content. Although the number of studies is limited and different species were evaluated in each study, these studies provide evidence to support hypersensitivity reactions in animals from exposure to cyanobacteria when cyanotoxins are not present (Shirai et al. 1986; Torokne et al. 2001) and when they are (Stewart et al. 2006c).

Cyanobacteria bloom samples collected from five different lakes or ponds were tested for allergenic and irritative effects in guinea pigs and rabbits, respectively (Torokne et al. 2001). The microcystin content (presumed to be total LR, RR, and YR) ranged from not detected to 2.21 mg/g. To determine sensitization, guinea pigs were initiated with an intradermal injection of freeze-dried cyanobacteria followed seven days later by topical application at the injection site. Sensitization was moderate to strong in 30–67 percent of guinea pigs and did not correlate with microcystin content. The *Aphanizomenon ovalisporum* sample (a non-toxin-producing strain) sensitized 91 percent of the animals and was the strongest allergen. Skin irritation tests in albino rabbits showed slight or negligible irritation, except for *Aphanizomenon ovalisporum*, which showed moderate irritation. The eye irritation evaluation in rabbits was positive for four of the five samples containing *Microcystis*.

Shirai et al. (1986) reported that C3H/HeJ mice, immunized intraperitoneal with either sonicated or live cells from a *Microcystis* water bloom, developed delayed-type hypersensitivity when challenged two weeks later with a subcutaneous injection sonicated *Microcystis* cells. A positive reaction, as assessed by footpad swelling, was seen in mice immunized with either live cells or sonicated cells. Both toxic and nontoxic *Microcystis* cells induced delayed-type hypersensitivity in this mouse study. Because this strain of mouse is unresponsive to lipopolysaccharide (LPS), the footpad delayed-type hypersensitivity was not related to LPS, thus, the antigenic component of the sonicated cyanobacterial cells is not known.

Stewart et al. (2006c) conducted a mouse ear swelling test in which cylindrospermopsin and *Cylindrospermopsis raciborskii* solutions generated irritation of the abdominal skin exposed during induction (two percent w/v lysed cell solution containing 73 µg/mL cylindrospermopsin). Subsequent dermal exposures to the *Cylindrospermopsis raciborskii* solution produced hypersensitivity reactions ($p = 0.001$). The cyanobacteria *Microcystis aeruginosa* and *Anabaena circinalis* elicited no responses in this test.

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Two of the cyanobacterial cell studies in animals found that rodents became sensitized after exposure and subsequent challenge to non-toxin strains (Shirai et al. 1986; Torokne et al. 2001). Torokne et al. (2001) found that a nontoxic strain was more sensitizing and irritating than the toxic strains evaluated. These experiments support the conclusion that there is no relationship between the cyanotoxin content and the allergenic effect of cyanobacteria.

D.1.2 Clinical and Laboratory Human Studies

Several types of studies and reports provide information on associations between cyanobacteria exposure and health effects. Clinical and in vitro studies (Bernstein et al. 2011; Geh et al. 2015; Pilotto et al. 2004; Stewart et al. 2006a) have been able to assess associations between cyanobacteria exposure and human health effects including dermal and allergenic reactions. Three clinical studies assessed dermal exposure to cyanobacterial cells using skin-patch or skin-prick testing in humans (Bernstein et al. 2011; Pilotto et al. 2004; Stewart et al. 2006a). Some of the exposed individuals showed mild irritation or allergenicity. No statistically significant dose-response relationships were found between skin irritation and increasing cyanobacterial cell concentrations. The allergenicity study suggests that cyanobacteria are allergenic, particularly among people with chronic rhinitis (Bernstein et al. 2011).

Skin-patch testing in humans was performed by Pilotto et al. (2004) with laboratory-grown cylindrospermopsin-producing *Cylindrospermopsis raciborskii* cells, both whole and lysed, which were applied using adhesive patches at concentrations ranging from < 5,000 to 200,000 cells/mL to the skin of 50 adult volunteers. After 24 hours, patches were removed and evaluation of the erythematous reactions were graded. Analysis of participants' reactions to patches treated with whole cells showed an odds ratio (OR) of 2.13 and a 95 percent confidence interval (CI) of 1.79–4.21 ($p < 0.001$). Lysed cells patch analysis showed an OR of 3.41 and a 95 percent CI of 2.00–5.84 ($p < 0.001$). No statistically significant increase or dose-response between skin reactions and increasing cell concentrations for either patches (whole or lysed) was observed. Subjects had skin reactions to the cylindrospermopsin, and positive control patches more frequently than to the negative control patches. The mean percentage of subjects with a reaction was 20 percent (95 percent CI: 15–31 percent). When subjects reacting to negative controls (39) were excluded, the mean percentage was 11 percent (95 percent CI: 6–18 percent). Evaluation of erythematous reactions showed that mild irritations (grade 2) were resolved in all cases within 24 to 72 hours.

Stewart et al. (2006a) conducted a skin-patch test with 39 volunteers (20 dermatology outpatients; 19 controls) who were exposed to six cyanobacterial suspensions, including toxigenic species, nontoxigenic species, mixed suspensions, and two cyanobacterial LPS extracts. All cyanobacterial suspensions of lyophilized cells were tested at three concentrations, 0.25 percent w/v, 0.05 percent w/v, 0.005 percent w/v, and the estimated doses of cyanotoxins were 2.4 ng/kg cylindrospermopsin and 2.6 ng/kg microcystins. Only one subject showed significant responses to cyanobacterial suspensions, specifically to two suspensions of cyanobacterial cells: *Cylindrospermopsis raciborskii* and mixed *Microcystis aeruginosa* and *Cylindrospermopsis raciborskii*, both of which contained one or more cyanotoxins. This subject showed no evidence of any dose-response effect in the dermal reactions. None of the participants reacted to the cyanobacterial LPS extracts, which ranged from 260 ppb to 31 ppm. This small clinical study demonstrated that dermal hypersensitivity reactions to cyanobacteria exposure occur infrequently, and further research into risk factors for predisposition to this type reaction could be beneficial.

Bernstein et al. (2011) studied skin sensitization to nontoxic extracts of *Microcystis aeruginosa* in 259 patients with chronic rhinitis over two years. Patients were evaluated with aeroallergen skin testing and

skin-prick testing. The authors found that 86 percent of the subjects had positive skin-prick tests to *Microcystis aeruginosa*, and that patients with existing allergic rhinitis were more likely to have reactions and sensitization to cyanobacteria than the controls (non-atopic health subjects). This study indicated that cyanobacterial allergenicity is associated with the nontoxic portion of the cyanobacteria.

Geh et al. (2015) studied the immunogenicity of extracts of toxic and nontoxic strains of *Microcystis aeruginosa* in patient sera (18 patients with chronic rhinitis and three non-atopic healthy subjects as documented in Bernstein et al. 2011). Enzyme Linked Immunosorbent Assay (ELISA) test was used to test IgE-specific reactivity, and gel electrophoresis, followed by immunoblot and mass spectrometry, was done to identify the relevant sensitizing peptides. The authors found an increase in specific IgE in those patients tested with the nontoxic *Microcystis aeruginosa* extract than the extract from the toxic strain. After pre-incubation of the nontoxic extract with various concentrations of microcystin, the authors found that phycocyanin and the core-membrane linker peptide were responsible for the release of β-hexosaminidase in rat basophil leukemia cells. The authors concluded that non-toxin-producing strains of cyanobacteria are more allergenic than toxin-producing strains in allergic patients, and that the toxin may have an inhibitory effect on the allergenicity of the cyanobacterial cells.

Facciponte et al. (2018) used polymerase chain reaction (PCR) to detect aerosolized cyanobacteria inhaled into the human respiratory tract. They found cyanobacteria at high frequencies in the upper respiratory tract (92.2 percent) and central airway (79.3 percent) of the study subjects (n = 77). The findings suggests that humans inhale aerosolized cyanobacteria, which can remain in the nostrils and the lungs.

D.1.3 Epidemiological Studies, Case Reports, and Outbreaks

Among the epidemiological studies discussed here, some identified significant associations between cyanobacteria exposure and a range of health outcomes including dermal, eye/ear, gastrointestinal (GI), and respiratory effects. Several of these studies also measured one or more cyanotoxins and found no association between cyanotoxin occurrence or exposure and health effects. Additional evidence from outbreak and case reports provides support for health effects associated with cyanobacteria exposure. The studies vary in study design, methods used, size of study population, cyanobacterial species evaluated, health effects identified, and cyanobacterial cell densities associated with human health effects. Therefore, substantial uncertainty remains regarding the associations between cyanobacterial cell exposure and human health effects. Overall, these studies provide evidence of statistically significant associations between cyanobacterial cell exposure and human health effects even in the absence of cyanotoxins. However, the reported associations between cyanobacterial cell densities and health outcomes are not consistent.

Eight epidemiological studies evaluated short-term health effects associated with recreational exposure to cyanobacterial blooms (El Saadi et al. 1995; Lévesque et al. 2014; Lin et al. 2015; Philipp 1992; Philipp and Bates 1992; Philipp et al. 1992; Pilotto et al. 1997; Stewart et al. 2006d). See Table D-1 for a summary list of these studies. The health outcomes evaluated included dermal, GI, respiratory, and other acute effects, such as eye or ear symptoms. Seven studies evaluated recreational exposure to freshwater cyanobacteria, and one evaluated exposure to marine water cyanobacteria (Lin et al. 2015). Two studies included field sites in the continental United States or Canada (Lévesque et al. 2014; Stewart et al. 2006d), three occurred in the United Kingdom (Philipp 1992; Philipp and Bates 1992; Philipp et al. 1992), and three were conducted in subtropical and tropical regions in Australia (El Saadi

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et al. 1995; Pilotto et al. 1997) and Puerto Rico (Lin et al. 2015). These epidemiological studies are discussed below in chronological order.

Table D-1. Cyanobacteria Epidemiological Studies Summary

Reference	Study Design, n, and Location	Cyanobacteria Identified	Cyanotoxins Measured	Health Association[a]	Lowest Significant Cyanobacterial Cell Density (cells/mL)
Philipp (1992)	Cross-sectional n = 246 United Kingdom (Hampshire)	*Microcystis* sp., *Gleotrichia* sp.	–	No statistically significant health associations	No quantitative cyanobacterial cell densities provided
Philipp and Bates (1992)	Cross-sectional n = 382 United Kingdom (Somerset)	*Microcystis* sp., *Gleotrichia* sp.	–	No statistically significant health associations	No quantitative cyanobacterial cell densities provided
Philipp et al. (1992)	Cross-sectional n = 246 United Kingdom (Lincolnshire, South Yorkshire)	*Oscillatoria* sp., *Aphanizomenon* sp., *Aphanothece* sp., *Merismopedia* sp.	–	No statistically significant health associations	No quantitative cyanobacterial cell densities provided
El Saadi et al. (1995)	Case-control n cases = 102 GI, 86 dermatological n controls = 132 Australia (South Australia)	*Anabaena* sp., *Aphanizomenon* sp., *Planktothrix* sp., *Anabaena circinalis*, *Microcystis aeruginosa*	–	No statistically significant health associations	No quantitative cyanobacterial cell densities provided
Pilotto et al. (1997)	Cross-sectional n = 295 exposed n = 43 unexposed Australia (South Australia, New South Wales, Victoria)	*Microcystis aeruginosa*, *Microcystis* sp., *Anabaena* sp., *Aphanizormenon* sp., *Nodularia spumigena*	Hepatotoxins detected by mouse bioassay	Significant positive association between combined symptoms (GI, dermal, respiratory, fever, eye or ear irritation) and cyanobacteria	> 5,000
Stewart et al. (2006d)	Cohort (prospective) n = 1,331 Australia (Queensland, New South Wales) and Florida	Cyanobacteria identified, species not specified	Microcystins detected by HPLC with photodiode array detection or ELISA; cylindro-spermopsin and anatoxin-a detected by HPLC-MS/MS; saxitoxins not detected by HPLC with fluorescence detection	Significant positive association between respiratory symptoms and cyanobacteria Significant positive association between combined symptoms (GI, dermal, respiratory, fever, eye or ear irritation) and cyanobacteria	> 100,000[b]

Reference	Study Design, n, and Location	Cyanobacteria Identified	Cyanotoxins Measured	Health Association[a]	Lowest Significant Cyanobacterial Cell Density (cells/mL)
Lévesque et al. (2014)	Cohort (prospective) n = 466 Canada (Quebec)	Cyanobacteria identified, species not specified	Microcystins detected by ELISA	Significant positive association between GI symptoms with fever and cyanobacteria	20,000–100,000
Lin et al. (2015)[c]	Cohort (prospective) n = 15,726 Puerto Rico (Boquerón)	Cyanophyte filament, *Pseudanabaena* sp., Picocyanophyte, *Synechococcus* sp., *Synechocystis* sp., Cyanophyte cell pair, *Phormidium* sp., *Lyngbya* sp., *Trichodesmium* sp., *Aphanothece* sp., *Johannesbaptistia* sp., *Komvophoron* sp., Cyanophyte colony, Cyanophyte unicell sphere	Lyngbyatoxin-a and debromo-aplysiatoxin measured but not detected by HPLC-MS	Significant positive association between respiratory illness and cyanobacteria other than picocyanobacteria	36.7–237.4
				significant positive association between rash and cyanobacteria other than picocyanobacteria	> 237.4

sp. = unspecified species of the genus; HPLC = high performance liquid chromatography; MS = mass spectrometry; MS/MS = tandem mass spectroscopy

[a] Includes only significant associations between recreational cyanobacteria exposure and health effects.

[b] Values were converted from cyanobacterial cell surface area (> 12.0 mm^2/mL) to cyanobacterial cell density (> 100,000 cells/mL) using conversions in NHMRC (2008). Relationship between biomass and cyanobacterial cell density can vary by species and cell size (Lawton et al. 1999; Stewart et al. 2006d).

[c] Lin et al. (2015) evaluated picocyanobacteria and cyanobacteria other than picocyanobacteria separately.

Three cross-sectional studies were conducted by Philipp et al. (Philipp 1992; Philipp and Bates 1992; Philipp et al. 1992) to evaluate health effects related to exposure to cyanobacteria from recreational activities including sailing, windsurfing, and fishing in water bodies in the United Kingdom. Questionnaires were administered to participants who visited one of six inland lakes to evaluate exposure and morbidity (including dermal, eye/ear, GI, and respiratory symptoms). Several species of cyanobacteria were identified and, in some cases, cyanobacterial levels exceeded the National Rivers Authority threshold for "potential to cause harm." Only minor morbidity was identified among recreators, and no statistically significant associations between cyanobacteria exposure and morbidity were identified.

El Saadi et al. (1995) conducted a case-control study in Australia to evaluate exposure to river water with detectable levels of cyanobacteria and GI and dermatological symptoms evaluated by a medical practitioner. This river was used as a source for drinking water, domestic water, and recreational water. The authors found no significant association between recreational exposure to river water with cyanobacteria and GI or dermatological symptoms. Cyanotoxins were not measured, but species of cyanobacteria were present that were capable of producing cyanotoxins.

These four studies (El Saadi et al. 1995; Philipp 1992; Philipp and Bates 1992; Philipp et al. 1992) provided no quantitative data on cyanobacterial cell densities. Therefore, they could not help inform determination of a quantitative level associated (or not associated) with health effects.

Four more recent epidemiological studies assessed the association between exposure to recreational waters containing cyanobacteria and human health and provide quantitative density data for cyanobacterial cells (Lévesque et al. 2014; Lin et al. 2015; Pilotto et al. 1997; Stewart et al. 2006d). These studies reported at least one statistically significant association between exposure to cyanobacteria and human health outcomes, including GI illness (Lévesque et al. 2014), respiratory symptoms (Lin et al. 2015; Stewart et al. 2006d), dermal symptoms (Lin et al. 2015), or combined symptomology (GI, dermal, respiratory, and other symptoms) (Pilotto et al. 1997; Stewart et al. 2006d). These associations were linked to a range of densities of cyanobacterial cells from as low as > 5,000 cells/mL (Pilotto et al. 1997) to as high as 100,000 cells/mL (analogous to ≥ 12 mm^2/mL (NHMRC 2008; Stewart et al. 2006d). In contrast to the studies that examined all cyanobacteria, Lin et al. (2015) evaluated picocyanobacteria, larger cyanobacterial cells, and total phytoplankton, and reported health effects associated with 37–1,461 cells/mL for cyanobacteria other than picocyanobacteria.

Pilotto et al. (1997) investigated the health effects from recreational exposures (including jet-skiing, water skiing, swimming, and windsurfing) to cyanobacteria in Australia. The study included 852 participants, 777 who had water contact and were considered exposed, and 75 not exposed. There were 338 recreators (295 exposed, 43 not exposed) after exclusion of those who experienced symptoms or had recreational exposure in the five days prior to the initial interview at the water recreation site (the *after exclusion* study group). Health outcomes evaluated included diarrhea, vomiting, flu-like symptoms (e.g., cough), skin rashes, mouth ulcers, fevers, or eye or ear infections. Water samples were collected for evaluation of cyanobacterial cell counts, hepatotoxins, and neurotoxins.

In the *after exclusion* study group, when all symptoms were combined, the authors found a significant trend of increasing symptom occurrence with duration of exposure at seven days post-exposure (p-value for trend =0.03). Similarly, in the *after exclusion* study group there was a significant trend of increasing symptom occurrence with increasing cyanobacterial cell count (p-value for trend = 0.04). To account for the combined effect of duration of exposure and cyanobacterial cell density, unexposed participants were compared with those exposed for up to 60 minutes and for more than 60 minutes to water with up to 5,000 cells/mL and to water with more than 5,000 cells/mL. For the *after exclusion* study group, a significant trend of increasing symptom occurrence with increasing levels of exposure was identified (p-value for trend = 0.004). In addition, participants with recreational exposure for more than 60 minutes to cyanobacterial densities above 5,000 cells/mL had a significantly higher symptom occurrence rate at seven days post-exposure than unexposed participants (OR = 3.44, CI: 1.09–10.82). In this study, the significant trends observed in the *after exclusion* study group were not observed when all participants were included.

Pilotto et al. (1997) reported toxicity data collected by the Australia Water Quality Center. Presence or absence of particulate (intracellular) hepatotoxins in concentrated surface water phytoplankton samples was measured by mouse bioassay. The authors reported that hepatotoxins were identified at one site on two separate interview days and at three sites for one day each. No evidence of neurotoxins was detected. They reported that no significant association was found between the presence of hepatotoxins and symptom occurrence at two and seven days after exposure. Data and analysis methods were not provided. The authors point out that trends were observed at seven days and not at two days after exposure and this might suggest a delayed rather than an immediate allergic response. The authors also stated they could not rule out other causative factors, such as other microorganisms, that could co-occur with cyanobacteria. The results from this study informed the recommendations made by WHO in *Guidelines for Safe Recreational Water Environments* (WHO 2003).

Stewart et al. (2006d) conducted a prospective cohort study to investigate the incidence of acute symptoms in individuals exposed to cyanobacteria via recreational activities in lakes and rivers in Australia and Florida. This study included 1311 recreators with any water contact-related activity (e.g., swimming, boat entry/egress). Cyanobacterial cell densities were characterized in terms of cell surface area rather than cell counts (to normalize for cell size differences among different species). Authors evaluated incidence of acute symptoms in recreators exposed to low, medium and high levels of cyanobacteria.

Study subjects were asked to complete a self-administered questionnaire before leaving for the day after enrollment and to submit to a telephone follow-up interview. The questionnaire and follow-up interview forms gathered information on various acute illnesses, their onset and severity. Respiratory symptoms among study participants in the high recreational exposure group (total cyanobacterial cell surface area > 12 mm^2/mL on day of recreation) were significantly greater compared to participants in the low recreational exposure group (< 2.4 mm^2/mL) (adjusted OR = 2.1, 95 percent CI: 1.1–4.0). Respiratory symptoms were defined as difficulty breathing, dry cough, productive cough, runny nose, unusual sneezing, sore throat, or wheezy breathing. Reports of any symptom among study participants in the high exposure group were significantly greater compared to reports among study participants in the low recreational exposure group (adjusted OR = 1.7, 95 percent CI: 1.0–2.9). However, when subjects with recent prior recreational water exposure were excluded the result remained positive but not significant (adjusted OR = 1.6, 95 percent CI: 0.8–3.2). A dose-response relationship between increased cyanobacterial biomass and increased symptom reporting was not identified. The authors speculated that the pattern in their data could be due to a threshold effect. No other significant associations with health effects were identified.

For water samples that contained potentially toxic cyanobacteria, Stewart et al. (2006d) measured cyanotoxins including microcystins, saxitoxins, cylindrospermopsin and anatoxin-a by HPLC or HPLC-MS/MS methods. Cyanotoxins were infrequently identified and only at low levels. Microcystins were detected on two occasions (1 and 12 μg/L). Cylindrospermopsin was found on seven occasions (ranging from 1 to 2 μg/L). Anatoxin-a was identified on a single recruitment day at a concentration of 1 μg/L. A statistically significant increase in symptom reporting was found to be associated with anatoxin-a exposure, but the number of exposed subjects was very low (n =18). No relationship between fecal indicator bacteria (fecal coliforms) and symptoms was identified.

Lévesque et al. (2014) conducted a prospective study of health effects including GI, respiratory, dermal, eye/ear, and other symptoms associated with cyanobacteria and microcystin exposure at three lakes in Canada (Quebec), one of which was a local supply of drinking water. The study evaluated acute symptoms in humans (466 subjects included in analysis) living in proximity to lakes affected by blooms and analyzed recreational exposure (full and limited contact) and drinking water exposure scenarios for both cyanobacterial cells and microcystins.

More severe GI symptoms, defined as diarrhea, vomiting, nausea and fever, or abdominal cramps and fever, were associated with recreational contact (full and limited) and cyanobacteria. For the more severe GI symptoms, the adjusted relative risk (RR) increased with cyanobacterial cell counts providing evidence of a dose-response relationship (p-value for trend = 0.001, < 20,000 cells/mL: RR = 1.52, 95 percent CI: 0.65–3.51; 20,000–100,000 cells/mL: RR = 2.71, 95 percent CI: 1.02–7.16; > 100,000 cells/mL: RR = 3.28, 95 percent CI: 1.69–6.37). No evidence of a dose-response relationship for cyanobacterial cell counts and the less severe GI symptoms was found. No relationship was observed between duration of contact or head immersion and risk of GI symptoms. A significant increase for both

the less and the more severe GI symptoms was found with contact in the more highly impacted lakes (median cell densities 20,001–21,485 cells/mL), but not in the less impacted lake (median 1,032 cells/mL). No relationship was observed between microcystin concentrations and risk of GI symptoms. No significant associations between recreational exposures to cyanobacteria and health effects other than GI effects were identified.

To evaluate possible co-exposures, authors measured microcystin concentrations and *E. coli* as a fecal indicator. Lévesque et al. (2014) measured particulate (intracellular) and dissolved microcystins by ELISA and found that microcystin concentrations varied by lake and by sample location (littoral versus limnetic). Microcystins were detected in all three lakes. At Lake William the median values were below the limit of detection at littoral and limnetic stations, with maximum values of 0.63 µg/L and 0.02 µg/L, respectively. At Lake Roxton littoral stations, the median concentration was 0.23 µg/L (range: 0.008 µg/L–108.8 µg/L) and at limnetic stations the median was 0.12 µg/L (range: 0.04 µg/L–1.12 µg/L). The Mallets Bay littoral stations had a median of 0.70 µg/L (range: under limit of detection – 773 µg/L) and the limnetic stations had a median of 0.35 µg/L (range: 0.001 µg/L–125 µg/L).

Lévesque et al. (2014) reported that as a whole the microcystin concentrations during contact were relatively low (first tertile: < 0.0012 µg/L; second tertile: 0.0012–0.2456 µg/L; third tertile: > 0.2456 µg/L). Symptoms were examined in relation to recreational and drinking water exposure to cyanobacteria and microcystins. Only GI symptoms were associated with recreational contact. The highest microcystin concentration at which an episode of GI symptoms was reported was 7.65 µg/L. There was no significant increase in adjusted RR of GI symptoms with recreational exposure to more than 1 µg/L microcystins. Adjusted RR (adjusted for gender, gastrointestinal (GI) symptoms reported in the two weeks prior to data collection, residence's source of drinking water) for GI illness without fever and GI illness with fever were 1.06 (95 percent CI=0.32–3.52) and 1.48 (95 percent CI = 0.41–5.23), respectively. There were significant increases in adjusted RR of several symptoms in participants who received their drinking water from a source contaminated by cyanobacteria (muscle pain, GI illness, skin, and ear symptoms).

Lévesque et al. (2014) found that the geometric mean of *E. coli* at the three lakes ranged from 0 to 145 CFU per 100 mL, and there was no association between GI illness and *E. coli* levels. The authors noted that GI symptoms could have other causes, such as *Aeromonas* infections; however, the symptoms were not related to fecal contamination as measured by culturable *E. coli.* They also noted that people avoided full recreational contact during blooms and more people engaged in limited contact recreation at higher cell counts. This observation explains the counterintuitive finding that participants with limited contact exposure (fishing, watercraft without direct water contact) had higher likelihood of symptom reporting compared to participants with full contact.

A follow-up analysis (Lévesque et al. 2016) characterized the same health data as Lévesque et al. (2014) to evaluate the relationship of bacterial endotoxin (e.g., LPS) concentration to GI symptoms. Endotoxin concentrations were slightly correlated with cyanobacterial counts (polychoric correlation coefficient = 0.57). The highest tertile of endotoxin concentration (> 48 endotoxin units/mL) was significantly associated with GI illness both with and without fever (GI illness without fever RR = 2.87, CI: 1.62–5.08; GI illness with fever RR = 3.11, CI: 1.56–6.22). Adjustment to the level of cyanobacteria did not alter the relationship between endotoxin and GI illness and authors hypothesize that other Gram negative bacteria might play a role in the relationship between endotoxin levels and GI illness as has been suggested in a previous study (Berg et al. 2011). Authors note that they stored filtered water samples at −80 ºC for several months prior to conducting endotoxin testing and that another study

(O'Toole et al. 2009) showed a 44 percent mean decline in the concentration of endotoxins in samples stored at -80 ºC for several weeks compared to samples stored at 4 ºC for 24 hours. Lévesque et al. (2016) caution that concentrations reported could be underestimated and should be interpreted on an ordinal basis. Two other studies conducting endotoxin testing on frozen samples found concentrations of a similar magnitude as this study (Berg et al. 2011; Rapala et al. (2002).

Lin et al. (2015) conducted a prospective study based on data collected in 2009 at Boquerón, Puerto Rico for 26 study days involving 15,726 enrollees to examine the association between phytoplankton cell counts and illness among beachgoers. Three categories of phytoplankton were evaluated: picocyanobacteria, cyanobacteria other than picocyanobacteria, and total phytoplankton. The analysis compared people exposed at phytoplankton cell count levels > 25th percentile (e.g., 25th to 75th percentile, > 75th percentile) to people exposed at levels < 25th percentile (range of cyanobacteria other than picocyanobacteria: < 37 to 1461 cells/mL).

The Lin et al. (2015) study reported significant associations between recreational exposure to cyanobacteria other than picocyanobacteria and respiratory symptoms, rash, and earache. For the other symptoms measured, including eye irritation, no significant associations were observed. More specifically, cyanobacterial (other than picocyanobacterial) densities of 37 to 237 cells/mL (> 25th to < 75th percentile) and densities ≥ 237 cells/mL (≥ 75th percentile) were associated with increased respiratory symptoms (> 25th to < 75th percentile, OR = 1.30, 95 percent CI: 1.08–1.56; ≥ 75th percentile, OR = 1.37, 95 percent CI: 1.12–1.67) in study participants who reported body immersion. Respiratory symptom occurrence was defined as any two of the following: sore throat, cough, runny nose, cold, or fever. Cyanobacterial (other than picocyanobacterial) densities >237 cells/mL were associated with rash (OR = 1.32, 95 percent CI = 1.05–1.66) and earache (OR = 1.75, 95 percent CI: 1.09–2.82). Study participants who reported head submersion or swallowing of water showed no relationship between recreational exposures to cyanobacteria (other than picocyanobacteria) and respiratory symptoms. There was no association between recreational exposures to cyanobacteria (other than picocyanobacteria) and respiratory symptoms in study participants who reported head submersion or swallowing of water. A statistically significant association between cyanobacterial cell exposure (other than picocyanobacterial cell exposure) and all health effects combined was also observed.

Lin et al. (2015) measured the dermatoxins, debromoaplysiatoxin, and lyngbyatoxin, using HPLC-mass spectrometry and did not detect levels above the limit of detection of 1.0 ppb. Authors reported that debromoaplysiatoxin and lyngbyatoxin-a are photolabile and are unlikely to persist in the water column (Moikeha and Chu 1971). They noted that the health effects identified in this study were consistent with previous blooms of *Lyngbya majuscula*, which can produce these toxins, though *Lyngbya* only comprised three percent of total planktonic cyanobacteria (other than picocyanobacteria). It is also possible that the cyanobacterial cells or associated contaminants could be having direct health effects as cyanotoxins levels were below the limit of detection.

To evaluate possible co-exposures, some studies measured cyanotoxins and fecal indicators. Lin et al. (2015), Lévesque et al. (2014), Pilotto et al. (1997), and Stewart et al. (2006d) measured one or more cyanotoxins or total hepatotoxins. In some cases, cyanotoxin levels were below the limit of detection. To determine if study participants possibly were exposed to fecal contamination, three of the studies (Lévesque et al. 2014; Lin et al. 2015; Stewart et al. 2006d) measured bacterial fecal indicators at some study locations and times. Of the studies that measured bacterial fecal indicators, none found an association between bacterial fecal indicators and health effects. Of these studies, the only one with data

available for viral fecal indicators or concentrations of waterborne pathogens was Lin et al. (2015) provided in Wade et al. (2010) and Soller et al. (2016).

In summary, although four studies identified significant associations between cyanobacteria exposure and health effects, the type of health effect identified varied. One study reported a significant association between GI illness and exposure to cyanobacteria (Lévesque et al. 2014). Stewart et al. (2006d) and Lin et al. (2015) identified statistically significant associations between cyanobacterial cell exposure and respiratory effects. Lin et al. (2015) also found a statistically significant association between earache and cyanobacterial densities. Both Pilotto et al. (1997) and Stewart et al. (2006d) found statistically significant associations between cyanobacterial cell exposure and all symptoms combined. The three cross-sectional studies conducted in the United Kingdom in 1990 found no statistically significant associations, although some minor elevated morbidity was observed in exposed individuals (Philipp 1992; Philipp and Bates 1992; Philipp et al. 1992). Another 1992 case-control epidemiological study in Australia found no statistically significant symptoms for exposed recreators (El Saadi et al. 1995).

The Centers for Disease Control and Prevention (CDC) has collected information on illness outbreaks associated with HABs, which commonly involve cyanobacteria. This information includes human health effects and water-sampling results voluntarily reported to the Waterborne Disease Outbreak Surveillance System via the National Outbreak Reporting System and the Harmful Algal Bloom-related Illness Surveillance System. CDC published summary information on HAB-associated outbreaks from recreational exposures focusing on 2009–2010 with limited additional information available for outbreaks that occurred in 2001, 2004, and 2011–2012 (Dziuban et al. 2006; Hilborn et al. 2014; Hlavsa et al. 2014; Yoder et al. 2004). CDC defines a recreational water-associated outbreak as the occurrence of similar illnesses in two or more persons, epidemiologically linked by location and time of exposure to recreational water or recreational water-associated chemicals volatilized into the air surrounding the water.

The 2009–2010 reporting cycle was notable, as almost half (46 percent) the recreational water outbreaks reported to CDC were associated with HABs (Hilborn et al. 2014). Three of the outbreaks confirmed the presence of cyanobacteria, and four confirmed the presence of microcystins at levels greater than 20 μg/L. GI and dermatologic symptoms were the most commonly reported symptom categories associated with HAB-related outbreaks in freshwater (Dziuban et al. 2006; Hilborn et al. 2014; Hlavsa et al. 2014; Yoder et al. 2004). For the cyanobacteria-associated outbreaks with reported symptom counts, the most common symptoms reported were GI related, including vomiting, diarrhea, and nausea (estimated to be > 40 percent). The second most frequent outbreak symptom reported was skin rash (> 27 percent cases reported). Fever, earache, skin irritation, and headache were the next most frequently reported symptoms (11 percent, nine percent, and nine percent of cases reported, respectively).

During 2009 and 2010 in the United States, 11 outbreaks of illness associated with HABs were reported to CDC, all occurring in freshwater lakes and reported via the National Outbreak Reporting System (NORS) and the Harmful Algal Bloom-related Illness Surveillance System (HABISS). Hilborn et al. (2014) analyzed the HAB outbreak data from 2009–2010 and found the 11 outbreaks affected at least 61 persons, resulting in two hospitalizations, and included GI, dermatologic, respiratory, neurologic, and other symptoms. Sixty-six percent of case patients were individuals aged one to 19 years (n = 38 of 58 total) and 35 percent were aged nine years or younger (n = 20). In addition, in a cyanobacteria-associated outbreak in 2001, 42 children were affected. Outbreak data are typically limited in scope and thought to represent an underreporting of the "true" occurrence of illness in a population, but available

information suggests that children may share a disproportional share of the health burden associated with recreational exposures to cyanobacterial HABs.

Dziuban et al. (2006) and Walker et al. (2008) reported on outbreaks in Nebraska. Dziuban et al. (2006) described two 2004 cyanobacteria-associated outbreaks in which 22 cases of illness were reported from exposure to Nebraska lakes. The predominant illnesses in both outbreaks included dermatitis and gastroenteritis, and individuals who sought medical care showed a combination of rashes, diarrhea, cramps, nausea, vomiting, and fevers. Walker et al. (2008) also reported about a Nebraska outbreak. Levels of total microcystins at the east swimming beach of Pawnee Lake exceeded 15 ppb on July 12, 2004, and a health alert was issued. However, heavy public use of Pawnee Lake occurred that weekend and more than 50 calls were received from the public, complaining about symptoms such as skin rashes, lesions, blisters, vomiting, headaches, and diarrhea after swimming or water skiing in Pawnee Lake (Walker et al., 2008).

D.2 Mode of Action

Few mechanistic investigations have been completed on how exposure to cyanobacterial cells might lead to inflammatory response. Torokne et al. (2001) evaluated the sensitization and irritation potential of *Microcystis*, *Anabaena*, *Cylindrospermopsis*, and *Aphanizomenon* bloom and strain samples and found no correlation between the cyanotoxin content and allergenicity. For example, the nontoxic *Aphanizomenon* was the most allergenic sample, more allergenic than the most toxic cyanobacterial cells they studied, *Microcystis aeruginosa*. Stewart et al. (2006e) concluded that cutaneous effects strongly suggest allergic reactions, and symptoms such as rhinitis, conjunctivitis, asthma, and urticaria (or hives) also indicate immediate hypersensitivity responses, which are probably explained by a cascade action of pro-inflammatory cytokines.

Bernstein et al. (2011) suggested that the allergenic structure of cyanobacteria might be associated with a non-toxin-producing part of the organism. Building on this conclusion, Geh et al. (2015) conducted a series of experiments to identify the cyanobacteria allergen(s) responsible for sensitization. Study participants were given skin-prick tests with extracts from nontoxic *Microcystis aeruginosa* strains. Serum from these individuals was collected from a subset of 15 patients who elicited strong skin test responses to *Microcystis aeruginosa* and from three healthy control subjects. The lysate from nontoxic *Microcystis aeruginosa* strains was significantly ($p < 0.01$) more immunoreactive than the lysate from the toxin-producing strains, which suggests that the nontoxic strain was more allergenic than the toxic strain. They found, however, that IgE binds to *Microcystis aeruginosa* peptides present in lysates of both the toxic and nontoxic strains. Geh et al. (2015) also performed a β-hexosaminidase release assay, as a surrogate assay for measuring histamine release, to identify functional activity of the *Microcystis aeruginosa* extracts using rat basophil leukemia cells. The authors concluded that the same allergen is present in toxic and nontoxic *Microcystis aeruginosa* lysates, but suggest the toxic *Microcystis aeruginosa* lysate might contain an endogenous inhibitor that prevents IgE from effectively binding to the specific allergen. The further analysis by Geh et al. (2015) of the sera of individuals exposed to nontoxic *Microcystis aeruginosa* lysate indicated that either linker core-membrane peptide or phycocyanin, or both, are potentially responsible for *Microcystis aeruginosa* allergenicity.

Epidemiological studies and case reports suggest respiratory effects that could be consistent with an allergic or hay fever type reaction (Giannuzzi et al. 2011; Stewart et al. 2006e). Inhalation exposure to bacterial endotoxins (i.e., a toxin that is part of the cyanobacterial cell as opposed to exotoxins such as microcystins and cylindrospermopsin) has been found to be associated with pulmonary disease,

including asthma, chronic obstructive airway disease, and emphysema (Stewart et al. 2006b). A recent review of the structure and effects of cyanobacterial LPS suggested that it could act as an antagonist of the TLR4 receptor and inhibit the inflammatory-response pathway (Durai et al. 2015).

Stewart et al. (2006e) also noted that, although symptoms and time to onset can be disparate, several reports described:

> "a collective group of symptoms resembling immediate or Type-I hypersensitivity reactions. Immediate hypersensitivity reactions are commonly associated with atopy, which is the familial tendency to react to naturally occurring antigens, mostly proteins, through an IgE-mediated process. Atopy frequently manifests as a spectrum of diseases, e.g., seasonal rhinitis, conjunctivitis, asthma, and urticaria."

Documentation of this type of respiratory response is consistent with results from Geh et al. (2015) and further supports that immune system response follows exposure to cyanobacteria.

In older literature, cyanobacterial LPS was suspected as being a cause of inflammatory response because this cell structure, also found in many Gram negative bacterial species, has been observed to initiate acute inflammatory responses in mammals that are typical of a host reaction to tissue injury or infection (Stewart et al. 2006b). The Stewart et al. (2006e) review, however, found evidence to support this mechanism lacking. Although all cyanobacteria contain the pigment phycocyanin, not all species of cyanobacteria have shown dermal reactions. Also, some species of cyanobacteria produce toxins that are known dermal irritants (e.g., lyngbyatoxin-a). Pilotto et al. (2004), however, found that 20–24 percent of the study participants exposed to cyanobacterial cells via skin patches for 24 hours showed dermal reactions to cyanobacteria species, both whole and lysed cells.

Stewart et al. (2006b) noted that the effects of microcystin- and cylindrospermopsin-producing bacteria on the GI tract could suggest that cyanotoxins and LPS from the cyanobacteria or other bacteria residing in the gut might cross a gut mucosal barrier that has been disrupted and enhance the adverse effects of cyanotoxins.

An aquatic invertebrate study using brine shrimp (*Artemia salina, Daphnia magna*, and *Daphnia galeata*) to determine the toxicity of microcystin and cylindrospermopsin in combination with cyanobacterial LPS found that pre-exposure to LPS increased the lethal concentration (LC_{50}) of cylindrospermopsin eight-fold (Lindsay et al. 2006). The authors concluded that the decrease in susceptibility to cylindrospermopsin was due to the effects of LPS on detoxification enzyme pathways; LPS decreased toxic metabolites of cylindrospermopsin by suppressing the invertebrate cytochrome P450 system, thus decreasing toxicity.

D.3 References

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APPENDIX E. INCIDENTAL INGESTION EXPOSURE FACTOR COMBINED DISTRIBUTION ANALYSIS

This appendix describes in detail the approach used to derive the value for ingestion rate in units of liters per day. The ingestion rate is used in the derivation of the recommended cyanotoxin values in this document.

To arrive at liters of ingestion per day, the EPA combined data on liters of ingestion per hour and the number of hours spent in the water per day. Both of these parameters were represented as log-normal distributions. The sources of the data were:

- Recreational water ingestion per hour – The lead author of Dufour et al. (2017) provided the EPA's Office of Water, Health and Ecological Criteria Division with the raw data collected and analyzed in the study, which included mL of water ingested during a swimming event. Each participant in the study also reported the length of time they spent in the water. The ingestion per event was normalized to one hour for each participant and converted to liters to arrive at liters ingested per hour. The mean and standard deviation were calculated for different age groups (6 to 10, 11 to 17, 18 years and up, and all ages). See Table E-1 below for summary statistics for this parameter. Subsequent to the EPA's analysis, Dufour et al. posted their raw dataset on data.gov (U.S. EPA 2018). There are few minor variations in the dataset analyzed here and the posted dataset (i.e., the posted dataset included an additional adult participant's results, specified time spent in the water as 45 minutes for two participants, rounded ingestion volumes of 0.5 up to 1, and indicated a higher ingestion volume for one adult woman). The EPA performed a sensitivity analysis to see if these differences impacted the results and found no significant effect. The very slight differences were within the rounding to the third decimal. No differences were observed between the datasets for the results of the combined distribution analysis for the six- to 10-year age group.

- Duration of swimming per day – the EPA's 2011 *Exposure Factors Handbook* (EFH; Table 16-20). Time Spent (minutes/day) in Selected Outdoor Locations, Doers Only, At Home in the Outdoor Pool or Spa). Table E-2 below shows the summary statistics provided by the EPA's EFH.

Table E-1. Parameters Used to Fit Ingestion Distributions

Ingestion Rate (L/hour)				
Age Group (sample size)	**Mean[a]**	**Standard deviation**	**Minimum**	**Maximum**
6 to 10 (child) (n = 66)	0.03745	0.03355	0.00033	0.20000
11 to 17 (child) (n = 170)	0.03996	0.04377	0.00067	0.26800
18+ (adult) (n = 312)	0.02811	0.04960	0.00012	0.36800
All (6 to 50+) (n = 549)	0.03290	0.04643	0.00012	0.36800

[a] Arithmetic mean based on raw data provided by the Dufour et al. (2017) study authors. The ingestion rates for age groups children (6 to 10), teens (11 to 15), and adults (16 and over) were reported as geometric means in Dufour et al. (2017).

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Table E-2. Parameters Used to Fit Recreation Duration Distributions

EPA 2011 EFH (Excerpt from Table 16-20) (minutes/day)					
Age Group (sample size)	**Mean**	**Standard deviation**	**Median (50th percentile)**	**Minimum**	**Maximum**
1 to 4 (n = 9)	85.6	86.3	60	15	255
5 to 11 (n = 15)	164.2	103.97	140	25	450
12 to 17 (n = 5)	97	53.8	100	40	180
18 to 64 (n = 44)	117.6	112.7	83	4	450
> 64 (n = 10)	78.9	85.3	53	1	258

R (open source programming language) was used to perform the calculations described in this appendix. The annotated R code is shown below, following a summary of what calculations were performed and assumptions.

The water ingestion rate per hour data from Dufour were used to compute an arithmetic mean and standard deviation, which are in turn used to compute the log geometric mean (GM) and log geometric standard deviation (GSD) using a mathematical conversion formula. The log GM and log GSD are used as distributional parameters to generate 10,000 random samples representing water ingestion rates per hour of recreational activity (L/hour).

The mean and standard deviation of the number of recreational hours spent in the water per day are reported as summary statistics in the EFH 2011, and are used to compute the log GM and log GSD using a mathematical conversion formula. The log GM and log GSD are used as distributional parameters to generate 10,000 random samples representing water ingestion rates per hour of recreational activity (hour/day).

The two component distributions are assumed to be statistically independent of each other and are multiplied to generate a combined distribution with 10,000 values for the ingestion rate of water per day of recreational activity in L/day. Summary statistics, including the mean, standard deviation, and point estimates of various percentiles, are then computed from the combined distribution. The EPA chose the 90th percentile point estimate for children six to 10 (0.21 L/day) to calculate the recommended cyanotoxin values.

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R Code

```
#Cyanotoxin recAWQC WA

# This script is to combine distributions for water ingestion rate (L/hr) and recreational exposure duration (hr/day) to develop a distribution for ingestion/day (L/day) and to generate a histogram of this combined distribution

# The first distribution is the incidental ingestion rate per hour from the Dufour dataset

# The second distribution is the recreational exposure duration (hr/day) from the EPA 2011 Exposure Factors Handbook Table 16-20. Time Spent (minutes/day) in Selected Outdoor Locations, Doers Only, At Home in the Outdoor Pool or Spa

# Both distributions are assumed to be log-normal


#####Read required libraries and set simulation sample size ##################


rm(list=ls()) # Remove all current R objects from memory


library(truncnorm) #import library for truncated normal distribution


nsamp = 1000000 # specify number of samples in monte-carlo analysis


set.seed(1984756) # set seed for analysis replicability


#########################################################


# The combined distribution function (cdist) assumes a log-normal distribution for ingestion rate (L/hour) and a log-normal distribution for exposure duration (hr/d)

#....using the mean and sd as parameter inputs. This function is called in later sections of the code for each age group analysis.


cdist<-function(nsamp,mean_dur,sd_dur,min_dur,max_dur,mean_ing,sd_ing,min_ing,max_ing){
```

```
n<-nsamp # number of samples to be drawn

#transform mean and sd of duration

sd_dur_ln<-sqrt(log((sd_dur/mean_dur)^2+1)) # standard deviation of duration in log space
mean_dur_ln<-log(mean_dur)-((sd_dur_ln^2)/2) # mean of duration in log space
min_dur_ln<-log(min_dur) # minimum duration in log space
max_dur_ln<-log(max_dur)

#transform mean and sd of ingestion rate

sd_ing_ln<-sqrt(log((sd_ing/mean_ing)^2+1))
mean_ing_ln<-log(mean_ing)-((sd_ing_ln^2)/2)
min_ing_ln<- -10^10
max_ing_ln<-log(max_ing)

# draw n samples from the truncated ingestion rate distribution in L/hr

ingperhr_ln_trunc<-exp(rtruncnorm(n=n, a=min_ing_ln, b=max_ing_ln, mean=mean_ing_ln,
sd=sd_ing_ln)) #truncated log normal distribution

# draw n samples from the truncated duration distribution (hr/d)

duration_hr_ln_trunc<-exp(rtruncnorm(n=n, a=min_dur_ln, b=max_dur_ln, mean=mean_dur_ln,
sd=sd_dur_ln))

# compute n samples for the combined ingestion rate per day distribution (L/d)

ingperday<-ingperhr_ln_trunc*duration_hr_ln_trunc #combine distributions
```

```
  print(summary(ingperday)) # print summary statistics of the combined distribution

  print(quantile(ingperday, probs=0.90)) # print 90th percentile of the combined distribution

  #Generate histogram

  hist(ingperday,xlab="Ingestion rate (L/day)",ylab="Probability", main ="Truncated hybrid distribution fit", xlim=c(0, 2.0), ylim=c(0, 1))
  h=hist(ingperday)
  h$density=h$counts/sum(h$counts)
  plot(h,xlab="Ingestion rate (L/day)",ylab="Probability", main ="Log-normal distribution fit", xlim=c(0, 1), ylim=c(0, 0.99), xaxp=c(0,1.5,15), freq=FALSE)

}

#########################################################

#I. Analysis for 6 to 10 age group

# These values are from 2011 EFH table 16-20 for ages 5 to 11.

mean_dur_min=164.2
sd_dur_min=103.97
min_dur_min=25
max_dur_min=450

# Convert exposure data from the EPA's EFH from min/day to hr/day

mean_dur<-mean_dur_min/60 #mean exposure duration hr/day
```

```
sd_dur<-sd_dur_min/60 #sd exposure duration hr/day

min_dur<-min_dur_min/60 #minimum exposure duration hr/day

max_dur<-max_dur_min/60 #maximum exposure duration hr/day


# These ingestion rate values are computed from the Dufour dataset


mean_ing<- 0.03745 # mean ingestion rate in L/hr

sd_ing<-0.03355 # sd ingestion rate in L/hr

min_ing<-0.00033 # minimum ingestion rate in L/hr

max_ing<-0.20000 # maximum ingestion rate in L/hr


cdist(nsamp,mean_dur,sd_dur,min_dur,max_dur,mean_ing,sd_ing,min_ing,max_ing) # call combined
distribution function



##########################################################


#II. Analysis for 11 to 17 age group


# These values are from 2011 EFH table 16-20 for age 12 to 17

mean_dur_min=97

sd_dur_min=53.81

med_dur_min=100

min_dur_min=40

max_dur_min=180


# Convert exposure data from the EPA's EFH from min/day to hr/day


mean_dur<-mean_dur_min/60 #mean exposure duration hr/day
```

```
sd_dur<-sd_dur_min/60 #sd exposure duration hr/day
med_dur<-med_dur_min/60 #median exposure duration hr/day
min_dur<-min_dur_min/60 #minimum exposure duration hr/day
max_dur<-max_dur_min/60 #maximum exposure duration hr/day

# These ingestion rate values are computed from the Dufour dataset

mean_ing<-0.03996 # mean ingestion rate in L/hr
sd_ing<-0.04377 # sd ingestion rate in L/hr
min_ing<-0.00067 # minimum ingestion rate in L/hr
max_ing<-0.26800 # maximum ingestion rate in L/hr

cdist(nsamp,mean_dur,sd_dur,min_dur,max_dur,mean_ing,sd_ing,min_ing,max_ing) # call combined
distribution function

#########################################################

#III. Analysis for 18+ age group
# Combine exposure duration data for 18 to 64 and for >64 age groups from 2011 EFH table 16-20.

mean_dur_min=(117.61+78.9)/2
sd_dur_min=sqrt((112.72^2+85.32^2)/2)
min_dur_min=1
max_dur_min=450

# Convert exposure data from the EPA's EFH from min/day to hr/day

mean_dur<-mean_dur_min/60 #mean exposure duration hr/day
```

```
sd_dur<-sd_dur_min/60 #sd exposure duration hr/day

min_dur<-min_dur_min/60 #minimum exposure duration hr/day

max_dur<-max_dur_min/60 #maximum exposure duration hr/day


# These ingestion rate values are computed from the Dufour dataset


mean_ing<-0.02811 # mean ingestion rate in L/hr

sd_ing<-0.04960 # sd ingestion rate in L/hr

min_ing<-0.00012 # minimum ingestion rate in L/hr

max_ing<-0.36800 # maximum ingestion rate in L/hr


cdist(nsamp,mean_dur,sd_dur,min_dur,max_dur,mean_ing,sd_ing,min_ing,max_ing) # call combined
distribution function



##########################################################


# IV. Analysis for all age groups (including 1-4 yo)


# Combine exposure duration data for all age groups (1 to 4, 5 to 11, 12 to 17, 18 to 64, >64) from 2011
EFH table 16-20.


mean_dur_min=(85.56+164.2+97+117.61+78.9)/5

sd_dur_min=103.71 # SD reported in EFH for all ages

min_dur_min=1

max_dur_min=450


# Convert exposure duration data from min/day to hr/day


mean_dur<-mean_dur_min/60 #mean exposure duration hr/day
```

```
sd_dur<-sd_dur_min/60 #sd exposure duration hr/day
min_dur<-min_dur_min/60 #minimum exposure duration hr/day
max_dur<-max_dur_min/60 #maximum exposure duration hr/day

# These ingestion rate values are computed from the Dufour dataset

mean_ing<- 0.03290 # mean ingestion rate in L/hr
sd_ing<- 0.04643 # sd ingestion rate in L/hr
min_ing<-0.00012 # minimum ingestion rate in L/hr
max_ing<-0.36800 # maximum ingestion rate in L/hr

cdist(nsamp,mean_dur,sd_dur,min_dur,max_dur,mean_ing,sd_ing,min_ing,max_ing) # call combined distribution function
```

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APPENDIX F. INGESTION STUDIES

The EPA reviewed seven studies to evaluate recreation-associated incidental ingestion (DeFlorio-Barker et al. 2017; Dorevitch et al. 2011; Dufour et al. 2006, 2017; Schets et al. 2011; Schijven and de Roda Husman 2006; Suppes et al. 2014). Evans et al. 2006 was also reviewed, but is the same dataset as Dufour et al. (2017), so it is not included in the table. The EPA's approach for estimating incidental exposure while swimming used by the EPA's Office of Pesticide Programs (OPP) is also summarized below.

F.1 DeFlorio-Barker et al. (2017)

DeFlorio-Barker et al. (2017) combined ingestion data from Dufour et al. (2017) and time spent in the water data from 12 cohorts of epidemiological studies to estimate the volume of water ingested per swimming event. They calculated the ingested volume per minute (mL/minute) for each Dufour et al. (2017) study participant, using the mL ingested and the self-reported time spent in the water for each participant. The National Epidemiological and Environmental Assessment of Recreational Water Study and Southern California Coastal Water Research Project epidemiological studies included 68,685 recreators at four freshwater and eight marine beaches. The participants in these studies estimated how much time they spent in the water. DeFlorio-Barker et al. (2017) combined the mL/minute ingestion rate from Dufour et al. (2017) and the self-reported time spent in the water for the epidemiological study participants to calculate the volume of water ingested per event. The results of this study corroborate other studies that demonstrate that, on average, children have higher incidental ingestion than adults when recreating.

F.2 Dorevitch et al. (2011)

Dorevitch et al. (2011) evaluated incidental ingestion associated with multiple types of water contact activities in both surface water (canoeing, fishing, kayaking, motor boating, and rowing) and in pools (canoeing, fishing, kayaking, swimming, wading/splashing, and walking around the pool as a control). The surface water activities did not include swimming because the water body was designated for secondary contact recreation only. Volume of ingestion was self-reported via interviews (3,367 participants: 2,705 individuals recreating in the Chicago Area Waterway System (CAWS, surface water) and 662 individuals recreating at a public outdoor swimming pool). At the end of their exposure, participants self-reported whether they ingested water, and how much, during their recreational experience. The authors used a subset of the pool exposures to assess cyanuric acid in urine to determine the accuracy of the self-reported ingestion volumes. There was strong agreement between self-reported results and cyanuric acid measurement (none = 0.0014±0.008 L; drop to teaspoon = 0.0094±0.011 L; mouthful = 0.026±0.037 L).

The results indicate that the odds of ingesting a teaspoon or more of water are significantly higher among swimmers than among those who just immersed their head in a swimming pool or those who participated in the other, more limited contact activities on surface waters. More specifically, rowing, motor boating, fishing, wading/splashing, and non-capsizing kayaking and canoeing were found to be low-ingestion activities, resulting in 95 percent upper confidence limit ingestion volumes between 0.01 and 0.012 L/hour. Less than five percent of limited contact recreators on surface waters reported swallowing any water. The study authors considered those who capsized during canoeing or kayaking a "middle ingestion category," with mean incidental ingestions of 0.006 to 0.005 L/hour. Swimmers were the highest ingestion category, with a mean of 0.01 L/hour. Swimmers in a pool were more than

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50 times as likely to report swallowing a teaspoon of water compared to people who canoed or kayaked in surface waters.

In surface water, participants ages six years and above incidentally ingested the most water while canoeing and capsizing compared to any other activity assessed (median = 0.0036 L; mean = 0.006 L; Upper 95 percent CI: 0.0199 L). Kayaking and capsizing in surface water resulted in nearly as high incidental ingestion (mean = 0.005 L; Upper 95 percent CI: 0.0165). In swimming pool water, participants ages six and above incidentally ingested the most water while swimming compared to any other activity assessed (median = 0.006 L; mean = 0.01 L; Upper 95 percent CI: 0.0348 L). Duration of activities was not reported, so the ingestion volumes are on a per event basis.

F.3 Dufour et al. (2006)

The EPA's *Exposure Factors Handbook* (EFH) (2011) presents values for incidental ingestion while recreating values citing Dufour et al. (2006). Dufour et al. (2006) measured the incidental ingestion of water while participants were swimming in a pool and found that children under the age of 18 ingested higher volumes of water while swimming than adults. The 2006 study design instructed participants to swim for at least 45 minutes, so the time the participants spent in the water is probably not representative of preferred or regular patterns for recreation duration and the actual duration was not recorded. Both studies reported higher ingestion among children compared to adults. The values presented in the EFH adjusted the Dufour et al. (2006) data from a per event basis to an hourly ingestion rate. The EFH recommends using the 97th percentile ingestion rate for children and the maximum reported value for adults because the dataset is limited (U.S. EPA 2011).

F.4 Evans et al. (2006)

Evans et al. (2006) presented results from an observational study of incidental water ingestion during recreational swimming activities using the same methodology as the Dufour et al. (2006) pilot study. This study characterized ingestion volumes for younger children verses older children and adults. Evans et al. (2006) reported higher ingestion volumes for younger children. Although study results were presented at a conference, they were not published, so the EPA did not cite this publication in the derivation of the recommended cyanotoxin values. However, Dufour et al. (2017) includes the data reported by Evans et al. (2006).

F.5 Schets et al. (2011)

A study in the Netherlands by Schets et al. (2011) used questionnaires to collect estimates of water swallowed while swimming/bathing in freshwater, marine water, and swimming pools. Of the 8,000 adults who completed the questionnaire, 1,924 also provided estimates for their eldest child (< 15 years of age). The participants estimated the amount of water they or their children swallowed while swimming. Participants chose between four categories of water volumes: (1) no water or only a few drops; (2) one to two mouthfuls (a shot glass); (3) three to five mouthfuls (coffee cup); and (4) six to eight mouthfuls (soda glass). Schets et al. (2011) also conducted a series of experiments to measure the amount of water that corresponded to a mouthful of water and converted the data in the four response categories to volumes of water ingested per event. Adult men swallowed, on average 0.030 L/hour and women swallowed 0.020 L/hour, with somewhat greater ingestion in marine waters than in freshwater or a swimming pool. In fresh and marine waters children swallowed about the same as adults, and in swimming pools they ingested more than adults, on average, 0.038 L/hour compared with 0.030 and 0.021 for males and females, respectively (Schets et al. 2011). The EPA made the assumption that

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exposure in a swimming pool is roughly equivalent to exposure in fresh and marine waters. Schets (2011) supports that assumption, although it is a somewhat more conservative assumption for children. However, when bodyweight is taken into account the greater exposure to children versus adults becomes clear. Additional research would be helpful to clarify uncertainty in differences in ingestion from different types of waters.

F.6 Schijven and de Roda Husman (2006)

Schijven and de Roda Husman (2006) studied sport and occupational diver incidental ingestion. The types of water studied for occupational divers (n = 37 divers) were open sea and coastal marine water, and freshwater. For sport divers (n = 483 divers), the types of water considered were open sea and coastal marine water, fresh recreational water, canals and rivers, city canals, and swimming pools. The divers were asked to estimate how much water they swallowed in terms of: none, few drops, shot glass, coffee cup, or soda glass. The authors translated the description of volumes from the questionnaires into average volumes. Occupational divers reported incidentally ingesting more water per dive in marine water (mean: 0.0098 L/dive; maximum: 0.1 L/dive) compared to freshwater (mean: 0.0057 L/dive; maximum: 0.025 L/dive). Sports divers wearing an ordinary diving mask reported incidentally ingesting the most water per dive in swimming pools (mean: 0.02 L/dive; maximum: 0.19 L/dive), followed by recreational freshwater (mean: 0.013 L/dive; maximum: 0.19 L/dive) and coastal marine water (mean: 0.0099 L/dive; maximum: 0.19 L/dive). Sports divers wearing a full face mask reported incidentally ingesting less water than sports divers wearing an ordinary diving mask. The mean ingestion rates in freshwater ranged from 0.0015 to 0.019 L/hour, with the highest mean being for adult recreational divers wearing an ordinary diving mask and the lowest mean for adult recreational divers wearing a full face mask. The mean ingestion rates in marine water ranged from 0.0005 to 0.014 L/hour, with the highest mean being for adult recreational divers wearing an ordinary diving mask and the lowest mean for adult recreational divers wearing a full face mask. The age of the divers was not included in the study report. Occupational divers dived on average 60–95 minutes and sport divers dived on average 42–52 minutes per dive.

F.7 Suppes et al. (2014)

Suppes et al. (2014) used a similar measurement method as Dufour et al. (2006, 2017), (i.e., using cyanuric acid as an indicator of pool water ingestion) to evaluate the rate of water ingested by 16 children ages five to 17 years. They and found that children on average ingested pool water at a higher rate than adult participants. Total time in water, quantified by viewing videos, was used to adjust pool water ingestion volumes to obtain rates. After adjustments for false-positive measurements were applied, the mean rate at which adults ingested water was 0.0035 L/hour with range 0–0.051 L. The mean rate at which children ingested water was 0.026 L/hour with range 0.0009–0.106 L/hour.

F.8 U.S. EPA (2003)

Additional estimates of incidental water ingestion rates while swimming in pools have been identified by the EPA's OPP. OPP calculated people's exposures to pool chemicals while they swim using its Swimmers Exposure Assessment Model (SWIMODEL) (U.S. EPA 2003). SWIMODEL uses incidental ingestion values for children that are twice the values used for adults. Incidental ingestion rates among adults while swimming competitively and noncompetitively are 0.0125 L/hour and 0.025 L/hour, respectively. The model assumes an incidental ingestion rate of 0.050 L/hour for children ages seven to 10 years and 11 to 14 years while swimming noncompetitively. The 0.050 L/hour value is the value used

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in the EPA OPP's Standard Operating Procedures (U.S. EPA 2000) and is based on recommendations from EPA's Risk Assessment Guidance for Superfund, Part A (U.S. EPA 1989, 2000, 2003).

F.9 Summary

Although these studies used different methodologies and have limitations with respect to reporting information for different age group categories, their results show a similar pattern compared to Dufour et al. (2006, 2017): children ingest water at a higher rate while swimming than adults. Dufour et al. (2017) and Dufour et al. (2006) identified mean ingestion rates for children of 0.037–0.040 and 0.049 L/hour, respectively, and adult rates of 0.028 and 0.021 L/hour, respectively. Depending on water type, Schets et al. (2011) found a mean ingestion volume for children aged zero to 14 years of 0.028–0.038L/hour for children and 0.020–0.036 L/hr for males and females. The most pronounced differences were for swimming pools, where children ingested at a higher rate (0.038 L/hour) than adults (males: 0.030 L/hour; females: 0.021 L/hour). Dorevitch et al. (2011) reported ingestion rates while swimming for all ages of 0.010L/hour. Suppes et al. (2014) reported an adjusted mean ingestion rate of 0.026 L/hour for children and a rate of 0.0035 L/hour for adults.

Table F-1 includes: sample size, measurement methodology, the maximum values or the upper confidence intervals (CI) for the mean ingestion per event, time spent in the water (mean or range), and the mean ingestion volume normalized to one hour (or range if a range of durations were reported). This information supports comparison of the studies and help with understanding the range of different recreational exposures from activities.

The column with normalized ingestion (mL/hour) was populated using the following methods:

- Dufour et al. (2017) – The EPA used the individual data points from this dataset. Each participant's volume ingested was adjusted to one hour based on the length of time that participant reported being in the water.

- Dufour et al. (2006) – The EPA assumed that all swimming events were 45 minutes in duration. The values reported in Table F-1 are the same as the values in EPA's EFH (2011).

- DeFlorio-Barker et al. (2017) – Normalized data are not included in Table F-1 because the authors used the Dufour et al. (2017) rate in their modeling, so including the normalized data would be duplicative of Dufour et al. (2017).

- Dorevitch et al. (2011) – Study authors included normalized values in the study publication.

- Schets et al. (2011) – The EPA used the mean duration values provided in the publication to calculate the normalized value for each age and activity category.

- Suppes et al. (2014) – Study authors reported volume per hour.

- Schijven and de Roda Husman (2006) – The EPA used the range of duration values provided in the publication to calculate the normalized value for each activity category.

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Table F-1. Studies of Incidental Ingestion Volumes While Recreating

Reference	Study Sample Size	Measurement Methodology	Water Type, Recreational Activity	Age Group[a] (Years Old)	Mean Ingestion (Maximum Value) (mL/event)	Mean Duration of Event (minutes)	Normalized Ingestion (mL/hour)
Dataset from Dufour (data collection methods reported in Dufour et al. (2017))[b]	>500	Cyanuric acid was measured in pool water and urine samples, and ingestion rate was calculated based on duration of swimming event	Swimming pool, Swimming	6 to 10	59.8 (245)	each participant reported a duration[c]	37
				11 to 17	35.6 (267)	each participant reported a duration[c]	40
				18+	23.7 (279)	each participant reported a duration[c]	28
				All ages (6+)	31.7 (279)	each participant reported a duration[c]	33
Dufour et al. (2006)	53	Cyanuric acid was measured in pool water and urine samples	Swimming pool, Swimming	6 to ≤ 18	37 (NR)	≥ 45	49
				18+	16 (NR)	≥ 45	21
				All ages (6+)	32 (NR)	≥ 45	43
DeFlorio-Barker et al. (2017)	12 cohorts totaling 68,685	Estimates of amount of water swallowed were self-reported	Freshwater	6 to 10	58.9 (142)[d]	(NR)	–
				11 to 17	55.5 (140) [d]	(NR)	–
				18+	21.9 (46.7)[d]	(NR)	–
			Marine Water	6 to 10	74.4 (180)[d]	(NR)	–
				11 to 17	75.6 (186.7)[d]	(NR)	–
				18+	32.4 (72) [d]	(NR)	–
Dorevitch et al. (2011)	3,367	Estimates of amount of water swallowed were self-reported	Surface water, Canoeing/capsizing	All ages (6+)	6 (19.9)[e]	No duration constraints	–
			Surface water, Kayaking/capsizing	All ages (6+)	5 (16.5)[e]	No duration constraints	–
		Estimates of amount of water swallowed were self-reported; cyanuric acid was measured in urine in a subset of participants	Swimming pool, Swimming	All ages (6+)	10 (34.8)[e]	60	10
			Swimming pool, Canoeing/capsizing	All ages (6+)	6.6 (22.4)[e]	60	6.6
			Swimming pool, Kayaking/capsizing	All ages (6+)	7.9 (7.9)[e]	60	7.9

Reference	Study Sample Size	Measurement Methodology	Water Type, Recreational Activity	Age Group[a] (Years Old)	Mean Ingestion (Maximum Value) (mL/event)	Mean Duration of Event (minutes)	Normalized Ingestion (mL/hour)
Schets et al. (2011)	9,924 (1,924 of which were children)	Descriptive estimates of the amount of water swallowed were self-reported by participants or parents of participants, and estimates were converted to volumes	Freshwater, Swimming	0 to 14	37 (170)[e]	79	28
				15+, males	27 (140)[e]	54	30
				15+, females	18 (86)[e]	54	20
			Marine water, Swimming	0 to 14	31 (140)[e]	65	29
				15+, males	27 (140)[e]	45	36
				15+, females	18 (90)[e]	41	26
			Swimming pool, Swimming	0 to 14	51 (200)[e]	81	38
				15+, males	34 (170)[e]	68	30
				15+, females	23 (110)[e]	67	21
Suppes et al. (2014)	38	Cyanuric acid was measured and total time in water was quantified using videos to adjust ingestion volumes to rates; authors adjusted ingestion volumes to correct for potential false-positive measurements from cyanuric acid carry-over between sample injections	Swimming pool, Swimming (adjusted)	5 to 17	26 (106)	60[f]	26
				18+	4 (51)	60[f]	3.5
				All ages (5+)	14 (106)	60[f]	14
			Swimming pool, Swimming (unadjusted)	5-17	59 (225)	60[f]	59
				18+	9 (NR)	60[f]	9
				All ages (5+)	32 (NR)	60[f]	32
Schijven and de Roda Husman (2006)	517	Descriptive estimates of the amount of water swallowed were self-reported, and estimates were converted to volumes	Freshwater, Recreational diving w/ordinary diving mask	Adults	13 (190)	42 to 52	15 to 19
			Freshwater, Recreational diving w/full face mask	Adults	1.3 (15)	42 to 52	1.5 to 1.9
			Freshwater, Occupational diving	Adults	5.7 (25)	60 to 95	4 to 6
			Marine Water (coastal), Recreational diving w/ordinary diving mask	Adults	9.9 (190)	42 to 52	11 to 14

Reference	Study Sample Size	Measurement Methodology	Water Type, Recreational Activity	Age Group[a] (Years Old)	Mean Ingestion (Maximum Value) (mL/event)	Mean Duration of Event (minutes)	Normalized Ingestion (mL/hour)
			Marine water (coastal), Recreational diving w/full face mask	Adults	1.3 (15)	42 to 52	1.5 to 1.9
			Marine Water (open sea), Recreational diving w/ordinary diving mask	Adults	7.7 (100)	42 to 52	9 to 11
			Marine water (open sea), Recreational diving w/full face mask	Adults	0.43 (2.8)	42 to 52	0.5 to 0.6
			Marine Water (coastal and open sea combined), Recreational diving w/ordinary diving mask	Adults	9.0 (190)	42 to 52	10 to 13
			Marine water (coastal and open sea combined), Occupational diving	Adults	9.8 (100)	60 to 95	6 to 10
			Swimming pool, Recreational diving w/ordinary diving mask	Adults	20 (190)	42 to 52	23 to 29
			Swimming pool, Recreational diving w/full face mask	Adults	13 (190)	42 to 52	15 to 19

[a] Age group ranges reflect the age groupings reported in the study. In some cases the authors did not separate data by different age groups among children or between adults and children.

[b] The values shown are arithmetic means calculated from the Dufour dataset. The Dufour et al. (2017) publication reported ingestion volumes as geometric means for children (6 to 10 years), teens (11 to 15 years), and adults (16 years and over).

[c] Each participant's volume ingested was adjusted to one hour based on the length of time that participant reported being in the water.

[d] No maximum values are reported in the study; 90th provided percentile in parentheses.

[e] No maximum values are reported in the study; upper limit of the CI is provided.

[f] Swimming duration was reported as ≥ 45 minutes, however authors derived and reported only hourly ingestion per event.

APPENDIX G. INFORMATION ON CELLULAR CYANOTOXIN AMOUNTS

The information in the tables in this appendix was generated from a brief survey of the peer-reviewed and published scientific literature. This survey was not a formal systematic literature search and was conducted to evaluate the availability of data needed to calculate a cyanobacterial cell density potentially associated with a specific cyanotoxin concentration.

The information in Tables G-3 and G-4 was generated from both a brief survey and a standardized search of the peer-reviewed and published scientific literature. The purpose of these searches was to evaluate the availability of cyanotoxin quota data (i.e., cyanotoxin content per cyanobacterial cell or per unit biomass, for microcystins and cylindrospermopsin) needed to calculate a cyanobacterial cell density potentially associated with a specific cyanotoxin concentration.

The EPA conducted a brief initial survey of the available peer-reviewed and published scientific literature in December 2016 and identified 29 studies with data on cellular toxin amounts. After reviewing the available data, a formal literature search was conducted. The purpose of this literature search and screening was to identify literature relevant to answering the following research question: What cyanotoxin cell quota data (i.e., cyanotoxin content per cyanobacterial cell or per unit biomass, for microcystins and cylindrospermopsin) are available in the peer-reviewed literature?

Search terms were identified with support from a subject matter expert and library science professionals and included genera of known microcystins or cylindrospermopsin producers, names of the toxins of interest, and keywords that could indicate that quota data were reported. The search was conducted in PubMed and results were limited to articles published in English from 1987 to March 2017. A summary of the literature search results is provided in Table G-1.

Table G-1. Summary of Cyanotoxin Cell Quota Data Literature Search Results

Database	Results	Notes/Limits
PubMed	253	1987 to present; English
Web of Science	472	1987 to present; English
Total Unique	**485**	

The EPA developed search strategies for each database. Both search strategies included the same set of keywords but varied in how these keywords were strung together. The Web of Science search strategy also included limits, a feature not characteristic of a search strategy conducted using PubMed. The search strategies are provided below.

PubMed

Date of Search: 3/01/2017
Date Limit: 1987 to present
Language = English

Set	PubMed Search Strategy
1	(Anabaena[tiab] OR Anabaena[mh] OR Anabaena-flos-aquae[tiab] OR Anabaenopsis[tiab] OR Aphanizomenon[tiab] OR Aphanizomenon[mh] OR C.-raciborskii[tiab] OR Chrysosporum-ovalisporum[tiab] OR Cuspidothrix[tiab] OR Cylindrospermopsis[tiab] OR Cylindrospermopsis[mh] OR Cylindrospermopsis-raciborskii[tiab] OR Cylindrospermum[tiab] OR Dolichospermum[tiab] OR Fischerella[tiab] OR Gloeotrichia[tiab] OR Lyngbya[tiab] OR

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Set	PubMed Search Strategy
	M.-aeruginosa[tiab] OR Microcystis[tiab] OR Microcystis[mh] OR Microcystis-aeruginosa[tiab] OR Nostoc[tiab] OR Nostoc[mh] OR Oscillatoria[tiab] OR Oscillatoria[mh] OR Phormidium[tiab] OR Planktothrix[tiab] OR Sphaerospermopsis[tiab] OR Synechococcus[tiab] OR Synechococcus[mh])
2	AND (microcystin[tiab] OR microcystins[tiab] OR microcystins[mh] OR cylindrospermopsin[tiab] OR cylindrospermopsin[Supplementary Concept])
3	AND (quota[tiab] OR cell-content[tiab] OR cellular-concentration[tiab] OR cyanotoxin-content[tiab] OR intracellular-content[tiab] OR intracellular-concentration[tiab] OR toxin-content[tiab] OR microcystin-content[tiab] OR microcystin-LR-content[tiab] OR MC-content[tiab] OR MCYST-content[tiab] OR MC-LR-content[tiab] OR intracellular-microcystin[tiab] OR intracellular-MC[tiab] OR microcystin-production[tiab] OR microcystin-LR-production[tiab] OR microcystins-production[tiab] OR MC-production[tiab] OR MCYST-production[tiab] OR MC-LR-production[tiab] OR CYN-content[tiab] OR particulate-CYN[tiab] OR cylindrospermopsin-production[tiab])

Web of Science
Date of Search: 3/01/2017
Date Limit: 1987 to present
Language = English
All terms searched in Topic (Title, Abstract, and Keywords)

Set	Web of Science Search Strategy
1	(Anabaena OR Anabaena-flos-aquae OR Anabaenopsis OR Aphanizomenon OR C.-raciborskii OR Chrysosporum-ovalisporum OR Cuspidothrix OR Cylindrospermopsis OR Cylindrospermopsis-raciborskii OR Cylindrospermum OR Dolichospermum OR Fischerella OR Gloeotrichia OR Lyngbya OR M.-aeruginosa OR Microcystis OR Microcystis-aeruginosa OR Nostoc OR Oscillatoria OR Phormidium OR Planktothrix OR Sphaerospermopsis OR Synechococcus)
2	AND (microcystin OR microcystins OR cylindrospermopsin)
3	AND (microcystin-RR-content OR MC-RR-content OR particulate-microcystin OR particulate-MC OR cylindrospermopsin-content OR intracellular-CYN OR quota OR cell-content OR cellular-concentration OR cyanotoxin-content OR intracellular-content OR intracellular-concentration OR toxin-content OR microcystin-content OR microcystin-LR-content OR MC-content OR MCYST-content OR MC-LR-content OR intracellular-microcystin OR intracellular-MC OR microcystin-production OR microcystin-LR-production OR microcystins-production OR MC-production OR MCYST-production OR MC-LR-production OR CYN-content OR particulate-CYN OR cylindrospermopsin-production)
Limits	AND Research Areas: (AGRICULTURE OR OCEANOGRAPHY OR ENVIRONMENTAL SCIENCES ECOLOGY OR PHARMACOLOGY PHARMACY OR EVOLUTIONARY BIOLOGY OR BIOCHEMISTRY MOLECULAR BIOLOGY OR FISHERIES OR PLANT SCIENCES OR BIODIVERSITY CONSERVATION OR PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH OR RESEARCH EXPERIMENTAL MEDICINE OR BIOTECHNOLOGY APPLIED MICROBIOLOGY OR SCIENCE TECHNOLOGY OTHER TOPICS OR CELL BIOLOGY OR CHEMISTRY OR LIFE SCIENCES BIOMEDICINE OTHER TOPICS OR TOXICOLOGY OR MARINE FRESHWATER BIOLOGY OR WATER RESOURCES OR METEOROLOGY ATMOSPHERIC SCIENCES OR ZOOLOGY OR MICROBIOLOGY)

The EPA conducted title and abstract screening of the 253 search results (generated from both database searches) and classified them as "relevant," "maybe relevant," or "not relevant." Titles were considered "relevant" if the title or abstract included mention of cell quota data for microcystins or

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cylindrospermopsin or if the title or abstract indicated that the study had quantitative information on cyanobacterial cell density and microcystins or cylindrospermopsin concentration and therefore may contain sufficient data to calculate a quota. Titles were considered "maybe relevant" if the title or abstract indicated the article might have information relevant to the research question. Title and abstract did not specifically include the term "quota" but indicated that it may have had quantitative information on cyanobacterial cell density and microcystins or cylindrospermopsin concentration or if cyanobacterial cells were only quantified by molecular methods such as PCR and toxin concentrations were measured. Titles were considered "not relevant" if the title/abstract did not appear to have information about microcystins or cylindrospermopsin quotas or densities/concentrations, if the study was a spiked cyanotoxin experiment (meaning cyanotoxins were added, not produced by cyanobacteria present), or if the study was not a peer-reviewed article, book, or government document.

The EPA prioritized the studies to facilitate the review. Prioritization yielded a high number of studies classified as "relevant" or "maybe relevant." Relevant studies were further prioritized for each cyanotoxin of interest based on date of publication. The approach for prioritization is presented in Table G-2. A full text review was conducted on Priority 1 studies only.

Table G-2. Summary of Study Prioritization

Toxin	Priority 1 Classification Criteria	Priority 2 Classification Criteria	Priority 3 Classification Criteria
Microcystins	Classified as relevant based on title/abstract screening; Did not use PCR quantification or evaluate benthic cyanobacteria; Identified predominant species without statistical analysis; Published in last 5 years; and Field study or study with both field and laboratory component.	Studies that use only PCR for quantification of cyanobacteria; and All laboratory studies (internal or external forcing, mitigation studies, studies evaluating non-nutrient pollutants).	Methods studies; and Studies on benthic cyanobacteria.
Cylindrospermopsin	Classified as relevant based on title/abstract screening; Did not use PCR quantification or evaluate benthic cyanobacteria; Identified predominant species without statistical analysis; Published in last 10 years; and Field study or laboratory study.	Studies that use only PCR for quantification of cyanobacteria.	Methods studies; and Studies on benthic cyanobacteria.

Extracted data from studies meeting the criteria for "Priority 1" are presented below in Table G-3 and are further summarized in Table G-4. Relevant quota data were extracted from both the text and figures in "Priority 1" studies. All figures were digitized using GraphPad Digitizer software, as appropriate. All extracted data from text and figures underwent primary and secondary review for quality assurance purposes.

The EPA's primary interest when reviewing the data was to identify the amount of toxin per cyanobacterial cell when toxin was present in a sample. In the environment, it is possible for cyanobacterial cells to be present with no toxin being produced (e.g., the cyanobacteria are a non-toxin-producing strain or environmental conditions do not support toxin production). The EPA only included quota data where toxin was detected.

The studies included in Table G-3 vary in methods used, conditions evaluated, and presentation of data. Typically, complete, raw data were unavailable. The EPA made choices regarding selection, presentation, aggregation, and conversion of data to develop the necessary standardization required for comparing and analyzing these data. Specifically, if quota values were from the same sample at a single location, the average and range were recorded; results from different sampling locations were recorded separately; and multiple mean quota values within the same study were recorded separately (note that separate mean values could be reported for different sampling sites or species within the same genera).

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The EPA found that study authors report toxin quota data in various forms, including but not limited to toxin mass per cyanobacterial cell, toxin mass per cyanobacterial biomass, and toxin mass per cyanobacterial biovolume. Scientific measurement units vary among studies. The EPA presents the cell quota data in Table G-3 in the units reported by the study authors (i.e., without conversion to standard units). However, when possible, the EPA converted data to a standard set of units, picograms (pg) per cell, in Table G-4 so that data could be summarized and compared. The EPA did not identify appropriate conversion factors that would allow genus-specific conversion of quotas described in mass per biovolume to mass per cell or mass per biomass to mass per cell. The EPA considered converting biovolume quotas using methods cited in the Australian national guidelines (Australian Government National Health and Medical Research Council, 2008) and Ackaalan (2006), but ultimately decided that the number of uncertainties associated with these methods were too great. Thus, data with unique units are summarized separately in Table G-3, Table G-4, and Table 7-14.

Within Table G-3 and Table G-4, the EPA categorized studies as either "field" or "lab." Field studies include studies where environmental samples were collected and analyzed for cell quota data without additional manipulation of growing conditions. In some studies, environmental samples were taken to a laboratory where growing conditions were optimized or manipulated to determine cyanotoxin cell quota. These studies were categorized as laboratory studies. Other laboratory studies analyzed cell quota in laboratory strains that were not collected in the environment for the purpose of the analysis. For laboratory studies, only control data were extracted. In laboratory studies where there was no true control the conditions closest to ambient conditions were selected (e.g., multiple conditions were tested and none was the clear control, all data were included).

While the traditional definition of toxin quota refers to the intracellular amount of toxin, some studies presented the total toxin present normalized by the cell density or the extracellular toxin normalized by cell density as a quota. In other cases, methods for calculation of the quota were not very clear. If a quota value was presented (i.e., intracellular toxin per cell) this was recorded. If this value was not available or was not clearly described, was recorded as presented by the study authors and assumed to be intracellular or the total amount of toxin per cell. Extracellular toxin per cell was not recorded. The EPA recognizes that the exclusion of extracellular toxin data could lead to an underestimation of the amount of toxin per cell, in particular for cylindrospermopsin as *Cylindrospermopsis* has been shown to constitutively produce the toxin, which can stay inside the cells during log phase growth and accumulate externally upon entering the stationary phase (Davis et al. 2014; Burford et al. 2016). Researchers have also demonstrated that cylindrospermopsin production can be excreted in response to phosphorus limitation and induce other cells to excrete alkaline phosphatase to the water body resulting in a phosphorus scavenging effect (Bar-Yosef et al. 2010).

Some field studies identified the presence of cyanotoxins and multiple cyanobacterial genera including more than one potential toxin producer with no clear predominant toxin-producing species. Table G-3 only includes cell quota values from field studies where there was a clear predominant toxin-producing genera. In these instances, the study was grouped with the predominant toxin-producing genera. In mixed samples with multiple cyanobacteria and no predominant toxin-producing species, quota data were not included. The EPA recognizes that this approach presents a possible limitation to conclusions on toxin quota as studies conducted under non-bloom conditions were excluded. Predominant species are easier to identify when there is a bloom, however, traditional microscopic identification of cyanobacteria does not distinguish between toxigenic and non-toxigenic strains. The proportion of toxigenic cells within a cyanobacterial community and the copy number of the *mcyD* gene per cell can vary significantly, both affected by environmental parameters (Davis et al. 2009).

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Table G-3 includes cell quota data for microcystin and cylindrospermopsin-producing genera. For each study, data are provided, where available, on the genus and species of the cyanobacteria, the site where the sample was collected or the clone used to estimate cellular toxin for, the type of study (i.e., field or laboratory), and the reported toxin quota data. Notes relevant to each study are reported in the final column of the table, when appropriate.

Relevant toxin data include the mean toxin quota per cell, the median toxin quota per cell, the minimum toxin quota per cell, or the maximum toxin quota per cell. These data are reported where available and not all data points were reported in each study. Data are presented using the units of measure reported by the study authors.

Table G-3. Cell Quota Data for Microcystin and Cylindrospermopsin-Producing Genera

Toxin	Genus/Species[a]	Site/Clone	Study Type[b]	Toxin Quota Data[c]	Reference	Notes
Microcystin	*Microcystis* spp.	Grangent Reservoir, France	Field	Mean: 0.576 pg/cell Min: 0.042 pg/cell Max: 4.19 pg/cell	Sabart et al. (2013)	Data digitized from Figure 6b; The authors report cell quotas for different size ranges of *Microcystis aeruginosa* cells and these values represent the minimum and maximum for all sizes; Mean calculated using all cell quota data reported at all time points for all sizes; Study provides highest reported mean for *Microcystis* spp. mass per cell, field and field and lab combined
	Microcystis spp.	Lake Victoria, Kenya	Field	Mean: 17 fg/cell Median: 553 fg/cell	Sitoki et al. (2012)	Sixteen *Microcystis* strains identified
	Microcystis spp.	Lake Taihu, China	Field	Mean: 0.015 pg/cell Min: 0 pg/cell Max: 0.159 pg/cell	Wang et al. (2013)	Data digitized from Figure 4a,b; Mean calculated using all cell quota data reported at all time points for all colony sizes; Study provides minimum cell quota value and lowest reported mean for *Microcystis* spp. mass per cell, field, and field and lab combined
	Microcystis spp.	Dapugang River, Lake Taihu, China	Field	Cell quota data not presented	Xue et al. (2016)	
	Microcystis spp.	Umia River, Galicia, Spain	Field	Max: 570 µg/g biomass	Alvarez et al. (2016)	Mixed bloom: *Microcystis aeruginosa*, *Scenedesmus* spp., *Kirchneriella* spp.; unclear which is predominant
	Microcystis spp.	Lake Taihu, China	Field	Mean: 640.59 µg/g biomass	Wei et al. (2016)	Data digitized from Figure 4a,b; Only microcystin-L-R

Toxin	Genus/Species[a]	Site/Clone	Study Type[b]	Toxin Quota Data[c]	Reference	Notes
				Min: 13.21 µg/g biomass Max: 1389.13 µg/g biomass		congener reported; Mean calculated using cell quota data for all time points; Study provides mean, minimum, and maximum cell quota values for *Microcystis* spp. mass per biomass, field
	Microcystis spp.	FACHB-905	Lab	Mean: 20.25 fg/cell Min: 17.05 fg/cell Max: 28.47 fg/cell	Wei et al. (2016)	Data digitized from Figure 1D and Figure 2D; Mean calculated using cell quota data for all time points
	Microcystis aeruginosa	Lake Huron, United States	Field	Mean: 140 fg/cell Mix: 10 fg/cell Max: 350 fg/cell	Fahnenstiel et al. (2008)	Study provides highest reported mean, maximum, and minimum cell quota values for *Microcystis aeruginosa* mass per cell, field, and field and lab combined
	Microcystis aeruginosa	Aguieira reservoir, Portugal	Field	Mean: 0.12 fg/cell Mix: 0.07 fg/cell Max: 0.22 fg/cell	Vasconcelos et al. (2011)	Data digitized from Figure 5; *Microcystis aeruginosa* was dominant microcystins producer; Mean calculated using all cell quota data for all yearly time points
	Microcystis aeruginosa	Lake Erie, United States	Field	Mean: 3.34 µg/mg biomass Min: 1.37 µg/mg biomass	Horst et al. (2014)	Data digitized from Figure 3 and Figure 6; Study provides mean and maximum cell quota value for *Microcystis aeruginosa* mass per biomass, field
	Microcystis aeruginosa	Hartbeespoort Dam, South Africa	Field	Min: 0.14 µg/g biomass Max: 268 µg/g biomass	Mbukwa and Mamba (2012)	Study provides minimum cell quota value for *Microcystis aeruginosa* mass per biomass, field
	Microcystis aeruginosa	BCCUSP232	Lab	Mean: 18.84 fg/cell Min: 15.07 fg/cell	Chia et al. (2016)	Data digitized from Figure 4b; Study provides lowest reported mean for

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Toxin	Genus/Species[a]	Site/Clone	Study Type[b]	Toxin Quota Data[c]	Reference	Notes
				Max: 22.61 fg/cell		*Microcystis aeruginosa* mass per cell, lab, field and lab combined and the minimum cell quota value for mass per cell, lab
	Microcystis aeruginosa	Model was used to simulate cyanobacteria	Lab	Mean: 91.5 fg/cell	Jähnichen et al. (2001)	Model used cell quota data reported by Long et al. (2001), Orr and Jones (1998), Jahnichen et al. (2001), and Watanabe et al. (1989); Study provides highest reported mean for *Microcystis aeruginosa* mass per cell, lab
	Microcystis aeruginosa	Model was used to simulate cyanobacteria	Lab	Min: 18 fg/cell Max: 23.7 fg/cell	Jähnichen et al. (2007)	Microcystins cell quota data reported in the presence of sodium and potassium, respectively; Study provides minimum cell quota value for *Microcystis aeruginosa* mass per cell, lab
	Microcystis aeruginosa	MASH01 non-axenic	Lab	Mean: 84.7 fg/cell Min: 41.53 fg/cell Max: 165.89 fg/cell	Orr and Jones (1998)	Data digitized from Figure 5; Mean calculated using quota data presented for each treatment
	Microcystis aeruginosa	MASH01-A19	Lab	Mean: 93.92 fg/cell Min: 46.58 fg/cell Max: 138.47 fg/cell	Orr and Jones (1998)	Data digitized from Figure 5; Mean calculated using quota data presented for each treatment; Study provides highest reported mean and maximum cell quota value for *Microcystis aeruginosa* mass per cell, lab
	Microcystis aeruginosa	PCC 7806	Lab	Min: 34.5 fg/cell Max: 81.4 fg/cell	Wiedner et al. (2003)	Mean quota value not reported, however data could be digitized from Figure 1B to calculate a mean

Toxin	Genus/Species[a]	Site/Clone	Study Type[b]	Toxin Quota Data[c]	Reference	Notes
	Microcystis aeruginosa	Lake Rotura, New Zealand	Lab	Mean: 0.064 pg/cell Min: 0.017 pg/cell Max: 0.134 pg/cell	Wood et al. (2012)	Data digitized from Figure 1B; Mean calculated using cell quota data from all time points; Study provides minimum cell quota value for *Microcystis aeruginosa* mass per cell, lab
	Microcystis aeruginosa	Ontario, Canada	Lab	Min: 40.3 fg/cell Max: 62.4 fg/cell	Pineda-Mendoza et al. (2014)	The range of quota data presented was assumed to be the minimum and maximum values
	Microcystis aeruginosa	New Mexico, United States	Lab	Min: 34.5 fg/cell Max: 136.3 fg/cell	Pineda-Mendoza et al. (2014)	The range of quota data presented was assumed to be the minimum and maximum values
	Microcystis aeruginosa	Umia River, Galicia, Spain	Lab	Mean: 11 µg/g biomass	Alvarez et al. (2016)	Study provides lowest mean and minimum cell quota value for *Microcystis* spp. mass per cell, field, and field and lab combined
	Microcystis aeruginosa	Dayet Afourgah lake, Morocco	Lab	Max: 688.4 µg/g biomass	Douma et al. (2017)	Maximum reported as total microcystins content
	Microcystis aeruginosa	Aguelmam Azigza lake, Morocco	Lab	Max: 699 µg/g biomass	Douma et al. (2017)	Maximum reported as total microcystins content
	Microcystis aeruginosa	Aguelmam Azigza lake, Morocco	Lab	Max: 859.6 µg/g biomass	Douma et al. (2017)	Maximum reported as total microcystins content
	Microcystis aeruginosa	Lake Erie, United States	Lab	Mean: 2.44 µg/mg biomass	Horst et al. (2014)	Data digitized from Figure 5; Study provides highest mean and maximum cell quota value for *Microcystis aeruginosa* mass per biomass, lab
	Microcystis aeruginosa, M. flos-aquae, M. novacekii	Cogotas, Spain	Field	Min: 1.2 pg/cell Max: 4.3 pg/cell	Cires et al. (2013)	Data digitized from Figure 1; Study provides maximum cell quota value for *Microcystis* spp. Mass per

Toxin	Genus/Species[a]	Site/Clone	Study Type[b]	Toxin Quota Data[c]	Reference	Notes
						cell, field, and field and lab combined
	Microcystis aeruginosa, M. flos-aquae, M. novacekii	Valmayor, Spain	Field	Min: 3.4 pg/cell Max: 4.1 pg/cell	Cires et al. (2013)	Data digitized from Figure 1; Study provides maximum cell quota value for *Microcystis* spp. mass per cell, field, and field and lab combined
	Microcystis aeruginosa, M. flos-aquae, M. viridis, M. wesenbergii	Lake Taihu, China	Field	Mean: 0.027 pg/cell Min: 0.001 pg/cell Max: 0.087 pg/cell	Tao et al. (2012)	Data digitized from Figure 2c; Mean calculated using all cell quota data for all time points
	Fisherella	NQAIF311 from Queensland, Australia	Lab	Max: 43 µg/g biomass	Cires et al. (2014)	Data digitized from Figure 1
	Geitlerinema	Florida, United States	Field	Min: 0.02 µg/g biomass Max: 0.10 µg/g biomass	Gantar et al. (2009)	
	Geitlerinema	Florida, United States	Lab	Mean: 0.40 µg/g biomass Min: 0.15 µg/g biomass Max: 0.30 µg/g biomass	Gantar et al. (2009)	
	Leptolyngbya	Florida, United States	Field	Min: 0 µg/g biomass Max: 0.08 µg/g biomass	Gantar et al. (2009)	
	Leptolyngbya	FLK BBD1; Florida, United States	Lab	Mean: 0.10 µg/g biomass Min: 0.06 µg/g biomass Max: 0.20 µg/g biomass	Gantar et al. (2009)	
	Phormidium	Florida, United States	Field	Mean: 0.026 µg/g biomass	Gantar et al. (2009)	

Toxin	Genus/Species[a]	Site/Clone	Study Type[b]	Toxin Quota Data[c]	Reference	Notes
	Planktothrix spp.	Occhito, Italy	Field	Median: 3.82 µg/mm^3 biovolume Min: 1.27 µg/mm^3 biovolume Max: 6.28 µg/mm^3 biovolume	Salmaso et al. (2014)	Data on minimum and maximum digitized from Figure 4a
	Planktothrix spp.	Pusiano, Italy	Field	Median: 0.59 µg/mm^3 biovolume Min: 0.37 µg/mm^3 biovolume Max: 0.87 µg/mm^3 biovolume	Salmaso et al. (2014)	Data on minimum and maximum digitized from Figure 4a
	Planktothrix spp.	Ledro, Italy	Field	Mean: 0.45 µg/mm^3 biovolume Min: 0.12 µg/mm^3 biovolume Max: 0.84 µg/mm^3 biovolume	Salmaso et al. (2014)	Data on minimum and maximum digitized from Figure 4a
	Planktothrix spp.	Garda, Italy	Field	Mean: 0.31 µg/mm^3 biovolume Min: 0 µg/mm^3 biovolume Max: 0.32 µg/mm^3 biovolume	Salmaso et al. (2014)	Data on minimum and maximum digitized from Figure 4a
	Planktothrix agardhii	Bassenwaithe Lake, England	Field	Mean: 91.2 fg/cell	Akcaalan et al. (2006)	
	Planktothrix agardhii	NIES 595	Lab	Mean: 75.6 fg/cell	Akcaalan et al. (2006)	
	Planktothrix rubescencs	Iznik Lake, Turkey	Field	Mean: 235.6 fg/cell	Akcaalan et al. (2006)	Study provides mean and maximum cell quota value for *Planktothrix rubescencs* mass per cell, field
	Planktothrix rubescencs	France	Field	Min: 0.13 pg/cell Max: 0.16 pg/cell	Briand et al. (2008)	Study provides maximum cell quota value for

Toxin	Genus/Species[a]	Site/Clone	Study Type[b]	Toxin Quota Data[c]	Reference	Notes
						Planktothrix rubescencs mass per cell, field, and lab and the minimum cell quota value for mass per cell, field
	Planktothrix rubescencs	SL 03; Turkey	Lab	Mean: 103.9 fg/cell	Akcaalan et al. (2006)	Study provides lowest mean and minimum cell quota value for *Planktothrix rubescencs* mass per cell, lab, and field and lab combined
	Planktothrix rubescencs	Sapanca Lake, Turkey	Lab	Mean: 108.2 fg/cell	Akcaalan et al. (2006)	
	Pseudanabaena	Florida, United States	Field	Min: 0.02 µg/g biomass Max: 0.04 µg/g biomass	Gantar et al. (2009)	
	Spirulina	Florida, United States	Field	Mean: 0.12 µg/g biomass	Gantar et al. (2009)	
	Synechococcus	Florida, United States	Field	Min: 0.08 µg/g biomass Max: 0.27 µg/g biomass	Gantar et al. (2009)	
	Multiple genera including *Microcystis aeruginosa, Anabaenopsis*	Kiwah Island pond, South Carolina	Field		Greenfield et al. (2014)	Data available but were not digitized
	Multiple genera including *Microcystis* spp., *Anabaena* spp., and *Planktolyngbya* spp.	Lake Victoria, Tanzania	Field		Mbonde and Kurmayer (2015)	Data available but were not digitized
	Microcystis, Aphanomenizon, and others	Quebec lakes, Canada	Field		Monchamp et al. (2014)	Data available but were not digitized

Toxin	Genus/Species[a]	Site/Clone	Study Type[b]	Toxin Quota Data[c]	Reference	Notes
	Multiple genera including *Microcystis* and *Anabaena*	Anzali wetland, Iran	Field		Rezaitabar et al. (2017)	Data available but were not digitized
	Multiple genera including *Microcystis* and *Anabaena*	Anzali wetland, Iran	Field		Rezaitabar et al. (2017)	Data available but were not digitized
	Multiple genera including *Microcystis, Dolichospermum,* others	Lake Chaohu, China	Field		Shang et al. (2015)	Data available but were not digitized
Cylindrospermopsin	*Aphanizomenon ovalisporum*	Florida, United States	Lab	Min: 7.39 µg/mg biomass Max: 9.33 µg/mg biomass	Yilmaz et al. (2008)	
	Cylindrospermopsis raciborskii[d]	Gazam Dam Lake, Saudi Arabia	Field	Min: 0.6 pg/cell Max: 14.6 pg/cell	Mohamed and Al-Shehri (2013)	Study provides maximum value for *Cylindrospermopsis raciborskii* mass per cell, field, and field and lab combined
	Cylindrospermopsis raciborskii	Queensland, Australia	Field	Mean: 23.12 fg/cell Median: 20.5 fg/cell Min: 5.9 fg/cell Max: 55.8 fg/cell	Orr et al. (2010)	Study provides minimum value for *Cylindrospermopsis raciborskii* mass per cell, field, and field and lab combined
	Cylindrospermopsis raciborskii	Queensland, Australia	Field	Median: 20.3 fg/cell Min: 10 fg/cell Max: 49.4 fg/cell	Orr et al. (2010)	
	Cylindrospermopsis raciborskii	CYP 030A; Australia	Lab	Min: 3.2 ng/10^6 cell Max: 5.7 ng/10^6 cell	Carneiro et al. (2013)	
	Cylindrospermopsis raciborskii	CYP 011K; Australia	Lab	Min: 12.1 ng/10^6 cell	Carneiro et al. (2013)	

Toxin	Genus/Species[a]	Site/Clone	Study Type[b]	Toxin Quota Data[c]	Reference	Notes
				Max: 24.7 ng/10^6 cell		
	Cylindrospermopsis raciborskii	Queensland, Australia	Lab	Min: 13.4 fg/cell Max: 14.9 fg/cell	Davis et al. (2014)	
	Cylindrospermopsis raciborskii	New South Wales, Australia	Lab	Mean: 31 fg/cell Min: 12 fg/cell Max: 52 fg/cell	Hawkins et al. (2001)	
	Cylindrospermopsis raciborskii	Queensland, Australia	Lab	Min: 19 fg/cell Max: 26 fg/cell	Pierangelini et al. (2015)	
	Cylindrospermopsis raciborskii	CS-506; Queensland, Australia	Lab	Mean: 0.0028 pg/cell	Willis et al. (2015)	Study provides lowest mean value for *Cylindrospermopsis raciborskii* mass per cell, lab, and field and lab combined and minimum cell quota value for mass per cell, lab
	Cylindrospermopsis raciborskii	CS-506; Queensland, Australia	Lab	Mean: 0.018 pg/cell	Willis et al. (2015)	
	Cylindrospermopsis raciborskii	Lake Wivenhoe, Australia	Lab	Mean: 165.75 fg/cell	Willis et al. (2016)	Calculated mean based on data in Table 1; Study provides highest mean value for *Cylindrospermopsis raciborskii* mass per cell, lab, and field and lab combined and maximum cell quota value for mass per cell, lab
	Cylindrospermopsis raciborskii	CHAB3438, China	Lab	Mean: 43.76 fg/cell Min: 35.89 fg/cell Max: 52 fg/cell	Yang et al. (2016)	Data digitized from Figure 2; Mean calculated using quota data presented for each time point
	Cylindrospermopsis raciborskii	Queensland, Australia	Lab	Min: 416 fg/μm^3 biovolume Max: 447 fg/μm^3 biovolume	Pierangelini et al. (2015)	

Toxin	Genus/Species[a]	Site/Clone	Study Type[b]	Toxin Quota Data[c]	Reference	Notes
	Multiple genera including *Aphanizomenon*, *Anabaena*, *Nostocales*, and *Cylindrospermopsis*	Germany	Field		Rücker et al. (2007)	Data available but were not digitized
	Multiple genera including *Aphanizomenon*	Langer See, Germany	Field		Wiedner et al. (2008)	Data available but were not digitized

Abbreviations: *M.* = *Microcystis*; spp. = multiple species in the genus

[a] Both the genus and species are reported where available. In some studies, the genus was reported but the species was not reported. In other studies, multiple species were analyzed within a specific genus but the specific species were not identified. In both instances, studies were categorized as the genus name (e.g., *Microcystis*) spp. Separately, in some studies multiple genera were considered. In these studies, available toxin quota data were not digitized as they could not be used for comparison purposes. Only information about the studies are presented in this table with a note that data are available but were not digitized.

[b] Studies were conducted in two different settings: the field (i.e., environmental) or a laboratory. In some instances, field samples were subjected to optimized growth conditions in the laboratory. These studies were classified as laboratory; not as field studies.

[c] Toxin cell quota data were not converted and are reported in the measurement units used by the study authors. Significant figures were not normalized among the data points.

[d] The genus *Cylindrospermopsis* has been renamed to *Raphidiopsis*.

Table G-4 provides the first step in summarizing and grouping cell quota data for microcystin and cylindrospermopsin-producing genera. Studies presented in Table G-3 were grouped by genus and species when possible. Studies that looked at more than one species within a specific genus or that did not specify which species were considered within that genus were placed in a single group (e.g., *Microcystis* spp., *Planktothrix* spp.). Within each genus/species group, studies were further grouped based on their study type and the quantification method used in that study. For each study type and quantification method group, data were aggregated on the mean, minimum, and maximum cell quota values presented in each study included in that group. In Table G-4, the range of the means, arithmetic mean (of the means), median of the means, minimum cell quota value, and maximum cell quota value are reported for the studies included in that group. Note that studies were not identified in the literature search for all quantification methods and study types for all genus/species groups. The EPA converted data to a standard set of units, pg per cell, when possible. No other conversions were attempted. Additional information about the approach used to summarize the available cell quota data is provided in the footnotes accompanying the table.

Table G-4. Cell Quota Appendix Summary Data for Microcystin and Cylindrospermopsin-producing Genera

Toxin	Genus, Species	Quantification Method[a]; Study Type[b]	Range of Means[c,d]	Mean[c,d]	Median of Means[c,e]	Minimum; Maximum[c,f]	References
Microcystin	*Microcystis* spp.	Mass per cell; Field and lab	0.015–0.576 pg/cell	0.13 pg/cell	0.017 pg/cell	0 pg/cell; 4.30 pg/cell	Sitoki et al. (2012); Tao et al. (2012); Cires et al. (2013); Sabart et al. (2013); Wang et al. (2013); Wei et al. (2016)
		Mass per cell; Field	0.015–0.576 pg/cell	0.16 pg/cell	0.022 pg/cell	0 pg/cell; 4.30 pg/cell	Sitoki et al. (2012); Tao et al. (2012); Cires et al. (2013); Sabart et al. (2013); Wang et al. (2013)
		Mass per cell; Lab	0.020 pg/cell	0.02 pg/cell	N/A	0.017 pg/cell; 0.028 pg/cell	Wei et al. (2016)
		Mass per biomass; Field	640.59 µg/g biomass	640.59 µg/g biomass	N/A	13.21 µg/g; 1389.13 µg/g biomass	Alvarez et al. (2016); Wei et al. (2016)
	Microcystis aeruginosa	Mass per cell; Field and lab	0.02–0.14 pg/cell	0.09 pg/cell	0.09 pg/cell	0.01 pg/cell; 0.35 pg/cell	Orr and Jones (1998); Jähnichen et al. (2001); Wiedner et al. (2003); Jähnichen et al. (2007); Fahnenstiel et al. (2008); Vasconcelos et al. (2011); Wood et al. (2012); Pineda-Mendoza et al. (2014); Chia et al. (2016)
		Mass per cell; Field	0.12–0.14 pg/cell	0.13 pg/cell	0.13 pg/cell	0.01 pg/cell; 0.35 pg/cell	Fahnenstiel et al. (2008); Vasconcelos et al. (2011)
		Mass per cell; Lab	0.02–0.09 pg/cell	0.07 pg/cell	0.08 pg/cell	0.02 pg/cell; 0.17 pg/cell	Orr and Jones (1998); Jähnichen et

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Toxin	Genus, Species	Quantification Method[a]; Study Type[b]	Range of Means[c,d]	Mean[c,d]	Median of Means[c,e]	Minimum; Maximum[c,f]	References
							al. (2001); Wiedner et al. (2003); Jähnichen et al. (2007); Wood et al. (2012); Pineda-Mendoza et al. (2014); Chia et al. (2016)
		Mass per biomass; Field	3,340 µg/g biomass	3,340 µg/g biomass	N/A	0.14 µg/g biomass; 3,340 µg/g biomass	Mbukwa and Mamba (2012); Horst et al. (2014)
		Mass per biomass; Lab	11–2,440 µg/g biomass	1225.5 µg/g biomass	1225.5 µg/g biomass	11 µg/g; 2,440 µg/g biomass	Horst et al. (2014); Alvarez et al. (2016); Douma et al. (2017)
	Fisherella	Mass per biomass; Lab	N/A	N/A	N/A	43 µg/g biomass	Gantar et al. (2009)
	Geitlerinema	Mass per biomass; Field	N/A	N/A	N/A	0.02 µg/g; 0.10 µg/g biomass	Gantar et al. (2009)
		Mass per biomass; Lab	0.40 µg/g biomass	0.40 µg/g biomass	N/A	0.15 µg/g; 0.40 µg/g biomass	Gantar et al. (2009)
	Leptolyngbya	Mass per biomass; Field	N/A	N/A	N/A	0 µg/g; 0.08 µg/g biomass	Gantar et al. (2009)
		Mass per biomass; Lab	0.10 µg/g biomass	0.10 µg/g biomass	N/A	0.06 µg/g; 0.20 µg/g biomass	Gantar et al. (2009)
	Phormidium	Mass per biomass; Lab	0.026 µg/g biomass	0.026 µg/g biomass	N/A	0.026 µg/g biomass	Gantar et al. (2009)
	Planktothrix spp.	Mass per biovolume; Field	N/A	N/A	N/A	0 µg/mm^3; 6.28 µg/mm^3 biomass	Salmaso et al. (2014)

Toxin	Genus, Species	Quantification Method[a]; Study Type[b]	Range of Means[c,d]	Mean[c,d]	Median of Means[c,e]	Minimum; Maximum[c,f]	References
	Planktothrix agardhii	Mass per cell; Field and lab	0.076–0.091 pg/cell	0.083 pg/cell	0.083 pg/cell	0.076 pg/cell; 0.091 pg/cell	Akcaalan et al. (2006)
		Mass per cell; Field	0.091 pg/cell	0.091 pg/cell	N/A	0.091 pg/cell	Akcaalan et al. (2006)
		Mass per cell; Lab	0.076 pg/cell	0.076 pg/cell	N/A	0.076 pg/cell	Akcaalan et al. (2006)
	Planktothrix rubescencs	Mass per cell; Field and lab	0.104–0.236 pg/cell	0.149 pg/cell	.108 pg/cell	0.104 pg/cell; 0.16 pg/cell	Akcaalan et al. (2006); Briand et al. (2008)
		Mass per cell; Field	0.236 pg/cell	0.236 pg/cell	N/A	0.13 pg/cell; 0.236 pg/cell	Akcaalan et al. (2006); Briand et al. (2008)
		Mass per cell; Lab	0.104–0.108 pg/cell	0.106 pg/cell	0.106 pg/cell	0.104 pg/cell; 0.108 pg/cell	Akcaalan et al. (2006)
	Pseudanabaena	Mass per biomass; Field	N/A	N/A	N/A	0.02 µg/g; 0.04 µg/g biomass	Gantar et al. (2009)
	Spirulina	Mass per biomass; Field	0.12 µg/g biomass	0.12 µg/g biomass	N/A	0.12 µg/g biomass	Gantar et al. (2009)
	Synechococcus	Mass per biomass; Field	N/A	N/A	N/A	0.08 µg/g; 0.27 µg/g biomass	Gantar et al. (2009)
Cylindrospermopsin	*Aphanizomenon ovalisporum*	Mass per biomass; Field and lab	N/A	N/A	N/A	7.39 µg/g ; 9.33 µg/mg biomass	Yilmaz et al. (2008)
	Cylindrospermopsis raciborskii[g]	Mass per cell; Field and lab	0.0028–0.17 pg/cell	0.05 pg/cell	0.03 pg/cell	0.006 pg/cell; 14.6 pg/cell	Orr et al. (2010); Mohamed and Al-Shehri (2013); Pierangelini et al. (2015); Willis et al. (2015); Yang et al. (2016a)

Toxin	Genus, Species	Quantification Method[a]; Study Type[b]	Range of Means[c,d]	Mean[c,d]	Median of Means[c,e]	Minimum; Maximum[c,f]	References
		Mass per cell; Field	0.023 pg/cell	0.023 pg/cell	N/A	0.006 pg/cell; 14.6 pg/cell	Orr et al. (2010); Mohamed and Al-Shehri (2013)
		Mass per cell; Lab	0.0028–0.17 pg/cell	0.057 pg/cell	0.031	0.0028 pg/cell; 0.17 pg/cell	Hawkins et al. (2001); Carneiro et al. (2013); Davis et al. (2014); Pierangelini et al. (2015); Willis et al. (2015); Willis et al. (2016); Yang et al. (2016)
		Mass per biovolume; Lab	N/A	N/A	N/A	416 fg/μm^3; 447 fg/μm^3	Pierangelini et al. (2015)

Acronyms and Abbreviations: fg = femtogram; pg = picogram; µg = microgram; N/A = not applicable.

[a] Various methods were used to quantify toxin quotas and quota values were presented in different forms, including toxin mass per cyanobacterial cell and toxin mass per cyanobacterial biomass.

[b] Studies were conducted in two different settings: the field (i.e., environmental) or a laboratory. In some instances, field samples were subjected to optimized growth conditions in the laboratory. These studies were classified as laboratory; not field.

[c] Study authors reported data using multiple measurement units. When possible, the EPA converted data to the standard units of pg per cell. The EPA did not identify appropriate conversion factors that would allow genus-specific conversion of quotas described in mass per biomass to mass per cell.

[d] Shows single reported mean if only one study was available or average of reported means.

[e] Median of means not calculated if only one mean value was available or if only minimum and/or maximum cell quota values were available.

[f] If reported toxin quota means from one study were the lowest or highest toxin quotas reported within a genus, then these values were listed as the minimum or maximum values, respectively, to better reflect the range of toxin quota values.

[g] The genus *Cylindrospermopsis* has recently been renamed to *Raphidiopsis*.

Appendix G References

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APPENDIX H. TABLES OF STATE-ISSUED GUIDELINES SPECIFIC TO ANIMAL CYANOTOXIN POISONING

H.1 California

Table H-1. California Environmental Protection Agency (2012) Action levels for Selected Pet and Livestock Scenarios

	Microcystins[a]	Cylindrospermopsin	Media (units)
Subchronic water intake, dog[b]	2	10	water (µg/L)
Subchronic crust and mat intake, dog	0.01	0.04	crusts and mats (mg/kg dw)[c]
Acute water intake, dog[d]	100	200	water (µg/L)
Acute crust and mat intake, dog	0.5	0.5	crusts and mats (mg/kg dw)[c]
Subchronic water intake, cattle[e]	0.9	5	water (µg/L)
Subchronic crust and mat intake, cattle[e]	0.1	0.4	crusts and mats (mg/kg dw)[c]
Acute water intake, cattle[e]	50	60	water (µg/L)
Acute crust and mat intake, cattle[e]	5	5	crusts and mats (mg/kg dw)[c]

[a] Microcystins LA, LR, RR, and YR all had the same RfD so the action levels are the same.
[b] Subchronic refers to exposures over multiple days.
[c] Based on sample dry weight (dw).
[d] Acute refers to exposures in a single day.
[e] Based on small breed dairy cows because their potential exposure to cyanotoxins is greatest.

Table H-2. California Environmental Protection Agency (2012) Reference Doses and Acute and Subchronic Action Levels for Canine Exposure to Cyanotoxins in Drinking Water

	Microcystin	Cylindrospermopsin
Water consumption L/kg-day	0.085	0.085
Uncertainty factor (unitless)	3	3
Acute RfD[a] mg/kg/day	0.037	0.04
Acute action level µg/L	100	200
Subchronic RfD mg/kg/day	0.00064	0.0033
Subchronic action level µg/L	2	10

Reference:

Butler N, Carlisle J, Kaley KB, and Linville R (2012). Toxicological Summary and Suggested Action Levels to Reduce Potential Adverse Health Effects of Six Cyanotoxins. http://www.waterboards.ca.gov/water_issues/programs/peer_review/docs/calif_cyanotoxins/cyanotoxins053112.pdf. Last Accessed: 11/27/2018.

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H.2 Indiana

Indiana has adopted guidance for cyanotoxins for dog exposures:

"A warning to dog owners using the Fort Harrison State Park Dog Park Lake will occur whenever any cyanotoxins are detected, and dogs will be prohibited from swimming at the values of 0.8 µg/L microcystin, any anatoxin-a detection, and 1.0 µg/L of cylindrospermopsin."

Reference:

Indiana Department of Environmental Management (2018). Blue-Green Algae: Indiana Reservoir and Lake Update.http://www.in.gov/idem/algae/. Last Accessed: 02/27/2018.

H.3 Oregon

Table H-3. Oregon Dog-specific Guideline Values for Cyanotoxins in Recreational Waters (µg/L)

	Microcystin	Cylindrospermopsin
Dog Guidance Value	0.2	0.4

Note: All dog-specific guideline values have been changed in this revision because California EPA's estimate of the amount of water an exercising dog consumes per kilogram body weight was updated in 2012 (from 0.168 to 0.255 L/kg-day). Current dog-specific guideline values are now consistent with the California EPA update. The dog-specific value for saxitoxins was further modified by application of an uncertainty factor to the dog-specific TDI for interspecies differences in sensitivity between humans (the species in the critical study) and dogs.

Reference:

Oregon Health Authority (2018). Oregon Harmful Algae Bloom Surveillance (HABS) Program Public Health Advisory Guidelines: Harmful Algae Blooms in Freshwater Bodies. https://www.oregon.gov/oha/ph/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Documents/HABPublicHealthAdvisoryGuidelines.pdf.

H.4 Grayson County, Texas

Table H-4. Grayson County, Texas Microcystin Guidelines for Dogs

Quantity of Lake Water Ingested to Receive a Potentially Lethal Dose of Microcystin, Assuming that Mouse and Dog Toxic Responses are Equivalent

	Gallons of Water	Pounds of Water
10-pound dog	2.70	22.50
80-pound dog	21.57	180.00

Quantity of Lake Water Ingested to Receive a Potentially Lethal Dose of Microcystin, Assuming that Mouse and Dog Toxic Responses are Equivalent (at actual concentrations found in Grand Lake, Oklahoma, in June 2011) Highest measured microcystin concentration was 358 ppb.

	Gallons of Water	Pounds of Water
10-pound dog	0.15 (19.3 ounces)	1.26
80-pound dog	1.21	10.06

*This is not including additional dose amounts that could be ingested from a dog self-grooming algae scum off its fur.
**LD_{50} for microcystin-mouse used in calculations = 45 µg/kg
***20 ppb microcystin is algal toxin threshold for BGA Warning (condition red)

Quantity of Lake Water Ingested to Receive a Potentially Lethal Dose of Cylindrospermopsin, Assuming that Mouse and Dog Toxic Responses are Equivalent 20 ppb Cylindrospermopsin in Lake Water

	Gallons of Water	Pounds of Water
10-pound dog	263	2,200
80-pound dog	2,109	17,601

*This is not including additional dose amounts that could be ingested from a dog self-grooming algae scum off its fur.
**LD_{50} for cylindrospermopsin-mouse used in calculations = 4400 µg/kg
***20 ppb cylindrospermopsin is algal toxin threshold for BGA Warning (condition red)

Reference:

Lillis J, Ortez A, and Teel JH (2012). *Blue-Green Algae Response Strategy*. Sherman, Texas. http://www.co.grayson.tx.us/upload/page/0206/docs/Blue-Green_Algae_Response_Strategy.pdf. Last Accessed: 12/5/2018.

United States Environmental Protection Agency

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Draft Technical Support Document:

Implementing the 2019 Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin

NMED Exhibit 94

Notice: This technical support document contains several questions and answers relating to the Environmental Protection Agency's (EPA) *Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin*.[1] Microcystins and cylindrospermopsin are two types of cyanotoxins that are produced from photosynthetic bacteria, called cyanobacteria. Exposure to the microcystins and cylindrospermopsin can pose health risks to humans and animals. Symptoms reported after recreational exposure to cyanobacterial blooms included skin irritations, gastrointestinal illnesses, hepatomegaly and kidney damage.

The information in this document is primarily intended to support states, authorized tribes, and territories (collectively referred to as "states and authorized tribes") interested in adopting the recommended criteria into their state or tribal water quality standards (WQS) or using the recommended values as the basis for swimming advisories and related public notification purposes.[2] EPA envisions that if states or authorized tribes decide to use the values for issuing swimming advisories they might do so in a manner similar to their current recreational water advisory programs.

Chemical and physical factors in a waterbody can play a role in the composition and production of cyanotoxins associated with a toxigenic cyanobacterial bloom (such factors include, but are not limited to, levels of nitrogen and phosphorus, the availability of organic matter, turbidity, turbulence or flushing of a waterbody, light attenuation, water temperature and pH). The recommended criteria and swimming advisory values were derived based on data related to exposure factors, including the rate of incidental consumption of water while swimming and the duration of time spent recreating in water, and are recommended for waters designated for primary contact recreation. Some states and authorized tribes may experience other hazards associated with cyanobacterial blooms that are not addressed in this document (e.g., with respect to cytokines or other cyanotoxins), therefore a more holistic approach to monitoring waterbodies may be necessary to ensure public health protection.

Exposure to cyanobacteria and their toxins can also occur through non-recreational pathways such as consumption of cyanotoxin-contaminated drinking water and food (including fish), and during bathing or showering. This document does not address or provide recommendations for non-recreational exposures. Although there are no national level recommended criteria for cyanotoxins in public water supply designated uses, in 2015, EPA published health advisories for the cyanotoxins, microcystins and cylindrospermopsin in finished drinking water. For information related to the drinking water health advisories for microcystins and cylindrospermopsin, see https://www.epa.gov/ground-water-and-drinking-water/drinking-water-health-advisory-documents-cyanobacterial-toxins.

This document provides background information on the factors that contribute to cyanobacterial growth and toxin production; recommendations on how to monitor for cyanobacteria and two of their known cyanotoxins (microcystins and cylindrospermopsin) in waterbodies; and information on how to complete assessments, list impaired or threatened waters, and develop Total Maximum Daily Load (TMDLs), based

[1] USEPA (U.S. Environmental Protection Agency). 2019. *Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin 2019.* EPA 822-R-18-004. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/wqc/recommended-human-health-recreational-ambient-water-quality-criteria-or-swimming-advisories.

[2] When a bloom or the presence of cyanotoxins is confirmed, the recreational waterbody manager usually issues a public notification (either a swimming advisory or a closure of swimming areas) to raise awareness of the potential risks associated with contact with the cyanobacterial bloom or its toxins in recreational waters. Swimming advisories are recommendations to limit swimming or other recreational water-contact activities, due to an increased health risk from contact with or ingestion of the cyanobacteria or cyanotoxins; whereas, a closure notification or posting typically means that the waterbody is officially closed to the public. Decisions to post an advisory or closure for a waterbody or a beach are local decisions. Information about communicating swimming advisories or closures to the public, including sample templates, is available at Communicating about Cyanobacterial Blooms and Toxins in Recreational Waters (webpage).

on WQS that adhere to EPA's 2019 recommended criteria for total microcystins and cylindrospermopsin. While this document cites statutes and regulations that contain requirements applicable to these programs, it does not impose legally binding requirements on EPA, states, authorized tribes, other regulatory authorities, or the regulated community. EPA, states, authorized tribes and other decision makers may adopt approaches on a case-by-case basis that differ from those provided in this document, as appropriate and consistent with statutory and regulatory requirements. Also, EPA may update this document as new scientific and technical information becomes available. In addition to this document, EPA has prepared the following information to support states and authorized tribes in their efforts to monitor and respond to cyanobacterial blooms and cyanotoxins in recreational waters:

- Cyanobacterial Harmful Algal Blooms in Water (website): https://www.epa.gov/cyanohabs
- Monitoring and Responding to Cyanobacteria and Cyanotoxins in Recreational Waters
- Recommendations for Cyanobacteria and Cyanotoxin Monitoring in Recreational Waters

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General Questions about Cyanotoxin Water Quality Criteria

1. What are EPA's recommended recreational water quality criteria for total microcystins and cylindrospermopsin?

In 2019, EPA issued its recreational water quality criteria recommendations for the cyanotoxins, microcystins and cylindrospermopsin, reflecting the latest scientific knowledge, public comments, and external scientific peer review. The criteria are designed to protect the public from incidental exposure to harmful levels of these cyanotoxins while participating in water-contact activities where immersion and incidental ingestion of water are likely. Such activities include but are not limited to swimming, water skiing, tubing, skin diving, water play by children, or similar water-contact activities in all waterbodies designated for such recreational uses.[3] EPA issues such recommendations under the statutory authority of the Clean Water Act (CWA), Section 304(a).

EPA's recommended recreational water quality criteria for total microcystins and cylindrospermopsin consist of three components:

- *Magnitude* — The numeric expression of the maximum amount of a pollutant that may be present in a waterbody while also protecting the designated use(s) of the waterbody. In this case, the magnitude represents the concentration of total microcystins (8 µg/L) or cylindrospermopsin (15 µg/L) in the water column that is not expected to result in adverse human health effects from short-term recreational exposure to the cyanotoxins via incidental ingestion while recreating (e.g., swimming), based on children's exposure parameters.
- *Duration* — Duration is the period of time over which the magnitude is calculated. Exposure to recreational waters containing microcystins or cylindrospermopsin at or below the recommended magnitude concentrations over the short-term ten-day duration would not be expected to result in the adverse health effects discussed in health effects assessment (Section 5) of the criteria document.
- *Frequency* of excursion — The number of times the contaminant may be present above the recommended criteria concentration (magnitude) over the specified period (duration). For these criteria, the frequency corresponds to how often (within a single recreational season, *and across* multiple recreational seasons) the concentration of total microcystins or cylindrospermopsin in a waterbody may exceed the magnitude concentration and be protective of the designated use. The recommended frequency within a single recreational season is no more than three excursions. The number of years that a pattern of more than three excursions can occur *across* recreational seasons and still deemed to be protective of the designated use—referred to in Question 3 as the *recurrence frequency*—is a risk management decision, to be made by a state or authorized tribe. If a state or authorized tribe chooses to adopt the recommended criteria into its state or tribal WQS, EPA recommends that the state or authorized tribe include this recurrence frequency number in its WQS (see Table 1, note b).

EPA developed the following criteria values for total microcystins and cylindrospermopsin concentrations for states and authorized tribes to consider as the basis for human health protection in primary contact recreational waters (see Table 1 for a summary of the magnitude, duration and frequency).

[3] For information about the scope and applicability of recreational criteria, see EPA's 2012 *Recreational Water Quality Criteria*, (Section 2.0 Applicability and Scope). Office of Water 820-F-12-058. https://www.epa.gov/sites/production/files/2015-10/documents/rwqc2012.pdf

Table 1. Recreational Water Quality Criteria Recommendations for Microcystins and Cylindrospermopsin [a]

Total Microcystins Magnitude (µg/L)	Cylindrospermopsin Magnitude (µg/L)	Duration	Frequency
8	15	1 in 10-day assessment period across a recreational season	Not more than 3 excursions in a recreational season in more than one year [b]

[a] States and authorized tribes can choose to adopt one or both criteria recommendations.

[b] An excursion is defined as a 10-day assessment period with any toxin concentration higher than the criteria magnitude. When more than three excursions occur within a recreational season and that pattern reoccurs in more than one year, it is an indication the water quality has been or is becoming degraded and is not supporting its recreational use. As a risk management decision, states and authorized tribes should include in their WQS an upper-bound frequency stating the number of years that pattern can reoccur and still support its recreational use.

Cyanobacterial blooms can occur naturally but can be an uncommon event due to a convergence of climatic and other environmental factors that result in a single short-term bloom lasting days or a couple of weeks. In some cases, multiple blooms can occur in a single year. Alternatively, longer-term cyanobacterial blooms can occur regularly in some waters lasting for a few weeks, months, or possibly all year. Cyanobacterial blooms can occur while conditions conducive to cyanobacterial proliferation exist and limit the use of the waterbody for primary recreation. The criteria components listed in Table 1, above, can help to identify a short- or long-term temporal trend or a spatial distribution pattern of cyanotoxin excursions that can be used to evaluate a waterbody.

EPA recognizes there are multiple environmental factors that can cause variability in bloom formation and toxin production, and that some years may produce HABs that occur for long periods, or HABs of shorter duration that occur repeatedly throughout a single recreational season, but such events may not occur every year. Therefore, EPA concludes that it is appropriate to consider a pattern of multiple excursions within a recreational season as well as a pattern of excursions in multiple years (i.e., more than one year) when determining whether the use is attained. It is important to note that the years with multiple excursions do not have to be consecutive to indicate a water-quality problem. The upper bound frequency (e.g., one year out of three years) is a risk management decision that states and authorized tribes need to determine when developing their WQS. States and authorized tribes should include the number of years a pattern of cyanotoxin excursions can occur for the recreational use to be supported.

EPA recommends that if toxin concentrations are higher than the criterion magnitude in a sample collected during a ten-day assessment period, then that period should be considered an excursion from the recreational criteria. A short-term cyanobacterial bloom that does not reoccur can result in a small number of excursions of the criteria but is not expected to result in impairment of the recreational use. Such cyanobacterial blooms may result from conditions that occur naturally (e.g., as a result of unusually hot conditions), but not frequently. EPA recommends that when more than three excursions (an exceedance during the ten-day assessment period) occur within a recreational season *and* that pattern reoccurs in more than one year, it is an indication that the water quality is or may be becoming degraded such that the waterbody may no longer support the recreational use. Multiple excursions over a single recreation season indicates that a waterbody may not support a recreational use for a significant proportion of the season. EPA recommends that a concentration of 8 µg/L total microcystins or 15 µg/L cylindrospermopsin not be exceeded in more than three ten-day assessment periods over the course of a recreation season in more than one year. EPA does not recommend averaging sampling data to determine an excursion, because averaging does not give a clear picture of the pattern of cyanobacterial bloom formation and cyanotoxin exposure to the population using the waterbody for recreational purposes.

The number of years over which time an observed pattern (of three or more ten-day excursions during a recreational season) can occur across recreational seasons is a risk management decision that states and

authorized tribes should consider when developing their criteria. States and authorized tribes should include the number of years a pattern of cyanotoxin excursions can occur for the use to be supported in their WQS. Furthermore, states and authorized tribes may make different risk management decisions for different types of waterbodies. EPA recommends states and authorized tribes clarify these differences in their WQS. For more information about how the criteria were developed, see: https://www.epa.gov/wqc/recommended-human-health-recreational-ambient-water-quality-criteria-or-swimming-advisories.

2. How can EPA's recommended recreational water quality criteria values for total microcystins and cylindrospermopsin be used for swimming advisories?

State, tribal or local governments can use swimming advisories to provide information to recreators on their potential exposure to cyanobacteria and their toxins. EPA envisions that if states or authorized tribes decide to use the values as swimming advisory values, they can manage a cyanotoxin monitoring and advisory program in the same way as they manage any already existing recreational water advisory programs (i.e., those for *E. coli* or enterococci). States and authorized tribes may choose to apply either or both recommended magnitude values as the basis for swimming advisories (i.e., public notifications) for recreational waterbodies. For this purpose, EPA recommends that the magnitude (i.e., 8 µg/L total microcystins or 15 µg/L cylindrospermopsin) not be exceeded on any given day.

Table 2. Swimming Advisory Recommendations for Microcystins and Cylindrospermopsin[a]

Total Microcystins Magnitude (µg/L)	Cylindrospermopsin Magnitude (µg/L)	Duration	Frequency
8	15	One day	Not to be exceeded

EPA recognizes that some states and authorized tribes may handle swimming advisories through their health departments and not through their environmental quality departments. As a result, inter-departmental coordination may be helpful to implement an advisory program which can also serve to inform drinking water providers and water quality practitioners. EPA has provided an example Cyanobacteria Bloom Response Contact List on its website to help state or tribal employees consider who to contact in the event of a cyanobacterial bloom.

Swimming advisories can be used to provide information to recreators on their potential exposure to cyanobacteria and their toxins. Some local and state governments currently post notifications for swimmers, in the form of advisories or warnings, when a cyanobacterial bloom is reported in recreational waters or when cyanotoxin levels exceed swimming advisory thresholds.

If using the recommended values for public notification purposes (swimming advisory or beach closure), EPA recommends that the relevant authority (typically a local health department official or environmental protection agency) notify the public whenever a sample exceeds the recommended criteria concentration value. EPA also recommends that an exceedance of the recommended criteria concentration result in a swimming advisory being issued until subsequent sampling results show that the toxin concentration has fallen below the recommended magnitude value of the criteria. By increasing the monitoring frequency at a site where a swimming advisory is issued, recreational waterbody managers will get a clearer understanding of the temporal and spatial nature of toxins that can be useful in making management decisions to protect the recreational use, including when to remove an advisory.

EPA also recognizes that environmental conditions may change rapidly from one sample period to the next, depending on the frequency of samples taken. For an example of how the state of Ohio uses toxin concentration results to make swimming advisory decisions, see the Example 1 text box below. Appendix B of the criteria document summarizes available information on state recreational water guidelines for

cyanotoxins and cyanobacteria (see: https://www.epa.gov/wqc/recommended-human-health-recreational-ambient-water-quality-criteria-or-swimming-advisories.

Example 1: State of Ohio example of a tiered approach to public notifications

The Ohio Environmental Protection Agency collaborated with the Department of Natural Resources and the Department of Health to develop a tiered notification system which takes different actions based on different numeric thresholds for cyanotoxin concentrations in recreational waters. That is, the state takes various actions—such as posting information about harmful algal blooms (HABs), issuing a recreational public health advisory, or temporarily closing recreational waters through a no contact advisory—depending on the severity of the bloom event.

Toxin of concern	Informational sign postings about HABs at recreational waters	Recreational public health advisory	Elevated recreational public health advisory (e.g. no contact)
Microcystin-LR	< 6 µg/L	6 µg/L	20 µg/L
Cylindrospermopsin	< 5 µg/L	5 µg/L	20 µg/L

Once an advisory is posted, Ohio conducts a standard sampling protocol for cyanotoxins and lifts the advisory once two consecutive samples taken at least one week apart show cyanotoxins have decreased below the advisory threshold. For more information, see the *State of Ohio Harmful Algal Bloom Response Strategy for Recreational Waters* (Ohio EPA, 2016).

EPA has published materials for recreational waterbody managers responsible for monitoring and responding to cyanobacterial blooms. These materials include a communication toolbox with examples of public messages, press releases, and warning and posting signage that recreational waterbody managers may use to inform the public of increased health risks associated with exposure to cyanobacteria and their toxins. In addition, EPA has provided recommendations for public health officials or waterbody managers (or relevant state, local or tribal officials) to consider various water monitoring, sampling and testing methods to determine whether a cyanobacterial bloom is producing toxins, whether the bloom presents an increased risk to water-contact recreators and human health, and whether immediate actions should be taken to notify the public if a closure is recommended based on waterbody test results.

- Communicating about Cyanobacterial Blooms and Toxins in Recreational Waters
- Monitoring and Responding to Cyanobacteria and Cyanotoxins in Recreational Waters
- Recommendations for Cyanobacteria and Cyanotoxin Monitoring in Recreational Waters

3. What flexibilities do states and authorized tribes have when they choose to adopt recreational water quality criteria for total microcystins and cylindrospermopsin?

When states or authorized tribes choose to adopt EPA's *Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin*, states and authorized tribes have flexibility to accommodate specific water quality-related circumstances while meeting the requirements of the CWA and the WQS regulation. In addition to considering the Agency's national recommended water quality criteria when revising their WQS, states and authorized tribes may adopt, where appropriate, other scientifically defensible criteria that differ from EPA's recommendations. For example, states and authorized tribes can:

- *Define the length of the recreational season.* States and authorized tribes can adopt seasonal designated uses of a waterbody with respect to various 304(a) recommended criteria, including the recommended criteria for total microcystins and cylindrospermopsin. Therefore, for states

and authorized tribes that have adopted seasonal uses, the recommended cyanotoxin criteria would apply only to the primary contact recreation season. 40 CFR 131.10(f) specifies that states and authorized tribes "may adopt seasonal uses as an alternative to reclassifying a waterbody or segment thereof to uses requiring less stringent water quality criteria. If seasonal uses are adopted, water quality criteria should be adjusted to reflect the seasonal uses, however, such criteria shall not preclude the attainment and maintenance of a more protective use in another season." The length of a "recreational season" is an important consideration because states and authorized tribes would likely monitor the quality of their highest-priority recreational waters throughout the recreational season (for more on prioritizing waterbodies for assessments, see Question 6). For purposes of establishing seasonal WQS, a change to the recreational season constitutes a change to the state's or authorized tribe's designated use in their WQS under 40 CFR 131.10(f) and would need to be reviewed and approved by EPA pursuant to section 303(c) of the CWA. Because local health departments or departments of parks and recreation may define the recreational seasons for inland waterbodies, it is important for states and authorized tribes to coordinate with these local authorities when identifying the length of the state's or tribe's recreational season in WQS.

- *Define a recurrence frequency.* The criteria for total microcystins and cylindrospermopsin recommend that the magnitude values should not be exceeded in *more than three ten-day periods per recreational season in more than one year*, but the criteria do not specify an upper-bound number of years that pattern can occur across recreational seasons (i.e., a recurrence frequency). This provides states and authorized tribes the flexibility to define a recurrence frequency. For example, some states or authorized tribes might count the recurrence frequency over a rolling 5-year period while others choose to count over a rolling 10-year period.

  If a state or authorized tribe chooses to adopt the recommended criteria, EPA expects the state or tribe to also include this recurrence frequency in its WQS. A state or authorized tribe may achieve this with a written statement in its standards. An example written statement could say, *"The concentration of total microcystins shall not exceed 8 µg/L in more than three ten-day periods per recreational season, for more than one recreational season, over a 5-year period."*

- *Derive site-specific criteria elements*. States and authorized tribes may adopt EPA recommended criteria or may modify the criteria to fit their unique situation based on site-specific data and information. For example, a state or tribe may derive site-specific criteria based, in part, on information about the exposure variables among the population that uses the waterbody (e.g., age and incidental ingestion rates) or to allow for specific cultural or land use practices at or near the site. The site-specific criteria must be scientifically defensible and protective of the designated use of the state's or tribe's waterbodies and approved by EPA pursuant to section 303(c) of the CWA.

- *Revise the designated uses of waterbodies within their state*. If a state or authorized tribe finds that attaining one of the designated CWA section 101(a)(2) uses[4] in its standards is not feasible, the state or authorized tribe may remove or modify the designated use based on appropriate use attainability analysis and documentation subject to EPA's review and approval. Therefore, if the recreational criteria for total microcystins or cylindrospermopsin cannot be attained, the state or authorized tribe can consider whether to modify or remove the designated use.

[4] Uses that provide for the protection and propagation of fish, shellfish, and wildlife, and recreation in and on the water, as well as for the protection of human health when consuming fish, shellfish, and other aquatic life (e.g. recreation use, aquatic life use).

4. What is the relationship between cyanobacterial blooms and the recommended criteria?

Cyanobacteria, commonly referred to as blue-green algae, are photosynthetic bacteria that occur naturally in waters, including waters used for primary contact recreation. Under certain conditions, cyanobacteria may grow rapidly to form accumulations known as cyanobacterial blooms. When the proliferation of cells making up the bloom also contains toxin-producing strains of cyanobacteria, there is the potential to have elevated concentrations of the cyanotoxins, microcystins and cylindrospermopsin, present. Generally referred to as a harmful algal blooms (HABs), these toxin-producing cyanobacterial blooms can cause harm to animals, people, or the environment. Accumulations of cyanobacteria have been associated with outbreaks of inflammatory illness (e.g., rashes) unrelated to the production of cyanotoxins.

Some states have chosen to adopt a value based on cell density as a screening tool, with further tests for specific toxins after confirming that a bloom is present. EPA did not develop recommended criteria or swimming advisories based on cyanobacterial cell density; however, the Agency summarized available information on adverse effects that may result from exposure to cyanobacterial cells and estimated a cell density value corresponding to the toxin-based criteria magnitude. For more information on the health effects from exposure to cyanobacterial cells, go to:

- Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin (see section 7.5 Cyanobacterial Cells)

Exposure to the toxins, microcystins and cylindrospermopsin, can pose additional health risks to humans and animals. Symptoms reported after recreational exposure to cyanobacterial blooms (including microcystin-producing genera) included skin irritations, allergic reactions or gastrointestinal illnesses. Symptoms of exposure to cylindrospermopsin have been reported to include fever, headache, vomiting, bloody diarrhea, hepatomegaly and kidney damage with the loss of water, electrolytes and protein.

For more information on the health effects from exposure to microcystins and cylindrospermopsin, go to:

- Health Effects Support Document for the Cyanobacterial Toxin Microcystins
- Health Effects Support Document for the Cyanobacterial Toxin Cylindrospermopsin

The presence of cyanobacteria does not necessarily mean that cyanotoxins are being produced, and conversely, cyanotoxins can be present at levels above the criteria magnitude when accumulations of cyanobacteria were not observed.[5] Benthic cyanobacteria, occurring at the bottom of the waterbody, may not be visible from the surface, but may still produce toxins.

For information on identifying blooms and specific cyanobacteria, go to:

- USGS Field and Laboratory Guide to Freshwater Cyanobacteria Harmful Algal Blooms for Native American and Alaska Native Communities.

[5] Lahti K, Rapala J, Färdig M, Niemelä M, & Sivonen K (1997b). Persistence of cyanobacterial hepatotoxin, microcystin-LR in particulate material and dissolved in lake water. *Water Research*, 31(5), 1005-1012.
Zastepa A, Pick F, & Blais J (2014). Fate and persistence of particulate and dissolved microcystin-LA from Microcystis blooms. *Human and Ecological Risk Assessment: An International Journal, 20*(6), 1670-1686.

5. Why should I consider nutrient pollution if I am implementing criteria for cyanotoxins?

Nitrogen and phosphorus loadings, or nutrient pollution input into recreational waterbodies from agricultural, industrial, and urban sources can provide optimal conditions for cyanobacterial blooms and cyanotoxin production. Preventing nutrient input and reducing nitrogen and phosphorus levels in a waterbody can help to reduce the occurrence of cyanobacterial blooms or the levels of cyanotoxins in blooms containing toxin-producing strains of cyanobacteria.[6]

The relationships between nutrients and other physical, chemical or environmental conditions is complex and can present an added challenge to recreational waterbody managers responsible for monitoring and responding to cyanobacterial blooms. In addition to nutrient concentrations, factors such as the availability of organic matter, turbidity, turbulence or flushing of a waterbody, light attenuation, temperature and pH can play a role in the composition and cyanotoxin production associated with a cyanobacterial bloom.

The sources of nutrients present in waterbodies are both natural and anthropogenic. Soil and erosion of phosphorus-containing rocks are the most significant natural sources of the phosphorus in surface waters, while bed sediment resuspension can be the major source of phosphorus to the lower water column. Significant natural sources of nitrogen include fixation of nitrogen gas, N_2, and dry and wet deposition of nitrogen compounds from the atmosphere. Human-induced nutrient pollution comes from several sources:

1. Stormwater runoff (e.g., urban and rural) contains nitrogen and phosphorus from fertilizers (especially those applied in excess or before a rain storm), yard clippings, leaves, and pet wastes that are washed away to local waterbodies or conveyed through storm sewer systems.
2. Municipal wastewater discharges (including septic systems) process billions of gallons of wastewater every day. Municipal wastewater contains nitrogen and phosphorus from human waste, food, and certain soaps and detergents.
3. Industrial wastewater discharges from industrial facilities, such as food processing and fertilizer manufacturing facilities, are sources of nitrogen and phosphorus.
4. Agricultural practices, including concentrated animal feeding operations and row crops, are sources of nitrogen and phosphorus. Other sources include: animal waste, gaseous nitrogen-based compounds like ammonia and nitrogen oxides released to the atmosphere from ventilated production houses, manure storage structures, or fields where manure (or other fertilizers) is applied and re-deposited onto land and eventually washes into surface waters.

Reductions in nutrient pollution help to reduce the occurrence of cyanobacterial blooms and waterbody eutrophication. Studies have shown that excess nitrogen can stimulate the growth of the cyanobacteria, *Microcystis*.[7] Elevated concentrations of total and dissolved phosphorus and soluble phosphates and nitrates provide optimal conditions for the increased production of microcystins. Controlling phosphorus and nitrogen inputs could reduce the biomass of cyanobacteria in the system, and the frequency and concentration of microcystins produced.

The World Health Organization: Guidelines for Safe Recreational Water Environments (PDF) contains a

[6] For the results of a study on how the experimental limitation of nutrient supplies aided in the diminishing of a cyanobacterial bloom, see:
Pace, M. et al. Reversal of a cyanobacterial bloom in response to early warnings. *Proceedings of the National Academy of Science. USA* 114, 352–357; DOI:10.1073/pnas.1612424114 (2017).

[7] See Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin, Section 3.0 Nature of the Stressors.

chapter on algae and cyanobacteria in fresh water, which includes short- and long-term management options—including nutrient management and implementation of control and abatement technologies, among other practices—with the goal of preventing or reducing the occurrence of cyanobacterial blooms in recreational waters.

As a long-term strategy to address eutrophication and cyanobacteria blooms, states and authorized tribes may consider adopting numeric nutrient criteria into their WQS or, alternatively, develop a numeric target to implement a narrative nutrient criterion that has already been adopted into their WQS. Numeric nutrient criteria or targets are useful as efficient and effective tools to support water quality assessments, watershed protection or restoration, TMDL development and permitting programs, where applicable. Specifically, numeric nutrient criteria or targets sets the foundation for states and authorized tribes to develop environmental baselines, manage water quality more effectively, measure progress, and support broader implementation initiatives (such as water quality trading, best management practices (BMPs), land stewardship, wetlands protection, voluntary collaboration, and stormwater runoff control strategies). EPA stands ready to provide technical assistance to states and authorized tribes who are developing numeric nutrient criteria or targets for different waterbody types through EPA's N-STEPS program.[8]

EPA continues to provide scientific and technical assistance to states and authorized tribes who are working to reduce nutrient pollution as a means of reducing the occurrence of cyanobacterial blooms. For more information on what EPA is doing to help reduce nutrient pollution and for tools to assist states and authorized tribes, refer to:

- Preventing Eutrophication: Scientific Support for Dual Nutrient Criteria Factsheet (PDF)
- Managing Microcystin: Identifying National-Scale Thresholds for Total Nitrogen and Chlorophyll a
- Deriving Nutrient Targets to Prevent Excessive Cyanobacterial Densities in U.S. Lakes and Reservoirs (PDF)
- Renewed Call to Action to Reduce Nutrient Pollution and Support for Incremental Actions to Protect Water Quality and Public Health (September 2016 EPA Memo) (PDF)
- Nutrient Pollution Policy and Data
- Toolkit of Resources to Assist States with Adopting and Implementing Numeric Nutrient Criteria
- Water Quality Standards Handbook
- A Compilation of Cost Data Associated with the Impacts and Control of Nutrient Pollution (PDF)

Implementation Questions about Monitoring, Assessment and Listing

6. What information should states and authorized tribes consider when prioritizing which waterbodies to monitor based on risk of elevated levels of cyanotoxins?

Recognizing the potential risks of exposure to cyanotoxins, states and authorized tribes across the country are monitoring for cyanobacteria (as a potential precursor to blooms), microcystins, cylindrospermopsin, or other algal toxins. Some states and authorized tribes have reported microcystins data through the Water Quality Portal, an interagency website that provides public access to water quality data.[9] Reporting data on cyanobacterial blooms and toxin levels can improve transparency with the public and help to provide a regional or national understanding of where blooms are taking place.

[8] https://www.epa.gov/nutrient-policy-data/n-steps
[9] https://www.waterqualitydata.us/

States and authorized tribes are encouraged to upload microcystins data to the Water Quality Portal (see: https://www.waterqualitydata.us/).

EPA recommends that states and authorized tribes prioritize their waterbodies, for monitoring purposes, based on risk factors relevant to the likelihood of a cyanotoxin or HABs event and its relative impact to recreational users of each waterbody. Prioritizing which waterbodies to monitor can help to direct often limited resources where they will be most effective.

States and authorized tribes may also consider their capacity to include cyanobacterial indicators as part of a robust monitoring and assessment program necessary to evaluate the condition of their waterbodies. Some states and authorized tribes consider existing phytoplankton data or use satellite imagery as a screening tool to identify waters that may need additional sampling.[10] States and authorized tribes may also use field test kits to screen for waters with elevated toxins before collecting a sample. States and authorized tribes are encouraged to collaborate with a range of state, tribal and local agencies, waterbody managers and citizen science/volunteer monitoring organizations to monitor local waterbodies, leveraging the presence of local resources to collect and analyze samples in a timely and appropriate manner for risk management and response activities.

CWA practitioners, public health officials, and other waterbody managers may consider a variety of information when prioritizing which waterbodies to monitor for potential cyanotoxins. Some of the factors listed below may help state, tribal and local officials to identify which waterbodies are most vulnerable:

- the type of waterbody, and types and numbers of recreational users;
- past/historical occurrence of HABs and cyanotoxin production;
- seasonal patterns of cyanobacterial blooms (influenced by temperature and precipitation, among other factors);
- point and nonpoint sources of contamination (especially nutrients) in the waterbody and in the watershed;
- physical and hydrologic factors (e.g., depth, fetch,[11] light attenuation, availability of organic matter, turbidity, pH and nutrients);
- chlorophyll-a and phycocyanin[12] levels (e.g., cell densities);
- other water quality limitations or impairments; and,
- any other information gathered as part of source water assessments or sanitary surveys.

EPA has developed materials to assist recreational waterbody managers interested in monitoring for and responding to cyanobacteria and cyanotoxins in recreational waters. In addition, EPA has provided recommendations for various water sampling and testing methods to determine whether a cyanobacterial bloom is producing cyanotoxins, whether the bloom presents a risk to human health, and whether actions should be taken to notify the public and reduce public health risks from various recreational uses of a waterbody, including if a closure is recommended.

- Monitoring and Responding to Cyanobacteria and Cyanotoxins in Recreational Waters.

[10] For a list of state recreational water guidelines relating to cyanobacteria or cyanotoxins, see Appendix B of the criteria document, https://www.epa.gov/wqc/recommended-human-health-recreational-ambient-water-quality-criteria-or-swimming-advisories.

[11] Fetch refers to the area of a lake surface over which the wind blows in an essentially constant direction, thus generating waves. The term also is used as a synonym for fetch length, which is the horizontal distance over which wave-generating winds blow.

[12] Phycocyanin is a pigment present in cyanobacteria.

- Recommendations for Cyanobacteria and Cyanotoxin Monitoring in Recreational Waters (PDF).

The following additional sources of information may inform states and authorized tribes when taking a risk-based approach to prioritizing recreational waterbodies.

- Cyanobacteria Assessment Network, CyAN: EPA's Office of Research and Development, the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA) and United States Geological Survey (USGS) are collaborating to provide interactive maps based on satellite imagery and data on chlorophyll-a levels in large waterbodies nationwide.[13]
- Field and Laboratory Guide to Freshwater Cyanobacteria Harmful Algal Blooms for Native American and Alaska Native Communities: This 2015 guide, produced by the USGS, provides field images to help differentiate between cyanobacterial blooms (some of which produce toxins), non-toxic algal blooms, and floating plants that might be confused with algae.
- Water Quality Portal: The National Water Quality Monitoring Council, USGS and EPA sponsor the Water Quality Portal, an interagency website that provides public access to water quality data collected by over 400 federal, state, tribal, and local agencies.
- Other resources may be found in pages 5 through 7 of EPA's document, Recommendations for Cyanobacteria and Cyanotoxin Monitoring in Recreational Waters (PDF).

7. How frequently and over what time period should states and authorized tribes collect data on cyanotoxin levels?

States and authorized tribes have discretion and flexibility when establishing a monitoring program for cyanotoxins. For example, states and authorized tribes may prioritize which waterbodies they monitor and how frequently they monitor those waterbodies (for information on prioritization, see Question 6). Baseline monitoring could include routine monitoring (e.g., weekly monitoring over the course of a recreation season), responsive/episodic monitoring (e.g., initiating sampling in response to a physical bloom or reported potential negative health impact to animals or humans), or a combination of the two. EPA recommends that states and authorized tribes use their monitoring strategy or annual workplans to identify the monitoring approach that will be implemented for the recreational season, considering available resources and the potential use of tools, such as remote sensing and citizens' volunteer monitoring.

[13] Algorithms to assess bloom frequency and severity have been developed; however, current satellite resolution and sensing capabilities limit the ability to apply the CyAN assessment methods on a national scale. Satellites with the highest resolution, such as Landsat, can capture 62% of lakes greater than 1 ha (2.47 acres) and 95% of the lakes with public drinking water intake locations. Unfortunately, these satellites make less frequent flyovers and are not equipped with sensors capable of distinguishing CyanoHABs from other types of HABs. Lower resolution satellites capture less than 1% of waterbodies and only 33% of drinking water intakes but make more frequent flyovers and can identify CyanoHABs. For more information, see:

Urquhart et al. *A method for examining temporal changes in cyanobacterial harmful algal bloom spatial extent using satellite remote sensing*. Harmful Algae, 67 (2017), pp. 144-152. https://doi.org/10.1016/j.hal.2017.06.001

Clark et al. *Satellite monitoring of cyanobacterial harmful algal bloom frequency in recreational waters and drinking water sources*. Ecological Indicators, 80 (2017), pp. 84-95. https://doi.org/10.1016/j.ecolind.2017.04.046

Stumpf et al. Challenges for mapping cyanotoxin patterns from remote sensing of cyanobacteria. Harmful Algae, 54 (2016), pp. 160-173. https://doi.org/10.1016/j.hal.2016.01.005

Following initial detection and confirmation of microcystins or cylindrospermopsin in waterbodies designated for primary contact recreation, EPA recommends more frequent monitoring until the bloom subsides or the cyanotoxin levels no longer exceed the cyanotoxin criteria magnitude level. Once the cyanotoxins have subsided, EPA suggests that regular monitoring of prioritized waterbodies continue for the duration of the recreation season.

For more information about monitoring for cyanotoxins, see EPA document:

- Recommendations for Cyanobacteria and Cyanotoxin Monitoring in Recreational Waters

8. How should states and authorized tribes analyze and interpret cyanotoxin monitoring data and information to evaluate ambient conditions and recreational use support?

The recommended ten-day duration component of the criteria naturally translates into use of ten-day assessment periods over the course of a recreation season to evaluate ambient waterbody condition and recreational use attainment. EPA recognizes that some states and authorized tribes have routine daily, weekly, biweekly, or monthly sampling schedules in place for different water bodies and recreational areas. Monitoring at other waterbodies may be event driven in response to a bloom. EPA recommends more frequent sampling if a bloom is detected, particularly if it is documented to have toxin levels that exceed the criteria magnitude.

Weekly monitoring may provide two samples within the ten-day assessment period, or weekly monitoring may provide data for two consecutive ten-day assessment periods (depending on how the weeks and ten-day periods align). If one or more samples are collected within the ten-day assessment period that exceed the criteria magnitude, these are counted as a single excursion. Biweekly or monthly sampling schedules can also be considered with respect to ten-day assessment periods, recognizing that some states and authorized tribes may choose to use fixed, *a priori* intervals while others may begin a ten-day period with the first sample that exceeded the criteria magnitude.

States and authorized tribes have flexibility delineating the ten-day assessment periods within their recreational season. The Example 2 text box is provided to illustrate how exceedances can count towards excursions when assessing use attainment. For the application of these criteria, an exceedance is defined as an instance when the monitoring data indicates a concentration of microcystins or cylindrospermopsin that is higher than the recommended magnitude value, and an excursion is defined as an instance of one or more exceedances within a ten-day assessment period that corresponds to the duration. The calendar figures in Example 2 illustrate two ways states and authorized tribes could set up their ten-day assessment periods, either by blocking out ten-day periods before the start of the recreation season (Example 2A) or by marking ten-day assessment periods from the date a bloom is detected and an exceedance is confirmed (Example 2B).

Example 2: Examples of How a State or Tribe Might Count Exceedances and Excursions

The following examples illustrate two hypothetical scenarios describing the evaluation of exceedances and determination of excursions for the ten-day duration period. These scenarios are intended to demonstrate how the number of excursions can be counted within a given recreation season. The red X shown on the example calendars denote days where cyanotoxin monitoring results were above the recommended cyanotoxin magnitude (exceedances). The shaded boxes represent ten-day assessment periods. An assessment period with one or more exceedances is counted as an excursion.

Example 2A: Predetermined Monitoring Schedule

June

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
8 X	9 X	10 X	11 X	12	13	14
15	16	17	18	19	20	21 X
22 X	23 X	24	25	26	27 X	28 X
29	30					

Example 2A. In this example, the state or authorized tribe establishes regularly-scheduled monitoring to begin on June 1, and on June 8 monitoring results showed an exceedance of the cyanotoxin magnitude. Subsequent monitoring showed exceedances June 9, 10 and 11, and later in the month on June 21, 22 and 23, and June 27 and 28. In this case, the nine exceedances equate to three excursions because the exceedances were detected across three separate ten-day assessment periods.

Example 2B: Responsive Ten-Day Periods

June

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
8 X	9 X	10 X	11 X	12	13	14
15	16	17	18	19	20	21 X
22 X	23 X	24	25	26	27 X	28 X
29	30					

Example 2B. In this example, the state or authorized tribe monitors for cyanotoxins in response to a suspected bloom, once the monitoring data indicates a concentration of microcystins or cylindrospermopsin that is higher than the recommended magnitude. On June 8 a suspected bloom was confirmed and monitoring results showed an exceedance of the cyanotoxin magnitude. Subsequent monitoring showed exceedances June 9, 10 and 11. A second bloom was suspected later in the month and confirmed through additional monitoring showed exceedances on June 21, 22, 23, 27 and 28. In this case, the nine exceedances equate to two excursions because the exceedances were detected across two separate ten-day periods.

9. What should states and authorized tribes consider when selecting an analytical method and sampling locations?

When selecting a method to monitor for cyanotoxins, states and authorized tribes should consider cost and practicality of various monitoring methods, and reliability and comparability of results, among other factors. More than 100 microcystin congeners are known to exist, although the majority of toxicological data on the effects of microcystins are available for microcystin-LR (a frequently monitored congener). Therefore, EPA established its recommended criterion for microcystins based on microcystin-LR and used it as a surrogate for other microcystin congeners. Two congeners of cylindrospermopsin have been identified. Analytical methods must be sufficiently sensitive to detect the cyanotoxins in question at concentrations below the criteria magnitude. Analytical results may vary depending on the analytical methods used.

Methods vary widely in sensitivity, rapidity, cost, and ease of use. As described below, there are both rapid screening tests and laboratory methods used to detect and identify cyanobacterial cells; determine the presence, absence, or count of individual congeners; or measure the concentration of total cyanotoxins in a water sample. In waterbodies that have been prioritized for monitoring, it may be cost effective to use field test kits at several locations throughout the waterbody prior to selecting samples for lab-based analysis (see below for description of field test kits). Some analytical methods measure the sum of all congeners while other methods measure specific congeners of interest. Each method has specific requirements for sample preparation/processing and analytical standards. These should also be considered when planning monitoring programs. EPA does not recommend any single method to monitor

for cyanotoxins and refers readers to the National Environmental Methods Index (https://www.nemi.gov/home/) for information on analytical methods.

Methods for quantifying cyanotoxins (total or individual congener concentrations) include:

- Lab-based enzyme–linked immunosorbent assay (ELISA) methods, to measure cyanotoxins in question. The ELISA method is typically run with only a microcystin-LR standard for comparison but can quantify a broad range of microcystin congeners (especially if using an ADDA-based antibody) and other compounds that are similar to microcystin congeners (e.g., nodularin).
- Field test kits (e.g., Abraxis test strip, Envirologix QualiTube). These field-based methods do not require laboratory instrumentation and can produce semi-quantitative results within about an hour; however, their relatively high limit of quantification (approximately 1-10 µg/L) may better suit these methods for screening purposes.
- Protein phosphatase inhibition assay (PPIA). This method has varying degrees of specificity depending on its substrate composition and may react to compounds in the sample, other than microcystins.
- High performance liquid chromatography (HPLC) combined with ultraviolet/photodiode array detectors (UV/PDA). This method requires known toxin standards to be run alongside the water sample(s) to quantify the toxin concentration(s) and its results are limited to only those congeners for which standards are available and analyzed. LC-UV methods are based on a non-selective detector and co-eluting interferents can prevent accurate identification of components and quantitation. It is less sensitive than mass spectrometry methods (see below).
- Liquid chromatography/tandem mass spectrometry (LC/MS/MS).[14] Like HPLC-PDA, this method typically requires known toxin standards to be run alongside the water sample(s) to quantify the toxin concentration(s) and its results are limited to only those congeners for which standards are available and analyzed. It is, however, the most precise method for quantitation of analytes (such as specific microcystin variants) if standards are available. May require use of solid phase extraction for analytes with weak product ion abundance (microcystins). The LC-MS/MS MMPB (2-methyl-3(methoxy)-4-phenylbutyic acid) method, however, analyzes the chemically cleaved ADDA group common to all microcystin variants and provides an alternative LC-based approach for analyzing total microcystins. The MMPB method may also detect microcystins break-down products and could potentially overestimate total microcystins concentrations in some settings.

EPA recognizes that several states or authorized tribes may monitor for cyanobacterial cell densities in addition to, or in lieu of, monitoring for cyanotoxins. Two methods for quantifying cyanobacterial cells include microscopy and quantitative polymerase chain reaction (qPCR) and microarrays/DNA chips.

Like other aspects of monitoring programs, decisions on sample location are guided by the management questions being addressed. For example, when monitoring recreational waters for public health protection, it's reasonable to target sample collection toward capturing the highest potential exposure risks; therefore, EPA recommends that states and authorized tribes collect single grab samples from designated swimming areas, near the shoreline, or composite samples from points within the splash zones where children play. Monitoring for other objectives may result in sampling at other areas of a waterbody (e.g., if sampling for source water protection, rather than the protection of recreational

[14] For more information on single laboratory validated methods for detecting cyanotoxins in freshwaters by LC/MS/MS, see (1) https://www.epa.gov/water-research/single-laboratory-validated-method-determination-cylindrospermopsin-and-anatoxin to detect cylindrospermopsin and anatoxin-a, and (2) https://www.epa.gov/water-research/single-laboratory-validated-method-determination-microcystins-and-nodularin-ambient to detect microsystins and nodularin (combined intracellular and extracellular).

uses).

EPA has produced technical materials to aid in the development of cyanobacteria and cyanotoxin monitoring programs, including information on available testing methods and sampling logistics. See materials at:

- For recommendations related to establishing a sampling and monitoring program, see: https://www.epa.gov/cyanohabs/recommendations-cyanobacteria-and-cyanotoxin-monitoring-recreational-waters;
- For a summary of methods used to detect cyanobacteria and cyanotoxins in water, see: Determination of Cyanotoxins in Drinking and Ambient Freshwaters; and,
- For a set of frequently asked questions related to laboratory analysis for microcystins in drinking water, see: Frequently Asked Questions: Laboratory Analysis for Microcystins in Drinking Water.

10. What data and information should states and authorized tribes assemble and evaluate to complete CWA water quality assessments with EPA's recommended cyanotoxin criteria?

States and authorized tribes are required under 40 CFR 130.7(b)(5) to assemble and evaluate all existing and readily available water quality-related data and information when determining which waterbodies belong on the state's or authorized tribe's CWA section 303(d) list of impaired and threatened waters. For states and authorized tribes that have adopted the recommended recreational criteria for total microcystins and cylindrospermopsin and are interested in assessing against the criteria, "readily available data and information" would include observed concentration levels for microcystins and cylindrospermopsin collected by the state, authorized tribe, or other stakeholders (e.g., citizen science water monitoring groups).

In addition to observed concentration levels of microcystins and cylindrospermopsin, EPA considers advisories to be existing and readily available data and information. Hence, for states and authorized tribes that implement the recommended swimming advisory levels but do not adopt the recommended criteria, advisories can be used to support water quality assessments using other applicable WQS (e.g., designated uses and narrative criteria). EPA recommends that states and authorized tribes include within their assessment methodologies information about how the state or tribe will use advisories to evaluate attainment of narrative water quality criteria and associated designated uses.

11. Should states and authorized tribes update their assessment methodology to include the evaluation of cyanotoxin data and information? If so, what should be considered in these updates?

States and authorized tribes should consider updating their water quality assessment methodology to address any water quality standard adopted by the state or authorized tribe. An assessment methodology constitutes the decision process that a state or authorized tribe employs to determine the water quality attainment status of waters in the state or on tribal lands. Under 40 CFR 130.7(b)(6), states and authorized tribes are required to provide documentation to EPA to support their determination to include or not include waters on its impaired and threatened waters list. States and authorized tribes are required to include a description of the methodology used to develop the list; a description of the data and information used to identify waters for the list, including a description of the data and information used by the jurisdiction; and, a rational for any decisions to not use existing and readily available data and information to develop the list.

EPA encourages states and authorized tribes to make the assessment methodology available to the public for review and comment prior to, or along with, solicitations for data and information. Such engagement helps facilitate stakeholder input to the state's or authorized tribe's assessment of water quality status, including recreational use assessments. If states and authorized tribes choose to adopt the recommended cyanotoxin recreational criteria, EPA recommends that they update their assessment methodologies to account for any criteria-specific considerations. For states and authorized tribes that use the swimming advisory recommendation, EPA also encourages them to describe in their assessment methodology how, if at all, the advisory information will be used to support water quality assessments using other applicable WQS (e.g., designated uses and narrative criteria).

12. What happens if a state or authorized tribe does not have sufficient data to make an assessment determination?

EPA recommends that states and authorized tribes submit an integrated water quality report that uses a five-category approach for classifying the WQS attainment status for each waterbody in their jurisdiction. Consistent with this approach, EPA recommends that waterbody segments be placed in waterbody assessment Category 3 of the Integrated Report when there is insufficient available data and/or information to make a use-support determination. Information on the appropriate use of Category 3 can be found in EPA's 2009 memo to assist states and authorized tribes in the preparation of the 2010 Integrated Water Quality Reports.[15]

13. What factors should be considered in defining waterbody segmentation (e.g., if dividing a waterbody into smaller assessment units for advisories and 303(d) listings)?

States and authorized tribes have flexibility to define the segmentation for waterbodies within their jurisdiction. Information on segmenting waters can be found in EPA's 2005 memo to assist states and authorized tribes in the preparation of the 2006 Integrated Water Quality Reports.[16]

14. How should states and authorized tribes approach waterbody assessments for a waterbody that is already on the CWA section 303(d) list?

Consistent with any applicable water quality standard, states and authorized tribes make future assessment decisions based on an evaluation of existing and readily available water quality-related data and information against the water quality standard and accompanying assessment method. The assessment decision informs whether a waterbody should be identified as impaired or threatened on the jurisdiction's Section 303(d) list.

States and authorized tribes can decide not to include a waterbody/pollutant combination that was previously identified as impaired or threatened on a state's or tribe's 303(d) list (also known as, "delist") for several reasons, including: (a) the water quality standard is now being met, (b) there were flaws in the

[15] USEPA (U.S. Environmental Protection Agency). 2009. Information Concerning 2010 Clean Water Act Sections 303(d), 305(b), and 314 Integrated Reporting and Listing Decisions. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/sites/production/files/2015-10/documents/2009_05_06_tmdl_guidance_final52009.pdf.

[16] USEPA (U.S. Environmental Protection Agency). 2005. Guidance for 2006 Assessment, Listing and Reporting Requirements Pursuant to Sections 303(d), 305(b) and 314 of the Clean Water Act. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/sites/production/files/2015-10/documents/2006irg-report.pdf

original listing, (c) a TMDL was developed and approved by EPA, or (d) other point sources or nonpoint source controls are expected to meet WQS as described in 40 CFR 130.7(a)(b)(1).

Implementation Questions about Water Quality Management Plans (e.g., TMDLs)

15. How should states and authorized tribes complete TMDLs for waterbodies that are listed under CWA section 303(d) as impaired or threatened due to cyanotoxins?

States and authorized tribes can develop TMDLs for the pollutant(s) that promote development of cyanobacterial blooms and elevated levels of microcystins and cylindrospermopsin above EPA's recommended criteria. As previously discussed in this document, nitrogen and phosphorus loadings can provide optimal conditions for the formation of cyanobacterial blooms and cyanotoxin production. Although accurately deriving the quantity of nutrient pollution reduction necessary to meet WQS for cyanotoxins (or cyanobacteria) is a complex process, states and authorized tribes can use tools EPA is currently developing to better understand the relationship between the causal variables—pollutant loads of nitrogen and phosphorus—and the response variables of the cyanotoxin microcystins.[17] States and authorized tribes may also want to conduct site-specific studies to help refine these relationships and should consider the state of the science as they prioritize and schedule TMDLs to address cyanotoxins.

[17] Additional research is currently being conducted by EPA and others to improve the understanding between cyanotoxins and nutrient pollution. For example, see:

1. Lester L. Yuan and Amina I. Pollard, Managing microcystin: identifying national-scale thresholds for total nitrogen and chlorophyll-*a*, *Freshwater Biology*, 59, 9, (1970-1981), (2014).
2. Lester L. Yuan and Amina I. Pollard, Deriving nutrient targets to prevent excessive cyanobacterial densities in U.S. lakes and reservoirs, *Freshwater Biology*, 60, 9, (1901-1916), (2015).
3. Lester L. Yuan and Amina I. Pollard, Using National-Scale Data to Develop Nutrient–Microcystin Relationships That Guide Management Decisions, *Environmental Science & Technology*, 51, 12, (6972), (2017).

United States Environmental Protection Agency

Office of Water

EPA **823-R-21-002**

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Final Technical Support Document:

Implementing the 2019 National Clean Water Act Section 304(a) Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin

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Notice: This technical support document is primarily intended to support states, authorized tribes,[1] and territories (collectively referred to as "states and authorized tribes") in implementing the Environmental Protection Agency's (EPA) national Clean Water Act (CWA) Section 304(a) *Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins*[2] *and Cylindrospermopsin*.[3] States and authorized tribes may adopt one or both of the national CWA Section 304(a) recommended criteria into their state or tribal water quality standards (WQS) or may use the recommended criteria magnitude values as the basis for swimming advisories and related public notification purposes.

This document provides general information about the recommended criteria and flexibilities states and authorized tribes have, if implementing the criteria. The document also provides recommendations on how to assemble and interpret monitoring data, how to use monitoring data and other available information to make CWA Section 303(d) assessment determinations, and how to develop water quality management plans, including Total Maximum Daily Loads (TMDLs) and National Pollutant Discharge Elimination System (NPDES) permits, aimed at addressing nutrients as a precursor to cyanotoxin production.

While this document cites statutes and regulations that contain requirements applicable to these programs, it does not impose legally binding requirements on EPA, states, authorized tribes, other regulatory authorities, or the regulated community. EPA, states, authorized tribes, and other decision makers may adopt approaches on a case-by-case basis that differ from those provided in this document, as appropriate and consistent with statutory and regulatory requirements. Also, EPA may update this document as new scientific and technical information becomes available. In addition to this document, EPA has prepared the following information to support states and authorized tribes in their efforts to monitor and respond to cyanobacterial blooms and cyanotoxins in recreational waters:

- Cyanobacterial Harmful Algal Blooms in Water (website): https://www.epa.gov/cyanohabs
- Monitoring and Responding to Cyanobacteria and Cyanotoxins in Recreational Waters (website): https://www.epa.gov/cyanohabs/monitoring-and-responding-cyanobacteria-and-cyanotoxins-recreational-waters
- Recommendations for Cyanobacteria and Cyanotoxin Monitoring in Recreational Waters (PDF): https://www.epa.gov/cyanohabs/recommendations-cyanobacteria-and-cyanotoxin-monitoring-recreational-waters

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[1] "Authorized tribes" in this document generally refers to those federally recognized Indian tribes with authority to administer a CWA Section 303(c) WQS program. (Under EPA's regulations, a tribe that is eligible to administer WQS is likewise eligible to administer CWA Section 401 water quality certifications). When this document discusses CWA Section 402 implementation authority, "authorized tribes" refers to federally recognized Indian tribes with authority to administer a CWA Section 402 program. When this document discusses CWA Section 303(d) implementation authority, "authorized tribe" refers to federally recognized Indian tribes with authority to administer a CWA Section 303(d) program.

[2] Microcystins comprise a class of over 100 congeners and unless specified otherwise, "microcystins" refers to *total* microcystins.

[3] USEPA. 2019. *Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin 2019.* EPA 822-R-18-004. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/wqc/recommended-human-health-recreational-ambient-water-quality-criteria-or-swimming-advisories.

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General Questions about Recommended Cyanotoxin Water Quality Criteria

1. What are EPA's national CWA Section 304(a) recommended recreational water quality criteria for microcystins and cylindrospermopsin?

In 2019, EPA issued its national Clean Water Act (CWA) Section 304(a) recreational water quality criteria recommendations for two cyanotoxins, microcystins and cylindrospermopsin, reflecting the latest peer-reviewed scientific knowledge. The criteria are designed to protect the public from incidental exposure to harmful levels of these cyanotoxins while participating in water-contact activities in freshwater where immersion and incidental ingestion of water are likely. Such activities include, but are not limited to, swimming, water skiing, tubing, skin diving, water play by children, or similar water-contact activities in waterbodies designated for such recreational uses.[4] EPA issued its 2019 recommended criteria under the statutory authority of CWA Section 304(a).

EPA's 2019 recommended criteria for microcystins and cylindrospermopsin are summarized in Table 1, below. For more information on the magnitude, duration and frequency components of the criteria, see *Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin 2019* (Section 6).

Table 1. National CWA Section 304(a) Recommendations for Recreational Water Quality Criteria for Microcystins and Cylindrospermopsin[a]

Microcystins Magnitude (µg/L)	**Cylindrospermopsin Magnitude** (µg/L)	**Duration**	**Frequency**
8	15	1 in 10-day assessment period across a recreational season	Not more than 3 excursions in a recreational season in more than one year[b]

[a] States and authorized tribes can choose to adopt one or both criteria recommendations.

[b] An excursion is defined as a 10-day assessment period with any toxin concentration higher than the recommended criteria magnitude. When more than three excursions occur within a recreational season and that pattern reoccurs in more than one year, it is an indication the water quality has been or is becoming degraded and is not supporting its recreational use. As a risk management decision, states and authorized tribes should include in their WQS an upper-bound recurrence frequency stating the number of years that pattern can reoccur and still support its recreational use.

[4] For information about the scope and applicability of recommended recreational water quality criteria, see EPA's 2012 *Recreational Water Quality Criteria*, (Section 2.0 Applicability and Scope). Office of Water 820-F-12-058. https://www.epa.gov/sites/production/files/2015-10/documents/rwqc2012.pdf.

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States and authorized tribes may adopt one or both of the national CWA Section 304(a) recommended criteria into their state or tribal water quality standards (WQS). Per WQS regulations at 40 CFR 131.20(a)[5], if a state or tribe chooses not to adopt water quality criteria for one or both of these cyanotoxins based either on EPA's recommendations or other scientifically defensible methods,[6] the state or authorized tribe must provide an explanation for not adopting such criteria as part of its triennial review.

EPA recognizes that multiple environmental factors can cause variability in algal bloom formation and toxin production, and that some years may produce blooms that occur for long periods, or blooms of shorter duration that occur repeatedly throughout a single recreational season, but such events may not occur every year. Therefore, EPA recommends that states and authorized tribes consider the pattern of excursions within a recreational season *and* across multiple years when determining whether the recreational use is attained.

The duration and frequency of cyanobacterial blooms can vary, with short-term blooms lasting days or weeks and long-term blooms lasting several months, or possibly all year. As a result, the frequency of excursions—defined as ten-day assessment periods during which time toxin concentrations have been measured above the recommended criteria magnitude—can also vary. States and authorized tribes that choose to adopt the national CWA Section 304(a) recommended criteria would analyze the pattern of excursions throughout the duration of each recreational season, and from one season to the next, as specified in state or tribal standards (see Question 3 for more on defining the length of a recreational season). For example, a 90-day recreational season with one ten-day excursion each month is a different pattern than a 90-day recreational season with three consecutive ten-day excursions in the final month of the recreational season. An understanding of the patterns of blooms can help waterbody managers respond effectively to protect public health. The recommended criteria components listed in Table 1, above, can help to identify a short- or long-term temporal trend or a spatial distribution pattern of cyanotoxin excursions that can be used to evaluate a waterbody (see Question 8, which provides detail on how to count excursions within a recreational season).

EPA recommends that when more than three excursions occur within a recreational season *and* a pattern (of more than three excursions per recreational season) reoccurs in more than one year, it is an indication that the water quality is or may be becoming degraded such that the waterbody no longer supports its recreational use. It is important to note that a pattern of more than three excursions per recreational season would not need to be *the same* pattern each year (e.g., the pattern of multiple excursions may resemble a long-term bloom of back-to-back excursions one year and several discrete, short-term excursions another year). A determination of whether the waterbody supports its recreational use would depend on the number of years when multiple cyanotoxin excursions are observed with respect to the *recurrence frequency*, which is specified by the state or authorized tribe that adopts the criteria. It is also important to note that the years with multiple excursions do not have to be consecutive to indicate a water quality problem. The recurrence frequency is a risk management decision that states and authorized tribes need to determine when developing their WQS. States and authorized tribes may make different risk management decisions for different types of waterbodies but should specify in their

[5] 40 CFR 131.20(a): "… if a State does not adopt new or revised criteria for parameters for which EPA has published new or updated CWA section 304(a) criteria recommendations, then the State shall provide an explanation when it submits the results of its triennial review to the Regional Administrator consistent with CWA section 303(c)(1) and the requirements of paragraph (c) of this section."

[6] 40 CFR 131.11(b)(iii)

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adopted criteria the number of years a pattern of multiple (i.e. more than three) cyanotoxin excursions per recreational season can occur for the recreational use to be supported (see Example 1 text box in Question 3).

2. How can EPA's recommended recreational water quality criteria values for microcystins and cylindrospermopsin be used for swimming advisories?

When a bloom or the presence of cyanotoxins is confirmed, the recreational waterbody manager typically issues a public notification (either a swimming advisory or a closure of swimming areas) to raise awareness of the potential risks associated with contact with the cyanobacterial bloom or its toxins in recreational waters. Swimming advisories are recommendations to limit swimming or other recreational water-contact activities, due to an increased health risk from contact with or ingestion of the cyanobacteria or cyanotoxins; whereas, a closure notification or posting typically means that the waterbody is officially closed to the public.

EPA envisions that if states or authorized tribes decide to use the recommended criteria magnitude values for swimming advisory purposes, they can manage a cyanotoxin monitoring and advisory program in the same way as they manage any existing recreational water advisory program (e.g., those for pathogen indicators, like *E. coli* or enterococci).[7] States and authorized tribes may choose to apply either or both recommended criteria magnitude values as the basis for public notifications (i.e., swimming advisories or closures) at recreational waterbodies. EPA's swimming advisory recommendations for microcystins and cylindrospermopsin are summarized in Table 2, below.

Table 2. Swimming Advisory Recommendations for Microcystins and Cylindrospermopsin[a]

Microcystins Magnitude (µg/L)	Cylindrospermopsin Magnitude (µg/L)	Duration	Frequency
8	15	One day	Not to be exceeded

[a] States and authorized tribes can choose to apply one or both recommended magnitude values as the basis for swimming advisories.

The guidelines for posting an advisory or closure for a waterbody are typically set at the state, tribal, or local level.[8] EPA recognizes that some states and authorized tribes may handle swimming advisories through their health departments and not through their environmental quality departments. As a result, inter-departmental coordination may be helpful to implement an advisory program which can also serve to inform drinking water providers and water quality practitioners. EPA has provided an example Cyanobacteria Bloom Response Contact List on its website to help state or tribal employees consider who to contact in the event of a cyanobacterial bloom (see: https://www.epa.gov/sites/production/files/2017-07/contact-list-rec-water.docx).

[7] Note, however, that monitoring, reporting and notification of potential exposure to cyanobacteria and their toxins in coastal recreation waters cannot be funded under the BEACH Act Grant program.

[8] We use the term, "jurisdictional level" to include state or tribal. See *Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin 2019* (Appendix B), which summarizes available information on state recreational water guidelines for cyanotoxins and cyanobacteria.

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If using EPA's swimming advisory recommendations for a swimming advisory or a closure, EPA recommends that the relevant authority (typically a local health department official or water quality management official) notify the public whenever the concentration of microcystins or cylindrospermopsin in a sample is higher than the recommended criteria magnitude value. EPA also recommends that a swimming advisory not be lifted until at least two subsequent samples, taken at least 24 hours apart, show that the toxin concentration has fallen below the recommended magnitude value of the criteria. States and authorized tribes may choose to extend the re-sampling period after issuing a swimming advisory over several days, to allow for additional photodegradation of the cyanotoxin.[9] The important point is to wait until the concentration of microcystins or cylindrospermopsin subsides below the recommended swimming advisory magnitude values before the swimming advisory is lifted. By increasing the monitoring frequency at a site where a swimming advisory is issued, recreational waterbody managers will get a clearer understanding of the temporal nature of toxins which can be useful in making management decisions to protect the recreational use, including when to remove an advisory.

EPA has published materials to help recreational waterbody managers responsible for monitoring and responding to cyanobacterial blooms. These materials include customizable infographics and a communication toolbox with examples of public messages, press releases, and signage that recreational waterbody managers may use to inform the public of increased health risks associated with exposure to harmful algal blooms (HABs), or cyanobacteria, and their toxins. In addition, EPA has provided recommendations for waterbody managers (or relevant state, local or tribal officials) regarding various water monitoring, sampling, and testing methods. These recommendations can help waterbody managers determine whether a cyanobacterial bloom is producing toxins, whether the bloom presents an increased health risk to water-contact recreators, and whether immediate actions should be taken to notify the public if a closure is recommended based on waterbody test results. For more information, follow these links:

- Infographics to Help Educate the Public on HABs Basics: https://www.epa.gov/cyanohabs/infographics-help-educate-public-habs-basics
- Communicating about Cyanobacterial Blooms and Toxins in Recreational Waters: https://www.epa.gov/cyanohabs/communicating-about-cyanobacterial-blooms-and-toxins-recreational-waters
- Monitoring and Responding to Cyanobacteria and Cyanotoxins in Recreational Waters: https://www.epa.gov/cyanohabs/monitoring-and-responding-cyanobacteria-and-cyanotoxins-recreational-waters

[9] For studies that demonstrated cyanotoxin breakdown in natural waters within a week, see:

1. Chiswell, R., Shaw, K., and Eaglesham, G.R. 1999. *Stability of cylindrospermopsin, the toxin from the cyanobacterium Cylindrospermopsis raciborski, effect of pH, temperature, and sunlight on decomposition*. Environmental Toxicology. 14:155-161.
2. Jones, G.J., Blackburn, S. I., and Parker, N.S. 1994. *A toxic bloom of Nodularia spumigena Mertens in Orielton Lagoon, Tasmania*. Australian Journal of Marine and Freshwater Research. 45:787-800.

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3. What flexibilities do states and authorized tribes have if they adopt the recommended recreational water quality criteria for microcystins and cylindrospermopsin?

If states or authorized tribes choose to adopt EPA's national CWA Section 304(a) *Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin*, several flexibilities are available to accommodate specific water quality-related circumstances while meeting the requirements of the CWA and EPA's WQS regulation.[10] In addition to considering the Agency's national recommended water quality criteria when revising their WQS, states and authorized tribes may adopt, where appropriate, other scientifically defensible criteria that differ from EPA's recommendations. For example, states and authorized tribes can:

- *Define the length of the recreational season.* States and authorized tribes can adopt seasonal designated uses of a waterbody with respect to various CWA Section 304(a) recommended criteria, including the recommended criteria for microcystins and cylindrospermopsin. For states and authorized tribes that have adopted seasonal uses, the recommended cyanotoxin criteria would apply only to the primary contact recreational season.[11] The length of a "recreational season" is an important consideration because states and authorized tribes would likely monitor the quality of their highest-priority recreational waters throughout the recreational season. For purposes of establishing seasonal WQS, a change to the recreational season constitutes a change to the state's or authorized tribe's designated use in their WQS and would need to be reviewed and approved by EPA pursuant to CWA Section 303(c). Because local health departments or departments of parks and recreation may define the recreational seasons for inland waterbodies, it is important for states and authorized tribes to coordinate with these local authorities when identifying the length of the state's or tribe's recreational season in WQS.
- *Prioritize waterbodies for monitoring.* EPA recommends that states and authorized tribes prioritize their waterbodies, for monitoring purposes, based on risk factors relevant to the likelihood of a cyanotoxin or HAB event and its relative impact to recreational users of each waterbody. Prioritizing which waterbodies to monitor can help to direct limited resources where they will be most effective (for more on prioritizing waterbodies for monitoring, see Question 6). For all recreational waterbodies—especially for those that are lower priority for monitoring—EPA also recommends that states and tribes communicate with their constituents about how to identify and report a potential cyanobacterial bloom (for templates and other communication tools, see Question 2).
- *Define a recurrence frequency.* The recommended criteria for microcystins and cylindrospermopsin recommend that the toxin concentrations should not be above the recommended criteria magnitude values in more than three 10-day periods per recreational season *in more than one year*, but the recommended criteria do not specify an upper-bound number of years that pattern can occur across recreational seasons (i.e., a recurrence frequency). This provides states and authorized tribes the flexibility to define what the recurrence frequency should be for their state or tribe. The recurrence frequency can be thought of as a sliding window of time during which patterns of excursions should be considered. For example, some states or authorized tribes might assess the pattern of excursions over a rolling 3-year period while others may choose to count over a rolling 5-year period, or longer. EPA recommends that each state or

[10] 40 CFR Part 131 – Water Quality Standards.

[11] 40 CFR 131.10(f) specifies that states and authorized tribes "may adopt seasonal uses as an alternative to reclassifying a waterbody or segment thereof to uses requiring less stringent water quality criteria."

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authorized tribe documents the recurrence frequency in the state or tribal water quality standards or supporting documents. Example 1, below, provides sample text that a state or authorized tribe could include in its adopted criteria to specify the recurrence frequency. EPA encourages states and authorized tribes to explain their selection of recurrence frequency to their constituents when they put their draft standards out for public comment.

Example 1: Written Statement to Specify Recurrence Frequency

> If a state or authorized tribe chooses to adopt the recommended criteria, EPA expects the state or tribe to also include the recurrence frequency in its WQS. A state or authorized tribe may achieve this with a written statement in its standards. An example written statement could say, *"The concentration of microcystins shall not exceed 8 µg/L in more than three 10-day periods per recreational season, for more than one recreational season, over a rolling 5-year period."*

- *Determine how to delineate the 10-day assessment period.* States and authorized tribes have flexibility in applying the 10-day assessment period. Some may choose to use predetermined 10-day assessment periods for waterbodies with a documented history of cyanobacterial blooms or cyanotoxin production (e.g., the month of June could have three 10-day assessment periods). Another approach is to begin the 10-day assessment period in response to a visible bloom that has been confirmed as toxin-producing. States and authorized tribes are encouraged to consider the application of the frequency and duration components to capture elevated toxin concentrations (which may or may not coincide with the general proliferation of total cyanobacteria at high densities). More information on delineating assessment periods throughout a recreational season is provided in Question 8.
- *Derive site-specific criteria elements*. States and authorized tribes may modify EPA-recommended criteria to fit their unique situation, based on site-specific data and information, pursuant to 40 CFR 131.11(b)(ii). For example, a state or tribe may derive site-specific criteria based, in part, on information about the exposure variables among the population that uses the waterbody (e.g., age and incidental ingestion rates) or to take into account specific cultural or land use practices at or near the site. The site-specific criteria must be based on sound scientific rationale and protective of the designated use of the state's or tribe's waterbodies pursuant to 40 CFR 131.11(a) and approved by EPA pursuant to Section 303(c) of the CWA.
- *Revise the designated uses of waterbodies within their state*. Pursuant to 40 CFR 131.10(g), states and authorized tribes may remove a designated CWA Section 101(a)(2) use,[12] which is not an existing use, if the state can demonstrate that attaining the designated use is not feasible because one of the attainability factors listed in 40 CFR 131.10(g) is met. The decision to remove a designated CWA Section 101(a)(2) use (e.g., primary contact recreation use) or a sub-category of such a use, or to designate a subcategory of such a use that requires less stringent criteria, must be based on an appropriate use attainability analysis, pursuant to 40 CFR 131.10(j). Additionally, revisions to designated uses are considered a change to water quality standards that must include documentation to support the use revision pursuant to 131.10 and 131.20 and are subject to

[12] CWA Section 101(a)(2) uses are those that provide for the protection and propagation of fish, shellfish, and wildlife, and recreation in and on the water, as well as for the protection of human health when consuming fish, shellfish, and other aquatic life (e.g. recreation use, aquatic life use).

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public participation requirements of 40 CFR 131.20(b) and to EPA's review and approval under CWA Section 303(c).[13]

- *Adopt a WQS variance.* A state or authorized tribe could adopt, and EPA could approve, a WQS variance in cases where the recreational use and associated criterion (microcystins or cylindrospermopsin, as translated to nutrients) are unattainable in the near-term, but it is possible to make feasible progress toward attaining that designated use and criterion.[14] For information on the connection between cyanotoxins and nutrients, see Question 16. For information on translating between microcystins and nutrient loads in lakes, see Question 17 and Question 18.

4. What is the relationship between cyanobacterial cell density and the recommended criteria?

EPA recognizes that some states and authorized tribes have included total cyanobacterial cell density values as an important part of their HAB management strategy. EPA did not recommend criteria based on cyanobacterial cell density because of the uncertainties quantifying the relationship between cell densities and observed health effects. Available information on cell density, health endpoints, and guidelines developed by other authorities on total cyanobacteria cells is described in the Effects Characterization section (Section 7.5) and in Appendix D of the national CWA Section 304(a) recreational water quality criteria recommendations for microcystins and cylindrospermopsin. EPA presents a toxigenic cell number based on the number of toxigenic cells that could produce microcystins equivalent to the recommended criteria magnitude. The Effects Characterization section also describes gene-based detection methods (i.e., quantitative polymerase chain reaction (qPCR)) that can target and quantify the toxigenic subpopulation of cyanobacteria that are present in a waterbody and used in some states or authorized tribes (see Section 7 of the national CWA Section 304(a) recreational water quality criteria recommendations for microcystins and cylindrospermopsin).

The presence of cyanobacteria does not necessarily mean that cyanotoxins are being produced, and conversely, cyanotoxins can be present at levels above the recommended criteria magnitude when accumulations of cyanobacteria were not observed.[15] Additionally, benthic cyanobacteria, occurring at the bottom of the waterbody, may not be visible from the surface, but may still produce toxins.

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[13] USEPA. 2006. *Use Attainability Analyses and Other Tools for Managing Designated Uses* 821-R-07-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC..

[14] The WQS Variance Building Tool is designed to help states, territories, and authorized tribes determine whether a WQS variance is an appropriate tool for a particular situation. For more information, see: https://www.epa.gov/wqs-tech/water-quality-standards-variance-building-tool.

[15] See *Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin*, Section 3.3.2 Persistence.

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5. What are the potential health effects of cyanotoxin exposure to humans, pets and livestock?

EPA's national CWA Section 304(a) recommended criteria for microcystins and cylindrospermopsin reflect the latest scientific knowledge on the potential human health effects from recreational exposure to these two cyanotoxins.[16] Potential human health effects from recreational exposure to cyanobacteria and these two cyanotoxins could range from gastrointestinal illnesses to liver and kidney damage. For information on the health effects of exposure to microcystins and cylindrospermopsin to humans, go to:

- Health Effects Support Document for the Cyanobacterial Toxin Microcystins
- Health Effects Support Document for the Cyanobacterial Toxin Cylindrospermopsin

Although the recommended recreational criteria values are for the protection of human health (not pets and livestock), common signs of cyanotoxin poisonings in pets and livestock may include repeated vomiting, diarrhea, loss of appetite, abdominal swelling, stumbling, seizures, convulsions, disorientation, inactivity, or skin rashes and hives, and in extreme cases collapse and sudden death. For more information on concerns relating to pet or livestock exposure to microcystins and cylindrospermopsin, including a summary of guidelines that several states or authorized tribes have developed, go to:

- Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin (Section 7.8 Livestock and Pet Concerns)
- Learn more about how to protect your dog (Protect Your Pooch: How to keep your dog safe from toxic algae)

In addition to the EPA resources listed above, the Centers for Disease Control and Prevention (CDC) provides multiple resources, such as frequently asked questions (FAQs), Veterinarian Cards and Animal Safety Alerts, to help educate the public of the dangers associated with cyanotoxin exposure to pets. The CDC suggests that pet owners prevent their animals from playing in—or drinking—scummy water. If a dog has been swimming in scummy water, the CDC recommends rinsing them off immediately to prevent the dog from licking cyanobacteria off their fur. The CDC also collects voluntarily reported data on individual human and animal cases of illnesses from HAB-associated exposures through its One Health Harmful Algal Bloom System.[17]

[16] Although accumulations of cyanobacterial cells have been associated with outbreaks of inflammatory illness (e.g., rashes) unrelated to the production of cyanotoxins, available data are insufficient to develop recreational values for a total cyanobacterial cell density related to inflammatory health endpoints among humans.

[17] https://www.cdc.gov/habs/ohhabs.html

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Implementation Questions about Monitoring, Assessment and Listing

6. What information should states and authorized tribes consider when prioritizing which waterbodies to monitor based on risk of elevated levels of cyanotoxins?

EPA recommends that states and authorized tribes prioritize their waterbodies, for monitoring purposes, based on an objective set of risk factors relevant to the likelihood of a cyanotoxin or HAB event and its relative impact to recreational users of each waterbody. Prioritizing which waterbodies to monitor can help to direct often limited resources where they will be most effective. It is important that a prioritization process is transparent, does not create inequities to vulnerable populations, and works to ensure that waterbodies with high recreational use and likelihood of having algal blooms are prioritized.

States and authorized tribes are encouraged to collaborate with a range of state, tribal and local agencies, waterbody managers and citizen science/volunteer monitoring organizations to monitor local waterbodies. By leveraging the presence of local resources to monitor, states and authorized tribes can more effectively coordinate risk management and response activities. For example, a local recreational waterbody manager who is collecting weekly samples for other indicators may be able to collect an additional sample for cyanotoxins. CWA practitioners, public health officials, and other waterbody managers may consider a variety of information when prioritizing which waterbodies to monitor for potential cyanotoxins. Some of the risk factors listed below may help state, tribal and local officials to identify which waterbodies are most vulnerable:

- the type of waterbody and numbers of recreational users (e.g., is it a public swimming area?);
- past/historical occurrence of cyanotoxin producing blooms;
- seasonal patterns of cyanobacterial blooms (influenced by temperature and precipitation, among other factors);
- point and nonpoint sources of nutrients in the waterbody and in the watershed;
- physical and hydrologic factors (e.g., depth, fetch[18], light attenuation, availability of organic matter, turbidity, temperature, pH);
- chlorophyll-a and phycocyanin[19] levels (i.e., cell densities);
- other water quality limitations or impairments; and,
- any other information gathered as part of source water assessments or sanitary surveys.

Some states and authorized tribes use screening tools to determine which waterbodies to prioritize for cyanotoxin sampling. They may look at related data such as cyanobacteria or phytoplankton data collected as part of their monitoring program. States and authorized tribes may consider using field test kits to screen for waters with elevated toxins before collecting a sample for laboratory analysis. Another screening tool based on satellite imagery is the Cyanobacteria Assessment Network (CyAN). EPA's Office of Research and Development developed the CyAN Mobile Application for the early detection of select algal blooms (those containing phycocyanin) in U.S waterbodies and freshwater lakes over one sq km in size to help local and state water quality managers make faster and better-informed management

[18] Fetch refers to the area of a lake surface over which the wind blows in an essentially constant direction, thus generating waves. The term also is used as a synonym for fetch length, which is the horizontal distance over which wave-generating winds blow.

[19] Phycocyanin is a pigment present in cyanobacteria. Sensors are available which measure the presence of this pigment and report relative cyanobacteria concentrations in cells/mL.

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decisions related to cyanobacterial blooms. It provides an easy-to-use, customizable interface for accessing algal bloom satellite data for over 2,000 of the largest lakes and reservoirs in the United States. The CyAN app is free and available for download in the Google Play™ store for Android™ devices, and a web-based version of the app is currently being developed. [20]

Reporting data on cyanobacterial blooms and toxin levels can improve transparency with the public and help to provide a regional or national understanding of where blooms are taking place. Some states and authorized tribes have reported microcystins data through the Water Quality Portal, an interagency website that provides public access to water quality data collected by over 400 federal, state, tribal and local agencies .[21] Anytime states are monitoring water quality and whenever authorized tribes or other organizations are using EPA grant money to perform water quality monitoring, they are required, as part of their grant terms and conditions, to upload their data to the Water Quality Portal. The Portal is one of many sources of information which may inform states and authorized tribes when taking a risk-based approach to prioritizing recreational waterbodies for monitoring.

Additional materials to assist recreational waterbody managers interested in monitoring for and responding to cyanobacteria and cyanotoxins in recreational waters are listed below:

- Monitoring and Responding to Cyanobacteria and Cyanotoxins in Recreational Waters.
- Recommendations for Cyanobacteria and Cyanotoxin Monitoring in Recreational Waters (PDF).
- Field and Laboratory Guide to Freshwater Cyanobacteria Harmful Algal Blooms for Native American and Alaska Native Communities: This 2015 guide, produced by the USGS, provides field images to help differentiate between cyanobacterial blooms (some of which produce toxins), non-toxic algal blooms, and floating plants that might be confused with algae.
- EPA Sanitary Survey App for Marine and Fresh Waters: EPA has updated its recreational sanitary survey app, *EPA Sanitary Survey App for Marine and Fresh Waters*, to help waterbody managers evaluate all contributing waterbody and watershed information including water quality data, pollution source data, and land use data. The updated app enables jurisdictions to easily gather

[20] Methods to assess bloom temporal frequency, spatial extent, magnitude, and lake occurrence with satellite data have been developed. The 300-meter resolution Sentinel-3 satellites capture less than 1% of waterbodies and approximately 33% of drinking water intakes but provide frequent monitoring and can readily identify cyanobacterial HABs. Therefore, CyAN assessment methods can be applied at a national scale but are limited to the largest lakes. Satellites with 10 to 30 m resolution, such as Landsat and Sentinel-2, can capture 62% of lakes greater than 1 ha (2.47 acres) and 95% of the lakes with public drinking water intake locations. These satellites make less frequent flyovers and are not as well equipped with sensors to easily distinguishing cyanobacterial HABs from other types phytoplankton. For more information, see:

1. Urquhart et al. *A method for examining temporal changes in cyanobacterial harmful algal bloom spatial extent using satellite remote sensing*. Harmful Algae, 67 (2017), pp. 144-152. https://doi.org/10.1016/j.hal.2017.06.001

2. Clark et al. *Satellite monitoring of cyanobacterial harmful algal bloom frequency in recreational waters and drinking water sources*. Ecological Indicators, 80 (2017), pp. 84-95. https://doi.org/10.1016/j.ecolind.2017.04.046.

3. Stumpf et al. *Challenges for mapping cyanotoxin patterns from remote sensing of cyanobacteria*. Harmful Algae, 54 (2016), pp. 160-173. https://doi.org/10.1016/j.hal.2016.01.005.

[21] Visit the Water Quality Portal here: https://www.waterqualitydata.us/. For help uploading data to the Water Quality Portal through the Water Quality Exchange (WQX), phone 1-800-424-9067, e-mail STORET@epa.gov, or visit https://www.epa.gov/waterdata/support-storage-and-retrieval-and-water-quality-exchange-data-owners.

information on possible existence of harmful algal blooms, in addition to likely sources of bacterial pollution.

7. How frequently and over what time period should states and authorized tribes monitor cyanotoxin levels?

States and authorized tribes have discretion and flexibility when establishing a monitoring program for cyanotoxins. For example, baseline monitoring could include routine monitoring (e.g., weekly monitoring over the course of a recreational season), responsive/episodic monitoring (e.g., initiating sampling in response to a physical bloom or reported potential negative health impact to animals or humans), or a combination of the two. EPA recommends that states and authorized tribes use their monitoring strategy or annual workplans to identify the monitoring approach that will be implemented for the recreational season, considering available resources and the potential use of tools, such as remote sensing and citizens' volunteer monitoring.

EPA recommends more frequent sampling if a bloom is detected, particularly if it is documented to have toxin levels above the recommended criterion magnitude. That is, once a concentration higher than the criterion magnitude is detected, a state or authorized tribe with a biweekly or responsive sampling program should switch to more frequent sampling (e.g., weekly or daily) until the bloom subsides or the cyanotoxin concentrations are no longer above their respective cyanotoxin criteria magnitude levels. Once the cyanotoxins have subsided, EPA recommends that regular monitoring of prioritized waterbodies continue for the duration of the recreational season. EPA also recommends that states and authorized tribes consider doing follow up monitoring at these sites in subsequent years to capture the recurrence frequency.

For more information about monitoring for cyanotoxins, see EPA document, Recommendations for Cyanobacteria and Cyanotoxin Monitoring in Recreational Waters.

8. How should states and authorized tribes analyze and interpret cyanotoxin monitoring data and information to evaluate ambient conditions and recreational use support?

The recommended 10-day duration component of the criteria naturally translates into the use of 10-day assessment periods over the course of a recreational season to evaluate ambient waterbody conditions and recreational use attainment.

The sampling frequency (daily, weekly, biweekly, etc.) is a risk-management decision made at the state, tribal, or local level. Weekly monitoring may provide two samples within the 10-day assessment period, or weekly monitoring may provide data for two consecutive 10-day assessment periods (depending on how the weeks and 10-day periods align). If one or more samples are collected within the 10-day assessment period that are above the criteria magnitude, these should be counted as a single excursion. EPA recognizes other sampling schedules may be used as long as they take into consideration the need to be protective of recreational use of the given waterbody.

States and authorized tribes have flexibility delineating the 10-day assessment periods within their recreational season. Example 2 text box, below, is provided to illustrate how samples with concentrations

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above the criterion magnitude can count towards excursions when assessing use attainment. For the application of these criteria, an excursion is defined as a 10-day assessment period during which time monitoring data shows a concentration of microcystins or cylindrospermopsin that is higher than the recommended magnitude value. When more than three excursions occur within a recreational season and a pattern of excursions reoccurs for more than one year within the recurrence frequency (described in Question 3), the criterion is exceeded (i.e., the waterbody would be considered impaired).

The calendar figures in Example 2 illustrate two ways states and authorized tribes could set up their 10-day assessment periods, either by blocking out 10-day periods before the start of the recreational season (Example 2A) or by marking 10-day assessment periods from the date a bloom is detected and an excursion is confirmed (Example 2B). Once an approach to delineating 10-day assessment periods is selected, the same approach should be used each year.

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Example 2: Examples of How a State or Tribe Might Delineate Assessment Periods

The following examples are intended to demonstrate how the number of excursions can be counted within a given recreational season. The red X shown on the example calendars denotes days when cyanotoxin monitoring results were *above* the recommended cyanotoxin criteria magnitude, and the blue check denotes days when monitoring results that were *below* the recommended cyanotoxin criteria magnitude. The shaded boxes represent 10-day assessment periods. A 10-day assessment period with one or more measured cyanotoxin concentrations above the criteria magnitude is counted as an excursion. Boxes without any shading, in Example 2B, represent days that are not included in a 10-day assessment period (because no recent bloom was observed).

Example 2A: Predetermined 10-Day Assessment Periods

June/July

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
✓ 1	2	3	4	5	6	7
✓ 8	9	10	11	12	13	14
X 15	16	17	18	19	20	21
✓ 22	23	24	25	26	27	28
X 29	30	1	2	3	4	5
✓ 6	7	8	9	10	11	12

Example 2A. In this example, the state or authorized tribe establishes a predetermined weekly monitoring schedule to begin on June 1 and has delineated consecutive 10-day assessment periods throughout the recreational season. On June 1, June 8, June 22, and July 6, weekly monitoring results showed a cyanotoxin concentration below the recommended criteria magnitude. However, monitoring results from June 15 and June 29 showed concentrations above the recommended criteria magnitude, resulting in two excursions in the month of June because the cyanotoxin concentrations were detected above the recommended criteria magnitude during two separate 10-day assessment periods.

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Example 2B: Responsive 10-day Assessment Periods

June/July

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
8	9	10	11	12 X	13	14
15	16	17	18	19 ✓	20	21
22	23	24	25	26	27	28
29 X	30	1	2	3	4	5
6 ✓	7	8	9	10	11	12

Example 2B. In this example, the state or authorized tribe monitors for cyanotoxins *in response to* a suspected bloom, once the monitoring data indicates a concentration of microcystins or cylindrospermopsin that is higher than the recommended criteria magnitude. On June 12, the first suspected bloom of the season was sampled and confirmed when monitoring results showed a cyanotoxin concentration above the recommended criteria magnitude. This started the 10-day assessment period and a sample taken one week later, on June 19th, showed that the cyanotoxin levels had subsided. Again, on June 29th, a suspected bloom was sampled and confirmed, triggering the start of a new 10-day assessment period (through July 8th). Once again, a sample taken one week later, on July 6th, showed that the cyanotoxin levels had subsided. (Note: If the sample on July 6th showed toxin concentrations above the recommended criteria magnitude, a new 10-day assessment period would begin on July 9th.) The measures above the recommended criteria magnitude equate to two 10-day excursions because the elevated cyanotoxin concentrations were detected across two separate 10-day periods. Response-based monitoring may be a better option for local jurisdictions with limited monitoring resources.

9. What should states and authorized tribes consider when selecting an analytical method?

States and authorized tribes may choose an analytical method that they deem appropriate for monitoring and assessment purposes. When selecting a method to monitor for microcystins or cylindrospermopsin, states and authorized tribes should consider cost and practicality of various monitoring methods, and reliability and comparability of results, among other factors. Well over 100 microcystin congeners are known to exist; however, the majority of toxicological data on the effects of microcystins are available for microcystin-LR (a frequently monitored congener). Therefore, EPA established its recommended criterion for microcystins based on microcystin-LR and used it as a surrogate for other microcystin congeners.

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Analytical methods should be sufficiently sensitive to detect the cyanotoxins in question at concentrations below the recommended criteria magnitude; however, analytical results may vary depending on the analytical methods used.

Methods vary widely in sensitivity, rapidity, cost, and ease of use. As described below, there are both rapid screening tests and laboratory methods used to detect and identify cyanobacterial cells; determine the presence, absence, or count of individual congeners; or measure the concentration of total cyanotoxins in a water sample. It may be cost effective to use field test kits at several locations throughout a waterbody prior to selecting samples for lab-based analysis (see below for description of field test kits). Some analytical methods measure the sum of all congeners while other methods measure specific congeners of interest. Methods that measure more congeners provide a more complete assessment of potential public health risk, while methods that identify specific congeners can be helpful to understand specific characteristics of the bloom. Each method has specific requirements for sample preparation/processing and analytical standards. These should also be considered when planning a monitoring program.

EPA does not require any single method to monitor for cyanotoxins. Analytical methods should be sufficiently sensitive with minimum detection levels lower than the recommended criteria magnitude of microcystins and cylindrospermopsin. In addition to the list below, EPA refers readers to the National Environmental Methods Index (https://www.nemi.gov/home/) for information on analytical methods. Also, the Interstate Technology and Regulatory Council Harmful Cyanobacterial Blooms project team has included a comprehensive summary of analytical methods and a method selection tool on its website (https://www.itrcweb.org/Team/Public?teamID=82).

Methods for quantifying cyanotoxins (total or individual congener concentrations) include, but are not limited to:

- EPA developed standardized methods for analyzing cyanotoxins in ambient and drinking water:
    - EPA Method 544, a standardized, single laboratory validated liquid chromatography/tandem mass spectrometry (LC/MS/MS) method for the detection of microcystins and nodularin in drinking water;
    - EPA Method 545, a standardized, single laboratory validated LC/MS/MS method for the detection of cylindrospermopsin and anatoxin-a in drinking water; and
    - EPA Method 546, a standardized, single laboratory validated method using an Adda enzyme-linked immunosorbent assay for the detection of microcystins and nodularin in ambient and drinking water.
- Lab-based Enzyme-Linked Immunosorbent Assay (ELISA) method. The ELISA method is typically run with only a microcystin-LR standard for comparison but can quantify a broad range of microcystin congeners (especially if using an ADDA-based antibody).
- Field test kits (e.g., Eurofins Technologies (formerly Abraxis) test strip, Envirologix QualiTube). These field-based methods do not require laboratory instrumentation and can produce semi-quantitative results within about an hour; however, these methods may be better suited for screening purposes, given their limited range of quantification.
- High performance liquid chromatography (HPLC) combined with ultraviolet/photodiode array detectors (UV/PDA). This method requires known toxin standards to be run alongside the water sample(s) to quantify the toxin concentration(s), and its results are limited to only those congeners for which standards are available and analyzed. HPLC-UV/PDA methods are based on a non-selective detector and co-eluting interferents can prevent accurate identification of components and quantitation. It is less sensitive than mass spectrometry methods (see below).

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- Liquid chromatography/tandem mass spectrometry (LC/MS/MS).[22] Like HPLC-UV/PDA, this method requires known toxin standards to be run alongside the water sample(s) to quantify the toxin concentration(s) and its results are limited to only those congeners for which standards are available and analyzed. It is, however, the most precise method for quantitation of analytes (such as specific microcystin congeners) if standards are available. This method may also require the use of solid phase extraction for analytes with weak product ion abundance (microcystins). The LC-MS/MS MMPB (2-methyl-3(methoxy)-4-phenylbutyic acid) method analyzes the chemically cleaved ADDA group common to all microcystin congeners and therefore provides an alternative LC-based approach for analyzing a broad range of microcystin congeners. The MMPB method may also detect microcystins break-down products and could potentially overestimate microcystin concentrations in some settings.
- Protein phosphatase inhibition assay (PPIA). This method has varying degrees of specificity depending on its substrate composition and may react to compounds in the sample other than microcystins.[23]

EPA recognizes that several states or authorized tribes may monitor for cyanobacterial cell densities in addition to, or in lieu of, monitoring for cyanotoxins. Laboratory-based methods for quantifying cyanobacterial cells include microscopy and quantitative polymerase chain reaction (qPCR) and microarrays/DNA chips. Field-based methods include, but are not limited to, remote sensing based on satellite imagery, FlowCam (imaging particle analysis), flow cytometry, and derivative spectrophotometry. For more on the relationship between cell densities and the recommended criteria, see Question 4.

10. What should states and authorized tribes consider when selecting sampling locations?

Like other aspects of a monitoring program, decisions on sample location are guided by the management questions being addressed. For example, when monitoring recreational waters for public health protection, it's reasonable to target sample collection toward capturing the highest potential exposure risks; therefore, EPA recommends that states and authorized tribes collect single grab samples from designated swimming areas, near the shoreline, or a composite of samples taken at the same time from points within the splash zones where children play (e.g., ankle-, knee- and chest-deep). EPA does not recommend averaging sampling data taken at different times because averaging data over time does not give a clear picture of the pattern of cyanobacterial bloom formation and cyanotoxin exposure to the population using the waterbody for recreational purposes. For example, states should not average data collected over different days in a ten-day assessment period.

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[22] For more information on single laboratory validated methods for detecting cyanotoxins in freshwaters by LC/MS/MS, see (1) https://www.epa.gov/water-research/single-laboratory-validated-method-determination-cylindrospermopsin-and-anatoxin to detect cylindrospermopsin and anatoxin-a, and (2) https://www.epa.gov/water-research/single-laboratory-validated-method-determination-microcystins-and-nodularin-ambient to detect microcystins and nodularin (combined intracellular and extracellular).

[23] Jarkko Rapala, Kirsti Erkomaa, Jaana Kukkonen, Kaarina Sivonen, Kirsti Lahti. *Detection of microcystins with protein phosphatase inhibition assay, high-performance liquid chromatography–UV detection and enzyme-linked immunosorbent assay: Comparison of methods*, Analytica Chimica Acta, Volume 466, Issue 2, 2002, Pages 213-231, ISSN 0003-2670, https://doi.org/10.1016/S0003-2670(02)00588-3.

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When collecting samples, it is essential to establish and follow quality assurance (QA) and quality control (QC) procedures. EPA has created guidance for producing quality assurance project plans (QAPP) to aid in documenting quality assurance/quality control (QA/QC) procedures.[24] It is recommended that a QAPP be in place for monitoring programs to assure the quality of the resulting data and the appropriateness of their use. Detailed procedures for collecting, handling, and analyzing samples are typically specified in the field standard operating procedures (SOPs) and analytical methods SOPs.[25]

SOPs may also be informed by sample collection and handling procedures established by the laboratory performing sample analysis. For example, a laboratory may require a specific type of bottle in which to collect a sample or may provide instructions for chilling a sample after collection. Laboratories establishing sample collection and handling procedures should adhere to protocols defined by the chosen analytical method but may also consult the USGS guidelines for design and sampling for cyanobacterial toxin and taste-and-odor studies in lakes and reservoirs.[26]

EPA has produced technical materials to aid in the development of cyanobacteria and cyanotoxin monitoring programs, including information on available testing methods and sampling logistics.

- For recommendations related to establishing a sampling and monitoring program, see: https://www.epa.gov/cyanohabs/recommendations-cyanobacteria-and-cyanotoxin-monitoring-recreational-waters;
- For a summary of methods used to detect cyanobacteria and cyanotoxins in water, see: Determination of Cyanotoxins in Drinking and Ambient Freshwaters; and,
- For a set of frequently asked questions related to laboratory analysis for microcystins in drinking water, see: Frequently Asked Questions: Laboratory Analysis for Microcystins in Drinking Water.

11. What data and information should states and authorized tribes assemble and evaluate to complete CWA water quality assessments with EPA's recommended cyanotoxin criteria?

States and authorized tribes are required under 40 CFR 130.7(b)(5) to assemble and evaluate all existing and readily available water quality-related data and information when determining which waterbodies belong on the state's or authorized tribe's CWA Section 303(d) list of impaired and threatened waters. "Readily available data and information" relevant to assessment against the recommended recreational criteria for microcystins or cylindrospermopsin would include observed concentration levels for

[24] For more information on how to create a Quality Assurance Project Plan, see https://www.epa.gov/quality/guidance-quality-assurance-project-plans-epa-qag-5.

[25] The National Aquatic Resource Surveys (NARS) collaborative programs between EPA, states, and tribes designed to assess the quality of the nation's waters include field and laboratory procedures for collecting algal toxin samples in the program QAPP, field operation manual and lab operation manual. Additionally, for examples of a state SOPs for collecting and analyzing algal toxin samples, see (1) https://www.kdheks.gov/algae-illness/Response_Plan/Appendix_J.pdf and (2) https://www.dec.ny.gov/docs/water_pdf/habsprogramguide.pdf.

[26] Graham, J.L., Loftin, K.A., Ziegler, A.C., and Meyer, M.T., 2008, Guidelines for design and sampling for cyanobacterial toxin and taste-and-odor studies in lakes and reservoirs: U.S. Geological Survey Scientific Investigations Report 2008–5038. Reston, VA. https://pubs.usgs.gov/sir/2008/5038/.

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microcystins and cylindrospermopsin collected by the state, authorized tribe, or other stakeholders (e.g., local health departments, federal agencies, or citizen science water monitoring groups).

EPA also considers swimming advisories to be existing and readily available data and information for completing water quality assessments. Hence, for states and authorized tribes that implement the recommended swimming advisory levels—regardless of whether or not they adopted the recommended criteria—advisories would support water quality assessments using other applicable WQS (e.g., designated uses and narrative criteria).

12. Should states and authorized tribes update their assessment methodology to include the evaluation of cyanotoxin data and information? If so, what should be considered in these updates?

States and authorized tribes should consider updating their water quality assessment methodology, if needed, to address any water quality standard adopted by the state or authorized tribe. An assessment methodology constitutes the decision process that a state or authorized tribe employs to determine the water quality standards attainment status of waters on the state or on tribal lands. Under 40 CFR 130.7(b)(6), states and authorized tribes are required to provide documentation to EPA to support their determination whether to include or not include waters on their impaired and threatened waters lists. States and authorized tribes are required to include a description of the methodology used to develop the list; a description of the data and information used to identify waters for the list, including a description of the data and information used by the jurisdiction; and a rationale for any decisions to not use existing and readily available data and information to develop the list. When updating their methodologies, states and authorized tribes should describe any expectations regarding data and information associated with their cyanotoxin criteria, including any data quality, quantity and representativeness considerations needed to evaluate the recurrence frequency aspect of the criteria. In addition, states and authorized tribes should update their methodologies to describe how they will identify the pollutants (e.g., nutrients) causing or expected to cause violations of the cyanotoxin criteria, consistent with 40 CFR 130.7(b)(4).

EPA encourages states and authorized tribes to make the assessment methodology available to the public for review and comment. Such engagement helps facilitate stakeholder input to the state's or authorized tribe's assessment of water quality status, including recreational use assessments. If states and authorized tribes choose to adopt the recommended cyanotoxin recreational criteria, EPA recommends that they update their assessment methodologies to account for any criteria-specific considerations. For states and authorized tribes that use the swimming advisory recommendation to inform attainment with a narrative water quality standard, EPA also recommends that they describe in their assessment methodology how the advisory information will be evaluated and used to determine attainment of applicable narrative water quality criteria and associated uses.

13. What happens if a state or authorized tribe does not have sufficient data to make an assessment determination?

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EPA regulations require that states and authorized tribes assemble and evaluate all existing and readily available water quality-related data and information to develop their CWA Section 303(d) list (40 CFR 130.7(b)(5)). As such, states and authorized tribes must be inclusive in the types of water quality data and information they collect and evaluate. However, EPA recognizes that there may be circumstances when it is not possible to make an attainment decision because the state or authorized tribe has determined that the readily available data and information are insufficient. With regard to EPA's 304(a) recommendation, examples of these circumstances may include, but are not limited to, determining that the cyanotoxin data and information were collected using insufficient QA/QC measures or are not representative of the conditions of the waterbody.

If a state or authorized tribe decides not to rely on certain available information and data in making listing decisions, it must provide a technical, science-based rationale. 40 CFR 130.7(b)(6)(iii). Waters identified as impaired and listed on the Section 303(d) list in the previous reporting cycle should not be removed in the subsequent listing cycle unless the state or authorized tribe can provide a rationale for doing so.

14. What factors should be considered in defining waterbody segmentation (e.g., if dividing a waterbody into smaller assessment units for advisories and CWA Section 303(d) listings)?

States and authorized tribes have flexibility to define the segmentation of waterbodies within their jurisdiction; there is no single approach to the development of a segmentation scheme. Assessment decisions can reflect the broader ecological system (e.g. an entire lake) or be partitioned to smaller components (e.g. smaller assessment units). Whatever approach a state or authorized tribe selects, waterbody segmentation should be consistent with water quality standards and capable of providing a spatial scale that is adequate to characterize attainment status. States and authorized tribes generally segment waters to represent homogeneity in physical, biological or chemical conditions.

15. How should states and authorized tribes approach waterbody assessments for a waterbody that is already on the CWA Section 303(d) list?

Consistent with any applicable water quality standard, states and authorized tribes make future assessment decisions based on an evaluation of existing and readily available water quality-related data and information against the water quality standard using the accompanying assessment method. The assessment decision informs whether a waterbody should be identified as impaired or threatened for microcystins or cylindrospermopsin on the jurisdiction's CWA Section 303(d) list. Waterbodies can be listed as impaired for multiple waterbody/pollutant combinations. When data and information indicate non-attainment for a waterbody that is already on the CWA Section 303(d) list (e.g., waterbodies having impaired recreation use due to *E. coli*, Enterococci or another pollutant), the state or authorized tribe should add microcystins and cylindrospermopsin to the list of impairments for the waterbody already listed as impaired.

For cyanotoxins, states and authorized tribes can decide not to include a waterbody/pollutant combination that was previously identified as impaired or threatened on a state's or tribe's 303(d) list (also known as "delist") for several reasons, including: (a) the water quality standard is now being met, (b) there were flaws in the original listing, (c) a TMDL was developed and approved by EPA, or (d) other point

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sources or nonpoint source controls are expected to meet WQS as described in 40 CFR 130.7(b)(1). Note that for microcystins and cylindrospermopsin, the number of years of data that would be needed to demonstrate that the water quality criteria are being met would tie back to the recurrence frequency that a state or tribe would have established in its WQS. In addition, for these cyanotoxins, states and authorized tribes could use swimming advisories to inform listing and delisting waters from their CWA Section 303(d) lists based on narrative criteria, as mentioned in Question 12.

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Implementation Questions about Water Quality Management Plans (e.g., TMDLs and NPDES permitting)

16. Why should I consider nutrient pollution if I am implementing the recommended criteria for cyanotoxins?

Loading of excess nutrients, including nitrogen and phosphorus, into recreational waterbodies from urban, industrial, and agricultural sources can contribute to cyanobacterial blooms and cyanotoxin production, as nitrogen and phosphorus are required for cyanobacterial growth. Reducing excess nitrogen and phosphorus in a waterbody can help to reduce the occurrence of cyanobacterial blooms or the levels of cyanotoxins in blooms containing toxin-producing strains of cyanobacteria.[27]

The relationships between nutrients and other physical, chemical, or environmental conditions are complex and can present added challenges to recreational waterbody managers responsible for monitoring and responding to cyanobacterial blooms. In addition to nitrogen and phosphorus concentrations, factors such as the availability of organic matter, turbidity, turbulence or flushing of a waterbody, light attenuation, temperature, and pH can play a role in the composition and cyanotoxin production associated with a cyanobacterial bloom. For more information on the factors influencing the occurrence of cyanobacterial blooms and toxin production, see Section 3.1.1 of the recommended criteria document.

The sources of nutrients present in waterbodies are both natural and anthropogenic. Soil and erosion of phosphorus-containing rocks are the most significant natural sources of the phosphorus in surface waters, while resuspension of bed sediment can be the major source of phosphorus to the lower water column. Significant natural sources of nitrogen include fixation of nitrogen gas, N_2, by diazotrophic organisms, as well as dry and wet deposition of naturally derived nitrogen compounds from the atmosphere. Human-caused nutrient pollution comes from several sources, for example:

1. Stormwater runoff in rural and urban areas contains nitrogen and phosphorus from fertilizers (especially those applied in excess or before a rainstorm), yard clippings, leaves, and pet wastes that are washed away to local waterbodies or conveyed through storm sewer systems. Land-based disturbances neighboring a waterbody (such as deforestation, soil compaction, reduced riparian buffers, erosion, or added impermeable surfaces) can increase stormwater runoff and can result in more nutrient pollution and sedimentation.
2. Discharges from municipal wastewater systems contain nitrogen and phosphorus from human waste, food, and certain soaps and detergents.
3. Discharges from industrial facilities, such as fertilizer manufacturers or food processing facilities, are sources of nitrogen and phosphorus.
4. Nonpoint source runoff from agriculture practices, such as the application of fertilizer to row crops and manure management can also be a source of nutrients.

Controlling excess phosphorus and nitrogen inputs could reduce the biomass of cyanobacteria in the system, and the frequency and concentration of microcystins and cylindrospermopsin produced. For

[27] For the results of a study on how the experimental limitation of nutrient supplies aided in the diminishing of a cyanobacterial bloom, see: Pace, M. et al. Reversal of a cyanobacterial bloom in response to early warnings. *Proceedings of the National Academy of Science. USA* 114, 352–357; DOI:10.1073/pnas.1612424114 (2017).

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more information on the impact of stressors, including elevated concentrations of total and dissolved phosphorus and nitrogen (e.g., soluble phosphates and nitrates), on the increased production of microcystins and cylindrospermopsin, see Section 3.0 of the national CWA Section 304(a) recommended criteria document.

As a long-term strategy to address eutrophication and cyanobacteria blooms, EPA recommends that states and authorized tribes consider adopting numeric nutrient criteria into their WQS or, alternatively, develop a numeric target to implement a narrative nutrient criterion that has already been adopted into their WQS. Numeric nutrient criteria or targets are useful tools to support water quality assessments, watershed protection or restoration, TMDL development, and permitting programs, where applicable. For information on translating between microcystins and nutrient loads in lakes, see Question 17 and Question 18. EPA stands ready to provide technical assistance to states and authorized tribes who are developing numeric nutrient criteria or targets for different waterbody types through EPA's Nutrient Scientific Technical Exchange Partnership and Support (N-STEPS) program.[28]

EPA continues to provide scientific and technical assistance to states and authorized tribes who are working to reduce excess nutrients as a means of reducing the occurrence of cyanobacterial blooms. For more information on what EPA is doing to help reduce excess nutrients and for tools to assist states and authorized tribes, refer to:

- Preventing Eutrophication: Scientific Support for Dual Nutrient Criteria Factsheet (PDF)
- Managing Microcystin: Identifying National-Scale Thresholds for Total Nitrogen and Chlorophyll a
- Deriving Nutrient Targets to Prevent Excessive Cyanobacterial Densities in U.S. Lakes and Reservoirs (PDF)
- Renewed Call to Action to Reduce Nutrient Pollution and Support for Incremental Actions to Protect Water Quality and Public Health (September 2016 EPA Memo) (PDF)
- Nutrient Pollution Policy and Data
- Toolkit of Resources to Assist States with Adopting and Implementing Numeric Nutrient Criteria
- Water Quality Standards Handbook
- A Compilation of Cost Data Associated with the Impacts and Control of Nutrient Pollution (PDF)

In addition to the EPA resources listed above, the document, World Health Organization: Guidelines for Safe Recreational Water Environments (PDF), contains a chapter on algae and cyanobacteria in freshwater, which includes short- and long-term management options—including nutrient management and implementation of control and abatement technologies, among other practices—with the goal of preventing or reducing the occurrence of cyanobacterial blooms in recreational waters.

17. How should states and authorized tribes complete TMDLs for waterbodies that are listed under CWA Section 303(d) as impaired or threatened due to cyanotoxins?

To address an impairment due to microcystins or cylindrospermopsin, states and authorized tribes would develop TMDLs for the pollutant(s) that promote development of cyanobacterial blooms capable of producing microcystins and cylindrospermopsin at levels above EPA's recommended criteria. As

[28] https://www.epa.gov/nutrient-policy-data/n-steps

previously discussed in this document, excess nutrients (nitrogen and/or phosphorus) and other factors (e.g., temperature) can provide optimal conditions for the formation of cyanobacterial blooms and cyanotoxin production. Accurately deriving the quantity, timing, and geographic distribution of pollutant reductions necessary to meet WQS for cyanotoxins (or cyanobacteria) is a complex process; however, states and authorized tribes can use technical tools to better understand the relationship between the pollutants and the biological and chemical responses associated with cyanobacterial blooms and the production of cyanotoxins such as microcystins. Technical tools that improve the understanding between nutrient pollution and adverse water quality effects associated with both non-toxic and toxic harmful algal blooms include empirical models developed for nutrient water quality criteria development,[29] as well as empirical and mechanistic models used for nutrient TMDLs that address impairments related to dissolved oxygen or elevated algal biomass (which can co-occur with toxic harmful algal blooms). States and authorized tribes may also want to conduct site-specific studies to help refine these relationships and should consider the state of the science as they prioritize and schedule TMDLs to address cyanotoxins.

18. Where a state or authorized tribe has adopted water quality criteria for microcystins and/or cylindrospermopsin, are National Pollutant Discharge Elimination System (NPDES) permits expected to include effluent limits for cyanotoxins?

In general, EPA does not anticipate NPDES permit limits for microcystins or cylindrospermopsin because most facilities subject to NPDES permit requirements do not typically discharge cyanotoxins directly. However, as previously discussed in this document, excess nitrogen and phosphorus loadings can provide optimal conditions for the formation of cyanobacterial blooms and cyanotoxin production. To better inform decisions around how best to control cyanotoxins and meet water quality standards, it may be helpful for NPDES permitting authorities to consider the risk of elevated levels of cyanotoxins in the receiving water when evaluating nutrient requirements in NPDES permits. States and authorized tribes can use technical tools to better understand the relationship between the pollutants—nitrogen and phosphorus—and the biological and chemical responses associated with toxic harmful algal blooms, including cyanotoxins. Technical tools that improve the understanding between nutrient pollution and adverse water quality effects associated with algal blooms, both non-toxic and toxic harmful algal blooms, include empirical models developed for nutrient water quality criteria development,[30] nutrient models

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[29] For example: *Ambient Water Quality Criteria to Address Nutrient Pollution in Lakes and Reservoirs* (EPA-822-R-21-005), U.S. EPA, Office of Water, published July 2021.

[30] For example:

1. Lester L. Yuan and Amina I. Pollard, Managing microcystin: identifying national-scale thresholds for total nitrogen and chlorophyll-a, Freshwater Biology, 59, 9, (1970-1981), (2014).

2. Lester L. Yuan and Amina I. Pollard, Deriving nutrient targets to prevent excessive cyanobacterial densities in U.S. lakes and reservoirs, Freshwater Biology, 60, 9, (1901-1916), (2015).

3. Lester L. Yuan and Amina I. Pollard, Using national-scale data to develop nutrient–microcystin relationships that guide management decisions, Environmental Science & Technology, 51, 12, (6972-6980), (2017).

4. Lester L. Yuan and Amina I. Pollard, Combining national and state data improves predictions of microcystin concentration, Harmful Algae, 84, (75-83), (2019).

5. Lester L. Yuan and John R. Jones, Rethinking phosphorus–chlorophyll relationships in lakes, Limnology and Oceanography, 65, (1847-1857), (2020).

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that target dissolved oxygen or elevated algal biomass (which can co-occur with toxic harmful algal blooms), and state and federal technical guidance specific to the development of NPDES permit requirements. The document, *Ambient Water Quality Criteria to Address Nutrient Pollution in Lakes and Reservoirs,* summarizes the latest scientific information on nutrient pollution in lakes and reservoirs.[31] This document was published in July 2021 and contains a valuable summary of the current science on the issue of nutrients and bloom formation.

States and authorized tribes may also want to conduct site-specific studies to help refine these relationships and consider the state of the science as they evaluate the need for nutrient requirements in NPDES permits where there are applicable water quality criteria for cyanotoxins. For waterbodies where TMDLs have been developed to meet applicable water quality criteria for cyanotoxins, and the TMDL includes a waste load allocation for nitrogen and phosphorus, based on translations from microcystin concentrations, the waste load allocation is used to establish permit limits for nitrogen and phosphorus to meet the water quality criteria per 40 CFR 122.44(d)(1)(vii)(B). Conversely, where there are applicable water quality criteria for cyanotoxins but no TMDL for nutrients based on a microcystin translation, NPDES permitting authorities should consider the available science in determining whether nutrient discharges cause, have reasonable potential to cause, or contribute to impairments of applicable water quality criteria for cyanotoxins. Where the Director of the permitting authority determines that nutrient discharges cause, have reasonable potential to cause, or contribute to such impairments, the permit must include nutrient limits that are derived from and comply with the applicable water quality criteria per 40 CFR 122.44(d)(1)(vii)(A).

[31] USEPA. 2021. *Ambient Water Quality Criteria to Address Nutrient Pollution in Lakes and Reservoirs.* EPA-822-R-21-005. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/nutrient-policy-data/epas-recommended-ambient-water-quality-criteria-nutrients.

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Harmful Algal Bloom (HAB) Advisory Guidance

Version 1.0

Prepared by

NMED Surface Water Quality Bureau

July 9, 2026

NMED Exhibit 96

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Introduction

Purpose

The New Mexico Environment Department (NMED) Surface Water Quality Bureau (SWQB) in collaboration with the New Mexico Department of Health (NMDOH), resource management agencies, and other stakeholders have developed a Harmful Algal Blooms (HABs) Advisory Program for New Mexico to inform collaborators and the public when HAB are present in New Mexico surface waters so they can make informed decisions to protect public and animal health. This HAB Advisory Guidance provides NMED, NMDOH, resource management agencies, and other cooperators with procedural guidelines should a HAB be suspected in surface waters in New Mexico. The plan also outlines the process should an HAB be identified in a public drinking water supply and information on reporting potential HAB-related illnesses. Publicly accessible lakes and reservoirs used for recreation are the primary focus of this plan and NM's HAB Advisory Program at this time because these waterbodies are the most likely to be associated with exposure of people or animals to cyanotoxins or other cyanobacteria-related irritants via water contact, accidental ingestion, or inhalation. Information in this plan can also be used for other surface waters where HABs occur. The plan will be reviewed at least annually by NMED SWQB and will be updated as new information on this emerging contaminant is determined and becomes available. When changes affect the scope, implementation, or outcome of HAB advisories, this guidance document will be revised accordingly.

Background and HAB Ecology

Cyanobacteria are naturally occurring important components of the aquatic environment. Cyanobacteria is commonly referred to as blue-green algae since cyanobacteria appear and function similarly to algae; however, cyanobacteria are not true algae. Under normal conditions, cyanobacteria are present in the water column or attached to surfaces at low levels.

HABs occur when dense concentrations of certain cyanobacteria capable of producing cyanotoxins that can have serious health consequences for humans, pets, and livestock quickly form, and can rapidly become toxic when these cyanotoxins are released into the water column when cells rupture or die. Other consequences of HABs include but are not limited to food web alterations and ecological dead zones (e.g., fish kills); ecotourism and property value losses; and negative impacts on drinking water supplies, agriculture, and wildlife (Carmichael 1992, Fawell et al. 1993, WHO 1999, WHO 2021).

When HABs occur, cyanobacteria typically become visibly abundant and form dense brown, tan, green, red, pink, or blue-green colonies. Blooms on or in the water may look like spilled paint,

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grass clippings, scums, or turbid water. Mat-forming HABs may occur on rocks, sediment, wood, aquatic vegetation, or artificial material, along with algae, microbes, and inorganic material.

Cyanotoxins can be produced by both planktonic (e.g., drifting or moving along in the water column) and mat-forming HABs (connected to the substrate). Many factors, including excess nutrients, sunlight, wind, flow, and temperature contribute to the formation of planktonic HABs. Although HABs can occur at any time, they are more likely to occur in late summer and early fall when temperatures are warm, water levels have stabilized, nutrients have been assimilated, and primary productivity increases. HABs may occur in some lakes and reservoirs following turn-over when nutrients are released from the bottom as cooler water is brought toward the surface. Shallow lakes and reservoirs with long residence times or elevated concentrations of nutrients have an increased likelihood of blooms. Mat-forming blooms are most common in wadable streams and rivers, but can also be found in lakes, reservoirs, and hot springs (CA NCRWCB 2022).

Exposure Routes and Health Effects

General health effects caused by exposure to toxic algae vary according to the type of toxin, the level of exposure, and the type of exposure (dermal, inhalation, and incidental ingestion).

Human symptoms include:

- skin irritation
- stomach cramps
- rashes
- kidney / liver damage
- fever
- sore throat
- headaches
- muscle / joint pain
- diarrhea
- neurotoxic effects
- hives
- nausea / vomiting
- increased asthma symptoms
- allergic reactions such as rhinitis (stuffy / runny nose)

Animals, especially dogs, may experience poisoning. Symptoms of pet poisoning include swelling of mouth, ear, or udder, vomiting, seizures, rashes, disorientation, staggering, inactivity, etc. and in extreme cases, sudden collapse and death (EPA 2019). See Appendix A for more information on pets and livestock.

There is inadequate evidence at this time to determine whether these toxins from algae cause cancer or other long term illness in humans or pets. See Appendix A for how thresholds were determined.

Advisory Guidance Thresholds

One objective of this plan is to identify cyanobacteria and cyanotoxin thresholds that will be used to inform the public and cooperators when human health risks may be present based on the presence of a HAB and the presence of cyanotoxin concentrations that exceed recreational thresholds (see Appendix A for additional details regarding how these thresholds were determined). This information can then be used by the public and cooperators to take appropriate precautions to protect the health of people and animals. Such actions may include, but are not limited to, avoiding areas with blooms, limiting access to waterbodies, cleaning fish properly, and conducting additional monitoring of public water supplies.

Table 1 details advisory guidance thresholds for recreational waters affected by HABs for three advisory levels – HAB WATCH, HAB WARNING, and HAB DANGER

Table 1. Advisory Status and Thresholds

	HAB WATCH	HAB WARNING	HAB DANGER
Toxigenic cyanobacteria cell density (cells/mL)[1,2,3]	Visual indication of HAB Presence (Determination by NMED based on photo and/or laboratory analysis)	>100,000 (determined by laboratory analysis)	none
Microcystins (µg/L) [1,2,3,4]	≥0.1	>8	>2,000
Cylindrospermopsin (µg/L) [3,4]	≥0.04	>15	none
Anatoxin-a (µg/L)[3,4,5,6]	≥0.1	>15	>90
Saxitoxins (µg/L) [3,5,7]	≥0.02	>8	>75

[1] WHO 2003
[2] WHO 2021
[3] USEPA 2019a
[4] Based on contract laboratory Reporting Limits used by NMED
[5] OHA 2021
[6] CWQMC 2016
[7] EFSA 2009

	HAB WATCH	HAB WARNING	HAB DANGER
Health risks	Low Risk, but Potential for risk level to quickly increase	Potential for long-term illness	Potential for acute poisoning Potential for long-term illness
		Short-term effects (e.g., skin and eye irritation, nausea, vomiting, diarrhea)	Short-term effects (e.g., skin and eye irritation, nausea, vomiting, diarrhea)
Recommended actions (NMED and resource managers)	Issue WATCH advisory to avoid primary contact recreation where HABs are observed	Issue WARNING advisory to avoid primary contact recreation	Issue DANGER advisory to avoid primary contact recreation
	Post WATCH signs	Post WARNING signs	Post DANGER signs
	Sampling recommended at least once every 2 weeks	Sampling recommended at least once every two weeks	Consider CLOSURE Sampling recommended at least once every two weeks

Table 2. Advisory Status and Recommendations for Recreationists

HAB WATCH
A **HAB WATCH** advisory means there is evidence that a harmful algal bloom is developing.
• As always, do not drink untreated surface water or get it in your mouth. • Avoid algae blooms while swimming and wading. Swimming is not recommended near visible blooms. • Supervise and keep pets away from both water and shoreline algae and rinse them with clean water if contact occurs. • Rinse fish with clean water prior to cooking thoroughly and eat only the fillet portion.

Table 2. Advisory Status and Recommendations for Recreationists (cont.)

HABWARNING
A **HAB WARNING** advisory usually means measured values exceed thresholds established by the NMED in a waterbody or portion of a waterbody. This is a strong indication that a harmful algal bloom is present.
• Do not drink the water or get it in your mouth • Do not swim or water ski. • Adults should avoid algae blooms while wading. • Supervise children and prevent them from entering the lake or playing near algae deposited on the shoreline. • Keep dogs or other animals away. • Avoid areas of algae when boating or paddleboarding. • Use caution when fishing because the effects of HAB toxins on fish are not well understood. If you choose to fish, rinse fish with clean water prior to cooking thoroughly and eat only the fillet portion.

HAB DANGER
A **HAB DANGER** advisory means measured values greatly exceed thresholds established by the NMED in a waterbody or portion of a waterbody. This usually means the bloom has become very large and/or high levels of dangerous toxins have been measured. A portion or the entire waterbody may be temporarily closed by the resource manager as part of the HAB DANGER Advisory.
• Do not drink water or get it in your mouth • Do not swim, wade, paddleboard, boat, or water ski • Keep dogs or other animals away. • Eating fish at these toxin levels is not recommended because the effects of HAB toxins in fish are not well understood. If you choose to fish, rinse fish with clean water prior to cooking thoroughly and eat only the fillet portion.

Advisory Guidance Process

The following procedures have been developed for notifying the resource managers and the public of recreation risks in surface waters associated with HABs. New Mexico's HAB response strategy is based on four steps: 1) Surveillance, Reporting and Preliminary Screening; 2) Data Collection; 3) Determining Advisories and Updating the HAB Advisory Map; and 4) Lifting Advisories

Step 1: Surveillance, Reporting and Preliminary Screening

One of the most important aspects of HAB surveillance is the recreating public. To maximize public participation in the advisory program as well as HABs reporting, NMED and cooperators should inform and educate the public about HABs and the advisory program. NMED may issue a press release at the beginning of the HABs season to remind the public of the upcoming season, the health risks associated with HABs, and how to identify and report HABs and HAB-related illnesses. NMED, DOH and cooperating agencies should work to inform the public of the adverse health effects associated with HABs and how to identify and report a suspected bloom and any cases of human or animal illness or death. Useful information about HABs, how to identify them, and what to do in the event of a HAB can be found on the NMED HAB Advisory webpage. In the event of a public health notification or closure, NMED, DOH and cooperating agencies should coordinate to ensure that information is disseminated via signs, press releases, videos, websites, social media, and other public forums.

NMED, DOH and all cooperators encourage anyone experiencing symptoms possibly related to a HAB event to call the New Mexico Poison and Drug Information Center at 1-800-222-1222. The Poison Information Center coordinates reported HAB cases with DOH to be reported to the EPA One Health Harmful Algal Blooms System (OHHABS). OHHABS is a collaborative network between state and federal partners and provides electronic reporting by state and local health departments via the National Outbreak Reporting System (NORS), case studies of HAB-related illness surveillance, and support from the Great Lakes Restoration Initiative that uses OHHABS data to inform their restoration objectives. More information and resources can be found on the OHHABS website. DOH will review the information and relay illness reports to NMED so follow-up monitoring can occur.

> To report a bloom, the public and resource managers should use EPA's bloomWatch app. BloomWatch is a participatory science app that allows users to find and report potential cyanobacteria blooms in water bodies. The data users provide help NMED and EPA track and manage water quality to protect public health and the environment from harmful blooms. NMED encourages everyone to download and review how to use the bloomWatch app to report suspected harmful algal blooms.

Waterbodies with heavy recreational use, particularly those with swimming beaches or those that are frequently used for swimming and similar water contact activities, should be visually inspected by management agencies weekly during periods of high recreational use (approximately May through November). Some priority lakes identified by NMED are routinely monitored, generally monthly, during the HAB season (approximately mid-July through November). Visual inspection should generally occur through observations by resource management agencies (e.g., New Mexico State Parks, National Park Service, New Mexico Wildlife Department, United States Forest Service, Bureau of Land Management, US Army Corps of Engineers, Bureau of Reclamation, United States Fish and Wildlife Service) as well as NMED, municipalities, and other cooperators.

Field tests are optional but may provide preliminary information on the potential health risks of a suspected HAB as well as the type of laboratory analysis that should be conducted. Once reported to NMED, suspected HABs can be evaluated by NMED or a cooperator using jar and/or stick tests to determine whether cyanobacteria are present (see procedures as well as safety protocols in NMED's HABs SOP 13.2 for procedure). Cooperators can also use field test strips (e.g., Abraxis Strip Test®) to test for cyanotoxins. Samplers should follow test strip protocols provided in their purchased test kit. Field test strips, jar and/or stick test will be used to prioritize sampling by NMED SWQB and cannot be used to determine exceedances of HAB WARNING and HAB DANGER thresholds.

Resource constraints may limit the number of lakes and reservoirs that can be inspected on a routine basis by resource management agencies, and the public may not consistently report suspected blooms. Therefore, NMED will use Cyanobacteria Assessment Network (CyAN) and EPA's HAB Forecasts satellite imagery can detect HABs due to the unique spectral signature of cyanobacteria. Although EPA is actively working to improve resolution, for lakes and reservoirs to be considered resolvable by CyAN, they currently must meet a minimum size requirement (300 by 300 meters) at this time. According to EPA, this size threshold results in approximately 14 New Mexico waterbodies that can be monitored remotely by NMED. NMED will analyze imagery for these waterbodies using screening metrics that determine the areal extent of blooms and bloom persistence over time. NMED may also use CyAN imagery to determine if smaller lakes and reservoirs should be investigated.

Step 2: Water Quality Data Collection

NMED SWQB will schedule a sampling event ASAP as resources allow as detailed in respective HABs and priority lake Sampling and Analysis Plans (SAPs) and SWQB's HABs Standard Operating Procedure (SOP) 13.2. NMED will take photos and collect water samples for cyanotoxin analysis as well as cyanobacteria identification and enumeration as resources allow. Total microcystins,

will generally be evaluated during all sampling events. Cylindrospermopsin and other cyanotoxins will be evaluated when they may be elevated and as resources allow.

NMED does not provide analytical support for private waterbodies unless there is a public health concern associated with the waterbody. If other entities or landowners are interested in having samples analyzed, a list of common laboratories that analyze cyanobacteria and cyanotoxins can be found on EPA's website: https://www.epa.gov/cyanohabs/laboratories-analyze-cyanobacteria-and-cyanotoxins.

Step 3: Determining Advisories and Public Notification Steps

NMED will utilize available data that meets the NMED SWQB quality assurance requirements to determine where to issue advisories based on exceedances of advisory thresholds. The public health notification process includes (1) updating New Mexico's HABs Advisory Map, (2) posting signs at the waterbody, and (3) optional additional public outreach via press releases or social media.

All current advisories will be available on the HABs Advisory Map. Additional information related to extent of the current advisory will be identified on the map. NMED encourages cooperators and recreationists to visit the webpage for the most up-to-date information.

When NMED Issues HAB Advisories, NMED will work with the resource managers on a public information campaign including signage at the waterbody. NMED will not always be able to post signage in a timely manner. It is expected for resource managers and cooperators to post the necessary signage whenever possible. NMED will share signage files for agencies to print and post. NMED will also work with resource managers to procure and distribute more durable signage where necessary.

Once an advisory has been issued for a waterbody, NMED and resource management agencies will continue to monitor the location, extent, and severity of HABs to provide the most up-to-date information to recreationists. NMED will discontinue routine monthly monitoring at the end of November. In circumstances where data indicates that an advisory should be changed (such as elevating a **HAB WATCH** to a **HAB WARNING** or lifting an advisory), the public health notification (e.g., map, listserv notice, etc.) will be updated accordingly. Resource management agencies should also ensure that any human illnesses or animal deaths have been reported to DOH.

Step 4: Lifting and Discontinuing Advisories

HAB WATCH will be lifted if there is evidence that a bloom has fully dissipated at a waterbody, as indicated laboratory cyanobacteria toxin analyses and/or cyanobacteria identification**. HAB WARNING** and **HAB DANGER** will be downgraded to the appropriate status if cyanotoxin concentrations from two consecutive sampling events at the site, separated by at least 1 week (i.e., 7 days, 168 hours), are below the applicable **HAB Advisory** thresholds. Any advisories that have not yet lifted will be lifted on November 30th due to winter conditions unless current toxin levels indicate otherwise. HABs can pop up anytime and anywhere, therefore it is best to always exercise caution; when in doubt stay out.

Once confirmed, NMED will change the waterbody status, or it will be removed from the Current Advisory tab on the NMED's HABs advisory Map. Cooperators and the public are encouraged to check the New Mexico HABs Advisory Map for information on sampling results and advisory status. Resource management agencies should continue to observe the waterbody and report new cyanobacterial blooms if they appear.

Contact information

Report a bloom: bloomWatch app

Immediate health concerns: New Mexico Poison Information Center: 1-800-222-1222

Animal illness info:

ASPCA Poison Control: 1-888-426-4435

Pet Poison Helpline: 1-855-764-7661

New Mexico Environment Department Surface Water Quality Bureau:

https://www.env.nm.gov/surface-water-quality/habs/

swqmonitoring@env.nm.gov

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Appendix A: Rationale for Selected Thresholds

Cyanotoxin Thresholds

In May 2019, the US Environmental Protection Agency (EPA) released *Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin* that states and authorized tribes can consider for inclusion as water quality criteria for the protection of primary contact recreation and/or for issuing public health advisories (USEPA 2019a). The recommended cyanotoxin thresholds are 8 µg/L total microcystins and 15 µg/L cylindrospermopsin**.** These recommendations are based on incidental ingestion by children while swimming since children represent the most vulnerable age group due to their extended periods of water play as well as the quantity of water they typically ingest during water play. The recommendations were derived from peer-reviewed scientific literature and criteria methodologies in EPA's Exposure Factors Handbook (2011). Thresholds were only developed for microcystin and cylindrospermopsin since these toxins have sufficient toxicological data. Sampling in New Mexico primarily targets microcystins and cylindrospermopsin as these are the two cyanotoxins that EPA has established recommended recreational criteria that are also in New Mexico's Water Quality Standards (20.6.4.900.D New Mexico Administrative Code, USEPA, 2019b).

EPA has not released recommended criteria for any other cyanotoxins. The program may expand to include other cyanotoxins as additional guidance, data, and understanding of the impacts of varying levels of these cyanotoxins become available. NMED will use the EPA recommended thresholds of **8 µg/L total microcystins and 15 µg/L cylindrospermopsin for the HAB WARNING** advisory; NMED will also use the same thresholds for anatoxin and saxitoxin established in Colorado by the Colorado Department of Public Health and Environment: **15 µg/L anatoxin** and **8 µg/L saxitoxin**. NMED will use Utah Department of Environmental Quality's established "Danger Advisory" threshold for New Mexico's **HAB DANGER** thresholds: **2000 µg/L total microcystins**, **90 µg/L anatoxin**, and **75 µg/L saxitoxin**. New Mexico's **HAB WATCH**

thresholds are based off of MDLs for analytical methods utilized by NMED; these are : **0.1 µg/L total microcystins,** 0**.04 µg/L cylindrospermospin**, 0**.1 µg/L anatoxin**, and 0**.02 µg/L saxitoxin**.

Thresholds included in this plan will be updated as additional cyanobacteria and cyanotoxin data are collected in New Mexico surface waters and new scientific information becomes available.

Cyanobacteria Thresholds

This plan also identifies potentially harmful levels of cyanobacteria because there may be risks associated with direct contact with cyanobacteria cells themselves, regardless of whether they can produce known cyanotoxins (USEPA 2019a). In addition, cyanobacteria may quickly transition from not producing cyanotoxins to producing cyanotoxins, and some genera of cyanobacteria can produce different toxins at different times, some of which may not be documented (Otten and Paerl 2015).

The type of cyanotoxins present in a waterbody depend on the species/genera of cyanobacteria, though some species/genera can produce multiple types of toxins. Moreover, toxigenic cyanobacteria, or those cyanobacteria with genes that allow for cyanotoxin production, may only produce cyanotoxins under certain environmental conditions. A list of toxigenic cyanobacteria and the cyanotoxins they can produce are listed in Table 3.

These cyanotoxins are categorized by their primary mode of action: dermatoxins (i.e., skin irritants), hepatotoxins (i.e., affect liver function), and neurotoxins (i.e., affect central nervous system).

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Table 1. Wyoming DEQ Chart of Cyanobacteria and Associated Cyanotoxins

Cyanobacteria Genera	Type		Dermatoxins			Hepatotoxins			Neurotoxins				
	Plank-tonic	Mat-forming	APL	LPS	LYN	CYL	MC	NOD	ATX	BMAA	GTX	NEO	SAX
Anabaena	X	X		X		X	X		X	X		X	X
Anabaenopsis	X			X			X						
Aphanizomenon	X			X		X	X		X	X		X	X
Aphanocapsa	X	X		X			X						
Aphanothece	X	X											
Calothrix	X	X					X						
Chroococcus	X	X											
Coelomoron	X	X											
Coelosphaerium		X					X						
Cyanodictyon	X							X					
Cylindrospermopsis	X	X		X		X			X	X			X
Cylindrospermum		X							X				X
Dolichospermum (prev. Anabaena)	X					X	X		X	X	X	X	X
Geitlerinema		X					X		X				X
Gloeotrichia	X			X			X						
Heteroleibleinia	X	X											
Leptolyngbya		X					X						
Limnothrix		X					X						X
Lyngbya		X	X	X	X	X				X			X
Merismopedia	X	X					X						
Microcoleus (prev. Phormidium)		X				X	X		X				X
Microcystis	X			X			X			X			
Nodularia	X	X		X			X	X		X			
Nostoc	X	X		X			X	X	X				
Oscillatoria	X	X	X	X	X	X	X		X	X			X
Phormidium		X				X	X		X				X
Planktothrix	X	X					X		X				X
Planktolyngbya	X			X									
Pseudanabaena	X	X		X			X		X				
Raphidiopsis	X					X			X				X
Schizothrix		X	X										
Spirulina		X					X			X			
Synechococcus	X			X			X		X	X			
Synechocystis	X						X						
Tolypothrix	X						X						
Woronichinia	X						X		X				

Toxin abbreviations are as follows: APL, aplysiatoxins; LPS, lipopolysaccharides; LYN, lyngbyatoxin-a; CYL, cylindrospermopsins; MC, microcystins; NOD, nodularins; ATX, anatoxins; BMAA, β-N-methylamino-L-alanine; GTX, guanitoxin; NEO, neosaxitoxins; SAX, saxitoxins.

When released from cyanobacteria cells, cyanotoxins are colorless and may remain in the water column after a bloom has dissipated. Studies have shown cyanotoxins persist anywhere from five days to several months in water and up to six months in dry scum (USEPA 2019a). The rate at which cyanotoxins are removed depends on environmental factors such as water pH and temperature, ultraviolet degradation, the presence of particulate matter, water depth, and bacterial breakdown (USGS 2008 USEPA 2019a). Studies have also shown that certain strains of

microcystin can remain in sediments for months or, conversely, bypass sediments and enter groundwater. Cyanotoxins and cyanobacteria can also flow downstream from lakes and reservoirs for indeterminate distances (Yang et al. 2016, USEPA 2019a).

Planktonic Blooms

Planktonic blooms, most often found in lakes and reservoirs in New Mexico, are characterized by cyanobacteria cells suspended in the water column, floating on the water surface, or aggregated on shorelines. Since planktonic blooms pose the greatest health risk to recreators exposed through direct contact with cyanobacteria dispersed in the water column or floating on the water surface, planktonic blooms are most commonly sampled via surface grab samples.

For planktonic blooms, **HAB WARNING** advisories are issued when cyanobacteria cell densities exceed **100,000 cells/mL**. This cell density was selected after reviewing scientific studies utilized by other state agencies and health organizations (Graham et al. 2009, Farrer et al. 2015). The cell density threshold was chosen after reviewing World Health Organization (WHO 1999) guidelines and represents the level at which acute health effects transition from low to moderate risk (Table 4). Any combination of cyanobacteria taxa found in a planktonic bloom can trigger a bloom advisory due to the high risk of dermal contact and inhalation presented by these types of blooms. **HAB WATCH** advisories will be issued on a case-by-case basis by NMED after evaluating all available evidence including photos, satellite data, preliminary testing, and laboratory analysis that indicate the presence of a developing HAB.

Table 2. World Health Organization guidelines for cyanobacterial bloom characterization (Graham et al. 2009)

Relative Probability of Acute Health Effects	Cyanobacteria[1] (cells/mL)	Microcystin-LR[2] (μg/L)	Chlorophyll-*a*[3] (μg/L)
Low	< 20,000	< 10	< 10
Moderate	20,000-100,000	10-20	10-50
High	100,000-10,000,000	20-2,000	50-5,000
Very High	>10,000,000	>2,000	>5,000

Cyanotoxins are emerging contaminants and while the advisory plan aims to protect public health, more research is needed to understand all of the risks posed by HABs. Specific areas of research include fish consumption, inhalation of aerosolized particles, and health effects on animals.

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Mat-Forming Blooms

Not enough data has been collected on Mat-Forming Blooms in New Mexico to currently include these in the response plan. The public is encouraged to visit the NMED HABs webpage for resources to help identify these and avoid them whenever possible. NMED SWQB is currently exploring adding Benthic HABs to the HABs Advisory Program and will be modeled after Utah DEQ's methodology.

Other Health Risks

Cyanotoxins are emerging contaminants and while the advisory plan aims to protect public health, more research is needed to understand all the risks posed by HABs. Specific areas of research include fish consumption, inhalation of aerosolized particles, and health effects on animals.

Fish Consumption

At this time, there is insufficient information to determine the risk of consuming fish caught in waters with a HAB. Studies have shown that toxins mainly accumulate in the liver and viscera of fish, and small amounts of microcystin has been detected in the fillet (Vasconcelos 1999, de Magalhaes et al. 2001, Kann 2008, WA DOE 2010, Kann et al. 2011). At a minimum, organs and skin should be removed and discarded, and fillets rinsed with clean water prior to cooking or freezing fillets. Caution should be taken with shellfish as cyanotoxins have been shown to accumulate in edible tissue (Vasconcelos 1999).

Pets and Livestock

Currently, there is insufficient information to determine the risk HABs pose to animals. It is suspected but not confirmed that dog deaths due to cyanotoxins have occurred in New Mexico. Oregon has established recreational use values for cyanotoxins and dogs that are much lower than the EPA recommended criteria for humans. NMED recommends never letting animals near water that is suspected of a HAB as they are likely to ingest the water or cyanobacteria causing the bloom. Please see the NMDOH HABs and Animals Fact Sheet for more information.

Aerosols

Currently, there is insufficient information to determine the risk aerosolized HABs pose to the public. It is suspected that cyanotoxins can become aerosolized especially with churning wave action and boating or waterskiing and it is possible that the aerosols could be transported for miles. Please see the Great Lakes HABs Collaborative fact sheet about HAB toxins in air for more information.